ECMWF/EUMETSAT NWP-SAF
Satellite data assimilation
Training course, 26 March 2026

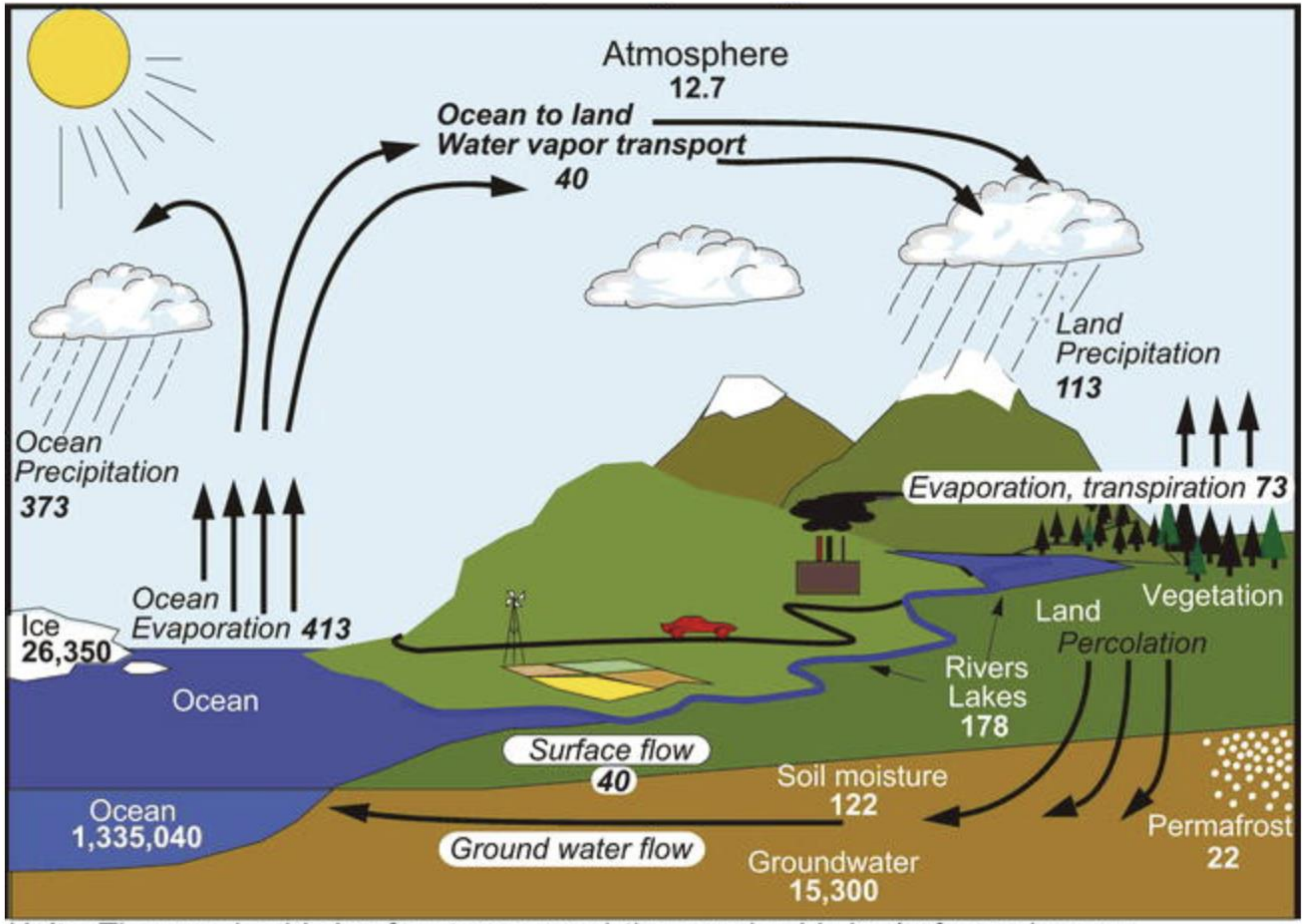
Satellite information on the land surface in a coupled system

Patricia de Rosnay

ECMWF

Earth system approach

Image: Trenberth et al
J. Hydrometeorol. 2007

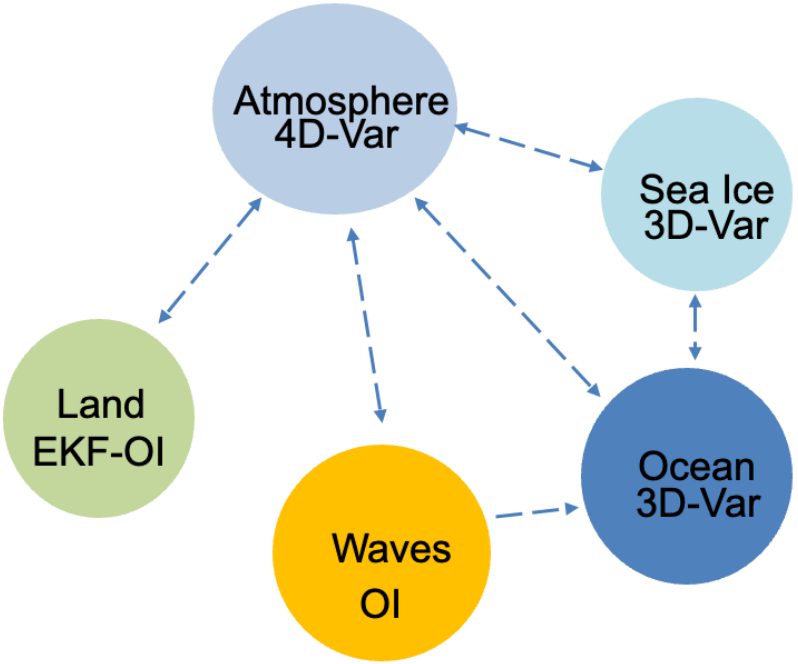


Units: Thousand cubic km for storage, and *thousand cubic km/yr* for exchanges

Earth system approach data assimilation

Over land: simplified Extended Kalman Filter and Optimal Interpolation methods

Integrated Forecasting System (IFS)



de Rosnay P. et al QJRMS 2022 → Coupled DA strategy

Browne et al. ECMWF Spring Newsletter 2026 → ocean-atmosphere outer loop coupling

Herbert et al. ECMWF Spring Newsletter 2026 → land-atmosphere outer loop coupling

Coupled data assimilation

- ECMWF forecasts are based on an Earth system model → need Earth system data assimilation
- Provide balanced initial conditions across the coupled forecast model components
- Improve exploitation of satellite data sensitive to several Earth system components towards an “all surface” approach → Interface observations

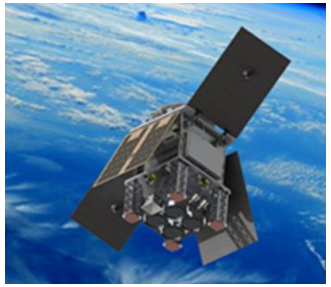
Existing missions | Future missions

ASCAT

SMOS

Sentinel-1

HydroGNSS



CRISTAL

LSTM

CIMR

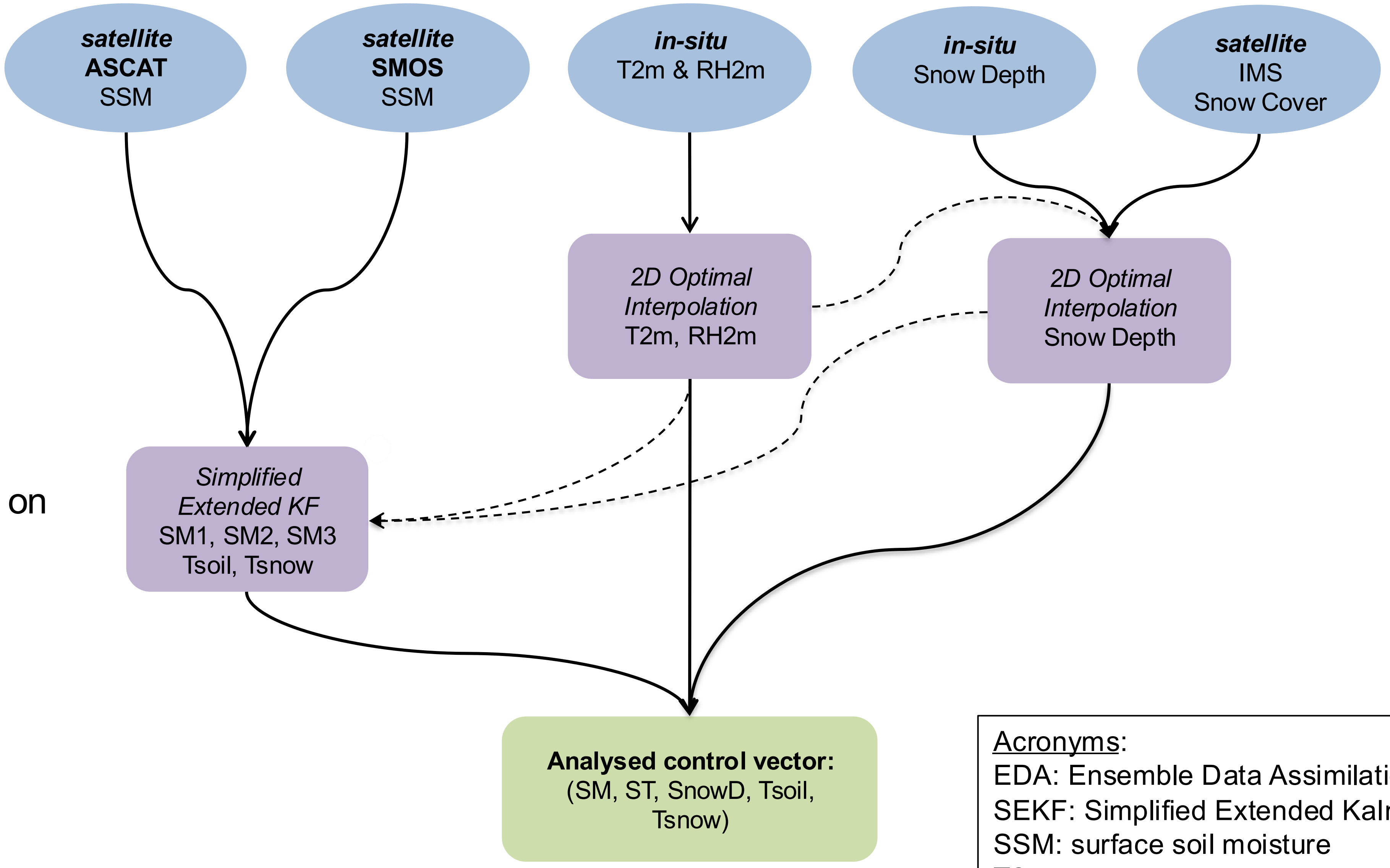
ECMWF Land Data Assimilation System (LDAS): IFS cycle 50r1

