Ensemble forecasting

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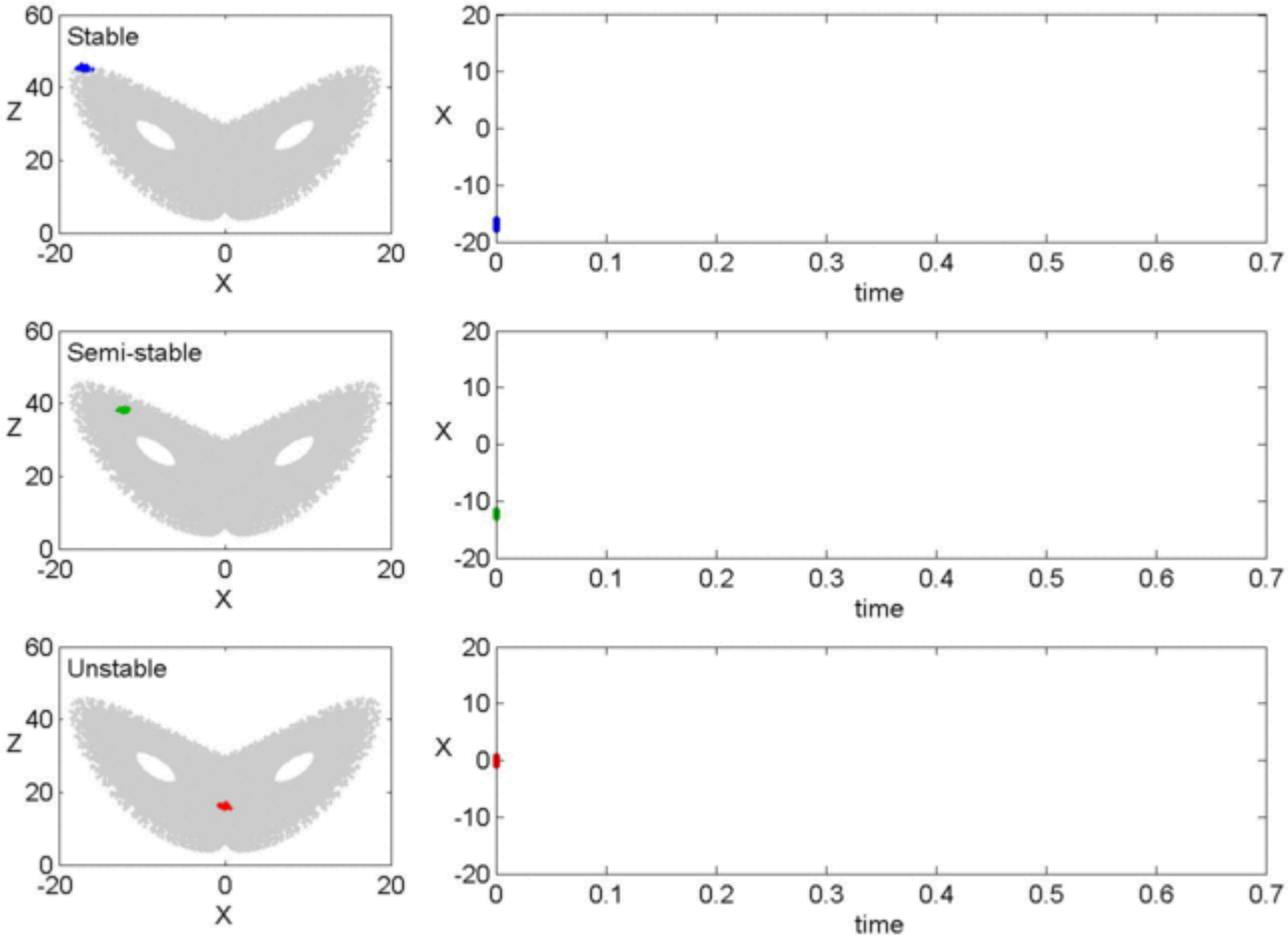
Outline

- Introduction
  - Why do forecast go wrong?
  - Observations, model, “chaos”
- The ECMWF ensemble
  - How does the ENS represent uncertainties?
  - Configuration of the ENS
- ENS products
  - Very short overview – much more in rest of course
- Use of ENS
  - Probabilities and decision support

Why are forecasts sometimes wrong?

- Initial condition uncertainties
  - Lack of observations
  - Observation error
  - Errors in the data assimilation
- Model uncertainties
  - Limited resolution
  - Parameterisation of physical processes
- The atmosphere is chaotic
  - small uncertainties grow to large errors (unstable flow)
  - small scale errors will affect the large scale (non-linear dynamics)
  - error-growth is flow dependant
- Even very good analyses and forecast models are prone to errors

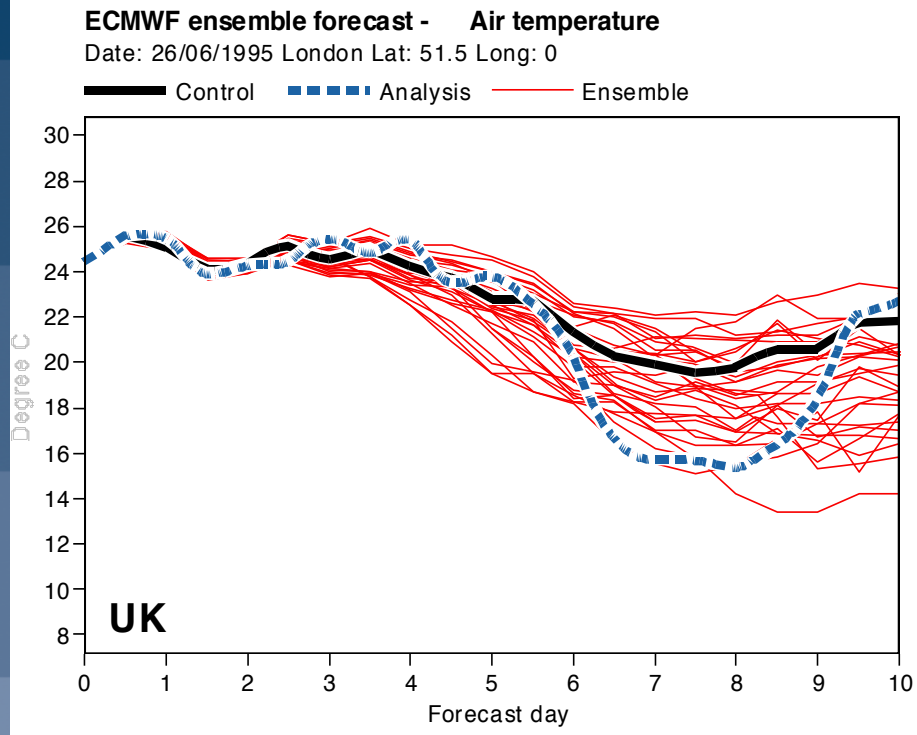
Chaos - the Lorenz attractor



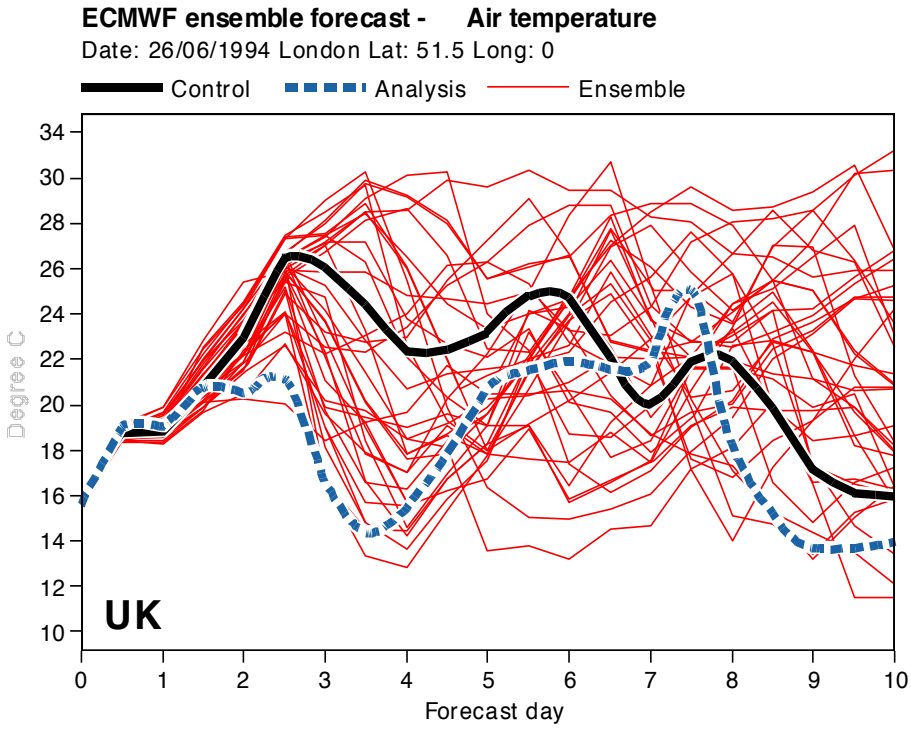
Tim Palmer, Oxford University

Flow dependence of forecast errors

26th June 1995



26th June 1994



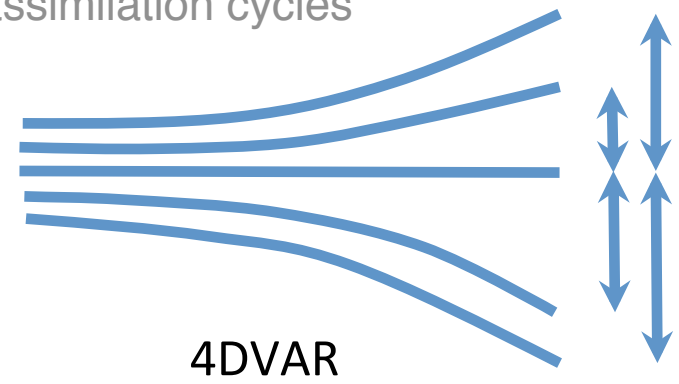
If the forecasts are coherent (small spread) the atmosphere is in a more predictable state than if the forecasts diverge (large spread)

What is an ensemble?

- A set of forecasts run from slightly different initial conditions to account for initial uncertainties
  - At ECMWF perturbations are generated using singular vectors and an ensemble of data assimilations
- The forecast model also contains approximations that can affect the forecast evolution
  - Model uncertainties are represented using "stochastic physics"
- The ensemble of forecasts provides a range of future scenarios consistent with our knowledge of the initial state and model capability
  - Provides explicit indication of uncertainty in today's forecast

Initial uncertainties

- Combination of 2 types of perturbations
- Ensemble of data assimilations (EDA)
  - Randomly perturbed observations and SST fields
  - Run 25 independent data assimilation cycles



- Singular vectors: perturbations that grow quickly over the first 48 hours of the forecast

- Best approach given limited available computer resources

Ensemble of data assimilations (EDA)

- EDA (initial EPS perturbations since June 2010)
  - Control + 25 ensemble members using 4D-Var assimilations
  - T399 outer loop
  - T95/T159 inner loop (reduced number of iterations)
  - Model error: Stochastically Perturbed Parametrization Tendencies
  - Randomly perturbed observations and SST fields
- EDA perturbations are not sufficient by themselves
  - Additional initial perturbations based on “singular vectors”

Initial uncertainties – singular vectors

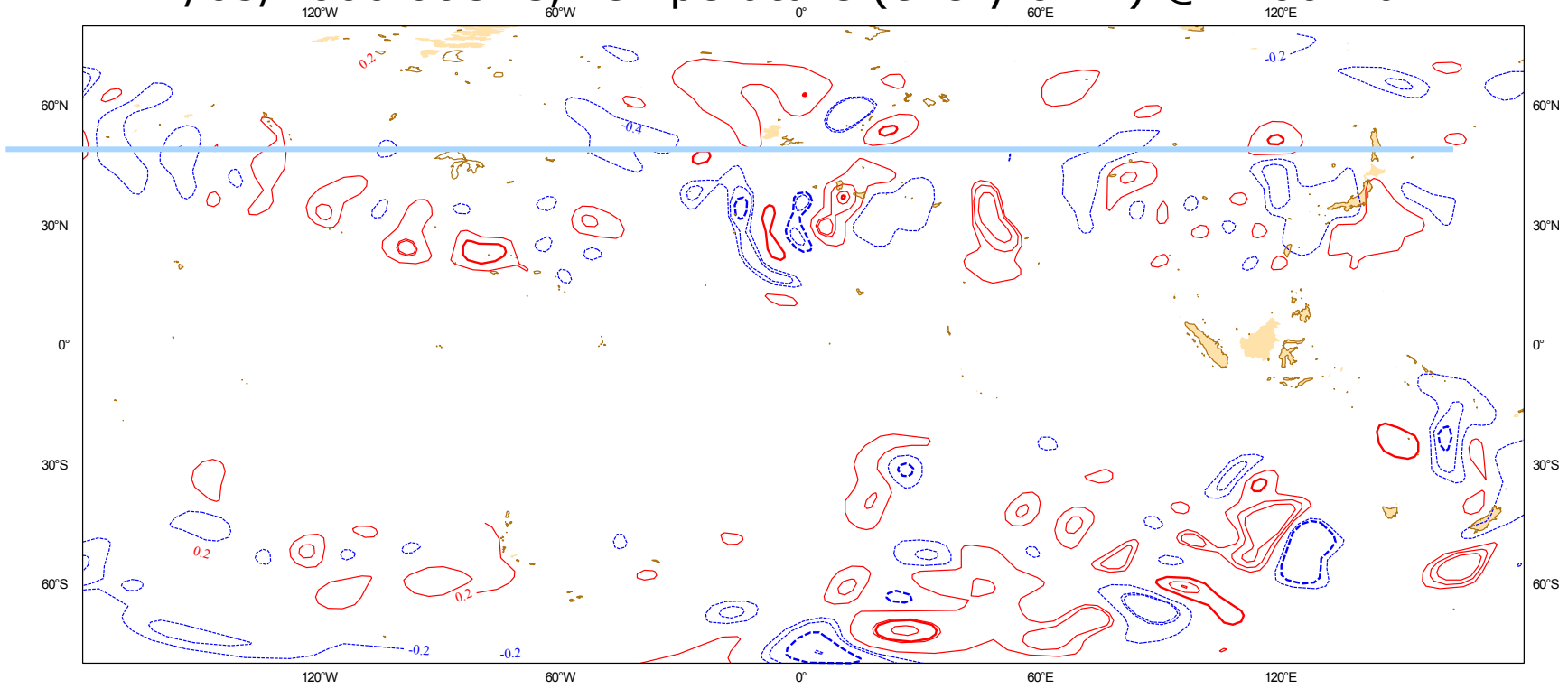
- The number of ensemble members is limited by available computer resources. How can we produce suitable perturbations?
- Look for perturbations that will grow fastest
- Singular vectors: perturbations that produce the greatest (linear) difference (total energy) over a fixed time interval (48 hours)
  - Uses the same tangent-linear and adjoint models as used for the 4D-Var analysis
- 50 perturbations generated by random (Gaussian) sampling from 50 singular vectors. Amplitude tuned to match error

Initial uncertainties – singular vectors

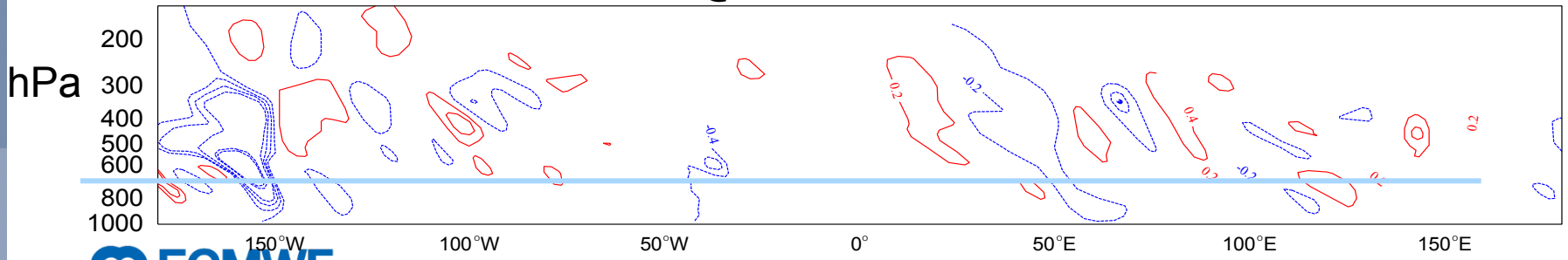
- Resolution: T42L62; optimisation interval: 48 h
- Extra-tropics
  - 50 SVs for N.-Hem. (30–90N) + 50 for S.-Hem.(30–90S).
  - Simple tangent-linear model (vert. diffusion and surf. friction only)
  - perturbations generated by random (Gaussian) sampling from 50 singular vectors. Amplitude tuned to match error
  - Perturbations from ensemble of data assimilations also used
- Tropical cyclones:
  - Up to 6 areas centred on existing tropical cyclones
  - 5 singular vectors per area, Gaussian (random) sampling
  - “moist SVs” – TL includes diabatic processes (large-scale condensation, convection, radiation, gravity-wave drag, vert. diff. and surface friction)

Example of initial perturbations

21/03/2006 00UTC, Temperature (every 0.2K) @~700hPa



@ 50°N



ENS initial perturbations

- SV- and EDA-based perturbations have different characteristics:
  - EDA-based perturbations are less localized than SV-based perturbations and have a smaller scale. They have a larger amplitude over the tropics. EDA-perturbations are more barotropic than SV-based perturbations, and grow less rapidly.
  - At initial time, SV-based perturbations have a larger amplitude in potential than kinetic energy, while EDA-based perturbations have a similar amplitude in potential and kinetic energy

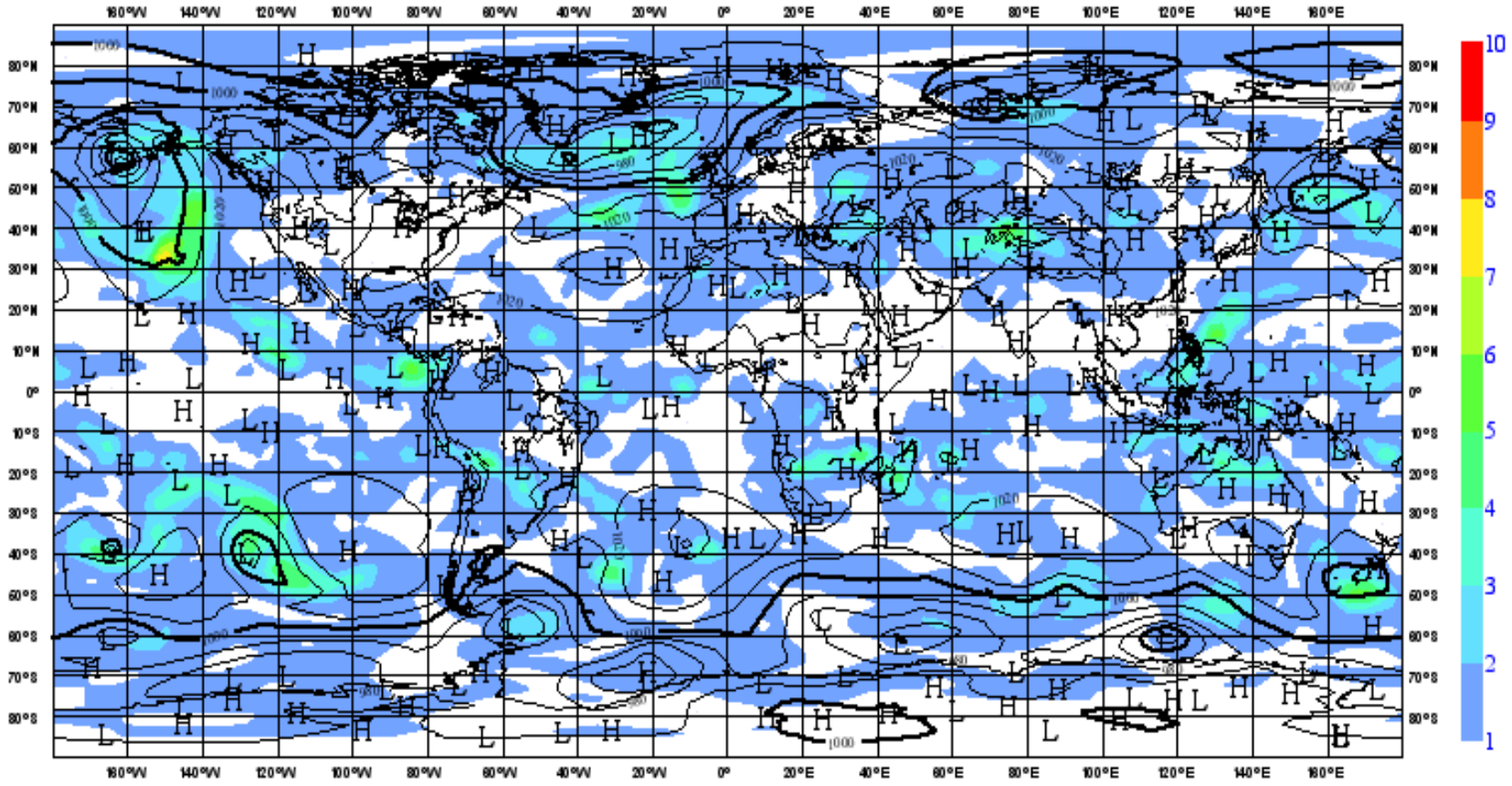
- Since June 2010 SV- and EDA-based perturbations are used together to construct the initial perturbations for the EPS

