Towards including anthropogenic surfaces in ECMWF model: challenge for global EO datasets

Modelling or mapping challenge?

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Joaquin Munoz-Sabater, Patricia de Rosnay, Irina Sandu, Nils Wedi, and others

Agricultural land, forest, lakes and rivers are all daily to seasonally managed especially in densely populated area and are exposed to long term changes due to climate-change and societal-pressure forcing, all affecting local whether for key forecasts variables such as near surface temperature. Moreover urban areas are also modifying the diurnal energy and water cycle, exacerbating the impact of extreme events such as heat-waves and flash floods. While coordinated modelling efforts indicate that simple to medium-complexity schemes may represent the main aspects of those surface processes in models, the lack of coordinated activities on the driving EO datasets and their internal consistency is posing a sizeable challenge for including more of the anthropogenic influence in global numerical weather prediction. This talk will cover current efforts to revise EO surface datasets at ECMWF and plans to enhance the use of satellite (eg. skin temperatures) data to validate Earth surface representation.

ECMWF

Rationale of talk

- Introduction
  - Current status of the ECMWF land surface modelling
  - Needs for representing land-use-chance & non-natural surfaces
- The case for water bodies
  - modelling challenge for input parameters or parameterisation?
- Irrigation
  - Can potential/actual evaporation and irrigation maps be used to simulate irrigation?
- Urban areas and land use change
  - What is the urban fraction? How can we represent LUC? Can we use EO data?
- Conclusion and outlook

HTESSEL land surface model at ECMWF (2016-2017)

- **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

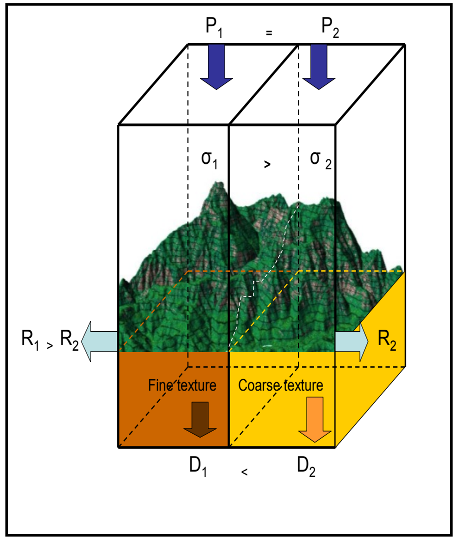
- **NEW LAI**
  - Boussetta et al. (2013)
  - New satellite-based
  - Leaf-Area-Index

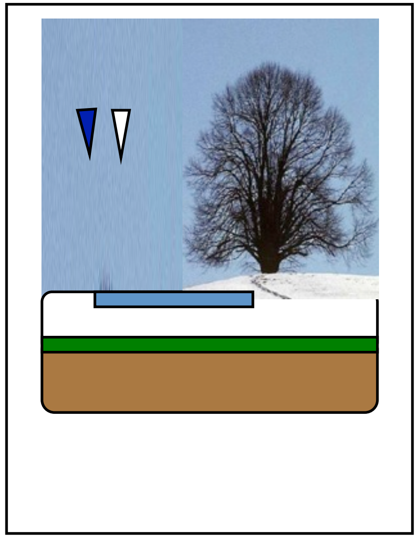
- **SOIL Evaporation**
  - Balsamo et al. (2011),
  - Albergel et al. (2012)

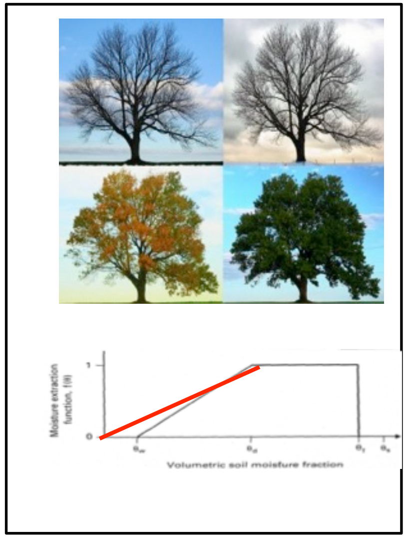
- **H_2O / E / CO_2**
  - Integration of
  - Carbon/Energy/Water
  - Boussetta et al. 2013
  - Agusti-Panareda et al. 2015

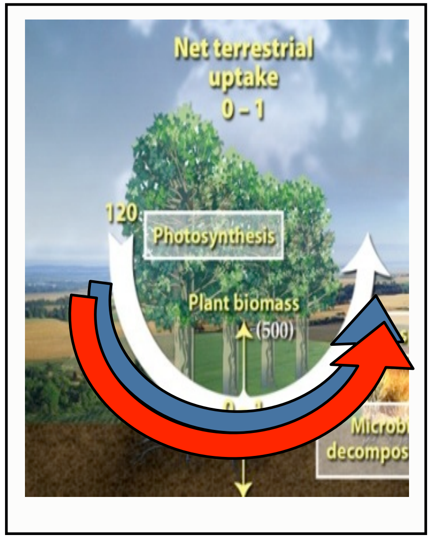
- **Lake & Coastal area**
  - Mironov et al (2010),
  - Dutra et al. (2010),
  - Balsamo et al. (2012, 2010)
  - Extra tile (9) to for sub-grid lakes and ice
  - LW tiling (Dutra)

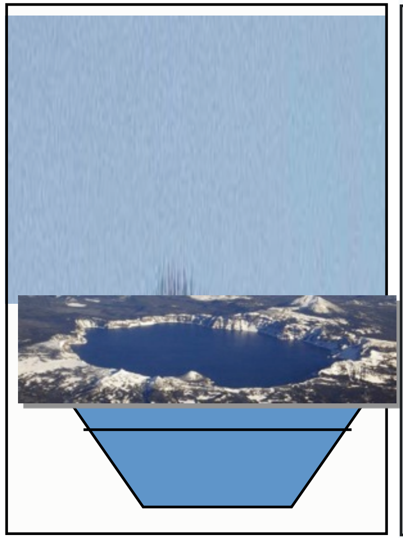
- **Enhance ML**
  - Snow ML5
  - Soil ML9
  - Dutra et al. (2012, 2016)
  - Balsamo et al. (2016)

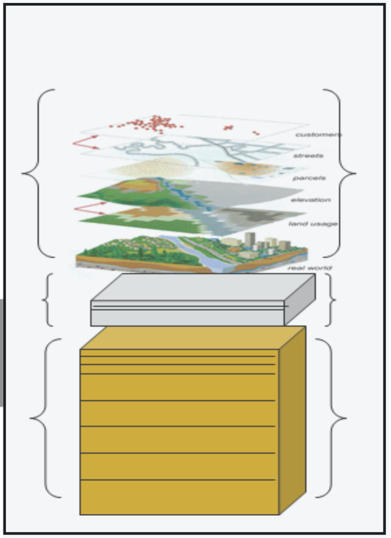












HTESSEL tiling concept to represent sub-grid variability

The tile scheme allows for a simple representation of surface heterogeneity.

