Neural network products in land surface data assimilation

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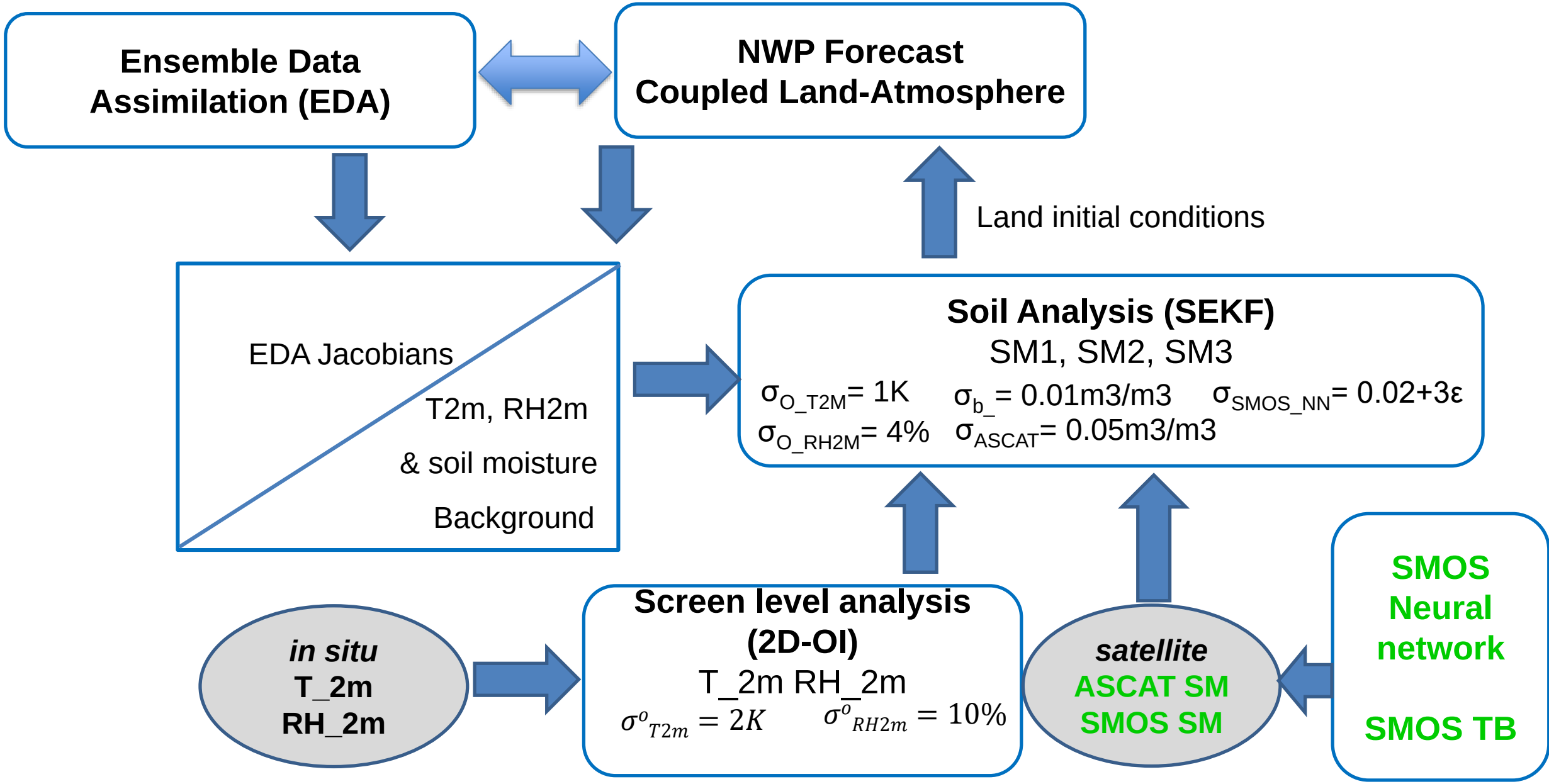
ECMWF

Contents

- Introduction and assimilation context
- SMOS neural network products
- ASCAT neural network
- Conclusions and future work

ECMWF Soil Analysis in IFS



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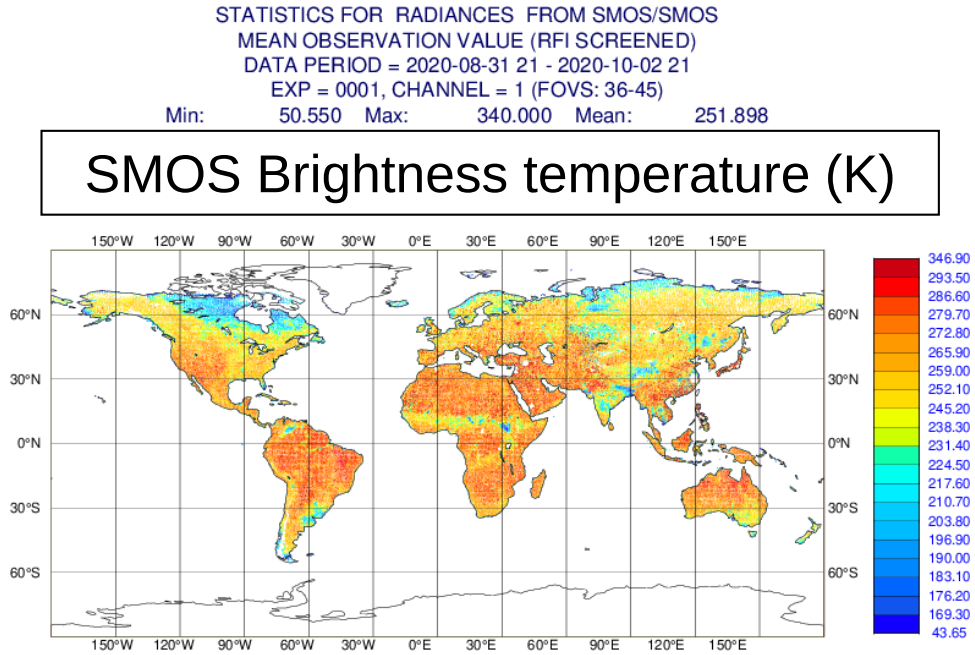
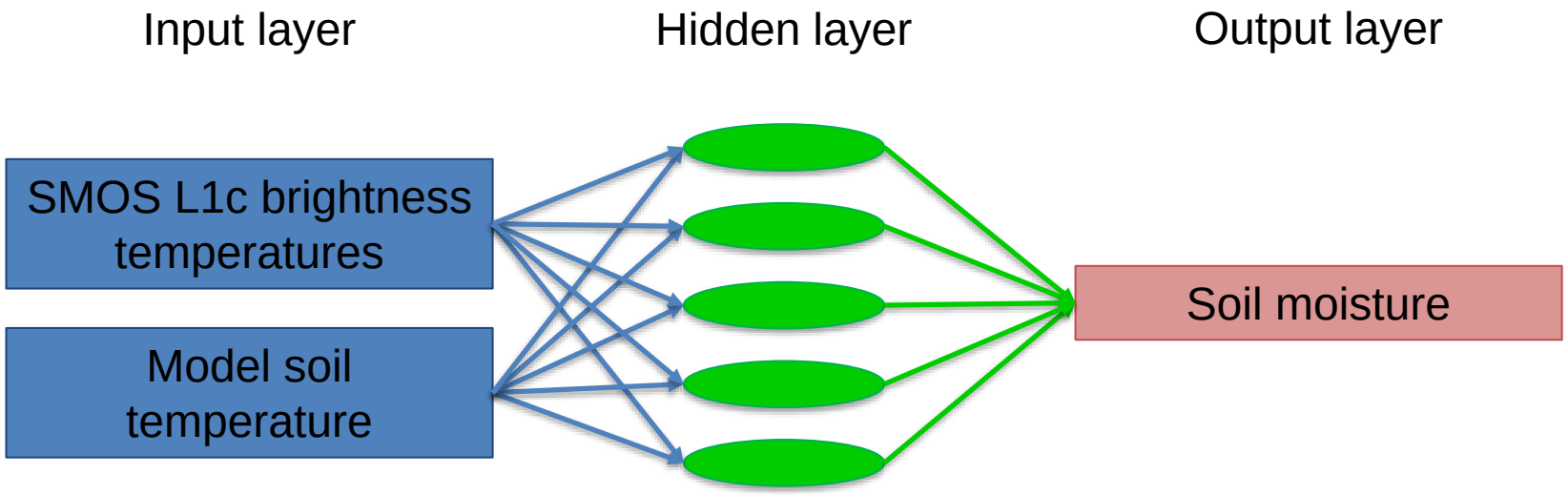
SMOS

