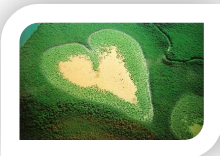
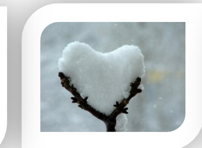
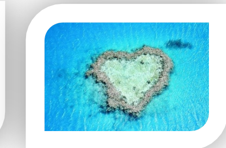
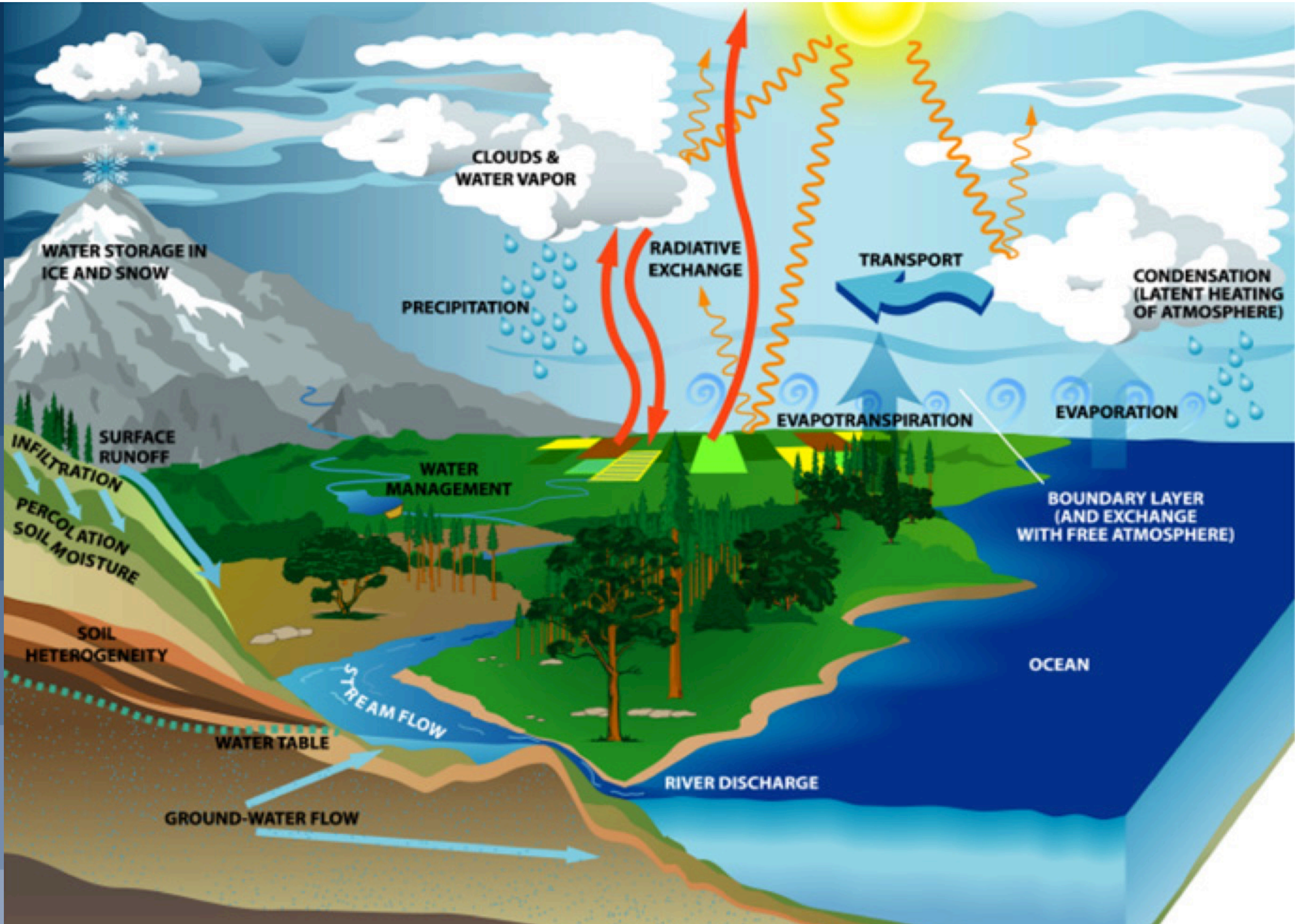
Land-Atmosphere interaction processes: Forecasting surface conditions

Gianpaolo Balsamo

ECMWF EUROPEAN CENTRE FOR MEDIUM-RANGE WEATHER FORECASTS

- **Introducing the land surface**
- Processes at Land-Atmosphere interface and their parameterisation in NWP
- Land perturbations for characterising uncertainties
- Outlook



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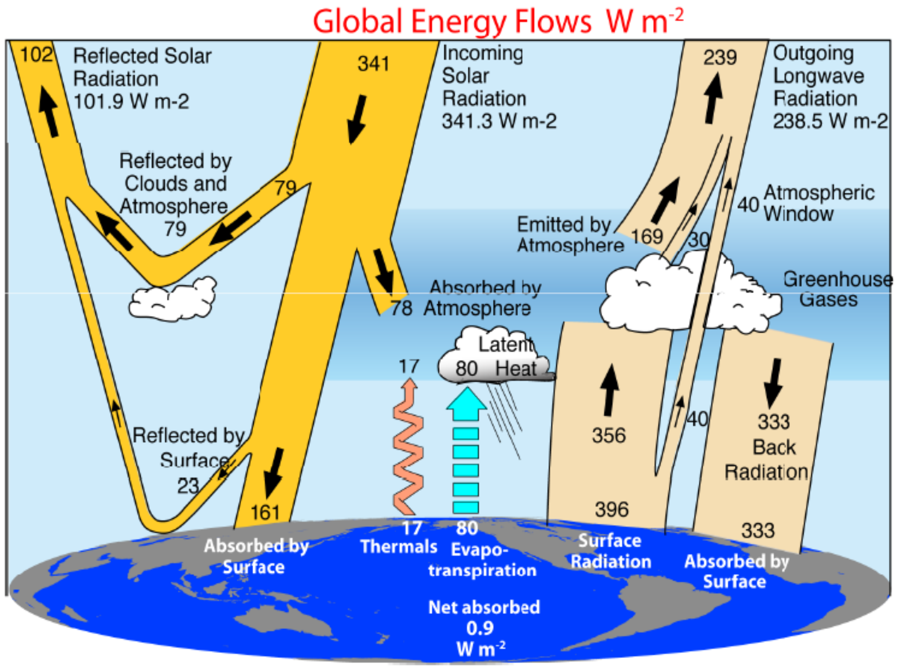
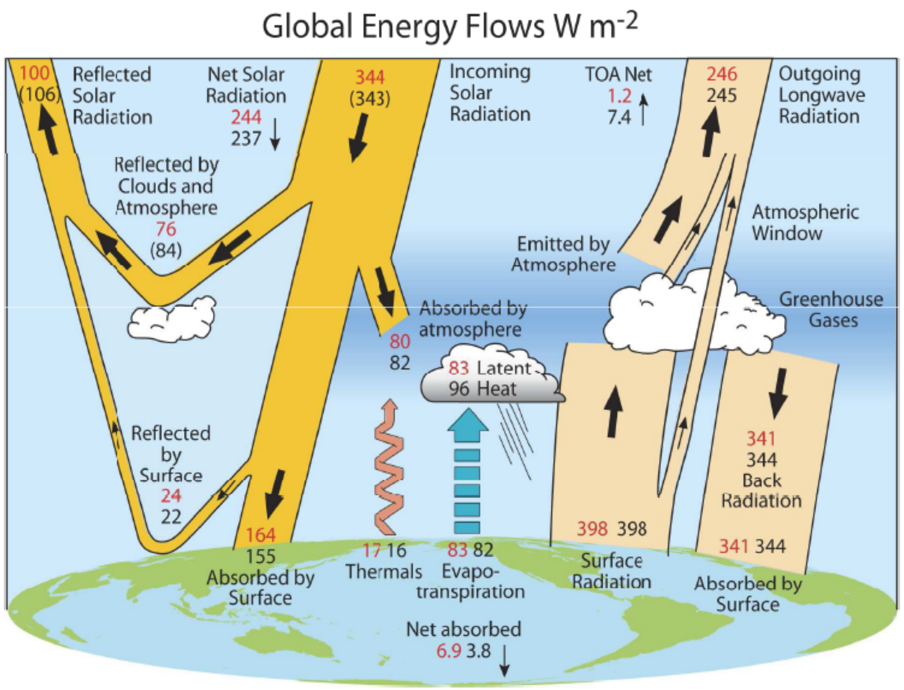
What is the role of land surface?

Atmospheric general circulation models need boundary conditions for the enthalpy, moisture (and momentum) equations: Fluxes of energy, water at the surface.

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



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



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

- Tiled ECMWF Scheme for Surface Exchanges over Land

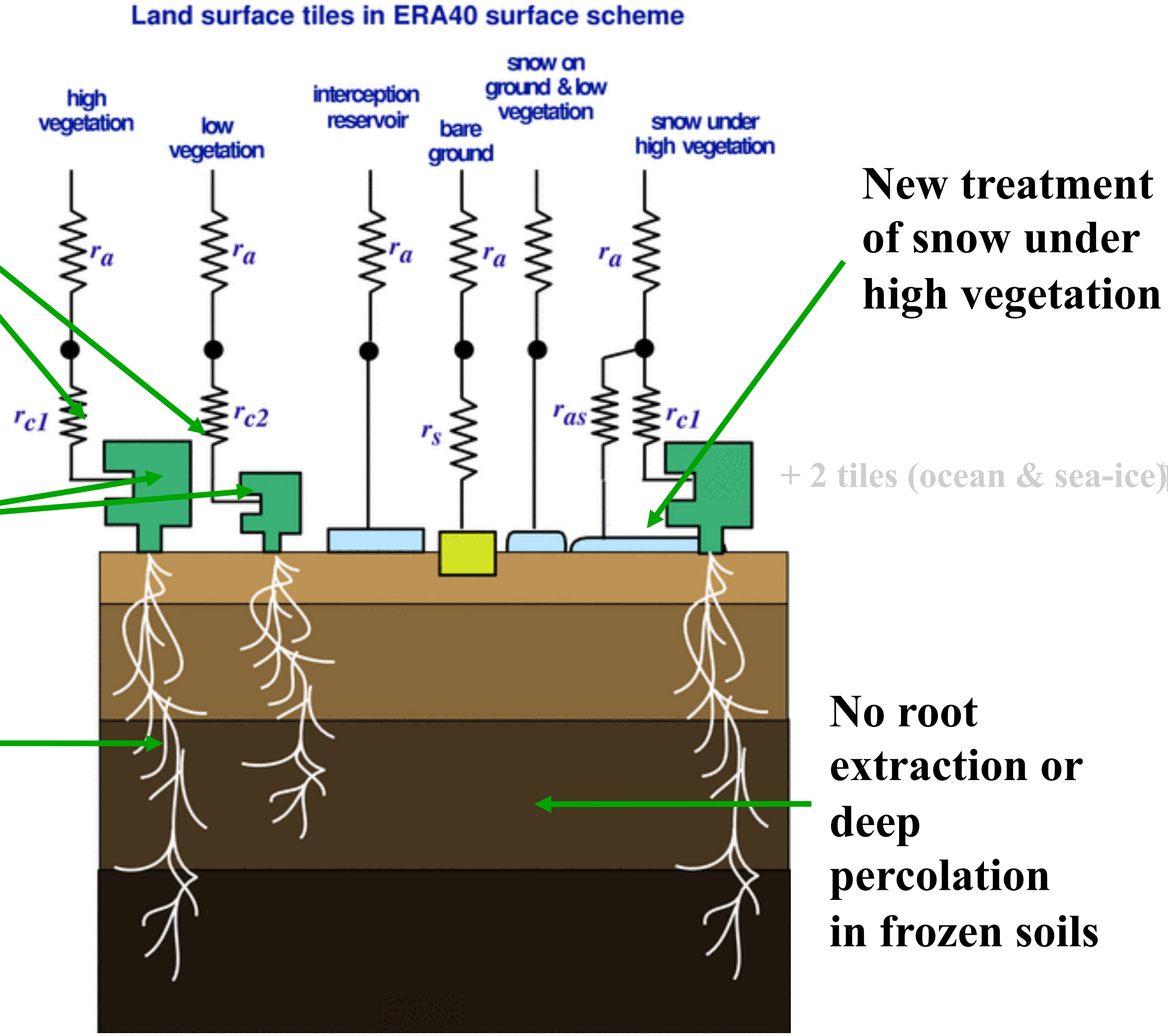
Revised canopy resistances, including air humidity stress on forest

