Overview of land data assimilation and modelling advances at ECMWF

presented at the EWGLAM/SRNWP 2022 Brussels

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With contributions of several colleagues acknowledged on the slides

ECMWF

Land surface modelling advances

Themes

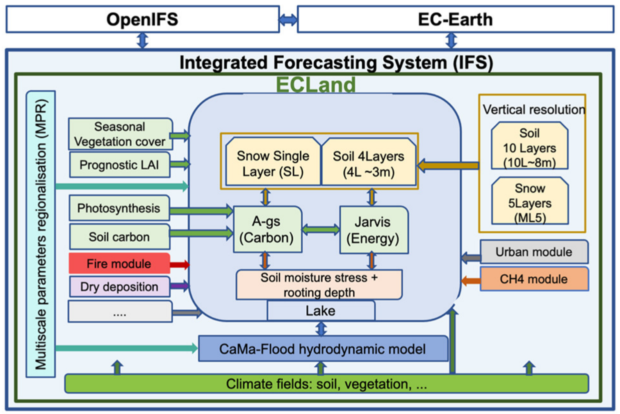
- **ECLand** further progress on the land-landcover calibration (from Boussetta et al. 2021) & cold processes
- **SnowML5** combined with a frozen soil revision improves permafrost (Cao et al. 2022) & river discharge
- **IFS-urban** including residential **anthropogenic CO2** ready for implementation (McNorton et al. 2022)
- 49r1 candidate for **New land reanalysis** (C3S) & **CO2** monitoring (**Land-Use** & **Leaf Area Index**)
- **River hydrology** soon to be coupled with IFS forecasts for hydrometeorological 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]



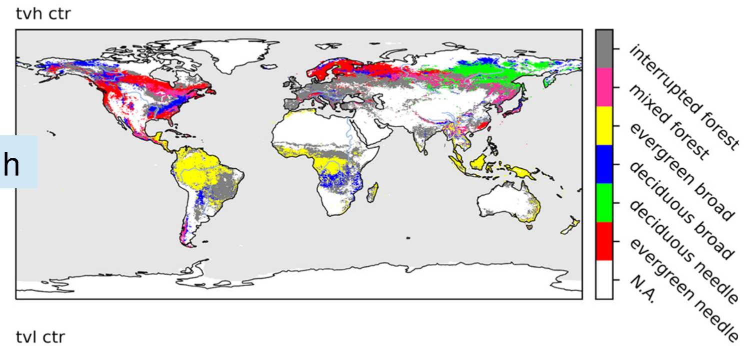
Changes in the land use land cover maps based on the C3S/ESACCI products

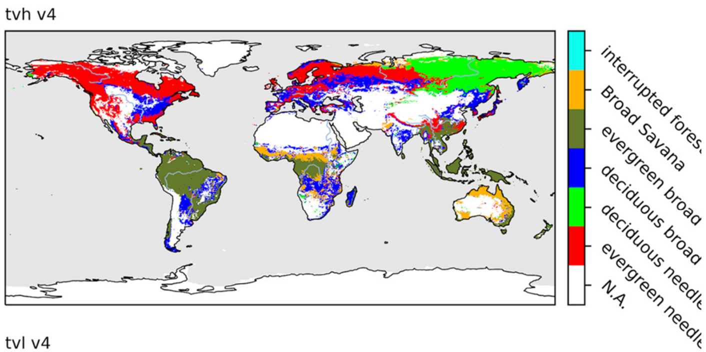
Operational GLCCv1.2 Vegetation Types

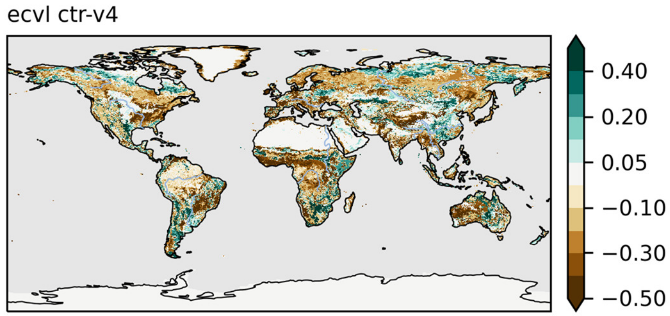
New ESACCI-V4 Vegetation Types

Effective vegetation cover difference (operational-GLCCv1.2 - ESACCI-V4)

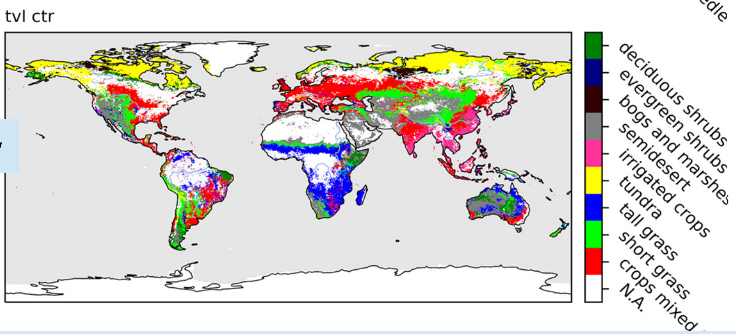
High

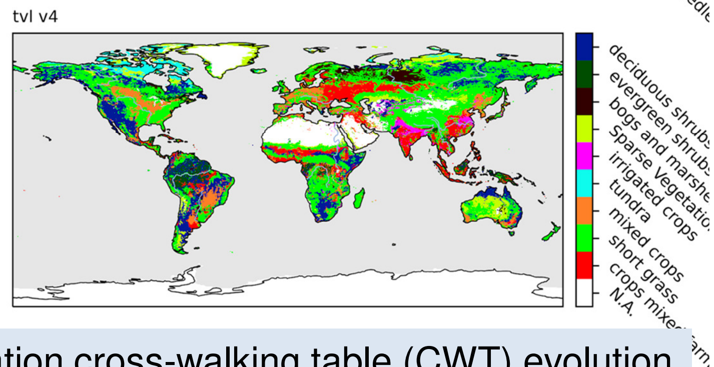


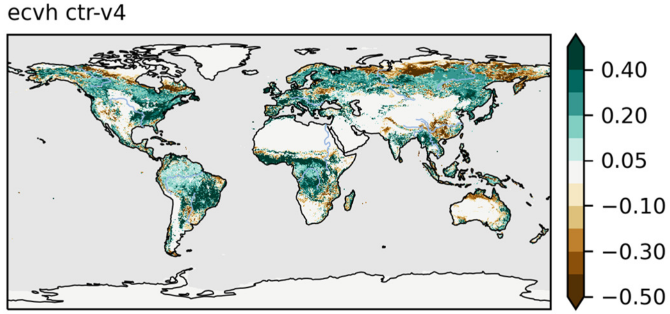


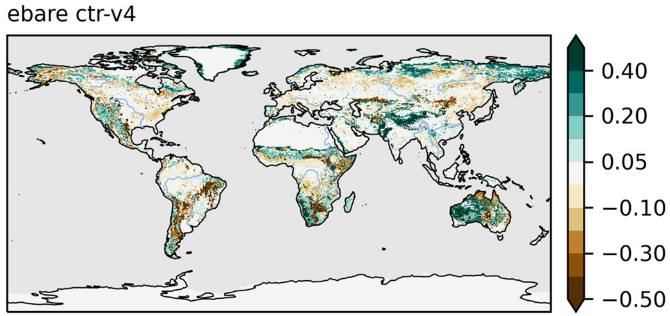


Low







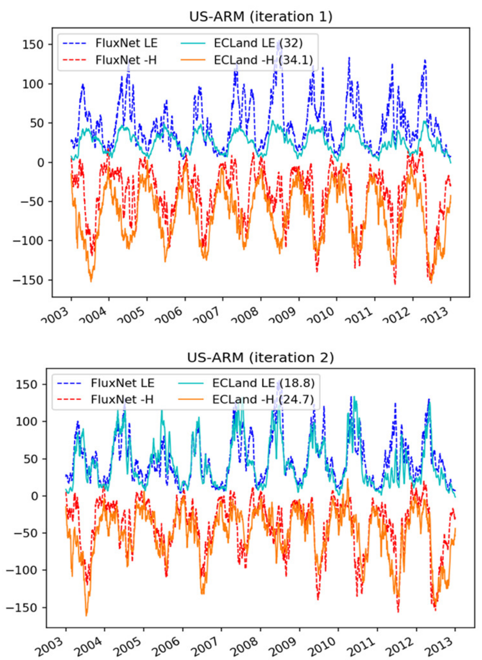


- ESACCI LU/LC–ECMWF BATS classification cross-walking table (CWT) evolution from v0 to v4 attempting to improve scores (initially in 2T/2D).
- Compared to current operational (GLCCv1.2) maps, the introduction of ESA-CCI maps is characterised by a decrease in the high vegetation cover and an increase in the low vegetation.

Thanks to Souhail Boussetta

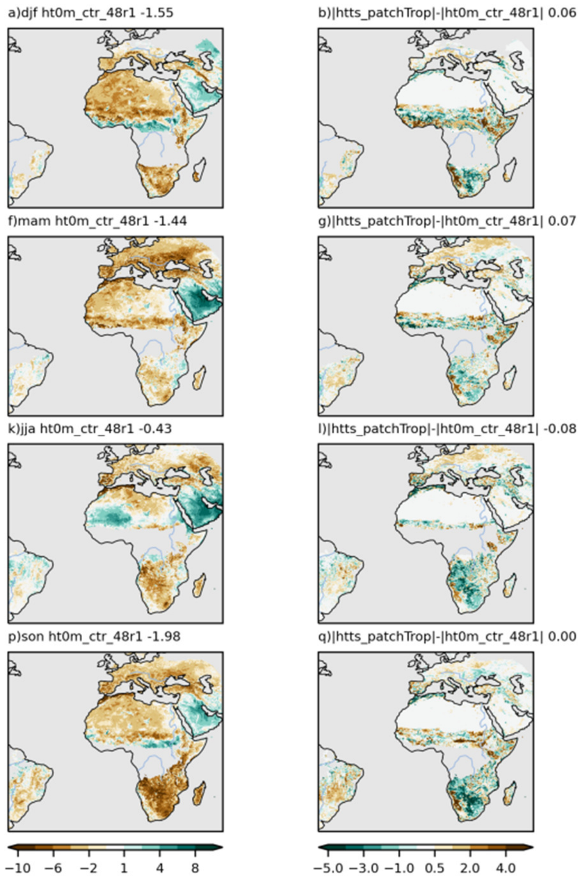
Does improved vegetation data lead to better prediction?

