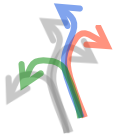


Probabilistic prediction at ECMWF

Roberto Buizza

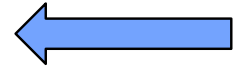
European Centre for Medium-Range Weather Forecasts

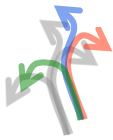
*Acknowledgements to Magdalena Balmaseda, Laura Ferranti,
Martin Janousek, Martin Leutbecher, David Richardson, Tim Stockdale,
Frederic Vitart, and the Predictability Division.*



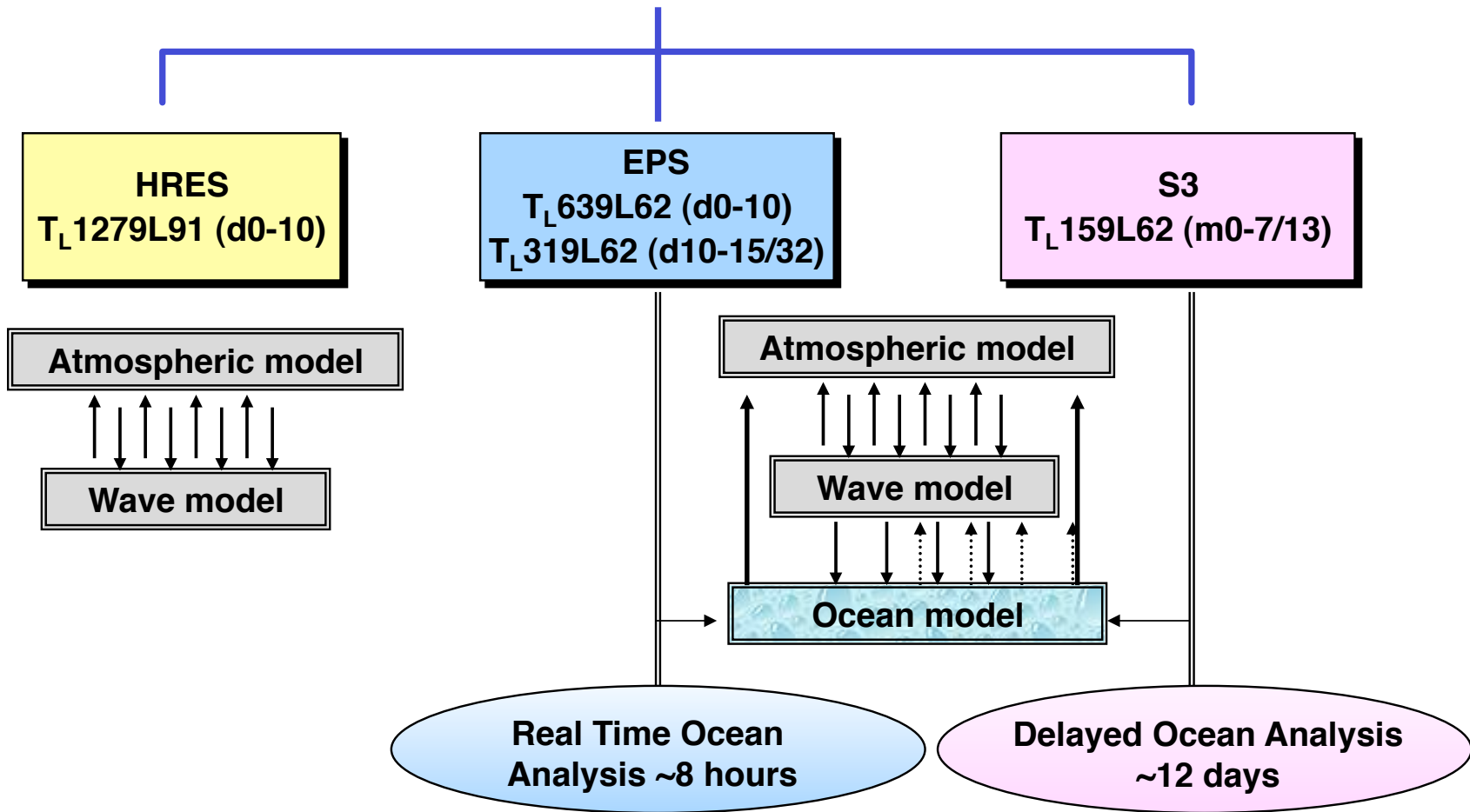
Outline

1. ECMWF medium-range probabilistic forecast systems: the EPS
2. ECMWF seasonal probabilistic forecast systems:
 - a) The operational S3 and EUROSIP
 - b) The forthcoming S4 (Q4-2011)
3. Conclusions





1. Baseline operational systems (2011)





1. The operational ECMWF EPS

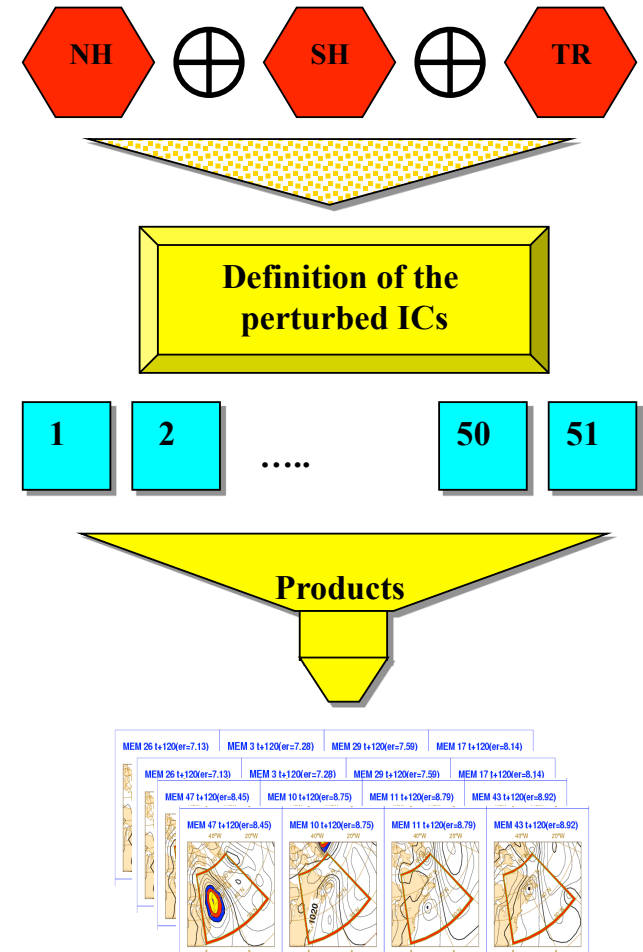
The operational version of the EPS includes 51 forecasts with resolution:

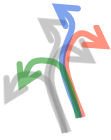
- $T_L639L62$ (~32km, 62 levels) from day 0 to 10
- $T_L319L62$ (~64km, 62 levels) from day 10 to 15 (32 at 00UTC on Thursdays).

Initial uncertainties are simulated by adding to the unperturbed analyses a combination of T42L62 singular vectors, computed to optimize total energy growth over a 48h time interval (OTI), and perturbations generated using the new ECMWF Ensembles of Data Assimilation (EDA) system.

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

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





1. Simulation on initial unc. with singular vectors

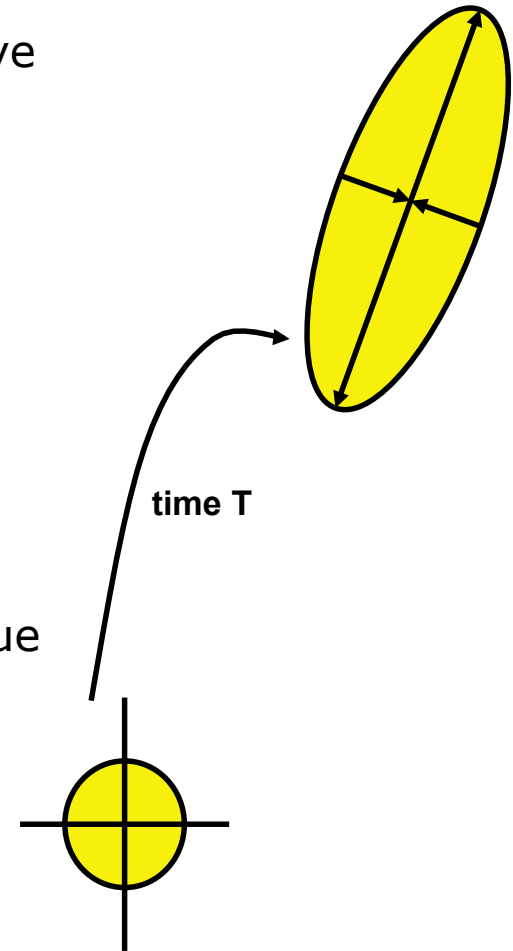
Since its implementation in 1992, initial uncertainties have been simulated in the EPS using **singular vectors**, i.e. perturbations with the fastest finite-time growth rate. Perturbation growth can be measured in terms of total energy E with a total-energy norm, and a perturbation time evolution can be linearly approximated:

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

Once the adjoint of the tangent forward propagator with respect to the total-energy norm is defined, total-energy singular vectors can be computed by solving an eigenvalue problem:

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

$$E^{-1/2} L^* E L E^{-1/2} \mathbf{v}_j = \sigma_j^2 \mathbf{v}_j$$





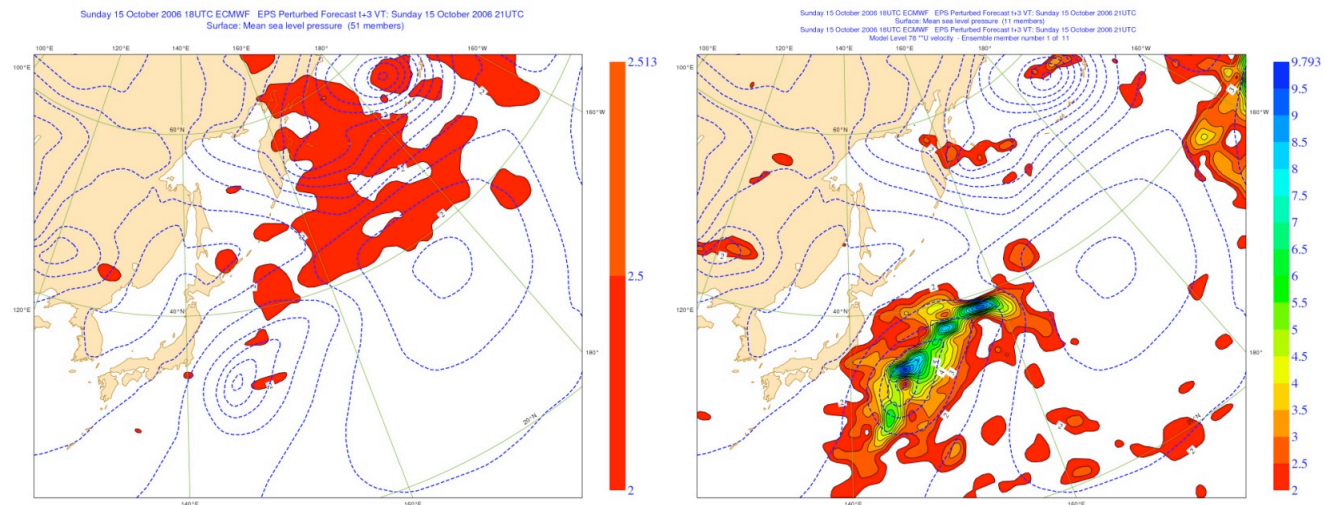
1. Simulation of initial unc. using the EDA

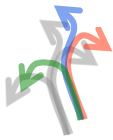
Since 22 June 2010, differences between 6h perturbed forecasts from the ECMWF Ensemble Data Assimilation system have been combined with singular vectors to generate the EPS initial perturbations.

The T_L399L91 EDA perturbed analyses are generated by **randomly perturbing the observations and the SST**, and by running the forecast model with the SPPT stochastic scheme. The random perturbations are defined by sampling a normal distribution with the observation error standard deviation.

It is worth to point out that since 18 May 2011, the EDA has been used to specify the background errors “of the day” in the high-resolution 4D-Var.

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

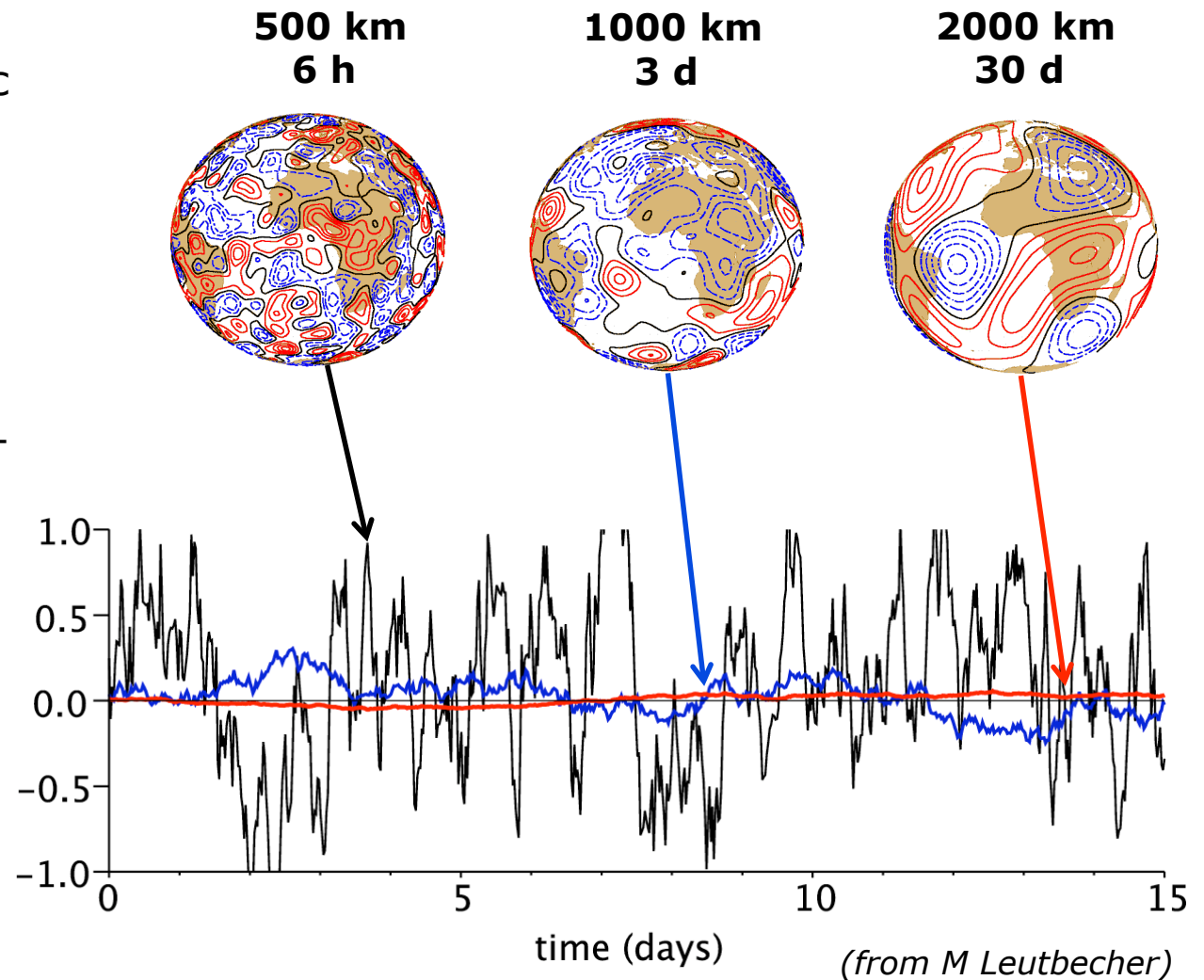


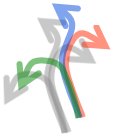


1. Simulation of model unc.: SPPT(1L) & SPPT(3L)

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

Since Nov 2010, the scheme includes a multi-scale pattern generator to account for parameterization errors on multiple spatial and temporal scales [SPPT(3L)].



