

Forecasting Tropical Cyclones in the Medium Range

Fernando Prates

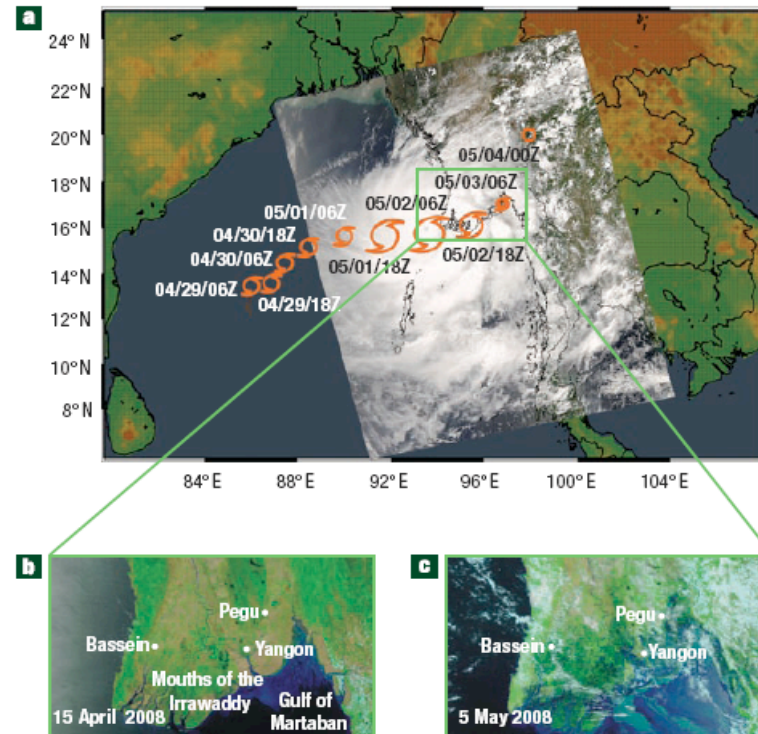
Meteorological Operations Section

Outline

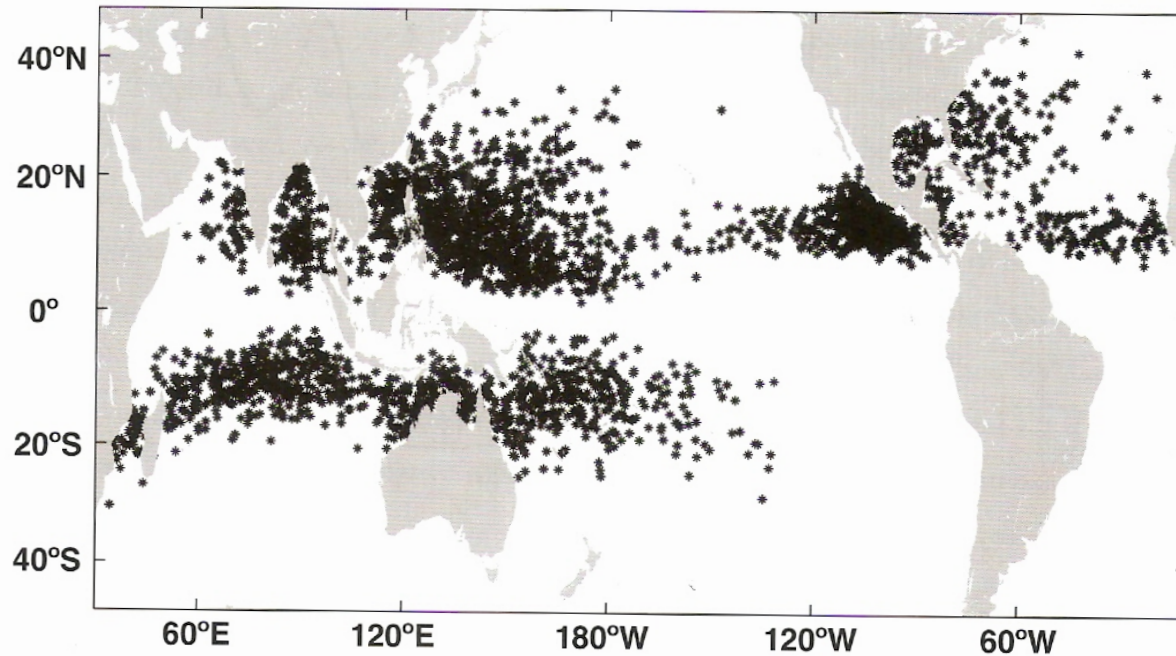
- Tropical Cyclones
 - **Conditions for TC genesis**
- Medium-range forecast products for Tropical Cyclones at ECMWF
 - **Recent model developments at ECMWF/ Product development/ TC activity during the forecast**
- Forecast performance of Tropical Cyclones
 - **Deterministic/ Probabilistic scores**

Why forecast Tropical Cyclones

- Most deadly (& spectacular) atmospheric phenomena
- On May 2008 TC Nargis struck Myanmar
- Estimated death toll: 100 000 people (P Webster,2008)



Genesis - Conditions for Tropical Cyclone Development



Origin points of tropical cyclones over a 30 year period

About 85 tropical cyclones develop globally each year

Genesis - Conditions for Tropical Cyclone Development

Genesis is confined to a region 30°N – 30°S

- In general they form in regions where $SST > 26^{\circ}\text{C}$
- Tropical cyclones do not form within 3° of the Equator
(nonzero Earth's vorticity)
- Small vertical shear of \vec{V}_H
- Low atmospheric static stability $\theta_{e(s)} - \theta_{e(500)} > 10\text{K}$
- Tropospheric humidity (to keep the saturation during ascent)

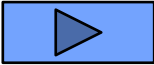


...but observed interannual variability of TC in some basins might be linked to phenomena like the ENSO episodes.

...El-Nino and MJO have a strong impact on the Tropical Cyclone modulation on a seasonal time scale.

Hurricanes do not develop spontaneously: a trigger is needed

Model improvements over the last 10y

Over recent years important model changes have had high impact on the ability to analyse and forecast Tropical Cyclones:

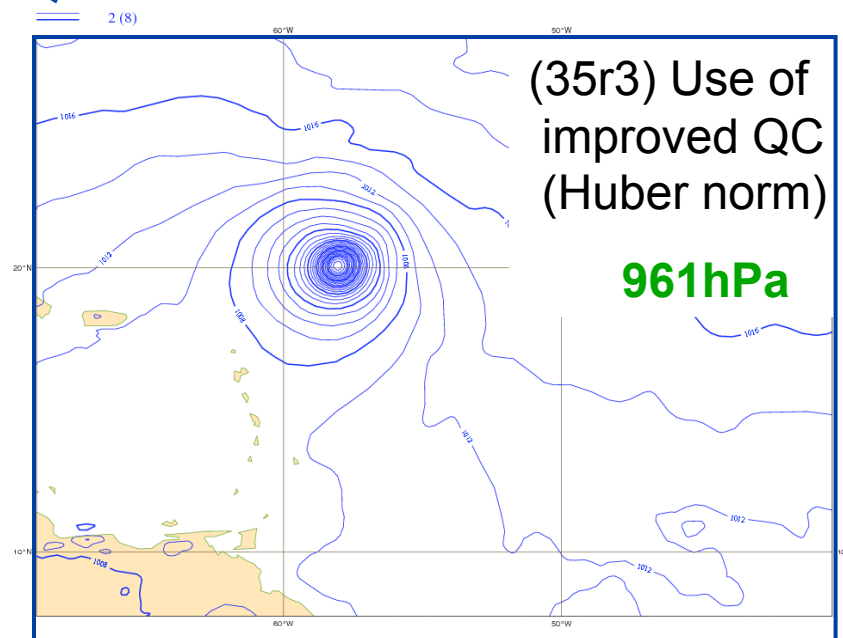
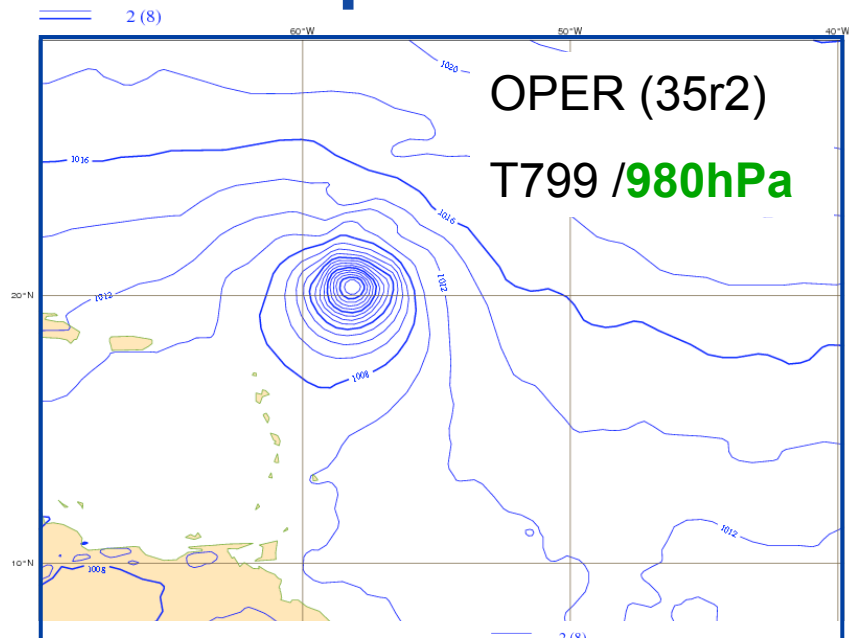
- Increase of model horizontal and vertical resolution 
- Wide number of satellite obs in Data Assimilation (DA) system 
- Dropsondes introduced in DA
- Physics (eg parametrization of convection)
- Coupling between the wave and atmospheric models.
- EPS evolved SVs , stochastic physics and perturbations target at observed TCs and more recently the implementation of Ensemble Data Assimilation 

..... At ECMWF there is no artificial bogus vortex scheme for TCs. We allow the observations to do their job

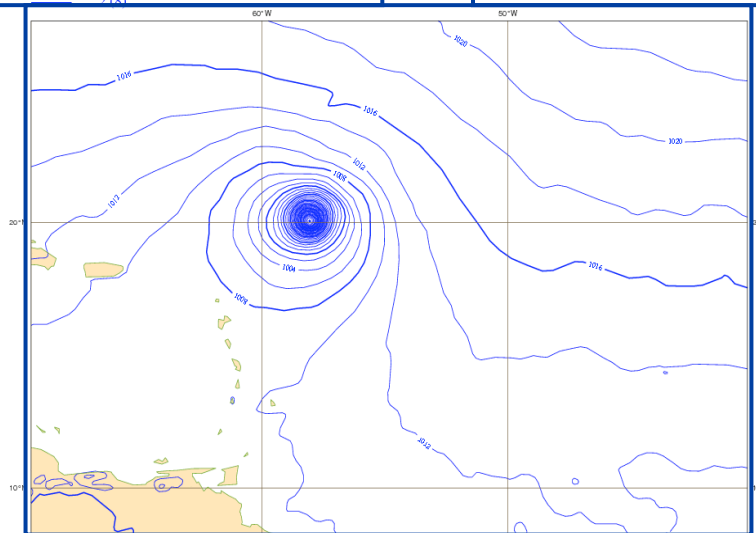


T1279 Tropical cyclone analyses improved

Improved Huber norm QC also beneficial



Hurricane Bill,
20 Aug. 2009
Observed MSL
pressure ~ **944hPa**

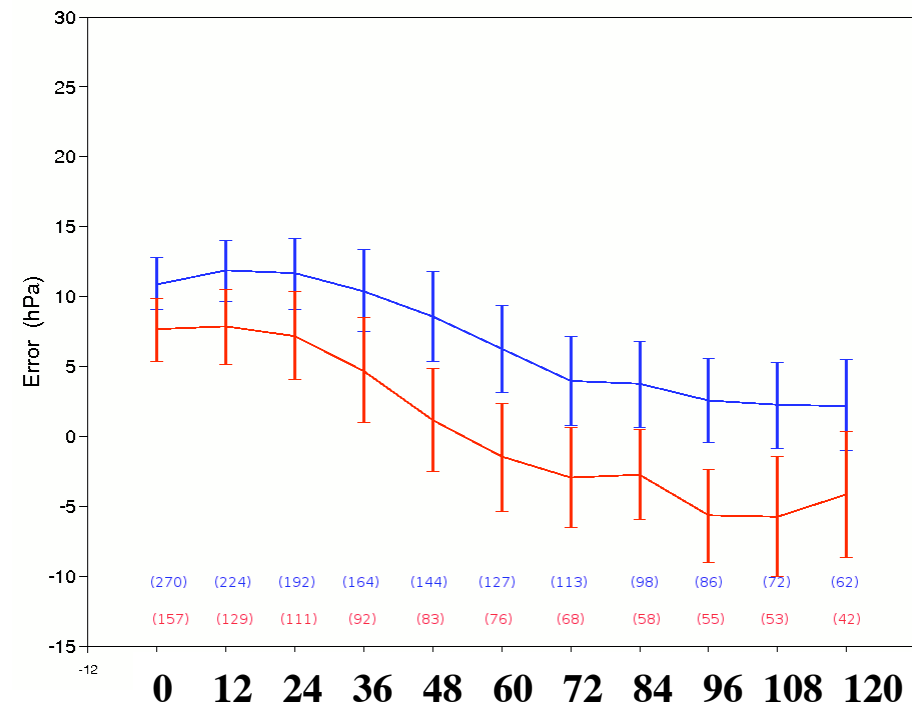
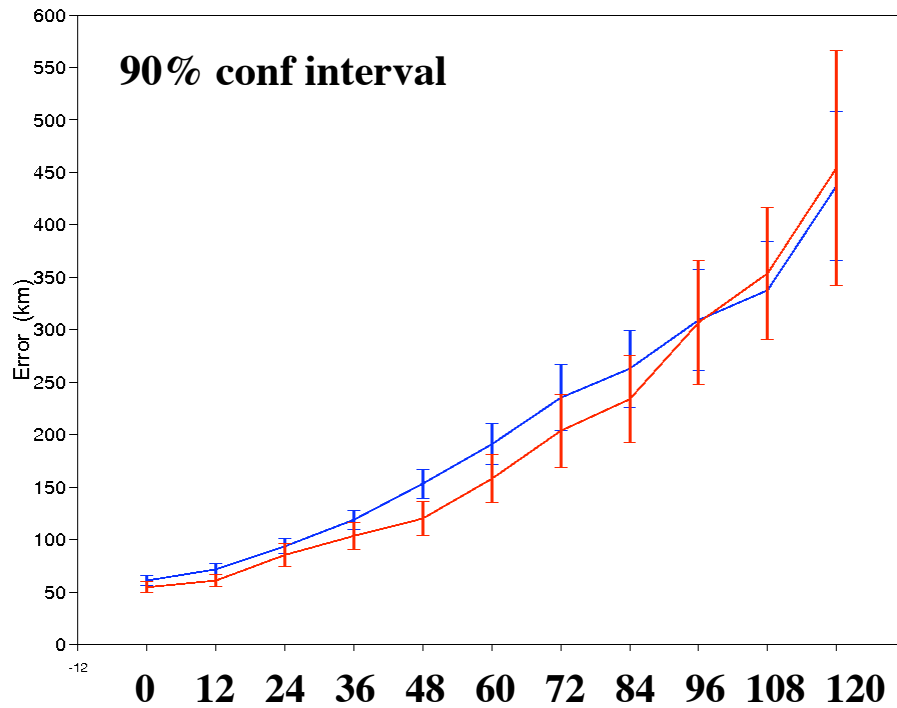


(36r1) High-res system
T1279+T159/T255/T255
945hPa

TC forecast performance T799 v T1279

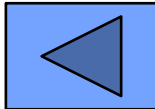
Tropical cyclone mean position error
fc period [20091004 to 20100121]

Tropical cyclone mean intensity error
fc period [20091004 to 20100121]



position

intensity



Assimilation of cloud and precipitation affected microwave radiances

forecast impact for Hurricane Katrina

850 hPa vorticity

12-hour rainfall

mean sea level pressure

ECMWF technical memorandum No 502 (Bauer et al 2006)

