

Estimating uncertainty with the ECMWF ensembles

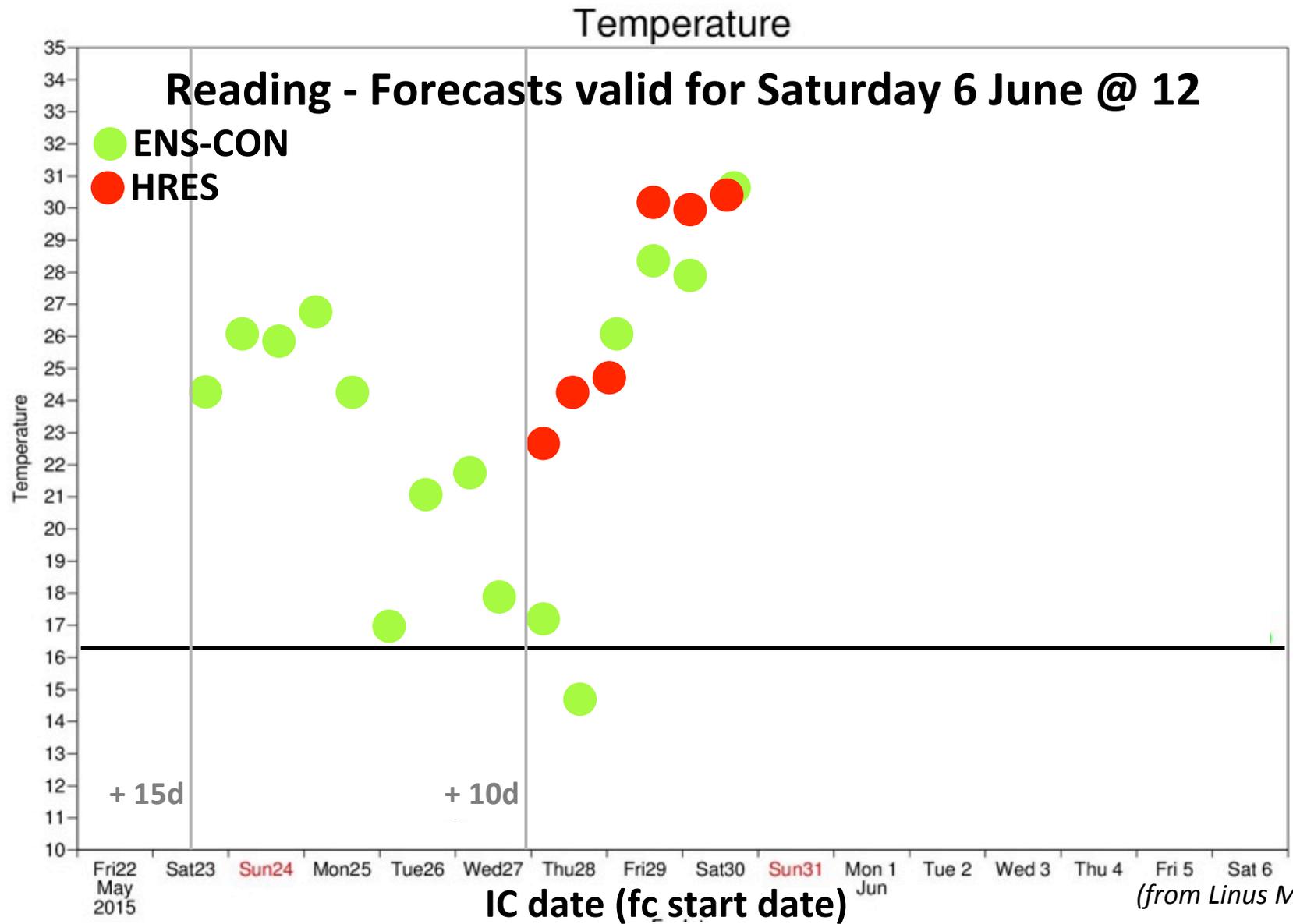
Roberto Buizza

European Centre for Medium-Range Weather Forecasts

1. Why do we need ensembles?
2. The ECMWF ensembles
3. The resolution upgrade of March 2016
4. Few key performance indices
5. Prediction of an extreme precipitation event in Houston
6. Conclusions

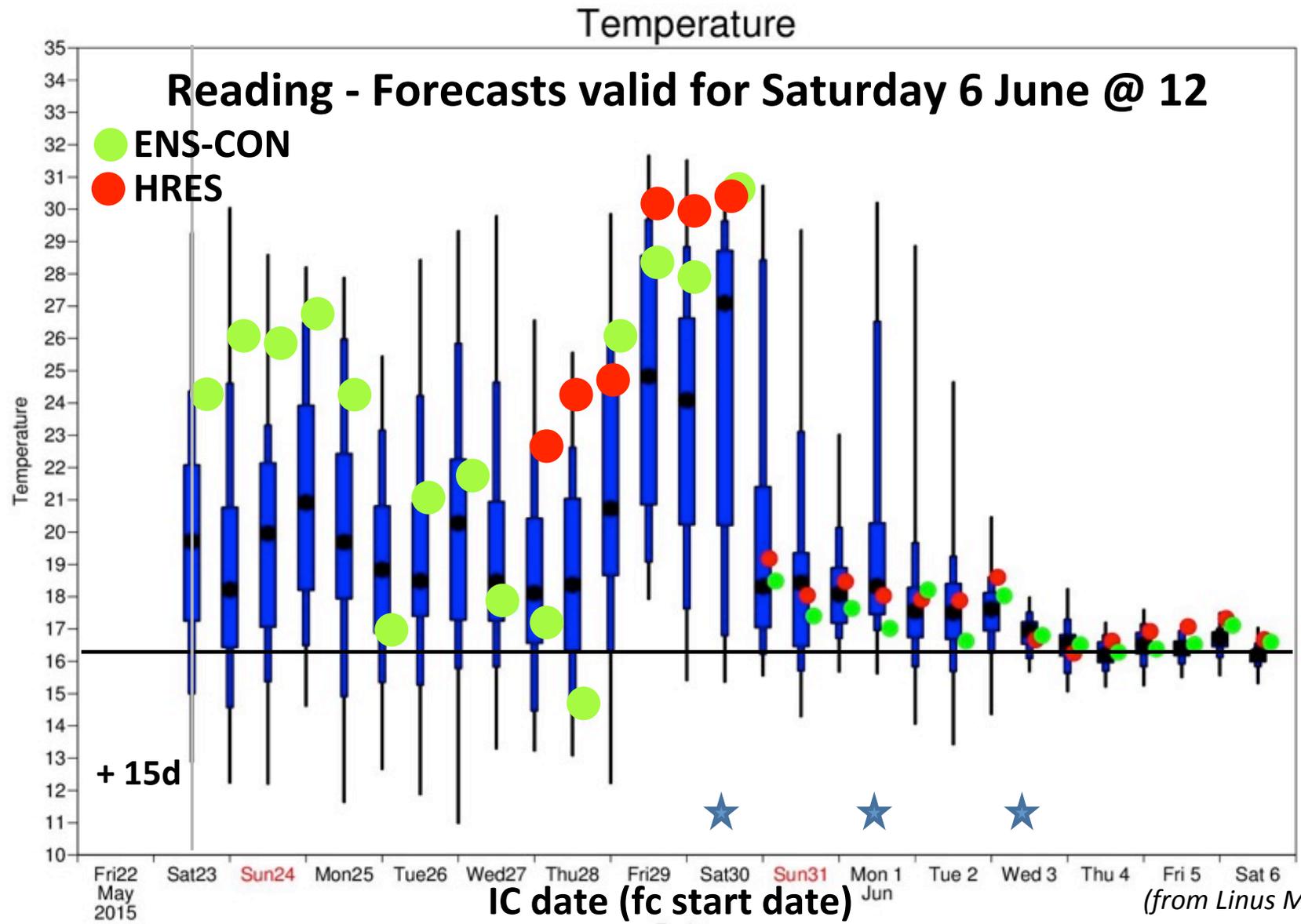


1. Why do we need ensembles?





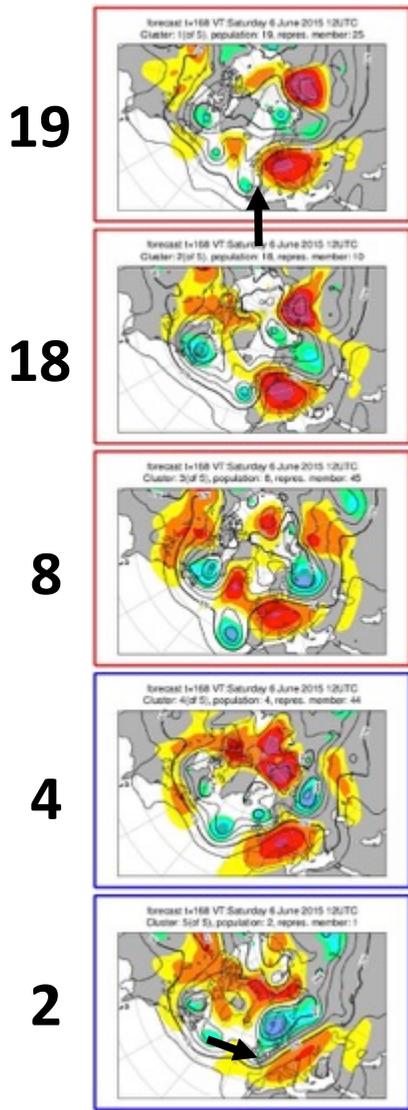
1. Why do we need ensembles?



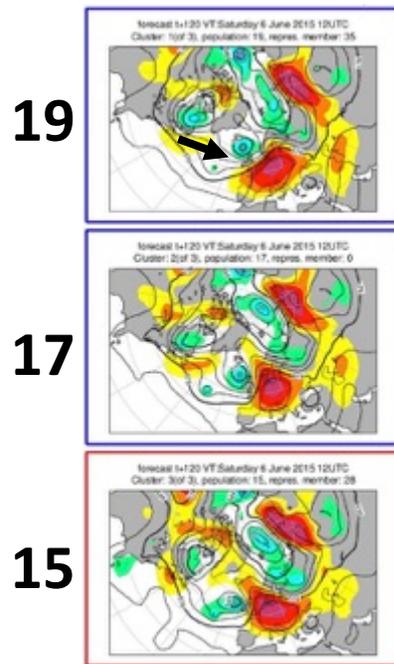


1. Why do we need ensembles?

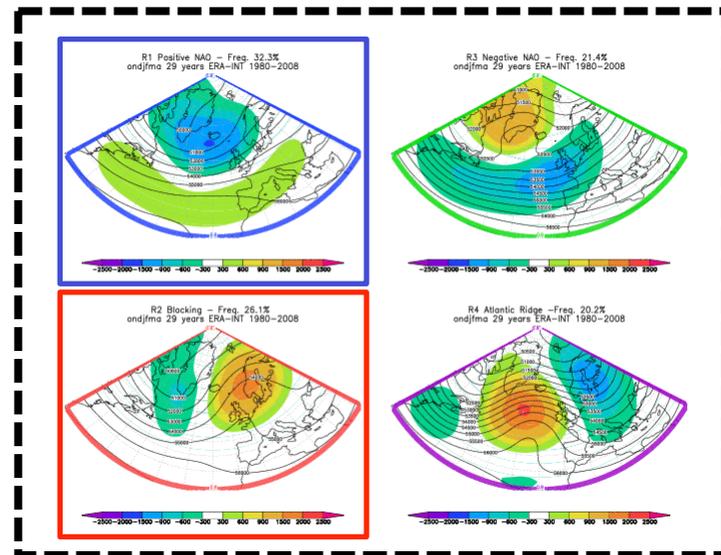
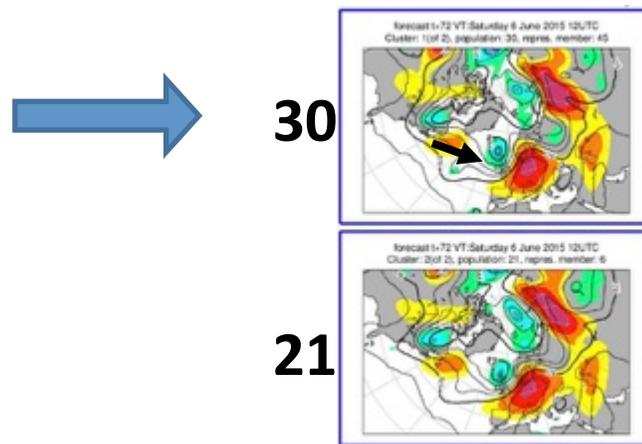
30 May + 168h



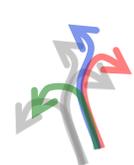
1 June + 120h



3 June + 72h



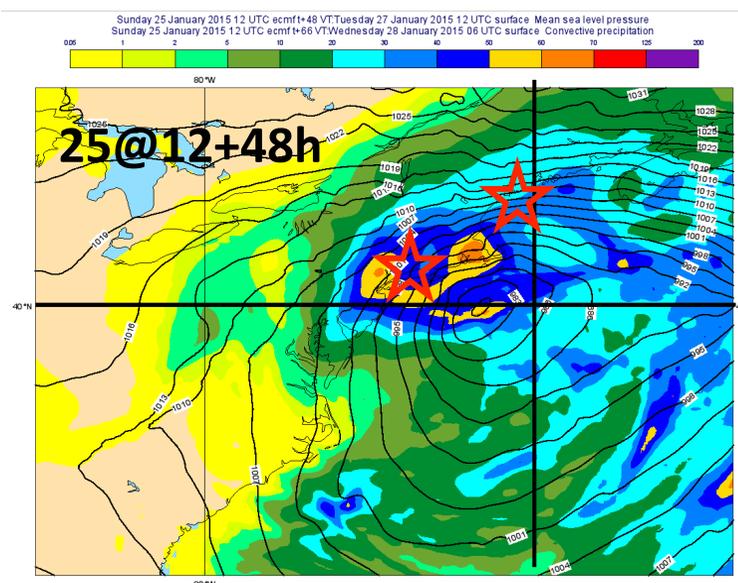
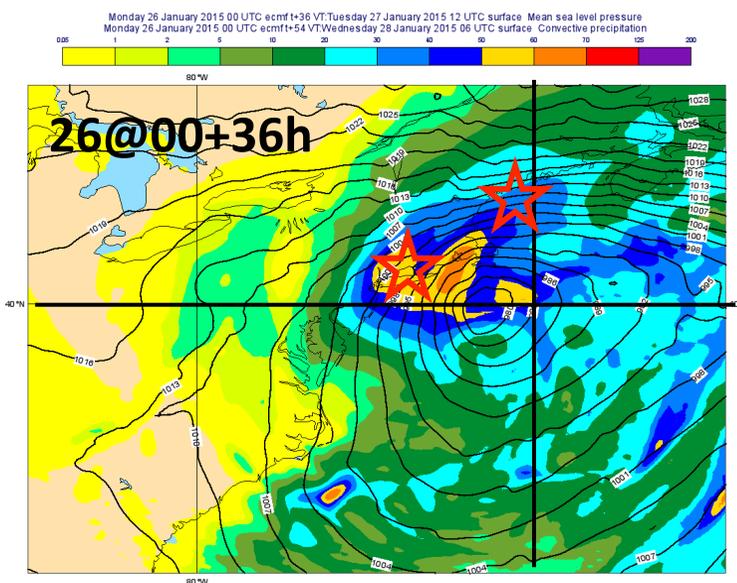
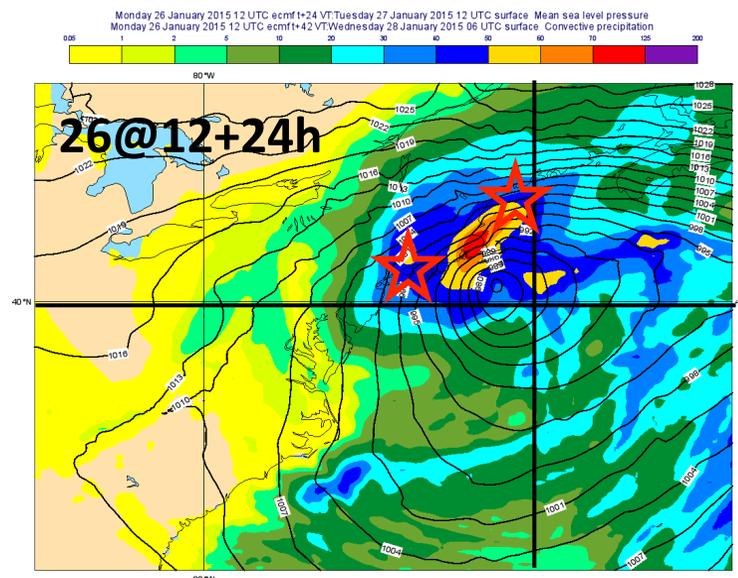
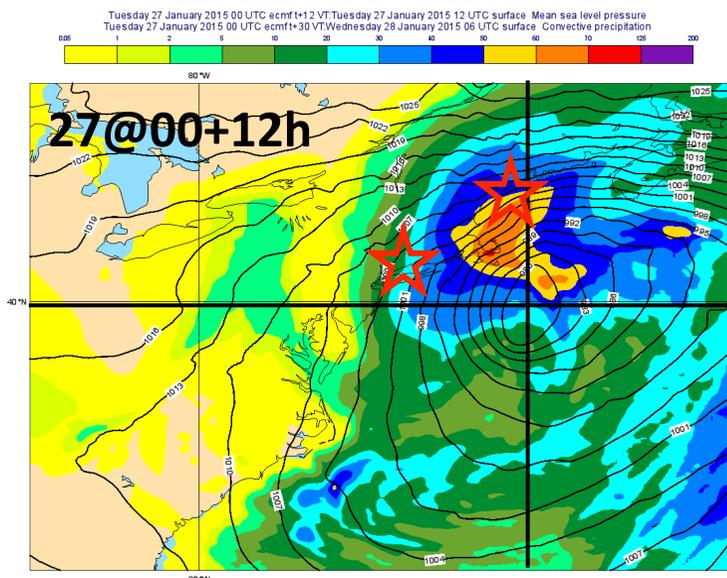
(from Linus Magnusson and Laura Ferranti)



1. We need ENS even in the short range (US Storm)

Single HRES fcs failed to positioned correctly the storm, and this led to snowfall overestimation for NY of in the 24-36-48h forecasts.

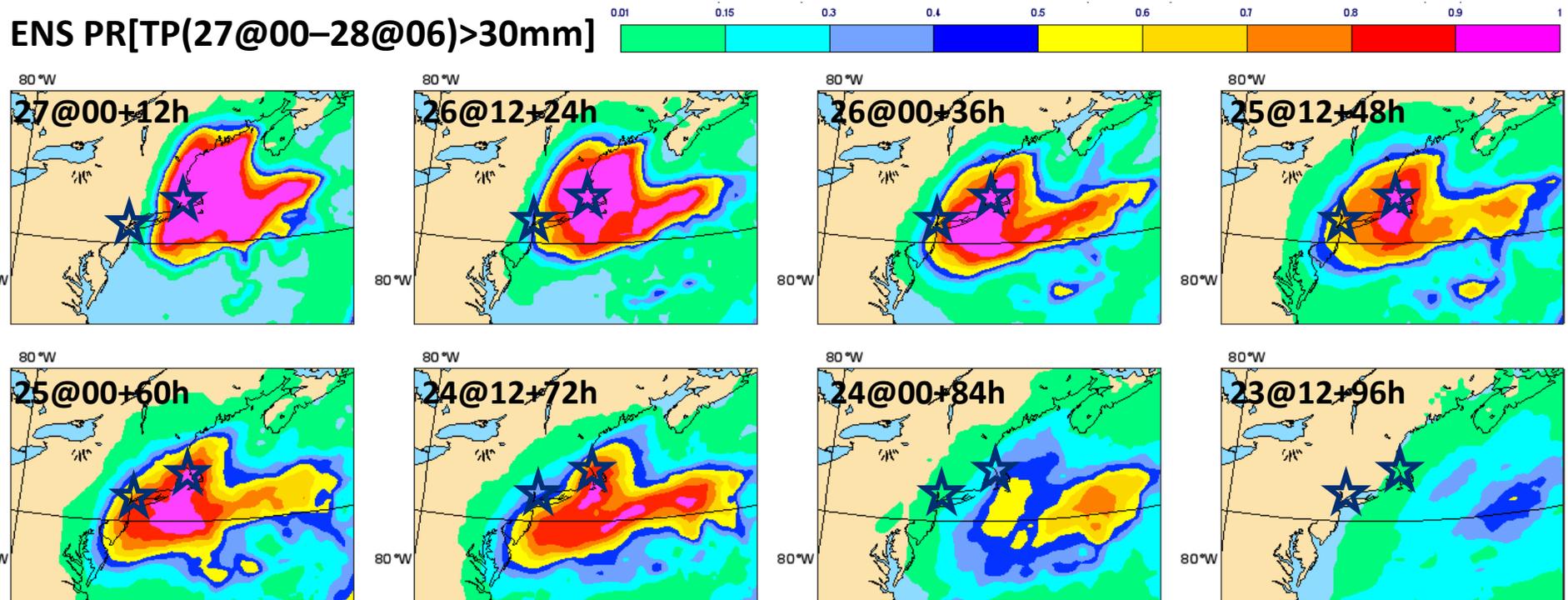
MLSP+TP maps show a 150-200 km eastward shift in the storm centre.





1. US Storm, 27-28/01/2015: ENS PR fcs

ENS-based probabilistic forecasts can be used to estimate the level of confidence (predictability) of single forecasts. They show that NY was closer to the edge of the area of high probability of +30mm of precipitation, indicating higher uncertainty.

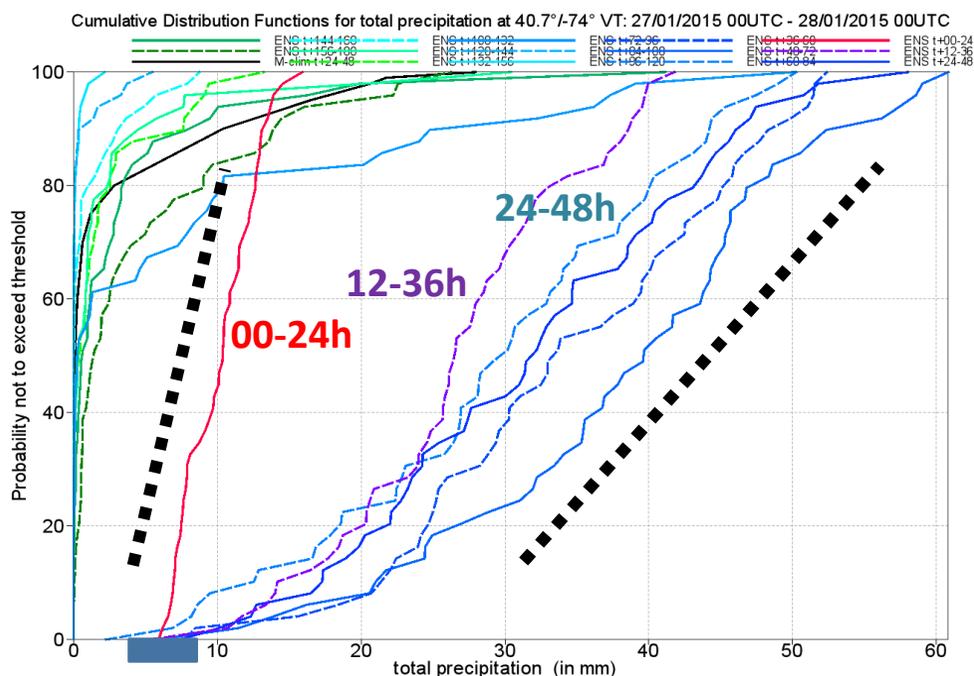




1. US Storm, 27-28/01/2015: forecast confidence

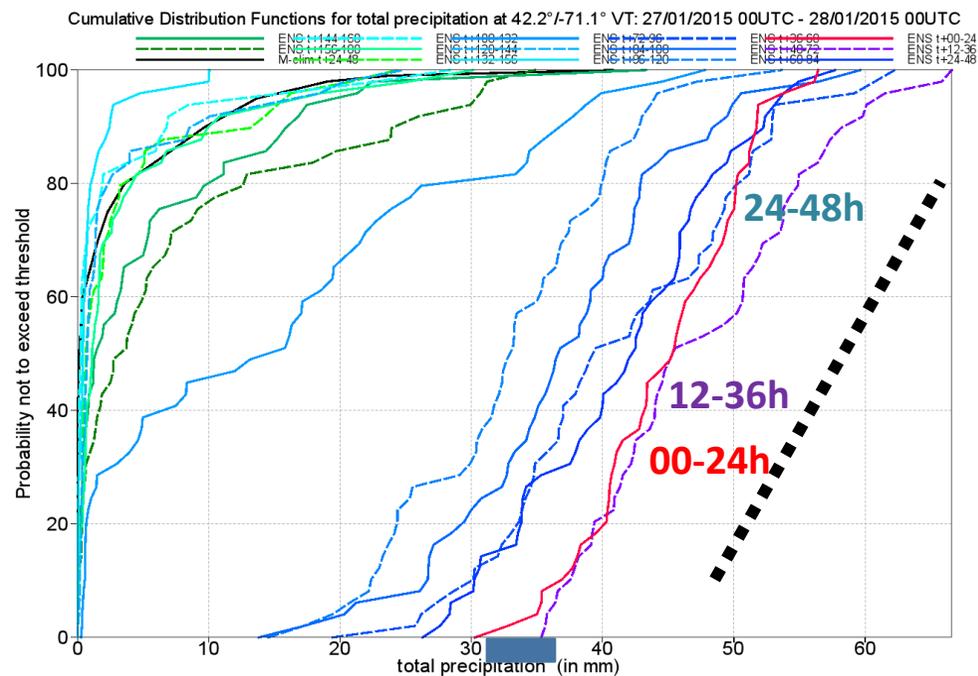
ENS-based probabilistic forecasts expressed in terms of CDF shows that the fcs for NY were more uncertain (the slope of the CDF curves is steeper) than the fcs for Boston.