- SMOS is the soil moisture and ocean salinity mission
- ESA Earth Explorer satellite launched in 2009
- Passive microwave instrument measuring L-band (1.4 GHz) brightness temperatures
  - Sensitive to ocean salinity and surface wind speed over ocean
  - Sensitive to soil moisture over land
- ESA run a physically based retrieval to produce L2 products including soil moisture
  - There is a considerable delay due to the timeliness of auxiliary input data
- A neural network approach trained on historical L2 soil moisture can be produced much faster



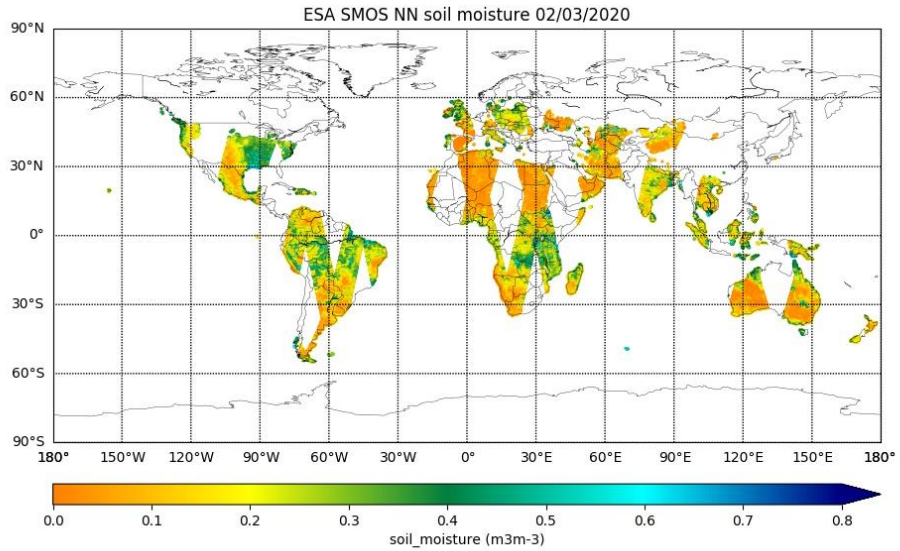
ESA level 2 SMOS NRT Soil Moisture product

Rodriguez-Fernandez et al, HESS 2017



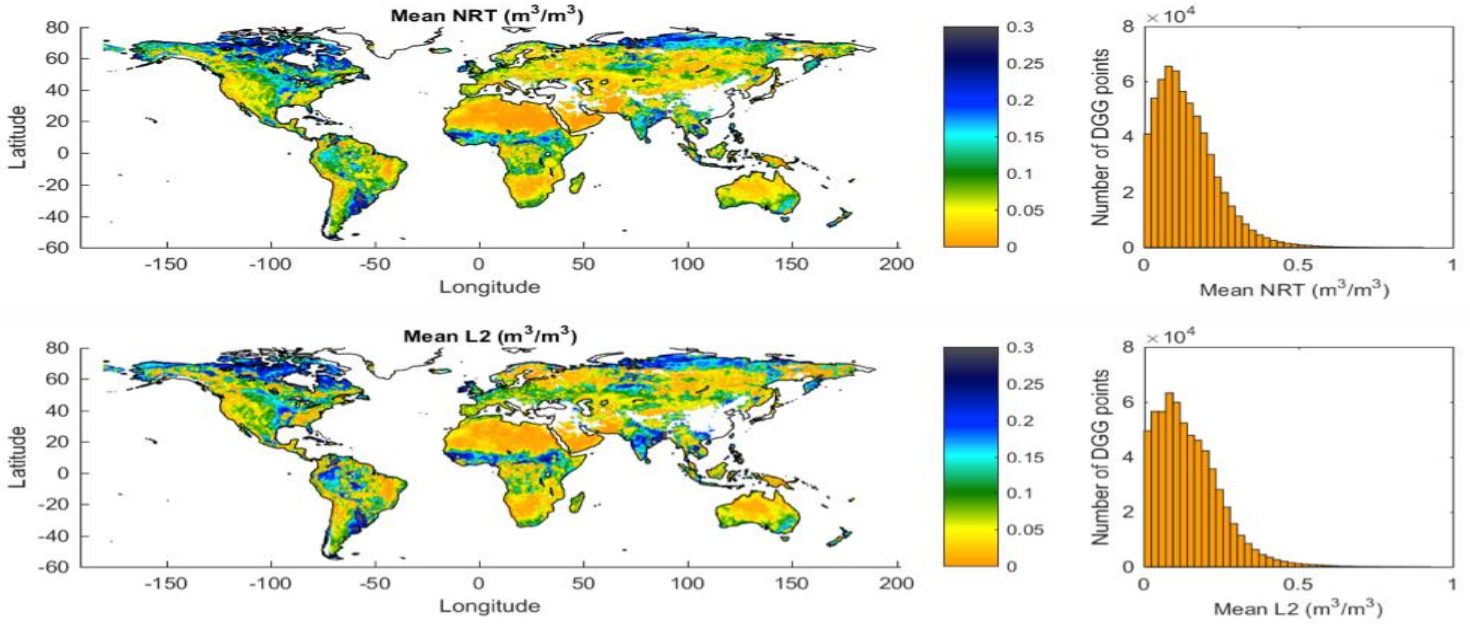
Designed by CESBIO/Estellus, Implemented by ECMWF