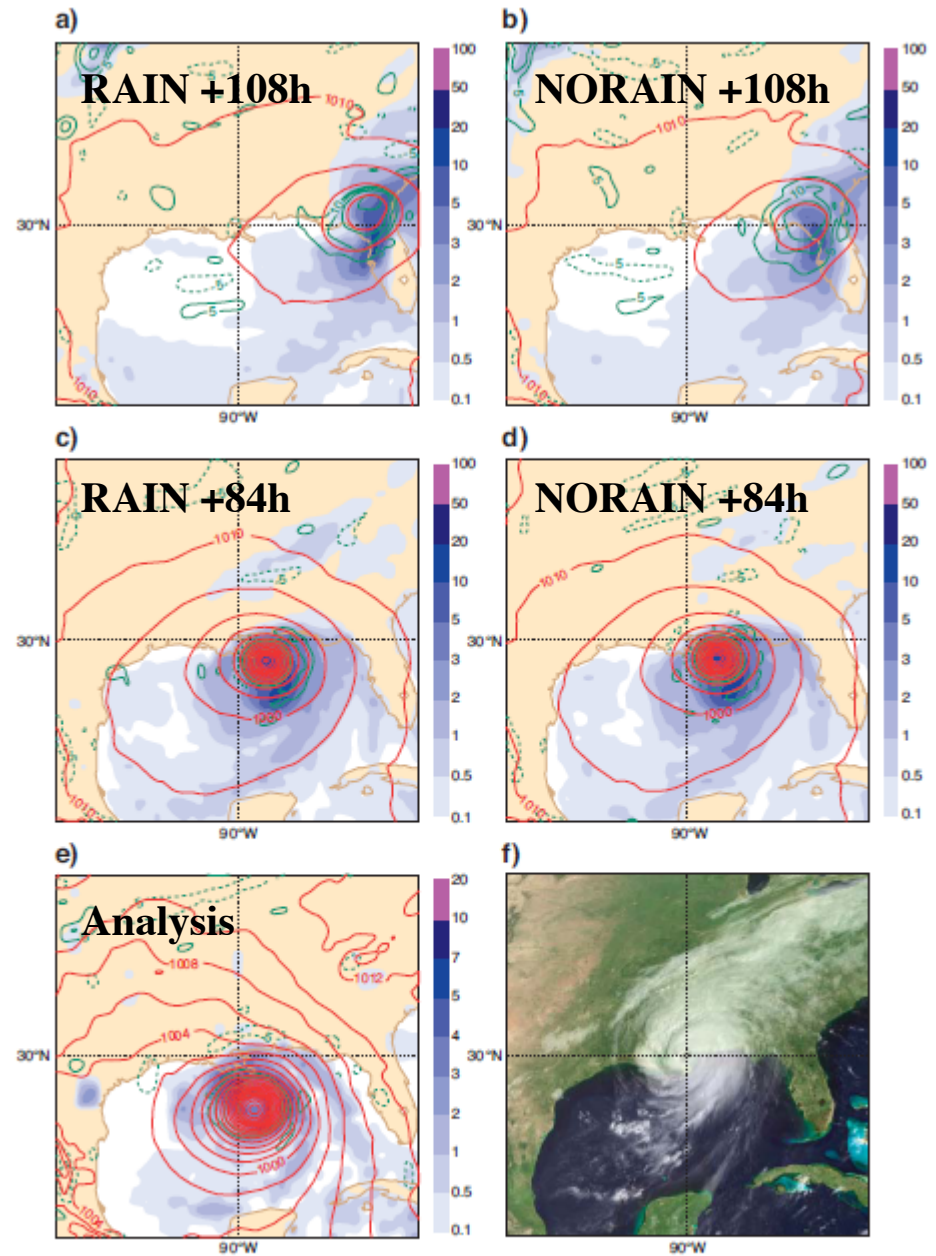
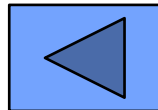
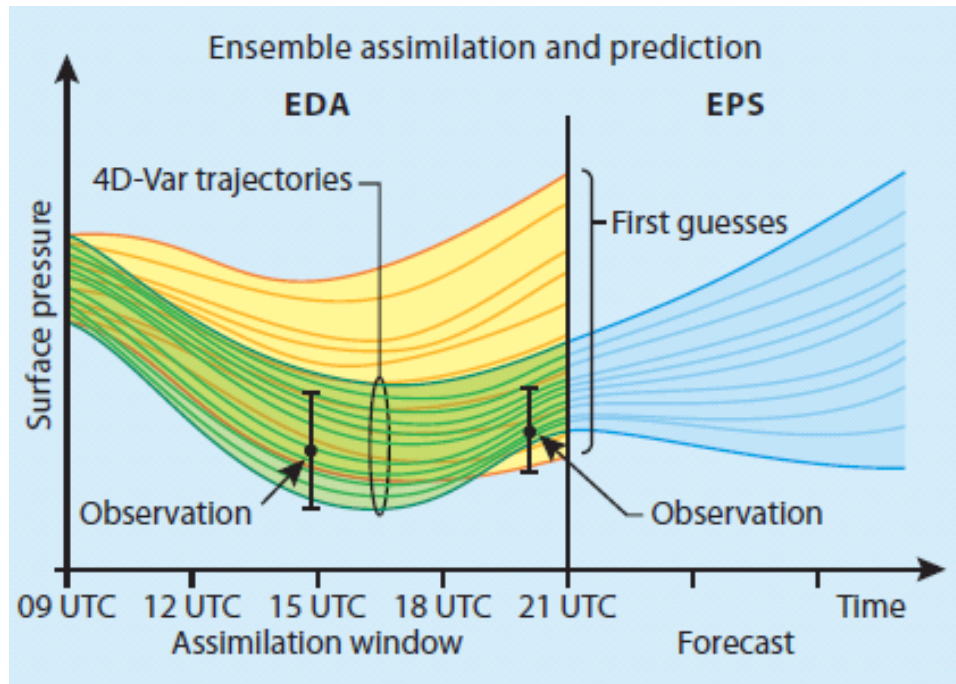


Figure 26: 4.5-day (108-hour) forecasts of mean-sea-level pressure (red isolines), 850 hPa potential vorticity (green isolines) and 12-hour accumulated rainfall (mm; blue shading) from experiment RAIN29R2 (a) and NORAIN29R2 (b) initialized on August 25, 2005, at 00 UTC. Same for 3.5-day (84-hour) forecasts from RAIN29R2 (c) and NORAIN29R2 (d) initialized on August 26, 2005, at 00 UTC. Verifying operational analysis (e) August 29, 2005, at 12 UTC and GOES-12 satellite imagery at 11:21 UTC.

Probabilistic Forecasts of TCs

- Since January 2002, tropical perturbations were added to the initial perturbations of the ECMWF Ensemble Prediction System (EPS). Rather than having perturbations for the entire tropical strip, **target areas** are defined in the vicinity of tropical cyclones.
- Since September 2004 the target areas are based on cyclone tracks from the previous forecast, allowing for a pole-ward extension of the perturbations.
- On 22nd of June 2010 the Ensemble Data Assimilation was implemented. The aim is to provide estimates of the analysis uncertainty and to improve the representation of the initial uncertainties for the EPS.

Ensemble Data Assimilation (since 22nd June 2010)



EDA first guesses trajectories

Analysis of trajectories

Observations (w/ error bars)

EDA is used to provide

1. Background error info for the analysis
2. Initial perturbation of the EPS

Ensemble Data Assimilation (since 22nd June 2010)

- The EDA-based perturbations are used instead of the evolved Singular Vectors (SV)
- The initial conditions are defined by adding to the unperturbed analysis an EDA-based perturbation and a linear combination of initial-time SVs
- EDA-based perturbation is the difference between one perturbed and the un-perturbed 6-hour forecast started from the previous EDA cycle (06UTC or 18 UTC)

$$a_j(d) = a_0(d) + \delta PA_j(d) + \delta SV_j(d)$$

$$\delta PA_{2k-1}(d) = [fg_{MOD(k, N_{EDA})}(d - 6h, 6h) - fg_0(d - 6h, 6h)]$$

$$\delta PA_{2k}(d) = -\delta PA_{2k-1}, k = 1, \dots, N_{pf}$$

$$\delta SV_j(d) = \sum_{s=1}^S \sum_{k=1}^{N_{SV,s}} [\alpha_{j,k,s} SV_{k,s}(d, 0, -6h)]$$

Impact of replacing evolved SV by EDA perturbations

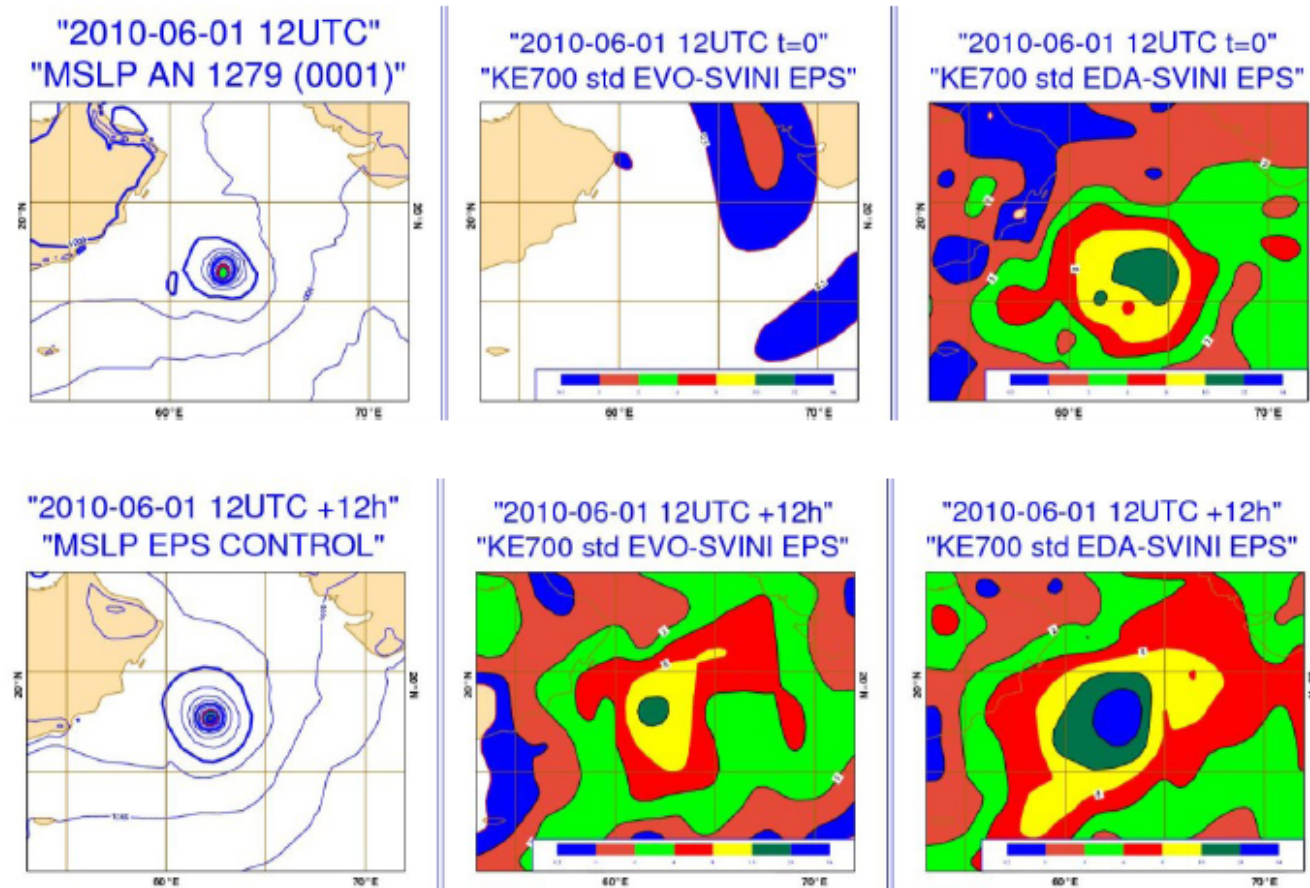
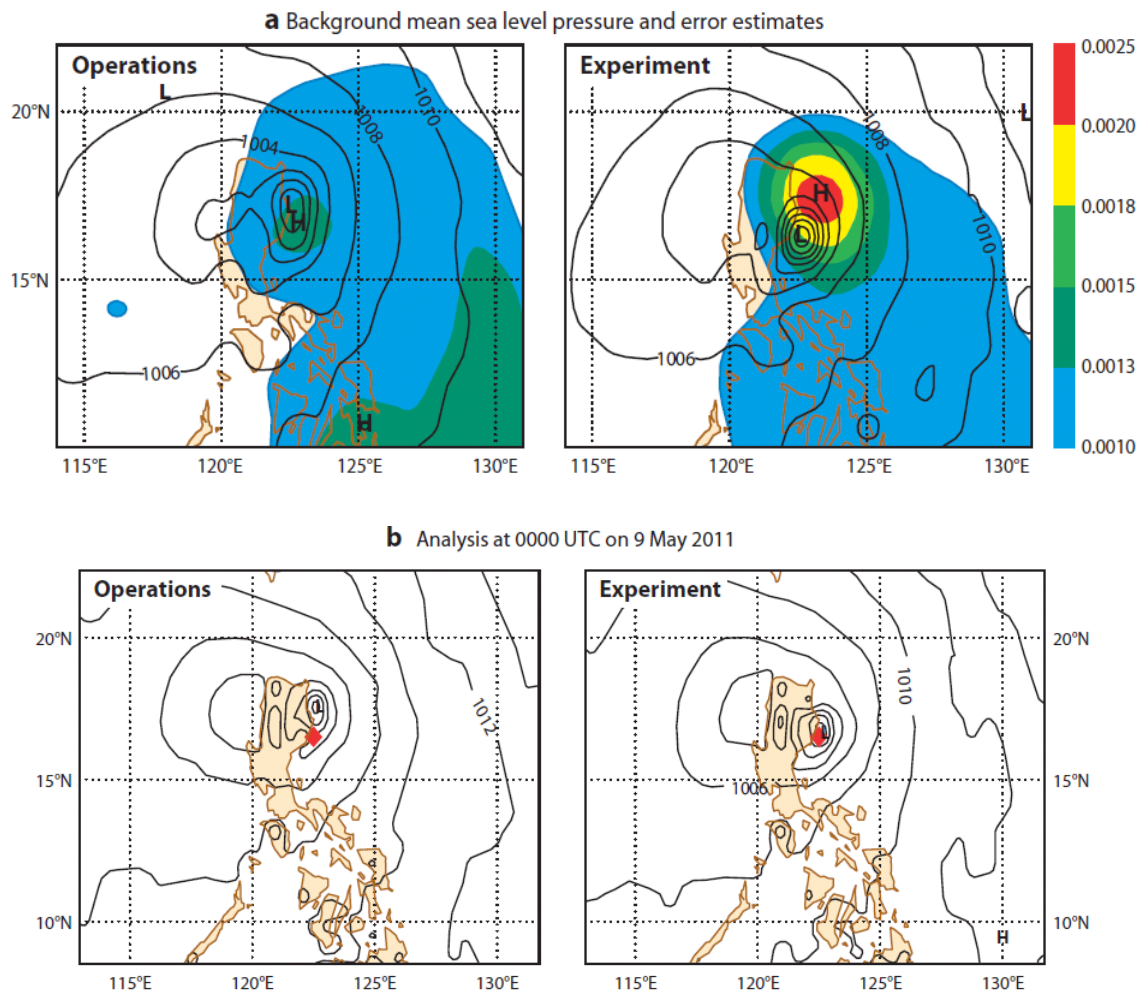
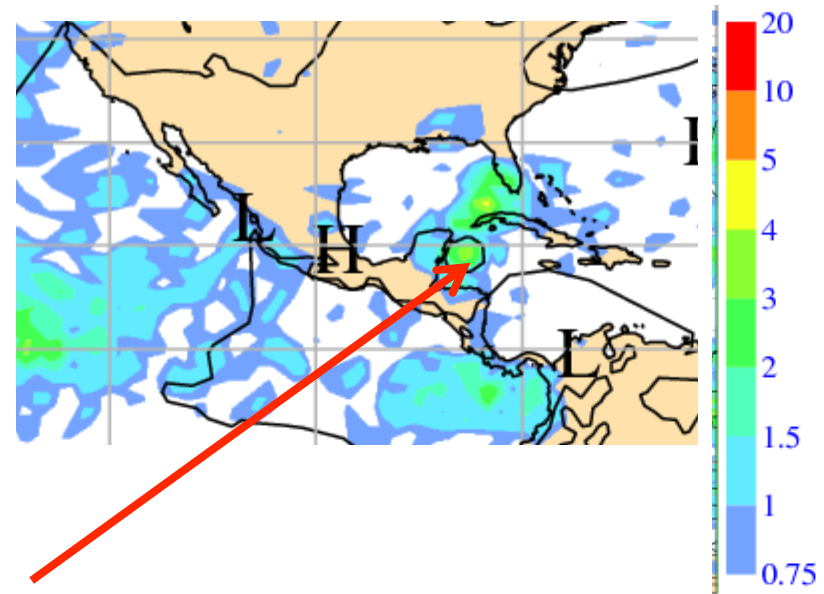
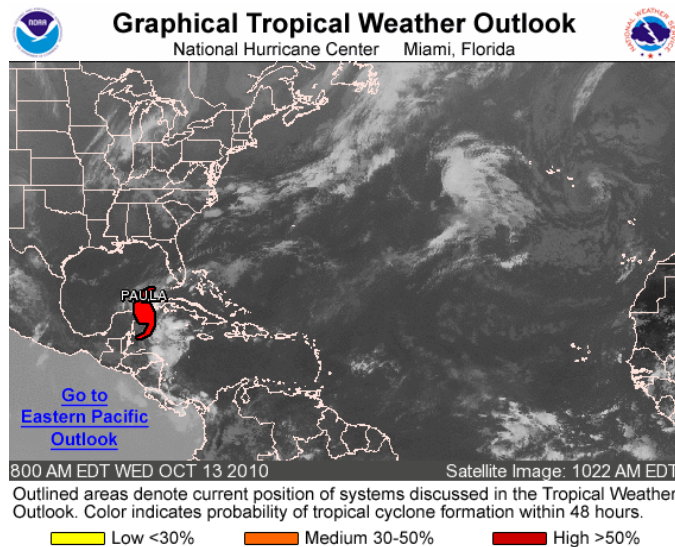


