

**Meteorological Operations Section** 



## **Objectives**

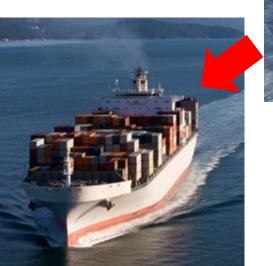
- Have a better understanding of the Tropical Cyclone Products at ECMWF
- Learn about the recent developments in the forecast system and its impact on the Tropical Cyclone forecast
- Learn about the TC forecast skill at ECMWF















## **Hurricane impact**

- Hurricanes can cause catastrophic damage in coastal (inland) areas specially in highly dense populated areas
  - Human impact: on May 2008 TC Nargis struck Myanmar. Estimated death toll: 100 000 people
  - Economical Impact: The actual cost of Hurricane Katrina's damage was between \$96-\$125 billion.
    - Affected 19% of U.S. oil production
    - • • •

• ¿"Despite \$50B In Damages, Hurricane Sandy Will Be Good For The Economy, Goldman Says"?, Forbes magazine.



## **Conditions for TC development**

- > Form over the oceans where  $SST > 26^{\circ}C$
- > Tropical cyclones do not develop within 3° of the Equator
  - (nonzero Earth's vorticity)
- Small vertical shear of horizontal wind
- > Unstable Atmosphere
- Tropospheric humidity (to keep the saturation during ascent)

**≻** But...

Hurricanes do not develop spontaneously: a trigger is needed eg: tropical waves play a role in about 70% of all Atlantic basin TC formations

MJO/QBO/El Nino



## **Recent model developments...**

Impact on the ability to analyse and forecast Tropical Cyclones:

- Increase of model horizontal and vertical resolution ①
- Satellite data in Data Assimilation (DA)
- Physics (parametrization of convection, new cloud microphysics,...)
- Coupling between the wave and atmospheric models.
- Methods for Global Ensemble Prediction : ENS evolved SVs , stochastic physics and perturbations target at observed TCs and <u>more</u> <u>recently</u> the implementation of Ensemble Data Assimilation 1

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

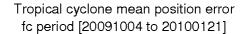
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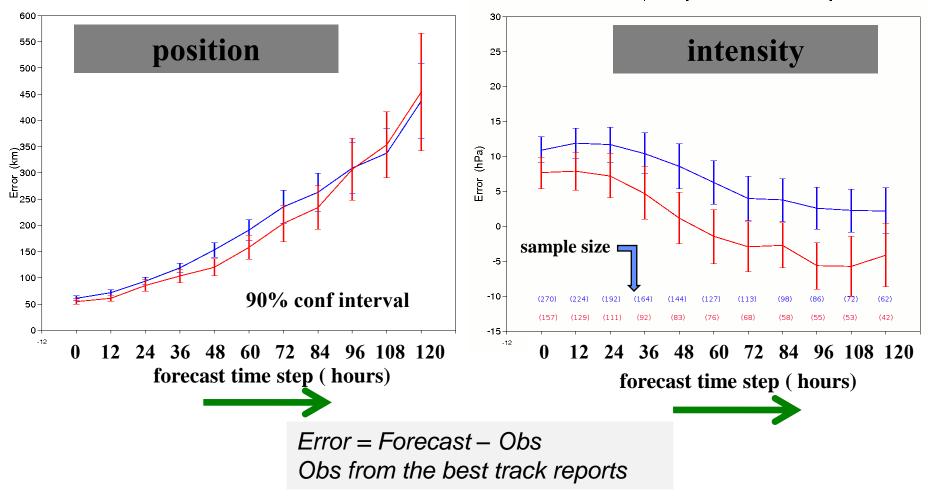




