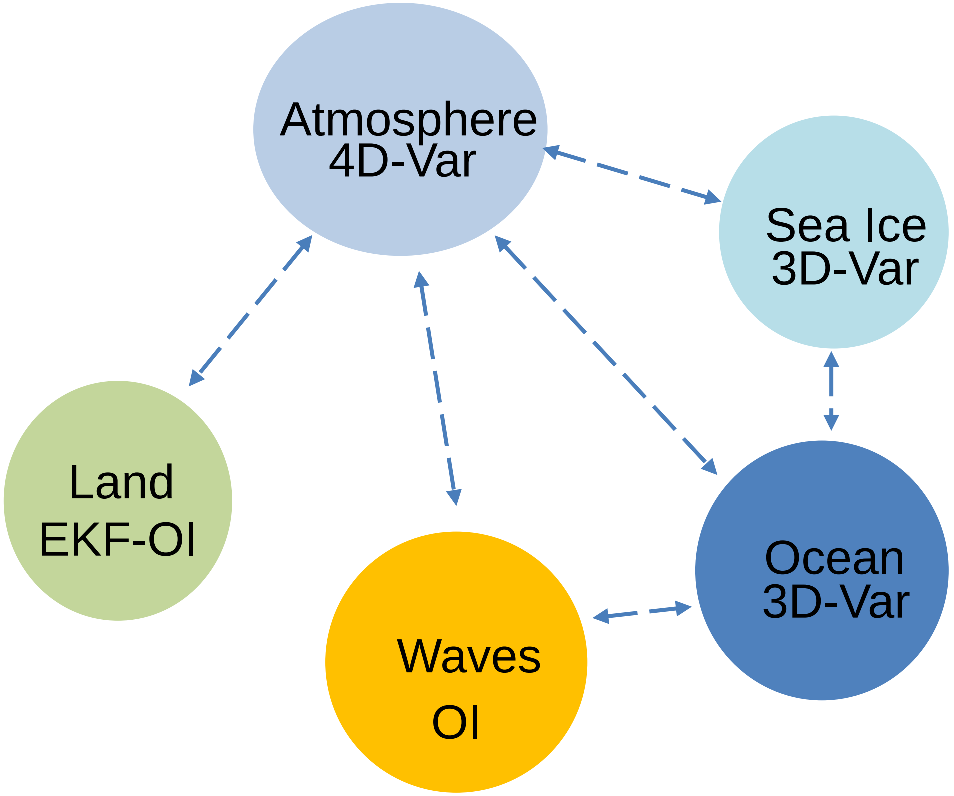
Overview of coupled land-atmosphere data assimilation at ECMWF

Patricia de Rosnay, David Fairbairn, Pete Weston, Yoichi Hirahara,
Phil Browne, Kenta Ochi, Dinand Schepers, Stephen English,
and many other colleagues

Toward coupled assimilation in ECMWF's operational systems



Integrated Forecasting System (IFS)

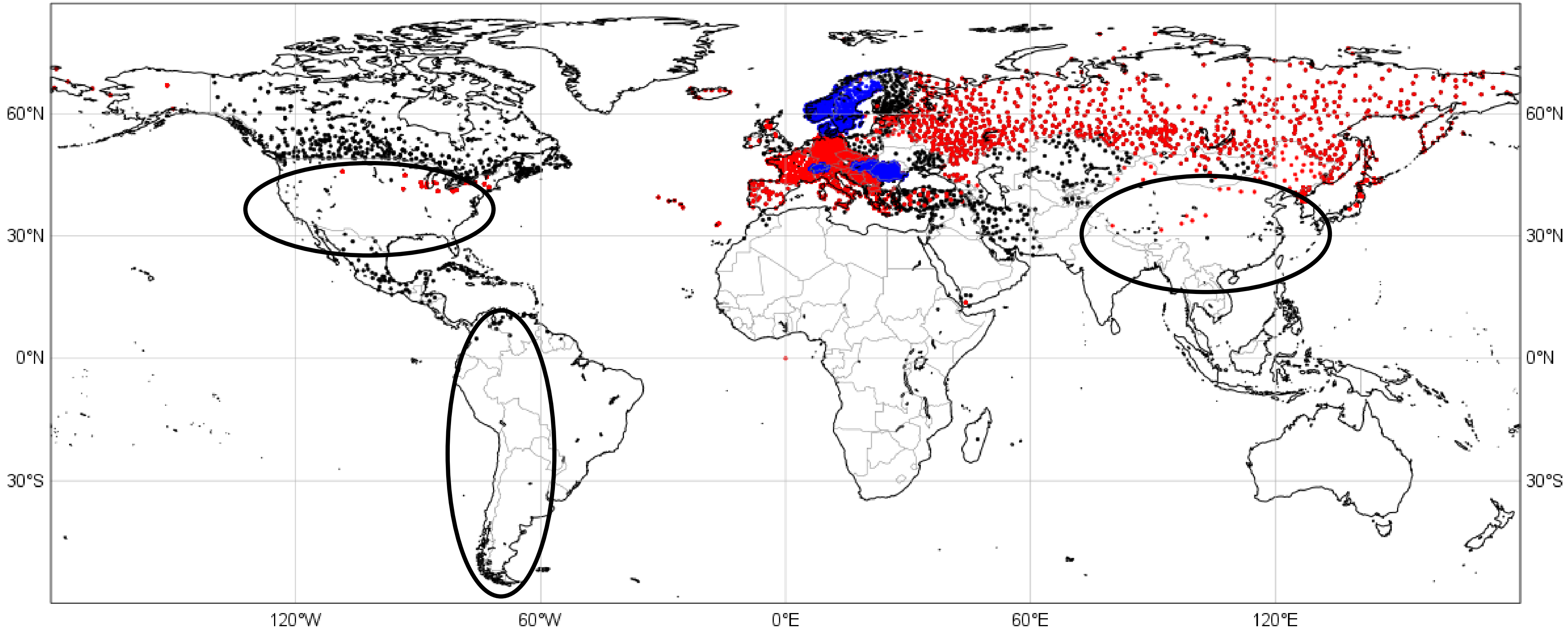
- Modularity to account for the different components in coupled assimilation
- Consistency of the coupling approaches across the different components of the Earth System
- Common infrastructure for ocean, sea ice, wave, land, atmosphere, for NWP and reanalysis

In situ snow depth observations

GTS Snow depth availability

SYNOP TAC SYNOP BUFR national BUFR data

15 January 2015



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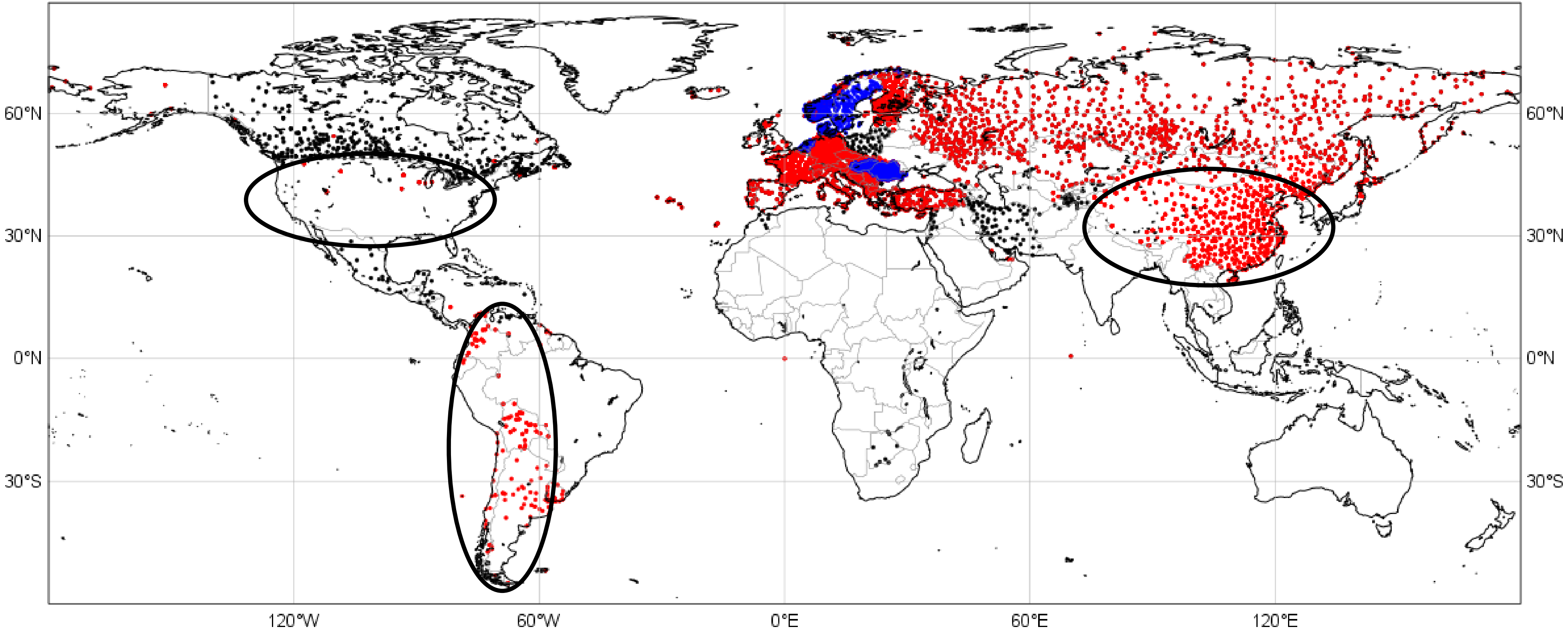
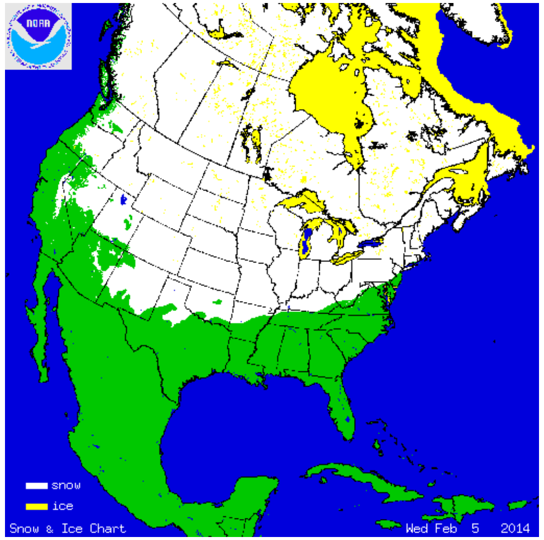


