Coupled processes at the surface-atmosphere interface

Relevance for medium-range prediction: the ECMWF experience

Gianpaolo Balsamo & CP-Team
With contributions of several Colleagues acknowledged on the slides

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ECMWF

Outline and Content

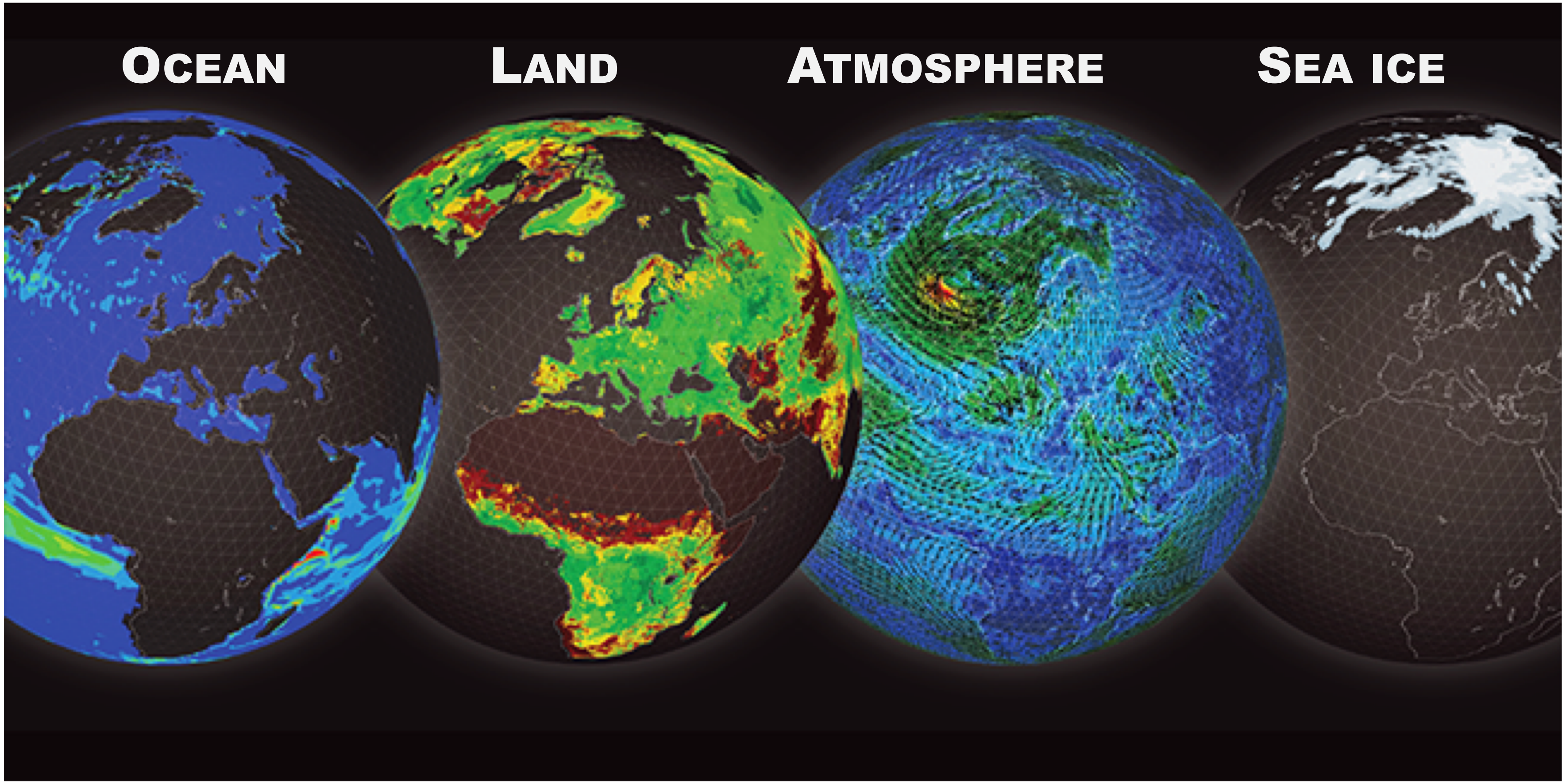
- Earth System Approach @ ECMWF
- Modelling Earth Surface: why it matters?
- Predicting extremes: what developments are most helpful?
- A look towards future: how and when to increase coupling?

Coupled processes at the surface-atmosphere interface and their relevance for medium-range prediction: the ECMWF experience

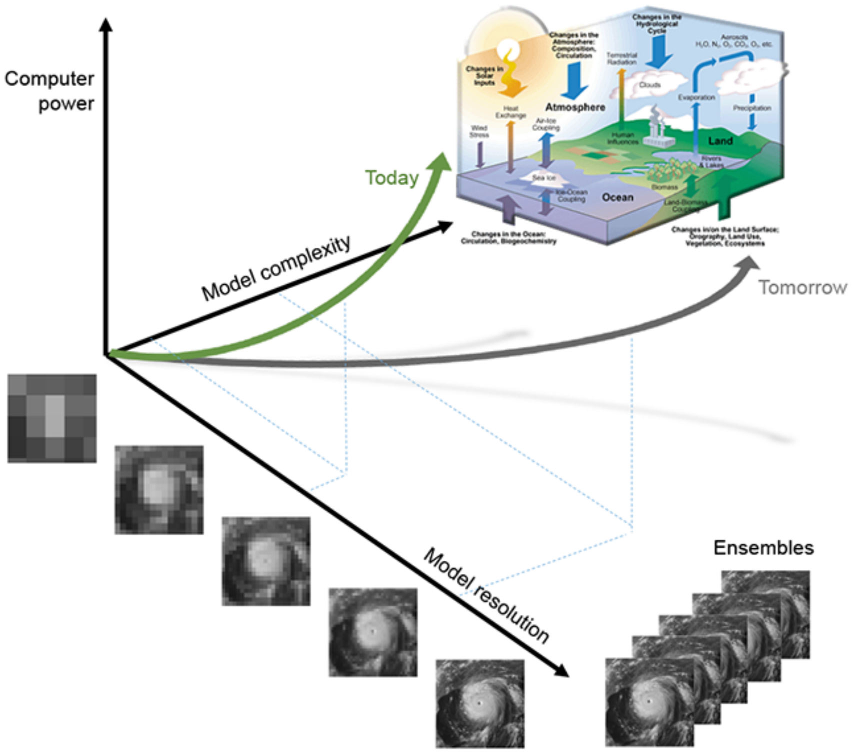
G. Balsamo & CP-Team

In recent years several revisions in the representation of surface-atmosphere coupling over land and oceans have been associated to improvements of predictive skills in the medium-range at ECMWF. In my talk I present some of the key Coupled Processes (CP) affecting the natural water cycle repartition at the surface, in particular soil moisture and snow-pack and their effect on near surface meteorology and hydrology in the ECMWF Integrated Forecasting System (IFS), that is used in global reanalyses such as in the C3S ERA5 and CAMS Interim-RA. I will also discuss the importance of evapotranspiration processes and a more realistic representation of the vegetation layer, in conjunction with human modifications of the land-use and water-use. These are important development to consider when transitioning towards more integrated environmental and climate applications.

Embracing an Earth System Model approach



Earth Observations and evolution of Earth surface models



Thanks to Peter Bauer, Andy Brown

Earth surfaces specificities

- Natural and anthropogenic complexity
- Simple parameterisation schemes
- Demanding data volume
- Observation representativity issues
- Complex observation operators
- Sectoral Earth science expertise (land, ocean, ice, urban)
- Resolution barriers model/data

Consequences

- EO-uptake of surface informative data in NWP/ESS not ideal
- Land surface scheme developed on in-situ and process abstraction
- EO-satellite not sufficiently used to develop models (lack of connection)
- ESS models not suitable to assimilate EO surface information

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**

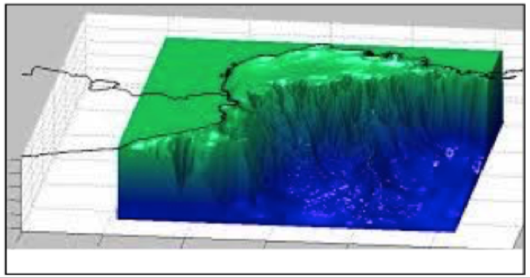
  The Louvain-la-Neuve Sea Ice Model

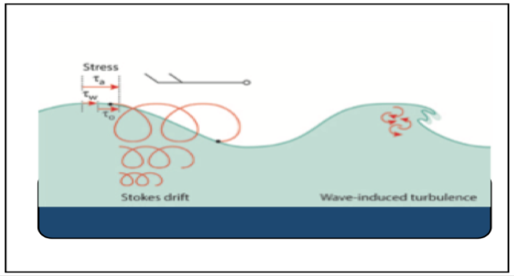
  Fichefet and Morales Maqueda (1997)

  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)

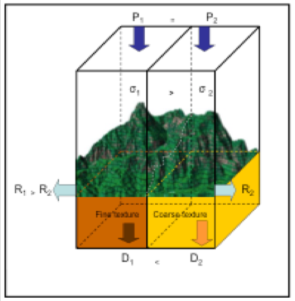
- **Enhance ML**

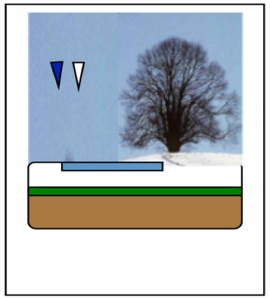
  Snow ML5

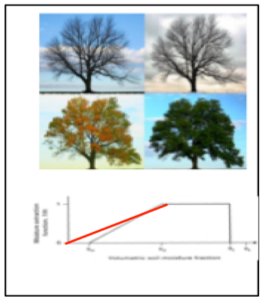
  Soil ML9

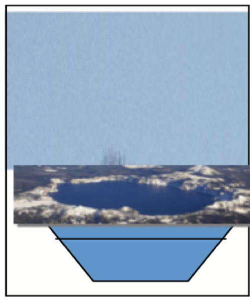
  Dutra et al. (2012, 2016)

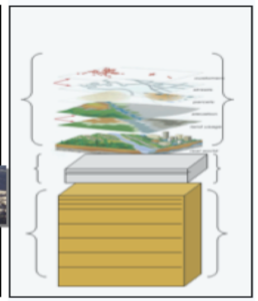
  Balsamo et al. (2016)











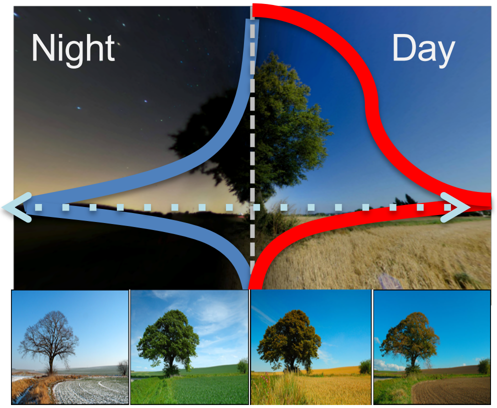
Atm/L and resol.	**ECMWF Config. in 2017**
80 km	ERAI*
32 km	ERA5* SEAS5
18 km	ENS
9 km	HRES+ ERA5Land

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.

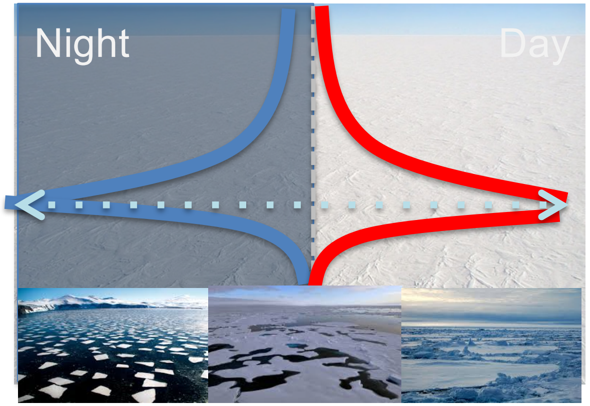
Modelling surface heterogeneity and coupling with the atmosphere

- 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

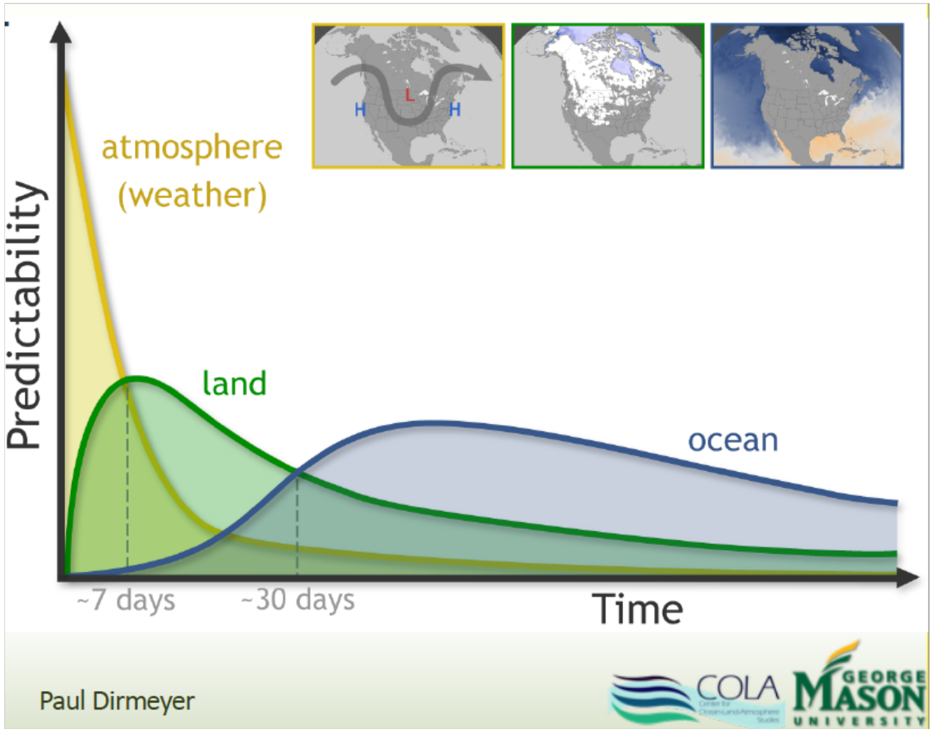
- Transition from open-sea to ice-covered conditions
- Sea-state dependent interaction wind induced mixing/waves
- Vertical transport of heat

