Land data assimilation at ECMWF

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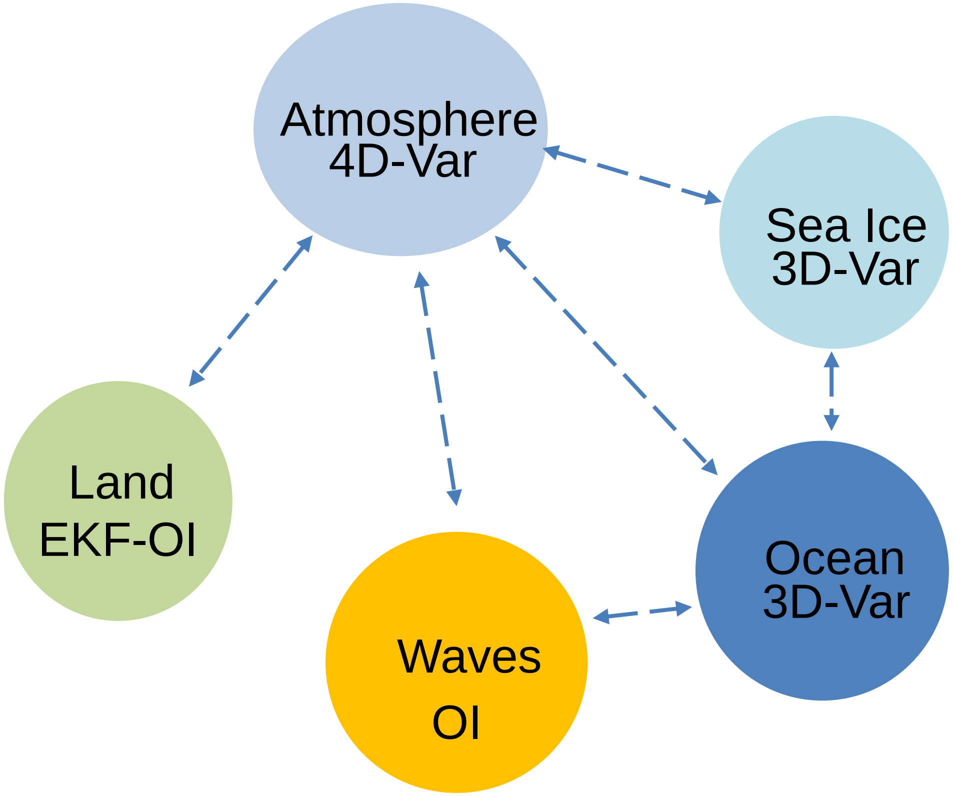
Thanks to: Gabriele Arduini, Gianpaolo Balsamo, Calum Baugh, Ervin Zsoter, Christel Prudhomme, and many other colleagues

Toward coupled assimilation in ECMWF's operational systems



Integrated Forecasting System (IFS)

Importance of interface observations: SST, sea ice, **snow, soil moisture**, LST etc..

Snow in the ECMWF IFS for NWP

Snow Model: Component of H-TESSEL **(Dutra et al., JHM 2010, Balsamo et al JHM 2009)**

Single layer snowpack

- Snow water equivalent SWE (m)
- Snow Density ρ_s

} **Prognostic variables**

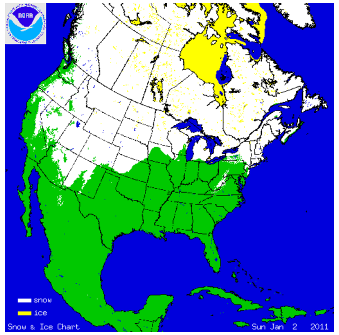
Currently single layer model
Nxt (2022): multi-layer snowpack (Arduini et al. JAMES, 2019)

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

- Conventional snow depth data: SYNOP and National networks
- Snow cover extent: NOAA NESDIS/IMS daily product (4km)

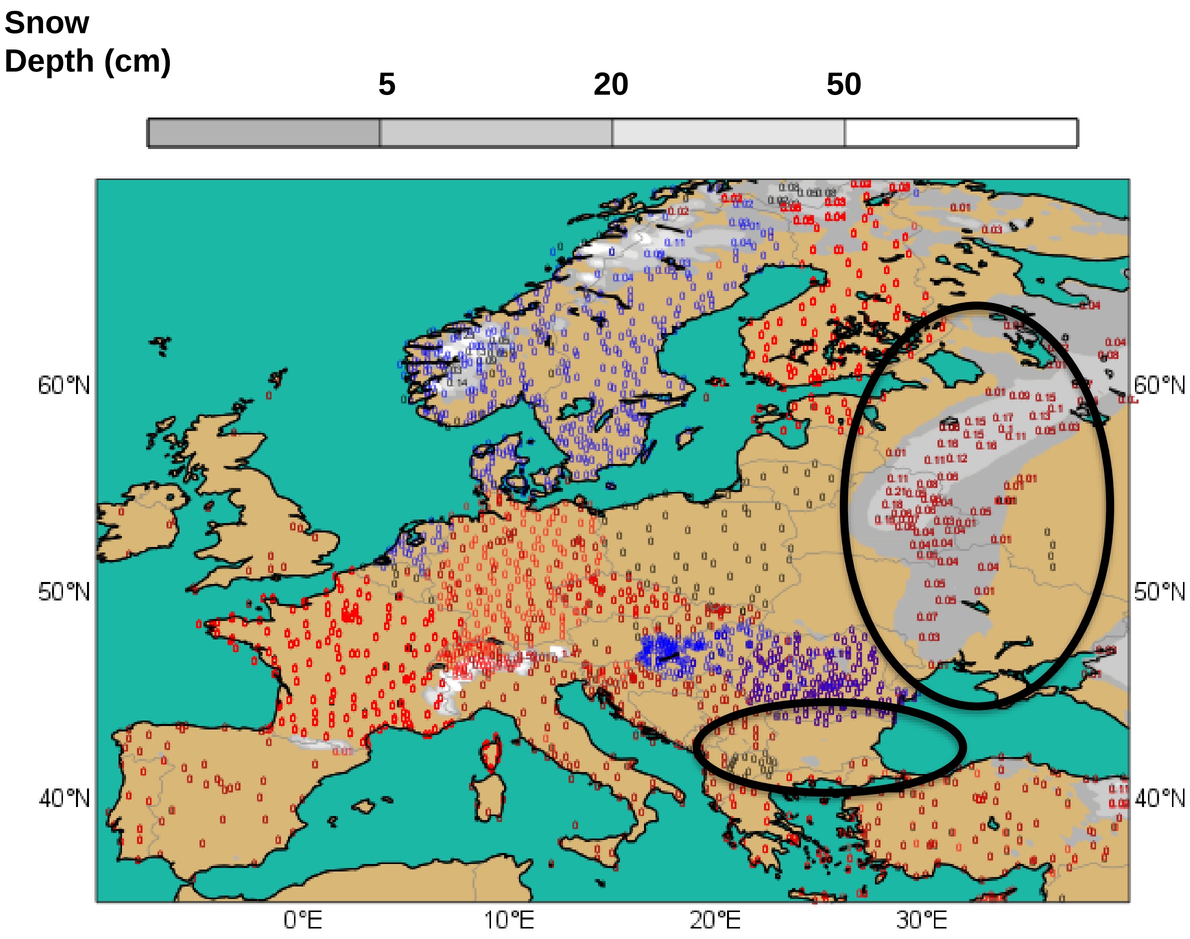
Data Assimilation: **de Rosnay et al SG 2014**