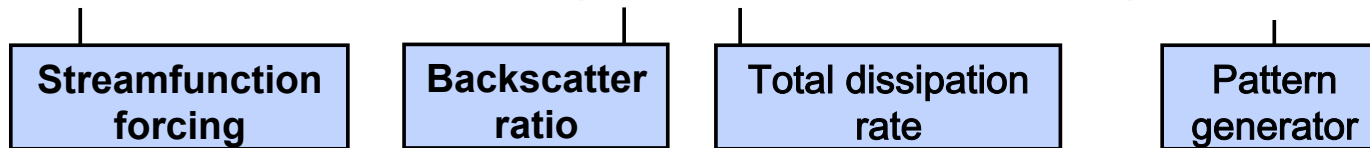


1. Simulation of model unc.: SPBS

Since Nov 2010, a stochastic backscatter scheme (SPBS) is also used in the EPS:

- Rationale: a fraction of the dissipated energy is backscattered upscale and acts as streamfunction forcing for the resolved-scale flow (*Shutts & Palmer 2004, Shutts 2005, Berner et al 2009*)
- Streamfunction forcing in the latest formulation (*M Steinheimer and G Shutts, 2010*) is given by :

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



Recent improvements/updates include:

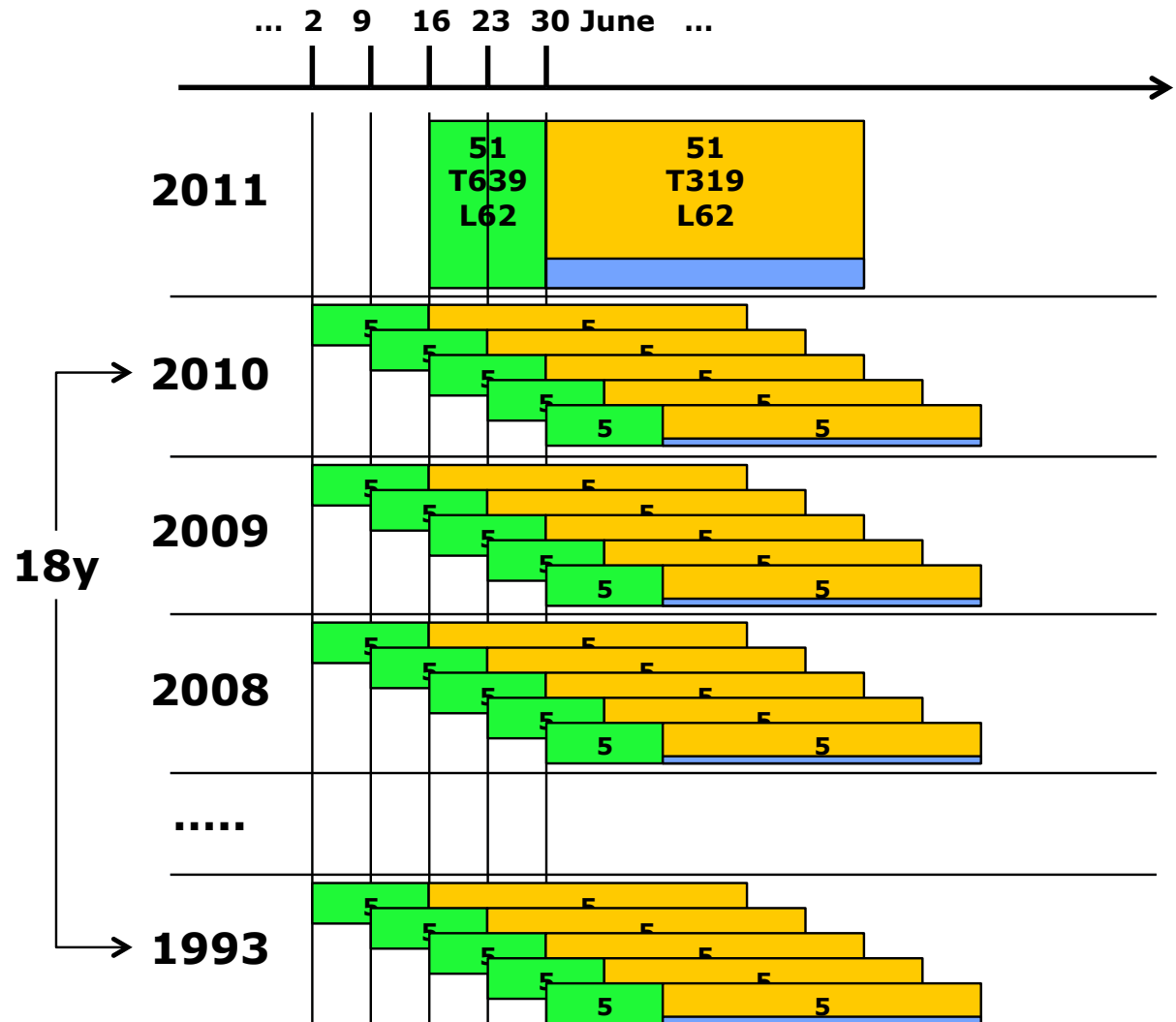
- Revised convective dissipation calculation
- Revised dissipation rate smoothing
- Changed pressure dependency of vertical correlations
- Option to force only part of the spectrum [reduces computational cost and avoids problems seen with small scale forcing (dissipation – forcing feedback, etc.)]



1. The EPS re-forecast suite

Some of the EPS products are bias corrected and calibrated using 450 EPS forecasts run for the past years:

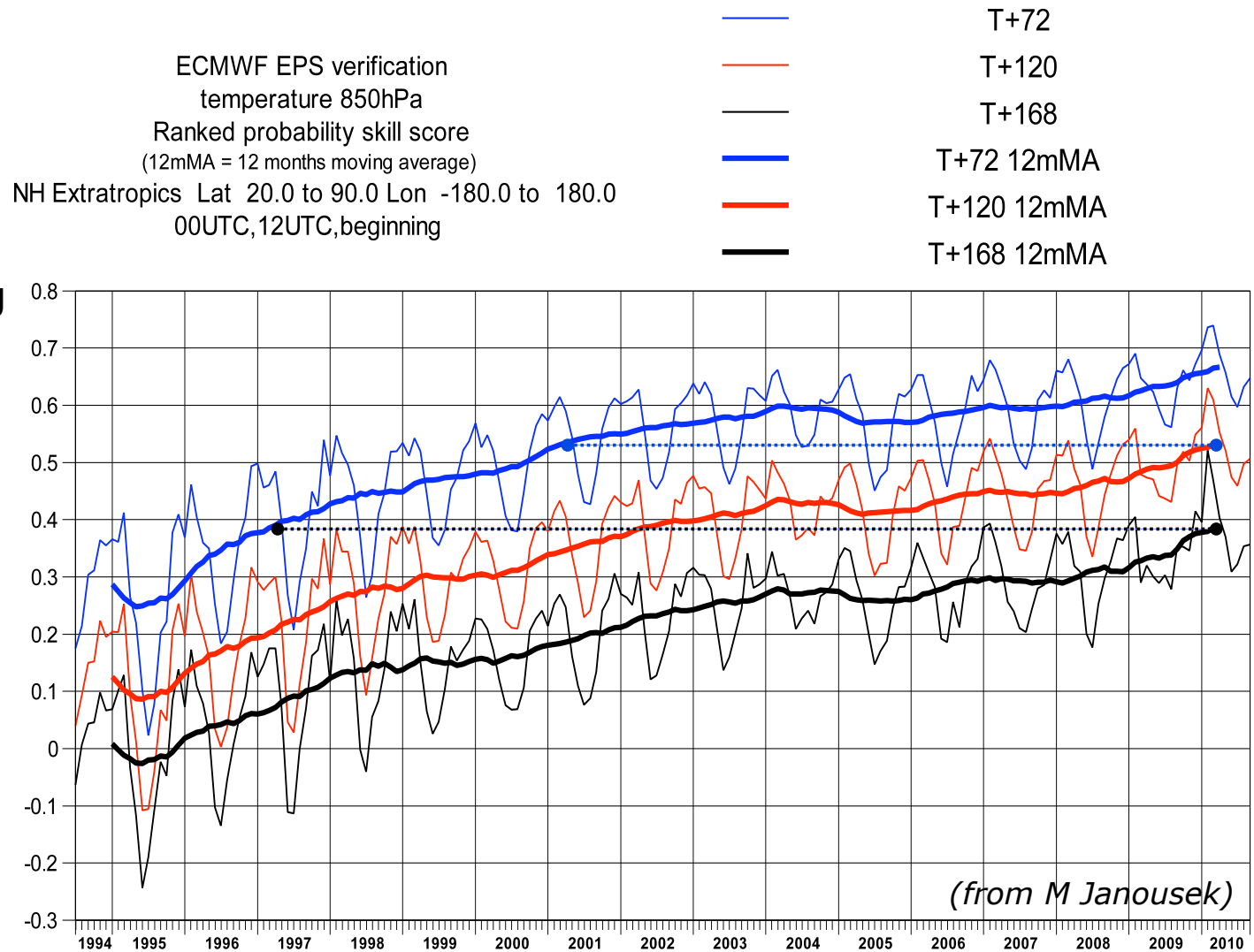
- 18 years (1993 – 2010)
- 5 initial dates (ERA-I): -14d, -7d, 0, +7d, +14d
- 5 members
- Same model version
- Same resolution
- Same fc length
- EDA initial perts from corresponding dates of current year (2011)
- Daily SVs





1. EPS performance: T850 v an, NH

The performance of the EPS has been improving continuously for upper level fields, as seen by looking at the RPSS for the t+72h, t+120h and t+168h probabilistic prediction of T850 over NH (verified against analyses). Results indicate a predictability gain of ~ 2 days/decade.





1. EPS performance: sp/sk relationship NH

In Nov 2010, two major changes were introduced to further improve the EPS spread/skill relation:

- The multi-scale SPPT(3L) replaced the original SPPT(1L), and SPBS was introduced
- The amplitude of the SV-initial perturbations was reduced by 50%

Ensemble Mean

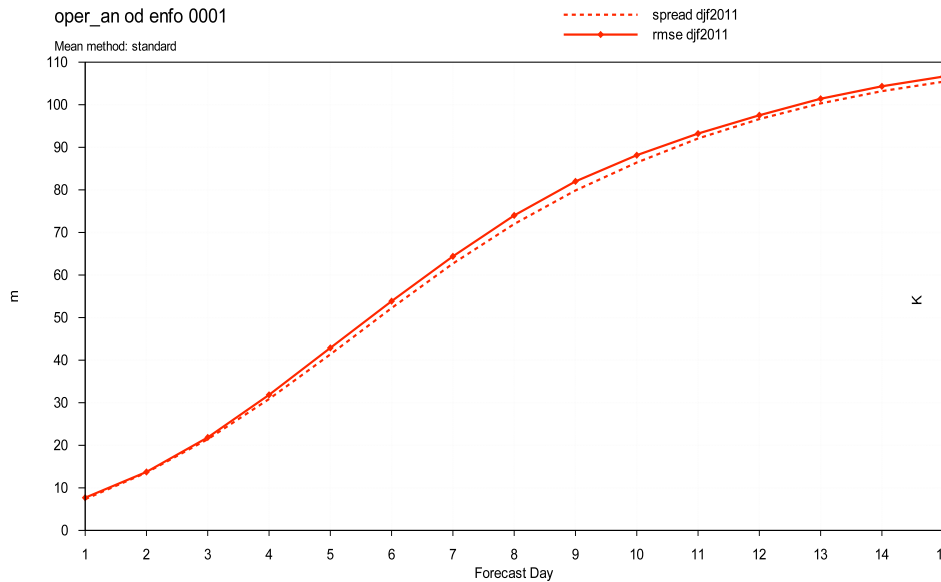
500hPa geopotential

N Hem Extratrop (lat 20.0 to 90.0, lon -180.0 to 180.0)

Date: 20101201 00UTC to 20110228 12UTC

oper_an od enfo 0001

Mean method: standard



Ensemble Mean

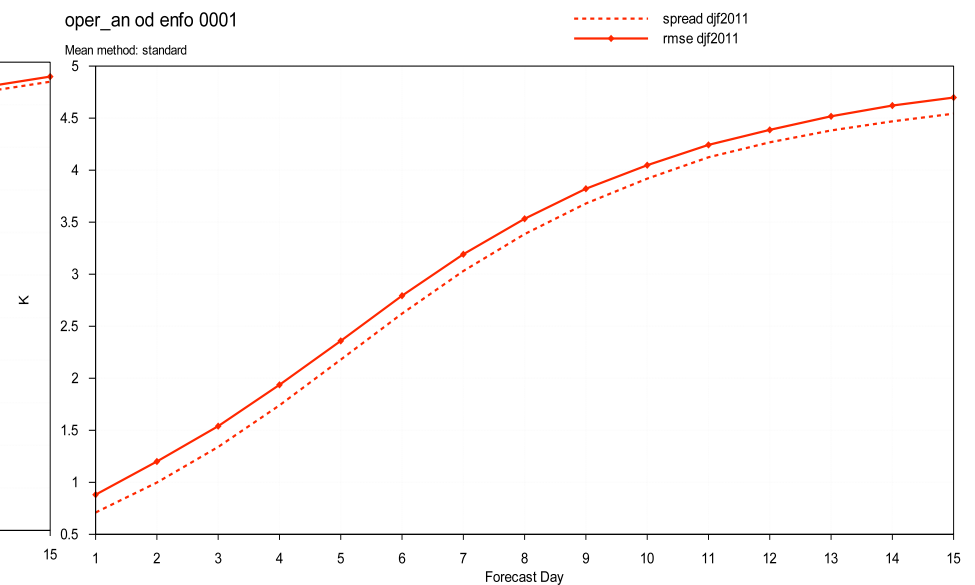
850hPa temperature

N Hem Extratrop (lat 20.0 to 90.0, lon -180.0 to 180.0)

Date: 20101201 00UTC to 20110228 12UTC

oper_an od enfo 0001

Mean method: standard

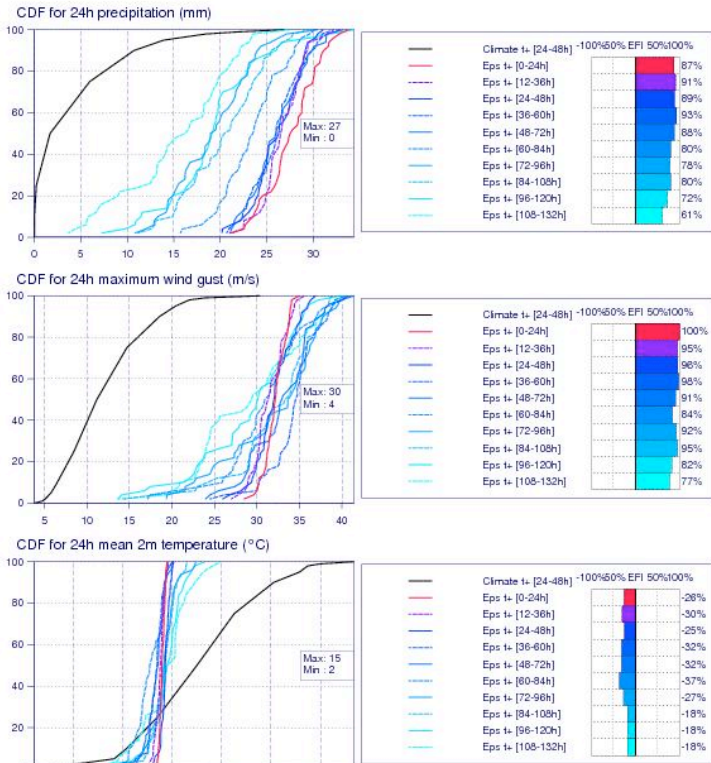


(from D Richardson)



1. EPS I-EFI for severe weather fc

Forecast and M-Climate cumulative distribution functions with EFI values at 57.87°N/6.44°W valid for 24 hours from Monday 23 May 2011 00 UTC to Tuesday 24 May 2011 00 UTC



Max: 27
Min: 0

Max: 30
Min: 4

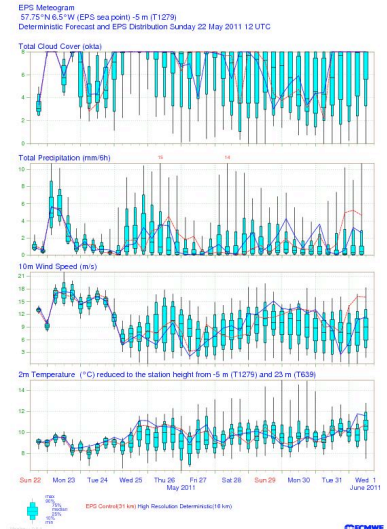
Max: 15
Min: 2

Max: 24-48h M-Climate extrema

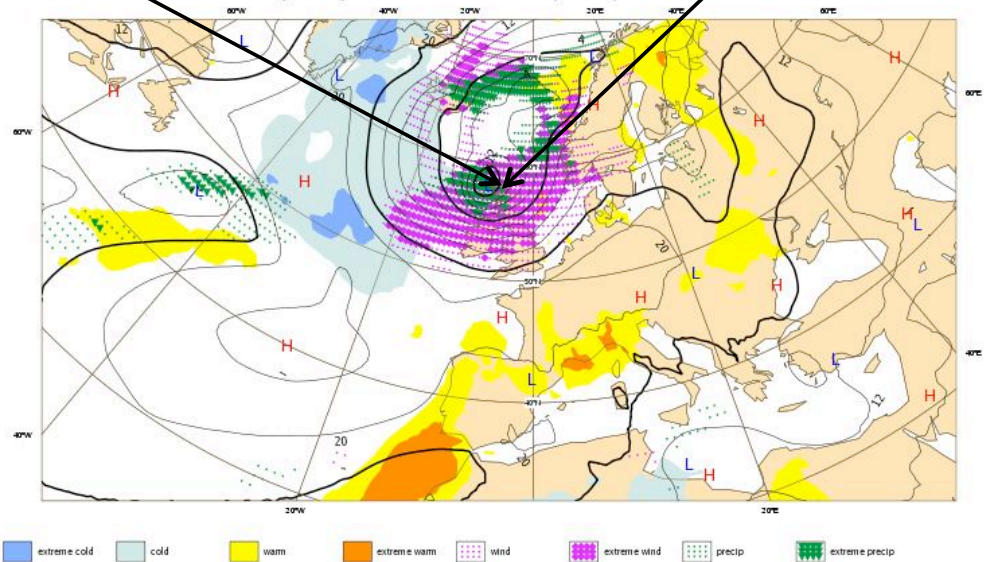
M-Climate: this stands for "Model Climate". It is a function of lead time, date (+/- ~15 days), and model version. It is derived by rerunning a 5 member ensemble, over the last 18 years, once a week (450 realisations). M-Climate is always from the same model version as the displayed EPS data. On this page only the 24-48h lead M-Climate is displayed.



