Earth surface modelling: coupling to the atmosphere

Land surface lecture 2

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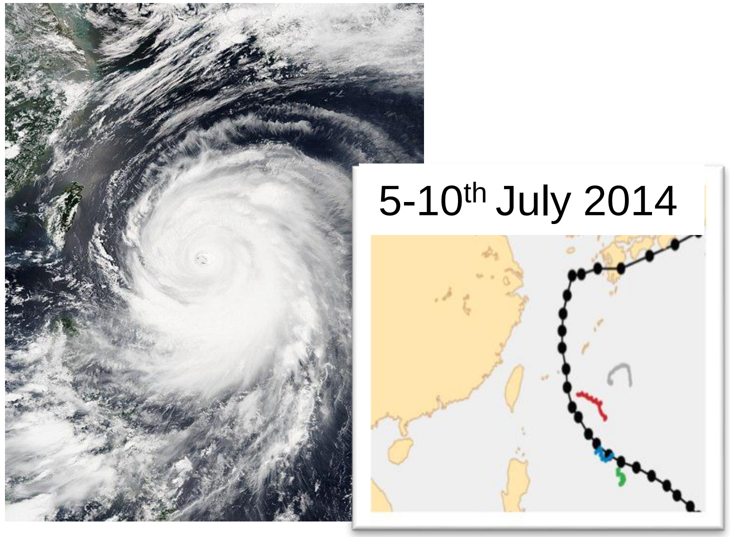
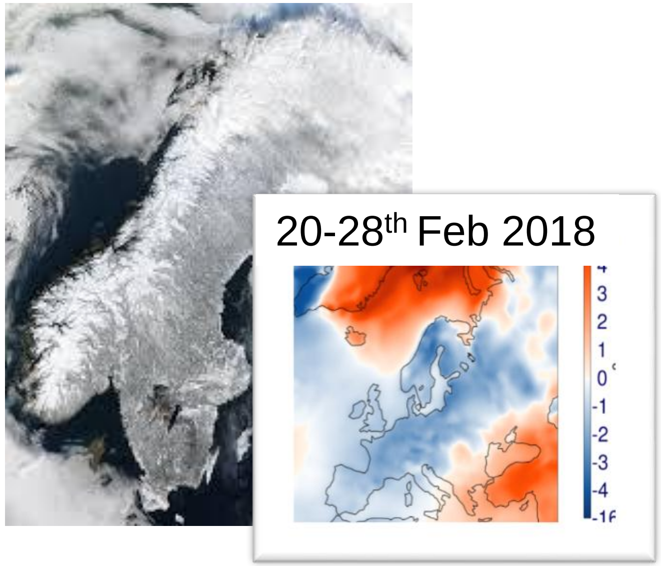
Coupling for improved diurnal cycle and impact on extremes

- **Introduction: the ECMWF forecasting systems in 2018**
- Three examples for surface-atmosphere coupling relevance:
  - Ocean-coupling effects on diurnal cycle of temperature and cyclones
  - Soil-coupling effects on soil moisture and extreme surface temperature
  - Snow-coupling effects on snow depth and extreme surface temperature

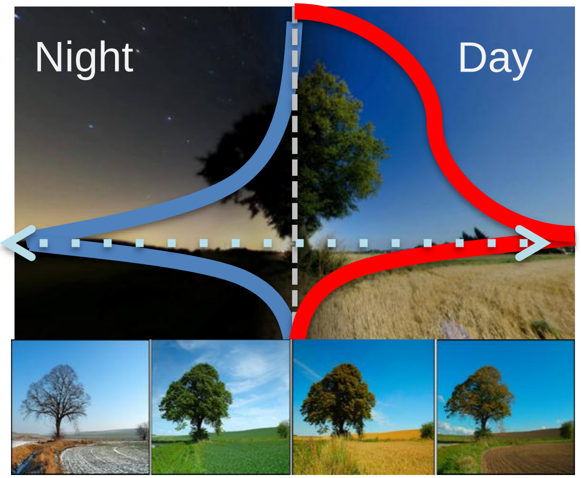




- Outlook
  - Improved surface coupling as key to hydrological & environmental applications

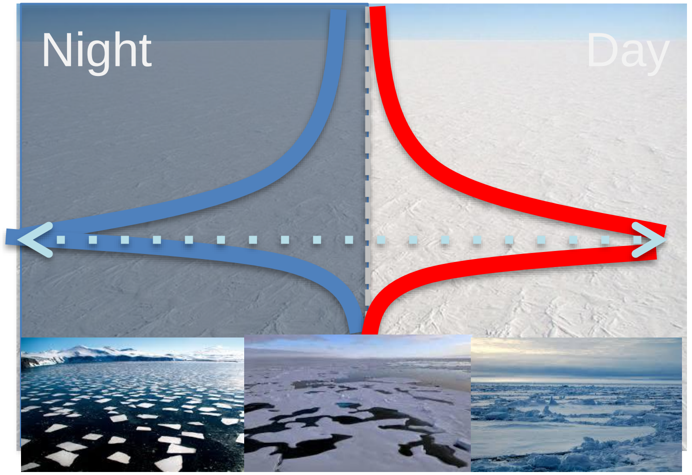
Modelling surface heterogeneity and coupling with the atmosphere

- 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

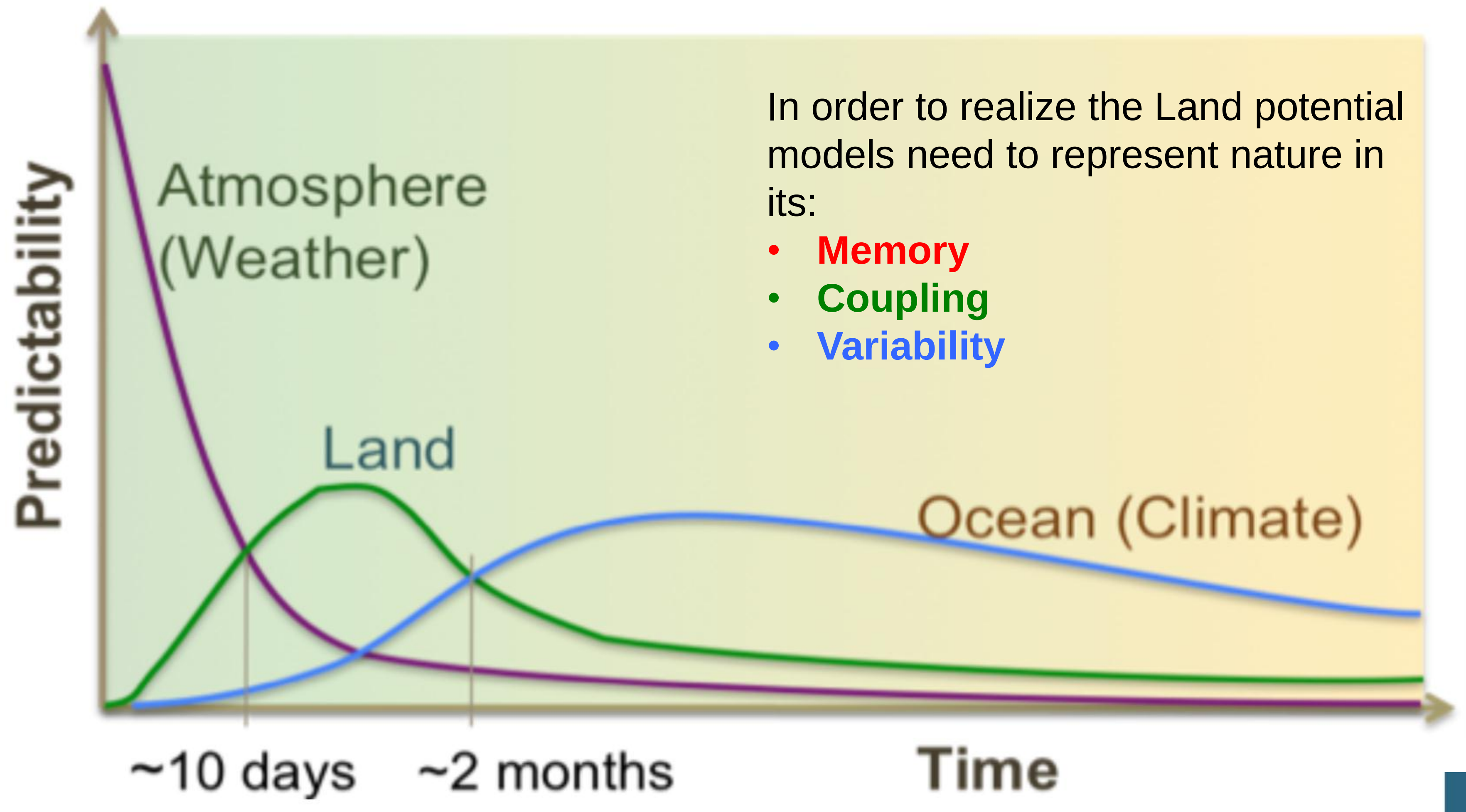
- Transition from open-sea to ice-covered conditions
- Sea-state dependent interaction wind induced mixing/waves
- Vertical transport of heat

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 coupling role in medium-range and S2S



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

- **Memory**
- **Coupling**
- **Variability**

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

ECMWF

WWOSC 2014
MONTRÉAL, CANADA

Earth surface modelling components @ECMWF in 2018

- **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**

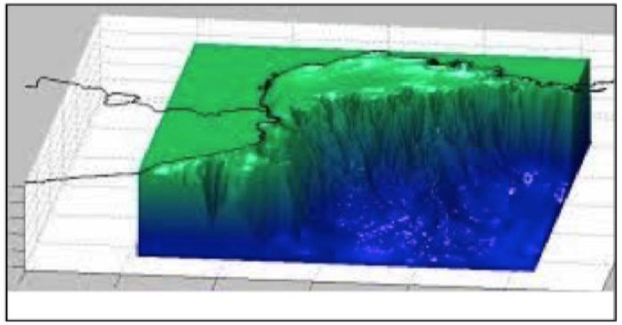
  The Louvain-la-Neuve Sea Ice Model

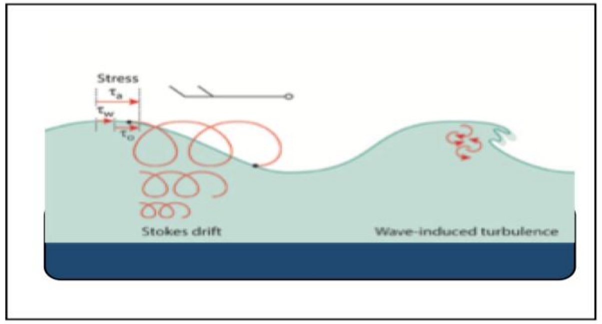
  Fichefet and Morales Maqueda (1997)