Point optimization with the OSM based on a simplified version Broyden-Fletcher-Goldfarb-Shanno heuristic minimization algorithm.



Ex: Minimum stomatal resistance optimization
Latent and sensible heat fluxes compared to FLUXNET2015 data at US-ARM site

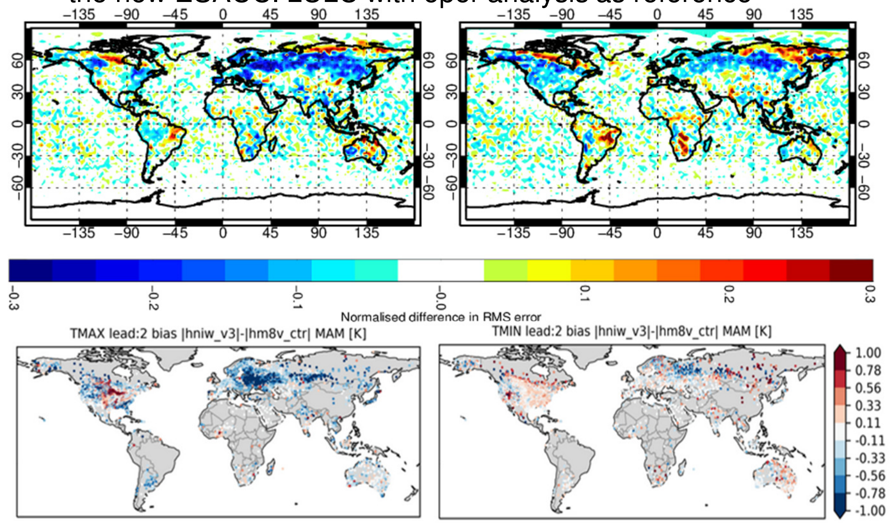
Global evaluation with satellite based LST

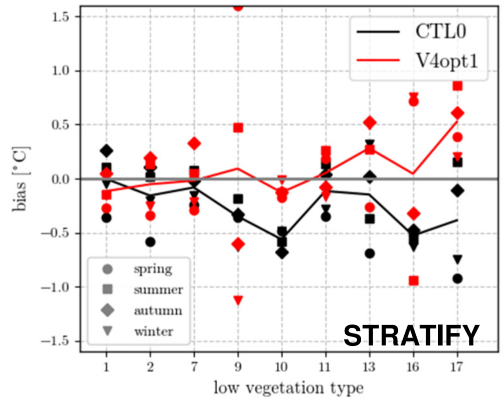


CTR LST bias   LST abs bias difference

2T/2D Global evaluation through fc experiments initialised with corresponding OSM, with reference to operational analysis experiment

Change in RMSE for MAM 2m temperature fc when using the new ESACCI LULC with oper analysis as reference

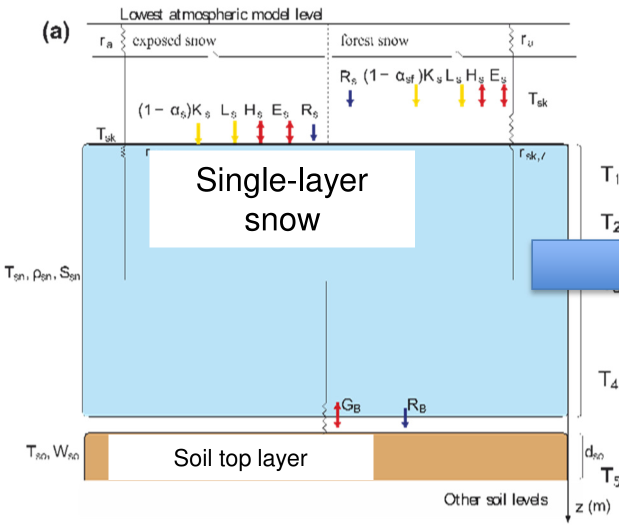


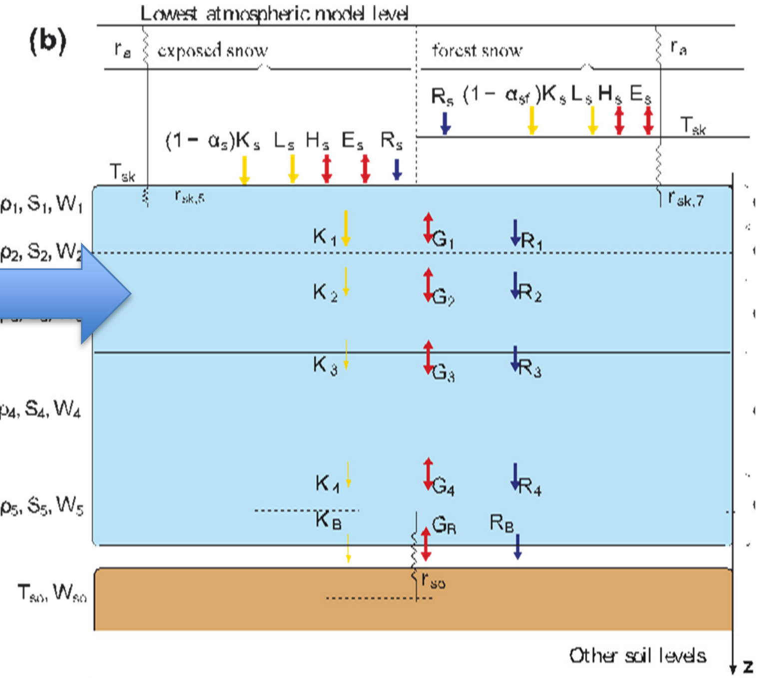


Low vegetation 2m temperature bias stratified by type for the operational system (black) and forecasts experiments based on the new v4 LULC/LAI maps (red) for 2019

Although point simulation/evaluation is very useful especially for process understanding global evaluation through synop observation and 4dvar are essential as areas with same LU (thus same model parameters) would differ for several reasons (different climate, different interaction type with the upper atm. ..)

A multi-layer snow scheme for the IFS in cycle 48r1 (Operational in Spring 2023)





Arduini et al., JAMES 2019;
Boussetta et al., Atmosphere, 2021

New multi-layer snow scheme:

- Active in cycle 48r1
- Intermediate complexity:
  - No microstructure
- 5-layer snow scheme
- Prognostic liquid water content
- Improved snow physics

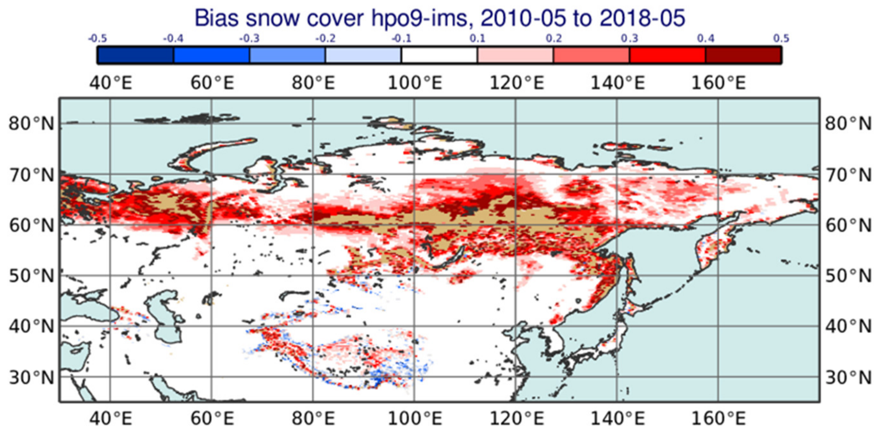
What's next ?

New forest-snow albedo leveraging the new ESA-CCI land-use maps

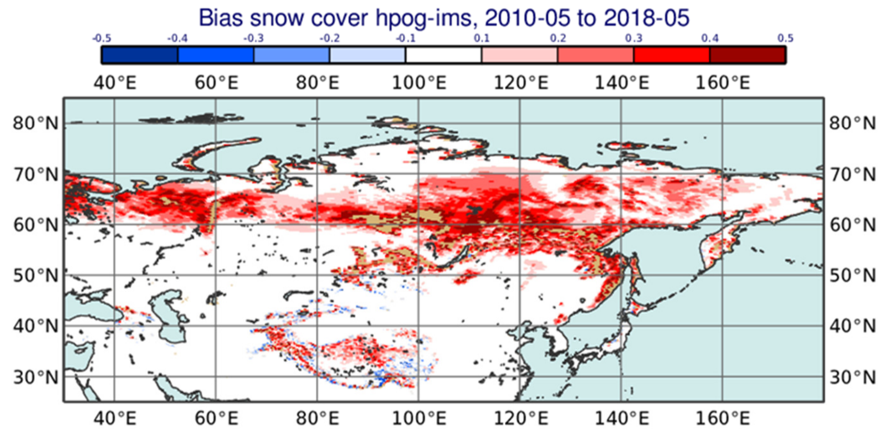
- Targeted for cycle 49r1
- Make use of MODIS monthly forest albedo + open-area snow-albedo
- Avoid using look-up table values for the albedo of snow-forest areas

Snow cover impact of new land-use & new snow-forest albedo (bias diff 2010-2018)

