L-band Satellite Data Assimilation over Land

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and many colleagues

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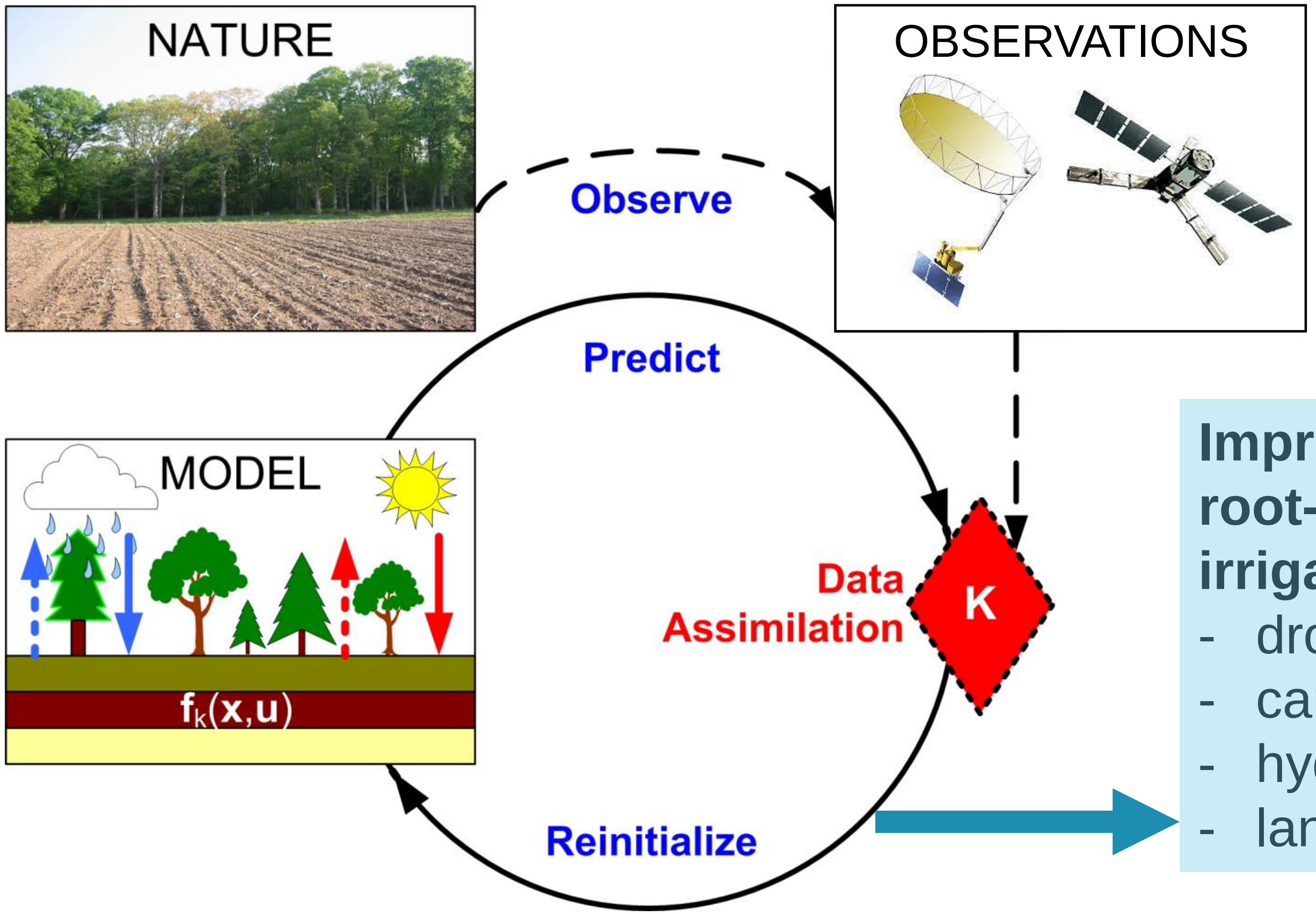
Land data assimilation

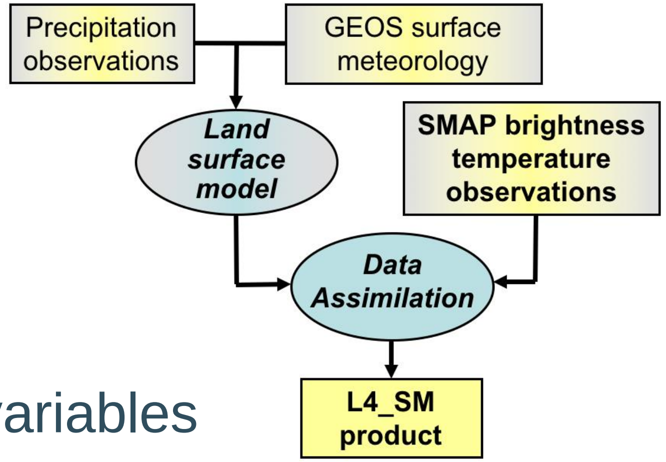


Tb,
SM,
VOD

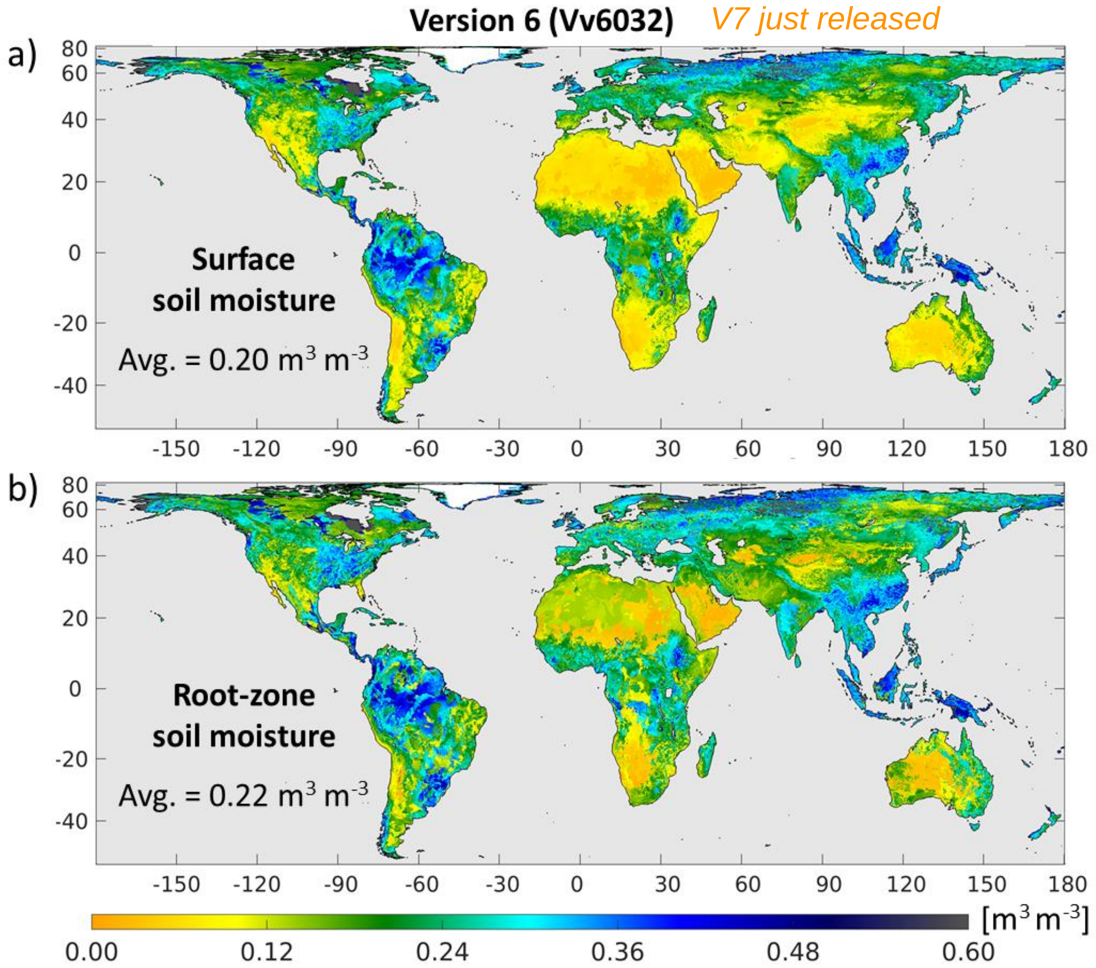
Improved surface soil moisture → root-zone soil moisture, vegetation, irrigation, groundwater, flux estimates

- droughts, agricultural monitoring
- carbon, ecosystem monitoring
- hydrological, hazard forecasting
- land-atmosphere interactions, weather

