SMOS Neural Network Soil Moisture Data Assimilation

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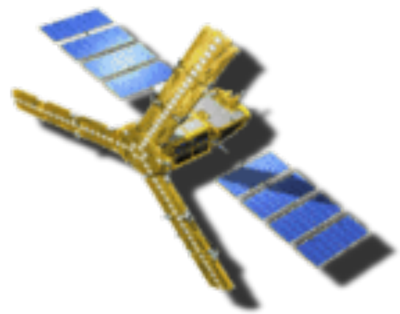
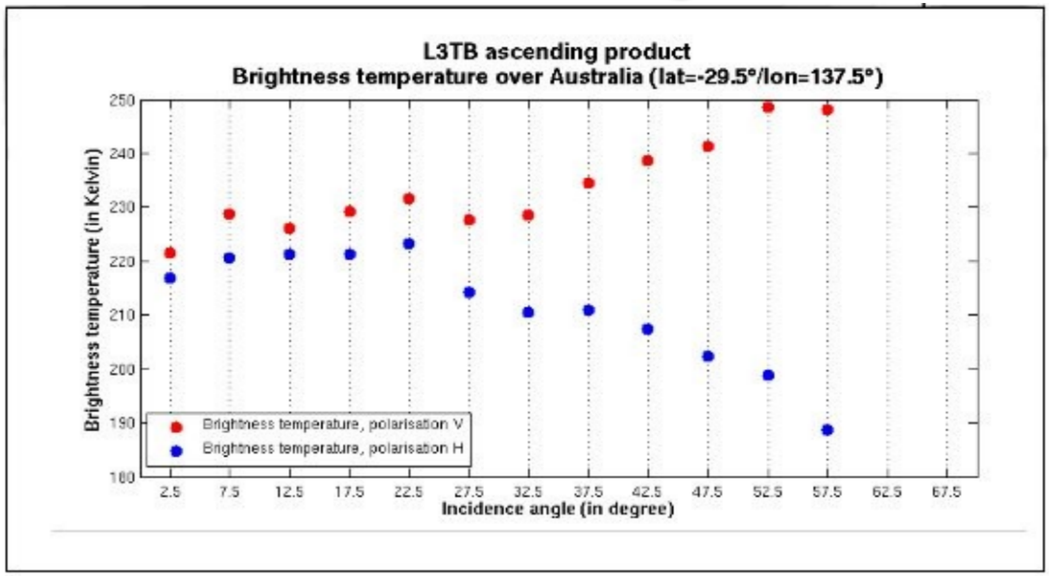
Soil Moisture and Ocean Salinity (SMOS)

- **Passive radiometer at L-band (1.4 GHz, 21 cm)**
  Full polarimetric and multi incidence angle capabilities (0º-60º)
- **Aperture synthesis**
  - 69 antennas, 4 meters arms -> resolution of a ~ 7 m antenna ~43 km (FWHM)
- Global coverage. Maximum revisit time of 3 days (equator). Overpasses 6 AM/6PM (Ascending/descending).



L-Band thermal emission

- Negligible attenuation by atmosphere
- Sensitivity to changes of surface temperature and roughness, soil moisture and ocean salinity
- Low attenuation due to vegetation
- Probes larger depth of the surface soil layer than shorter wavelengths
- Absolute values of soil moisture



Forward modeling / observation operator

Measured brightness temperature

Comparison and new modeling step if needed for SM retrievals or bias-correction for assimilation

