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SMR/1849-2

Conference and School on Predictability of Natural Disasters for our Planet in Danger. A System View; Theory, Models, Data Analysis

25 June - 6 July, 2007

Severe weather prediction with the ECMWF ensemble system

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Severe weather prediction with the ECMWF ensemble system

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Outline

1. The value of Ensemble Prediction
2. Hydrological applications
   - 2.a The JCR European Flood Alert System (EFAS)
   - 2.b The flood of Italy of 1966: a revisitation
   - 2.c George Tech prediction of flooding in Bangladesh
3. Typhoon prediction
   - 3.a Simulation on initial uncertainties in the tropics
   - 3.b Mindulle (July ‘04)
   - 3.c Talin (Sep ’05)
   - 3.d Saomai & Wukong (Aug ’06)
   - 3.e Ioke, Shanshan, Yagi & Xangsane (Sep ’06)
4. Conclusions

1. The value of ensemble prediction

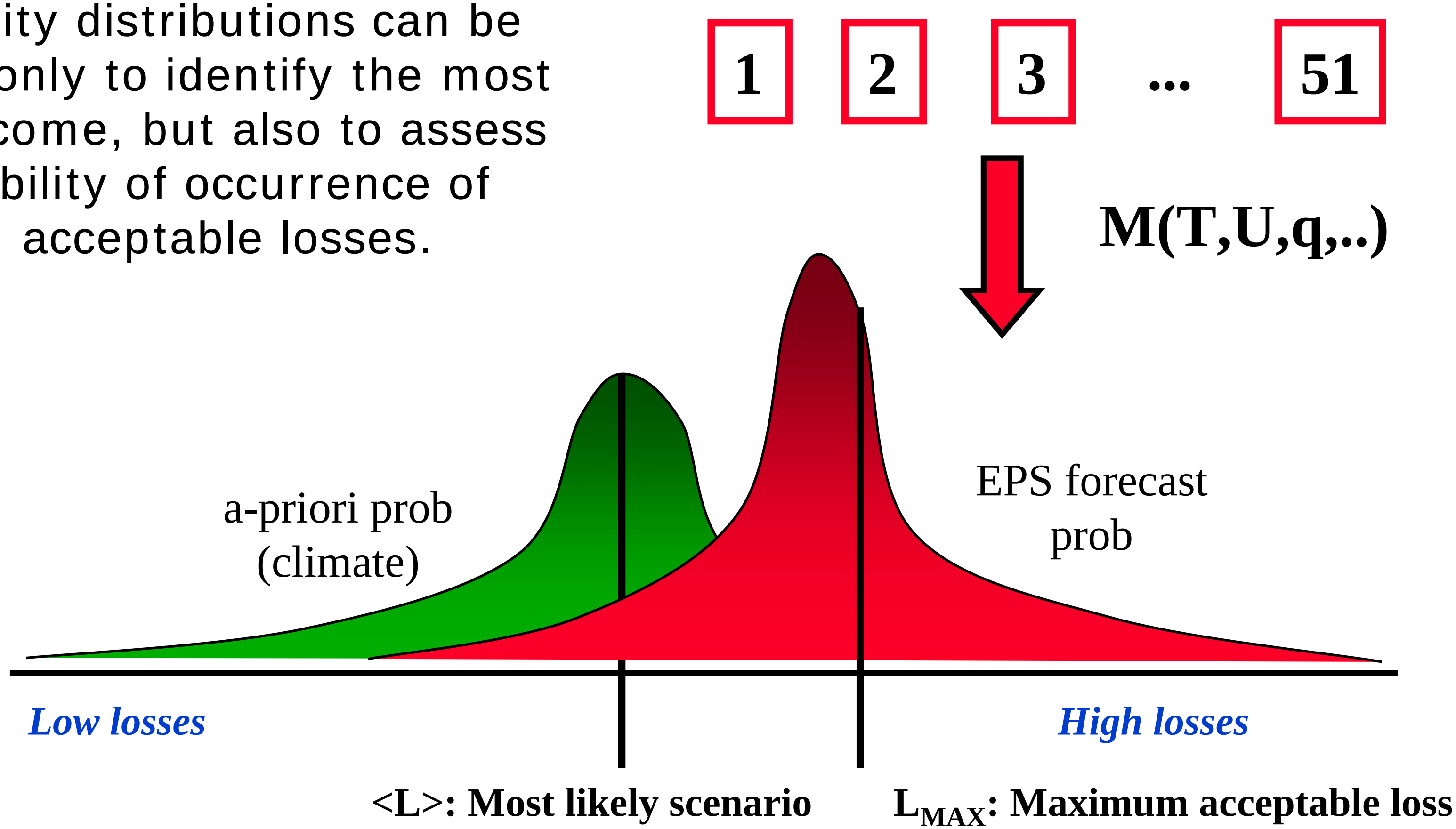
Two main reasons why ensemble predictions are valuable:

• Ensemble prediction systems can be use to estimate the whole probability distribution function of forecast states. **These distributions can be used not only to identify the most likely outcome, but also to assess the probability of occurrence of maximum acceptable losses**.

• Ensemble-based deterministic (e.g. the ensemble-mean) and probabilistic forecasts are more accurate than single deterministic forecasts. This can be measured, e.g., by comparing the economic value of single deterministic and ensemble forecasts.

1. The value of ensemble prediction: scenario analysis

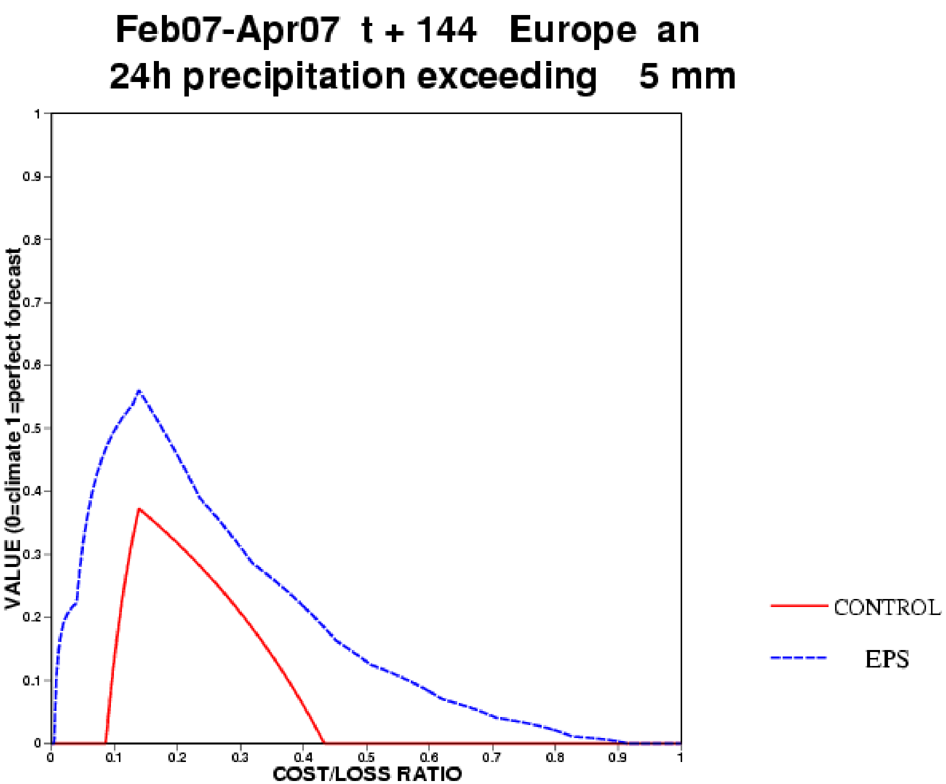
- Ensemble forecasts can be *translated* into forecast probability distribution of gains/losses.
- Probability distributions can be used not only to identify the most likely outcome, but also to assess the probability of occurrence of maximum acceptable losses.

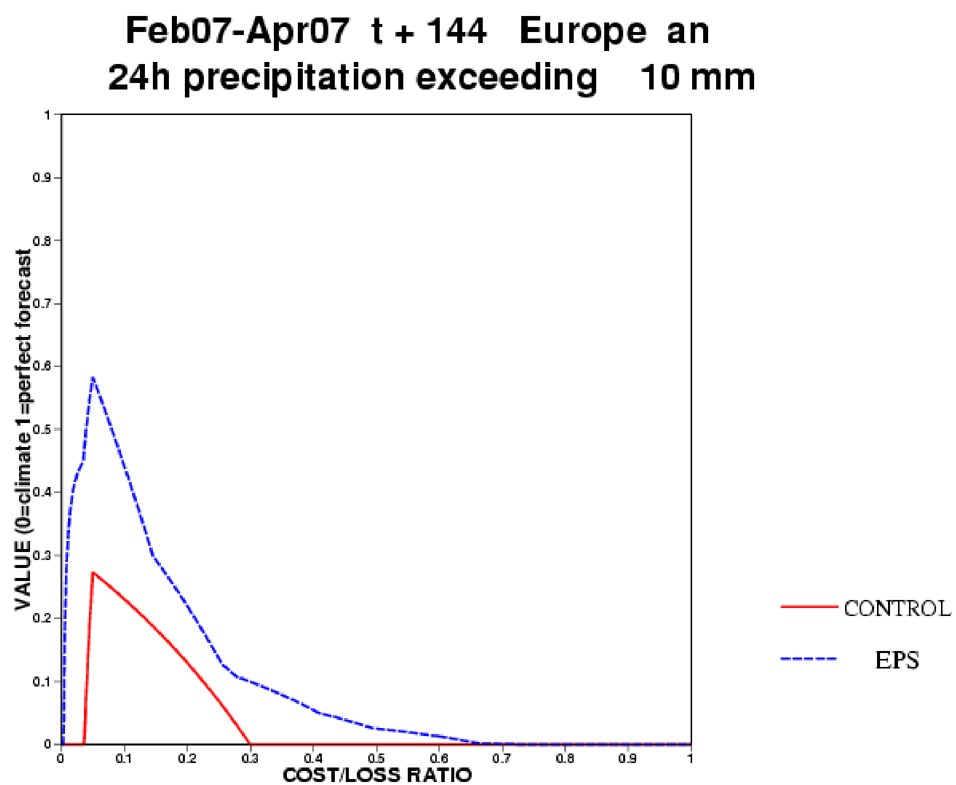


1. Potential economic value

The potential economic value of a forecast is the reduction of mean expenses that can be achieved using it relative to the reduction of that can be achieved by using a perfect forecast, estimated using a simple cost/loss model.

EPS probabilistic forecasts have higher PEV than the single control forecast.





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2. Flood prediction with a cascade of M$^{\sim al}$ & H$^{\sim al}$ models

Global meteorological ensemble forecasts can be used to ‘drive’ hydrological models, either directly or indirectly after a dynamical downscaling cascade, so that probabilistic predictions of hydrological events can be generated.

Observations	Data assimilation	Global M$^{\sim al}$ modelling	Local M$^{\sim al}$ modelling	Basin H$^{\sim al}$ modelling	Quality control
•Weather data •Hydro data	• ECMWF ERA40 (T_L159L31) • ECMWF High-res T_L511L60 DA experiments	• ECMWF +240h 40km (T_L511L60) deterministic predictions • ECMWF +240h 80km EPS (51*T_L255L40) probabilistic predictions	• ISAC/CNR BOLAM +72h 18km (*pater*) • ISAC/CNR BOLAM+72h 6km (*filius*) • ISAC/CNR MOLOCH +48h 2km (non-hydr.)	• University of Brescia (IT) simple rainfall/runoff model	• Verification of precipitation and runoff predictions

2.a JRC European Flood Alert System (EFAS)

• Following the disastrous floods in the Elbe and Danube river basins in August 2002, the European Commission announced in the communication (COM(2002)-481) the development of a European Flood Alert System (EFAS). EFAS - developed within the WDNH project - will be capable of providing medium-range flood simulations across Europe with a lead-time between 3 to 10 days.

• EFAS should provide the European Commission with useful information for the preparation and management of aid during a flood crisis. National Water Authorities should benefit from additional medium-range flood information that might contribute to increased preparedness in an upcoming flood event.

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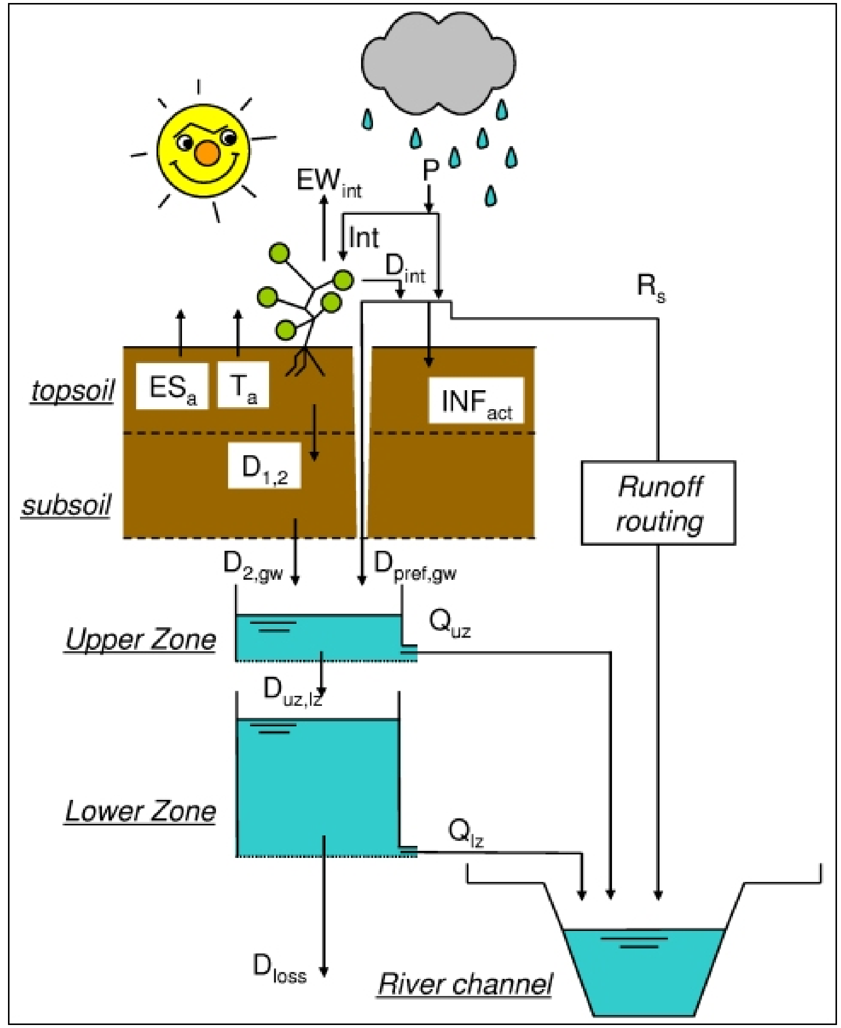
(Source: J Bartholmens, J Thielen)

2.a JRC EFAS

The JRC EFAS system is based on the LISFLOOD model.

LISFLOOD is a grid-based catchment model that has been developed to simulate floods in large European river basins. Because the model is spatially distributed, changes in e.g. land use can be easily included in a LISFLOOD simulation. The typical size of one grid cell is 1 by 1 km, although the model can be run at both much finer and coarser resolutions if needed.

LISFLOOD is currently being used and tested for flood forecasting (EFAS), scenario modelling, and drought forecasting.

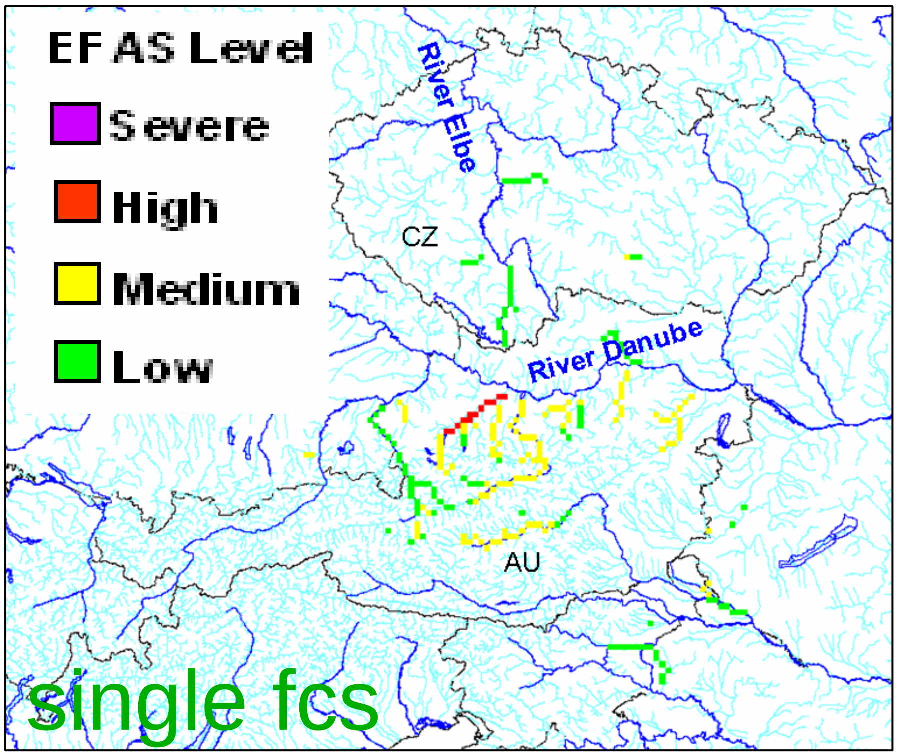


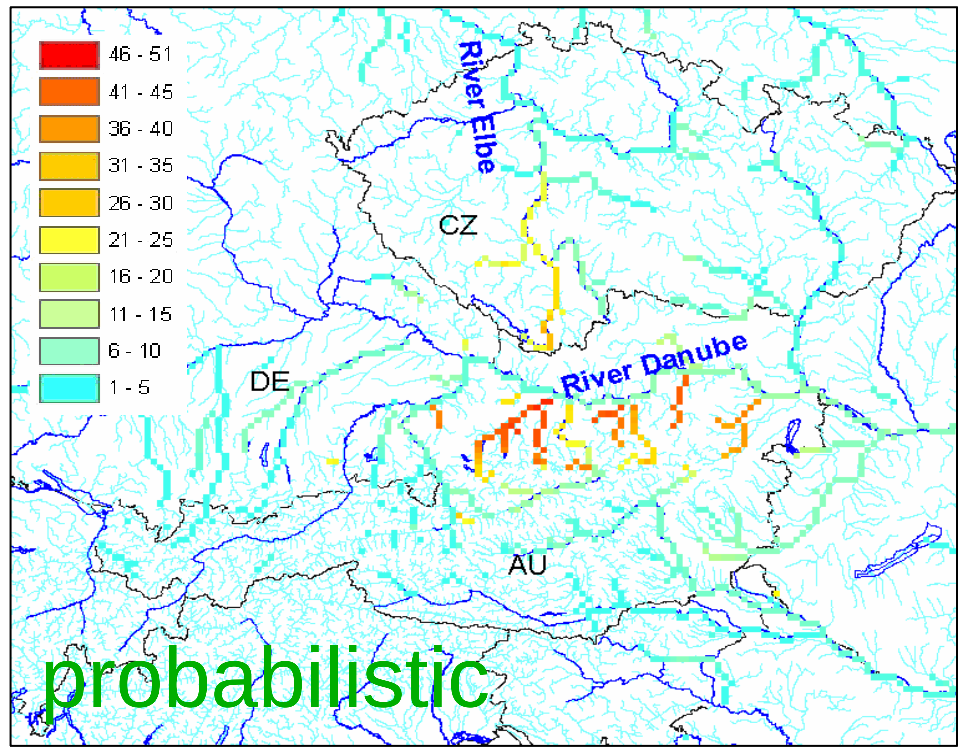
(Source: J Bartholmens, J Thielen)

2.a JRC European Flood Alert System (EFAS)

EFAS products include a map of Europe showing the risk of flooding for all rivers with a catchment larger than 3000 km^2. Forecast are based both on single forecasts, with LISFLOOD driven by the ECMWF and the DWD high-resolution single forecasts, and on ensemble forecasts, with LISFLOOD driven by ECMWF ensemble forecasts.

