Earth surface modelling: representing heterogeneity

Land surface lecture 1

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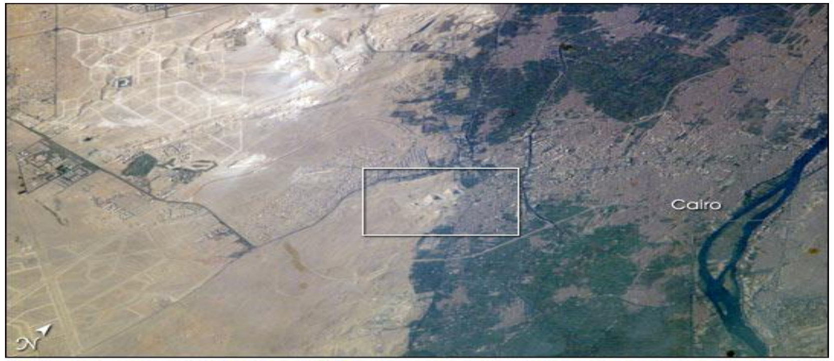
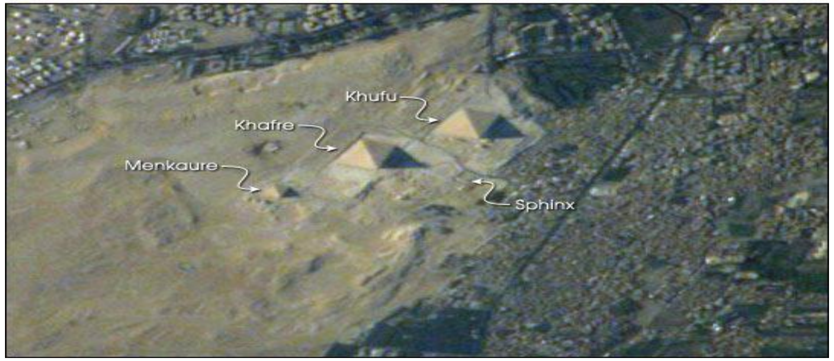
Outline

- Introduction: the role of land surface in Earth System Models
- Tiled ECMWF Surface Scheme for Exchanges over Land (TESSEL)
- Towards representing natural and anthropogenic surfaces

Land surface complexity and challenge for models to represent heterogeneity





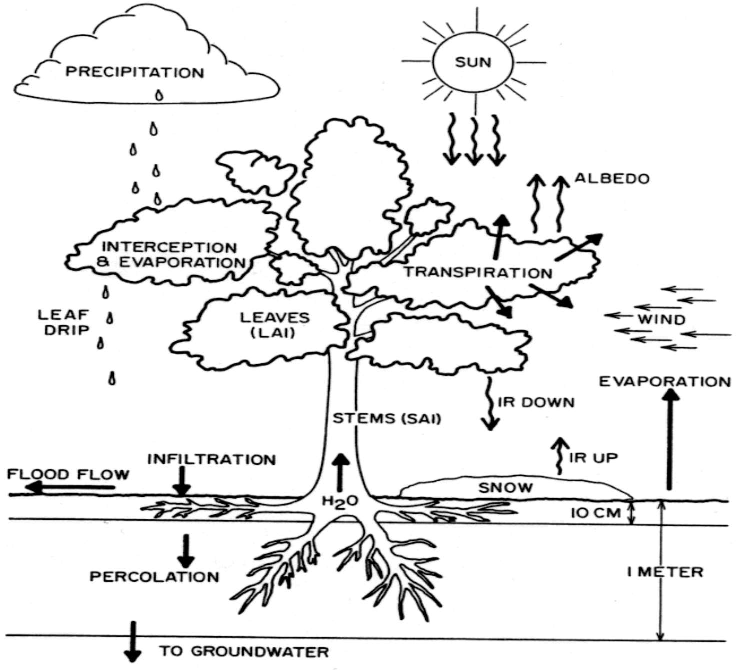
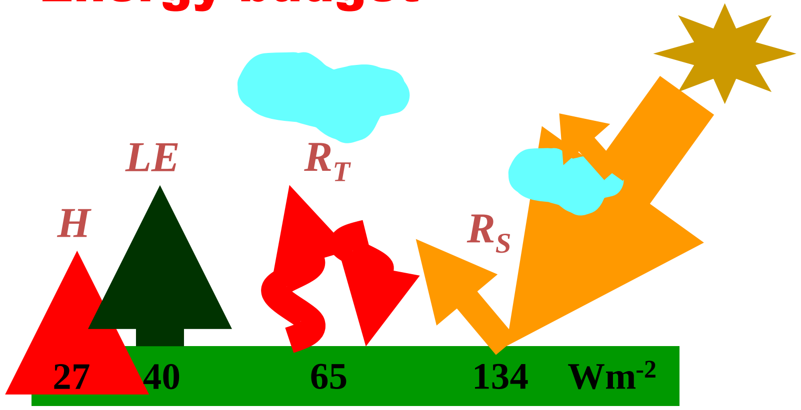
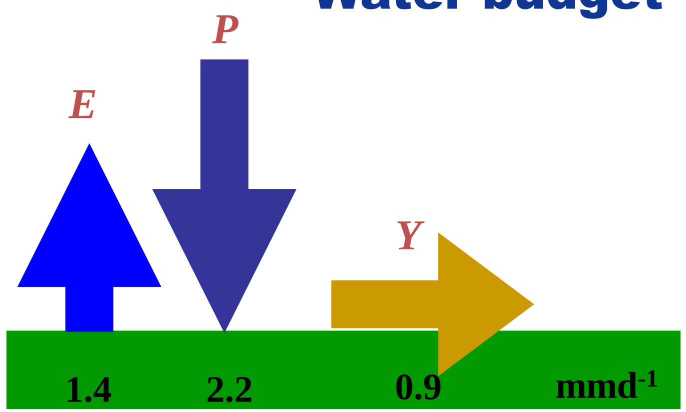


Figure 7
Water and energy processes at the Earth surface in the presence of vegetation.

Energy and Water budgets: the model perspective





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

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

Energy and Water budgets: the data assimilation perspective

$$T_s^{\,A} = T_s^{\,F} + \Delta T_s$$

$$S^A = S^F + \Delta S$$

The land surface schemes (ECMWF TESSEL tiled scheme)

- Tiled ECMWF Scheme for Surface Exchanges over Land

van den Hurk et al (2000)

Viterbo et al (1999)

Viterbo and Beljaars (1995)

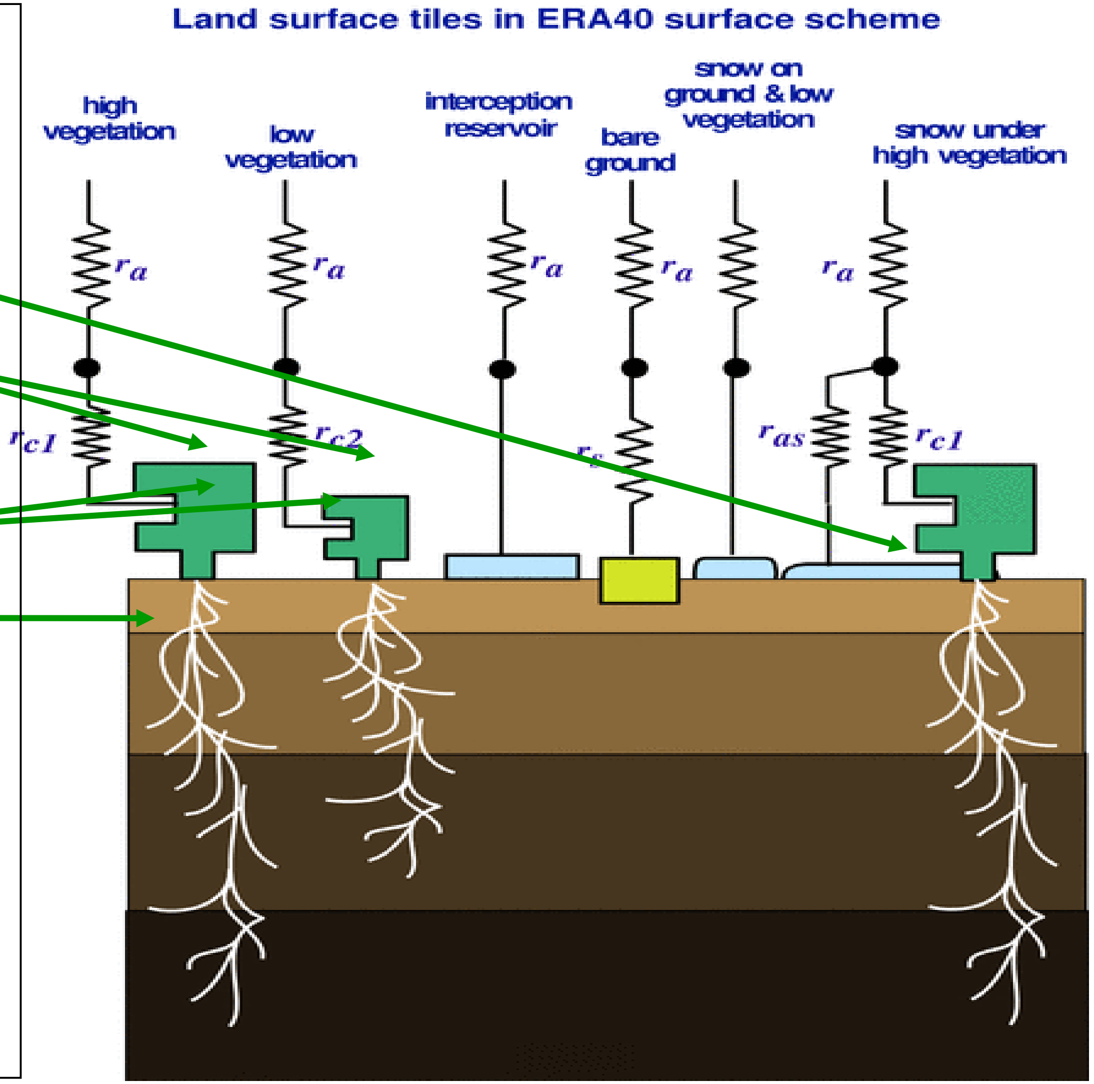
Treatment of snow under high vegetation

Canopy resistances, including air humidity stress on forest

High and low vegetation treated separately

Variable root depth

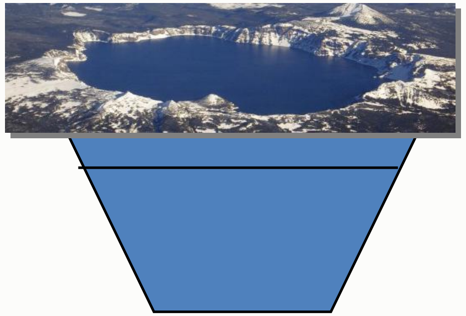
ERA-Interim LSM version (2006)



