20 years of ensemble prediction at ECMWF

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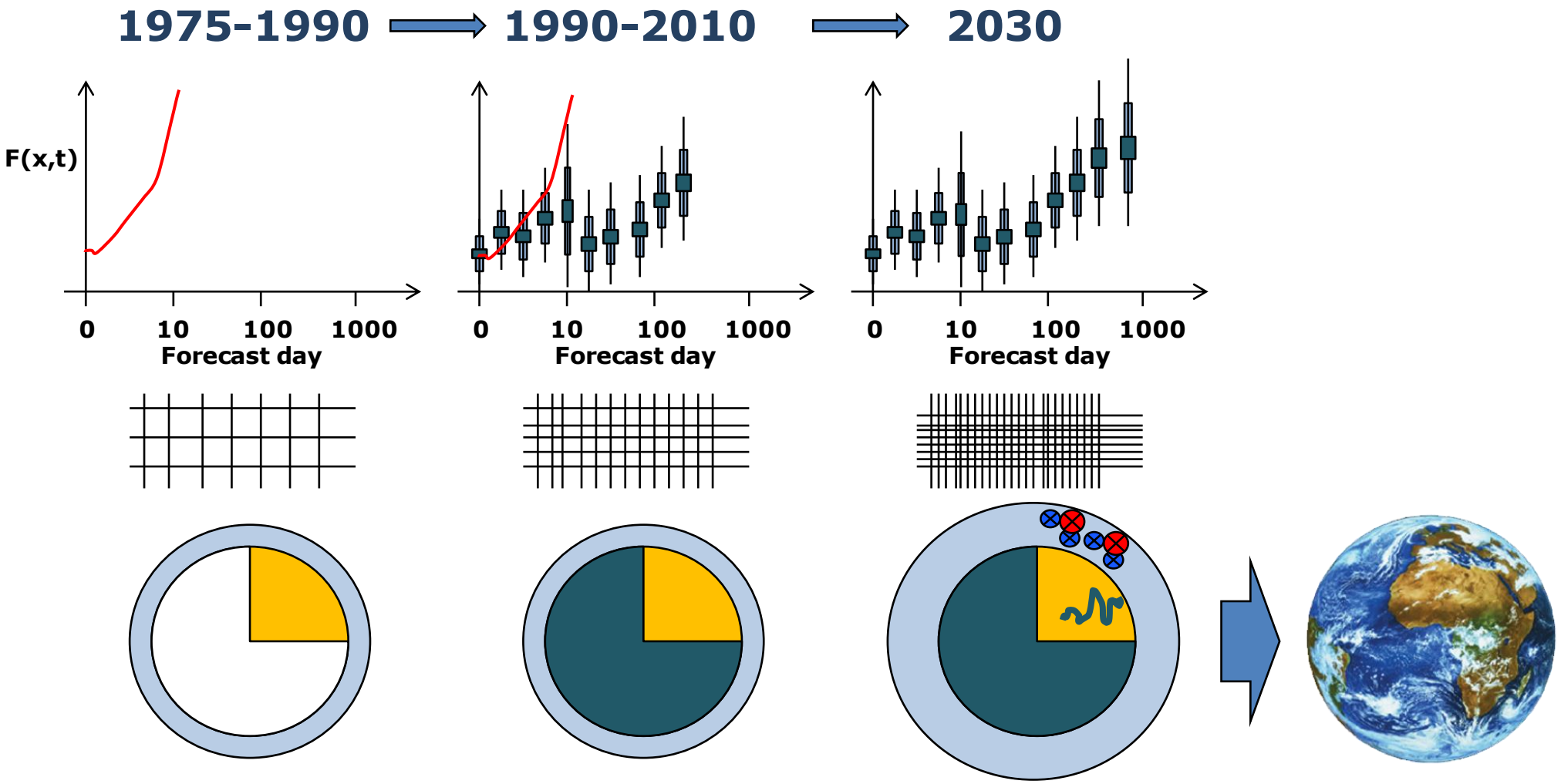
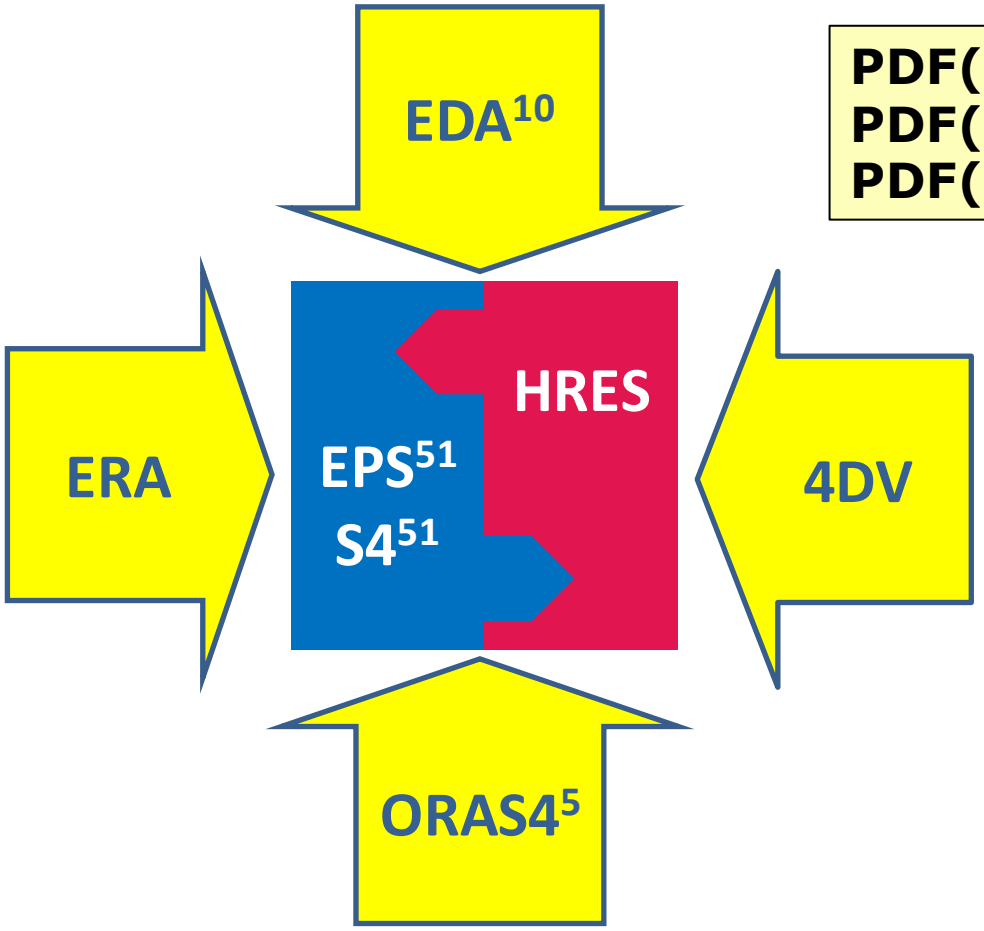
European Centre for Medium-range Weather Forecasts

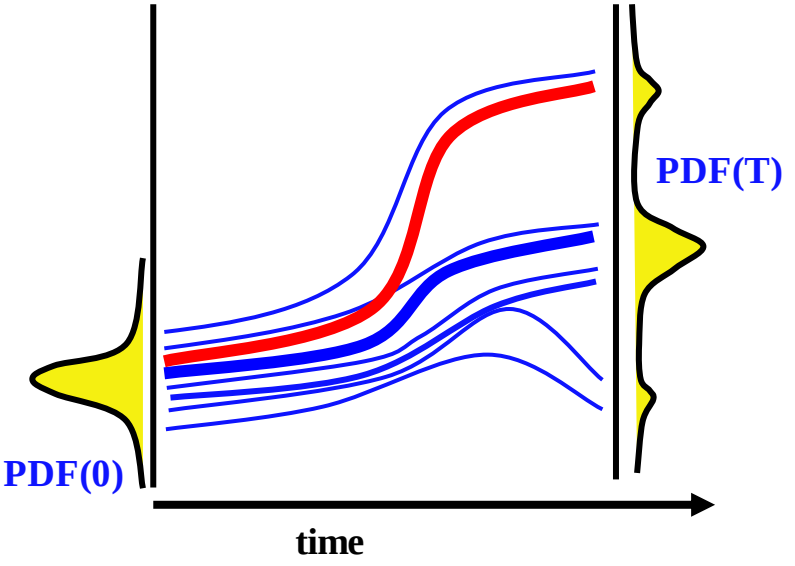
1975 > 1992 > 2012: from 10d-single to 13m-ensemble fcs