  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)

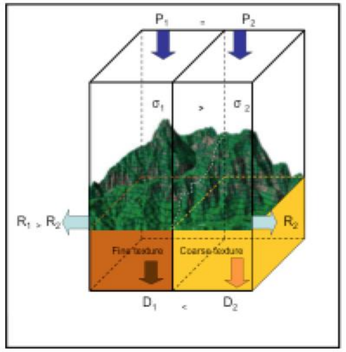
- **Enhance ML**

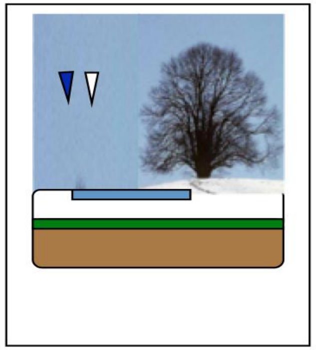
  Snow ML5

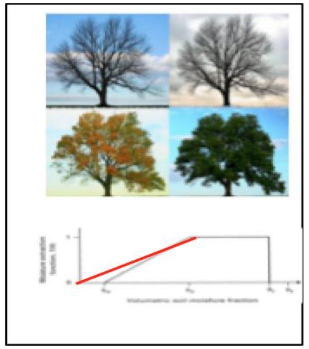
  Soil ML9

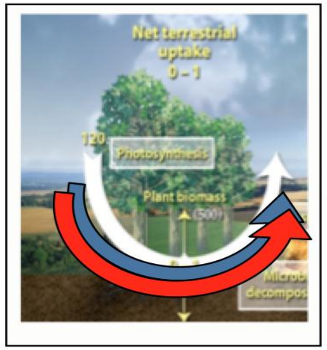
  Dutra et al. (2012, 2016)

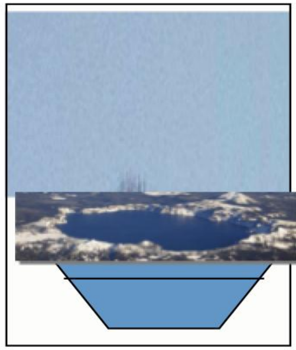
  Balsamo et al. (2016)

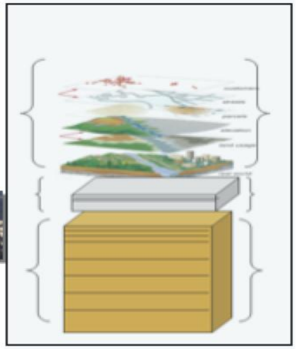












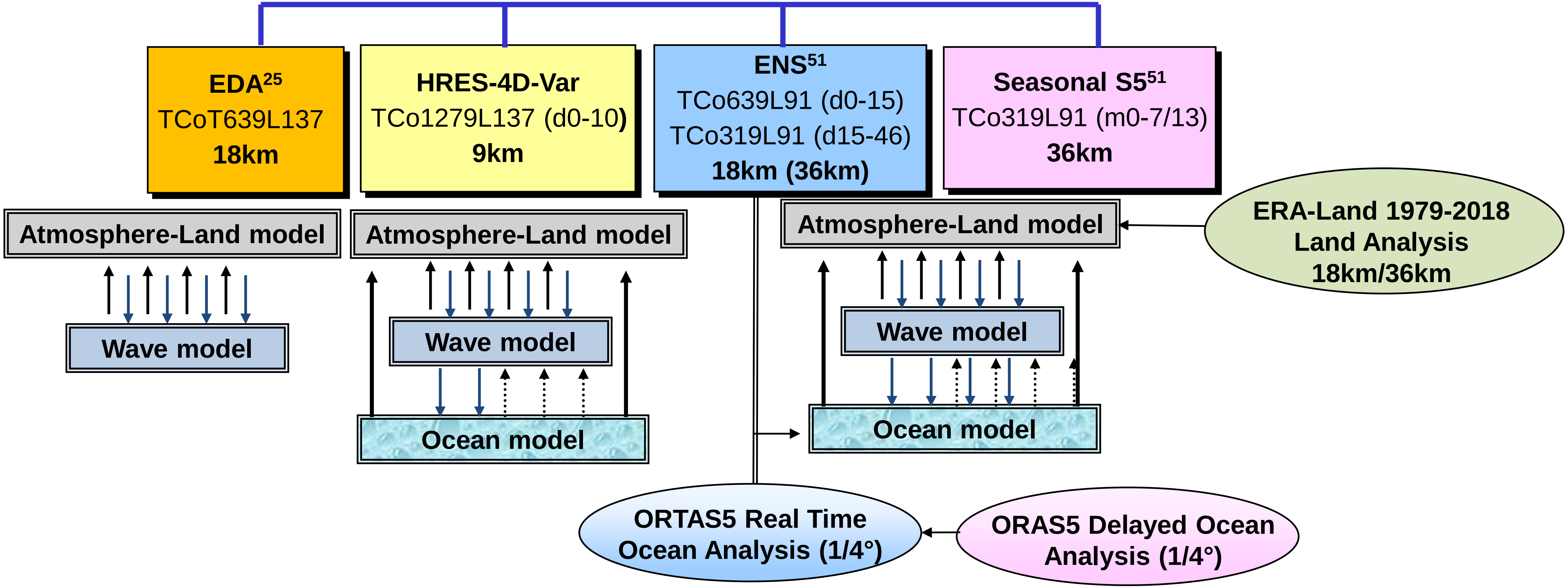
Atmos Land Resol.	ECMWF in 2018
80 km	ERAI
32 km	ERA5+ SEAS5+*
18 km	ENS+*
9 km	HRES+*

**Ocean*
used across forecast systems and in Ocean reanalysis

(*migration completed with HRES-coupled operational from the 5th June 2018)

+Land
used across forecast systems and new Climate reanalysis

Seamless surface-atmosphere coupling of Integrated Forecasting System As operational on June 5th, 2018



See Buizza et al (2018), Keeley et al (2018), Mogensen et al (2018), published in the ECMWF 2018 Summer Newsletter

Coupling for improved diurnal cycle and impact on extremes

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- **Three examples for surface-atmosphere coupling relevance:**
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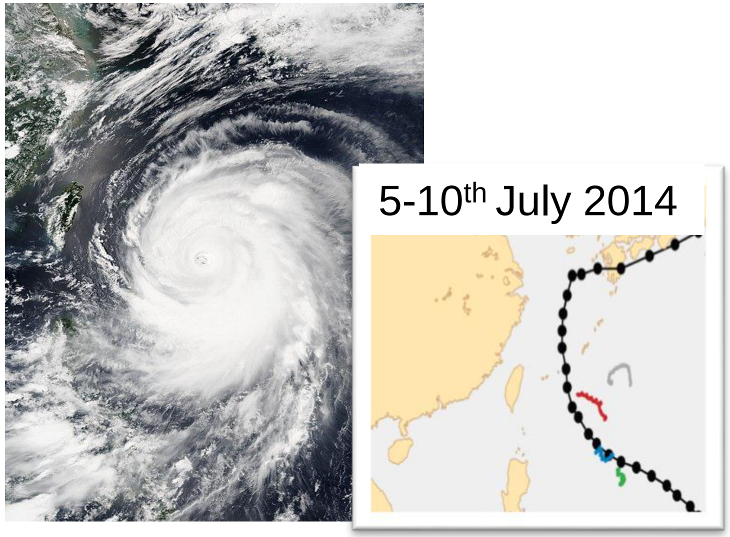

