# Land surface processes

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Prepared for the Sub-Seasonal Predictability workshop at ECMWF
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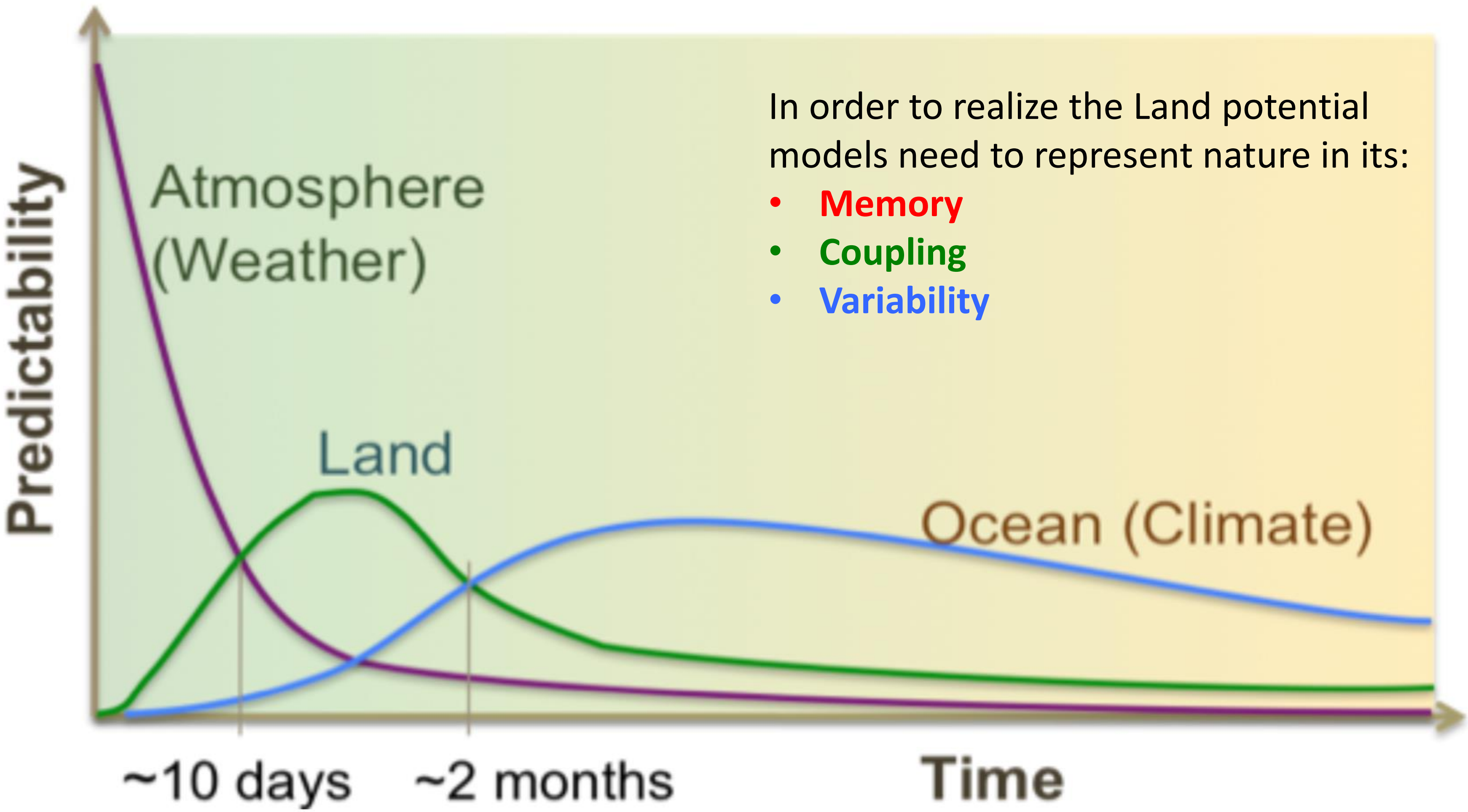
Acknowledgement of team effort and in particular to Clément Albergel, Anton Beljaars, Souhail Boussetta, Patricia De Rosnay, Emanuel Dutra, Joaquin Munoz-Sabater, Irina Sandu

- Role of land surface in S2S and beyond.
- Land processes representation and their uncertainties at ECMWF
- Outlook: what to do first?

# Land surface role in S2S




In order to realize the Land potential models need to represent nature in its:

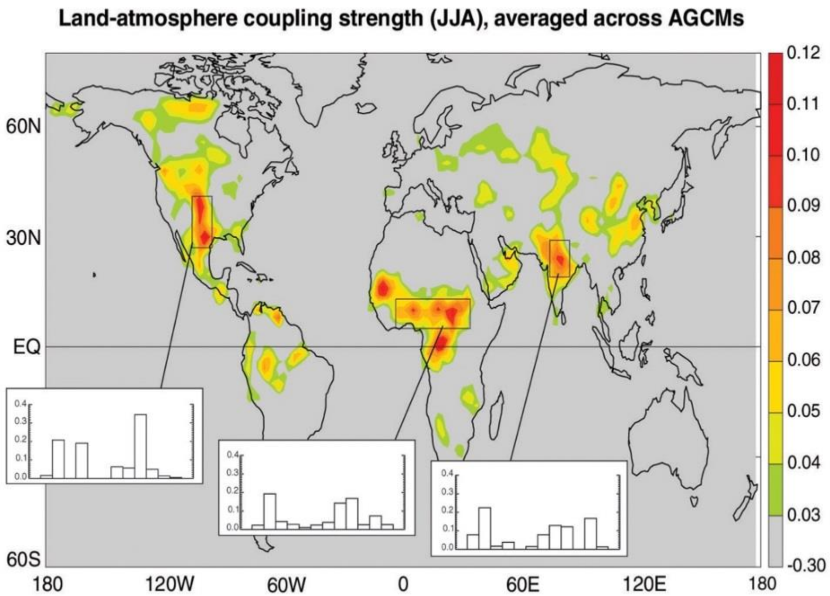
- Memory
- Coupling
- Variability

Dirmeyer et al. 2015: http://library.wmo.int/pmb_ged/wmo_1156_en.pdf

# Land surface role in S2S: 10-year of R&D

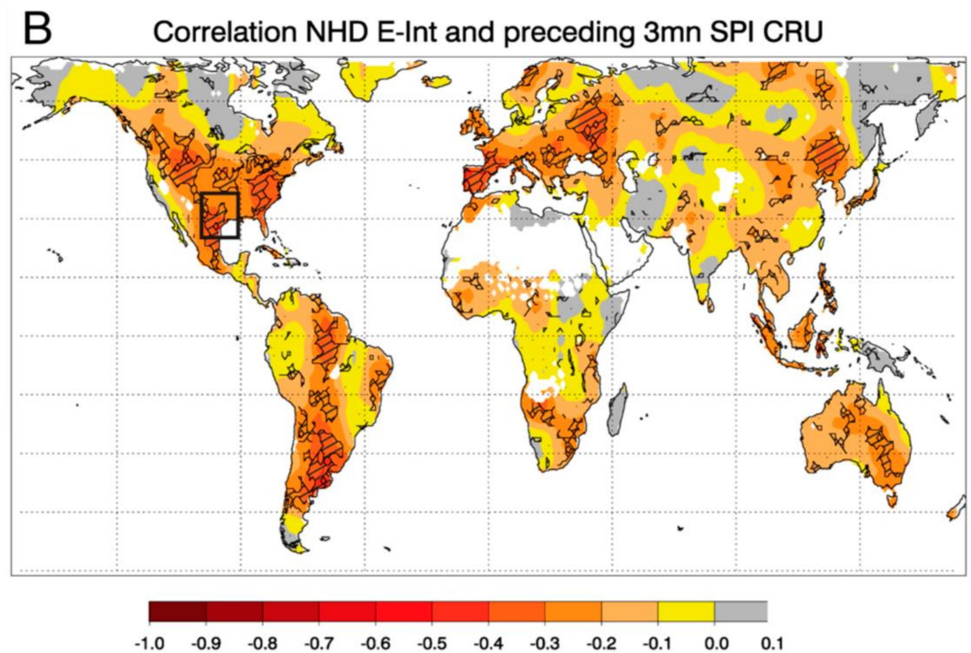
Koster et al. 2004 Science

Land-coupling (SM-T) in Northern Hemisphere JJA




Mueller and Seneviratne 2012 PNAS

Hot-Days correlation with 3-month antecedent P deficit




Albergel et al. 2013JHM show dominance of significant drying trends for soil moisture in both reanalysis and satellite-based soil moisture dataset, with possibly larger areas of land surface predictability

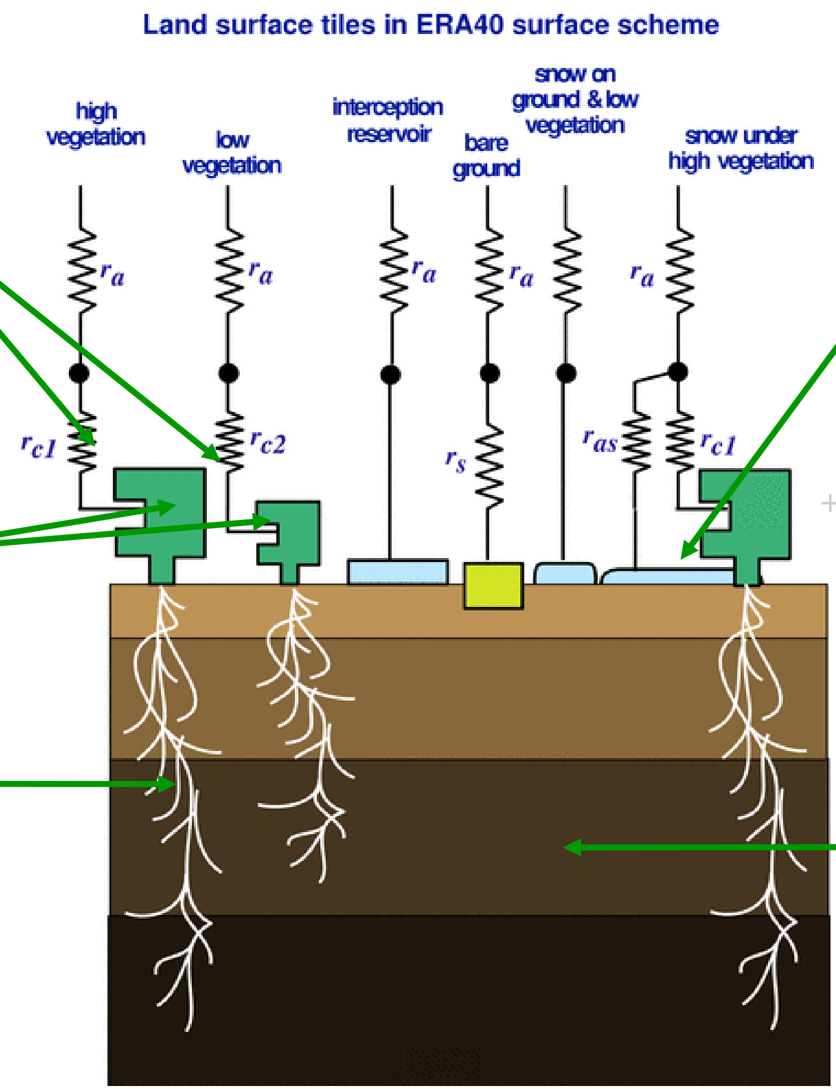
# ECMWF Land surface model main structure in the ERA-Interim scheme

- Tiled ECMWF Scheme for Surface Exchanges over Land

Revised canopy resistances, including air humidity stress on forest

High and low vegetation treated separately

Variable root depth




New treatment of snow under high vegetation

+ 2 tiles (ocean & sea-ice)

No root extraction or deep percolation in frozen soils

# Land surface model status in 41R2 (ERA5) and its evolution since ERA-Interim scheme

| 2007/11 | 2009/03-09 | 2010/11 2011/11 | 2012/06 | 2015/05 |
|---|---|---|---|---|

