ECMWF: towards coupled earth system modelling and assimilation

Including Copernicus services

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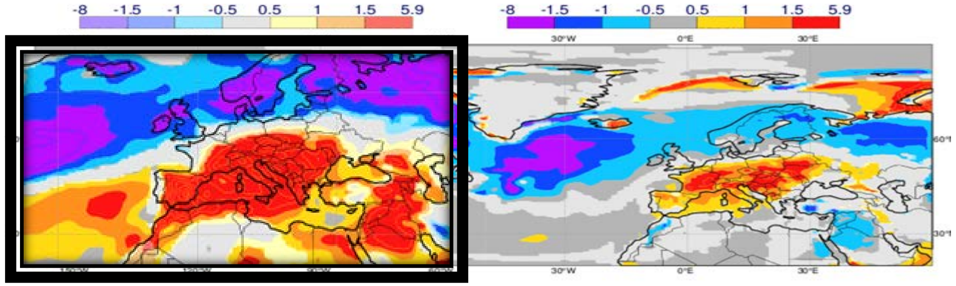
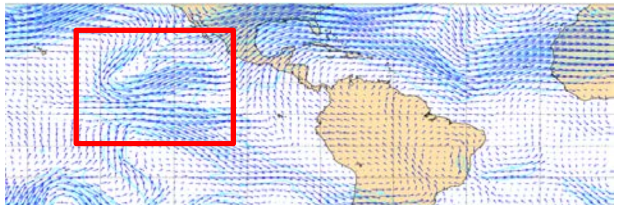
Challenges

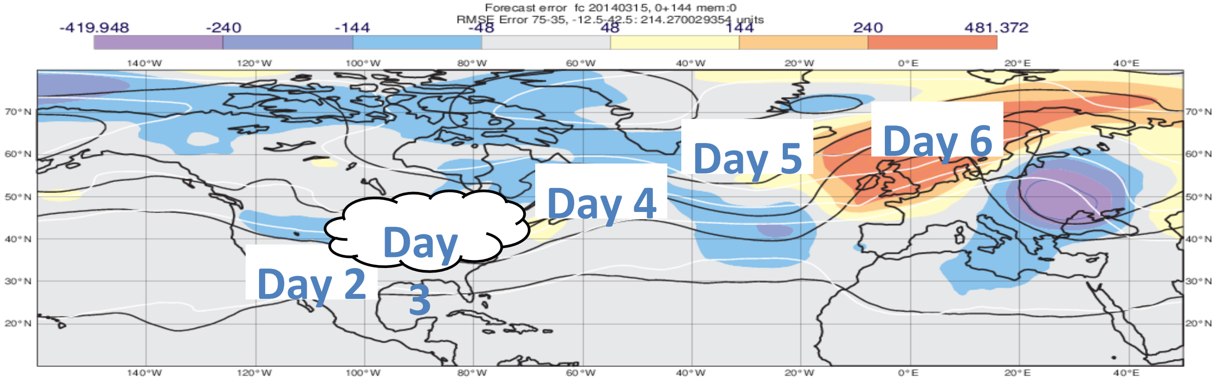
- Predicting European weather a month ahead ("beyond ten days")
- Understanding the influence of the tropics on global weather
- Understanding the influence of the stratosphere on the troposphere during winter
- Describing the interactions between atmosphere, oceans, sea-ice, land surface and composition

EU summer heatwave 2-4 week ahead



200 mb winds on 15 March 2014





ECMWF EUROPEAN CENTRE FOR MEDIUM-RANGE WEATHER FORECASTS

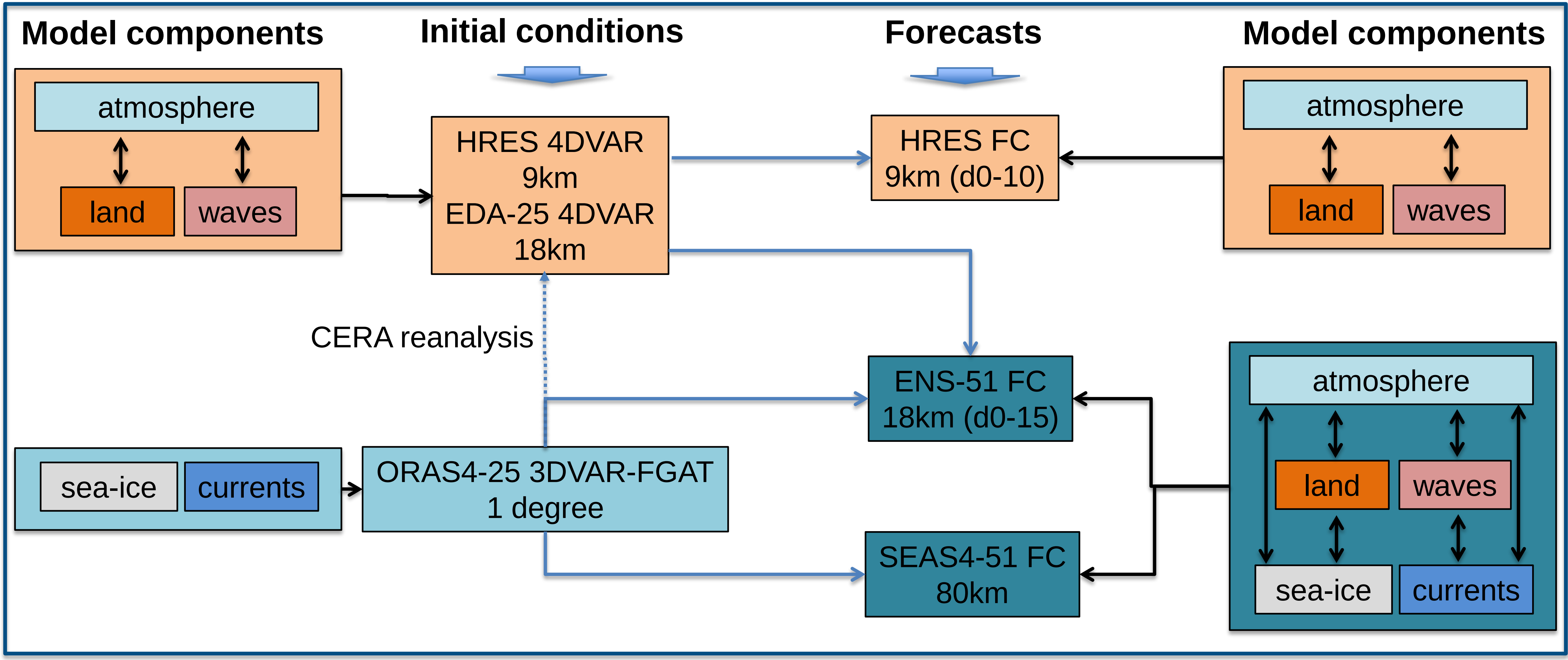
ECMWF 2016-2025 strategy: overview

- Focus on high-impact weather, regime transitions and global-scale anomalies
- Integrated ensemble at high resolution at 5km by 2025

Performant Earth-System model and analysis which includes relevant processes (variables/observables) with an estimate of process/model uncertainty

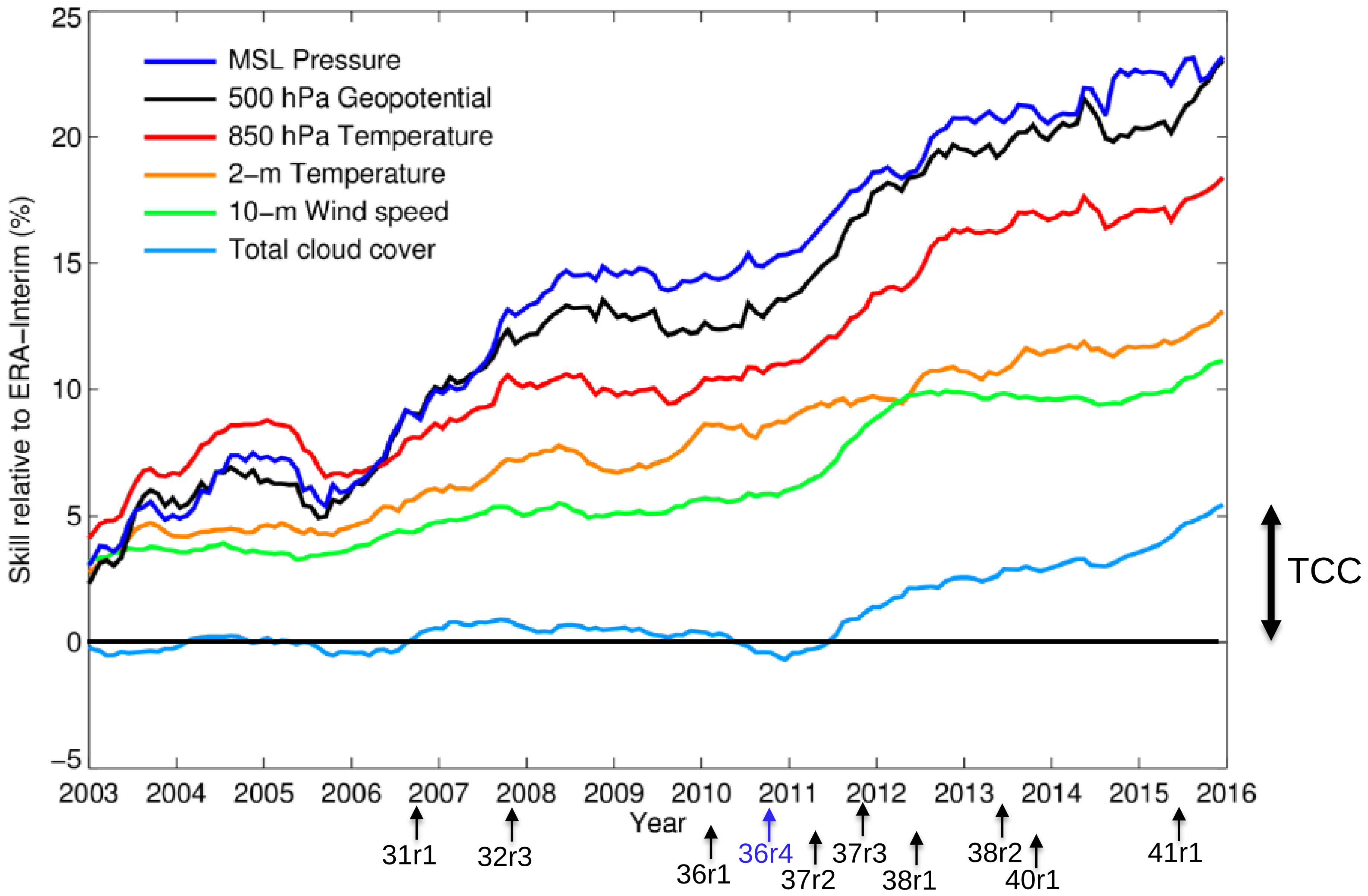
- Scalable computation
- Environmental information services: Copernicus

IFS components (as of Oct 2016)



Improvement in cloud cover skill – the last decade

See also Haiden et al (2015) ECMWF Newsletter 143



Evolution of skill of the HRES forecast at day 5, expressed as relative skill compared to ERA-Interim (12 month running mean)