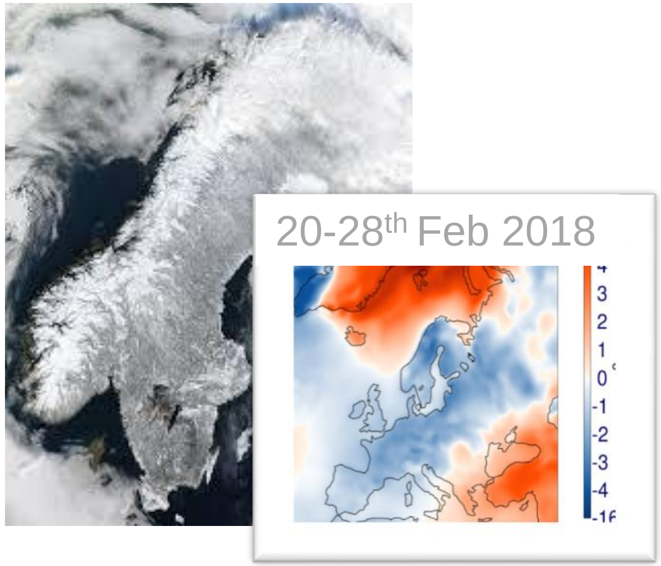

- Outlook
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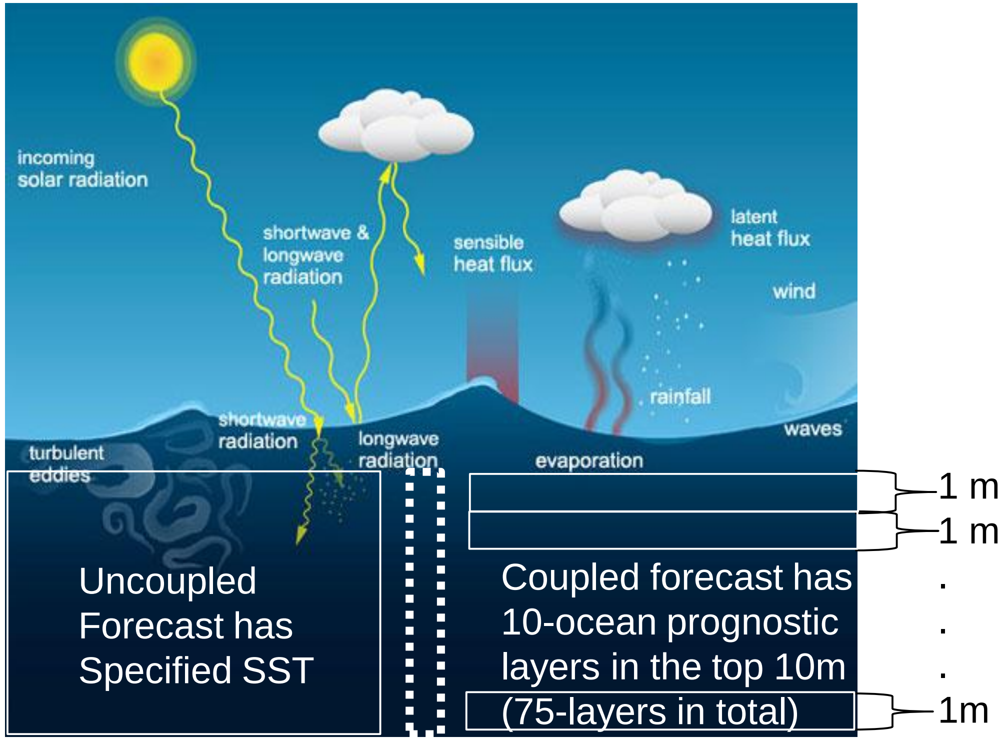
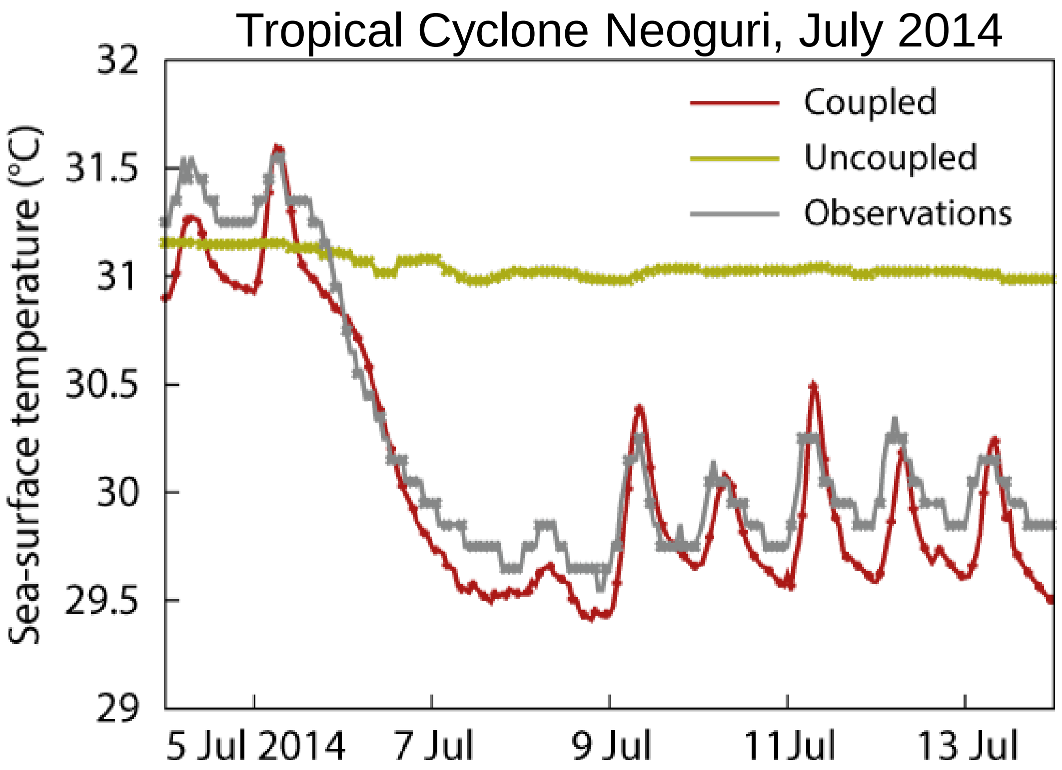
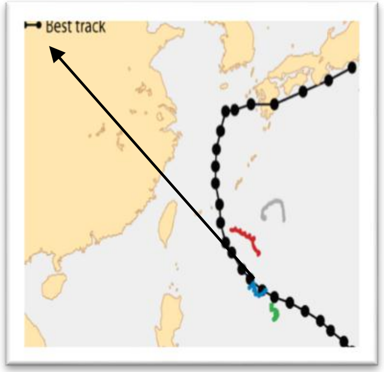
Ocean-coupling and local effects on sea surface temperature (SST)





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

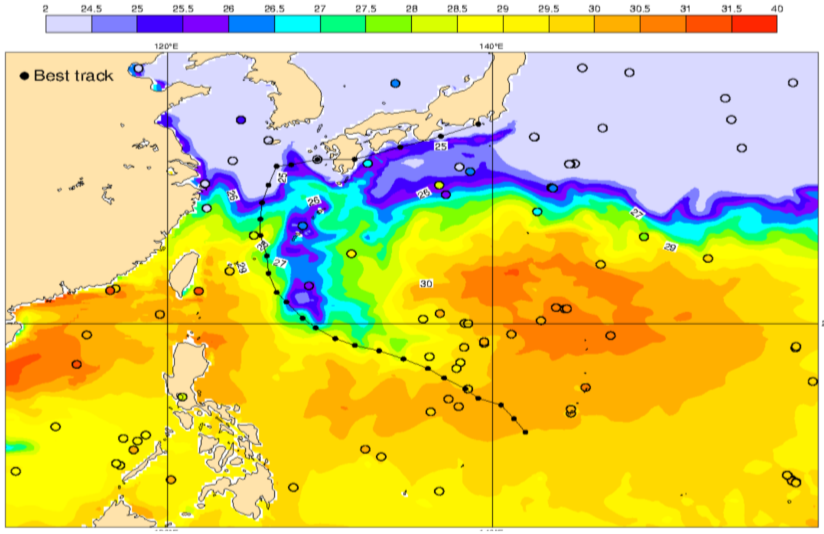


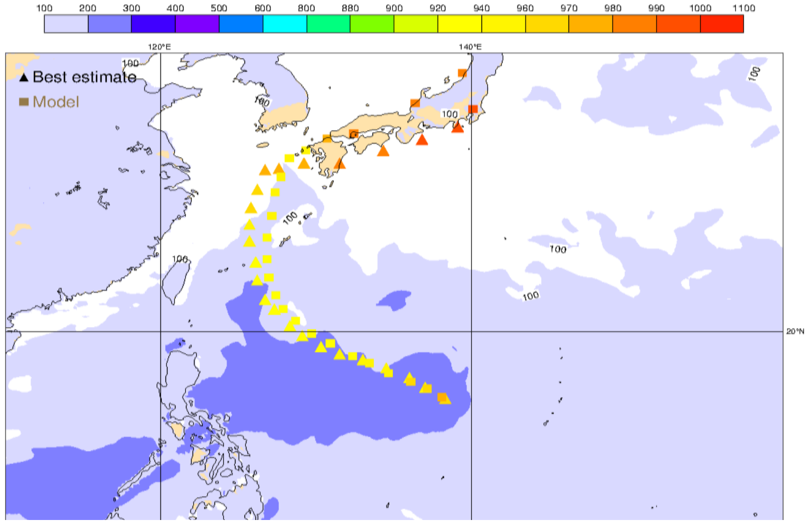
Mogensen et al 2018

Impact of Ocean-coupling along the track of Tropical Cyclone Neoguri

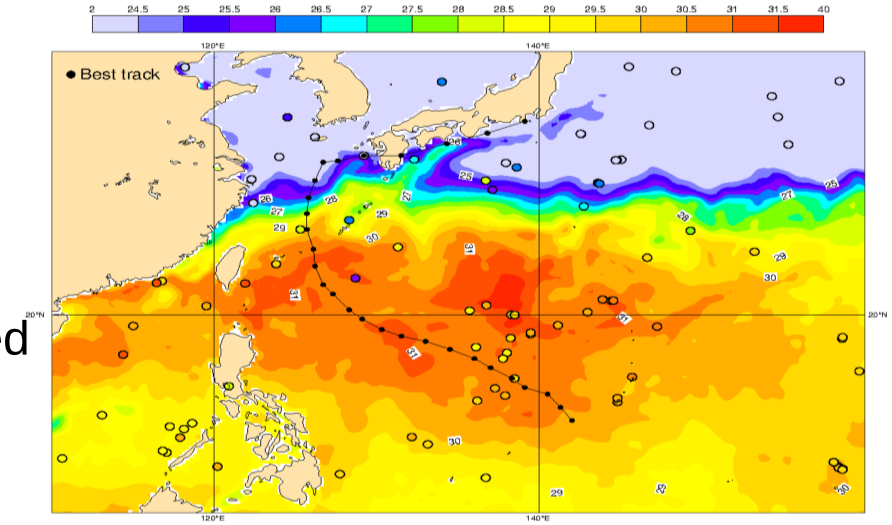
Sea surface temperature | Surface heat flux

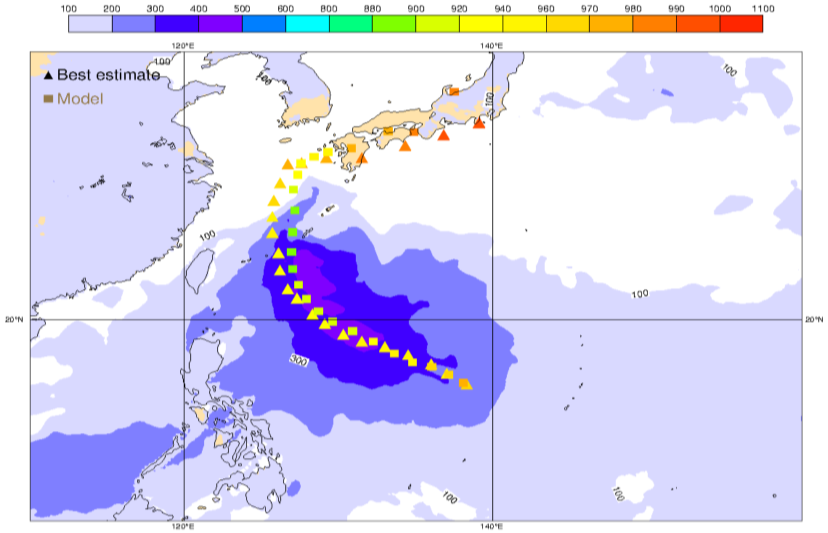
ECMWF Ocean Coupled 5-day Forecast





ECMWF Ocean Uncoupled 5-day Forecast





Coupled Forecast:

- Gets the SST cooling better
- Reduced Heat flux to atmos.
- Gets the TC Intensity Better

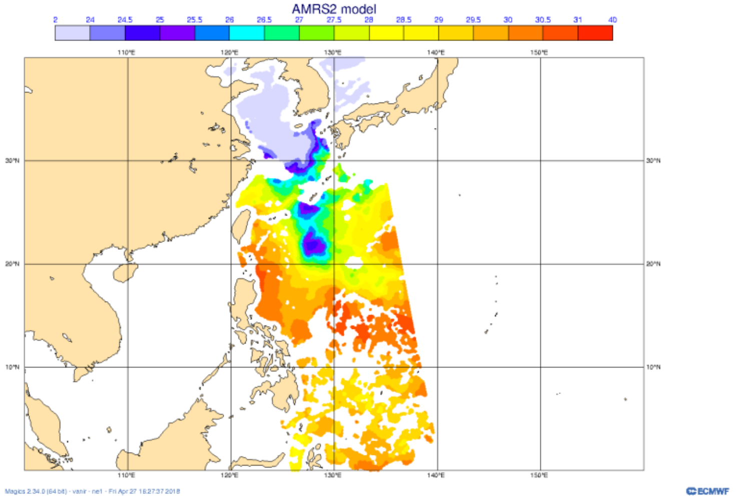
Thanks to Kristian Mogensen

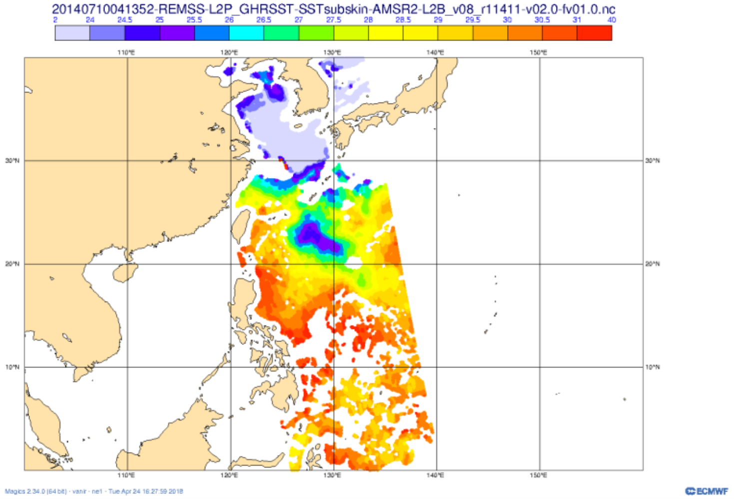
Comparing forecasts with satellite-based sea surface temperature

Sea surface temperature (forecast)

Sea surface temperature (observation)

ECMWF Ocean Coupled 5-day Forecast





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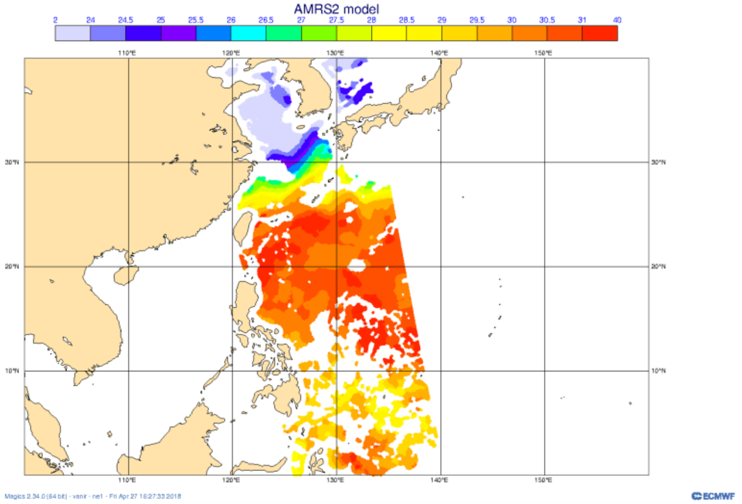


Satellite Observations from AMSR2 MW SST

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

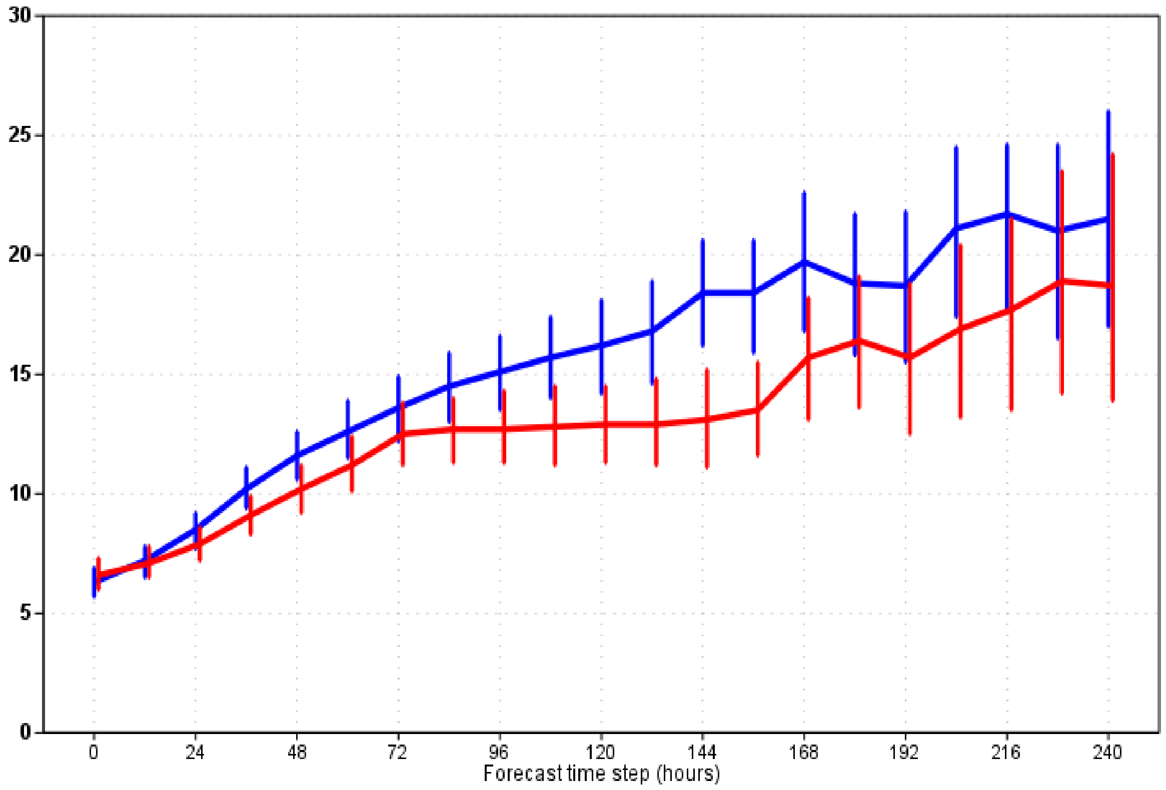
ECMWF

Thanks to Kristian Mogensen

Impact of Ocean-coupling on Tropical Cyclones and relevance for 2018 season

Tropical Cyclones Intensity is generally improved when looking at recent cases (past 2-years)

MSLP Error (hPa)



The red curve is for the ECMWF HRES Coupled as implemented on the 5th of June 2018

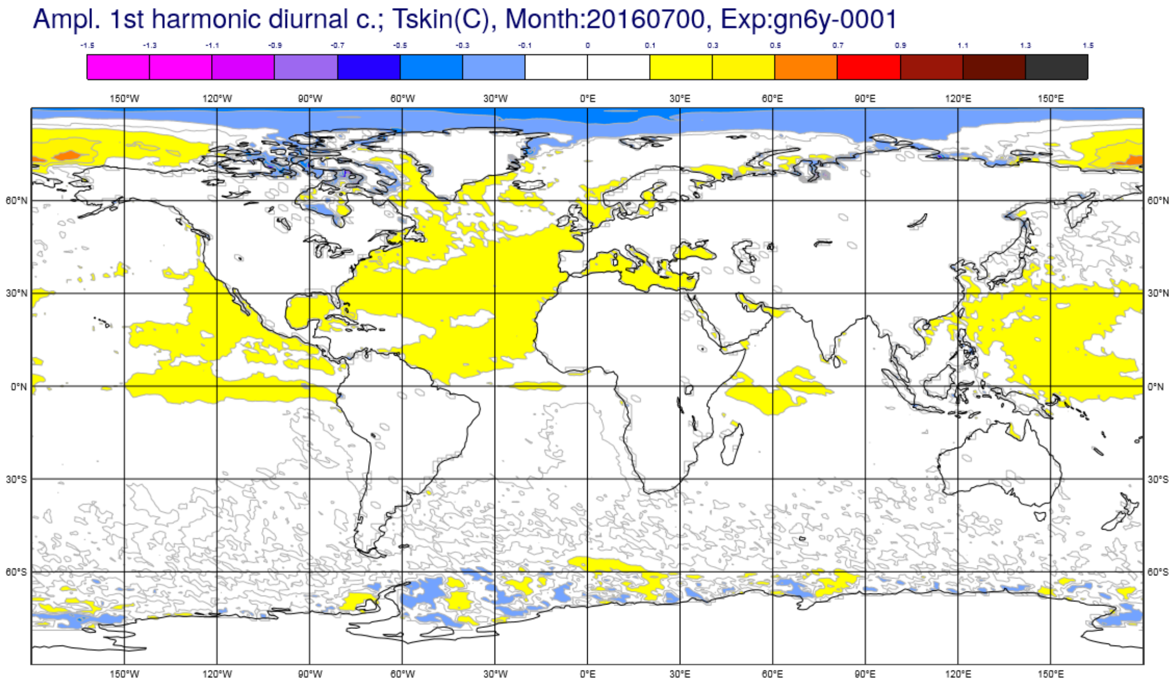
Mean-sea-level-pressure, MSLP in hPa, of new 45r1 (red) & 43r3 (blue). The data sample includes about 750 cases at initial time, decreasing to about 200 at forecast day 5-6 and to about 50 at day 10. Bars indicate 95% confidence.

Thanks to Kristian Mogensen & Fernando Prates

What happens to the temperature diurnal cycle enhancing surface coupling?