HTESSEL

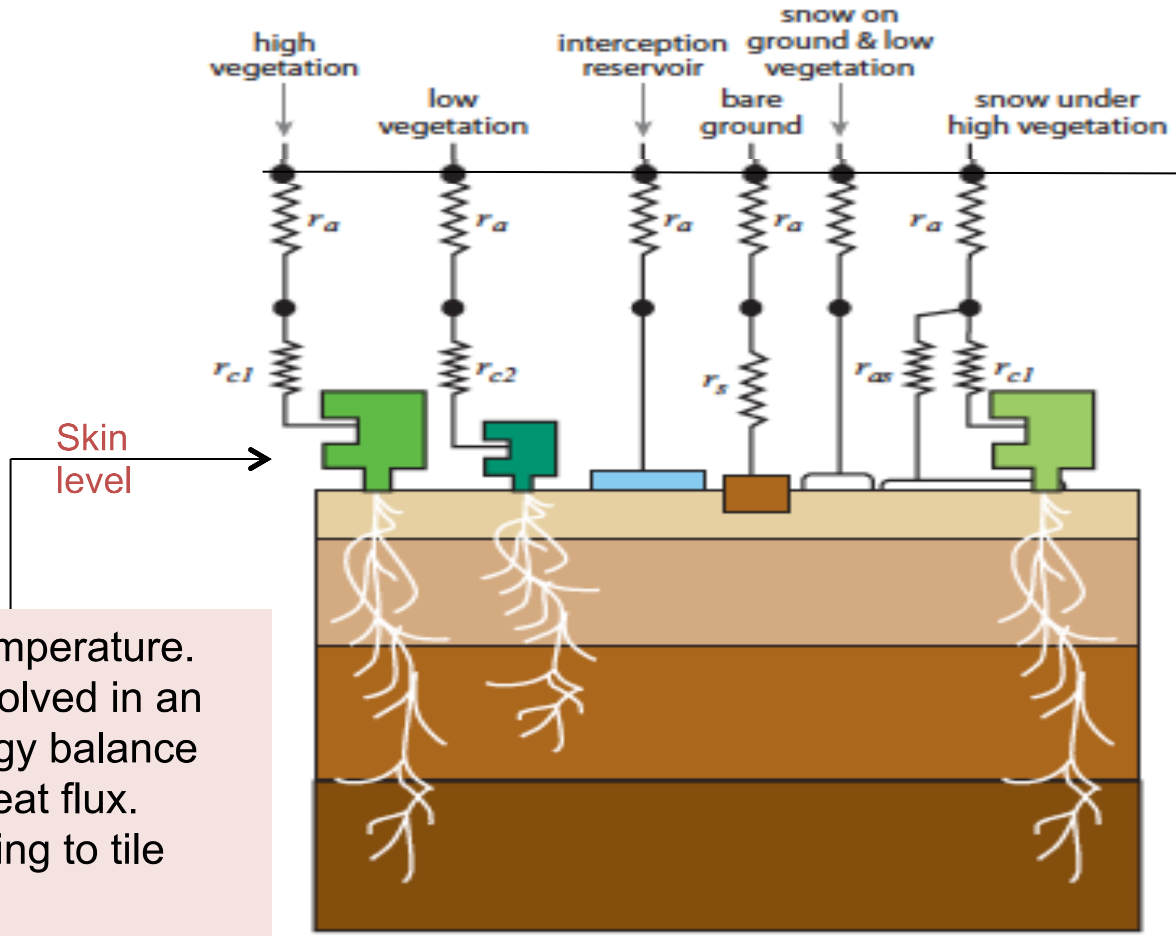
Hydrology - Tiled ECMWF

Scheme for Surface Exchanges over Land

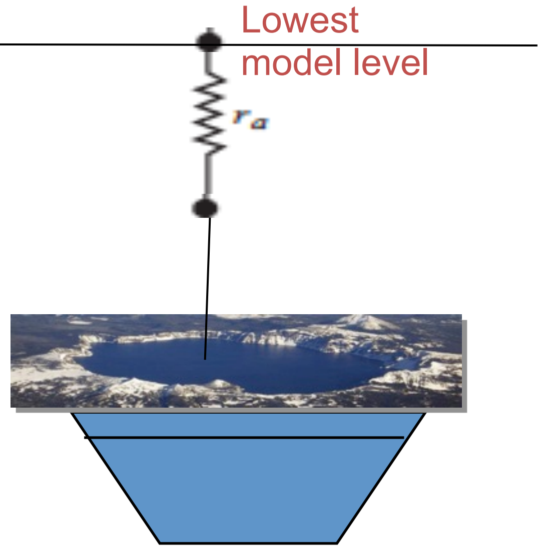
+

FLAKE (DWD-version)

Fresh water Lake scheme



Each tile has its own skin temperature. The skin temperatures are solved in an Penman-Monteith type energy balance equation including ground heat flux. Fluxes are averaged according to tile fraction



Extra tile for FLAKE model

Mironov et al (2010),

Balsamo et al. (2010, 2012, 2013) Dutra et al. ()

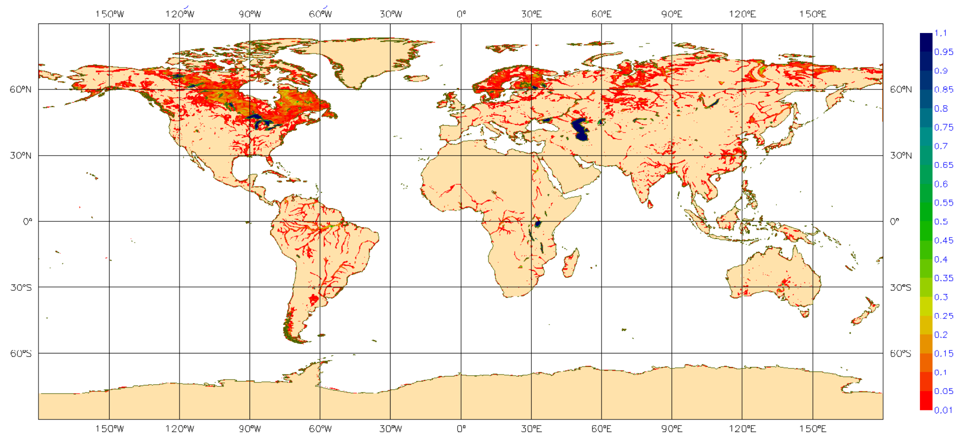
HTESSEL driving datasets and derived properties

- GLOBCOVER land-sea mask and lake cover
- GLCC vegetation data with 4 fixed fields:
  - Low vegetation cover
  - High vegetation cover
  - Low vegetation type (10 types)
  - High vegetation type (6 types)
- MODIS (c5) Albedo (4-bands) monthly climatology
- MODIS (c5) Leaf Area Index (LAI) monthly climatology
- FAO Soil texture climatology for assigning van Genuchten (1980) hydraulic parameters
- Interception reservoir scales with LAI
- Vegetation-dependent canopy resistance based on Jarvis formulation with dependencies on:
  - Radiation
  - Soil moisture in root zone
  - Atmospheric water vapour deficit (for high vegetation only)
  - Seasonal LAI (divides stomatal resistance)
- Vegetation-type dependent parameters:
  - minimal stomatal resistance,
  - Roughness lengths for momentum and heat/moisture
  - Rooting depth
  - Thermal coupling coefficient between canopy and soil
- GLDB v1 lake depth dataset and ETOPO1 bathymetry

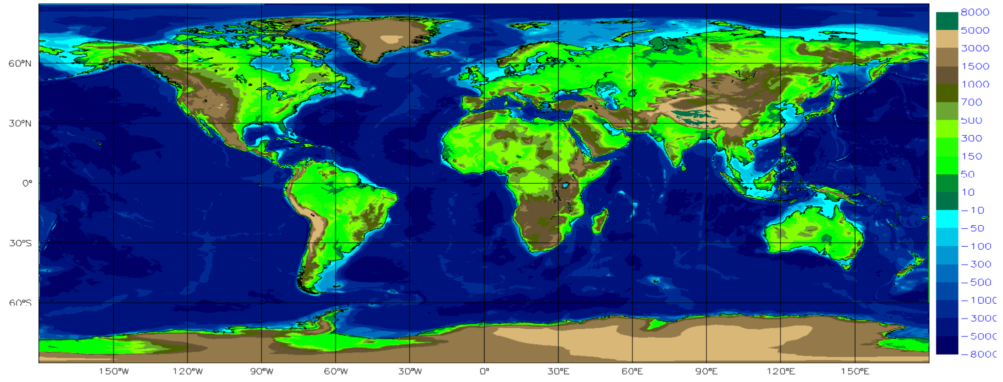
Global surface physiography description: e.g. Lake cover/depth

Sizeable fraction of land surface has sub-grid lakes: different radiative, thermal roughness characteristics compare to land → affect surface fluxes to the atmosphere

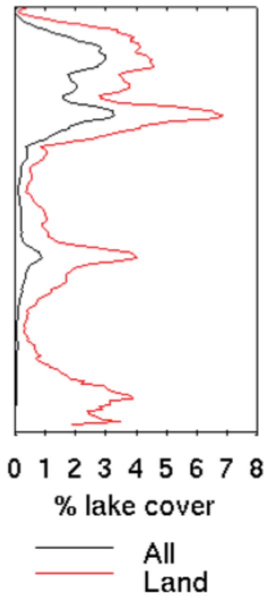
LAKE COVER FRACTION



LAKE & SEA BATHYMETRY / NEW OROGRAPHY



Nº Points 0.05< lake fraction<0.5



Canada	309/754 **41%**
USA	175/482 **36%**
Europe	170/385 **44%**
Siberia	104/467 **22%**
Amazon	81/629 **13%**
Africa	74/584

- Lake cover & lake bathymetry are among the surface important fields to describe size and volume of the water bodies that are associated to thermal inertia. Physiography has been completely revised in 40R3
- source: ESA-GlobCover/GLDBv1

