Current status and future developments of the ECMWF Ensemble Prediction System

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Outline

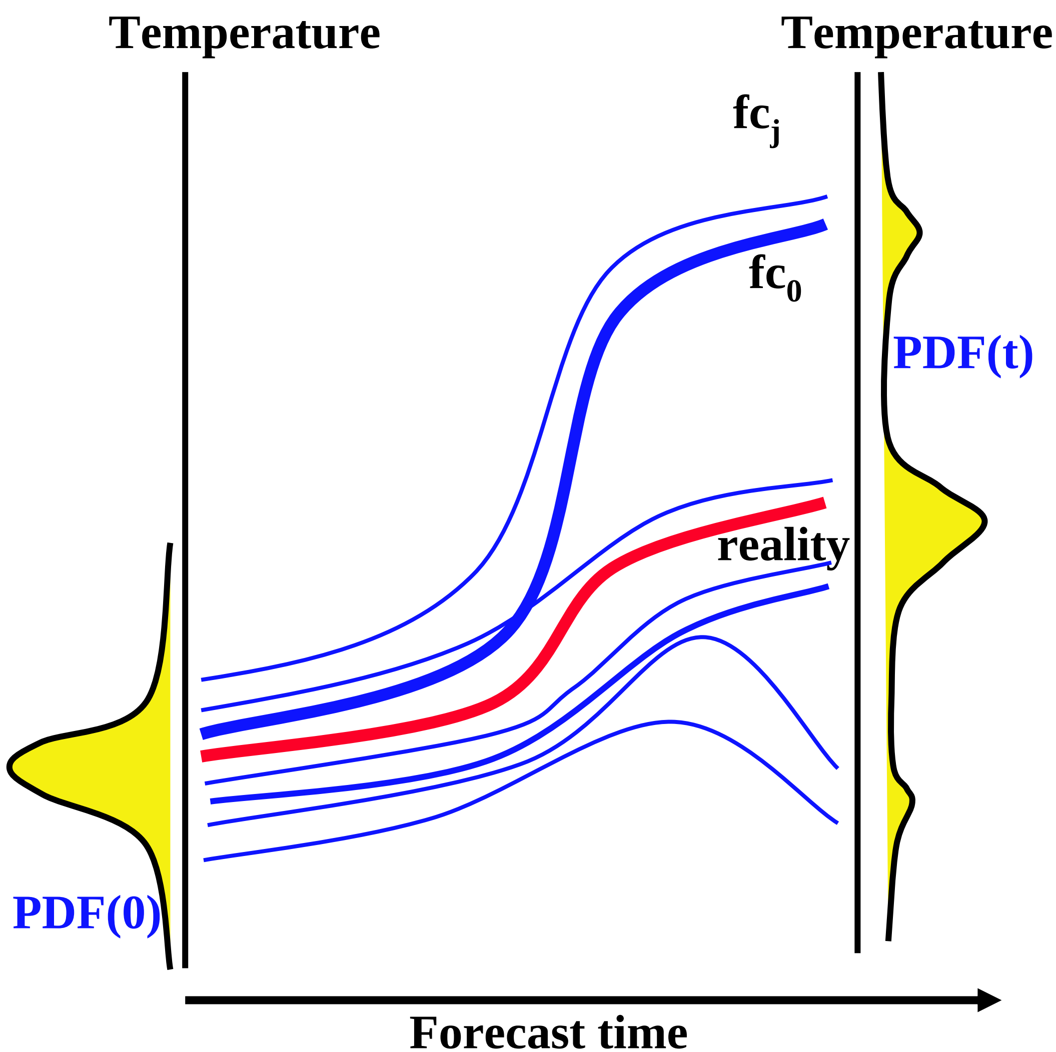
1. **The ECMWF ensemble prediction system (EPS)**
2. **Seamless prediction with the new 32-day ensemble system**
3. **EPS performance**
4. **Ensemble prediction and data assimilation**
5. **Forecasts for Africa 1978**
6. **The EPS and severe weather**
7. **Conclusions**

1. Schematic of ensemble prediction

Two are the main sources of error growth: initial and model uncertainties.

Predictability is flow dependent.

A complete description of weather prediction can be stated in terms of an appropriate probability density function (PDF). Ensemble prediction based on a finite number of deterministic integration appears to be the only feasible method to predict the PDF beyond the range of linear growth.



1. The ECMWF operational probabilistic system

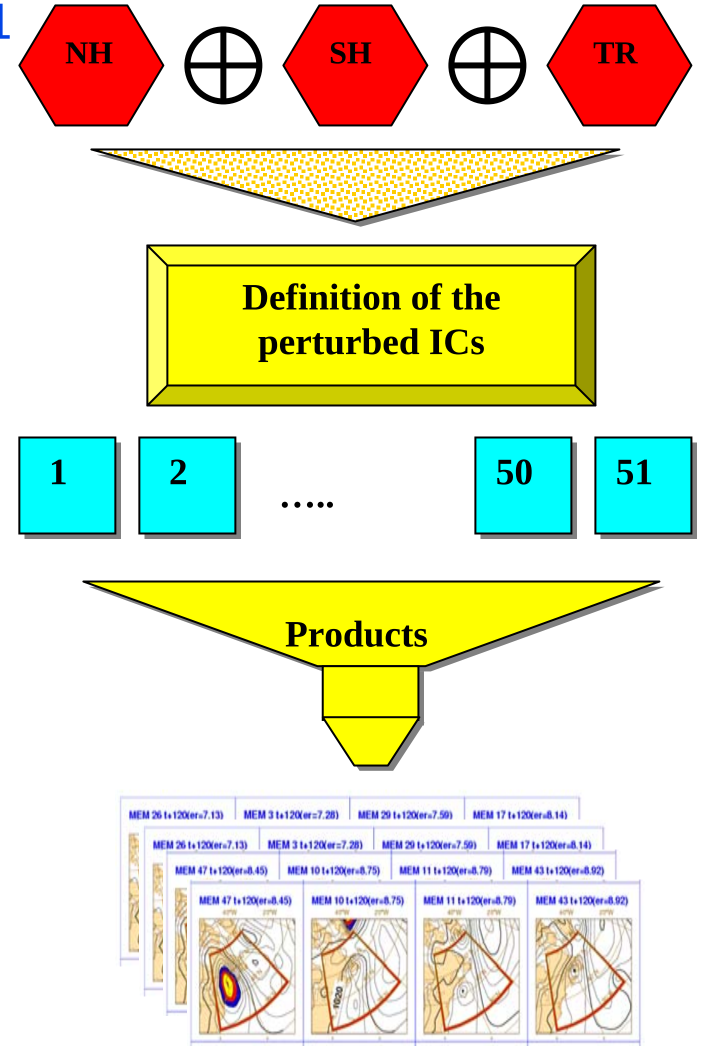
The medium-range probabilistic system consists of 51 forecasts run with variable resolution:

- T_L399L62 (~50km, 62 levels) from day 0 to 10
- T_L255L62 (~80km, 62 levels) from day 10 to 15/32

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 T42L62 singular vectors, computed to optimize total energy growth over a 48h time interval.

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



1. Since its introduction the ensemble changed 16 times

Since its implementation the ECMWF system changed several times: ~50 model cycles (these included changes in the model and DA system) were implemented, and the EPS configuration was modified 16 times, e.g.:

- Dec 1992: the ensemble started with 33 members run for 10 days, three times a week only (starting at 12UTC on Fri-Sat-Sun)
- May 1994: from 1 May 1994 the ensemble has been run every day
- Sep 2006: the ensemble forecast range was extended to 15 day (VAREPS)
- March 2008: the 15-day VAREPS and the coupled monthly have been merged

Date	Description	Singular Vectors's characteristics						Forecast characteristics					
		HRES	VRES	OTI	Target area	EVO SVs	sampl	HRES	VRES	Tend	#	Mod Unc	Coupling
Dec 1992	**Oper Impl**	T21	L19	36h	globe	NO	simm	T63	L19	10d	33	NO	NO
Feb 1993	**SV LPO**	"	"	"	NHx	"	"	"	"	"	"	"	"
Aug 1994	**SV OTI**	"	"	48h	"	"	"	"	"	"	"	"	"
Mar 1995	**SV hor resol**	T42	"	"	"	"	"	"	"	"	"	"	"
Mar 1996	**NH+SH SV**	"	"	"	(NH+SH)x	"	"	"	"	"	"	"	"
Dec 1996	**resol/mem**	"	L31	"	"	"	"	TL159	L31	"	51	"	"
Mar 1998	**EVO SV**	"	"	"	"	YES	"	"	"	"	"	"	"
Oct 1998	**Stoch Ph**	"	"	"	"	"	"	"	"	"	"	YES	"
Oct 1999	**ver resol**	"	L40	"	"	"	"	"	L40	"	"	"	"
Nov 2000	**FC hor resol**	"	"	"	"	"	"	TL255	"	"	"	"	"
Jan 2002	**TC SVs**	"	"	"	(NH+SH)x+TC	"	"	"	"	"	"	"	"
Sep 2004	**sampling**	"	"	"	"	"	Gauss	"	"	"	"	"	"
Jun 2005	**rev sampl**	"	"	"	"	"	"	"	"	"	"	"	"
Feb 2006	**resolution**	"	L62	"	"	"	"	TL399	L62	"	"	"	"
Sep 2006	**VAREPS**	"	"	"	"	"	"	TL399(0-10)+TL255(10-15)	"	15d	"	"	"
Mar 2008	**VAREPS-mon**	T42	L62	48h	(NH+SH)x+TC	YES	Gauss	TL399(0-10)+TL255(10-15)	L62	15d/32d	51	YES	from d10

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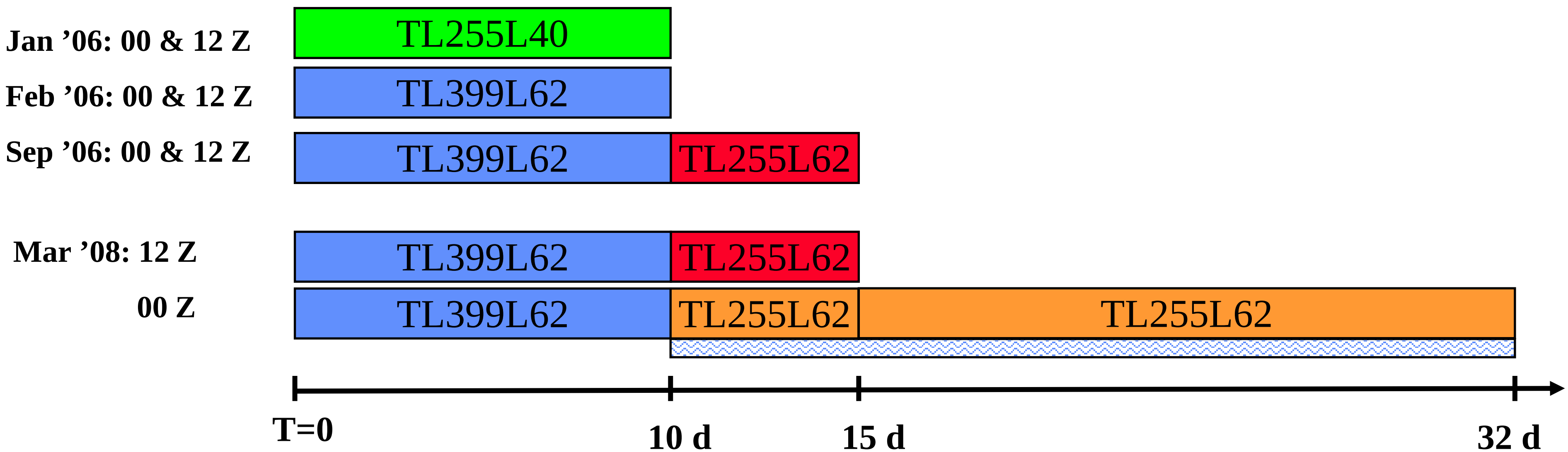
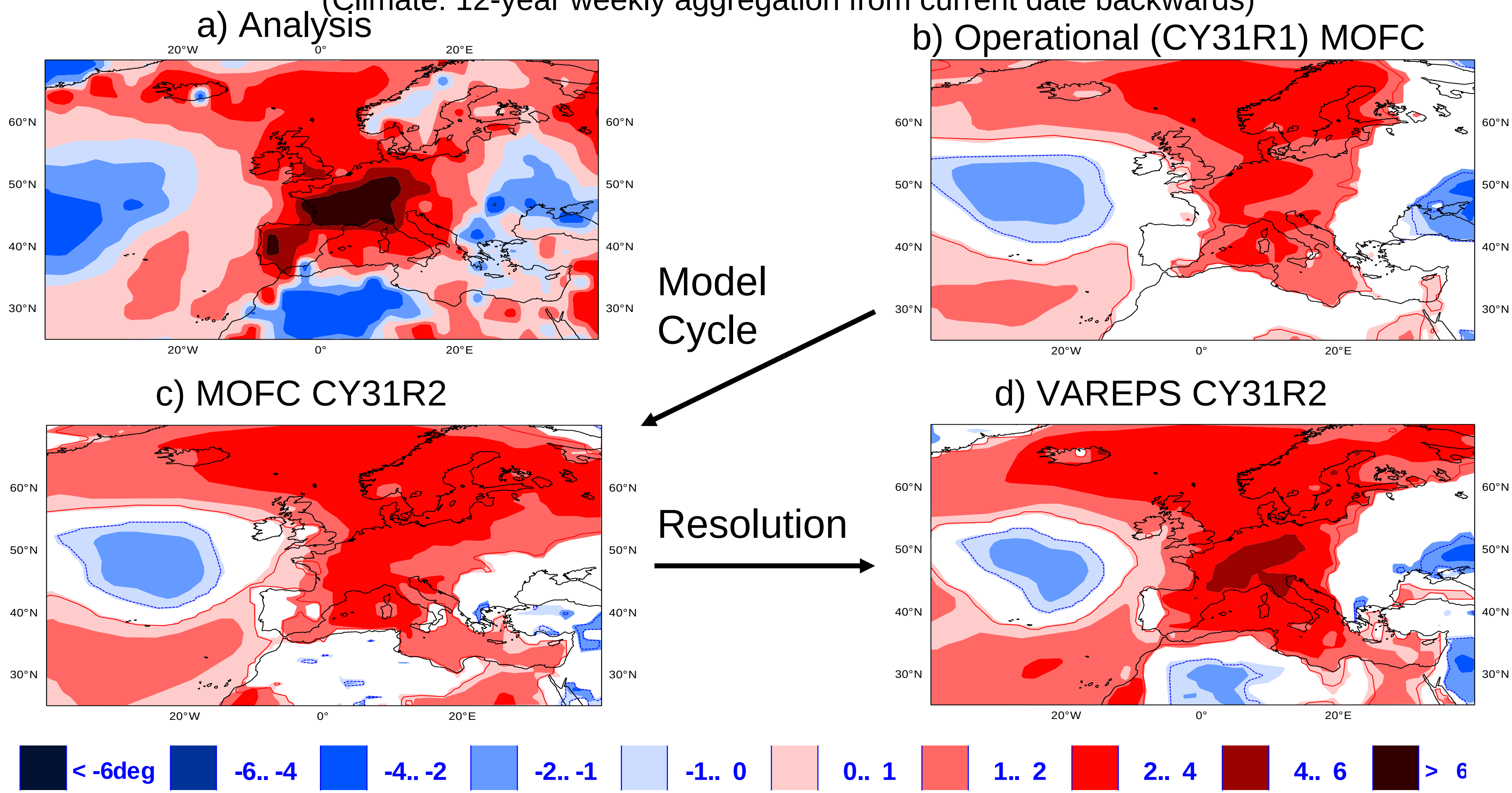
2. The 32-day VAREPS/monthly ensemble (since 11 March 2008)

- Until 1 Feb '06, the EPS had 51 10-day forecasts at T_L255L40 resolution
- On the 1st of Feb '06, the 10-day EPS resolution was upgraded to T_L399L62
- On the 12th of Sep '06, the new Variable Resolution EPS (VAREPS) was introduced, and the ensemble forecast range was extended to 15 days
- On the 11th of Mar '08 the 15-day VAREPS has been linked with the monthly forecast system



Forecasts started on 23 July 2003 for 2m-temperature anomalies for period 3-9 August 2003 (fc-day 12-18): Impact of model cycle and upgrade to 32-day VAREPS.

