Land Surface Warm Processes for Seamless Predictions

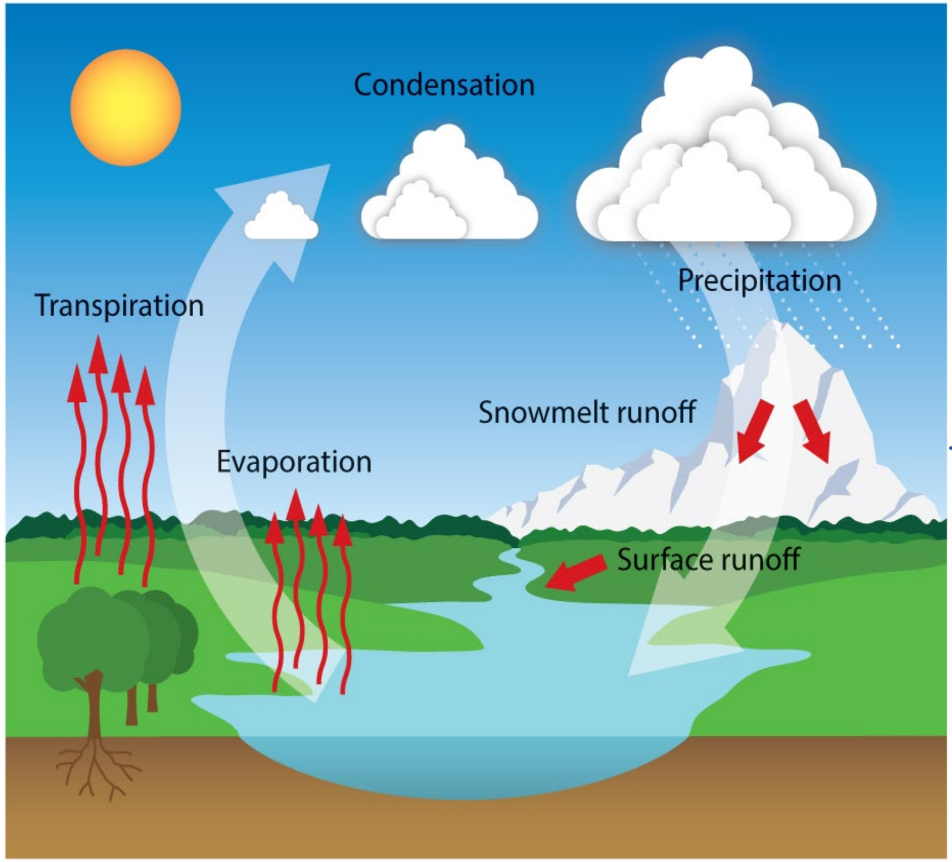
Souhail Boussetta

Thanks to: Gianpaolo Balsamo, Gabriele Arduini, Margarita Choulga, Joe McNorton, Anton Beljaars, Emanuel Dutra, Anna Agusti-Panareda, Xabier Pedruzo Bagazgoitia, Jasper Denissen, Patricia de Rosnay, Cinzia Mazzetti, Christel Prudhomme, Irina Sandu, Magdalena Balmaseda, Nils Wedi, Ervin Zsoter

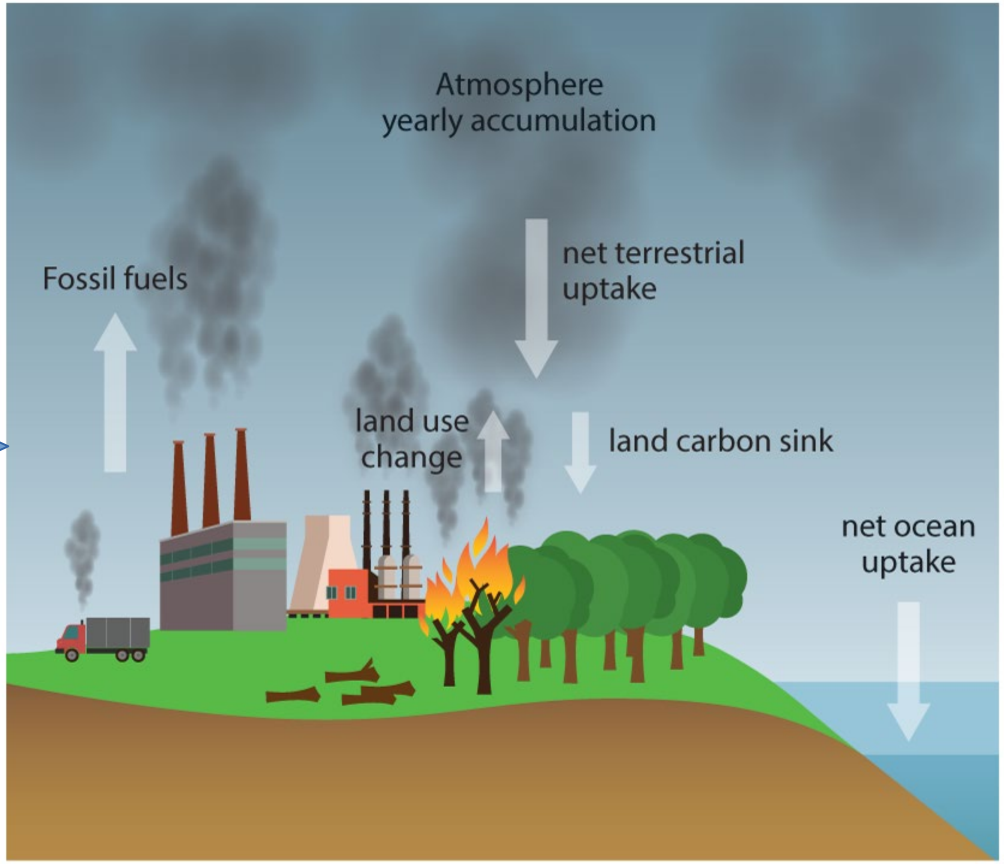
ECMWF

Land surface parametrization

Water & Energy cycles



Carbon cycle



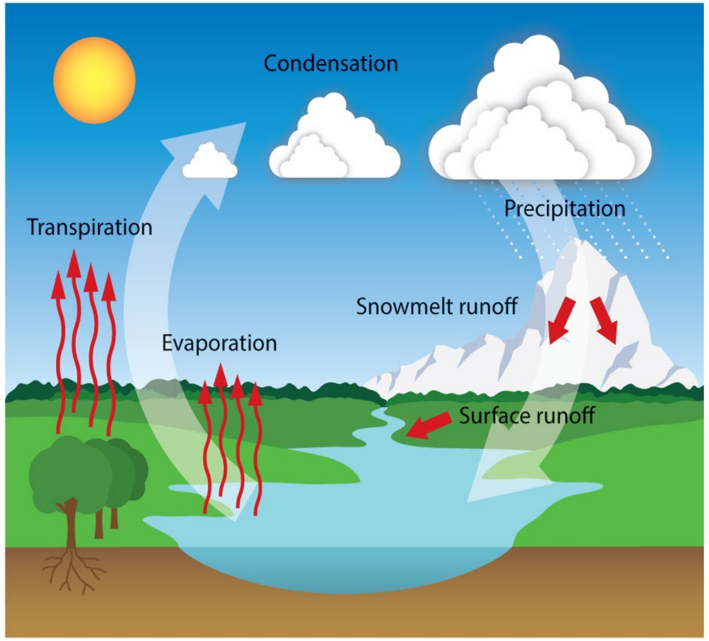
Why land surface matters?

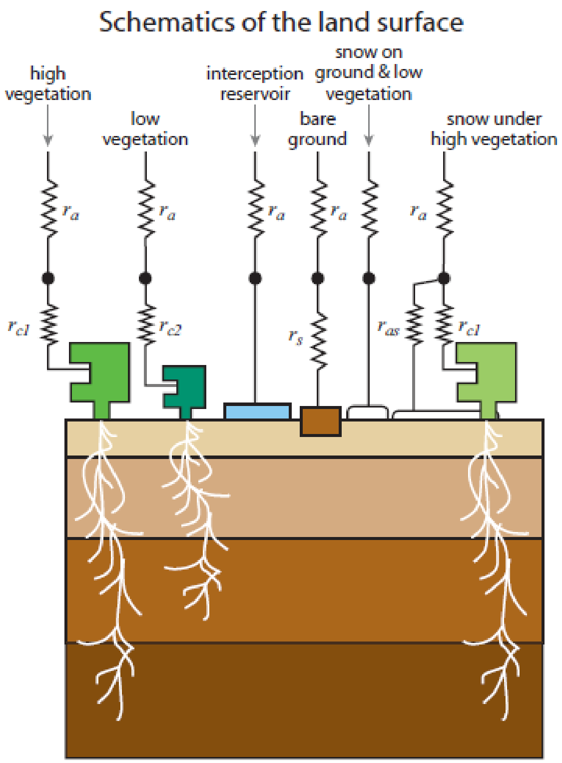
- **Because it affects**
  - Evapotranspiration and energy partition
  - Boundary layer development
  - Cloud and precipitation ...
  - the global carbon cycle and interact with climate change conditions
  - It is a key link for the water, food and energy nexus.

- **Earth System Models are evolving:**
  - Higher resolution
  - Needs for higher physical complexity
  - Better representation of the surface and vegetation dynamic
  - Consideration of anthropogenic effects

- **Satellite observations information on the Surface state are becoming more and more available and with higher accuracy & frequency**

Tiling concept and resolution: Seamless in space?