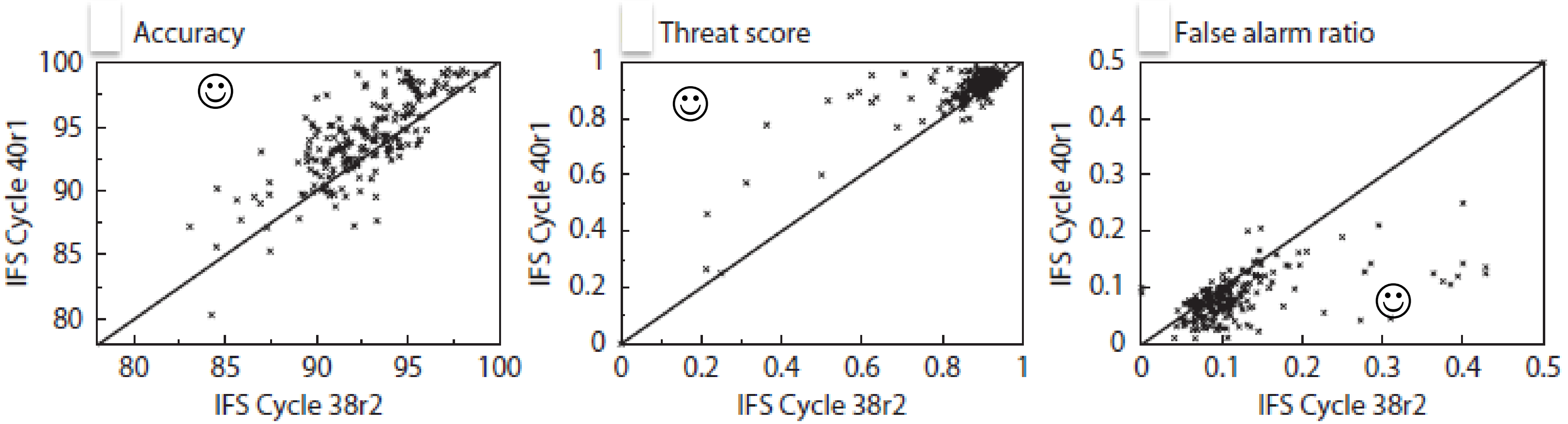
2021: Expected improvement in the US (NOAA)

Snow analysis: 2D-OI Forecast impact

NOAA/NESDIS IMS data

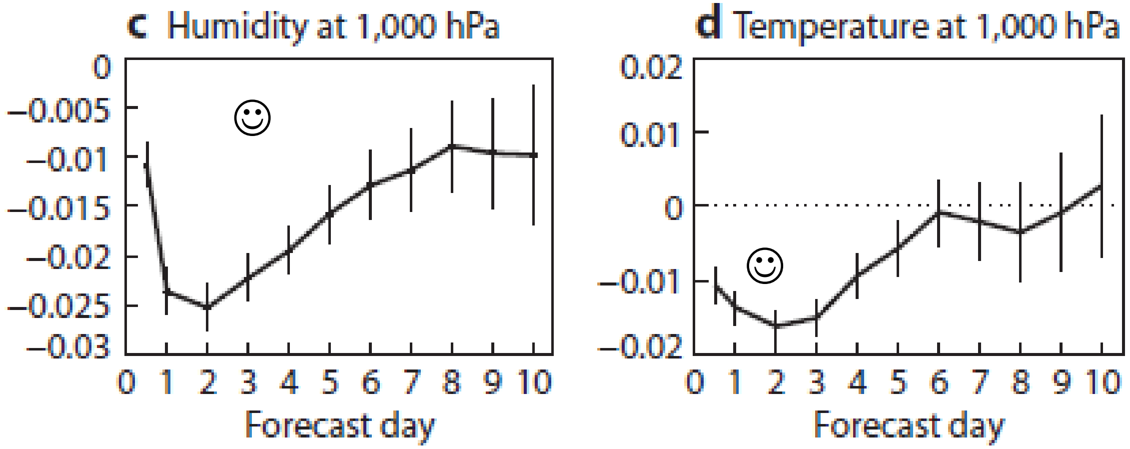


Impact on snow October 2012 to April 2013 (251 independent *in situ* observations)



Impact on atmospheric forecasts

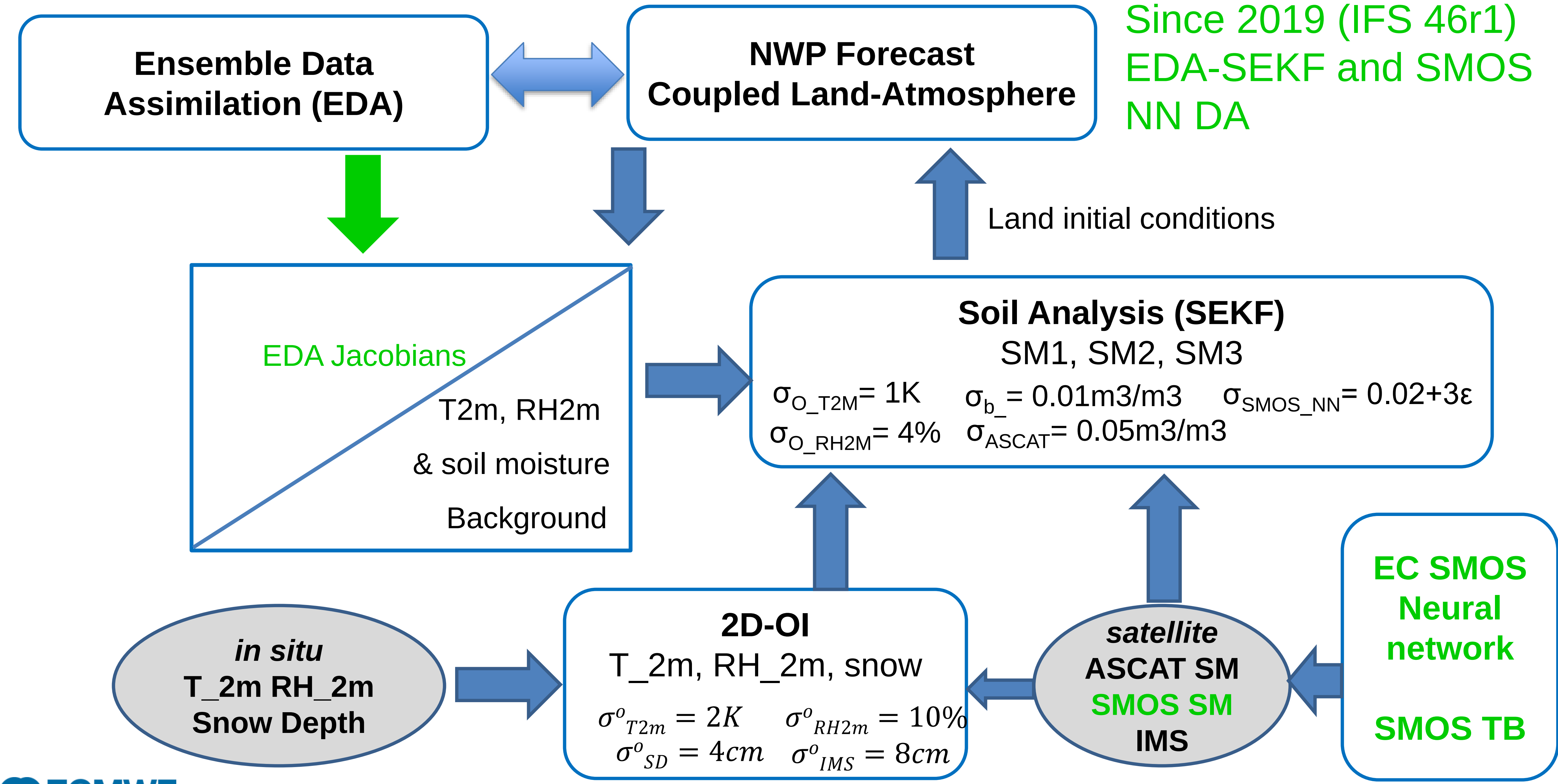
October 2012 to April 2013 (RMSE new-old)