Surface to root-zone soil moisture



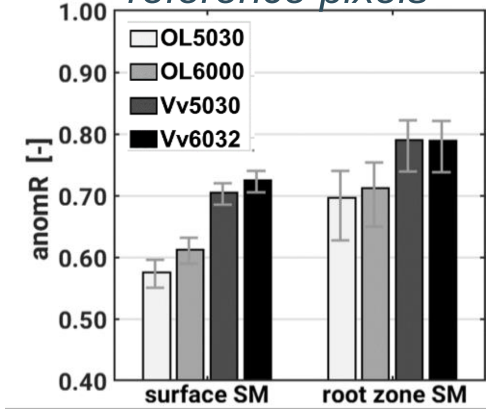
V7 just released



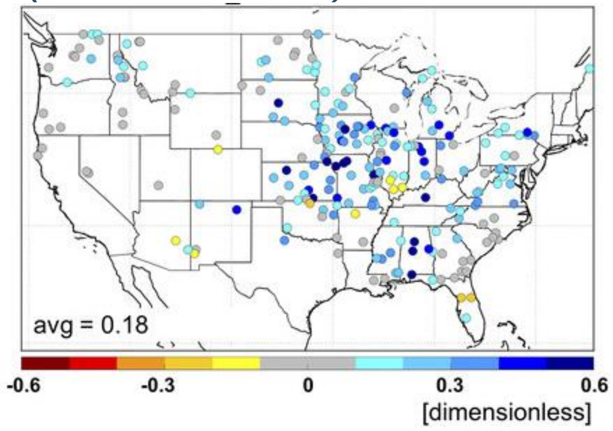
SMAP L4_SM:
Global 3-hourly, 9-km
Surface, root-zone SM
All other geophysical variables

In situ validation:

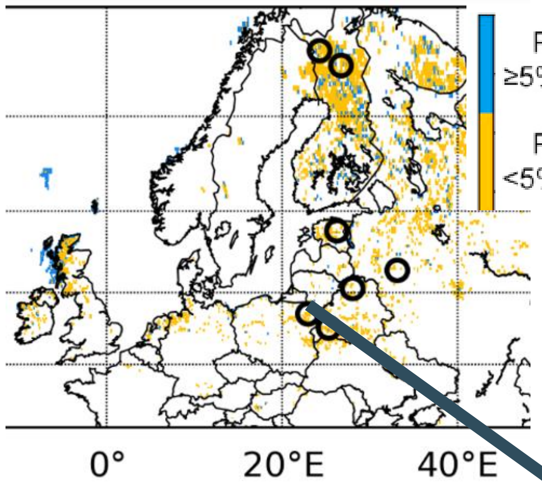
9-km reference pixels



Streamflow ΔR (L4_SM – CTRL)



To groundwater in peatlands

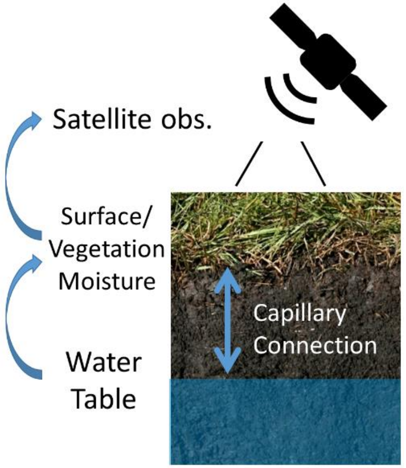


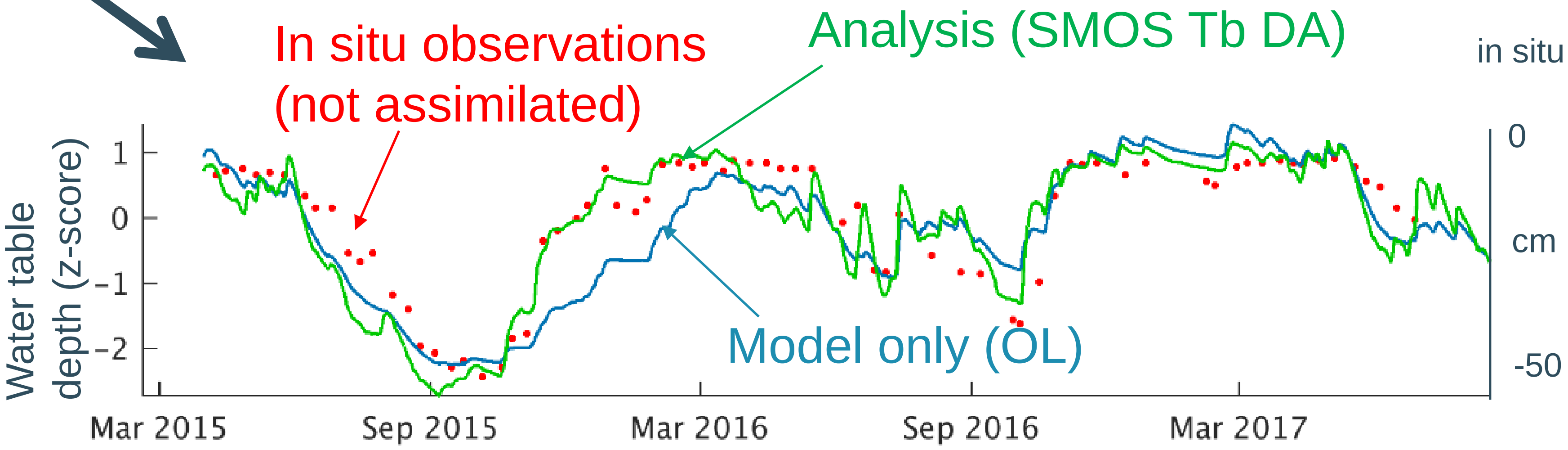
SMOS Tb DA (9-km) evaluated
w/ in situ groundwater levels:

- 59 sites, 13 regional clusters
- many peatlands only part of SMOS footprint
  → finer spatial resolution better

Biebrza National Park

→ Included in SMAP L4_SM V7





Improving soil moisture and groundwater

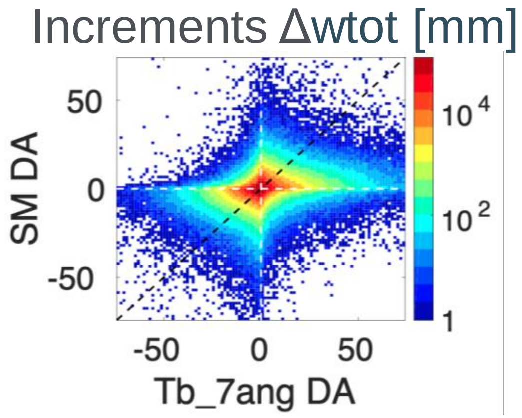
Past to current state-of-the-art

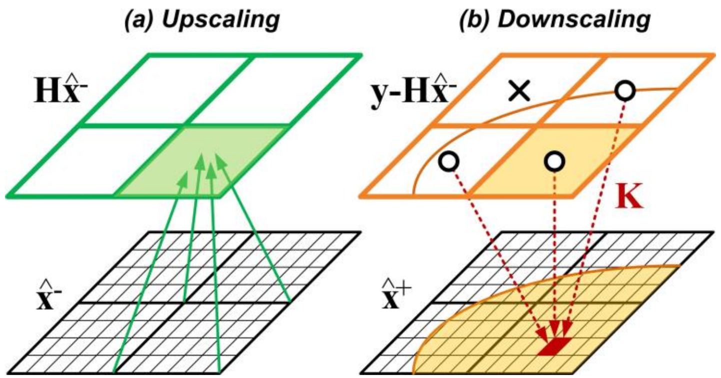
- AMSR-E DA → SMOS/SMAP Tb DA (clear improvements in SM)
- SM or Tb DA?
- Tb DA via RTM or NN; rescaling?
- Combine SMOS & SMAP (frequency)
- 1D DA → 3D DA for downscaling

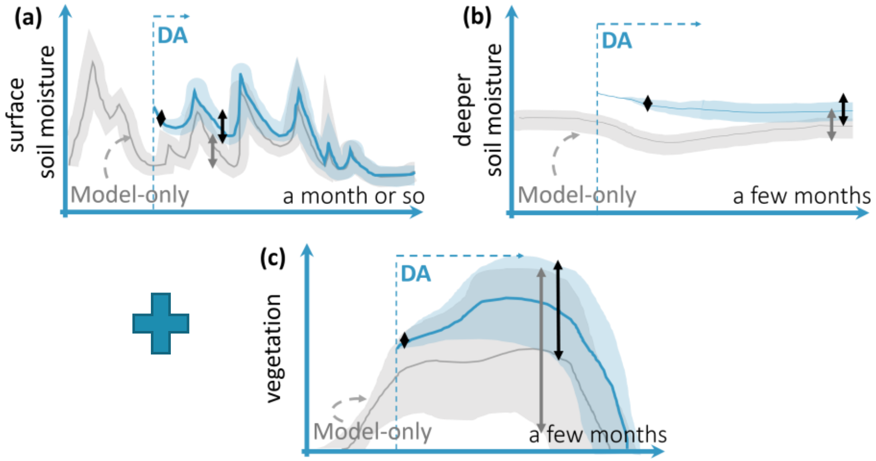
Ongoing developments

- SMAP/SMOS Tb DA → multivariate, vegetation updating to improve SM
  - only in the RTM, or parameters
  - also in LSM, dynamic vegetation
- SM & VOD or Tb DA? → need multiple incidence angles, polarizations