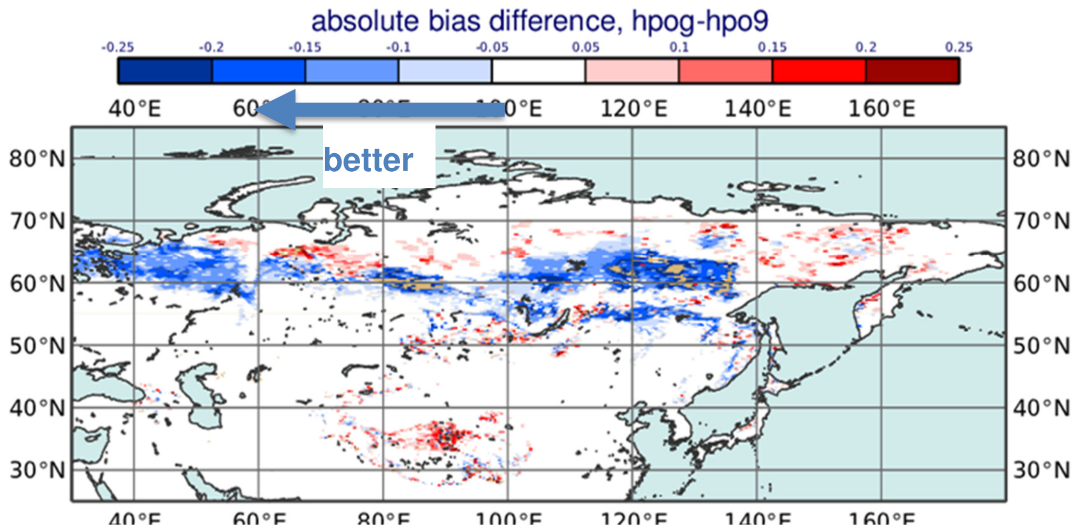
CTL (snowML+clim.v020)

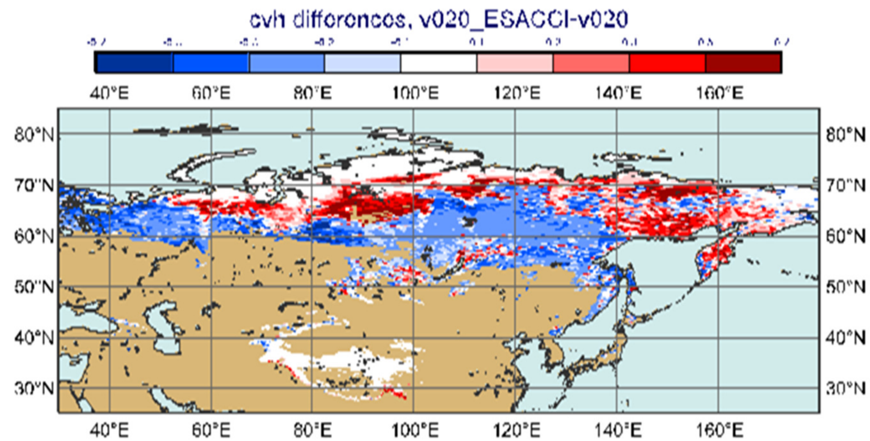


CTL + Landuse + snow-forest



[CTL + Landuse + snow-forest] -- [CTL]





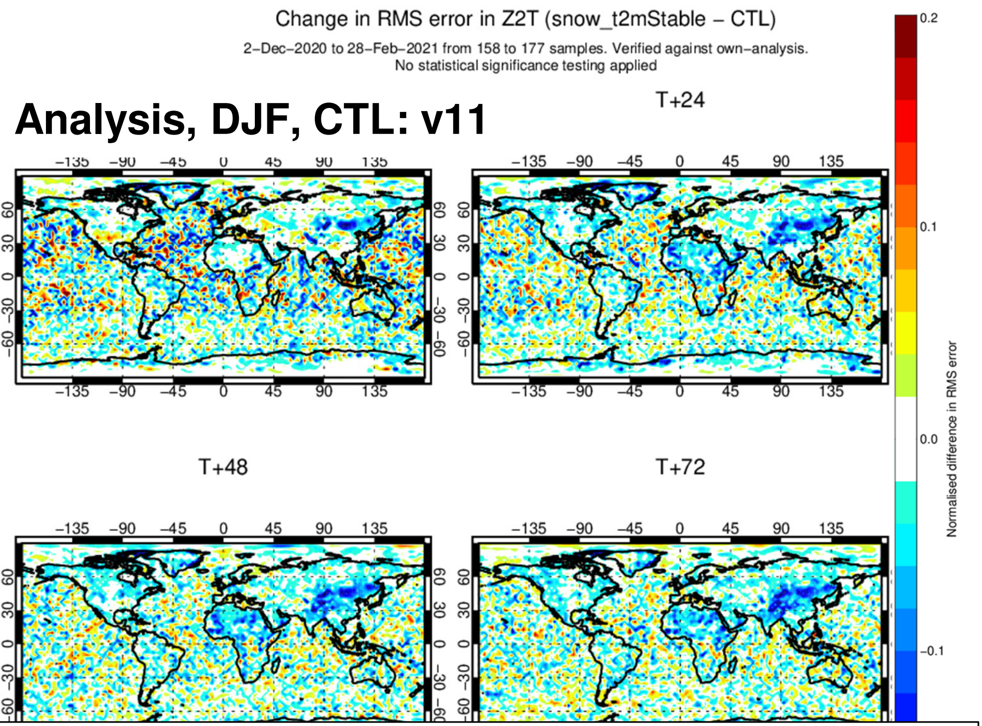
Thanks to Gabriele Arduini

Updates for 49r1: snow and T2m

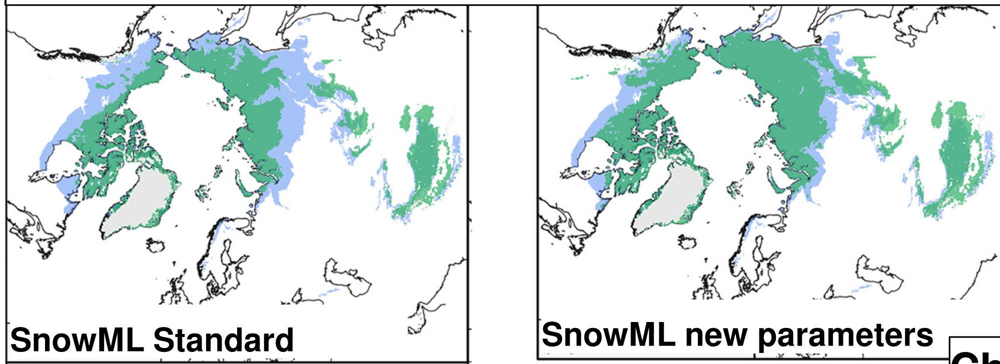
Updated snow and frozen soil params (with Ervin):

- Improved river discharge in permafrost ([Zsoter et al., 2022])
- Improved permafrost extent ([Cao, Arduini and Zsoter, 2022])

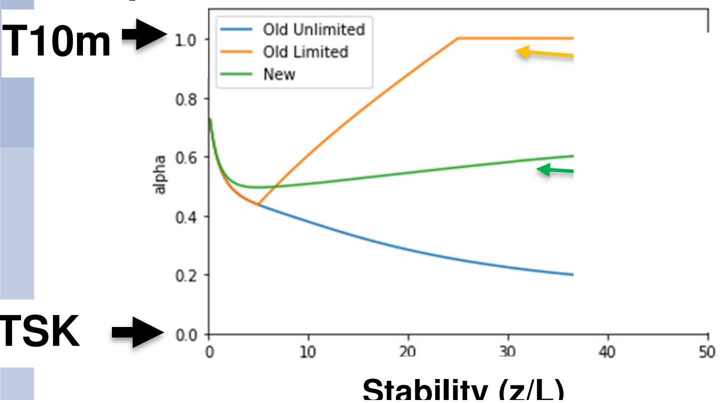
Analysis, DJF, CTL: v11



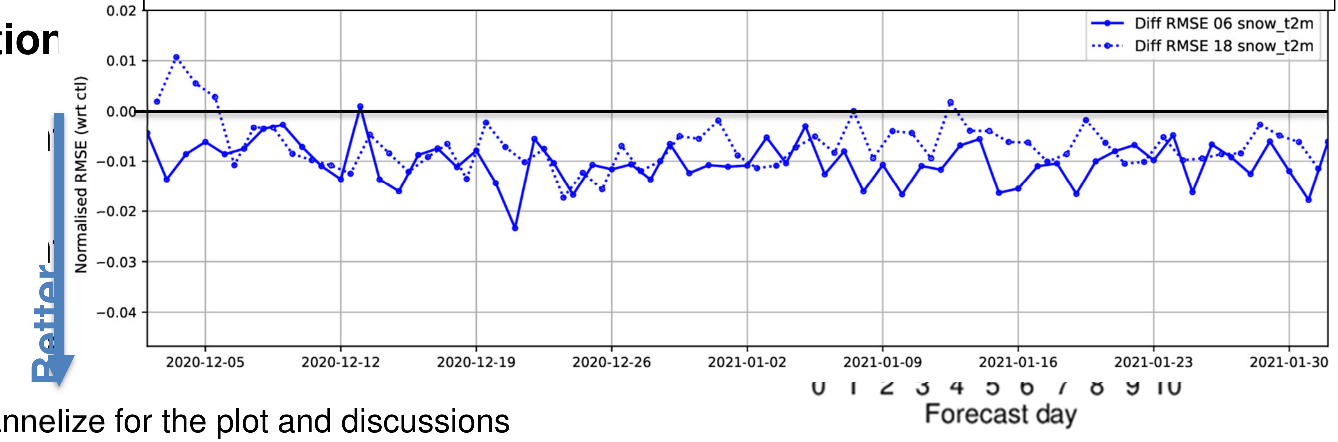
Permafrost extent from obs (cyan) and model (green)



