A decade of HEPEX: ECMWF progress and the rise of ensembles

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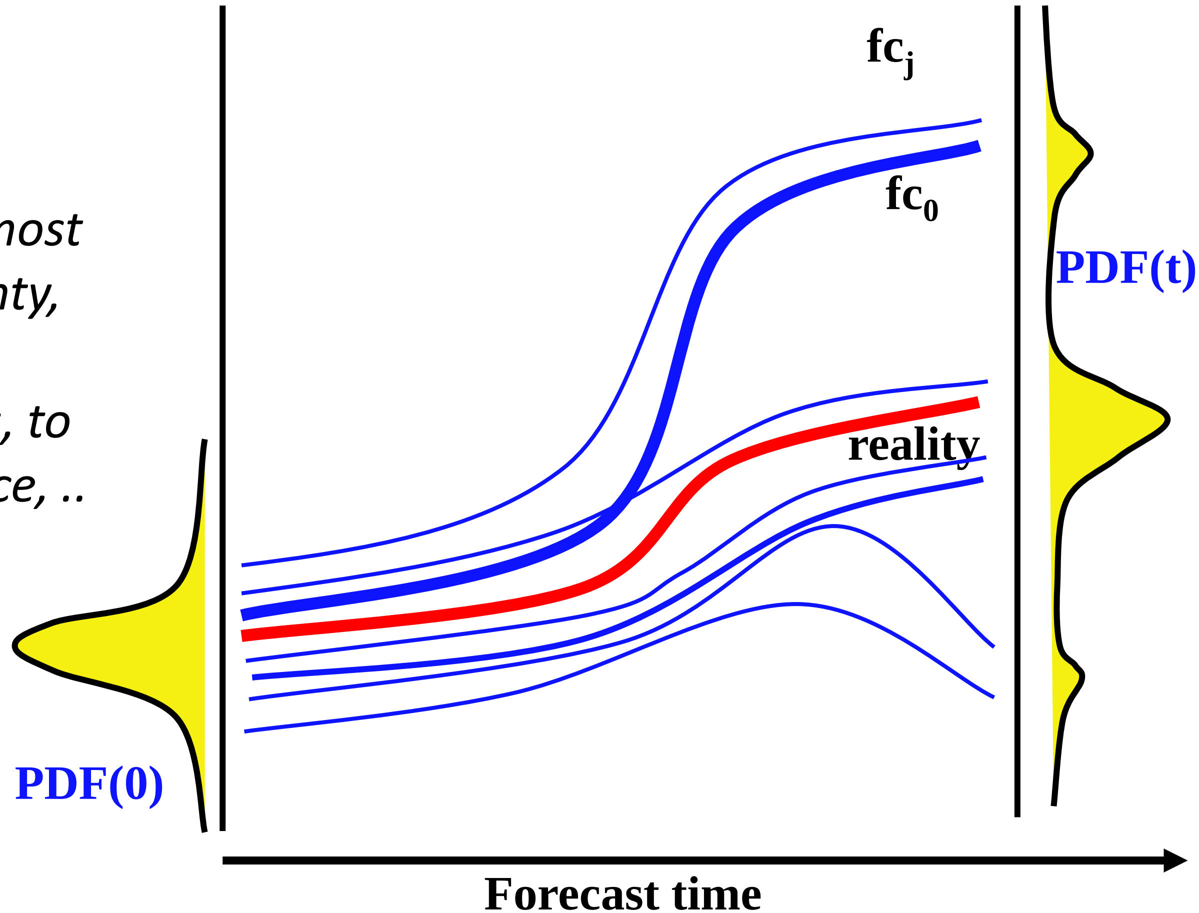
Ensembles: why?

To predict the time evolution of the probability density function of forecast states.

In other words, to predict the most likely scenario and its uncertainty, expressed e.g. in terms of probabilities of weather events, to estimate the forecast confidence, ..



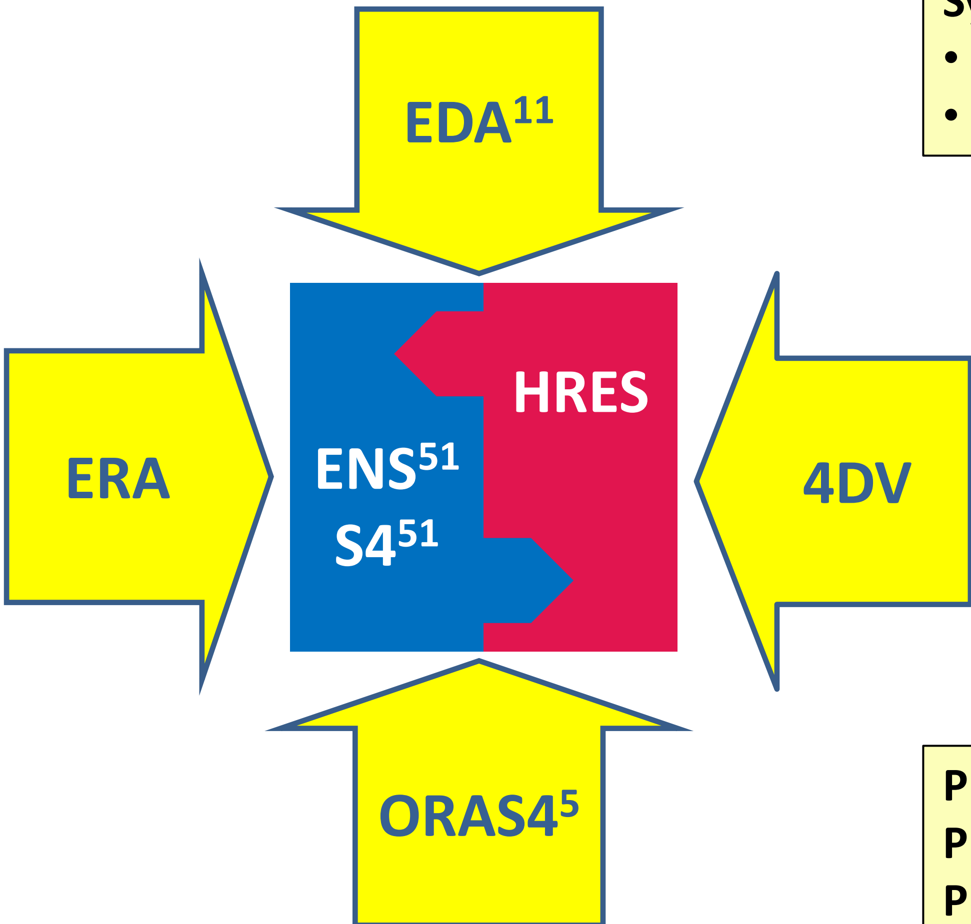
2004: ensembles were used only in forecast mode

System components simulate the effect of:

- **Initial uncertainties**
- **Model uncertainties (1 stochastic scheme)**

PDF(0) << N/A
PDF(0) << N/A
PDF(T) << HRES+ENS^{51}/S2^{31}

2014: ensembles are used in analysis and forecast modes



System components simulate the effect of:

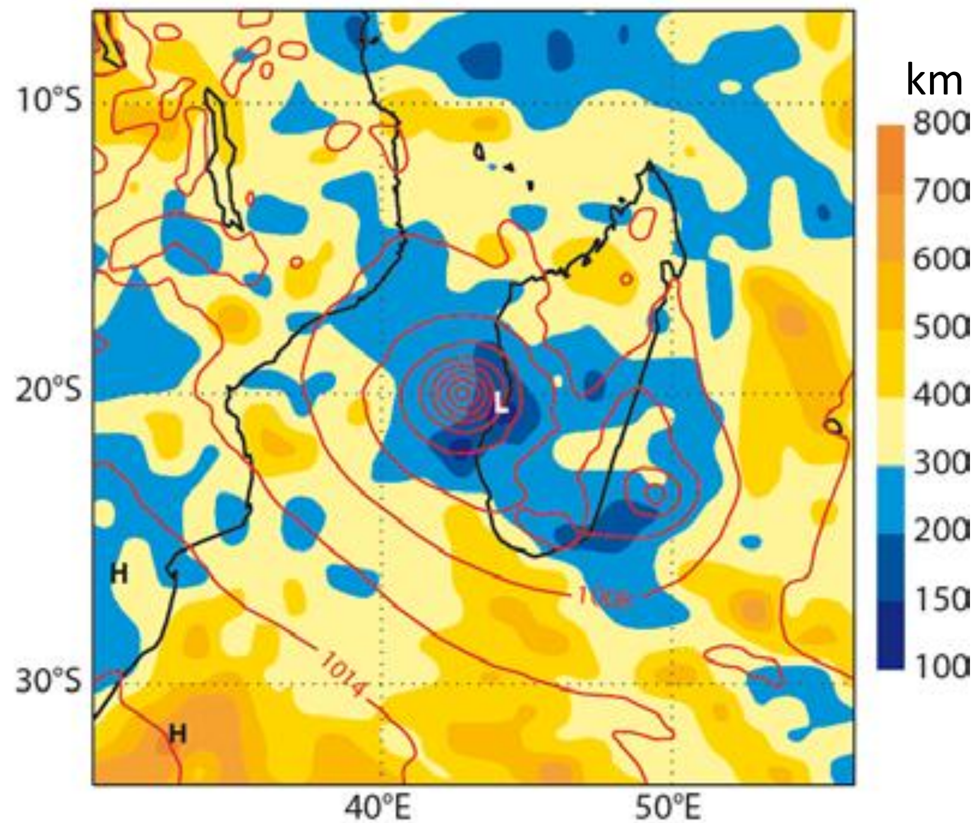
- **Observation uncertainties**
- **Model uncertainties (2 stochastic schemes)**

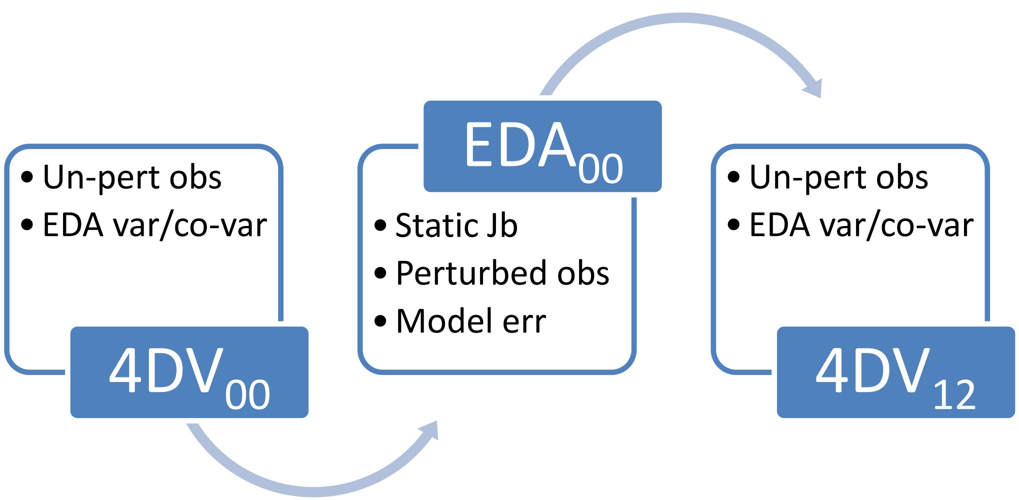
PDF(0) << 4DV+EDA^{11}+ORAS4^{5}
PDF(0) << ERA+ORAS4^{5} (the past)
PDF(T) << HRES+ENS^{51}/S4^{51}

Ensembles are now used to estimate flow dependent stats

Nov 2013: the **EDA size has increased from 10 to 25 members**, to provide 4DV-HRES also with flow dependent background error co-variances. EDA-based perturbations from the past 12 days will be used (sample size=600).

Background error correlation length scale for long(p_{msl}) and p_{msl}



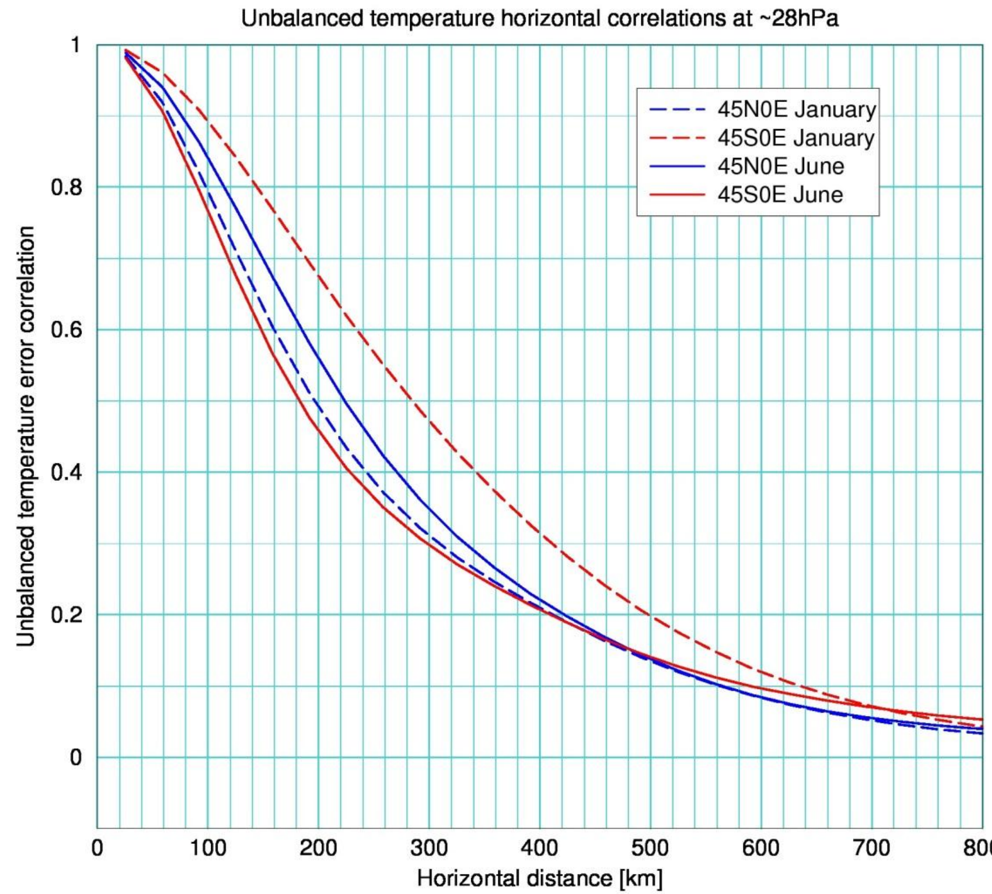


Flow dependent est. are key to properly assimilate obs

With the new calculation of background error covariances, the correlation length scales now vary significantly in time.

This figure shows the differences between temperature correlations at ~28 hPa for two points (45N/0E and 45S/0E) for a day in January and June from cycle 40r1 EDA.

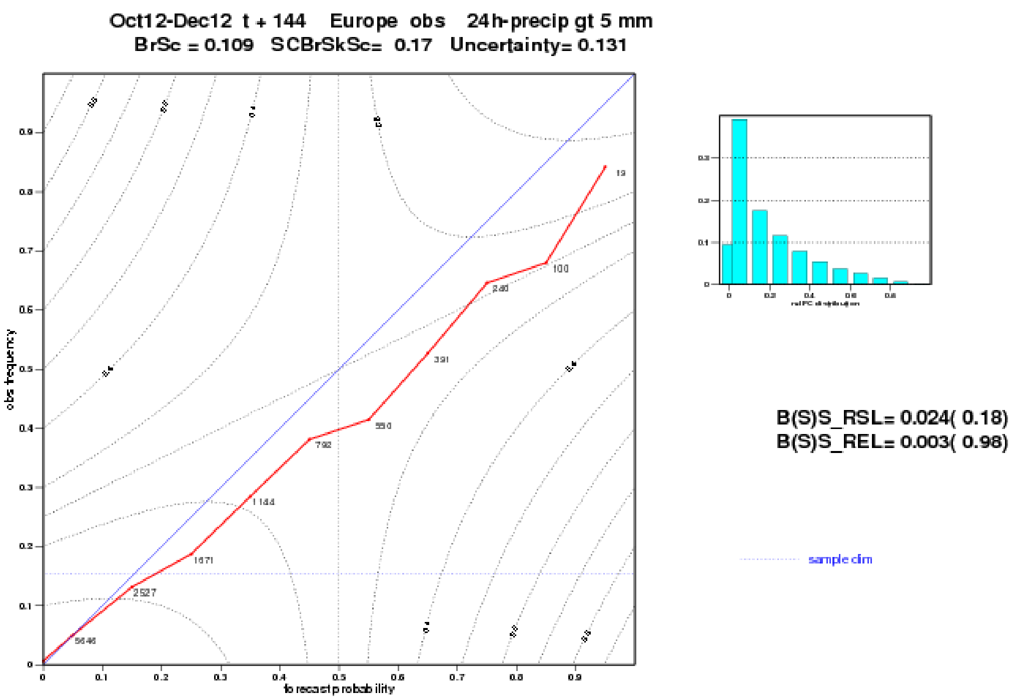
It is clear that the SH winter (red solid) and summer (red dashed) temperature correlations are significantly different, a feature that cannot be accurately presented by climatological correlations.



