A roadmap to
Earth surface kilometre-scale simulations

G. Balsamo, A. Agusti-Panareda, G. Arduini, A. Beljaars, S. Boussetta, M. Choulga, E. Dutra, H. Hersbach, J. Munoz-Sabater, P. de Rosnay, I. Sandu, N. Wedi
and several others

Outline: (i) land reanalysis past & present, (ii) modelling enhancement, (iii) mapping challenge.

Presented on 17 November 2017, 5th International Conference on Reanalysis, Rome
ECMWF, Earth System Modelling Section, Coupled Processes Team

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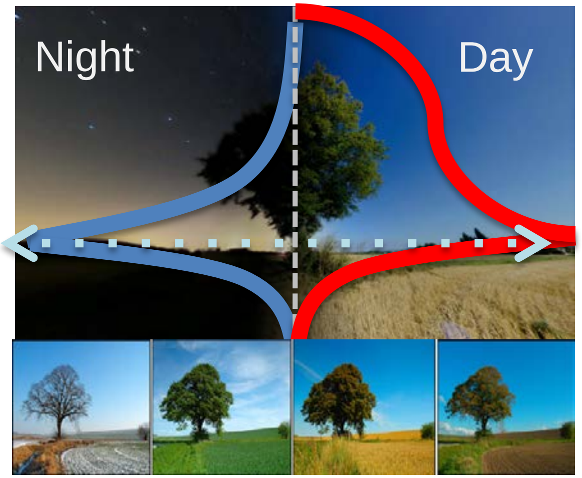
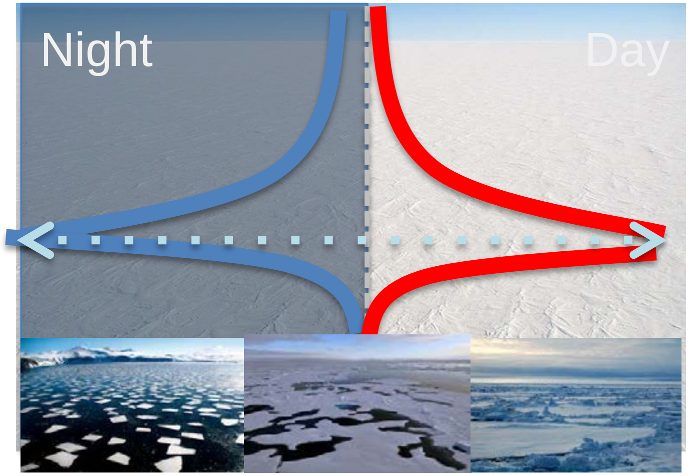
Modelling surface heterogeneity and coupling with the atmosphere

- The processes that are most relevant for near-surface weather prediction are also those that are most interactive and exhibit positive feedbacks or have key role in energy partitioning



Over Land

- Snow-cover, ice freezing/melting have positive feedback via the albedo
- Vegetation growth and variability interact with turbulence & moisture
- Vertical heat transport in soil/snow



Over Ocean/Cryosphere

- Transition from open-sea to ice-covered conditions
- Sea-state dependent interaction wind induced mixing/waves
- Vertical transport of heat

Over Water-bodies

- Lakes have large thermal inertia
- Different albedo & roughness

Spatial heterogeneity calls for high-resolution horizontal/vertical to represent the surface-atmosphere coupling

Earth surface modelling components @ECMWF

- **NEMO3.4**

  NEMO3.4 (Nucleus for European Modelling of the Ocean)

  Madec et al. (2008)

  Mogensen et al. (2012)

  ORCA1_Z42: 1.0° x 1.0°

  ORCA025_Z75 : 0.25° x 0.25°

- **EC-WAM**

  ECMWF Wave Model

  Janssen, (2004)

  Janssen et al. (2013)

  ENS-WAM : 0.25° x 0.25°

  HRES-WAM: 0.125° x 0.125°

- **LIM2**

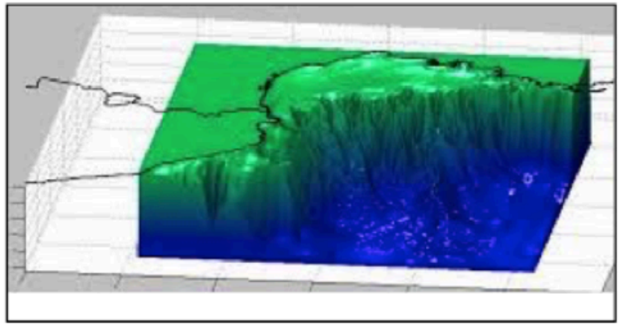
  The Louvain-la-Neuve Sea Ice Model

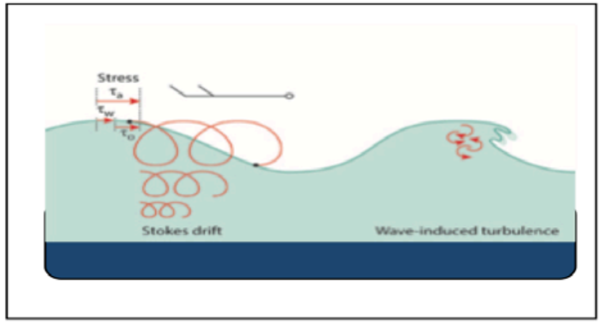
  Fichefet and Morales Maqueda (1997)

  Bouillon et al. (2009)

  Vancoppenolle et al. (2009)

  ORCA025_Z75 : 0.25° x 0.25°





- **Hydrology-TESSEL**

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

  Global Soil Texture (FAO)

  New hydraulic properties

  Variable Infiltration capacity & surface runoff revision

- **NEW SNOW**

  Dutra et al. (2010)

  Revised snow density

  Liquid water reservoir

  Revision of Albedo and sub-grid snow cover

- **NEW LAI**

  Boussetta et al. (2013)

  New satellite-based

  Leaf-Area-Index

- **SOIL Evaporation**

  Balsamo et al. (2011),

  Albergel et al. (2012)

- **H_2O / E / CO_2**

  Integration of

  Carbon/Energy/Water

  Boussetta et al. 2013

  Agusti-Panareda et al. 2015

- **Lake & Coastal area**

  Mironov et al (2010),

  Dutra et al. (2010),

  Balsamo et al. (2012, 2010)

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

  LW tiling (Dutra)

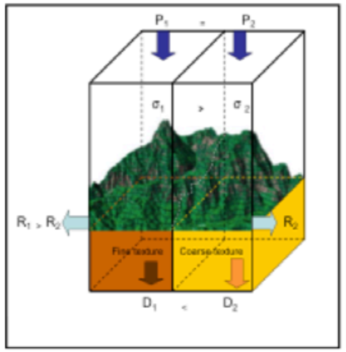
- **Enhance ML**

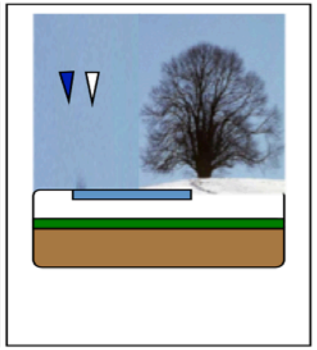
  Snow ML5

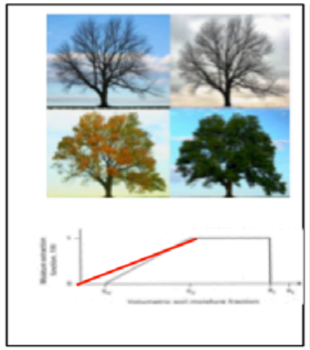
  Soil ML9

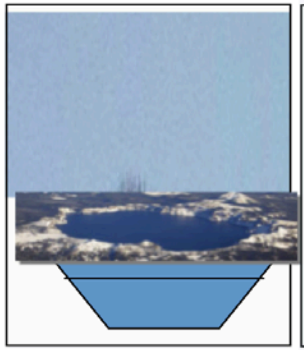
  Dutra et al. (2012, 2016)

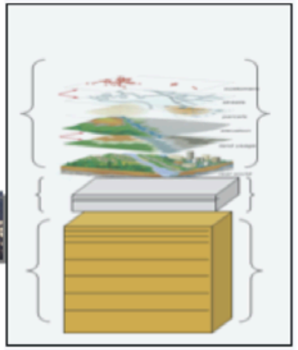
  Balsamo et al. (2016)











Atm/L and resol.	**ECMWF Config. in 2017**
80 km	ERAI*
32 km	ERA5* SEAS5
18 km	ENS
9 km	HRES$^+$

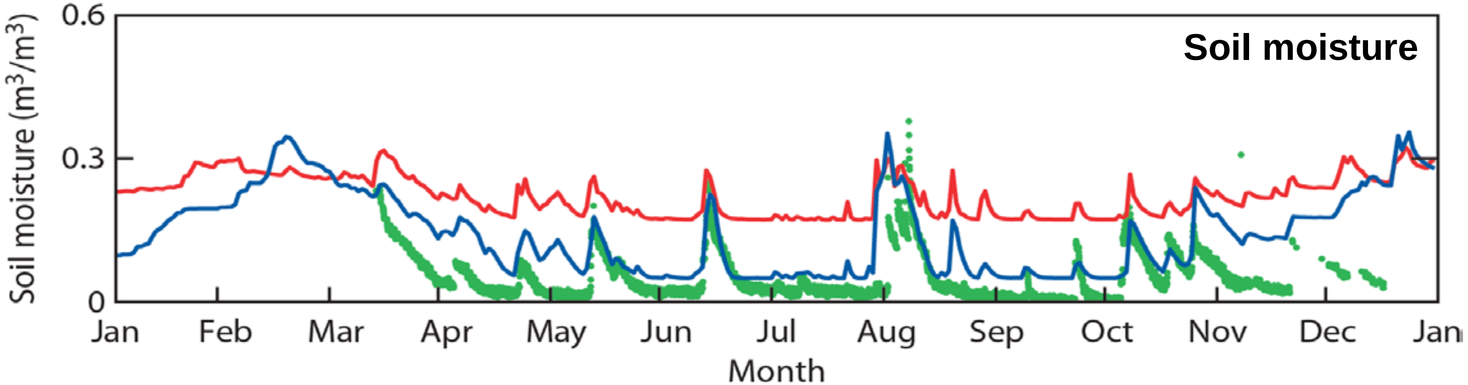
Ocean 3D-Model Surface Waves and currents, Sea-ice.
**(ocean-uncoupled)*
$^+$(coupled in 2018)

Land surface 1D-model soil, snow, vegetation, lakes and coastal water (thermodynamics).
Same resol. as Atm.