High and low vegetation treated separately

Variable root depth

New treatment of snow under high vegetation

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**

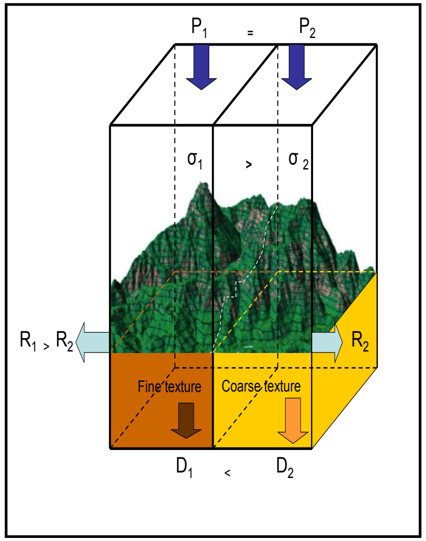
  Mironov et al (2010),

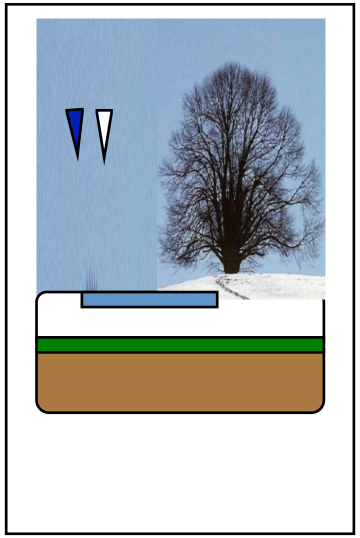
  Dutra et al. (2010),

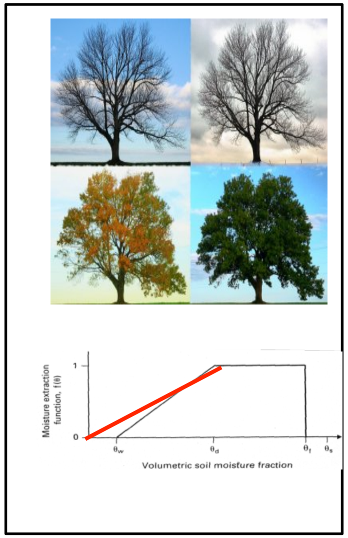
  Balsamo et al. (2012, 2010)

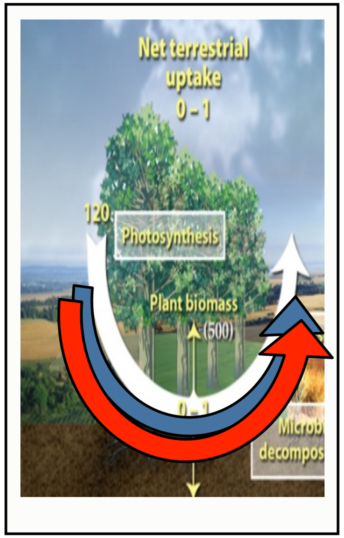
  Extra tile (9) to for sub-grid lakes and ice

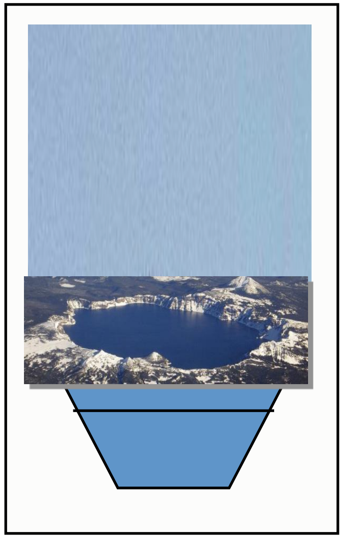
  LW tiling (Dutra)





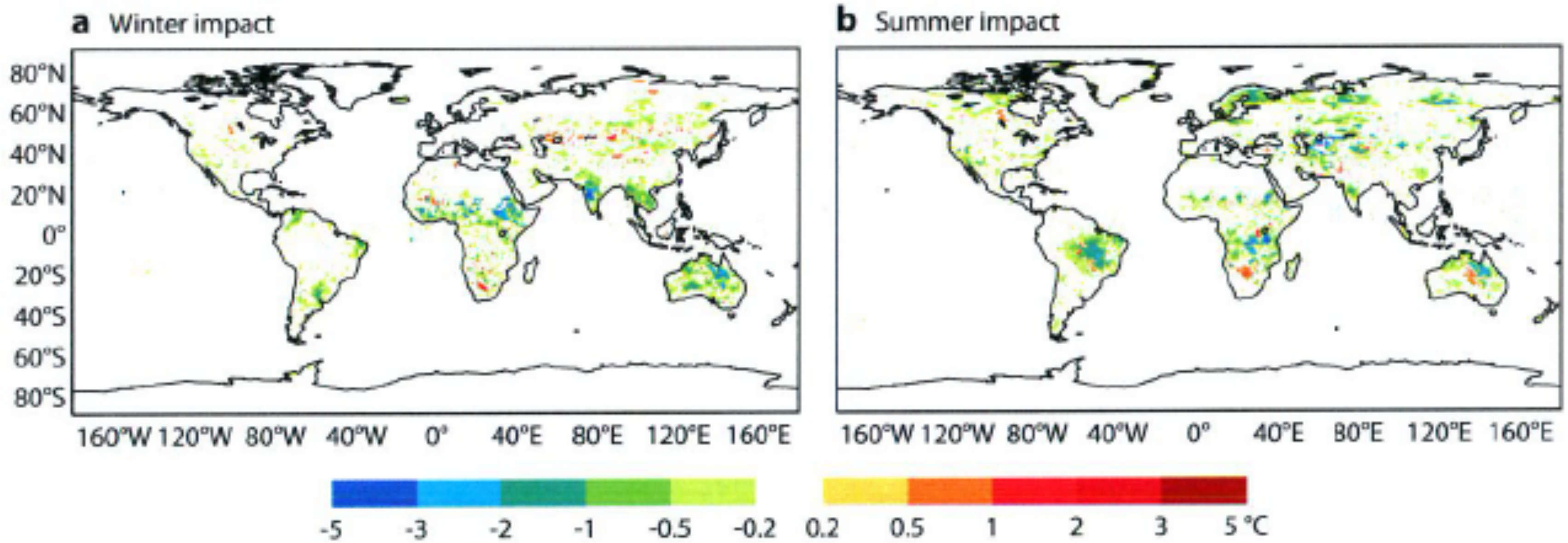






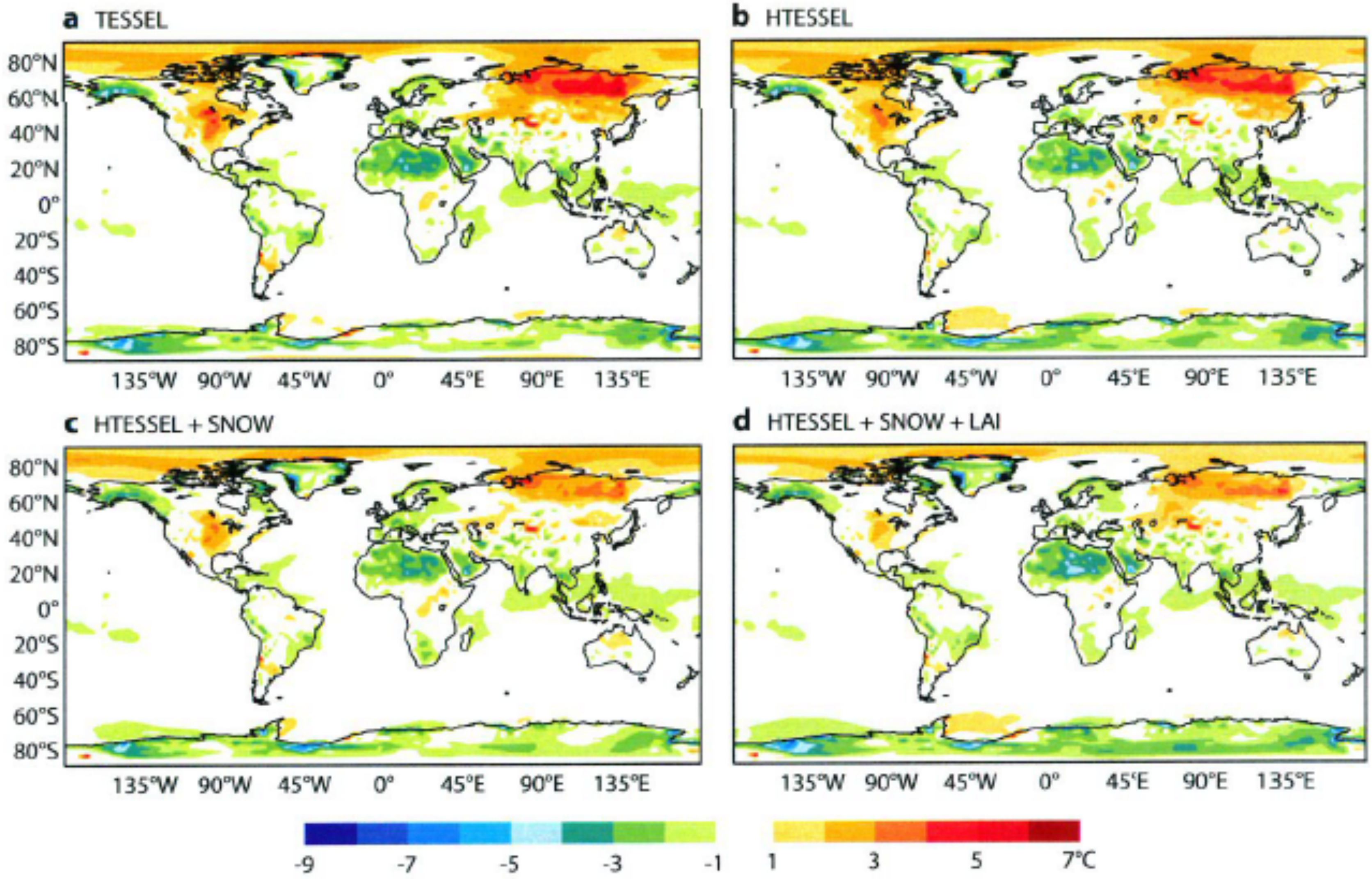
Forecasts impact of improved soil/snow hydrology

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



Improving 2m temperature Degrade 2m temperature

Climate and impact of land surface development

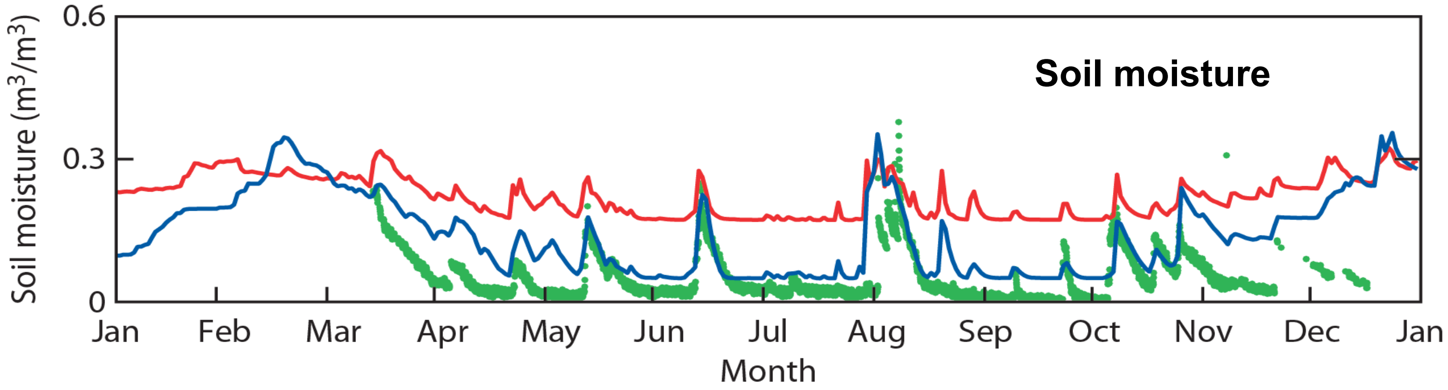


simulations colder than ERA-Interim Warmer than ERA-Interim

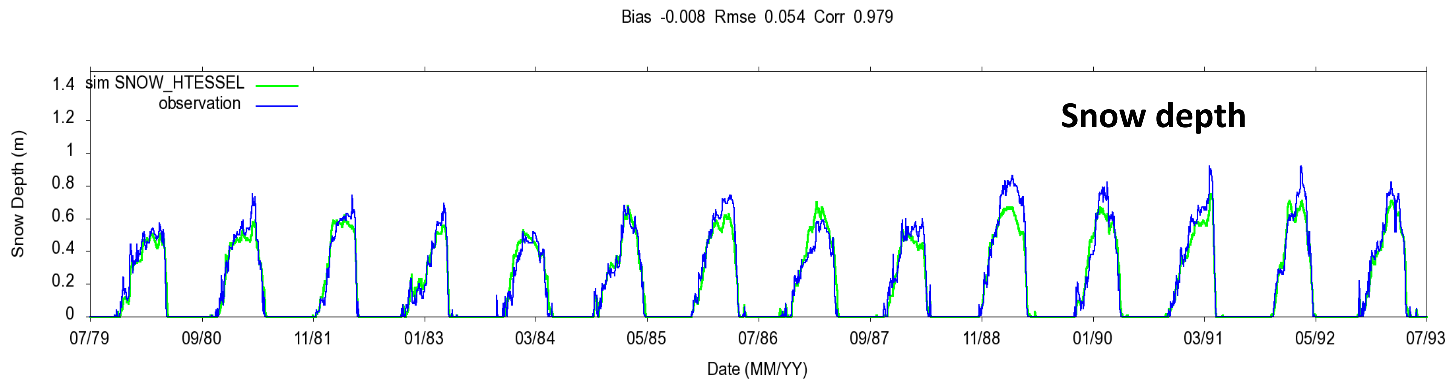
Land water storages verification

Balsamo et al. (2015 HESS)