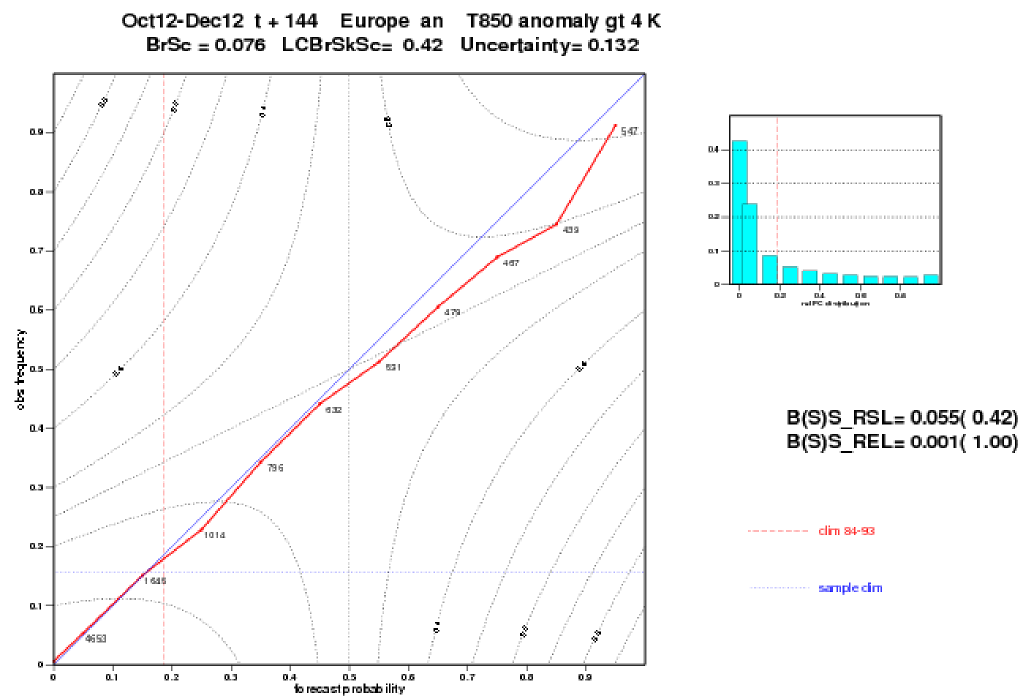
How does ENS perform in terms of reliability?

Reliability is a key property that probabilistic forecasts must have.

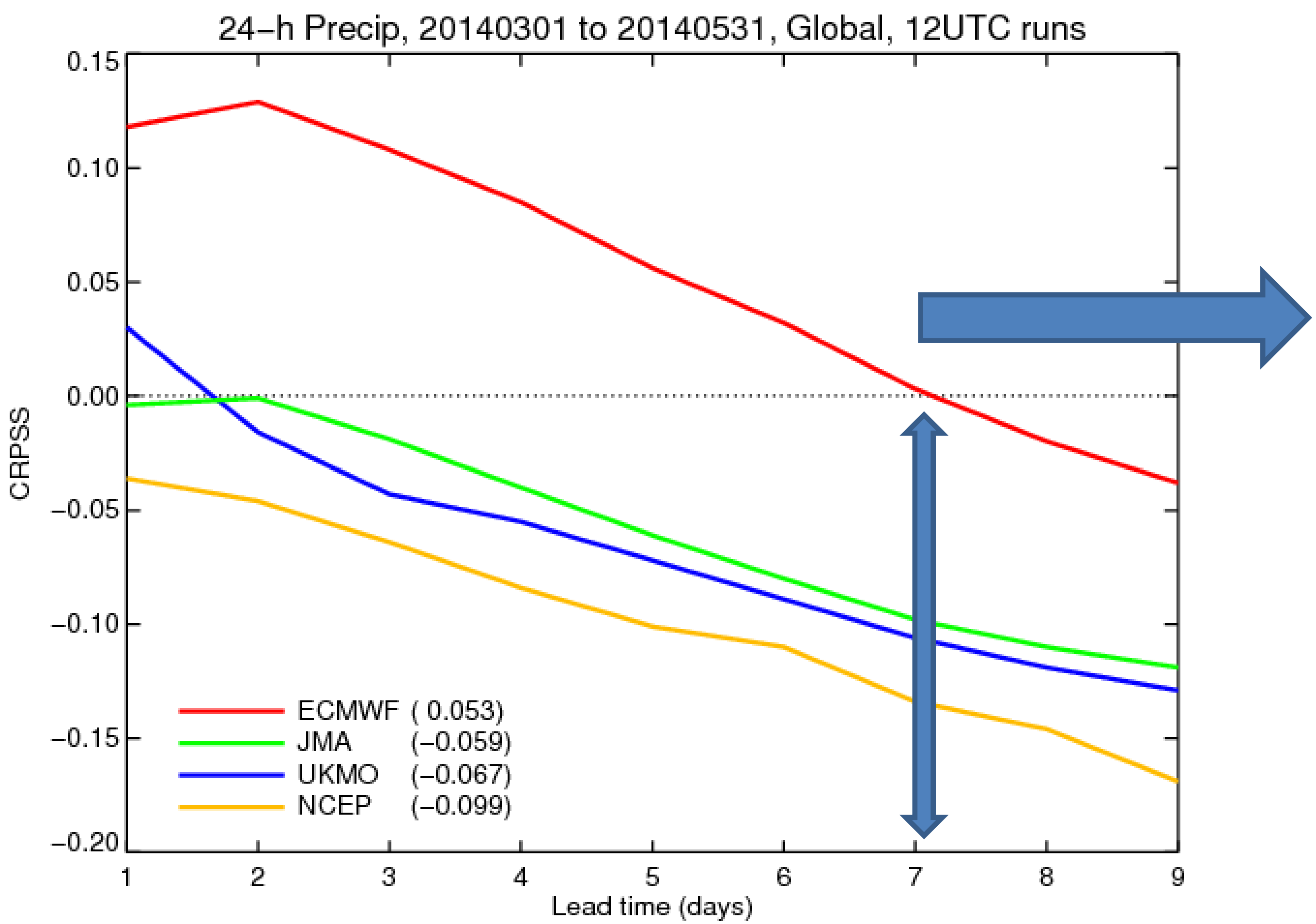
EU, OND12
PR(TP24>5mm;+144h) v obs



EU, OND12
PR((T850-CLI)>4k;+144h) v AN



How does ENS perform in terms of prob(TP)?

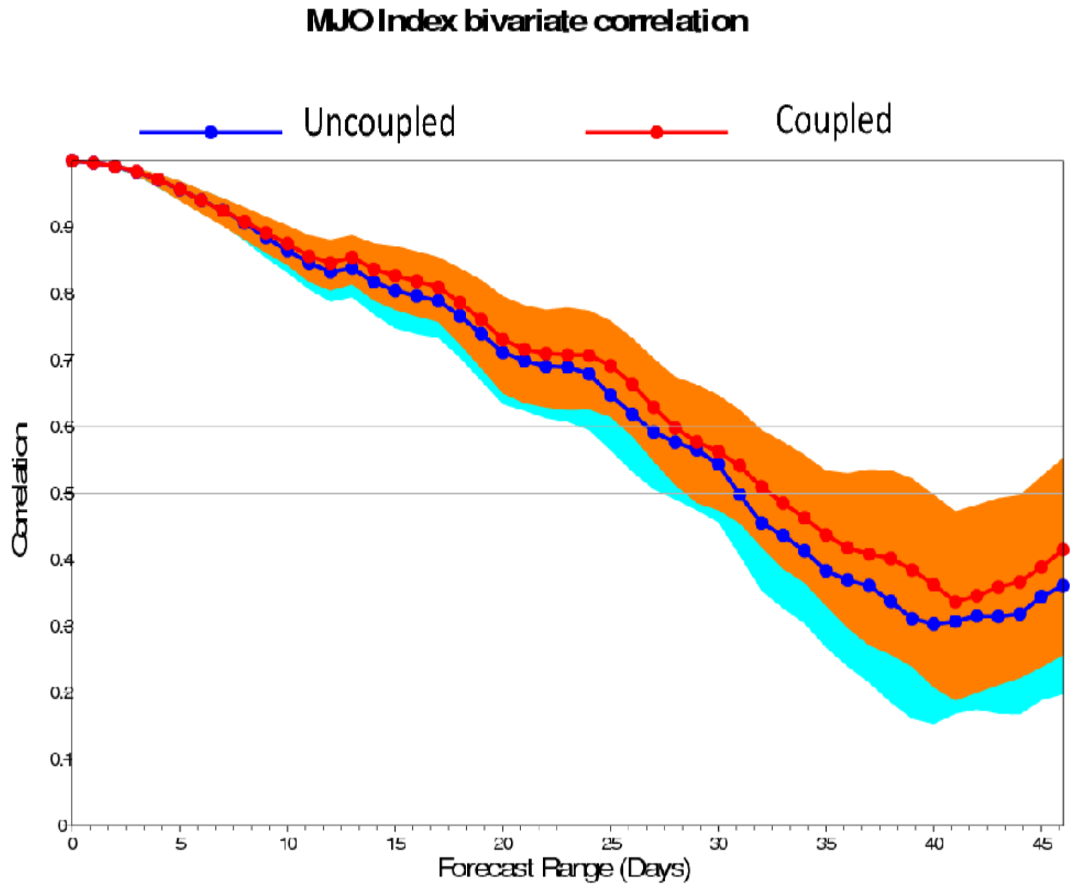


How can we Extend it?

ENS now runs to 32d and is coupled to an ocean from d0

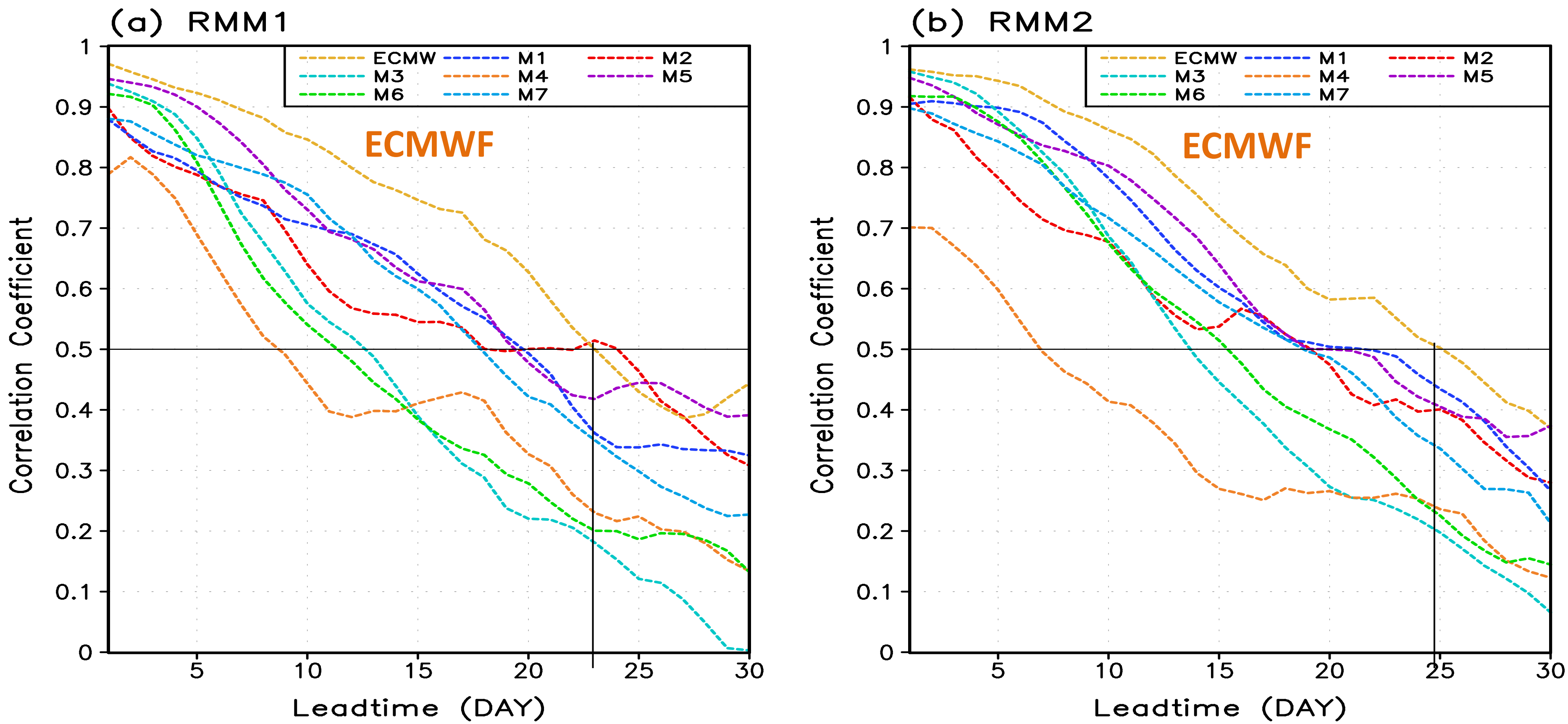
Nov 2013: **coupling from initial-time** to a new version of the ocean model (NEMO), with 1-way wave-currents coupling, has improved skill, especially in the monthly time-range.

Work is progressing to introduce a better, unified wave-currents-sea-ice model (LIM). The new model based on NEMO is under testing at higher resolution, ORCA_025_Z75. It will be implemented in H2-2015.

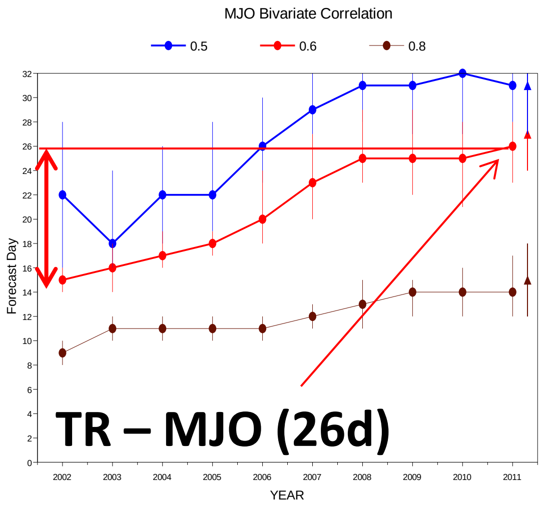


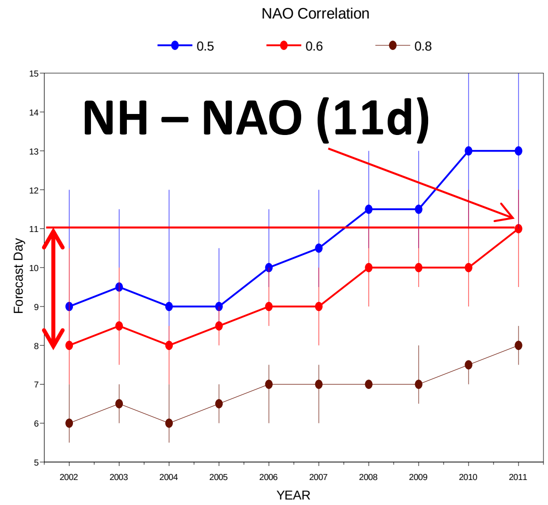
How does ENS perform in the sub-seasonal range? MJO

The ECMWF ensemble predicts the MJO up to about 25 days.