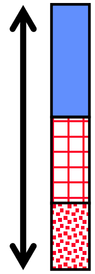
(Climate: 12-year weekly aggregation from current date backwards)

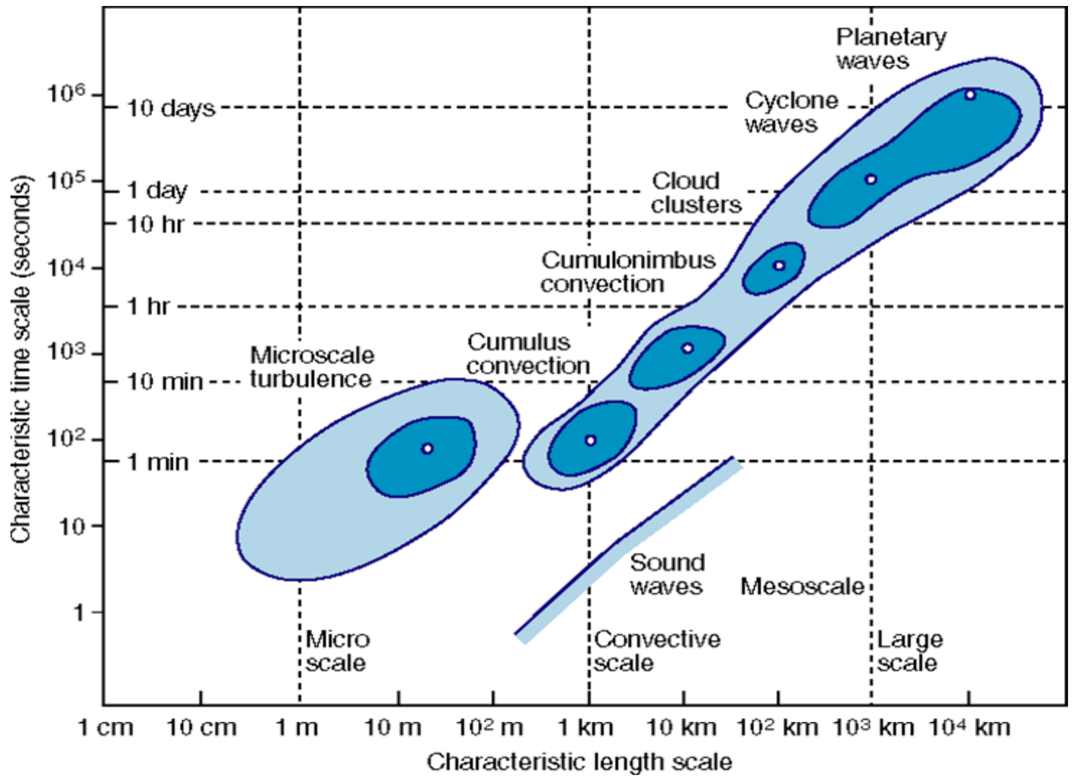


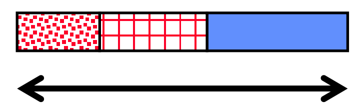
(from F Vitart)

2. The advantage of a seamless probabilistic system

One of the advantages of having merged the 15-day and the monthly ensemble systems is that users have access to (seamless) probabilistic forecasts generated using the same model ranging from weeks to hours ahead:







- In the long-range, weekly-average forecasts (of anomalies wrt model climate) can be used to predict large-scale weather patters.
- In the medium-range, daily probabilistic forecasts can be used to estimate more precisely the timing and location of future weather events.
- In the early forecast range (t<3d) hourly forecast (EPS-grams) can be used to predict in more details local weather conditions.

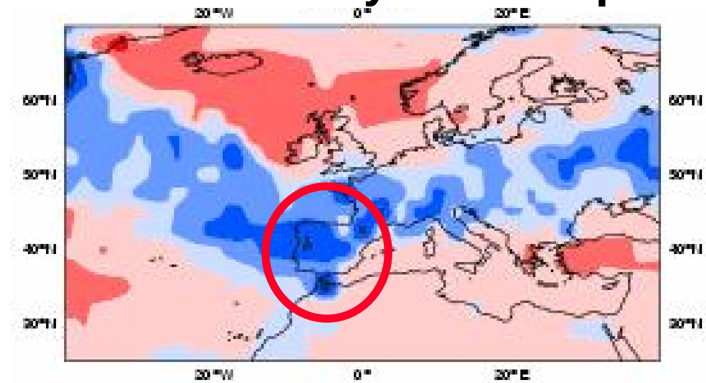
2. From weekly to daily predictions

Seamless probabilistic forecasts from weeks to few hours ahead can be generated with the new ensemble system.

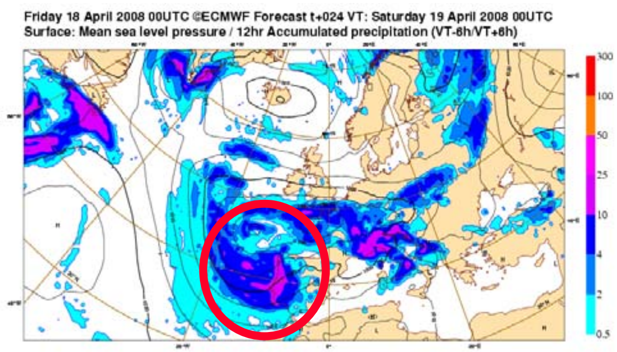
This is illustrated considering the wet period over Portugal and Spain between 14-20 April 2008, and in particular the intense precipitation of 18-19 and 19-20 April.

The forecasts used in the example are the operational ones available to the ECMWF Member States from the ECMWF web pages.

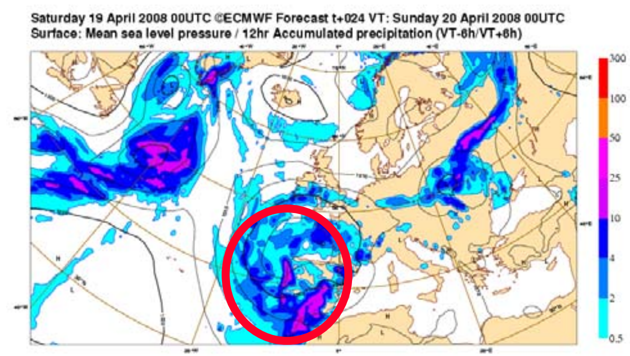
TP-anomaly 14-20 Apr



TP 18-19 Apr



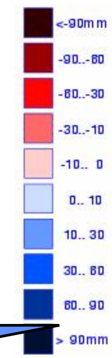
TP 19-20 Apr

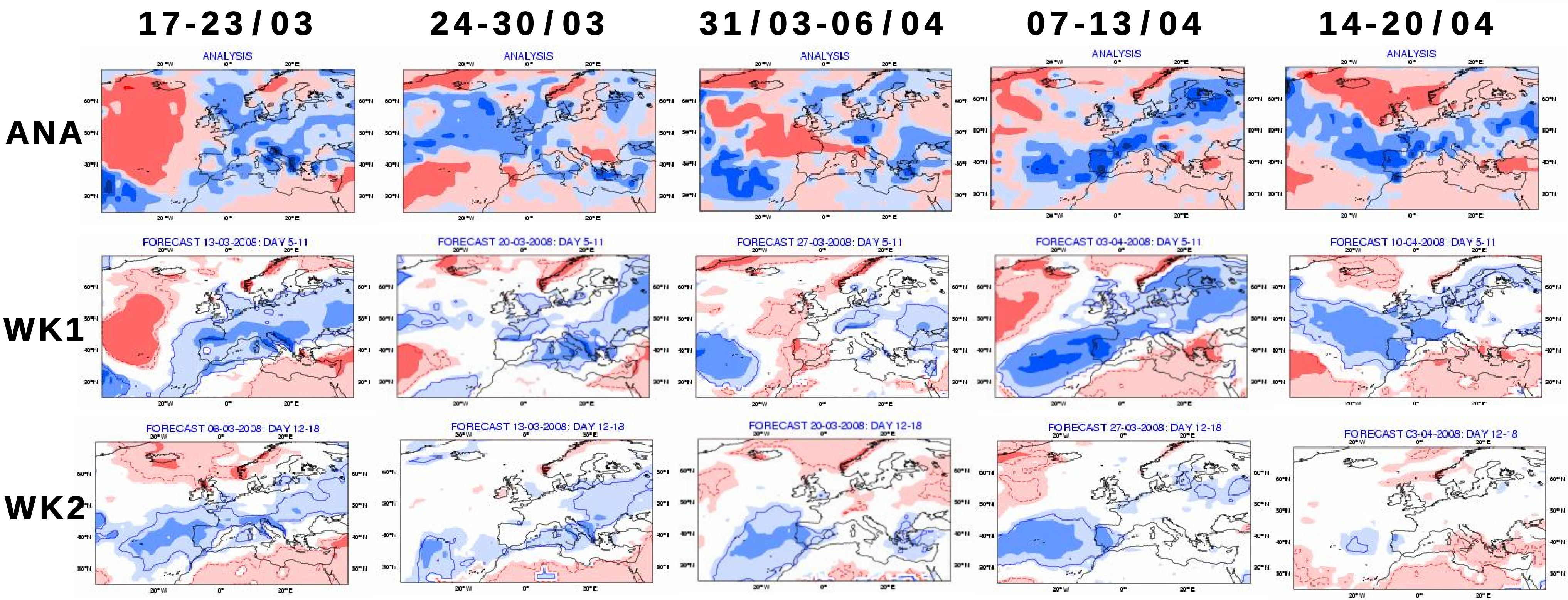


Observations	18-19 Apr	19-20 Apr
Lisbon	43mm	17mm
Gibraltar	17mm	16mm

2. March-April 2008: week-1 and week-2 TP’ fcs

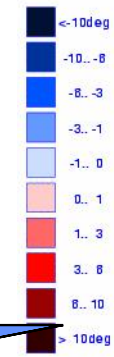
Week-1 (d5-11) average anomaly forecasts correctly predicted the transition to wet conditions over the Iberian peninsula and central Europe between the end of March and the beginning of April 2008. Week-2 (d12-18) average anomaly forecasts are less accurate, but in some cases gave the right signal.

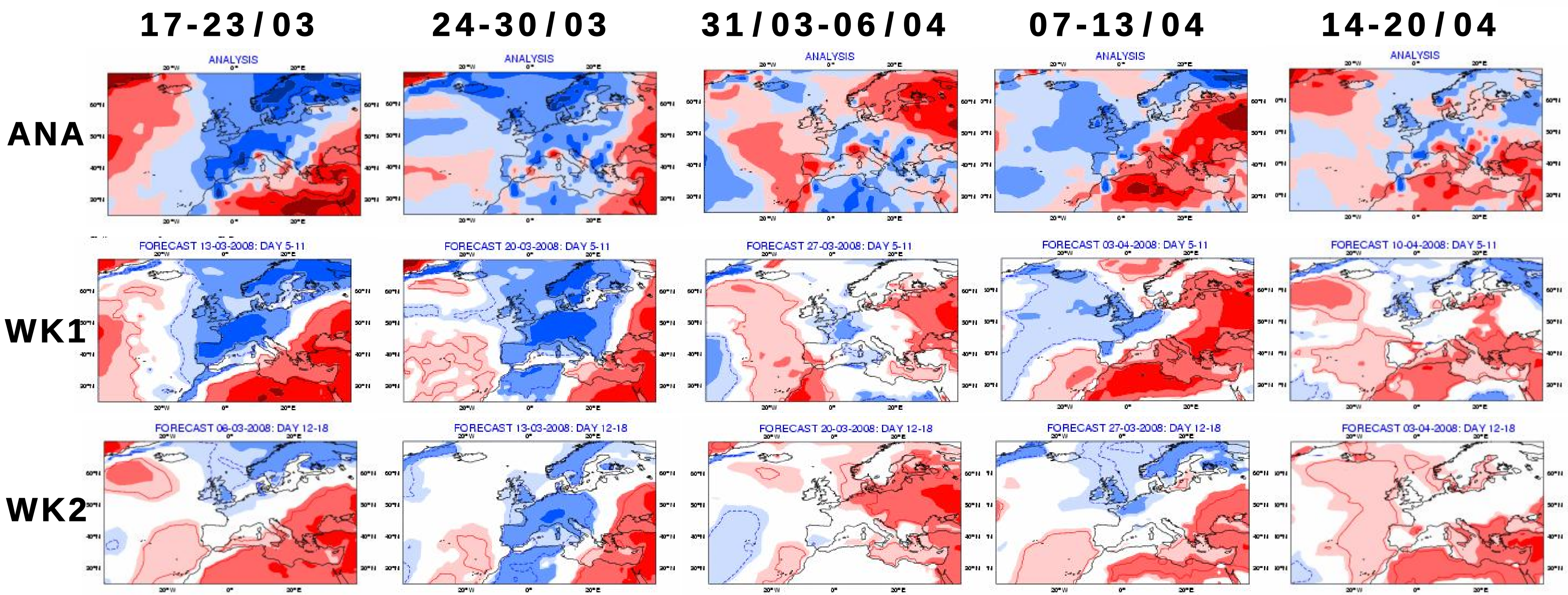




2. March-April 2008: week-1 and week-2 2mT' fcs

Week-1 (d5-11) average 2m-temperature anomaly forecasts correctly predicted the areas of cold/warm anomalies between the end of March and the beginning of April 2008. Week-2 (d12-18) average anomaly forecasts are less accurate, but in some cases gave the right signal.





2. Intense rainfall in Portugal and Spain on 18-20 April

Between the 18th and the 20th of April 2008, intense rainfall affected Portugal and Spain. The intense rainfall followed ~ 10 days of 'wetter than average' conditions.

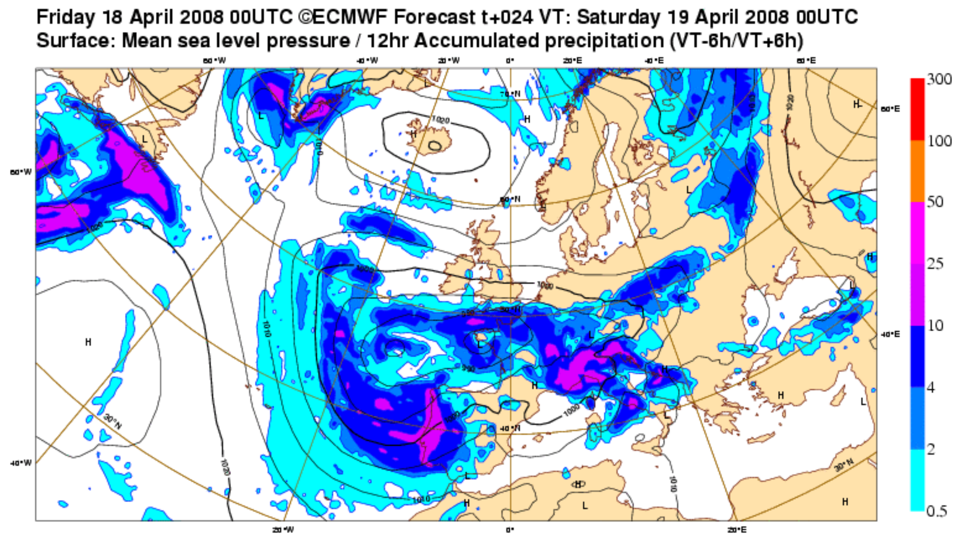
Seamless probabilistic forecasts from weeks to few hours ahead can be generated with the new ensemble system.

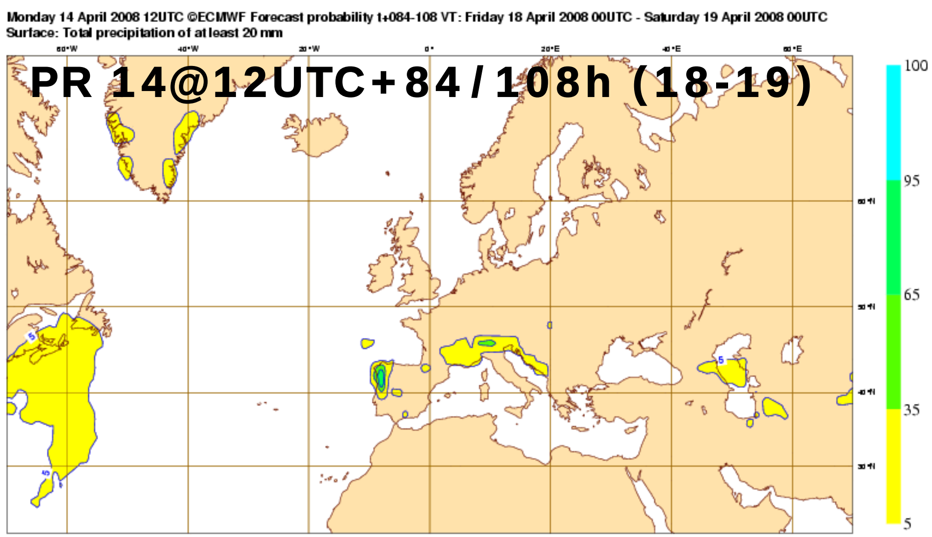
- Did the ensemble predictions of week-average states predict a 'wetter than normal' period? See discussion above (point 4.a)
- Did the ensemble predictions of daily probabilities identify the period 18-20 April as a very wet period?
- Did the ensemble predictions at a specific location (EPS-gram) correctly predict the rainfall amount?

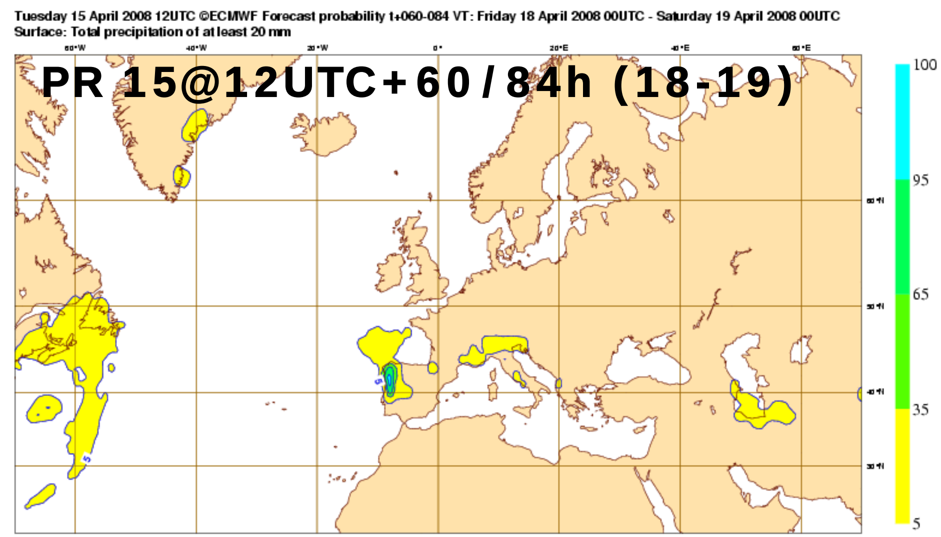
2. Daily prediction: PR fc for 18-19

Let’s focus on the forecasts for 18-19 April, and let’s see how the probabilities change as we get closer to the event.