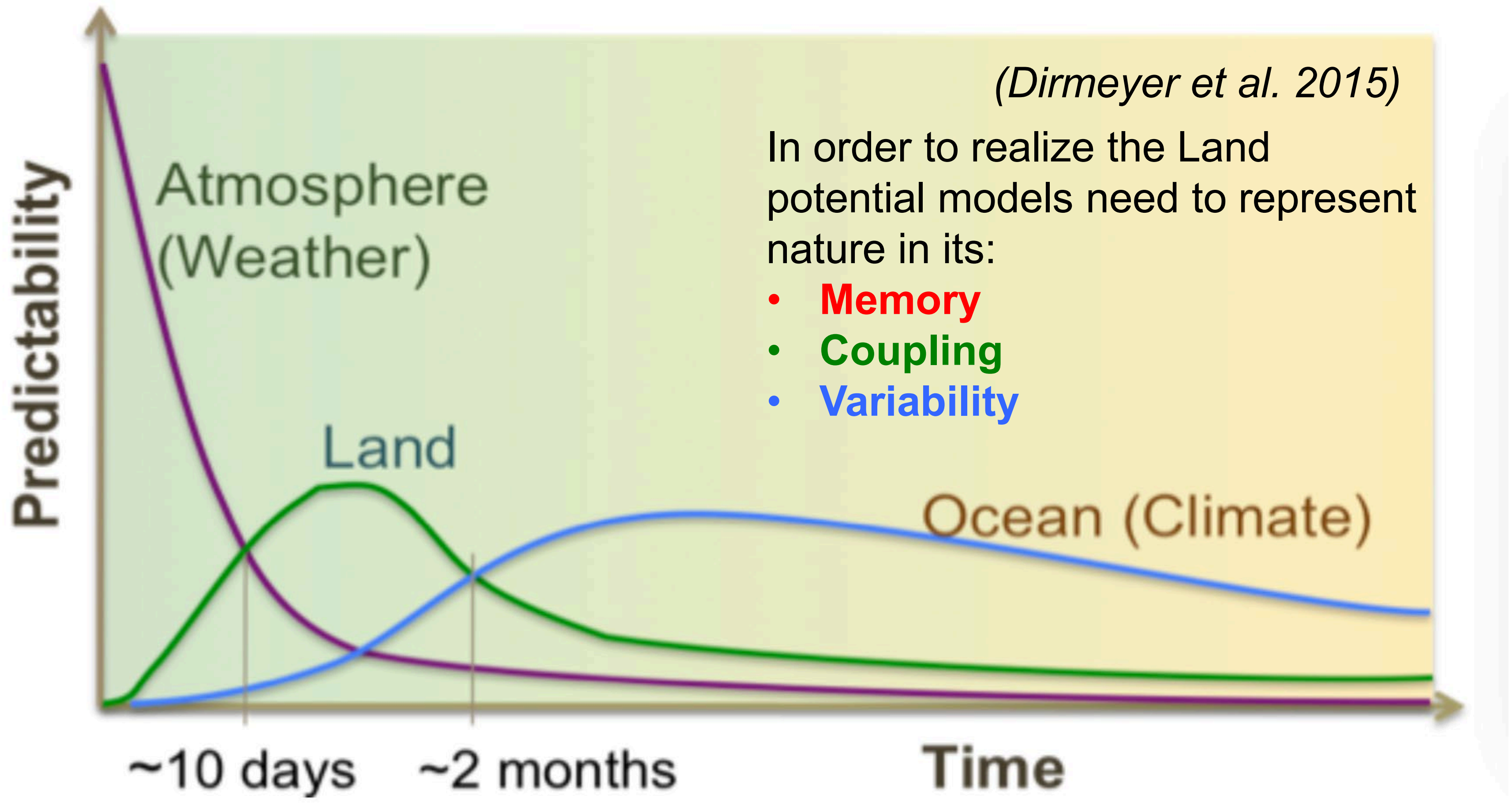




Land/vegetation	Sea and ice
High vegetation	Open sea / unfrozen lakes
Low vegetation	Sea ice / frozen lakes
High vegetation with snow	
Snow on low vegetation	
Bare ground	+ Urban tile
Interception layer	

Spatial heterogeneity calls for high-resolution horizontal/vertical to better represent the surface-atmosphere coupling,
- but even with very high resolution the tiling concept would be still valid.
- and could vary according to the target applications/outputs.

Seamless in time ?



As boundary and initial conditions, land surface could affect the atmosphere from "instantaneous" time scale to climate predictions time scales. (ex: skin temperature → deep soil temperature → energy redistribution and also soil respiration for the carbon cycle)
This call for application oriented(increased complexity) and "cascade" type modelling.

Land surface model evolution @ECMWF

- **Hydrology-TESSEL**

  Balsamo et al. (2009)
  van den Hurk and Viterbo (2003)

  Global Soil Texture (FAO)

  New hydraulic properties

  Variable Infiltration capacity & surface runoff revision

- **NEW SNOW**

  Dutra et al. (2010)

  Revised snow density

  Liquid water reservoir

  Revision of Albedo and sub-grid snow cover

- **NEW LAI**

  Boussetta et al. (2013)

  New satellite-based

  Leaf-Area-Index

- **SOIL Evaporation**

  Balsamo et al. (2011),

  Albergel et al. (2012)

- **H_2O / E / CO_2**

  Integration of

  Carbon/Energy/Water

  Boussetta et al. 2013

  Agusti-Panareda et al. 2015

- **Lake & Coastal area**

  Mironov et al (2010),

  Dutra et al. (2010),

  Balsamo et al. (2012, 2010)

  Extra tile (9) to for sub-grid lakes and ice

  LW tiling (Dutra)

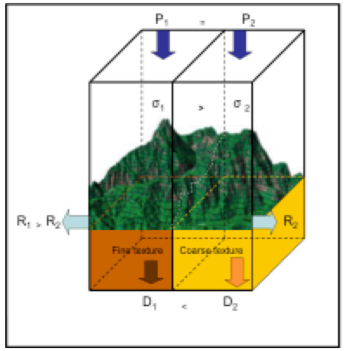
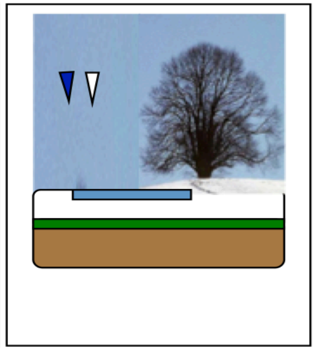
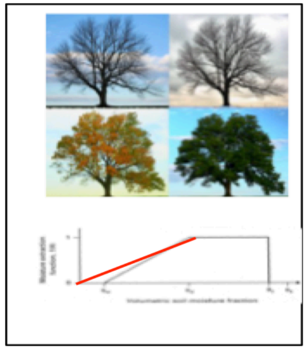
- **Enhance ML**

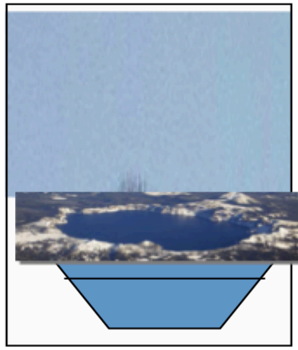
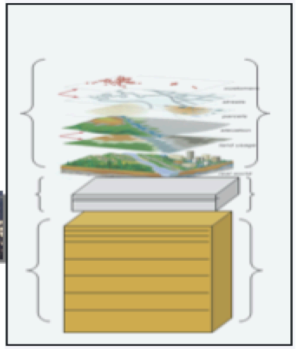
  Snow ML5

  Soil ML9

  Dutra et al. (2012, 2016)

  Balsamo et al. (2016)

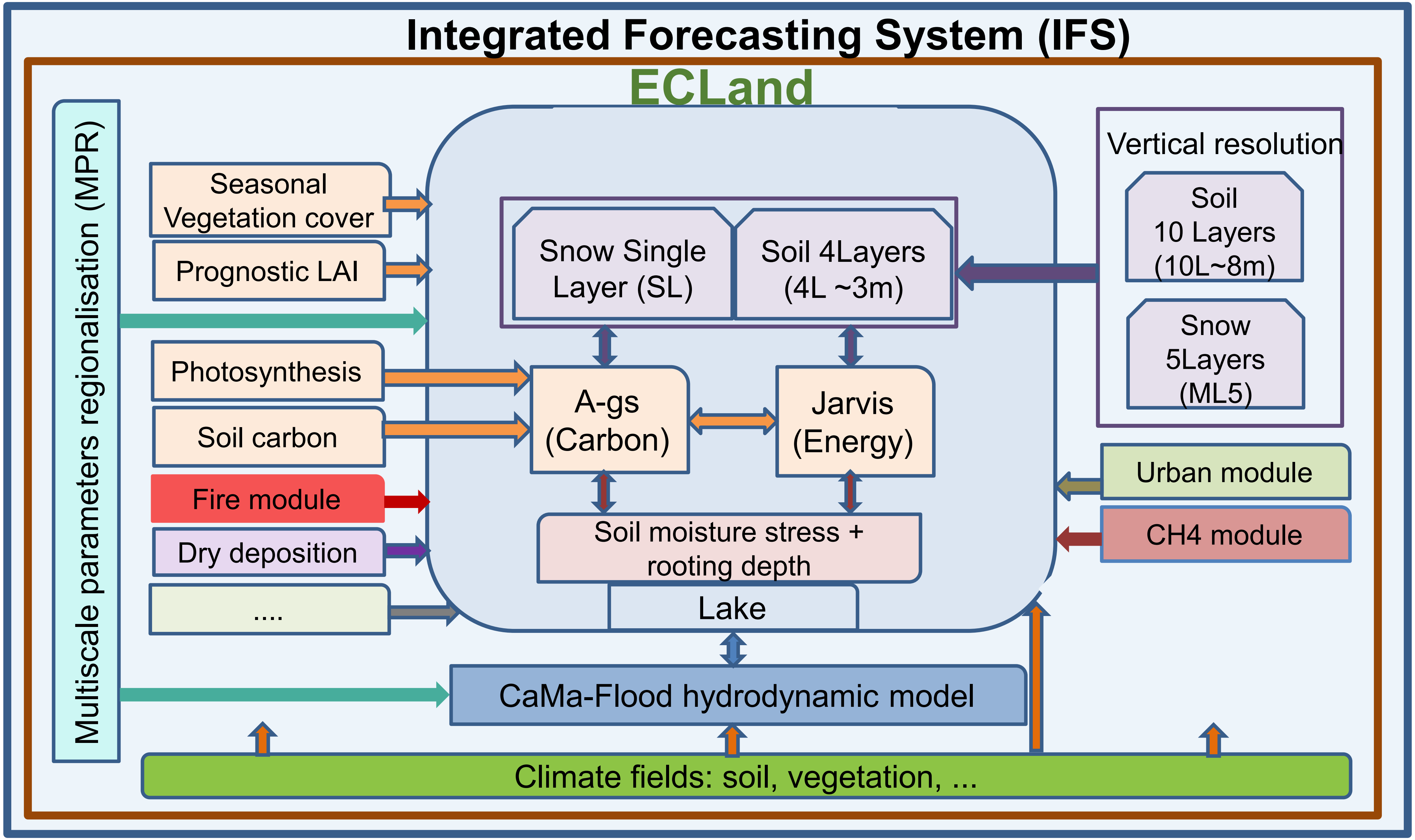




Atm/ Land resol.	ECMWF Config. in 2022
32 km	ERA5* SEAS5
18 km	ENS
9 km	HRES^{+} ERA5Land

Land surface 1D-model soil, snow, vegetation, lakes and coastal water.

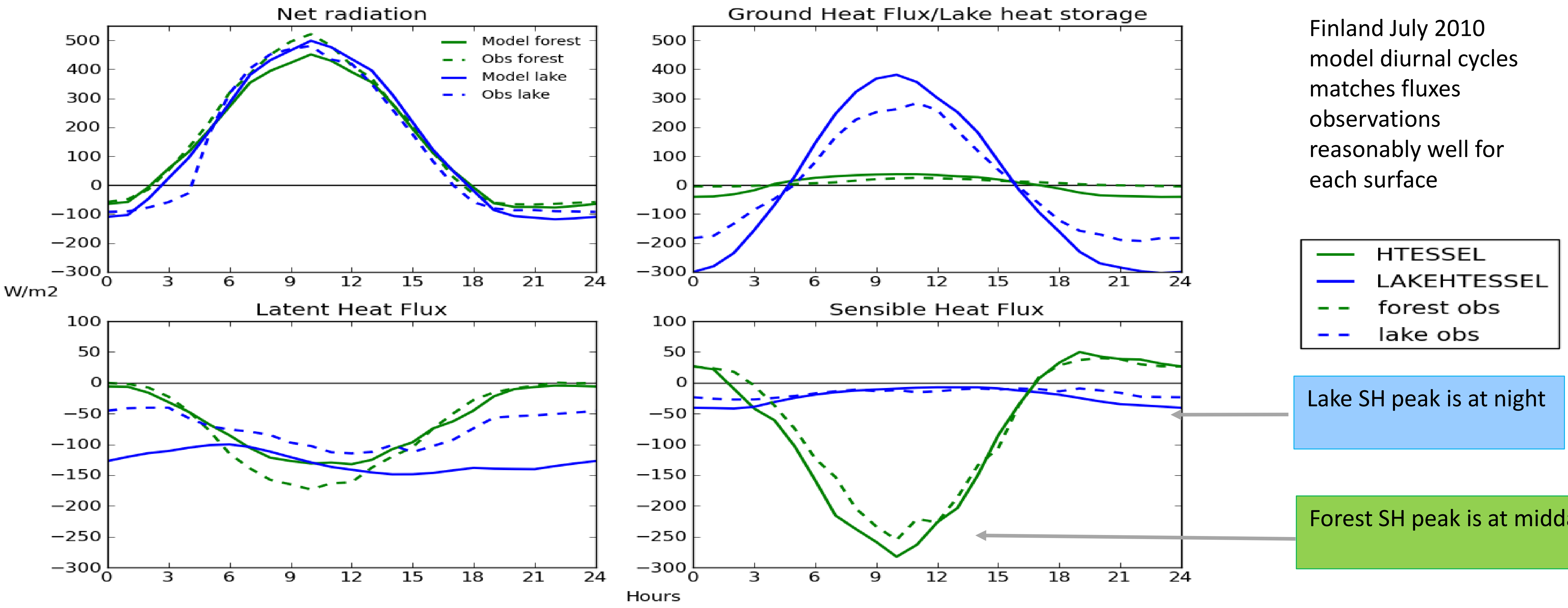
ECMWF

Modularity for increased complexity



Surface heterogeneity: taking into account lakes

Why lakes are important? Compare a lake with a nearby forest energy partitioning on a summer day



