
**Petroleum and natural gas
industries — Arctic operations —
Metocean, ice, and seabed data**

*Industries du pétrole et du gaz naturel — Opérations en Arctique
— Données océano-météorologiques et données sur les glaces et les
planchers océaniques*

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

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For an explanation on the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see the following URL: www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 67, *Materials, equipment and offshore structures for petroleum, petrochemical and natural gas industries*, Subcommittee SC 8, *Arctic operations*.

Introduction

The series of documents on arctic operations (currently ISO 35101 to ISO 35106) addresses operational requirements for use by the petroleum and natural gas industries in arctic and cold regions. Through their application, the intention is to ensure human life safety and to minimize environmental damage. At the same time, the series of documents is intended to provide wide latitude in the choice of operational and design solutions without hindering innovation. Sound engineering judgment is, therefore, necessary in the use of these documents.

This document is developed to provide a coherent and consistent definition of data requirements for operations and designs in arctic and cold regions. With application to offshore, coastal and onshore situations, the document focuses on meteorological, oceanographic, seabed and ice considerations. In addition to the requirements of this document, the requirements of ISO 19901-1 for metocean data, ISO 19906 for ice properties data and ISO 19901-4 and ISO 19901-8 for seabed data also apply.

For many geographical regions, physical environmental data are insufficient for rigorous statistical determination of appropriate extreme and abnormal environmental actions and are insufficiently detailed for the conduct of specialized operations. The determination of relevant operational and design parameters therefore relies on the interpretation of the available data by subject matter experts, together with an assessment of other meteorological, oceanographic, seabed and ice information. In particular, uncertainties can arise from analyses based on limited data sets.

[Annex A](#) provides background to and guidance on the use of this document and it is intended to be read in conjunction with the main body of this document. The clause numbering in [Annex A](#) is the same as in the normative text to facilitate cross-referencing.

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Petroleum and natural gas industries — Arctic operations — Metocean, ice, and seabed data

1 Scope

This document specifies requirements and provides recommendations and guidance for the collection, analysis and presentation of relevant physical environmental data for activities of the petroleum and natural gas industries in arctic and cold regions. Activities include design and operations, which involve planning and actual execution.

Reference to arctic and cold regions in this document is deemed to include both the Arctic and other locations characterized by low ambient temperatures and the presence or possibility of sea ice, icebergs, shelf ice, glaciers, icing conditions, persistent snow cover, frozen surfaces of lakes and rivers, localized and rapidly changing weather systems and/or permafrost.

This document outlines requirements for a range of different operations that have been or are presently being undertaken and for existing design concepts. This document can also be used for other operations and new design concepts in arctic and cold regions as long as it is recognized that all data requirements are not necessarily addressed.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 12494, *Atmospheric icing of structures*

ISO 19900, *Petroleum and natural gas industries — General requirements for offshore structures*

ISO 19901-1, *Petroleum and natural gas industries — Specific requirements for offshore structures — Part 1: Metocean design and operating considerations*

ISO 19901-4, *Petroleum and natural gas industries — Specific requirements for offshore structures — Part 4: Geotechnical and foundation design considerations*

ISO 19901-6, *Petroleum and natural gas industries — Specific requirements for offshore structures — Part 6: Marine operations*

ISO 19901-8, *Petroleum and natural gas industries — Specific requirements for offshore structures — Part 8: Marine soil investigations*

ISO 19906, *Petroleum and natural gas industries — Arctic offshore structures*

ISO 35101, *Petroleum and natural gas industries — Arctic operations — Working environment*

ISO 35103, *Petroleum and natural gas industries — Arctic Operations — Environmental monitoring for offshore exploration*

ISO 35104, *Petroleum and natural gas industries — Arctic operations — Ice management*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 35101, ISO 35103, ISO 35104, ISO 19900, ISO 19901-1, ISO 19901-6, ISO 19906 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <http://www.electropedia.org/>

3.1

accretion

accumulation of snow, ice and other forms of frozen precipitation on surfaces

3.2

active layer

soil layer above the permafrost that is subjected to annual freeze-thaw cycles

3.3

arctic jet

low-level wind directed parallel to an ice edge or ice lead

3.4

areal density

number of ice features per unit area

Note 1 to entry: Usually averaged over a specific time interval.

3.5

bergy bit

floating glacial ice mass with waterline length between 5 m and 15 m

3.6

calibration

process by which physical parameter values are related to instrument readings

3.7

calving event

break-up of an iceberg or other glacial ice mass into two or more pieces

3.8

coastal region

offshore region adjacent to the coast where the physical environment is influenced by the coast

3.9

data analysis

data interpretation

expert assessment of physical environmental data to satisfy design or operational requirements

Note 1 to entry: Data analysis can include verification with other data sources or physical process models.

3.10

data storage

organization of physical environmental data into an accessible and documented database

3.11

data collection

data measurement

application of human systems or instruments for recording physical environmental data

3.12

data presentation

provision of physical environmental data in a format suitable to the design process or operational decision-making

3.13**downtime**

time interval for which an operation is suspended

Note 1 to entry: Downtime can be planned or unplanned.

3.14**expert**

individual who through training and experience is competent to provide advice specific to the subject in question

3.15**first-year ice****FY ice**

sea ice formed during the current or prior winter that has not survived one summer melt season

[SOURCE: ISO 19906:—¹), 3.16]

3.16**floe size**

waterline dimension of a sea ice floe

Note 1 to entry: Floe size can be defined as either the maximum waterline dimension or the diameter of a circular floe with the same plan area.

3.17**freezing degree days****FDD**

cumulative sum of average freezing daily air temperatures from the start of the winter season

Note 1 to entry: The reference point can be 0 °C or the freezing temperature of sea water.

Note 2 to entry: Usually initiated when the average daily temperature averaged over a specified period, for example, 30 days, falls below 0 °C or the freezing temperature.

3.18**growler**

floating piece of glacial ice with waterline length less than 5 m

3.19**ice action**

external load, displacement, deformation or acceleration applied to a structure as a consequence of an ice scenario

3.20**iceberg draft**

distance between the deepest point in the keel of an iceberg and the water surface

3.21**ice cover**

distribution of ice on the surface of a lake, river or ocean

3.22**ice edge**

line of demarcation between open water and floating *ice cover* ([3.21](#))

Note 1 to entry: Ice edge can be diffuse or compact, depending on the orientation of wind and current actions on the ice cover.

Note 2 to entry: Ice edge is sometimes based on a minimum concentration threshold over a specified averaging area in satellite imagery.

1) To be published. Stage at time of publication ISO/DIS 19906:2017.

Note 3 to entry: The concentration threshold can be dictated by the tolerance of the operation to *ice actions* (3.19).

3.23

ice encroachment

movement of sea ice onto the surface of a platform or man-made island

Note 1 to entry: Ice encroachment can result from ice ride-up, pile-up, and ride-down processes.

Note 2 to entry: Ice encroachment is typically associated with operational or design criteria.

[SOURCE: ISO 19906:—, 3.26]

3.24

ice feature

continuous mass of ice, floating or grounded, having a greater thickness than the surrounding *ice cover* (3.21)

3.25

ice hazard

ice threat

ice feature (3.24) or conditions associated with operational criteria

Note 1 to entry: In this document, referred to without the “ice” qualifier.

3.26

ice length

accumulated distance travelled by the *ice cover* (3.21) past a point regardless of direction

3.27

ice management

processes and activities used to mitigate risks from ice

Note 1 to entry: Ice management can be used to alter icing, sea ice or iceberg environments or accumulations with the intent of reducing *downtime* (3.13) and reducing or avoiding ice action effects.

Note 2 to entry: Ice management can involve ice detection, forecasting, threat assessment, removal, alteration and destruction.

Note 3 to entry: Ice management is often conducted in the context of operating criteria such as alert procedures (see also ISO 19906 and ISO 35104).

3.28

ice ridge

linear feature formed of ice blocks created by the relative motion between ice sheets

Note 1 to entry: Ice pressure ridges are formed when ice sheets are pushed together and a shear ice ridge is formed when ice sheets slide along a common boundary.

[SOURCE: ISO 19906:—, 3.34]

3.29

ice season

period during the year when sea ice exceeds a specified concentration or when *ice features* (3.24) exceed a specified *areal density* (3.4)

Note 1 to entry: Specified criteria can be different for the start and end of season.

3.30

ice shelf

floating ice sheet of considerable thickness attached to the shore

Note 1 to entry: Ice shelf can be determined based on freeboard in excess of 2 m.

3.31**ice scenario**

combination of circumstances involving the presence of ice, resulting in ice events

[SOURCE: ISO 19906:—, 3.35]

3.32**ice thickness**

vertical dimension of ice, measured from the bottom surface to the top surface

Note 1 to entry: Ice thickness can be determined as an average or maximum value over a specified horizontal scale or over the plan area of an *ice feature* (3.24).

3.33**ice type**

ice identified in WMO categorization according to the stage of development

3.34**icing**

ice accretion on the surface of a structure

Note 1 to entry: Icing can involve atmospheric or sea spray processes.

3.35**icing conditions**

combination of metocean, ice and operational conditions under which *icing* (3.34) can occur

3.36**katabatic wind**

gravity-driven flow of dense cold air from higher to lower elevations

Note 1 to entry: Katabatic winds are often associated with glaciers.

3.37**landfast ice****fast ice**

ice that remains attached to a shoreline, island or grounded *ice feature* (3.24)

[SOURCE: ISO 19906:—, 3.37]

3.38**level ice**

ice formed primarily as a result of thermal conduction and radiation processes and excluding mechanical processes

Note 1 to entry: Ice subjected to small amounts of rafting during the initial formation process is generally considered as level ice.

Note 2 to entry: Thicker level ice can vary by several centimetres over distances of several metres.

3.39**marginal ice zone**

sea ice region affected by waves and swell

3.40**multi-year ice****MY ice**

sea ice that has survived at least two summers' melt seasons

[SOURCE: ISO 19906:—, 3.44]

3.41

old ice

sea ice that has survived at least one summer's melt season

Note 1 to entry: Old ice includes both second-year ice and multi-year ice.

[SOURCE: ISO 19906:—, 3.45]

3.42

pack ice

sea ice consisting of discrete floes that is not landfast

[SOURCE: ISO 19906:—, 3.46]

3.43

pack ice pressure

horizontal pressure acting within pack ice

Note 1 to entry: Generally, pack ice pressure is the result of wind and current forcing, but can also result from larger scale mechanics of the *ice cover* (3.21).

Note 2 to entry: Pressure can be measured on an ordinal scale based on the closing rate of icebreaker tracks.

3.44

persistence

duration of a physical environmental parameter with respect to a specified threshold

3.45

rafted ice

ice feature (3.24) formed from the superposition of two or more ice sheet layers

[SOURCE: ISO 19906:—, 3.50]

3.46

region of interest

<design> geographical region around the facility selected to ensure data accuracy and representativeness

3.47

region of interest

<operation> geographical region over which an operation is undertaken and is influenced by ice and metocean processes

3.48

rolling event

distinct and sudden change in the vertical orientation of an iceberg or other floating glacial ice mass

3.49

second-year ice

SY ice

sea ice that has survived one summer's melt season

[SOURCE: ISO 19906:—, 3.62]

3.50

sea ice

thermally-grown ice formed on the surface of saline water bodies

3.51

season boundary

start or end of the *ice season* (3.29) according to specified criteria

3.52**shelf break**

seaward extent of the continental shelf characterized by a significant increase in slope of seafloor

Note 1 to entry: Shelf break can be used to determine the average seaward extent of sea ice.

Note 2 to entry: Shelf break can be used to determine the seaward limit of potential iceberg contact with the seabed.

3.53**snow cover**

areal distribution of snow on the ground or ice surface

3.54**stability**

state of hydrostatic or hydrodynamic equilibrium with respect to vertical orientation, usually with reference to icebergs

3.55**sub-gouge deformation**

displacement of seabed soil beneath a gouging *ice feature* (3.24)

3.56**waterline length**

maximum dimension of an *ice feature* (3.24) in the plane of the water surface

3.57**waterline width**

maximum dimension of an *ice feature* (3.24) perpendicular to the *waterline length* (3.56) in the plane of the water surface

3.58**wind chill**

perceived temperature due to the combined effect of low ambient temperature and wind

4 Symbols and abbreviated terms**4.1 Symbols**

d	distance from the ice edge
E	wave energy
E_0	wave energy in open water
h	ice thickness
M	ice sample mass
p_t	true precipitation
p_m	measured precipitation
S	salinity
T	air temperature
T_{wc}	wind chill temperature
U_{10}	wind speed at 10 m elevation

U	wind speed at the elevation parameter is to be estimated
V	ice sample volume
α	wave attenuation factor
ρ_i	ice density

4.2 Abbreviated terms

EER	escape, evacuation and rescue
FDD	freezing degree days
FEED	front-end engineering and design
FY	first-year, with reference to sea ice
HSE	health, safety and environment
IMO	International Maritime Organization
MY	multi-year, with reference to sea ice
SY	second-year, with reference to sea ice
WMO	World Meteorological Organization

5 General requirements

5.1 General

5.1.1 Physical environmental data requirements

An assessment of the physical environmental parameters affecting an operation or proposed offshore structure shall be made.

Information about the following physical environmental data should be determined.

- Distributions of parameters, which are required to determine actions and/or action effects associated with extreme and abnormal environmental events. These parameters are used to define design situation(s) and to perform design checks for structural limit states.
- Long-term distributions of parameters, in the form of cumulative conditional or marginal statistics. These parameters are used to define design situation(s) and to perform design checks for the fatigue limit state, and to make evaluations of downtime/workability/operability during a certain period of time, for the structure or for associated items of equipment.
- Normal environmental conditions, which are expected to occur frequently during the design service life of the structure, are required for carrying out checks for serviceability limit states, for developing actions and action effects to determine when particular operations can safely take place, and for planning construction activities, e.g. fabrication, transportation or installation, or field operations, e.g. drilling, production, offloading, underwater activities.
- Regional environmental oscillations, cycles and long-term trends associated with the parameters in a) through c).

5.1.2 Relationship with ISO 19901-1 and ISO 19906

General requirements, guidelines and information for metocean data are given in ISO 19901-1 for all regions. Mechanical properties of ice and derived physical parameters for arctic and cold regions are given in ISO 19906. This document deals with all other physical environmental and ice parameters for arctic and cold regions, including actions from snow and ice accretion.

5.1.3 Data sources

All data sources and methods used to generate physical environmental data shall be described and documented. The quality and validity of data shall be assessed by subject matter experts. Specific descriptions for relevant parameters are given in [Clauses 6 to 17](#).

All limitations with regard to data quality and/or validity shall be explicitly defined and taken into account in design and/or when planning operations.

If local data are not available and data from nearby areas are applied, the methods and models used in their application shall be documented, including all assumptions made. In addition, any uncertainties and how these have been dealt with should be included.

5.1.4 Selection of appropriate parameters

Sufficient data should be collected, analysed and interpreted to meet the requirements of the standards under which the design or operation is carried out. Sufficiency can involve, but is not limited to the location, spatial resolution, frequency, and accuracy of the data.

The selection of the appropriate physical environmental parameters depends on the location of interest, the type of structure or operation concerned, the design situation involved and the limit state considered. Different parameters can be required for different structure types, different designs or operational situations, and different limit states.

The seasonality and time periods associated with the operations should be taken into account according to [5.2.3](#) and [5.2.4.1](#).

Site-specific data on physical environmental parameters shall be collected, analysed and presented based on the requirements of [Clause 5](#) and the additional requirements for:

- oceanographic processes (waves, currents, water levels, temperatures, salinities) as included in [Clause 6](#), [Clause 8](#), [Clause 9](#), [Clause 10](#), [Clause 14](#) and [Clause 16](#);
- atmospheric processes and effects (wind, temperature, precipitation, visibility, drainage) as included in [Clause 7](#), [Clause 11](#), [Clause 14](#), [Clause 16](#) and [Clause 17](#);
- sea ice (thickness, extent, drift, origin, physical properties) as included in [Clause 12](#) and [Clause 16](#);
- icebergs and other discrete ice features (morphology, drift, physical properties) as included in [Clause 13](#) and [Clause 16](#); and
- seabed and subsurface processes (ice gouge, strudel scour, permafrost) as included in [Clause 15](#), [Clause 16](#) and [Clause 17](#).

5.1.5 Physical environmental data monitoring

All instrumentation and data collection devices should be designed for, or protected with respect to, icing, snow accumulation, ice encroachment, anticipated temperature range, moisture, frost, as well as anticipated combinations of ice and metocean conditions. Routine verification of data streams should be made to minimize gaps in data, particularly with respect to [5.2.2](#).

5.1.6 Data storage

All physical environmental data collected in the region of interest as part of offshore operations in arctic and cold regions should be archived.

5.2 Particular aspects

5.2.1 Region of interest

The region of interest for operations:

- a) shall be defined as the geographical region over which the operation or phase of the operation is undertaken, including the vessels supporting the operation;
- b) shall be defined as the geographical region over which ice and metocean features and processes affect the operation or phase of the operation;
- c) should include ice management, EER routes, mobilization and demobilization, local supply, overwintering sites for drilling and support vessels and personnel transfer. This region should be sufficiently large to ensure the accuracy of data within the regions defined in a) and b) and sufficiently constrained to ensure their representativeness within these regions.

For design, the region of interest shall be

- sufficiently large to ensure the accuracy of data at the location of the facility, and
- sufficiently constrained to ensure the representativeness of the data at the facility.

The size of the region of interest can vary depending on the particular parameter under consideration.

5.2.2 Criticality

The importance of the physical parameters should be understood in the context of operability, limit states for design and consequences involving life-safety, environmental damage and asset loss.

For critical operations, consideration should be given to the identification and use of maximum anticipated parameter values and combinations of parameter values with maximum consequences.

5.2.3 Variability

Different scales of variability can be distinguished for physical environmental parameters in arctic and cold regions.

- a) Short term variability is associated with events lasting less than an hour. Typical examples are ice concentrations or floe sizes and ice drift heading changes.
- b) Medium term variability is associated with events lasting from hours to days. Typical examples are ice drift rate, iceberg or sea ice feature proximity and wind and wave variability during polar lows.
- c) Seasonal variability is associated with natural seasonal cycles. Typical examples are seasonal sea ice and iceberg presence.
- d) Inter-annual variability is associated with longer cycles and climate change. Arctic ice thickness and extent vary on decadal time scales. Inter-annual variability is more pronounced between northern latitudes of 65° and 80°.

An analysis of parameter variability should be conducted for all important parameters in arctic and cold regions. Typically, the analysis should identify monthly or seasonal variability, including anticipated maximum and minimum values as well as physical limits on parameter values, where appropriate. Inter-annual variability should be accounted for, particularly when operating with data records for a limited number of years.

Variations in physical environmental parameters can be expressed in terms of

- the proportion of time for which the parameter values exceed or are less than a specified value, or
- the probability of exceeding or being less than a specified value within a given time period.

5.2.4 Statistical

5.2.4.1 General

Basic statistics, probability distributions, extreme values, abnormal values and relationships with associated parameters should be provided according to the design and operational requirements. Ranges, confidence intervals, biases and other measures of uncertainty should be documented for statistical data.

If redundant, independent measurements are made, they can be used to reduce the uncertainty through averaging techniques.

Site-specific ice and metocean data should be interpreted to identify monthly and seasonal variations and for application to operating time windows.

Datasets for ice parameters can be developed directly from site-specific measurements and from measurements at nearby locations or through the establishment of relationships between the desired parameters and other contributing factors. Due account shall be made for uncertainties, whether because of short time series or limitations of the models used.

Metocean datasets can either be established by site-specific measurements over a period of years or as an alternative, by numerical modelling (hindcasts) of historical events.

If hindcasts are used, the modelled results should be calibrated (or verified) against measurements from nearby locations for which measurements exist. If such measurements do not exist, hindcast models can be calibrated or verified against measurements from analogous sites with a similar climate.

If measurements or hindcasts exist for nearby locations, these datasets may be used, provided that conditions are similar in climate and that appropriate factors are applied.

5.2.4.2 Relationship between parameters

Data values should be tagged spatially, temporally and associated with specific features for the development of joint events. Emphasis should be placed on ensuring correct spatial, temporal and feature references.

Joint probability distributions shall be developed for important design and operational parameters that are correlated. In many cases, poorly sampled parameters can be related to parameters with more extensive measurements as long as uncertainties in these relationships are taken into account.

When developing parameter combinations in design formulae, joint probabilities shall be assessed to ascertain whether the combinations are stochastically dependent, stochastically independent or mutually exclusive.

5.2.4.3 Persistence

Persistence statistics should be developed for parameter values associated with human performance (see ISO 35101), for winterization, for marine operations and for aerial operations.

Reference should be made to [5.2.6](#) for persistence data for weather-restricted operations.

5.2.4.4 Record length

Where record lengths of local data are limited, relationships with measurements of other parameters for which longer periods of record are available should be considered.

Limited record lengths should be reflected in the uncertainty associated with parameter estimates. Seasonal, annual and regional biases shall be taken into account when estimating parameter uncertainties.

5.2.5 Forecasting

Forecasts of physical environmental conditions should be started as early as possible in the planning stage of operations to ensure timely collection of important parameters and to ensure that forecast accuracy can be quantified.

Forecasts should be verified with measured data, so that the accuracy can be reliably estimated and the forecasts can be improved over time.

Weather and physical environmental predictions required for operations should be monitored constantly and updated as necessary.

Regardless of accuracy, forecasts based on at least two independent models should be consulted and evaluated. The forecasts shall be based on up-to-date input data and shall be issued on a timely basis with respect to operational requirements.

The period over which a forecast is accurate shall be defined based on past forecasts and site-specific measurements. Forecasts may be used for executing marine operations carried out within the period of accuracy when contingency is sufficiently accounted for.

5.2.6 Weather windows

5.2.6.1 Criteria

Physical environmental data criteria for operations depend on the planned duration of the operation, including contingency.

For each specific phase of the operation, the design and operational physical environment criteria shall be defined as follows.

- The design criteria are the set of values of the physical environmental parameters for which design calculations are carried out and against which the structure and/or operation is checked.
- For weather-unrestricted operations, the operational physical environmental data criteria are the same as the design criteria.
- For weather-restricted operations, the operational physical environmental data criteria are set at values that cannot be exceeded at the start of the operation and for which forecasts are not exceeded for the duration of the operation.

Physical environmental data criteria can be set in the context of operational limits, systematic alert procedures and operational responses.

5.2.6.2 Weather-restricted operations

Weather-restricted operations shall be planned using accurate time history data that indicate not only the probability of not exceeding the limiting criteria but also the persistence of such conditions for the season in question. Reference to weather includes ice and other physical environmental criteria.

Consideration should be given to reducing the limiting criteria to account for uncertainties in the duration of the operation, in the data, and in forecast accuracy.

Weather windows should be developed based on thresholds of the key sensitive parameters of the operation. For example, the duration statistics for favourable conditions should be computed based on known limiting thresholds for physical environmental parameters.

5.2.6.3 Margins on weather

Planning for operational activities that are dependent upon specific physical environmental conditions shall take into consideration the quality and confidence level in the forecasts. The confidence level will vary depending upon the available data, the variability in the parameter being forecast and the experience of the forecaster. Forecasts for critical operations should indicate the probability that operational criteria associated with ice and other physical environmental parameters are met.

If the physical environmental criteria are based on statistical maxima, an appropriate margin should be added to account for inaccuracies in the calculation model and the probability of exceeding the maxima.