These plots show the PR(TP>20mm/d) valid for 18-19 Apr and issued on 14 @12UTC (t+84/108) and on 15 @12UTC: PR(TP>20) fcs are consistent and increase for shorter fcs time.



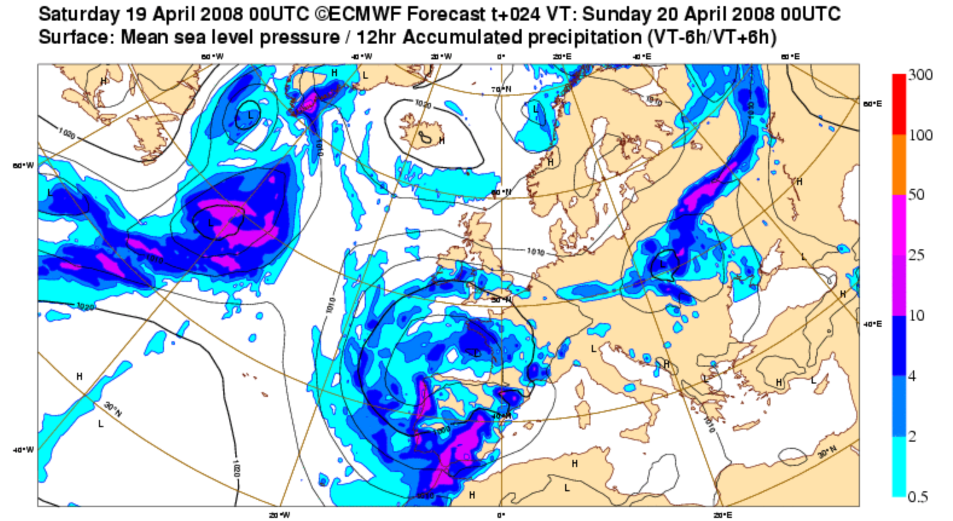


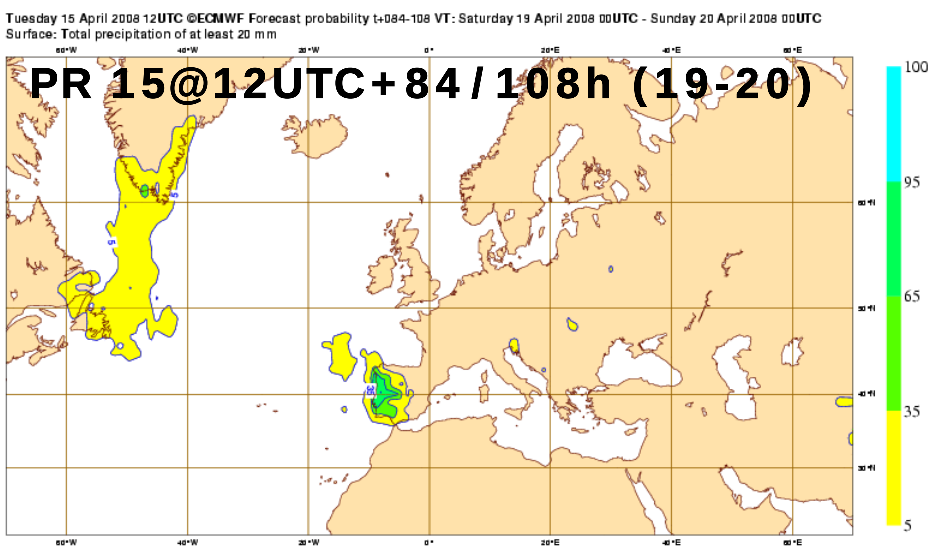


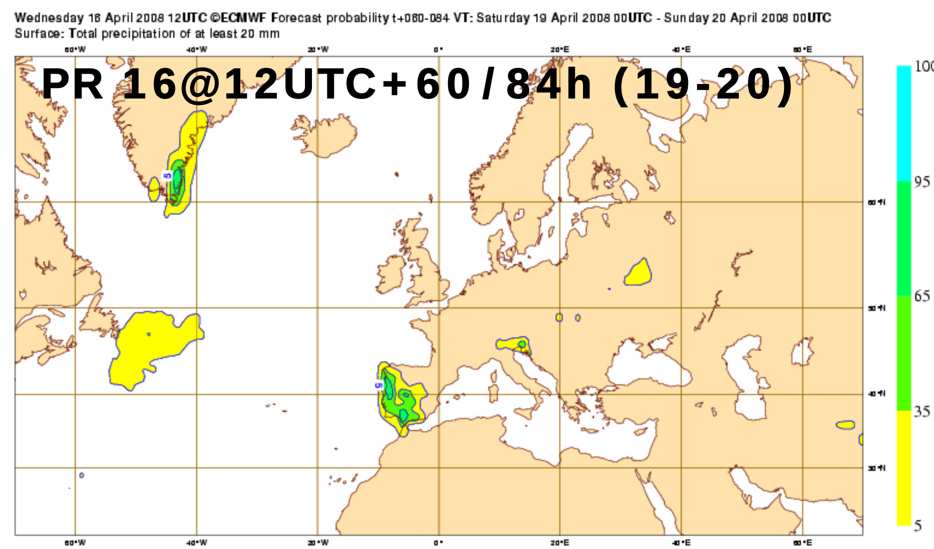
2. Daily prediction: PR fc for 19-20

Let’s focus on the forecasts for 19-20 April, and let’s see how the probabilities change as we get closer to the event.

These plots show the PR(TP>20mm/d) valid for 19-20 Apr and issued on 15 @12UTC (t+84/108) and on 16 @12UTC: PR(TP>20) fcs are consistent and increase for shorter fcs time.





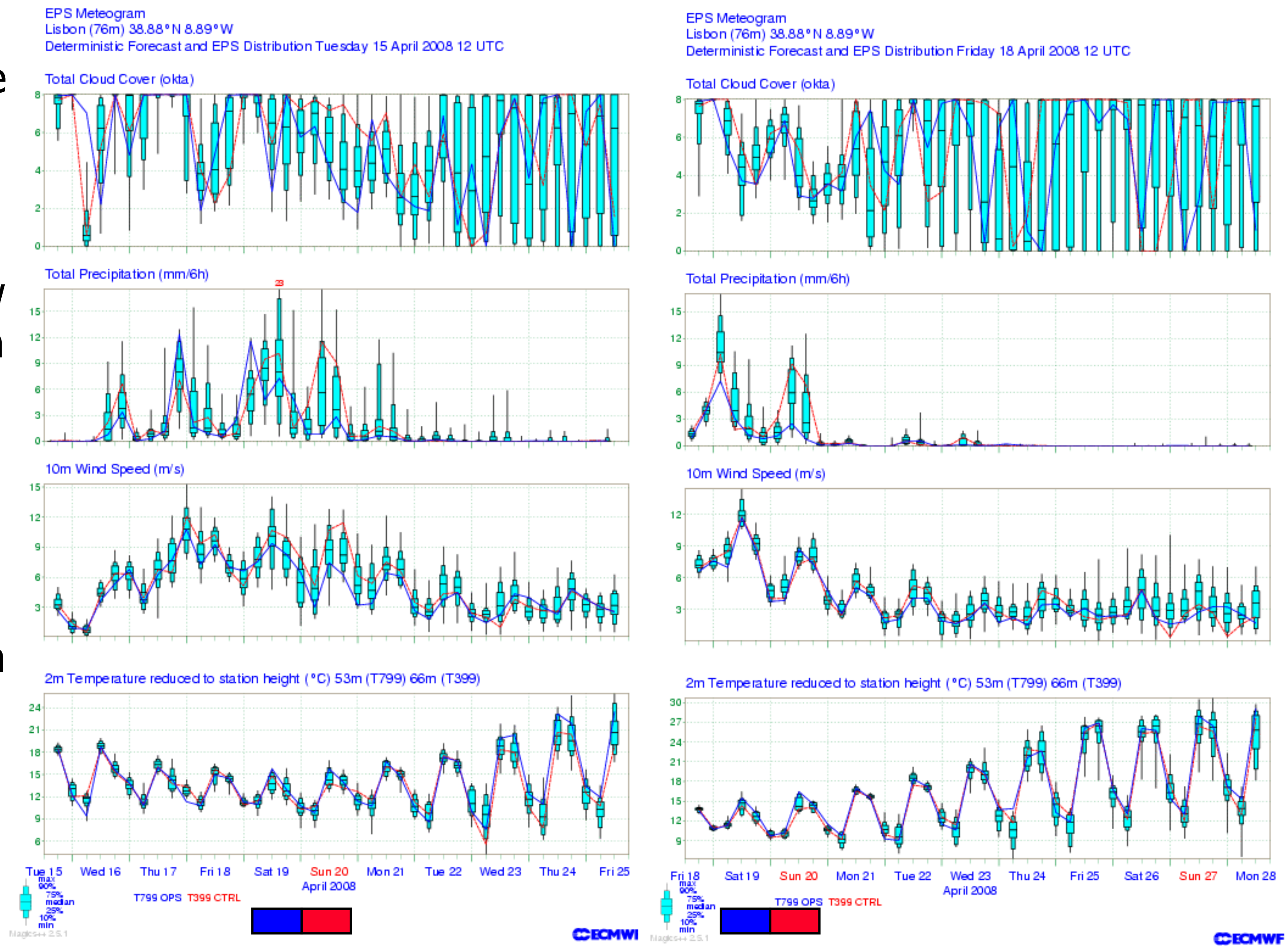


2. Daily grid-point prediction: EPSgram Lisbon

EPS-grams for a single location can be used to make more localized weather forecasts.

These two plots show EPS-grams for Lisbon based on the ensemble forecasts started on 15 and 18 Apr @12UTC.

Between 06UTC of 18-19 (19-20) 43mm (17mm) of rainfall were observed.



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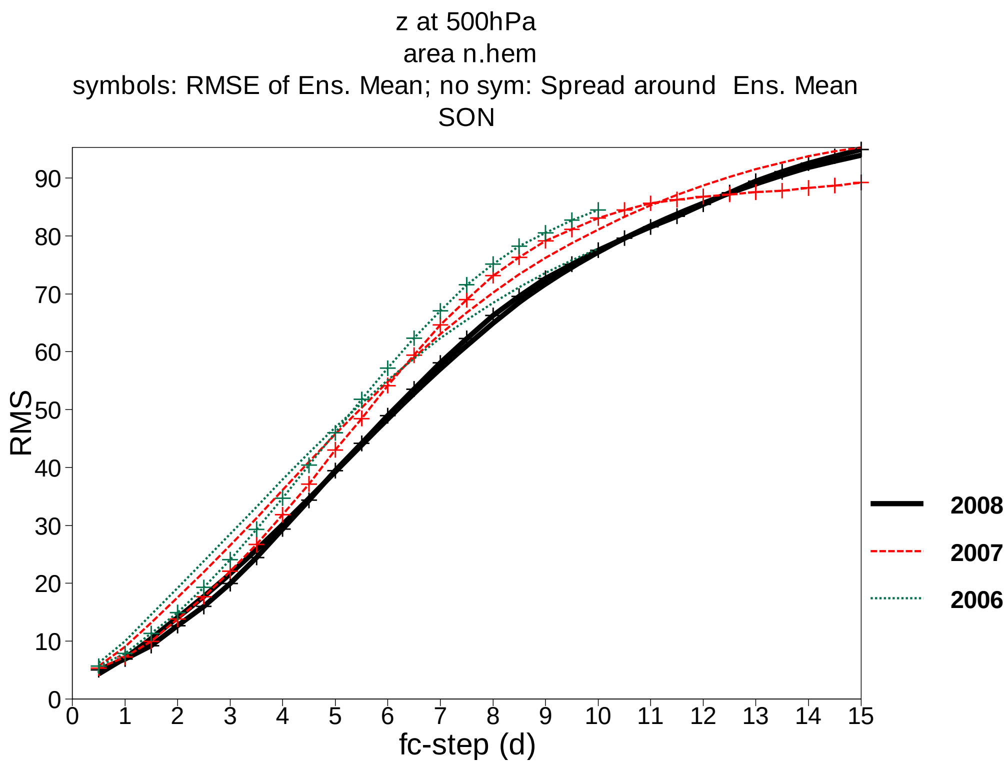
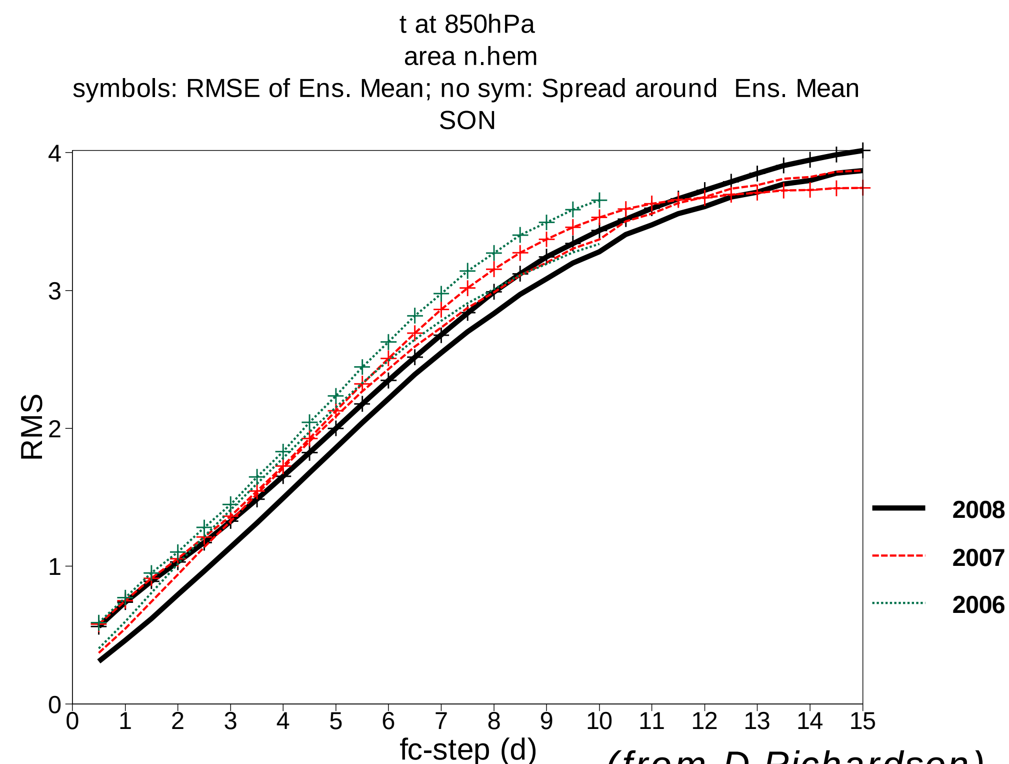
3. Ensemble spread SON: std/err(EM) for Z500 & T850 over NH

These plots compare the ensemble-mean error and the spread computed for Z500 (left) and T850 (right) over NH in the last season (SON). Compared to the past two years, in SON08 the ensemble spread (measured by the std) has been very well tuned for Z500, but still too small for T850. In 2008, the ensemble-mean error was also the smallest.