Energy fluxes: diurnal cycle impact of lakes

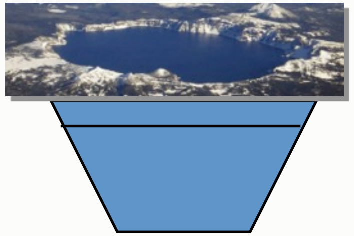
- **Lake tile**

Mironov et al (2010),

Dutra et al. (2010),

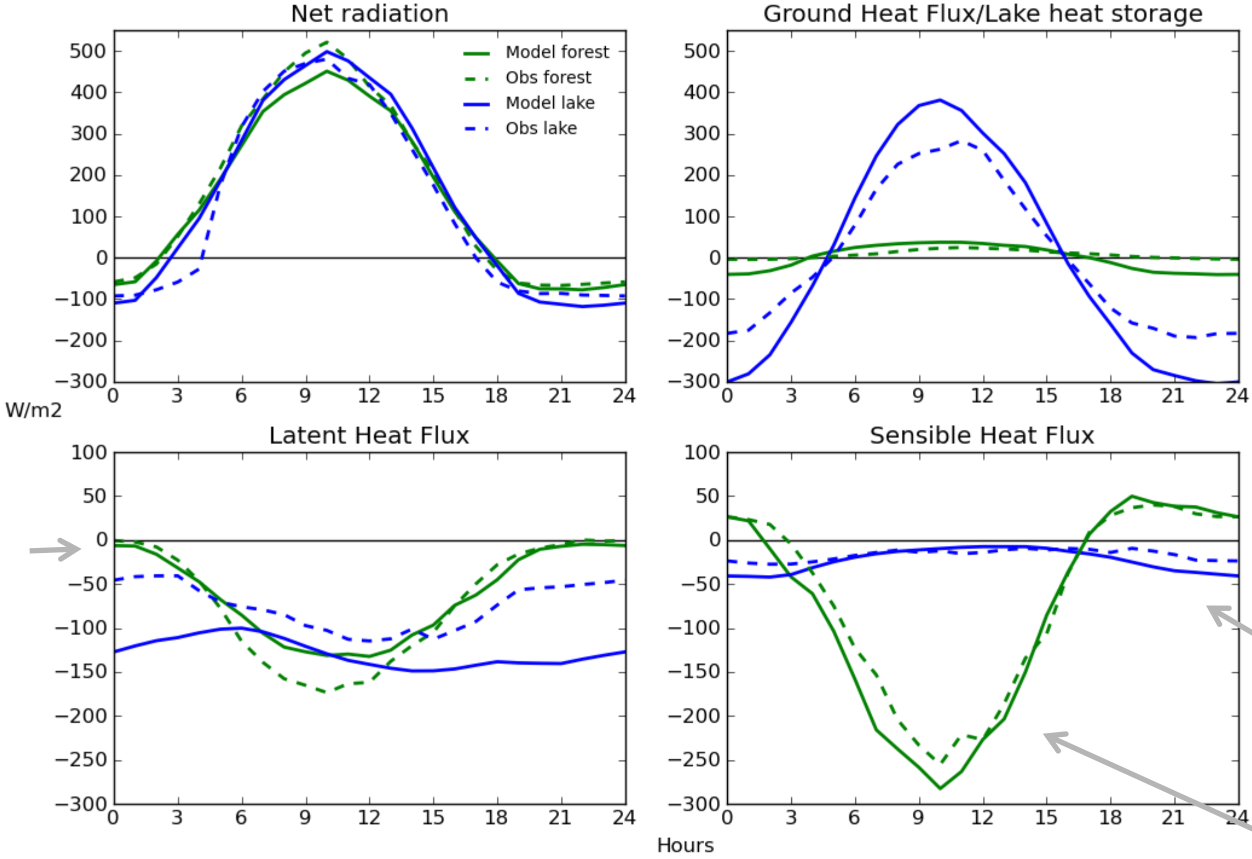
Balsamo et al. (2010, 2012, 2013)

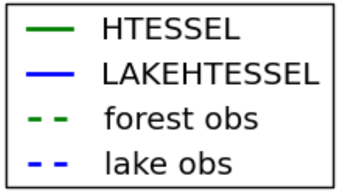
Extra tile (9) to account for sub-grid lakes



Manrique-Suñén et al. (2013, JHM)

Monthly diurnal cycle of energy fluxes for July





Very good representation by the model of diurnal cycles and particularities of each surface

Forest evaporation is driven by vegetation, so it is zero at night

Lake LH diurnal cycle: over-estimation in evaporation

Lake SH maximum is at night

Forest SH maximum is at midday

Main difference between lake & forest sites is found in energy partitioning

ECMWF

Lake surface temperature verification using satellites

JJA 2015 (91-days AN vs OSTIA-lake)

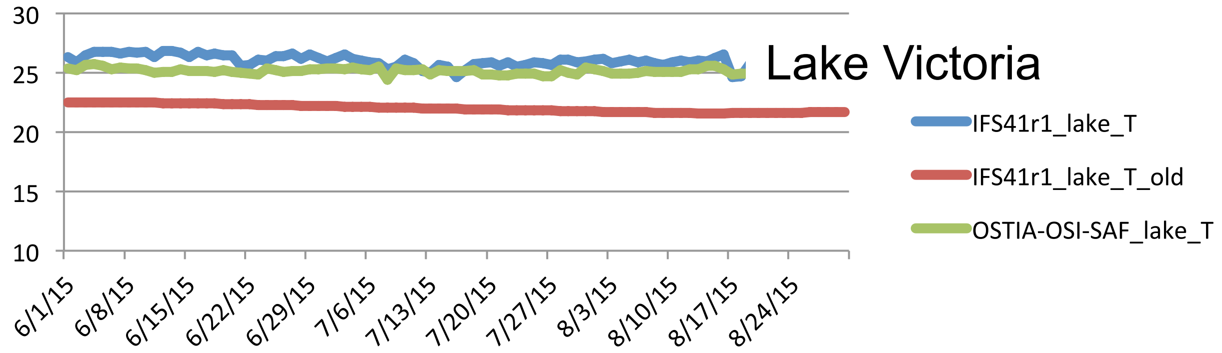
Lake AFRICA	RMSE	BIAS	Correlation	Mean Model	Mean Obs	Stdev Model	Stdev Obs
Victoria_IFS41R1	0.957	0.826	0.491	25.665	24.849	0.554415	0.230933
Victoria_IFS40R1	3.157	-3.14	0.328	21.743	24.849	0.322463	0.230933

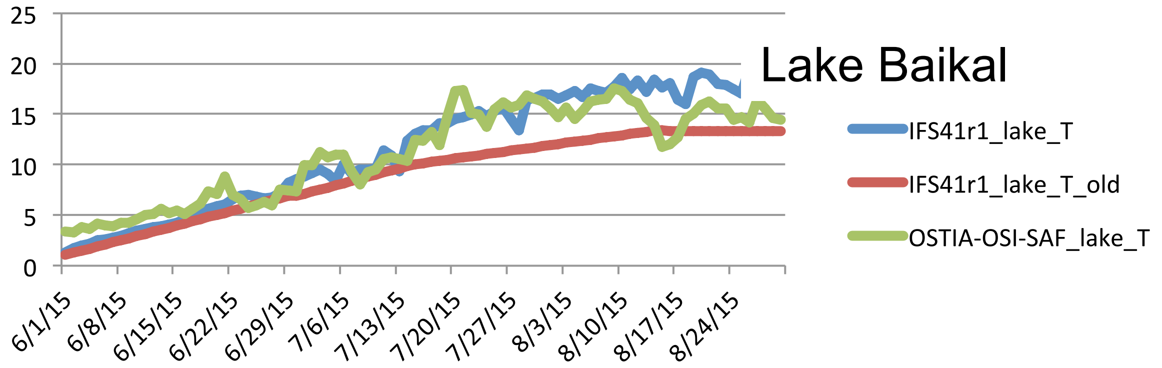
Lake CANADA	RMSE	BIAS	CORR	Mean Model	Mean Obs	Stdev Model	Stdev Obs
Great_Bear_IFS41R1	2.875	1.877	0.927	5.225	3.368	3.87317	1.96852
Great_Bear_IFS40R1	5.401	4.598	0.894	7.916	3.368	4.45394	1.96852

Lake S. AMERICA	RMSE	BIAS	CORR	Mean Model	Mean Obs	Stdev Model	Stdev Obs
Titicaca_IFS41R1	0.611	-0.425	0.822	12.322	12.742	0.739826	0.482809
Titicaca_IFS40R1	3.804	-3.789	0.752	8.995	12.742	0.463688	0.482809

Lake EU	RMSE	BIAS	CORR	Mean Model	Mean Obs	Stdev Model	Stdev Obs
Ladoga_IFS41R1	2.45	2.051	0.958	14.207	12.178	4.22985	4.60613
Ladoga_IFS40R1	1.443	-0.295	0.984	11.886	12.178	3.3881	4.60613

Lake sub-grid EU	RMSE	BIAS	CORR	Mean Model	Mean Obs	Stdev Model	Stdev Obs
Haukivesi_IFS41R1	1.706	-0.02	0.807	15.188	15.207	2.24239	2.88615
Haukivesi_IFS40R1	2.915	-2.733	0.964	12.504	15.207	3.44774	2.88615

