



# Recent developments of the ECMWF EPS

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## The three key messages of this talk

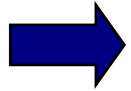
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- ❖ **Verification.** Considering the prediction of the synoptic scale flow, the ECMWF Ensemble Prediction System (EPS) has been continuously improving, with probabilistic products gaining  $\sim 2$  d/de in predictability, but improvements are smaller if one considers probabilistic precipitation predictions verified against observations. Compared to the other 3 operational global ensemble systems, the ECMWF EPS has  $\sim 1$  day longer predictive skill.
- ❖ **Development.** Recent changes (definition of tropical areas, Gaussian sampling, use of more SVs) have improved EPS forecasts. Future changes in the ensemble configuration (VAREPS), and in the simulation of initial and model uncertainties are expected to improve the accuracy of EPS forecasts. VAREPS will extend the EPS to 15 days, and will be the first step towards a seamless probabilistic prediction system.
- ❖ **The future.** Collaborations between ECMWF, its users and the whole international community will help addressing open issues in probabilistic forecasting and designing future probabilistic analysis and forecasting systems.



## Outline

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### **1. Verification: performance of the ECMWF EPS from May 1994 to date**

### **2. Development:**

- Changes in the simulation of initial and model uncertainties
- The forthcoming VARIable Resolution EPS (VAREPS)

### **3. The future:**

- TIGGE
- Towards a fully probabilistic analysis and prediction system



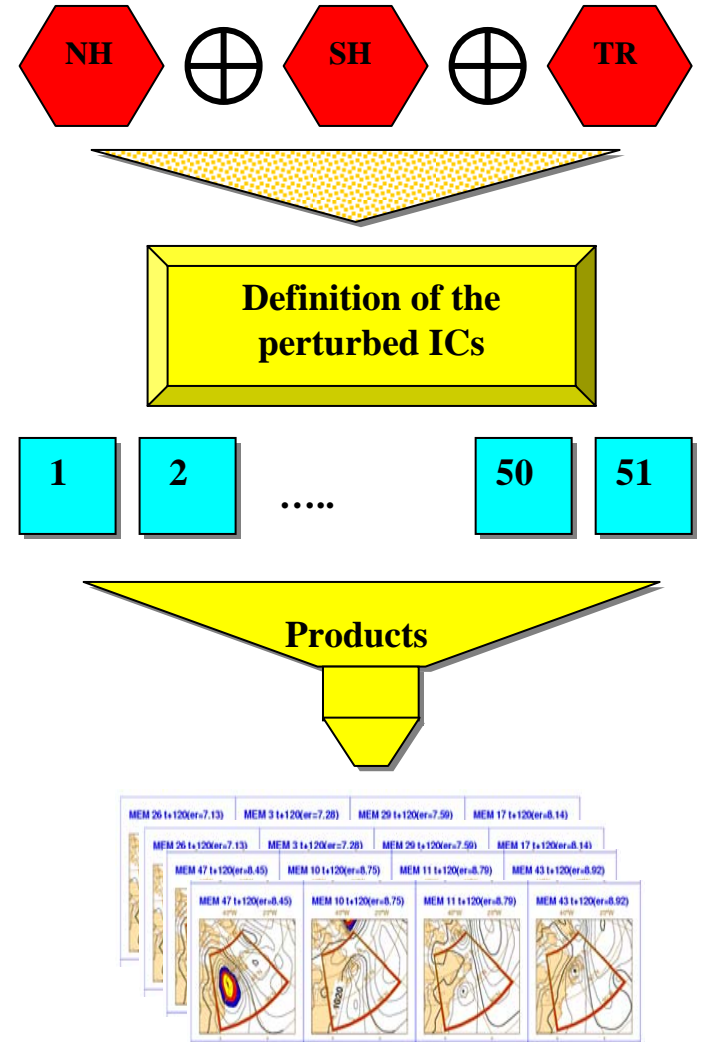
# 1. The ECMWF Ensemble Prediction System

The Ensemble Prediction System (EPS) consists of **51** 10-day forecasts run at resolution **T<sub>L</sub>255L40** (~80km, 40 levels) [1,5,7,8,13,11,15].

The EPS is run twice a-day, at 00 and 12 UTC.

**Initial uncertainties** are simulated by perturbing the unperturbed analyses with a combination of T42L40 singular vectors, computed to optimize total energy growth over a 48h time interval (OTI).

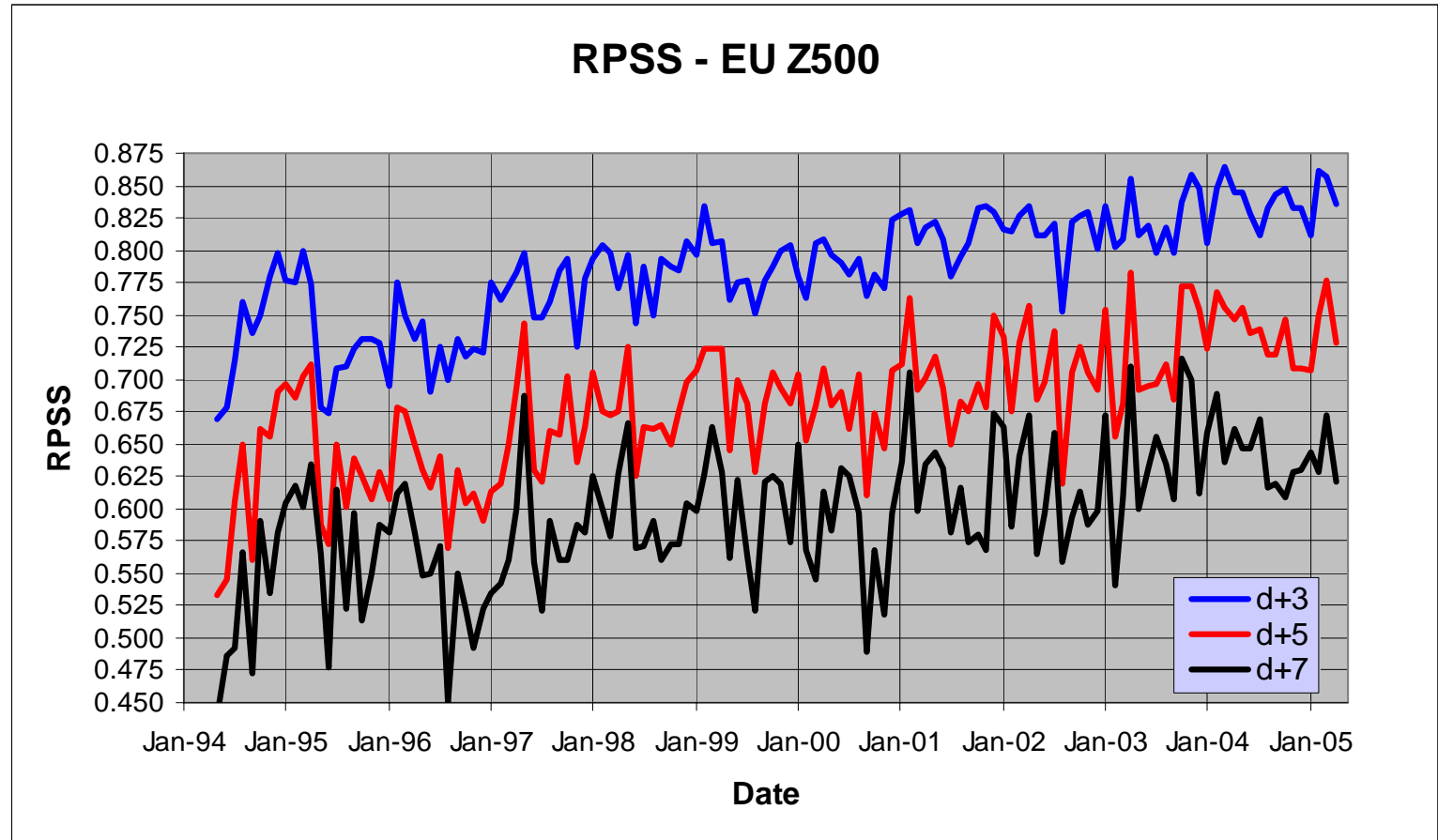
**Model uncertainties** are simulated by adding stochastic perturbations to the tendencies due to parameterized physical processes.





# 1. The EPS performance has been continuously increasing

Improvements over Europe have been slightly smaller, as can be detected by comparing the time evolution of the RPPS for 500 hPa geopotential height predictions over Europe (left) and NH (previous slide).