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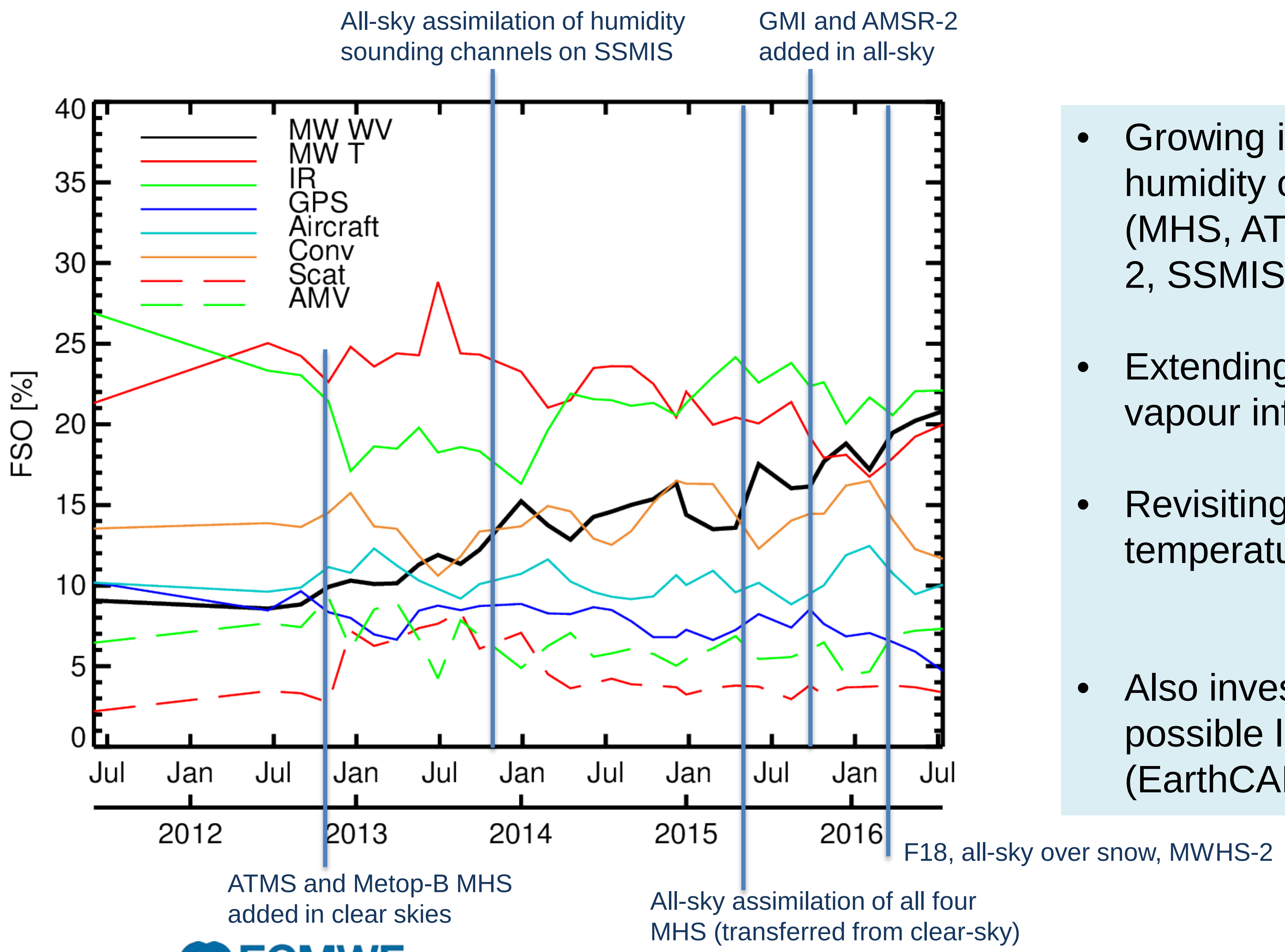
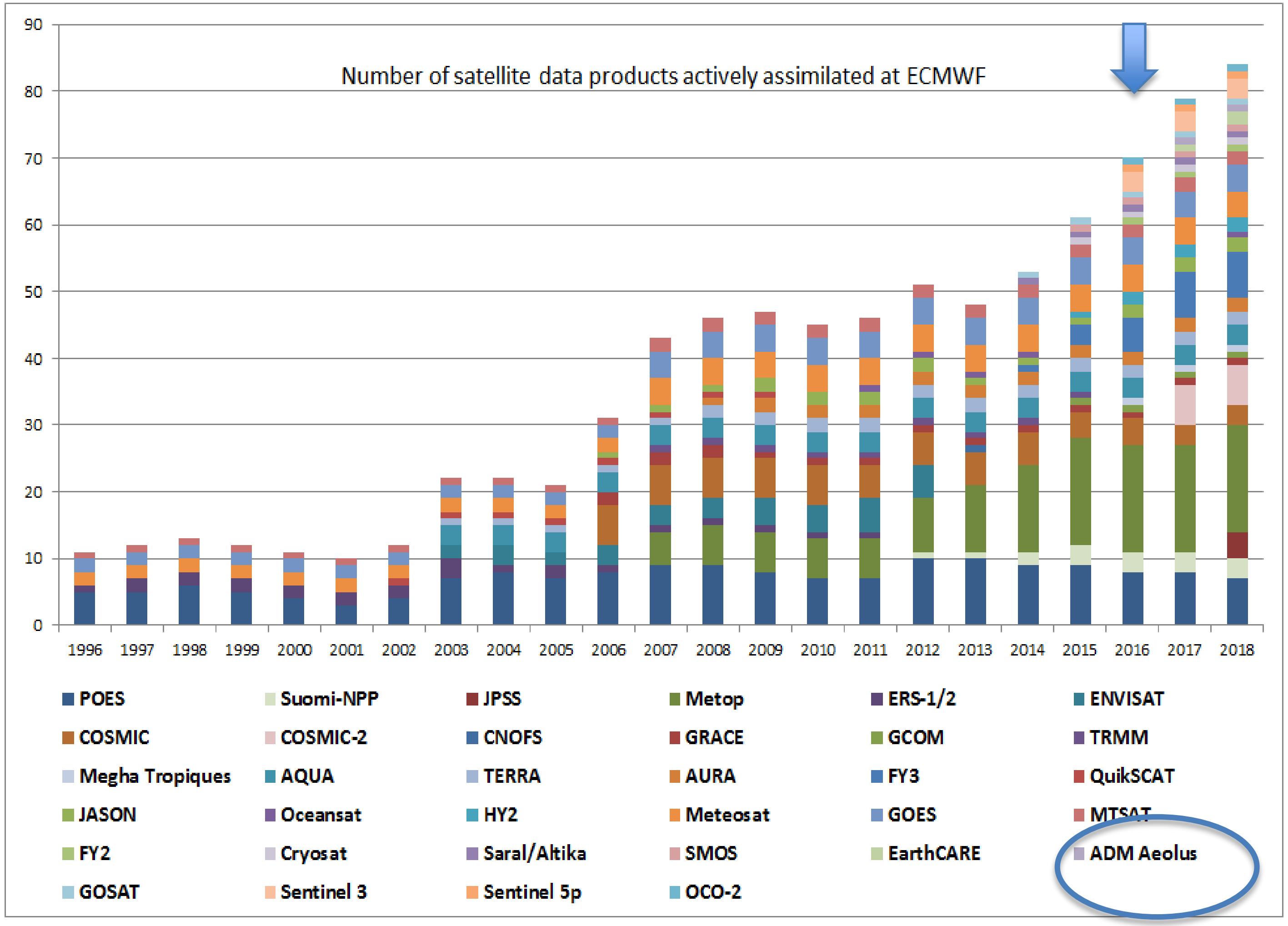
Observation changes: the rise of all-sky!



- Growing importance of microwave humidity observations (MHS, ATMS, MWHS-2, SSMIS, AMSR2, GMI, SAPHIR).
- Extending this to infrared water vapour information.
- Revisiting all-sky microwave temperature observations.
- Also investigating radar, lidar, and possible lightning observations (EarthCARE, Aeolus, GOES-R, MTG).

New observations

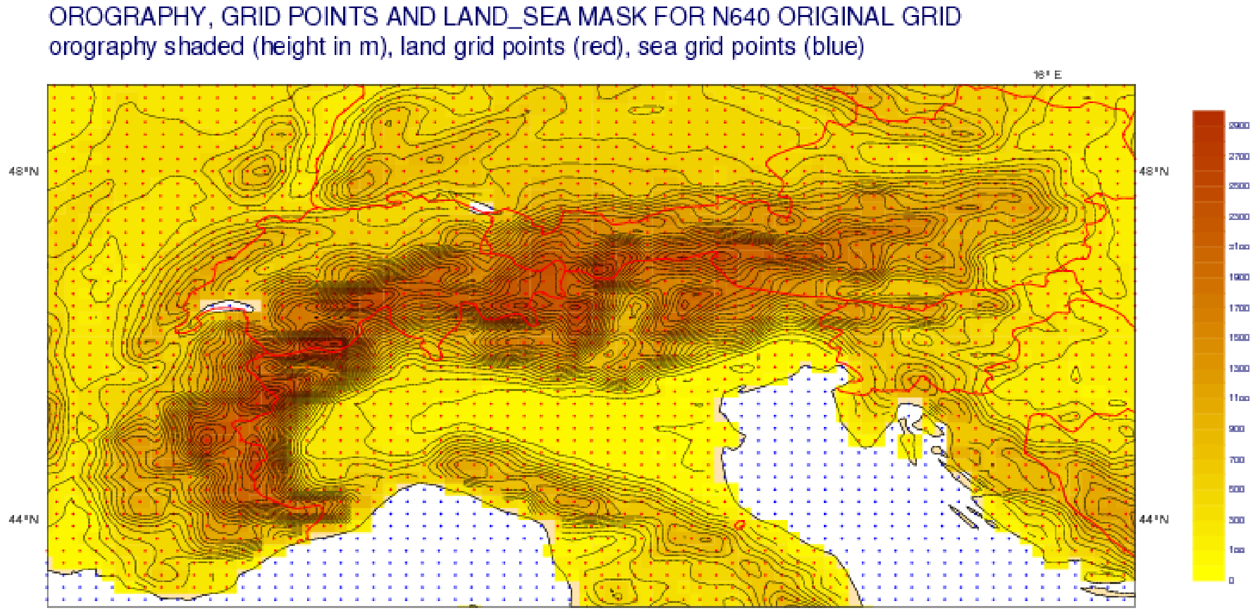


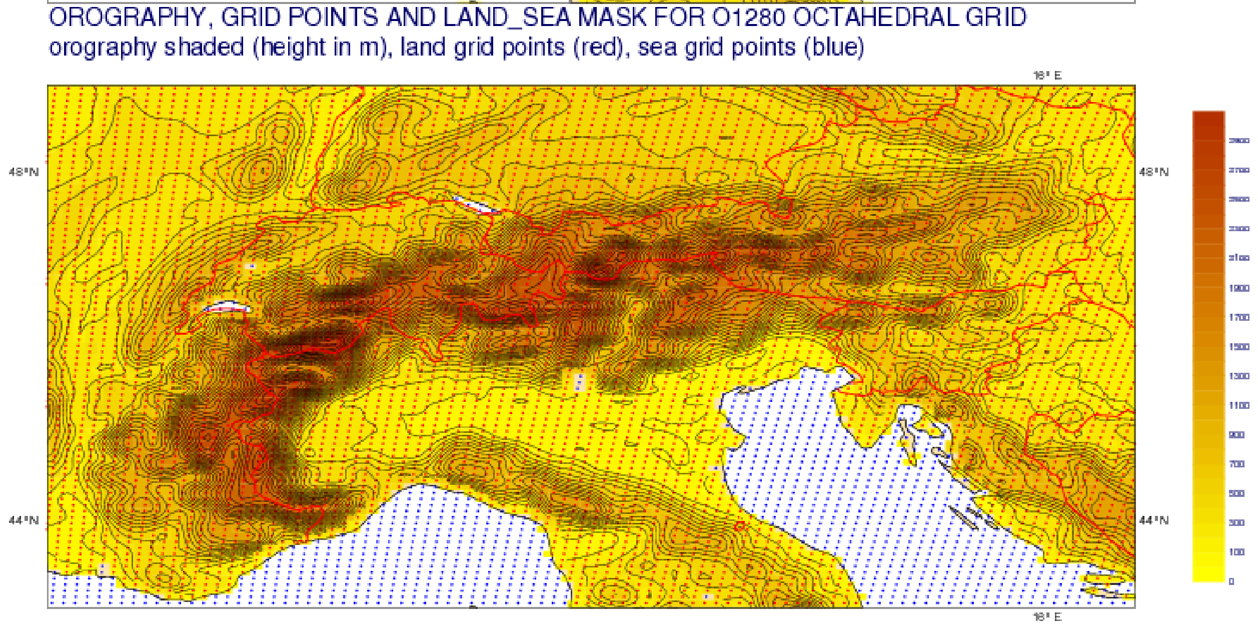
41r2: Resolution upgrade – 8 March 2016

41r1 → 41r2

Grid res.	HRES	ENS LegA	ENS LegB/M'ly	4DV inner loops 1st	4DV inner loops 2nd	4DV inner loops 3rd	EDA Outer	EDA 1st	EDA 2nd
128 km				TL255	TL255 ↓	TL255 ↓		TL159 ↓ TL191	TL159 ↓ TL191
64 km			TL319 ↓	workshop/	TL319	TL399	TL399 ↓		
32 km		TL639 ↓	TCo319						
16 km	TL1279 ↓	TCo639 (D10 → D15)					TCo639		
9 km	TCo1279								

From Tl1279 (16 km) to TCo1279 (9 km)

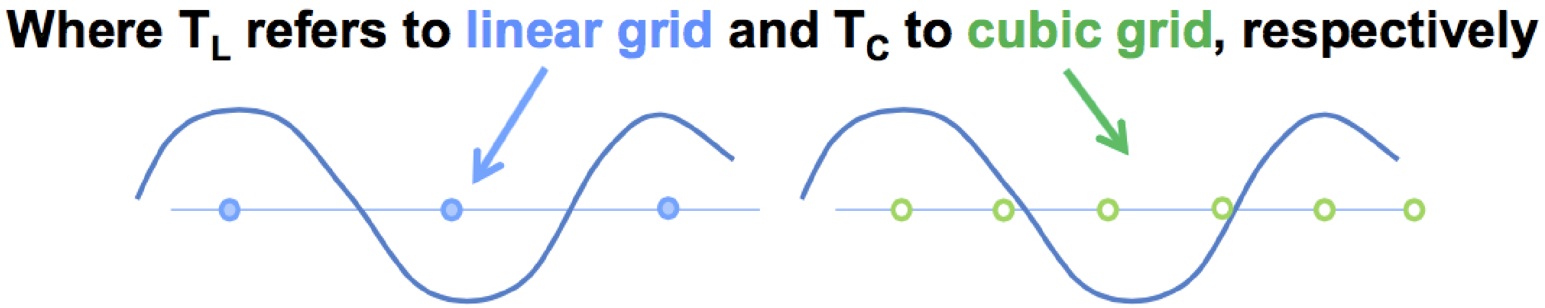




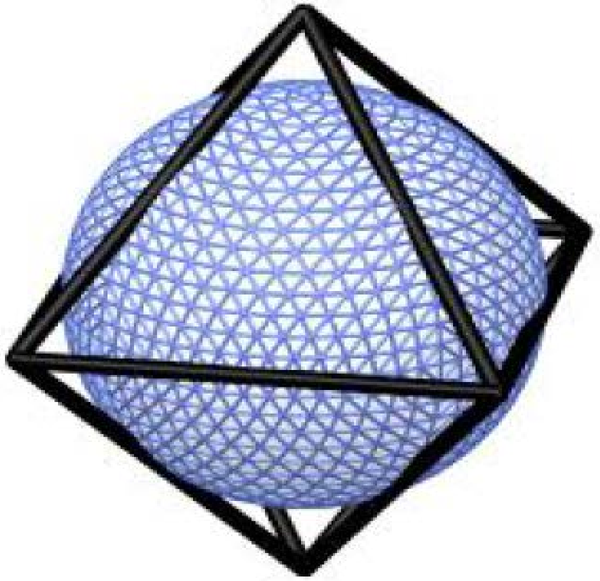
- Two grids use same spectral truncation
- Spectral fields, here the orogrophay look nearly the same, but not quite (more detail!!) why?