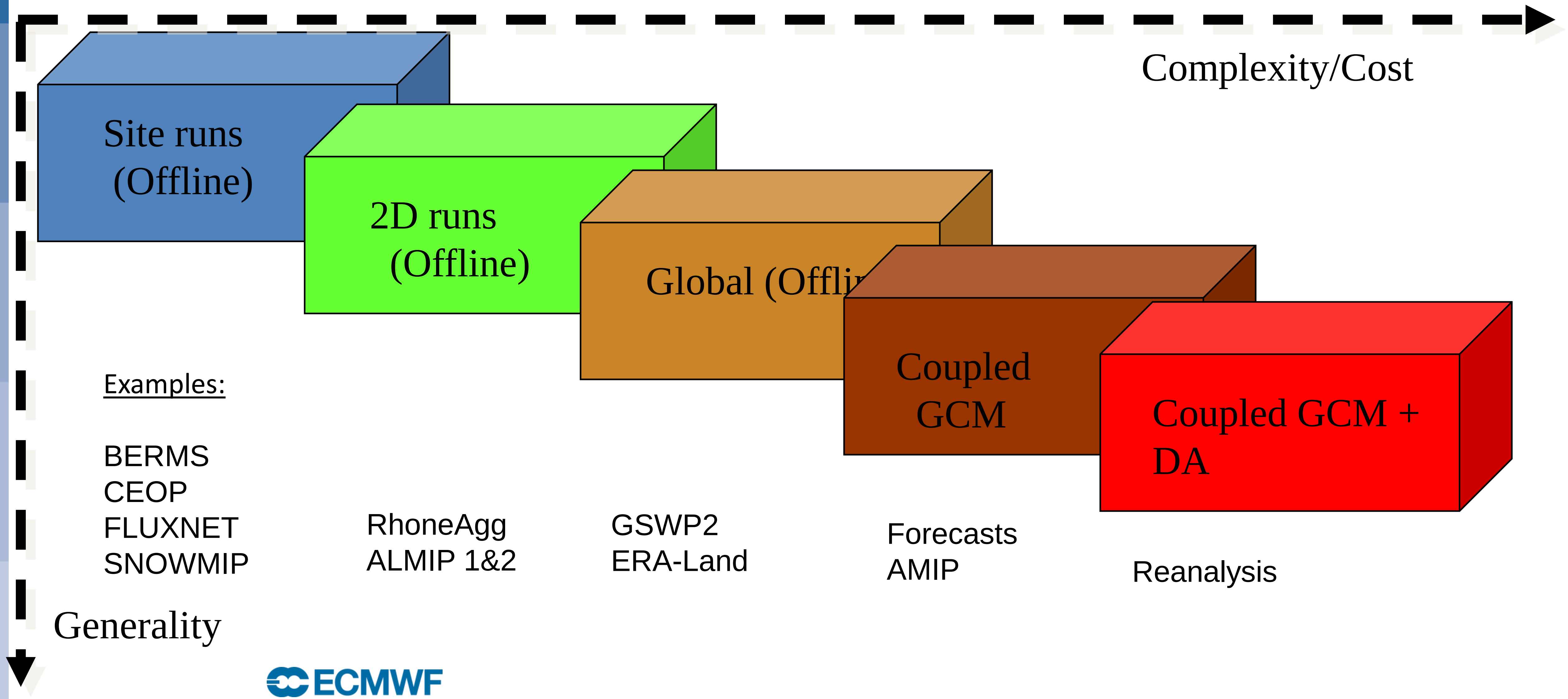
- **Lake tile (in progress)**

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

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

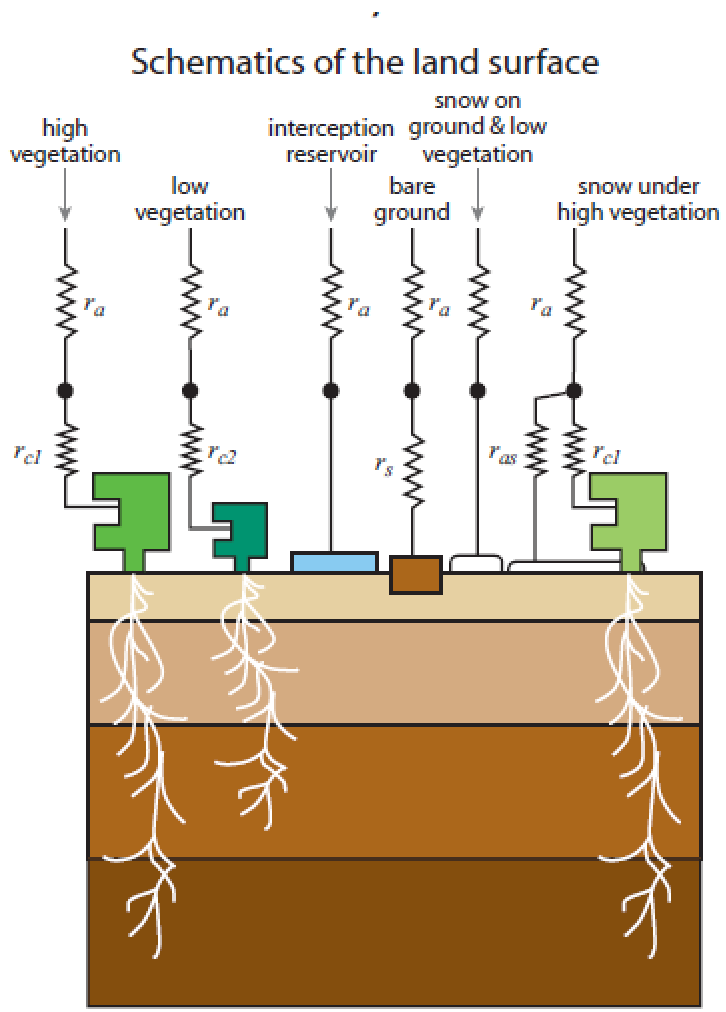


A step-wise approach to model complexity



ECMWF

CHTESSEL :a tiles approach



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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	
Interception layer	

How does vegetation impact on screen-level Temperature?

For vegetated area the evapotranspiration is parameterized as:

$$E_i = \frac{\rho_\mathrm{a}}{r_\mathrm{a} + r_\mathrm{c}} [q_\mathrm{L} - q_\mathrm{sat}(T_{\mathrm{sk},i})]$$

Where the canopy resistance r_c is defined following Jarvis(1976) as:

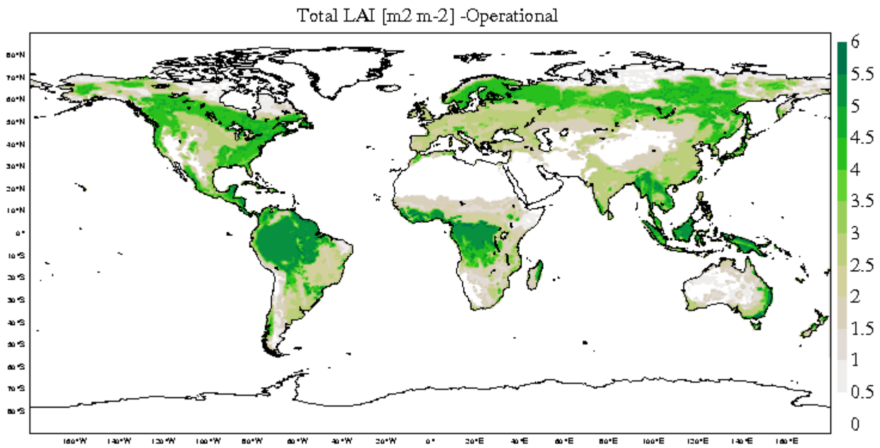
$$r_\mathrm{c} = \frac{r_{\mathrm{S,min}}}{LAI} f_1(R_\mathrm{s}) f_2(\bar{\theta}) f_3(D_\mathrm{a})$$

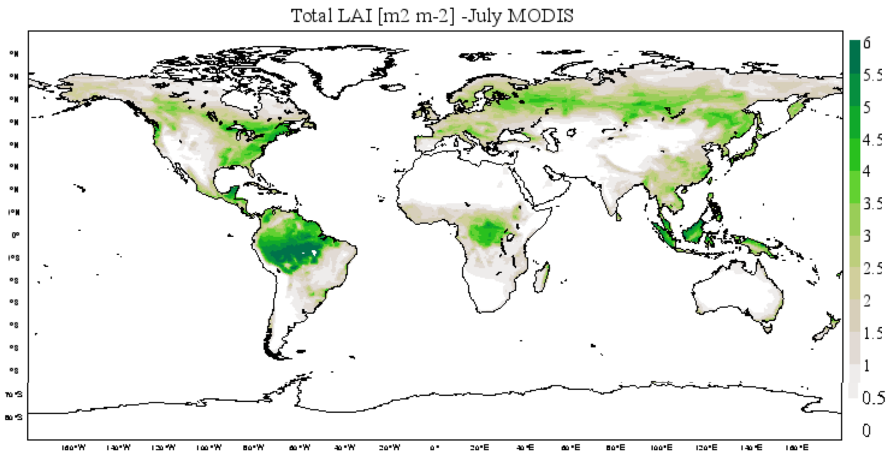
Where $r_{s,min}$ is the minimum stomatal resistance, ***LAI*** is the leaf area index and $f1$, $f2$, $f3$ are respectively function of the downward shortwave radiation R_s, soil moisture θ and vapour deficit D_a