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



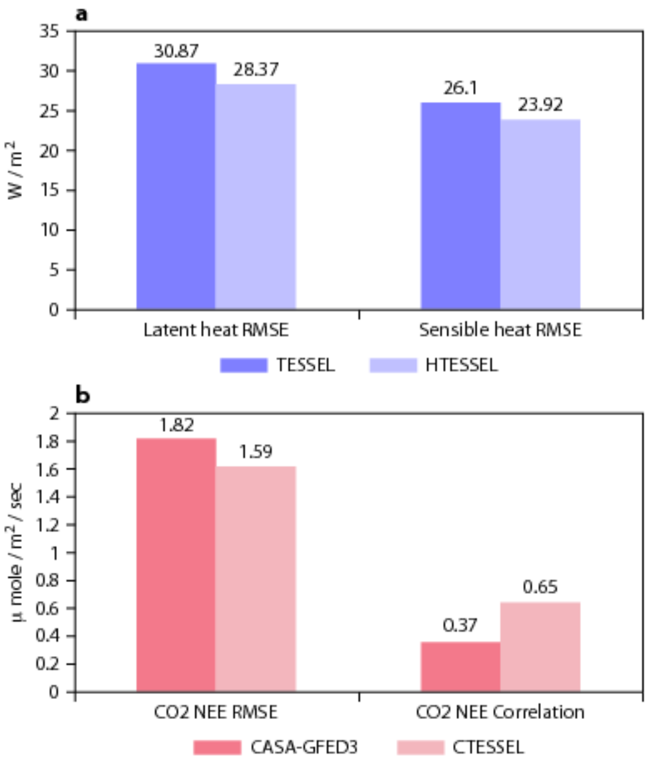
Evolution of soil moisture for a site in Utah in2010. Observations, ERA-Interim, and ERA-Interim/Land.



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.

ERA-Interim/Land: fluxes verification

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



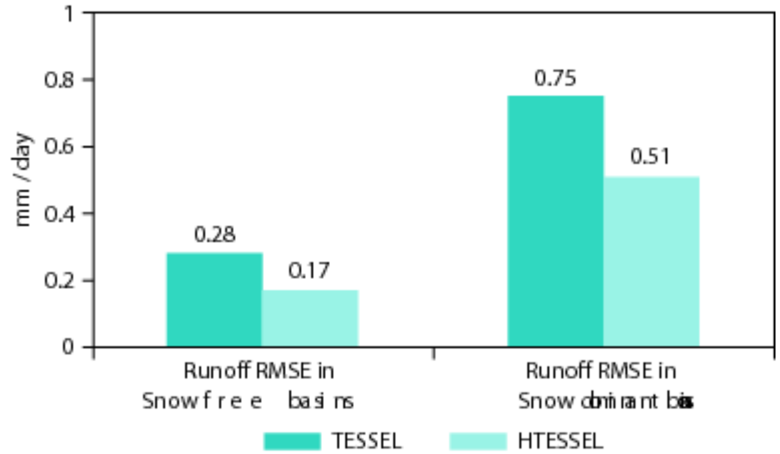
E

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

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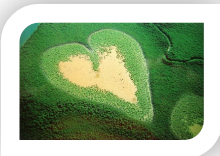
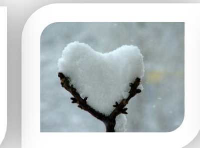
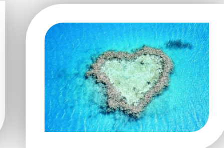
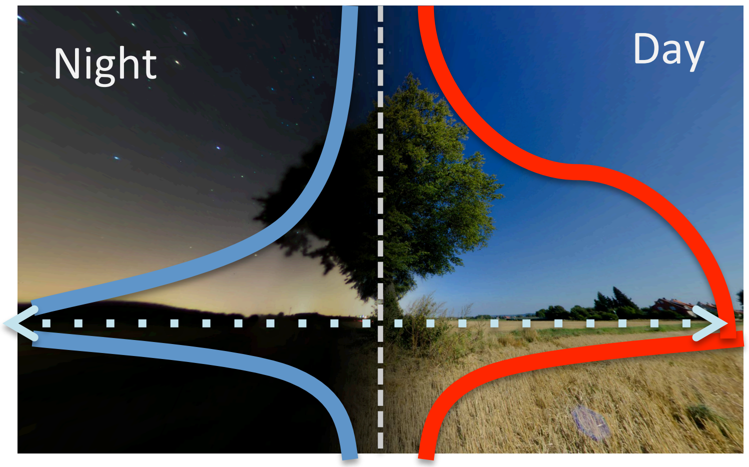
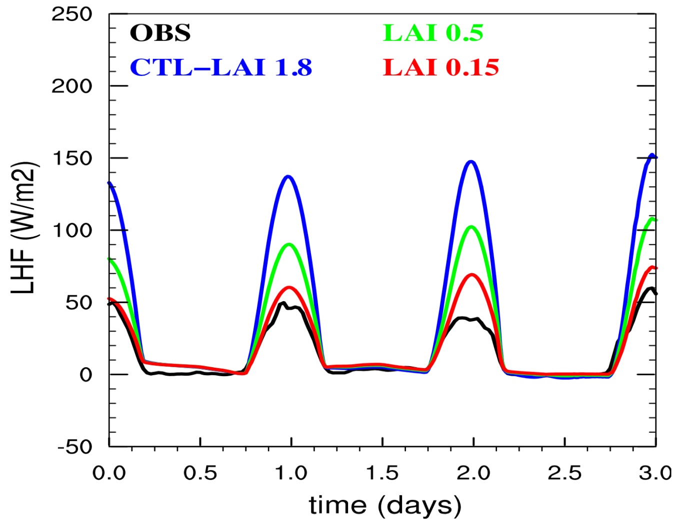




Coupling with the vegetation/soil layer with Atmosphere



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

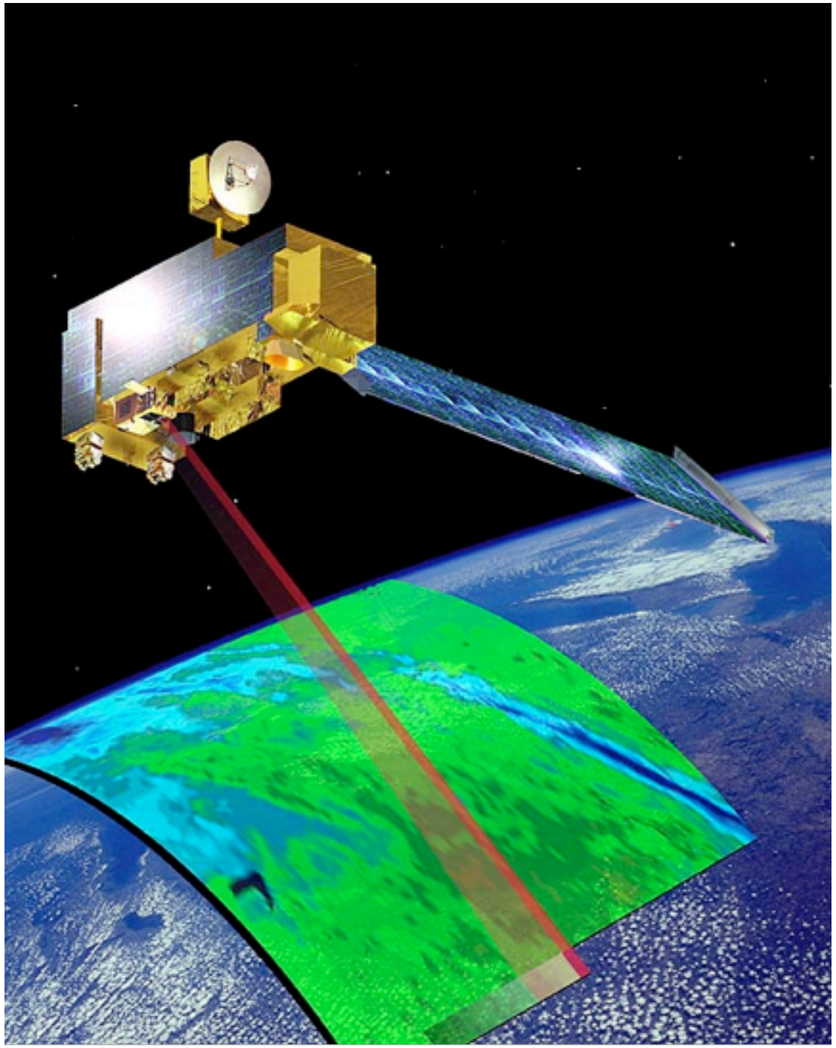


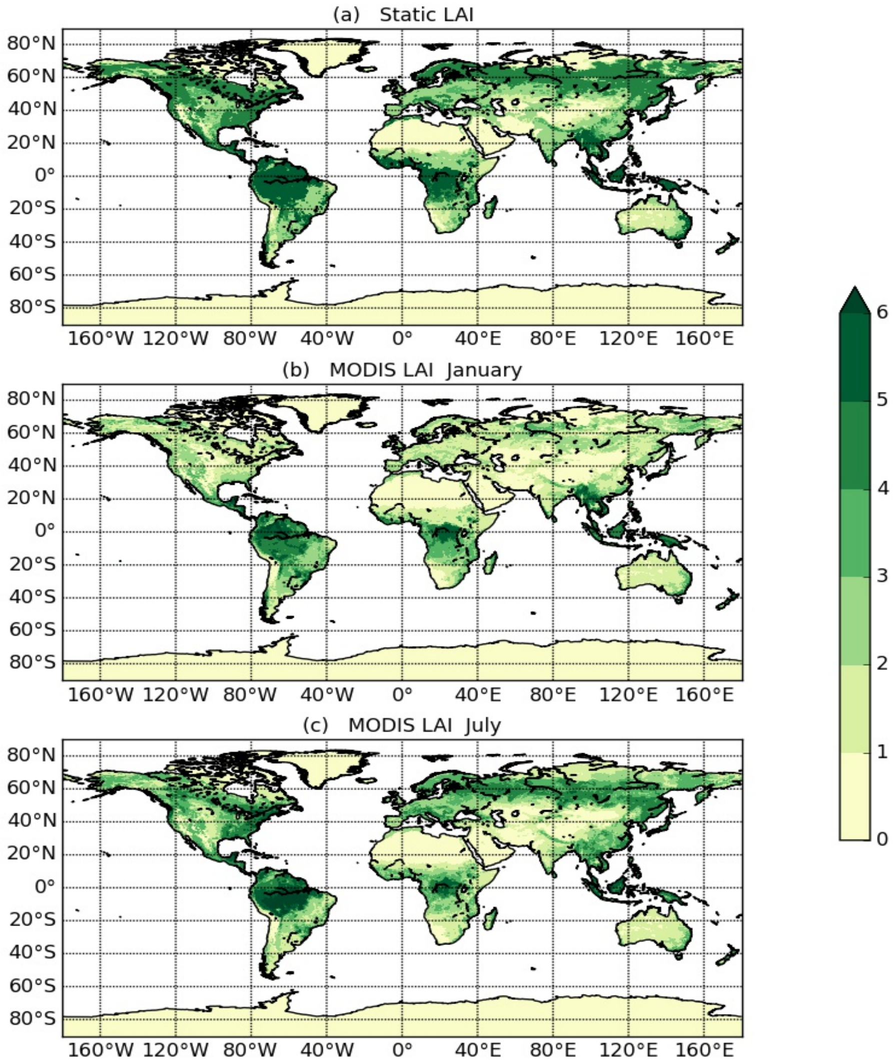
Sandu et al. 2014 (GEWEX poster)