SMOS DA



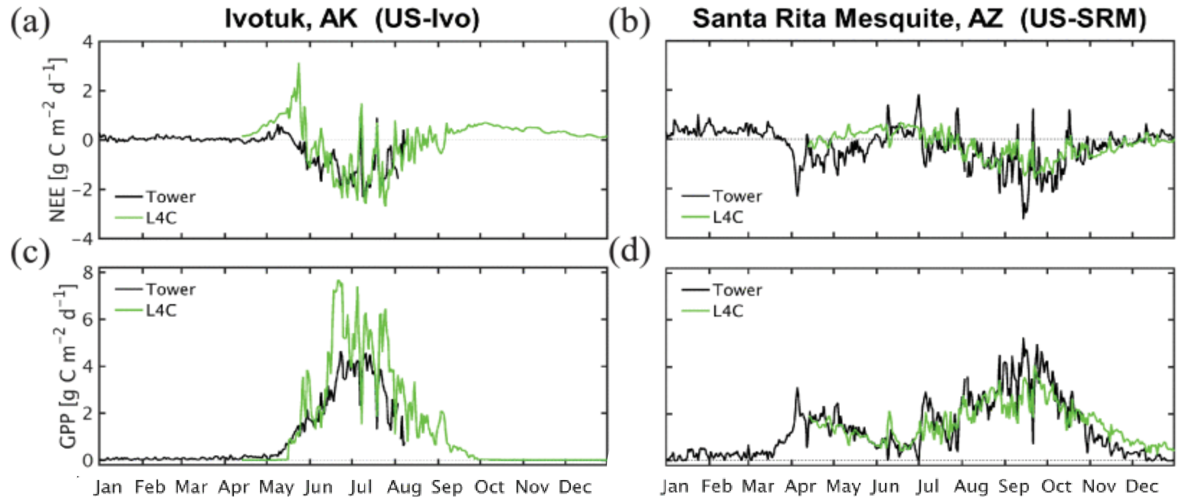




To carbon, vegetation and evapotranspiration

SMOS/SMAP **SM DA**

- SMOS SM DA in Carbon Cycle Data Assimilation System (CCDAS)
- SMOS SM DA in Global Land Evaporation Amsterdam Model (GLEAM)
- SMAP L4_SM as input to net ecosystem CO_2 exchange estimates → SMAP L4_C
- SMAP L4_SM to constrain MODIS-based ET → improve in water-limited regions
- SMAP Tb or SM DA → turbulent fluxes
- Success depends on SM-vegetation-ET coupling strength (in reality and in model)



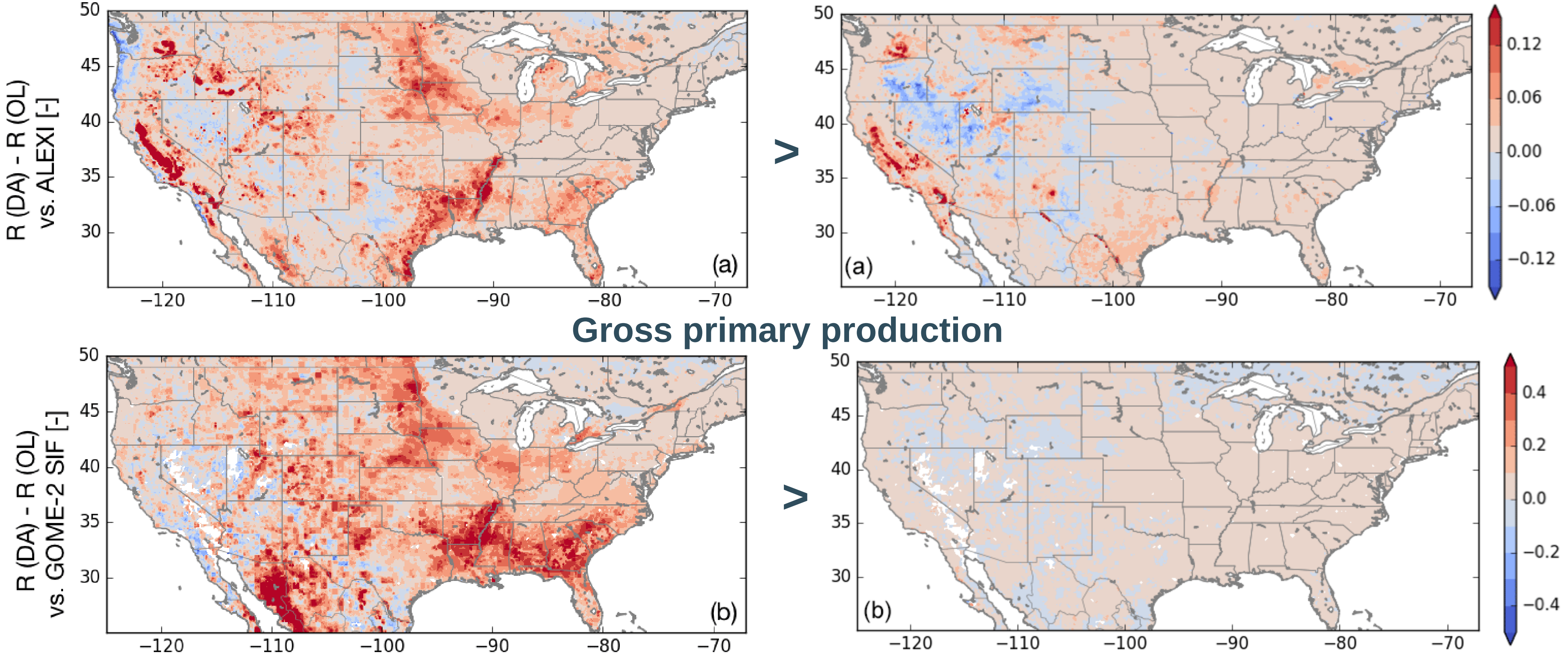
To carbon, vegetation and evapotranspiration

SMAP **VOD DA**

SMAP **SM DA**

Evapotranspiration

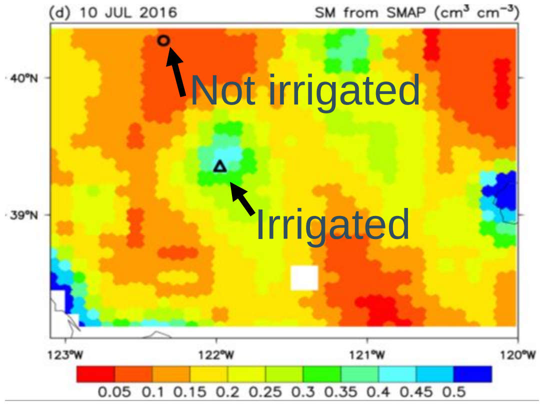
Gross primary production



To irrigation

likelihood that SMOS/SMAP signal responds to irrigation
~ size of the irrigated area → need higher spatial resolution (1)
~ overpass time → need higher temporal resolution (2)

(1)



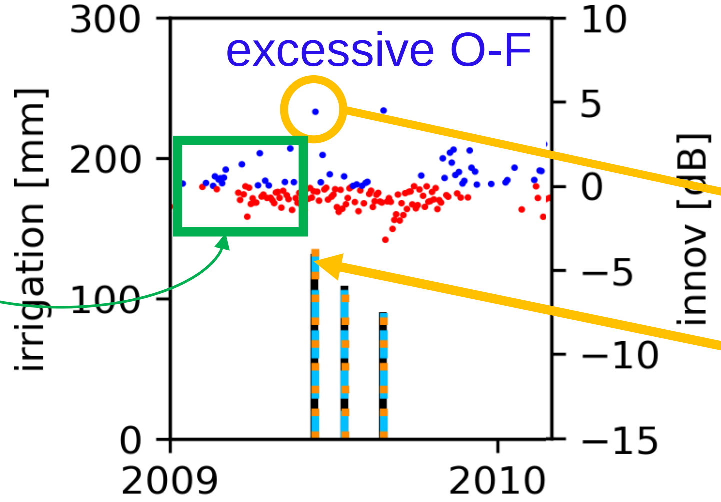
California Central Valley
SMAP enhanced (9-km)

(2)

- Increase in GPP or SM after SMAP_E **DA** → irrigation **detection**
- Difference O-F backscatter (innov)