New York



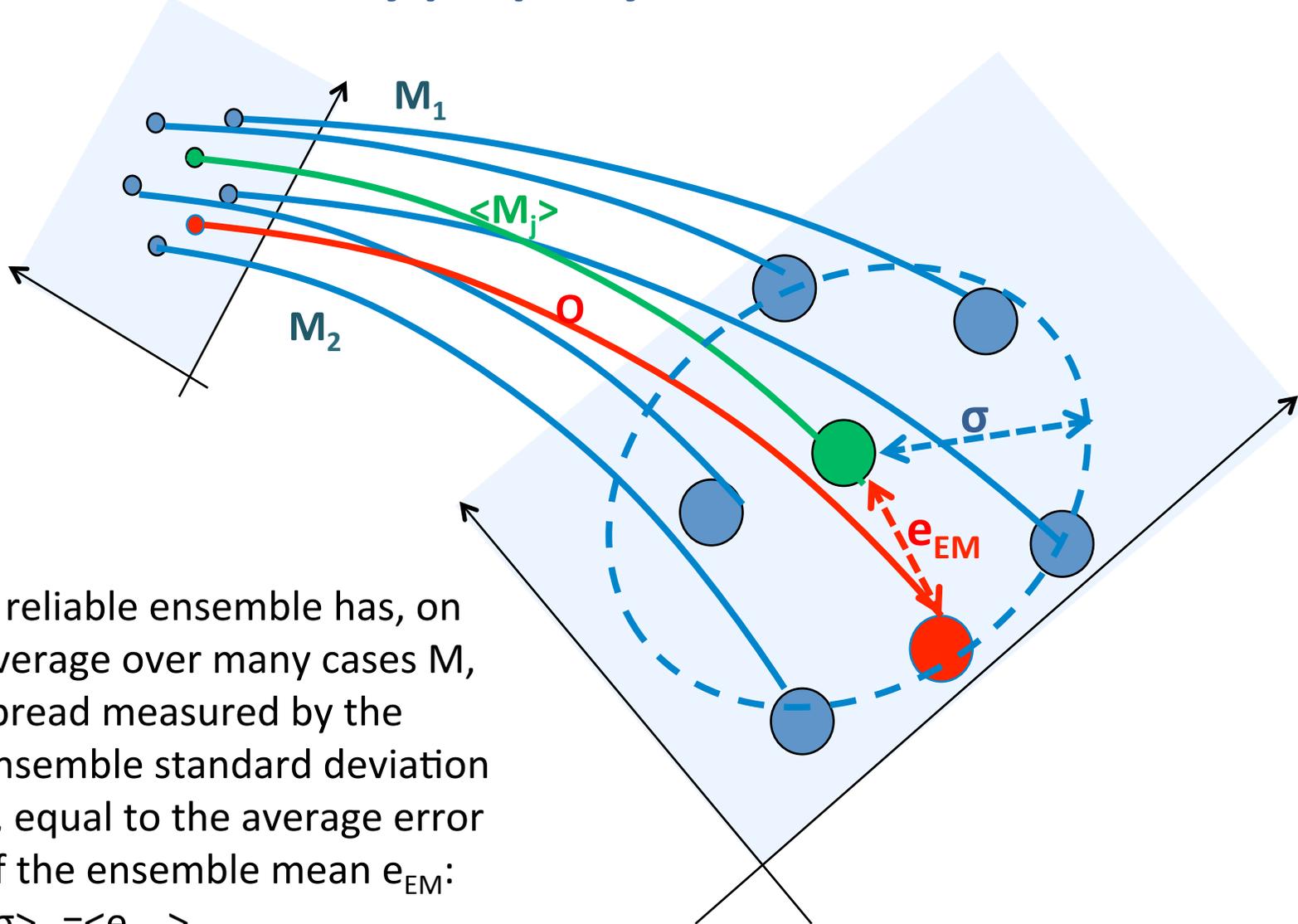
Obs (NEXRAD) 5-10 mm

Boston



Obs (NEXRAD) 30-35 mm

1. A necessary property for ENS to be valuable: reliability

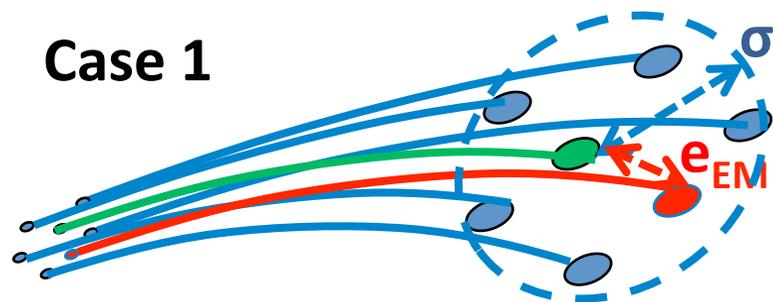


A reliable ensemble has, on average over many cases M , spread measured by the ensemble standard deviation σ , equal to the average error of the ensemble mean e_{EM} :

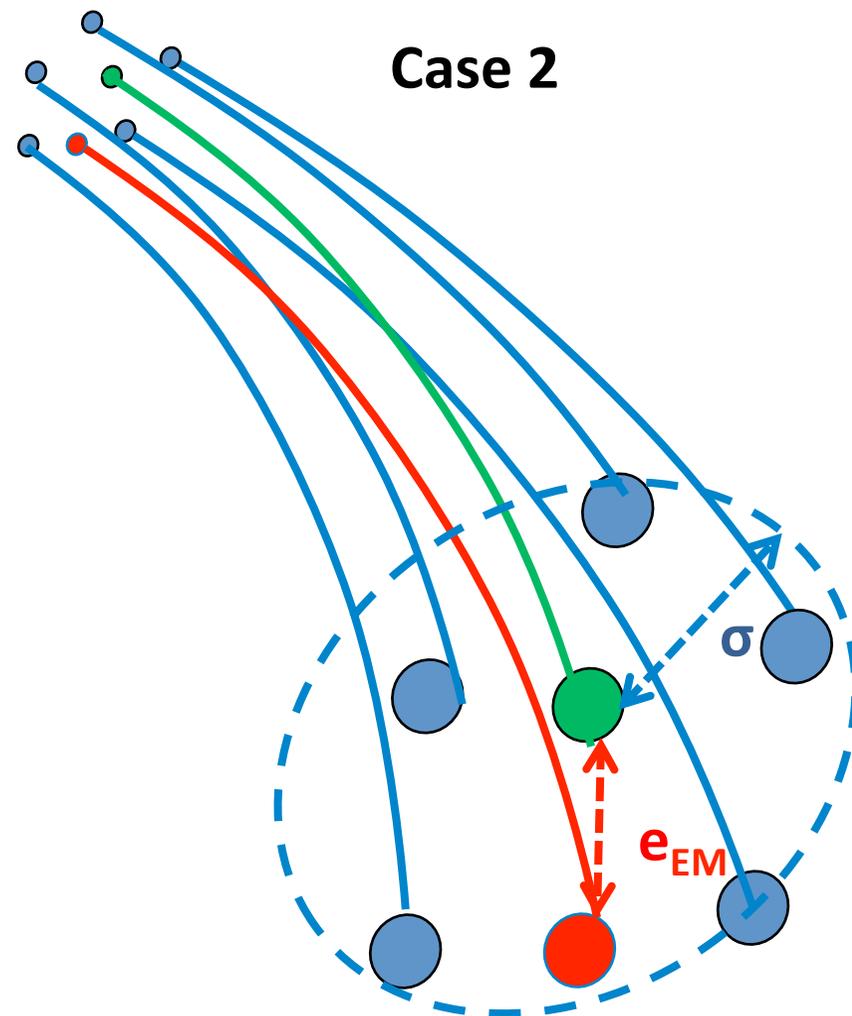
$$\langle \sigma \rangle_M = \langle e_{EM} \rangle_M$$

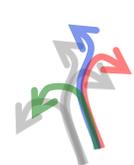


1. In a reliable ENS, small spread >> high predictability



In a reliable ensemble, small ensemble standard deviation indicates a more predictable case, i.e. a small error of the ensemble mean e_{EM} .

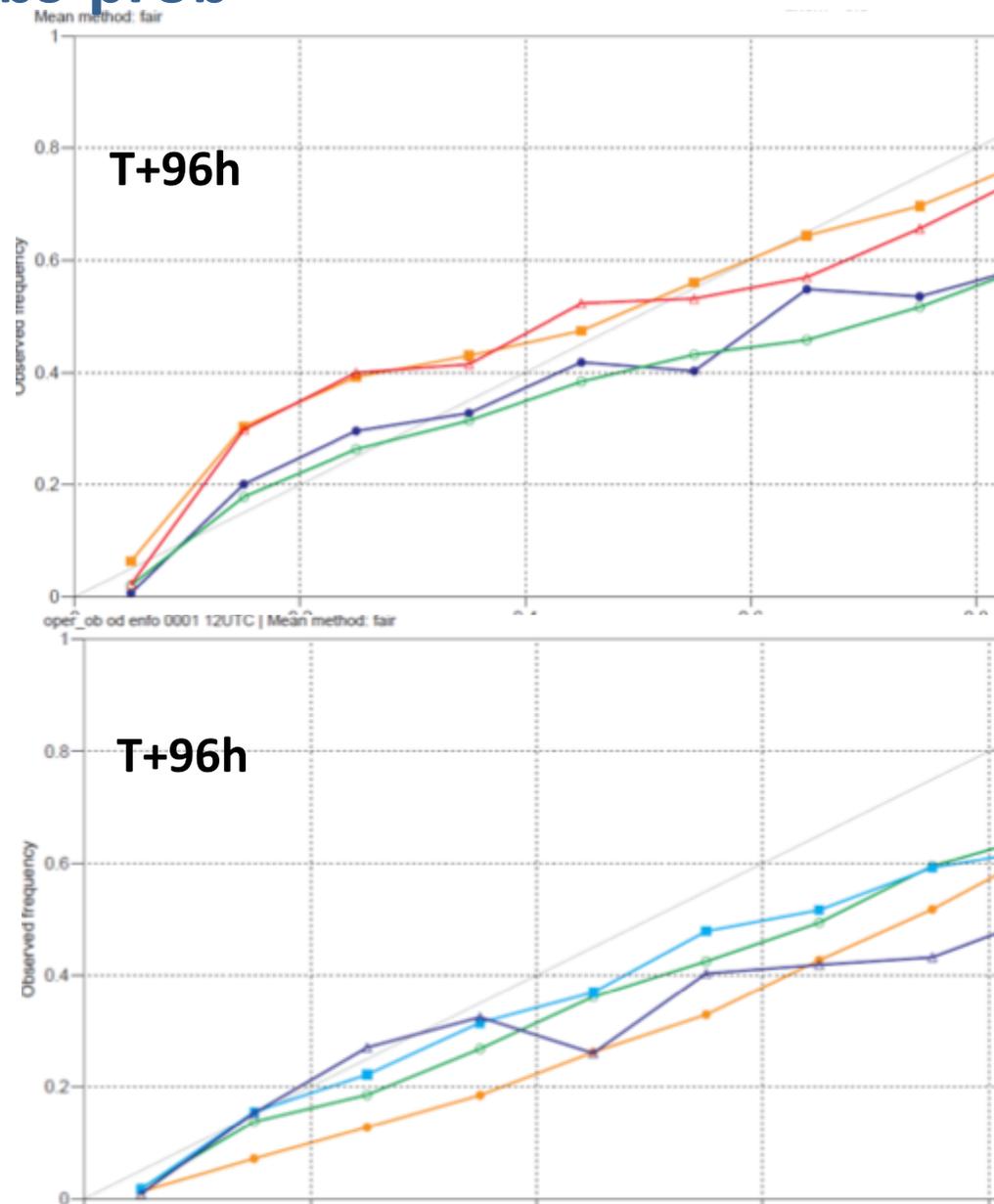




1. Reliability: $\langle \text{fc-prob} \rangle \sim \langle \text{obs-prob} \rangle$

One way to check the ensemble reliability is to assess whether the average forecast and observed probabilities of a certain event are similar.

These plots compare the two probabilities at t+144h for the event '24h precipitation in excess of 1/5/10/20 mm' (top) and '2mT gt/lit 4/8 degrees' over Europe for MAM16 (verified against observations).





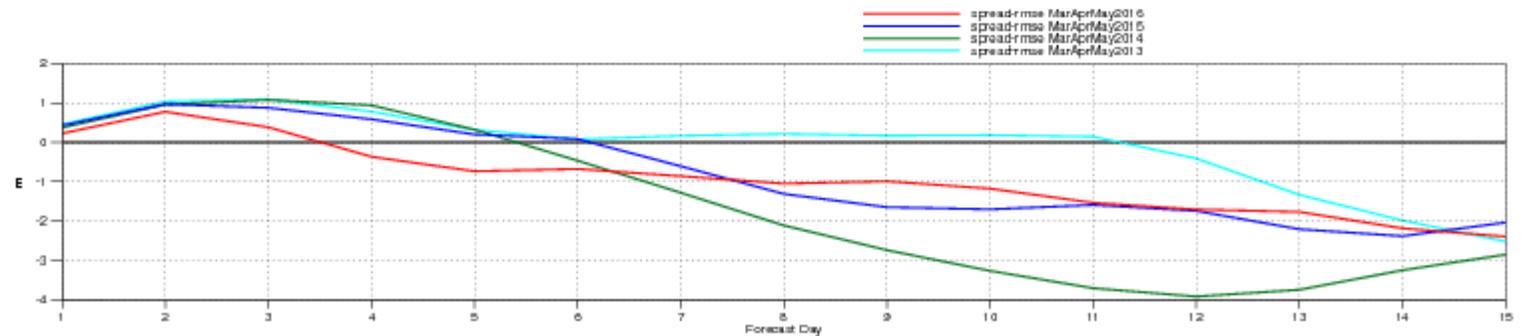
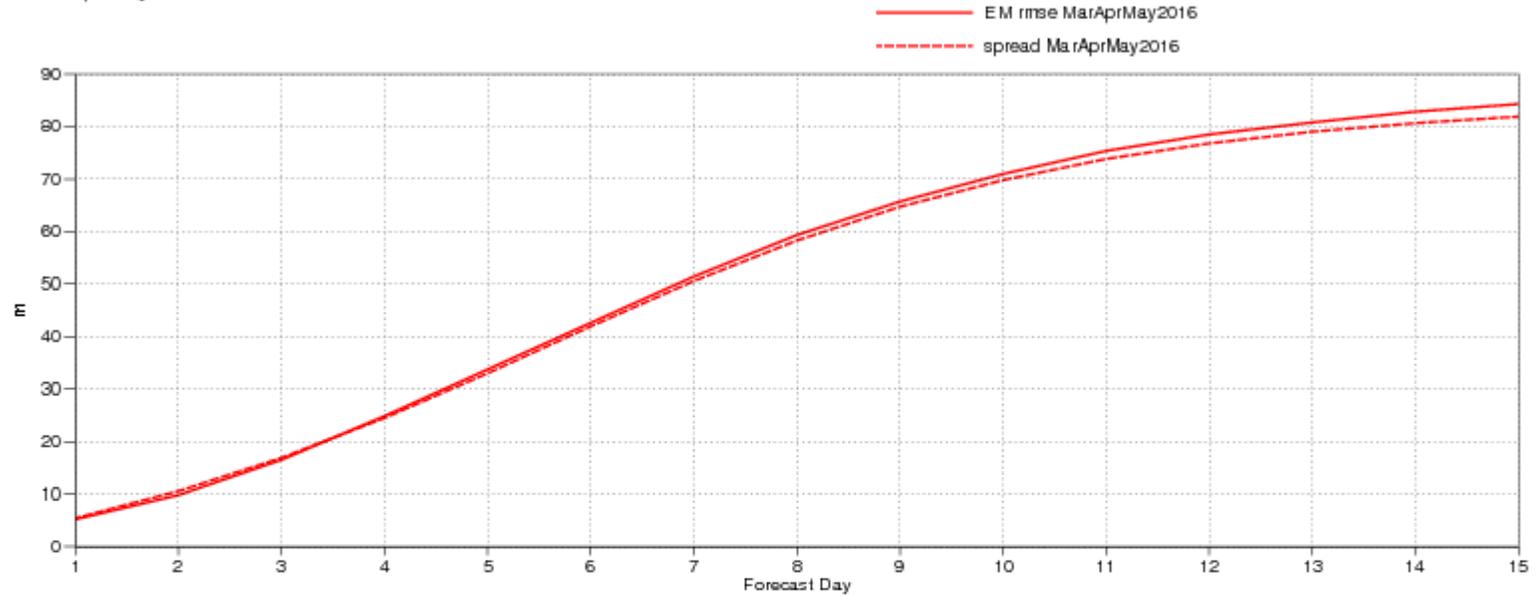
1. ENS reliability: Z500 over NH (MAM16)

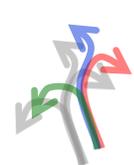
ENS Mean RMSE and ENS Spread

500hPa geopotential
 NHem Extratropics (lat 20.0 to 90.0, lon -180.0 to 180.0)
 MarAprMay

In a reliable ensemble the average spread matches the average error of the ensemble mean.

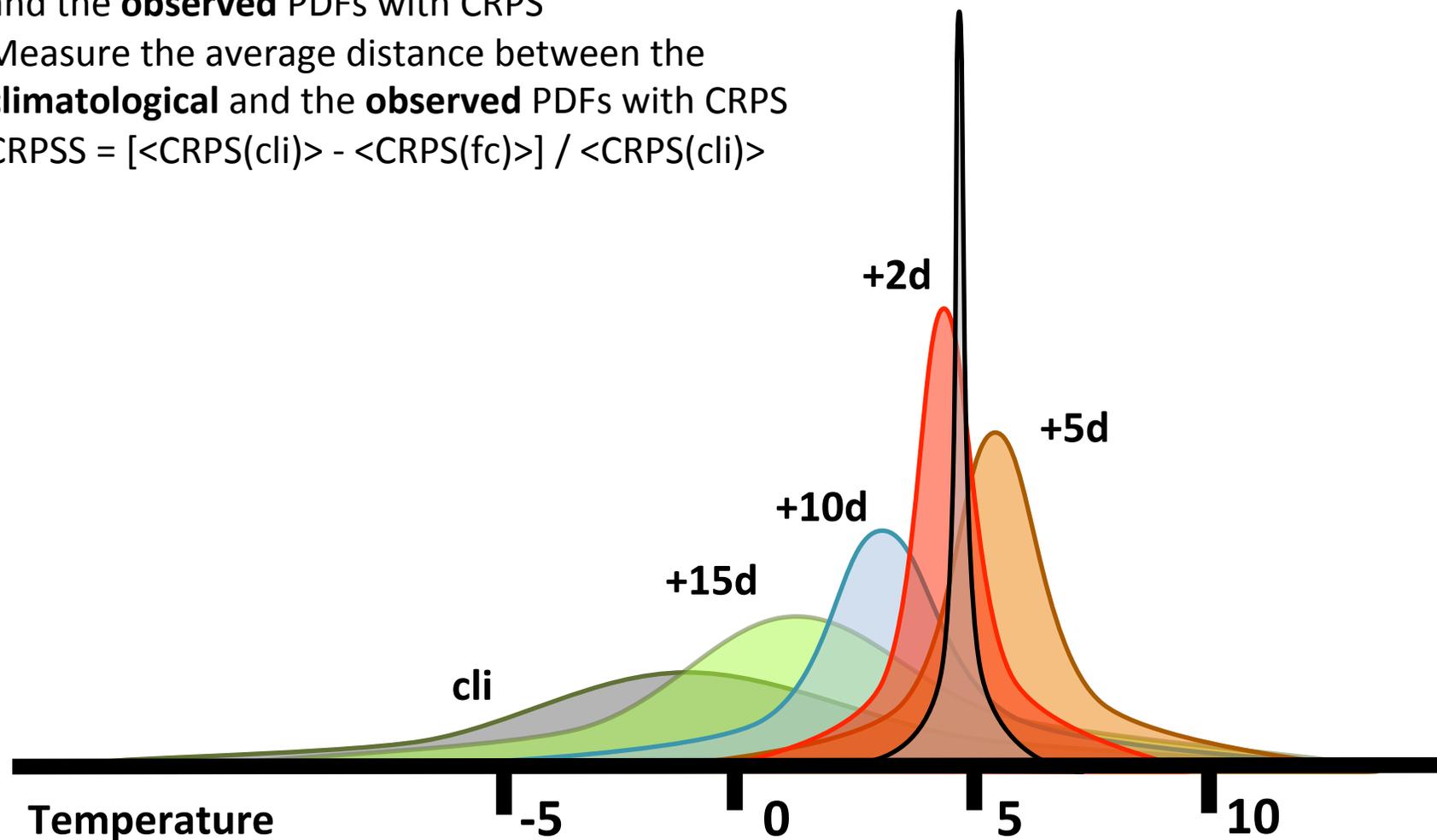
This plot shows the two curves for Z500 over NH in FMA16.