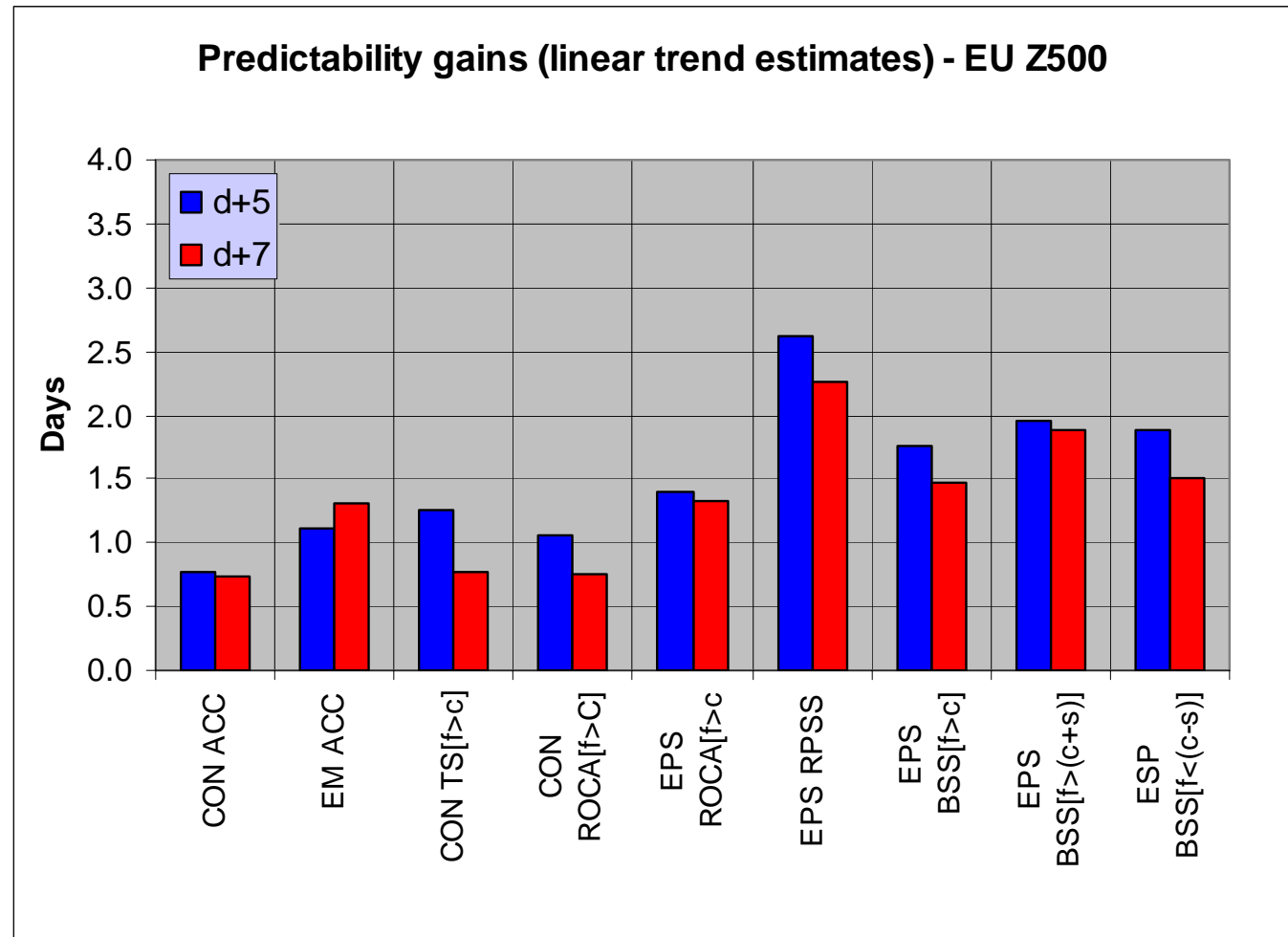




# 1. Summary: predictability gains for Europe Z500

Results are slightly less positive for Europe, for which diagnostic studies have indicated that:

- ❖ the EPS control has improved by  $\sim 0.75\text{d/de}$
- ❖ the EPS ens-mean has improved by  $\sim 1\text{d/de}$
- ❖ the EPS probabilistic products have improved by  $\sim 1.5\text{d/de}$

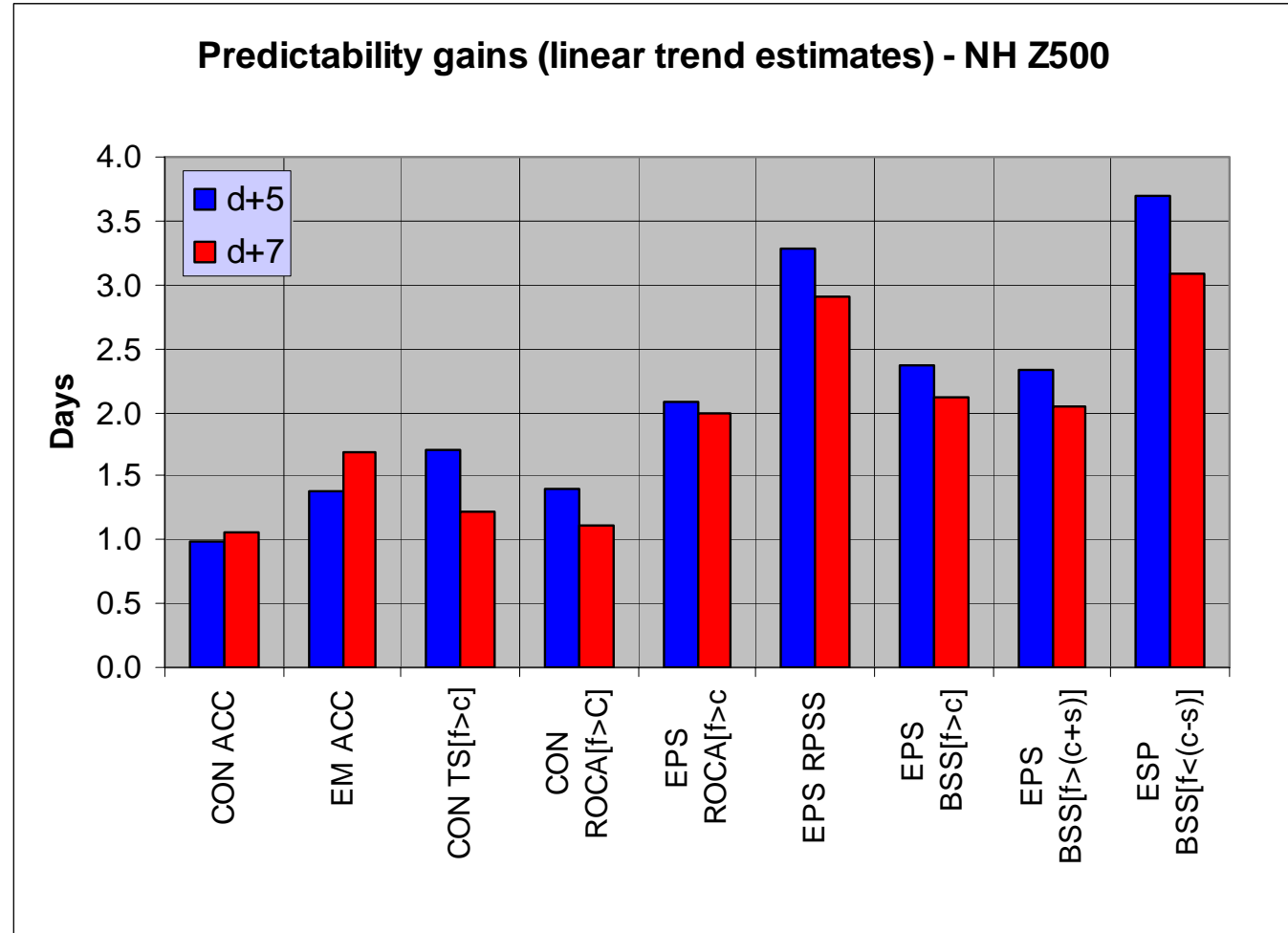




# 1. Summary: predictability gains for NH Z500

Considering 500 hPa geopotential height predictions over the NH at d+5 and d+7, diagnostic studies have indicated that:

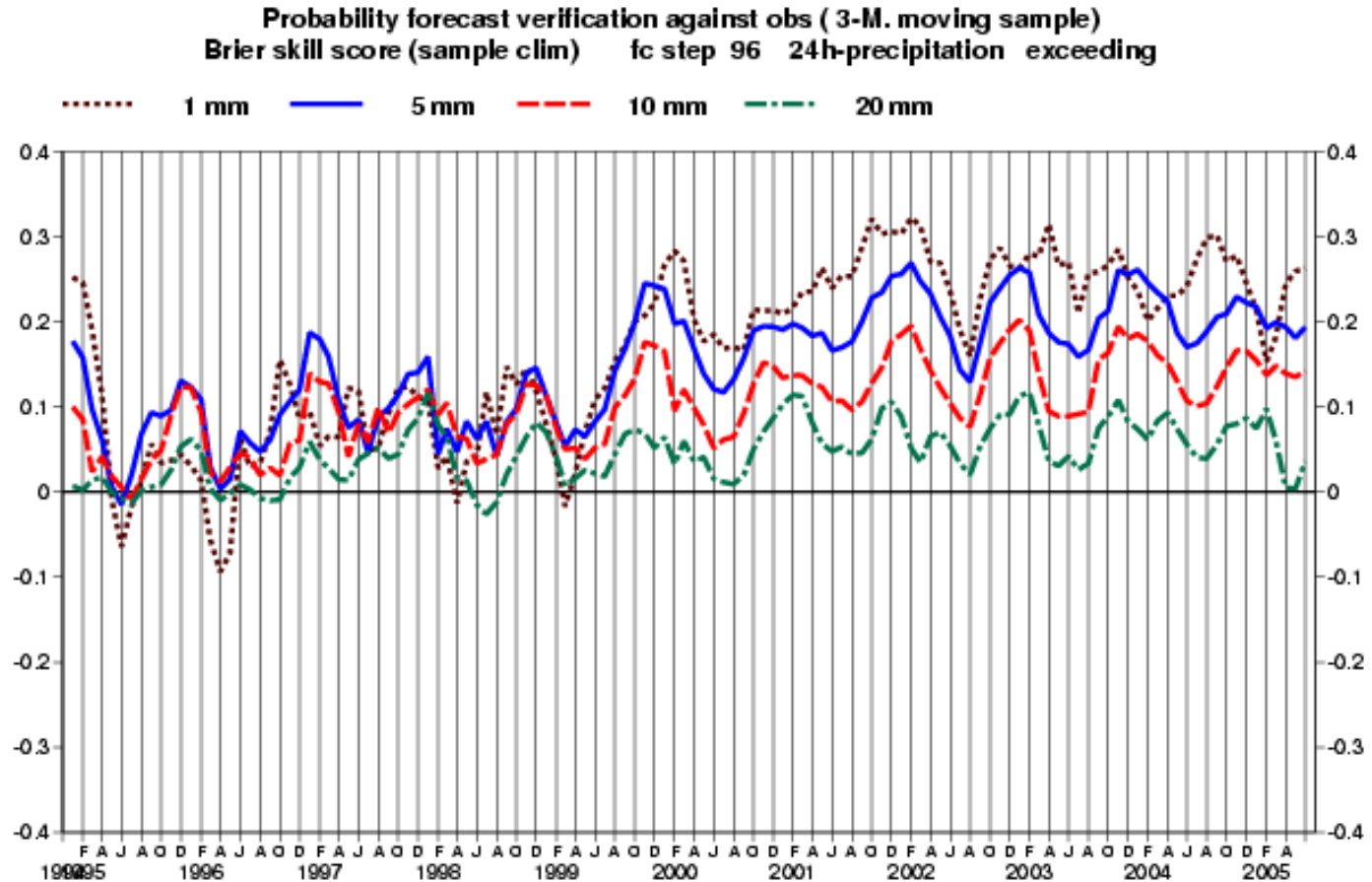
- ❖ the EPS control has improved by more than 1d/de
- ❖ the EPS ens-mean has improved by ~1.5d/de
- ❖ the EPS probabilistic products have improved by more than 2d/de