→ irrigation model computes irrigation **amount** based on root-zone SM

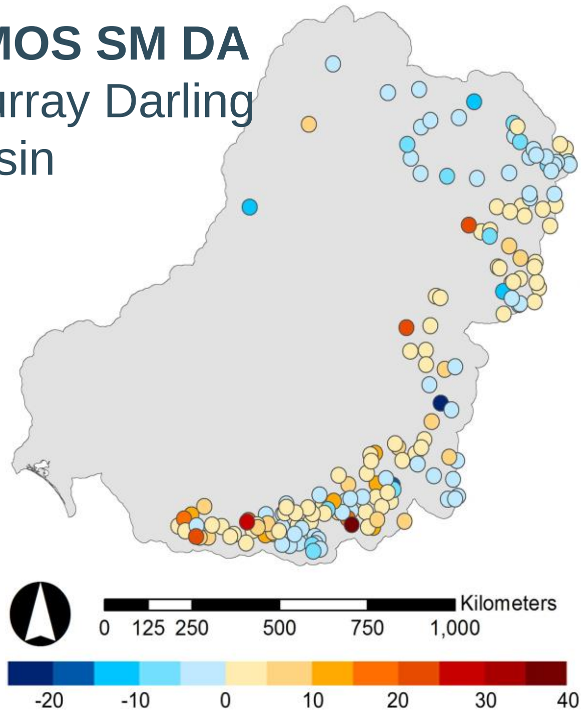
DA → update root-zone SM

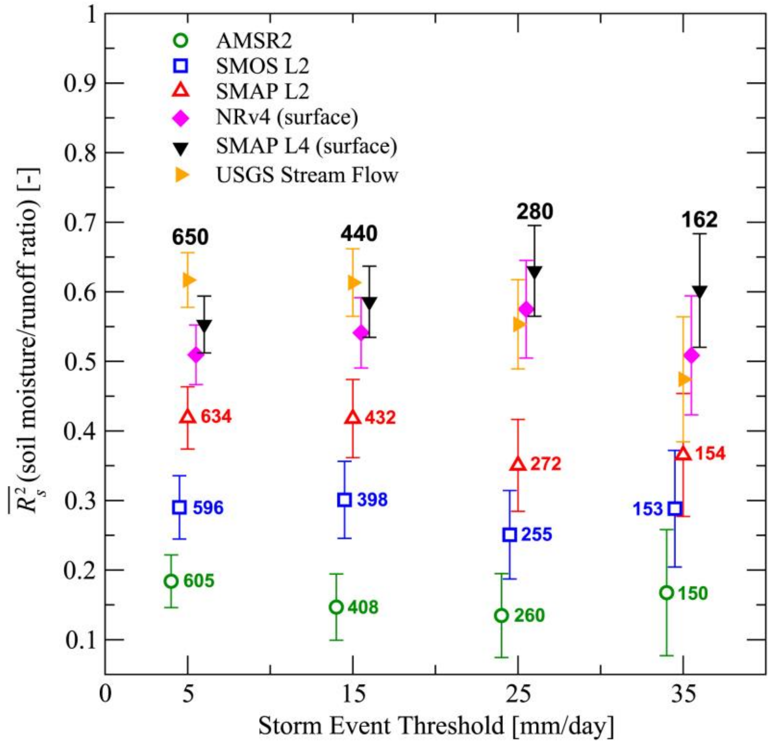


Irrigation model computes **irri amount**

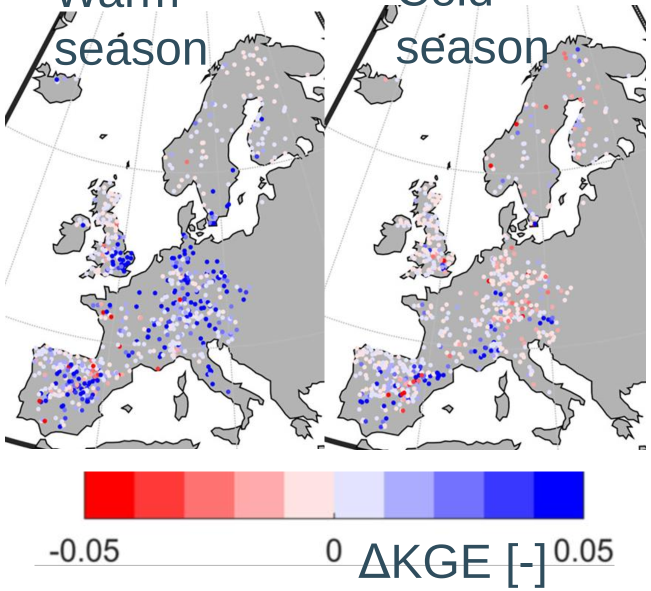
To river discharge

SMOS SM DA
Murray Darling basin





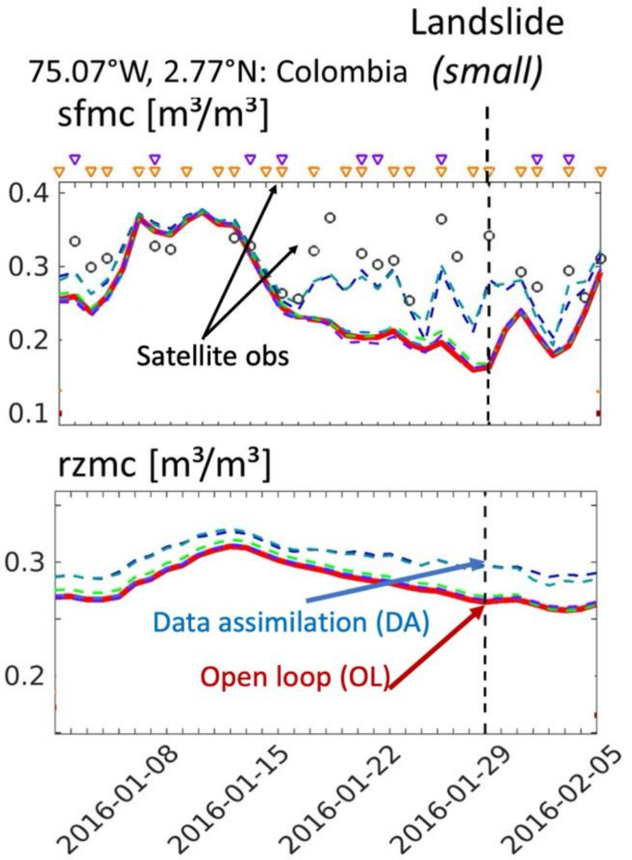
ESA CCI SM DA

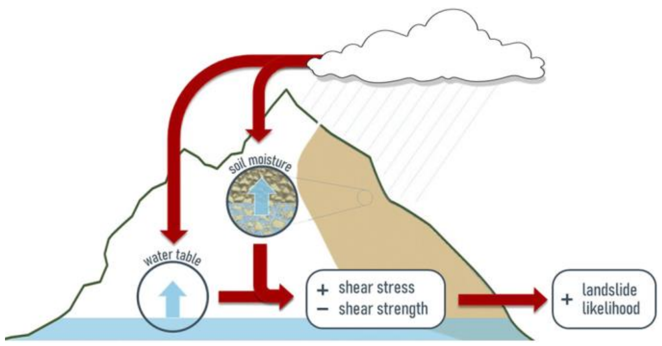


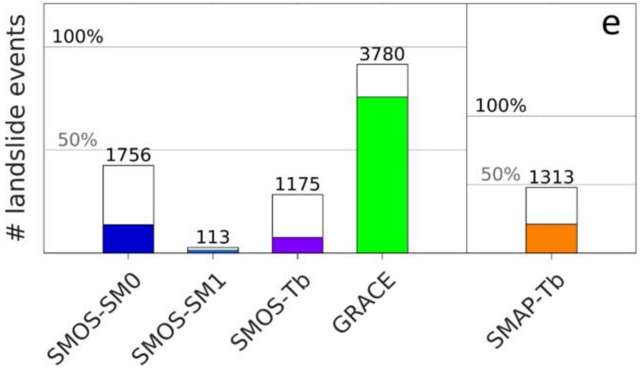
- Spatial variation in SM → higher spatial resolution → better estimate of travel time to river
- SMOS DA in GloFAS: most impact for high flow events → need data at the right time
- Success depends on SM-runoff coupling (in reality and in model)

To hazards

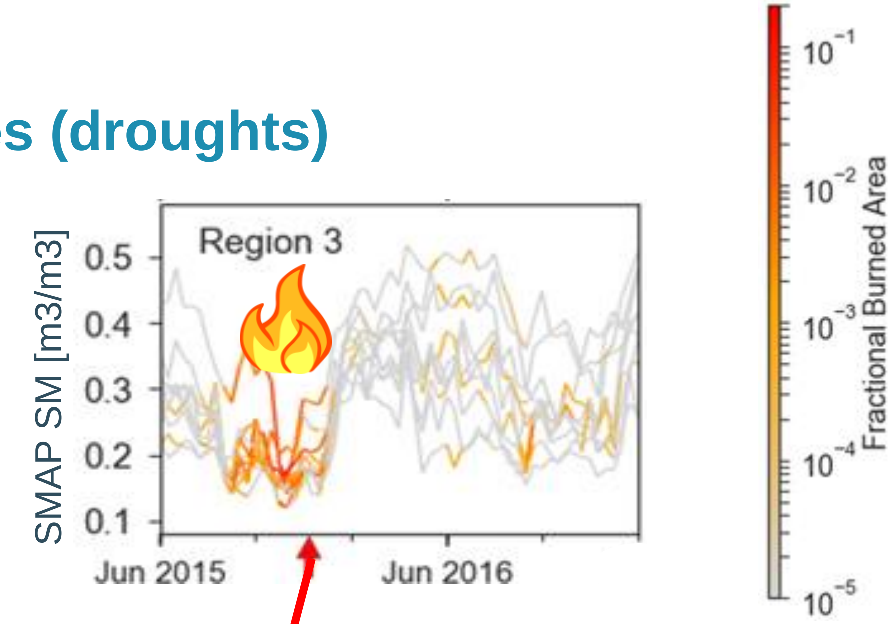
Landslides (wet spells)