Margins should reflect the nature of the operation and whether suspension is possible once the operation is initiated. For operations requiring a continuous window, margins should be increased accordingly.

5.2.7 Climatic trends

Climatic trends should be assessed for key time-varying parameters, with specific consideration of air and water temperatures, as well as sea ice and iceberg presence.

Parameters used for design should take into account projected trends in climate, as justified by the most recent climate science, if the net effect leads to more severe conditions. Design criteria should not be reduced based on projected climatic trends.

The influence of climatic trends on data used for planning operations should be assessed when the operations are expected to take place over several years.

5.2.8 Expertise and experience

The collection, interpretation, analysis, storage and presentation of all physical environmental data and derived products within the scope of this document shall be performed or supervised by subject matter experts.

Operations personnel shall be trained in the collection and interpretation of physical environmental data pertinent to their responsibilities and have access to subject matter experts on a timely and reliable basis.

Interpretation of physical environmental data and forecasts associated with critical operational situations, as defined in [5.2.5](#), shall be conducted by subject matter experts.

6 Water depth, tides and storm surges

6.1 General

Water depth, tides and storm surge parameters shall be determined in accordance with ISO 19901-1.

Specific consideration should be given to tide and storm surge data during the months when icebergs and sea ice are present.

Particularly in shallow water environments, such as estuaries and river mouths, seasonal variations in water depth as a result of fresh water inflow and ice formation/melting processes should be characterized.

Deviations in the water surface elevation as a result of tides and storm surges shall take into account the presence of the sea ice cover.

Changes in water surface elevation should be characterized in a manner that allows for safe icebreaking operations, safe vessel transit and any other anticipated vessel and structure operations.

Ranges of water surface elevation should be determined to assist with the specification of operational and design values of ice loads on structures fixed to the seabed, on geotechnical structures and on natural and man-made shore facilities. Displacements, deformations, damage and abrasion of these facilities should also be considered in the specification of water level data.

6.2 Bathymetry

Accurate bathymetric data shall be consulted prior to the planning and conduct of operations and before designs are completed. Bathymetric data shall be collected where existing data do not meet the requirements of this document.

Changes to the local and regional bathymetry as a result of dredging, berms and structures shall be taken into account in the specification of parameters in this document.

The above-mentioned requirements regarding bathymetric data should cover the region of interest for operations and design (see [5.2.1](#)).

6.3 Tides

Tidal variations should be characterized from measurements, interpretations and forecasts at an accuracy and frequency consistent with requirements relating to:

- the formation of ice features;
- the grounding of ice features;
- drift and displacements of the ice cover and ice features;
- stresses transmitted to the ice cover;
- ice encroachment;
- EER systems;
- ice management and other vessel operations.

6.4 Storm surges

Water levels associated with storm surges shall be characterized from measurements, interpretations and forecasts with sufficient accuracy and frequency consistent with requirements relating to:

- the maximum and minimum elevations of ice actions;
- the maximum elevation to which floating ice features can be deposited on shore;
- the refloating of grounded ice features;
- displacements of the ice cover;
- ice encroachment on beaches, rockfill structures and other man-made structures;
- EER systems;
- ice management and other vessel operations.

7 Wind

7.1 General

Wind-related parameters shall be determined in accordance with ISO 19901-1.

Wind speed values shall be qualified by elevation, duration and averaging interval.

The joint distribution of wind speeds, air temperatures, and any other contributing parameters shall be interpreted for the determination of wind chill indices, sea spray icing, and other forms of snow and ice accretion to surfaces. Typically, data shall be interpreted in terms of normal values for operations planning and extreme values for design.

7.2 Polar lows

Information on polar low activity in the operating area should be collected in advance of operations and the likelihood of occurrence should be noted explicitly in the weather forecasts during operations.

If the effects of polar lows are not considered in wind hindcasts, their contribution to design values should be included through specific consideration of these events.

7.3 Katabatic wind

Information on Katabatic winds and contributing factors should be collected and interpreted if operations and structures are situated in areas that can be exposed to them.

7.4 Low level arctic jet

Where applicable, data should be collected and interpreted on the wind speeds associated with low-level jets as well as contributing parameters.

8 Waves

8.1 General

Information on waves and wave data shall be determined in accordance with ISO 19901-1.

The frequency of wave measurements during operations should be sufficient to capture relevant changes in key parameters.

For operations vulnerable to the combined effect of waves and ice, accurate measurement and timely dissemination of wave data should be prioritized.

Possible effects of long term reduction in ice extent and ice concentration on fetch should be considered in design and planning of operations.

8.2 Wave-induced ice motions

The basis for wave-induced motions of ice features should be the appropriate joint probability distribution between wave height and wave period at the relevant probability of exceedance.

Guidance on wave-induced ice motions of ice features can be found in ISO 19906.

8.3 Wave transmission through sea ice

In marginal ice zones, the potential for wave transmission through sea ice should be assessed.

Where operations are affected by interactions between sea ice and wave conditions, data should be collected to document and assist with the forecasting of changes to these conditions. Data for other contributing parameters, such as winds and currents, should be considered as well.

For design, the local wave regime and sea ice climate should reflect potential effects of wave transmission through sea ice.

9 Currents

9.1 General

Currents shall be determined in accordance with ISO 19901-1.

The local current regime shall be characterized for understanding ice drift patterns in the vicinity of the facility, the estimation ice interaction velocities with structures and for vessel operations, such as loading/unloading and ice management. Local anomalies in current fields should be identified, characterized and integrated into operational criteria. Particular attention should be given to currents in the vicinity of shelf breaks and in nearshore areas subjected to significant tidal effects or freshwater inflow. Conductivity and temperature measurements with depth can be used to supplement direct current measurements.

The regional current regime shall be characterized for understanding ice presence and deformation processes and for the development and implementation of drift forecasting algorithms.

Far-field current regimes can be used to understand ice formation processes and to assist with the sourcing of local ice features.

Vertical current profiles should be measured periodically where there is scour potential of berms, slope protection, piles, sheet-pile and other ice-resistant structural components.

9.2 Currents for sea ice and iceberg drift prediction

Ocean currents shall be assessed in terms of their influence on sea ice and iceberg drift. Consideration should be given to increased spatial, depth and temporal resolutions of data and models.

For sea ice drift forecasting, the surface current regime should be assessed by means of measurements, current models, inference from ice drift rates or some combination of these approaches.

For iceberg drift forecasting, the current regime through the water column to the depth of the deepest iceberg draft anticipated in the region should be assessed by means of measurements, current models, inference from iceberg drift data or some combination of these approaches.

9.3 Current records

Currents in arctic areas are generally poorly mapped.

In new areas, currents should be measured in accordance with ISO 19901-1 during the course of operations with durations of several weeks or longer.

Where activities are planned to take place over several years, simultaneous measurements of ice drift and local current measurements should be considered.

10 Temperature

10.1 General

Air and water temperatures shall be recorded according to the requirements of ISO 19901-1.

10.2 Sea water temperature

The freezing point of sea water shall be documented for the range of salinities present in the region.

Particular consideration should be given to sea water temperatures around the freezing point, potentially involving increased frequency, depth resolution and spatial resolution of measurements. Thermocline temperature profiles should be measured to forecast frazil ice formation and onset of new ice growth.

Where melting of ice features is a design or operational consideration, sea water temperatures should be measured to a depth at least equal to the draft of the largest ice features in the region.

10.3 Air temperature

Instruments used to measure air temperatures in arctic areas with temperatures lower than $-40\text{ }^{\circ}\text{C}$ shall be designed accordingly. This requirement exceeds the specifications outlined in ISO 19901-1.

The averaging interval and elevation associated with air temperature measurements shall be documented.

Wind chill shall be calculated for evaluating outdoor working conditions in cold climates. Wind and air temperature relationships should also be assessed in the context of ice growth, equipment performance and material properties.

11 Atmospheric parameters

11.1 General

Measurements of atmospheric parameters should be recorded in accordance with WMO standards and distributed to relevant national weather service providers. The requirements of this clause are incremental with respect to ISO 19901-1.

Atmospheric pressure shall be measured to assist with the interpretation of weather forecasts.

Consideration should be given to ultraviolet (UV) forecasts for operations involving outdoor personnel.

Geomagnetic storm forecasts should be consulted prior to commencement of operations.

11.2 Daylight considerations

Daylight conditions vary significantly throughout the year in the Arctic, stretching from complete darkness during winter to 24 h of daylight during summer. For planning operations, daylight conditions shall be taken into account.

11.3 Visibility and cloud ceiling

Atmospheric parameters should be measured to address optical visibility as well as the effectiveness of various imaging systems used for ice detection and characterization. Visibility measurements should be recorded in the horizontal and vertical directions.

Seasonal trends in fog conditions and their relationship with ice coverage should be assessed for operations planning. Inter-annual trends should be reviewed when increased incidence is anticipated in the future.

Visibility and cloud ceiling should be monitored and logged during operations.

11.4 Precipitation

Precipitation in the form of snow, rain, sleet and hail should be documented based on historical data prior to commencement of operations and should be monitored as part of operations.

Special requirements for the collection and interpretation of precipitation data in arctic and cold regions are given in [Clause 14](#).

12 Sea ice

12.1 General

Sea ice data shall be considered for all operations and for all phases of a structure's design service life in regions where sea ice has been present historically. Requirements for the consideration of sea ice actions are given in ISO 19906.

Sea ice information can be obtained from actual observations from the region of interest through the collection of new data or from representative historical data.

If ice data are unavailable for the region of interest, if local data records are less than 10 years in length or if local records do not accurately represent the expected ice conditions, information from nearby regions with similar ice environments and more significant archives can be used. If data from nearby regions are applied, any assumptions should be documented and uncertainties should be accounted for in the application of these data.

The region of interest for sea ice (see [5.2.1](#)) shall include the area of operations as well as the surrounding area. The surrounding area shall include an updrift distance based on a maximum drift rate, the full range of potential drift directions and a conservative estimate of the lead times associated with the proposed operations (see [5.2.1](#)).

Sea ice information collected during operations should be presented clearly and readily interpretable by all operational decision-makers.

Sea ice conditions can be influenced by the presence of engineered structures, abandoned berms or foundations and by dredging and icebreaking operations. Resulting changes to the ice cover, the presence of grounded features and sea ice mobility shall be documented and incorporated in design bases and operational protocols.

All sea ice data monitored during operations should be collected, verified and archived, if not otherwise dealt with by national and international ice services.

12.2 Sea ice season

12.2.1 Operations planning

Prior to the commencement of any offshore operations in regions where sea ice can occur, a historical study of sea ice season boundaries shall be conducted for the region of interest.

In areas where ice does not persist through the summer, the start of the ice season is when the first new ice growth takes place. Where ice can reach the region of interest at any point during the year, the start of the ice season is when the concentration of any ice type reaches a specified minimum value. The end of the ice season is when the total ice concentration falls below a specified value and remains so until the ice-free season begins.

In the absence of other information, a total of sea ice concentration of 1/10th in the region of interest can be used to define the end of the sea ice season unless the operation and equipment involved have zero tolerance to ice actions. Where new ice growth marks the start of the sea ice season, a total ice concentration in excess of 1/10th can be used as long as there is some ice tolerance to the operation and

equipment. Sea ice concentrations associated with season boundaries can vary with the nature of the operation and the vessels involved in its conduct.

The variability in the ice season start and end dates shall be assessed, with due account for uncertainties. Significant inter-annual variability in sea ice conditions is common in all arctic regions.

The frequency and duration of ice intrusions within the open water season shall be assessed.

12.2.2 During operations

Criteria defining the ice season boundaries shall be tracked prior to and throughout the operation.

Ice data defined in 12.3 through 12.6 shall be collected within the ice season boundaries defined in 12.2.1 and should be collected for a sufficient period prior to the start of operations to ensure data quality, to allow for training and to verify communications protocols.

Regardless of when an operation is undertaken, sea ice data shall be collected if ice is present or is forecast to be present in the region of interest.

12.2.3 Design

Ice season length should be assessed for the region of interest using the guidelines provided in 12.2.1. Season boundary definitions used for design situations should be developed specifically to accommodate parameters associated with these situations.

Where possible, the period of record for ice season length should be extended based on freezing degree day data for air temperatures.

12.3 Sea ice coverage

12.3.1 Operations planning

Sufficient ice cover data shall be collected and analysed to ensure that the important contributing factors to the formation, distribution and decay of sea ice are understood.

Local ice concentration shall be monitored under circumstances where ice coverage can impose operational constraints. Operational constraints can apply for EER, vessel access to a platform and weathervaning of moored vessels.

An assessment of historical frequency of sea ice incursions into the region of interest during the planned operating season should be made. Where relevant, a separate assessment of the frequency and variability of old ice incursions into the region of interest should be made.

Prior to the commencement of operations affected by sea ice, a historical study of sea ice concentrations and floe sizes by ice type in the region of interest shall be conducted.

A longer-term seasonal ice conditions forecast model for the region of interest should be applied if available and validated for the region of interest.

In marginal ice zones, historical data regarding seasonal and inter-annual variations in ice edge location shall be documented. The ice edge definition should be consistent with the requirements of the operations. Consideration should be given to the use of the national ice service definition as well, where different from the primary one used for operations.

12.3.2 During operations

Sea ice concentrations and floe sizes by ice type should be recorded at a frequency consistent with the requirements of the operation.

When physical ice management methods are used to reduce floe size (see ISO 35104 and ISO 19906), ambient and managed sea ice conditions, including floe size, shall be recorded.

Even if sea ice is not present within the region of interest, data on the concentrations of different sea ice types of the nearest sea ice should be monitored.

Ice edge (see [12.3.1](#)) positions shall be monitored prior to and for the full duration of the operation. Isolated areas of ice with total concentration in excess of the documented ice edge threshold shall be monitored.

Metocean conditions should be documented in accordance with ISO 19901-1 and archived together with the sea ice data as included in [Clauses 6](#) to [10](#). Forecast and measured data should be archived.

12.3.3 Design

Prior to the design of any offshore structure or vessel that services an offshore operation, a historical study of sea ice total concentrations and partial concentrations in the region of interest shall be conducted to document the frequency and attributes associated with the various ice types present.

Areal coverage of ridges, rubble fields, rafted ice and any other features distinguishable within the sea ice shall be assessed (see also [12.6](#)).

Data should be collected to document the length of sea ice passing by the site of interest over the course of one or more winter seasons. Ice length can be estimated by integrating the product of the ice concentration and the drift speed over the duration of the winter season.

Metocean conditions associated with sea ice occurrence should be identified and assessed as included in [Clauses 6](#) to [10](#). Fetch length characterization for wave-affected ice processes should also be considered.

12.4 Sea ice thickness

12.4.1 Operations planning

An assessment shall be made as to the sufficiency of ice thickness ranges provided in ice chart data. If not, the requirements of [12.4.3](#) for ice thickness estimation shall apply.

The thickness of all ice types interpreted from ice charts for the location(s) of the operation shall be considered.

12.4.2 During operations

Actual sea ice thickness should be recorded at locations and with a frequency that are consistent with the requirements of the operation. The measurements should also be consistent with the performance requirements of the vessels used in the operation.

Reference should be made to [12.6.3](#) for the thickness of specific ice features.

12.4.3 Design

Local measurements of ice thickness, where available, shall be used for design. Where local measurements are unavailable, data from nearby sites with similar temperatures, snow cover and sea ice regime may be used with proper justification.

Thermal growth models may be used to estimate ice thickness, if calibrated using data from local and regional sites with similar ice, wind, current and snow regimes. Due account shall be made for differences in these factors and in the potential for rafted ice contributions to the overall thickness.

Spatial differences in ice thickness shall be characterized on a scale consistent with design requirements.

With reference to [12.3.3](#), the annual average length of ice associated with different thickness and drift speed ranges should be estimated for use in local pressure and structural fatigue calculations (see ISO 19906).

Probability distributions of ice thickness and joint distributions with other parameters should be developed as required.

12.5 Sea ice drift and movement

12.5.1 Operations planning

All available records of regional sea ice drift within the region of interest should be collected for analysis and documented.

Prior to the commencement of operations, a historical study of sea ice drift speed variability and predominant directions in the region of interest shall be conducted.

Evidence of rapid changes in drift direction and contributing factors should be investigated.

An assessment of the respective influences of winds and currents on historical ice drift speeds, directions and pack ice pressure and dynamics shall be made prior to the commencement of offshore operations. Reference should be made to wind data ([Clause 7](#)) and current data ([Clause 9](#)) requirements.

Where relevant to the operations, evidence of tidally-induced movements of landfast ice shall be assessed.

12.5.2 During operations

Sea ice drift speeds and directions should be recorded at a frequency consistent with the requirements of the operation.

Drift speeds and directions for the nearest sea ice within the region of interest shall be monitored and estimates shall be made of travel time to the site of the facility or operation. Even if there is no sea ice present within the region of interest, the drift of the nearest sea ice should be monitored at a frequency consistent with potential time of entry into the region of interest.

Where relevant to the operation, sea ice drift and significant changes thereof should be forecast (see ISO 35104).

An assessment of the respective influences of winds and currents on ice drift speeds, directions and ice pack pressure shall be made throughout the duration of the operation. Consideration should be given to the drift of different ice types, e.g. first-year ice, old ice, new ice, as classified by the ice observation standard in the country where operations take place.

Landfast ice displacements should be documented and assessed where these have a material effect on operations.

12.5.3 Design

A historical study of sea ice drift speeds and directions in the region of interest shall be conducted.

The joint probability distribution of drift speed and direction shall be calculated. Site-specific data shall be collected, where necessary, to define the distribution. Effects of ice thickness, ice type, floe size and particular ice features on the distribution should be assessed.

Drift direction changes can be characterized in terms of drift track curvature and its relationship with drift speed.

In marginal ice zones, the influence of waves on the speed of ice features should be characterized and included, where appropriate, in probability distributions to be used for impact calculations.

In regions of landfast ice subjected to tidal actions, rates of ice movement away from shore should be characterized. Where historical data are not available, data should be collected. The effects of air temperature, tidal range and other relevant parameters on ice displacement rate should be assessed.

12.6 Sea ice features and conditions

12.6.1 General

Many sea ice scenarios can be defined in terms of readily identifiable ice features or conditions that are not dealt with specifically in [12.1](#) to [12.5](#).

Sea ice features of potential interest include extensive areas of rafted ice, ridges and rubble fields, stamukhi or grounded rubble piles, features formed or consolidated in the tidal zone and second-year or multi-year floes (old ice). Particular consideration should be given to features that are

- of large areal extent and consolidated to thicknesses in excess of the thermally-grown level ice thickness for a single winter, or
- of any size that are consolidated to thicknesses well in excess of the thermally-grown level ice thickness for a single winter.

Sea ice scenarios of potential interest can involve pressure, brash ice build-up, break-up, break-out, encroachment and other incursions.

12.6.2 Operations planning

Historical evidence of the areal density or frequency, magnitude and contributing factors relating to identifiable ice features and conditions shall be documented. Focus should be on expected parameter ranges as well as their seasonal and inter-annual variations.

Data shall be interpreted to allow the specification of robust operational criteria, in the form of unambiguous assessments of ice feature dimensions, ice conditions and metocean conditions.

Site-specific data shall be collected if available historical data are insufficient or if ice features and conditions cannot be inferred from existing local and regional data.

Consideration should be given to the clustering of ice features if this can have a material effect on the operation, such as for assessing ice management requirements.

12.6.3 During operations

The region of interest for data collection and observation shall be consistent with the requirements of the operation and for vessels involved in the operation.

Ice features and ice conditions should be monitored by dedicated and properly trained ice observers within the region of interest.

The locations, drift rates, significant attributes and dimensions of all identifiable ice features, as well as ice conditions in the region of interest, shall be recorded at a frequency commensurate with the safety requirements of the operation. Attributes, such as degree of consolidation for ridges, rubble fields and stamukhi that are measured or inferred based on resistance to icebreaking, should be recorded.

Data on previously observed features should be verified and updated as new observations are obtained. All measured data shall be saved for easy retrieval and interpreted data summaries shall be made available to operations personnel. Data shall also be placed in the context of thresholds associated with the ice operations criteria.

All operational data relating to ice features and conditions shall be archived and summarized for presentation following the completion of the operation or annually for ongoing operations.

12.6.4 Design

Measurement programs and interpretation procedures should provide unbiased estimates of the areal density (number of features per unit area) for ice features defined in 12.6.1. Typical values of interest for design include average values and ranges of values.

Measurement programs and interpretation procedures should also focus on obtaining unbiased probability distributions for the ice feature dimensions, e.g. waterline dimensions, thickness, mass, to be used for estimation of extreme values and other values used in design. Consideration should be given to the joint distribution of feature dimensions with other ice conditions, e.g. pack ice pressure, drift speed, and surrounding ice thicknesses and concentrations and physical environmental parameters, e.g. wind, waves, currents.

Due account should be taken for uncertainties resulting from limited record length (see 5.2.4.4) and other factors related to the relevance and accuracy of the data (see 5.1.3, 5.1.4 and 5.2.4.1).

The frequency of ice scenarios, such as encroachment, should be estimated by means of direct measurements or inference from contributing ice and metocean conditions. If inference is used to estimate frequency, the relationships used should be verified by means of field data.

12.7 Physical properties

The physical properties of ice include:

- ice temperature;
- ice density;
- sea ice salinity; and
- ice rubble porosity.

Physical properties of ice should be measured within the region of interest. If physical properties have not been measured within this region, data from regions with similar properties can be used with suitable justification. Justification should also be provided when ancillary data are used to correct parameter values measured in other regions.

The number of measurements and the accuracy of measurements should be consistent with their contribution to the design or operational situation.

Preference should be given to measurements made *in situ*. If ice property measurements are not made *in situ*, transportation and storage methods should ensure minimal changes to the state of the ice prior to testing.

Requirements relating to derived physical properties and mechanical properties of ice are included in ISO 19906.

13 Icebergs

13.1 General

13.1.1 General data requirements

Iceberg data shall be collected and assessed for structural design and to provide safe marine operations and EER for offshore facilities. Requirements for the consideration of iceberg actions are given in ISO 19906.

Iceberg data requirements should take into account the type of facility, the range of operations to be undertaken and the potential presence of vessels and equipment.

Unless stated specifically, the term “iceberg” is taken to encompass a range of glacial and similar ice features, including icebergs, bergy bits, growlers, ice islands and ice shelf fragments.

More specific information on regional iceberg climatology is included in ISO 19906.

13.1.2 Data collection

Requirements for the collection of iceberg frequency, size, shape and drift data, as well as associated sea ice and metocean data, are specified in [13.2](#) to [13.5](#). Requirements for the collection of physical iceberg properties are outlined in [13.6](#).

Sufficient redundancy in measurements and verification processes should be in place to ensure data correctness and accuracy.

13.1.3 Data analysis and presentation

13.1.3.1 Operations and design

Analysis and presentation requirements common to the various iceberg and associated parameters are provided in [13.1.3.2](#) to [13.1.3.4](#). Further requirements for specific data types are provided in [13.2](#) to [13.6](#).

13.1.3.2 Operations planning

Historical data for the area of interest should be summarized and presented in a summary report highlighting important features of the data and potentially their context in terms of operational criteria.

Iceberg drift forecast models should be verified in the region of interest with measured drift tracks and forecast accuracy should be documented. The spatial and temporal resolution of the models should be consistent with the needs of the operations.

Measurement equipment recommendations should be made to ensure that operational data are collected efficiently and accurately.