- **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

- **Flake**

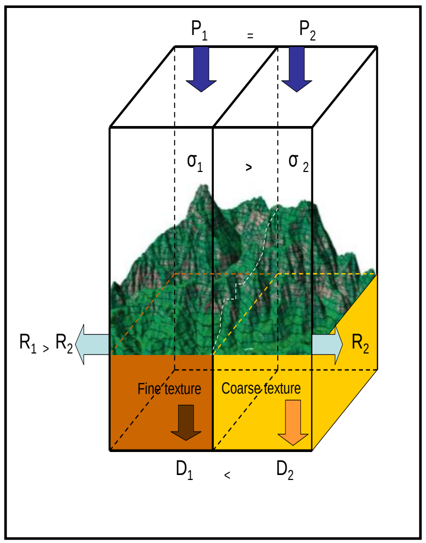
  Mironov et al (2010),

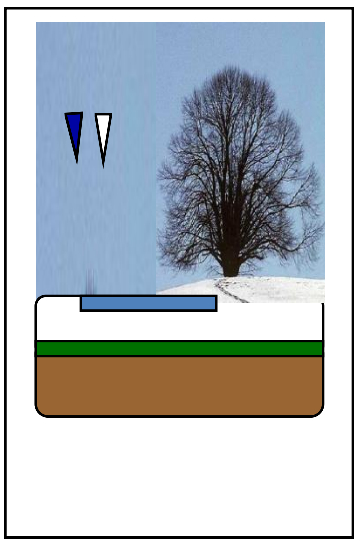
  Dutra et al. (2010),

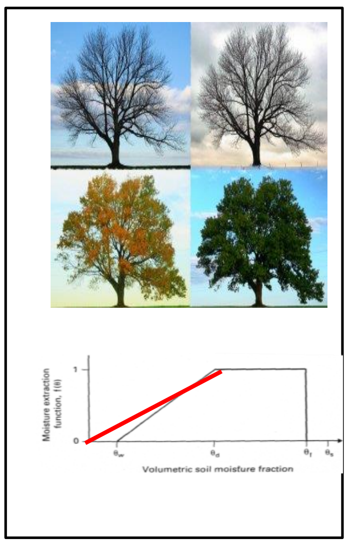
  Balsamo et al. (2012, 2010)

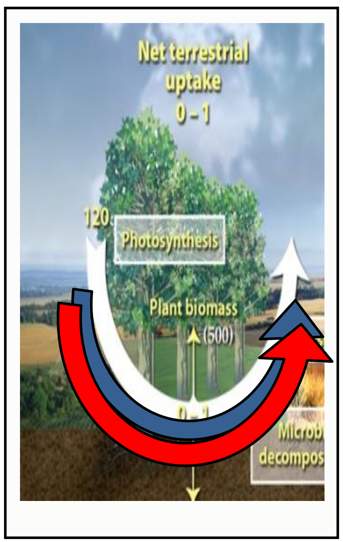
  Extra tile (9) to for sub-grid lakes and ice

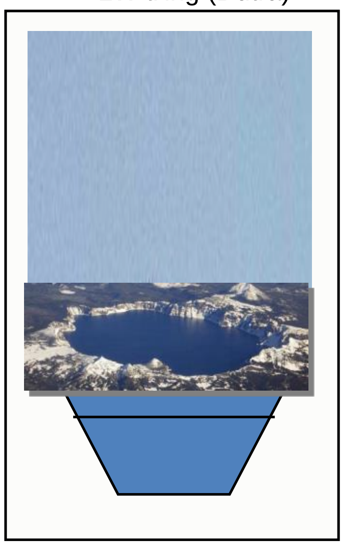
  LW tiling (Dutra)





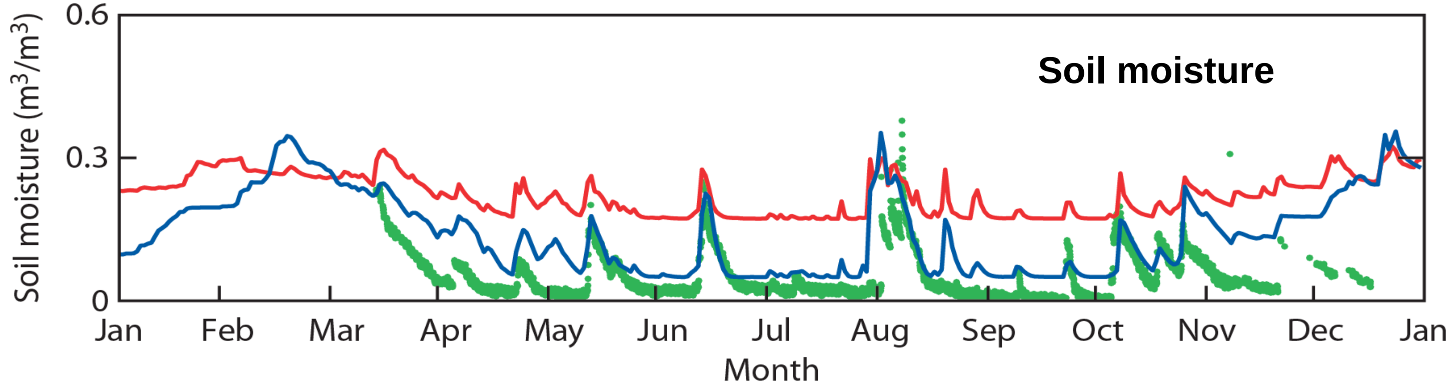



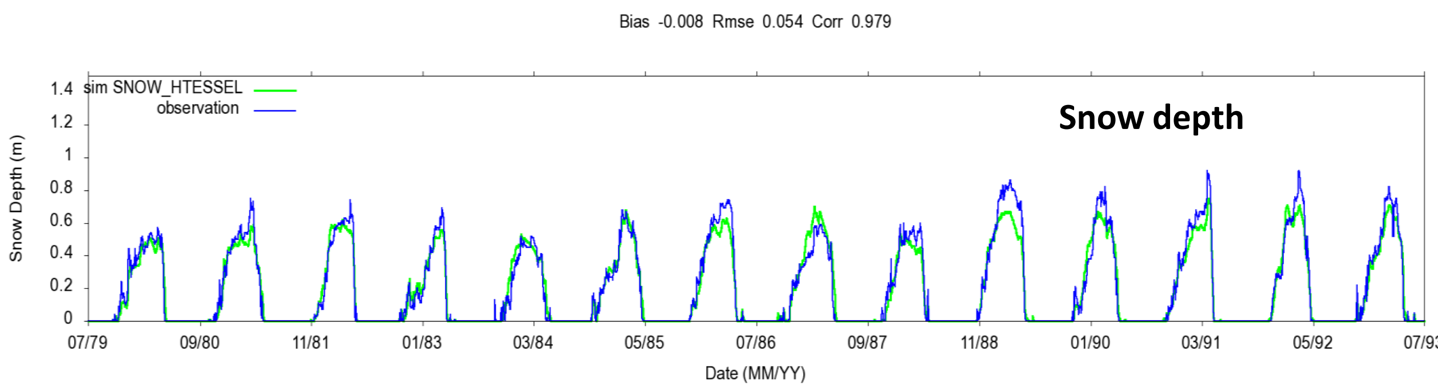
# Land water storages: soil moisture and snow

Balsamo et al. (2015 HESS)

ERA-Interim/Land integrates land surface modelling improvements with respect to ERA-Interim surface scheme.



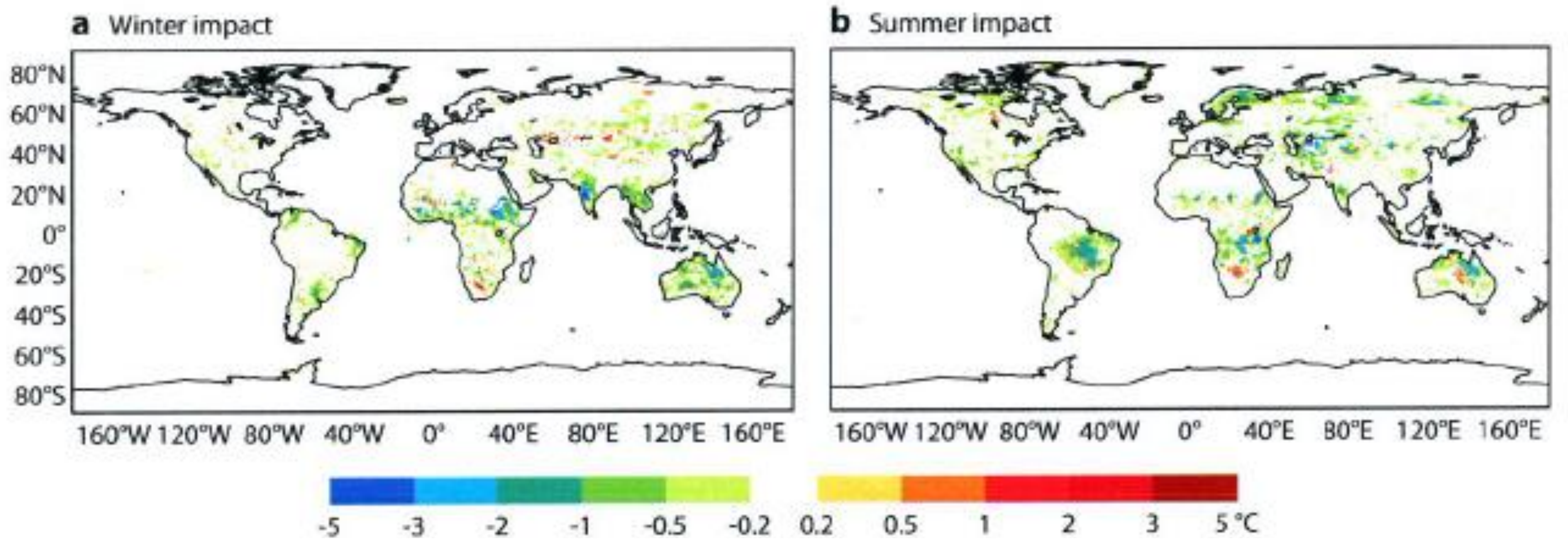

Evolution of soil moisture for a site in Utah in2010. Observations, ERA-Interim, and ERA-Interim/Land.




Evolution of snow depth for a site in Perm Siberia (58.0N, 56.5E) ERA-Interim/Land and **in-situ observation** between 1979 and 1993.

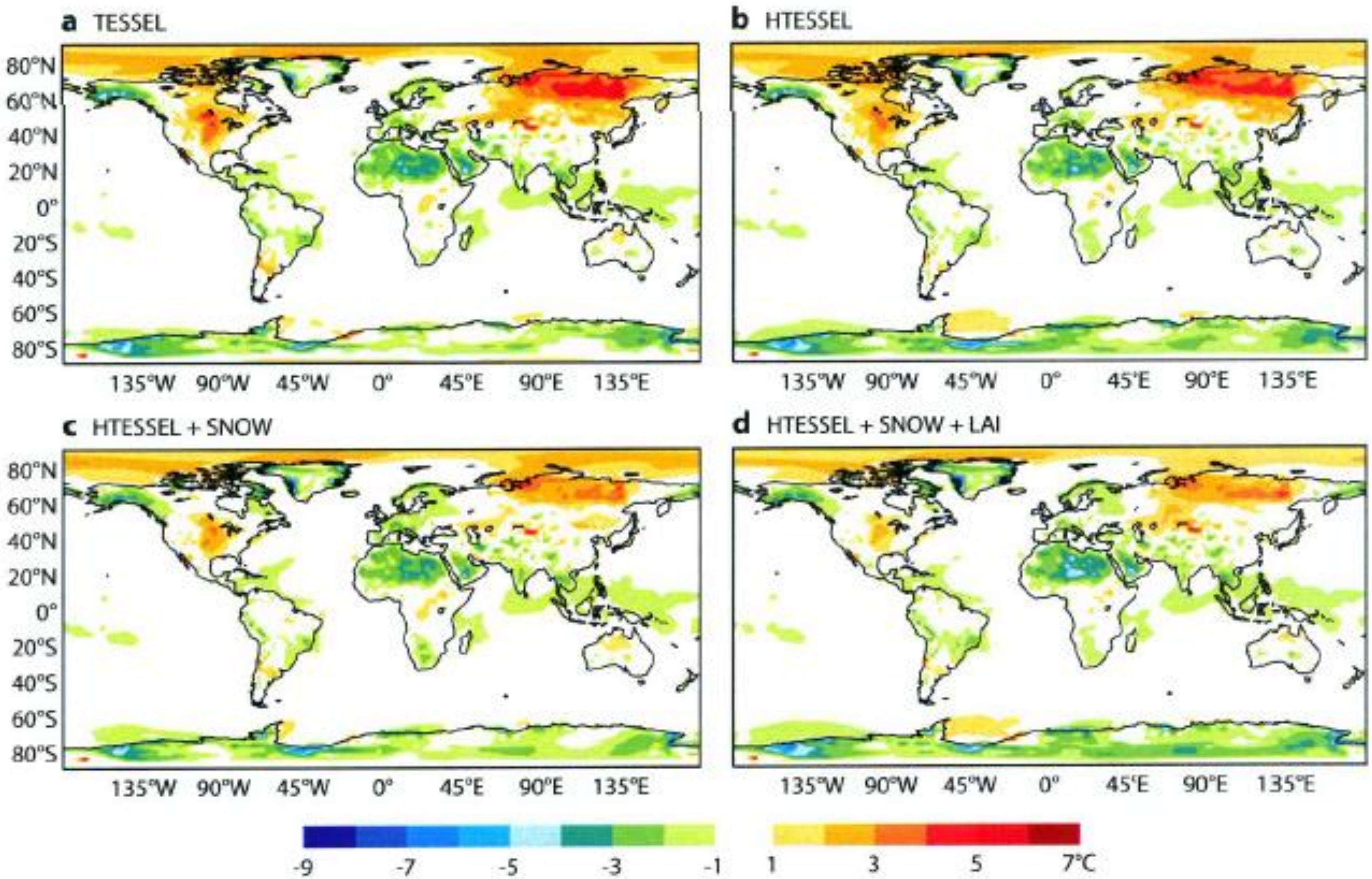
# Forecasts impact of improved soil/snow hydrology