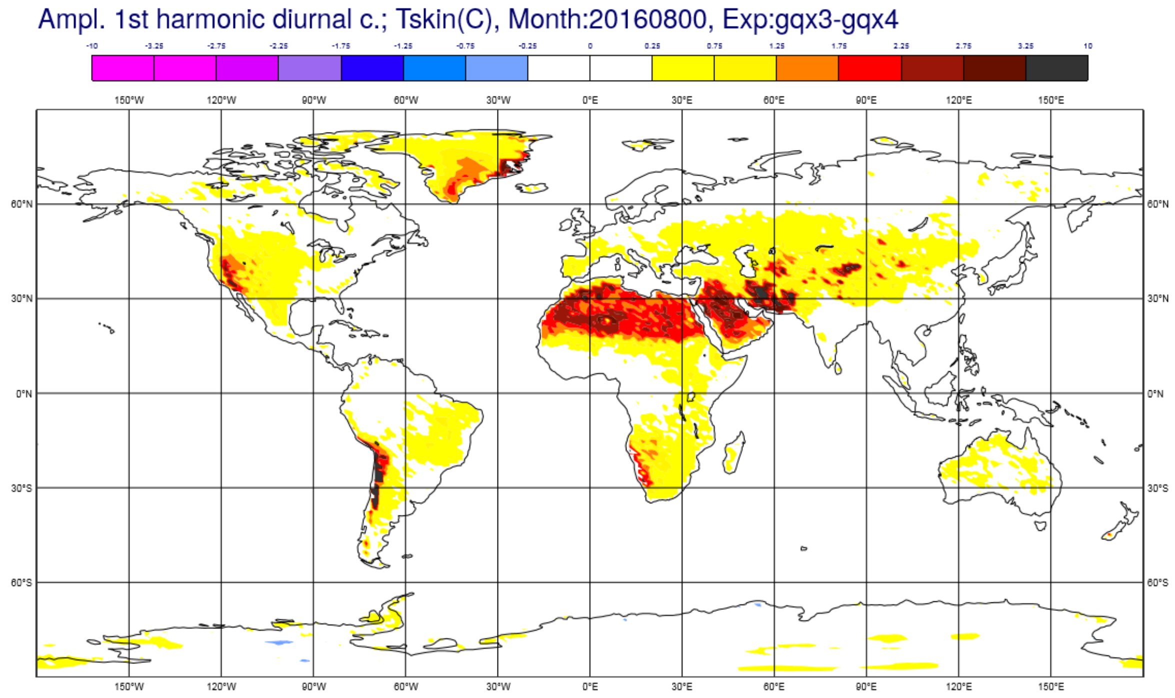
- Towards more realistic surface temperature (skin and below) particularly in clear/sky
- Towards increased variability and surface responsiveness to atmospheric forcing

Ocean skin



Difference in diurnal cycle amplitude due ocean-coup

Land skin



Difference due to enhance multi-layer land-coup

Coupling for improved diurnal cycle and impact on extremes

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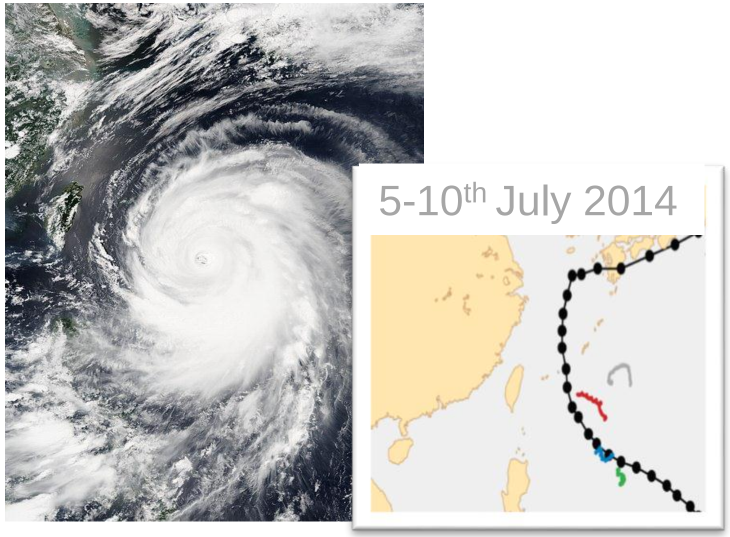
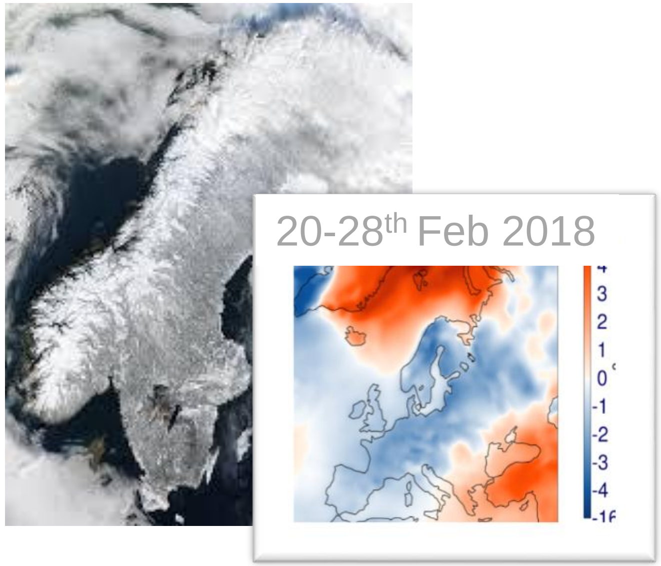


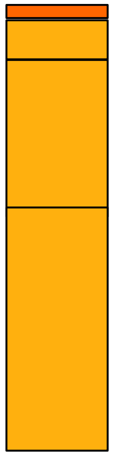


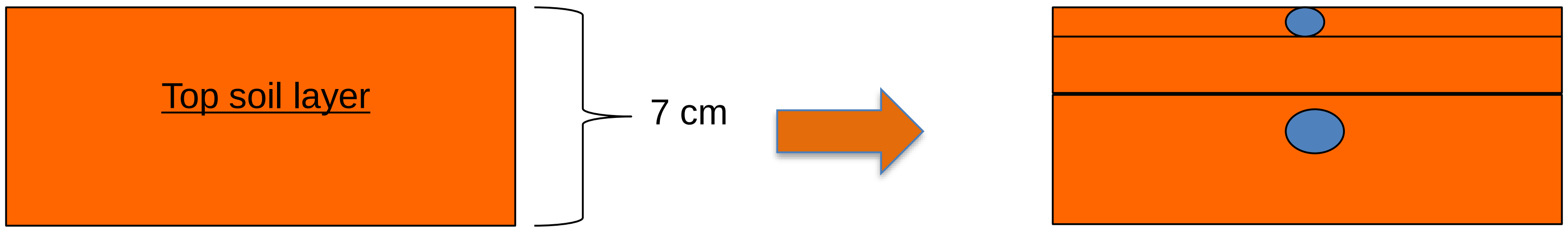
- Outlook
  - Improved surface coupling as key to hydrological & environmental applications

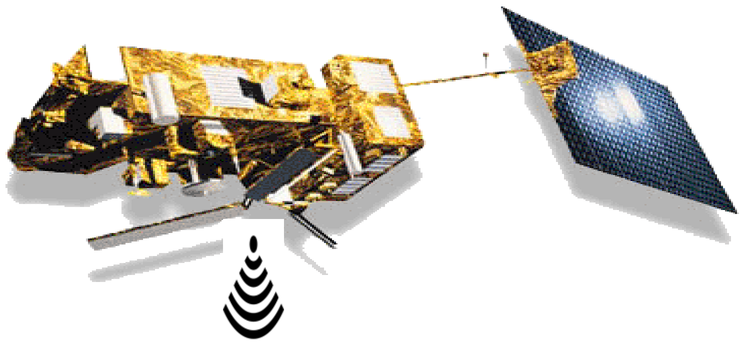
Increased soil model vertical resolution to improve use of satellite data

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

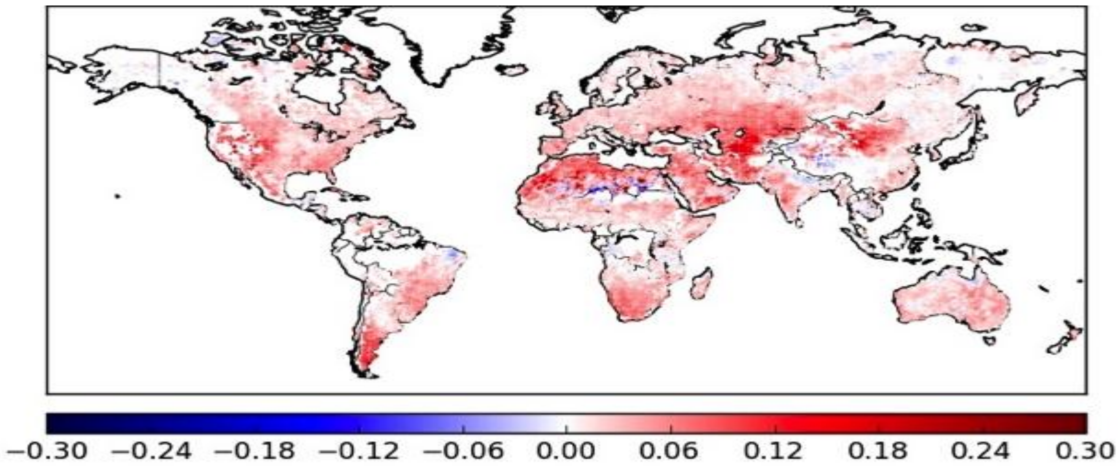
4-layers:
 # 0-7 cm
7-28 cm
28-100 cm
100-289 cm







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



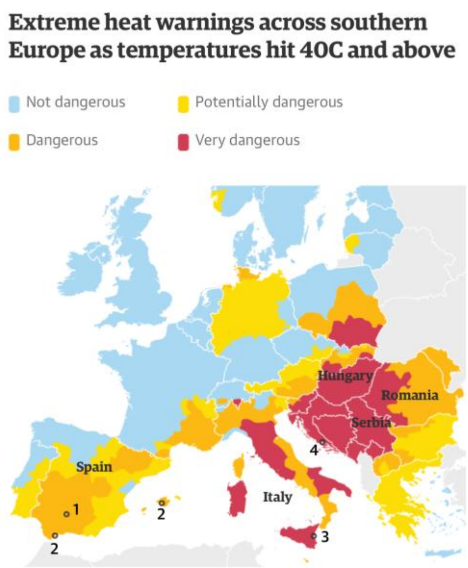
Thanks to Clément Albergel, Patricia De Rosnay, LDAS-Team