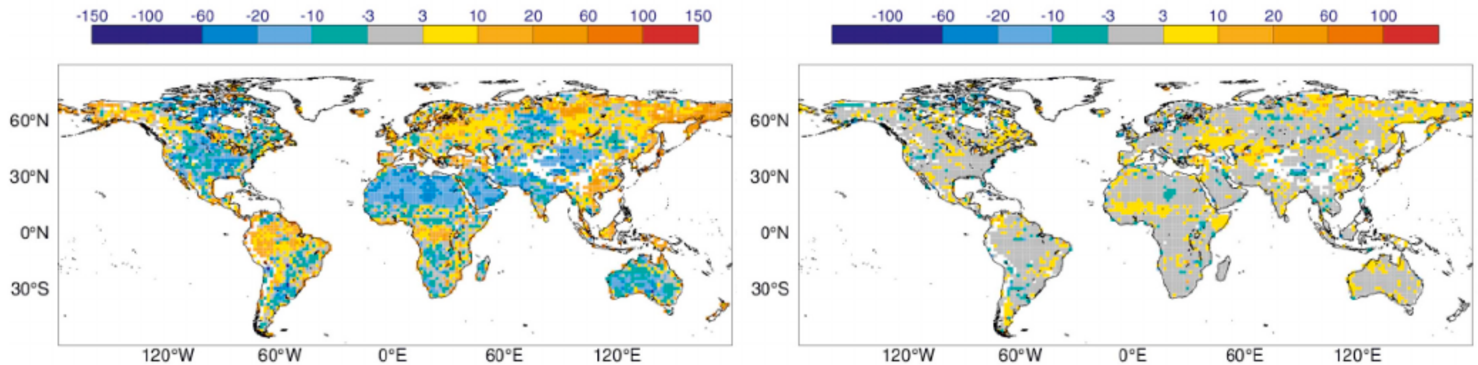
Modeled brightness temperature

Radiation transfer: CMEN, L-Meb…

Soil parameters: moisture, temperature, roughness land cover…

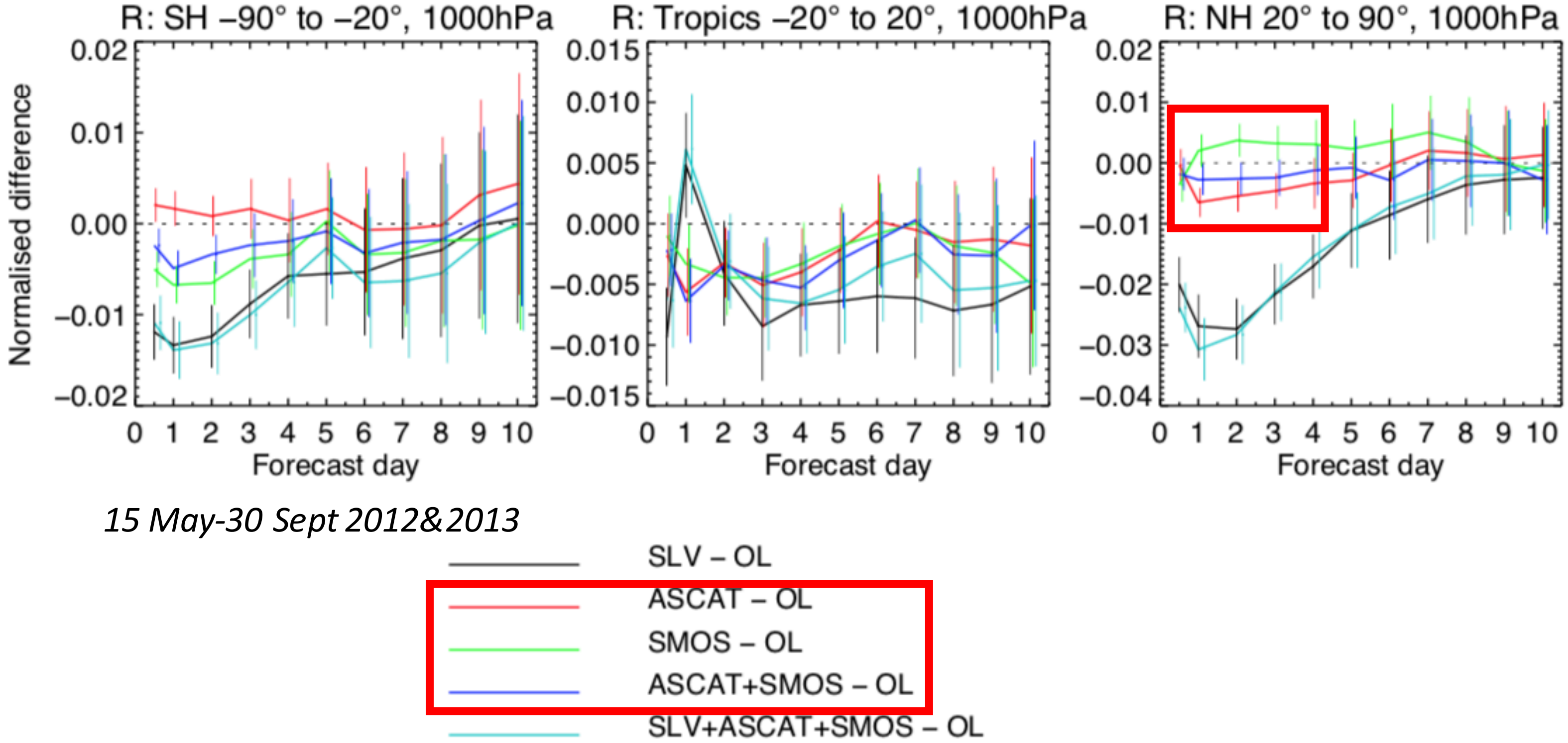
Retrievals
- SMOS L2 SM, Kerr et al. (2012, TGARS)
- SMOS L3 SM, Al Bitar et al. (2017, ESSD)
- SMOS INRA-CESBIO Fernandez-Moran et al. (2017)

SMOS Tb monitoring and data assimilation experiments
- Munoz Sabater et al. (2019, QJRMS)
- De Rosnay et al. (2020, RSE)



(b) Bias (Observation - Model) (K) **De Rosnay et al. (2020, RSE)**

Assimilation of SMOS TB (atmospheric impact)



15 May-30 Sept 2012&2013

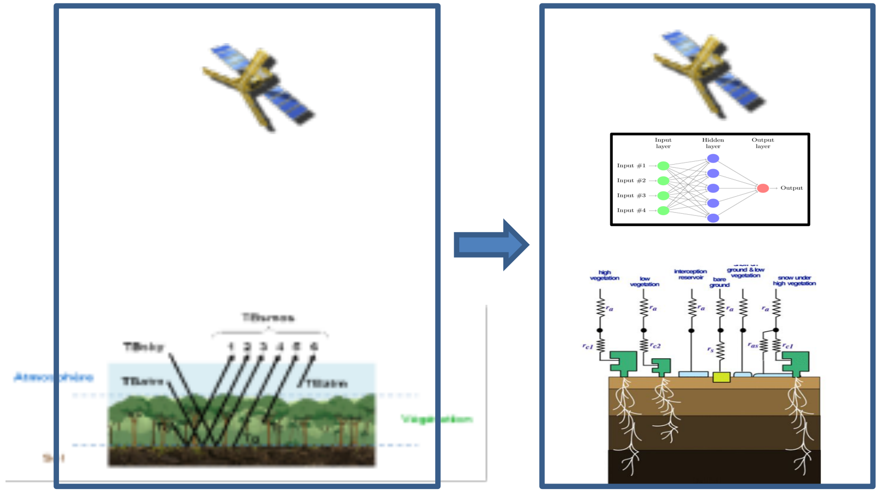
Muñoz-Sabater et al., 2019 QJRMS

- Mostly neutral impact on atmospheric states
- Slight degradation of air humidity in NH with SMOS TB assimilation only: pattern in the Great Plains where SM was improved → model inconsistency between SM and air humidity

Towards a new generation of satellite surface products ? Soil moisture, skin temperature,...