**Forecast Impact (+36-hour forecast, mean error at 2m temperature)**




Improving 2m temperature Degrade 2m temperature

# Impact of land surface development in reducing systematic model error



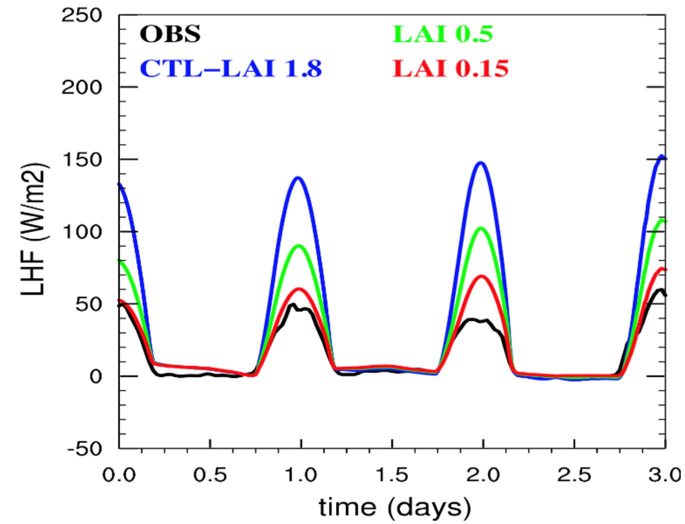

simulations colder than ERA-Interim    Warmer than ERA-Interim

# Coupling with the vegetation/soil layer with Atmosphere



Boussetta et al. 2015 (RSE) showed that albedo and vegetation state are important for accurate surface ET & weather FC during extremes.

Agusti-Panareda et al. 2014 (ACP) showed that $CO_2$ can be predicted using land fluxes of CHTESSEL

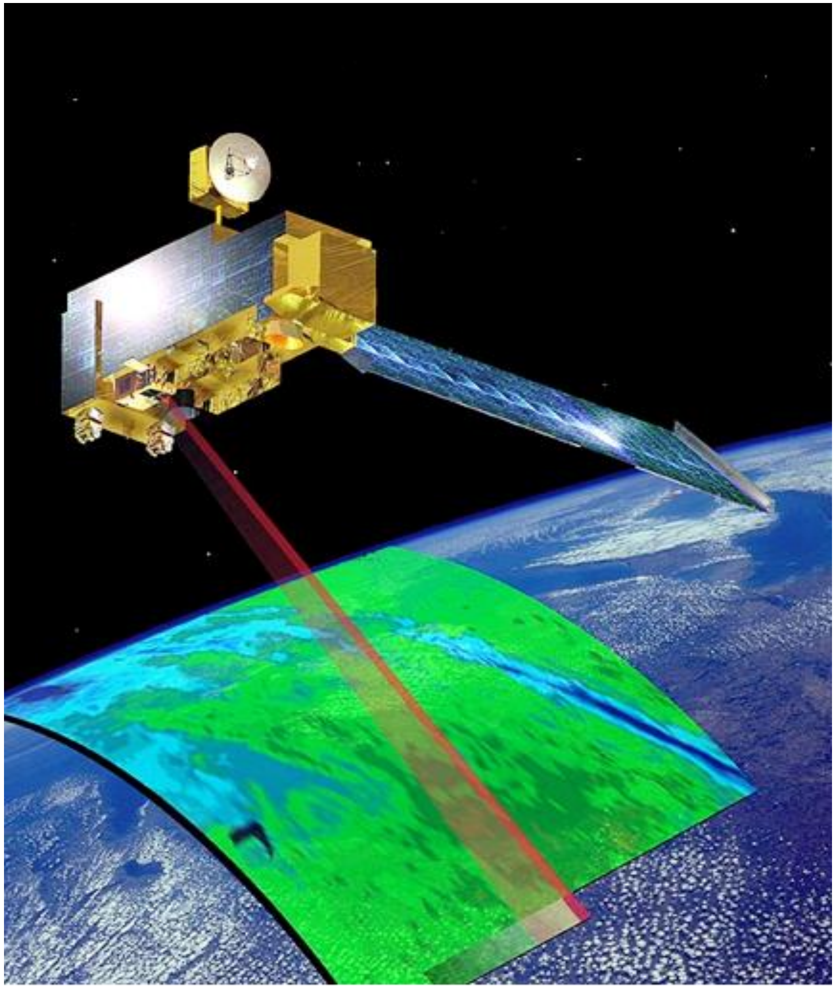


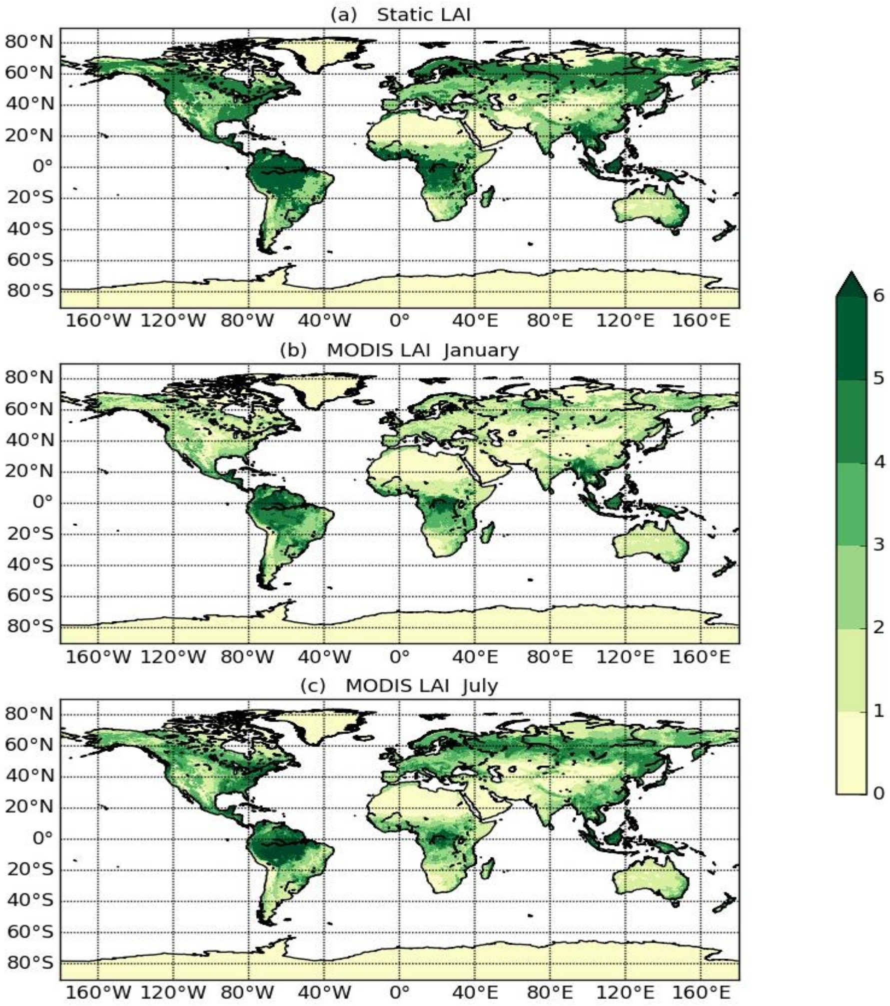

Sandu et al. 2014 (GEWEX poster)

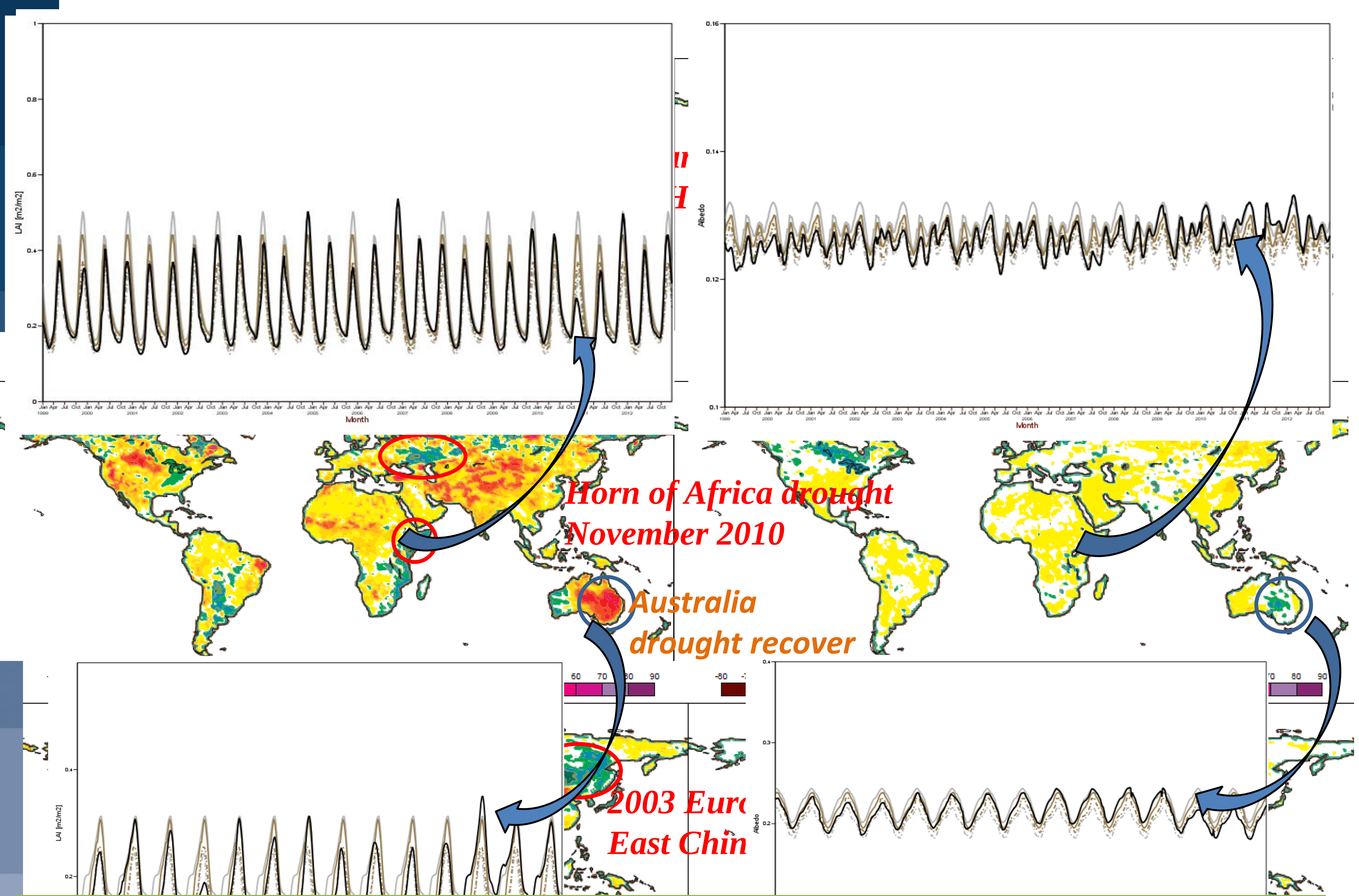
Diurnal cycle Couple Experiment (DICE, Lock and Best UKMO) has shown an important effect of vegetation litter shielding water extraction for evaporation processes.