2012: ensembles are used in analysis and prediction



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



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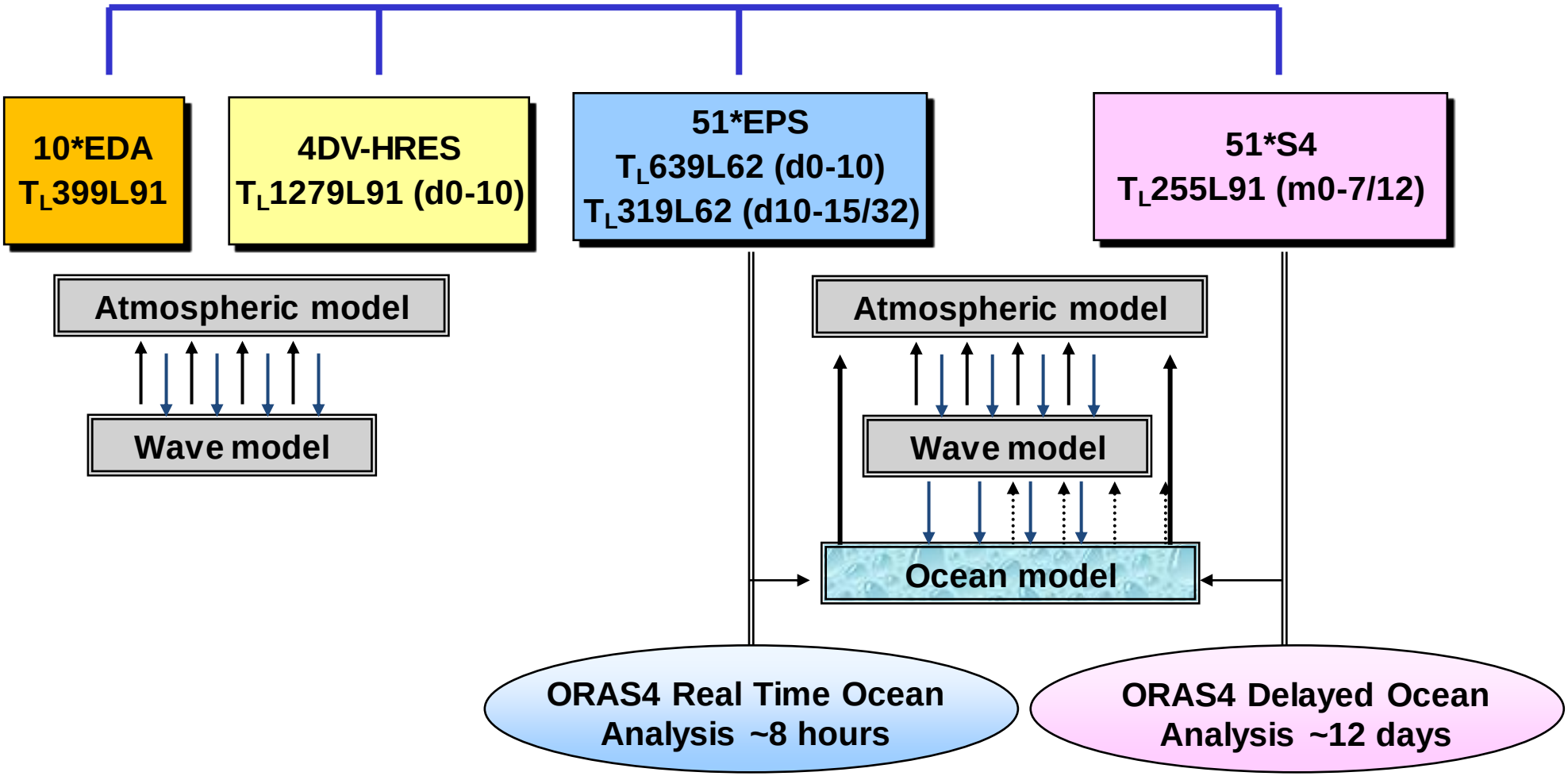
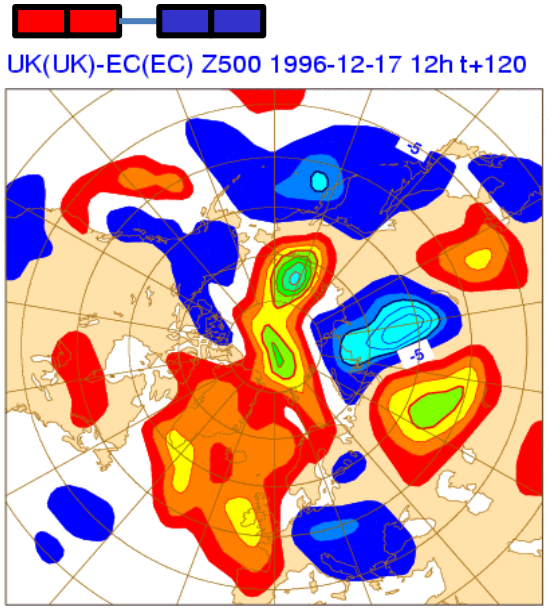
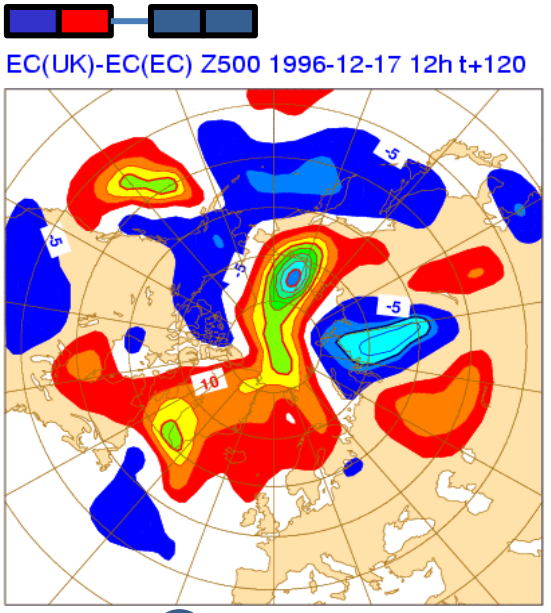


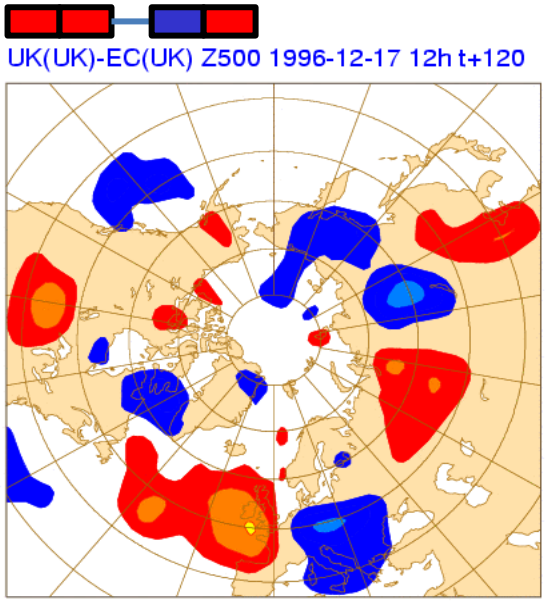
How did we design the EPS? Sensitivity to ICs and model

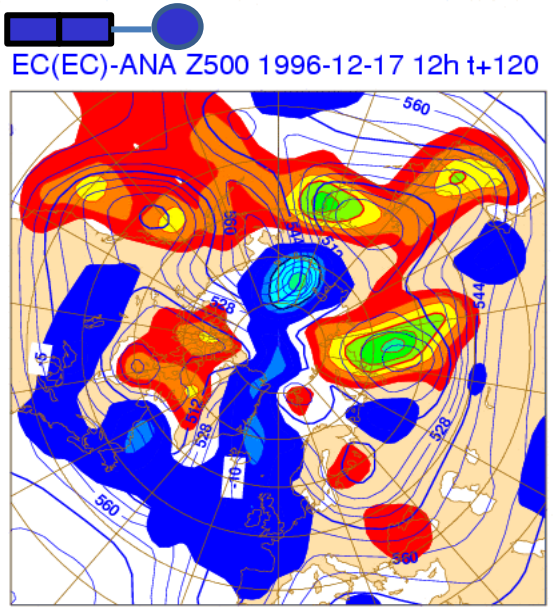
What is the relative contribution of initial and model uncertainties to forecast error?

Harrison et al (1999) showed that initial differences explains most of the differences between ECMWF-from-ECMWF-ICs and UKMO-from-UKMO-ICs forecasts.







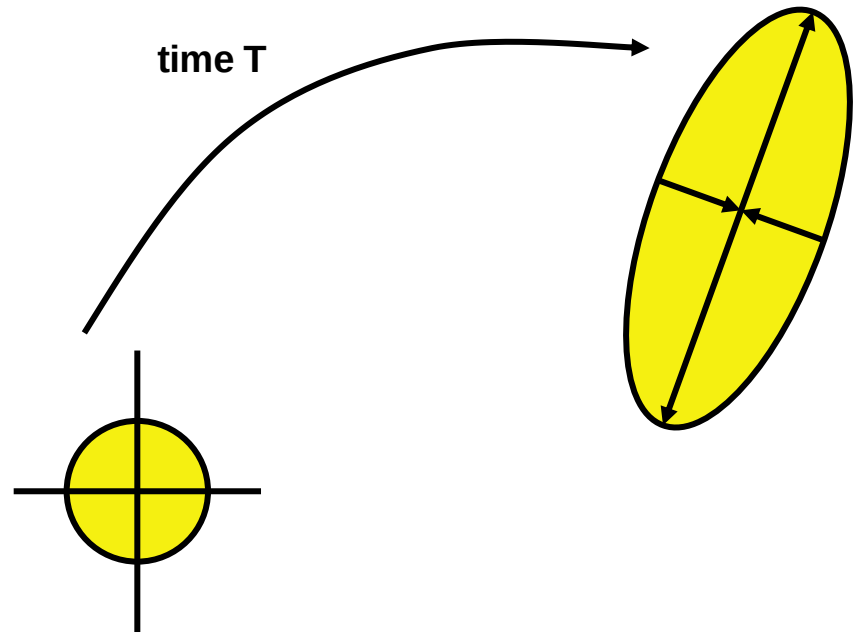


How did we simulate initial uncertainties?

Initial error components along the directions of maximum growth amplify most. These are the most relevant directions to sample.

To formalize the computation of the directions of maximum growth a metric (inner product) should be defined to 'measure' growth.

The metric used at ECMWF in the ensemble system is total energy.



$$< x; E_{TE}\, y >= \frac{1}{2}\iint (\nabla\Delta^{-1}\zeta_x \cdot \nabla\Delta^{-1}\zeta_y + \nabla\Delta^{-1}D_x \cdot \nabla\Delta^{-1}D_y + \frac{C_p}{T_r}T_x T_y)d\Sigma \frac{\partial p}{\partial \eta}d\eta$$

$$+ \int (R_d \frac{T_r}{p_r} \ln \pi_x \ln \pi_y)d\Sigma$$

1992: simulation on initial uncertainties with SVs

Since its implementation in 1992, singular vectors, i.e. perturbations with the fastest finite-time growth rate initial uncertainties have been used to simulate initial uncertainties.

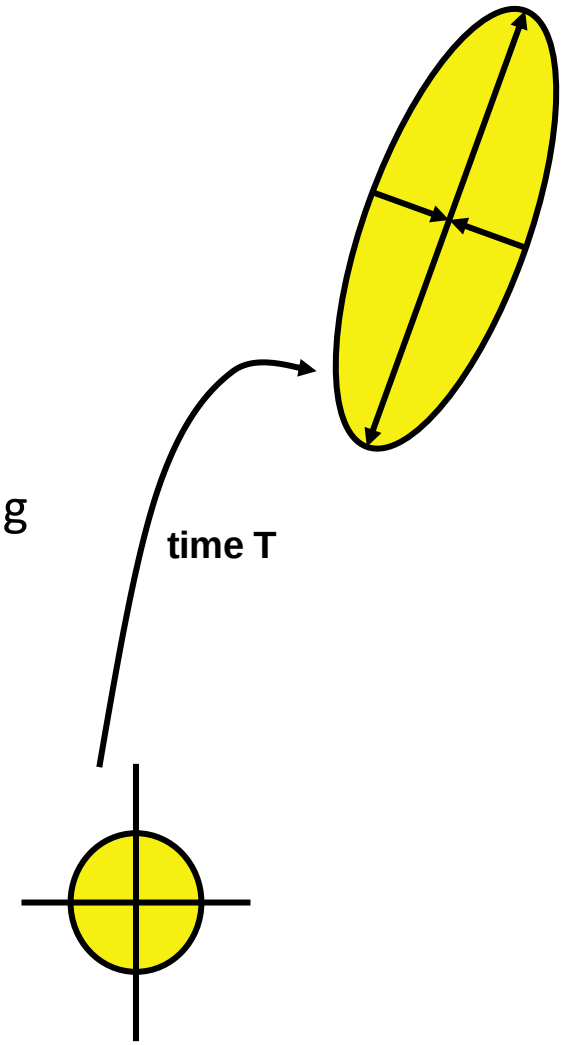
The perturbation time evolution can be linearly approximated:

$$z'(t) = L(t,0)z'_0$$

and the total-energy singular vectors can be computed by solving the eigenvalue problem:

$$\|z'(t)\|^2 = < z'(t); Ez'(t) > = < L(t,0)z'_0; EL(t,0)z'_0 >$$

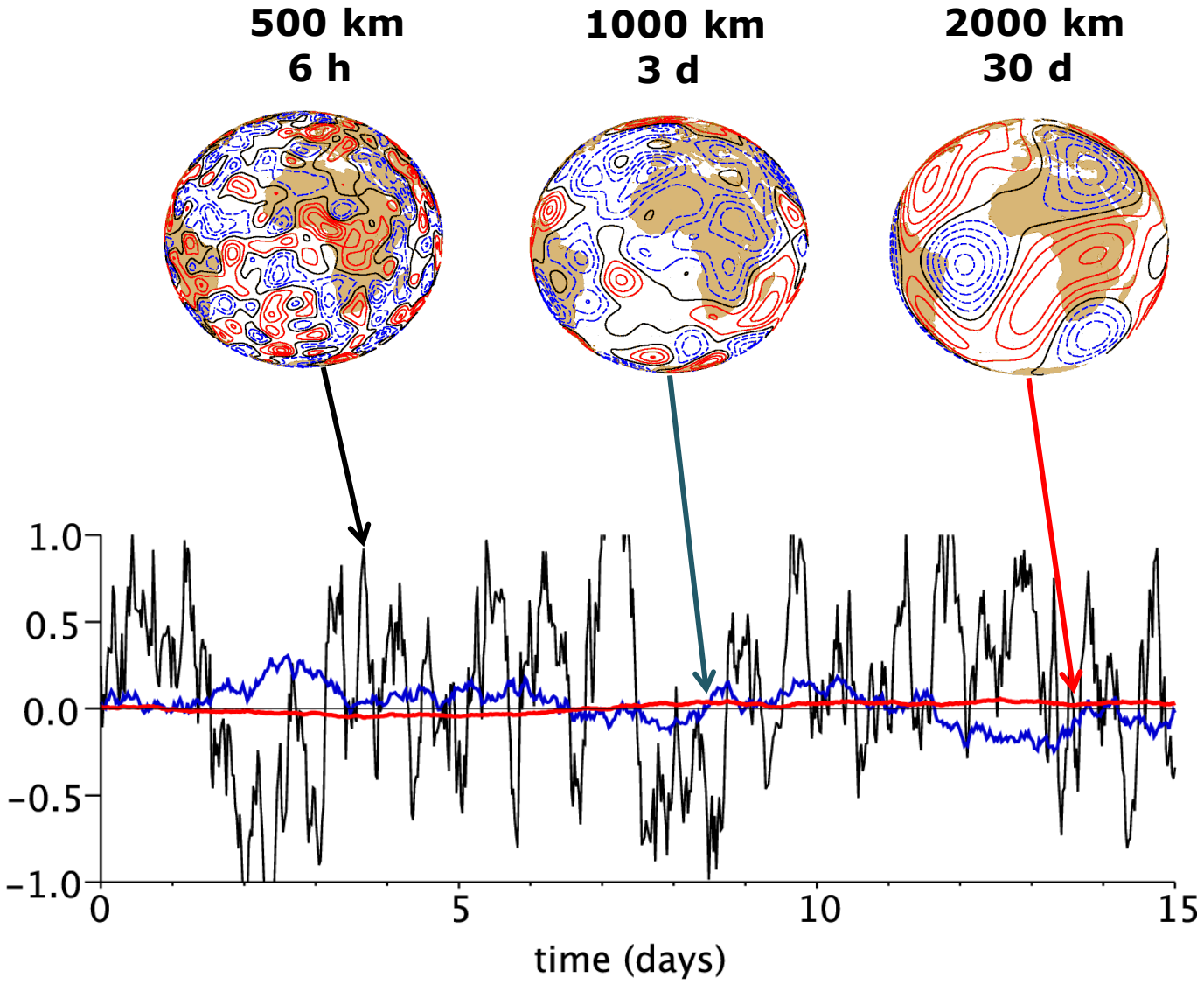
$$E^{-1/2}L^*ELE^{-1/2}v_j = \sigma_j^2 v_j$$



1998: inclusion of model uncertainties with SPPT

Since Oct 1998, the EPS has included a stochastic simulation of random errors due to parameterized physical processes [SPPT(1L)].

Since Nov 2010, the scheme includes a multi-scale pattern generator [SPPT(3L)].



2010: inclusion of the back-scatter scheme SPBS

Since Nov 2010, a stochastic backscatter scheme (SPBS) is added to SPPT to simulate the fact that a fraction of the dissipated energy is backscattered upscale and acts as streamfunction forcing for the resolved-scale flow (*Berner et al* 2009).

The streamfunction forcing in the latest formulation (*M Steinheimer and G Shutts*, 2010) is given by :

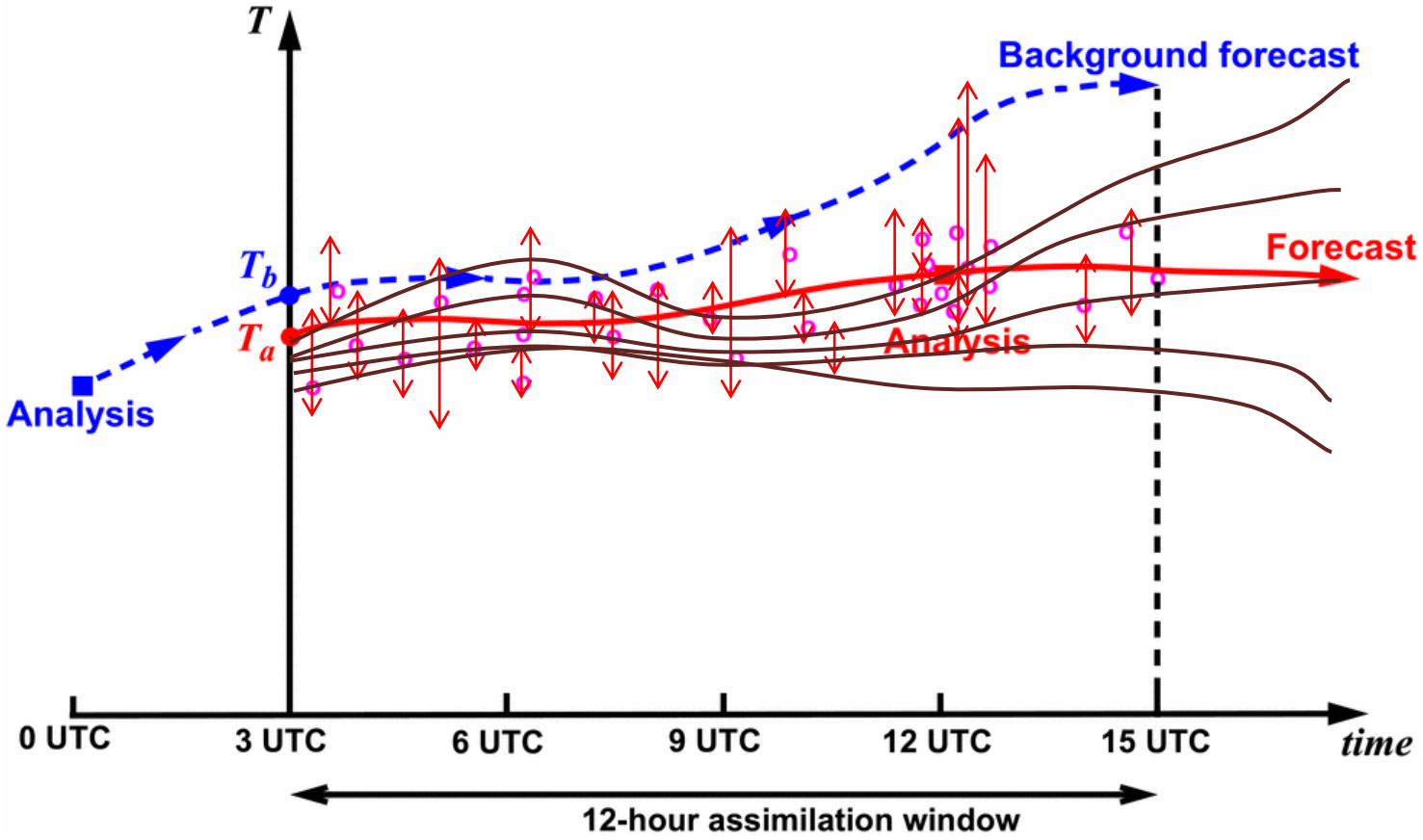
$$F_\Psi(\lambda,\mu,z,t) = \left(b_R \widehat{D_{tot}}(\lambda,\mu,z,t)\right)^{\frac{1}{2}} F^*_\Psi(\lambda,\mu,z,t)$$

- F_Ψ: **Streamfunction forcing**
- b_R: **Backscatter ratio**
- $\widehat{D_{tot}}$: **Total dissipation rate**
- F^*_Ψ: **Pattern generator**

2010: addition of EDA-based perturbations to SVs

Each observation has an error (instrument, representativeness) and also each model trajectory should take model error into account.

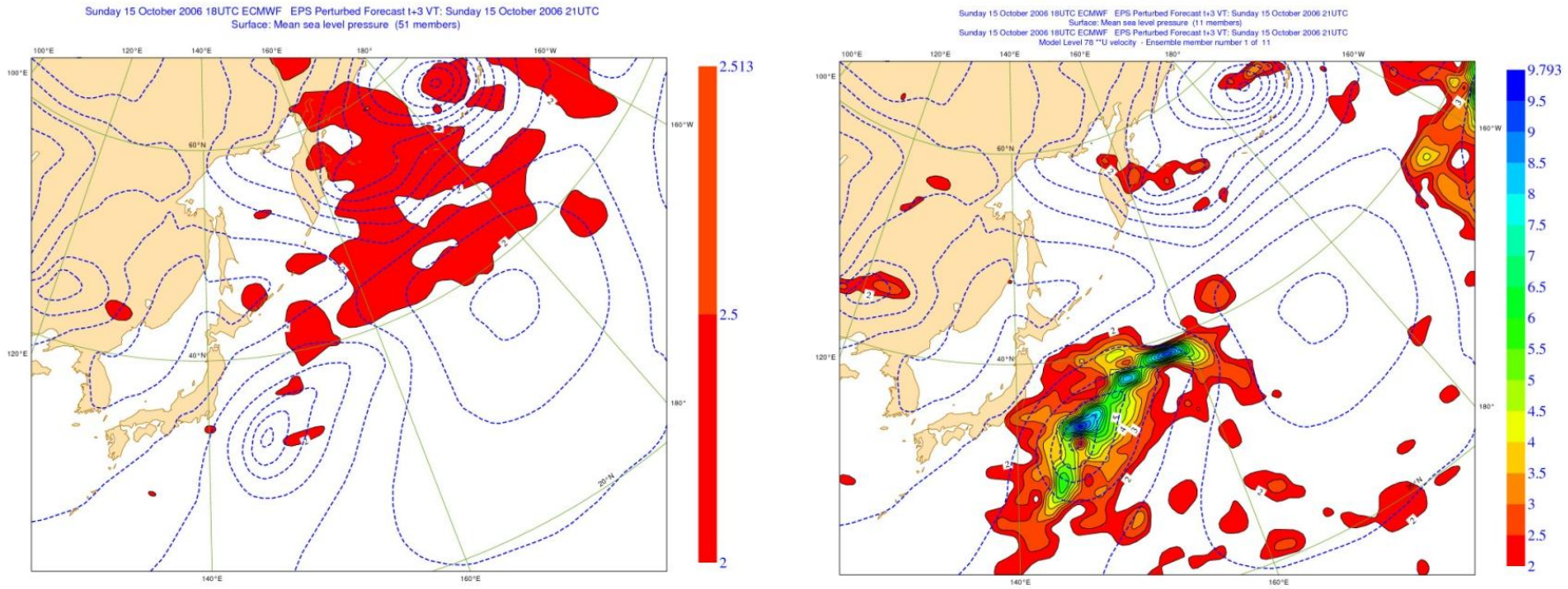
A way to simulate both these effects is to follow an ensemble approach.



2010: simulation on initial uncertainties with SVs and EDA

The EDA captures the flow-dependent analysis uncertainty due to observation and model uncertainty. Since June 2011 the EDA is used in the HRES 4D-Var to estimate the background error variances.