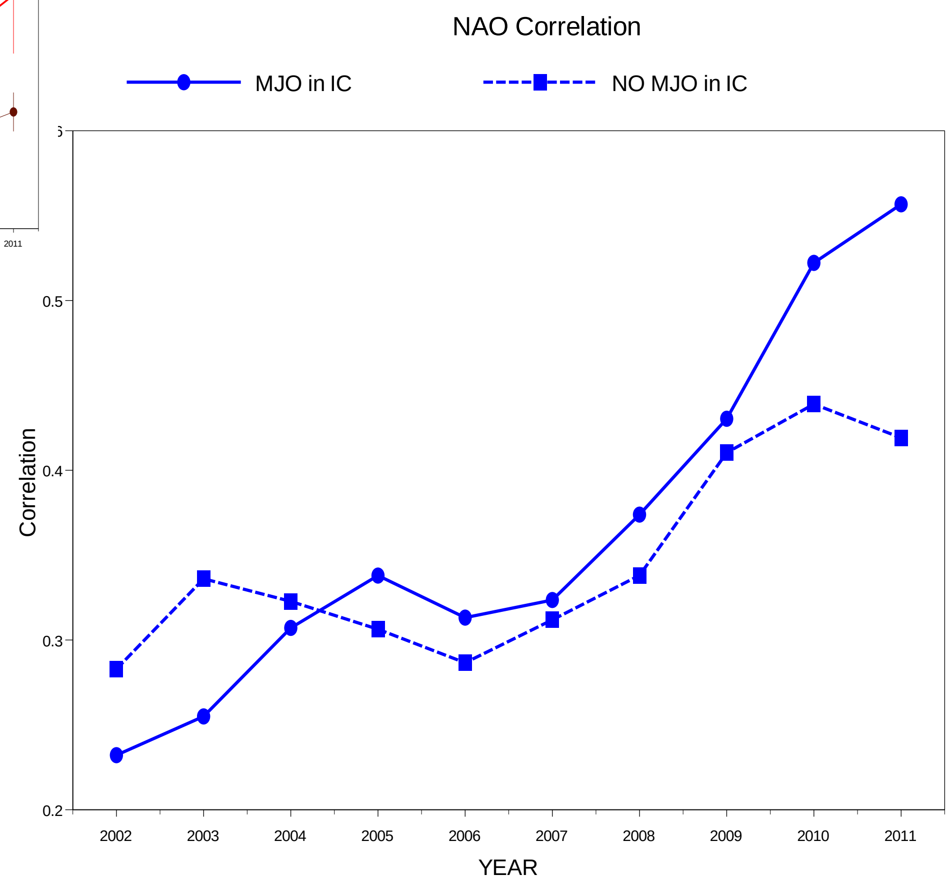
How does ENS perform in the sub-seasonal? MJO & NAO



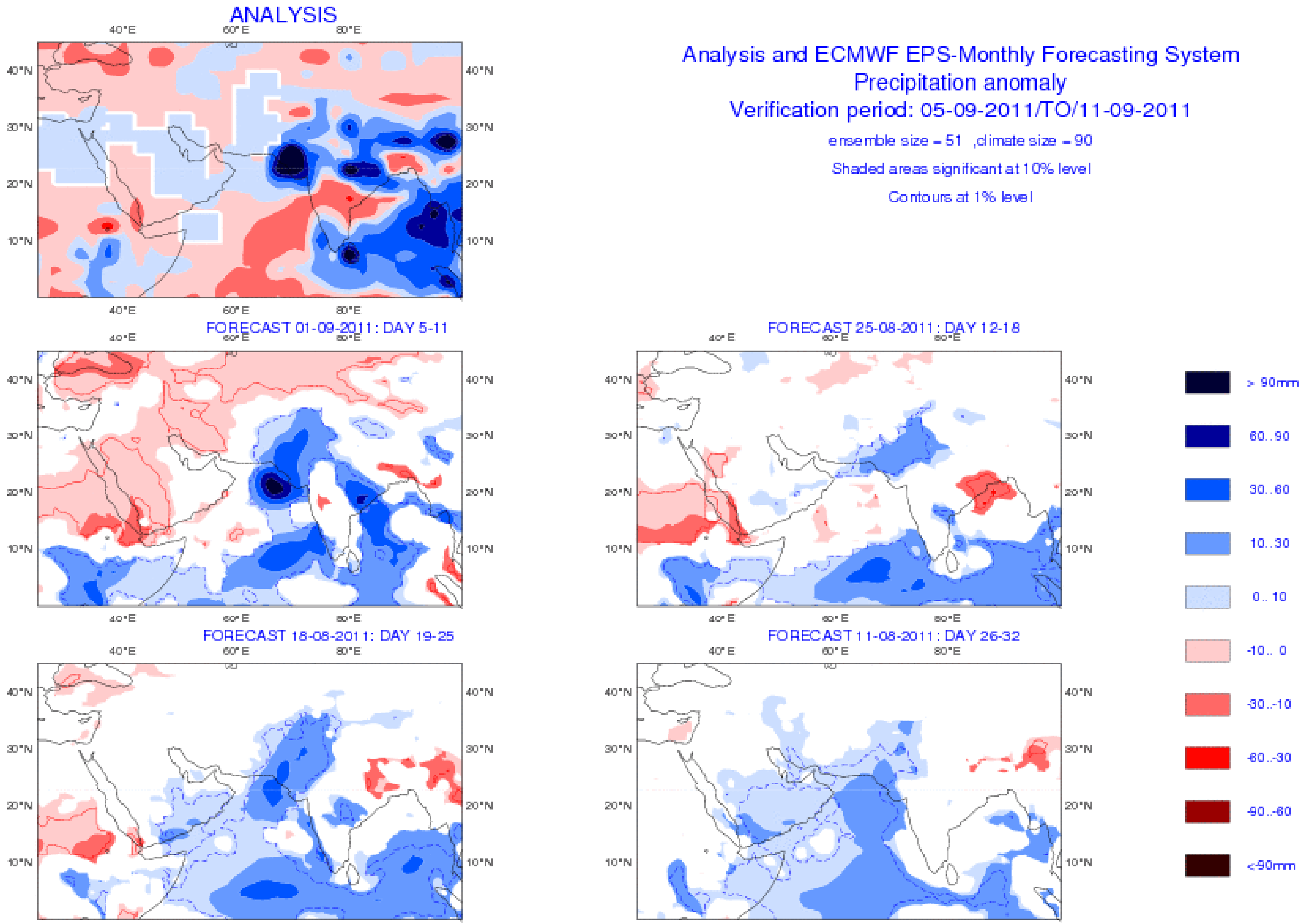


The skill of monthly forecasts have been continuously improving both in the tropics for the MJO (top left) and the extra-tropics for the NAO (top right).

Improvements in the physics have led to better teleconnection between tropics and extra-tropics (bottom).

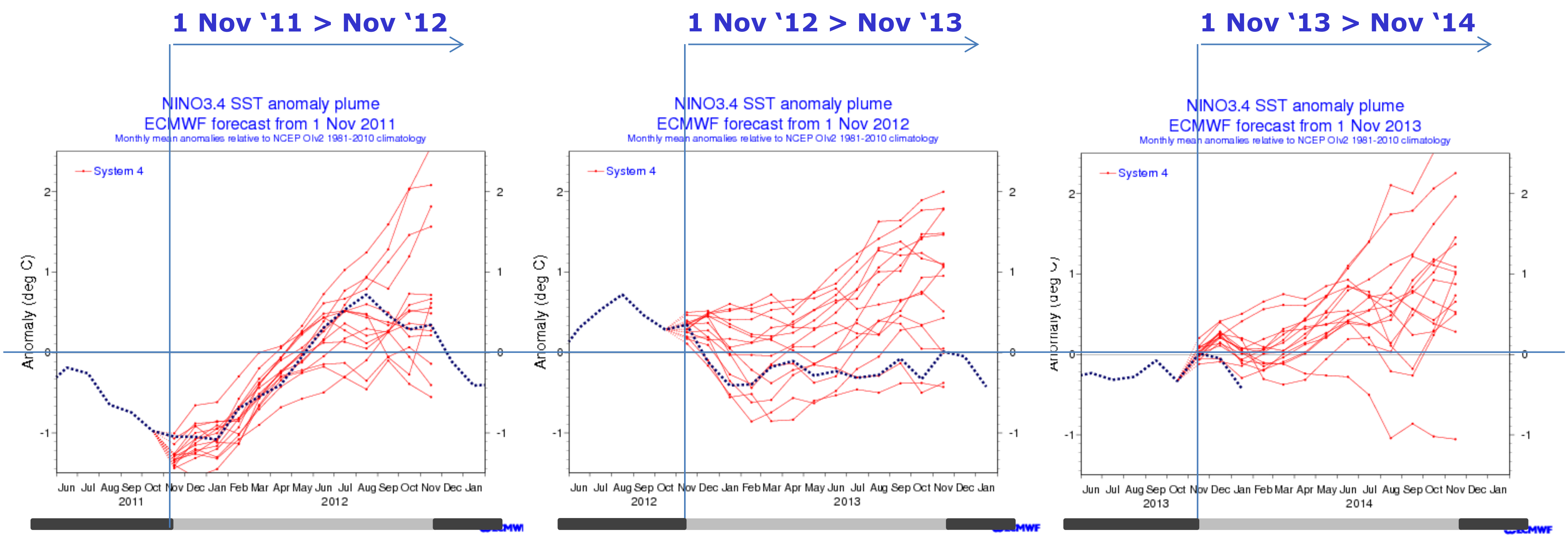


In some cases, precip events are predicted weeks ahead

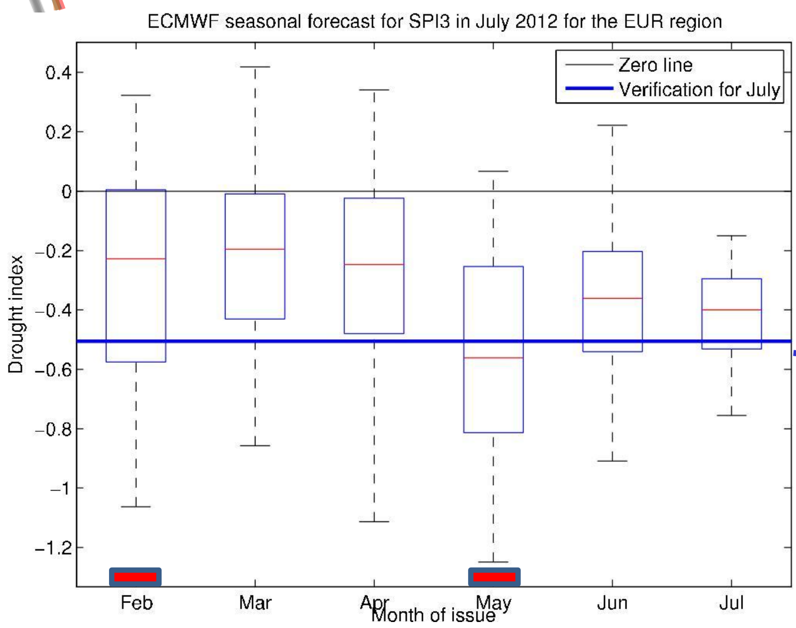


Seasonal system S4 provides probabilities up to 1y

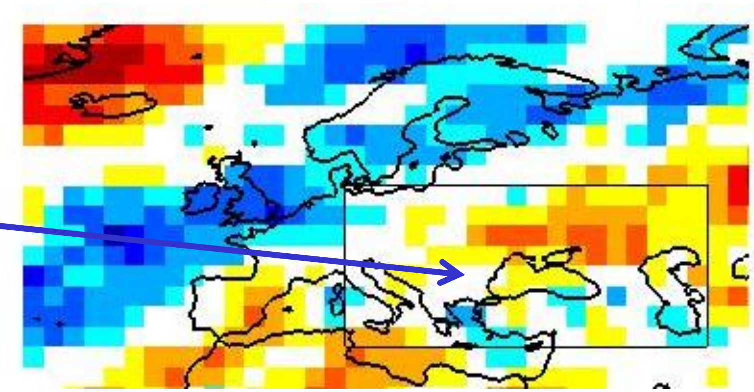
The tropics remain the area where seasonal prediction has the highest skill, as indicated e.g. by the accuracy of 1-year forecasts of SST anomaly in the Nino3.4 area.



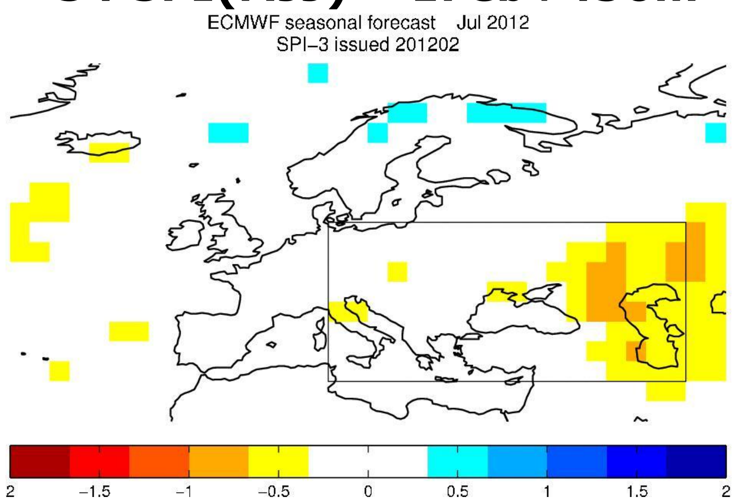
In some cases, anom. over xTR are predicted months ahead



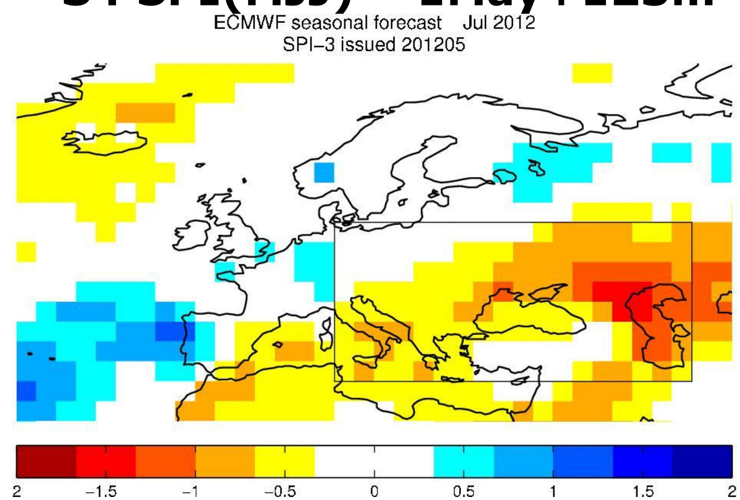
SPI(MJJ) – ERA-I



S4 SPI(MJJ) – 1Feb+456m



S4 SPI(MJJ) – 1May+123m

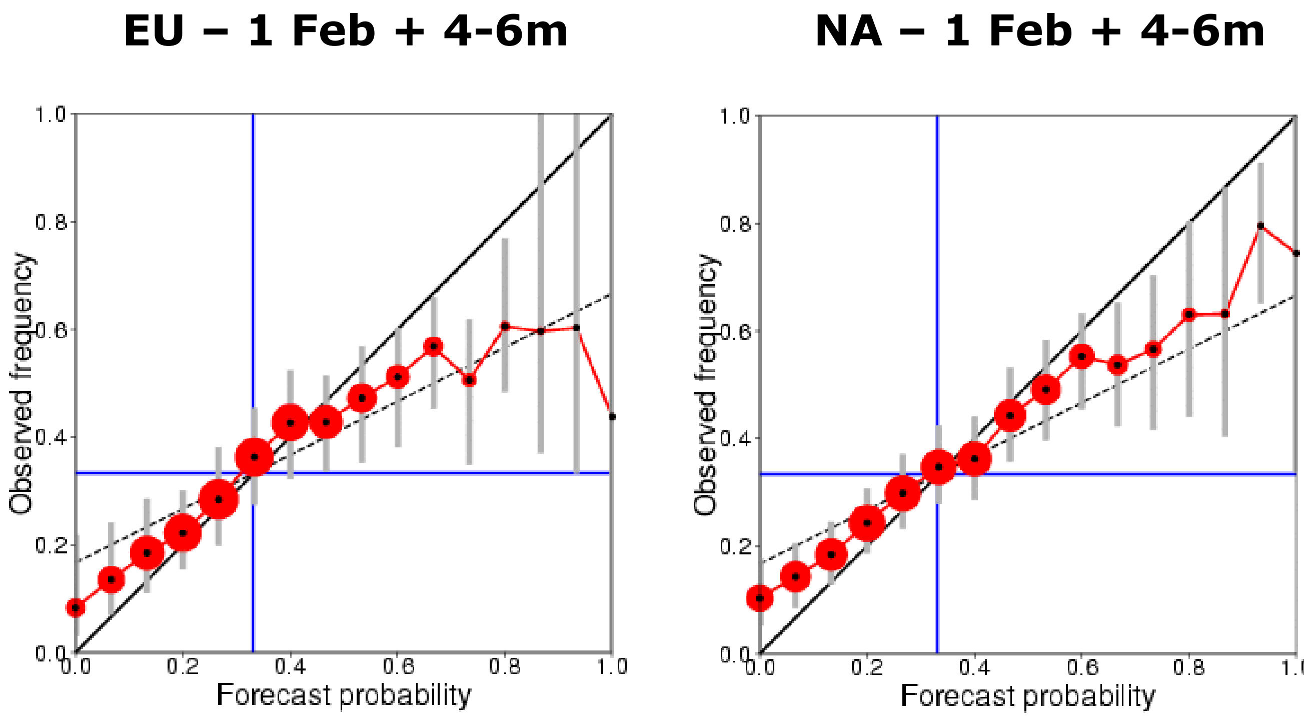


Est EU MJJ12.