- Optimal Interpolation (OI) is used to optimally combine the model first guess, in situ snow depth and IMS snow cover
- The result of the data assimilation is the analysis of SWE and snow density
  → used to initialize NWP.



Snow Observations

Snow SYNOP and National Network data in Europe



2018 11 15 at 06UTC

In general, good coverage in Europe, but …

- Zero snow depth reporting is an issue with some countries providing observations only when snow depth > zero (e.g. Ukraine)
- Still areas with relatively few snow depth reports

Dedicated network to exchange meteorological data: Global Telecommunication System (GTS)

ECMWF

Snow data assimilation OSEs

Winter 2014-2015 (December to April) - Assess the impact of the snow observing system

Expts	SYNOP	National Data	IMS snow cover
0- OL (no snow data assimilation)			
1- Snow DA: SYNOP+IMS	✓		✓
2- Snow DA: SYNOP+Nat (all in situ)	✓	✓	
3- Snow DA SYNOP+Nat+IMS (all)	✓	✓	✓

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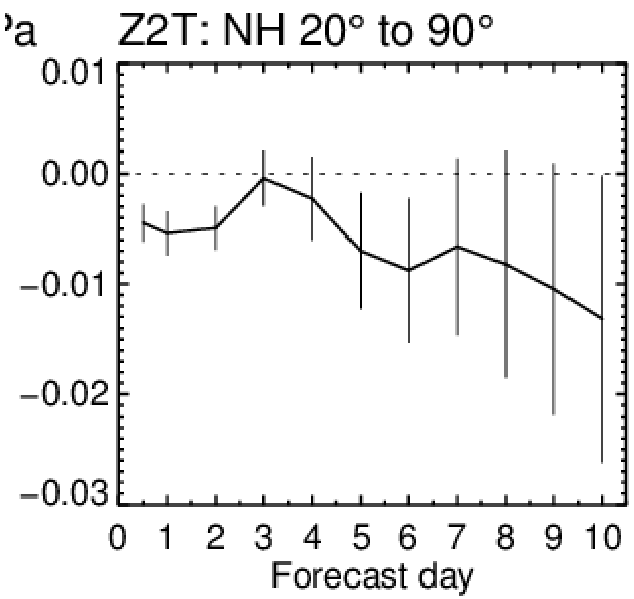
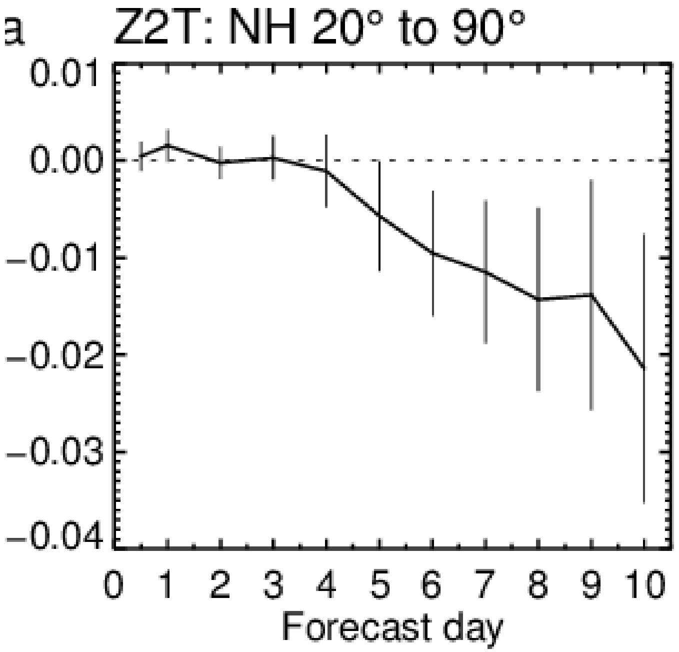
Impact of IMS snow cover assimilation (case 3-2)



All data assimilated (Synop+Nat+IMS)
compared to all in situ data assimilated (SYNOP+Nat)
-> Further T2m forecasts error reduction,
significant at short range

Impact of National data (case 3-1)

All data assimilated (SYNOP+Nat+IMS)
compared to SYNOP+IMS assimilation
-> Further T2m forecasts error reduction at medium range



Contribution & complementarities of each observation types to improve T2m forecasts at short and medium ranges

