Workshop Report: Observations and analysis of sea-surface temperature and sea-ice for Numerical Weather Prediction and Climate Applications.

ECMWF | Reading | 22-25 January 2018

More than 50 ocean and data assimilation experts came together at the European Centre for Medium-Range Weather Forecasts (ECMWF) from 22 to 25 January 2018 to discuss the way forward for the use of observations of sea-surface temperature and sea ice in numerical weather prediction and climate reanalyses applications, and to advise ECMWF on how to best exploit the observational information.

This workshop was intended to bring together experts in all aspects of the field, including the treatment of ocean surface observations (both satellite and in situ), data assimilation techniques and modelling. Three days of presentations were followed by working group meetings which tried to assess the current state of the art and identify areas where significant improvements and progress can be made, which can be summarized as follows:

Overarching recommendations

1. ECMWF was encouraged to follow an evolution towards the assimilation of radiances for the constraint of sea surface temperature and sea-ice in the context of running fully coupled systems, and this will require extensive collaboration with space agencies and experts outside ECMWF.

2. While there are exciting synergies between assimilation of ocean-surface sensitive radiances and coupled data assimilation, there are no blocking inter-dependencies foreseen, so the two developments can proceed largely in parallel exploiting the available resources and expertise.

3. In the spirit of moving towards coupled data assimilation, the quality of the individual ocean and sea-ice components—both model and data assimilation—should receive adequate attention.

4. There is generally good guaranteed future provision of operational satellite data to support these activities, with the possible exception of gaps with respect to low frequency passive microwave data. This should be matched by the adequate level of support and governance for the in situ component.

5. International coordination is also required to optimise the use of sea surface temperature and sea ice information for their used in Earth System Reanalyses.

Motivation and background

An accurate characterisation of the ocean in terms of its surface temperature and sea ice coverage is vital for Numerical Weather Prediction (NWP) forecasts for a few days in advance out to the seasonal range. The landscape of users and applications of Sea Surface Temperature (SST) and Sea Ice (SI) information has changed considerably in the past few years. Observations, applications and methodologies are undergoing a major shift. In the case of SST and SI, the paradigm of Earth System Forecasting systems has brought together activities and communities traditionally separated, such as the weather and marine communities, and the weather and climate communities. There is a pressing need to revisit the current practices in view of new potential and current deficiencies, to provide guidelines for future directions, and to prepare the ground for institutional collaboration at international level.

The workshop was timely for ECMWF, which is embarking on an ambitious program to develop Earth system analyses and forecasts as part of its 10-year strategy. This workshop gave the opportunity to discuss with experts how best to proceed in this area.

Workshop structure

Twenty-four speakers explored a wide range of topics, from observation operators for SST to the latest research on data assimilation systems in which the ocean and the atmosphere are coupled. The workshop revolved around four central themes: observations of SST and SI, processing chains (e.g. retrievals, gap filling, product delivery), applications and new methods.

The presentations were followed by working group discussions, where experts gathered into three splinter groups that focused on (1) SI, (2) applications and (3) SST. The working groups were asked to address the following questions:

- What are the possible visions for SST and sea ice information at ECMWF in the time range of 10 years?
- What are the current deficiencies, gaps, and future barriers (observations, forward models, methods)?
- What should be the next steps for ECMWF to improve SST and sea ice in NWP and reanalysis?
- What recommendations would you make to space/observations agencies?
- Which observations and processing level should drive the evolution of our systems?

Summary of working group discussions and recommendations

Working groups discussed avenues for the development of data assimilation, observing systems and observation processing chains. They articulated a long-term vision for the provision of SST and sea-ice information in line with the needs of weather forecasting and climate applications. They also made recommendations for steps ECMWF can take to improve the processing of surface information.

The benefits and shortcomings of assimilating the different observations processing levels were spelled out. ECMWF currently uses level-4 (L4) products to constrain the SST and Sea Ice. L4 products consists on spatially gridded and gap-filled analysis of geophysical variables, usually from multiple instruments. Although the L4 products used by ECMWF are state of the art, their information content is not sufficient. Sub-optimal timeliness, temporal and feature resolution and accuracy of the current L4 products have been identified as contributors to forecast error. The consensus recommendation was for ECMWF to move towards the direct assimilation of radiances (L1) for SST and Sea Ice within the context of the NWP atmospheric analysis. This could be done best within a fully coupled ocean-atmosphere-sea ice data assimilation system, although partially coupled systems might also prove successful. Assimilation of L1 SST and SI concentration (SIC) is a major enterprise, which will require careful planning and a strong collaboration among different European institutions.