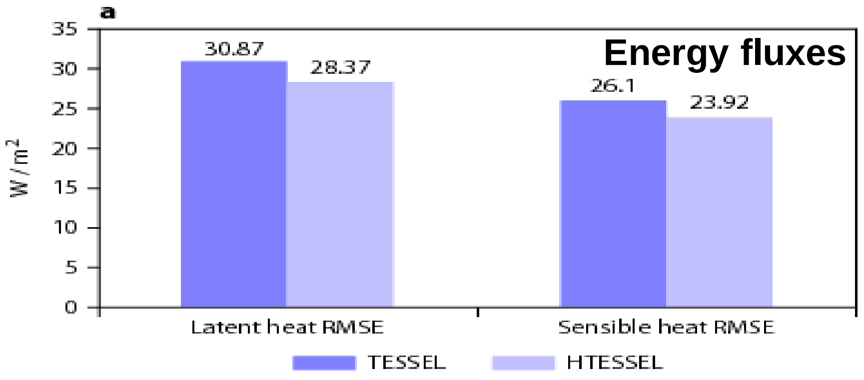
ERA-Interim/Land: a 80 km land-reanalysis (open-loop + precipitation correction)

Balsamo et al. (2015 HESS)

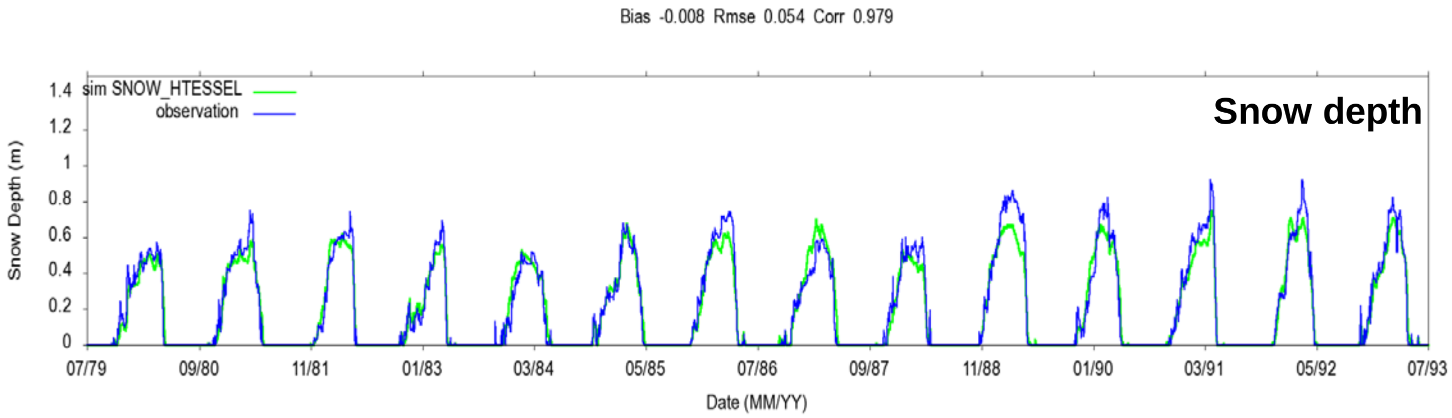
ERA-Interim/Land had the same horizontal resolution of ERA-Interim (80km) integrates land surface modelling improvements with respect to ERA-Interim and provided a balanced initial condition for the Monthly/Seasonal Re-Forecasts



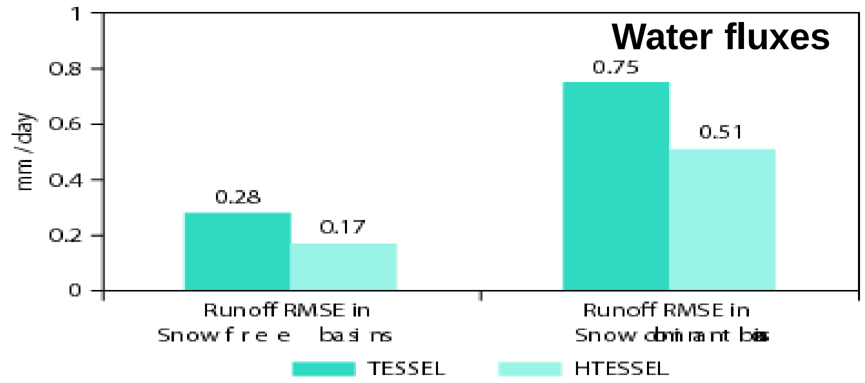
Evolution of soil moisture for a site in Utah in2010.
Observations, ERA-Interim, and ERA-Interim/Land.



Mean performance measured over 36 stations with hourly Fluxes from FLUXNET & CEOP Observations



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.

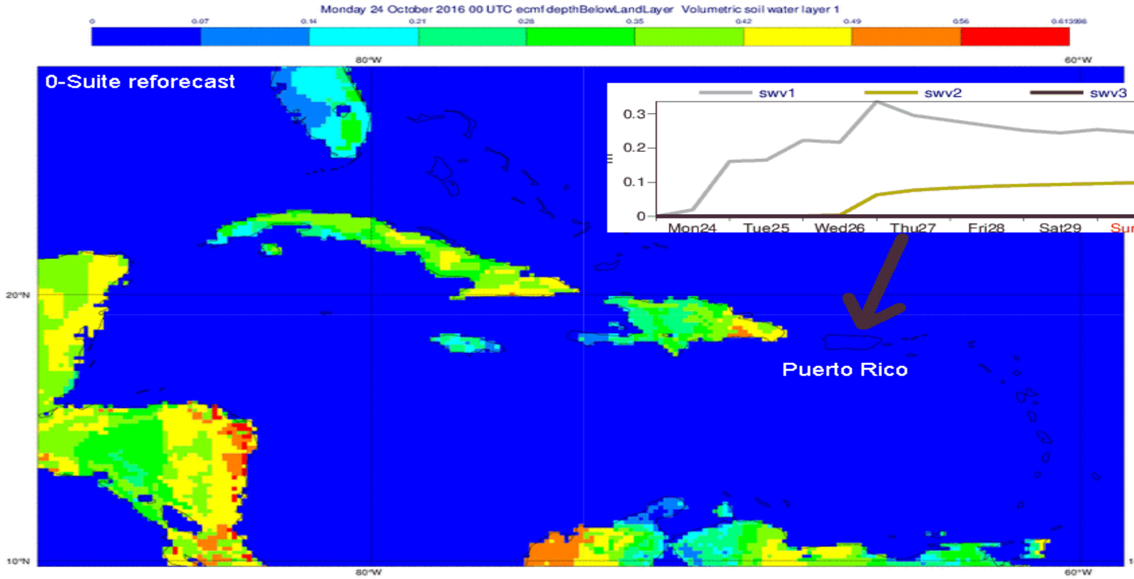


Mean performance measured for the monthly rivers discharge verified with GRDC observations

ERA-Interim/Land approach has been applied in EartH2Observe H2020 project (http://www.earth2observe.eu), Schellekens et al (2017 ESSD)

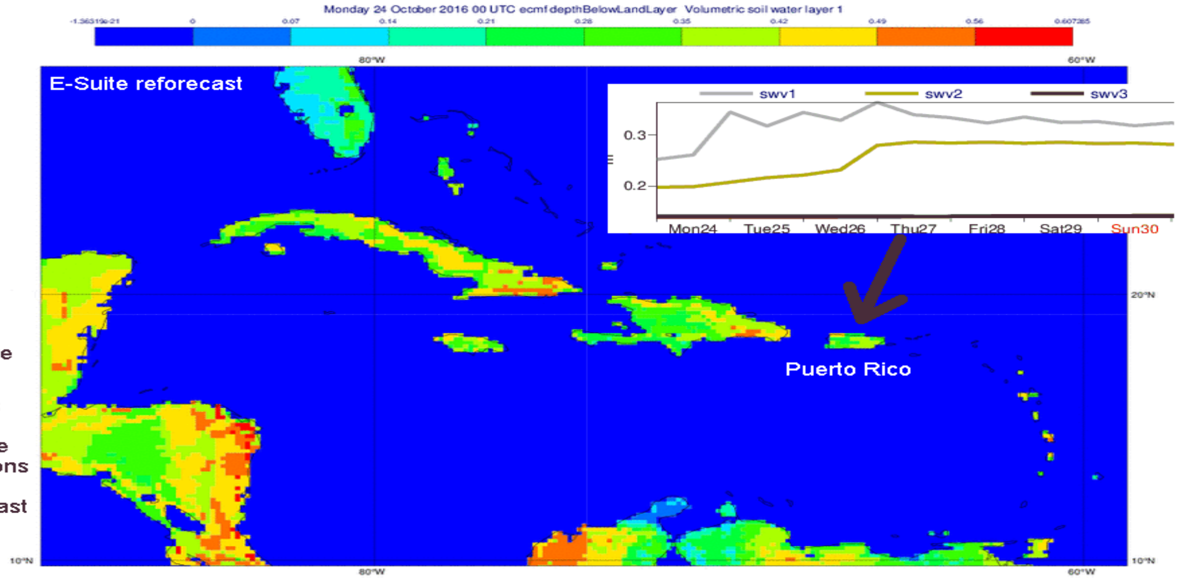
ERA5-Land: a 9-km land reanalysis (open-loop + high-resolution downscaling)

ERA5/Land benefits from the R&D done in EartH2Observe H2020 project and Copernicus, is based on the new ERA5 and it run at 9-times higher resolution than ERA-Interim and 3.5-times higher resolution than ERA5. ERA5/Land will match the highest resolution currently operational at ECMWF (HRES 9km)