Observations

Assimilation

SEKF Jacobians based on the EDA spread

Output



Acronyms:
EDA: Ensemble Data Assimilation
SEKF: Simplified Extended Kalman Filter
SSM: surface soil moisture
T2m: two-metre temperature
TH2m: two-metre relative humidity

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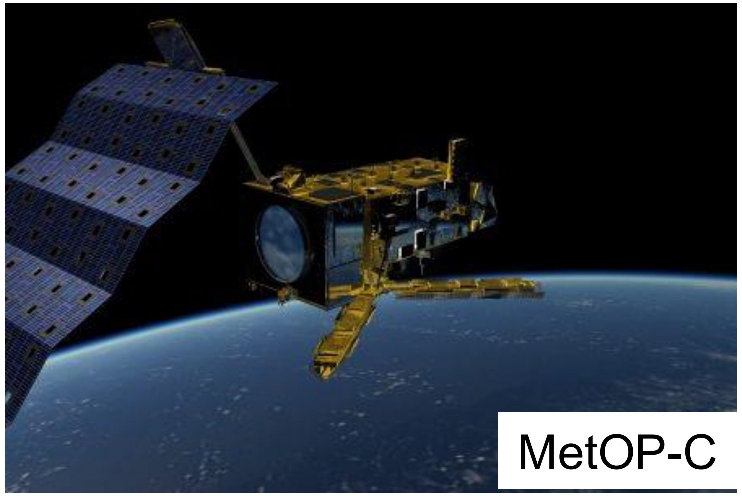
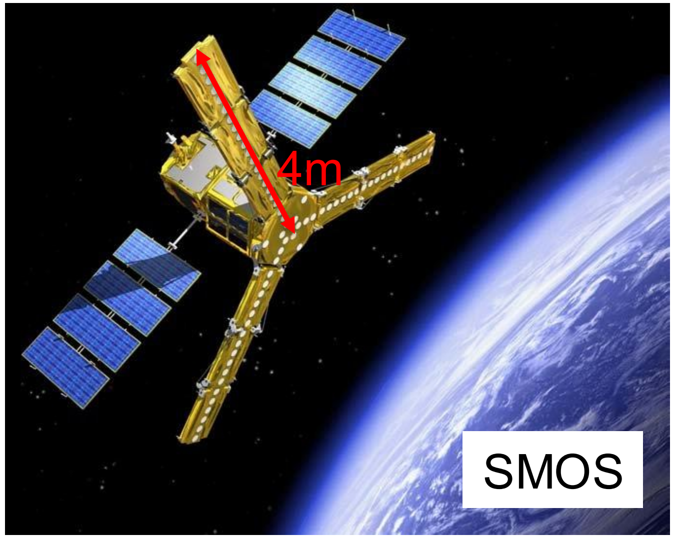
Soil moisture satellite observations used for NWP
(along with in situ T2m, RH2m screen level observations)

Active microwave data:
ASCAT: Advanced Scatterometer
MetOP-B (2012-), MetOP-C (2018-)
C-band (5.6GHz) **backscattering coefficient**
EUMETSAT Operational mission



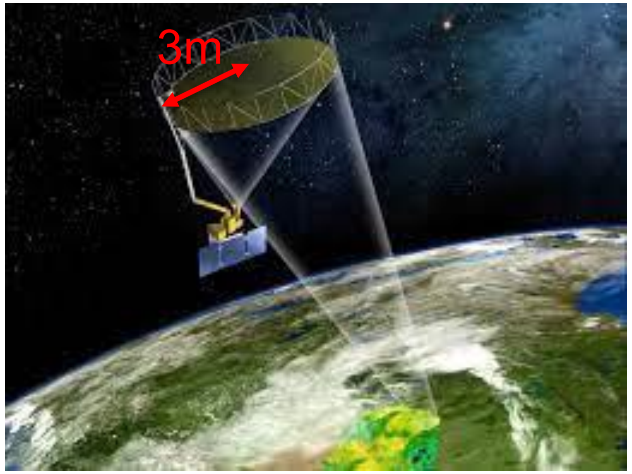
Scatterometer soil moisture also used in ERA5 and ERA6 (ERS-SCAT, Metop/ASCAT)

Passive microwave data:
SMOS: Soil Moisture & Ocean Salinity (2009-)
L-band (1.4 GHz) **Brightness Temperature (TB)**
ESA Earth Explorer, dedicated soil moisture mission
(Kerr et al., 2016)



SMOS also used in ERA6

SMAP (monitoring)
L-band TB 2015-
NASA Dedicated
soil moisture mission

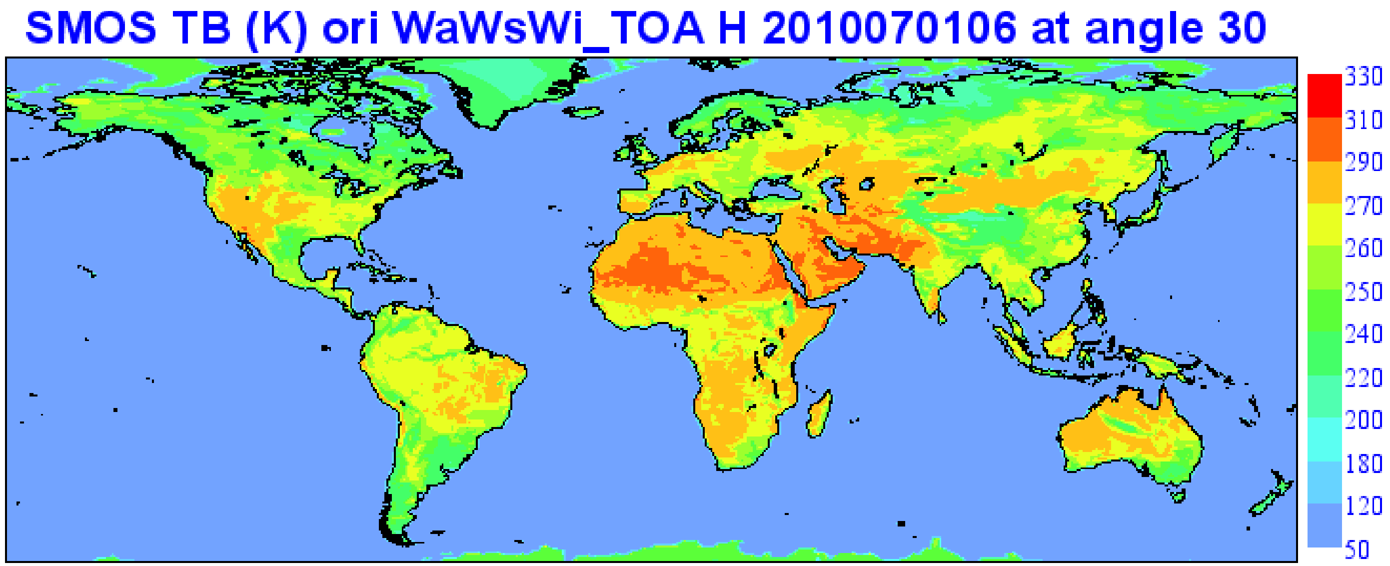


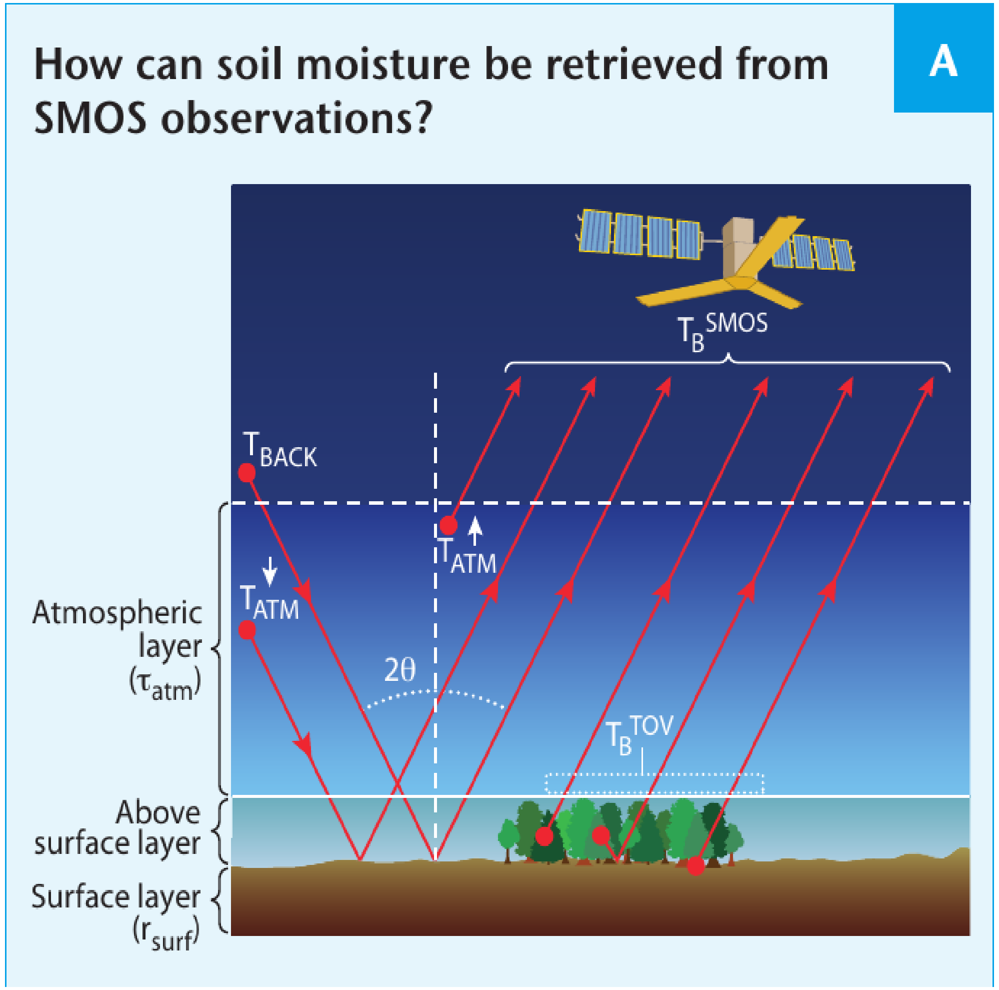
Large antennas once deployed in space

CMEM Simulations of L-Band Brightness Temperature (TB)

