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| WEATHER CLIMATE WATER | **World Meteorological Organization****COMMISSION FOR WEATHER, CLIMATE, WATER AND RELATED ENVIRONMENTAL SERVICES AND APPLICATIONS****Second Session**17 to 21 October 2022, Geneva | **SERCOM-2/INF. 5.1(1)** |
| Submitted by:President of INFCOM and President of SERCOM14.X.2022 |

# UPDATES TO THE [*MANUAL ON GLOBAL DATA-PROCESSING AND FORECASTING SYSTEM*](https://library.wmo.int/index.php?lvl=notice_display&id=12793) (GDPFS) (WMO-NO. 485)PROPOSED BY SERCOM STANDING COMMITTEES

The following text has been developed by the Standing Committees on Hydrological Services (SC-HYD), jointly with SC-ESMP and SG-CRYO, and on Marine Meteorology and Oceanographic Services (SC-MMO). It will be considered during INFCOM-2 through [INFCOM-2/Doc. 6.4(2)](https://meetings.wmo.int/INFCOM-2/_layouts/15/WopiFrame.aspx?sourcedoc=/INFCOM-2/English/1.%20DRAFTS%20FOR%20DISCUSSION/INFCOM-2-d06-4(2)-AMENDMENTS-TO-GDPFS-MANUAL-WMO-NO-485-draft1_en.docx&action=default) Amendments to the Manual on the Global Data-Processing and Forecasting System (WMO-No. 485).

Proposed amendments are highlighted in addition or ~~deletion~~ to the [Manual in the Global Data-processing and Forecasting System](https://library.wmo.int/index.php?lvl=notice_display&id=12793) (WMO-No. 485) and the numbering of the text below refers to the Manual.

Any changes derived from discussion at SERCOM-2 to the text proposed below will be reflected in [INFCOM-2/Doc. 6.4(2)](https://meetings.wmo.int/INFCOM-2/_layouts/15/WopiFrame.aspx?sourcedoc=/INFCOM-2/English/1.%20DRAFTS%20FOR%20DISCUSSION/INFCOM-2-d06-4(2)-AMENDMENTS-TO-GDPFS-MANUAL-WMO-NO-485-draft1_en.docx&action=default).

1.2.6.3 Requests for designation as a WMC or RSMC shall be put forward by the Permanent Representative of the country of the candidate centre, or, in the case of international organizations, by either the Permanent Representative of the country where the candidate centre is located or the president of the relevant regional association(s) (RA(s)).

Note: The Permanent Representative of the country consults with the Hydrological Adviser with respect to requests of the designation as a Centre relevant to operational hydrology and its application to water management as per Regulation 5 of General Regulations (WMO-No. 15).

**2.2.1.X Sub-seasonal to seasonal (S2S) hydrological prediction**

Centres conducting sub-seasonal to seasonal (S2S) hydrological prediction (Regional Specialized Hydrological Centres (RSHC) for S2S hydrological prediction) shall:

(a) Produce ensemble forecast fields of basic and/or derived hydrological variables;

(b) Provide forecast data and products at spatial and temporal resolutions that are scientifically and technically appropriate given S2S predictability considerations;

(c) Produce, where applicable, related forecast information products including categorical probability forecasts (such as tercile forecasts comprising probabilities of above normal, normal, below normal conditions) relative to a reference climatology, in the form of maps, charts and tables;

(d) Make available on WIS a range of these products; the list of mandatory and highly recommended S2S ensemble hydrological products to be made available is given in Appendix 2.2.XX;

(e) To the extent possible, make verification statistics available according to the standards defined in Appendix 2.2.YY;

(f) Make available online up-to-date supporting information on the characteristics of their global S2S ensemble hydrological prediction system, including key datasets and model versions, summary description of important ancillary methods (such as data assimilation and post-processing), and key references and contacts; the minimum information to be provided is given in Appendix 2.2.ZZ.

Note: The bodies in charge of managing the information contained in the present Manual related to global ensemble NWP are specified in Table X

Table X. WMO bodies responsible for managing information related to
global S2S hydrological prediction

|  |
| --- |
| Responsibility |
| Changes to activity specification |
| To be proposed by: | INFCOM/SC-ESMP |  SERCOM/SC-HYD |  |
| To be recommended by: | INFCOM | SERCOM |  |
| To be decided by: | EC/Congress |  |  |
| Centres designation |
| To be recommended by: | RA | SERCOM | INFCOM |
| To be decided by: | EC/Congress |  |  |
| Compliance |
| To be monitored by: | SERCOM/SC-HYD |  |  |
| To be reported to: | INFCOM/SC-ESMP | INFCOM | SERCOM |

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**APPENDIX 2.2.XX. global ensemble S2S hydrological products**

1. Introduction

This appendix presents a list of core mandatory products (section 2) and recommended (section 3) global ensemble S2S hydrological products and services to be supported by qualifying centres. Additional information about the products is included in section 4, and related material describing product verification and system information is included in Appendices 2.2.YY and 2.2.ZZ, respectively.

2. Mandatory Products

Centres must operationally produce ensemble or probabilistic forecasts (including a central highly tendency and spread) for the variables listed in Table X1 for a global extent, where appropriate. Cryosphere-related products will not be valid over all land areas, though such data products may retain global dimensions. Expanded variable definitions are given in Section 4.6.

Table X1. Mandatory variables

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Variable Name** | **Spatial resolution** | **Temporal resolutions (time step)** | **Forecast lead times** | **Update Frequency** | **Latency** |
| Runoff (Discharge). See details in Section 4.6 | 5–25 km grids or mesoscale catchments | Between 1 day and 1 month | From 0 to 12 months with minimum range of 3 months | Between 1 day and 1 month | Between 1 and 10 days |

3. Highly Recommended Products

In addition to the core (mandatory) products, Centres are welcome and encouraged to provide probabilistic information products for other variables to give a fuller context to the primary forecast outputs listed above. Expanded variable definitions are given in Section 4.6.