Finland July 2010 model diurnal cycles matches fluxes observations reasonably well for each surface

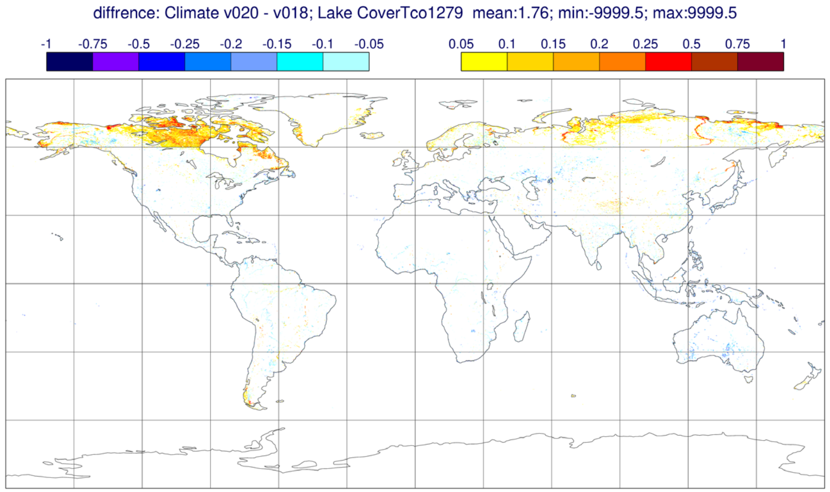
Lake SH peak is at night

Forest SH peak is at midday

Manrique-Suñén et al. (2013, JHM)

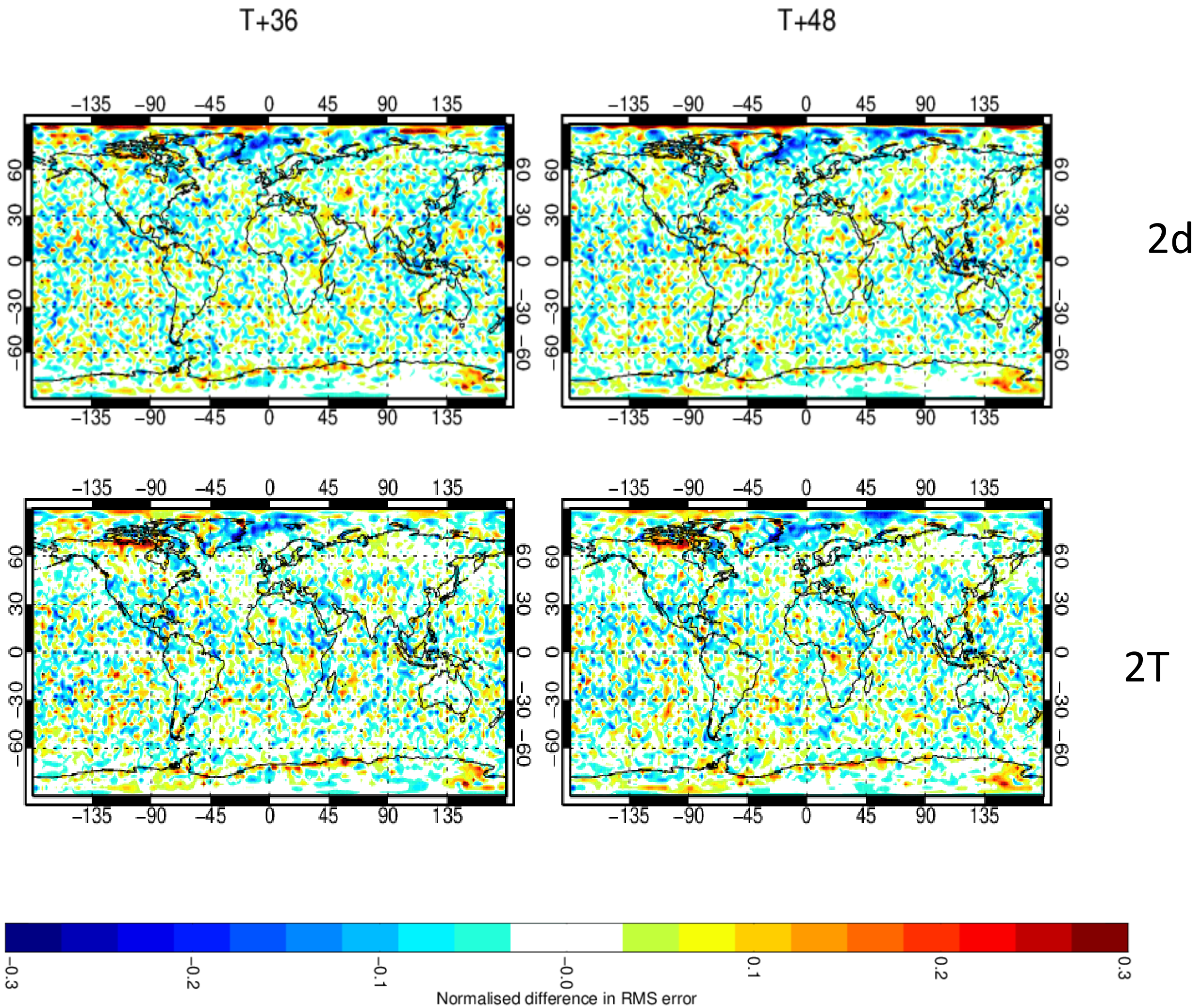
Taking Lakes into account allow to better simulate the right partition between different surface fluxes

Surface water update for 48R1 (climate v.020)



Lake cover difference between the new map based on GSWE and the operational map

RMSE difference (Summer)



Neutral to positive impact for 2T/2d RMSE for the Summer over the areas with differences in the water coverage

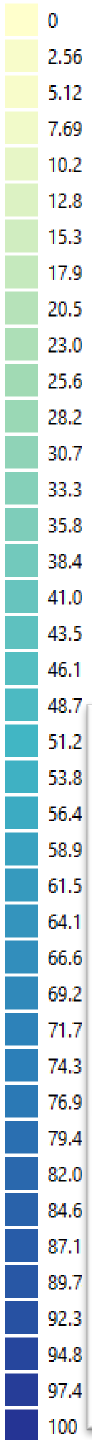
Towards time-varying water cover

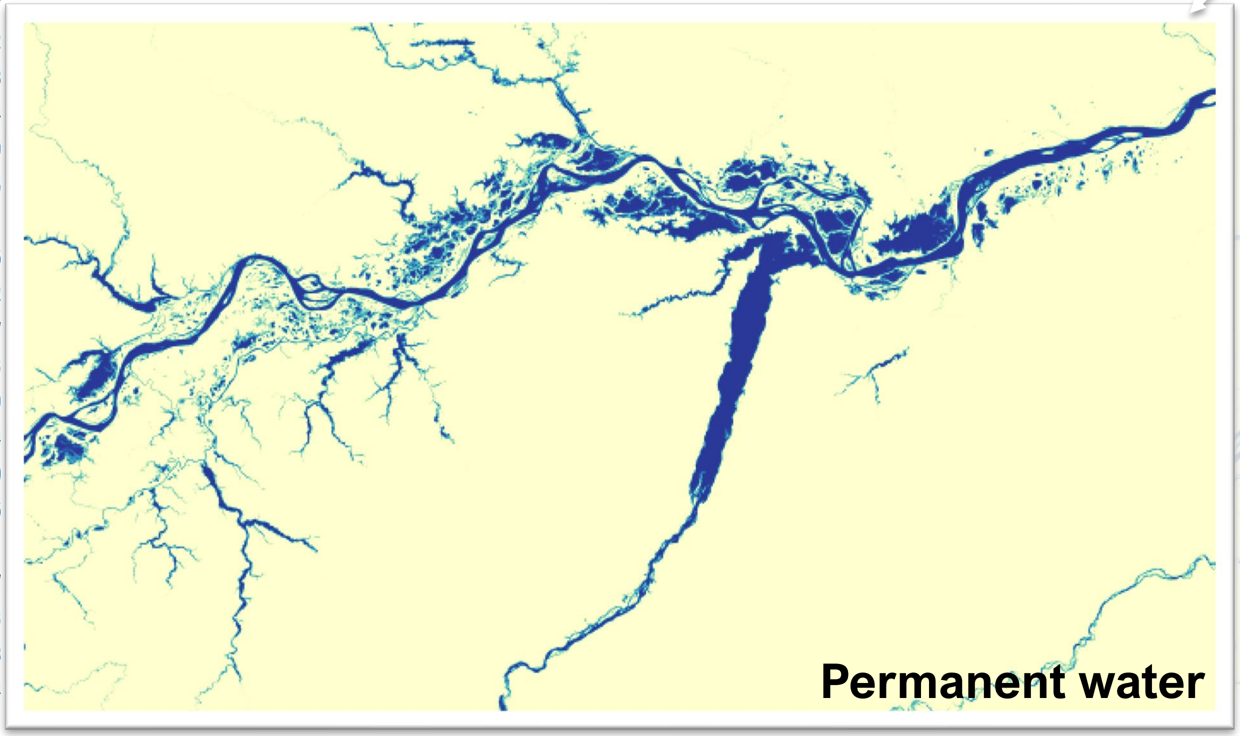
Margarita Choulga et al.

