Accounting for Irrigation at ECMWF: NWP and hydrological approaches

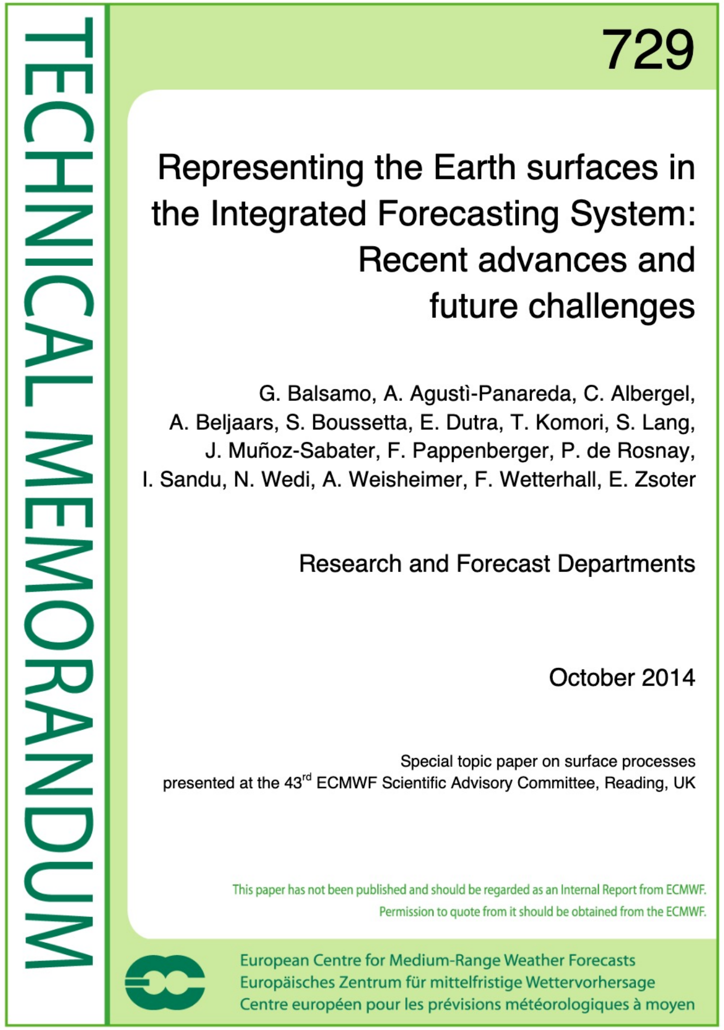
Gianpaolo Balsamo, Gabriele Arduini, Souhail Boussetta, Margarita Choulga,
David Fairbarn, Joe McNorton, Cinzia Mazzetti, Patricia de Rosnay,
Christel Prudhomme, Jamie Towner, Peter Weston, Ervin Zsoter

Presented at the Irrigation cross-cut KO Meeting (GEWEX)

4-5 November 2021

ECMWF

Recognizing irrigation needs and motivation at ECMWF



TECHNICAL MEMORANDUM

729

Representing the Earth surfaces in the Integrated Forecasting System: Recent advances and future challenges

G. Balsamo, A. Agustì-Panareda, C. Albergel, A. Beljaars, S. Boussetta, E. Dutra, T. Komori, S. Lang, J. Muñoz-Sabater, F. Pappenberger, P. de Rosnay, I. Sandu, N. Wedi, A. Weisheimer, F. Wetterhall, E. Zsoter

Research and Forecast Departments

October 2014

Special topic paper on surface processes presented at the 43rd ECMWF Scientific Advisory Committee, Reading, UK

This paper has not been published and should be regarded as an Internal Report from ECMWF. Permission to quote from it should be obtained from the ECMWF.

European Centre for Medium-Range Weather Forecasts
Europäisches Zentrum für mittelfristige Wettervorhersage
Centre européen pour les prévisions météorologiques à moyen

Representing the Earth surfaces in the IFS — ECMWF

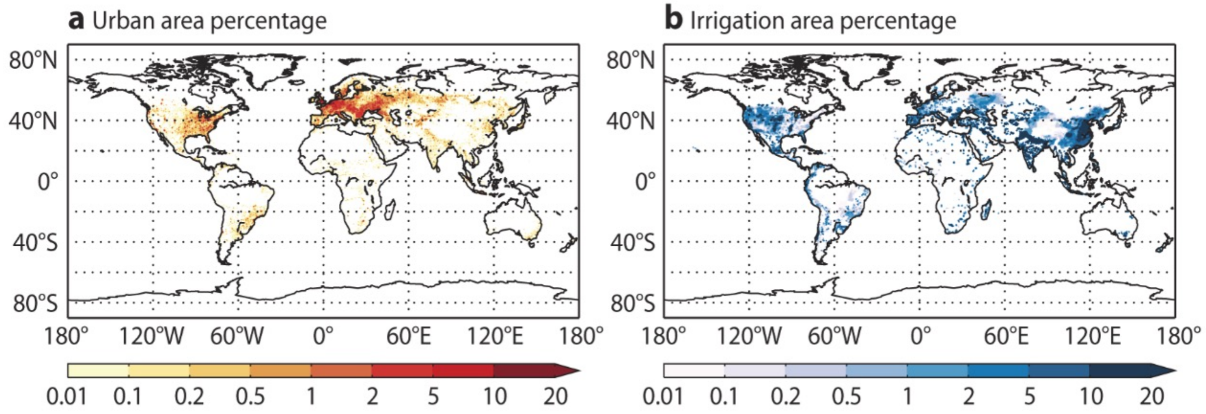


Figure 20: Urban area (a, in %, from ECOCLIMAP, Masson et al., 2003) and irrigated area (b, in %, from Döll and Siebert, 2002).

Balsamo et al. 2014, doi.org/10.13140/2.1.4248.0324

Land surface modelling recent advances in 2021

Themes

- **ECLand** replace *TESSEL legacy of scheme for enhanced COP/DestinE collaborations (Boussetta et al. 2021)
- **ECLand** has global km-scale capability and feature a high scalability (global **1km** simulations at about 1year/day)
- **SnowML5** ready for operational implementation in 48r1 (including 4D-Var interaction and ERA compatible)
- Preparation for **New land reanalysis** (C3S) & **CO2** monitoring (**Land-Use** & **Leaf Area Index**)
- **IFS-urban** first coupled forecasts + progress on **anthropogenic fluxes** (in particular CO2 & CH4 emissions)
- Including enhanced **Soil & River hydrology** (preparing for inundation/irrigation) for Hydromet. applications

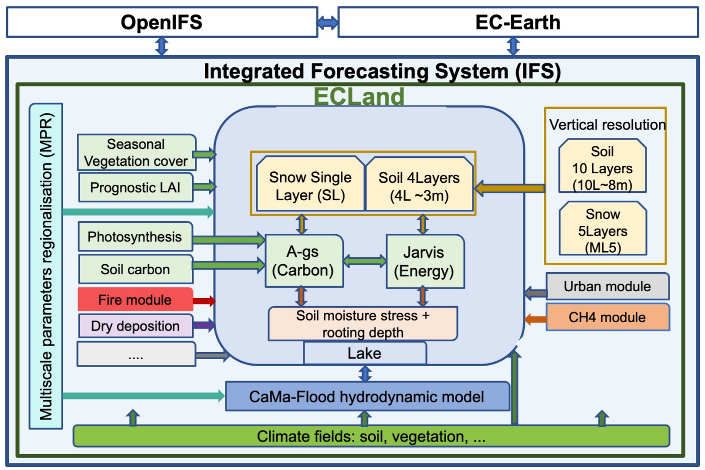
atmosphere MDPI

Article

ECLand: The ECMWF Land Surface Modelling System

Souhail Boussetta [1,*], Gianpaolo Balsamo [1,*], Gabriele Arduini [1], Emanuel Dutra [2,3], Joe McNorton [1], Margarita Choulga [1], Anna Agustí-Panareda [1], Anton Beljaars [1], Nils Wedi [1], Joaquín Munõz-Sabater [1], Patricia de Rosnay [1], Irina Sandu [1], Ioan Hadade [1], Glenn Carver [1], Cinzia Mazzetti [1], Christel Prudhomme [1], Dai Yamazaki [4] and Ervin Zsoter [1]

Boussetta et al 2021https://www.mdpi.com/2073-4433/12/6/723



Accounting for irrigation in NWP at ECMWF

Essentially 3 ways envisaged in the ECMWF system try to account for irrigation effect

1. Land Data Assimilation of water-sensitive observations able to add water increments

- Surface water balance P – E – R = DW/dt → P – E – R = DW/dt + DA/dt (analysis increments)

Advantage: LDAS system exist and crucial for NWP ; Disadvantage: Only active at Initial Condition time

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3. Considering point 2. within **closed water budget** where irrigation is subtracted from water reservoirs

Advantage: Proper account of water; more realistic Disadvantage: Challenging water balance

Accounting for irrigation in NWP at ECMWF: The LDAS approach

AGU PUBLICATIONS

Geophysical Research Letters

RESEARCH LETTER

10.1002/2017GL074884

Key Point:
- Reanalysis soil moisture additions resemble spatial and temporal irrigation patterns

Correspondence to:
O. A. Tuinenburg,
O.A.Tuinenburg@uu.nl

Citation:
Tuinenburg, O. A., & de Vries, J. P. R. (2017). Irrigation patterns resemble ERA-Interim reanalysis soil moisture additions. *Geophysical Research Letters*, *44*, 10,341–10,348. https://doi.org/10.1002/2017GL074884

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Accepted article online 14 SEP 2017
Published online 18 OCT 2017

Irrigation Patterns Resemble ERA-Interim Reanalysis Soil Moisture Additions

O. A. Tuinenburg[1] **and J. P. R. de Vries**[1]

[1]Copernicus Institute of Sustainable Development, Department of Environmental Sciences, Utrecht University, Utrecht, Netherlands

Abstract Irrigation modulates the water cycle by making water available for plants, increasing transpiration and atmospheric humidity, while decreasing temperatures due to the energy that is needed for evaporation. Irrigation is usually not included in atmospheric reanalysis systems, but moisture can be added to the soil due to data assimilation. This paper compares these soil moisture additions to the irrigation patterns. In the ERA-interim atmospheric reanalysis, 2 m temperature observations are assimilated. A mismatch between modeled and observed temperatures is corrected by adding or removing moisture from the soil. These corrections show a clear pattern of mean soil moisture additions in many areas. To determine the cause of these increments, the spatial and temporal patterns of these soil moisture increments are compared to irrigation water demand and precipitation bias. In irrigated areas, the annual means and cycles of soil moisture increments correlate well with irrigation, and less with precipitation bias. Therefore, in irrigated areas, the soil moisture increments are more likely caused by irrigation than by the precipitation bias. In nonirrigated areas, a weak statistical relation between soil moisture increments and precipitation bias is present. Irrigation is currently not included in reanalysis systems. However, as irrigation indirectly influences the water balance in atmospheric reanalysis systems, we recommend to include this process in reanalysis models. Moreover, the influence of irrigation on the local and regional atmosphere should be taken into account when interpreting atmospheric data over strongly irrigated areas.

- Surface water balance

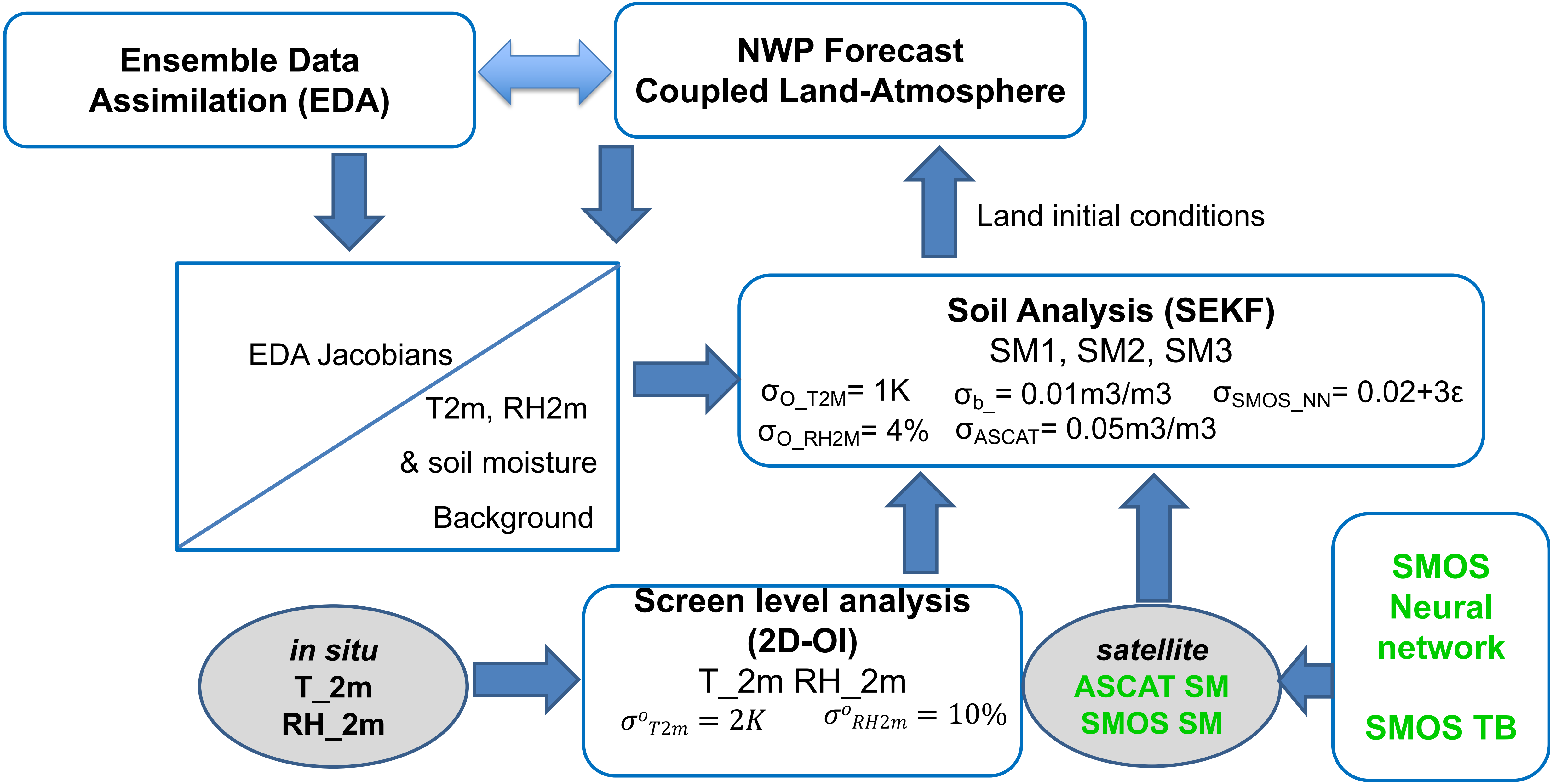
$$P - E - R = DW/dt$$

$$P - E - R = DW/dt + DA/dt$$

- Analysis increments accounts for missing Irrigation
- This is shown for ERA-Interim
- ERA5 may potentially have larger signal since SMOS/ASCAT are assimilated.

