Forecasting Tropical Cyclones in the Medium Range

Fernando Prates

Evaluation Section

ECMWF

# Forecasting Tropical Cyclones in the Medium Range

Fernando Prates

Meteorological Operations Section

ECMWF

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 improvements in recent years

ECMWF

Impacts

Use & interpretation of ECMWF products, Oct 2013
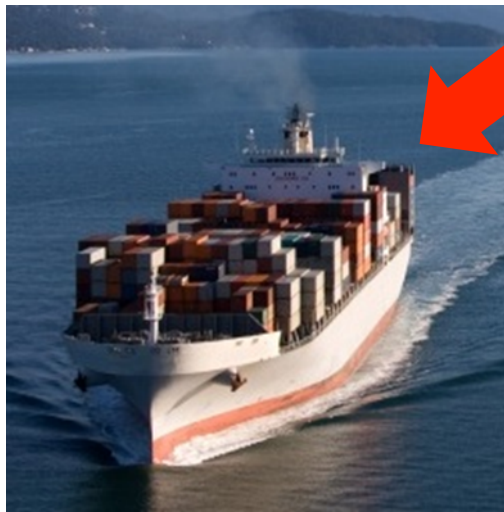
Hurricane impact

➢ 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.*

➢

CCECMWF

Conditions for TC development

➢ Form over the oceans where SST > 26°C

➢ Tropical cyclones "do not" develop within 3° off 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

ECMWF

Recent model developments...impact in the TC forecast performance

Impact on the ability to analyse and forecast Tropical Cyclones:

- Increase of model horizontal and vertical resolution ⓘ

- 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 **more recently** the implementation of Ensemble Data Assimilation ⓘ

- Soon:

  - *The atmosphere-ocean coupling of the ENS will be active from initial time of the forecast using a new version of the NEMO ocean model (cy40r1)*