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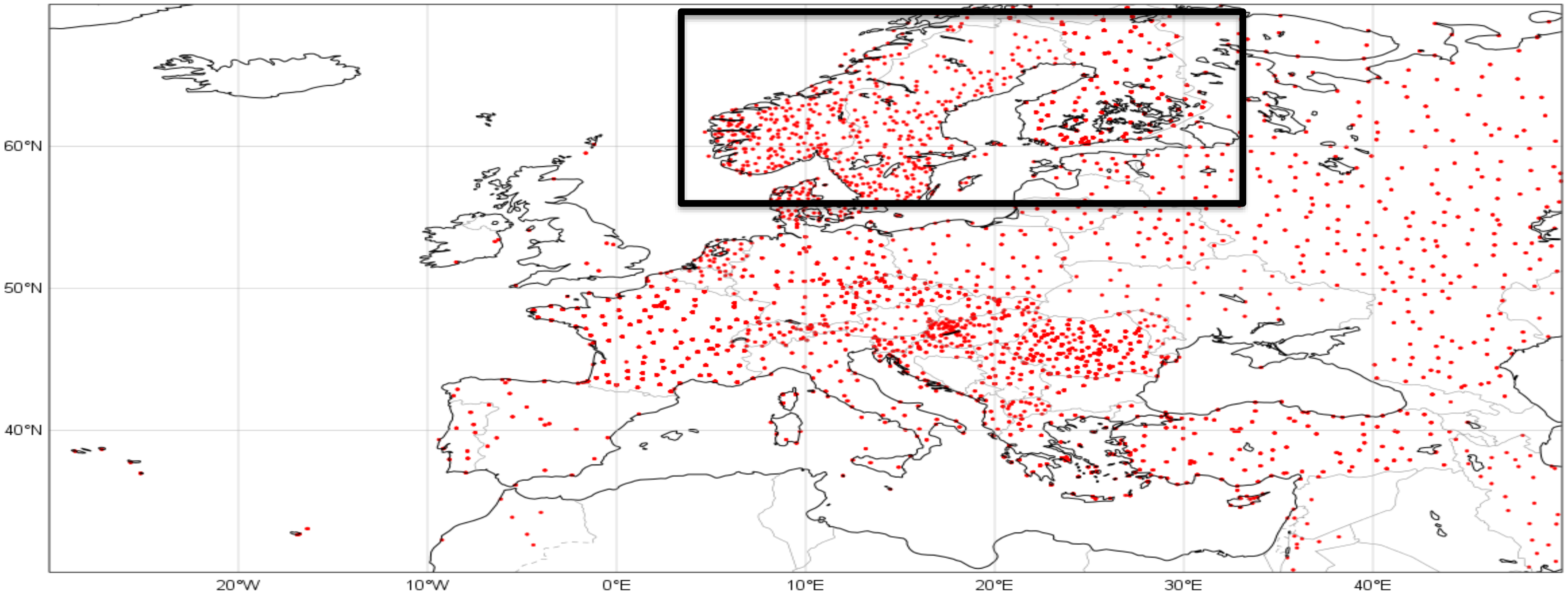
Snow depth observations in Europe

SYNOP + national BUFR data

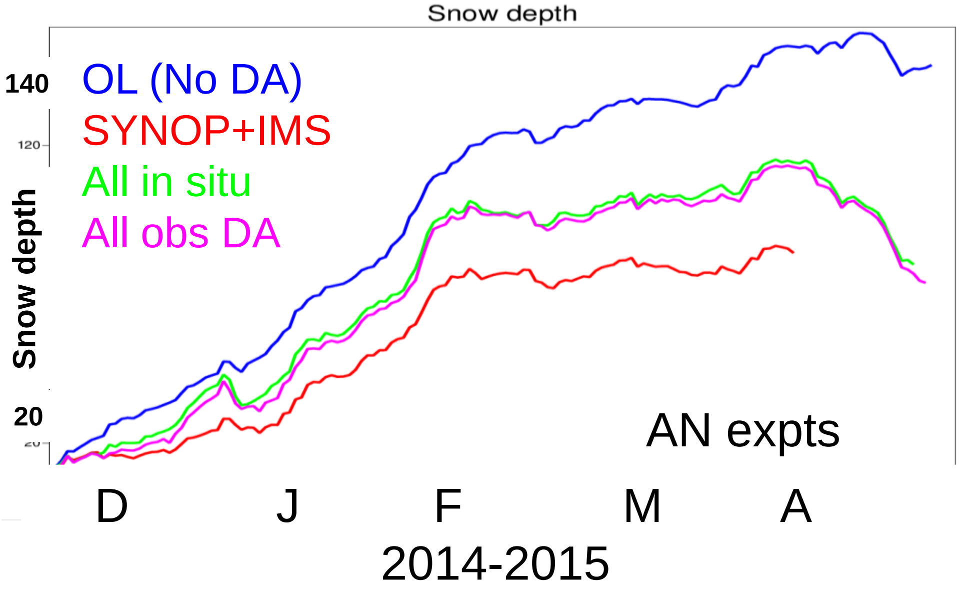
(GTS)



Very good coverage of snow observations in Scandinavia
→ Impact on extended range forecasts ?
→ Impact on river discharge?