13.1.3.3 During operations

Iceberg data shall be interpreted to ensure accuracy in the re-identification and tracking of individual features.

Interpretation should be consistent with requirements for forecasting and deployment of ice management resources.

Sufficient data should be collected and recorded to allow the assessment of success for iceberg management operations.

All iceberg and associated physical environmental data relevant to the operations should be summarized in a daily report. Trends and changes in the data should be highlighted in each daily report.

All iceberg data collected during operations shall be archived. Incorrect data shall be corrected or flagged in the archive. Emphasis should be placed on the clear definition of parameters and on format for ease of retrieval.

Data should be summarized in a report following time-limited operations and annually for ongoing operations. The reports shall contain observational strategies and details of the measurements. Clear distinction should be made between actual observations and inference.

The performance of tactical and seasonal forecast models should be evaluated after completion of the operation.

13.1.3.4 Design

Iceberg data shall be analysed to provide the following information:

- probability distributions of parameters;
- estimates of uncertainty due to limitations of the instruments, number of data points, frequency of measurements and spatial resolution in the data;
- relevant correlations and relationships between parameters.

Reference should be made to ISO 19906 for a description of design situations.

Focus should be placed on removing biases in key parameters, including iceberg areal density and size.

13.2 Iceberg location and areal density

13.2.1 Operations planning

Prior to the commencement of any offshore operations in iceberg-prone regions, a historical study of iceberg frequency shall be conducted. Iceberg frequency shall be represented in terms of areal density (average number per unit area) for features in excess of a specified size. Iceberg size can be represented in terms of maximum waterline length, mass and other measures appropriate for the operation being undertaken. Iceberg frequency can also be represented in terms of the number of features crossing a particular latitude or into a geographical area over a specified period of time.

A region of interest shall be defined to include the actual area of operations. An extended region of interest, including an area updrift over which icebergs will be monitored, shall also be defined. The distance updrift will depend upon the rate of iceberg drift and the lead times associated with the operations and the procurement or allocation of resources.

All historical records of iceberg locations (generally expressed in terms of latitude and longitude) shall be assessed for the region of interest. Historical records shall be interpreted to minimize bias as a result of different iceberg detection methods. Projected future trends in iceberg frequency for the region of interest should be considered in operations planning and particular consideration should be given to circumstances that involve increased iceberg frequency.

Inter-annual variations, as well as seasonal and monthly variations in areal density, should be estimated to assess potential ice management and other operational requirements.

Where relevant for the operations, historical records of ice island, growler and bergy bit frequencies should be collected for the region of interest. A comparison with the frequency of accompanying icebergs should also be made.

13.2.2 During operations

Icebergs in the region of interest shall be tracked over time. Where possible, unique identifiers should be assigned to each iceberg. The iceberg status as freely-floating, grounded, gouging, under tow or influenced by another ice management technique shall be documented. Details of physical iceberg management operations shall be documented.

Iceberg positions shall be recorded in terms of latitude and longitude and consideration should be given to the provision of positions in terms of range and bearing from offshore facilities and service vessels.

The observation method or methods used to identify and track each iceberg target shall be documented.

Focus should be placed on the accuracy of iceberg positions, the frequency of iceberg observations and the re-identification of individual features. Typically, hourly positions should be recorded for all icebergs, day and night, within the region of interest.

The position of growlers and bergy bits observed in the region of interest should be recorded, if relevant for the operation. Growlers and bergy bits produced as the result of calving events should be tracked relative to the originating iceberg.

Consideration should be given to the forecasting of monthly and seasonal iceberg conditions for the region of interest and an extended region of interest.

13.2.3 Design

For offshore structure design purposes, historical records of iceberg positions, in terms of latitude and longitude, shall be collected for the region of interest (see [13.2.1](#)). Each iceberg position measurement should be tagged according to the detection system used for the measurement and the resolution of each measurement system should be documented.

Iceberg areal density, expressed in terms of the number of icebergs per unit area averaged over the course of the year, shall be estimated at the site of the facility. Seasonal (or monthly) and inter-annual variations in the iceberg areal density should be determined. Projected future trends in iceberg frequency should be considered and particular consideration should be given to circumstances involving increased iceberg frequency.

When counting icebergs, the smallest iceberg size (usually expressed in terms of waterline length) should be recorded to minimize bias in areal density estimates.

Iceberg data for preliminary design shall include, but not be limited to, areal density over a specified size threshold and an estimate of the proportion below this threshold.

Detailed design shall include but not be limited to annual and seasonal breakdowns of iceberg areal density and the location and duration of grounding events.

Where applicable for the design of offshore structures, growler and bergy bit areal densities shall be estimated.

13.3 Size, shape and stability

13.3.1 Operations planning

Historical records of iceberg sizes and shapes from the region of interest shall be collected. Seasonal and inter-annual variability of iceberg dimensions and shapes shall be assessed.

Where distinct iceberg populations are present, such as icebergs and ice islands, the relative proportions of these different populations should be estimated.

Available historical records of icebergs that have been observed to calve or roll in the region of interest should be collected and an assessment of the frequency with which icebergs were observed to calve or roll should be made.

Historical measurements of iceberg dimensions, profile information and metocean parameters should be assessed in terms of their influence on the frequency of observed rolling and calving events.

13.3.2 During operations

During operations, the dimensions and shapes of all icebergs observed in the region of interest shall be recorded. An assessment of the relative proportions of iceberg shapes and sizes shall be made throughout the operation.

The draft of all icebergs shall be measured or estimated based on above-water dimensions. Iceberg mass can be estimated based on above-water dimensions and profiles.

Underwater profile information should be collected when it is relevant for the operation.

Observed changes to iceberg dimensions as a result of melting, calving or rolling should be documented. Any observed iceberg calving and rolling events should be documented.

The frequency with which icebergs of different shapes and sizes are observed to roll or overturn should be documented.

Iceberg profile information should be collected as an indicator of instability. Long-period roll motions, symptomatic of unstable icebergs, should be noted and recorded.

13.3.3 Design

All historical records of iceberg dimensions and shapes from the region of interest around the facility shall be collected.

Iceberg data for preliminary design shall include, but not be limited to, probability distributions for waterline length and relationships between iceberg mass and waterline length.

Data for detailed design shall include, but not be limited to, further data on index dimensions, such as width, height, and draft, and relevant local and global shape data, preferably linked to the index dimensions.

Distinction shall be made between tabular and non-tabular icebergs and any other significant shape categorizations.

The relative proportions of icebergs with differing significant shapes and geographical origins, as well as their inter-annual variability, should be estimated.

Data shall be collected to define the size distribution of icebergs from all relevant shape categorizations.

Iceberg profiling should be conducted or interpreted to define global shape (for stability on impact, contact frequency and mass estimation) and local shape (for impact load estimation). Sufficient data should be analysed to ensure robust relationships between index iceberg dimensions and shape parameters used in the design.

Local iceberg shape data for icebergs in the area of interest shall be interpreted to minimize size bias. Where data for the region of interest are lacking, data from other areas where iceberg sizes and the degree of iceberg deterioration are similar can potentially be used.

If icebergs are present from different sources with distinct sizes and shape attributes, the above shape characterization shall be defined for each separate population.

Site-relevant iceberg profiling should be conducted to relate iceberg dimensions to potential hydrodynamic instabilities on impact with facilities.

Probability distributions of growler and bergy bit dimensions shall be developed for the design of structures with potential for damage from these features.

13.4 Iceberg drift

13.4.1 Operations planning

All available historical records of iceberg trajectories within the region of interest shall be collected for analysis and documented.

An assessment shall be made regarding the variability in drift directions and any predominant directions, considering the uncertainties of the records and their representation of local and regional conditions.

An assessment shall be made regarding the variability in iceberg drift speed, size effects, regional and water depth considerations, the mean and median speeds and extreme values of drift speeds.

A comparison between observed and modelled (hindcast or simulated forecast) iceberg trajectories should be performed to evaluate forecast accuracy for use in operations.

13.4.2 During operations

During operations, the drift speeds and directions of all icebergs observed within the region of interest shall be recorded at a frequency commensurate with the operational safety and decision-making requirements of the operation.

Drift velocity time series shall be plotted and analysed to identify anomalies and errors in positional information.

Drift velocity records shall be tagged to identify whether the iceberg was freely-floating, under tow or grounded.

Iceberg drift should be forecast using models verified with observed drift tracks in the region of interest. Uncertainty in drift forecasts should be based on past model performance and can be expressed in terms of 50 %, 90 % and 99 % iso-probability curves. Forecast models should be updated to reflect the latest available positional information and consideration should be given to correction of forecasts based on measured drift data. Additional iceberg drift forecasting requirements are given in ISO 35104.

Where applicable, an assessment of the drift of growlers and bergy bits relative to that of larger icebergs nearby should be made.

13.4.3 Design

All available historical records of iceberg drift speeds and directions in the region of interest shall be assessed. Focus should be on instantaneous speeds when considering ice impact scenarios.

The probability distribution of iceberg drift speed should be developed and any relationships or correlations with iceberg size, water depth and contributing metocean parameters should also be documented.

When ice scenarios involve bergy bits and growlers, probability distributions of drift speeds for these features shall also be developed. For bergy bits, growlers and larger icebergs under some circumstances, wave-induced velocities should be combined with the drift velocities to provide probability distributions for impact velocities against ships and structures.

The joint probability distribution between drift speed and direction (or velocity components) should also be developed when relevant to the design situation.

13.5 Metocean and sea ice context

13.5.1 Operations planning

Measured or hindcast wind, wave and current data shall be collected for the region of interest for periods in which iceberg drift and areal density data are available (see [13.2](#) and [13.4](#)). Sea ice cover data shall also be collected for the same periods.

An assessment of the respective influences of winds, waves, currents and sea ice on historical iceberg areal density and drift velocities shall be undertaken.

13.5.2 During operations

An assessment of the respective influences of winds, waves, currents and sea ice on observed iceberg drift velocities shall be undertaken during offshore operations. The effects of iceberg size and shape should be considered in the assessment.

Particular consideration shall be given to the detection of icebergs, bergy bits and growlers in waves and sea ice. Iceberg observations shall be tagged with information relating to sea state and sea ice concentrations, types and thickness in their vicinity.

Scenarios involving icebergs, sea ice presence and higher sea states should be forecasted.

13.5.3 Design

Measured or hindcast wind, wave and current data shall be collected for the region of interest for periods in which iceberg drift and areal density data are available (see 13.2 and 13.4). When only hindcast data are available, these should be verified with actual measurements. Sea ice cover data shall also be collected for the same periods.

Relationships between wave conditions and orbital velocities of bergy bits and growlers shall be developed.

Available historical records of icebergs observed in the presence of sea ice in the region of interest shall be collected and assessed, including information relating to the extent, concentration, type and thickness of the sea ice.

Changes in sea state as a result of sea ice presence should be assessed and correlated with iceberg presence.

13.6 Physical properties

Where relevant to the operation or design, the ranges in density of the ice and surface temperatures should be established. These can be based on local data or inferred from data collected in other regions.

Data requirements on the mechanical properties of ice are given in ISO 19906.

14 Snow and ice accretion

14.1 General

14.1.1 Consideration of accretion

The effects of snow and ice accretion shall be assessed for operations and structures in regions where these forms of accretion occur. For time limited operations, it is sufficient to consider only the part of the year when operations are carried out.

Effects and associated risks that can influence the integrity, performance, operation, HSE and EER characteristics of a facility shall be assessed when determining the data needs. Requirements for snow and ice accretion data should account for the particular characteristics of each structure and operation.

14.1.2 Accretion data collection

Snow and ice accretion data shall be collected on all permanent structures in arctic and cold regions and should be collected on all vessels and rigs.

The snow and ice accretion data should include:

- a general description of the facility or operation;
- a general description of the accretion event;
- details of the accretion measurements, including the thickness of the accretion on affected surfaces;

- complementary data on the physical environmental conditions causing the accretion, the orientation and operation of the vessel or facility, the properties and locations of the impacted surfaces, e.g. the type of surface material, and presence and type of coating and the mitigation measures in place; and
- photographic documentation.

The frequency of measurements should be sufficient to estimate start and end times for the event, to trigger operational responses and to estimate average and maximum accumulation rates.

When data collection is not possible or in other situations of missing data, calibrated hindcast models can be applied to estimate missing values. The stability of the calibration method shall be documented prior to use of the hindcast model for a specific area.

Reference objects should be defined for accretion measurements to represent variations in exposure, elevation and other pertinent characteristics of the structure, operation and physical environment.

The snow and ice accretion data should be specified for the reference objects and conditions in 14.2 to 14.4. The reference conditions should not include such effects as heat from the facility, anti-icing, de-icing and any other passive or active mitigation measures. The reference conditions can include the effects of natural melting.

Permanent locations for data collection on the facilities should be identified for comparison of different events. The locations should account for the variability of the facilities' exposure to these processes, including weathervaning or predominant cold weather directions. The locations should cover areas where high accretion is expected and less exposed areas where accretion is critical for safe operations.

14.2 Snow accretion

14.2.1 Classification

Snow can be classified as dry snow or wet snow. Other forms of precipitation are dealt with in 14.3.

Important parameters for the occurrence of snowfall and the development of snow drifts include:

- precipitation;
- vertical profile of air temperature;
- wind speed and direction;
- geometry of the structure.

14.2.2 Data collection

14.2.2.1 Prior to operations (in design and planning phase)

Site-specific snow data should be used if available. If site-specific data are not available, meteorological data from nearby coastal stations should be used. If site-specific metocean recordings are not available or cannot be applied directly, data from hindcast models should be applied. If hindcast data are used, proper calibration based on data from sites in the region or from sites elsewhere with similar conditions shall be documented.

Unless documented otherwise, it should be assumed that all precipitation at air temperatures equal to or below +1 °C falls as sleet or snow.

Snow drift and its effects are part of the action assessment for a particular structure or operation and will depend on the wind speed and direction and geometry of the structure.

14.2.2.2 During operations

Information about the amount of snow and the snow type during accumulation events should be collected from structures and vessels operating in winter. Operators are encouraged to make agreements with national forecasting agencies ensuring that data are stored in a systematic manner and made available to the public.

The following parameters should be recorded at least every 6 h during snow events:

- a) the snow thickness and the snow type for accumulations on surfaces that are near to horizontal and where the local wind perturbations do not influence snow accumulations;
- b) thickness, mass per area and horizontal extent of snow accumulation at locations where the largest snow accumulations are observed on the facilities;
- c) associated conditions (active or passive mitigation measures; heat from the facility);
- d) mitigation means used to remove the snow, if relevant (method, time and frequency of use); and
- e) photographic documentation.

Mass per unit area or alternatively snow thickness should be recorded on two or more surfaces located in different areas of the structure. In addition, all critical events due to snow accretion should be documented.

- All snow events that affect the operation of the facilities, in particular with regard to HSE and EER capabilities, should be documented with equal or better accuracy than that for normal snow events.
- The impeding snow accumulation and the accumulation scenario should be detailed.

During data collection, the temperature, the wind speed and the wind direction, the precipitation, the structure or vessel position, speed and heading should be recorded. Furthermore, drawings showing details of the geometry of the facilities with the associated information about the wind where the data are collected should be available.

All observations should be documented and summarized in an event log. At the end of every season, a summary report should be prepared with a presentation of key events and key features of snow accretion during the season. The report should include the log of all events as an attachment.

14.2.3 Analysis and presentation

Snow precipitation should be specified in terms of water equivalent at each location for a reference flat sheltered (where the wind effect is minimal) surface on a generic facility.

Due account should be made for the effect of wind on snow depth measurements.

Estimates of short-term (limited to one event with sufficient time and mild conditions in-between the events) and accumulated over a whole season (if applicable) snow amount should be made. Average, extreme and abnormal estimates should be developed.

The data presentation should include frequency, intensity and persistence of the events. Snow precipitation versus wind distribution (speed and direction) should be provided.

14.3 Atmospheric ice accretion

14.3.1 Classification

Atmospheric ice accretion (atmospheric icing) is traditionally classified according to the different formation processes.

- a) Precipitation icing:
 - 1) freezing rain or drizzle;
 - 2) accumulation and refreezing of sleet; or
 - 3) accumulation and refreezing of wet snow.
- b) In-cloud icing: formed at higher altitudes (including glaze, hard and soft rime).
- c) Hoarfrost: formed when water vapour transforms directly to ice at low temperatures (occurs near open sea, near cold land and in ice-covered waters).

14.3.2 Data collection

14.3.2.1 Prior to operations (in design and planning phase)

Site-specific atmospheric icing data should be used if available. If site-specific data are not available, relevant meteorological data from nearby coastal stations should be used with appropriate corrections for known deviations. If measurements are not available or cannot be applied directly, data from relevant hindcast models should be applied. If hindcast data are used, proper calibration based on data from sites in the region or from sites elsewhere with similar conditions shall be documented.

There are no requirements for data collection on atmospheric icing prior to time-limited operations, such as seismic surveys and exploration drilling.

14.3.2.2 During operations

Information on atmospheric icing should be collected from facilities. The following parameters should be recorded on a regular basis during atmospheric icing events:

- a) the thickness of the ice accretion on several surfaces where the atmospheric ice accretion is particularly large and description of the icing cross-section geometry (for icing on slender elements);
- b) a description of the type of ice accretion or alternatively the weight of ice per unit length (and the dimensions of the structure) or the weight of ice per unit surface area;
- c) characteristics of the local structural elements at the observation locations, i.e. diameter of slender elements, surface inclination;
- d) associated conditions (anti-icing, de-icing, heat from the facility);
- e) mitigation means used to remove the ice, if relevant (method, frequency of use);
- f) photographic documentation.

In addition, all critical events due to atmospheric icing accretion should be documented with better accuracy than normal atmospheric icing events.

All observations should be documented and summarized in an event log. At the end of every season, a summary report should be prepared with a presentation of key events and key features of atmospheric ice accretion during the season. The report should include the log of all events as an attachment.

If possible, the source of the icing (see [14.3.1](#)) should be reported separately, as thickness with corresponding densities.

14.3.3 Analysis and presentation

The data representing atmospheric icing events shall be analysed to find the best estimate of the range of the amount of atmospheric ice accumulations.

Atmospheric ice accretion shall be specified in terms of thickness and corresponding density for reference objects and different heights above sea level, as specified in ISO 12494.

Estimates of short-term ice amounts (discrete and independent events) and amounts accumulated over an entire season (if applicable) shall be made. Average, extreme and abnormal estimates shall be developed.

The data presentation shall include frequency, intensity and persistence of the events. Where relevant, the effect of wind speed and direction should be documented.

14.4 Sea spray ice accretion

14.4.1 Classification

Sea spray ice accretion can result from

- white cap spray, resulting from wind-wave interaction, and
- interaction spray, resulting from wave interaction with the vessel or facility.

14.4.2 Data for collection

14.4.2.1 Prior to operations (in design and planning phase)

If data collected from similar structures in similar conditions are available, these data shall be used as a basis for accretion estimates. If site-specific metocean recordings are not available or cannot be applied directly, data from hindcast models shall be applied. If hindcast data are used, proper calibration against measurements shall be documented.

An assessment shall be made on the probability of and potential amount of accretion of sea spray icing prior to all operations in arctic and cold regions. The assessment shall be based on all available historical information at the area of the activity.

14.4.2.2 During operations

All collected data, measurements and observations on accreted sea spray icing during events when data have been collected shall be stored in a database for possible later re-analysis to identify relevant design values for ice accretion during arctic operations. The database organization shall be documented.

Information about the amount of sea spray ice accretion and the density of the ice in extreme sea spray ice accretion events shall be collected from a facility for future planning of arctic and cold climate design and operations. The following parameters shall be recorded for sea spray icing events:

- a) the total thickness of the ice accretion on several surfaces where the sea spray ice accretion is particularly large; the surfaces shall be representative of different areas of the structure and cover at least two different elevations;
- b) a physical description of the sea spray ice accretion or alternatively the weight of ice per unit length or the weight of ice per unit surface area;
- c) frequency and height of wave-splash;

- d) associated conditions (anti-icing, de-icing, heat from the facility);
- e) mitigation means used to remove the ice, if relevant (method, frequency of use);
- f) photographic documentation;
- g) lowest and highest elevation of observed sea spray icing.

Particular attention should be given to the documentation of events where the sea spray icing accretion is significant.

During data collection, the air and sea water temperature, the wind speed and direction, precipitation, the significant wave height, period and direction, structure or vessel response to waves (pitch and heave amplitudes), structure or vessel characteristics affecting the wave response and interaction, structure position, speed and heading and presence of sea ice shall be recorded. Furthermore, drawings showing details of the geometry of the facilities (including local characteristics of the structure at the recording points) with the associated information about the wind where the data are collected shall be available.

All observations should be documented and summarized into a log filled on an event basis. At the end of every season, a summary report should be prepared with a presentation of key events and key features of sea spray icing accretion during the season. The report should include the log of all events as an attachment. The presentation shall include the frequency of spray ice for relevant categories of geometries and facilities as well as frequency and duration of icing events per month.

14.4.3 Analysis and presentation

Data from sea spray icing events shall be analysed to estimate sea spray ice accumulations during an event.

Sea spray ice accretion shall be documented in terms of thickness and density for the reference objects.

Estimates of short-term (discrete and independent events) and accumulated icing over an entire season (if applicable) shall be made. Average, extreme and abnormal estimates shall be developed.

The data presentation shall include frequency, intensity and persistence of the events. Sea spray ice accretion data versus wind distribution (speed and direction) shall be provided.

As a minimum, assessments of accretion shall consider the following processes:

- spray generation;
- spray transport;
- spray collision, freezing and run-off.

Estimates of sea spray icing shall include local maxima and the associated areal mean.

15 Seabed considerations

15.1 Context

15.1.1 General

The seabed considerations are limited to ice gouge, strudel scour and permafrost issues.

The requirements of this clause are incremental to the data collection and analysis requirements of ISO 19906, ISO 19901-4 and ISO 19901-8.

15.1.2 Design issues

Ice gouge, strudel scour and permafrost data can be required for the design of offshore facilities, such as subsea structures, pipelines, platforms, island approaches, anchoring systems and excavations.

The geographical coverage of the survey should be sufficient to cover the anticipated area of the facility. Areas in close proximity can be used, provided ice conditions, ice drift, water depth and other relevant processes are representative.

If a survey program is conducted, it shall be designed such that relevant data are obtained for the application of concern.

15.1.3 Operational issues

Operational considerations can include, but are not limited to, maintenance of structures, anchoring, dredging, post-incident assessment and potential damage to seabed and subsea facilities from deep-draft ice features.

Aspects of concern for offshore operations can include:

- ice gouge;
- infill;
- seabed mobility;
- seabed properties;
- strudel scours;
- permafrost.

Although the purpose of surveys dealt with in this clause is to assist with offshore operations, many such surveys can be conducted well in advance of the operation.

The geographical coverage of the survey (the region of interest; see [5.2.1](#)) should be sufficient to cover the anticipated area over which the operation will take place.

15.2 Ice gouge

15.2.1 Requirements for collection

15.2.1.1 Measurement program design

Ice gouge issues are best addressed by surveying the seabed directly. Some information can be obtained by surveying ice features that could potentially contact the seabed.

The formation rate, location and characteristics of ice gouging can be subject to annual variability. As a consequence, ice gouge data shall be collected over a long enough period by means of repetitive mapping and over a sufficient area to allow reliable evaluations of the gouging regime.