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 relevance in medium-range, S2S, A2D prediction



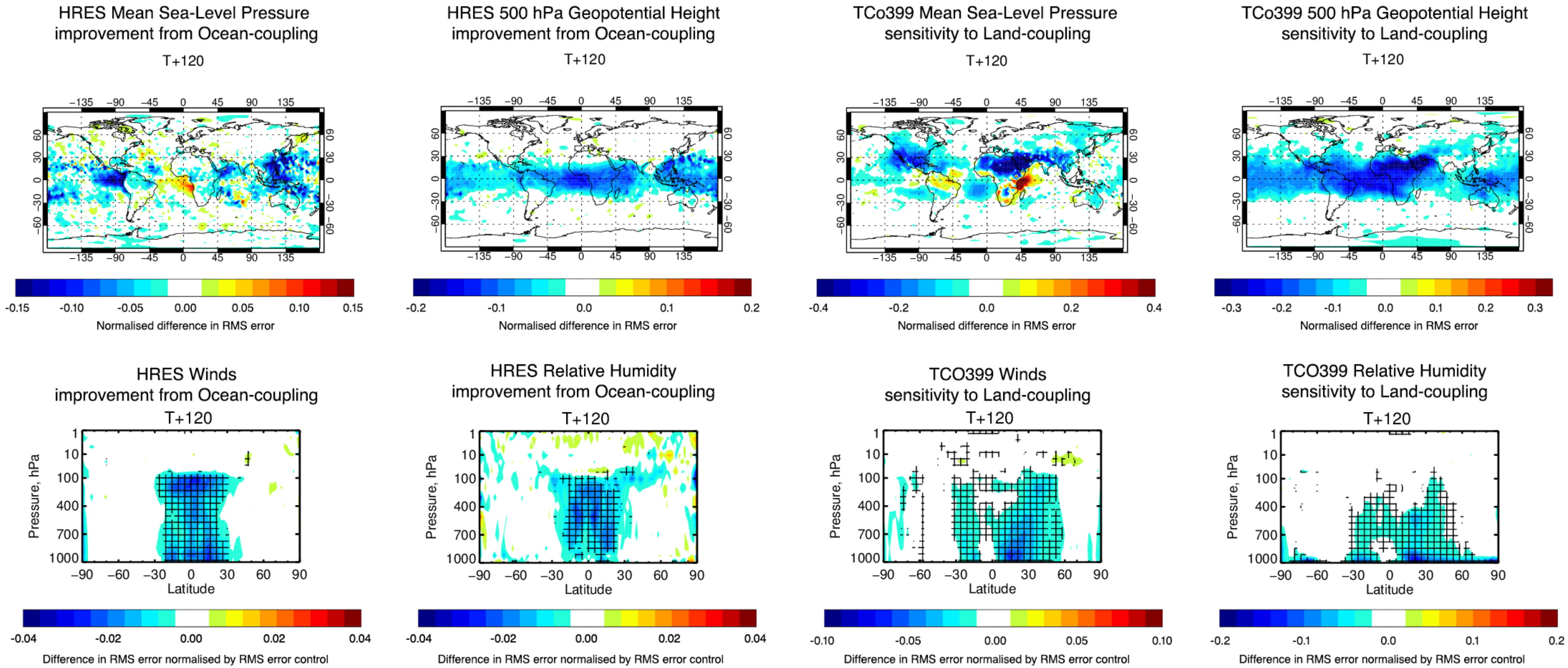
In order to realize the Land potential models need to represent nature in its:

- Memory
- Coupling
- Variability

On the relative contribution of land and ocean on ECMWF day-5 forecast

Forecast improvements at Day+5 (**1 year**)
Coupled-Ocean vs Uncoupled (only skin-interaction)

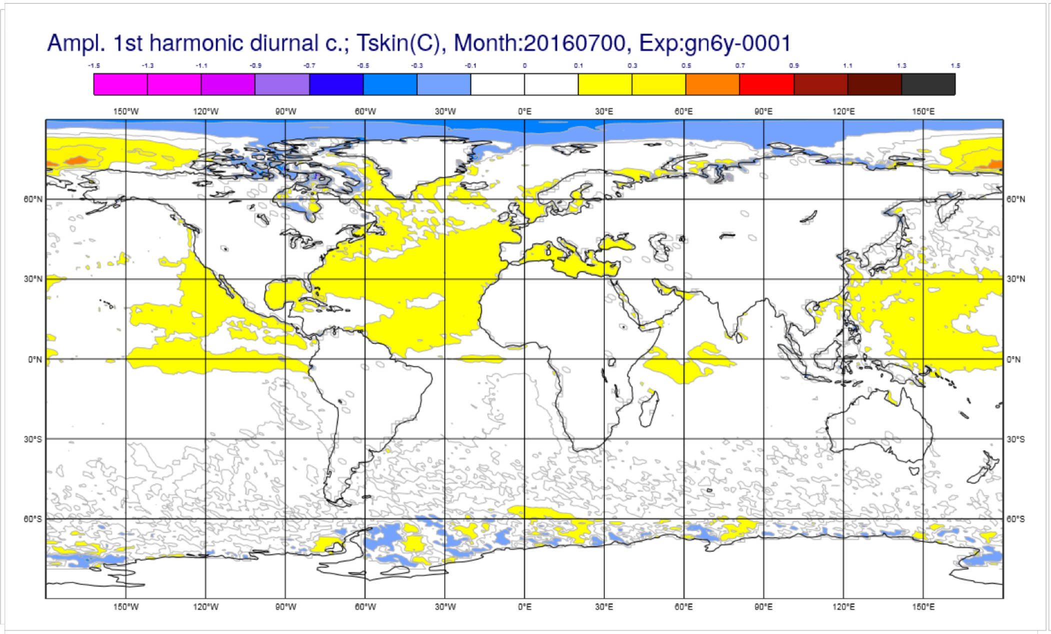
Forecast improvements at Day+5 (**1 year**)
Coupled-Land vs Uncoupled (only skin-interaction)



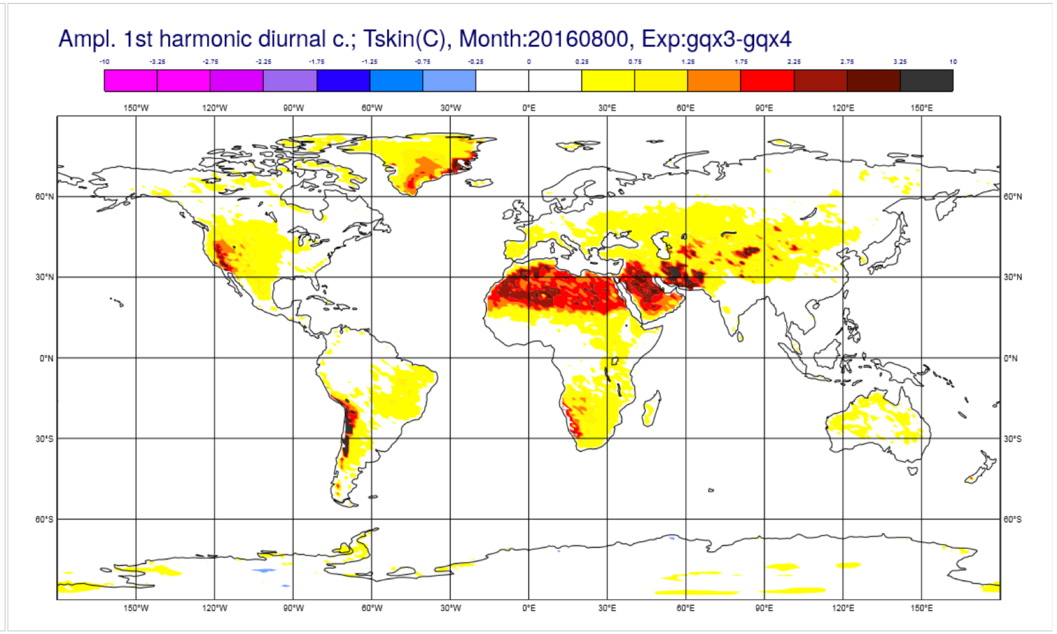
Balsamo et al. 2017 WGNE-Blue-book

Impact on diurnal cycle from enhancing surface coupling components

- Improve the realism of surface temperature (skin and below) particularly in clear/sky
- Improve the realism of surface drag elements (orography, waves, ice, soil, vegetation, lakes)
- These are key driver for IFS model complexity (discretization H/V, physics, ancillary, coupling)

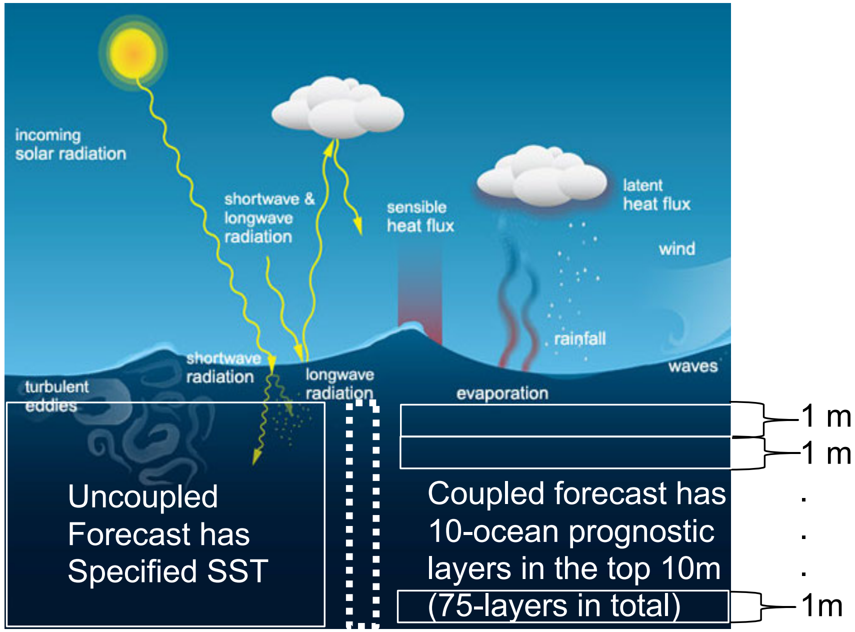


Difference in diurnal cycle amplitude due 3D ocean

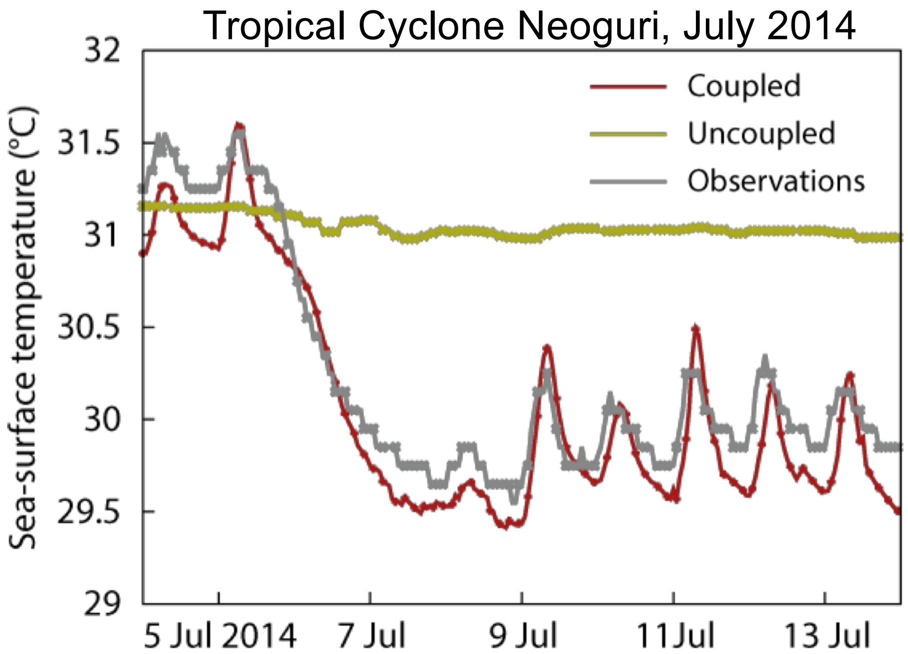


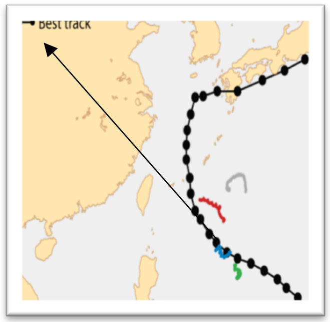
Difference due to enhance multi-layer soil

Ocean-coupling and sea surface temperature (SST) validated with in-situ



Uncoupled **Coupled**





- The ECMWF Ocean-coupled (red) model is better simulate the cool wake after the passage of Tropical cyclone Neoguri. A more realistic response is observed comparing the 10-day forecast with an on-track DRIBU observation of SST, both for TC passage and diurnal cycle

Mogensen et al 2018

Comparing forecasts with in-situ sea surface temperature (buoys & moorings)

Sea Surface Temperature Diurnal Amplitude (**dSST**)

Along the forecast FC 1, 3, 5, 7, 9-days ahead)

Ocean-Uncoupled   Ocean-Coupled

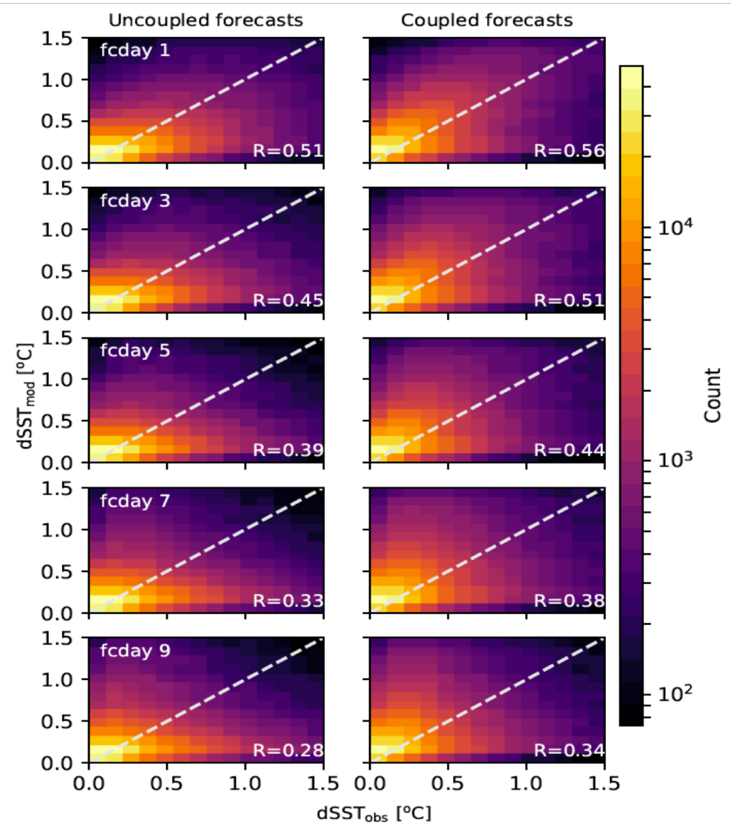


Figure 3: 2D density plots of $dSST_{obs}$ and $dSST_{mod}$ estimates on select days of the forecast validity range for (left column) uncoupled and (right column) coupled simulations.

