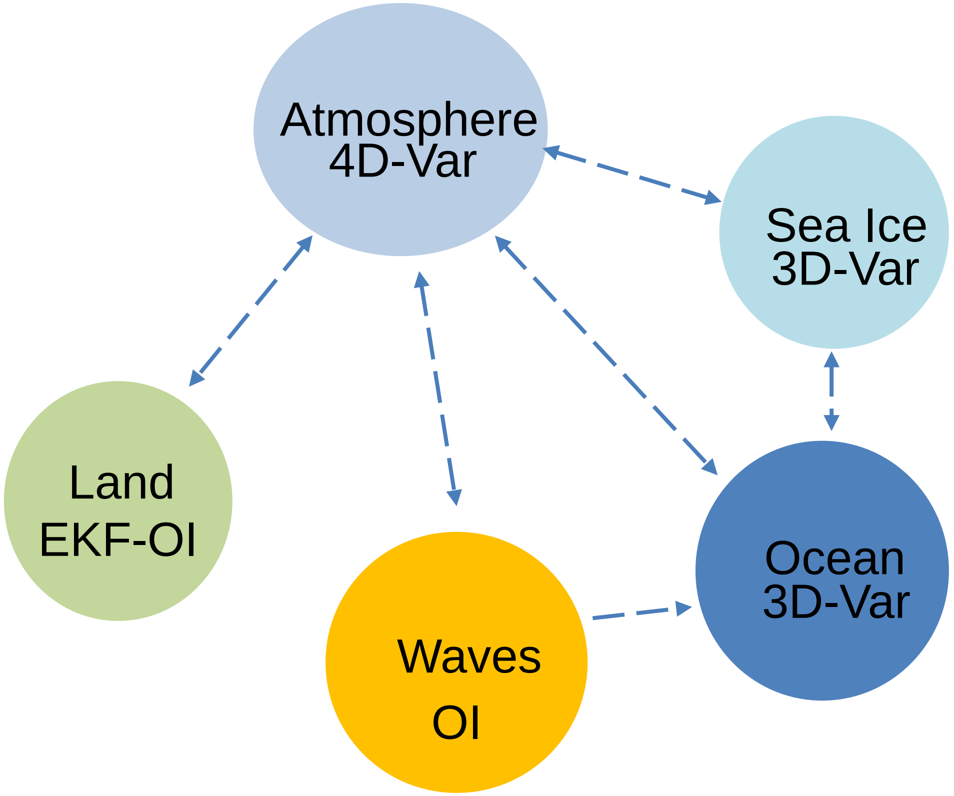
Coupled land-atmosphere data assimilation for operational NWP and reanalyses

Patricia de Rosnay, David Fairbairn, Pete Weston, Phil Browne,
and many other colleagues