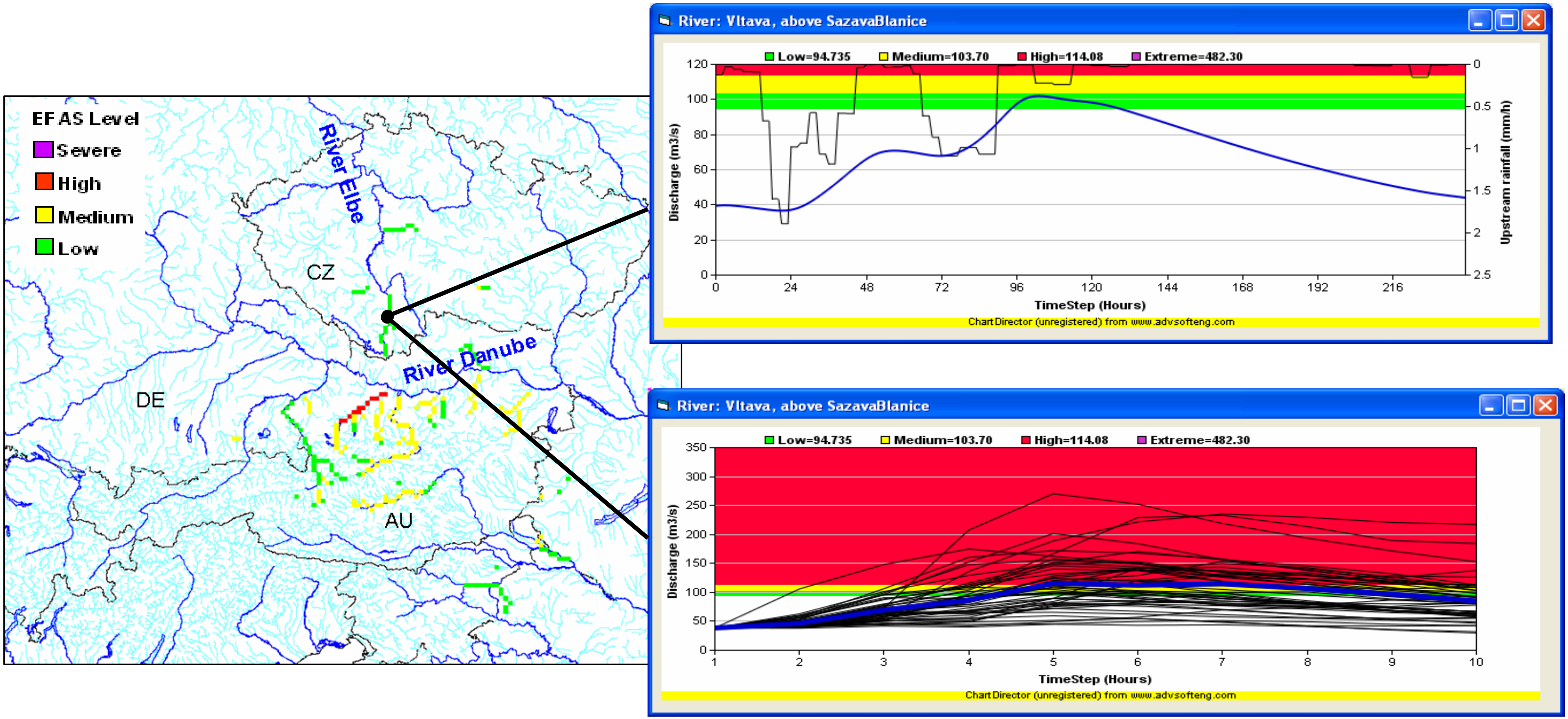
(Source: J Bartholmens, J Thielen)





2.a EFAS map and grid point forecasts

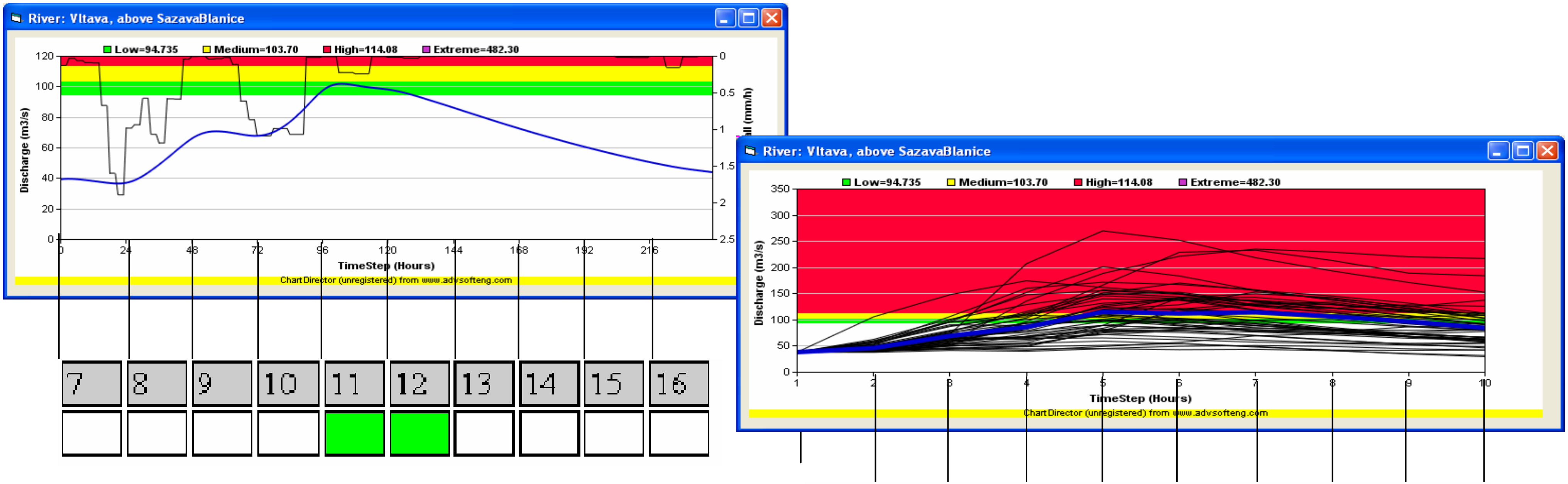
EFAS products include also grid point information.



(Source: J Bartholmens, J Thielen)

2.a EFAS forecast display system

Grid point single and probabilistic forecasts are simplified …



Forecast Day	8	9	10	11	12	13	14	15	16
EPS > HAL		1	8	22	24	22	17	14	5
EPS > SAL									

(Source: J Bartholmens, J Thielen)

2.a EFAS forecast: 2006 flood of Vlatava/Elbe & Morava

Country: Czech Republic

Rivers/catchments: Vltava/Elbe, Morava

Date of event: 29th March 2006 - ongoing

foto: PRÁVO/Lukáš Táborský

(Source: J Bartholmens, J Thielen)

2.a EFAS forecast: 2006 flood of Vltava/Elbe & Morava

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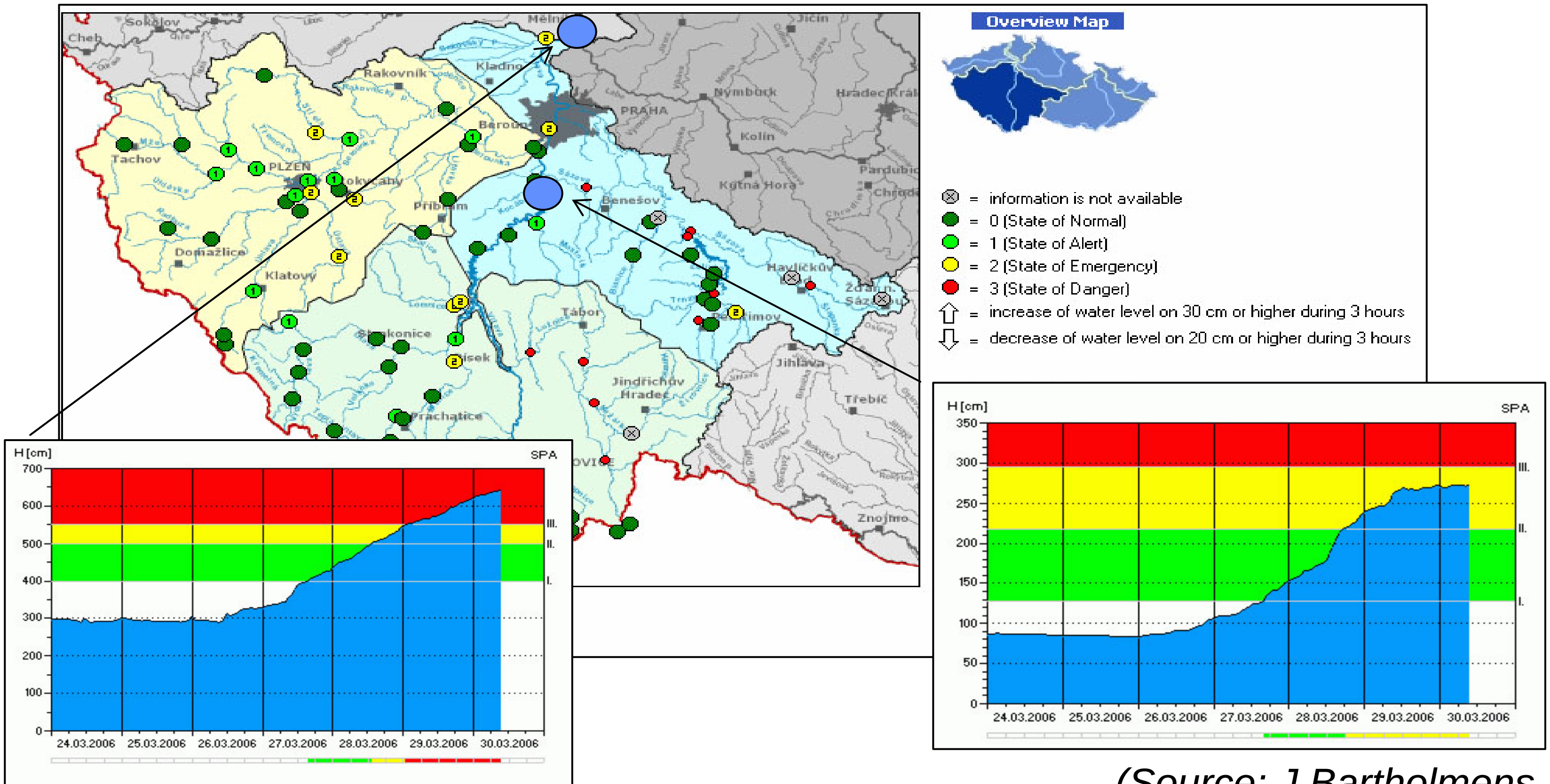


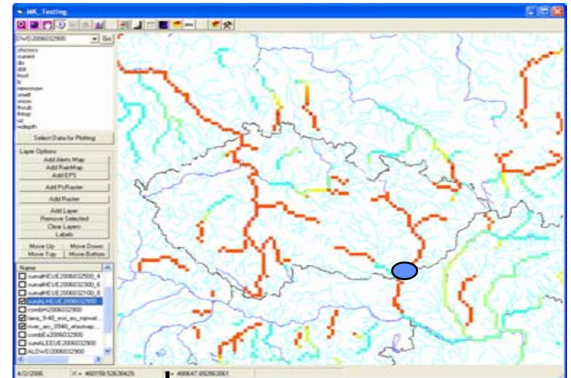
(Source: J Bartholmens, J Thielen)

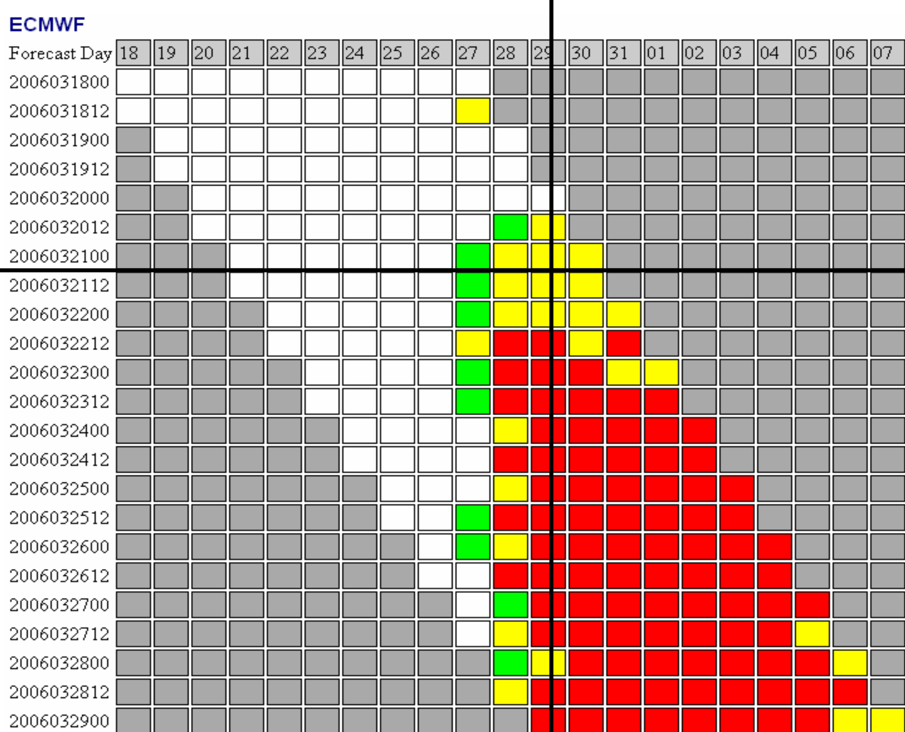
2.a EFAS forecast: 2006 flood downstream Morava

Single (left) and ensemble-based (right) forecasts of the risk of flooding downstream the Morava river.

On 21 March 2006, many ensemble members were forecasting high-alert conditions for 29 March.

(Source: J Bartholmens, J Thielen)





EPS > HAL

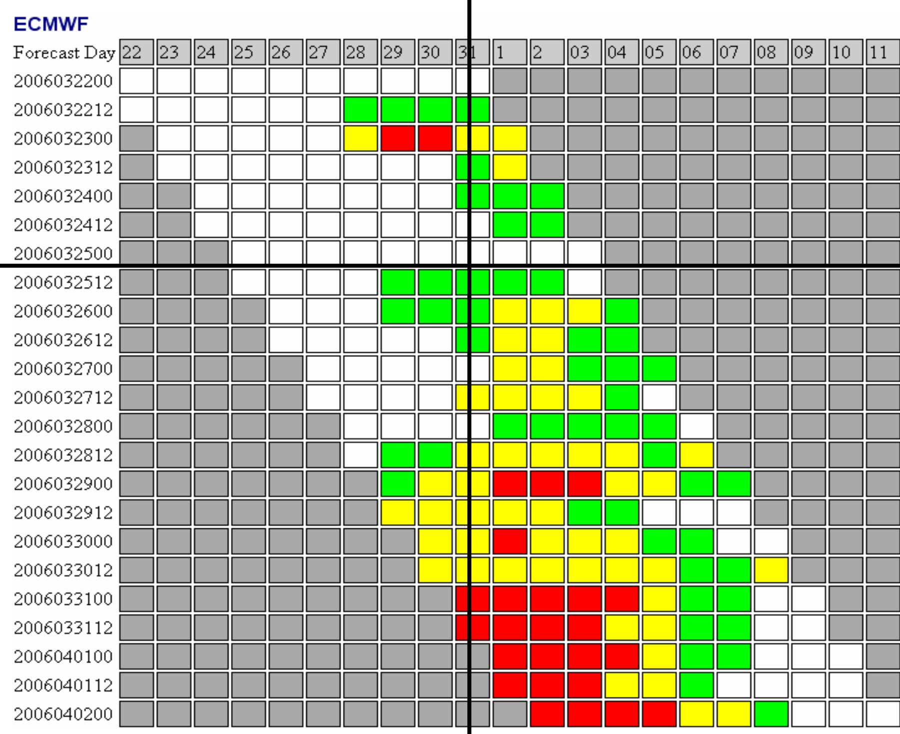
Forecast Day	18	19	20	21	22	23	24	25	26	27	28	29	30	31	01	02	03	04	05	06	07
2006031800										1											
2006031812										1											
2006031900										1	1										
2006031912											3										
2006032000										4	15	19									
2006032012										5	11	18									
2006032100											12	25	31								
2006032112										9	22	26	28								
2006032200										1	20	31	37	32							
2006032212										6	27	28	22	22							
2006032300											17	29	31	18	14						
2006032312										5	26	36	34	31	26						
2006032400											27	40	36	28	29	32					
2006032412											28	33	29	29	25	20					
2006032500											25	46	44	42	43	40	22				
2006032512											33	40	39	38	36	29	16				
2006032600											41	48	46	46	46	42	21	9			
2006032612											33	45	45	47	45	41	20	10			
2006032700											2	46	47	49	50	50	40	28	18		
2006032712											36	50	51	51	51	51	49	36	27		
2006032800												39	49	51	51	51	51	48	34	29	
2006032812												36	51	51	51	51	51	51	42	38	
2006032900												51	51	51	51	51	51	51	50	47	34

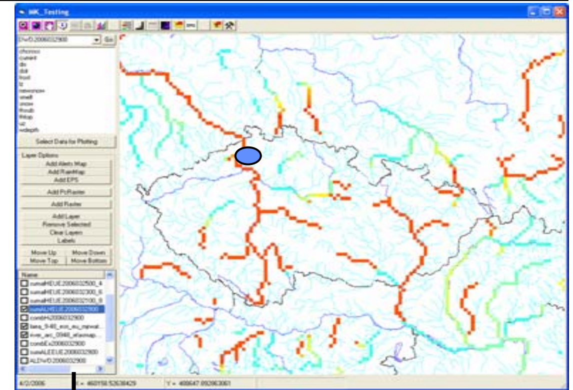
2.a EFAS forecast: 2006 flood downstream Vltava/Elbe

Single (left) and ensemble-based (right) forecasts of the risk of flooding downstream the Vlatava/Elbe river.