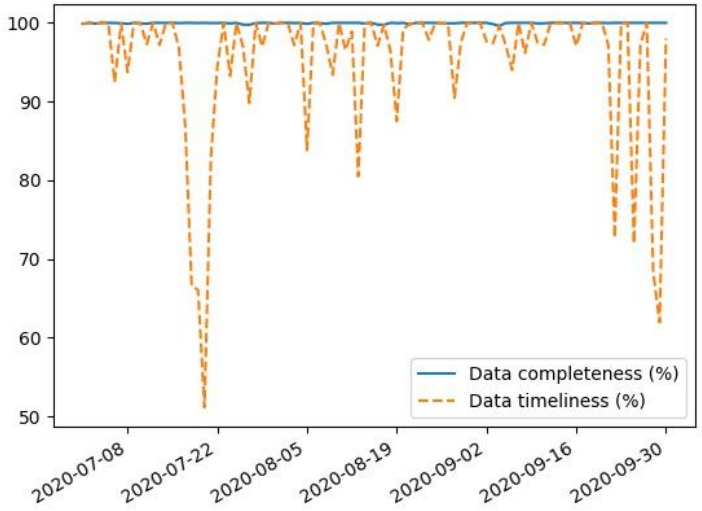
- Neural Network used to retrieve SMOS L2 SM:
  - Trained on SMOS L2 soil moisture
  - Single hidden layer, 5 neurons
- Product available within 30 minutes of receiving SMOS data (< 4 hours of sensing time)
- Available in NetCDF, since March 2016 on ESA SMOS Online Dissemination service *https://smos-ds-02.eo.esa.int/oads/access*



ESA level 2 SMOS NRT Soil Moisture product

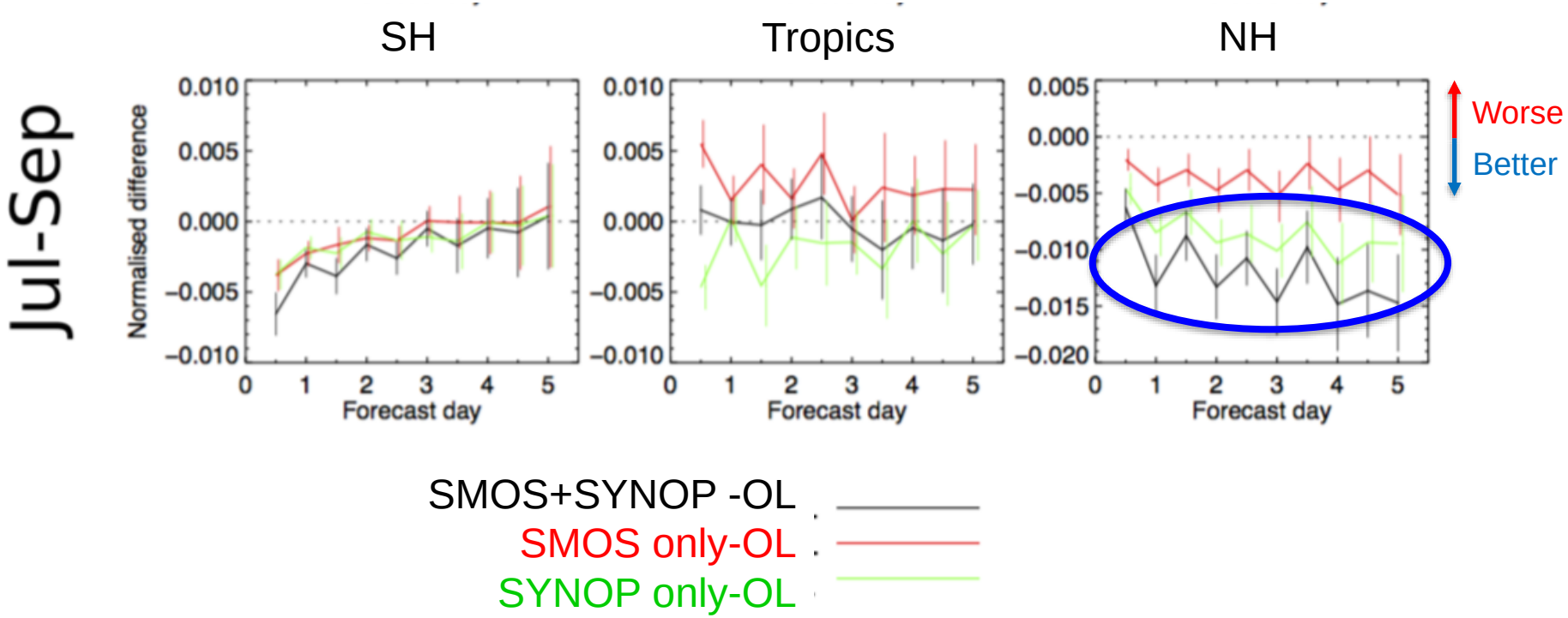
- Neural network outputs agree well:
  - With L2 soil moisture
  - With in-situ stations (USCRN, SCAN) R= 0.71
- Neural network processing run operationally and maintained at ECMWF
  - Completeness and timeliness of dissemination monitored
- Currently working with CESBIO to re-train the NN using newly re-processed SMOS data





SMOS Neural Network SM assimilation in H-TESSEL

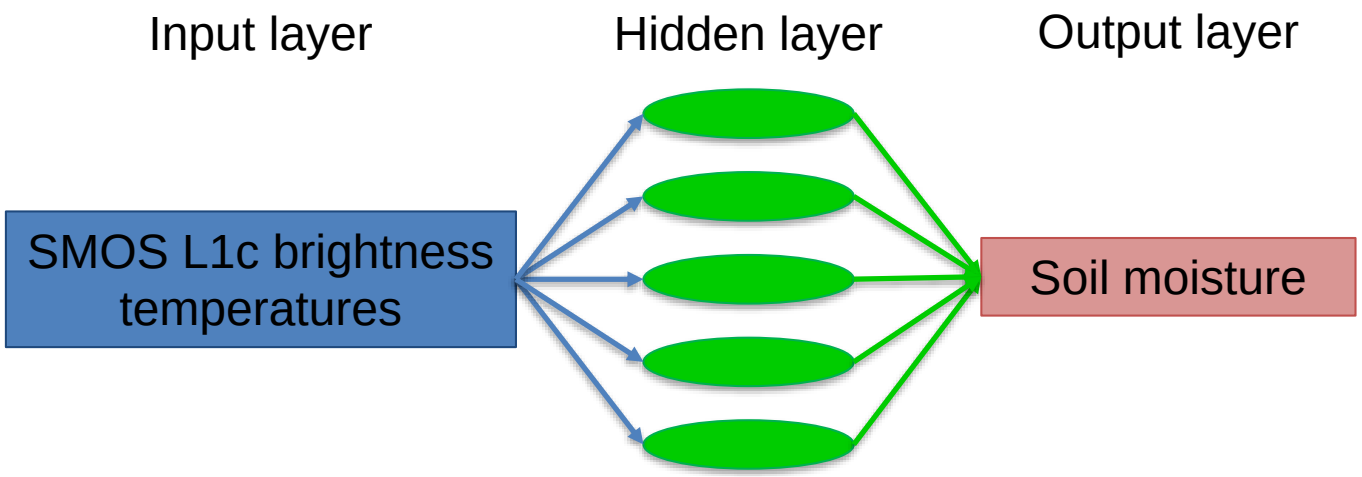
- First experiments assimilating a SMOS neutral network product
- Offline assimilation in H-TESSEL and initialisation of stand-alone atmospheric forecasts (2012)
- Reference H-TESSEL with no assimilation: Open Loop (OL)
- Impact on two-meter air temperature forecasts (JAS 2012)

