Coupled land-atmosphere data assimilation at ECMWF

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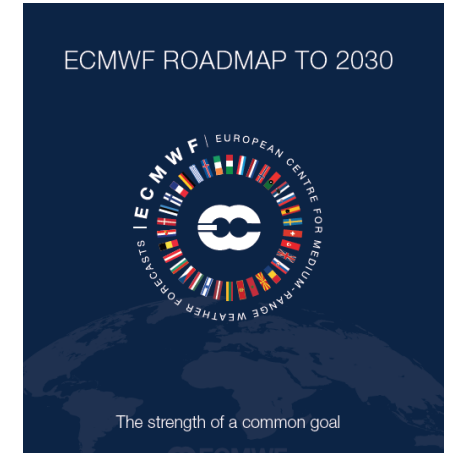
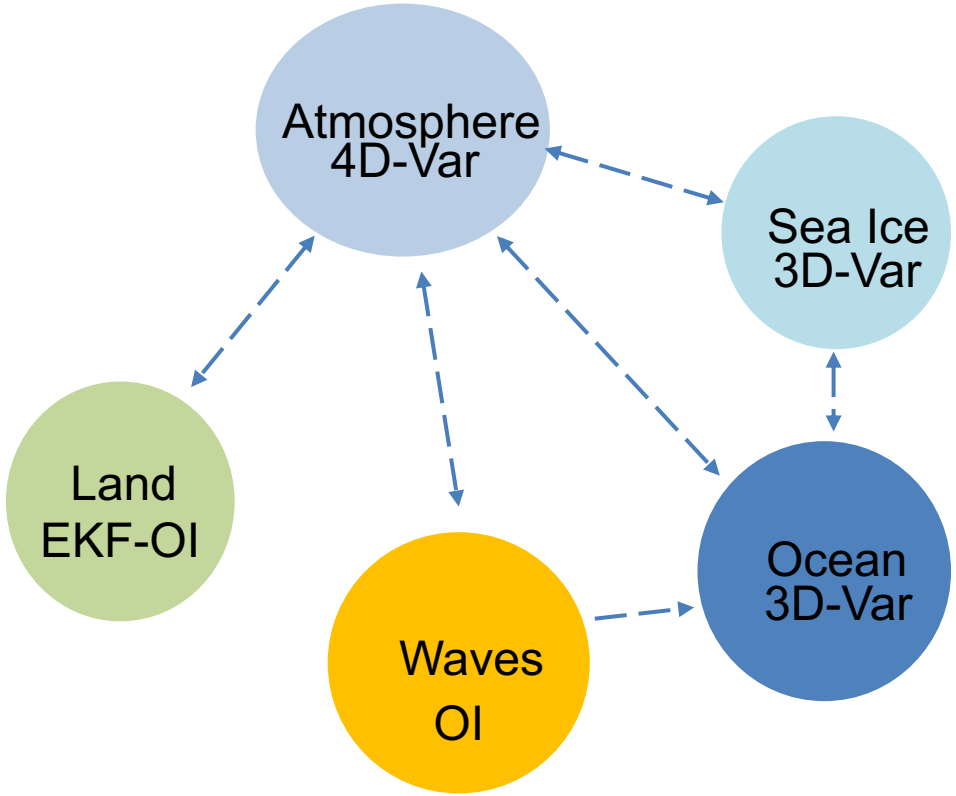
Thanks to: Massimo Bonavita, Niels Bormann, Phil Browne, Mohamed Dahoui, Steve English, Alan Geer, Elias Holm, Martin Leutbecher, Tony McNally, and many others

ECMWF

Earth system approach





Integrated Forecasting System (IFS)

- Coupled assimilation developments for NWP and reanalyses
- Importance of interface observations (e.g. LST, snow, soil moisture)

Coupled assimilation in operational systems

Observing system availability, acquisition and monitoring:

- Access to observations, acquisition, pre-processing, file format, quality control, data selection, feedback files, monitoring, auto-alert system, …

Methodology and infrastructure:

- Developments in each component, consistency, coupling strategy and level of coupling, etc
- Link to unified framework development (e.g. OOPS at ECMWF)
- Consistent & modular suite definition and file system across components, for Res & Oper

Interface observations:

- Exploitation of observations that depend on more than one component, forward operator coupling, and explore AI/ML approaches in support of ‘all surface’ approach developments

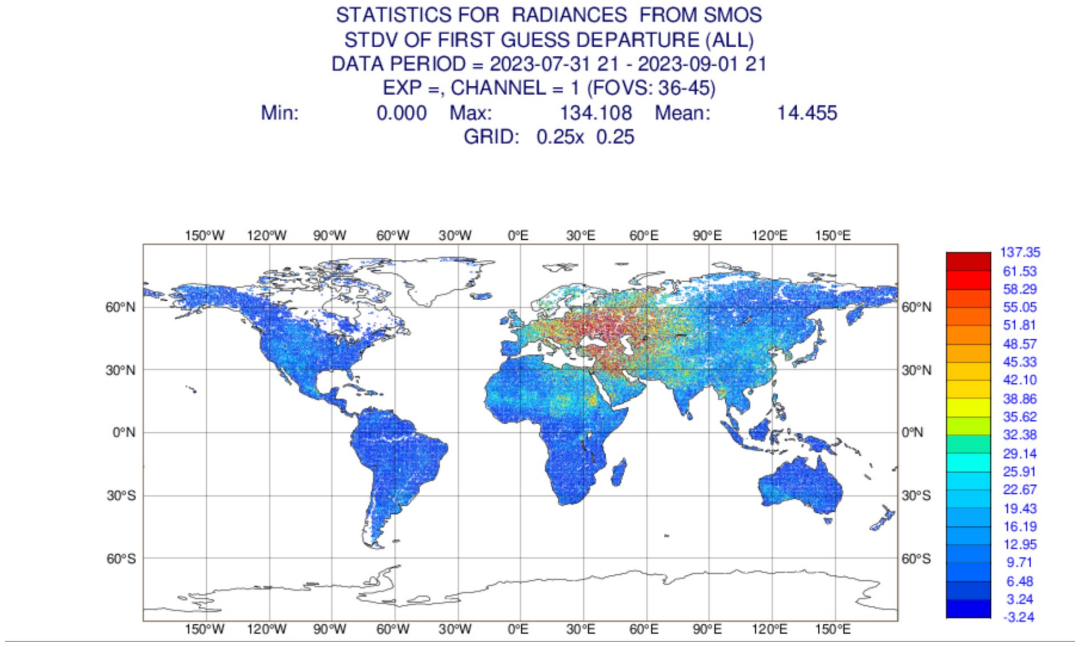
Observing system and monitoring

Need timely, sustainable and reliable access to observations across the Earth system components

- **Observations sustainability** for land, cryosphere and ocean
  → level of support from governing bodies to ensure data provision, relevance of WMO data policy evolutions; works of JET-EOSDE, GCW, etc…

- **Observations acquisition:**
  - Operational acquisition streams needed

- **Observations monitoring:**
  - Ocean operational monitoring (since 2017)
  - Land operational monitoring (since 2013), SYNOP monthly ‘blocklist’ & auto-alert (since Sept 2020)



→ **Coupled assimilation relies on a consistent workflow for land, ocean and atmospheric observations**