Surface forward operator: Community Microwave Emission Modelling Platform (CMEM)

de Rosnay et al. RSE 2020
Hirahara et all. Rem Sens. 2020





Muñoz Sabater et al ECMWF newsletter 127, Spring 2011

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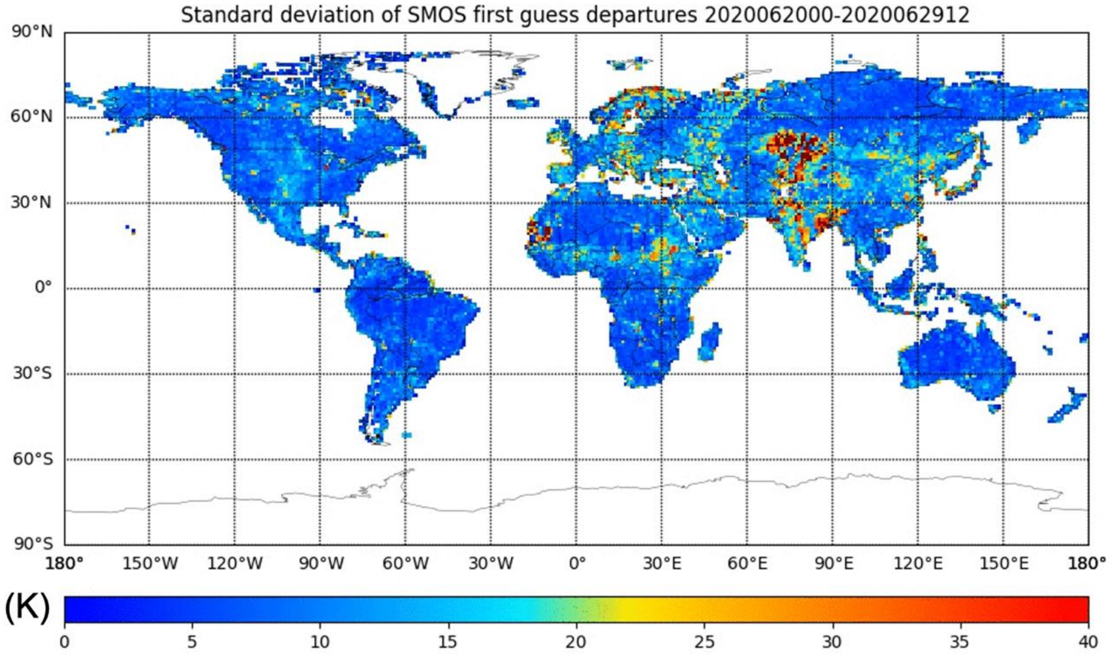
SMOS near real time brightness temperature monitoring

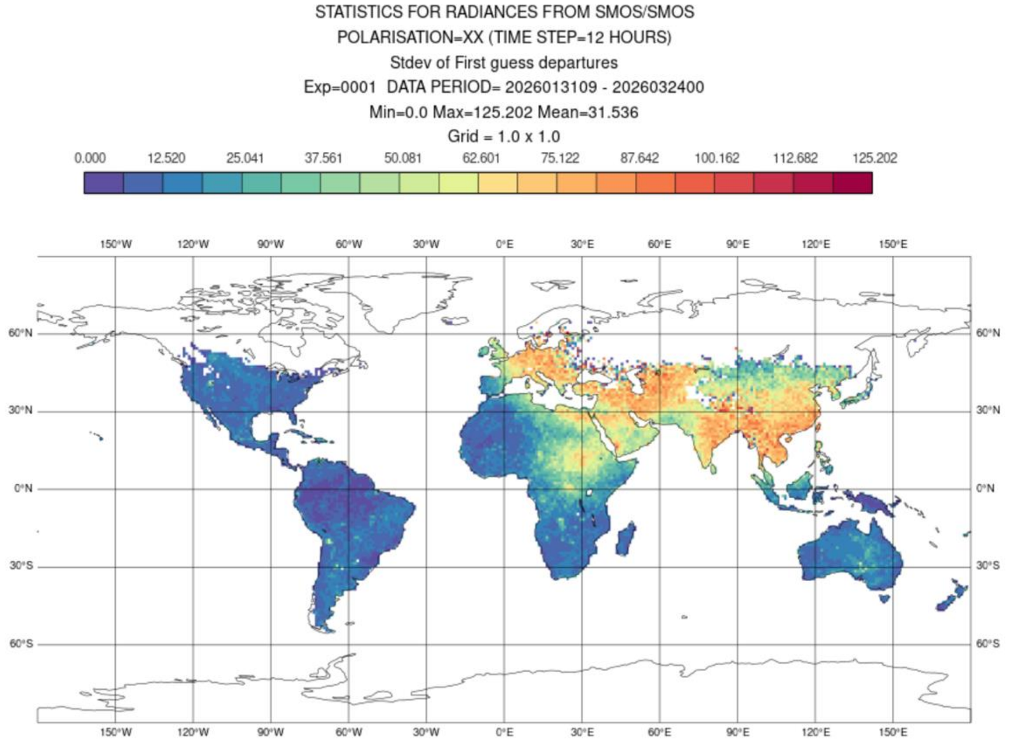
- Filtering of snow and frozen conditions (→ no monitoring at high latitudes in winter)
- Some areas are affected by RFI (Radio Frequency Interference) contamination

→ Shown with large StDev of first guess departure (observation minus model)

→ RFI detection and filtering importance for data assimilation



In June 2020



In Feb-March 2026

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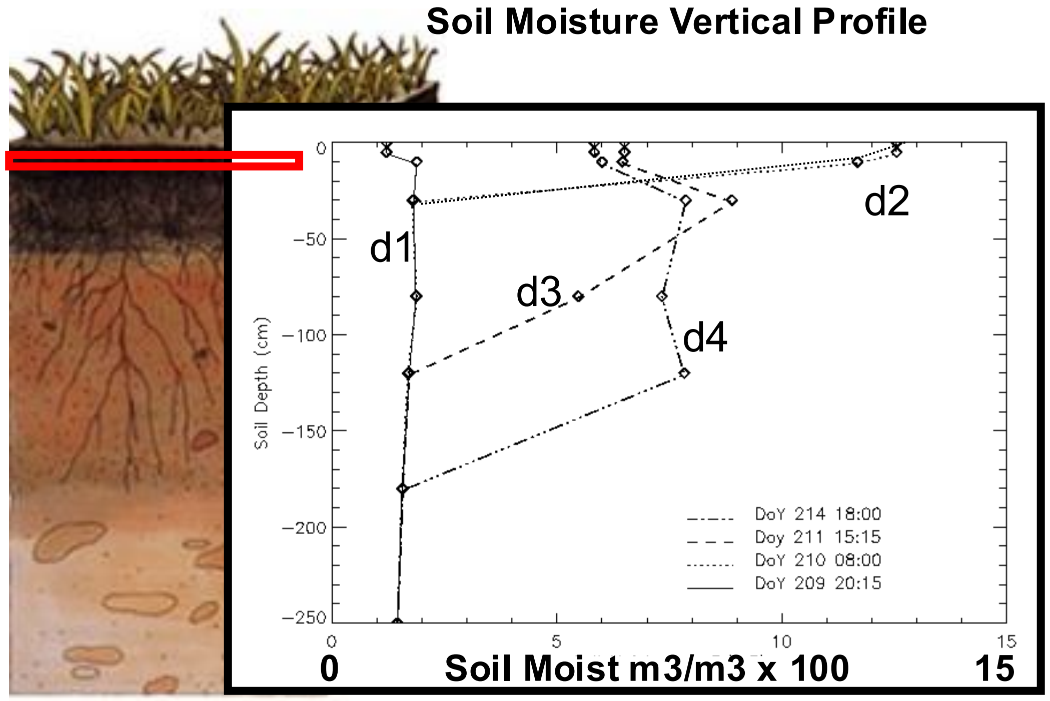
From satellite to root zone soil moisture

Satellite data → <u>Surface Soil Moisture</u> information

Soil moisture (SM) sampling depth typically 0-2cm ASCAT, 0-5cm SMOS

Root Zone SM is the variable of interest for Soil-Vegetation-Atmosphere interactions, Climate, NWP and hydrological applications



→ Accurate retrieval requires to account for physical processes

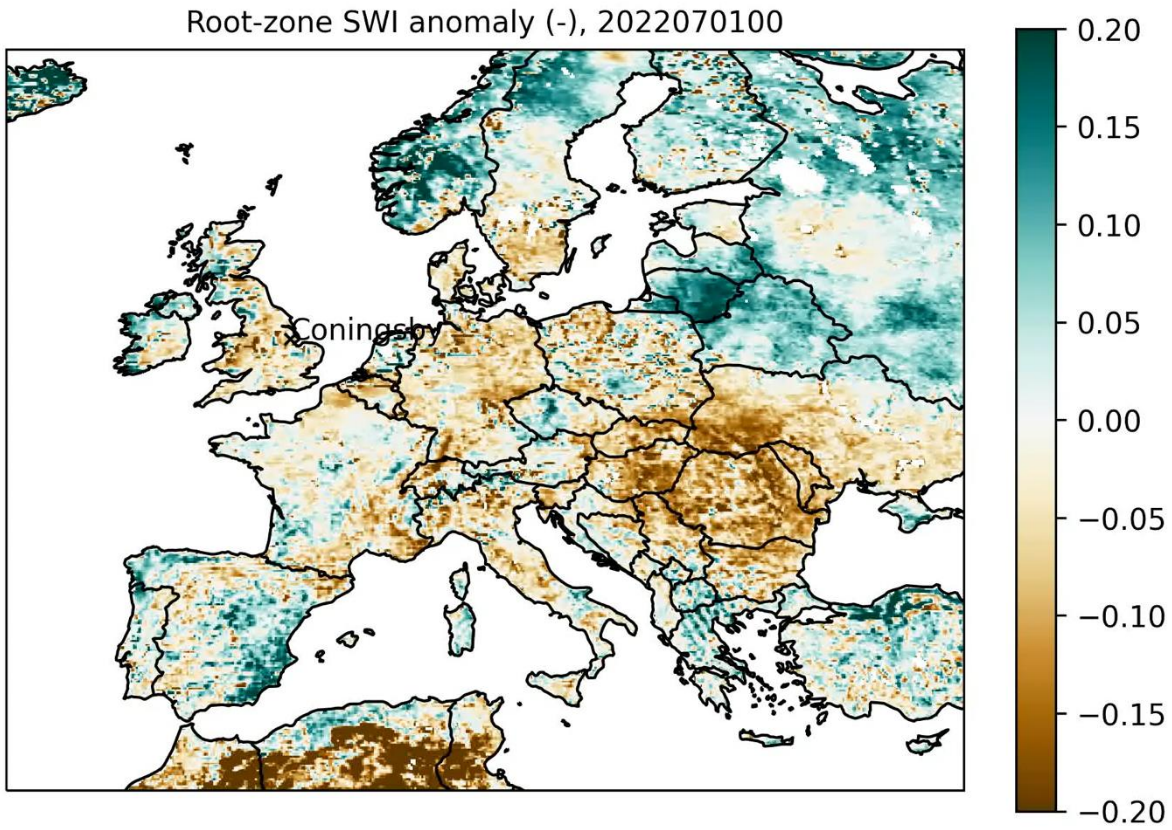
→ Retrieval of root zone soil moisture using satellite data relies on data assimilation