Table X2. Additional variables

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Variable Name** | **Spatial resolution** | **Temporal resolution (time step)** | **Forecast lead times** | **Update Frequency** | **Latency** |
| Streamflow depth (river stage) | 5–100 km reach lengths; Points | Between 1 day and 1 month | From 0 to 12 months with minimum range of 3 months | Between 1 day and 1 month | Between 1 and 10 days |
| Water table depth | 5–25 km or equivalent catchments |
| Evaporative variables | 5–25 km or equivalent catchments |
| Groundwater | 5–50 km or equivalent catchments  |
| Surface precipitation and 2-meter air temperature | 5–25 km or equivalent catchments |
| Hydrologic indices | 5–25 km or equivalent catchments |
| Snow Water Equivalent | 5–25 km or equivalent catchments |
| Soil Moisture | 5–25 km or equivalent catchments  |

4. Additional Supporting Information

4.1 Spatial Resolution

The spatial resolution of the information products shall be determined by factors including usefulness and usability for local, regional and global-scale stakeholders as well as scientific and technical considerations to ensure that products can be reliably generated, effectively disseminated, and exhibit statistical skill. The mandatory spatial unit of the forecasts is a regular grid, but centres are also encouraged to provide products for other spatial units including watersheds or other delineations (such as administrative units), provided that the formal spatial reference definition is accepted by the community and is publicly available and accessible. It is expected that most qualifying products will adopt an intermediate spatial scale resolution (25–1000 km2 or approximately 5–25 km grid spacing). Streamflow or discharge products would be provided for a channel network of commensurate resolution, but also strive to provide outputs for existing and available monitoring gages, which will enhance the products’ relevance to stakeholders.

4.2 Temporal Resolution and Lead time

The primary S2S outlook products are temporally coarse, with predictand durations of 1 day to 1 month for lead times of up to one year. Given the skill profile of S2S climate and hydrologic phenomena, shorter predictand durations (e.g., 1 or 2 weeks) are appropriate for short lead times (up to approximately two months), and longer durations are appropriate for longer lead times. In addition, for some types of forecast outputs, such as ensemble predictions of streamflow, higher time resolution sequences for each ensemble member are commonly provided for use as inputs to subsequent modelling analyses (e.g., reservoir simulation models that may require a daily or sub-daily time resolution inputs).

4.3 Issuance Frequency and Latency

The update frequency is related to the temporal resolution, such that products are updated with sufficiently low latency (the lag between the time for which the forecast is initialized and the release or publication of the final forecast) and high frequency that the first lead time is still valid at time of issuance. For example, Centres producing forecasts with a 1 week temporal resolution should strive for a latency of 3 days or less and an update frequency of one week or less, while those producing forecasts of 1 month time resolution should strive for a latency of 10 days or less and an update frequency of one month or less.

4.4 Uncertainty estimation (ensemble size)

S2S forecasts should quantitatively and reliably characterize uncertainty because the ratio of signal to noise at S2S lead times is often relatively low. Ensemble-based systems should use a sufficient number of ensemble members (*i.e.,* ensemble size) to estimate forecast central tendency well (with a suggested minimum of 30 members). Statistical forecast systems or methodologies, which are not uncommon for regional applications, should estimate uncertainty from analysis of rigorously cross-validated prediction error rather than from model calibration error.

4.5 Output Type and Formats

The S2S products will ideally be presented in multiple forms and formats. To facilitate interpretation by stakeholders, a primary form of communication should include the presentation of forecast anomalies (e.g., percentile, percent of average, difference from average) calculated with respect to a retrospective climatology (mean annual and/or monthly to seasonal). Forecast anomalies may be for a particular percentile (e.g., 10th, 50th, 90th) and/or statistic (e.g., ensemble mean). Forecasts of the most probable outlook category are also a common derived product, and such categorical forecasts are not limited to the common tercile formulation (i.e., normal, below and above normal categories). The reference forecast and observational climatology should be based on a long enough record to define robust statistical thresholds for defining different conditions – preferably two decades or longer. Forecasts often suffer from systematic mean and variability bias, and the presentation of forecasts in terms of anomalies can aid in circumventing bias as well as standardizing products across multiple sources or centres. The calculation of anomalies should be calibrated to account for variability biases between the observational reference and the forecast system. Additional forms of forecast output are encouraged, including the full value of the raw forecast, forecasts transformed into standardized or normalized index form, as well as supporting information (such as the climatology for each output) as described in Appendix 2.2.ZZ.

Products shall be made available by the Centre on public facing website(s) in multiple formats, including graphical products (maps) as well as raw or post-processed data files (in standard formats, including ascii/text or binary files, such as NetCDF or grib). Centres are encouraged to use data archive facilities that provide user-oriented functionality and web services for interactive and automated sub-setting and downloading of forecast data. Lastly, regular forecast product discussions are encouraged, highlighting areas of interest or potential concern for users (such as droughts or flood potential). The Centre shall also provide a listing of clear contact points and/or a mechanism for inquiries and feedback from users.

