Modelling and data assimilation for land surface & cryosphere at ECMWF: recent progress

presented at EWGLAM/SRNWP 2021

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ECMWF Research Department

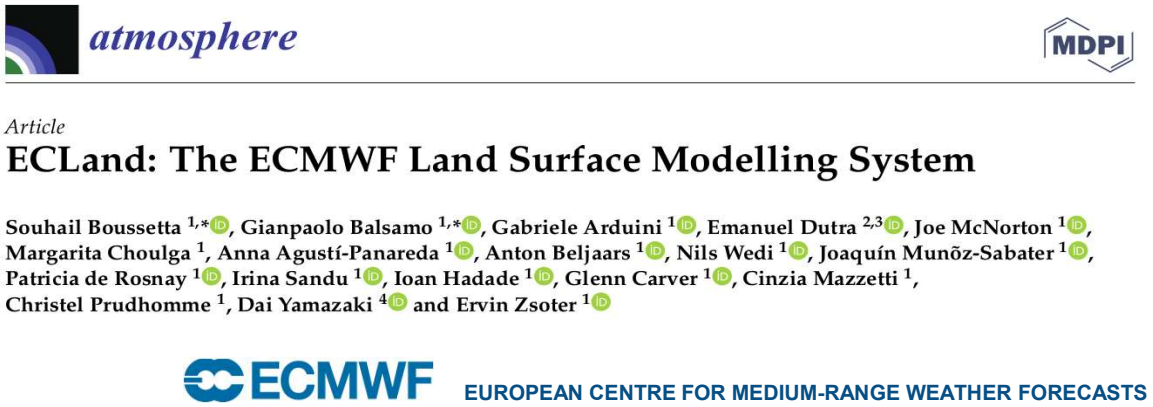
With contributions of several colleagues acknowledged on the slides

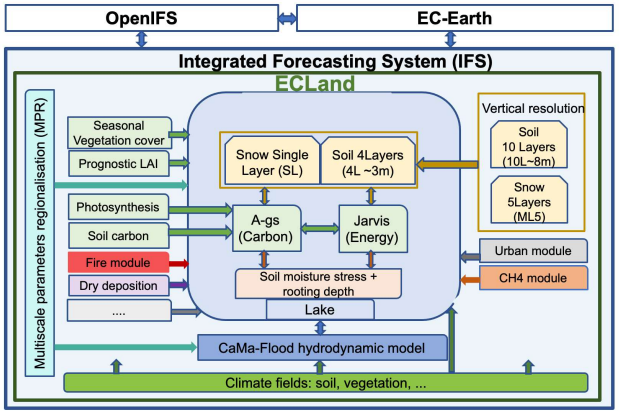
ECMWF

Land surface modelling advances

Themes

- **ECLand** for enhanced COP/DestinE collaborations, first results for 49r1 (Boussetta et al. 2021)
- **SnowML5** ready for operational implementation in 48r1 (including 4D-Var, GRIB2, RF initialisation)
- Preparation for **New land reanalysis** (C3S) & **CO2** monitoring (**Land-Use** & **Leaf Area Index**)
- Exploring **Soil & River hydrology** revision for hydrometeorological applications
- **IFS-urban** first coupled forecasts + ongoing **anthropogenic changes** (CO2 & CH4, Irrigation/inundation)

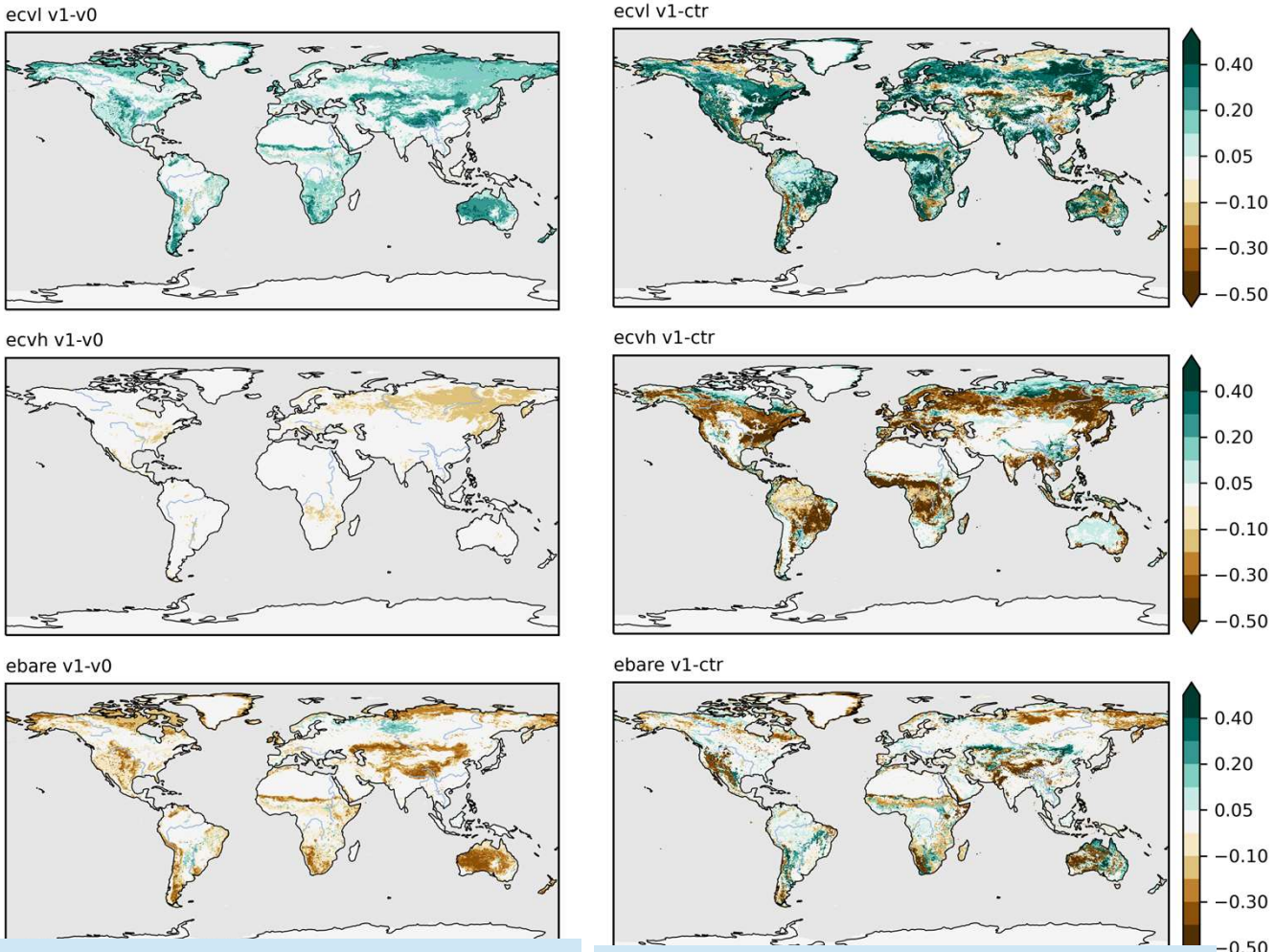




New Land use/Land cover global 1km dataset (from ESA-CCI) foreseen in cycle 49r1

Revision of the C3S/ESACCI LU/LC–ECMWF BATS classification cross-walking table (CWT)

Souhail Boussetta, Emanuel Dutra et al.



Difference with cross-walking table v0

Difference with oper maps

Increase in low vegetation and decrease in high vegetation fraction w.r.t the current map and the initially tested CWT .

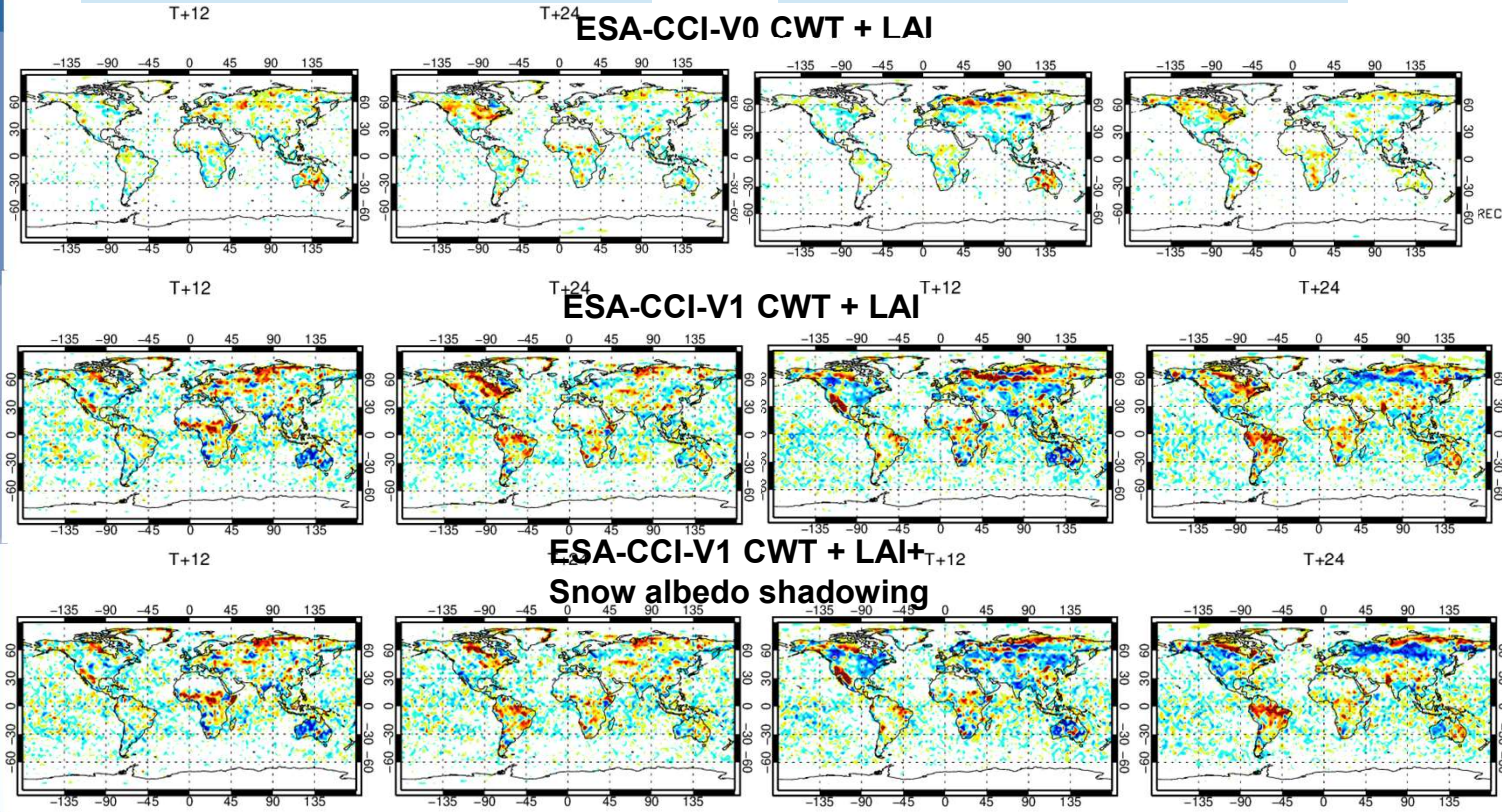
CWT v1 reduces the “overestimated” bare-soil fraction of CWT v0 as compared to the oper ==>This would bring more flexibility for the introduction of the vegetation cover seasonality.