Resolution upgrade: cubic grids->octahedral reduced Gaussian grid

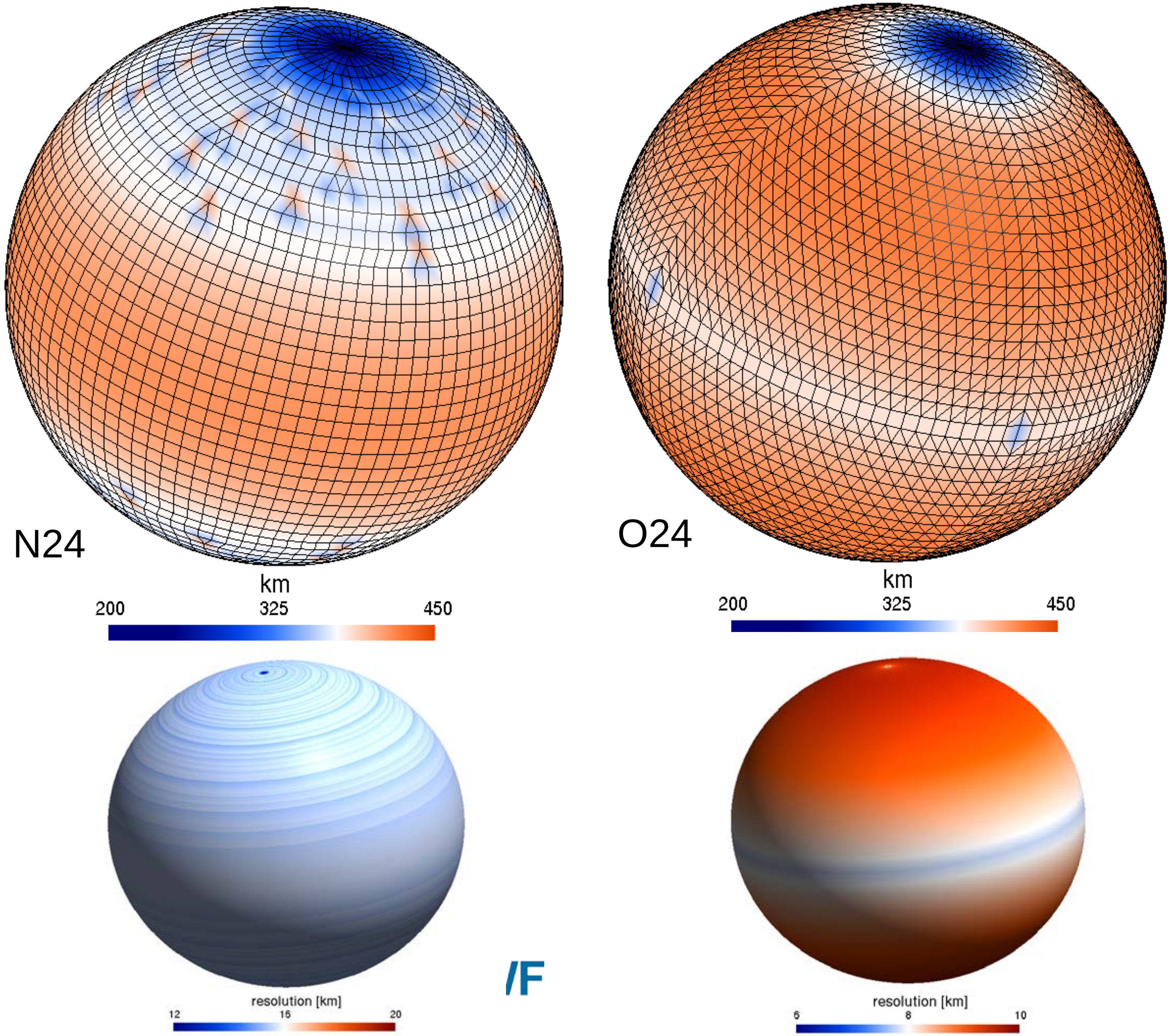
2N+1 gridpoints to N waves : T_L linear grid
4N+1 gridpoints to N waves : T_c cubic grid



- Mathematically more correct in the presence of cubic non-linearities in the equations
- Less numerical filtering – almost no numerical diffusion, no dealiasing
- Better mass conservation
- Less expensive than the equivalent linear grid



Resolution upgrade: octahedral reduced Gaussian grid



N640 T_L1279 (linear, ~16km) ≈ 2.1 million grid points per level

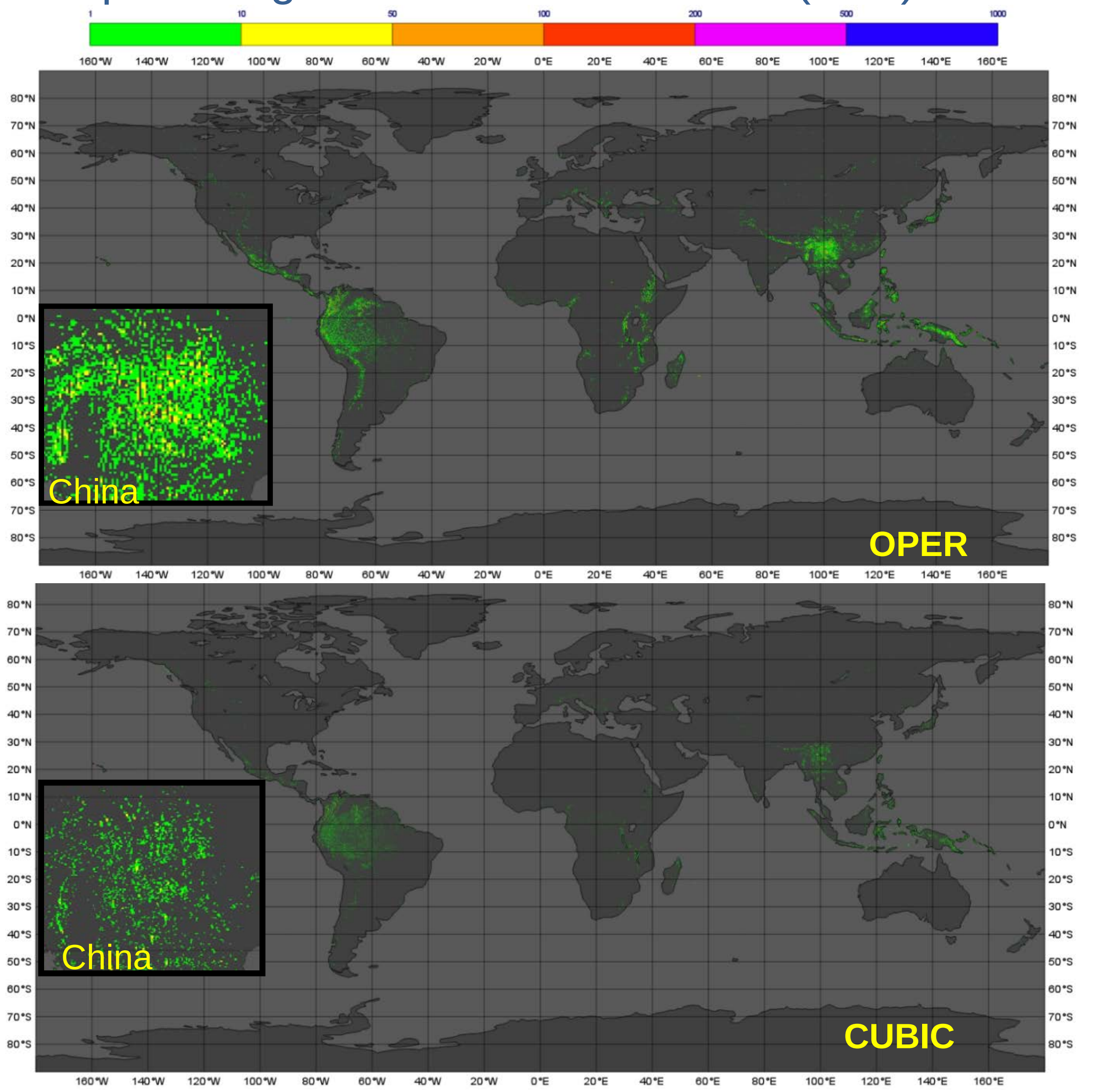
N1280 T_C1279 (cubic, ~8km) ≈ 8.5 million grid points per level

O1280 $T_{Co}1279$ (cubic, ~9km) ≈ 6.6 million grid points per level (octahedral cubic reduced Gauss. grid)

Improvements: ….

Strong reduction of spurious grid-scale rainfall events (LSP)

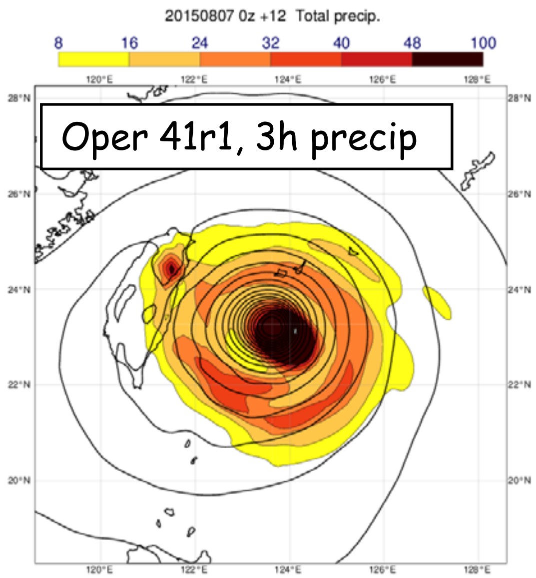
Frequency of rain events >20mm/6h

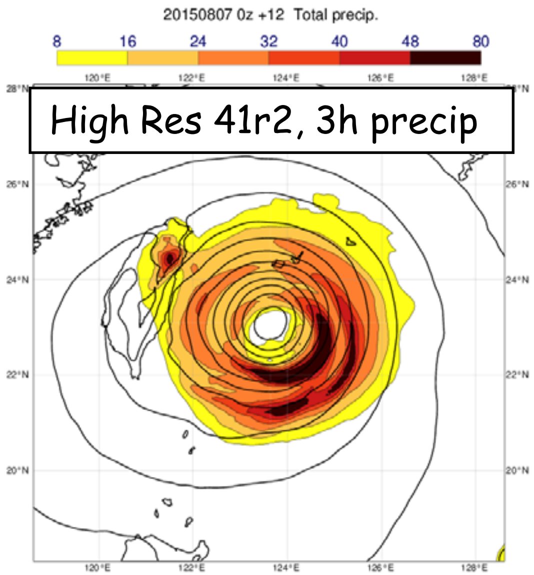


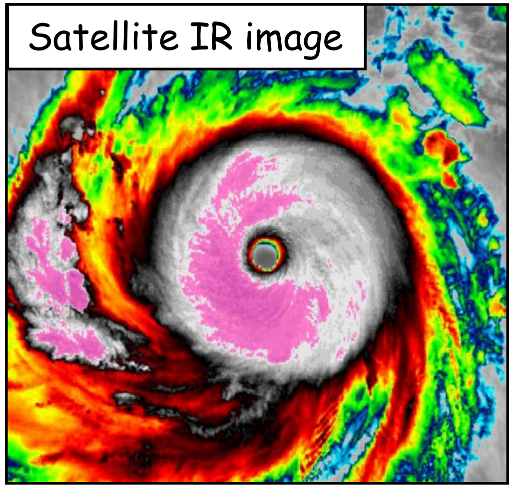
Improvements: resolve instabilities in Numerics (Advection)