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)

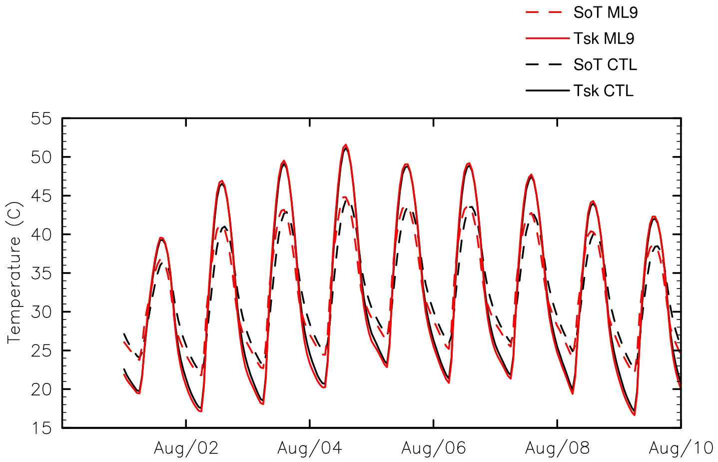
See Dorigo et al. (2017 RSE)

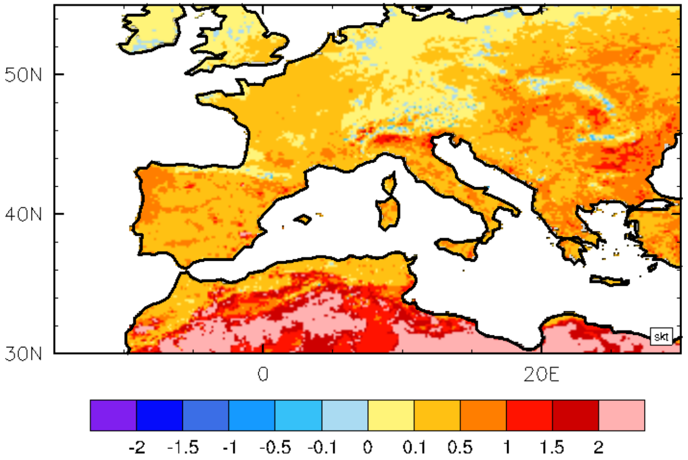
Impact of the soil model vertical resolution: heatwaves severity



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

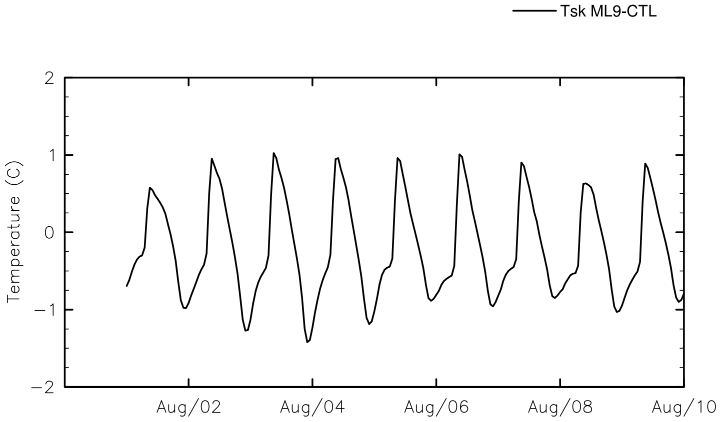
ECMWF Land model ML9 & ML4 (offline)





Differences in the maximum skin temperature ML9-ML4

Difference ML9-ML4 soil model (offline)



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

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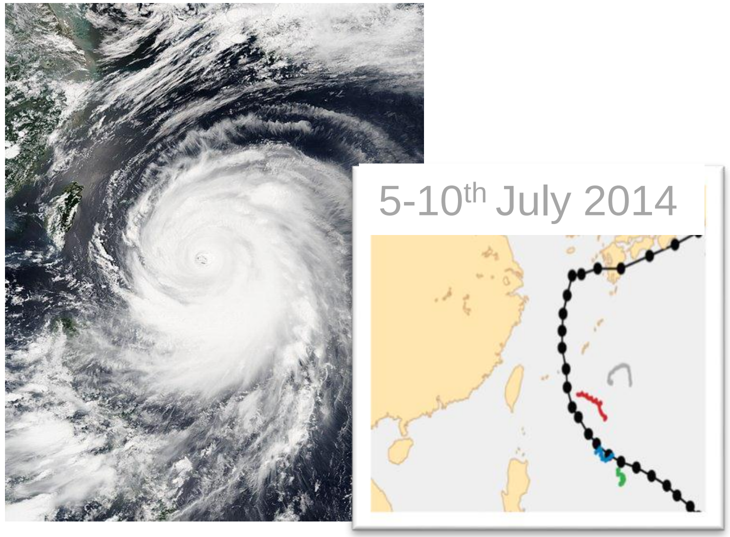

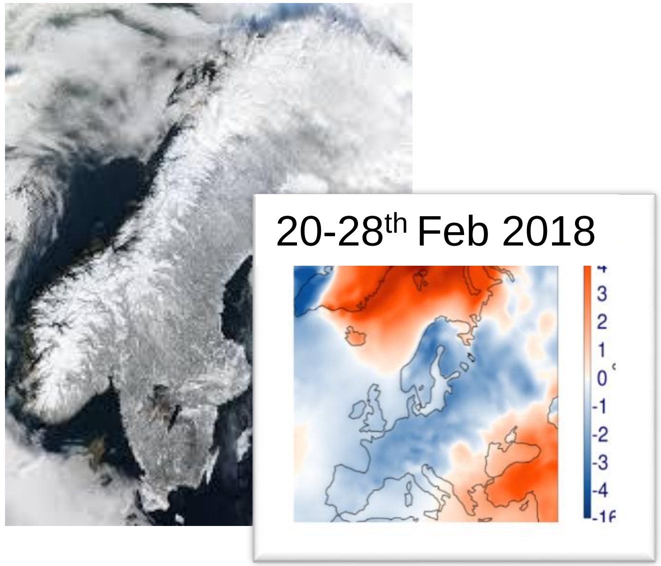

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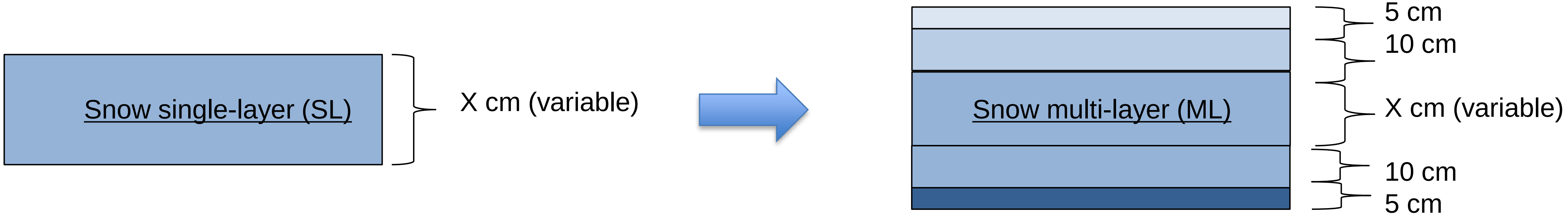
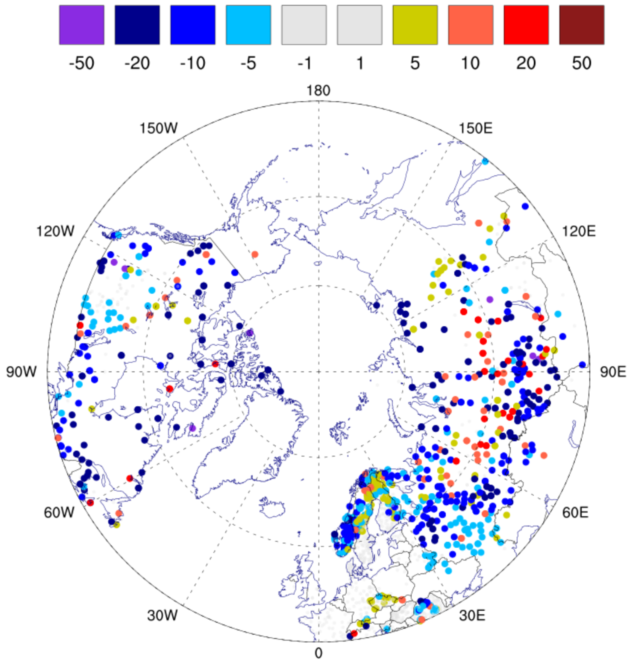
Increased snow model vertical resolution: impact in cold regions climate

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

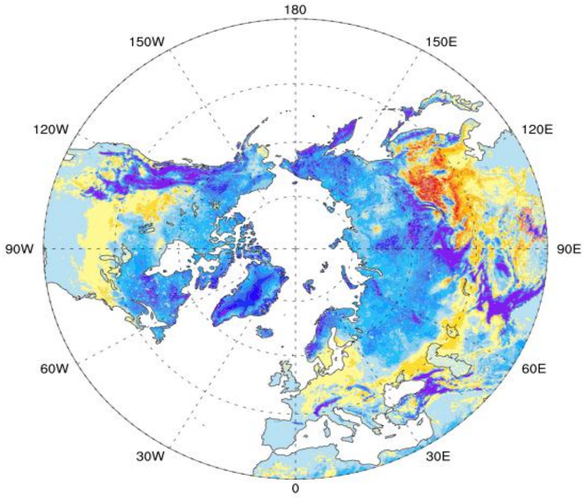


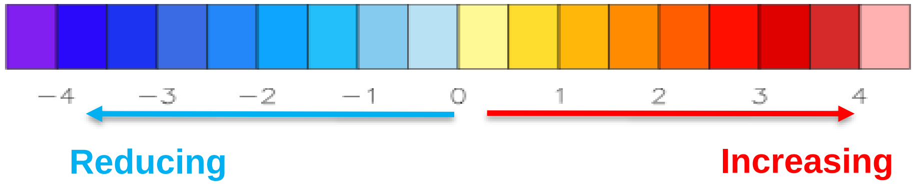
Difference ML- SL in Snow depth RMSE winter (DJF)