Hydrology SAF Root Zone Soil Moisture

Case study: Soil moisture anomalies during July 2022 drought

The EUMETSAT Network of Satellite Application Facilities | H SAF Support to Operational Hydrology and Water Management

David Fairbairn



Data assimilation used to propagate in space and time the ASCAT surface swath soil moisture information
→ Root Zone SM products

H26 anomaly (28-100 cm depth)
with respect to 1992-2021 H141/H142 July mean

- Fractional soil wetness index anomaly
- Extremely dry anomalies develop over most of Europe (<-15%)

H SAF: hsafcdop@meteoam.it

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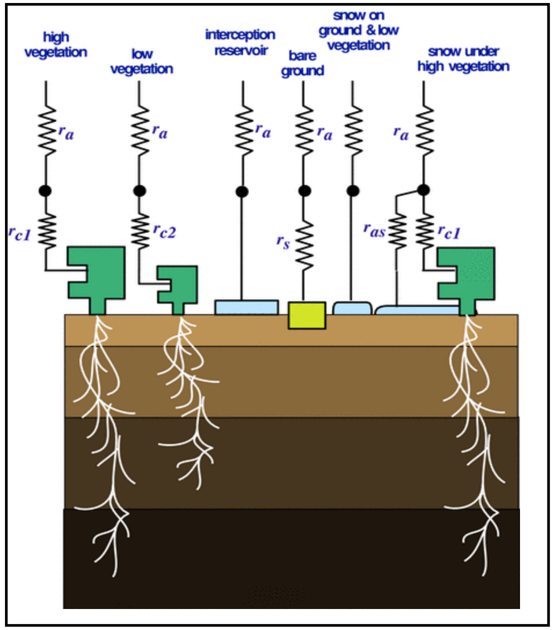
Surface soil moisture (SSM) data assimilation in the IFS

A **Simplified Extended Kalman Filter (SEKF)**
is used to corrects the soil moisture trajectory
of the Land Surface Model



SEKF: de Rosnay et al QJRMS 2013, Fairbairn et al JHM 2019

NWP Forecast
Coupled Land-Atmosphere

background

Soil Analysis (SEKF)
SM1, SM2, SM3

$\sigma^o{}_{T2m} = 1K$ $\quad \sigma^b = 0.02\ m^3m^{-3}$

$\sigma^o{}_{RH2m} = 4\%$ $\quad \sigma^o{}_{ASCAT} = 0.05\ m^3m^{-3}$

$\sigma^o{}_{SMOS} = 0.02 + a\ SM\_ERR\ m^3m^{-3}$

Initial Conditions

Observations

T_2m RH_2m
ASCAT SM
SMOS SM

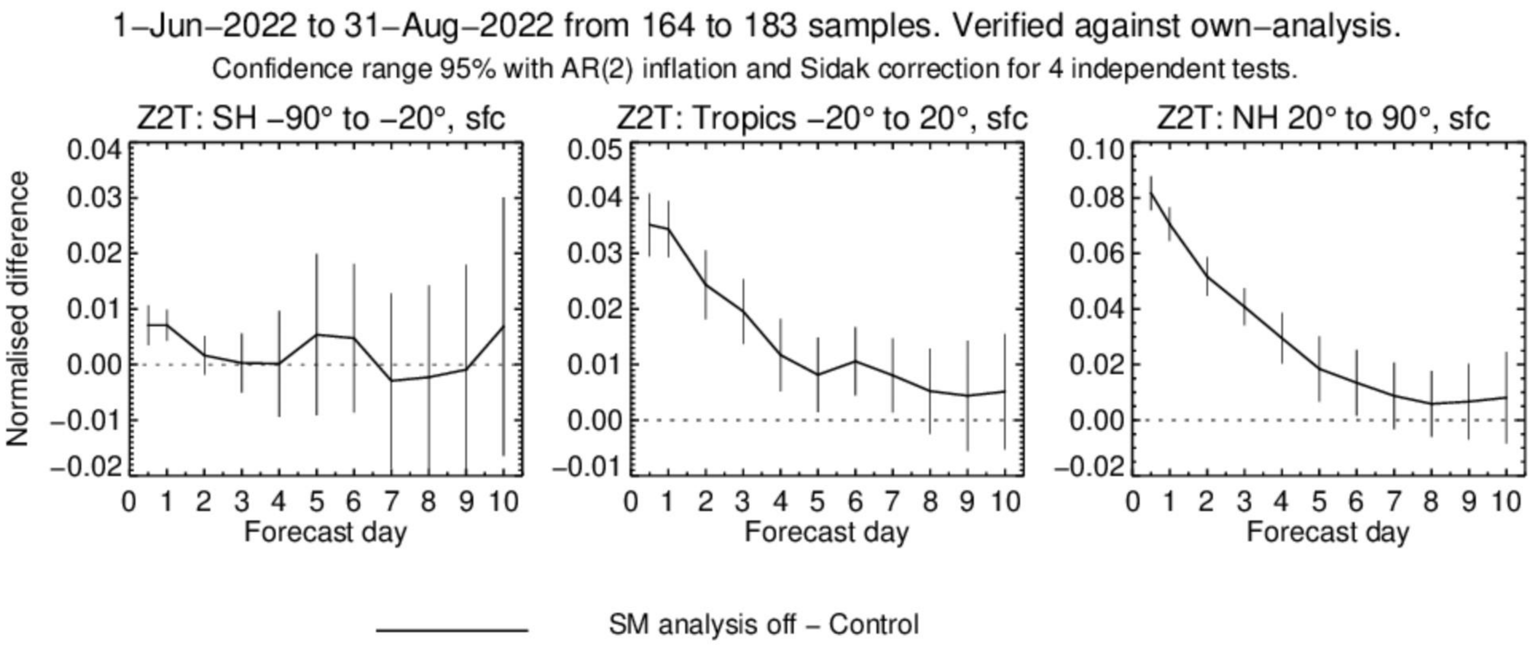
SMOS ECMWF XGBoost
SMOS L1 NRT TB → **SMOS SSM**

ASCAT level 2 surface Soil Wetness index
→ Rescaling to SSM

Soil moisture analysis impact on the atmospheric forecast

T2m RMSE

JJA 2022
IFS cycle 49r1

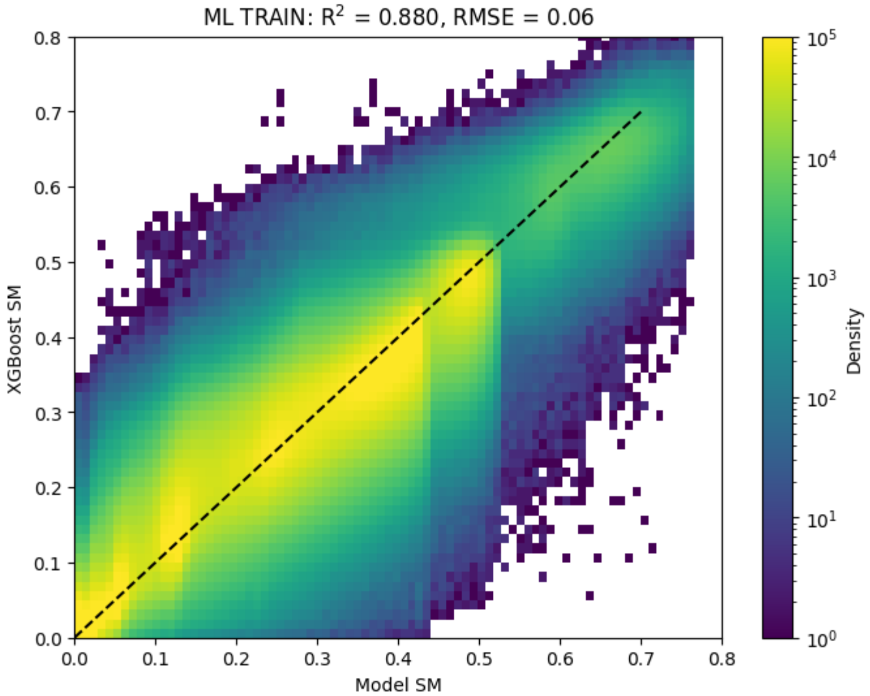


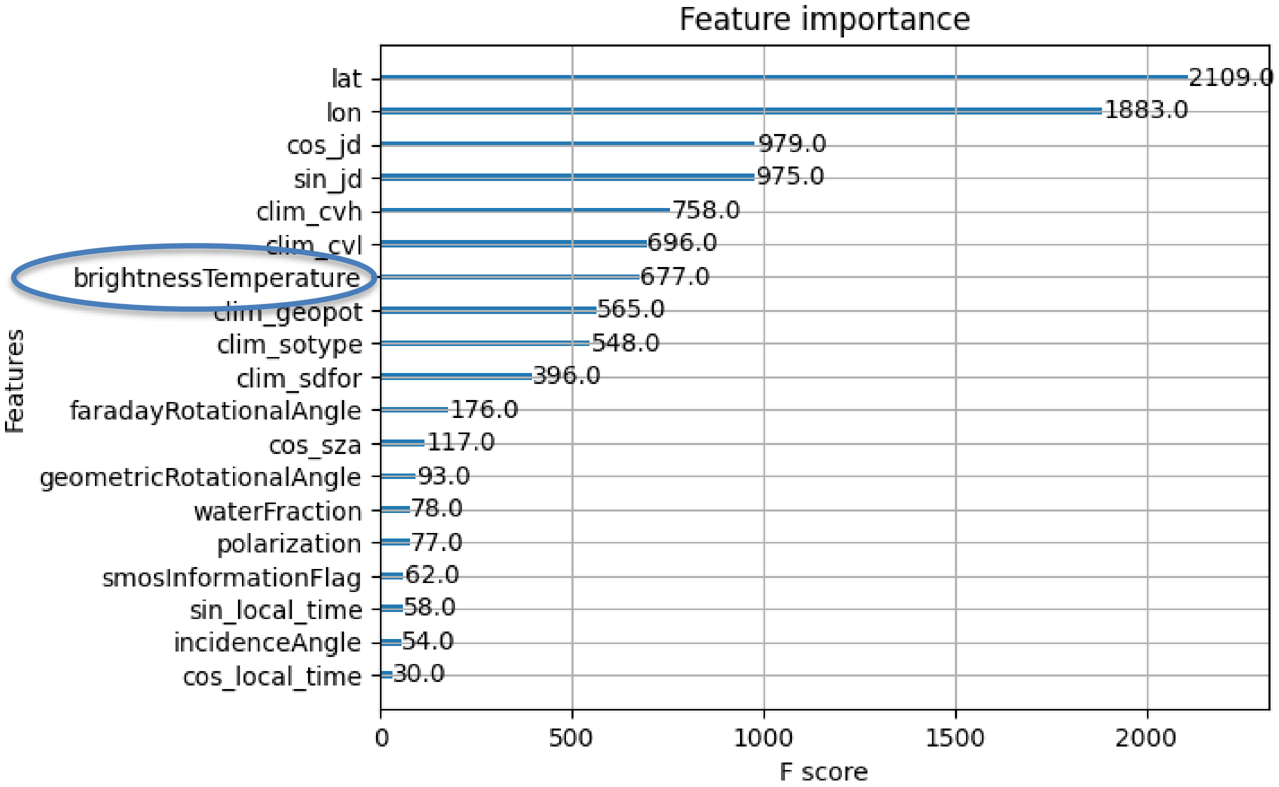
Degradation when no SM DA

→ **Significant positive impact of soil moisture (SM) data assimilation (DA) on low level atmospheric temperature forecasts**