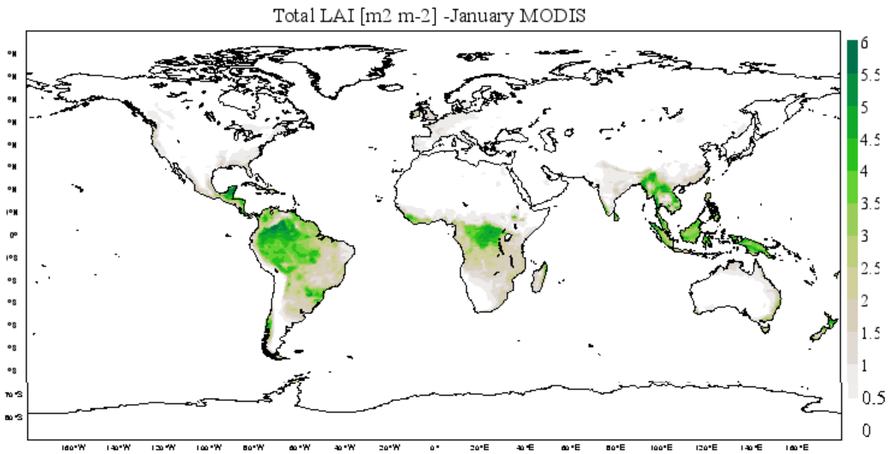
If *LAI* ↘ then r_c ↗ and *E* ↘ so *T2m* ↗

If *LAI* ↗ then r_c ↘ and *E* ↗ so *T2m* ↘

Seasonal Varying Leaf Area Index





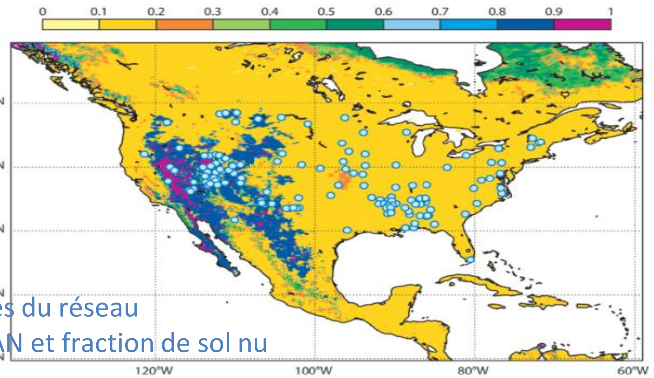


Obtained by the inversion of a 3D radiative transfer model which compute the LAI and FPAR based on the biome type and an atmospherically corrected surface reflectance thanks to a look-up-table

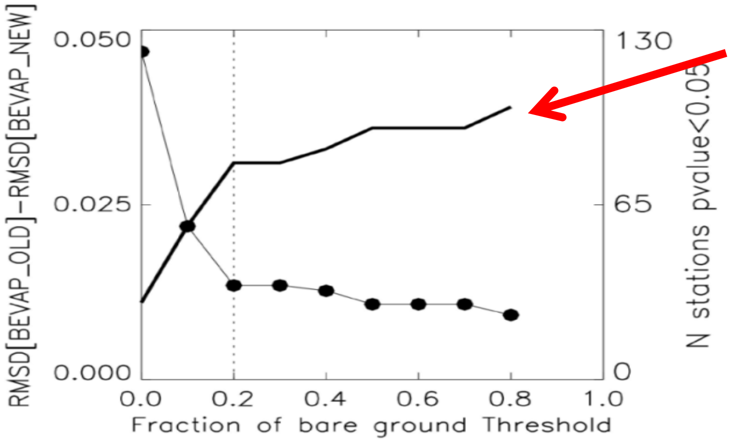
➔derived 8years (2000-2008) climatological time serie

Arid areas and soil moisture dynamical range (via Evaporation)

Albergel et al. (2012), *HESS*

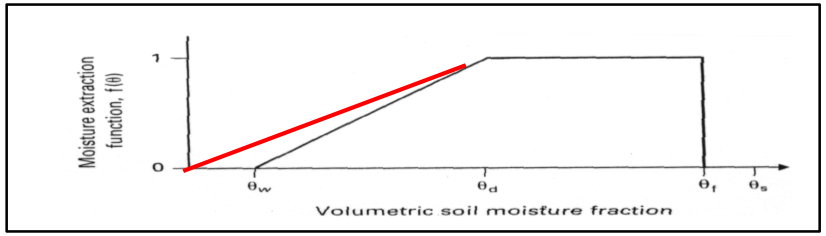


Sites du réseau
SCAN et fraction de sol nu

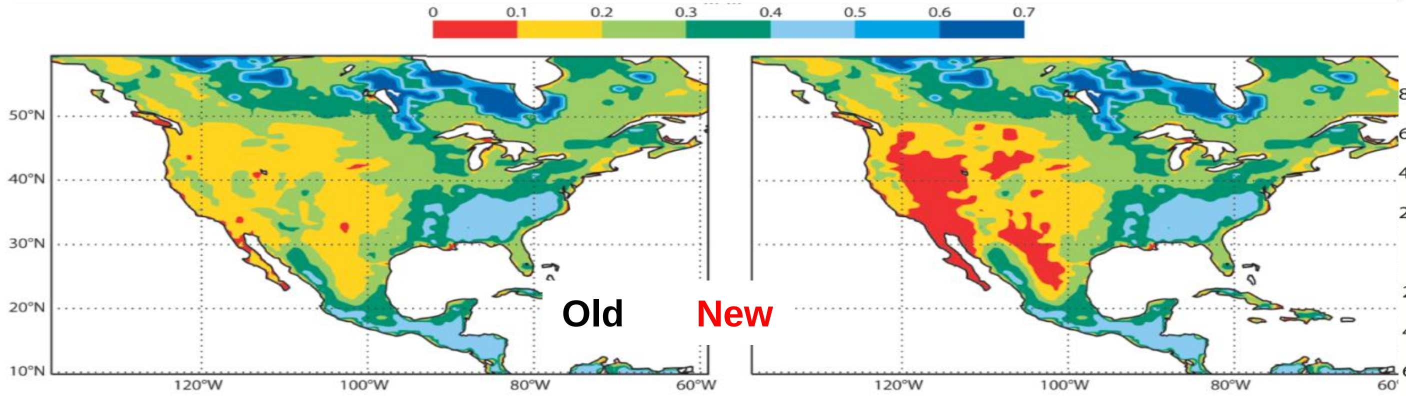


Improved fit to SCAN soil moisture data (reduced RMSE over 122 stations) as a function of bare soil.

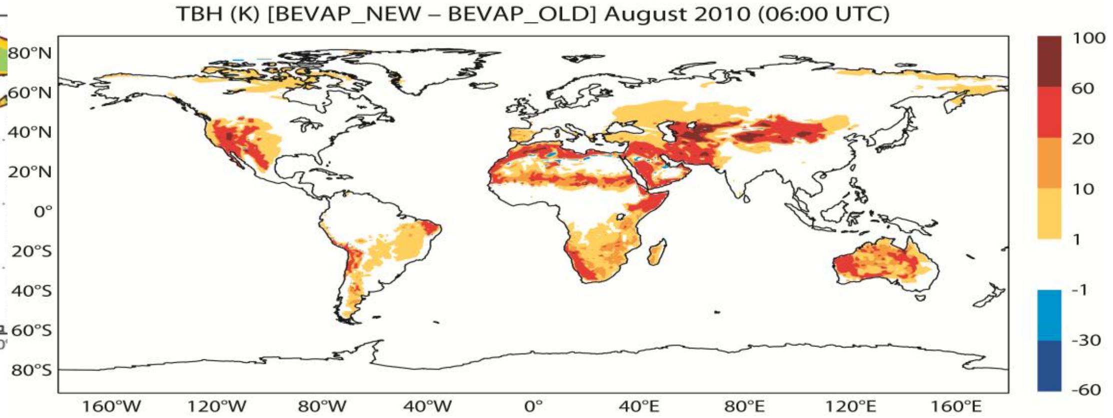
SOIL Evaporation



A revision of the bare soil evaporation which is allowed to extract water below the wilting point in arid regions produces a soil moisture drying



The drying effect impact enhancing SMOS/SMAP T_b (L-band) in the forward operator

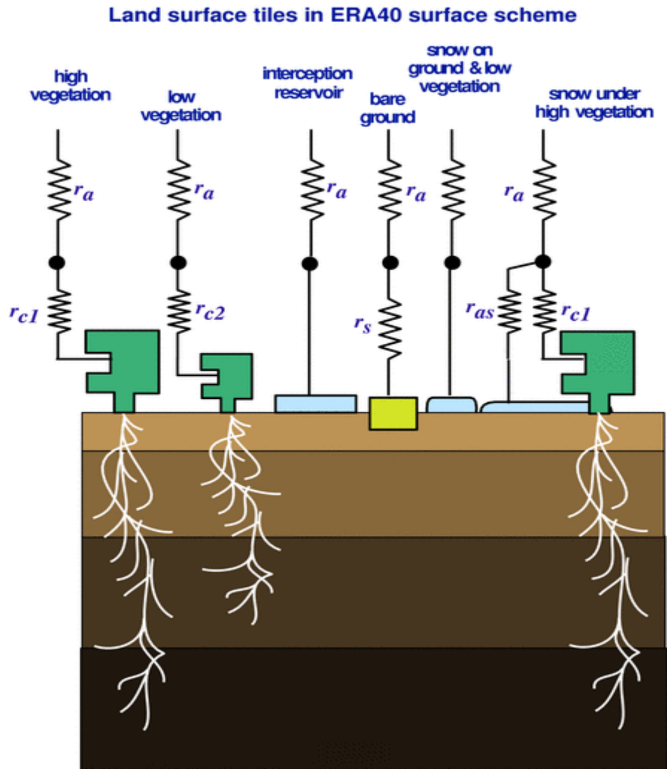


ECMWF

Modelling inland water bodies

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

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**

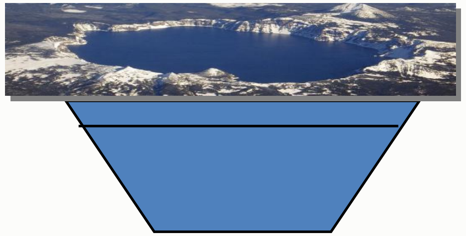
  Mironov et al (2010),

  Dutra et al. (2010),

  Balsamo et al. (2010, 2012, 2013)