On 25 March 2006, many ensemble members were forecasting high-alert conditions for 31 March.

(Source: J Bartholmens, J Thielen)



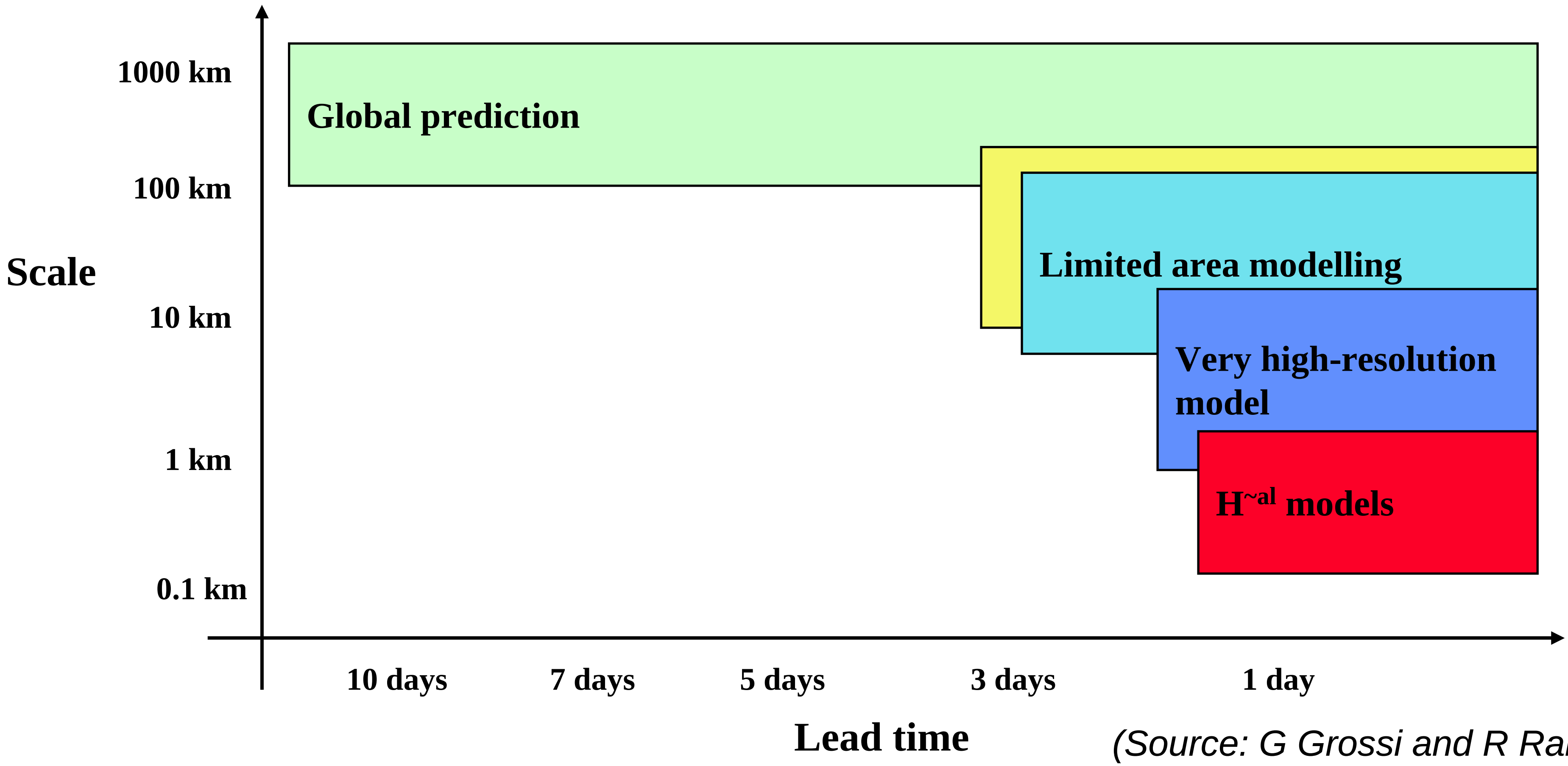


EPS > HAL

Forecast Day	22	23	24	25	26	27	28	29	30	31	1	2	03	04	05	06	07	08	09	10	11
2006032200									2	8											
2006032212								2	2	6											
2006032300									1	1	2										
2006032312								5	8	12	16										
2006032400									1	7	9	12									
2006032412									2	7	13	17									
2006032500									2	13	24	27	25								
2006032512									7	15	25	25	24								
2006032600									3	16	24	29	25	18							
2006032612									2	9	20	25	21	14							
2006032700										7	24	32	32	24	15						
2006032712									8	33	42	41	41	34	28						
2006032800										7	36	43	44	39	36	23					
2006032812										25	51	51	51	45	37	30					
2006032900										48	51	51	51	51	49	48	42				
2006032912										50	51	51	51	48	43	30	18				
2006033000											51	51	51	51	51	42	34	24			
2006033012										3	51	51	51	51	50	47	23	14			
2006033100										51	51	51	51	51	51	50	42	22	10		
2006033112										51	51	51	51	51	51	48	26	12	6		
2006040100											51	51	51	51	51	48	20	6	5	3	
2006040112											51	51	51	51	51	44	18	4	4	5	
2006040200												51	51	51	51	51	29	8	1	1	2

2.b Flood fcs using a cascade of M~al & H~al models

G Grossi and *R Ranzi* (University of Brescia), *A Buzzi* and *P Malguzzi* (ISAC/CNR Bologna) and *R Buizza* and *S Uppala* (ECMWF) have investigated the prediction of the floods of Nov 1966 using a cascade of M~al and H~al models.



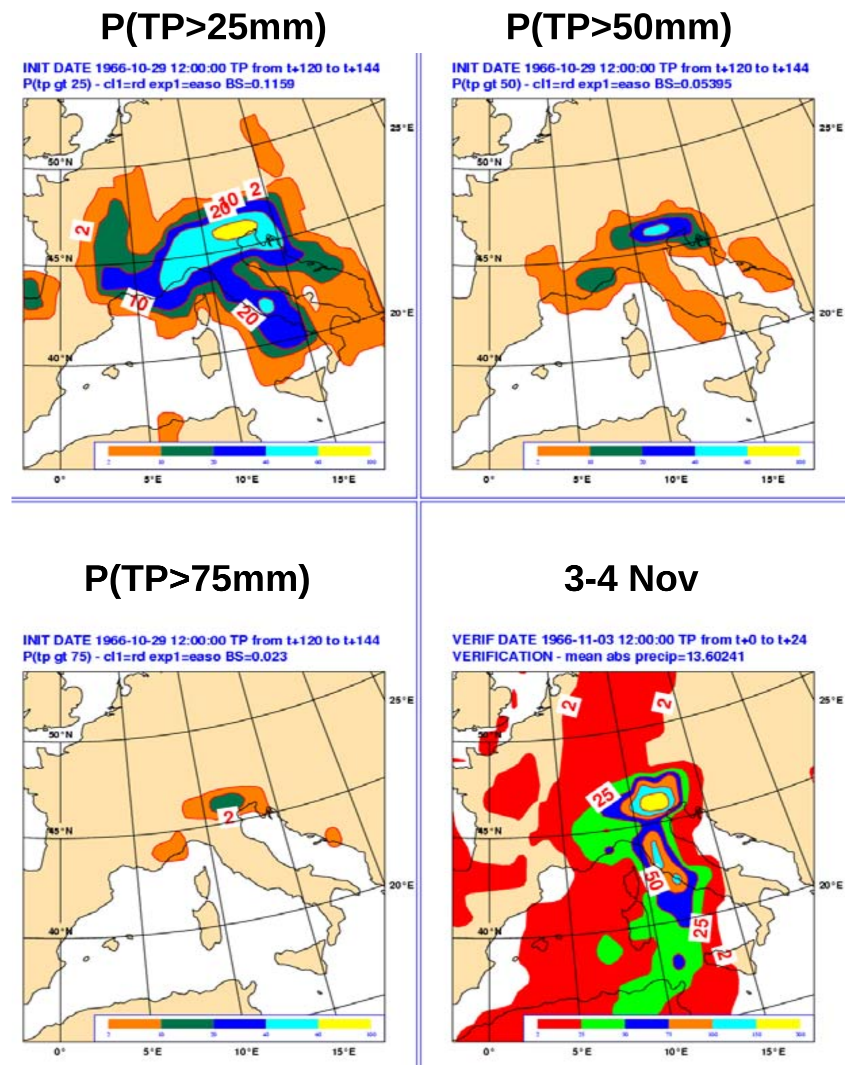
(Source: G Grossi and R Ranzi)

2.b The M$^{\sim al}$ EPS 80km global t+120-144h prob pred

This figure shows three EPS probabilistic forecasts started at 12UTC of 29 October (120-144h) and valid for 3-4 November 1966, for 24-h accumulated precipitation in excess of 25, 50 and 75 mm *[16]*.

At this forecast range, the EPS gives a 40-60% probability of TP>50mm/24h over NE Italy and a weaker signal over Tuscany (contour isolines for probabilities are 2-10-20-40-60-100%).

The right-bottom panel shows a proxi for verification.



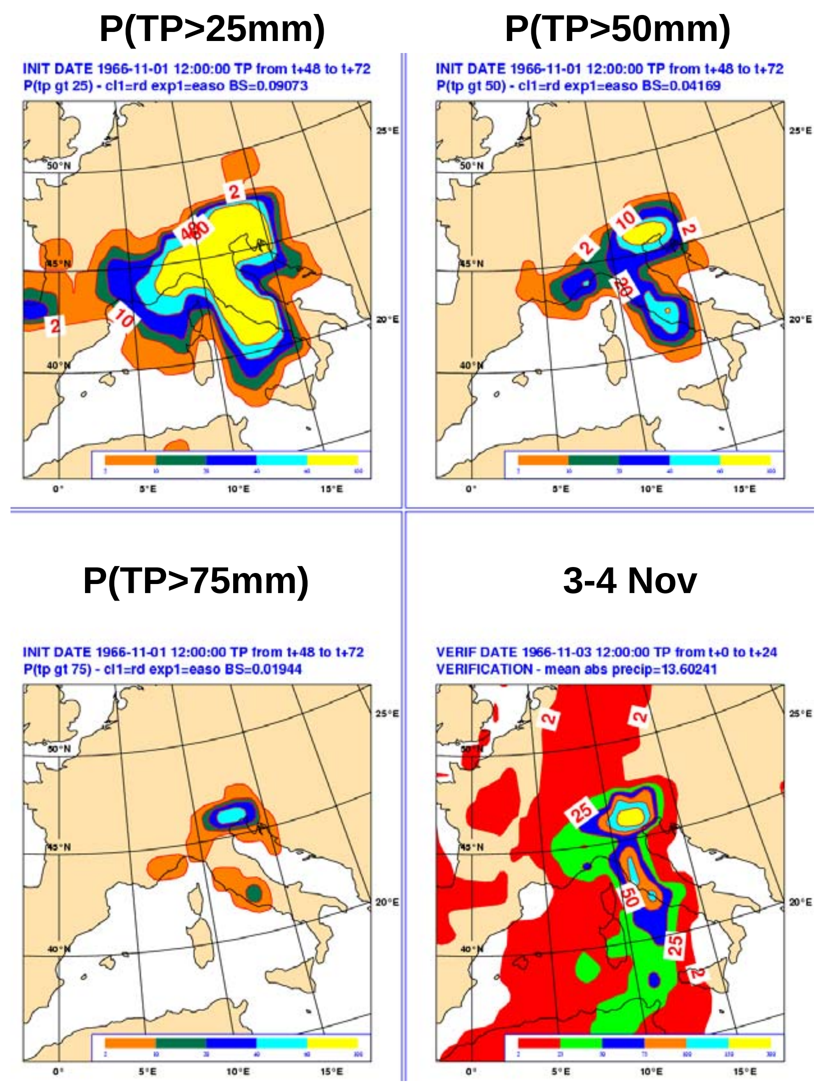
(Source: G Grossi and R Ranzi)

2.b The M$^{\sim al}$ EPS 80km global t+48-72h prob pred

This figure shows three EPS probabilistic forecasts started at 12UTC of 1 November (48-72h) and valid for 3-4 November 1966, for 24-h accumulated precipitation in excess of 25, 50 and 75 mm *[16]*.

At this earlier forecast range, the EPS gives a +80% probability of TP>50mm/24h over NE Italy and a 60-80% probability over Tuscany (contour isolines for probabilities are 2-10-20-40-60-100%).

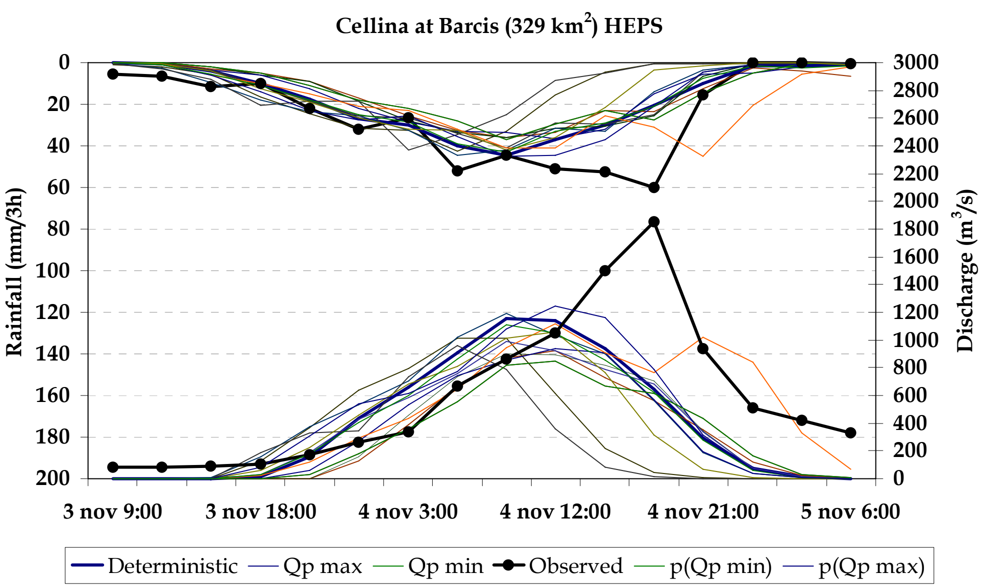
The right-bottom panel shows a proxi for verification.

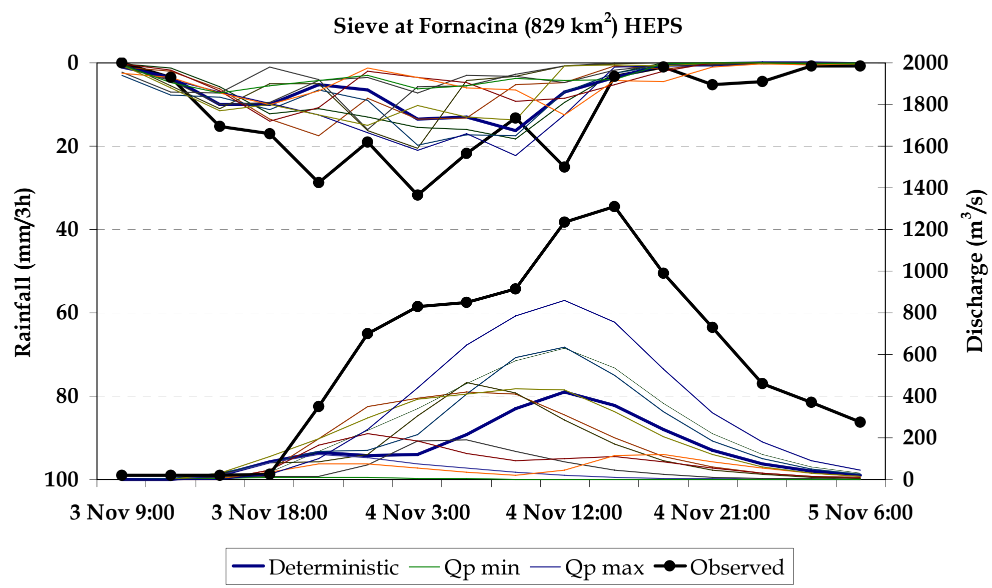


(Source: G Grossi and R Ranzi)

2.b The M~al EPS 80km global t+48-72h prob pred

Global ensemble forecasts have been used to drive the Univ. of Brescia DIMOSOP model. This figure shows some earlier results, with rainfall and discharge forecasts of Cellina at Barcis and Sieve at Fornacina, predicted using EPS forecasts started at 12UTC of 1 November. The on-going research project aims to identify suitable strategies to select representative members of a global ensemble system to be dynamically downscaled using a cascade of a meso-scale model and a hydrological flood model.





(Source: G Grossi and R Ranzi)

2.c Flood prediction in Bangladesh (CFAB)

Damaging Floods:

- early floods in May, June
- more than normal peak floods in July, August
- late floods extending in September

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

- 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 capitol city Dhaka (10 million people) under water

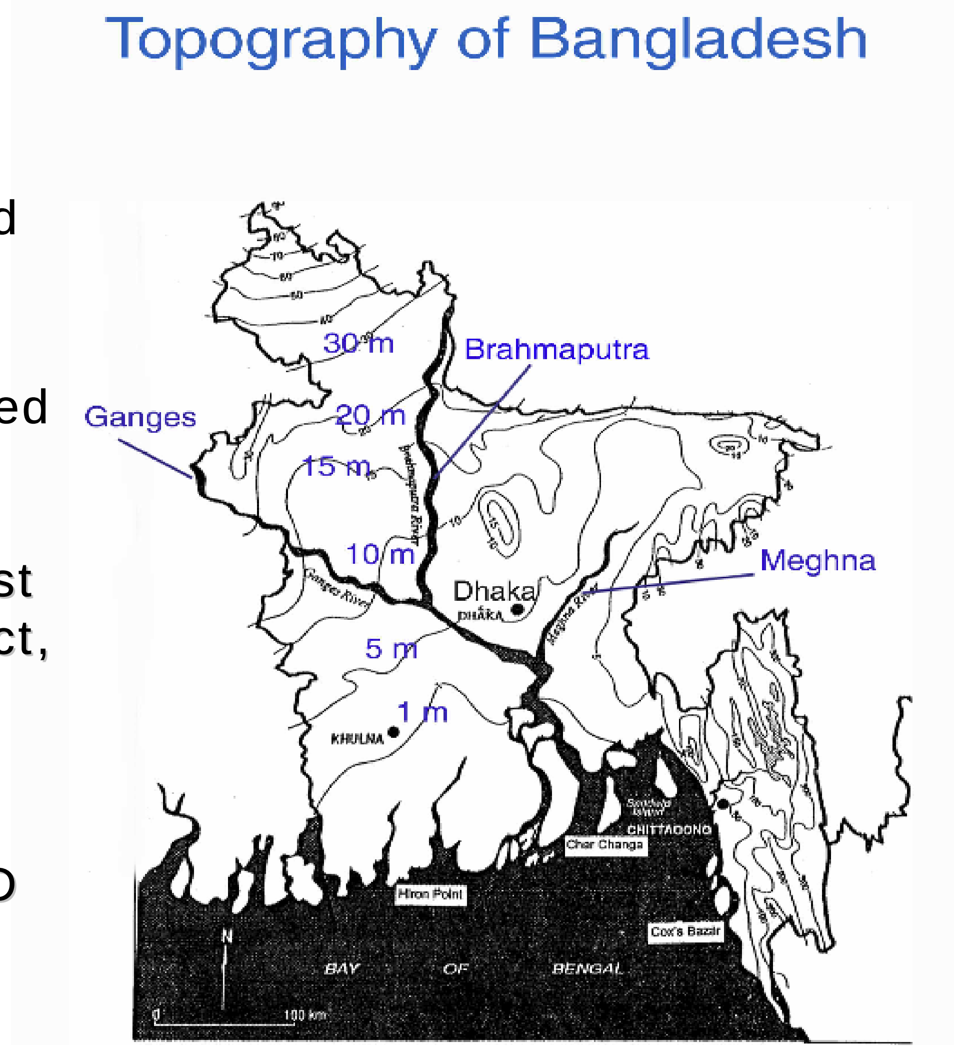
(Source: T Hopson, P Webster)

2.c Flood prediction in Bangladesh (CFAB)

This project is extremely important especially in view of the potential impact that climate change may have on Bangladesh: a 5m raise in sea-level would flood ~30% of the country, and displace hundred million people.