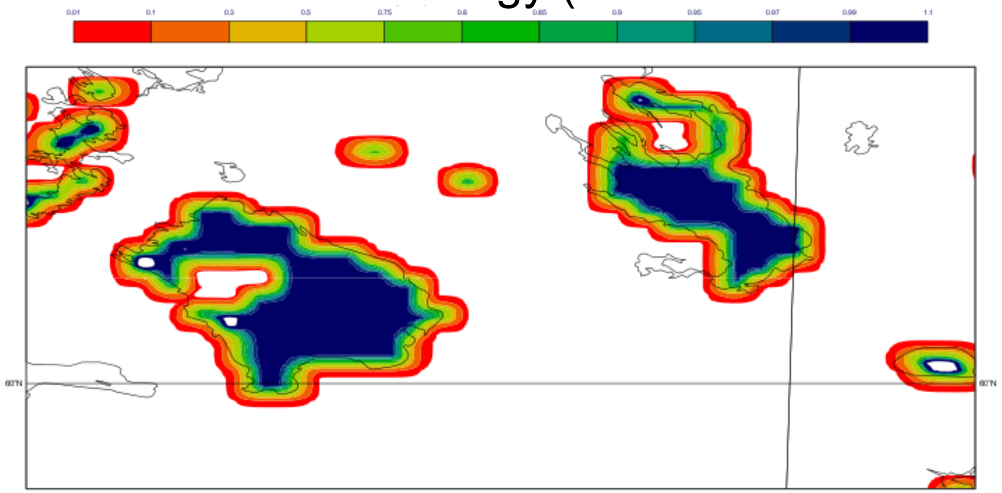




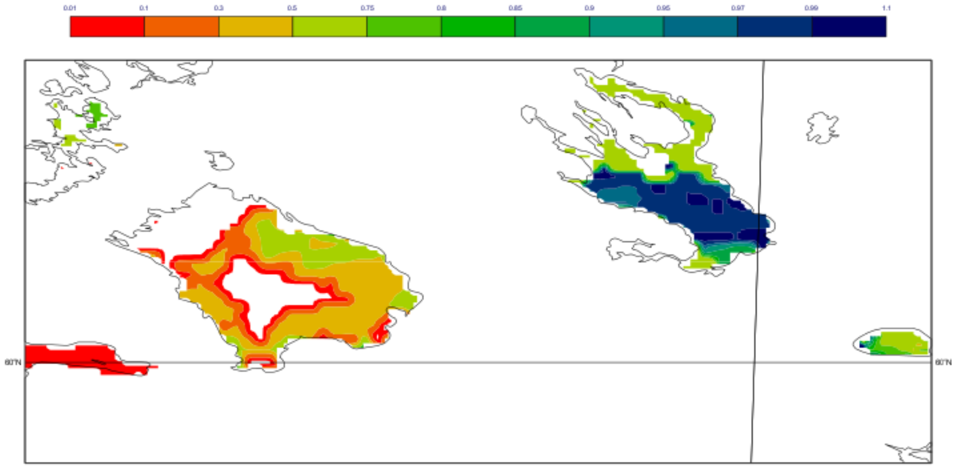
Improved representation of lake ice melting: Lakes Ladoga and Onega

Case Study of 18 April 2016:
The Largest European Lakes:
Lake Lagoda & Lake Onega
started to melt lake ice, with
Faster melting occurring in Ladoga

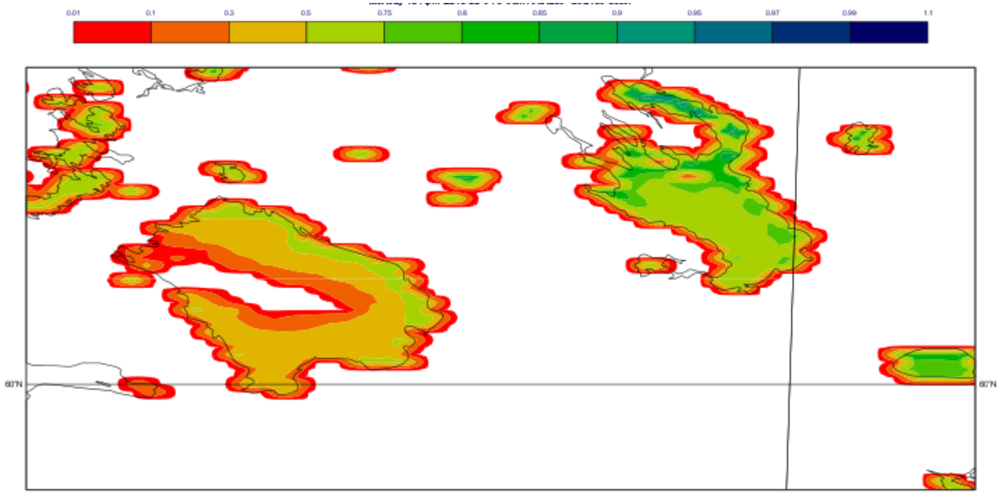
ECMWF Old model climatology (no difference in melting)



OSI-SAF Satellite Ice cover 18 April 2016:



ECMWF IFS Lake Ice Cover (Ladoga melting faster)



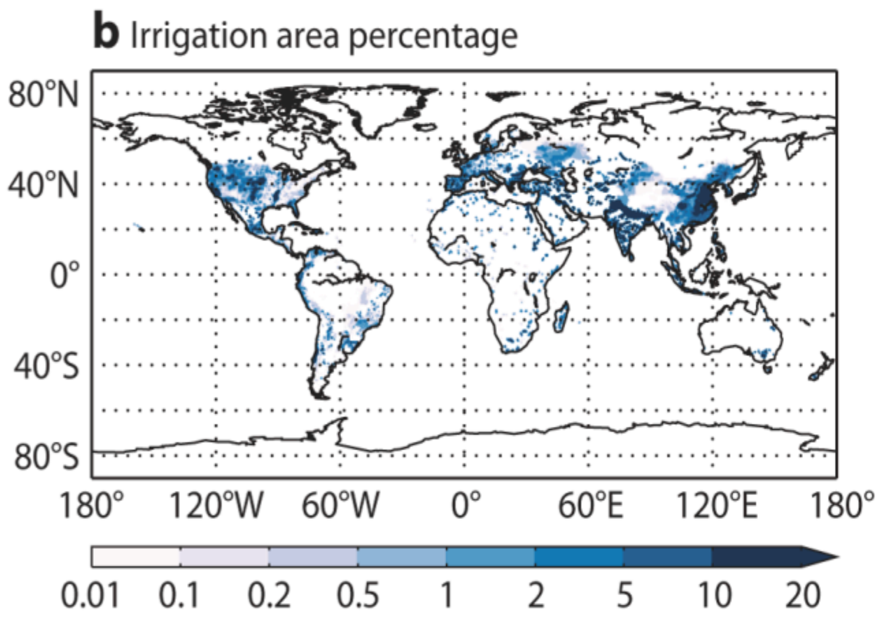
Inland water bodies dataset: a moving target?

http://aqua-monitor.appspot.com

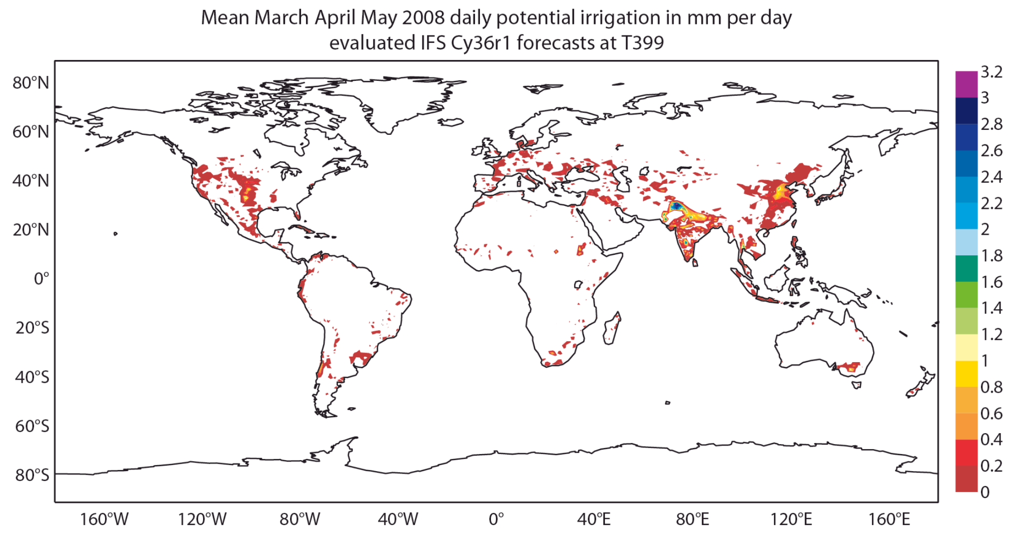
- Lake Aral in 1989 and 2014 (source: NASA)

Irrigation

- Human action on the land and water use is at present neglected in ECMWF forecast and it is considered among the model errors corrected by the LDAS system



- Irrigated area (b, in %, from Döll and Siebert, 2002)



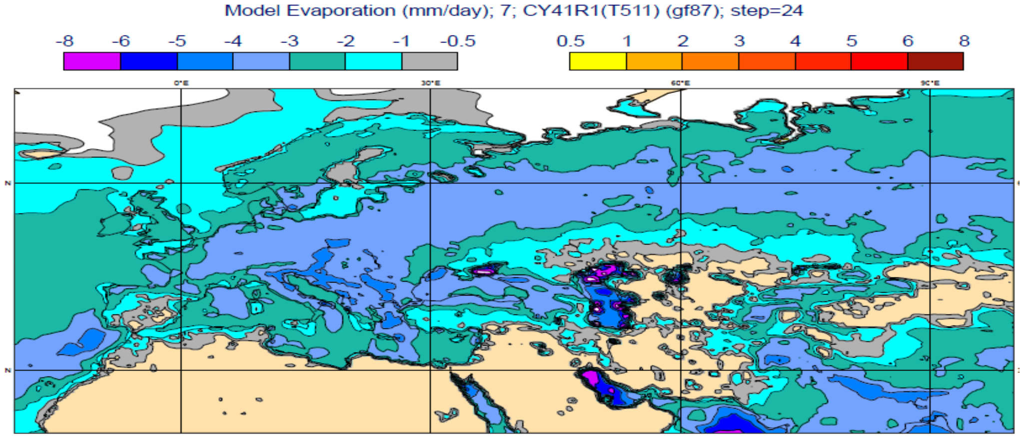
- Irrigation additional water flux estimated as Epot-Et (optimal) following approach by Wisser at al (2008), de Rosnay et al. (2003)