New T2m interpolation in stable condition

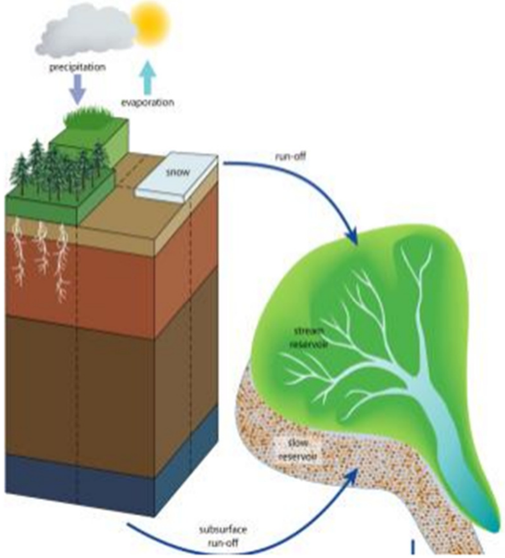


Change in RMSE (normalized) of FG departure against obs



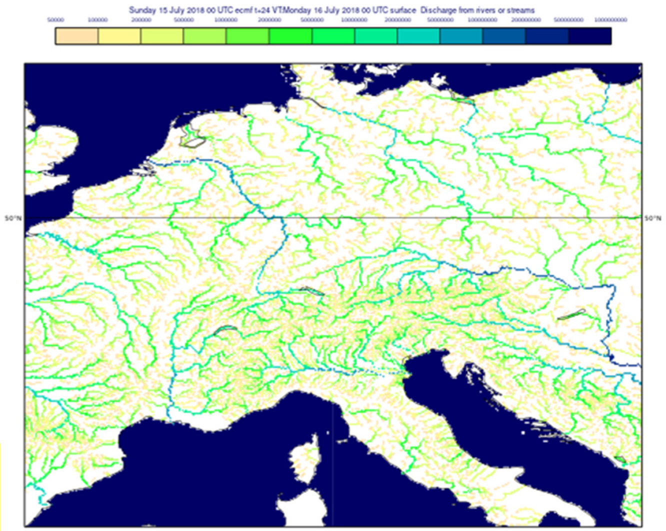
Thanks to Annelize for the plot and discussions

Toward simulating floods & inundations in ecLand and in the IFS



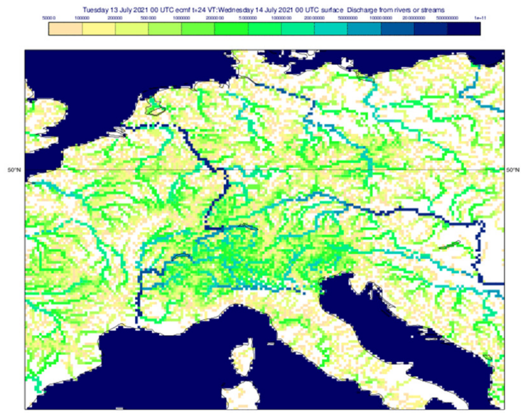
ECLand + CaMA-Flood

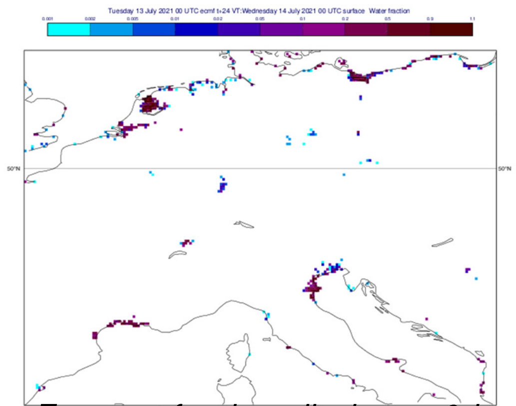
- Improved surface code efficiency allows for increased resolution and complexity
- Coupling river discharge to the top soil in future high resolution land reanalysis



ERALand prototype (4.5km) including river Discharges candidate for land reanalysis

- Coupling within the IFS is ongoing to permit forecasting river floods



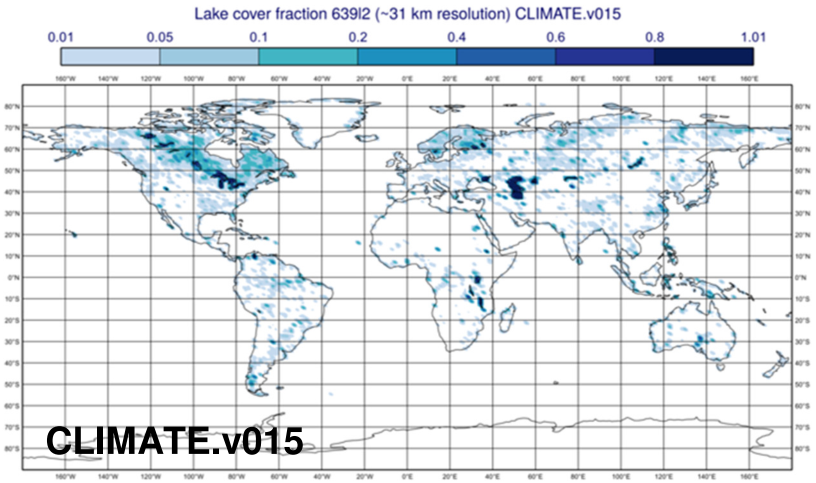


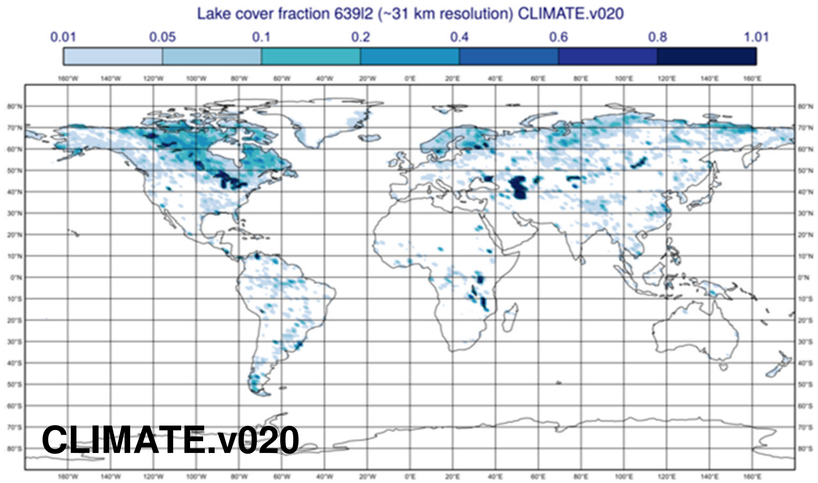
5-day Forecast for river discharge & inundated area for the German flood of July 2021 (9km)

Thanks to Xabier Pedruzo, Jasper Denissen, Gabriele Arduini

Thanks to Margarita Choulga

Lake cover temporal upgrade

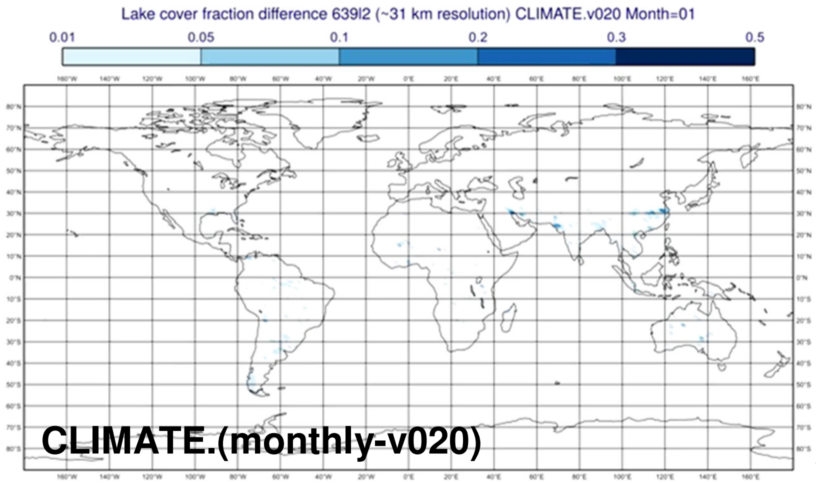




__CLIMATE.v015__ **(water)** main source **GlobCover 2009** ecosystem map (nominal **resolution 300 m**, 2009); corrected over **Iceland** and **polar regions**.

__CLIMATE.v020__ **(permanent water)** main source **JRC Global Surface Water Mapping Layer v1.2** water transition map (nominal **resolution 30 m**, 1984-2018); corrected over **glacier regions**.

__CLIMATE.v020+monthly__ **(permanent + seasonal water)** main source in addition **JRC Monthly Water History v1.3** monthly maps (nominal **resolution 30 m**, 2010-2020); **fraction ≥ permanent** water.