The EPS-based I-EFI and related products (EPSgram, CDF) have become key products used to predict severe weather conditions.



Anomalous weather predicted by EPS: Sunday 22 May 2011 at 12 UTC
1000 hPa Z ensemble mean (Monday 23 May 2011 at 12 UTC)
and EFI values for Total precipitation, maximum 10m wind gust and mean 2m temperature (all 24h)
valid for 24 hours from Monday 23 May 2011 at 00 UTC to Tuesday 24 May 2011 at 00 UTC

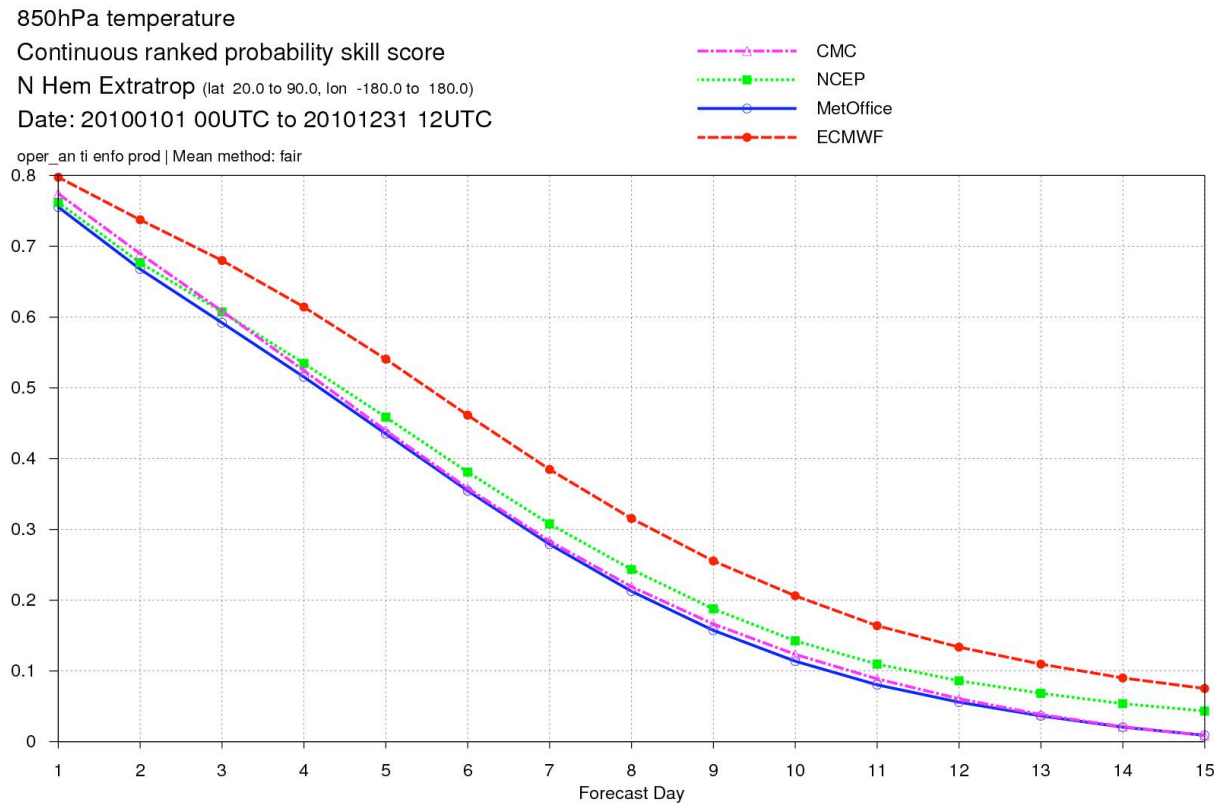




1. EPS & TIGGE: T850 NH, 2010, v ERA-int

CRPSS for T850
over NH for 2010
verified against own
analysis of the 4
best TIGGE
ensembles:

- ❖ ECMWF (red)
- ❖ NCEP (green)
- ❖ MetOffice (blue)
- ❖ CMC Canada (violet)



(from M Janousek)

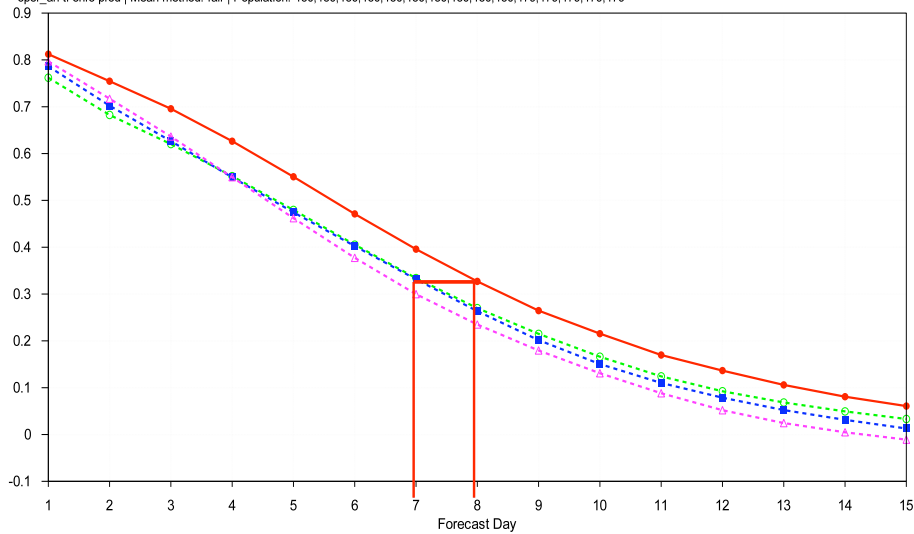


1. EPS & TIGGE: T/V850 NH, D10-JF11, v ERA-int

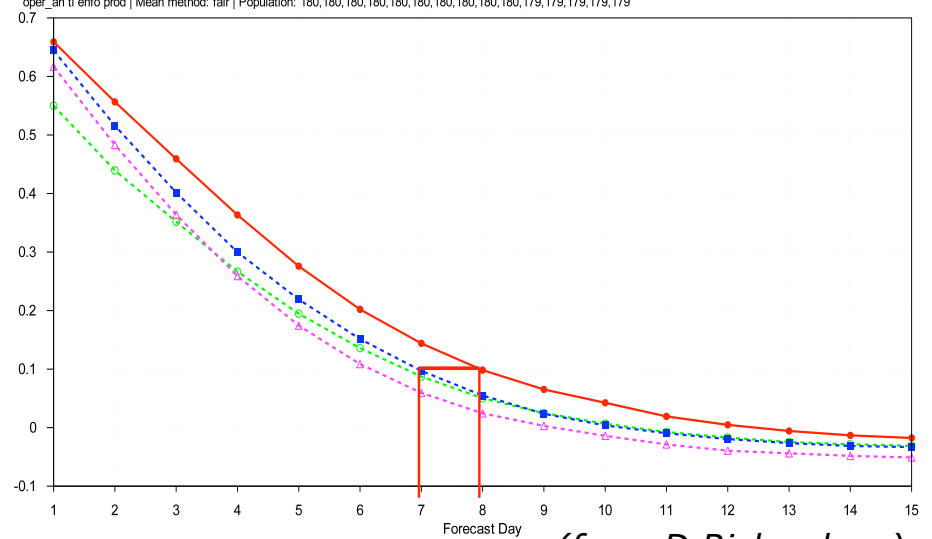
The skill of the TIGGE ensemble systems is continuously monitored.

This figures show the CRPSS for T850 (left) and WS850 (right) over NH for D10-JF11 verified against own analysis of the 4 best TIGGE ensembles: ECMWF (red), NCEP (green), MetOffice (blue) and CMC Canada (violet).

850hPa temperature
Continuous ranked probability skill score
N Hem Extratrop (lat: 20.0 to 90.0, lon: -180.0 to 180.0)
Date: 20101201 00UTC to 20110228 12UTC
oper_an ti enfo prod | Mean method: fair | Population: 180,180,180,180,180,180,180,180,180,180,179,179,179,179,179

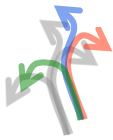


850hPa wind speed
Continuous ranked probability skill score
N Hem Extratrop (lat: 20.0 to 90.0, lon: -180.0 to 180.0)
Date: 20101201 00UTC to 20110228 12UTC
oper_an ti enfo prod | Mean method: fair | Population: 180,180,180,180,180,180,180,180,180,180,179,179,179,179,179



(from D Richardson)

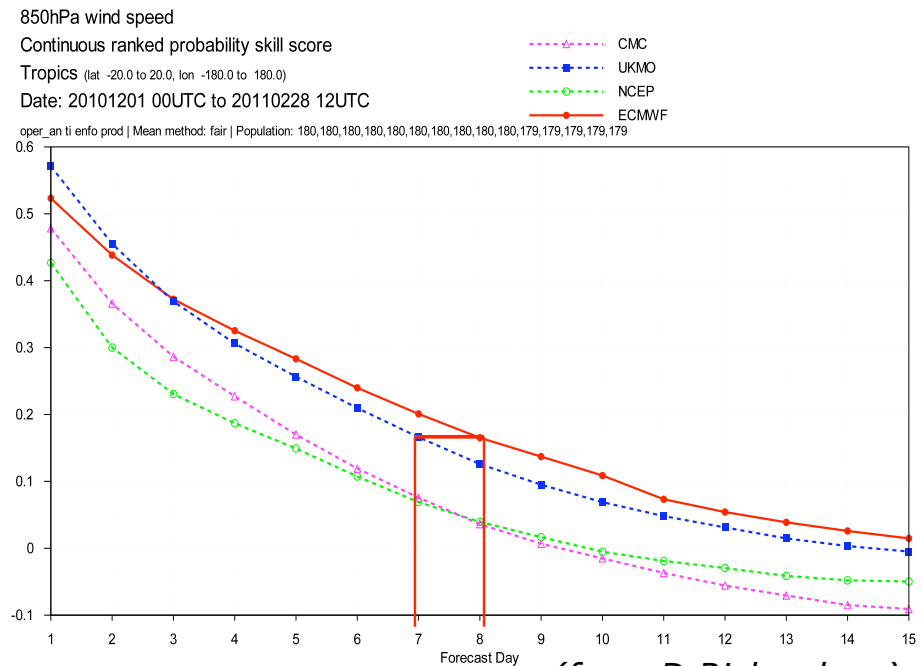
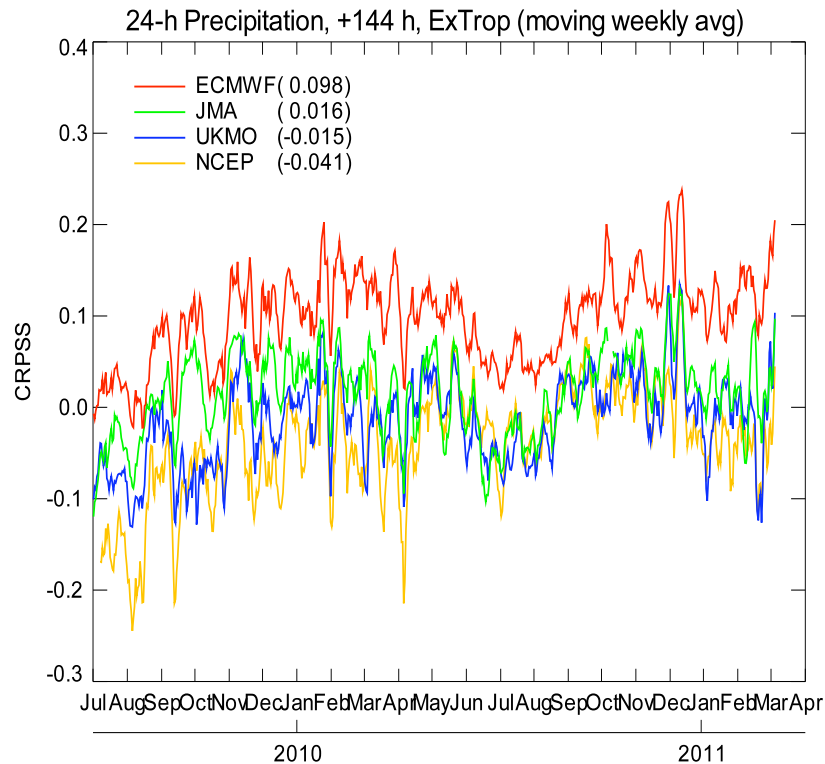




1. EPS & TIGGE: TP NHx and WS850 TR

The left figure shows the CRPSS for 24h accumulated precipitation verified against synop observations for 2010-11.

The right panel shows the CRPSS of WS850 over the tropics for D10-JF11 verified against ERA-Interim.



(from D Richardson)

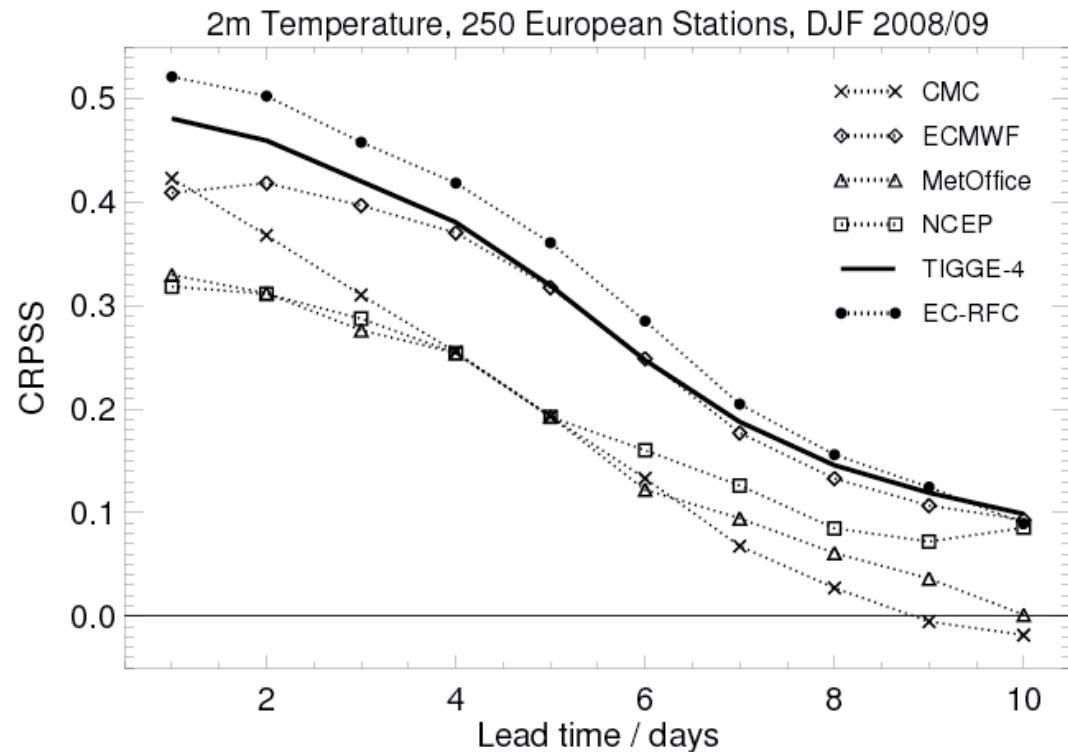




1. EPS & TIGGE: 2mT EU, D08JF09, obs

CRPSS for 2mT forecasts in DJF 2008/09 verified against observations at 250 European stations.

Results are shown for the four single-models (dotted lines with symbols) contributing to the TIGGE-4 multi-model (solid line without symbols) and the reforecast calibrated ECMWF model (dotted line with bullet symbols).