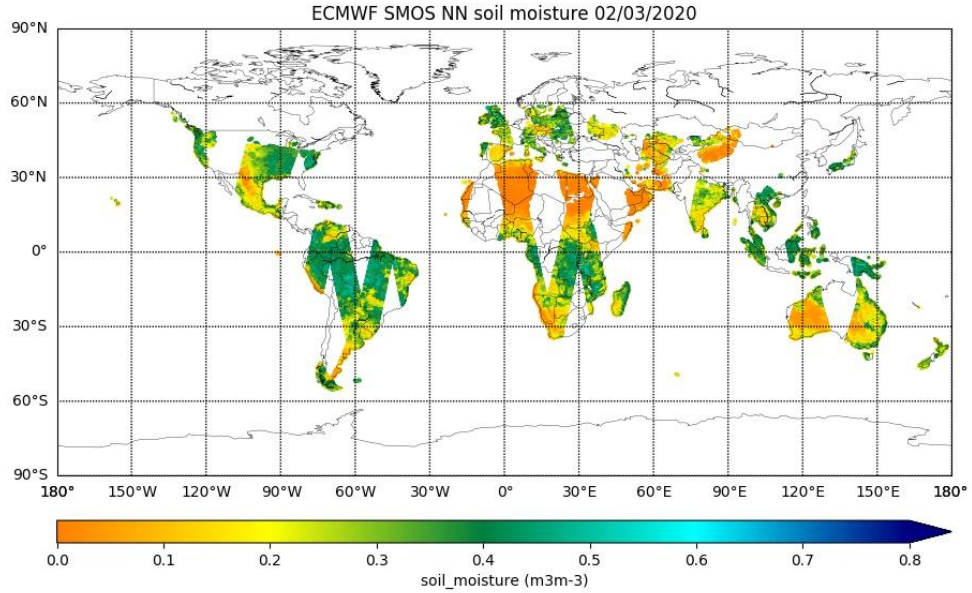


→ Proof of concept of SMOS NN assimilation for NWP initialisation

Rodriguez-Fernandez et al, Remote sensing, 2019

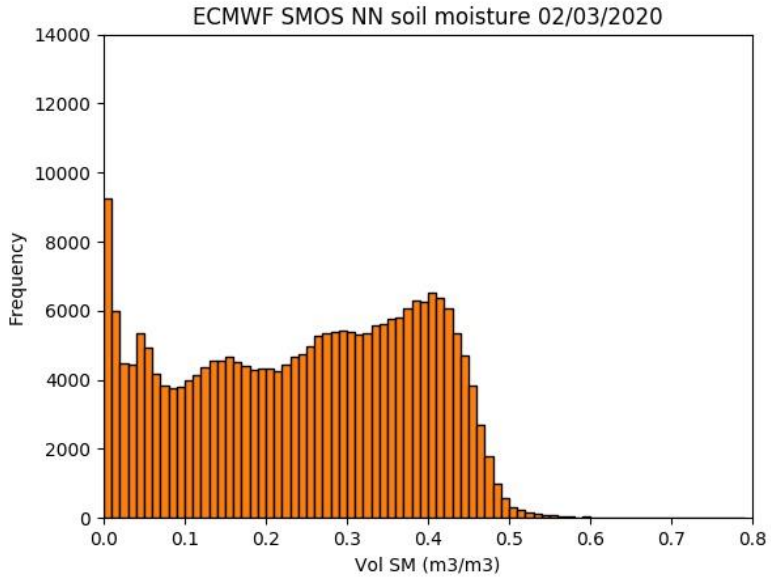
ECMWF level 2 SMOS Neural Network soil moisture (2018)
For data assimilation purposes



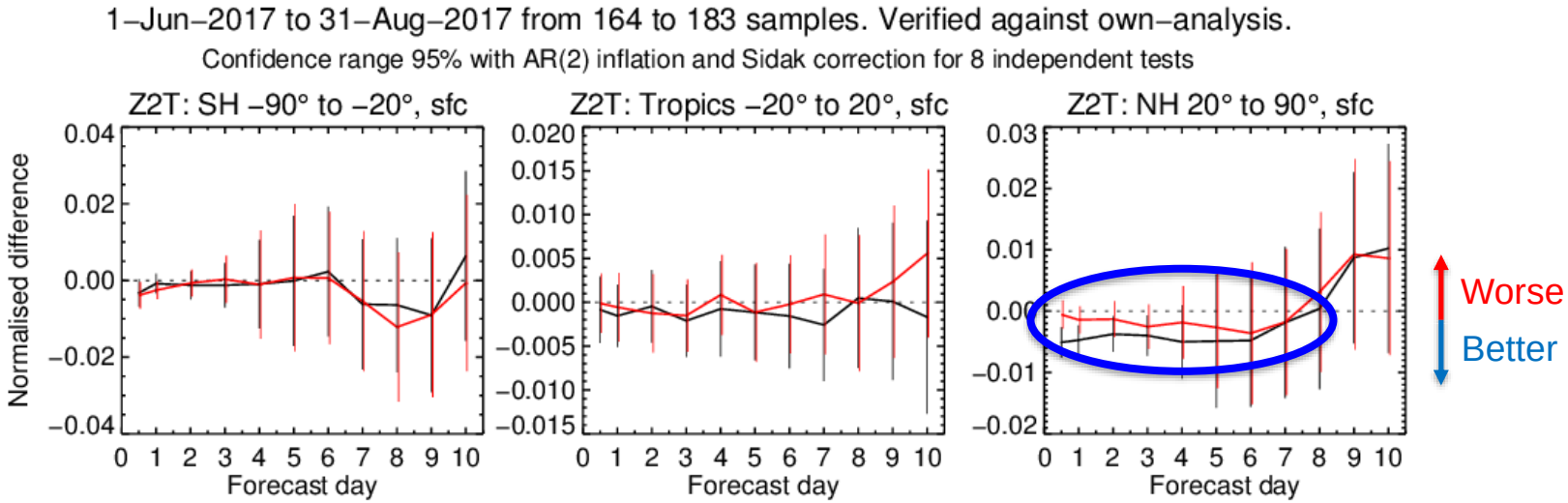


- Neural Network trained on ECMWF model soil moisture:
  - SMOS soil moisture with no bias compared to ECMWF model soil moisture
  - NRT availability
- Suitable for data assimilation

