Probabilistic Predictions

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Acknowledgements: Renate Hagedorn, Martin Leutbecher, Young-Youn Park, Tim Stockdale, Frederic Vitart and Ervin Zsoter

Outline

1. The ECMWF Probabilistic Prediction Systems
   - 1.1 The 15-day VAriable Resolution Ensemble Prediction System (VAREPS)
   - 1.2 The 32-day monthly ensemble system, and the unified 32-day VAREPS
   - 1.3 The seasonal ensemble system
2. The anomalous events of summer 2007
   - 2.1 The hot (cold) anomaly over South-Eastern (North-Western) Europe
   - 2.2 The strong rain over the Indian sub-continent and the Brahamaputra floods
3. Conclusions

1. The current ECMWF Ensemble Prediction System

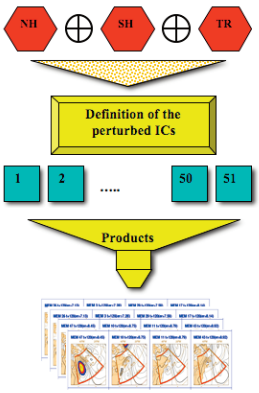
The Ensemble Prediction System consists of 51 forecasts run with variable resolution:

- T_L399L62 (~60km, 62 levels) from day 0 to 10
- T_L255L62 (~80km, 62 levels) from day 10 to 15.

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

Initial uncertainties are simulated by perturbing the unperturbed analyses with a combination of T42L62 singular vectors, computed to optimize total energy growth over a 48h time interval (OTI).

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



1.1 The ECMWF operational VAREPS

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

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

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

Initial perturbations are defined using evolved and initial SVs

$$e_j(d,0) = e_0(d,0) + de_j(d,0)$$

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

The unperturbed analysis $e_j(d,0)$ is the T_L399L62 truncation of the operational T_L799L91 analysis, generated with the 12-hour cycling, 4-dimensional variational assimilation system. (See [1], [2], [3] for more details).

1.1 Since May '94 the EPS configuration changed 15 times

Between Dec 1992 and Sep 2006 the ECMWF system changed several times: ~50 model cycles (which included changes in the model and DA system) were implemented, and the EPS configuration was modified 15 times.

	Date	Description	Singular Vectors's characteristics						Forecast characteristics					
			HRES	VRES	OTI	Target area	EVO SVs	sampl	HRES	VRES	Tend	#	Mod Unc	Coupling
EPS / VAREPS	Dec 1992	Oper Impl	T21	L19	36h	globe	NO	simm	T63	L19	10d	33	NO	NO
	Feb 1993	SV LPO	"	"	"	NHx	"	"	"	"	"	"	"	"
	Aug 1994	SV OTI	"	"	48h	"	"	"	"	"	"	"	"	"
	Mar 1995	SV hor resol	T42	"	"	"	"	"	"	"	"	"	"	"
	Mar 1996	NH+SH SV	"	"	"	(NH+SH)x	"	"	"	"	"	"	"	"
	Dec 1996	resol/mem	"	L31	"	"	"	"	TL159	L31	"	51	"	"
	Mar 1998	EVO SV	"	"	"	"	YES	"	"	"	"	"	"	"
	Oct 1998	Stoch Ph	"	"	"	"	"	"	"	"	"	"	YES	"
	Oct 1999	ver resol	"	L40	"	"	"	"	"	L40	"	"	"	"
	Nov 2000	FC hor resol	"	"	"	"	"	"	TL255	"	"	"	"	"
	Jan 2002	TC SVs	"	"	"	(NH+SH)x+TC	"	"	"	"	"	"	"	"
	Sep 2004	sampling	"	L40	"	"	"	Gauss	"	"	"	"	"	"
	Jun 2005	rev sampl	"	"	"	"	"	"	"	"	"	"	"	"
	Feb 2006	resolution	"	L62	"	"	"	"	TL399	L62	10d	"	"	"
	Sep 2006	VAREPS	T42	L62	48h	(NH+SH)x+TC	YES	Gauss	TL399(0-10)+TL255(10-15)	L62	15d	51	YES	NO
MONTHLY	Mar 2002	Oper Impl	T42	L40	48h	(NH+SH)x+TC	YES	simm	TL159	L40	32d	51	YES	YES
	Sep 2004	sampling	"	"	"	"	"	Gauss	"	"	"	"	"	"
	Feb 2006	resolution	"	L62	48h	(NH+SH)x+TC	YES	Gauss	TL159	L62	32d	51	YES	YES
32d VAREPS / MONTHLY	2007/08	32d-VAREPS	T42	L62	48h	(NH+SH)x+TC	YES	Gauss	TL399(0-10)+TL255(10-32)	L62	32d	51	YES	YES from d10

1.1 The ECMWF VAriable Resolution EPS (VAREPS)

The key idea behind VAREPS ([2]) is to resolve small-scales only up to the time range when resolving them improves the forecast. VAREPS was implemented in September 2006 with the following configuration:

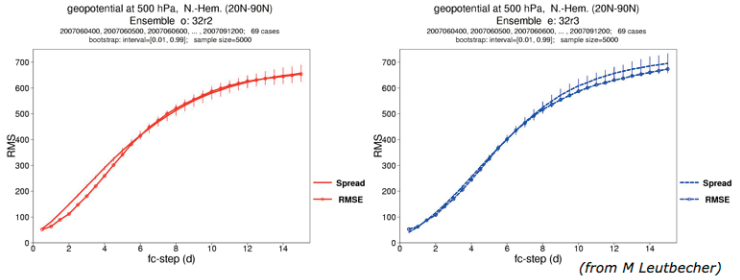
- T_L399L62 resolution from day 0 to day 10
- T_L255L62 resolution from day 10 to day 15

The implementation of VAREPS increased the value of the ensemble system in the short range, by providing more skilful predictions of the small scales, and in the medium-range, by extending the range of skilful products to 15 days.

On 7 November 2007, a new model cycle (32r3) has been introduced. The new model is more active, due to changes in the convection and vertical diffusion schemes. To compensate for the spread increase due to the model changes, the initial amplitude of the EPS perturbations has been reduced by 30%.