In-situ Observations from Buoys & Moorings

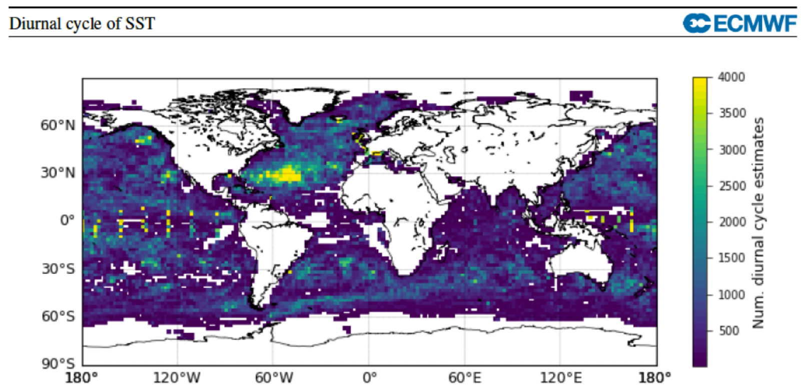


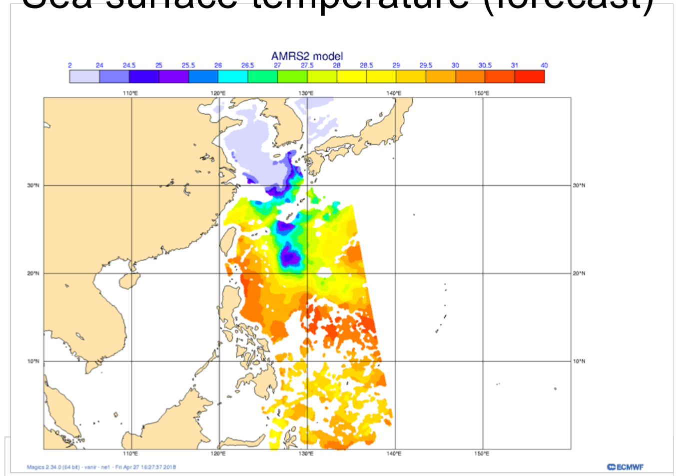
Figure 2: The number of diurnal cycle estimates in each 2° × 2° grid box for the year of 10-day forecasts.

D. Salisbury et al. 2018 ECMWF TM826, doi:10.21957/jd8f37cqm

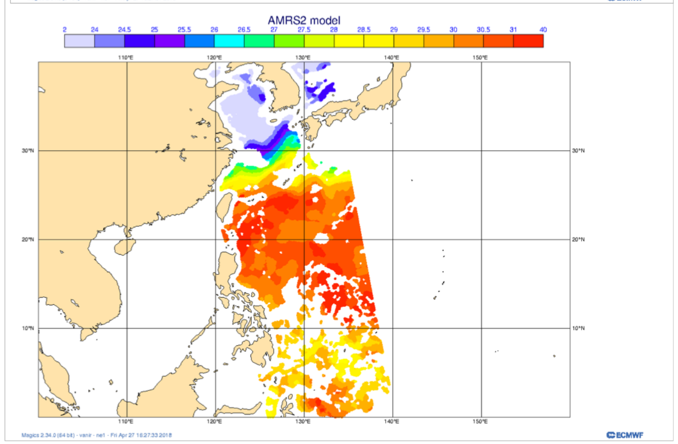
Comparing forecasts with satellite-based sea surface temperature (AMSR2)

Sea surface temperature (forecast)

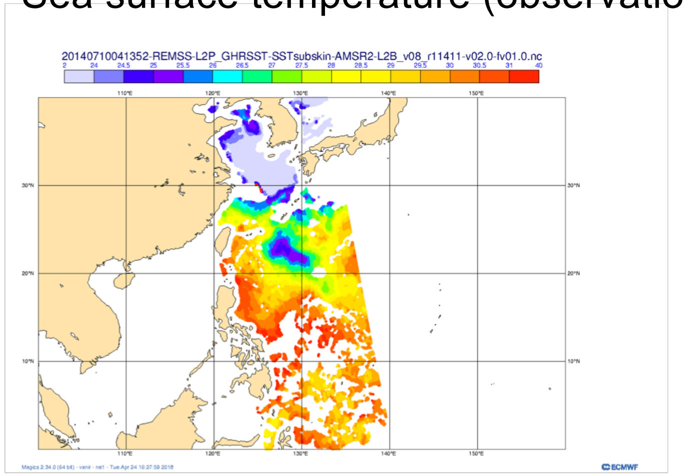
ECMWF Ocean Coupled 5-day Forecast



ECMWF Ocean Uncoupled 5-day Forecast



Sea surface temperature (observation)



Satellite Observations from AMSR2 MW SST

After the passage of Tropical Cyclone Neoguri, 10th of July 2014

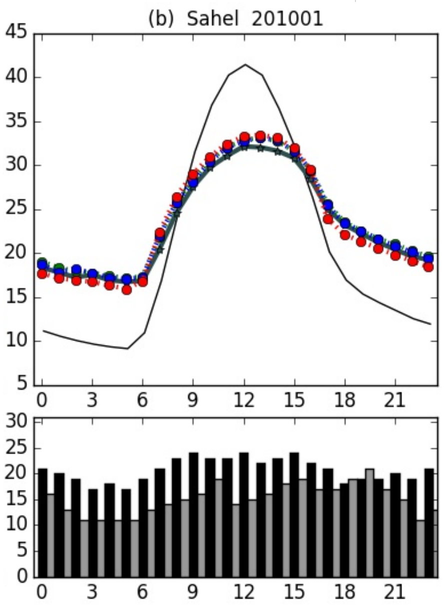
Coupled forecast:

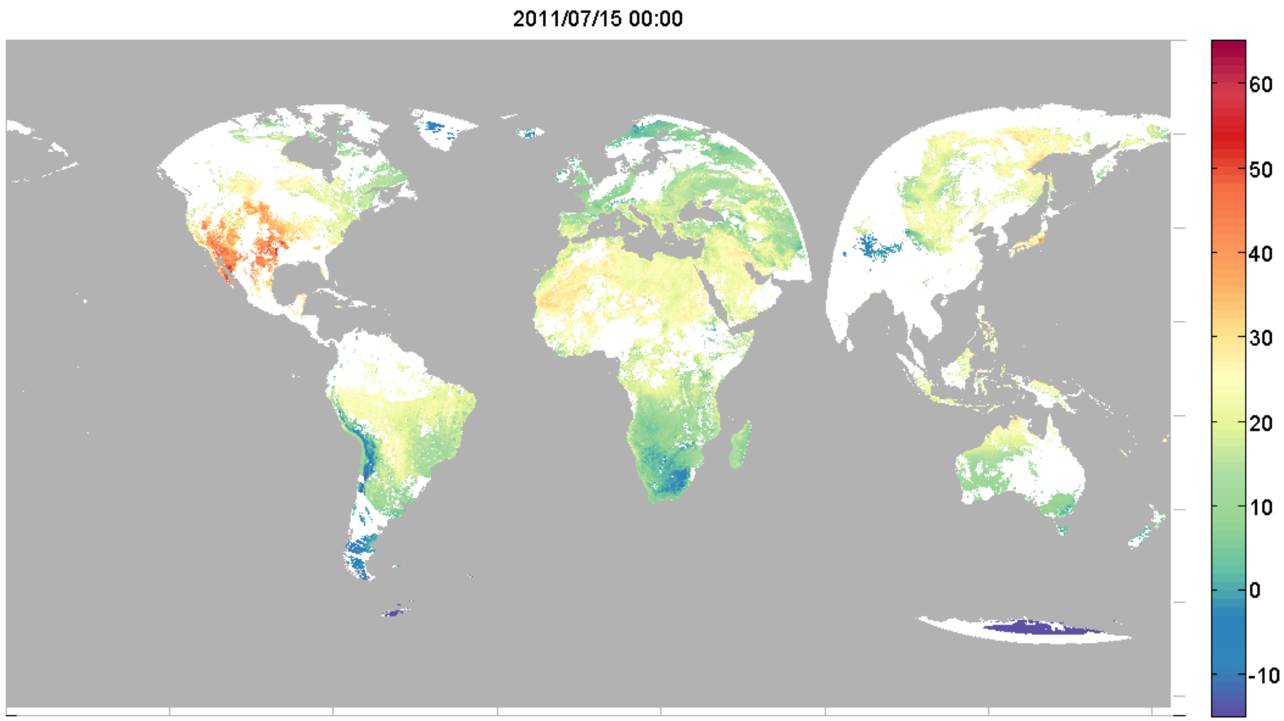
- Gets the SST cooling after the passage of Tropical Cycle in better agreement with EO data of Satellite SSTs

Thanks to Kristian Mogensen

Using more Earth Observations for surface model development

- An example of external collaboration using ESA-CCI LST – 5km global (Isabel Trigo, IPMA)
- LST used to constrain HTESSEL parameter values (Orth et al., 2017)
- LST Diurnal cycle
needs ML upgrade



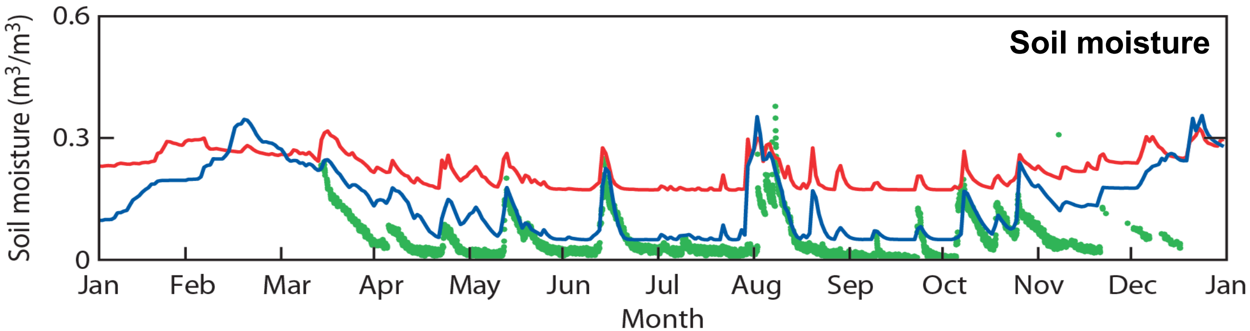


Thanks to Isabel Trigo and LSA-SAF-Team

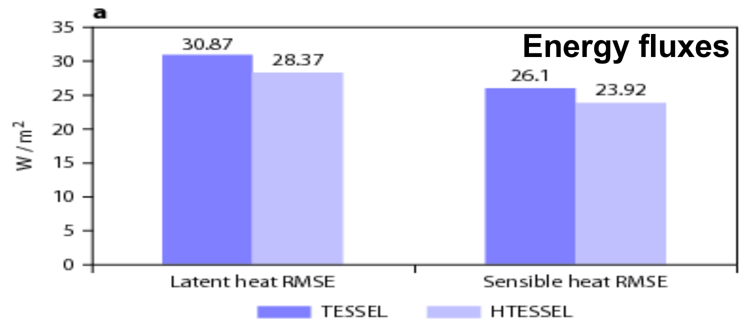
ERA-Interim/Land (Energy & Water) land-reanalysis and its added value

Balsamo et al. (2015 HESS)

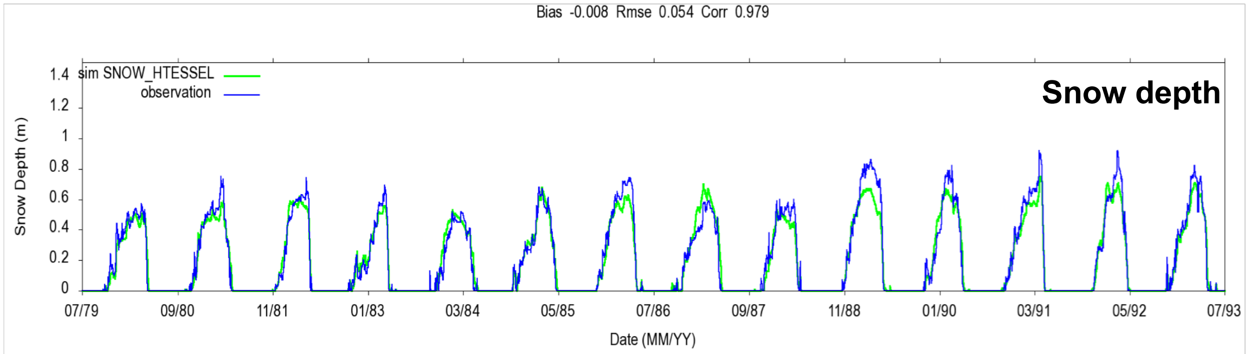
ERA-Interim/Land had the same horizontal resolution of ERA-Interim (80km) integrates land surface modelling improvements with respect to ERA-Interim and provided a balanced initial condition for the Monthly/Seasonal Re-Forecasts



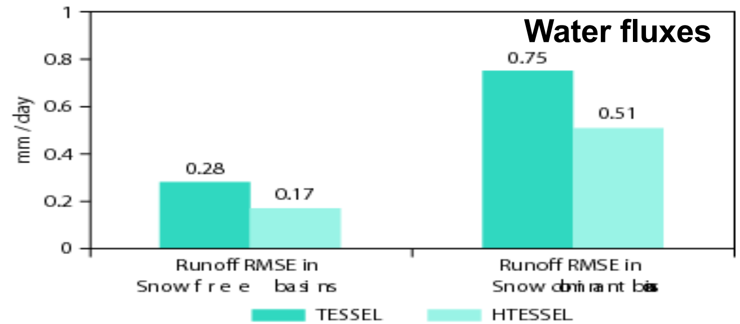
Evolution of soil moisture for a site in Utah in2010.
Observations, ERA-Interim, and ERA-Interim/Land.