Toward coupled assimilation in ECMWF's operational systems



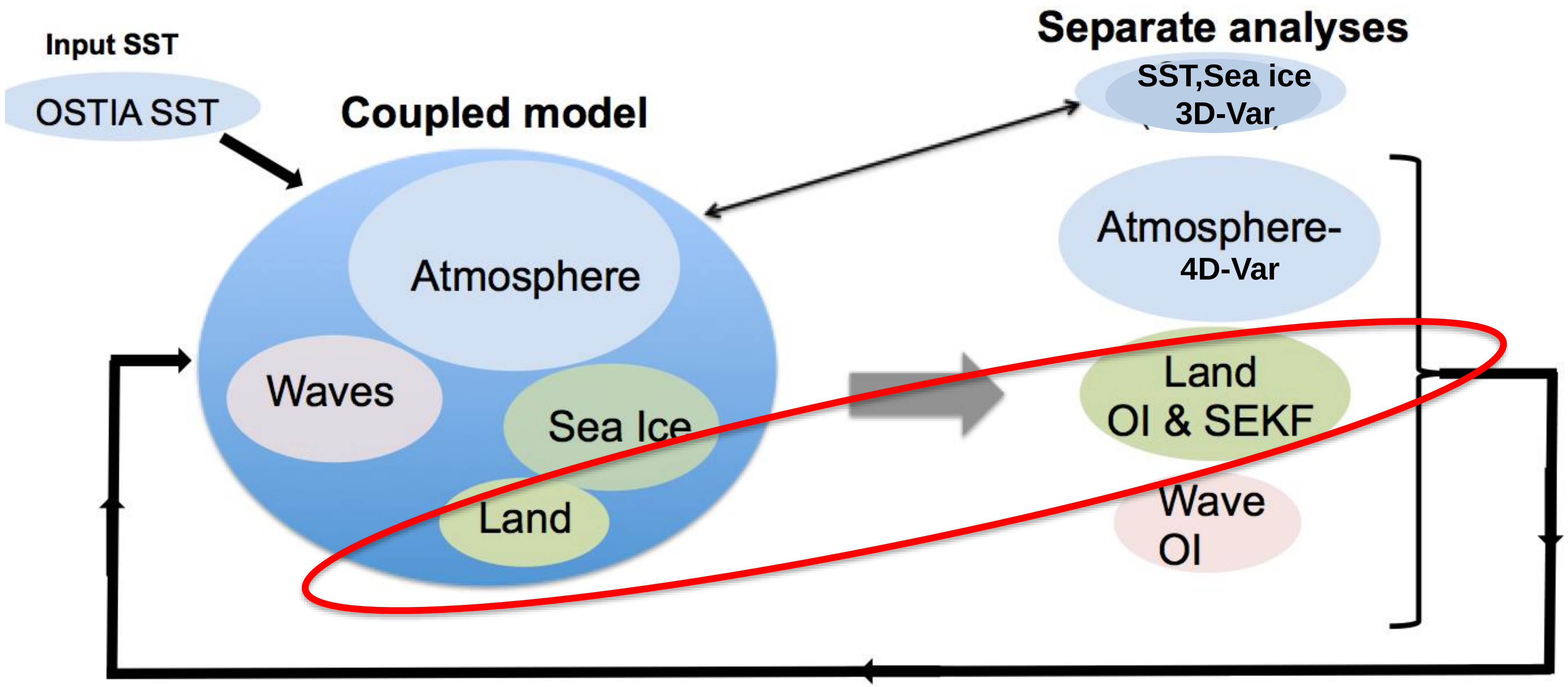
Earth system approach

Integrated Forecasting System (IFS)

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

Current operational NWP system at ECMWF

<u>Weakly coupled</u> land-atmosphere-wave and sea ice assimilation



Plans to develop land-atmosphere coupling at the outer-loop level of the atmospheric 4D-Var

Coupled assimilation in operational systems

Methodology:

- Coupled assimilation challenges, coupling strategy from weak to strong coupling, etc
- Link to methodology and unified framework development (e.g. OOPS at ECMWF)

Infrastructure:

- Earth System approach → consistent & modular suite definition for land and atmosphere, use same file system for all components,
- Develop/maintain consistent research offline and coupled, and operational coupled tools

Observing system and monitoring:

- Access to observations, common acquisition for land & atmosphere, observation pre-processing, quality control, data selection, feedback files, monitoring, auto-alert system, …

Observation operators:

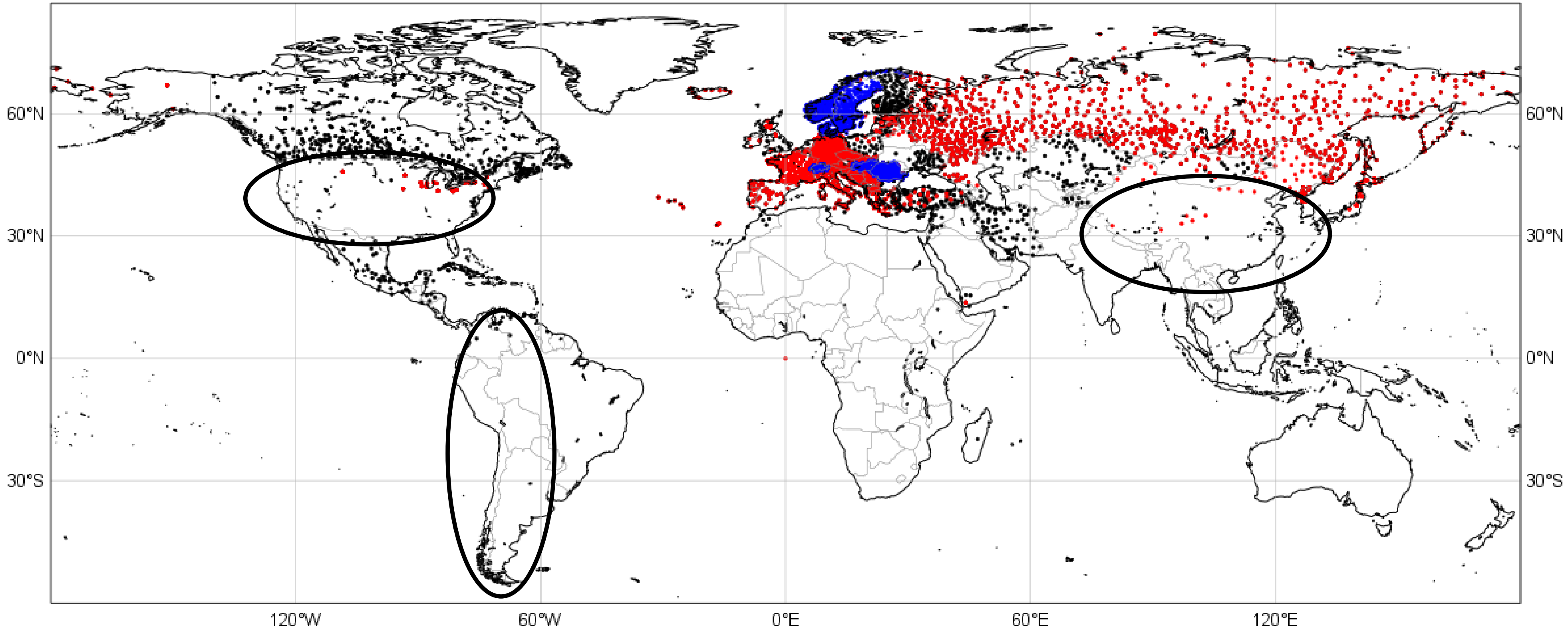
- Coupling for observations that depend on more than one sub-system (e.g. low frequency MW observations sensitive to the surface), explore AI/ML approaches