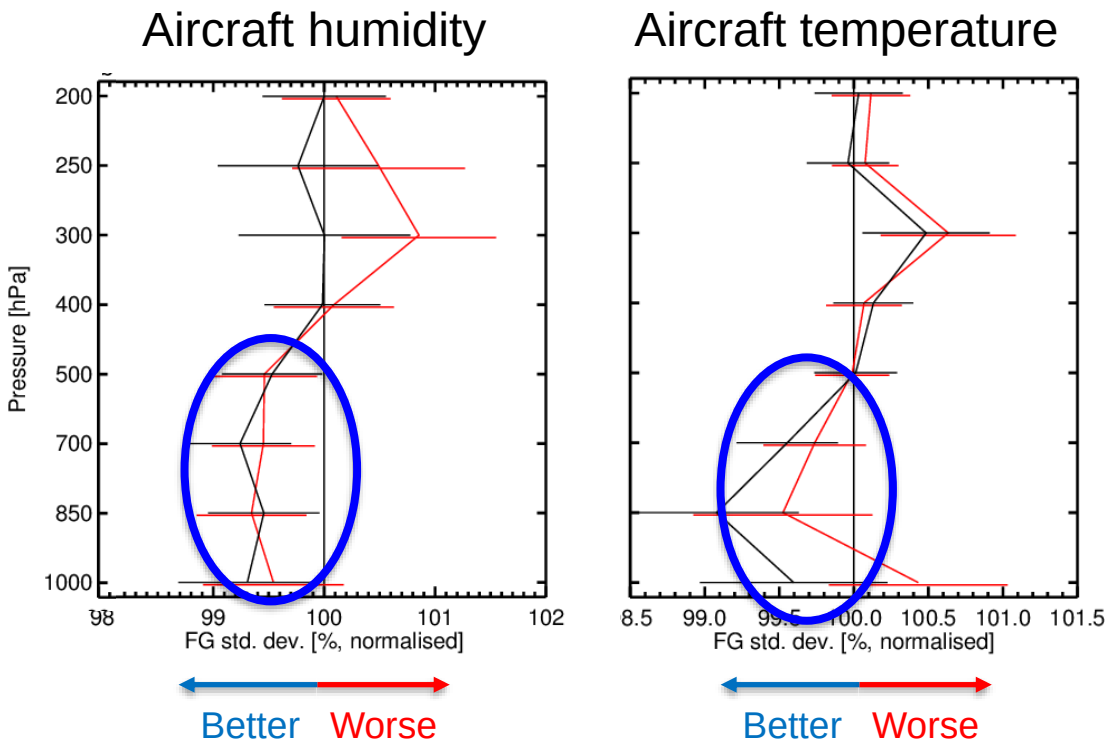
- Assimilated into the ECMWF SEKF land-surface analysis since June 2019



SMOS NN DA impact



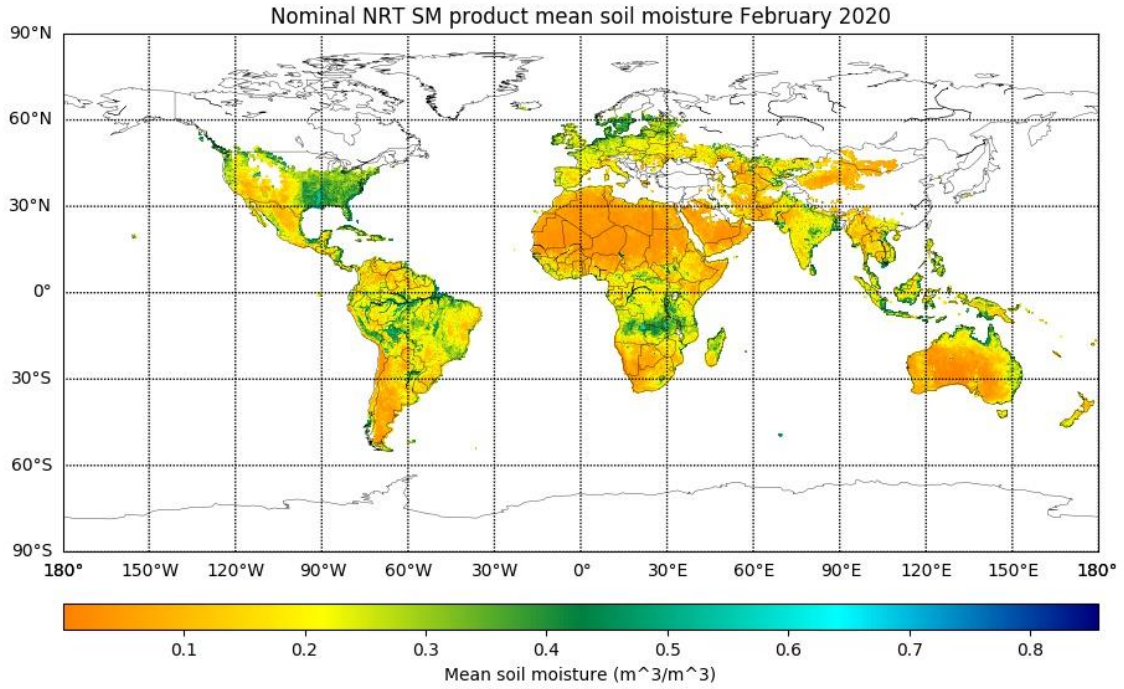
- Results from assimilating soil moisture from SMOS in coupled land-atmosphere forecasting system:
  - Neutral/slightly positive impact on T2m in the Northern hemisphere
  - Improved first-guess fits to aircraft humidity and temperature in lower troposphere



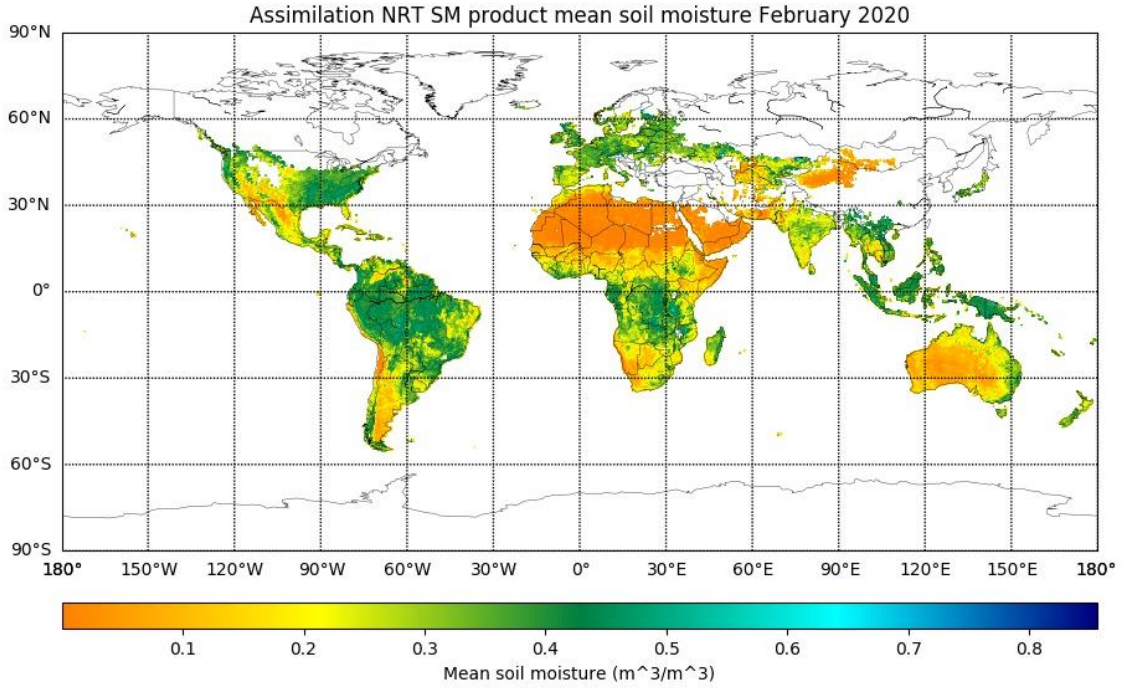
SMOS NN nominal and assimilation soil moisture comparisons