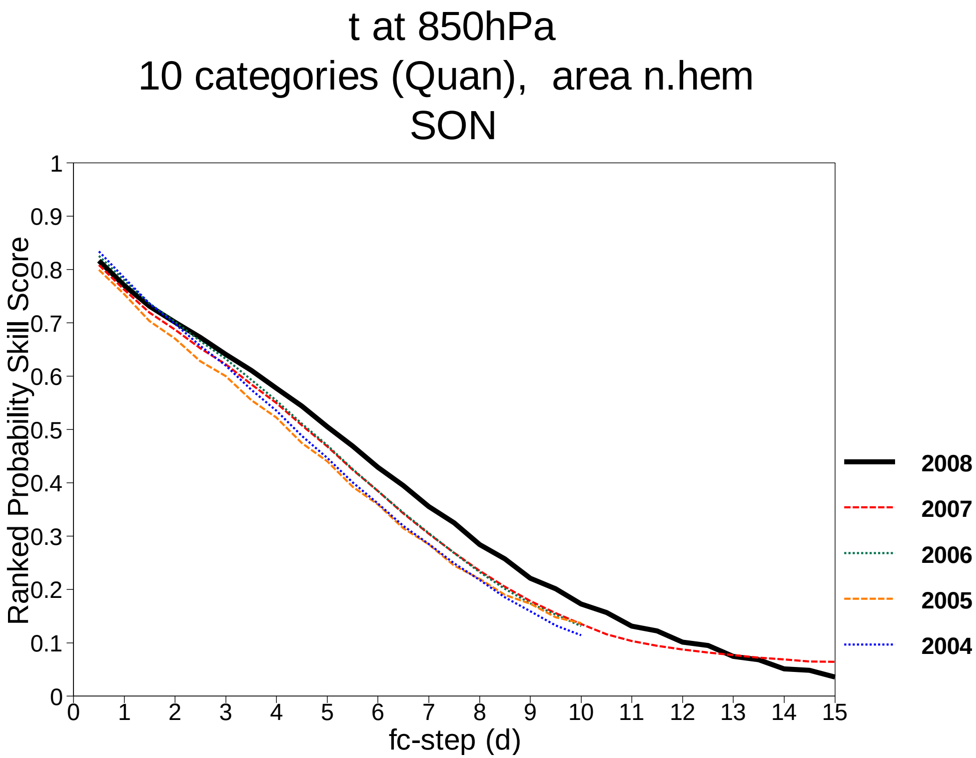


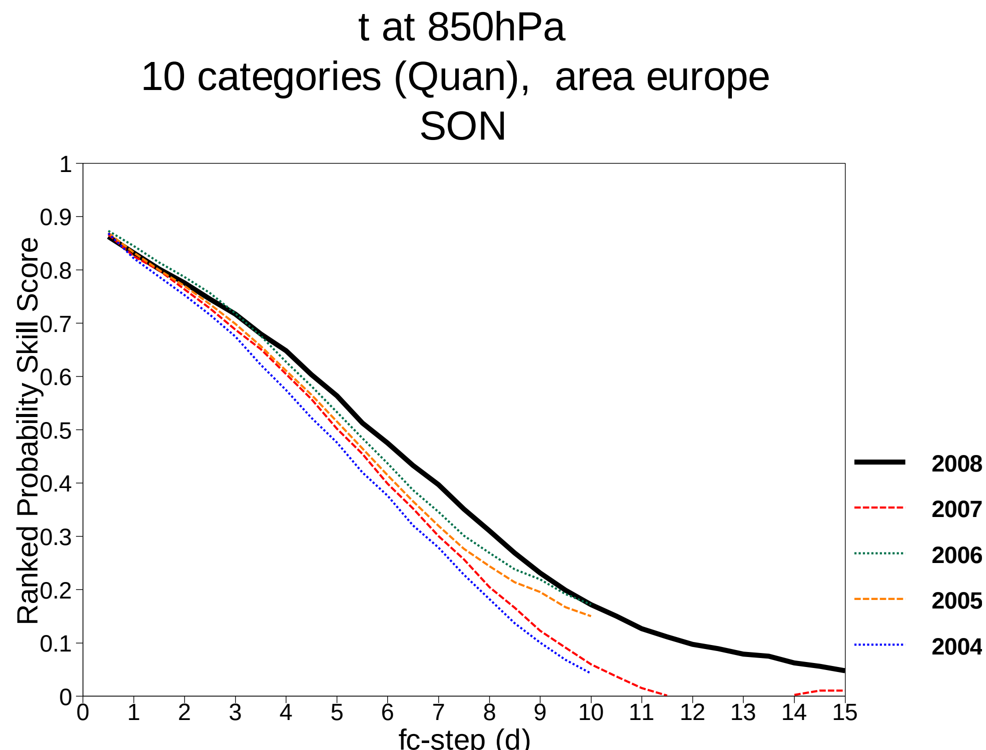


(from D Richardson)

3. Skill probabilistic forecasts: RPSS(T850) SON over NH and Europe

These plots compare the RPSS for T850 over NH (left) and Europe (right) in the last season (SON). Compared to the past two years, in SON08 the ensemble probabilistic fcs (measured by RPSS) were overall the best.

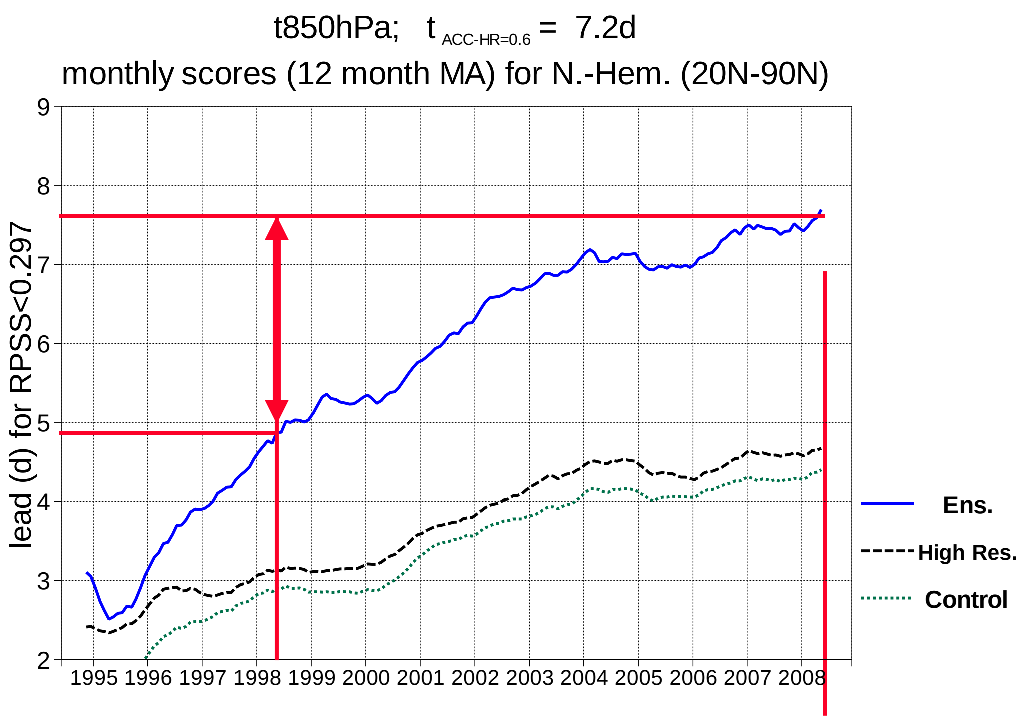


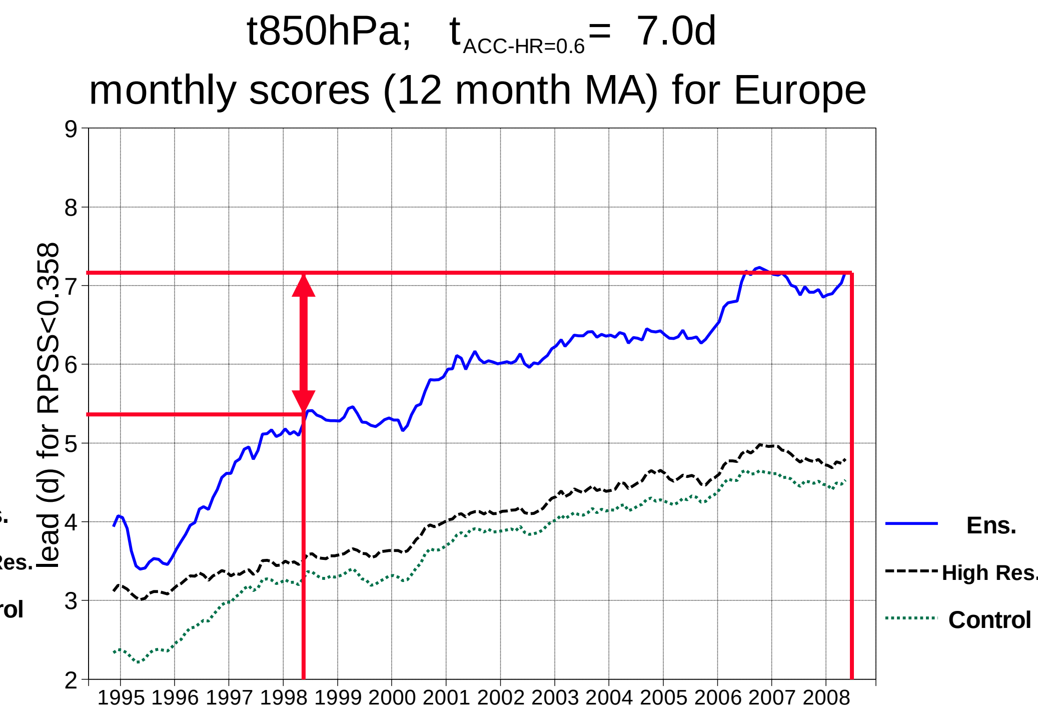


(from D Richardson)

3. Trends in ensemble scores: RPSS(T850) over NH and Europe

Improvements of single and probabilistic forecasts measured by the lead time when RPSS reaches a specified threshold. The left (right) plot shows the fc-time when the RPSS(NH)≤0.297 (RPSS(EU)≤0.358), which corresponds to the time the ACC(HRES)≤0.6. In the 10 years between 1998-2008 the EPS increased predictability by ~2.5 days over NH (~2 days over Europe). Note that in the earlier days the improvements were most consistent.



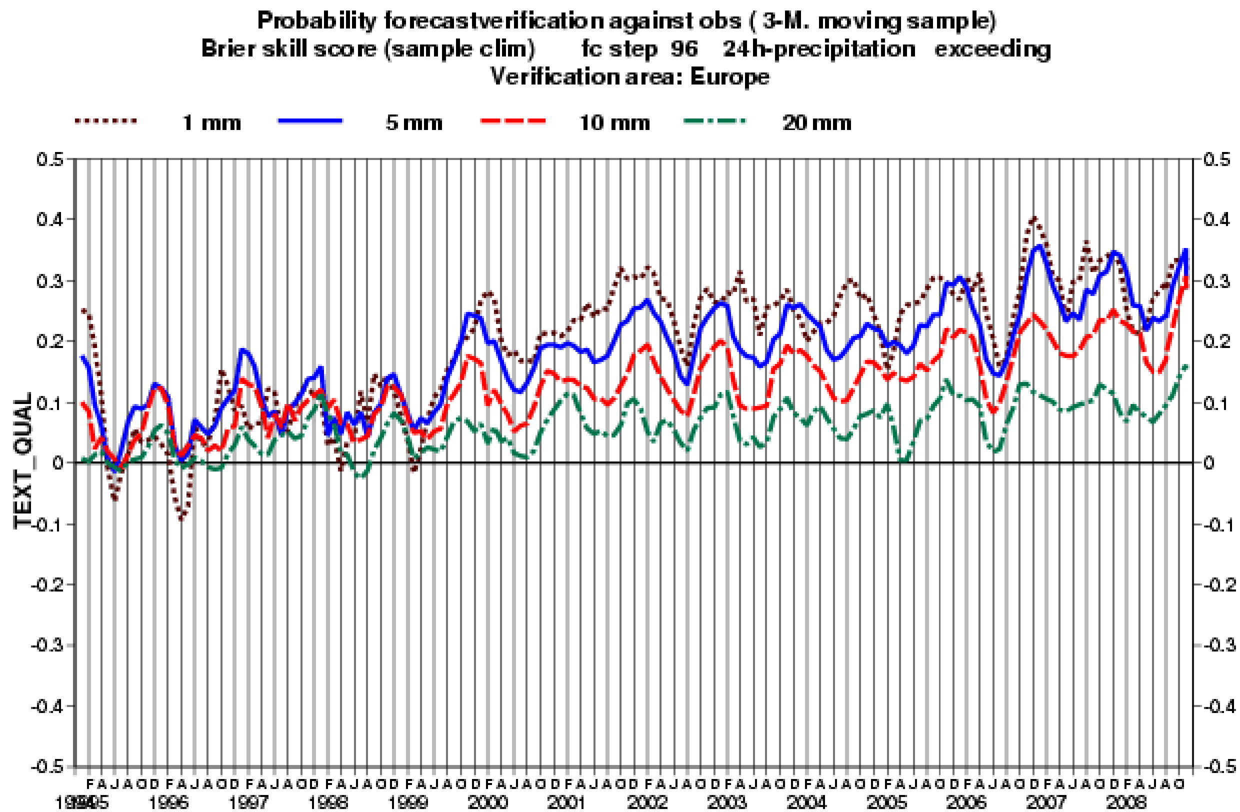


(from D Richardson)

3. Skill probabilistic forecasts: BSS(TP24h) over Europe (v obs) d4

This plot shows the BSS (with respect to the sample climate) of EPS 72-to-96h probabilistic forecasts of 24h-TP exceeding 1, 5, 10 and 20 mm/d over Europe, verified against synop observations.

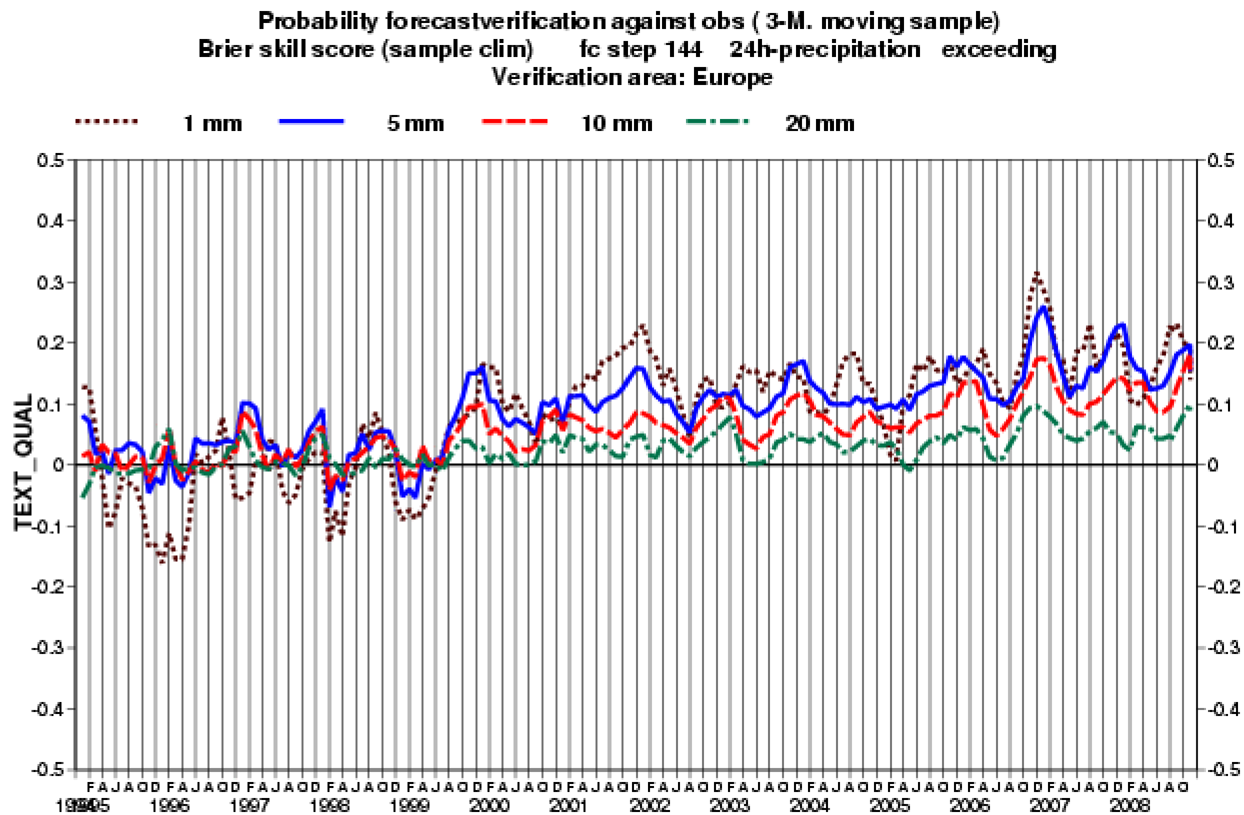
Forecasts have been improving over the years, e.g. when resolution was increased (1996, 2000, 2007). Results also indicate a positive impact of the introduction of model cycle 33r1 (new convection scheme) in 2008.



3. Skill probabilistic forecasts: BSS(TP24h) over Europe (v obs) d6

This plot shows the BSS of EPS 120-to-144h probabilistic forecasts of 24h-TP exceeding 1, 5, 10 and 20 mm/d over Europe, verified against synop observations.

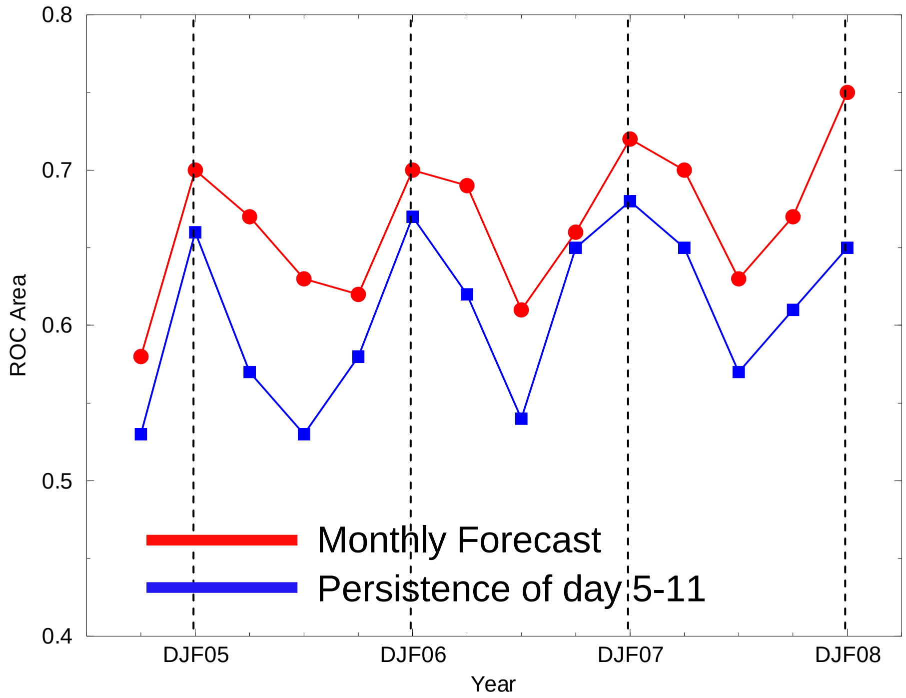
Skill at this forecast range is lower, but still positive with respect to a forecast based on the sample climate.