# 1. Trends in BSS for d+4 probabilistic precipitation prediction

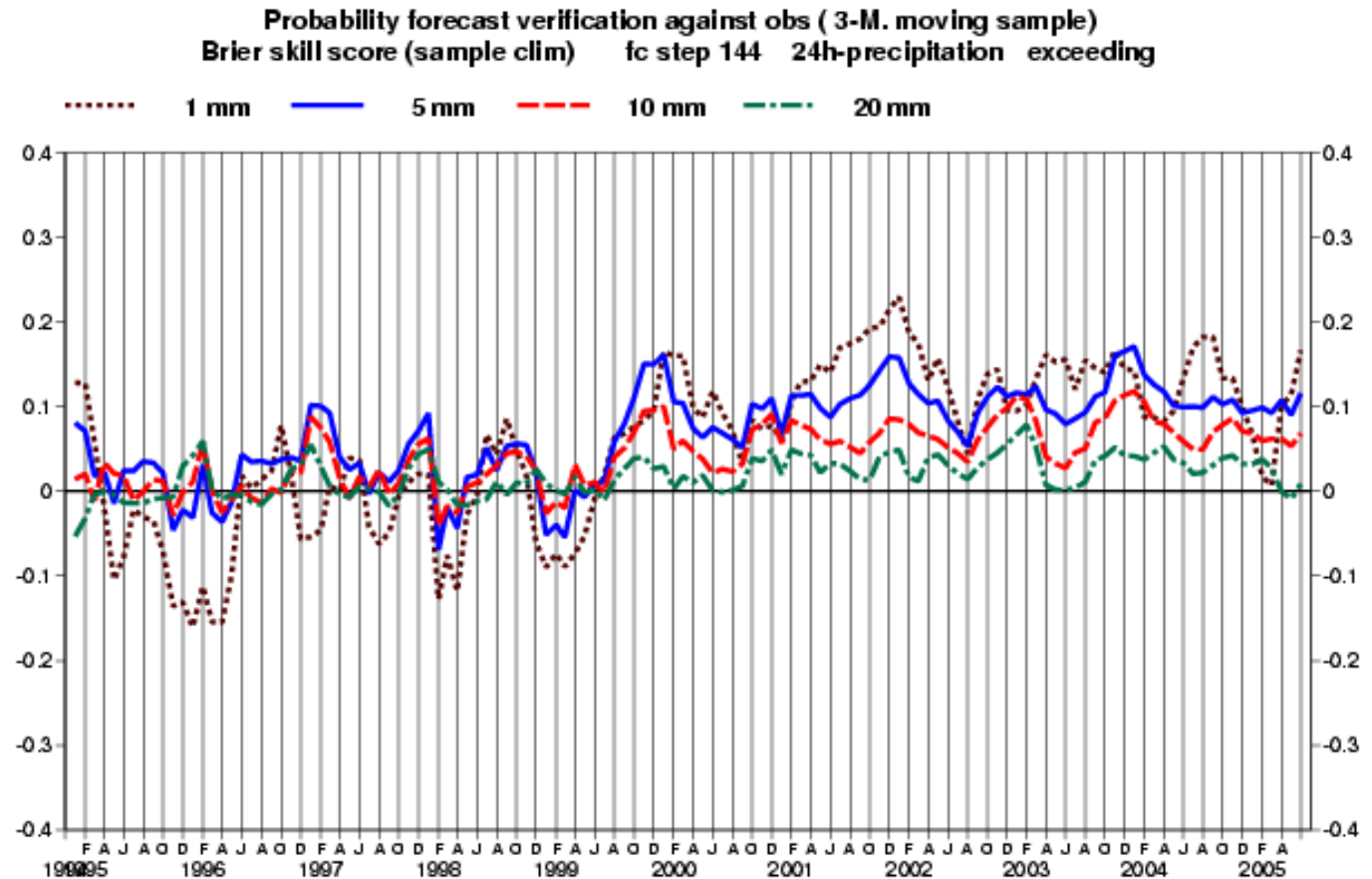
EPS probabilistic predictions of precipitation over the NH between d+3 and d+4 have improved following the introduction of stochastic physics (Oct 1998) and the system upgrade from TL159 to TL255 in Nov 2000.





# 1. Trends in BSS for d+6 probabilistic precipitation prediction

EPS probabilistic predictions of precipitation over the NH between d+3 and d+4 have improved following the introduction of stochastic physics (Oct 1998) and the system upgrade from TL159 to TL255 in Nov 2000.



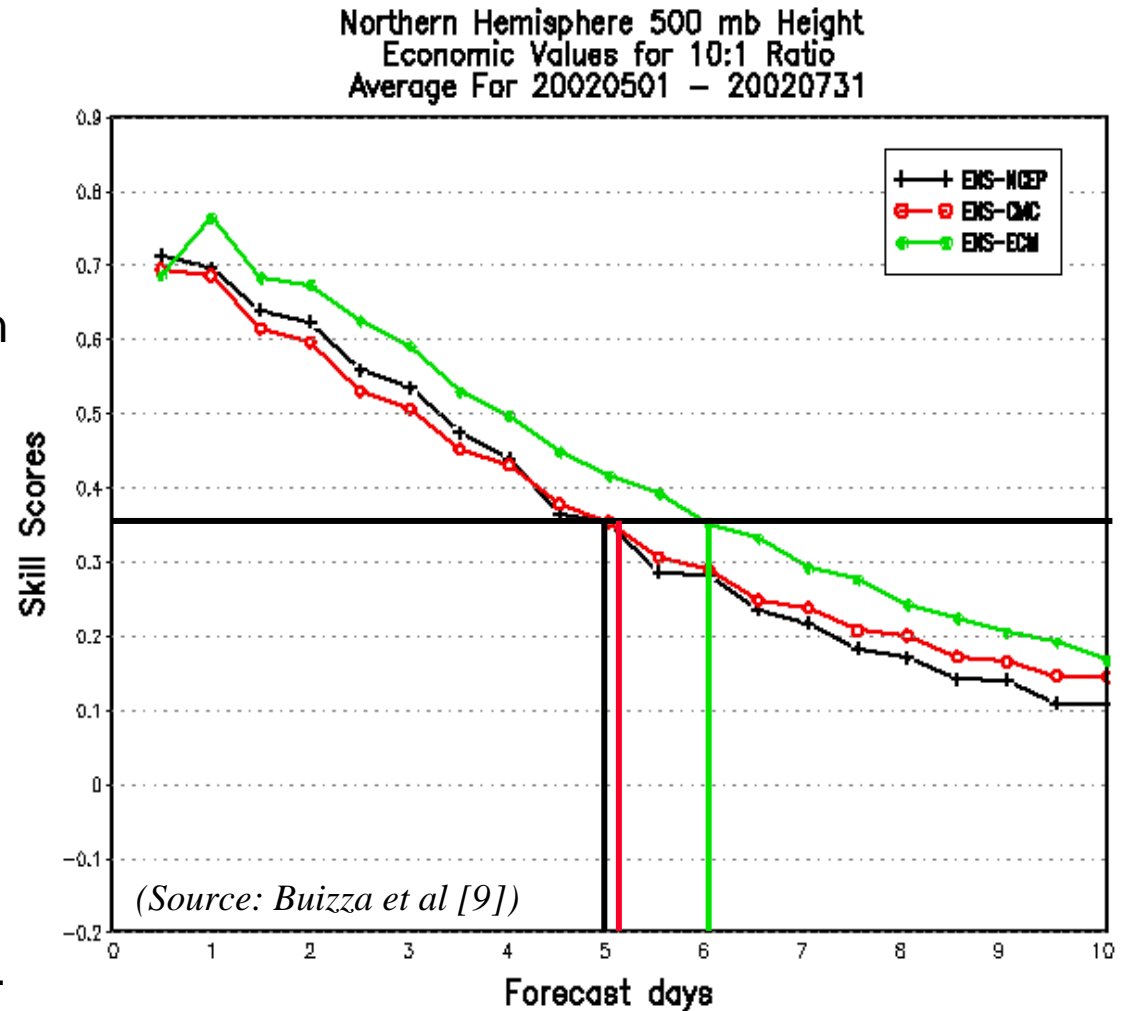


# 1. Comparison of the ECMWF, MSC and NCEP EPSs (JJA02)

Recent studies [2,9] have shown that, accordingly to many accuracy measures, the ECMWF EPS can be considered the most accurate single-model ensemble system.

This is shown, e.g., by the comparison of the EV\* of 10-member ensembles based on the ECMWF, MSC (Meteorological Service of Canada) and NCEP (National Centers for Environmental Predictions) EPSs [9] (Z500 over NH).

\* EV, the potential economic value, is the reduction of the mean expenses with respect to the reduction that can be achieved by using a perfect forecast [4, 16].