1.1 The introduction of the new model cycle (32r3)

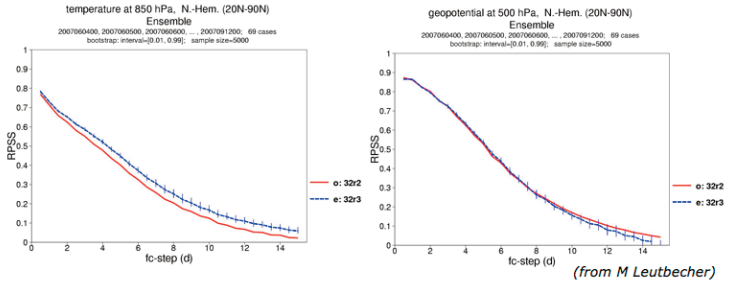
With the introduction of the new model cycle on 7 Nov 2007 (32r3, right panel), the ensemble has a better tuned spread. Between fc-day 1 and 4, the ensemble is only slightly over-dispersive, and the ensemble spread is well tuned from fc-day 1 to fc-day 8. But after fc-day 8 the system is now slightly over-dispersive. Between fc-day 3 and 7 the ensemble-mean of the e-suite has a significantly smaller error.



(from M Leutbecher)

1.1 JA07: ECMWF o- & e-suites – T850 & Z500 NH

Over NH, the introduction of the new model cycle (32r3, right panel) improves the quality of the probabilistic prediction of T850, measured by the RPSS (left panel). But the difference in quality is very small and not statistically significant if one considers Z500 (right panel).



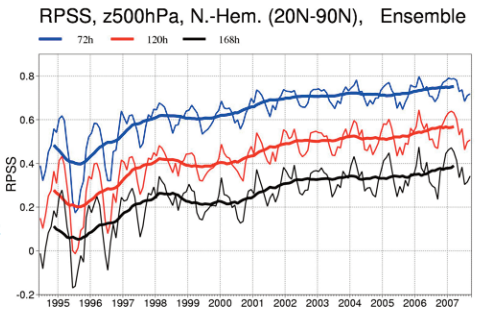
(from M Leutbecher)

1.1 Trends in ensemble RPSS for Z500 & T850, NH

The RPSS for the probabilistic prediction of Z500 anomalies indicates that during the past 10 years ensemble predictability has increased.

Over NH, the t+120h RPSS in 2006 was higher than the t+72h RPSS in 1996, indicating a gain in predictability of more than 2 days in a decade.

This increase is due to improvements in the quality of the analysis, in the model accuracy, and in the ensemble configuration.



(from M Leutbecher)

1.1 Characteristics of the TIGGE ensembles compared

To assess the quality of the ECMWF ensemble system, its performance has been compared with the performance of the other global ensemble systems available in the TIGGE archive. Note that ensembles differ, especially in resolution and size. In the comparison, each ensemble has been verified against its own analysis.

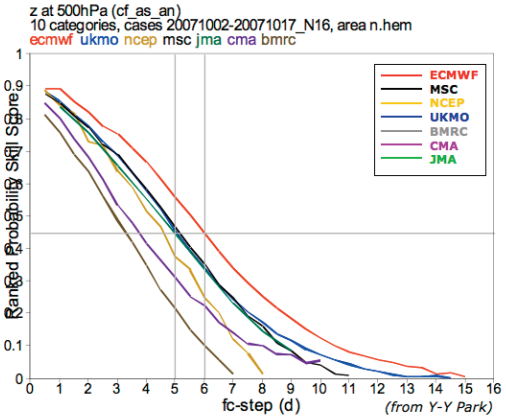
	BMRC	CMA	ECMWF	JMA	KMA	MSC	NCEP	UKMO
Model error	NO	NO	YES	NO	NO	YES	NO	YES
Init perturb	SVi	BVs/SVs	SVi+e	BVs	BVs	Sys-Sim	ET-BVs	ETKF
Perturb area	NH+SH	NH+TR	Globe	NH+TR	NH	NH	Globe	Globe
HRES fcs	TL119	T213	TL399(d0-10) TL255(d10-15)	T106	T213	TL149	T126	N144 (~80km)
# vert-lev	19	31	62	40	40	28	28	38
fc length (d)	10	10	15	9	10	16	16	15
# pert mem	32	14	50	50	16	20	20	23
# runs (d)	2 (00/12)	2 (00/12)	2 (00/12)	1 (12)	2(00/12)	2(00/12)	4 (00/06/ 12/18)	2 (00/12)
# mem (d)	66	30	102	51	34	42	84	48

1.1 Oct07: EC/MSC/NCEP/UK/BMRC/CMA/JMA–Z500NH

Most recent TIGGE results: this figure shows the Oct07 (16 cases) average RPSS for Z500 over NH of all the 7 ensembles archived in TIGGE.

The EC ensemble outperforms the group of 2nd best ensembles (MSC, UKMO and JMA for this period), with ~0.9d gain in predictability at t+5d.

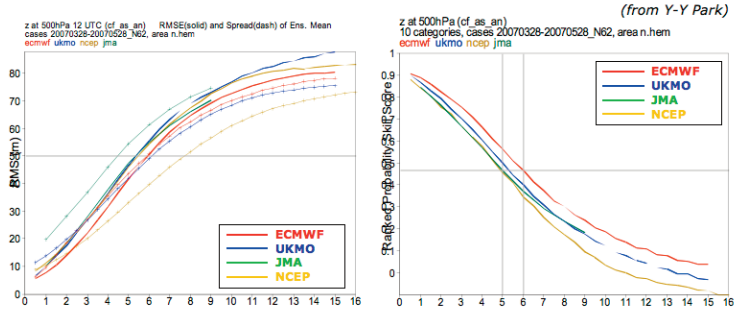
This confirms the results for other 3 analyzed periods (total of ~240 cases).



1.1 Apr-May07 (62c): EC/UK/NCEP/JMA - Z500 NH

- spread (left, dashed): EC best match of std & rmse(EM); UK similar to EC after day 2; JMA too large, NCEP too small.
- rmse(EM) (left, solid): EC has lowest rmse for whole forecast range.
- RPSS (right): EC has best skill (at t+5d, ~0.75d gain in predictability).