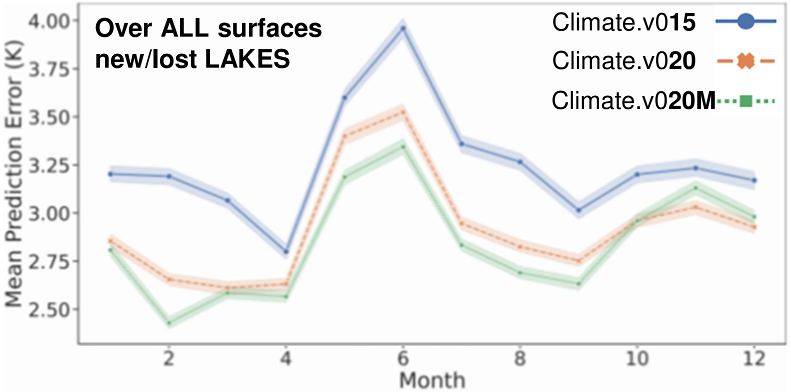


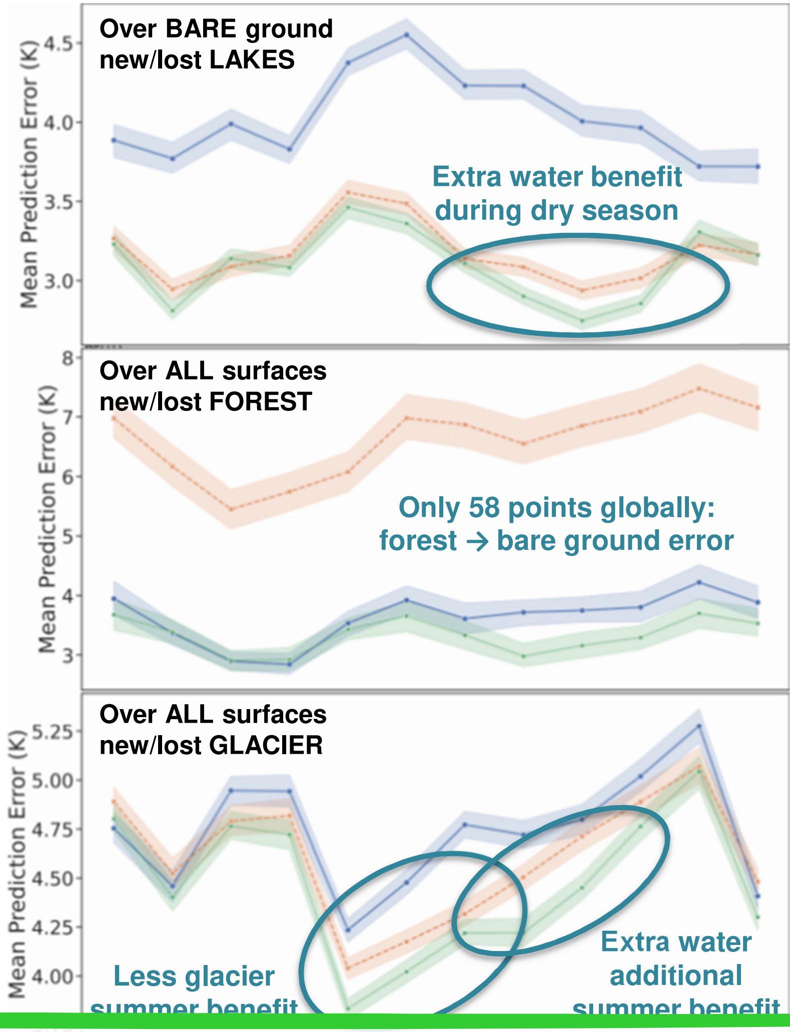
Collaboration with EFAS & GLOFAS team

Up-to-date yearly and monthly lake cover from 30m data source

Machine learning using ERA5 & MODIS Tskin + different climate fields

Collaboration with Oxford University





To **assess** IFS **benefit** of **new**/upgraded **lakes** fully connected **neural network** model using **ERA5**, **MODIS** and **climate** field data was **trained** over **2016**, and **forecasted 2019** land **skin temperature** at ~**31 km** resolution.

Table shows errors averaged over LAKES changed areas.

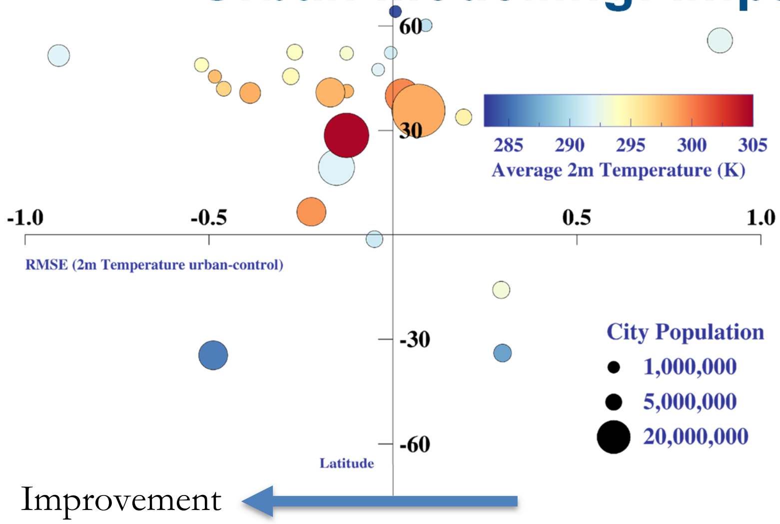
Climate fields	Mean Abs. Error, K	Std. Deviation, K
v015: **oper**	3.27	3.23
v020: **new**	2.95 (-0.3K ↓)	2.64
v020M: **new + monthly lakes**	2.87 (-0.4K ↓)	2.58

NB! Need to separate fresh and saline lakes.

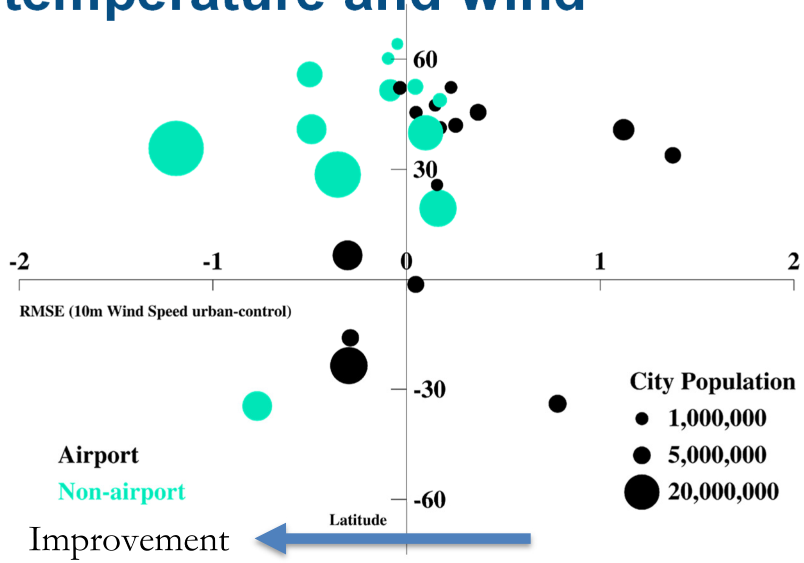
NB! Challenging to assess benefit (cloud contamination!).

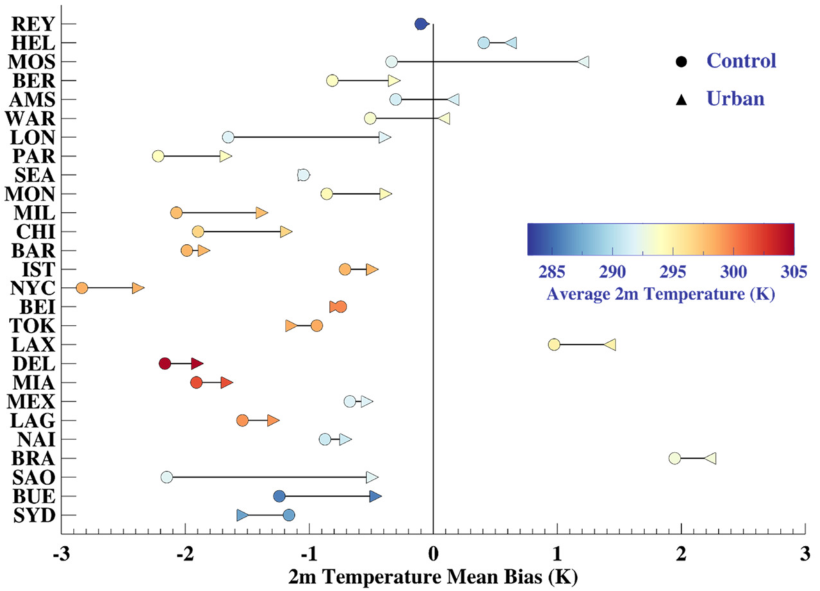
Better/timely inland water can substantially impact surface weather.

Urban Modelling: impact on near surface temperature and wind



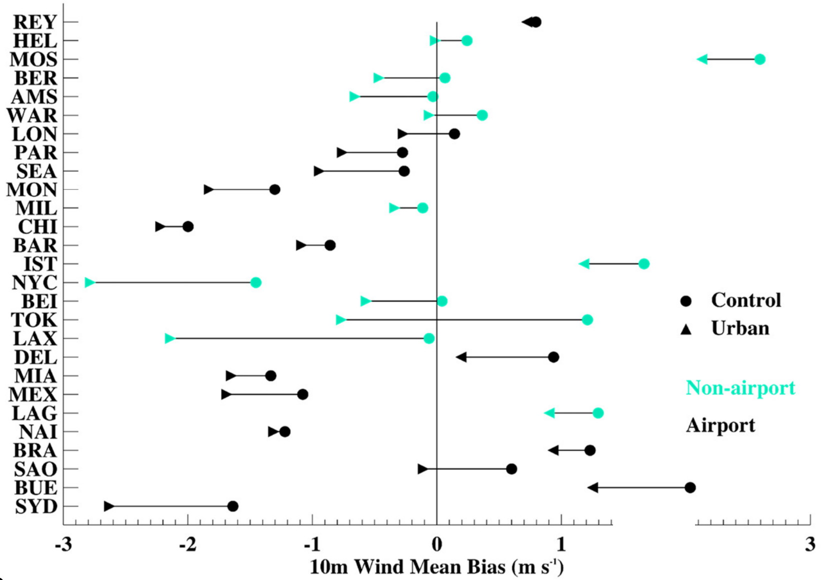
ΔRMSE Urban-Control v SYNOP
2m Temperature (left)
10m wind (right)
JJA 2018
27 Urban Sites