The Georgia Institute of Technology started in 2000 the Climate Forecast Applications for BangladeshUniversity of Washington started few years ago the Climate Forecast Applications for Bangladesh (CFAB) project, aiming to investigate the possibility to provide medium-range to seasonal forecasts to Bangladesh.

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



(Source: T Hopson, P Webster)

2.c Flood prediction in Bangladesh (CFAB)

CFAB has designed and developed a three-tier system:

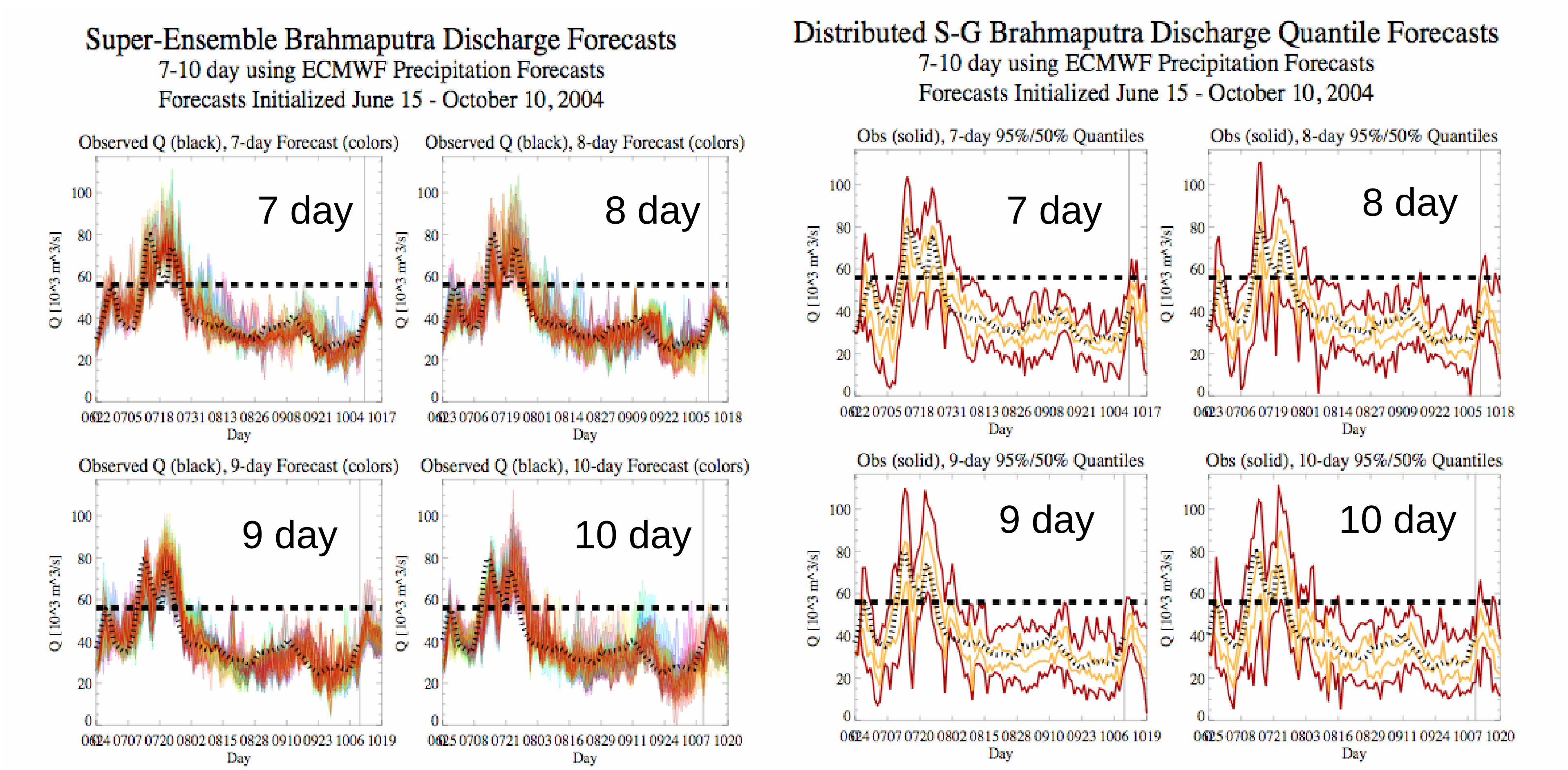
- **SEASONAL OUTLOOK:** "Broad brush" probabilistic forecast of rainfall and river discharge. Updated each month. Produced out to 6 months, currently most useful skill out 3 months

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

- **1-15 DAY FORECAST:** Forecast of rainfall and precipitation in probabilistic form updated every day. Considerable skill out to 5-days. Moderate skill 5-10 days.

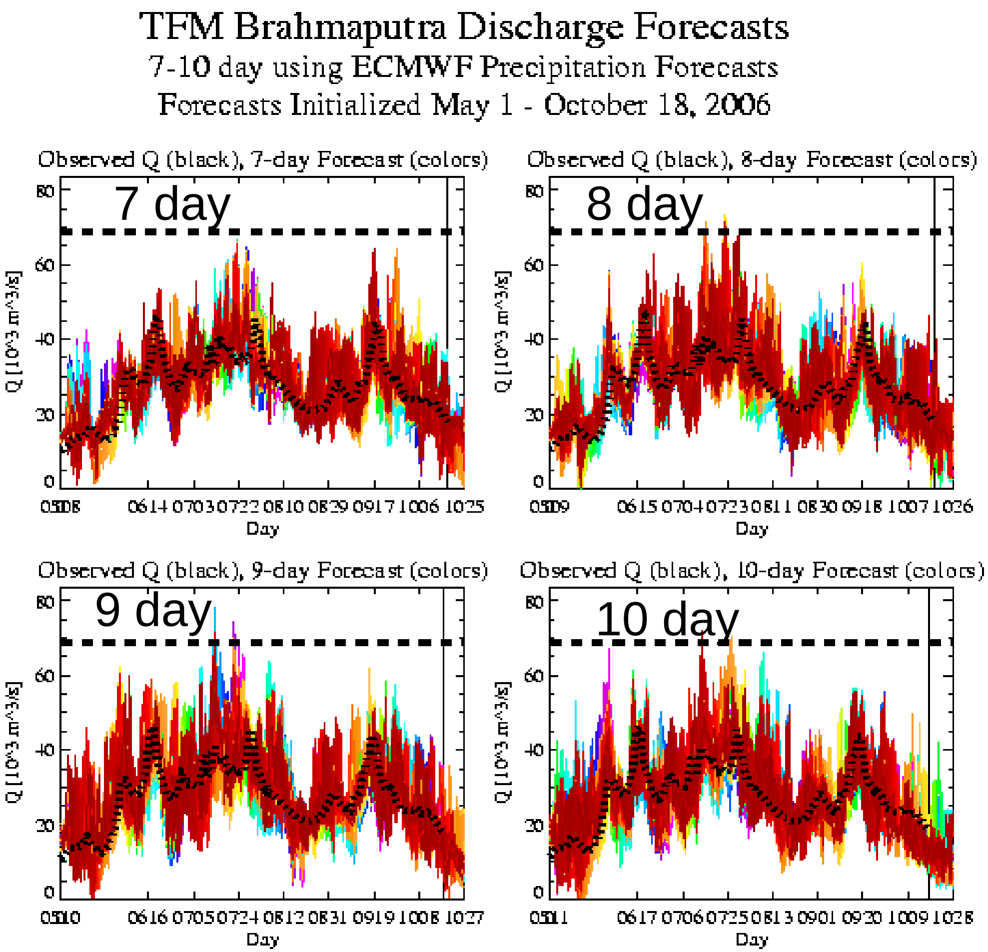
(Source: T Hopson, P Webster)

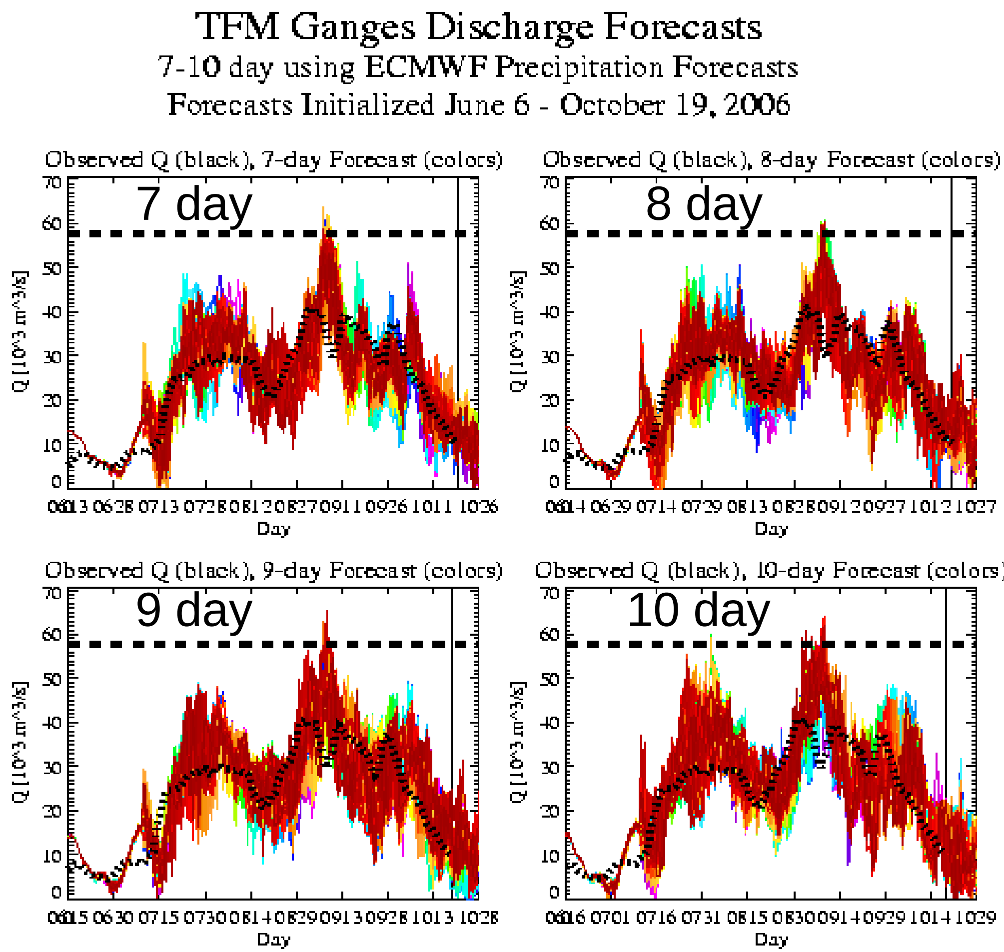
2.c 7-10 day ensemble discharge forecasts for 2004



(Source: T Hopson, P Webster)

2.c 7-10 day ensemble discharge forecasts for 2006





(Source: T Hopson, P Webster)

2.c CFAB project: preliminary results

Results so far have indicated that:

• 1-10 discharge forecasts show good daily skill at daily resolution out to 6-8 days for the Ganges, 7-10 days Brahmaputra

• Climate forecasts show skill out approximately 3 months at monthly resolution

It is expected that new techniques will extend skill in both 1-10 day and seasonal forecasts:

• statistical techniques for both

• river routing improvements and Dartmouth FloodWatch Program

• seasonal flood forecast initialized from daily forecasts

In 2006, USAID/CARE has guaranteed 4-year funding commitment. 5 pilot studies aiming to implement the use of 1-10day forecasts along the Brahmaputra have started.

(Source: T Hopson, P Webster)

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3.a Initial unc: definition of the TC-SVs' target areas

Before September 2004, tropical singular vectors (TR-SVs) were computed inside areas with northern boundary with $\lambda \leq 25°N$: this was causing an artificial ensemble-spread reduction when tropical cyclones were crossing 25°N. Furthermore, TR-SVs were computed only if WMO cl-2 TC were detected between 25°S-25°N, and too few tropical areas (up to 4) were considered.

On 28 September 2004, the following changes were introduced (*M Leutbecher*):

- Target areas are computed considering TC-track predictions
- Areas are allowed to extend north of 30ºN
- Up to 6 areas can now be targeted
- Tropical depression (WMO cl≥1) detected between 40°S-40°N are targeted
- SVs are computed using a new ortho-normalization procedure

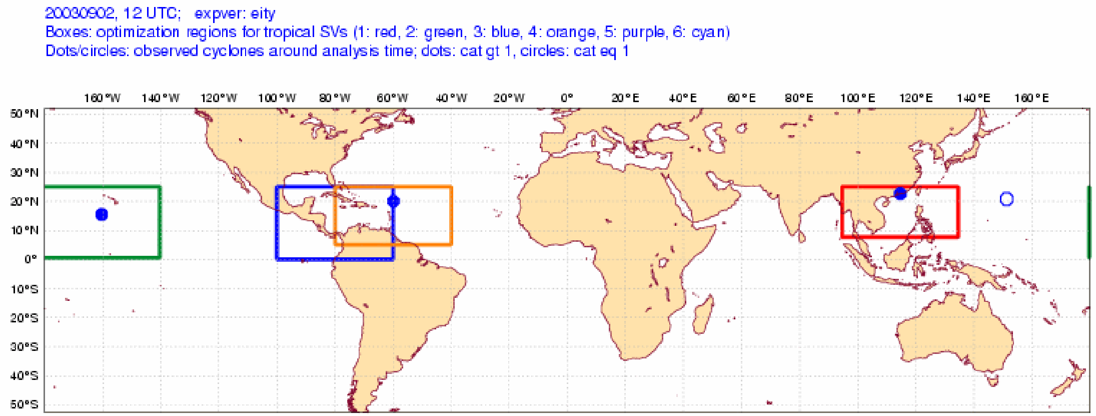
3.a TR-SVs' target areas: the Sep '04 change

This figures shows the impact of the changes introduced on 28 Sep 2004 on the TR-SVs on one case (12UTC of 2 Sep 2003):

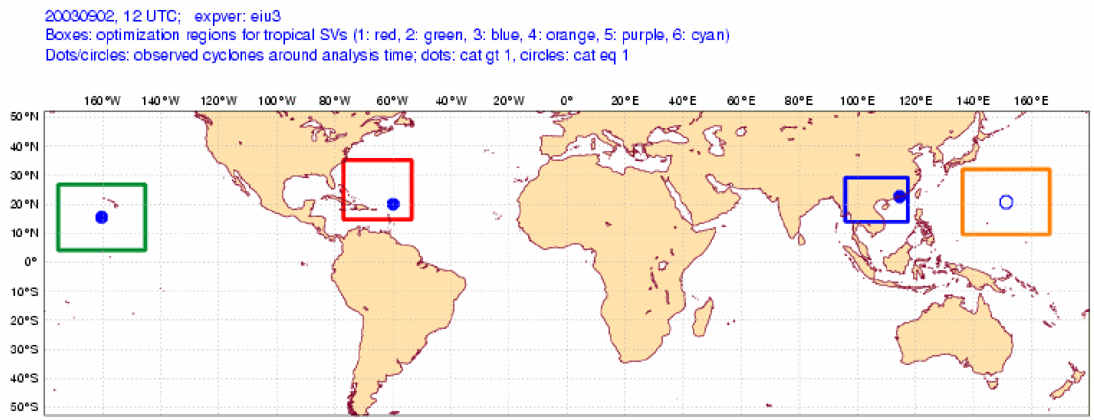
- Tropical depressions are also targeted
- Areas extend north of 30°N, and are defined considering the predicted TCs' tracks
- Overlapping areas are merged

tropical SV optimisation regions, 2 September 2003, 12 UTC

old EPS config



new EPS config

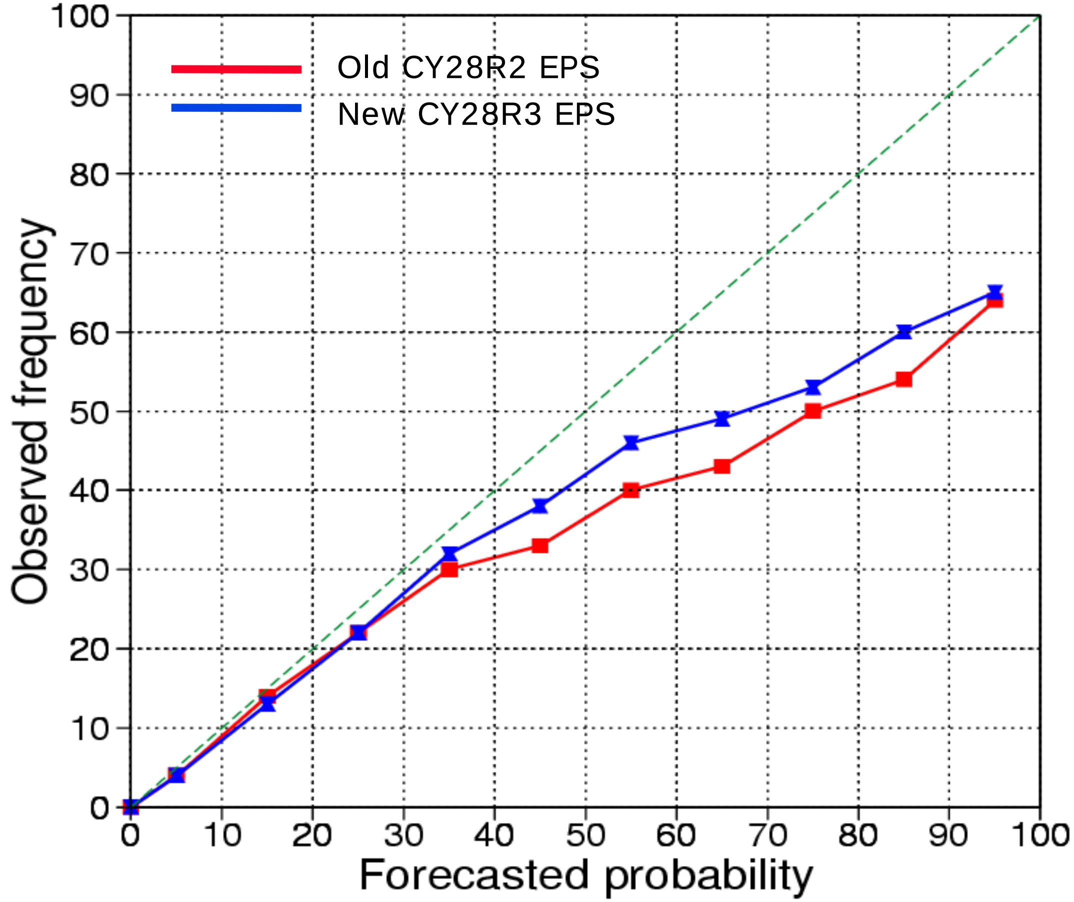


(from Martin Leutbecher)

3.a TR-SVs' target areas: impact of the Sep '04 change

Results based on 44 cases (from 3 Aug to 15 Sep 2004) indicate that the changes implemented in Sept 2004 in the computation of the tropical areas has a positive impact on the reliability diagram of strike probabilities.