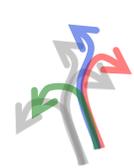




1. PDF forecast skill: how do we measure it?

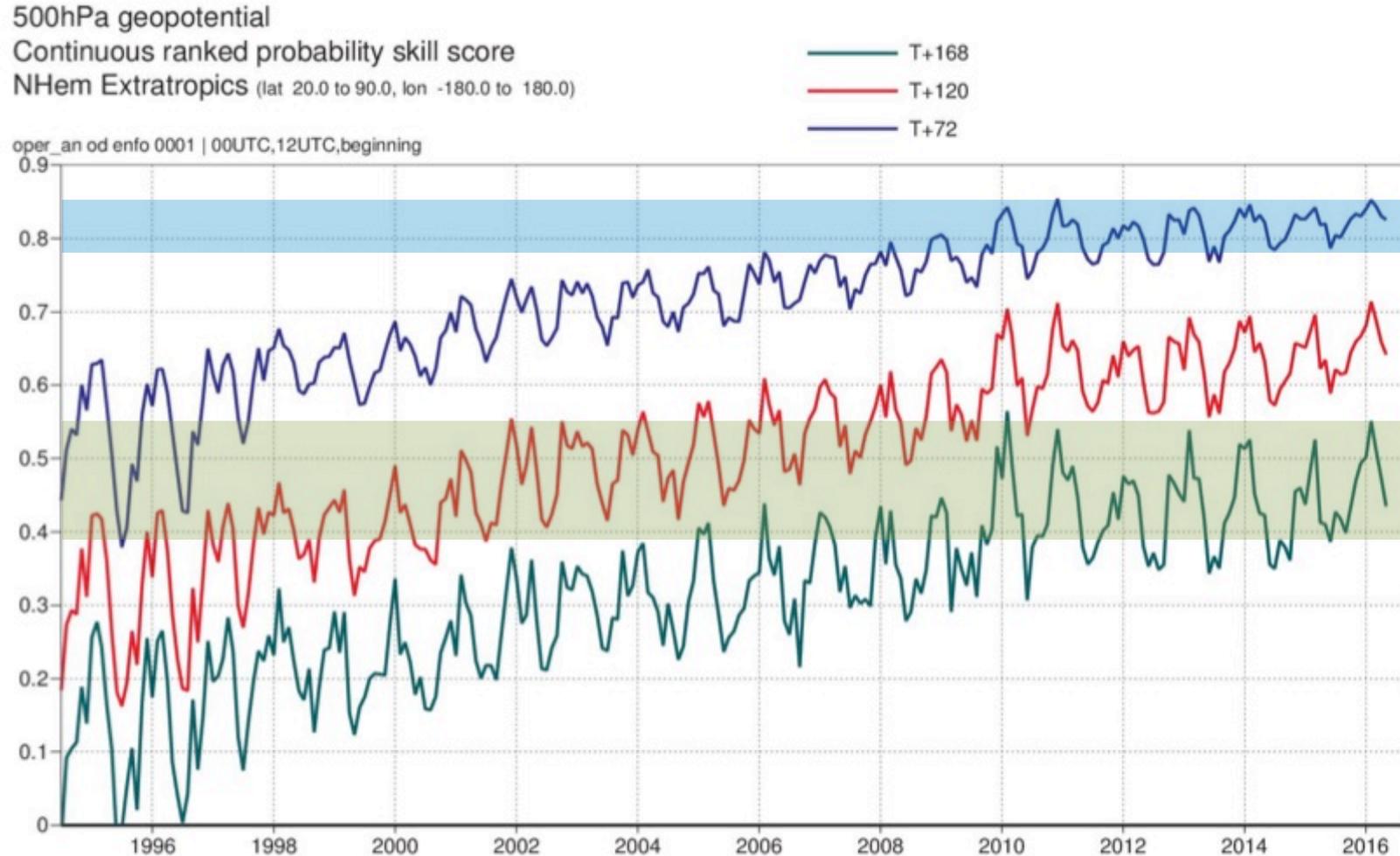
- Measure the average distance between the **forecast** and the **observed** PDFs with CRPS
- Measure the average distance between the **climatological** and the **observed** PDFs with CRPS
- $CRPSS = [\langle CRPS(cli) \rangle - \langle CRPS(fc) \rangle] / \langle CRPS(cli) \rangle$





1. ENS skill over the NH

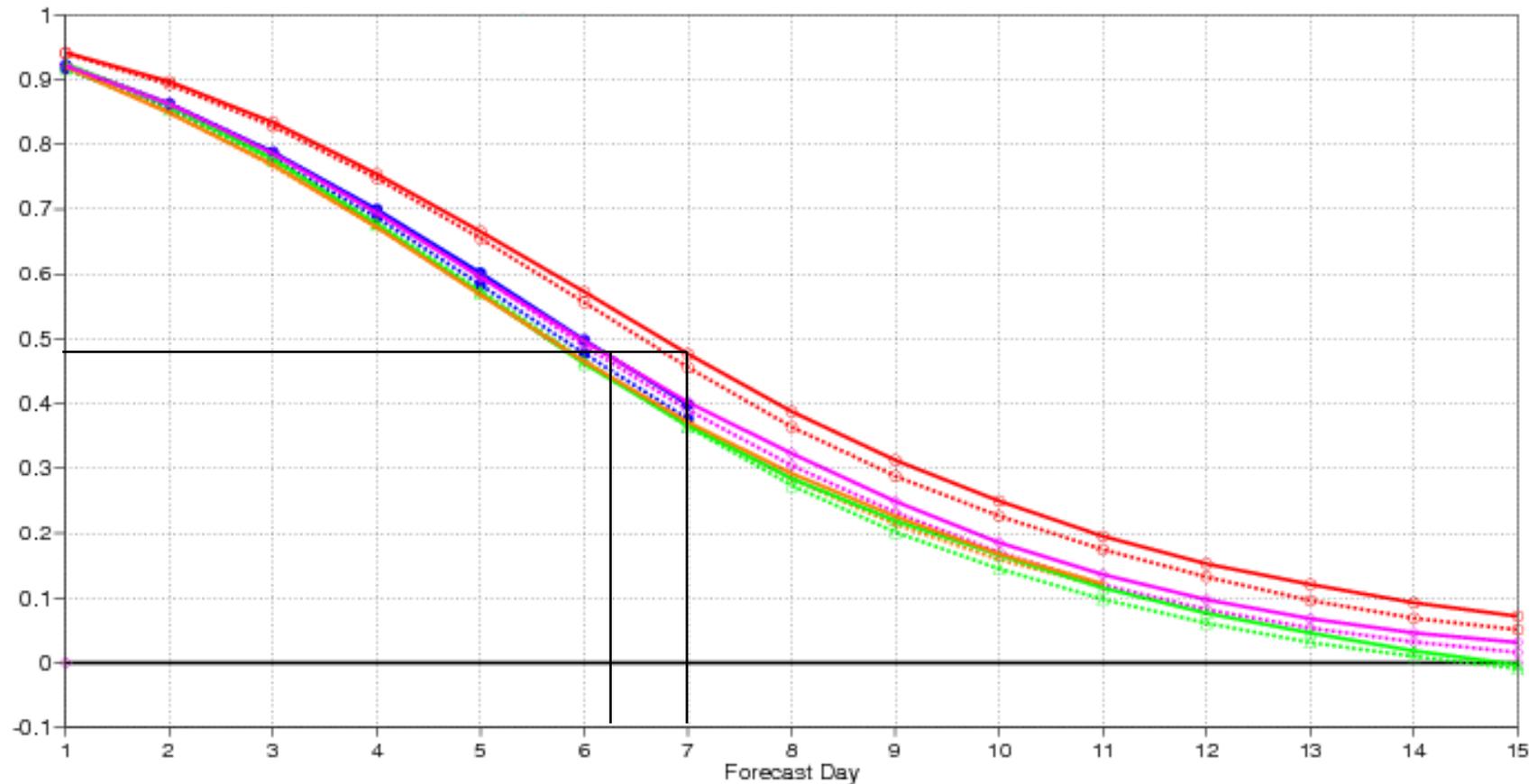
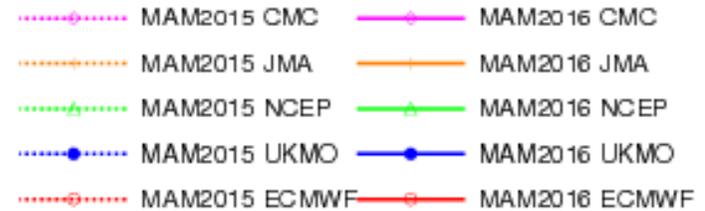
CRPSS is a measure of skill. Today, +7d fcs are as good as +3d fcs 20y ago!





1. The TIGGE ensembles: Z500 over NH, MAM16

500hPa geopotential
Continuous ranked probability skill score
NHem Extratropics (lat 20.0 to 90.0, lon -180.0 to 180.0)
MarAprMay



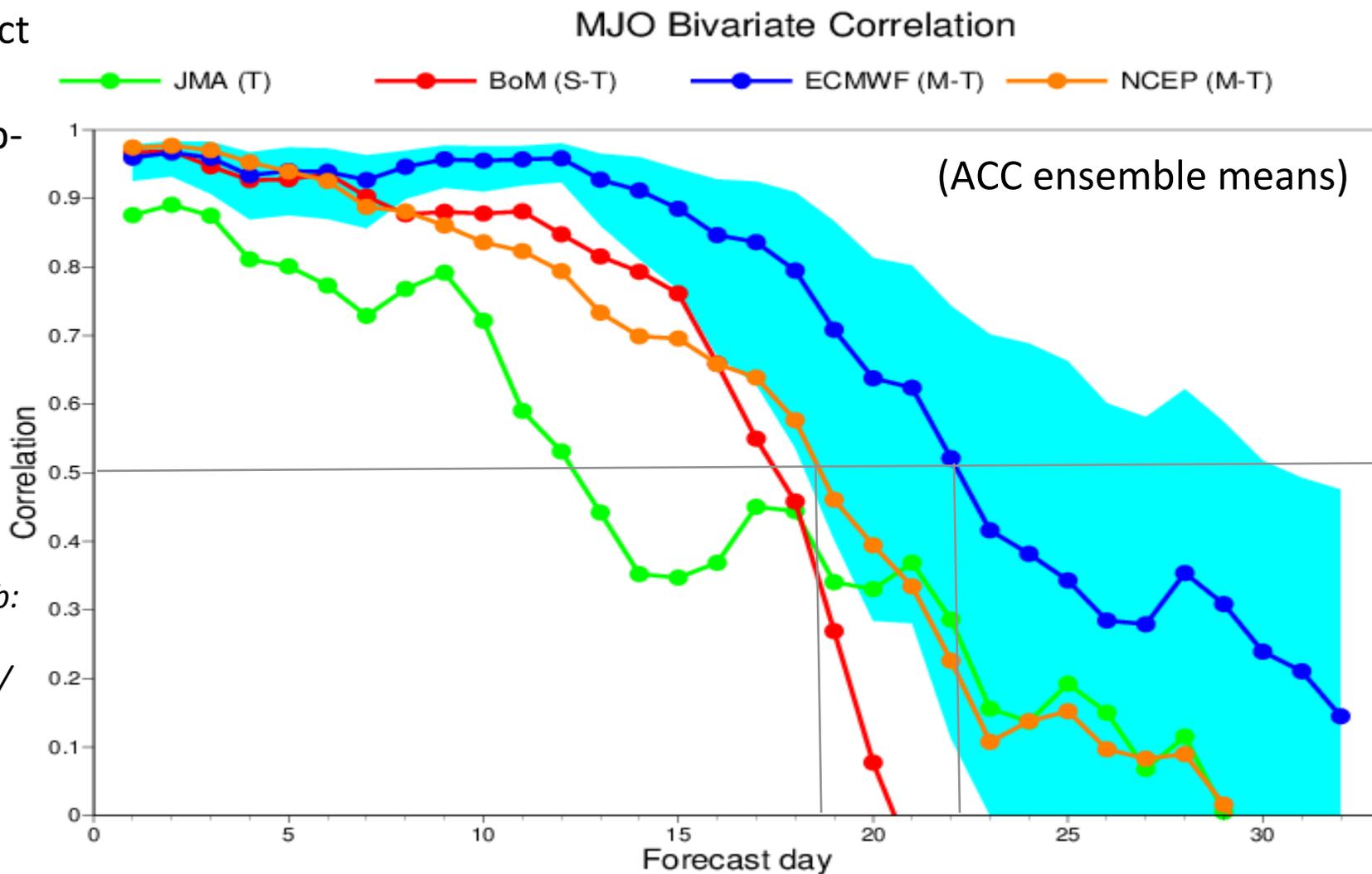


1. The S2S ensembles: MJO skill

The **S2S** (WWRP & WCRP) project is helping us to understand sub-seasonal to seasonal predictability.

(S2S @ ECMWF web: <https://software.ecmwf.int/wiki/display/S2S/Home>)

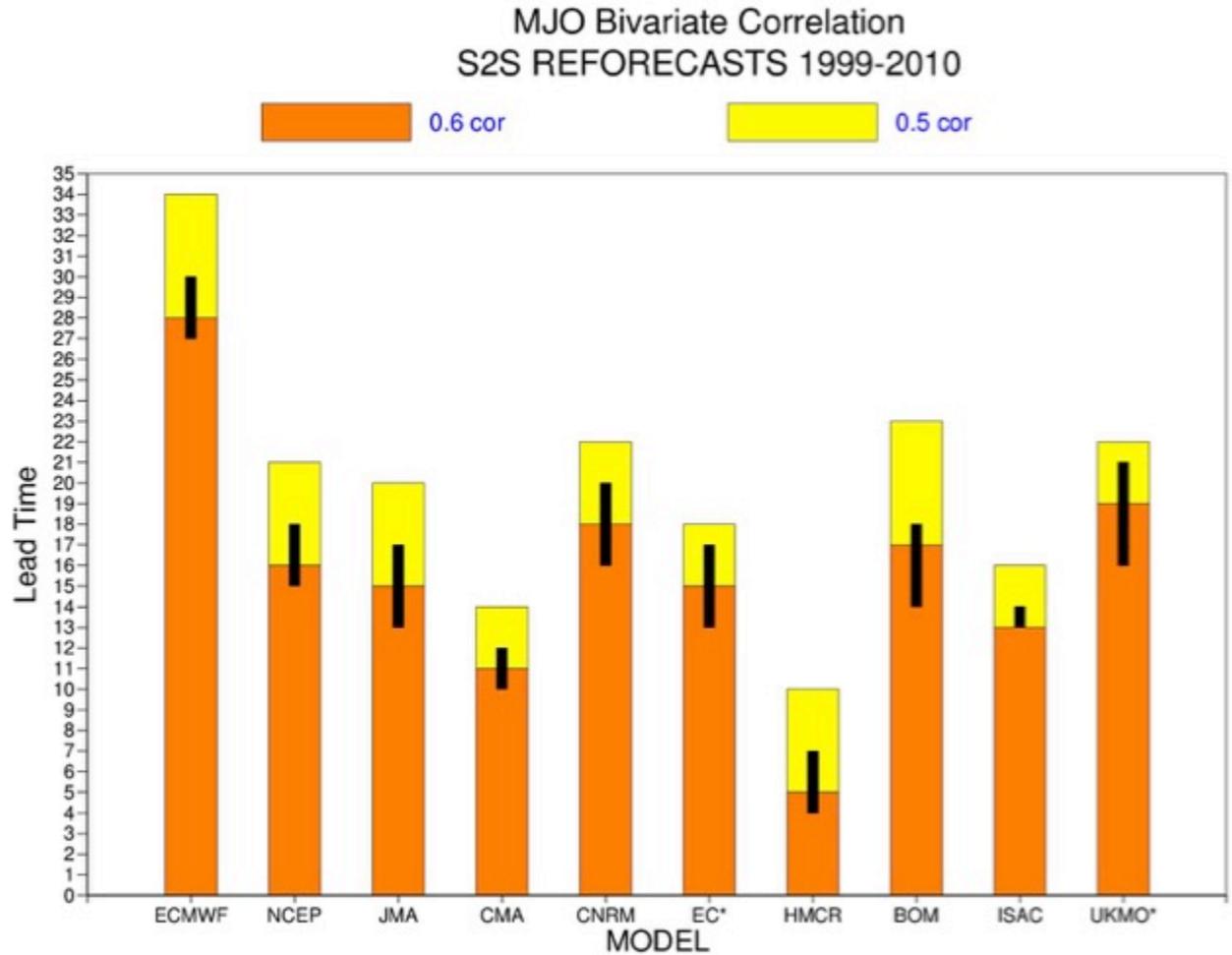
(from Frederic Vitart)





1. The S2S ensembles: MJO skill

Forecast lead-time when the ACC for the prediction of the Madden-Julian-Oscillation (MJO) reaches 0.6 correlation (orange bars) and 0.5 correlation (yellow bars). The black lines indicate the 95% confidence interval of the time when the 0.6 correlation is reached. Results are based on the reforecast from 1999 to 2010 from all the models, verified against ERA-Interim analyses.



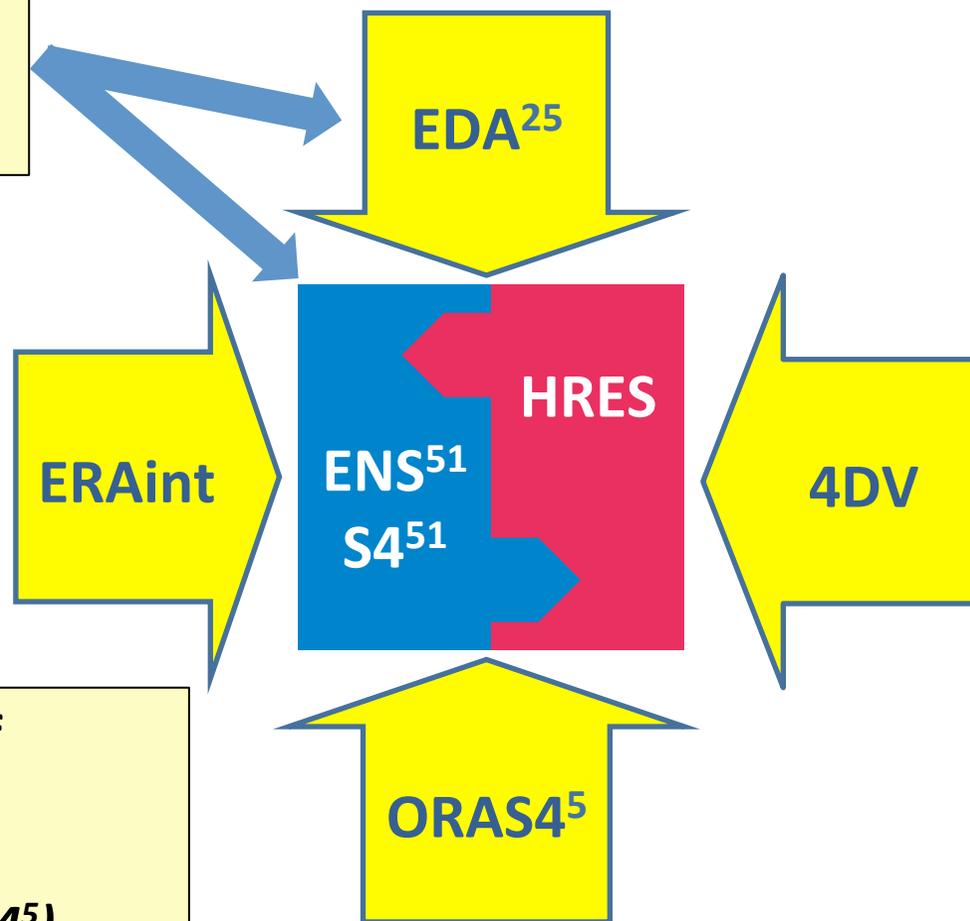
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2. Ensembles are used at analysis and forecast time

The ensembles simulate the effect of:

- Observation/initial uncertainties
- Model uncertainties (2 stochastic schemes)



The ensembles give us estimates of the PDF of analyses and forecast states:

$$\text{PDF}(0) \ll 4\text{DV} + \text{EDA}^{25} + \text{ORAS4}^5$$

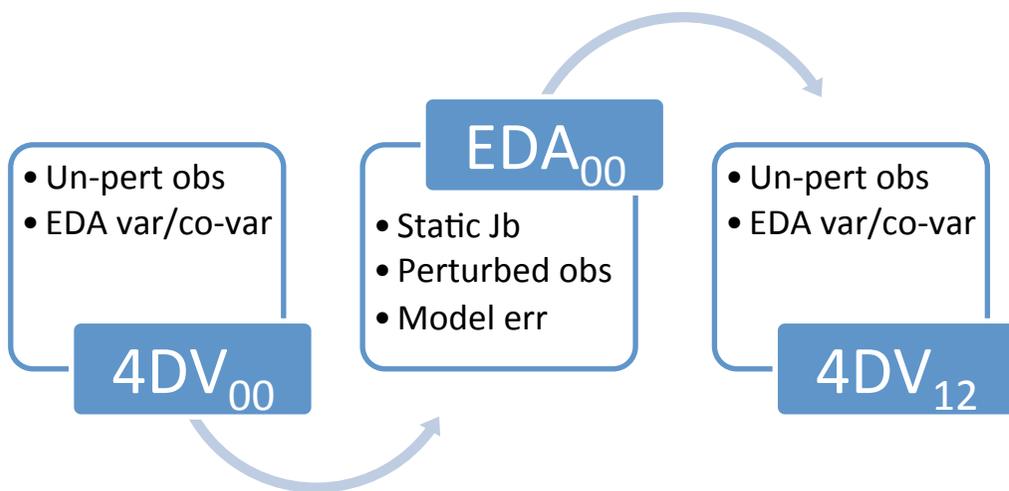
$$\text{(for the refc: PDF}(0) \ll \text{ERAint} + \text{ORAS4}^5)$$

$$\text{PDF}(T) \ll \text{HRES} + \text{ENS}^{51} / \text{S4}^{51}$$

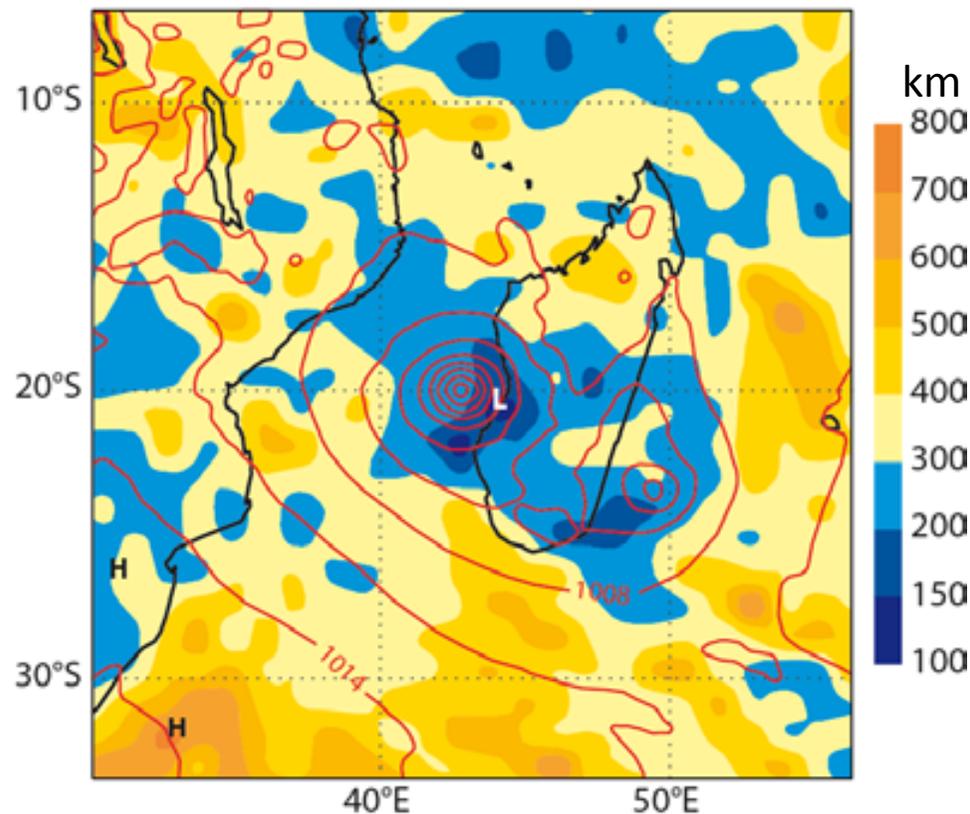


2. The EDA is used to provide flow dependent stats

The 25-member **Ensemble of Data Assimilations** provides the 4DV-HRES with flow dependent background error statistics.