Important to know vegetation state and its activity (e.g. using Sentinel satellite fluorescence data).
Vegetation cover variability is most important for NWP and linked with physiography work.
See presentation from Souhail for phenology impact

# Vegetation state from satellite data



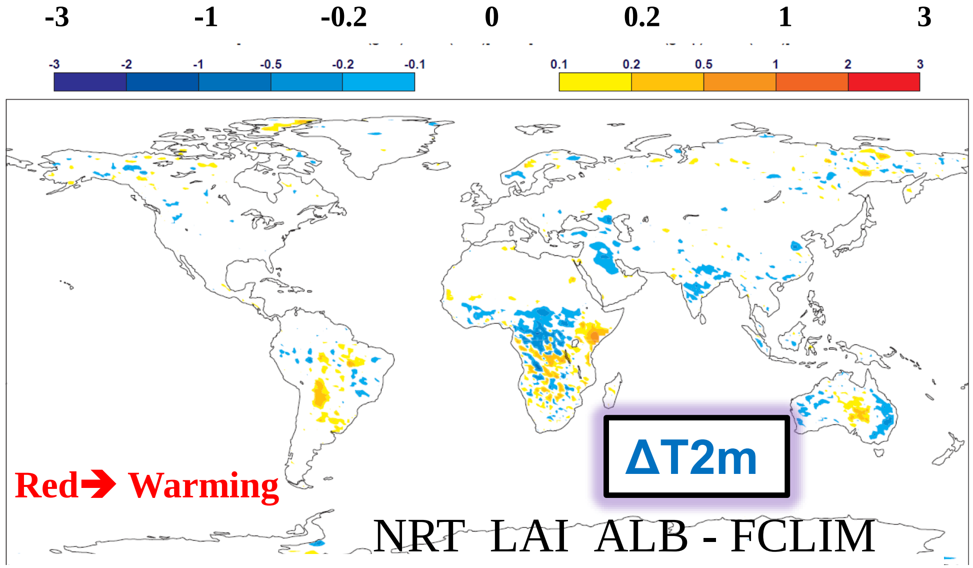


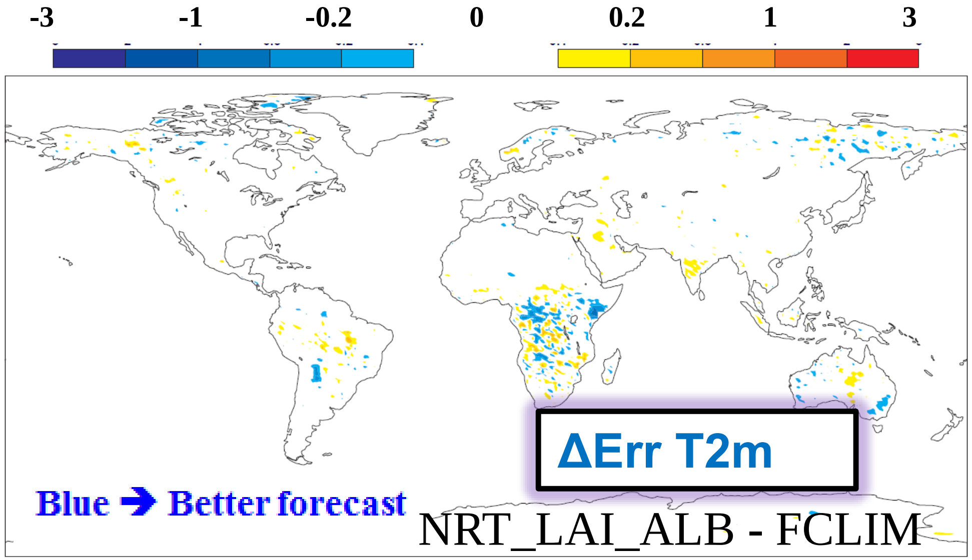



- ➔ Vegetation state can be detect/monitor from space and show anomalous year
- ➔ The analysed Leaf-Area-Index and albedo signal are covariant during wet year.
- ➔ Is there a forecast impact?

# 2m temperature forecast sensitivity and impact

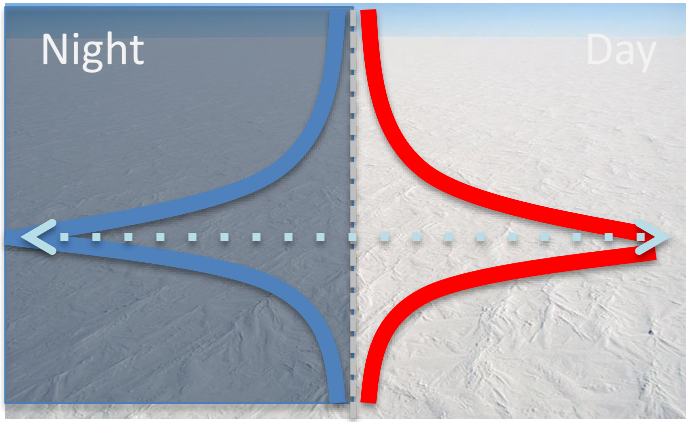
Boussetta et al. 2015, RSE



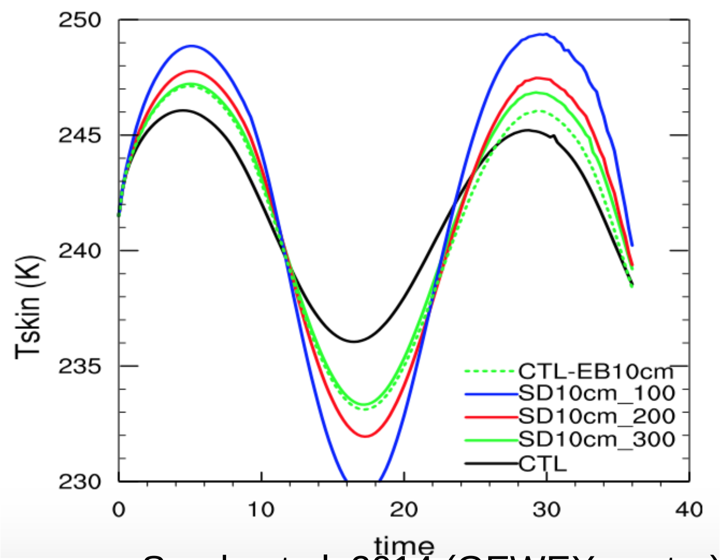



# Coupling and diurnal cycle: snow and ice

See presentation from Emanuel Dutra




GABLS experiment and interaction with CEN-MF led to a study on snow-atmosphere coupling over permanent snow area.



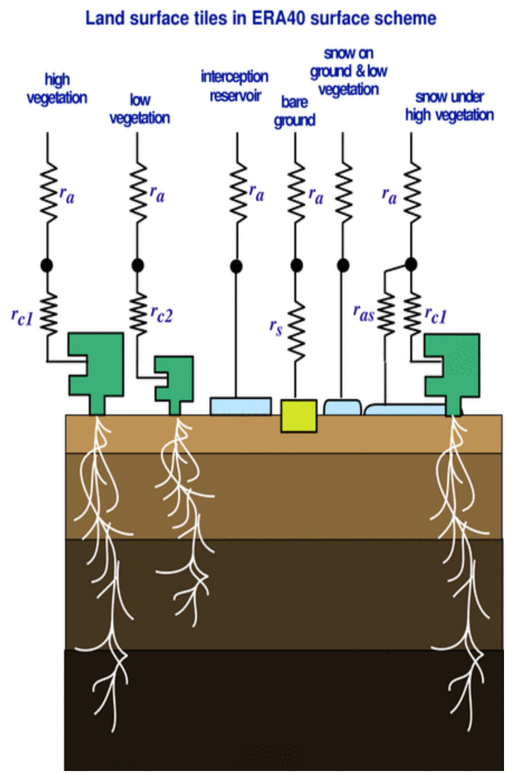

Sandu et al. 2014 (GEWEX poster)

Dutra et al. 2015 (TM) show that
a shallower snow layer over Antarctica can improve the match to satellite measured skin temperature,
Supporting investment in a multi-layer snow scheme.

However there is a **sizeable technical development** to host Multi-layer surface fields in operations.

# Modelling inland water bodies


A representation of **inland water bodies and coastal areas** in NWP models is essential to simulate large contrasts of albedo, roughness that affect fluxes and the lake heat storage



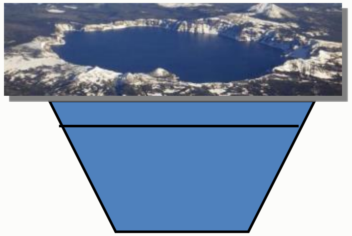

- **Lake tile**

  **Mironov et al (2010),**

  **Dutra et al. (2010),**

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

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

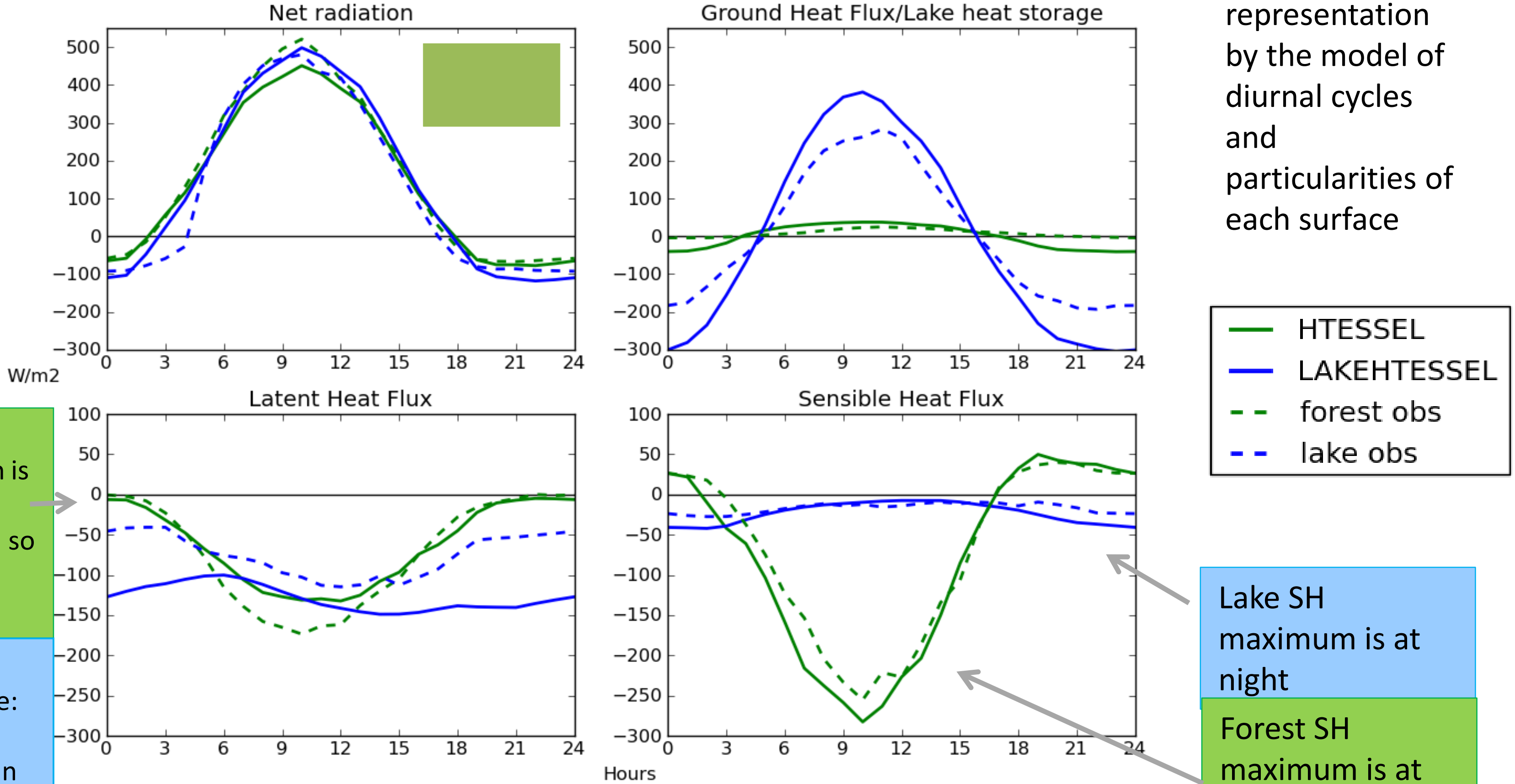


A lake and shallow coastal waters parametrization scheme has been introduced in the ECMWF Integrated Forecasting System combining

