NWP SAF Workshop on Satellite Observations of the Earth System Interfaces: Summary and recommendations

Angela Benedetti, ECMWF
Catherine Prigent, Observatoire de Paris
Joel Bedard, ECCC
Nadia Fourrié, Meteo-France
Niels Bormann, ECMWF
Patricia de Rosnay, ECMWF
Peter Lean, ECMWF
Philip Browne, ECMWF
Sean Healy, ECMWF

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Executive summary

From 19 to 22 November 2024, ECMWF hosted the NWP SAF Workshop on Satellite Observations of the Earth System Interfaces. The workshop continued the successful series of highly focused meetings organised at ECMWF on behalf of EUMETSAT's NWP SAF and aimed to advance the exploitation of satellite data in NWP.

In the context of the development of wider Earth System prediction approach, the relevance of observations that are sensitive to multiple components, including the atmosphere, land, sea ice, snow, and the ocean ("interface observations") is ever increasing. These observations are key for NWP and for the reanalysis of past weather and climate.

In a coupled data assimilation framework, used in Earth system approaches, satellite-sensed interface observations have the unique potential to simultaneously constrain various components, providing consistent initial and boundary conditions to prediction models. This not only benefits the models via an improved and more consistent analysis, but it increases the level of synergistic exploitation of the satellite observations, and, consequently, their value-for-money, as space-borne sensors are being used across different Earth science domains.

More than 50 experts from across the world participated in the workshop. In addition to 23 presentations, there was plenty of opportunity for discussion during a poster viewing session.

Three working groups were established to address relevant questions for future developments in the exploitation of interface observations. The themes were: observation opportunities, forward operators and coupled data assimilation. The recommendations which emerged from the working group discussions are summarized below by thematic area.

A key outcome of the workshop was the recognition that many existing satellite interface observations are presently under-exploited in NWP. Significant progress towards better use of such data was nevertheless presented, driven by the general extension of NWP towards wider Earth system prediction. Some of the main outcomes were:

- Progress on the use of interface observations requires interaction of several different scientific communities. The SAF network has a strong role to play, in particular in the area of forward-model development that underpins the use of level 1 data. It is recommended to take this into account during the CDOP-5 planning.
- Machine learning is recognised as a powerful method to advance the exploitation of interface observations, especially for complex surfaces where purely physical forward models are challenging.
- Coupled data assimilation is emerging as a way to underpin the better exploitation of interface observations. It brings its own challenges, for instance,

in terms of optimal coupling strategies and diagnostics. Further research and development in these areas are recommended.

More details at: https://www.ecmwf.int/en/about/media-centre/news/2024/experts-meet-discuss-satellite-observations-earth-system-interfaces

WG1 Observation Opportunities

Recommendations for ECMWF/NWP centres

Both past and new observations present opportunities and challenges when applied to learning about the interfaces. These challenges should be addressed in collaboration with the scientific community and the space agencies.

Recognising that some existing datasets are at the moment only partially utilized (i.e. scatterometer data over land), ECMWF and other NWP centres are encouraged to continue the exploitation of scatterometer data and to make use of the full information content over all surfaces. The use of Syntheric Aperture Radar (SAR) and visible observations for sea ice and snow is also encouraged.

In the perspective of new satellite observations becoming available, it is recommended to ECMWF and other NWP centres to make more use of observation of surface stress and reflected GNSS.

Recognising the importance of independently derived level 2 datasets for model development and evaluation, ECMWF and other NWP centres are encouraged to increase their use to understand processes and model biases.

For surface-sensitive microwave channels, Radio Frequency Interference (RFI) is recognised as a growing issue, and further work is required to develop strategies to identify and screen out affected observations.

Recommendations for SAFs/EUMETSAT/other space agencies/ national entities

Given the long-standing collaboration between space agencies and NWP centres, it is recommended to continue (and enhance) communication between data providers and end users (via expert points of contact) for each dataset.

Recognising the importance of fiducial reference measurements, national and international funding agencies, in collaboration with space agencies, are encouraged to continue to maintain and to expand in-situ observation networks and to support research field campaigns which play a vital role in anchoring satellite datasets, in model development and machine learning.

The importance of sharing of observational datasets e.g. through central portals which aggregate data and documentation, is recognized and data providers are encouraged to support activities to promote FAIR (Findable, Accessible, Interoperable, and Reusable) data. It is also critical to support enhanced usage of interface observations in NWP systems.

Specific recommendations on ML

ML techniques should be exploited to research and understand the relative impact of specific observations and to identify which observations could be better exploited for NWP, particularly in the context of the AI_DOP (direct observation prediction) activities.

WG2 – Forward operators

Recommendations for ECMWF

Acknowledging that the main challenges related to forward models are evaluation, error quantification and availability/reliability of input variables, ECMWF and the scientific community are encouraged to keep working together for the development of forward operators. Reprocessed observations can be used for evaluation and further development. However independent observations are essential to address these challenges.