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



(from Massimo Bonavita)



2. The medium-range/monthly ensemble (ENS)

ENS includes **51 forecasts** with resolution:

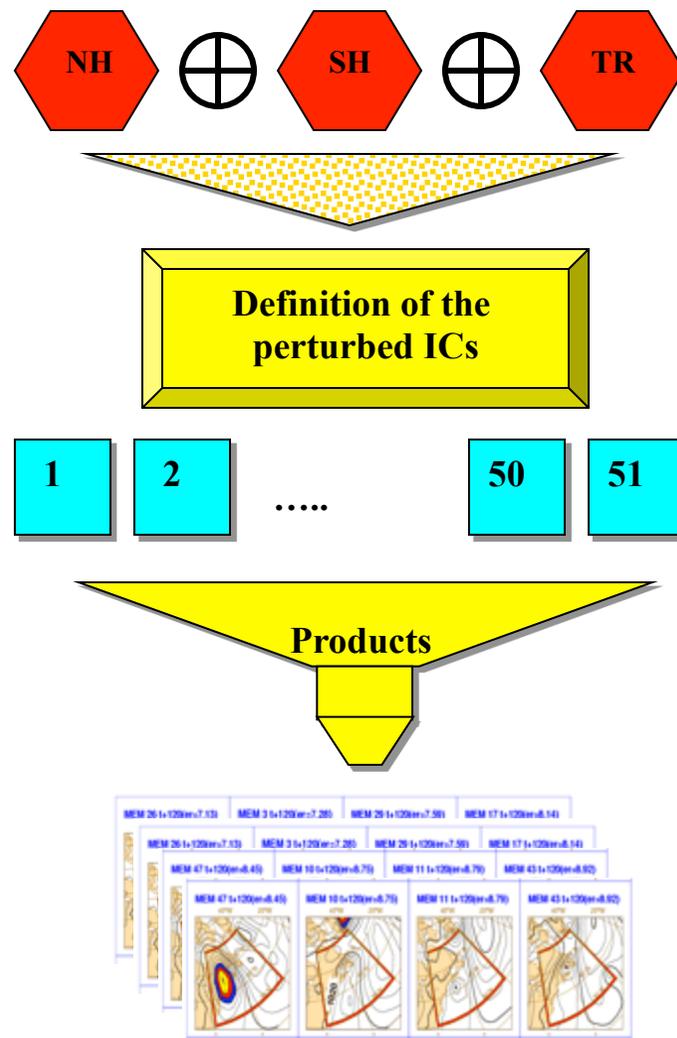
- $T_{co}639L91$ (~**18km**, 91 levels) from **day 0 to 15**
- $T_{co}319L91$ (~**36km**, 91 levels) from **day 15 to 46** (only at 00UTC on Mon and Thu).

Initial uncertainties are simulated by adding to the unperturbed analyses a combination of **T42L91 singular vectors**, computed to optimize total energy over 48h hours, and perturbations generated by the ECMWF **$T_{co}639L137$ EDA** (Ensembles of Data Assimilation).

Model uncertainties are simulated by adding stochastic perturbations to the tendencies due to parameterized physical processes (**SPPT and SKEB schemes**).

The unperturbed analysis is given by the $T_{co}1279L137$ 4DVAR.

ENS runs daily at 00 and 12 UTC, with a TOA at 0.01 hPa.





2. The ECMWF operational ensemble (ENS) today

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

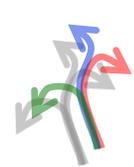
$$e_j(d, T) = e_j(d, 0) + \int_0^T [A(e_j, t) + P(e_j, t) + \delta P_j(e_j, t)] dt$$



$$\delta P_j(\lambda, \varphi, p) = r_j(\lambda, \varphi) P_j(\lambda, \varphi, p) + F_\psi(\lambda, \varphi, p)$$

SPPT: Stochastically Perturbed Parameterized Tendencies
(to represent uncertainty associated with parameterisations)

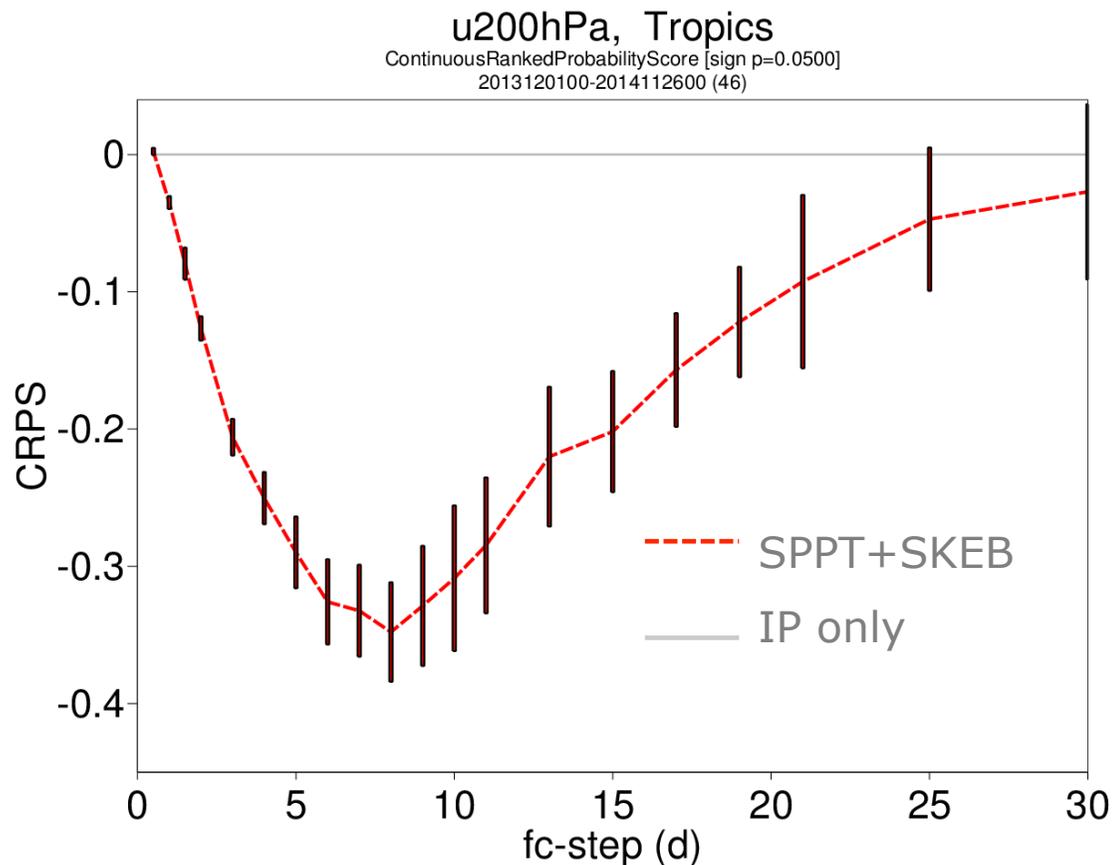
SKEB: Stochastic Kinetic Energy Backscatter
(to represent unresolved upscale energy transfer)



2. Including model uncertainties improves ENS forecasts

Including model perturbations via the SPPT and SKEB schemes gives rise to better ensembles:

- The ensemble is **more reliable** (less under-dispersive);
- **Improved probabilistic skill** is observed at a range of lead times (e.g. see in plot improved CRPS for high-level winds in the Tropics)



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3. The octahedral cubic grid

It is a reduced Gaussian grid with the same number of latitude circles ($NDGL$) than the standard Gaussian grid (\leftrightarrow Gaussian weights) but with a new rule to compute the number of points per latitude circle.

Number of points per latitude

$NLOEN(lat_N) = 20 \rightarrow$ Poles

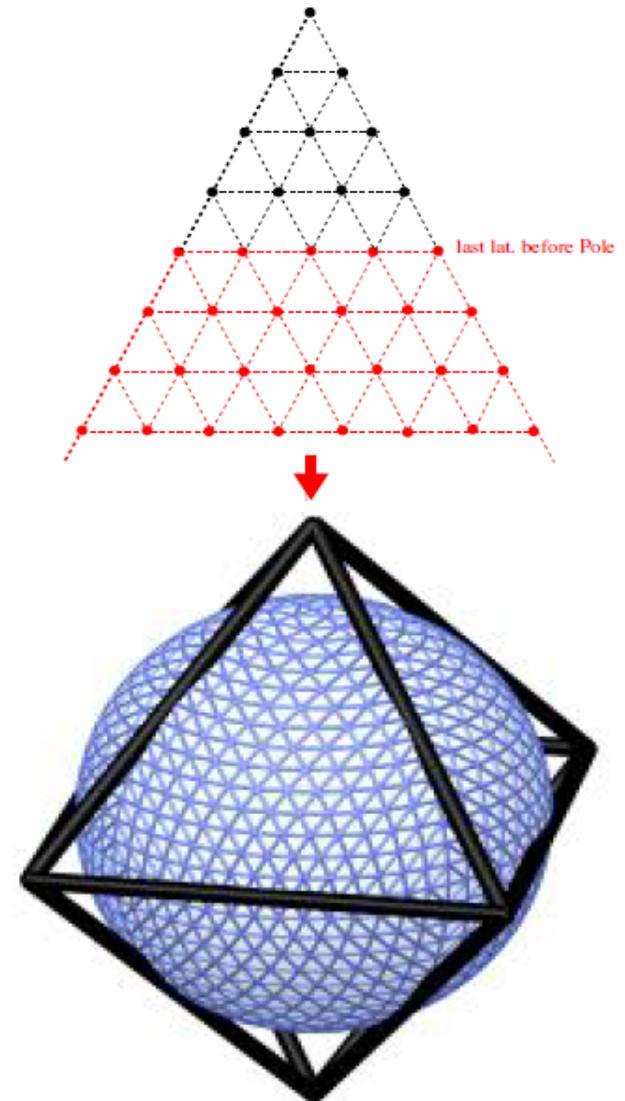
$NLOEN(lat_i) = NLOEN(lat_{i-1}) + 4$

TL1279 : 2.14 Mpoints

TC1023 : 5.45 Mpoints

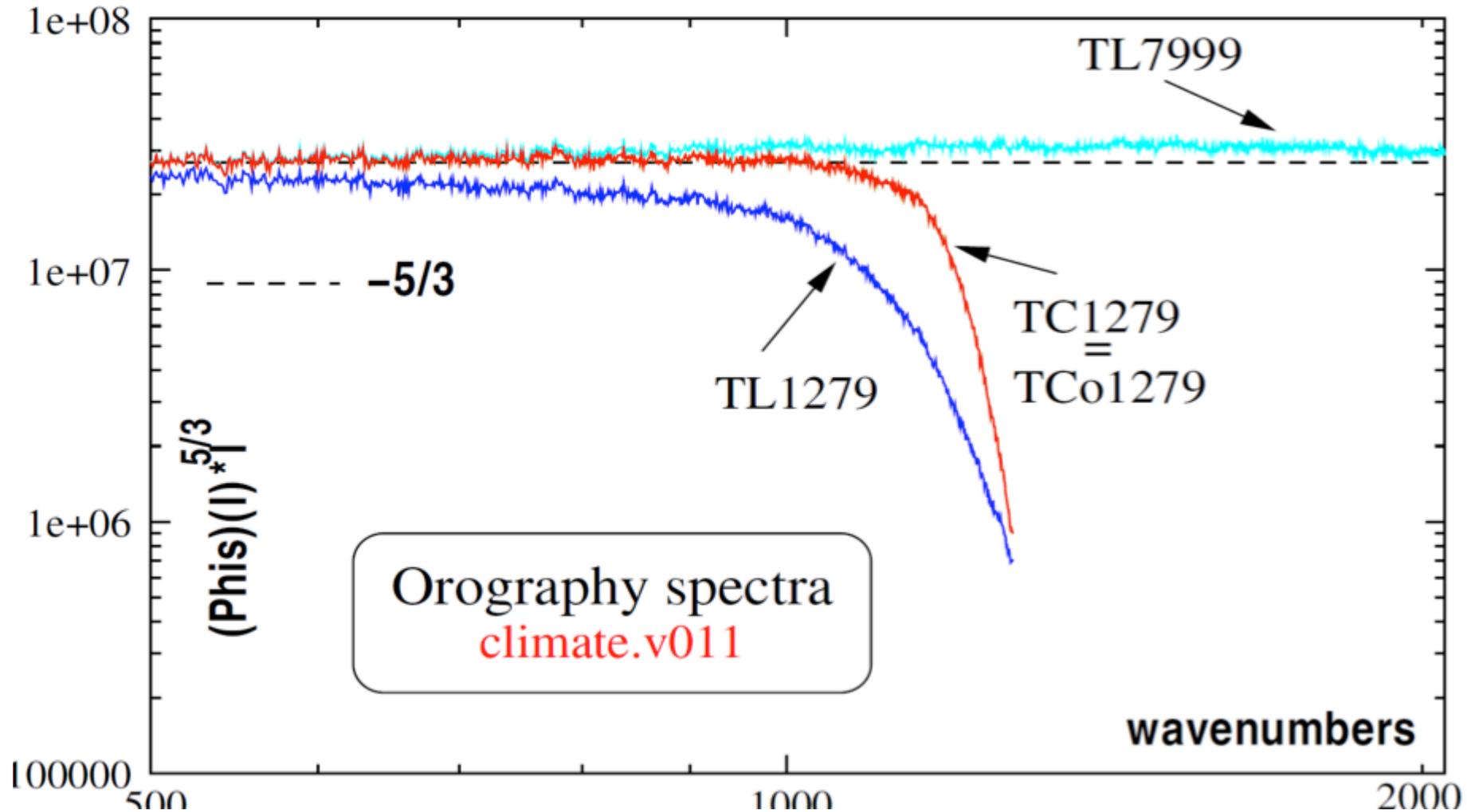
TC1279 : 8.51 Mpoints

TCo1279 : 6.59 Mpoints





3. Orographic variance of different grids





3. March 2016: the resolution of all suites was increased

	Operational suite	Uncertainty sources		
		Obs	ICs	Model
HRES - 9km	T _{CO} 1279 (~9 km) L137 (0-10d)	--	--	--
4DVAR- 9km	T _{CO} 1279 (inner T _{CO} 255/319/399) L137	--	--	--
EDA – 18km	25 members: T _{CO} 639 (~18km) L137	δo	--	SPPT(1L)
ENS – 18km	51 members: T _{CO} 639 (~18km) L91 (0-15d) T _{CO} 319 (~36km) L91 (15-46d)	--	EDA ²⁵ & SVs ^{50*} Nareas	SPPT(3L) & SKEB
	- Ocean: NEMO ORCA100z42 (to 025z75 in Q4)	--	ORAS4 ⁵	--
S4 – 80km	51 members: T _L 255 (~80km) L91 (to T _{CO} 319L137 in 2017)	--	SVs	SPPT(3L) & SKEB
	- Ocean: NEMO ORCA100z42 (to 025z75 in 2017)	--	ORAS4 ⁵	--

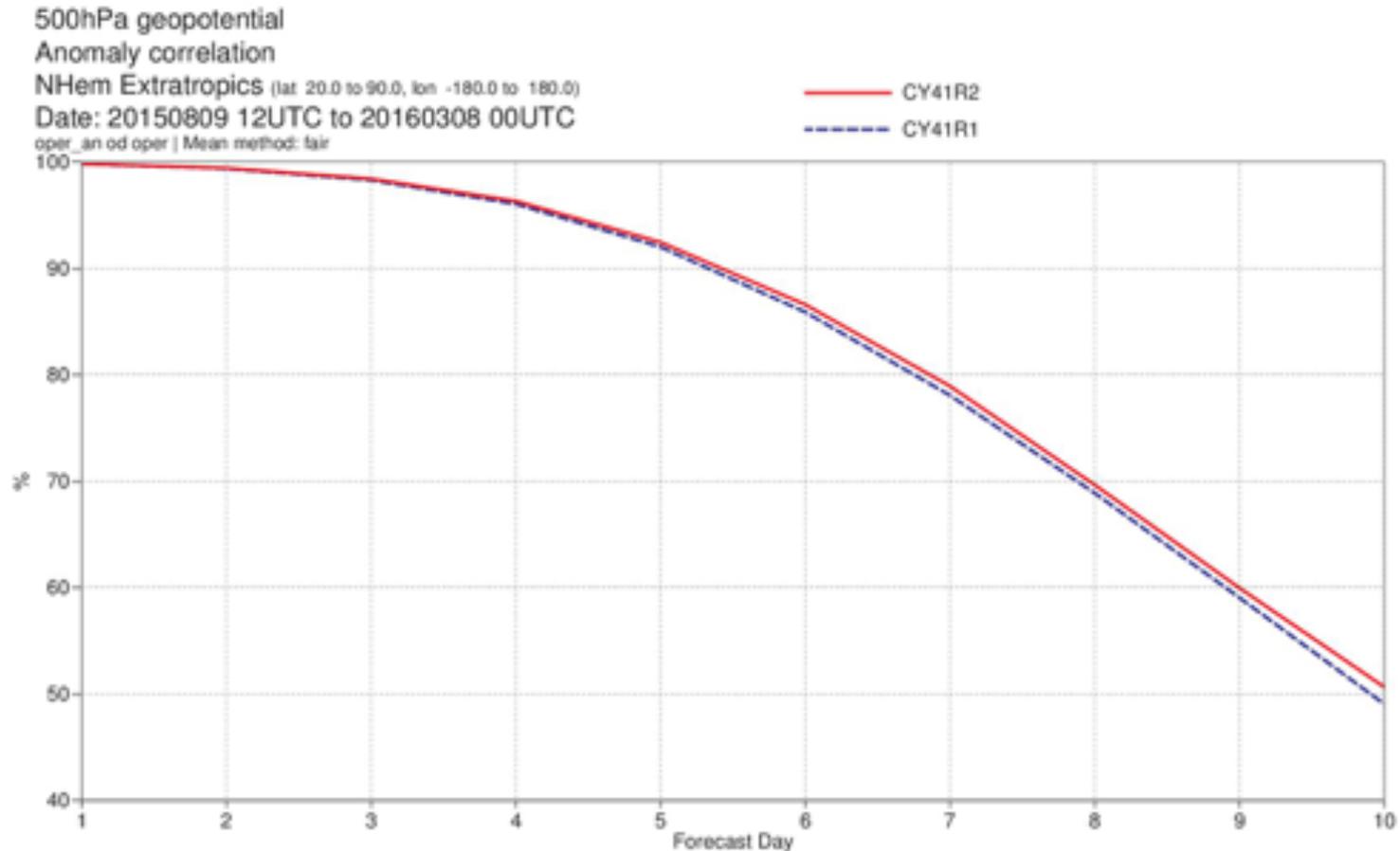
T_{CO} – Cubic octahedral Gaussian reduced grid

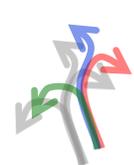
T_L – Gaussian linear grid



3. Impact of recent upgrade on single high-resolution fc

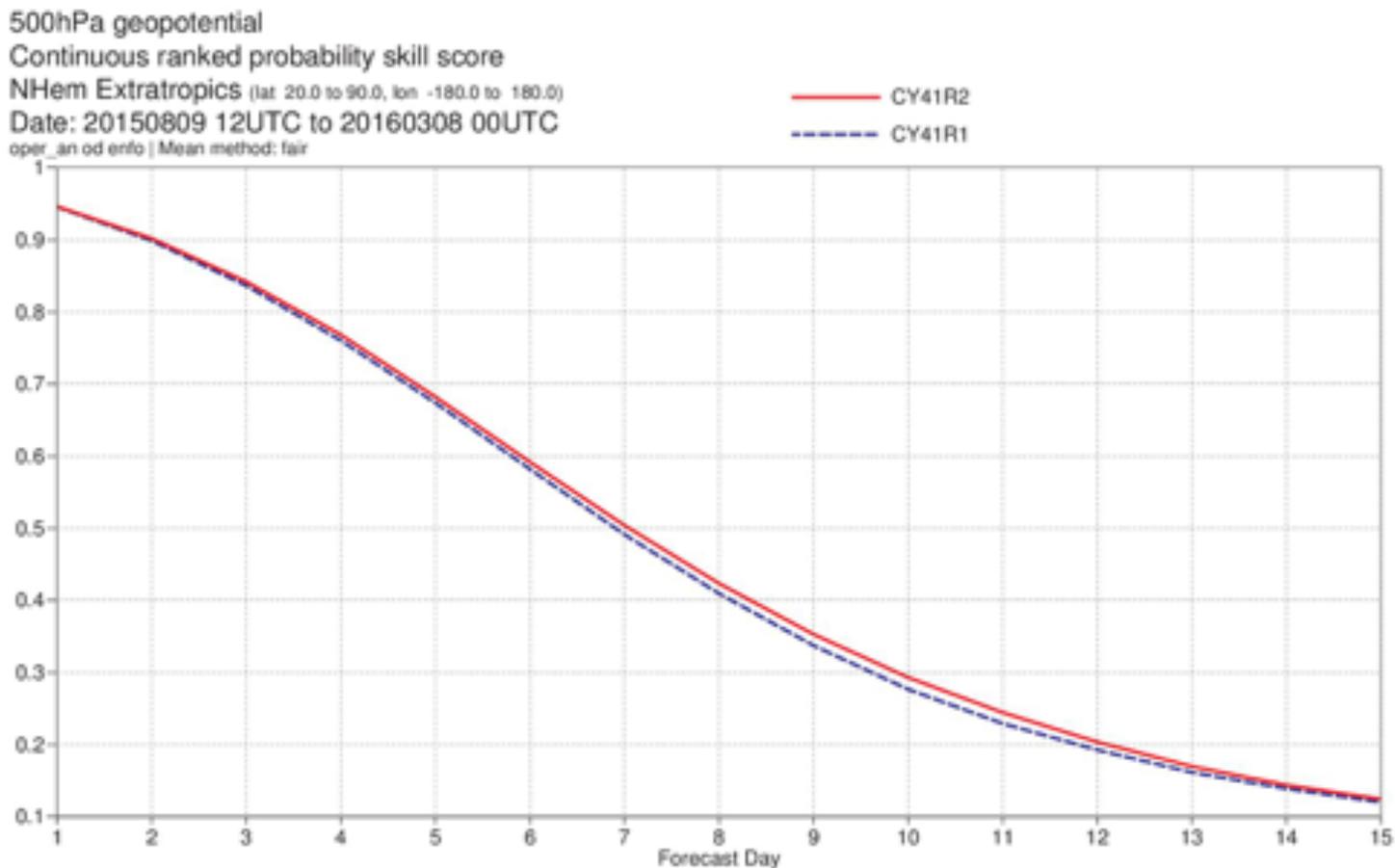
Results based on 7 months indicate predictability gains for single high-resolution forecasts in the medium-range of **about 3 hours** (up to 6 hours for surface variables).





3. Impact of recent upgrade on ensemble fcs

Results based on 7 months indicate predictability gains for the ensemble in the medium-range of **about 6 hours** (up to 12-18 hours for surface variables).