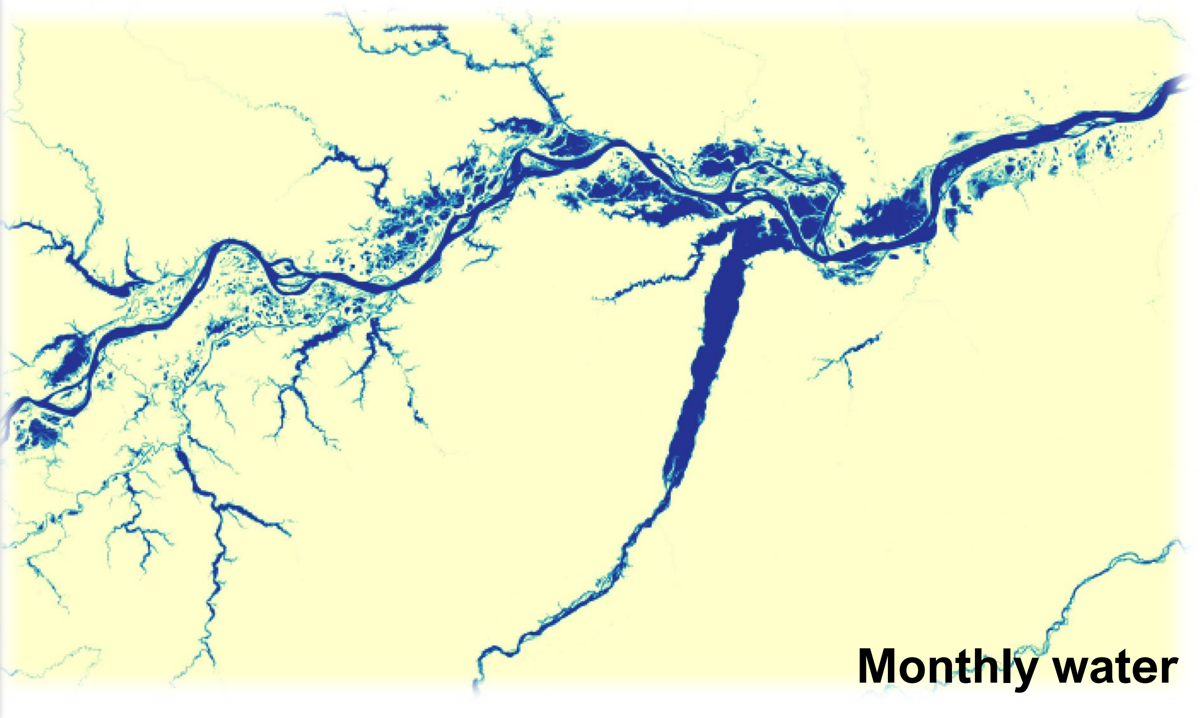
Monthly water distribution based on 2010-2020 monthly **30 m resolution** maps **represent** water year cycle more **realistic** than static yearly map → step **towards dynamic inundation model** (CAMA-Flood).

Similar work is ongoing for the Wetland & Rice fractions.

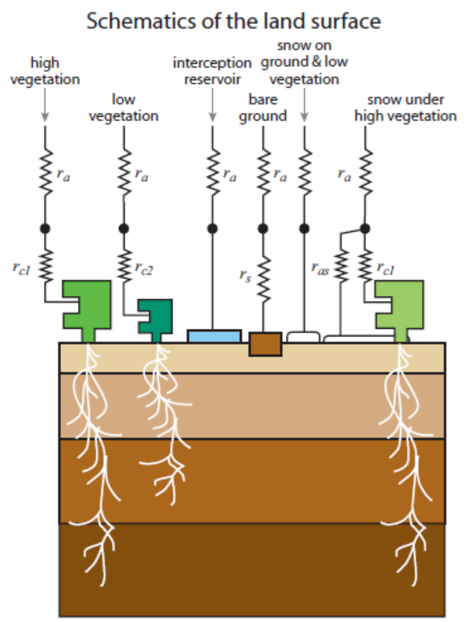
Example: Water fraction in **Amazon river** at **1 km resolution**.

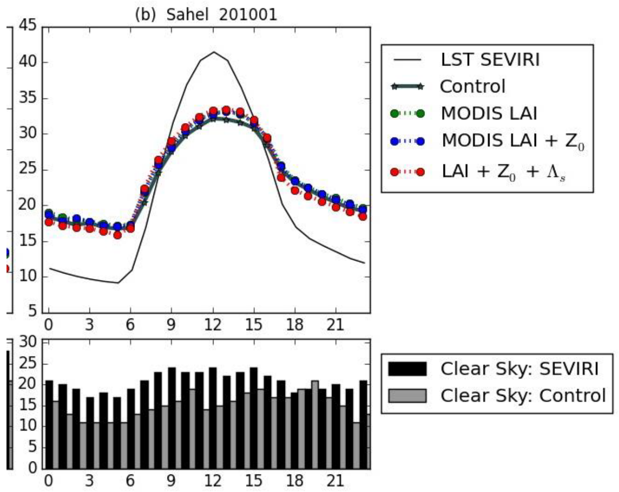


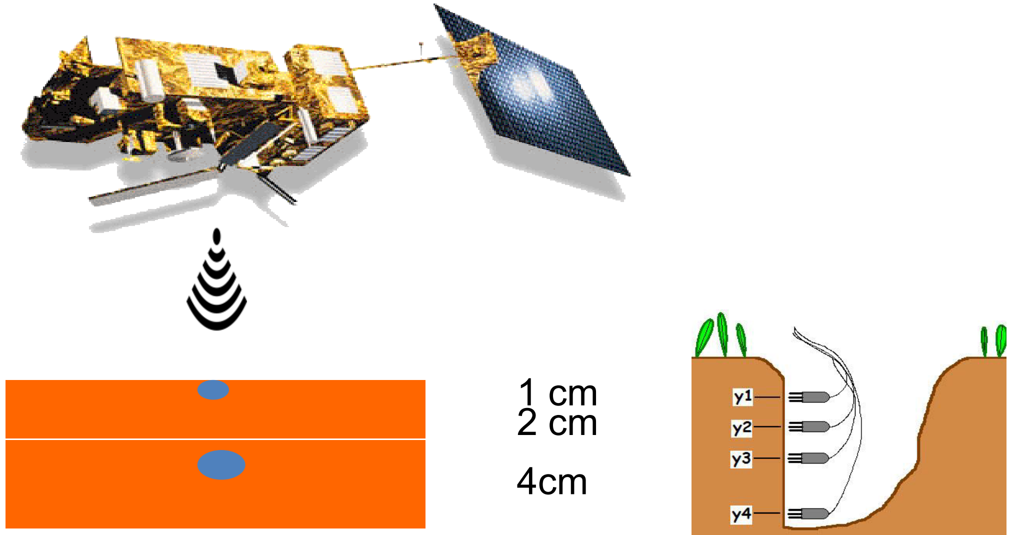




Vertical Soil discretization







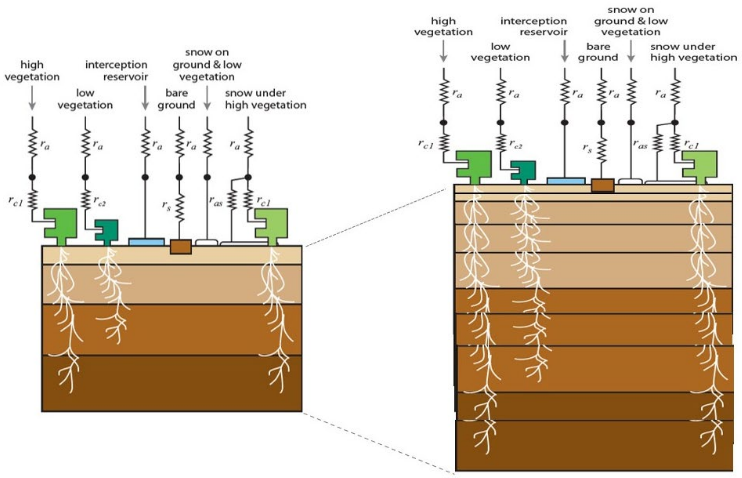
Thinner surface layers

The model underestimate Tskin diurnal cycle amplitude (*Trigo et al. 2015)*

vertical discretization would improve the match with Observation

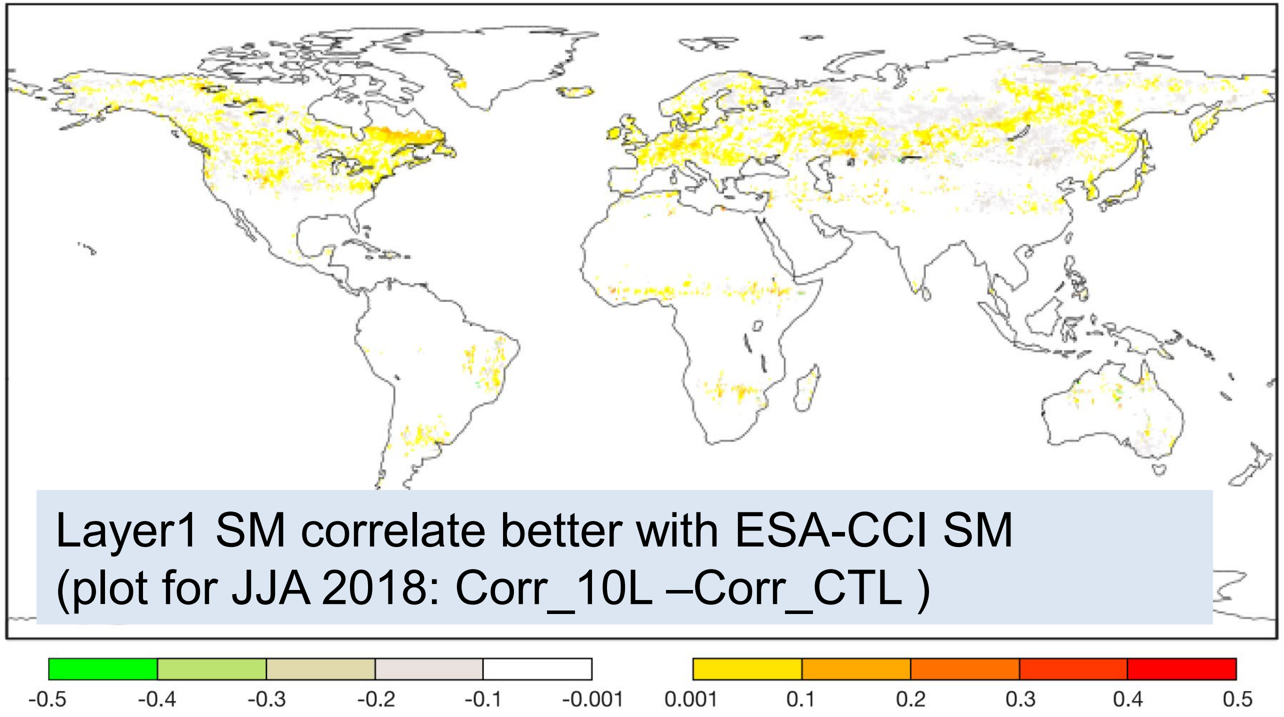
Dirmeyer et al. 2021, also showed the importance of an accurate SM representation for a proper L-A feedback that could simulate drought such us the European 2018 one

Extending the soil discretization



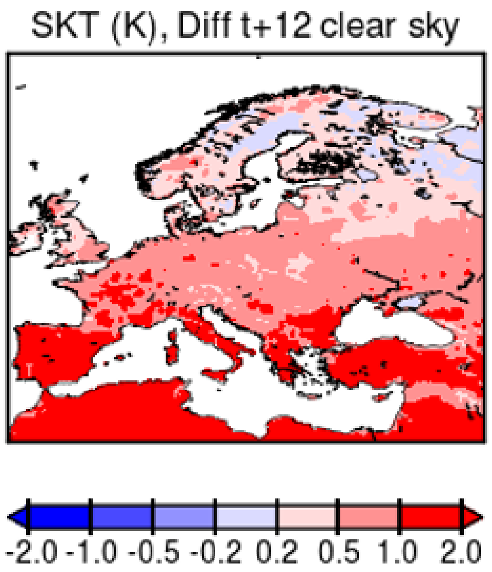
4 Layers: 2.89m

10 Layers: 8m

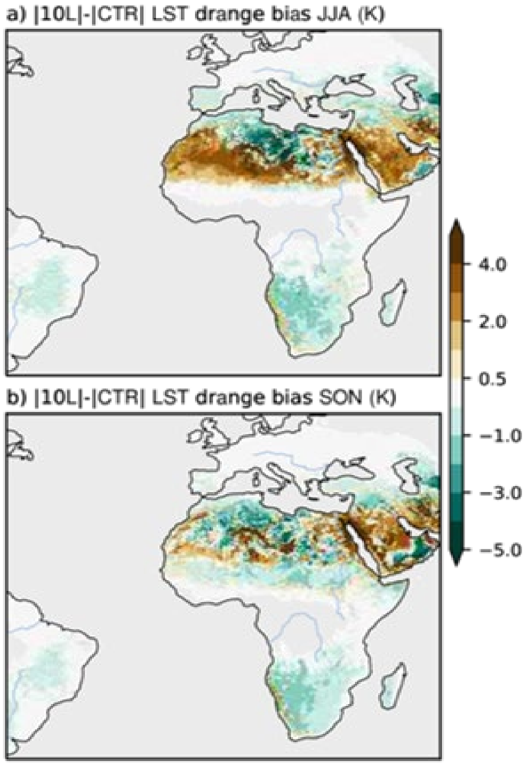


Layer1 SM correlate better with ESA-CCI SM
(plot for JJA 2018: Corr_10L –Corr_CTL)