Land surface models within NWP models show outstanding performances when comparing to in situ measurements of SM
Albergel et al. (2012), Kerr et al. (RSE, 2016), Dorigo et al. (2013), Rodriguez-Fernandez et al. (2016)

Instead of computing the complex radiation transfer trough the biosphere why not linking directly the best remote sensing observations to the best NWP models ?
Prigent & Aires 2006, JGR; Prigent, Aires, et al. 2005, JGR



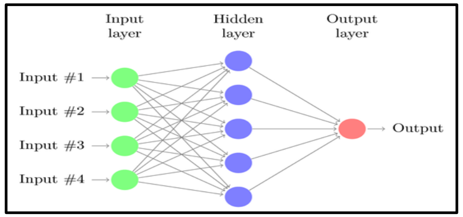
One interesting application will be efficient Data Assimilation. The retrieved datasets are similar to the model fields, by construction, but they are driven by the remote sensing input data *Aires, Prigent, Rossow 2005, JGR*

Neural network SM can be produced **in near-real-time** and **with associated errors** *Rodriguez-Fernandez et al. (2017, HESS)*

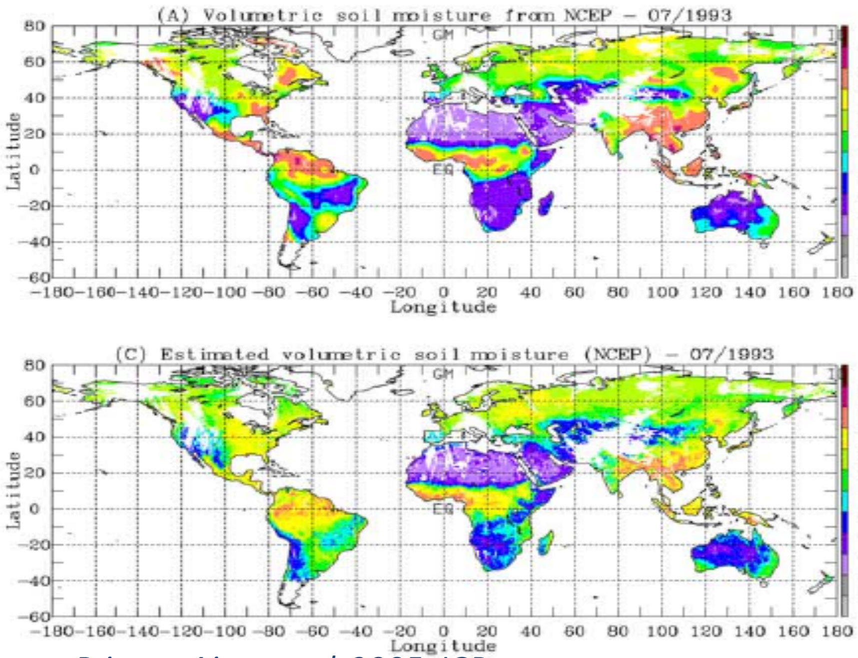
Global retrieval of soil moisture using neural networks

Neural networks can also be used to develop a new retrieval algorithm linking remote sensing observables to global soil moisture simulated fields from NWP models.

***Monthly means of*: ERS, SSM/I, NDVI (AVHRR), Tskin (ISCCP)**



Soil moisture

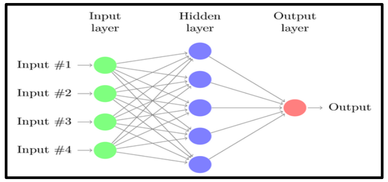


Prigent, Aires, et al. 2005, JGR
Aires, Prigent, Rossow 2005, JGR

Training with NCEP or ECMWF models

Statistical retrievals using Neural Networks

Input data: SMOS TBs,...



NN soil moisture

Training: comparison and new modeling step if needed

Soil moisture reference (depends on the goal)

- Surface models (Rodriguez-Fernandez et al. 2015, TGARS)
- Radiation transfer simulations (Rodriguez-Fernandez et al. IGARSS 2017a)
- In situ measurements (Rodriguez-Fernandez et al. IGARSS 2017b)
- SMOS Level 2 SM (Rodriguez-Fernandez et al. 2017, HESS)