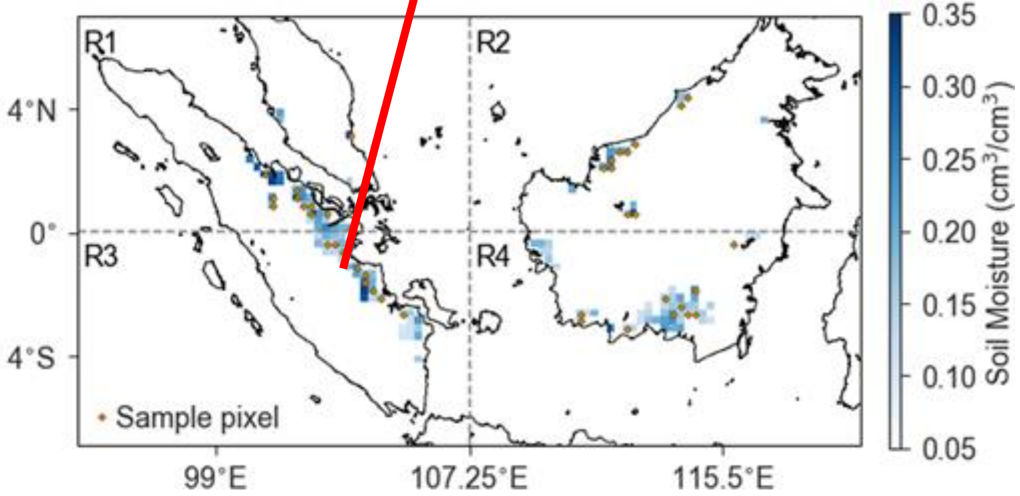






Fires (droughts)





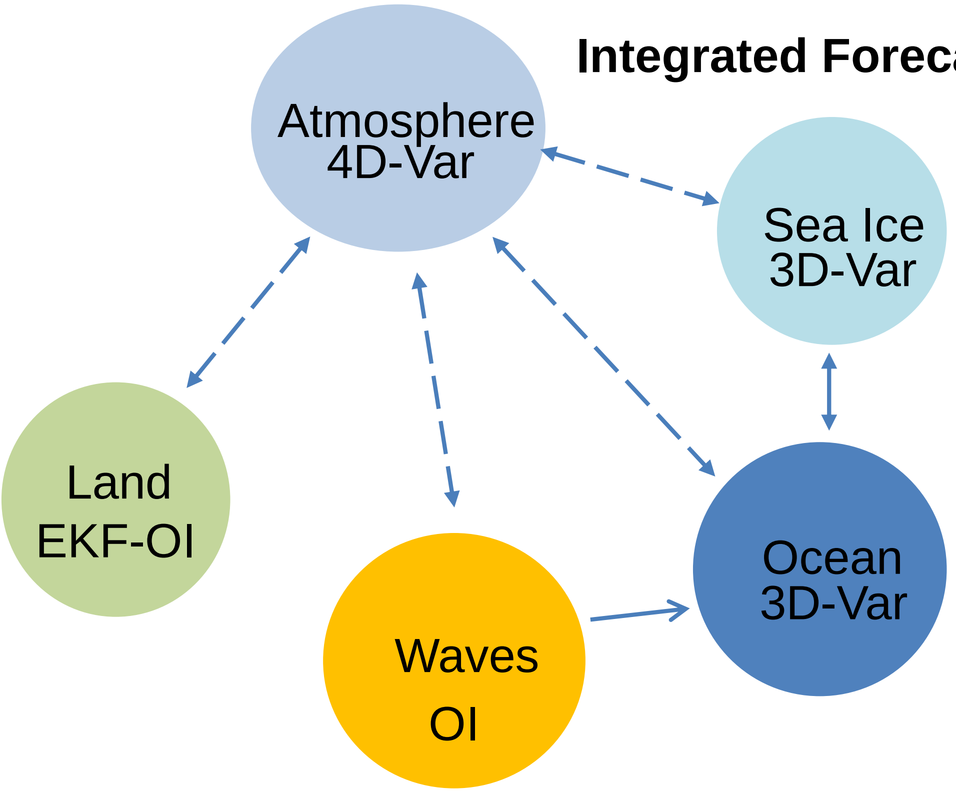
- Data frequency insufficient + need deeper SM → DA
- Finer spatial and temporal resolution better

L-BAND DATA FOR NUMERICAL WEATHER PREDICTION AND EMERGENCY SERVICES AT ECMWF

Pete Weston, Patricia de Rosnay, Nemesio Rodríguez-Fernández, Calum Baugh,
David Fairbairn, Francesca Di Giuseppe, Ruth Coughlan, Joaquín Muñoz-Sabater,
Stephen English, Christel Prudhomme, Matthias Drusch,
and many other colleagues

Earth System approach
Coupled assimilation for NWP & reanalyses

Integrated Forecasting System (IFS)



- Coupled Forecast Model

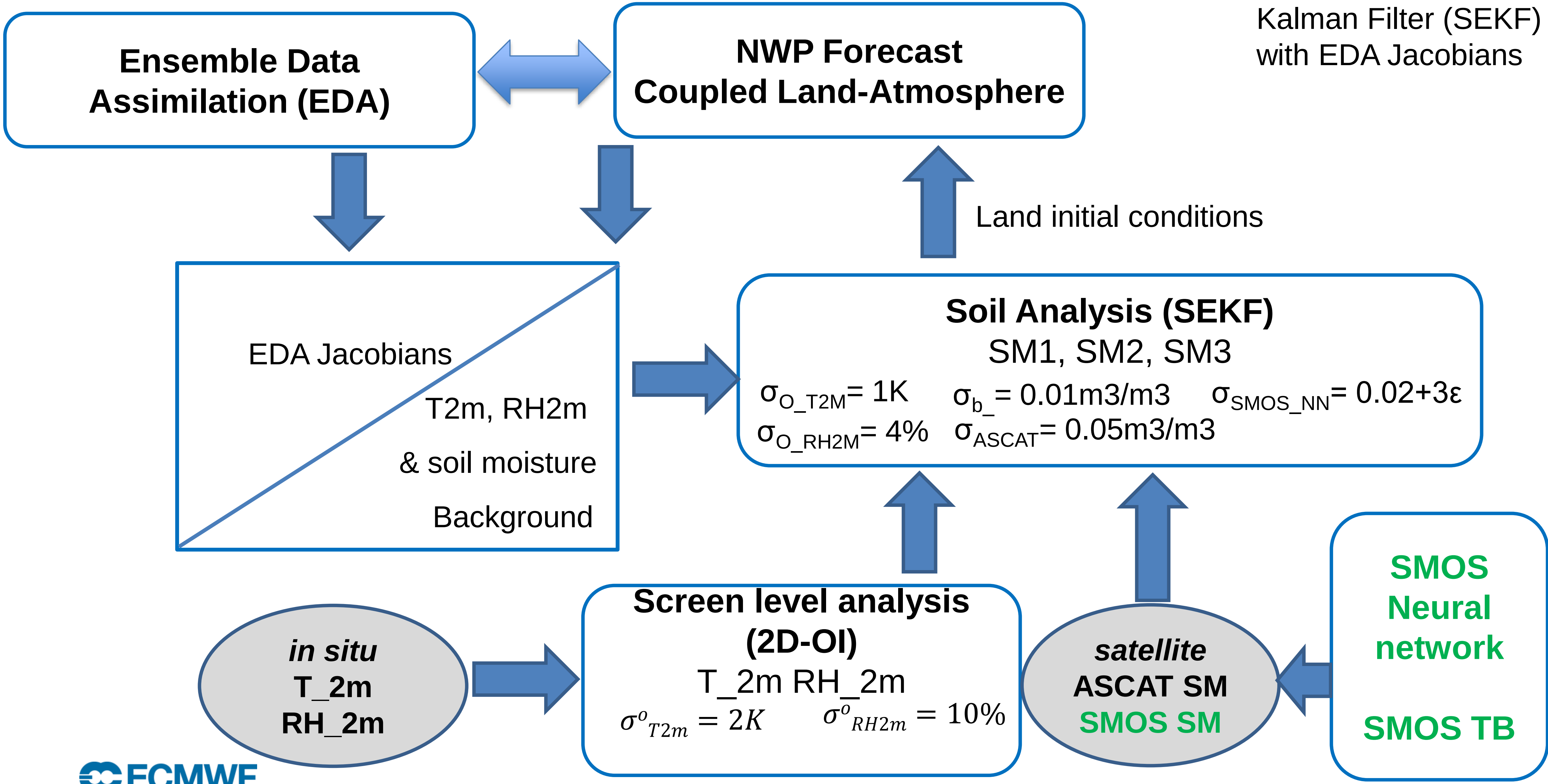
- Coupled assimilation (de Rosnay et al., QJRMS 2022)
  - Ocean-atmosphere (Browne et al., Rem. Sens. 2019)
  - Land-atmosphere (de Rosnay et al., Surv. Geophys. 2014)

Importance of observations sensitive to interface variables, e.g. SST, sea ice, snow and soil moisture