U850 background error standard deviation
Randomization method (left) – EDA (from cy36r4, right)



2012: the operational EPS

The EPS includes 51 forecasts with resolution:

- T_L639L62 (~32km, 62 levels) from day 0 to 10
- T_L319L62 (~64km, 62 levels) from day 10 to 15

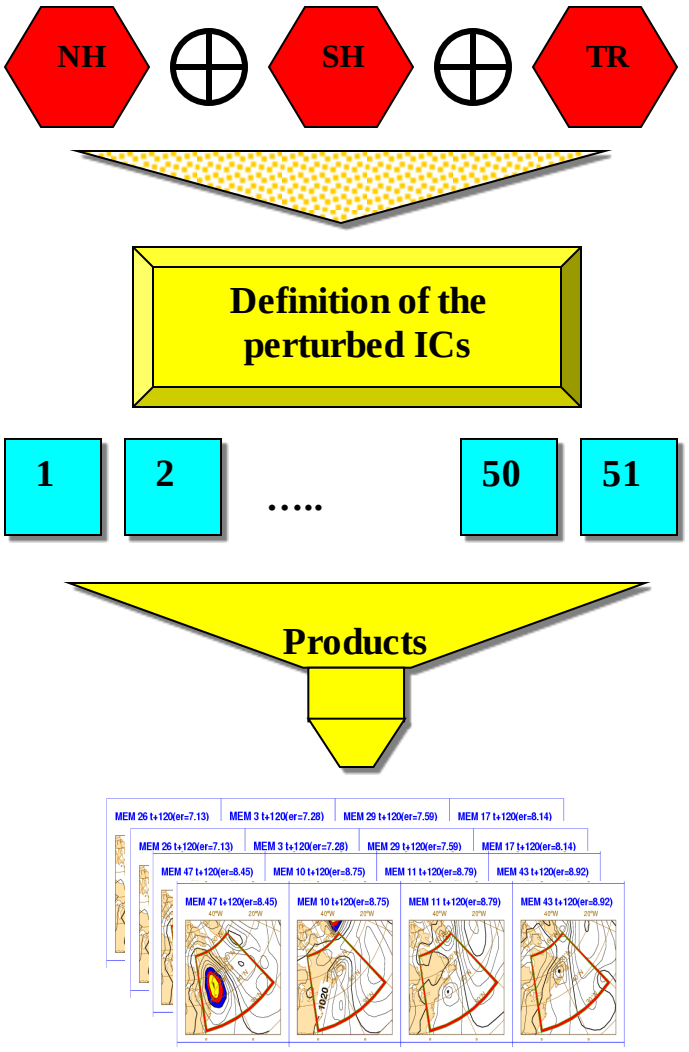
Initial uncertainties are simulated with T42L62 SVs and T399 EDA-based perturbations.

Model uncertainties are simulated using two stochastic schemes (SPPT and SPBS).

The EPS is run daily at 00 & 12UTC up to 15d.

It is coupled to a wave model from day 0 and to a dynamical ocean from day 10.

Every Mon & Thu at 00UTC it is extended to 32d.

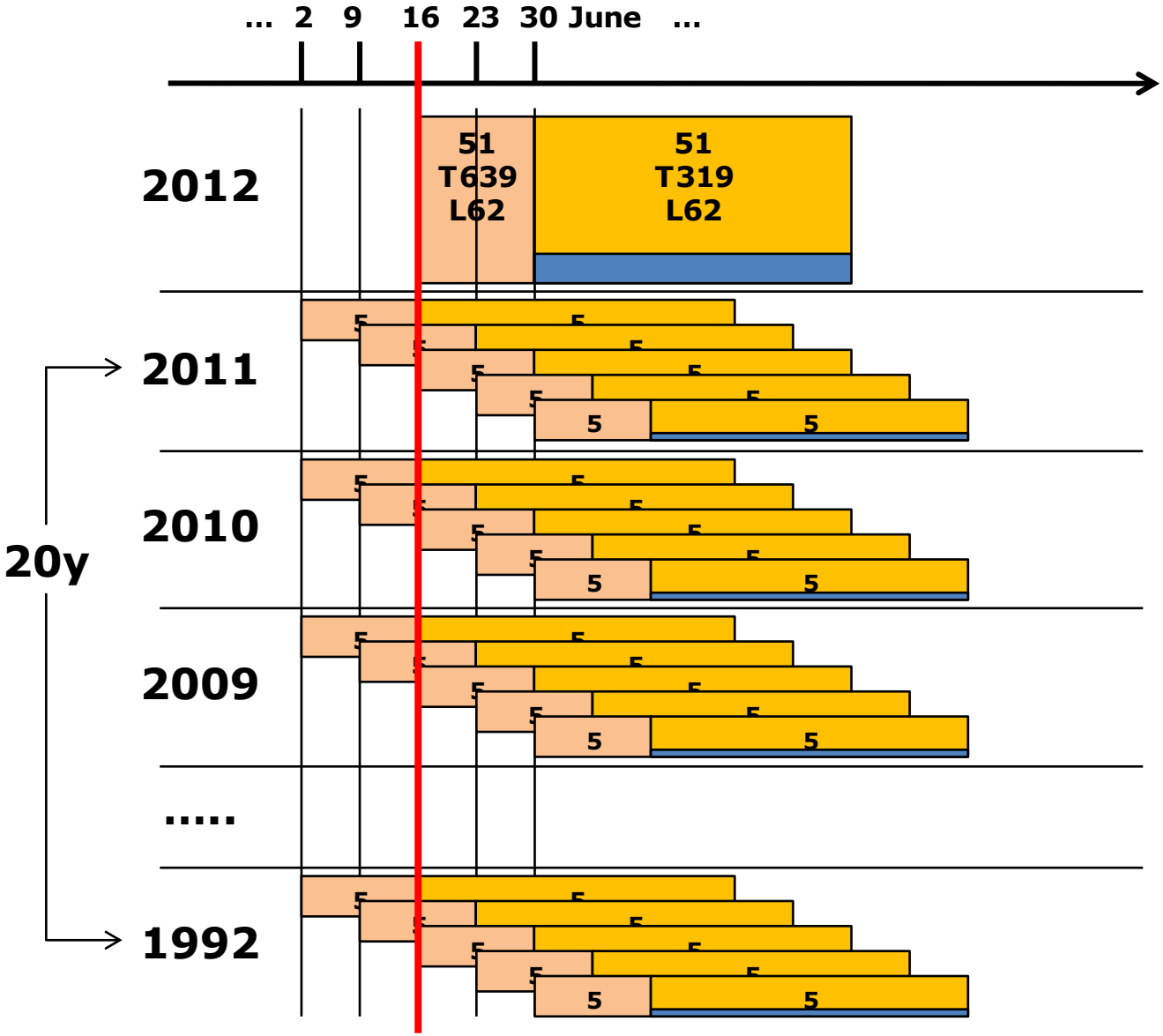


The EPS re-forecast suite to estimate the M-climate

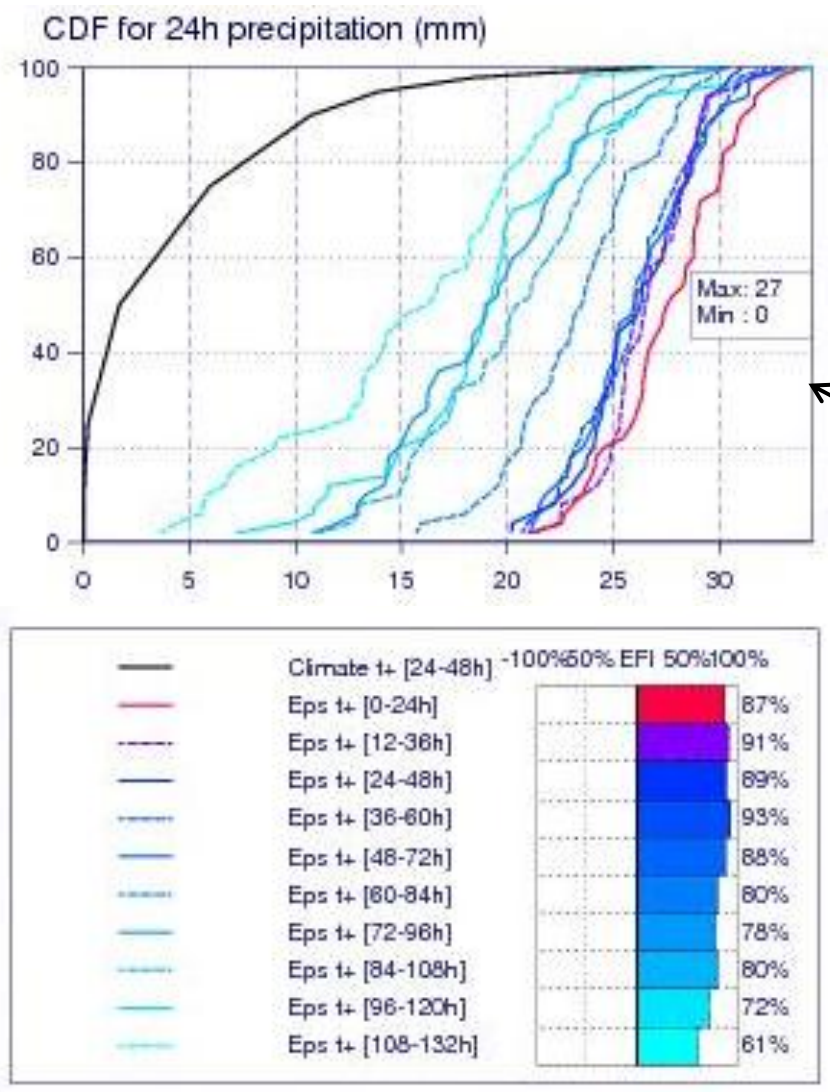
Following *Thomas Hamill* work, a re-fc suite is part of all ECMWF ensemble systems. Each day, the M-climate is estimated using **500 EPS re-forecasts**:

- 20 years (1992 – 2011)
- 5 ICs (-14d,-7d,0,+7d,+14d)
- 5 members

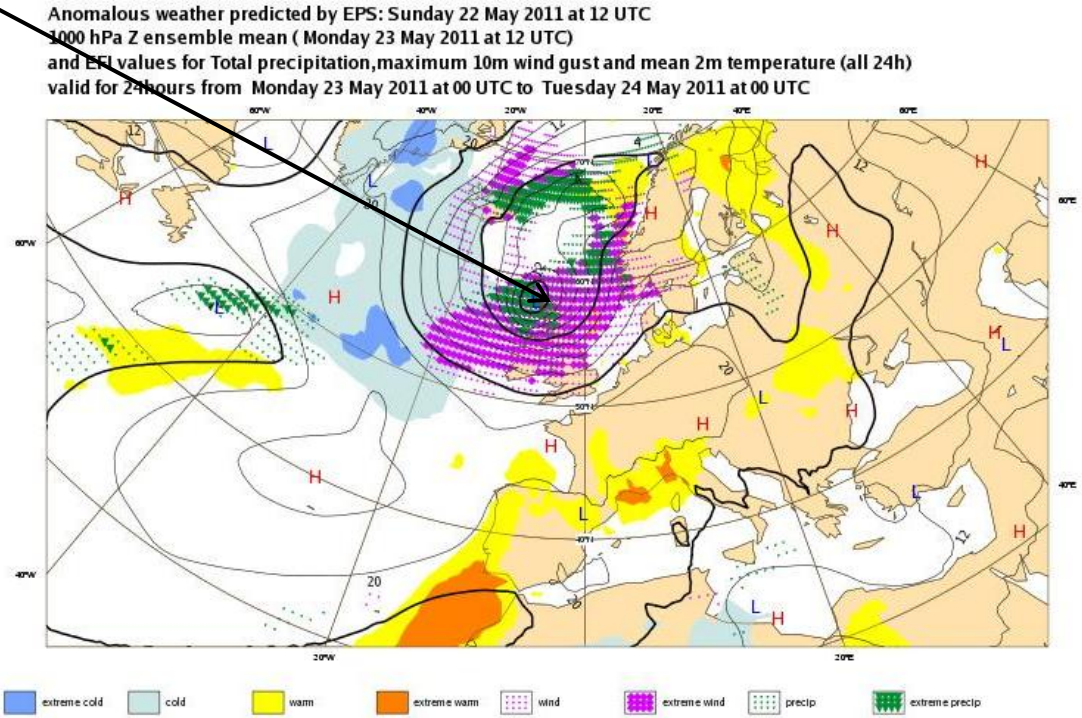
Some of the EPS products (e.g. the Extreme Forecast Indices) are bias corrected and/or calibrated using the model climate.