ECMWF

Irrigation formulation: a caveat

- Potential evaporation in HTESSEL is calculated as the unstressed evaporation in CY41R1 (PE in plots):
- The surface energy balance solver is called a second time without the soil moisture term in the canopy resistance formulation

E (mm/day)

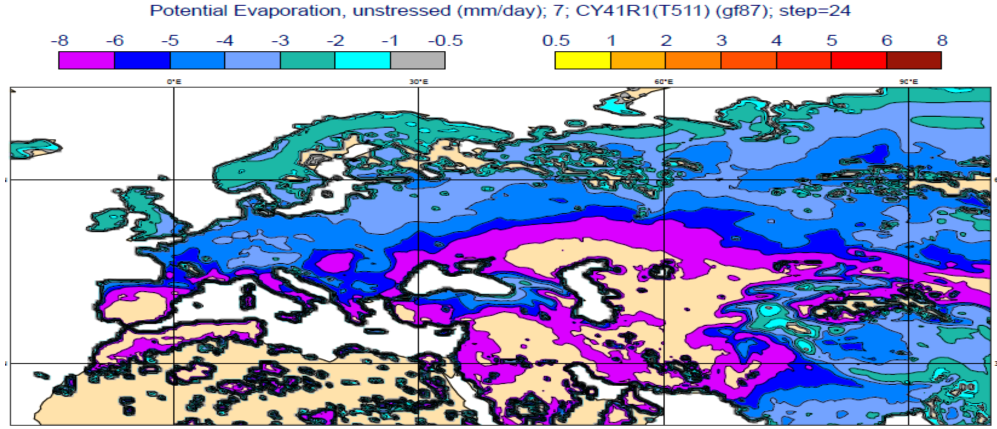


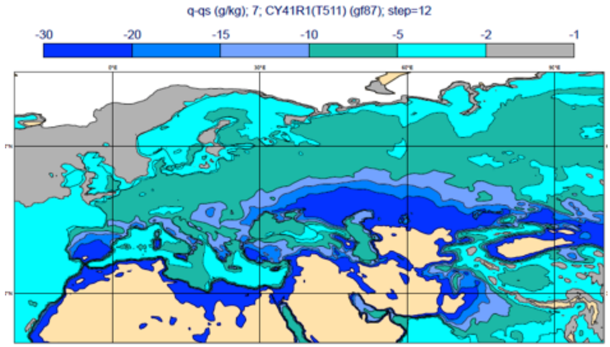
$$\lambda E = \rho\lambda\{q_a - q_{sat}(T_s)\}/(r_a + r_s)$$

$$H = \rho C_p\{T_a - T_s\}/r_a$$

$$r_a = \{|U|C_H\}^{-1}$$

PE (mm/day)



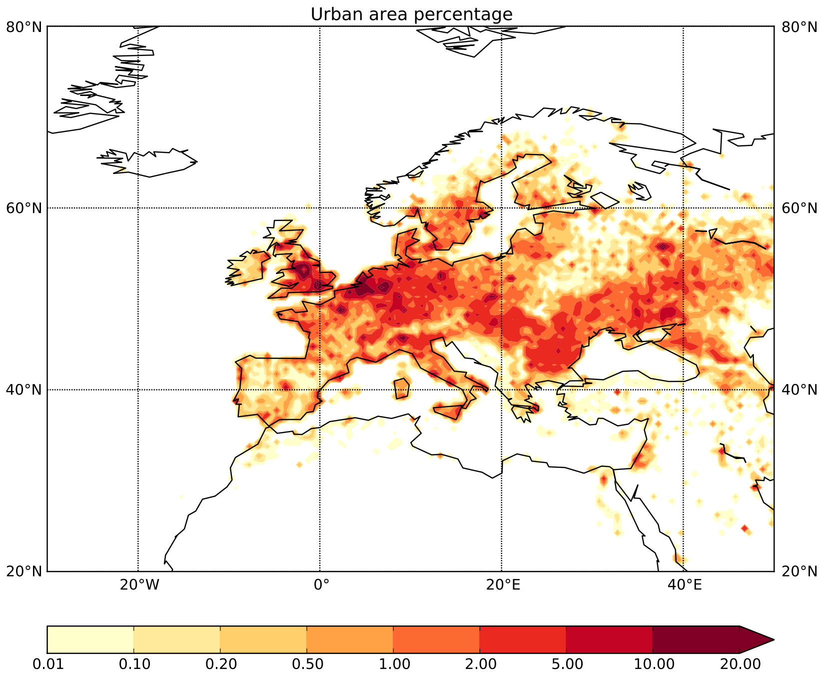


q-qs (g/kg)

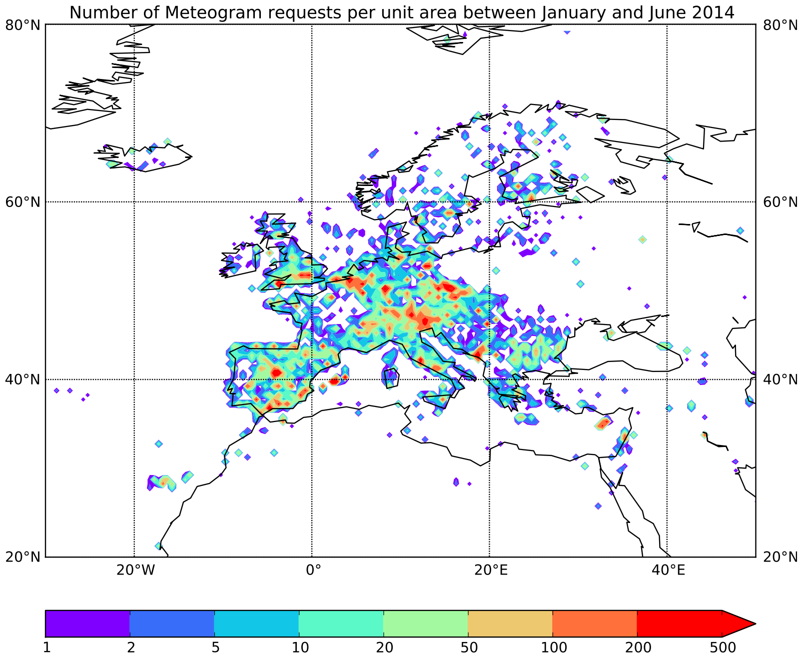
- However this generates a too high PE in dry land due to lack of feedback (moisture deficit term)

Is there a case for urban modelling at global scale?

- Urban areas are important for the accurate prediction of extreme events such as heatwaves and urban flooding and need to be represented in models.
- Best and Grimmond (2015) suggested that simple models may be well adapted to global applications
- Users lives urban areas



- Urban area (a, in %, from ECOCLIMAP, Masson et al., 2003)