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)



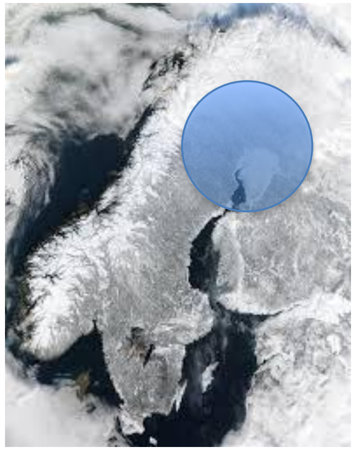


Winter reduction of the 2m minima temperatures with increasing diurnal-cycle. DIFF Tmin 2-4 K colder in ML compared to SL snow. Increased variability

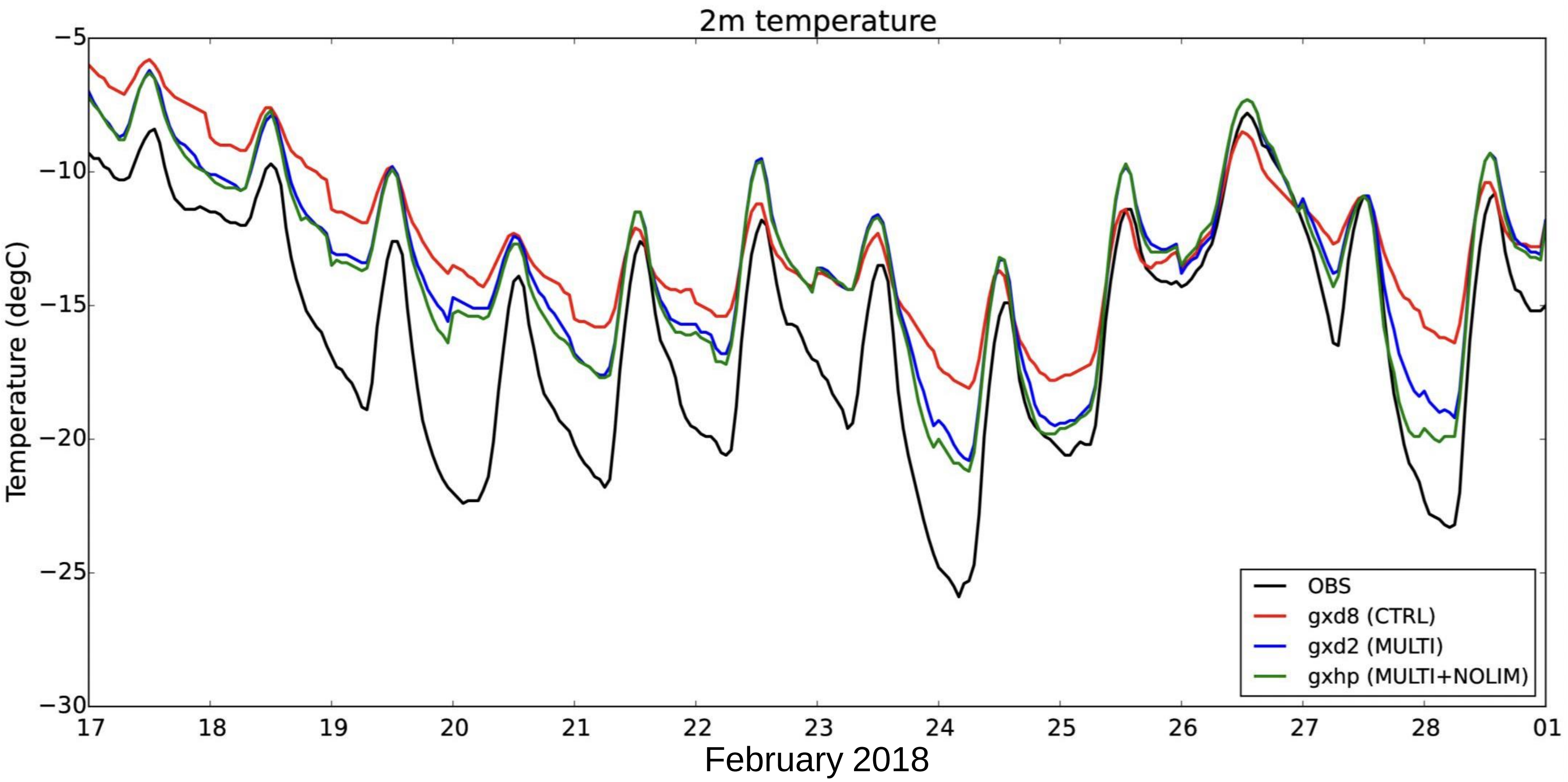
Thanks to Gabriele Arduini, Jonny Day, Linus Magnusson

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.

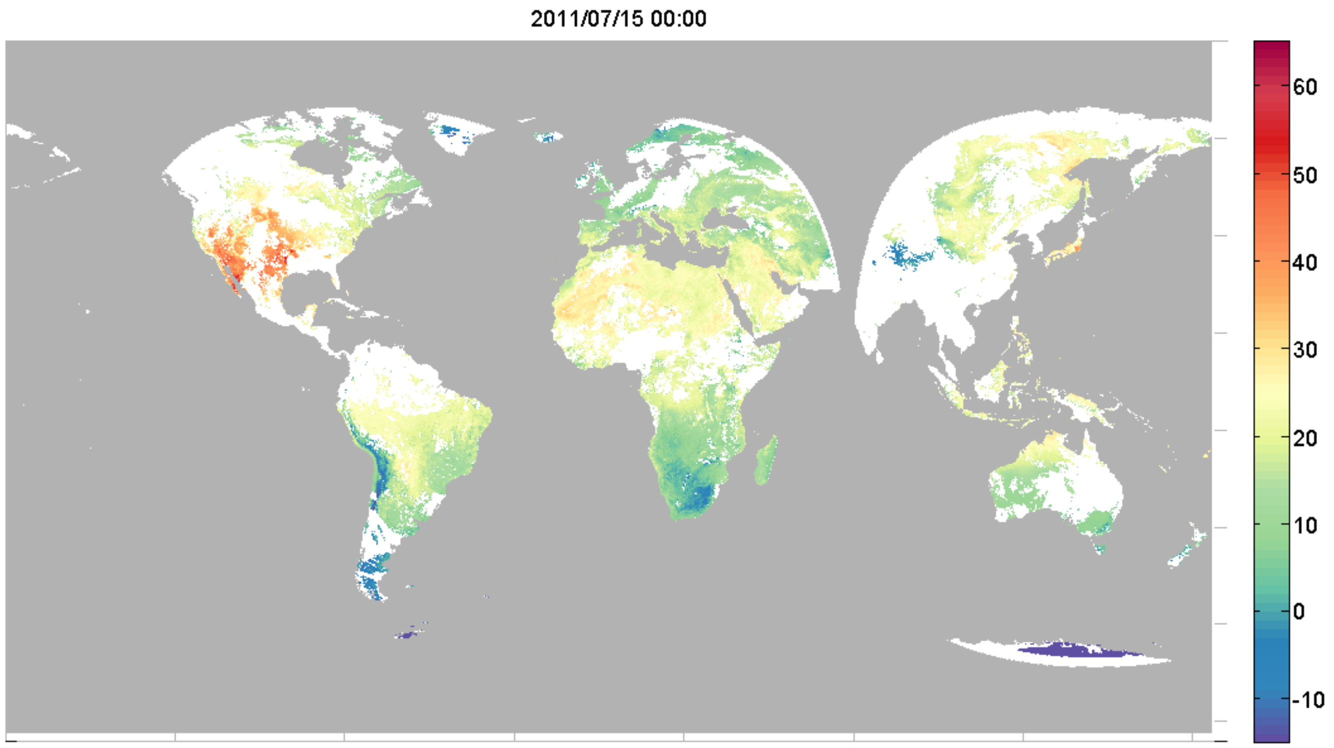
The increased variability in the diurnal cycle is beneficial for ensemble forecasting.

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

Earth Observations for surface coupled model development: the example of LSTs

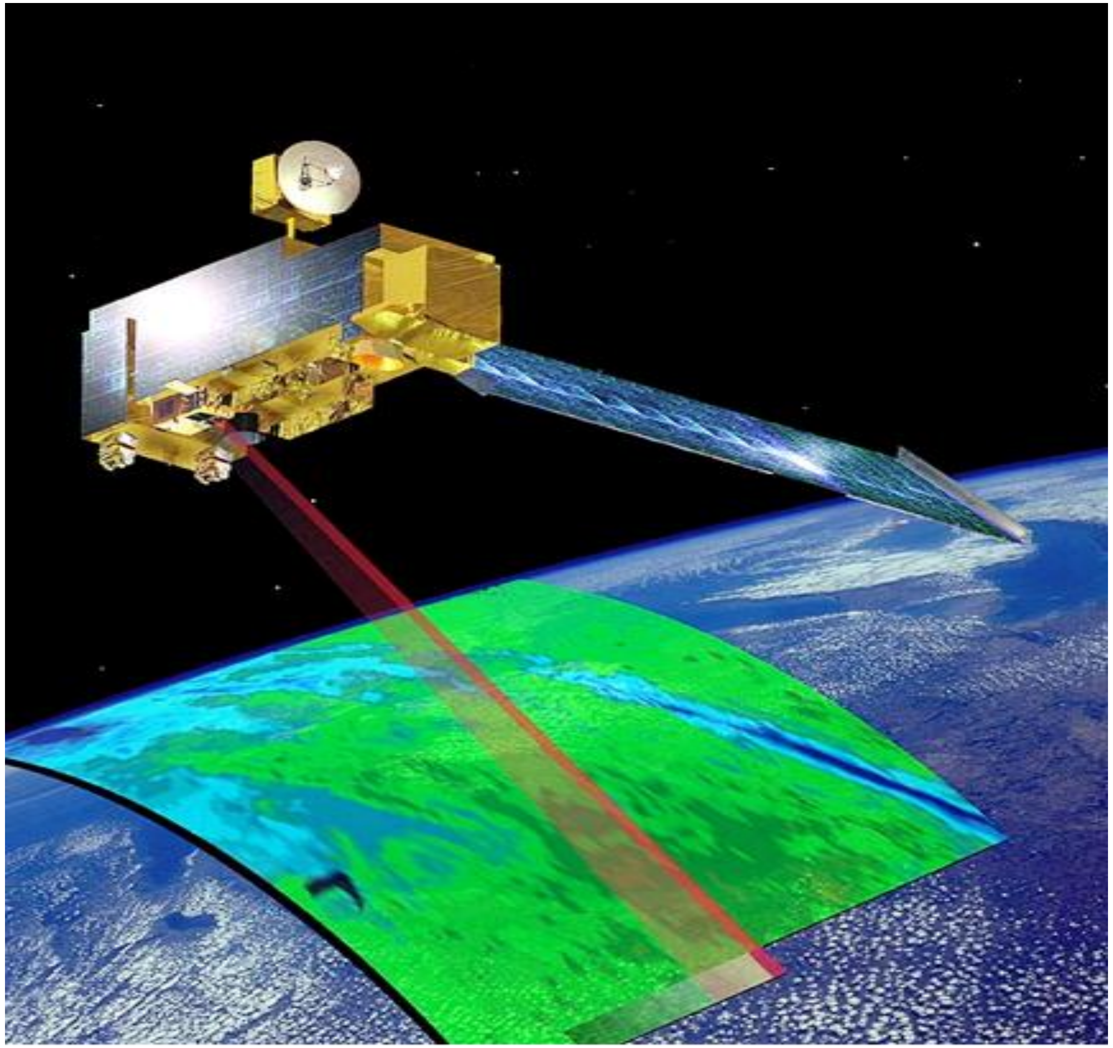
Land Surface Temperatures (LSTs) provides validation and guides diurnal cycle model development:

- LST to evaluate impact of vegetation modelling (see Trigo et al. 2015, used EUM-LSA-SAF)
- LST to constrain HTESSEL coupling parameters (see Orth et al., 2017, used ESA-CCI)
- LST to show value multi-layer snow over Antarctica (see Dutra et al 2017, used MODIS)

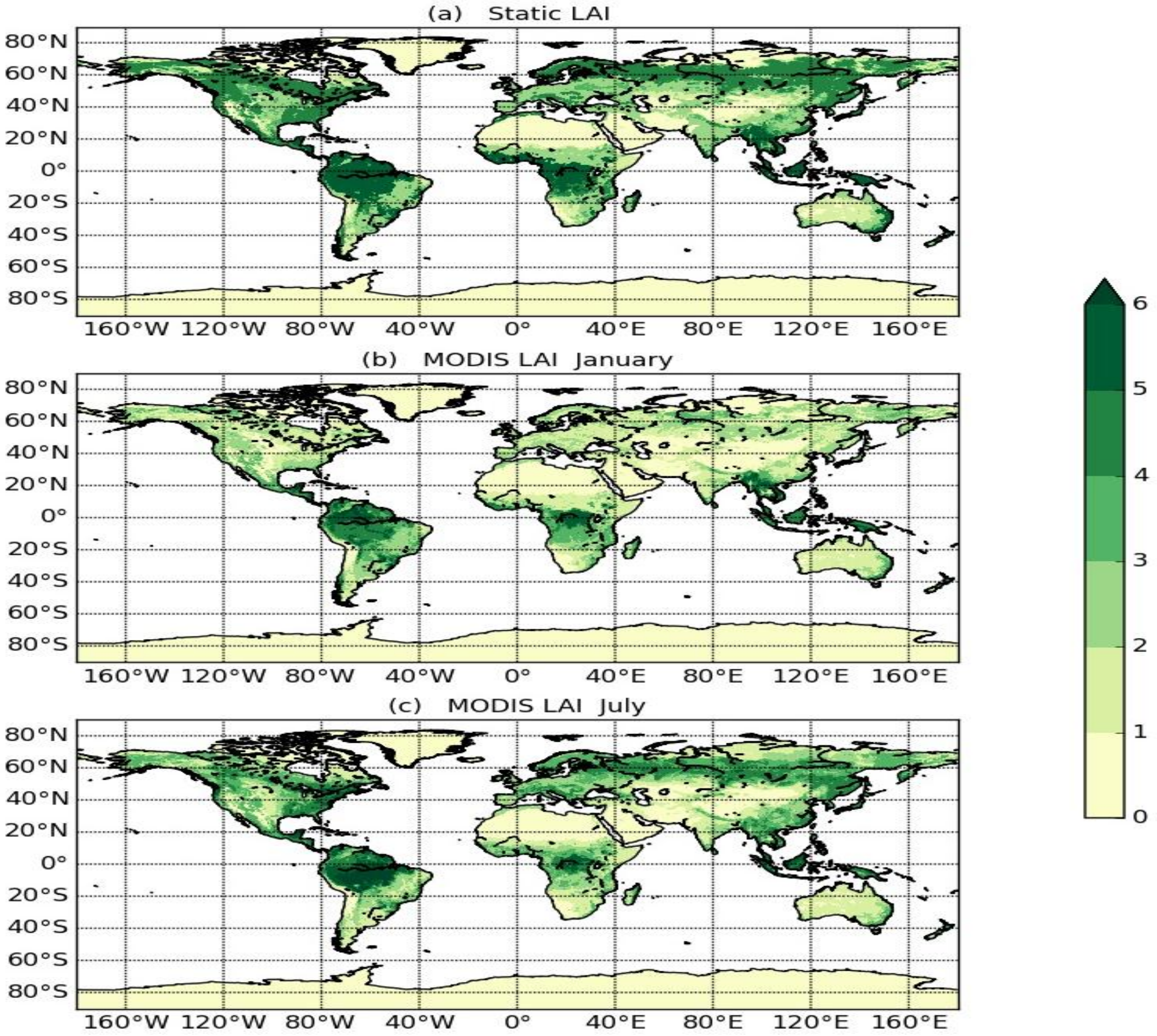


Thanks to Isabel Trigo, Ben Ruston & ISWG Team

Mapping the vegetation state from satellite data



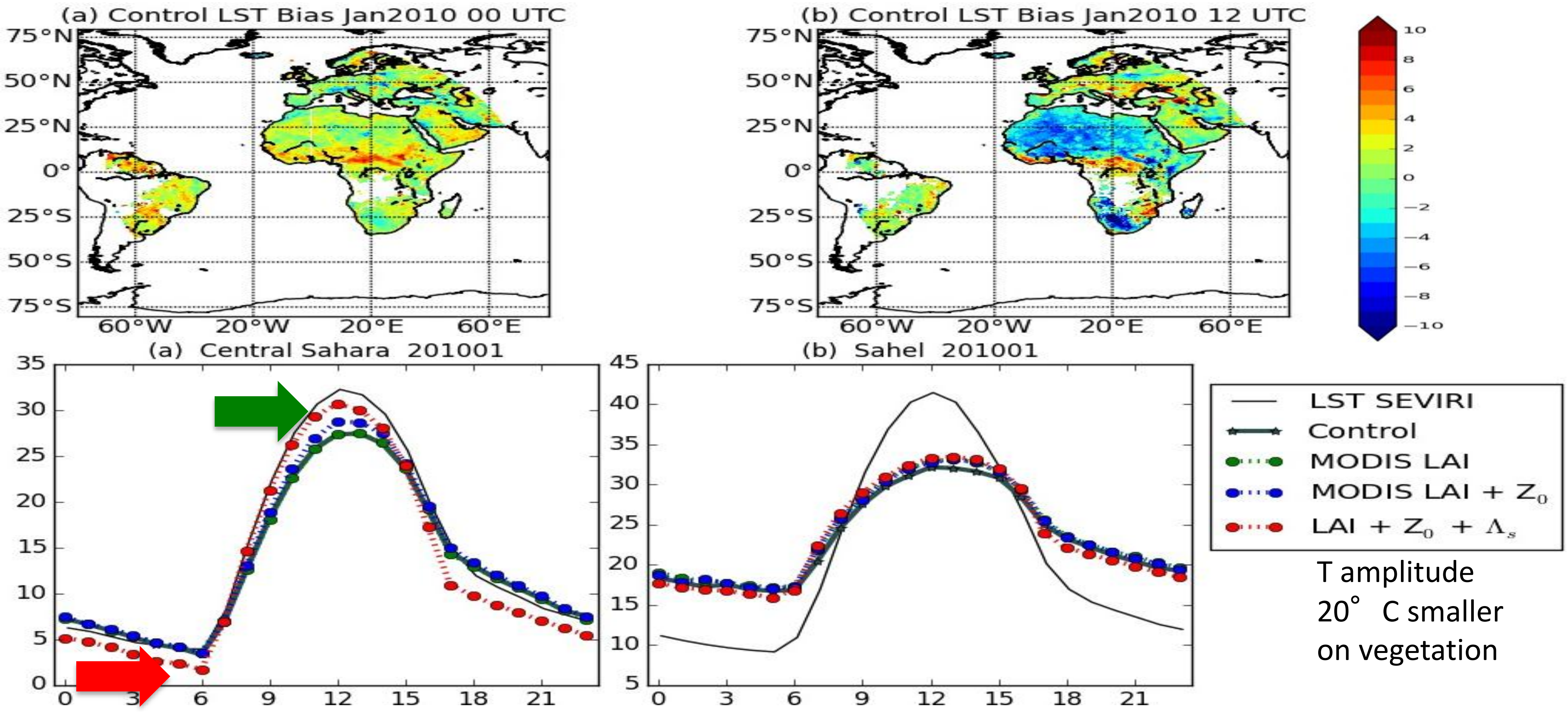
Boussetta et al. (2015, RSE)



ECMWF

Coupling and diurnal cycle: vegetation

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



T amplitude
20° C smaller
on vegetation

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

ECMWF

Summary

- Model development on diurnal cycle improvements connects to capability of better representing Extreme events (good argument in favor of seamless approach)
- Three cases shown: Ocean-coupling, Soil-layers, Snow-layers enhancements
- Systematic model errors when reduced will introduce larger variability (skill $_{vs}$ rmse)
- Energy & Water cycle improvements (e.g. soil moisture, snow) support hydro-apps
- Carbon cycle forecasting skills strongly depend on temperature & moisture, fluxes

Outlook:

- EO-observations (Tskin, MW) can validate increase complexity in surface modelling
- Progressive inclusion across-models of human impact (CO2, Water-use, Land-use)

An example in the CO2 Human Emissions project https://www.che-project.eu

CO2 Human Emissions