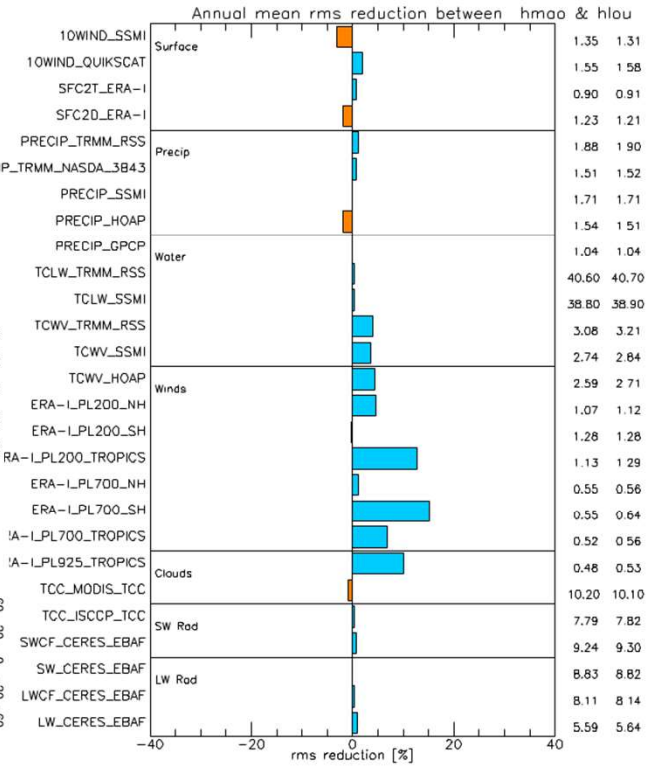
Forecast impact of the new Land use/Land cover – results before calibration

Change in 2T RMSE for Winter

Change in 2T RMSE for Spring

Climplot experiment



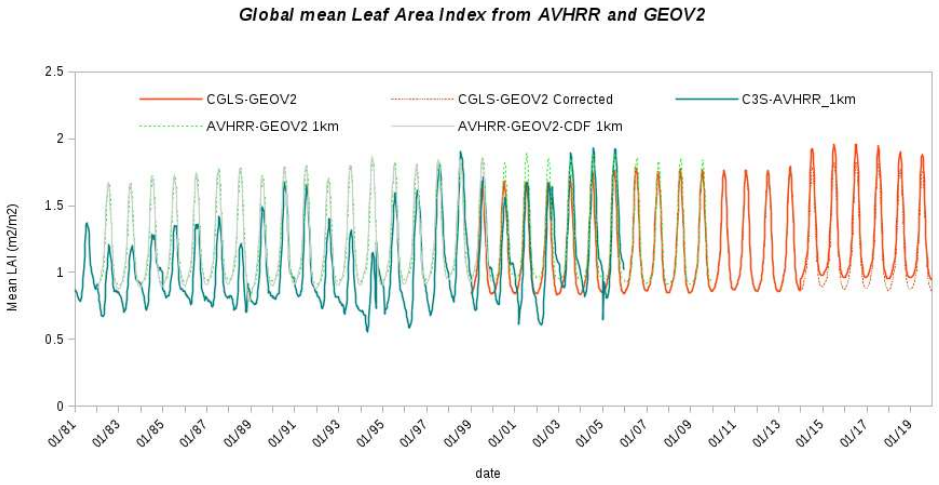


- Substantial atmospheric impact with V1 CWT compared to V0 (attributed to the initial change in roughness length)
- Further Parameters optimization will be needed to maximise the skill in weather parameters, preliminary results are however encouraging

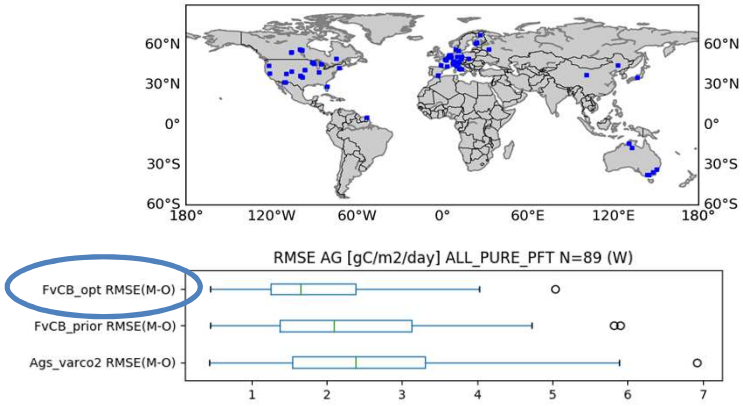
Towards time-varying vegetation & photosynthesis for reanalysis & CO2

Souhail Boussetta, Anna Agusti-Panareda et al.

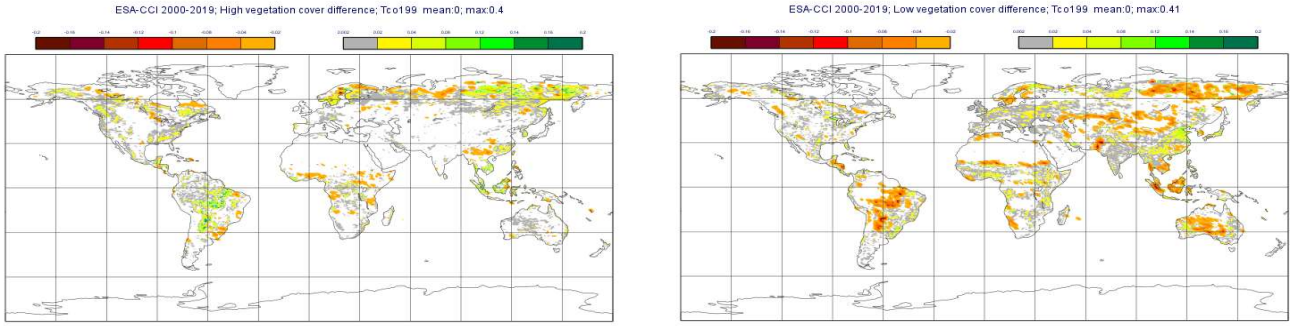
Harmonization of multi-source LAI 1993-2019 time series.



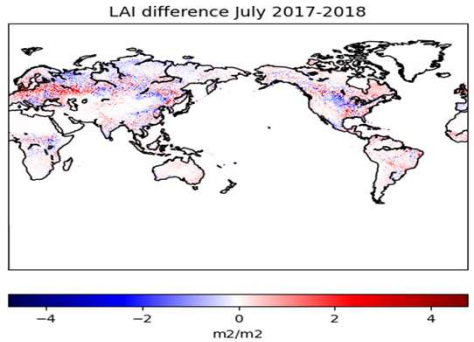
Optimisation for CO2 (GPP) using FLUXNET (89) sites



Vegetation cover differences between 2000 -2019 (right) for low & (left) high vegetation:



Europe drought can be detected in LAI (2018)



1993-2019 annual LU/LC and monthly LAI maps based on C3S/ESACCI data ==> new homogenised dataset

A urban tile holds promise to locally enhance heatwave in cities in cycle 49r1

Joey McNorton, Margarita Choulga, Gabriele Arduini et al.