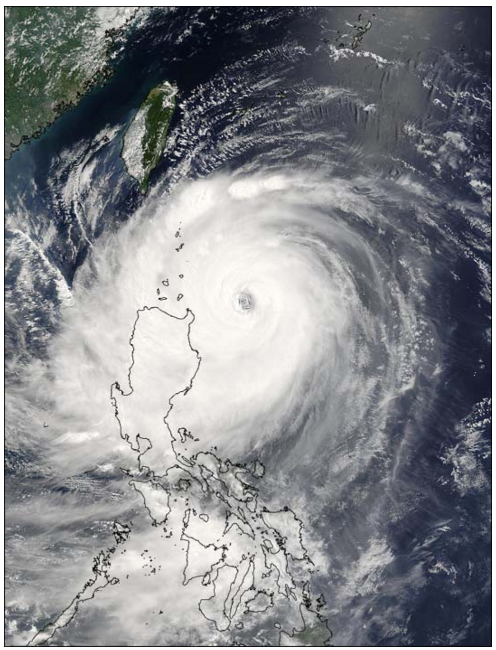
Reliability diagram for strike probabilities

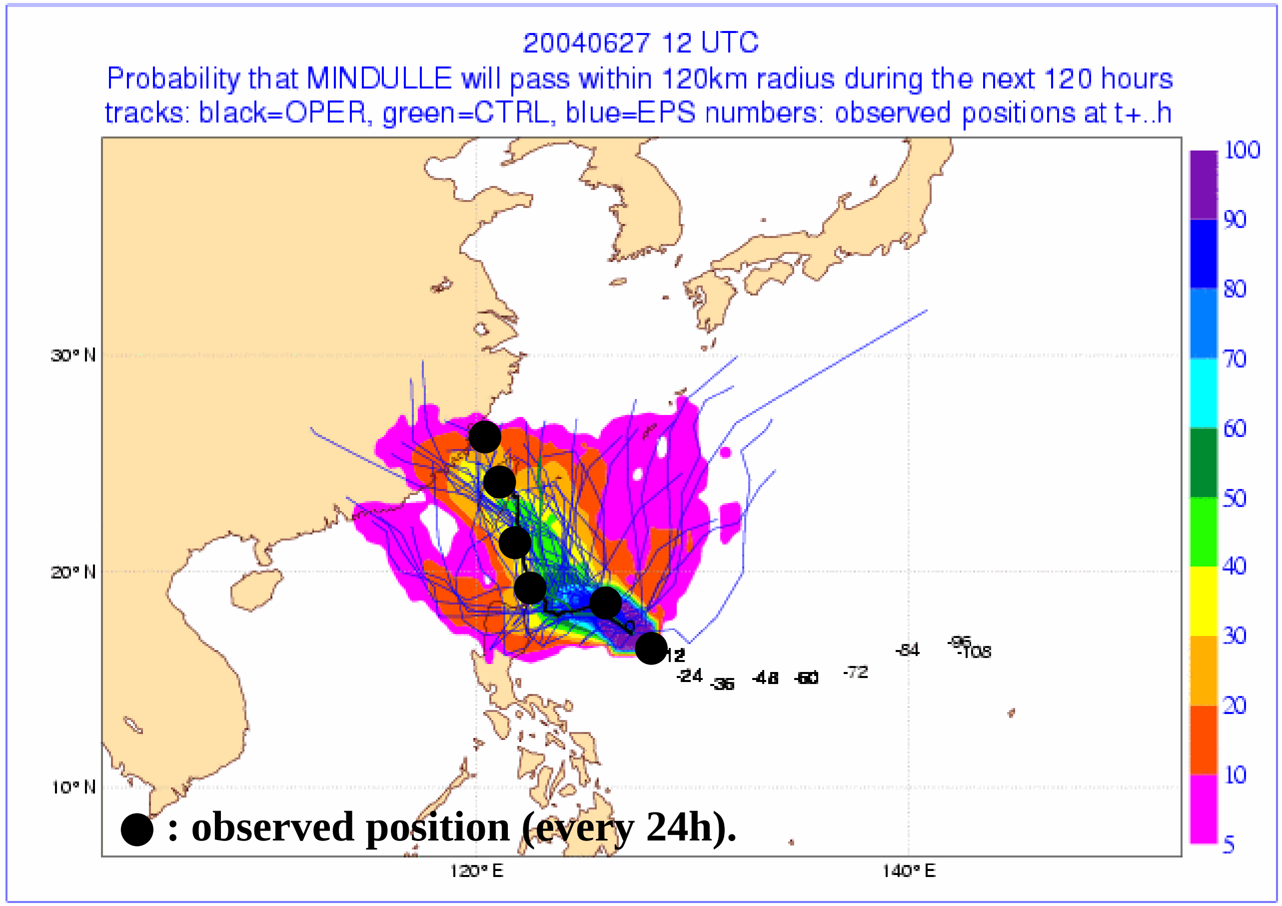


(from Martin Leutbecher)

3.b Mindulle: EPS tracks from 12UTC of 27 Jun ‘04

Tropical Storm Mindulle skirted along the coast of Eastern China in early July 2004, bringing torrential rain to that region.

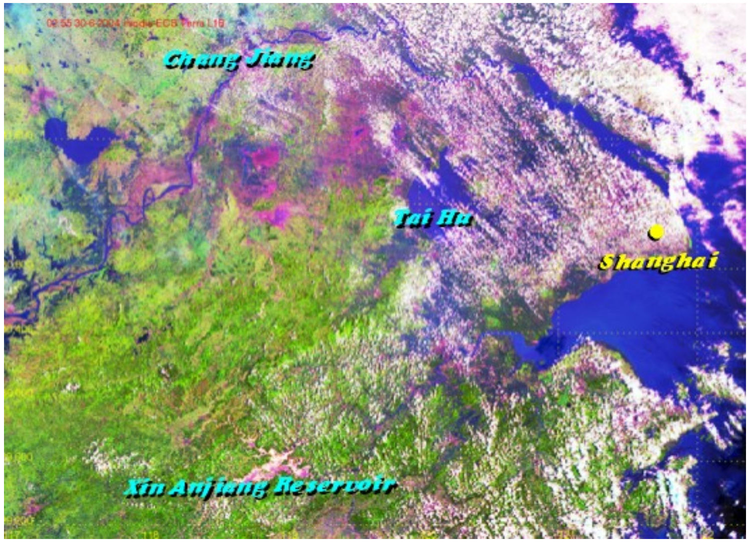


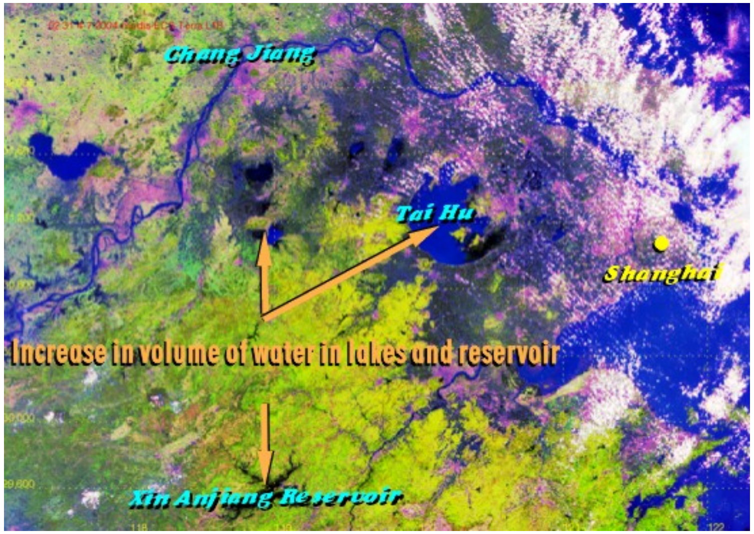


3.b Typhoon Mindulle and PPP over China, Jul '04

Tropical Storm Mindulle caused an increase in volume of water in Tai Hu and Xin Anjiang Reservoir (in blue colour), as can be seen by comparing two high-resolution satellite images, one taken before (30 June) and one after (4 July) Mindulle landfall.

"By 12 July 2004, 33,109,000 people have been affected by floods, which claimed 296 lives and left 12,102 injured. 1,847,800 hectares of crops had been affected, 131,400 housing units have collapsed and 487,000 were damaged. The situation is expected to worsen as heavy rains are forecast in areas from south-western to north-eastern parts of China." (from the press).

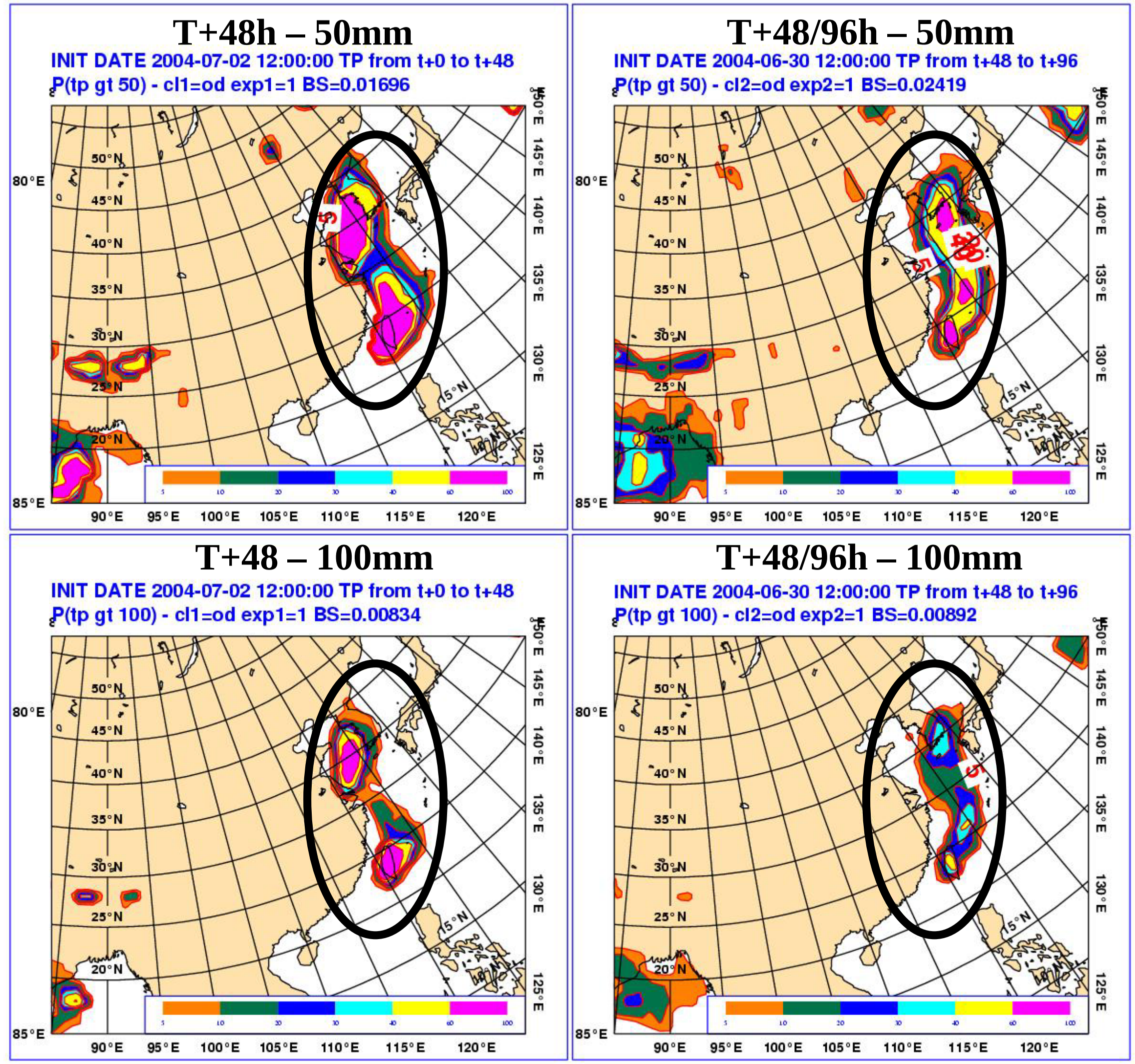


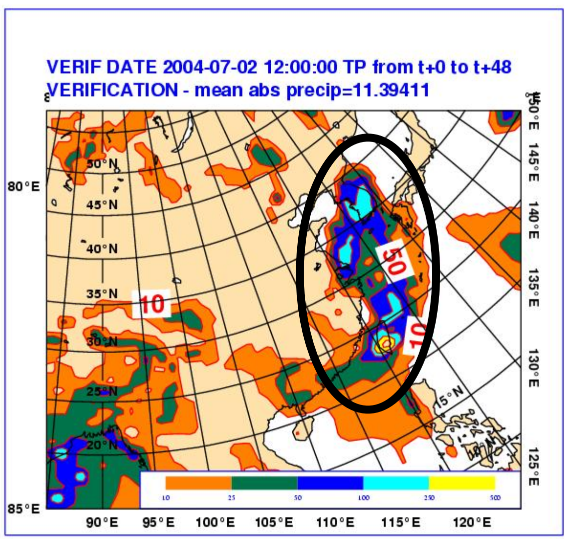


3.b Mindulle, 2-4 Jul '04: +48h & +96h PP

This figure shows the probability of 48h acc. Precipitation (PP) in excess of 50 mm (top) and 100 mm (bottom), predicted on 02/07 (t+48h, left) and 30/06 (t+48/96h, right) (df=5/10/20/30/40/60%).

The bottom left panel shows a proxi for verification (HRES +48h, df=10/25/50/100/250/500mm).

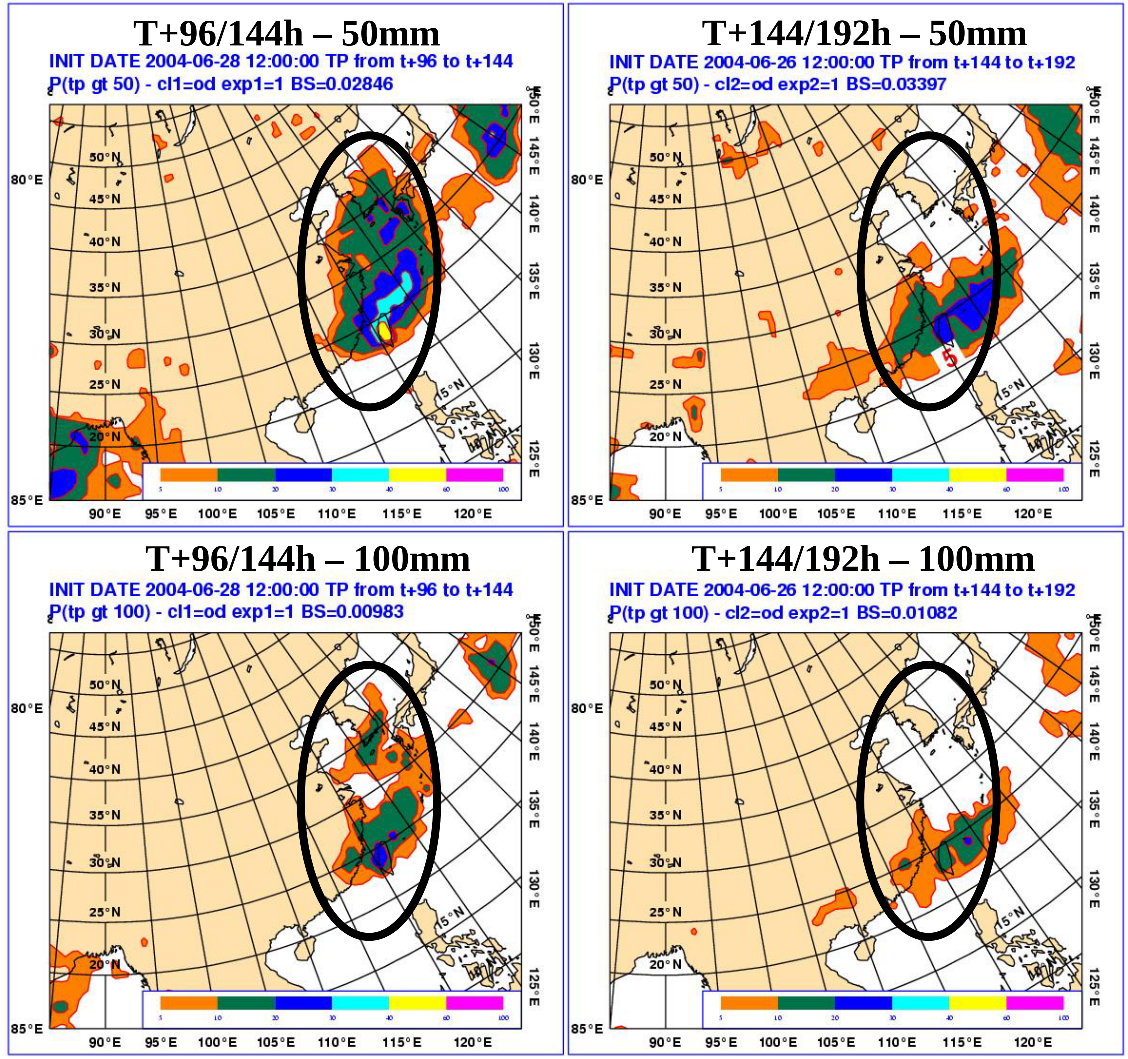


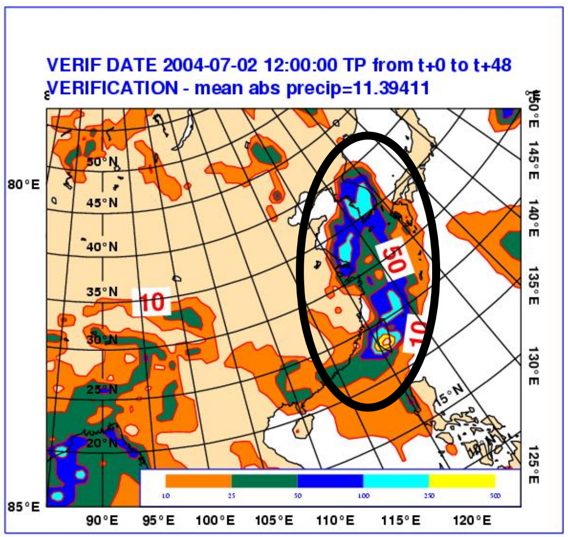


3.b Mindulle, 2-4 Jul ‘04: +144h & +192h PP

This figure shows the probability of 48h acc. precipitation (PP) in excess of 50 mm (top) and 100 mm (bottom), predicted on 28/06 (t+96/144h, left) and 26/06 (t+144/192h) (df=5/10/20/30/40/60%).