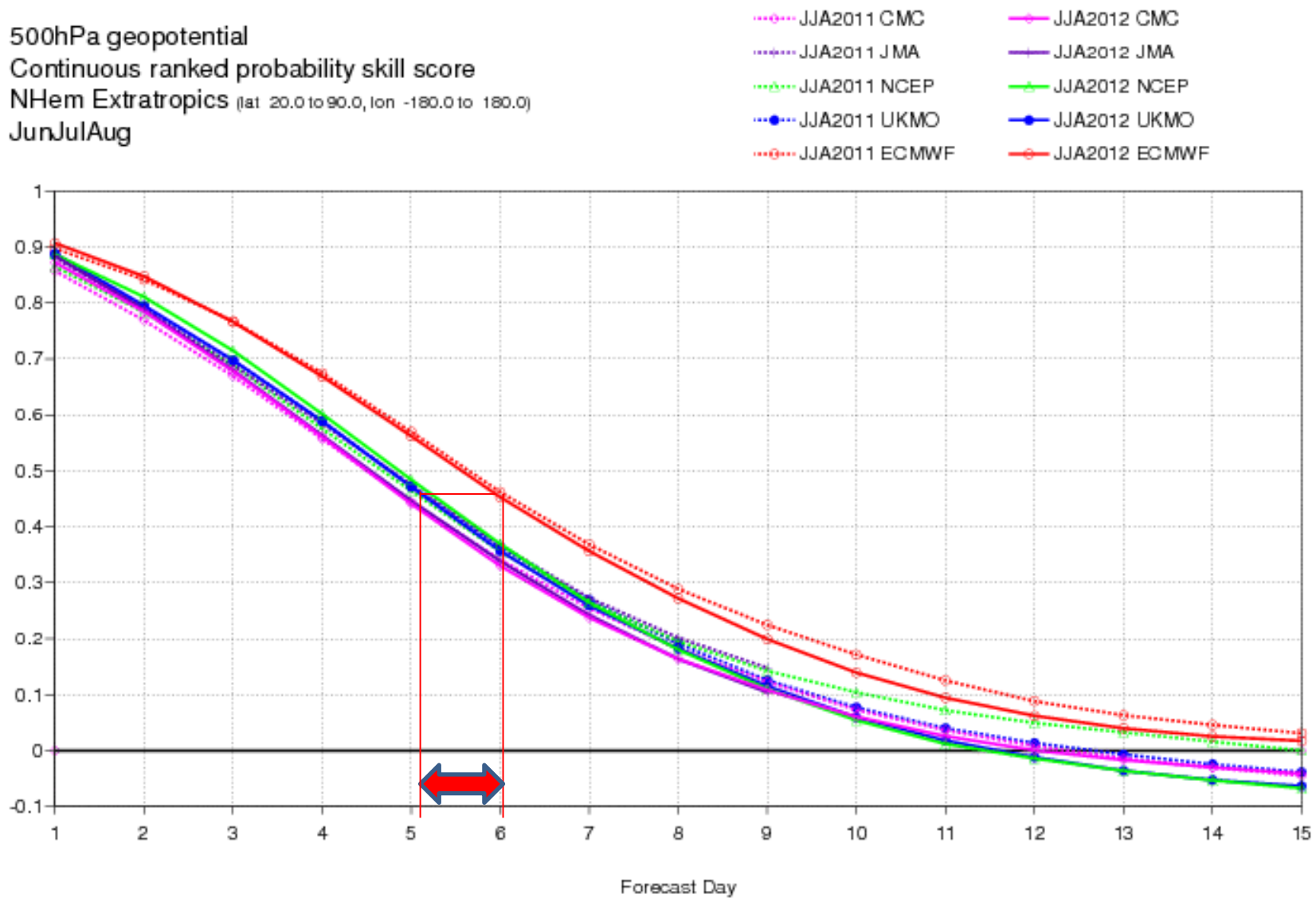
EPS-based products for severe weather: the EFI



The EFI (Extreme Forecast Index) is computed by comparing the **model climate CDF** and the **forecast CDF** (coloured lines). EFI indices for surface variables are key products to predict severe weather conditions. The EFI maps extremes from the model phase space to reality.



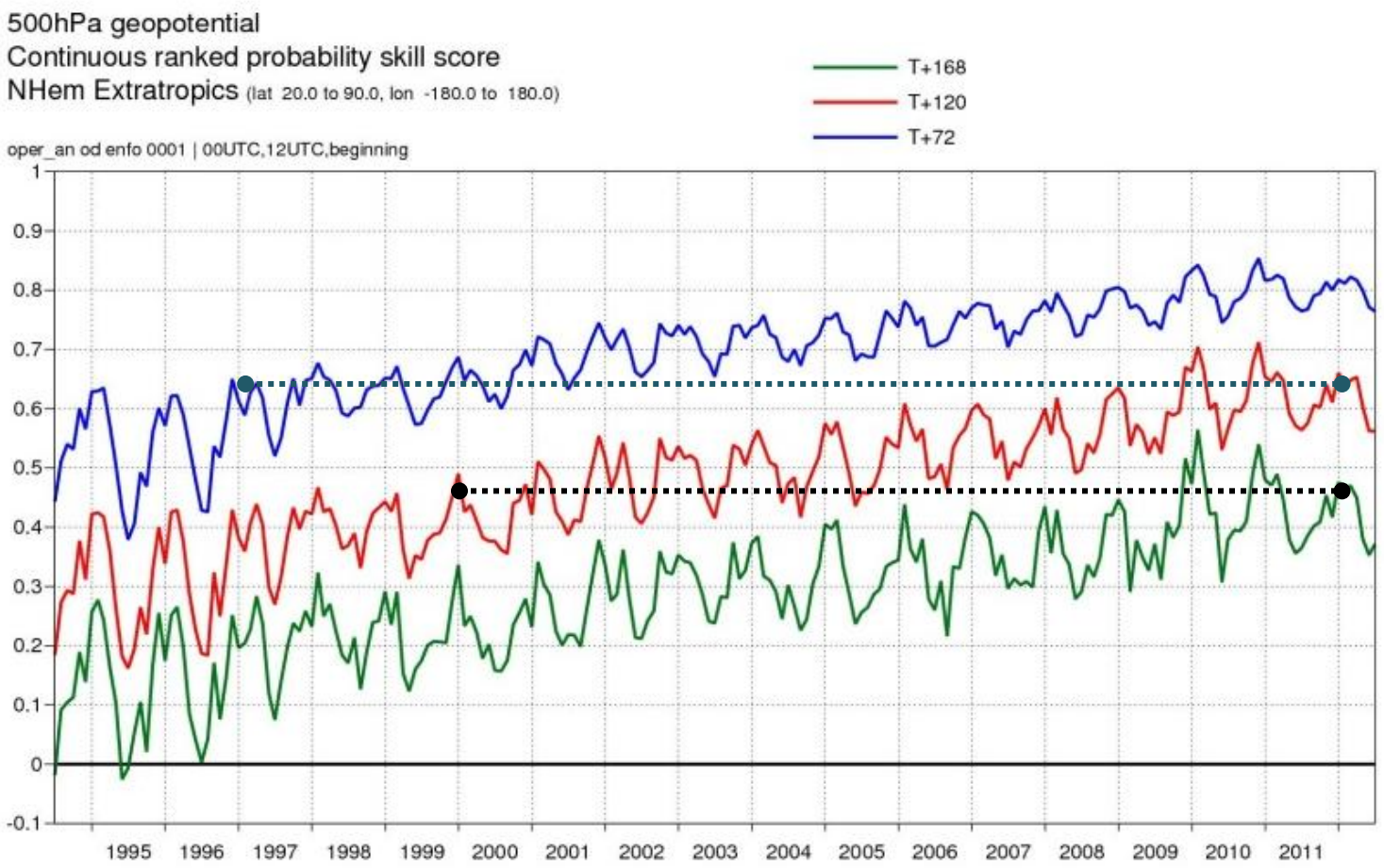
Latest EPS scores: JJA 2012, CRPSS for Z500 over NH



EPS performance: T850 v an, NH

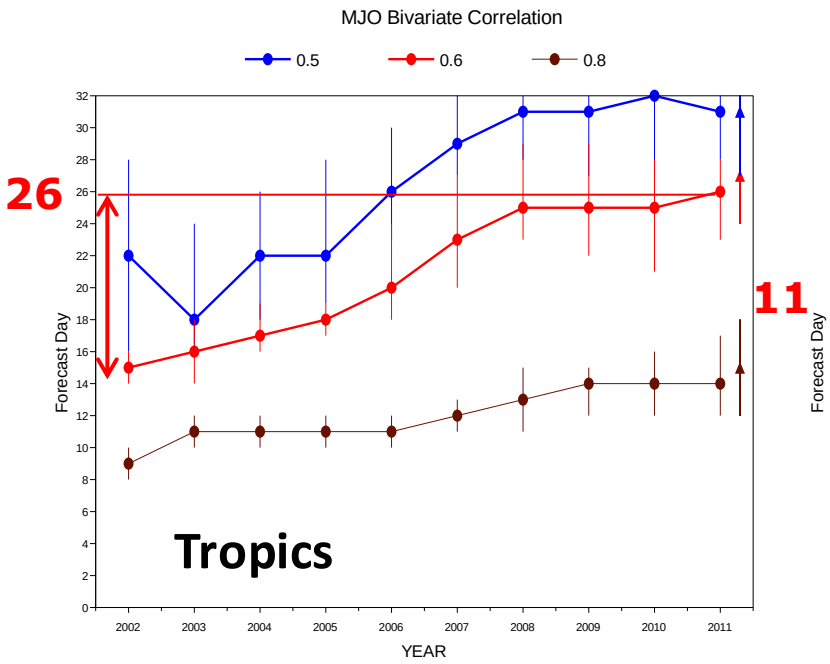
The performance of the EPS has been improving continuously for upper level fields.

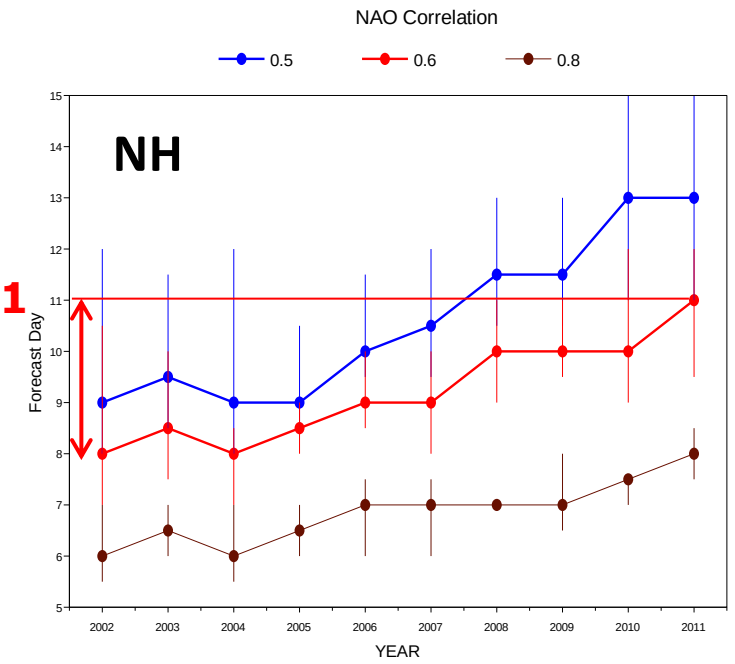
Results indicate predictability gains of ~1.5-2.0 days/decade.