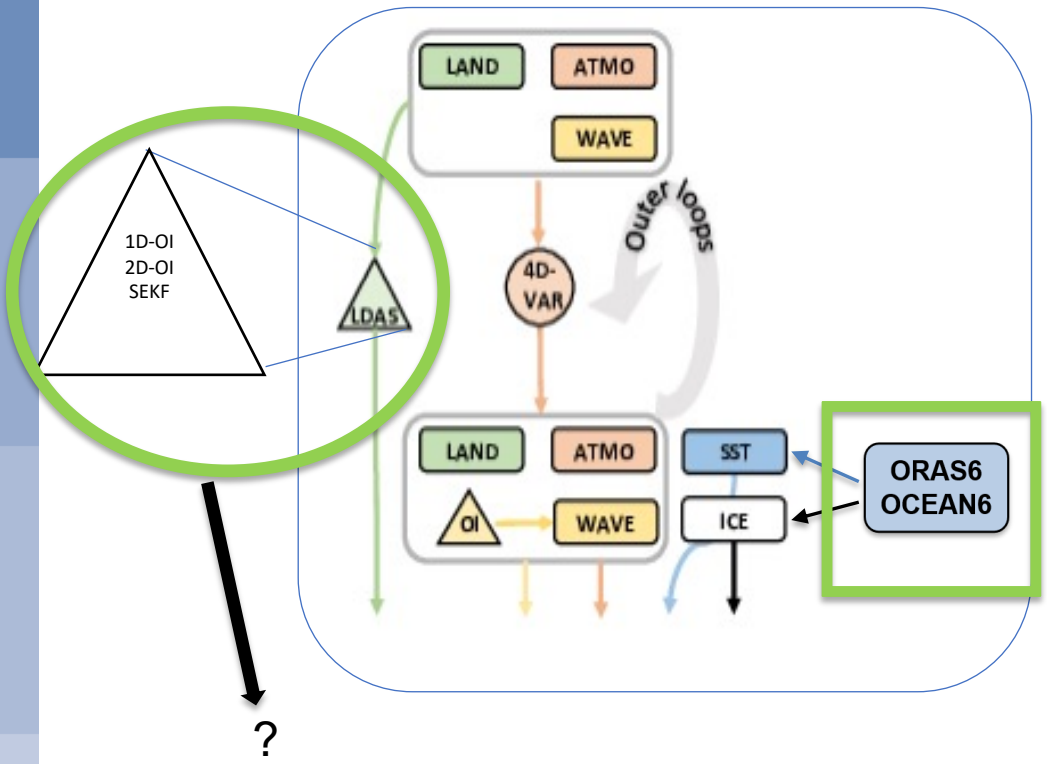
https://www.ecmwf.int/en/forecasts/quality-our-forecasts/monitoring-observing-system

Coupled data assimilation

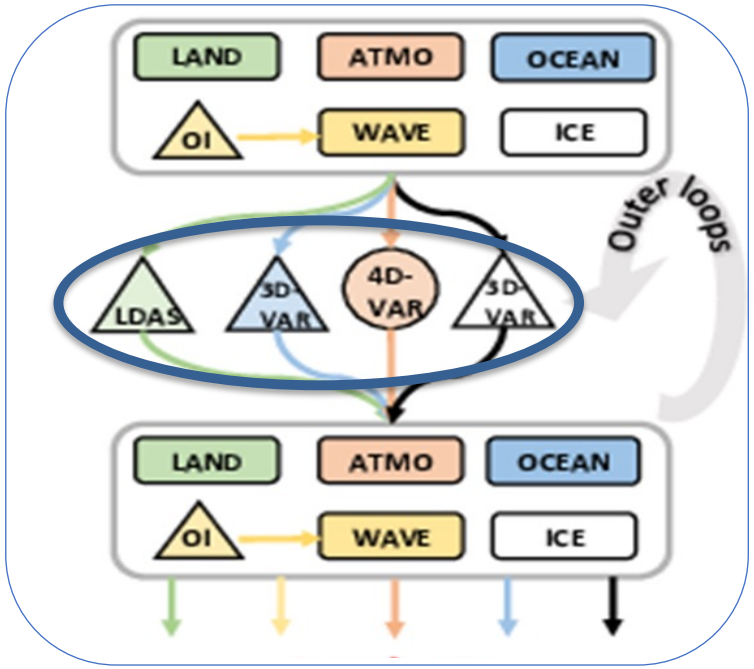
- What: Exchange of information between data assimilation systems so that observations from one component can influence the analysis of other components (Penny et al., WMO white paper, 2017)
- Why: to provide balanced initial conditions across the coupled forecast model components (e.g. Laloyaux et al.,QJRMS 2016)
- How: Diversity of methodologies ranging from weak to strong coupling (e.g. Fujii et al., QJRMS 2021, Browne et al., 2019; Fairbairn et al. JHM 2019; Schepers et al., ECMWF NewsLett 2018, Storto et al., MWR 2018; Karspeck et al., QJRMS 2018, Frolov et al., MWR 2016, Smith et al., TellusA, 2015);

Coupling for NWP and reanalysis: status and plans

Weakly coupled data assimilation for
- Land-atmosphere-waves (ERA5)
- Land-atmosphere-waves-ocean-sea ice (NWP & ERA6)

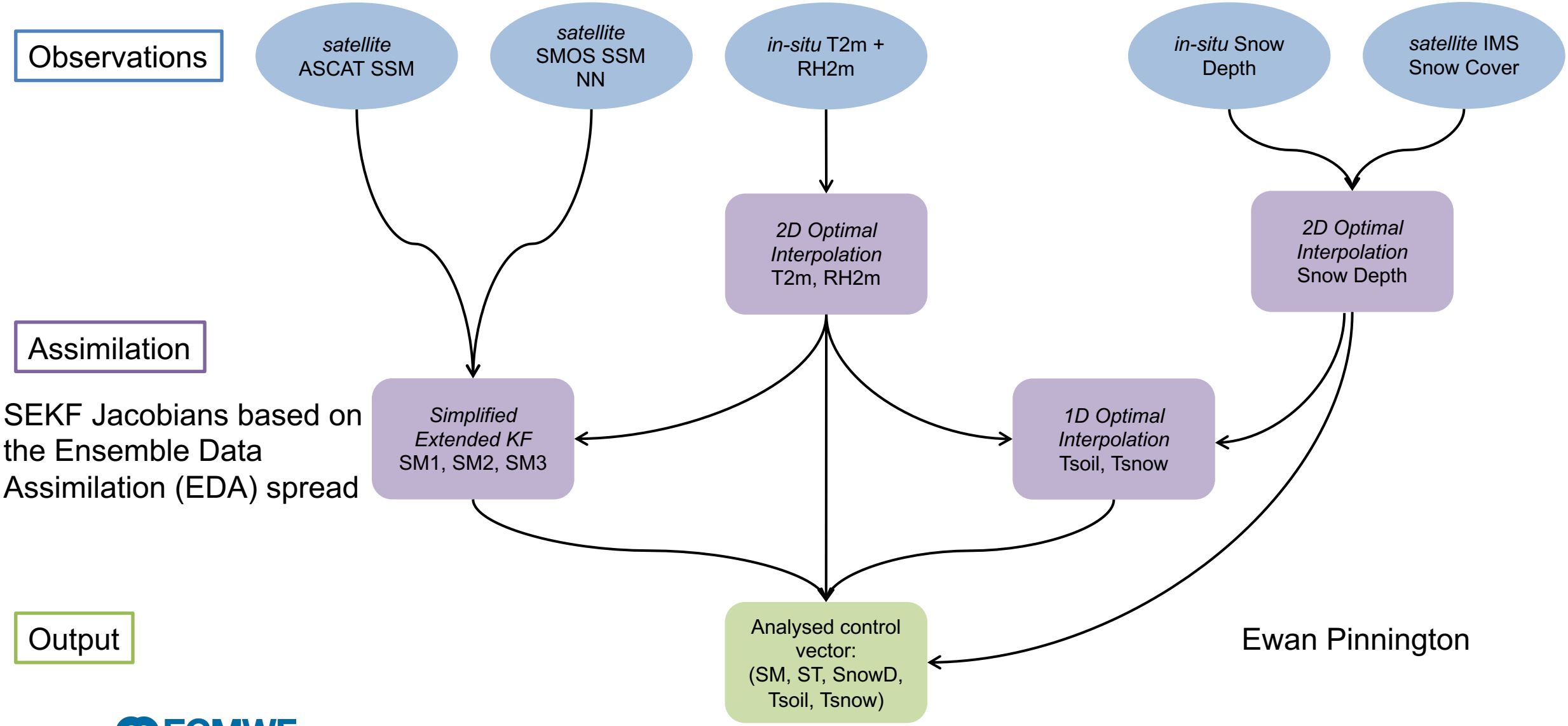


Enhanced outer coupled data assimilation for
- Land-atmosphere-waves-ocean-sea ice
→ future NWP and ERA7