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

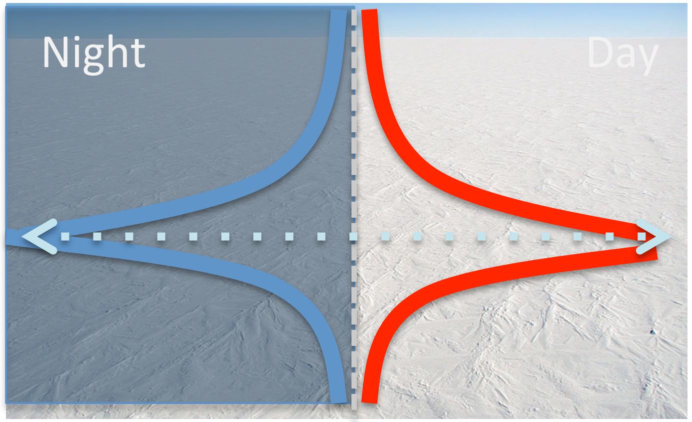
Important to know vegetation state and its activity (e.g. using Sentinel satellite fluorescence data).
Vegetation cover variability is most important for NWP and linked with physiography work.
See presentation from Souhail for phenology impact

Vegetation state from satellite data

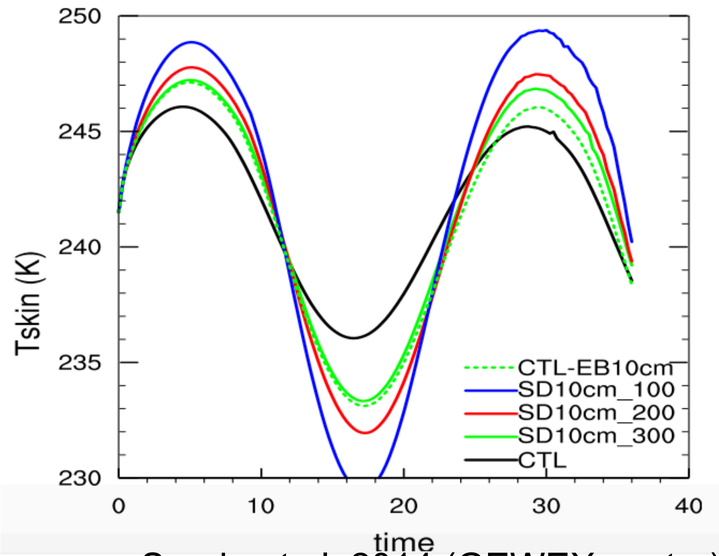




Coupling and diurnal cycle: snow and ice



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



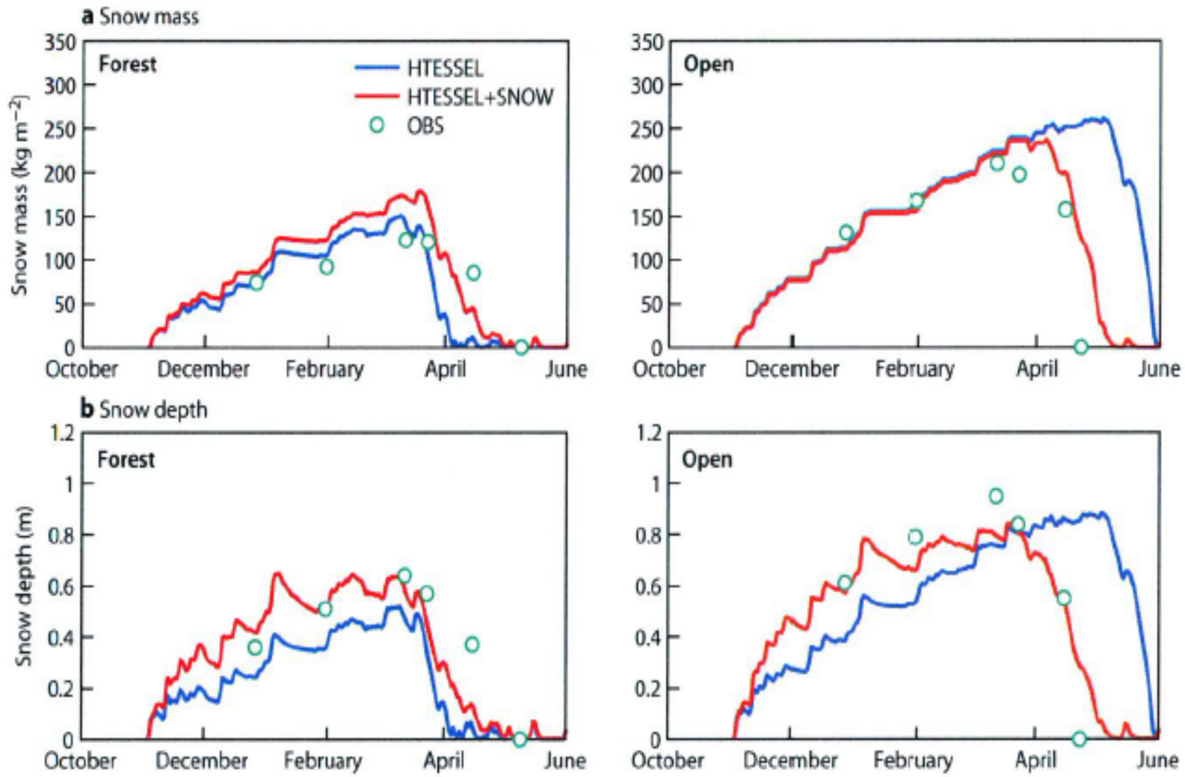
Sandu et al. 2014 (GEWEX poster)

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.

Snow-pack modelling

Dutra et al. 2010 JHM, Balsamo et al. 2011 EC-NL



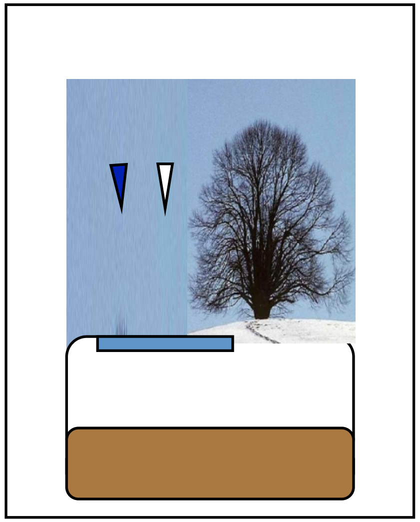
- **SL1 SNOW**

  Dutra et al. (2010)

  Improved snow density

  Liquid water (diagnostic)

  Revision of Albedo
  and sub-grid snow
  cover

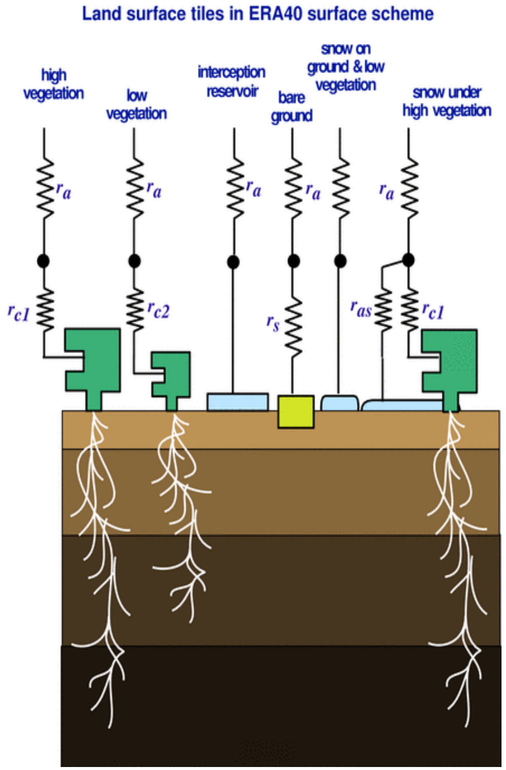


The key elements of the current ECMWF snow schemes developed under EC-Earth collaboration (IPMA-Portugal) are in the treatment of snow density (including the capacity to hold liquid water content in the snowpack). The SNOWMIP 1&2 projects with their observational sites have been essential for the calibration/validation of the new scheme which was improved with respect to the ERA-Interim snow scheme.

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

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



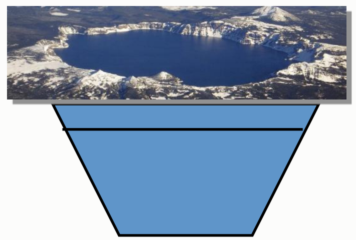
- **Lake tile**

Mironov et al (2010),

Dutra et al. (2010),

Balsamo et al. (2010, 2012, 2013)

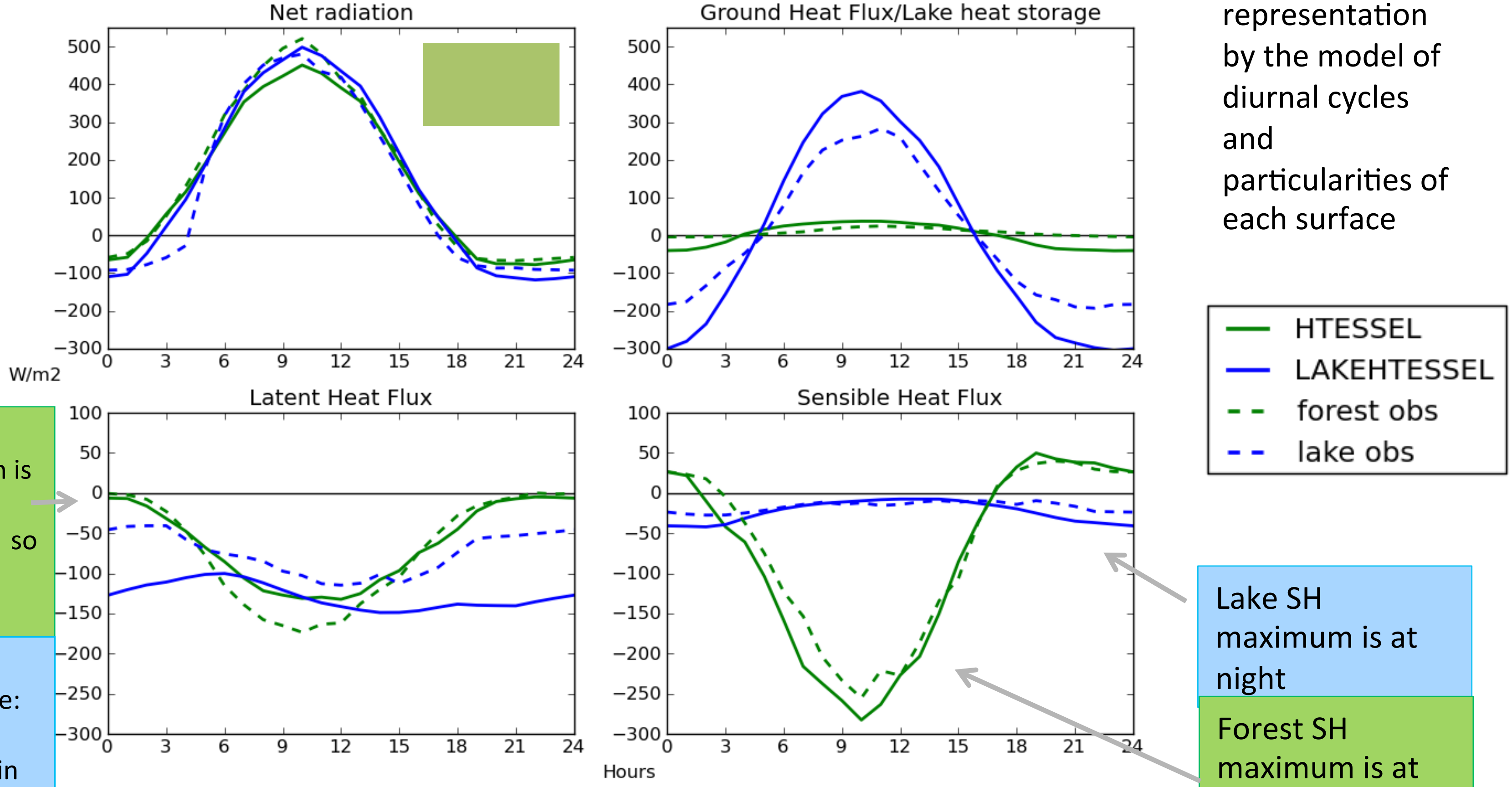
Extra tile (9) to account for sub-grid lakes