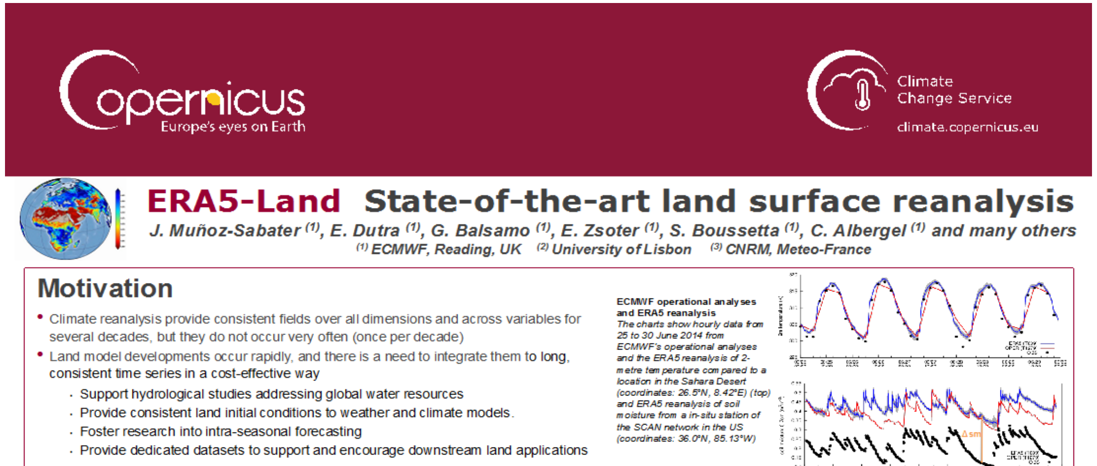


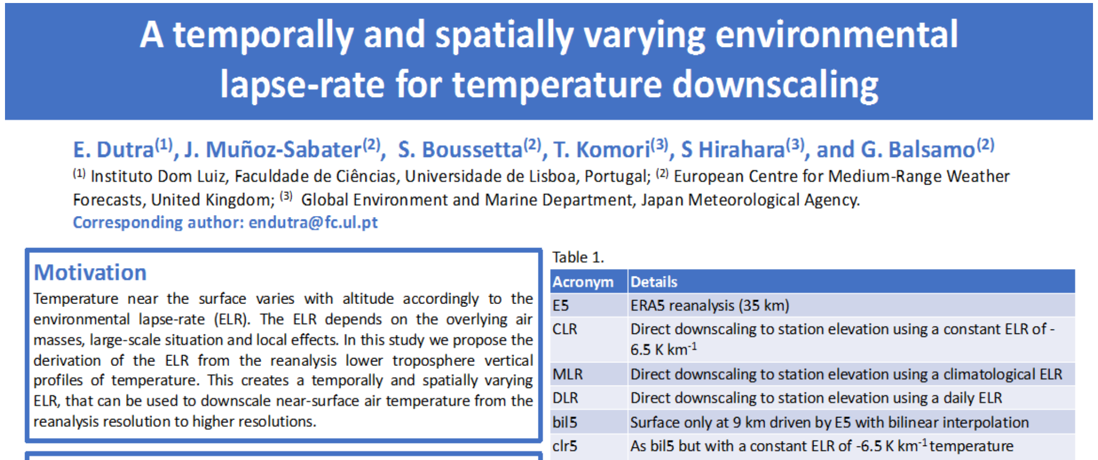
Maps show level 1 Soil Moisture at T+0

Profiles show example evolutions from a reforecast



See poster of **Munoz-Sabater et al** on ERA5-Land description and performance & poster of **Dutra et al** on high resolution downscaling and performance

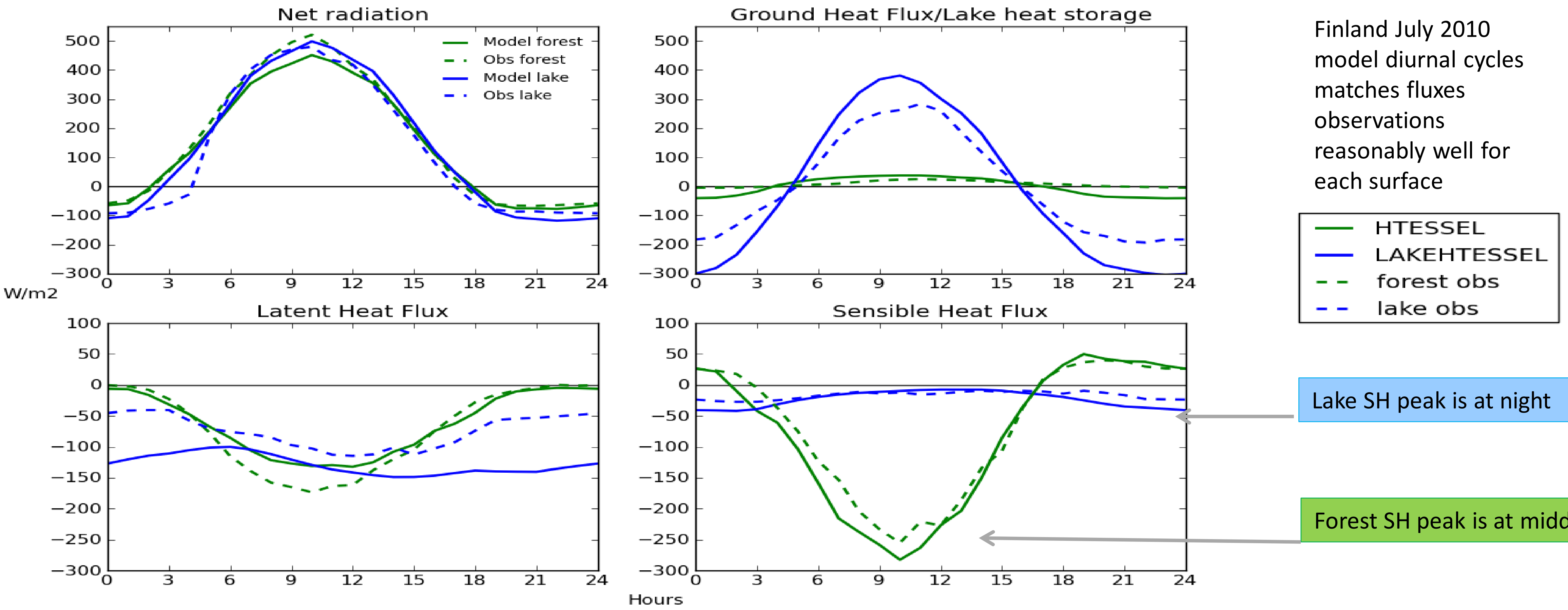




ERA5 & ERA5-Land include lakes

Manrique-Suñén et al. (2013, JHM)

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



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

Lake SH peak is at night

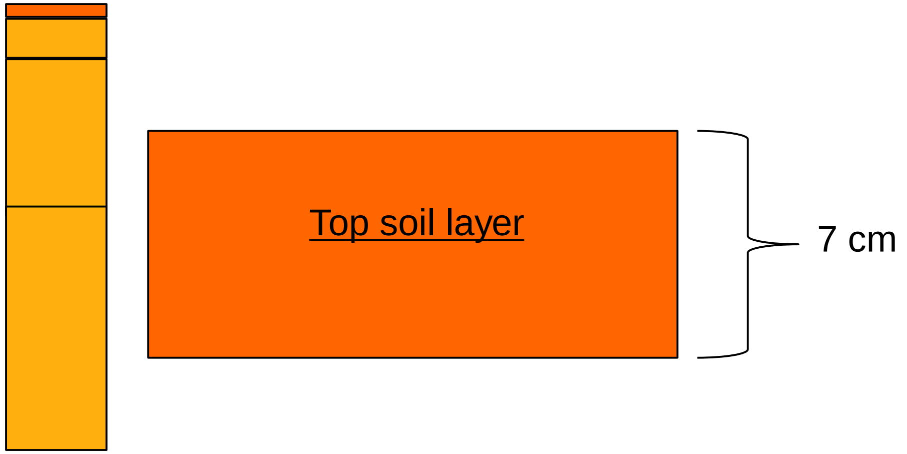
Forest SH peak is at midday

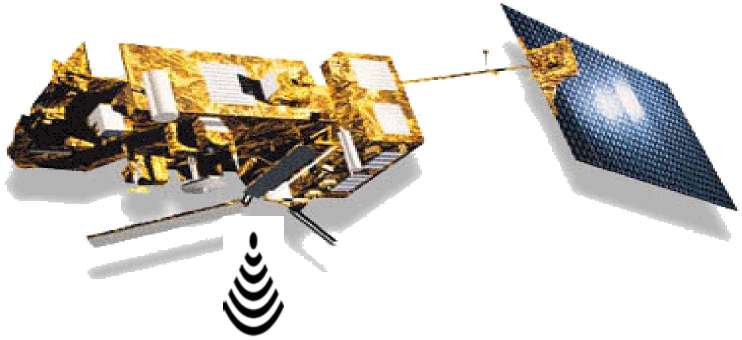
ERA-Interim reanalysis (near surface meteorological forcing) has enable to study the impact of lakes and this research is now integral part of ERA5

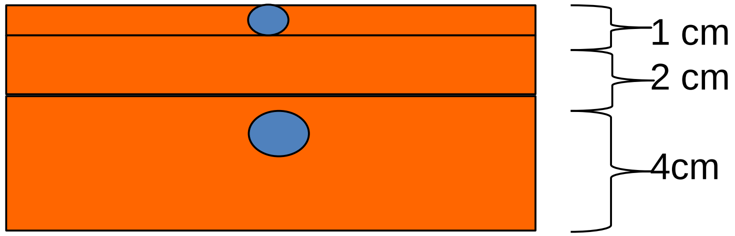
Future enhanced soil model vertical resolution to increase use of satellite data

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.