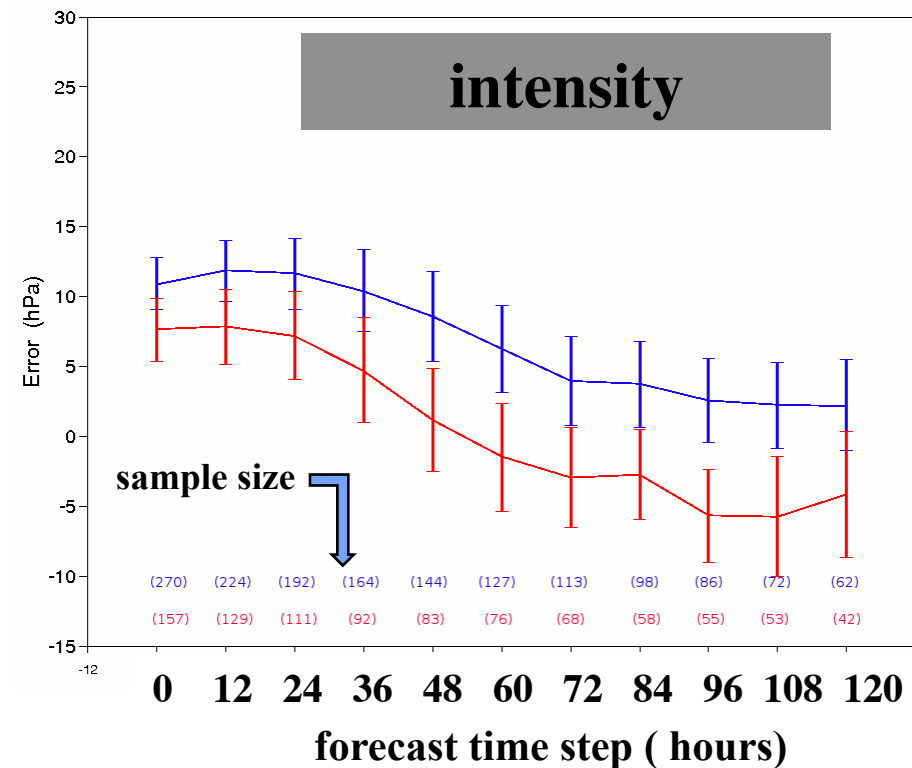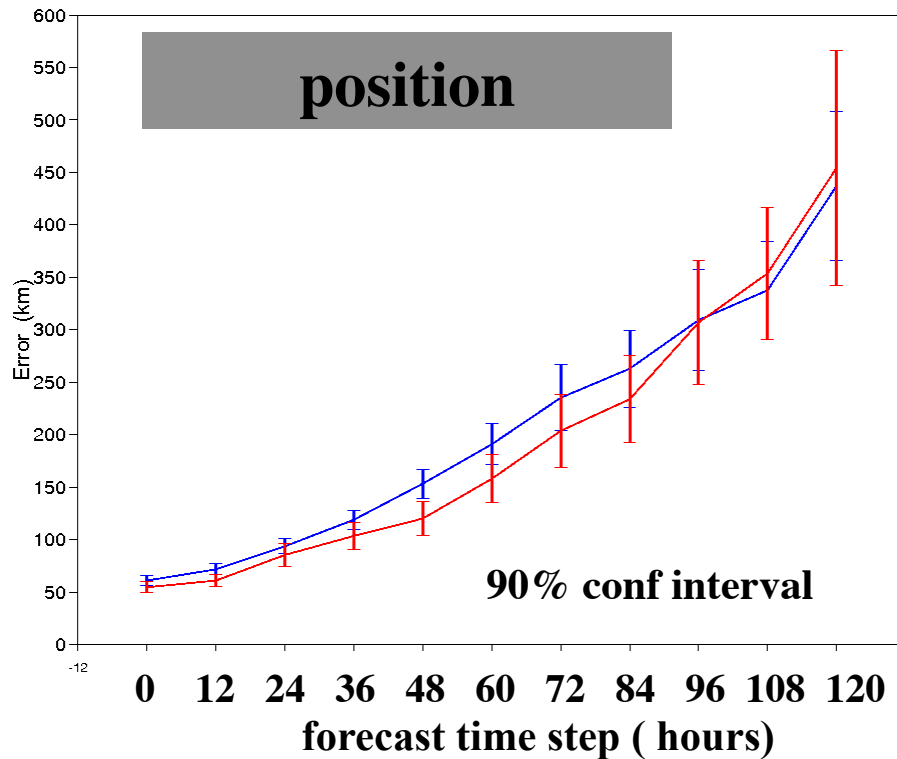….. At ECMWF there is no artificial bogus vortex scheme for TCs. We allow the observations to do their job …..

Click me to jump to the next slide ▶

⊂⊃⊂ECMWF

TC forecast performance T799 v T1279
(~25 km)   (~16 km)

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

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

position

90% conf interval

intensity

sample size

| (270) | (224) | (192) | (164) | (144) | (127) | (113) | (98) | (86) | (72) | (62) |
| (157) | (129) | (111) | (92) | (83) | (76) | (68) | (58) | (55) | (53) | (42) |

forecast time step (hours)

forecast time step (hours)

Error = Forecast – Obs
Obs from the best track reports

CECMWF

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

OPER (35r2)

T799 /980hPa

(35r3) Use of improved QC (Huber norm)