- Number of ECMWF Meteograms product requests from Member-States

ECMWF

Urban cover uncertainties

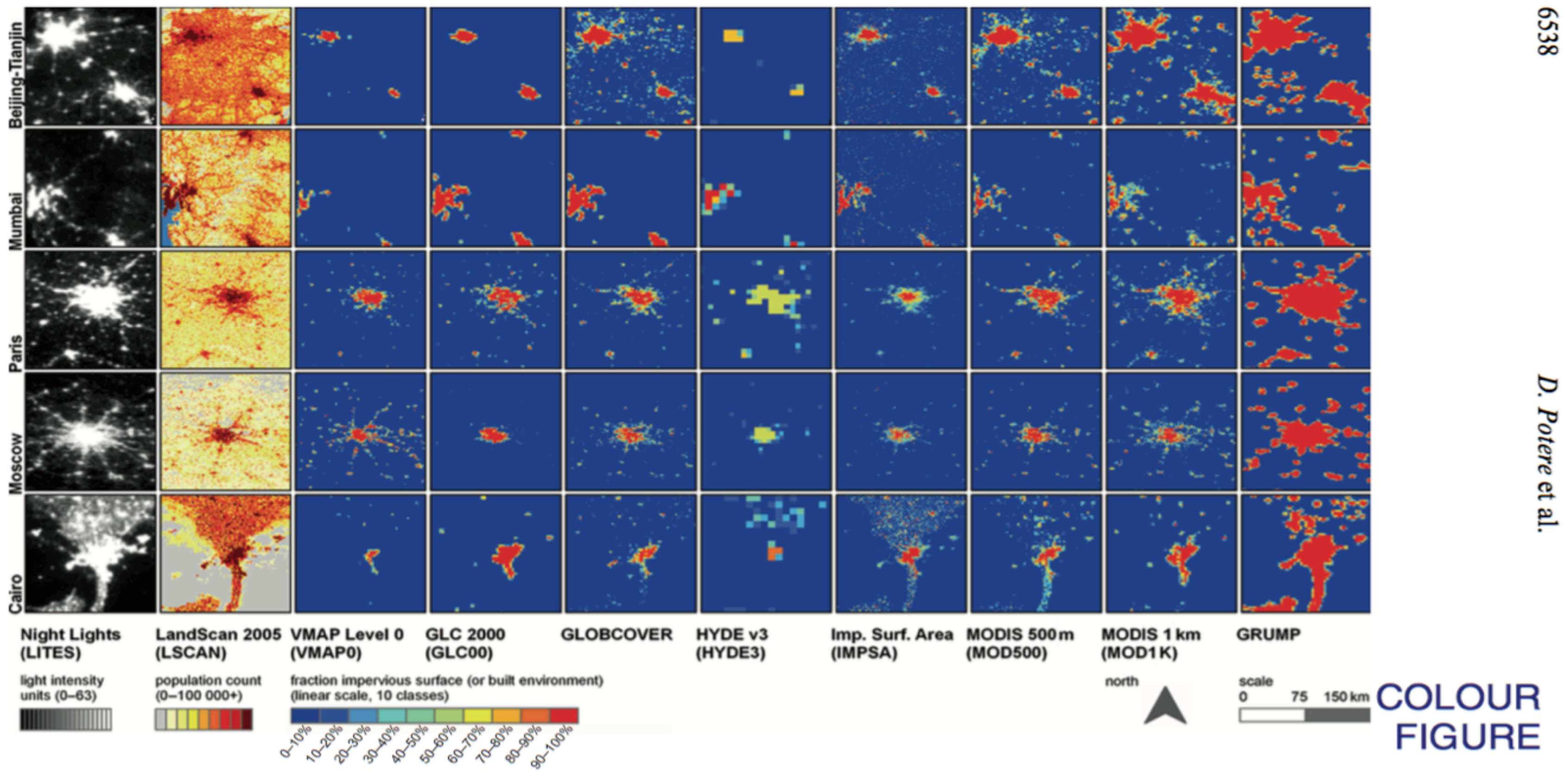
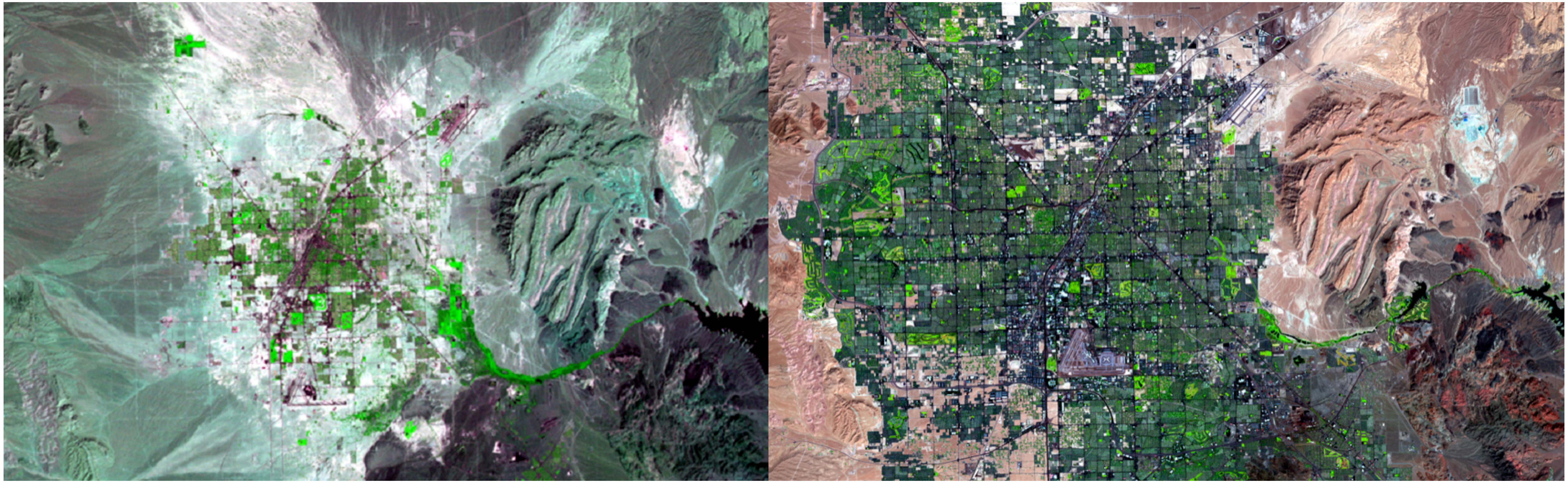


Figure 1. The eight global urban maps and two urban-related maps for Beijing-Tianjin, China (top row), Mumbai, India (second row), Paris, France (third row), Moscow, Russia (fourth row), and Cairo, Egypt (bottom row). LITES, LSCAN and IMPSA are at native 30 arc-second resolution, HYDE3 is at native 5 arc-minutes, and the remaining maps have been aggregated from 30 arc-seconds to 1.5 arc-minutes for display. This aggregation effectively converts their legends from binary (urban/rural) to continuous (percentage urban).

- Urban area dataset comparison on selected cities (Potere et al., 2009 IJRS) reveal large uncertainties and discrepancies

Urbanization change over time



- Urban area changes significantly over time (Sept 1972, Landsat 1 image, Sept 2015 Landsat 8 images compared over Las Vegas (US)

Conclusion and Outlook

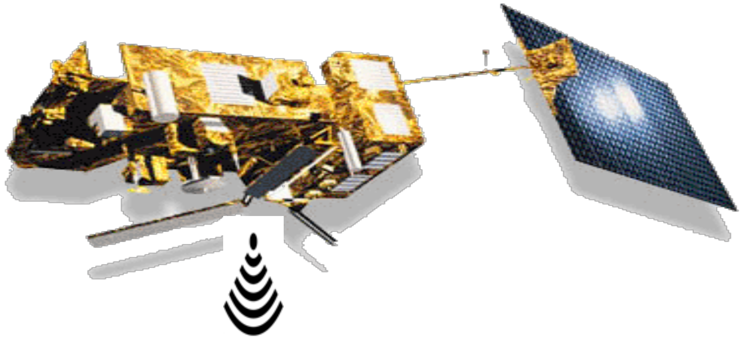
- Variation in lake water fraction, land use change, urbanisation areas all affects the surface energy balance and therefore have impact on local meteorology and should be represented in NWP.
- Moderate complexity parameterizations well adapted to NWP exist already and can be explored for global forecasting applications
- However a correct representation of non-natural surfaces involves a large effort on the collection of authoritative physiographic dataset at a target resolution of 1km or better
- Initiatives in WGNE (group on surface drag, led by Ayrton Zadra) and from NOAA (uncertainty estimation, led by Tom Hamill) are aiming to collect/compare physiography datasets and would benefit from GEWEX interaction/initiatives.
- The availability of multiple dataset in a coherent form may allow to achieve internal consistency among the different dataset. An encouraging example in Tuanmo and Jetz (2014) EarthEnv dataset
- Encouraging results from multivariate use of EO data for validation/calibration (Orth et al. 2016)
- Challenging needs from reanalyses to represent surface condition over a long period of time (decades at least and up to century long) enhances even further the requirements.
- How do we advance further as a community to coordinate HRES EO dataset collection?

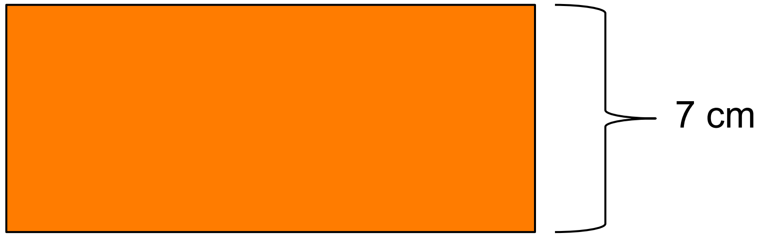
Thank you for your attention

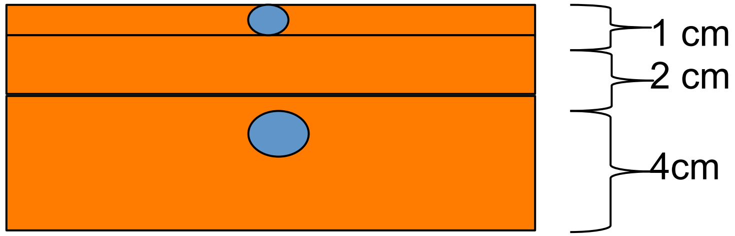
Extra slides for Q&A

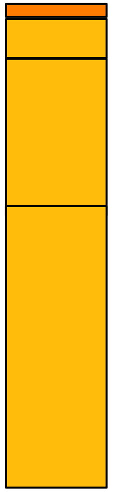
Upcoming developments: An enhanced soil vertical resolution

The model bias in Tskin amplitude shown by *Trigo et al. (2015)* motivated the development of an enhanced soil vertical discretisation to improve the match with satellite products.