EL PAÍS NEWS

SUMMER IN SPAIN >

Spain prepares for record-breaking high temperatures as heatwave intensifies

Meteorologists say the thermometer could reach close to 47ºC in the south of Spain, while in Madrid it could exceed 40ºC for three consecutive days

A woman shades herself from the sun in Córdoba in Andalusia. SALAS / EFE

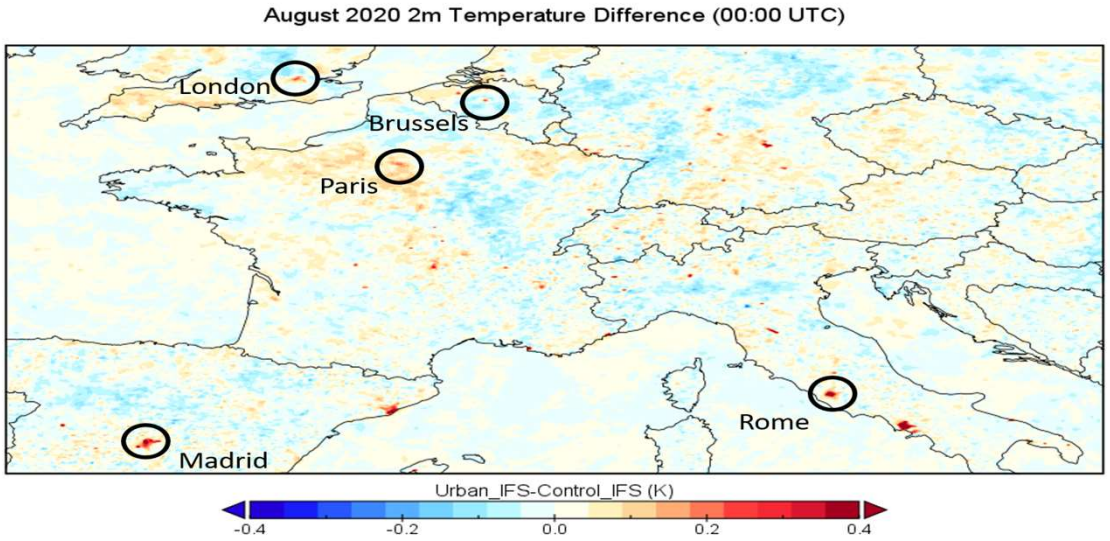
JAMES | Journal of Advances in Modeling Earth Systems

Research Article | Open Access

An Urban Scheme for the ECMWF Integrated Forecasting System: Single-Column and Global Offline Application

J. R. McNorton, G. Arduini, N. Bousserez, A. Agustí-Panareda, G. Balsamo, S. Boussetta, M. Choulga, I. Hadade, R. J. Hogan

First published: 02 April 2021 | https://doi.org/10.1029/2020MS002375 | Citations: 2



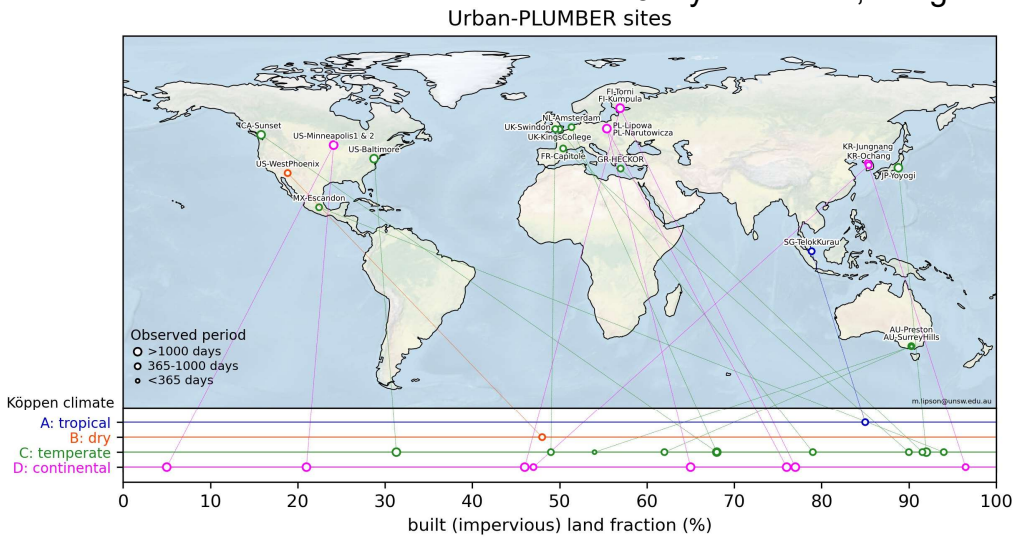
McNorton et al. 2021

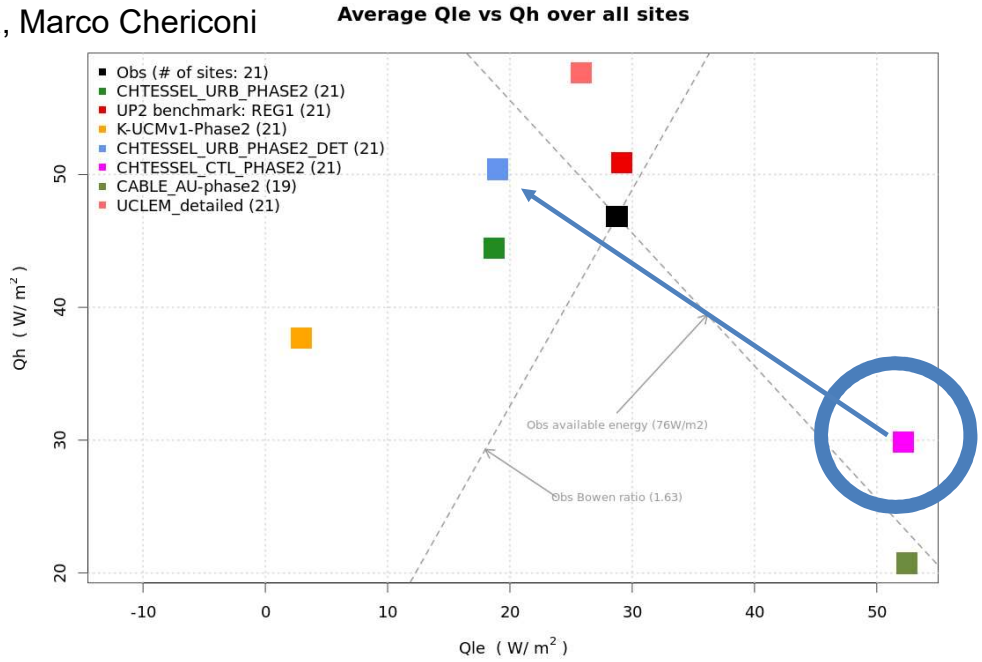
T2m sensitivity to Urban areas. First coupled 4km IFS runs with Urban tile. Average of FC+24 to +120 for the month of August 2020

Urban tile integrated in ECLand, foreseen for activation in cycle 49r1
SLIM project delivered a new Urban mapping software

Urban model evaluation ongoing in PLUMBER with observed properties

Joey McNorton, Margarita Choulga, Marco Chericoni

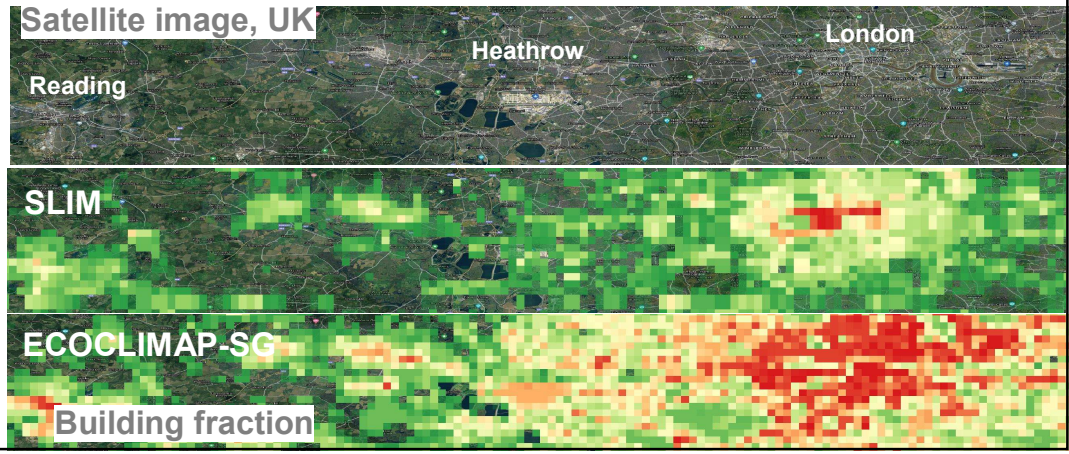




- Urban Plumber evaluates urban models across 21 sites
- Preliminary results show a model improvement in the partitioning of Latent and Sensible heat flux

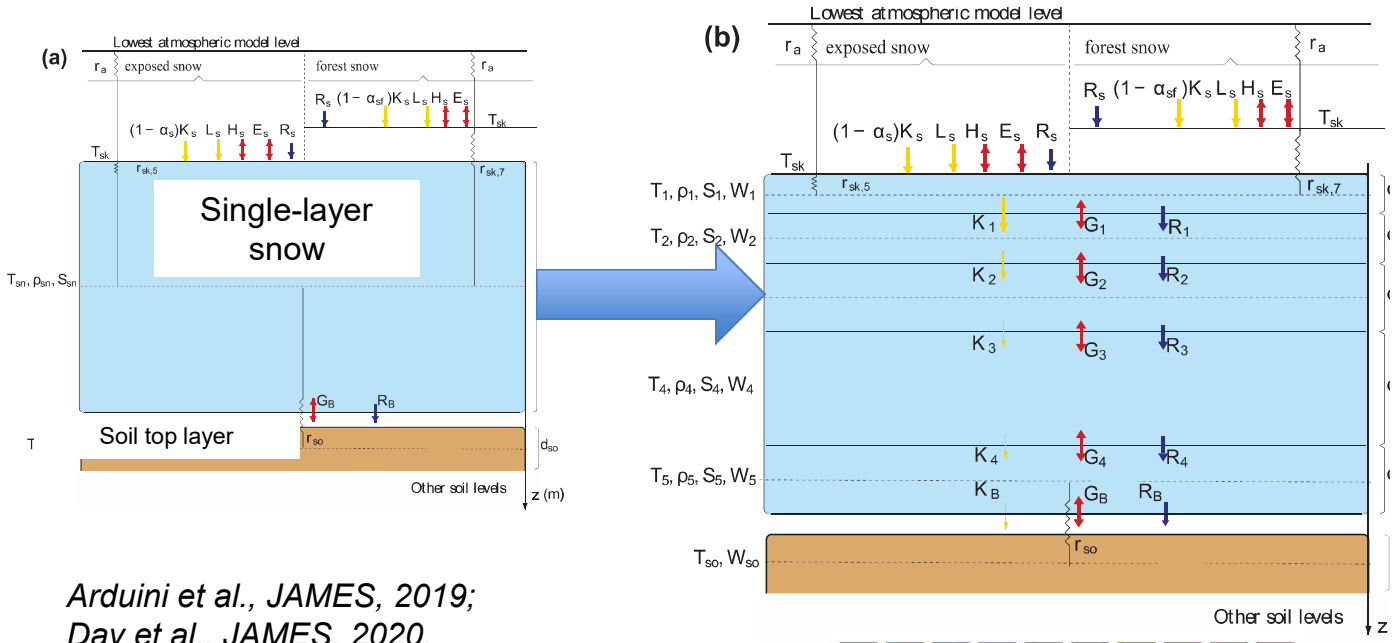
- Over next 2 years urban scheme will be used to activate online anthropogenic CO2 emissions in CAMS/CoCO2

- A key component to enable to implement the urban scheme will be the quality of urban mapping dataset



A 5-layer snow model to replace the single-layer representation in cycle 48r1

Gabriele Arduini, Day, et al.