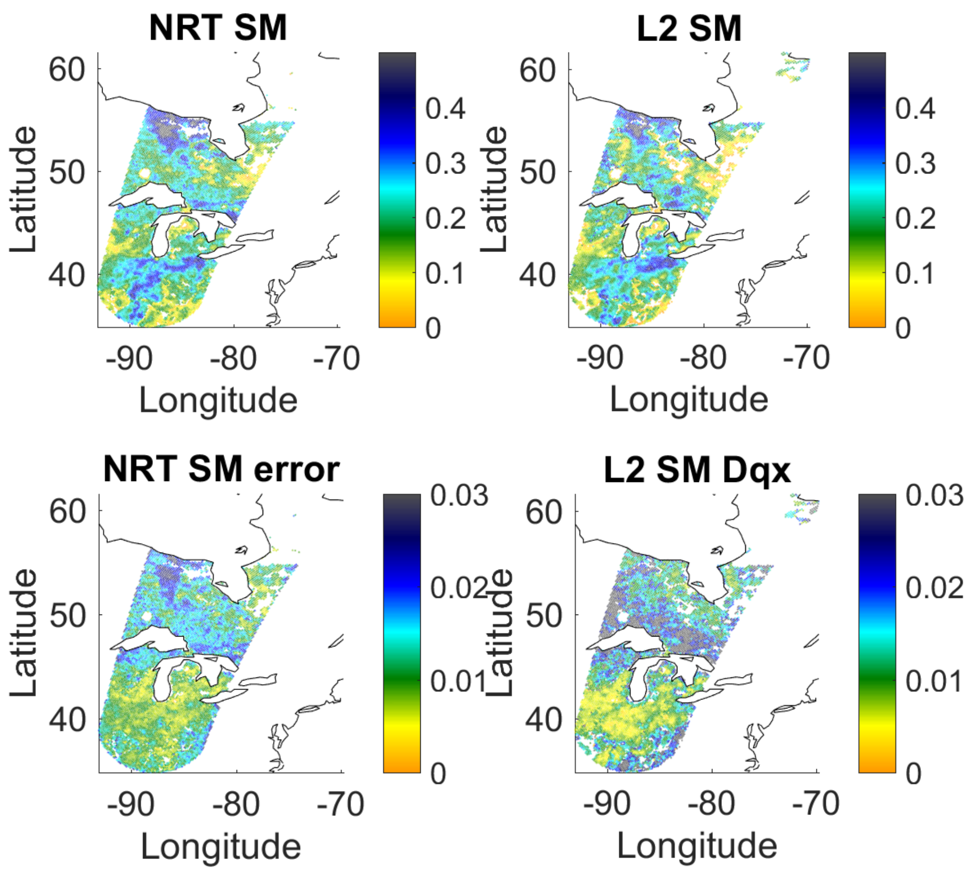
Test different input data

Adapt NN weights

No global bias with respect to the reference data

Once trained, the NN output is only driven by the remote sensing input data

ESA neural net near-real-time soil moisture



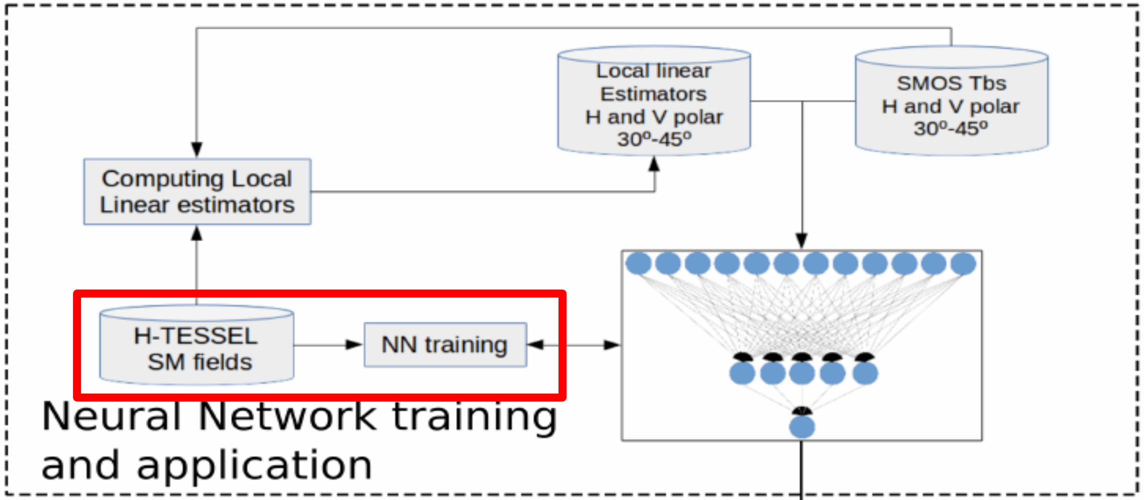
SMOS ESA NRT SM

- Training on SMOS Level 2 SM
- Includes error estimation
- Disseminated by ESA and EUMETCast since 2016
- Maximum latency: 3.5 hours

(Rodriguez-Fernandez et al. 2017, HESS)