See Tuinenburg & de Vries, 2017 https://doi.org/10.1002/2017GL074884

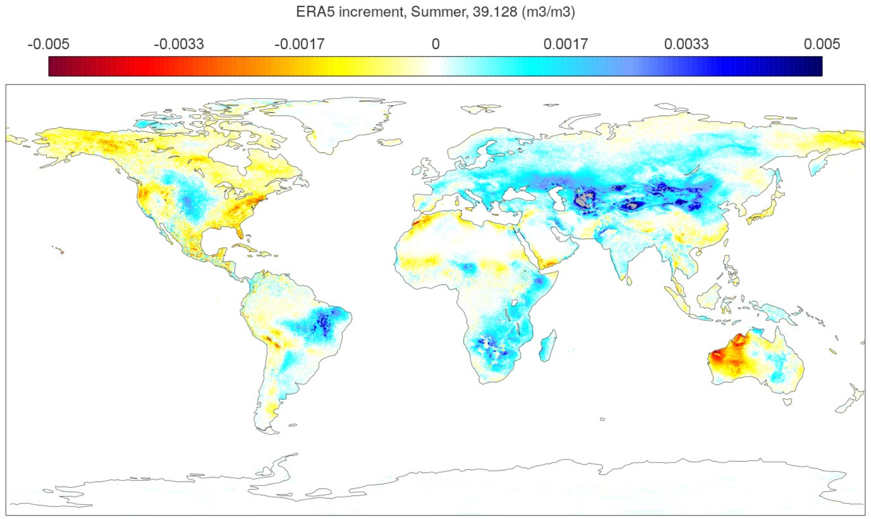
ECMWF Soil Analysis in the Integrated Forecasting System



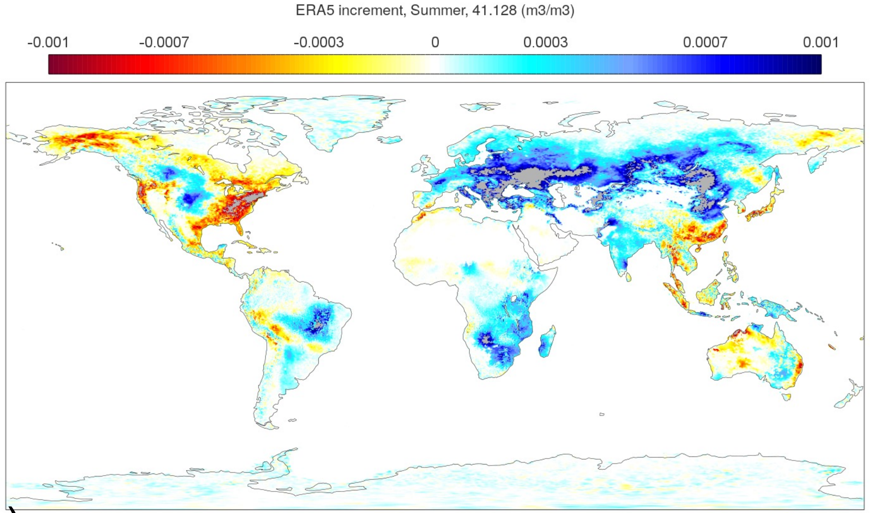
ERA5 average summer soil moisture increments (2005-2007)

Peter Weston, David Fairbarn, Patricia De Rosnay

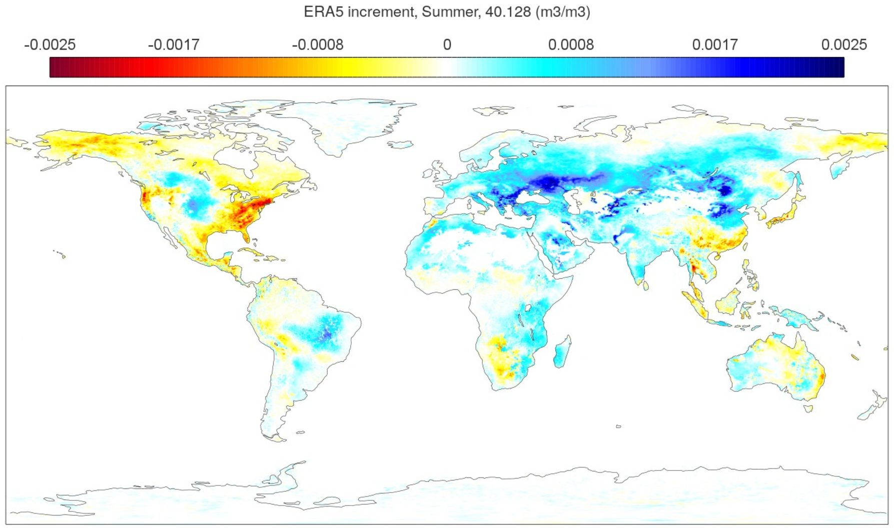
Layer 1 (0-7 cm depth)



Layer 3 (28-100 cm depth)



Layer 2 (7-28 cm depth)



Accounting for irrigation in NWP at ECMWF

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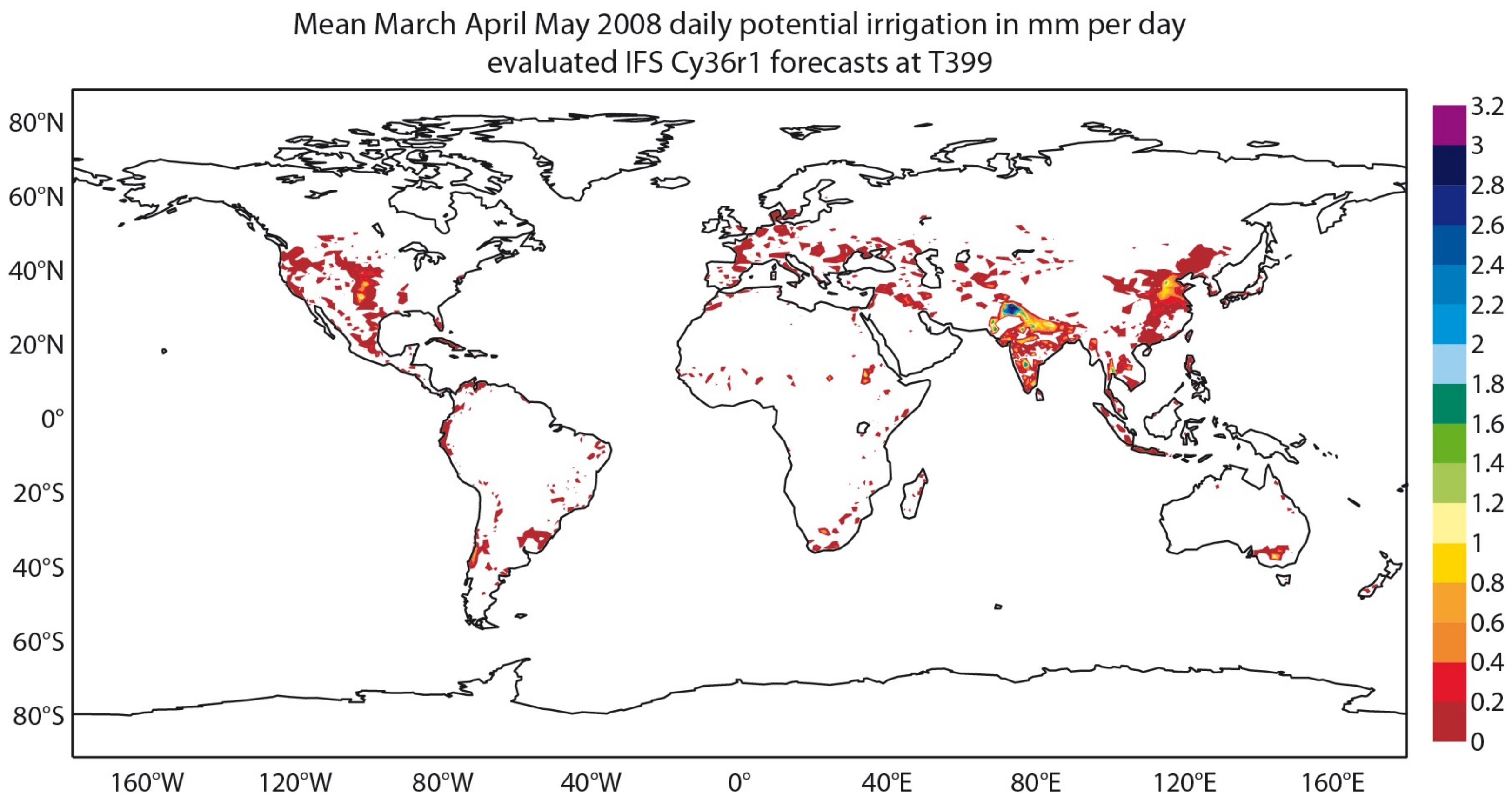
Accounting for irrigation in NWP at ECMWF: The “Idealised” irrigation



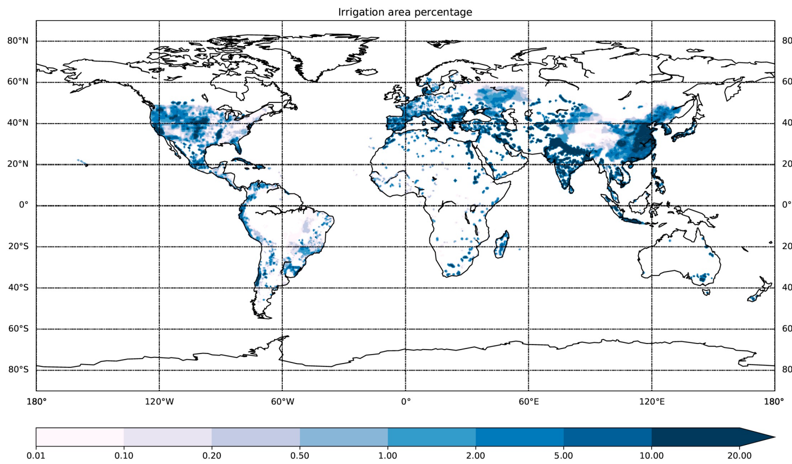
- Surface water balance

P – E – R = DW/dt

P+I – E – R = DW/dt + DA/dt

- An extra flux account for Irrigation

I= (PET – ET) * Irrigation_switch



This irrigation flux is calculated based on water needs and on the irrigation fraction, but it does not attempt to represent human decision.

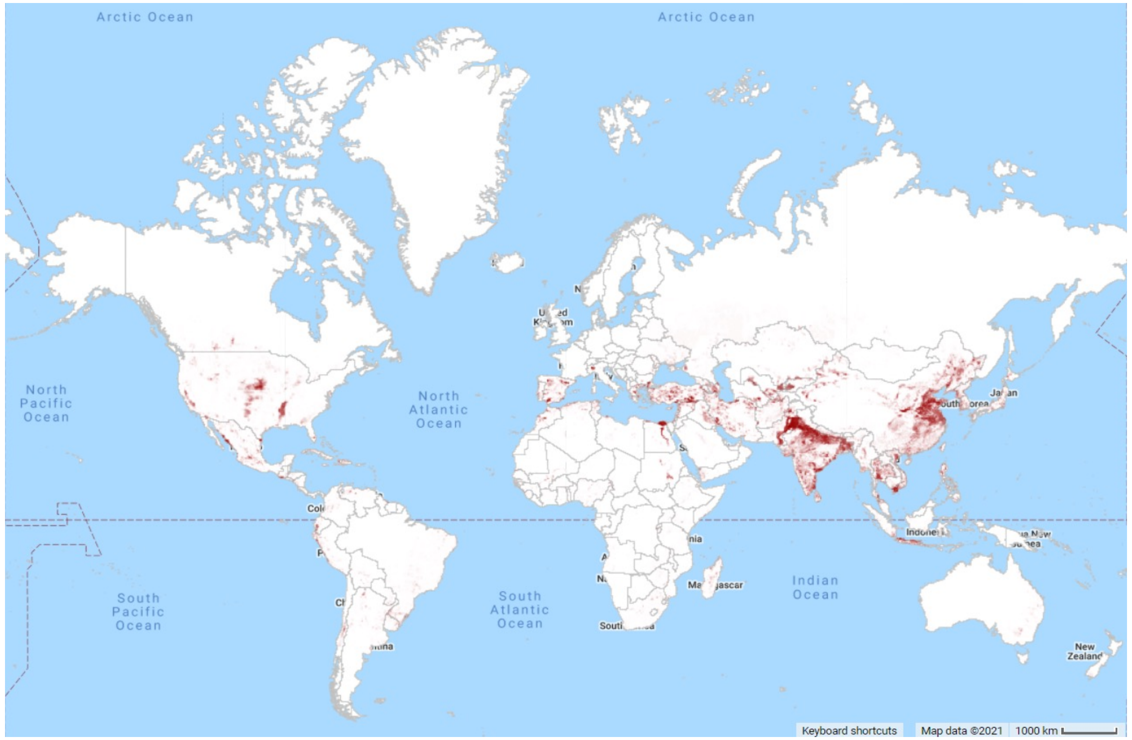
ECMWF

Accounting for irrigation in NWP at ECMWF: When/where activate irrigation?

I= (PET – ET) * Irrigation_switch

Where?

When?



SPAM dataset: https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/PRFF8V

How to constrain temporal irrigation occurrence?

Which observations can detect irrigation?

Can we estimate irrigation occurrence indirectly?

Human decision to irrigate is complex to model-
Observation-driven Machine-Learning can help?

LST, L-Band, SAR, combined with LULC/LAI could feed ML schemes to infer irrigation occurrence?