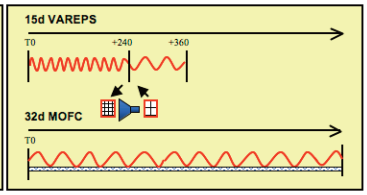
(from Y-Y Park)



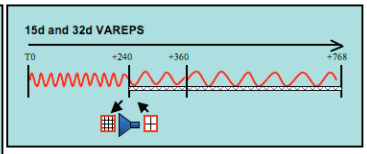
1.2 The 32-day unified VAREPS

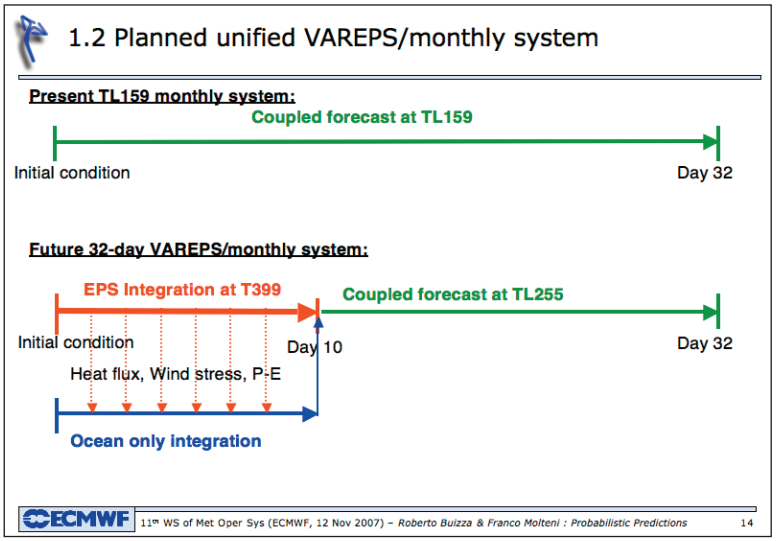
The plan is to unify the 15d VAREPS and the 32d monthly ensemble systems into the unified 32d VAREPS:

- Twice-a-day (at 00 and 12 UTC):
  - d 0-10: T_L399L62 uncoupled
  - d 10-15: T_L255L62 uncoupled
- Once a week:
  - d 0-32: T_L159L62 **coupled**



- Twice-a-day (at 00 and 12 UTC):
  - d 0-10: T_L399L62 uncoupled
  - d 10-15: T_L255L62 (**coupled at 00**)
- Once a week:
  - d 0-10: T_L399L62 uncoupled
  - d 10-32: T_L255L62 **coupled**




1.2 Planned unified VAREPS/monthly system
Present TL159 monthly system:
Coupled forecast at TL159
Initial condition
Day 32
Future 32-day VAREPS/monthly system:
EPS Integration at T399
Coupled forecast at TL255
Initial condition
Day 10
Day 32
Heat flux, Wind stress, P-E
Ocean only integration
ECMWF
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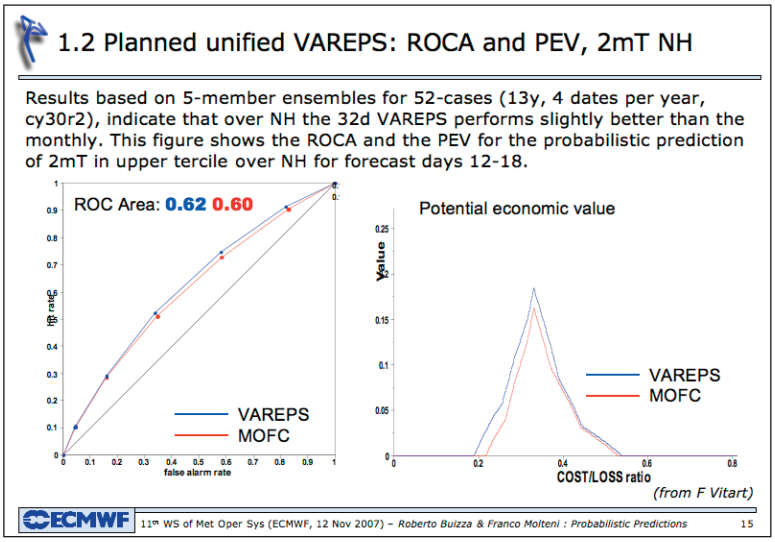
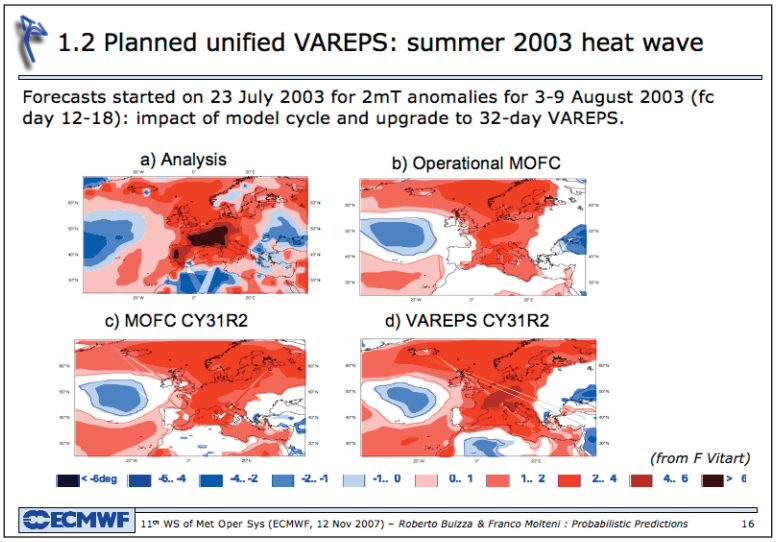
14


1.2 Planned unified VAREPS: ROCA and PEV, 2mT NH
Results based on 5-member ensembles for 52-cases (13y, 4 dates per year, cy30r2), indicate that over NH the 32d VAREPS performs slightly better than the monthly. This figure shows the ROCA and the PEV for the probabilistic prediction of 2mT in upper tercile over NH for forecast days 12-18.
ROC Area: 0.62 0.60
hit rate
false alarm rate
VAREPS
MOFC
Potential economic value
Value
COST/LOSS ratio
VAREPS
MOFC
(from F Vitart)
ECMWF
11th WS of Met Oper Sys (ECMWF, 12 Nov 2007) – Roberto Buizza & Franco Molteni : Probabilistic Predictions
15


1.2 Planned unified VAREPS: summer 2003 heat wave
Forecasts started on 23 July 2003 for 2mT anomalies for 3-9 August 2003 (fc day 12-18): impact of model cycle and upgrade to 32-day VAREPS.
a) Analysis
b) Operational MOFC
c) MOFC CY31R2
d) VAREPS CY31R2
(from F Vitart)
< -6deg
-6.. -4
-4.. -2
-2.. -1
-1.. 0
0.. 1
1.. 2
2.. 4
4.. 6
> 6
ECMWF
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16

1.2 Use of reforecasts for calibration

With the implementation of the unified 32d VAREPS-Monthly forecast system, a new reforecast suite will be run operationally. The reforecasts from this suite can be used as training data to calibrate both medium-range and monthly forecasts.