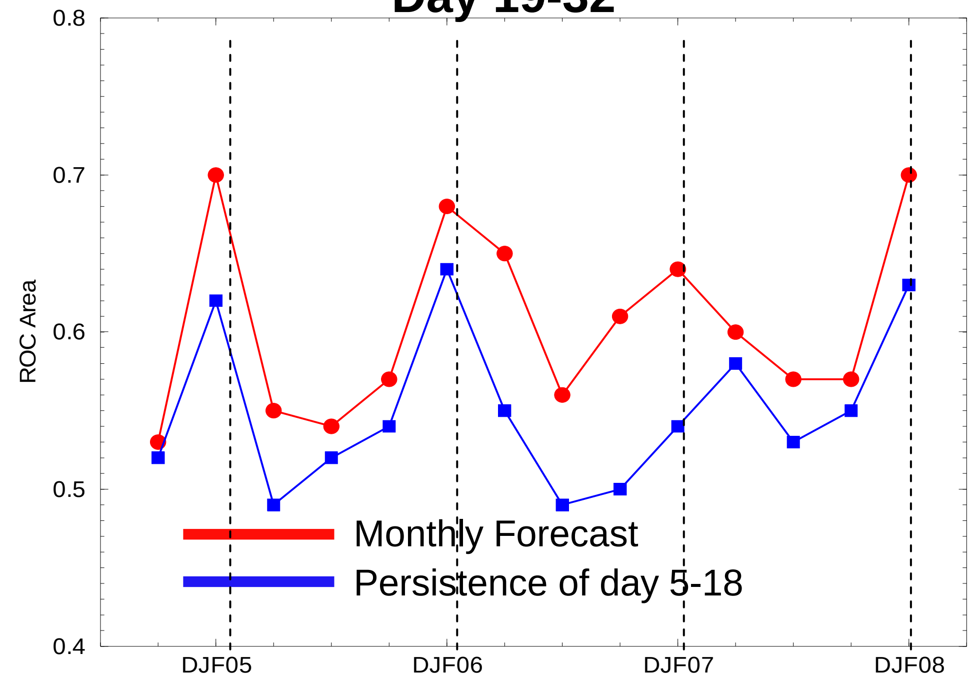
3. Monthly system: ROCA for PR(2mT>0.33c) NH

The monthly forecasting system has been running since 2005. Week-1 and week-2 probabilistic forecasts of some variables (e.g. 2m temperature anomalies) have been proven to be more skilful than climatological forecasts, or persistence. For some case, weekly probabilistic forecasts of accumulated precipitation has also shown to be skilful. Preliminary results have indicated that the new VAREPS/monthly system is in some cases even more accurate.

Day 12-18



Day 19-32



(from F Vitart)

3. Performance of the TIGGE ensembles

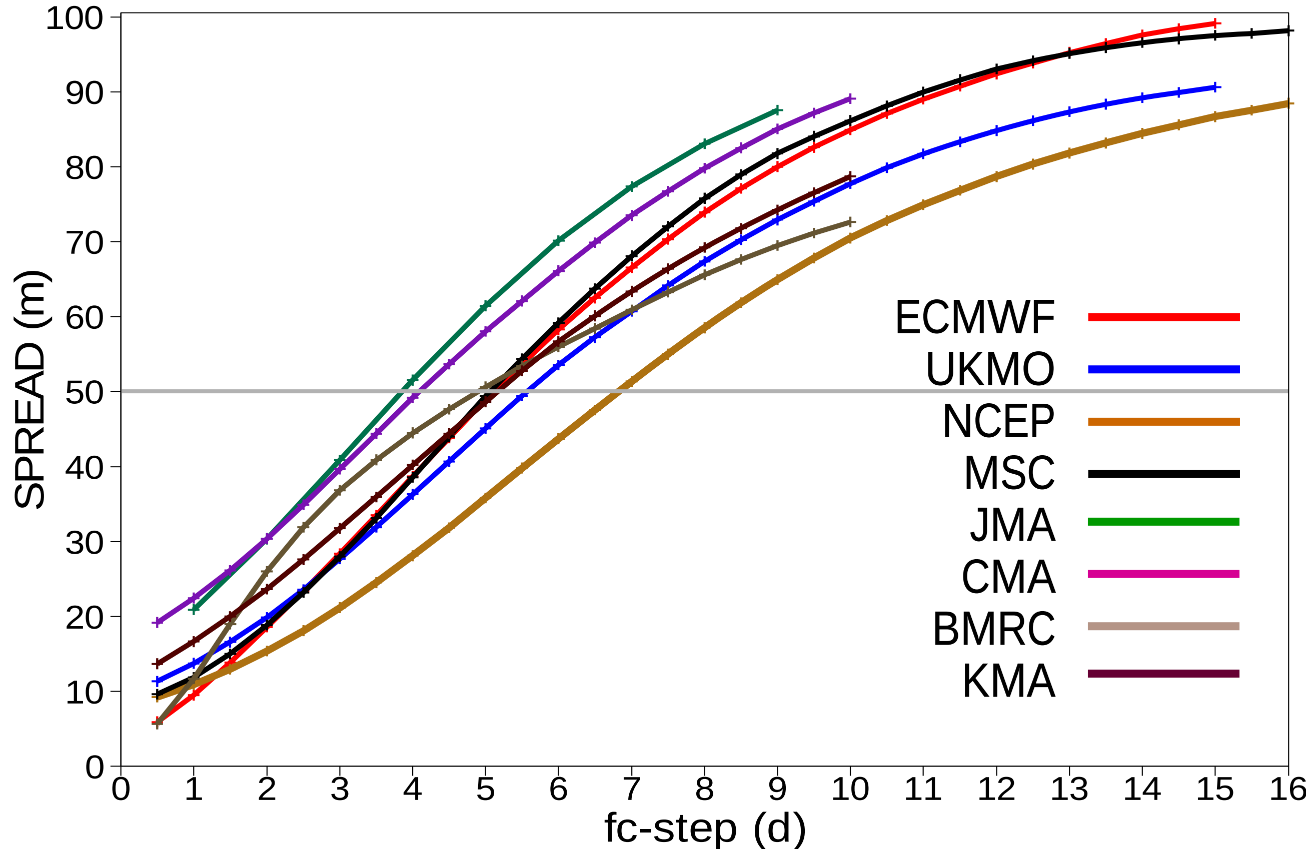
The TIGGE data-base has given us the opportunity to assess the performance of almost all the operational global medium-range ensemble systems (that agreed to contribute to TIGGE). The following table lists the key characteristics of the ensembles compared in a a recent study (Park et al 2008).

Centre	Initial pert method (area)	Model error simul	Horizon res	Vert res	Fcst length (days)	# pert mem	#runs per day (UTC)	# mem per day	operation from*
BMRC(Australia)	SVs(NH,SH)	NO	TL119	19	10	32	2(00/12)	66	3 Sep 07
CMA (China)	BVs (globe)	NO	T213	31	10	14	2(00/12)	30	15 May 07
ECMWF	SVs (globe)	YES	TL399	62	0-10	50	2(00/12)	102	1 Oct 06
			TL255	62	10-15				
JMA (Japan)	BVs (NH+TR)+	NO	TL159	40+	9	50	1(12)	51	1 Oct 06
KMA(Korea)	BVs (NH)	NO	T213	40	10	16	2(00/12)	34	3 Oct 07
MSC(Canada)	EnKF (globe)	YES	TL149	28	16	20	2(00/12)	42	3 Oct 07
NCEP(USA)	BVs(globe)	NO	T126	28	16	20***	4(00/06/12/18)	84	5 Mar 07
UKMO(UK)	ETKF (globe)	YES	1.25x0.83deg	38	15	23	2(00/12)	48	1 Oct 06

3. From *Park et al* (2008): ON07 (45c), Z500 STD over NH

Most recent TIGGE results: this figure shows the ON07 average ensemble STD for Z500 over NH. The EC and the MSC ensembles have similar values. The NCEP ensemble has the lowest spread, while the CMA and JMA ensembles have the largest. The EC and BMRC ensembles have the smallest initial spread, and the fastest growth during the first 2 fc days.

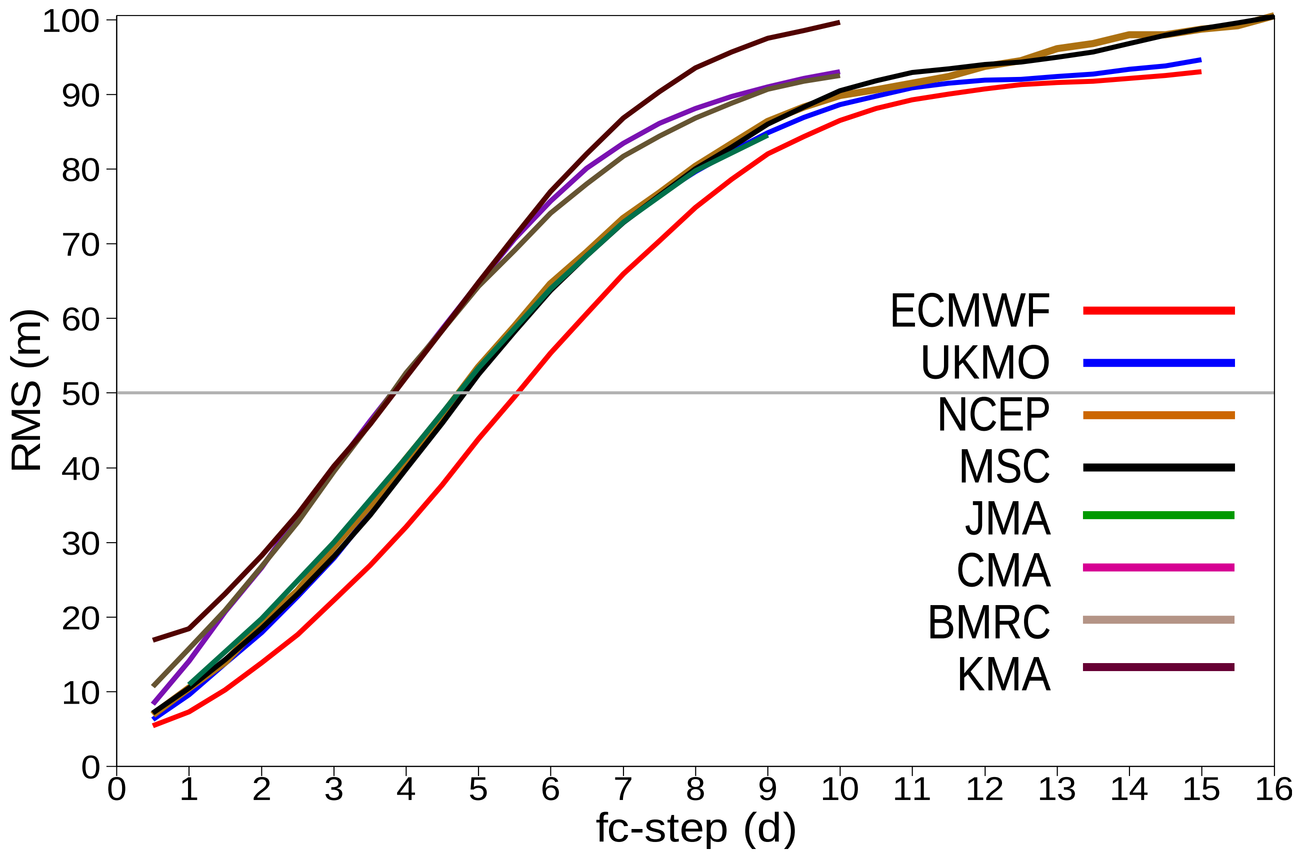
This differences in ensemble spread strongly depend on the ensemble design (e.g. use of SVs) and model resolution/activity.



3. From *Park et al* (2008): ON07 (45c), Z500 RMSE(EM) over NH

Most recent TIGGE results: this figure shows the ON07 average RMSE of the ensemble-mean (EM) fc for Z500 over NH. The EC EM outperforms the group of 2nd best ensembles (MSC, NCAP, UKMO and JMA for this period) for the whole fc range, with ~0.75d gain in predictability at t+5d.

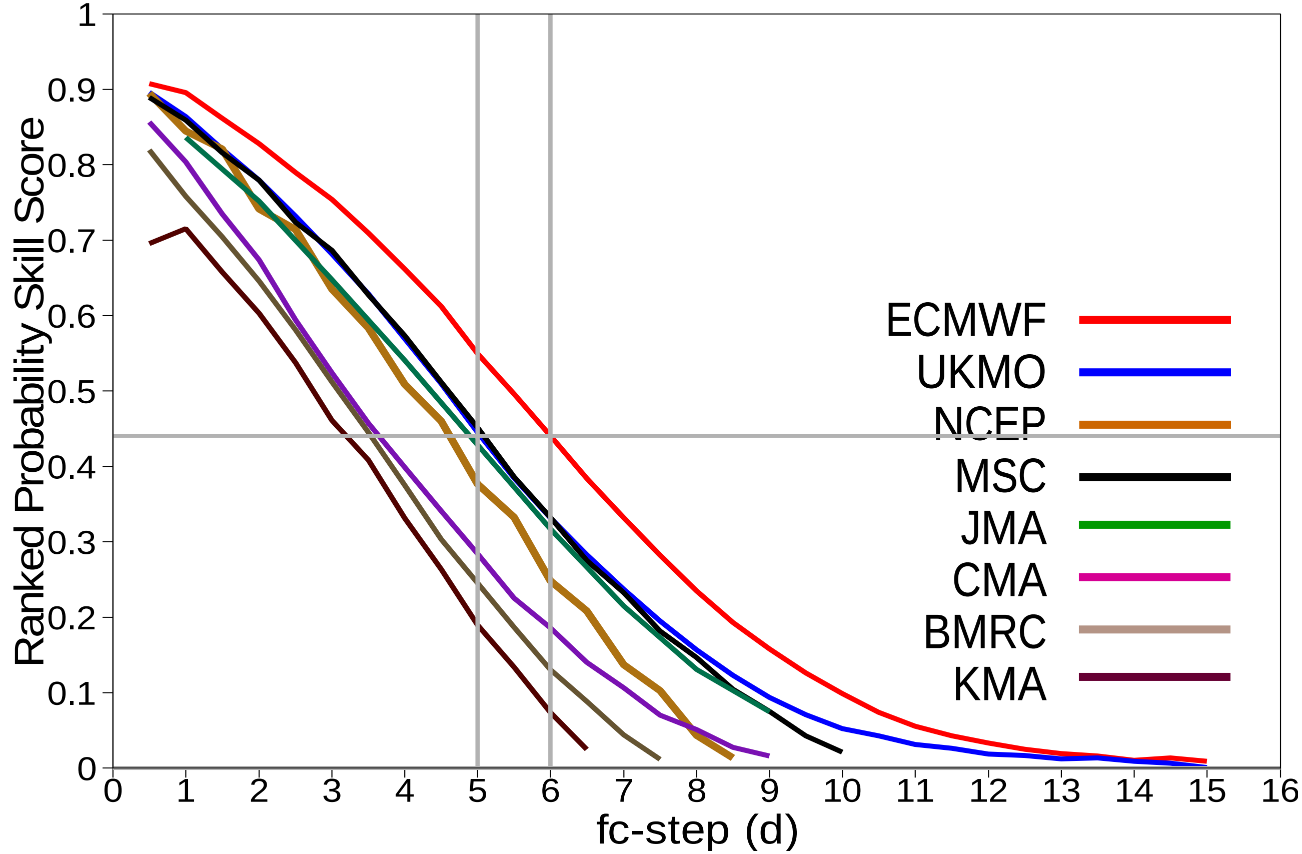
This indicates that the differences in skill of the ensemble probabilistic forecasts is not only due to model/analysis, but also to the ensemble design (e.g. use of SVs).



3. From *Park et al* (2008): ON07 (45c), Z500 RPSS over NH

Most recent TIGGE results: this figure shows the ON07 average RPSS of the ensemble fcs for Z500 positive anomalies over NH. The EC ensemble outperforms the group of 2nd best ensembles (UKMO, NCEP, MSC and JMA for this period) for the whole fc range, with ~1.0d gain in predictability at t+5d.

This also indicates that the differences in skill of the ensemble probabilistic forecasts is not only due to model/analysis, but also to the ensemble design (e.g. use of SVs).