961hPa
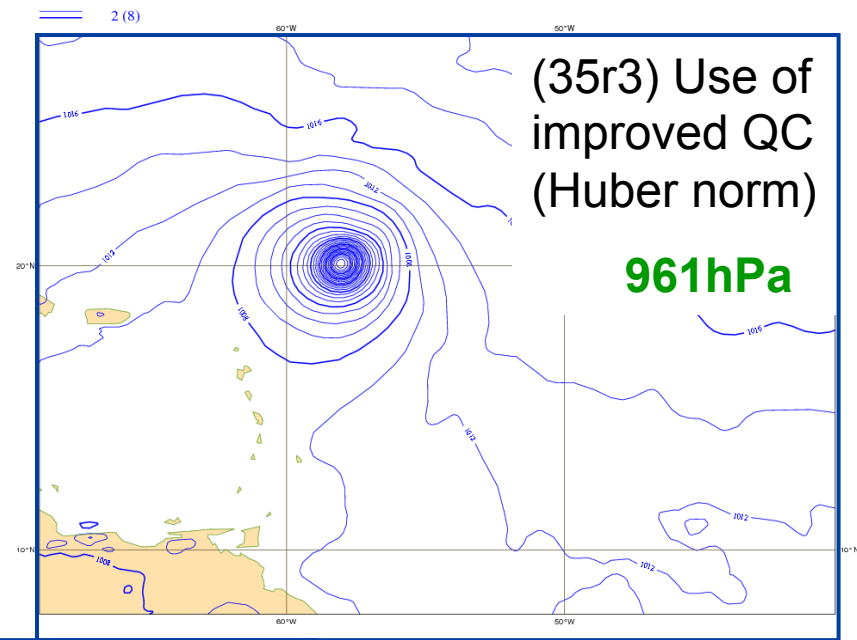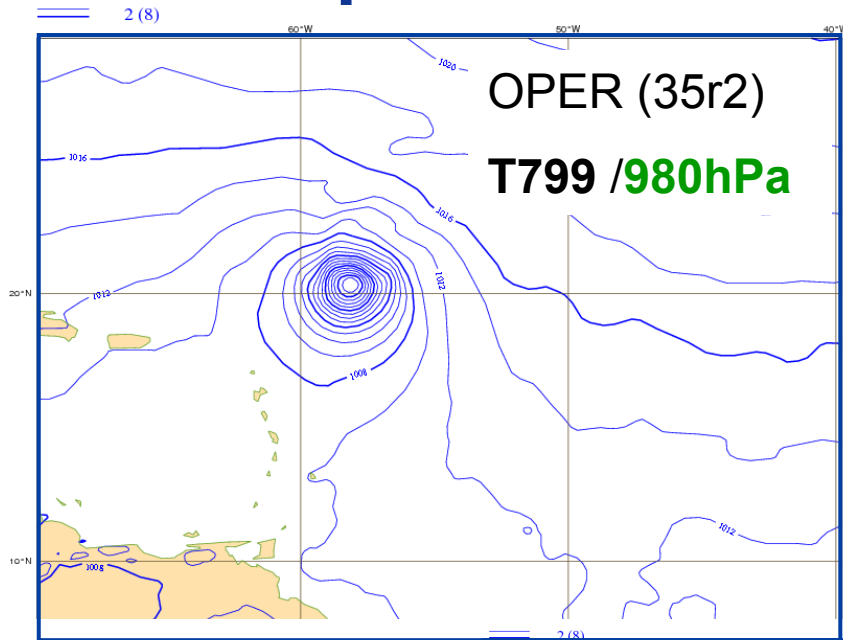
Hurricane Bill,

20 Aug. 2009

Observed MSL pressure~**944hPa**
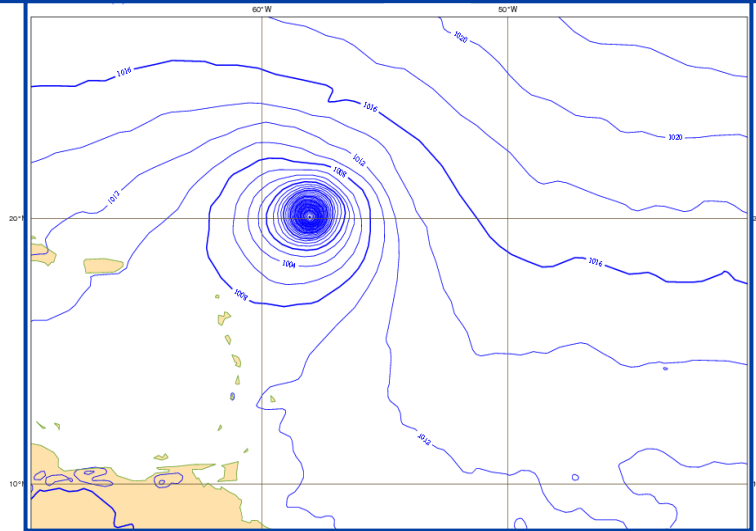
(36r1) High-res system T1279+T159/T255/T255