→ Consistent improvement of snow and atmospheric forecasts
→ Importance of snow cover observations

de Rosnay et al., ECMWF newsletter 143, Spring 2015

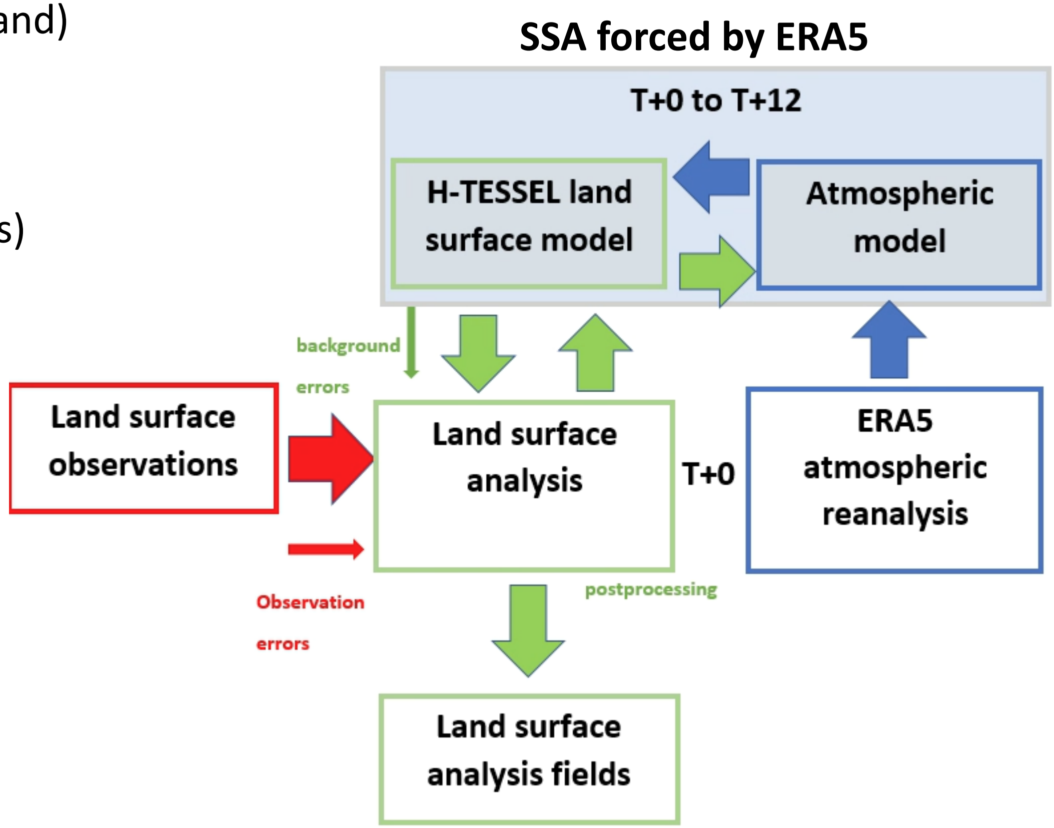
Soil Moisture coupled data assimilation



Stand-alone Surface Analysis and offline systems → Support land surface reanalysis

Three options:

1. Offline surface model forced by atmospheric reanalysis (e.g. ERA5-land)
   - ☺ Allows enhanced surface model/resolution
   - ☹ No land-atmosphere coupling and no land DA
2. Offline soil moisture DA (e.g. H SAF ASCAT soil moisture data records)
   - ☺ As (1), but offline soil moisture analysis included
3. Stand-alone surface analysis (SSA, Fairbairn *et al*., 2019)
   - ☺ Full land DA system in IFS (soil moisture, snow, etc…)
   - ☺ Coupled land-atmosphere model
   - ☹ Significantly more computationally expensive than (1) and (2)

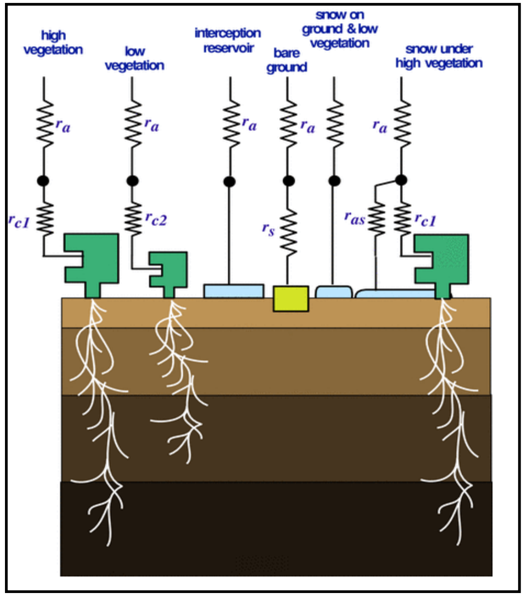


D. Fairbairn, P. de Ronsay, and P. Browne, "The new stand-alone surface analysis at ECMWF: Implications for land-atmosphere DA coupling," *J. Hydrometeor*, 2019. https://doi.org/10.1175/JHM-D-19-0074.1

Simplifed EKF soil moisture analysis

$$x_a = x_b + K\,(y - \mathcal{H}[x_b])$$

de Rosnay et al., QJRMS, 2013



Elements of the SEKF for each individual grid point in the case of:

- Assimilation of 4 observations: T2m, RH2m, $ASCAT_{sm}$, $SMOS_{sm}$
- State vector **x**: volumetric soil moisture (SM) of the model layers, L1, L2, L3 (in m3/m3)

Control vector

$$\mathbf{x}b_{(t)} = \begin{bmatrix} SM_{L1(t)} \\ SM_{L2(t)} \\ SM_{L3(t)} \end{bmatrix}$$

Observations vector

$$y_{(tobs)} = \begin{bmatrix} T_{2m} \\ RH_{2m} \\ ASCAT_{sm} \\ SMOS_{sm} \end{bmatrix} \quad \begin{matrix} [K] \\ [\%] \\ [m^3/m^3] \\ [m^3/m^3] \end{matrix}$$

Observations operator

$$\mathcal{H}[x_b^t]) = \begin{bmatrix} T_{2m} \\ RH_{2m} \\ SML_1 \\ SM_{L1} \end{bmatrix}$$

Observation error

$$R = \begin{pmatrix} 1^2 & 0 & 0 & 0 \\ 0 & 4^2 & 0 & 0 \\ 0 & 0 & 0.05^2 & 0 \\ 0 & 0 & 0 & (0.02 + 3smos\varepsilon)^2 \end{pmatrix}$$

Background error

$$P = \begin{pmatrix} 0.01^2 & 0 & 0 \\ 0 & 0.01^2 & 0 \\ 0 & 0 & 0.01^2 \end{pmatrix}$$

ECMWF

Soil moisture satellite observations used operationally

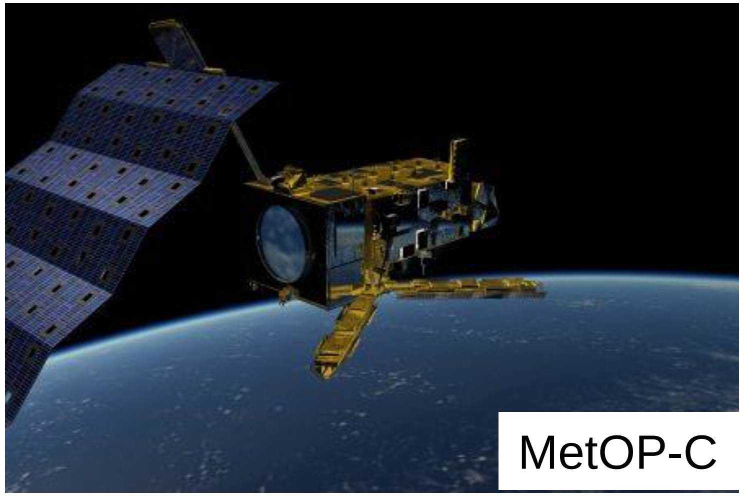
Active microwave data:

ASCAT: Advanced Scatterometer

On MetOP-A (2006-), MetOP-B (2012-), MetOP-C (2018-)

C-band (5.6GHz) backscattering coefficient

EUMETSAT Operational mission



MetOP-C

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

Passive microwave data:

SMOS: Soil Moisture & Ocean Salinity (2009-)

L-band (1.4 GHz) Brightness Temperature

ESA Earth Explorer, dedicated soil moisture mission

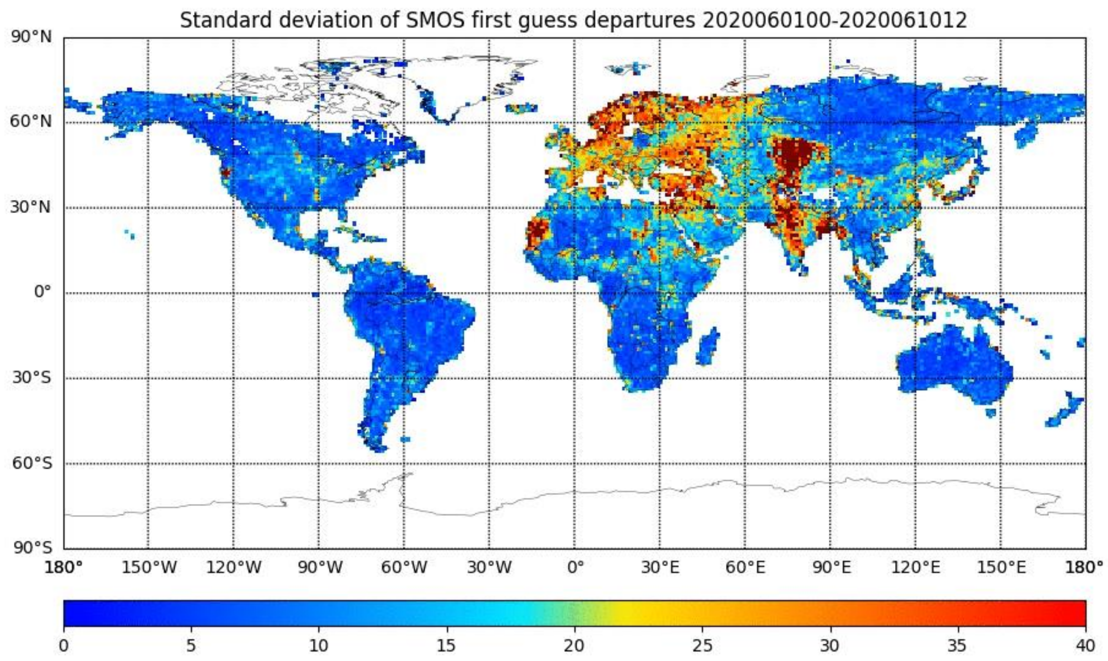
(Munoz-Sabater et al., GRSL, 2012)