Below a compilation of the working groups discussions.

1. What are the possible visions (10 years) for SST and sea ice information at ECMWF?

There was overall agreement that the assimilation L1 information for SST and SI should be pursued at ECMWF as a means of maximally utilising the information from the satellite observing constellation within the forecast/DA systems. This line of work is highly complementary to the development of coupled forecasting systems (both in modelling and data assimilation), a key element in the ECMWF strategy. Specifically, in the context of coupled data assimilation (CDA), direct assimilation of radiance observations will allow a more consistent attribution of contributions from the atmospheric column and the ocean surface. This will ideally allow making better use of observations for simultaneous correction in all components. At the same time, direct radiance assimilation will make the system more robust by including all available satellite sensor data and by reducing dependency on external derived products.

The assimilation of L1 information for this particular application may require specific emphasis on improving radiative transfer modelling of ocean and frozen surface emissivity at all sensor wavelengths. This development should be shared with the wider community an provided/supported by central facilities like the EUMETSAT NWP-SAF or OSI-SAF. The ECMWF radiance assimilation system already identifies and removes observations contaminated by clouds, aerosols and precipitation, but again for this specific application the tolerances may have to be reviewed. Finally it will have to be investigated if the current ECMWF variational approach for radiance bias correction (addressing sensor calibrations and radiative transfer systematic errors) is appropriate in this context. Development to address calibration issues should be undertaken in collaboration with current producers of L2/L3 information to ensure knowledge transfer is achieved. The Global Space-based Inter-Calibration System (GSICS) provides real-time calibration fields for geostationary sensors, which could complement the ECMWF variational bias correction.

If the assimilation of L1 is to be made within a coupled data assimilation framework, the individual model components should be improved accordingly in order to represent the processes that may currently be adjusted for in L2/L3 products, so that they can realistically represent snow and melt ponds on sea ice, the diurnal cycle of SST, SST fronts, upwelling areas and mixing processes.

Recommendations:

- An evolution towards L1 data usage has benefits that should be followed unrelated to CDA (similar to the move to variational data assimilation in the atmosphere).

- Coupled DA and modelling has demonstrated benefits and should be further developed in any case, independent on decisions on the assimilation of L1 data.
- Fully coupled L1-DA is aspirational, but at this stage speculative. A stepwise approach needs to be followed as science and resources allow (and needs to consider wider aspects such as the land / composition / hydrology).
- Forward models should be shared by community and provided/supported by central facility.
- The fitness of the individual model components (ocean, sea ice, land, ocean surface waves) and their respective data assimilation schemes for the purpose of assimilating L1 data needs to be evaluated.
- ECMWF should seek to exploit opportunities, campaigns and collaboration as they arise (SAFs, ESA, EUMETSAT, all existing partnerships, GHRSST).

2. What are the current deficiencies, gaps, and future barriers?

Timeliness of SST L4 analyses produced once per day is insufficient, and the SST used in the analysis can be up to 48 hours old by the time it is used by NWP at 00z, leading to up to 57 hours delay in the SST used in the short forecasts that provides background for the analysis. Delivery of a daily product of L4 SST and sea-ice concentration a few hours earlier (to make 00z cut off) would help reduce this maximum delay by about half. The possibility of delivering a daily product twice per day could be investigated. The time of all the satellite data needed to constrain the analysis should be revisited.

Spatial scale: ECMWF could investigate a new prototype of SST product from OSTIA, which already exists. This new product has reduced spatial smoothing for evaluating the impact on NWP products. Specific sensitivity studies to define the spatial scales requirements (including gradients and curvature) from the NWP perspective are needed.

Time sampling: Currently the L4 information is limited to daily averages. Better temporal sampling is possible with LEO (Low Earth Orbit) satellites at night, and GEO (Geostationary satellite). In situ observations help, but their spatial coverage is insufficient.

Information accuracy for SST: There have been reports of jumpiness on the daily OSTIA product, possibly as a consequence of infilling when there is missing data. In general the level of accuracy in SST required for NWP applications is difficult to quantify without specific studies. ECMWF needs to define sensitivities (random/drift/gross) and give feedback to the GHRSST community.