Observing system: the example of in situ snow depth

Near-Real-Time access to observations

SYNOP TAC SYNOP BUFR national BUFR data

15 January 2015



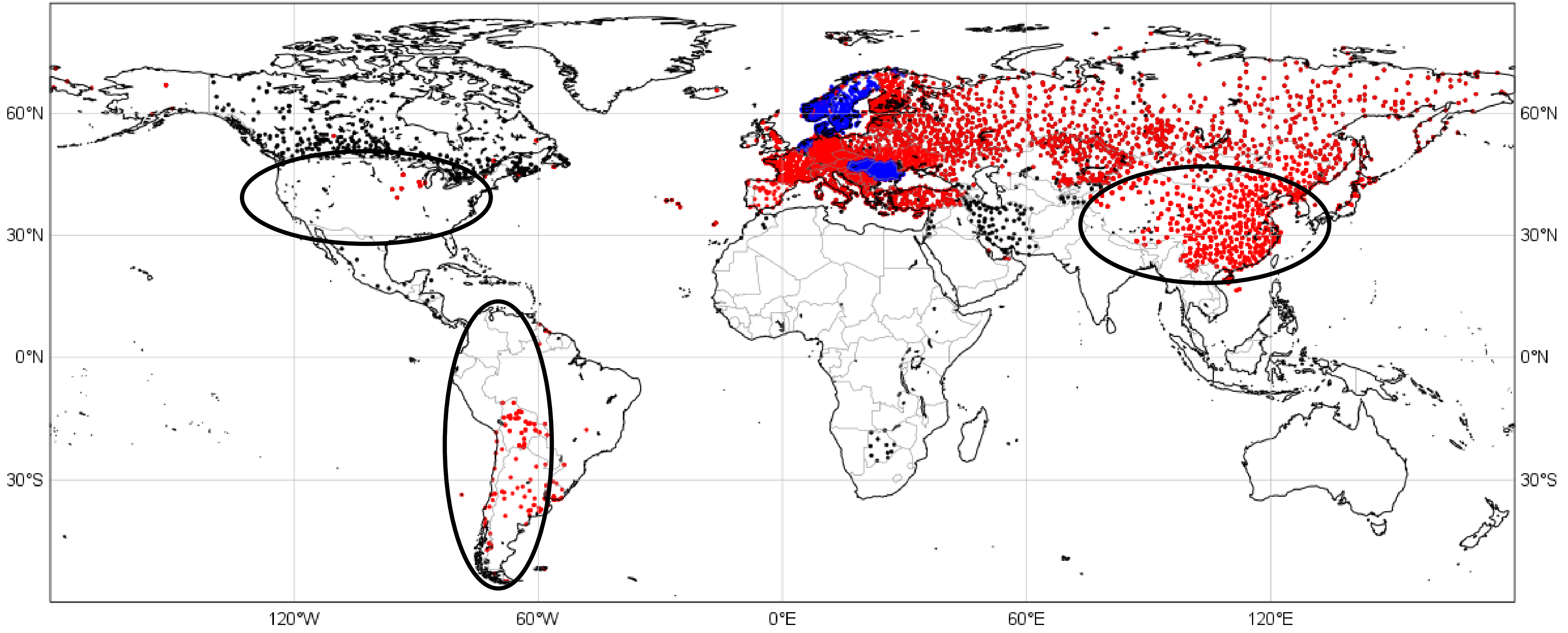
Snow depth availability o the Global Telecommunication System (GTS)

Observing system: the example of in situ snow depth

Near-Real-Time access to observations

SYNOP TAC SYNOP BUFR national BUFR data

15 January 2021



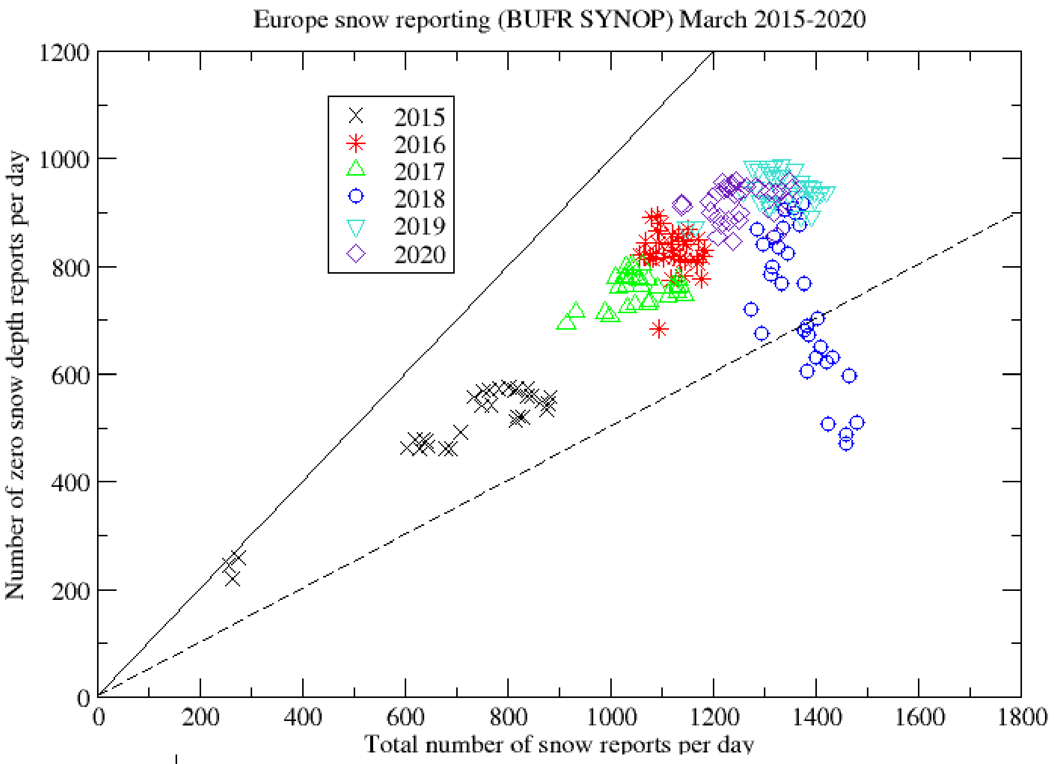
Snow depth availability o the Global Telecommunication System (GTS)