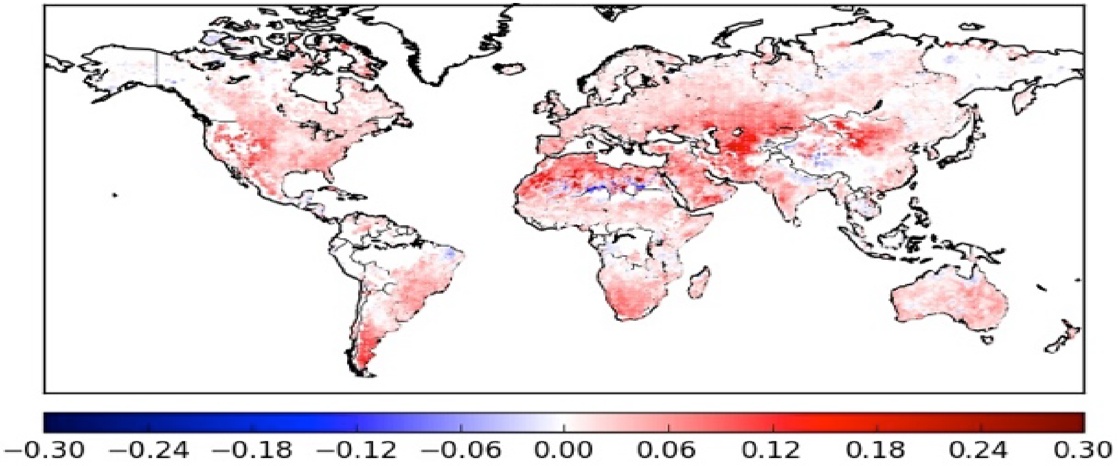
4-layers:
 # 0-7 cm
7-28 cm
28-100 cm
100-289 cm







9-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
200-300 cm



Thanks to Clément Albergel

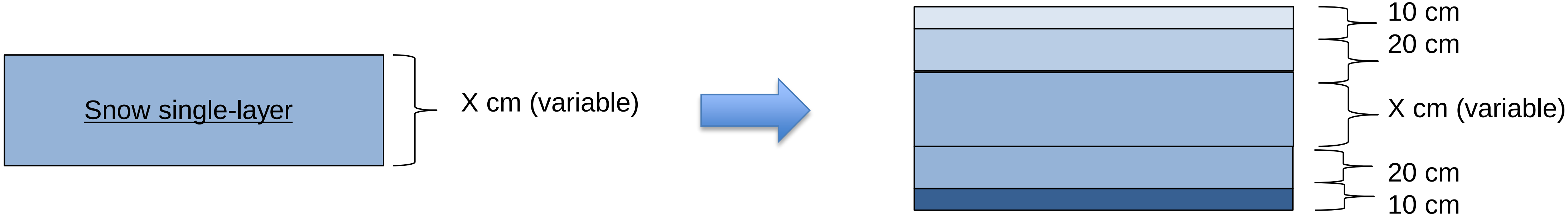
Comparison with ESA-CCI soil moisture remote sensing (multi-sensor) product.(1988-2014). A finer soil model improves the correlation with measured satellite soil moisture

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

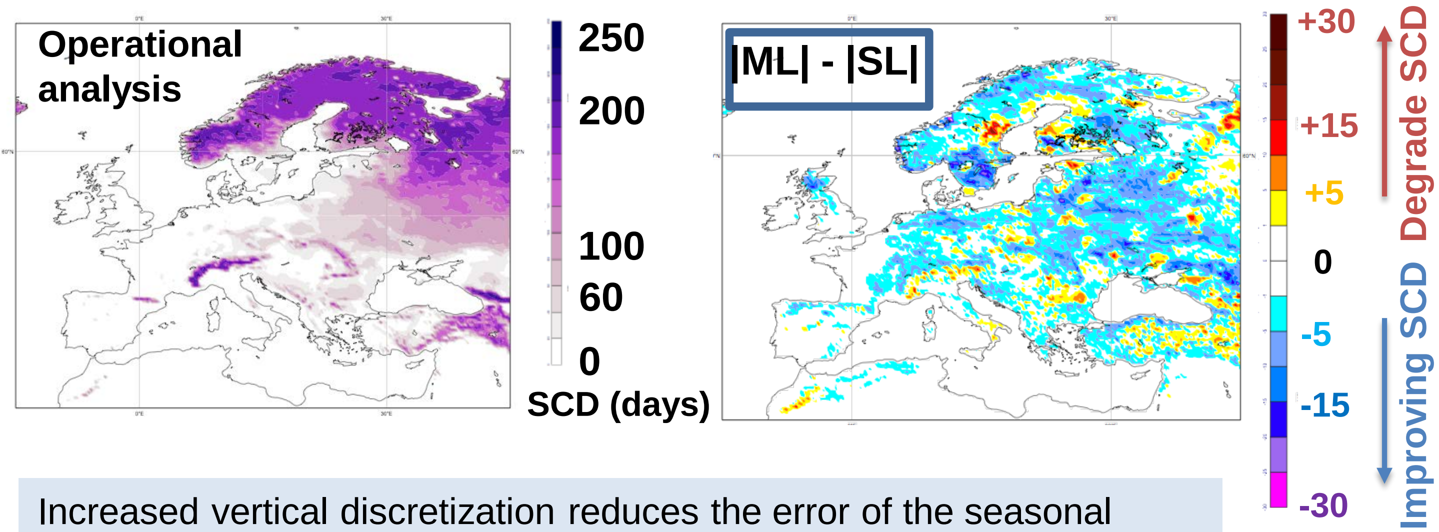
Dorigo et al. (2017 RSE)

Future enhanced snow model vertical resolution: impact in cold regions climate

Increased vertical discretization of the snowpack (**up to 5 layers**) permits a better physical processes representation

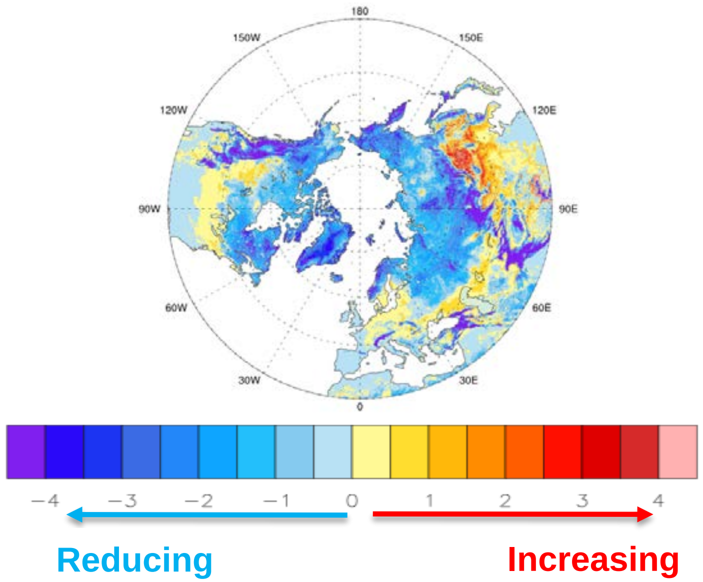


Snow cover duration (SCD) over Europe 2016/2017



Increased vertical discretization reduces the error of the seasonal snow cover duration by 5 to 15 days (evaluated in ERA5-Land mode)

Difference in T_{skin} minimum winter (DJF)



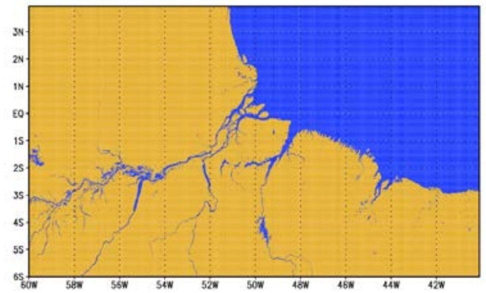
Potential for reducing the 2m temperature diurnal-cycle bias

Thanks to Gabriele Arduini, Souhail Boussetta, Emanuel Dutra

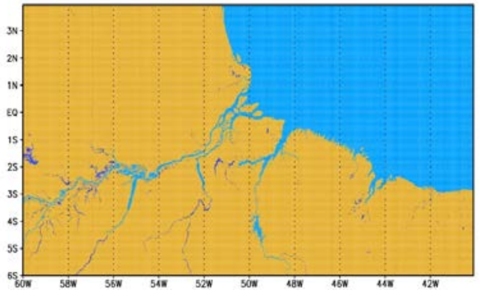
Mapping the surface at 1km: water bodies and changes over time

Classifying automatically inland water bodies is a complex task. A 1-km water bodies cover and bathymetry have been produced

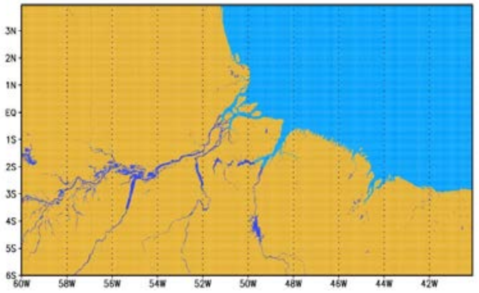
ESA GlobCOVER has no water class



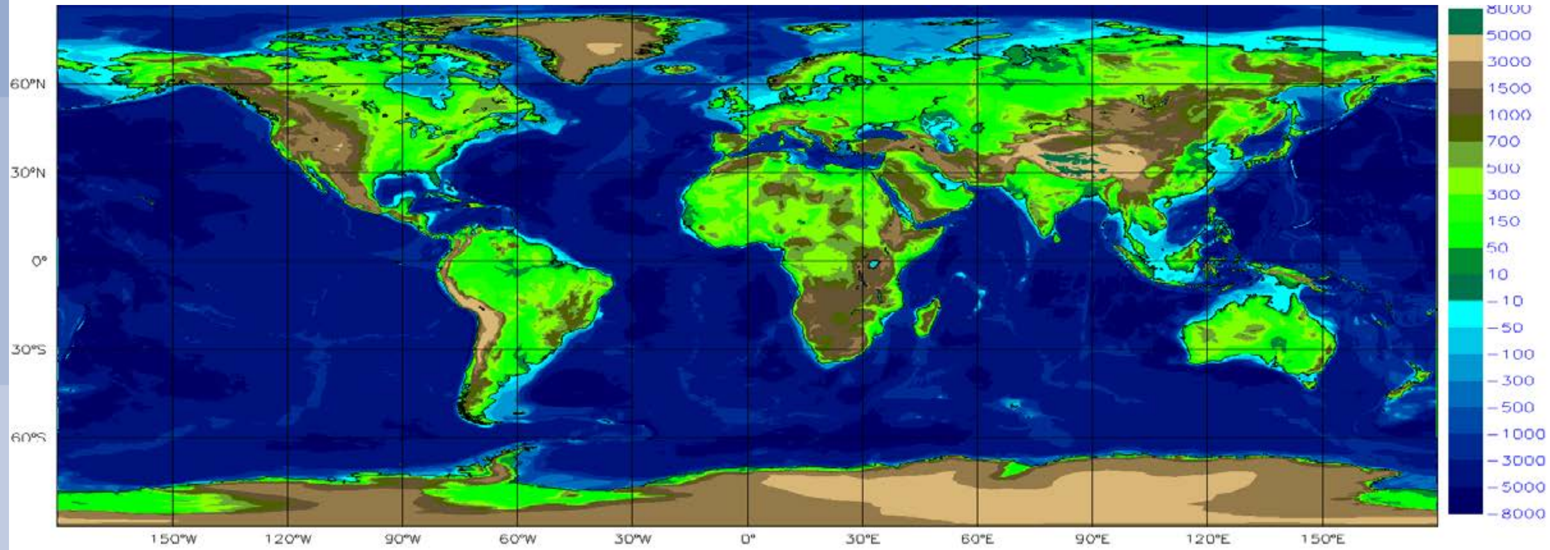
Flooding allows classify, problems w. large rivers