Observing System Experiments

→ Extended Range impact

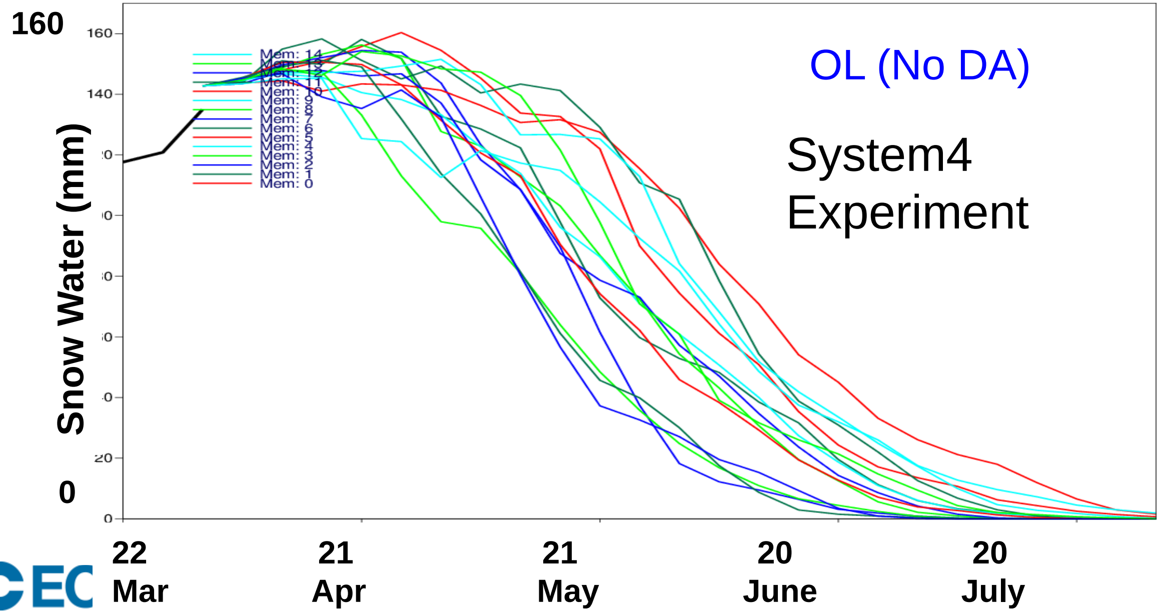


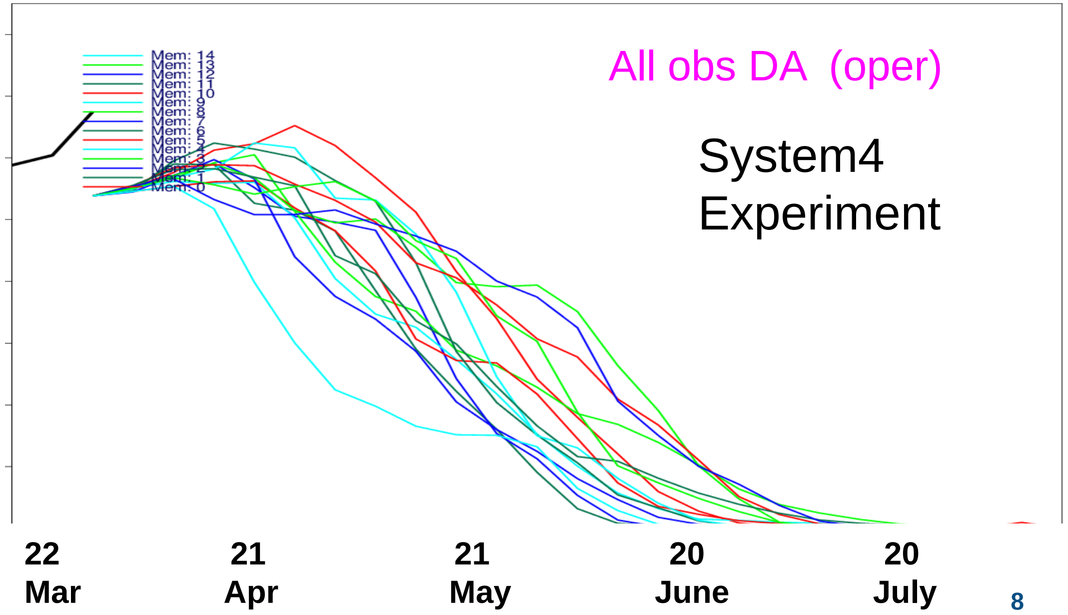
Model too long to melt snow → OL has more snow

Impact of snow data assimilation on Seasonal forecast and river discharge in Scandinavia

Earlier melting in S4 with in situ snow DA
Next: River discharge for OL and All obs DA

Linus Magnusson





Simplifed EKF soil moisture analysis

For each grid point, analysed soil moisture state vector $\boldsymbol{x}_a$:

$$\boldsymbol{x}_a = \boldsymbol{x}_b + \boldsymbol{K}(\boldsymbol{y} - \mathcal{H}[\boldsymbol{x}_b])$$

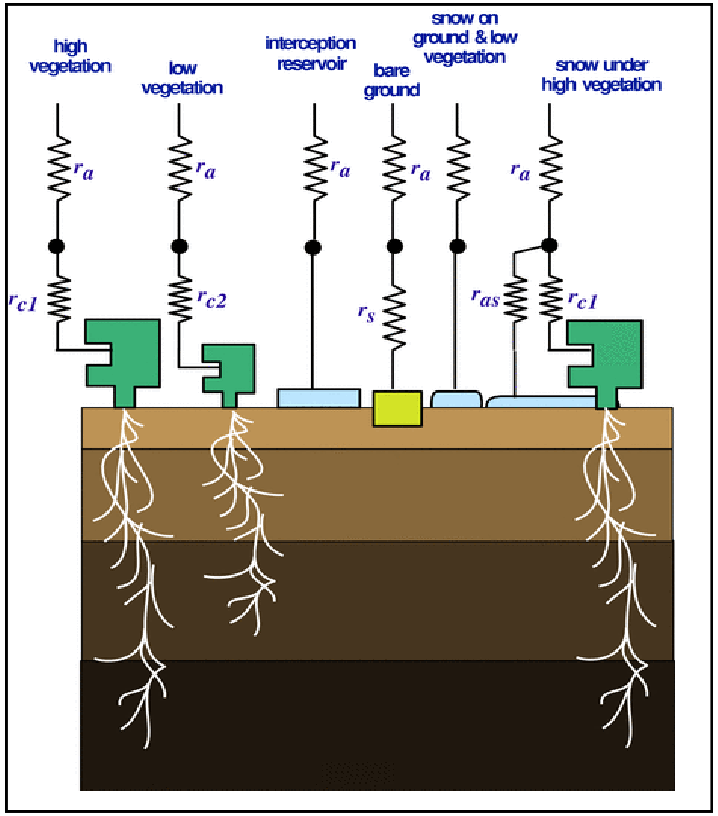
x background soil moisture state vector,
$\mathcal{H}$ non linear observation operator
y observation vector
K Kalman gain matrix, fn of
H (linearsation of $\mathcal{H}$), **P** and **R** (covariance matrices of background and observation errors).

Drusch et al., GRL, 2009
de Rosnay et al., ECMWF News Letter 127, 2011
de Rosnay et al., QJRMS, 2013

Used at ECMWF since Nov. 2010 (operations and ERA5)