- Instability in Numerics due to departure point calculation in the semi-Lagrangian advection, leading to unrealistic tropical cyclone structures

Tropical Cyclone Soudelor
Aug 2015







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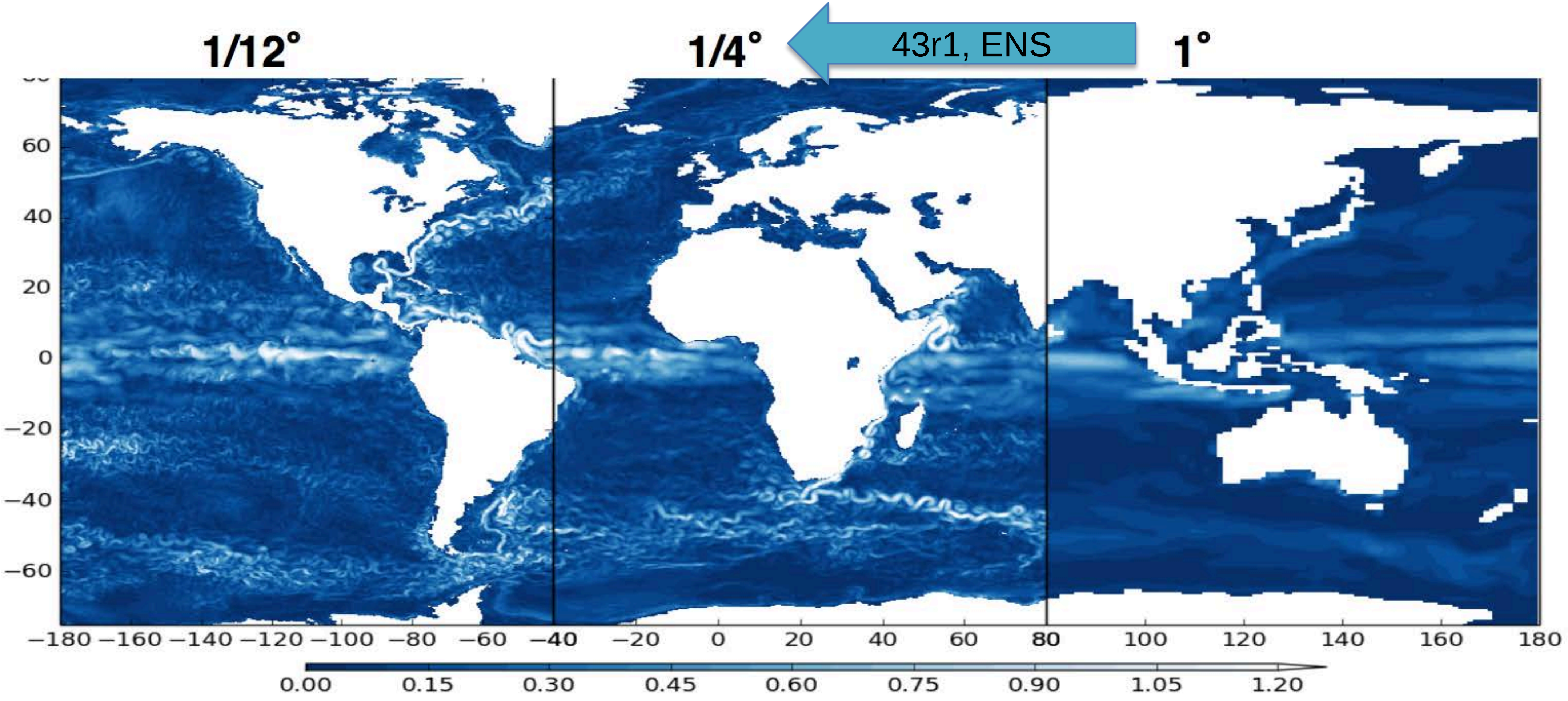
Ocean surface currents at various resolutions



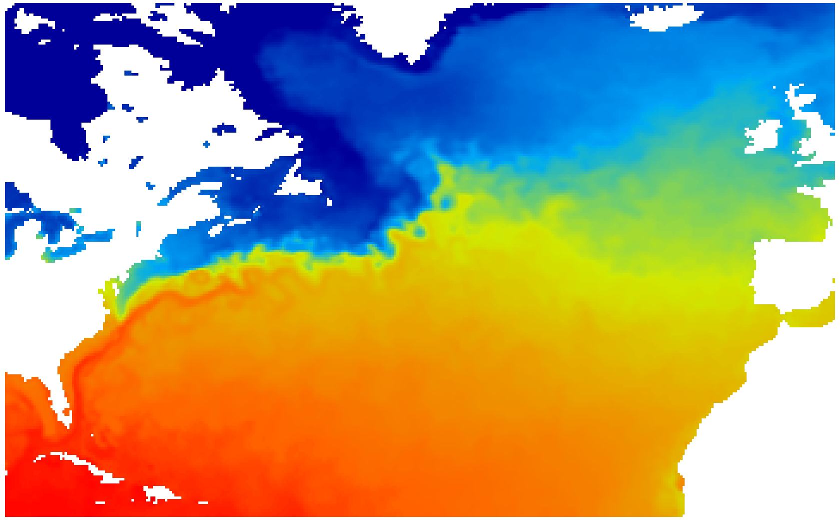
Eddy resolving

Eddy permitting

Eddy parameterising

Thermal coupling of ocean

Coupled ocean-atmosphere simulations are exposed to the problem of initial shock as the Atmosphere and the rest of earth surface is not yet in balance with the ocean.

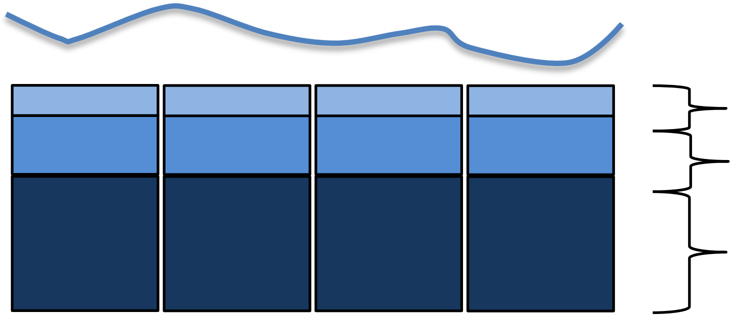


OSTIA 1/20 deg (5km) SST field has details of the eddies not resolved by ocean models

Data assimilation 4D-VAR uses

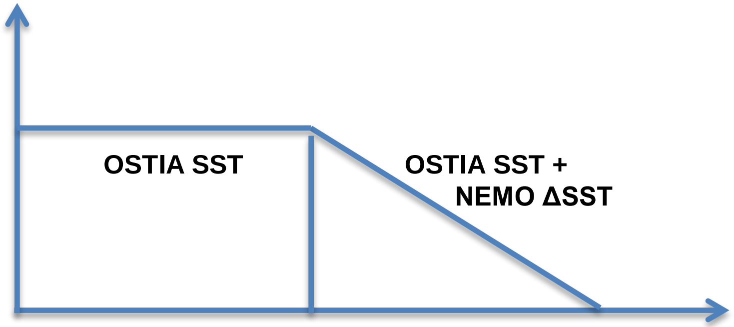
OSTIA SST

- 1/20 degree SST from OSTIA
- 1/4 degree SST from NEMO
  - dynamic, ocean tendencies
  - uncertainties



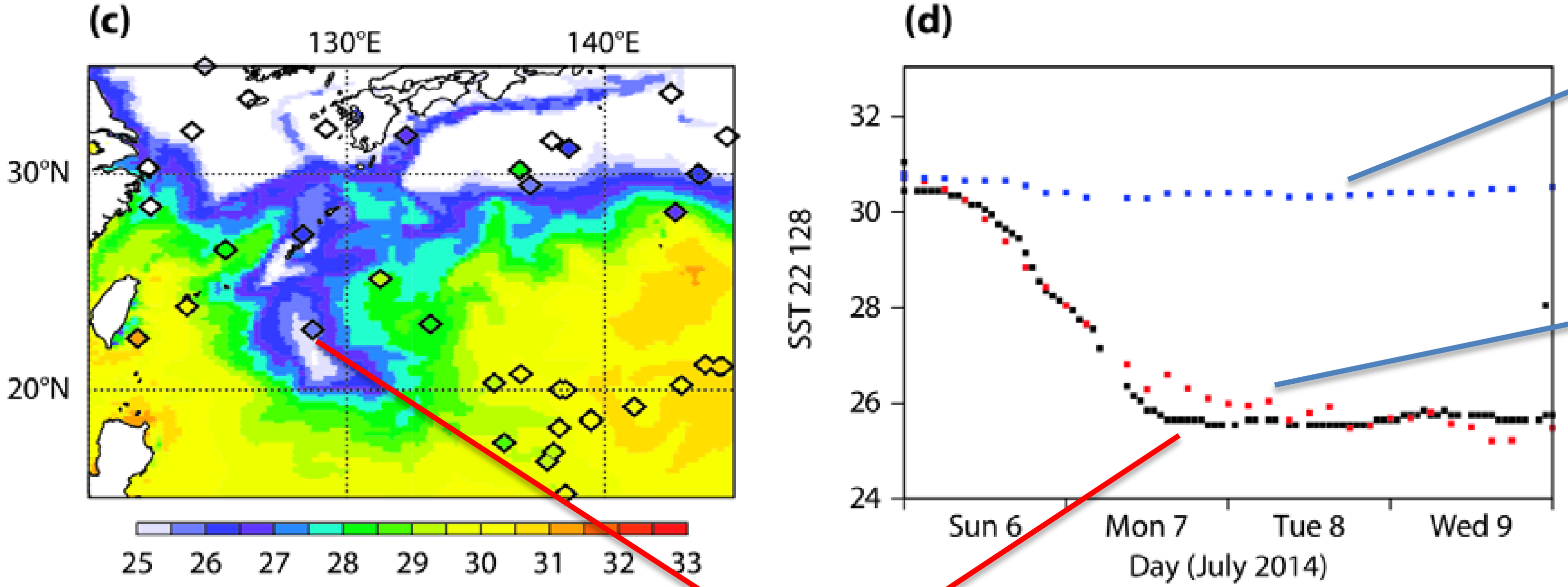
The **PARTIAL COUPLING** works well only in the short range as ocean eddies are assumed stationary
FULL COUPLING uses the dynamic ocean to advect eddies from day 0

OSTIA SST 1/20 degree is applied for 4-days and then relaxed to 0 gradually taper-down from day 4 to day 8
From day 8 onwards **FULL COUPLING**



Coupled ocean vs uncoupled simulation

Tropical cyclone *Neoguri* with TCo1279 (HRES)



uncoupled

coupled

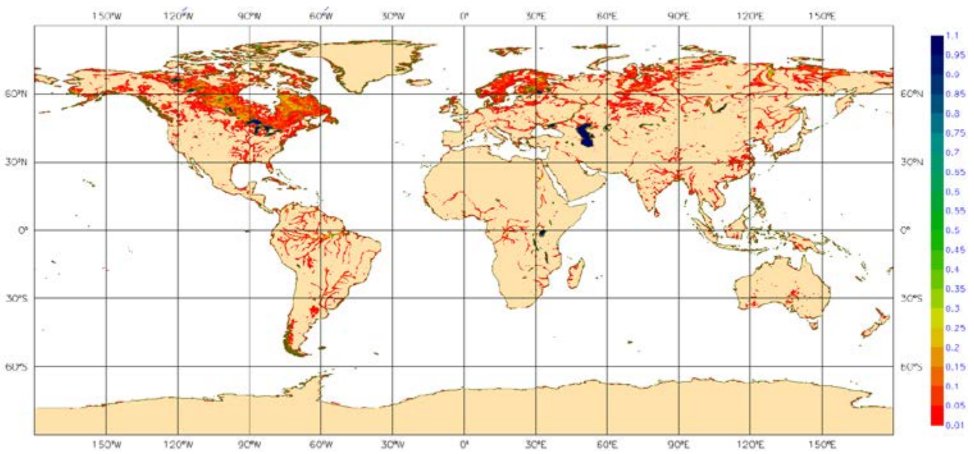
Buoy observation
at 22°N, 128°E

4-day forecast SSTs from the coupled forecast initialised at 0UTC on 6 July 2014 at the location of a buoy with approximate position 22°N, 128°E.