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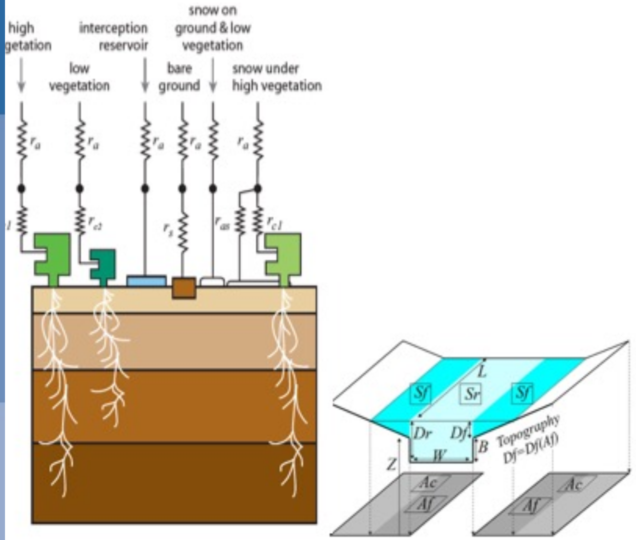
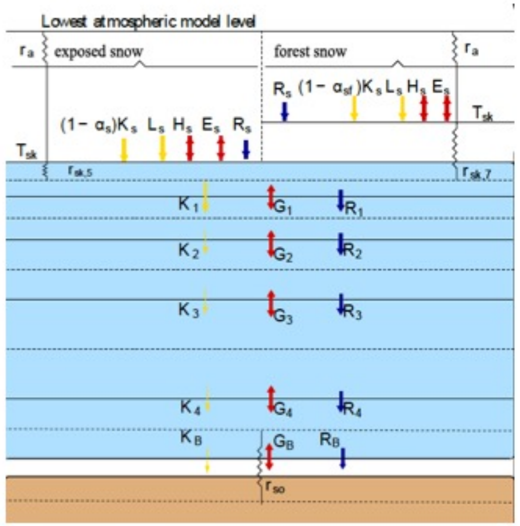
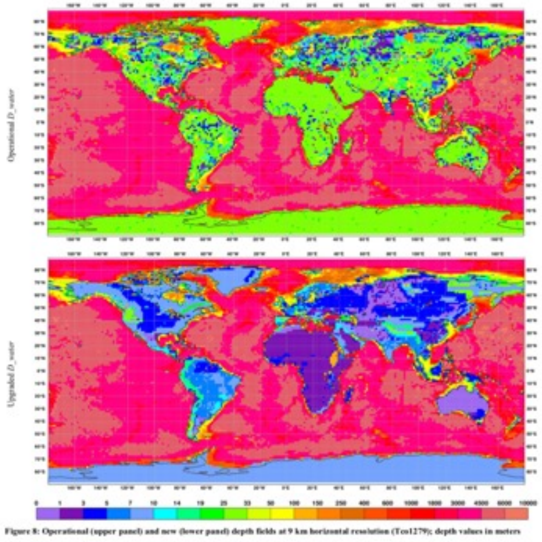
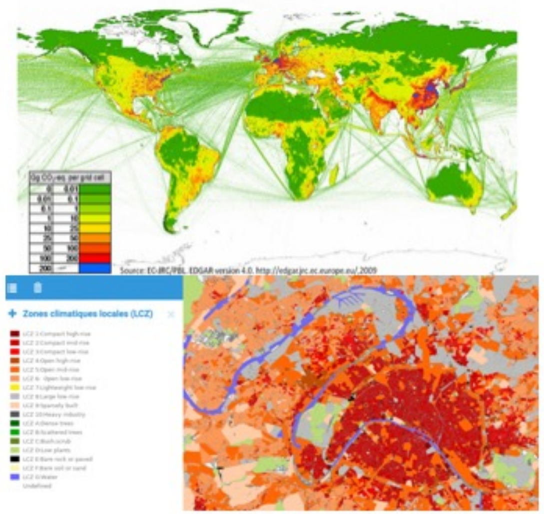
Land hydrology, biosphere and anthropogenic surface modelling









•HTESSEL-CAMA-Flood

•Improvements

- •River discharge coupled to runoff passive in 2019
- •Post-processing of tiles diagnostics in 2020

• Collaborations

- CMEMS
- CONTROL
- Global Routing
- HTESSEL-Calibration

• Offline/Coupling test

- Ongoing offline testing

•SNOW ML5

•Improvements

- •ML5 Snow physics passive in 2019

• Ongoing/Planned

- ML GRIB input/output (collaboration with FD/IFS)
- ML coupled to ice (APPLICATE)
- Snow Albedo revision (SnowAPP/APPLICATE-2)
- Blowing snow (ISSI-BJ-HTP)

Orsolini et al. (2019)
Arduini et al. (2019)

•WATER Tile Mapping

•Improvements

- •GLDBv3 + new LSM/CL ready in 2020

• Ongoing/Planned

- Extend to other physiography fields
- Focus ESA-CCI Maps
- Orography and Bathymetry at native 1km
- Choulga et al. (2019) on Water Mapping

URBAN Tile+CO2 Mapping

•Improvements

- City mapping (C3S ITT)
- Multi-cities OSM
- CO2 mapping
- CO2 uncertainties
- CO2 ensemble

• Offline/Coupling test

- Ongoing CHE Tier-2 runs

McNorton et al. (2019) on CO2 model error specification

Choulga et al (2020) on CO2 emissions & uncertainties

Towards time-varying water cover

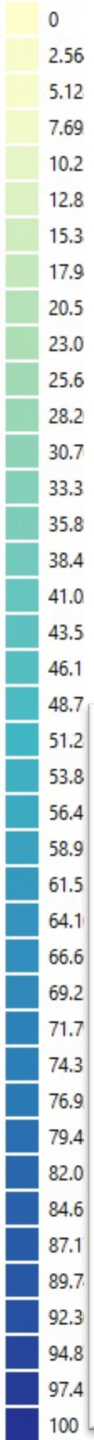
Margarita Choulga et al.

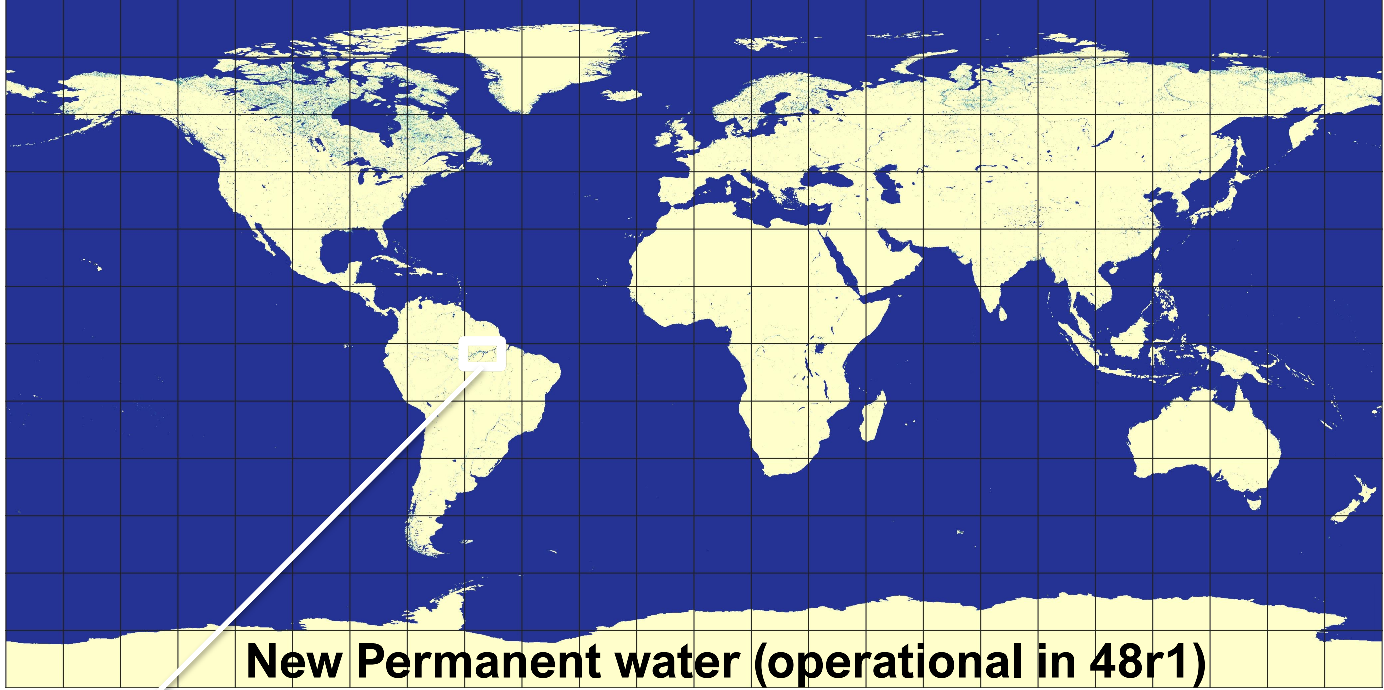
New static **land sea mask**, **lake** and **glacier covers** based on permanent water 1984-2018 to be **operational** in cycle **48r1** (climate.v020) in 2022/Q4.

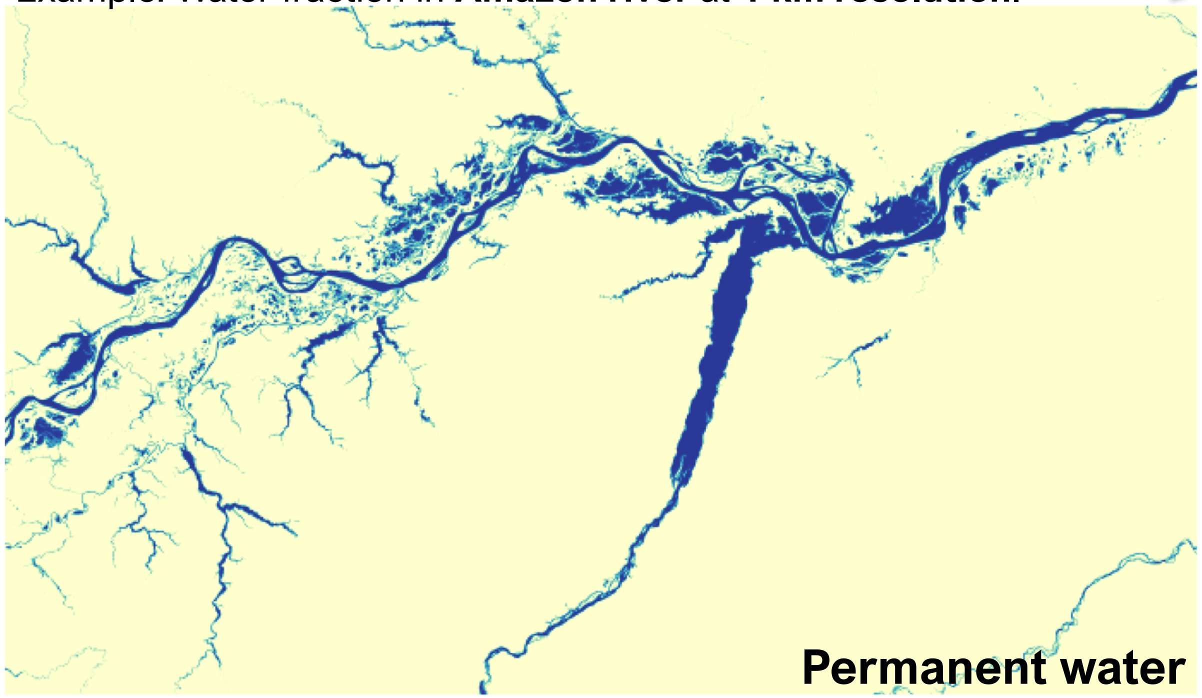
Monthly water distribution based on 2010-2020 monthly **30 m resolution** maps **represent** water year cycle more **realistic** than static yearly map → step **towards dynamic inundation model** (CAMA-Flood).

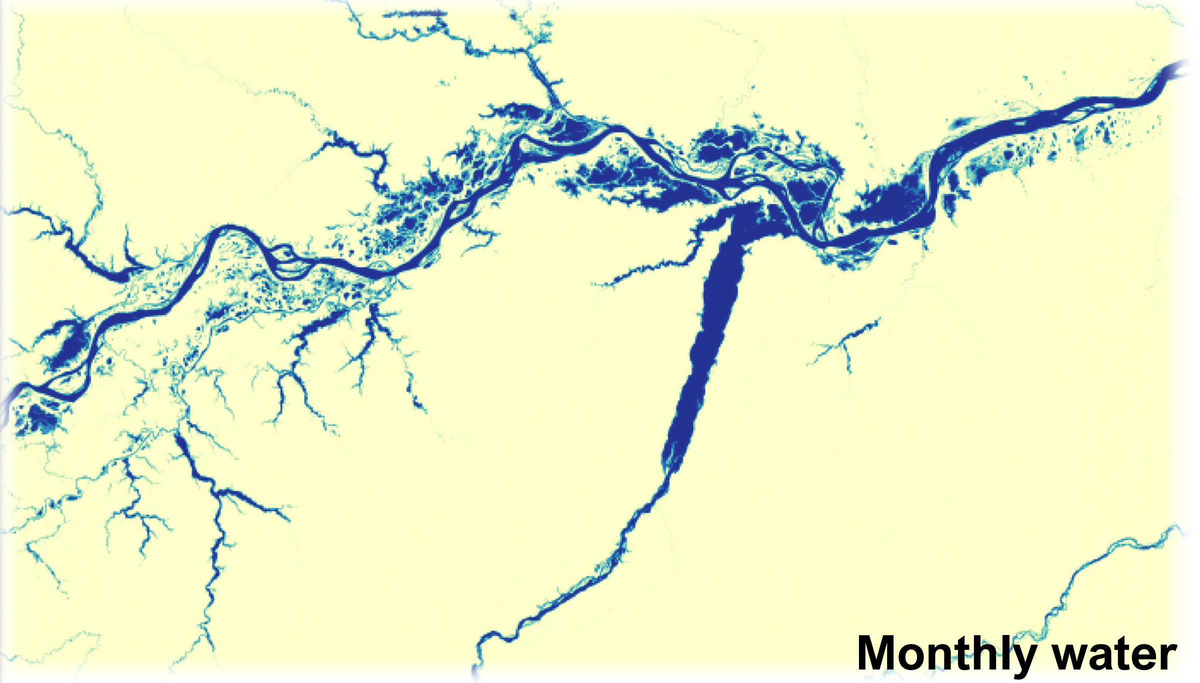
Similar work is ongoing for the Wetland & Rice fractions.