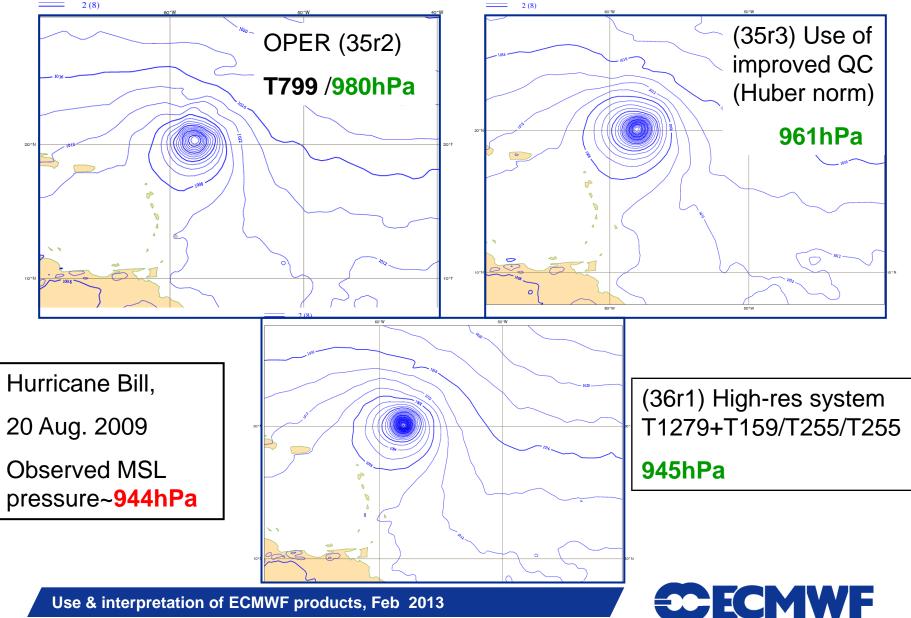
## TC forecast performance T799 v T1279



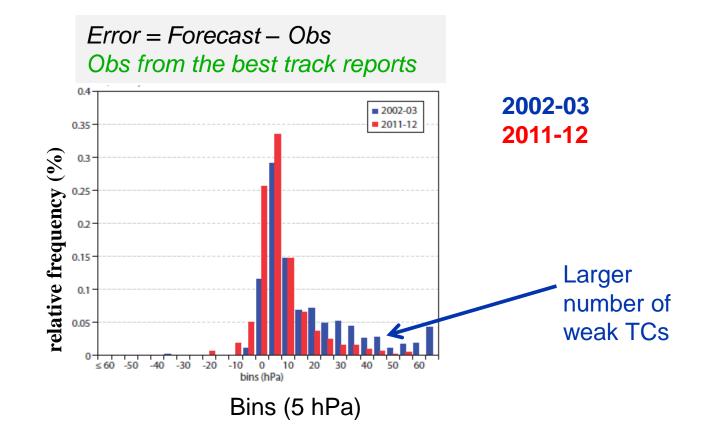
Tropical cyclone mean intensity error fc period [20091004 to 20100121]



#### T1279 Tropical cyclone analyses improved Improved Huber norm QC also beneficial



#### Histogram for MSLP fc errors (at center of TCs): analysis time



Strong reduction of the errors largely attributed to new observation systems in DA and an increase of model resolution





Assimilation of cloud and precipitation affected microwave radiances (left)

forecast impact for Hurricane Katrina

850 hPa vorticity 12-hour rainfall mean sea level pressure

**ECMWF** technical memorandum No 502 (Bauer et al 2006)

#### Deeper system and larger accumulated rainfall quantities

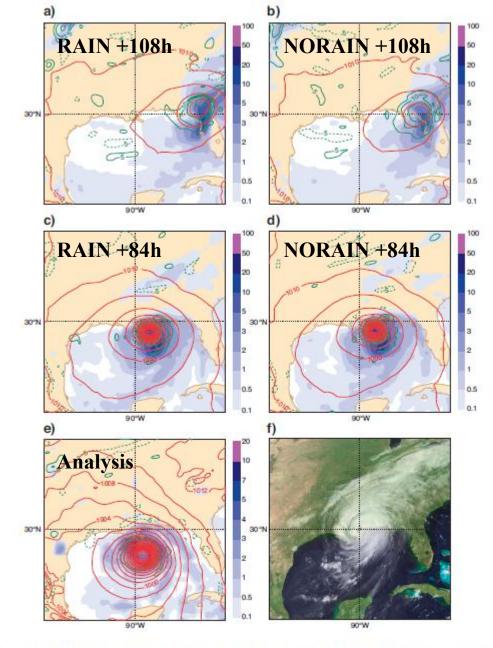
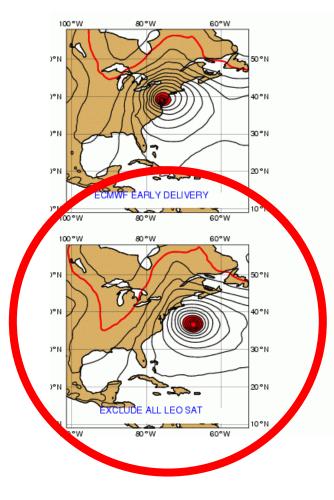
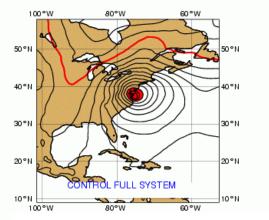
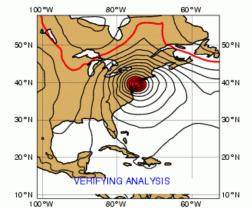