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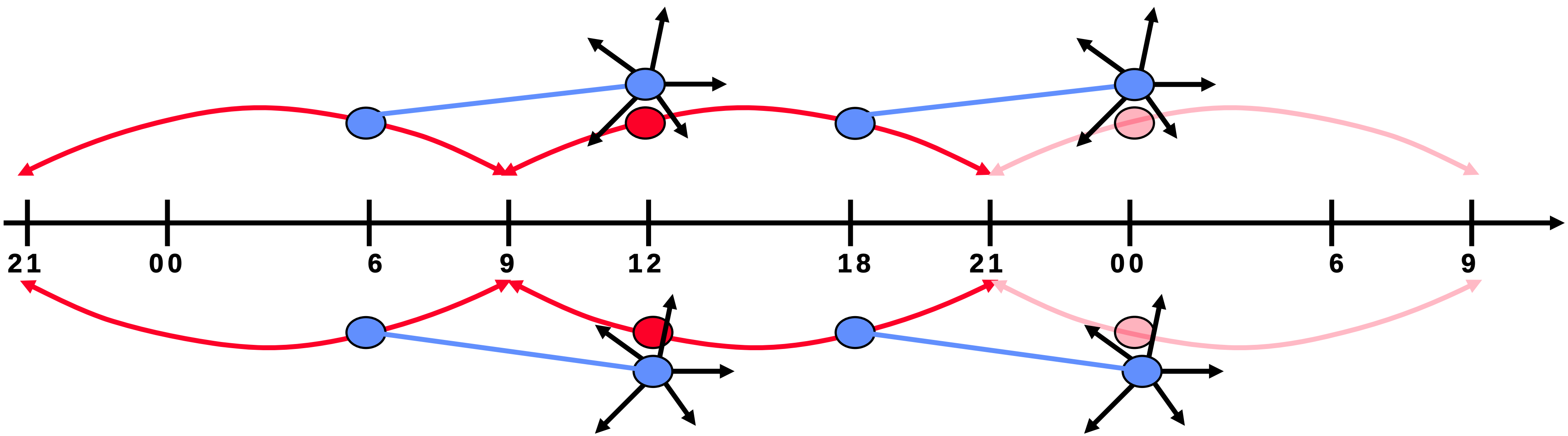
4. The EVO-SVINI and EDA-SVINI ensemble systems

The EDA analyses A_j are used at forecast step +6 hour:

$$PA_j(d,0) = A_{TL799}(d,0) +/- f \cdot [A_j(d-6h,6h) - A_0(d-6h,6h)]$$



The choice of using 6h forecasts is consistent with data-assimilation practice followed when computing J_b statistics. In an operational framework, this choice implies that the EPS can start as soon as the 'center' analysis (e.g. T_L799L91) is ready since the day *d* EDA-perturbations are generated using +6h forecasts started from the previous cycle.

4. The EVO-SVINI and EDA-SVINI ensemble systems

Each ensemble forecast is given by the time integration of perturbed equations

$$e_j(d,T) = e_j(d,0) + \int_0^T [A(e_j,t) + P(e_j,t) + \delta P_j(e_j,t)]dt$$

$$\delta P_j(\lambda,\phi,p) = r_j(\lambda,\phi) P_j(\lambda,\phi,p)$$

Initial perturbations are defined using evolved and initial SVs

$$e_j(d,0) = A_{TL799}(d,0) + de_j(d,0)$$

$$de_j(d,0) = \sum_{area} \sum_{k=1}^{N_{SV}} [\beta_{j,k} \cdot SV_k(d-48,48) + \alpha_{j,k} \cdot SV_k(d,0)]$$

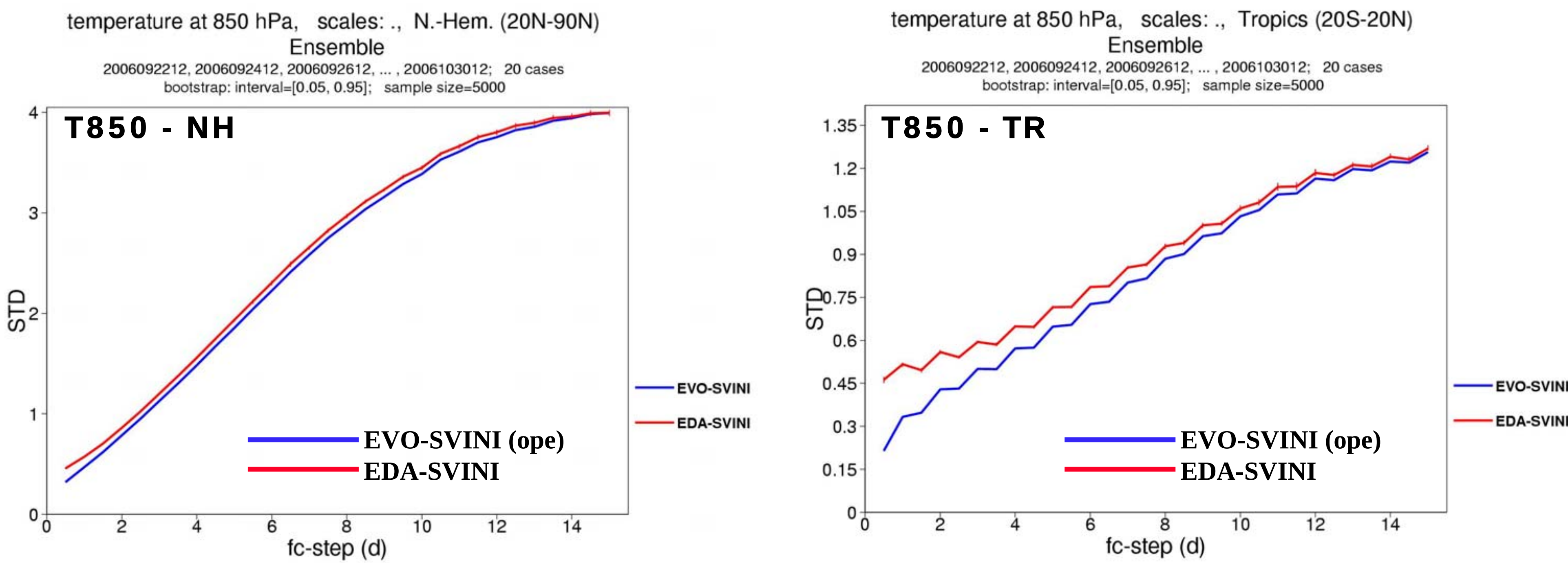
or using perturbed analyses (generated by the EDA ensemble) and initial SVs

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

$$PA_j(d,0) = A_{TL799}(d,0) +/- f \cdot [A_j(d-6h,6h) - A_0(d-6h,6h)]$$

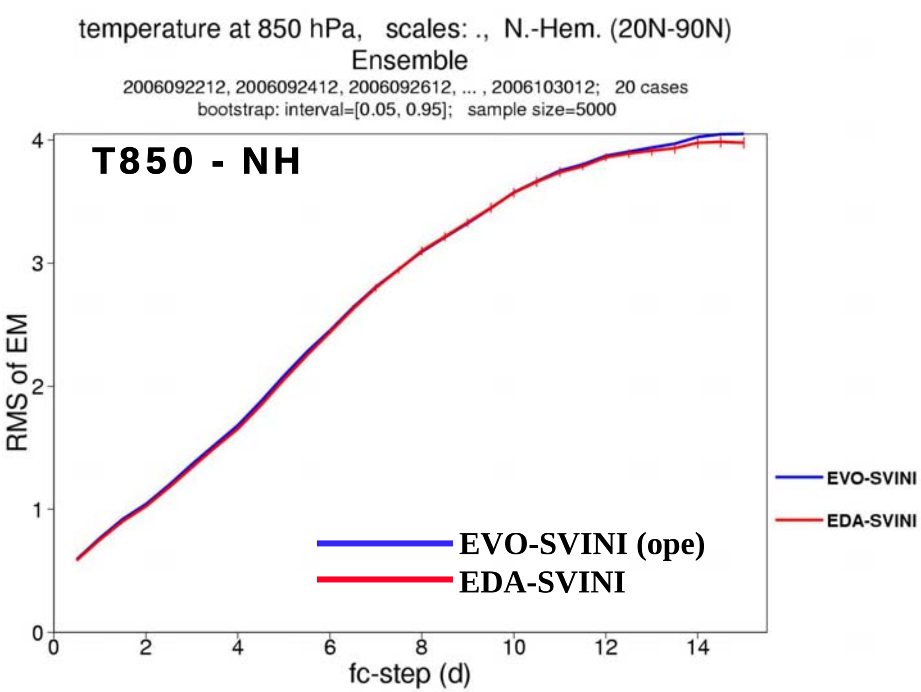
4. STD EDA-SVINI and EVO-SVINI (20 cases)

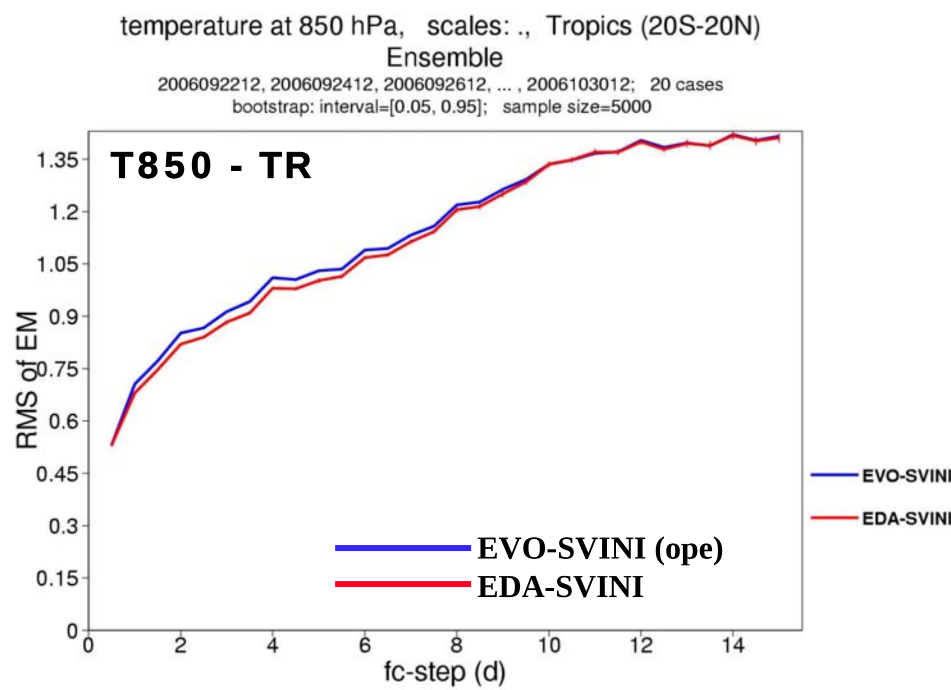
On average the EDA-SVINI system has larger spread than the EVO-SVINI (operational) system, especially over the tropics.



4. RMSE of the EM, EDA-SVINI and EVO-SVINI (20 cases)

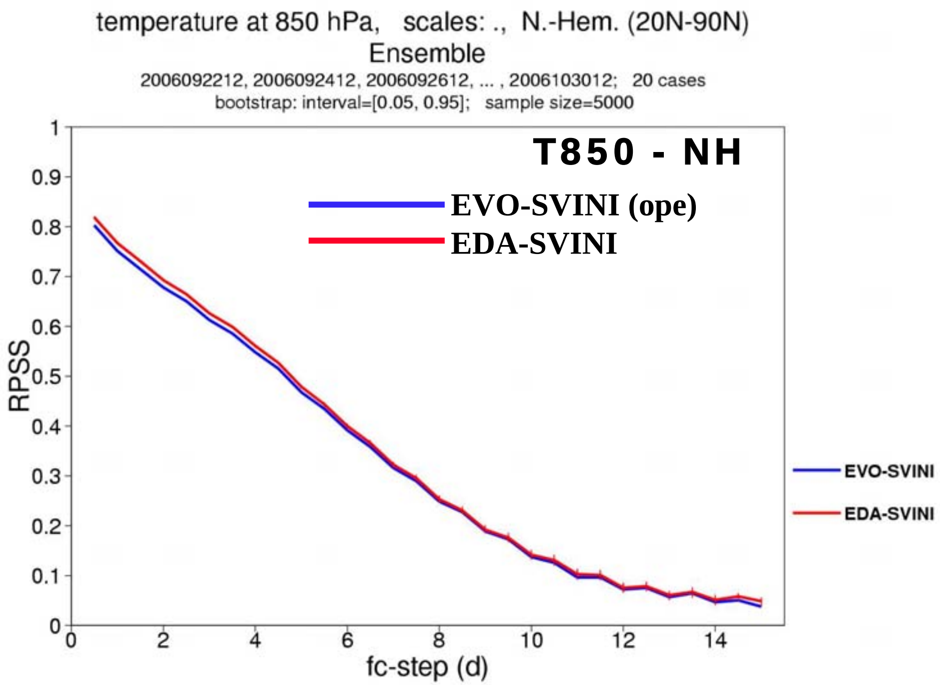
Over NH, the ensemble-mean of the EVO-SVINI and the EDA-SVINI systems have similar RMSE, but over the tropics the EDA-SVINI system has a lower RMSE up to about forecast day 8 (differences are statistically significant).

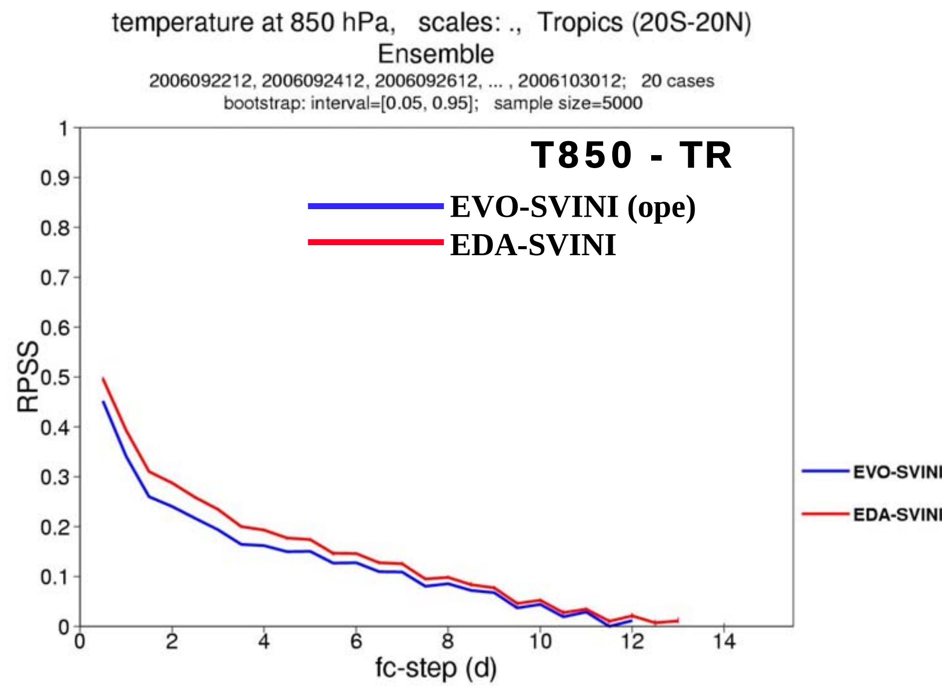




4. RPSS EDA-SVINI and EVO-SVINI (20 cases)

In terms of probabilistic forecasts, the EDA-SVINI system is better than the operational EVO-SVINI system over NH up to forecast day 4 and over the tropics up to forecast day 8.





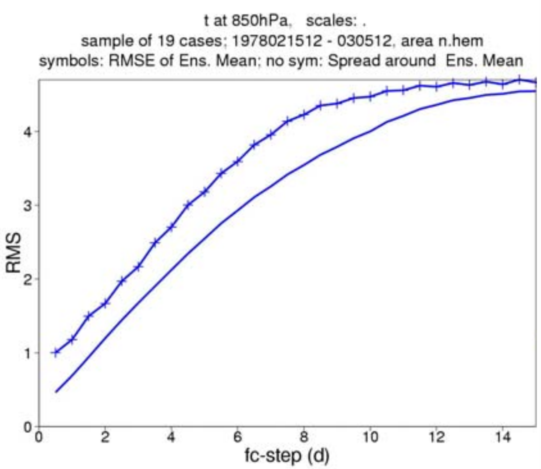
Outline

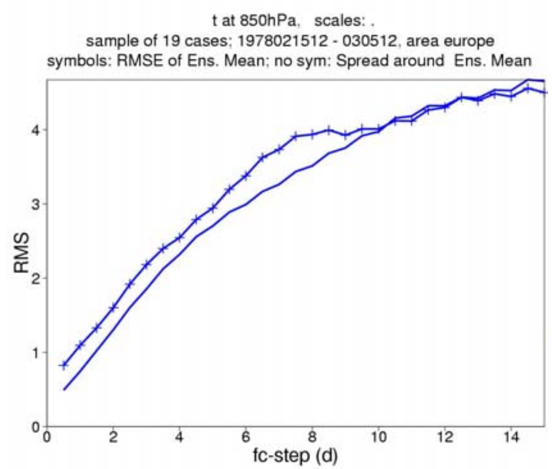
1. **The ECMWF ensemble prediction system (EPS)**
2. **Seamless prediction with the new 32-day ensemble system**
3. **EPS performance**
4. **Ensemble prediction and data assimilation**
5. **Forecasts for Africa 1978**
6. **The EPS and severe weather**
7. **Conclusions**

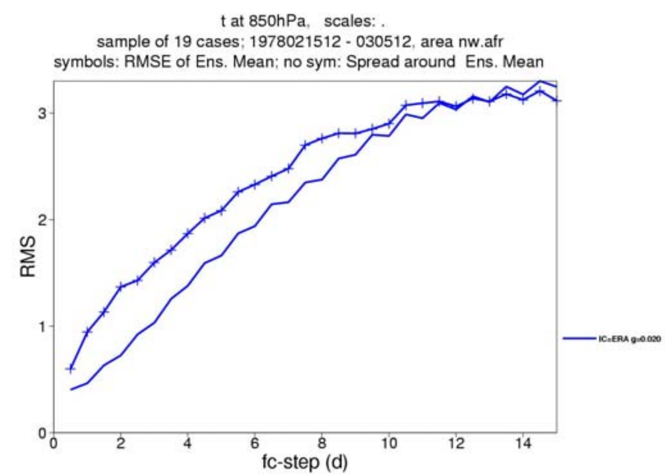
5. VAREPS forecasts for Africa (Feb-Apr 1978)

VAREPS ensembles are being run for the period 15 Feb to 15 Apr 1978 (19 cases have been completed). These forecasts are run in the operational configuration, with model cycle 33r1. ICs are defined by ERA-40. Initial perturbations are scaled larger (γ=0.020 instead of 0.014) than in the operational EPS to take into account the fact that ERA-40 T159 analyses are less accurate than operational T799L91 analyses.