SMOS

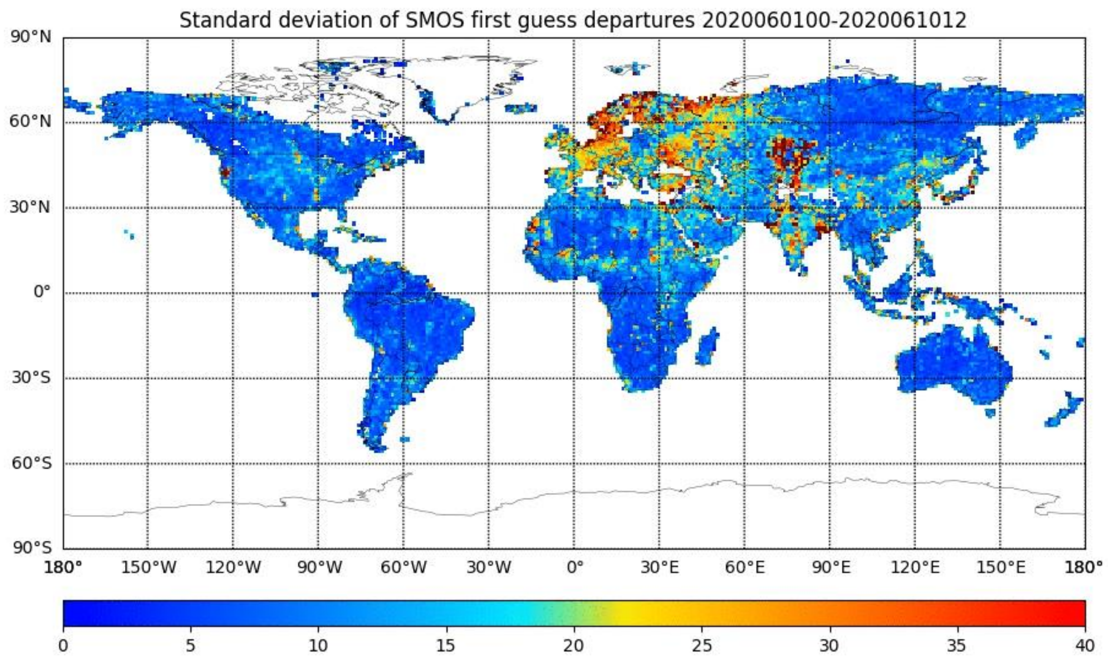
SMOS near real time brightness temperature monitoring

- In early July we detected a large area of RFI (Radio Frequency Interference) contamination over South-East China
- The new screening does a better job of filtering it out but still not perfect
  - Hence the need for further improvements in RFI filtering flags