4-layers:

 # 0-7 cm

7-28 cm

28-100 cm

100-289 cm

10-layers:

 # 0-1 cm

 # 1-3 cm

 # 3-7 cm

7-15 cm

15-25 cm

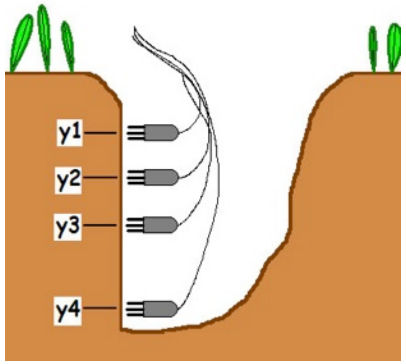
25-50 cm

50-100 cm

100-200 cm

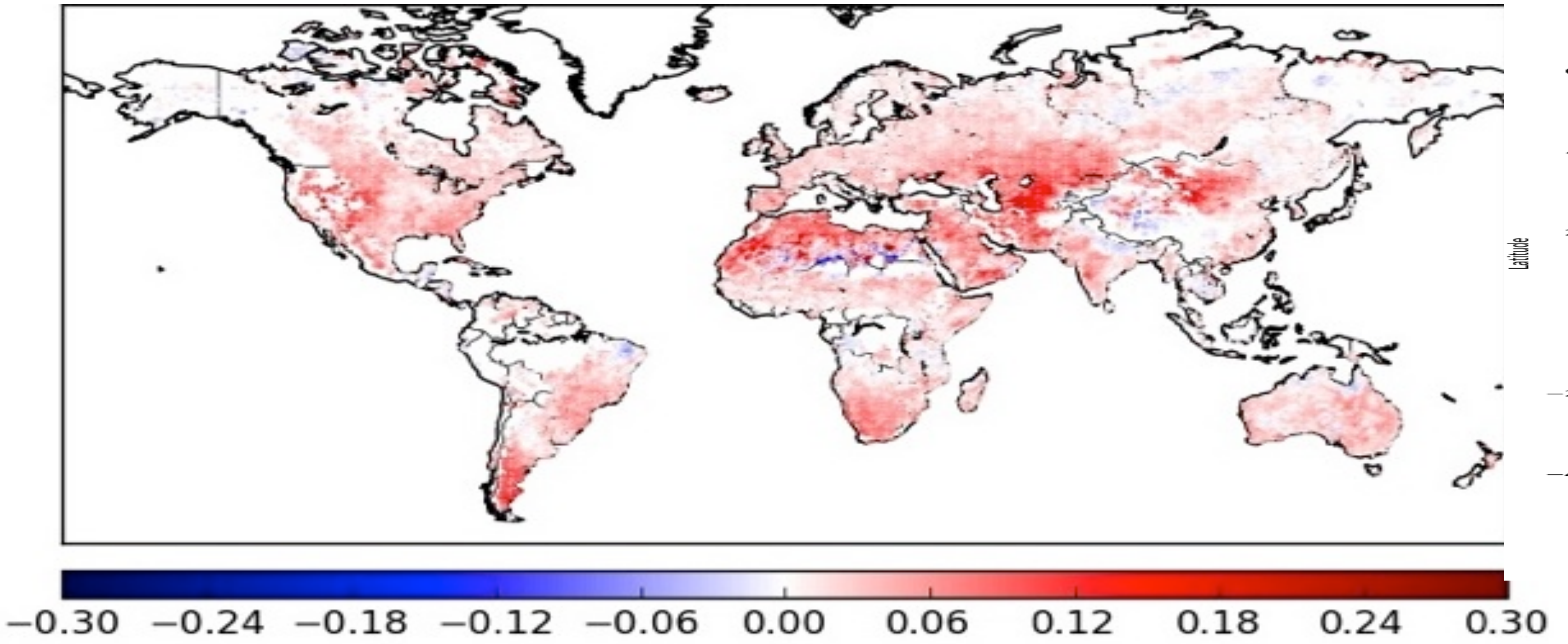
200-400 cm

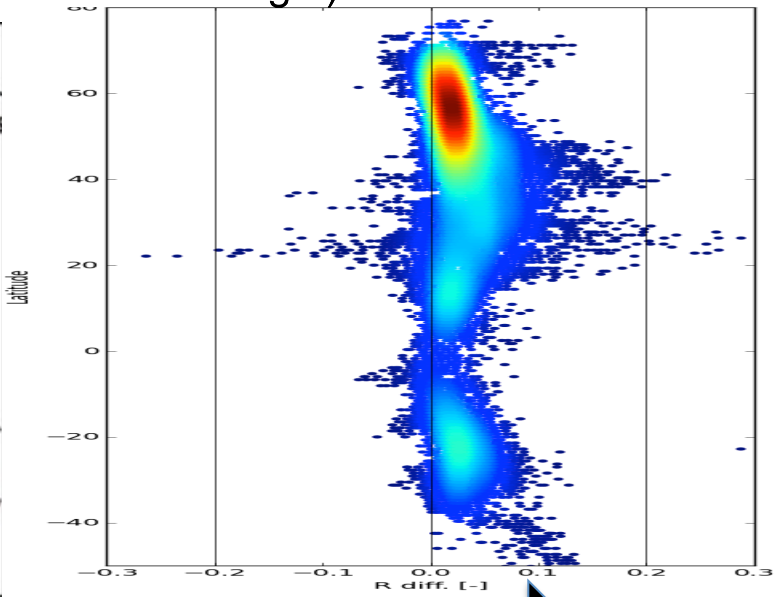
 # 400-800 cm



Impact of soil vertical resolution for satellite soil moisture

Impact on Anomaly Correlation with ESA-CCI satellite soil moisture (courtesy of Clément Albergel)





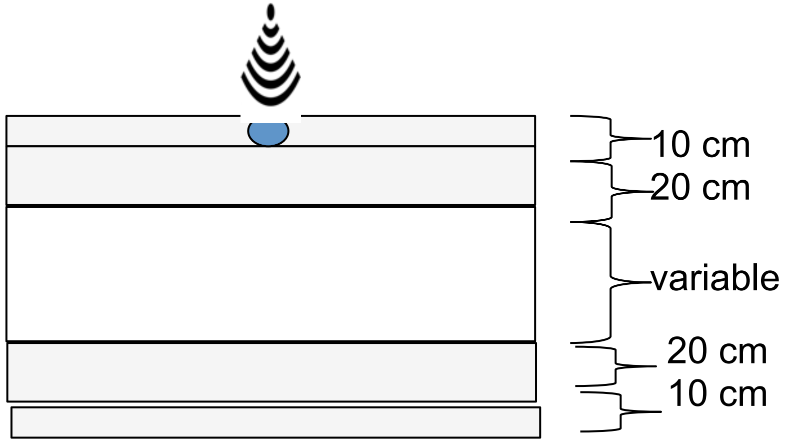
Globally Improved match to satellite soil moisture (shown is ΔACC calculate on 1-month running mean)

Anomaly correlation (1988-2014) measured with ESA-CCI soil moisture remote sensing (multi-sensor) product. This provide a global validation of the usefulness of increase soil vertical resolution.

An enhanced snow vertical resolution

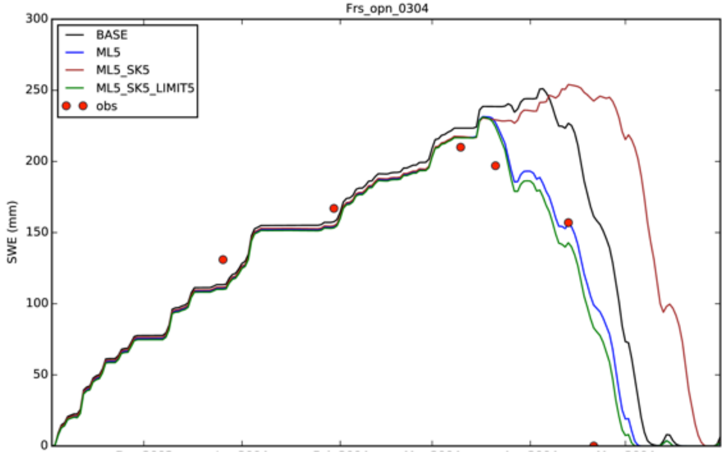
The snow temperature representation in a 5-layer scheme can take into account the coupling to the atmosphere and to the underlying soils with dedicated timescale that can better represent accumulation and melting.