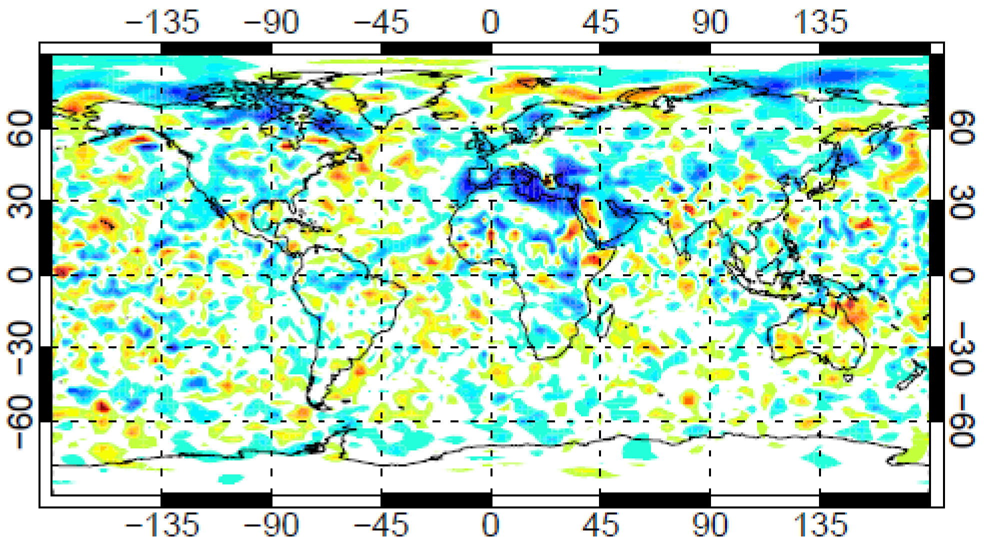
(Rodwell et al, ECMWF Technical Report 759, 2015)

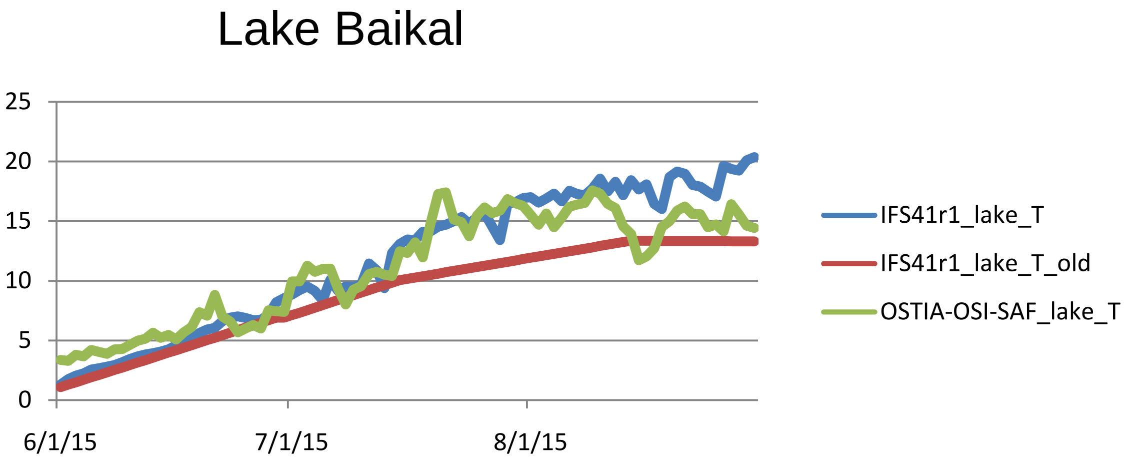
Lake model 2015, one of the new Earth System components

LAKE COVER FRACTION



T+48; 1000hPa



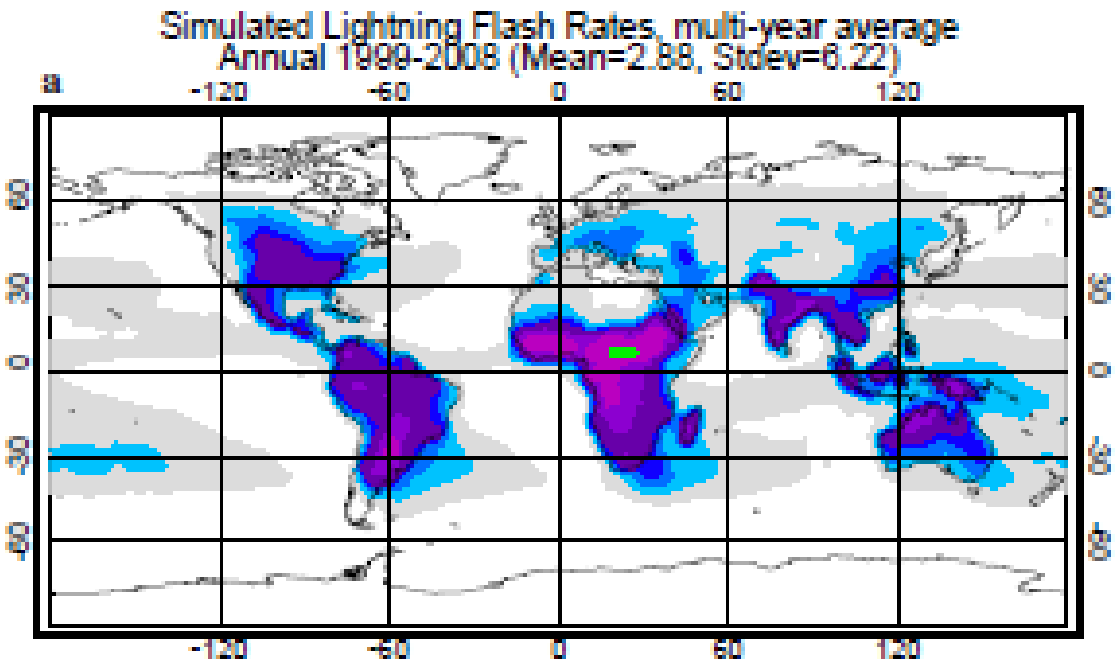


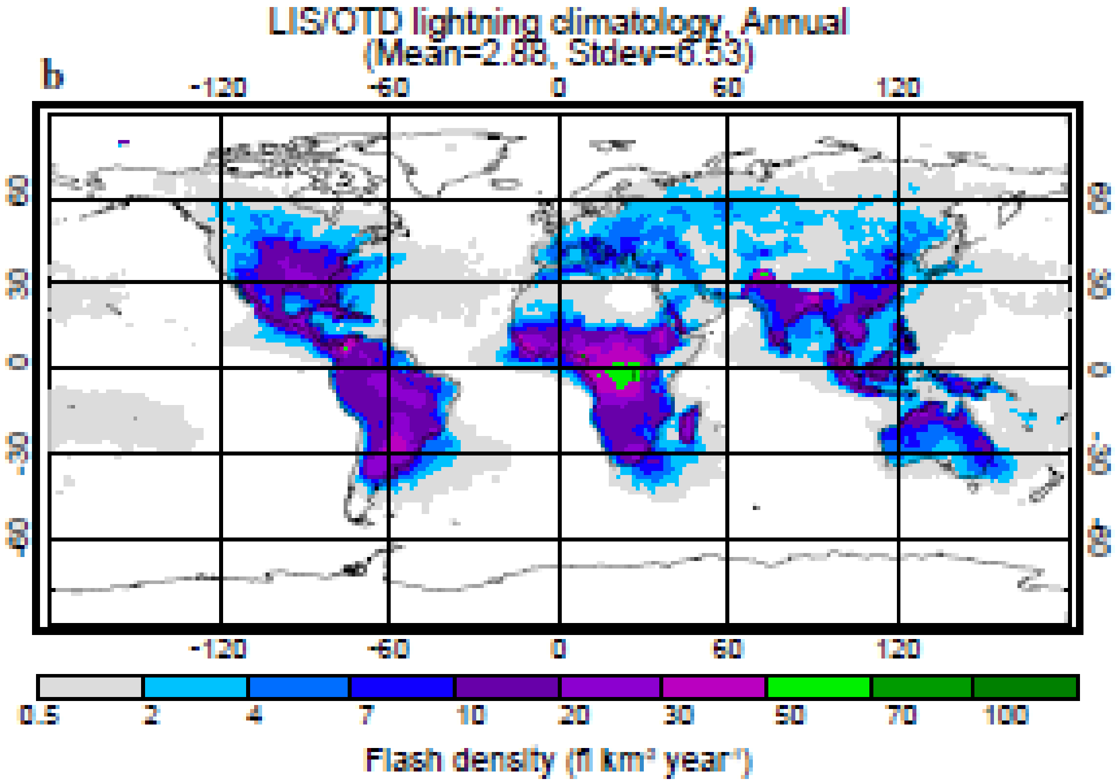
Forecast of 2m temperature are improved in proximity of lakes and coastal areas

Why also coastal areas, these are not Lakes ?!...... cause before if land-sea mask>0.5 then only land point

(Balsamo et al, ECMWF Newsletter 137, Tellus-A, 2012)

A new and simple lightning parametrisation - also for use in data assimilation

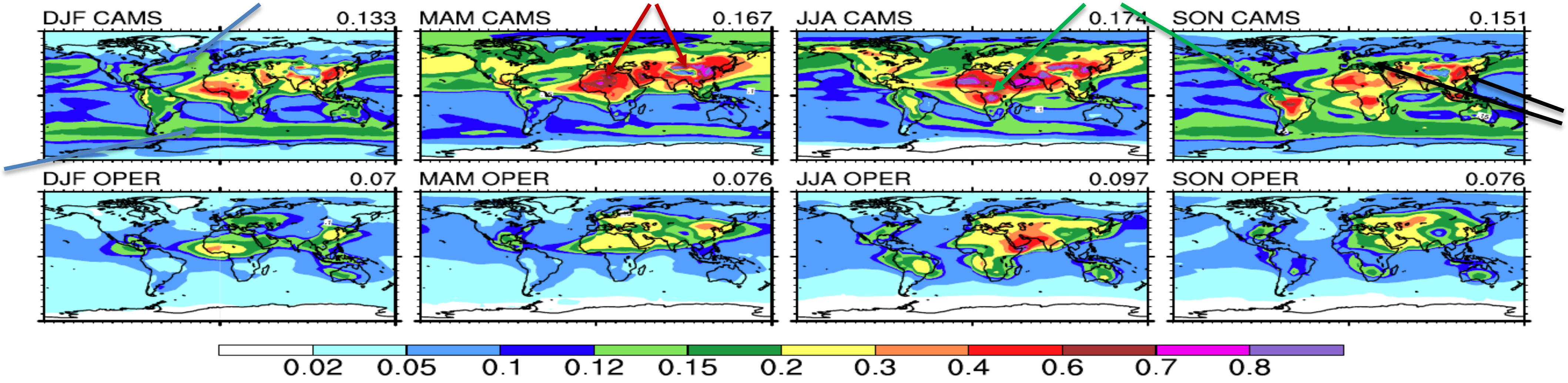




P. Lopez 2016 MWR

Climatological AOD at 550 nm distribution

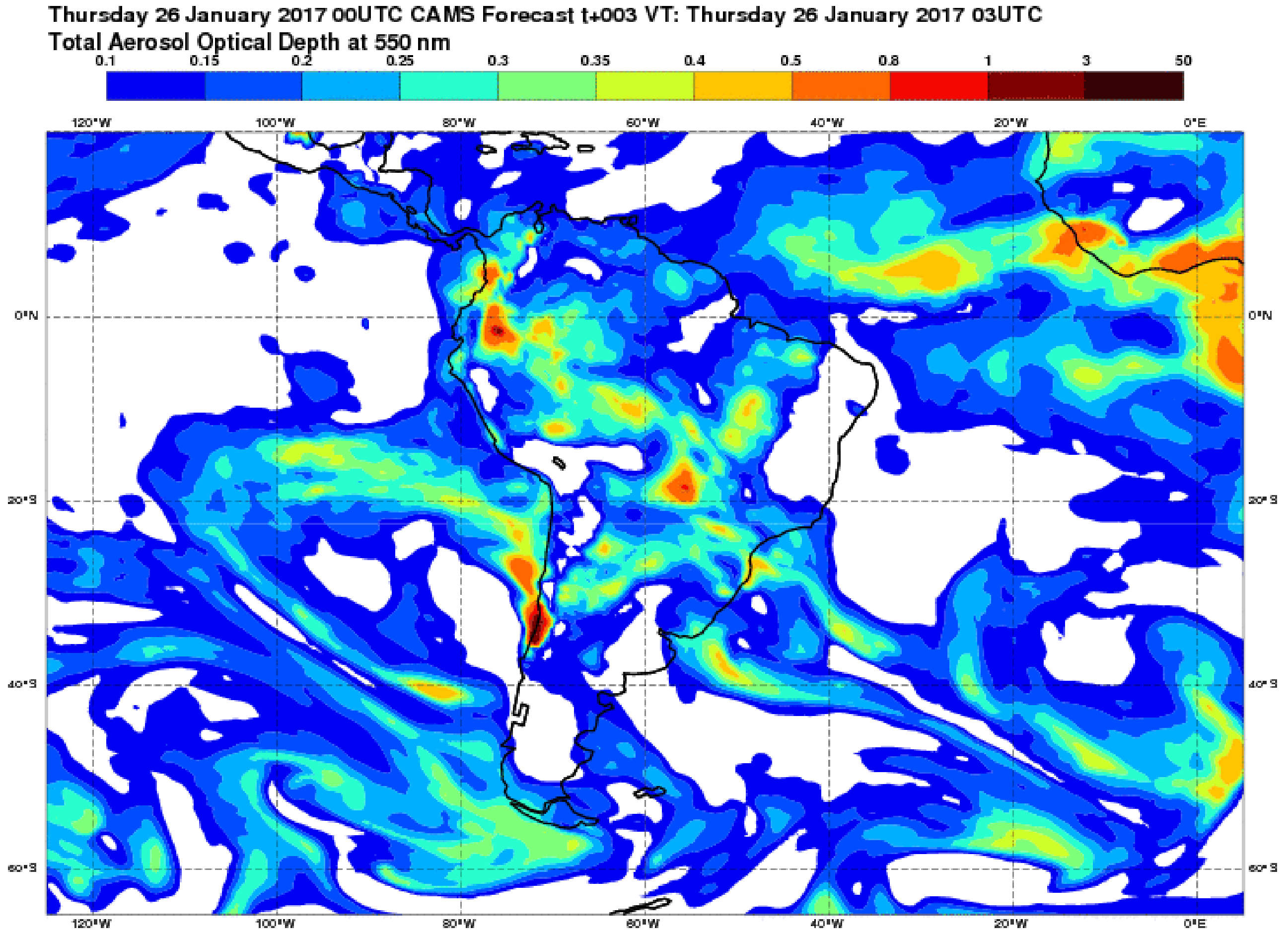
CAMS vs operational climatology (based on Tegen et al. 1997)