Information accuracy for SI: Difficulties have been reported with inaccurate SIC along coastlines and over Baltic, among others. There are also problems with Passive Microwave retrievals in summer due to the presence of melt ponds. It is practically impossible to deliver a “one-size-fits-it-all” L4 product for sea-ice concentration that would represent all these challenging cases to the satisfaction of all users.

Scope and metadata (errors): There are issues related to lack of uncertainty information (especially in L4 products), and if uncertainty information is available it is not always used. ECMWF should use more Quality Control (QC) and uncertainty information supplied with the products.

Underutilization of observations: Currently ECMWF only uses information on SIC but not SI thickness. The multivariate relations and spatial correlation scales in the assimilation of SST and SIC need to be improved. In-situ information of SST and SIC is also underutilized. In the case of SIC, this is made difficult by different file formats.

Historical time records for consistent reanalyses: there are difficulties with long-term temporal consistency of SI concentration and with missing data in L4 products used for the ERA5 atmospheric reanalysis. There should be a concerted plan for the provision of SST and SI information for reanalyses that are consistent, accurate, and robust to changes in the observing system.

3. What should be the next steps for ECMWF to improve SST and sea ice in NWP and reanalysis?

a) Recommendations for improving the use of L4

- Actively engage with GHRSST to optimise the properties of SST observations for NWP applications. Provide feedback on which uncertainty information would and could be used by ECMWF. This applies to L1/L2/L3/L4.
- Make use of diurnal cycle SST information in addition to foundation temperature
- Uncertainty information in the L4 product should be used when provided.
- Validation of SST forecasts should be done against foundation temperature, drifting buoy depth and skin temperature SST analyses (indirectly validating near-surface dynamics in the forecasts).

b) Recommendations for transition to L3-L2

- Initially use OSI-SAF L3 and then L2 products of SST and sea ice for assimilation into the ocean model. This will improve timeliness, allow using latest NWP input data and enable using QC information. This step will require consistent L2-L3 reprocessing for reanalyses. It will also require improving the methodology for assimilation of surface information into the ocean/sea-ice models.
- Start using CryoSat-2 (and Sentinel-3) thickness data, first for validation (already done for SMOS), in near-real-time.
- Seek collaboration for advancing assimilation of L2-L3 Sea Ice Thickness and SST into the sea-ice and ocean models.
- Assess availability/accessibility of sea-ice in-situ data, and start using it for verification.
- Encourage in-situ data providers to adopt standard formats and procedures/protocols.

c) Recommendations for significant progress on assimilating L1

- Formulate a roadmap for assimilation of L1 information and identify collaborations.

- L1-SST assimilation initial efforts could be compared with the L2-SST assimilation carried out with a prognostic model of skin temperature (e.g., like that carried out at the UK Met Office). L2 assimilation will inform L1 assimilation by developing methods for spreading information vertically and horizontally.

- Work towards implementation of SIC retrieval algorithms in house (code supplied and supported by OSI-SAF). Initial results could be compared with existing products. This is a step towards full radiance assimilation, analogous to NWP retrieving of T-Q profiles. Learn from difficulties encountered in NWP context, e.g. error correlation between retrieval and background state.

- Enable the handling of clouds / aerosol for SST information and microwave emission properties frozen surfaces, use of Scatterometer data (currents/stress/ambiguity).

d) Recommendations on reanalyses and methodology

- ERA6 will be based on a tried and tested operational NWP system. Timings and plans for the degree of coupling (based on issues in the extra-tropics) need to be confirmed in good time.

- C3S CMEMS dialogue and coordination to optimise use of OSTIA SST / ice information.

- In the spirit of moving to CDA and Earth system approach, support for ocean reanalysis should be on a level consistent with that for atmospheric reanalyses.

- Engage with historical SST observation community for centennial-scale reanalyses.

- There should be work towards a consistent DA framework for the ocean and atmosphere (and land, ocean waves, ice and aerosols). Develop a technical and scientific DA (observation operators / Jacobians / covariances) to allow for various degrees of coupled DA using a wide range of observation types.

- Advance methodology for assimilation of pre-satellite-era SST that could smoothly transition to modern day assimilation of L1/2/3 SST data.