ECMWF

ECMWF Soil Analysis for NWP

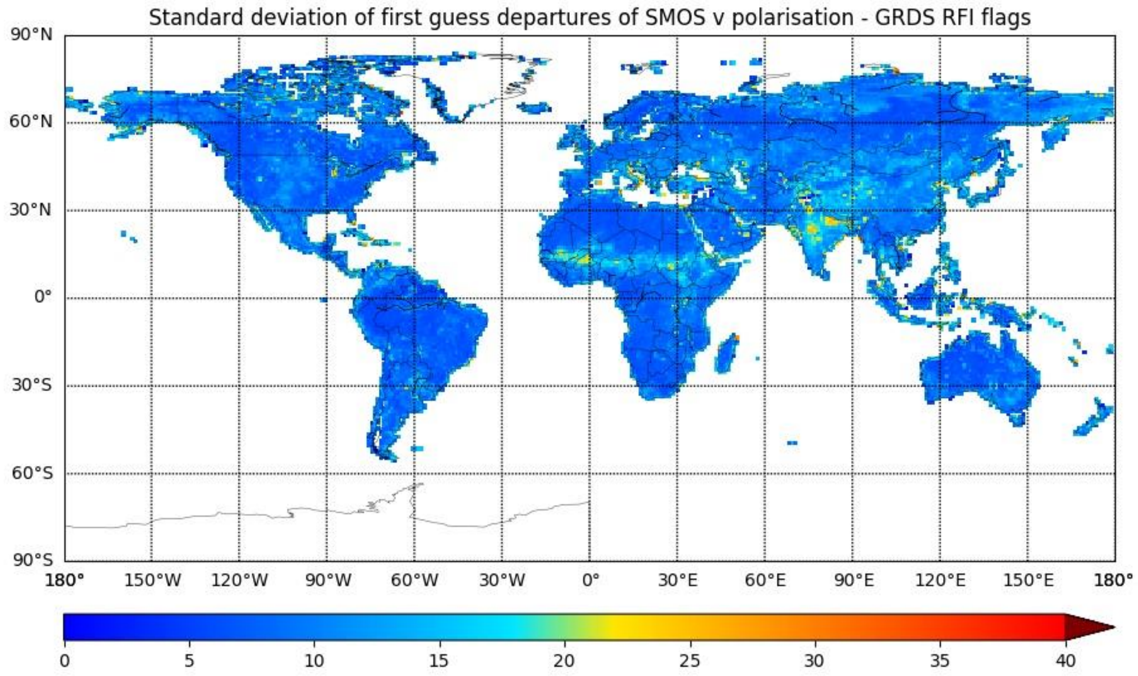
Simplified Extended Kalman Filter (SEKF) with EDA Jacobians



Observation monitoring and quality control

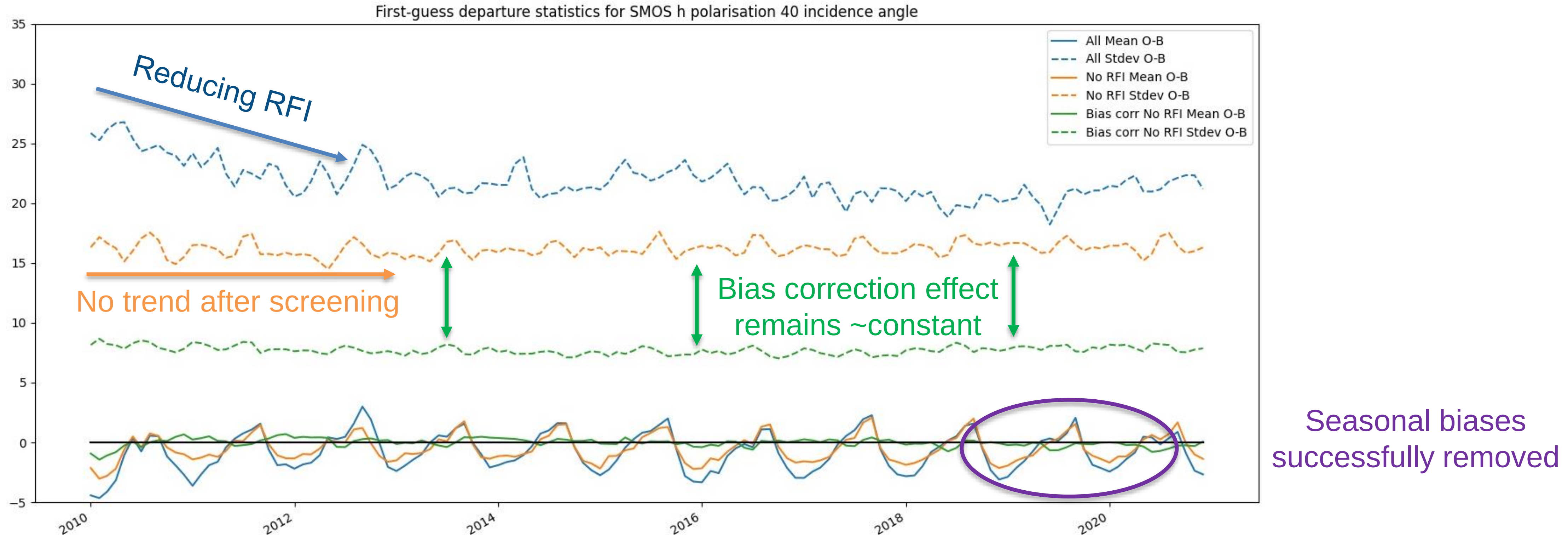
SMOS brightness temperature operational monitoring

- RFI has significantly affected SMOS measurements
  - Lessons learnt led to development of onboard filtering for SMAP and CIMR (could be used for SMOS-HR too)
- Improved screening (GRDS, Oliva et al, 2021) does a better job of filtering it out but still not perfect
  - **Comparing observations to NWP forecasts can be a powerful validation tool**
  - Quality control is vital for assimilation applications
- Future evolution:
  - **Higher spatial resolution potentially means more pixels without RFI contamination**
  - Potential to run GRDS operationally as part of the ground segment for current/future MW instruments



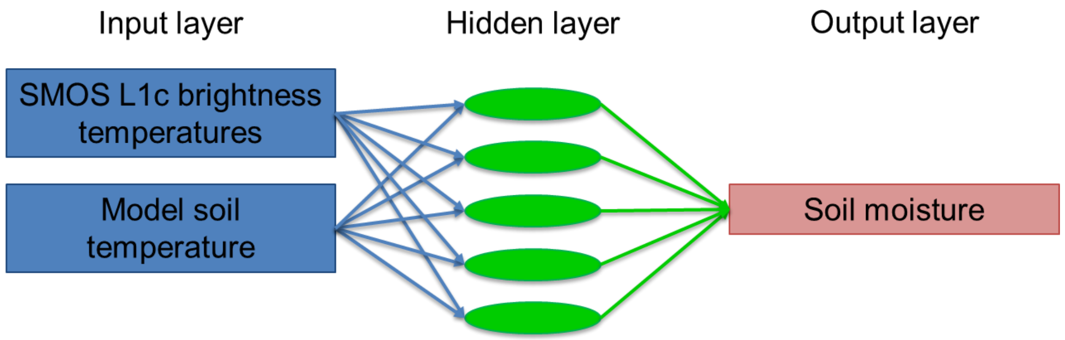
SMOS multi-year monitoring

- Monitor latest re-processed v724 SMOS L1C Tbs against stable ERA5 reference from 2010 to 2021



- Key take aways:
  - Improved RFI screening (orange v blue)
  - Newly developed bias correction performs consistently (green v orange)
  - Data quality is consistent over entire lifetime (after screening) – potential assimilation into future reanalyses

SMOS neural network soil moisture assimilation



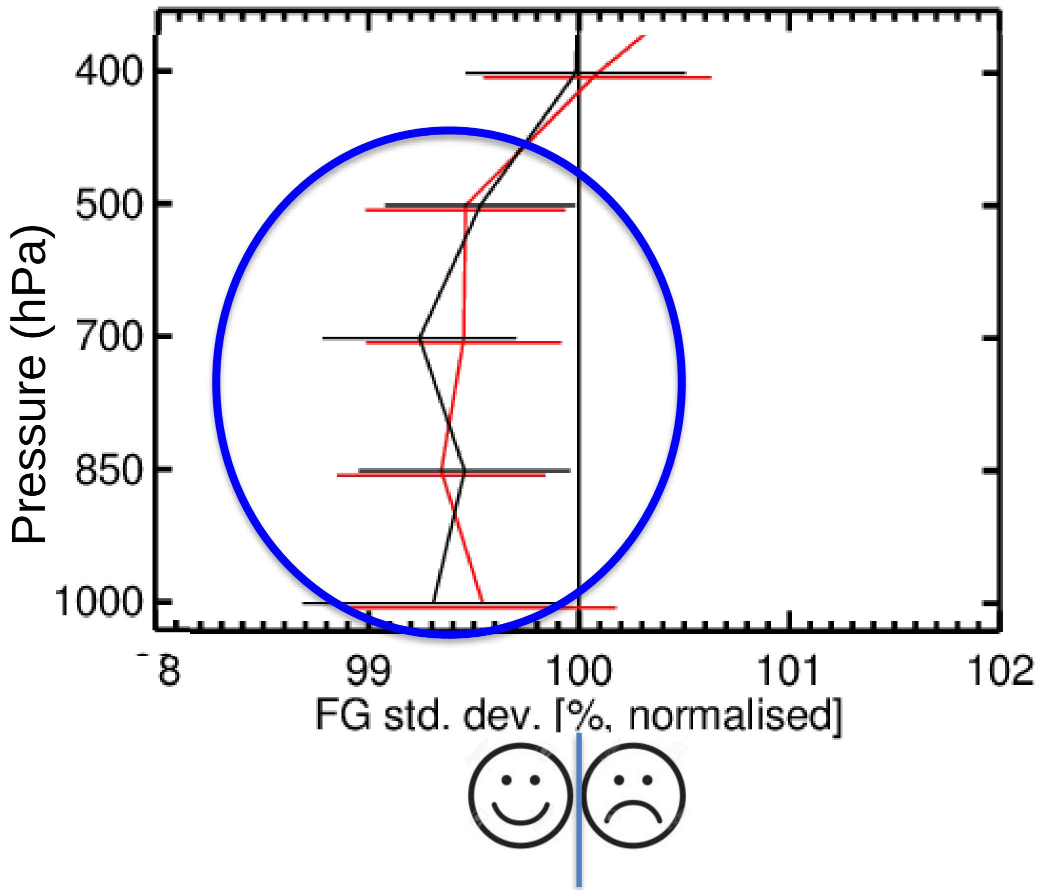
Rodriguez-Fernandez et al., HESS 2017, RS 2019