- **Manrique-Sunen et al (2013)**

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

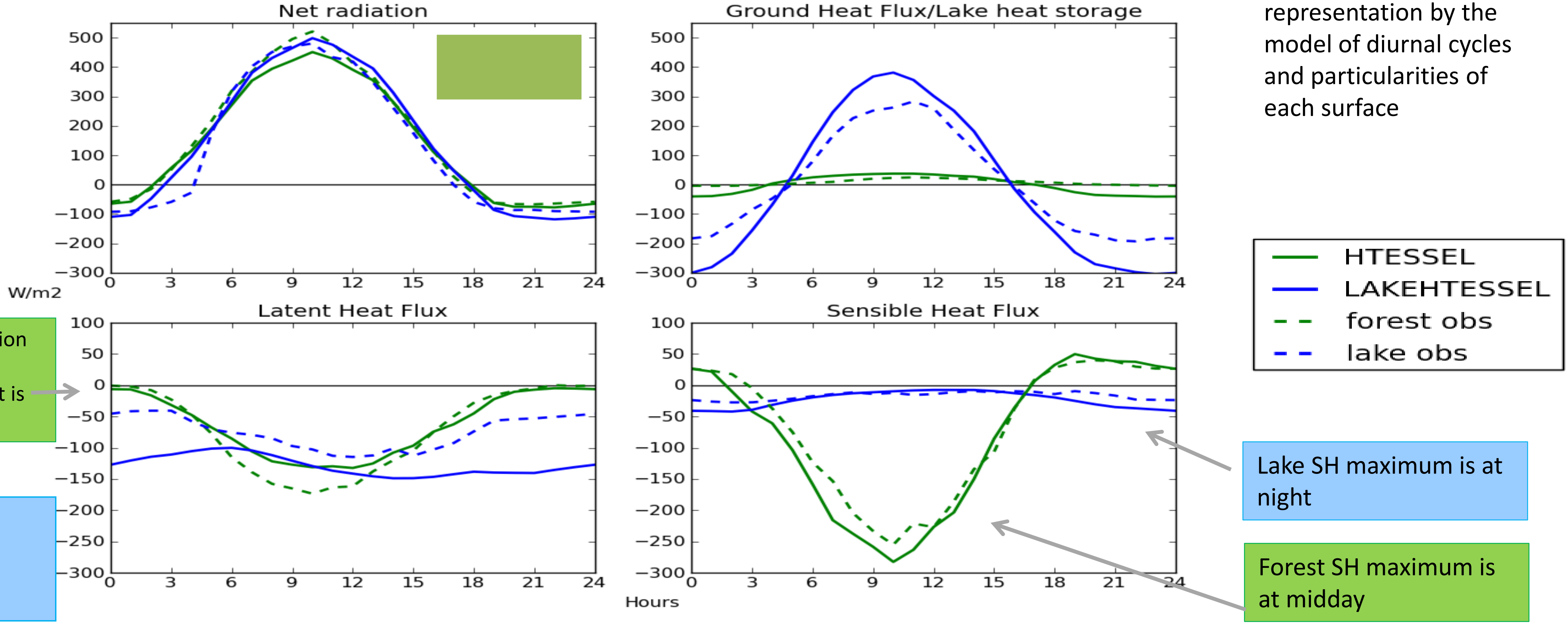


Diurnal cycles: difference forests &lakes

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

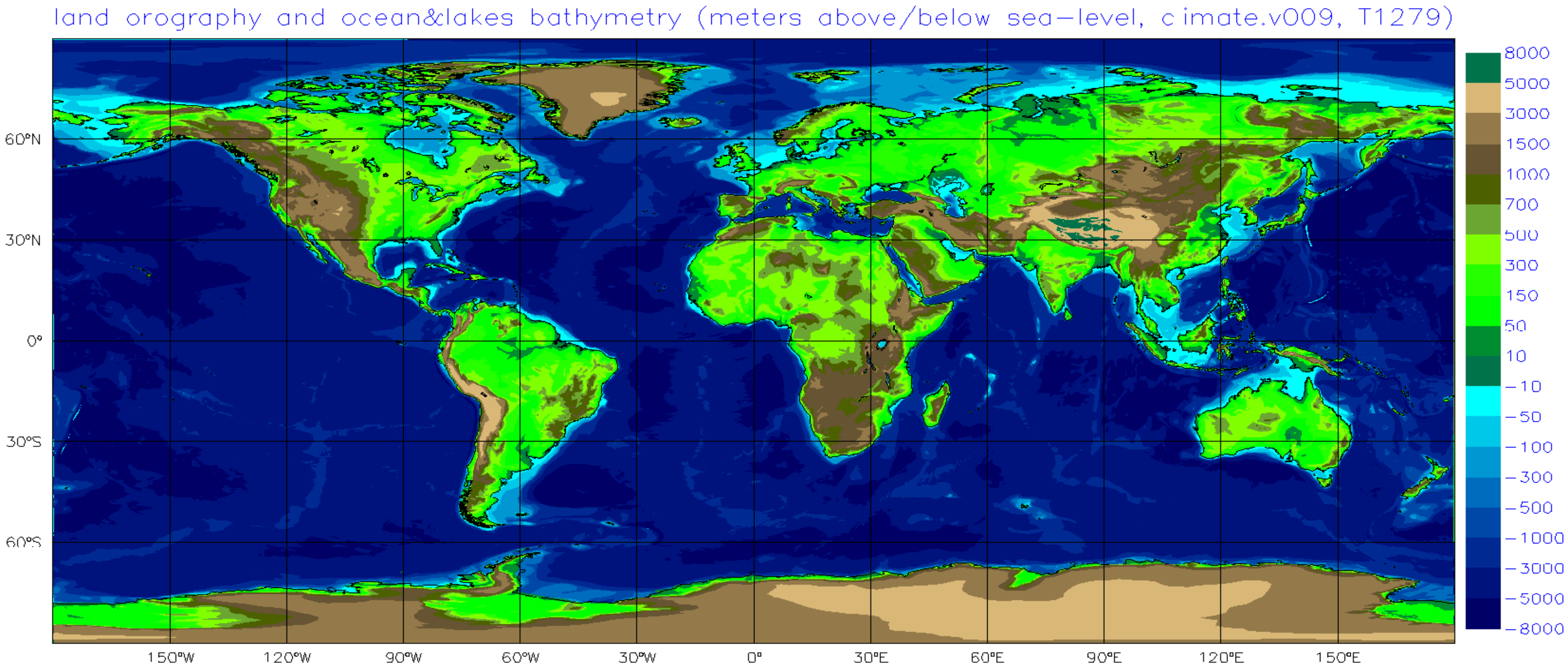
Forest SH maximum is at midday

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

ECMWF

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

Given the large impact of including inland water bodies in forecasting near surface weather parameters investment in physyography Dataset has increased: here is shown a global Orography and Bathymetry (elevation above/below sea-level in m). Another seamless aspect!

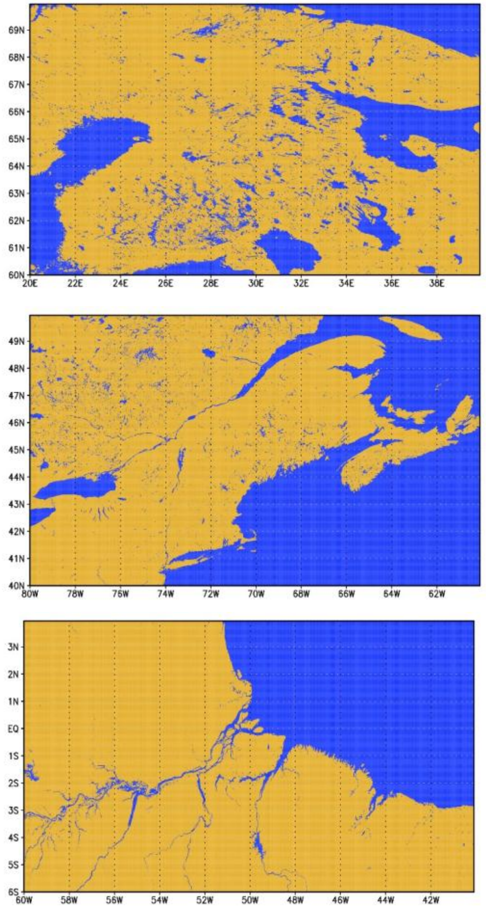


ECMWF

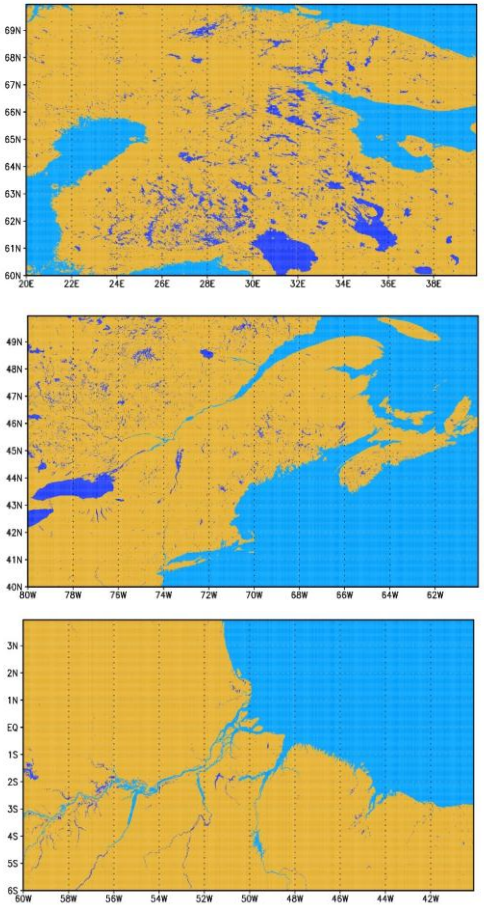
Mapping the surface at 1km: water bodies and changes over time