- Monthly means - February 2020
- Same observation inputs but trained on datasets with different characteristics
  - Can be used to diagnose model biases and inconsistencies between SMOS L2 and ECMWF model soil moisture

Nominal



Assimilation



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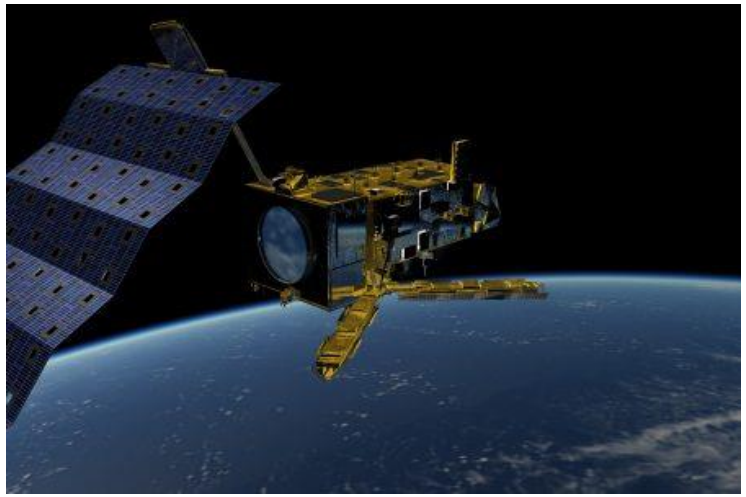
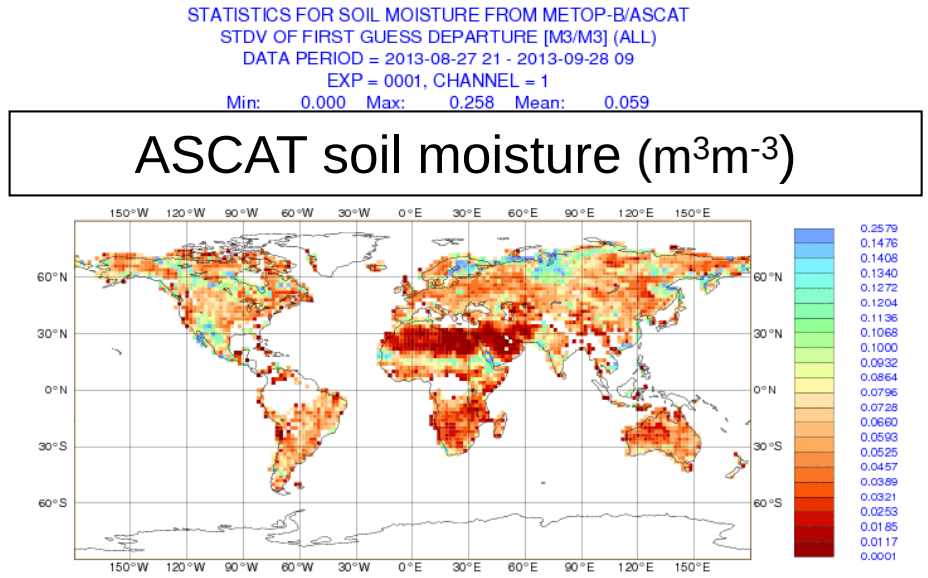
ASCAT

- ASCAT is the Advanced Scatterometer
- On MetOp-A (2006-), MetOp-B (2012-), MetOp-C (2018-)
- EUMETSAT operational satellites
- Active microwave instrument measuring C-band (5.6GHz) backscattering coefficient
  - Sensitive to surface wind-speed over ocean
  - Sensitive to root-zone soil moisture over land
- Level 2 soil moisture product assimilated into SEKF