Mean JJA difference of Tskin diurnal cycle amplitude
10L-control, JJA, clear sky



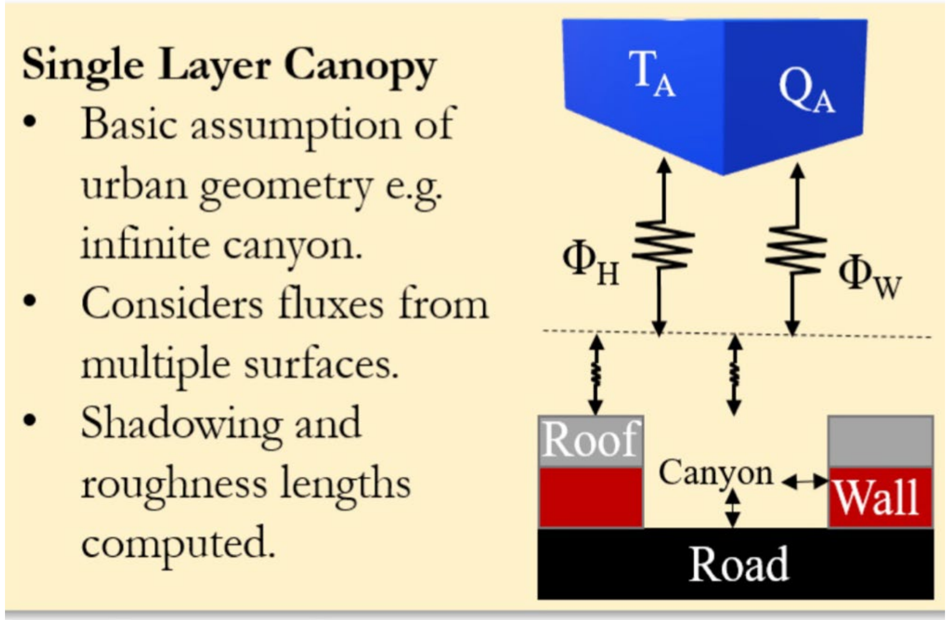
Bias difference in Tskin amplitude with Land-SAF LST

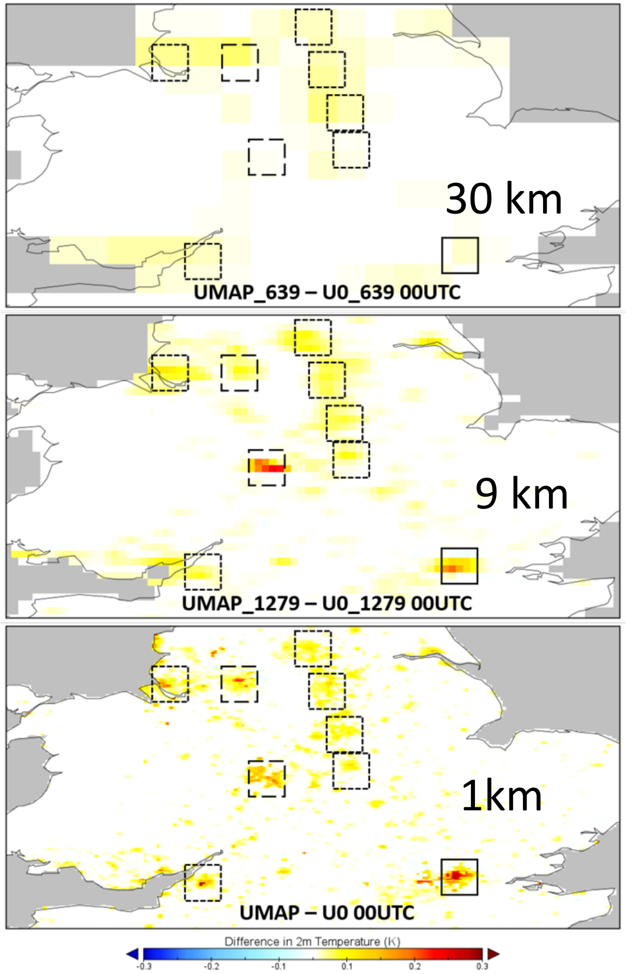


Increased Tskin amplitude and better match with Land-SAF LST ==> Foreseen better interaction with the atmosphere , with need for special care to the water budget and hydrological scores as groundwater table is not yet represented

An NWP high resolution-oriented parametrization: Urban model

Single layer canopy urban model type is adapted for NWP applications





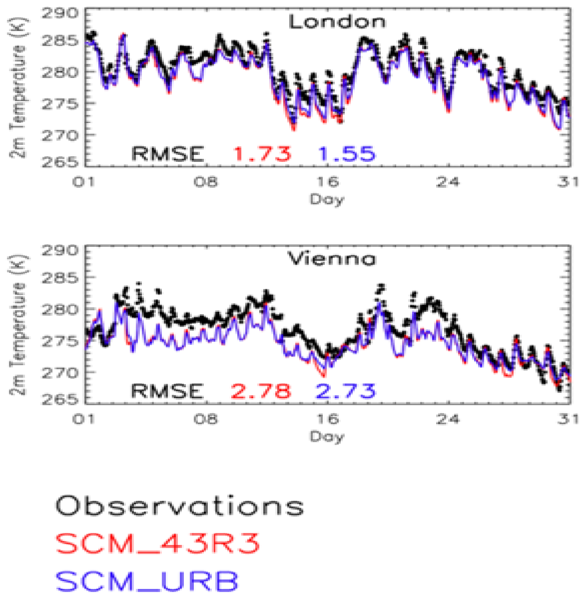
Monthly mean 2m temperature difference between urban and control runs for central UK at 0 UTC January 2019.

Boxes indicates conurbations larger than1000km2(solid), 500km2(dashed) and100km2(dotted)

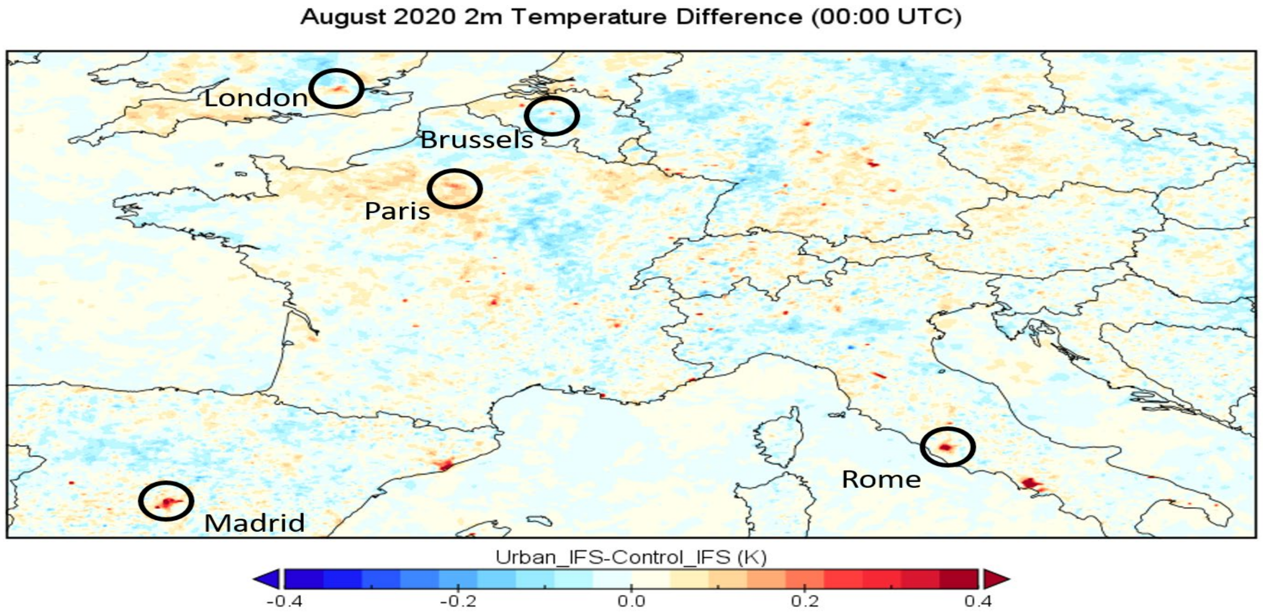
ECMWF

The urban tile locally enhance heatwave in cities future cycle (49r1)

Coupled Forecast simulations



T2m from urban sites for January 2012 (black circles). Urban (blue) no-urban (red).
Numbers indicate RMSE values when compared to observations



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

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

Urban tile integrated in ECLand, foreseen for activation in cycle 49r1

ECMWF

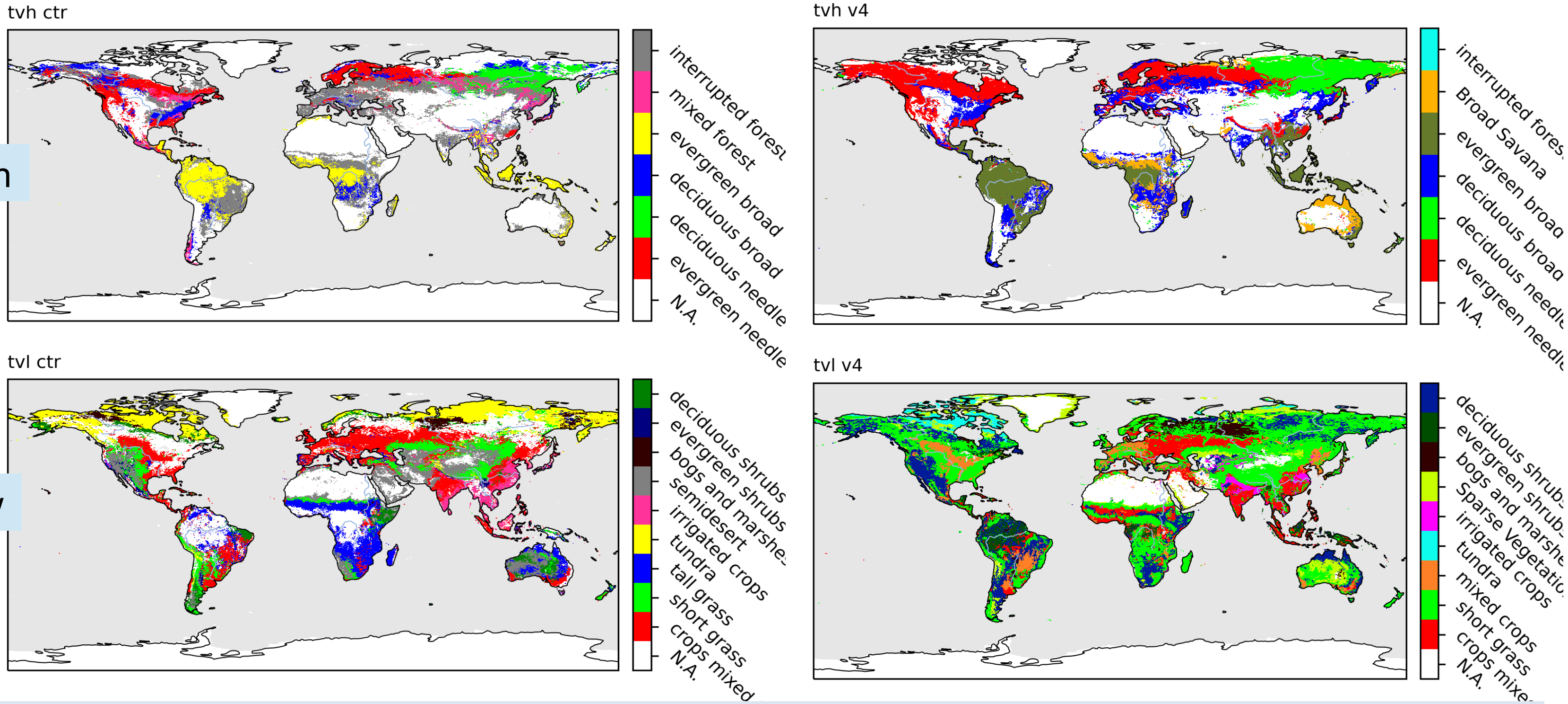
Changes in the land use land cover maps based on the C3S/ESACCI products