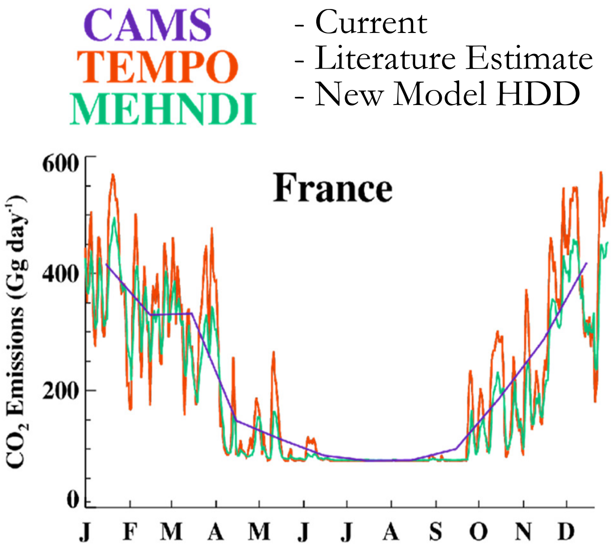
Mean Bias v SYNOP
2m Temperature (left)
10m wind (right)
JJA 2018
27 Urban Sites

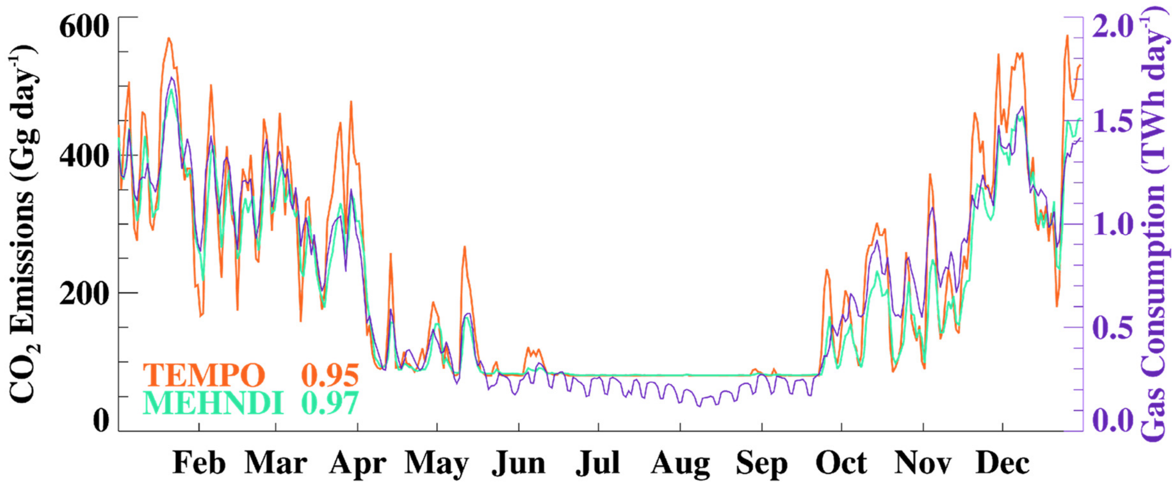
Paper in review (JAMES)
Passively implemented
Activation aim in IFS cycle 49R1



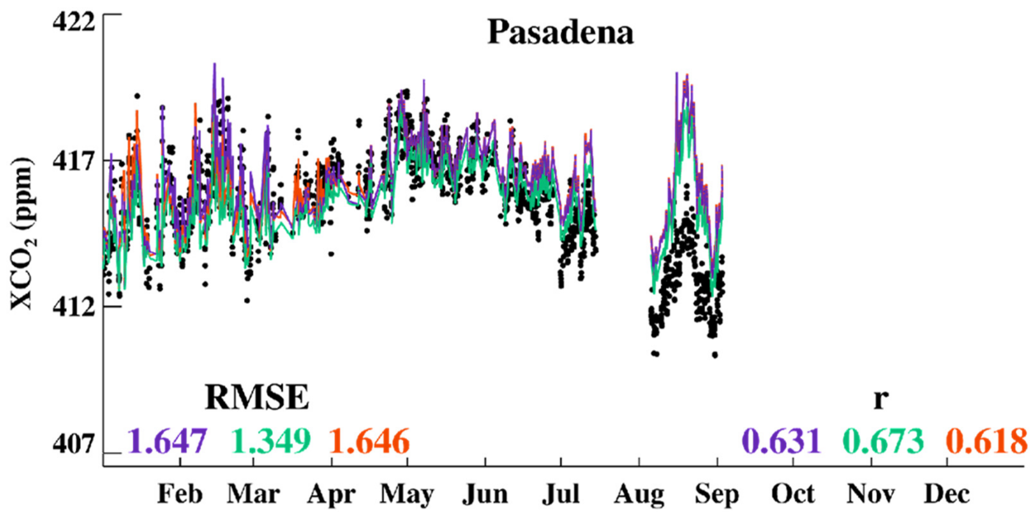
Thanks to Joey McNorton

Residential CO_2 emissions

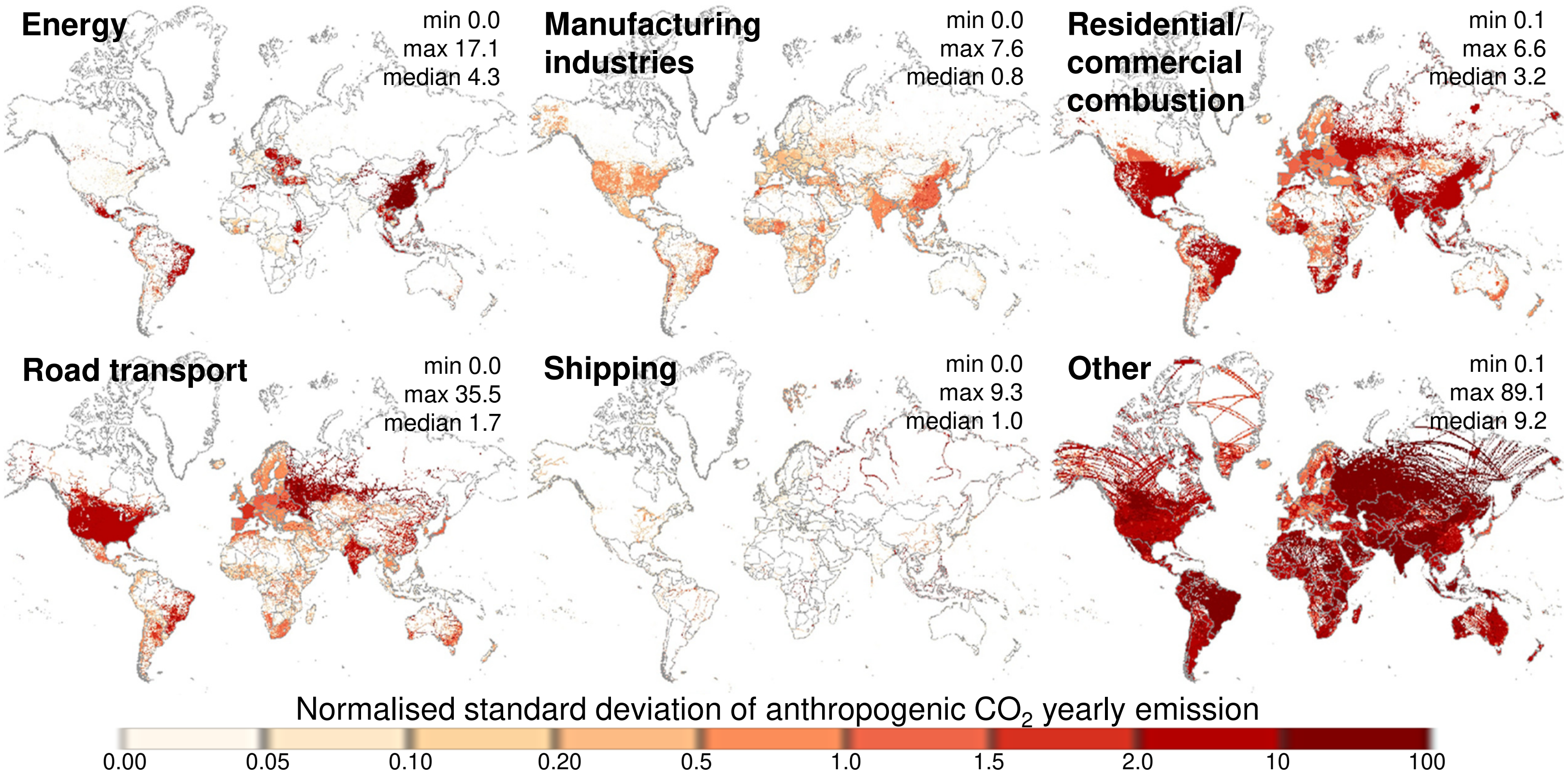




- Introduction of CO_2 residential emissions model (MEHDNI) based on heating-degree-days and urban cover.
- Compares well with existing heating degree day models, improving temporal resolution of CAMS product (top-left).
- Results agree well with gas consumption data (top right).
- When simulated in IFS, MEHNDI improves CO_2 concentrations (validation with TCCON – bottom-right).