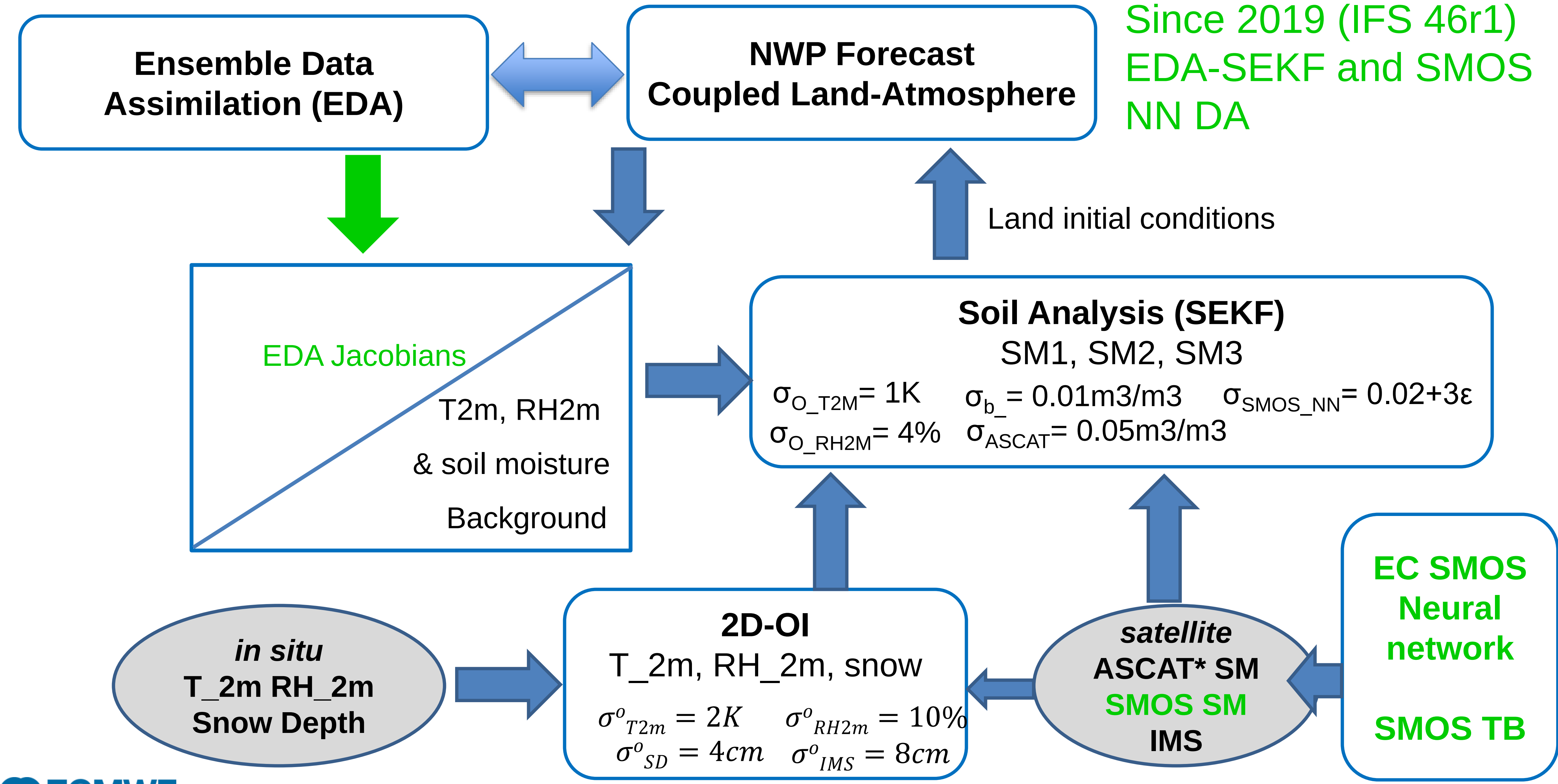
Upgraded to use Ensemble DA Jacobians since June 2019

The simplified EKF is used to corrects the soil moisture trajectory of the Land Surface Model



ECMWF

coupled land-atmosphere data assimilation



* ASCAT A/B/C

ASCAT CDF matching bias correction

- SEKF method assumes observations are unbiased with respect to model climatology – designed to correct random errors rather than systematic errors;
- ECMWF employs a linear CDF matching (Scipal et al., 2008): first two moments of the observation CDF are rescaled to match the model equivalent
  - Slope *B* and intercept *A* calculated from standard deviations and means of model *x* and observations *y* over climatological period (typically 5 years or more):

$$B = \frac{\sigma_x}{\sigma_y}$$

$$A = \bar{x} - B\bar{y},$$

- Rescaled scatterometer observations ($\hat{y}$):

$$\hat{y} = A + B.y$$

- Seasonal CDF matching employed using 3-month moving average (de Rosnay et al. internal report 2011, Draper et al., 2009; Barbu et al., 2014)

- By design, CDF matching converts units of ASCAT from soil wetness index to volumetric.

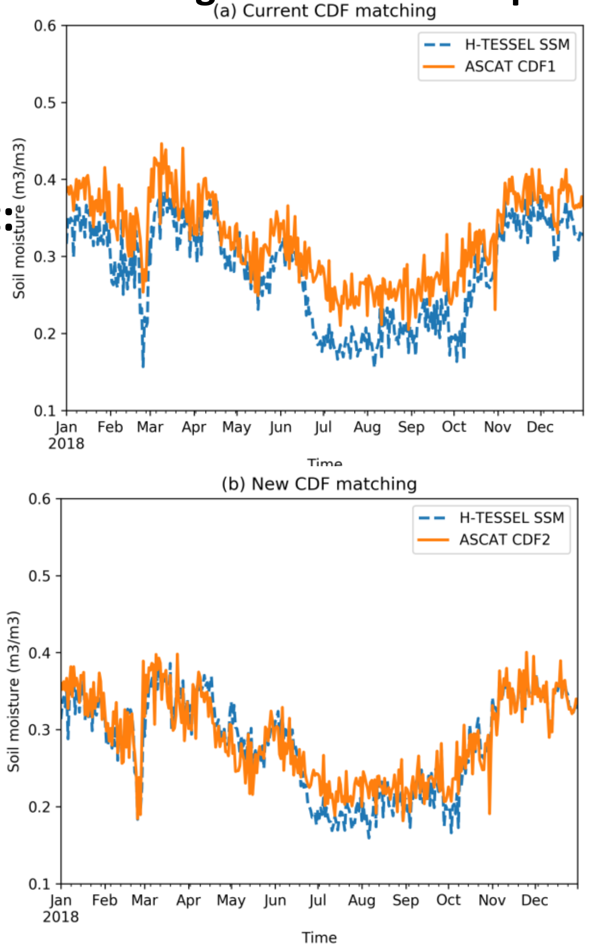
ASCAT soil moisture bias correction

- Reduction in fg departures and low level RH2m mean forecast errors (evaluated over June-September 2020)
- Adaptive bias-correction to be explored in 2021