de Rosnay et al., QJRMS 2022
https://doi.org/10.1002/qj.4330

ECMWF Land Data Assimilation System (LDAS)



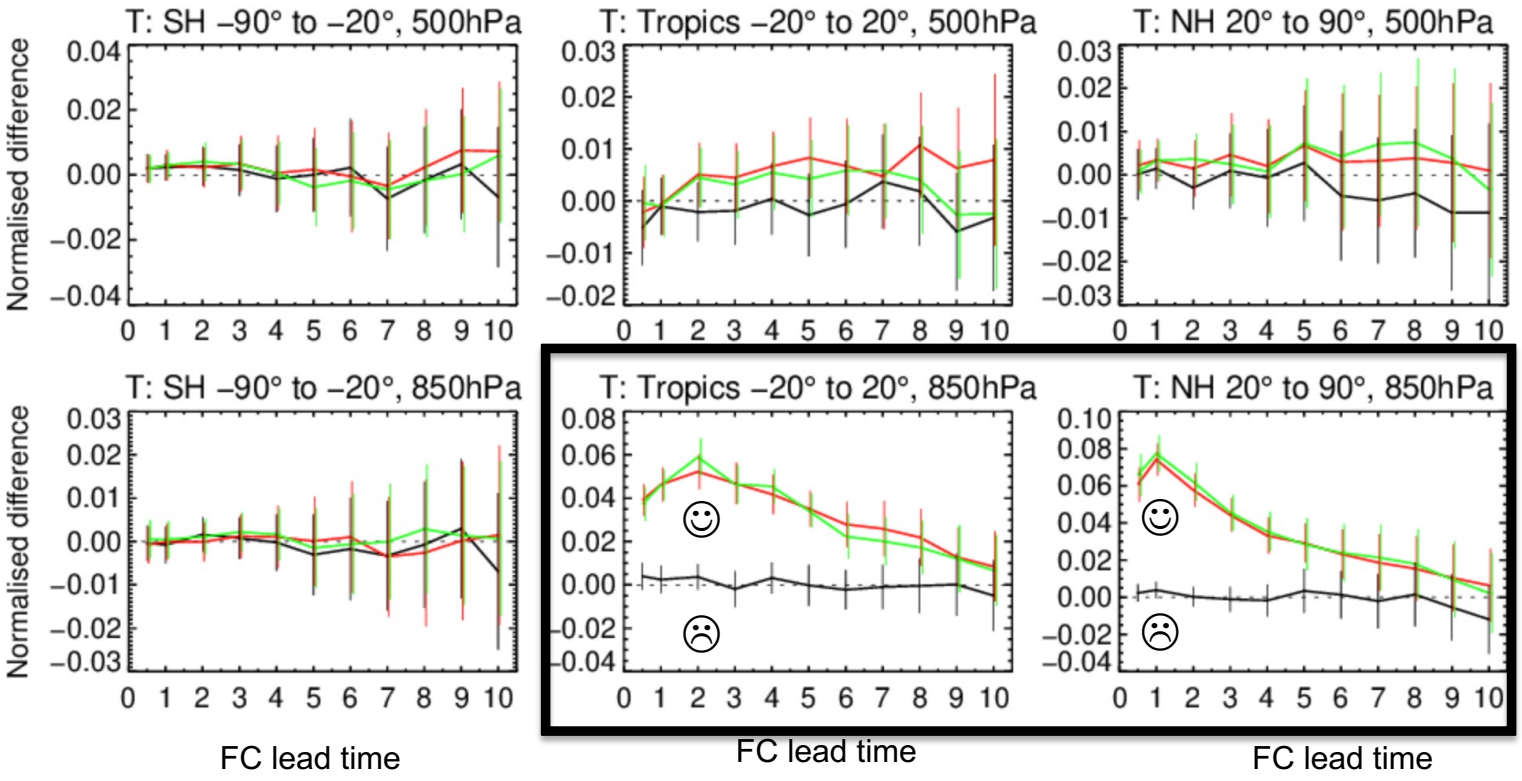
Ewan Pinnington

ECMWF

Soil analysis for NWP: impact on the atmospheric forecast

Temperature RMSE

JJA 2020
IFS cycle 48r1



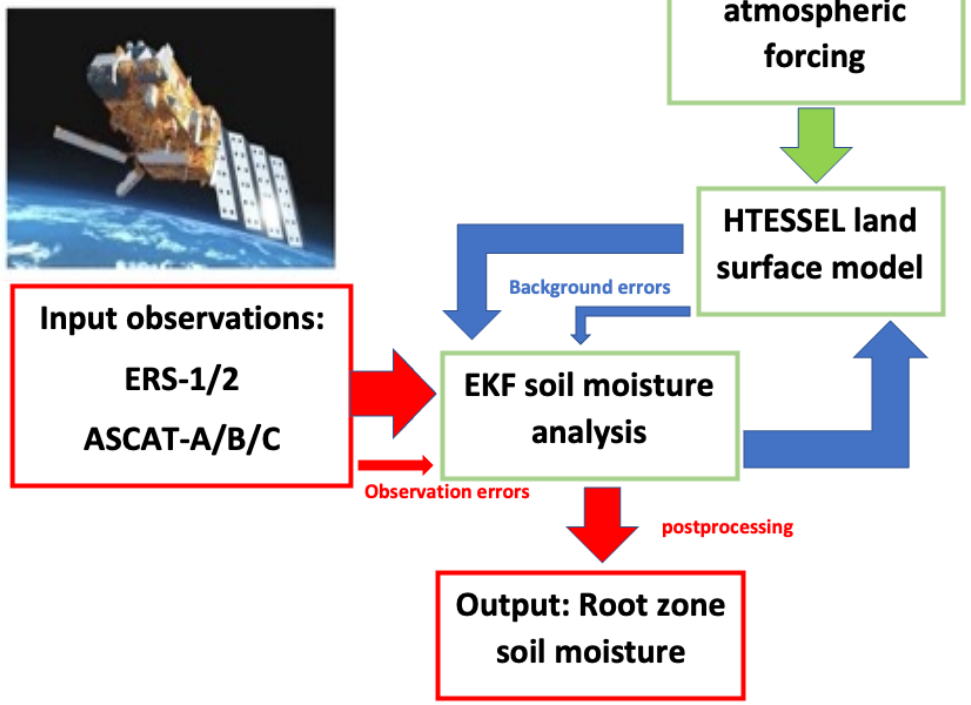
Without soil moisture DA
Without soil moisture DA
With soil moisture DA

Significant positive impact of land DA on low level atmospheric temperature forecasts