The suite will run once week and produce reforecasts for the last 18 years (1989-2006 of the respective operational date in 2007) and with 5 ensemble members.

Results based on comparing ECMWF and GFS 10d-calibration ([7]) indicate that:

- ECMWF forecasts, as well as GFS forecasts, can be improved through calibration
- The main improvement are due to bias correction (60-80%), but advanced methods (e.g. NGR) lead to better calibrated ensemble spread, thus adding some extra improvements, in particular at early lead times
- Improvements occur mainly at locations with low skill

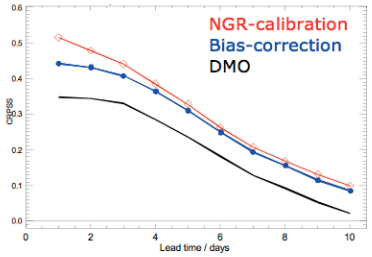
(from R Hagedorn)

1.2 Use of reforecasts for calibration

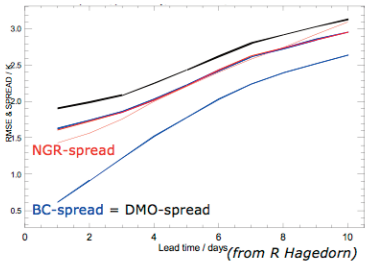
2m temperature forecasts (1 Sep – 30 Nov 2005), 250 European stations

REFC-data: 15 members, 20 years, 5 week window

CRPSS

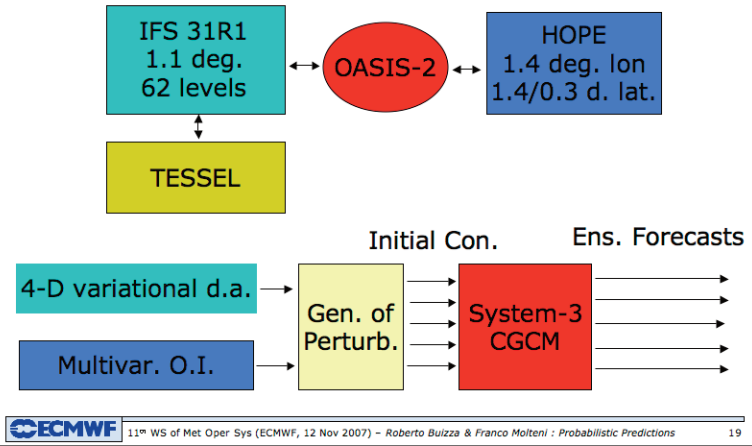


RMSE & spread



(from R Hagedorn)

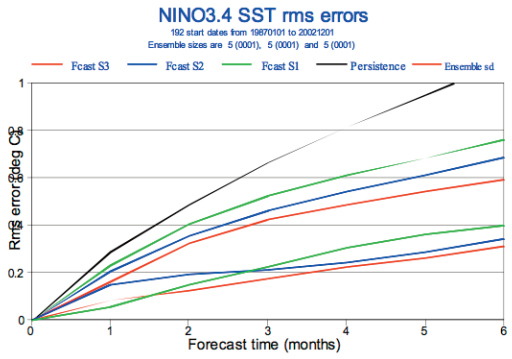
1.3 The ECMWF Seasonal forecast system (Sys-3)



1.3 New features of the seasonal fc. System-3

- COUPLED MODEL (IFS + OASIS2 + HOPE)
  - Recent cycle of atmospheric model (Cy31R1)
  - Atmospheric resolution TL159 and 62 levels
  - Time varying greenhouse gasses.
  - Includes ocean currents in wave model
- INITIALIZATION
  - Includes bias correction in ocean assimilation.
  - Includes assimilation of salinity and altimeter data.
  - ERA-40 data used to initialize ocean and atmosphere in hindcasts
  - Ocean reanalysis back to 1959, using ENACT/ENSEMBLES ocean data
- ENSEMBLE GENERATION
  - Extended range of back integrations: 11 members, 1981-2005.
  - Revised wind and SST perturbations.
  - Use EPS Singular Vector perturbations in atmospheric initial conditions.
- Forecasts extended to 7 months (to 13 months 4x per year).

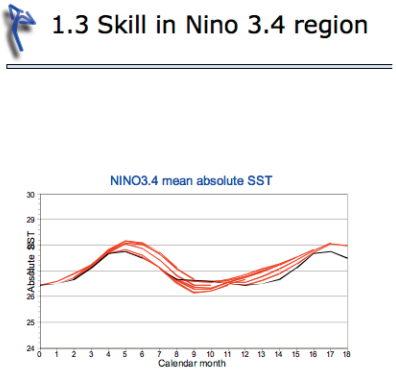
1.3 Nino3.4 rms error/spread in ECMWF seas. fc. systems

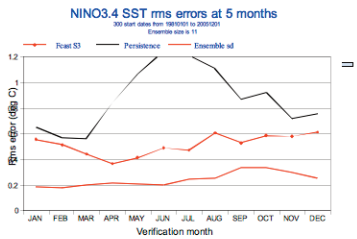


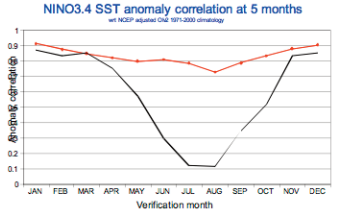
Rms error of forecasts has been systematically reduced (solid lines) ....

.. but ensemble spread (dashed lines) is still substantially less than actual forecast error.