The timing of an ice gouge survey should take account of infill rates and degradation rates due to waves and currents.

The ice gouge program should be designed to consider the parameters of concern, which can include:

- a) geographical location of the ice gouge mark on the seabed;
- b) date or year of the event producing the ice gouge mark;
- c) ice gouge feature type, i.e. pit or furrow;

- d) plan dimensions, orientation, and elevation change (rise-up) of the feature;
- e) depth of the incision below the mudline;
- f) seabed disturbance beneath the incision in soil types where this can be ascertained.

A measurement program should provide necessary context and include collection of parameters affecting the accuracy of the results. Ancillary data can include:

- bathymetric data;
- spatial and depth distributions of soil type;
- geotechnical parameters.

Seabed surveys conducted in the presence of sea ice or other ice features shall satisfy the ice management requirements of ISO 35104.

15.2.1.2 Ice gouge measurements

Geophysical surveys shall be conducted that are sufficient in quantity, resolution and coverage to meet the design requirements specified in ISO 19906 and in this document.

Instruments that provide quantitative three-dimensional data such as multi-beam sonar shall be used for obtaining information on ice gouge geometry and orientation and should be used for collection of ice gouge depth and formation rate. For certain applications, systems that produce only two-dimensional profiles of seabed elevation can be used for extracting ice gouge formation rate and depth.

The accuracy of the ice gouge depth measurements shall be sufficient to meet the design and operational requirements.

The spatial resolution of the geophysical measurements should be sufficient to adequately characterize key ice gouge features including length, width, orientation, change in elevation (rise-up) over the length of the ice gouge, variations in incision depth and the level of the adjacent undisturbed seabed.

Data shall be compensated for motion of the instrument over the entire survey area. Known deviations shall be identified.

In regions where ice gouges are frequent, multiple geophysical surveys should be conducted in order to obtain information on the annual variability. A minimum of three years of data collection is recommended, but this can be adjusted depending on the nature of the ice conditions and any prior knowledge of ice gouge variability.

Horizontal and vertical registration shall be of sufficient accuracy to ensure positive identification of ice gouge marks on previous or subsequent surveys. This requirement shall be over and above any other survey requirements.

For environments in which ice gouges are infrequent, but have produced a lasting record in the seabed, e.g. icebergs, a single survey can be sufficient if alternative methods for estimating gouging rates are available. In such cases, consideration should be given to discrimination of relict and recent ice gouges.

In regions where the seabed is mobile, surveys should be conducted as soon as practical after the ice cover is no longer present to minimize infill effects. In very dynamic areas, repeat surveys of specific features are required to quantify infill rates. These could be from a separate survey, e.g. in spring and autumn, or at the end of the spring survey, depending on the infill conditions.

The geophysical survey(s) should be of sufficient spatial coverage to generate a large enough sample size. This can involve extending the survey beyond the region of interest surrounding the proposed facility or operation.

15.2.2 Requirements for analysis and interpretation

Where repetitive mapping data are not available, dating of features using indirect techniques shall be undertaken and the associated levels of uncertainty shall be documented. In addition, simulation or other modelling techniques can be used to estimate ice gouge formation rates if their accuracy has been verified. Ice gouge formation rates should be assessed through different and independent means.

While ice gouge features are very well preserved in some regions, degradation as a result of waves and currents and infill as a result of sedimentation, can occur very rapidly in other regions, soil types and water depth ranges. Degradation and infill should be assessed when dating ice gouge features.

The form of the probability distribution used to characterize ice gouge depth should take into consideration previous experience in terms of ice features, i.e. of glacial or sea ice origin, seabed material, seabed slope, local ice regime and predominant drift directions.

Consideration should be given to separate interpretation procedures for pit and furrow features.

If ice gouge parameters cannot be estimated directly from surveys, inference can be made through mathematical or physical models, for which guidance is provided in ISO 19906.

15.2.3 Requirements for documentation

Ice gouge survey data shall be summarized according to:

- a) the location and physical attributes of each ice gouge feature;
- b) an estimate of when the ice gouge mark was created;
- c) the sensor(s) used for the interpretation;
- d) the resolution and accuracy of the measurements;
- e) the local characteristics of the seabed material.

Probability distributions shall be defined for key ice gouge parameters (depth and width). Interrelationships, i.e. joint probability distributions, between the different ice gouge parameters should be developed where appropriate.

Where different soil types are present in the survey area, statistical ice gouge data for each soil type should be documented.

Presentation of ice gouge data should address considerations of water depth, seabed slope and seabed orientation with respect to the dominant ice drift direction.

Full-resolution survey data, whether multibeam sonar or shallow geophysical, shall be stored in an accessible form for visualization.

Geographical registration of the survey data shall be provided in standard coordinates, e.g. latitude/longitude or universal transverse mercator projection.

15.3 Strudel scours

15.3.1 Context

Strudel scouring potential should be established through the identification of sources for fresh water inflow.

Sea ice conditions should be documented in the vicinity of the fresh water sources.

Evidence of fresh water flow over the sea ice and for drainage through the sea ice should be documented by direct observation or remote interpretation.

Potential changes to the sea ice environment, as a result of heat loss from submarine pipelines, should be established.

Correlations between freshwater flow rates, winter severity, frequency of strudel scour formation and size of strudel scour features should be established. Year to year variability should be taken into account.

15.3.2 Measurements

Strudel scour parameters of concern can include:

- potential sources of freshwater runoff onto the sea ice;
- velocity and extent of freshwater jet at seabed;
- location and frequency of strudel scour features;
- mudline dimensions, depth and shape of strudel scour features;
- variability in dimensions as a function of soil parameters and water depth;
- mechanical properties of the soil.

Surveys documenting the formation rate and dimensions of strudel scour features should cover representative areas in terms of proximity to freshwater inflow and similarity to ice conditions in the region of interest.

Where possible, rates of strudel scouring should be based on repetitive mapping of the seabed.

Surveys shall be conducted annually over subsea assets located in areas and water depths prone to strudel scour formation.

The dimensions of strudel scour features shall be measured and documented. Such measurements should include maximum plan dimensions and maximum depth and can include plan shape and depth variation over the footprint of the feature.

Survey resolution should be consistent with the objectives of the survey. For example, smaller strudel scour features could be of more importance for free spans of a small diameter pipeline.

15.3.3 Analysis and interpretation

Where repetitive mapping data are not available, dating of features using indirect techniques shall be undertaken and the associated levels of uncertainty shall be documented. In the absence of measurements, rate of occurrence and feature size shall be estimated based on realistic assumptions regarding the formation process, with due account for associated uncertainties.

When estimating formation rate and feature dimensions, consideration shall be given to wave, current or flow driven infill effects, which can occur very rapidly.

The probability distributions used to characterize strudel scour dimensions should take into consideration previous experience in other regions and the properties of the seabed material.

15.4 Submarine permafrost

15.4.1 General

Permafrost parameters of concern can include:

- areal distribution of permafrost and associated distributions of soils;
- depth of active layer and thickness of permafrost;

- thermal properties of the permafrost, including present temperature and salinity profiles and their state relative to thermal equilibrium and potential for salt migration;
- mechanical properties of the soil and permafrost, including ice content.

Potential changes in permafrost parameters and their distribution over time should be considered, including those resulting from operations.

The presence of permafrost should be documented through the entire soil column to its maximum depth.

Soil types associated with permafrost zones should be identified.

Permafrost zones should be classified according to whether or not they are ice-bearing and ice-bonded. Ice lenses should also be identified.

15.4.2 Design issues

Permafrost temperatures should be measured or inferred as an indicator of potential future thaw instability. Ice content and pore-water salinity should be measured since they can impact the performance of structures.

The perimeter of permafrost zones projected to the surface should be identified because of association with gas venting and correspondingly less stable soils.

The potential influence of temperature changes on shear strength and thaw settlement of soils should be assessed and documented. Observed trends and future projections of temperature trends should be included when considering the implications for soil stability and permafrost conditions.

15.4.3 Operational issues

The presence of gas in permafrost zones should be identified.

The potential influence of temperature changes on shear strength and settlement of soils should be assessed and documented.

15.4.4 Site investigations

The instruments, sampling methods and processing techniques used to identify and map subsea permafrost shall be identified.

The context of geophysical investigations should be substantiated through the mapping of features, such as sediment volcanoes, pockmarks and thaw depressions on or within close proximity to the seabed.

For geotechnical investigations, handling of samples should ensure minimum disturbance and temperature change. Pore-water salinity and the proportions of unfrozen versus frozen moisture of permafrost should be documented.

16 Coastal considerations

16.1 Context

Additional provisions relevant to physical environmental data for operations in arctic coastal regions are given in this clause. Requirements and guidance provided in [Clauses 5 to 15](#) and [Clause 17](#) can also apply to coastal regions, including requirements for data collection, interpretation, analysis, documentation and storage.

16.2 General coastal considerations

Data collection should be planned to allow quantification of the potential effects of operations on the physical environment.

16.3 Specific coastal considerations

16.3.1 Water levels

Data should be collected to document possible correlation between extreme water level fluctuations and other parameters such as wind (and co-wind wave state), current or sea ice state.

The effect of water level changes on displacements of landfast ice shall be documented.

16.3.2 Wind

Directional distributions of wind relative to the predominant direction of the shoreline should be documented.

16.3.3 Waves

Data should be collected to document potential effects of sea ice presence on wave fetch distances.

The effect of operations and structures on the local wave climate shall be addressed.

16.3.4 Currents

The effect of operations and structures on the local current climate shall be addressed.

16.3.5 Temperature

The influence of wind direction on air temperatures should be addressed and documented.

The effect of local currents and freshwater inflow on water temperatures and salinities should be addressed.

The effect of operations and structures on local air and water temperatures shall be addressed and documented.

16.3.6 Visibility

Consideration should be given to visibility in coastal regions due to wave generated sea spray and fog in the shore-coastal transition area.

16.3.7 Sea ice

Data should be collected on coastal sea ice features, including:

- a) landfast ice (thickness, displacement, persistence);
- b) stamukhi (location, size, frequency);
- c) ice in tidal zone (thickness, growth, lateral dimensions of features);
- d) shore ice or ice foot (onshore extent, thickness, persistence);
- e) ice pile-up and encroachment on shore;
- f) tidal cracks and their locations;

g) coastal polynyas.

The effect of operations on the presence, drift and morphology of sea ice shall be documented. Specific consideration should be given to

- the extent, movement, and duration of landfast ice,
- the amount and duration of moving sea ice,
- the amount and thickness of brash ice, and
- the location and morphological attributes of ice rubble fields.

16.3.8 Icebergs

Bathymetric considerations at the glacier front and in the drift path of icebergs can be used to limit the morphological properties of icebergs reaching the open ocean and the area of interest.

16.3.9 Snow and ice accretion

Onshore snow depth data shall be collected as they pertain to snow loads and where drifting snow can impede operations in coastal regions.

The influence of local water temperatures, air temperatures, wind speed and wave climate shall be considered in the planning of operations and designs influenced by sea spray icing.

Locally-measured parameters of relevance for atmospheric icing, such as humidity, air temperature and precipitation, should be assessed and applied in coastal regions.

16.3.10 Seabed considerations

The requirements of this subclause are incremental to the requirements of ISO 19901-4 and ISO 19901-8.

Data requirements relating to permafrost are dealt with in [15.4](#) and [17.2](#).

Changes to local bathymetry as a result of littoral transport and deposition from rivers shall be acknowledged for design and planning and monitored subsequently. The effect of man-made structures shall be considered.

Charting of previously uncharted waters shall be conducted in the vicinity of operations and planned structures to allow for safe icebreaking operations and for the identification of potential locations where ice features can ground.

17 Onshore considerations

17.1 Context

Relevant requirements given for offshore ([Clauses 6 to 15](#)) and coastal ([Clause 16](#)) zones shall also apply to onshore areas, including requirements for data collection, interpretation, analysis, documentation and storage.

Physical environmental data associated with

- permafrost thawing,
- coastal and riverine land erosion,
- snow accumulations and flooding as a consequence of poor water drainage, and
- meteorological impacts on transportation,

shall be collected, analysed, and presented to support design and operations in onshore regions.

17.2 Onshore permafrost considerations

17.2.1 General

Local onshore permafrost conditions and related thermal properties should be documented and monitoring programs should be established well in advance of design and operations.

Permafrost temperatures and characteristics should be measured or inferred as indicators for potential future soil instability.

17.2.2 Design issues

Permafrost data shall be collected and documented for the design of onshore facilities, such as pipelines, treatment and processing facilities, roads and airstrips and housing and warehouse facilities. If a survey program is conducted, it shall be designed such that sufficient data are collected to characterize the permafrost for the application of concern. The scope should include permafrost occurrence and characterization, ground thermal regime, surficial geology, presence of ground ice and groundwater and pore-water salinity (see [17.2.5.2](#)).

The geographical coverage of surveys shall be sufficient to cover the region of interest (see [5.2.1](#)). Data from areas in close proximity may be used where terrain, climatic processes and geothermal processes are representative. In the case of linear structures, such as roads and pipelines, a survey corridor several kilometres wide can be considered to provide sufficient breadth to optimize routing.

Soil and sediment conditions, permafrost and ground ice presence shall be documented as part of the characterization and logging of the subsurface for the entire soil column to its maximum depth.

In regions where permafrost is present, ongoing permafrost surveys, including monitoring and data programs, should be established and archived for future reference.

Historical and projected future trends in local permafrost conditions, ground temperatures, active layer thickness, permafrost degradation and implications for ground stability should be considered. The past and expected future trends in permafrost temperatures and stability can be based on geothermal modelling of permafrost changes, local knowledge, analysis of core samples, geotechnical properties; characterization of subsurface stratigraphy, remote sensing analyses, climate change projections and regional standards and guidelines for permafrost foundations.

Where ice-rich permafrost cannot be avoided, it shall be documented with ongoing monitoring programs, as outlined in [17.2.3](#).

17.2.3 Operational issues

Operational considerations can include, but are not limited to, maintenance of structures and the mitigation of permafrost processes that impact the constructed facilities.

Aspects of concern for onshore operations can include

- terrain stability, including but not limited to, thermokarst development and slope instability,
- thaw settlement and/or frost heave of pipelines, and
- creep deformation of permafrost foundations.

Where thaw sensitive conditions are noted and documented, ongoing monitoring surveys should be established to track the temperatures of the ground and air, to measure changes in the permafrost properties and to monitor the engineering performance of foundations and facilities.

Although the purpose of surveys dealt with in this subclause is to assist with onshore operations, many such surveys can and should be conducted well in advance of the operation.

17.2.4 Terrain data requirements

17.2.4.1 Context

The spatial context for permafrost stability and thawing rates should be established according to permafrost and soil types, surficial geology, periglacial landforms, organic soil layers, air and soil temperatures, snow cover, surface and subsurface hydrology, vegetation cover, as well as the heritage of past climate conditions.

17.2.4.2 Mapping

Terrain mapping should be conducted to provide information on the following:

- presence or absence of permafrost terrain;
- identification of terrain units and surface geology;
- identification of terrain susceptible to thaw instability or frost heave;
- identification of permafrost geohazards, including mass wasting processes and thermokarst development.

17.2.4.3 Data sources

Terrain mapping shall be produced to a resolution and scale sufficient to identify relevant landforms for development and project phases.

Validation of remotely-sensed data shall be provided through secondary means.

17.2.5 Permafrost characterization

17.2.5.1 Context

Adequate characterization of the permafrost regime within the study area shall be undertaken to provide both a baseline of the permafrost regime and to provide input for the prediction of project effects on the permafrost regime. The determination of “adequate” should be considered in light of the project scale and other land use during the development phase of the project.

Permafrost characterization should consider the overall project needs and requirements.

17.2.5.2 Data requirements

The following permafrost attributes shall be characterized:

- subsurface stratigraphy, lithology and engineering properties;
- ground temperatures;
- ground ice content.

Data collection should be facilitated by geotechnical investigations, including the drilling of boreholes, geophysical surveys, soil and rock sampling, *in-situ* testing, laboratory testing, installation of instrumentation and related activities.

17.2.5.3 Subsurface stratigraphy

The subsurface characterization should be performed using tools and techniques that take into consideration project scale, development phase, access, and seasonality of the investigation.

To provide sufficient characterization, the following techniques should be considered:

- borehole drilling;
- recovery of undisturbed frozen core samples;
- *in-situ* testing in warm permafrost;
- installation of instrumentation, such as thermistor beads.

Soil, rock and permafrost descriptions shall be described and characterized using a recognized standard. Any deviations from the standards being used shall be documented.

17.2.5.4 Ground temperatures

Ground and/or air temperatures shall be monitored over an adequate period of time to ensure that the annual ground temperature regime can be developed. The depth of ground temperature monitoring should be suitable for the project type and scope.

Ground temperatures shall be monitored using calibrated multi-bead thermistor cables or similar devices that can determine ground temperatures over the entire depth of interest.

Ground temperatures shall be plotted with depth as a “trumpet curve” to illustrate the annual range of ground temperature variations and for defining the thickness of the active layer.

17.3 Land erosion risks

17.3.1 General

Data on wave action, snowmelt, rainfall events, and thawing permafrost shall be collected to document their influence on rates of erosion of shorelines and riverbanks, as well as the occurrence of landslides and thaw slumps.

17.3.2 Shoreline and riverine erosion

Erosion changes and rates shall be monitored, recorded and documented in the vicinity of onshore facilities located in regions with vulnerable coastal and riverine erosion.

Historically observed trends in shoreline and riverine erosion shall be analysed and documented.

Where possible, estimates of future trends in erosion rates should be made.

17.3.3 Flooding and drainage risks

Climate, weather and hydrological data associated with surface drainage risks should be collected and summarized, as needed. These data can include air temperature, precipitation amounts and types by season, extreme precipitation events and their local impacts. Local knowledge can be used to fill in data gaps, as needed.

Where available, hydrological data should be collected and used for site drainage system planning and operations.

Topographic data (see [17.2.4.2](#)) shall be assembled and used for drainage planning.

In the absence of locally measured data, information from climatologically representative nearby stations having sufficiently complete weather/climate data can provide an initial estimate for design.

When incomplete or uncertain data are used, assumptions regarding their use should be stated and limits concerning their accuracy and applicability should be factored into the planning methodology.

17.4 Transportation access

17.4.1 General

Data shall be collected, analysed and documented to support inland transportation design and operational initiatives. Key parameters should include those dealing with visibility, bearing capacity, permafrost, erosion, snow and water drainage issues.

17.4.2 Ice road data needs

Lake ice monitoring of freeze-up and break-up dates, ice thickness and ice quality shall be undertaken to support construction, operations, safety and load limits of winter roads and their support facilities.

Ice thickness, flooding and presence of large cracks should be monitored daily throughout the operating season of ice roads.

17.5 Inland snow data

17.5.1 General

Snow accumulations shall be documented for snow loads associated with buildings and other engineered structures, operational requirements for snow clearing, transportation operations, spring snowmelt and drainage risks and permafrost thawing.

Snow properties can be characterized in terms of snowpack depths, snowpack water equivalents, daily and seasonally accumulated snowfalls and proportion of area covered by snow.

Reference should be made to [Clause 14](#) and more specifically to [14.2](#) for requirements on the measurement, interpretation and storage of snow data.

17.5.2 Snow measurements

The frequency, accuracy, spatial resolution and extent of the remote sensing and automated sensor technologies for snow measurements should be commensurate with operational and design requirements.

Annex A (informative)

Additional information and guidance

NOTE The clauses and subclauses in this annex provide additional information and guidance on the clauses in the normative part of this document. The same numbering system and heading titles have been used for ease in identifying the subclause in the normative part of this document to which it relates. Entries to tables have been left blank in circumstances where no specific guidance is provided, the attribute does not apply or a wide range of values for the attribute can apply.

A.1 Scope

No additional guidance is offered.

A.2 Normative references

No additional guidance is offered.

A.3 Terms and definitions

The following terms used in this document are intended to have the definitions given in ISO 35101:

- anti-icing;
- cold climate conditions;
- de-icing;
- hazard (see also ISO 35103, ISO 35104, ISO 19900 and this document);
- weather protection;
- winterization;
- working environment.

The following terms used in this document are intended to have the definitions given in ISO 35103:

- emergency;
- environmental impact;
- hazard (see also ISO 35101, ISO 35104, ISO 19900 and this document);
- risk (see also ISO 35101);
- safety.

The following terms used in this document are intended to have the definitions given in ISO 35104:

- design;
- hazard (see also ISO 35101, ISO 35103, ISO 19900 and this document);
- ice detection;

- ice management (see also ISO 19906);
- ice regime;
- polar low (see also ISO 19901-1);
- recording.

The following terms used in this document are intended to have the definitions given in ISO 19900:

- abnormal environmental event;
- action;
- characteristic value;
- design criteria;
- design service life;
- design situation;
- design value;
- extreme environmental event;
- fixed structure;
- floating structure;
- hazard (also defined in this document);
- limit state;
- operator;
- platform;
- reliability;
- return period (also ISO 19901-1);
- scour (see also ISO 19901-1);
- structure;
- topsides.

The following terms used in this document are intended to have the definitions given in ISO 19901-1:

- hindcasting;
- long-term distribution;
- short-term distribution;
- marginal distribution;
- mean sea level;
- operating conditions;
- polar low;
- return period;

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- seabed (see also ISO 19901-4);
- sea state;
- significant wave height;
- storm surge;
- water depth.

The following term used in this document is intended to have the definition given in ISO 19901-4:

- seabed (see also ISO 19901-1).

The following term used in this document is intended to have the definition given in ISO 19901-6:

- weather window

The following terms used in this document are intended to have the definitions given in ISO 19906:

- broken ice;
- consolidation;
- consolidated layer;
- first-year ice;
- floe;
- freeze-thaw;
- ice alert;
- iceberg;
- ice concentration;
- ice detection;
- ice encroachment;
- ice gouge;
- ice island;
- ice management (see also ISO 35104);
- ice ridge;
- ice scenario;
- infill;
- landfast ice;
- level ice;
- multi-year ice;
- old ice;
- pack ice;
- permafrost;

- ridge keel;
- ridge sail;
- rubble field;
- rubble pile;
- sea floor/mudline;
- second-year ice;
- shelf ice;
- stamukha;
- strudel scour.

Additional ice terminology not defined in this document or in the above-referenced standards can be found in the WMO sea ice nomenclature^[15] or in MANICE^[16]. Additional meteorological terminology can be found in the WMO guide to meteorological instruments and methods of observation^[17].

A.4 Symbols and abbreviated terms

No additional guidance is offered.

A.5 General requirements

A.5.1 General

A.5.1.1 Physical environmental data requirements

It is recommended to store all data recorded during the course of operations for a period of at least 30 years following the end of the operation.

A.5.1.2 Relationship with ISO 19901-1 and ISO 19906

No additional guidance is offered.

A.5.1.3 Data sources

No additional guidance is offered.

A.5.1.4 Selection of appropriate parameters

Appropriate data characterizing the physical environment should be collected and analysed as part of the operations planning process and should be updated as more data become available during the operation.

Appropriate physical environmental data should be collected and analysed prior to concept selection and detailed data should be used for the development of final designs.

Measurement programs conducted prior to operations and design should build on previous data for the region, draw on local expertise and provide a consistent basis for measurement programs associated with subsequent operations.

A.5.1.5 Physical environmental data monitoring

Appropriate physical environmental parameters should be monitored and recorded during all project stages to ensure safe operational procedures and their continued improvement.