Figure 26: 4.5-day (108-hour) forecasts of mean-sea-level pressure (red isolines), 850 hPa potential vorticity (green isolines) and 12-hour accumulated rainfall (mm; blue shading) from experiment RAIN29R2 (a) and NORAIN29R2 (b) initialized on August 25, 2005, at 00 UTC. Same for 3.5-day (84-hour) forecasts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

## **Forecast verification 18L SANDY Oct 2012**





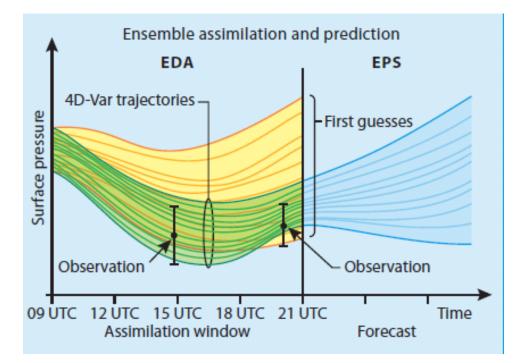


- re-run ECMWF operations from the 20th October at full resolution (T1279)
- incremental 4D-Var (i.e. non early delivery system) to provide a clean control.
- The denial experiments are identical to the control except that all LEO or GEO etc..satellite observations are withheld
- Day five forecasts launched from the 25<sup>th</sup>