- The perturbations are constructed so that all perturbed members are equally likely

- All perturbations are flow-dependent: they are different from day to day

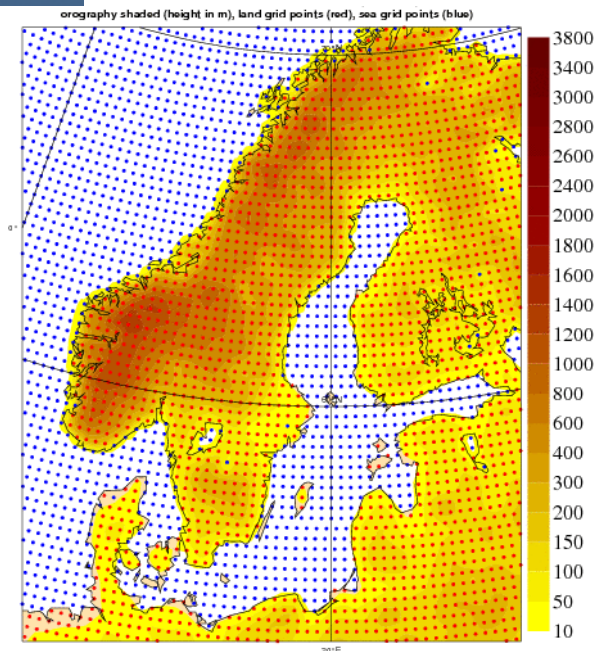
Ensembles of Data Assimilation (EDA)

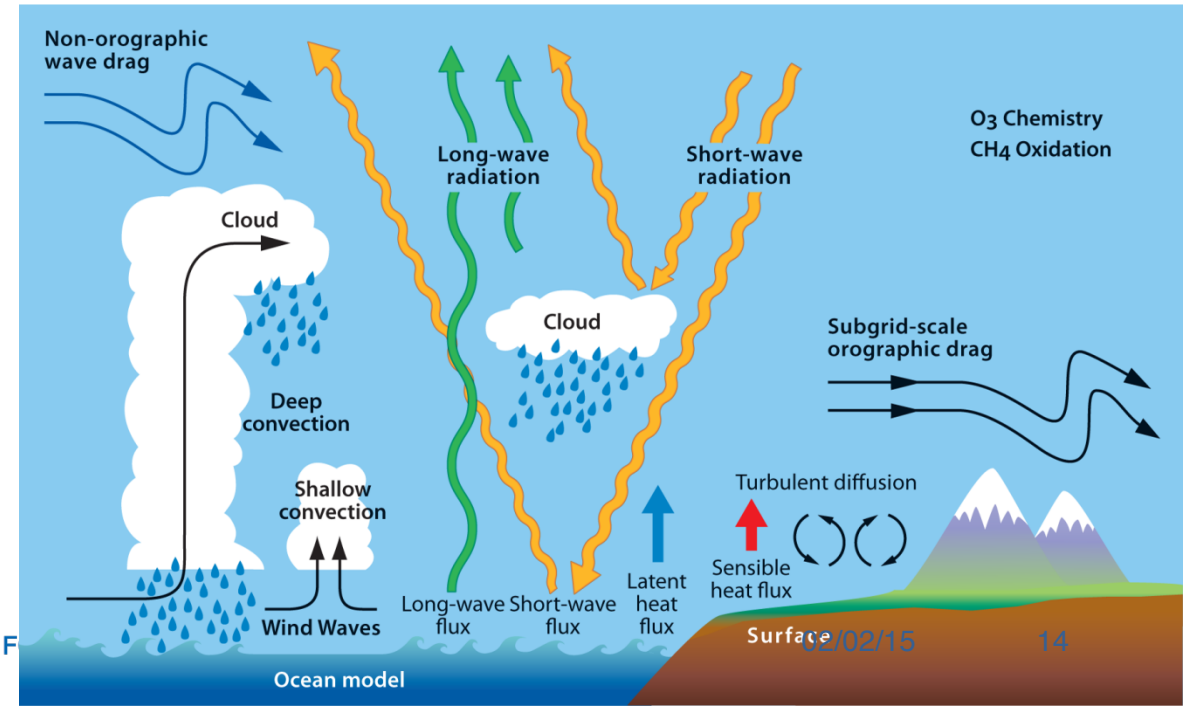
The ensemble spread is flow-dependent but noisy. A filter is applied to remove it. This plot shows the EDA std in terms of vorticity at 500 hPa, +9h after filtering.



Model uncertainties – stochastic physics

- Parametrization – represent effects of unresolved (or partly resolved) processes on the resolved model state
- Statistical ensemble of sub-grid scale processes within a grid box; in equilibrium with grid-box mean flow
- Stochastic physics represents statistical uncertainty
  - allows for energy transfer from sub-grid scale to resolved flow, non-local effects





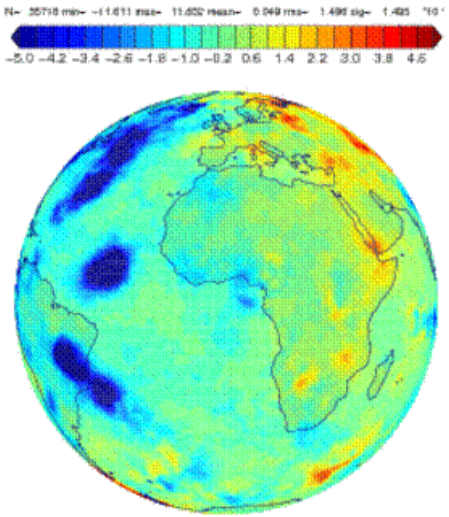
Stochastically Perturbed Parametrization Tendencies (SPPT)

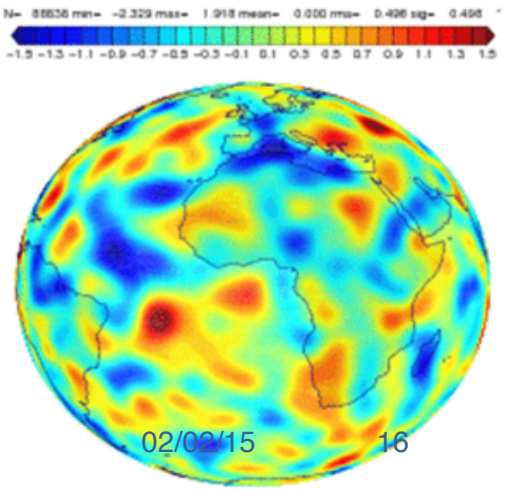
Buizza et al 1999	Revised scheme (35r3)
$\Delta X_p = (1 + r_X)\,\Delta X_c$	$\Delta X_p = (1 + \mu r)\,\Delta X_c$
Random numbers r_X constant in 10° by 10° lat/lon boxes, and for 6 model time steps (3h in T399)	**Random pattern r based on multiple independent AR(1) processes in spectral space, with de-correlation scales 500 km and 6 h**
Uniform distribution between −0.5 and +0.5	**Gaussian distribution with stdev 0.5 (limited to ±3stdev)**
Independent random numbers r_X for X=T, q, u, v	**Same random number r for X=T, q, u, v**
Perturbations in entire column	**No perturbations in lowest 300 m and above 50 hPa ($0 \leq \mu \leq 1$)**

Model uncertainties – stochastic physics

- Stochastically Perturbed Parametrization Tendencies (SPPT)
  - Random pattern of perturbation to model fields
  - Initial scheme introduced 1999, revised 2009 (cycle 35r3)

- Spectral stochastic backscatter scheme (SPBS)
  - A fraction of the dissipated energy is backscattered upscale and acts as streamfunction forcing for the resolved-scale flow
  - Introduced in addition to SPPT in November 2010 (cycle 36r4)





ECMWF medium-range forecasts

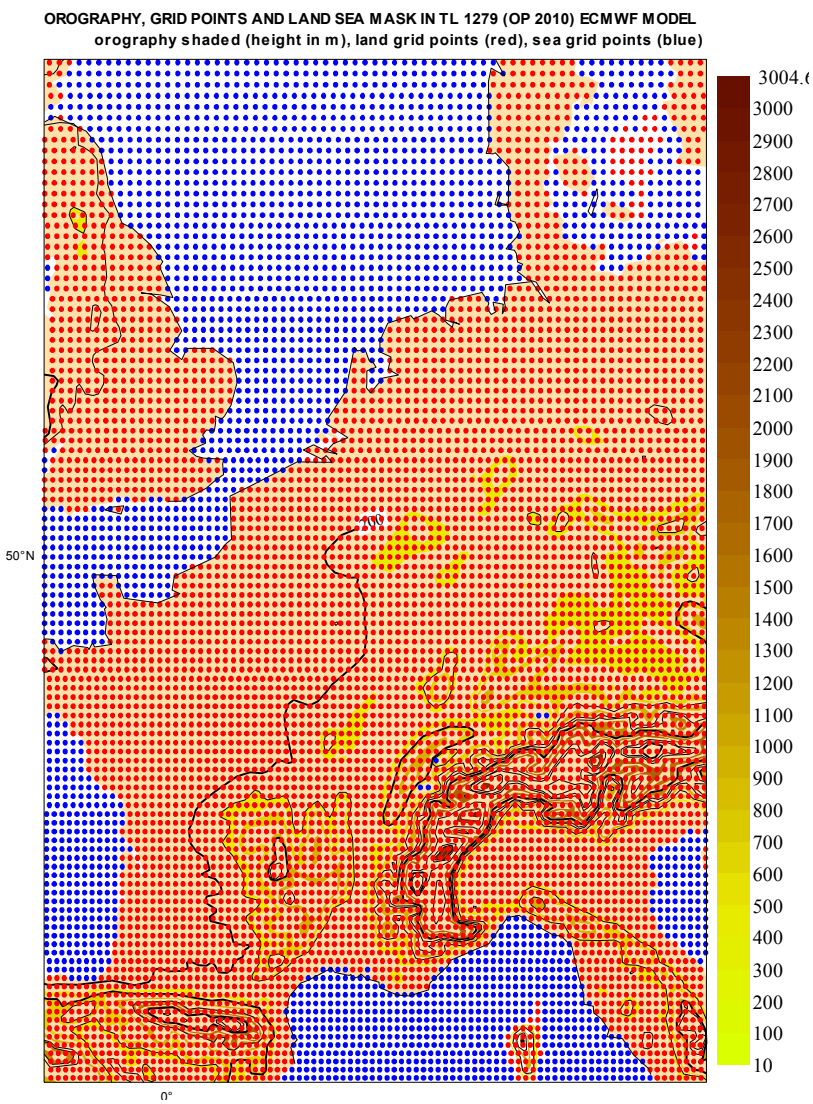
- High-resolution forecast (16 km grid, 137 levels) runs twice every day to 10 days
- Ensemble: same model but run at lower resolution (32 km, 91 levels; 64 km after day 10)
  - ensemble control (run from high-resolution analysis, no perturbation)
  - 50 perturbed members (account for initial and model uncertainties)
  - Ensemble coupled to ocean model from start of forecast

The ECMWF ensemble

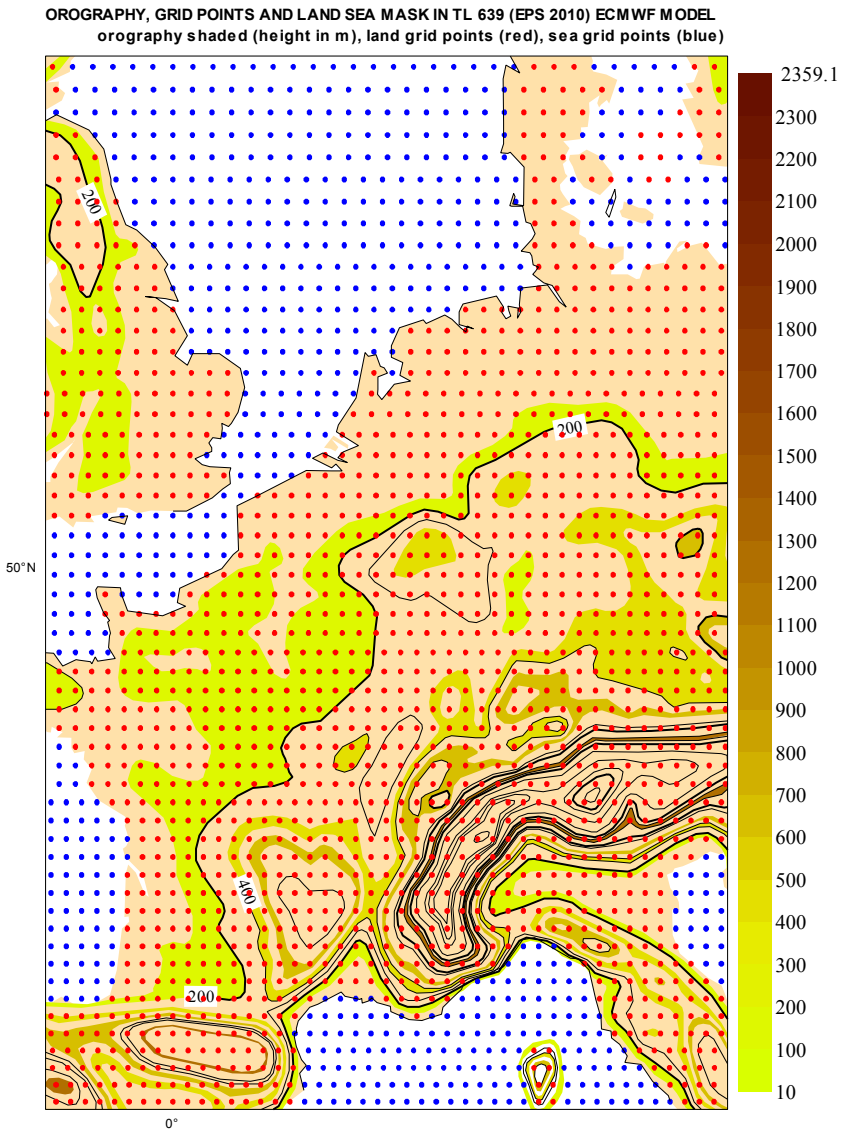
- 91 levels, 32km (T639) to day 10, then 65km (T319) to day 15
- 1 control + 50 perturbed members
- Runs twice per day (00 and 12)
- Coupled to ocean model from start of forecast
- Extended to 32 days twice per week for monthly forecast (00 Thursday, Monday)

Model grids:

HRES (16km, T1279)



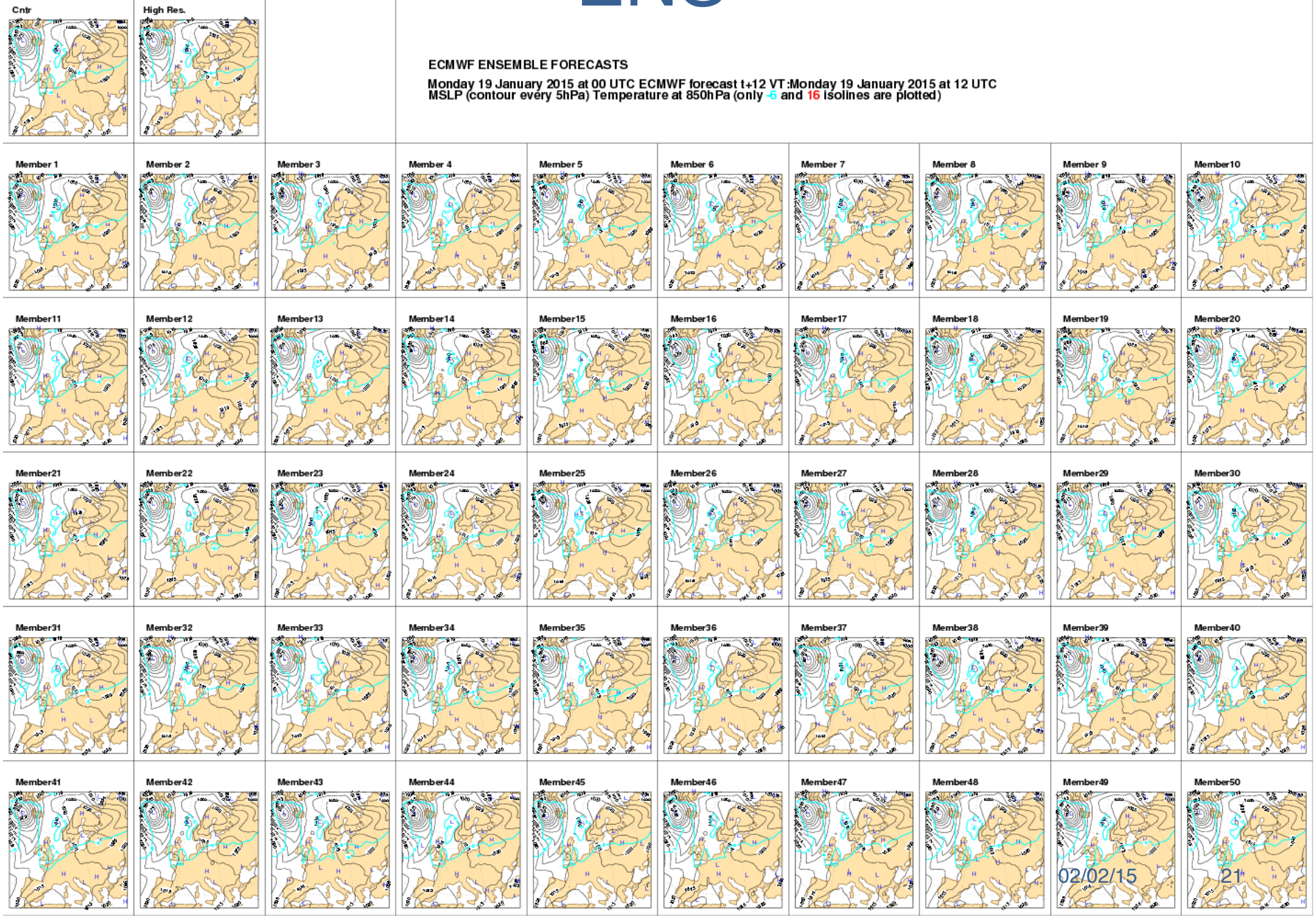
ENS (32 km, T639)