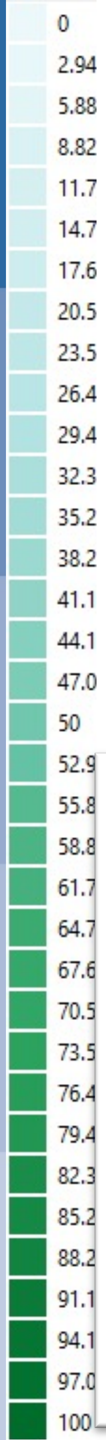
Example: Water fraction in **Amazon river** at **1 km resolution.**









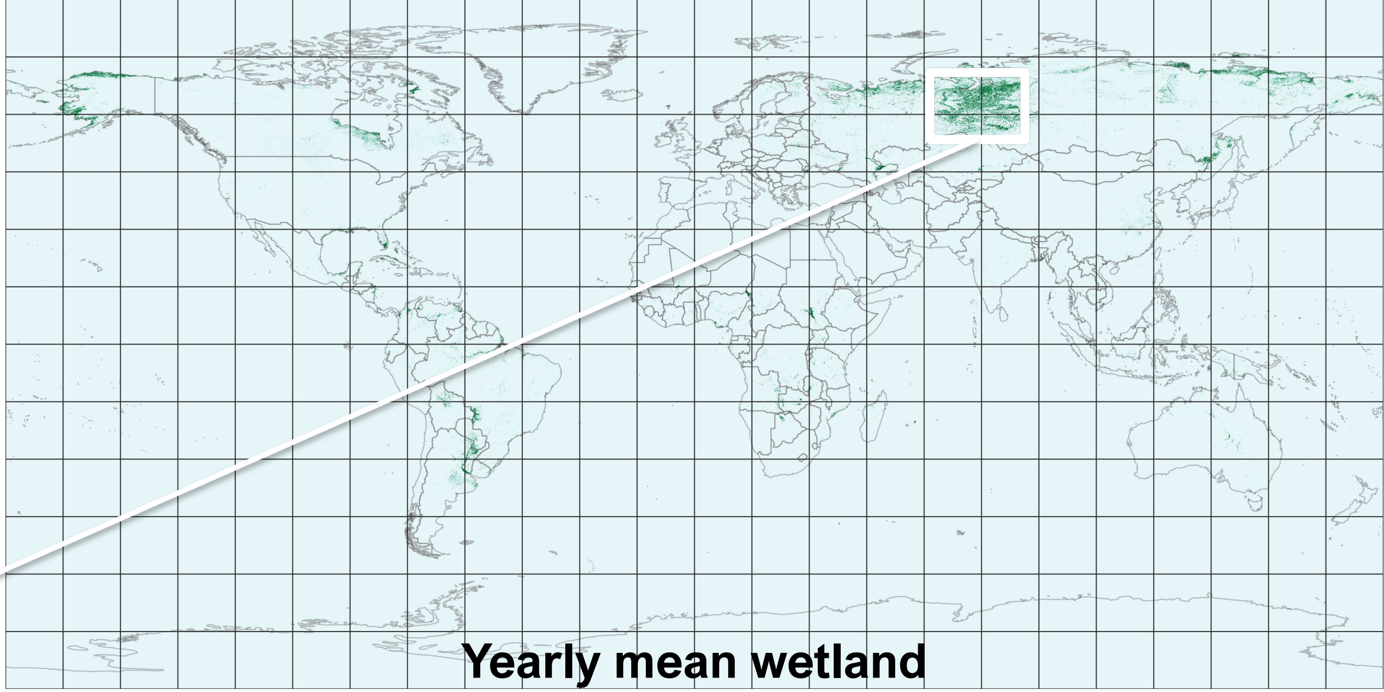


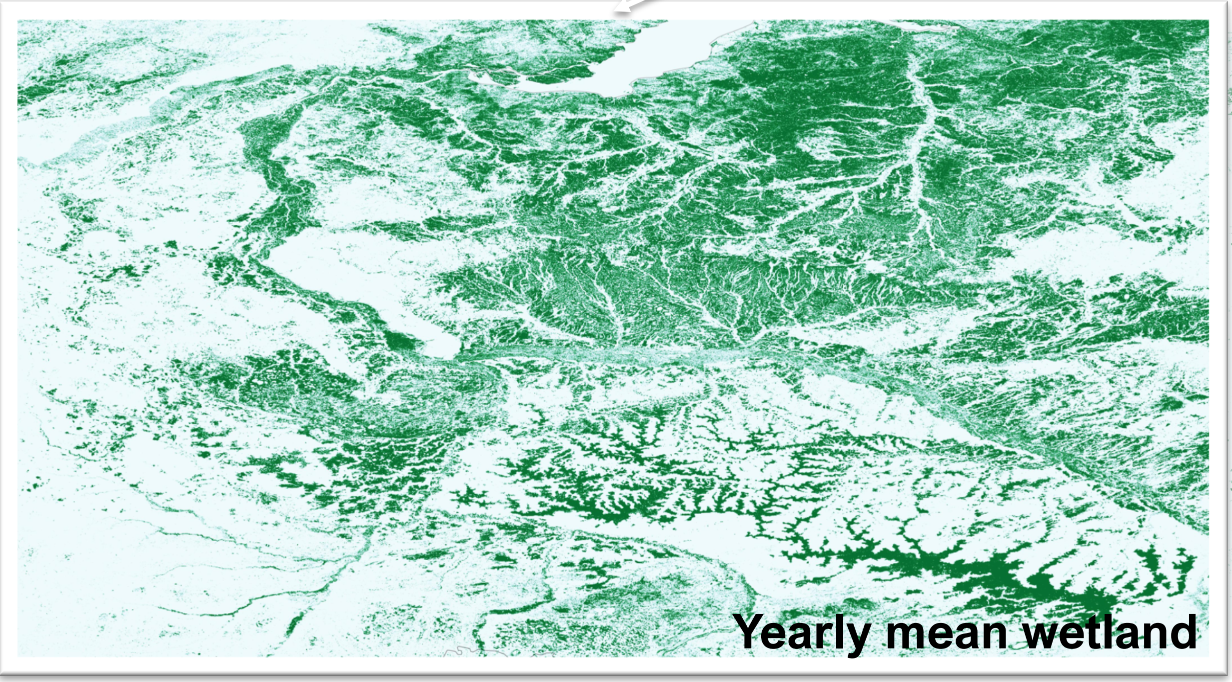
Towards yearly & monthly wetland

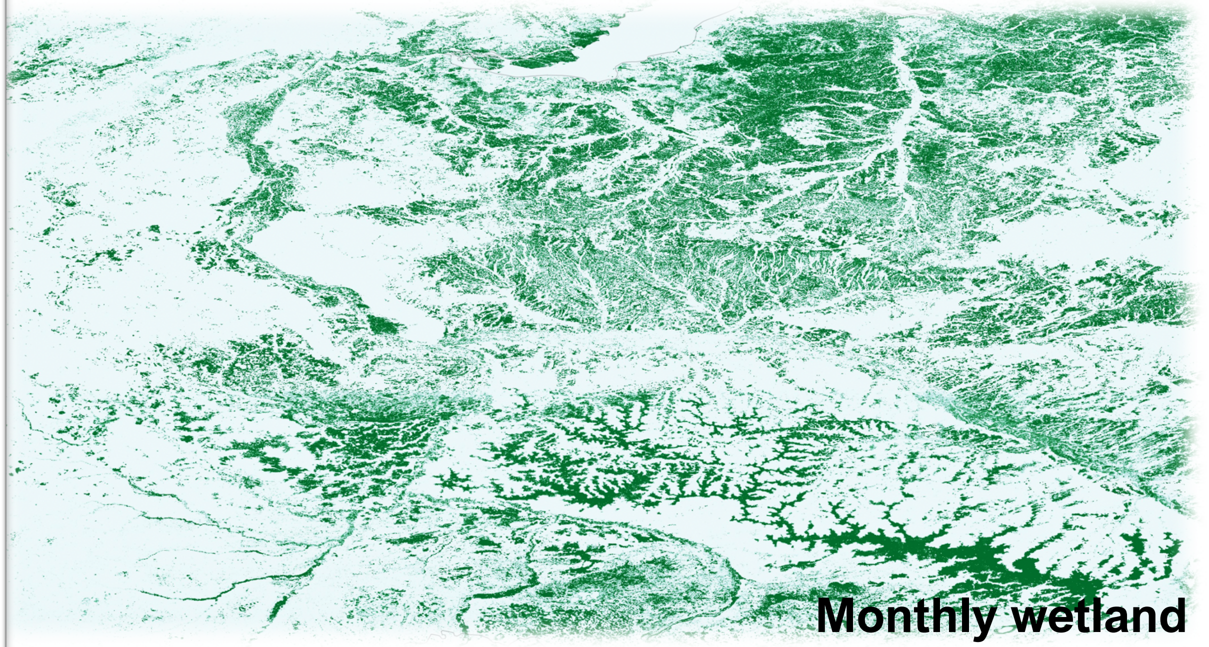
Margarita Choulga et al.

Created **monthly wetland** distribution maps: **yearly wetland** distribution based on 2019 Copernicus 100 m resolution map **+ monthly coefficients** based on 2000-2020 SWAMPSv3.2 25 km resolution daily wetland/water microwave data; global continuous **wetland type** and **rice** distribution maps → required **for** the best use of **dynamic inundation model** (CAMA-Flood), and to **correctly represent methane** emissions.

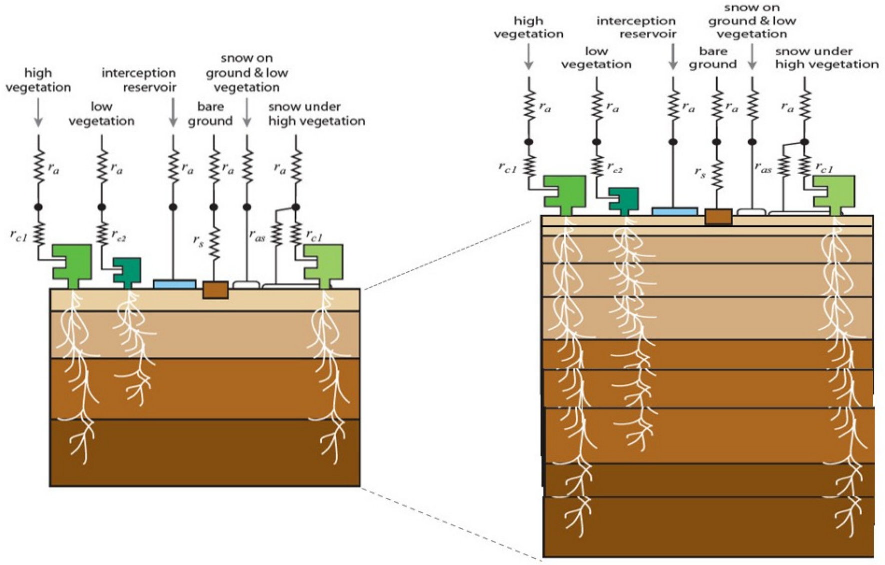
Figures below show **Russian (Yamalo-Nenets)** region (68.0/55.0°N, 60.0/84.0°E) at **1 km resolution** wetland fraction.

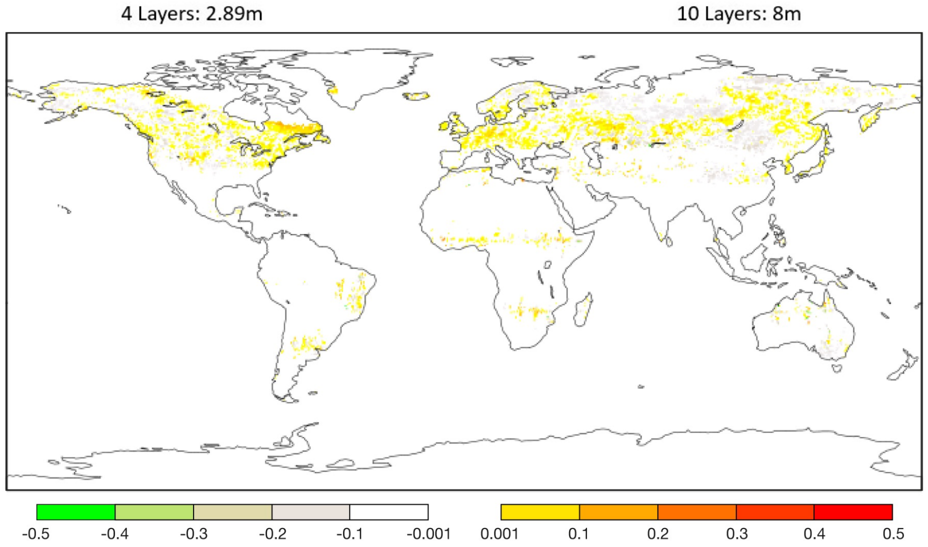






Toward an improved the soil and river-catchment hydrology representation



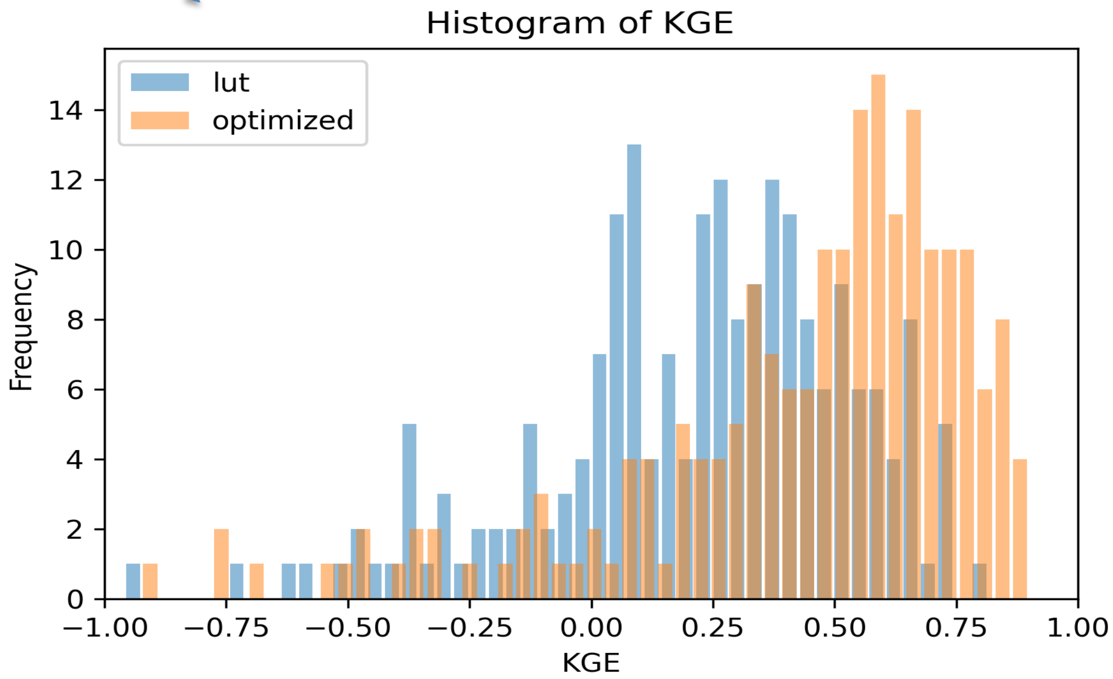


Improved correlation with the ESA-CCI surface soil moisture product between when using thinner surface layers (10-layer) & the current 4-layer scheme for JJA