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

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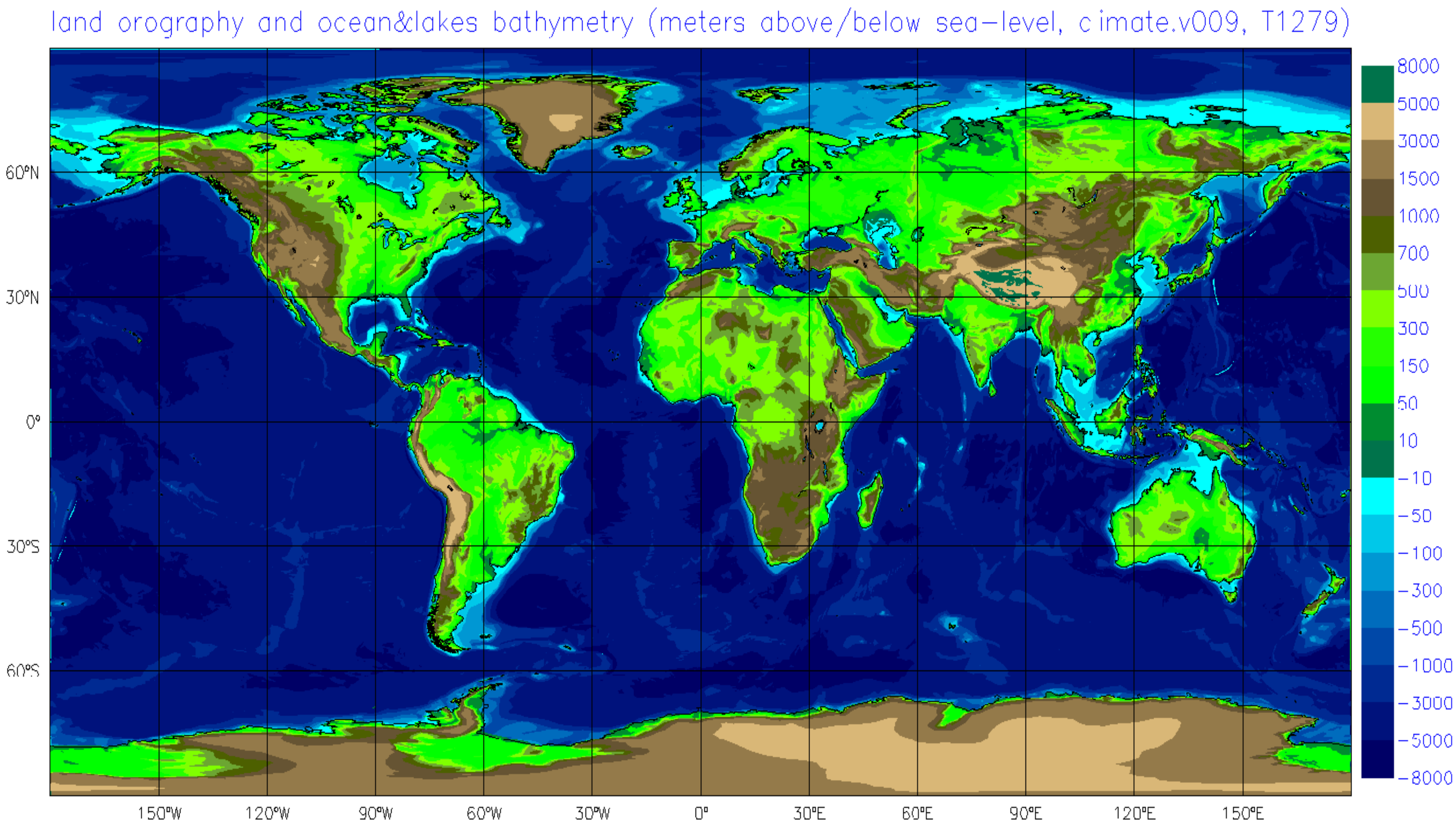
Operational inland-water bodies in IFS cycle 41r1 (May 2015)



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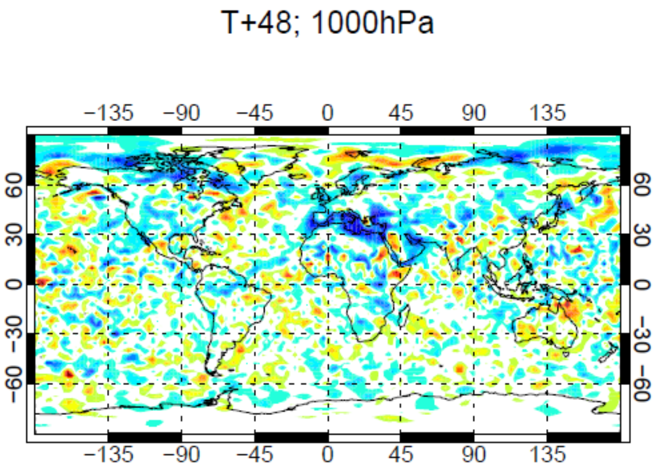
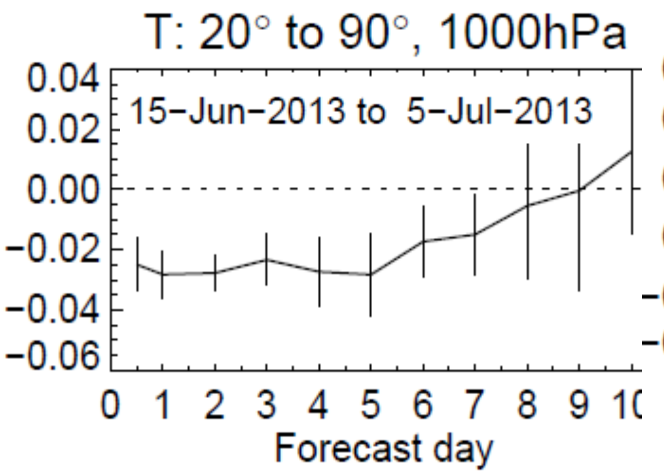
Impact of water bodies in the 40R3 analysis cycles

Summer experiment

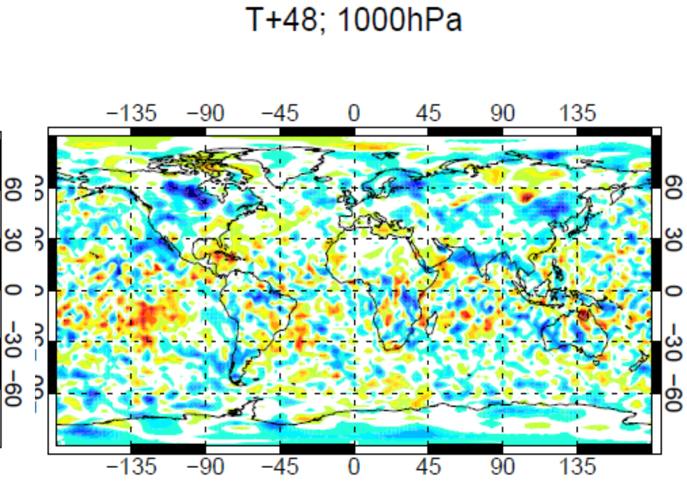
(Temperature scores)

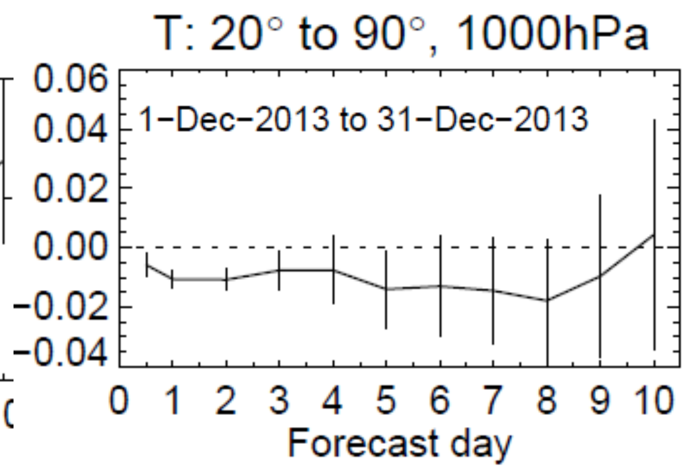




Winter experiment

(Temperature scores).



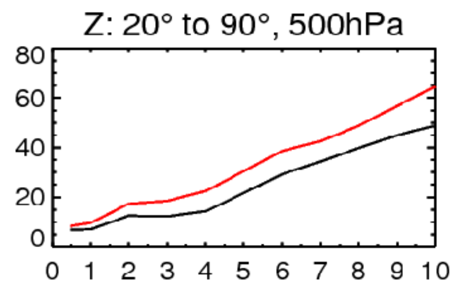


In CY40R3 forecast of 2m temperature are improved in proximity of lakes and coastal areas

Winter RMSE impact is positive as well but around 1% improvement

In summer the impact is estimated in 2-3% relative improvement in RMSE of T1000hPa significant up to 7 days

In summer also the Z500 mean error is reduced



First results from the lake operational monitoring

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

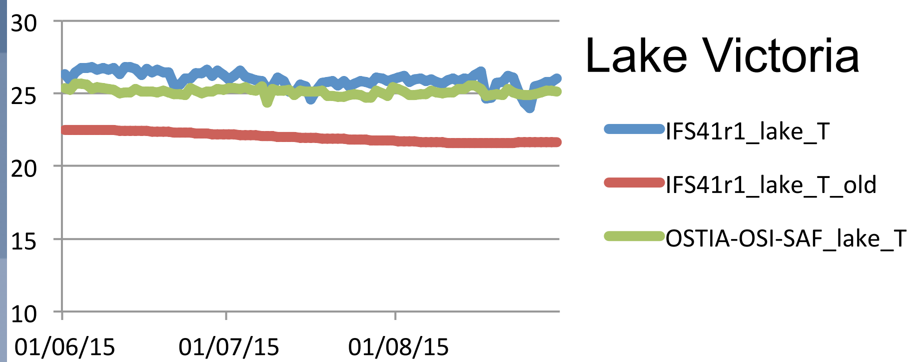
Lake AFRICA	RMSE	BIAS	Correlation	Mean Model	Mean Obs	Stdev Model	Stdev Obs
Victoria_IFS41R1	0.957	0.826	0.491	25.665	24.849	0.554415	0.230933
Victoria_IFS40R1	3.157	-3.14	0.328	21.743	24.849	0.322463	0.230933

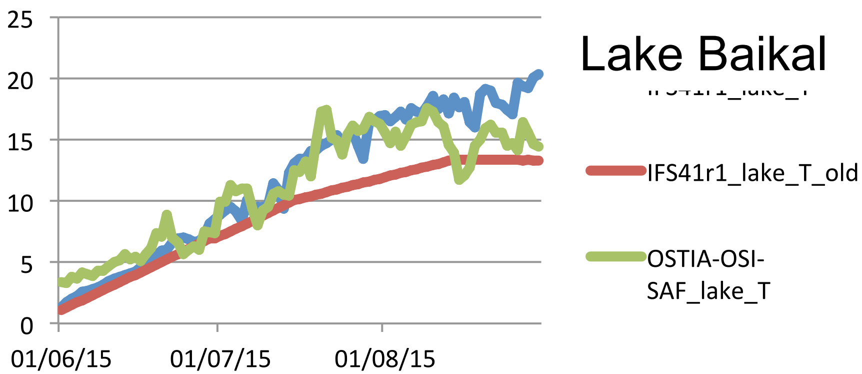
Lake CANADA	RMSE	BIAS	CORR	Mean Model	Mean Obs	Stdev Model	Stdev Obs
Great_Bear_IFS41R1	2.875	1.877	0.927	5.225	3.368	3.87317	1.96852
Great_Bear_IFS40R1	5.401	4.598	0.894	7.916	3.368	4.45394	1.96852