Arduini et al., JAMES, 2019;
Day et al., JAMES, 2020,
Boussetta et al., MDPI-Atm., 2021

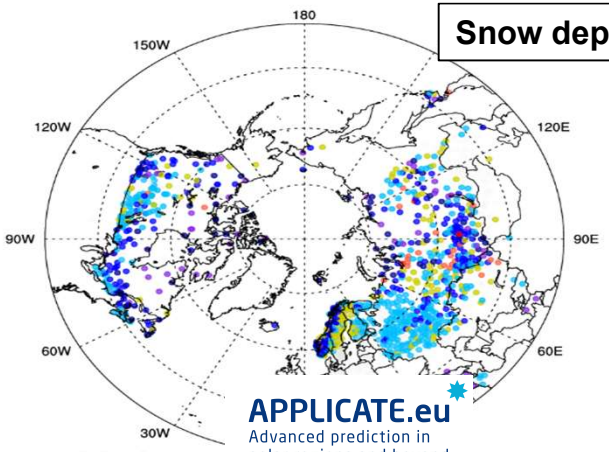
- Substantial improvement in **snow depth**
- Reduced error also in the forecasts of **minimum temperature** (+24h).
- Explorative work for snow on sea-ice.

New multi-layer snow scheme:

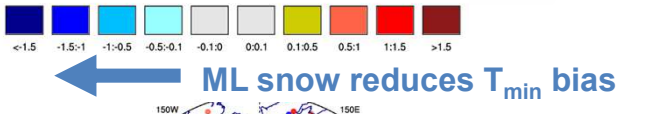
- Targeted for cycle 48r1 (2022/2023)
- 5-layer snow scheme
- Prognostic liquid water content
- Improved snow physics

ML reduced snow$_{depth}$ RMSE — increase RMSE

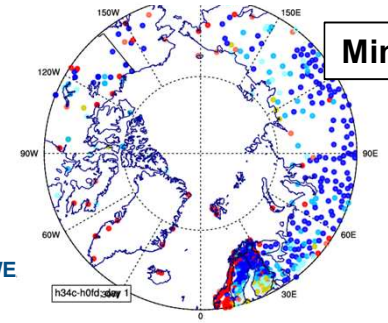
Snow depth



ML snow reduces T_{min} bias



Minimum T2m



bias :: CTL =8.9; EXP =5.2
rmse:: CTL =20.6; EXP =18.3
mae :: CTL =14.1; EXP =11.9

APPLICATE.eu
Advanced prediction in polar regions and beyond

ECMWF EUROPEAN CENTRE FOR MEDIUM-RANGE WE

Towards time-varying water cover

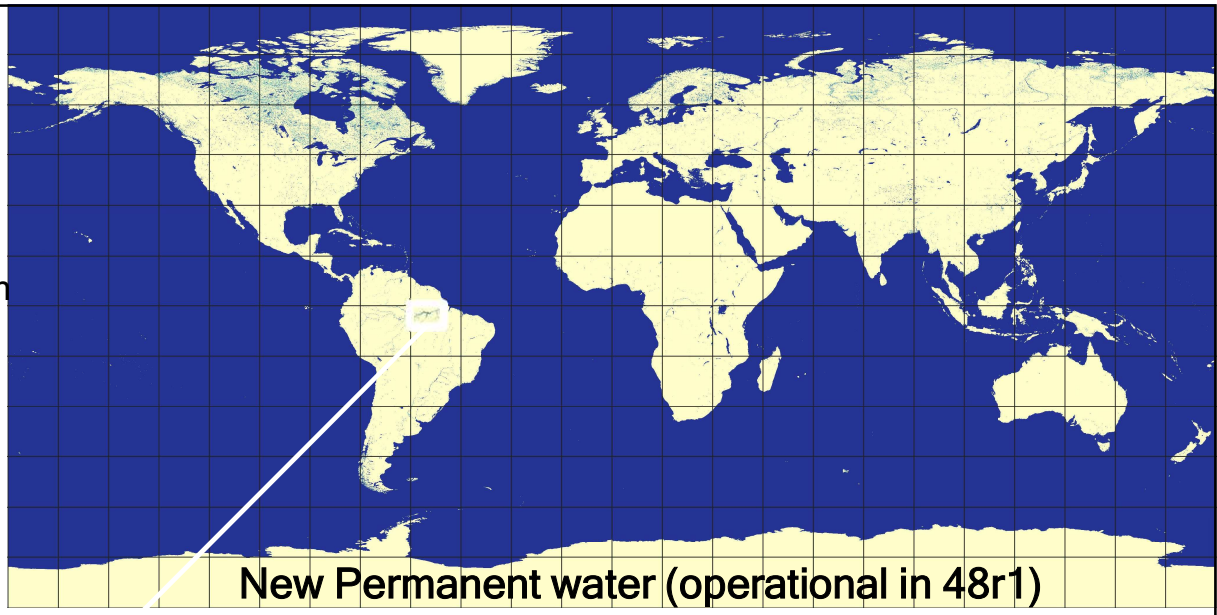
Margarita Choulga et al.

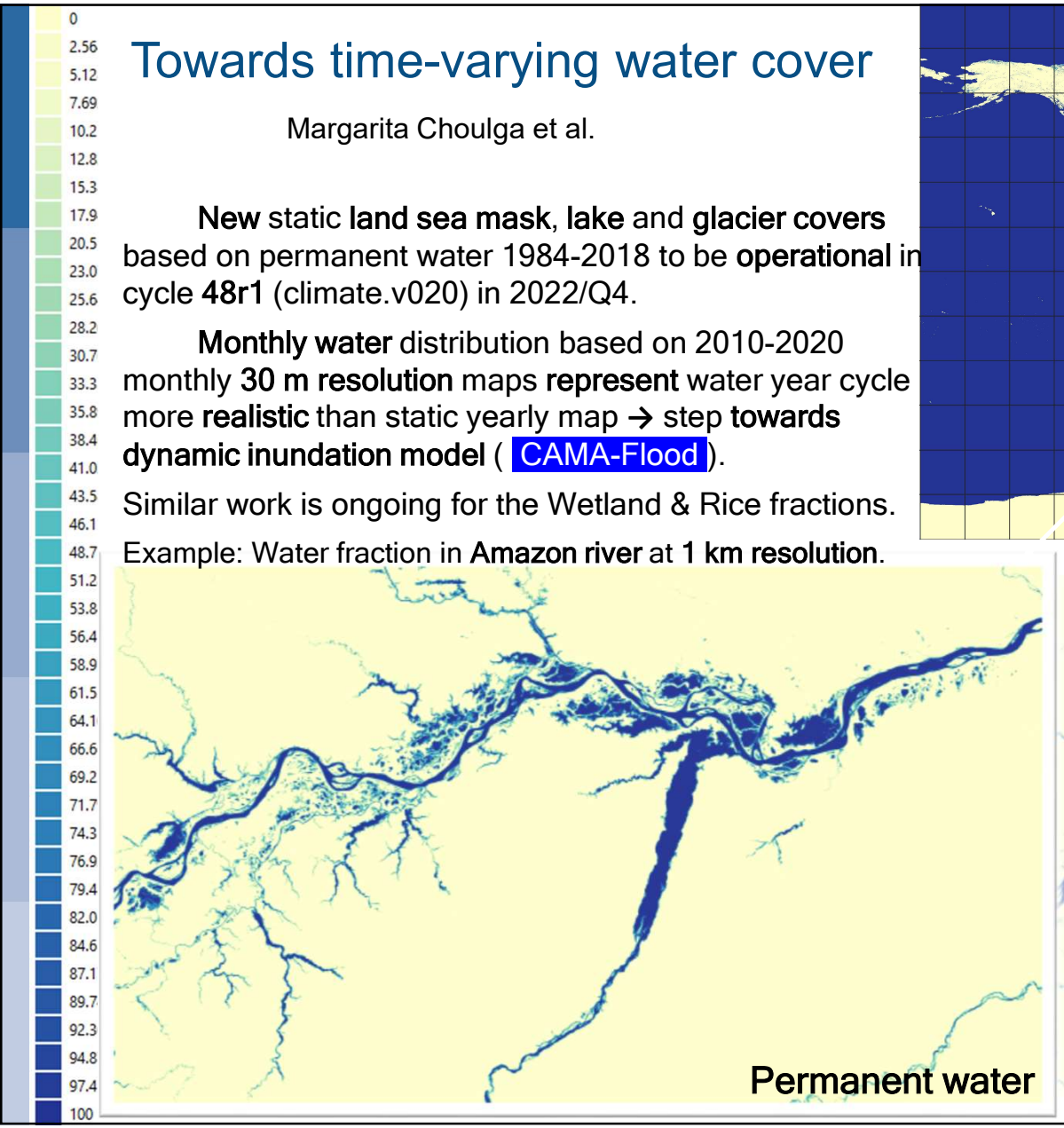
New static **land sea mask**, **lake** and **glacier covers** based on permanent water 1984-2018 to be **operational** in cycle **48r1** (climate.v020) in 2022/Q4.