These plots show the 19-case average error of the ensemble-mean (blue with symbols) and the std (blue) for T850 over NH (left), Europe (middle) and North-west Africa (12.5S≤λ≤35N, -22.5≤Θ≤12.5, left).

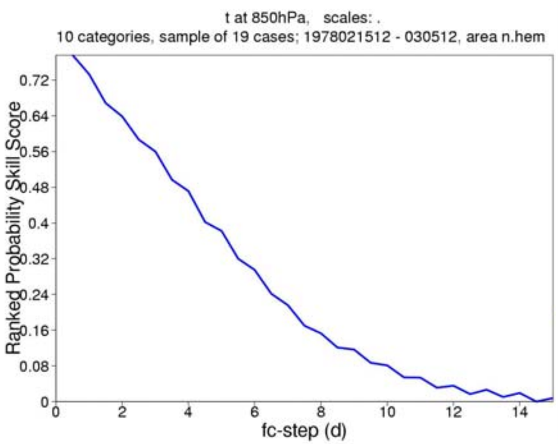


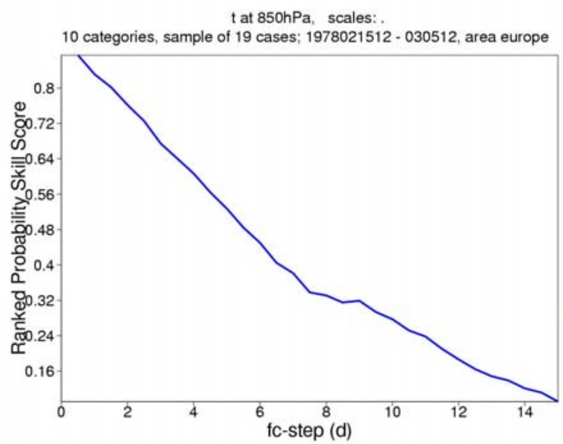


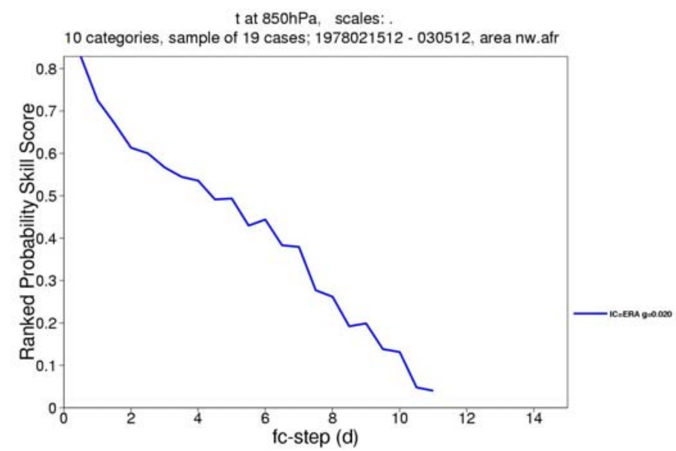


5. VAREPS forecasts for Africa (Feb-Apr 1978)

These plots show the 19-case average RPSS for T850 over NH (left), Europe (middle) and North-west Africa (12.5S≤λ≤35N, -22.5≤Θ≤12.5, left).







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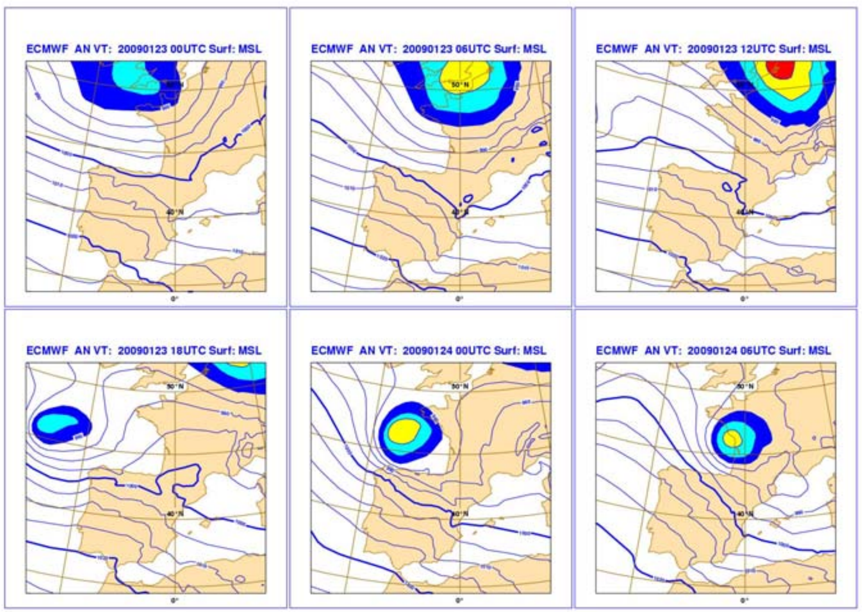
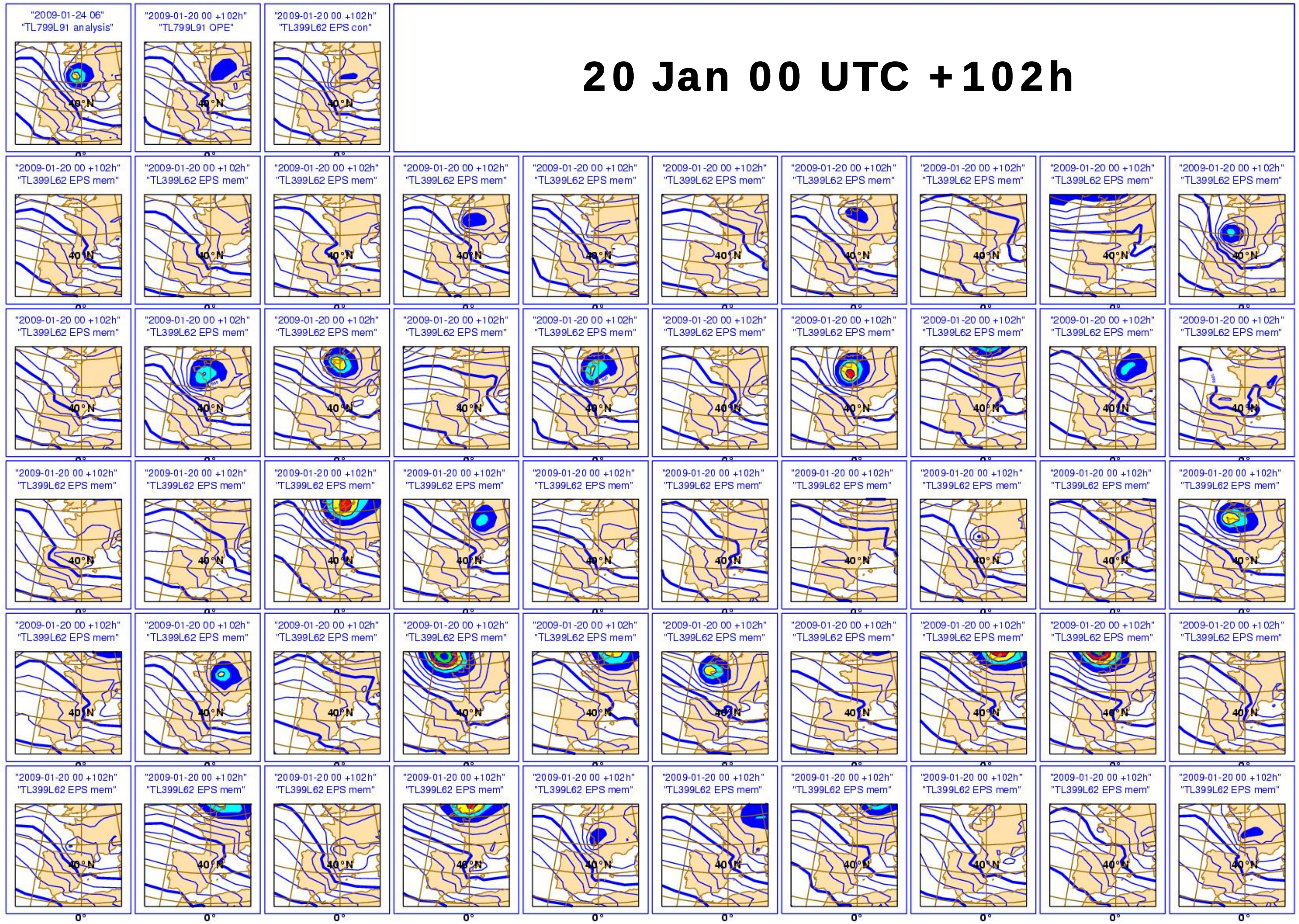
6. EPS and severe weather: the storm of 24 January 2009

On 24 January, a very intense storm hit Northern Spain and France, causing casualties and a lot of damages. The storm developed in the Atlantic on 22 and 23 January, moved very rapidly in the strong westerly flow, and reached the east coast of France at 6UTC of 24 January.



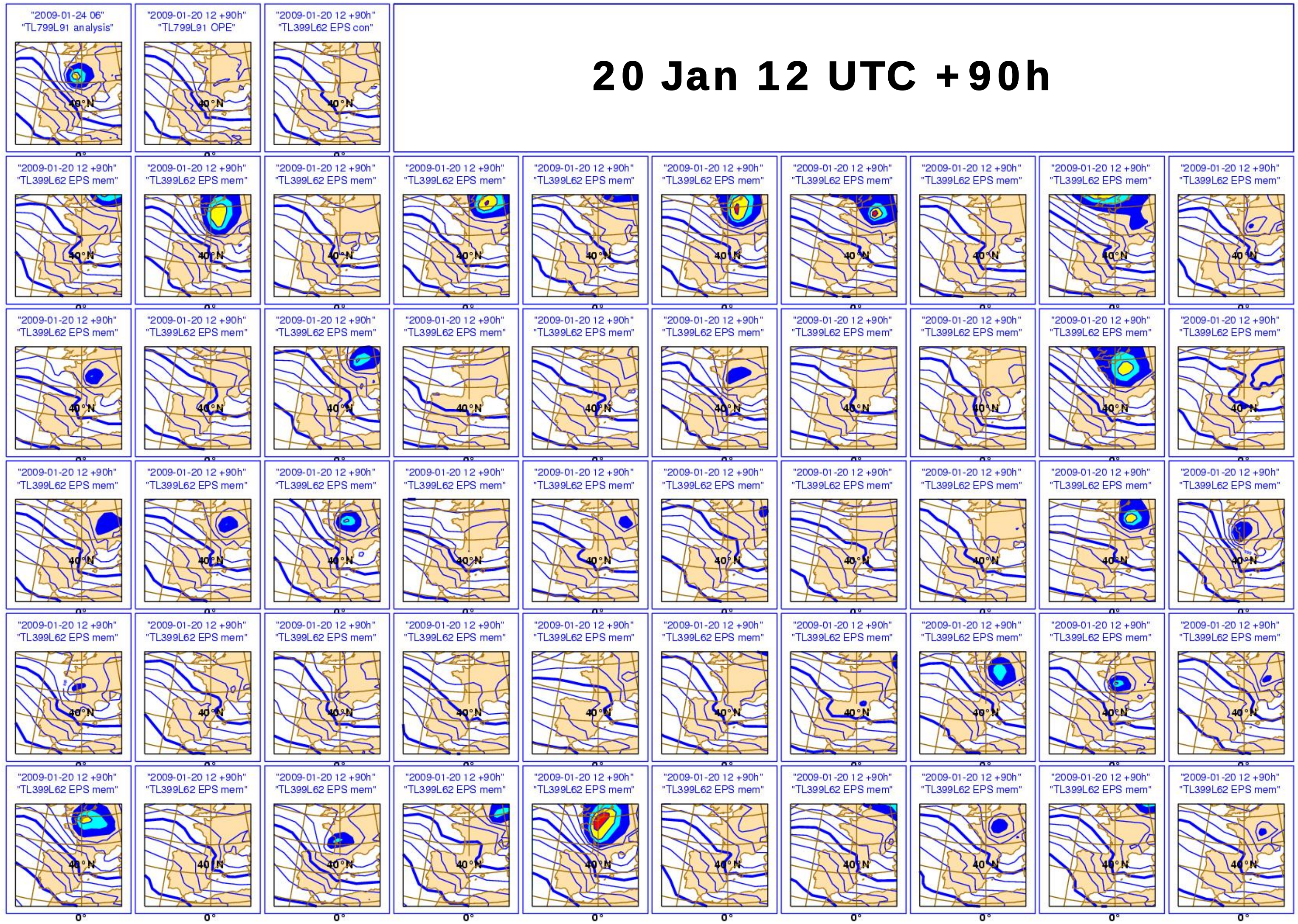
6. EPS and severe weather: the storm of 24 January 2009

This plot shows the MSLP analysis (top-left) at 06 UTC of 24 Jan, and the t+102h fcs from HRES, EPS-control and all the EPS-members.



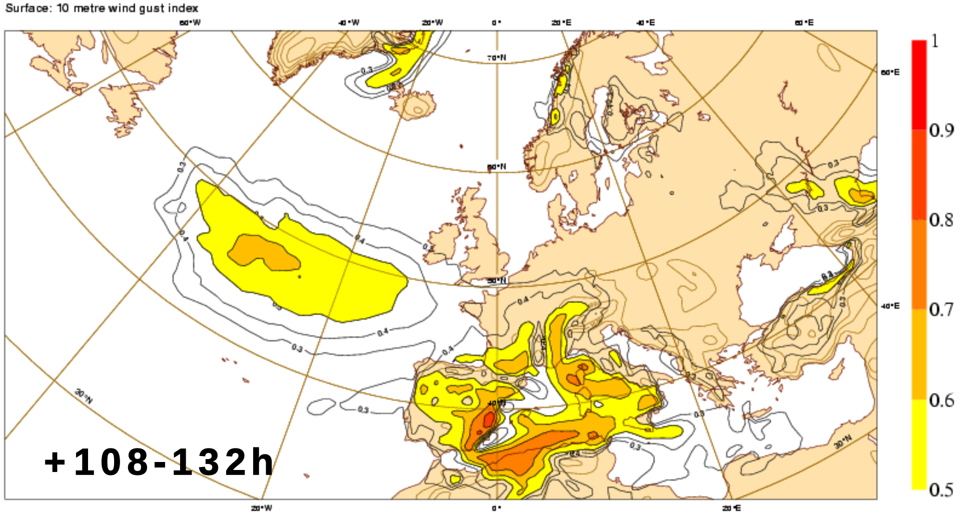
6. EPS and severe weather: the storm of 24 January 2009

This plot shows the MSLP analysis (top-left) at 06 UTC of 24 Jan, and the t+90h fcs from HRES, EPS-control and all the EPS-members.