Basic RFI screening

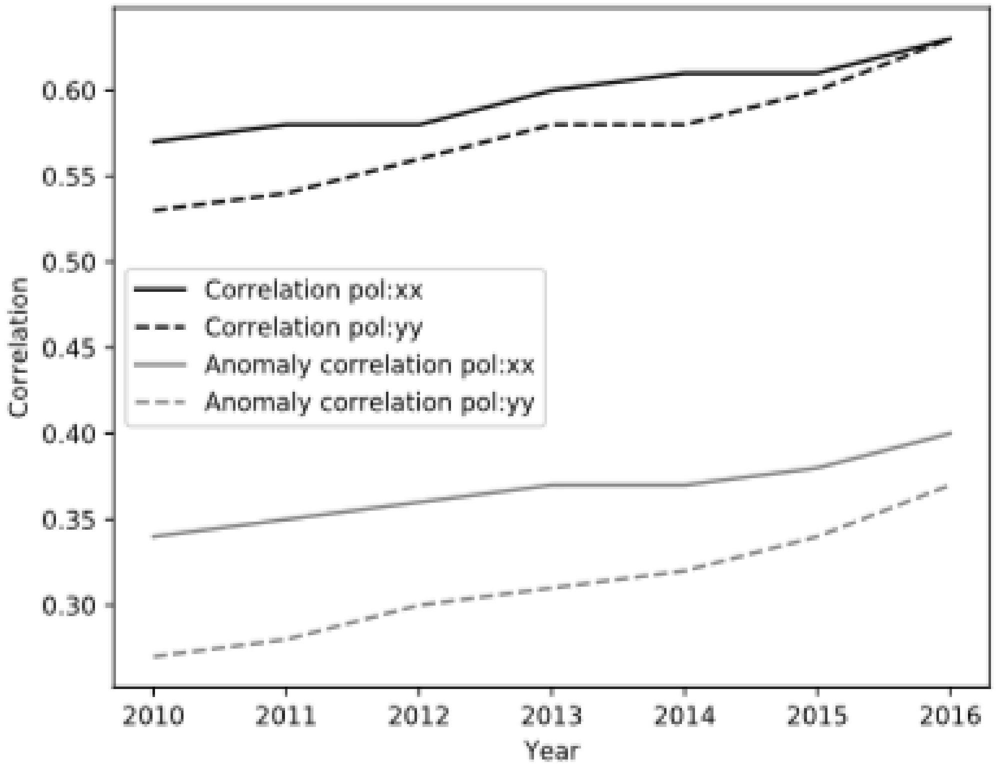


Stronger RFI screening

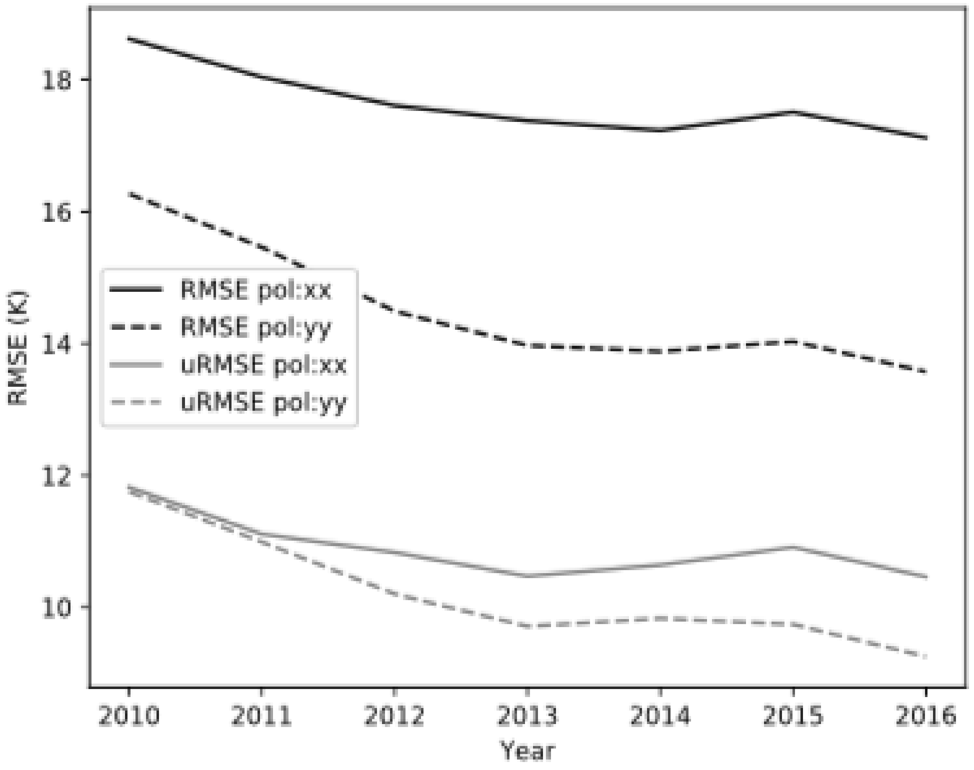


Slide from Pete Weston

Comparison between SMOS and ECMWF forward TB for 2010-2016



(a) Correlation

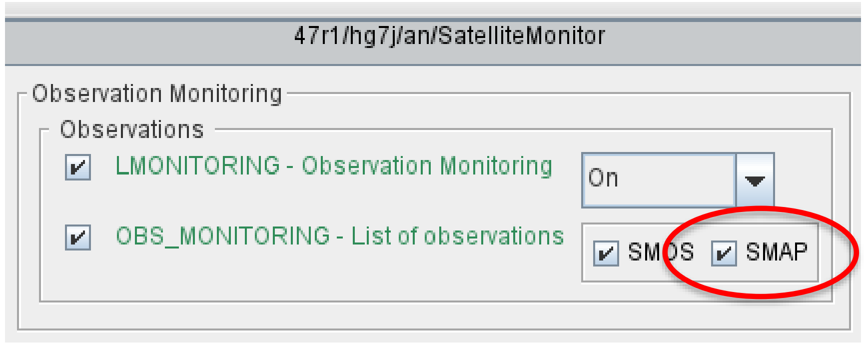


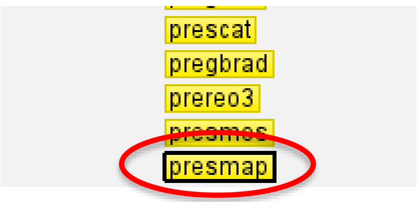
(b) Root mean square error

CMEM: Community Microwave Emission Modelling platform

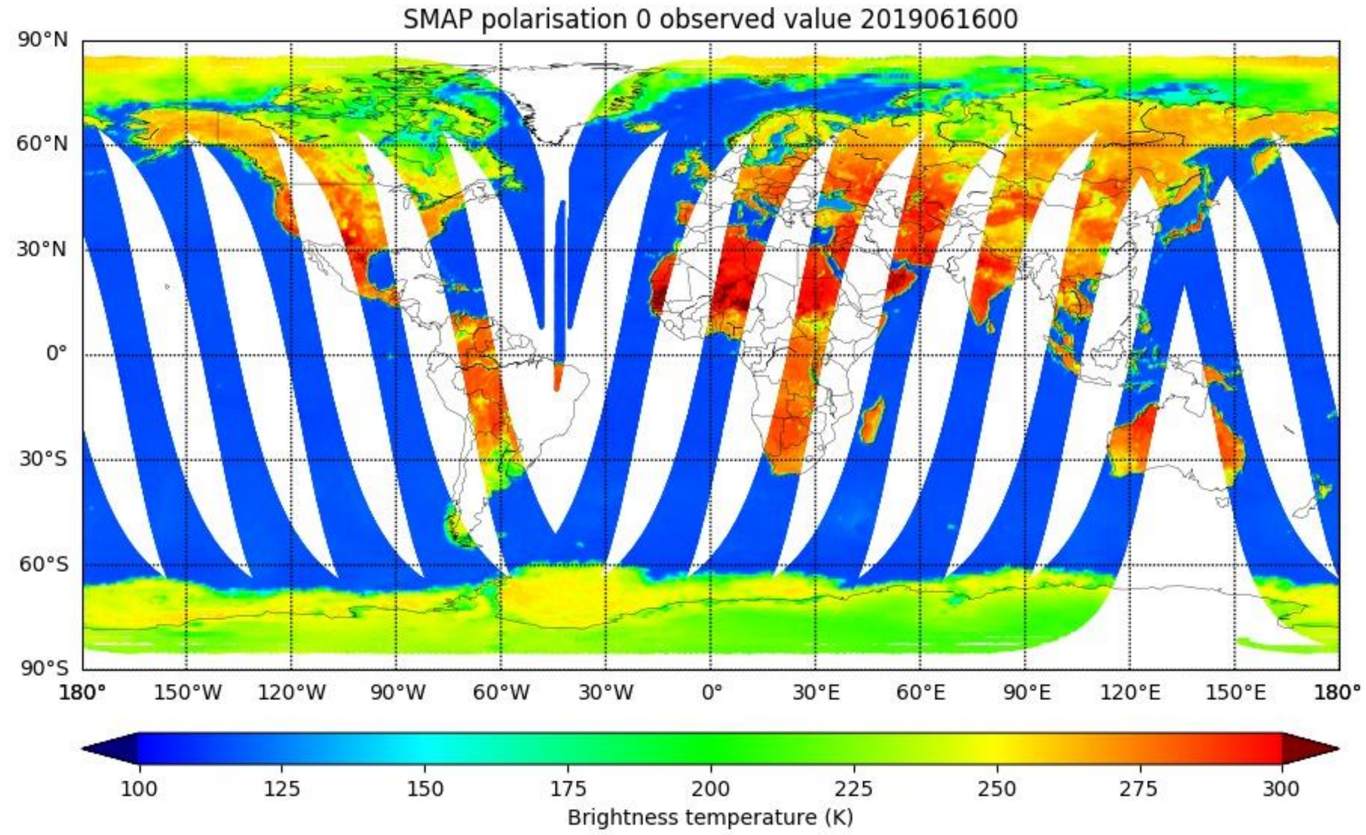
de Rosnay et al, RSE, 2020

SMAP monitoring



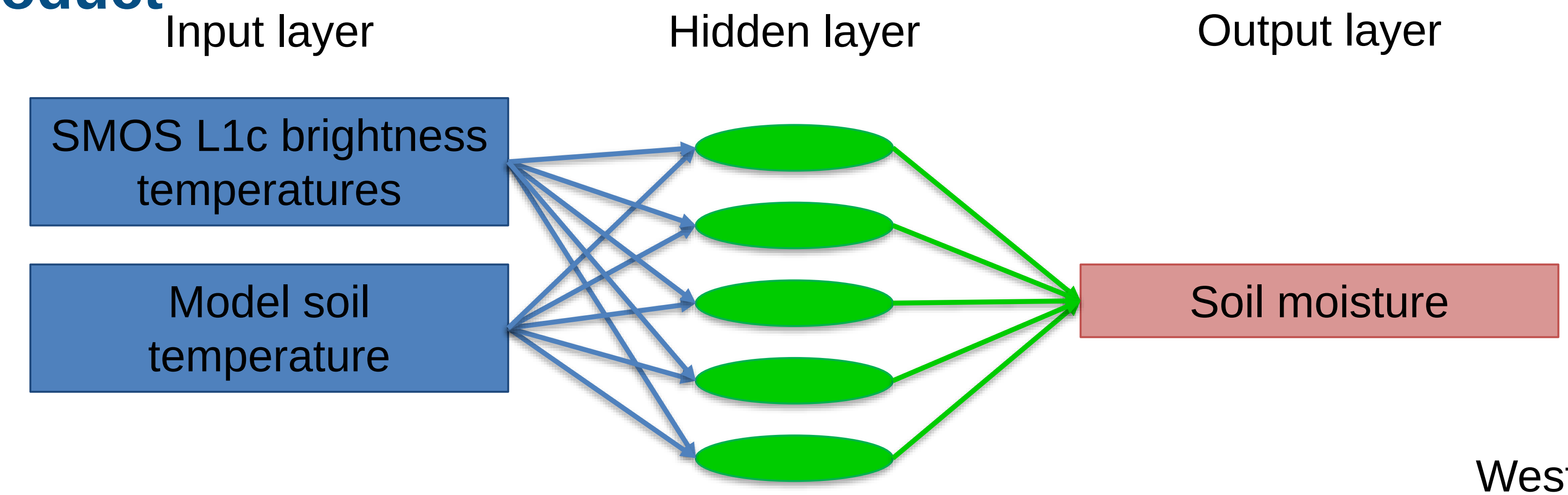


- Scripts, suite and prepIFS changes complete
- IFS changes in progress
- Experiments to test assimilation into SEKF in 2021



Slide from Pete Weston

SMOS Neural network: ESA level 2 SMOS NRT Soil Moisture product



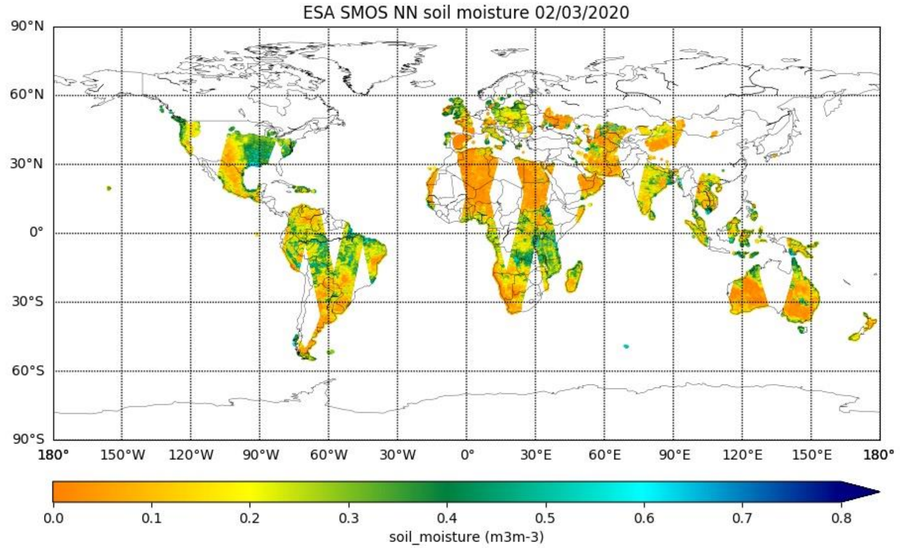
Weston et al., 2020

Designed by CESBIO/Estellus, Implemented by ECMWF

Rodriguez-Fernandez et al, HESS 2017

- Neural Network used to retrieve SMOS L2 SM:
  - Trained on SMOS L2 soil moisture
  - Single hidden layer, 5 neurons
- Product available within 4 hours of sensing time
- Available in NetCDF, since March 2016 on ESA SMOS Online Dissemination service