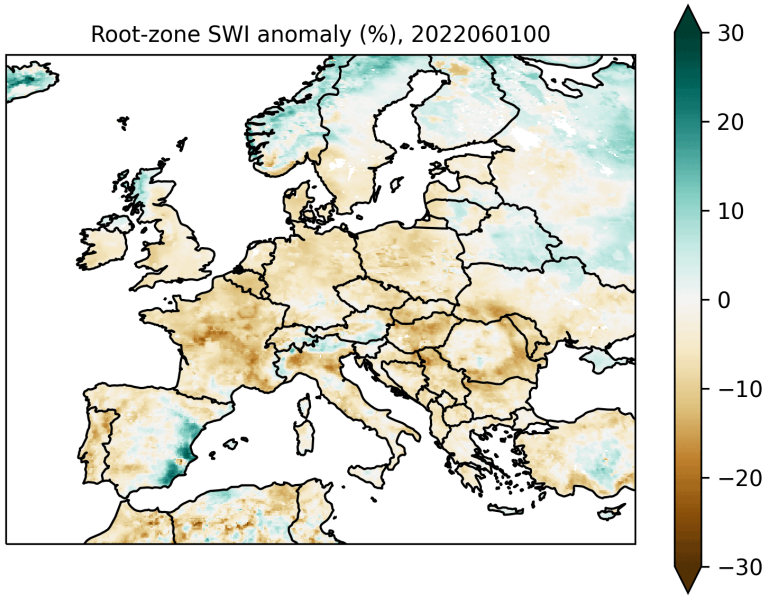
Sébastien Garrigues

H SAF root zone soil moisture data record

EUMETSAT H SAF
SUPPORT TO OPERATIONAL HYDROLOGY AND WATER MANAGEMENT



- Preparation of new SM data record (1992-2023, planned release 2024)
- Offline land DA with adaptive ASCAT SM bias-correction following Draper et al., JHM 2015

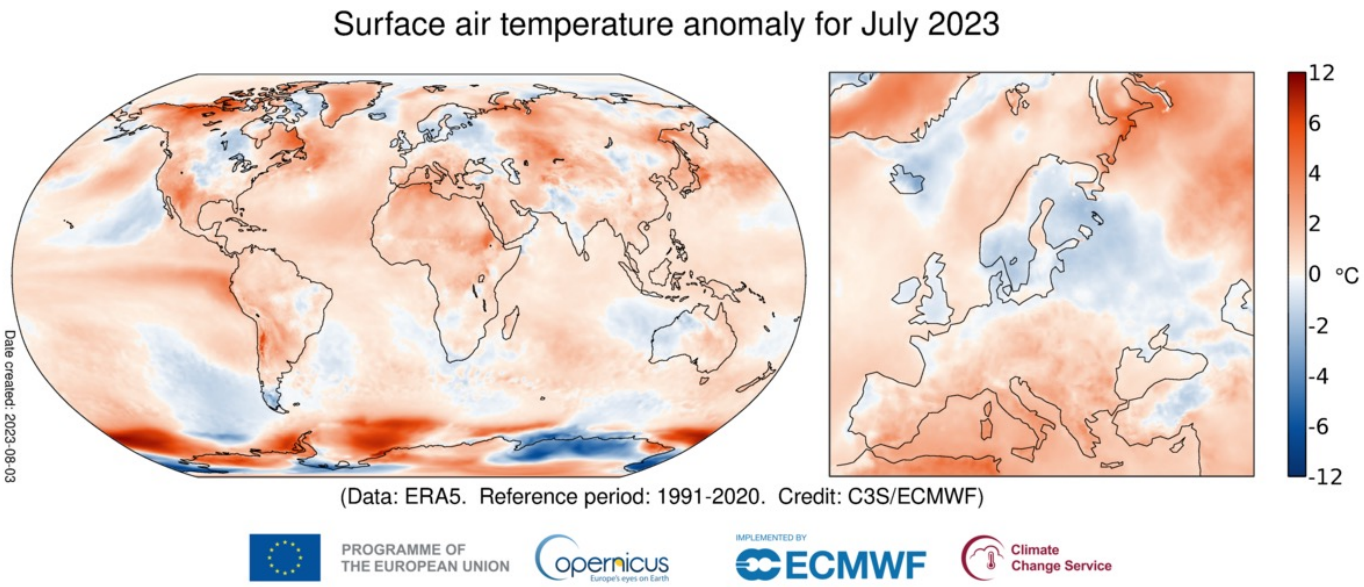


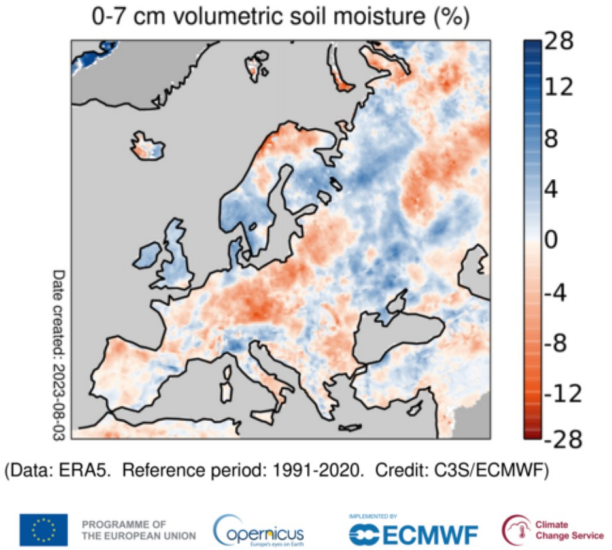
H SAF product RZSM-SCAT-ASCAT-CDOP-4-CDR-10km (H145)
+ offline extension (H146)

David Fairbairn

Land-atmosphere coupling progresses

- Developments of Land DA systems in the past 20 years (soil moisture, satellite DA, snow DA etc), but still univariate approach.
- And relatively little effort has been dedicated to land-atmosphere coupled data assimilation, despite the fact that near-surface conditions over land are of critical interest to users.





https://climate.copernicus.eu/climate-bulletins

CERISE Horizon Europe project

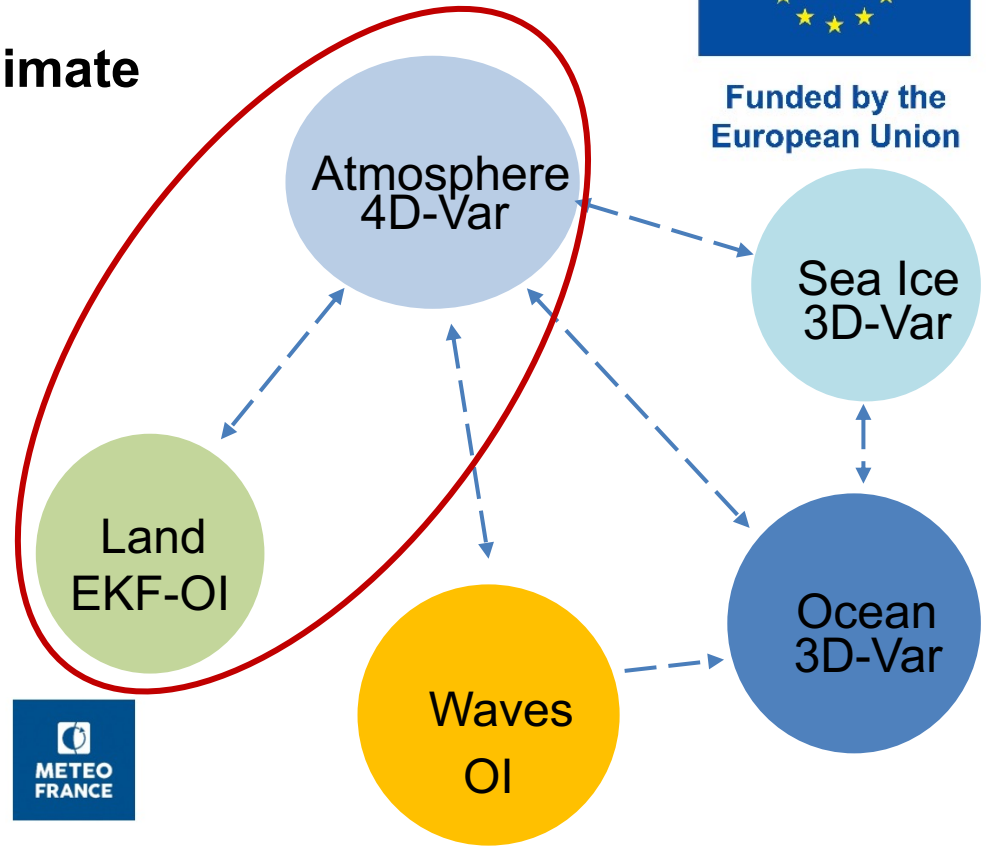
CERISE: CopERnIcus climate change Service Evolution (2023-2026)