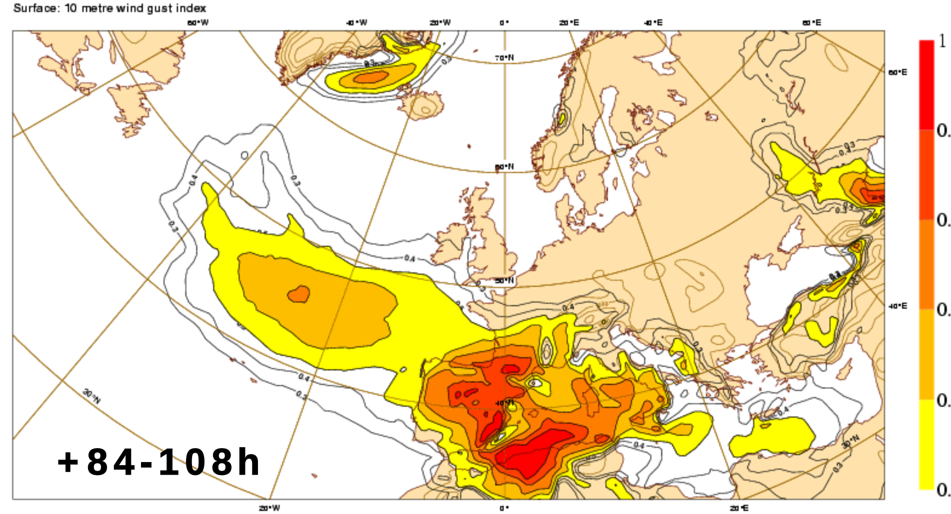


6. EPS EFI(10m wind gust) fcs valid for 24@00-25@00

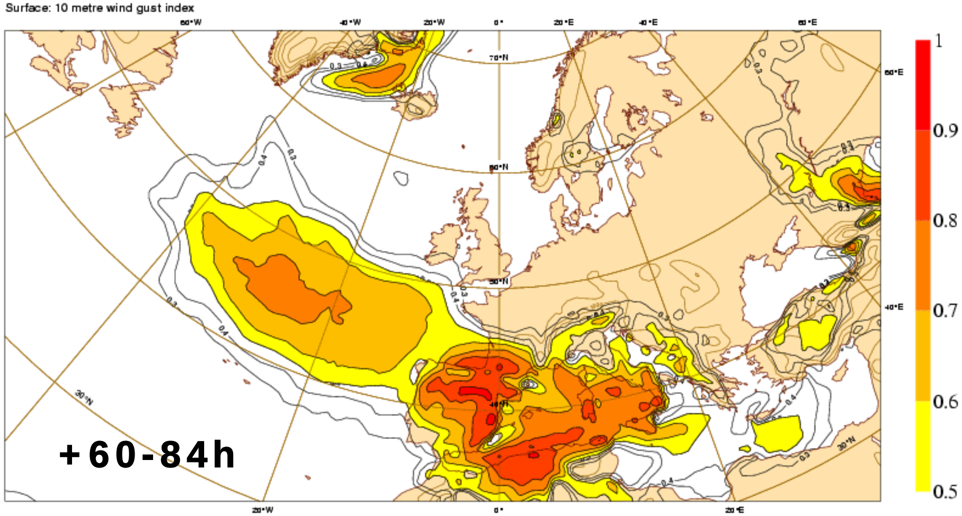
Monday 19 January 2009 12UTC ©ECMWF Extreme forecast index t+108-132 VT: Saturday 24 January 2009 00UTC - Sunday 25 January 2009 00UTC
Surface: 10 metre wind gust index



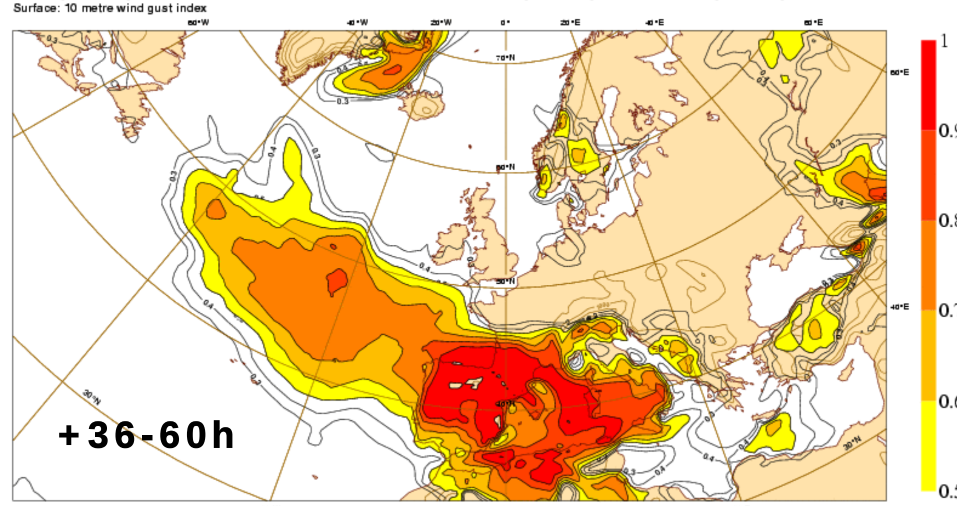
Tuesday 20 January 2009 12UTC ©ECMWF Extreme forecast index t+084-108 VT: Saturday 24 January 2009 00UTC - Sunday 25 January 2009 00UTC
Surface: 10 metre wind gust index



Wednesday 21 January 2009 12UTC ©ECMWF Extreme forecast index t+060-084 VT: Saturday 24 January 2009 00UTC - Sunday 25 January 2009 00UTC
Surface: 10 metre wind gust index



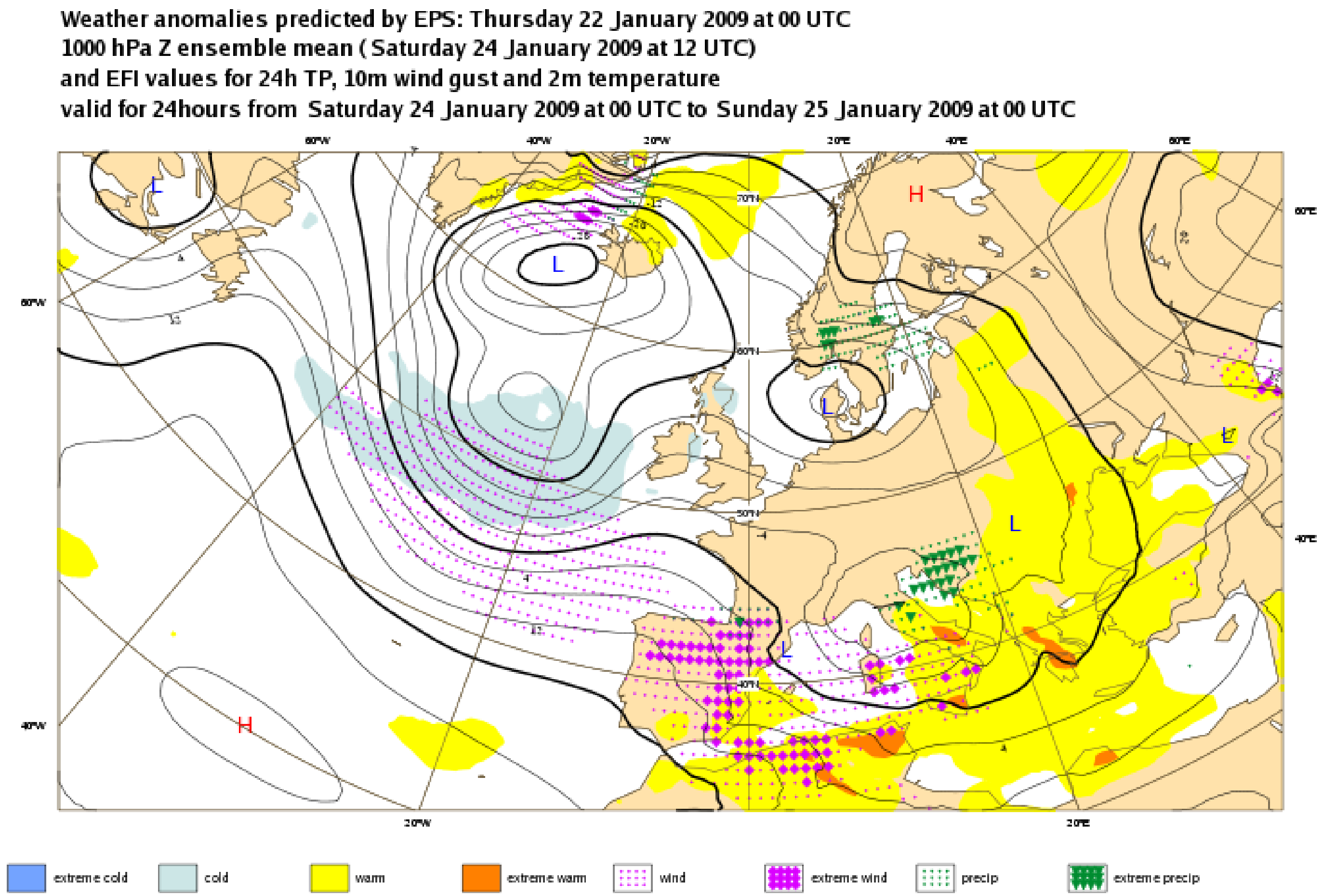
Thursday 22 January 2009 12UTC ©ECMWF Extreme forecast index t+036-060 VT: Saturday 24 January 2009 00UTC - Sunday 25 January 2009 00UTC
Surface: 10 metre wind gust index



6. EPS and severe weather prediction: interactive EFI product

A new interactive EFI product has been developed (left). It shows EFI values for 24hTP, 10m wind gust and 2m temperature.

By clicking on a point on the map, users will be able to display CDF fcs for one grid point.

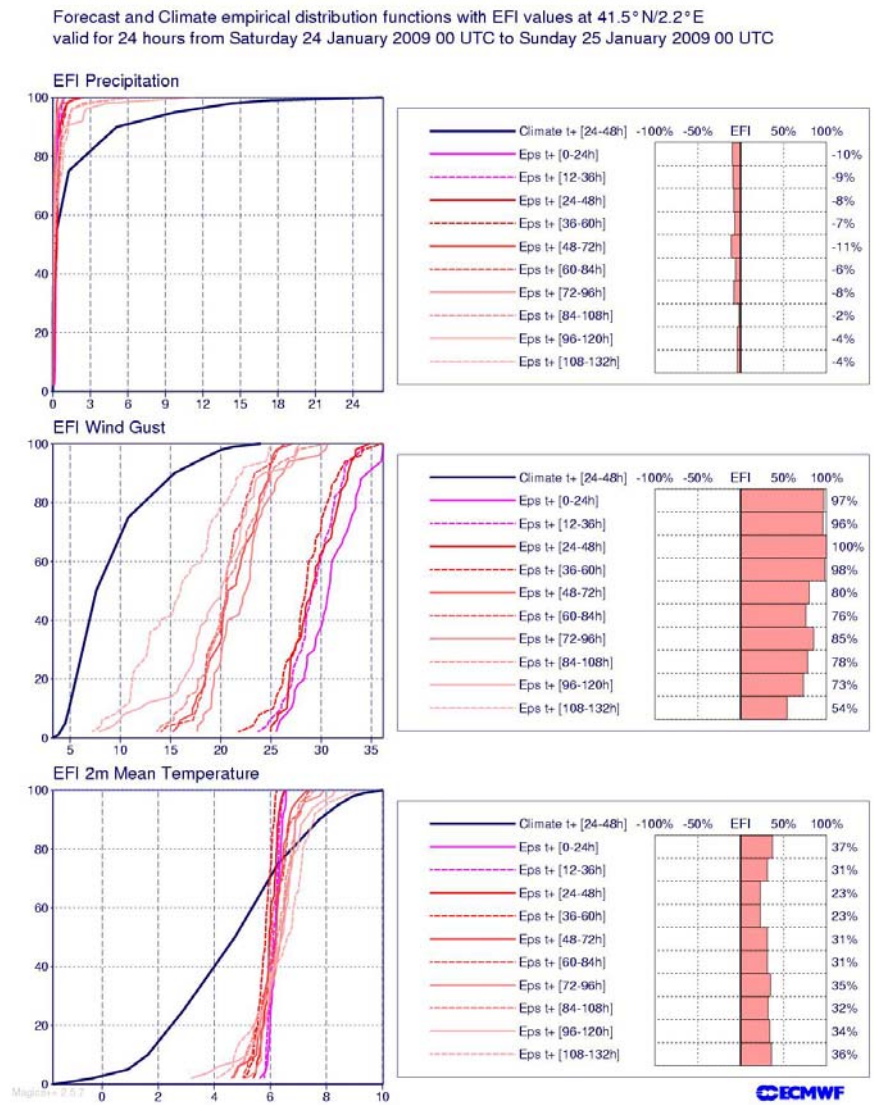


6. EPS and severe weather prediction: interactive EFI product

This plot shows the CDF forecasts from +132h to +24h at Barcelona valid for the period from 00 UTC of the 24th to 00 UTC of the 25th of January for the three parameters shown in the interactive-EFI map. The climate CDF is also shown (black), so that it is easier to identify extreme events.

Note how the CDF for 10m wind gust progressively shifts to the right with the forecast time, indicating increasing risk of severe wind conditions.

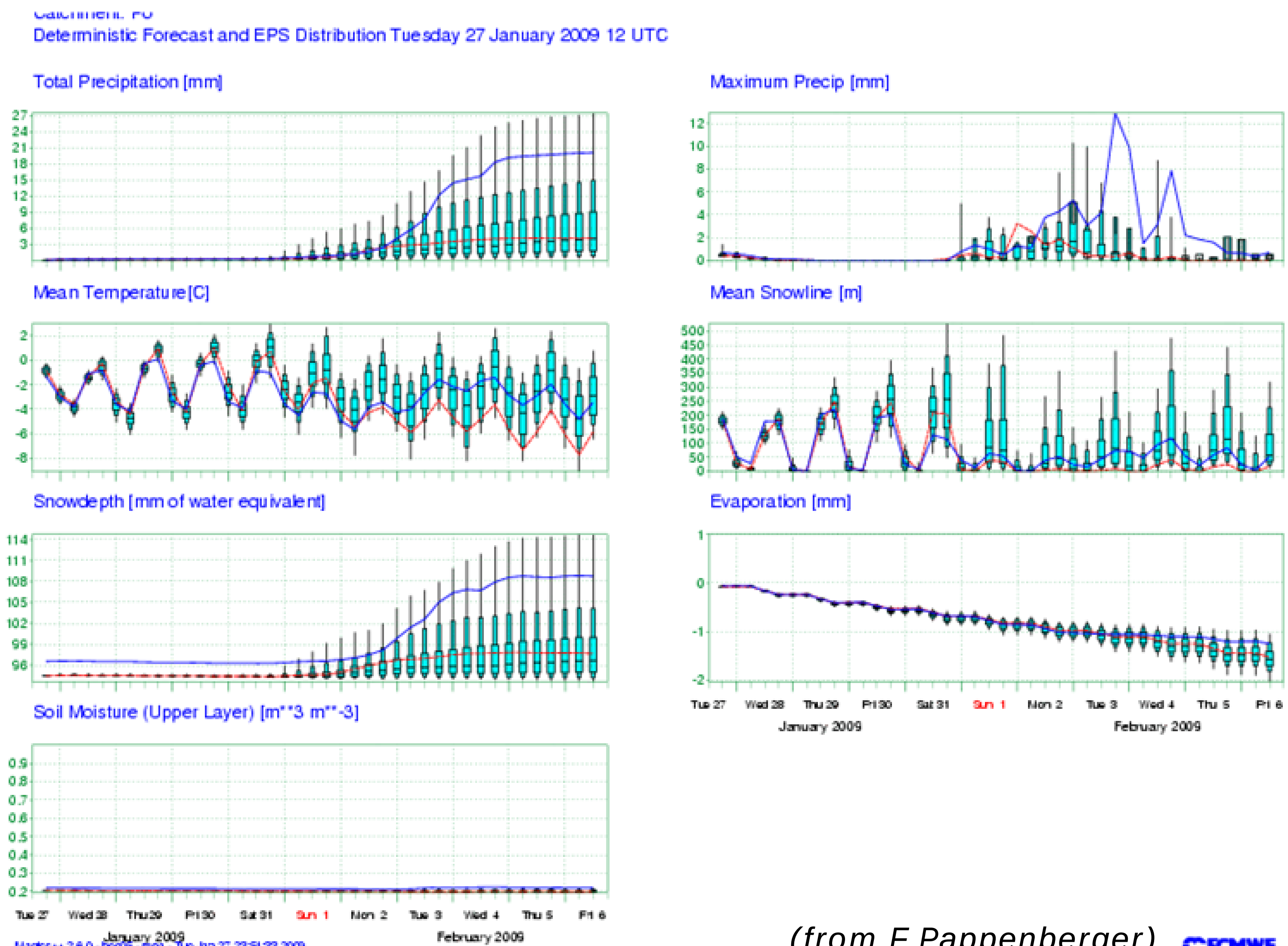
This product should help users to use ensemble forecasts.



6. EPS and severe weather prediction: EPS-rivergrams

Another new product under final testing is the EPS-rivergram, which displays a range of variables averaged (T,SD,MSL,EV) or accumulated (TP, MaxTP, SM) on a river basin.

This plot shows the EPS-rivergram from 12UTC of 29 Jan for the Po'.



(from F Pappenberger)

7. Conclusions: key messages

1. **Operational EPS** – In March 2008 the 15-day variable resolution ensemble was merged with the coupled monthly system:
2. **Performance of the EPS** – Recent results have indicated that the EPS has a well-tuned ensemble spread. Compared to the past 3 years, in SON08 has reached the highest probabilistic scores.
3. **Seamless prediction** – Since March 2008 the EPS has been producing seamless 32-day forecasts (15d fcs twice-a-day, 32d fcs once-a-week), thus making it is easier to generate and compare long-range and short-range forecasts valid for the same verification date.
4. **Ensemble data assimilation and prediction** - The use of ensemble data assimilation in ensemble prediction is under investigation: results indicate that replacing the evolved SVs with an ensemble of analyses improves the performance of the ensemble system.
5. **Forecasts for Africa 1978** – Experimentation has started.
6. **Severe weather** – New ensemble products under development and final testing, such as the interactive EFI, will make it easier to use and interpret ensemble-based probabilistic forecasts.

7. Future changes

- **Calibration suite (Q1):**
  - use of T255 ERA-interim initial conditions instead of T159 ERA-40
- **Simulation of initial uncertainties (Q2-Q4):**
  - Use of ensemble data assimilation to generate initial perturbations (Q2).
  - Tropical SVs covering the whole tropical area (Q3-Q4)
- **Simulation of model uncertainties (Q2-Q4):**
  - Introduce Stochastic Back Scatter scheme (Q2)
  - Revise Stochastic Diabatic Tendency Scheme (Q4)
- **Ensemble resolution (Q4):**
  - Increase resolution from TL399(0-10)-TL255(>10) to TL639(0-10)-TL319(>10)
- **Coupled ocean model (Q4):**
  - Introduce new NEMO ocean model
  - Couple from d10 also at 12UTC

Acknowledgements

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 is acknowledged.

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