Figure 9: Mean sea level pressure for tropical cyclone Phet, south of Oman, valid at 12 UTC 1 June 2010. Analysis (top-left panel) and 12h EPS control forecast (bottom-left panel), and ensemble standard deviation expressed in terms of the kinetic-energy per unit mass at 700hPa at initial time (top) and at 12h (bottom) of the EVO-SVINI (middle panels) and the EDA-SVINI (right panels). Contour isolines every 2.5 hPa for the analysis and 0.5/1/2/4/8/16/32/64 $m^2 s^{-2}$ for kinetic energy.

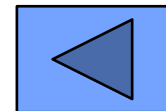
Impact of replacing evolved SV by EDA perturbations



Tue Oct 12th 12Z +9h VT: Oct 12th 21 Z MSLP & 500 hPa StDev Vorticity



Hurricane Paula



ECMWF TC Tracker...

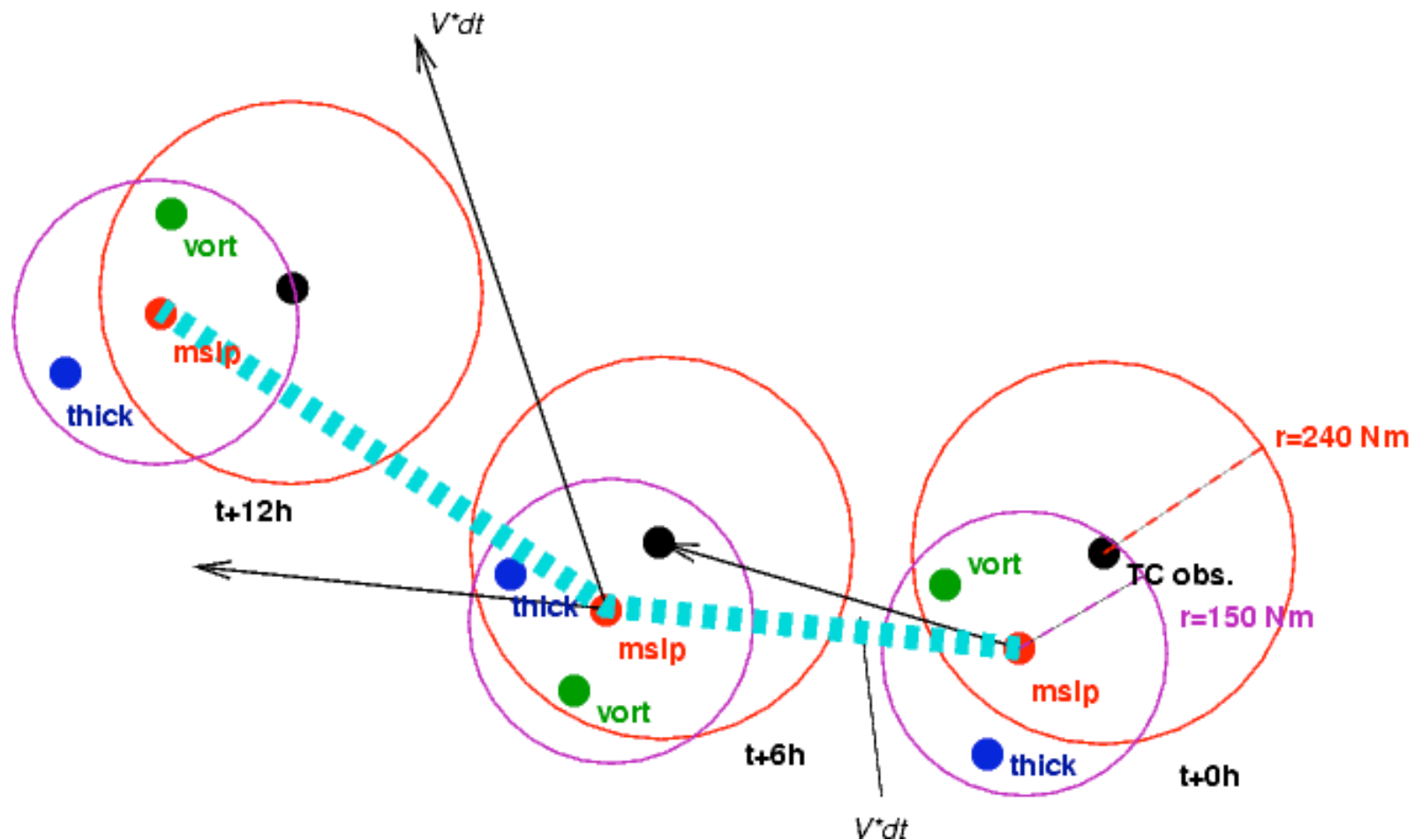
- **A new tracker will replace the current operational algorithm used to identify Tropical Cyclones (TCs) present in the initial conditions and medium range forecast (see Newsletter no. 130, 2011/12).**
- **tracks for 00UTC and 12UTC for high resolution model and EPS**
- **generates a track which is nothing more (and less) than sequence of locations of minimum in MSLP every 6 hours (currently every 12 hours for the EPS).**
- **allows the generation of guidance products for TC prediction such as strike probability maps and lagrangian EPSgrams (and assess the forecast performance of TCs)**
- **Technical changes in operational suite allow the TC tracking information from deterministic model to be disseminated 1 hour earlier (since June last year).**

ECMWF TC Tracker – How it works

vort 850hPa

V 850,700,500,200 hPa

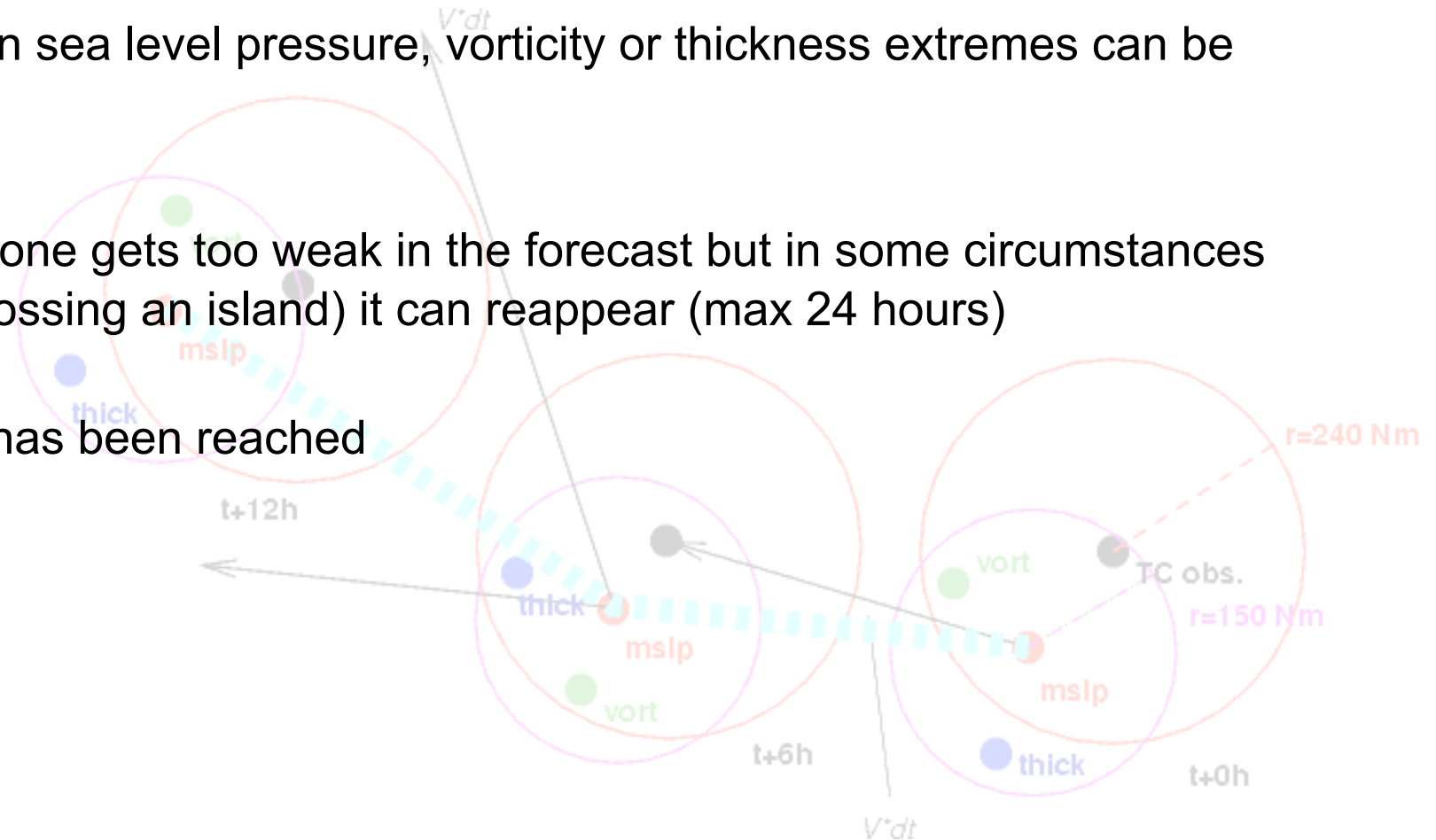
warm core 500-200 hPa



ECMWF TC Tracker – How it works

The tracker will stop if...

- no mean sea level pressure, vorticity or thickness extremes can be found
- the cyclone gets too weak in the forecast but in some circumstances (like crossing an island) it can reappear (max 24 hours)
- t+360h has been reached



Tracker output (available in BUFR format)

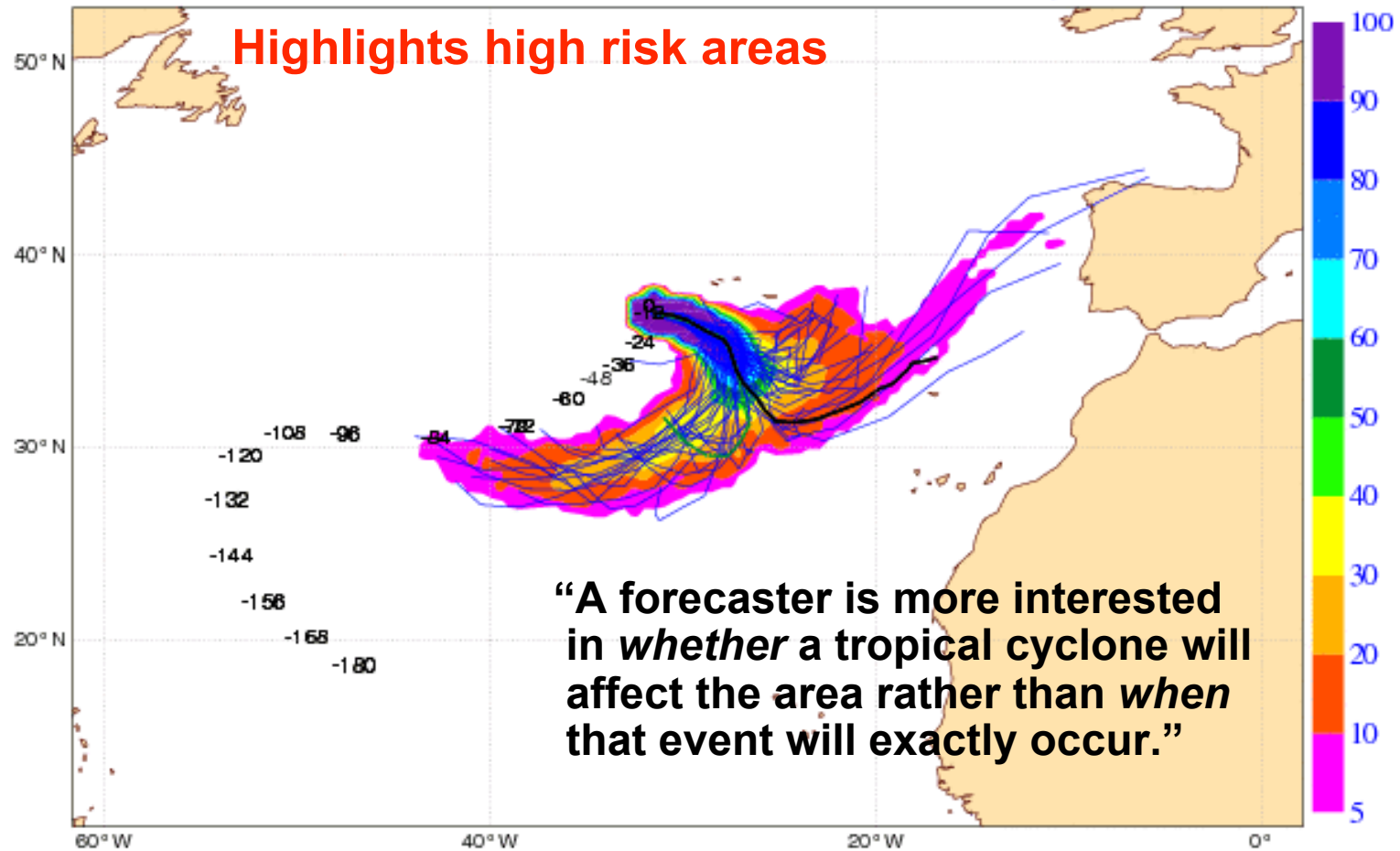
Lat	Lon	EPS member (1, ...,51)	fc date	hour	mslp
36.94	-38.96	1	20121001	0	988
36.13	-39.4	1	20121001	1200	997.6
35.4	-38.89	1	20121002	0	999.7
35.09	-38.54	1	20121002	1200	999.6
34.52	-37.83	1	20121003	0	1005.6
33.99	-36.13	1	20121003	1200	1006.1
34.75	-33.02	1	20121004	0	1003.6
37.2	-29.58	1	20121004	1200	995
.....					
36.93	-38.96	52	20121001	0	987.9
36.52	-39.09	52	20121001	600	986.9
36.02	-39.12	52	20121001	1200	992.6
35.61	-38.91	52	20121001	1800	993.6
35.37	-38.45	52	20121002	0	994.6