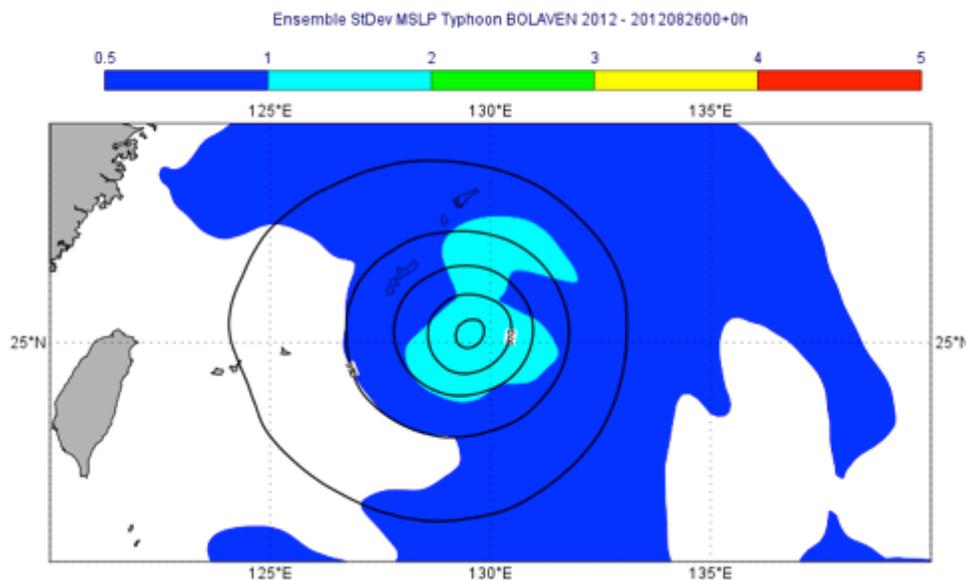




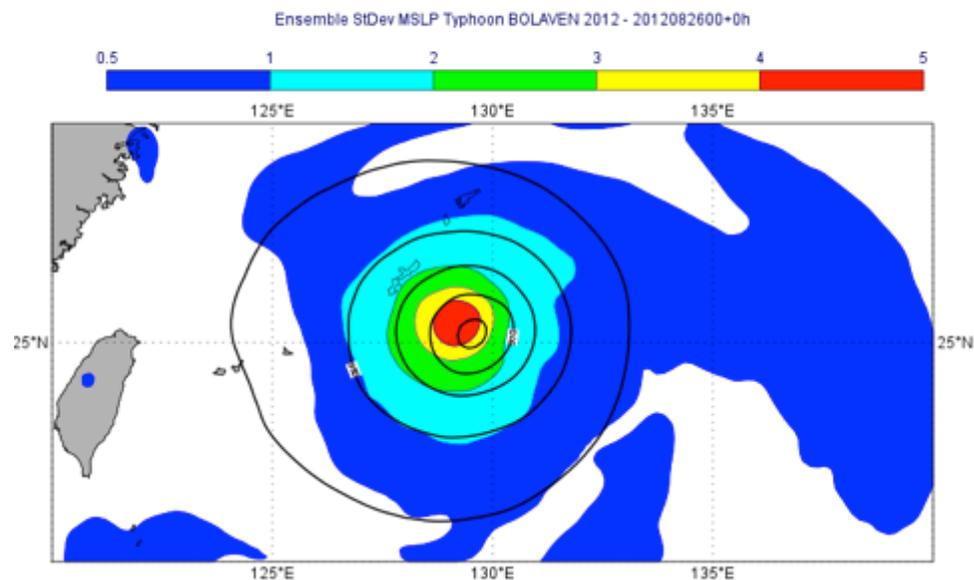
3. Impact of using a higher-resolution EDA

An increase in the resolution of the EDA outer loops from T_L399 to T_L639 improves the estimation of the analysis uncertainty and thus the ENS initial conditions. This figure shows the impact on the ENS spread (std) in the case of typhoon Bolaven (26 Aug 2012).

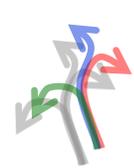
Ensemble with perturbations from 399 EDA



Ensemble with perturbations from 639 EDA



(From Simon Lang)

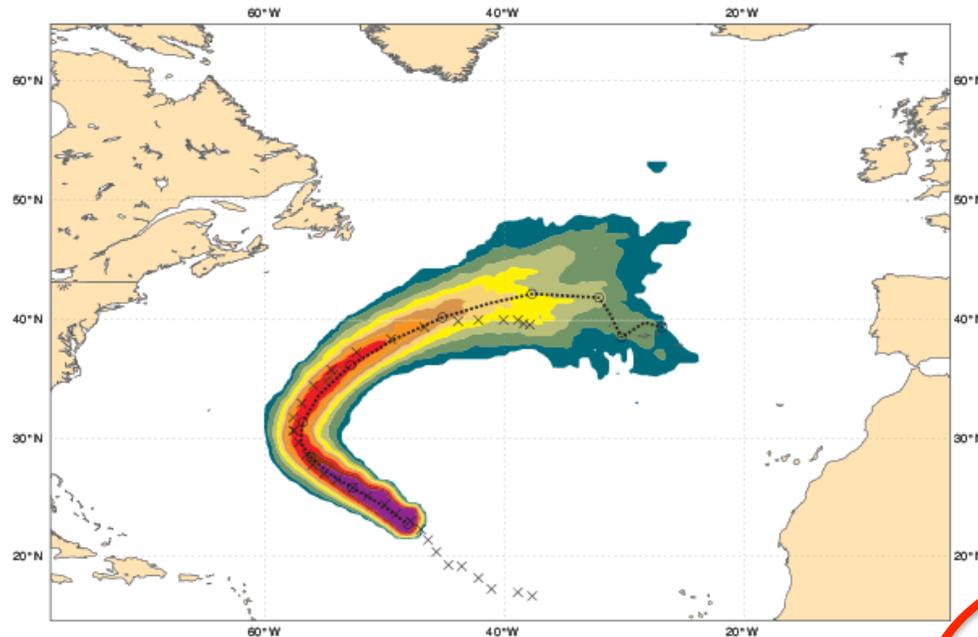


3. Combined impact of increasing EDA & ENS resolution

OPE: T_L1279 An, T_L399 EDA, T_L639 ENS

Date 20140914 00 UTC @ECMWF

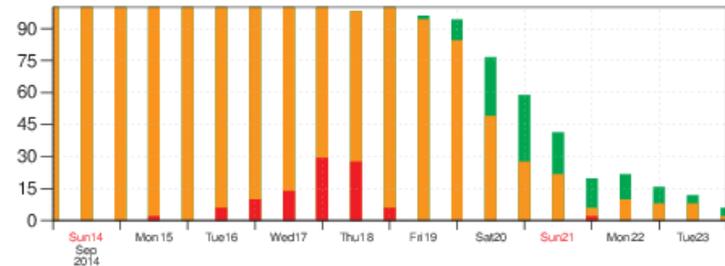
Probability that **EDOUARD** will pass within 120 km radius during the next 240 hours
 tracks: **solid**=HRES; **dot**=Ens Mean [reported minimum central pressure (hPa) **994**]



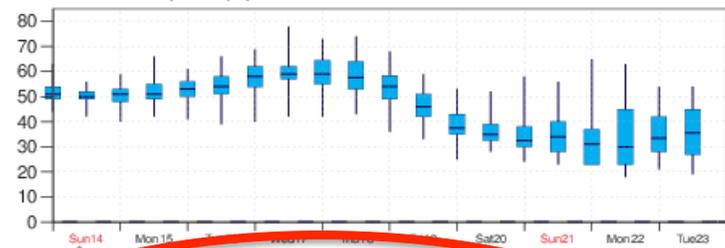
List of ensemble members numbers forecast Tropical Cyclone
 Intensity category in colours: **TD**[up to 33] **TS**[34-63] **HR1**[64-82] **HR2**[83-95] **HR3**[>95 kt]

+024 h:	ct 01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50			
+048 h:	ct 01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50			
+072 h:	ct 01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50			
+096 h:	ct 01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50			
+120 h:	ct 01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50			
+144 h:	ct 01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	22	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	44	45	46	47	48	49	50						
+168 h:		02	03	04	05	08	10	11	12	13	14	19	20									19	20		24	25	27	28	29	30	31	33	34	35	36	37	38	42	44	45	46												
+192 h:							10															20	21		25	27	28	31	34	36																							
+216 h:							10															20	21		27	28	29	31	34																								
+240 h:																						20	21		31																												

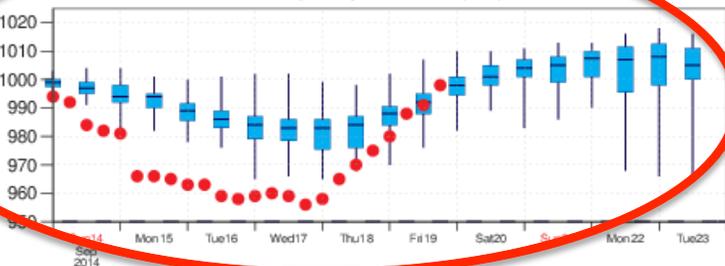
Probability (%) of Tropical Cyclone Intensity falling in each category
TD[up to 33] **TS**[34-63] **HR1**[64-82] **HR2**[83-95] **HR3**[> 95 kt]



10m Wind Speed (kt) **solid**=HRES; **dot**=Ens Mean



Mean Sea Level Pressure in Tropical Cyclone Centre (hPa) **solid**=HRES; **dot**=Ens Mean



(From Simon Lang)

Too small initial spread and deepening not captured

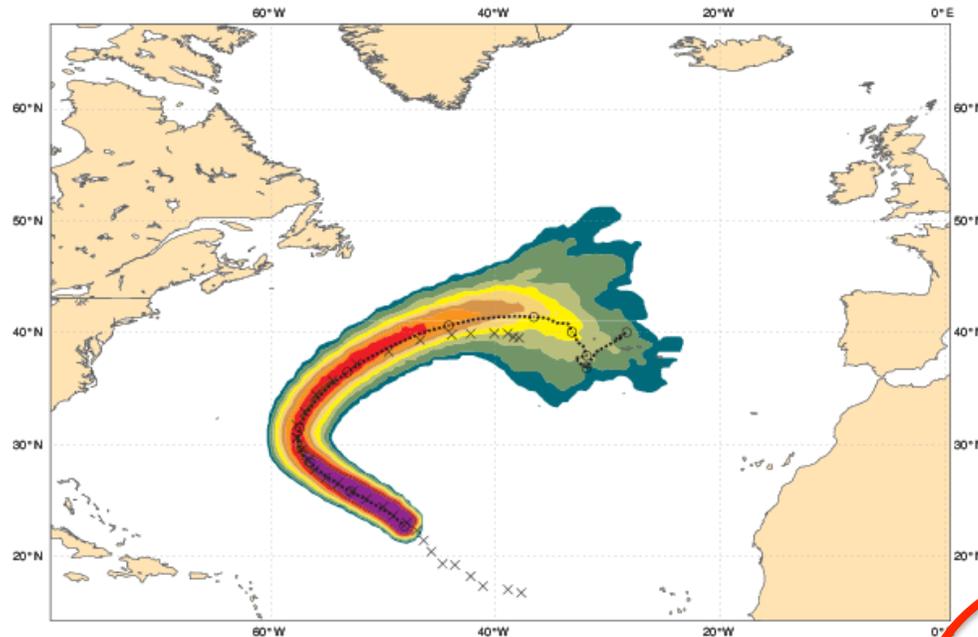


3. Combined impact of increasing EDA & ENS resolution

OPE: T_L 1279 An, T_L 639 EDA, T_{CO} 639 ENS

Date 20140914 00 UTC @ECMWF

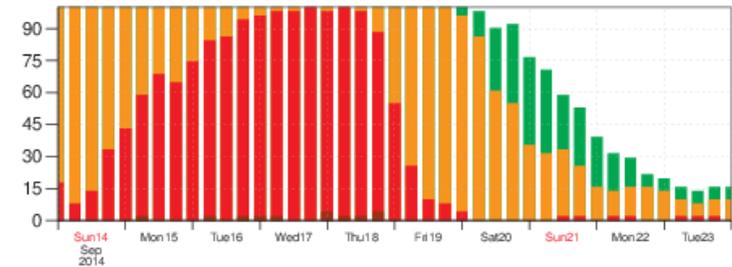
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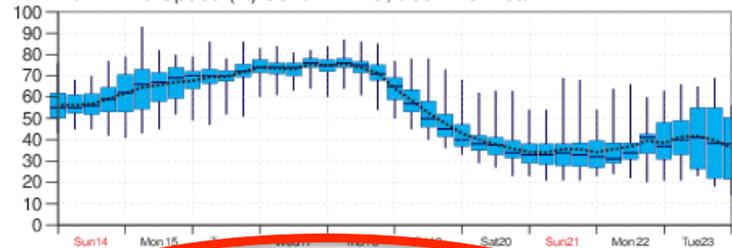
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 Intensity category in colours: **TD**[up to 33] **TS**[34-63] **HR1**[64-82] **HR2**[83-95] **HR3**[>95 kt]

+024 h:	ct	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50						
+048 h:	ct	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50						
+072 h:	ct	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50						
+096 h:	ct	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50						
+120 h:	ct	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50						
+144 h:	ct	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50						
+168 h:	ct	02	03	04	05	08	09	10	11	13	16	17	18	20	21	22	23	24	25	26	27	28	29	30	33	34	35	36	38	39	40	41	42	43	44	45	46	47	48																		
+192 h:		02	03	08	08	10	11	13	18	21	24	25	26	29	33	34	37	39	40	42	44	47																																			
+216 h:		02	08	09	13	18	25	26	29																																																
+240 h:		03	08	11	13	18	25	29																																																	

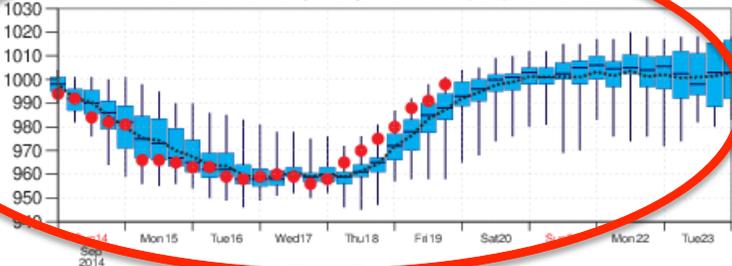
Probability (%) of Tropical Cyclone Intensity falling in each category
TD[up to 33] **TS**[34-63] **HR1**[64-82] **HR2**[83-95] **HR3**[> 95 kt]



10m Wind Speed (kt) **solid**=HRES; **dot**=Ens Mean



Mean Sea Level Pressure in Tropical Cyclone Centre (hPa) **solid**=HRES; **dot**=Ens Mean



(From Simon Lang)

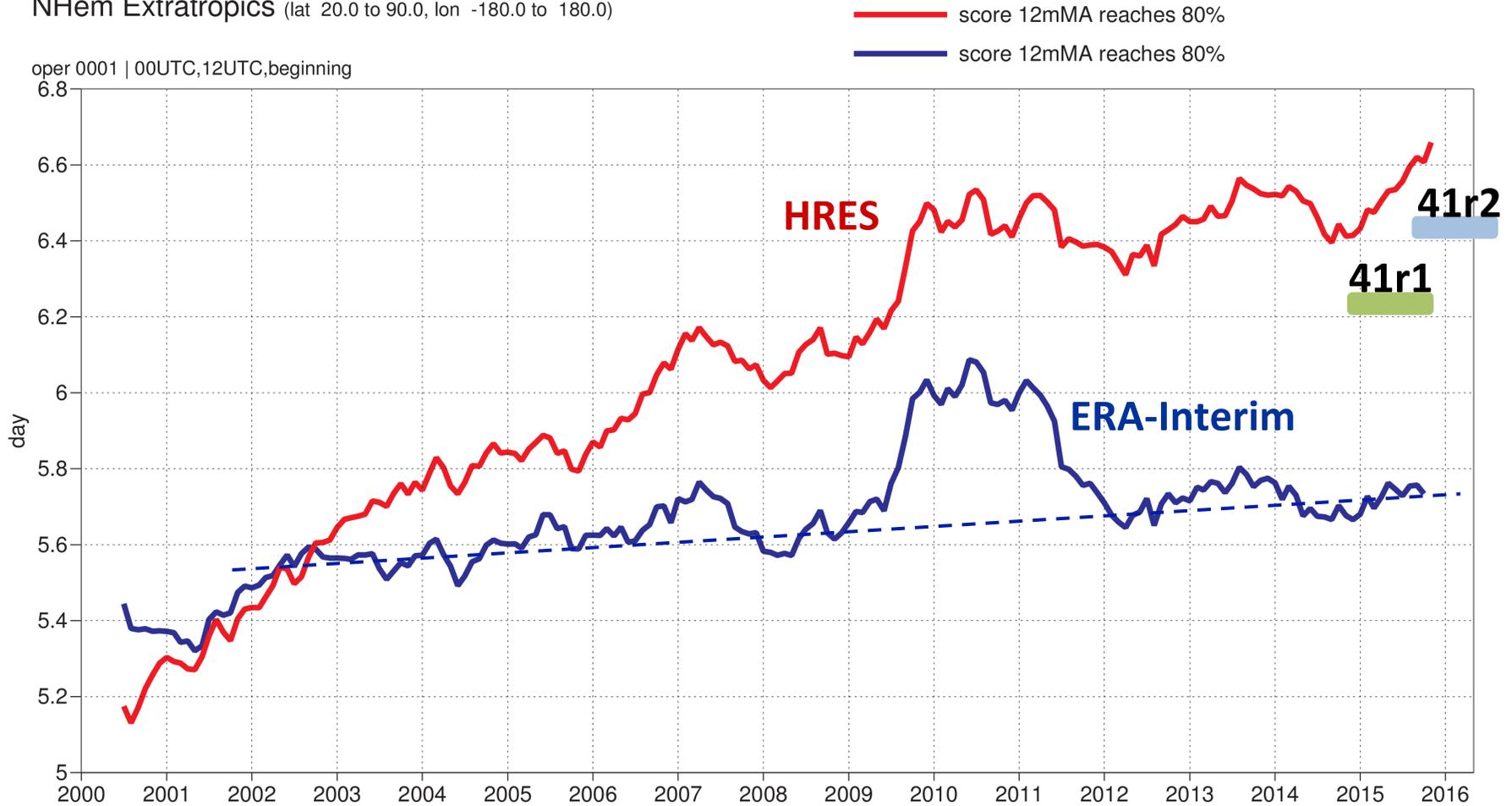
Deepening is captured and spread reflects uncertainty

1. Why do we need ensembles?
2. The ECMWF ensembles
3. The resolution upgrade of March 2016
4. Few key performance indices
5. Prediction of an extreme precipitation event in Houston
6. Conclusions



4. HRES and ERAI headline score – Z500 ACC NH

500hPa geopotential
Lead time of Anomaly correlation reaching 80%
NHem Extratropics (lat 20.0 to 90.0, lon -180.0 to 180.0)



(From Thomas Haiden)



4. (HRES-ERA) headline score – Z500 ACC NH

500hPa geopotential

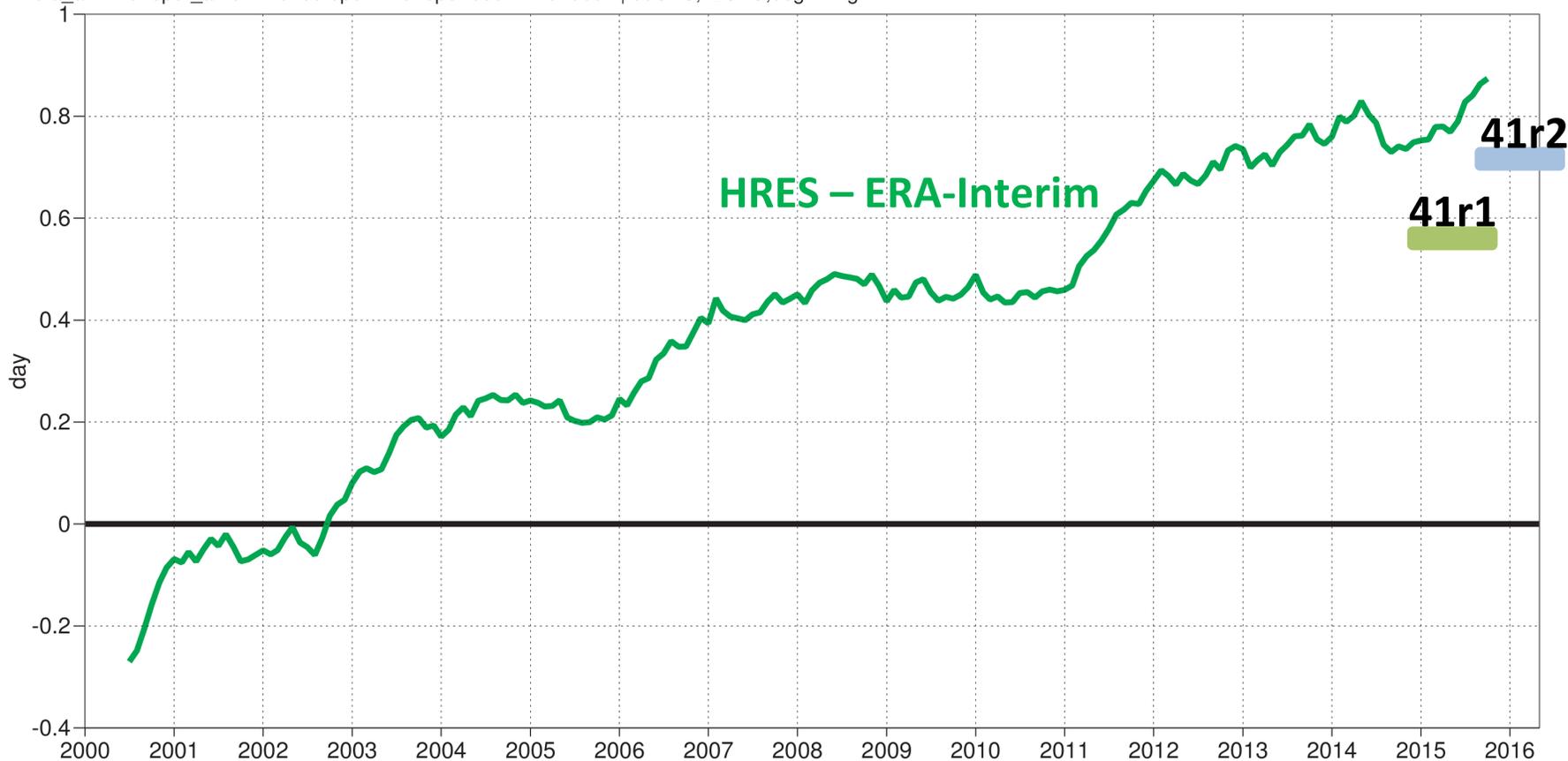
Lead time of Anomaly correlation reaching 80%

NHem Extratropics (lat 20.0 to 90.0, lon -180.0 to 180.0)

T+⁻¹ T+⁰ ... T+²⁴⁰

era_an*-1.0+oper_an ei*-1.0+od oper*-1.0+oper 0001*-1.0+0001 | 00UTC,12UTC,beginning

score 12mMA reaches 80%

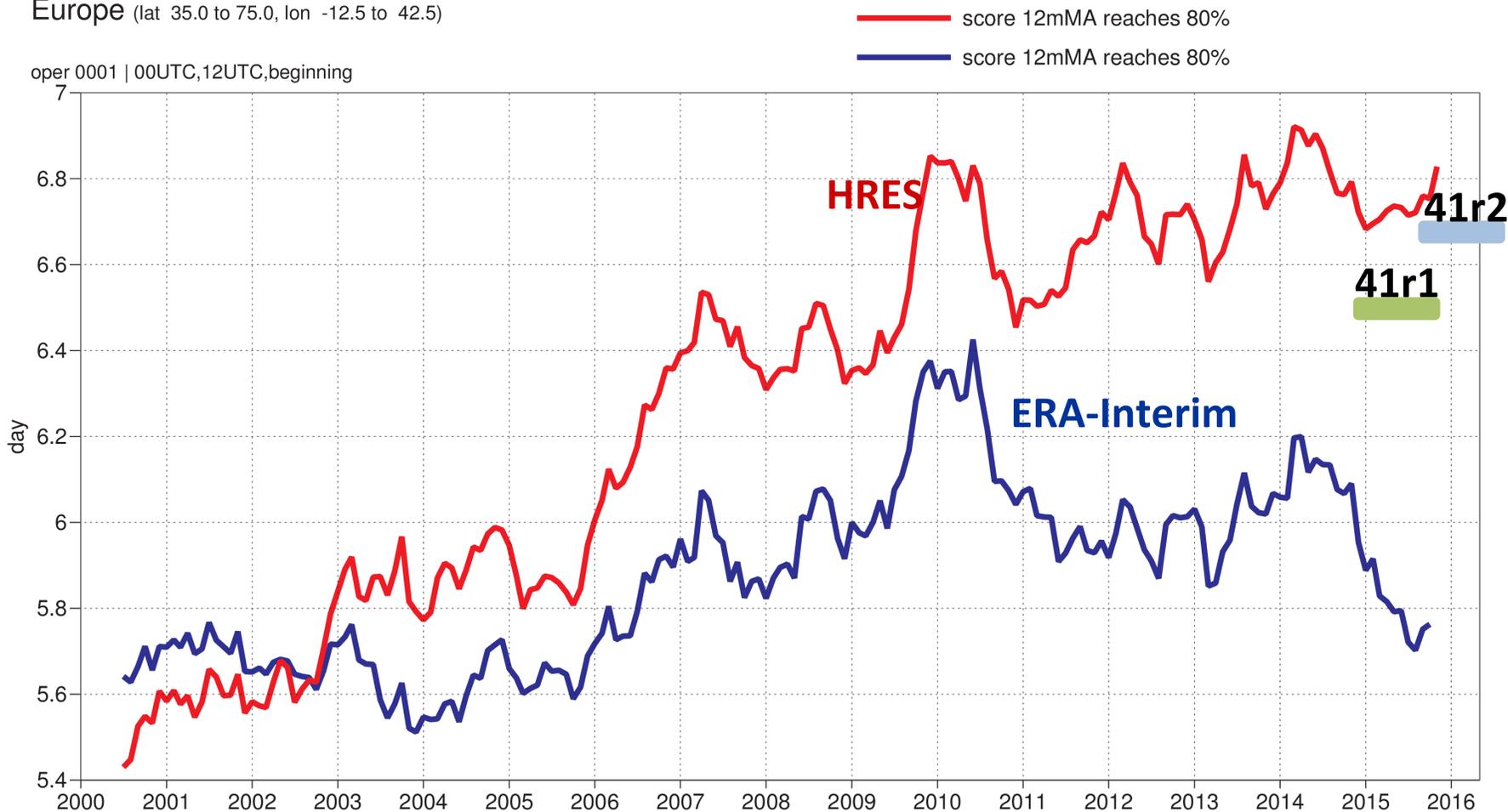


(From Thomas Haiden)