4.6 Expanded variable information

Table X3. Variable Definitions

|  |  |
| --- | --- |
| **Variable Name(s)** | Description |
| Runoff (Discharge) | Water input to the river channel network or streamflow. Runoff may be expressed as total runoff and/or one or more of its components, namely surface runoff and subsurface discharge (volume/time unit). Runoff also may be supplied in the form of streamflow (or discharge), which includes the effect of channel routing  |
| Snow Water Equivalent | Water depth equivalent of the snow and glacier mass above the land surface (length unit) |
| Soil Moisture | Water depth within the hydrologically active range of the subsurface, typically ranging from 2–20 m in depth (length unit) |
| Groundwater or Aquifer Storage | Water depth stored in aquifers below the active subsurface soil moisture layers (length unit) |
| River stage | Depth of water in a stream or river channel, which is often linked to impact and management thresholds. Accurate river stage estimation and prediction requires interaction with local experts and authorities or detailed and regularly updated channel geometry information, and is more difficult to offer as a global product than discharge. (length unit) |
| Water table depth | Depth to the upper surface of saturated soil moisture zone (length unit) |
| Evaporation variables | Evaporation-related variables include actual and potential evapotranspiration (the evaporation that would occur from bare soil or a plant if sufficient water were available and absent any restriction), as well as lake and reservoir evaporation. (length/time unit) |
| Surface precipitation and 2-meter air temperature | Climate forecast variables provide additional context for understanding hydrologic forecast variables. While climate forecasts are available from S2S climate forecasting centres, they may differ in multiple respects from those used directly in producing the hydrologic forecasts. Hydrological forecast centres are encouraged to make available at least the primary climate forecast variables (precipitation and 2-meter air temperature) associated with the hydrologic forecasts. (length or mass/time unit for precipitation and degrees Celsius or Kelvin units for temperature) |
| Hydrologic and/or drought indices | Some management communities use common indices such as the PDSI to inform decision-making on drought and other extremes. (non-dimensional standardized or normalized units). WMO-No. 1173 provides a list of index definitions, including the following, though this list does not include all indices of interest.* Palmer Hydrological Drought Index (PHDI)
* Standardized Reservoir Supply Index (SRSI)
* Standardized Streamflow Index (SSFI)
* Standardized Water-level Index (SWI)
* Streamflow Drought Index (SDI)
* Surface Water Supply Index (SWSI)
* Aggregate Dryness Index (ADI)
* Standardized Snowmelt and Rain Index (SMRI)
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**APPENDIX 2.2.YY. STANDARDIZED VERIFICATION OF S2S HYDROLOGIC PREDICTIONS**

1. Introduction

This appendix describes procedures for the production and exchange of a standard set of verification scores for S2S hydrological prediction data and products generated by GDPFS centres for incorporation into the GDPFS. Such centres may generate other hydrological prediction data and products that are not integrated into the GDPFS and are not subject to this verification requirement. The goal is to provide consistent verification information on the S2S products of participating forecast centres that will assist users, including forecasters in regional and national centres who use the information to inform regional and national seasonal outlooks. It will provide quantitative benchmarks for documenting and intercomparing the skill of participating centres. The verification scores described are to be calculated based on retrospective forecasts (hindcasts). Producing centres will calculate and make the verification scores available via their centre websites. Skill measures recommended for use by participating centres in verification of S2S hydrological forecasts include those described here.

2. Verification Metrics and Skill Scores

The following metrics and skill scores are required for the mandatory prediction variable(s) and derived products.

* Measures of accuracy and skill for ensemble mean and median forecasts, including bias, relative bias, correlation and anomaly correlation, mean absolute error and mean squared error; and associated relative terms, where appropriate: e.g., relative bias, relative mean absolute error, expressed as a percentage.
* Measures of probabilistic skill, including the continuous ranked probability score (CRPS) and the ranked probability score (RPS), and their 3-part decompositions (including, e.g., the reliability terms).
* For categorical forecasts, such as tercile predictions, common categorical skill metrics shall be provided, such as hit rates, false alarm ratios, critical success indices, or multicategory Brier scores.
* These metrics should also be expressed in the form of a skill score using two separate references: (1) climatology; (2) persistence.
* The observational datasets for the validation of hydrologic predictions can be of two types. Official agency observations should be used where available, such as for an appropriate (e.g., naturalized or not) streamflow (discharge) value at a river location. Where such observations are not available, such as for sub-surface variables or spatially distributed runoff, a high-quality reanalysis may be used. The nature of the validating data set should be documented along with the presentation of results.

Provision of the statistical significance of scores and/or confidence intervals is not currently mandatory but is strongly recommended. Participating centres are free to choose the method of the calculation.

3. Application of Metrics and Skill Scores

The scores shall be calculated at the temporal and spatial resolution for which the forecasts are provided (e.g., gridded, reach-based, point-based) or as constrained by the available observations and reanalyses, depending on the type of validation being performed.

Forecast scores must be stratified by lead time (weekly or monthly) and initialization date or time of year (calendar month, or season), recognizing the seasonally varying nature of hydrologic prediction skill and its dependence on the influence of initial conditions versus boundary forcings.

Forecast centres are encouraged to provide regional summaries of verification metrics and skill scores, but this is not required. If they are provided, the centre should provide accompanying guidance on the interpretation of such regional summaries, given the heterogeneity of underlying hydrologic processes across catchments and sub-basins within the region. Innovative pooling strategies for increasing sample size are also encouraged, if they are well documented.

4. Variables

All mandatory variables listed in the first table of Appendix 2.2.50 and the derived categorical or anomaly products shall be verified. Verification is also required for recommended variable forecasts and associated products that are to be integrated with the GDPFS. A centre may produce recommended (but not mandatory) variables without verification, but they will not be integrated into the GDPFS.

5. Hindcast Data set

The hindcast period for the hindcast data set used in forecast verification shall be at least 20 years to provide a minimum sample size for assessing forecast performance. Hindcast initialization frequency shall be a minimum of once per month with a minimum ensemble size of 10 members, or an alternate strategy that provides at least 10 members per month shall be used (e.g., lagged/pooled members across multiple initialization dates within a month). Hindcast datasets shall be generated with the same prediction system that is used to generate the real-time forecasts to the extent possible. It is recognized that some aspects of real-time systems may differ (by necessity) from the hindcasting system, such as the data assimilation that is used, and the other details such as ensemble size and update frequency (and even resolution) may differ due to computational constraints. These differences, and their expected or potential impact on the validity of the performance scores calculated from the hindcasts, shall be briefly summarized in documentation available from the Centre website.