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.



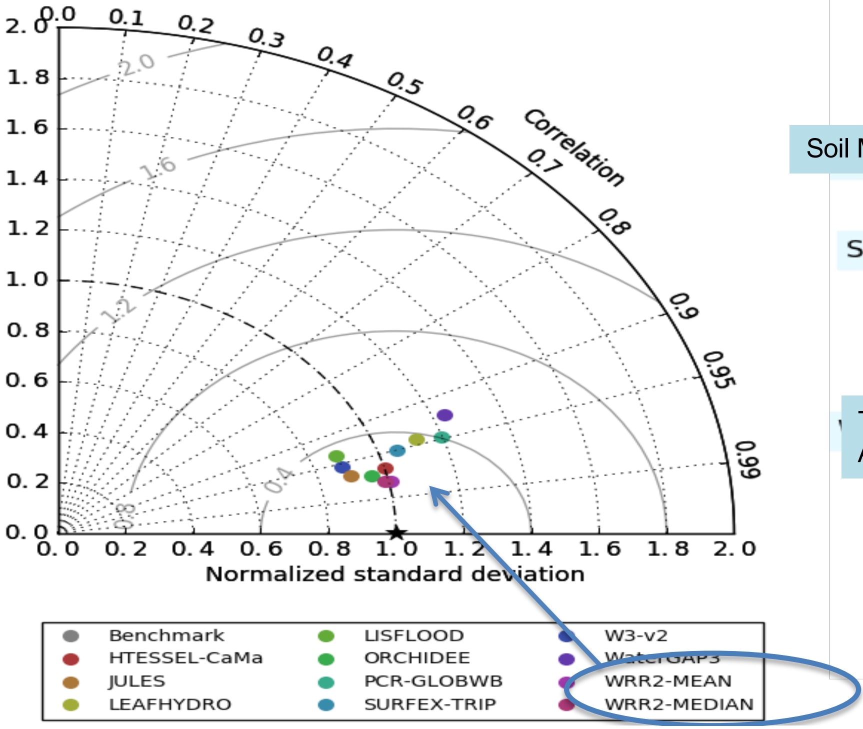
Mean performance measured for the monthly rivers discharge verified with GRDC observations

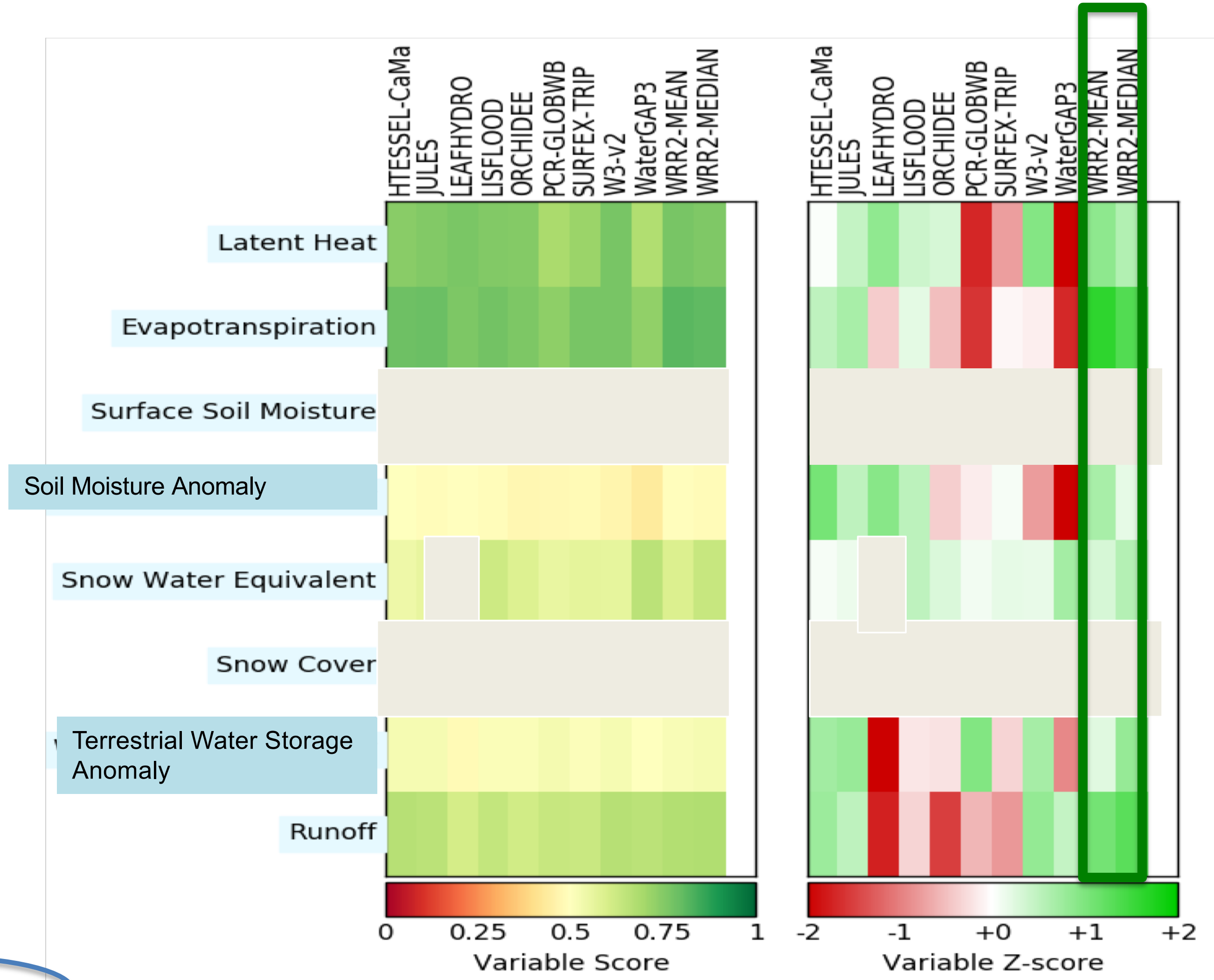
ERA-Interim/Land approach has been applied in EartH2Observe H2020 project (http://www.earth2observe.eu), Schellekens et al (2017 ESSD)

EarthH2Observe H2020 multi-model GHP/LSMs ensemble and its added value

Multi-model mean/median outperforms single models for most of the variables

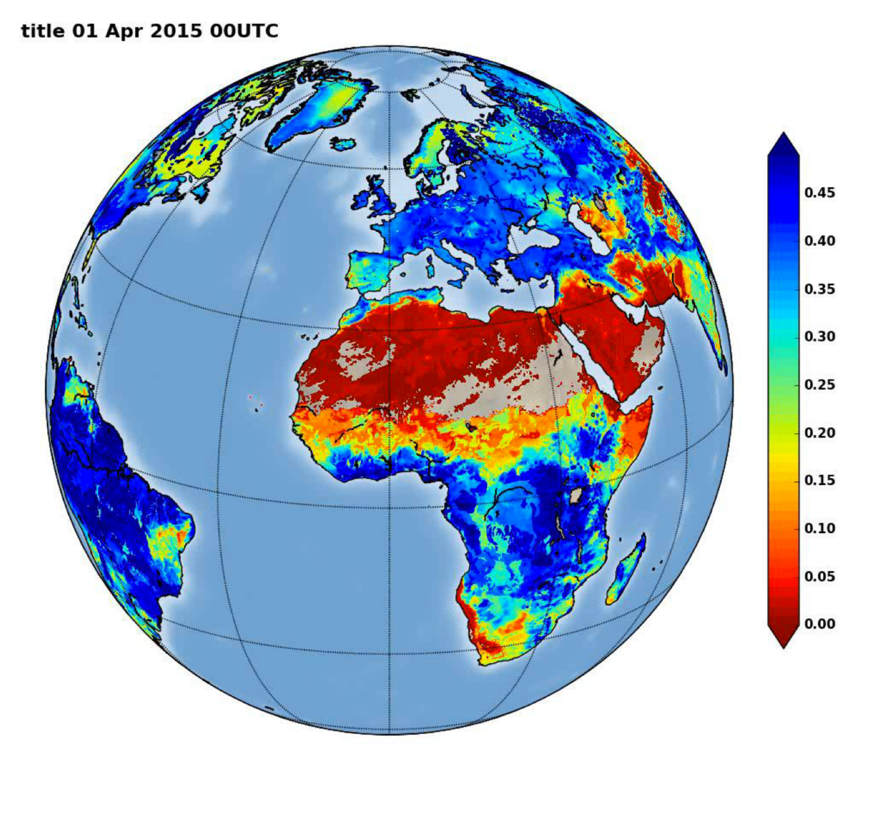
Spatial distribution score of latent heat





Thanks to Emanuel Dutra, Alberto Martinez, Eleanor Blyth, and E2O-Team

ERA5 and ERA5-Land operational reanalyses replacing ERA-Interim from 2019



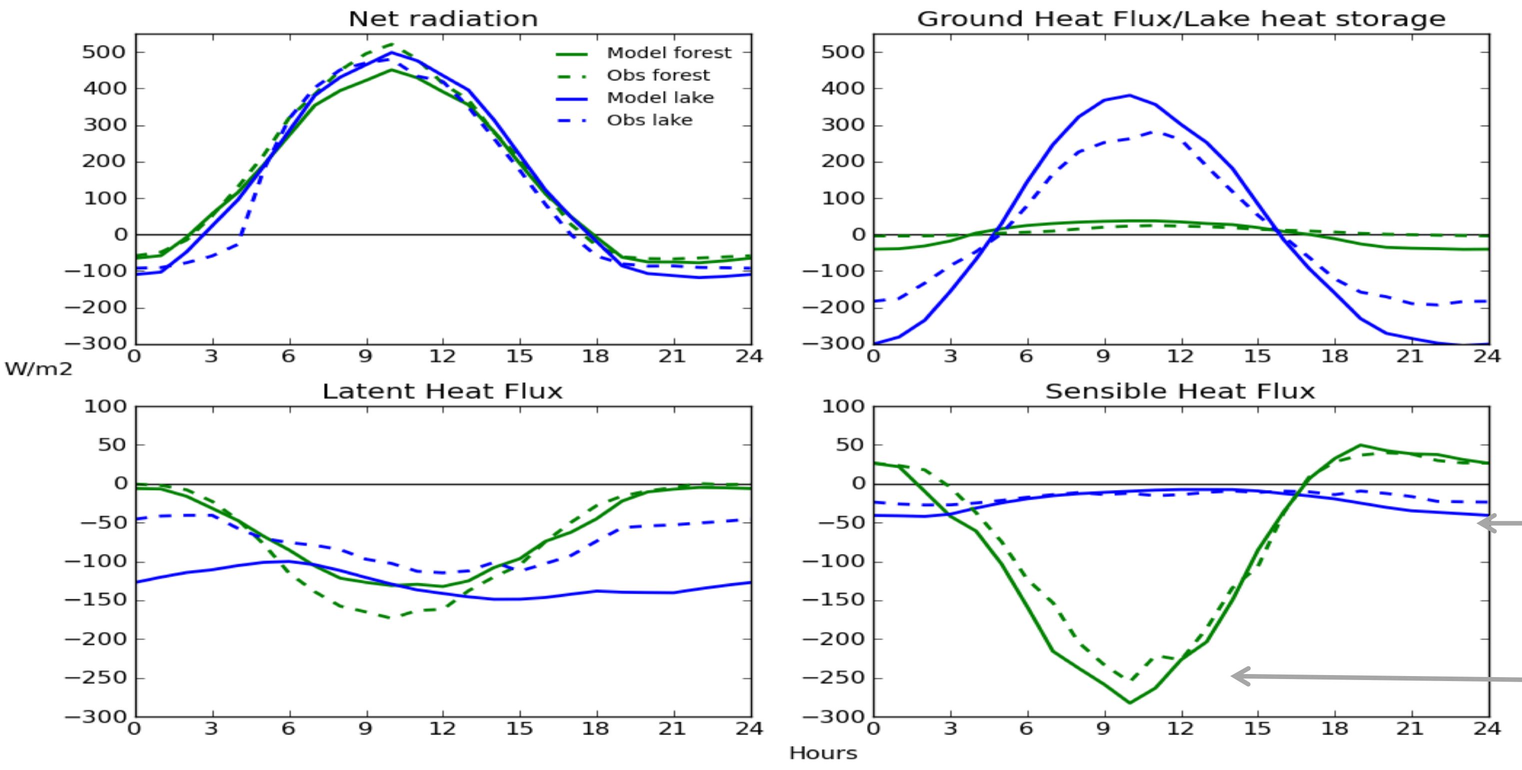
	ERA-Int	Era-Int/Land	ERA5	ERA5-Land
Period covered	Jan 1979 – NRT(*)	Jan 1979 – Dec 2010	Jan 1979 - NRT	Jan 1979 - NRT
Spatial resolution	~79km / 60 levels	79 km	~32 km / 137 levels	~9 km
Model version	IFS (+TESSEL)	HTESSEL cy36r4	IFS (+HTESSEL)	HTESSEL cy43r1
LDAS	cy31r1	NO	cy41r2	NO
Uncertainty estimate	-	-	Based on a 10-member 4D-Var ensemble at 62 km	Based a 10-member atmospheric forcing at 31 km
Output frequency	6-hourly Analysis fields	6-hourly Analysis fields	Hourly (three-hourly for the ensemble)	Hourly (three-hourly for the ensemble)

Thanks to Hans Hersbach, Joaquin Munoz-Sabater, ERA Team

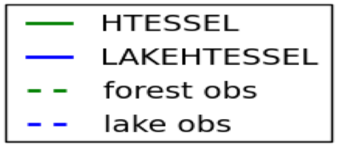
ERA5 & ERA5-Land include representation of lakes