Ongoing/near future: improvement in the US (NOAA)

ECMWF

Snow data exchange and WMO

- 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 WMO Infrastructure Commission) → relevant for coupled assimilation

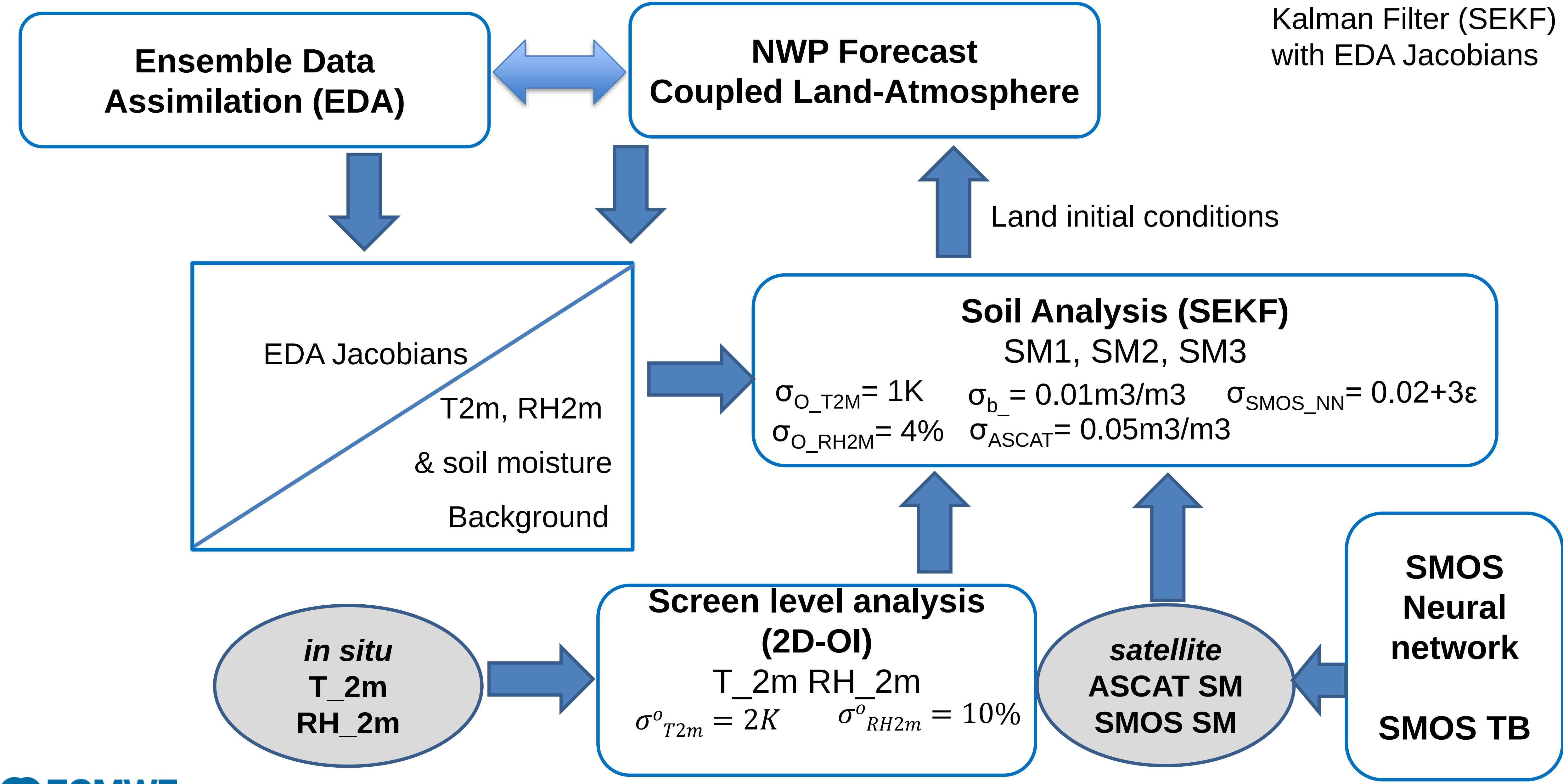


6. Improvements in the reporting of 'zero' snow depth from SYNOP stations

WIGOS Newsletter April 2020

ECMWF Soil Analysis for NWP

Simplified Extended Kalman Filter (SEKF) with EDA Jacobians



Uncouped Land surface analysis systems

→ Support research and land surface reanalysis

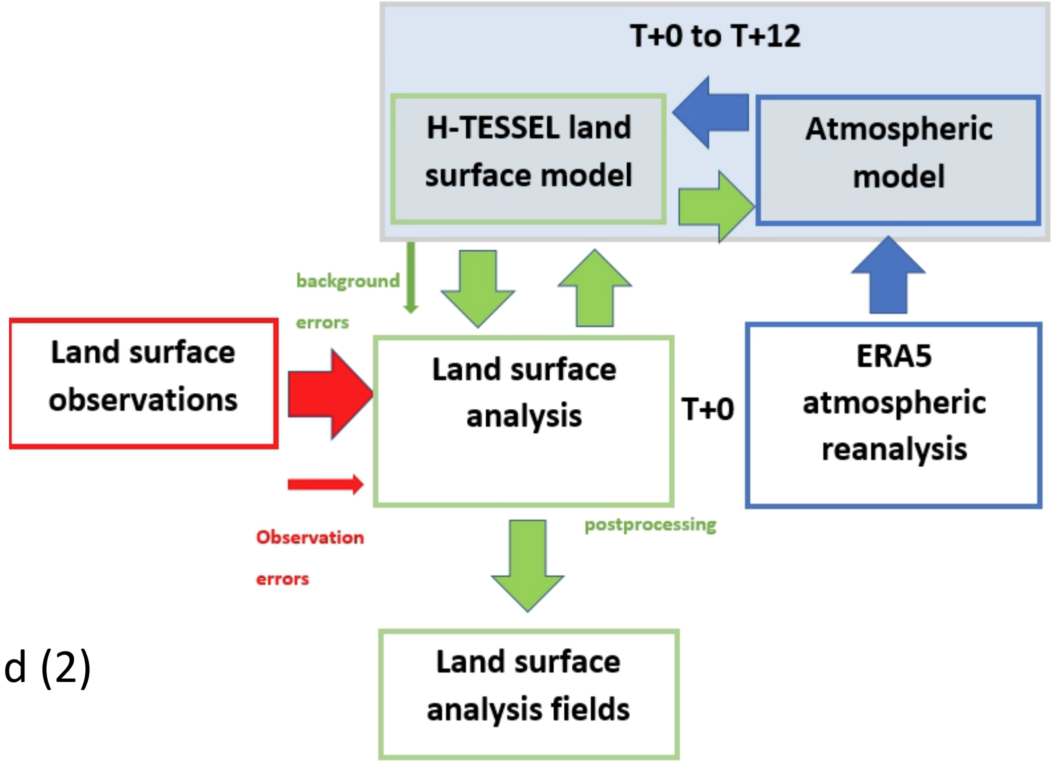
System(s) consistency and maintenance

1. Offline surface model forced by atmospheric reanalysis (e.g. ERA5-land)
   - ☺ Allows enhanced surface model/resolution
   - ☹ No land DA