**Thanks to Tony McNally** 



## Ensemble Data Assimilation (since 22nd June 2010)



**EDA first guesses trajectories** 

**Analysis of trajectories** 

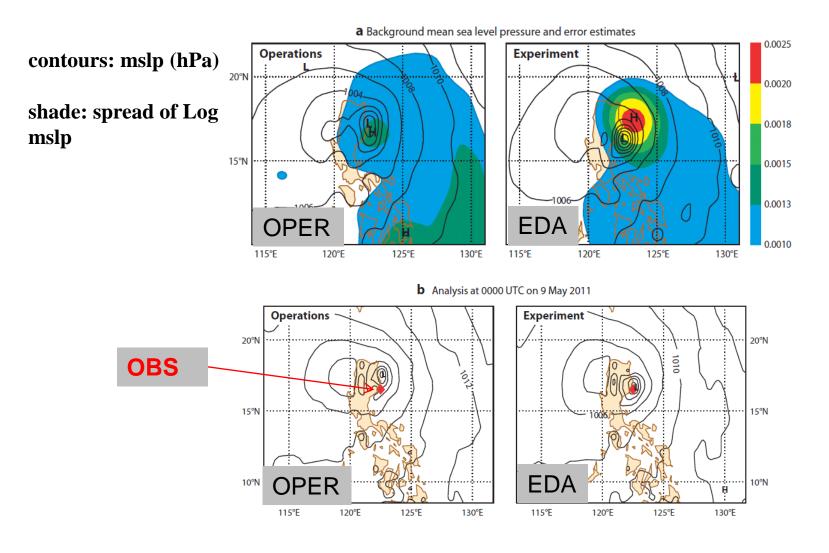
**Observations (w/ error bars)** 

#### EDA is used to provide

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



#### Impact of replacing evolved SV by EDA perturbations



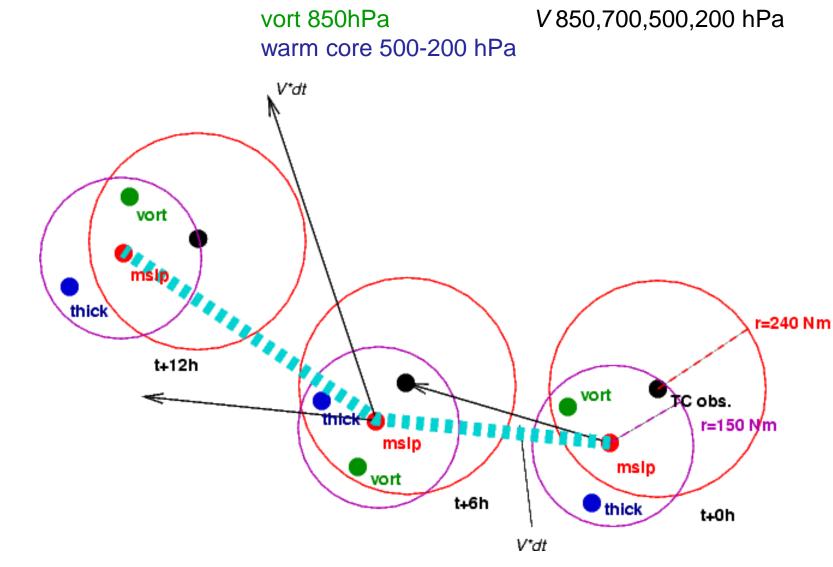
**CECMWF** 

## **ECMWF TC tracking scheme...**

- A new tracking scheme will replace the current operational algorithm used to identify TCs present in the initial conditions and/or forecasts (see Newsletter no. 130, 2011/12).
- > The algorithm runs twice a day (00 & 12 UTC) for high HRES model and ENS
- generates a track which is nothing more (and less) than a sequence of locations of minimum (max) in MSLP (10m speed) 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
- Fechnical changes in operational suite allow the TC tracking information from deterministic model to be disseminated 1 hour earlier (since June 2011).



## **ECMWF TC Tracker – How it works**

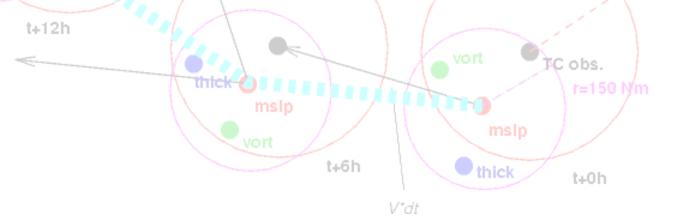


**ECMWF** 

## **ECMWF TC Tracker – How it works**

The tracker will stop if...