# Diurnal cycles: difference forests &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

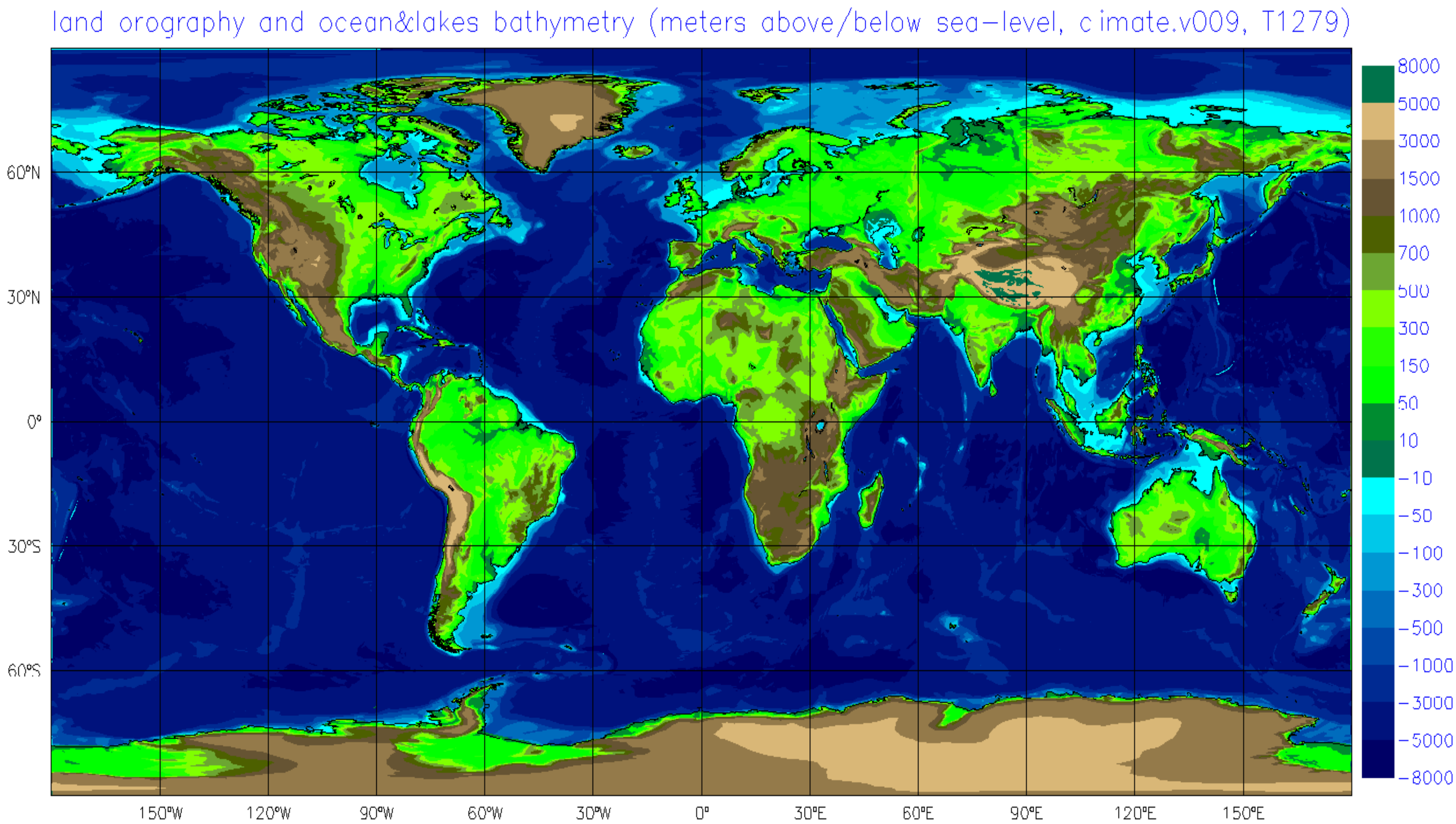
**Lake** LH diurnal cycle: over-estimation in evaporation

Lake SH maximum is at night

Forest SH maximum is at midday

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

# Operational inland-water bodies in IFS cycle 41r1 (May 2015)



# First results from the lake operational monitoring

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

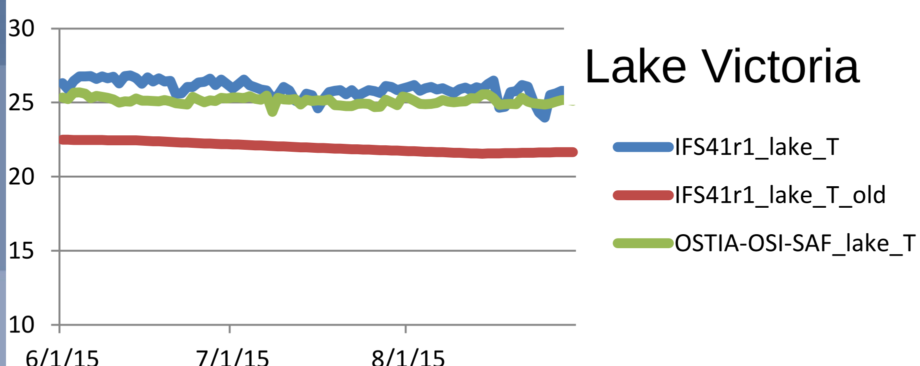
| Lake AFRICA | RMSE | BIAS | Correlation | Mean Model | Mean Obs | Stdev Model | Stdev Obs |
|---|---|---|---|---|---|---|---|
| Victoria_IFS41R1 | **0.957** | **0.826** | 0.491 | 25.665 | 24.849 | 0.554415 | 0.230933 |
| Victoria_IFS40R1 | 3.157 | -3.14 | 0.328 | 21.743 | 24.849 | 0.322463 | 0.230933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

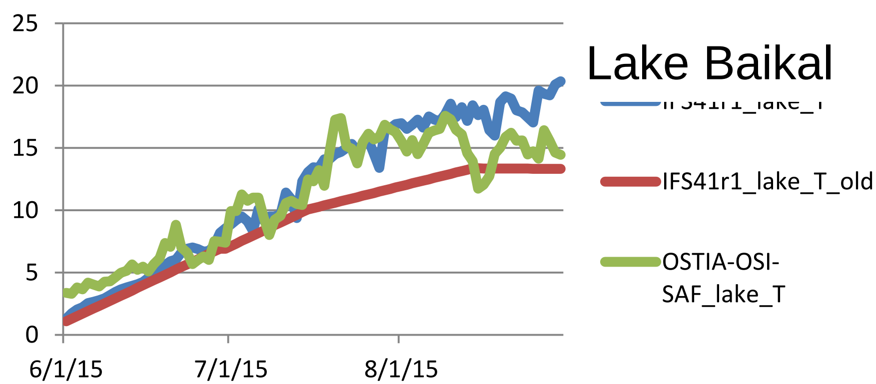
| Lake CANADA | RMSE | BIAS | CORR | Mean Model | Mean Obs | Stdev Model | Stdev Obs |
|---|---|---|---|---|---|---|---|
| Great_Bear_IFS41R1 | **2.875** | **1.877** | 0.927 | 5.225 | 3.368 | 3.87317 | 1.96852 |
| Great_Bear_IFS40R1 | 5.401 | 4.598 | 0.894 | 7.916 | 3.368 | 4.45394 | 1.96852 |

| 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 |



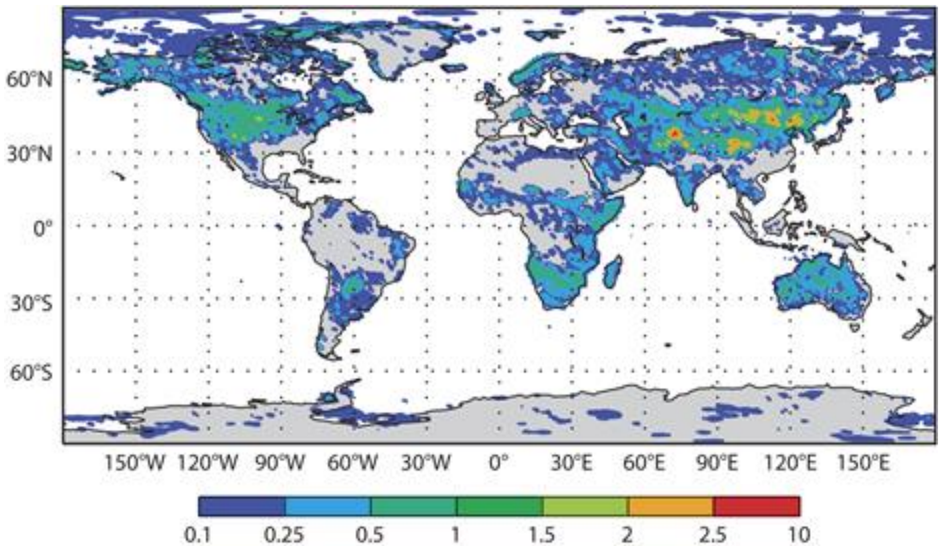



# Representing land-related forecast uncertainties

Lang et al. (2013, RM)

- Forecasting is a probabilistic problem at all forecast-range and a more comprehensive representation of uncertainties including land surface variables had to be introduced
- EDA/ENS provide a framework to extend the methodology used for Atmospheric perturbations also to soil moisture, soil temperature and snow variables

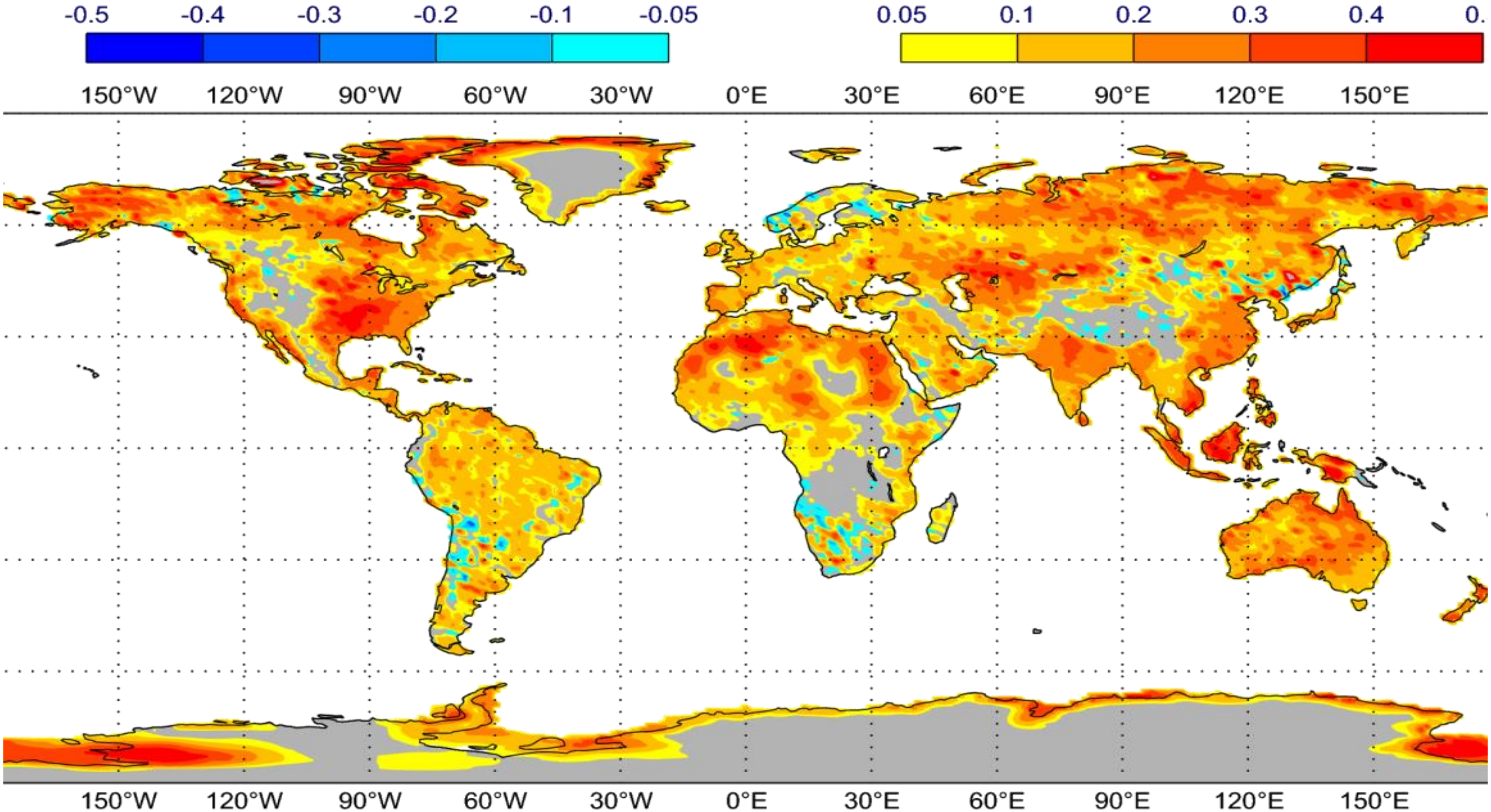
$$x = x_{AN} \pm (x_{EDA,k} - \overline{x_{EDA}})$$




The effects are visible on the 2-m temperature ENS spread which is enhanced 12 hours forecast (compared to no-surface-perturbations)

- The perturbation of the near surface observations used in EDA surface analyses permit to enhance the spread in near surface temperatures by a further 0.5-1 K.