4. HRES and ERAI headline score – Z500 ACC Europe

500hPa geopotential
Lead time of Anomaly correlation reaching 80%
Europe (lat 35.0 to 75.0, lon -12.5 to 42.5)



(From Thomas Haiden)



4. (HRES-ERA) headline score – Z500 ACC Europe

500hPa geopotential

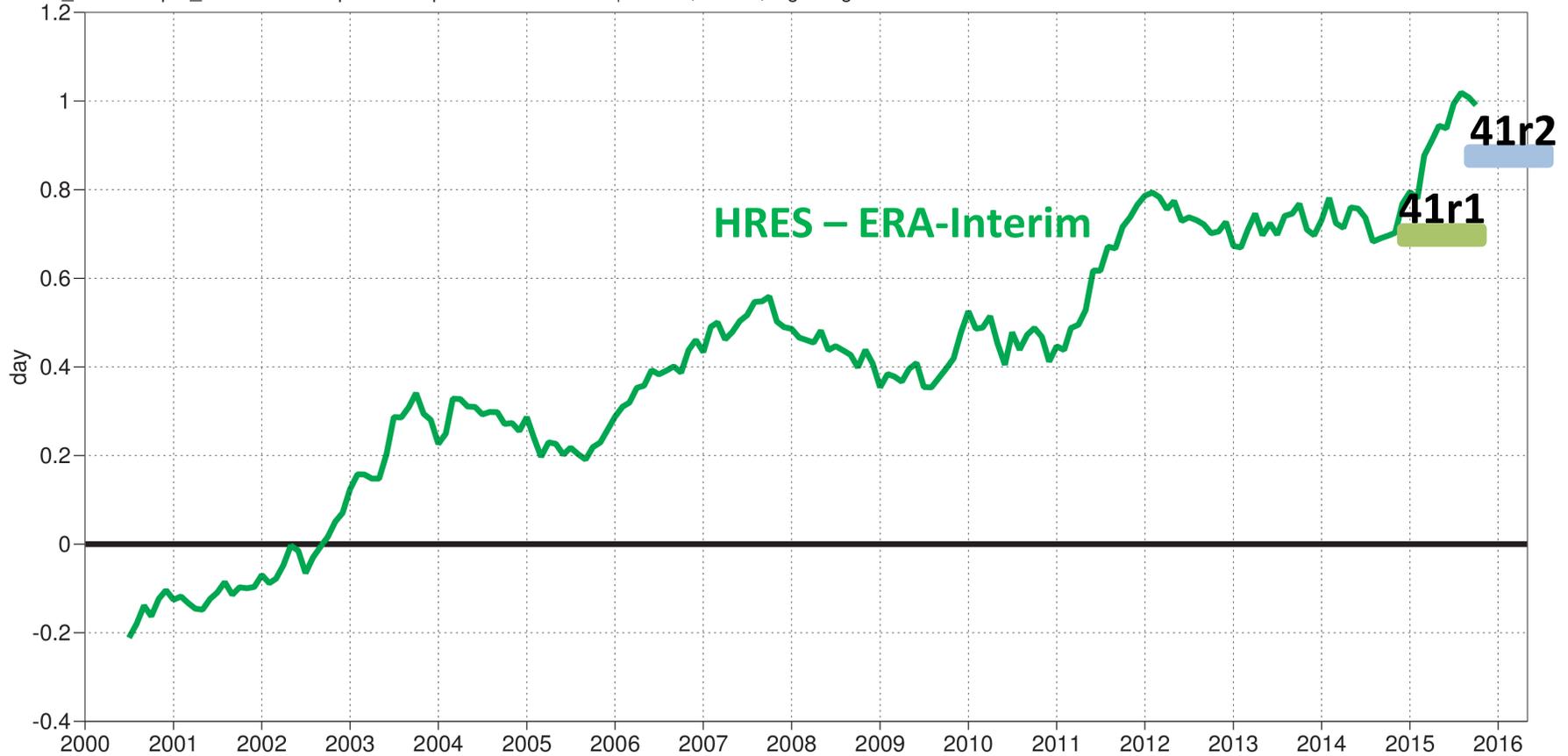
Lead time of Anomaly correlation reaching 80%

Europe (lat 35.0 to 75.0, lon -12.5 to 42.5)

T+1 T+0 ... T+240

era_an*-1.0+oper_an ei*-1.0+od oper*-1.0+oper 0001*-1.0+0001 | 00UTC,12UTC,beginning

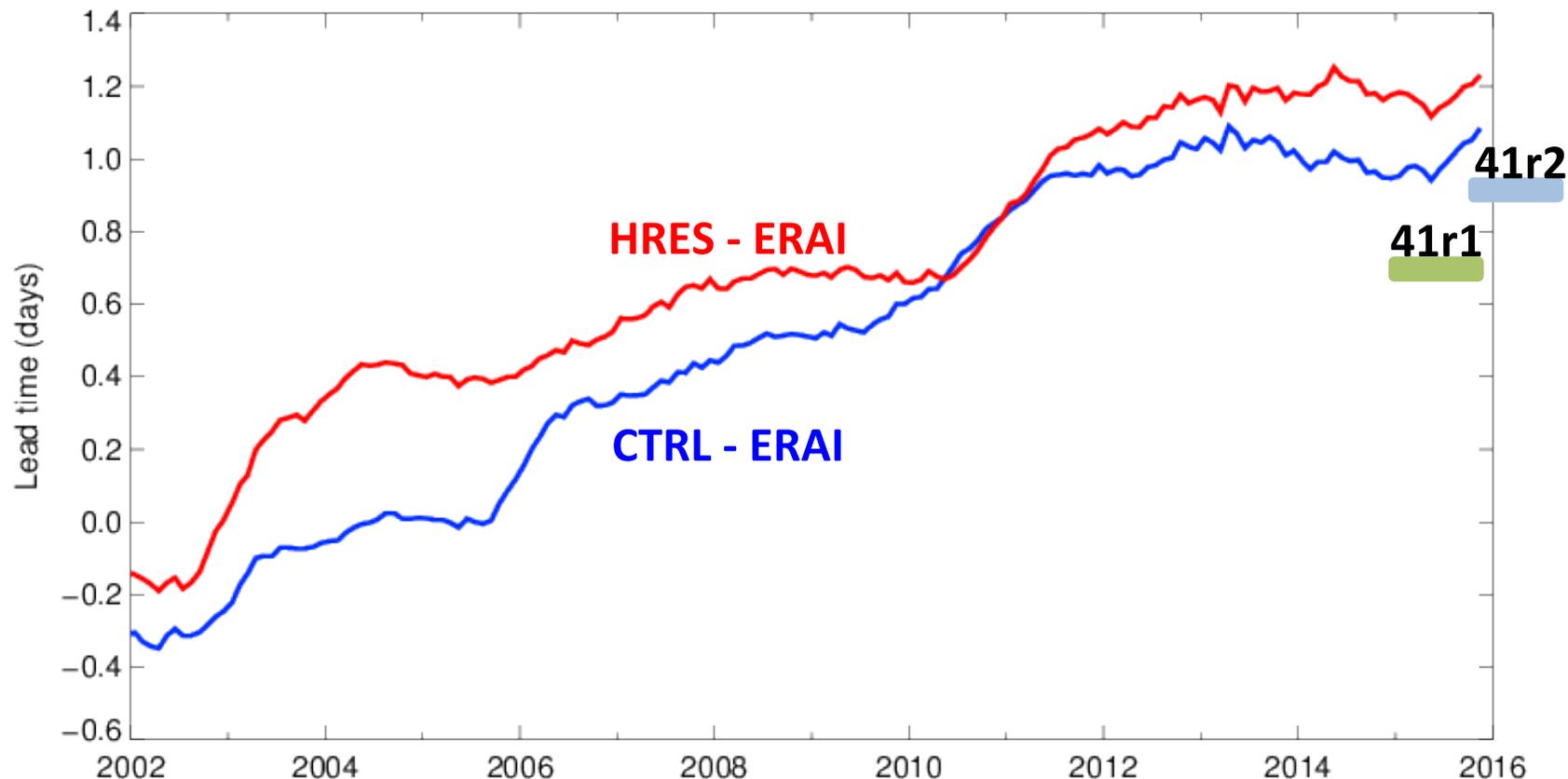
score 12mMA reaches 80%



(From Thomas Haiden)



4. HRES, ENS-CON, ERAI – 24-h precipitation NH

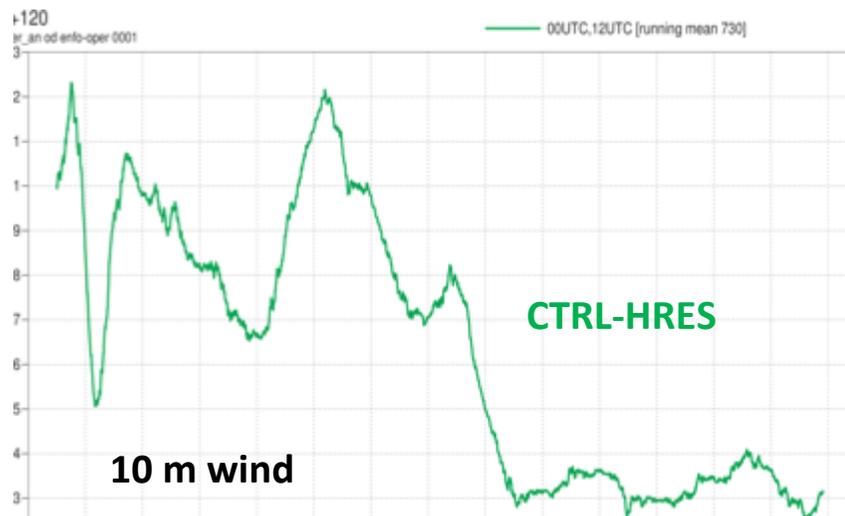
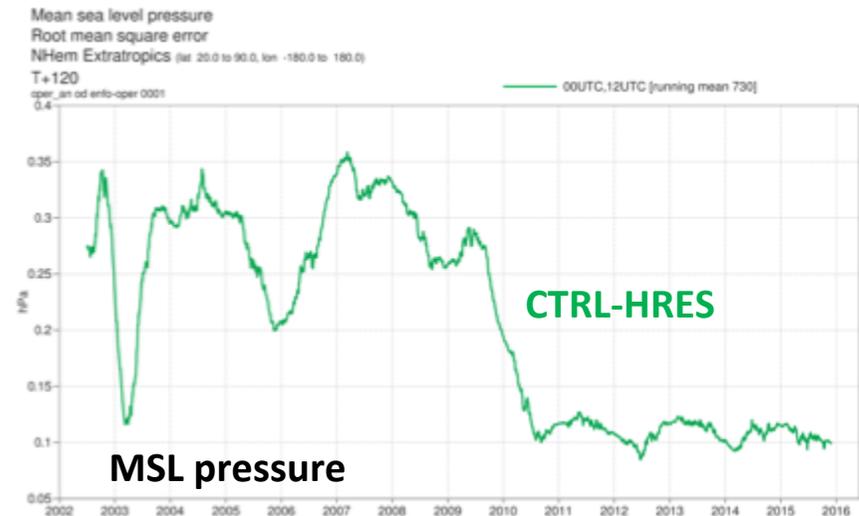
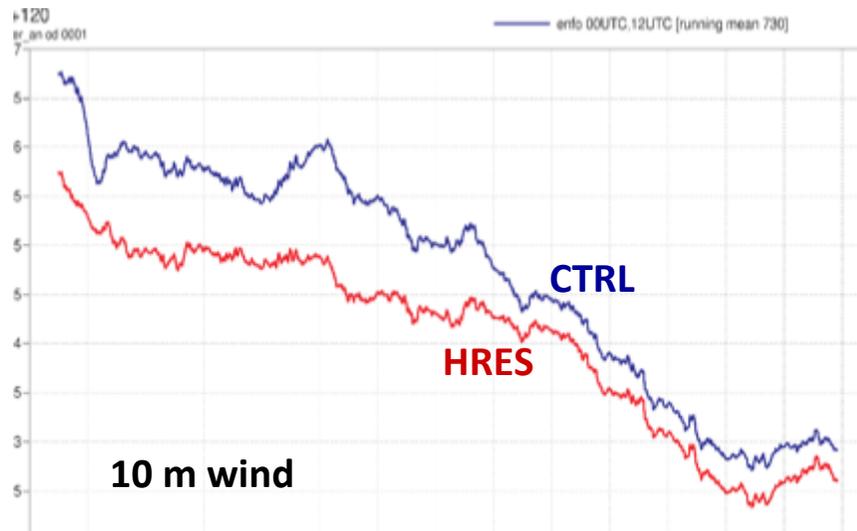


Difference HRES-CTRL: reduced with 41r1, but no strong signal from 41r2 (yet).

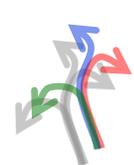
(From Thomas Haiden)



4. HRES and ENS-CON – NH

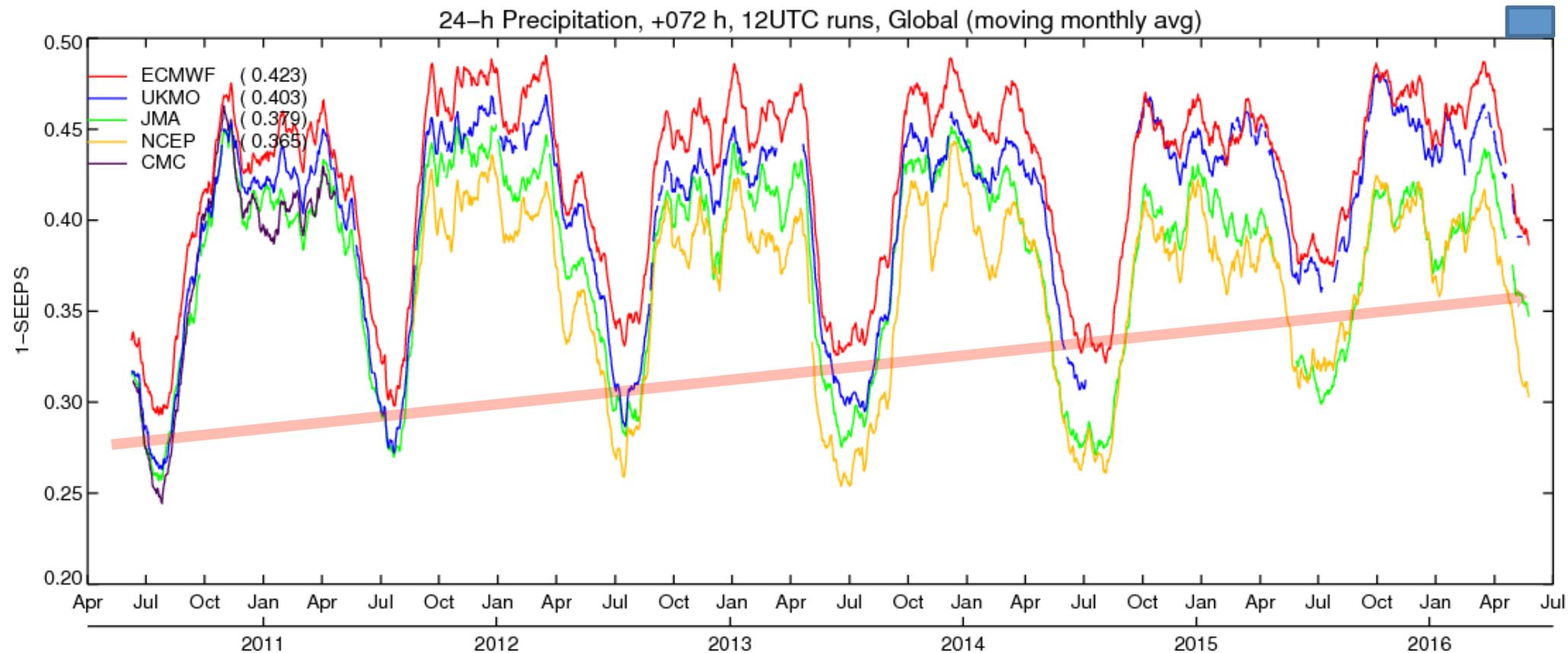


(From Thomas Haiden)



4. High-resolution single precipitation fc: t+72h

The accuracy of single high-resolution 72-h precipitation forecast (verified against observations), measured by the SEEPS score, for ECMWF and UKMO has been slowly improving.

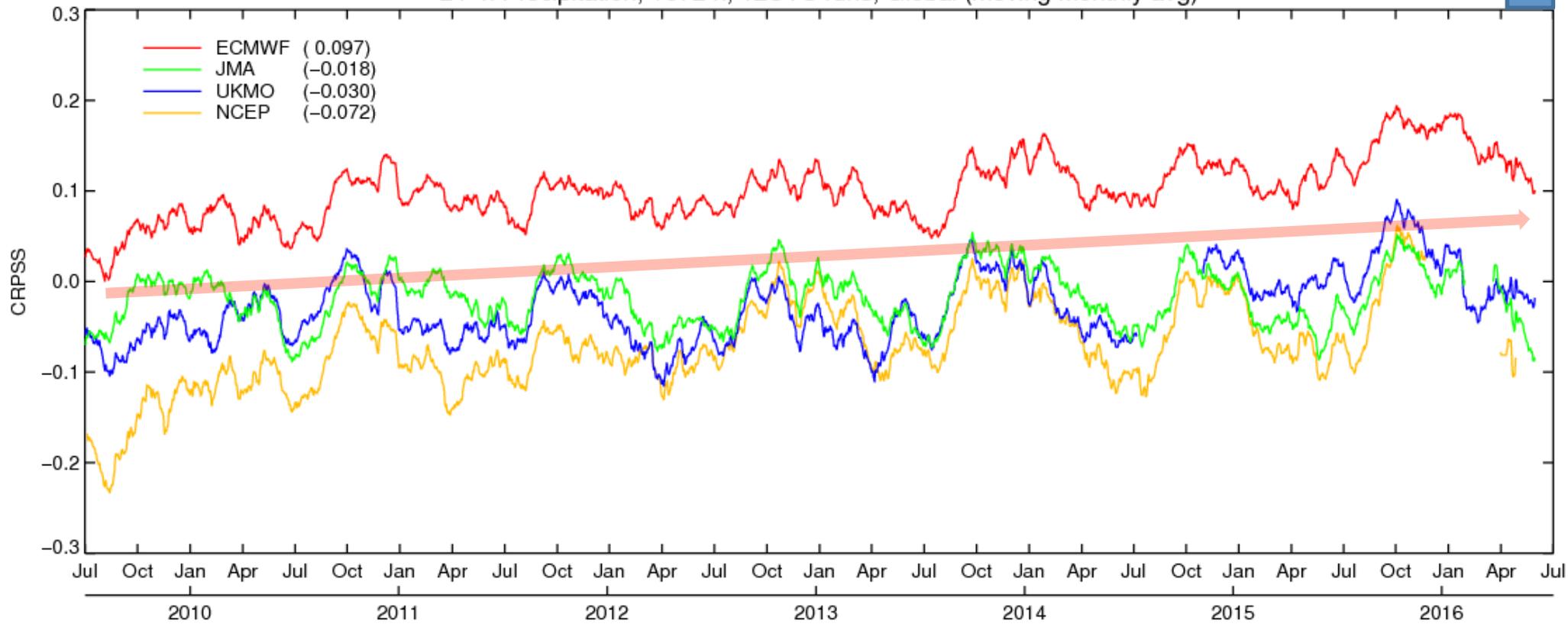




4. Impact of recent upgrade on single high-resolution fc

The accuracy of 72-h probabilistic precipitation forecast (verified against observations), measured by the CRPSS, has also been slowly improving.