945hPa

ECMWF

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

Error = Forecast – Obs
Obs from the best track reports

2002-03
2011-12

Larger number of weak TCs

Bins (5 hPa)
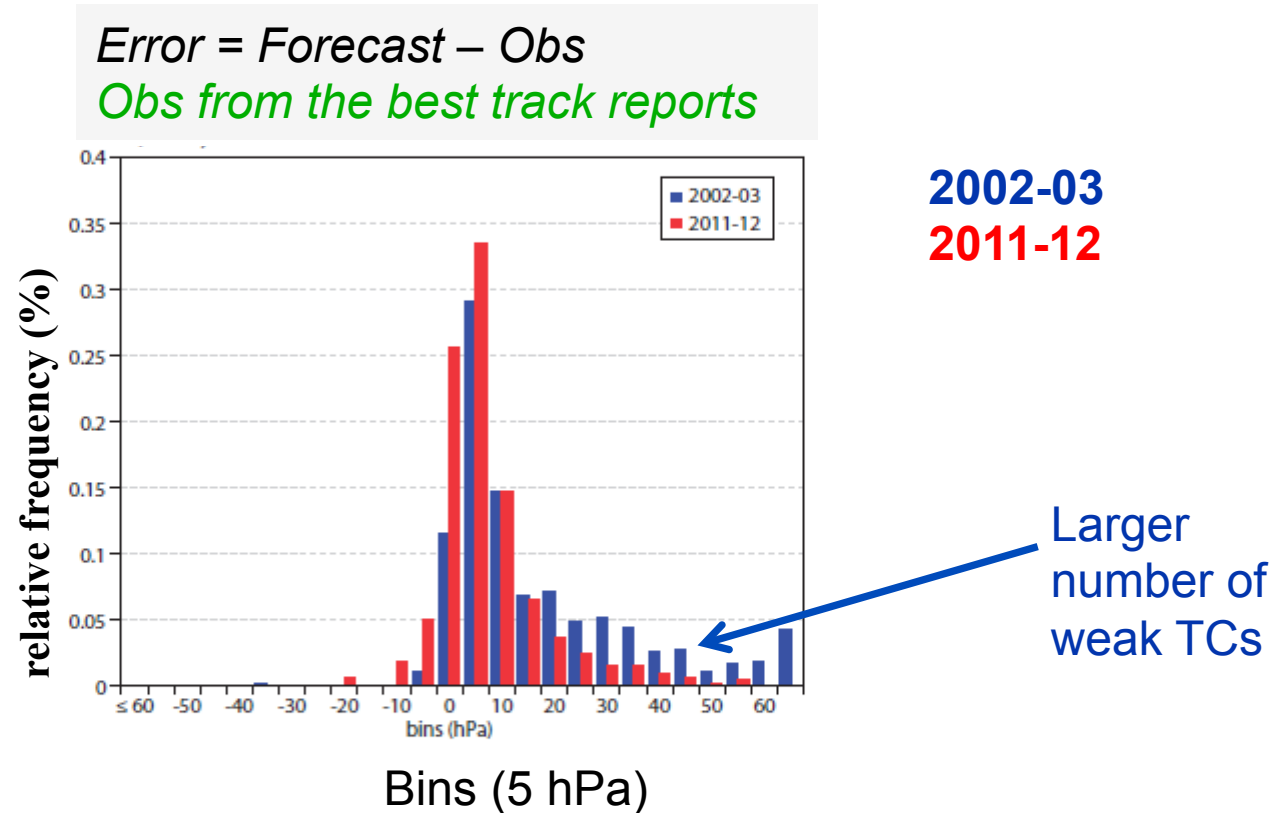
Strong reduction of the errors largely attributed to new observation systems in DA and an increase of model resolution
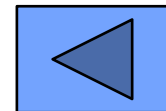
ECMWF

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)