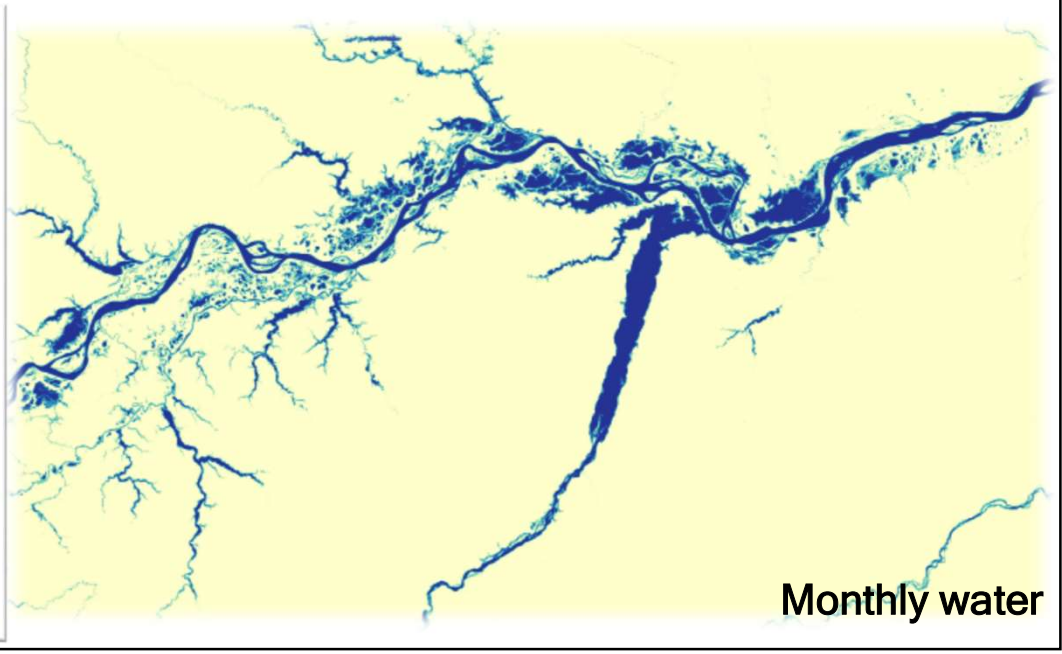
Monthly water distribution based on 2010-2020 monthly **30 m resolution** maps **represent** water year cycle more **realistic** than static yearly map → step **towards dynamic inundation model** (CAMA-Flood).

Similar work is ongoing for the Wetland & Rice fractions.

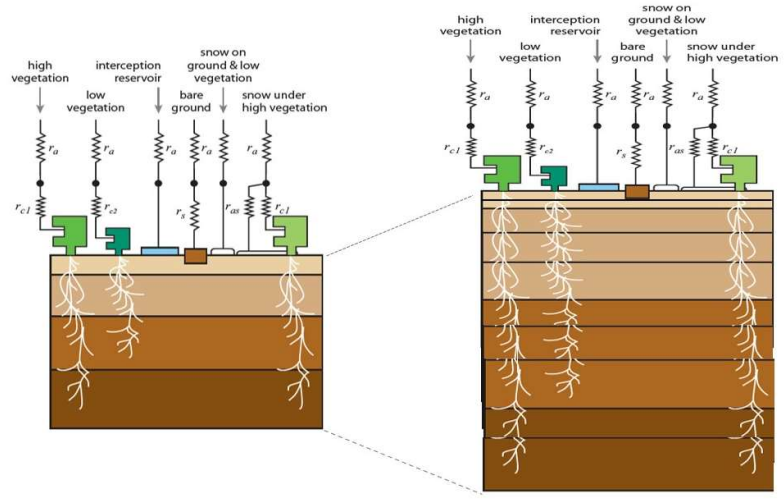
Example: Water fraction in **Amazon river** at **1 km resolution**.

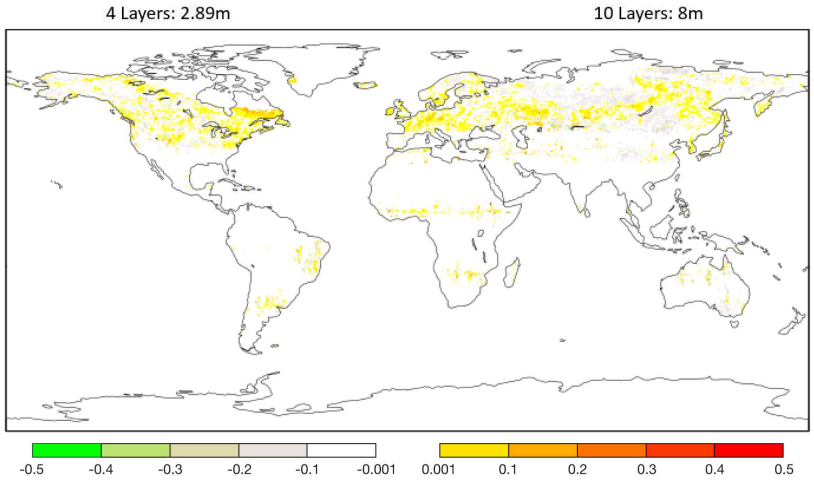






Toward an improved the soil and river-catchment hydrology representation



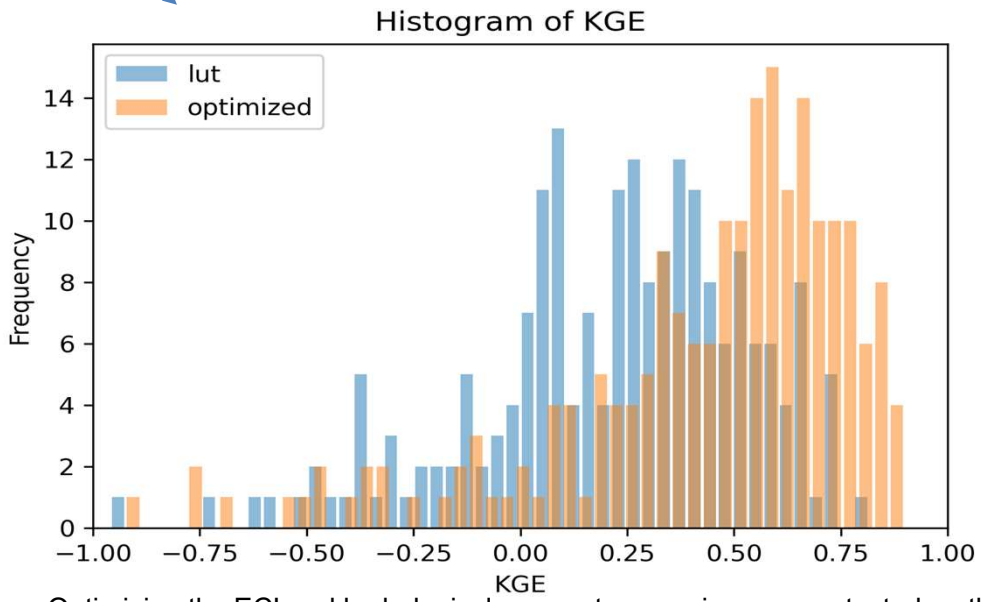


Improved correlation with the ESA-CCI surface soil moisture product between when using thinner surface layers (10-layer) & the current 4-layer scheme for JJA

Development for cycle beyond 49r1, in collaboration with Emergency Management

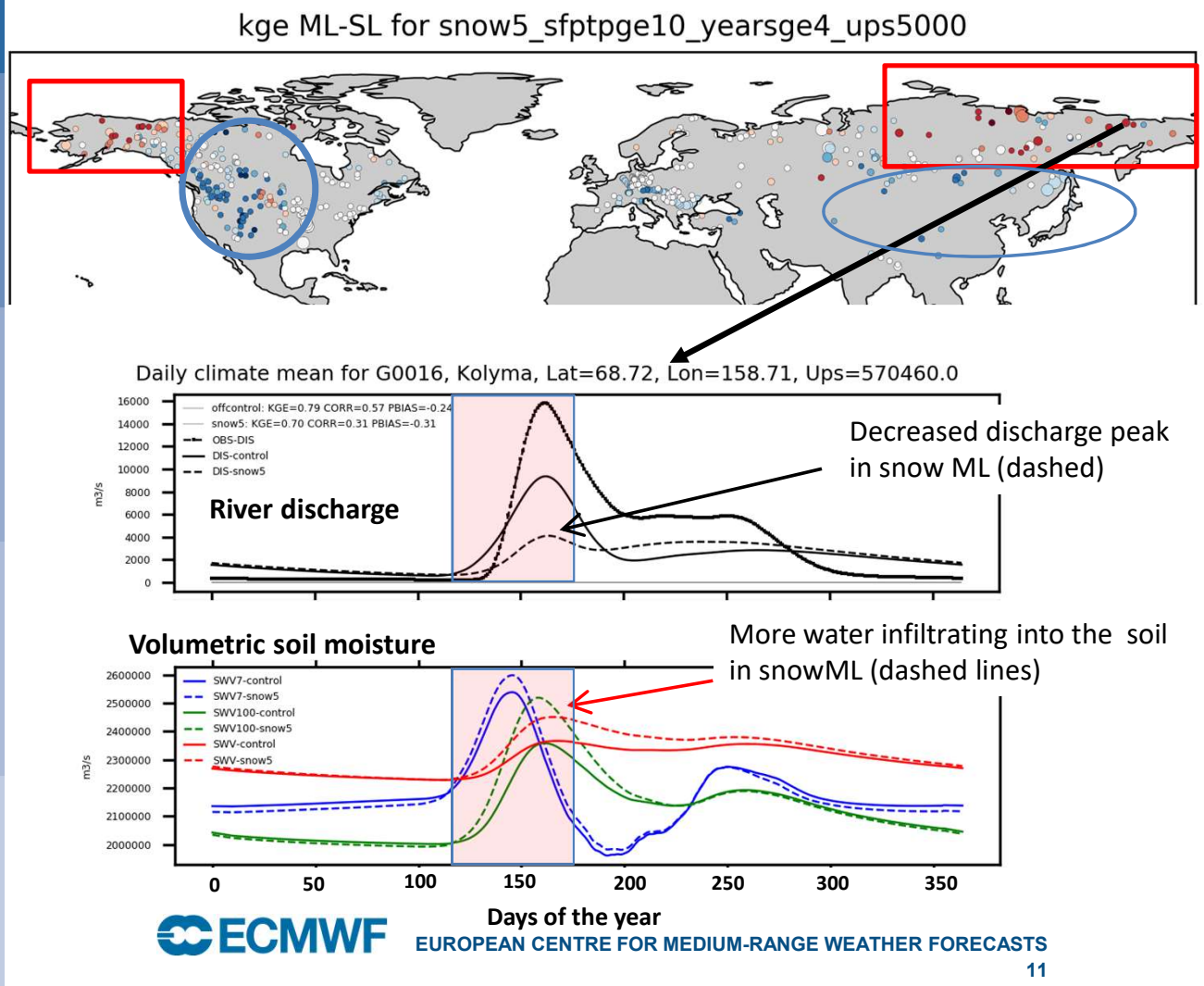
- Improving the soil vertical discretisation shows potential improvement for Better match with satellite surface soil moisture observation