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

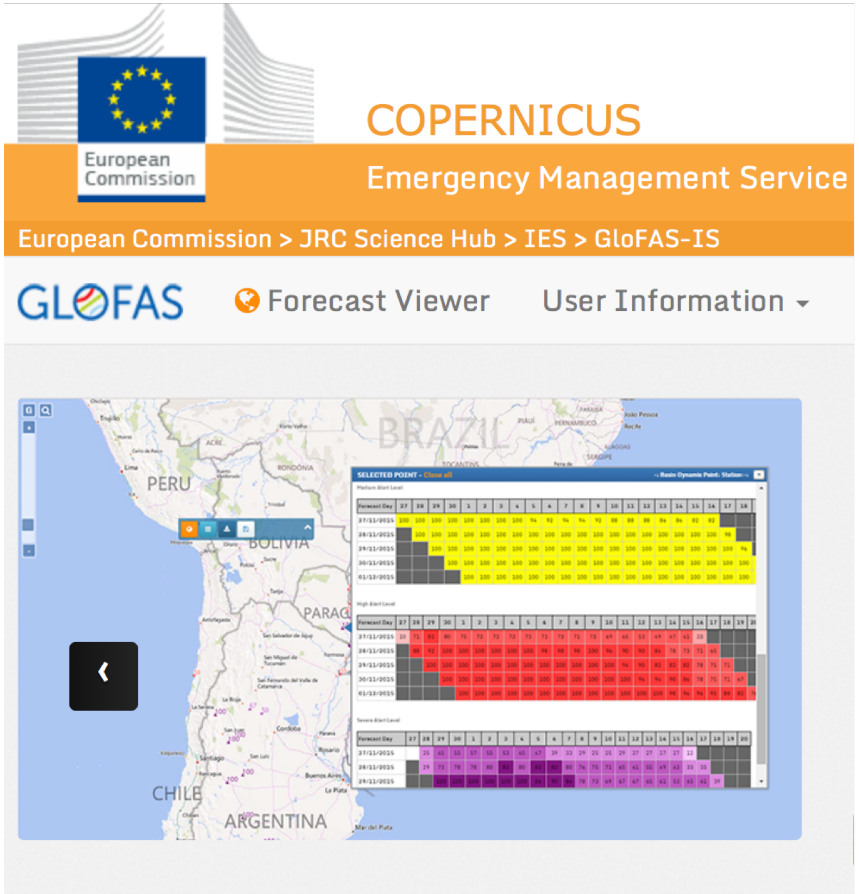
Forest SH peak is at midday

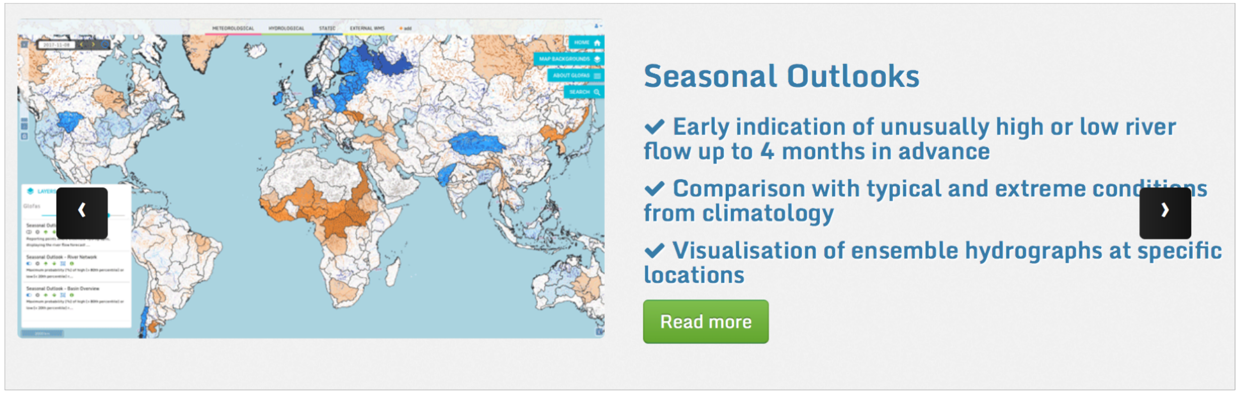
ECMWF

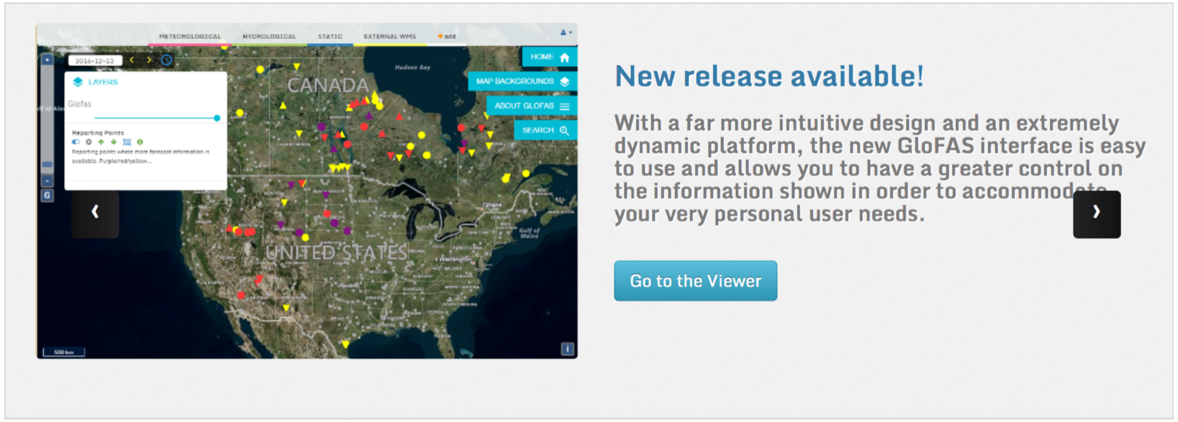
ERA-Interim reanalysis (near surface meteorological forcing) has enabled to study the impact of lakes and this research is now integral part of ERA5

Global Flood Awareness – A Copernicus Emergency Management Service

- http://globalfloods.jrc.ec.europa.eu



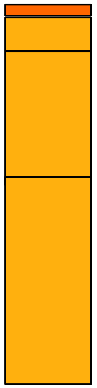




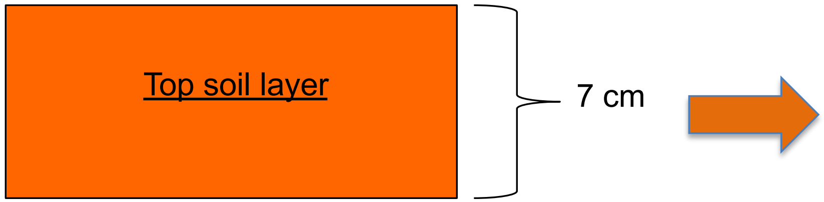
Thanks to the GloFAS Team

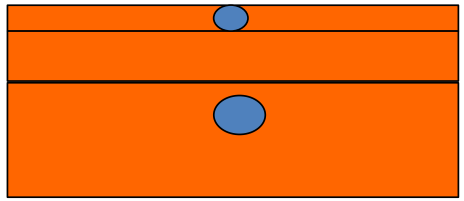
Increased soil model vertical resolution to improve use of satellite data

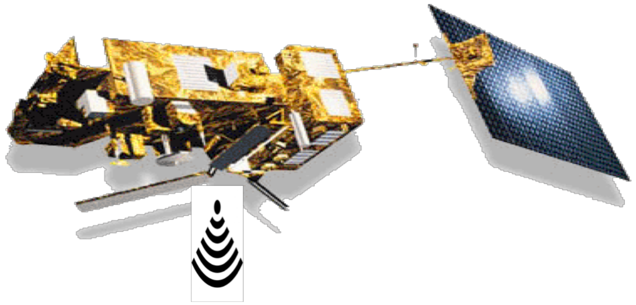
An enhanced soil vertical layer is motivated by land data assimilation as it shown to better correlate with satellite products of soil moisture.



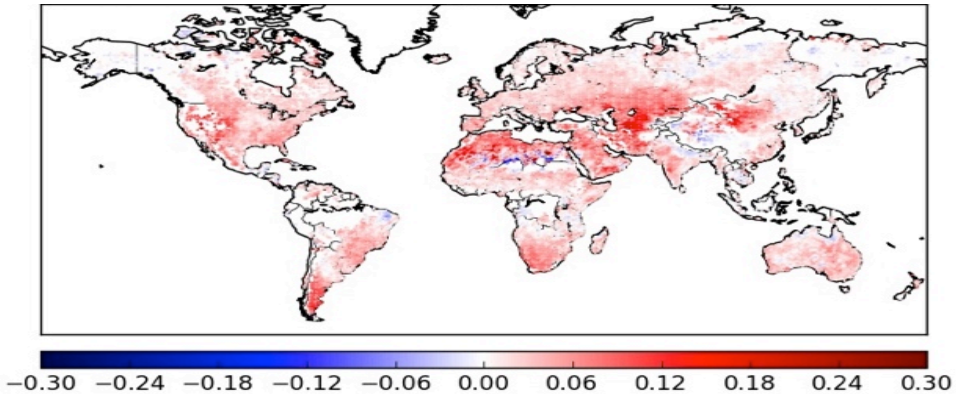
4-layers:
 # 0-7 cm
7-28 cm
28-100 cm
100-289 cm







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, Patricia De Rosnay, LDAS-Team

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

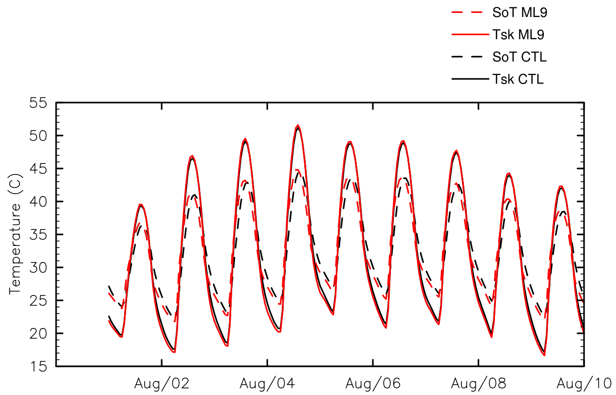
Globally Improved match to satellite soil moisture (shown is Anomaly correlation ΔACC calculate on 1-month running mean)

See Dorigo et al. (2017 RSE)

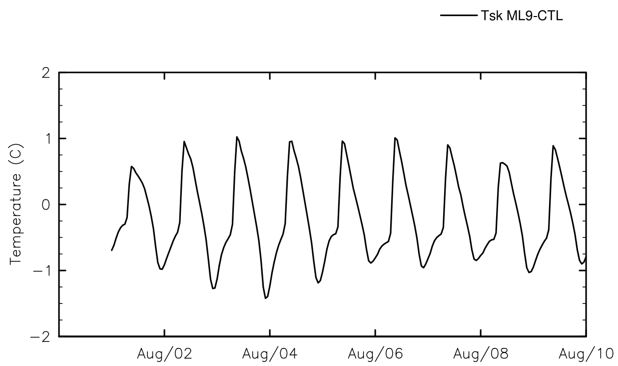
Impact of the soil model vertical resolution: heatwaves severity

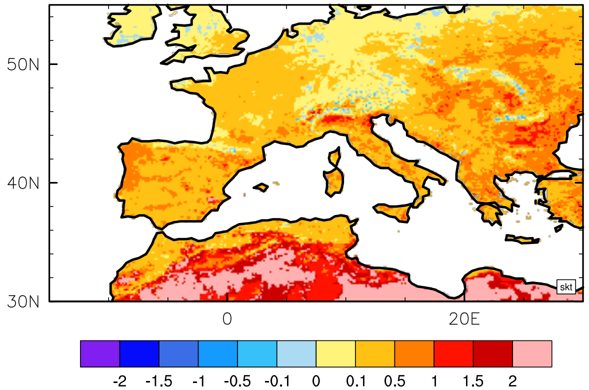
During summer 2017 the effect of multi-layer is examined for European heatwave, here shown for Corboba (Spain) where temperatures went above 40º Celsius on the 6th of August 2017

ECMWF Land model ML9 & ML4 (offline)



Difference ML9-ML4 soil model (offline)





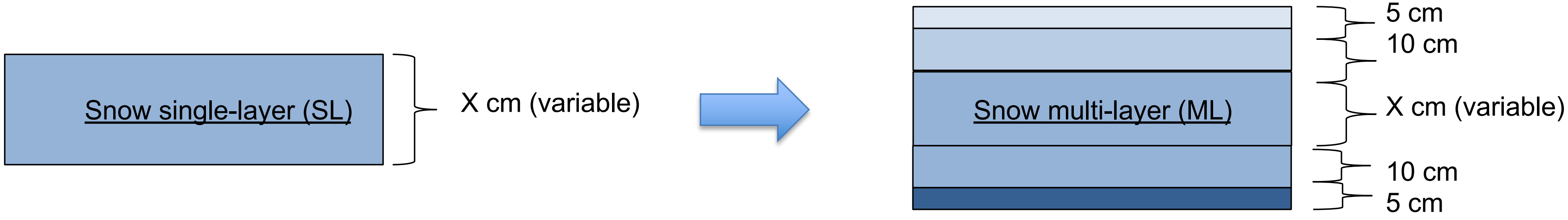
Differences in the maximum skin temperature ML9-ML4

An enhanced soil vertical discretisation is increasing the amplitude of the diurnal cycle. Extremes heatwave are up to 1 K hotter

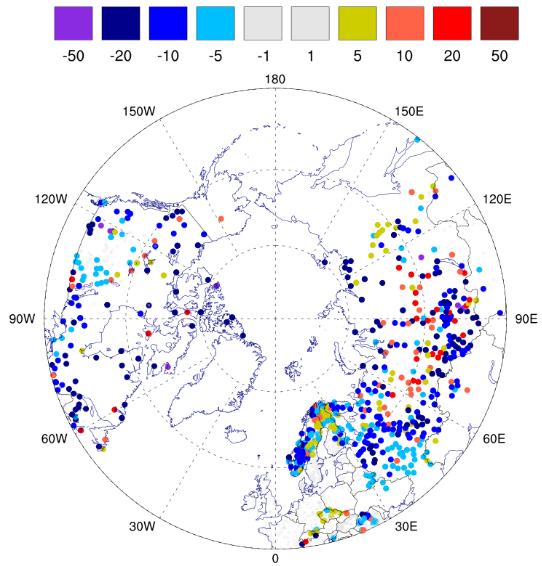
Thanks to Gabriele Arduini

Increased 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

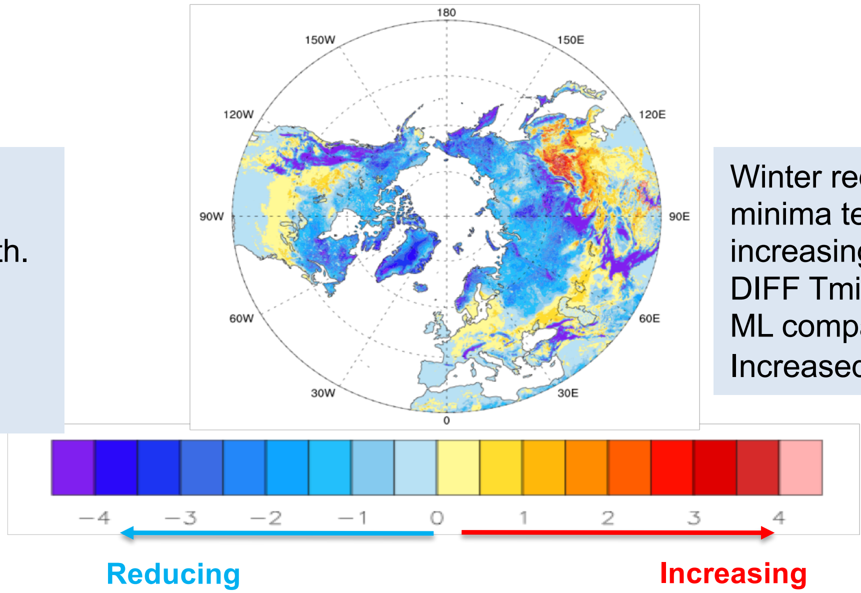


Difference ML- SL in Snow depth RMSE winter (DJF)



An improved snow depth (ML – SL) evaluated with in-situ SYNOP snow depth. RMSE of 0.19m (0.23m) in ML (SL).
This is 17% RMSE error reduction in snow depth.