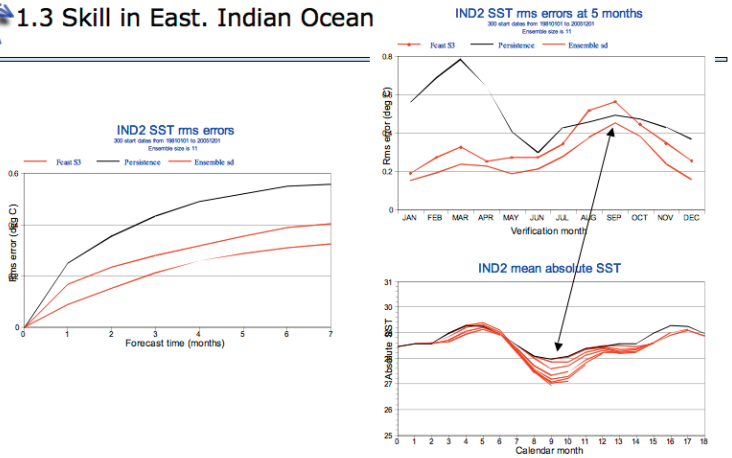
1.3 Skill in Nino 3.4 region







1.3 Skill in East. Indian Ocean



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2. The anomalous events of summer 2007
   - 2.1 The hot (cool) anomaly over South-Eastern (North-Western) Europe
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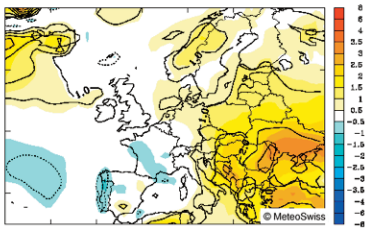
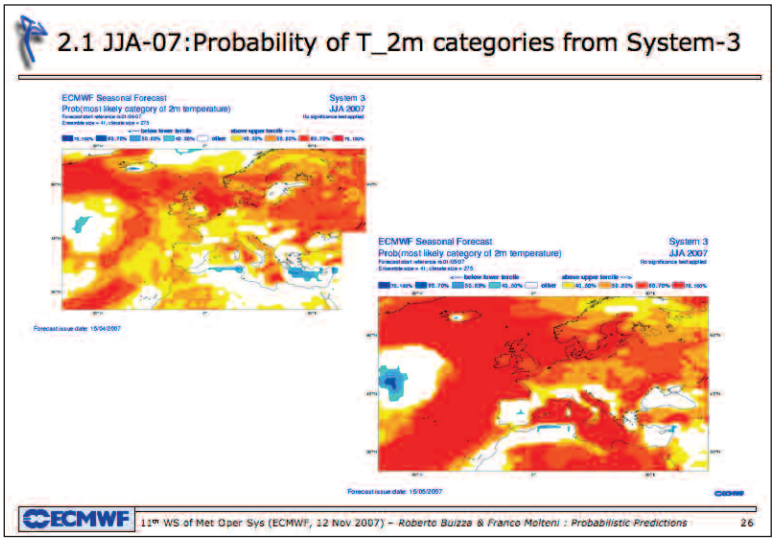
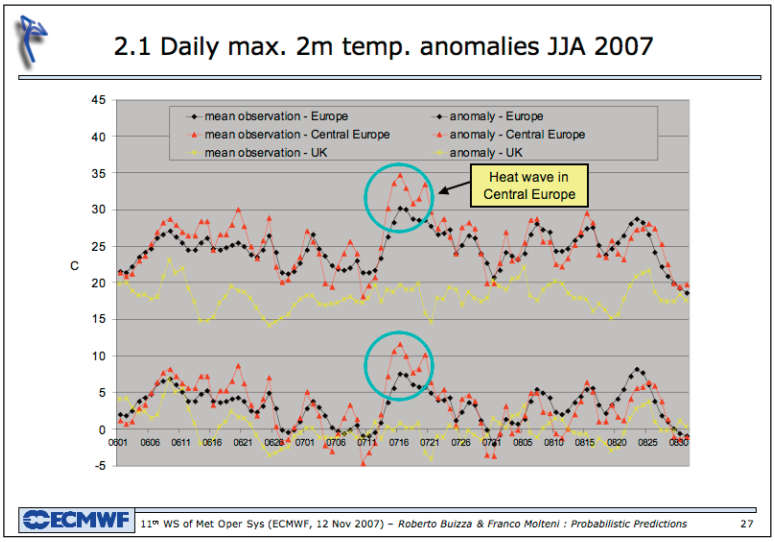
3. Conclusions

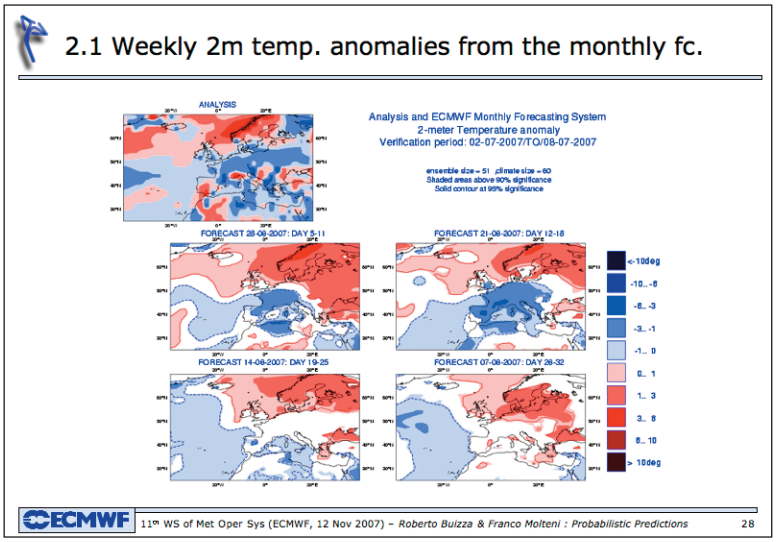
2.1 Summer 2007 : hot in SE Europe, wet in NW Europe



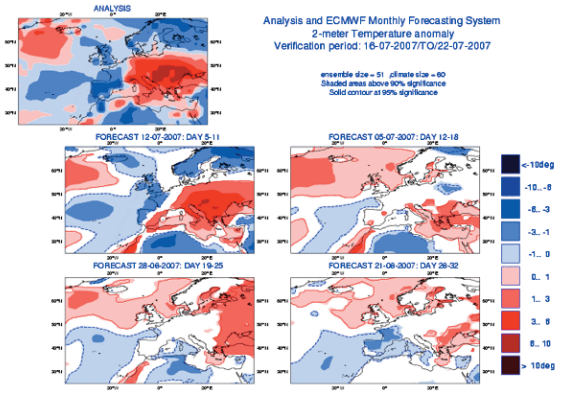
June-July-August 2007 T_2m anomaly (from Meteo-Swiss)


2.1 JJA-07:Probability of T_2m categories from System-3
ECMWF Seasonal Forecast
Prob(most likely category of 2m temperature)
System 3
JJA 2007
ECMWF Seasonal Forecast
Prob(most likely category of 2m temperature)
System 3
JJA 2007
ECMWF
11th WS of Met Oper Sys (ECMWF, 12 Nov 2007) – Roberto Buizza & Franco Molteni : Probabilistic Predictions
26