Since Feb S4 predicts 75% probability of below normal conditions.

How does S4 perform in terms of reliability? 2mT

On average (30 years), 4-6 month probabilistic predictions of 2mT over North America and Europe started in Feb for MJJ (t+4-6m) are reliable and skilful compared to climatology (BSS>0).

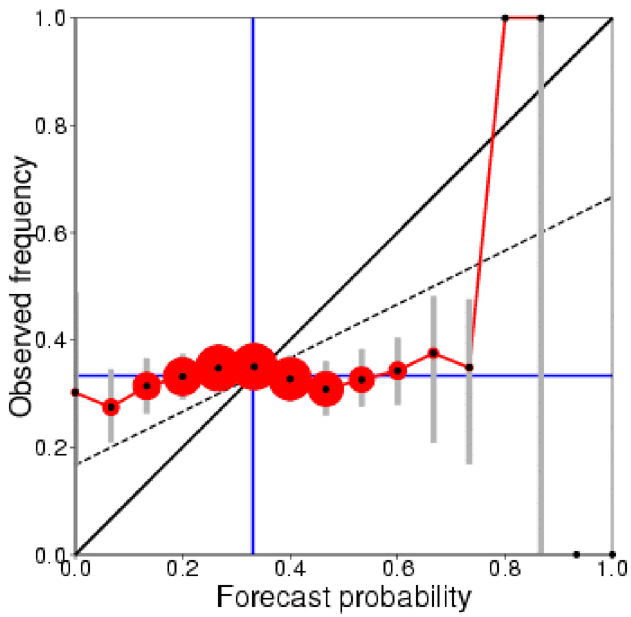


BSS PR(2mT>U3)	EU	NA
1 Feb > MJJ (t+ 4-6m)	0.064	0.050
1 Apr > MJJ (t+2-4m)	0.058	0.074

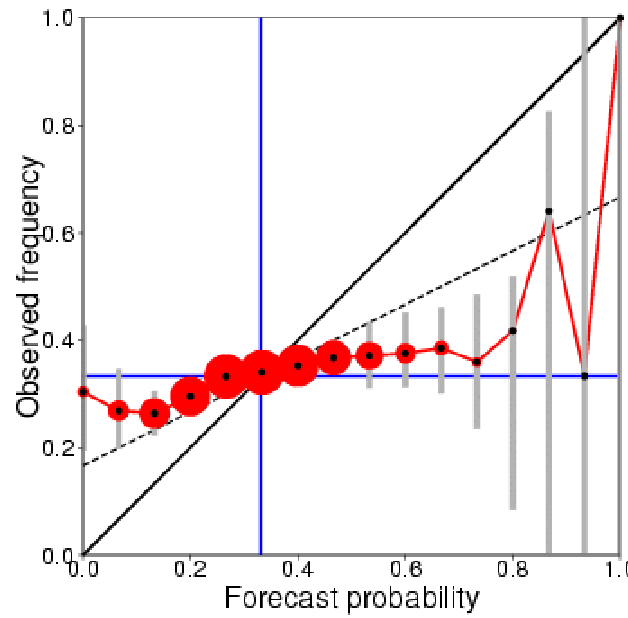
… but for precipitation, reliability is very poor!

On average (30 years), even shorter-range 2-4 month probabilistic predictions of TP over North America and Europe started in Apr for MJJ (t+2-4m) are **not** reliable and **less** skilful than climatology.

EU – 1 Apr + 2-4m



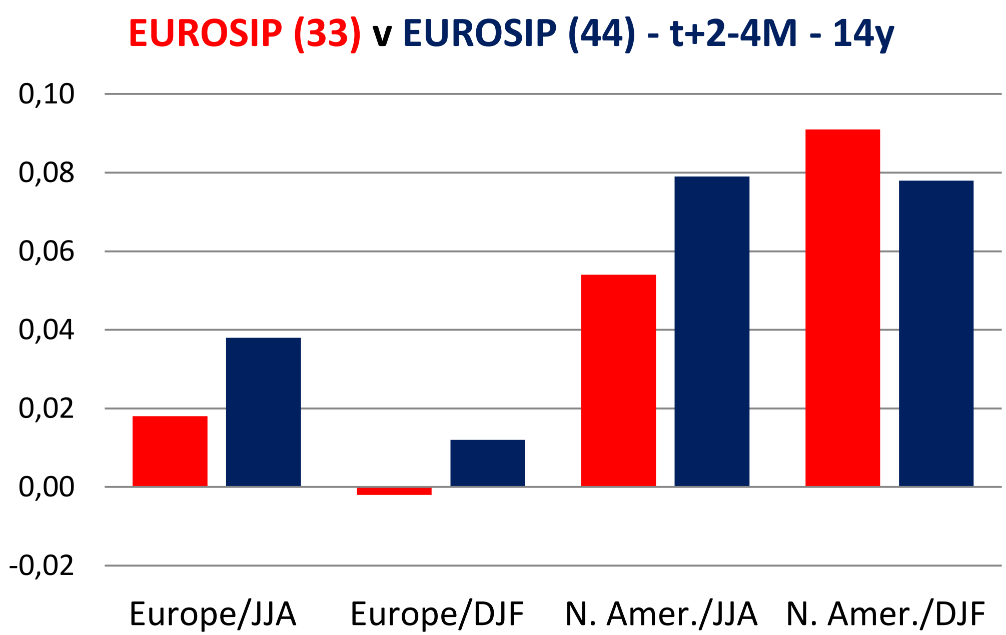
NA – 1 Apr + 2-4m

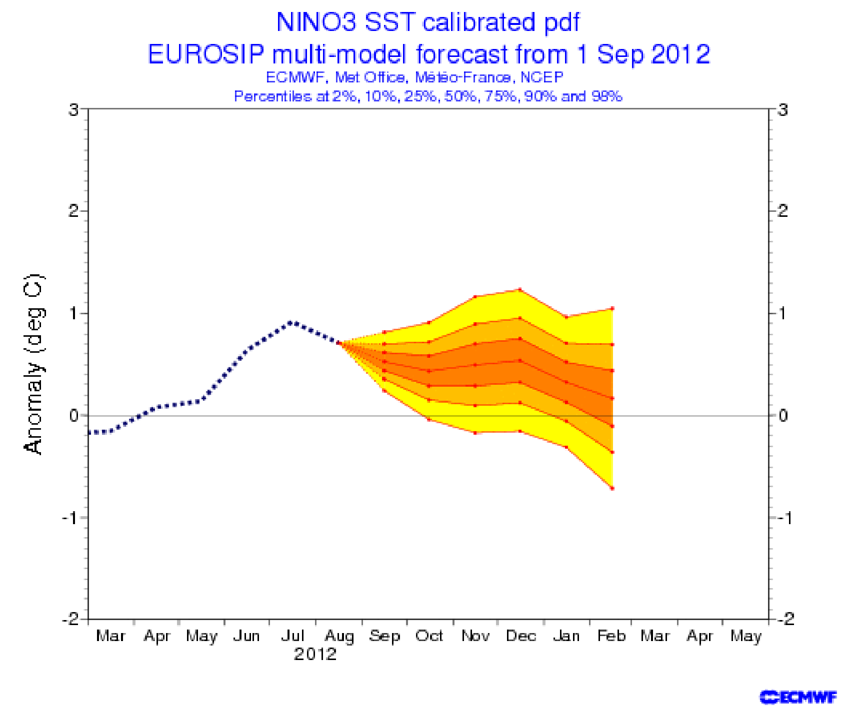


BSS PR(TP<L3)	EU	NA
1 Feb > MJJ (t+ 4-6m)	-0.049	-0.052
1 Apr > MJJ (t+2-4m)	-0.072	-0.052

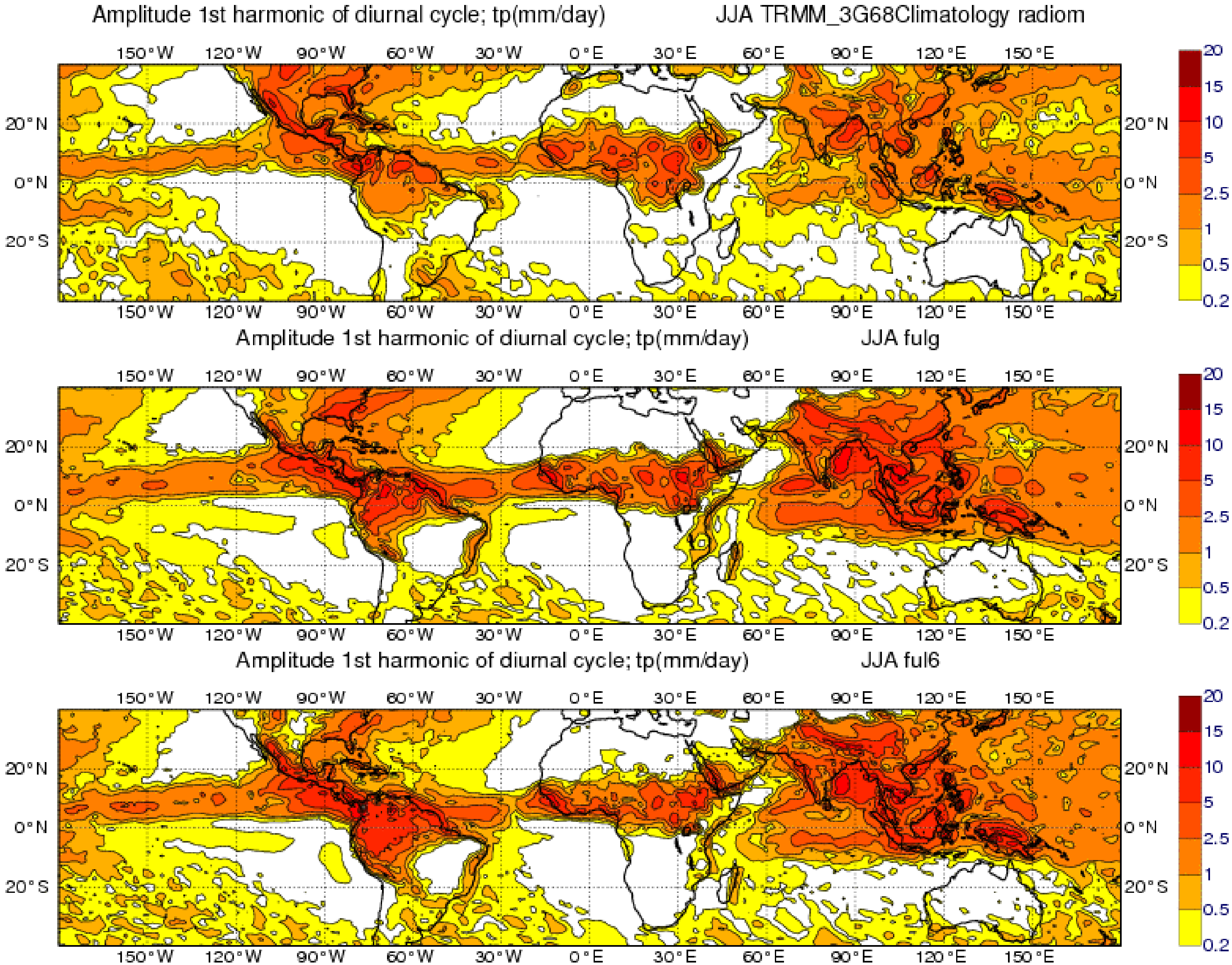
EUROSIP: a multi-system approach for the seasonal range

In 2012, for the first time, European (ECMWF, Meteo France and UK Met Office) and American (NCEP) ensemble systems are used to generate operational products. This follows research that has shown that better and more reliable seasonal forecasts can be created by combining the output from several systems.





Model quality is key: TP diurnal cycle, JJA (ampl. mm/d)

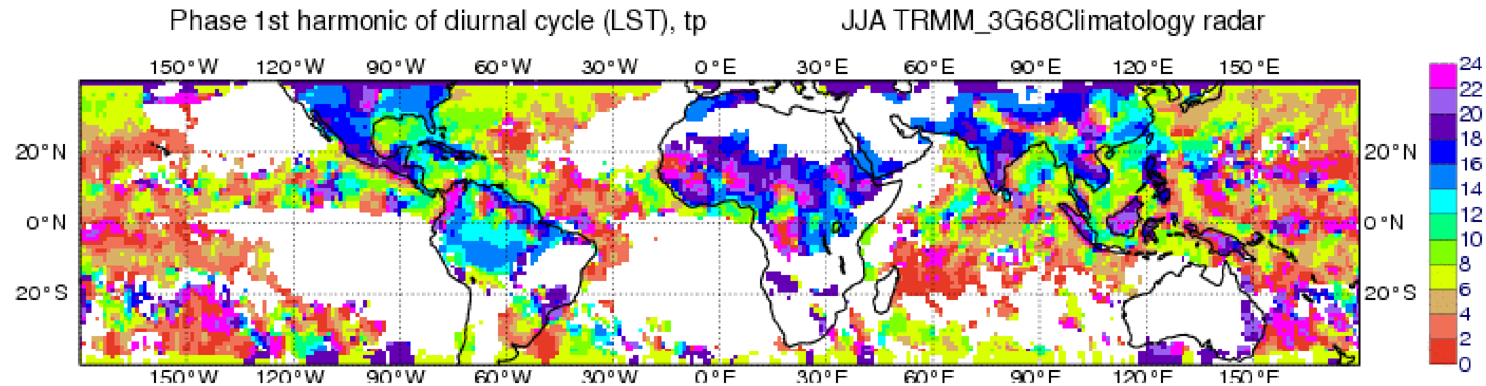


TRMM

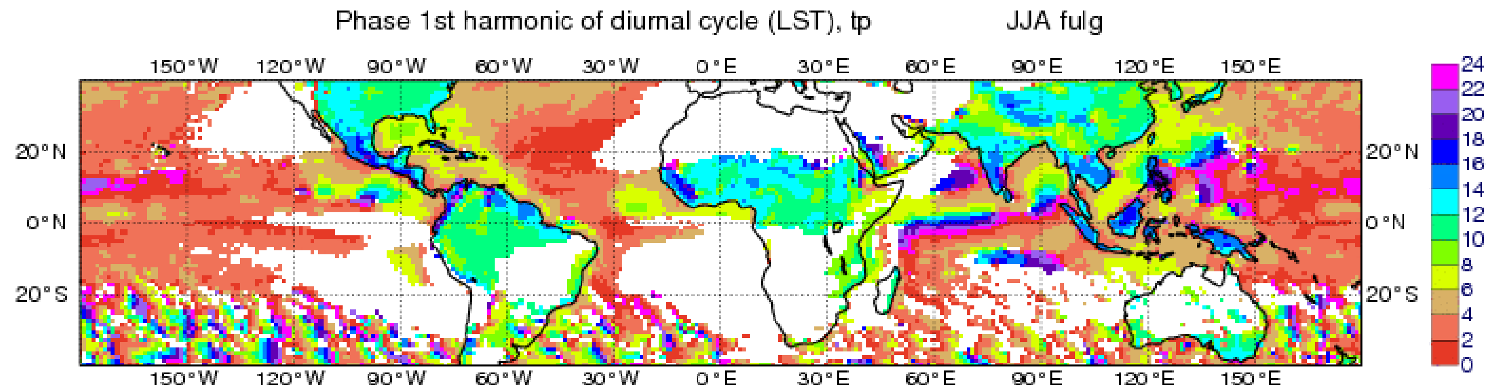
Ctrl=Oper

39r1/40r1

Model quality is key: TP diurnal cycle, JJA (phase, LT)