SMOS soil moisture for data assimilation: retrieval using XGBoost

- Retrieval: using SMOS TB as feature and soil moisture as target based on ECMWF soil moisture
- Including the time related features improves the correlation and decreases the RMSE

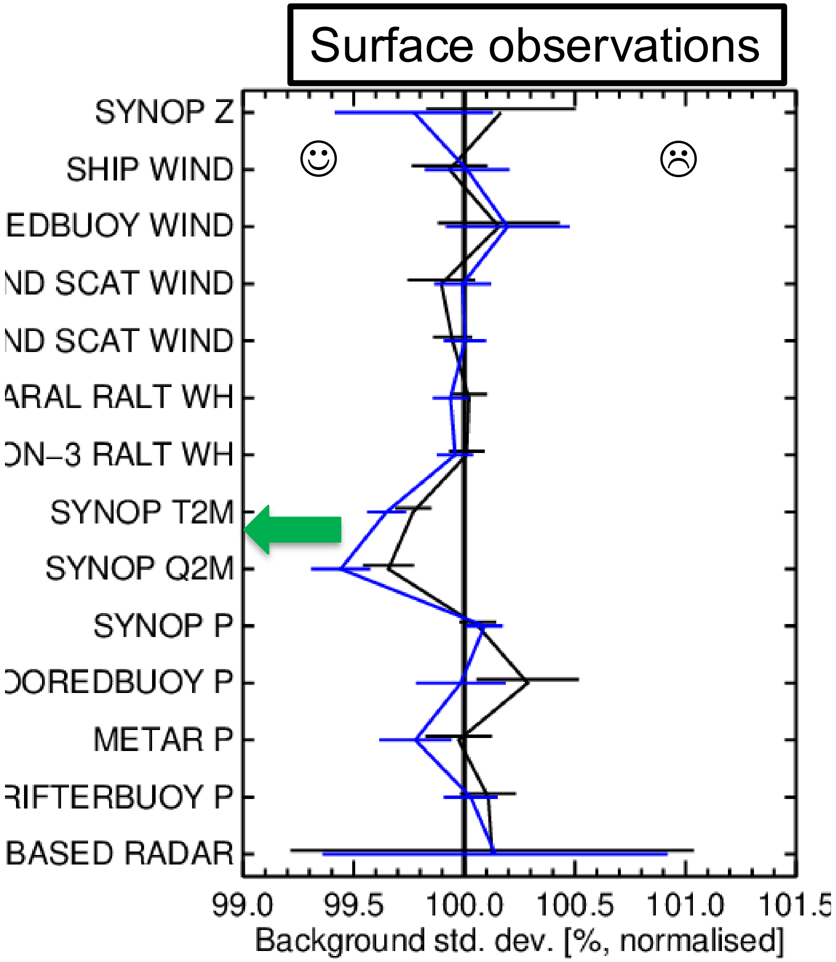


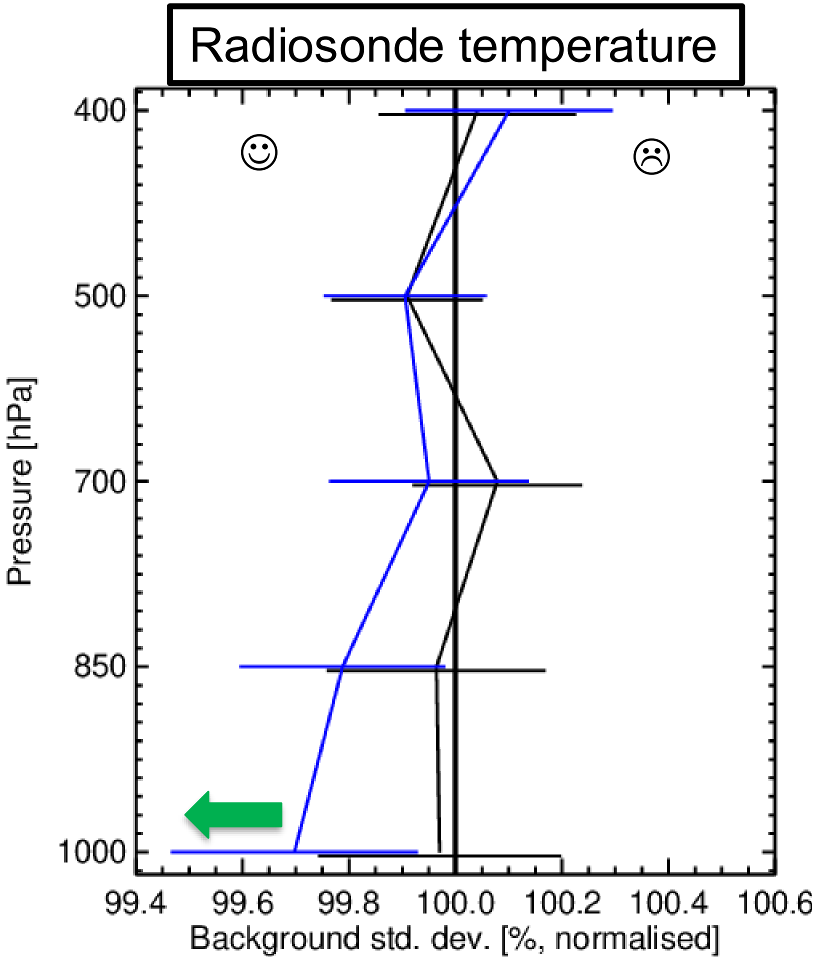


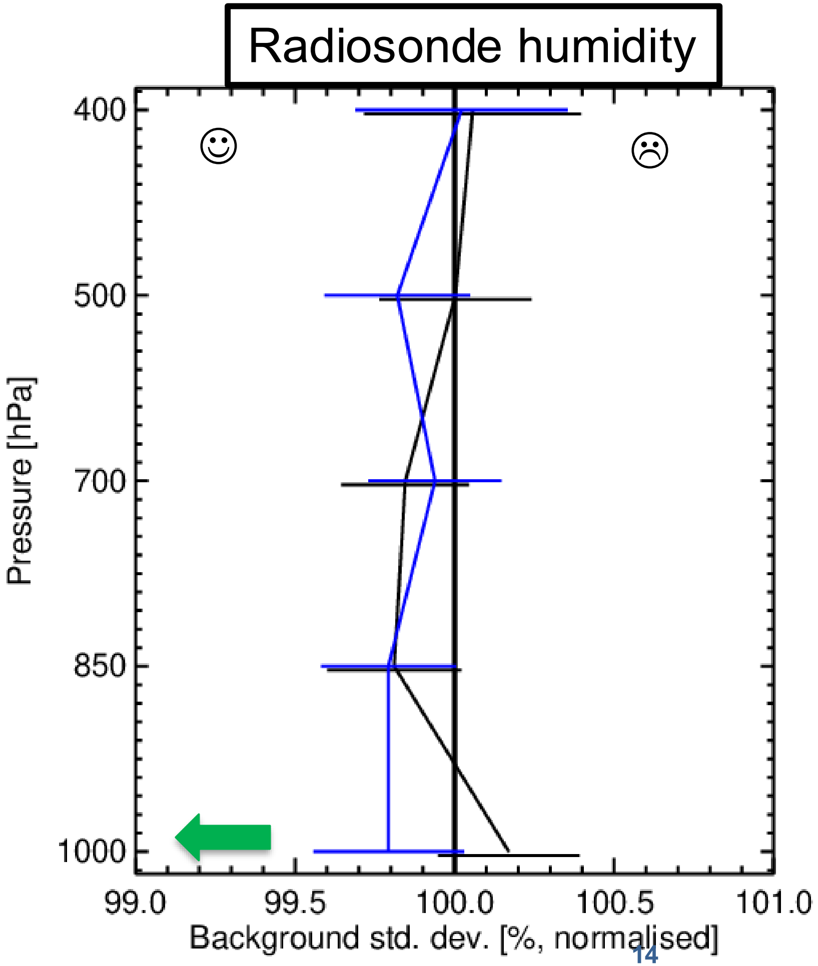
Kirsti Salonen

SMOS data assimilation impact

- Comparing random forest (XGBoost, used since 2025) and Neural Network (2019-2025) SMOS DA
- **SMOS soil moisture DA has positive near surface impact when compared to no SMOS DA (100% line).**
- The positive impact of SMOS DA is stronger with **XGBoost** than **NN** SMOS soil moisture in 49r1.