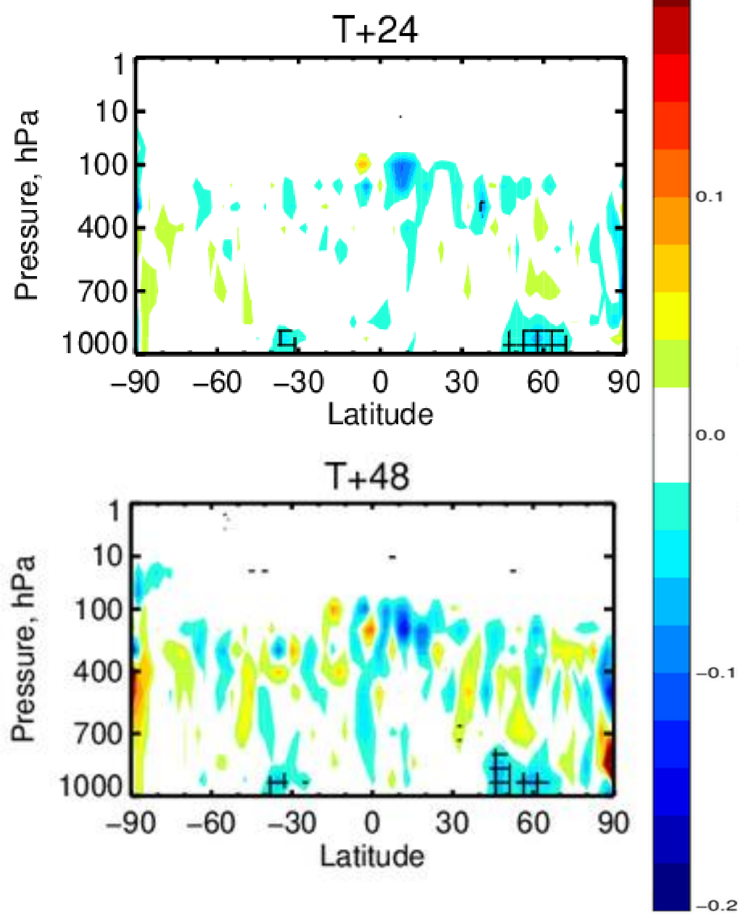
Average SSM over Europe:

Current:

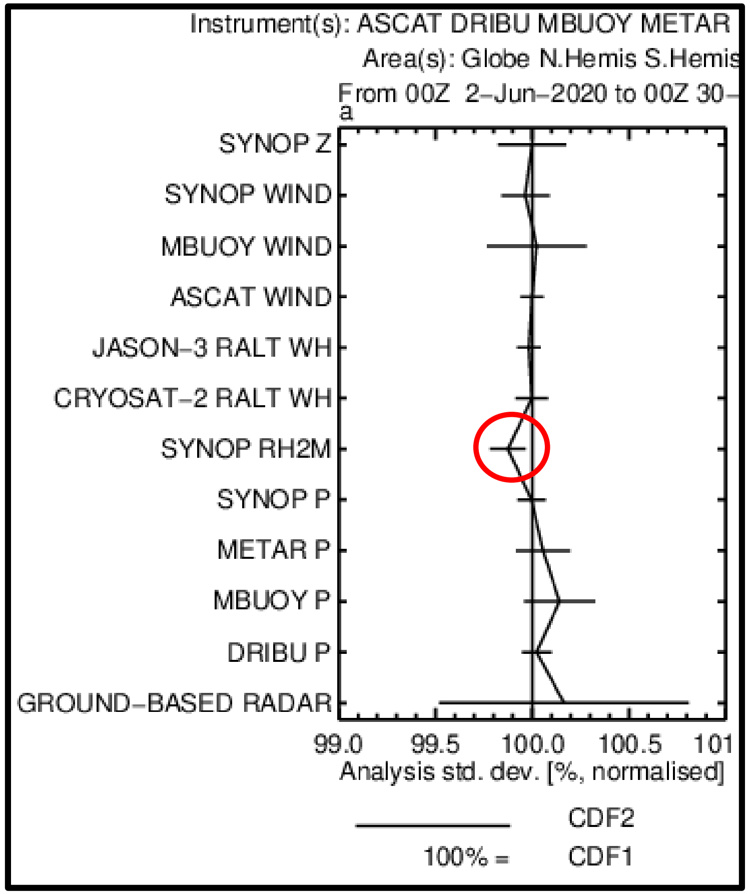
New:



Relative mean error in RH (-):