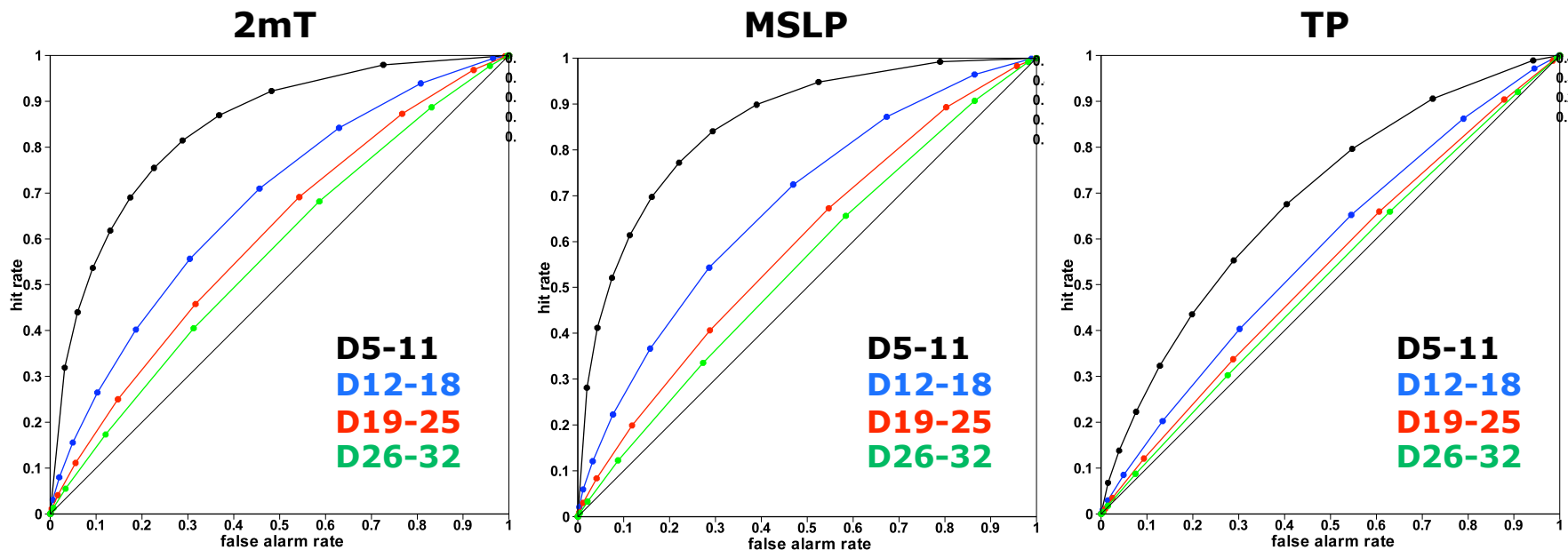
(from R Hagedorn)



1. 32d EPS scores over NH (ROCA)

Results based on 45 cases (ICs 4 times a year from '91 to '02, 5m) indicate that 32d EPS weekly average probabilistic forecasts of 2mT, MSLP and TP over NH land points have some level of skill up to forecast day 32.

This is shown hereafter for the probabilistic prediction of occurrence of 2mT, MSLP and TP values upper tercile values.

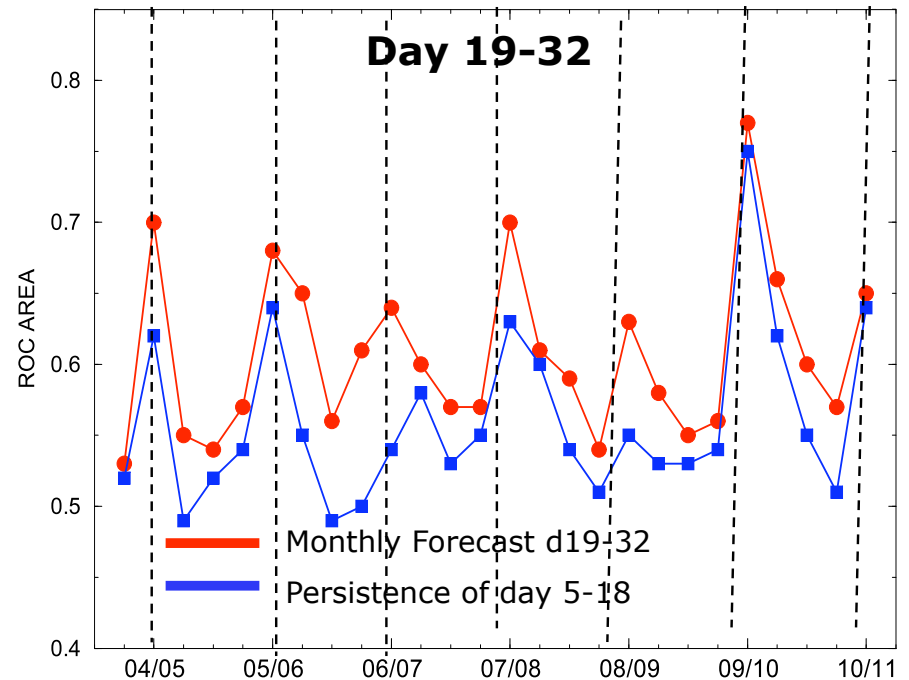
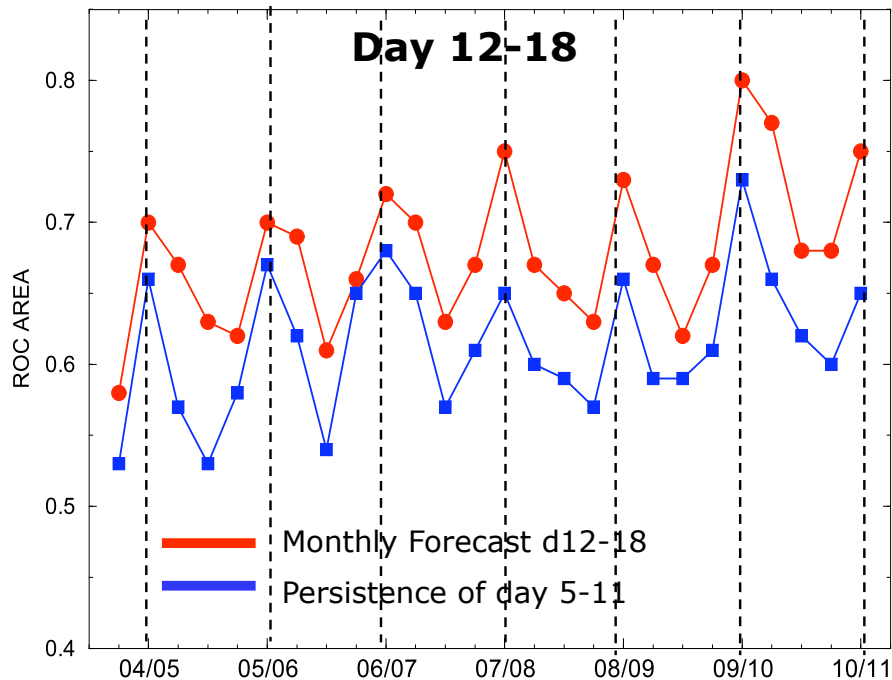


(from F Vitart)



1. EPS monthly extension: ROCA for 2mT over NH

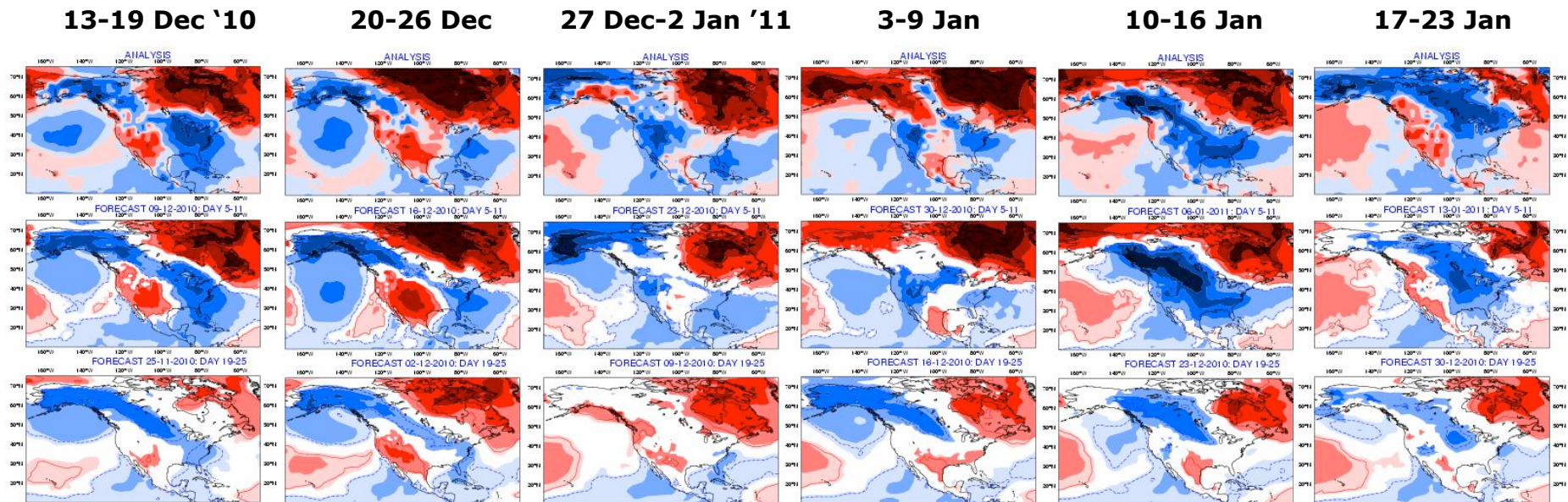
The EPS forecast range is extended to 32-days twice-a-week (00UTC of Mon and Thu). The performance of EPS weekly-average forecasts has also been continuously improving up to fc-day 18 (left). The signal for longer fc days is weaker (right). This is shown here in terms of the ROC-area for the probabilistic prediction of 2mT in the upper tercile.





1. EPS d5-11 & d19-25 fcs: 2mT NA, D10J11

These plots show a time series of weekly average analysis (top row) and EPS ensemble-mean forecasts for d5-11 (middle row) and d19-25 (bottom row) 2mT forecasts over North America valid for the period 13 Dec '10-23 Jan '11. Red/blue shading indicate areas where the ensemble-mean is significantly (at 10% level) warmer/colder than the model climatology.

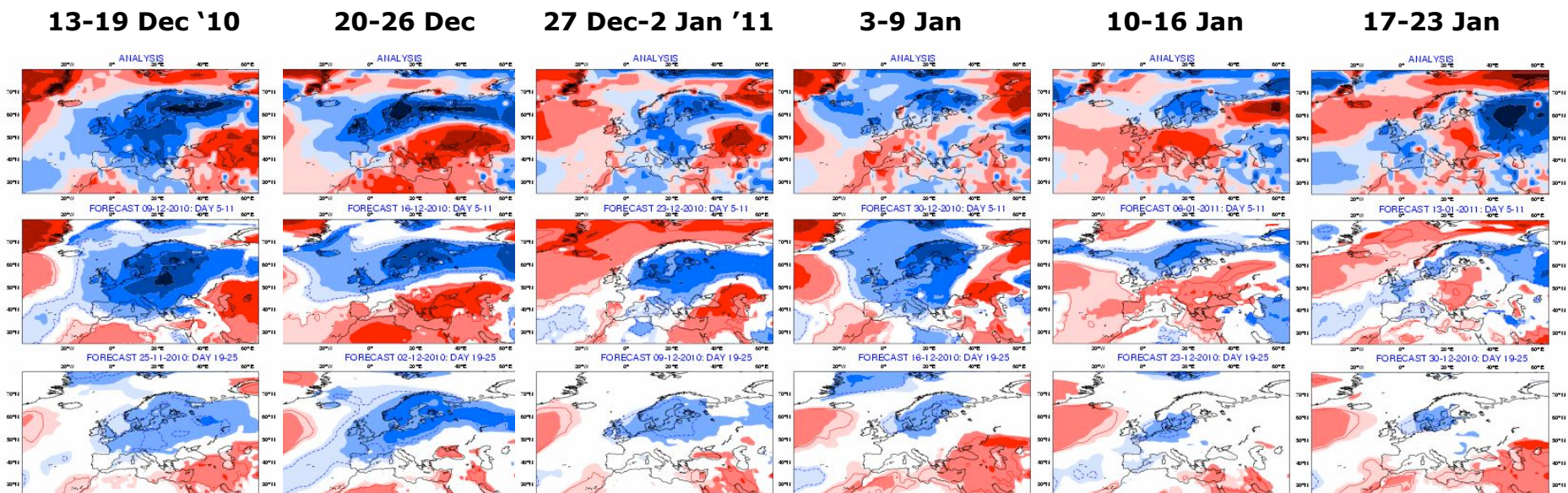




1. EPS d5-11 & d19-25 fcs: 2mT EU, D10J11

These plots show a time series of weekly average analysis (top row) and EPS ensemble-mean forecasts for d5-11 (middle row) and d19-25 (bottom row) 2mT forecasts over Europe valid for the period 13Dec '10-23 Jan '11.

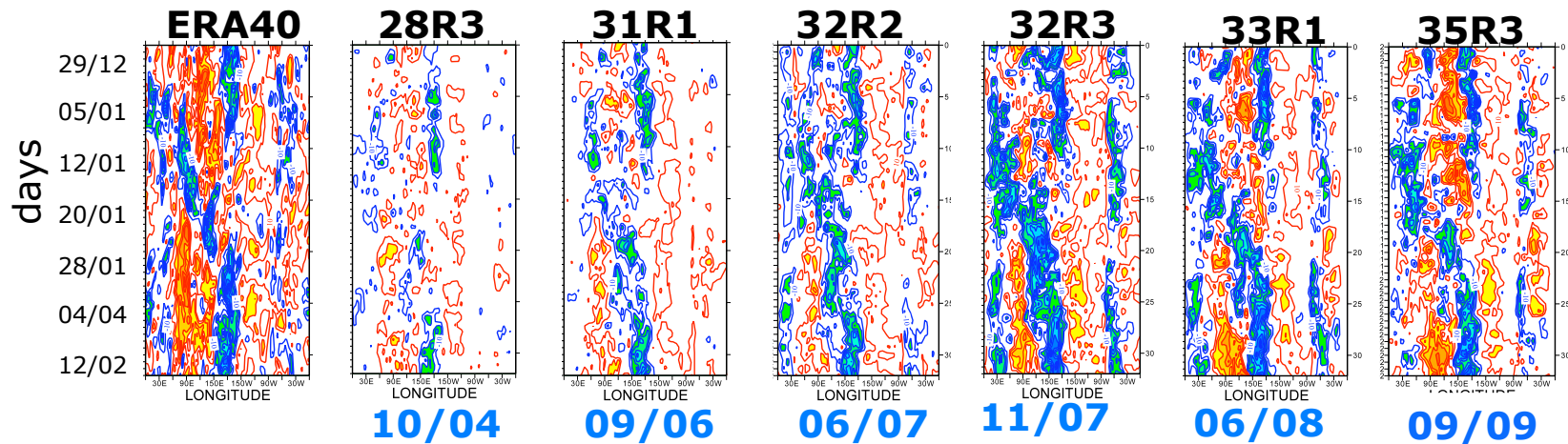
Red/blue shading indicate areas where the ensemble-mean is significantly (at 10% level) warmer/colder than the model climatology.





1. MJO: OLR anomalies at forecast day 15

This plot shows Hovmoeller diagrams of OLR from ERA40 (left panel) and forecasts at day 15 from 6 successive versions of the ECMWF model since the monthly forecasting system became operational. Results show that there has been a considerable improvement in the amplitude of the MJO since the monthly forecasting system became operational, especially after the revision of the convection scheme in 2007 (cycle 32r3). Despite these improvements, the propagation of the MJO is too slow over the Indian Ocean in the last model cycles.