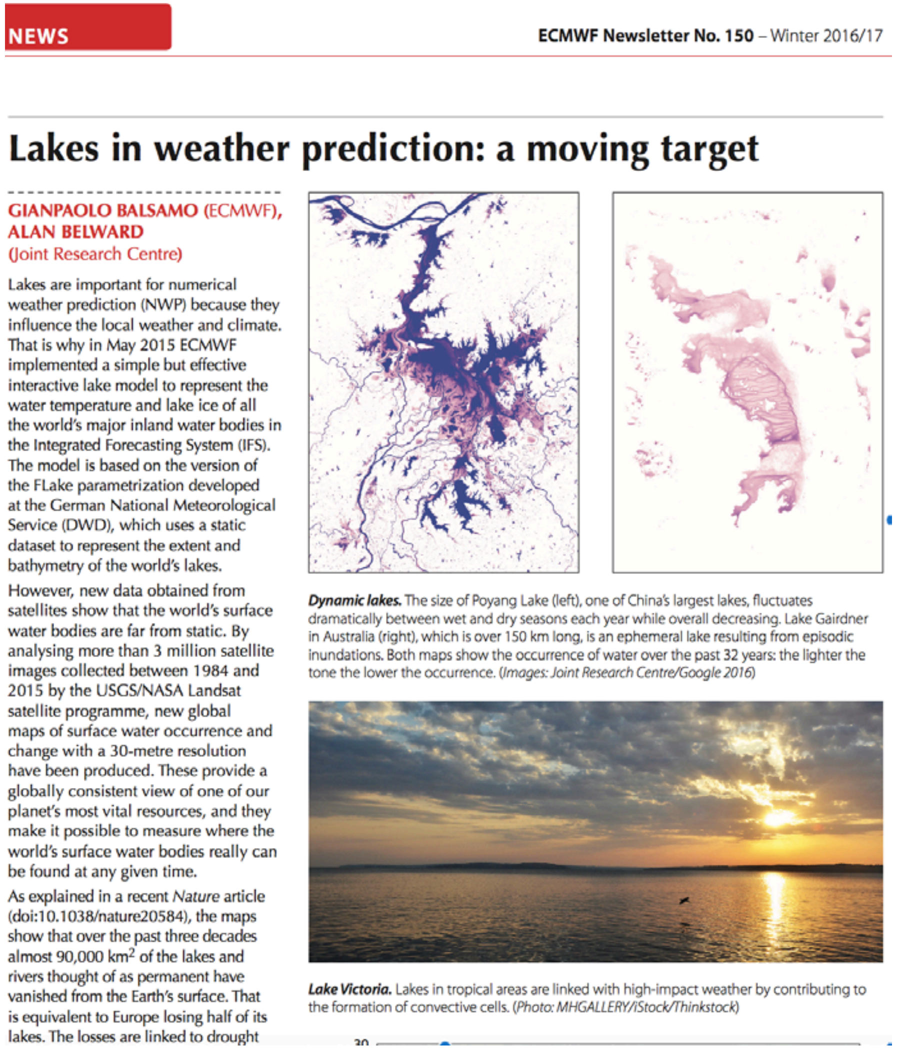
New classification algo works well at 1km



A new 1-km global bathymetry and orography map (SRTM+/GEBCO/GLDB)



ESA GlobCOVER is combined with JRC/GLCS to detect Lake cover changes


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 km² 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, Souhail Boussetta, Irina Sandu, Nils Wedi

Mapping the surface at 1km: urban cover, its expansion and uncertainties

Classifying automatically urban areas (fraction and height) is an extremely complex task. Urban areas expand each year

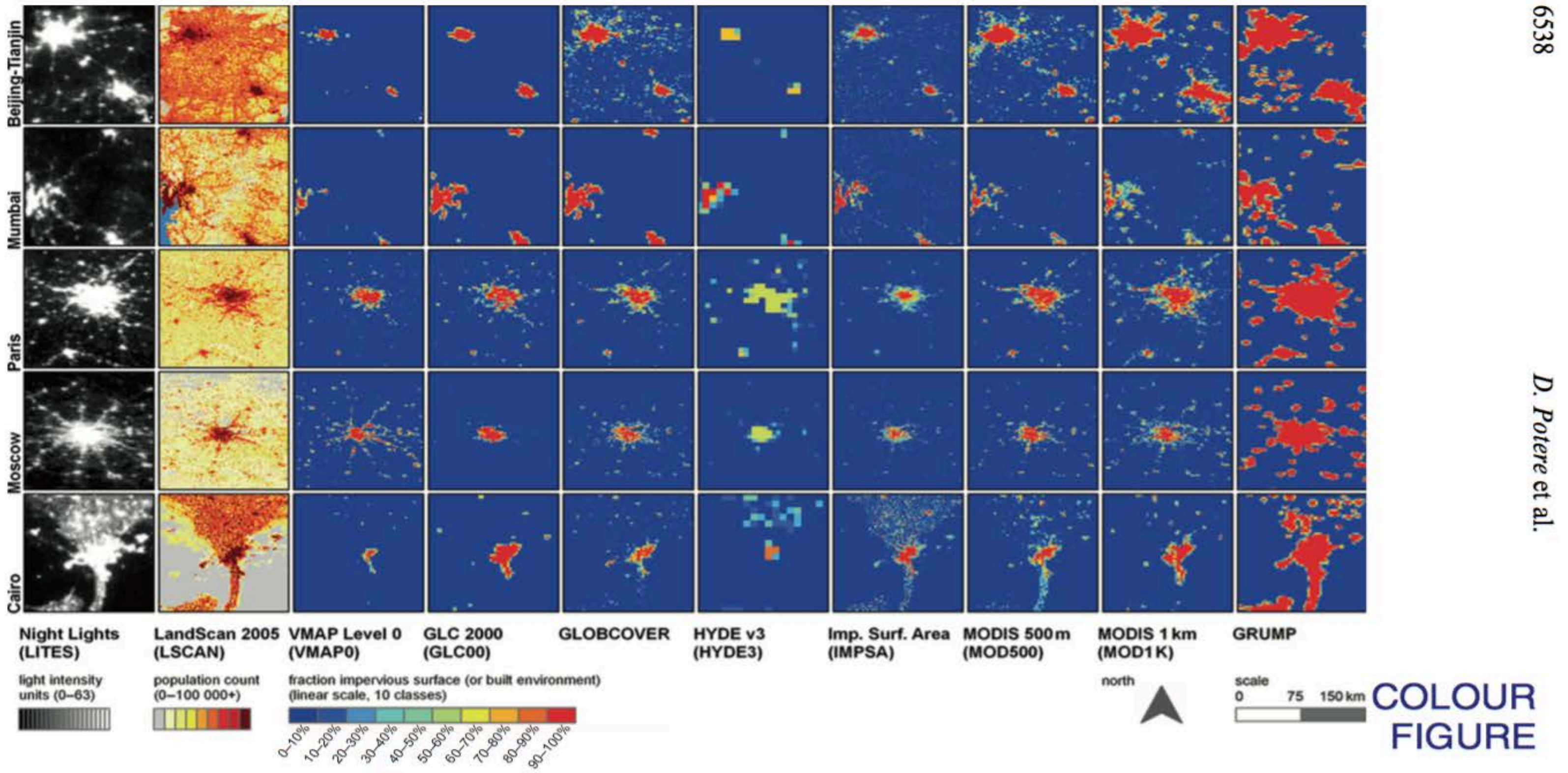
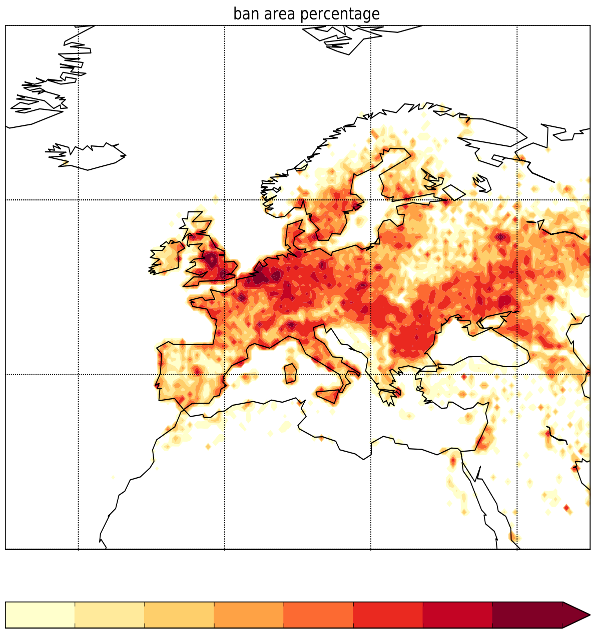