Classifying automatically inland water bodies is a complex task. A 1-km lake cover is a baseline for a monthly climatology

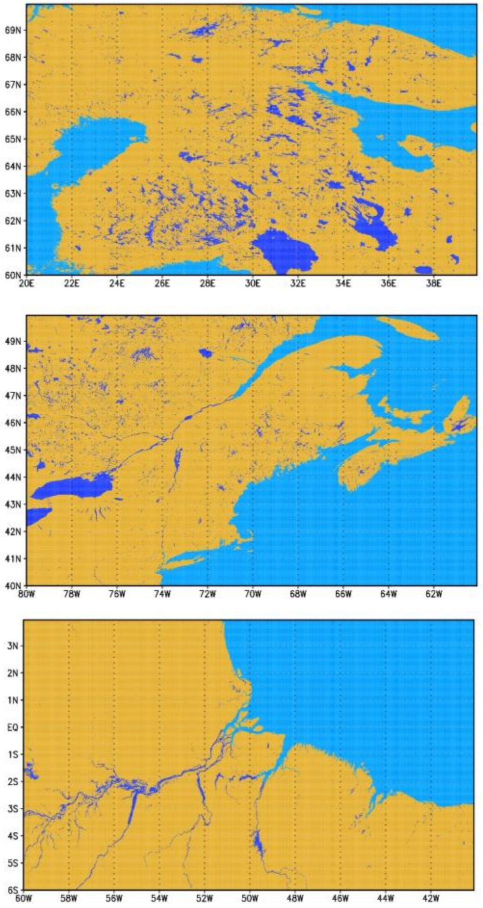
ESA GlobCOVER
has no water class

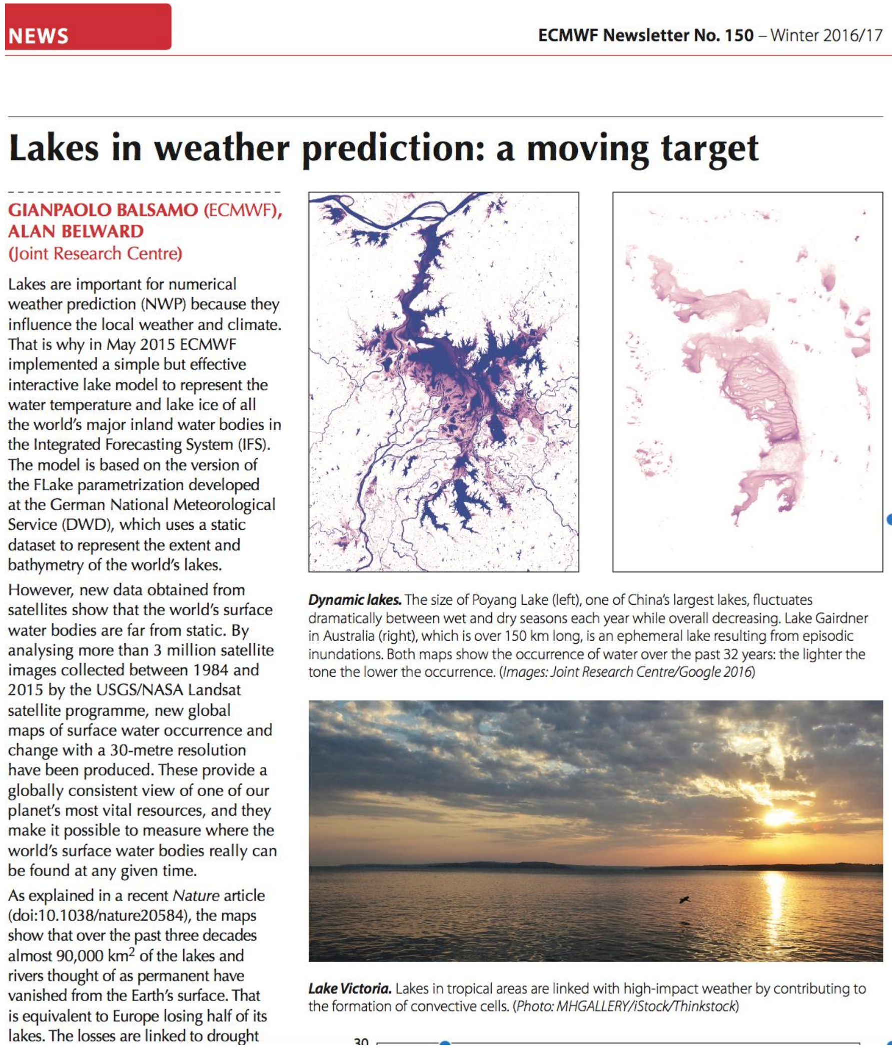


Flooding allows classify,
problems w. large rivers



New classification algo
works well at 1km





NEWS — ECMWF Newsletter No. 150 – Winter 2016/17

Lakes in weather prediction: a moving target

GIANPAOLO BALSAMO (ECMWF), **ALAN BELWARD** (Joint Research Centre)

Lakes are important for numerical weather prediction (NWP) because they influence the local weather and climate. That is why in May 2015 ECMWF implemented a simple but effective interactive lake model to represent the water temperature and lake ice of all the world's major inland water bodies in the Integrated Forecasting System (IFS). The model is based on the version of the FLake parametrization developed at the German National Meteorological Service (DWD), which uses a static dataset to represent the extent and bathymetry of the world's lakes.

However, new data obtained from satellites show that the world's surface water bodies are far from static. By analysing more than 3 million satellite images collected between 1984 and 2015 by the USGS/NASA Landsat satellite programme, new global maps of surface water occurrence and change with a 30-metre resolution have been produced. These provide a globally consistent view of one of our planet's most vital resources, and they make it possible to measure where the world's surface water bodies really can be found at any given time.

As explained in a recent *Nature* article (doi:10.1038/nature20584), the maps show that over the past three decades almost 90,000 km^2 of the lakes and rivers thought of as permanent have vanished from the Earth's surface. That is equivalent to Europe losing half of its lakes. The losses are linked to drought

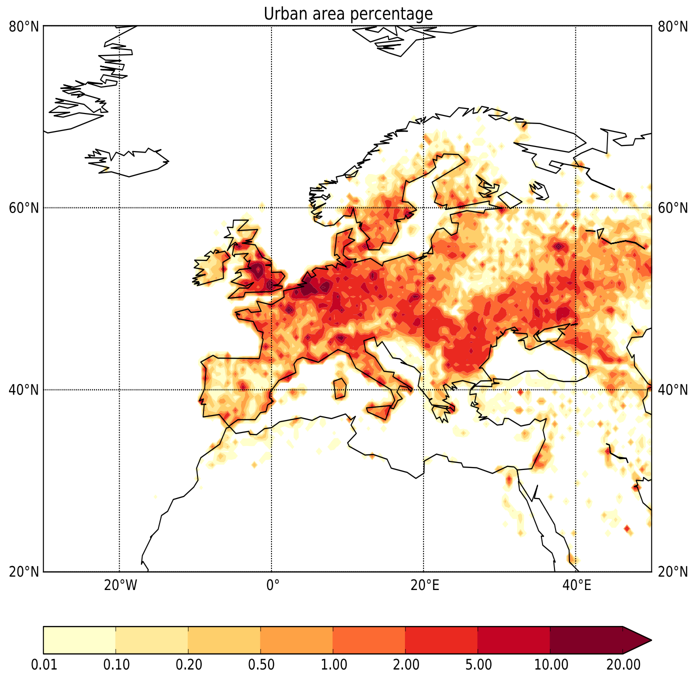
Dynamic lakes. The size of Poyang Lake (left), one of China's largest lakes, fluctuates dramatically between wet and dry seasons each year while overall decreasing. Lake Gairdner in Australia (right), which is over 150 km long, is an ephemeral lake resulting from episodic inundations. Both maps show the occurrence of water over the past 32 years: the lighter the tone the lower the occurrence. (*Images: Joint Research Centre/Google 2016*)

Lake Victoria. Lakes in tropical areas are linked with high-impact weather by contributing to the formation of convective cells. (*Photo: MHGALLERY/iStock/Thinkstock*)

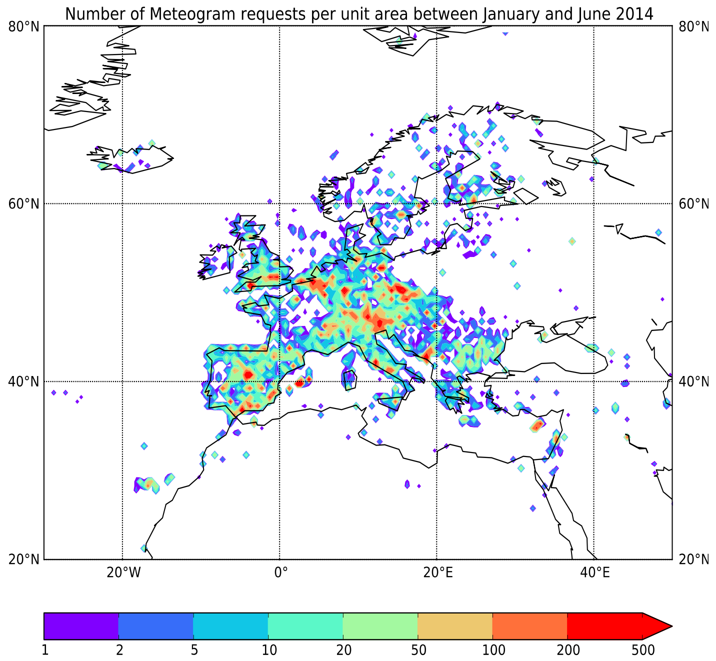
Thanks to Margarita Choulga and Souhail Boussetta