Measurement techniques should be selected to ensure that the intended parameter values are obtained. Measurements should be calibrated properly and calibrations should be verified periodically over the measurement period. Measurements should be verified using independent means prior to their use and for selected time periods or on a continuous basis thereafter depending on criticality.

A.5.1.6 Data storage

Consideration should be given to the storage of collected data, measurements and observations in a database for ease of retrieval and for integration with other data sources. Potential uses include efficient data access during future operations and the development of design criteria.

A.5.2 Particular aspects

A.5.2.1 Region of interest

No additional guidance is offered.

A.5.2.2 Criticality

Consideration should be given to the use of maximum wind speeds and currents when forecasting the drift of potentially hazardous ice features in the proximity of platforms, structures and loading or unloading operations.

A.5.2.3 Variability

No additional guidance is offered.

A.5.2.4 Statistical

A.5.2.4.1 General

In arctic environments, recognition should be made of potentially short-time records of measured data, e.g. ice parameters, or uncertainties associated with physical processes, e.g. ice formation, drift and deterioration.

Designers can require ice and metocean parameters at (very) low probabilities of occurrence. Since data covering long periods are rarely available, extrapolation of existing data is necessary. The extrapolation can be performed using statistics of extreme values. In doing so, the choice of probability distributions should provide accurate fits to the measured data and be consistent with the nature and bounds associated with the processes being represented. In general, extrapolation will be more accurate for longer datasets. Comparison of different methods, provision of full details for methods applied, and documented assumptions can ensure better verification.

In some relatively homogeneous areas, metocean hindcasts can be used to extend the time basis for estimating return period values at a particular site, thereby reducing the amount of extrapolation needed. However, even with long datasets, estimates of (very) low probability parameter values can still depend to a considerable degree on the extrapolation method.

It should be noted that understanding of ice climatology is not at a stage where robust hindcasting is feasible as in the case of metocean parameters.

Many ice scenarios can be represented in terms of episodic occurrences, characterized by an event magnitude and an event frequency. It can be useful to use probabilistic modelling for this

characterization, in which magnitude and frequency can be established based on different sets of contributing parameters.

A.5.2.4.2 Relationship between parameters

Design examples of parameter combinations are given in ISO 19906.

A.5.2.4.3 Persistence

Persistence is the duration for which parameter values are maintained relative to specified criteria. Such criteria can involve values less than minimum criteria, within a specified range or in excess of maximum criteria. The criteria can involve combinations of parameters as well.

Human performance in arctic and cold regions is often tied to persistence statistics involving temperature, wind speed, darkness, visibility and precipitation. In addition, performance is also impaired due to the accretion of snow and ice and the resulting ground conditions as well as vehicle performance.

Icebreaking and other ice management operations can involve persistence statistics of ice thickness, ice type, drift speed, rate of direction change and pack ice pressure criteria. Marine operations and winterization can also rely on persistence data.

A.5.2.4.4 Record length

The record length, whether evaluated in number of years, events or features, should be sufficient to allow a reasonable estimation of parameter uncertainty.

Where available, local and nearby data should be used to define the working environment. Specific attention should be given to air temperature, wind, precipitation and visibility.

A.5.2.5 Forecasting

Large amounts of information can be required to produce, monitor and verify weather and ice forecasts for an operation. Shore-based forecasters can assist trained advisors located onsite. Constant communication can be necessary between the land base and operations.

Local verification of current forecast models should precede their use for sea ice and iceberg drift forecasting. Real-time correction of drift forecasts with local data is encouraged.

In addition to forecasts of meteorological, oceanographic and ice parameters, other scenarios affecting the operation can be forecasted, including:

- polar low occurrence probability;
- ice accretion conditions;
- lightning activity;
- magnetic storms.

A.5.2.6 Weather windows

Operational physical environmental data criteria are the same for weather-unrestricted operations as for design criteria to ensure that risks to life and to the environment are not compromised. To illustrate the point, repeated operations at the same site based on lower safety criteria would result in greater risks than a permanent facility to accomplish the same objective.

For operations requiring a continuous weather window, the forecast window is typically twice as long as the anticipated duration of the operation or longer, depending on the forecast accuracy.

A.5.2.7 Climatic trends

The natural variability in arctic environments has important implications for data uncertainties, monitoring programs and lengths of records needed to reduce uncertainties in any analyses. As a result, time scales ranging from years to decades should be accounted for when considering observations and trends. The long-term trends in sea ice cover should be monitored using time periods of at least two decades and preferably four to five decades, if data are available.

In arctic regions, temperatures have increased at nearly twice the rate of the rest of the earth, resulting in trends towards later freeze-up and earlier break-up of ice and reductions in the duration of ice cover for many regions. Significant changes have occurred in the extent of September sea ice in the arctic basin since 1980.

Future warming, coupled with new weather extremes, can potentially cause decreases in ice cover and a likely change from an arctic marine environment dominated by old ice to one dominated by first-year sea ice processes.

Natural variability of temperature, wind, ice conditions and other factors can mask or enhance the long-term trends. Studies show that, even in a warming world with long-term decreasing ice cover, there remains a significant (one-in-three) chance that any seven-year or longer period can see no sea ice loss or even a slight increase. The chaotic variability of weather patterns can also occasionally produce very rapid sea ice loss, e.g. 2001 to 2007, even though long-term trends in ice loss are slower.

Projected changes in conditions from the present into the future (20 years to 50 years) can be estimated through analogues and use of global and regional climate change models, as indicated by the most recent climate science. An ensemble or set of multiple climate models can be used to develop future climate change projections. Care should be exercised when extrapolating data trends more than a couple of years into the future. Trends in several contributing parameters and their inter-relationships should be considered when such data are available.

It is emphasized that a warming climate can potentially lead to more severe ice conditions. Warmer temperatures could lead to glacier surge and a corresponding increased iceberg frequency, or a flushing of ice from areas where the ice can remain stationary for several years. A more severe wave climate can also result from decreasing sea ice coverage.

A.5.2.8 Expertise and experience

Subject matter experts can include experienced field personnel, as well as individuals with advanced training in human factors, meteorology, oceanography, remote sensing, ice engineering, ice science, materials, geophysics, geotechnical engineering, hydrology and climate science.

A.6 Water depth, tides and storm surges

A.6.1 General

Regardless of the cause, changes in water surface elevation can influence the grounding and refloating of ice ridges, stamukhi, icebergs and ice islands.

Water level changes can also lead to the destabilization and break-up of landfast ice.

Measurements relating to water depth, tides, and storm surges are summarized in [Table A.1](#) for operations and in [Table A.2](#) for design.

Table A.1 — Water level data sampling and reporting requirements for operations (example)

Feature	Parameter	Measurement details	Frequency	Spatial resolution	Accuracy	Comments
Bathymetry	x,y,z	Multibeam; vessel motion correction; z relative to local datum; x,y UTM	Prior to operations; after dredging or berm construction	1 m to 5 m, as required	<0,1 m	Area of operations (site survey); source area for ice features
Tide	Minimum or maximum elevation	Relative to local datum; predictions from constituents; verification with surge-corrected local data	Recorded at 10 min intervals; reported hourly		<0,1 m	At site; source area for ice features
Storm surge	Elevation	Relative to local datum	Recorded at 10 min intervals; reported hourly		0,1 m	Identification of significant events; correlation with other metocean parameters
		Forecast	As required		0,1 m (approx.)	For significant events

Table A.2 — Water level sampling and reporting data requirements for design (example)

Feature	Parameter	Measurement details	Comments ^a
Bathymetry	x,y,z	Multibeam; vessel motion correction; z relative to local datum; x,y UTM	To hydrographic service accuracy or better; local and source areas of ice features
Tide	Elevation	Relative to local datum; local correction of predictions based on measurements	Monthly means, maxima, and minima; historical time series (measured); reconstructed historical time series (predicted); local and source areas of ice features; effects of ice cover
Storm surge	Elevation	Relative to local datum	Event frequency; event magnitude distribution; extreme maximum and minimum elevations; effects of ice cover

^a Statistics, characteristic values, probability distribution, correlated parameters.

A.6.2 Bathymetry

Navigational charts in arctic regions can have large errors due to old, inaccurate and sparsely collected data. The accuracy of navigational charts should be verified by contacting the responsible hydrographical issuing offices. Operators should be prepared for large deviations from water depths reported in official charts.

Vessels with seabed survey capability should be used to collect data whenever possible.

Man-made berms and structures, as well as natural bathymetric features can contribute to the formation of ice rubble and stamukhi and can act as stabilizing features on the local sea ice cover. Such structures and bathymetric features can also influence the draft of ice features reaching the area of operations or facilities.

A.6.3 Tides

The tidal jacking mechanism can be responsible for gradual but significant displacements of landfast ice away from shore. With each tidal cycle, water can fill cracks in the ice in the tidal zone and its subsequent freezing can generate thermal stresses and displace the ice cover away from shore. Contributing factors include the local bathymetric profile, the presence of nearby shorelines, the presence of nearby areas of thinner ice or open water, tidal range, air temperature and rate of change of air temperature.

Tides and other repeated changes in water surface elevation promote the freezing of ice to the surface of piles and along the face of other structures. These features, known as ice bustles (see ISO 19906) are most commonly formed in landfast ice environments. Usually in combination with the formation of ice bustles, changes in water surface elevation can contribute to vertical loads on such structures.

Tidal action can result in the accretion of ice on previously grounded ice features, usually on shallow beach slopes or shoals, resulting in significantly thicker overall dimensions or increased consolidation. High tides can also be responsible for the refloating and entrainment of these features into the ice cover.

A.6.4 Storm surges

Changes to the ice regime, in terms of ice concentration, ice thickness and floe size, can have an influence on storm surge elevations. Changes as a result of natural processes and human intervention should be addressed.

A.7 Wind

A.7.1 General

Wind measurements are summarised in [Table A.3](#) for operations and in [Table A.4](#) for design.

Table A.3 — Wind parameters of relevance for operations (example)

Feature	Parameter	Measurement details	Frequency	Spatial resolution	Accuracy	Comments
Wind	Speed	10 m (onshore); minimum unobstructed elevation (offshore)	Recorded at 10 min intervals; reported hourly		See ISO 19901-1	10 min average; 3 s gust; time series; monthly minima, maxima, and statistics
	Direction	10 m (onshore); minimum unobstructed elevation (offshore)	Recorded at 10 min intervals; reported hourly		See ISO 19901-1	Same as for speed
	Event details	Duration; maximum speed; average direction				Time series; type of event (polar low, arctic jet, katabatic)
Wind forecast	Speed	Surface (10 m)	1 h	As required		Over area of ice drift forecasts
	Direction	Surface (10 m)	1 h	As required		Over area of ice drift forecasts

Table A.4 — Wind parameters of relevance for design (example)

Feature	Parameter	Measurement details	Comments ^a
Wind	Speed	10 m (onshore); minimum unobstructed elevation (offshore)	3 h (or better) time series; monthly minima, maxima, statistics, and extremes; annual extremes; persistence above specified thresholds
	Direction	10 m (onshore); minimum unobstructed elevation (offshore)	Joint frequency table with speed; monthly statistics and ranges
Wind hindcast	Speed	10 m; surface	3 h (or better) time series; monthly minima, maxima, statistics, normal values, and extremes; annual extremes; persistence above specified thresholds; over area of ice drift forecasts
	Direction	10 m; surface	Joint frequency table with speed; monthly statistics and ranges; over area of ice drift forecasts

^a Statistics, characteristic values, probability distribution, correlated parameters.

A.7.2 Polar lows

Polar lows are small and often intense low pressure phenomena that can form over open arctic seas from late fall to early spring. A polar low typically forms when a cold arctic air mass is advected over the relatively warm open ocean, creating an atmospheric instability that can grow into a low pressure centre of several hundred kilometres in extent. Because of strong convection cells within polar lows, they are associated with severe weather, thunderstorms, strong gusting winds, waves, icing and heavy snow. Due to their relatively small scale (about one tenth the size of a normal low pressure system), they have proved hard to forecast and to track.

Energy to drive these low pressure systems is provided by heat and moisture transferred from the sea and by energy transformation within the atmosphere. The propagation speed of polar lows is normally within the range of 8 m/s to 14 m/s, although some features can be close to stationary.

In a typical scenario, the wind speed will increase 2 to 4 levels in the Beaufort scale (5 m/s to 15 m/s) within a couple of hours due to the passing of a polar low. A sudden change in wind direction is associated with the change in wind speed. For identification of polar lows, the following criteria were suggested in Reference [18]:

- wind speed in excess of 14 m/s;
- horizontal extent in the 200 km to 600 km range;
- cyclonic appearance; and
- development is associated with cold air outbreaks from the polar cap, large scale winds flowing in a northwesterly to northeasterly direction.

Polar lows are found mainly in the European sector of the sub-arctic and arctic. Most of the polar lows affecting Norwegian and Russian waters originate in the regions south of Svalbard and east of Jan Mayen and move eastward into the Barents Sea. Their frequency decreases from west to east in the Barents Sea. Polar lows originating in the Iceland-Greenland region mostly affect Scotland and the North Sea. Polar lows are most frequent from October through March, during which period, on average, five to ten polar lows occur.

The importance of polar lows lies in how they develop, their intensity and speed of propagation and how these effects can influence operations. These features are seldom registered by the ground observation network due to their scarcity and their small size and hence, are difficult to forecast. Satellite remote

sensing has, therefore, become the most important tool to detect polar lows and the ability to forecast their occurrence has improved.

When a polar low moves, it grows in size. The problems of prediction are most difficult in the far north and improve with increasing southerly latitude. If a polar low moves towards the south, it normally maintains its intensity and can finally reach sufficient size that it can be observed and predicted. Polar lows move southward with the speed of the wind at high altitude, with some reduction caused by friction at the surface. Forecasting agencies should be able to forecast most polar lows about 6 h to 12 h before they arrive; see Reference [19].

Field measurements and studies of wind and waves during polar lows for the Barents Sea region show that the strongest observed wind is 35 m/s and the highest observed significant wave height is around 10 m; see Reference [20]. Although neither of these values is at the design level for most arctic regions, the impact of polar lows on operations should be taken into account. In some cases, the winds and the sea state can grow equally fast because the polar low can move at a speed comparable to that of the group velocity of the dominant waves. Waves close to being fully developed can, therefore, appear approximately simultaneously with the onset of strong winds; see ISO 19901-1.

A typical duration for a polar low at a location is 1 h to 6 h, after which the weather conditions generally improve, although the temperature is usually somewhat lower than prior to the onset of the polar low. The duration of the polar low in itself is between 6 h and 2 d to 3 d.

Polar lows cannot be expected to be properly represented in wind hindcasts due to their relatively small scale. Normally, the wind and wave conditions associated with polar lows will be less severe than extreme and abnormal winds, which normally are caused by large scale extra-tropical cyclones.

Although there is no specific requirement for length of record when assessing polar low activity, effort should be made to obtain evidence from the range of sources available, including local knowledge, nearby weather stations, vessel transit data and site-specific measurements. The data should be relevant for seasons when polar lows occur and effort should be made to understand causative factors.

National forecasting services include References [21], [22], Environment Canada²⁾ and the United States National Weather Service³⁾.

A.7.3 Katabatic wind

Katabatic winds are generated at higher elevations from the downslope movement of cold and dense air under the force of gravity. These winds typically form over elevated ice shelves or in mountainous areas that experience strong radiation cooling. Katabatic winds can be channelled in valleys and fjords. Katabatic winds are very local, thus very hard to forecast, but they can be very strong and intense (the Piteraq, off east coast Greenland can reach 70 m/s to 80 m/s winds). Since the source of the air is cold, the moisture content at lower elevations is relatively low, so precipitation is not generally associated with these winds. Due to the combination of high winds and low temperature within the air mass, the cooling effect is significant which can lead to rapid sea ice growth if seawater temperature is close to freezing. The potential for sea spray icing to occur during the onset of katabatic winds is also high.

Although connected to coastal regions, the winds can reach far offshore (10 km to 100 km) and should therefore also be considered for offshore operations.

Although there is no specific requirement for length of record when assessing the likelihood and severity of katabatic winds, the site under consideration should be compared to other sites with similar geography for which data are available. Local knowledge should be solicited and site-specific measurements should be considered where the consequences of katabatic winds could be of concern.

2) https://weather.gc.ca/canada_e.html

3) <http://www.weather.gov/>

A.7.4 Low level arctic jet

Low-level air jets can occur in the proximity of ice edges, leads and polynyas. Low level jets can involve high wind speeds and strong vertical and horizontal wind shear. Due to the large surface temperature differences found on the boundary between sea ice and open water, a pressure gradient due to density differences in air masses can occur. This can lead to the development of a low-level jet blowing parallel to the ice edge with ice edge on the right hand side. The strong wind shear associated with these jets can potentially impact aerial operations.

A.8 Waves

A.8.1 General

Waves can be important for a number of design and operational situations, including:

- motions of vessels and floating structures;
- wave-induced velocities and vertical point of action for impacts of sea ice features and icebergs with fixed structures, floating structures and vessels;
- combined actions of ice and waves;
- detection of ice features (visual, marine radar, satellite sensors);
- EER in sea ice;
- wave-induced motions of icebergs during ice management operations;
- ice deposition on beaches and shoals, and subsequent growth and refloating;
- spray icing on vessels and structures;
- landfast ice break-up;
- floe size reduction and break-up of ice ridges;
- iceberg and sea ice decay;
- stability and integrity of foundation berms, mats used for slope stabilization, and other rockfill structures, including those intended to provide protection against ice interactions.

In a number of the above situations, waves act in combination with other processes at magnitudes less than extreme values. In some situations, extreme wave values can provide reasonable, although conservative, estimates to be used in combination with other parameters.

Wave measurements are summarized in [Table A.5](#) for operations and in [Table A.6](#) for design.

Table A.5 — Wave parameters of relevance for operations (example)

Feature	Parameter	Measurement details	Frequency	Spatial resolution	Accuracy	Comments
Waves	Significant height		20 min sampling and reporting	As required	0,5 m or 10 %, whichever is less	As per ISO 19901-1; time series; monthly minima, maxima, and statistics
	Maximum height		20 min	As required	0,5 m or 10 %, whichever is less	As per ISO 19901-1; time series; monthly minima, maxima, and statistics
	Zero crossing period; spectral peak period		20 min	As required	0,5 s	As per ISO 19901-1; time series; monthly minima, maxima, and statistics
	Direction	Mean; spread	20 min	As required	10°	As per ISO 19901-1; time series; monthly minima, maxima, and statistics
Wave forecast	Significant height		3 h	As required		Over areas of vessel operations and ice drift forecasts
	Maximum height		3 h	As required		Over areas of vessel operations and ice drift forecasts
	Zero crossing period; spectral peak period		3 h	As required		Over areas of vessel operations and ice drift forecasts
	Direction	Mean	3 h	As required		Over areas of vessel operations and ice drift forecasts
Wave attenuation	Coefficient	Ice concentration, floe size, and thickness associated with events	Event-based			

Table A.6 — Wave parameters of relevance for design (example)

Feature	Parameter	Measurement details	Comments ^a
Wave hindcast	Significant height		3 h time series; monthly maxima and statistics; winter season extremes
	Maximum height		3 h time series; monthly maxima and statistics; winter season extremes
	Zero crossing period; spectral peak period		3 h time series; monthly maxima and statistics; winter season extremes
	Direction	Mean; spread	3 h time series; monthly ranges; joint frequency table with speed
Ice response to waves	Transfer functions	Surge and heave; amplitude and velocity	For ice features of range of dimensions; based on diffraction theory; structure and seabed effects
Wave attenuation	Coefficient	Ice concentration, floe size, and thickness variation	For marginal ice zones
^a Statistics, characteristic values, probability distribution, correlated parameters			

A.8.2 Wave-induced ice motions

Wave-excited impacts of ice features, whether of sea ice or glacial origin, can result in potentially hazardous operational situations and contribute to design ice actions.

Smaller ice features typically follow wave particle trajectories and can potentially impact structures both above and below the still water level. Transfer functions used for wave-induced ice motions should consider:

- the influences of extent, draft, and shape of the ice features;
- the influence of proximity to vessels, structures, berms, and the seabed;
- potential influence of ice concentration for wave-induced motions of sea ice.

A.8.3 Wave transmission through sea ice

Although waves are usually dampened quickly as a function of distance into sea ice, long period waves and swell can propagate significant distances into the ice cover.

The incident wave energy at the ice edge is the primary basis for assessments of wave transmission through sea ice.

If wave attenuation is considered for operations and design, the effects of sea ice concentration, thickness, and floe size should be assessed. Due account should be taken for the effects of the duration of wave incursion events on the state of the ice cover.

For operations planning and design, the documentation of wave transmission through sea ice should include:

- significant wave height;
- wave period (zero crossing or spectral peak);
- wave direction;
- distance of facility or operation from ice edge;
- ice concentration, ice thickness and average floe size profiles to ice edge;
- duration of event (persistence).

Wave energy decays exponentially with an attenuation coefficient that varies between $2 \times 10^{-4} \text{ m}^{-1}$ for long waves to $8 \times 10^{-4} \text{ m}^{-1}$ for 8 s to 9 s waves, corresponding to e-folding distances of about 5 km to 1,2 km (see References [23] and [24]). These values are based on “mean” values and it should be noted that there is considerable uncertainty regarding the exact values and how they depend on the state of the ice cover (see References [25] and [26]).

The decay of wave energy is given by the exponential [Formula \(A.1\)](#):

$$E(d) = E_0 e^{-\alpha d} \quad (\text{A.1})$$

where

E is the wave energy;

d is the distance from the ice edge;

E_0 is the wave energy in open water;

α is the wave attenuation factor.

[Formula \(A.1\)](#) assumes that the wave period is constant with distance into the ice.

A.9 Currents

A.9.1 General

In many situations, the separation of currents into tidal and residual components can be useful for isolating net drift from higher frequency diurnal and semi-diurnal ice motions.

At various sites in arctic and cold regions, the frequencies of inertial and tidal ice motions are similar and care should be taken to distinguish between the two.

Examples of where extreme values of currents can be important are when the impact of ice features is a governing design situation and for planning ice management or forecasting operations. High currents can also lead to the degradation of rockfill structures (often used in shallow water areas in arctic and cold regions) as a result of ice gouge processes or accelerate the deterioration of ice gouge marks on the seabed. High currents can contribute to sea ice ridge formation and reduce the rate of growth of landfast ice.

Strudel scours in seabed sediments are the direct result of fresh water flow over ice and the resulting vertical jets (currents) through the water column to the seabed.

Measurements relating to ocean currents are summarised in [Table A.7](#) for operations and in [Table A.8](#) for design.

Table A.7 — Ocean current parameters of relevance for operations (example)

Feature	Parameter	Measurement details	Frequency	Spatial resolution	Accuracy	Comments
Current	Speed	As a minimum: surface; mid-depth; deep	10 min sampling, hourly recording	Local to facility	0,05 m/s	Measurement and forecast; as per ISO 19901-1; time series; monthly minima, maxima, and statistics; profiles to assess scour potential
	Direction	As a minimum: surface; mid-depth; deep	10 min sampling, hourly recording	Local to facility	10°	Same as for speed
Current forecast	Speed		Daily; 3 h (if tidal predictions)	As required		Over areas of vessel operations and ice drift forecasts
	Direction		Daily; 3 h (if tidal predictions)	As required		Over areas of vessel operations and ice drift forecasts
	Conductivity temperature depth (CTD)	Through water column	As required	As required		

Table A.8 — Ocean current parameters of relevance for design (example)

Feature	Parameter	Measurement details	Comments ^a
Current hindcast	Speed	From current model; for multiple layers	Time series; monthly minima, maxima, and statistics; local and regional
	Direction	From current model; for multiple layers	Time series; monthly minima, maxima, and statistics; local and regional
Current	Speed	Acoustic doppler current profiler (ADCP) or current meter	Potentially in conjunction with ice drift measurements; separation of steady, surge, and tidal components
	Direction	Acoustic doppler current profiler (ADCP) or current meter	
	Conductivity temperature depth (CTD)	Profile through water column; spatially	As required

^a Statistics, characteristic values, probability distribution, correlated parameters.