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





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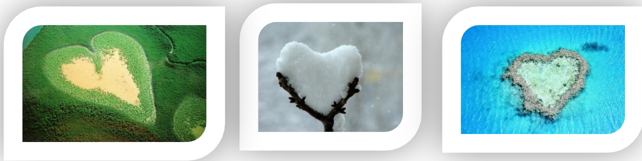
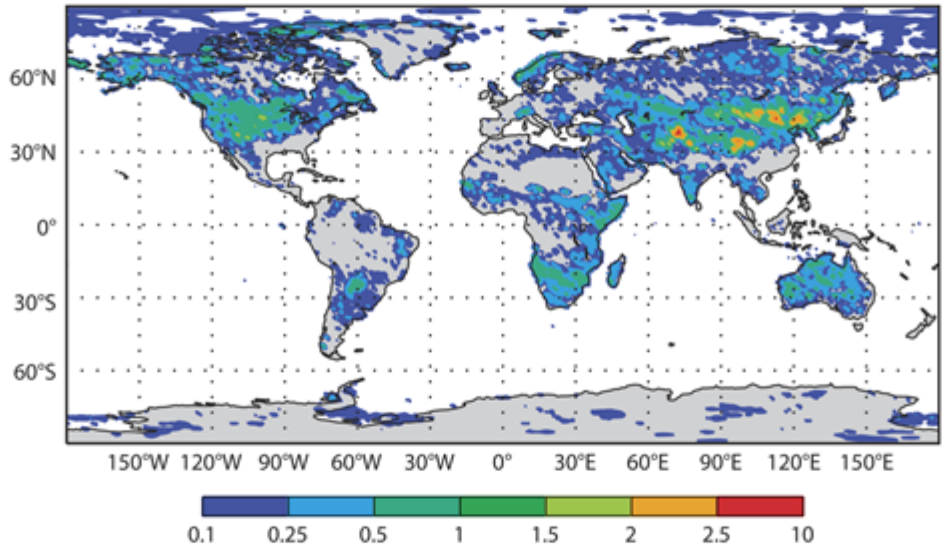


Representing land-related forecast uncertainties

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

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

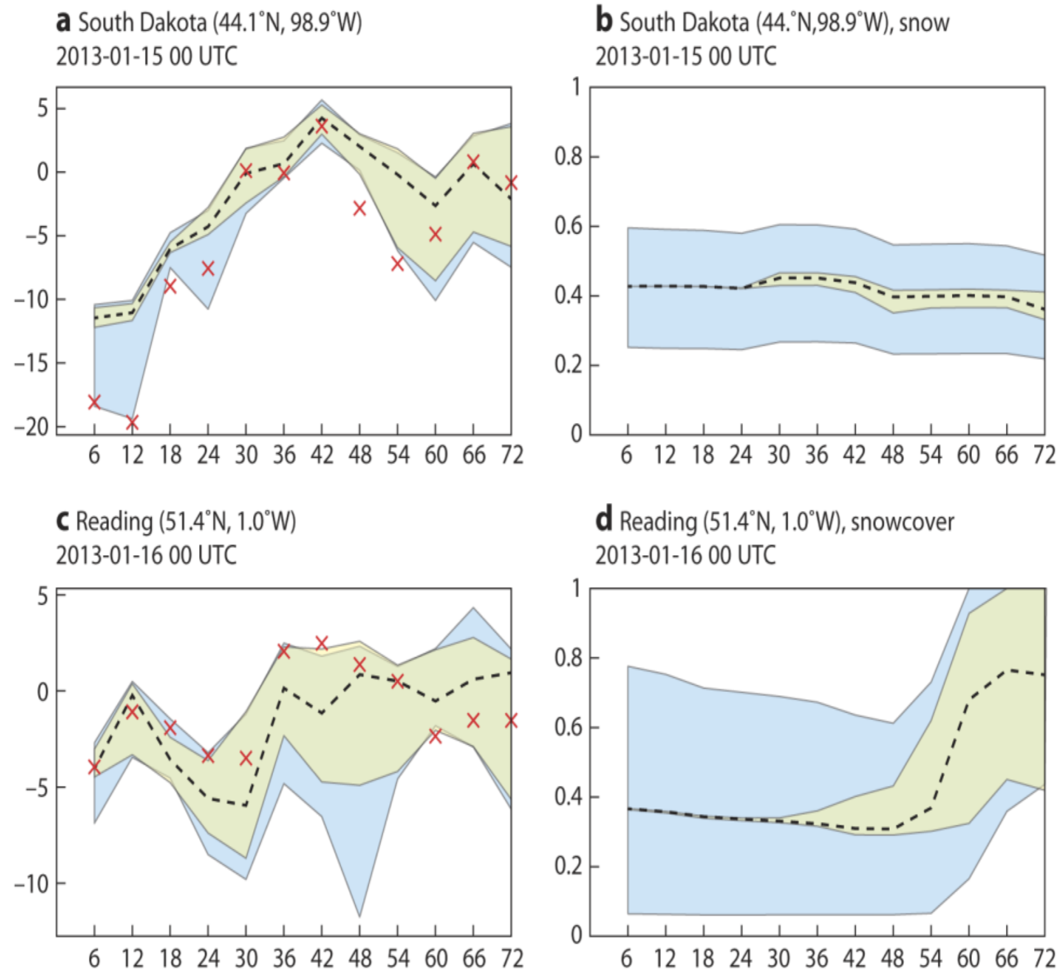


The effects are visible on the 2-m temperature ENS spread which is enhanced 12 hours forecast (compared to no-surface-perturbations)

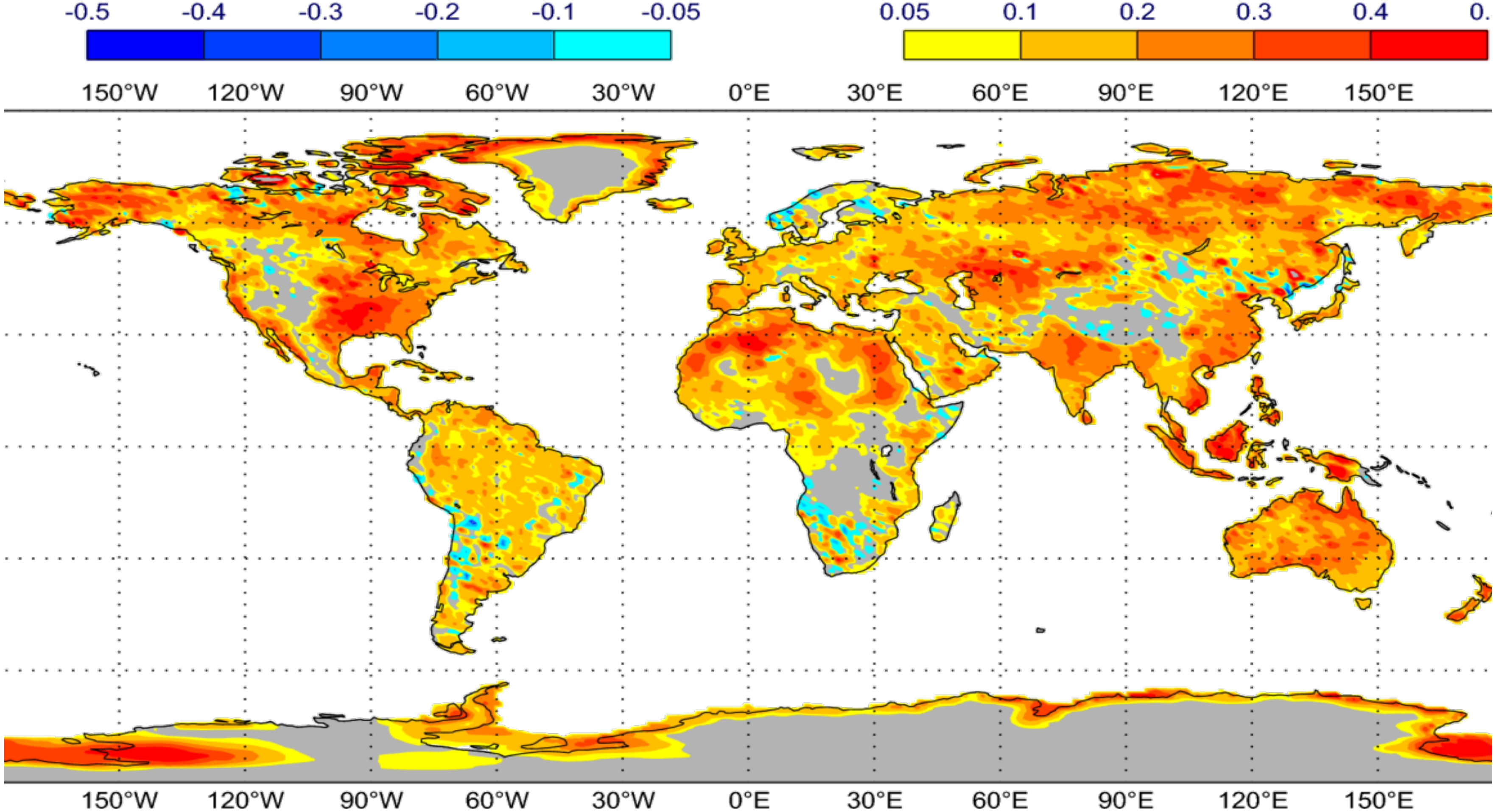
- The perturbation of the near surface observations used in EDA surface analyses permit to enhance the spread in near surface temperatures by a further 0.5-1 K.

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 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

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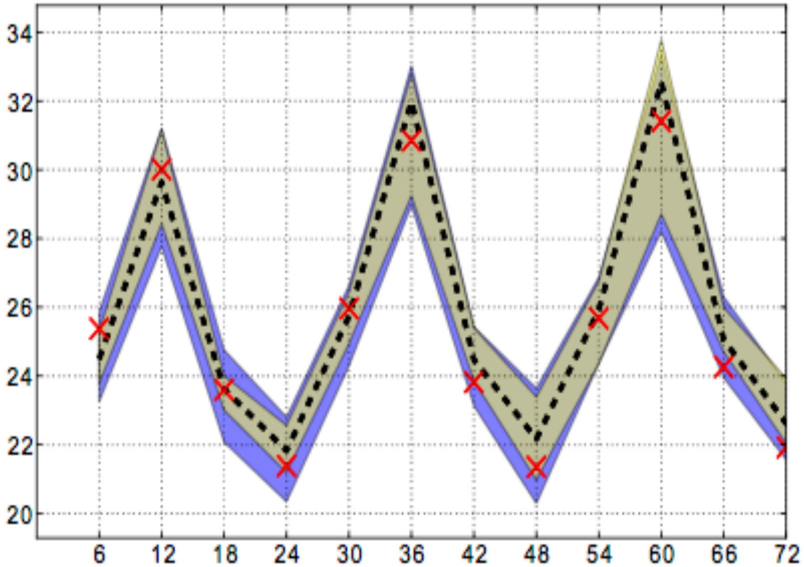
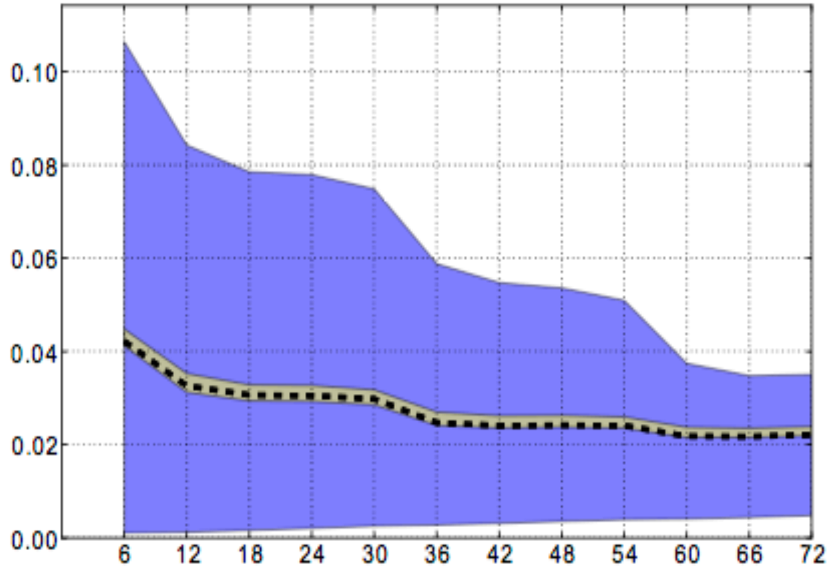
Soil moisture related uncertainties