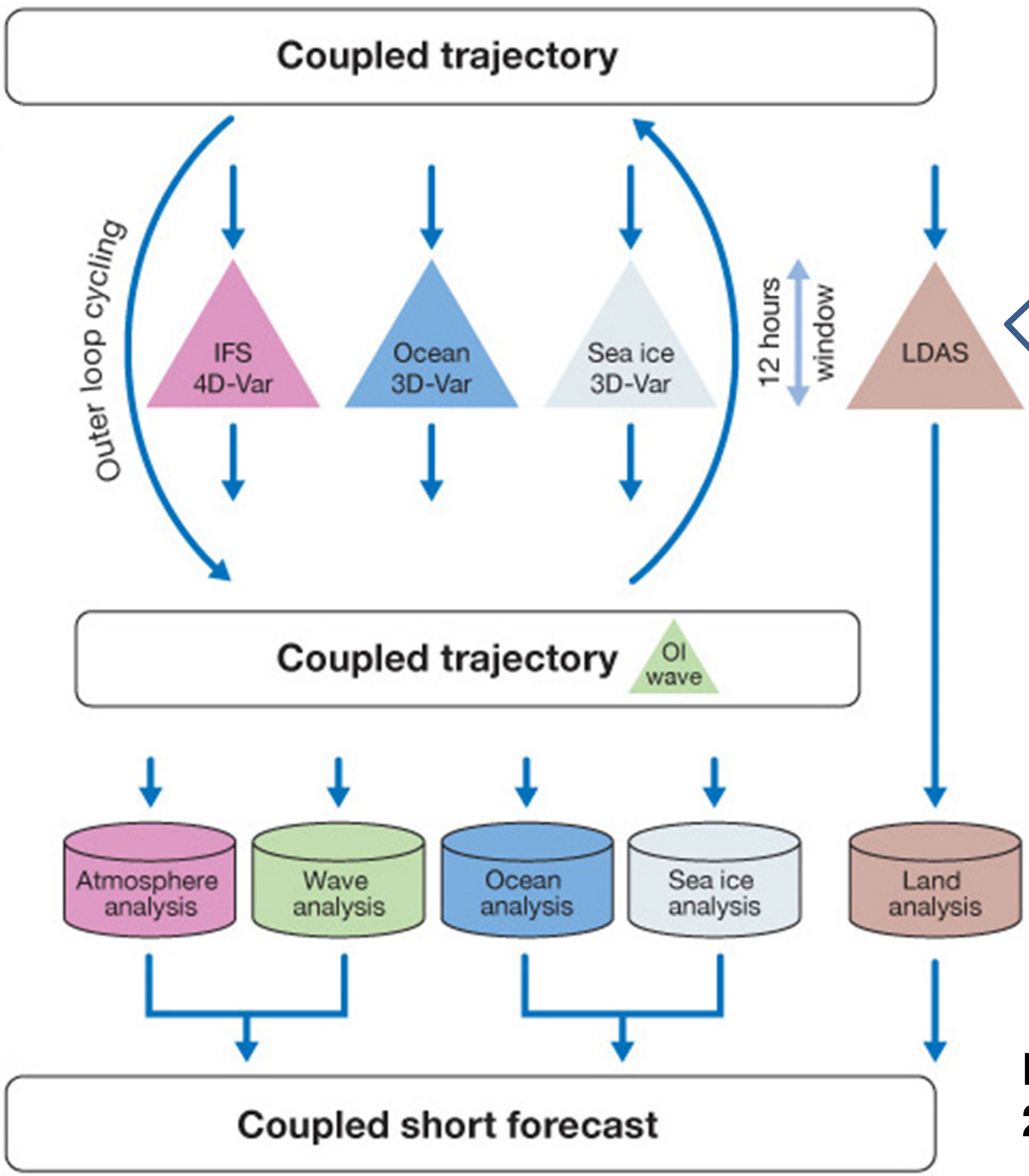
Anthropogenic CO_2 emission yearly gridded uncertainty per group



Collaboration within CoCO2 project

NB! In case of substantial amount of grid cells with small emissions (e.g. when distributed according to population density, rather than allocated sources) this may cause unrealistically high values for normalized standard deviation per grid cell (main problematic countries are China, Russia, USA, Canada).

CO_2 emissions refinement needed for DA applications (CO2MVS).



Coupled land-atmosphere assimilation

- T2m, RH2m 2D-OI
- Snow 2D-OI
- Soil moisture SEKF
- Tsoil, Tsnow 1D-OI

Preparation of next generations of C3S reanalysis systems.

- Global: ERA6-Land and ERA7
- Regional and Arctic: CERRA2, CERRA-Land, CARRA3, CARRA-Land, and beyond

Further reading on coupled assimilation (QJRMS 2022): https://doi.org/10.1002/qj.4330

Snow DA in the land SEKF

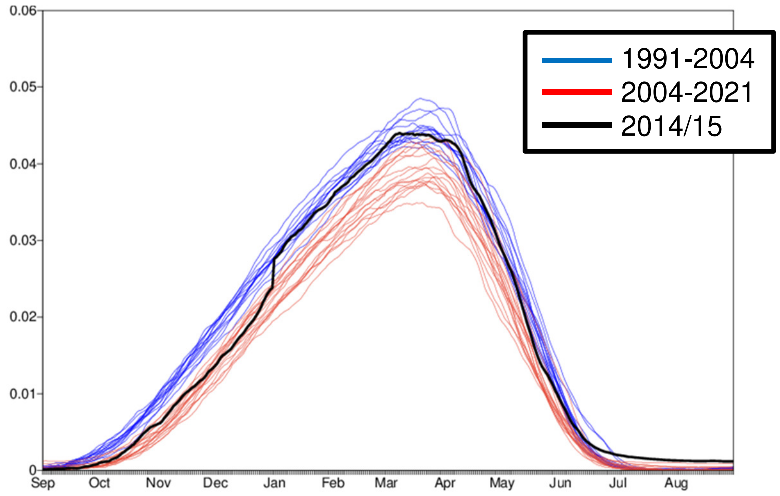
- Snow DA now available in the offline land SEKF
  - with ESA CCI snow cover (1982-2018) or IMS (2004-)

- Some issues with ERA5 snow
  - Inconsistency around 2004 (with or without IMS)
  - Discontinuity in 2014/15
  - Excessive snow on the Tibetan Plateau (See slide 4)

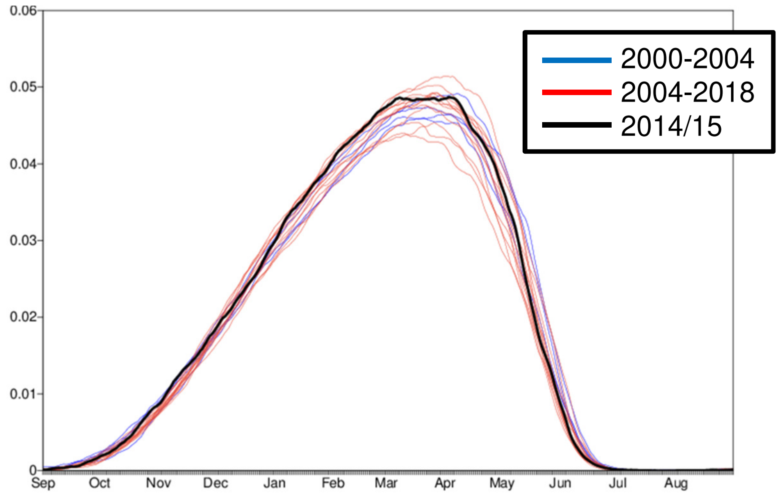
- More consistent around 2004 and 2014 in the offline LDAS

Thanks to Kenta Ochi

SWE averaged in the NH (**ERA5**)



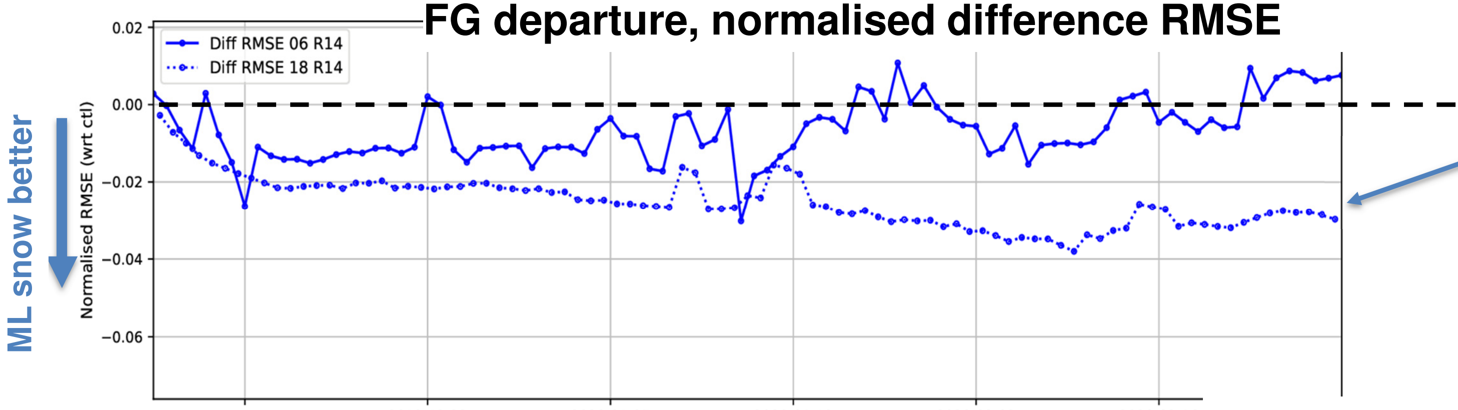
SWE averaged in the NH (**Offline LDAS**)



Snow data assimilation with the new multi-layer snow scheme

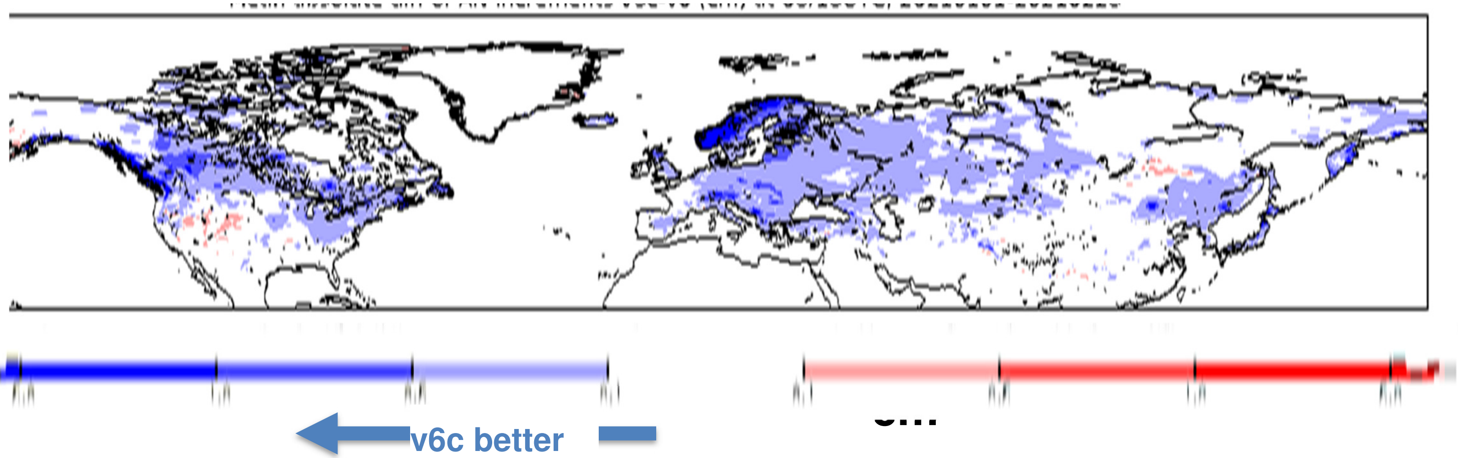
Winter, 47r1.3, Tco399L137; 3 months analysis (DJF 2019/2020)