TRMM



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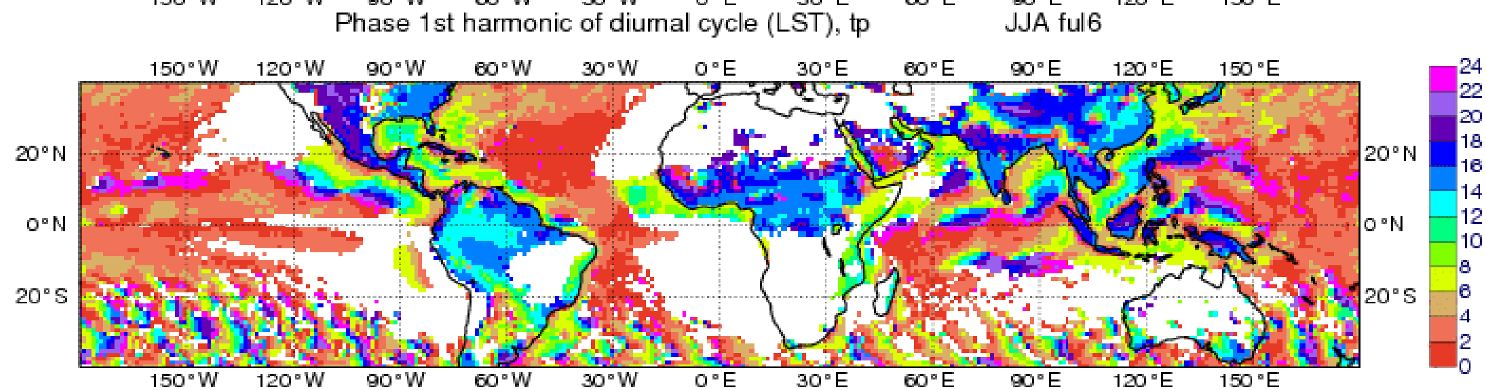
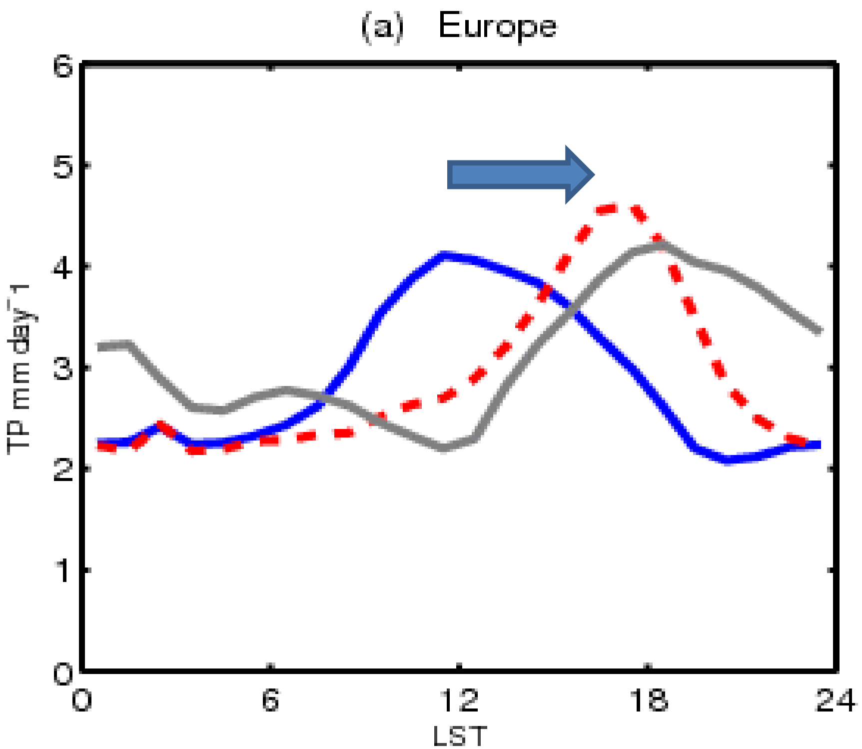


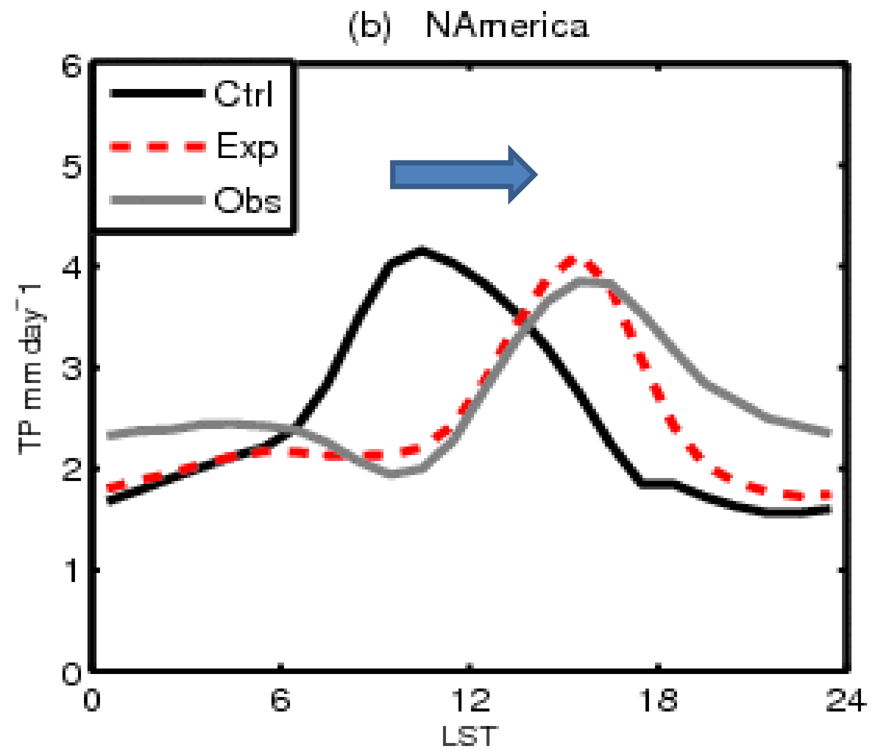
39r1/40r1

Nov 2013: diurnal cycle of TP (comparison with radar data)

JJA 2011 EURRAD



JJA 2011 & 2012 NEXRAD



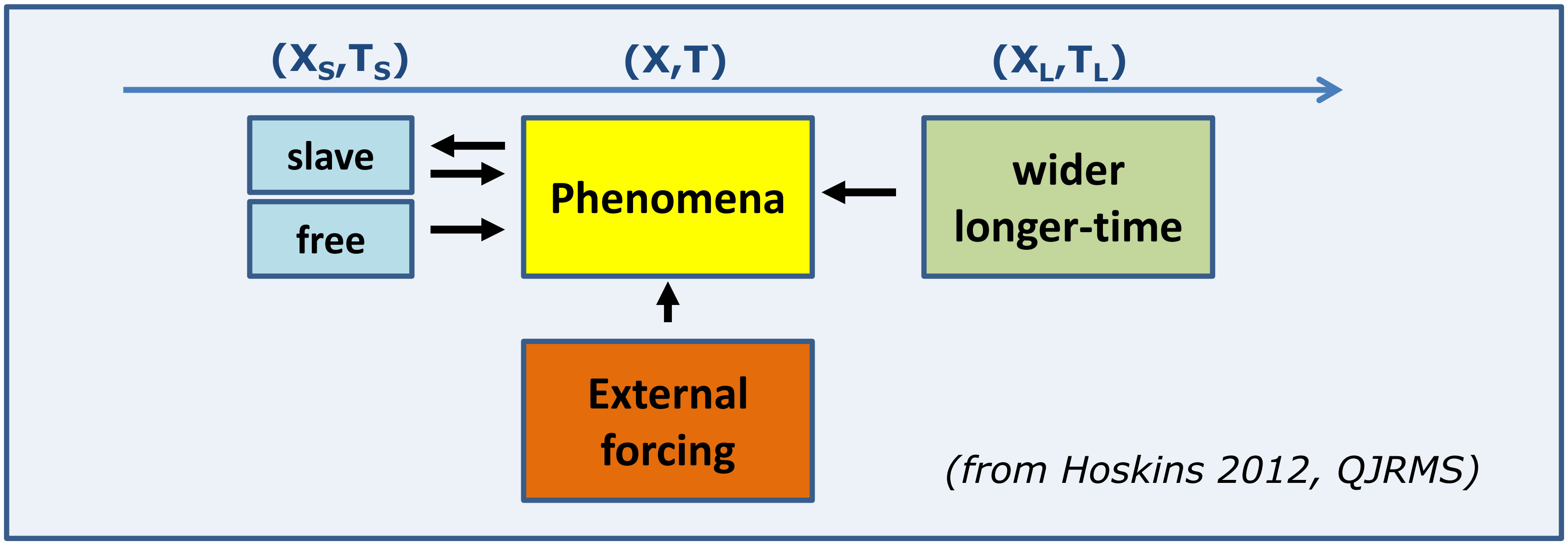
Nota: NEXRAD is calibrated with rain gauges, while EURRAD is not.

The main challenges: model processes and initialization

The main **challenges** that we are facing are:

a) to design systems that simulate many scales and include all relevant processes, and

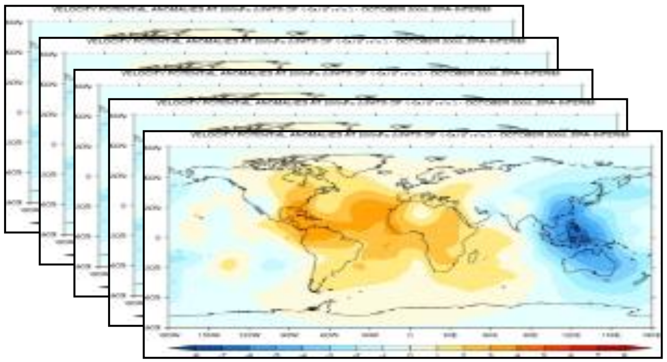
b) to initialize the forecast integrations with accurate initial conditions.



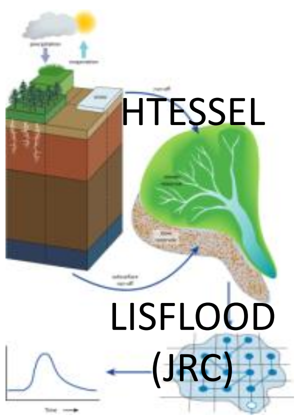
The future …

The future: more reliable/better ENS to drive hydro apps

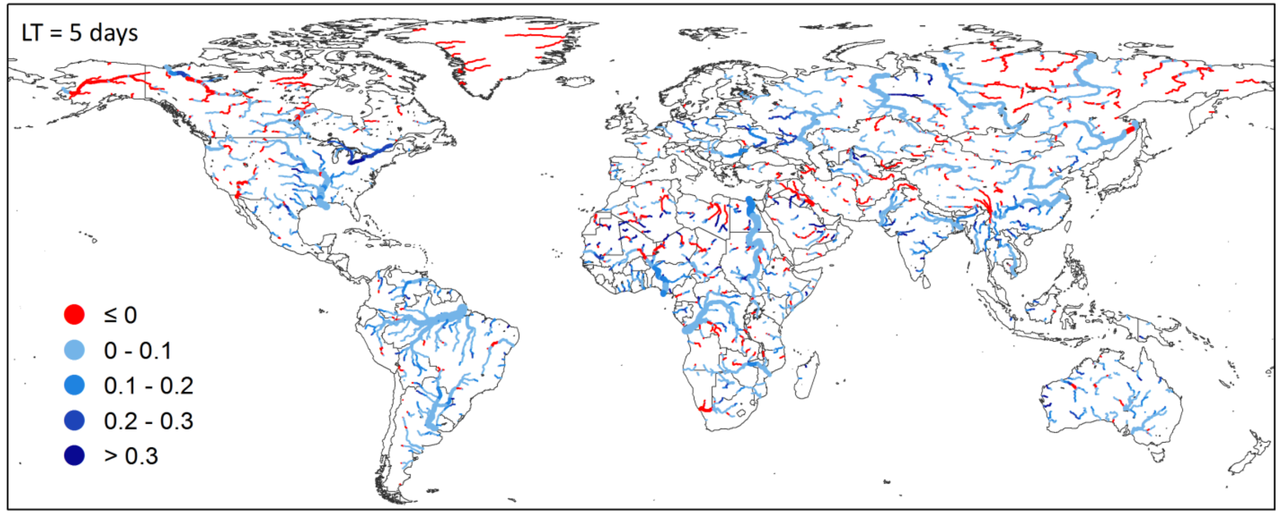
Global probabilistic weather forecast (ECMWF**)**

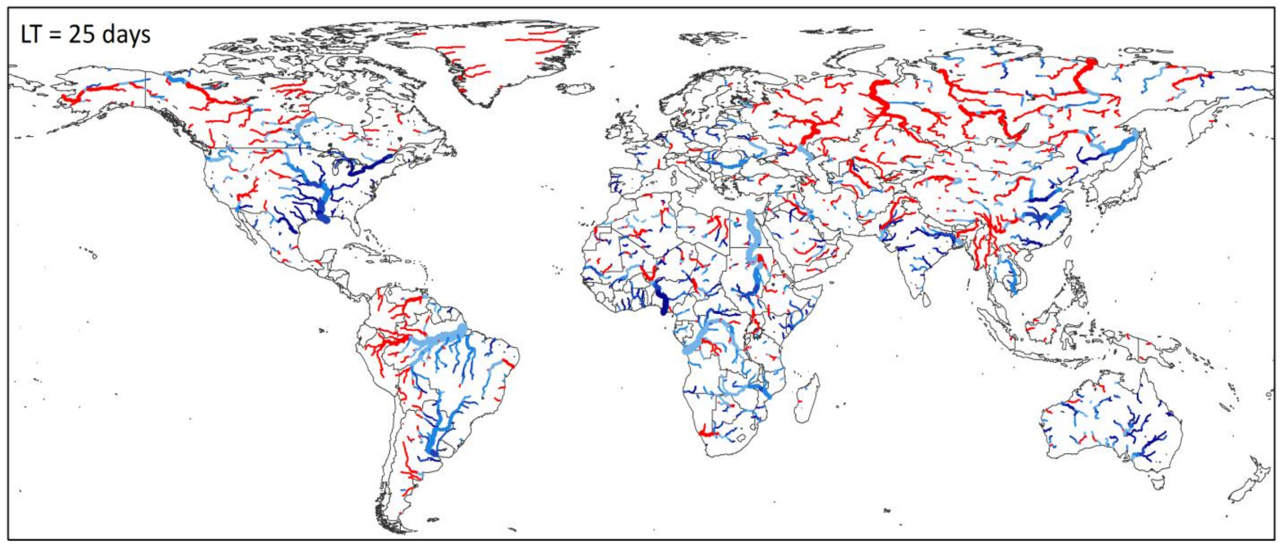


hydrological model



Validation against observed floods: 2-year experiment (2009-10)



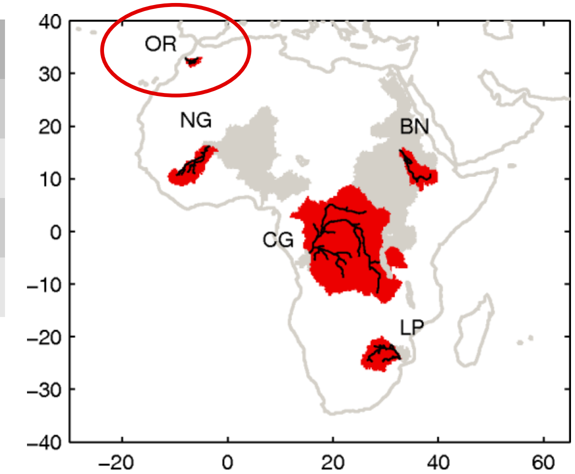


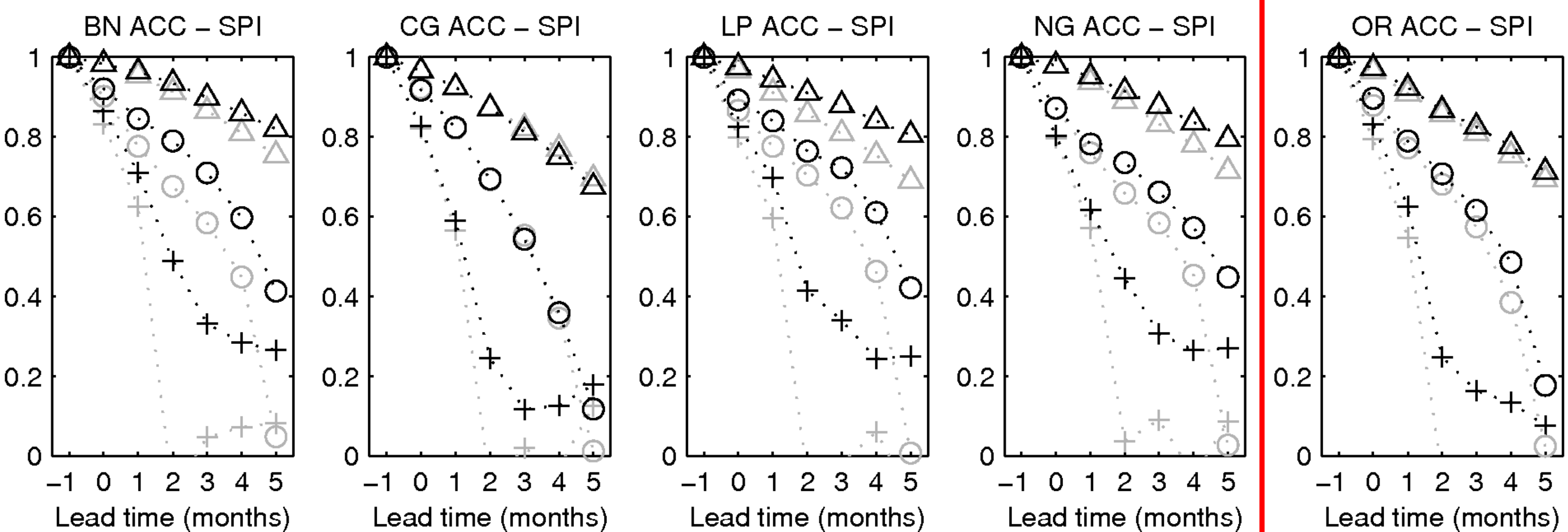
The future: more reliable/better ENS to predict droughts

A trial test focussing on 4 river basins using a blending to calculate the Standardised Precipitation Index (SPI).