→ **Support the long-term evolution of C3S (Copernicus Climate Change Service) for:**

- regional and global climate reanalysis and

- multi-system seasonal prediction,

towards an Earth system approach with a focus on land-atmosphere coupling.



Funded by the European Union

https://www.cerise-project.eu/

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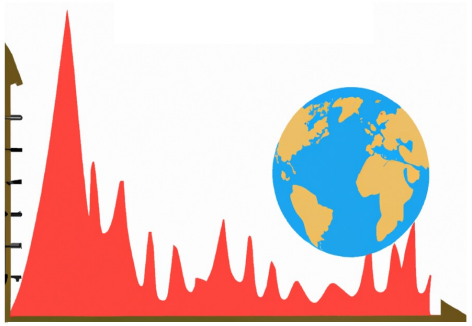
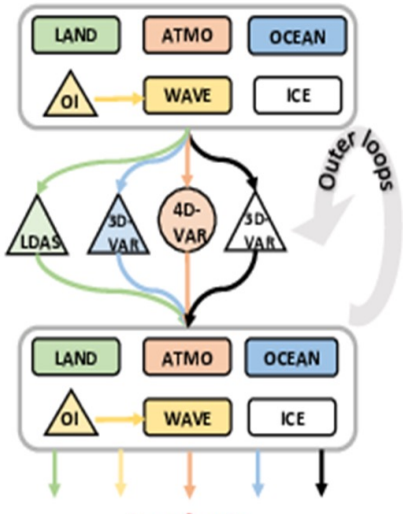
CERISE developments

- Land and coupled land-atmosphere data assimilation
- Explore ML-based observation operators to improve the exploitation of satellite observations

- Multidecadal representation of evolving vegetation and lakes, building up on CONFESS H2020
- Prototypes of seamless reanalysis and multi-system seasonal prediction → High readiness level: ERA6-Land, ERA7, SEAS7
- Novel diagnostic tools to assess physical consistency of Earth system reanalysis and prediction





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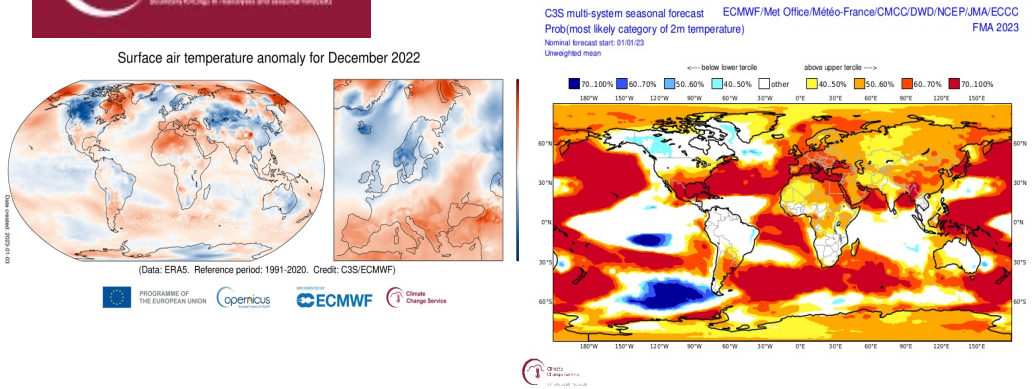

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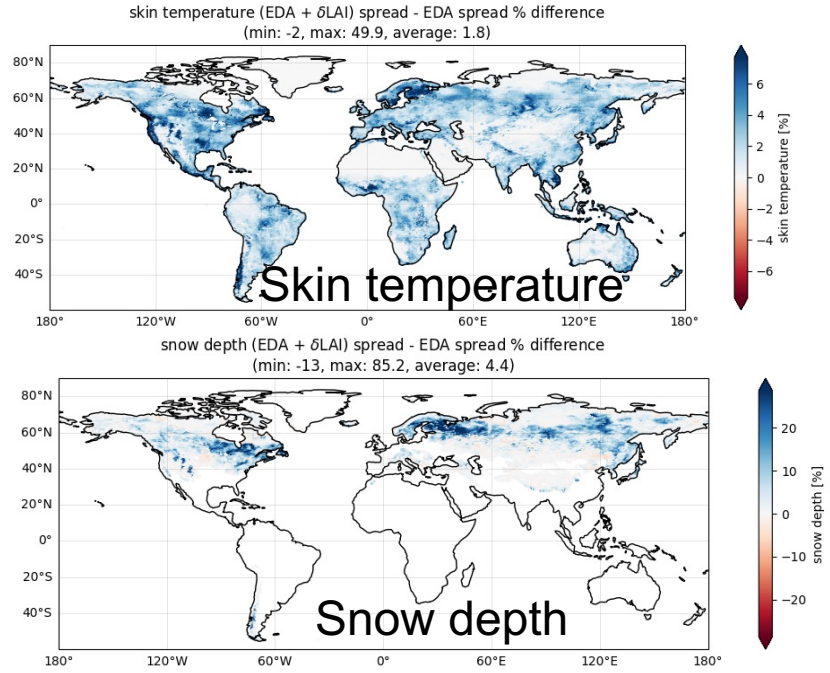
Land surface parameter perturbations

→ Ewan Pinnington's presentation yesterday

- The ECMWF Ensemble of Data Assimilations (EDA) is under-spread at the surface
- As part of CERISE project, we explore methods to increase ensemble spread at the land surface for future Land Surface Data Assimilation Systems (LDAS)
- Stochastic Parameter Perturbation approach for Leaf Area Index (LAI) and vegetation fraction in the offline land DA system
- Draper et al., JHM 2021 also investigated surface parameter perturbations https://doi.org/10.1175/JHM-D-21-0016.1



Differences in spread between the EDA offline surface ensemble with and without perturbations.