FG departure, normalised difference RMSE

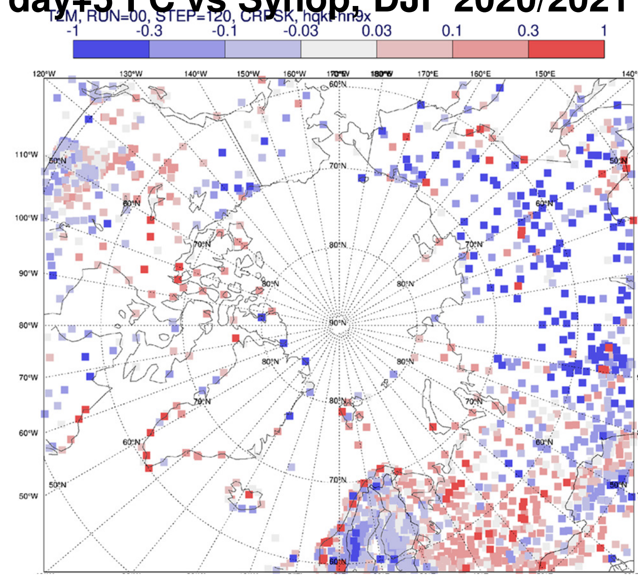


~2-3% reduction of snow depth FG departure

Mean absolute diff of Snow Depth AN increments, v6c-v0 (in cm) DJF 2020/2021

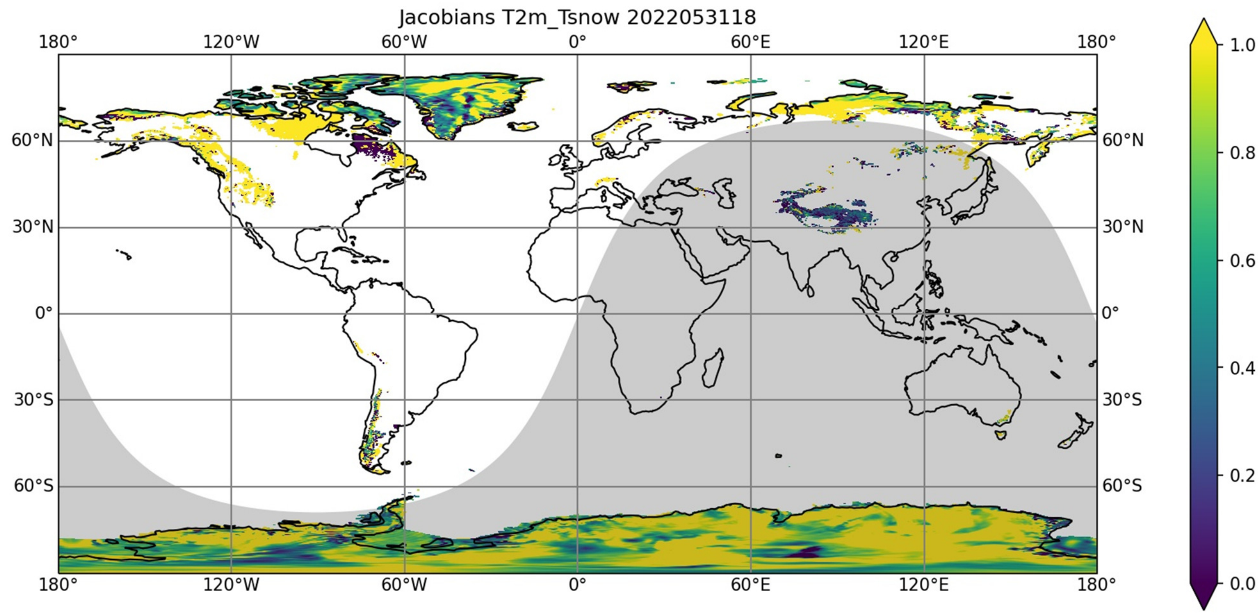


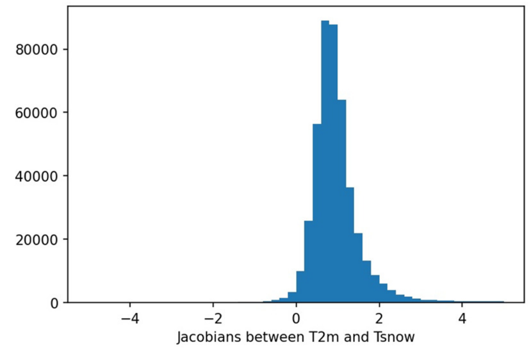
Difference in ENS - CRPS of T2m day+5 FC vs Synop, DJF 2020/2021



Soil temperature and snow temperature analysis:
EDA-based computation of Jacobians

- Analysing Jacobians between control variables (snow and multi-layer soil temperature) and screen-level variables (2-m temperature and 2-m relative humidity)





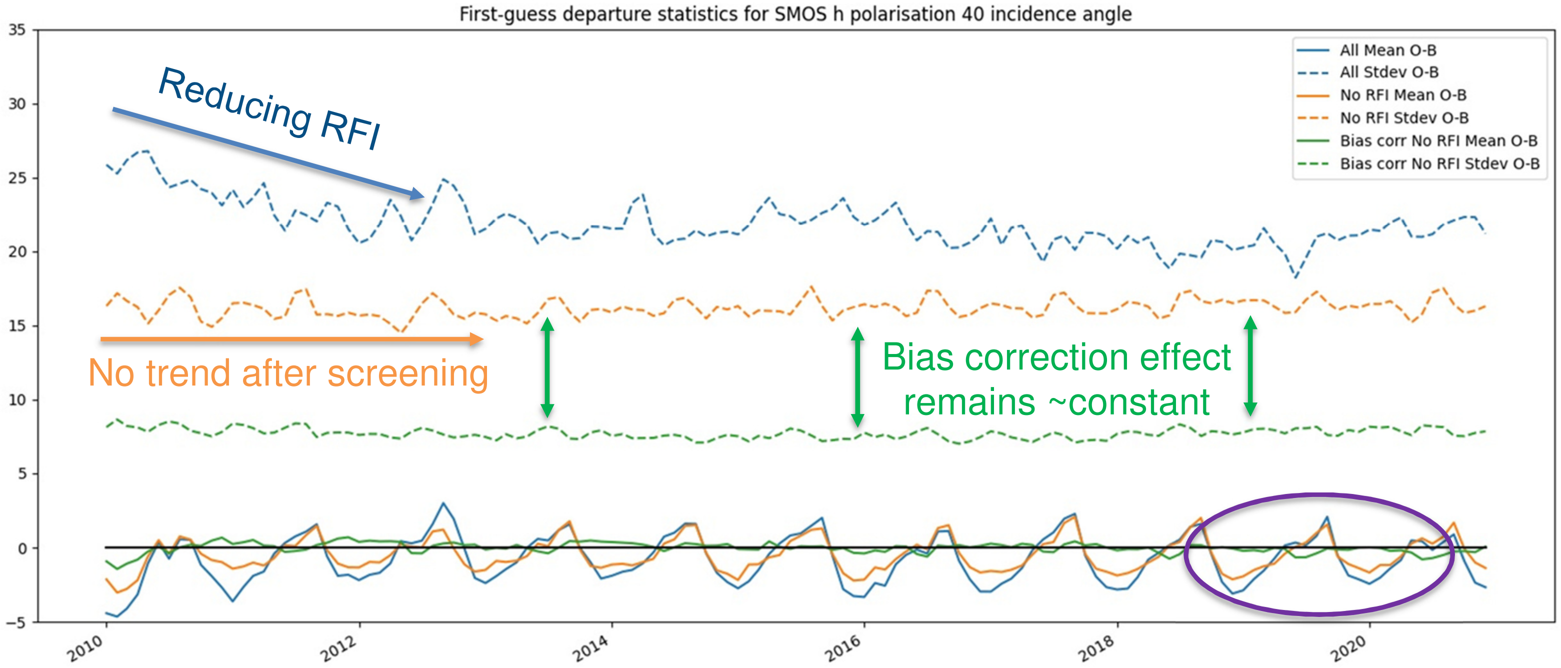
$$H_{ij} = \frac{Covar(y_i, x_{bj})}{Var(x_{bj})}$$

$$y(t_{obs}) = \begin{bmatrix} T_{2m} \\ RH_{2m} \\ \begin{pmatrix} ASCAT_{SM} \\ SMOS_{SM} \end{pmatrix} \end{bmatrix}$$

Thanks to Christoph Herbert

Importance of consistent time → SMOS multi-year monitoring

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



Seasonal biases successfully removed

Thanks to Pete Weston

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

Summary

- **Coupled Land-Atmosphere** modelling & assimilation at ECMWF for operational NWP and future generations of reanalyses → NWP, Copernicus Services, and high-resolution Destination Earth (de Rosnay et al., 2022)

- **ECLand** summarise the ongoing modelling efforts (Boussetta et al., 2021), plus improved river discharge in permafrost (Zsoter et al., 2022) permafrost extent (Cao, Arduini and Zsoter, 2022)

- Relevance and strong impact of **interface observations** such as snow depth and soil moisture

- Development of **unified land data assimilation** has started

- Next steps for stronger coupled data assimilation approach and forward operator developments