- no mean sea level pressure, vorticity or thickness extremes (warm core) 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 (+240h for the HRES)





## **Tracker output** (available in BUFR format)

Lat	Lon	ENS 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
		HRES m	nodel		

**CECMWF** 



## **Tropical Cyclone products at ECMWF**

> Whenever a Tropical Cyclone is observed at the start of a forecast

- http://www.ecmwf.int/products/forecasts/d/tccurrent
  - New product (Newsletter, 120, winter 2011/12)
- Tropical Cyclone activity in the forecast
  - http://www.ecmwf.int/products/forecasts/d/charts/medium/eps/genesis/ta\_genesis/

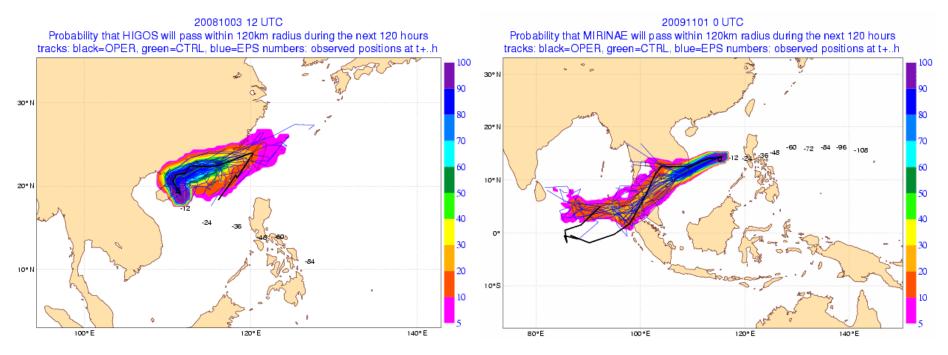


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### **Tracking spurious features during the forecast Examples**



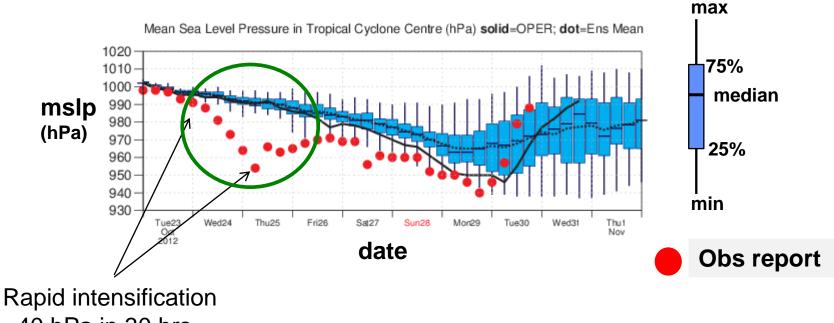
The remnants of a TC over land can become difficult to track and sometimes it can happen that another (non related) maximum (vorticity) and minimum (mslp) feature in the vicinity is picked up by the tracker



## **TC intensity forecast**

Rapid intensification of TCs is still poorly handled by the current global models