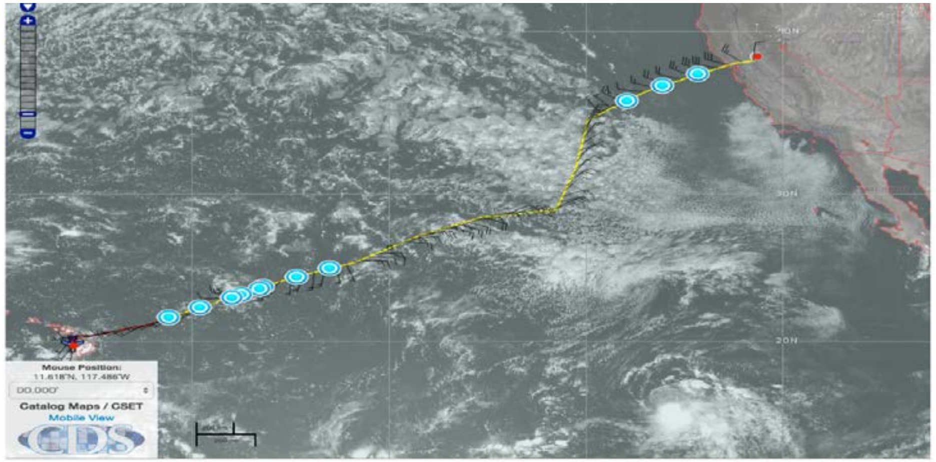
- Aerosol climatology computed using the CAMS-Interim reanalysis (Flemming et al. 2016)
- Some highlights:
  - Larger Sea Salt radiative forcing (~1 W/m^2 more reflection at TOA over oceans)
  - Changes in biomass burning seasonal cycle (up to 20 W/m^2 difference in total SW absorption locally)
  - Changes in dust distribution, higher on Sahara and Taklamakan, lower on Indian Ocean and Australia
  - Anthropogenic emissions lower over Europe, higher over E Asia

ECMWF

And real time Analysis and Fc of Aerosols within Copernicus Atmospheric monitoring system
recent fires in Chile



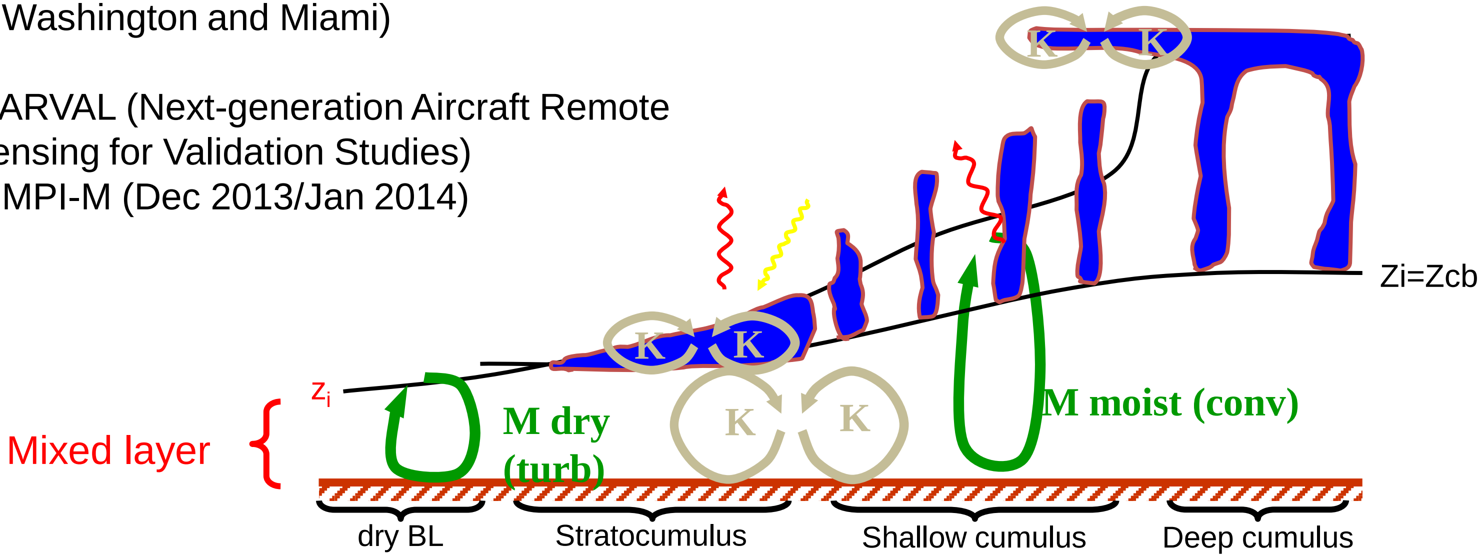
Evaluating forecasts against observations



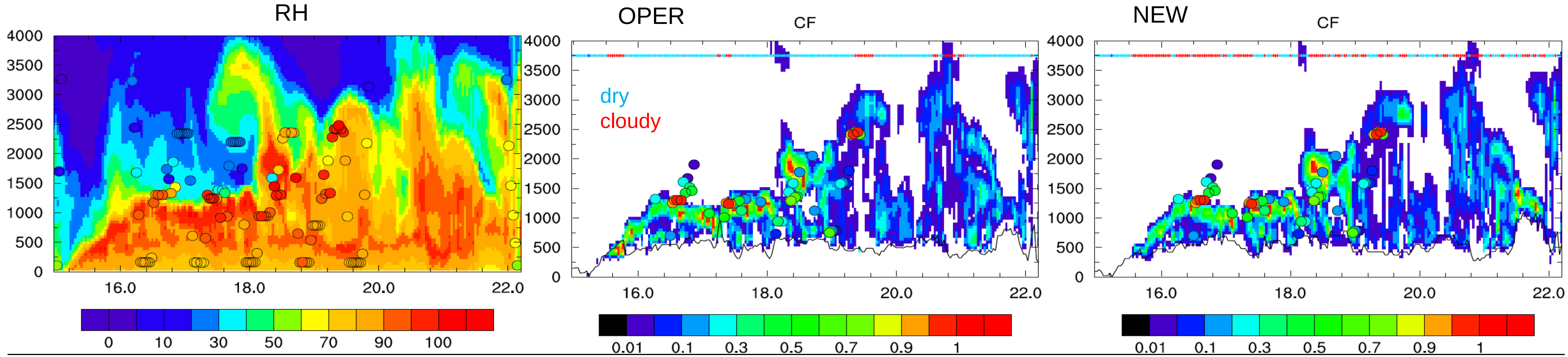
One of the flights during CSET

CSET, the Cloud System Evolution in the Trades
– July/August 2015 (University of
Washington and Miami)

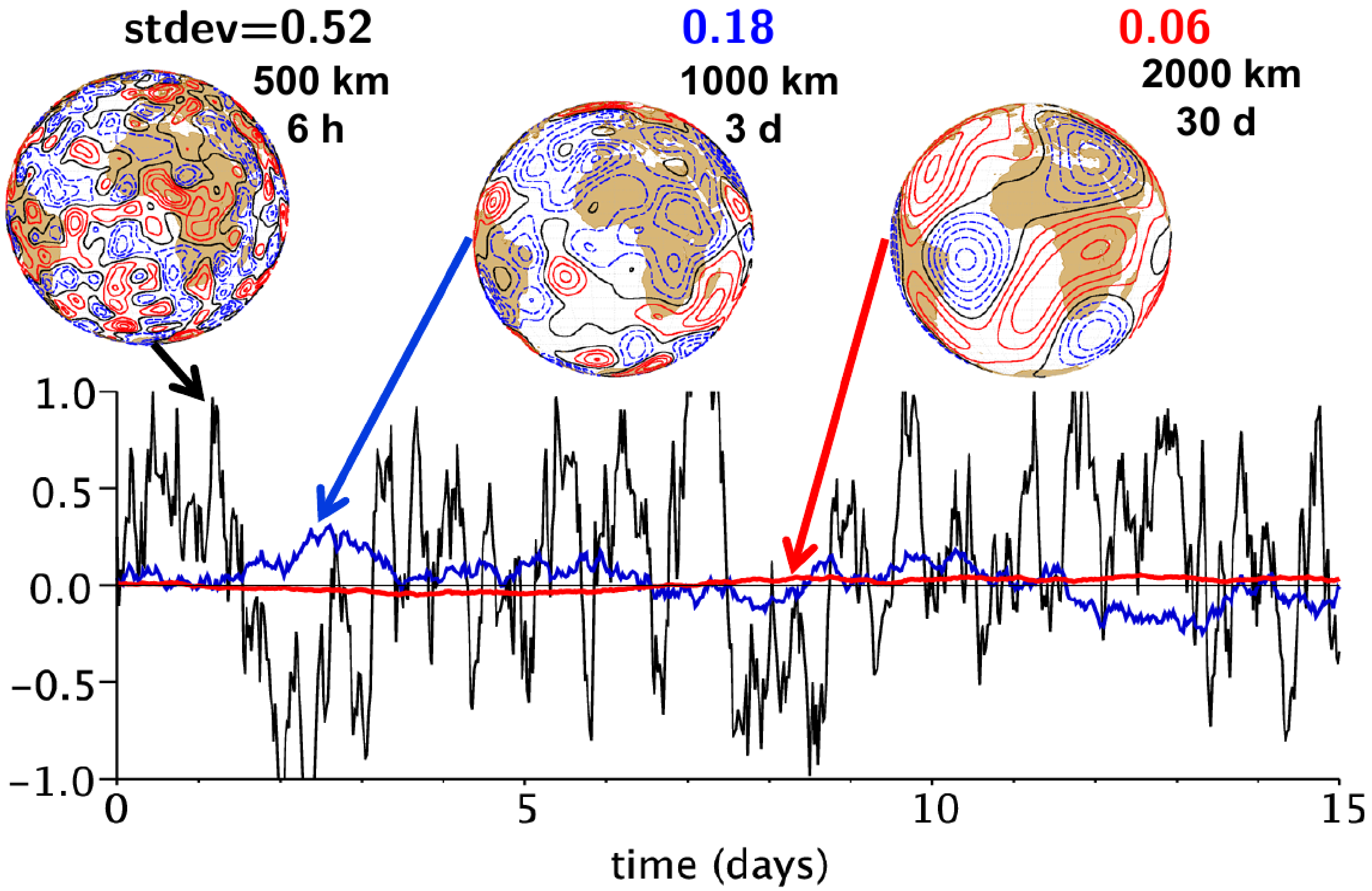
NARVAL (Next-generation Aircraft Remote
sensing for Validation Studies)
– MPI-M (Dec 2013/Jan 2014)