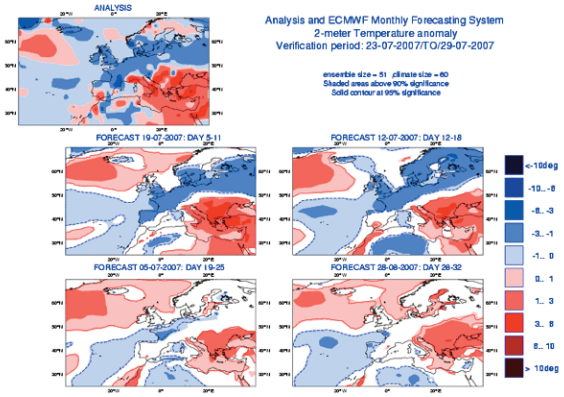

2.1 Daily max. 2m temp. anomalies JJA 2007
mean observation - Europe
anomaly - Europe
mean observation - Central Europe
anomaly - Central Europe
mean observation - UK
anomaly - UK
Heat wave in Central Europe
C
45
40
35
30
25
20
15
10
5
0
-5
0601 0606 0611 0616 0621 0626 0701 0706 0711 0716 0721 0726 0731 0805 0810 0815 0820 0825 0830
ECMWF
11th WS of Met Oper Sys (ECMWF, 12 Nov 2007) – Roberto Buizza & Franco Molteni : Probabilistic Predictions
27


2.1 Weekly 2m temp. anomalies from the monthly fc.
ANALYSIS
Analysis and ECMWF Monthly Forecasting System
2-meter Temperature anomaly
Verification period: 02-07-2007/TO/08-07-2007
ensemble size = 51 climate size = 60
Shaded areas above 90% significance
Solid contour at 99% significance
FORECAST 28-06-2007: DAY 5-11
FORECAST 21-06-2007: DAY 12-18
FORECAST 14-06-2007: DAY 19-25
FORECAST 07-06-2007: DAY 26-32
<-10deg
-10.. -8
-8.. -3
-3.. -1
-1.. 0
0.. 1
1.. 3
3.. 8
8.. 10
> 10deg
ECMWF
11th WS of Met Oper Sys (ECMWF, 12 Nov 2007) – Roberto Buizza & Franco Molteni : Probabilistic Predictions
28

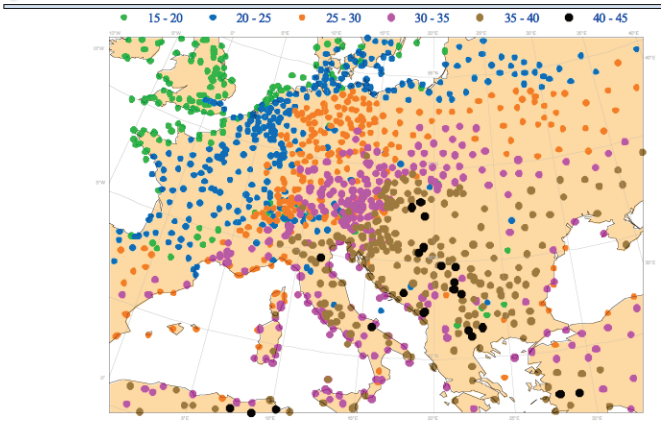
2.1 Weekly 2m temp. anomalies from the monthly fc.

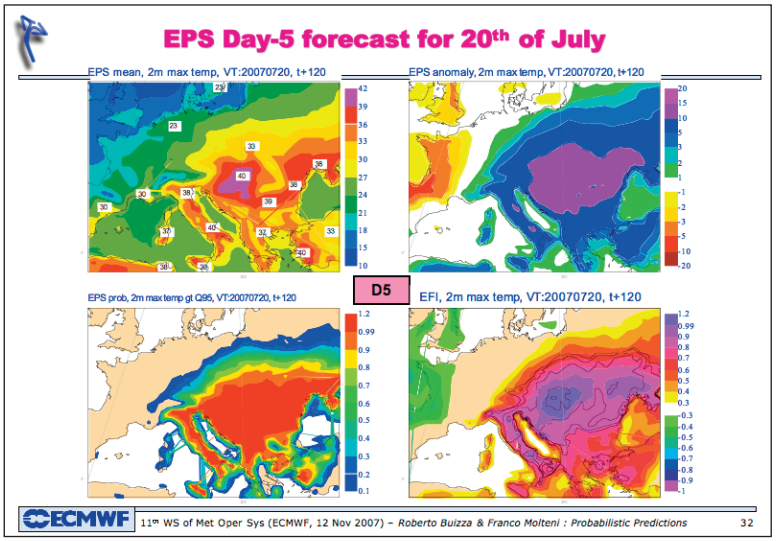


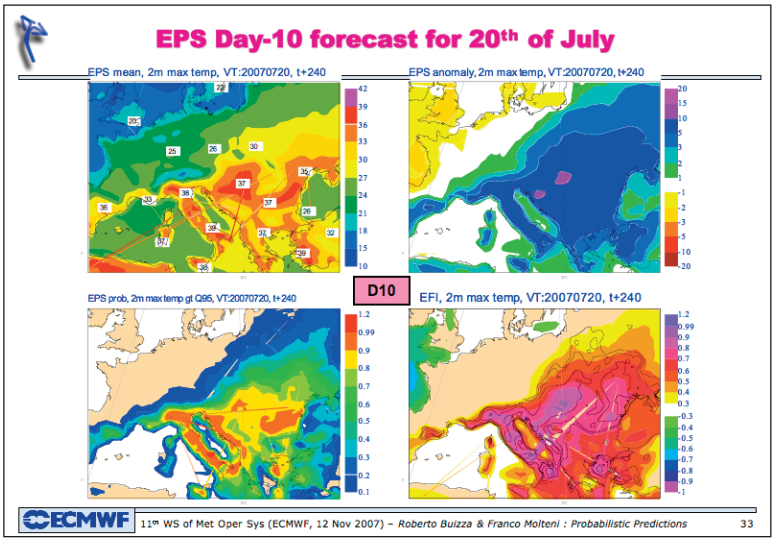
2.1 Weekly 2m temp. anomalies from the monthly fc.