Difference ML - SL in T_{skin} minimum winter (DJF)



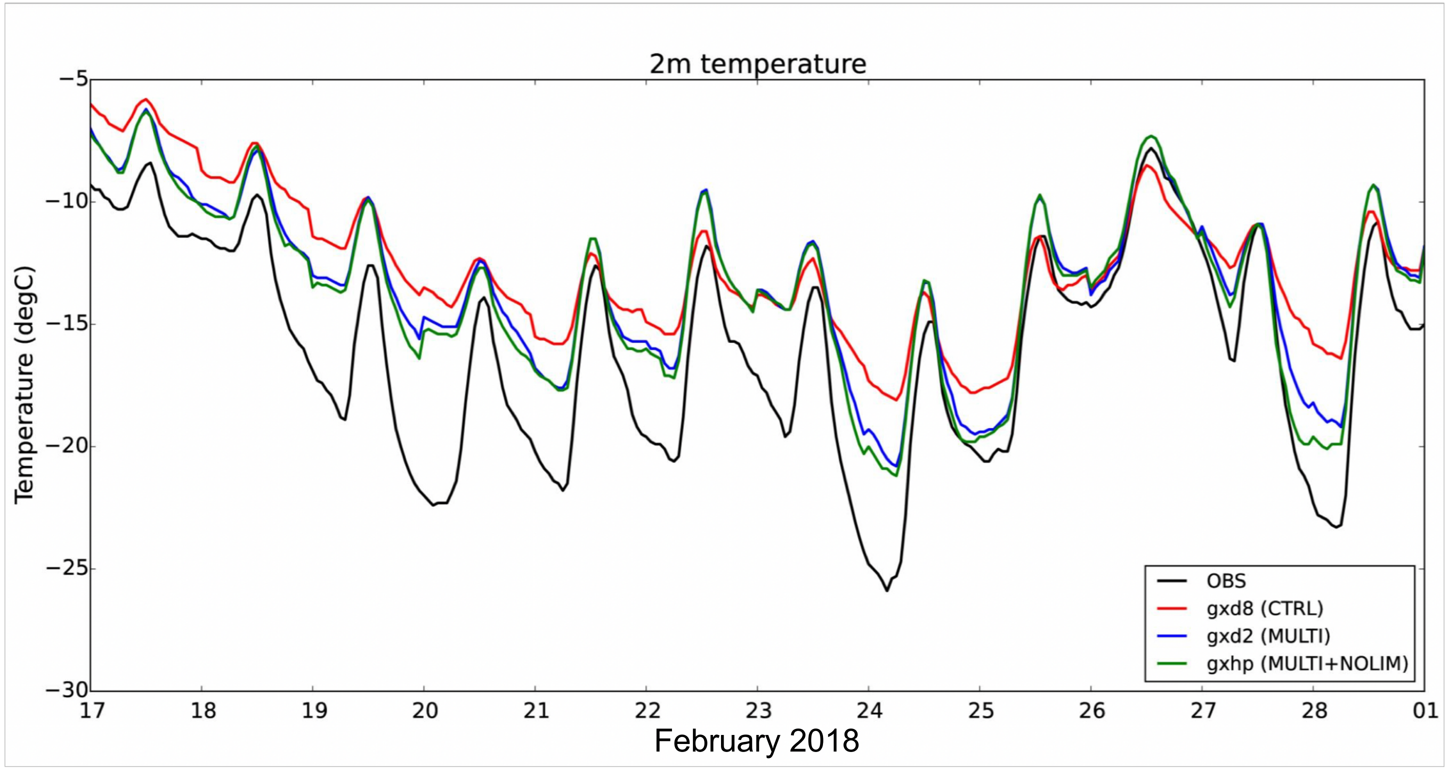
Winter reduction of the 2m minima temperatures with increasing diurnal-cycle.
DIFF Tmin 2-4 K colder in ML compared to SL snow.
Increased variability

Thanks to Gabriele Arduini, Jonny Day, Linus Magnusson

Impact of snow model vertical resolution increase on near surface temperature

Increased vertical discretization of the snowpack (**up to 5 layers**) permits a better 2-m forecast: here hourly day-2 forecasts are shown for 24-hour to 47-hour ahead, concatenated to form a continuous time-series

T2m Observations, T2m forecast (current snow, SL), T2m forecast (ML)



In clear-sky the MULTI-layer snow scheme is capable to produce stronger winter inversions improving observation match.

NOLIM indicates a stability limiter safety is deactivated.

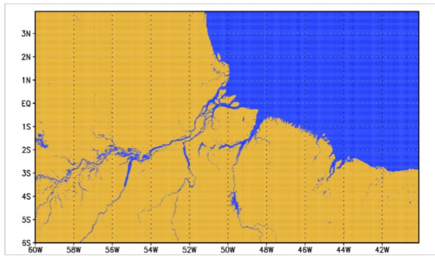
The increased variability in the diurnal cycle is beneficial for ensemble forecasting.

Thanks to Gabriele Arduini, Thomas Haiden, Irina Sandu & USURF Team

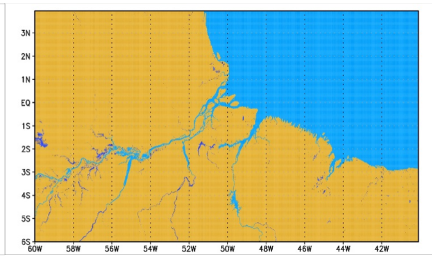
Mapping the surface at 1km: water bodies and changes over time

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

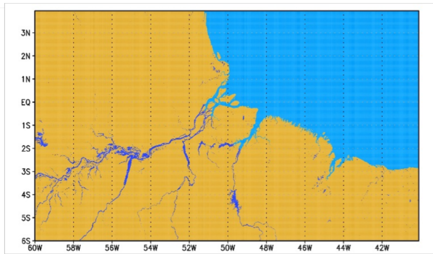
ESA GlobCOVER has no water class



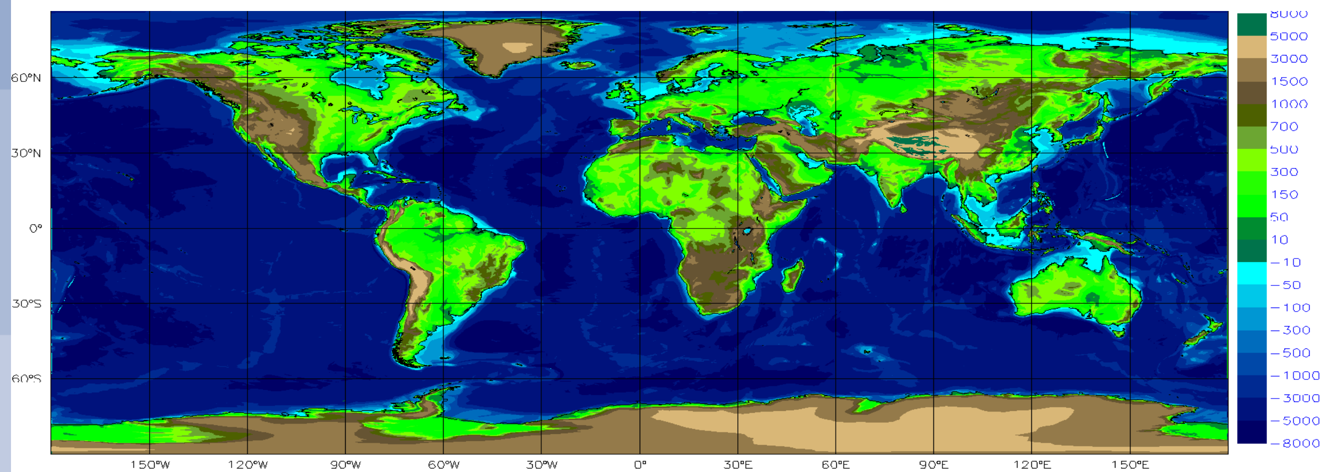
Flooding allows classify, problems w. large rivers



New classification algo works well at 1km



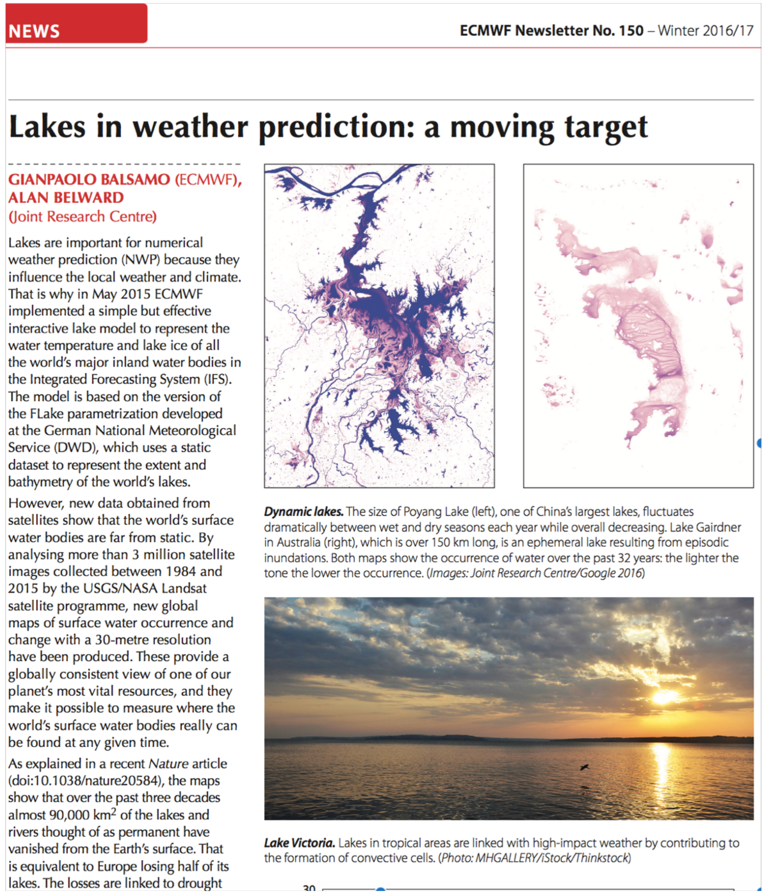
A 1-km global bathymetry and orography map (SRTM+/GEBCO/GLDB)



ECMWF

Thanks to Margarita Choulga, Souhail Boussetta, Irina Sandu, Nils Wedi

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 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)*

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

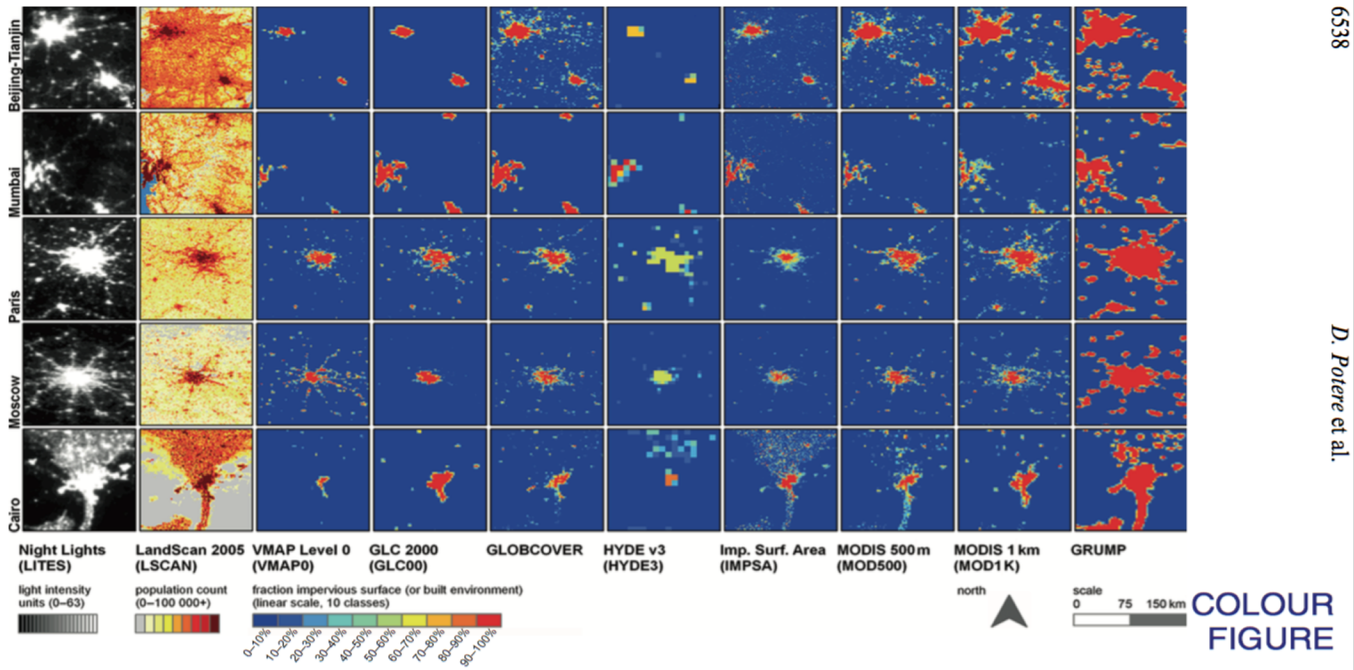
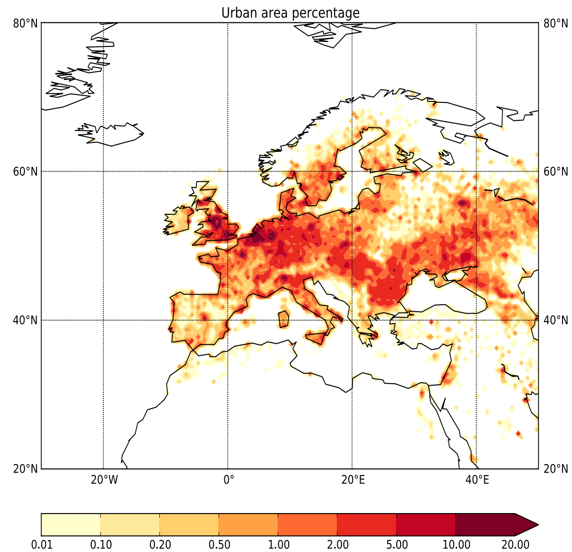