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**APPENDIX 2.2.ZZ. Supporting information on the S2S hydrological prediction system**

This appendix presents a listing of the information required to be made available by centres providing S2S hydrological predictions within the GDPFS, describing the nature of the system, datasets and methods used to produce the forecasts and other relevant metadata. The information must be updated in a timely fashion when system upgrades are implemented, and includes the following elements.

* Formal name and date of implementation of the current forecast system producing the S2S predictions.
* Summary of the configuration of the system, including the details of its major sub-components (e.g., ocean, land, sea-ice, atmosphere), their version numbers, horizontal and vertical resolutions and extent (e.g., number of levels if appropriate), and the coupling of those components.
* Summary of the forecast initialization approach, including key observational datasets used in initialization, and the method used for data assimilation (if any).
* Summary of the ensemble forecast generation approach and ensemble forecast details (including size or number of members, timestep of saved outputs, update frequency, latency, lead time range, and list of core output variables).
* Description of any major external boundary forcings or constraints, if appropriate.
* Summary of associated hindcasting activities, including hindcast period, ensemble size, frequency, ensemble construction approach, timestep of saved outputs, time/space extent of outputs, and other relevant details (such as list of core output variables, data format).
* Summary of verification activities or completed studies addressing the performance of the system for the variables being contributed to the GDPFS.
* Description of access points to forecasts and hindcasts provided for integration with the GDPFS (typically these are URLs).
* Point(s) of contact, including either personnel names and office information such as email, website, and/or telephone number. This should not be a general agency entry point but rather a programmatic or technical contact.
* List of key references or documentation on the forecast system and its sub-components and methods, if those are not included in the forecast system documentation.

**2.2.1.X Snow cover prediction**

**Centres conducting snow cover prediction (RSHCs for snow cover prediction) shall:**

1. Prepare analyses of snow cover parameters over land surfaces;
2. Make available on WIS a range of these products; the list of mandatory and highly recommended products to be made available is given in Appendix 2.2.XX;
3. Produce verification statistics according to the standard defined in Appendix 2.2.YY and make them available on their website;
4. Make available on a website up-to-date information on the characteristics of their snow cover prediction systems; the minimum information to be provided is given in Appendix 2.2.ZZ.

The Centres should:

1. Prepare forecasts of snow cover parameters over land surfaces;
2. Make available on WIS a range of these products; the list of products to be made available is given in Appendix 2.2.XX;
3. Produce verification statistics according to the standard defined in Appendix 2.2.YY and make them available on their website.

Note: The bodies in charge of managing the information contained in the Manual related to snow cover prediction are specified in the table below.

**Table X. WMO bodies responsible for managing information related to snow cover prediction**

|  |
| --- |
| *Responsibility* |
| *Changes to activity specification* |
| To be proposed by: | INFCOM/SC-ESMP | SERCOM/SC-HYD |  |
| To be recommended by: | SERCOM | INFCOM |  |
| To be decided by: | EC/Congress/ |  |  |
| *Centre designation* |
| To be recommended by: | RA | SERCOM | INFCOM |
| To be decided by: | EC/Congress/ |  |  |
| *Compliance* |
| To be monitored by: | SERCOM/SC-HYD |  |  |
| To be reported to: | INFCOM/SC-ESMP | INFCOM |  SERCOM |

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**APPENDIX 2.2.XX MANDATORY AND HIGHLY RECOMMENDED SNOW COVER PREDICTION PRODUCTS TO BE MADE AVAILABLE ON THE WMO INFORMATION SYSTEM**

Snow cover analysis products are mandatory, but can be provided either on a grid or at the basin-scale (or both). Snow cover forecasts are highly recommended, but not mandatory. However, in all cases the same two parameters are mandatory: snow cover area and water equivalent of snow cover.

**Gridded snow analysis products**

|  |  |  |  |
| --- | --- | --- | --- |
| *Parameter* | *Spatial resolution* | *Frequency* | *Latency* |
| Snow cover area\* | 10 km (ideally 1 km or better) | Once per day (ideally twice per day) | Less than 12 hours (ideally less than 6 hours) |
| Water equivalent of snow cover\* |
| Snow depth |
| Vertical average of snowpack temperature profile |
| Liquid water content of snow [% of total mass] |
| Snowmelt runoff at the base of the snowpack |

\*Mandatory products for gridded snow cover analysis

* Altitude at which parameters are valid must be provided
* Within a given grid cell, parameters can be provided for multiple combinations of altitude, slope, aspect and vegetation type, but a grid cell average should also be provided

**Gridded snow forecast products**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| *Parameter* | *Spatial resolution* | *Forecast range* | *Time steps* | *Frequency* | *Latency* |
| Snow cover area\* | 10 km (ideally 1 km or better) | Up to 3 days / Beyond 3 days, up to 32 days | 3 hours / 24 hours | Once per day (ideally twice per day) | Less than 12 hours (ideally less than 6 hours) |
| Water equivalent of snow cover\* |
| Snow depth |
| Vertical average of snowpack temperature profile |
| Liquid water content of snow [% of total mass] |
| Snowmelt runoff at the base of the snowpack |

\*Required products for gridded snow cover forecast (if forecasts are provided)

* Altitude at which parameters are valid must be provided
* Within a given grid cell, parameters can be provided for multiple combinations of altitude, slope, aspect and vegetation type, but a grid cell average should also be provided

**Basin-scale snow analysis products**

|  |  |  |  |
| --- | --- | --- | --- |
| *Parameter* | *Spatial resolution* | *Frequency* | *Latency* |
| Snow cover fraction\* | Basin average (ideally 5000 km² or better) | Twice monthly (ideally once per day) | Less than 7 days (ideally less than one day) |
| Water equivalent of snow cover\* |
| Snow depth |
| Vertical average of snowpack temperature profile |
| Liquid water content of snow [% of total mass] |
| Snowmelt runoff at the base of the snowpack |