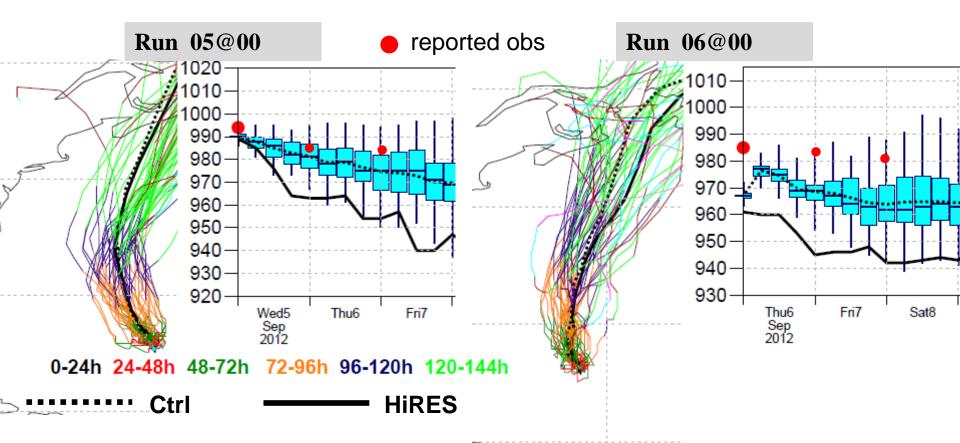
HR Sandy (18L)



~40 hPa in 30 hrs

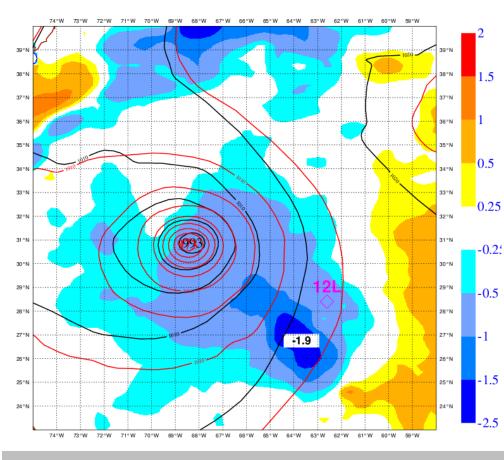


## **Coupled ocean and atmosphere - impact Hr Leslie (12L)**



Each line represents an individual TC track ENS member (colours change every 24h forecast) The individual tracks suggest a very slow moving storm during the first days The HiRes analysis shows a too deep storm between 6 and 8<sup>th</sup> September

## **Coupled ocean and atmosphere (cont...)**



Control: operational T639 (constant SST anomaly)

Experiment: coupled oceanatmosphere model

contours: MSLP (hPa) shaded: SST (K) difference (Exper-Ctrl)

Minimum Central Pressure: 993 hPa (Experiment) 973 hPa (Control)



Use & interpretation of ECMWF products, Feb 2013

03 Sep 12 UTC

+120h VT: 08 Sep 12 UTC

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

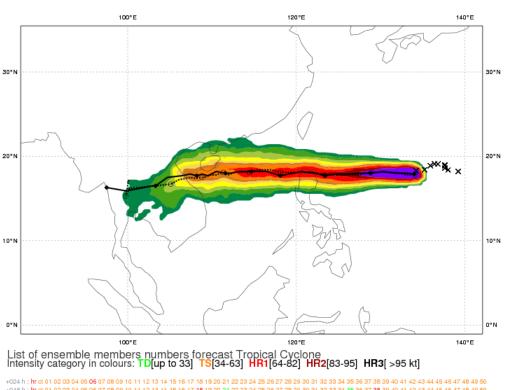
80-90

70-80

#### Date 20110929 00 UTC @ECMWF

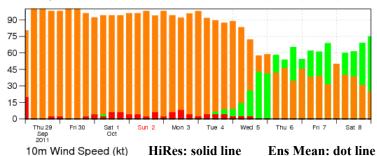
Probability that **NALGAE** will pass within 120 km radius during the next **240** hours tracks: **solid**=OPER; **dot**=CTRL [reported minimum central pressure (hPa) **980** ]

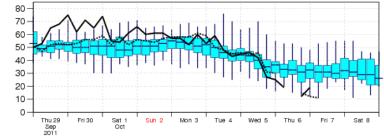
5-10 10-20 20-30 30-40 40-50 50-60 60-70