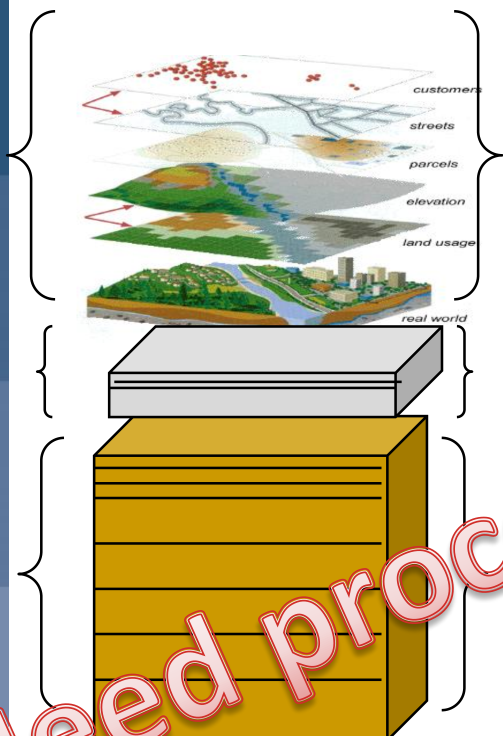
# Soil temperature related uncertainties




Mean difference of soil temperature between experiment with and without surface perturbations after 12 hours forecast-time; the positive values indicate larger spread

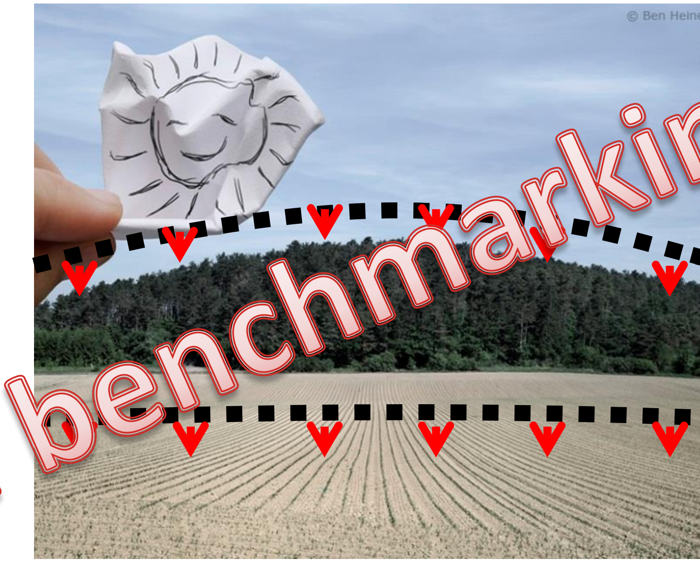
# Perspectives for Earth System Prediction

Towards integrated
Ecosystems modelling




- Better characterisation of the vertical profiles
- Better respresentation on heterogeneity and ecosystems interaction
- Unification of processes (cryosphere)

Modularity of the land system is a key to ESP model integrations and inter-operability of parameterizations

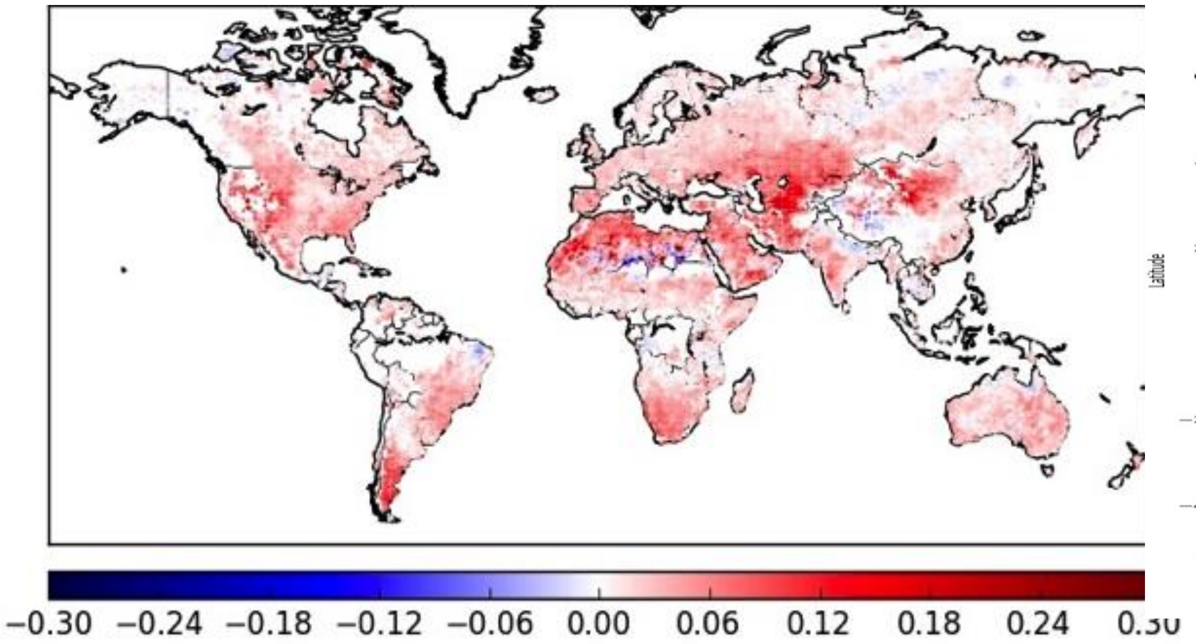


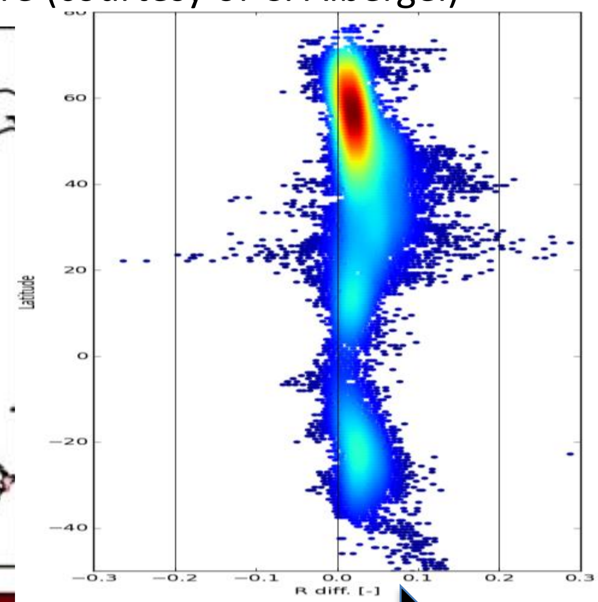

- Complexity needs a step-wise approach
- The assimilation methods are integral part of the model diagnostics
- A better coupling between sub-systems is the ultimate goal, achievable by enhanced knowledge on each sub-system and the mutual interactions

**Need process-level benchmarking!**

# Impact of soil vertical resolution for satellite soil moisture

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



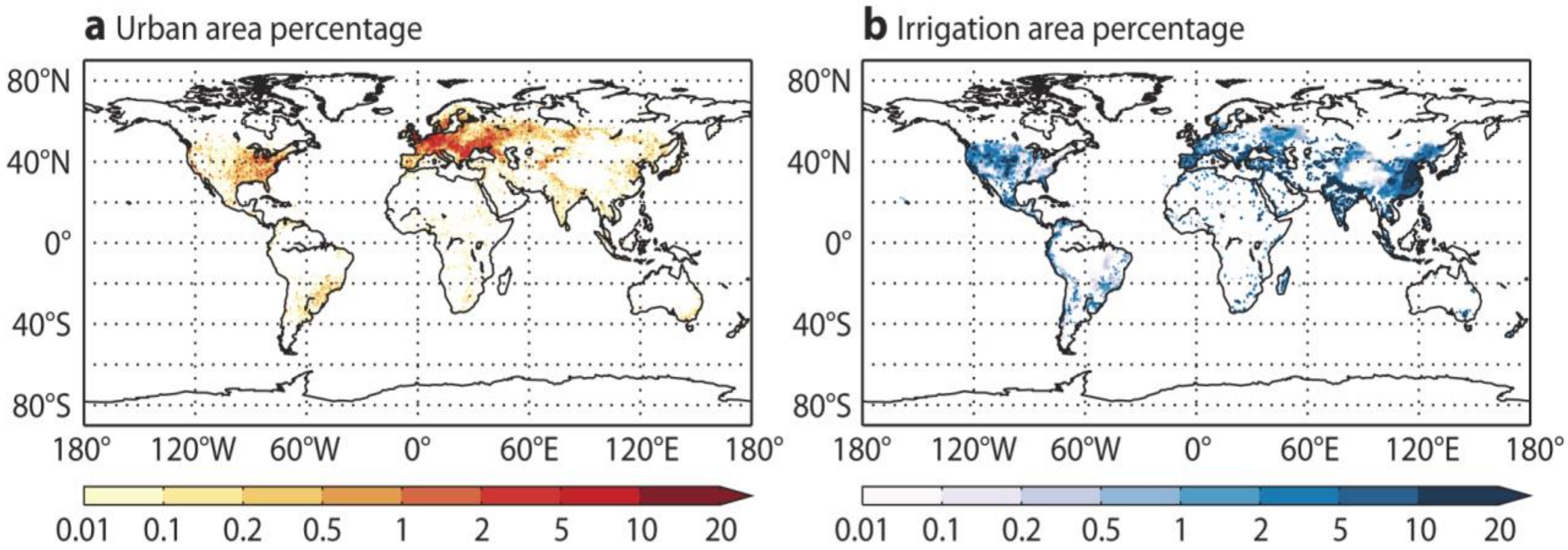




Globally Improved match to satellite soil moisture (shown is ΔACC calculate on 1-month running mean)

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.

# Missing surface components

- Human action on the land and water use is currently neglected in most models…




- Urban area (a, in %, from ECOCLIMAP, Masson et al., 2003) and
- Irrigated area (b, in %, from Döll and Siebert, 2002)

# Summary and Outlook

- Land-Atmosphere interaction is a core research area for sub-seasonal predictability. At ECMWF natural surface elements are parameterized guided by satellite EO data.
- Focusion on memory terms (soil moisture, vegetation, lakes) carry predictability potential provided a realistic coupling is in place and the geographical area is characterized by temporal variability.
- Initialization and data assimilation of new satellite EO-data support model development and provides observation guidance on required/sustainable complexity

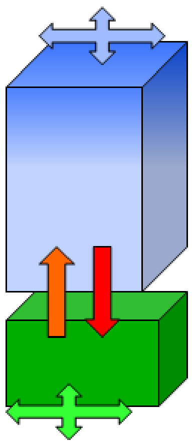
Ways forward for NWP/Monthly impact of land processes:

- Increase vertical resolution in the soil-snow-ice schemes would permit more timely interactions with the atmosphere and better heat-water distribution (this is demonstrated in recent results). Diurnal-cycle improvements affect all FC range.
- Improve physiography will lead to better prediction for the water, energy and $CO_2$.
- Anthropic surfaces will be considered (urban, irrigated areas) to improve the validity of forecasts where people live.

# Land Surface processes and error representation

Improving the realism of soil, snow, vegetation and lakes parameterisations has been subject of several recent research efforts at ECMWF. These Earth surface components work effectively as **energy and water storage** terms with **memory** considerably longer than the atmosphere counterpart.