2. Offline soil moisture DA (Rogriguez-Fernandez et al, 2019)
   - ☺ As (1), but offline soil moisture analysis included
   - ☹ A priori observation processing and gridding
   - ☹ No snow DA

3. Stand-alone surface analysis (SSA, Fairbairn *et al*., 2019)
   - ☺ Full land DA system in IFS (soil moisture, snow, etc…)
   - ☺ Coupled land-atmosphere model
   - ☺ Same observation interface than NWP
   - ☺ No atmosphere DA so cheaper than coupled DA system
   - ☹ Still significantly more computationally expensive than (1) and (2)

SSA forced by ERA5

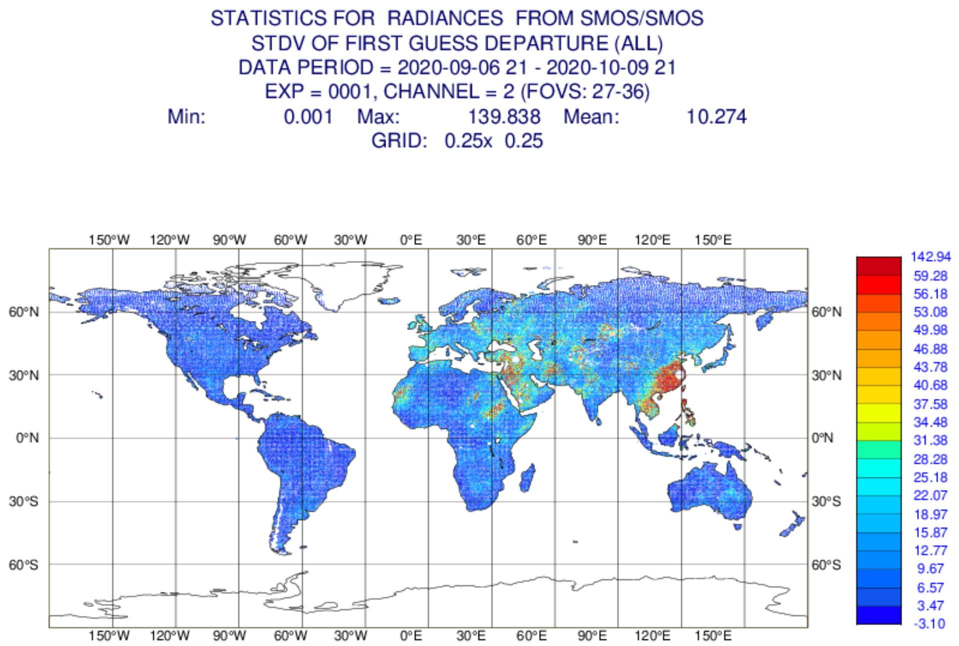


Fairbairn et al., 2019 *J. Hydrometeor*, 2019. https://doi.org/10.1175/JHM-D-19-0074.1
Rodriguez-Fernandez et al., Rem. Sens. 2019 https://www.mdpi.com/2072-4292/11/11/1334