High

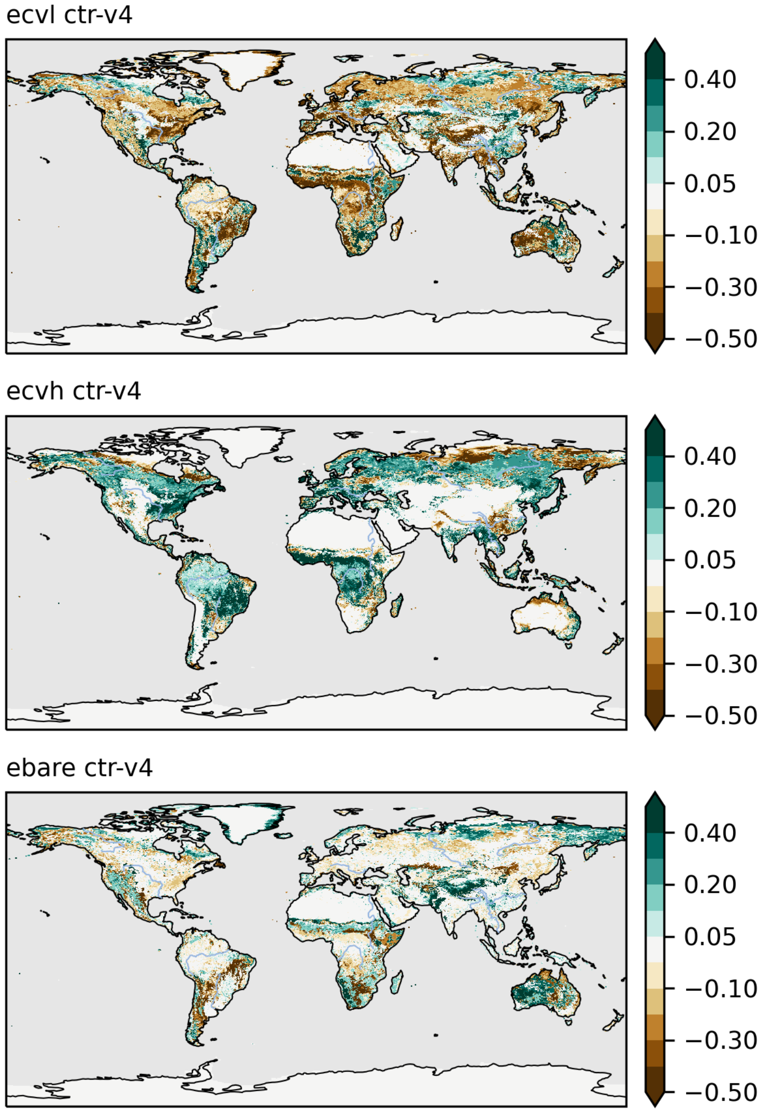
Low

Operational GLCCv1.2 Vegetation Types

New ESACCI-V4 Vegetation Types



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



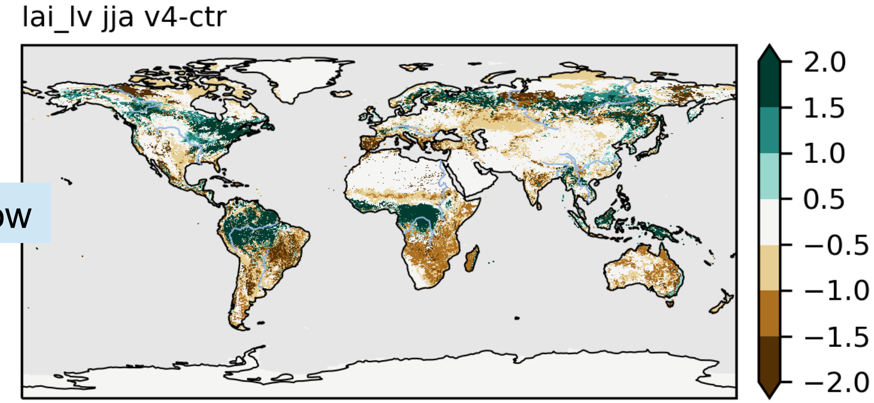
- ESACCI LU/LC–ECMWF BATS classification cross-walking table (CWT) evolution from v0 to v4 attempting to improve scores (initially in 2T/2D).
- Compared to current operational (GLCCv1.2) maps, the introduction of ESA-CCI maps is characterised by a decrease in the high vegetation cover and an increase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

ECMWF

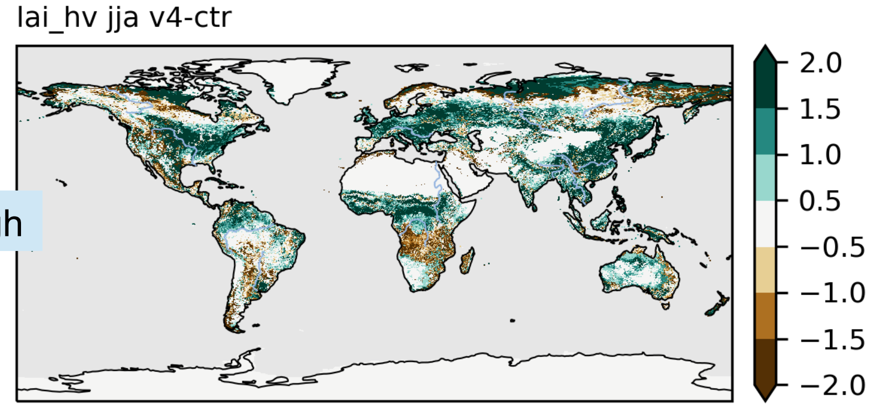
Changes in the LAI maps (C3S/CGLS) and the disaggregation operator

LAI difference for JJA (V4 – CTR)

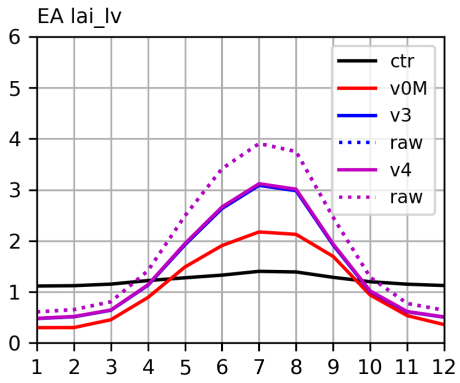
Low

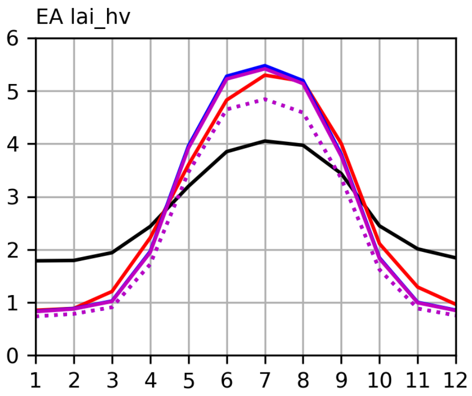


High

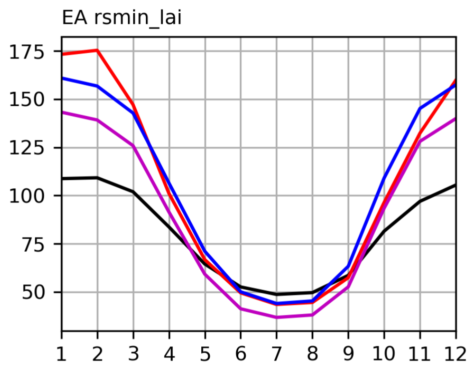


LAI seasonal cycle for East America (EA)





Minimum stomatal resistance scaled by the LAI for EA

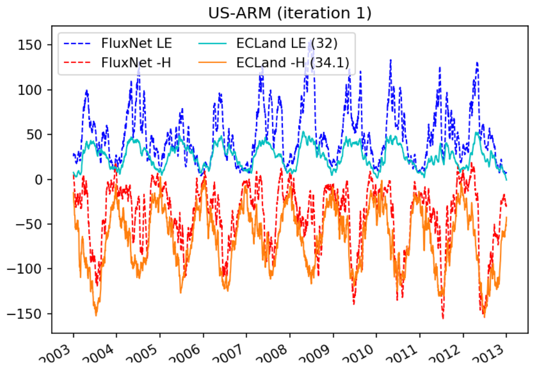


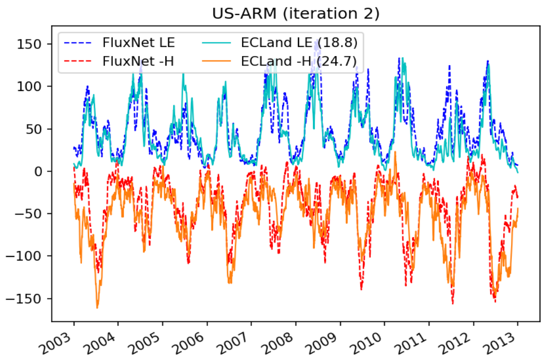
	ctr	v0M	v3	v4
cvl	0.15	0.50	0.47	0.47
cvh	0.83	0.42	0.47	0.47
ecvl	0.14	0.44	0.41	0.41
ecvh	0.74	0.38	0.42	0.42
ebare	0.12	0.18	0.17	0.17
rLDJF	107.78	169.46	158.38	140.78
rLJJA	50.27	45.81	46.42	38.65

- The new disaggregation operator brings more realistic seasonality (in-line with the satellite OBS) which results in an overall increase in the canopy resistance during winter and spring.
- Some regions are characterised by a strong decrease in LAI for both high and low vegetation (Iberia, Central Africa, East Brazil) where the model struggle to give the "right" evapotranspiration (as parameters change would impact other areas)

Does improved vegetation data lead to better prediction?