Ensemble at variable resolution

- Small-scale features of the forecasts are wrong after a few days, so it makes sense to start the forecast at high resolution and then to decrease resolution
- For a given amount of computing resource, this allows to have higher resolution at the beginning, which makes the forecast better
- The additional skill can extend into the lower resolution segment (for some parameters, not all)
- Run ENS to day 10 at 32km resolution, then extend to day 15 at lower resolution (65km)

ENS


Cntr
High Res.
ECMWF ENSEMBLE FORECASTS
Monday 19 January 2015 at 00 UTC ECMWF forecast t+12 VT:Monday 19 January 2015 at 12 UTC
MSLP (contour every 5hPa) Temperature at 850hPa (only -6 and 16 isolines are plotted)
Member 1
Member 2
Member 3
Member 4
Member 5
Member 6
Member 7
Member 8
Member 9
Member10
Member11
Member12
Member13
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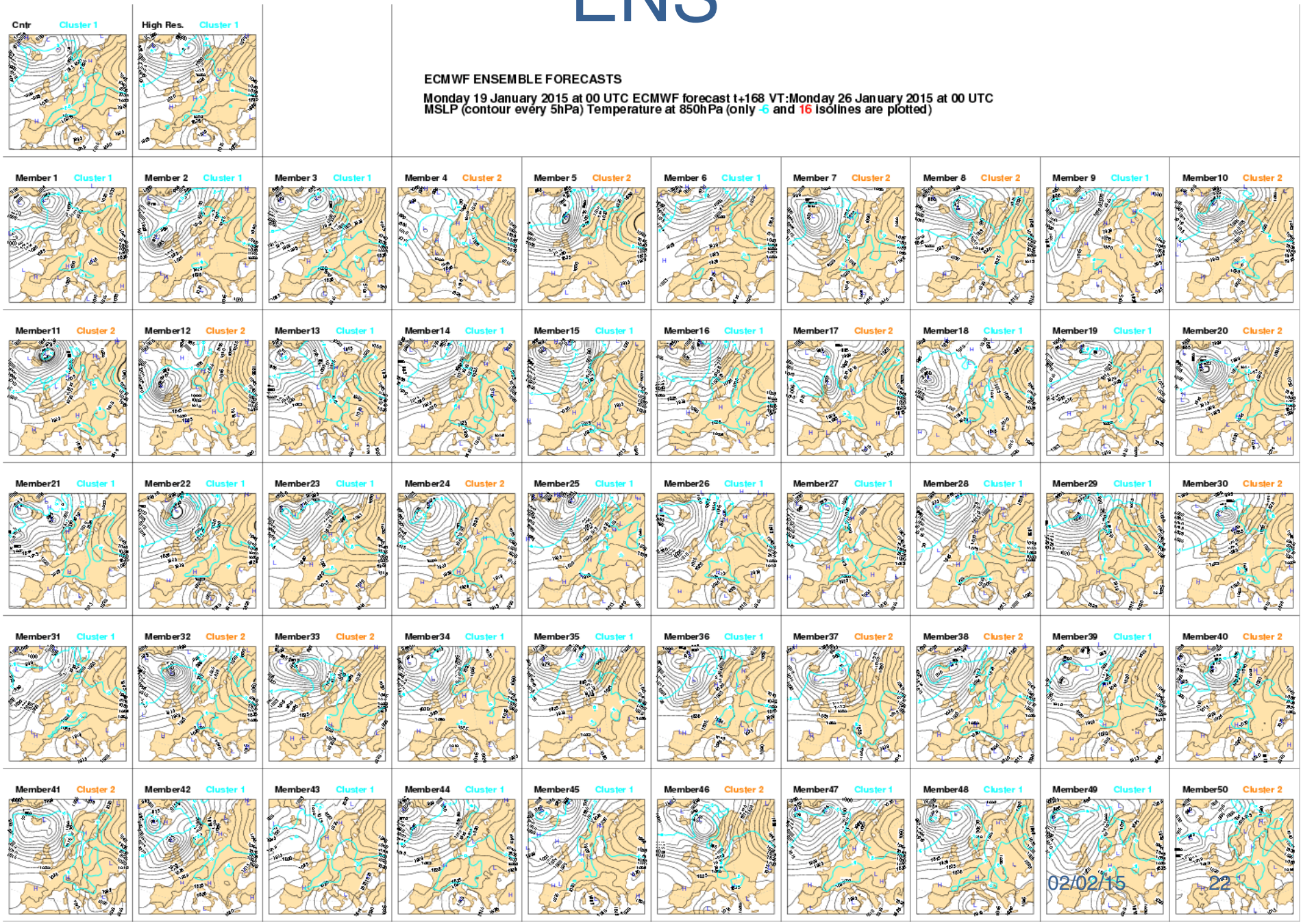
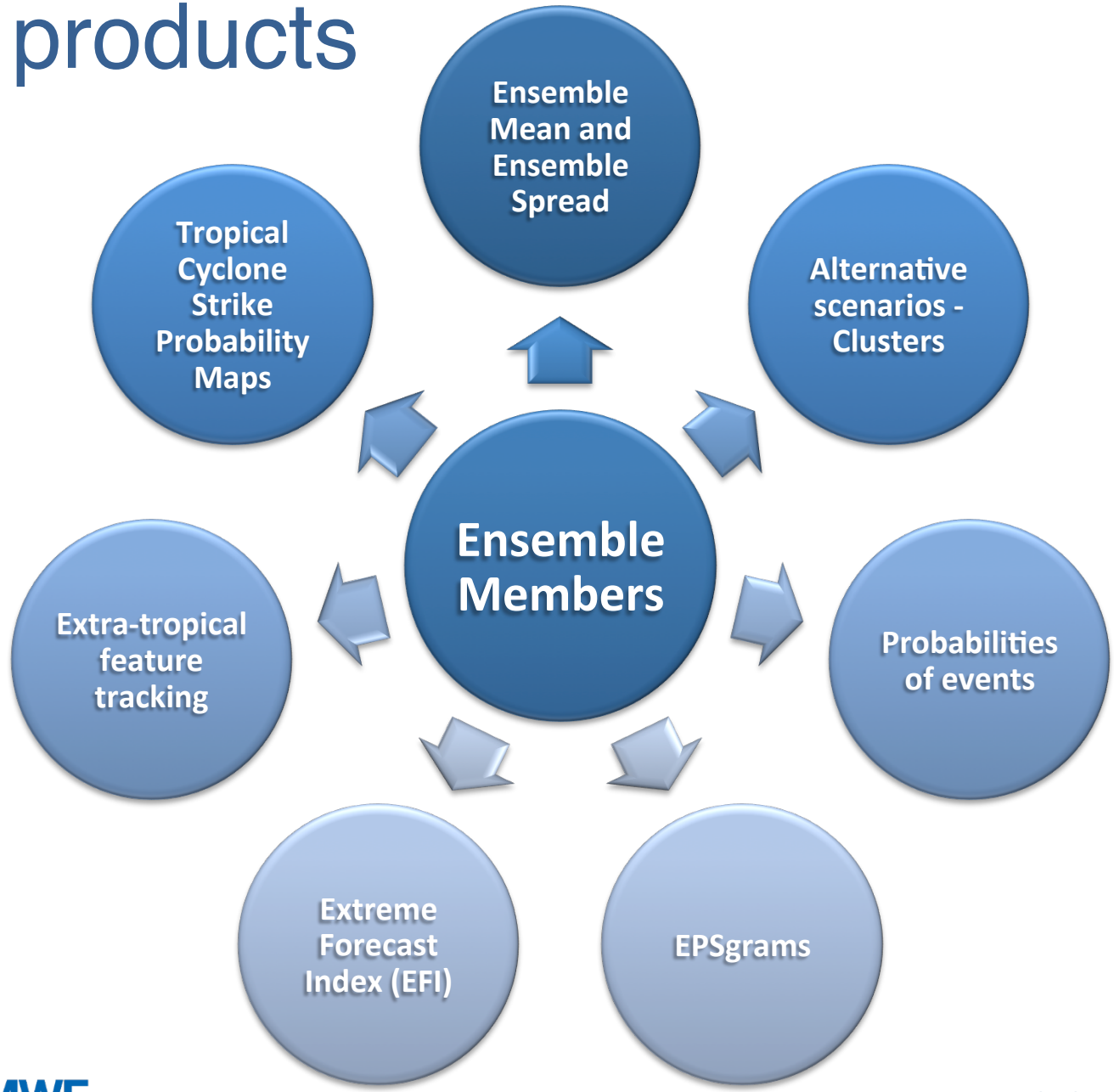
ENS

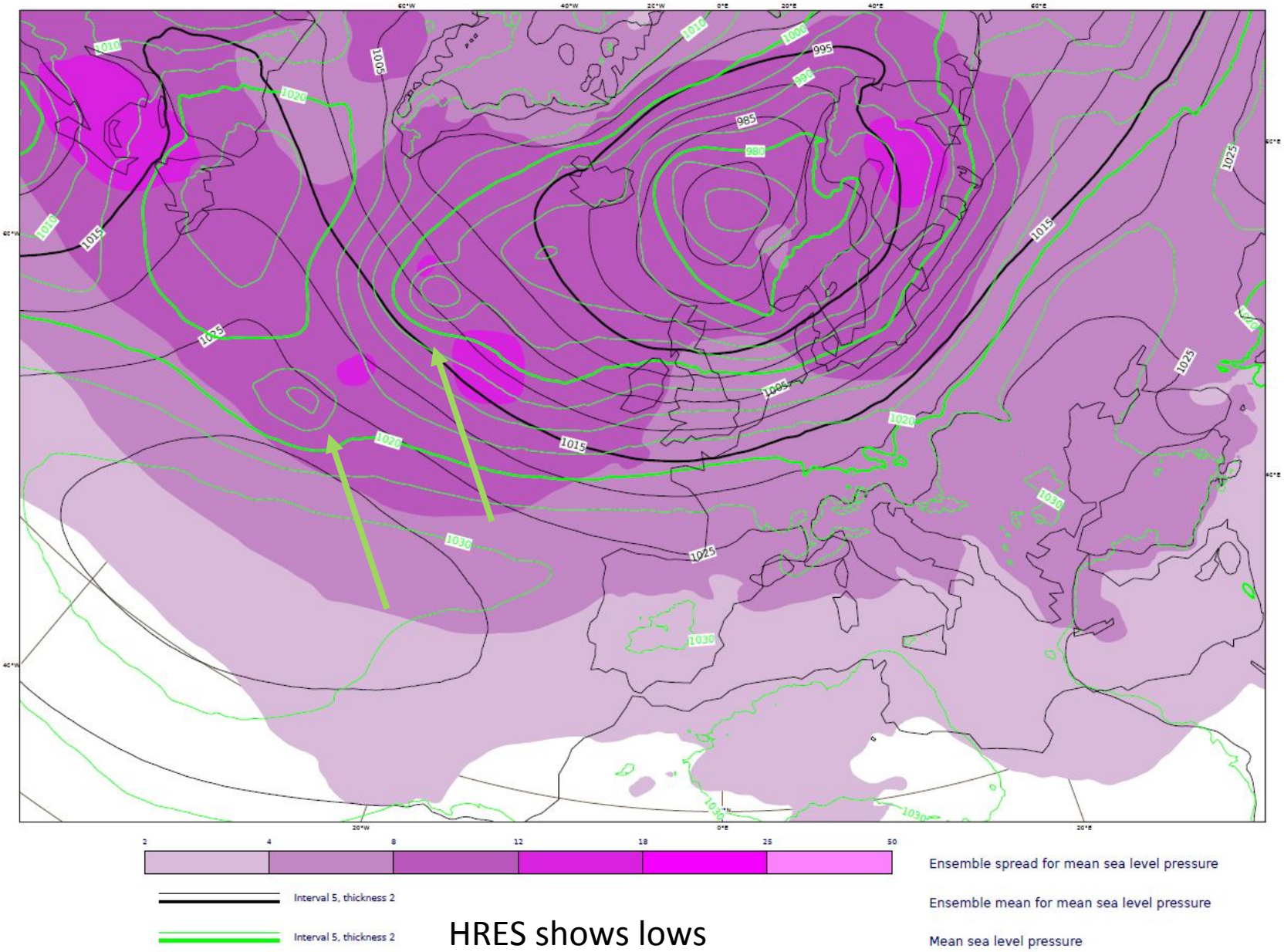

Cntr Cluster 1
High Res. Cluster 1
ECMWF ENSEMBLE FORECASTS
Monday 19 January 2015 at 00 UTC ECMWF forecast t+168 VT:Monday 26 January 2015 at 00 UTC
MSLP (contour every 5hPa) Temperature at 850hPa (only -6 and 16 isolines are plotted)
Member 1 Cluster 1
Member 2 Cluster 1
Member 3 Cluster 1
Member 4 Cluster 2
Member 5 Cluster 2
Member 6 Cluster 1
Member 7 Cluster 2
Member 8 Cluster 2
Member 9 Cluster 1
Member10 Cluster 2
Member11 Cluster 2
Member12 Cluster 2
Member13 Cluster 1
Member14 Cluster 1
Member15 Cluster 1
Member16 Cluster 1
Member17 Cluster 2
Member18 Cluster 1
Member19 Cluster 1
Member20 Cluster 2
Member21 Cluster 1
Member22 Cluster 1
Member23 Cluster 1
Member24 Cluster 2
Member25 Cluster 1
Member26 Cluster 1
Member27 Cluster 1
Member28 Cluster 1
Member29 Cluster 1
Member30 Cluster 2
Member31 Cluster 1
Member32 Cluster 2
Member33 Cluster 2
Member34 Cluster 1
Member35 Cluster 1
Member36 Cluster 1
Member37 Cluster 2
Member38 Cluster 2
Member39 Cluster 1
Member40 Cluster 2
Member41 Cluster 2
Member42 Cluster 1
Member43 Cluster 1
Member44 Cluster 1
Member45 Cluster 1
Member46 Cluster 2
Member47 Cluster 1
Member48 Cluster 1
Member49 Cluster 1
Member50 Cluster 2