https://smos-ds-02.eo.esa.int/oads/access



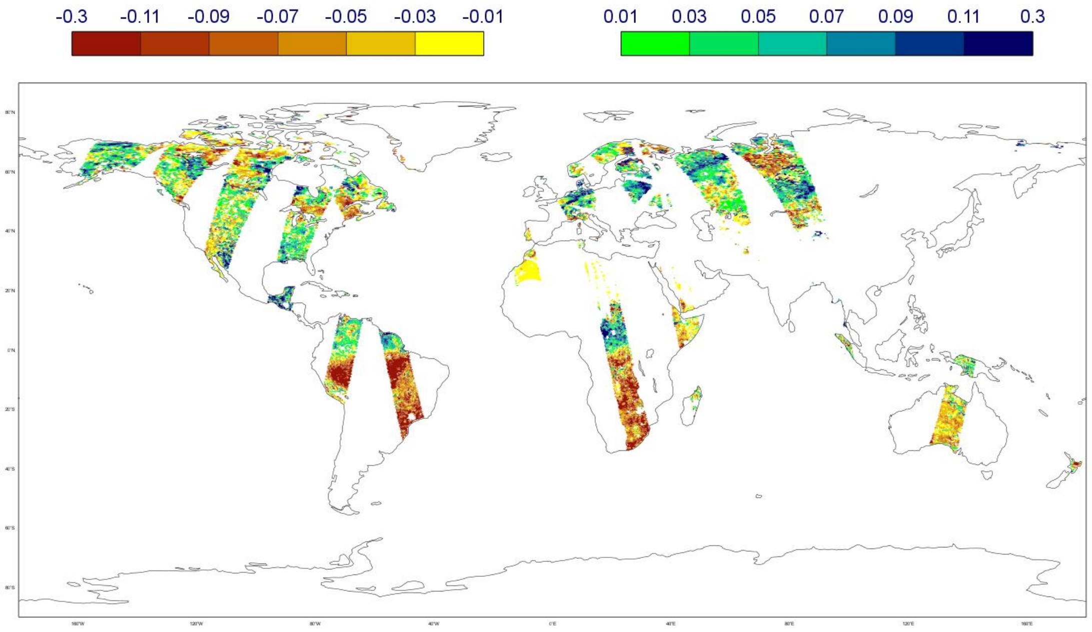
ECMWF esa CESBIO

SMOS Neural Network in the IFS and Ensemble SEKF approach

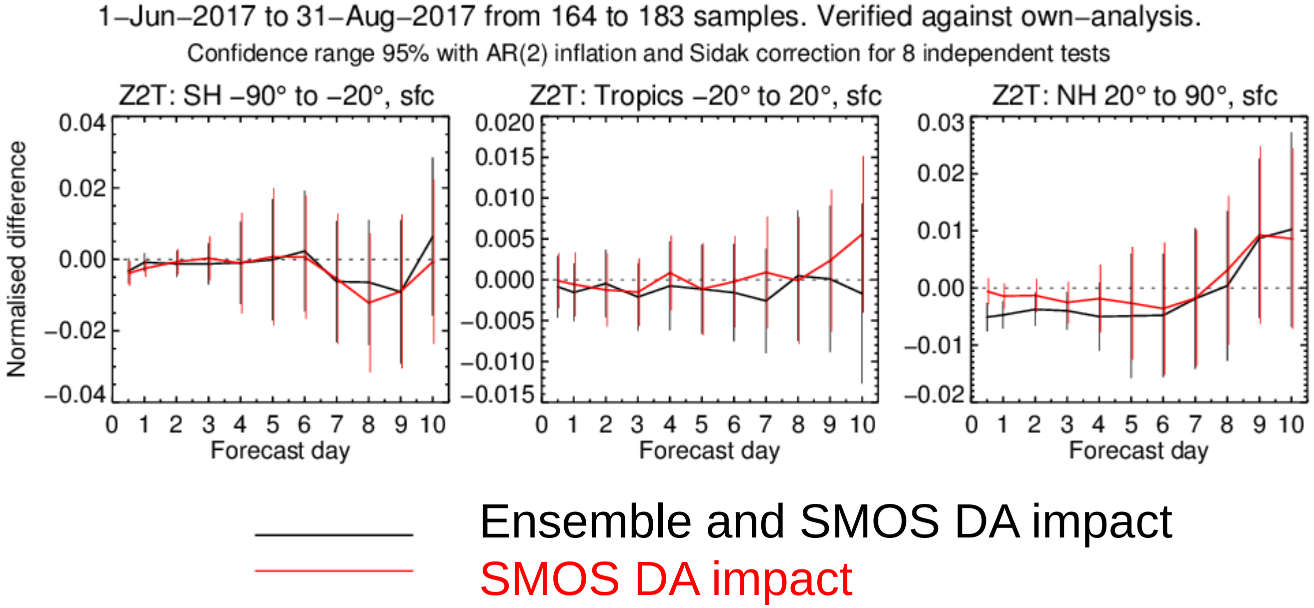
Reduction of the SEKF CPU cost by a factor ~3.6

Resol.	NPES*THREADS	45r1	46r1
Tco 1279 (9km)	300*9	1580	435

Impact of:
- Use the Ensemble Data Assimilation (EDA) in the SEKF
- SMOS neural network soil moisture assimilation



SMOS innovation (obs-model)
01 August 2017 (m3/m3)

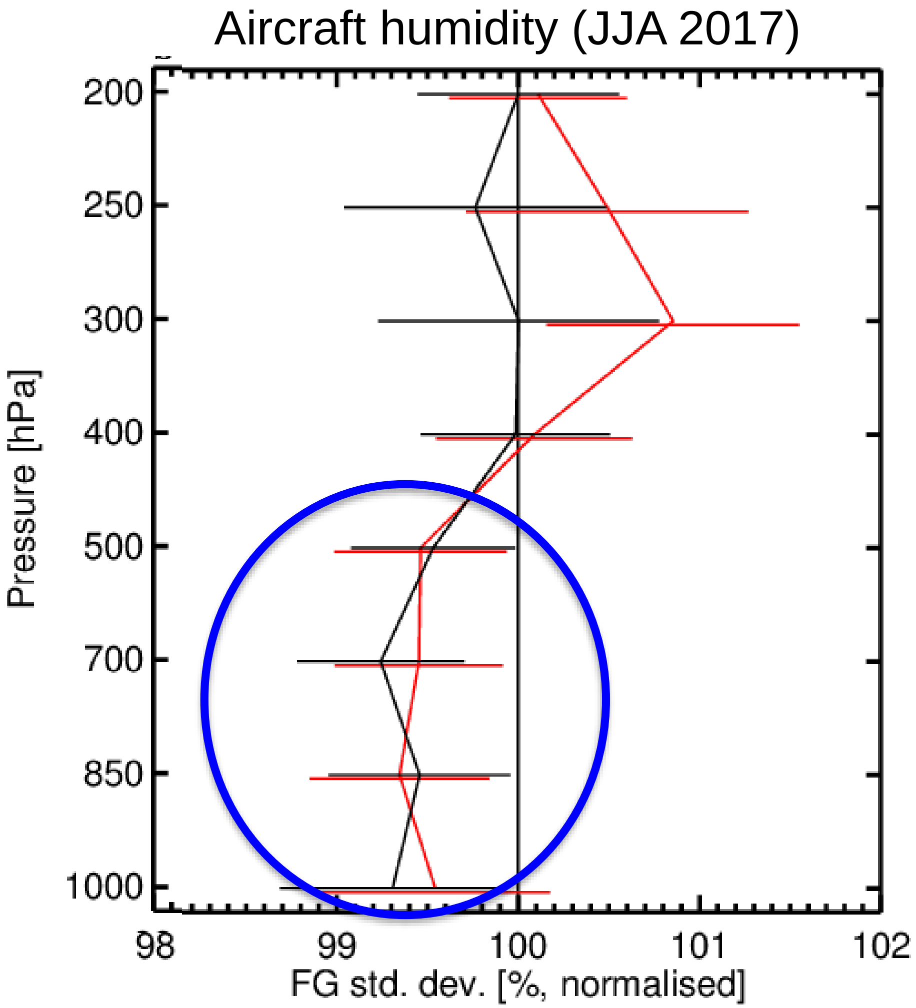


de Rosnay et al, ESA_LPS 2019

Atmospheric forecasts impact (T2m) compared to CTRL

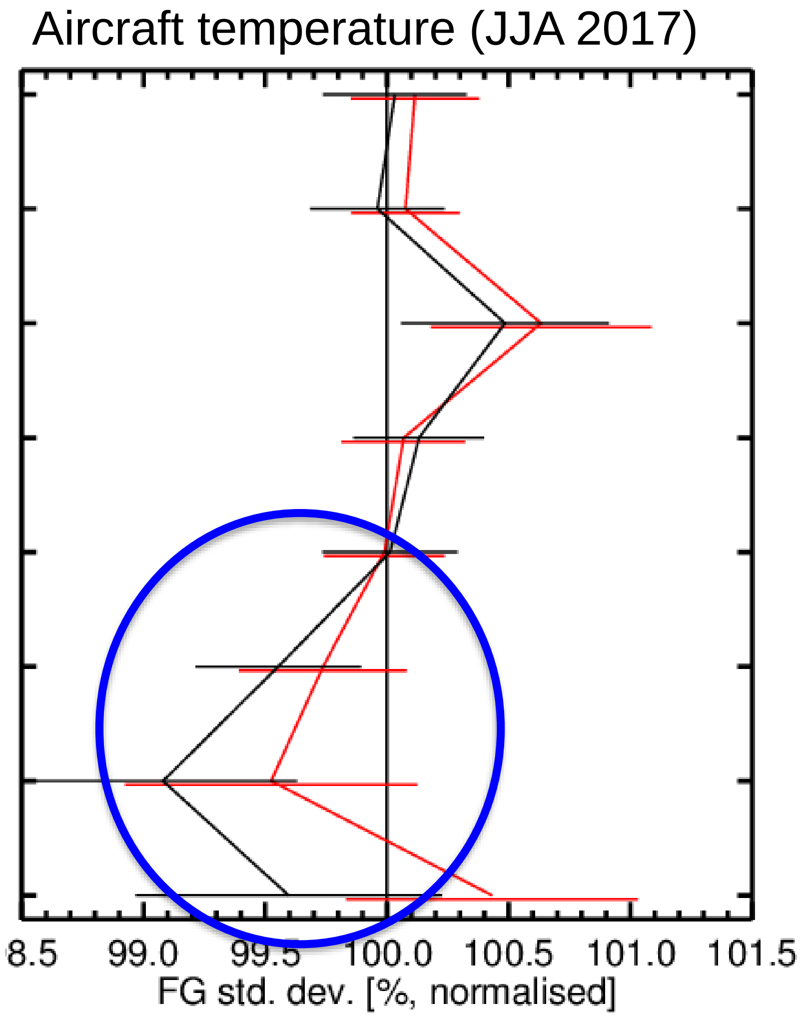
(CTRL has no Ensemble and no SMOS)

Atmospheric impact: fit to aircraft observations



SMOS impact
EDASEKF+SMOS impact

Improved fit
low troposphere



Summary and outlook

- ECMWF land data assimilation: combine OI, and EDA-SEKF

- Satellite data used operationally: SMOS, ASCAT, IMS

- Coupling developments: EDA-SEKF, multi-layer snow MW observation operator, coupling with hydrology, future outer-loop coupling → consistent with ocean coupling

- Continuous integration of reanalysis capabilities → preparation of ERA6 and ERA6Land

- Obs usage plans: near future SMAP data, VOD assimilation, LST

- Ongoing developments: soil temperature and snow in the SEKF

- Work on surface mapping (→ Balsamo, Boussetta, Arduini, Choulga)

- Consistency NWP, hydrology, CO2 →link to Copernicus Services (C3S, CEMS, CAMS)

Special Issue "Remote Sensing of Land Surface and Earth System Modelling"

- Special Issue Editors
- Special Issue Information
- Keywords
- Published Papers

https://www.mdpi.com/journal/remotesensing/special_issues/Land_Surface_Earth_System_Modeling

A special issue of *Remote Sensing* (ISSN 2072-4292). This special issue belongs to the section "Biogeosciences Remote Sensing".