Passive and MW observation operators

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

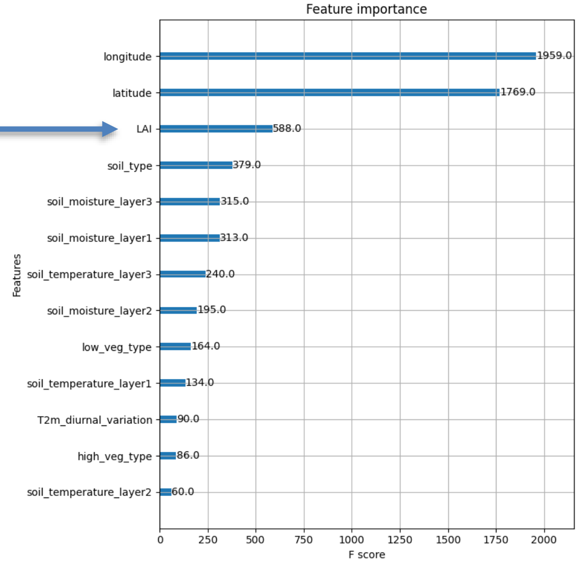
→ Development of Machine Learning (ML)-based observation operators

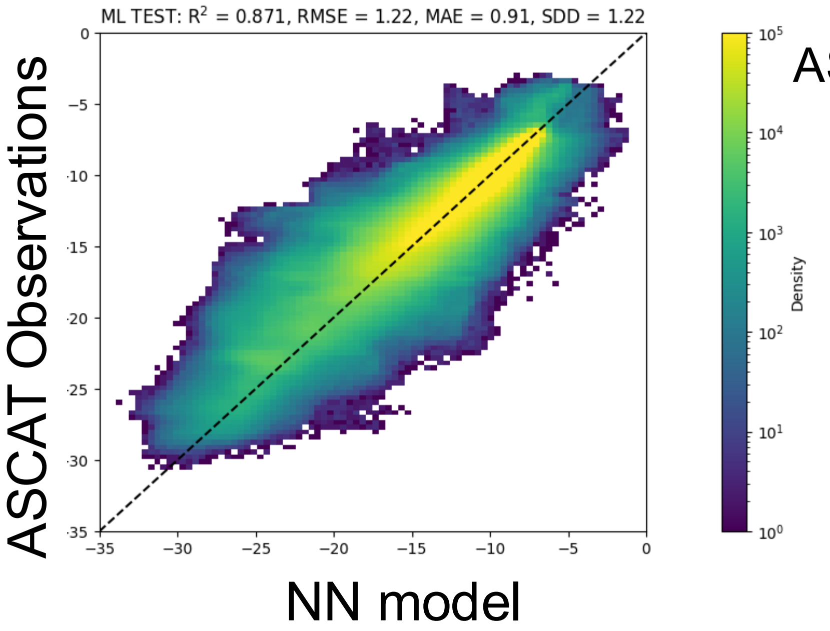
CORSO
CO2MVS Research on Supplementary Observations

Funded by the European Union

Information content analysis

LAI: Leaf Area Index





ASCAT backscatter over land

Sébastien Garrigues

→ Ongoing implementation in the IFS

→ Prepares 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

ECMWF

The CORSO project (grant agreement No101082194) is funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the Commission. Neither the European Union nor the granting authority can be held responsible for them.

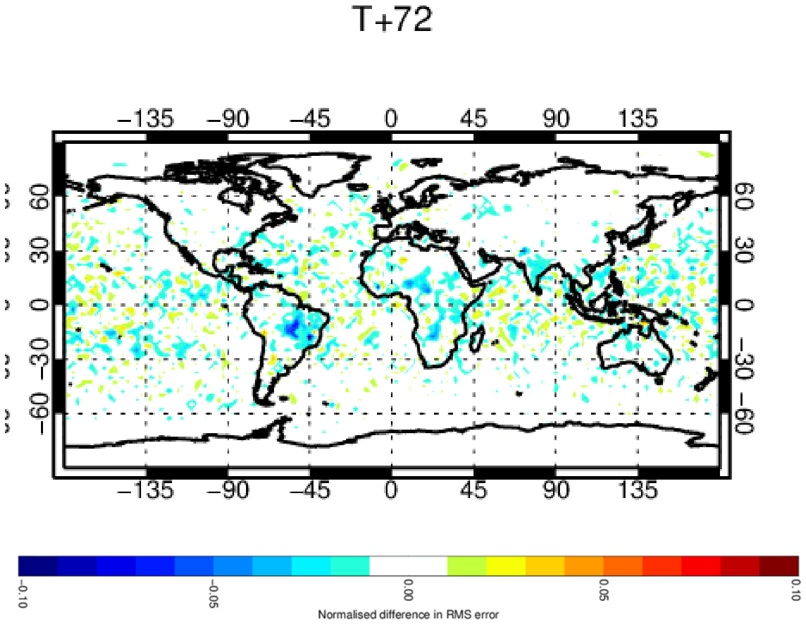
SMOS Vegetation Optical depth (VOD) assimilation

Assimilation of 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

Prototype system for a Copernicus CO_2 service

Funded by the European Union



T2m RMSE reduction (blue) 2018-2021

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

Pete Weston et al

Calvet et al.: Demonstrator systems for using remote sensing data (LAI, VOD, SIF) in online global prior fluxes for the CO2MVS prototype", CoCO2 H2020 project D3.4, June 2023, https://coco2-project.eu/sites/default/files/2023-11/CoCO2-D3-4-V2-1.pdf

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LAI analysis using Solar Induced Fluorescence (SIF)

CORSO
CO2MVS Research on Supplementary Observations

Funded by the European Union

https://doi.org/10.5194/essd-13-5423-2021

Data description paper |

The TROPOSIF glob
dataset from the S

Luis Guanter, Cédric Bacour, Andre
Christian Retscher, Philipp Köhler, Chi

Article | Assets | Peer review | Metrics | Related articles

nature > scientific data > data descriptors > article

Data Descriptor | Open access | Published: 20 July 2022

A long-term reconstructed TROPOMI solar-induced fluorescence dataset using machine learning algorithms

Xingan Chen, Yuefei Huang, Chong Nie, Shuo Zhang, Guangqian Wang, Shiliu Chen & Zhichao Chen

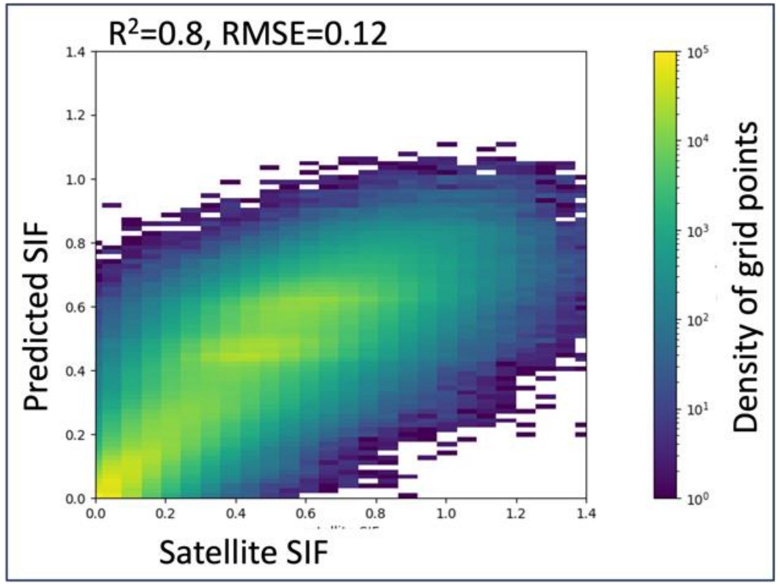
SIF: electromagnetic signal emitted by the chlorophyll of assimilating plants

→ part of the energy absorbed by chlorophyll is not used for photosynthesis but emitted at longer wavelengths in the near infrared

→ Relevant to analyse vegetation LAI and Gross Primary Production

TROPOMI SIF 743-758 nm

Exploratory work to use SIF at ECMWF. Observation operator development



Sébastien Garrigues et al., QJRMS 2026

ECMWF

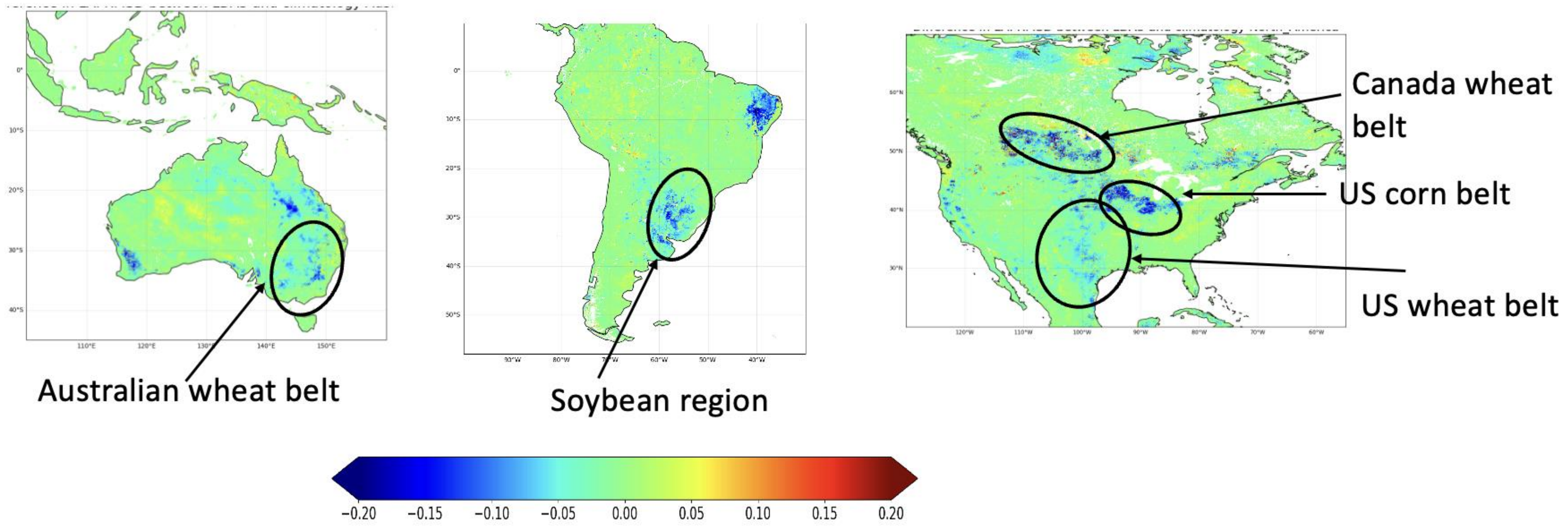
LAI analysis using Solar Induced Fluorescence (SIF)

CORSO
CO2MVS Research on Supplementary Observations

Funded by the European Union

Impact of SIF DA shown as LAI RMSD differences with vs without SIF data assimilation against satellite (Copernicus Land) LAI for 2022

Improvement for cropland



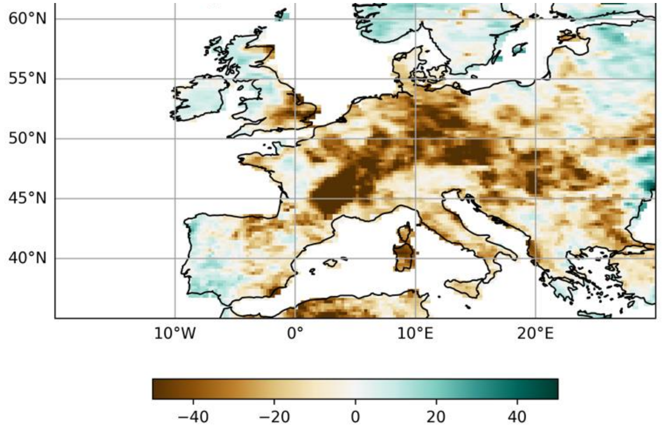
ECMWF

Time varying vegetation for land reanalysis

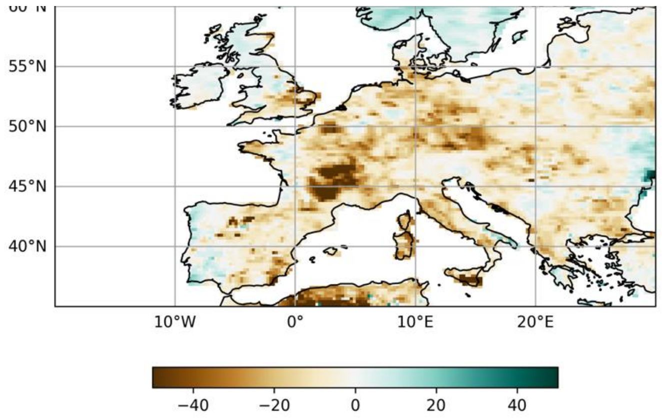
European 2003 heatwave – LAI/Land Cover impact

David Fairbairn et al.