- Similar to SMOS L2 SM but available in NRT for your operations applications

An offline SMOS NN SM DA experiment



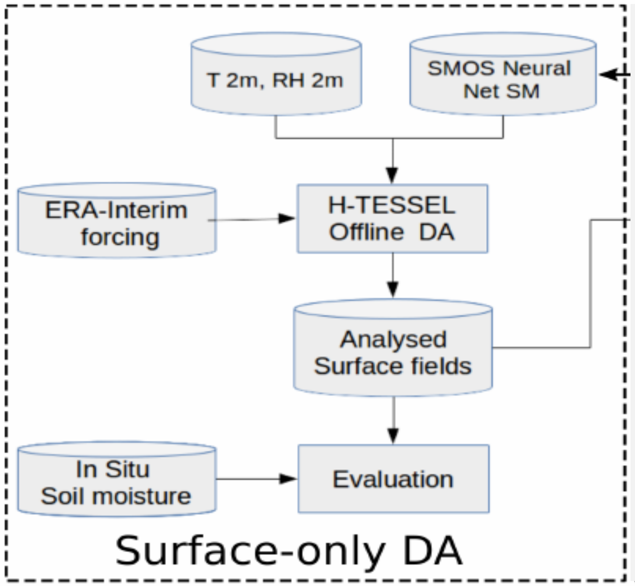
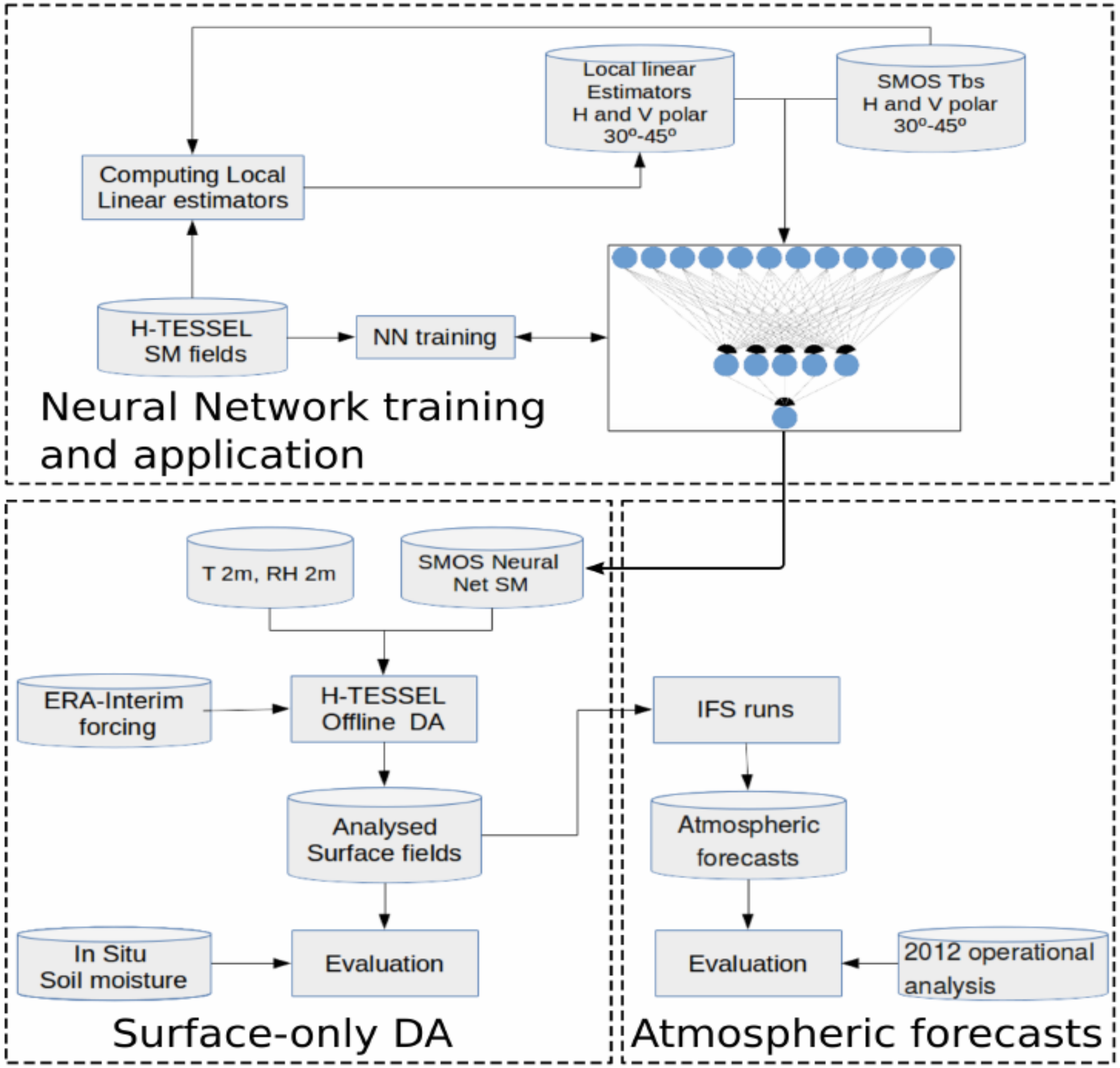


Table 2. Comparison of the IFS Land Data Assimilation System (LDAS) and the surface-only LDAS.

	IFS-LDAS	so-LDAS
Assimilation technique	SEKF	SEKF
Assimilation window	12 h	24 h
Surface-atmosphere coupling	fully coupled	uncoupled, surface forced by ERA-Interim
Observation input grid	independent of the model grid	Same grid as the model grid
Analysis	RH_{2m}, T_{2m}, SM, soil temperature, snow cover and snow temperature	SM
Observation input	RH_{2m}, T_{2m}, ASCAT SM, LST, snow cover and snow temperature, SMOS TBs (in development)	RH_{2m} and T_{2m} analysed with IFS-LDAS, ASCAT SM, SMOS SM
Increment applied	analysis time	Initial time step and additional trajectory
Background error	0.01 m^3m^{-3}	5% of water holding capacity