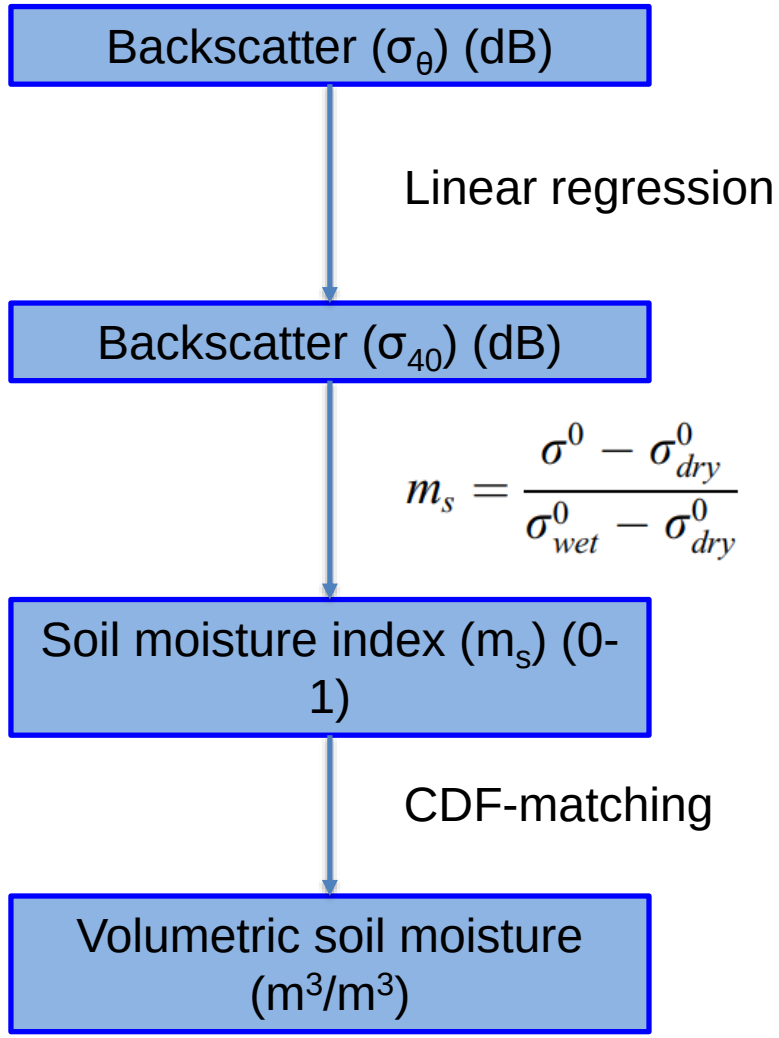


From backscatter to soil moisture

Wagner et al, Remote Sens. Environ., 1999

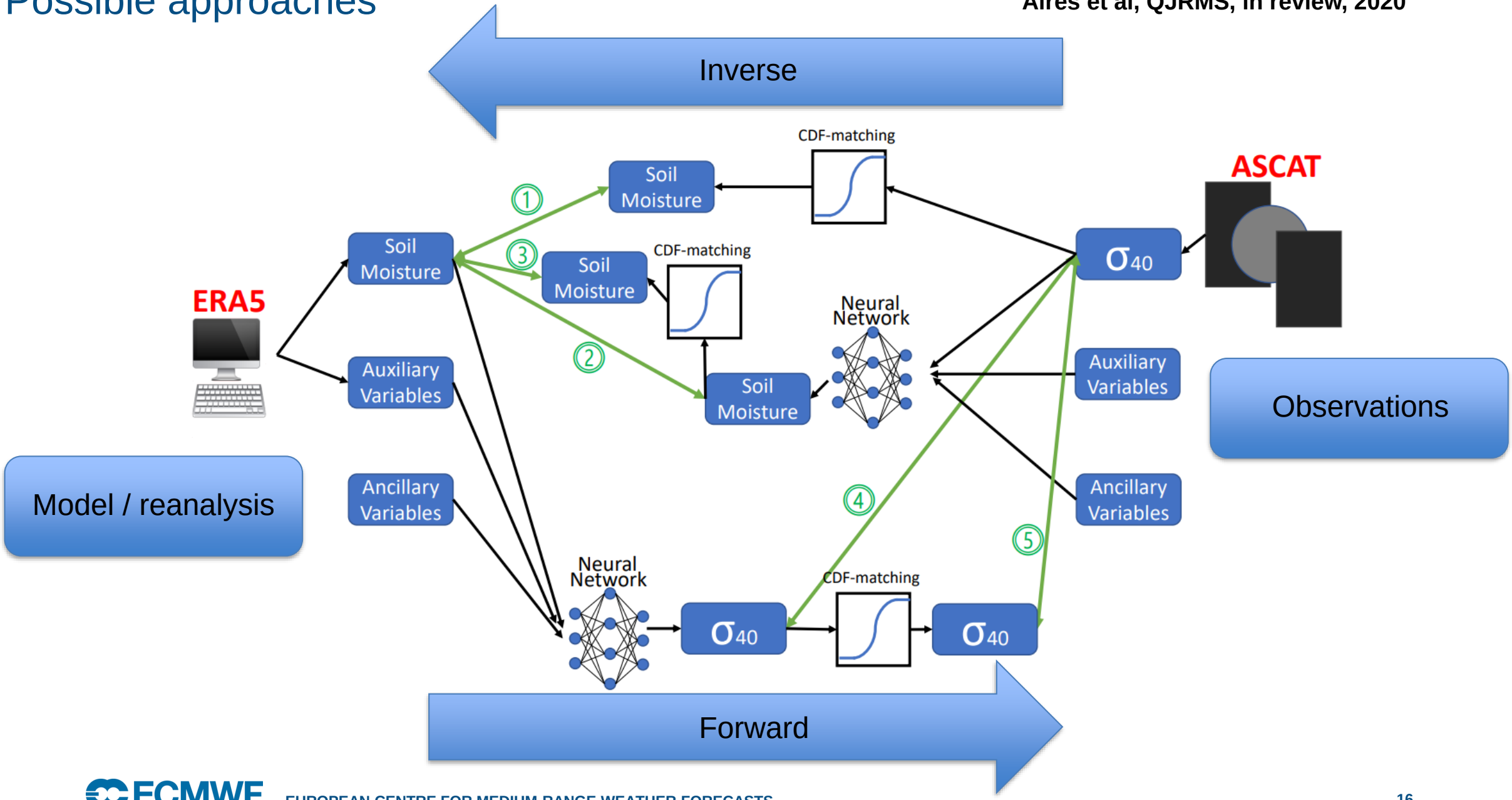
- Modern approach is to assimilate L1 measurements (backscatter) where possible:
  - Requires fast and accurate observation operator, not currently available

- Alternative approach is to retrieve soil moisture (L2 product) and assimilate this:
  - Wagner approach plus CDF-matching
  - Neural network
  - Neural network plus CDF-matching