1. Hydrological benchmarking in collaboration with GloFAS team shows the benefits of calibrating the soil hydrology using river discharges



Optimising the ECLand hydrological parameters can improve as tested on the river discharge

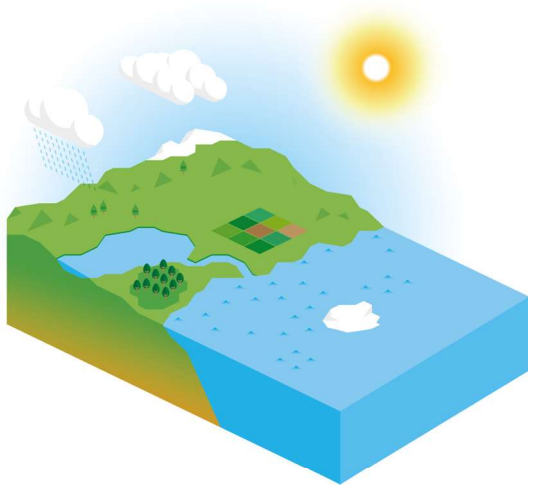
Evaluating land-surface model developments using river discharges observations, the example of the multi-layer snow scheme



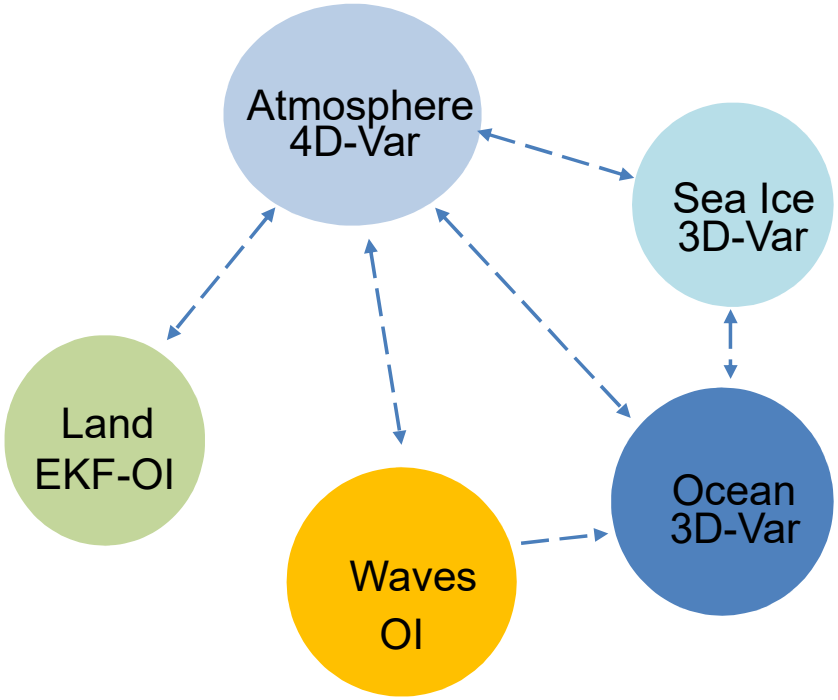
- More catchments show improvements, in particular over Rockies and mid-latitude Eurasia
- Many catchments in cold climates show lower KGE/correlation than the single-layer snow experiment (e.g. permafrost regions)
- In permafrost areas, the increase in water infiltrating into the soil due to warmer soil temperature in snowML, amplifies river discharge pre-existent biases.
- Different parametrizations for frozen soil are currently under testing

Zsoter, Arduini et al. in preparation

Coupled assimilation developments for NWP and reanalyses



Integrated Forecasting System (IFS)

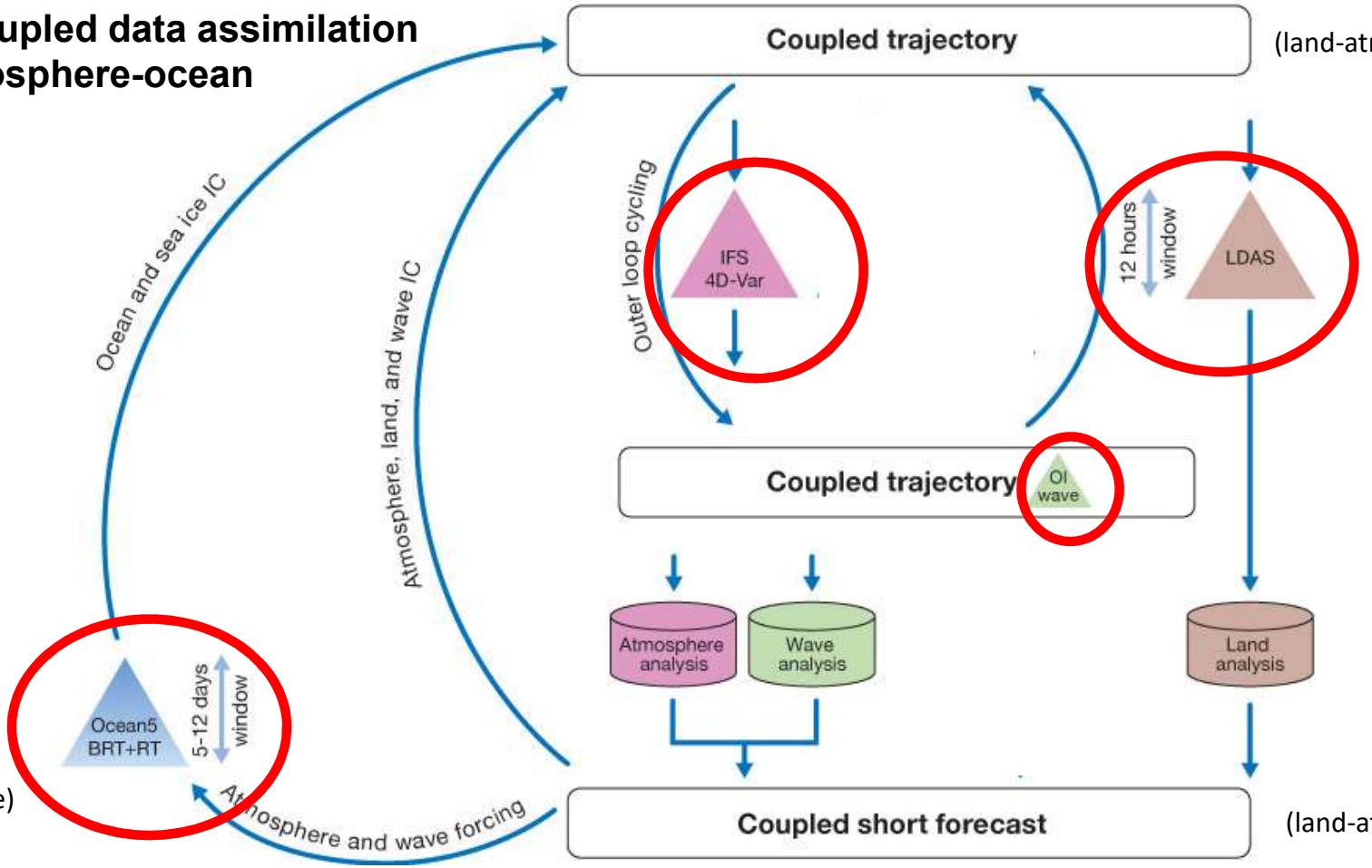


- Importance of the Earth system approach
- Importance of interface observations (e.g. snow, soil moisture, SST, sea ice)

ECMWF

Coupled Assimilation for operational NWP at ECMWF

Weakly coupled data assimilation
Land-atmosphere-ocean



(ocean and sea ice)

Observing system and monitoring

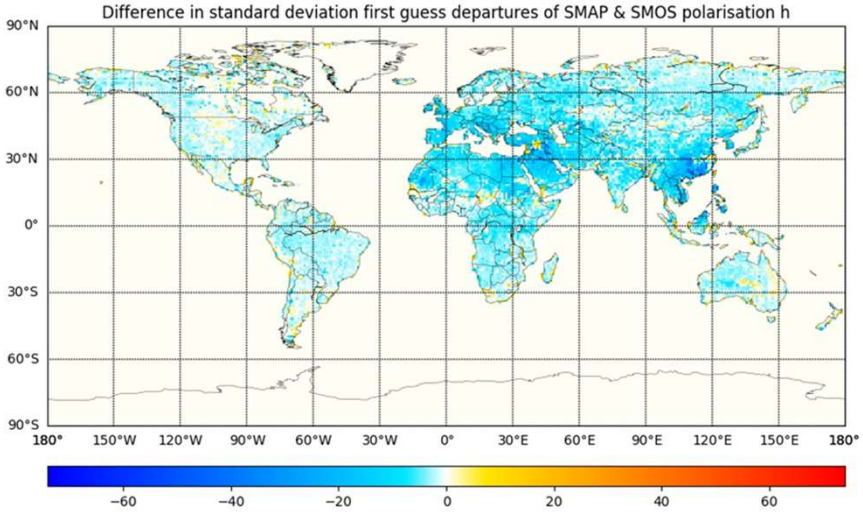
Need timely, sustainable and reliable access to observations across the Earth system components