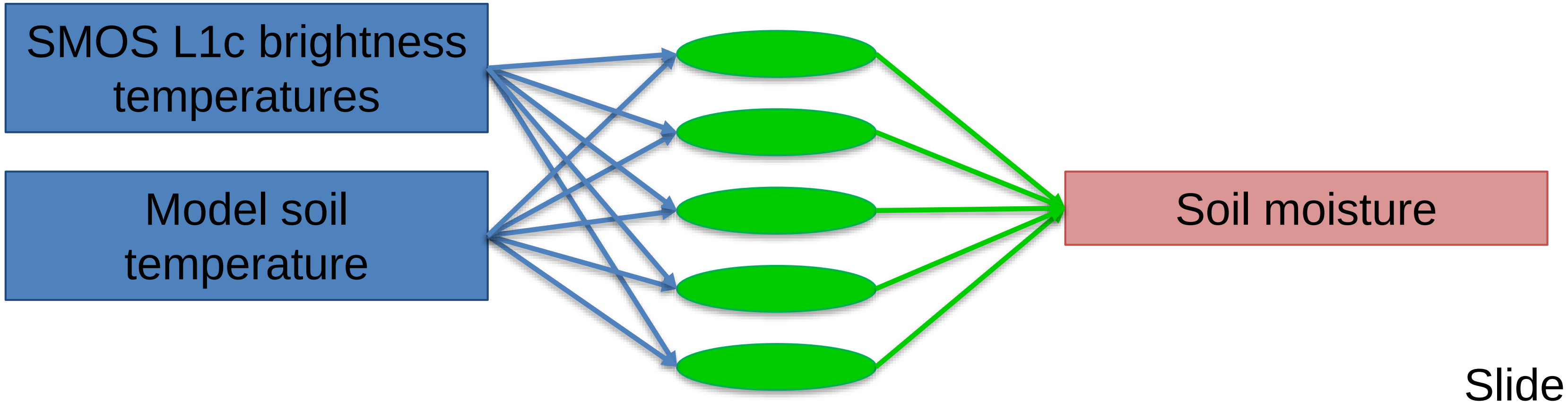


Obstat scores



David Fairbairn

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



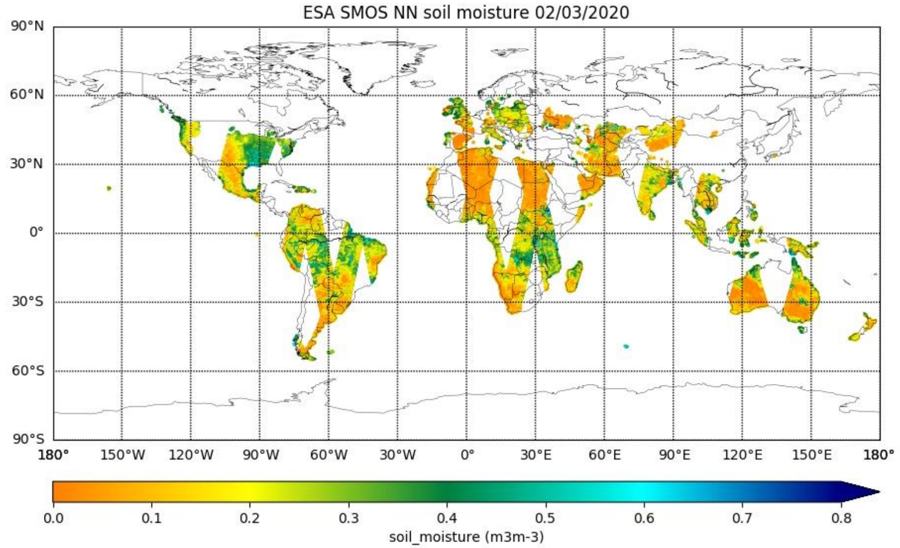
Slide from Pete Weston

Designed by CESBIO/Estellus, Implemented by ECMWF

Rodriguez-Fernandez et al, HESS 2017

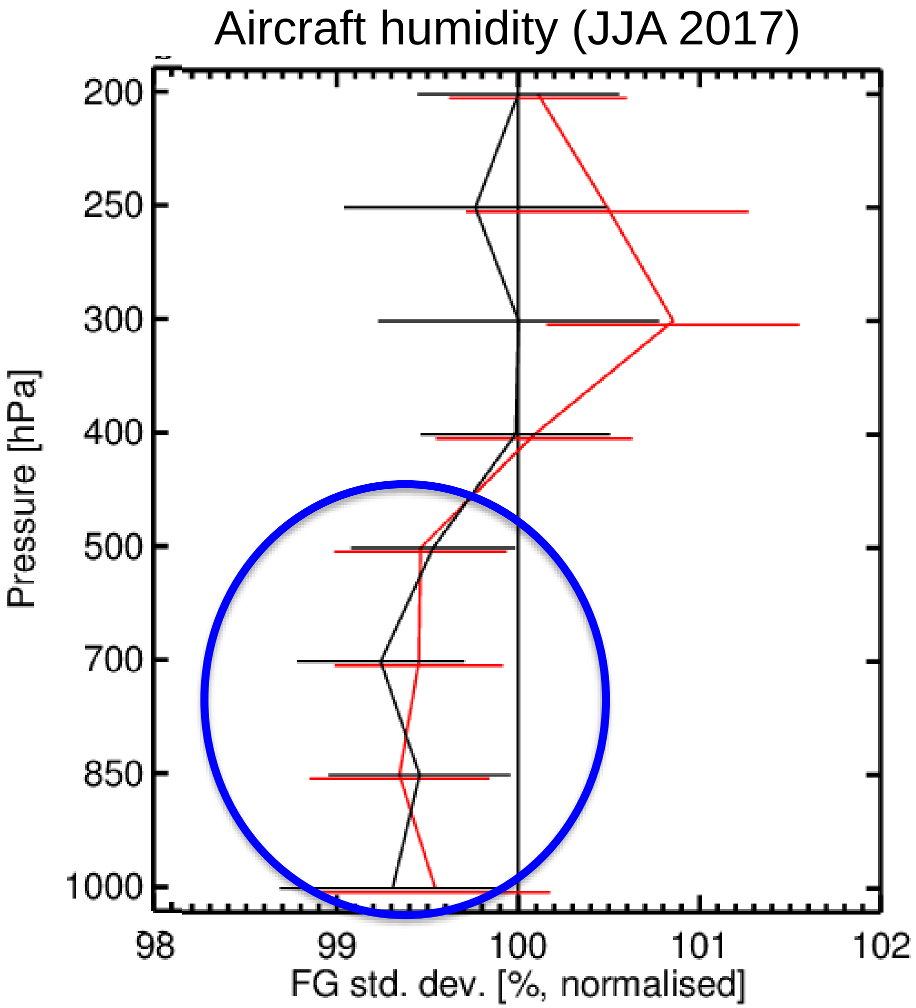
- Neural Network used to retrieve SMOS L2 SM:
  - Trained on SMOS L2 soil moisture
  - Single hidden layer, 5 neurons
- Product available within 4 hours of sensing time
- Available in NetCDF, since March 2016 on ESA SMOS Online Dissemination service

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



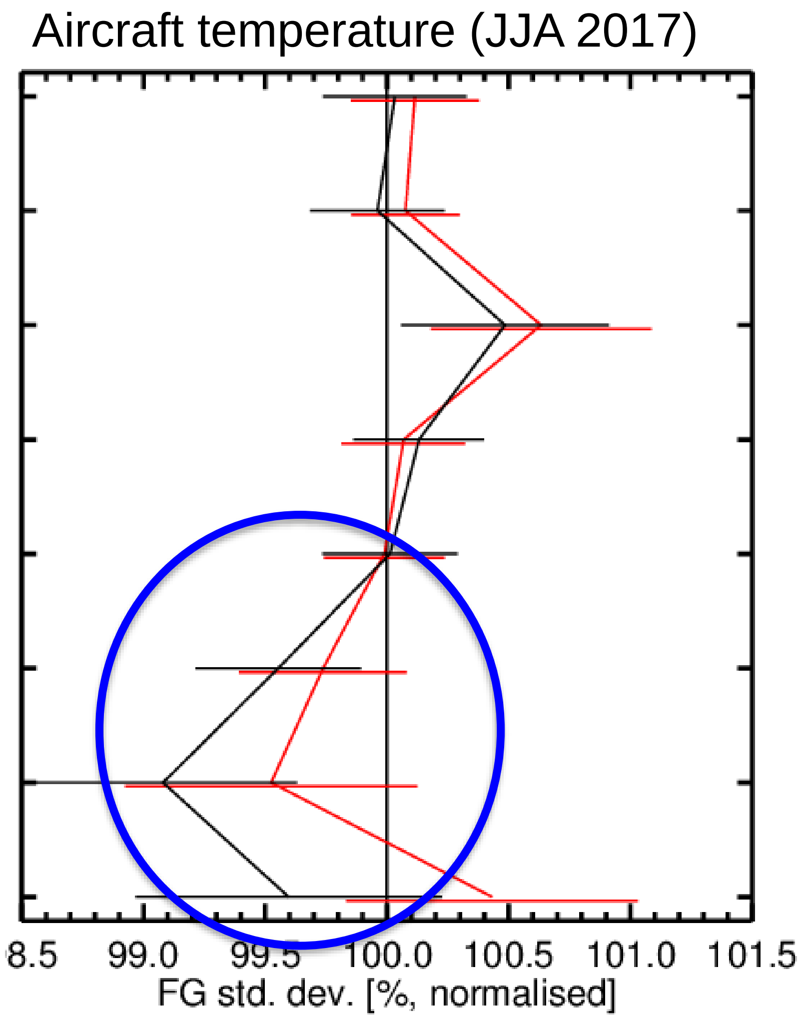
ECMWF esa CESBIO

Forecast impact (EDA-SEKF and SMOS neural network)