\*Mandatory products for basin-scale snow cover analysis

**Basin-scale snow forecast products**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| *Parameter* | *Spatial resolution* | *Forecast range* | *Time steps* | *Frequency* | *Latency* |
| Snow cover fraction\* | Basin average (ideally 5000 km² or better) | Up to 32 days | 24 hours | Twice monthly (ideally once per day) | Less than 7 days (ideally less than one day) |
| Water equivalent of snow cover\* |
| Snow depth |
| Vertical average of snowpack temperature profile |
| Liquid water content of snow [% of total mass] |
| Snowmelt runoff at the base of the snowpack |

\*Required products for basin-scale snow cover forecast (if forecasts are provided)

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**APPENDIX 2.2.YY STANDARDIZED VERIFICATION FOR SNOW COVER PREDICTION PRODUCTS**

1. Introduction

This appendix presents detailed procedures for the generation of a standard set of verification scores for snow cover predictions. Standard verification methods are presented for the two mandatory parameters (snow cover fraction and water equivalent of snow on the ground) as well as one highly recommended parameter (snow depth). Different verification methods are also presented for deterministic and probabilistic snow cover predictions.

2. Verification metrics

For water equivalent of snow on the ground (SWE) and snow depth (SD), verification statistics shall include mean error (ME) and root mean square error (RMSE). These shall be provided for deterministic forecasts as well as for the mean of the predictive distribution (or ensemble mean) in the case of probabilistic forecasts.

The CRPS shall be used to evaluate probabilistic predictions of SWE and SD. The decomposition of CRPS into a potential CRPS and a reliability term shall be provided (see Hersbach, 2000, Weather and Forecasting).

For verification of deterministic predictions of snow cover area (SCA), a 2x2 contingency table shall be used in order to identify true positives (TP), true negatives (TN), false positives (FP) and false negatives (FN). Areas where modelled snow depth is lower than the detection threshold of the verifying observations shall be considered snow free.

In addition to the contingency table itself, summary statistics obtained from this contingency table shall be provided, and in particular accuracy, precision, recall and the F score (see Cooper et al., 2018, Atmospheric Measurement Techniques).

For verification of probabilistic predictions of SCA, the Brier score shall be provided, as well as its decomposition into uncertainty, reliability and resolution components (see Murphy, 1973, Meteorology and Climatology).

3. Verifying observations

Ideally, predictions shall be verified against independent in-situ or remotely sensed observations. Because of the persistence of snowpack in time, model errors are strongly correlated in time. Hence, observations from a given network or platform cannot generally be considered independent of model predictions made at an earlier time if the same observation network or platform was used to initialize the model.

Recognizing the challenge of obtaining independent observations for model verification, it is deemed acceptable to verify predictions through a data denial experiment. If such an approach is used, the details of the data denial experiment shall be provided by the centre together with the verification statistics.

When verification against independent observations or through data denial experiments is not possible, verifications shall be made against the centre’s own analysis as well as against at least one other analysis product. Differences between the scores obtained using the centre’s own analysis and using other analyses shall be provided.

When verifying gridded snow predictions, the difference between the model topography and the altitude of the verifying observation shall not exceed 400 m.

4. Temporal and spatial aggregation

Pooling of prediction/observation pairs in time and space shall be performed in order to obtain a sample size large enough to compute stable verification metrics as well as to provide summary statistics for regions and periods of interest.

Pairs valid during the same month shall be pooled together for reporting purposes. Pooling of prediction/observation pairs in space shall be done by basins and sub-basins and/or ecological zones and/or mountain zones. The details of the strategy used for spatial aggregation shall be provided by the centre.

Basin boundaries shall be obtained from the WMO Basins and Sub-Basins (WMOBB) database. Ecological zones shall be obtained from the Global Ecological Zones data set distributed by the FAO. Mountain zones shall be obtained from the UN Environment Programme World Conservation Monitoring Centre (UNEP-WCMC). Further stratification by altitude, slope and aspect can be considered.

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**APPENDIX 2.2.ZZ CHARACTERISTICS OF SNOW COVER PREDICTION SYSTEMS**

* + - 1. System
* System name and version
* Date of implementation

2. Configuration

* Horizontal resolution of the model, with indication of grid spacing in km:
* Number of snow layers:
* Forecast length and forecast step interval:
* Runs per day (times in UTC):
* Integration time step:
* Additional comments:

3. Initial conditions

* Data assimilation method:
* In-situ datasets assimilated:
* Remotely sensed datasets assimilated:
* Additional comments:

4. Boundary conditions

* List of atmospheric driving variables:
* Source of information for atmospheric driving variables:
* Timestep and horizontal resolution of atmospheric driving variables:
* Lower boundary conditions (to compute ground thermal flux):
* Additional comments:

5. Probabilistic predictions

* Are probabilistic predictions provided? If so, describe method briefly:
* Additional comments:

6. Other details of model

* List of prognostic variables:
* Is snow microstructure represented? If so, describe method briefly:
* Is blowing snow sublimation represented? If so, describe method briefly:
* Is wind-induced snow transport represented? If so, describe method briefly:
* Is interaction with tall vegetation represented? If so, describe method briefly:
* Are the effects of slope and aspect on incoming radiation represented?
* Additional comments:

7. Verification approach

* What verification approach is used to evaluate the analyses and the forecasts?
* In-situ datasets used for verification:
* Remotely sensed datasets used for verification:
* Additional comments:

8. Further information

* Operational contact point:
* URLs for system documentation:
* URL for list of products:

**2.2.2.XX Flash flood forecasting**

**Centres conducting flash flood forecasting (Regional Specialized Hydrological Centres (RSHCs) for flash flood forecasting) shall:**

1. **Produce flash flood products and provide specific products to National Hydrological and Meteorological Services (NMHSs), which are agreed with participating countries in advance. The list of mandatory and highly recommended products is specified in Appendix 2.2.XX;**
2. **Support NMHSs in the generation of flash flood forecasting information;**
3. **Make a range of these products available on the WIS and/or another web-based platform;**
4. **Prepare verification statistics and make them available on a website (Some recommendations on the verification are given in appendix 2.2.YY);**
5. **Make available on a website up-to-date information on the characteristics of Flash Flood Forecasting System. The minimum information to be provided is specified in Appendix 2.2.ZZ.**

Note: The bodies in charge of managing the information contained in the Manual related to flash flood forecasting are specified in the table below.