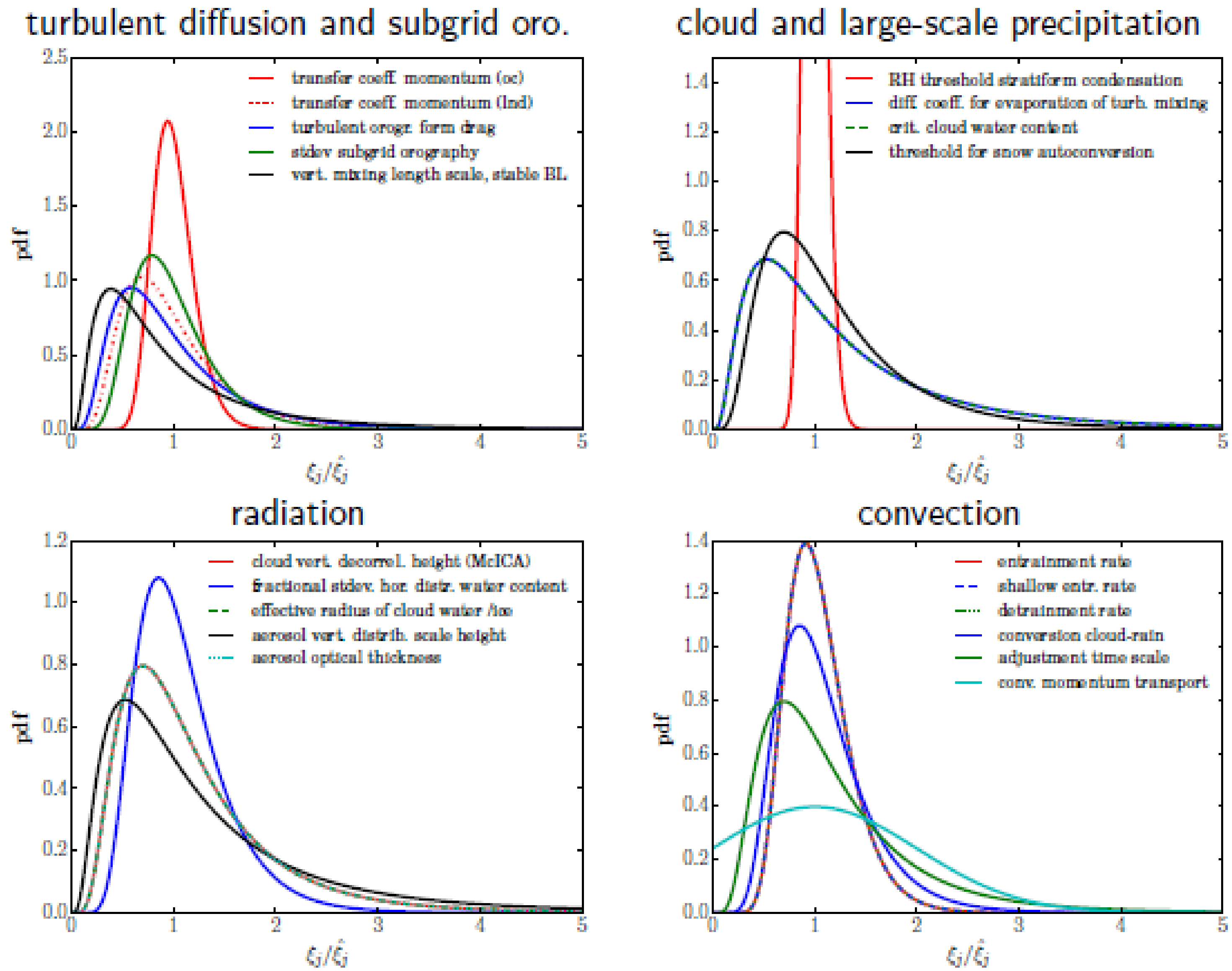
Towards a more unified turbulence, convection, cloud interaction



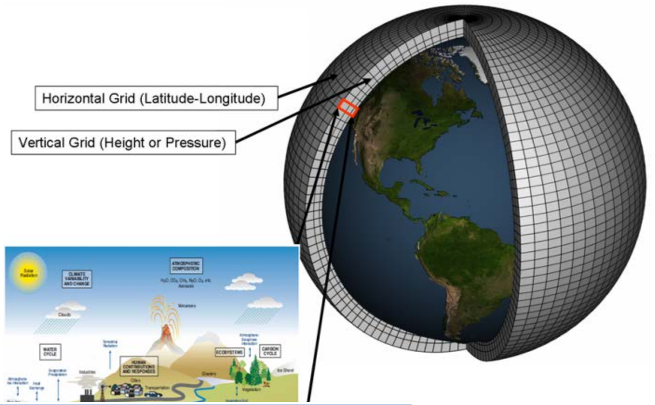
Ensemble and stochastic physics: Pattern generator



Ensemble and stochastic physics: Perturbed parameter distributions



The Scalability Challenge



Today:

	Observations	Models
Volume	20 million = **2 x 10^{7}**	5 million grid points 100 levels 10 prognostic variables = **5 x 10^{9}**
Type	98% from 60 different satellite instruments	physical parameters of atmosphere, waves, ocean

Tomorrow:

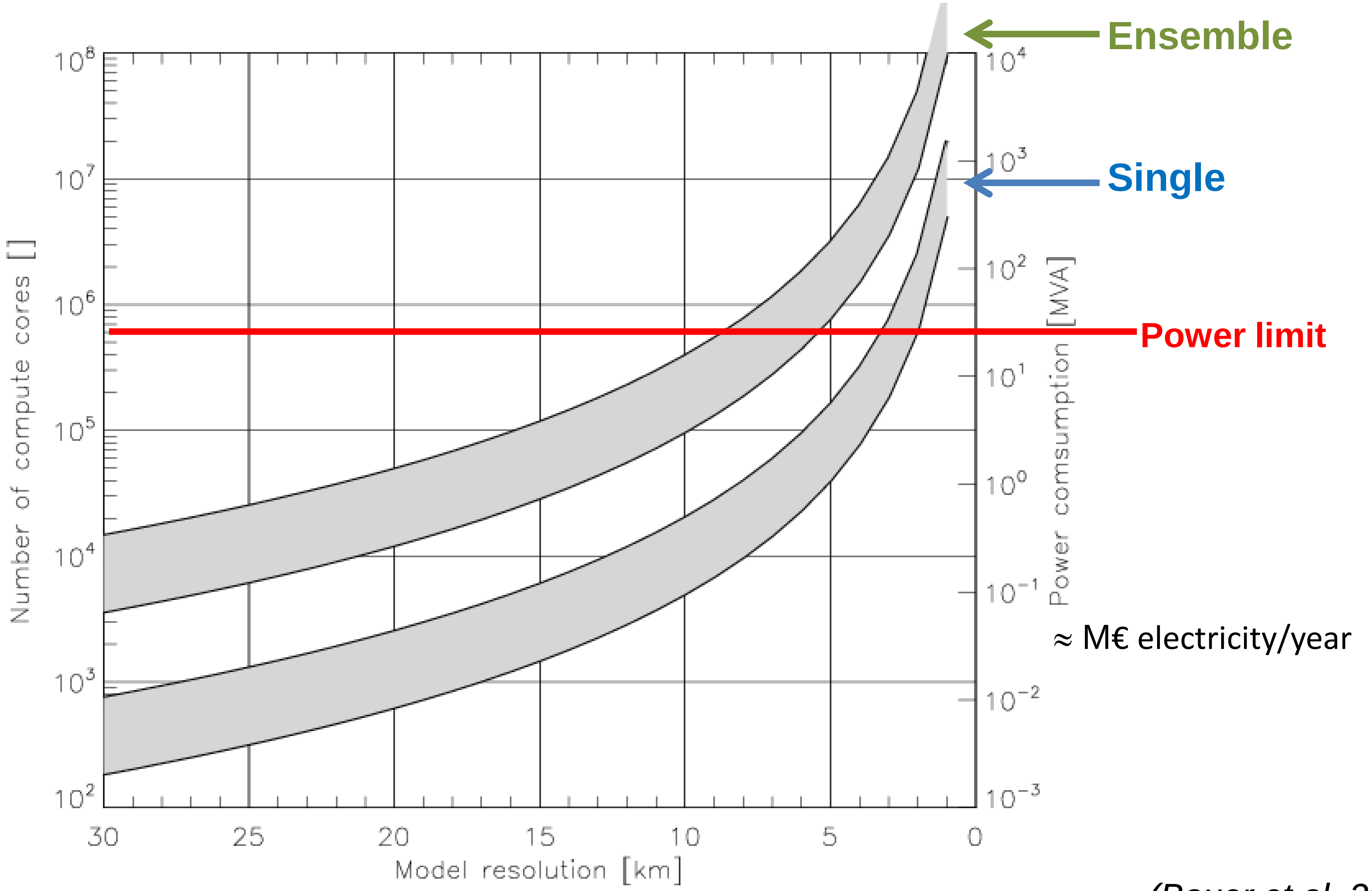
	Observations	Models
Volume	200 million = **2 x 10^{8}**	500 million grid points 200 levels 100 prognostic variables = **1 x 10^{13}**
Type	98% from 80 different satellite instruments	physical and chemical parameters of atmosphere, waves, ocean, ice, vegetation

→ Factor 10 per day

→ Factor 2000 per time step

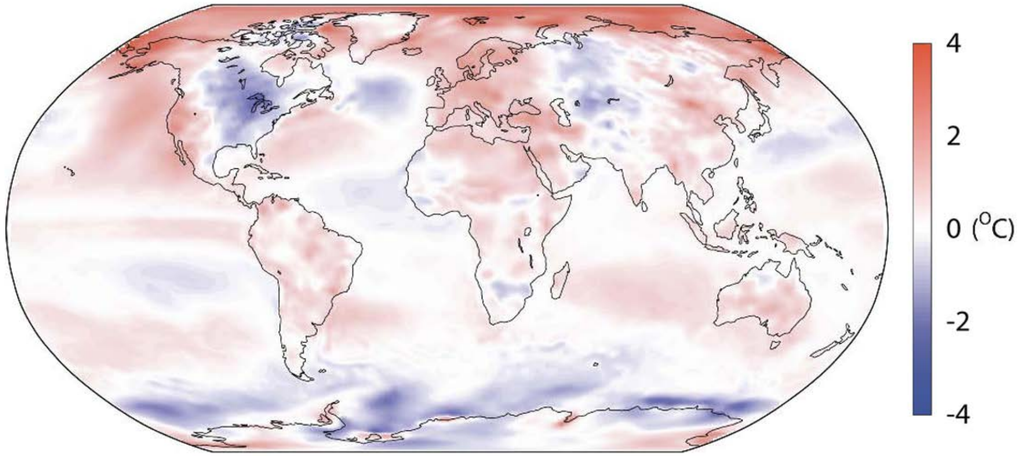
(10-day forecast today = 1440 time steps, but more time steps with increased resolution)

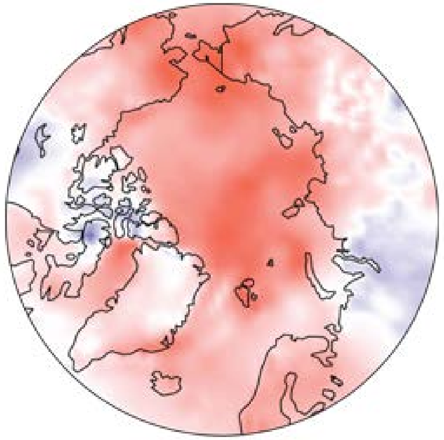
Simple compute projection (only resolution)



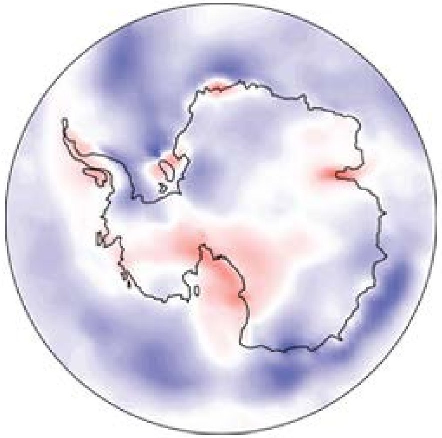
(Bauer et al. 2015, Nature)

Copernicus climate services: Reanalysis provides a truly global view…

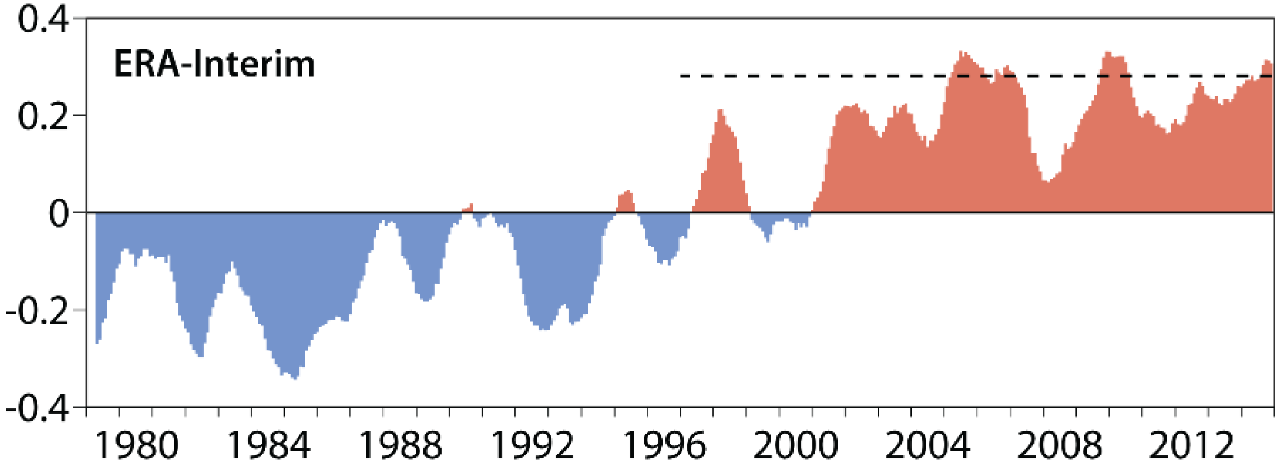




Arctic pattern of temperature anomalies



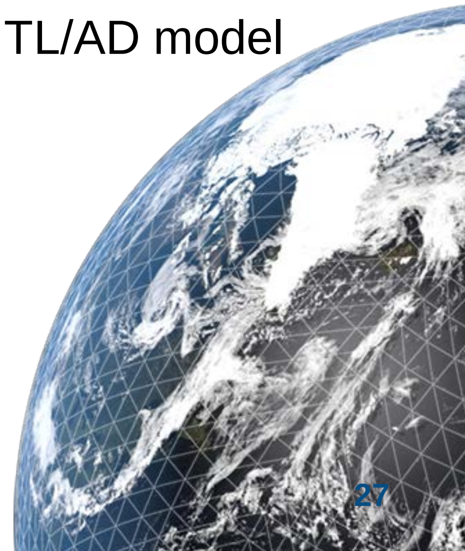
Antarctic pattern of temperature anomalies