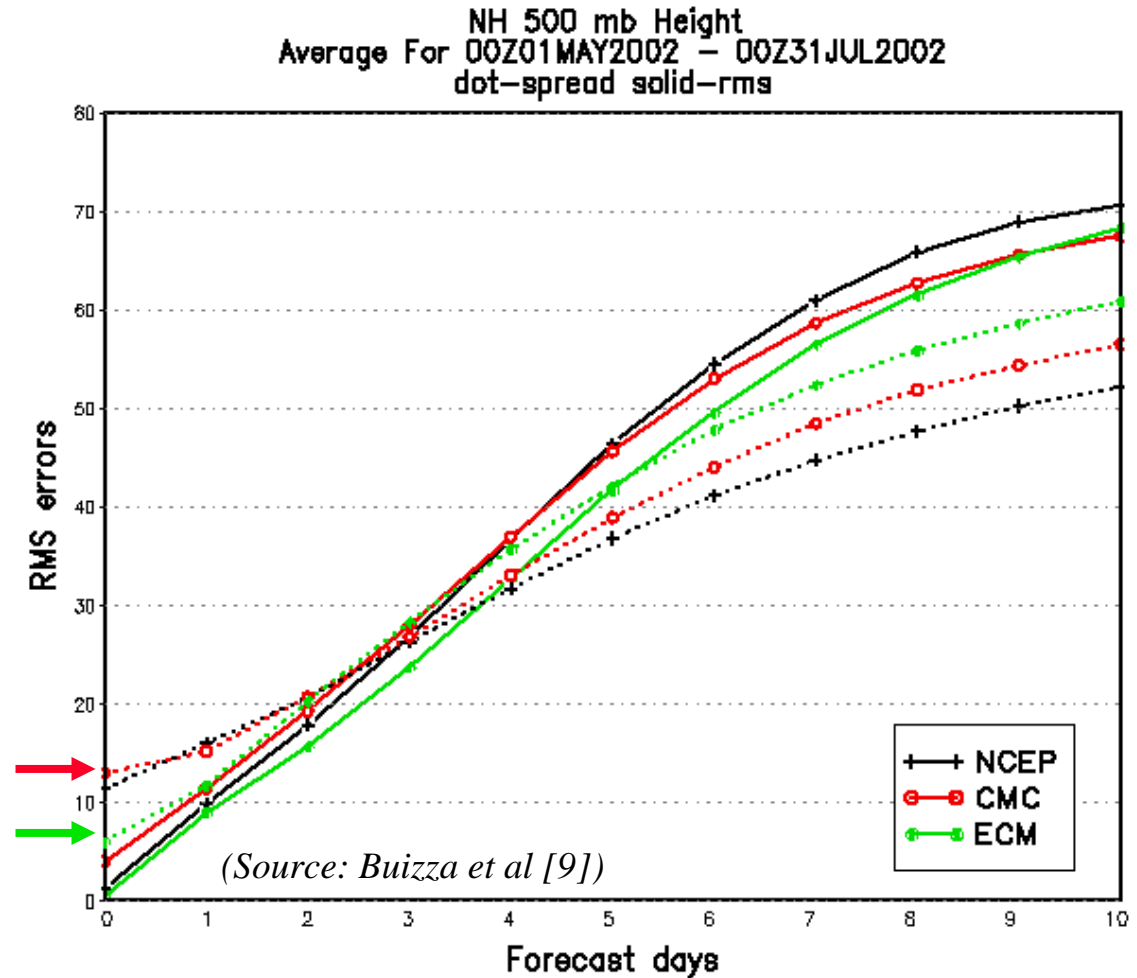


# 1. Comparison of the ECMWF, MSC and NCEP EPSs (JJA02)

The ECMWF leading performance [9], estimated to be equivalent to a gain of ~1 day of predictability, has been linked to:

- ❖ A better analysis
- ❖ A better model
- ❖ A better estimation of the PDF of forecast states.

This latest point can be seen, e.g., by comparing the ensemble spread and the ensemble-mean forecast error of 10-member ensembles based on the NCEP, MSC and ECMWF EPSs (Z500 over NH).



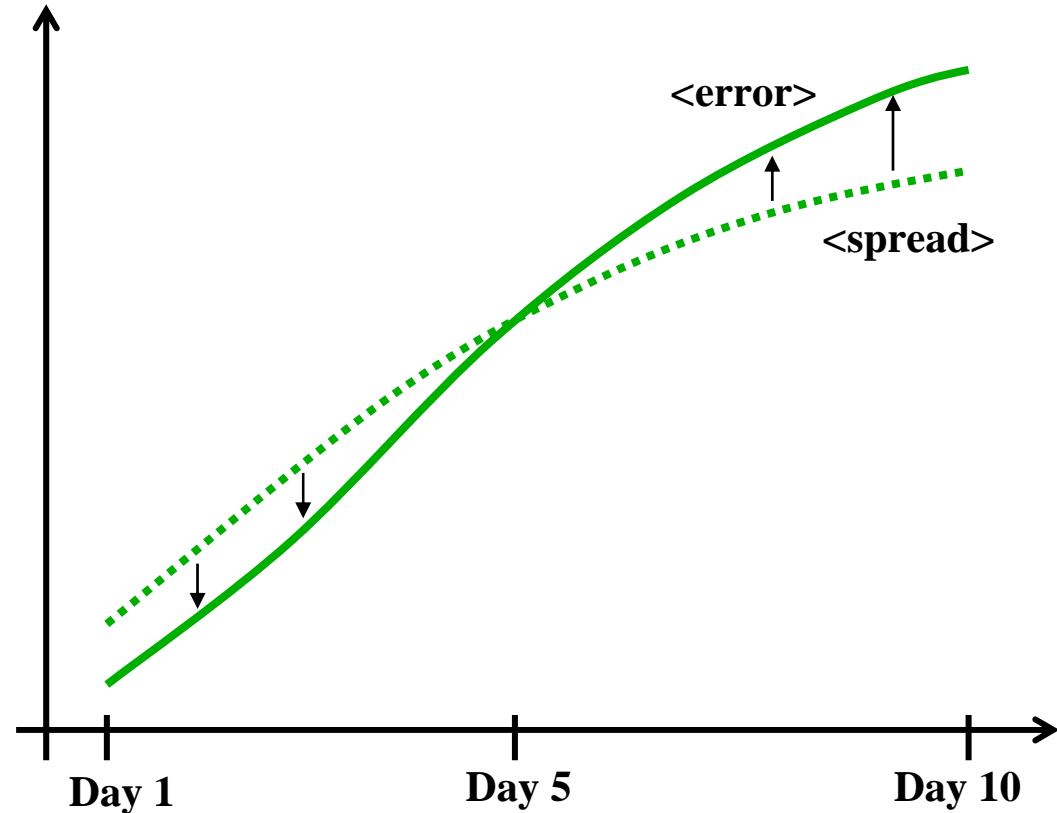


# 1. ECMWF, MSC and NCEP EPSs lack medium-range spread

This comparison indicated that in the ECMWF-EPS:

- ❖ initially, the EPS perturbations are growing too quickly compared to error growth
- ❖ in the medium-range, the EPS is under-dispersive

These two problems are more evident in the NCEP and the MSC EPSs due to the slower growth of their initial perturbations, and to a combination of lower resolution and different simulation of model uncertainties.

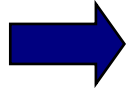




# Outline

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## 2. Initial uncertainties: definition of the TC-SVs' target areas

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The EPS before September 2004 had one weakness linked to the definition of the target areas used to compute the tropical singular vectors [1, 15]:

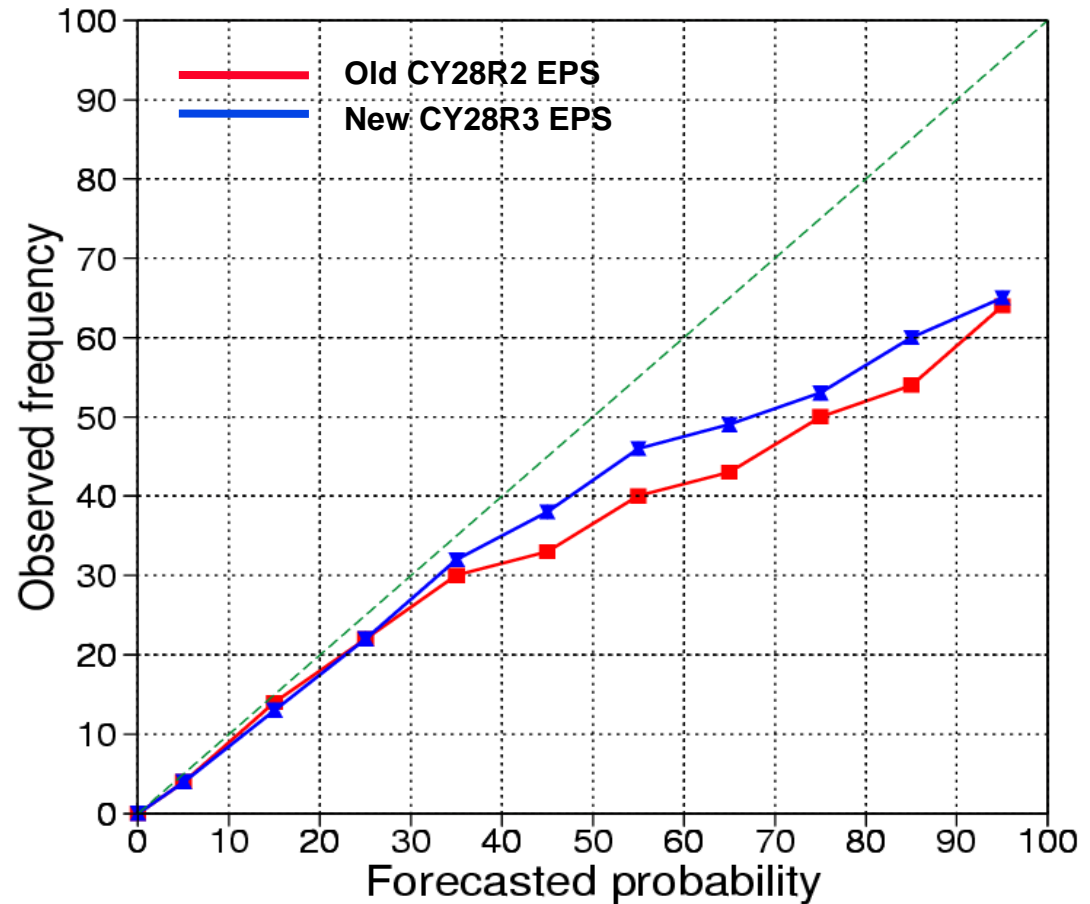
- ❖ TR-SVs were computed inside areas with northern boundary with  $\lambda \leq 25^\circ\text{N}$ : this was causing an artificial ensemble-spread reduction when tropical cyclones were crossing  $25^\circ\text{N}$
- ❖ TR-SVs were computed only if WMO cl-2 TC were detected between  $25^\circ\text{S}$ - $25^\circ\text{N}$
- ❖ Too few tropical areas (up to 4) were considered



## 2. TR-SVs' target areas: impact of the Sep '04 change

Results based on 44 cases (from 3 Aug to 15 Sep 2004) indicate that the implemented changes in the computation of the tropical areas has a positive impact on the reliability diagram of strike probability.