(from M Janousek)

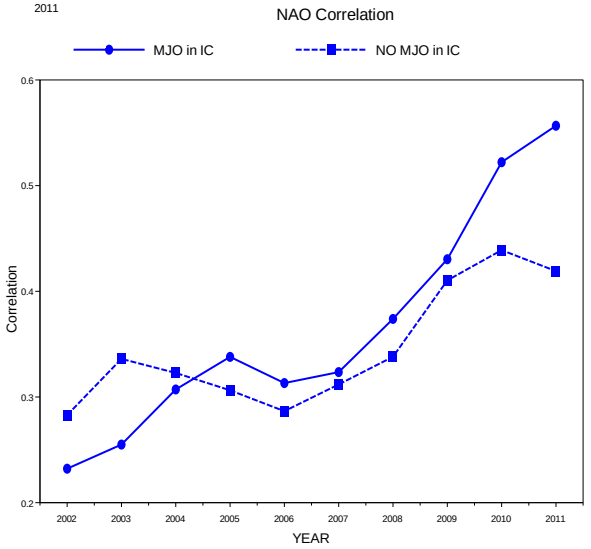
Performance of the monthly Forecasts since 2002



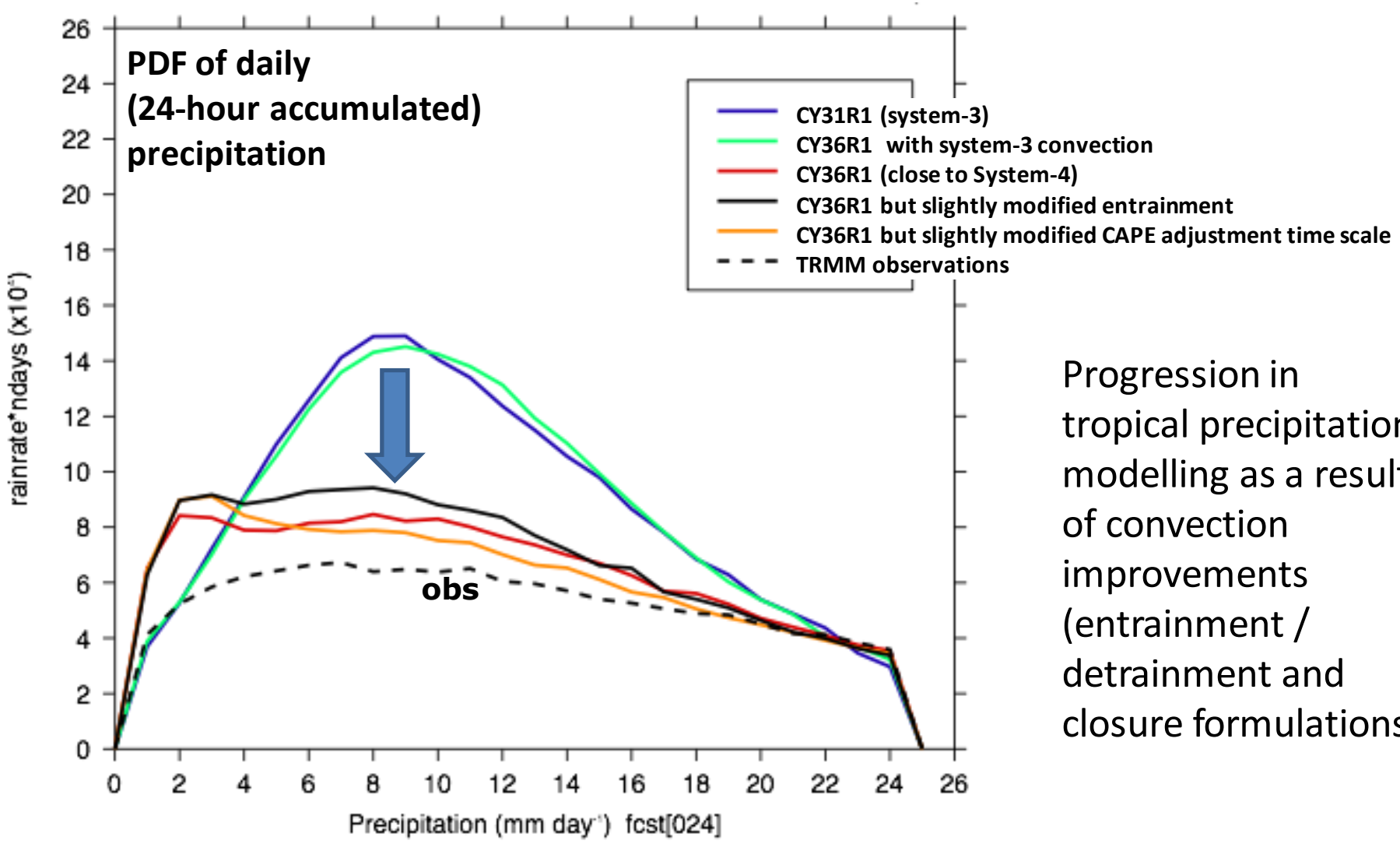


The skill of monthly forecasts have been continuously improving both in the tropics for the MJO (top left) and the extra-tropics for the NAO (top right).

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



Changes in convection improves tropical precipitation

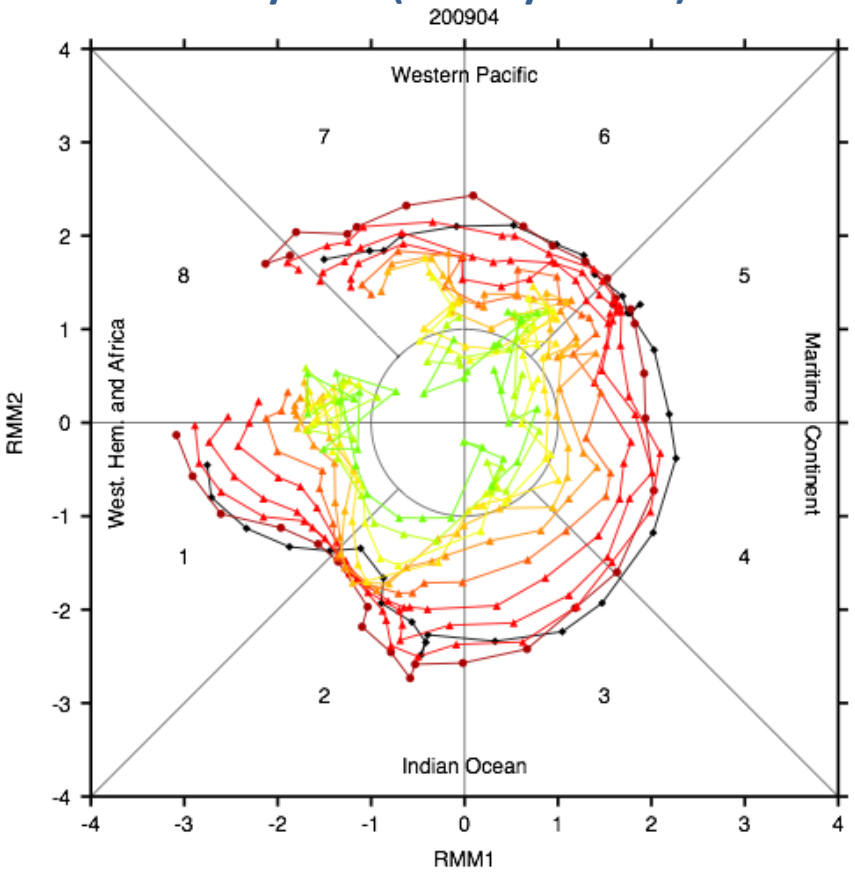


Progression in tropical precipitation modelling as a result of convection improvements (entrainment / detrainment and closure formulations)

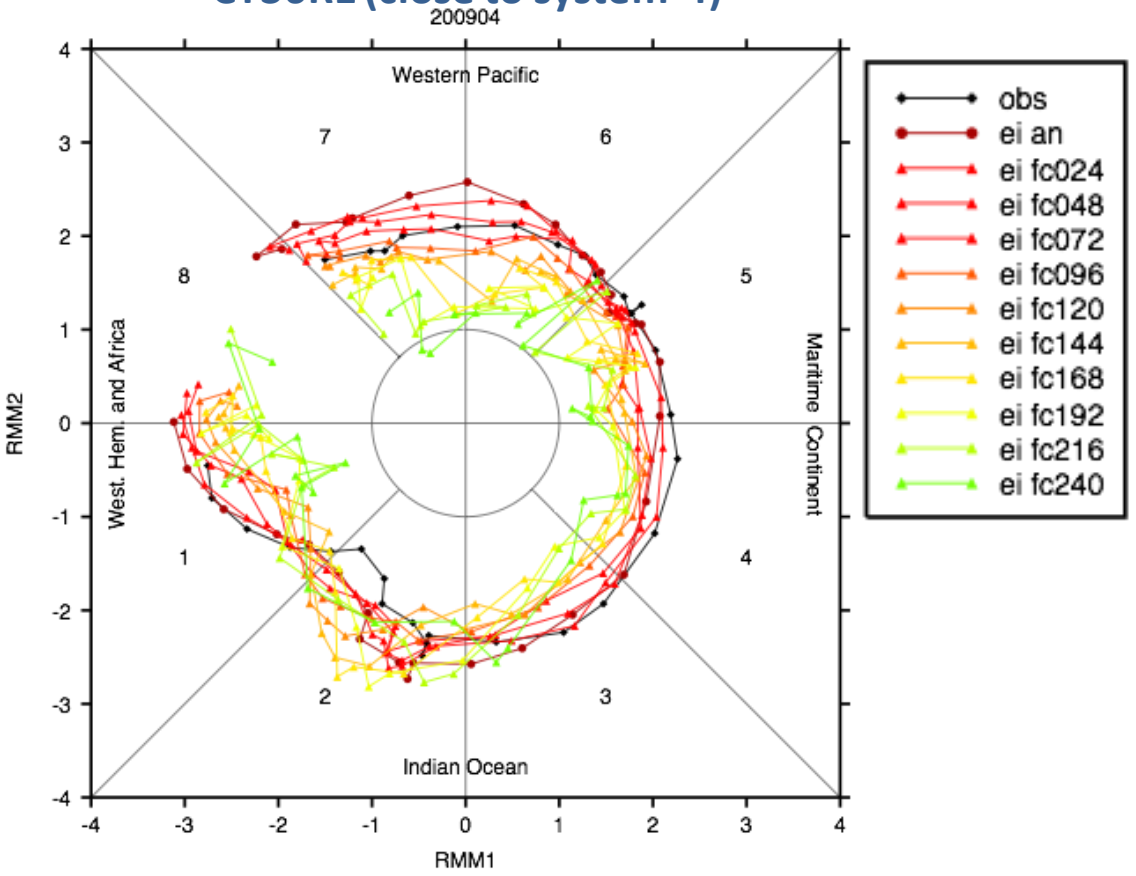
Better physics > more realistic MJO propagation

Progression in MJO modelling as a result of convection improvements (entrainment / detrainment and closure formulations).