SMOS impact
EDASEKF+SMOS impact

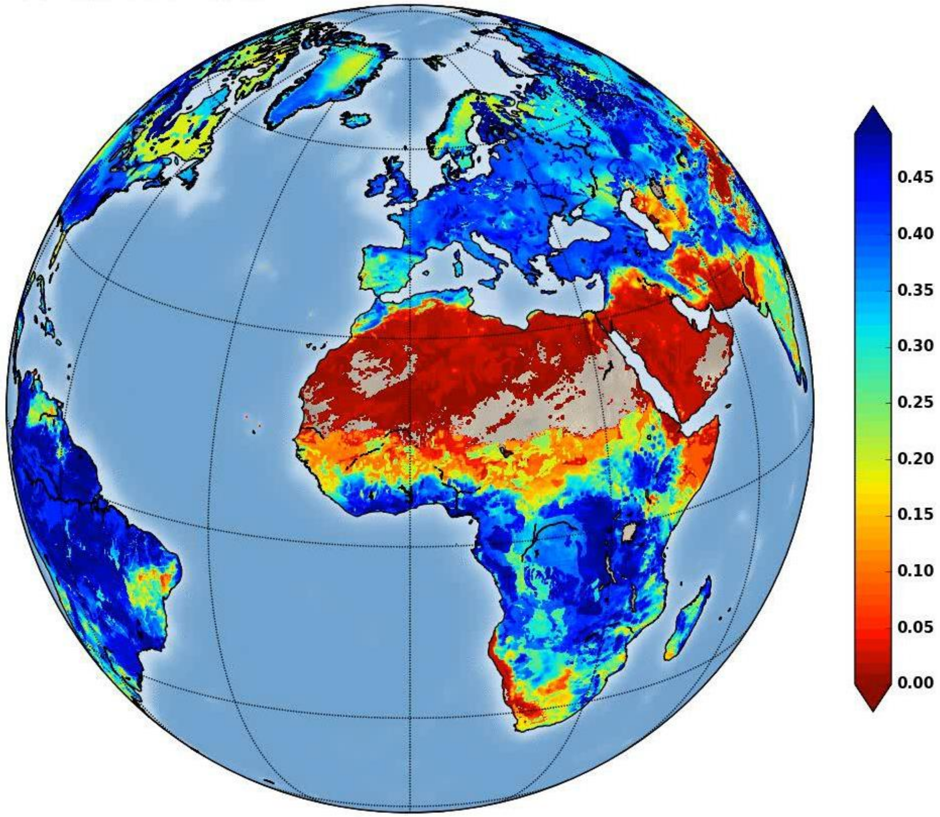
Improved fit
low troposphere



ECMWF

ERA5 reanalysis

ERA5, two operational land products:



Land of ERA5: 31km with coupled land-atm. data assimilation Incl. IMS snow cover and ASCAT soil moisture DA

ERA5-Land: 10km without land data assimilation

	ERA-Int	Era-Int/Land	ERA5	ERA5-Land
Period covered	Jan 1979 – NRT(*)	Jan 1979 – Dec 2010	Jan 1979 - NRT	Jan 1979 - NRT
Spatial resolution	~79km / 60 levels	79 km	~32 km / 137 levels	~9 km
Model version	IFS (+TESSEL)	HTESSEL cy36r4	IFS (+HTESSEL)	HTESSEL cy43r1
LDAS	cy31r1	NO	cy41r2	NO
Output frequency	6-hourly Analysis fields	6-hourly Analysis fields	Hourly (three-hourly for the ensemble)	Hourly (three-hourly for the ensemble)

Hersbach et al., QJRMS 2020

Summary

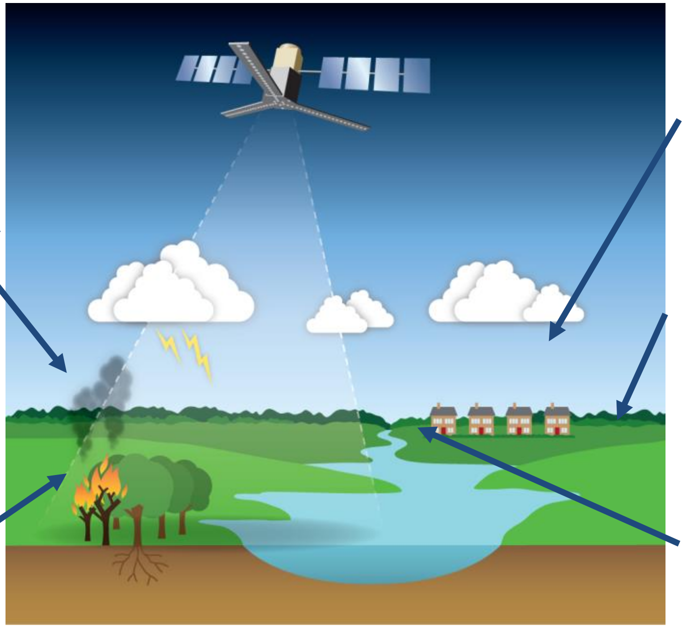
- Coupling developments for land-atmosphere-hydrology-ocean **for NWP and reanalysis**
- Also stand alone (Fairbairn et al. JHM 2019) and offline (Rodriguez-Fernandez et al 2019) land assimilation
- Dvpts: Multilayer model and DA, land surface mapping, SMOS NN DA, EDA-SEKF, VOD DA, SMAP, LST…
- Consistency NWP, hydrology, CO_2 →link to Copernicus Services and link to Modelling and EFAS/GloFAS Teams led by G. Balsamo and C. Prudhomme (Zsoter et al, JHM 2019, Baugh et al Rem Sens 2020)

FIRE

Identify dry lightning ignition potential

Modulation of fire emissions

SMOS biomass load → fuel for burning



FLOOD

SMOS, ERA5, EFAS benchmarking

EFAS (Europe) & GloFAS (global) flood forecast systems initialisation

Flood forecasts and the role of soil moisture excess

Illustration from Francesca Di Giuseppe

Copernicus The European Earth Observation Programme

ECMWF

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)

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