ENS products

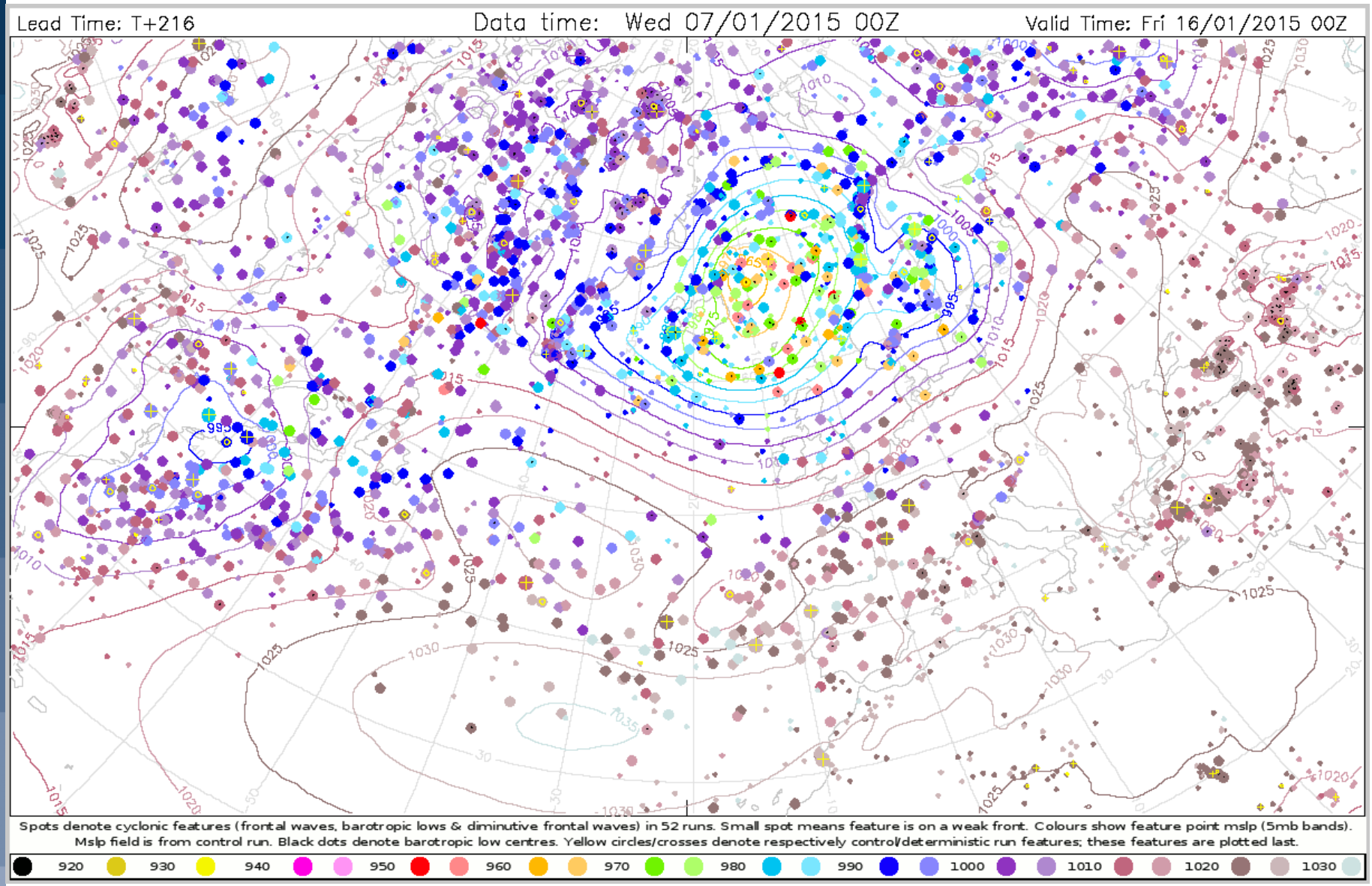


plumes - Thursday 8 Jan 2015, 00 UTC VT Friday 16 Jan 2015, 00 UTC Step 192

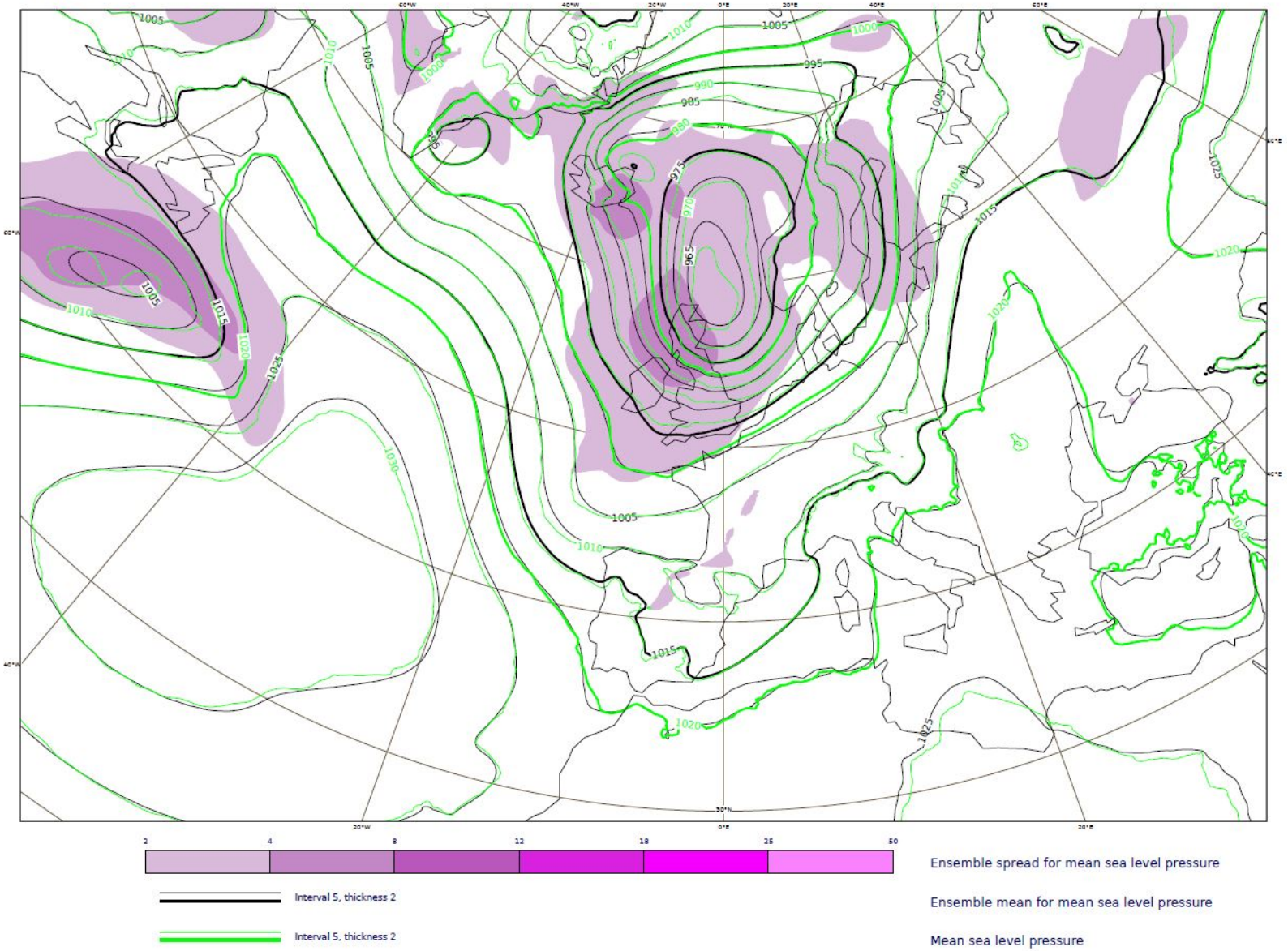
Day 8, green = HRES, black=ENS Mean

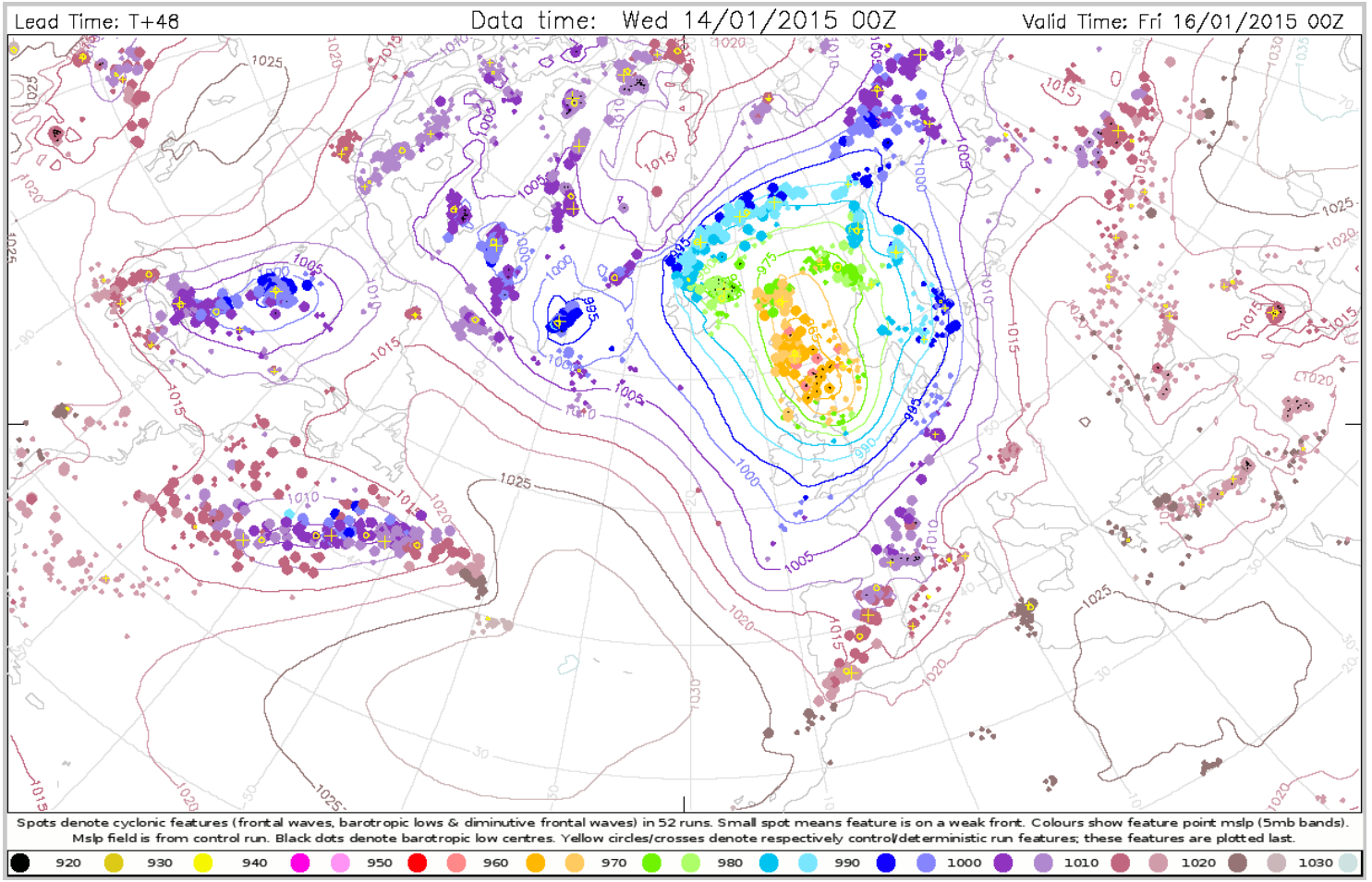


HRES shows lows


Lead Time: T+216
Data time: Wed 07/01/2015 00Z
Valid Time: Fri 16/01/2015 00Z
Spots denote cyclonic features (frontal waves, barotropic lows & diminutive frontal waves) in 52 runs. Small spot means feature is on a weak front. Colours show feature point mslp (5mb bands).
Mslp field is from control run. Black dots denote barotropic low centres. Yellow circles/crosses denote respectively control/deterministic run features; these features are plotted last.
920 930 940 950 960 970 980 990 1000 1010 1020 1030

Much better agreement at day2

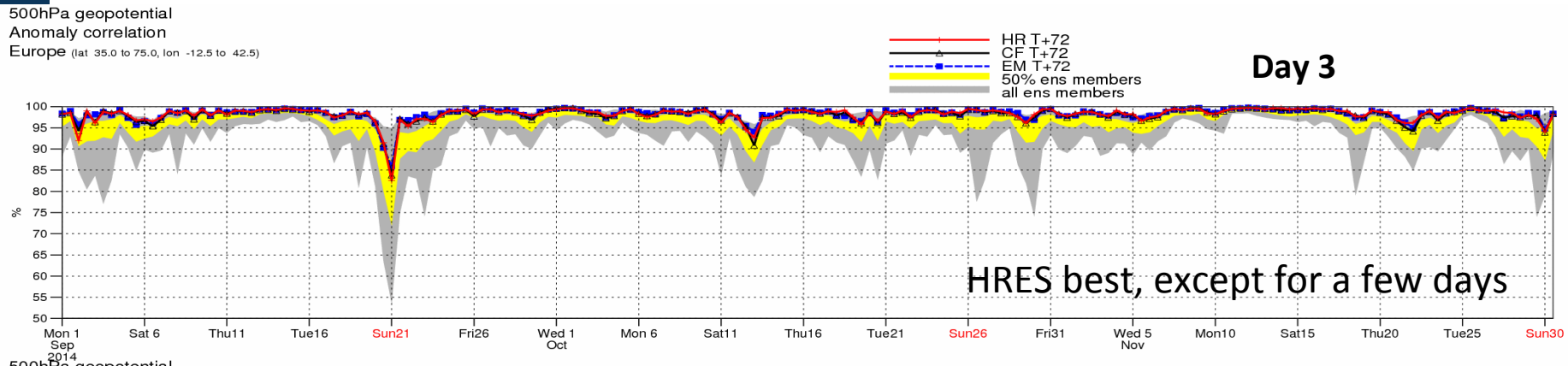



Lead Time: T+48
Data time: Wed 14/01/2015 00Z
Valid Time: Fri 16/01/2015 00Z
Spots denote cyclonic features (frontal waves, barotropic lows & diminutive frontal waves) in 52 runs. Small spot means feature is on a weak front. Colours show feature point mslp (5mb bands).
Mslp field is from control run. Black dots denote barotropic low centres. Yellow circles/crosses denote respectively control/deterministic run features; these features are plotted last.
920 930 940 950 960 970 980 990 1000 1010 1020 1030

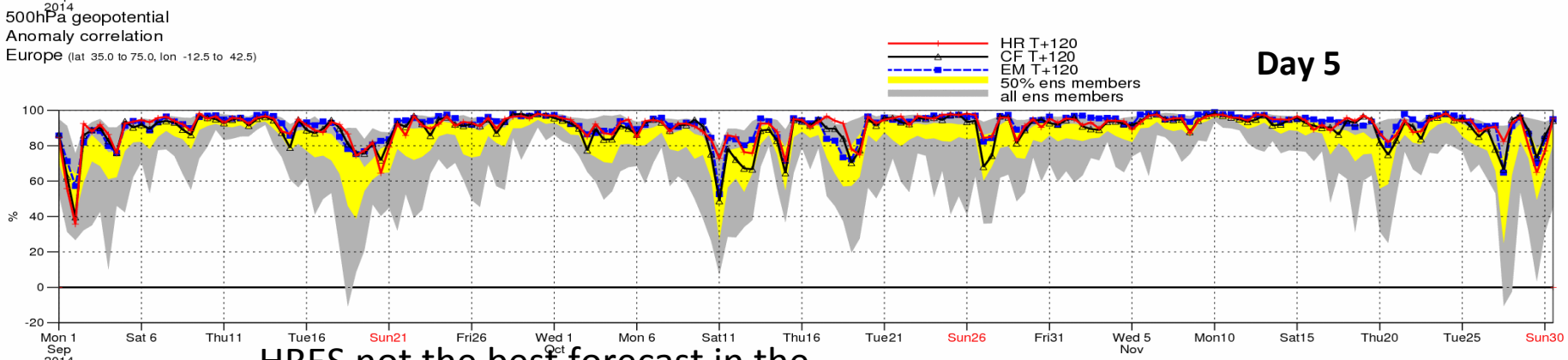
Ensemble mean and spread

- The ensemble mean is the average over all ensemble members
- It will smooth the flow more in areas of large uncertainty (spread)
- This cannot be achieved with a simple filtering of a single forecast
- the ensemble mean is the best estimate for any parameter beyond D+3/D+4 (Z500, T2m, Precipitation)
- If there is large spread, the ensemble mean can be a rather weak pattern and may not represent any of the possible states
- The ensemble mean should always be used together with the spread

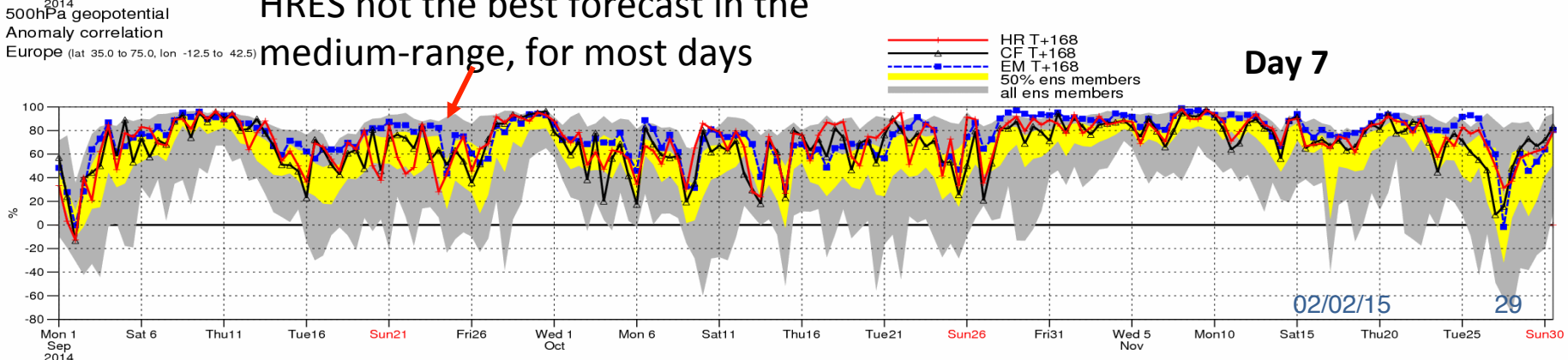
Ensemble skill Z500 Europe



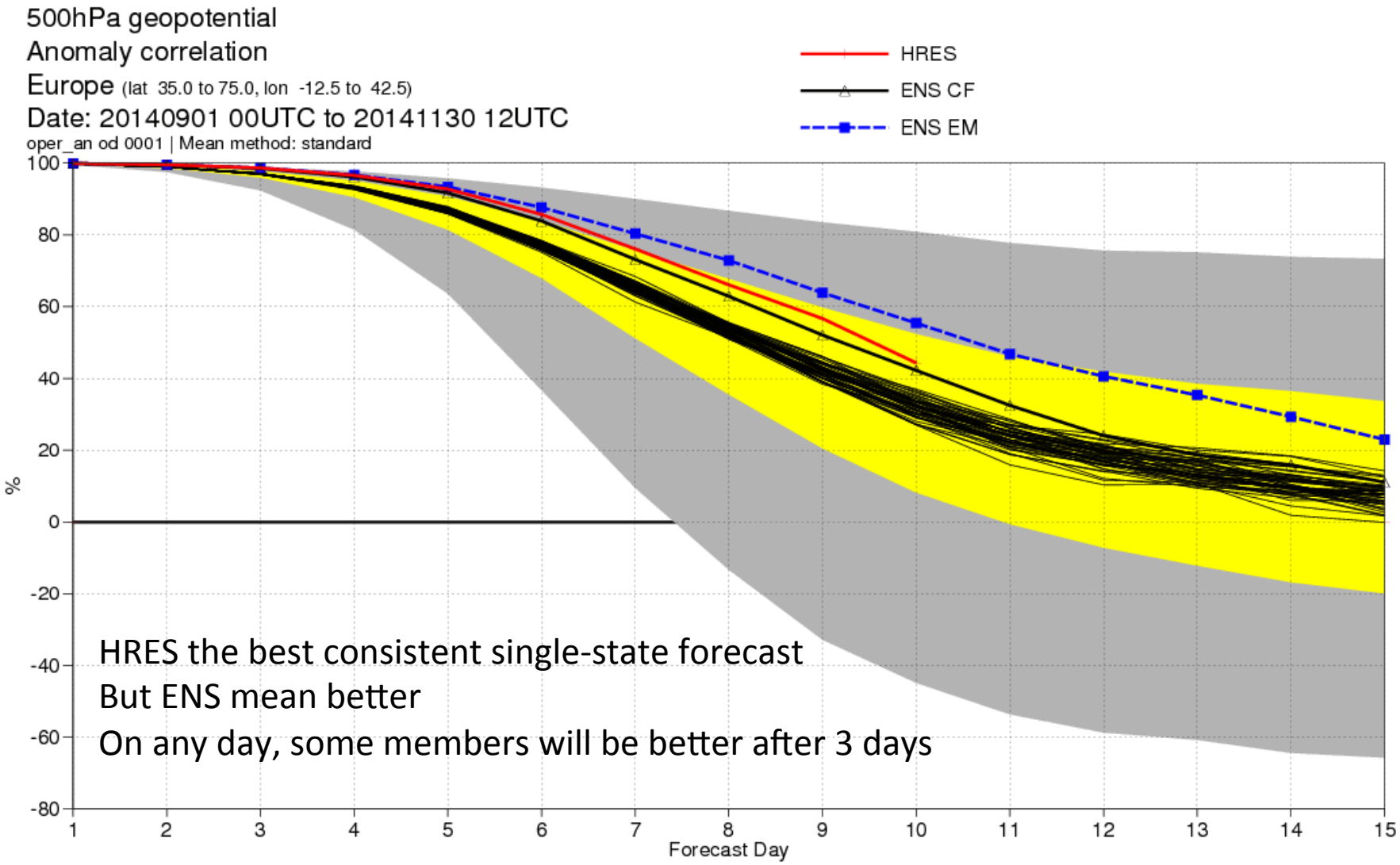
HRES best, except for a few days



HRES not the best forecast in the medium-range, for most days



Ensemble skill Z500 Europe



ENS forecasts: timeseries (meteogram)

Highest value of all members

90th centile

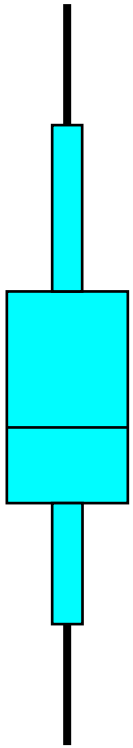
75th centile

Median

25th centile

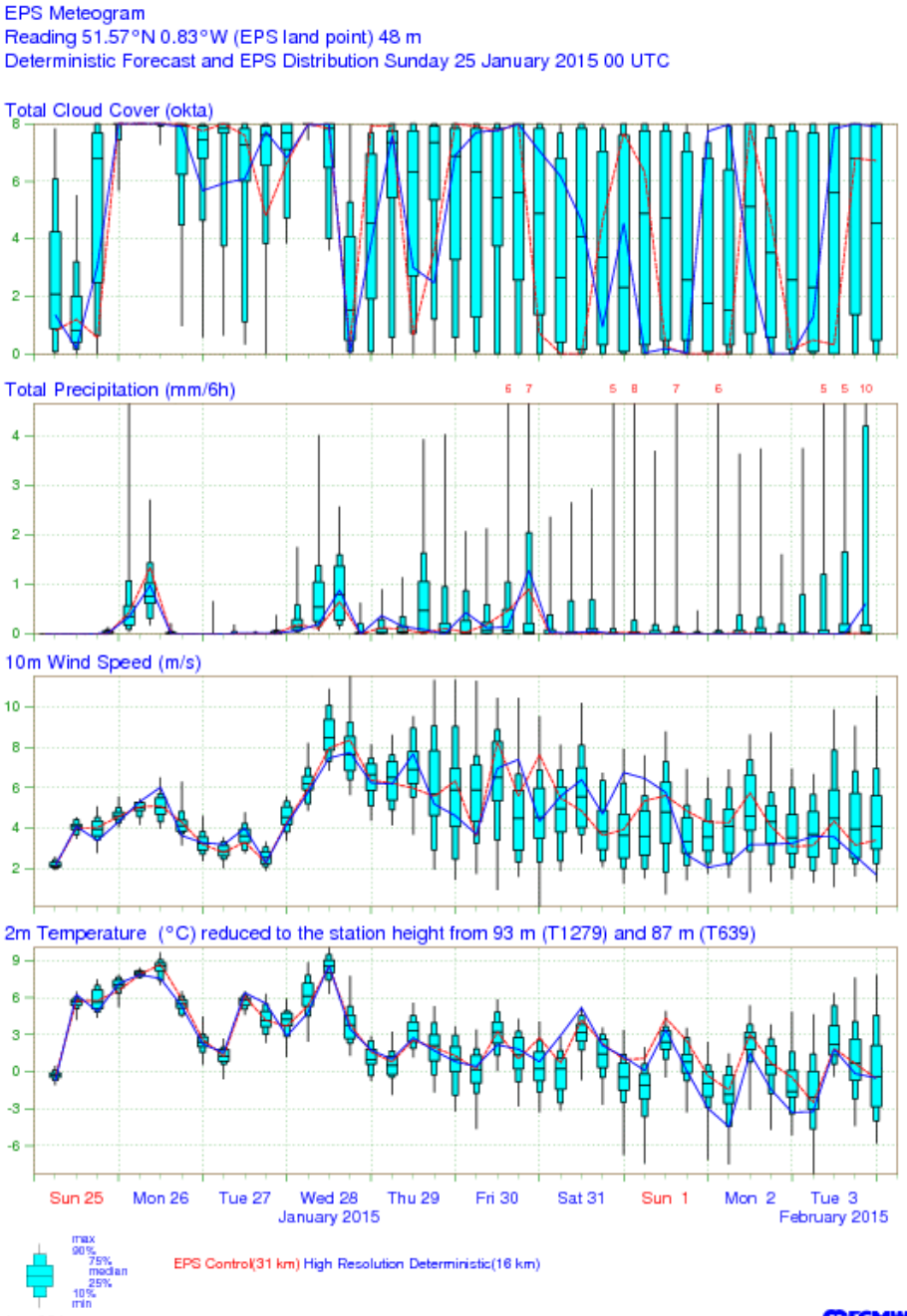
10th centile

Lowest value of all members



EPSgram for Reading

Start Sun 25/01/15 00 UTC



Extreme forecast index (EFI)