A.9.2 Currents for sea ice and iceberg drift prediction

Measurements of surface currents in the uppermost 10 m can be collected during the ice-free season to help calibrate oceanographic models used as input for sea ice drift forecasting models.

The importance of accurate current input for iceberg forecasting is emphasized. Consideration should be given to site-specific and higher resolution current forecast models and real-time measurements for verification and assimilation.

A.9.3 Current records

Few current measurements exist in many arctic regions and oceanographic models have seldom been validated in these areas.

A.10 Temperature

A.10.1 General

ISO 19901-1 provides guidance on air and sea water temperature ranges found in different regions of the world.

Measurements relating to air and water temperatures are summarised in [Table A.9](#) for operations and in [Table A.10](#) for design.

Table A.9 — Temperature parameters of relevance for operations (example)

Feature	Parameter	Measurement details	Frequency	Spatial resolution	Accuracy	Comments
Air	Temperature		10 min sampling, hourly recording	At site	1 °C	Daily average for freezing degree days (FDD); atmospheric and spray icing; human factors; machinery operation
	Wind chill		10 min sampling, hourly recording	As required	1 °C	Calculated using local 10 m wind speed
Water	Temperature	Near-surface	Daily	At site	<1 °C	Spray icing; ice growth and deterioration; frazil ice formation; diving
	Temperature	In water column	As required	As required	<1 °C	Application to iceberg deterioration
	Temperature	Near seabed	As required	As required	<1 °C	Changes to permafrost regime

Table A.10 — Temperature parameters of relevance for design (example)

Feature	Parameter	Measurement details	Comments ^a
Air	Temperature	3 h sampling (LAST definition; see ISO 19906); daily average	Time series of freezing degree days (FDD); probability distribution; extremes; winterization; machinery specifications; operations planning
Water	Temperature	Near-surface	Time series; probability distribution; extremes
	Temperature	In water column	Time series; extremes

^a Statistics, characteristic values, probability distribution, correlated parameters.

A.10.2 Sea water temperature

Sea water temperature profiles should be collected whenever possible to support operational decision-making for sea spray icing, frazil ice development (implications for water intakes), sea ice formation, iceberg deterioration and changes to the permafrost regime.

A.10.3 Air temperature

Because of its importance for marine and atmospheric icing, snow and sea ice formation, iceberg deterioration and sea ice melting, local air temperatures should be monitored on a routine basis.

Freezing degree days (FDD), the primary determining index for sea ice growth, are based on daily average air temperatures.

The winterization of facilities generally relies on time-averaged temperatures. Averaging periods should be suitable for the particular situation and a 5-day period has proved to be useful in a number of situations.

The averaging period should be taken into account when calculating correlations with associated parameters.

Minimum air temperatures used for personnel comfort, equipment operation, and material specifications can be based on hourly to daily values, depending on the circumstances.

Wind chill is dealt with in ISO 19906 for the design of offshore facilities and in ISO 35101 for working environment.

Wind chill is the perceived temperature due to the combined effect of low ambient temperature and wind. Wind blowing over an object will result in a higher rate of heat loss and a more rapid cooling of the object. The heat loss is proportional to the wind speed. The attempt to maintain a given surface temperature in an environment of faster heat loss results in both the perception of lower temperatures and an actual greater heat loss. In other words, the air "feels" colder than it is because of the chilling effect of the wind on the skin. Wind chill can present a real danger to personnel working outside.

Scientists and medical experts in the U.S. and Canada have developed a wind chill index by iterating a model of skin temperature under various wind speeds and temperatures. The model uses standard engineering correlations of wind speed and heat transfer rate. Heat transfer was calculated for a bare face in wind, facing the wind, while walking into it at 1,4 m/s. The model corrects initially the wind at 10 m elevation to wind speed at the face height, assuming the person is in an open field. The wind chill temperature is defined in Reference [27] as [Formula \(A.2\)](#):

$$T_{wc} = 13,12 + 0,6215 \cdot T - 11,37 \cdot U_{10}^{0,16} + 0,3965 \cdot T \cdot U_{10}^{0,16} \quad [^{\circ}\text{C}] \quad (\text{A.2})$$

where

T_{wc} is wind chill temperature in degrees Celsius;

T is air temperature in degrees Celsius;

U_{10} is wind speed at 10 m height in kilometres per hour.

[Formula \(A.2\)](#) is applicable if the human body is on ground (1,5 m elevation) while winds are at a 10 m elevation, since this is the onshore standard for forecasted and recorded winds. Offshore, winds are usually recorded at higher elevations and converted to the deck elevations based on empirical formulations. If winds are from the same elevation as wind chill temperature is calculated, [Formula \(A.3\)](#), the following transformed version of [Formula \(A.2\)](#), is recommended:

$$T_{wc} = 13,12 + 0,6215 \cdot T - 14,89 \cdot U^{0,16} + 0,519 \cdot T \cdot U^{0,16} \quad (\text{A.3})$$

where

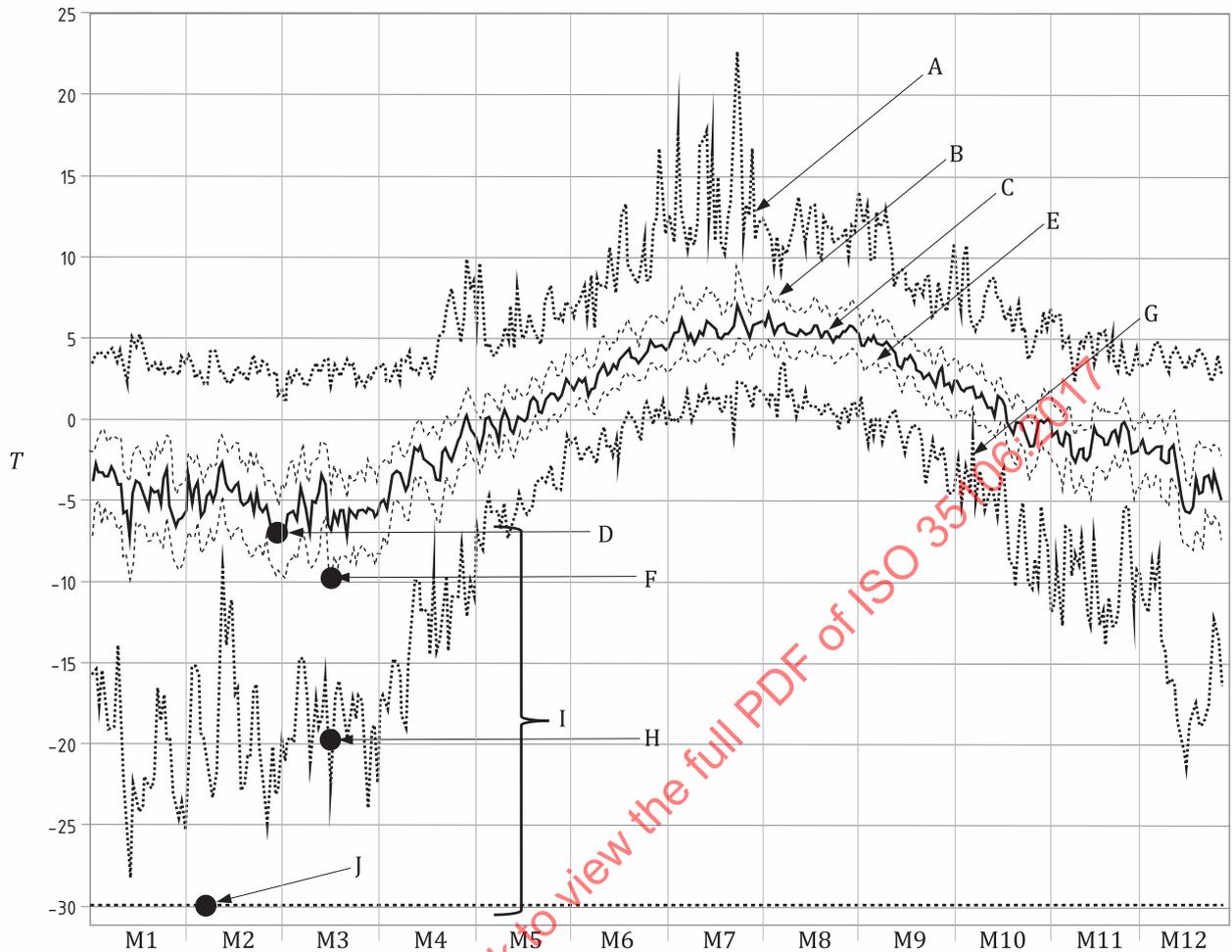
U is wind speed at the height wind chill is to be calculated in kilometres per hour.

An overview over the different types of temperatures and associated standards is provided in [Table A.11](#). Further details on low temperature definitions can be found in ISO 19906.

Table A.11 — Low temperature definitions and associated standards

Symbol	Definition	Reference	Applicability
DAT(t)	Design ambient temperature	DNV GL Rules for Ships ^[10] Bureau Veritas Rules for Ships ^[4]	Class notation for structural material selection
PST	Polar service temperature	IMO Polar Code ^[13]	Polar Code compliance
LMDAT	Lowest mean daily average temperature	IACS UR S6.3 ^[12] DNV GL Rules for Ships ^[10] DNVGL-OS-C101 ^[9] Bureau Veritas Rules for Ships ^[4] Bureau Veritas Rules for Offshore Units ^[3]	Setting design temperatures Selecting steel grade
LMDLT	Lowest mean daily low temperature	IMO Polar Code ^[13]	Setting PST; $PST \leq LMDLT - 10 \text{ }^\circ\text{C}$
ELT	Extreme low temperature	DNVGL-OS-A201 ^[8] Bureau Veritas Rules for Ships ^[4]	Setting winterization temperature No prescribed definition
LAST	Lowest anticipated service temperature	ISO 19902 ^[1] , ISO 19906	Offshore facility design
RP100	Extreme low temperature with an annual probability of exceedance not greater than 10^{-2}	ISO 19906, NORSOK N-003 ^[14]	Setting LAST

The relationship between the different temperature measures is illustrated for a particular location in [Figure A.1](#) for a 15-year measurement period.



Key

A	Absolute maximum temperature	M1	January
B	MDHT: Mean daily high temperature	M2	February
C	MDAT: Mean daily average temperature	M3	March
D	LMDAT: Lowest mean daily average temperature	M4	April
E	MDLT: Mean daily low temperature	M5	May
F	LMDLT: Lowest mean daily low temperature	M6	June
G	Absolute minimum temperature	M7	July
H	PST: polar service temperature (\leq LMDLT -10 °C)	M8	August
I	ELT: Extreme low temperature	M9	September
J	RP100: Extreme low temperature at a 10^{-2} annual probability of exceedance	M10	October
T	Air temperature, expressed in °C	M11	November
		M12	December

NOTE Data source: Norwegian Meteorological Institute.

Figure A.1 — Temperature definitions in Table A.11 illustrated using observations at Bjørnøya (1998 to 2012)

A.11 Atmospheric parameters

A.11.1 General

Since visibility in arctic and cold regions depends not only on precipitation, fog and haze, but also on the ice cover, visibility indices from coastal stations can differ from those at offshore locations. As a result, the latter should be used to calculate frequency of occurrence of visibility.

Above-water ice detection systems involve visual observations, optical imaging, infrared imaging, radar imaging, and multispectral imaging. Consequently, atmospheric parameter measurements should address all of the relevant systems in operation and potentially used as part of ice operations. Helicopters operating offshore should be equipped with a ceilometer, reporting cloud ceiling.

Air drag coefficients used for forecasting sea ice and iceberg drift are dependent on atmospheric stability. This dependence should be addressed at the operational planning stage either through wind profile and other atmospheric measurements or through the calibration of drag coefficients in well-documented verification cases. Stability should be assessed in real-time to ensure that accurate drag coefficients are used.

Geomagnetic storm effects are of greater concern in arctic regions and can lead to power disruptions, impair not only operations but emergency preparedness. For geomagnetic storm forecasts, see the Spaceweather website⁴⁾.

Measurements relating to atmospheric processes are summarised in [Table A.12](#) for operations and in [Table A.13](#) for design.

Table A.12 — Atmospheric parameters of relevance for operations (example)

Feature	Parameter	Measurement details	Frequency	Spatial resolution	Accuracy	Comments
Daylight		Sunrise; sunset				
Visibility	Horizontal distance; vertical distance	Haze; fog; precipitation	10-min sampling, hourly recording			
Cloud cover	Percentage/octal		10-min sampling, hourly recording	Operations area		For aerial operations
Precipitation	Event	Total precipitation in water equivalent	10-min sampling and recording			
	Event	Duration	10-min sampling and recording			
	Event	Maximum hourly precipitation rate	10-min sampling and recording			

4) <http://spaceweather.com>

Table A.13 — Atmospheric parameters of relevance for design (example)

Feature	Parameter	Measurement details	Comments ^a
Daylight		Sunrise; sunset	Variation over the year
Visibility	Horizontal distance; vertical distance	Haze; fog; precipitation	Proportion of time on a monthly basis; persistence statistics
Precipitation	Event	Total precipitation in water equivalent	Snow, rain, sleet, hail; statistics
	Event	Duration	Statistics; proportion of time on a monthly basis
	Event	Maximum hourly precipitation rate	Statistics

^a Statistics, characteristic values, probability distribution, correlated parameters.

A.11.2 Daylight considerations

Information on daylight hours and twilight can be found in the NOAA sunrise/sunset calculator⁵⁾ and the U.S. Naval Observatory daylight calculator⁶⁾. Sunrise and sunset are the times when the upper edge of the sun is on the horizon under average atmospheric conditions and accounting for refraction effects but ignoring any differences in elevation. Different measures of twilight are provided in the NOAA sunrise/sunset calculator⁵⁾.

A.11.3 Visibility and cloud ceiling

Advection fog is the most common type of fog experienced in arctic waters. Its origin is warm moist air advected over colder water and is most frequent during summer months. Advection fog is usually quite thick and covers large areas. Advection fog can have an impact on aircraft and helicopter operations, visual observations, and optical imaging systems.

Frost smoke occurs when very cold air flows over relatively warm water. This is typically found along the ice edge during wintertime and in and around polynyas. Since frost smoke occurrence is usually patchy, it presents fewer operational challenges.

A.11.4 Precipitation

As with fog, precipitation can cause significant reductions in visibility, sometimes to as little as several metres. Moreover, radar range can be reduced far more due to precipitation than due to fog. Precipitation in the form of rain, snow and hail can absorb increasing amounts of radar energy with increasing precipitation intensity.

Ice detection systems rely heavily on platform-based and vessel-based marine radar systems, as well as on airborne and satellite-based radar systems. Consequently, the documentation of precipitation is essential in the assessment of radar system effectiveness for the detection of sea ice and iceberg features.

A.12 Sea ice

A.12.1 General

Sea ice information can be obtained by various methods, including:

- aerial reconnaissance;
- surface observations from ships, platforms and other structures;

5) <http://www.esrl.noaa.gov/gmd/grad/solcalc/sunrise.html>

6) http://aa.usno.navy.mil/data/docs/RS_OneYear.php

- drifter buoys;
- sub-surface observations, such as those taken by upward looking sonar for measurement of ice draft;
- satellite imagery.

Airborne observations can provide information about ice conditions when weather conditions permit and can generally provide ice information at a higher spatial and temporal scale than permitted by satellite imagery.

Trained ice observers can provide information about ice conditions in close proximity to the operation. Video imagery or radar can aid in surface observations of ice.

Different satellite sensors can be used to characterize ice conditions. Synthetic aperture radar (SAR) satellite sensors are useful for their ability to provide images independent of the weather conditions or daylight. However, they can be challenging to interpret, particularly if there is water on the ice. Visual or infrared (IR) satellites can provide useful information on a broader scale, but data are limited when there is darkness, fog, and cloud cover. Passive microwave satellites can give an overview of the region. Higher resolution imagery can be useful if an operation is at a fixed location. Depending on the location of the operation, satellite imagery might not be available at the frequency required for monitoring.

Table A.14 provides a list of typical sea ice parameters relevant during offshore operations, while Table A.15 provides a list of typical parameters for design. Neither of these tables is intended to be comprehensive. Careful consideration should be given to understanding the local and regional sea ice environments, and their effect on operations and design. For operations, the parameter list should focus on general icebreaking conditions, identification of potentially hazardous features, parameters relating to global load levels on structures and station-keeping systems and managed ice conditions. For design, the parameter list should include, as a minimum, the parameters associated with limit stress, energy, and driving force considerations for the structure types and the local ice conditions (see ISO 19906).

Table A.14 — Sea ice parameters of relevance for operations (example)

Feature	Parameter	Measurement details	Frequency	Spatial resolution	Accuracy	Comments
Ice season	Start + end dates	Typically based on concentration threshold				
Concentration	Total concentration		Daily			
	Partial concentrations	Of each identified ice type				
	Stage of development or thickness	Corresponding to partial concentrations				
	Floe size	Corresponding to partial concentrations				
	Ridged proportion	Corresponding to partial concentrations				
Drift	Drift speed		1-3 h			Measurements and forecasts
	Drift direction					Measurements and forecasts

Table A.14 (continued)

Feature	Parameter	Measurement details	Frequency	Spatial resolution	Accuracy	Comments
Ice edge	Position		Daily, unless critical			Measurements and forecasts
FY ice	Level ice thickness					
	Rafted ice thickness					
	Rafted ice extent					
	Floe diameter (unmanaged and managed)	Equivalent diameter of circular floe with the same area (see A.12.6)	Every 3 h			Distribution; maximum for managed floes
FY ridge, rubble field, or stamukha	Frequency; areal density	Number per unit length; number per unit area				
	Plan length					
	Plan width	Perpendicular to length				
	Maximum keel draft	Relative to water surface				Grounded or ungrounded state
	Average keel draft	Relative to water surface				
	Maximum sail height	Relative to water surface				
	Consolidated layer thickness	Average value				Also, porosity of grounded features
MY ice	Thickness	Average, maximum values				
	Floe diameter (for plan length and width)	Equivalent diameter of circular floe with the same area (see A.12.6)				Focus on specific features; can consider parameters of conglomerate floe consisting of FY or SY and MY ice
MY ridge	Frequency; areal density	Number per unit distance; number per unit area				Number per unit width passing operation or facility
	Plan length					
	Plan width					
	Maximum keel draft					
	Average keel draft					

Table A.14 (continued)

Feature	Parameter	Measurement details	Frequency	Spatial resolution	Accuracy	Comments
Brash ice	Concentration					Within ship tracks or managed area
	Maximum thickness					Freezing or consolidation potentially of concern
	Average thickness					
	Largest piece size					
Open water lead	Frequency	Number per unit length				
	Width					
	Length					
Ice encroachment	Maximum height	Relative to water or structure surface				
	Incursion distance relative to shoreline or edge of structure	Maximum value across lateral extent				
	Lateral extent	Perpendicular to incursion distance				

Table A.15 — Sea ice parameters of relevance for design (example)

Feature	Parameter	Measurement details	Comments ^a
Ice season	Season length	Based on minimum concentration criterion (typically 1/10th)	
	Freezing degree days (FDD)		Correlation with season length; progression over year for relationship with ice thickness
Concentration	Total concentration		Progression over winter season
	Partial concentrations	Of each identified ice type	
	Stage of development or thickness	Corresponding to partial concentrations	
	Floe size	Corresponding to partial concentrations	
Drift	Drift speed		Probability distribution
	drift direction		Probability distribution; joint distribution with speed
	Landfast	Proportion of time or season	
FY ice	Level ice thickness		Probability distribution
	Rafted ice thickness	Average value over lateral extent consistent with mechanism leading to load	Probability distribution

Table A.15 (continued)

Feature	Parameter	Measurement details	Comments ^a
	Floe diameter	Equivalent diameter of circular floe with the same plan area (see A.12.6)	Can be relevant if only FY ice present; probability distribution; correlation with level ice thickness
FY ridge	Plan length		Probability distribution
	Plan width	Perpendicular to length	Probability distribution; correlation with plan length
	Keel draft	Relative to water surface	Average and maximum values; probability distribution over all ridges; correlation with plan length
	Sail height	Relative to water surface	
	Consolidated layer thickness	Average value over lateral extent consistent with mechanism leading to load	Probability distribution over all ridges
	Frequency; areal density	Per unit length; per unit area	Average
	Orientation	Long axis relative to north	
FY rubble field	Plan length		Probability distribution
	Plan width	Perpendicular to length	Probability distribution; correlation with plan length
	Keel draft	Relative to water surface	Average and maximum values; probability distribution over all rubble fields
	Sail height	Relative to water surface	
	Consolidated layer thickness	Average value over lateral extent consistent with mechanism leading to load	Probability distribution over all rubble fields
	Frequency; areal density	Per unit length; per unit area	Average
MY ice floe	Thickness		Probability distribution
	Diameter	Equivalent diameter of circular floe with the same plan area (see A.12.6)	Can consider parameters of conglomerate floe consisting of FY or SY and MY ice; probability distribution; correlation with thickness
	Frequency	Per unit length or unit area	
MY ridge	Plan length		Probability distribution
	Plan width	Perpendicular to length	Probability distribution; correlation with plan length
	Keel draft	Relative to water surface; average value over lateral extent consistent with mechanism leading to load	Probability distribution; correlation with plan length
	Sail height	Relative to water surface	

Table A.15 (continued)

Feature	Parameter	Measurement details	Comments ^a
	Frequency; areal density	Per unit length; per unit area	
	Orientation	Long axis relative to north	
Stamukha or other large feature (shear ridge)	Plan length		Probability distribution
	Plan width	Perpendicular to length	Probability distribution; correlation with plan length
	Thickness (or keel draft and sail height)	Average value over lateral extent consistent with mechanism leading to load	Grounded state; porosity; probability distribution; correlation with water depth, plan length, contributing ice thickness
	Frequency; areal density	Per unit length; per unit area	
Ice encroachment	Height	Relative to water or structure surface	Profile; location of maximum value; distribution of maximum value
	Incursion distance relative to shoreline or edge of structure	Maximum value across lateral extent	Distribution
^a Statistics, characteristic values, probability distribution, correlated parameters.			

A.12.2 Sea ice season

The start and end of the sea ice season with respect to thermal ice growth and decay can potentially be related to the time-averaged accumulated freezing degree days and melting degree days, respectively. If such relationships are used for forecasting season boundaries, they should be calibrated based on historical data.

Water temperature and the slope of the thermocline can also be used to forecast early-season ice formation.

A.12.3 Sea ice coverage

Sea ice can be classified according to the WMO sea ice nomenclature^[15] frequently referred to as the "Egg Code". An example of this format is MANICE^[16], involving partial concentrations of ice in different stages of development and with different floe sizes.