HiRes model

Forecast product – Strike Probability

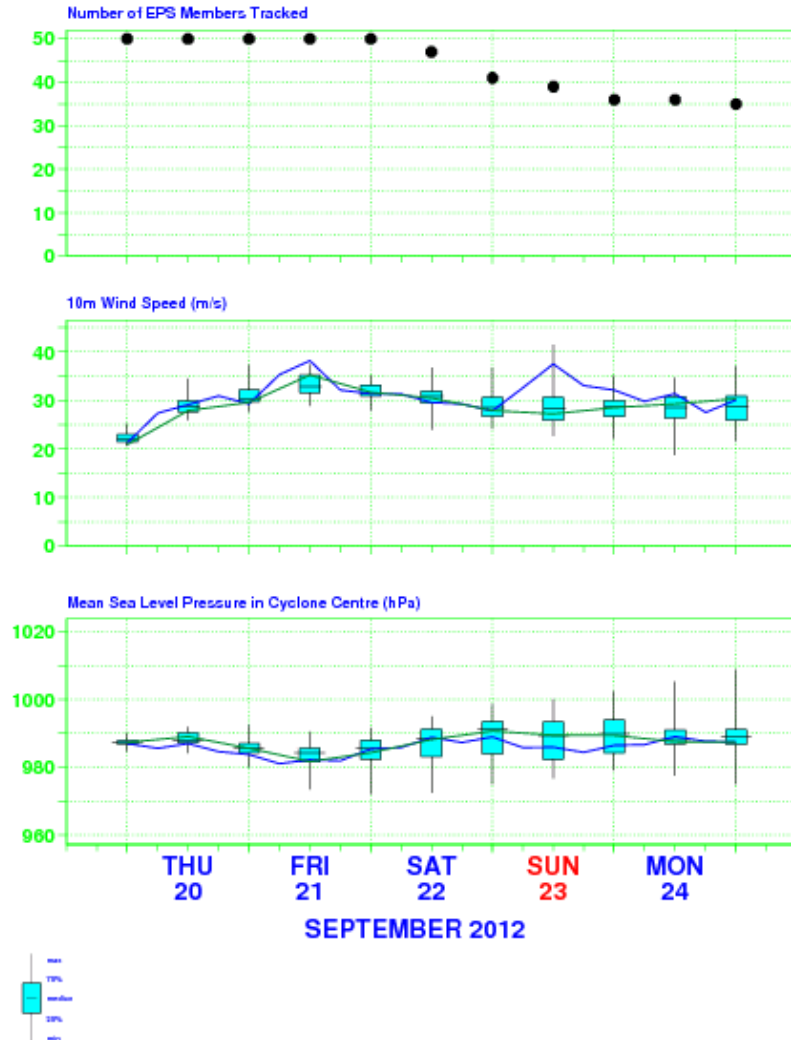
20120920 0 UTC

Probability that NADINE will pass within 120km radius during the next 120 hours
tracks: black=OPER, green=CTRL, blue=EPS numbers: observed positions at t+..h



Forecast product – Lagrangian EPSgram

EPS Lagrangian Meteogram
Tropical Cyclone NADINE (14L) starting from 37.3 N 31.7 W
Deterministic Forecast and EPS Distribution 20 September 2012 0 UTC



Feature based instead of grid point based.

Blue line – High Resolution model

Green line – Control model (EPS)

Dots – number of members predicting the feature

Availability of products

- Strike probability maps and Lagrangian EPSgrams are available on the web for member state and WMO users!!

<http://www.ecmwf.int/products/forecasts/>

- Tropical cyclone tracks are available for dissemination to the member states since 15 March 2005.

The screenshot shows the ECMWF website interface. At the top, there is a navigation menu with links for Home, Your Room, Login, Contact, Feedback, Site Map, and Search. Below this, there are sections for About Us, Products, Services, Research, Publications, and News&Events. The main content area is titled 'Latest Tropical Cyclones' and features a world map showing the distribution of tropical cyclones. The map is divided into regions labeled with Roman numerals (I-XII) and RSMC locations. A red circle highlights the RSMC La Réunion (VI) region. The page also includes a search bar for tropical cyclones and a date stamp '16-03-2004'.

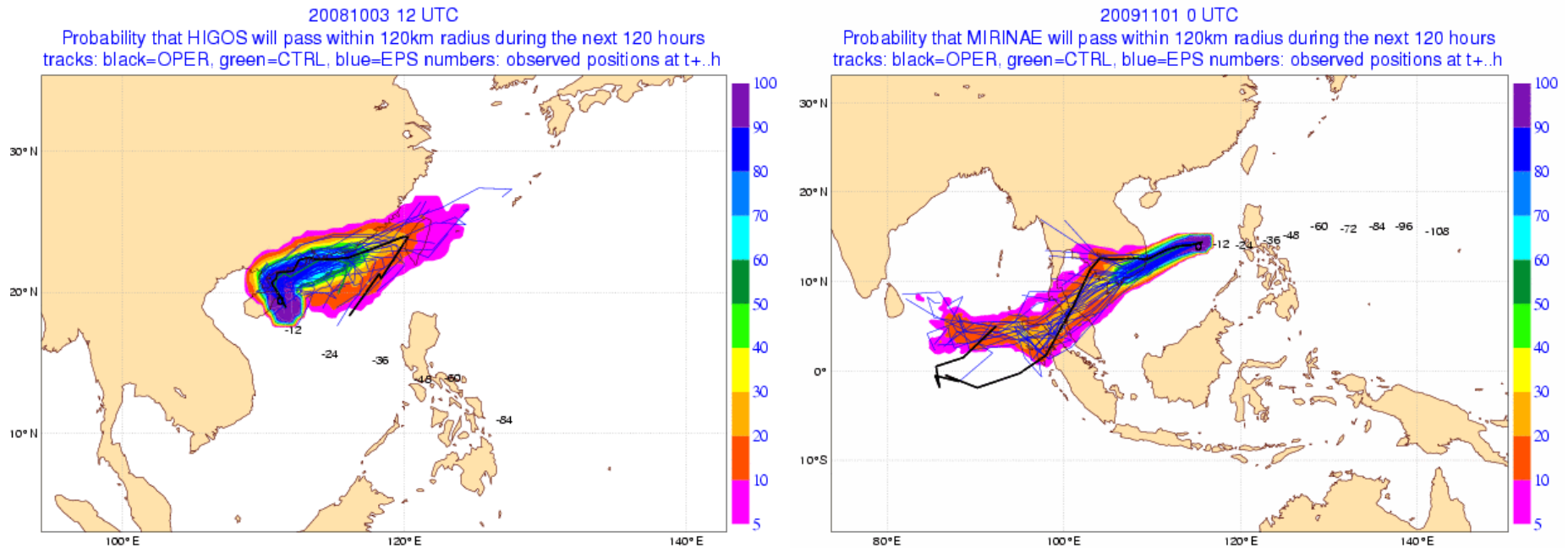
chart updated 4 hours ago

This map shows the latest active tropical cyclones as reported by WMO RSMCs. The name of the RSMCs and their area of responsibility is also shown. Each tropical cyclone has an active link to ECMWF numerical forecasts. Areas in the Tropics where ECMWF Ensemble Prediction System (EPS) has been refining the computation of uncertainties in the initial conditions (Singular Vectors) are shown as colour rectangles (more details can be found in the [User Guide](#)).

Finally it should be reminded that information on these pages are generated automatically without any editing by forecast experts. Therefore it may be useful to consolidate any judgment based on these forecasts by accessing the [WMO Severe Weather Information Centre](#).

Tracking spurious features during the forecast

Examples

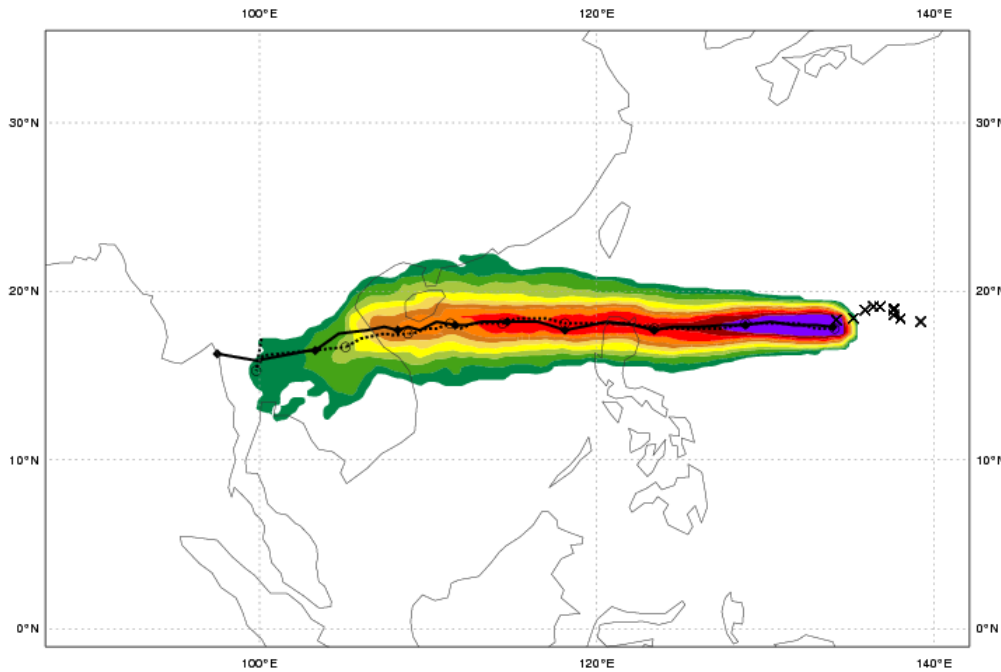


The remnants of a TC over land can become difficult to track and sometimes it can happen that another maximum (vor) and minimum (mslp) feature in the vicinity is picked up by the tracker

New TC product – Strike probability Plot pre-operational (coming soon)

Date 20110929 00 UTC @ECMWF
 Probability that NALGAE will pass within 120 km radius during the next 240 hours
 tracks: **solid**=OPER; **dot**=CTRL [reported minimum central pressure (hPa) 980]

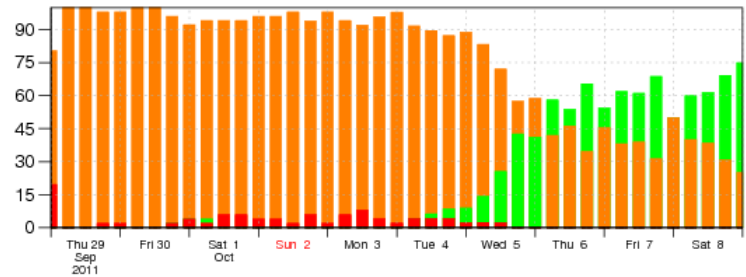
5-10 10-20 20-30 30-40 40-50 50-60 60-70 70-80 80-90 > 90 %



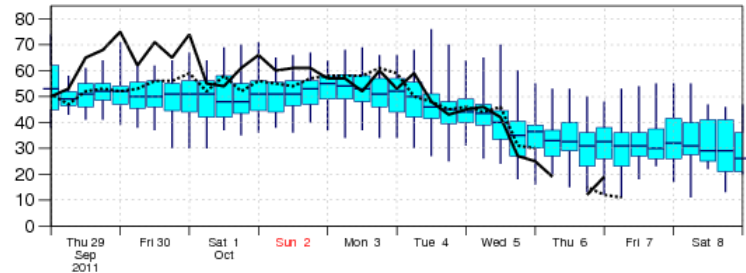
List of ensemble members numbers forecast Tropical Cyclone Intensity category in colours: TD[up to 33] TS[34-63] HR1[64-82] HR2[83-95] HR3[>95 kt]

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

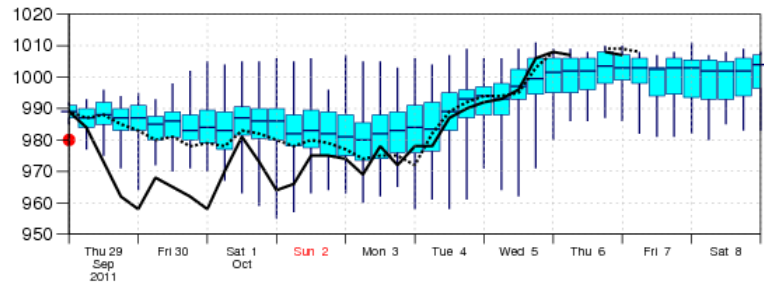
Probability (%) of Tropical Cyclone Intensity falling in each category
 TD[up to 33] TS [34-63] HR1[64-82] HR2 [83-95] HR3 [> 95 kt]



10m Wind Speed (kt) HiRes: solid line Ens Mean: dot line



Mean Sea Level Pressure in Tropical Cyclone Centre (hPa)



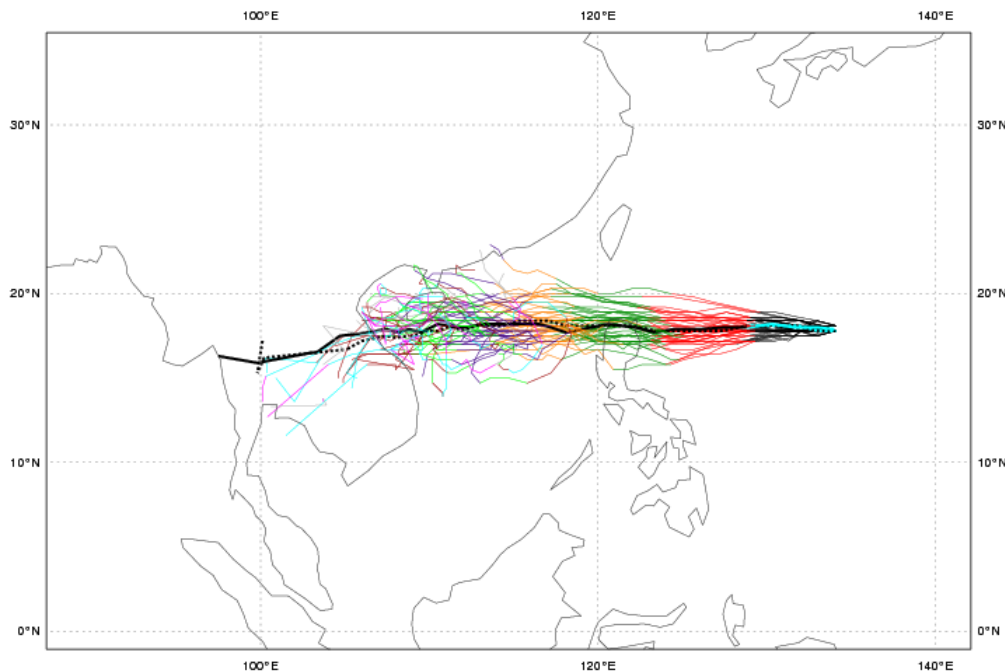
New TC product – Plume Plot

Date 20110929 00 UTC @ECMWF

Individual trajectories for **NALGAE** during the next 240 hours

tracks: **thick solid**=OPER; **thick dot**=CTRL; **thin solid**=EPS members [coloured]

0-24h **24-48h** **48-72h** **72-96h** **96-120h** **120-144h** **144-168h** **168-192h** **192-216h** 216-240h