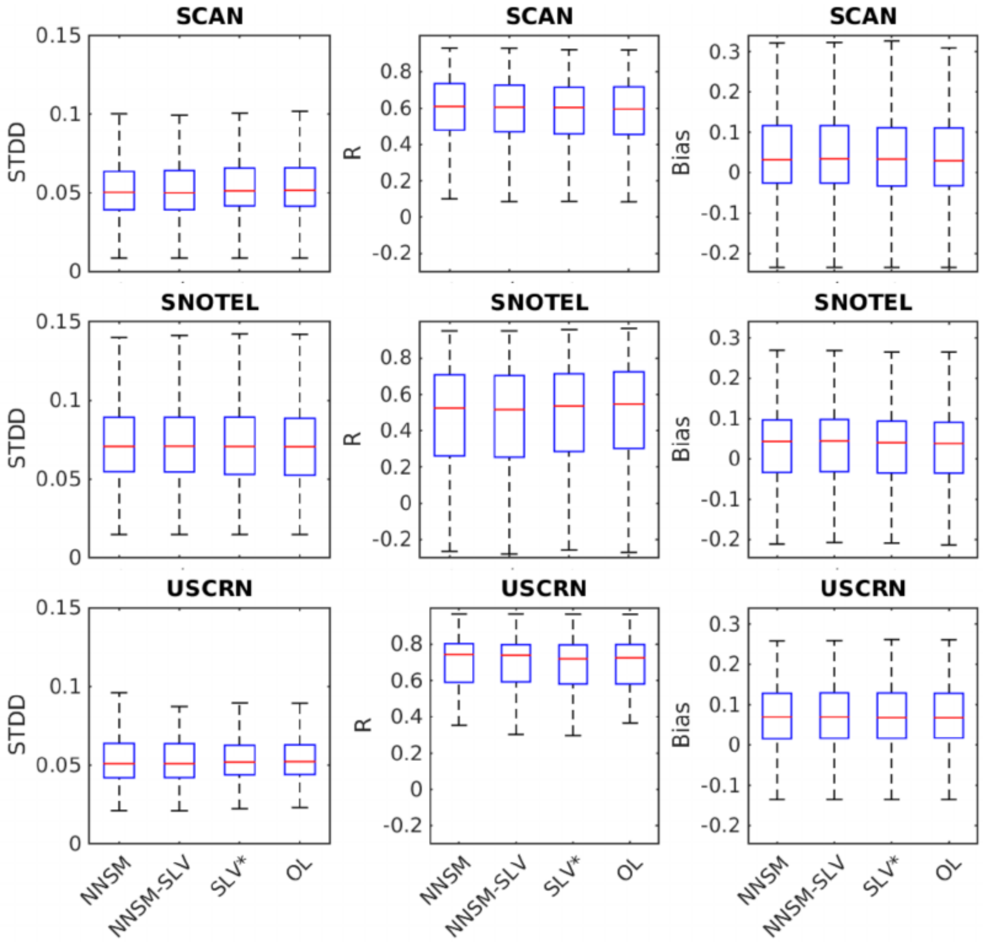
An offline SMOS NN SM DA experiment

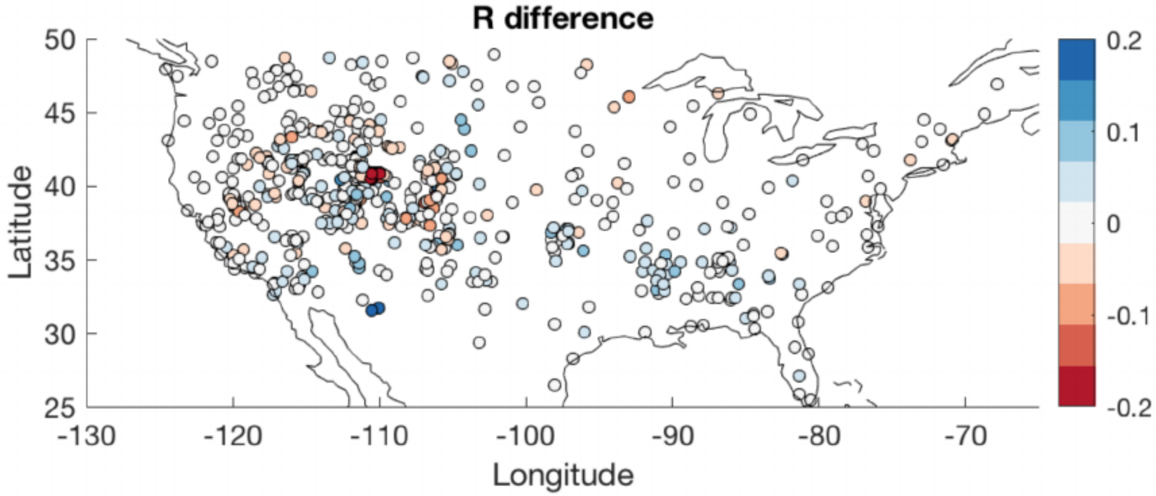


- **Experiments**

Label	SM	σ_{SM}	SLV
OL	no	...	no
NNSM	yes	$3 \times \sigma_{NN}$	no
NNSM-SLV	yes	$3 \times \sigma_{NN}$	yes
$NNSM_{LW}$	yes	$9 \times \sigma_{NN}$	no
SLV*	yes	$9 \times \sigma_{NN}$	yes

NNSM DA: evaluation against in situ SM

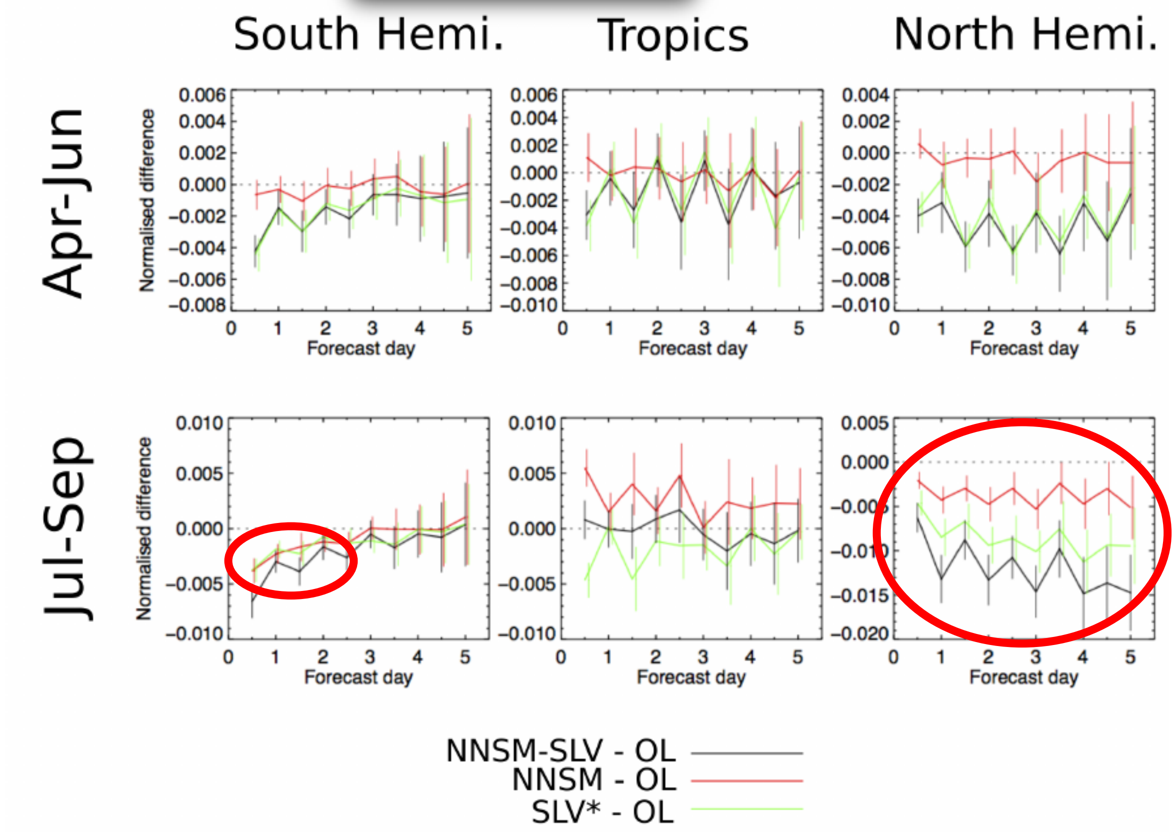




- Small impact on surface SM at the positions with in situ measurements … where models are already strongly constrained by conventional observations