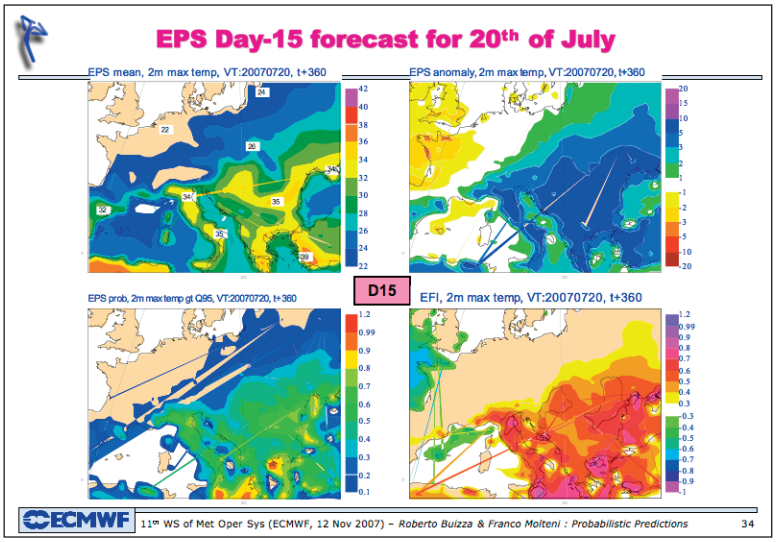


2.1 Heat wave in central and S.-East. Europe: 20 July

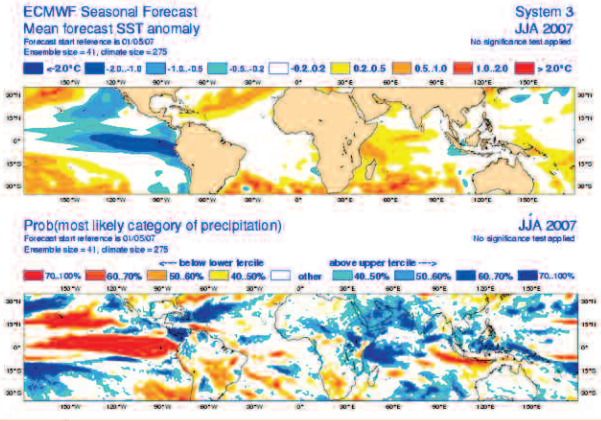



EPS Day-5 forecast for 20th of July
EPS mean, 2m max temp, VT:20070720, t+120
EPS anomaly, 2m max temp, VT:20070720, t+120
D5
EPS prob, 2m max temp gt Q95, VT:20070720, t+120
EFI, 2m max temp, VT:20070720, t+120
ECMWF
11th WS of Met Oper Sys (ECMWF, 12 Nov 2007) – Roberto Buizza & Franco Molteni : Probabilistic Predictions
32

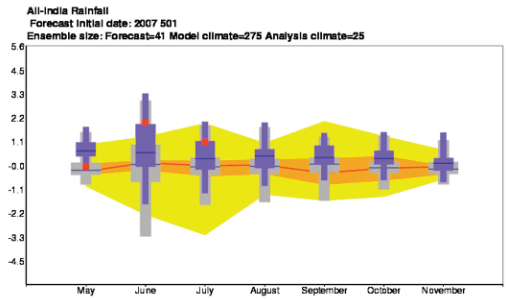

EPS Day-10 forecast for 20th of July
EPS mean, 2m max temp, VT:20070720, t+240
EPS anomaly, 2m max temp, VT:20070720, t+240
D10
EPS prob, 2m max temp gt Q95, VT:20070720, t+240
EFI, 2m max temp, VT:20070720, t+240
ECMWF
11th WS of Met Oper Sys (ECMWF, 12 Nov 2007) – Roberto Buizza & Franco Molteni : Probabilistic Predictions
33


EPS Day-15 forecast for 20th of July
EPS mean, 2m max temp, VT:20070720, t+360
EPS anomaly, 2m max temp, VT:20070720, t+360
D15
EPS prob, 2m max temp gt Q95, VT:20070720, t+360
EFI, 2m max temp, VT:20070720, t+360
ECMWF
11th WS of Met Oper Sys (ECMWF, 12 Nov 2007) – Roberto Buizza & Franco Molteni : Probabilistic Predictions
34

2.2 Above-average rainfall over the Indian sub-cont.



2.2 All India Rainfall: "climagram" from 1 May



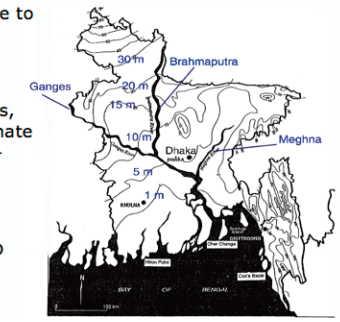
2.2 Flood predictions in Bangladesh (CFAB)

In 2000, The Georgia Institute of Technology started the Climate Forecast Applications for Bangladesh (CFAB) project, with the aim to investigate the feasibility of medium-range to seasonal forecasts of river discharge and flood alerts to Bangladesh.

The project has important societal benefits, also in view of the potential impact of climate change on Bangladesh: a 5m raise in sea-level would flood ~30% of the country, affecting ~ hundred million people.

The project has been sponsored by USAID and uses ECMWF medium-range and seasonal ensemble forecasts to drive hydrological models.

Topography of Bangladesh



(Source: T Hopson, P Webster)

2.2 Flood prediction in Bangladesh (CFAB)

CFAB has designed and developed a three-tier system:

❖ **SEASONAL OUTLOOK:** "Broad brush" probabilistic forecast of rainfall and river discharge. Updated each month. Produced out to 6 months, currently most useful skill out 3 months

❖ **20-25 DAY FORECAST:** Forecast of average 5-day rainfall and river discharge 3-4 weeks in advance. Updated every 5 days

❖ **1-10 DAY FORECAST:** Forecast of rainfall and precipitation in probabilistic form updated every day. Considerable skill out to 5-days. Moderate skill 5-10 days.