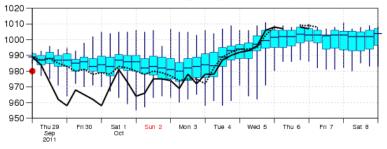
08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 28 29 30 31 32 33 hr ct 01 02 03 04 05 06 07 08 09 10 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 36 37 38 40 42 43 44 45 46 47 48 49 50 +168 h 12 13 14 15 16 17 18 40 49 50 13 14 16 17 27.28 46 47 13 14 28 30 32 40 46 47 50 01 02 03 14 28 30 32 46 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]





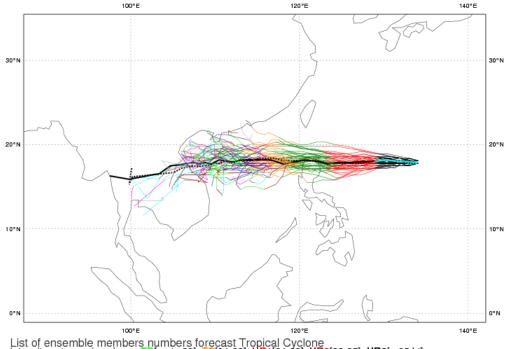
Mean Sea Level Pressure in Tropical Cyclone Centre (hPa)





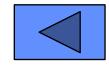
## **New TC product – Plume Plot**

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]

r ct 01	02 03	04 05	06 07	7 08 (	09 10	0.11	12	13	14	15 1	6 1	7 18	19	20.2	1 22	2 23 1	24 25	526	27 2	28.2	9 30 3	1 32	33 3	4 35	36	37 3	8 39	40	41.4	12 43	3 44	45	46 4	7 48	149	50
r ct 01	02 03	04 05	06 07	7 08 (	09 10	11	12	13	14	15 1	6 13	7 18	19	20 2	12	2 2 3 1	24 2	5 26	27 2	28.2	9 30 3	1 32	33 3	4 35	36	37 3	8.39	40	41.4	12 4/	3 44	45	46.4	7 48	49	50
r ct 01	02 03	04 05	06 07	7 08 (	09 10	11	12	13	14	15 1	6 13	7 18	19	20.2	1 22	2 23 3	24 25	526	27 2	28.2	9 30 3	1 32	33 3	4 35	36	37 3	8.39	40	41.4	12 4/	3 44	45	46.4	7 48	49	50
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& 10 & 11 & 21 & 31 & 41 & 51 & 61 & 71 & 81 \\ cc & 0 & 10 & 20 & 30 & 40 & 50 & 60 & 70 & 80 & 91 & 01 & 11 & 21 & 31 & 41 & 51 & 61 & 71 & 81 \\ cc & 10 & 10 & 20 & 30 & 40 & 50 & 60 & 70 & 80 & 91 & 01 & 11 & 21 & 31 & 41 & 51 & 61 & 71 & 81 \\ cc & 10 & 10 & 20 & 30 & 40 & 50 & 60 & 70 & 80 & 91 & 01 & 11 & 21 & 31 & 41 & 51 & 61 & 71 & 81 \\ cc & 10 & 10 & 20 & 30 & 40 & 50 & 60 & 70 & 80 & 91 & 01 & 11 & 21 & 31 & 41 & 51 & 61 & 71 & 81 \\ cc & 10 & 10 & 20 & 30 & 50 & 60 & 70 & 90 & 11 & 21 & 31 & 41 & 51 & 61 & 71 & 81 \\ cc & 10 & 10 & 20 & 30 & 50 & 70 & 90 & 12 & 13 & 14 & 51 & 61 & 71 & 81 \\ cc & 10 & 10 & 20 & 30 & 50 & 70 & 90 & 13 & 14 & 16 & 17 & 71 \\ cc & 10 & 20 & 30 & 09 & 13 & 14 & 16 & 71 & 71 \\ \end{array}$	ct 01 0 2 03 0 4 05 0 50 7 08 0 9 10 11 12 13 14 15 16 17 86 19   ct 01 0 2 03 0 4 05 0 5 0 7 08 0 9 10 11 12 13 14 15 16 17 86 19   ct 01 0 2 03 0 4 05 0 5 0 7 08 0 9 10 11 12 13 14 15 16 17 86 19   ct 01 0 2 03 0 4 05 0 5 0 7 08 0 9 10 11 12 13 14 15 16 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& 93 & 03 & 13 & 23 & 33 & 63 & 73 \\ c1 & 01 & 02 & 03 & 05 & 60 & 70 & 91 & 01 & 11 & 13 & 14 & 15 & 16 & 17 & 18 & 19 & 20 & 12 & 22 & 42 & 52 & 62 & 72 & 82 & 93 & 03 & 23 & 58 & 37 & 33 \\ c1 & 01 & 02 & 03 & 05 & 60 & 70 & 91 & 12 & 13 & 14 & 15 & 16 & 17 & 18 & 19 & 20 & 12 & 22 & 42 & 52 & 62 & 72 & 82 & 93 & 03 & 2 & 34 & 53 & 64 & 73 \\ c1 & 02 & 03 & 05 & 60 & 70 & 91 & 12 & 13 & 14 & 16 & 17 & 18 & 92 & 02 & 12 & 22 & 42 & 52 & 72 & 82 & 93 & 32 & 37 & 33 \\ c1 & 01 & 02 & 03 & 05 & 67 & 09 & 13 & 14 & 16 & 17 & 20 & 21 & 22 & 27 & 28 & 30 & 32 & 32 & 37 & 33 \\ c1 & 01 & 02 & 03 & 00 & 91 & 13 & 14 & 16 & 17 & 20 & 21 & 22 & 27 & 83 & 30 & 32 & 32 & 37 & 33 \\ c1 & 01 & 02 & 03 & 00 & 91 & 13 & 14 & 19 & 21 & 22 & 28 & 30 & 32 & 32 & 34 & 35 & 34 & 34 & 34 & 34 & 34 & 34$	cl 01 0 2 03 0 4 05 0 6 07 08 0 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 13 23 33 44 55 36 37 88 39   cl 01 0 2 03 0 4 05 0 6 07 08 0 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 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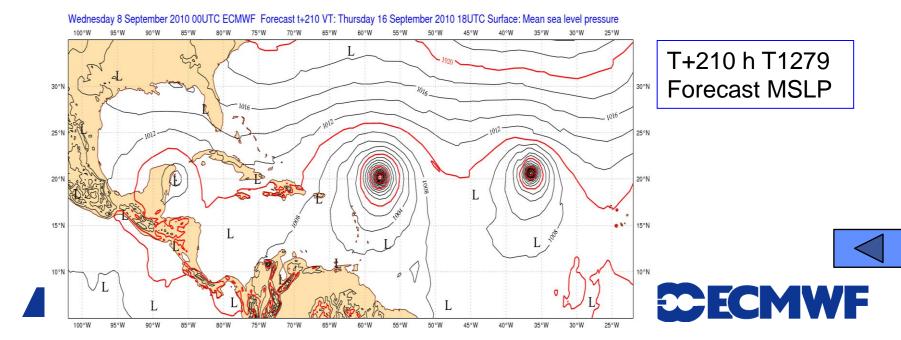