- ERA-Interim estimates for 2014 are slightly cooler than those from station data alone
- Mainly due to the Antarctic
- Consistent with independent observations of sea-ice extent
- ERA-5 now underway

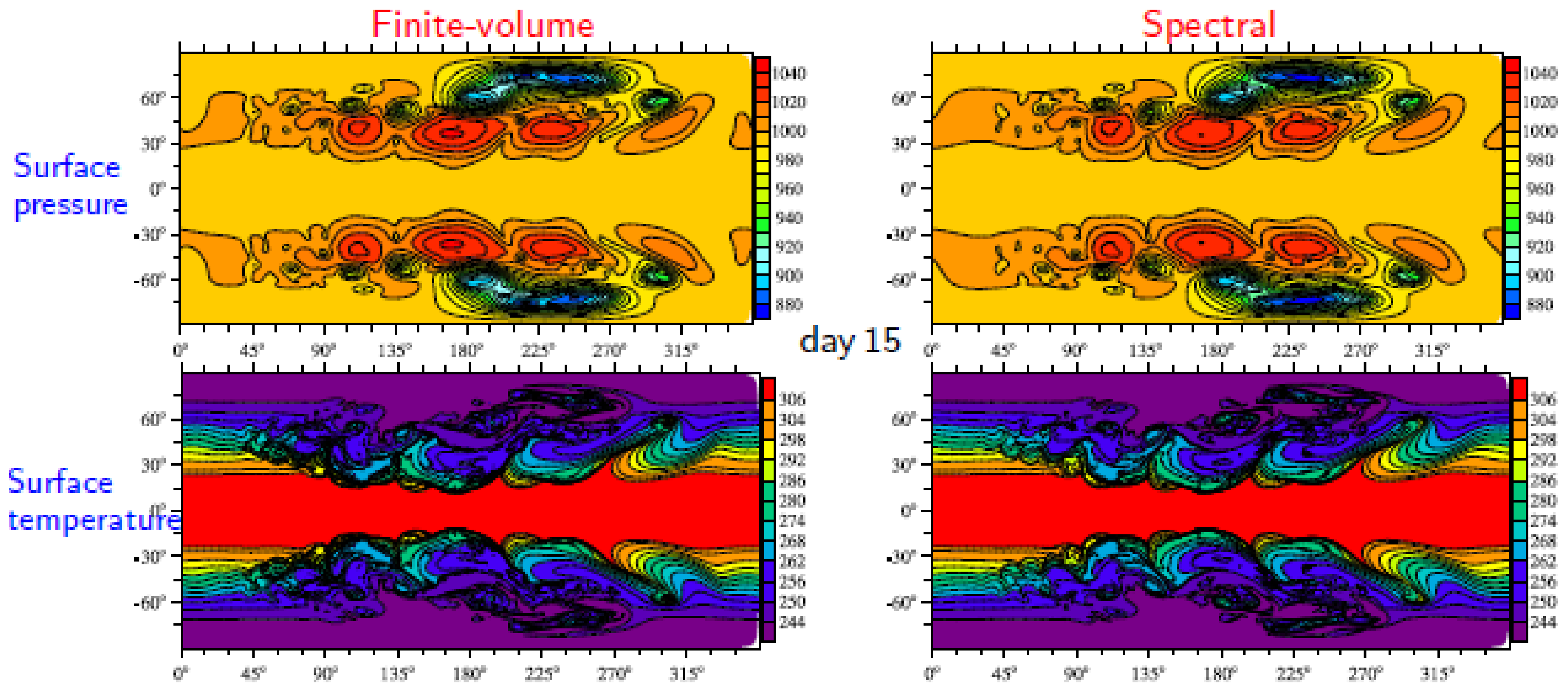
This leaves us with uncertainty in the uncertain times …….

- Dynamical core: spectral or Finite Volume Method
- Physics: which additional prognostic equations (in microphysics-convection, Ozone and dust+sea salt aerosols coupled with radiation?
- Mult-layer snow scheme
- First wish of our satellite microwave assimilation people is to have “prognostic convective snow”
- Data assimilation: which hybrid method, continue with ensemble 4DVar (maintaining TL/AD model veeery work intensive but still pays off)
- Scalability



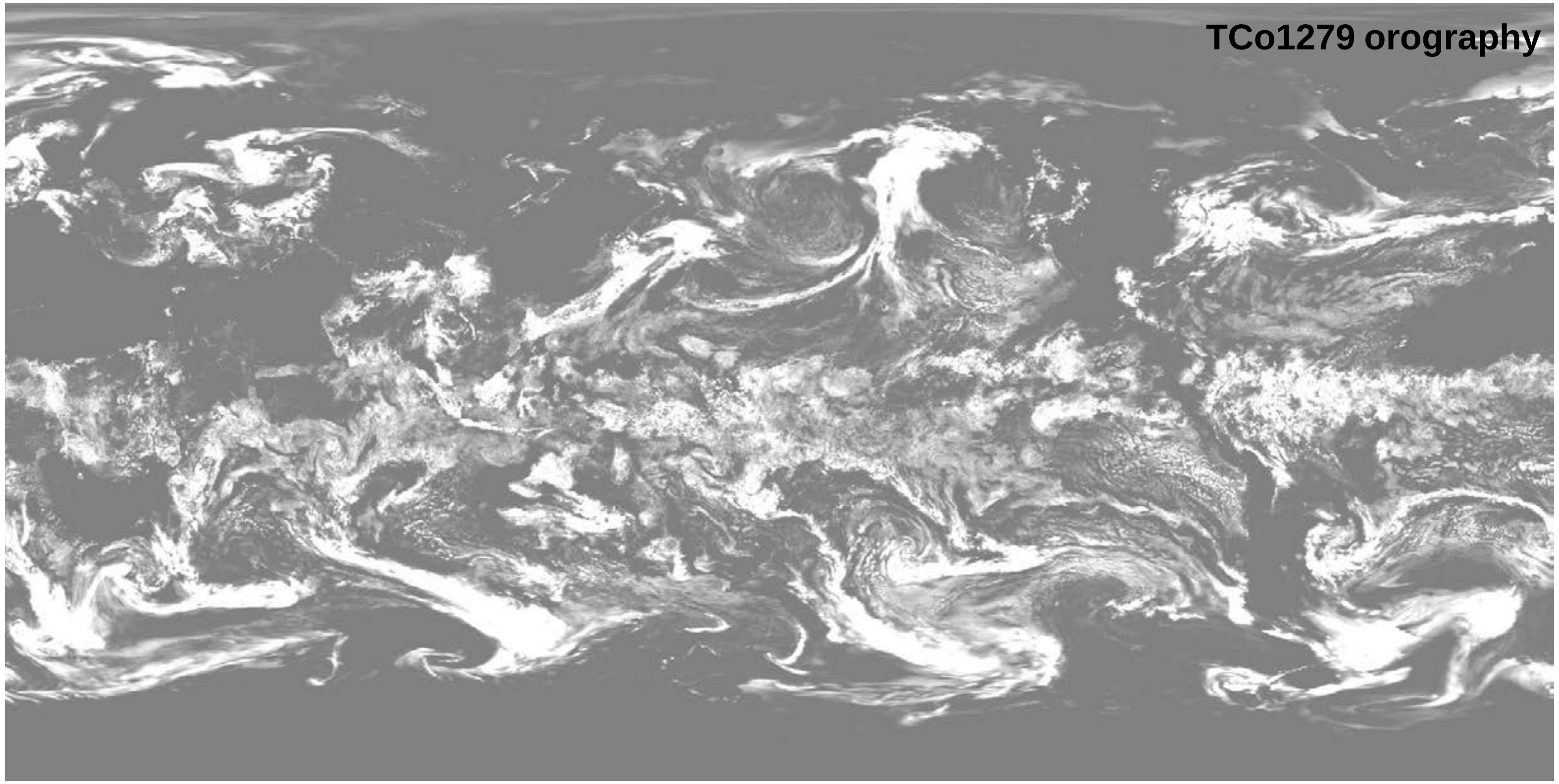
“Dry” evaluation of the FVM vs IFS

Dry baroclinic instability, FVM (O640) versus the spectral IFS ($T_{co}639$):



C. Kuehnlein and P. Smolarkiewicz

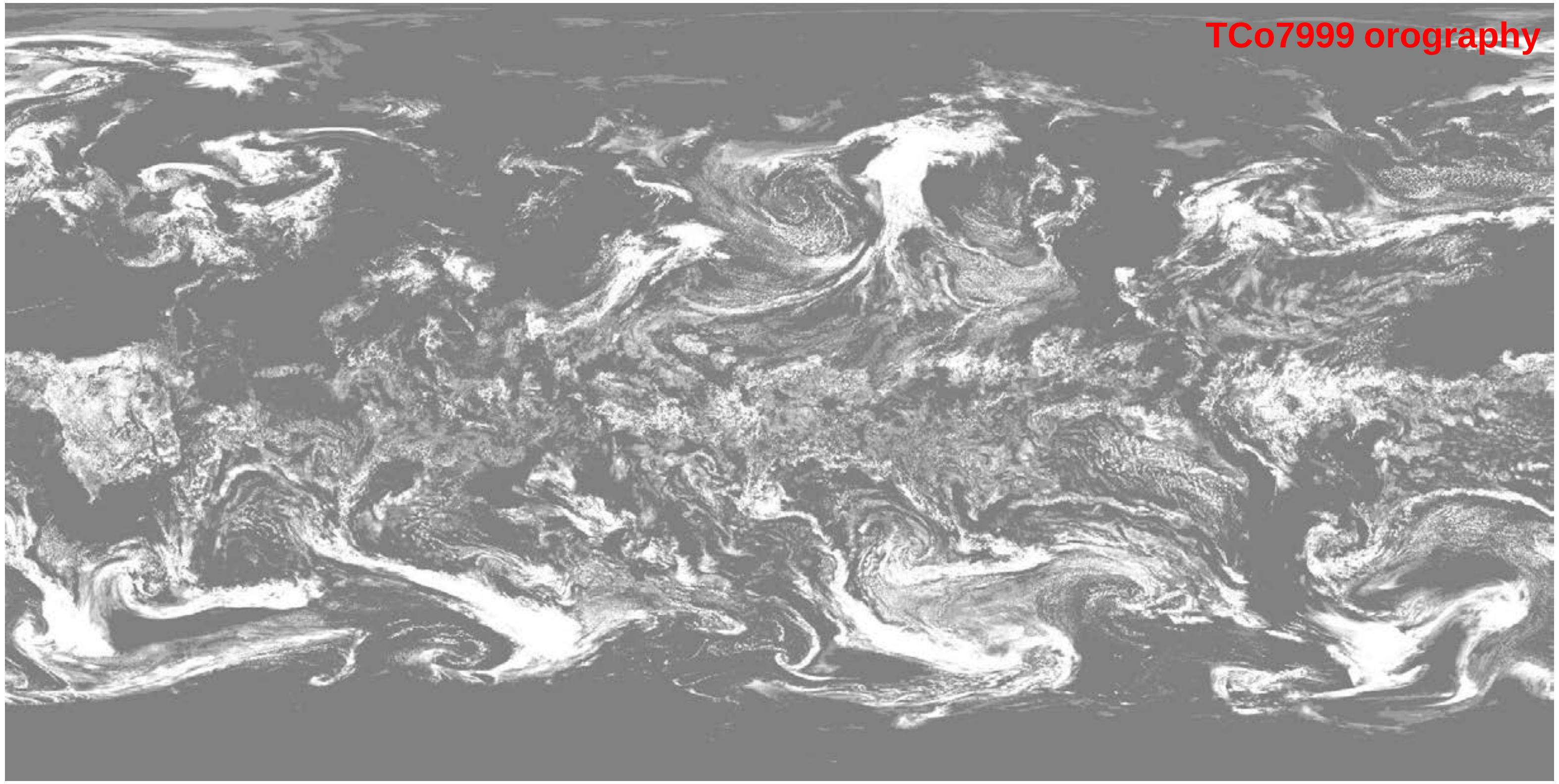
TCo1279 total column liquid water (12h simulation at 9 km)



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

TCo7999 total column liquid water (12h simulation at 1.3 km)

The latest spectral transform model news …



(*hydrostatic*, no deep convection parametrization, 120s time-step, 960 Broadwell nodes, ~10s per timestep)