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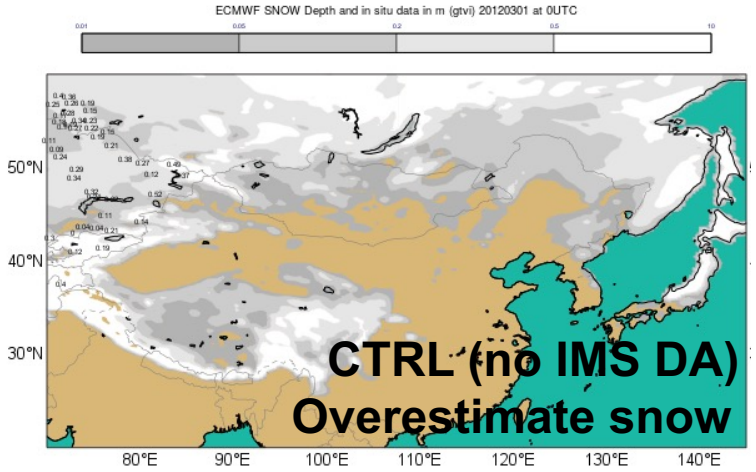
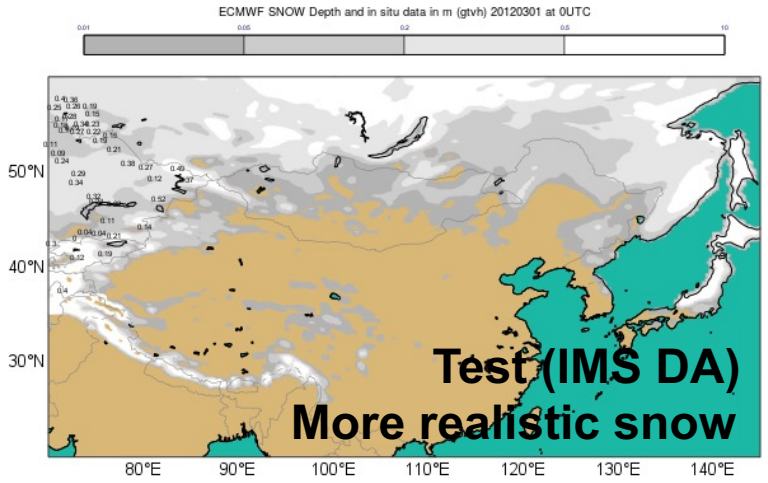
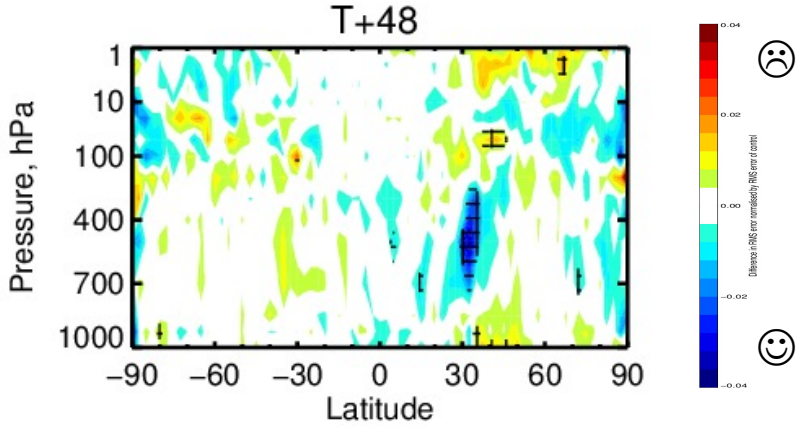
Coupled snow-atmosphere data assimilation





Impact on albedo and momentum
→ Modifies the jet circulation

Change in humidity FC error
Oct 2011 – June 2012

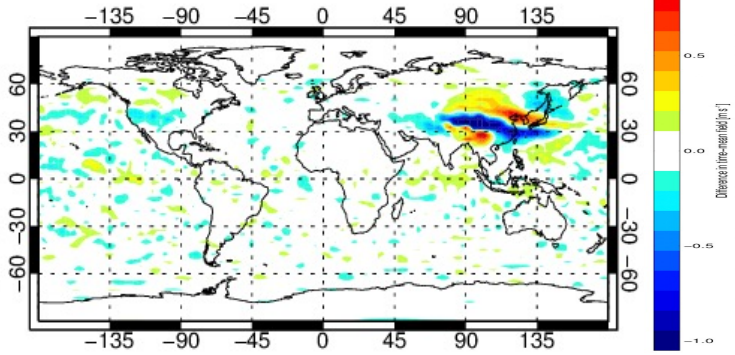


In previous studies, we showed the potential of snow cover data assimilation over the Tibetan Plateau (Orsolini et al, TC 2019, de Rosnay et al.).

Challenges related to model biases and snow-boundary layer coupling needed to be addressed to mitigate mixed atmospheric impact.

Multi-layer snow model reduced the snow model biases and enhanced consistency between snow and boundary layer processes. (Arduini et al, JAMES, 2020, https://doi.org/10.1029/2019MS001725)

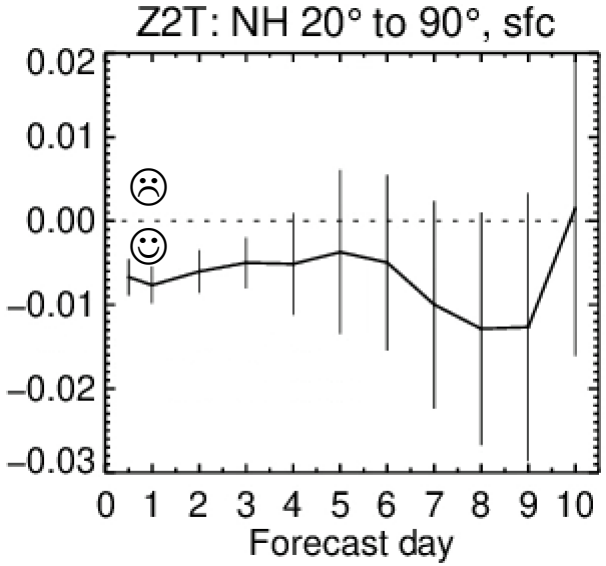
Change in zonal wind
Oct 2011 – June 2012



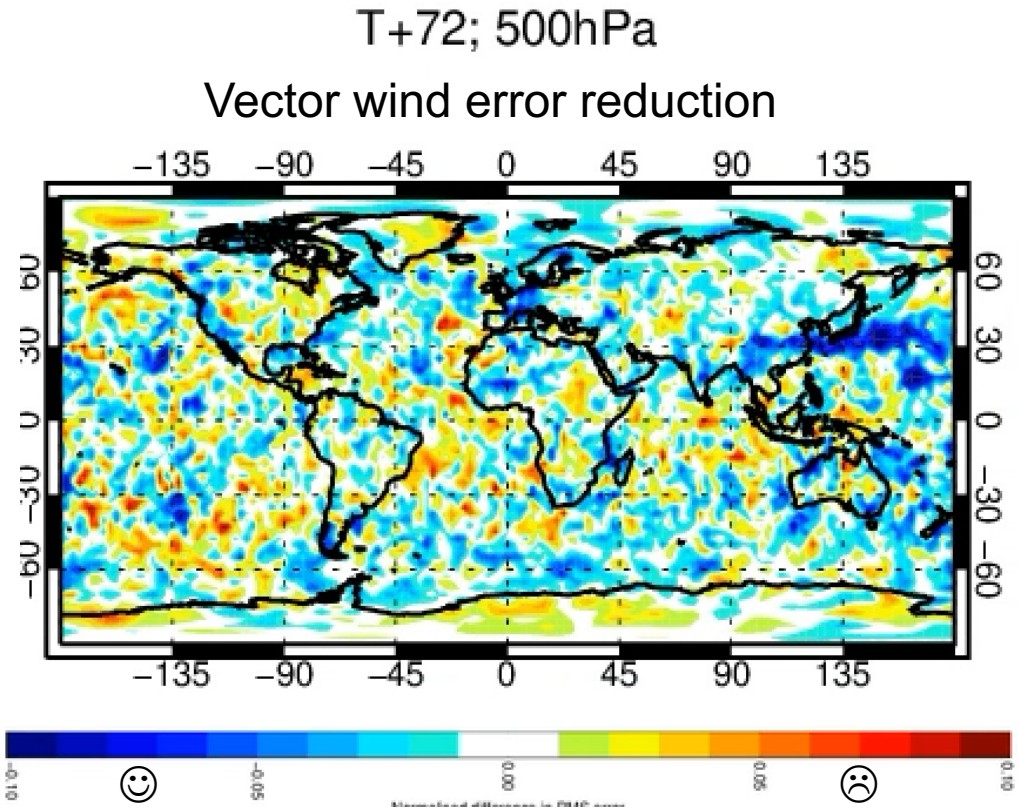
Further snow data assimilation improvements (IFS cycle 49r1 & ERA6)