**ECMWF** 

## **Forecast period of enhanced Hurricane Activity, 9 days ahead**



Goes-East visible image 16 September 18 UTC



## **Forecast performance**

- The forecast performance for TCs is checked regularly and compared with the previous years for the Global HRES model and ENS. The results are reported to the Technical Advisory Committee every year.
- Mean position error for HRES, Control models and ENS mean
- Mean intensity error (ME)
- Mean speed error (ME) for HRES
- Reliability and ROC for the Strike Probability Products
- ENS Spread & EM Error

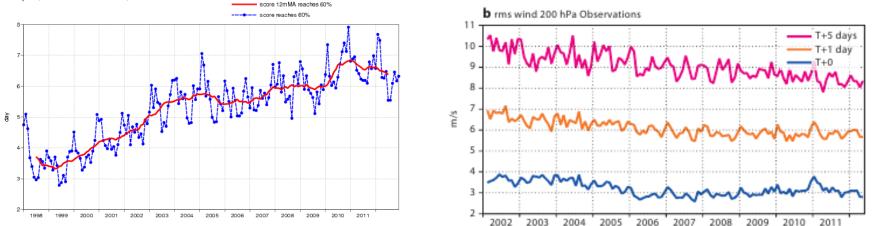


## Lead Time of ACC 60% winds 850 hPa RMS winds 200 hPa (against observations)

ECMWF deterministic 00,12UTC forecast skill

850hPa vector wind

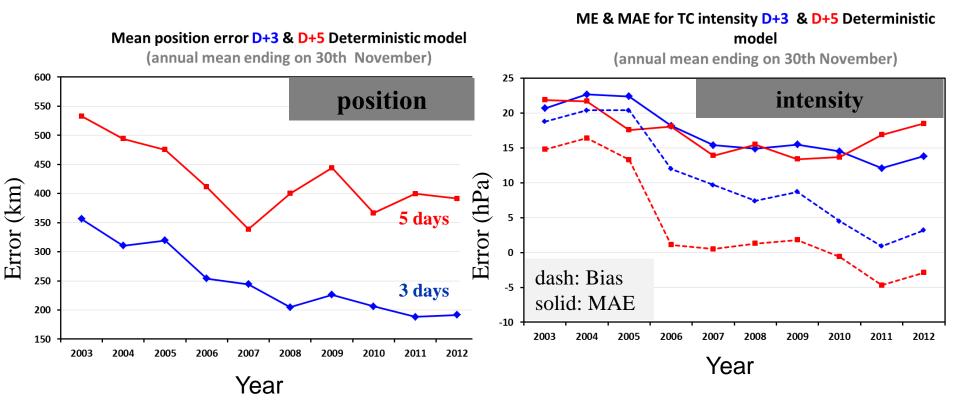
Lead time of Anomaly correlation reaching 60% Tropics (lat -200 to 20.0, lon -180.0 to 180.0)



A performance gain of ~2.5 days since early 2000 for winds at 850 hPa



## Verification HRES (12 month means ending on 30 November)



Error = Forecast – Obs Obs from the best track reports



#### **TC verification by Hong Kong observatory Other NWP Centres**

- 2011 verification results
- ECMWF is clearly best model
- ECMWF is comparable to or better than the multi-centre ensemble mean ("NWP ensemble")

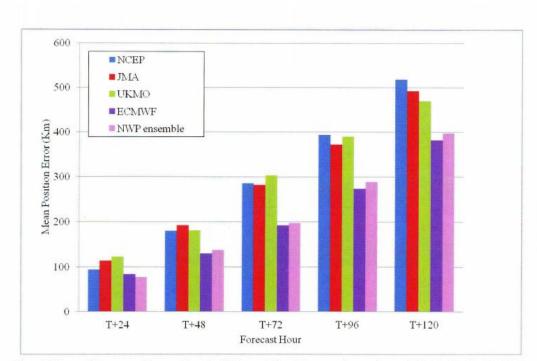


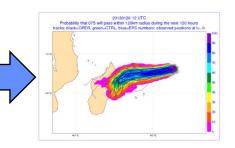
Figure 7. Mean position errors of forecasts from the NWP ensemble and the respective member models for T+24 to T+120 in 2011.

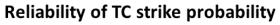




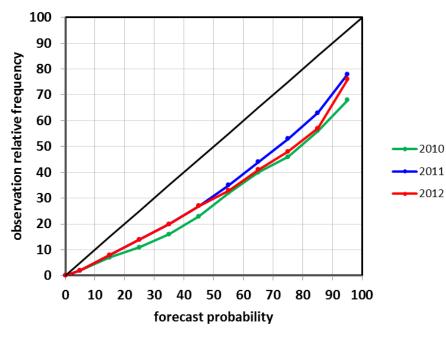


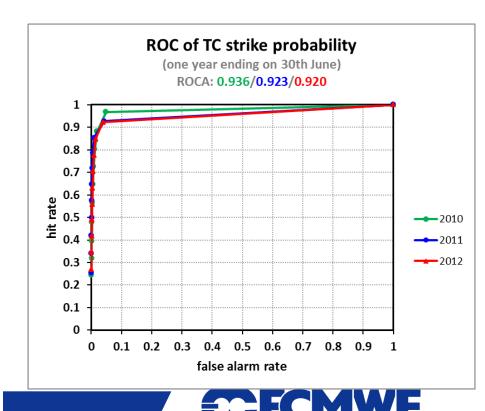
Strike probability of TC within 120 km in the next five days





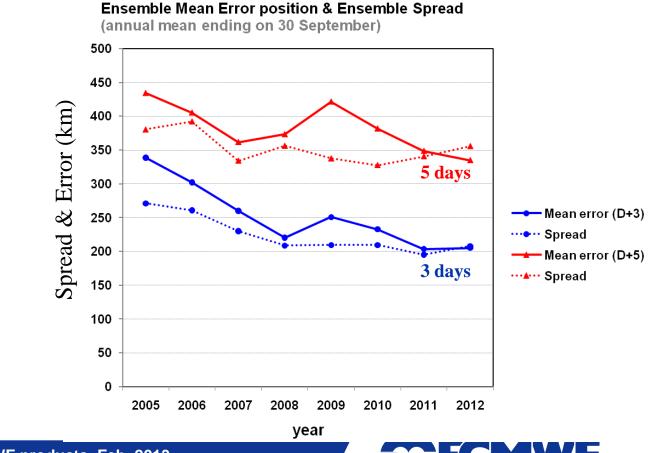
(one year ending on 30th June)





## **ENS SPREAD & EM ERROR**

A calibrated ENS should provide consistency between the error and spread.



# **QUESTIONS**?