Deadline for manuscript submissions: 31 May 2021

- Land surface data assimilation
- Land surface re-analysis
- Land surface forward modelling (VIS/IR/MW),
- Inverse modelling and machine learning
- Land surface parameter retrieval
- Coupled assimilation (land-hydrology-atmosphere)
- Intercomparison (model and DA)

Special Issue Editors

Guest Editor
Dr. Patricia De Rosnay
European Center For Medium-Range Weather Forecasts, UK
Website | E-Mail
Interests: Land surface data assimilation; coupled assimilation; Earth system modelling; Land surface observations; Forward modelling

Guest Editor
Dr. Clement Albergel
Affiliation: Météo-France/ Centre National de Recherches Météorologiques (CNRS), France
Website | E-Mail
Interests: land surface modelling; climate change; hydrology; data analysis

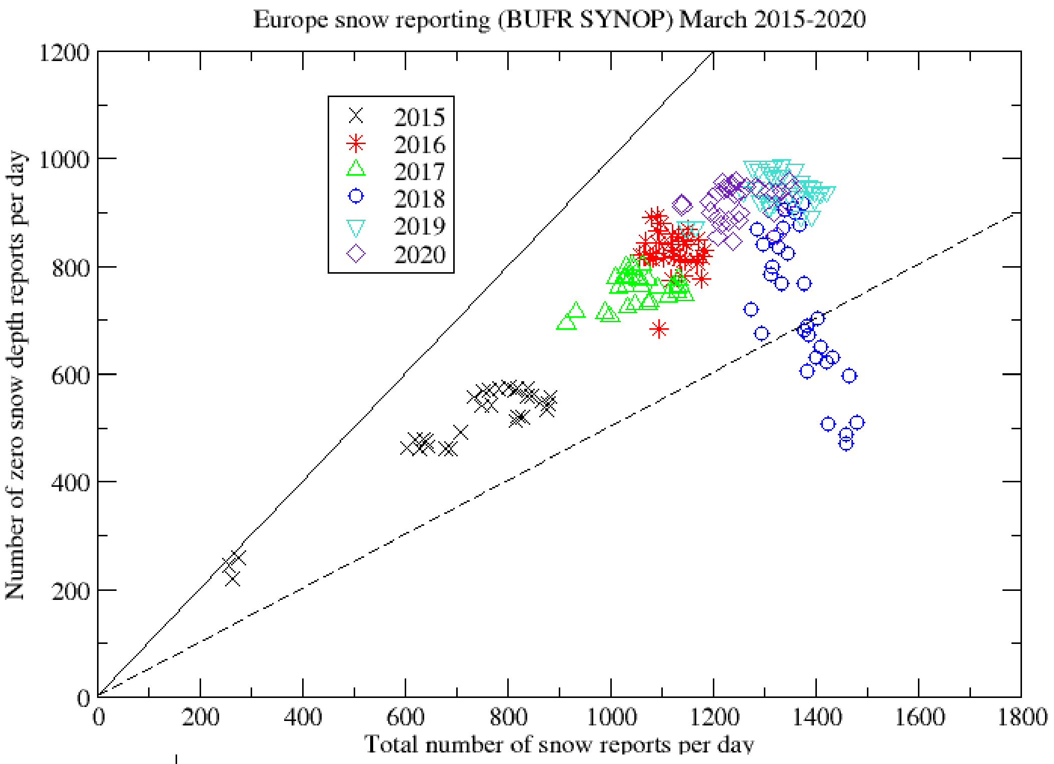
Guest Editor
Dr. Sujay Kumar
Hydrological Sciences Lab, NASA Goddard Space Flight Center, 8800 Greenbelt Rd, Greenbelt, MD, 21042, USA
Website | E-Mail
Interests: land surface modelling; hydrology; data assimilation; remote sensing; Optimization

A few slides on snow data assimilation

Snow data exchange and WMO activities

- Global Cryosphere Watch (GCW) and Snow Watch Team
  → snow data exchange WMO regulation, BUFR template (with Observation Team), link to GODEX

- SG-CRYO and JET-EOSDE (both Infrastructure Commission) → relevant for polar observations for coupled assimilation



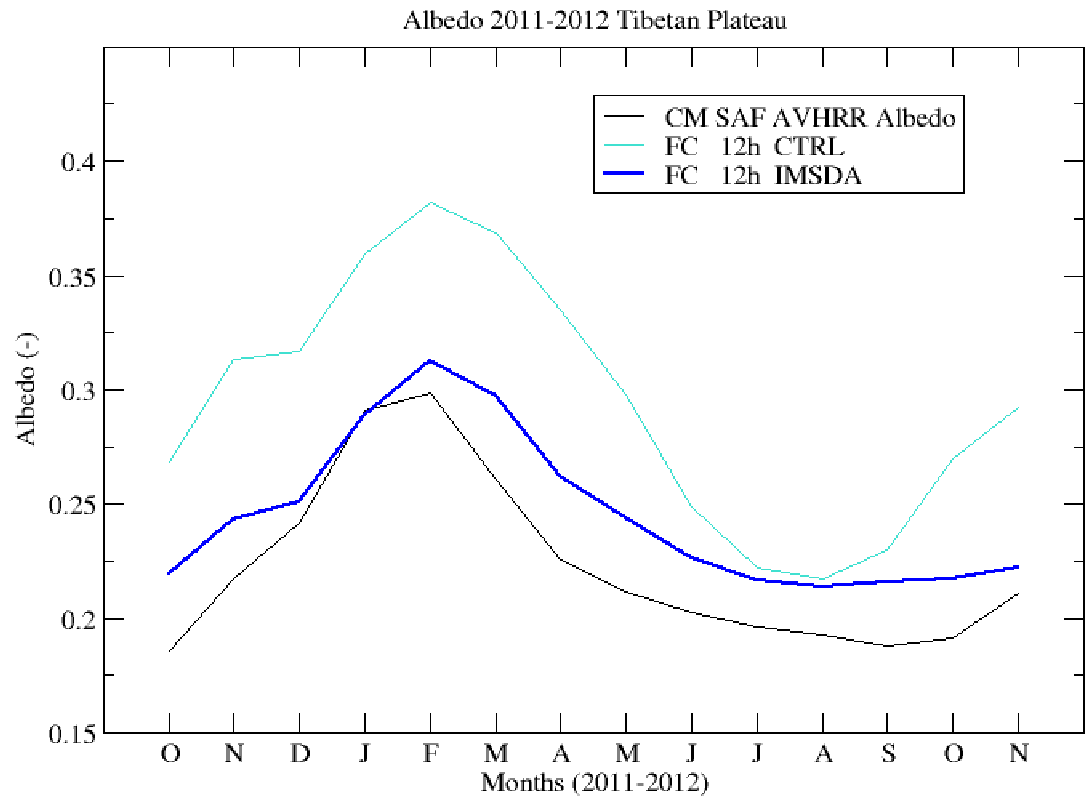
6. Improvements in the reporting of 'zero' snow depth from SYNOP stations

(de Rosnay, Pullen, and Nitu WIGOS NL April 2020)

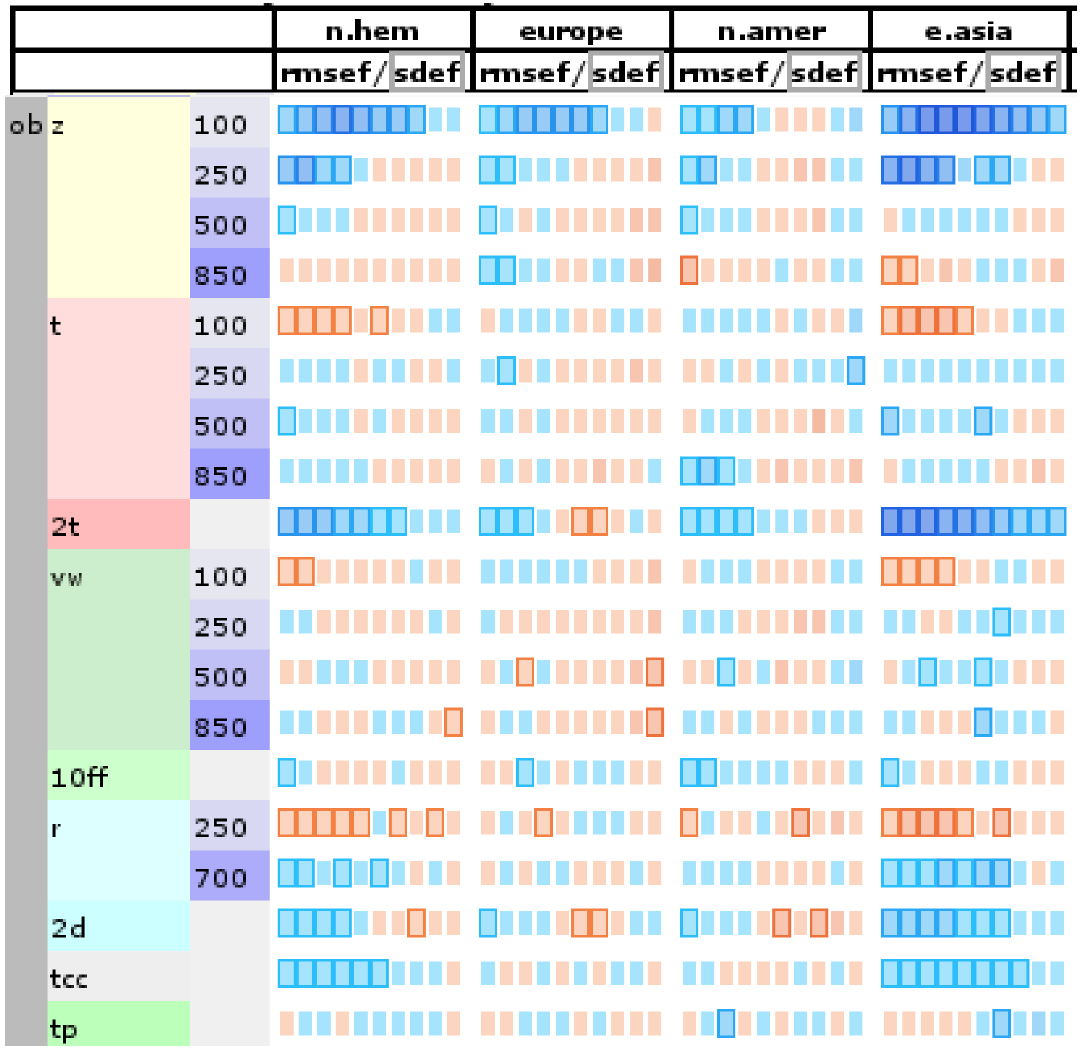
ECMWF

Snow cover data assimilation in mountainous areas

Further work on snow assimilation impact on theTibetan Plateau (de Rosnay et al in prep)