The bottom left panel shows a proxi for verification (HRES +48h, df=10/25/50/100/250/500mm).





3.b Heavy rain in Henan Province, 17-19 Jul '04

Henan Province (Central China): between 17 and 18 July 2004 torrential rains lashed areas between the Yellow and Huaihe rivers, resulting in massive flooding of the Shaying and Hongru rivers, two tributaries of the Huaihe River.

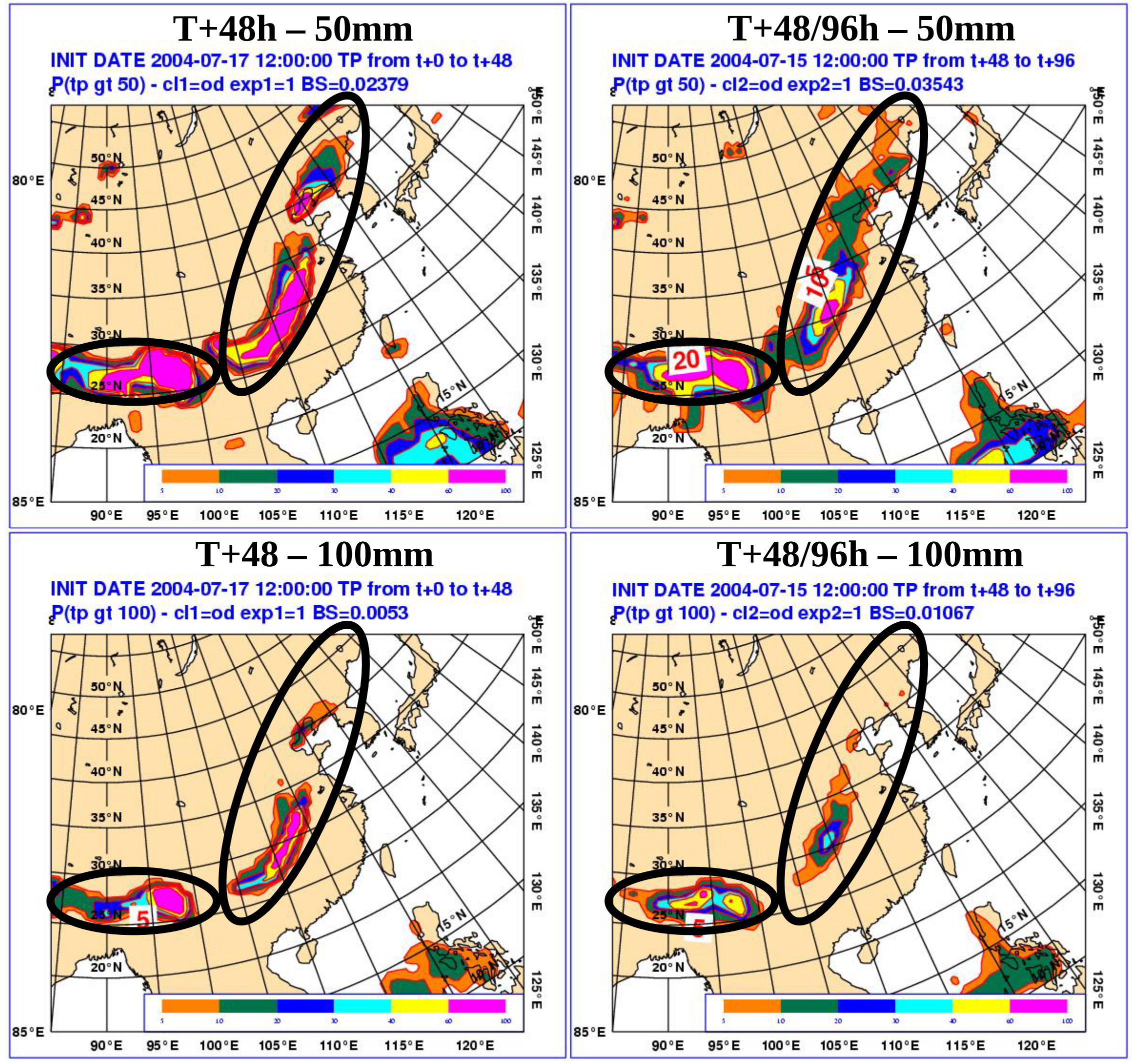
Intense flood strain builds up

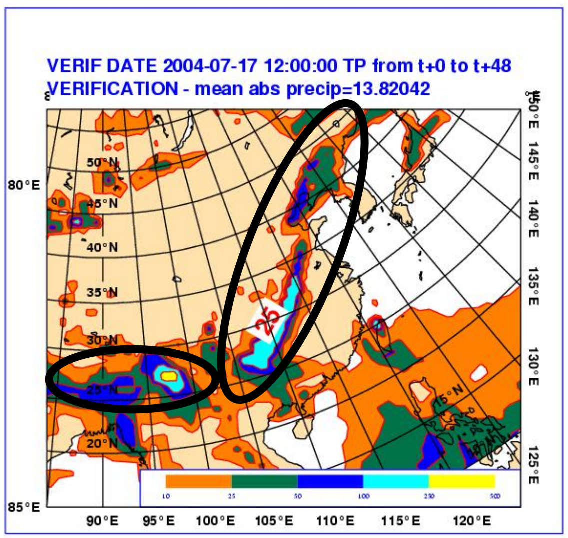
"*Officials fear the danger for more flooding on the nation's rain-swollen rivers could worsen as the summer's major flood season officially begins. Heavy rains and stormy weather are expected in many areas, with precipitation reaching as much as 60 to 253 millimetres in eastern parts of Southwest China, the Hanshui River Valley, most areas between the Yellow and Huaihe rivers, Northeast China and South China provinces like Guangxi.*" (from China Daily, 2004-07-20 00:45).

3.b Mindulle, 17-19 Jul '04: +48h & +96h PP

This figure shows the probability of 48h acc. Precipitation (PP) in excess of 50 mm (top) and 100 mm (bottom), predicted on 17/07 (t+48h, left) and 15/07 (t+48/96h, right) (df=5/10/20/30/40/60%).

The bottom left panel shows a proxi for verification (HRES +48h, df=10/25/50/100/250/500mm).

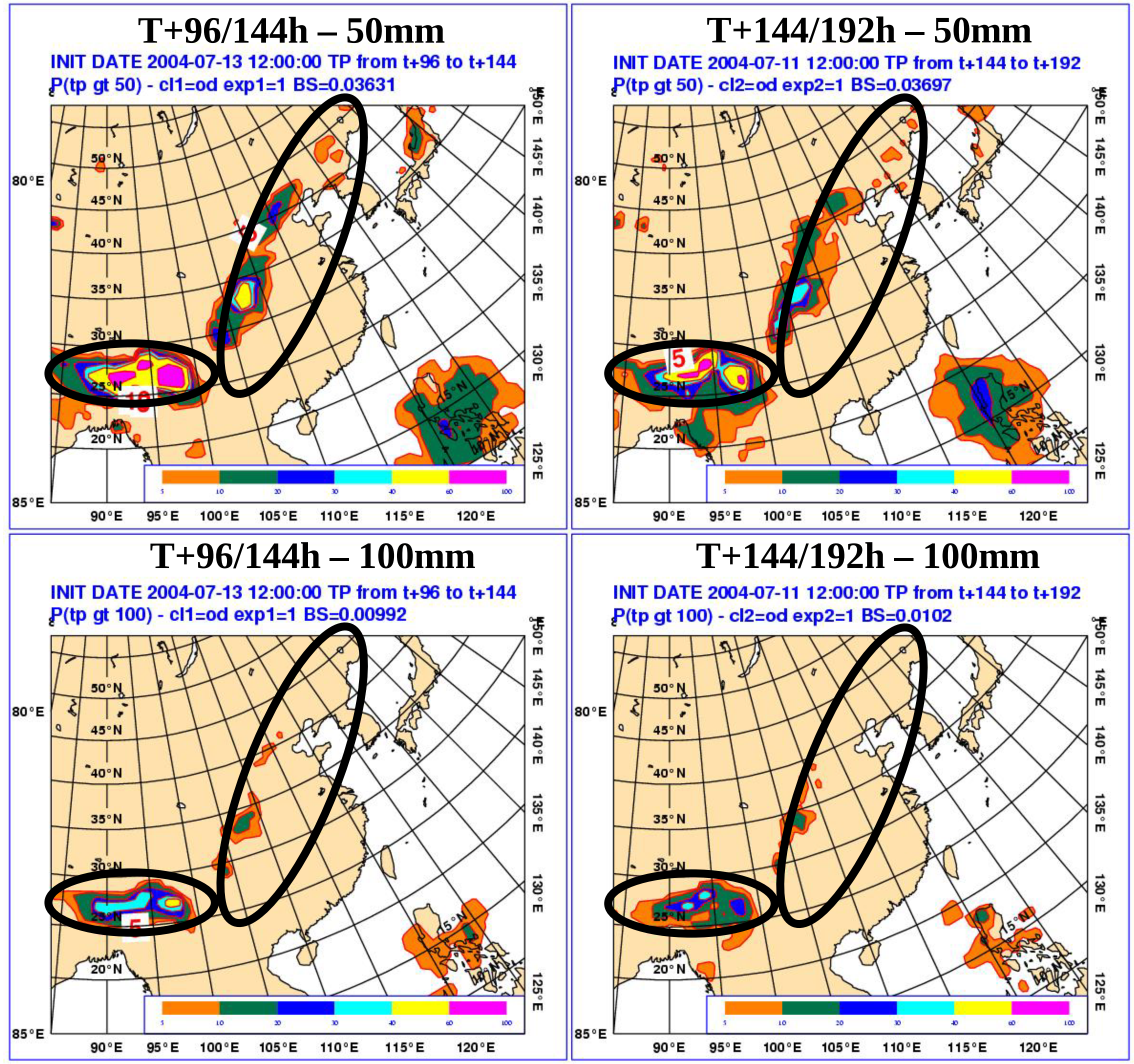


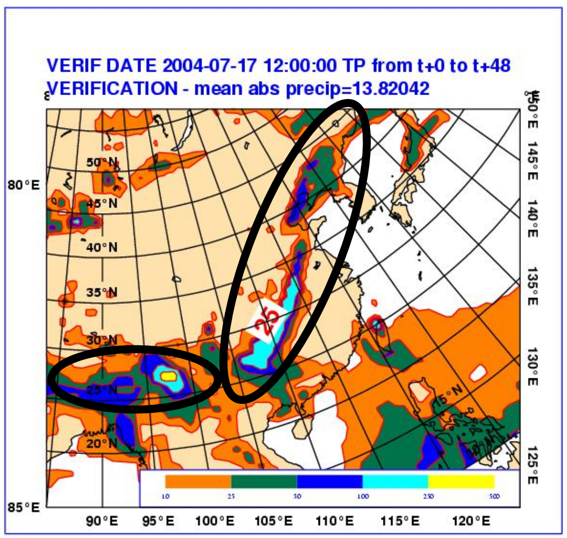


3.b Mindulle, 17-19 Jul ‘04: +144h & +192h PP

This figure shows the probability of 48h acc. Precipitation (PP) in excess of 50 mm (top) and 100 mm (bottom), predicted on 13/07 (t+96/144h, left) and 11/07 (t+144/192h, right) (df=5/10/20/30/40/60%).

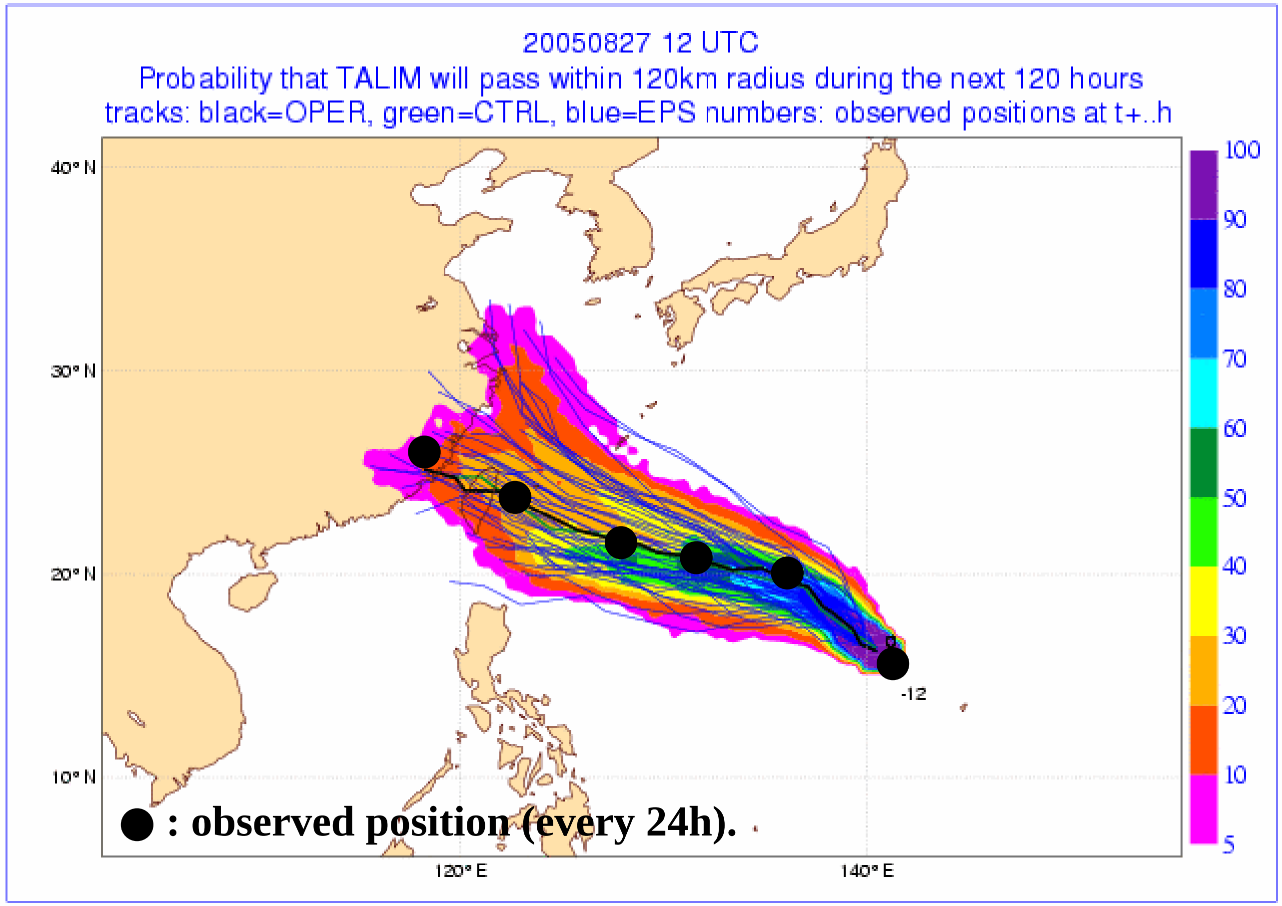
The bottom left panel shows a proxi for verification (HRES +48h, df=10/25/50/100/250/500mm).





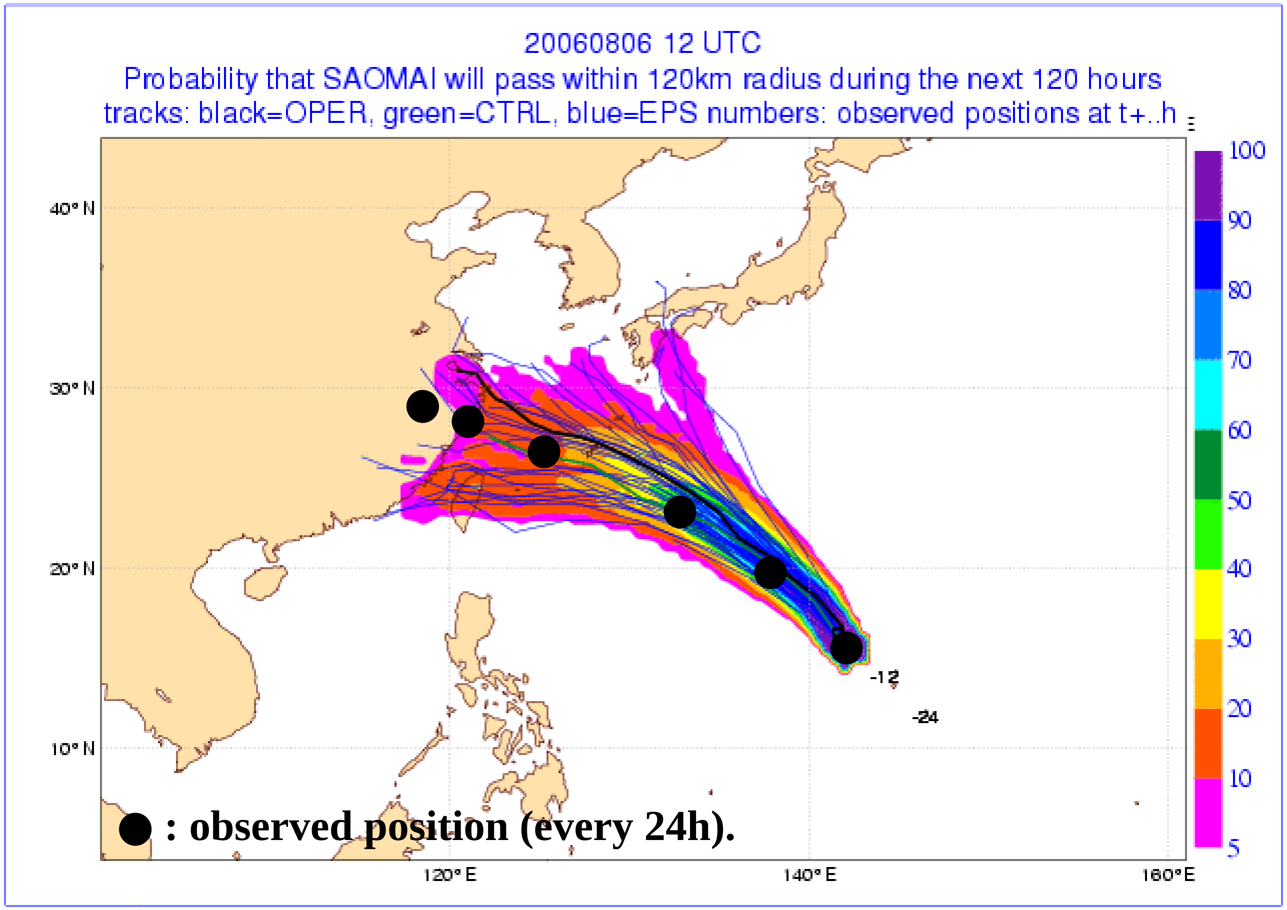
3.c Talin: EPS tracks from 12UTC of 27 Sep '05

"Damages due to Typhoon Talin's flooding and landslides are 7.8 billion yuan (US$960 million), mainly in East China's Fujian, Zhejiang, Anhui and Jiangxi provinces. In the Anhui Province, at least 53 were killed." (from the press).