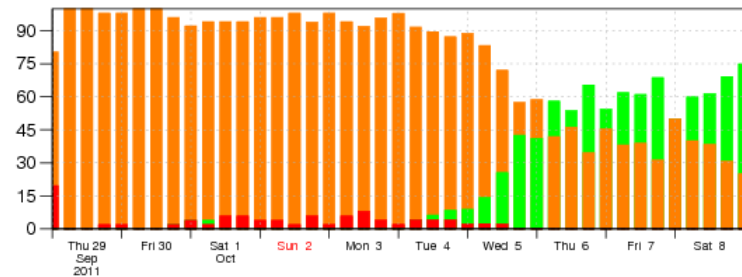


List of ensemble members numbers forecast Tropical Cyclone Intensity category in colours: **TD**[up to 33] **TS**[34-63] **HR1**[64-82] **HR2**[83-95] **HR3** [>95 kt]

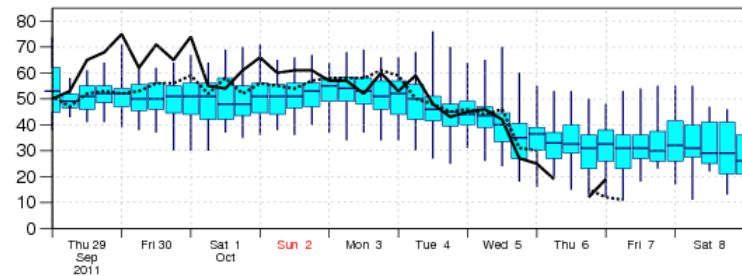
+024 h :	hr	ct	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
+048 h :	hr	ct	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41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

Probability (%) of Tropical Cyclone Intensity falling in each category

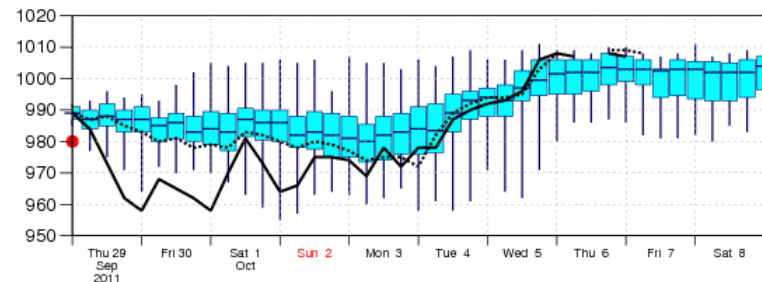
TD[up to 33] **TS** [34-63] **HR1**[64-82] **HR2** [83-95] **HR3** [> 95 kt]



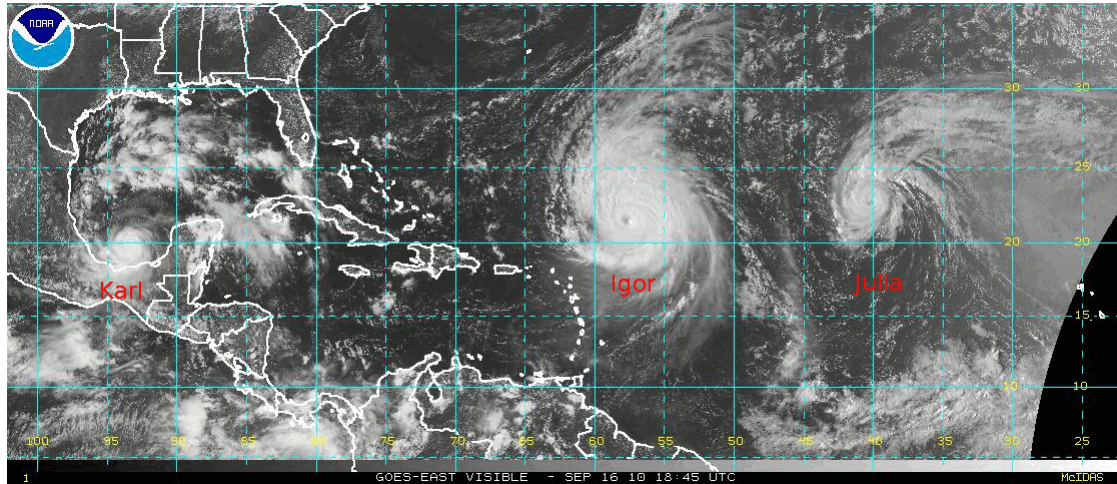
10m Wind Speed (kt) **HiRes: solid line** **Ens Mean: dot line**



Mean Sea Level Pressure in Tropical Cyclone Centre (hPa)

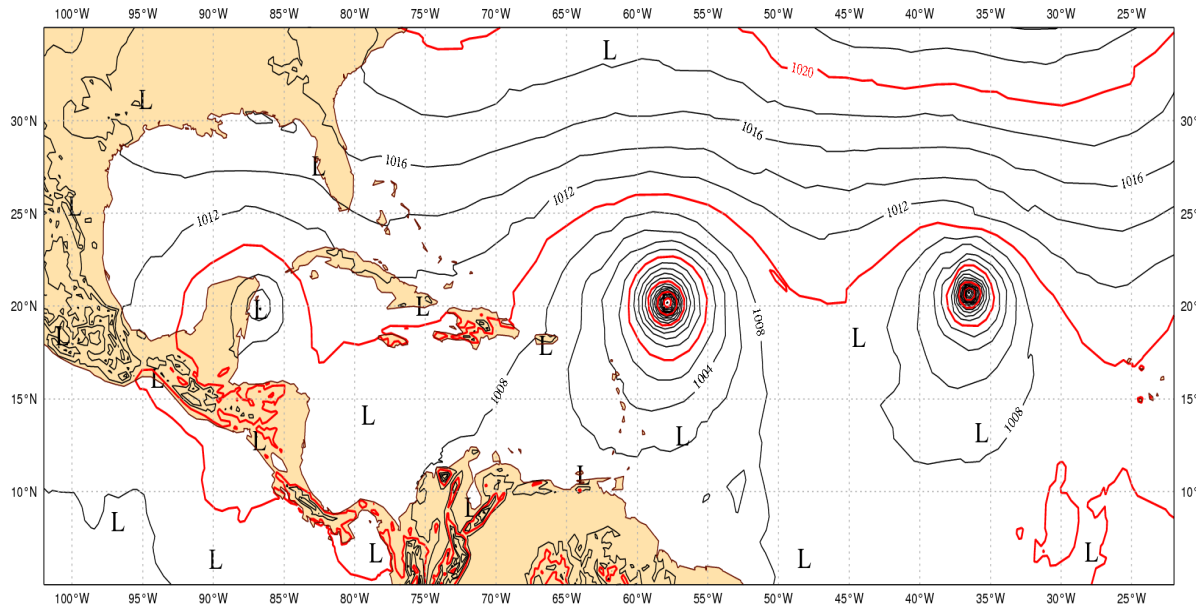


Forecast period of enhanced Hurricane Activity, 9 days ahead



Goes-East visible image
18 September 18 UTC

Wednesday 8 September 2010 00UTC ECMWF Forecast t+210 VT: Thursday 16 September 2010 18UTC Surface: Mean sea level pressure



T+210 h T1279
Forecast MSLP



Tropical Cyclone Activity Medium Range EPS

Selected forecast steps covering the next 12 days

Maps: global view and 7 additional TC basins



Tropical cyclone activity (including genesis)

Range: 24-72 Intensity: Tropical storms Area: Global Forecast base time: Tue 25 Jan 2011 12UTC

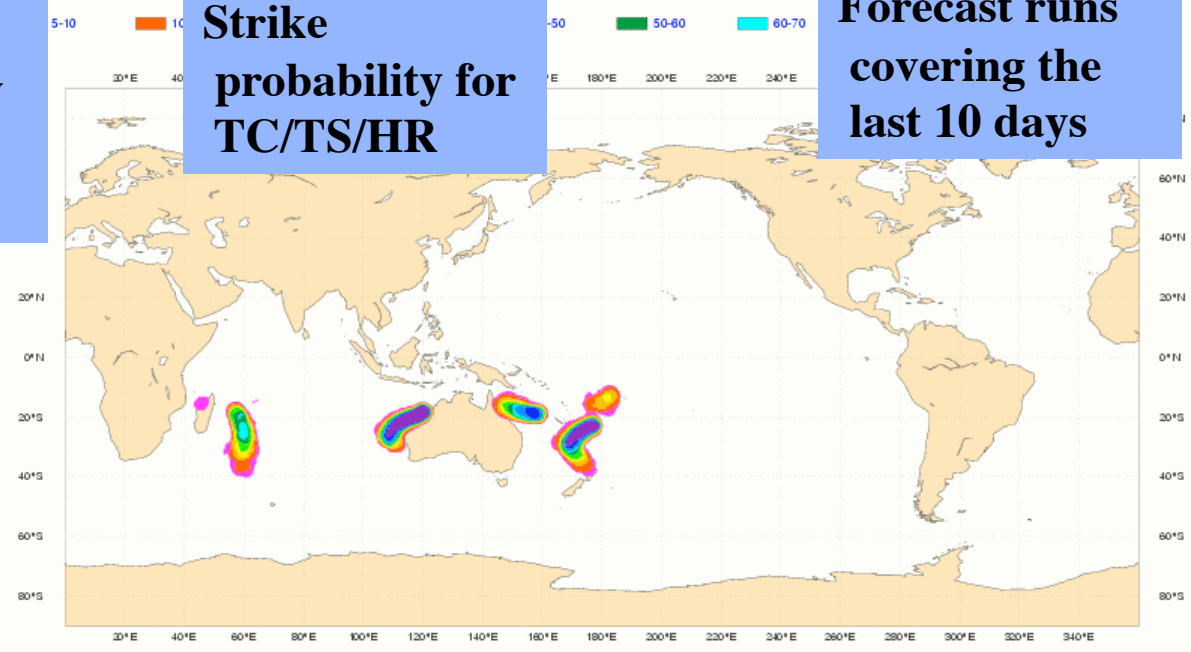
Not (yet) available to WMO

A short explanation about the products is available here by clicking in the show guide

Tropical Storm Strike Probability Start date Tuesday 25 January 2011 at 12 UTC
Valid for 48hours from Wednesday 26 January 2011 at 12 UTC to Friday 28 January 2011 at 12 UTC
Probability of a Tropical Storm passing within 300km radius

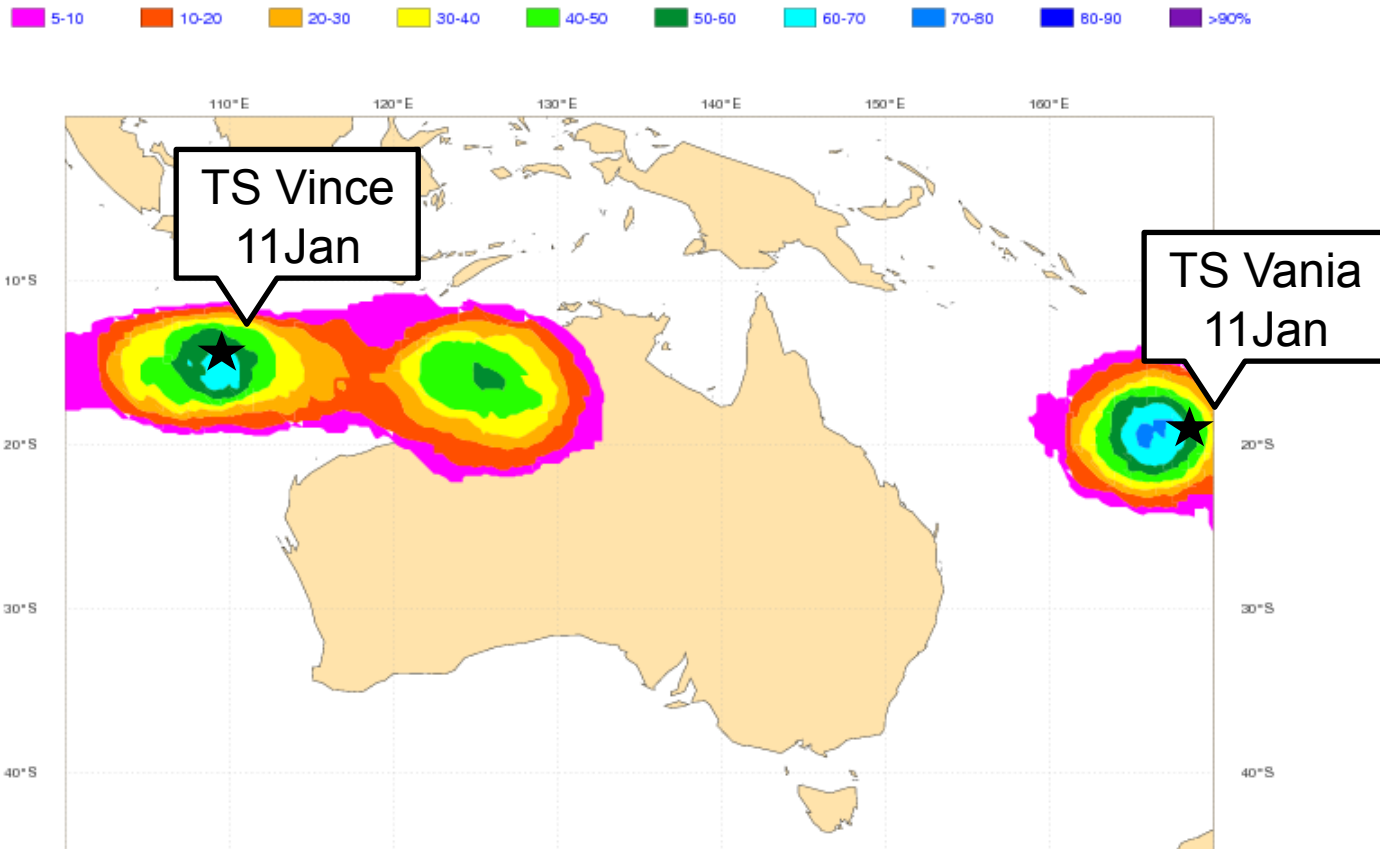
Strike probability for TC/TS/HR

Forecast runs covering the last 10 days



New Product: TC activity during the forecast

Tropical Storm Strike Probability Start date Saturday 08 January 2011 at 00 UTC
valid for 48hours from Monday 10 January 2011 at 00 UTC to Wednesday 12 January 2011 at 00 UTC
Probability of a Tropical Storm passing within 300km radius