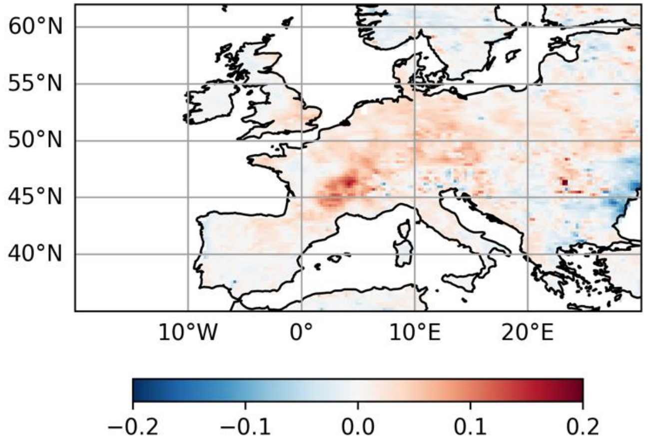
Low veg LAI anomaly (%), July 2003



High veg LAI anomaly (%), July 2003



T2m sensitivity (K)



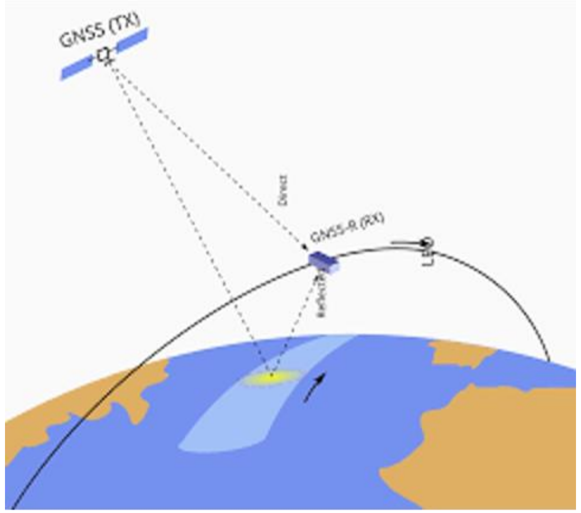
Negative LAI anomaly (~-40%) relative to static maps over central/western Europe due to anomalously dry conditions during July 2003

→ Enhanced 12 UTC T2m anomaly with time-varying vegetation vs control (static climatological vegetation)

LAI: based on Copernicus Global Land Monitoring Service
→ SPOT (1999-2013) and PROBAV (2014-2019) harmonized with the AVHRR-based data (1993-1999) (https://confess-h2020.eu/2021/08/18/vegetation-dataset-of-land-use-land-cover-and-leaf-area-index/) Souhail Boussetta

The CERISE project (grant agreement No101082139) is funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the Commission. Neither the European Union nor the granting authority can be held responsible for them.

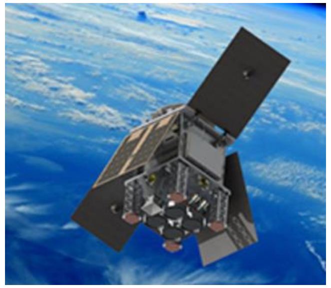
Investigate GNSS-R observation usage over land surface



- GNSS (Global Navigation Satellite System) systems include GPS (Global Positioning System), Galileo (European GNSS system, GLONASS (Russian system), BeiDou (Chinese system)

- GNSS-R (Reflectometry) gets information from the signal reflected at the surface, e.g from the CYGNSS constellation and HydroGNSS ESA scout mission

HydroGNSS
Launched Nov 2025



→ Potential of GNSS-R DA over land for NWP and reanalysis

Eleni Kalogeraki, Jana Kolassa

Snow in the ECMWF IFS for NWP

Snow Model: Component of the ECMWF land surface model H-TESSEL (Balsamo et al, JHM 2009)

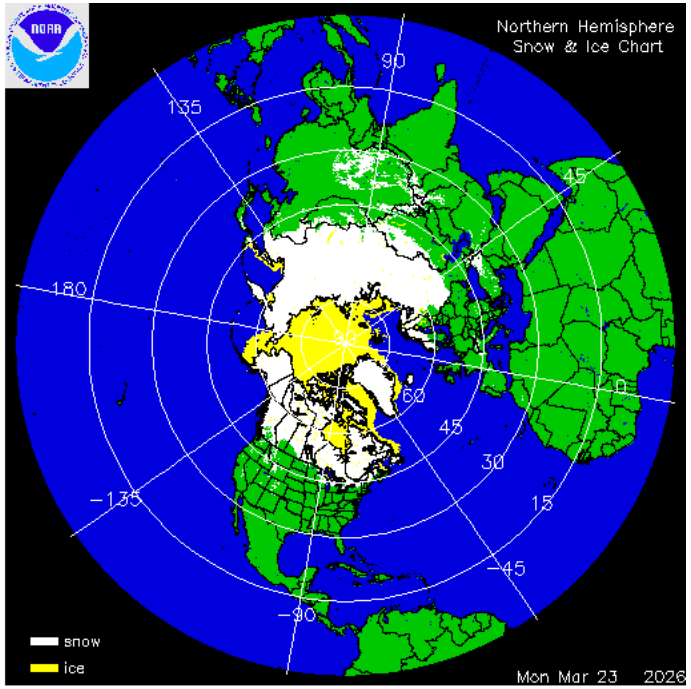
- Single layer snowpack until 2023 (Dutra et al, JHM 2010),
- Multi-layer snowpack from June 2023 (Arduini et al., James 2019)

Observations: **de Rosnay et al ECMWF Newsletter 2015**

- Snow depth in situ data: SYNOP and National networks
- Snow cover extent: NOAA NESDIS/IMS daily product (4km)
  (Used only at altitude lower than 1500m)

Data Assimilation: **de Rosnay et al SG 2014**

- **Optimal Interpolation (OI)** → optimally combine the model and obs
- The result of the data assimilation is the analysis



https://usicecenter.gov/Products/ImsCharts

IMS: Interactive Multisensor Snow and Ice Mapping System

→ **Initialize NWP**

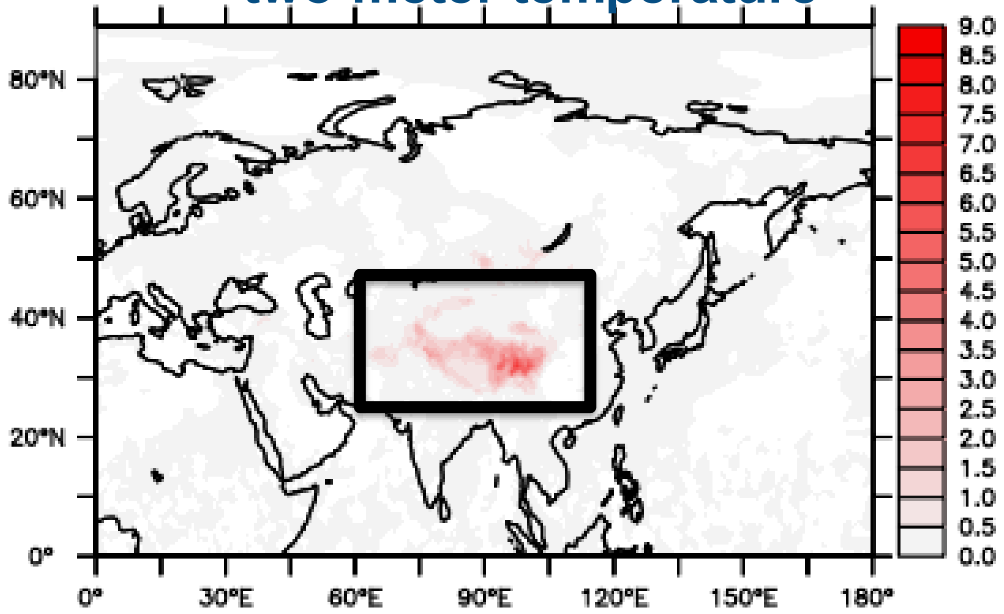
ECMWF

Impact of snow cover assimilation on the Tibetan plateau

Snow cover assimilation removes snow
→ More realistic snow compared to in situ data
→ warmer surface conditions than CTRL

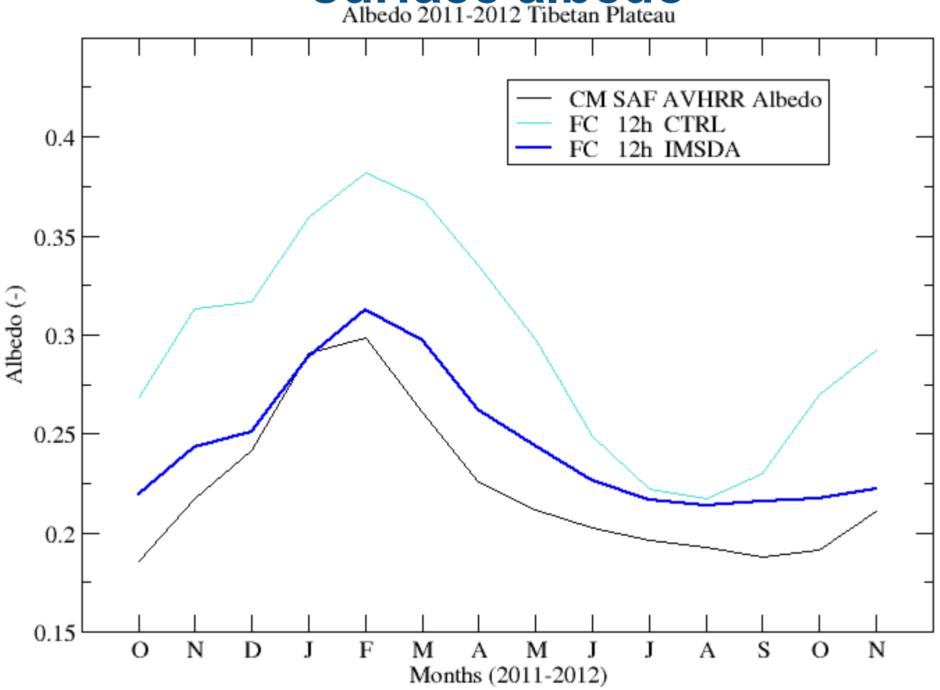
Less snow → lower surface albedo

two-meter temperature



T2m diff (Snow cover DA-CTRL) (K)
Forecast day-10
Oct 2011-Sept 2012

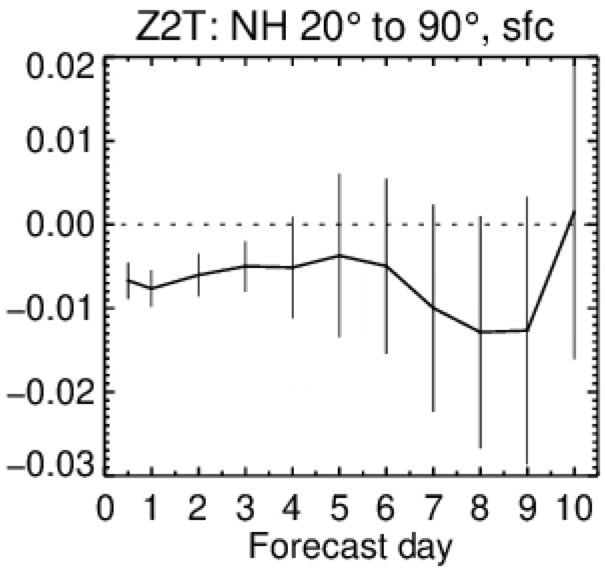
surface albedo



Use Climate Monitoring SAF CLARA-2 albedo product (Karlsson et al. 2017)