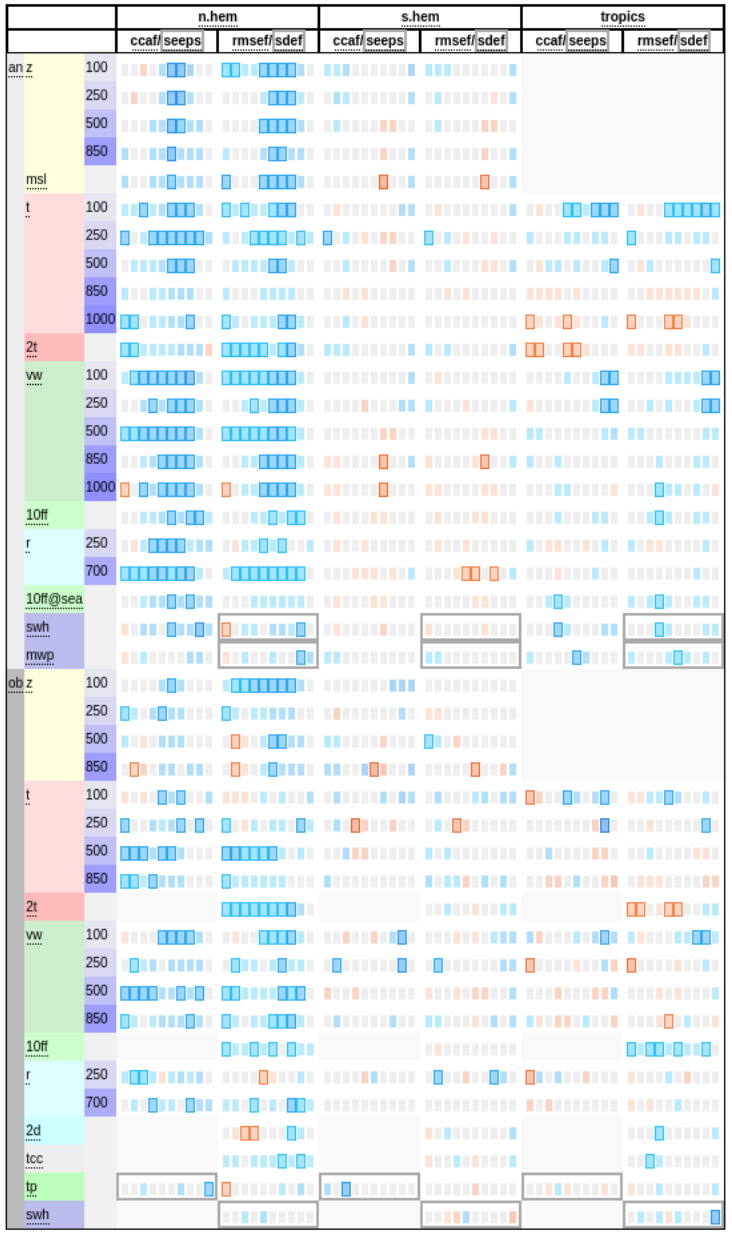
Refined snow cover modelling and assimilation methodology.

→ positive impact of IMS snow cover assimilation in mountainous areas
→ IFS cycle 49r1 & 49r2 (ERA6 and ERA6-Land)



Surface air temperature improvement





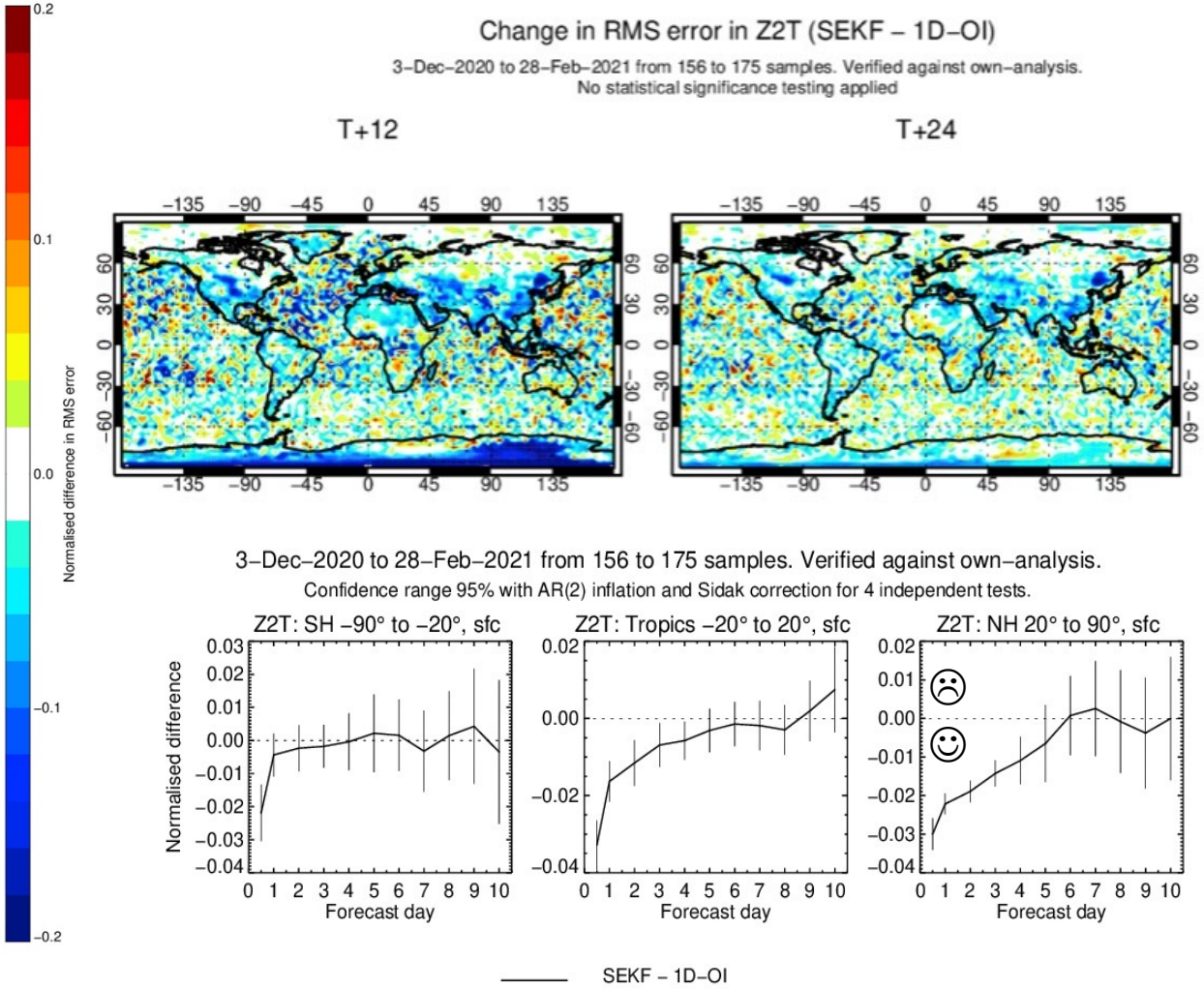
Scorecard →
(blue= improved
red=degraded)

Kenta Ochi

Soil and snow temperature analysis

Integration of the soil and snow temperature analysis in the SEKF, instead of using a 1D-OI approach

control variables $x_i =$ [swvl1, swvl2, swvl3, **stl1**, **stl2**, **stl3**, **tsn**]



- Significant improvement in T2m analysis and forecasts

- Steps towards unified LDAS

CoCO2 Horizon 2020 project

CoCO2
Prototype system for a Copernicus CO_2 service

Assimilation of Vegetation Optical Depth (VOD) from passive microwave sensors to constrain vegetation water and carbon cycle variables.