**Table X. WMO bodies responsible for managing information related to flash flood forecasting**

|  |
| --- |
| *Responsibility* |
| *Changes to activity specification* |
| To be proposed by: | INFCOM/SC-ESMP | SERCOM/SC-HYD |  |
| To be recommended by: | SERCOM | INFCOM |  |
| To be decided by: | EC/Congress |  |  |
| *Centre designation* |
| To be recommended by: | RA | SERCOM | INFCOM |
| To be decided by: | EC/Congress |  |  |
| *Compliance* |
| To be monitored by: | SERCOM/SC-HYD |  |  |
| To be reported to: | INFCOM/SC-ESMP | INFCOM | SERCOM |

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**APPENDIX 2.2.XX MANDATORY AND HIGHLY RECOMMENDED FLASH FLOOD FORECASTING PRODUCTS TO BE MADE AVAILABLE FOR THE PARTICIPATING COUNTRIES**

**Mandatory products**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| *Parameter / Product / Variable* | *Forecast lead time* | *Issuance frequency* | *Temporal resolution* | *Spatial resolution* |
| *Flash flood risk (in categories)* (e.g., high, moderate, low) | *Up to 36 hours* | *As necessary for the region of interest and available forcing data, but not more than 6 hours* | *Temporal steps ranging from less than 1 hour to 6 hours, depending on modelling uncertainties and the source of available rainfall data* | *Basin areas / grid-cells size up to 200 km2, depending on input sources and modelled domain* |

**Highly recommended products**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| *Parameter / Product / Variable* | *Forecast lead time* | *Issuance frequency* | *Temporal resolution* | *Spatial resolution* |
| *Peak discharge* | *Up to 36 hours* | *As necessary for the region of interest and available forcing data, but not more than 6 hours.* | *Temporal steps ranging from less than 1 hour to 6 hours, depending on modelling uncertainties and the source of available rainfall data.* | *Basin areas / grid-cells size up to 200 km2, depending on input sources and modelled domain.* |
| *Flash flood threshold* |

Products may be generated in a number of formats selected to facilitate their usage by different stakeholders and partners, and processing by other centres and decision support systems, compliant with approved WMO data exchange files formats.

The standard and recommended practices covering the format and content are described in the Technical Regulations, Volume III: Hydrology (WMO-No. 49).

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**APPENDIX 2.2.YY RECOMMENDATIONS ON VERIFICATION FOR FLASH FLOOD FORECASTING PRODUCTS**

This appendix presents procedures for the generation of a standard set of verification scores for mandatory products of the RSHC for flash flood forecasting based on available ground-truth data and whether flash flood flows or flash flood occurrences were forecasted by NMHSs based on flash flood forecasting products and information. The goal is to provide consistent verification information on the flash flood forecast products from different centres for forecasters in the hydrological forecast services and to help Regional Specialized Hydrological Centres for flash flood forecasting to compare and improve their forecasts. The RSHC shall create and maintain website for flash flood verification information, so that potential users will benefit from a consistent presentation of the results.

The standardized verification should provide key relevant information appropriate to the state of the art in flash flood forecasting, ensuring a consistent verification methodology applied to forecasts from different RSHCs, and the use of a common set of observations.

Appropriate forecast verification procedures and metrics will be used as allowed by the available ground-truth data and whether flash flood flows or flash flood occurrences are forecast. Contingency tables for the mandatory flash flood products provide the number of forecast products and actual events, linking the matches, false warnings and misses. The resulting table will produce statistics of the probability of detection, false alarm ratio and probability of a miss.

Other examples of verification metrics include second moment residual statistics and critical success index. Underlying hydrologic models will be verified by using usual metrics. For instance, the Nash-Sutcliffe efficiency criterion (NSE) and the index of volumetric fit (IVF).

Forecast verifications shall be made on an annual basis, with due consideration of the lack of reliability of the scores when computed on a reduced number of cases.

The model verification shall be initially made during the implementation of the system. Further verifications should be made on an annual basis or when there is evidence of poor performance. The model verification should be made in all basin outlets where observed data are available and with sufficient record length.

For systems allowing forecaster adjustments, verification will also be done on forecaster adjusted products and in the resultant warnings.

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**APPENDIX 2.2.ZZ CHARACTERISTICS OF FLASH FLOOD FORECASTING SYSTEMS**

System

* System name and version;
* Date of implementation:

Configuration

* Geographical coverage of the system;
* Horizontal resolution of the model;
* Forecast length and forecast step interval:
* Runs per day (times in UTC).

Other details of the system

* Hydrological modelling
* Soil moisture modelling
* Satellite and radar precipitation information
* Configuration and implementation of weather prediction models

Products

* Description of the products and methods for the calculation
* Other details, if necessary

Further information

* Operational contact point:
* URL for system documentation
* URL for list of products

**APPENDIX 2.2.11 MANDATORY AND HIGHLY RECOMMENDED**

**NUMERICAL OCEAN WAVE PREDICTION PRODUCTS TO BE MADE**

**AVAILABLE ON THE WMO INFORMATION SYSTEM**

Additional highly recommended products:

* U and v component of 10-meter wind or 10 m wind speed and direction;
* Full 2-D wave spectra at subset of grid points;
* Wind sea and swell split at all grid points, including swell partitioned parameters;
* Derived parameters including wave steepness, directional spreading and rogue wave potential.