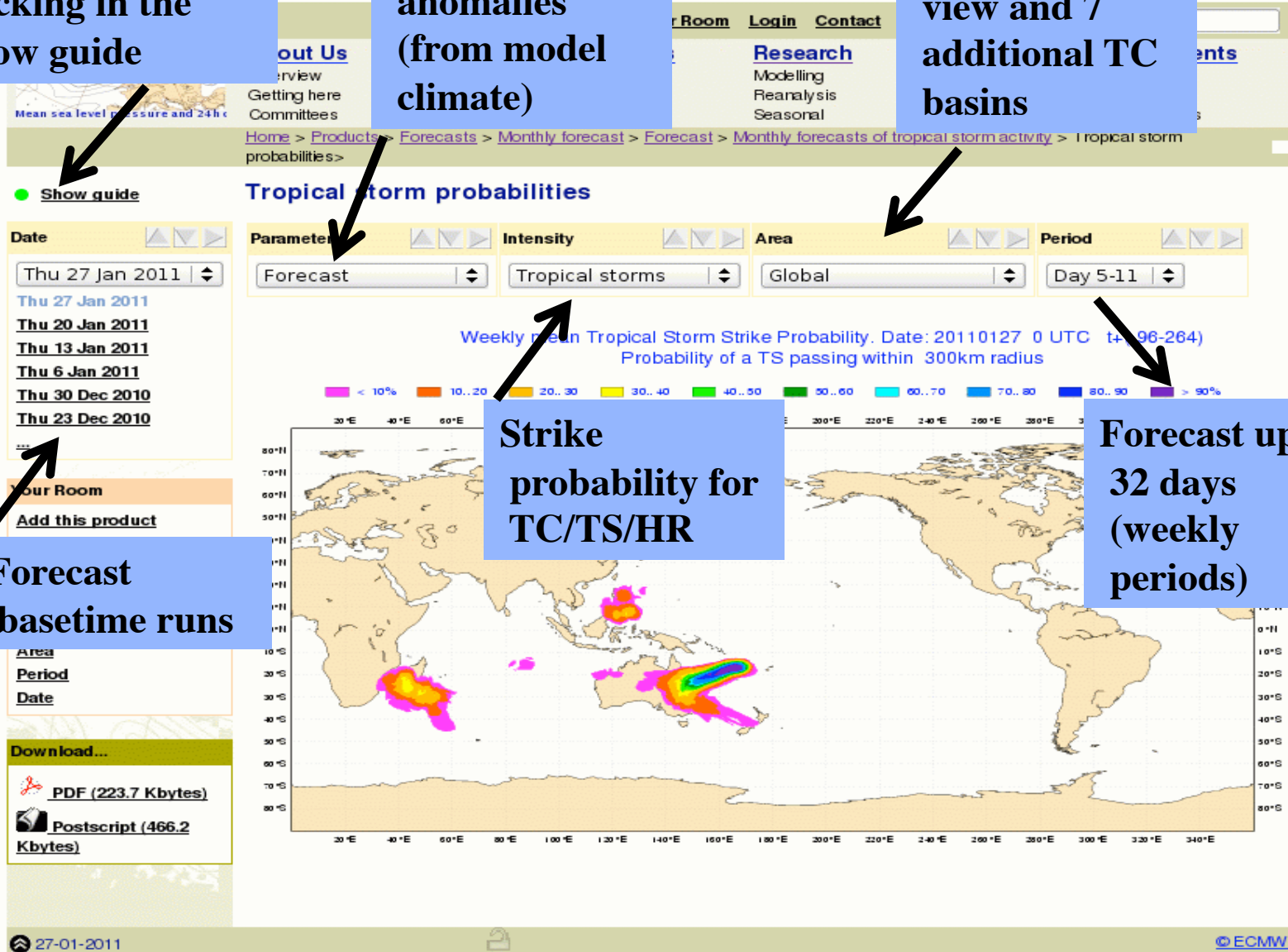


Cyclical variability in the Monthly Forecast

A short explanation about the products is available here by clicking in the show guide

Strike probability or probability anomalies (from model climate)

Maps: global view and 7 additional TC basins



Forecast basetime runs

Strike probability for TC/TS/HR

Forecast up to 32 days (weekly periods)

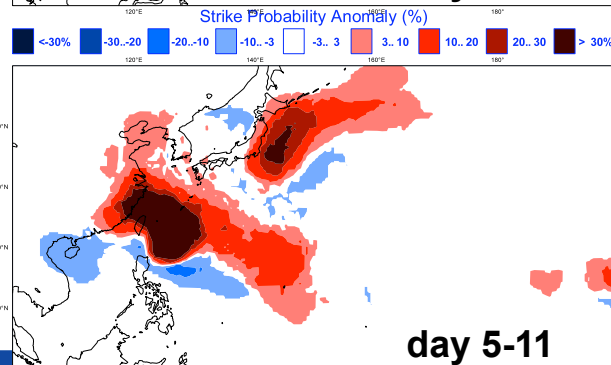
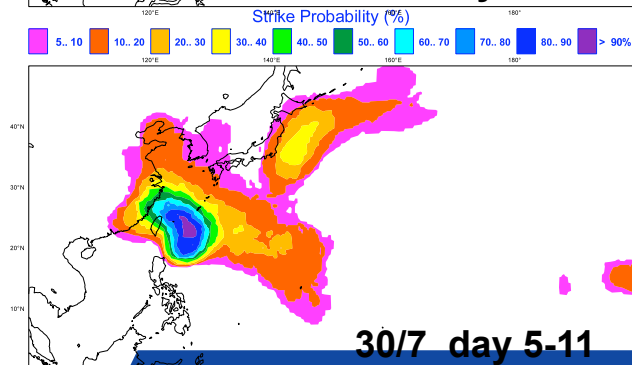
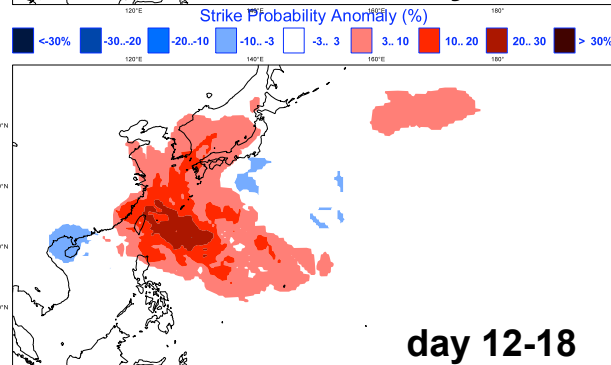
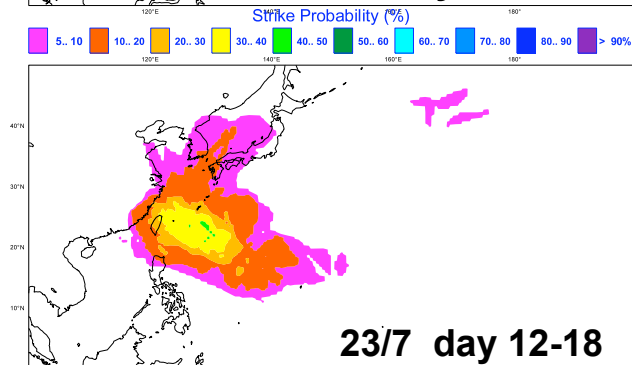
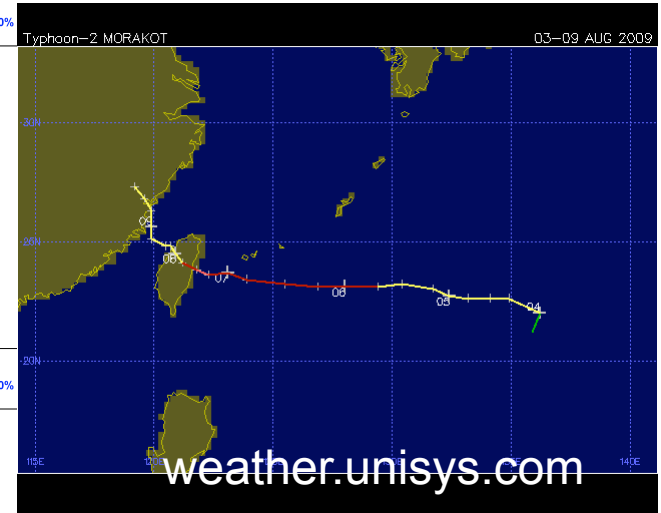
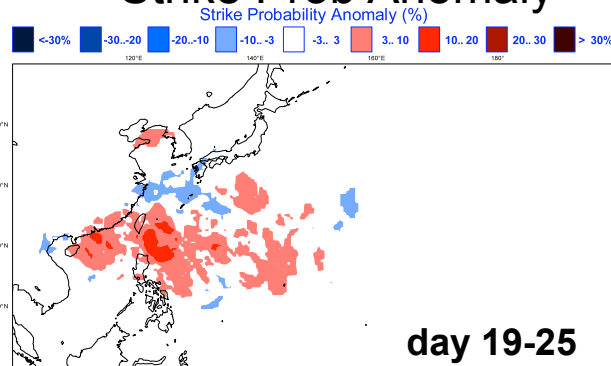
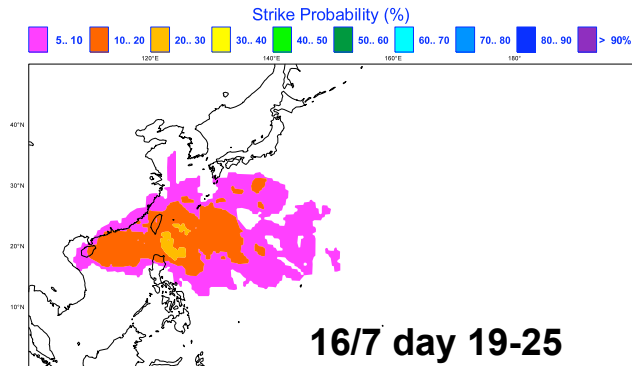
Typhoon Morakot (Taiwan) 3-9 August 2009

Strike probability that TC will pass within 300 km for days 5-11, 12-18, 19-25

probability anomaly (%) = difference between forecast probability and climate probability

valid for 3-08-09 to 9-08-09

Strike Prob Anomaly

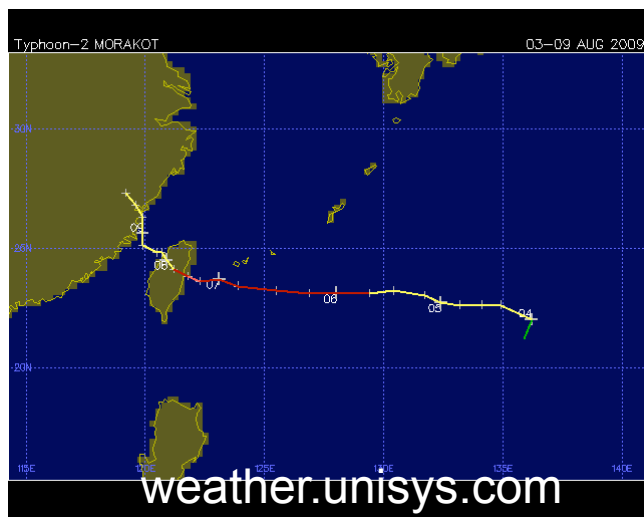
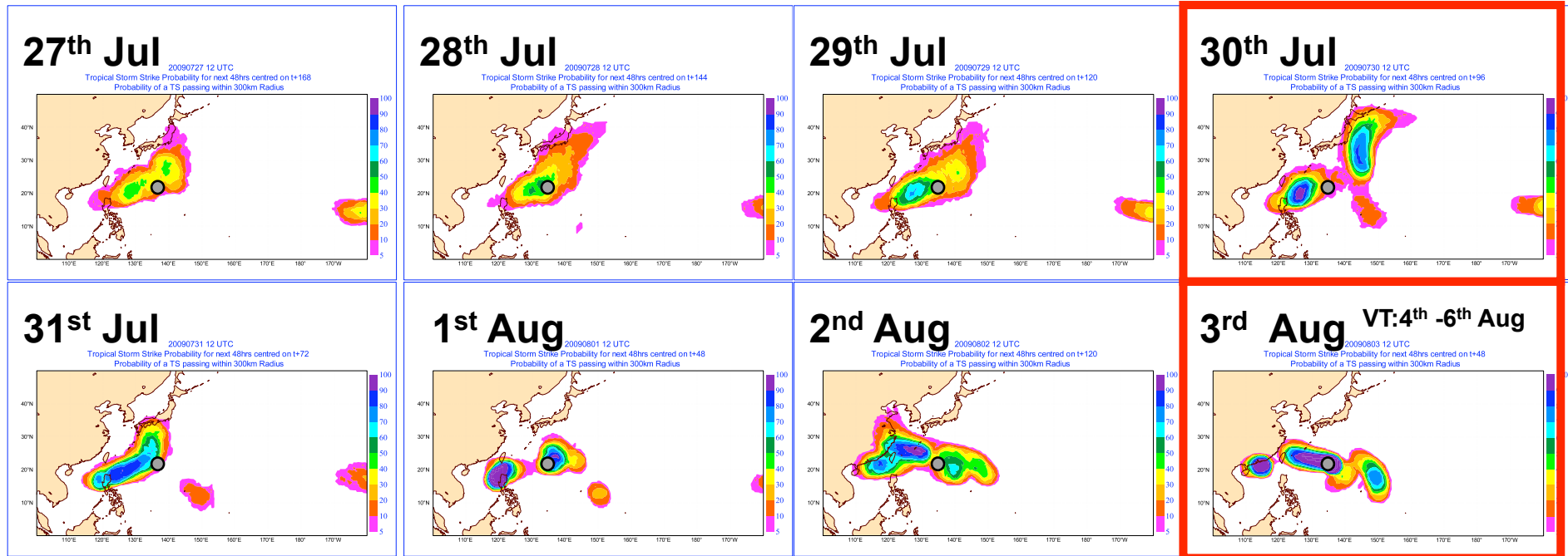


Strike probability anomaly for the monthly forecast increased as the lead time becomes shorter

Typhoon Morakot (Taiwan) 3-9 August 2009

EPS: strike probability that TC will pass within 300 km for 48-hrs

VT: 12Z 2nd Aug 09 – 12Z 4th



Strike probabilities showed a gradual increasing of the signal for shorter lead times.

Grey dot represents the location of the first reported observation of TS Morakot.

By day 1-3 (1st Aug run) the maximum probability coincides with observed position.

The EPS has also predicted a few false alarm cases.

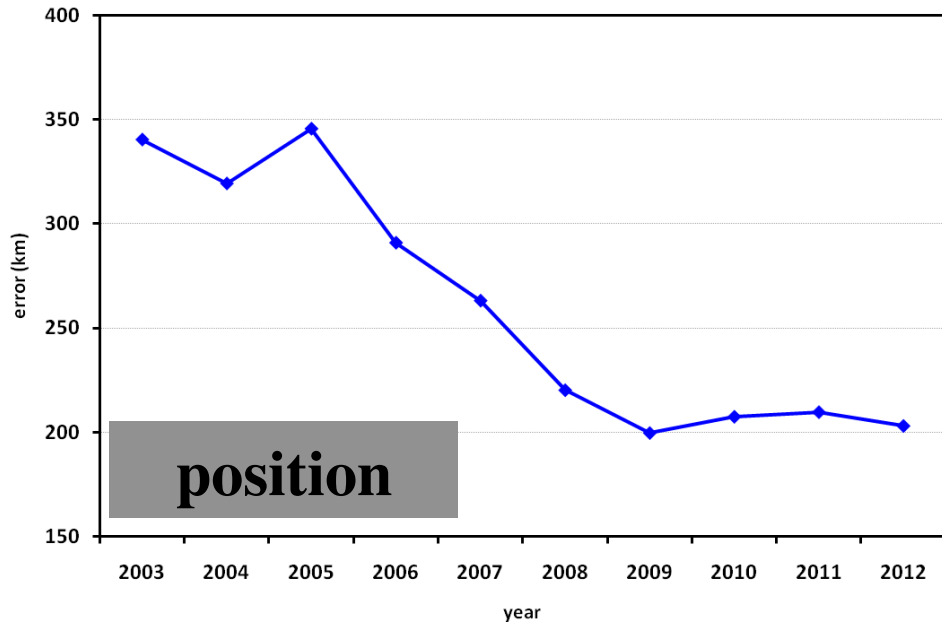
Forecast performance

The forecast performance for TCs is checked regularly and compared with the previous years for the Global high resolution model and EPS. The results are reported to the Technical Advisory Committee every year.