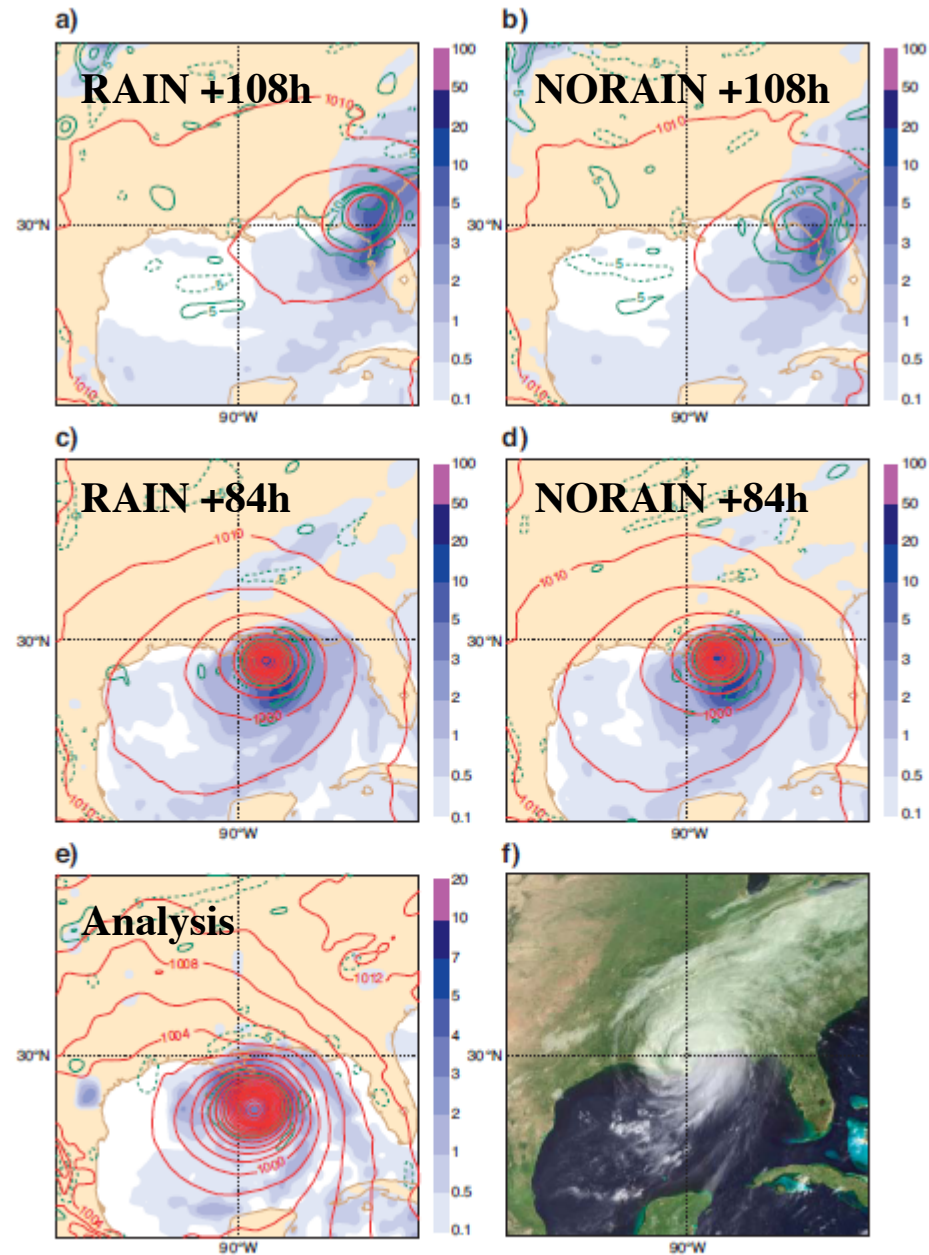**Deeper system and larger accumulated rainfall quantities**