**Reliability diagram for strike probabilities**



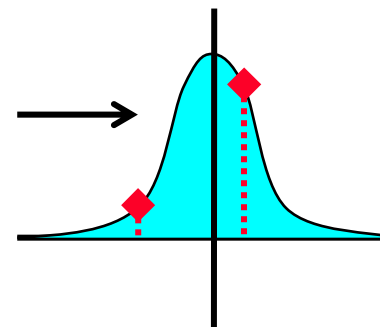


## 2. The Sep '04 and the forthcoming changes in SVs' sampling

Before September 2004, the distributions of the  $\alpha_{j,k}$  and  $\beta_{j,k}$  coefficients was defined by the rotation algorithm and was not Gaussian:

$$de_j(d) = \sum_{area} \sum_{k=1}^{N_{SV}} [\alpha_{j,k} \cdot SV_k(d,0) + \beta_{j,k} \cdot SV_k(d-2,+2)]$$

Since Sept 2004, the distributions of the  $\alpha_{j,k}$  and  $\beta_{j,k}$  coefficients that define the EPS initial perturbations have been set to be Gaussian [11]. (Between Sept 2004 and June 2005, the 50 EPS initial perturbations have not been symmetric, but symmetry was re-introduced on 28 June 2005.) Since June 2005 50 NH and 50 SH (extra-tropical) SVs are used to define the EPS initial perturbations.





## 2. Initial uncertainties – Ongoing research

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Why shall the definition of the EPS initial perturbations be changed?

In the current EPS:

- ❖ SVs are computed at T42L40 resolution over a 48h time optimization interval
- ❖ Extra-tropical SVs are still computed with a tangent dry physics [3]
- ❖ Tropical SVs are computed with a tangent moist physics [1, 12, 15], but with the state vector still defined in terms of  $[V, D, T, \ln(sp)]$  only (i.e. without humidity)

To better capture perturbations' growth, especially in cases of intense, small-scale cyclonic developments, it is thought that a tangent moist physics should be used. Recent results [10] have indicated that when moist processes are considered, a T63 truncation would be better than a T42, and a 24h OTI is more suitable than the 48h OTI used for dry SVs. The use of 24h, T<sub>L</sub>95 SVs computed with the new moist tangent physics is under testing.



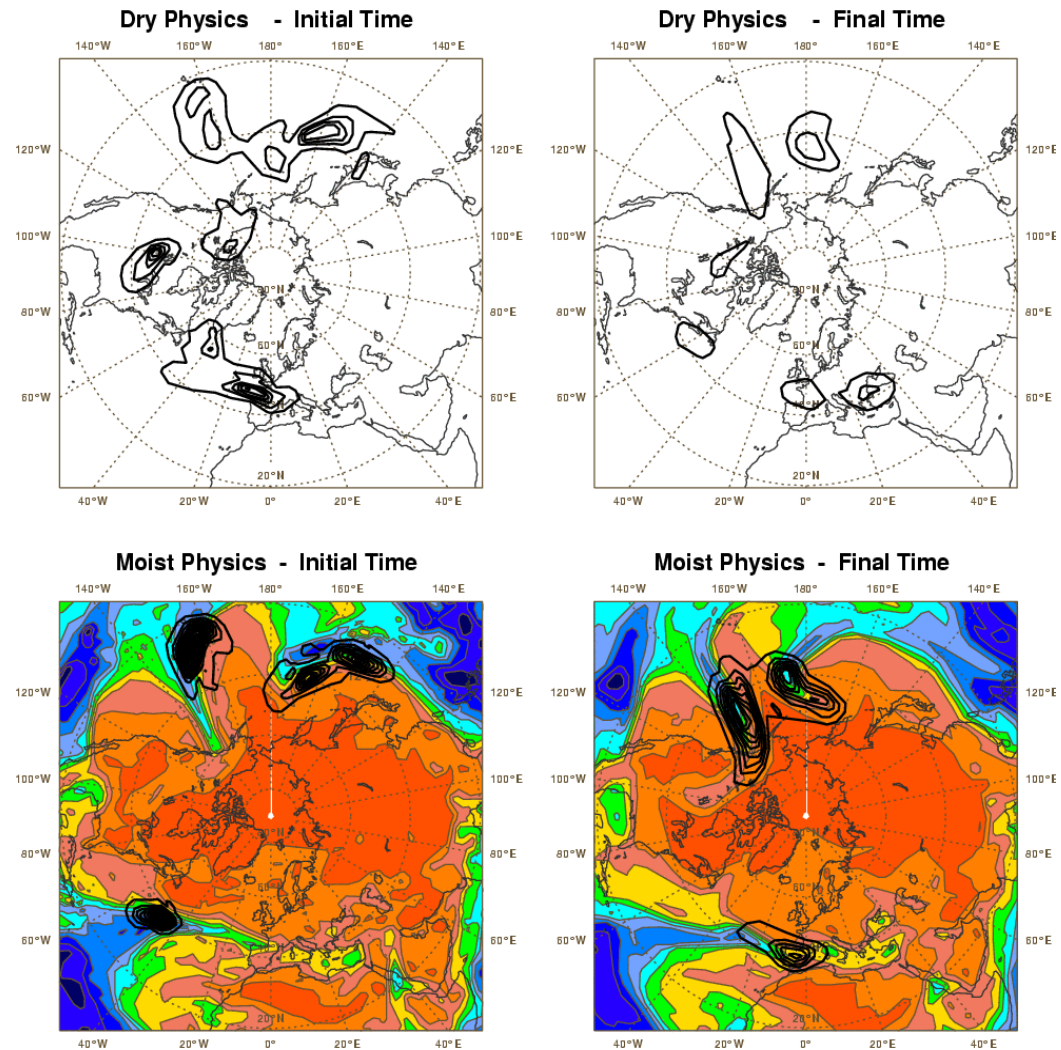
## 2. Impact of moist processes on T63L31-24h SVs

27 Dec '99 00Z: French storm  
Martin.

The top panels [10] show a weighted geographical distribution of the first 10 T63L31-24h dry SVs at initial and final time (ci x50 at final time).

The bottom panels show the weighted distribution of the first 10 T63L31-24h full-physics SVs, superimposed on the basic state total column water content.

In the moist experiment, SVs evolve along the upstream side of the tongue of moisture into the storm region.



(Source: Coutinho et al [10])



## 2. Model imperfections – Should the approach be changed?

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In the current EPS:

- ❖ Model imperfections are simulated using ‘stochastic physics’, a simple scheme designed to simulate the **random errors in parameterized forcing** that are coherent among the different parameterization schemes (moist-processes, turbulence, ...).
- ❖ Coherence with respect to parameterization schemes has been achieved by applying the stochastic forcing on **total tendencies**. Space and time coherence has been obtained by imposing **space-time correlation** on the random numbers.

The scheme has been shown [14] to have a positive impact on the EPS, especially on the accuracy of probabilistic precipitation prediction. But diagnostics and recent studies [17] have indicated that the scheme has some weaknesses:

- ❖ In the lower levels, it seems to generate too large spread and too intense rainfall
- ❖ In the upper levels its impact on the ensemble spread is rather limited (~5%)
- ❖ Random numbers have a very crude spatial and temporal correlations
- ❖ It is controlled by parameters that have been tuned in a rather ‘ad-hoc’ manner



## 2. Cellular Automaton Stochastic Backscatter Scheme

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The new Cellular Automaton Stochastic Backscatter Scheme [17] (CASBS):

- ❖ CASBS is based on the physical argument that kinetic energy sources that counteract energy drain occurring in the near-grid scale can improve the performance of numerical models.
- ❖ Kinetic energy is backscattered by introducing vorticity perturbations into the flow with a magnitude proportional to the square root of the total dissipation rate.
- ❖ The spatial form of vorticity perturbations is derived from an exotic pattern generator (cellular automaton) that crudely represents the spatial/temporal correlations of the atmospheric meso-scale

T<sub>L</sub>159L40 EPS experiments for 10 cases have indicated that:

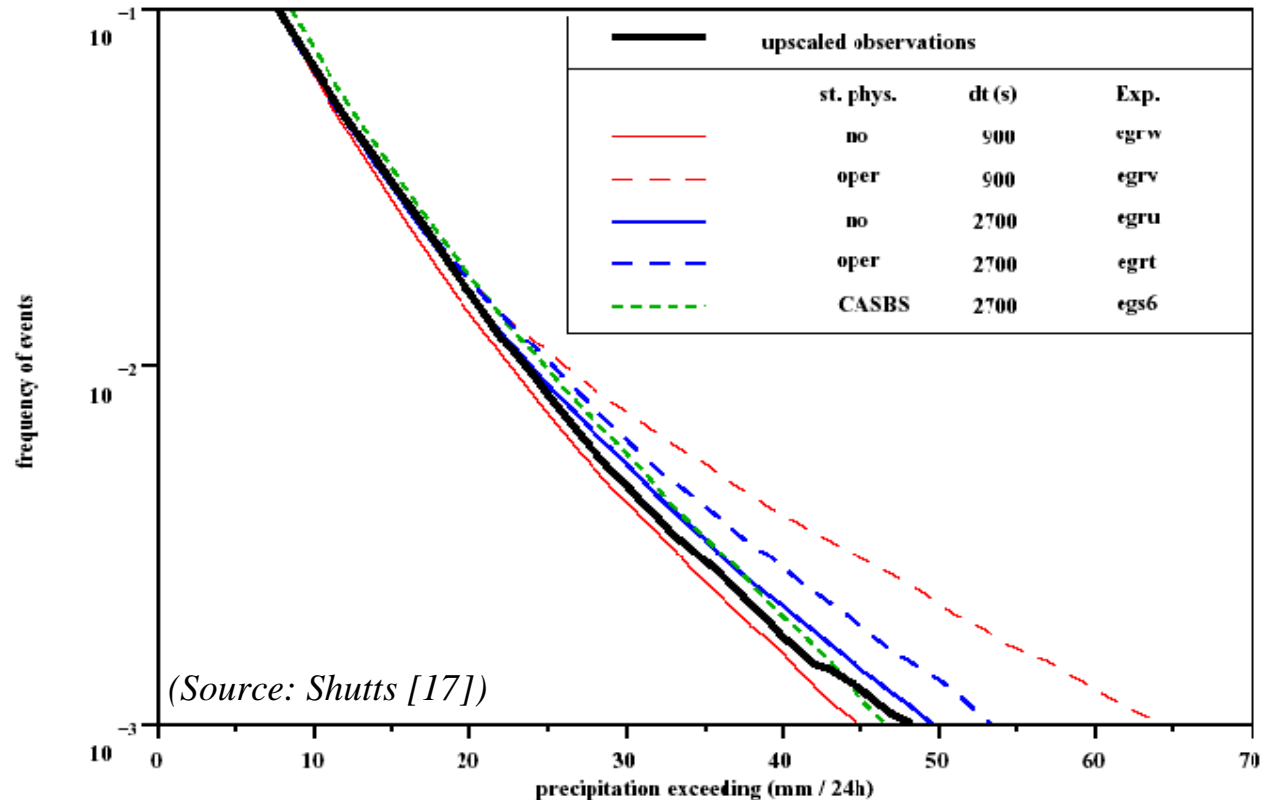
- ❖ CASBS reduces the excessive heavy rainfall events
- ❖ It is more effective at generating model spread
- ❖ It generates a better meso-scale energy spectrum



## 2. CASBS' positive impact on heavy precipitation events

Experiments based on T<sub>L</sub>159L40 EPS forecasts for 10 cases indicate that:

- ❖ The operational stochastic physics scheme (dashed blue) generates too many cases of heavy precipitation
- ❖ CASBS (dash green) performs more in agreement with observed statistics (black solid)

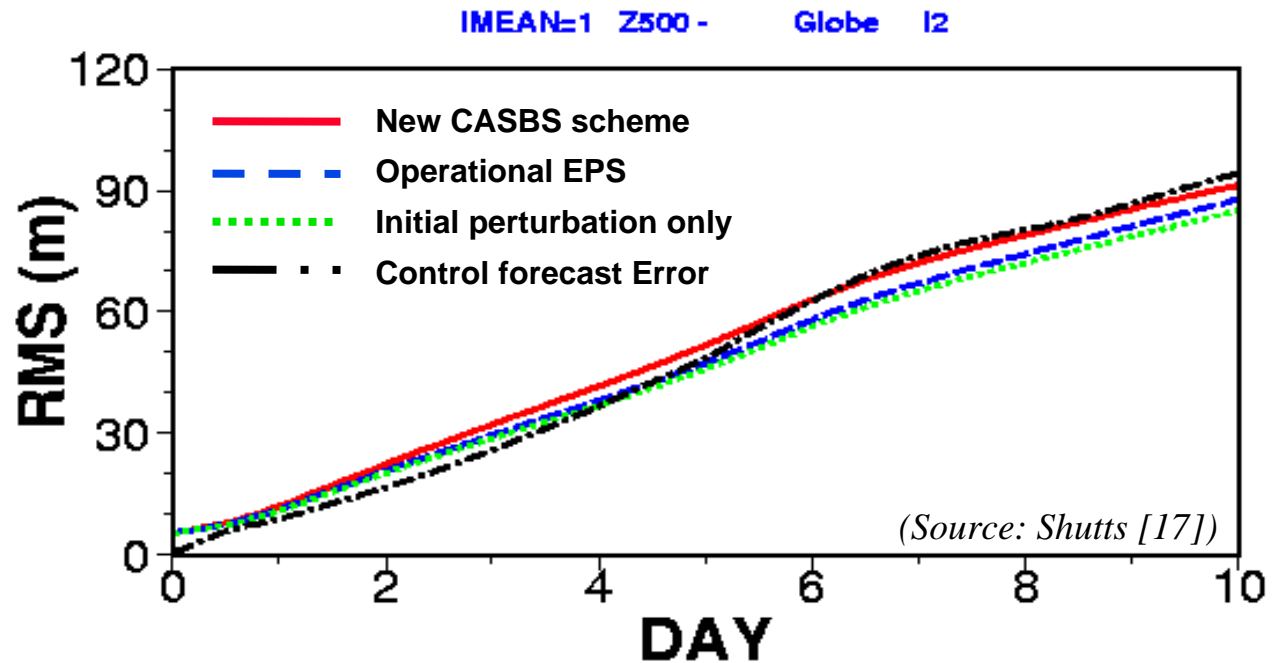




## 2. CASBS' positive impact on EPS spread

Experiments based on  $T_L159L40$  EPS forecasts for 10 cases indicate that:

- ❖ CASBS (red solid) induces more divergence among the ensemble members than the operational scheme (blue dashed)
- ❖ CASBS' ensemble-spread around the control is closer to the average error of the control forecast (black chain-dashed)





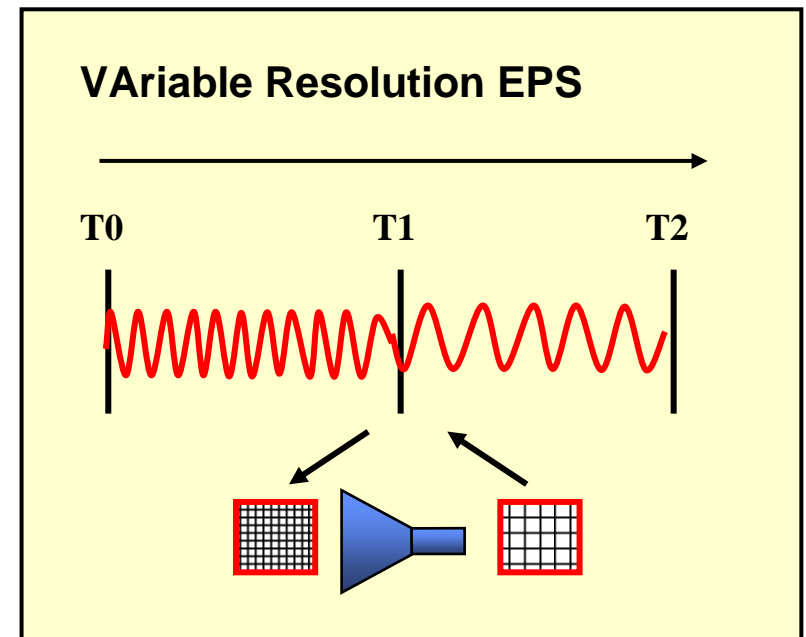
## 2. VAREPS

### ❖ Rationale:

- $T_L399$  resolution up to 15 days is unaffordable, and the benefits of extending the EPS to day 15 outweighs the disadvantages of losing resolution
- Predictability of small scales is lost relatively earlier in the forecast range. Therefore, while forecasts benefit from a resolution increase in the early forecast range, they do not suffer so much from a resolution reduction in the long range.