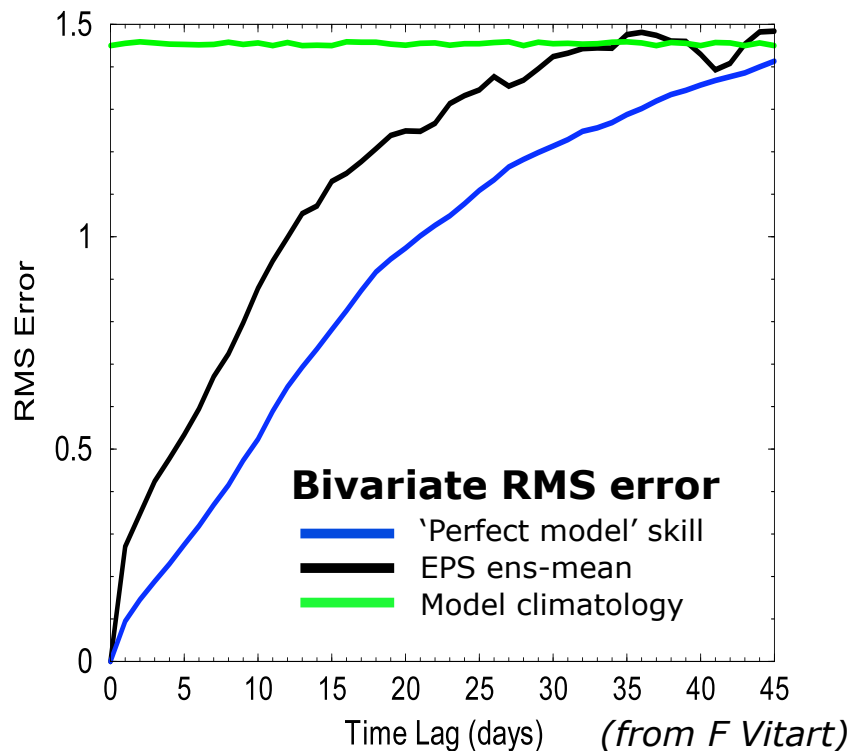
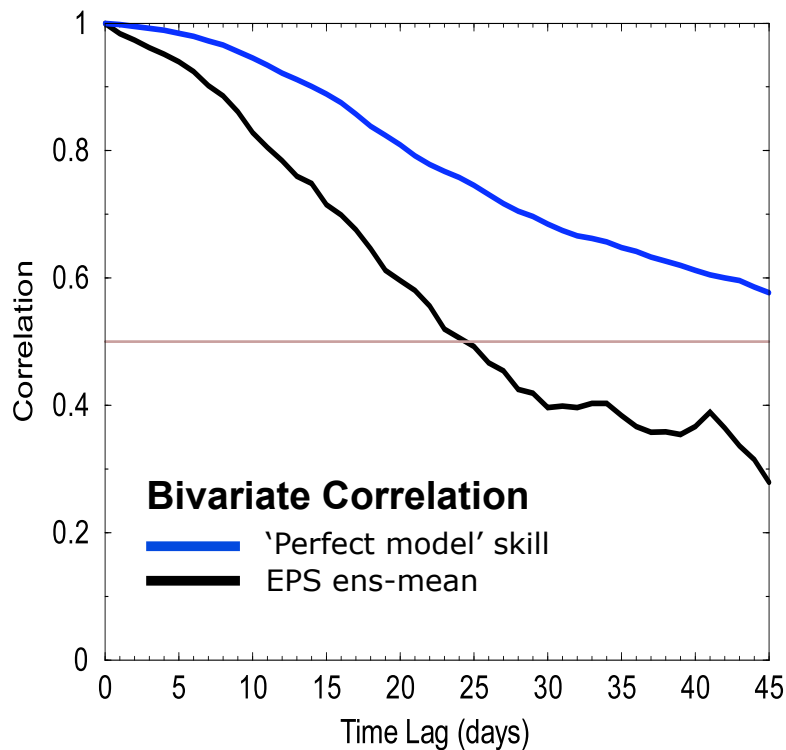


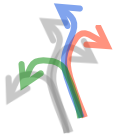
(from F Vitart)



1. EPS 32d (monthly) extension: MJO index

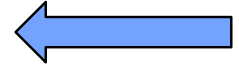
To assess MJO skill, forecasts are projected into combined EOFs of U200, U850 and OLR (*Wheeler & Hendon, 2004*). The two dominant combined EOFs represent about 12% of the total variance each, and give a good representation of the MJO propagation. These plots show the skill of EPS forecasts of the MJO along these dominant EOFs.





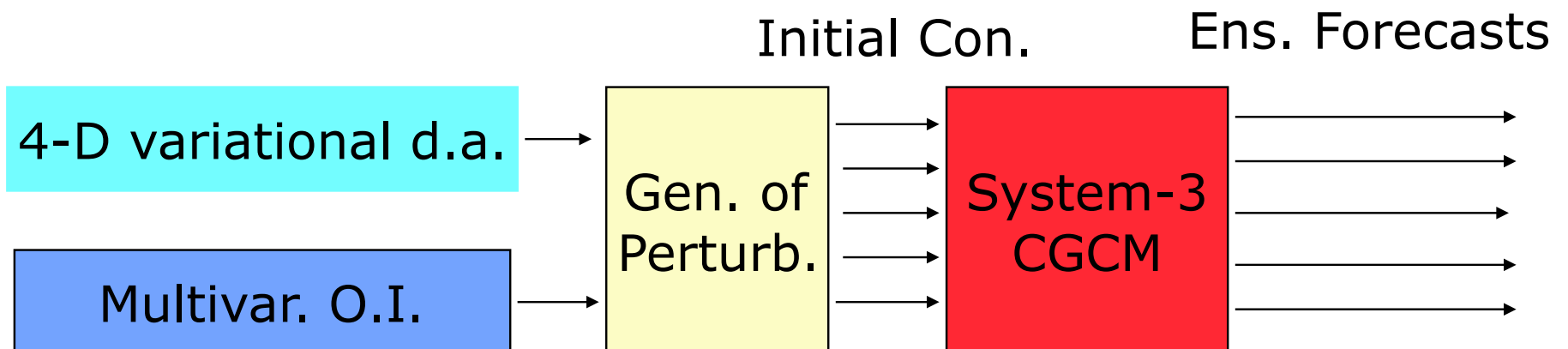
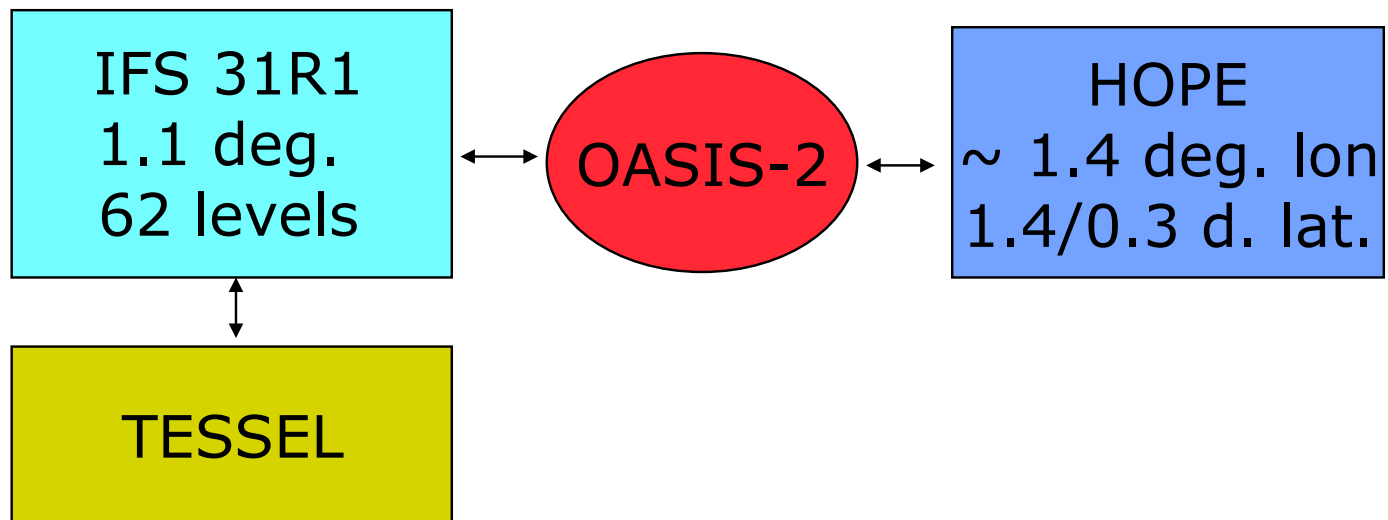
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1. ECMWF medium-range probabilistic forecast systems: the EPS
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2.a Seasonal prediction: S3 (2006-2011)





2.a S3 initial and model uncertainties

S3 simulates both initial and atmospheric model uncertainties:

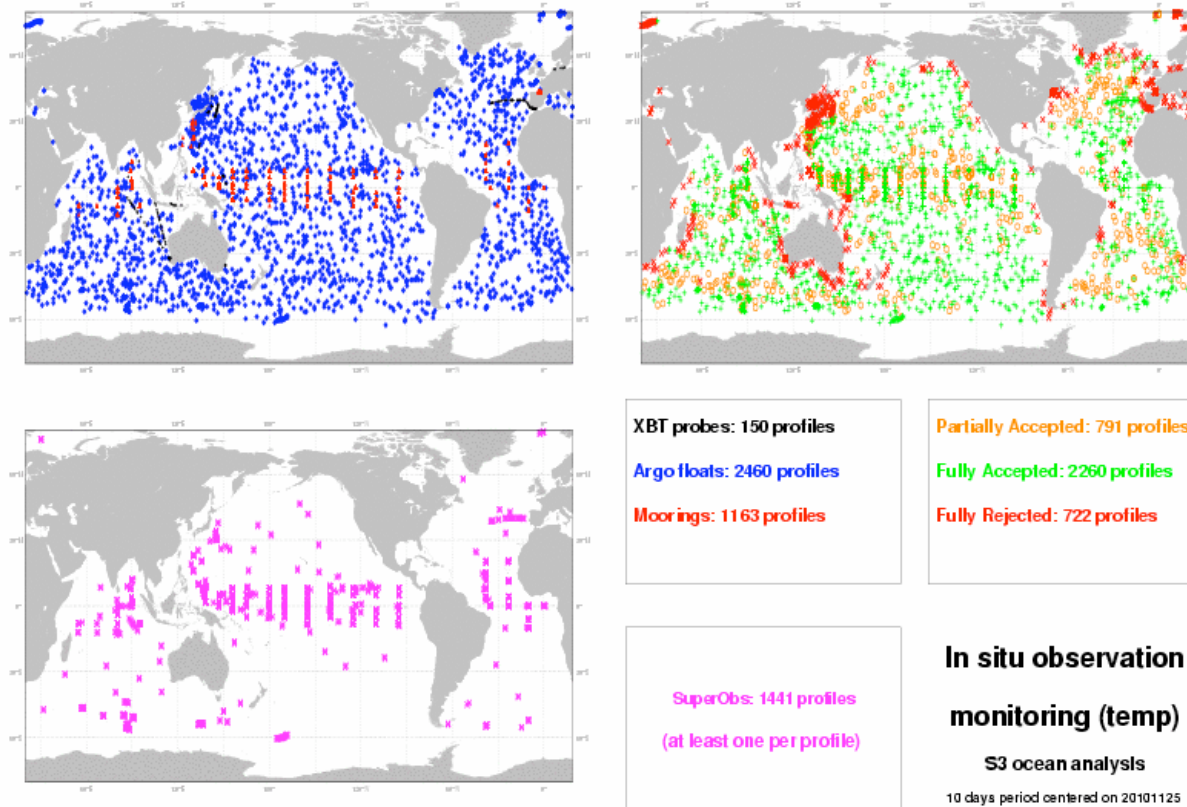
- Initial uncertainties:
 - **Ocean:** initial uncertainties are simulated by using a 5-member ensemble ocean assimilation system. Each analysis is created by using perturbed versions of the wind forcing.
 - **SST:** Prior to starting our coupled model forecasts, the ocean analyses are further perturbed by adding estimates of the uncertainty in the sea surface temperature to the ocean initial conditions.
 - **Atmosphere:** initial uncertainties are simulated using SVs
- Model uncertainties:
 - **Atmosphere:** model uncertainties are simulated by the SPPT scheme (as in the EPS)

System	Ocean Coupling	Ocean		SST	Atmosphere	
		Ini unc	Mod unc	Ini unc	Ini unc	Mod unc
EPS	>d10	--	--	yes	EDA+SV	SPPT(3TL)+SPBS
S3	d0	O-EDA	--	yes	SV	SPPT(1TL)



2.a S3 Ocean ICs: real-time analysis

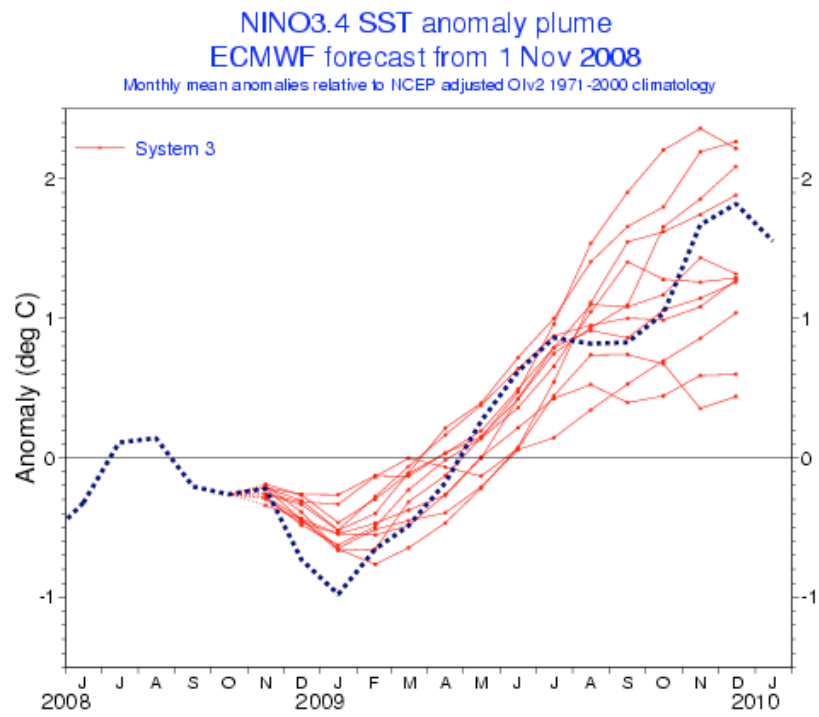
The ocean analysis is performed over a 10 day window. All obs within a centered 10-days window are gathered and quality controlled. In the S3 HOPE-OI system, in addition to subsurface temperature, the scheme assimilates altimeter derived sea-level anomalies and salinity data.



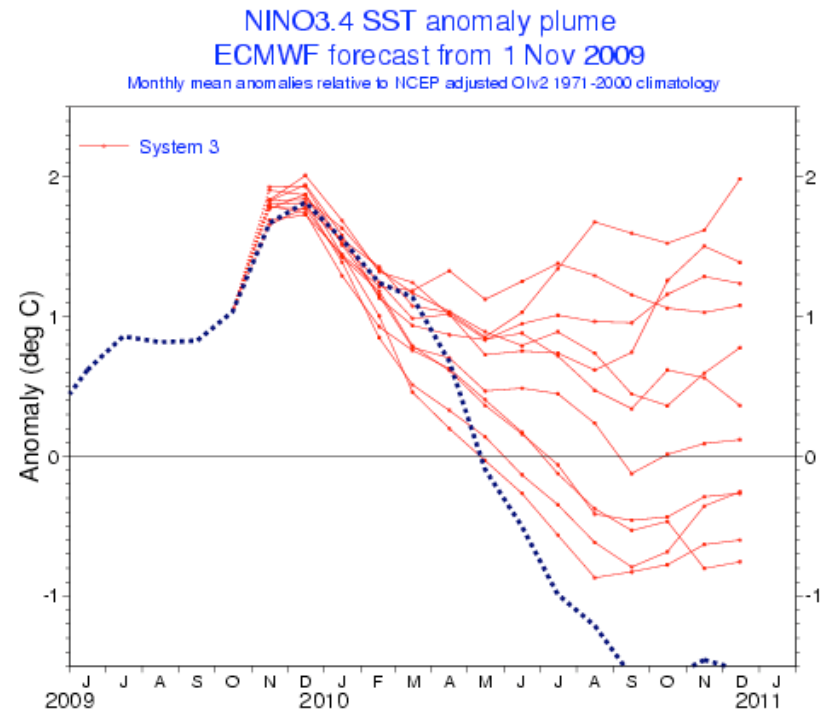


2.a S3 1-year ENSO outlook: 2009-2010

The tropics is the area where seasonal predictability is higher, controlled mainly by ENSO, a coupled ocean-atmosphere phenomenon centred over the tropical Pacific. S3 13m integrations are generated every quarter, based on an 11-member ensemble. They gave good predictions of the most recent El Nino events.



Forecast issue date: 15 Nov 2008



Forecast issue date: 15 Nov 2009



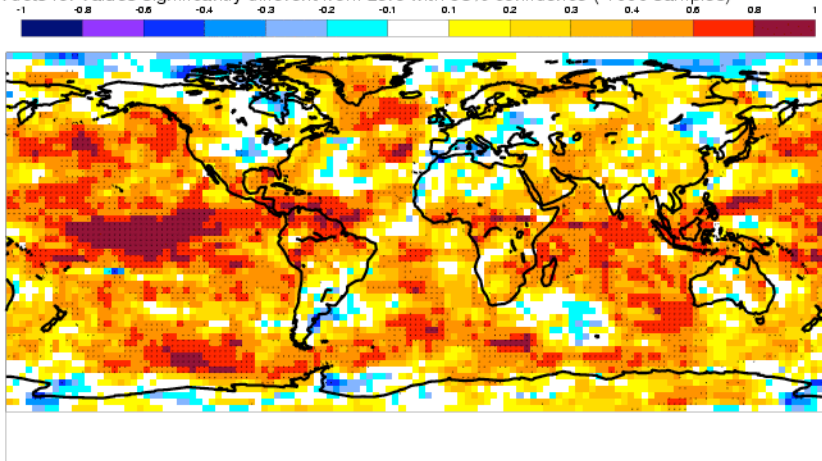


2.a S3 2mT-anomaly fcs from 1 Dec: ave ROCA

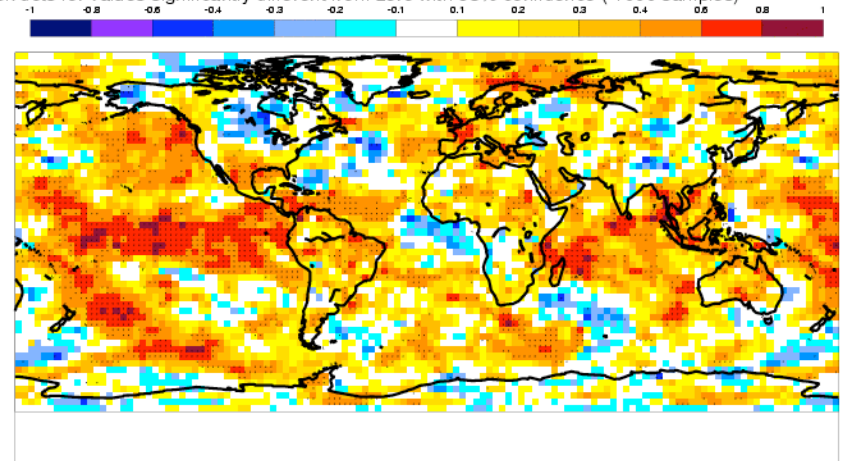
These plots show a measure of the accuracy of seasonal probabilistic forecasts, the area under the Relative Operating Characteristics (ROCA) of the probabilistic forecasts of the 2mT anomaly being below the lower tercile forecasts with 1 Dec starting date. The ROCA has been evaluated considering S3 25-years (1985-2005) 11-member hindcasts.