Cy 31r1 (as in system-3)

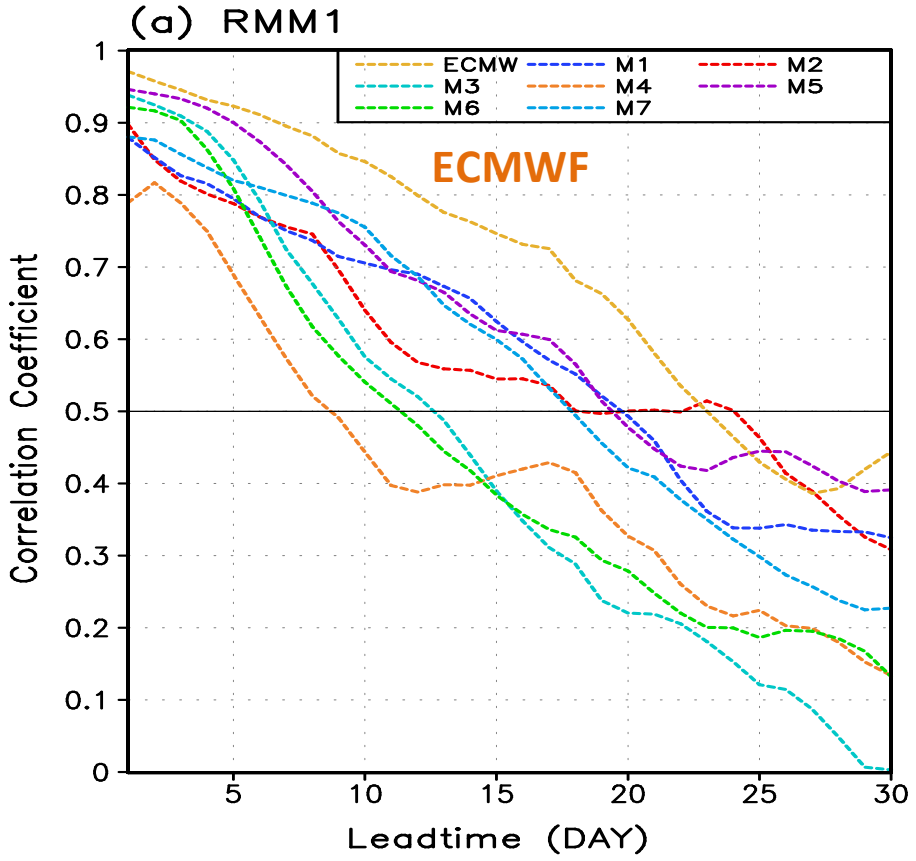


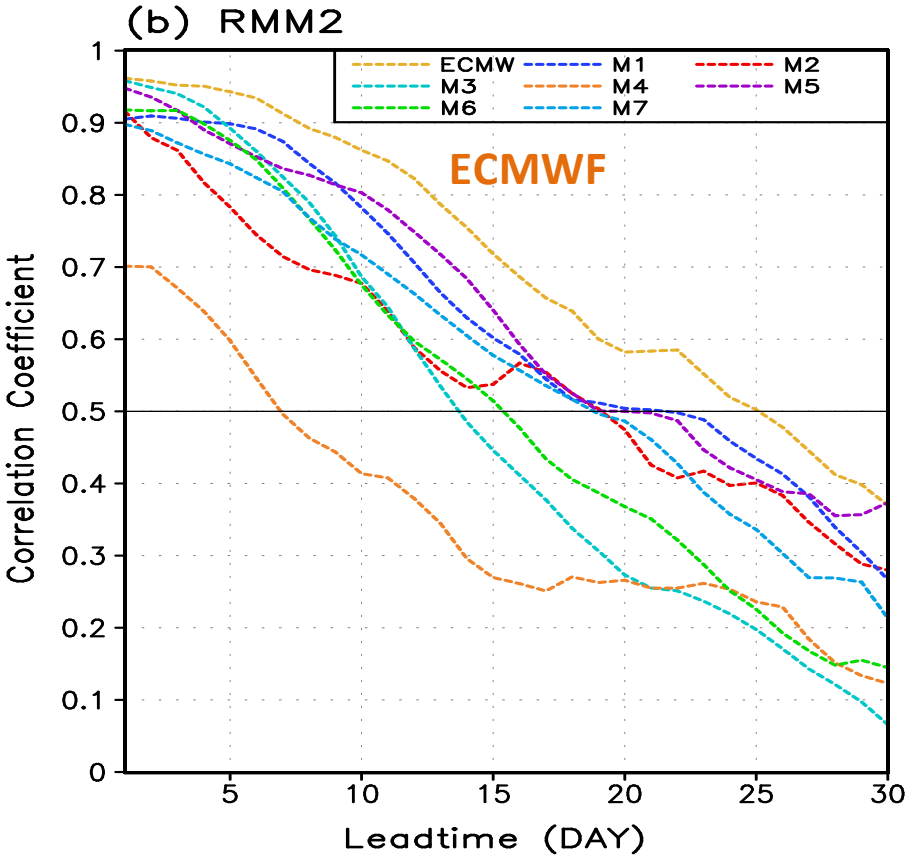
CY36R1 (close to system-4)



Today, ECMWF MJO predictions are skilful up to 3 weeks

Considering the MJO, the ECMWF system is capable to predict it up to about 25 days, better than any other operational system.





(From B Wang and J-Y Lee)

On going research that should lead to further improvements

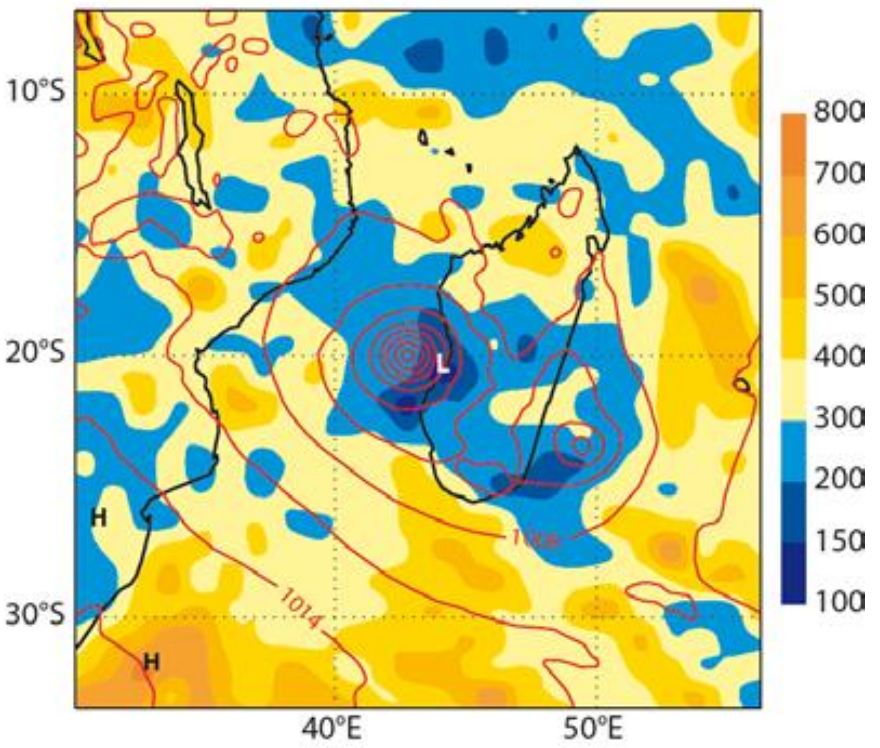
Work is progressing in many areas to continue to improve the EPS. Among them:

a) Improve EDA and couple more the EDA and the EPS

The plan is to assess:

- *The impact of increasing EDA size (25, 51), both on 4DV (to provide flow dependent correlations) and on EPS;*
- *The impact of increasing resolution (T511, T639);*
- *The possibility to inflate EDA-based perturbation in EPS and reduce SV role*

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



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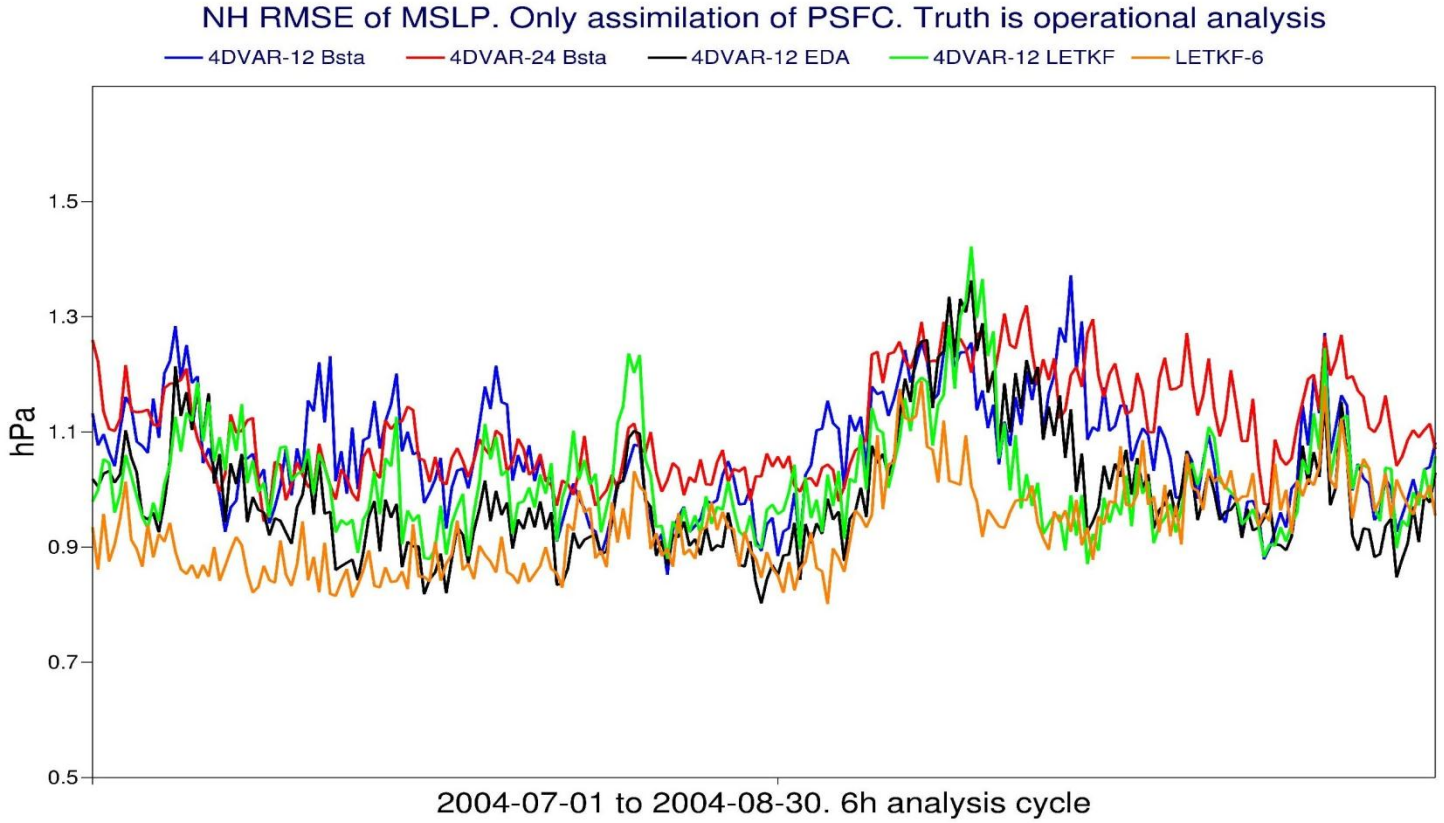
a) Improve EDA and couple more the EDA and the EPS

b) Explore other hybrid systems and EPS initial perturbation strategies

The plan is to test in the EPS other initial perturbation strategies (e.g. LETKF, implemented at ECMWF by J Whitaker).