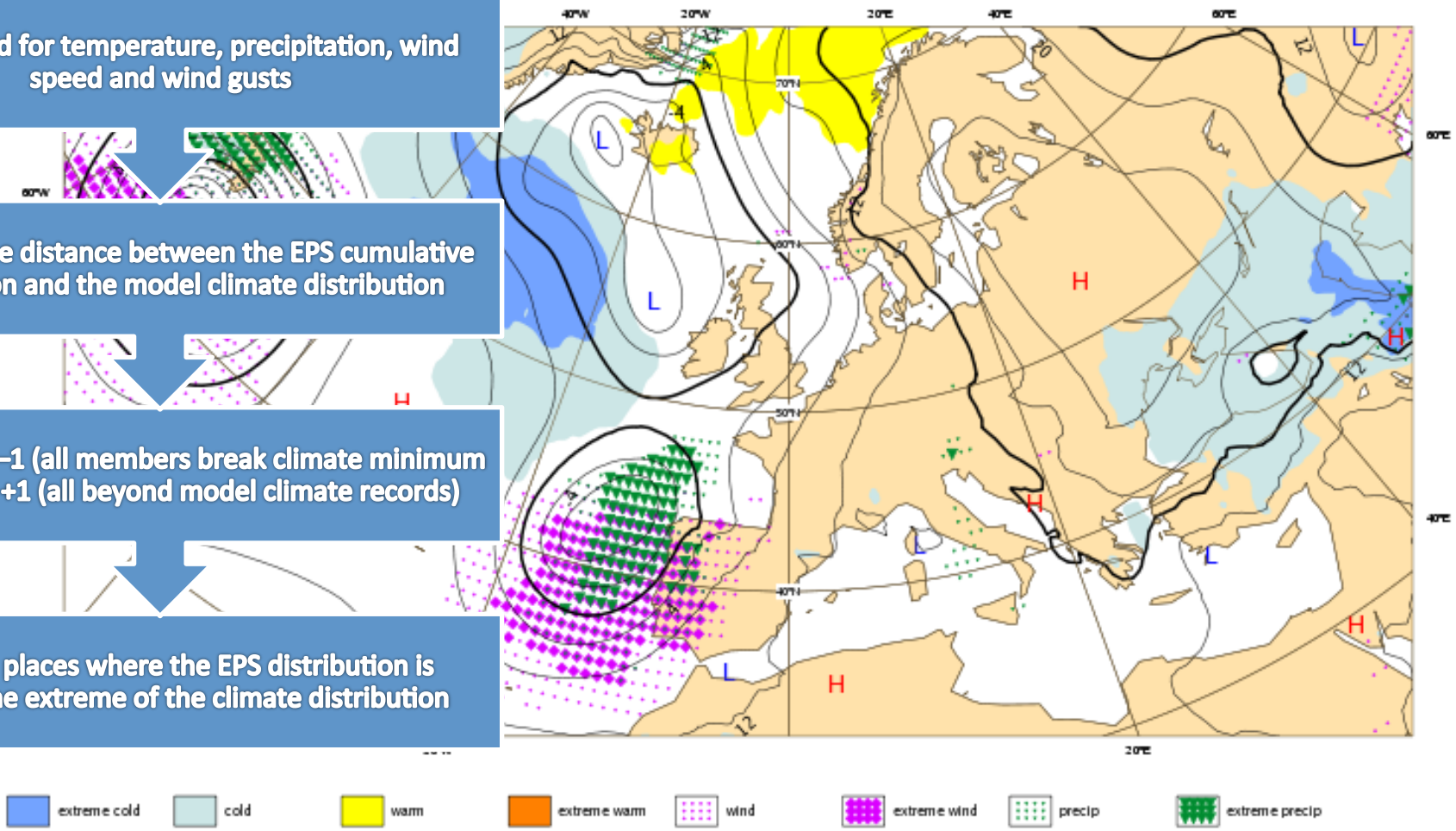
Anomalous weather predicted by EPS: Tuesday 25 October 2011 at 00 UTC
1000 hPa Z ensemble mean (Wednesday 26 October 2011 at 12 UTC)
and EFI values for Total precipitation,maximum 10m wind gust and mean 2m temperature (all 24h)
valid for 24hours from Wednesday 26 October 2011 at 00 UTC to Thursday 27 October 2011 at 00 UTC

Is computed for temperature, precipitation, wind speed and wind gusts

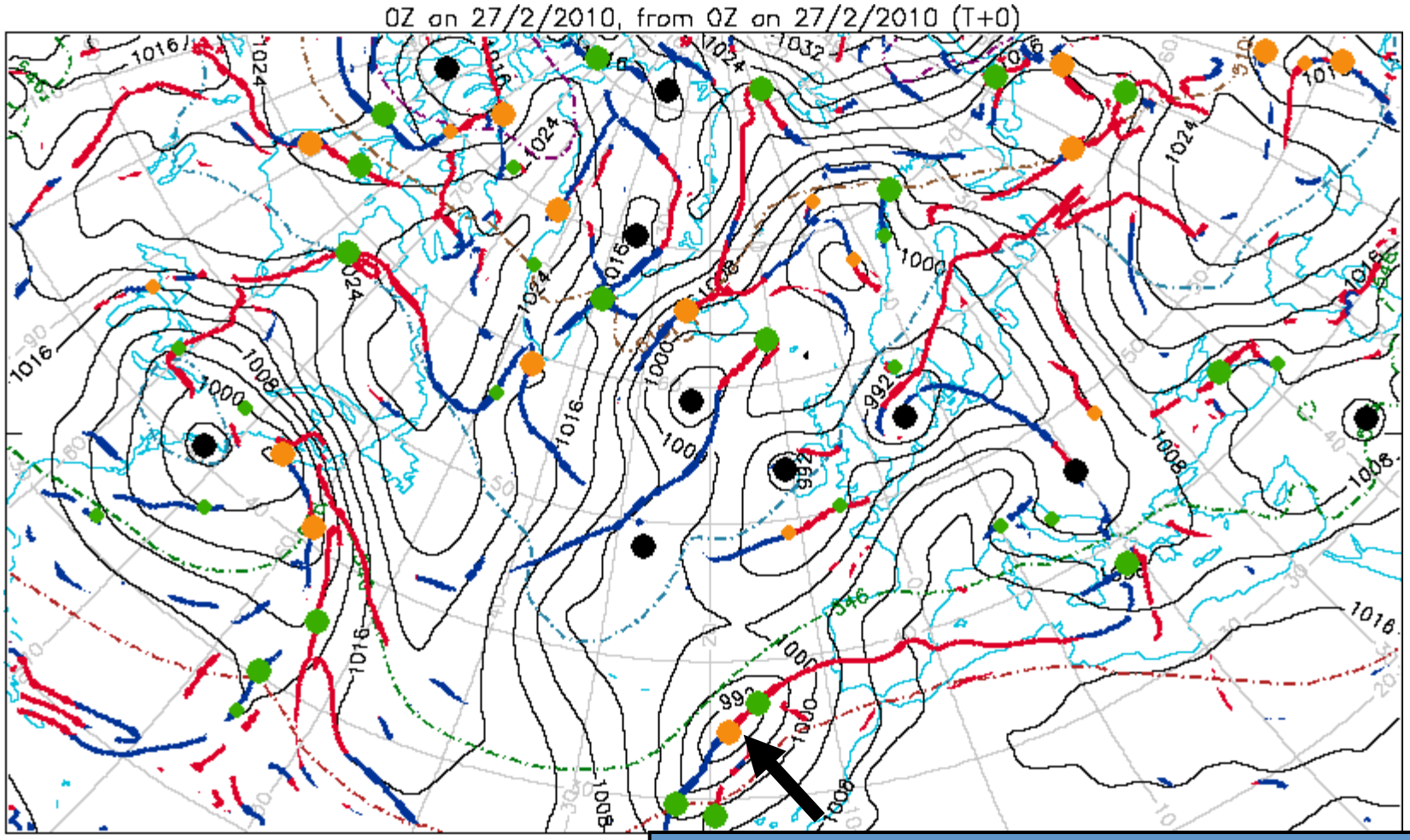
Measures the distance between the EPS cumulative distribution and the model climate distribution

Ranges from –1 (all members break climate minimum records) to +1 (all beyond model climate records)

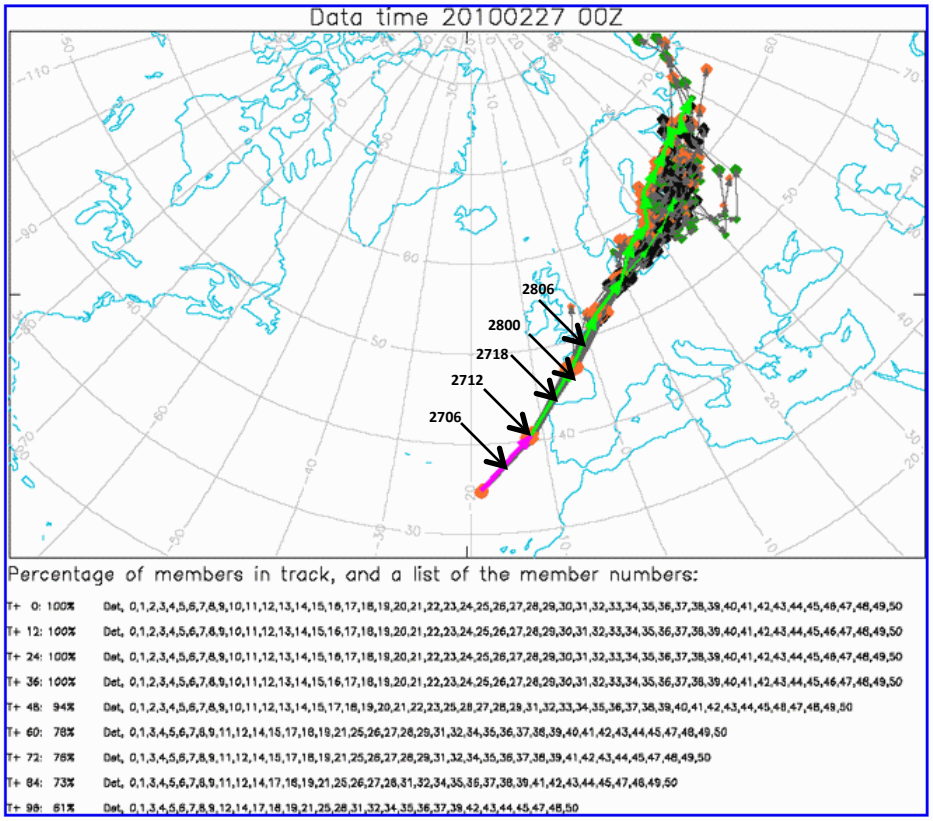
Indicates places where the EPS distribution is towards the extreme of the climate distribution

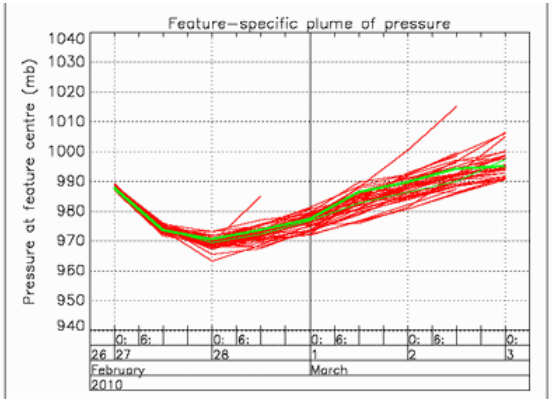


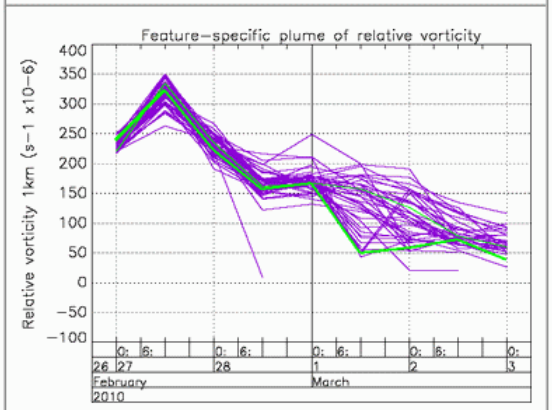
Extra-tropical feature tracking: Xynthia

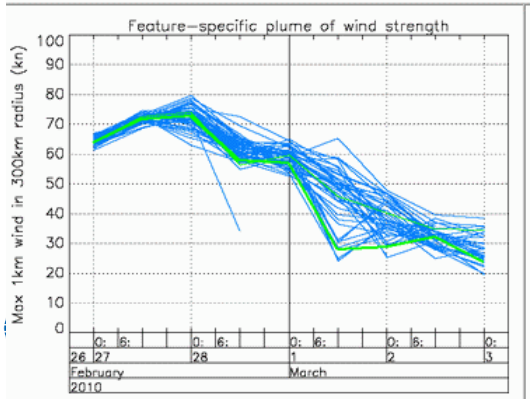


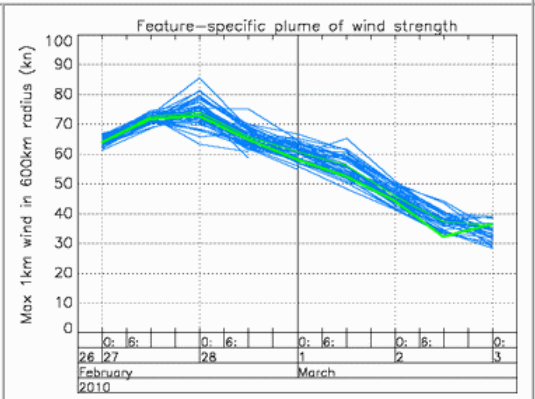
User can click on any spot (= cyclonic feature) to see how that feature evolves in the EPS

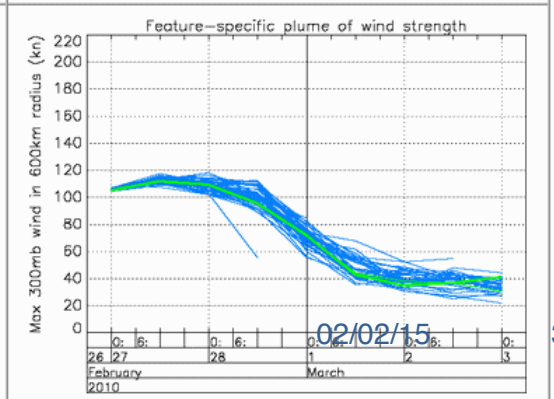

Data time 20100227 00Z
2806
2800
2718
2712
2706
Percentage of members in track, and a list of the member numbers:
T+ 0: 100% Det, 0,1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36,37,38,39,40,41,42,43,44,45,46,47,48,49,50
T+ 12: 100% Det, 0,1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36,37,38,39,40,41,42,43,44,45,46,47,48,49,50
T+ 24: 100% Det, 0,1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36,37,38,39,40,41,42,43,44,45,46,47,48,49,50
T+ 36: 100% Det, 0,1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36,37,38,39,40,41,42,43,44,45,46,47,48,49,50
T+ 48: 94% Det, 0,1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,17,18,19,20,21,22,23,25,28,27,28,29,31,32,33,34,35,36,37,38,39,40,41,42,43,44,45,48,47,48,49,50
T+ 60: 78% Det, 0,1,3,4,5,6,7,8,9,11,12,14,15,17,18,19,21,25,26,27,28,29,31,32,34,35,36,37,38,39,40,41,42,43,44,45,47,48,49,50
T+ 72: 76% Det, 0,1,3,4,5,6,7,8,9,11,12,14,15,17,18,19,21,25,26,27,28,29,31,32,34,35,36,37,38,39,41,42,43,44,45,47,48,49,50
T+ 84: 73% Det, 0,1,3,4,5,6,7,8,9,11,12,14,17,18,19,21,25,26,27,28,31,32,34,35,36,37,38,39,41,42,43,44,45,47,48,49,50
T+ 96: 61% Det, 0,1,3,4,5,6,7,8,9,12,14,17,18,19,21,25,28,31,32,34,35,36,37,39,42,43,44,45,47,48,50


Feature-specific plume of pressure
Pressure at feature centre (mb)
1040
1030
1020
1010
1000
990
980
970
960
950
940
26 27 28 1 2 3
February
March
2010


Feature-specific plume of relative vorticity
Relative vorticity 1km (s-1 x10-6)
400
350
300
250
200
150
100
50
0
−50
−100
26 27 28 1 2 3
February
March
2010


Feature-specific plume of wind strength
Max 1km wind in 300km radius (kn)
100
90
80
70
60
50
40
30
20
10
0
26 27 28 1 2 3
February
March
2010

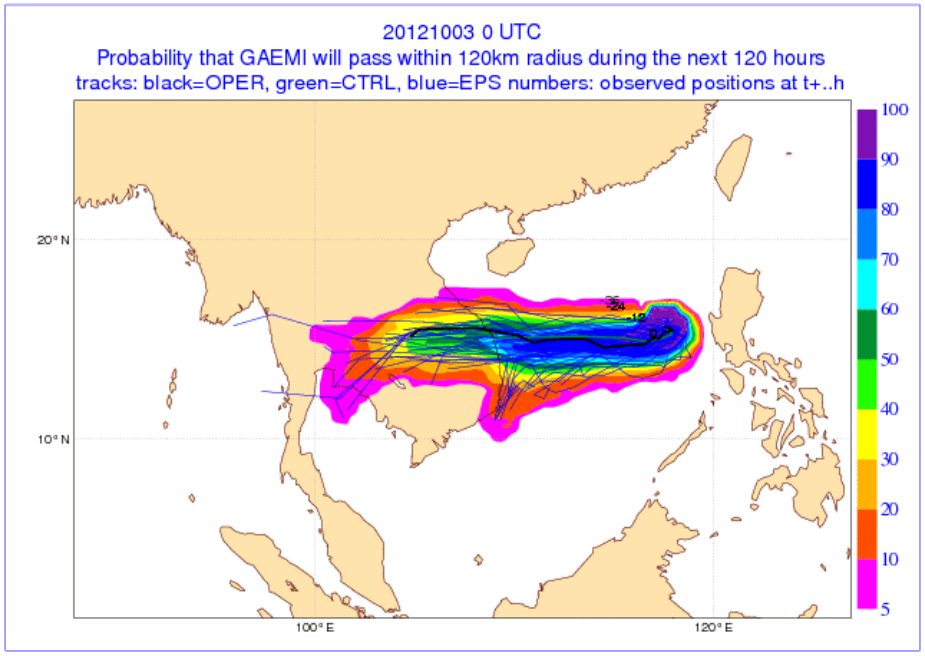

Feature-specific plume of wind strength
Max 1km wind in 600km radius (kn)
100
90
80
70
60
50
40
30
20
10
0
26 27 28 1 2 3
February
March
2010