24-h Precipitation, +072 h, 12UTC runs, Global (moving monthly avg)



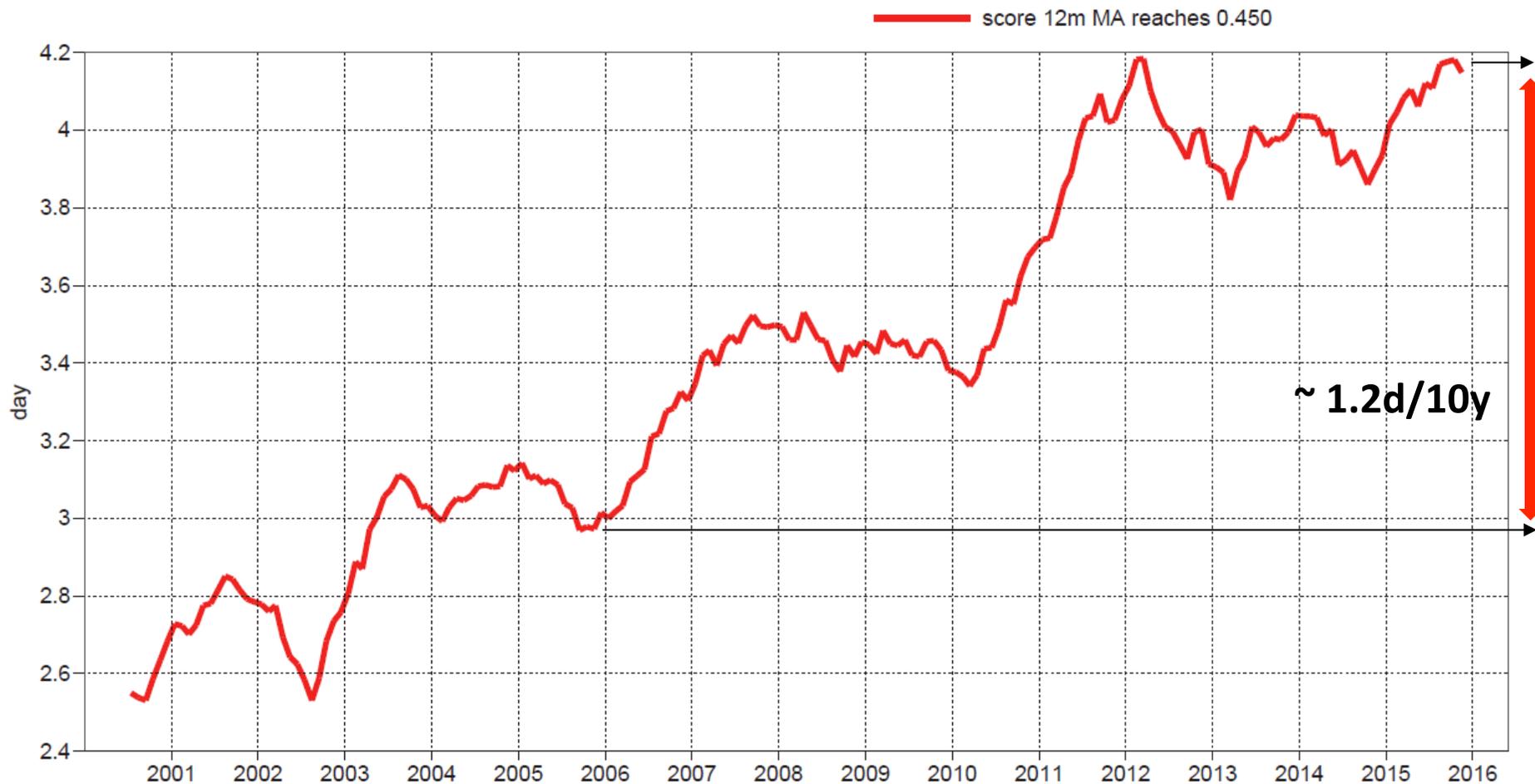


4. ENS CRPSS – 24-h precipitation NH

total precipitation

1-SEEPS

Extratropics (lat -90 to -30.0 and 30.0 to 90, lon -180.0 to 180.0)



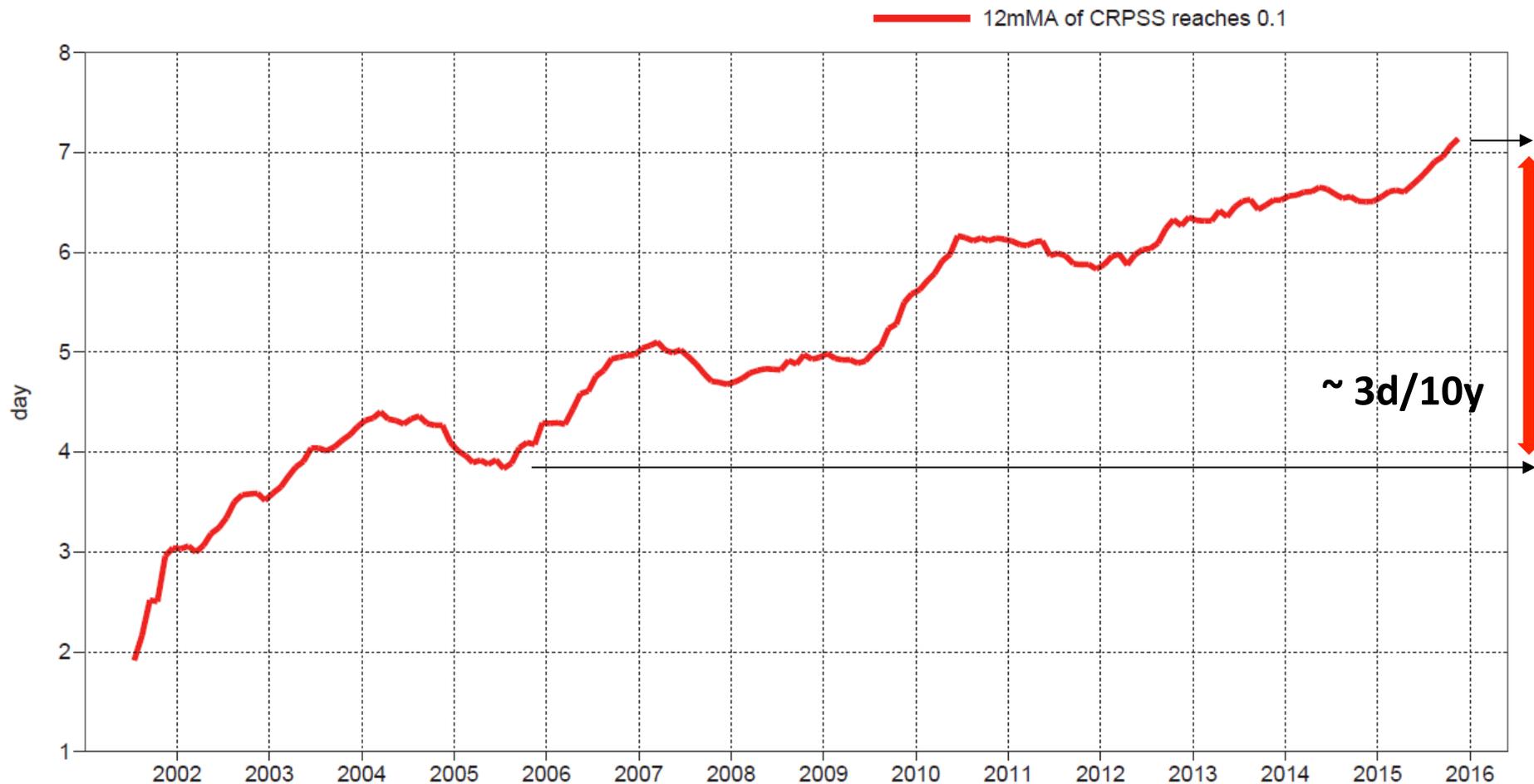


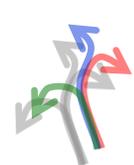
4. ENS CRPSS – 24-h precipitation NH

total precipitation

Continuous ranked probability skill score

Extratropics (lat -90 to -30.0 and 30.0 to 90, lon -180.0 to 180.0)



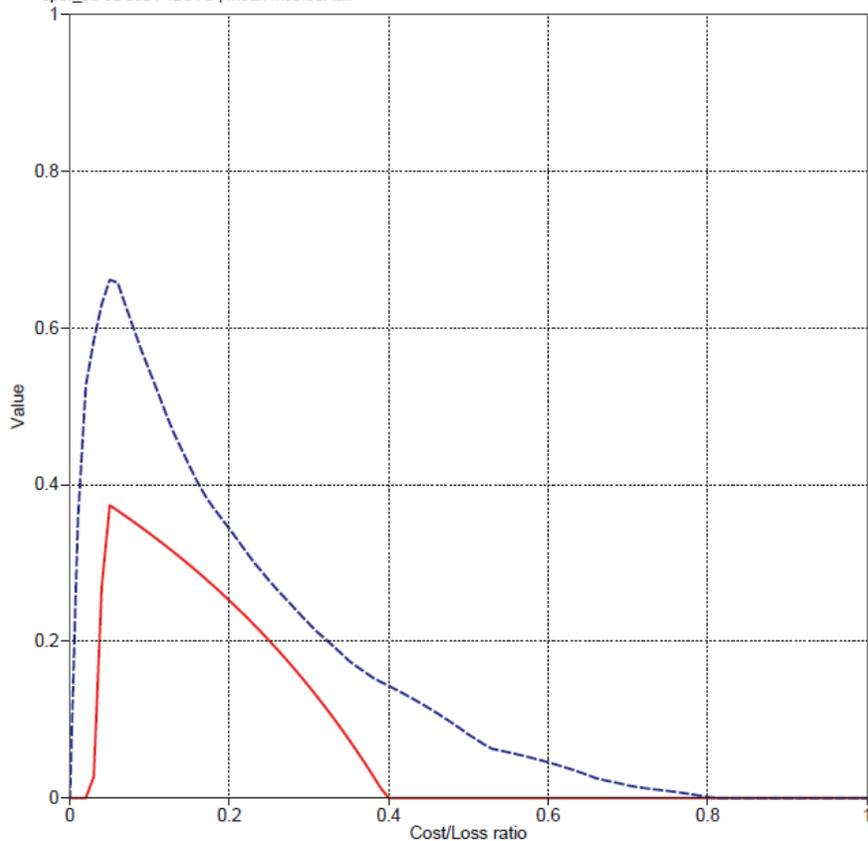


4. The Potential Economic Value: a cost-loss based metric

A cost-loss model can be used to assess the Potential Economic Value of single and probabilistic forecasts. Results indicate that these latter are more valuable.

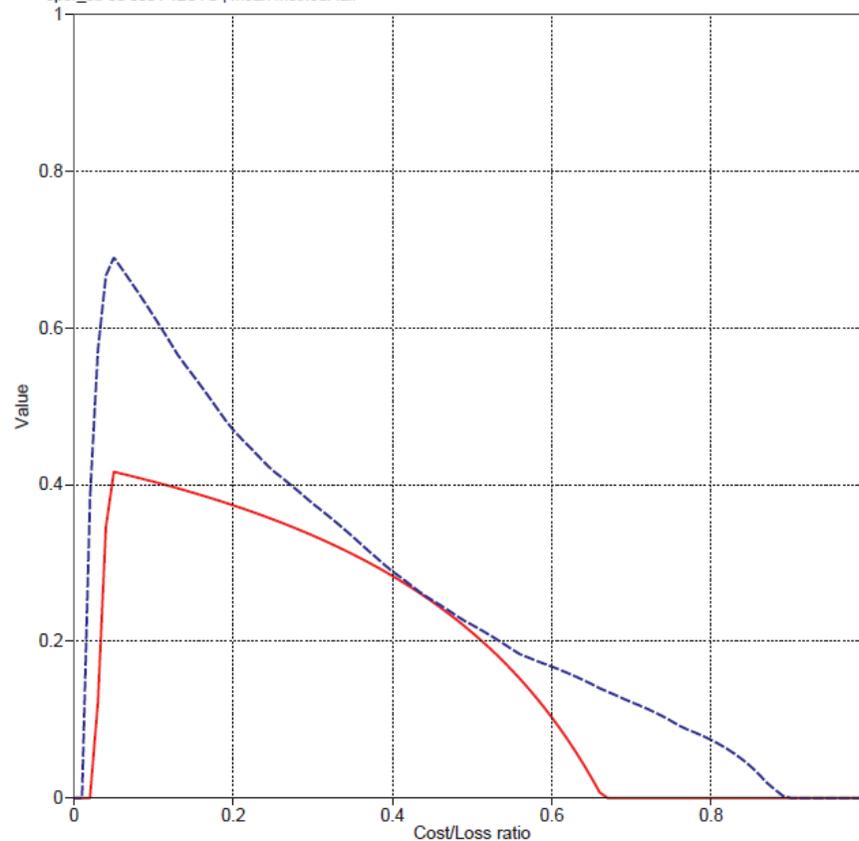
Surface total precipitation
value >10.0

Europe N Africa (lat 25.0 to 70.0, lon -10.0 to 28.0) — ENS
20160301 12UTC to 20160531 12UTC T+96 — HR
oper_ob od 0001 12UTC | Mean method: fair

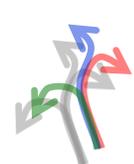


Surface 2 meter temperature
anom>8.0

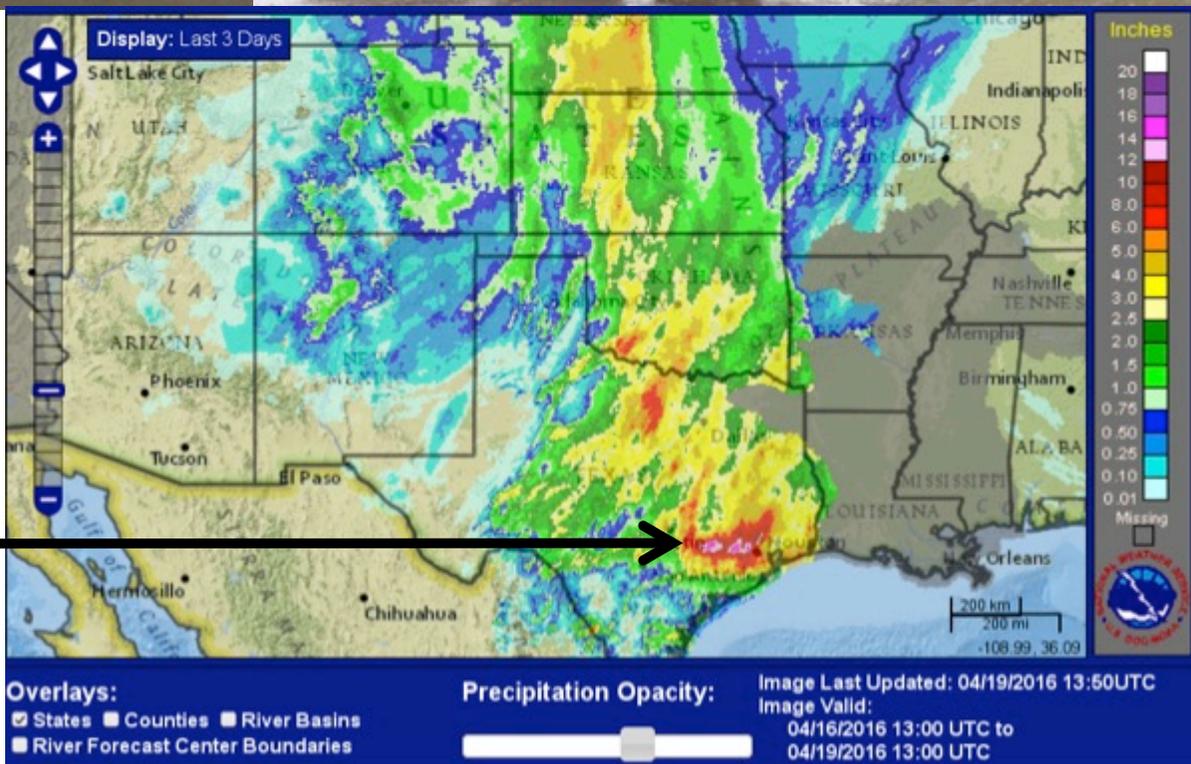
Europe N Africa (lat 25.0 to 70.0, lon -10.0 to 28.0) — ENS
20160301 12UTC to 20160531 12UTC T+96 — HR
oper_ob od 0001 12UTC | Mean method: fair



1. Why do we need ensembles?
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6. Houston, Texas – April 2016: 16@12 to 19@12



Up to 400-450 mm in mainly just over a day

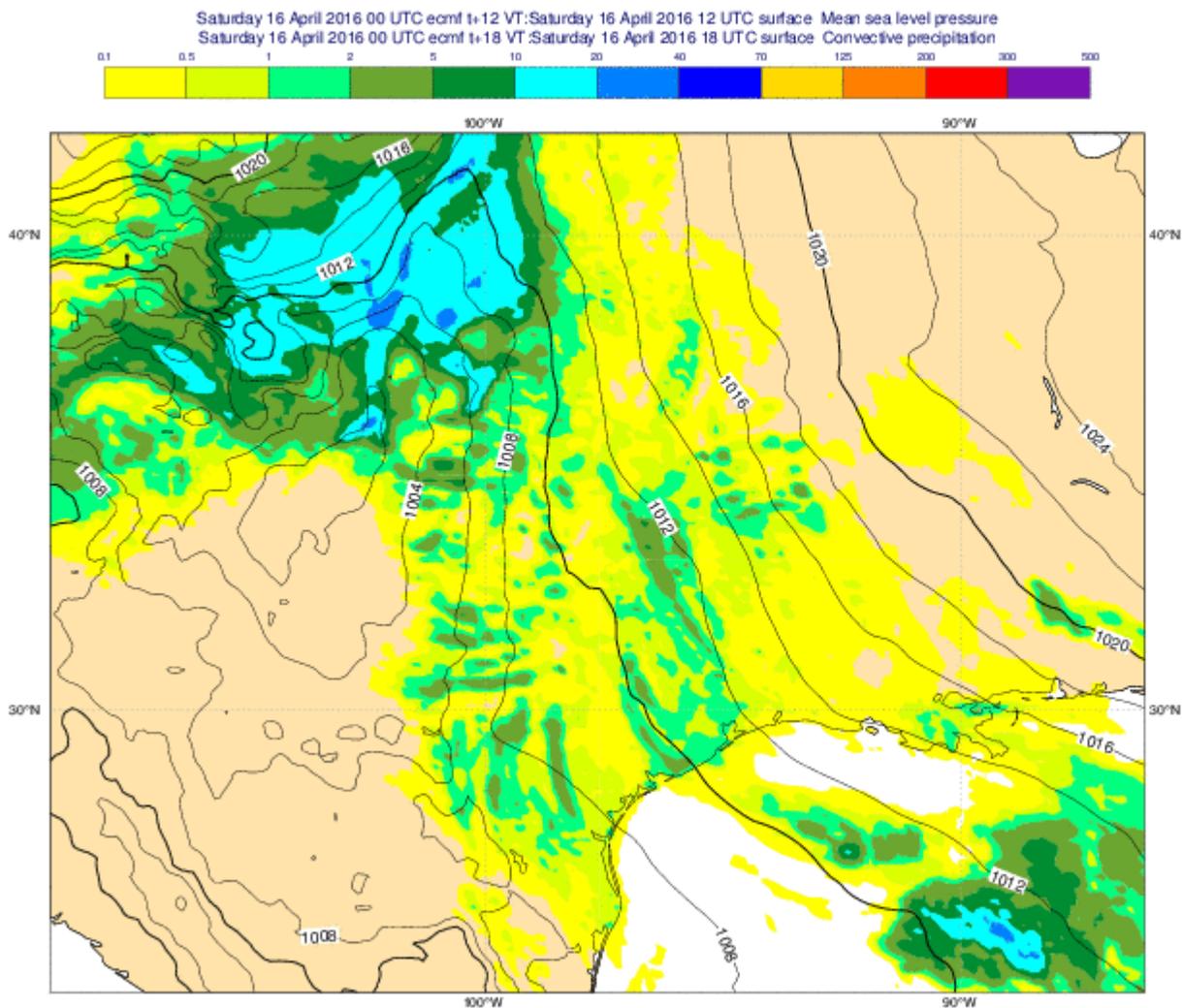
(From Ervin Tsoter)





6. Houston, Texas, 16-19 April 2016

A very slow moving system bringing a continuous supply of warm and moist air from the Gulf.

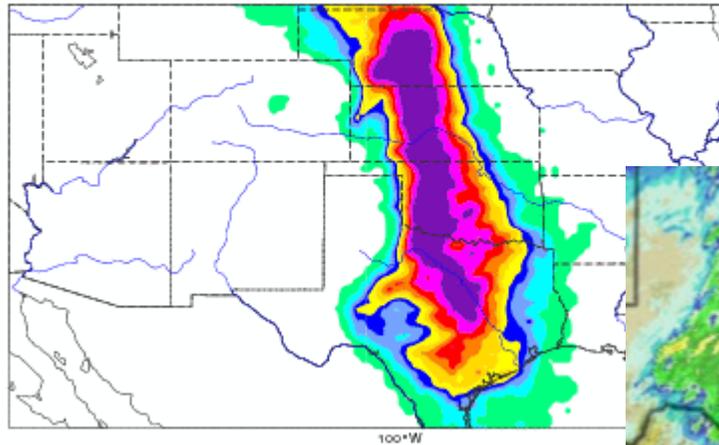


(From Ervin Tsoter)

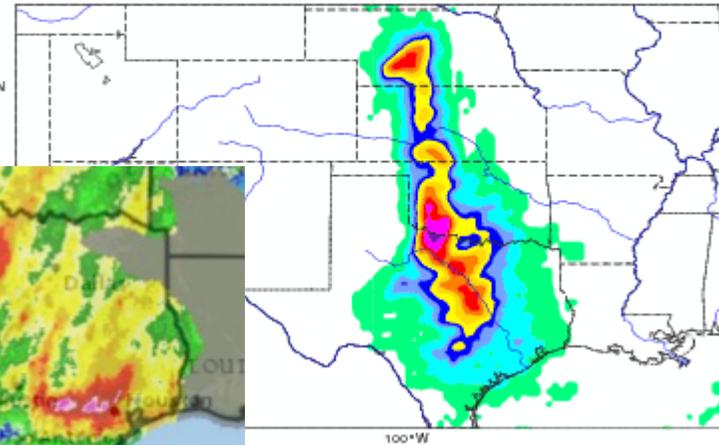


6. +3d to +1d fcs of TP between 16@12 to 19@12

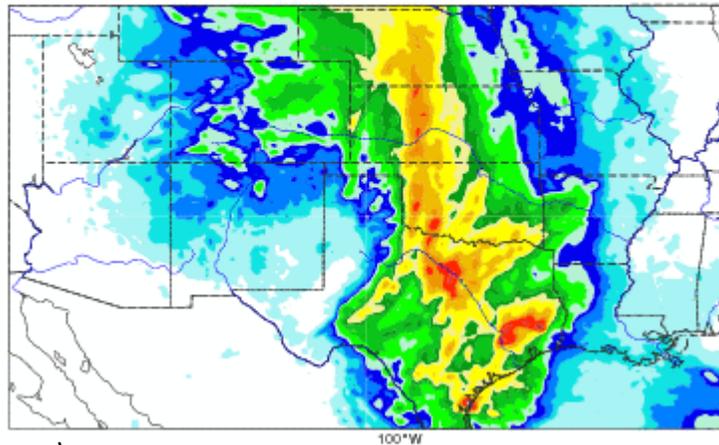
Saturday 16 April 2016 12 UTC ecmf1+72 VT: Tuesday 19 April 2016 12 UTC surface. Total precipitation



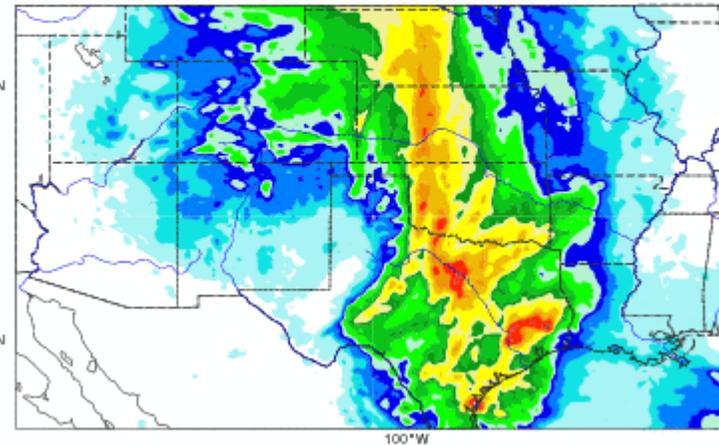
Saturday 16 April 2016 12 UTC ecmf1+72 VT: Tuesday 19 April 2016 12 UTC surface. Total precipitation



Saturday 16 April 2016 12 UTC ecmf1+72 VT: Tuesday 19 April 2016 12 UTC surface. Total precipitation



Saturday 16 April 2016 12 UTC ecmf1+72 VT: Tuesday 19 April 2016 12 UTC surface. Total precipitation



ENSprob > 60mm

ENSprob > 100mm

HRES

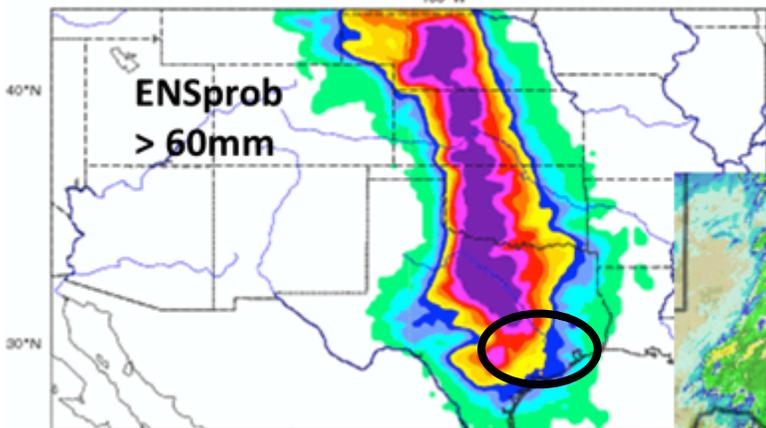
HRES

(From Ervin Tsoter)