(Source: T Hopson, P Webster)

2.2 Flood prediction in Bangladesh (CFAB)

Damaging Floods:

❖ early floods in May, June

❖ above-normal peak floods in July, August

❖ late floods extending in September

Recent severe flooding: 1974, 1987, 1988, 1997, 1998, 2000, 2004 and 2007

❖ 1988: 3/4 of country inundated, 1300 people killed, 30 million homeless, $1 billion in property loss

❖ 1998: 60% of country inundated for 3 months, 1000 killed, 40 million homeless, 10-20% total food production lost

❖ 2004: flooding in Brahmaputra basin killed 500 people, displaced 30 million for 3 weeks, 40% of capital city Dhaka (10 million people) under water

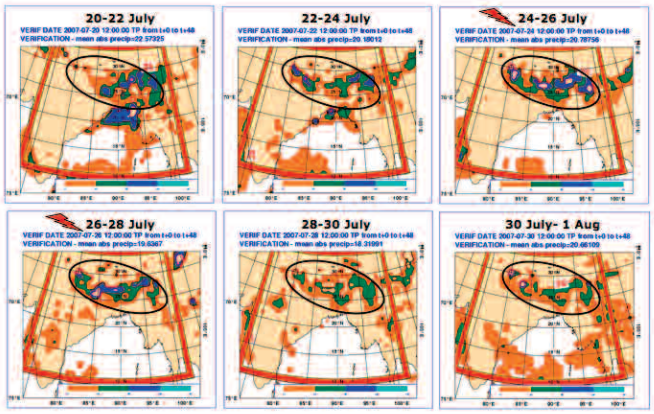
(Source: T Hopson, P Webster)

2.2 July/August 2007 floods in Bangladesh

"Seven people had died and thousands have been forced to leave their homes in Bangladesh because of worsening floods. Officials said that nearly half a million people remained marooned in seven flood-hit districts in the country's north west and in the south." (8 August 2007, from *http://news.bbc.co.uk*).

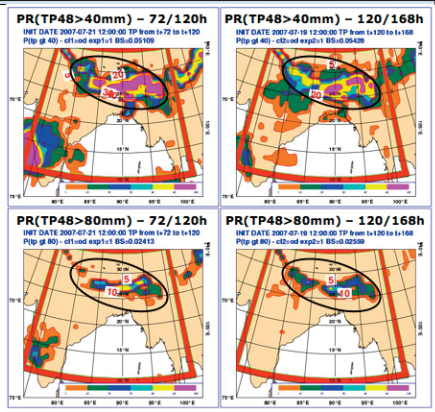
2.2 July/August 2007: floods in Bangladesh

In July/ August 2007, the floods were linked to intense precip. towards the end of July, notably from 24 to 28 July.

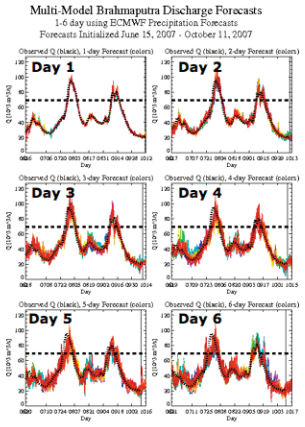


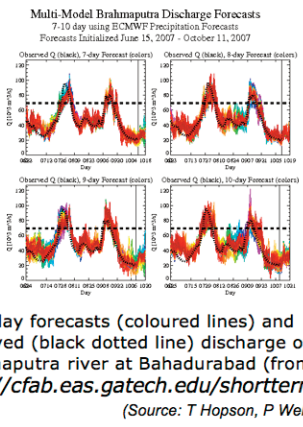
2.3 2007 floods in Bangladesh – fcs for 24/07-26/07

The right figure shows the 72/120h (left) and the 120/168h (right) fc probabilities of 48h-accumulated rainfall in excess of 40 (top) and 80 (bottom) mm (CI 5/10/20/30/40/60%).



2.2 2007 floods in Bangladesh: fcs for the Brahmaputra

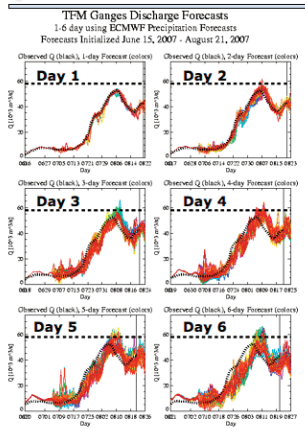


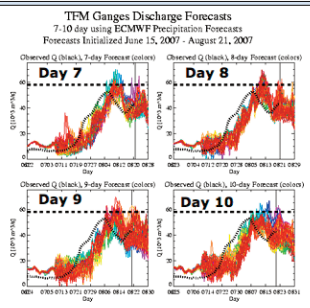


1-10 day forecasts (coloured lines) and observed (black dotted line) discharge of the Brahmaputra river at Bahadurabad (from *http://cfab.eas.gatech.edu/shortterm/*)

(Source: T Hopson, P Webster)

2.2 2007 floods in Bangladesh: fcs for the Gange





1-10 day forecasts (coloured lines) and observed (black dotted line) discharge of the Gange river at Hardinge Bridge (from *http://cfab.eas.gatech.edu/shortterm/)*

(Source: T Hopson, P Webster)

2.2 2007 floods in Bangladesh

"… thank you very much for your efforts on 1-10 days flood forecasting for major rivers in Bangladesh. We were able to inform the people in advance and on 25th July we started communicating the information to as many people as possible about the certainty of exceeding danger levels along the Brahmaputra …

… The local partners, NGO networks and DMC members were advised to inform to the poorest of the poor especially people living in river chars …

… The forecast was of great value to the people in Rajput union and many other locations along the Brahmaputra river to undertake the preparatory measures in advance. The 10 days forecasts helped the FFWC engineers immensely to give advance information and they were confident to face the press …"

(extract from a letter sent from the Asian Disaster Preparedness Centre to Georgia Tech)

(Source: T Hopson, P Webster)

3. Conclusions

- The ECMWF Probabilistic Prediction Systems:
  - 15-day VAREPS: The implementation of model cycle 32r2 (7 Nov '07) has lead to a better tuned spread. Recent comparison based on TIGGE data indicates that the ECMWF ensemble system is outperforming the other global EP systems.
  - 32-day Monthly: The planned VAREPS-monthly system is expected to deliver better forecast skill in the extra-tropics, with more realistic representation of extreme events
  - Seasonal system: The new System 3, implemented in March 2007, delivers improved predictions of tropical SST and reduced model bias wrt the previous System 2. Improvements in skill for atmospheric variables are more evident during the NH summer
- The anomalous events of summer 2007:
  - Europe: The warm anomalies in SE Europe were reasonably well predicted by both the seasonal and the monthly fc. but the cold/wet anomalies in NW Europe were not captured by the seasonal fc. Excellent EPS prediction of the late July heat wave.
  - India: Skillful seasonal predictions of above-average rainfall in India/Bangladesh. EPS input to the CFAB system led to successful flood alert in Bangladesh.