***2.2.1.9 Global numerical ocean prediction***

**Centres conducting global numerical ocean prediction shall:**

**(a) Prepare global analyses of oceanographic variables ~~-parameters~~;**

**(b) Prepare global forecast fields of basic and derived oceanographic variables** **~~parameters~~**;

**(c) Make available on WIS a range of these products; the list of mandatory and highly recommended products to be made available is given in Appendix 2.2.13;**

**(d) Prepare verification statistics and make them available on a website;**

**(e) Make available on a website up‑to‑date information on the characteristics of their global numerical ocean prediction systems; the minimum information to be provided is given in Appendix 2.2.14.**

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***APPENDIX 2.2.13. MANDATORY AND HIGHLY RECOMMENDED GLOBAL NUMERICAL OCEAN PREDICTION PRODUCTS TO BE MADE AVAILABLE ON THE WMO INFORMATION SYSTEM***

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| *Parameter*  | *Level*  | *Minimum resolution*  | *Forecast range*  | *Minimum time steps*  | *Frequency*  |
| Sea-surface elevation  | Surface  | ~~0.5~~~~0~~ ~~x 0.5~~~~o~~0.250 x 0.250 | Up to 6 days  | Every 24 hours  | Once a day  |
| SST  | Surface (mixed layer)  |
| Surface u, v  | Surface  |
| Sea-surface absolute salinity  | Surface  |
| u, v  | Depth to be determined  |
| Conservative Temperature  | 10/50/100/250/500(m)  |
| Absolute Salinity | 10/50/100/250/500 (m) |
| Mixed layer depth\*  |   |

 \*Mixed layer depth based on temperature and/or density criteria

**Additional highly recommended products:**

* ~~None~~.
* Tropical Cyclone Heat Potential (TCHP)
* Ocean Initial Conditions for seasonal forecast
* Sea-ice thickness and sea-ice extent.

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***APPENDIX 2.2.14. CHARACTERISTICS OF THE GLOBAL NUMERICAL OCEAN PREDICTION SYSTEMS***

**1. System**

* System name (version):
* Date of implementation:

**2. Configuration**

* Horizontal resolution of the model, with indication of grid spacing in km:
* Number of model levels:
* ~~Bottom of model:~~Topography data of model:
* Forecast length and forecast step interval:
* Runs per day (times in UTC):
* Is model coupled to atmosphere, wave, sea-ice models? Specify which models:
* Atmosphere model characteristics (such as, but not limited to configuration, initial and boundary conditions):
* Wave model characteristics (such as, but not limited to configuration, initial and boundary conditions):
* Sea ice model characteristics (such as, but not limited to resolution, rheology, number of sea ice category):
* Integration time step:

- Horizontal and vertical coordinate system of the model:

* Additional comments:

**3. Initial conditions**

* Climatology data of the model:
* Data assimilation method, including brief description:
* Observations being assimilated:
* Assimilated window:
* Additional comments:

**4. Surface boundary conditions**

* Surface forcing, briefly describe method(s), frequency and origin of atmospheric surface forcing:
* Lateral boundary conditions (for example, river discharge)? If so, briefly describe method(s), frequency and origin of lateral boundary conditions:
* Additional comments:

**5. Other details of the model**

* What kind of mixing scheme is in use?

- List vertical and horizontal mixing, diffusion schemes and ad-hoc parameterization in use

- ~~How are radiations parameterized?~~

- Parameterization of surface boundary conditions (heat, freshwater, momentum)?

* What kind of large-scale dynamics is in use (for example, grid-point semi-Lagrangian)? Hydrostatic or non-hydrostatic?

~~- Data assimilation scheme?~~

* Quality control scheme?
* Verification approach?
* Other relevant details?

**6. Products delivered**

* Resolution of the products
* Interpolation method if products are post processed
* Frequency of the products
* Latency of the products (time between production and availability)
* Length of the time series available in the past
* Definition of the Tropical Cyclone Heat Potential

**~~6~~7. Further information**

* Operational contact point:
* URLs for system documentation:
* URL for list of products:

- Graphic and model data output:

2.2.2.12 ***Marine ~~environmental~~ emergency response***

Centres conducting Marine Emergency Response (MER) shall:

(a) Prepare, on request from an authorized person (the person authorized by the Permanent Representative of the WMO Member to request RSMC support; normally the NMHS operational contact point), MER forecast or hindcast products relating to events in which marine pollution, Search and Rescue (SAR) needed; the criteria for activation of the regional support procedures and the request form are given in Appendices 2.2.X and 2.2.X+1, respectively

(b) As soon as possible, but usually within two hours of a request from an authorized person, make available a range of products to the NMHS operational contact point (designated by the Permanent Representative) by email or retrieval from the RSMC password protected designated website; the list of mandatory and highly recommended products to be made available, including parameters, forecast range, time steps and frequency, is given in Appendix 2.2.XX+2;

(c) Use agreed default emission source parameters for essential parameters when actual source information is not available; default source parameters for a range of release scenarios are given in Appendix 2.2.XX+3;

(d) Make available on a website up-to-date information on the characteristics of their MER systems (minimum information to be provided is given in Appendix 2.2.XX+4) and a use interpretation guide for MER products.

Notes:

~~1. Operations, including practices, procedures and specifications are described in the Manual on Marine Meteorological Services (WMO-No. 558), Volume I;~~

~~2. Functions and responsibilities to be defined by the SERCOM/SC-MMO during the intersessional period;~~

~~3.~~ The bodies in charge of managing the information contained in the *Manual* related to marine environmental emergency response are specified in the table below.

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**APPENDIX 2.2.XX ACTIVATION OF SUPPORT FOR MARINE EMERGENCY RESPONSE**

Marine emergencies can be caused by a range of events. The scope of MER activities includes: spills of oil and other noxious and hazardous substances; discharges of radioactive material in marine and coastal zones; other marine environmental hazards (e.g. harmful algal blooms); SAR.