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

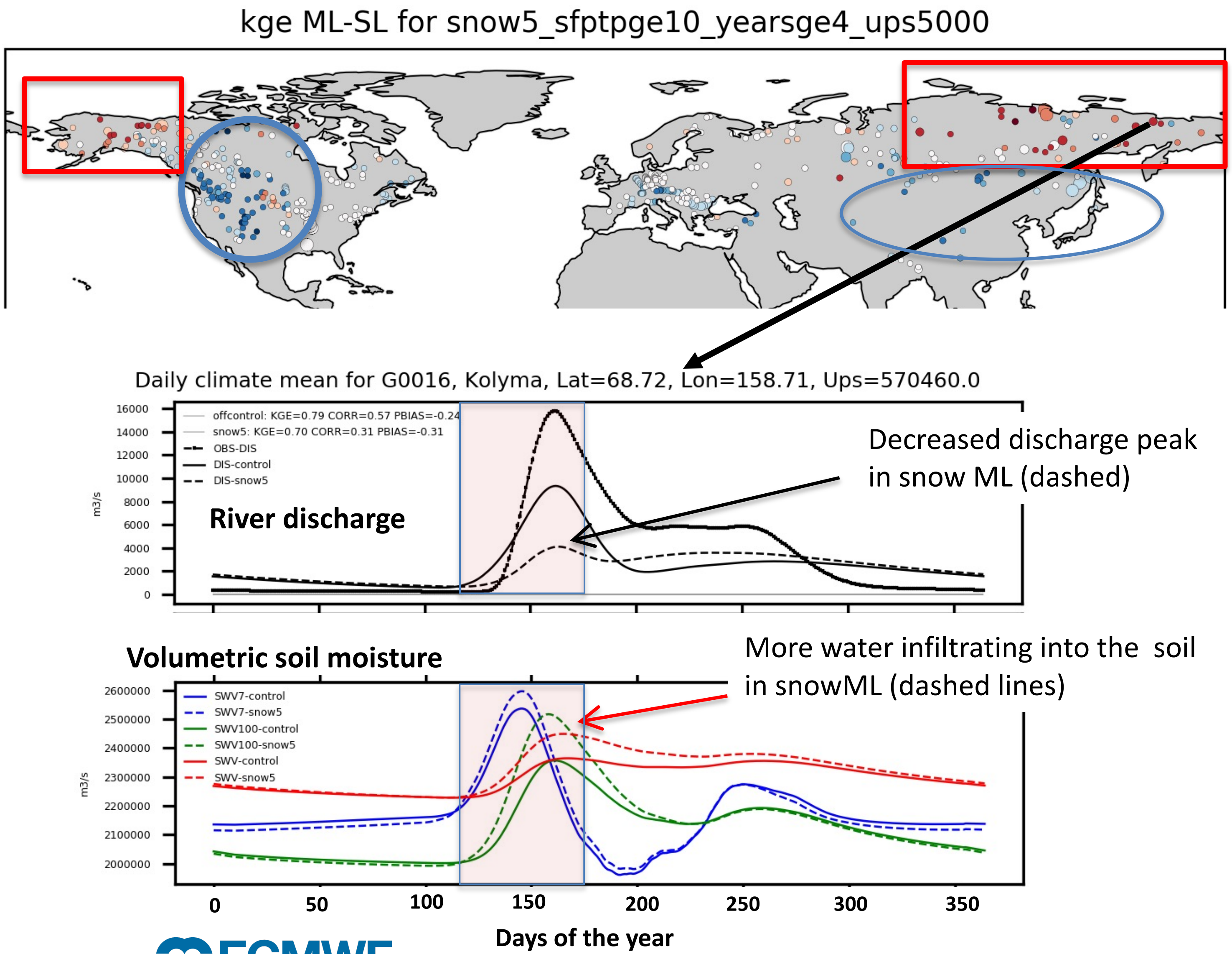
- Improving the soil vertical discretisation shows potential improvement for
  Better match with satellite surface soil moisture observation

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

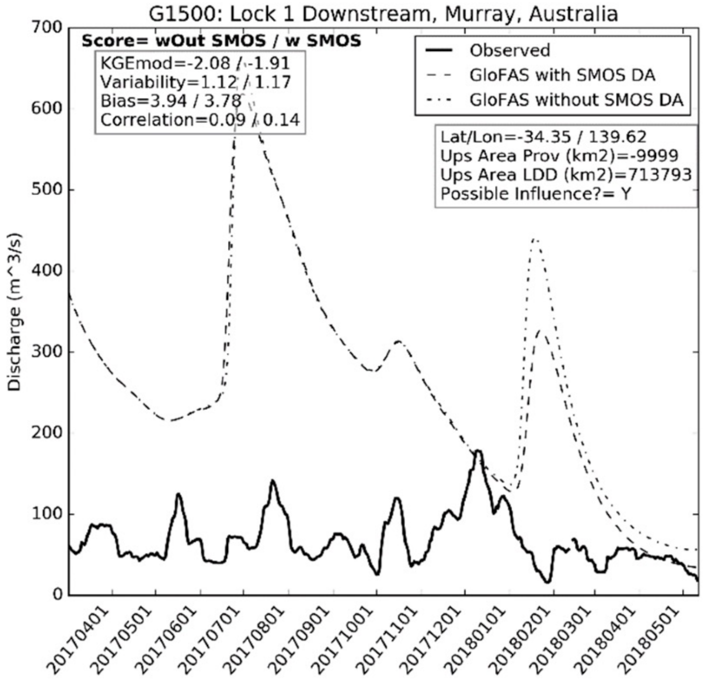
Zsoter, Arduini et al. in preparation

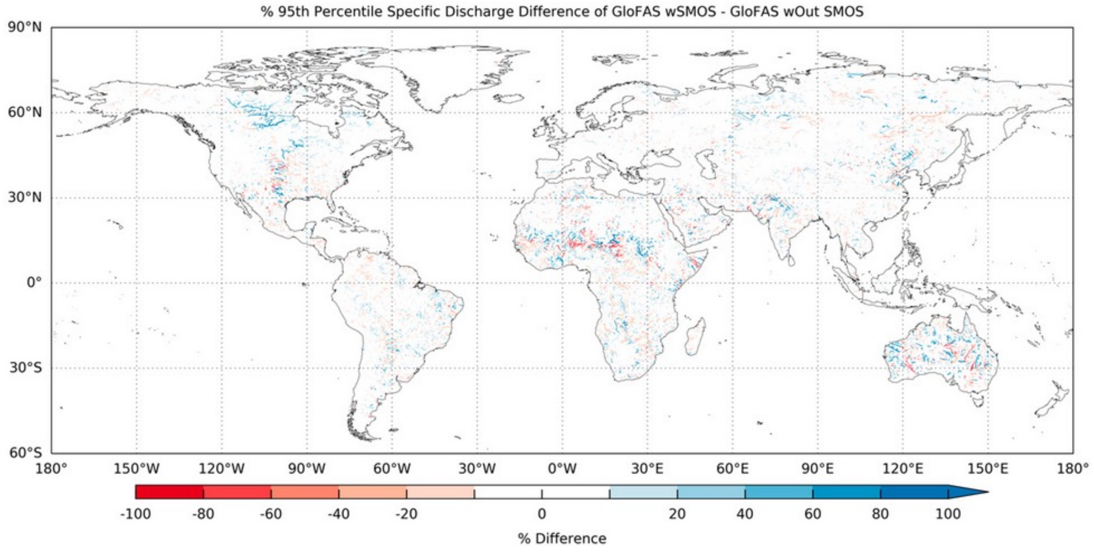
SMOS applications for the Copernicus Emergency Management Service (CEMS)

Data assimilation impact on hydrology

- Data denial experiments with SMOS

Baugh et al. 2020 https://doi.org/10.3390/rs12091490





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

Conclusions and perspectives for Irrigation

- Adding Irrigation is acknowledged to be very relevant for ECMWF forecasts & reanalysis at the resolutions currently considered (HRES & near-future ENS at 9 km, ERA5Land at 9km).
- Currently only the LDAS accounts implicitly for irrigation effects via data assimilation increments
- Using the Potential Evaporation within the model (calculated as unstressed ET) would allow to calculate an idealized Irrigation flux (*this parameterization could be tested in future Intercomparison efforts*). Caveats are the lack of closure and the assumption on when/where irrigation occurs.
- The inclusion of a river discharge and flood inundation scheme and the characterization of monthly varying water variability are first steps towards a more closed water cycle.
- A key information still missing is the timing of irrigation. A monthly climatology of irrigated areas would be a substantial improvement. LST & Microwave data may help combined with Machine Learning?

- The time is right to focus on irrigation and more broadly anthropogenic water use as there is high interest/demand, for both coupled Earth system modelling & operational hydrological applications

Thank you for your attention

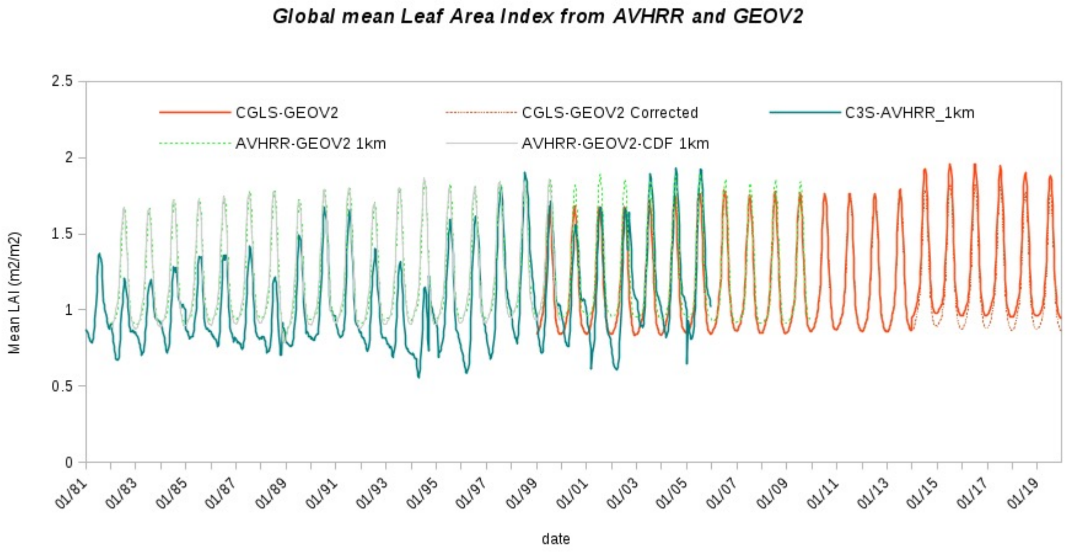
- Please contact us for any further questions gianpaolo.balsamo@ecmwf.int

- Extra slides on recent Land Modelling and Data Assimilation advances follows hereafter

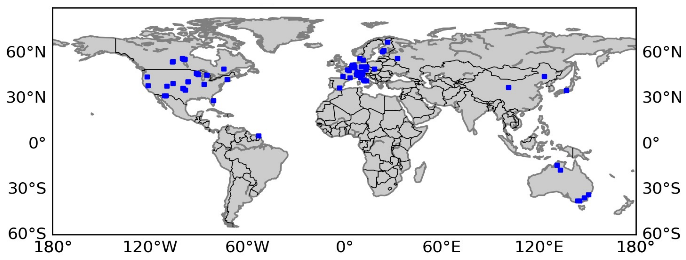
Towards time-varying vegetation & photosynthesis for reanalysis & CO2

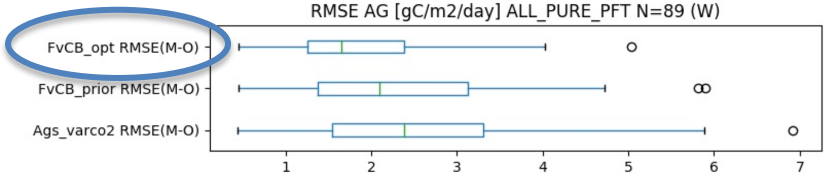
Souhail Boussetta, Anna Agusti-Panareda et al.

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

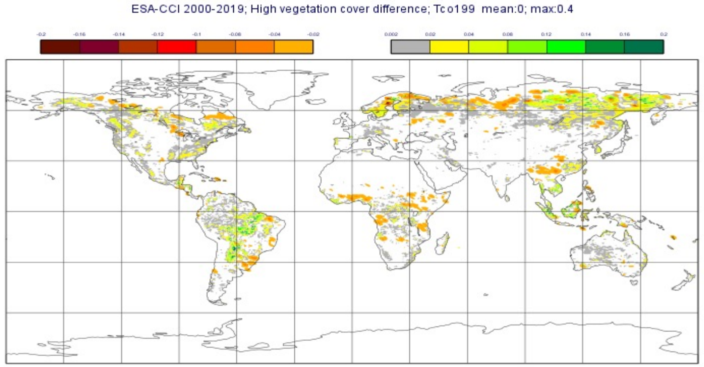


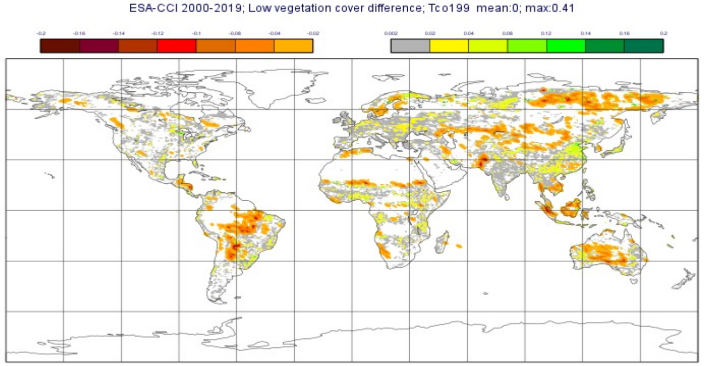
Optimisation for CO2 (GPP) using FLUXNET (89) sites



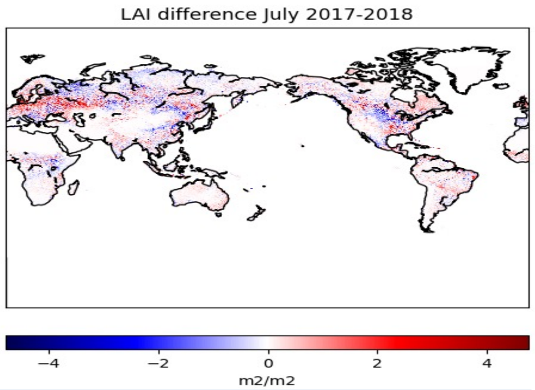


Vegetation cover differences between 2000 -2019 (right) for low & (left) high vegetation:





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.