Towards representation of urban areas in global models

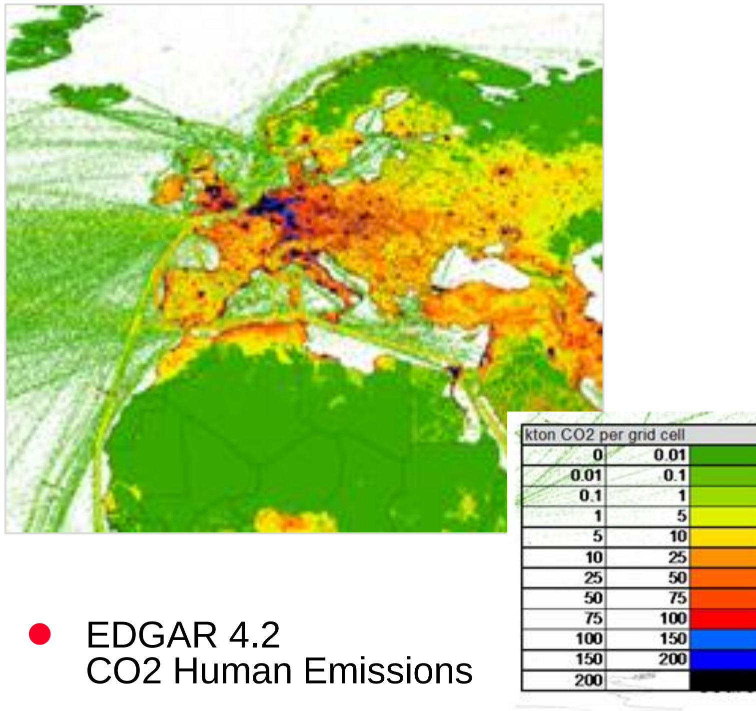
- Urban areas are important for the accurate prediction of extreme events such as heatwaves and urban flooding and need to be represented in ECMWF model.
- Best and Grimmond (2015) suggested that simple models may be well adapted to global applications
- Users lives urban areas and look at the forecast for urban locations.
- Urban maps combined with emission factors can provide first guess CO2 anthropogenic fluxes



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



- Number of ECMWF Meteograms product requests from Member-States

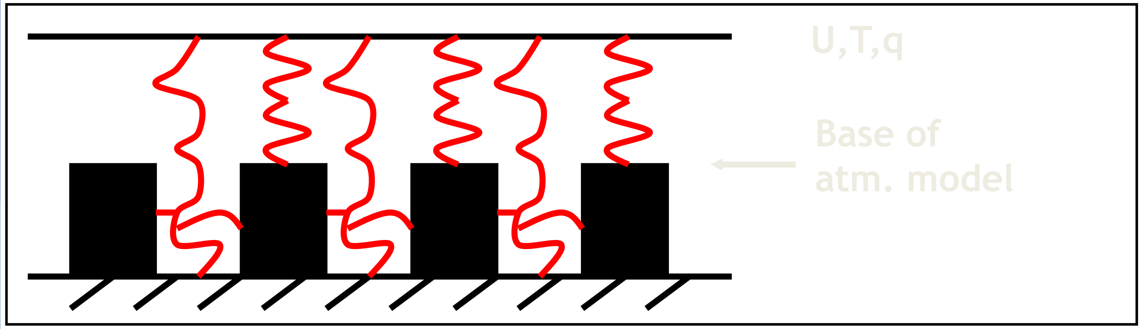


- EDGAR 4.2 CO2 Human Emissions

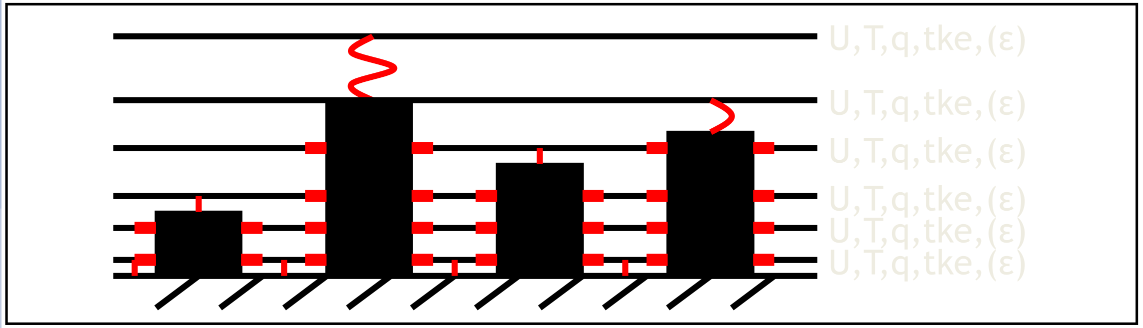
ECMWF

Urban surface models

Single-layer urban canopy models (Masson 2000, TEB)



Multi-layer urban canopy models (Martilli, 2002)

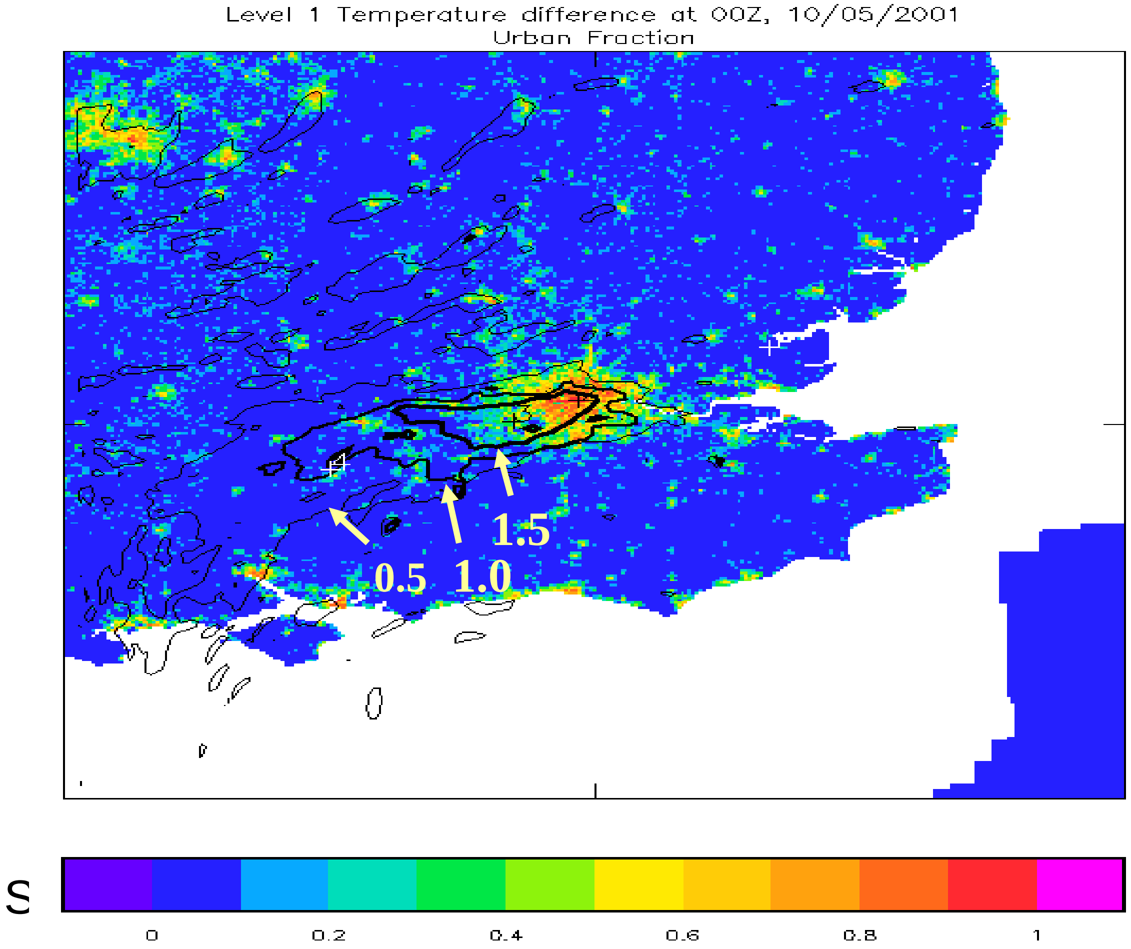


courtesy of ***A. Lemonsu***

Urban Heat Island

Simulation of London UHI for an easterly wind

Best (2002), Met Office



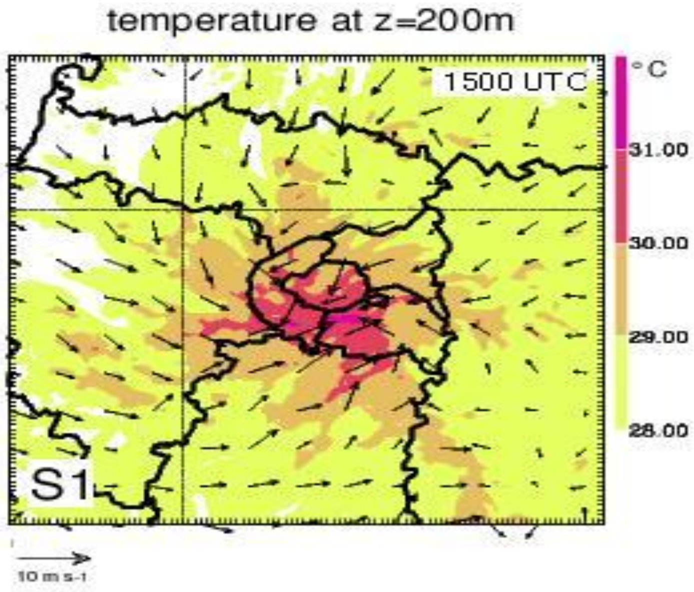
Urban surface models (2)