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**APPENDIX 2.2.XX+1 REQUEST FORM TO ACTIVATE REGIONAL SPECIALIZED METEOROLOGICAL CENTRE SUPPORT (MER)**

MER request for WMO Regional Specialized Meteorological Centre support by authorized person1

(a) This form should be sent by email to one of the RSMCs’ operational contacts in the Regional Association when support is needed for releases that have the potential for long-range impacts.

(b) If the RSMC does not confirm the reception of the request within 20 minutes, the requester will telephone the RSMC.

(c) The RSMC will make available its products as soon as possible but usually within two hours. An email will be sent by the RSMC with information on where to access the products. The requester will confirm reception by email.

**Date and time of**

**request:**.....................................................................................

**(a) Mandatory information:**

– Status(exercise/event):.............................................................................

– Name, title, organization/agency, country, phone number and email of the requester:

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– Select type of event and provide brief description or details:

– Oil spill

– Radioactive material

– Other marine environmental hazards

– Search and Rescue

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1 The person authorized by the Permanent Representative of the WMO Member to request RSMC support; this is normally the NMHS operational contact point

Date and start time of release (DD/MM/YYYY and UTC):..........................................

– Location of release (as accurately as possible) in order of preference:

* 1. Geographic coordinates (decimal degrees or degrees, minutes and seconds):

|  |  |
| --- | --- |
| Latitude(specify N or S) | .................................. |
| Longitude(specify E or W) | .................................. |

* 1. (If appropriate) address, city, country:

................................................................................................................

................................................................................................................

(b) Other information – If known, the following would be useful for the modelling and should be provided as well (if not provided, modeller will use default parameters or make a reasonable assumption):

 – Name of object (name of vessel, IMO number, news release etc.):

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– Meteorological conditions at location at the start of the release (wind speed and direction, weather, cloudiness, presence of inversion, etc.):

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– Name or type of pollutant(s) to be modelled if known (oil, radioactive material, harmful algal bloom, human being etc.) – if unknown, a tracer will be used:

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– Quantity (mass) or release rate (mass per unit time) of pollutant if applicable. If unknown, one unit mass or one unit mass per hour will be used:

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– Expected or estimated release duration:

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– Duration of simulation for the dispersion model run:

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– Size of area of interest (for example, within 300 nm of source):

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 – Base of release:

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– If quantity (mass) and name of pollutant(s) are provided, what concentrations should be displayed on modelling outputs? Please specify:

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..............................................................................................................................

– Any other information that may be useful:

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**APPENDIX 2.2.XX+2 MANDATORY PRODUCTS**

The following mandatory MER products shall be provided:

In coordination with appropriate national authorities, the RSMC shall provide historical and predicted information on:

Wind speed and direction;

State of the sea;

Visibility, both vertical and horizontal;

• Ocean currents and other oceanographic information.

For different scenarios, the RSMC shall provide:

– Oil spill and other noxious substances (default values in Appendix 2.2.XX+3 shall be used for source parameters not provided)

• Forecast duration 48 hours;

• Relative concentrations

• Images at intervals of one, three or six hours;

– Discharge of radioactive material in marine and coastal zones

• Forecast duration 48 hours;

• Relative concentrations from the surface to 200 m

• Images at intervals of one, three or six hours

– Other marine environmental hazards (e.g. harmful algal blooms)

• Forecast duration 48 hours;

• Relative concentrations

• Image at intervals of one, three or six hours;

– Search and Rescue Operations

• Forecast duration 48 hours;

• Image at intervals of one, three or six hours;

The following recommended MER products could be provided:

In coordination with appropriate national authorities, the RSMC could provide historical and predicted information on:

Tide height and time;

For different scenarios, the RSMC is recommended to provide, if feasible:

contouring to be determined based on specifics of the event or the request

The RSMC shall perform a quick assessment of the products before they are issued and shall provide a short explanatory message if any issues of concern are noted.

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**APPENDIX 2.2.XX+3 DEFAULT SOURCE PARAMETERS (MER)**

|  |  |  |  |
| --- | --- | --- | --- |
| *Scenario\** | *Type of event* | *Material released* | *Vertical distribution* |
| Oil Spill | Oil | Tracer | Surface |
| Radioactive material/chemical release | Radioactive material/chemical | Tracer | Constant from the surface to 200 m |
| Other marine environmental emergency | Algae etc. | Tracer | Surface |
| Search and rescue | Human/wrecks | Tracer | Surface |
| Other events | RSMC defined | Tracer | RSMC defined |

\* Default date and start time of release are those given in the request form (mandatory information) in Appendix 2.2.XX+1. If not provided, the date and time of reception of the request will be used.

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**APPENDIX 2.2.XX+4 CHARACTERISTICS OF MARINE DRIFTING MODELLING SYSTEMS (MER)**

1. System

– System Name (version)

– Type of pollution model

– Oceanographic model and NWP model used

– Implementation date

– References

2. Initial conditions and trajectory algorithm

– Input (pollutant data)

– Input (environmental data)

– Trajectory algorithm: wind

– Trajectory algorithm: current

– Trajectory algorithm: waves (generation method, effect on advection)

– Fate algorithm: evaporation, emulsification

3. Other details of the model

– Model validation

– Application area

– Real-time response capacity

4. Further information

– Operational contact point

– Supporting Services and other relevant contact points

– Marine Pollution Emergency Response Authority

– URLs for system documentation

– URLs for list of trials and actual marine pollution emergencies

**3. The Regional Specialized Meteorological Centres for general purpose activities are:**

Numerical ocean wave prediction

RSMC Exeter

RSMC INCOIS (India)

RSMC Melbourne

RSMC Montreal

RSMC Tokyo

RSMC Toulouse

Acronyms not previously defined: INCOIS – Indian National Centre for Ocean Information Services

Global numerical ocean prediction

RSMC Exeter

RSMC INCOIS (India)

RSMC Montreal

**4. The Regional Specialized Meteorological Centres for specialized activities are:**

Marine emergency response

RSMC INCOIS (India)

RSMC Oslo

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