1-layers:
0-X cm



5-layers:

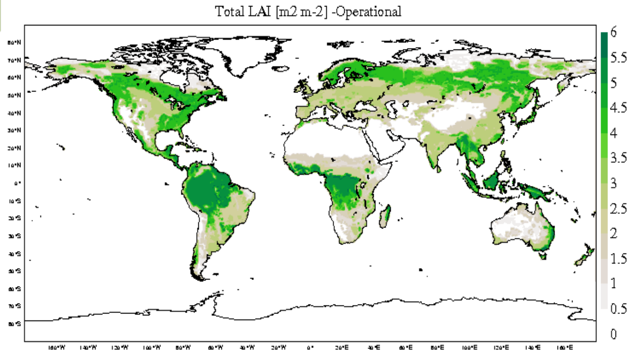
from Emanuel Dutra



Simulations of Snow Water Equivalent (SWE- mm) for the 2003/04 winter season at the Fraser open site (USA Rocky mountains) comparing observations (red circles) with **current** 1-layer model (BASE-black), 5-layers **new** snow model (ML5-green).

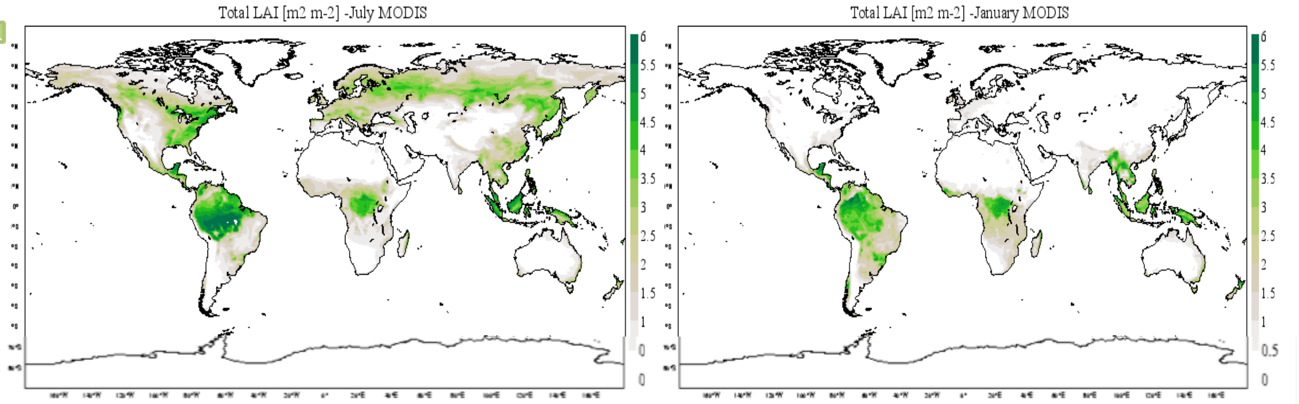
From constant to seasonal varying (current) to NRT (future) Leaf Area Index

1



➔Fixed LAI based on vegetation type in ERA-Interim

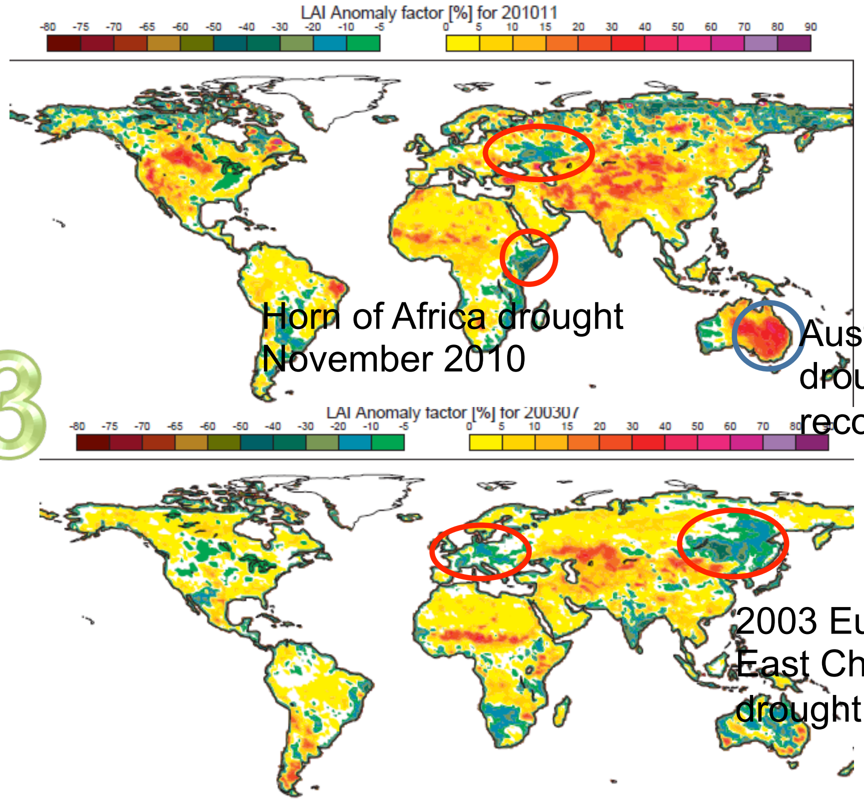
2



➔Monthly derived 8years (2000-2008) climatological (MODIS c5), Boussetta et al. 2011, current ECMWF operational and ERA5 reanalysis

LAI anomaly

3

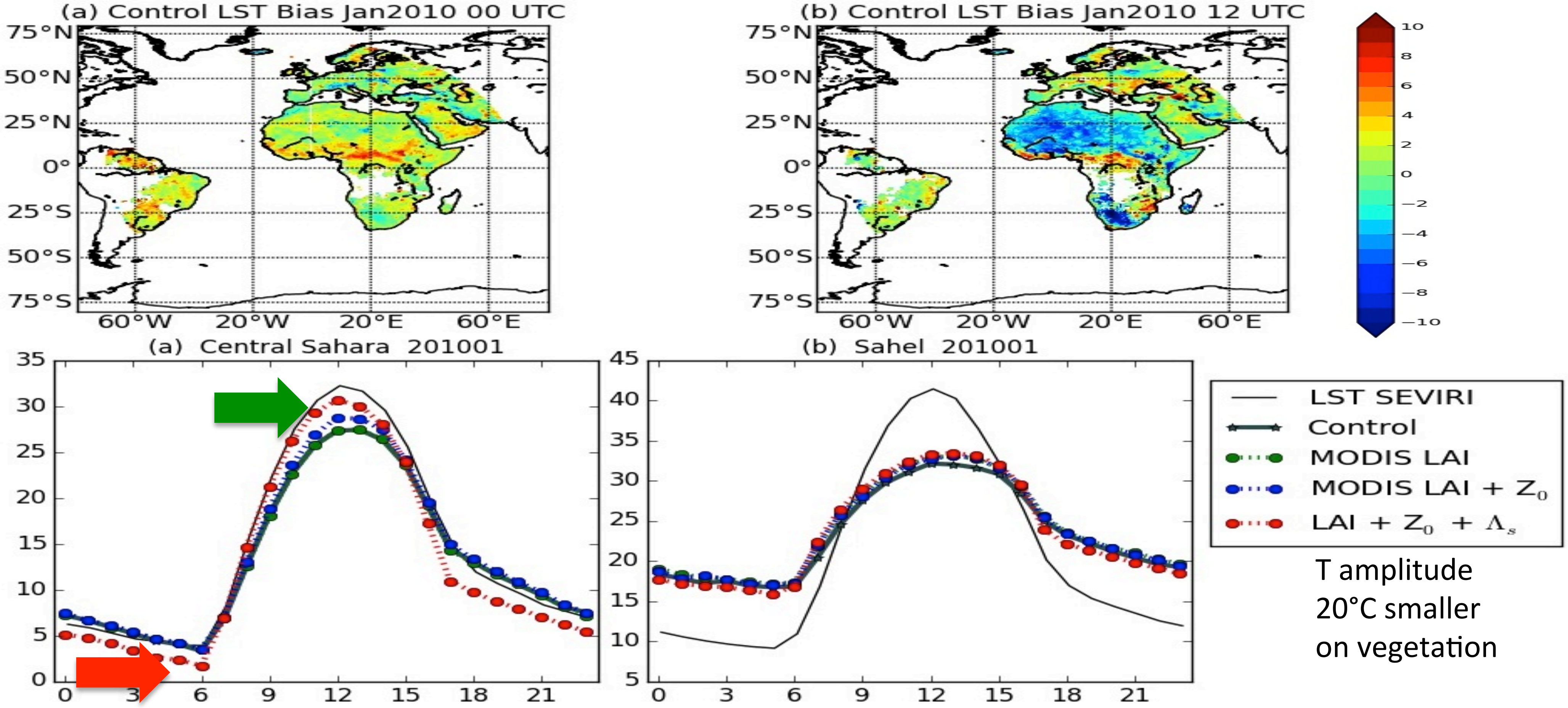


➔ NRT analysed LAI is able to fairly detect/monitor anomaly (IMAGINES/Copernicus Global Land product)

Boussetta et al. 2015, research version

Coupling and diurnal cycle: the impact of vegetation

Trigo et al. (2015, JGR in rev.), Boussetta et al. (2015, RSE)



T amplitude
20°C smaller
on vegetation

Findings of large biases in the diurnal temperature reposed on the use of MSG Skin Temperature.
However with the current model version we are limited (both over bare soil and vegetation)

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