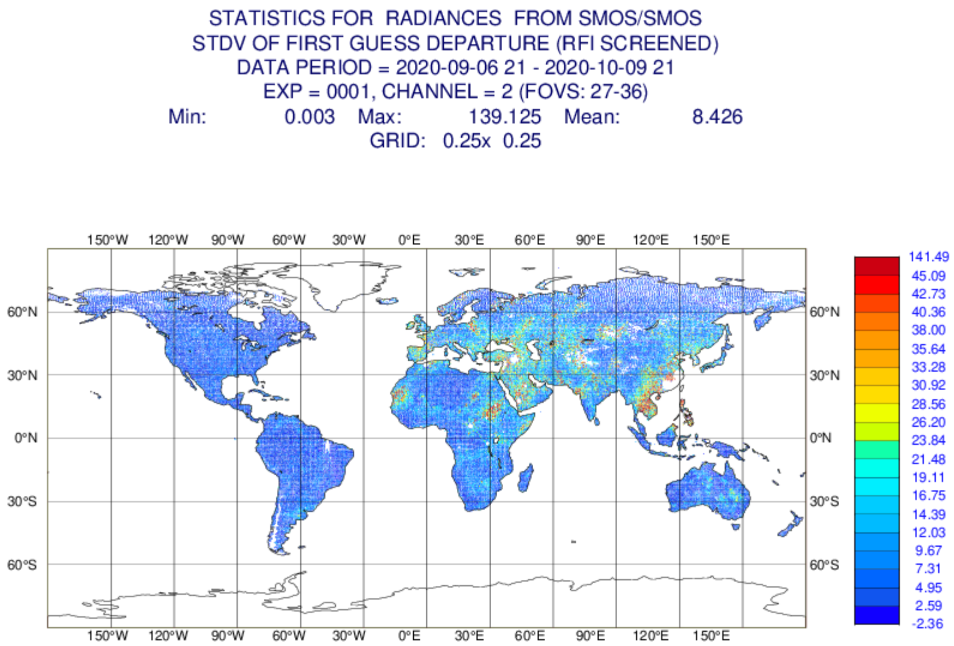
Observation monitoring and quality control

SMOS brightness temperature operational monitoring

- Summer 2020: a large area of RFI (Radio Frequency Interference) contamination over South-East China
- Improved screening does a better job of filtering it out but still not perfect
  - Need for further improvements in RFI filtering flags
  - **Importance of <u>quality control</u>**