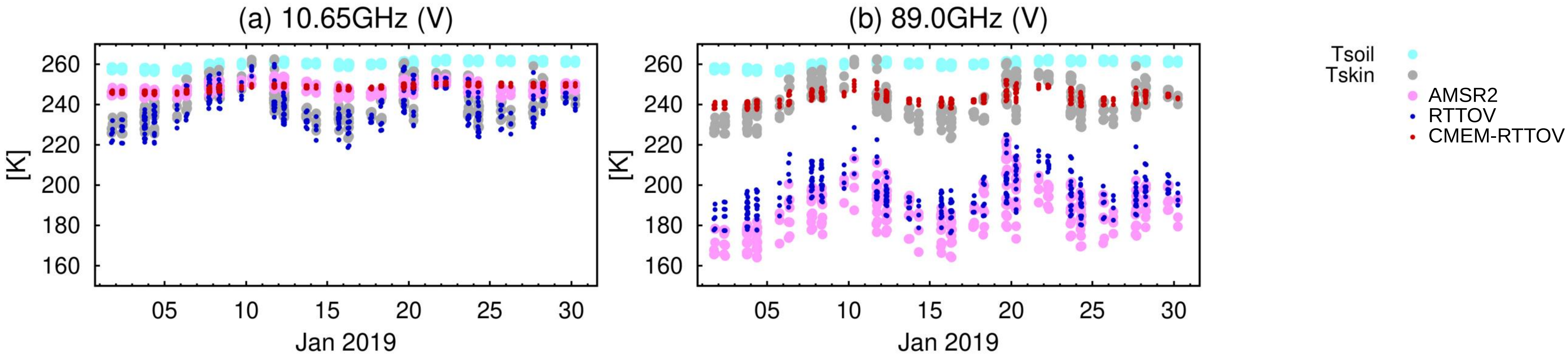
Scorecard March-April-May



Toward assimilation of surface-sensitive satellite data over land

- New interface between CMEM and RTTOV, processing of surface sensitive observations through the all-sky code path.

- Implementation of multi-layer snow radiative transfer scheme in CMEM (complementarity with multi-layer snow pack model from Arduini et al., JAMES, 2019)



ECMWF, JMA

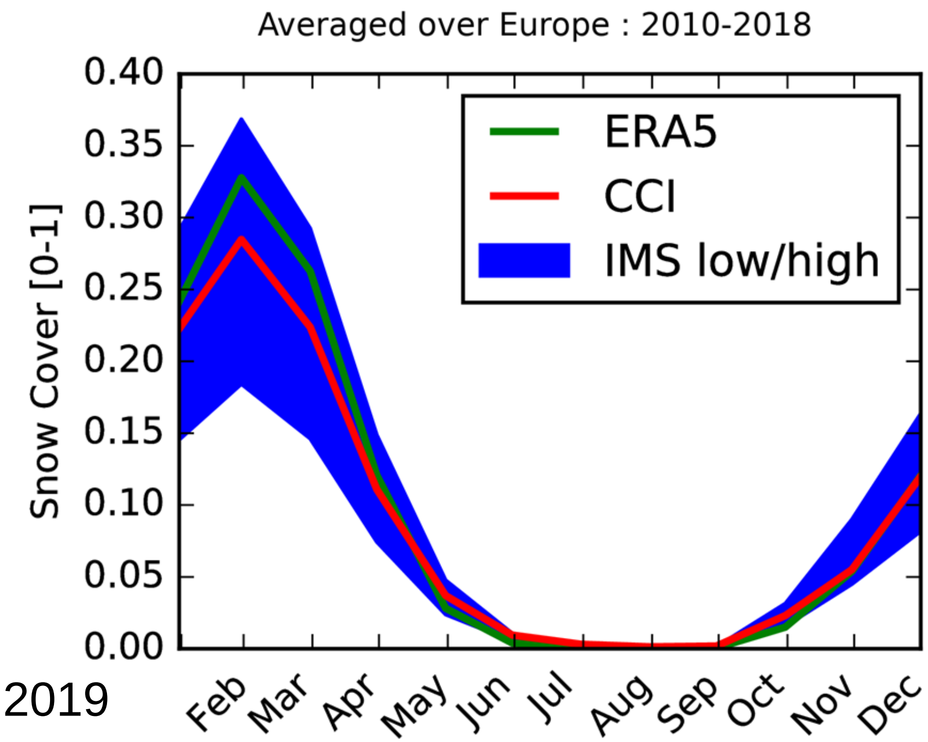
ECMWF

Hirahara et al *Remote Sens.* **2020**, *12*(18), 2946; https://doi.org/10.3390/rs12182946

Toward assimilation of surface-sensitive satellite data over land

- Next steps:
  - → SEKF using CMEM-RTTOV through all-sky from April 2021 (Pete)
  - → Soil temp and snow in the SEKF (Kenta, from April 2021)
  - → Initialization of multi-layer sow conditions from satellite radiances assimilation

- Current collaboration with Kenta (JMA)
  - Comparison between ERA5, JRA55 and the ESA CCI+ snow cover v1.0 (1981-)
  - Potential for snow cover reanalysis

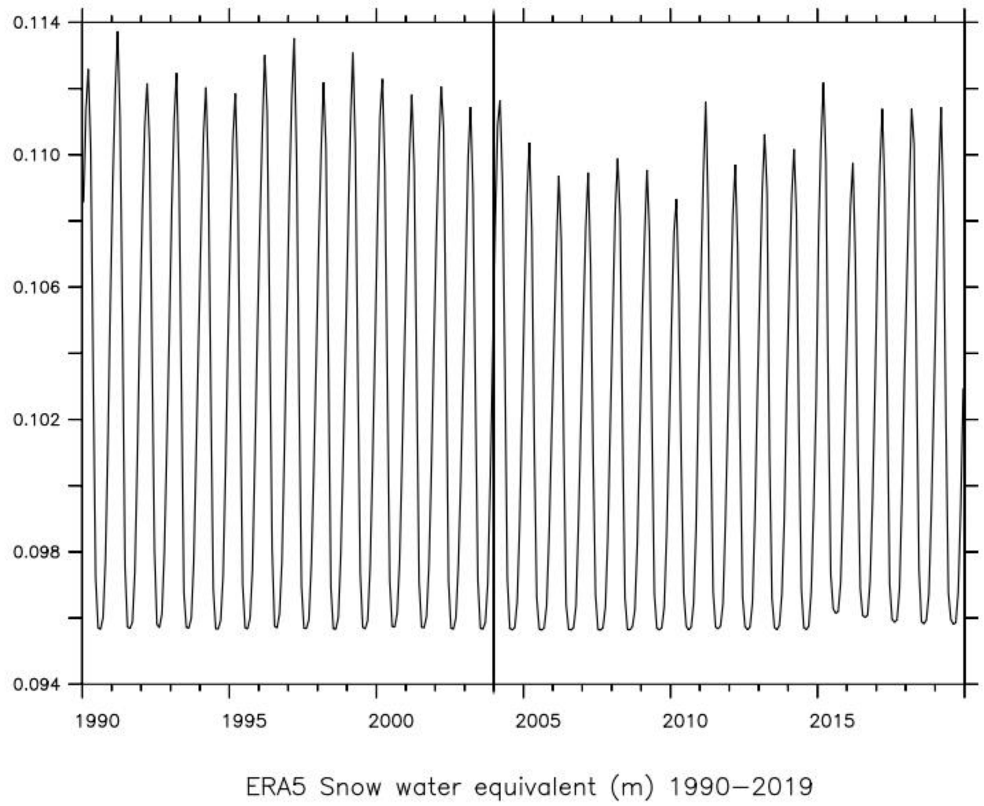


ERA5, CCI, IMS comparison:
ECMWF VS of Clément Albergel, Nov. 2019

ECMWF

ERA5_Snow: snow reanalysis using conventional snow only

-Discontinuity in ERA5 snow analysis from 2004 when IMS assimilation starts (Daily report 13/03/2020)
-Ervin's memo on impact of spurious trends in ERA5 (mainly precip and snow) → Zsótér et al TM-871



- Stand-alone reanalysis ERA5_Snow to be compared to ERA5, ERA5Land and snow CCI
  Production with 21 two-year streams July-June

- Good test of reanalysis capabilities in 47r2 using conventional obs only (thanks Dinand!)

- Link to Kenta's work to investigate ESA CCI+ snow cover assimilation for future reanalysis

One slide on plans for land assimilation developments in OOPS

Land data assimilation in OOPS

- Internal discussion in Q4 2020 to define land DA in OOPS strategy

- Developments to start implementing the SEKF in OOPS in 2021

- Solve usage of gridded observations → develop ODBs for snow cover and pseudo screen level observations

- Need to code the EDA Jacobians (read EDA spread)

- Longer term possibilities to explore EnKF, taking advantage of JCSDA EnKF and IFS EnKF existing infrastructure

- Land DA should be in OOPS to enable consistent coupling approaches with atmosphere and ocean

- Resources needed to support Land DA in OOPS → possibilities in Destination Earth ?