Their role regulating land-atmosphere **fluxes** is particularly relevant in presence of large weather and climate anomalies (i.e. extreme events)

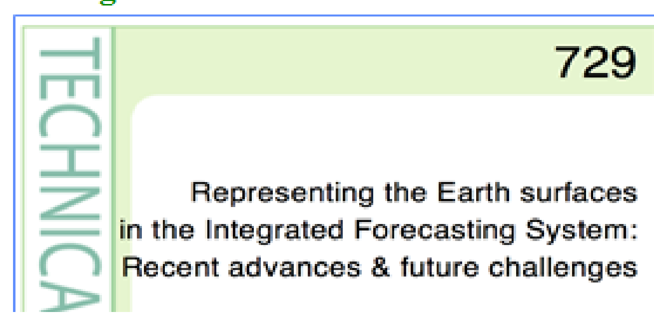


$$(\rho C)D\frac{\partial T_s}{\partial t} = R_n + LE + H + G$$

$$\frac{\partial TWS}{\partial t} = P + E - R$$

$$\frac{\partial CO2^A}{\partial t} = GPP + \mathrm{Re} + A$$

Validity for $H_2O$ / E / $CO_2$ cycles: surface R&D directed towards improved **storages** and **fluxes**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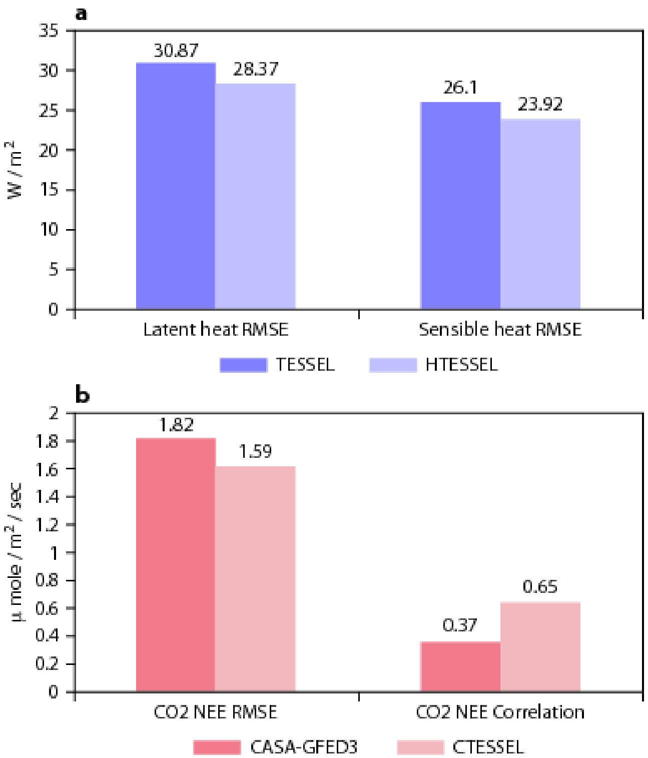
Representing the Earth surfaces
in the Integrated Forecasting System:
Recent advances & future challenges

# Land fluxes

The ERA-Interim/Land fluxes are validated with independent datasets used as benchmarking.



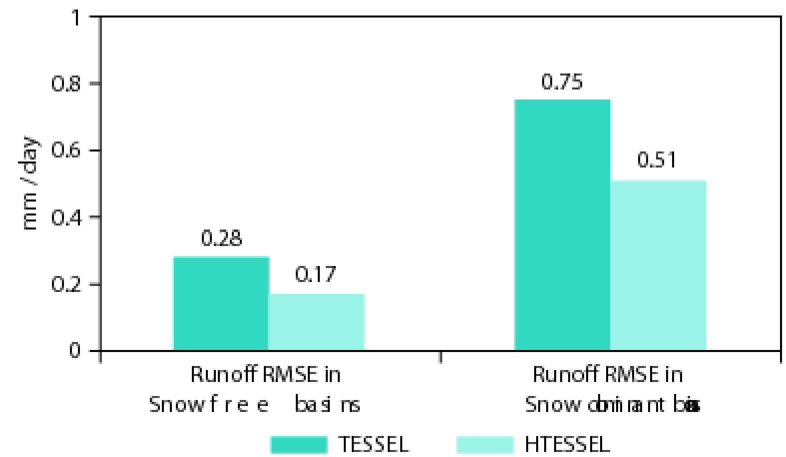

E

$CO_2$

GEOLAND-2 R&D support

Figure 1: Mean performance measured over 36 stations with hourly Fluxes from FLUXNET & CEOP Observations networks

## Validation of $H_2O$ / E / $CO_2$ cycles



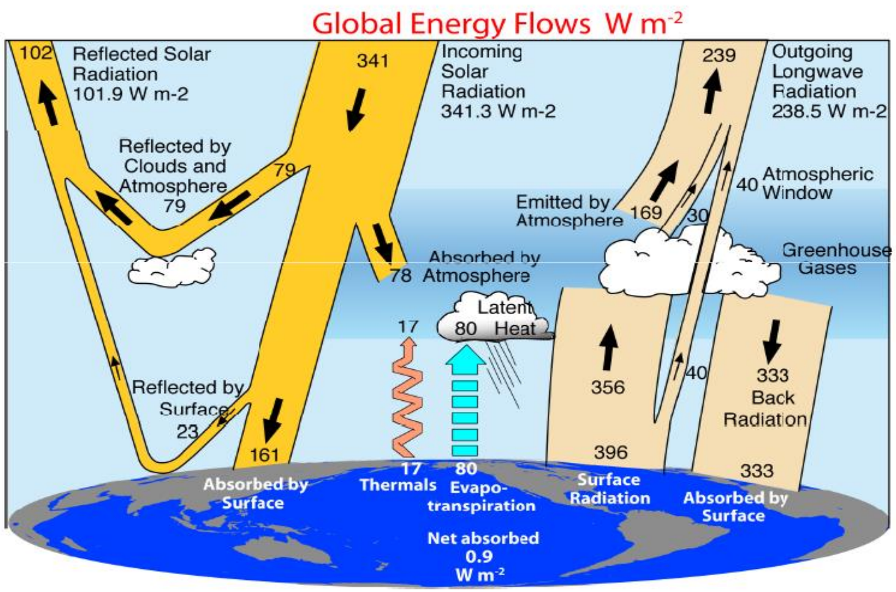

$H_2O$

Figure 2: Mean performance measured for the monthly rivers discharge verified with GRDC observations

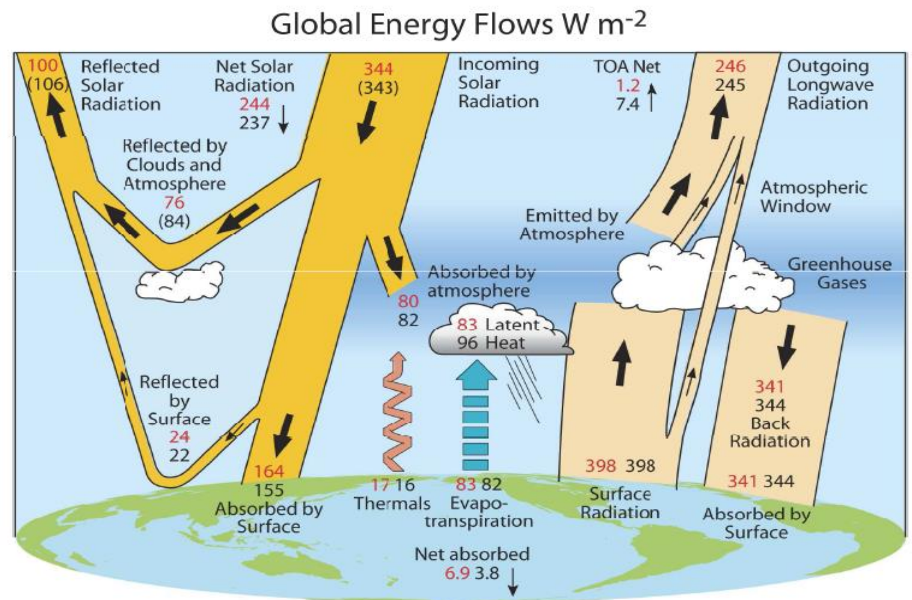
# Land surface role in reanalysis and climate

Atmospheric general circulation models need boundary conditions for the enthalpy, moisture (and momentum) equations: Fluxes of energy, water at the surface. This role has to evolve in Earth System Modelling

Trenberth *et al.* 2009:
Earth's global energy budget



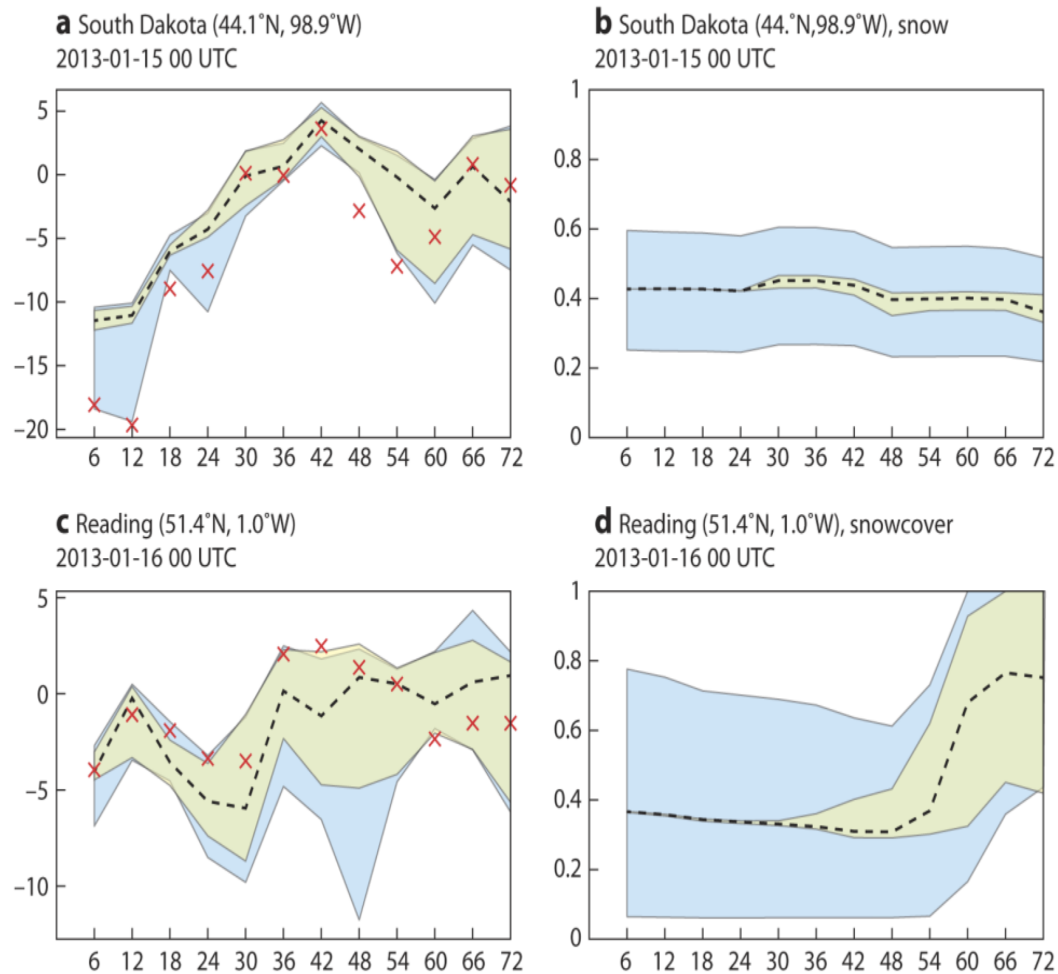

ERA-Interim 1989-2008 ERA-40 1989-2001




See also Wild et al 2015 as presented at ECMWF Annual Seminar http://www.ecmwf.int/en/annual-seminar-2015