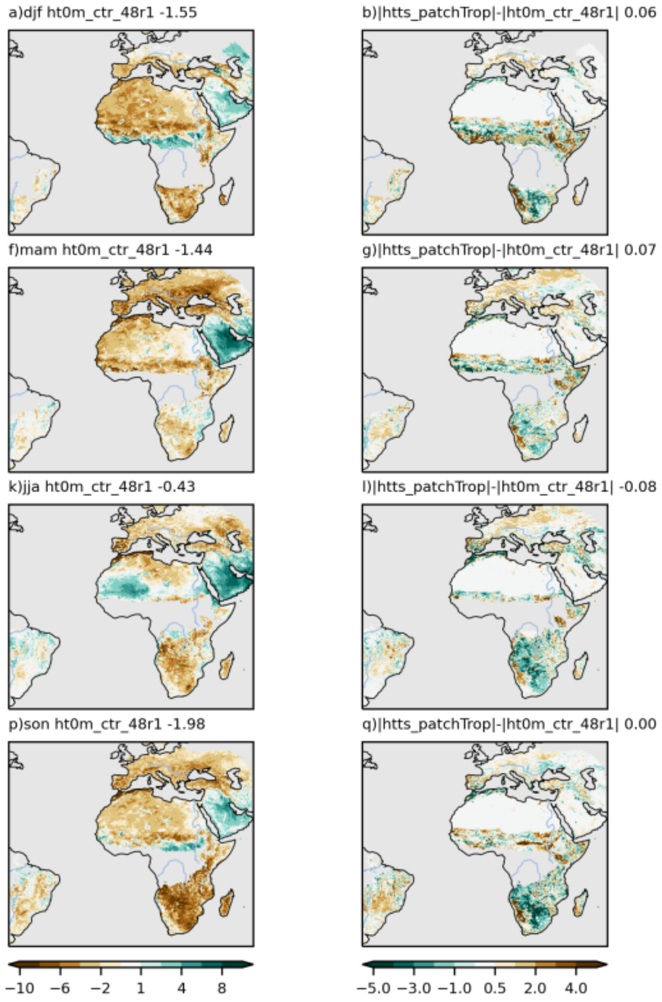
Point optimization with the OSM based on a simplified version Broyden-Fletcher-Goldfarb-Shanno heuristic minimization algorithm.





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

Global evaluation with satellite based LST

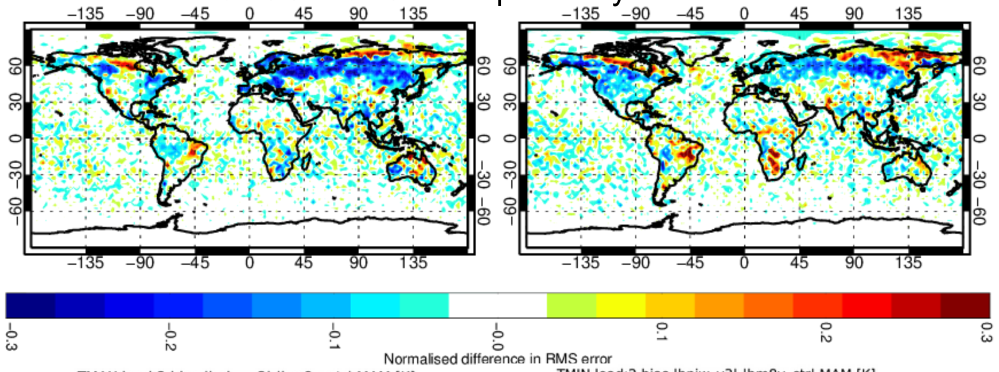


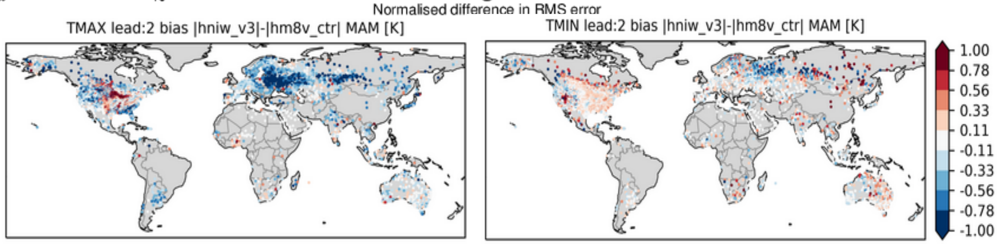
CTR LST bias

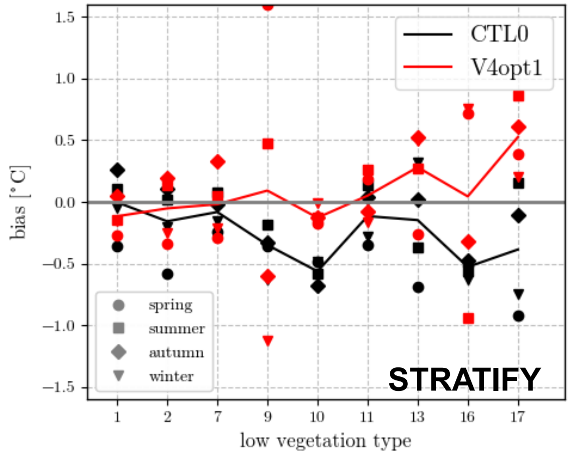
LST abs bias difference

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





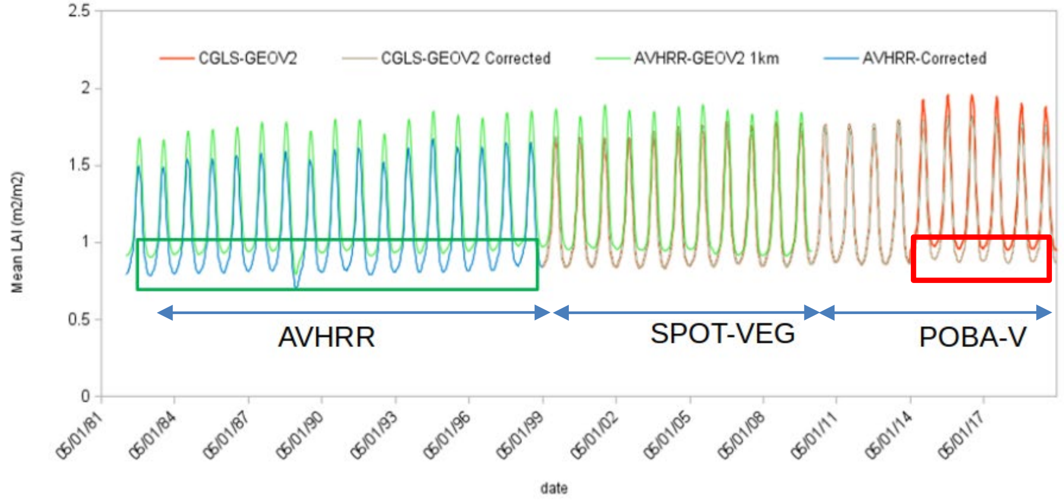


Low vegetation 2m temperature bias stratified by type for the operational system (black) and forecasts experiments based on the new v4 LULC/LAI maps (red) for 2019

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. ..)

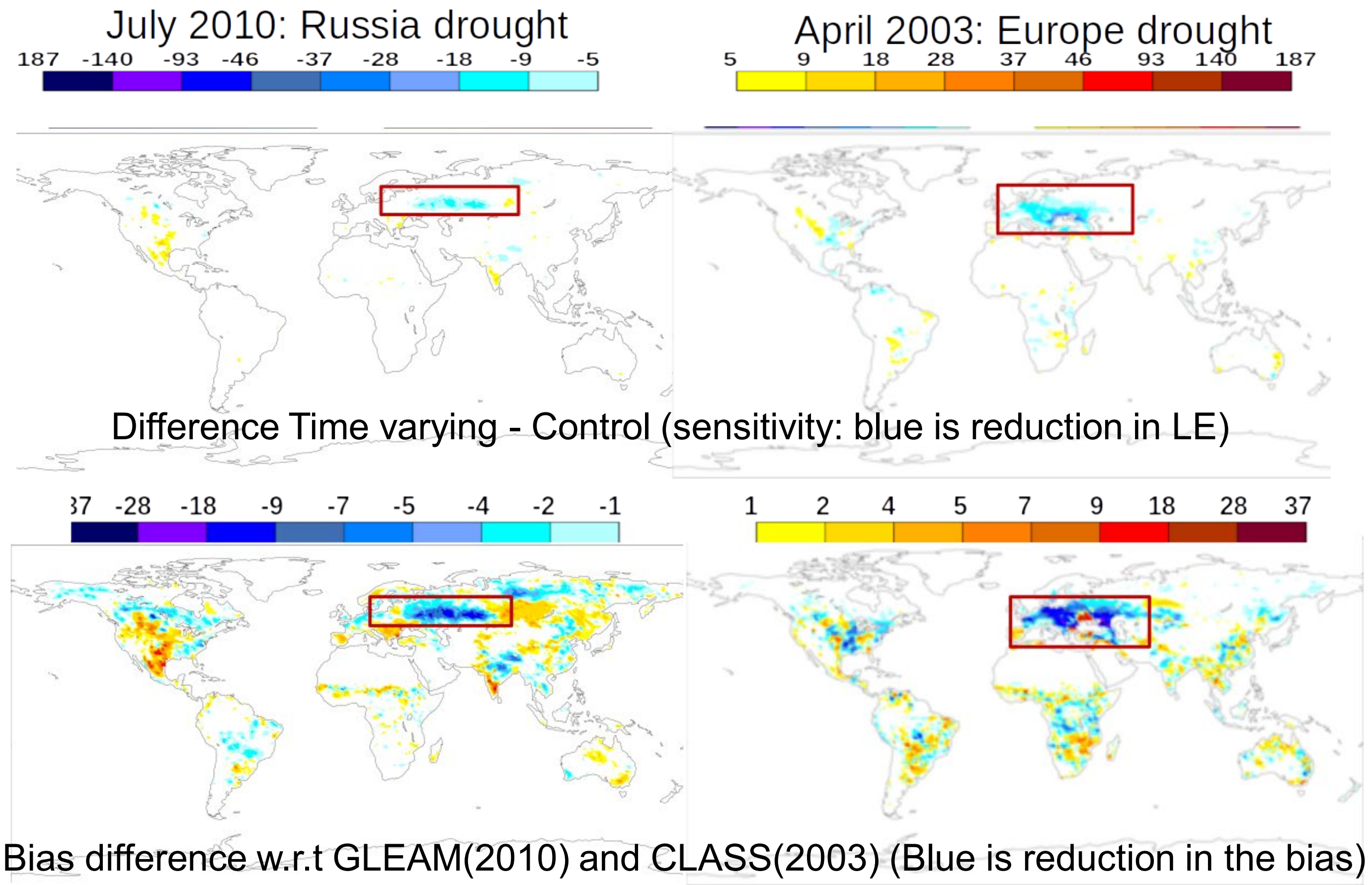
Towards time-varying vegetation for reanalysis

Implementation under the offline surface suite for CONFESS



Harmonized multi-source LAI data for a consistent high resolution 1993-2019 time series.