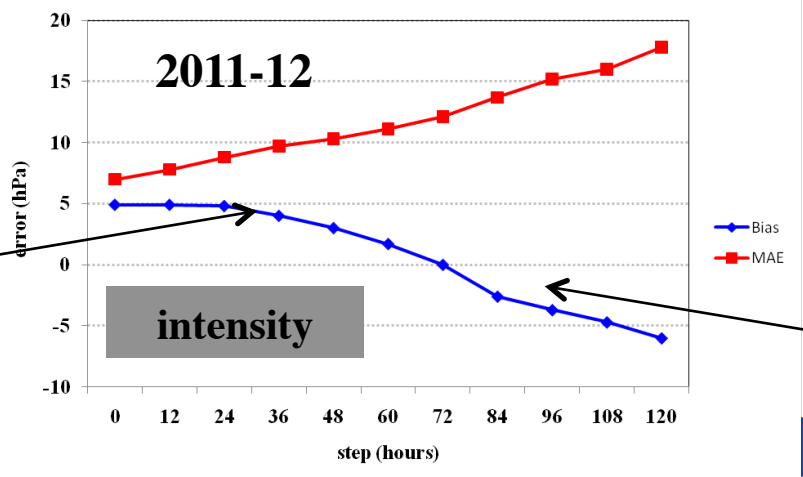
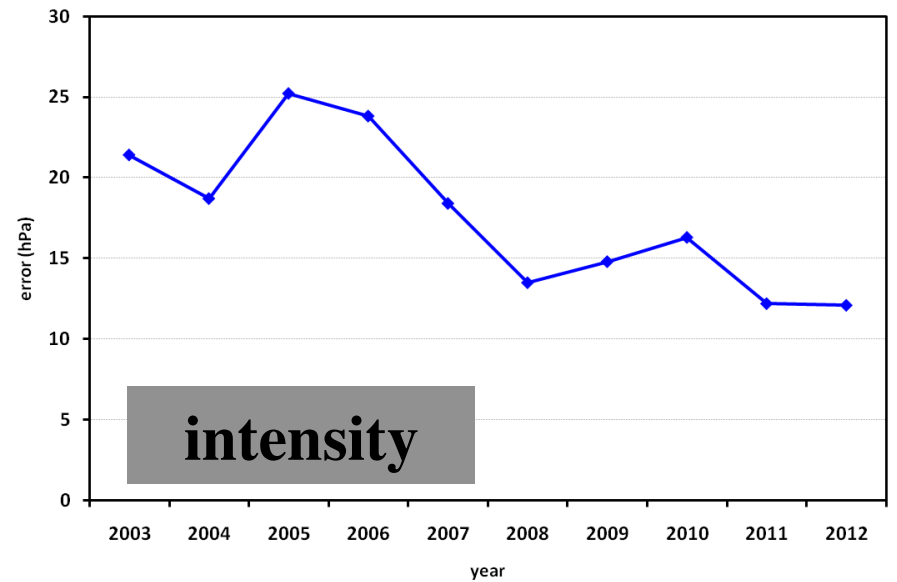
- Mean position error for High Resolution, Control models and EPS mean
- Mean intensity error (ME) for the same systems
- Mean speed error (ME) for High Resolution and Control models
- Reliability and ROC for the Strike Probability Products

Verification – deterministic score

Mean position error D+3 Deterministic model
(annual mean ending on 30th June)



Mean absolute intensity error D+3 Deterministic model
(annual mean ending on 30th June)



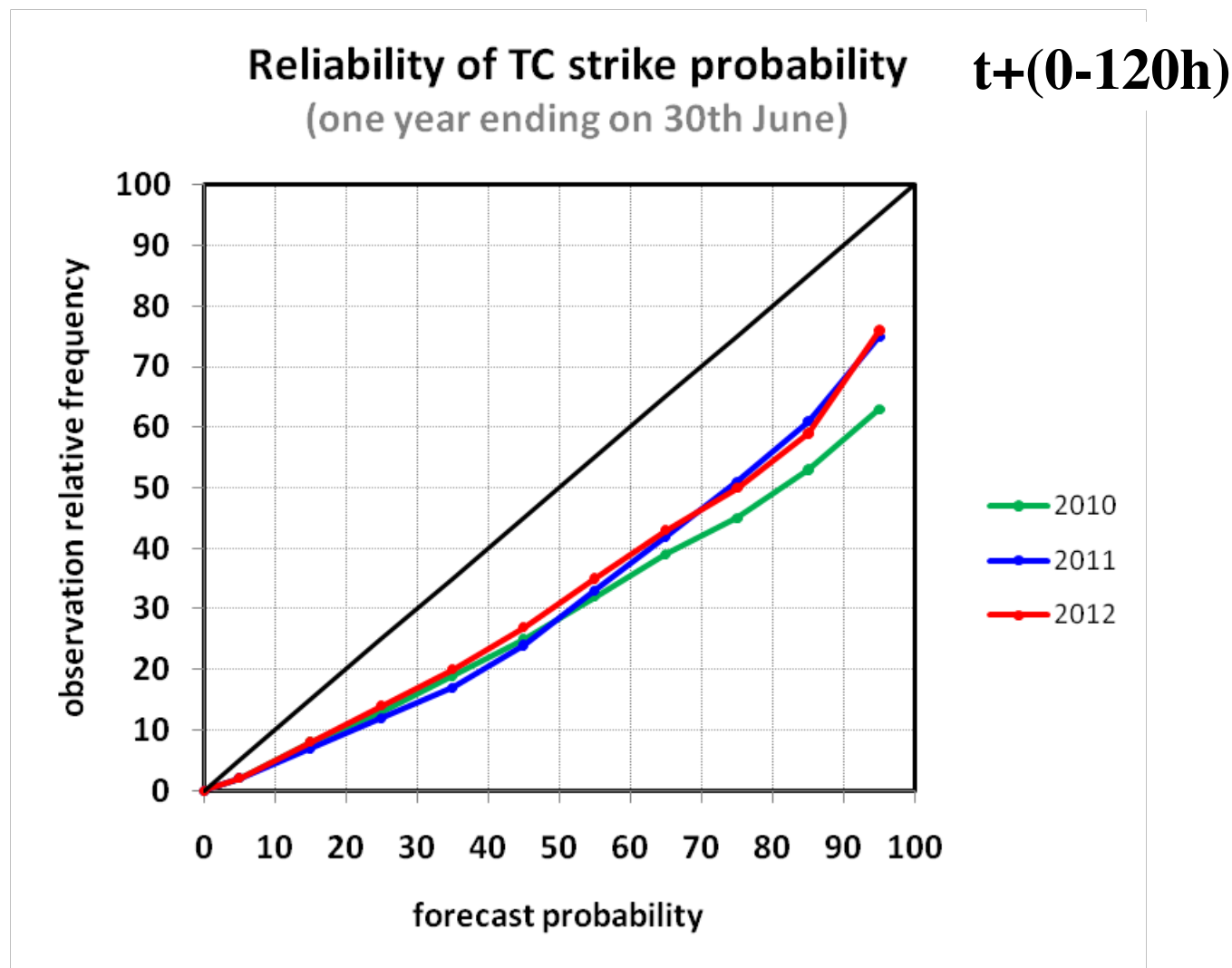
too weak

too strong

Use & interpretat

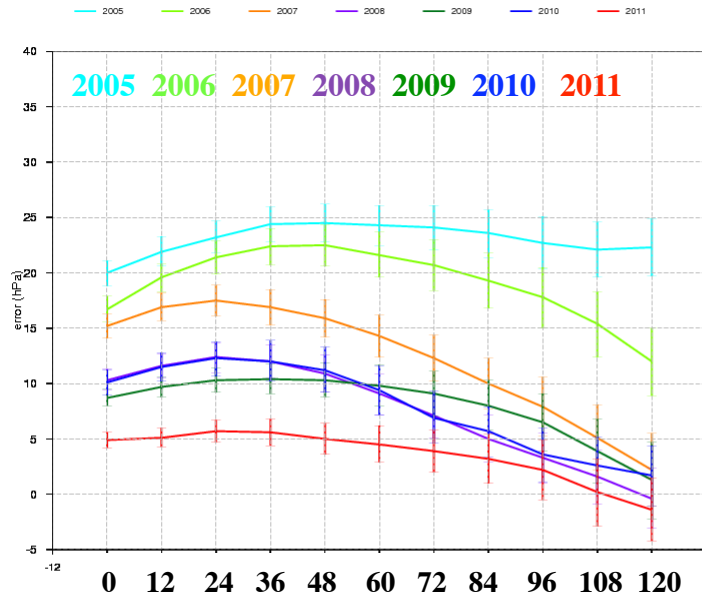


TC strike probability – probabilistic verification for existing tropical cyclones.

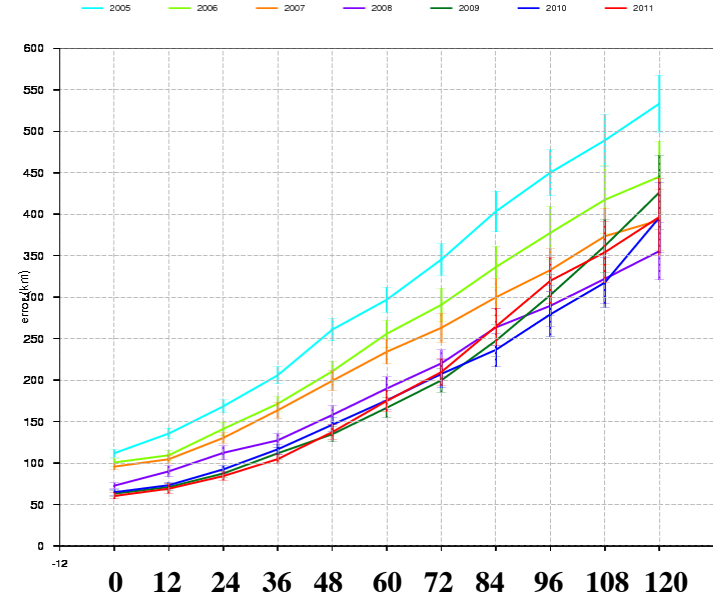


Verification: High Resolution model

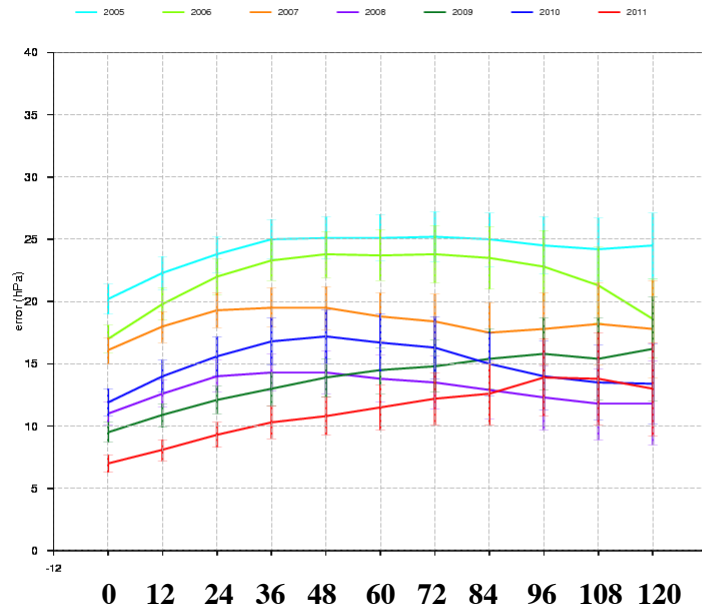
Tropical cyclone mean intensity error
annual mean ending 30th June



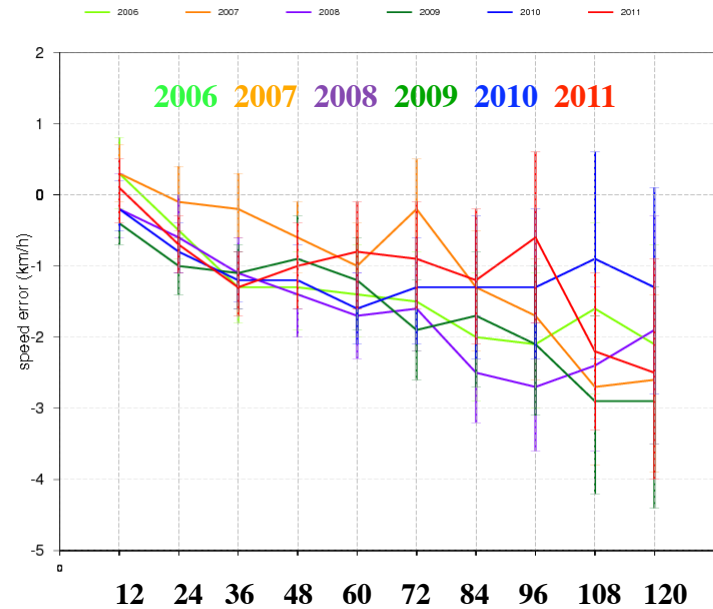
Tropical cyclone mean position error
annual mean ending 30th June



Tropical cyclone mean absolute intensity error
annual mean ending 30th June

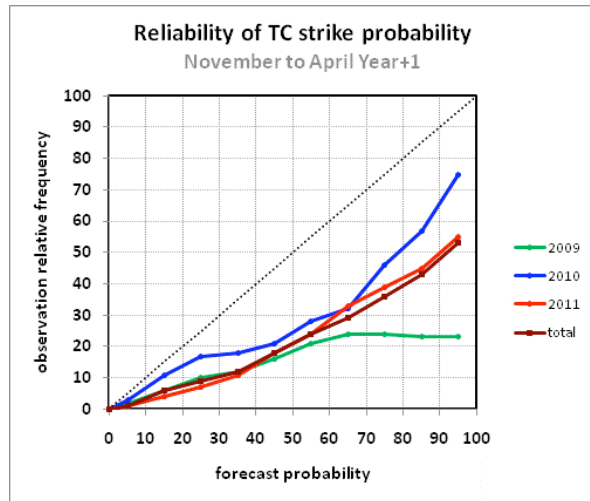


Tropical cyclone mean speed error
annual mean ending 30th June

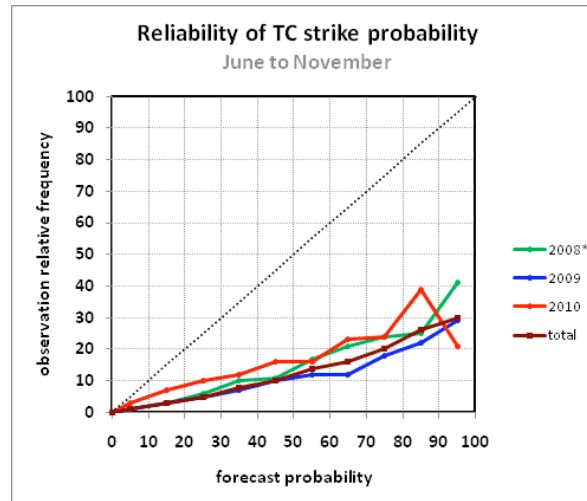


Verification: TStorm/Hurricane Activity during the forecast t+48-96h

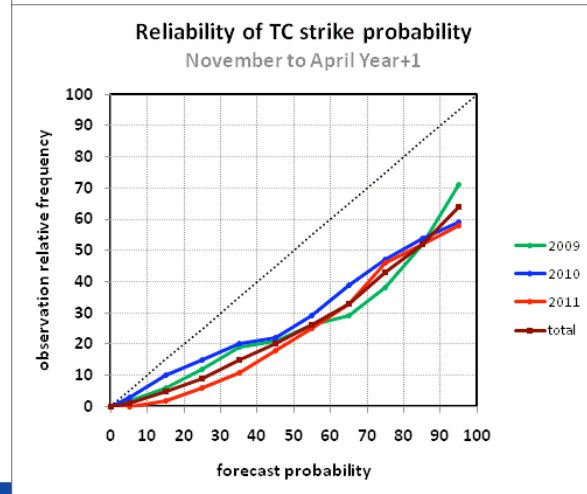
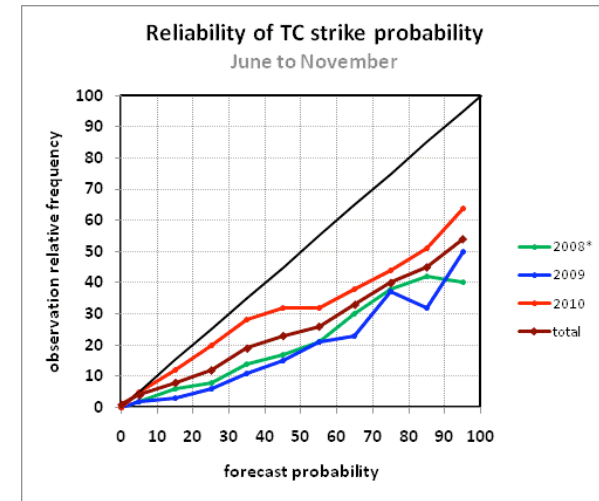
North Australia