When planning operations in waters that have seasonal ice coverage, climatological ice conditions can provide a basic understanding of the seasonal variability of ice concentration and type in the region of interest. Ice conditions can vary considerably from year to year. The duration of historical records will vary depending on the region; 10 years of records are barely adequate, while the climatological standard of 30 years (as per WMO^[28]) provides some degree of confidence that most seasonal variations are considered.

The Canadian Ice Service ice charts define ice edge as the open water or ice-free boundary. The Norwegian ice service specifies the ice edge from the 3/10ths ice concentration boundary, which is the minimum concentration that can be detected using passive microwave satellite sensors. During all aspects of an arctic operation, the requirement for accurate data collection and documentation on the presence of sea ice is vital for building a database, which can be used in the planning and design of future operations. The data collection can involve:

- long-term time series of sea ice concentration and type information for a specific location and a larger region of interest;

- statistical information on concentration and type of sea ice for a specific location and a larger region of interest.

A.12.4 Sea ice thickness

Ice thickness is defined as the distance from the top surface of the ice to the bottom surface of the ice, regardless of whether there exists air or water gaps in between. For operations and design, the ice thickness can be defined as the maximum thickness over some horizontal distance, such as the lateral dimension of an ice floe or feature. Where ice thickness is measured on a continuous basis, it can be sufficient to represent thickness in terms of a probability distribution.

Sea ice can consist of a single layer of ice or can be formed from two or more layers of ice rafted over top of each other. Rafted ice layers can be partially or fully bonded and subsequent freezing can take place on the bottom surface.

Upward-looking sonar devices can be deployed on the seabed to monitor ice draft continuously at a fixed point as ice drifts overhead. When deployed in conjunction with an acoustic Doppler current profiler, the sonar data can be interpreted as a spatial draft profile along the line of drift.

Ice freeboard above the water surface can be obtained from laser altimetry along a line or from laser scanners along a swath.

Estimates or measurements of ice and water density can be used along with hydrostatic equilibrium considerations to obtain the total ice thickness from above-water or below-water measurement devices. Considerable uncertainty can result for keel draft estimation based on freeboard measurements.

Total ice thickness can be measured from ice blocks turned up during icebreaker transit.

Ground-penetrating radar (GPR) and electromagnetic (EM) induction are remote measurement techniques used to estimate ice thickness, whether glacial ice (floating or grounded), sea ice, and lake ice. GPR measurements rely on electromagnetic scattering at air-ice, ice-water and ice-soil/rock interfaces, while EM measurements rely on differences in electromagnetic conductivity for ice, water and soil. EM systems are usually combined with laser altimetry to locate the upper surface of the ice. GPR systems with their higher frequencies are typically more accurate, but are limited in terms of penetration depth for sea ice and can be ineffective except for freshwater and brackish ice. Each type of system has limitations for measuring the keels of ridges and rubble fields; GPR because of scattering off many ice block surfaces, and EM because of lack of horizontal resolution (typically several metres) and the conductivity of the combination of ice blocks and water of different salinities. Both systems will tend to underestimate the maximum draft of ridges and rubble fields and be inaccurate near the edges of ice features. For level ice or ice with smoothly varying surfaces, EM ice thickness measurements are accurate to within about 20 cm, while GPR measurements are typically more accurate.

A.12.5 Sea ice drift and movement

Drifting satellite-communicating buoys placed on ice floes can be used to remotely monitor the location and movement of the floes. They are also useful for gathering ice drift data prior to an offshore operation or construction of an offshore structure, as they provide historical data on local ice drift conditions. Concurrent deployment of weather stations and acoustic Doppler current profilers on floes can be used to supplement the drift data.

Sea ice drift can also be determined by re-identification of specific features on marine radar, from airborne or satellite imagery or visually from vessels, platforms and aircraft. Drift time series at a particular location can also be obtained from moored acoustic Doppler current profilers.

The following information can be determined from historical information:

- drift speed distributions;
- seasonal and inter-annual variability in drift speeds;
- multi-year and multi-decadal trends in drift speed and predominant drift direction.

Typically, direction should be measured to an accuracy of one azimuthal degree and speed should be measured to an accuracy of 0,1 knots (0,05 m/s).

Sea ice drift speed and direction depend on the local wind and current fields, the transfer of stress at the air-ice and ice-water interfaces, Coriolis forces, the slope of the sea surface and the mechanical behaviour of the ice cover. All these processes should be considered in drift forecast models, although mechanical behaviour can often be ignored for lower ice concentrations. Timely and accurate input data, in terms of wind and current forcing, as well as the state of the ice cover, are important for successful forecasts. Drag coefficients and turning angles should be consistent with the state of the respective boundary layers and with the levels at which the winds and currents are forecast. Extensive verification and correction of biases based on real-time drift measurements can help enhance accuracy and quantify uncertainties.

Traditional weather forecasts are usually inaccurate beyond 72 h. In arctic regions, weather forecasts are likely to be of reduced accuracy and consequently, the ability to provide ice drift forecasts for more than 72 h is limited.

Aside from speed and direction, drift forecast models should provide information on the curvature of the drift track and the rate of change of drift direction, in combination with drift speed information. Initiation of movement for a stationary ice cover can also be a priority in certain areas, particularly in shallower water and in proximity to shore.

A.12.6 Sea ice features and conditions

Sea ice scenarios of interest can involve specific types of ice features, particular ice conditions and combinations thereof.

Examples of features in sea ice environments include:

- a) extended areas of rafted sea ice;
- b) consolidated (refrozen) first-year ridges and rubble fields;
- c) dislodged grounded rubble fields and stamukhi that were consolidated during the formation process or as a result of water level changes;
- d) refloated beach ice features that have been altered by water level changes;
- e) second year or multi-year ice floes, i.e. old ice;
- f) old ice ridges or hummock fields;
- g) ice island, ice shelf, and glacial ice fragments not normally contained within the sea ice.

Sea ice feature definitions are not always clear-cut, as in the case of conglomerate floes composed of first-year and old ice and the definitions should be consistent with the design or operational requirements.

Examples of ice scenarios include:

- pressured ice (ice cover in hydrostatic compression, rather than as a result of motion relative to a facility);
- flushing of river ice as a result of spring melt;
- displacements of previously grounded or beached ice features;
- ice rubble build-up and encroachment onto working surfaces of structures, docking facilities and other man-made structures.

Available historical records of ice features tracked or observed in the region of interest or representative region should be considered. The dimensions (lateral and thickness) and areal density of such features should be identified, with an assessment of seasonal and inter-annual variability. Floe size can be defined

as the diameter of a circular floe of equivalent plan area. Differences in the drift speeds and directions relative to the surrounding sea ice should be identified. If site-specific data are unavailable, data from nearby regions can be used with due account for factors that might result in regional differences.

Ridge length is the maximum observable horizontal length of the above-water portion of the ridge. Ridge width is the maximum width of the feature in the plane of the ice surface, typically for the below-water portion since it is wider than the above-water portion. For visual observations, ridge sail height is typically measured as the vertical distance from the surface of the level ice to the peak of the ridge. For automated measurements, the reference for ridge sail height is usually the water surface. Ridge keel draft is the vertical distance from the water surface to the deepest point in the keel. The consolidated layer of a ridge or rubble field is the portion that has completely refrozen subsequent to the formation of the feature. Sail and keel thicknesses are sometimes considered to exclude the consolidated layer. Depending on the design or operational situation, ridge spacing, orientation and areal density can also be of interest.

Previously grounded ice features can be defined in terms of maximum or average thickness and plan dimensions such as length and width or the equivalent diameter of a circle with the same plan area. The bulk porosity for grounded features can be less than that for features formed in the absence of seabed contact.

Ice encroachment and grounded rubble can be characterized in terms of block size, highest elevation relative to the water surface, horizontal location of highest point relative to the edge of the structure or beach, height and profile of the structure or beach, and the contributing ice and metocean parameters.

Pressured ice can be characterized in terms of average pressures per unit horizontal width or using an ordinal scale that is potentially related to operating criteria such as rate of ship track closure. Consideration should be given to the metocean and ice conditions leading to ice pressure scenarios.

A.12.7 Physical properties

A.12.7.1 Temperature

For continuous logging of ice temperature, strings of temperature sensors can be deployed through ice holes and allowed to freeze in place. Sensor spacing will depend on measurement objectives. For example, tracking the location of the bottom surface of the ice requires a fine spacing, whereas measurement of temperature gradients typically only requires 5 cm to 10 cm spacing. The strings should generally be installed through the thickness of the ice and into the water below to allow for ice growth during the deployment period. When monitoring temperatures in warm and melting conditions, the solar radiation will tend to heat the string itself more than the surrounding ice. As a result, the albedo of the string should be reduced as much as possible to ensure that the measurements represent actual *in-situ* ice temperatures.

For measurements at a single time, cores (typically about 10 cm diameter) can be extracted and temperatures measured at specified depths by inserting a probe into drilled holes. The holes should be deep enough to avoid surface warming or cooling during the extraction process and their diameter should just larger than the probe. In cold weather, it is advisable to start profiling from the bottom since this part of the ice is warmest and will change its *in situ* temperature fastest. The temperatures should be measured as soon as possible after extraction of the core and the probe should be inserted for sufficient time for the temperature to stabilize at the ice temperature.

A.12.7.2 Salinity

For level first-year sea ice, the salinity is usually expressed as the fraction by mass of the salts contained in a unit mass. It is usually quoted as a ratio of grams per kilogram of sea ice (or its melt), that is, in parts per thousand (‰ or ppt, also psu, “practical salinity unit”, more or less equivalent to ppt).

Ice salinity is obtained by measuring the electrolytic conductivity of melted samples cut from ice cores. When extracting ice cores, care should be exercised to minimize brine drainage. While *in situ*

techniques also exist, these are not in widespread use. Ice surface salinity can also be estimated from satellite microwave sensors through relationships established based on direct measurements.

In sea ice, there is usually some salinity variation with depth in the ice sheet. This depth dependence of the salinity changes throughout the winter as the salt within the ice migrates downward through the ice. While there can be marked salinity variations even within a small sample, the average salinity, expressed as parts per thousand by mass, of a cold, growing ice sheet is related to the ice thickness (see Reference [29]):

$$S = 4,61 + \frac{0,916}{h} \quad (\text{A.4})$$

where

S is the salinity, expressed in ‰ or ppt;

h is the ice thickness, expressed in metres.

For decaying ice, much of the brine has drained and the salinity can typically range from close to zero up to 4 ppt (see Reference [30]).

The brine volume fraction for sea ice can be determined from salinity and temperature, see ISO 19906.

A.12.7.3 Density

There are several different methods to measure the density of ice. The most common technique is the mass/volume technique by which an ice block is cut from an ice sheet and trimmed to a standard size, which provides the volume, while weighing the sample provides the mass. The ice density is then calculated according to [Formula \(A.5\)](#):

$$\rho_i = \frac{M}{V} \quad (\text{A.5})$$

where

ρ_i is the density of the ice sample;

V is the volume of the ice sample;

M is the mass of the ice sample.

Measurements done by a large number of researchers (see Reference [31]) show that

- the sea ice density ranges between 720 kg/m³ and 920 kg/m³,
- *in situ* sea ice densities are different above and below the waterline,
- above the waterline, sea ice density ranges from 840 kg/m³ to 910 kg/m³ for first-year ice and from 720 kg/m³ to 910 kg/m³ for multi-year ice, and
- below the waterline, sea ice density is more consistent, ranging from 900 kg/m³ to 920 kg/m³ for both types of ice.

A.12.7.4 Keel porosity

A first-year ice ridge or rubble field consists of a sail and a keel, which is further subdivided into a consolidated layer and the underlying unconsolidated rubble. The sail and the rubble are porous features with a non-zero macro-porosity, whereas the consolidated layer has zero macro-porosity.

Keel porosity is defined as the volume of voids divided by the total volume of the rubble in the keel. Porosity can be estimated by drilling vertically through the rubble and recording the ranges of depths

where there is no resistance to the drill. Lack of resistance can be interpreted as a void between ice blocks. While both mechanical and thermal drilling can be used, the latter technique is more practical at depth. Volumetric porosity can be estimated from the length of voids and weak ice versus the total length of the drilled holes. A typical hole diameter is about 5 cm. Since rubble porosity estimates using the length ratio can potentially underestimate volumetric porosity, the test method should be verified and any necessary corrections should be applied.

Local measurement on a number of ridges and rubble fields is recommended because of significant variations in porosity, both within individual rubble features and from one feature to the next. Ridge keel porosity can be influenced by the buoyancy induced pressure between ice blocks. The keel porosity typically increases with depth, starting from 0,1 or 0,2 just beneath the consolidated layer and increasing to 0,4 or 0,5 at the keel bottom. The porosity of FY ridge keels can potentially decrease during the summer melt season.

A.13 Icebergs

A.13.1 General

During all aspects of an arctic operation, the requirement for accurate data collection and documentation on the presence of icebergs is vital for building a database which can be used in the planning and design of future operations. The data collection should result in the following:

- long-term time series of iceberg areal density for a specific location and a larger region of interest;
- statistical information on the median, and maximum, annual distribution and type of icebergs for a specific location and a larger region of interest.

Information regarding the presence of icebergs should be collected from all structures involved in the life cycle of the project, including exploration rigs and production facilities. Date and time of the observation as well as the confidence level of the data should be collected. During data collection of iceberg positions, corresponding environmental (current profiles, winds, wave heights and direction, air and water temperature) information should be collected. The frequency of iceberg information collection should be commensurate with the determined threat and proximity to the facility. Ideally, positions should be obtained hourly or more frequently if required. The types of data to be collected should include:

- a) location (latitude and longitude, in decimal degrees);
- b) above waterline dimensions;
- c) draft;
- d) shape indices;
- e) above water and underwater profiles;
- f) rolling/calving events;
- g) images or photographs;
- h) drift speed and direction.

The detection, and collection, of iceberg information can be obtained by various methods, including:

- aerial reconnaissance;
- surface observations from ships, platforms and other structures;
- sub-surface profiling sonar;
- drifter buoys;

- radar detection;
- satellite imagery;
- other devices, such as infrared cameras.

Airborne observations can provide tactical information about the iceberg conditions updrift of the project site, when weather conditions permit. They can be useful for providing local ice information at a higher spatial and temporal scale than permitted by satellite imagery, and can be used as a means of verifying satellite radar targets. Flight plans should be developed and approved by all end-users at a frequency that is commensurate with the iceberg distribution in the region of interest. Flights should focus on the operations area, transit routes for vessels, and areas updrift of facilities. The main objective should be to positively identify all glacial ice features, logging their position, size, shape and obtain visual images for distribution to operations personnel. Specific consideration should be given to larger features, such as ice island fragments, including their drift, to assist with the threat assessment.

Trained iceberg observers on vessels and platforms can provide information about iceberg conditions in close proximity to the operation. Visual imagery and marine radar can aid in surface observations of icebergs.

Sub-surface profiling sonar can provide information on iceberg maximum draft and keel shape. The data provided by the sub-surface profiling sonar are useful for providing information on local iceberg underwater keel geometries and maximum drafts, which can be used to estimate regional iceberg masses prior to or during offshore operations, to assist with operational planning, design of towing gear, or for the design of facilities. Ground-penetrating radar can also be used to provide iceberg draft data.

Drifting satellite-communicating buoys placed on icebergs can be used to remotely monitor the location and movement of icebergs, particularly icebergs embedded in sea ice. The frequency of the data collection and the type of data collected should be appropriate for the type of operation. The drifter buoys are useful prior to offshore operations and for design studies since they can provide closely-spaced positional data for the development of drift distributions and for forecasting studies.

Many marine radar systems (X-Band or S-Band) are unable to detect small pieces of ice, such as bergy bits and growlers or distinguish icebergs surrounded by pack ice. Specialized radar systems configured for ice detection should be used on all facilities in the operations area, ice management vessels and supply vessels, and operated by trained ice observers.

In regions where aerial reconnaissance is not a viable option, high-resolution optical satellite imagery can be used to positively identify icebergs. Synthetic aperture radar (SAR) satellite sensors can be used to detect larger icebergs, although caution should be exercised to distinguish between the very similar target signatures for icebergs and ships. Satellite detection should be used with caution in regions with extensive shipping activities. SAR satellite imagery can be used in combination with high-resolution optical satellites.

Whenever possible, iceberg sightings should be linked to previous sightings of the same iceberg. This helps to build a history of the path, deterioration and melt of the iceberg that can be used to improve iceberg trajectory forecasts.

[Table A.16](#) provides a list of typical iceberg parameters for offshore operations, while [Table A.17](#) provides a list of typical parameters for design. Neither is intended to be comprehensive. Careful consideration should be given to understanding the local and regional iceberg environments and their effect on operations and design. For operations, the parameter list should focus on detection, location, distance from operation, drift, presence of sea ice, towing considerations and size. For design, the parameter list should include, as a minimum, the parameters associated with detection, management, local actions and global actions.

Table A.16 — Iceberg parameters of relevance for operations (example)

Feature	Parameter	Measurement details	Frequency	Spatial resolution	Accuracy	Comments
Spatial density	Number of icebergs per square kilometre or nautical mile	Obtain from high-resolution satellite imagery and marine radar with ice processor, aircraft observation	At least daily	Representative area of 1 degree square (or about 100 km × 100 km)	1 iceberg	Should be performed as historical analysis for operations planning in addition to monitoring during operation, also consider frequency of incursion into the region of interest
Location (nearest icebergs)	Latitude/longitude coordinates	Obtain from high-resolution satellite imagery and marine radar with ice processor, or tracking beacons, aircraft observation	At least hourly		100 m (or significantly better for estimating drift speed from hourly positions)	For operations planning, consider inter-annual variability in frequency of iceberg incursions, locations, also consider variability during operations
Physical state	Visual appearance	Opacity				Potential implications for strength and deterioration
Drift	Drift speed	Obtain from high-resolution satellite imagery, marine radar with ice processor, tracking beacons	At least hourly		0,1 kts	Measurement and forecast; Variability in speed and standard statistics (mean, median, maximum, standard deviation); Meander coefficients
	Drift direction	Obtain from high-resolution satellite imagery, marine radar with ice processor, tracking beacons	At least hourly		1°	Measurement and forecast; Variability in direction and statistics (mean, median, maximum, standard deviation)

Table A.16 (continued)

Feature	Parameter	Measurement details	Frequency	Spatial resolution	Accuracy	Comments
Iceberg dimensions	Waterline length	Use digital single lens reflex (SLR) photography if possible	Initially and after rolling/calving events		5 m	Consider variability and standard statistics (mean, median, maximum, standard deviation)
	Maximum width	Perpendicular to length	Initially and after rolling/calving events		5 m	Consider variability and standard statistics (mean, median, maximum, standard deviation)
	Maximum draft	Relative to water surface	Initially and after rolling/calving events		5 m	Consider variability and standard statistics (mean, median, maximum, standard deviation), and grounded or ungrounded state
	Maximum sail height	Relative to water surface	Initially and after rolling/calving events		2 m	Consider variability and standard statistics (mean, median, maximum, standard deviation)
Iceberg shape	Above-water profile	Classify visually	Initially and after rolling/calving events			Consider variability in shapes
	Underwater profile	Scanning or multi-beam sonar	Initially and after rolling/calving events			Consider variability in underwater profiles
Iceberg mass		Estimate using standard formulations based on dimensions and shape	Initially and after rolling/calving events		5 % to 10 %	Consider variability and standard statistics (mean, median, maximum, standard deviation)
Iceberg grounding	Location; water depth	Same as for location	As required		100 m	
Iceberg management	Location; tow force; tow speed; tow direction	Tow data inferred from vessel data	Hourly		100 m on position; 10 % to 20 % on tow force, speed; 5° on tow direction	Time series while under tow; reasons for end of tow
Presence of sea ice		Obtain from satellite imagery, visual observation, aircraft observation, marine radar with ice processor, record sea ice location, drift speed and direction	At least hourly			Consider variability and standard statistics (mean, median, maximum, standard deviation) in sea ice drift speeds, directions, thicknesses, concentrations, masses and drift speeds and directions of icebergs in sea ice.

Table A.16 (continued)

Feature	Parameter	Measurement details	Frequency	Spatial resolution	Accuracy	Comments
Presence of growlers and bergy bits		Obtain from high-resolution satellite imagery, visual observation, marine radar with ice processor, aircraft observation, record growler/bergy bit location, drift speed and direction if possible	At least hourly			Consider variability and standard statistics (mean, median, maximum, standard deviation) in sizes/masses, spatial density, drift speeds and directions
Iceberg stability		Record all rolling events for each iceberg				Consider variability in frequencies of rolling events for different iceberg shapes, sizes
Iceberg season	Season length	Based on minimum iceberg presence in terms of spatial density				Consider inter-annual variability in season length for operations planning

Table A.17 — Iceberg parameters of relevance for design (example)

Feature	Parameter	Measurement details	Comments ^a
Spatial density	Number of icebergs per square km or n.mi.	Obtain from high-resolution satellite imagery and marine radar with ice processor, aircraft observation	Mean and maximum historical values, historical probability distribution
Drift	Drift speed	Obtain from high-resolution satellite imagery, marine radar with ice processor, tracking beacons	Mean and maximum historical values, historical probability distribution
	Drift direction	Obtain from high-resolution satellite imagery, marine radar with ice processor, tracking beacons	Joint probability density function with drift speed; predominant directions
Iceberg dimensions	Waterline length	Use digital single lens reflex (SLR) photography if possible	Maximum historical values, historical probability distribution.
	Maximum width	Perpendicular to length	Historical probability distribution, correlate with waterline length
	Maximum draft	Relative to water surface	Maximum historical values, historical probability distribution, correlate with waterline length
	Maximum sail height	Relative to water surface	Historical probability distribution, correlate with waterline length

^a Statistics, characteristic values, probability distribution, correlated parameters.

Table A.17 (continued)

Feature	Parameter	Measurement details	Comments ^a
	Shape (block coefficients, vertical or horizontal profiles, or full shape)	Above water – digital photogrammetry; Below water – profiling sonar; Need for reference points on iceberg to correct for iceberg and sensor platform motions	
Iceberg mass	Calculated from volume and density	Volume calculated from above water and underwater profiles	Historical probability distribution, correlate with waterline length
Iceberg season	Season length	Based on minimum iceberg presence in terms of spatial density	Mean and maximum historical values, historical probability distribution
Iceberg location	Incursion distance relative to shoreline or edge of structure, historical frequency of incursion into region of interest		Historical probability distribution
Waves	Significant wave height; period.	Measurements or hindcasts verified with local measurements	Time series; joint probability density function weighted by iceberg frequency
Currents	Speed, direction, vertical profile to maximum iceberg draft	Measurements or hindcasts verified with local measurements	Joint probability density function, weighted by iceberg frequency and potentially integrated through iceberg depth
Presence of sea ice	Sea ice edge; concentration	Obtain from high-resolution satellite imagery, visual observation, aircraft observation, marine radar with ice processor, record sea ice location, drift speed and direction	Mean and maximum historical values of concentration, thickness, drift speed and direction of sea ice, mass and drift speed and direction of icebergs in sea ice, historical probability distributions
Presence of growlers and bergy bits	Position; position relative to parent iceberg; areal density; drift speed and direction	Obtain from high-resolution satellite imagery, visual observation, marine radar with ice processor, aircraft observation	Mean and maximum values of spatial density, size/mass, drift speed and direction, historical probability distributions

^a Statistics, characteristic values, probability distribution, correlated parameters.