Atmospheric circulations: urban breezes and urban plumes

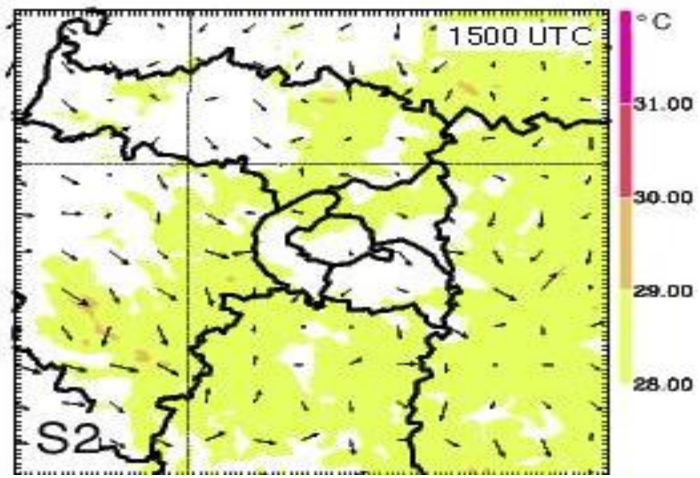
Urban over Paris during summertime (Meso-NH including TEB)

Lemonsu and Masson, BLM (2002)

With TEB



Without TEB



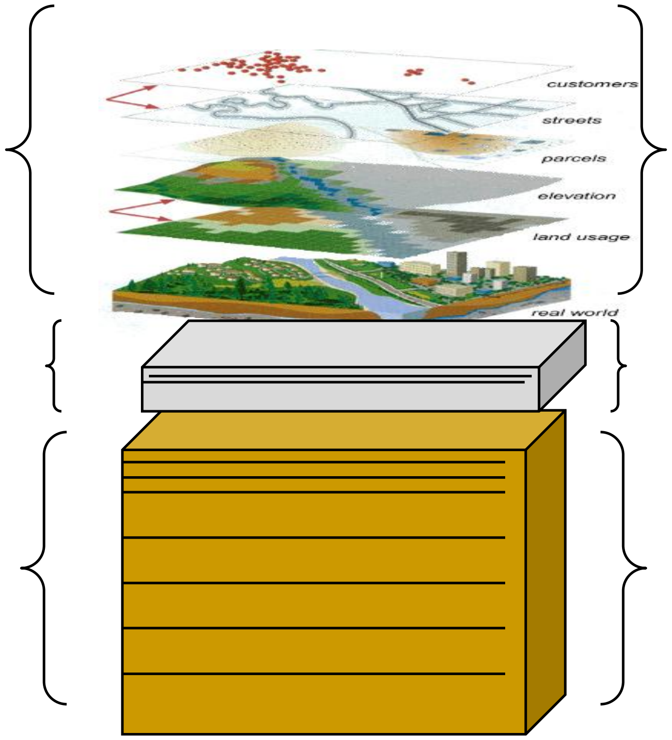
courtesy of ***A. Lemonsu***

Summary and Outlook

- **Earth surface** moving from a necessary boundary condition to a **key predictability element**
- Efforts up to present towards representing the surface slowly-evolving processes
  - Land, (Ocean and Sea-ice) that carry predictability due the memory effect
- **Diurnal cycle focus** interactions provide a complexity requirement guidance
- Moving towards Earth System for **Environment prediction & Extended-range** requires:
  - An increased investment on **mapping** surface characteristics at kilometer scale
  - A **stepwise** approach to **increased complexity** (process-based verification)
  - A **better use of EO data** informative of HRES Mapping & Modelling (e.g. Tskin, MW Tb)
  - A **large collaborative efforts** (@ECMWF and within the NWP & Climate community)

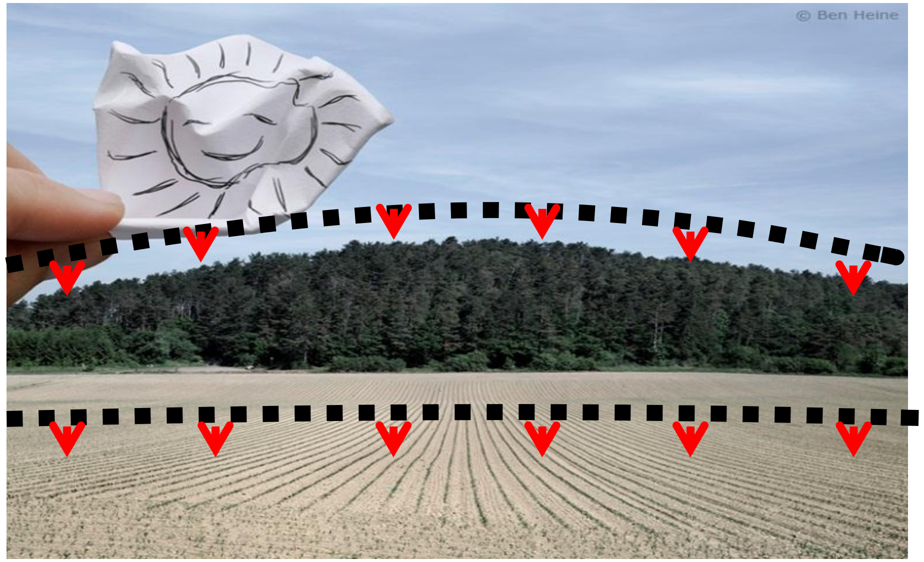
Perspectives for Earth System Prediction

Towards integrated Ecosystems modelling



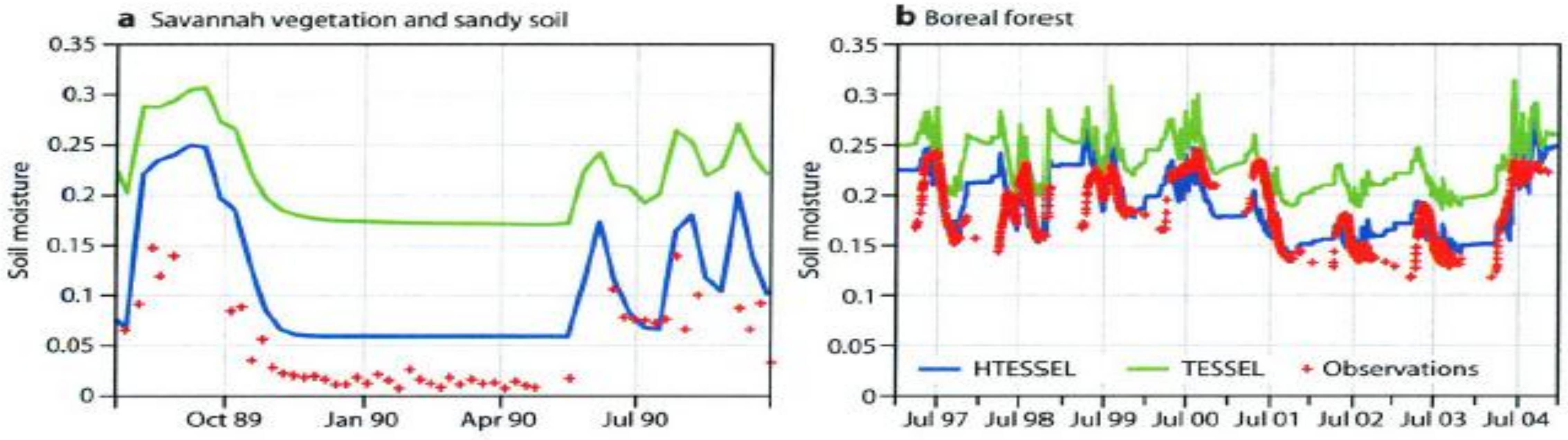
- Better characterisation of the vertical profiles
- Better respresentation on heterogeneity and ecosystems interaction
- Unification of processes (cryosphere)