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.
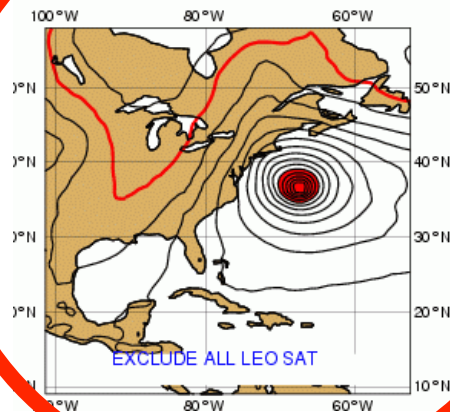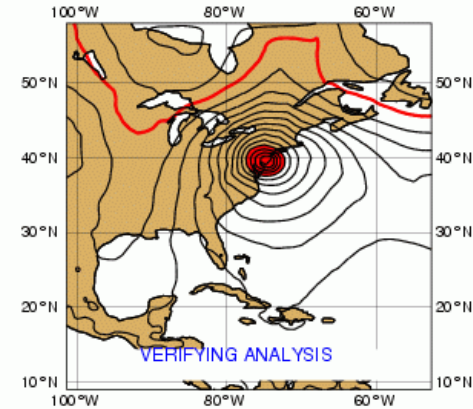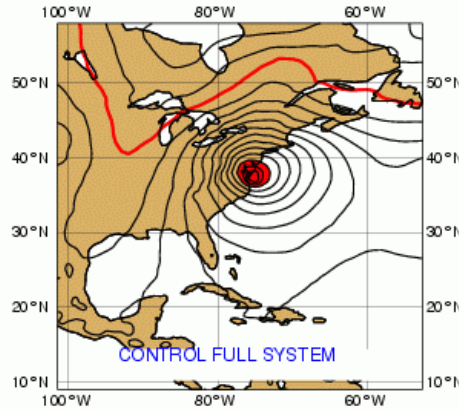
Date 20121023 12 UTC @ECMWF
Probability that **SANDY** will pass within 120 km radius during the next **240** hours
tracks: **solid**=OPER; **dot**=Ens Mean [reported minimum central pressure (hPa) **997**]

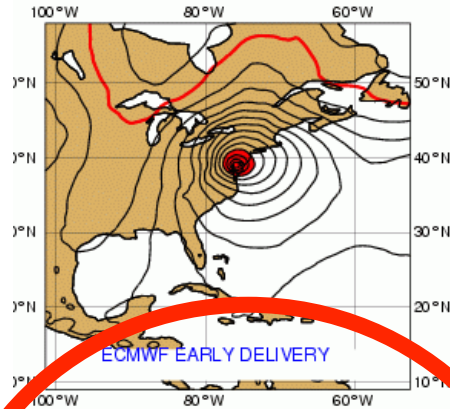5-10 10-20 20-30 30-40 40-50 50-60 60-70 70-80 80-90 > 90 %

Date 20121023 12 UTC @ECMWF
Probability that **SANDY** will pass within 120 km radius during the next **240** hours
tracks: **solid**=OPER; **dot**=Ens Mean [reported minimum central pressure (hPa) **997**]

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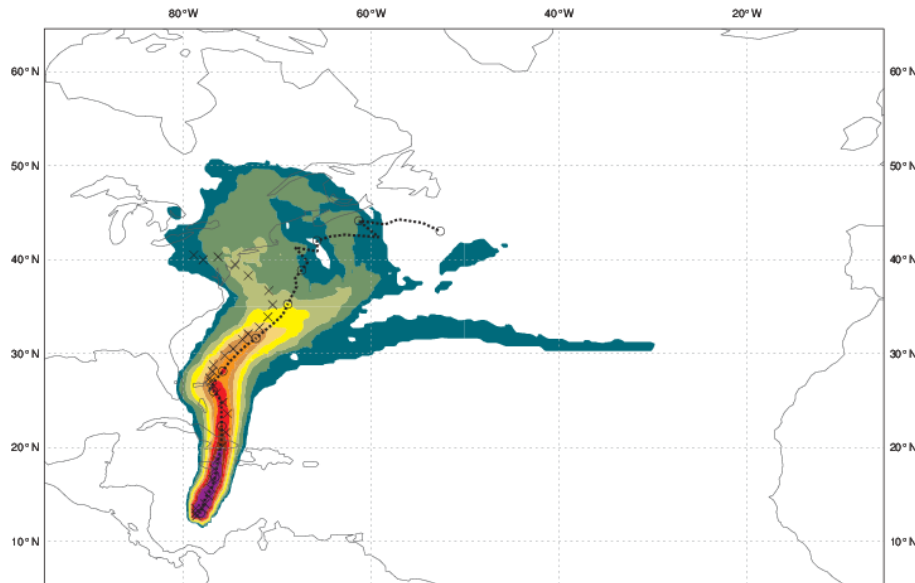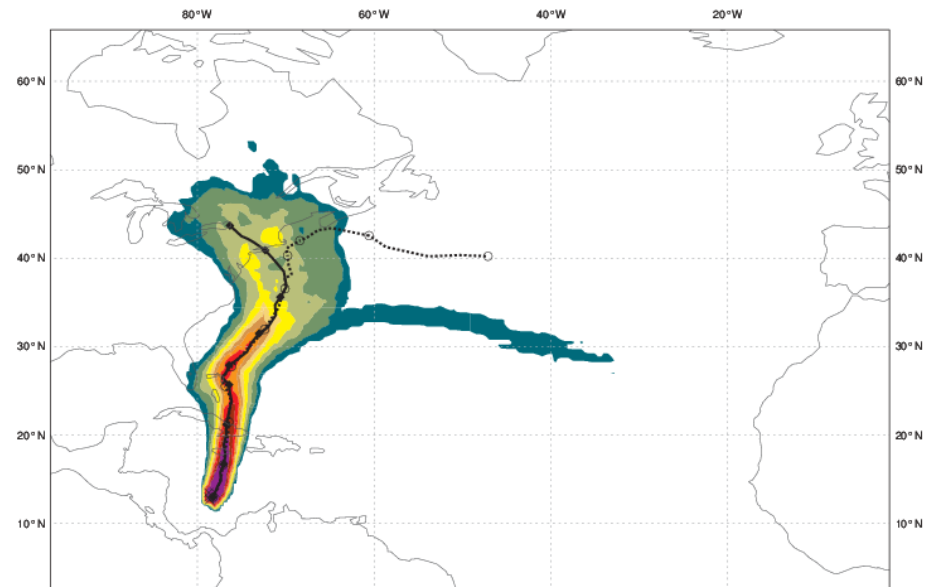
ECMWF