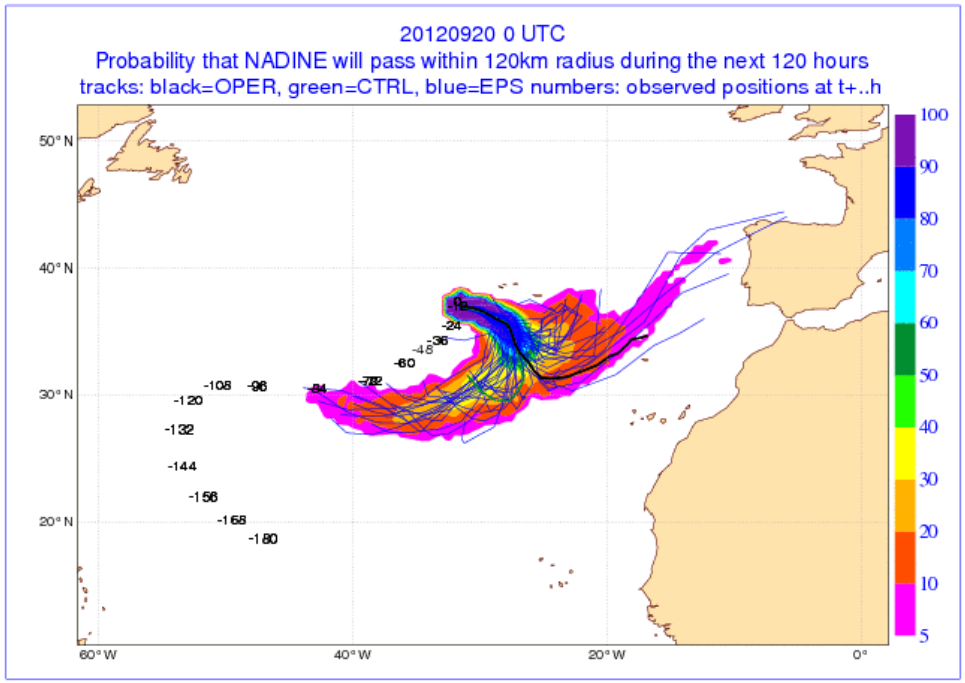

Feature-specific plume of wind strength
Max 300mb wind in 600km radius (kn)
220
200
180
160
140
120
100
80
60
40
20
0
26 27 28 1 2 3
February
March
2010

Tropical cyclone tracks

Gamei

Nadine

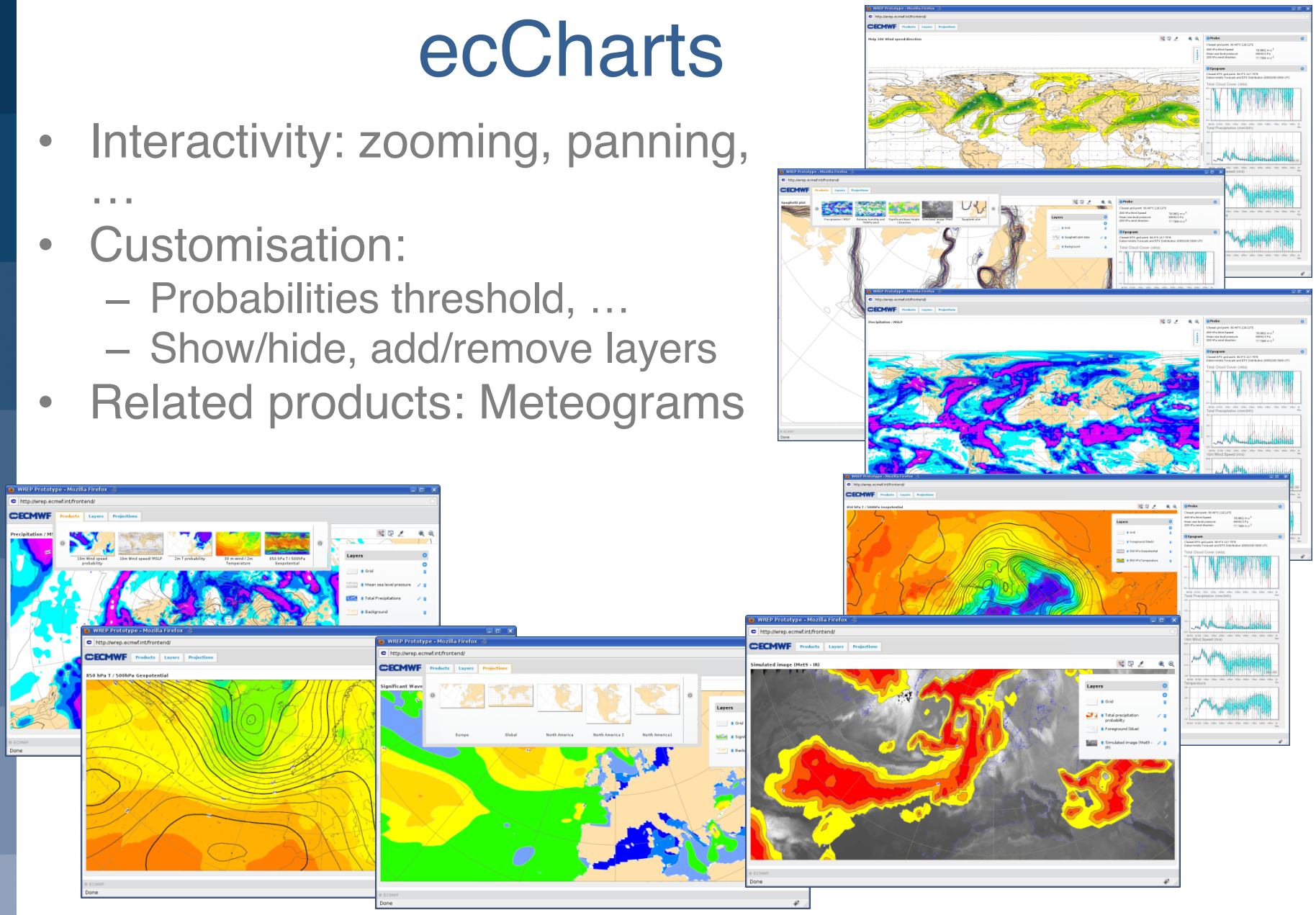




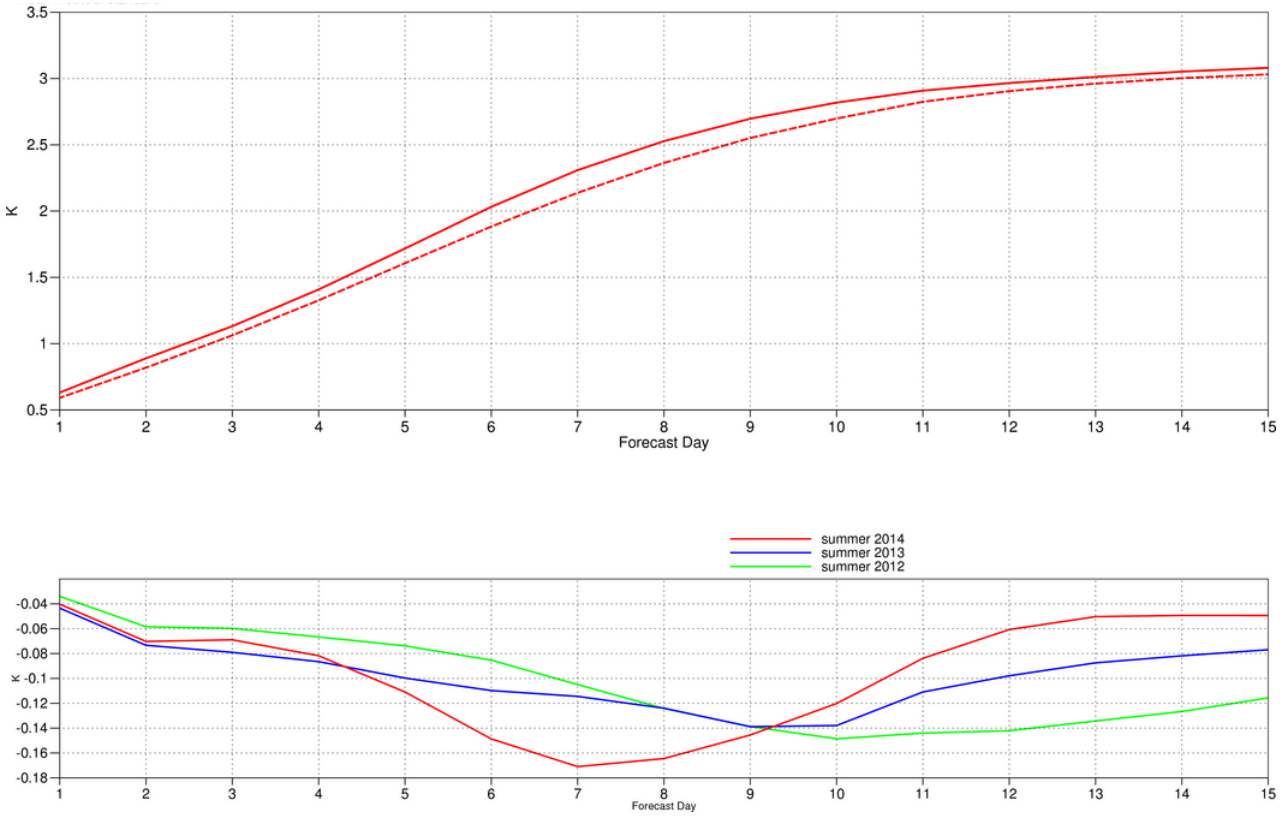
strike probability

ecCharts

- Interactivity: zooming, panning, …
- Customisation:
  - Probabilities threshold, …
  - Show/hide, add/remove layers
- Related products: Meteograms



ENS spread and error

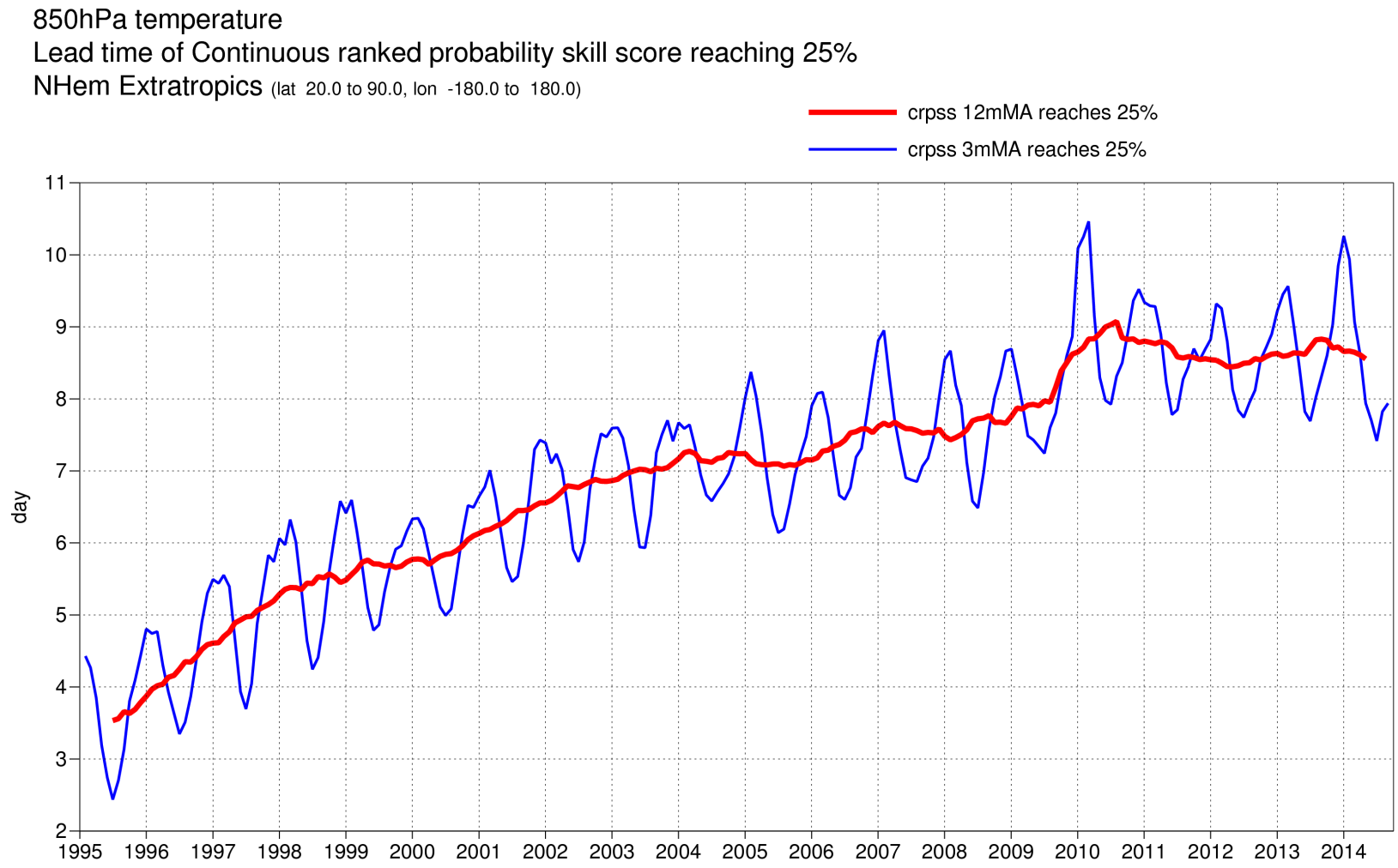


850 hPa temperature, N.Hemisphere

ENS spread (dashed), RMS error of ensemble-mean (full lines), and their difference (below) in summer.

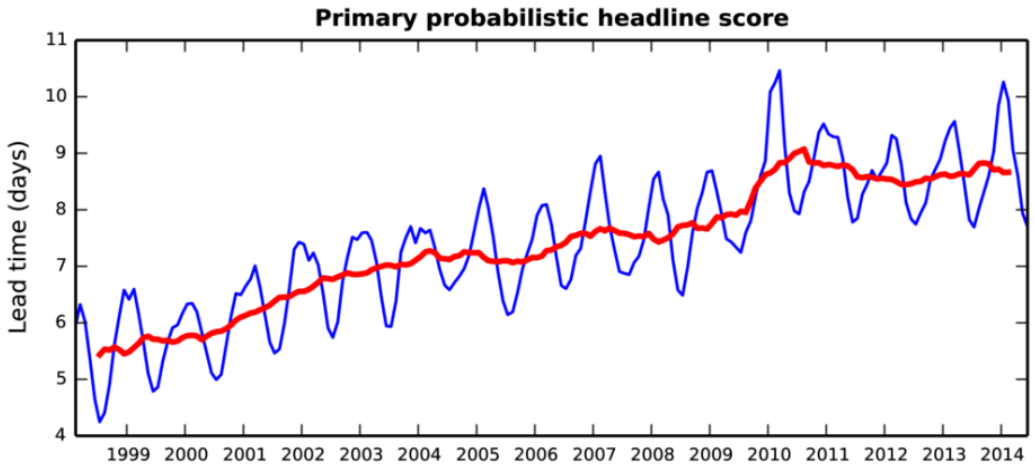
ENS Probabilistic Score

CRPSS. Temperature at 850 hPa N hemisphere

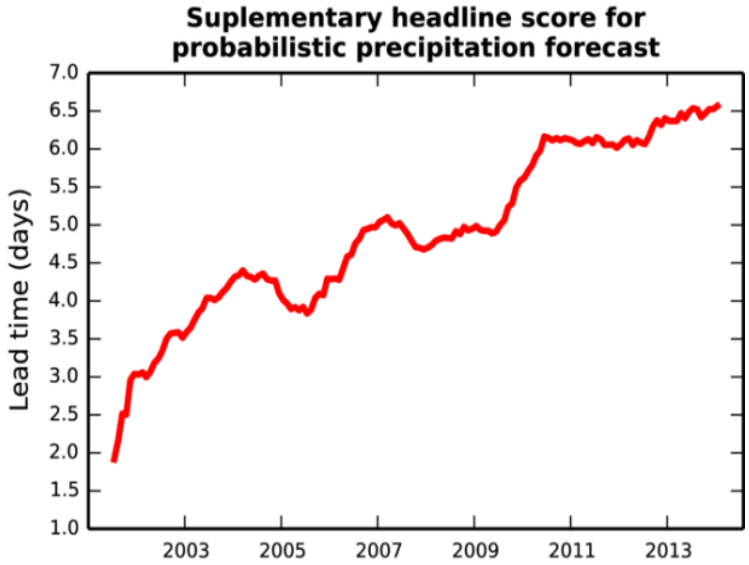


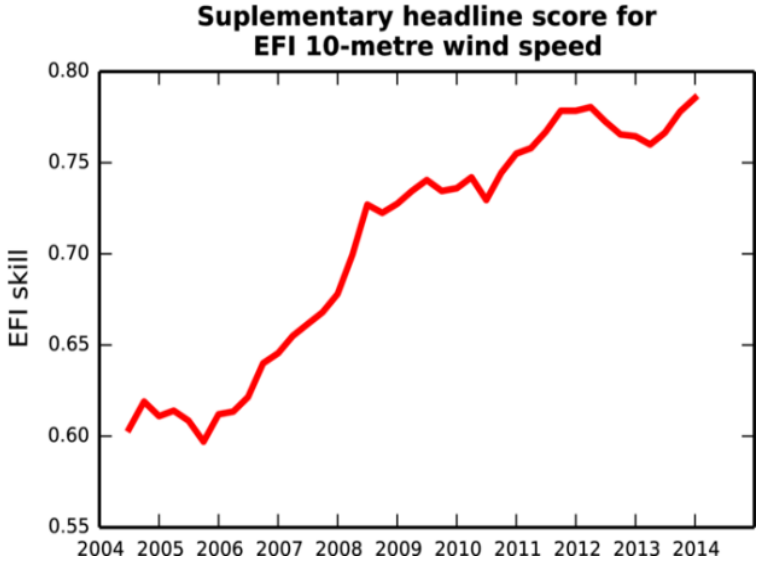
Monthly score (blue), and 12-month running mean (red) of Continuous Ranked Probability Skill Score. Day at which score reaches 25%.