West Pacific

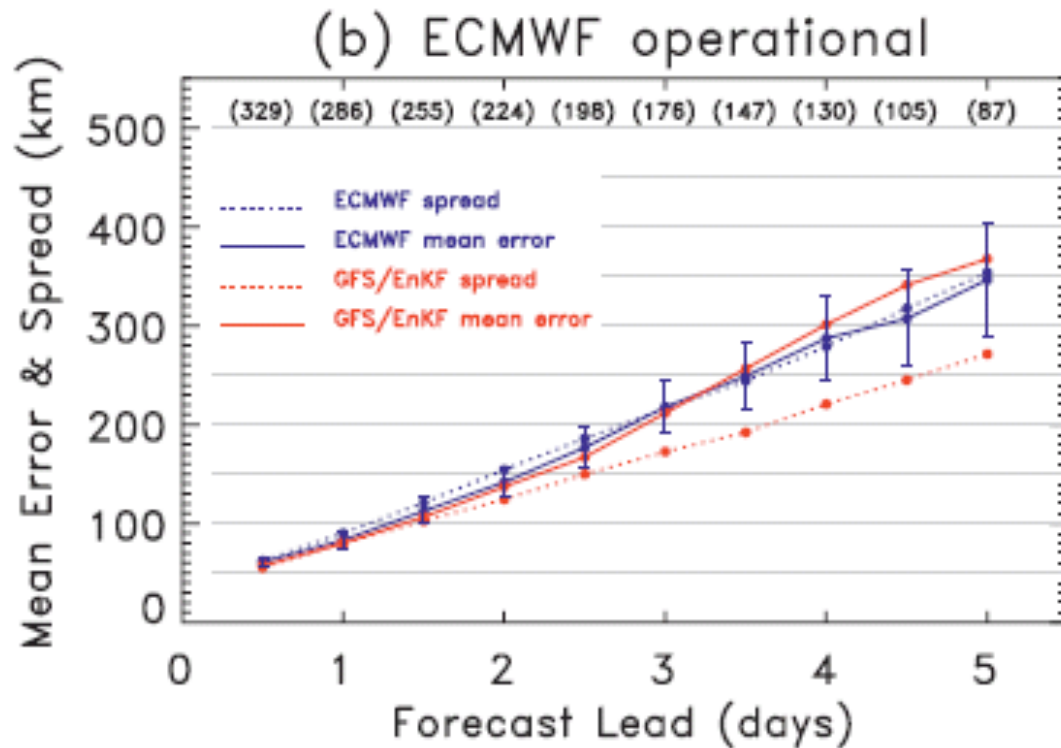


North Atlantic



South Indian

Spread & EM error of TC forecast tracks



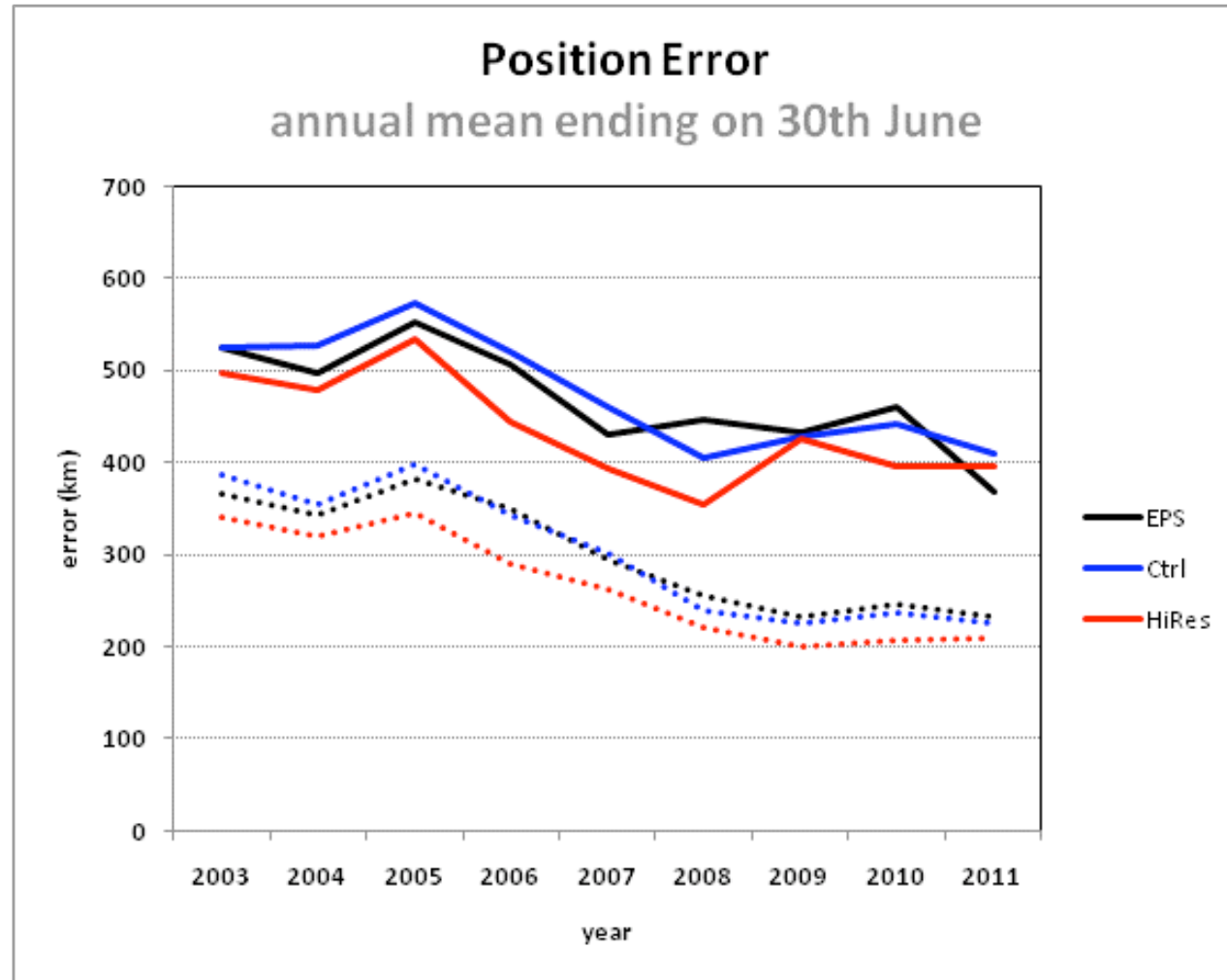
verification period: JJASO 2010

ECMWF EDA/T639

Source: T. Hamill et al, MWR, 2011

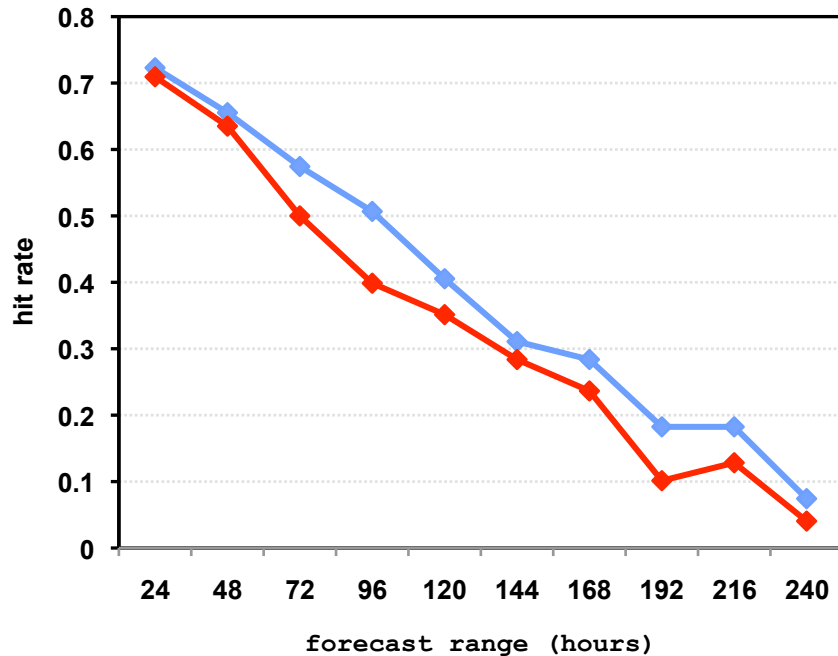
Verification: Evolution of the error

◆—◆ D+5
◆- -◆ D+3

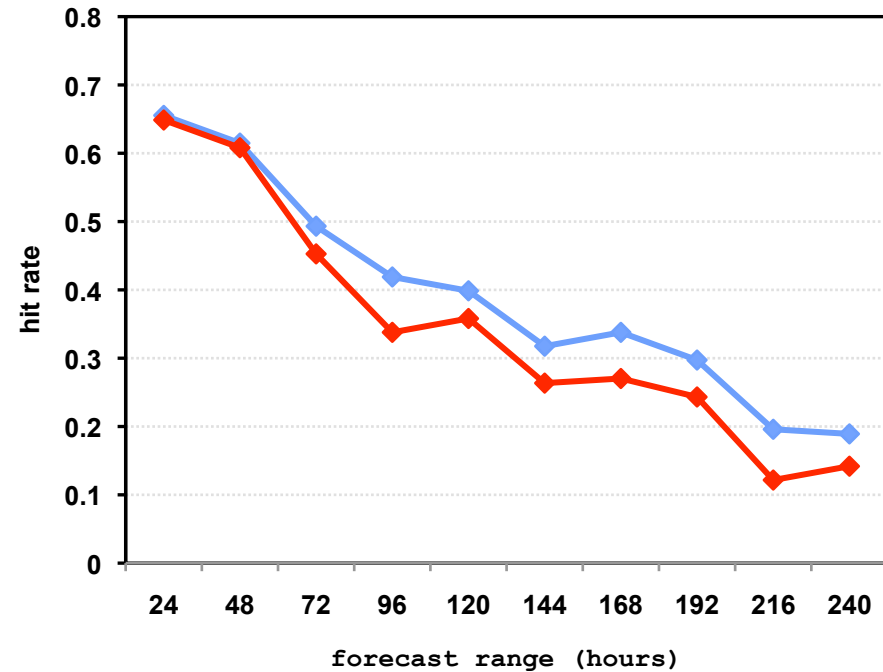


TC verification Hit Rate T799 v T399

TS/HR within 3°deg ± 1 day (± 0 day)
verification period: 20080715-20100125
number storms 148 HiRes Forecast (T799)



TS/HR within 3°deg ± 1 day (± 0 day)
verification period: 20080715-20100125
number storms 148 Control Forecast (T399)



Summary and conclusions

- **The need of having accurate Tropical Cyclone forecasts is of obvious importance. Those weather systems can cause loss of life and severe damages on infrastructures and property especially in densely populated coastal regions.**
- **Increase in resolution, introduction of new observation systems (satellite), robust DA system, coupled atmospheric-wave models and implementation of EDA improved the representation of TC in the EC forecast systems in the last years.**
- **ECMWF has developed a tropical cyclone tracker which allows the production of new tropical cyclone forecast tools.**
- **New products will be soon available to WMO Members: the EPS Strike probability of TCs during the forecast for the medium range and monthly systems.**
- **TC forecast performance has improved in the last years (position and intensity)**

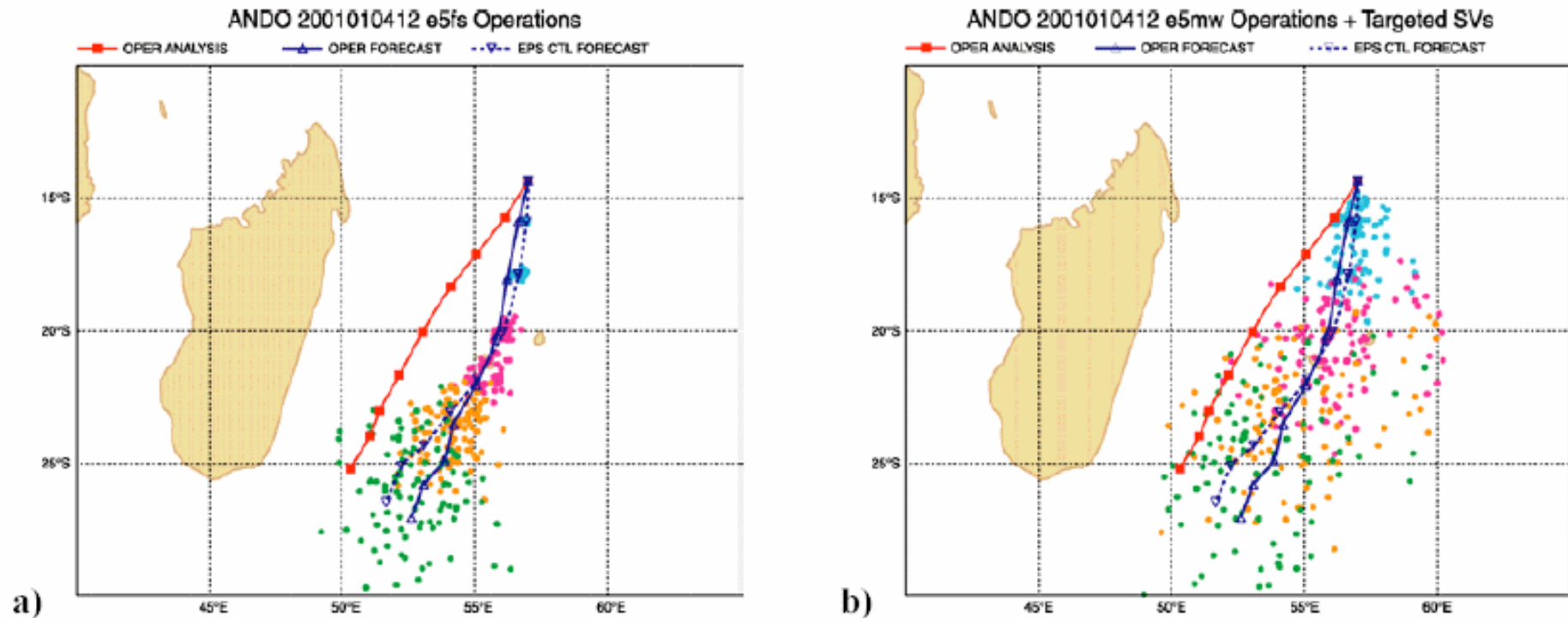
Summary and conclusions (cont'd)

- **Although suffering from systematic errors in intensity and speed, the ECMWF high resolution model does make very skilful TC forecast.**
- **The lack of ensemble spread in the EPS implies that the system is too confident in predicting the position of TCs. The new EPS initial perturbations, implemented last year, is expected to improve the spread of the EPS in the tropics, in particular, the calibration of the forecast probabilities of TCs.**
- **There is still difficulties in representing very deep Tropical Cyclones in the forecast or very rapid intensification which remains an issue of ongoing research.**

Tropical Cyclones are the most destructive weather phenomena known.

- **Most Intense:** **870 hPa** by dropsonde in Super typhoon Tip, western North Pacific Ocean, 12 October 1979 (Dunnavan and Diercks, 1980); reports from the JTWC indicate that the 12 most intense cyclones on record occurred in the western North Pacific Ocean.
- **Highest:** Wind Gust: **78 ms⁻¹** Chetumal, Mexico, 27-28 September 1953 (Dunn and Miller, 1964). Sustained winds of Hurricane Camille (1969) and Hurricane Allen (1980) were estimated to **85 ms⁻¹**.
- **Highest Wave:** **34 m** from USS Ramapo in the western North Pacific, 6-7 February, 1933 (GBR, 1991); also in the western North Pacific, 25 m on 26 September, 1935 (Arakawa and Suda, 1953).
- **Most Deadly:** The death toll in the infamous Bangladesh Cyclone of 1970 has had several estimates, some wildly speculative, but it seems certain that at least **300,000** people died from the associated storm tide in the low-lying deltas. A series of disastrous floods in the Yangtze River Valley in the mid-1850s resulted in many millions of deaths.

Impact of targeted tropical perturbations - example



Tropical cyclone positions up to 4 days ahead for cyclone ANDO in the (a) operational and (b) experimental EPS using targeted tropical perturbations, started from 4 January 2001. Symbols denote the cyclone position in the EPS for 0-to-24 hour (blue), 24-to-48 hour (purple), 48-to-72 hour (orange) and 72-to-96 hour (green) forecasts. The red line denotes the analysed track (symbols denote the position every 12 hours), the solid blue line the track predicted by the operational forecast and the dotted blue line the track predicted by the EPS control forecast.