The left panel shows the ROCA of the 2-4m average forecast, and the right panel the ROCA of the 5-7m average forecast.

ROC Skill Score for ECMWF with 11 ensemble members and 12 bins
Near-surface temperature anomalies below the lower tercile
Hindcast period 1981-2005 with start in December average over months 2 to 4
Threshold computed ranking the sample
Black dots for values significantly different from zero with 95% confidence (1000 samples)



ROC Skill Score for ECMWF with 11 ensemble members and 12 bins
Near-surface temperature anomalies below the lower tercile
Hindcast period 1981-2005 with start in December average over months 5 to 7
Threshold computed ranking the sample
Black dots for values significantly different from zero with 95% confidence (1000 samples)

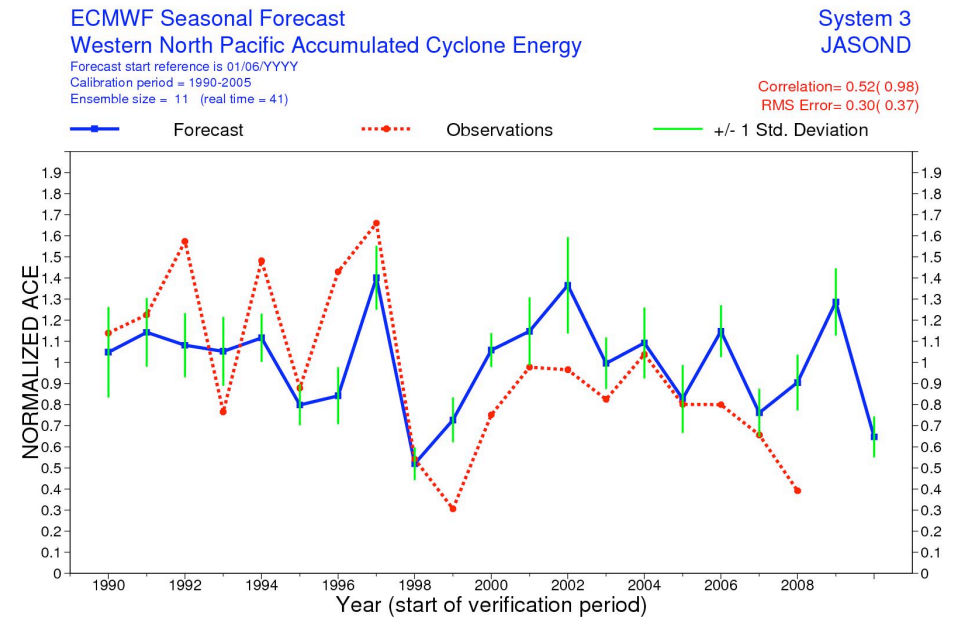
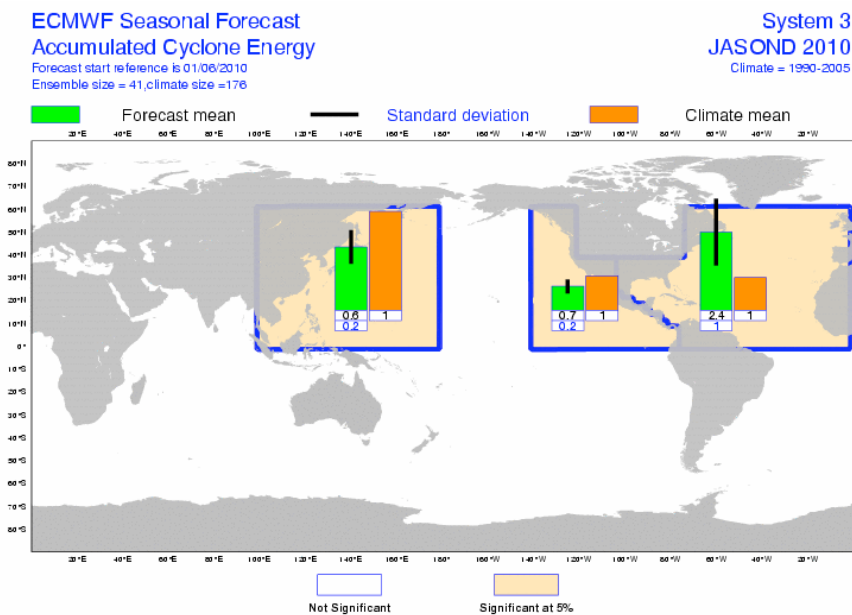




2.a S3 Accumulated Cyclone Energy (ACE) forecast

One of the operational seasonal forecasts is ACE (an index of storm activity defined by the sum of the square of the estimated maximum sustained velocity of every active tropical storm). The left panel shows the ACE forecast issued on 1 June 2010 for JASOND10.

The right panel shows that the accuracy of this product over WPAC (CC 52%).



(from F Vitart)

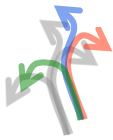


2.a EUROSIP

EUROSIP is a multi-model seasonal forecasting system consisting of three independent coupled systems: ECMWF, Met Office and Météo-France (all integrated in a common framework). This table summarizes the configuration of the 3 seasonal systems that are currently used to generate EUROSIP operational products.

NCEP will be joining very soon. Germany and Canada has expressed interest to join as well.

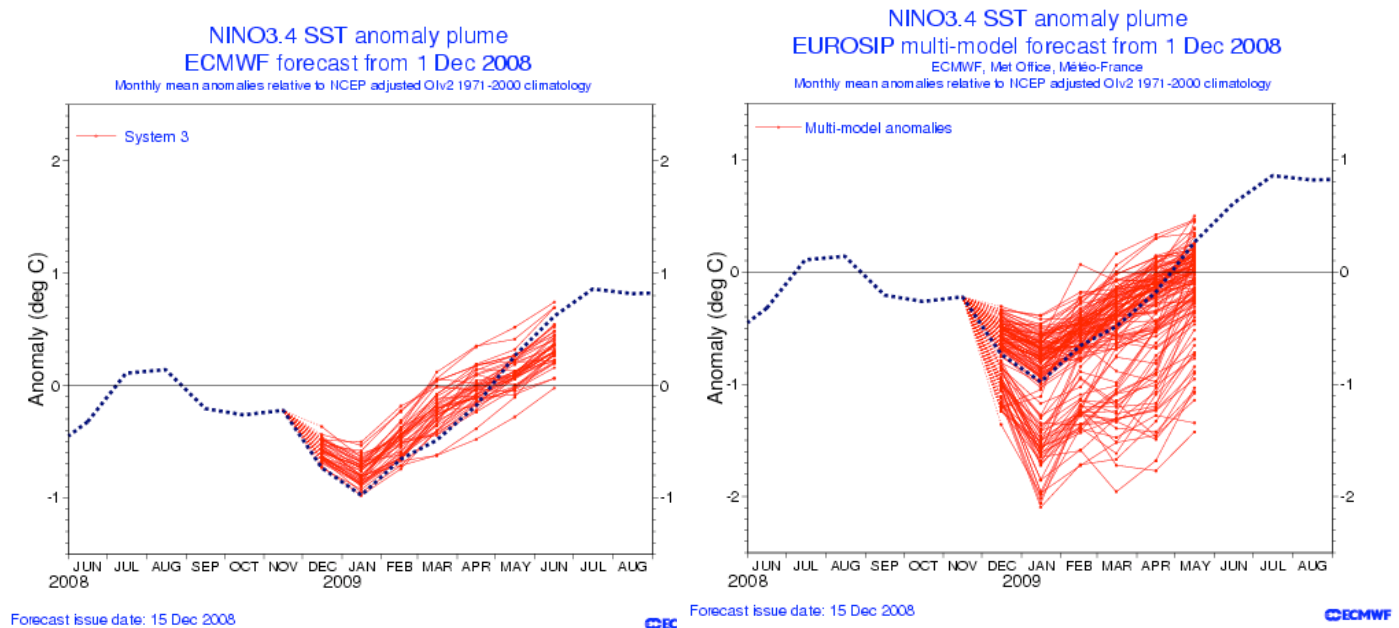
	Ocean	Atmos horiz resol	Atmos vert resol	Forecast Members	Hindcast years	Hindcast Members
EC S3	HOPE (ORCA1Z42)	~ 120km (T ₁ 159)	L62 < 0.5	41 (0÷7m) 5 (7÷13m)	25 (‘81-‘05)	11 (0÷7m) 5 (7÷13m)
MF	OPA (ORCA2Z42)	~ 300km	L91	41 (0÷6m)	30 (‘81-‘10)	11 (0÷6m)
UK S5	NEMO (ORCA1Z75)	~ 120km (N96)	L85	28 lagged (0-6m)	14 (‘89-‘02)	12 (0÷6m)



2.a S3 & EUROSIP 6m ENSO outlook: 1 Dec 08

EUROSIP is a multi-model seasonal forecasting system consisting of three independent coupled systems: ECMWF, Met Office and Météo-France (all integrated in a common framework). NCEP will be joining soon.

ECMWF (left) and EUROSIP 3-system SST anomaly forecasts for NINO3.4 area issued on 1 Dec 2008 and valid for 6 months. The observed SST anomaly lies at the edge of the ECMWF plum. Compared to the single ECMWF plum, the EUROSIP plum has a larger dispersion and gives a higher probability of cold conditions.

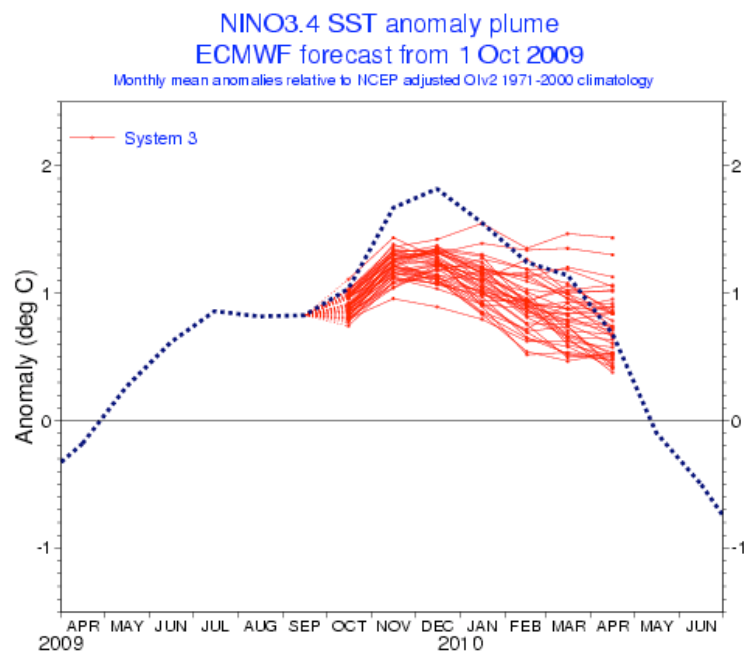




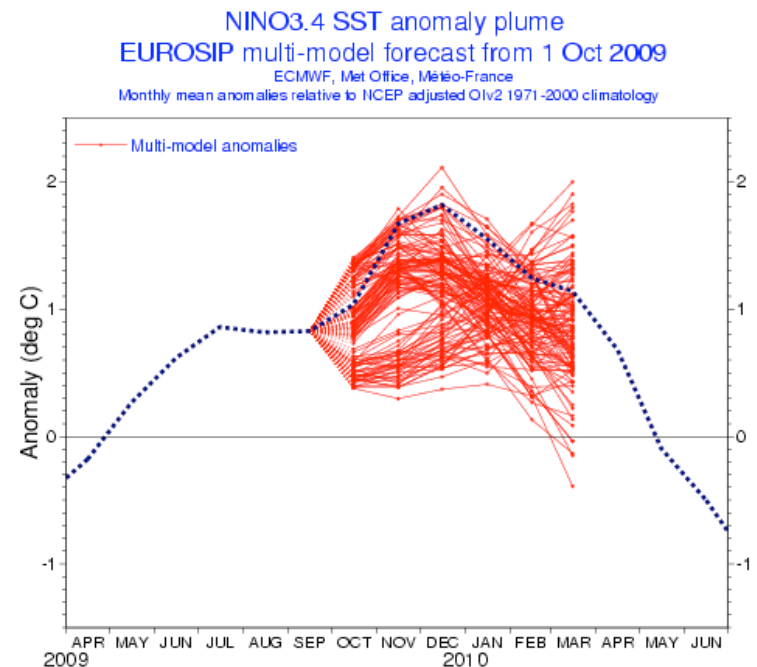
2.a S3 & EUROSIP 6m ENSO outlook: 1 Oct 09

ECMWF (left) and EUROSIP 3-system SST anomaly forecasts for NINO3.4 area issued on 1 Oct 2009 and valid for 6 months.

In this case the observed SST anomaly lies outside the edge of the ECMWF plum. Compared to the single ECMWF plum, the EUROSIP plum has a larger dispersion and includes the observed SST within the forecast range.



ECMWF



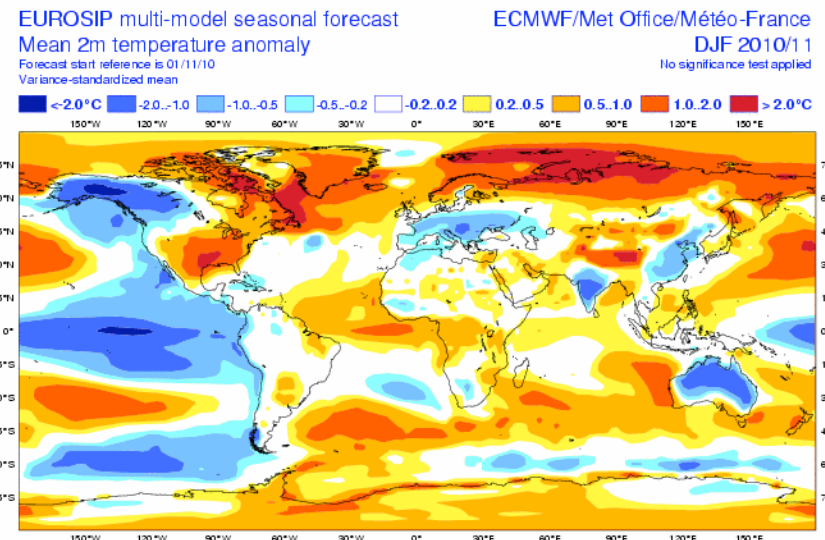
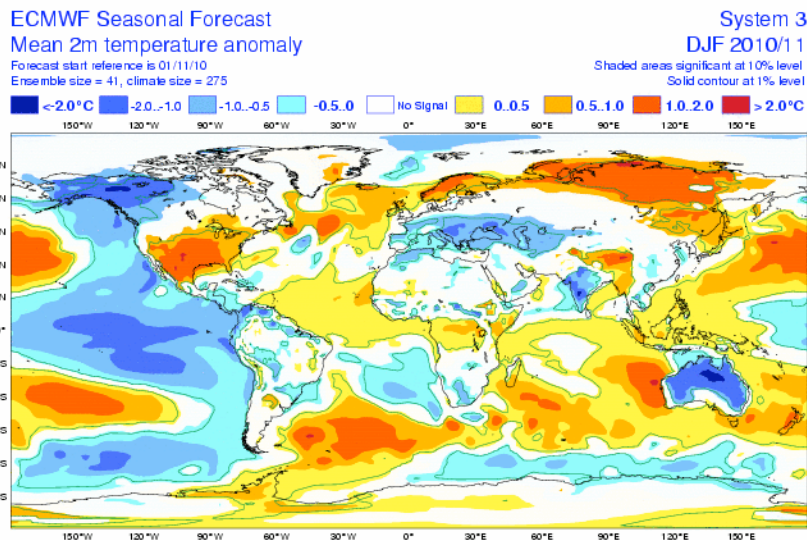
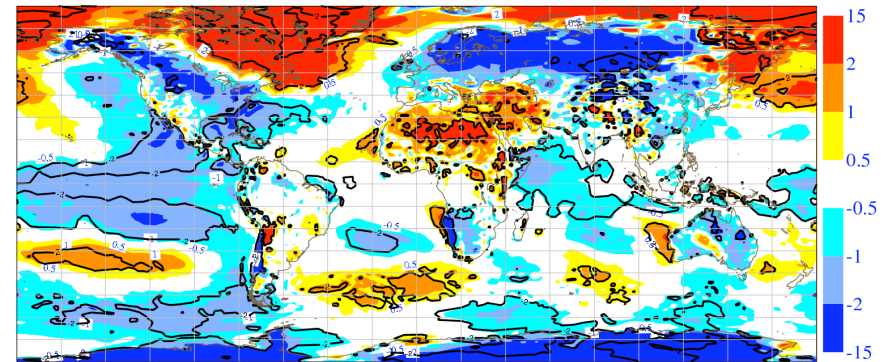
ECMWF