ENS Probabilistic Scores

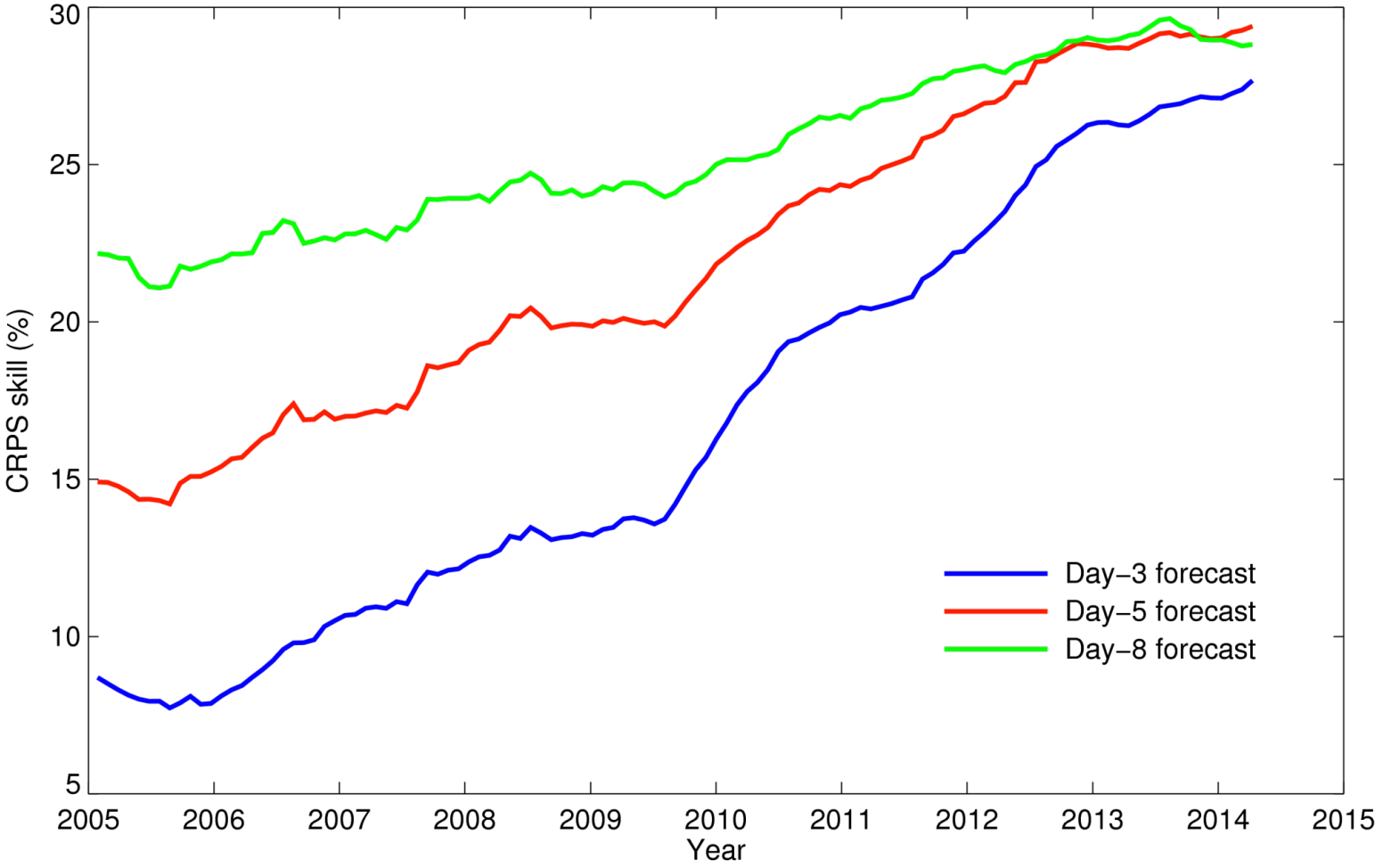


CRPSS, Temperature at 850 hPa N hemisphere 12-month running mean of Continuous Ranked Probability Skill Score. Day at which score reaches 25%.



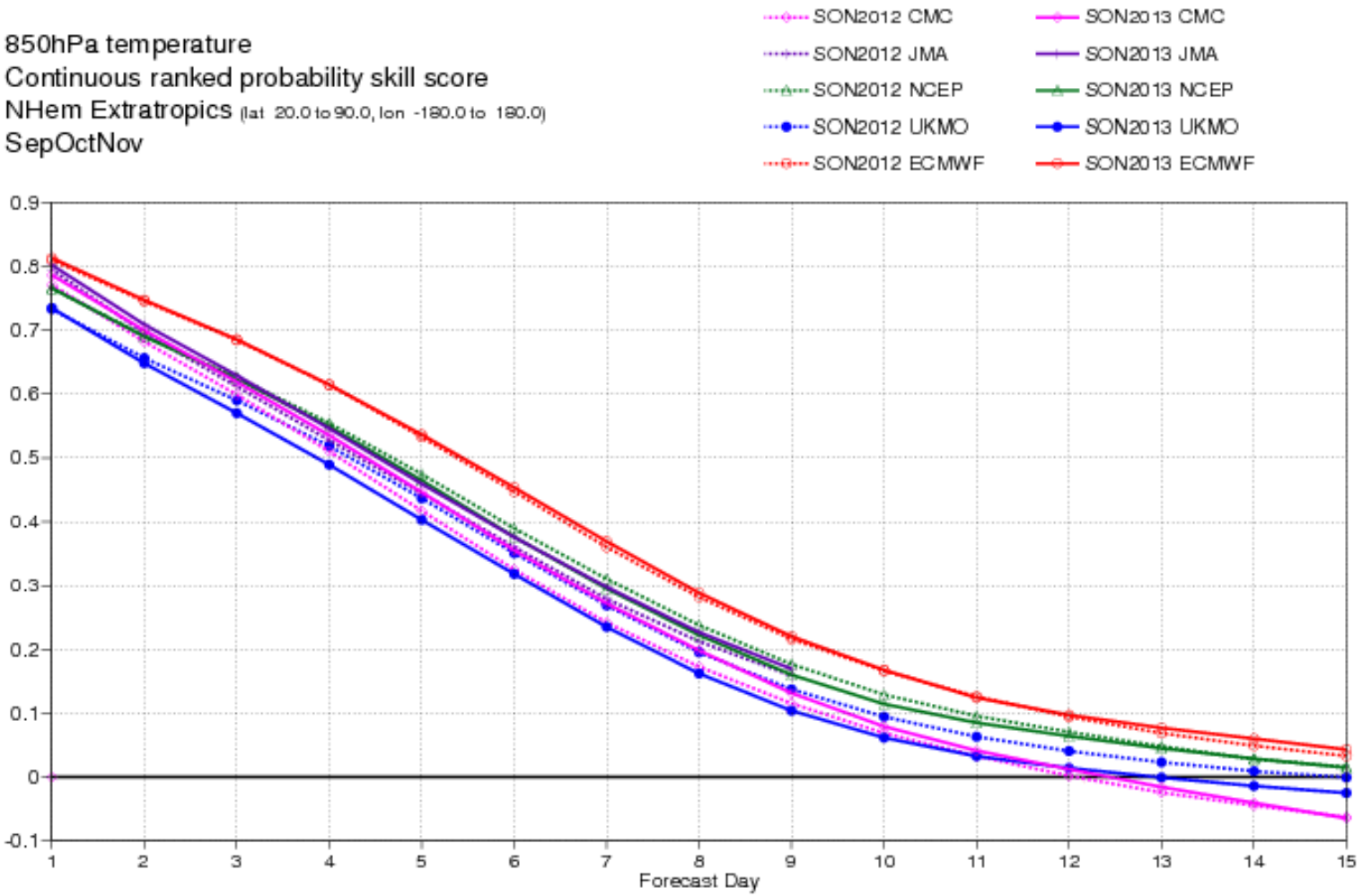


Ensemble skill T850 NH relative to ERA-Interim



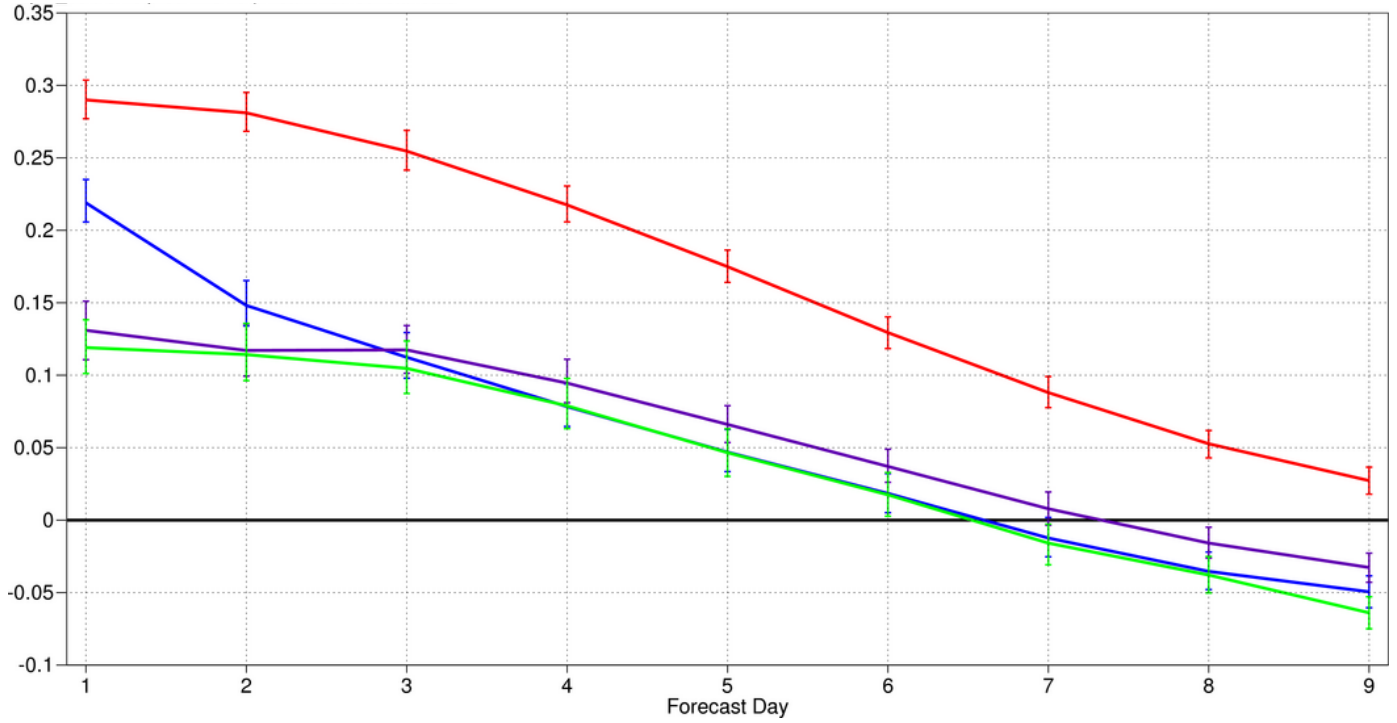
ENS Probabilistic Score

CRPSS, Temperature at 850 hPa N hemisphere



ENS skill compared to other centres
24-hour precipitation (extra-tropics)

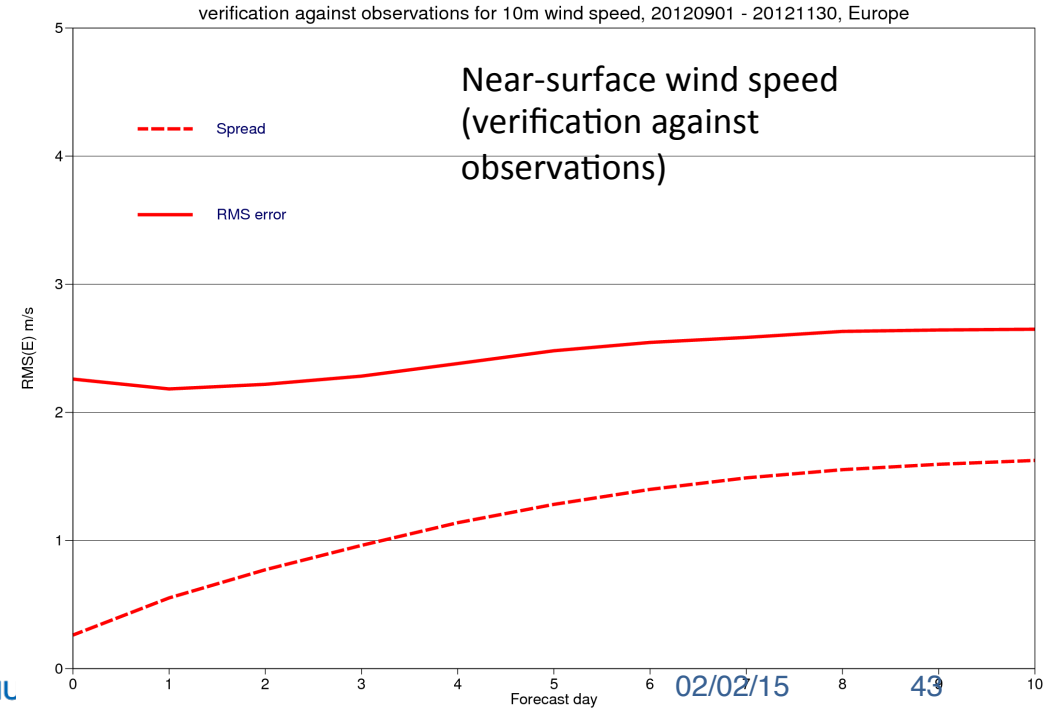
August 2013 to July 2014



ECMWF (red), Met Office (blue), JMA (magenta), NCEP (green)

Surface perturbations

- ENS had too little spread for near surface weather parameters (e.g. 10-m wind)
  - representativeness (an individual observation is not equivalent to a model grid box average) and errors in the observations
  - ENS resolution: difficult to represent small-scale phenomena such as sting jets
  - Additional sources of uncertainty?
- Land-surface perturbations
  - Added November 2013

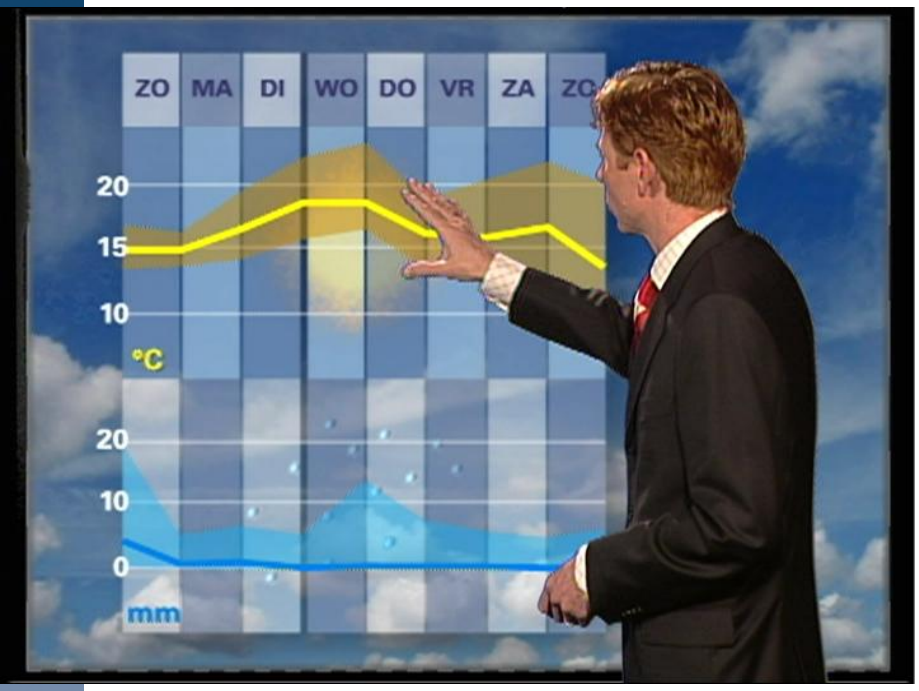


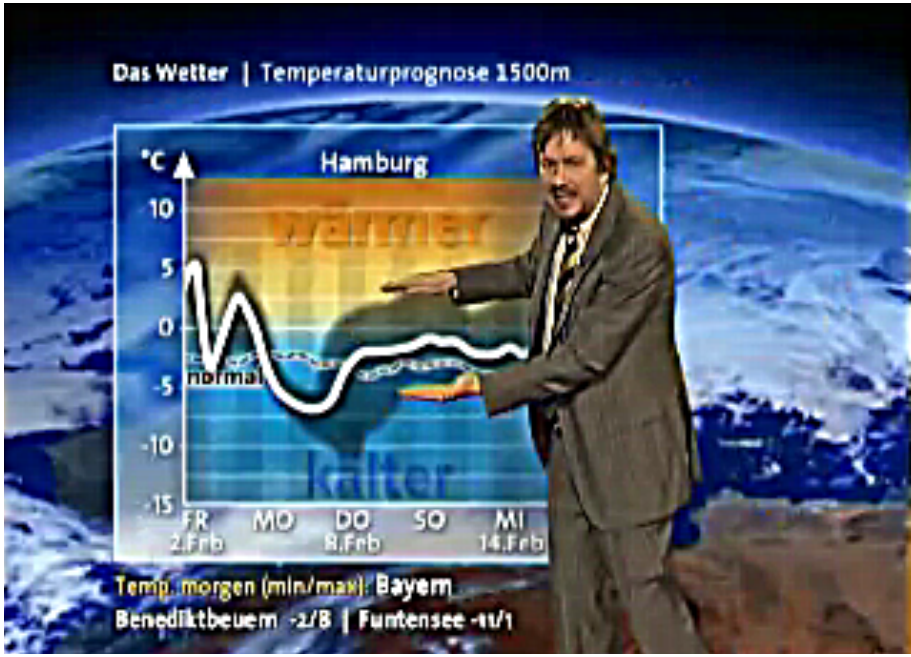
Ensemble spread (dashed) and root-mean-square error of ensemble-mean (solid)
autumn (September-November) 2012 over Europe

ENS – communicating uncertainty

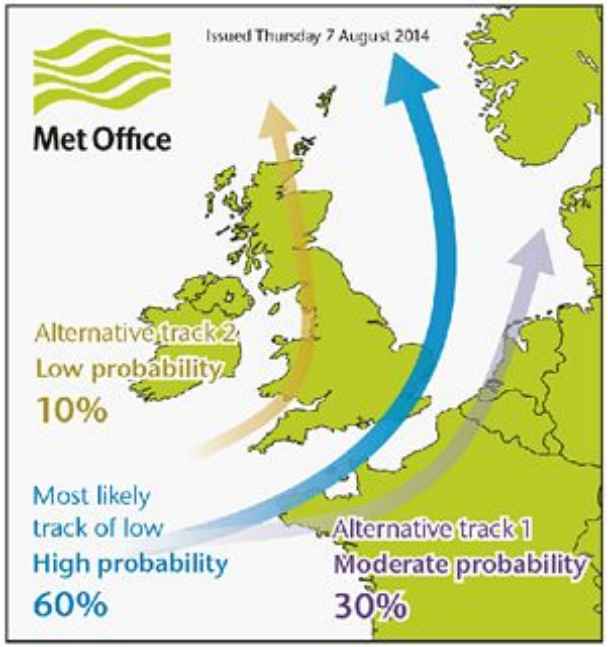
- All forecasts have errors
- It can be important for the user to know about the uncertainty in a forecast
  - what else could happen? what is the worst possibility?
- This is not a new idea
  - Forecasters are used to adjusting their forecast with their experience of model errors (flow dependence, forecast range dependency)
  - Inconsistency of the forecasts (in time, from one model to the other) were used as indication of the (un-)predictability of scenarios
- Ensembles give more information – they provide an explicit, detailed representation of model uncertainties, and potential of unusual events