Recent updates and plans for future implementation

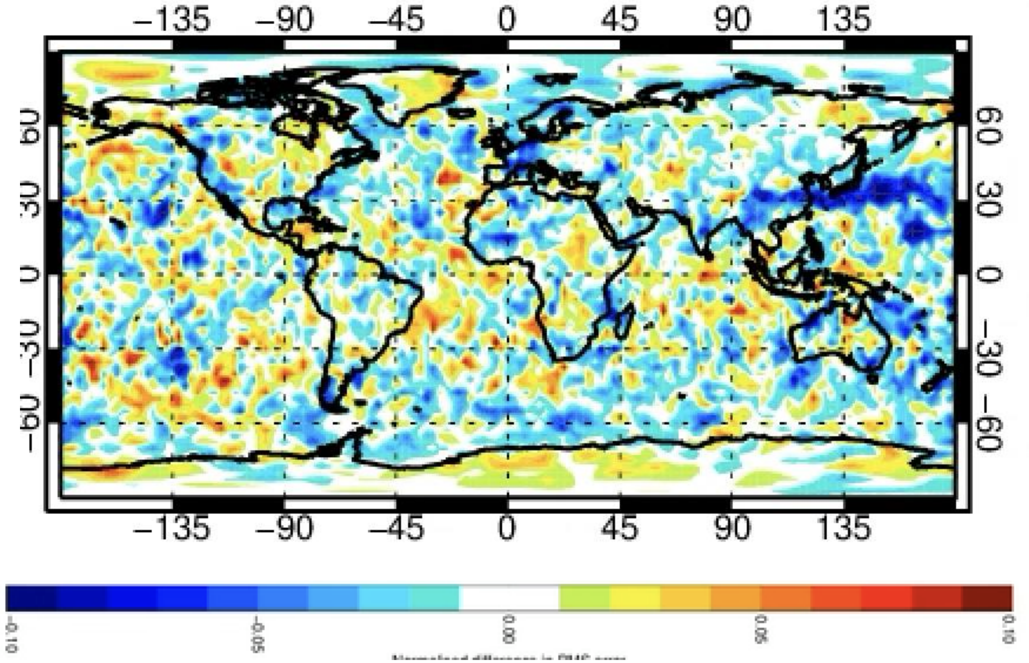
Future improvements (e.g. multi-layer snow model) lead to enhanced consistency between snow and boundary layer processes.
→ Impact of IMS snow cover assimilation in mountainous areas using improved system give promising results



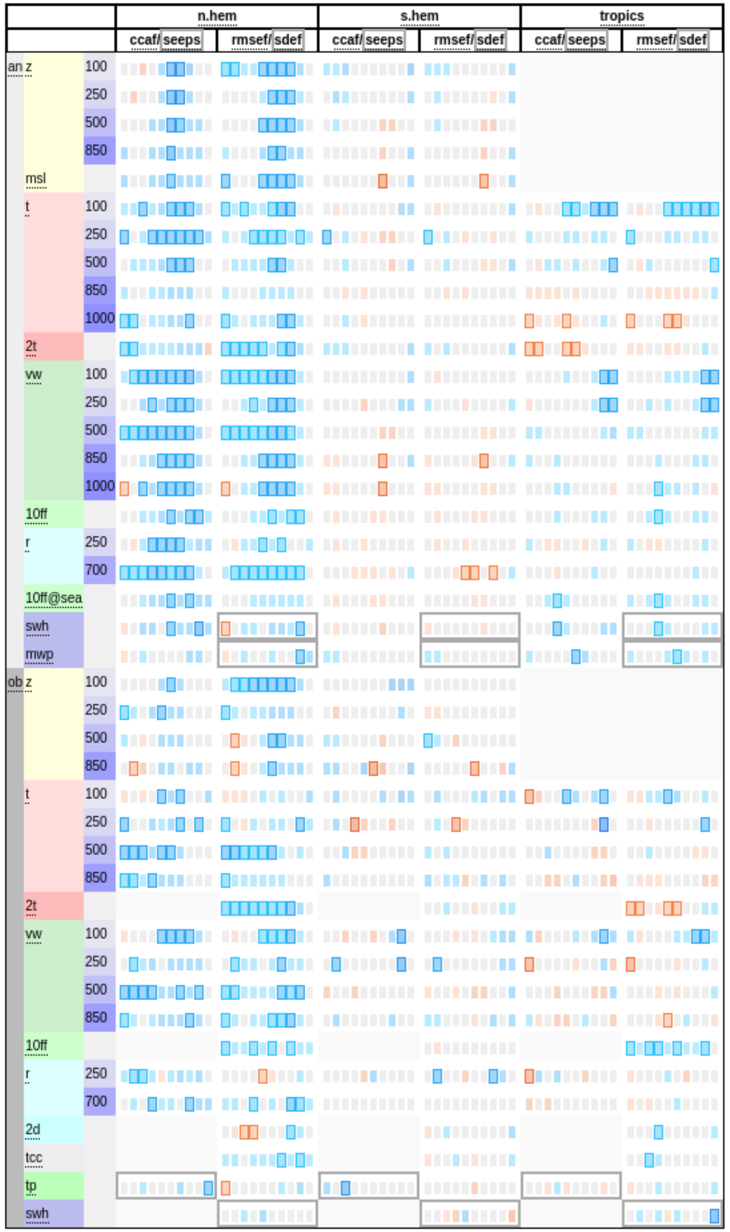
Surface air temperature improvement

T+72; 500hPa

Vector wind error reduction



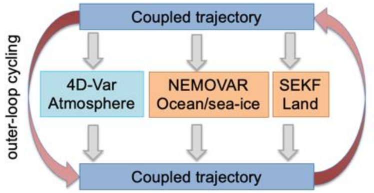
Scorecard →
(blue= improved
red=degraded)

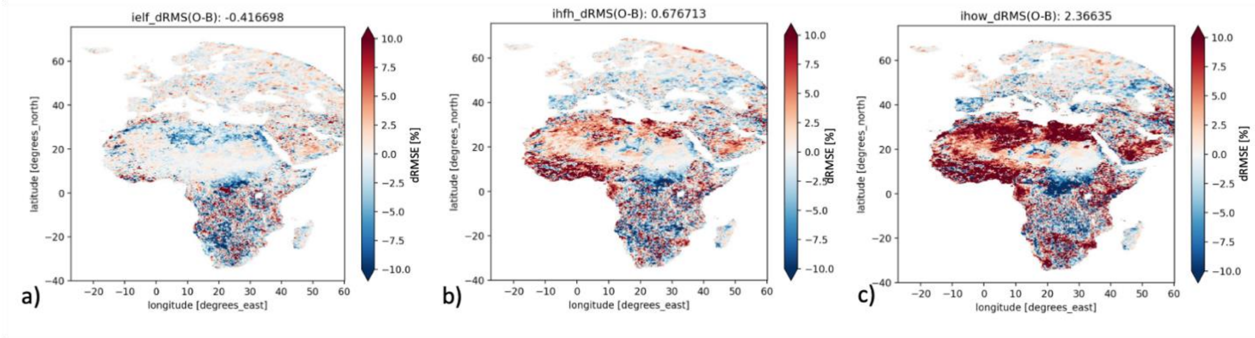


Kenta Ochi

Usage of Land Surface Temperature (LST) data

- **To validate and support coupled data assimilation developments**
- **Ongoing developments of Land Surface Temperature data assimilation in coupled data assimilation**





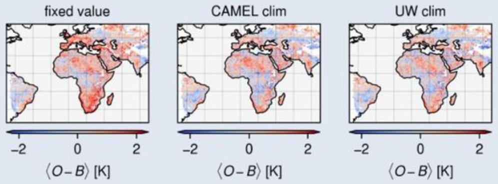
RMSE of ECMWF LST vs SEVIRI Land Surface SAF MSG LST (DJF 2022-2023) for different coupled DA configurations

Christoph Herbert, Zdenko Heyvaert

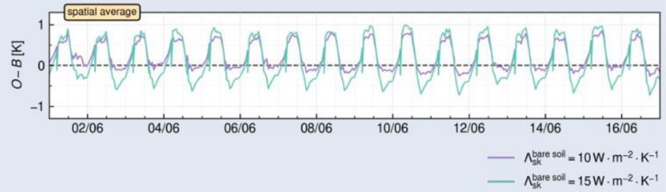
Coupled system

Extend forward modelling capabilities

- Blocklist adapted: no masking of **SEVIRI channel 9** over land
- Sensitivity of **first guess departures** to:
  1. Land surface emissivity: different atlases were compared



  2. Bare soil skin thermal conductivity: impact on diurnal cycle



- Explored role of the dust filter on departures
- Next step: add SKT sink variable to the SEKF

ECMWF

Summary

- ECMWF soil moisture and snow based on data assimilation of in situ observations and satellite data (ASCAT, SMOS, snow cover), for NWP and reanalysis ERA5 & upcoming ERA6
- Strong impact of soil and snow analyses on NWP
- ECMWF SMOS soil moisture assimilated for NWP: Neural network 2019-2024, XGBoost 2025-
- EUMETSAT H SAF ASCAT root zone products: NRT and Climate data record
- Impact of LAI analysis to constrain water and carbon cycle variables
- Ongoing developments to enhance interface observations DA: microwave data, Land surface temperature, Solar-Induced Fluorescence, GNSS-R, LST
- Also preparing future missions (e.g. CIMR, LSTM)
- Longer term: Assimilation of integrated hydrological variables such as river discharge.