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

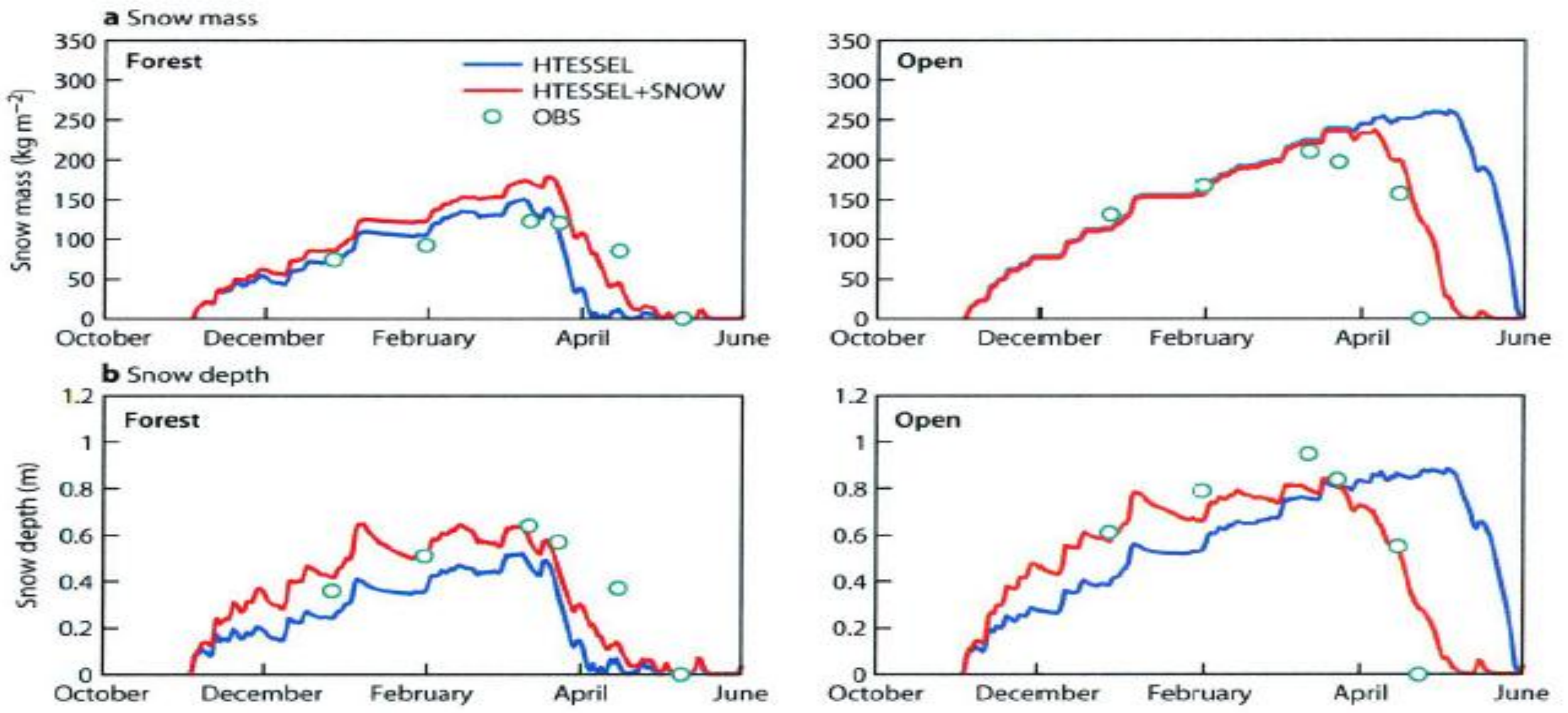


- Complexity needs a step-wise approach
- The assimilation methods are integral part of the model diagnostics
- A better coupling between sub-systems is the ultimate goal, achievable by enhanced knowledge on each sub-system and the mutual interactions

Soil hydrology
(Balsamo et al. 2009)

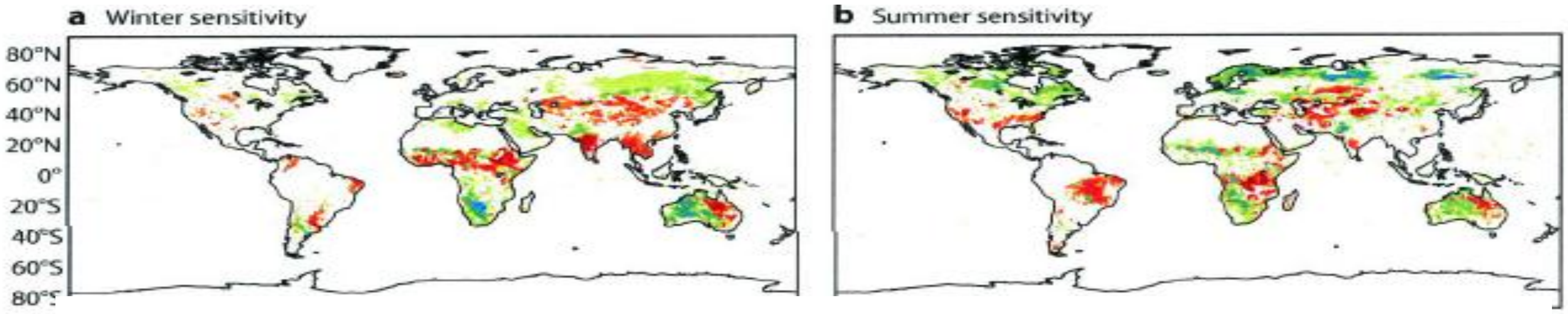


New snow scheme
(Dutra et al. 2010)

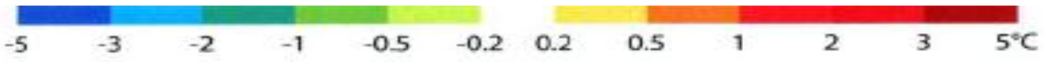


Forecasts (+36-h) sensitivity and impact

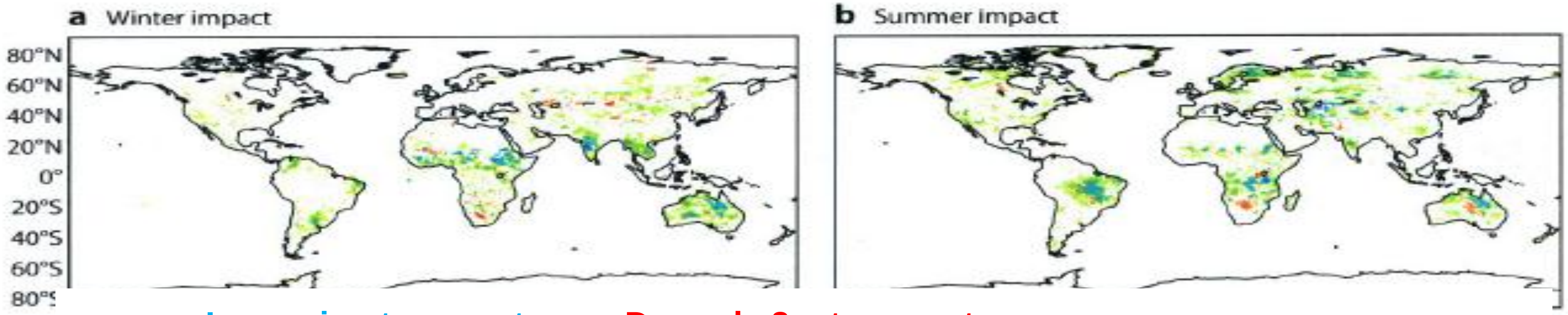
Forecast sensitivity



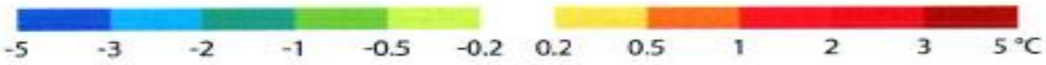
Cooling 2m temperature Warming 2m temperature



Forecast Impact

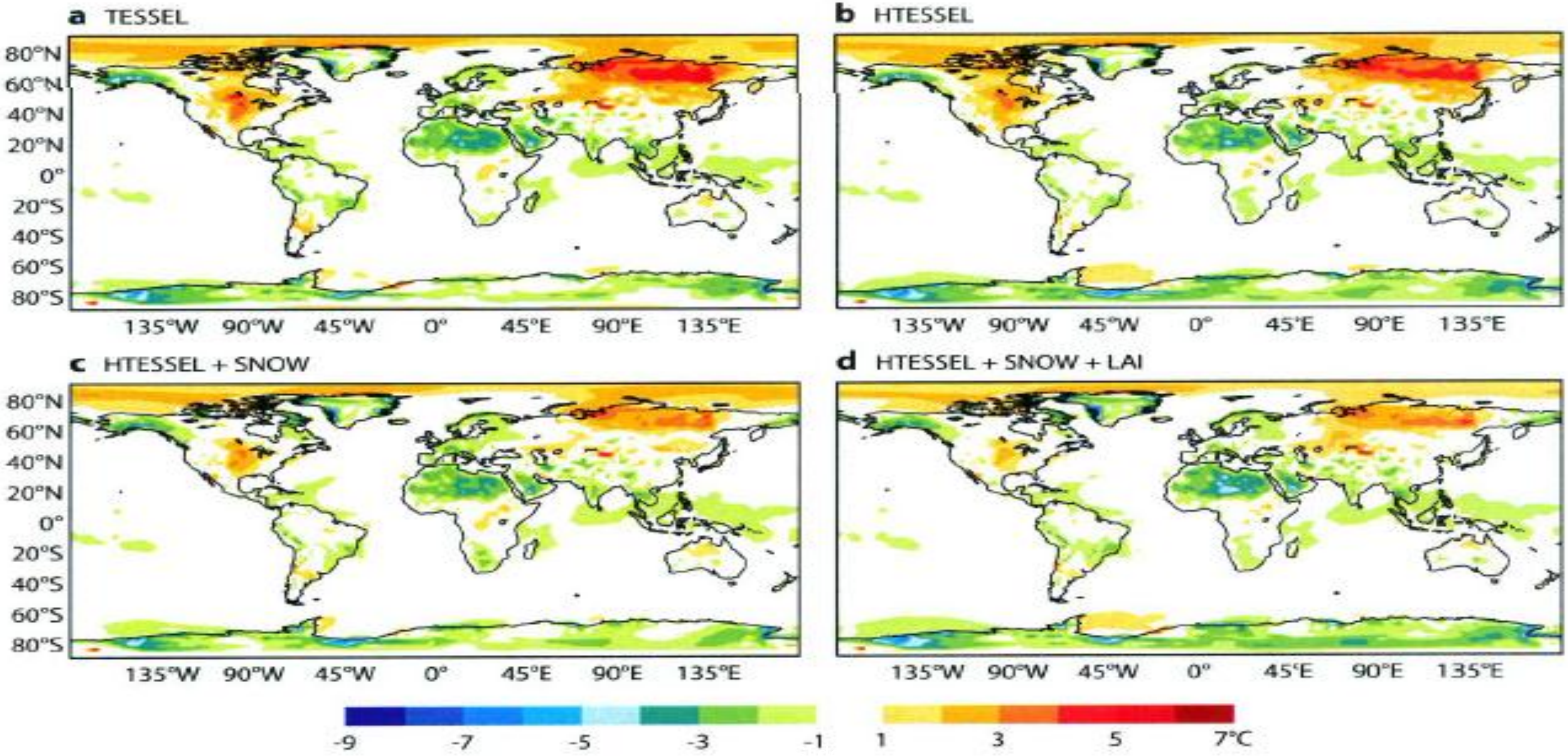


Improving temperature Degrade 2m temperature



Extended-range impact (1-year) of land surface model development on model error

Impact of the soil/snow/vegetation revision in HTESSEL on 2m temperature (in 13-month long integrations (Balsamo et al. 2009, Dutra et al. 2010, Boussetta et al. 2013)



simulations colder than ERA-Interim **Warmer than ERA-Interim**