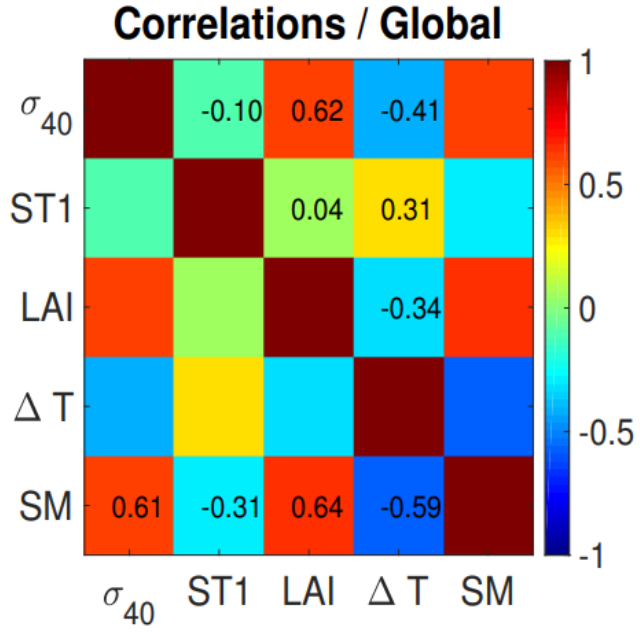
Possible approaches

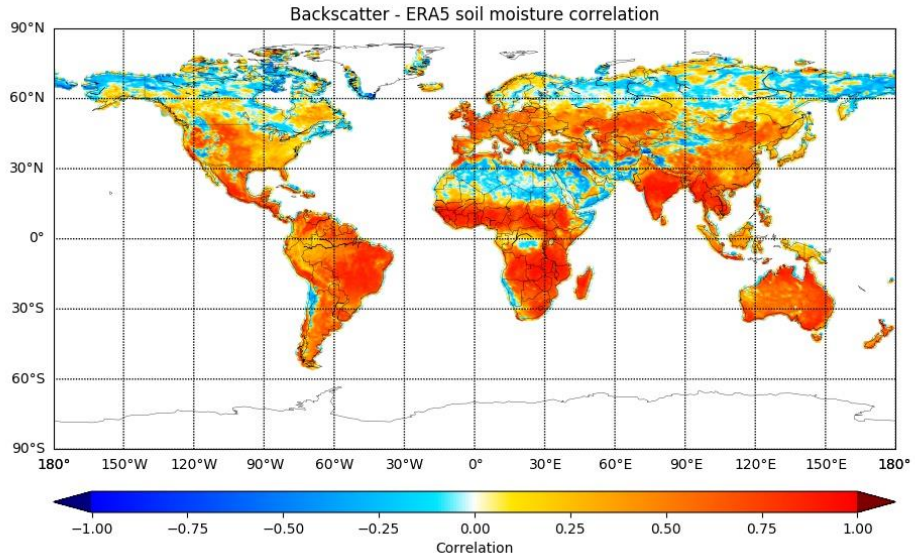
Aires et al, QJRMS, in review, 2020



ASCAT neural network setup

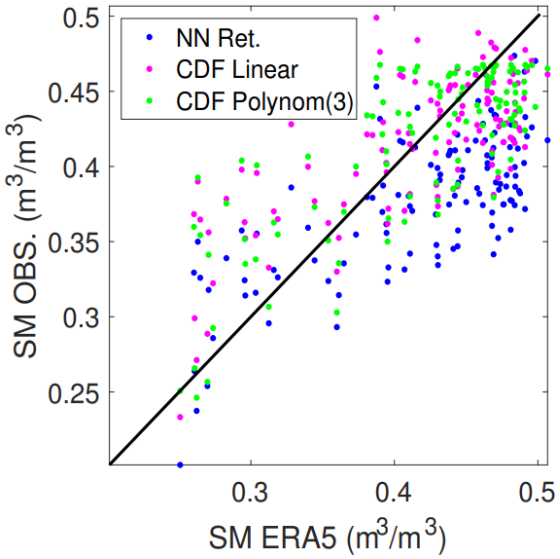
- Inputs (features):
  - ASCAT backscatter at 40 degree incidence angle
  - ERA5 soil temperature in layer 1 (0-7cm)
  - ERA5 leaf area index
  - ERA5 magnitude of the diurnal cycle of 2 metre temperature
- Target:
  - ERA5 volumetric soil moisture in layer 1 (0-7cm)
- Single hidden layer with 10 neurons
- Sampling/quality control:
  - 2016-2019 (60% training, 20% testing, 20% validation)
  - Land-sea mask > 0.95
  - Avoid frozen surfaces, wetland, mountainous areas



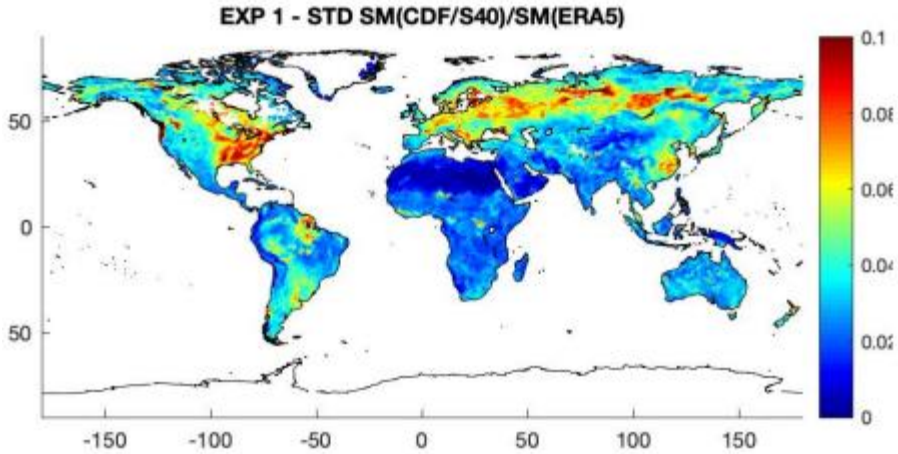


Preliminary validation results

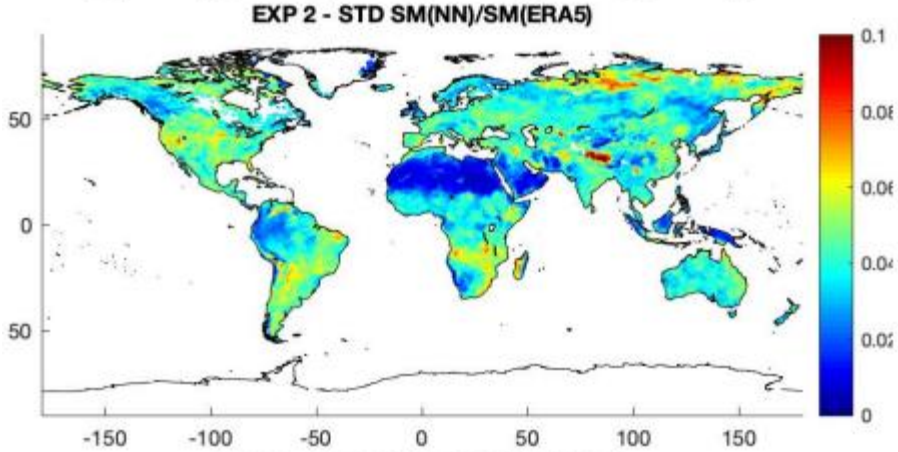
- Pure CDF-matching works best:
  - Over tropics, Southern extra-tropics
  - Smallest biases
- Neural network better:
  - Over Northern extra-tropics
- NN + CDF-matching reduces biases compared to NN only



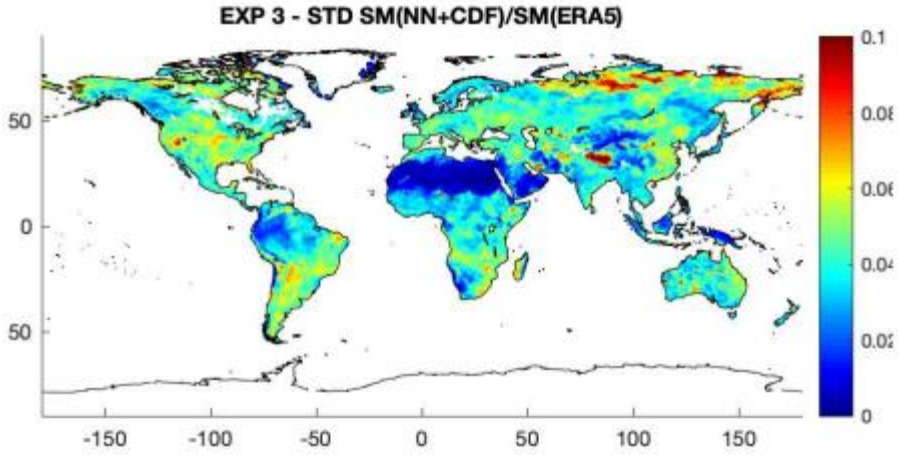
1: CDF-matching



2: Neural network



3: NN + CDF



Contents

Conclusions and future work

- SMOS neural network:
  - Nominal neural network product provides timely soil moisture information
  - Assimilation of neural network product improves T2m and short-range near-surface humidity forecasts
  - Re-training using latest re-calibrated SMOS data
- ASCAT neural network:
  - Aires et. al. (2020), QJRMS, in review:
    - Promising initial ASCAT neural network results for inversion
    - Comparison between NN, CDF-matching and combined methods
  - HSAF visiting scientist mission by F.Aires in 2021:
    - Further development and evaluation
    - Assimilation experiments
  - New soil moisture product planned for HSAF CDOP-4
  - Development of an observation operator for direct backscatter assimilation