Iceberg information can be obtained from actual observations from the region of interest, from medium or high-resolution satellite imagery or historical data. If iceberg data are unavailable in the region of interest or local data records are less than 10 years in length or do not accurately represent the expected iceberg conditions, information from nearby locations/regions, which have more significant archives with similar iceberg environments can be used. If data are obtained from nearby regions, any assumptions and uncertainties in the application of these data to a different region should be carefully documented. Consideration should be given to the collection of iceberg data updrift and from the source glaciers, particularly when assessing potential for deep drafts and large plan dimensions. If site-specific wind, wave or current data are not available, data from the closest offshore station or data from a hindcast model could be considered. If a hindcast model is used; proper calibration against records should be documented.

A significant factor in determining site-specific and regional iceberg climatology is that there is a significant inter-annual variability in parameter distributions, including the types (sizes and shapes)

and areal density. Multiple glacier calving events occur each year; however, their frequency can vary significantly on a seasonal basis, which can have an impact on the distribution of icebergs in the region.

Prior to any offshore operations commencing in regions prone to icebergs, a historical study should be completed, using all available sightings from previous offshore programs and reconnaissance survey missions (either airborne or satellite) for the project location or region of interest. Data to be collected and analysed can include:

- a) location;
- b) waterline dimensions;
- c) maximum draft;
- d) shape;
- e) drift speed and direction;
- f) full profile;
- g) presence of bergy bits and growlers;
- h) areal density.

A.13.2 Iceberg location and areal density

Tow status should be supplemented with relevant information including details of the towing operation, tow force applied, direction of tow force, time to secure iceberg, duration of tow, reason for undertaking tow, reason for end of tow and details of repeated tow attempts. Similar information should be provided for other physical management techniques such as water cannons.

A longer-term seasonal iceberg conditions forecast model can be used if such a model is available and has been validated for the region of interest.

When estimating iceberg areal density, the smallest recorded iceberg size can be dictated by the observational technique, whether visual, marine radar and satellite sensor or by the design requirements.

A.13.3 Size, shape and stability

Iceberg length is the maximum waterline dimension.

Iceberg width is the maximum waterline dimension perpendicular to the waterline length.

Iceberg height is the maximum vertical distance from the mean waterline to the elevation of the highest point on the iceberg, also termed freeboard or sail height.

Iceberg draft is the maximum depth of the iceberg relative to the mean waterline.

[Table A.18](#) lists the seven internationally recognized iceberg size classes based on sail height and waterline length (MANICE^[16]) In the event of a conflict between these definitions for a particular iceberg, waterline length can be used as the determining factor.

Table A.18 — Iceberg size categories (MANICE^[16])

Description	Sail height	Waterline length
Growler	<1 m	<5 m
Bergy bit	1 m to <5 m	5 m to <15 m
Small iceberg	5 m to 15 m	15 m to 60 m

Table A.18 (continued)

Description	Sail height	Waterline length
Medium iceberg	16 m to 45 m	61 m to 120 m
Large iceberg	46 m to 75 m	121 m to 200 m
Very large iceberg	>75 m	>200 m

For visual re-identification as part of operations, icebergs can be categorized based on the size categories in [Table A.18](#) and on a shape categorization such as the one shown in [Table A.19](#). Iceberg terminology should follow standard and documented practice and new terms should be properly defined and documented. Some icebergs will not fit uniquely into one these categories, particularly when multiple views are available. It is emphasized that the MANICE^[16] shape classification is not generally of use for design and measured above-water profiles should be used.

Table A.19 — Iceberg shape categories (MANICE^[16])

Category	Description
Tabular	Flat-topped iceberg with vertical sides; usually very stable; however, tabular icebergs are typically among the largest in size
Pinnacle	Large central spire or pyramid or one or more spires dominating the shape
Dry-dock	Eroded such that a large U-shaped slot is formed with twin columns or pinnacles; slots extend into the iceberg or close to the water
Wedge	Iceberg with one side usually at sea level
Dome	Smooth, rounded iceberg
Blocky	A block-like shape, tall iceberg with vertical sides, similar to a tabular iceberg, but much higher

A quantitative measure of iceberg shape is the ratio of the volume of the iceberg to the volume of the rectangular prism (or cuboid) that contains it. This ratio, sometimes termed the block coefficient, is generally defined for the above-water portion but can also be defined for the underwater portion or for the entire iceberg. The above-water block coefficient is calculated as above-water volume / (waterline length × waterline width × height). Since icebergs are often only viewed from one or a small number of directions, projected areas can be used as measures of size and shape. The waterplane area is calculated from the projection in the plane of the water surface, while many different projected areas exist in the vertical plane depending on the viewpoint. Iceberg volume can be estimated using one or more projected areas and approximate shape measures, such as area block coefficients. In the plane of the water surface, the area block coefficient is calculated as projected area / (waterline length × waterline width).

Iceberg mass is generally inferred from estimates of volume and ice density, either for the above-water portion or for the entire iceberg. Hydrostatics can be used to relate the above-water and underwater volumes of an iceberg.

Although the stability of an iceberg with respect to rolling can be calculated from full three-dimensional profiles using hydrostatics, measurement accuracy is seldom sufficient to do this accurately, particularly when an iceberg is only marginally stable.

Using marine radar to determine the range from the observation point, above-water dimensions can be estimated visually and by using known vessel or offshore structure dimensions for scale. More accurate methods for determining above-water dimensions, such as digital imaging with appropriate geometrical corrections, are generally recommended.

Although statistical methods have been developed to estimate the maximum draft and mass of icebergs based on above-water dimensions, more accurate data from sonar measuring devices should be used if possible.

In the absence of direct measurements, the draft of grounded icebergs can be estimated reliably based on bathymetric data. A grounded state can be ascertained by repeated position measurements that are within the positional accuracy of the measuring system.

Potential uses of iceberg shape data for design include:

- estimation of impact frequency (matching iceberg and facility dimensions, including topsides);
- iceberg hydrodynamics (on approach and subsequent to impact);
- contact location and moments of inertia;
- progression of contact area between ice and structure (following impact).

Each of these uses requires detailed iceberg shape data. Above-water profiling can involve imaging from multiple viewpoints, stereo photogrammetry or laser profiling. Underwater profiling can involve multibeam or scanning sonar, whether mounted to a ship, lowered through the water column, or mounted to a surface or submersible vehicle. Regardless of approach, important aspects of shape measurement include the re-identification of surface points on the iceberg from multiple views and scaling based on the relative positions of the sensor and the iceberg, often involving iceberg drift and rotation over the survey period.

Since it is only feasible to measure a small proportion of the iceberg population, the challenge is to obtain a representative and unbiased sample. This process can involve distinguishing populations with different characteristics, such as ice islands and other icebergs and treating aspects of their shape independently. Within distinct populations and size ranges, it can be useful to assume some sort of geometric similarity, potentially scaling measured shapes or profiles according to waterline length or draft. Scaling to waterline length, for which many measurements exist and for which seasonal and inter-annual biases have been resolved, can potentially provide for a more representative population of iceberg shapes.

Local iceberg shape is of particular importance because it relates directly to the nominal contact area and therefore the load imparted to the structure (see ISO 19906). Characterization of local shape can potentially involve actual measured surface points, horizontal or vertical profiles and functional fits relating distance normal to the surface and projected area. For structure design purposes, it can be useful to express the data or derived relationships statistically.

A.13.4 Iceberg drift

The following information can be determined from historical information:

- seasonal drift speed statistics (and distributions);
- inter-annual trends in mean drift speed and predominant drift direction;
- predominant ice drift directions and mean drift speeds for the planned operating season, as well as an assessment of their variability within the operating period.

Drift speed and direction can be inferred from successive position measurements. Effort should be made to obtain hourly position fixes, thereby ensuring that tidal and inertial contributions to drift are captured adequately. Direction should be estimated to an accuracy of one azimuthal degree, and speed should be estimated to an accuracy of 0,05 m/s.

Iceberg drift speed and direction depend on the local wind, wave and current fields. Regional differences and the effects of iceberg size and water depth can also be characterized.

A.13.5 Metocean and sea ice context

Metocean and sea ice context include, but are not limited to:

- wind;
- waves;
- currents;

- air and water temperatures;
- atmospheric parameters (including fog, cloud cover, and precipitation);
- sea ice (concentration, floe size, thickness, landfast state).

These parameters can influence detection, drift (including forecasting), deterioration, physical management, vessel transit and impact situations associated with operations and design in waters where icebergs are present.

If site-specific wind, wave and current data are not available, data from the closest offshore station or data from a hindcast model can be used. If a hindcast model is used, proper calibration against available records should be documented.

Winds, waves and currents used as input for drift forecasting models should be verified against locally measured data and uncertainties identified.

A.13.6 Physical properties

A.13.6.1 Temperature

Iceberg temperature can potentially be used for the estimation of deterioration rate and calving potential, as well as for the estimation of mechanical properties. Iceberg core temperature is controlled by the physical environment in which it was formed, while surface temperatures are governed by the ambient conditions. Typically, core temperatures are relatively constant and there is a steep temperature gradient within a metre or so of the iceberg surface. Temperatures near the surface are controlled by the air and water temperatures (and other convection related parameters), radiative processes, and mechanical calving processes. As a result, surface temperatures are highly variable and typically range from $-20\text{ }^{\circ}\text{C}$ (or less) to $0\text{ }^{\circ}\text{C}$.

A.13.6.2 Density

The density of iceberg ice is typically used to relate volume and mass. Density is governed primarily by the presence of voids (air and other gas bubbles), but also by impurities in the ice (atmospherically transported particles, biological matter, sediments, and rocks).

Average density and variability within individual icebergs and across the iceberg population can be assessed based on site-specific measurements or using data from icebergs or glaciers that are representative of the same population.

In the absence of measured data, an iceberg density of between 890 kg/m^3 to 900 kg/m^3 can be assumed. While pure ice has a density of approximately 917 kg/m^3 at $0\text{ }^{\circ}\text{C}$, the density of iceberg ice is less because of air trapped within. The presence of silt and rocks within the ice matrix can yield greater densities, while the presence of large quantities of air can lead to lower densities.

A.14 Snow and ice accretion

A.14.1 General

Snow and ice accretion involve build-up on the surface of an object and can involve additional loading, changed shape, obstruction, or altering of friction properties. Effects and associated risks that can influence structure integrity, operation, HSE and EER characteristics include:

- a) consequences of increased weight (on stability or structural integrity);
- b) consequences of skew loading on heeling of structures (in particular, semisubmersible rigs);
- c) slippery decks, ladders, and handrails;
- d) malfunctioning winches, derricks and valves;

- e) falling ice endangering the workplace;
- f) communication and measuring equipment not working due to ice on antennas or measuring devices;
- g) evacuation routes blocked;
- h) life-saving and fire-fighting equipment rendered unusable;
- i) increased size of structural members causing higher lateral wind and wave forces;
- j) increased size of structural members causing vortex generation and severe vibrations;
- k) reduction of ventilation capacity.

Although this document is limited to snow and ice accretion data, it is neither always easy nor practical to distinguish between data, e.g. icing thickness on a reference object, and actions, e.g. icing load on a particular object.

General recommendations for snow and ice accretion include the following.

- Develop data for reference objects and conditions. These data can be used both for validation and benchmarking purposes as well as for further refined analyses.
- During the early design stages, simplified snow and icing estimates can be used such as provided in NORSOK N-003[14].
- From the front-end engineering design (FEED) project stage, advanced (numerical) analyses using best available methods should be used for a particular structure. Credibility of the results should be demonstrated by proper stage-wise validation of the model and input data.

A 6-hour or better data collection interval is recommended during accretion events. Reference [32] provides examples for data collection, reporting and storage.

Examples of parameters required for snow and ice accretion are summarised in [Table A.20](#) for operations and in [Table A.21](#) for design.

A.14.2 Snow accretion

A.14.2.1 Classification

Whether precipitation reaches the surface as rain or snow depends on the temperature profile in the atmosphere. Temperatures in the 850 mb layer have to be below 0 °C for snow crystals to form. If temperatures below this altitude are above 0 °C, falling snow crystals melt again and sleet, rain or freezing rain can form. Snow is most likely to form when the whole column up to 850 mb is below freezing.

Wet snow forms when the surface of the snowflakes melts. This happens where the wet-bulb temperature is above 0 °C. This means dry snow can exist at temperatures above 0 °C, if the relative humidity is below 100 % (see Reference [33]). A major difference between wet and dry snow is that wet snow adheres more readily to surfaces and can accrete on vertical surfaces and small objects whereas dry snow would simply bounce off.

Snow density depends on parameters such as temperature during formation and during and after deposition, grain shape and size, overburden pressure, wind speeds and liquid water content. The large variability of density is important when converting precipitation amounts to snow depths.

Wind not only increases the density of the snow pack, but also redistributes the snow, thus increasing snow thickness in some places while reducing it other places. In general, snow is eroded by wind from areas of high velocity and deposited in areas of low velocity (lee zones). The wind flow around an object therefore defines how deposited snow will be distributed.

EN 1991-1-3^[11] provides further information on classification and properties of the snow.

For offshore snow events in open water, the ocean will act as a sink for snow particles landing outside of the structure. In contrast to locations onshore or in coastal regions, offshore structures will not typically be affected by wind-drifted snow from nearby locations. Snow loads estimated by accumulated precipitation will generally be conservative as significant amounts of the snow falling on the structure will be blown off. In design, the effect of wind drift can be taken into account by the use of calibrated and verified snow drift models.

Table A.20 — Snow and ice accretion parameters of relevance for operations (example)

Feature	Parameter	Measurement details	Frequency	Spatial resolution	Accuracy	Comments
Accretion	Type					Snow, sleet, sea spray icing, atmospheric icing
	Reference location			As per requirements		Elevation; from site plans
	Thickness		3-h	Defined reference locations	1 mm	More frequent, where relevant
	Density			Defined reference locations	As required	Average for event
	Salinity					Where applicable
	Horizontal extent	Presence/no presence			Defined reference locations	As required
Associated conditions	Surface condition	Surface geometry (inclination, diameter if slender element) roughness, rust, or type of surface coating				
	Active mitigation	Means of removal				
	Passive mitigation	Documentation of energy transfer mechanisms	Event			Solar radiation; heat source
	Vessel	Speed, heading	As per log			Loading conditions, etc.
	Wind	Speed, direction	3-h			Bias; sheltering
	Air temperature	Elevation	3-h			
	Water temperature		3-h			
	Precipitation	Specific to type of accretion	3-h			
	Wave	Height, period, direction	3-h			
	Humidity		3-h			

Table A.21 — Snow and ice accretion parameters of relevance for design (example)

Feature	Parameter	Measurement details	Comments ^a
Accretion	Type		
	Reference location		Elevation, sheltering
	Thickness		Statistics; probability distribution; extremes; correlation with associated conditions
	Density		Statistics; probability distribution; correlation with associated conditions
	Salinity		Statistics; correlation with associated conditions
	Horizontal extent		
Associated conditions	Surface condition	Surface geometry (e.g. inclination, diameter if slender element) roughness, rust, or type of surface coating	
	Passive mitigation measures		Average or statistics; associated with accretion measurements
	Vessel	Speed, heading	
	Wind	Speed, direction	
	Air temperature		
	Water temperature		
	Precipitation	Specific to type of accretion	
	Wave	Height, period, direction	
	Humidity		
^a Statistics, characteristic values, probability distribution, correlated parameters.			

A.14.2.2 Data collection

No additional guidance is offered.

A.14.2.3 Analysis and presentation

Spatial variability of snow accumulation for a particular structure should be evaluated. Snow actions should include local peaks and background mean loads.

All automated rain gauges (pluviometers) are affected by wind. In particular, precipitation measurements of snow are significantly underestimated during strong wind events. Scientists from the Norwegian Meteorological Institute (NMI), Statkraft and the Norwegian Water Resources and Energy Directorate (see Reference [34]) have performed detailed measurements of precipitation over a period of three winter seasons in the high mountains in Norway. The results displayed a clear temperature dependency and a non-linear relationship with wind speed.

Two correction formulae for precipitation in the form of snow when measured in connection with temperature and wind are provided in [Formulae \(A.6\)](#) and [\(A.7\)](#). For wind speed measured at the same height as the pluviometer, the true precipitation can be estimated from:

$$p_t = p_m \left[\left\{ 0,82 - \frac{0,81e^{\left(\frac{T-0,69}{1,15}\right)}}{1+e^{\left(\frac{T-0,69}{1,15}\right)}} \right\} e^{-\left(\frac{U}{3,41}\right)^{1,58}} + \frac{0,81e^{\left(\frac{T-0,69}{1,15}\right)}}{1+e^{\left(\frac{T-0,69}{1,15}\right)}} + 0,18 \right]^{-1} \quad (\text{A.6})$$

where

- p_t is the true precipitation;
- p_m is the measured precipitation;
- U is the measured wind speed in metres per second;
- T is air temperature in degrees Celsius.

For wind speed measured at the standard 10 m height, the true precipitation can be estimated from:

$$p_t = p_m \left[\left\{ 0,82 - \frac{0,81e^{\left(\frac{T-0,66}{1,07}\right)}}{1+e^{\left(\frac{T-0,66}{1,07}\right)}} \right\} e^{-\left(\frac{U_{10}}{4,24}\right)^{1,81}} + \frac{0,81e^{\left(\frac{T-0,66}{1,07}\right)}}{1+e^{\left(\frac{T-0,66}{1,07}\right)}} + 0,18 \right]^{-1} \quad (\text{A.7})$$

where

- U_{10} is wind speed measured at the standard 10 m height in metres per second.

[Formulae \(A.6\)](#) and [\(A.7\)](#) are recommended for temperatures below 3 °C.

Snow accumulations on flat surfaces corresponding to annual probabilities of exceedance of 10^{-2} and 10^{-4} can be estimated by identifying the maximum accumulated snow mass each winter, fitting a relevant probability distribution, e.g. Gumbel, to the annual extremes and extrapolating to 10^{-2} and 10^{-4} levels.

Actions from accumulated snow result from the combined snow precipitation and snow drift processes. Snow precipitation can be estimated from, in prioritized order:

- a) locally recorded snow data;
- b) recorded local precipitation together with information on air temperature (snow if T less than +1 °C);
- c) precipitation from calibrated hindcast data together with information on air temperature (snow if T less than +1 °C);
- d) tabulated values, e.g. EN 1991-1-3[11].

Actions from accumulated snow (both locally and globally) can be estimated from, in prioritized order:

- 1) locally recorded snow data;
- 2) numerical simulations of snow drift processes (including assessments of blow-off, erosion and accumulations);
- 3) tabulated values, e.g. EN 1991-1-3[11].

Assuming snow accumulation over an entire winter season can give over-conservative estimates of snow mass. This is partly due to the fact that all snow blowing off a structure will disappear when

hitting the sea surface (unless there is a continuous ice sheet) and partly due to melting during periods with high temperatures. There will therefore be a continuous snow reduction process in parallel with subsequent snow fall events and consideration should be given for characterizing the reduction process.

A number of models exists for estimation of temperature effects, including References [35], [36], [37], [38] and [39] addressing the effect of wind drift. Accurate effects of wind drift are difficult to estimate without modelling all structure details and the ability to run computational fluid dynamics simulations for several snow-wind events.

At an early stage in a development project (before FEED), the following simplifications can be made when estimating extreme and abnormal snow accumulations. The annual maximum snow accumulation can be assumed to be represented by the maximum amount of water equivalent falling as snow over a period of 10 d.

If a time series with precipitation and air temperature at 6-hour intervals (for example) is used as a basis, the snow precipitation can be calculated by summing up the amount of water falling under temperatures below a certain threshold for 10-day intervals. This is done for each time step by considering data within the next 10 d ahead. By selecting maximum values for each winter and fitting a Gumbel distribution to the annual maximum values, extreme and abnormal estimates can be made by extrapolation.

A.14.3 Atmospheric ice accretion

A.14.3.1 Classification

ISO 12494 provides further information on classification and properties of atmospheric icing.

A.14.3.2 Data collection

A.14.3.2.1 Prior to operations (in design and planning phase)

When planning operations in arctic regions, specific attention should be given to risks related to atmospheric icing as these differ from other metocean and ice risks and are not necessarily captured when considering action and action effects. Atmospheric icing can affect operation of equipment on vessels and platforms. Since it can form high up on structures, it can decrease stability by raising the centre of gravity. Atmospheric icing can also cause complications for aircraft operations. Falling ice is a well-known phenomenon and potential risks should be assessed prior to any operation.

A.14.3.2.2 During operations

The thickness of ice accretion should be collected on at least

- four vertical surfaces (two different elevations and members with different diameters: 1 cm to 1 m), and
- one horizontal surface.

A.14.3.3 Analysis and presentation

An estimate of sleet accretion on the structure can be found in the following manner.

- a) A time series of the sleet precipitation is constructed based on the hindcast data set. Sleet is defined as the precipitation falling at air temperatures between $-1\text{ }^{\circ}\text{C}$ and $+1\text{ }^{\circ}\text{C}$. The effect from local variations in collision efficiency should be included.
- b) For each continuous sleet event, the temperature after the event is checked. If the temperature drops below $-1\text{ }^{\circ}\text{C}$, it can be assumed that the sleet of this event accumulates on the structure, i.e. refreezes. If the temperature does not drop, it can be assumed that the sleet of this event does not accumulate on the structure.

- c) Amounts from consecutive sleet events with successive freezing can be added unless there is a 24 h period of air temperatures above 0 °C in between events.

Refrozen sleet will usually fall off or melt after 24 h of air temperatures above 0 °C.

Conditions for formation of super-cooled cloud drops and occurrence of in-cloud icing can be set to:

- $-2\text{ °C} < T < -10\text{ °C}$;
- relative humidity $>92\%$; or
- no precipitation.

In the temperature range 0 °C to -2 °C it is assumed that droplets colliding will not freeze due to release of latent freezing heat and, in case of precipitation (snow), it is assumed that the clouds will dissolve. Theoretically, the relative humidity for saturated conditions should be 100 %. Fog observations from meteorological stations in the arctic regions suggest a conservative limit for saturation of 92 %.

Based on this criterion, in-cloud icing events can be estimated from the hindcast dataset. Time series of in-cloud icing can be constructed using, for example, the methodology presented in References [40], [41] and [42].

A.14.4 Sea spray ice accretion

A.14.4.1 Classification

Icing caused by freezing sea spray is widely reported and usually the most serious form of icing at sea. Ice accretion by sea spray depends on the following parameters, e.g. Reference [43]:

- a) wind speed;
- b) air temperature;
- c) sea water temperature;
- d) wave height and period;
- e) geometry of the structure and response to waves;
- f) speed of the vessel, where relevant.

The main processes in sea spray icing are:

- spray generation;
- spray transport; and
- ice accumulation by freezing of water.

Sea spray icing has two main sources: white cap spray and interaction spray.

White cap spray is connected to wind-wave interaction and is expected to increase strongly at high wind speeds when spume droplets are formed.

Interaction spray is formed when waves interact with a structure and produce a spray cloud. Interaction spray factors such as vessel shape, size, and heading relative to the wind play an important role in the patterns of spray produced under a given set of meteorological conditions.

At present, there are no empirical or analytical methods that accurately predict sea spray icing on a wide range of vessels and structures. The approach presented in Reference [44] has been used traditionally for estimation of sea spray icing potential for small-to-medium size vessels. Numerical calculations of varying complexity have been used during the recent years to estimate sea spray icing on different offshore structures. However, the validation of the numerical calculations is generally limited.