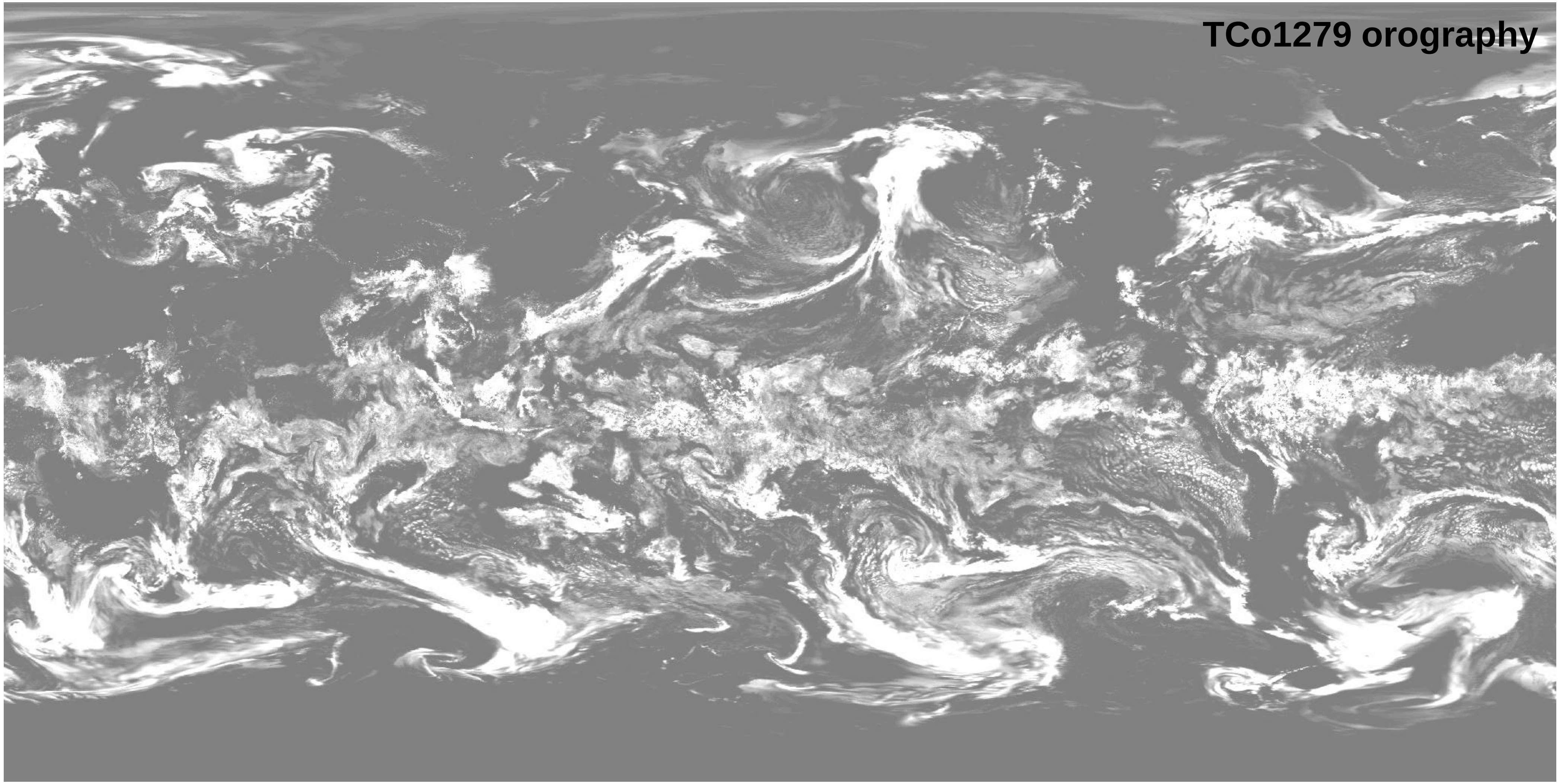
Figure 1. The eight global urban maps and two urban-related maps for Beijing-Tianjin, China (top row), Mumbai, India (second row), Paris, France (third row), Moscow, Russia (fourth row), and Cairo, Egypt (bottom row). LITES, LSCAN and IMPSA are at native 30 arc-second resolution, HYDE3 is at native 5 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



- Urban area (a, in %, from ECOCLIMAP Masson et al., 2003) see:
- Balsamo et al. 2014 ECMWF TM729
- CHE H2020 Project http://www.che-project.eu

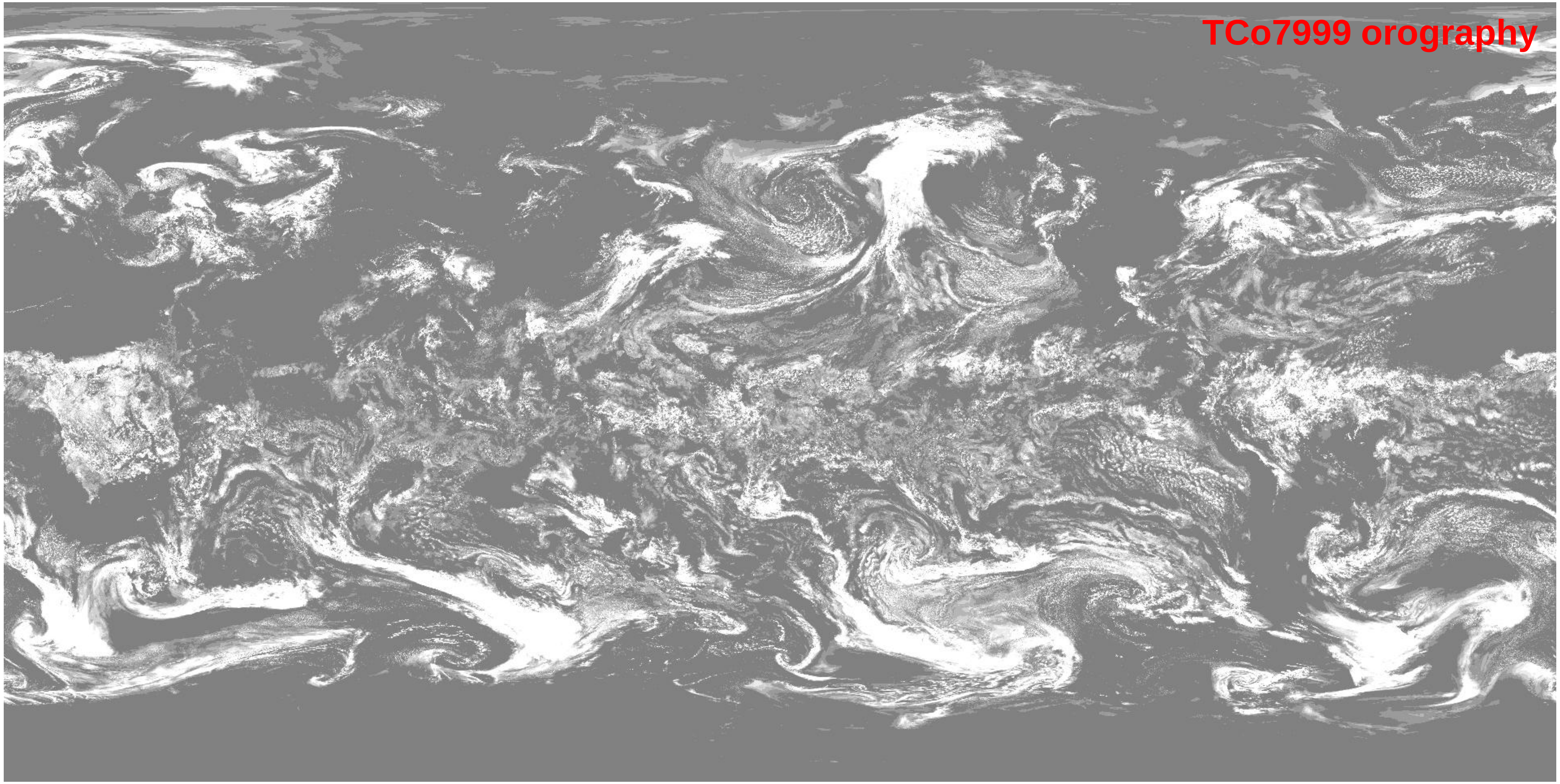
Current km-scale: TCo1279 (~9km) highest global operational NWP today



(12h forecast, *hydrostatic*, with deep convection parametrization, 450s time-step, 240 Broadwell nodes, ~0.75s per timestep)

Equivalent to 6.6 Megapixel camera

Towards km-scale: TCo7999 test-case (~1.3km) highest NWP test @ECMWF



(12 h forecast, *hydrostatic*, no deep convection parametrization, 120s time-step, 960 Broadwell nodes, ~6s per timestep in SP)

ECMWF

Thanks to Nils Wedi and NM-Team

Equivalent to 256 Megapixel camera 

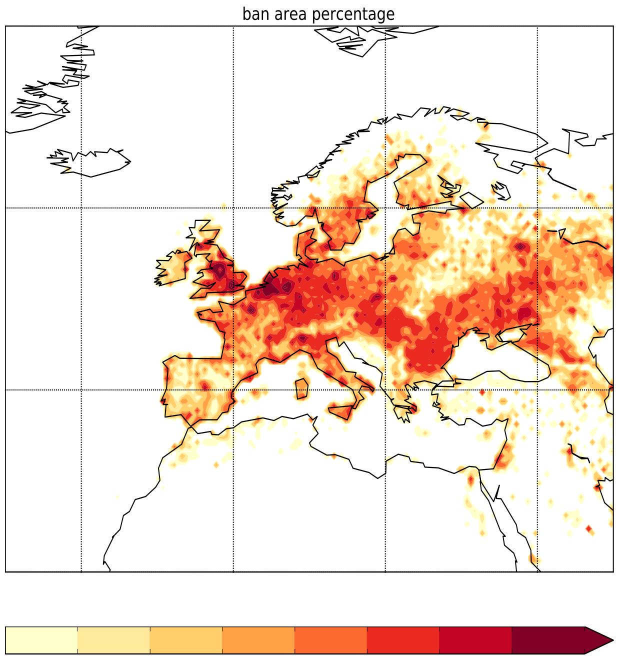
Summary and outlook

- Land Reanalyses benefit from high resolution/discretisation in horizontal and vertical
- NWP systems are moving towards Environmental prediction & Extended-range
- Supporting streams of Reanalyses: Climate-LRES, Satellite-MRES, Satellite-HRES
- Modelling activities are coordinating (GEWEX/WCRP/WWRP) greater use of EO-data
- Mapping activities are yet insufficiently coordinated to meet global modelling challenges
- A global km-scale (short) reanalysis can effectively enhance linkage with monitoring and mapping activities and support monitoring, eg. Copernicus Sentinels, GEO/LEO high-res.