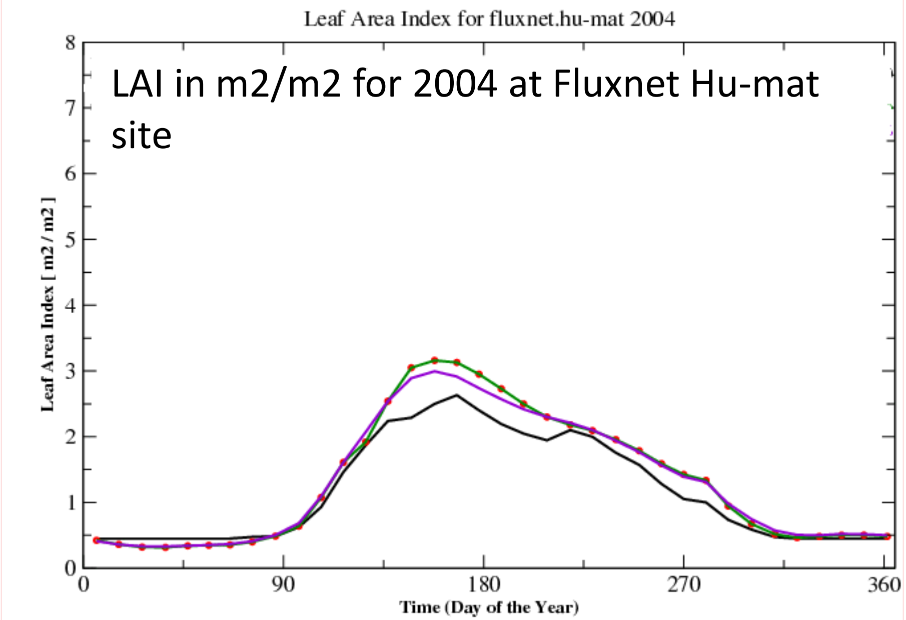
Extreme event evaluation: Latent heat flux (LE)



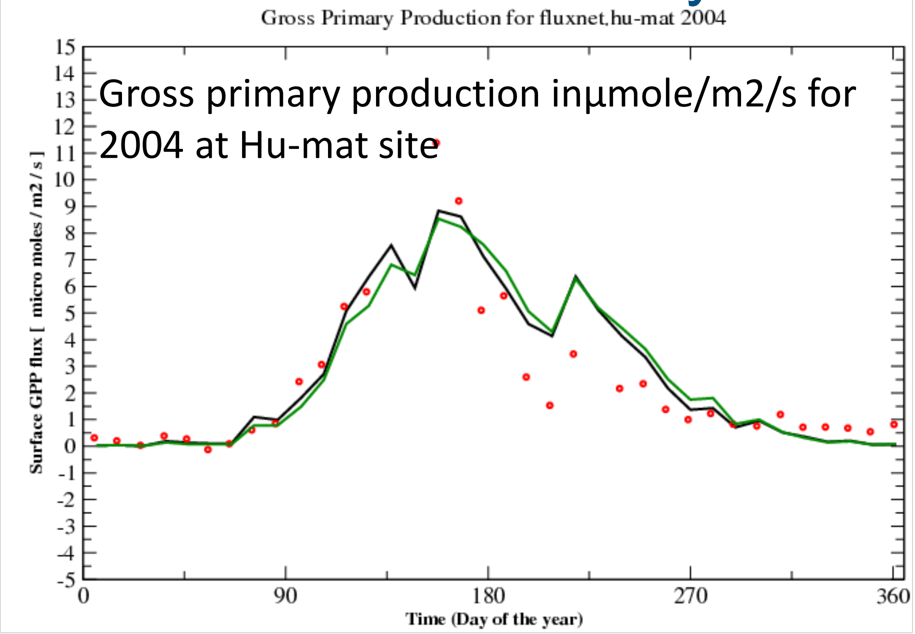
+ The IAV simulations could detect a reduction in LE of the order of 5-30 Wm-2
+ Comparison with CLASS (Hobeichi et al. 2020) and GLEAM (Martins et al. 2017) latent heat flux data shows up to 18 Wm-2 reduction in the bias when using the IAV vegetation data

=> Potential for next land reanalysis.

Towards a prognostic Leaf Area Index to represent inter-annual variability

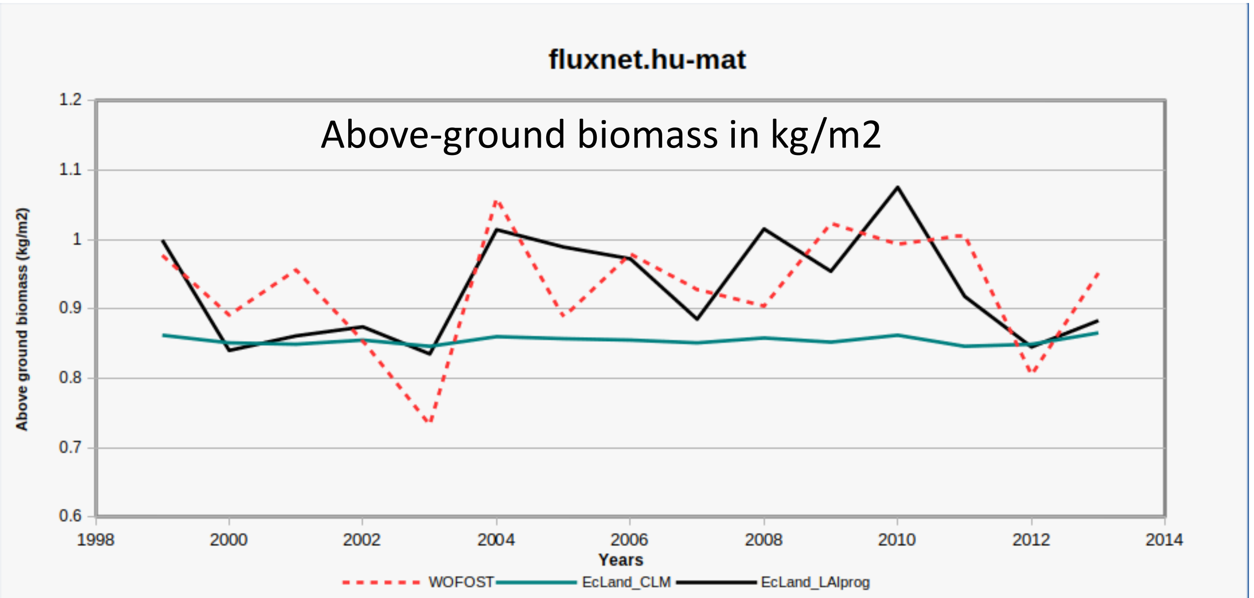


NRT obs(green with red dots) , climatology(purple), prognostic (black)



Obs (red dots), with prescribed LAI(green), with prognostic LAI (black)

WOFOST (red), ECLand with climatological LAI (green) and ECLand with prognostic LAI (black)

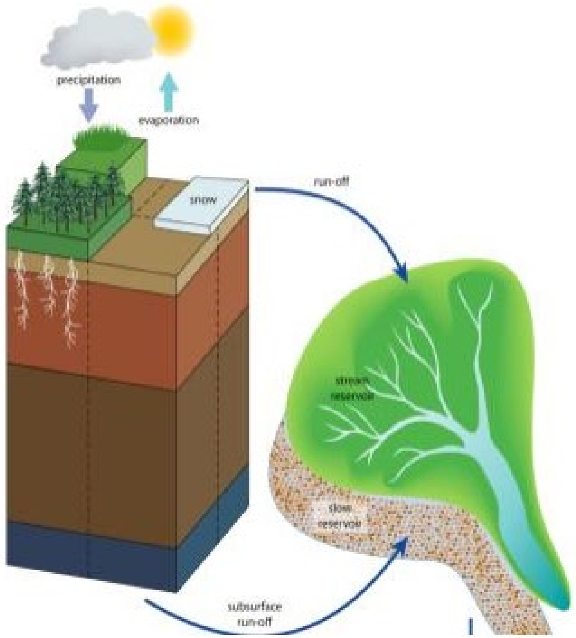


The model is able to reasonably simulate LAI and predict comparable Above-ground biomass with the JRC WOFOST products

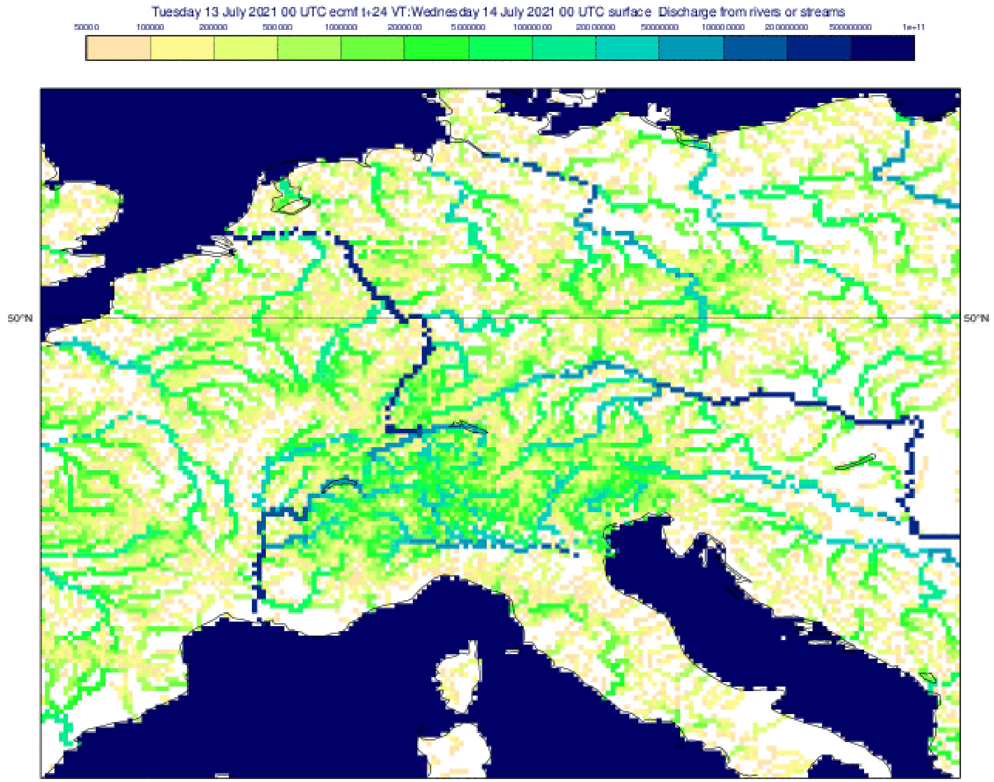
ECMWF

(Collaboration under ImagineS FP7 project)

Toward predicting floods & inundations along the IFS forecasts



ECLand + CaMA-Flood



		(Forecast days/day)	
Resolution	I/O	Control	Parallel
9km (HRES and ERA5Land)	hourly	102	2875
1km (VHRES)	daily	N/A	300

5-day Forecast for river discharge for the German flood of July 2021. DestinE extreme case TCo1279 48r1 forecast 1-way-coupled to a 6arcmin CaMA-Flood

(See additional details on hydrology simulations in Gabriele' talk)

Improved Efficiency: Technical development are as important to allow increased resolution and complexity

Land surface modelling: additional thoughts

- In big data Era and with computing time (r)evolution high resolution global model are becoming reality.
- With increased resolution ESMs will have to take into account additional layers of physical complexity such as:
  - better vertical representation for soil and snow,
  - vegetation interaction with snow/frozen soil,
  - surface- atmosphere coupling and link with satellite LST
  - better CO_2/evapo-transpiration coupled processes with link to satellite fluorescence observation
  - realistic vegetation dynamics for accurate representation of surface fluxes and better atmospheric predictability.
  - Enhanced connections between albedo, LAI, vegetation cover (and roughness) in Earth System Models (ESMs) will most likely increase the sensitivity to vegetation dynamics.
  - Including anthropogenic effects (Irrigation, crops, LU management..)
  - Modularity with application oriented outputs is one way to tackle the increase in complexity.

- With increased surface related satellite observation/products there are potentials for further improvements linked with land surface of NWP systems but also climate simulations and reanalysis
  - better initialisation
  - better process description
  - possibility to better tune non-observable model parameters.

- ML/AI are more affordable with better perspectives for process understanding