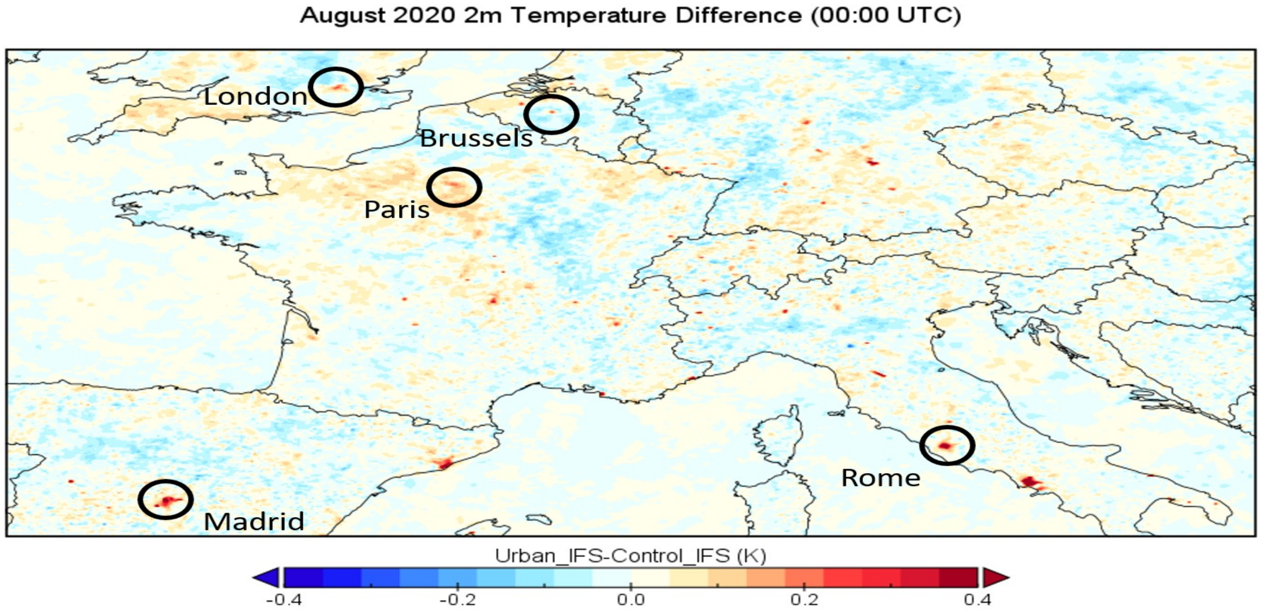
EL PAÍS NEWS

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



McNorton et al. 2021

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

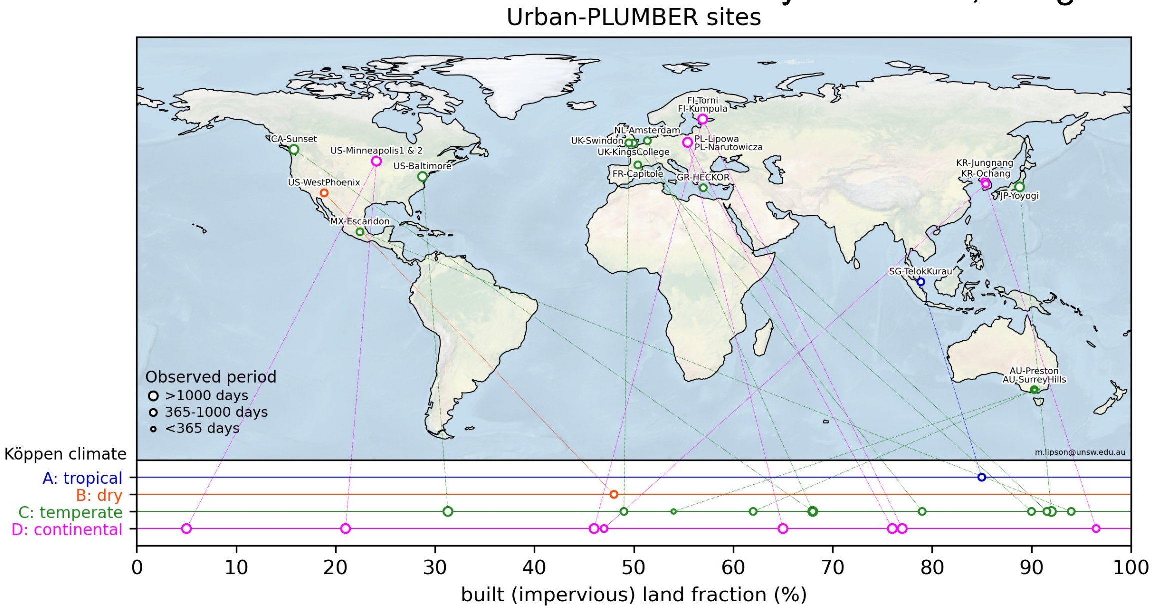
First published: 02 April 2021 | https://doi.org/10.1029/2020MS002375 | Citations: 2

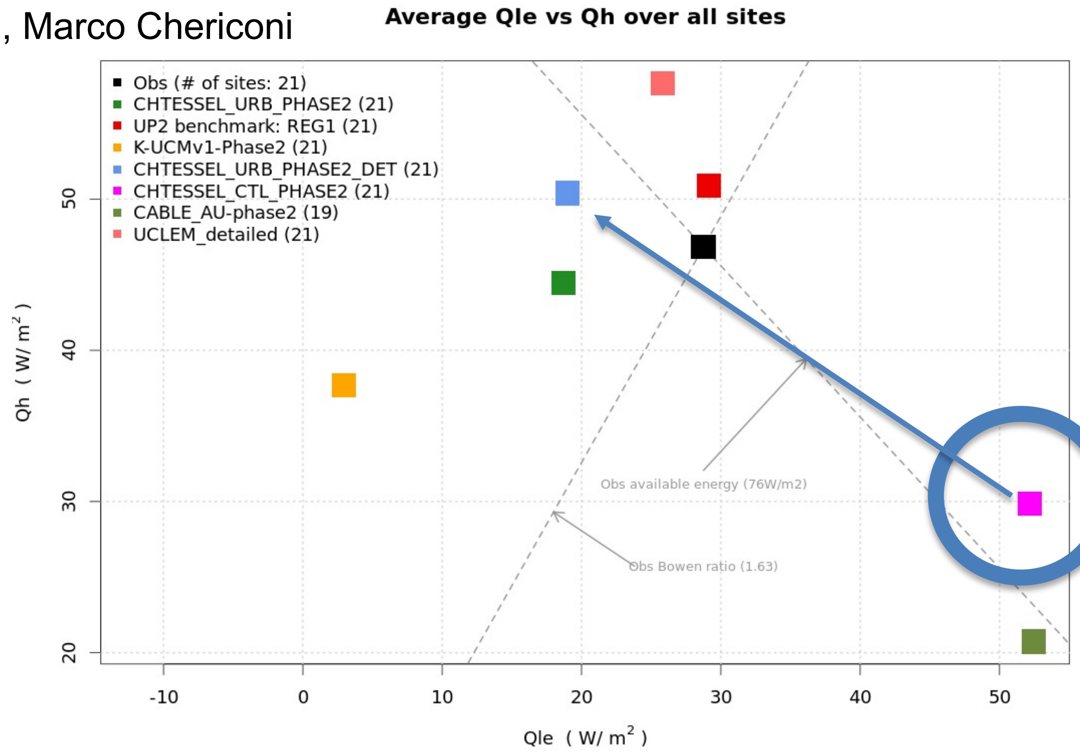
T2m sensitivity to Urban areas. First coupled 4km IFS runs with Urban tile. Average of FC+24 to +120 for the month of August 2020

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

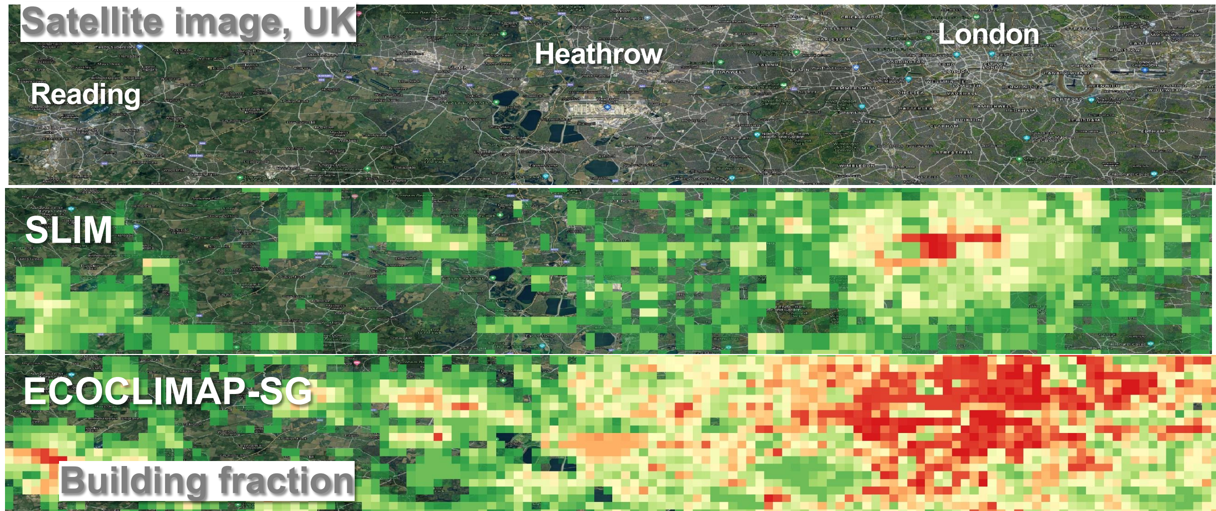
Urban model evaluation ongoing in PLUMBER with observed properties

Joey McNorton, Margarita Choulga, Marco Chericoni



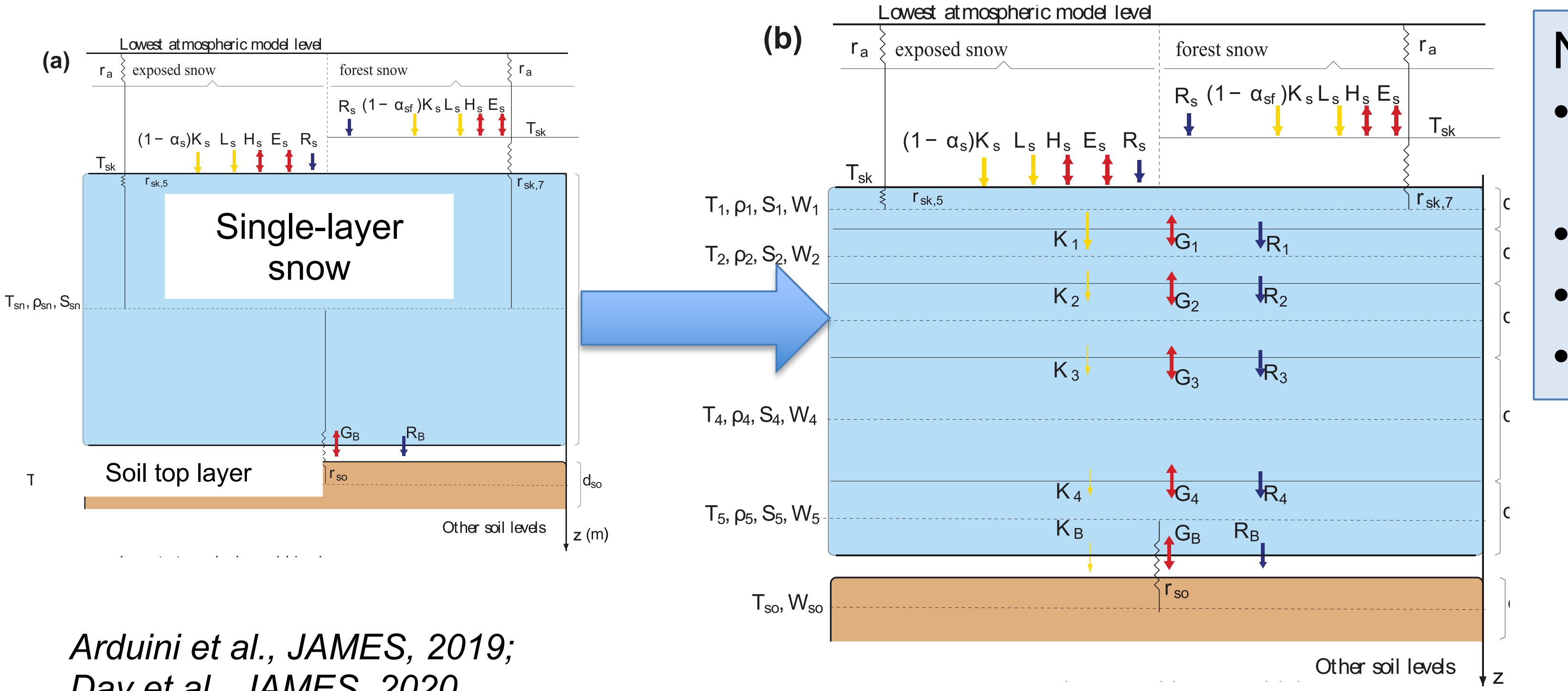


- Urban Plumber evaluates urban models across 21 sites
- Preliminary results show a model improvement in the partitioning of Latent and Sensible heat flux
- Over next 2 years urban scheme will be used to activate online anthropogenic CO2 emissions in CAMS/CoCO2
- A key component to enable to implement 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.