- **Observations sustainability** for land, cryosphere and for the ocean → level of support from governing bodies to ensure in situ data provision, relevance of WMO data policy evolutions; works of JET-EOSDE, GCW, SG-CRYO, GOOS, etc…

- **Observations acquisition:**
  - Operational acquisition streams needed, e.g. Interface Control Document for Sea Level and SST Observations acquisition
- **Observations monitoring:**
  - Ocean operational monitoring (since 2017)
  - Land operational monitoring (since 2013), SYNOP monthly 'blocklist' & auto-alert (since Sept 2020)

SMOS and SMAP L-band observations Operational monitoring in the IFS

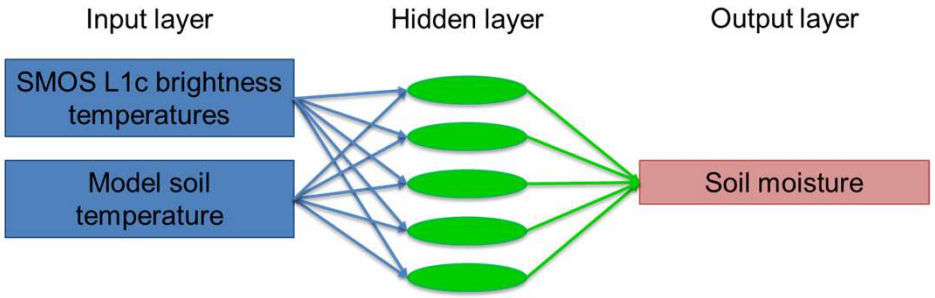
Obs-Model (First guess departure) StDev SMAP-SMOS difference in K



https://www.ecmwf.int/en/forecasts/quality-our-forecasts/monitoring-observing-system

ECMWF

SMOS neural network soil moisture assimilation



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

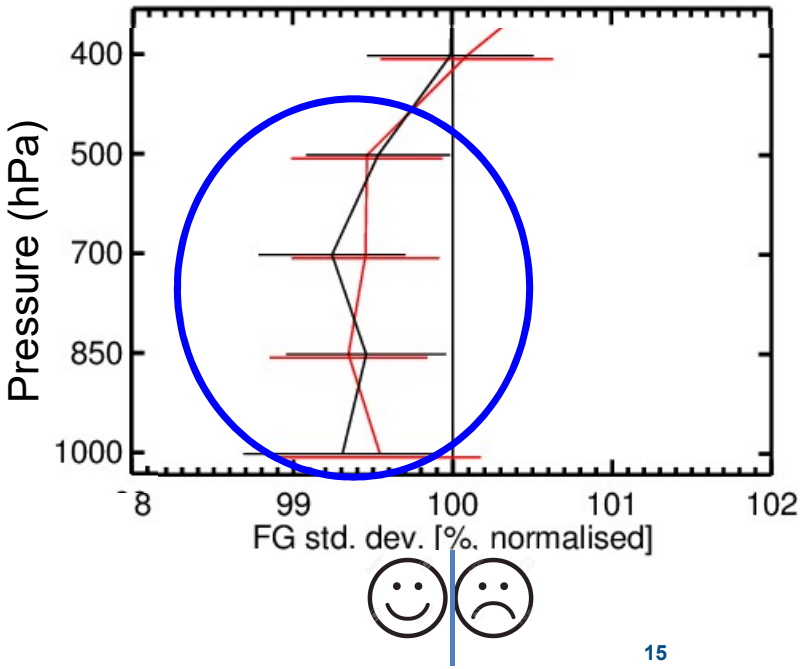
A priori training of the SMOS neural network processor
-> retraining when L1Tb or IFS soil change
Online training possibilities?

Further explore ML/AI for forward modelling for passive and active land observation usage

Aires et al., QJRMS 2021

SMOS DA impact

Aircraft humidity (JJA 2017)

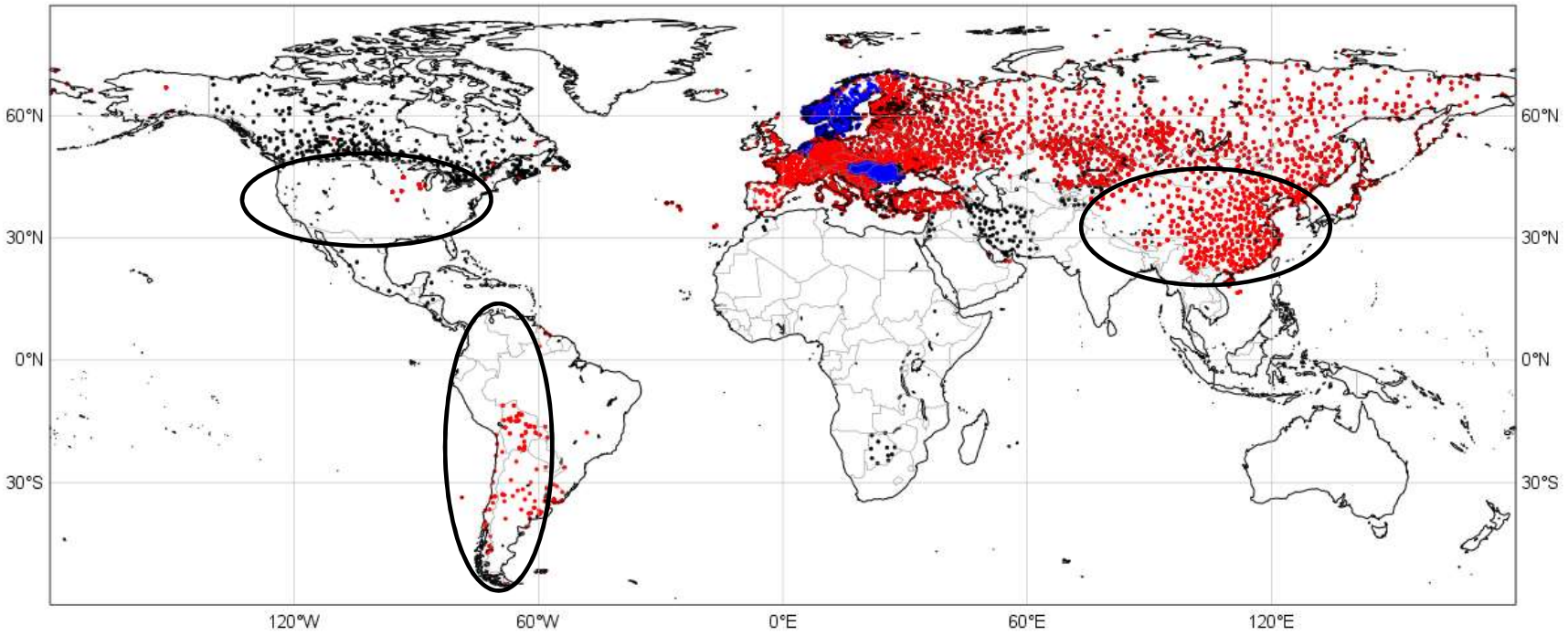


Land observing system: the example of in situ snow depth

Near-Real-Time access to observations

15 January 2021

SYNOP TAC SYNOP BUFR national BUFR data

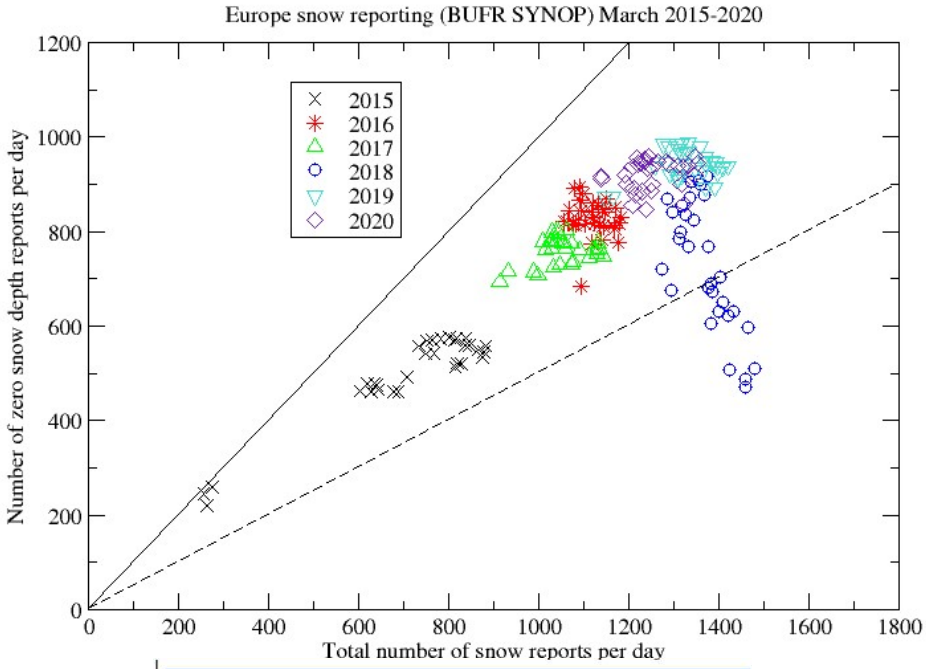


Snow depth availability on the Global Telecommunication System (GTS)