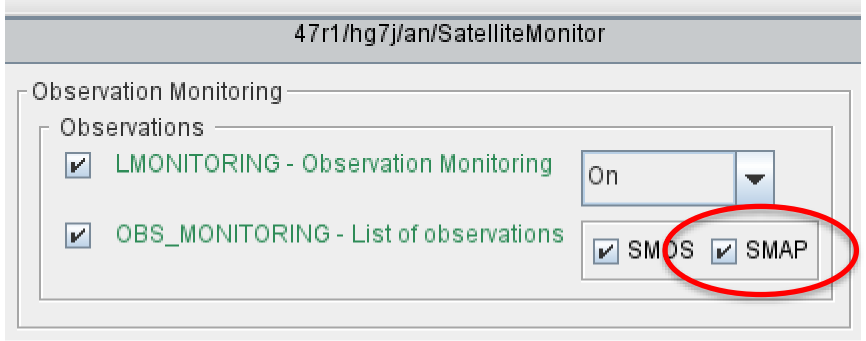
Basic RFI screening

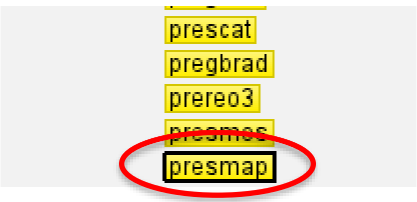


Stronger RFI screening

New observation implementation

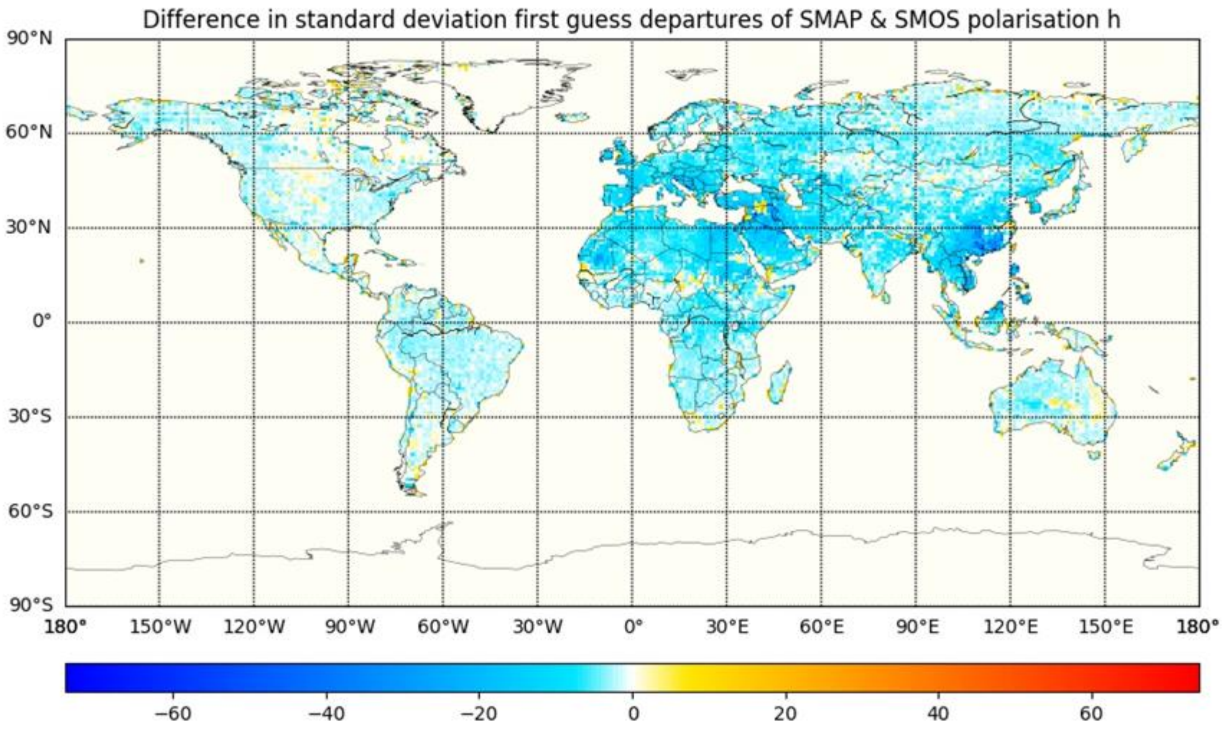
SMAP monitoring (May 2021)





- Set-up operational NRT acquisition
- Scripts suite and prepIFS changes complete
- SMAP Observation interface (Obs Data base, ODB)
- Script and Fortran changes
- Suite definition and prepIFS
- Monitoring webpage update

- Next: SMAP assimilation



→ Full chain of developments to integrate new observations in a complex (Earth) system

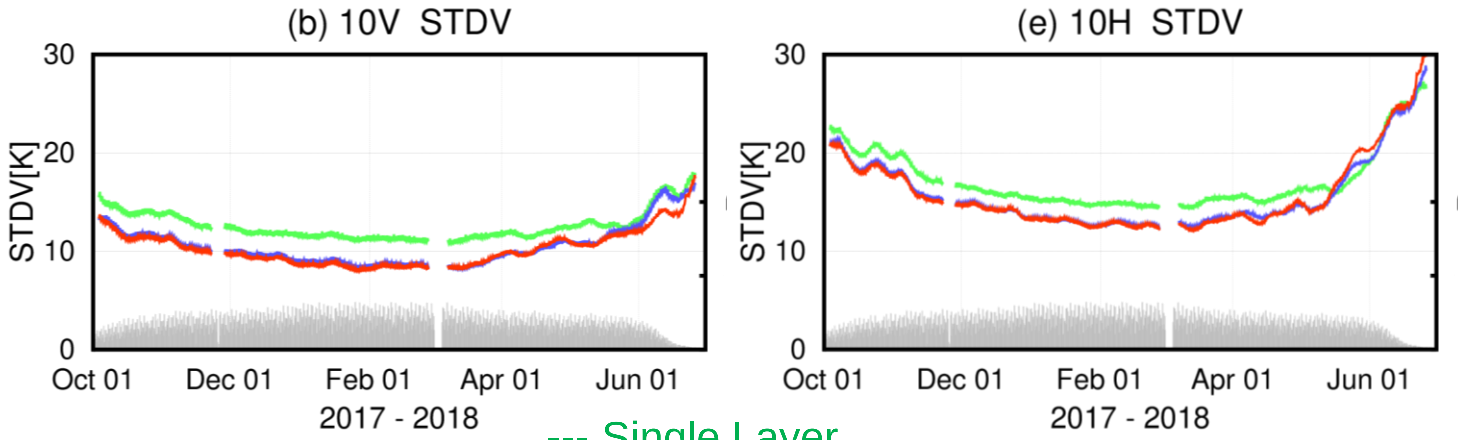
Pete Weston

Coupling through the observation operator

- New interface between CMEM (surface) and RTTOV (atmosphere) radiative transfer schemes
- Multi-layer snow radiative transfer scheme (HUT, Lemmetyinen et al., 2010) in CMEM offline
- **Adapt to <u>model cycle</u> changes, take advantage to improve coupled DA**

Use the multi-layer snowpack model (Arduini et al JAMES 2019) to assess the impact of multi-layer approach on snow emissions against AMSR2 10GHz data

Multi-layer snowpack scheme leads to reduce STDV and gives higher correlation values between ECMWF forward and AMSR2 observed brightness temperatures at 10GHz