2.a S3 & EUROSIP: 1 Nov fcs of 2mt for D10JF11

- Pac: good distribution of temp anomalies
- Mid-lat Atl and Indian Ocean: colder than fcs
- Austr: cold conditions were predicted although the amplitudes underestimated
- Eur: cold temperatures were not predicted
- Greenland, West Canada and West Asia: good predictions of warm/cold/warm anomalies

2mT analysis



(from L Ferranti)



2.b The forthcoming S4 (Q4-2011): main features

	Ocean	Atmos	Horizontal resolution	Vertical resolution	Atmos mod uncertainty	Forecast Members	Hindcast years	Hindcast Members
S3	HOPE	31r1	T _L 159	L62 < 0.5	1-lev SPPT	41 (0÷7m) 5 (7÷13m)	25 (‘81-‘05)	11 (0÷7m) 5 (7÷13m)
S4	NEMO	36r4	T _L 255	L92 < 0.01	3-lev SPPT and SPBS	51 (0÷7m) 15 (7÷13m)	30 (‘81-‘10)	15 (0÷7m) 15 (7÷13m)

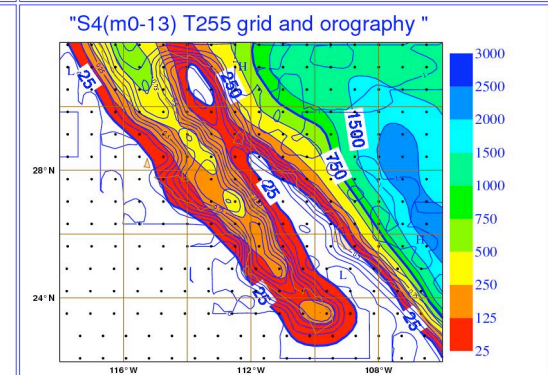
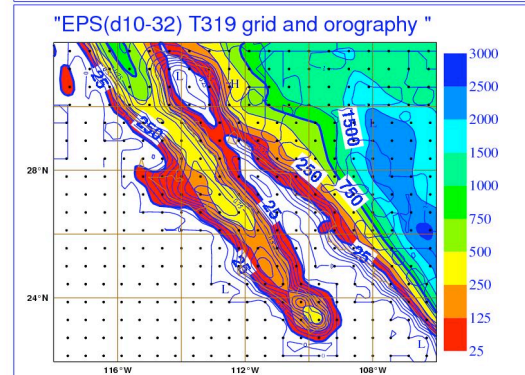
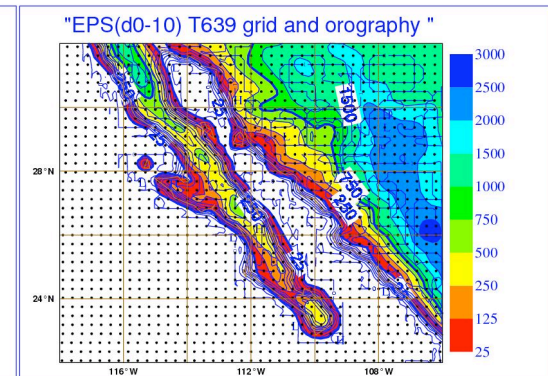
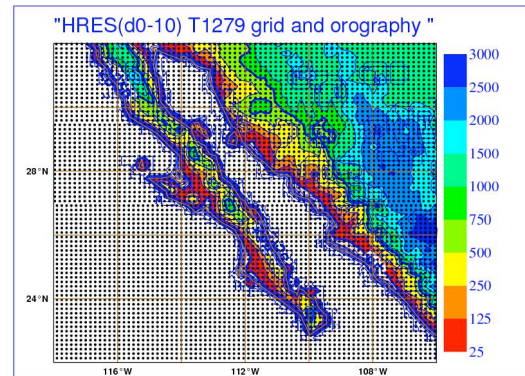
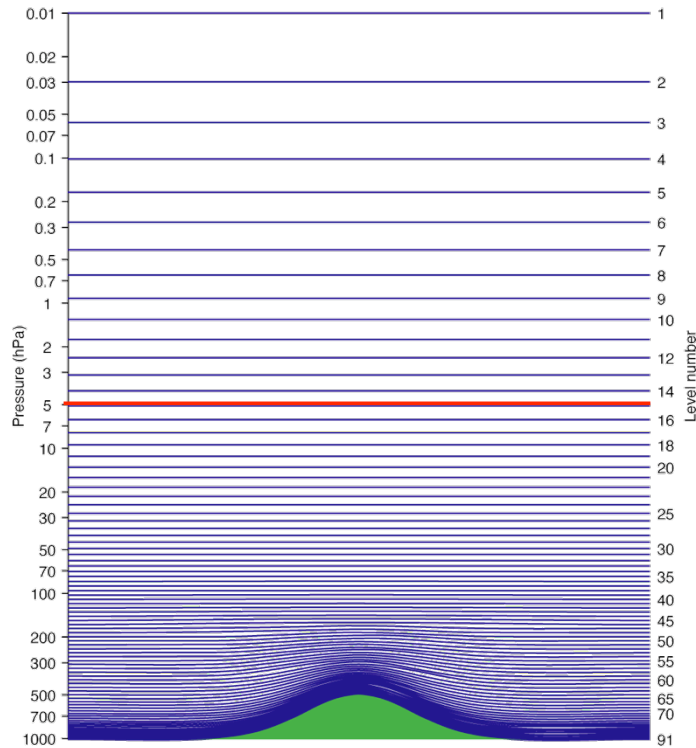
- New ocean model: NEMO v. 3.0 + 3.1 coupling interface, ORCA-1 configuration (~1-deg. resol., ~0.3 lat. near the equator) , 42 vertical levels, 20 levels with z < 300 m
- 3D variational ocean data assimilation (NEMOVAR)
- New physics package, including HTESSEL land-surface scheme, snow model (with EC-Earth), new land surface initialization
- Prescribed sea-ice concentration with sampling from recent years

System	Ocean		SST	Sea ice	Atmosphere	
	Ini unc	Mod unc	Ini unc		Ini unc	Mod unc
S3	O-EDA	--	yes	--	SV	SPPT(1TL)
S4	O-EDA	--	yes	yes	SV	SPPT(3TL)+SPBS



2.b Operational coupled systems from Q4-2011

	# fcs	Hor resolution		Vert lev	Fc length	Wave	Ocean		
HRES/DA	1	T1279	16 km	91 (<0.01 hPa, 75km)	0-10d	WAM (0.25°, 30km)	No		
EPS	51	T639	32 km	62 (<5 hPa, 35km)	0-10d	WAM (0.5°, 60km)	No		
		T319	64 km		10-15/32d		NEMO	0.3-1.0 deg	z42
S4	51	T255	100km	91(<0.01 hPa, 75km)	0-13m	WAM (1.0°, 120km)	NEMO	0.3-1.0 deg	z42

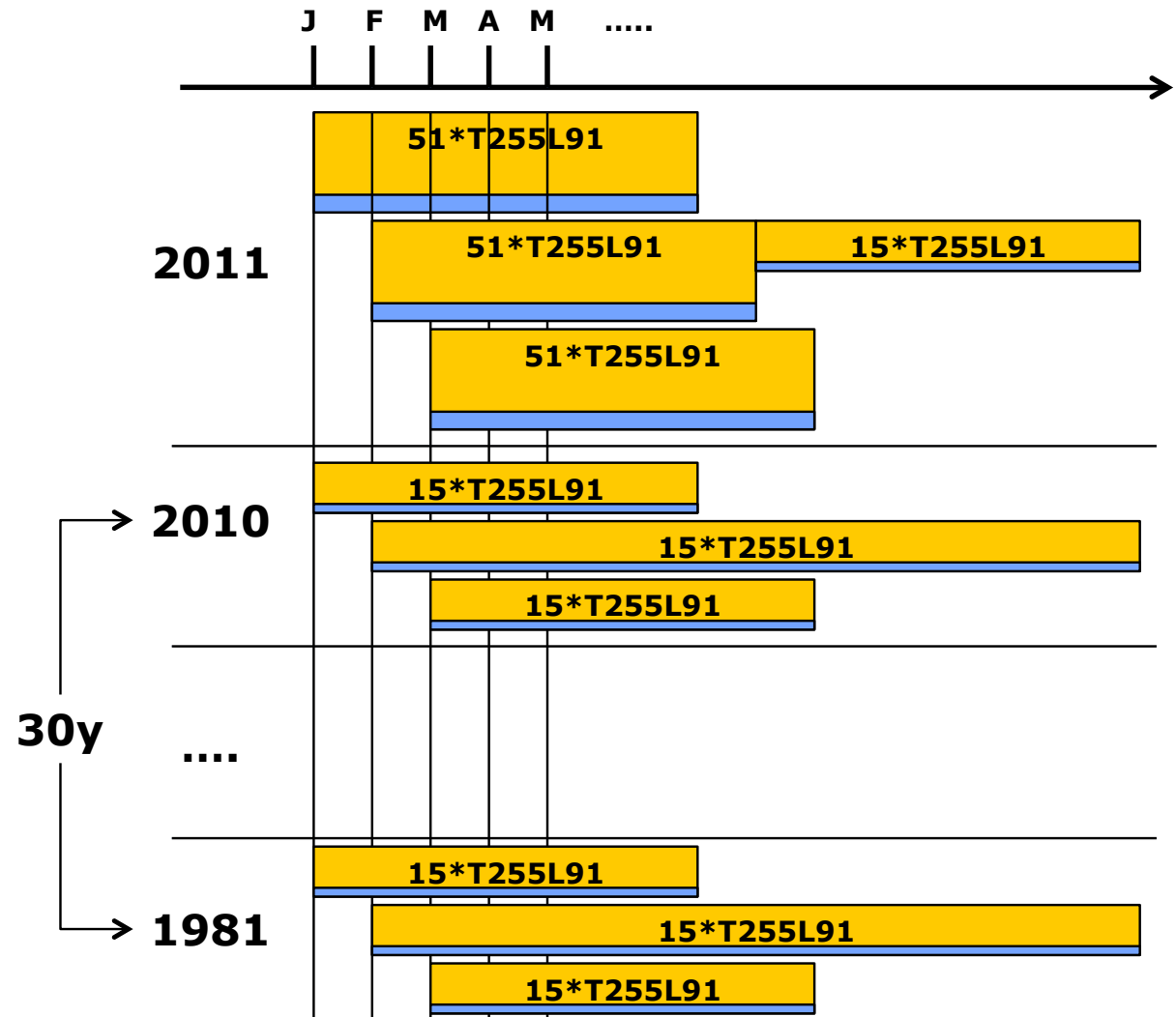




2.b The S4 hindcasts

Seasonal products are bias corrected and calibrated using 450 S4 forecasts run for the past years:

- 30 years (1981 – 2010)
- 15 members (up to 7m, extended to 13m every quarter)
- Same model version
- Same resolution
- ICs from ERA-I and ORAS4
- Same initial perts

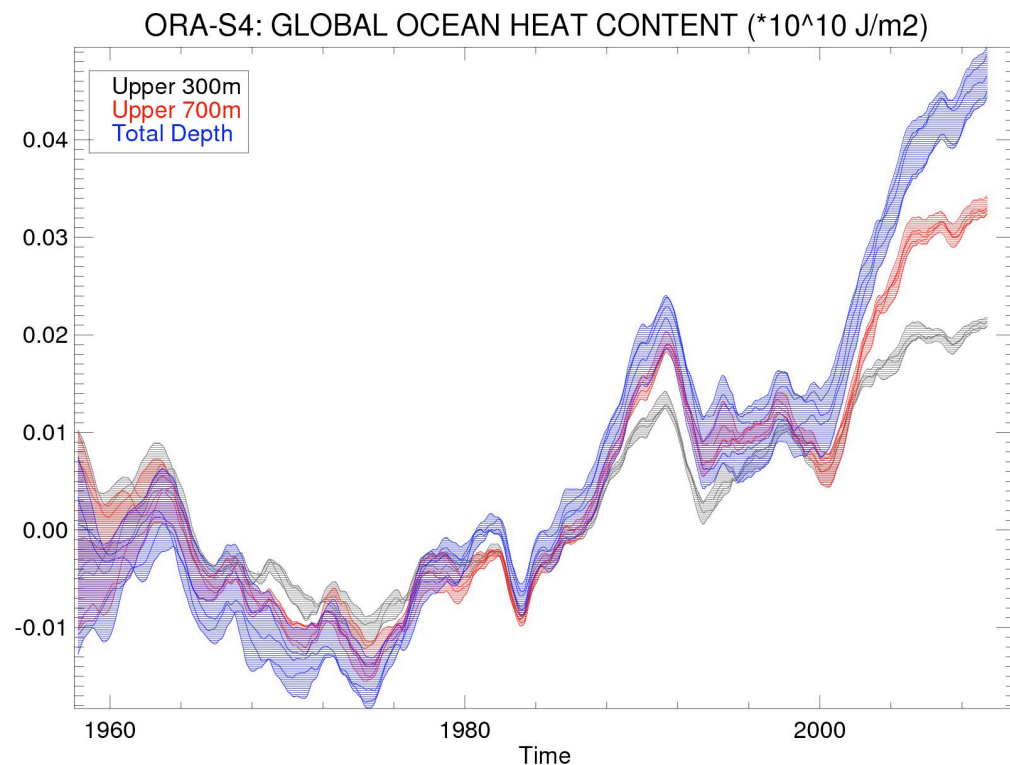




2.b S4 ocean re-analysis (ORAS4)

- Based on NEMO/NEMOVAR
- Model configuration: ORCA1, smooth coastlines, closed Caspian Sea
- Forced by ERA40 (until 1989) + ERA Interim (after 1989)
- Assimilates Temperature/Salinity from EN3 and altimeter data
- Strong relaxation to SST (OI_v2)
- Online bias correction scheme

This plot shows the time evolution of the ocean heat content in ORAS4 (anomalies respect the period 1960-2010) for 3 different depth ranges. Around 2002, the warming stabilizes in the upper ocean, but continues in the deeper ocean. The implication is that the ocean may be absorbing more heat than anticipated.

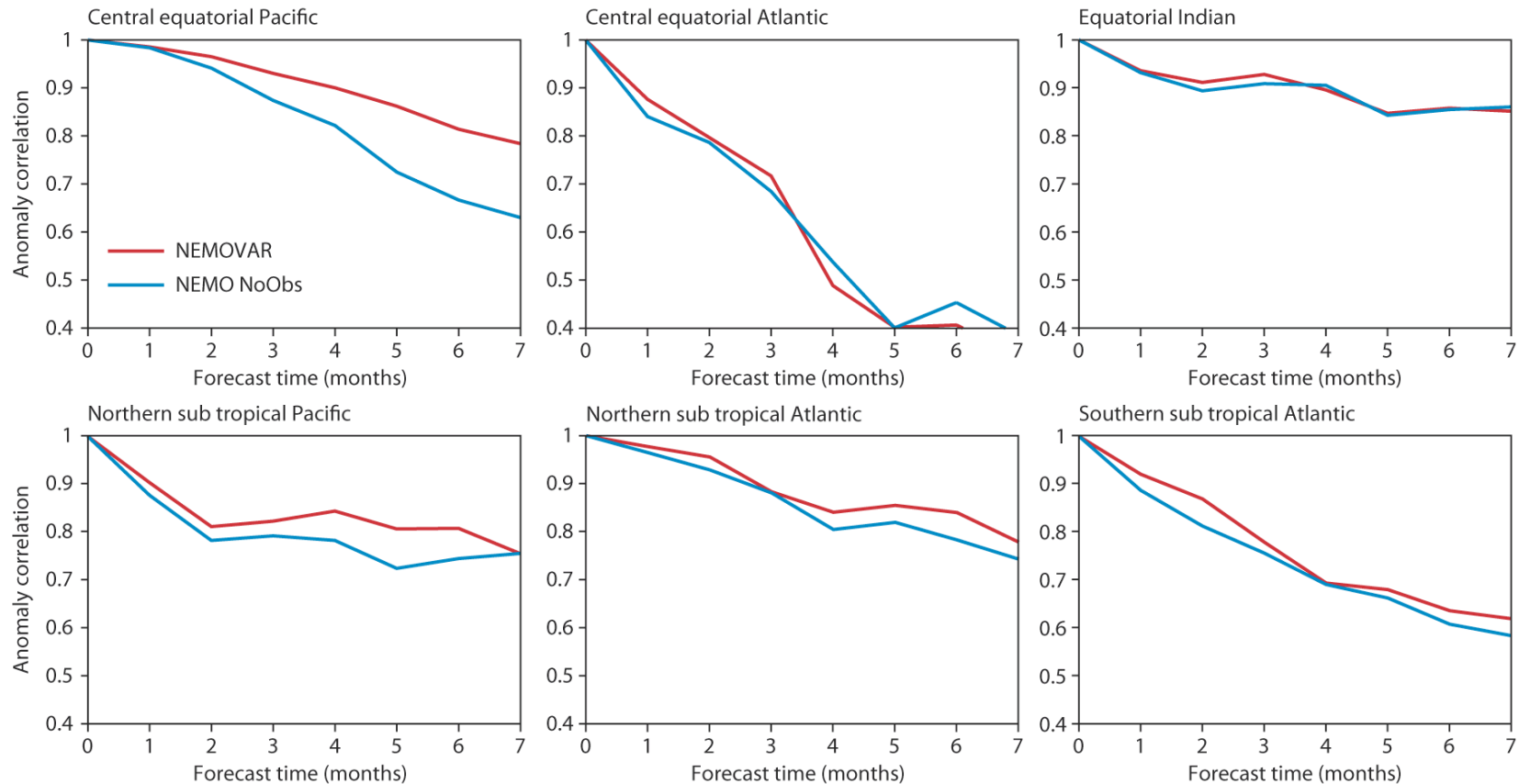


(from M Balmaseda)

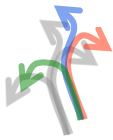


2.b Impact of ocean DA on SST forecasts

S4 experiments (20years, 11-member ensembles) indicate that ocean data assimilation with NEMOVAR improves the SST forecast skill at different lead times and different regions.