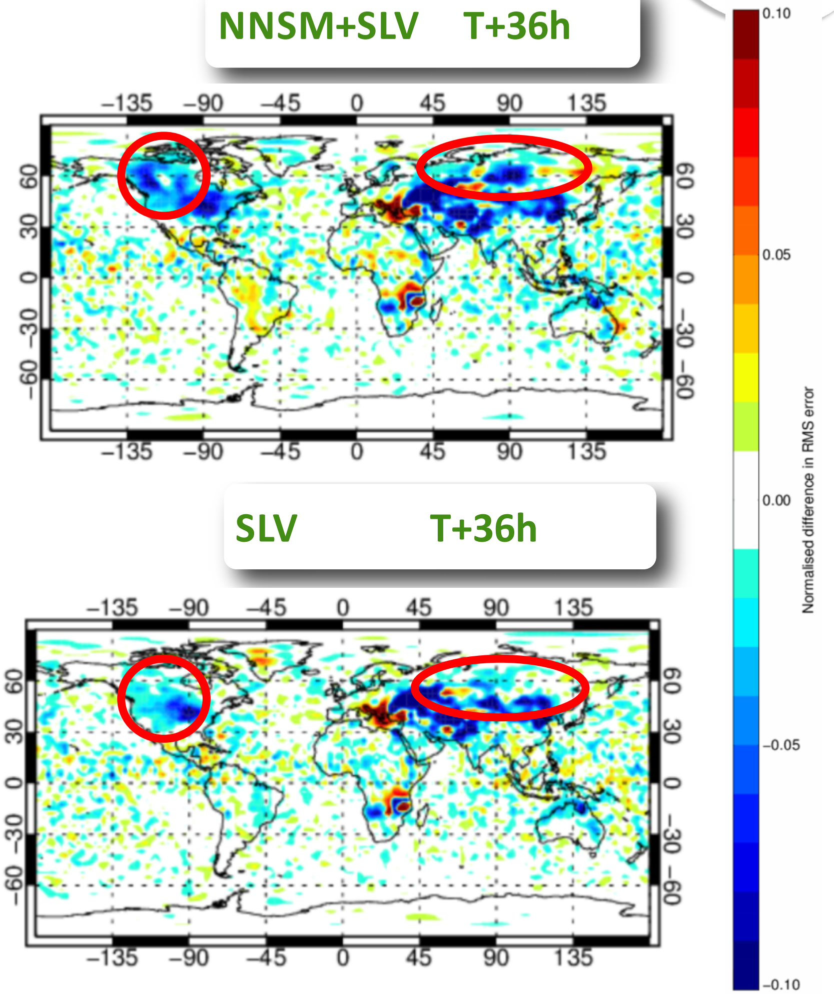
NNSM DA: evaluation of atmospheric forecasts using the surface analysis

- T 2m



NNSM+SLV T+36h

SLV T+36h



A specific NRT SMOS SM for DA

- Polarizations: H and V
- Incidence angles: three bins 30-35, 35-40, 40-45
- Brightness temperatures (BTs)
- Local linear estimators, index *I2,* computed from extreme BTs

$$I_{1_{\lambda\phi}}(t) = \frac{T_{\mathrm{b}_{\lambda\phi}}(t) - T^{\min}_{\mathrm{b}_{\lambda\phi}}}{T^{\max}_{\mathrm{b}_{\lambda\phi}} - T^{\min}_{\mathrm{b}_{\lambda\phi}}} \qquad I_{\lambda\phi}(t) = \mathrm{SM}^{T_{\mathrm{b}}^{\min}}_{\lambda\phi} + \left[\mathrm{SM}^{T_{\mathrm{b}}^{\max}}_{\lambda\phi} - \mathrm{SM}^{T_{\mathrm{b}}^{\min}}_{\lambda\phi}\right] \times I_{1_{\lambda\phi}}(t)$$

- In contrast to ESA NRT SM product
    - no soil temperature is used for the DA-specific NN
    - the training is done using ECMWF SM (0-7 cm) from AUXEC files, instead of Level 2 SM

- Designed at CESBIO/Obs. Paris
- Implemented and running at ECMWF
- ESA funded

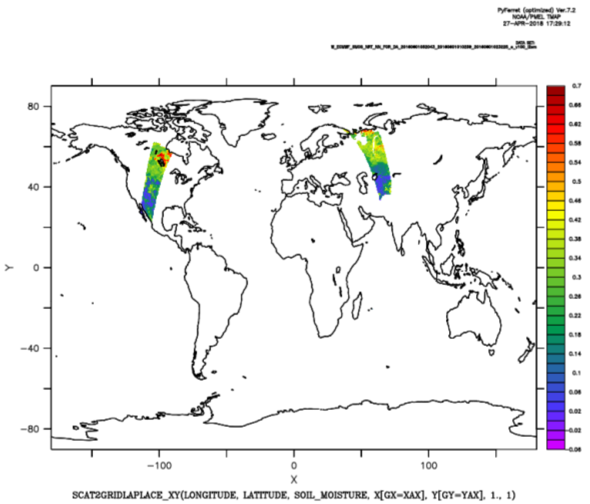
- Operationally assimilated at ECMWF since June 2019