Forecast verification 18L SANDY Oct 2012

ECMWF EARLY DELIVERY

CONTROL FULL SYSTEM

VERIFYING ANALYSIS

EXCLUDE ALL LEO SAT

- **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 25th

(Tony McNally, ECMWF Newsletter No 134 - Winter 2012/13)
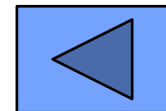
Ensemble Data Assimilation (since 22nd June 2010)
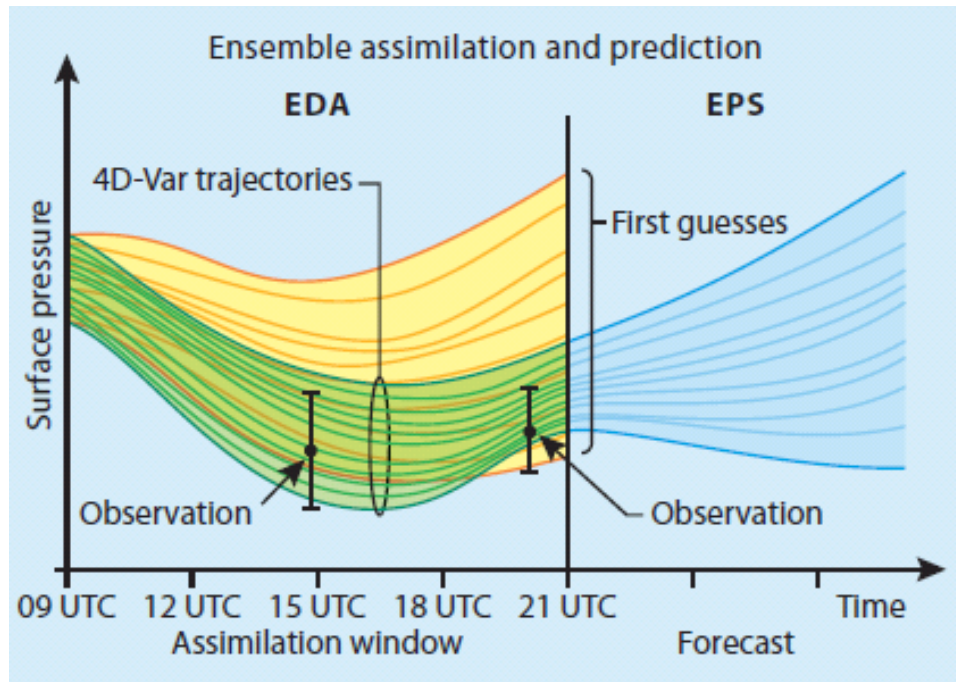
EDA first guesses trajectories