- L-band VOD (1.41GHz) from SMOS
- C-band VOD (6.9GHz) and X-band VOD (10.65GHz) from AMSR2

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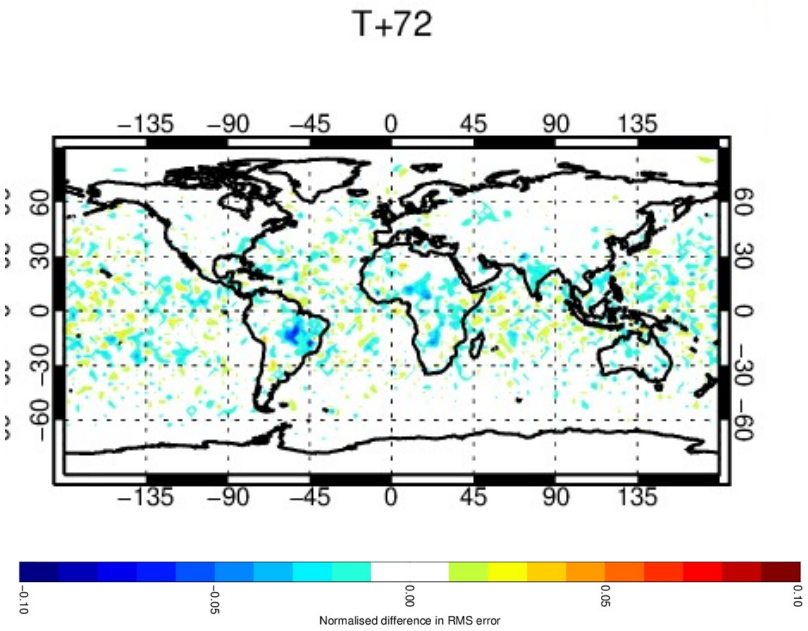


T2m RMSE reduction (blue) 2018-2021

→ Positive impact of VOD assimilation on NWP
→ Challenges in terms of GPP impact

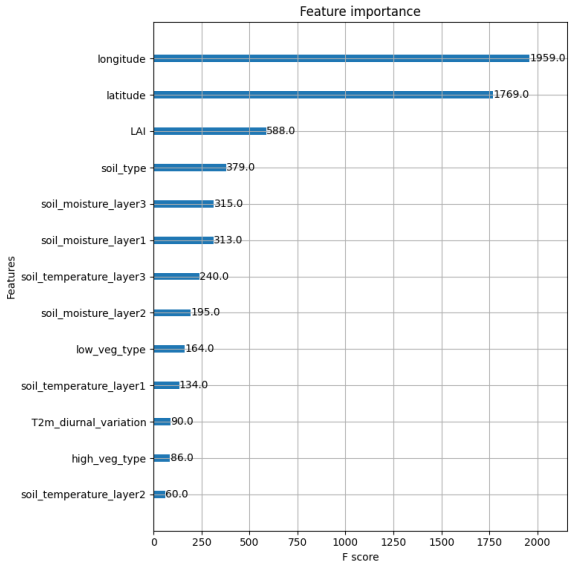
→ Pete Weston's presentation this afternoon

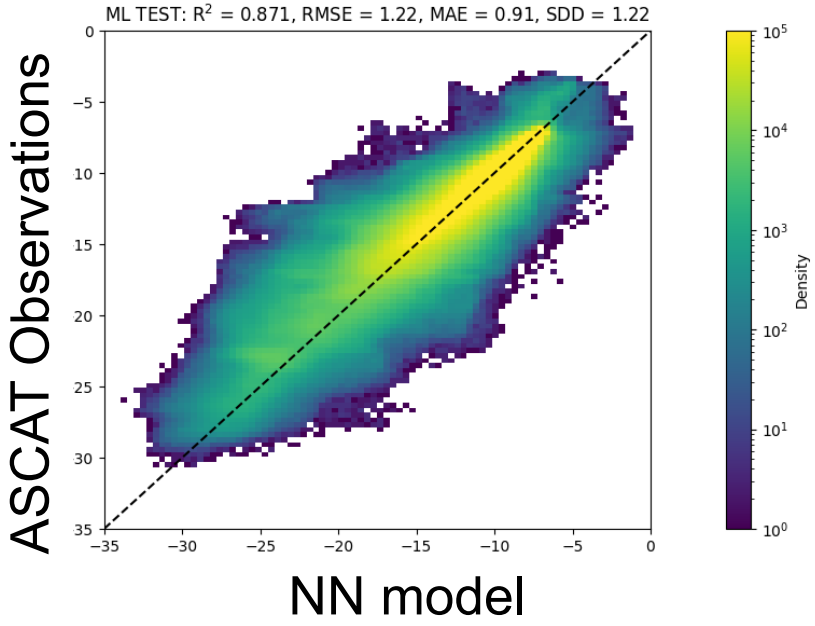
CORSO Horizon Europe project

Enhance the exploitation of satellite observations in coupled land-atmosphere assimilation to constrain vegetation water and carbon cycle variables.

→ Development of ML-based observation operators for MW and SIF observations

Information content analysis





Funded by the European Union

Sébastien Garrigues

→ Pave the way for future observations assimilation such as Metop-SG/SCA, Copernicus Expansion CO2 and CIMR missions, which are all relevant to consistently constrain vegetation and carbon fluxes in CO2MVS

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Summary (1/2)

- Progressive implementation of coupled assimilation at ECMWF for operational NWP and future generations of reanalyses → **NWP, Copernicus Services, and high-resolution Destination Earth**

- Relevance of interface observations, e.g. Snow (cover, water equivalent, depth), vegetation-related observations, soil moisture, for NWP and reanalysis → importance of future missions such as Metop-SG, CIMR

- Challenges of Earth System approach for NWP, e.g. Coupling through the observation operator, e.g. snow surfaces. Opportunities to enhance the exploitation of current and future satellite data

Summary (2/2)

- **Transition to lower level (level 1) products assimilation**: key for coupled assimilation to enhance assimilation of observations that are sensitive to the surface
  - Work on skin temperature DA over ocean → extend to land
  - Investigate multivariate soil and vegetation analysis (consistent water and carbon cycle)
  - Further developments on forward operator coupling, integrating ML/AI to tackle challenges of radiative transfer over complex surfaces in support of an all-surface approach

- **Earth system approach → also extend to more components,** e.g. river and flood forecast system

ECMWF

Special Collection Quarterly Journal of The Royal Meteorological Society

“Coupled Earth system data assimilation”

Submission deadline: 31 December 2023

https://rmets.onlinelibrary.wiley.com/