### ❖ VAREPS planned configuration:

- **D0-7:  $T_L399L40$ ,  $dt=1800s$**
- **D7-15:  $T_L255L40$ ,  $dt=2700s$**

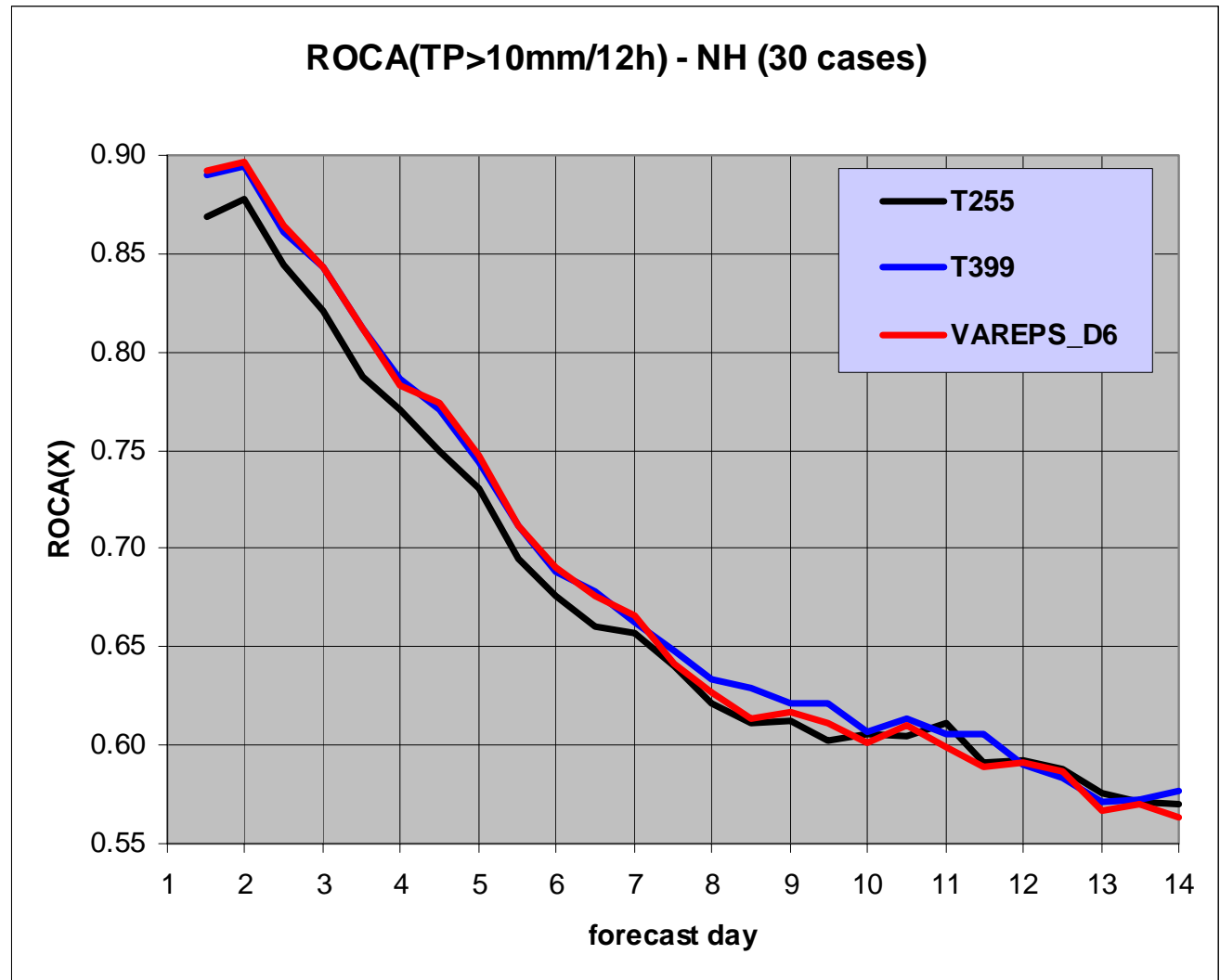




## 2. Expected impact of EPS upgrade: $\pi(TP \geq 10\text{mm}/12\text{h})$

Results based on 30 cases, 51-member ensembles (CY28R3) indicate a positive impact of EPS upgrade.

Considering ROCA as accuracy measure for probabilistic predictions of TP in excess of 10mm/12h over NH, results indicate a gain of ~12h during the first 7 forecast days.

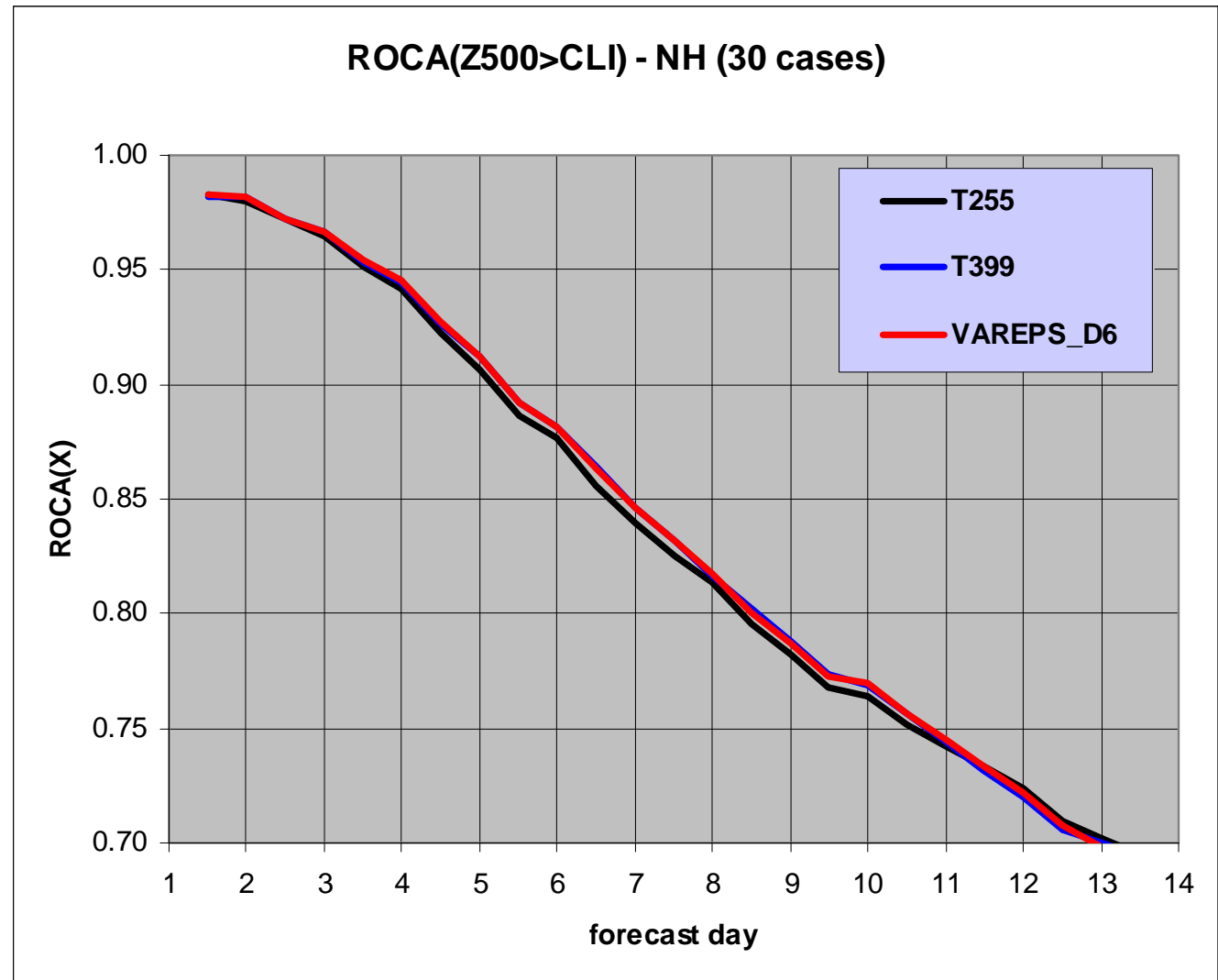




## 2. Expected impact of EPS upgrade: $\pi(Z500 \geq cli)$

Results based on 30 cases, 51-member ensembles (CY28R3) indicate a positive impact of EPS upgrade.

Considering ROCA as accuracy measure for probabilistic predictions of positive Z500 anomalies over NH, results indicate a small gain up to forecast day 11 (~6h at forecast day 7).





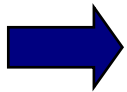
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### 3. TIGGE

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TIGGE (the THORPEX Interactive Grand Global Ensemble) is a framework for international collaboration in development and testing of ensemble prediction systems.

TIGGE could lead to:

- ❖ An enhanced international collaboration between operational centres and universities
- ❖ A deeper understanding of the contribution of observation, initial and model uncertainties to forecast error, and the design of more valuable ensemble systems
- ❖ The developments of new methods of combining ensembles from different sources and of correcting for systematic errors (biases, spread over-/under-estimation)



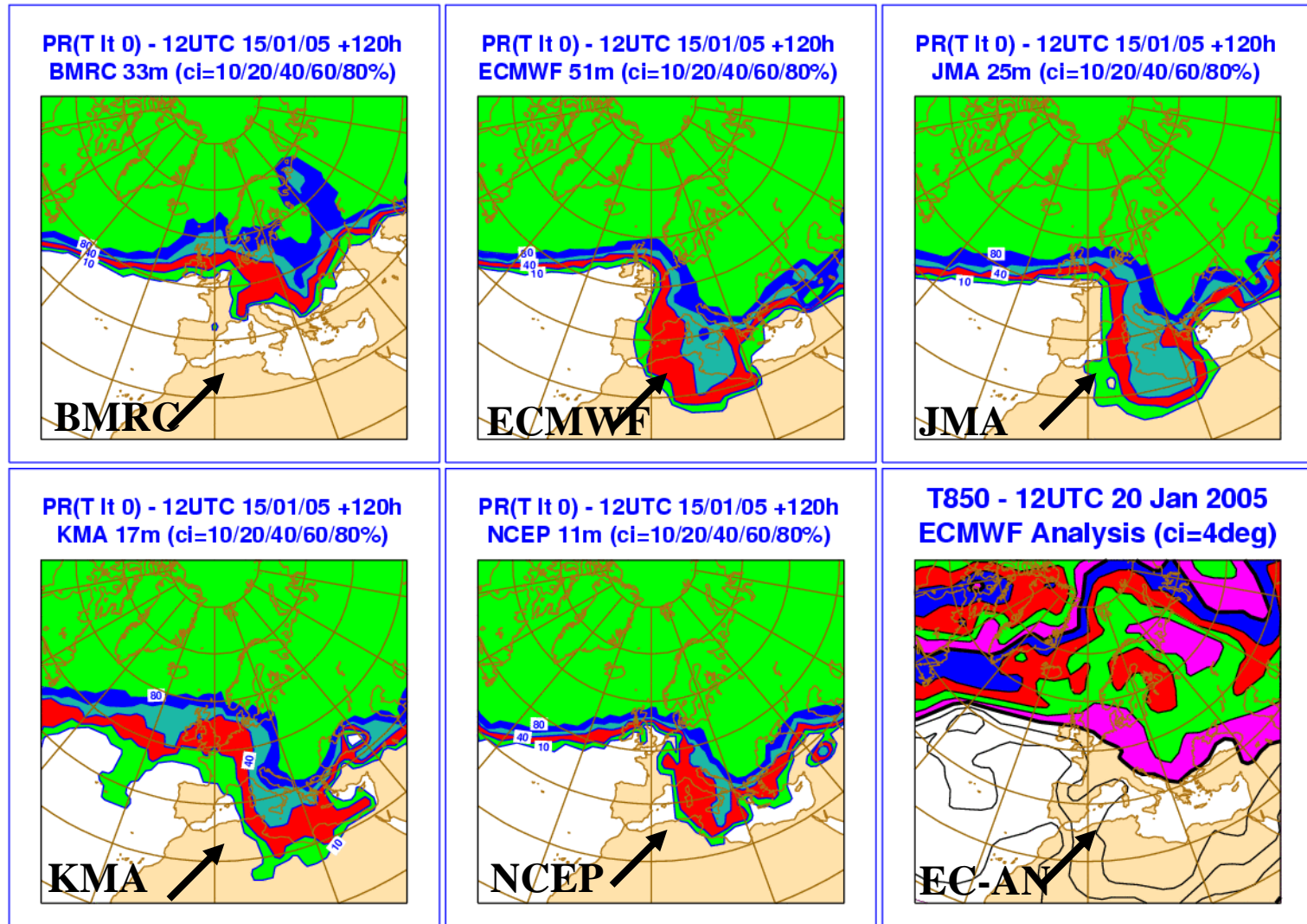
### 3. Ex: $\pi_{Z500}(12,120h)$ : BMRC, ECMWF, JMA, KMA, NCEP

Europe: 120h  
forecast  
probability of  
 $T850 < 0$  degrees.