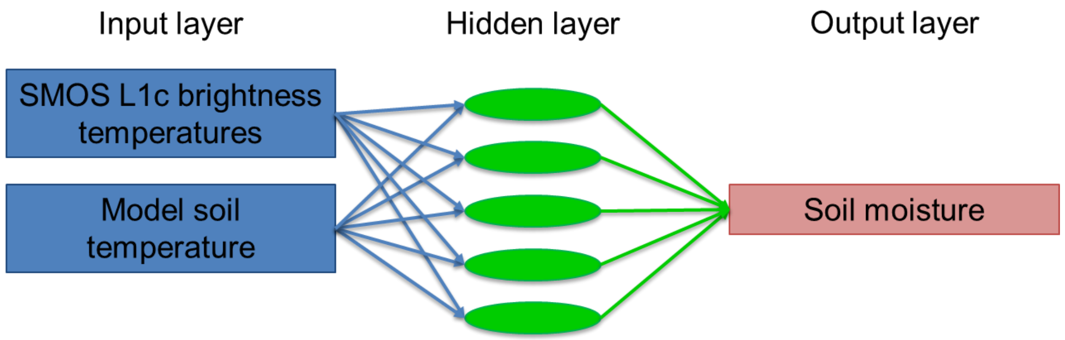


--- Single Layer
--- Multi-layer snowpack and RT
--- Multi-layer snowpack only

Hirahara et al., 2020
https://doi.org/10.3390/rs12182946

ECMWF

SMOS neural network soil moisture assimilation



Rodriguez-Fernandez et al., HESS 2017, RS 2019

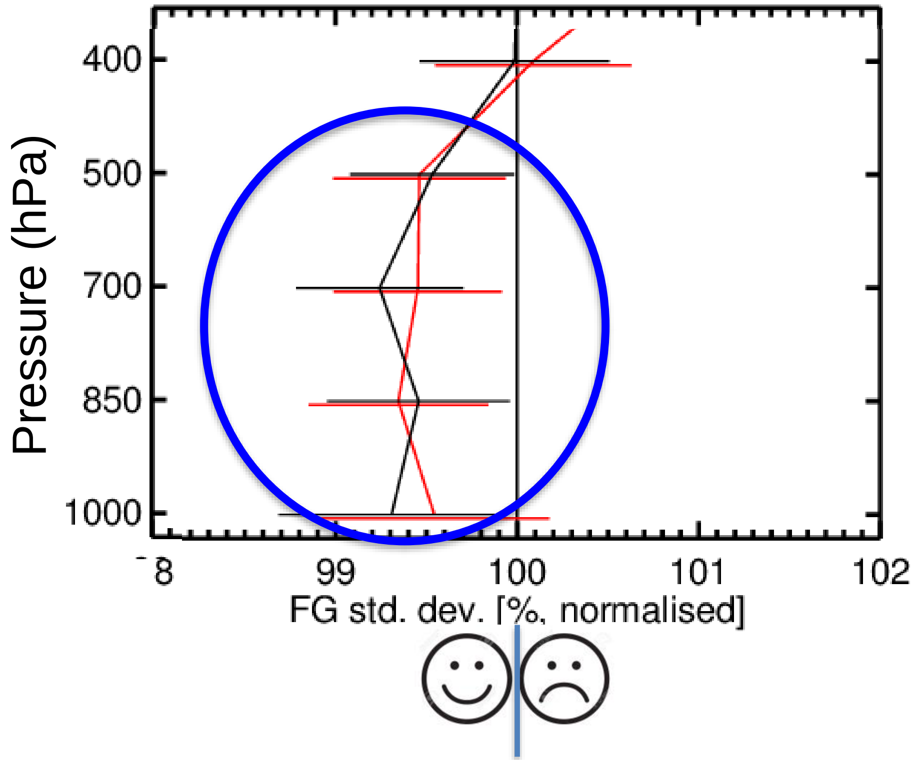
A priori training of the SMOS neural network processor
-> retraining when L1Tb or IFS soil change
Online training possibilities?

Further explore ML/AI for forward modelling

Recent work from **Aires et al QJRMS 2021**: use neural network to investigate the relation between ASCAT backscatter and soil moisture

SMOS DA impact

Aircraft humidity (JJA 2017)



ECMWF

Summary

model cycle
modularity data acquisition
feedback file operations
online training offline
data exchange monitoring observing system
reanalysis outer-loop coupling data format
near real time
sustainability archiving auto-alert system
NWP consistency
data selection
code infrastructure
seamless weak coupling
research suite definition
observation interface quality control

Future plans

- Land DA
  - Unified multivariate ensemble-based land DA system: progressively include more variables in the SEKF control vector, use the EDA to estimate flow-dependent B, enhance observation usage
  - Move towards level 1 observation usage: develop forward operator using combined physical and include ML approaches tackle challenges of complex surfaces radiative transfer modelling

- Coupled land-atmosphere DA
  - Develop modular coupling infrastructure to enable different degrees of coupling flexibility under a single suite definition (optimal maintenance, useful for land reanalysis and initialisation of reforecasts)
  - Develop outer loop coupling consistent with ocean-atmosphere coupling
  - Observation operator coupling to enhance the exploitation of satellite observations e.g. over snow covered surfaces
  - Assimilate 4D-Var Extended Control Variable as land pseudo-observations (e.g. skin temperature)