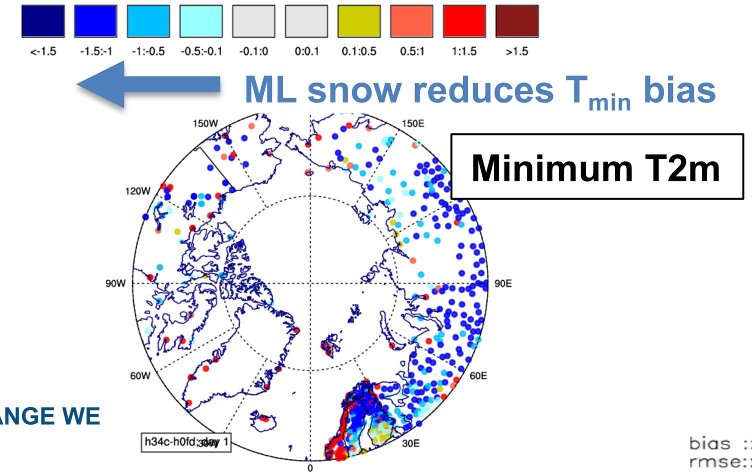
New multi-layer snow scheme:

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

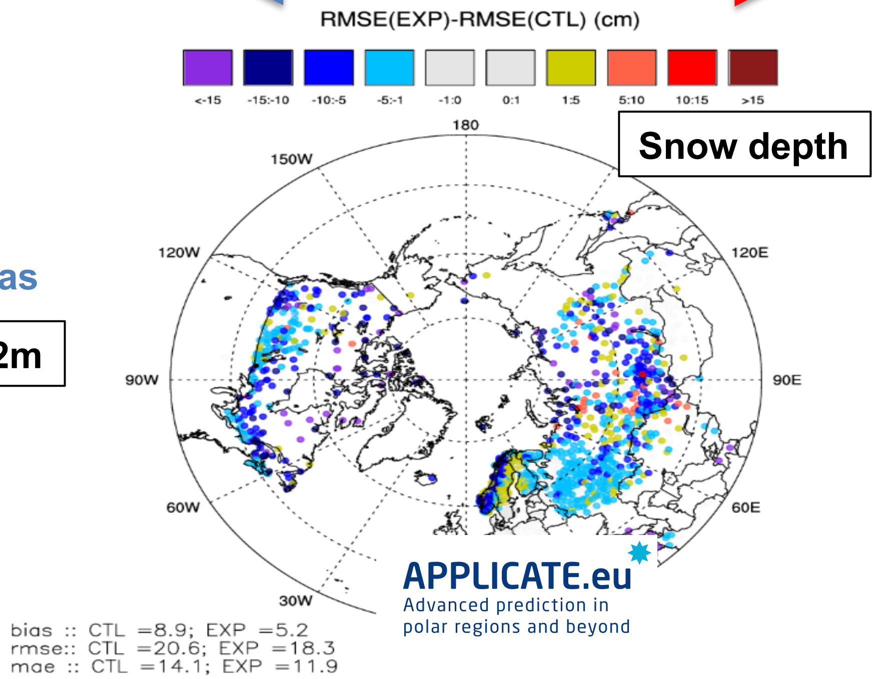
Arduini et al., JAMES, 2019;
Day et al., JAMES, 2020,
Boussetta et al., MDPI-Atm., 2021

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

ML snow reduces T_{min} bias

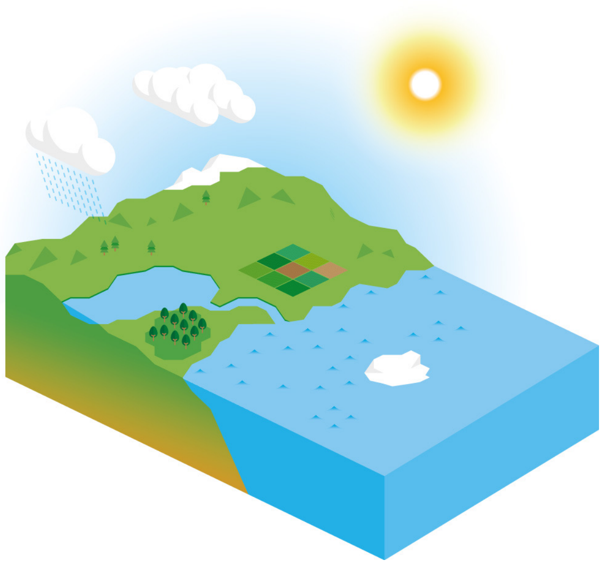


ML reduced $snow_{depth}$ RMSE **increase RMSE**

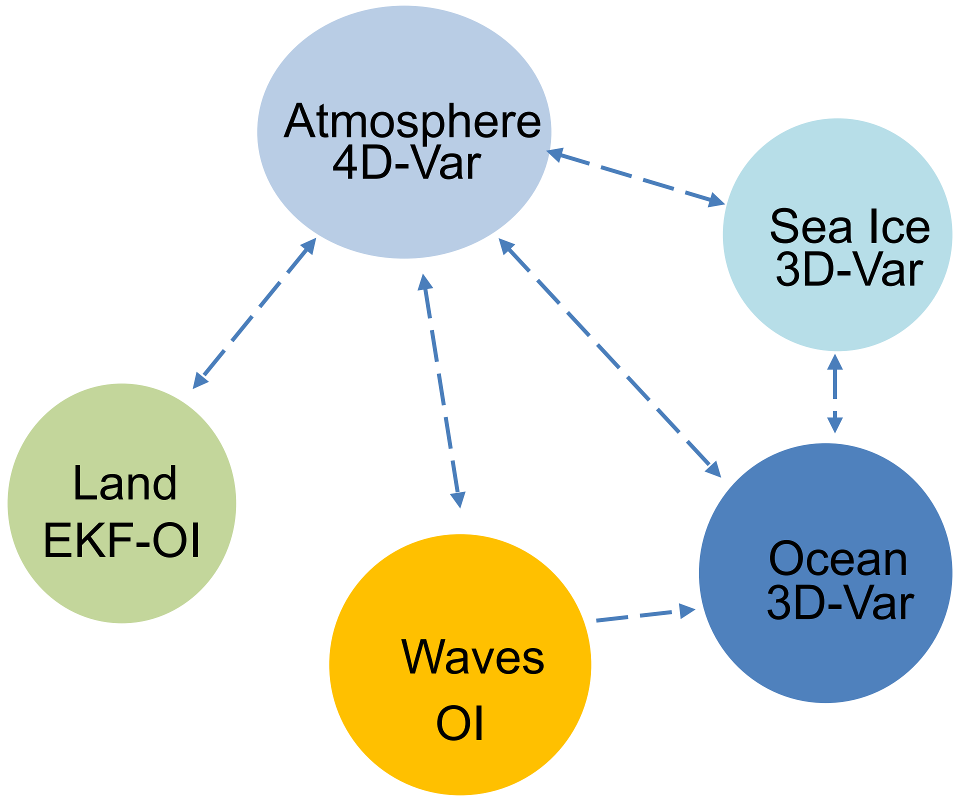


APPLICATE.eu Advanced prediction in polar regions and beyond

Coupled assimilation developments for NWP and reanalyses at ECMWF



Integrated Forecasting System (IFS)

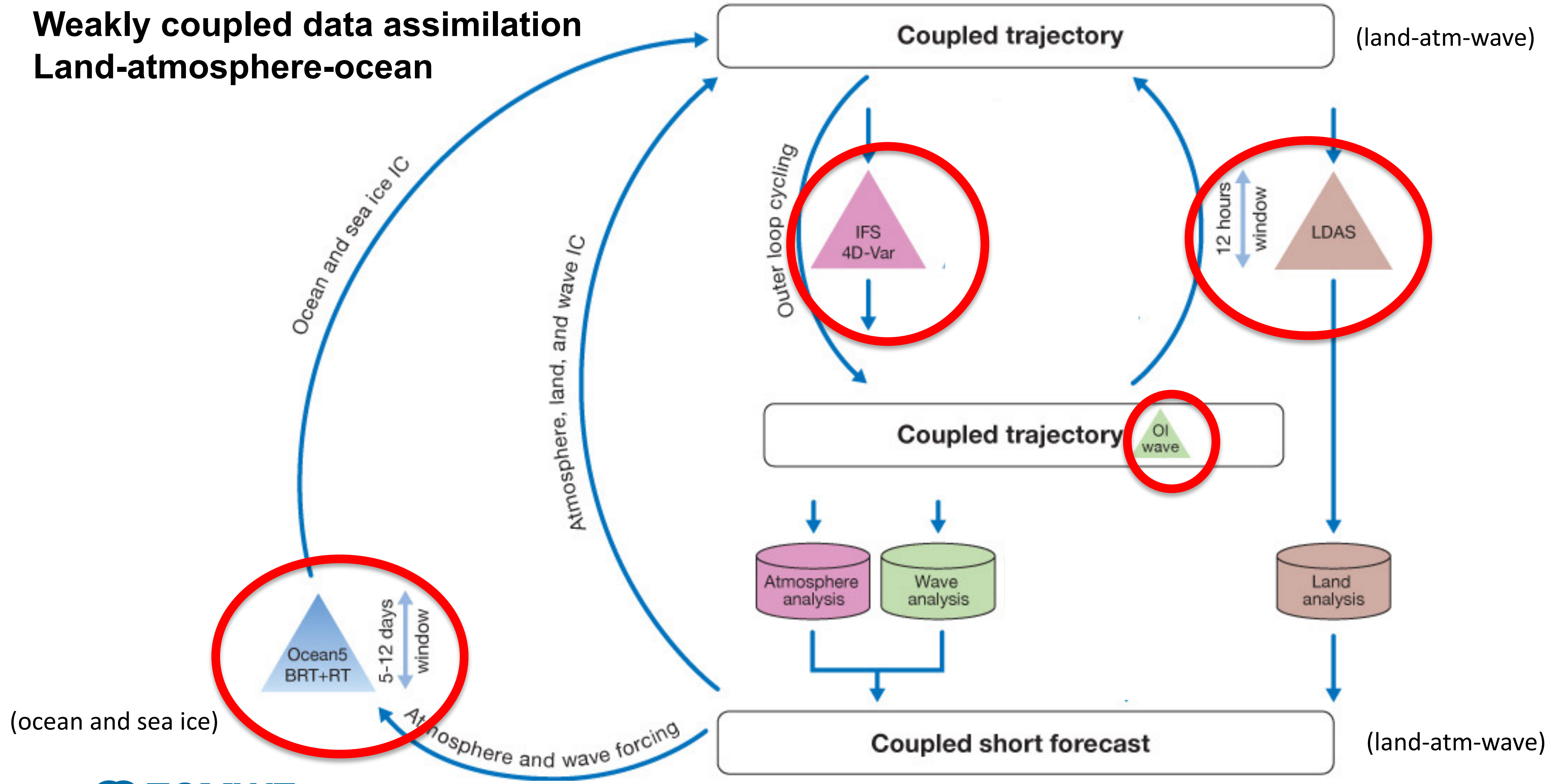


- Importance of the Earth system approach
- Importance of interface observations (e.g. snow, soil moisture, SST, sea ice)

Coupled Assimilation for operational NWP at ECMWF

Patricia De Rosnay et al. 2021

Weakly coupled data assimilation
Land-atmosphere-ocean



Observing system and monitoring

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

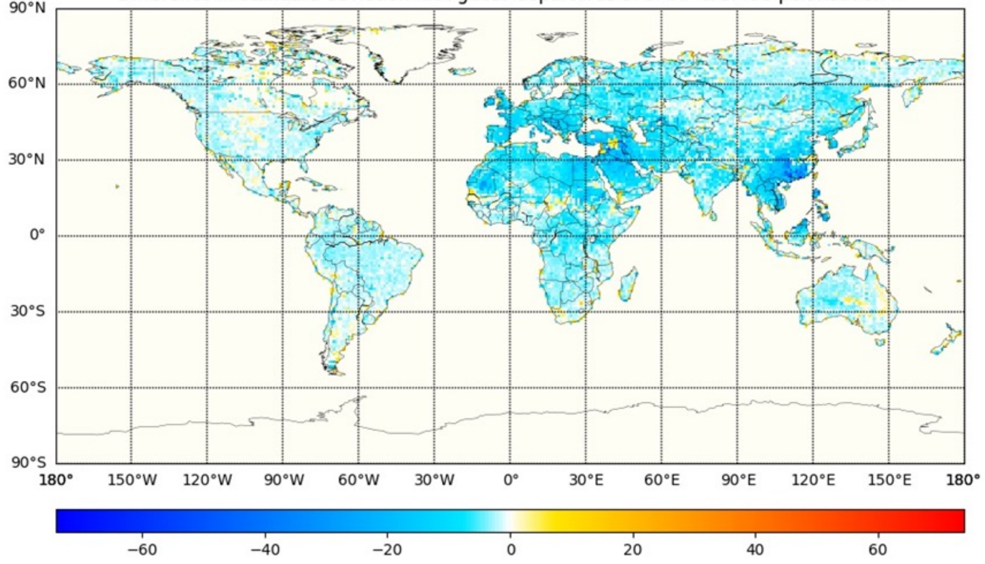
- **Observations sustainability** for land, cryosphere and for the ocean → level of support from governing bodies to ensure in situ data provision, relevance of WMO data policy evolutions; works of JET-EOSDE, GCW, SG-CRYO, GOOS, etc…

- **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

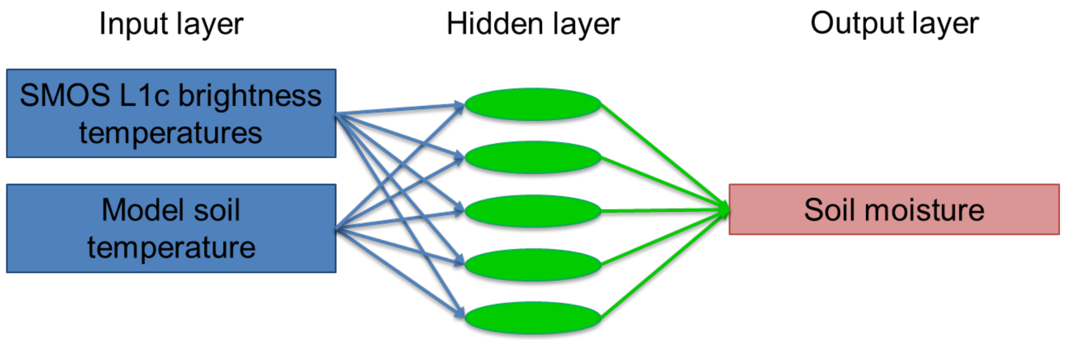
Difference in standard deviation first guess departures of SMAP & SMOS polarisation h



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

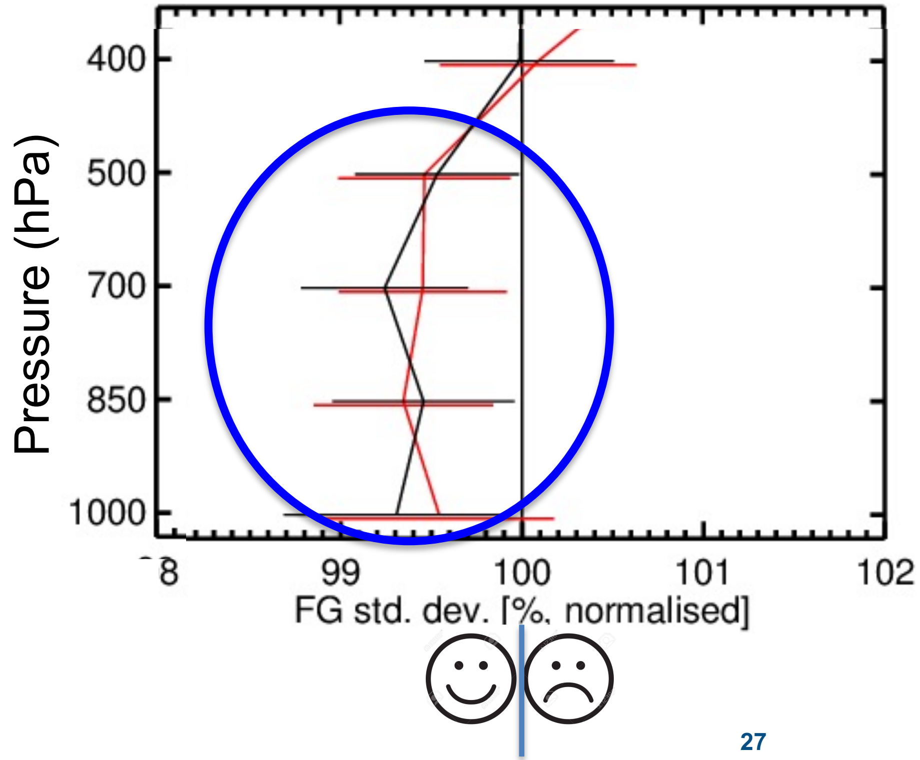
A priori training of the SMOS neural network processor
-> retraining when L1Tb or IFS soil change
Online training possibilities?