- Develop DA algorithms that can exploit spatial and temporal observation error correlations.

- Continue improving the modelling of atmospheric, ocean, ice, wave and their interactions.

- For improved SI analysis, start using SI thickness observations from field campaigns and satellites (SMOS, CryoSat-2, Sentinel-3, ICESat2). As a first step, focus on model validation and forecast verification.

- Seek collaboration for advancing assimilation of sea-ice thickness, e.g., through the NEMOVAR consortium.

4. What recommendations would you make to space/observations agencies?

a) Space agencies

- Provision and continuity of global passive microwave radiometry (AMSR-2 like, including C-band) and L-band (SMOS like) is a priority demand, with improved radiometric uncertainty and feature resolution (5-15 km).
- Provision and continuity of CryoSat altimetry (high latitude coverage) is a priority demand.
- Explore the use of protected frequencies (2.6-2.7, 4.3, 4.9 GHz) as an alternative to or complement to the unprotected band at 6.9-7.1 GHz. Provide passive microwave observations protected against radio-frequency interference (RFI).
- Develop observations/missions capable of assessing snow-on-ice information to support sea ice model improvements and coupled assimilation developments.
- Support coupled radiative transfer science development for the sensors that are planned to fly, that currently fly and have previously flown. For example: the fundamental physics of surface emission at SST-relevant microwave bands is not adequately constrained or modelled; radiative transfer uncertainties are poorly understood.
- Specific recommendations for continuous improvement L1/L2/L3 and L4 products are given by the working group on SST (see WG 3 presentation).

b) Other data agencies, including national services, in-situ providers Copernicus Services

- In-situ observations (e.g. 2 m temperature from ice buoys) are very valuable to operational centers, but need to be properly documented and archived, ideally in a central location (GTS, BUFR, ESA-CCI efforts, …).
- OSI-SAF to expand focus from being a data/product provider to a provider of retrieval algorithms and forward models (like NWP-SAF providing RTTOV).
- National Services to provide digitized ice chart and other information (as shape files and gridded) including uncertainties in standard formats (Global Digital Sea Ice Data Bank).
- Dissemination of a mixed L1/L2 product (sea and ice) would be a valuable support of long term evolution. A product currently exists that could be used as a prototype.
- Support recovery / reprocessing / climate-standard homogenisation/harmonisation of operational and historical data (including QC / meta data / format), both satellite and in-situ, for CDA reanalyses.
- Ocean and SI observations need a similar level of coordinated protection and governance as atmospheric networks to ensure suitability for CDA.
- Ongoing funding and support for reprocessing (e.g., quality control and calibration improvement) and understanding (e.g., uncertainty characterisation, bias dependencies) of observations of all kinds is needed to support Copernicus services.

5. Which observations and processing level should drive the evolution of our systems?

The working groups discussed the suitability for assimilation of the different observation processing levels L4 to L1. See the report from WG3 for a detailed summary.

The three working groups all agreed that an evolution towards level 1 data usage has considerable benefits that should be followed for ocean and sea ice assimilation in the context of an Earth system approach.

The data assimilation coupling approach currently under implementation and evaluation for NWP and reanalysis is based on an outer loop coupling (so called quasi strongly CDA). It relies on L2 to L4 ocean and sea ice products assimilation. In parallel, developments are absolutely and urgently needed to start the transition to consistent L1 data assimilation in all the components of the coupled assimilation system, including ocean and sea ice. These will require:

- to develop a Jacobian facility to passively monitor L1 ocean data,
- to improve emission modelling across MW frequencies over all surfaces.
- to improve all aspects of radiative transfer models (atmosphere / surface), including in particular the concept of a coupled Earth system radiative transfer model.

The transition to L1 data assimilation for ocean analysis is a key component of the Earth system approach. It will require major technical and scientific developments. It urgently needs strong support and high-level coordination within ECMWF (RD, COPD, FD) and between ECMWF and the Copernicus Marine service and the space agencies.

For sea ice, observations of parameters other than sea-ice concentration need to be considered in order to improve consistency and robustness of the sea-ice analysis. Of primary importance are observations of sea-ice thickness, but also observations of snow and melt ponds on sea ice, as well as the effective surface albedo should be used once model and data assimilation have advanced sufficiently.