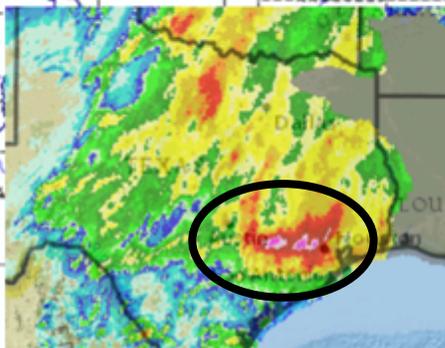
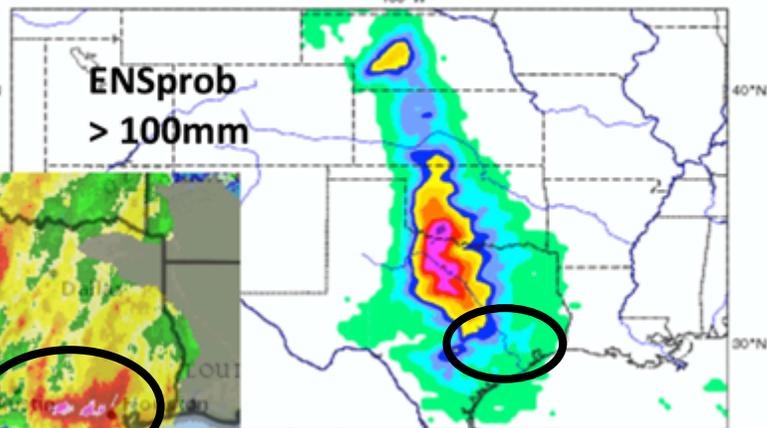


6. +3.5d fcs of TP between 16@12 to 19@12

Saturday 16 April 2016 00 UTC ecmt1+84 VT: Tuesday 19 April 2016 12 UTC surface. Total precipitation

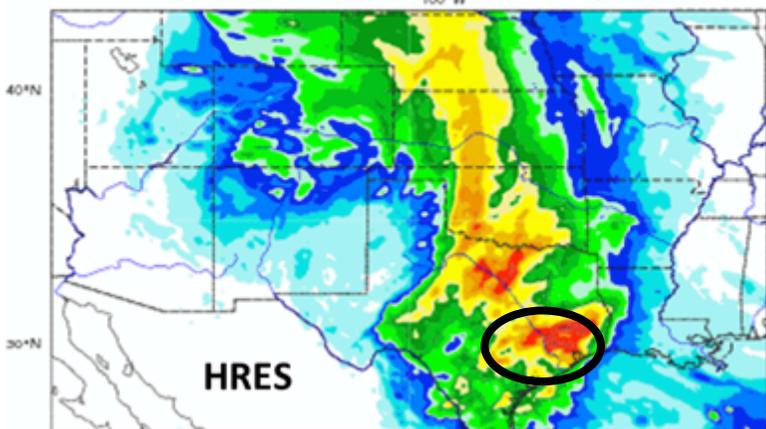


Saturday 16 April 2016 00 UTC ecmt1+84 VT: Tuesday 19 April 2016 12 UTC surface. Total precipitation

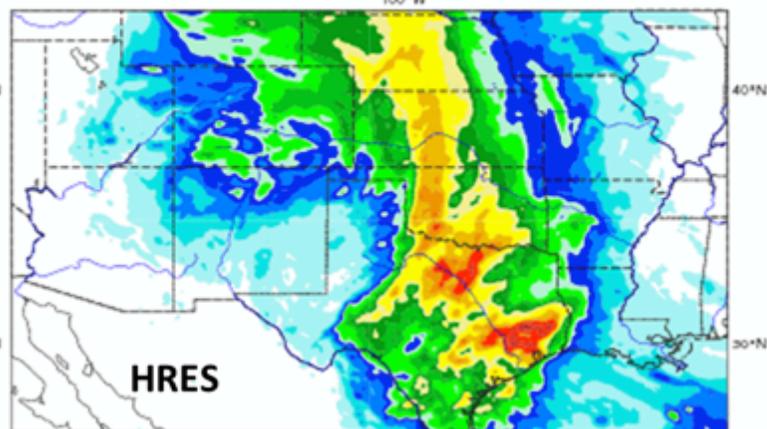


16th 00z T+12-84h

Saturday 16 April 2016 00 UTC ecmt1+84 VT: Tuesday 19 April 2016 12 UTC surface. Total precipitation



Saturday 16 April 2016 00 UTC ecmt1+84 VT: Tuesday 19 April 2016 12 UTC surface. Total precipitation

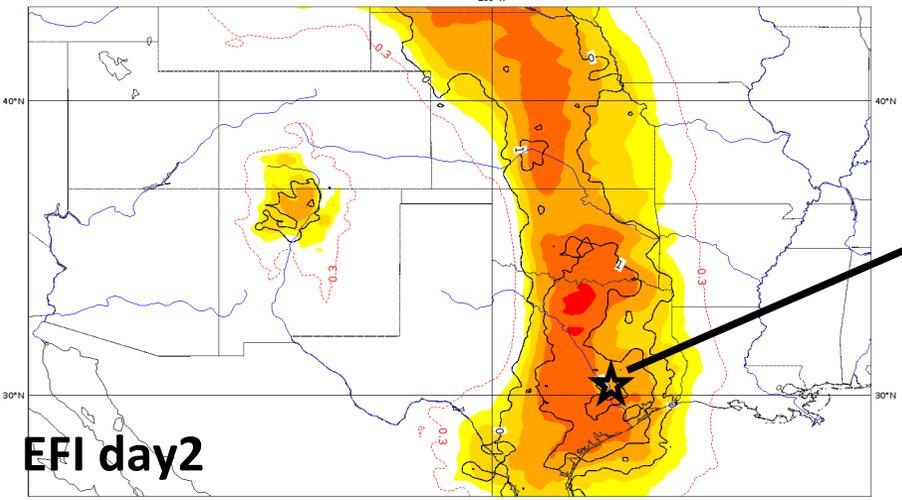


(From Ervin Tsoter)



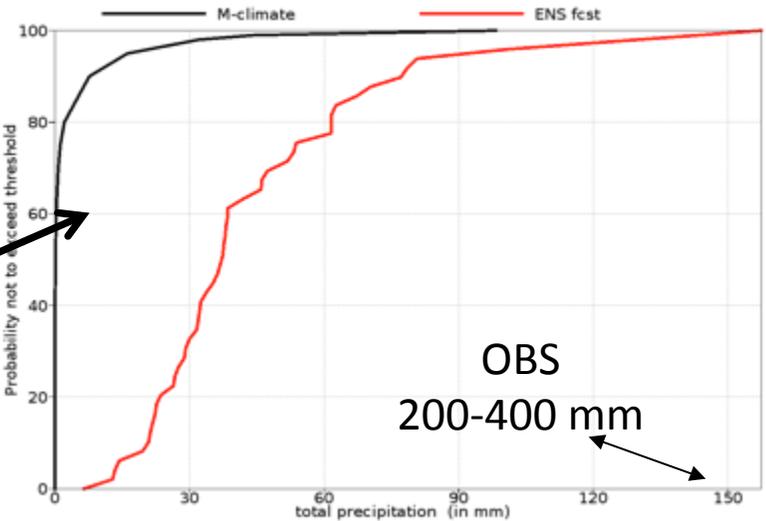
6. +2d and +3d fcs of TP between 16@12 to 19@12

Sun 17 Apr 2016 00UTC @ECMWF VT: Mon 18 Apr 2016 00UTC - Tue 19 Apr 2016 00UTC 24-48h
Extreme forecast index and Shift of Tails (black contours 0,1,5,10,15) for: total precipitation

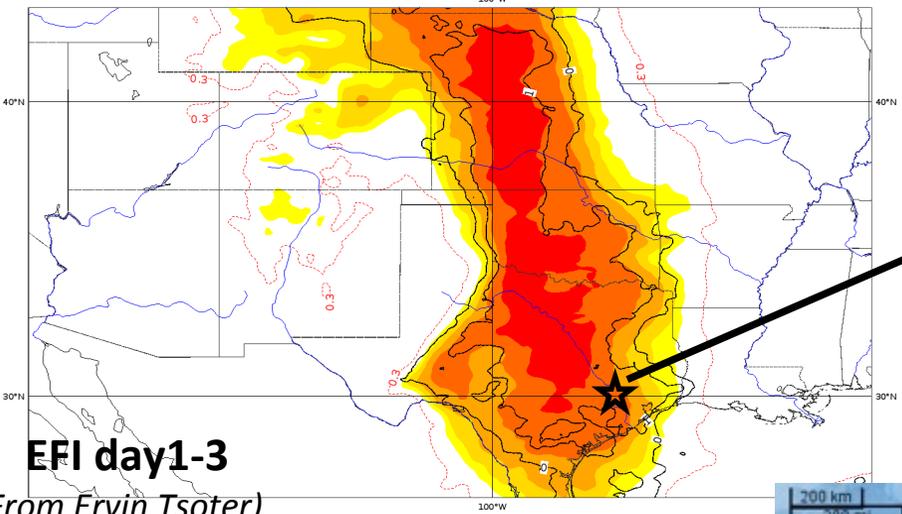


EFI day2

Sunday 17 Apr 2016 00UTC ©ECMWF t+24-48 VT: 18-04-2016 00UTC - 19-04-2016 00UTC
Cumulative Distribution Functions for total precipitation at 30°/-95.8°

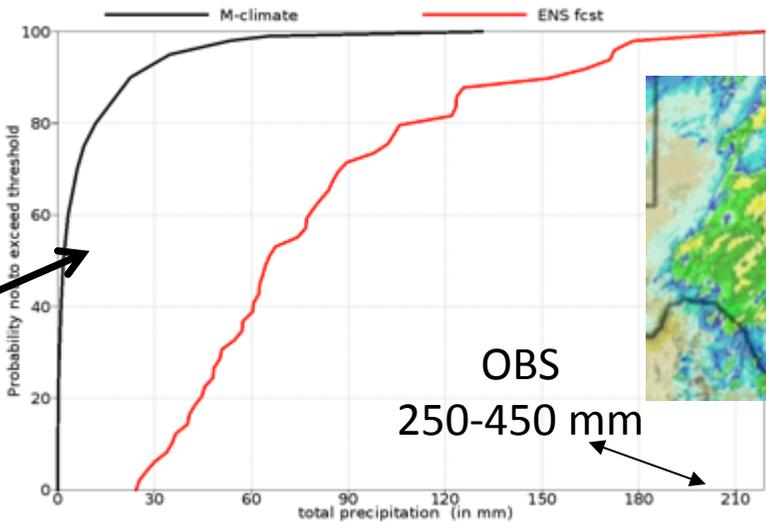


Sat 16 Apr 2016 12UTC @ECMWF VT: Sun 17 Apr 2016 00UTC - Wed 20 Apr 2016 00UTC 12-84h
Extreme forecast index and Shift of Tails (black contours 0,1,5,10,15) for: total precipitation



EFI day1-3

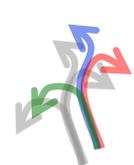
Saturday 16 Apr 2016 12UTC ©ECMWF t+12-84 VT: 17-04-2016 00UTC - 20-04-2016 00UTC
Cumulative Distribution Functions for total precipitation at 30°/-95.8°



(From Ervin Tsoter)

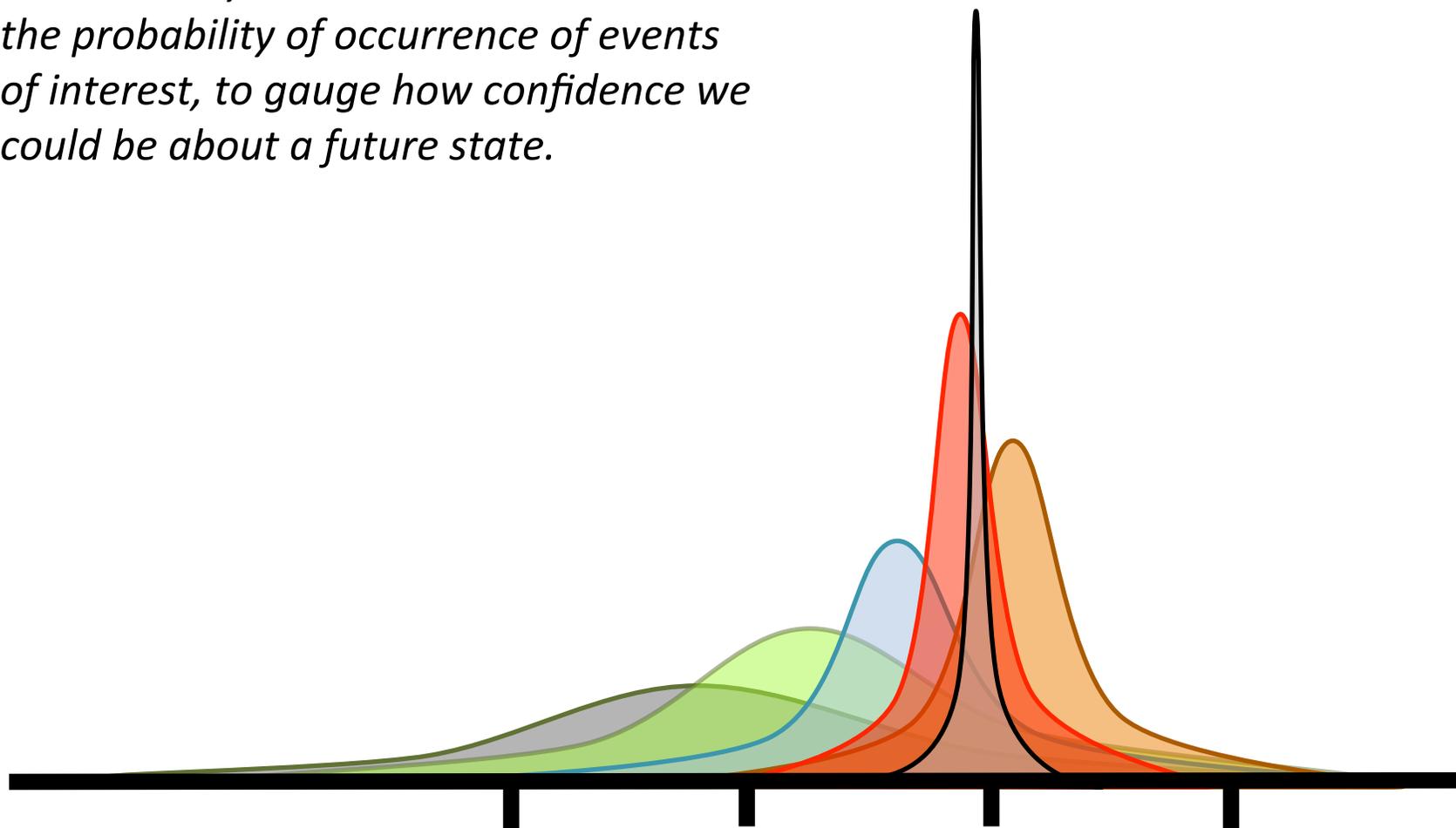


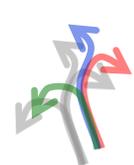
1. Why do we need ensembles?
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6. Ensembles are the cornerstone of our future

Because they can be used to estimate the probability of occurrence of events of interest, to gauge how confidence we could be about a future state.





6. How can we keep improving the ensembles?

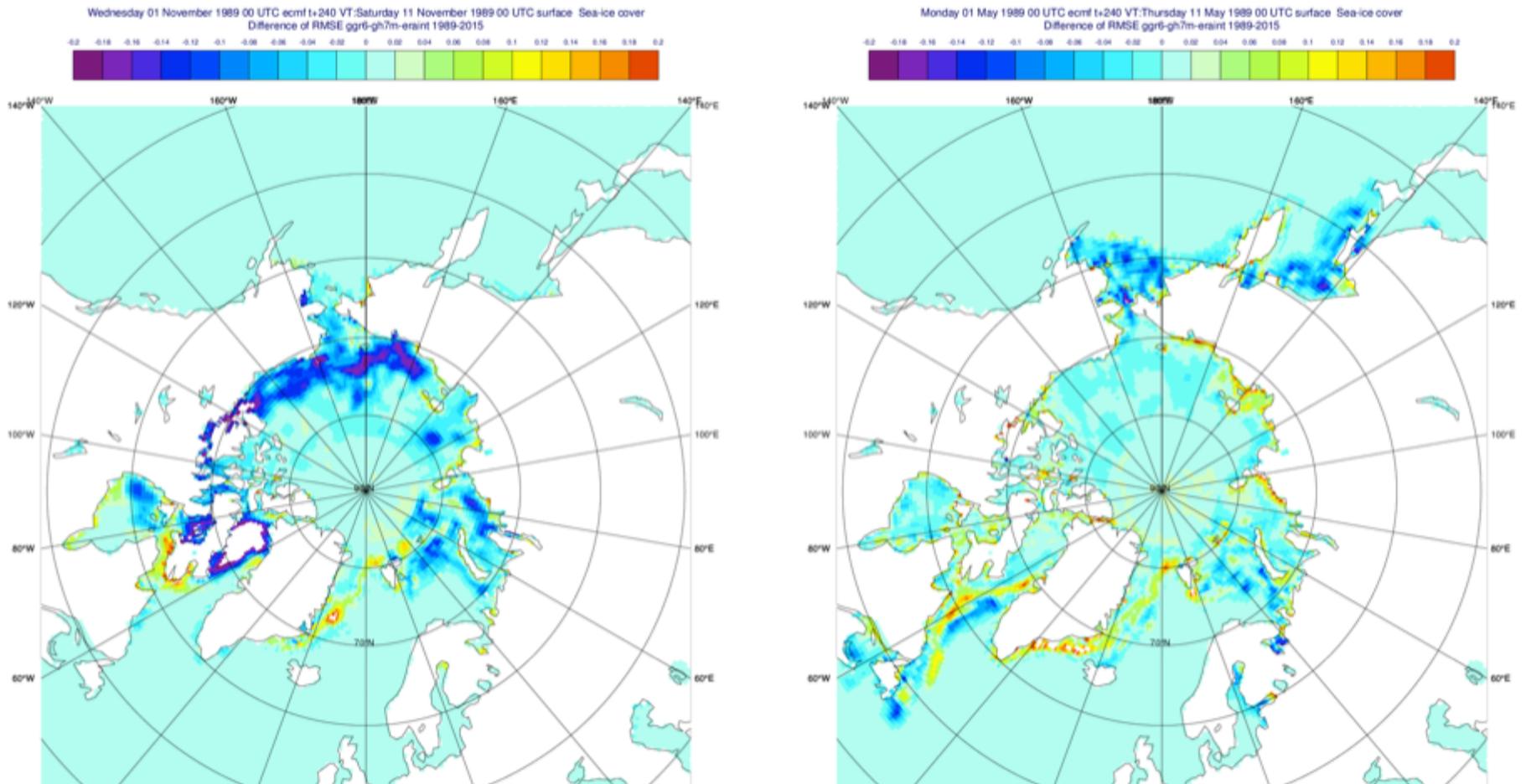
Work is progressing on many areas to further improve the ECMWF ensembles:

1. **Modelling** (including model uncertainty simulation): improve all model components (land, atmosphere and ocean) and increase resolution; upgrade the stochastic schemes that simulate model uncertainty
2. **Initial Conditions** estimation: integrate further the analysis and forecast ensembles (EDA/ORR and ENS) and re-assess the potential benefit of starting ENS directly from EDA analyses; assess the impact of using a more strongly coupled DA
3. **Predictability**: identify sources of predictability, and ways to extract predictable signals for the ensemble PDF
4. **Ensemble methods**: assess whether different ensemble configurations (IC/model unc, membership, truncation, refc suite, ...) could lead to more accurate and reliable PDF fcs



6. Q4-16: ENS with higher-res ocean (0.25°-z75) & sea-ice

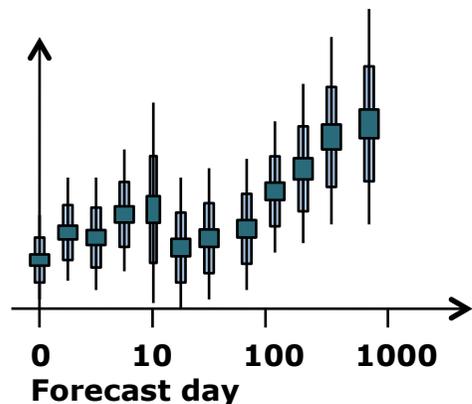
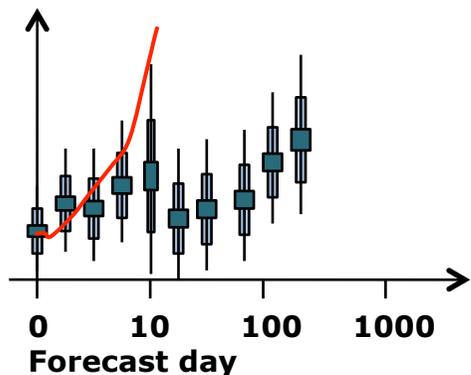
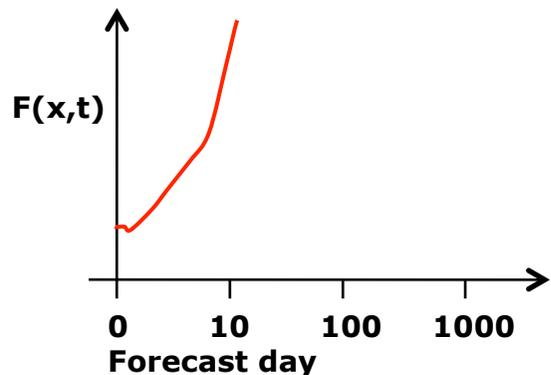
The next model cycle will include a higher-resolution ocean (0.25° degrees with 75 layers) with dynamical sea-ice in ENS, with ICs from ORAS5 ensemble of analyses.



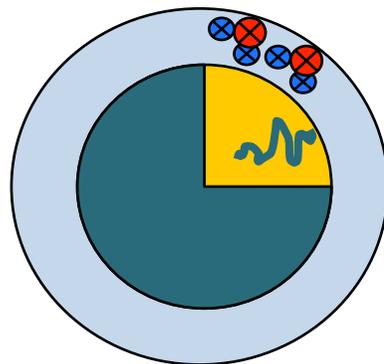
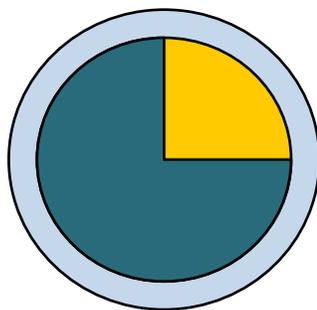
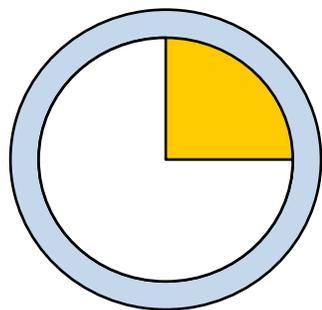
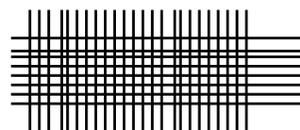
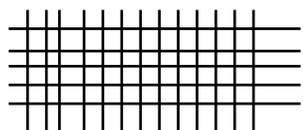
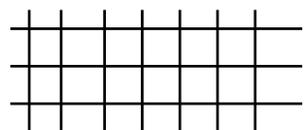


6. 10y strategy: ensemble of Earth-system model and DA

1975-1990 → 1990-2010 → 2030



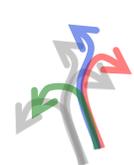
We aim to include all relevant Earth-system processes in our analyses and forecast ensembles.



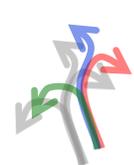


6. So that we can further extend the fc skill horizon





Thank you very much for your attention ...



ECMWF Annual Seminar 5-8 Sept 2016: Earth-system ...

Annual Seminar 2016

Earth system modelling for seamless prediction

5-8 September

On which processes should we focus to further improve atmospheric predictive skill?

The main themes of the 2016 ECMWF Annual Seminar are what Earth system processes are needed, and what level of complexity is required to further extend atmospheric predictive skill. These themes will be discussed taking into account the ECMWF strategy for the next 10 years, which sees Earth system modelling and assimilation as the way to improve further skill in the 1-day to 1-year forecast range covered by the ECMWF forecasts. The key questions that speakers will tackle while presenting progress and challenges in different areas of Earth system modelling are: if we want to improve the skill of weather predictions, on which of the already-simulated processes should we focus? If we introduce new processes, how much complexity is actually required?