In general, using S4 forecasts increases the skill of SPI forecasts (see e.g. BN, LP and NG).

Blue Nile (BN)
Congo (CG)
Limpopo (LP)
Upper Niger (NG)
Oum er-rbia (OR)

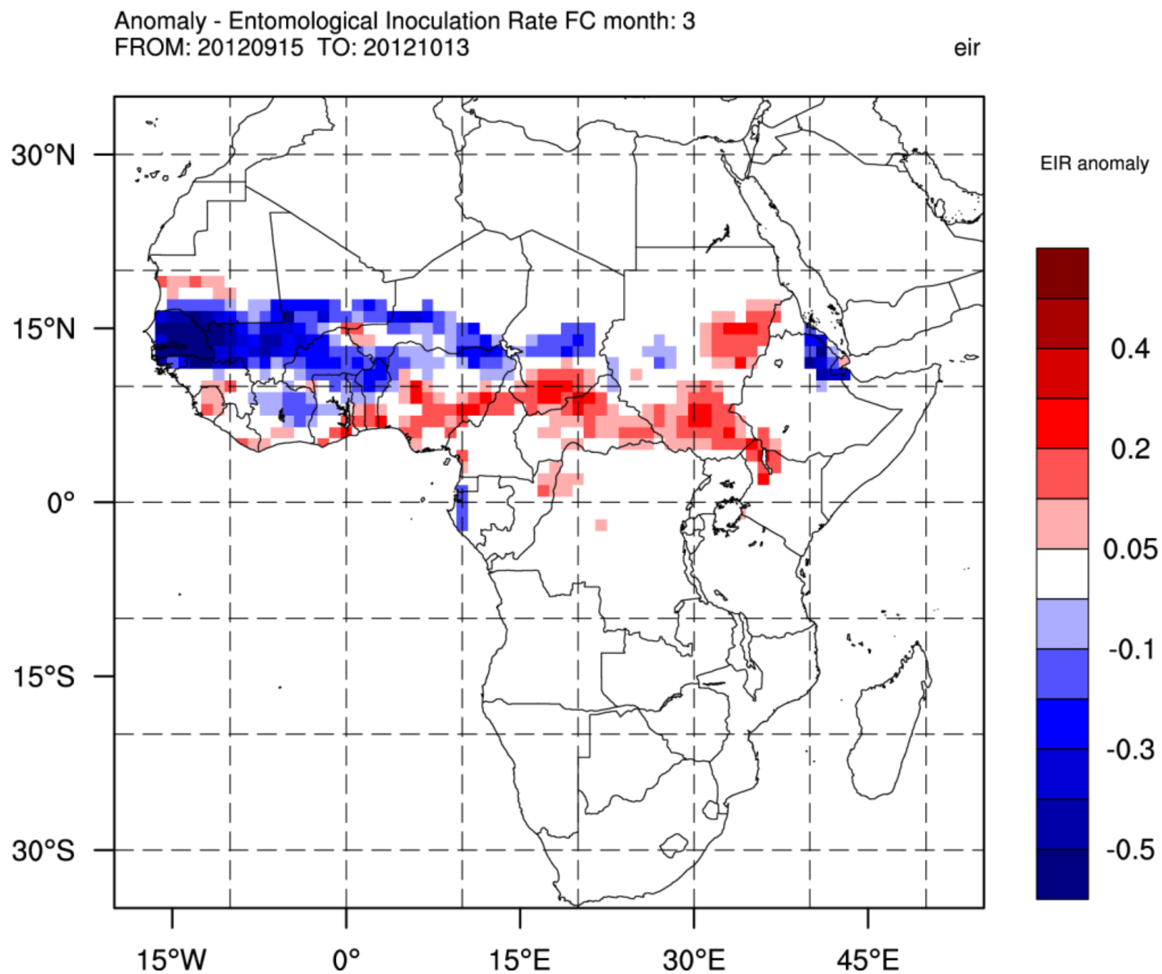




The future: more reliable/better ENS to drive health apps

ECMWF is helping users develop tailored applications in the health sector (**QWECI** project). This figure shows the first malaria outbreak forecast.

The figure shows a prototype 3m forecast for 15 Sep – 13 Oct 2012 of the Entomological Inoculation Rate (EIR) computed using the ICTP malaria model **VECTRI**, driven by S4 t+3m daily TP and T2m.



The future: more of the same or radical changes?

We aim to continue to improve and deliver more reliable and skilful forecasts. How?

a) The NWP problem has to be addressed in **probabilistic terms**, and **ensembles** are the only practical tool to give us estimates of the PDF at initial and forecast times

b) **Higher-resolution** is needed to resolve relevant scales

c) **Better models** that include all relevant processes (i.e. fully coupled earth-system models) are also needed

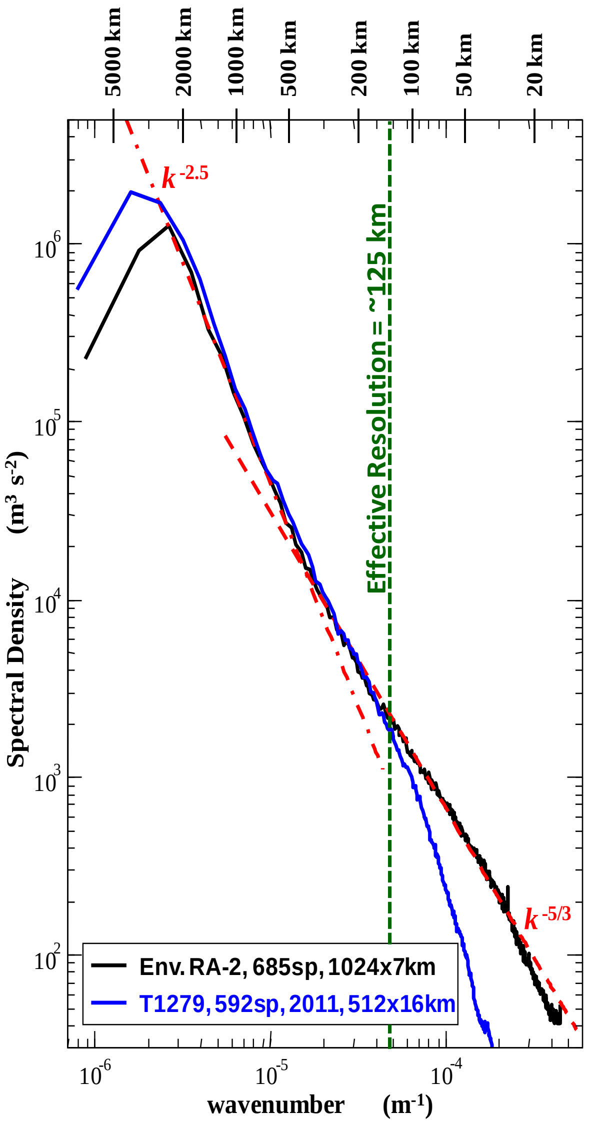
d) **Re-forecasts** are essential to estimate the model climate, thus to calibrate products

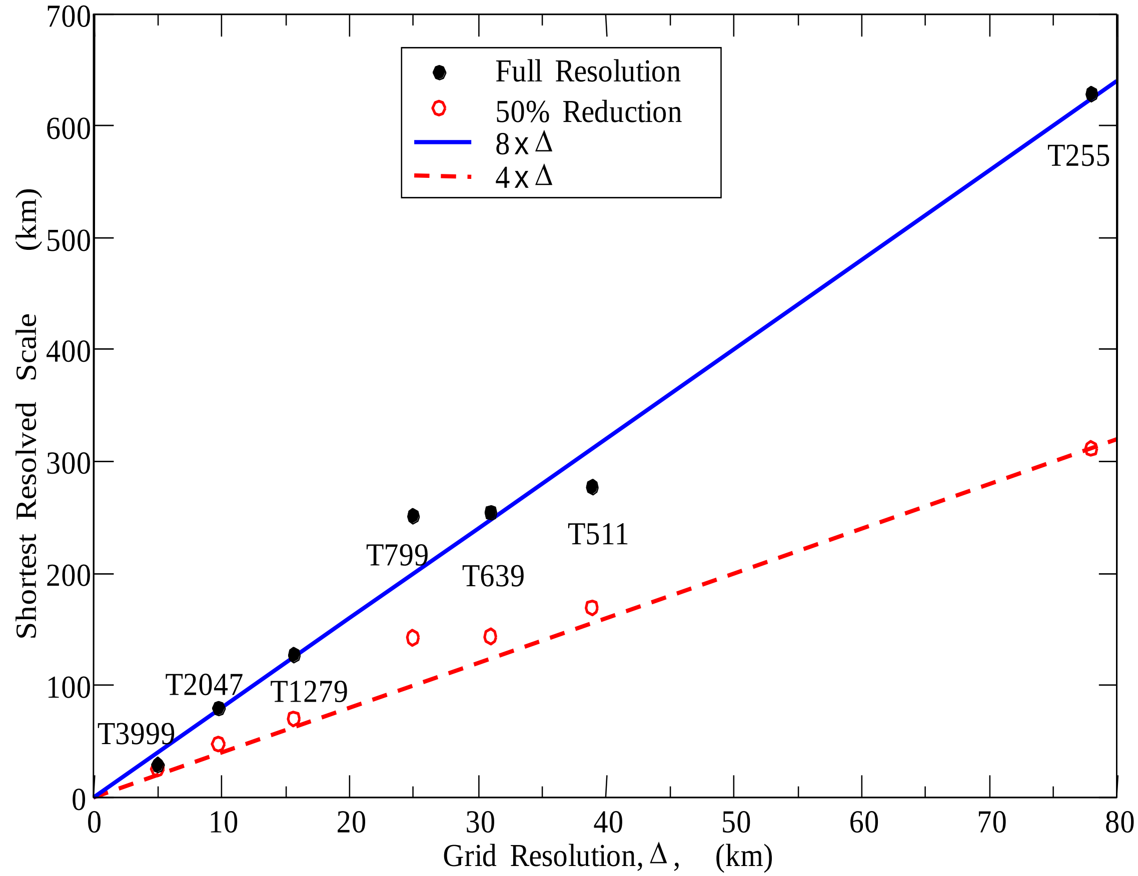
e) As ensemble reliability and skill improves, **forecast length** will be extended

f) Predicting in the medium (d3-10), the sub-seasonal (1m) and the seasonal range (6-12m) is **an initial value problem**: thus we need good quality initial conditions. *This is an area where the methods used to generate them might change …*

g) We need to improve the way we simulate **initial** (observation, DA assumptions, BC, ..) **and model uncertainties**. *The way we simulate them could also change …*

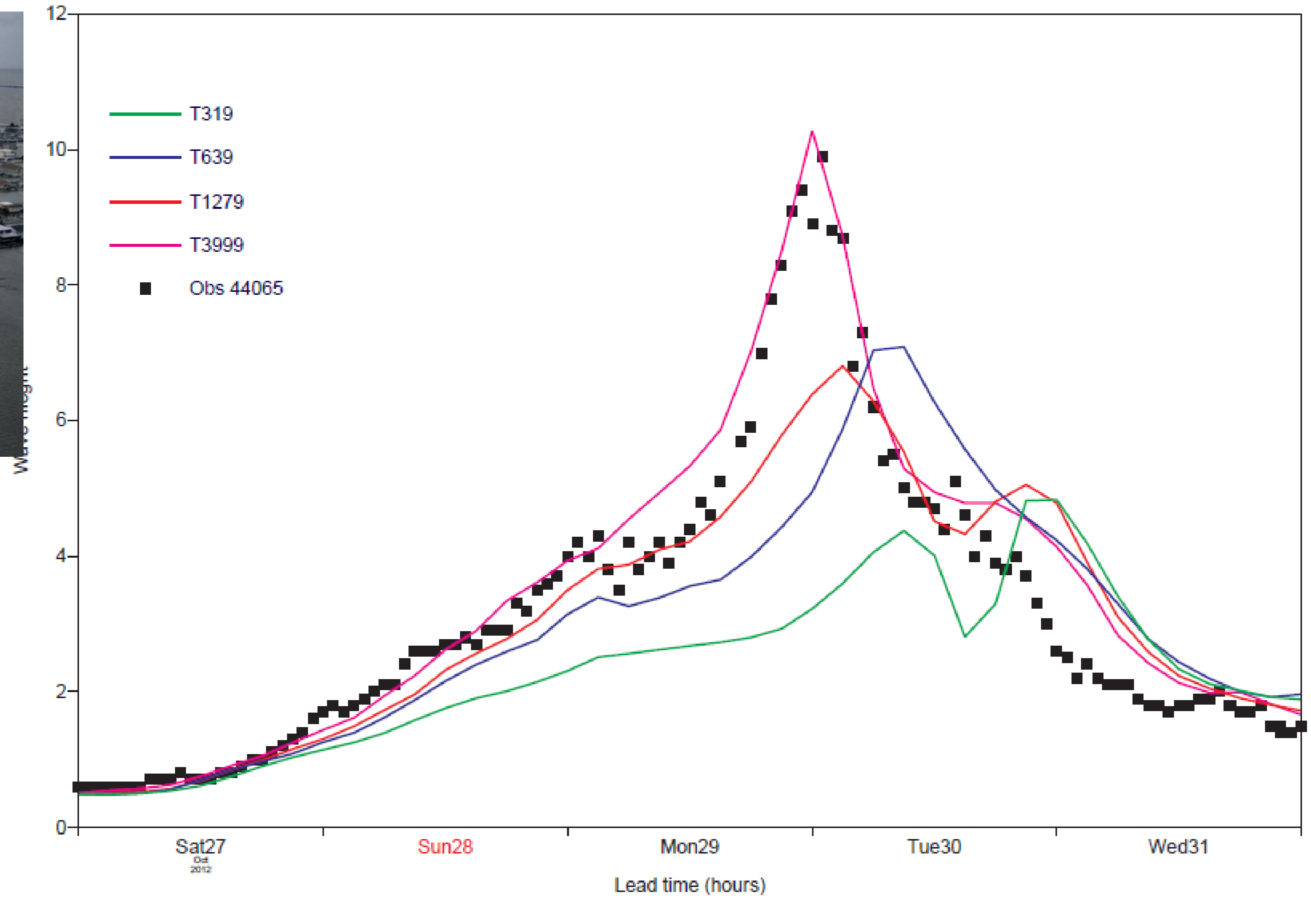
The effective model resolution is only ~8x the grid spacing



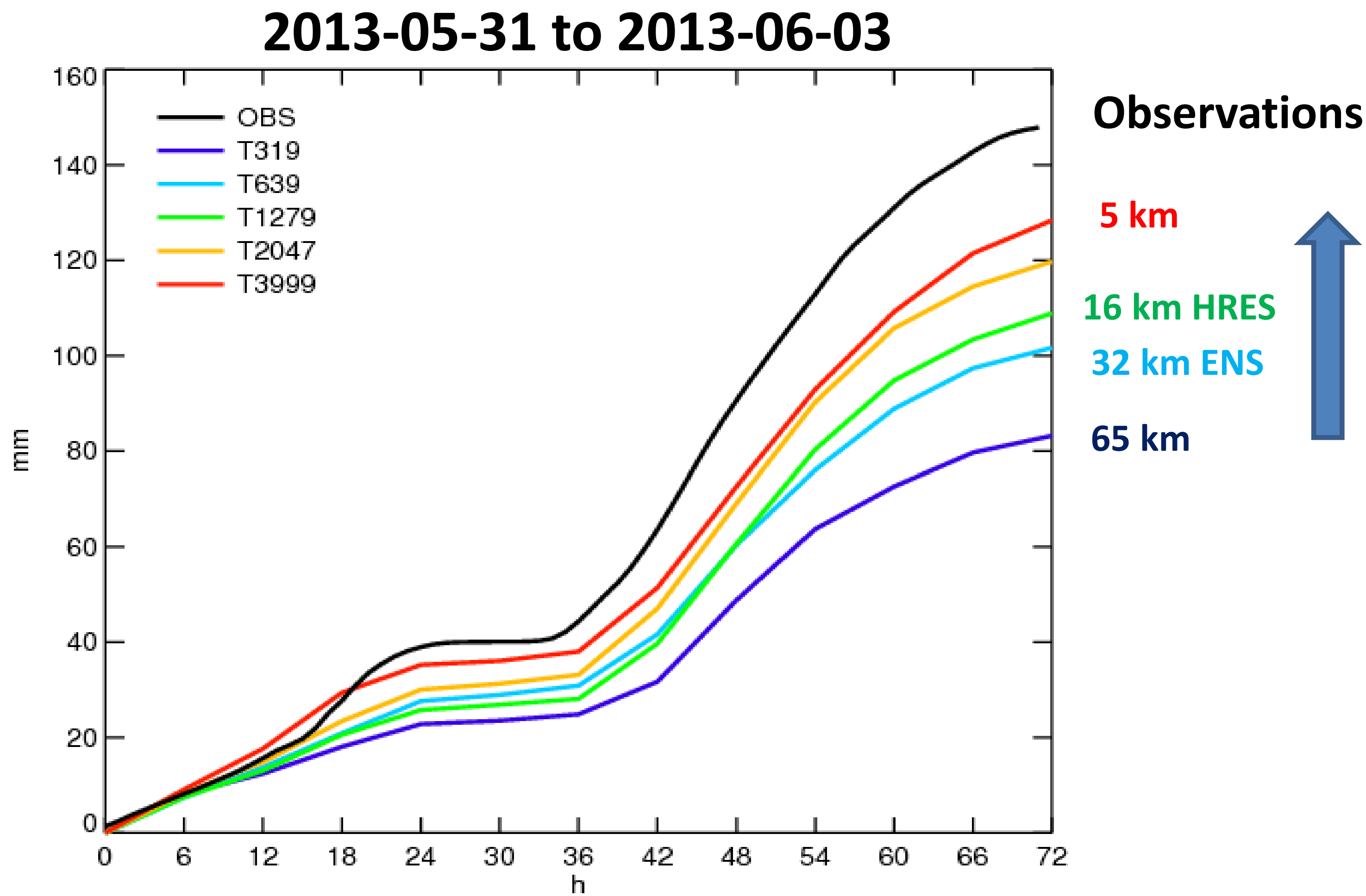


Going higher resolution: T_L3999 (5 km) wave fc (+72h)

72-hour forecast for significant wave height (colour shadings in metres) for 00 UTC on 30 October 2012 coupled to a 0.5° to 0.1° (fro T3999) global wave model.