Figure 1. The eight global urban maps and two urban-related maps for Beijing-Tianjin, China (top row), Mumbai, India (second row), Paris, France (third row), Moscow, Russia (fourth row), and Cairo, Egypt (bottom row). LITES, LSCAN and IMPSA are at native 30 arc-second resolution, HYDE3 is at native 5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

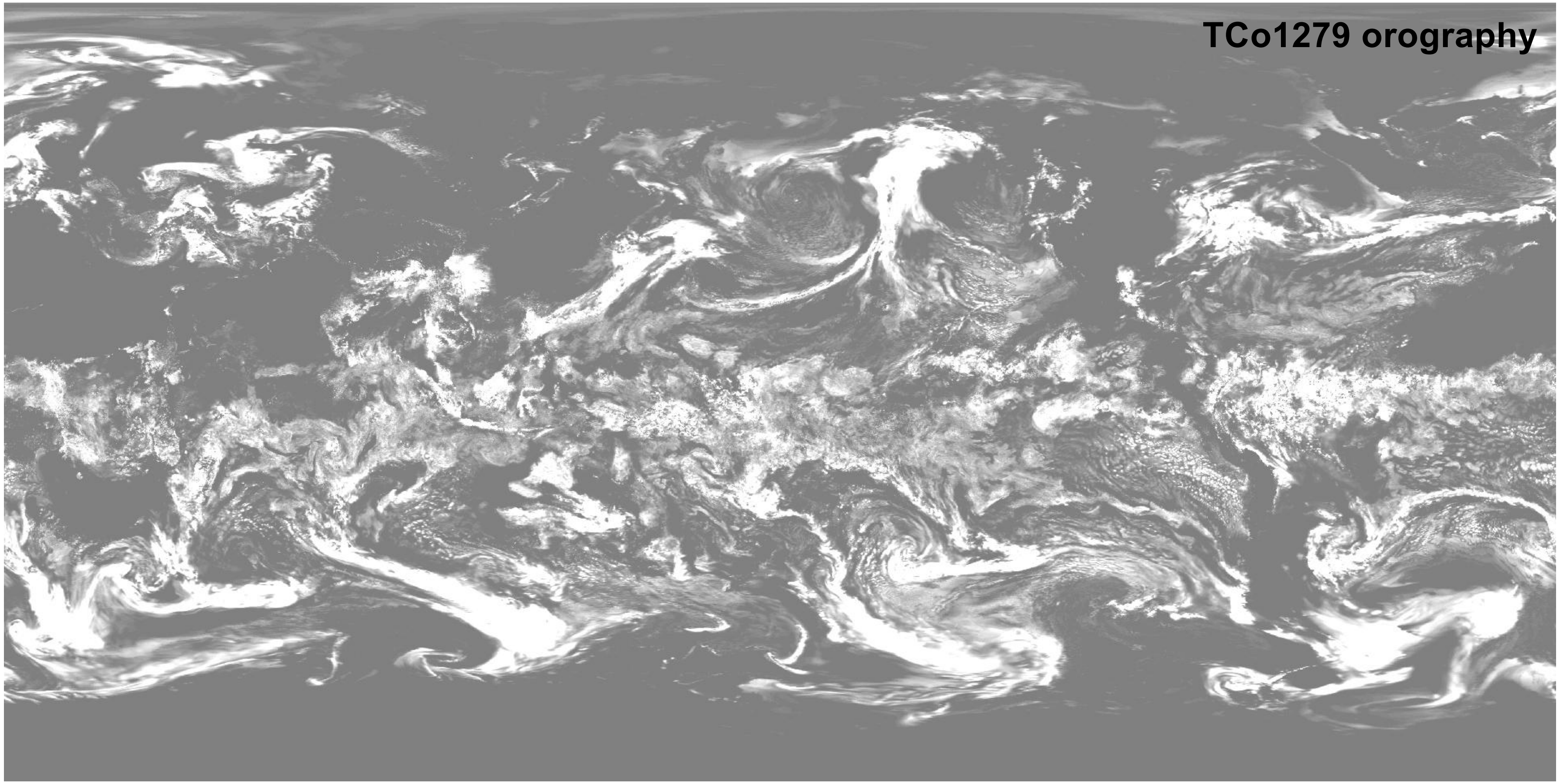


- Urban area dataset comparison on selected cities (Potere et al., 2009 IJRS) reveal large uncertainties and discrepancies. New datasets are promising, such as HSL by JRC

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

ECMWF

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

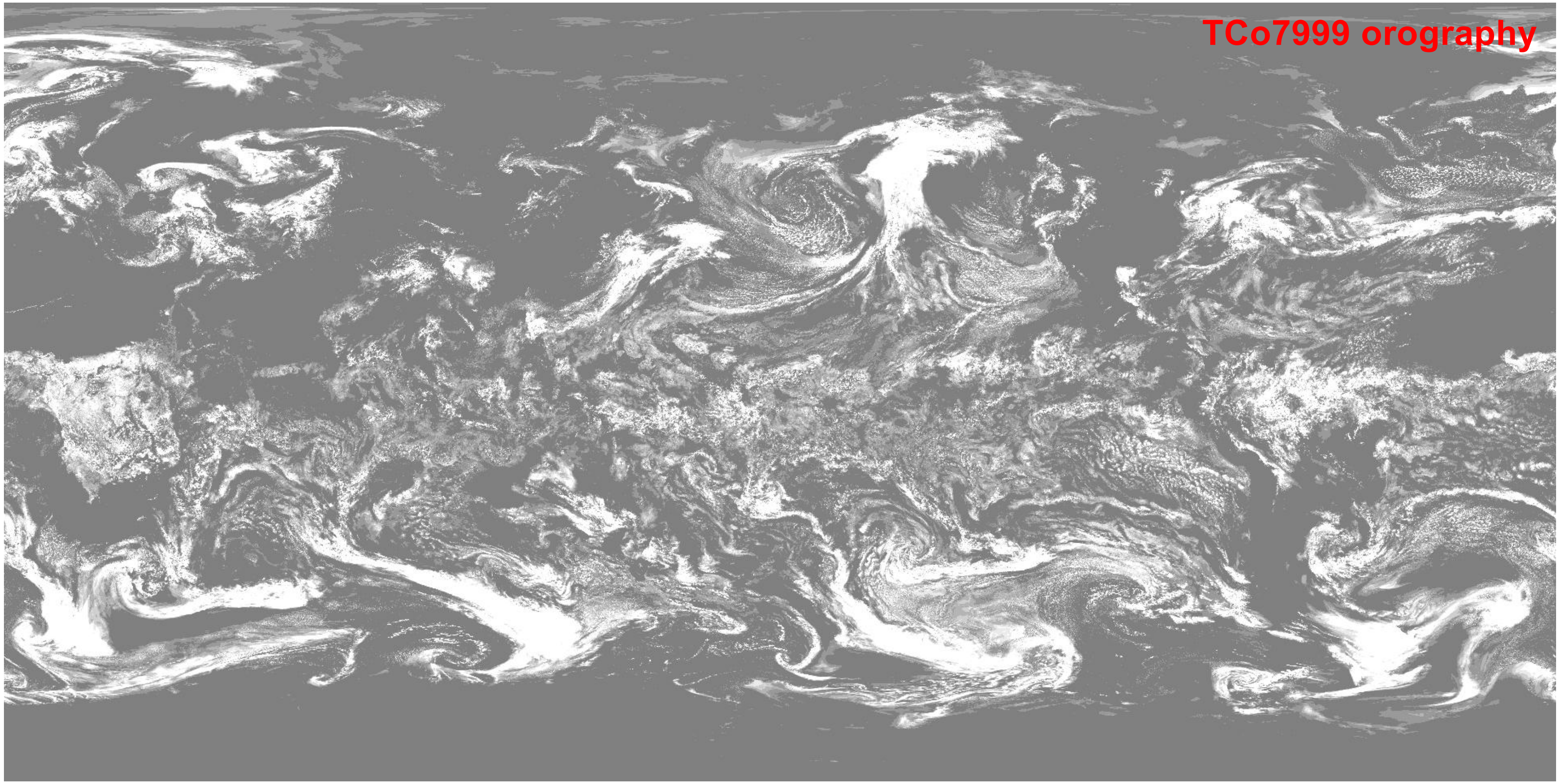


(12h forecast, *hydrostatic*, with deep convection parametrization, 450s time-step, 240 Broadwell nodes, ~0.75s per timestep)

ECMWF

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)

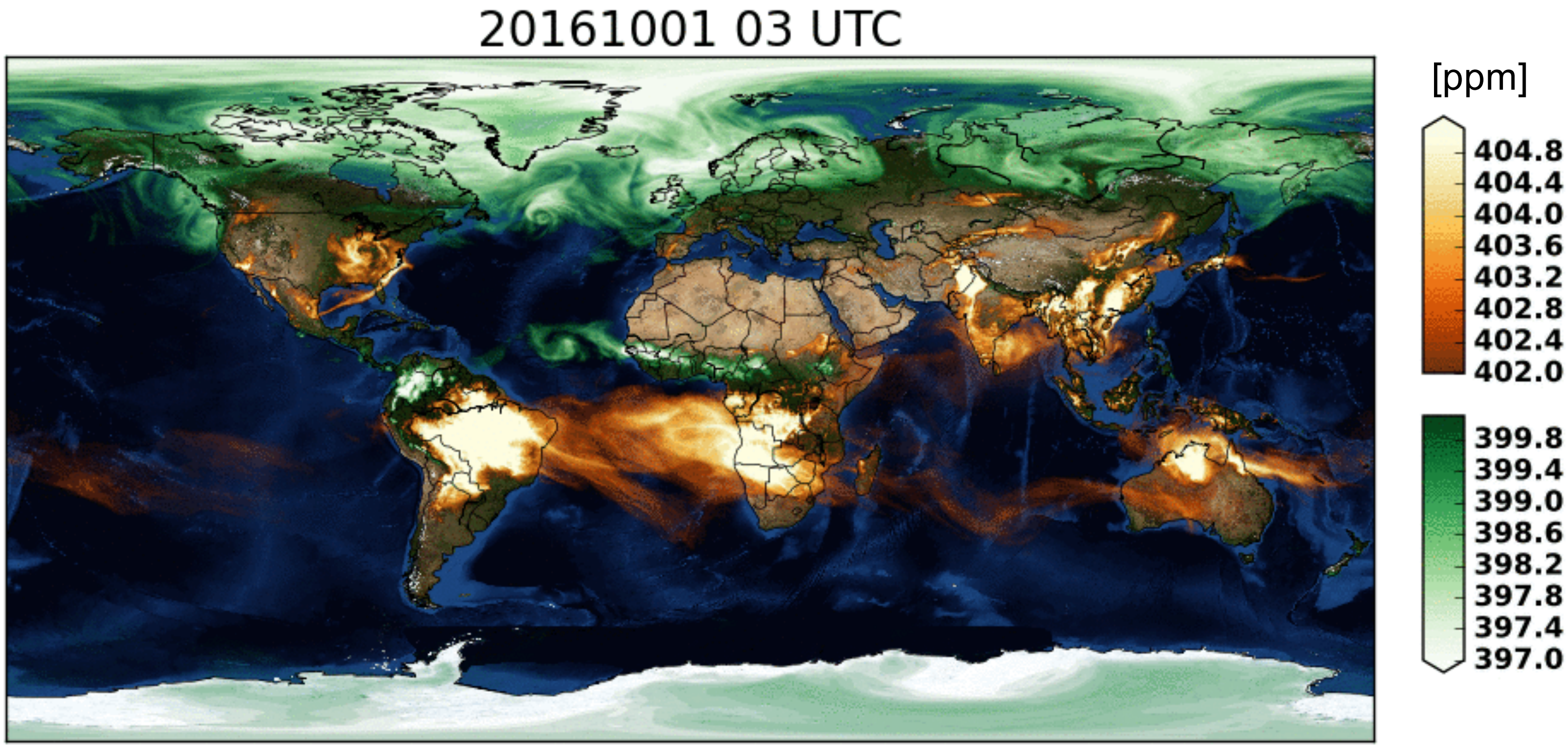
ECMWF

Thanks to Nils Wedi and NM-Team

Equivalent to 256 Megapixel camera 

The CO2 Human Emission Project make use of ECMWF IFS 9km 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

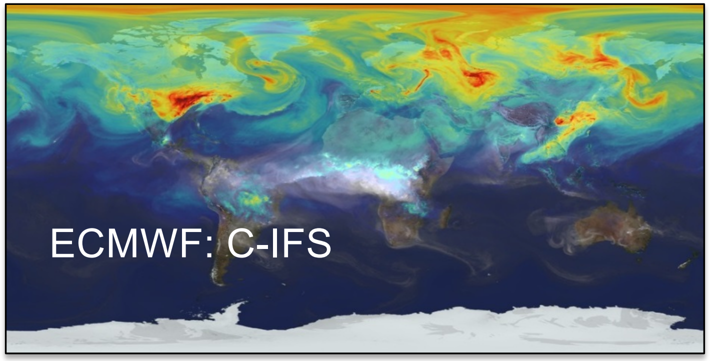
- CTESSEL NEE (BFAS correction Agusti-Panareda et al. ACP 2016
- EDGARv4.2FT2010
- Takahashi et al. (2009)
- GFAS biomass burning
- IFS transport
- Bermejo & Conde mass fixer (Agusti-Panareda et al. GMD 2017)