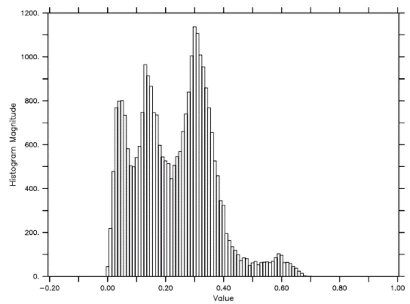
SMOS neural network: Implementation in the ECMWF Integrated Forecasting System (IFS)

de Rosnay et al., 2020, in prep

New SMOS-EC neural network

→ Operational SMOS NN SM for assimilation





Initial Conditions

NWP Forecast
Coupled Land-Atmosphere

background

Soil Analysis (SEKF)
SM1, SM2, SM3

$\sigma^o{}_{T2m} = 1K \quad \sigma^b = 0.01\ m^3m^{-3}$

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

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

Observations

T_2m RH_2m
ASCAT SM
SMOS NN SM

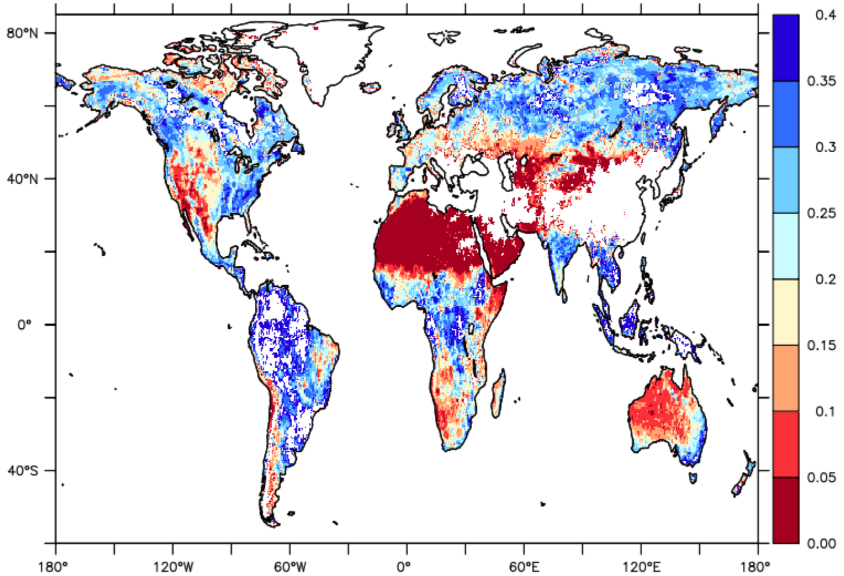
SMOS EC Neural Network

SMOS L1 NRT TB

SMOS EC SM

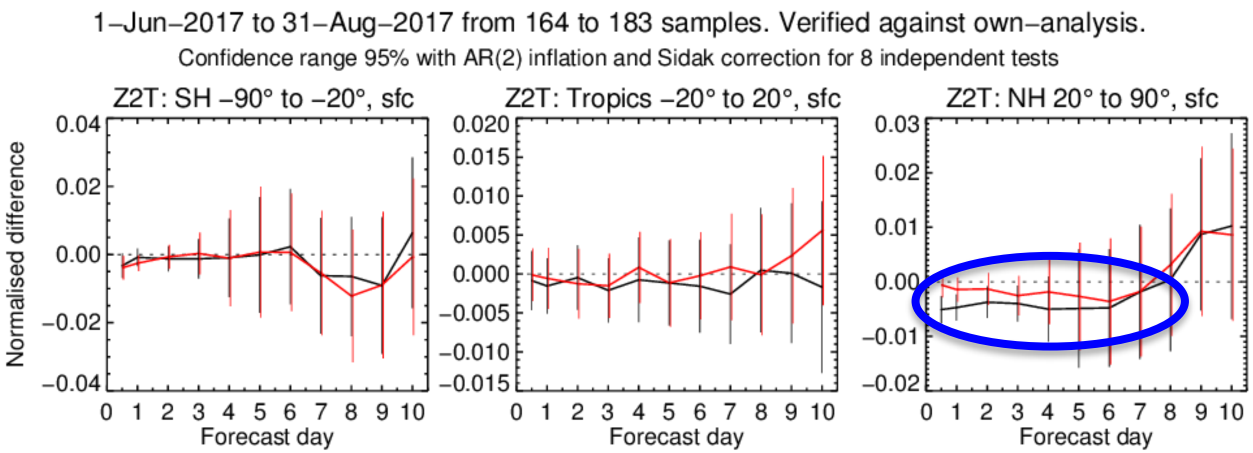
EDA SEKF and SMOS NN DA impact

- **Enhanced coupling:**
  - Use the EDA to compute the SEKF Jacobian
  - assimilate soil moisture from SMOS in coupled land-atmosphere forecasting system
- **Improved efficiency:**
  - CPU reduction (factor 3.6) from EDA SEKF, cost neutral for SMOS



SMOS NN SM (m3/m3) JJA 2017

Atmospheric impact (T2m)



gykr EDA&SMOS - CTRL
gykk SMOS – CTRL

de Rosnay et al, 2020, in prep

Summary

- The use of a neural network to link SMOS brightness temperatures to ECMWF SM field have given good results in and offline DA experiment
- A near-real time SMOS SM processing chain specific for DA at ECMWF has been implemented in parallel to the ESA SMOS NRT product
- This SMOS NRT is assimilated operationally by ECMWF with promising results

- Think of this alternative approach for your DA … if you want to assimilate SMOS data we can provide support

Thanks for your attention !

- **More information**

SMOS blog

@SMOS_satellite

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