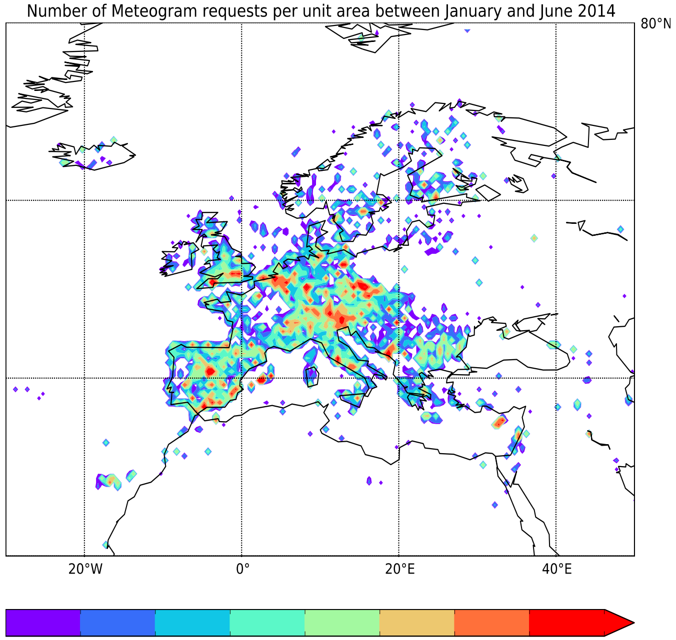
Thanks for any questions, comments, remarks! Contact email: gianpaolo.balsamo@ecmwf.int

Why global models move towards urban-scale modelling?

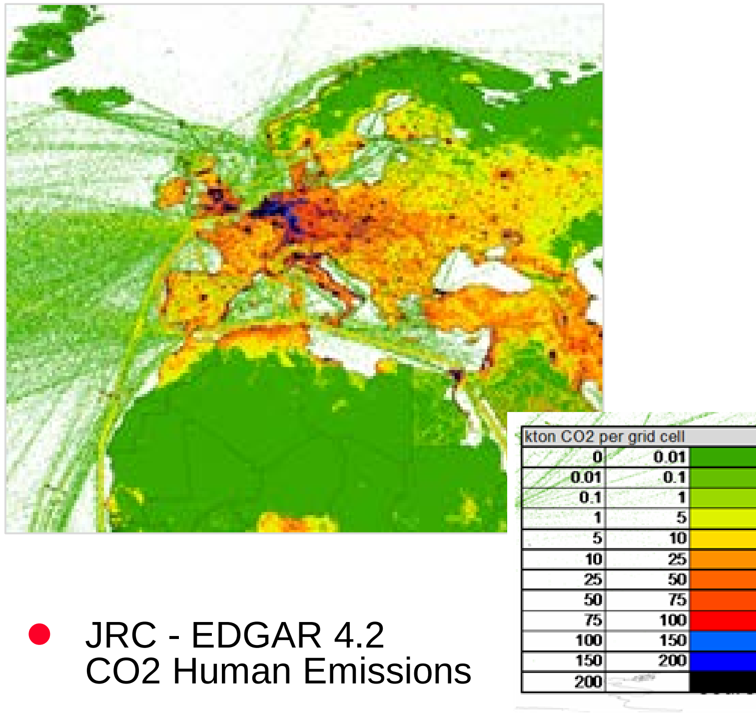
- Urban areas are important for the accurate prediction of extreme events such as heatwaves and urban flooding and need to be represented in ECMWF model.
- Best and Grimmond (2015) suggested that simple models may be well adapted to global applications
- Users lives in urban areas and look at the forecast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



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



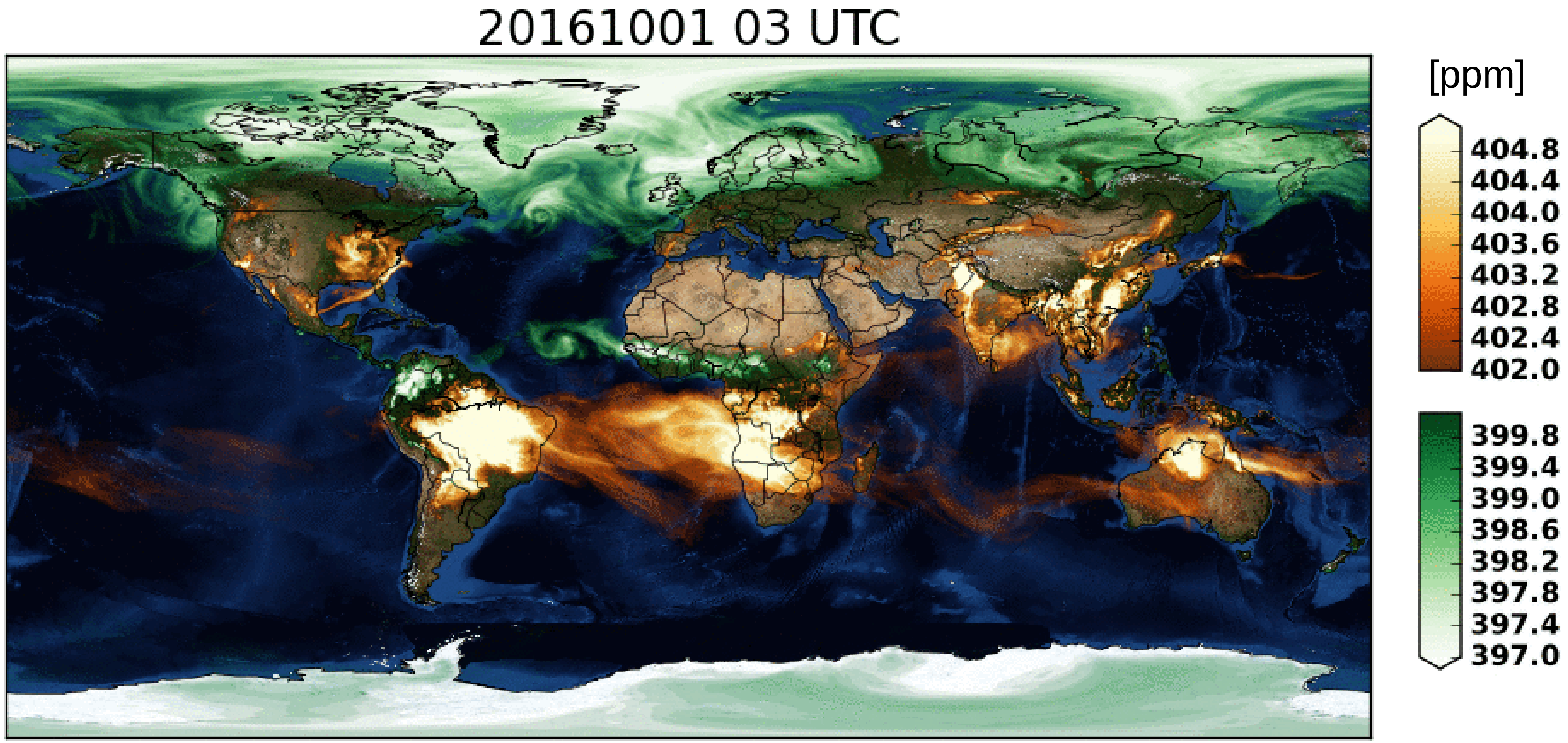
- Number of ECMWF Meteograms product requests from Member-States



- JRC - EDGAR 4.2 CO2 Human Emissions

The CO2 Human Emission Project will make use of ECMWF IFS 9km and CAMS configuration to study anthropogenic emissions

Forecasts of the CO2 variations from a 400 ppm concentration background. Another call for high res.!



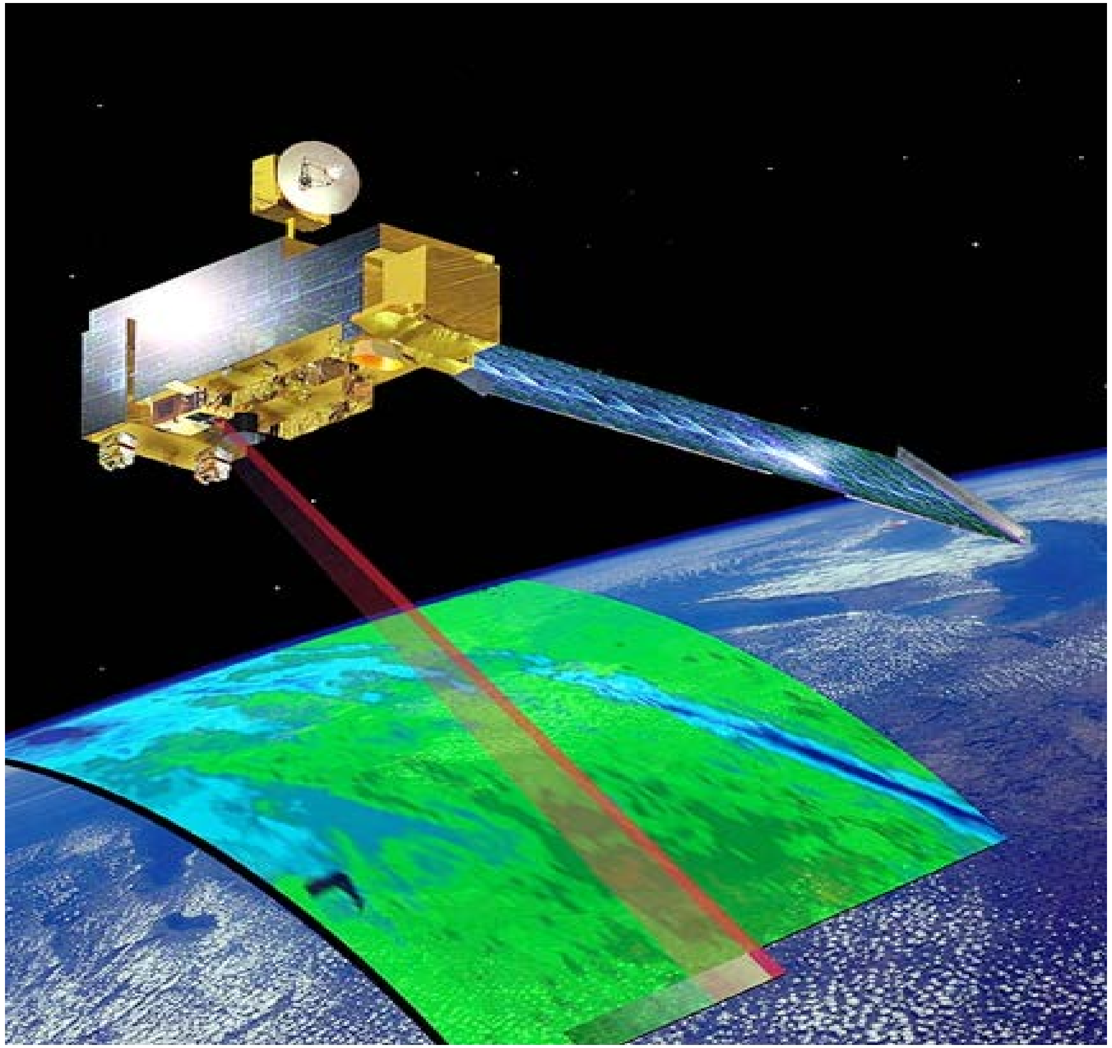
CO_2, CH_4, linCO, tagged tracers at Tco1279 (~9km) L137