ECMWF

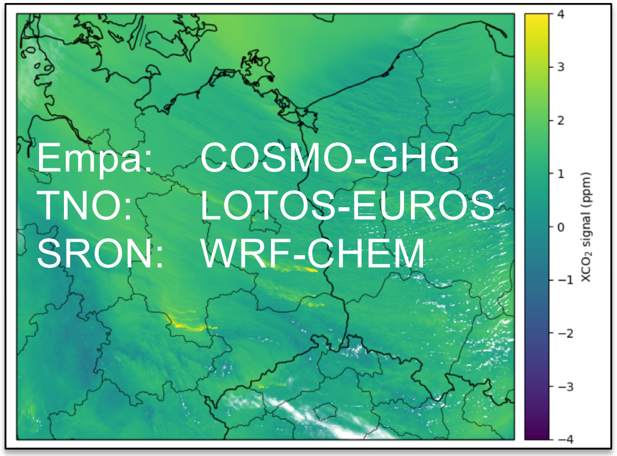
Thanks to Anna Agusti-Panareda, Richard Engelen & CAMS

Embracing multi-scale to evaluate uncertainties, from local to global

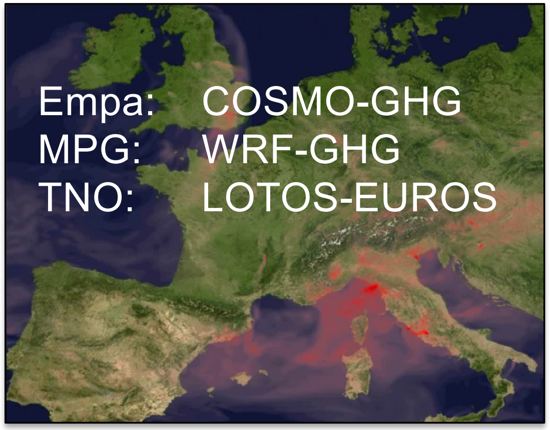
Global, ~ 9km resolution, ECMWF



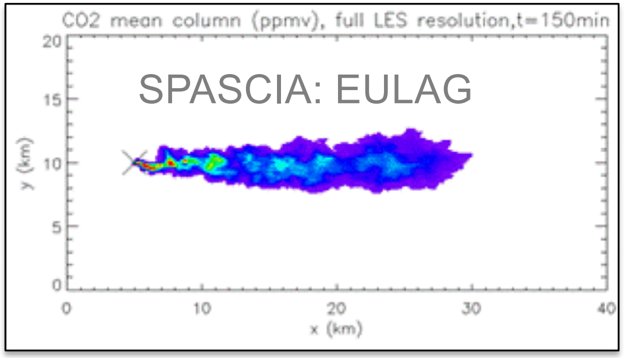
Regional, ~ 1 km, Empa, TNO, SRON



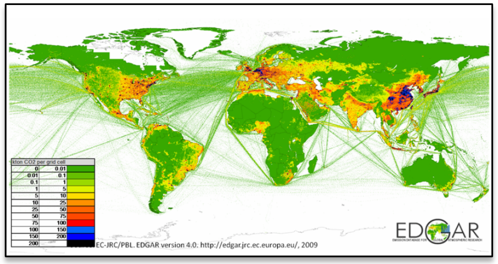
Europe, ~ 5 km, Empa, TNO, MPG

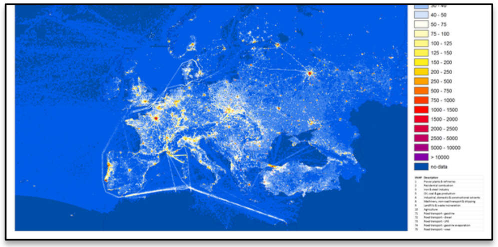


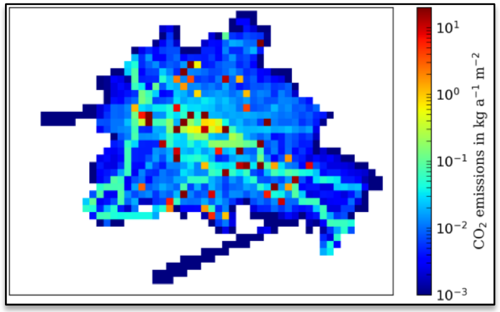
Point source, ~ 100 m, SPASCIA



Global, Regional City emission

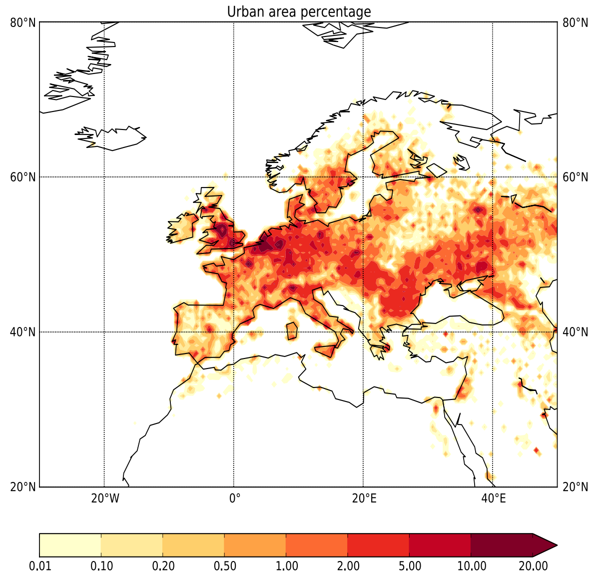




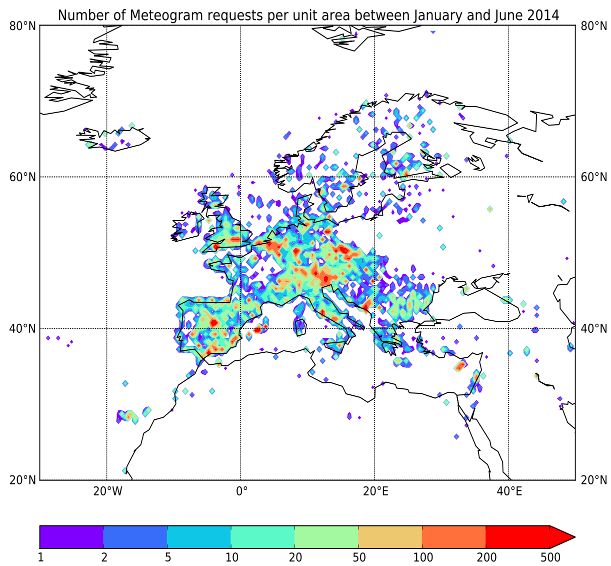


CHE linkage with the mapping of urban areas & human activity

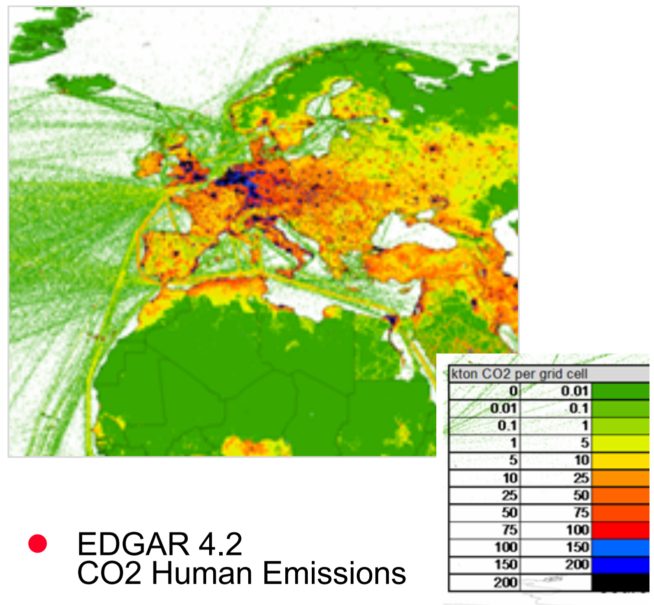
- Urban areas are important for the accurate prediction of extreme events such as heatwaves and urban flooding and need to be represented in ECMWF model.
- Best and Grimmond (2015) suggested that simple models may be well adapted to global applications
- Users lives urban areas and look at the forecast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



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



- Number of ECMWF forecast product requests from Member-States



- EDGAR 4.2 CO2 Human Emissions

ECMWF

Summary and outlook

- Progress for Earth System Seamless Coupling at ECMWF in representation of Ocean, Land, Atmosphere with a unified configuration across systems
  - In 2018 Ocean-coupling across ECMWF forecasting systems (HRES ENS SEAS5)
- **Modelling** activities coordination(GEWEX/WCRP/WWRP) greater use of EO-data
- **Mapping** activities yet insufficiently coordinated to meet global modelling challenges
- A global km-scale is necessary to enhance linkage with modelling and mapping activities and support **Monitoring**, eg. Copernicus Sentinels, GEO/LEO high-res.
- Earth Observations and Earth Surface Modelling experts working closer together can boost development of advanced parameterisation (e.g. ISWG initiatives)

- The CO2 Human Emission EU-funded Project will drive forward requirements for a global km-scale Monitoring System

https://www.che-project.eu

A Surface Integrated Scheme for Terrestrial Ecosystems Modelling & Assimilation

Land Surface Models are essential & evolving components of Earth System Models

- CLASS, CLM, ISBA-DF/ES, JULES-HYDRO, JSBACH, LPJGUESS, MPR, NOAH-MP, ORCHIDEE, TERRA, CH-TESSEL, SURFEX, UTOPIA, …
- GHMs are evolving towards LSMs and LSMs towards GHMs
- Several elements & challenges in common (e.g. Land-use, Water-use, Coupling)
- Unified forcing & fluxes list already enable a Multi-Model Framework (e.g. S2S)
- Unified I/O (e.i. NetCDF4) surface archived output consistently (e.g. EartH2Observe)

Integrated Forecasting System needs lean scalable efficient code & **Community efforts**

- OpenIFS https://www.ecmwf.int/en/research/projects/openifs
- Scalability https://www.ecmwf.int/en/about/what-we-do/scalability

An **International Surface Working Group** is setup to enhance use of **Earth Observations**

19-20 July 2017, Monterey, California

ISWG Scientific Topics:

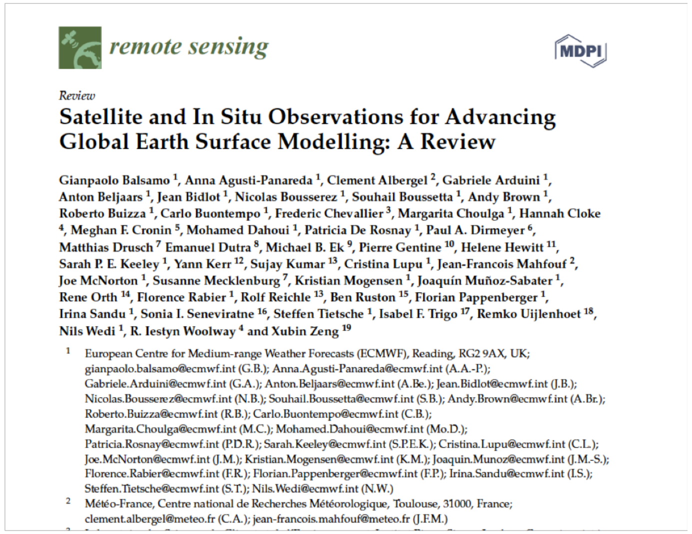
Assimilation of surface sensitive observations: IR/MW, active/passive ; Land surface schemes for modeling & assimilation ; Radiative transfers and emissivity/reflectivity models: VIS/IR/MW surface ; Retrievals of surface parameters: land surface temperature, soil moisture, snow and ice, albedo water-body extent, sea surface wind, salinity, canopy parameters, vegetation water content, vegetation state

26-28 June 2018, Lisbon, Portugal

Satellite/in-situ observations drive Earth surface monitoring & forecasting skill

As part of the ISWG efforts a 2018 Special Issue on:
"Advancing Earth Surface Representation
via Enhanced Use of Earth Observations
in Monitoring and Forecasting Applications" is published
in *MDPI journal Remote Sensing*

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


remote sensing

MDPI

Review

Satellite and In Situ Observations for Advancing Global Earth Surface Modelling: A Review

Gianpaolo Balsamo [1], Anna Agusti-Panareda [1], Clement Albergel [2], Gabriele Arduini [1], Anton Beljaars [1], Jean Bidlot [1], Nicolas Bousserez [1], Souhail Boussetta [1], Andy Brown [1], Roberto Buizza [1], Carlo Buontempo [1], Frederic Chevallier [3], Margarita Choulga [1], Hannah Cloke [4], Meghan F. Cronin [5], Mohamed Dahoui [1], Patricia De Rosnay [1], Paul A. Dirmeyer [6], Matthias Drusch [7] Emanuel Dutra [8], Michael B. Ek [9], Pierre Gentine [10], Helene Hewitt [11], Sarah P. E. Keeley [1], Yann Kerr [12], Sujay Kumar [13], Cristina Lupu [1], Jean-Francois Mahfouf [2], Joe McNorton [1], Susanne Mecklenburg [7], Kristian Mogensen [1], Joaquín Muñoz-Sabater [1], Rene Orth [14], Florence Rabier [1], Rolf Reichle [13], Ben Ruston [15], Florian Pappenberger [1], Irina Sandu [1], Sonia I. Seneviratne [16], Steffen Tietsche [1], Isabel F. Trigo [17], Remko Uijlenhoet [18], Nils Wedi [1], R. Iestyn Woolway [4] and Xubin Zeng [19]

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2 Météo-France, Centre national de Recherches Météorologique, Toulouse, 31000, France; clement.albergel@meteo.fr (C.A.); jean-francois.mahfouf@meteo.fr (J.F.M.)

3rd International Surface Working Group (**ISWG#3**) to be hosted by ECCC with support of GCW & ESA

15-17 July 2019, Montreal, Canada

Coupled processes at the surface-atmosphere interface

Relevance for medium-range prediction: the ECMWF experience

Gianpaolo Balsamo & CP-Team
With contributions of several Colleagues acknowledged on the slides

Presented to the ICCARUS 2019, DWD, Germany, 18th-20th March 2019

ECMWF, Earth System Modelling Section, Coupled Processes Team
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