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



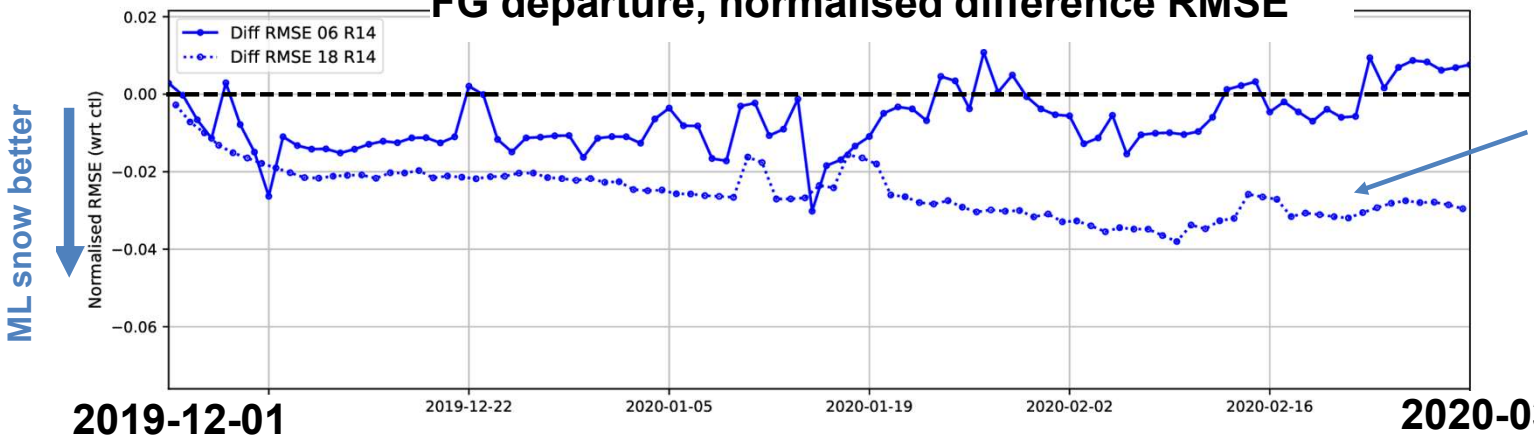
6. Improvements in the reporting of 'zero' snow depth from SYNOP stations

WIGOS Newsletter April 2020

Snow data assimilation with the new multi-layer snow scheme

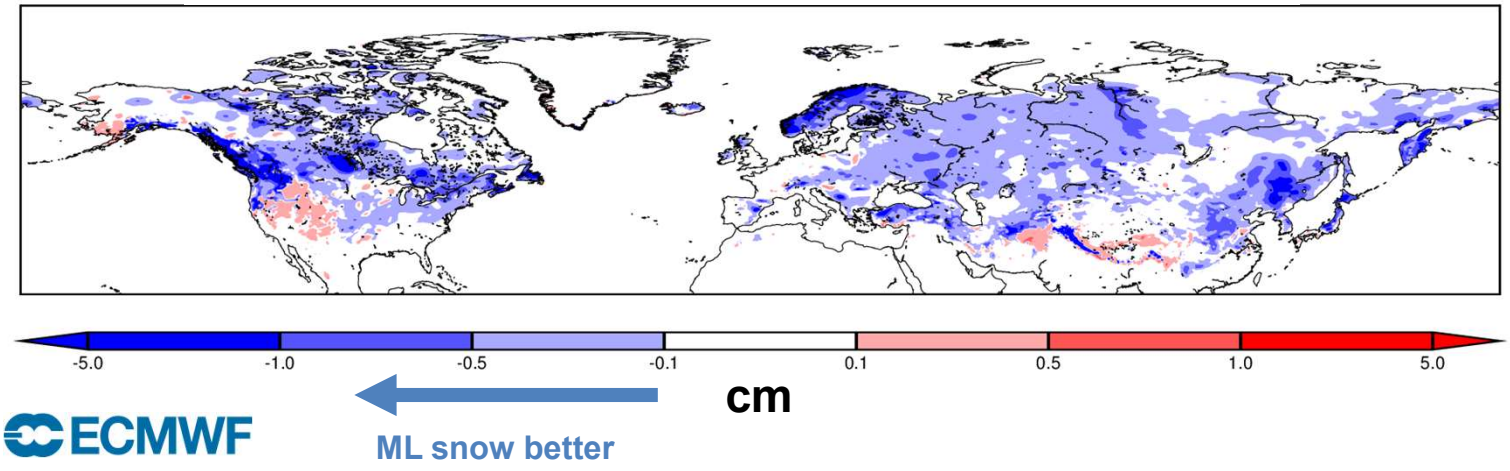
Winter, 47r1.3, Tco399L137; 3 months analysis (DJF 2019/2020)

FG departure, normalised difference RMSE



~2-3% reduction of snow depth FG departure

RMSE diff in AN increments for Jan 2020, 06UTC/18UTC



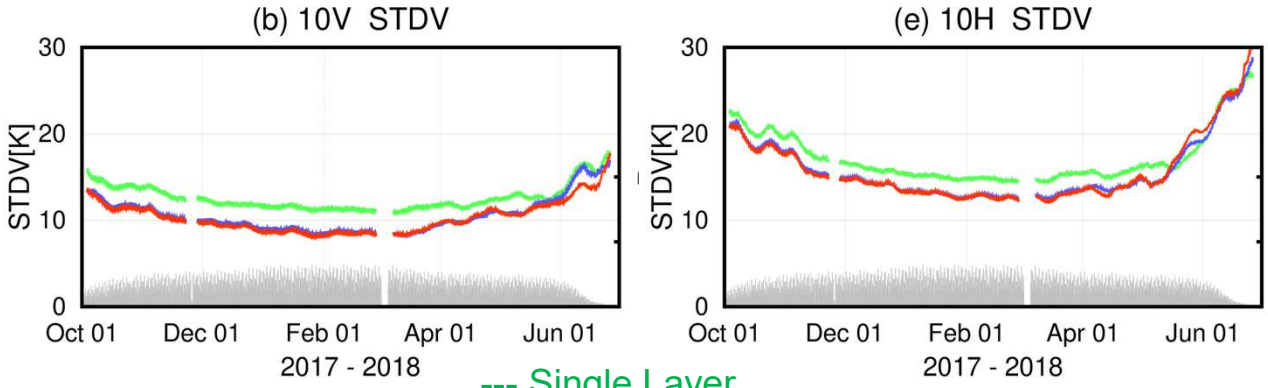
ECMWF

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
- **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



ECMWF

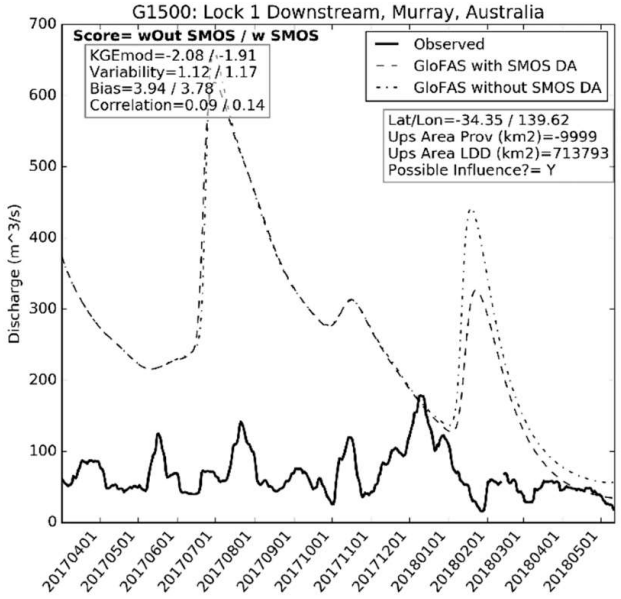
Hirahara et al., 2020
https://doi.org/10.3390/rs12182946

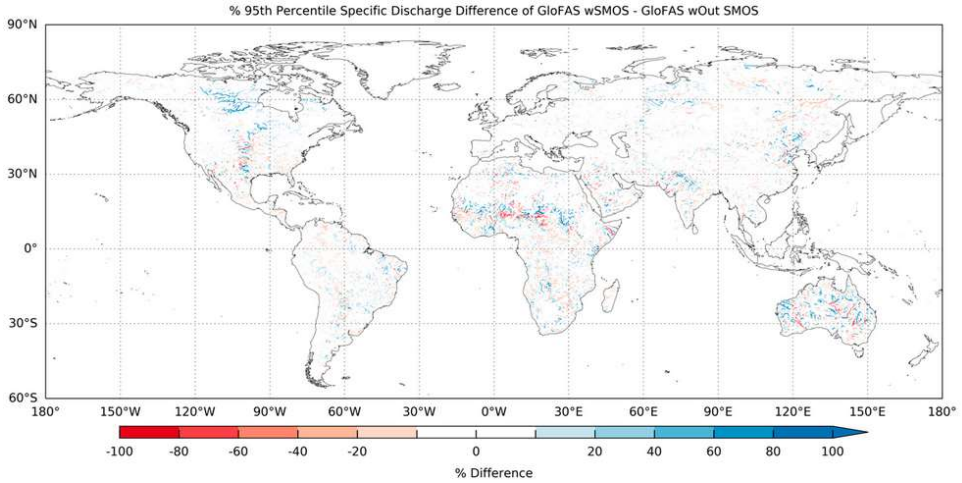
SMOS applications for the Copernicus Emergency Management Service (CEMS)

Data assimilation impact on hydrology

- Data denial experiments with SMOS

Baugh et al., Rem. Sens. 2020





- Neutral impact of SMOS on river discharge
- Very small impact mostly on peak flow
- Poor representation of river regulation, irrigation and lake storage
- Further work towards coupled land-hydrology DA

Summary

- Coupled Land-atmosphere modelling & assimilation at ECMWF for operational NWP and future generations of reanalyses (NWP, Copernicus Services, and high resolution Destination Earth)
- ECLand summarise the ongoing modelling efforts (Boussetta et al 2021, MDPI-Atmosphere)
- Relevance and strong impact of interface observations such as snow depth and soil moisture
- Development of consistent observation monitoring across the components is ongoing
- Challenges of Earth System approach for NWP:
  - Observations availability, sustainability (e.g. snow, ocean)
  - Coupling through the observation operator (e.g. for snow surfaces) → opportunities to enhance the exploitation of satellite data
- Next steps: Uniformise ECMWF Land DA system & enhance exploitation of land observations

ECMWF

Special Collection Quarterly Journal of The Royal Meteorological Society "Coupled Earth system data assimilation"

- In the context of the first Joint WCRP-WWRP Symposium on Data Assimilation and Reanalysis

- We invite contributions on coupled assimilation developments for research and operational applications.

  We welcome papers that address methodological aspects of coupled assimilation as well as scientific investigations on coupling degrees and impact studies.

- Submission deadline: 31 December 2022

https://rmets.onlinelibrary.wiley.com/