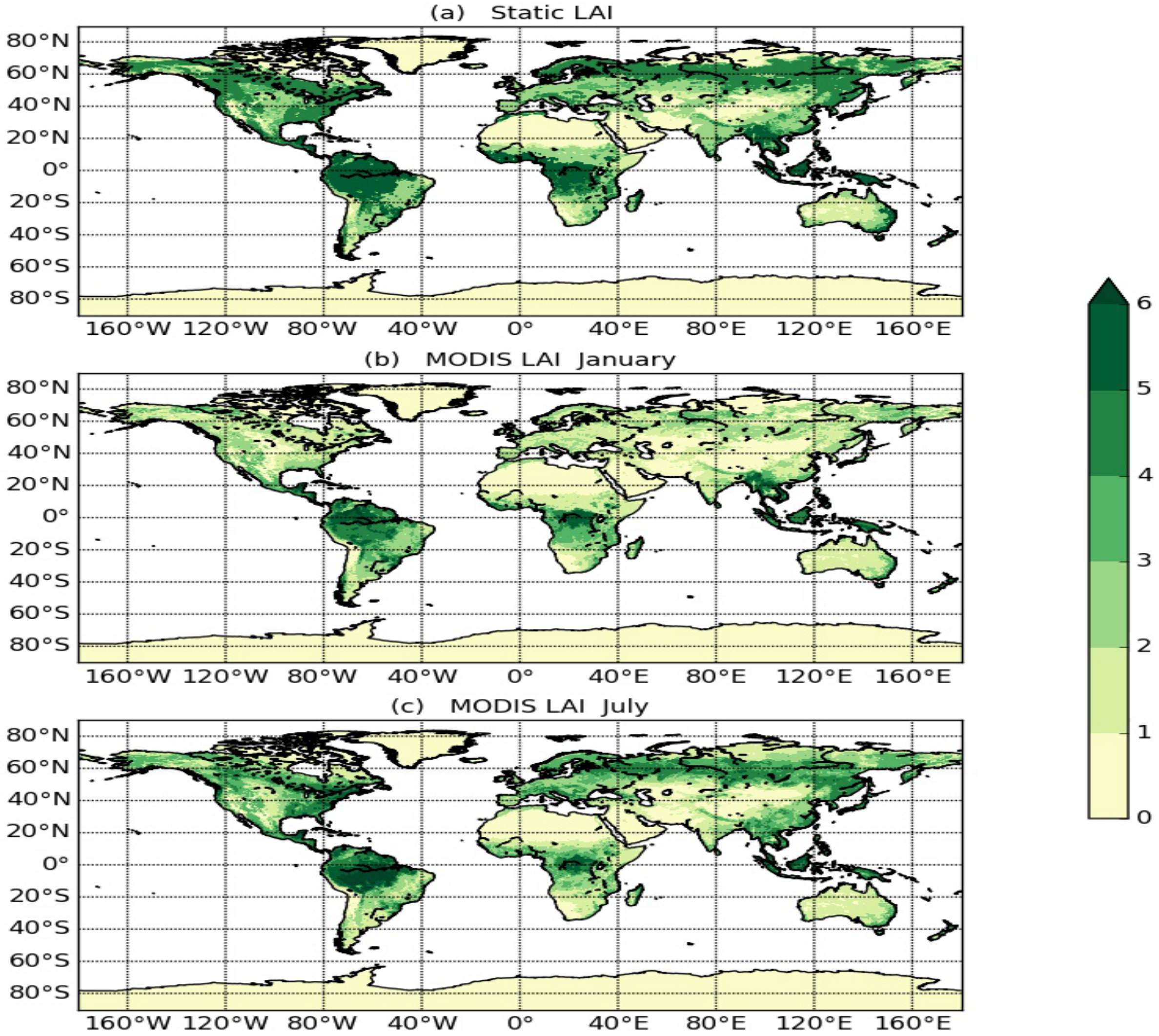
- CTESSEL NEE (BFAS correction Agusti-Panareda et al. ACP 2016
- EDGARv4.2FT2010
- Takahashi et al. (2009)
- GFAS biomass burning
- IFS transport
- Bermejo & Conde mass fixer (Agusti-Panareda et al. GMD 2017)

Thanks to Anna Agusti-Panareda, Richard Engelen & CAMS

Monitoring vegetation state from satellite data

Vegetation assimilate CO2 and is a powerful sink to regulate atmospheric concentrations. CO2 and Water/Energy fluxes are linked!





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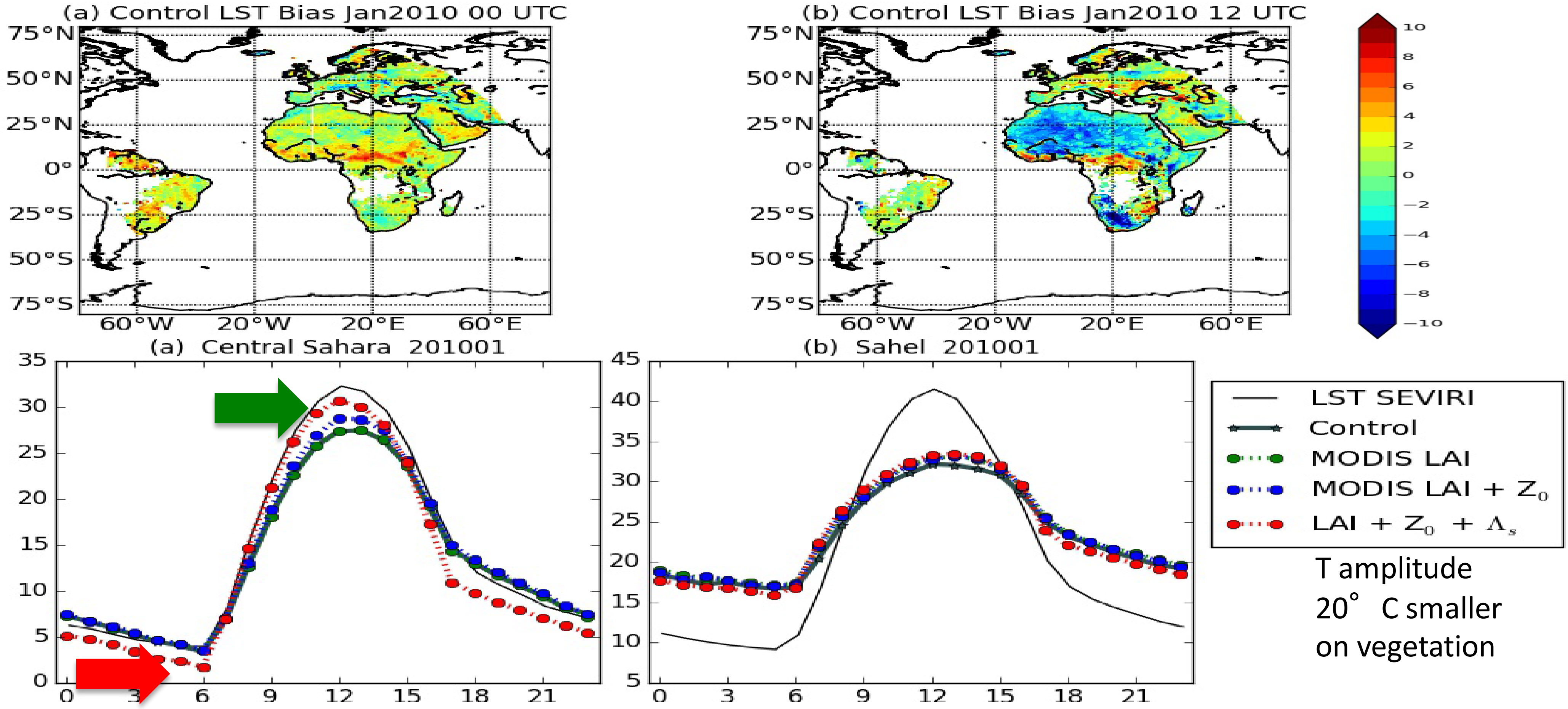
Thanks to Souhail Boussetta

Diurnal cycle: the effect of 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)

ECMWF

A roadmap to Earth surface kilometre-scale simulations

The strive to produce increasingly more accurate forecasts has pushed horizontal resolutions of global Earth System Models (ESM) to break into single-digit kilometre-scale (e.g. 9 km for global HRES forecasts at ECMWF with a vision to increase it further towards 2025), while many National Meteo-Hydrological Services already run at 1-2 km resolution on wide regional domains. At about **1km** there is close to a billion grid points covering the Earth surface involving the use of High Performance Computing to be timely simulated. However, there are not only computing and software challenges involved, as accuracy requires to be able to characterise the **surface ancillary conditions** at those resolution (vegetation and soil, water-land-snow-ice fractions, and any meteorologically relevant properties) therefore involving satellite remote sensing observations and **optimisation/inversion** algorithms to estimate non-observable quantities.

Global high-resolution simulation capacity can benefit enormously **next generation reanalyses** products when combined with refinements in the treatment of physical processes to better account for regional and local meteorological/climate/human-induced changes.

This presentation will cover current efforts to characterise the Earth surface at kilometre-scale making use of recent remote-sensing dataset in collaboration with the **Copernicus Services** and it will illustrate some of the challenges with the internal consistency across datasets and with their use in long reanalysis.

Contribution to Earth surface research using EO data

remote sensing

Special Issue "Advancing Earth Surface Representation via Enhanced Use of Earth Observations in Monitoring and Forecasting Applications”

http://www.mdpi.com/journal/remotesensing/special_issues/earthsurface_RS

Extended submission to Spring 2018.