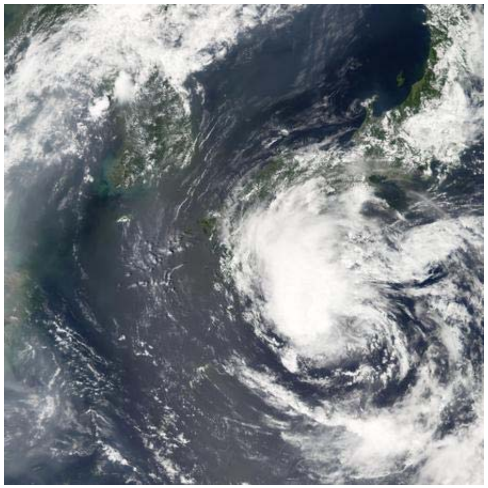
3.d Saomai: EPS tracks from 12UTC of 6 Aug '06

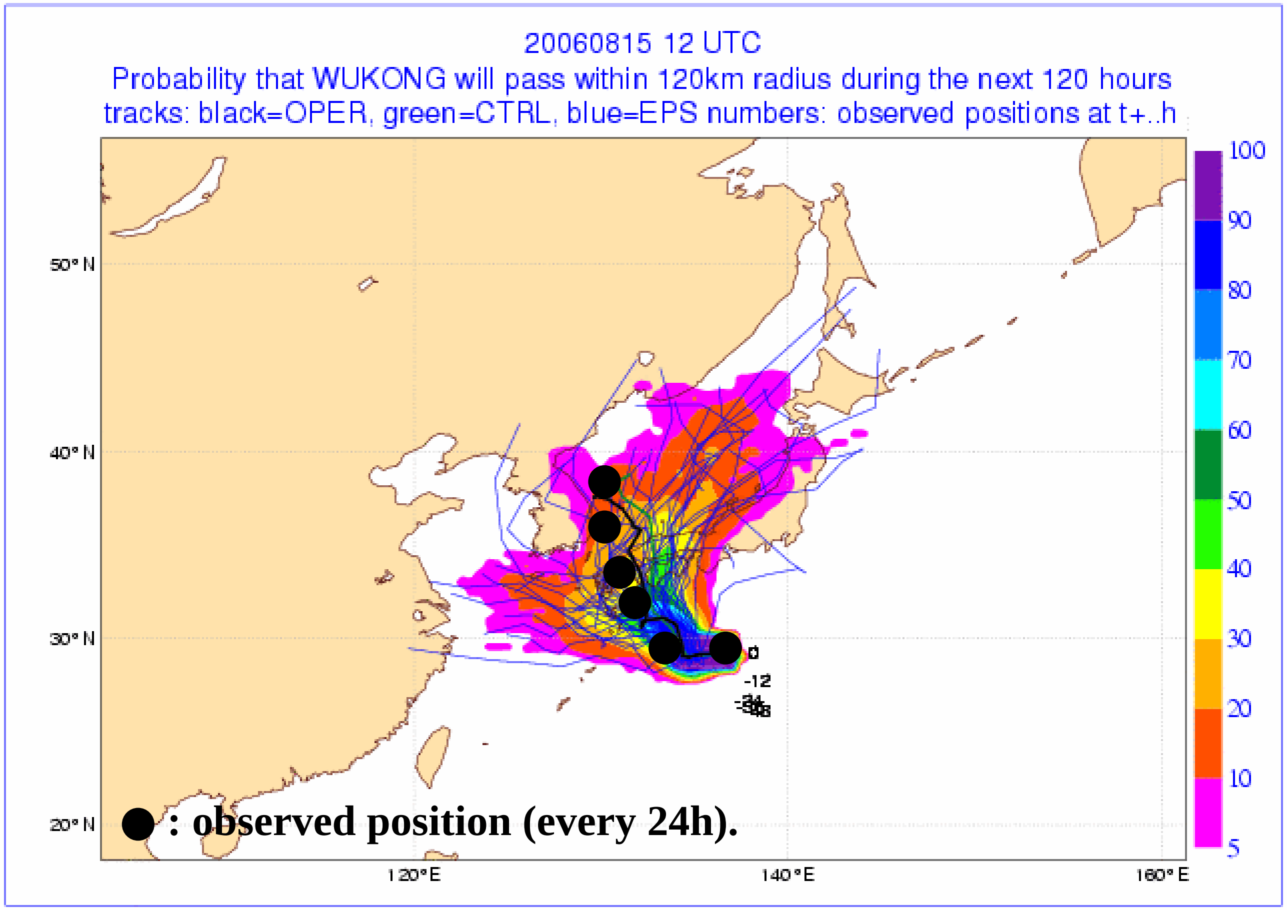
"China's most powerful storm in 50 years, Typhoon Saomai, has left at least 104 people dead. More than a million people were evacuated from their homes .. more than 50,000 houses had been destroyed." (from the press).



3.d Wukong: EPS tracks from 12UTC of 15 Aug '06

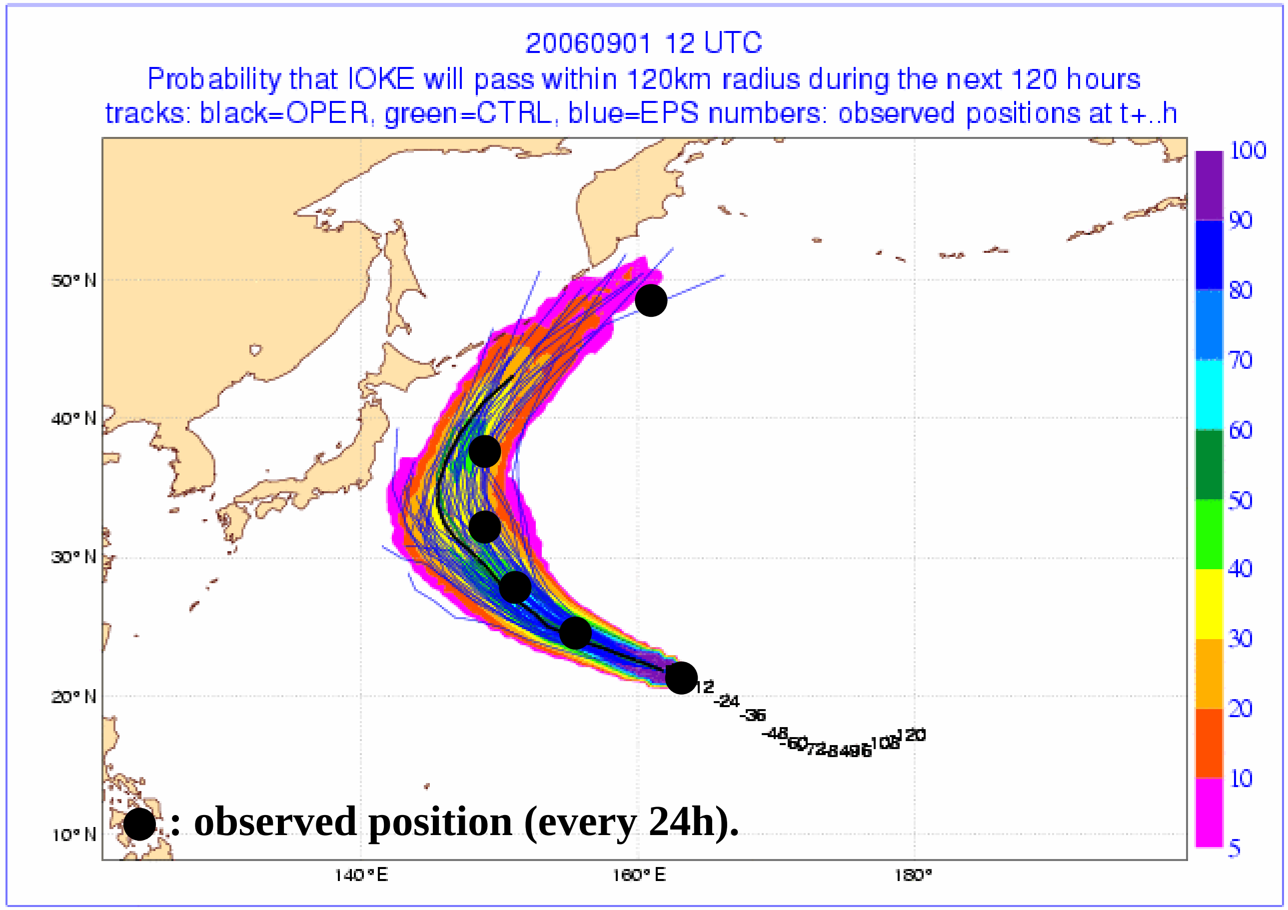
"Typhoon Wukong ('monkey king') left Japan today after causing at least three deaths, landslides and disrupting public transport. Wukong moved near the Korean peninsula after ravaging the island of Kyushu." (from the press).





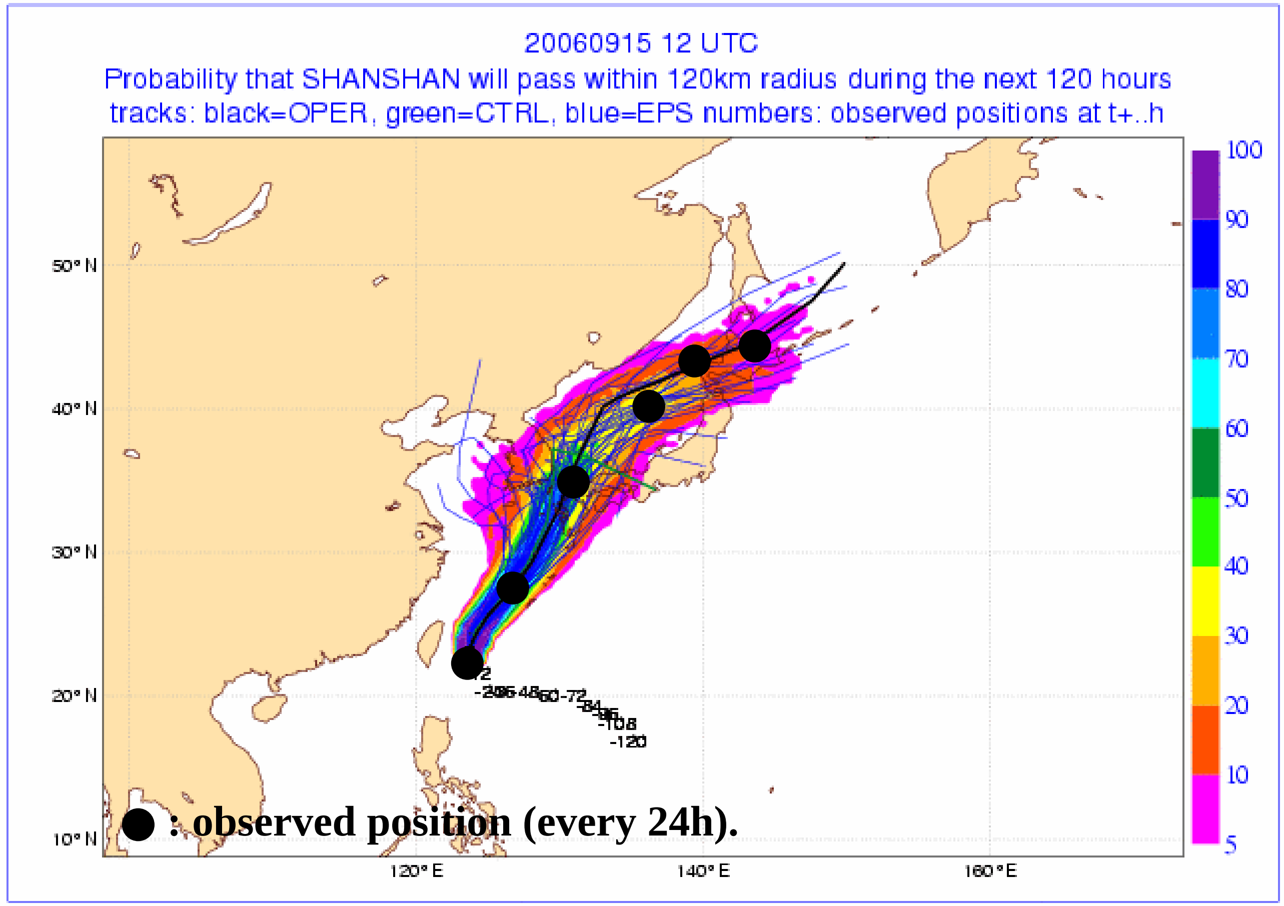
3.f Ioke: EPS tracks from 12UTC of 1 Sep ‘06

Typhoon Ioke, the Central Pacific's biggest storm in a decade damaged 70 percent of the buildings on Wake Island when it slammed ashore last month, the U.S. Air Force said Wednesday.



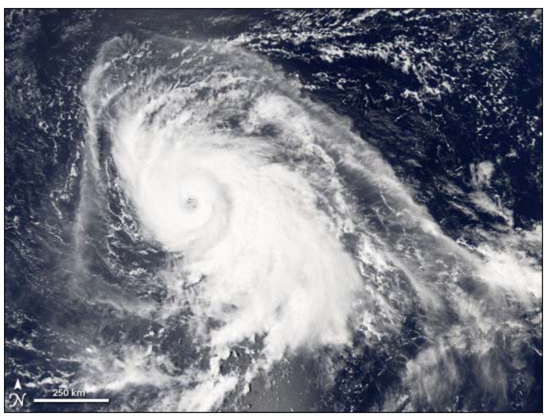
3.f Shanshan: EPS tracks from 12UTC of 15 Sep 2006

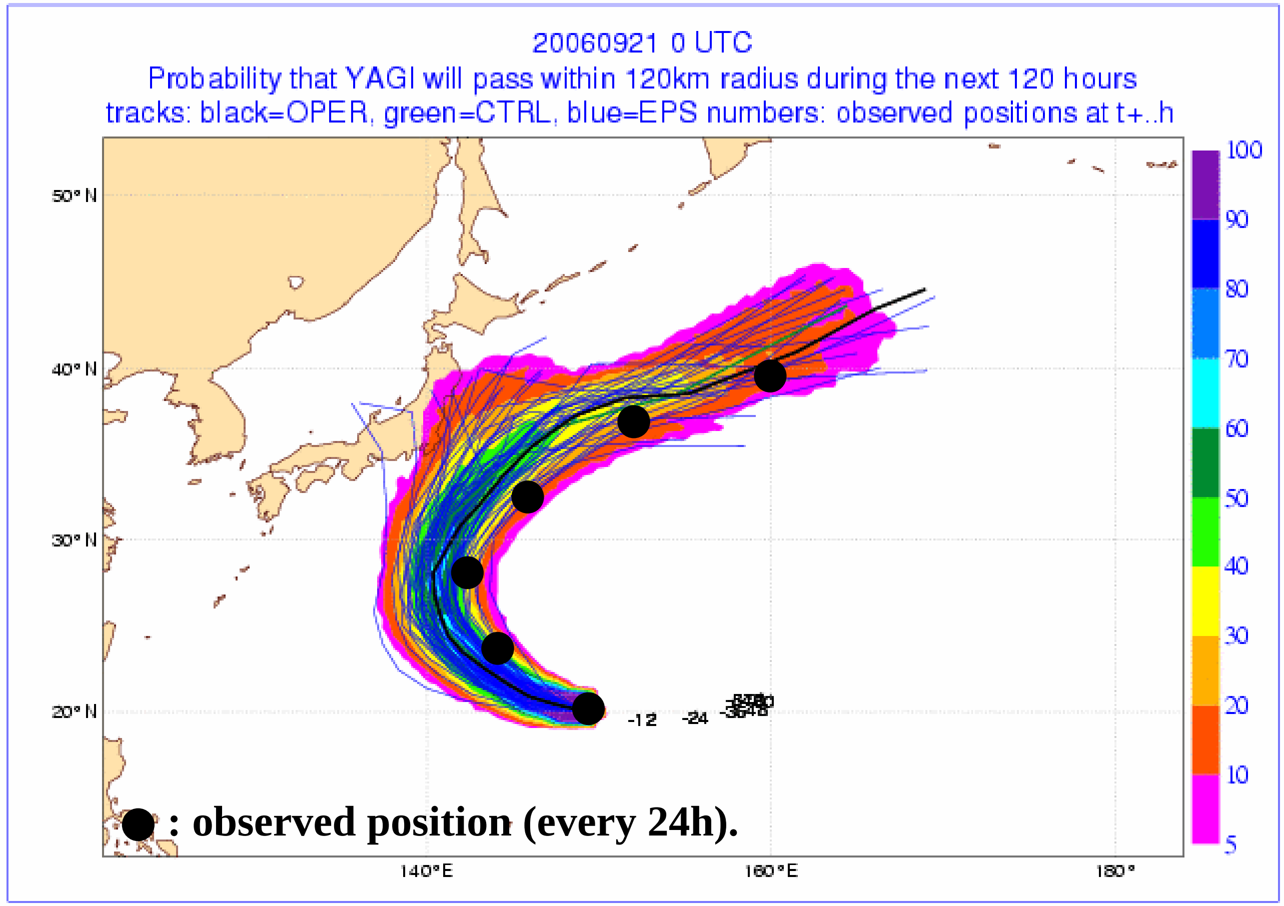
Typhoon Shanshan that has been buffeting Japan for the last few days has left nine people dead and more than 200 injured. Shanshan caused torrential rains that triggered flash floods and landslides.