A priori training of the SMOS neural network processor
-> retraining when L1 Tb or IFS soil change

Further explore ML/AI for forward modelling

NWP
SMOS soil moisture impact

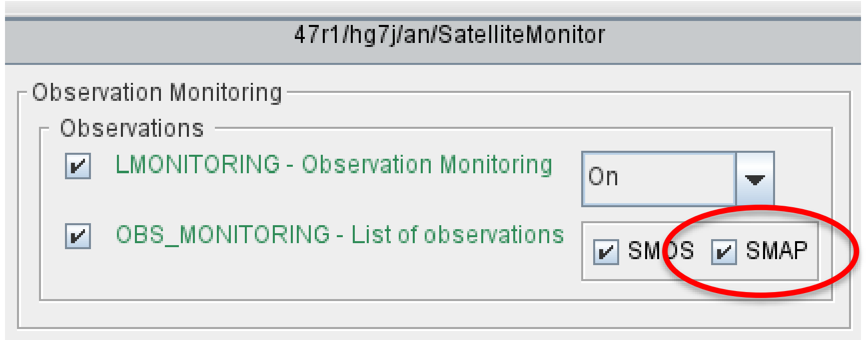
Aircraft humidity (JJA 2017)



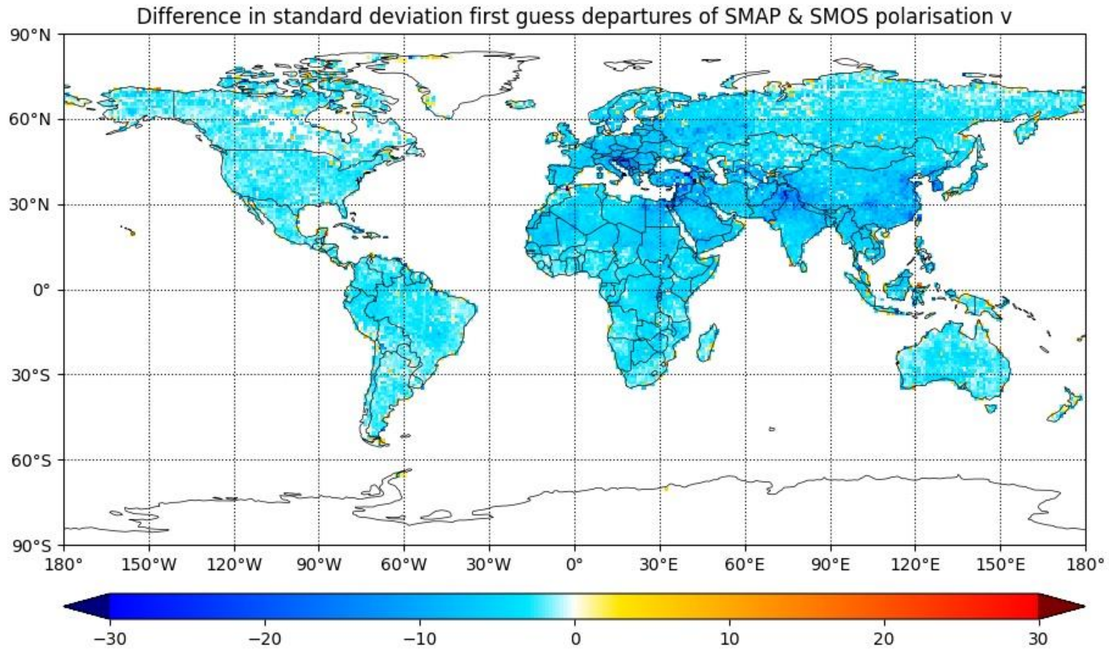
ECMWF

SMAP L-band data

Operational in the IFS
for monitoring since May 2021



- Set-up operational NRT acquisition
- IFS processing changes
- SMAP Observation interface (Obs Data base, ODB)
- Monitoring webpage update
- Allows comparisons between SMOS and SMAP
- Future: SMAP Tb assimilation evaluation



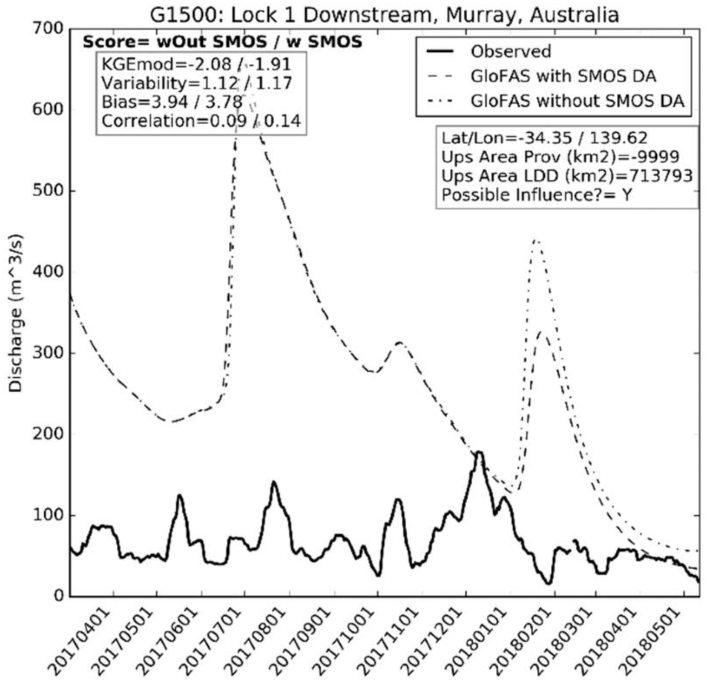
→ SMOS and SMAP L-band operational

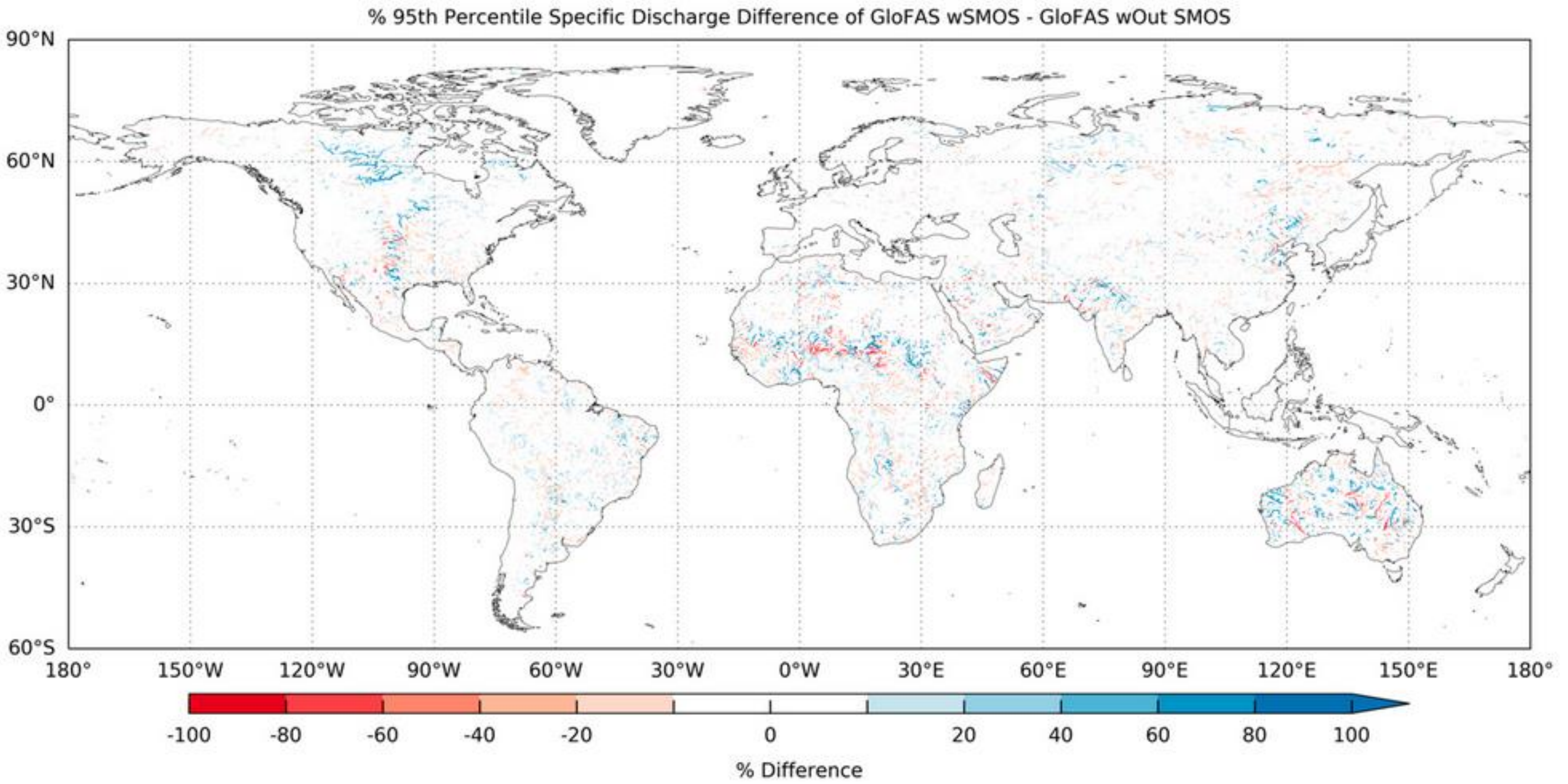
SMOS applications for the Copernicus Emergency Management Service (CEMS)