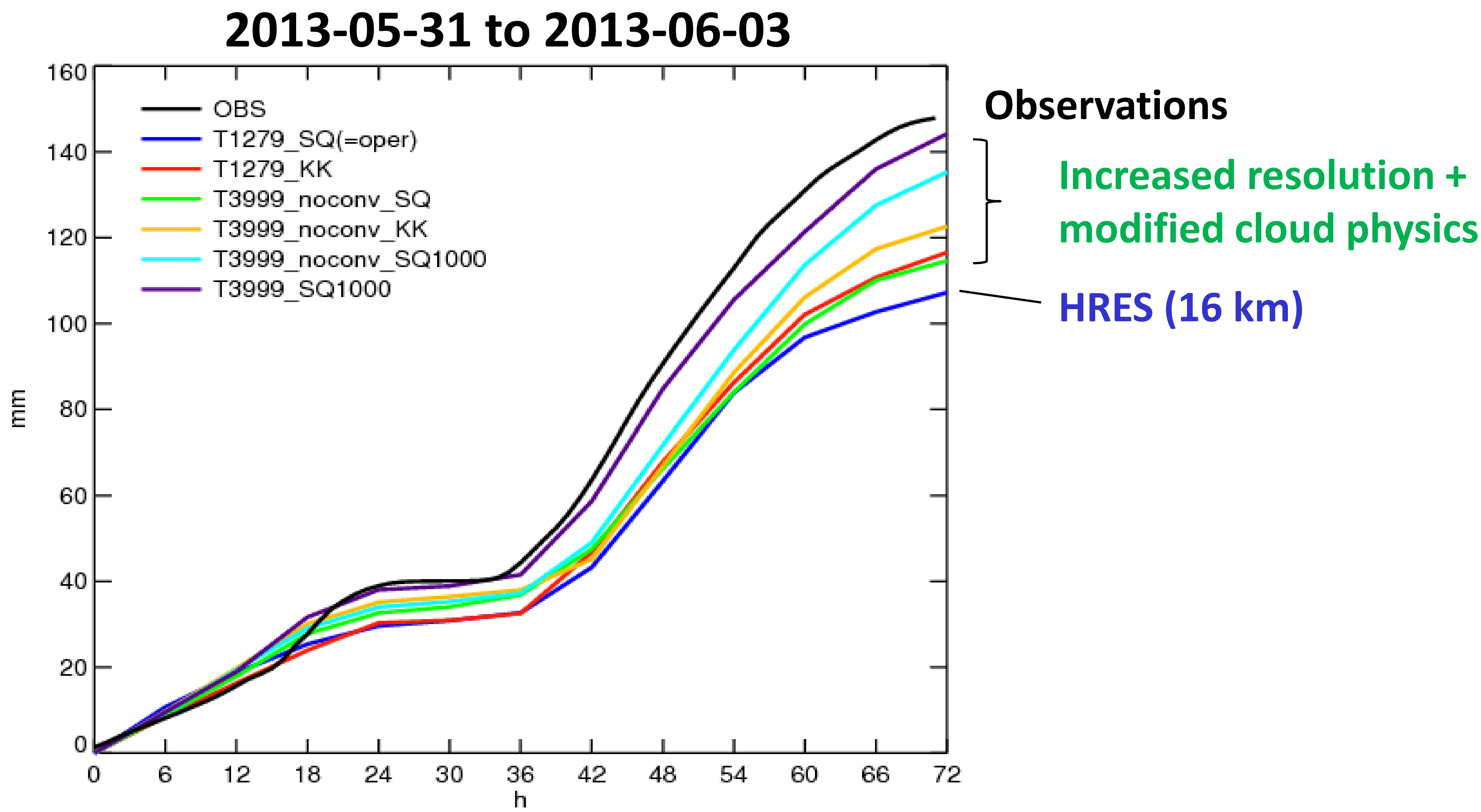


Going higher resolution: T_L3999 (5 km) TP fc (+72h)



(from Fredrik Wetterhall)

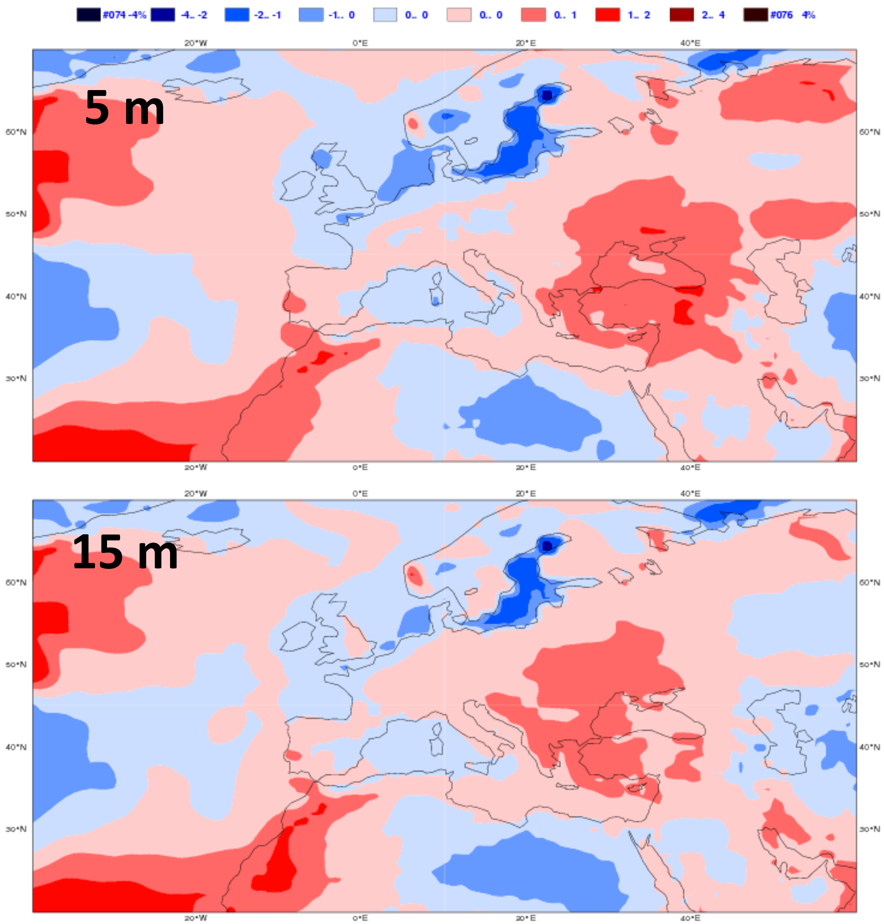
Higher resolution and physics: T_L3999 (5 km) TP fc (+72h)



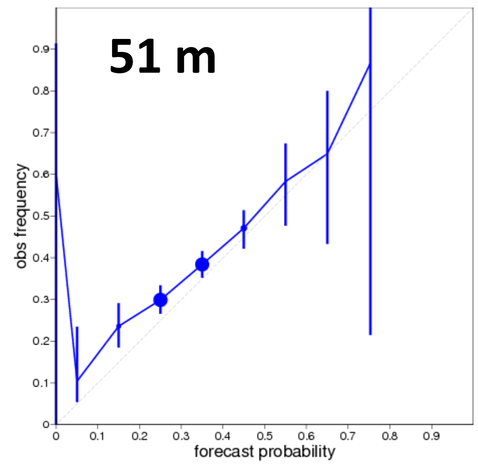
(from Fredrik Wetterhall)

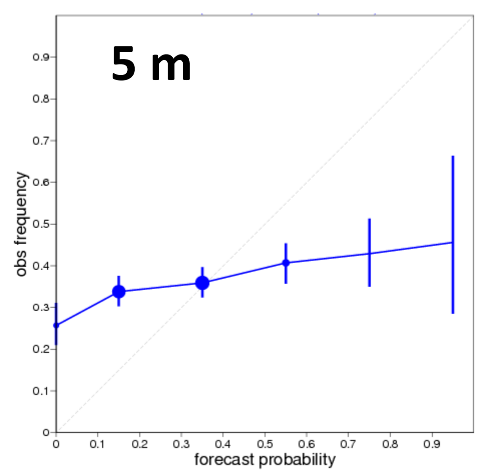
ENS refc size will increase from 5 to 15 members

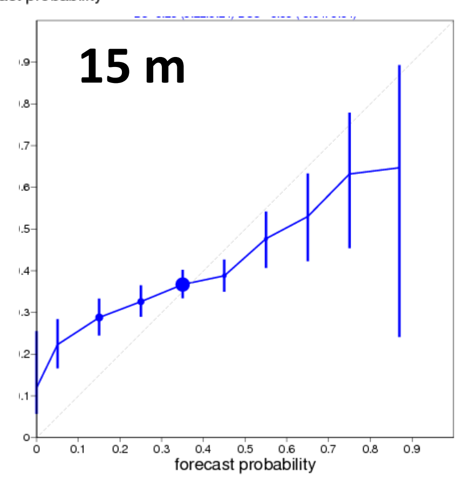
Impact on calibration
2mtm anomalies – Day 26-32



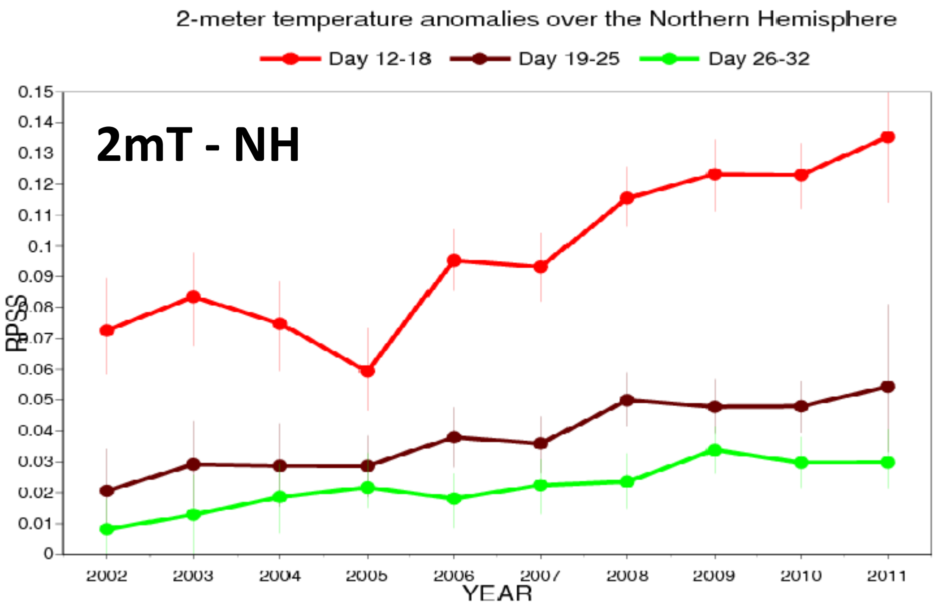
Impact on verification
T850- Upper terciles – Week 4