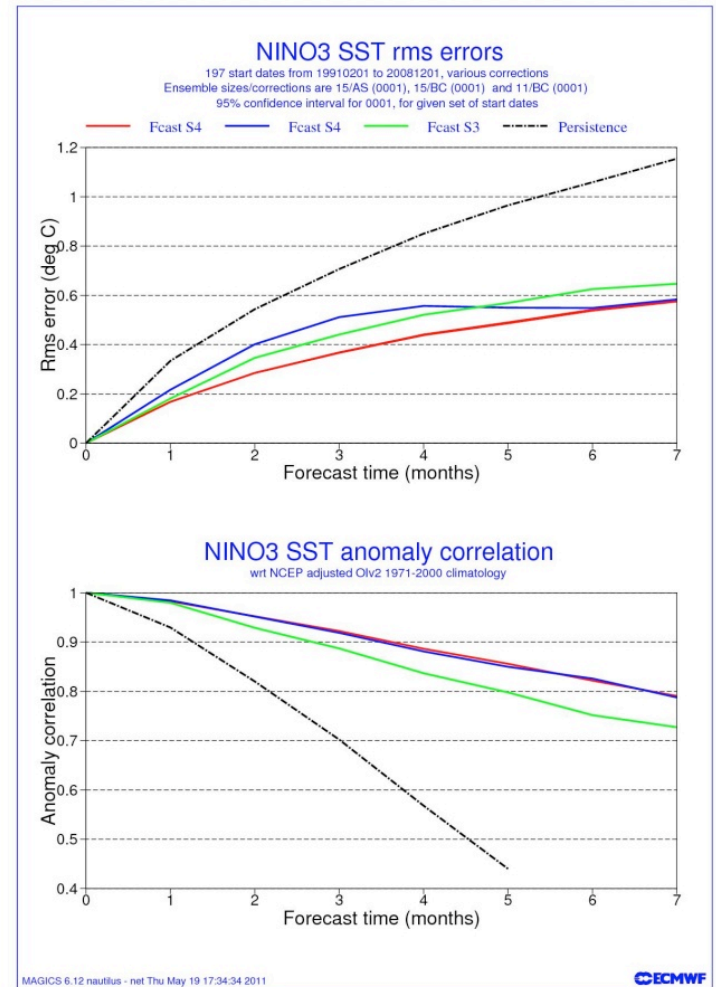
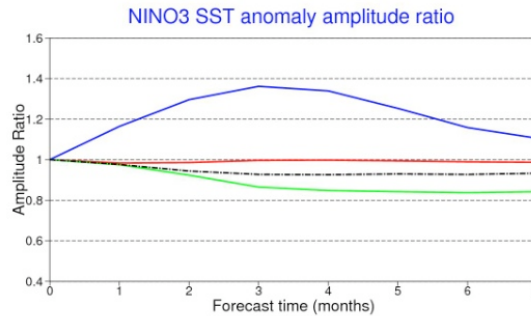
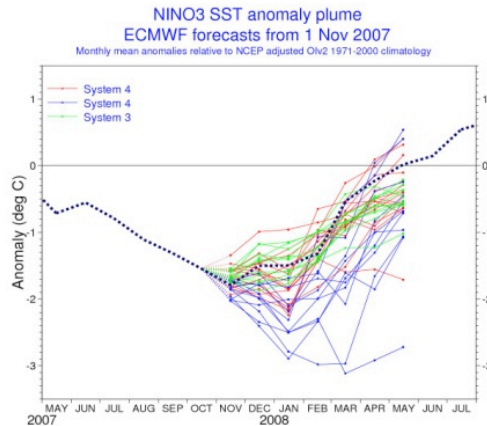


(from M Balmaseda)



2.b S4 re-scaled SST plume anomalies

S4 SST forecasts are re-scaled to correct for the too large variability, with re-scaling coefficients computed in cross-validation mode. SST forecast amplitudes are substantially too large in S4, and the re-scaling is important to give reasonable RMS error scores (and, more importantly, accurate forecast plumes).

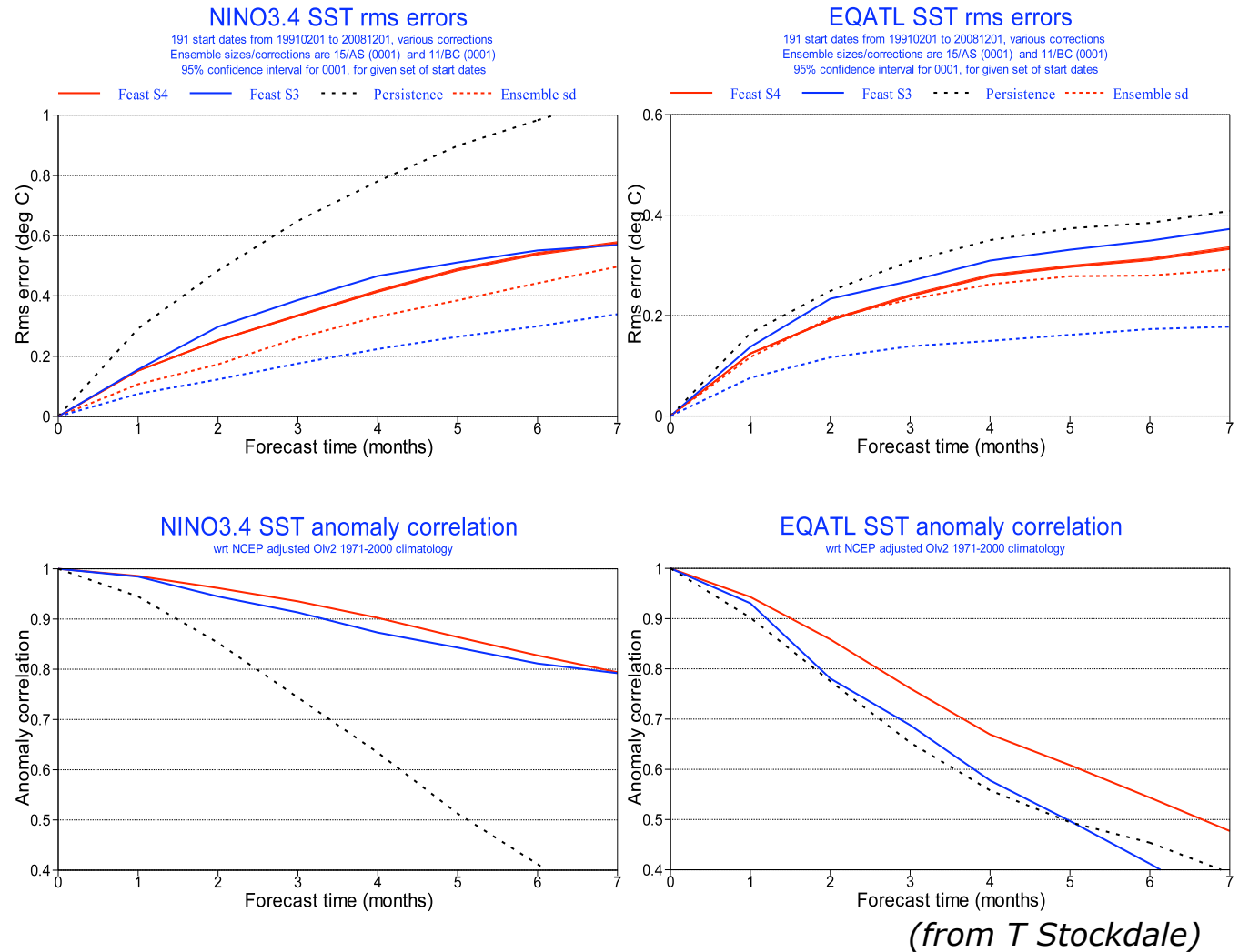


(from T Stockdale)



2.b S4 and S3 NINO3.4 and EQATL SST fcs

Preliminary results based on 18y 15m hindcasts indicate that S4 has more realistic spread. In terms of skill, over the EC-Pac the re-scaled S4 ensemble-mean forecasts are better (see plot for NINO3.4), but over West-Pac are comparable. Over the Atlantic, re-scaled S4 ensemble-mean forecasts are more skilful.

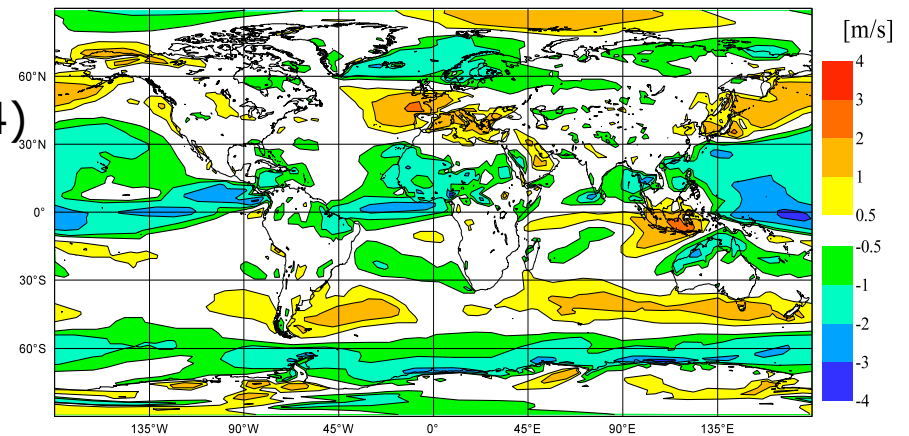




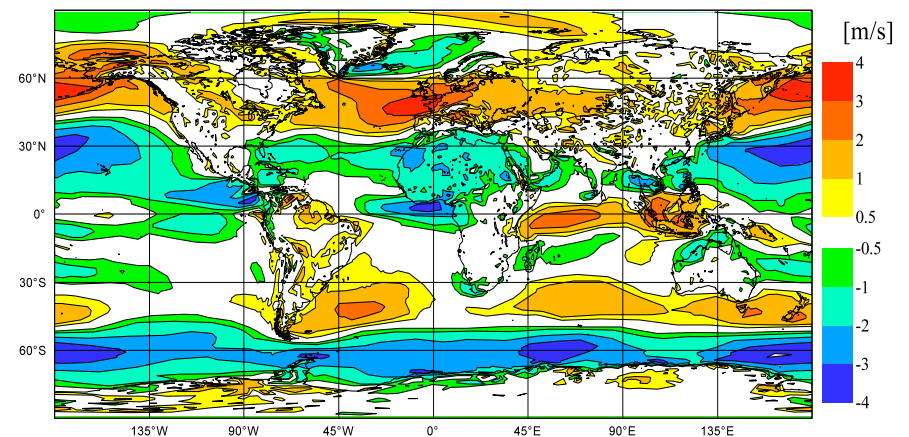
2.b S4 and S3: comparison based on 18y hindcasts

- Preliminary results based on hindcasts run for 18 years indicate that the S4 model climate is better (see plot that shows U925 model biases of S3 and S4)
- S4 atmospheric scores are less well sampled at this stage, but are in the positive to neutral range
- S4 forecasts are not better over the West Pacific mainly because of too strong easterlies in the equatorial Pacific

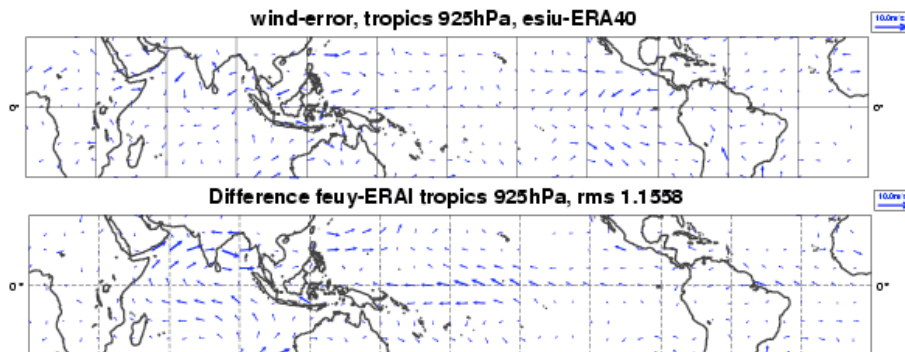
925hPa zonal wind S4(15)-ERA Int 1991-2008 DJF
Global rms error: 0.876 NH:0.69 TR:0.993 SH:0.786

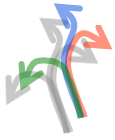


925hPa zonal wind S3(11)-ERA Int 1991-2008 DJF
Global rms error: 1.28 NH:1.32 TR:1.16 SH:1.47



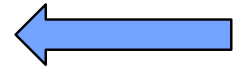
(from T Stockdale)

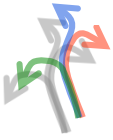




Outline

1. ECMWF medium-range probabilistic forecast systems: the EPS
2. ECMWF seasonal probabilistic forecast systems:
 - a) The operational S3 and EUROSIP
 - b) The forthcoming S4 (Q4-2011)
3. Conclusions





3. Conclusions

- Ensemble-based systems are used at ECMWF to estimate not only the most-likely scenario but also its uncertainty:
 - In the analysis with the Ensemble Data Assimilation system (EDA, since Jun 2010)
 - In the medium-range (<1m) with the Ensemble Prediction System (EPS, since 1992)
 - In the seasonal range (<13m) with seasonal System-3 (S3, since 1998)
- The EPS uses a combination of EDA- and SV-based perturbations to simulate initial uncertainties, and stochastic schemes to simulate model uncertainties. It is based on 51 forecasts run with a 639v319L62 atmosphere model. It is coupled to the HOPE (1.0-0.3 deg) ocean model from day 10, and is run twice a day. Forecasts starting at 00UTC on Mon & Thu are extended to 32days. In Q3-2011 HOPE will be replaced by NEMO (with a 1.0-0.3 deg resolution, with initial conditions constructed with NEMOVAR).
- The S3 uses a 159L62 old (31r1) version of the atmosphere model and the HOPE ocean model. In Q4-2011 the new S4, based on a more recent and higher-resolution 255L91 atmosphere model, and the NEMO ocean model will be introduced.



Conclusions

Work will continue to further improve the ECMWF probabilistic forecasting systems in different areas:

- 1. Increase the vertical resolution** – ECMWF is planning to increase the vertical resolution of the HRES/DA, EDA and EPS (\sim L95) systems (2012). Work to assess the impact on the EPS will start soon.
- 2. Improve the model error simulation schemes** – Work is progressing to assess the impact of using the SPBS scheme in the EDA, and to investigate potential upgrades of the stochastic schemes in the EDA and EPS.
- 3. Further exploit the link between the EDA and the EPS** – The use of initial-time land-surface and SST perturbations generated using the EDA is under investigation. Work to assess the potential value of using 25 or 50 EDA members will start soon.
- 4. Include a dynamical sea-ice model and a mixed-layer model** – Work has started to assess whether using the LIM2/LIM3 dynamical sea-ice model and a mixed-layer model can lead to further improvements.
- 5. Increase the resolution of the ocean model and test coupling from d0** – Work will start soon to assess the impact of using a higher-resolution ocean model (1/4 degree NEMO) in the probabilistic forecasting systems. For the EPS, the possibility to couple from initial time will also be investigated.