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



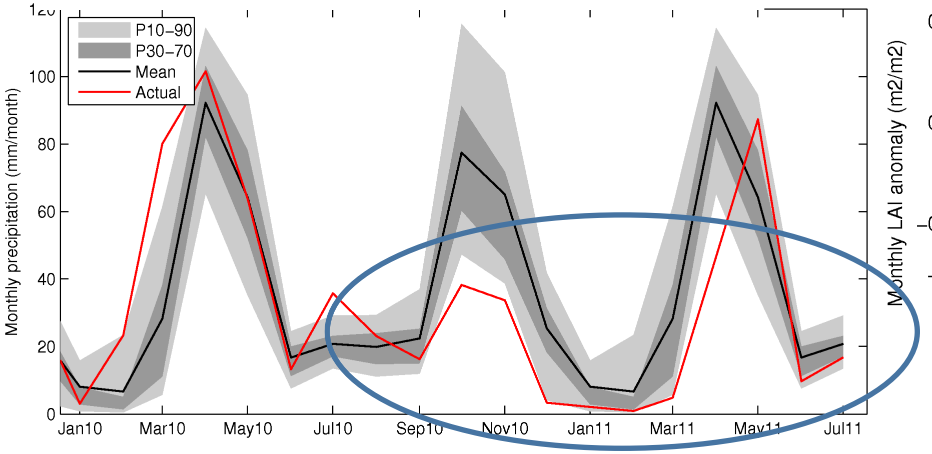
(e) Somalia, (6.7 °N, 48.4 °E), 2m temperature, 2012-12-18 00 UTC



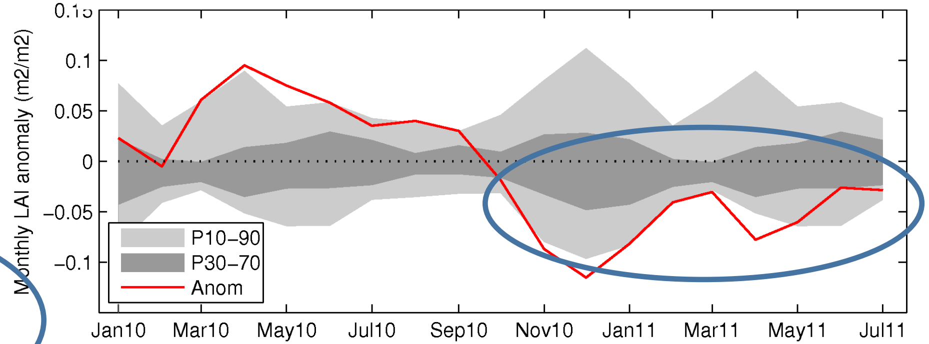
(f) Somalia, (6.7 °N, 48.4 °E), volumetric soil water in layer 1, 2012-12-18 00 UTC

Monitoring droughts

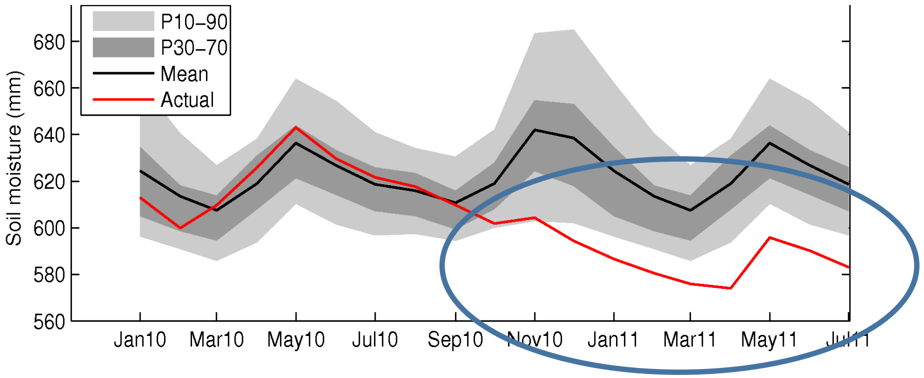
ERAI climate and 2010/11 precipitation



CTESSEL Leaf area Index anomaly (research)



ERAI climate and 2010/2011 full soil moisture

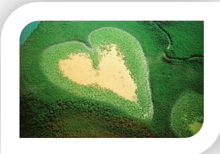
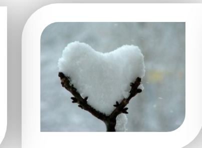
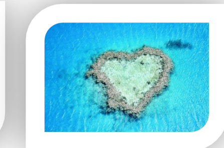


Based on **CTESSEL- research version** :with **interactive LAI**.

CTESSEL e-suite (based on MODIS-LAI monthly climatology with **no inter-annual variability of vegetation**)

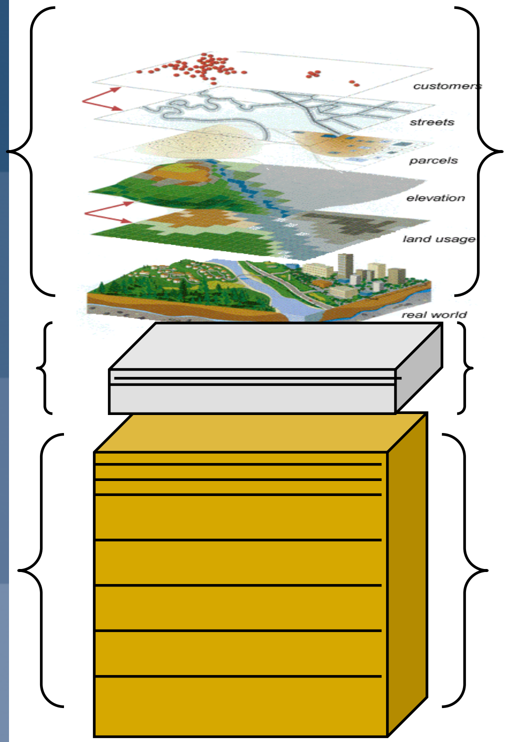
- Precipitation anomalies are followed by soil moisture
- LAI anomalies follow the reduced water availability
- Soil moisture and LAI anomalies are consistent with long recover (memory effect)

- Introducing the land surface
- Processes at Land-Atmosphere interface and their parameterisation in NWP
- Land perturbations for characterising uncertainties
- **Outlook**

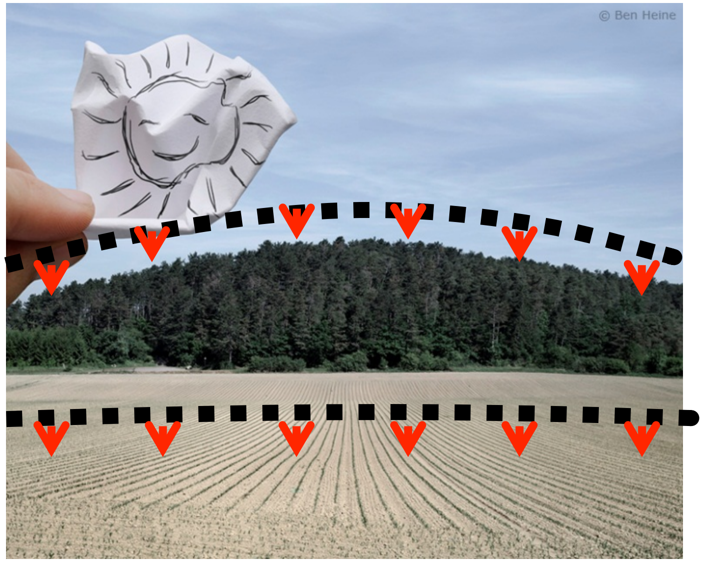
Perspectives for Earth System Prediction

Towards integrated
Ecosystems modelling



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

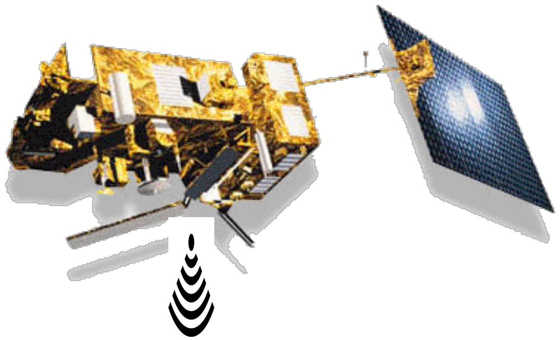
Modularity of the land system is a key to ESP model integrations and inter-operability of parameterizations

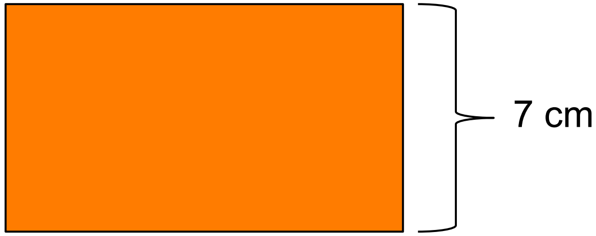


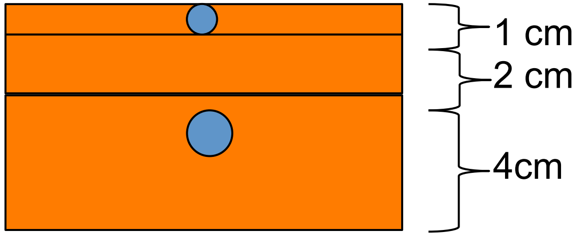
- Complexity needs a step-wise approach
- The assimilation methods are integral part of the model diagnostics
- A better coupling between sub-systems is the ultimate goal, achievable by enhanced knowledge on each sub-system and the mutual interactions

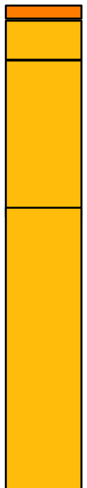
An enhanced soil vertical resolution

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.







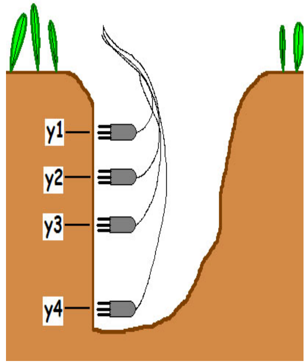


4-layers:

 # 0-7 cm
7-28 cm
28-100 cm
100-289 cm

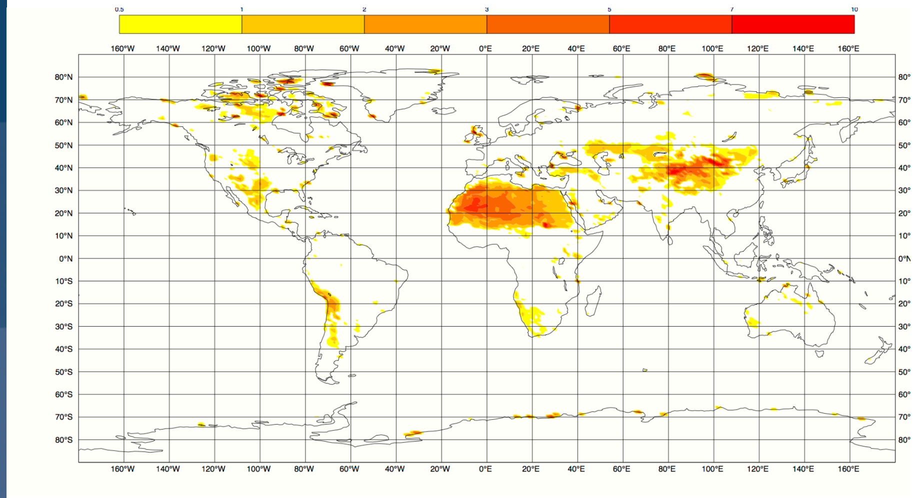
10-layers:

 # 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



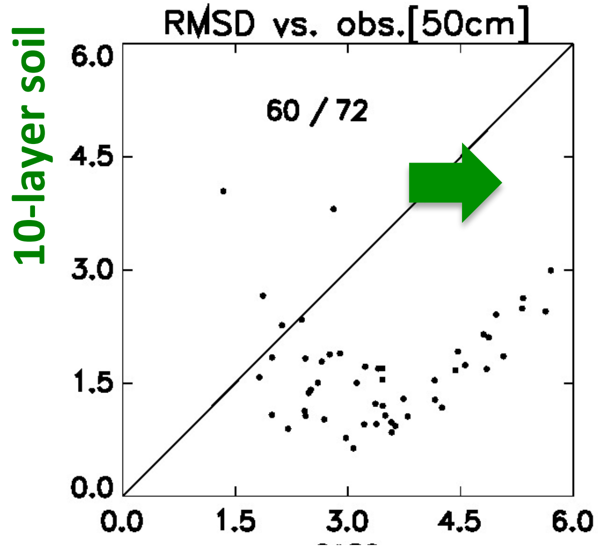
Impact of soil vertical resolution on soil temperature

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

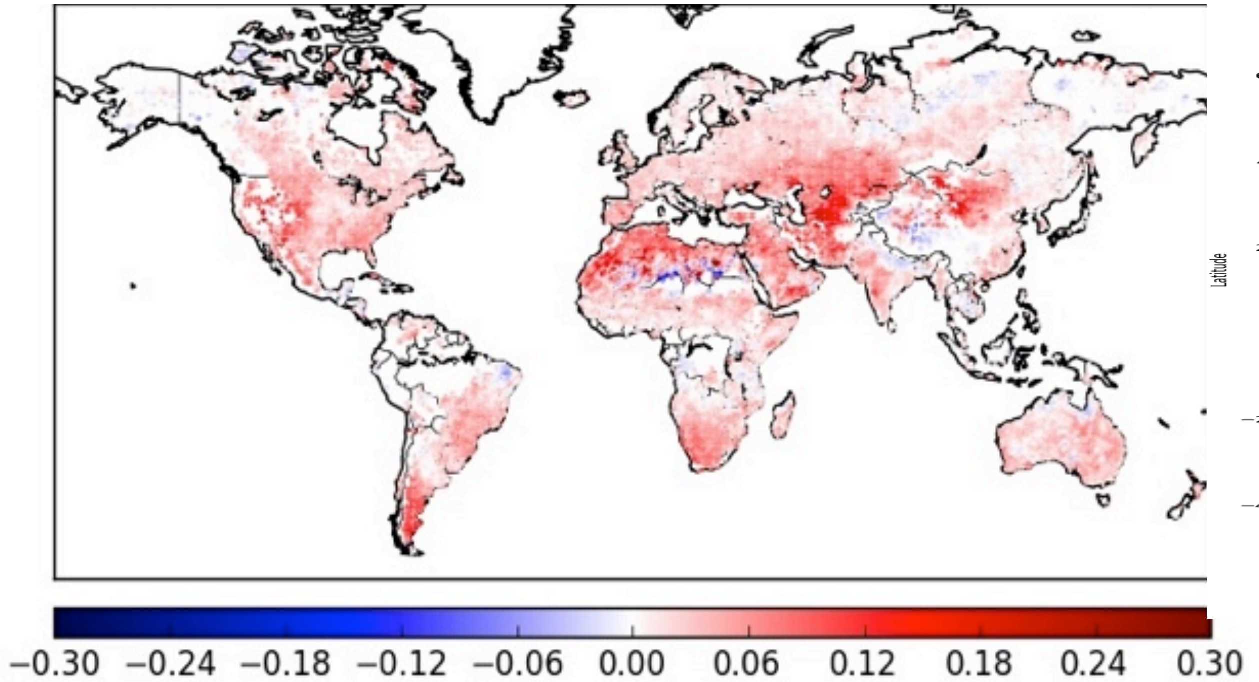


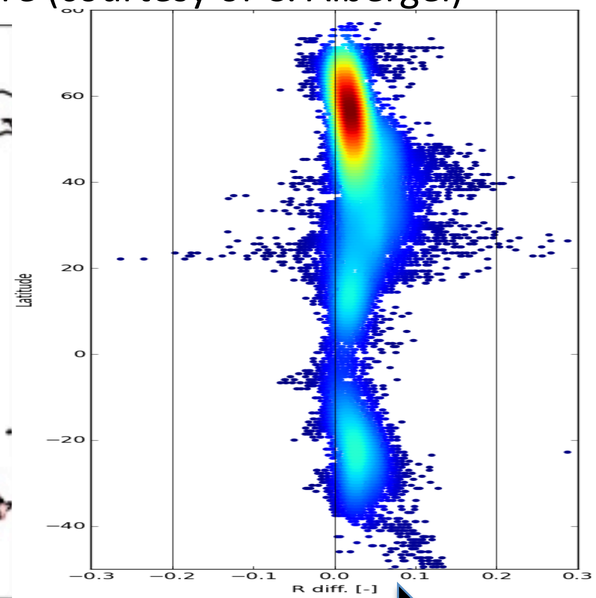
4-layer soils
Improved match to deep soil temperature
(shown is correlation and RMSD)

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).

Impact of soil vertical resolution for satellite soil moisture

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



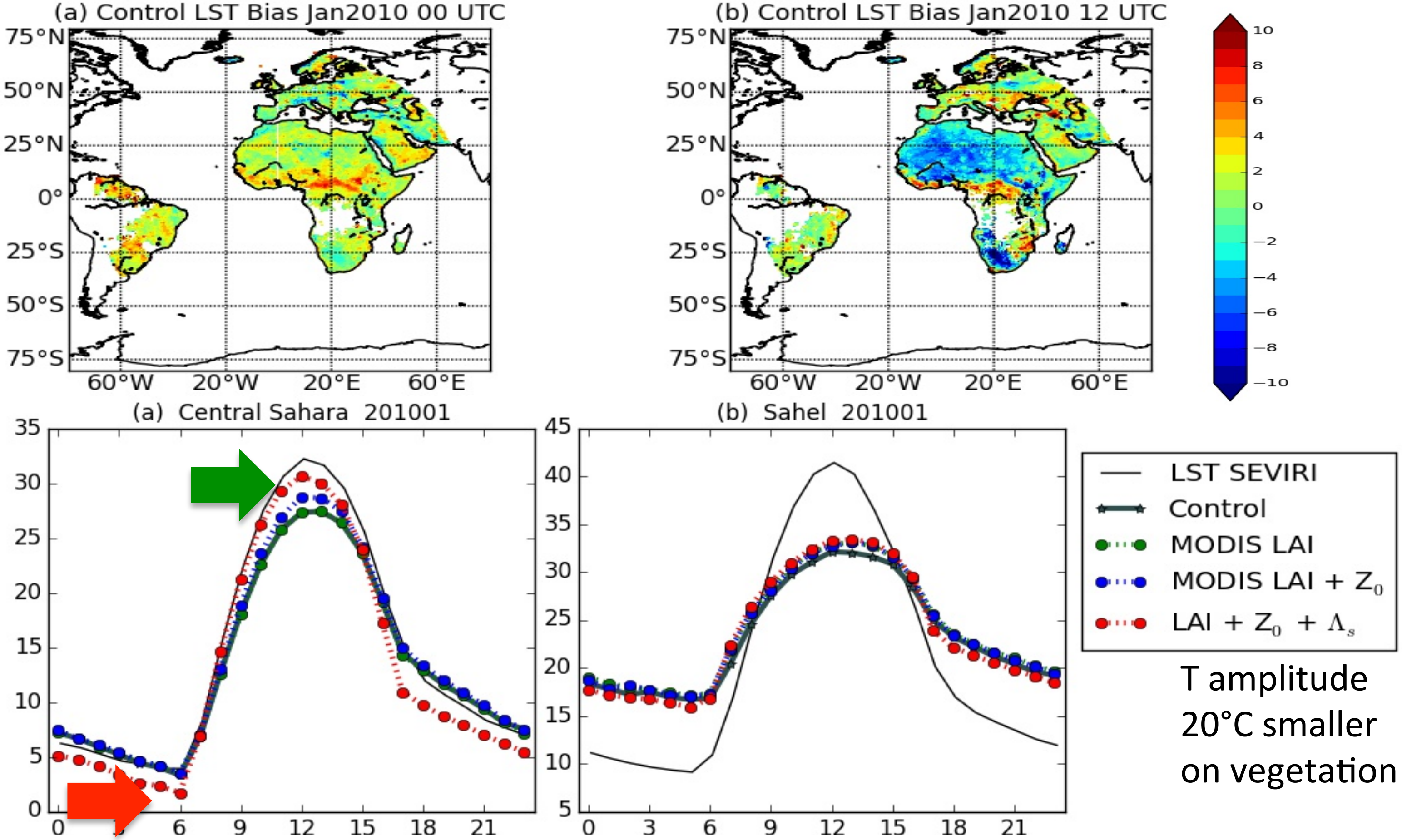


Globally Improved match to satellite soil moisture (shown is ΔACC calculate on 1-month running mean)

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.

Coupling and diurnal cycle: vegetation

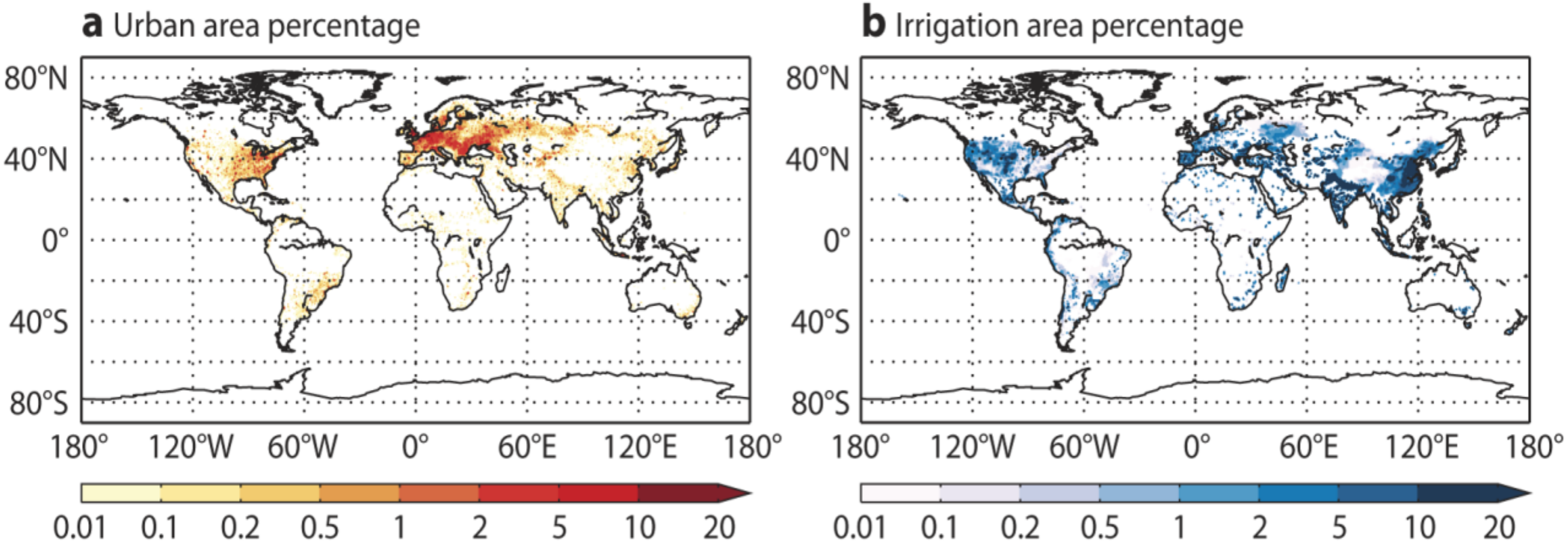
Trigo et al. (2015, JGR in rev.), Boussetta et al. (2015, RSE)



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)

Missing surface components

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



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

Summary and Outlook

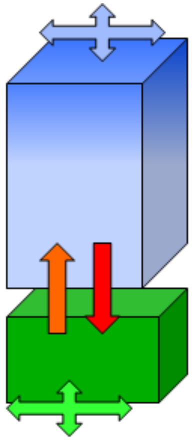
- Land-Atmosphere interaction is a core research area at ECMWF and all natural surface elements are parameterized
- Tiled full energy budgets extended the tiling to cover all major natural surfaces including lakes at resolution higher than the atmospheric grid-point.
- Very high resolution surface will be possible and rely on the quality of the ancillary information (soil/vegetation/lakes).

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 new RD results). Diurnal-cycle improvement affect all FC range.
- Improve physiography will lead to better prediction for the water, energy and CO2
- Urban surface will be considered 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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729
Representing the Earth surfaces in the Integrated Forecasting System: Recent advances & future challenges