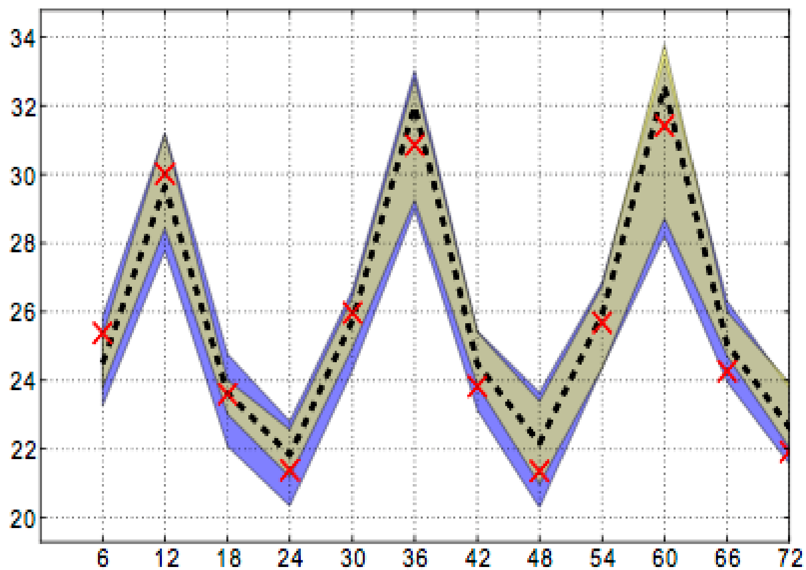
# Snow related uncertainties

- EDA/ENS system includes land surface components (CY40R1) and perturbation also to the assimilated observations (CY40R3)
- Accounting for land surface uncertainties (particularly for snow) enhances the ensemble spread of 2m temperature prediction and its usefulness for forecasters
- The uncertainty is situation dependent and perturbations permit to capture the occurrence of extremes (e.g. clear sky nights combined with snow covered surface can generate very cold temperatures)
- Small snow cover errors → large temperature impact

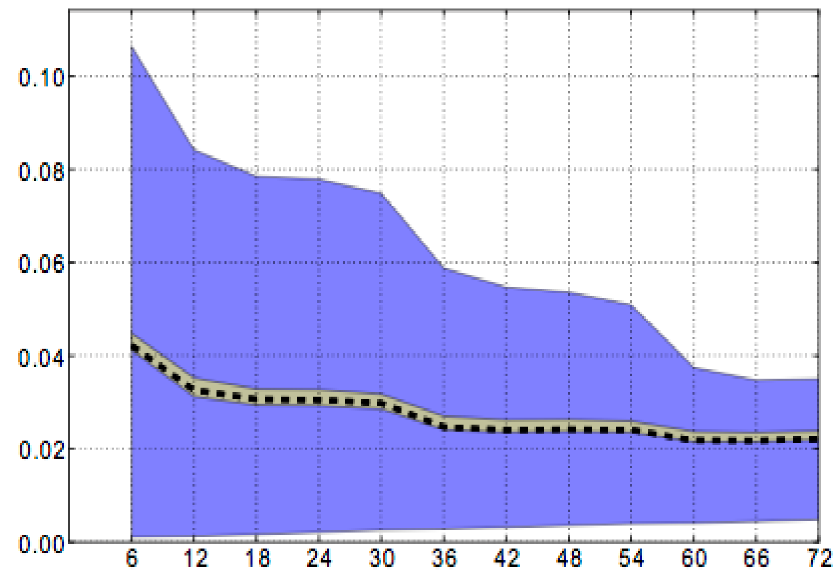


# Soil moisture related uncertainties

- EDA/ENS system includes soil moisture which obtain a more homogeneous spread in the 2m temperature forecast.



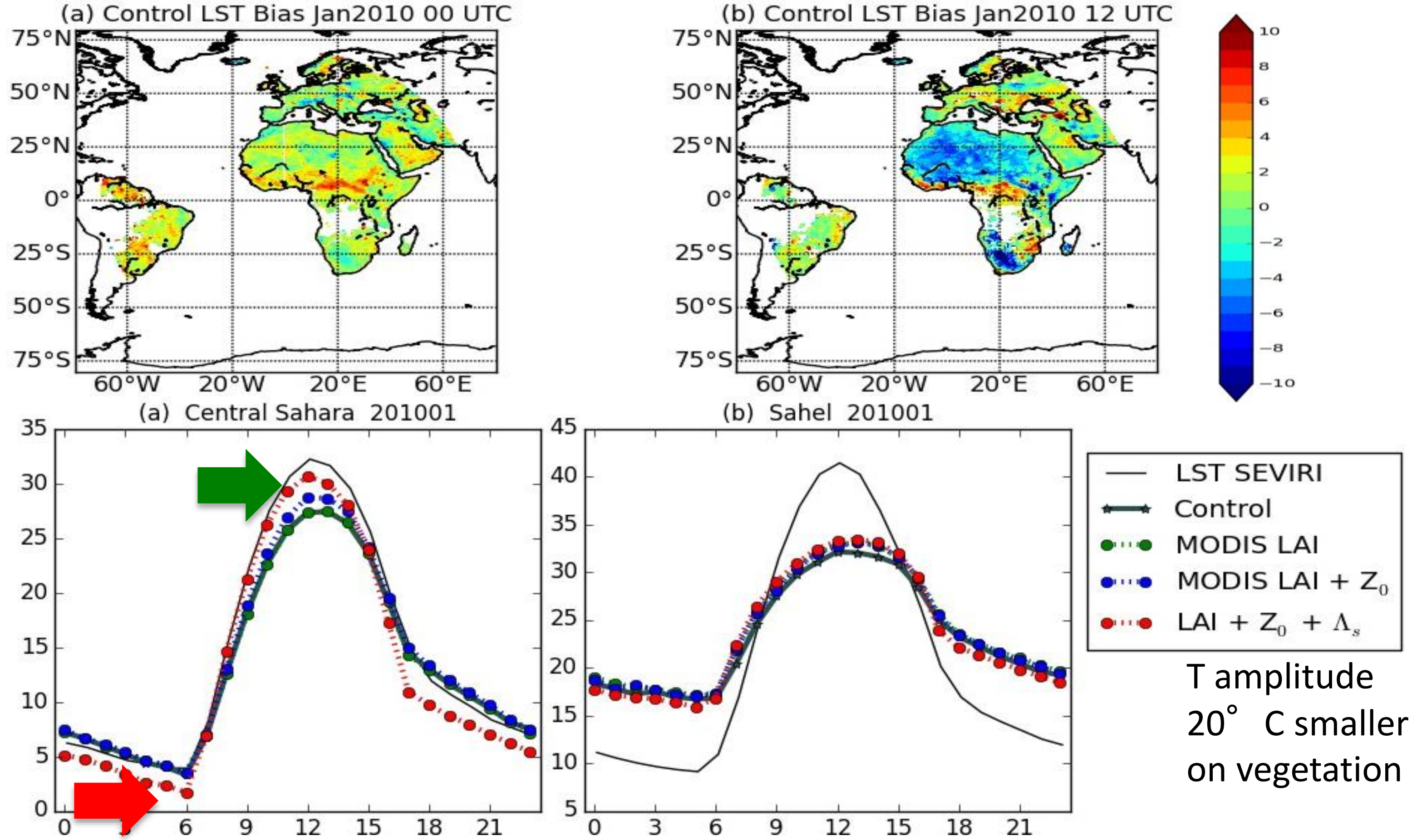

(e) Somalia, (6.7 °N, 48.4 °E), 2m temperature, 2012-12-18 00 UTC




(f) Somalia, (6.7 °N, 48.4 °E), volumetric soil water in layer 1, 2012-12-18 00 UTC

# Diurnal cycle and vegetation variability

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

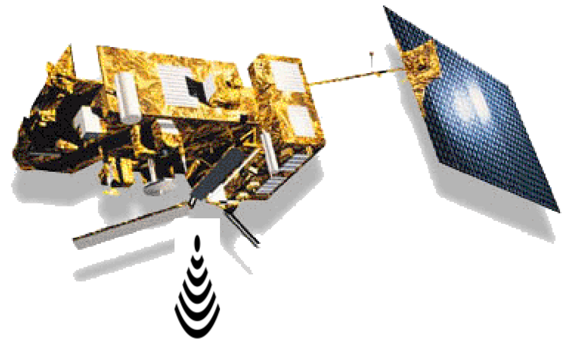


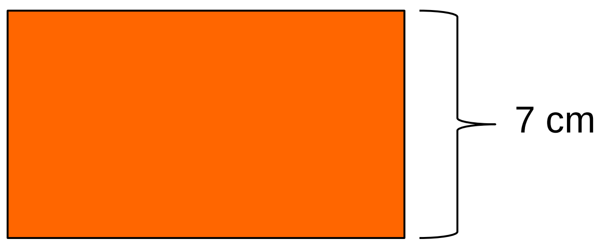

T amplitude 20° C smaller on vegetation

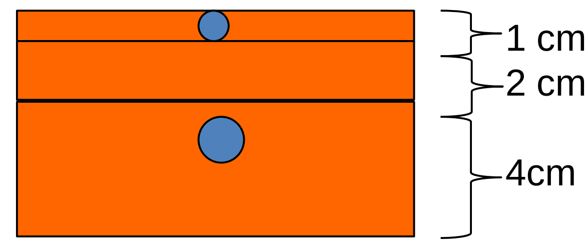
**Findings of large biases in the diurnal temperature reposed on the use of MSG Skin Temperature. However with the current model version we are limited (both over bare soil and vegetation)**

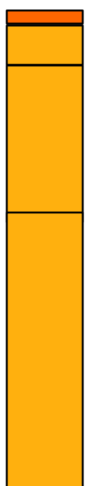
# An enhanced soil vertical resolution

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

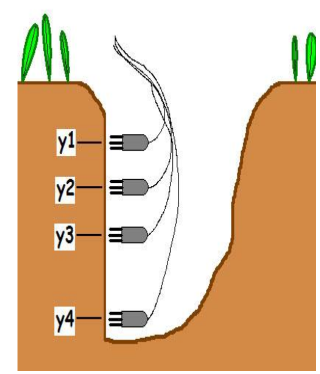
# 25-50 cm

# 50-100 cm

# 100-200 cm

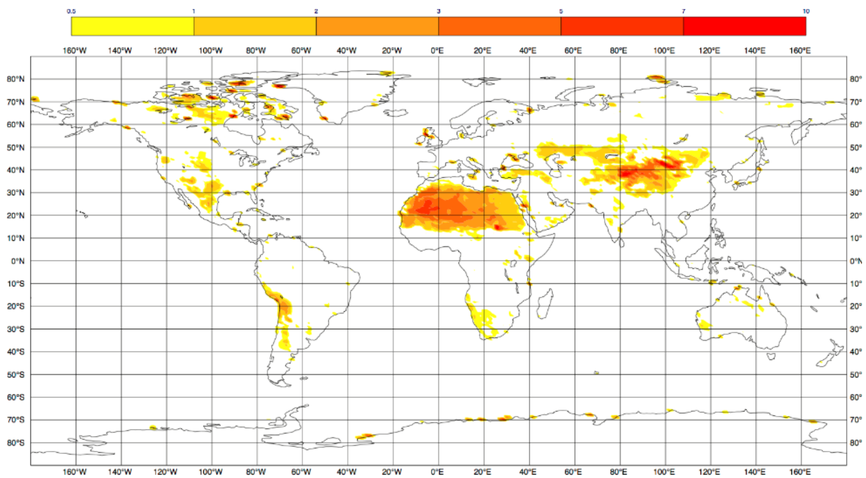
# 200-400 cm

**# 400-800 cm**



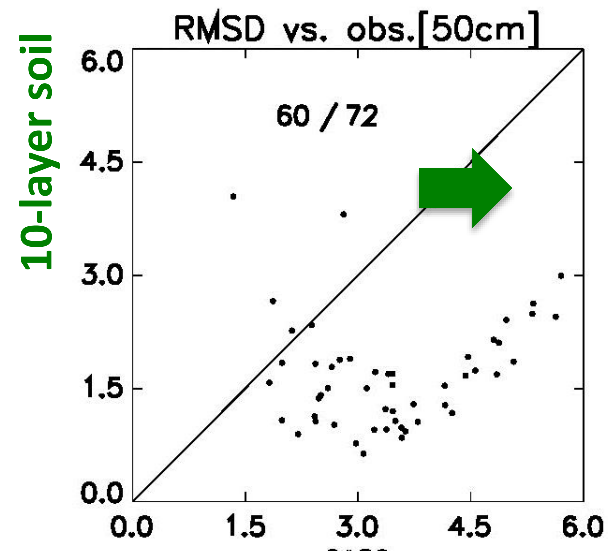
# Impact of soil vertical resolution on soil temperature

Sensitivity Max Tskin for July 2014



Higher T-max at the L-A interface
up to 3 degrees warmer on bare soil
(without symmetric effect on Tmin!)
Offline simulations with **10-layer soil**
Compared to **4-layer soils**

In-situ validation at 50cm depth
(on 2014, 64 stations)
Results by Clément Albergel




**4-layer soils**

Improved match to deep soil temperature
(shown is correlation and RMSD)

Correlation with in-situ soil temperature validate the usefulness of increase soil vertical resolution for monthly timescale (0.50 cm deep). Research work will continue using satellite skin temperature data (2nd visit of René Orth ETH).

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