Data assimilation impact upon hydrology

Figures from Baugh *et al.*, *Rem. Sens.* 2020

- Data denial experiments with SMOS show similar results
    - i.e. muted impact on streamflow





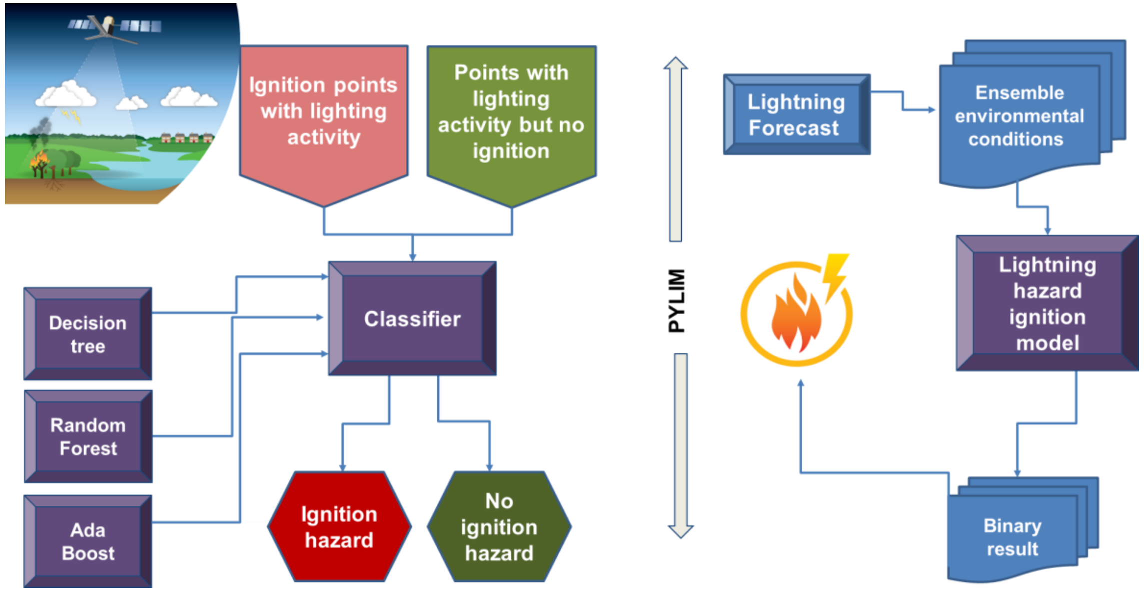
- ECMWF LDAS corrects for random errors, not systematic ones
- Process errors in Australia for example, maybe poor representation of processes such as irrigation and lake storage
- High spatial resolution important for this application

Other SMOS SM & VOD applications

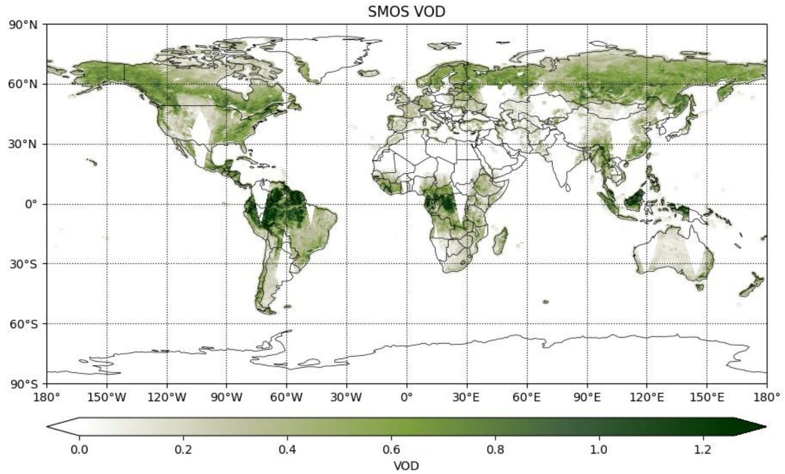
- Copernicus Emergency Management Service (CEMS):
  - Using machine learning to predict **fire** ignition occurrences from:
    - Lightning forecasts
    - Environmental conditions, including **SMOS NN soil moisture**
  - Classification algorithms used:
    - Decision tree, AdaBoost, Random Forest
    - Updated model using **SMOS L-VOD** data

Emergency Management

Coughlan et al., Met App 2021

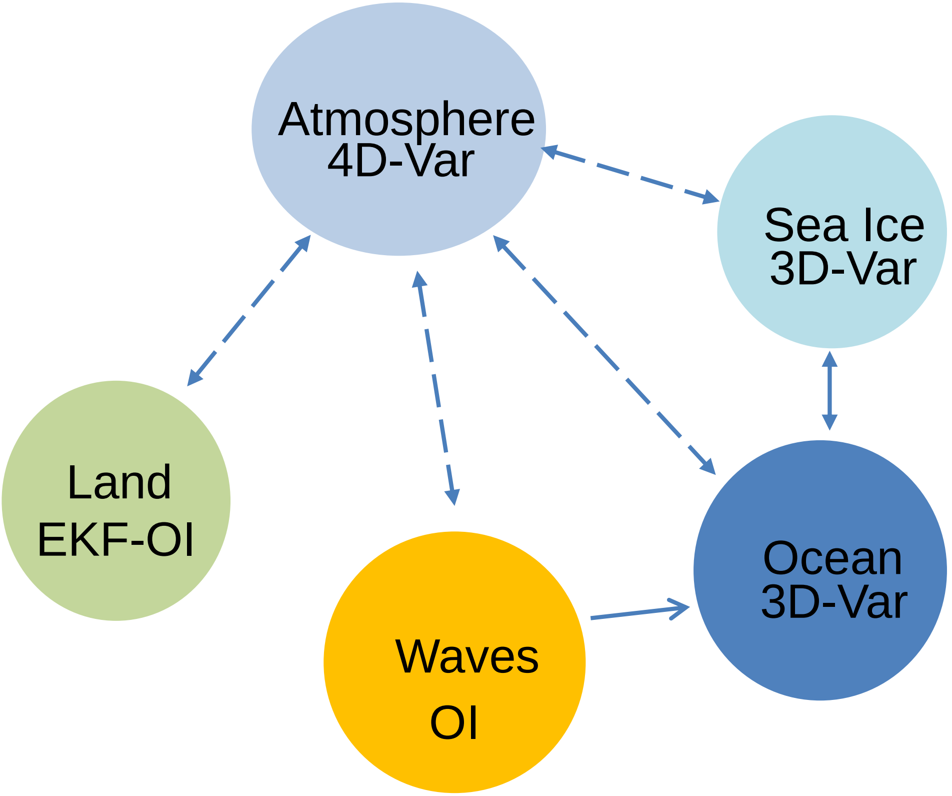


- CoCO-2 (H2020 project):
  - Prototype system for a Copernicus **CO_2 emission** monitoring service
    - Assimilation of **SMOS L-VOD** to analyse LAI



ECMWF

Summary and perspectives



- ECMWF Earth-system approach:
  - Interface observations -> relevance of L-band data

- Many **different applications** use L-band Tbs and derived products at ECMWF:
  - NWP – land and atmosphere (via coupling)
  - Ocean salinity and sea-ice
  - Hazards – floods and fires
  - CO_2 – vegetation
  - Climate – use in reanalyses for long-term trends

- Regular increases model and assimilation resolution at ECMWF:
  - 9km HRES and ENS in 2023 -> ~5km in mid-late 2020s
  - Importance of **high spatial resolution observations** to initialise higher resolution models (Destination Earth)

- Relevant future projects in support of Copernicus Evolution
  - CERISE: improved L-band MW observation operator
  - CORSO: direct L-band Tb assimilation to analyse vegetation

Summary and perspectives

	Spatial	Temporal	Polarization/frequency/ incidence angles	Comment
Climate, drought, carbon monitoring	coarse	low	**yes**	Dynamic vegetation updating still in infancy
Agriculture: crop	**fine**	low	**yes**	Field/farm-scale, management
Agriculture: irrigation	**fine**	**high**	no	
Ecosystems, peatlands	**fine**	low	yes	Nature preservation, peatland restoration
Hazards	fine	**high**	no	Water-related hazards (flood, landslide, fire)
NWP	towards finer	**high**	no	ECMWF **operational**

Research potential

Finer → wider user community

Yes → multivariate (incl. vegetation) updating

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