ECMWF is encouraged to develop more the assimilation and forward modelling of IR channels over all surfaces, with focus on land. The use of emissivity atlases should be the first step, and then moving to a more complex modelling (over sea ice and land). The collaboration with the UK Met Office on emissivity retrievals is encouraged.

ECMWF is encouraged to continue working on passive and active microwave forward models/ sensors in order to exploit the benefits of both sensing techniques. Where possible, the consistency of the operators for passive and active should be checked, including in PARMIO.

For snow, sea ice and land, the problem is more complex than for the ocean but there are synergies between passive and active models that could be exploited. ECMWF should continue to develop forward operators for different degrees of coupled approaches and, when possible, should use external developments, such as fast emissivity models like SURFEM_SNOW, SURFEM_SEAICE, etc.

Forward operators for active microwave sensing and other observation types (e.g.. SIF, GNSS-R, ...) should also be explored for other applications such as land surface, carbon cycle, precipitation over ocean in an all-sky and all-surface approach, etc.

Recommendations for SAFs/EUMETSAT and the community

Given the relevance of the Earth-system approach, the SAFs are encouraged to collaborate more closely on interface related topics by fostering exchange of expertise, for instance, through visiting scientist programs and leveraging the newly proposed innovation layer.

The community is encouraged to integrate their forward models, developed for example by international teams (e.g. ISSI) into the NWP SAF's work and the SAF network should support this with funding initiatives (with appropriate support from EUMETSAT).

Specifically, the community and all relevant SAFs forward operators should be ideally integrated into RTTOV (NWP SAF) to exploit synergies and facilitate uptake at operational centres and other users.

The successful collaboration across NWP centres for atmosphere and ocean surfaces should be reproduced for land, snow and sea ice.

The extension of NWP systems into Earth system prediction should be taken into account during the design and scoping of CDOP-5, to ensure efficient forward-modelling development across the SAF network.

Recommendations on ML vs physical models

Machine learning is recognised as a powerful method to derive forward operators, especially for complex surfaces where forward models are not applicable at global scales.

Physical models might not be fast enough or require input variables that are not modelled properly, have high uncertainties or are simply unavailable.

ML operators should be checked for physical consistency and should not be black boxes. Physical understanding of processes and related errors is crucial.

ML can be used to understand relationships between multiple observations and input variables and support, in return, physical model development.

ECMWF is encouraged to continue adopting a flexible approach to ML, physical and hybrid forward models for coupled DA and the exploitation of interface observations.

Working Group 3 – Coupled DA

Recommendations to ECMWF and other NWP centres

Many challenges were identified in exploiting interface observations for DA. The use of level 1 data continues to be seen as most relevant approach to achieve a consistent use across different Earth systems, though practical considerations mean that some observation families employ level 2 data. The WG discussed in particular the complexity of the observation operators, the complexity of the coupled system and the extra computational cost, the need for ancillary data which can represent a source of error, the model biases and the unbalance between the number of observations for each domain (i.e. atmosphere-sensitive observations dominate).

Recognizing that, additionally, there are still open challenges connected to different timescales/spatial resolutions and system design for the various components of the coupled DA system, ECMWF and other NWP centres are encouraged to keep investigating how to best couple those components.

Developing the DA code in a modular manner towards a unified framework should be pursued within this effort to facilitate exploitation of observations sensitive to interfaces (including lateral boundaries such as coastlines). The interface itself can be seen as a point of control and flexibility, rather than a “weak point”. Development should be incremental to avoid divergence of scientific developments in each individual component.

Considering the importance of consistent cross-domain quality control (QC) and monitoring, it is recommended to pay attention to the various method available for QC and to use offline systems for making retrospective QC decisions. Investing in QC for specific Earth system components (i.e. the ocean) and at the interfaces is also recommended.

ECMWF is also encouraged to keep evaluating the biases in the coupled system and engage with the wider scientific community and the modelers to address them. This includes the investigation of systematic increments in extended control variables at the interface.

The importance of evaluation and diagnostics that are tailored to the coupled DA system was highlighted. It was recommended to develop monitoring for coupled increments, including increments derived in extended control variables in the atmosphere and subsequently used in the ocean analysis. In addition, it was noted that the evaluation methods may be different for each component. This means an increased need for cross-education for scientists used to evaluating changes for the atmospheric system only. In addition, some Earth system aspects have additional requirements for evaluation periods (e.g., longer periods for land and ocean; “shoulder” seasons for sea ice, etc.)

Considering these aspects, ECMWF is encouraged to run extra control periods for different components. The definition of these periods should be done in collaboration with the developers. Ideally a full year (or even two!) should be run, but it is recognized that this might pose too much of a demand on computing resources.