Here, LETKF is compared to 4DVAR and hybrid methods in ERA-20C like surface pressure only assimilation.



(From M Hamrud)

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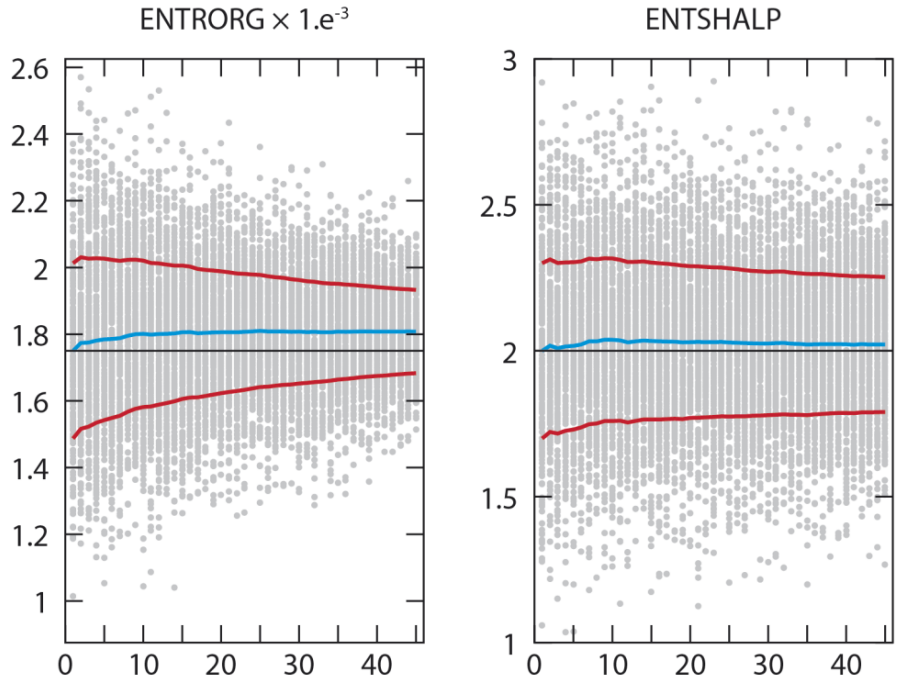
b) Explore other hybrid systems and EPS initial perturbation strategies

c) Improve the simulation of model uncertainties (more process based)

The plan is to develop a unified, more process-based approach to model:

- *Revise operational schemes (SPPT, SKEB), and assess potential benefit of making them more physically based;*
- *Explore new ides (e.g. automatic optimisation and estimation of model parameters)*
- *Test impact of SKEB on EDA*



(From P Ollinaho and H Järvinen)

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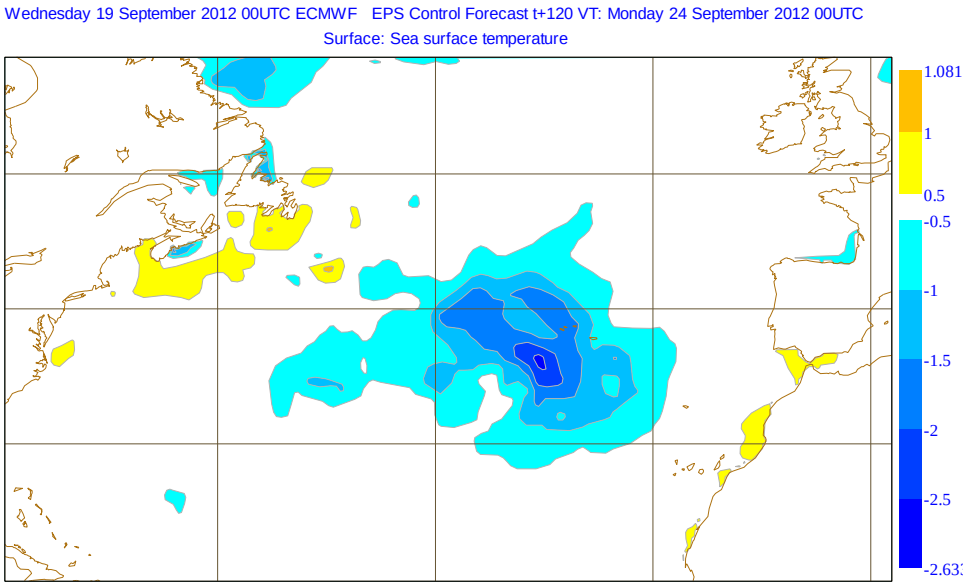
c) Improve the simulation of model uncertainties (more process based)

d) Couple from d0 to a unified, high-res wave/ocean/sea-ice model

A new system based on NEMO (ORCA025Z75) with dynamical sea-ice (LIM) is under testing. The plan is to test it in DA and prediction mode from d0. Preliminary results indicate a positive impact of coupling at d0 on SST (see fig. in the case of TC Nadine) and on MJO.



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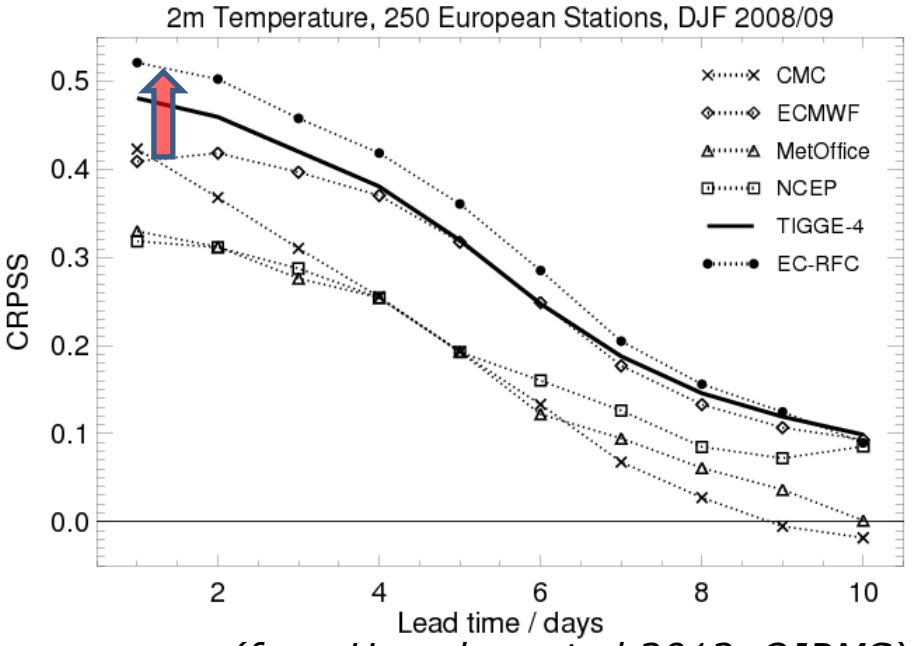
d) Couple from d0 to a unified, high-res wave/ocean/sea-ice model

e) Investigate the possibility to generate calibrated products

Research has shown that ECMWF-EPS re-fc calibrated forecasts outperforms TIGGE4-best forecasts. The plan is to investigate, in collaboration with Academia and MS whether, and how, to help users to exploit the re-fc dataset to improve forecast products.

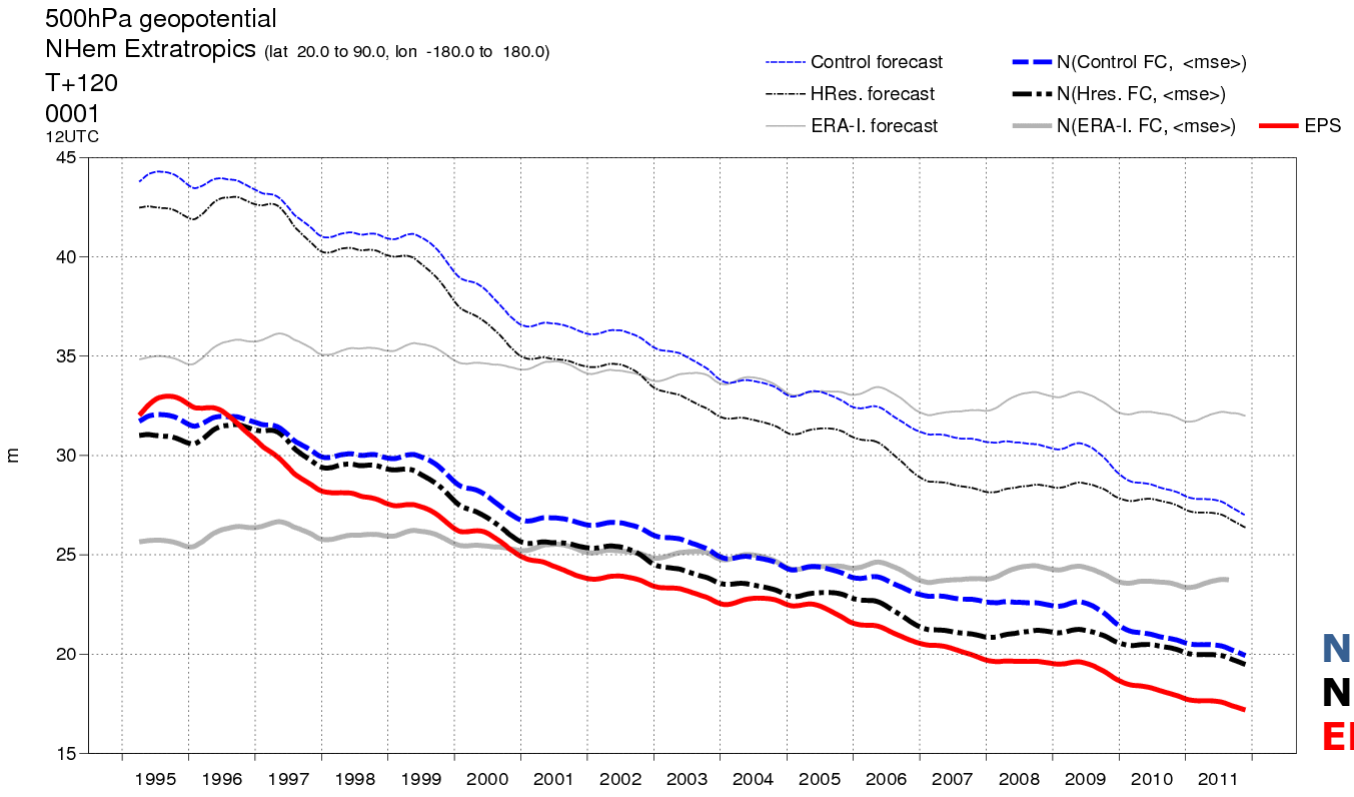


(from Hagedorn et al 2012, QJRMS)

Trends in skill: EPS (CRPS) & single fcs (MAE) – NH +5d

f) Develop new diagnostic tools to understand sources of increased predictability

The plan is to estimate the contribution to EPS advances coming from improvements in processes simulation, data-assimilation, resolution, initial and model uncertainty estimations, by comparing EPS and benchmark ensembles.



N(CON,<err>)
N(HRES,<err>)
EPS

Conclusions

20 years ago ECMWF was issuing one forecast up to 10 days.

Today, we are issuing up to 13m PDF fcs, and 'spaghetti' charts are on all forecast desks.

The future will see each analysis/forecast product have an uncertainty estimation.

(3 Dec 2012 at ECMWF: Talks on '20y of EPS', see www.ecmwf.int)