3.f Yagi: EPS tracks from 12UTC of 21 Sep '06

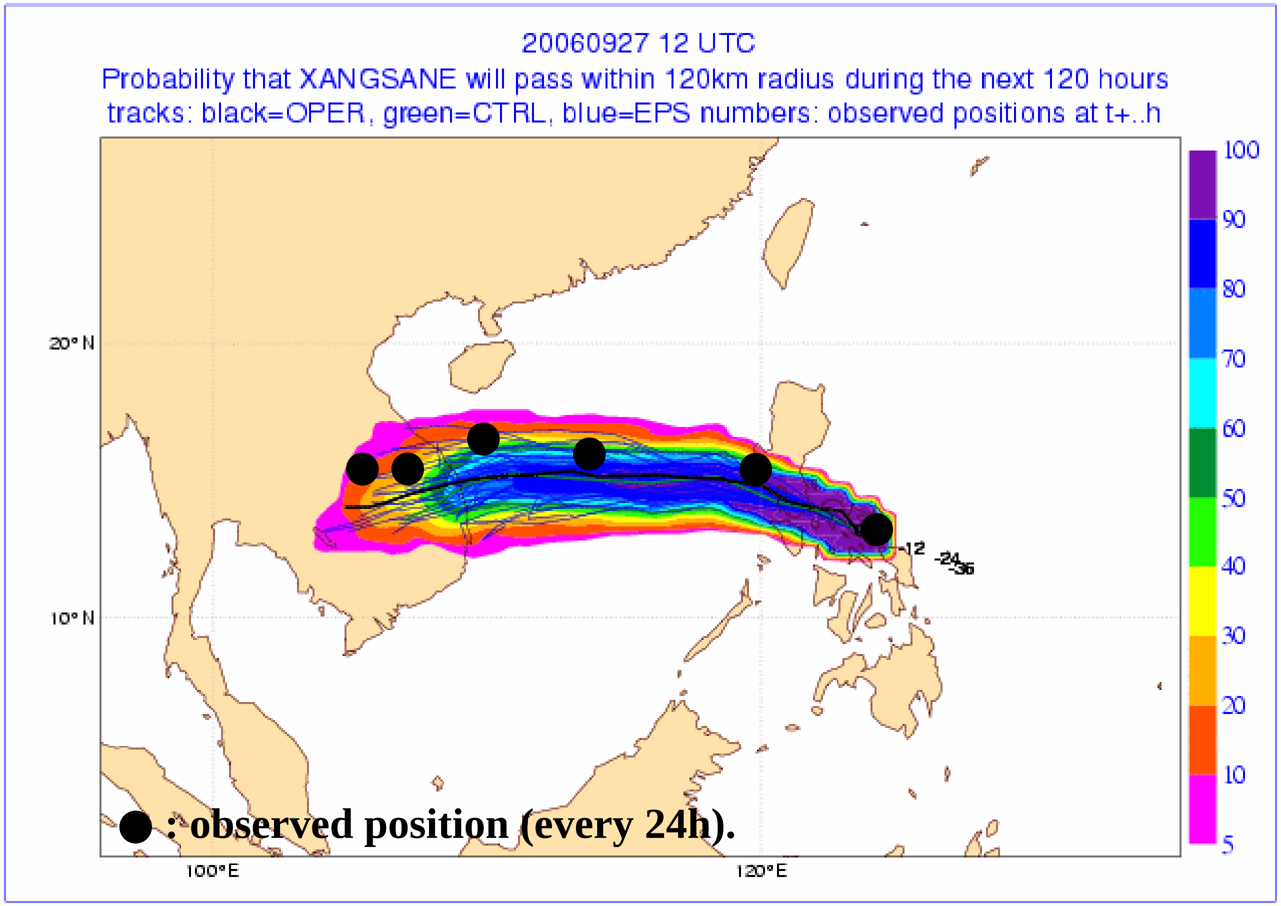
Powerful typhoon Yagi packing winds of up to 198 km (124 miles) per hour was moving slowly towards Japan on Friday, and forecasters said it could brush past Tokyo over the weekend before veering back into the Pacific.





3.f Xangsane: EPS tracks from 12UTC of 27 Sep '06

"Typhoon Xangsane caused the death of at least 15 people in Vietnam; thousands of homes were destroyed in the coastal city of Danang. The typhoon devastated areas of the Philippines last week, killing at least 76 people and leaving millions without power and clean drinking water." (from the press).

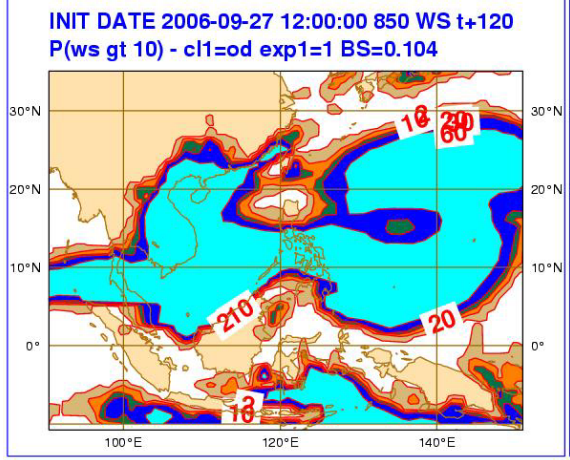


3.f Xangsane: EPS +120h and +72h 850 hPa PWS

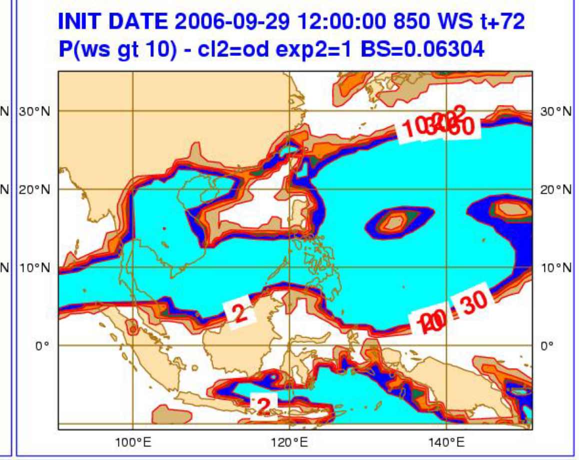
This figure shows the probability of wind speed (PWS) at 850 hPa in excess of 10 m/s (top) and 20 m/s (bottom), predicted on 27/09 (t+120h, left) and 29/09 (t+72h, right) (df=5/10/20/30/40/60%).

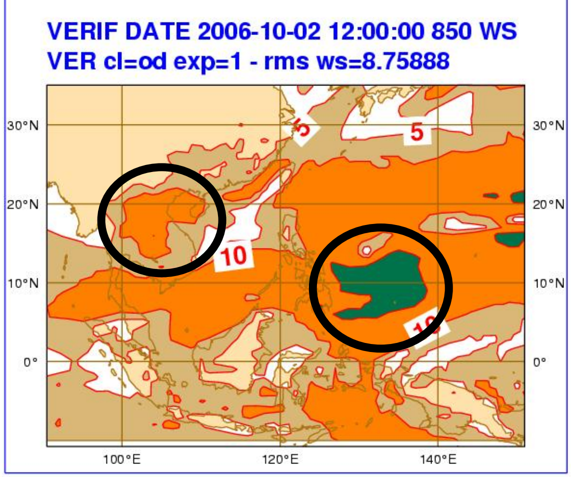
The bottom left panel shows the analysis (df=5/10/20/40/50m/s).

T+120 – 10m/s

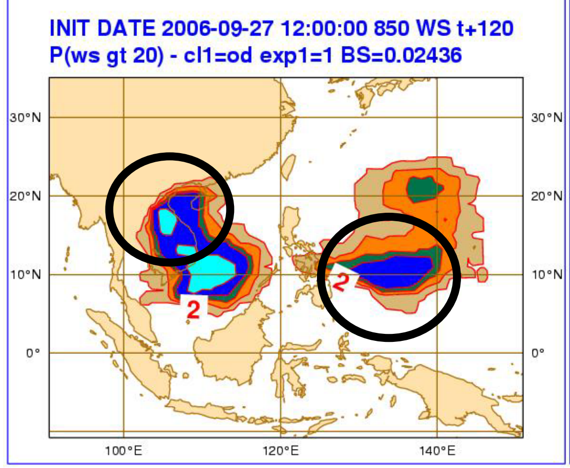


T+72h – 10m/s

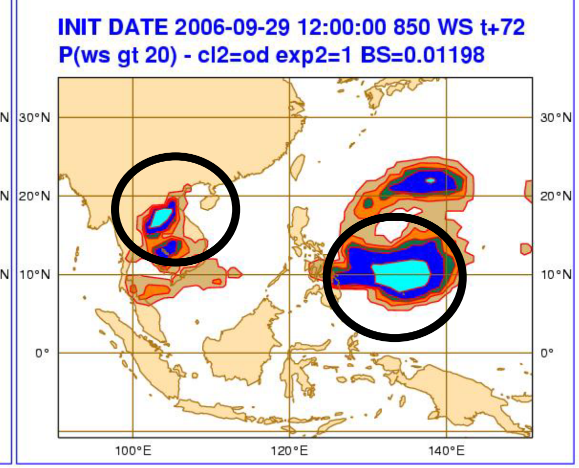




T+120 – 20m/s



T+72h – 20m/s



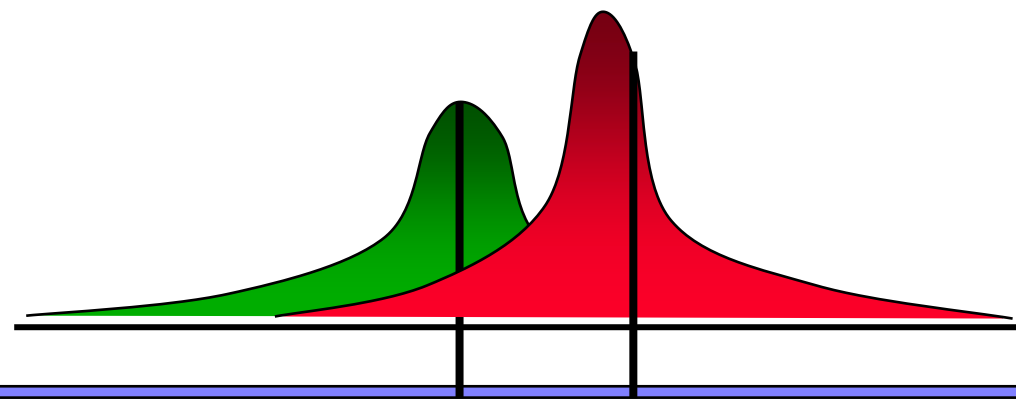
Outline

1. The value of Ensemble Prediction
2. Hydrological applications
   - 2.a The JCR European Flood Alert System (EFAS)
   - 2.b The flood of Italy of 1966: a revisitation
   - 2.c George Tech prediction of flooding in Bangladesh
3. Typhoon prediction
   - 3.a Simulation on initial uncertainties in the tropics
   - 3.b Mindulle (July ‘04)
   - 3.c Talin (Sep ’05)
   - 3.d Saomai & Wukong (Aug ’06)
   - 3.e Ioke, Shanshan, Yagi & Xangsane (Sep ’06)
4. Conclusions

4. Conclusions

• Some results of hydrological ensemble predictions have been shown, ranging from large-scale to small-scale river basins. Results indicate that probabilistic (ensemble-based) forecasts provide very valuable information that single forecasts cannot provide.

• One of the key advantages of predicting the full probability distribution of forecast states is that it can be used not only to identify the most likely outcome, but also to assess the probability of occurrence of maximum acceptable losses.



4. Conclusions

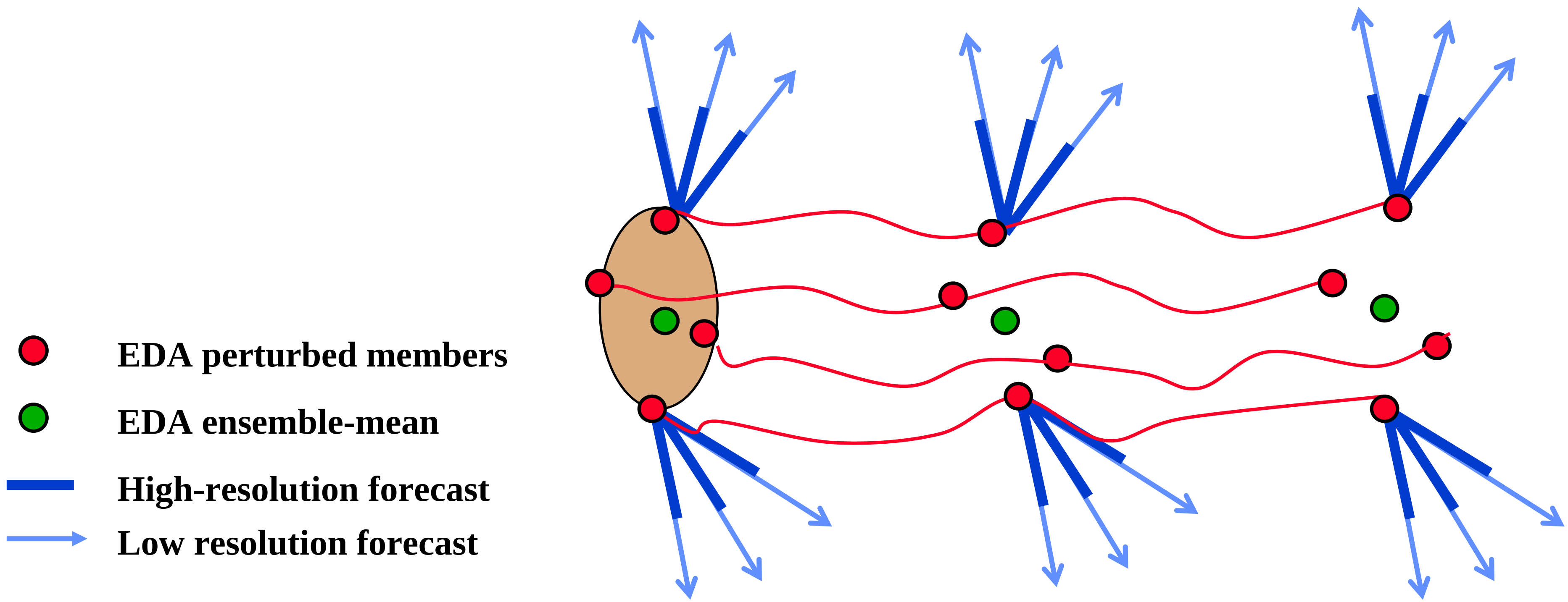
• A synoptic evaluation of typhoon tracks' predictions suggests that EPS 0-120h strike probability maps are very valuable. Results have also shown that the EPS can provide very valuable probabilistic precipitation and wind-speed ('gusts') predictions.

• Work is continuing to further improve the ECMWF ensemble system, e.g. work has resumed to test the potential benefits of using ensemble data assimilation methods to generate the ensemble initial states and to improve the simulation of model uncertainties (not shown).

4. The future probabilistic analysis & forecasting system

Ensemble Data Assimilation (EDA) *[6]* may be used in the future to generate the EPS initial perturbations. A future EPS configuration could include:

- N-member EDA (e.g. N=11)
- N*M member EDA-SV EPS, T_L399(d0:10)+T_L255(d10:15) (e.g. M=51)
- ICs from each perturbed members and/or the EDA ensemble-mean



4. Ensemble Data Assimilation and Ensemble Prediction

This research aim to assess whether an ensemble of analyses can be used in the EPS to improve the sampling of initial uncertainties.

Experiments are going to be run to test the use of an ensemble of analyses in the EPS. For example, the ensemble of analyses could be used in the following two ways:

- Using each analysis as a center around which to add SV-based perturbations *(fig 1)*
- Using the ensemble of analyses to generate a set of perturbations to be used in conjunction with SV-based perturbations, starting from either a reference analysis (e.g. the high-resolution unperturbed analysis), or the mean of the ensemble of analyses *(fig 2)*

This work may lead to the use of the ensemble of analyses instead of the evolved SVs in the EPS.

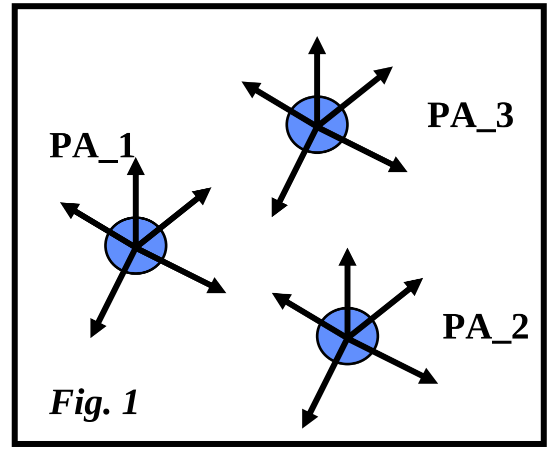


Fig. 1

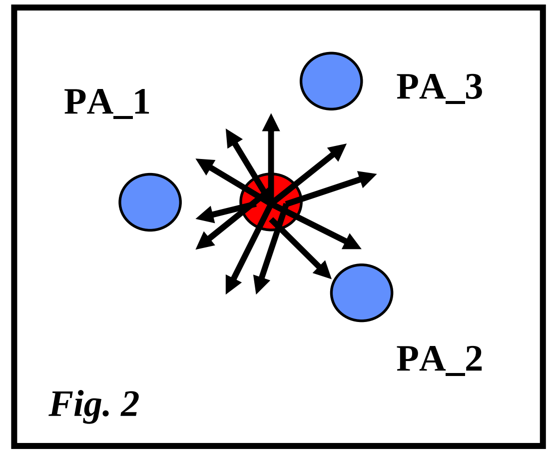


Fig. 2

Acknowledgements

The success of the ECMWF EPS is the result of the continuous work of ECMWF staff, consultants and visitors who had continuously improved the ECMWF model, analysis, diagnostic and technical systems, and of very successful collaborations with its member states and other international institutions.

The work of all contributors is acknowledged: *Judith Berner, Jean Bidlot, Manuel Fuentes, Mats Hamrud, Graham Holt, Martin Leutbecher, Tim Palmer, Frederic Vitart* and *Nils Wedi*, and former ECMWF staff who worked directly on the ECMWF Ensemble Prediction System: *Jan Barkmeijer, Franco Molteni, Robert Mureau, Anders Persson, Otto Pessonen, Thomas Petroliagis, David Richardson, Stefano Tibaldi*, and visitors and consultants *Bill Bourke, Mariane Coutinho, Martin Ehrendorfer, Ron Gelaro, Isla Gilmour, Dennis Hartmann, Andrea Montani, Steve Mullen, Kamal Puri, Carolyn Reynolds, Joe Tribbia*. (I hope that the list of names is complete: please forgive me if this is not the case.)