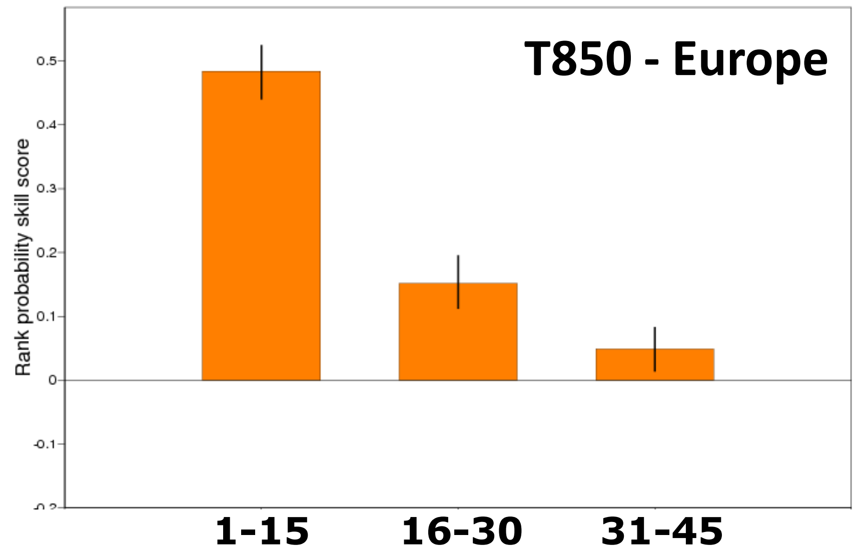


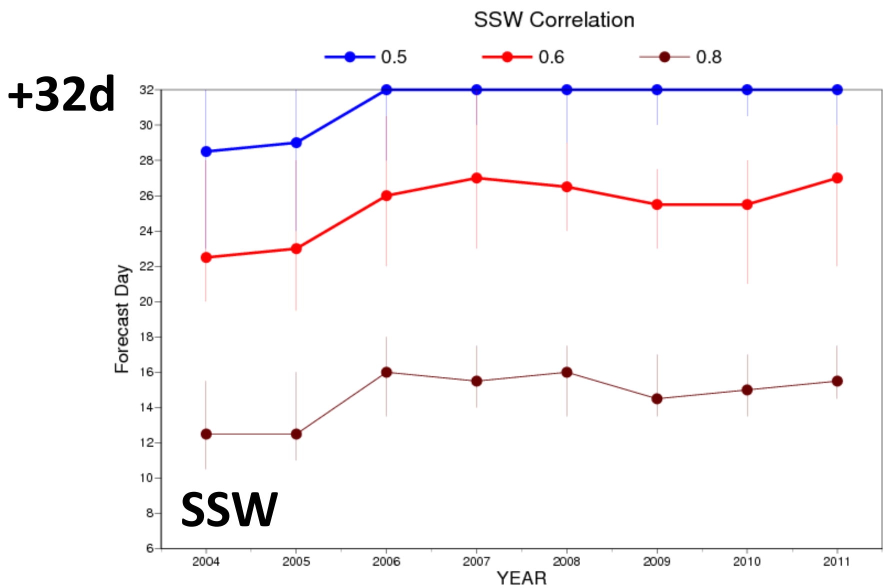


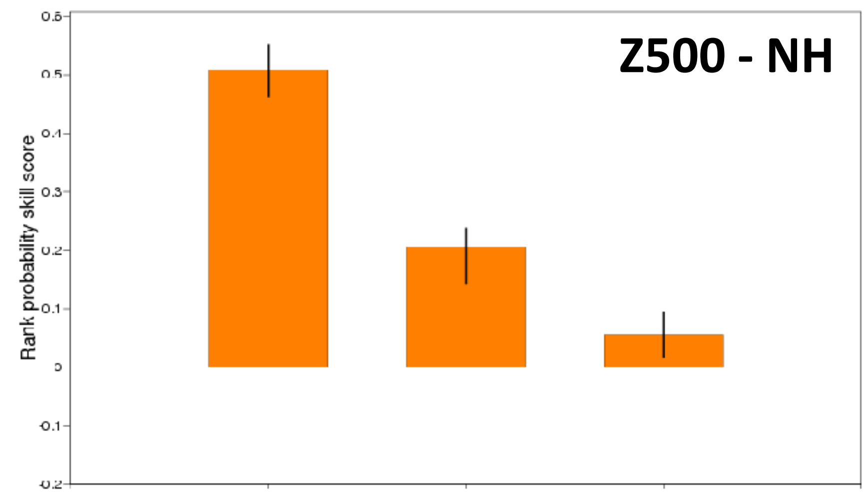


Extend the ENS to 45d/60d to exploit increased skill





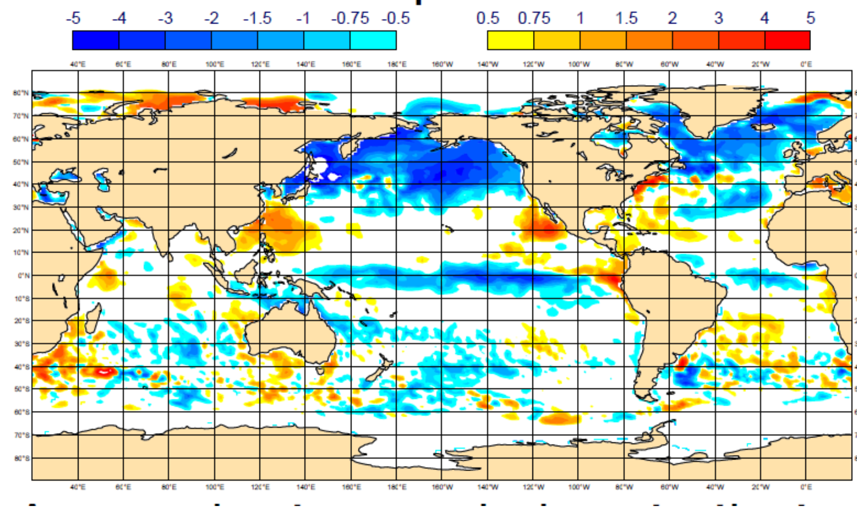




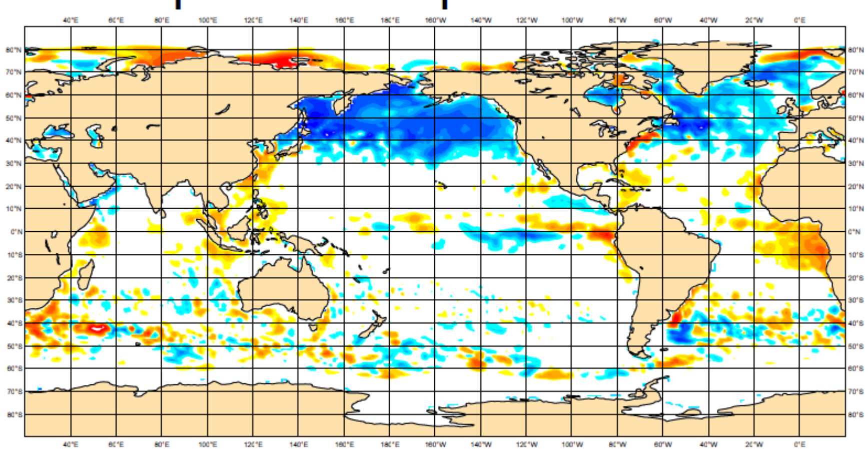
Coupled ocean-atmo. data-assimilation to improve ICs

Results based on 1 month (Sep 2010) show that SST biases are substantially reduced with a coupled ocean-atmosphere data assimilation.

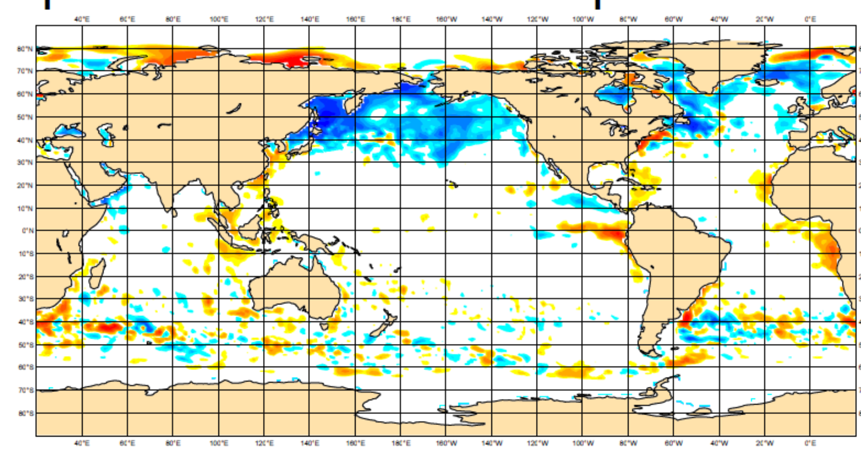
Free coupled model



Atmospheric coupled assimilation

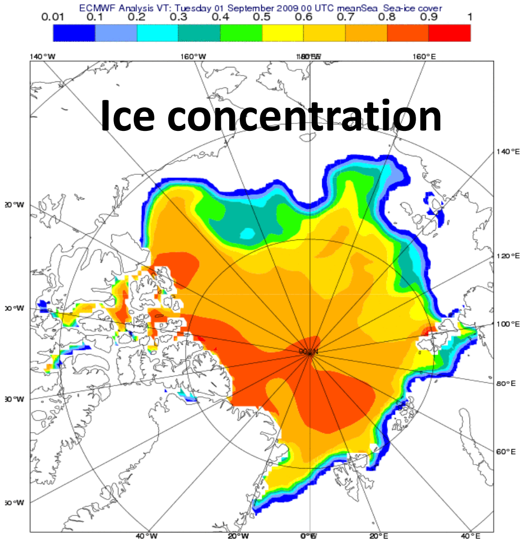


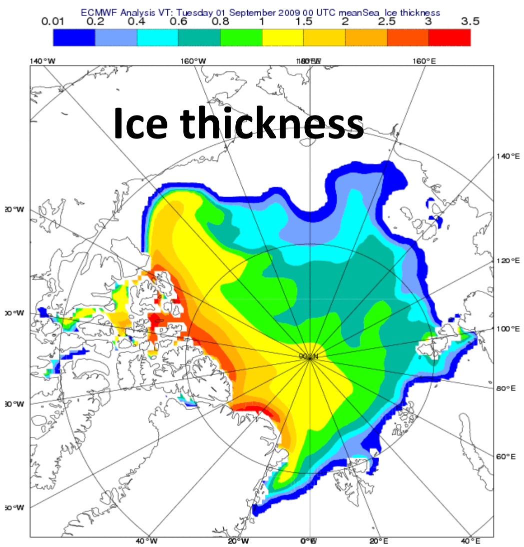
Atmospheric and ocean coupled assimilation



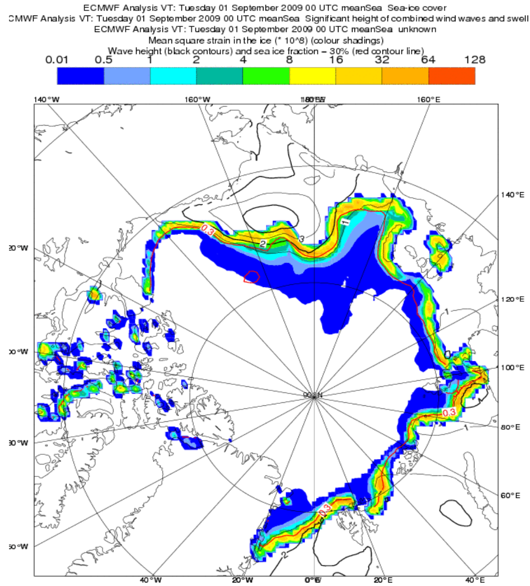
Modelling: coupling waves, currents and sea-ice

LIM



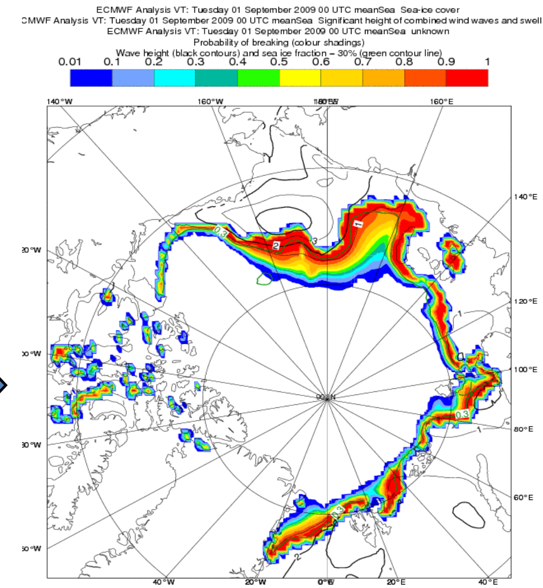


WAM



Mean square strain in the ice

LIM



Probability of exceeding breaking strain in the ice

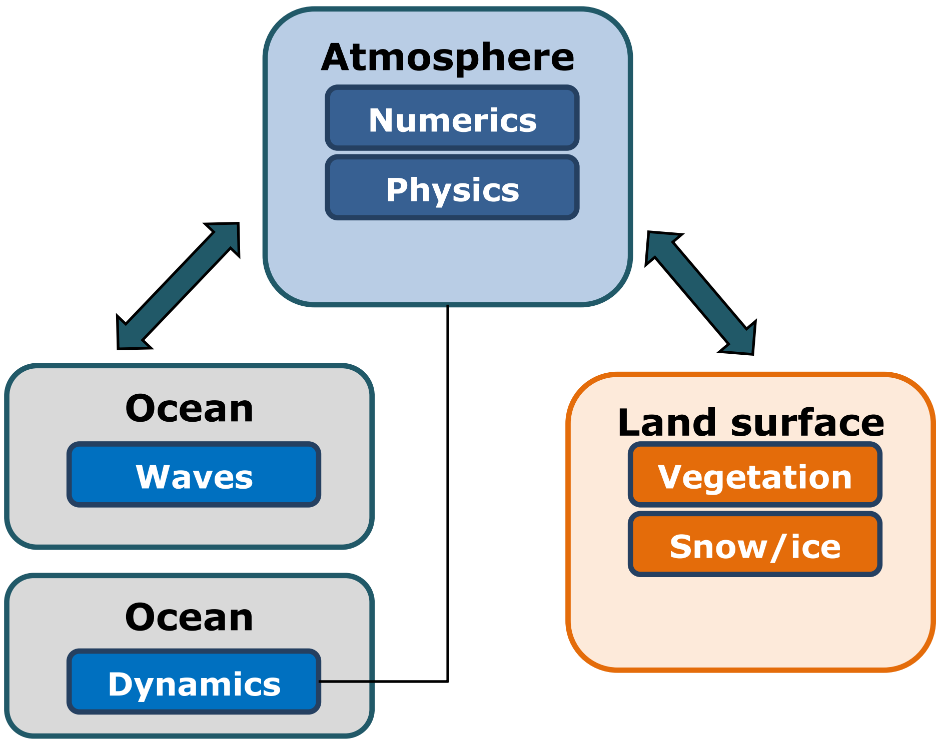
The challenges we are facing

- Scalability
- Dynamical core
- Coupling (land/ocean/atmospheric composition/meteorology)
- Predictability and seamless ensembles (EDA/ENS/monthly/seasonal)
- DA science (mainstream/reanalysis; maximize use of observations, algorithms)
- Physical processes (resolved and unresolved)
- Climate monitoring (ERA, MACC)
- Feedback: core <-> applications
- Infrastructure and compute support to enable pioneering science
- Adaptability

Opportunities rely on building better coupled models …

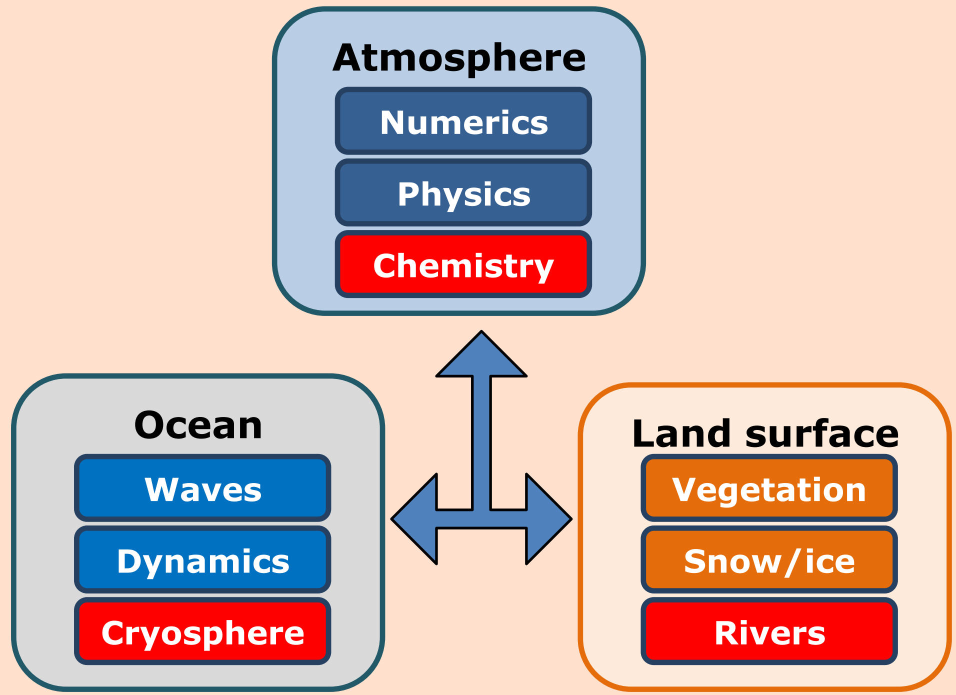
Today:

Integrated Forecasting System (IFS)



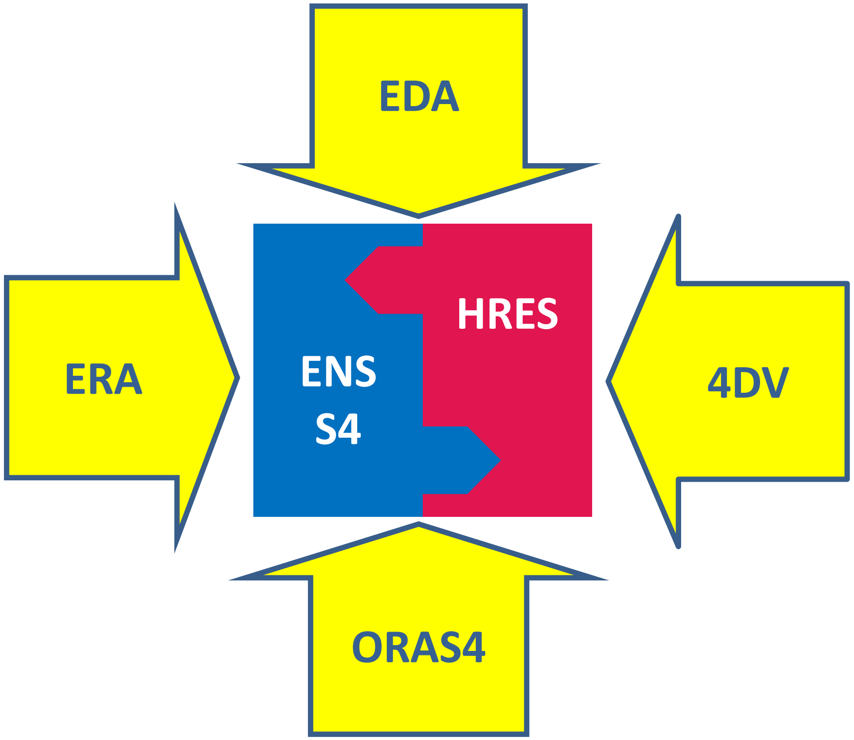
The future:

Integrated Earth-System Model (IESM)



... and on integrating/unifying the different components.

Today



PDF(0) << 4DV+EDA+ORAS4
PDF(0) << ERA+ORAS4 (past)
PDF(T) << HRES+ENS/S4

The future

PDF(0) << coupled analysis and
re-analysis (past) stream
PDF(T) << medium/long range stream