What is the  
PR( $T850 < 0$ ) in  
Tunisia?

*BMRC gives a  
zero probability.\**

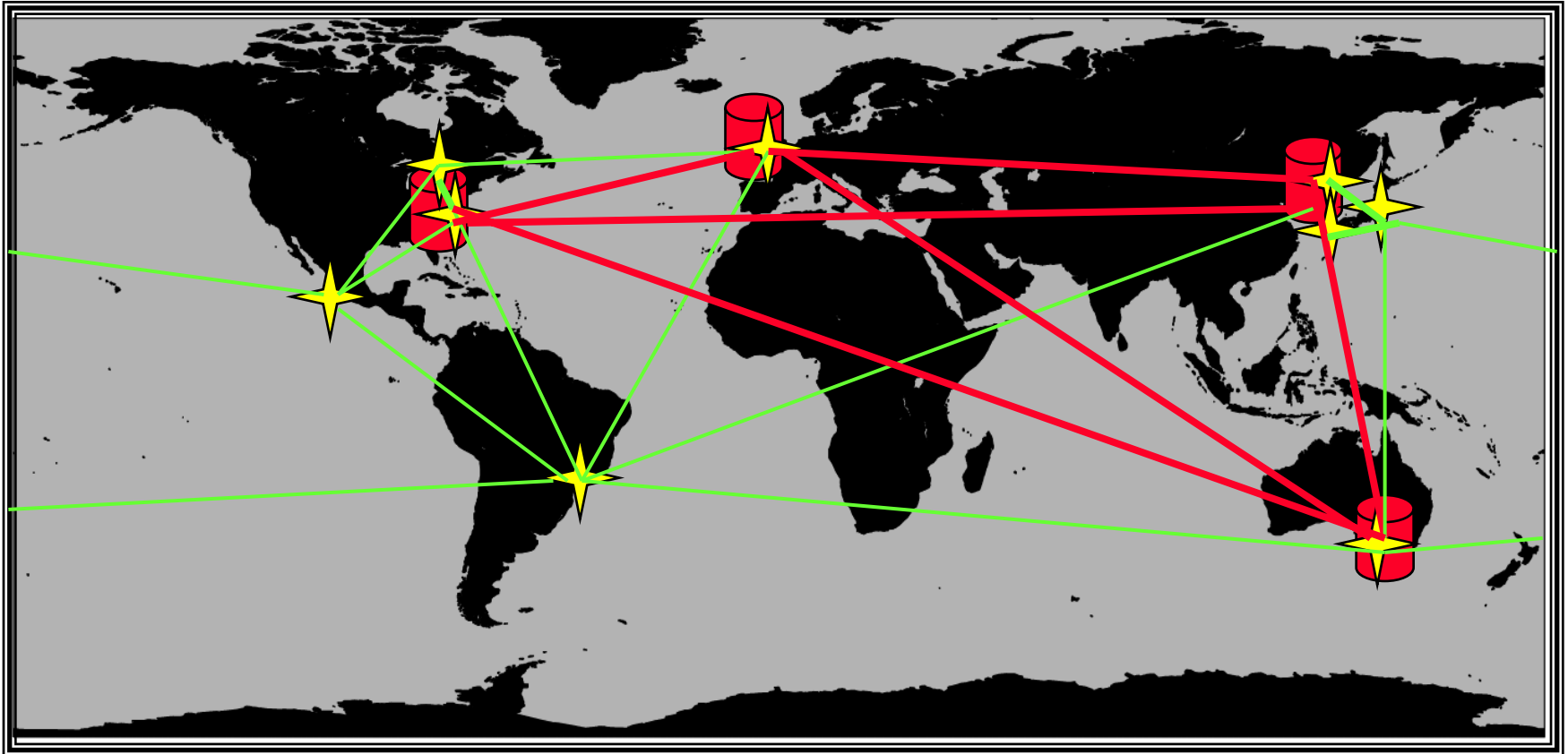
*\* This is just one case:  
probability forecasts  
should be verified on a  
large dataset.*





### 3. TIGGE could lead to a MUMMA-GEPS

TIGGE could lead to a **Multi-Model, Multi-Analysis Global Ensemble Prediction System (MUMMA-GEPS)**, with N production centers (yellow stars) and few data-hubs (red) connected by high-speed, high-capacity communication lines.

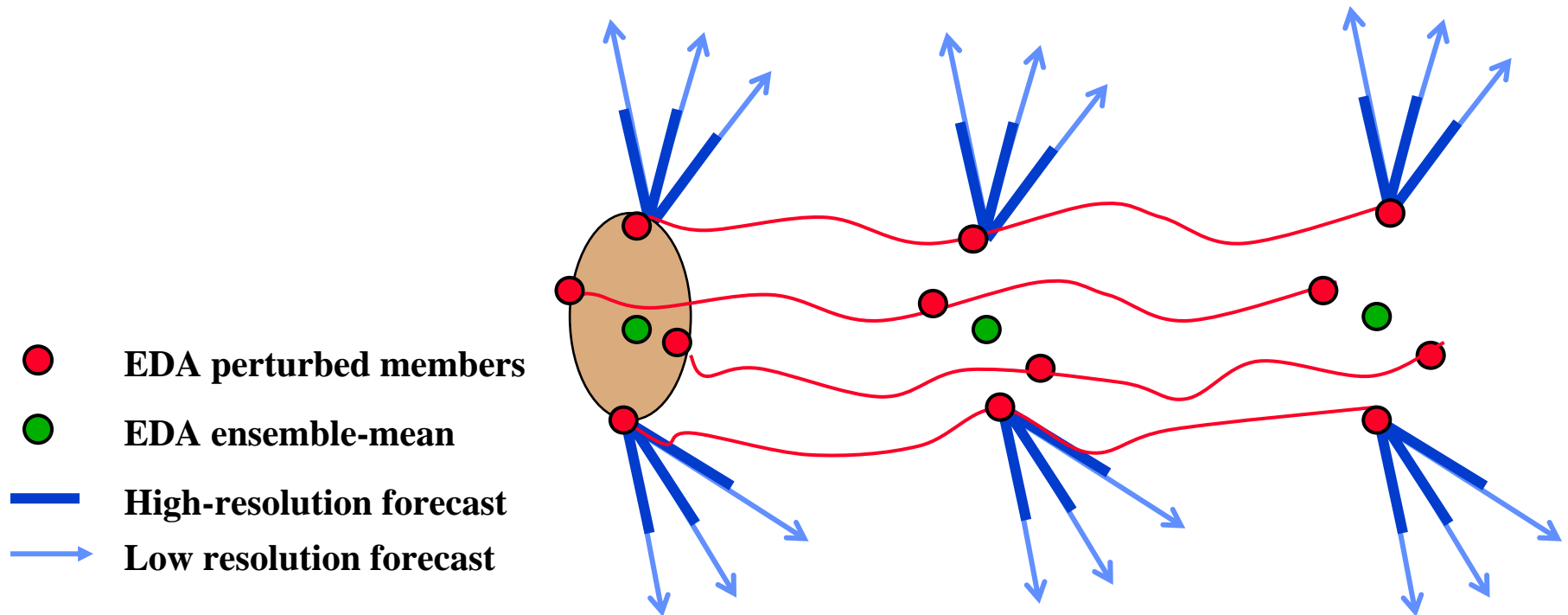




### 3. EDA: towards a probabilistic analysis & forecast system?

Ensemble Data Assimilation [6] may be used in the future to generate the EPS initial perturbations. A future EPS configuration could include:

- ❖ N-member EDA
- ❖ N\*M member EDA-SV EPS,  $T_{L399}(d0:7)+T_{L255}(d7:15)$
- ❖ ICs from each perturbed members and/or the EDA ensemble-mean





## Acknowledgements

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The success of the ECMWF EPS is the result of the continuous work of ECMWF staff, consultants and visitors who had continuously improved the ECMWF model, analysis, diagnostic and technical systems, and of very successful collaborations with its member states and other international institutions.

The work of all contributors, and in particular of former ECMWF staff (*Jan Barkmeijer, Franco Molteni, Robert Mureau, Anders Persson, Otto Pessonen, Thomas Petroligis, David Richardson, Stefano Tibaldi*), visitors and consultants (*Bill Bourke, Mariane Coutinho, Martin Ehrendorfer, Ron Gelaro, Isla Gilmour, Dennis Hartmann, Andrea Montani, Steve Mullen, Kamal Puri, Carolyn Reynolds, Joe Tribbia*) who worked directly on the ECMWF Ensemble Prediction System is acknowledged (I hope that the list of names is complete: please forgive me if this is not the case).



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