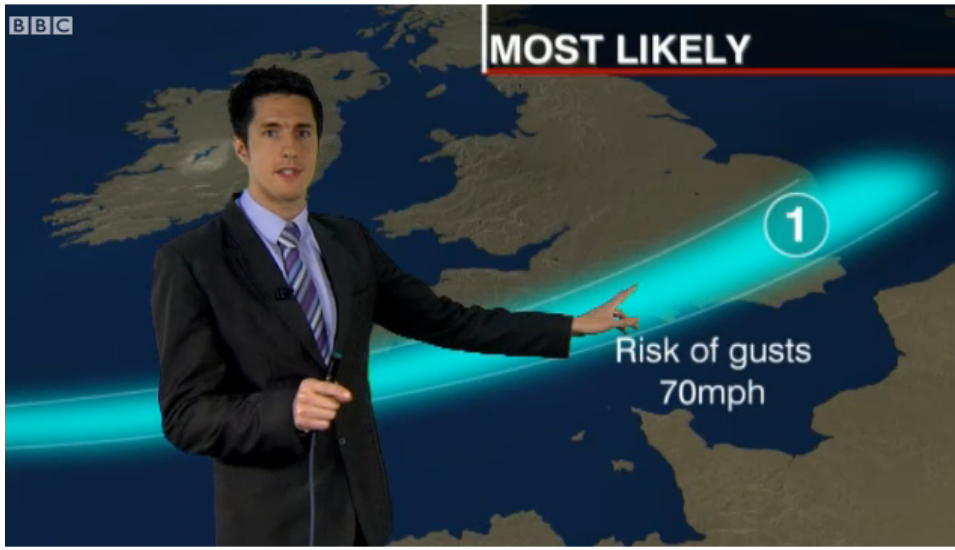
Uncertainty information to public





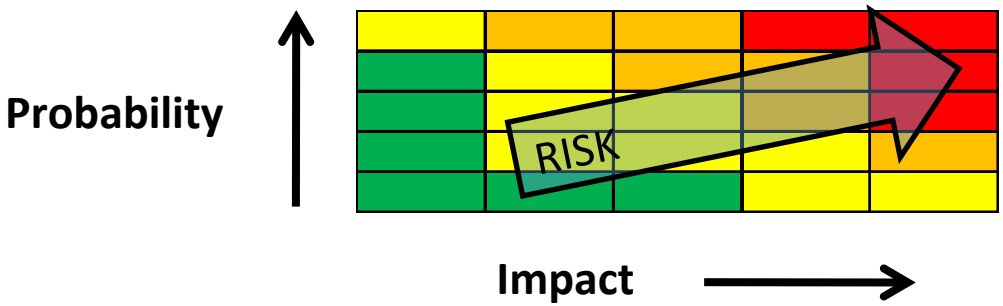
Uncertainty information to public

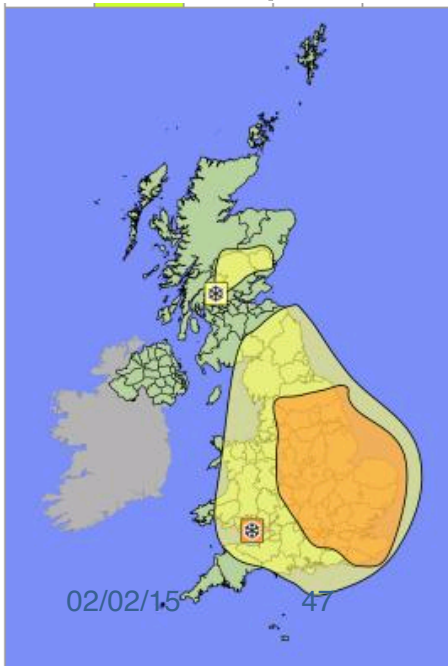




Value: the economic or societal worth of forecasts

- Forecasts only have value if people use them
  - make a decision or take an action which would not otherwise have been made
- Decisions can be based on deterministic forecasts, but …
- Decisions involve assessment of risk
- Risk = probability x impact
- To make a good decision need to know the probability and the impact (consequence to the individual user)





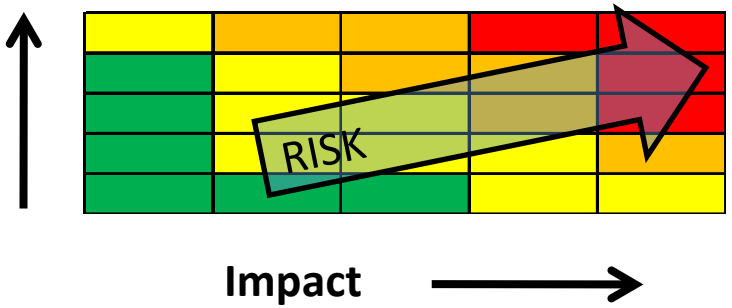
Met Office

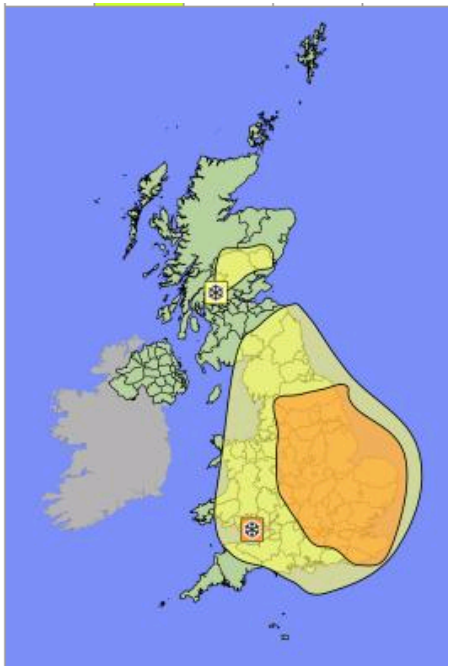
Amber Alert of Snow 04 Feb 2012, 12:00

Issued at - **03 Feb 2012, 12:07**
Valid from - **04 Feb 2012, 12:00**
Valid to - **04 Feb 2012, 23:59**

A band of wet weather over Northern Ireland and western Scotland early Saturday will move slowly east and southeastwards across the United Kingdom during the day. As it does so it will readily turn to sleet and snow away from western and southwestern coastal areas giving accumulations of 2-5cm in places and 5-10cm widely in the amber warning area. The snow is expected to turn to rain over some northwestern areas later. As skies then clear in this area after dark, icy patches will develop. The public are advised that this is likely to lead to some travel disruption, and it is recommended to keep up to date with forecasts as the event approaches.

The public is advised to take extra care, further information and advice can be found here: http://www.metoffice.gov.uk/weather/uk/links.html





Met Office cold weather alert

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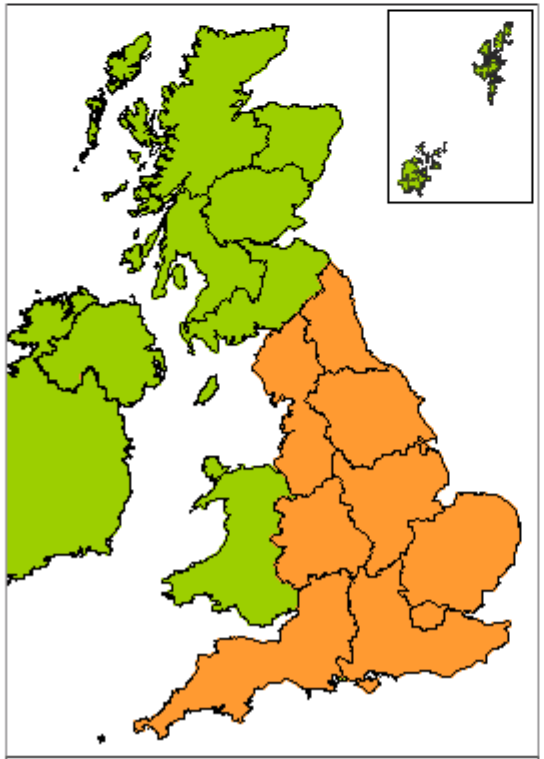
  - Cold weather alert
  - Surface pressure charts
  - Mountain area forecast
  - Severe weather advice
  - Severe weather impact links



Current alert level: Level 3 - Cold Weather Action in one or more regions of England

Issued at: Saturday 4 February 2012 at 10:04

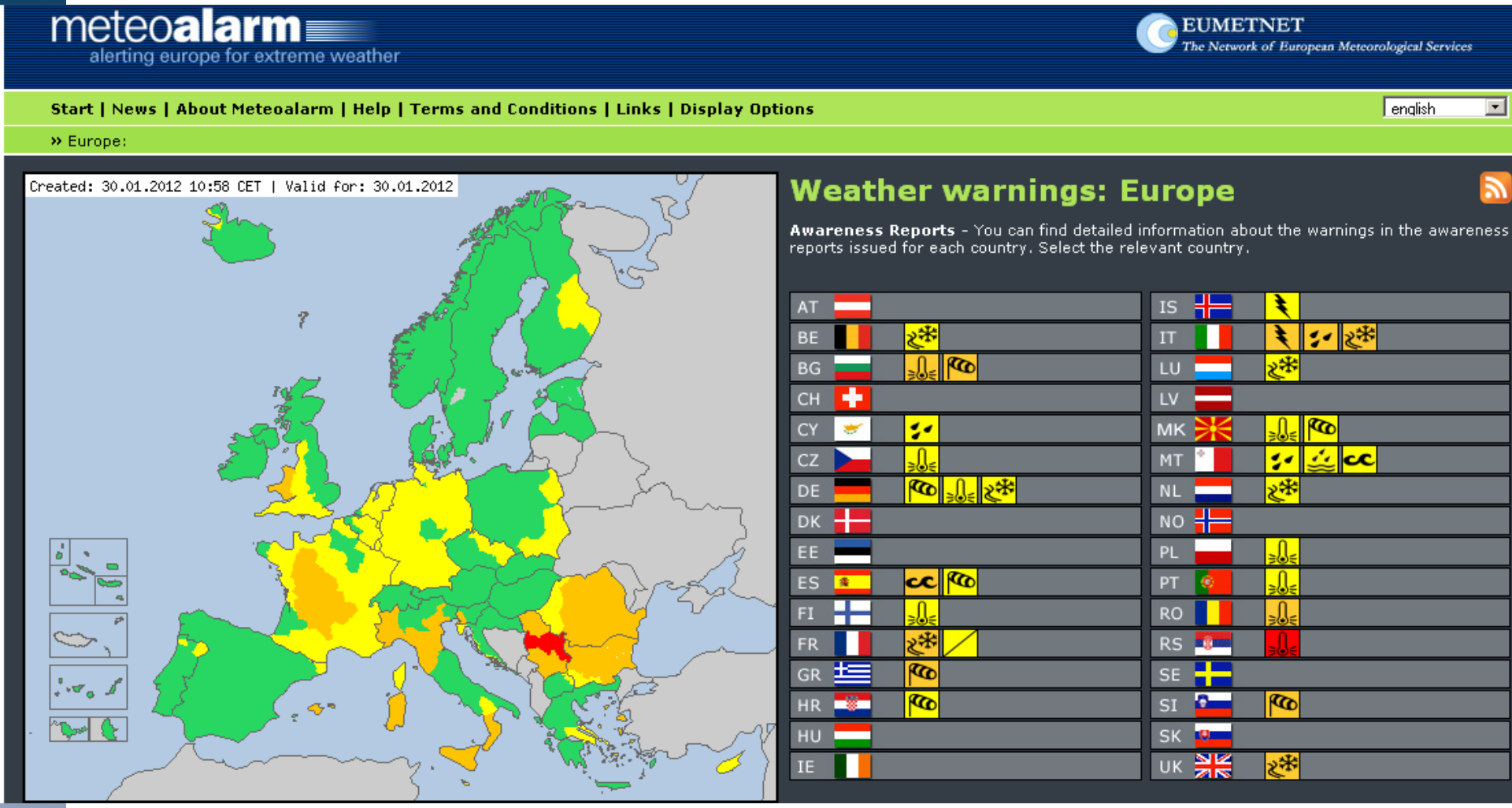
There is a 100 % probability of severe cold weather/icy conditions/heavy snow between 1000 on Saturday and 1000 on Wednesday in parts of England. This weather could increase the health risks to vulnerable patients and disrupt the delivery of services. Please refer to the national Cold Weather Plan and your Trust's emergency plan for appropriate preventive action.

A band of rain, sleet and snow during today and tomorrow morning will bring a transition to less cold conditions for many when compared to previous days. Mean temperatures however are expected to continue to be below 2 Celsius into next week in all parts of England, except Southwest England. Please see the Met Office Severe Weather Warnings for the latest information regarding warnings in your region.

Regional breakdown

Region	Risk	Comments

MeteoAlarm


meteoalarm
alerting europe for extreme weather
EUMETNET
The Network of European Meteorological Services
Start | News | About Meteoalarm | Help | Terms and Conditions | Links | Display Options
english
» Europe:
Created: 30.01.2012 10:58 CET | Valid for: 30.01.2012
Weather warnings: Europe
Awareness Reports - You can find detailed information about the warnings in the awareness reports issued for each country. Select the relevant country.
AT
BE
BG
CH
CY
CZ
DE
DK
EE
ES
FI
FR
GR
HR
HU
IE
IS
IT
LU
LV
MK
MT
NL
NO
PL
PT
RO
RS
SE
SI
SK
UK

Summary - why do we run an ensemble?

- The best method we have to produce flow-dependent probabilistic weather forecasts
- The ensemble gives a range of future scenarios consistent with our knowledge of the initial state and model capability
  - explicit indication of uncertainty in today's forecast
  - Potential of high-impact events
  - Range of ensemble-based products for different users
- Ensembles provide the required input for a range of application models (hydrology, ship routing, energy demand), explicitly propagating the atmospheric uncertainty
- Read more in the ECMWF products User Guide
  - http://www.ecmwf.int/products/forecasts/guide/

Ensemble references

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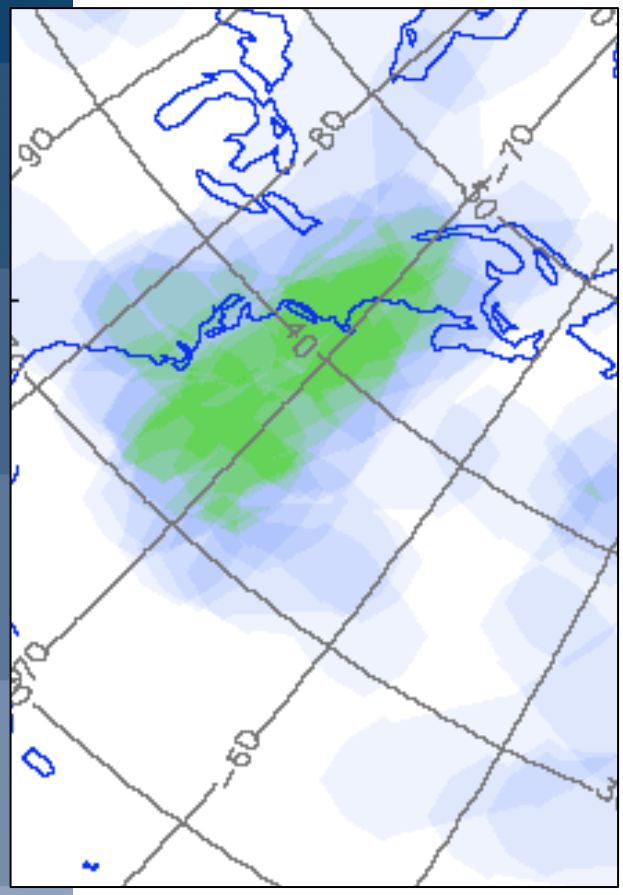
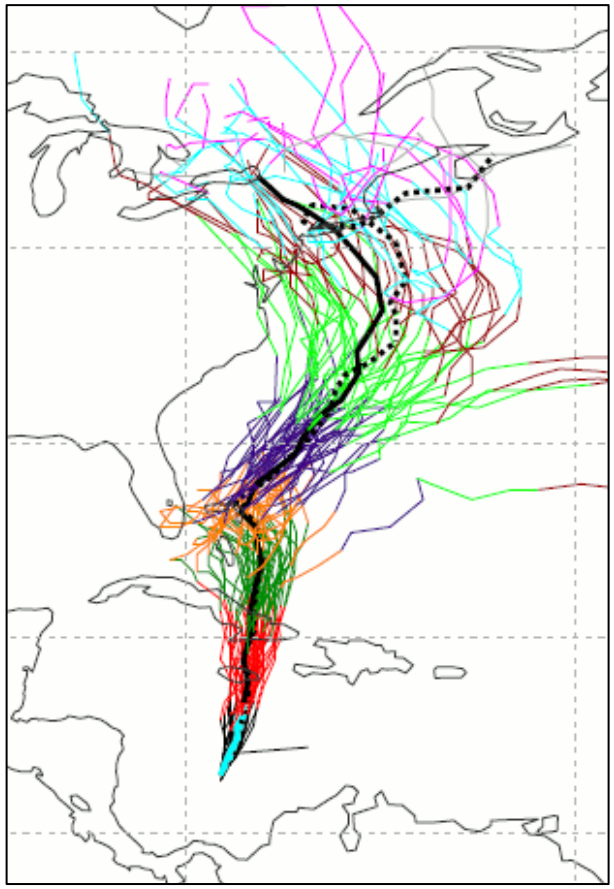
- Palmer, T. N., Buizza, R., Doblas-Reyes, F., Jung, T., Leutbecher, M., Shutts, G. J., Steinheimer M., & Weisheimer, A., 2009: Stochastic parametrization and model uncertainty. ECMWF RD TM 598, Shinfield Park, Reading RG2-9AX, UK, pp. 42.
- Richardson, D. S., 2000. Skill and relative economic value of the ECMWF Ensemble Prediction System. *Q. J. R. Meteorol. Soc.,* 126, 649-668.
- Richardson, D.S., 2003. Economic value and skill. In *Forecast verification: a practitioner's guide in atmospheric science*, Jolliffe, I. T. and Stephenson, D. B., Eds., Wiley, 240pp.
- Vitart, F., Buizza, R., Alonso Balmaseda, M., Balsamo, G., Bidlot, J. R., Bonet, A., Fuentes, M., Hofstadler, A., Molteni, F., & Palmer, T. N., 2008: The new VAREPS-monthly forecasting system: a first step towards seamless prediction. *Q. J. Roy. Meteorol. Soc.*, 134, 1789-1799.
- Zsoter, E., Buizza, R., & Richardson, D., 2009: 'Jumpiness' of the ECMWF and UK Met Office EPS control and ensemble-mean forecasts'. *Mon. Wea. Rev.*, 137, 3823-3836.
- Zsótér E. 2006. Recent developments in extreme weather forecasting. ECMWF Newsletter 107, Spring 2006, pp 8–17.
- Zsoter, E., Pappenberger, F. and Richardson, D., 2014, Sensitivity of model climate to sampling configurations and the impact on the Extreme Forecast Index. Met. Apps. doi: 10.1002/met.1447

Superstorm Sandy

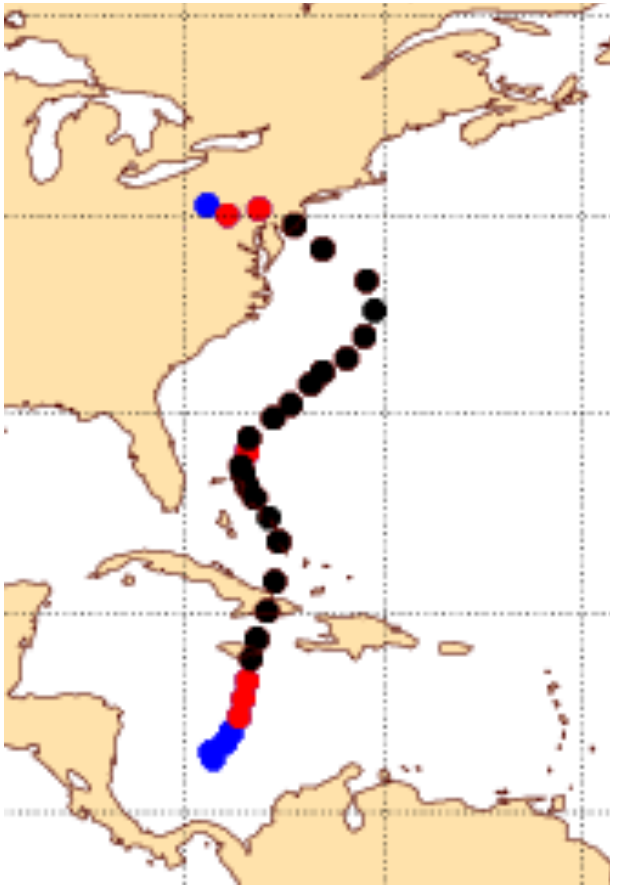
First indications
9.5 days before landfall



Track forecasts
6.5 days before landfall



Observed track of Sandy



2 days before Sandy formed (9.5 days before landfall in New Jersey) there was already a significant probability (25%) of a severe wind storm affecting NE USA

Sandy: ENS PV evolution

Forecast from 0 UTC on 25 October

three ensemble members:
- control (top)
- M09 (bottom L) “caught” too late
- M19 (bottom R) “escaped”

PV on 320K (6h steps)