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)

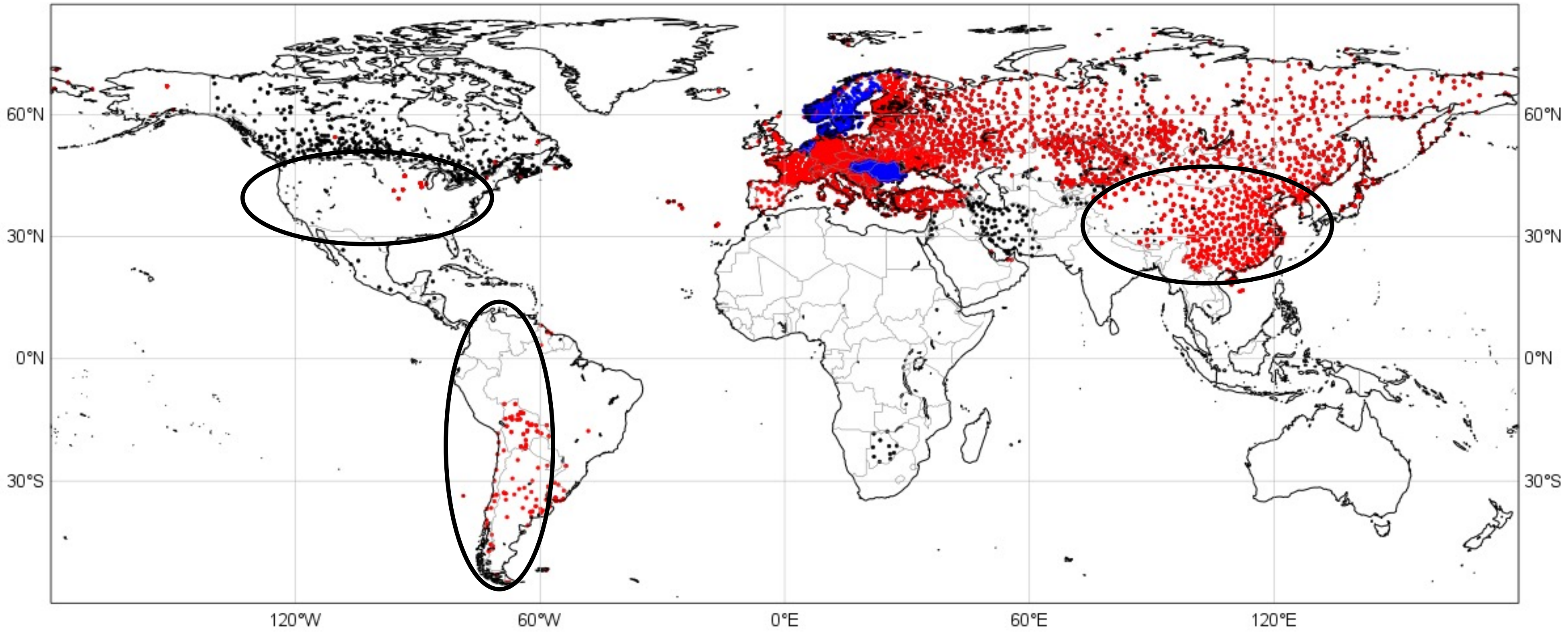


Land observing system: the example of in situ snow depth

Near-Real-Time access to observations

15 January 2021

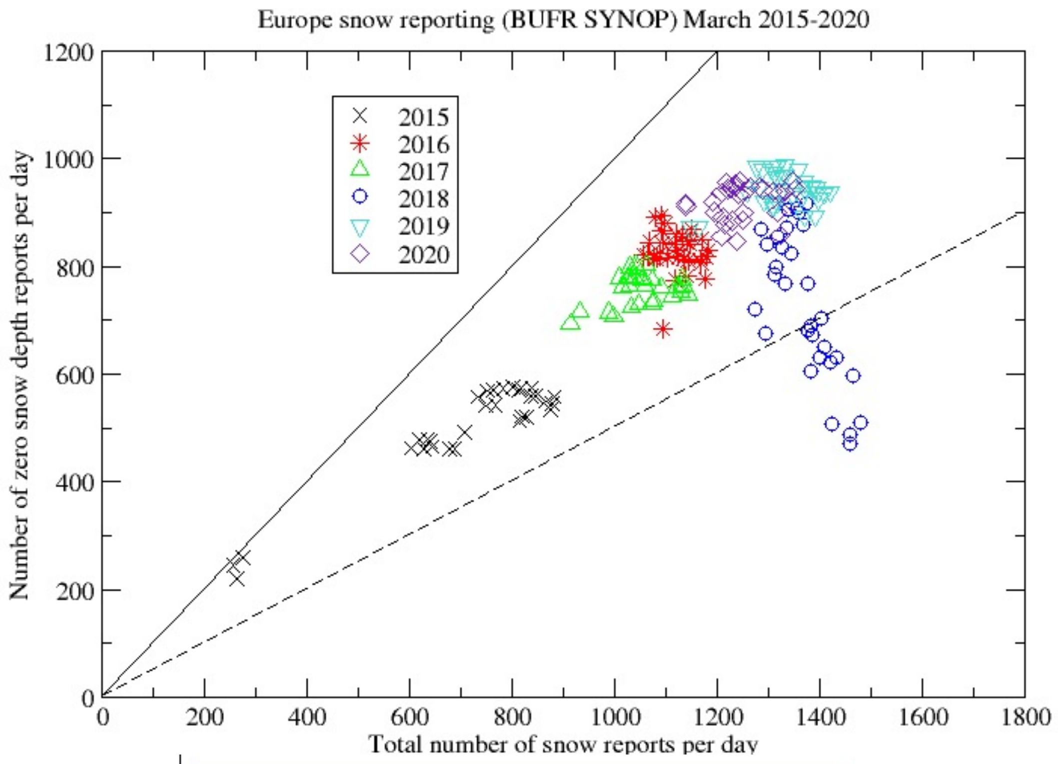
SYNOP TAC SYNOP BUFR national BUFR data



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

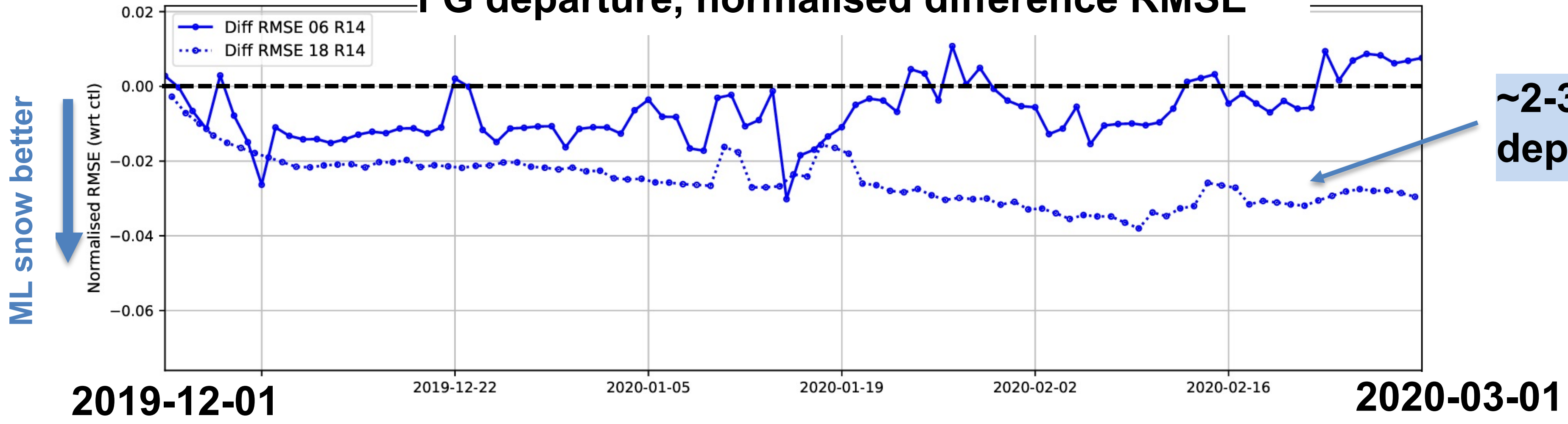
WIGOS Newsletter April 2020

ECMWF

Snow data assimilation with the new multi-layer snow scheme

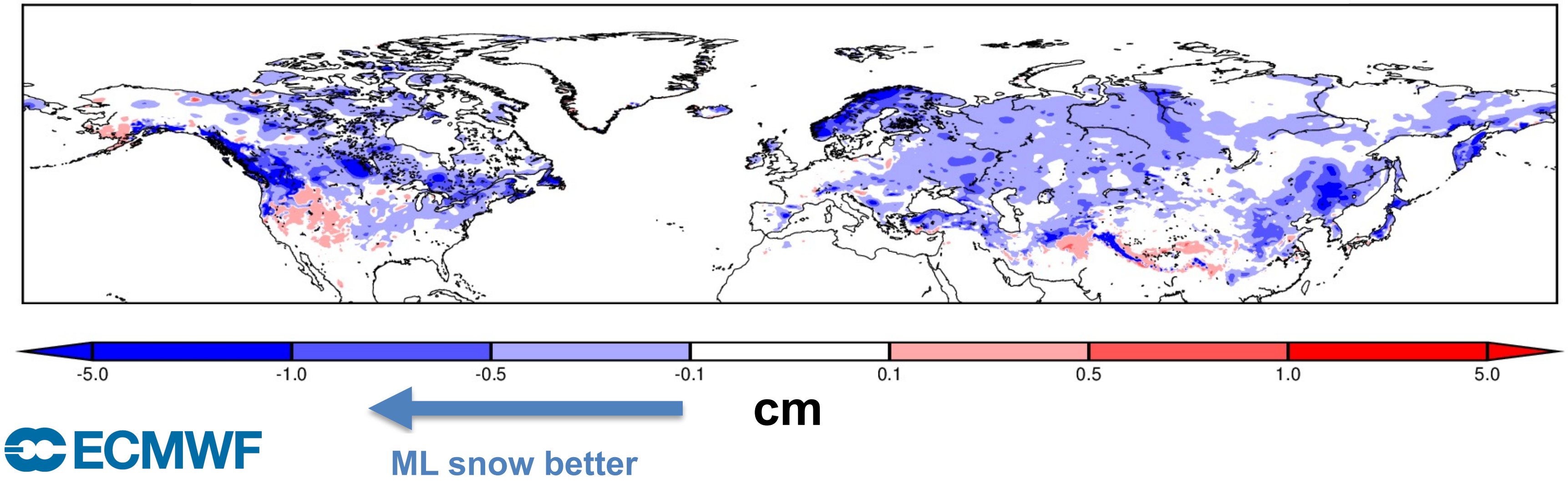
Winter, 47r1.3, Tco399L137; 3 months analysis (DJF 2019/2020)

FG departure, normalised difference RMSE



~2-3% reduction of snow depth FG departure

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



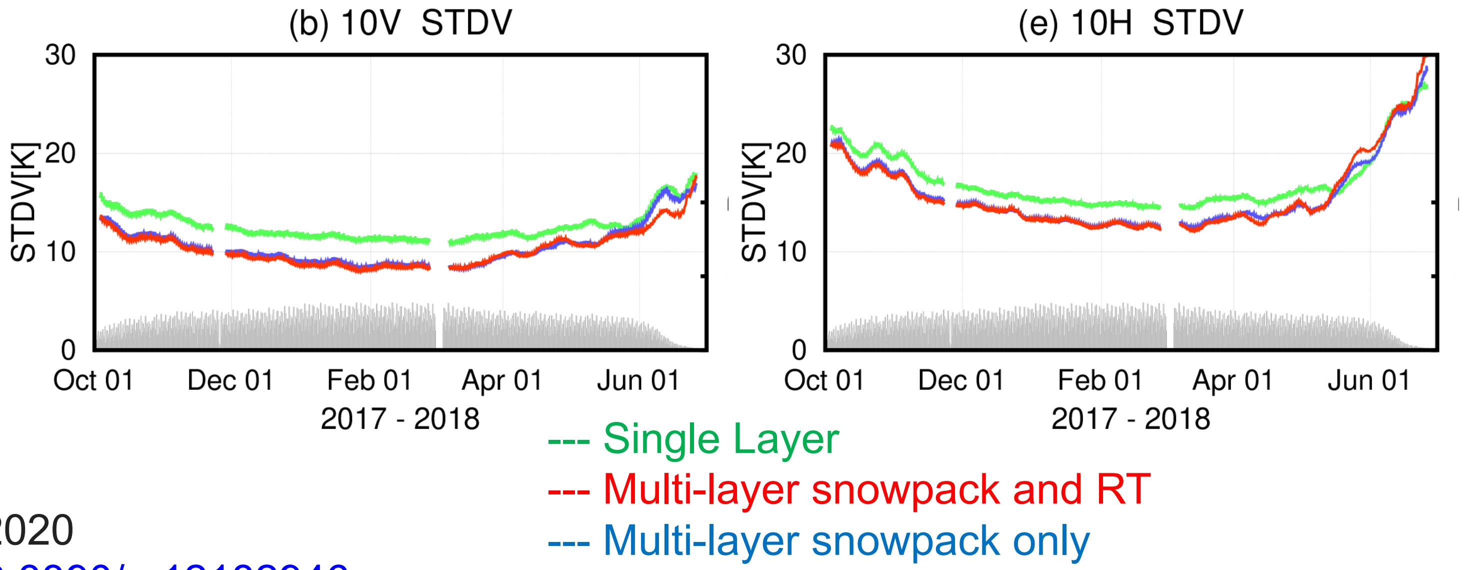
ECMWF

Simulating snow microwave radiances through an enhanced 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 model cycle 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

Summary of Coupled Modelling and Data Assimilation activities over Land

- 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/