Analysis of trajectories

Observations (w/ error bars)
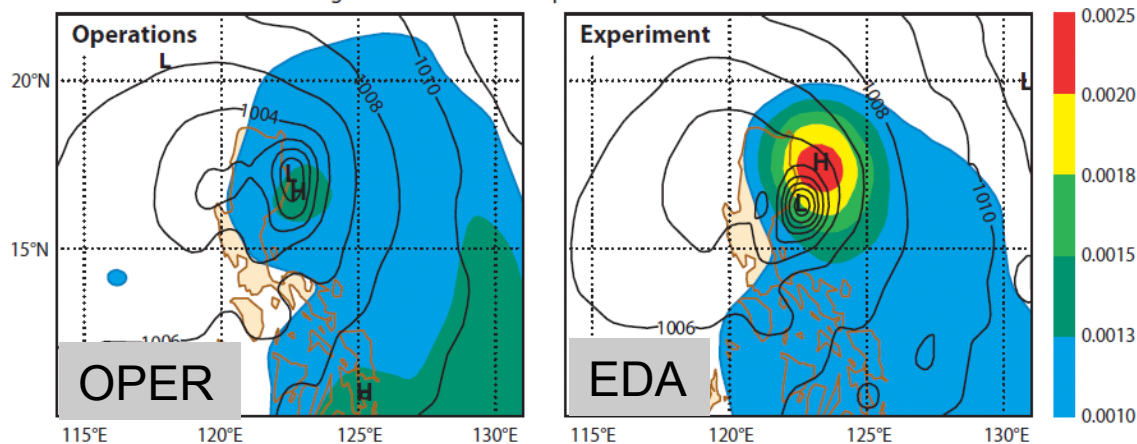
EDA is used to provide
1. **Background error info for the analysis**
2. **Initial perturbation of the EPS**
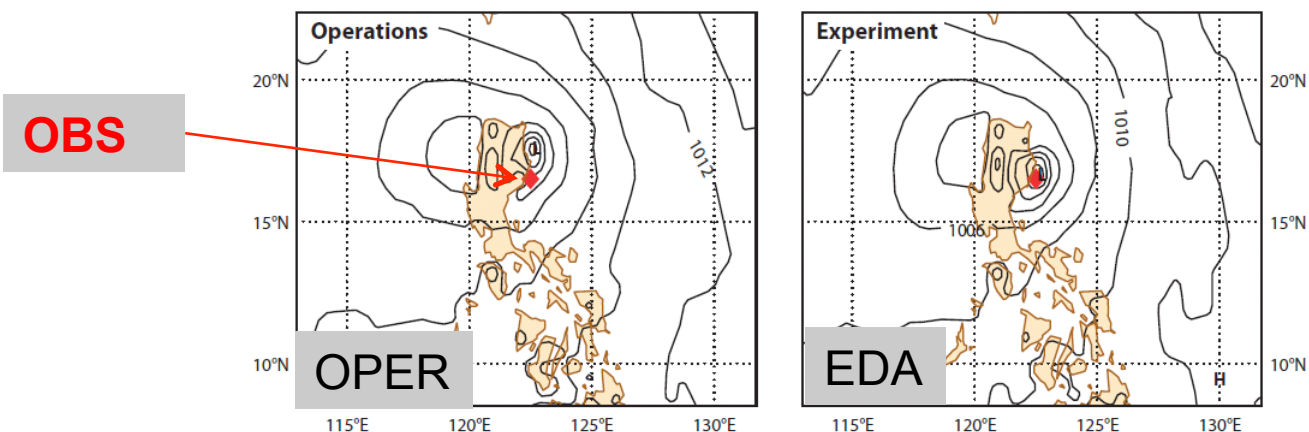
ECMWF

Impact of replacing evolved SV by EDA perturbations

contours: mslp (hPa)

shade: spread of Log mslp

OBS

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

➤ **Technical changes in operational suite allow the TC tracking information from deterministic model to be disseminated 1 hour earlier (since June 2011).**

ECMWF

ECMWF TC Tracker – How it works

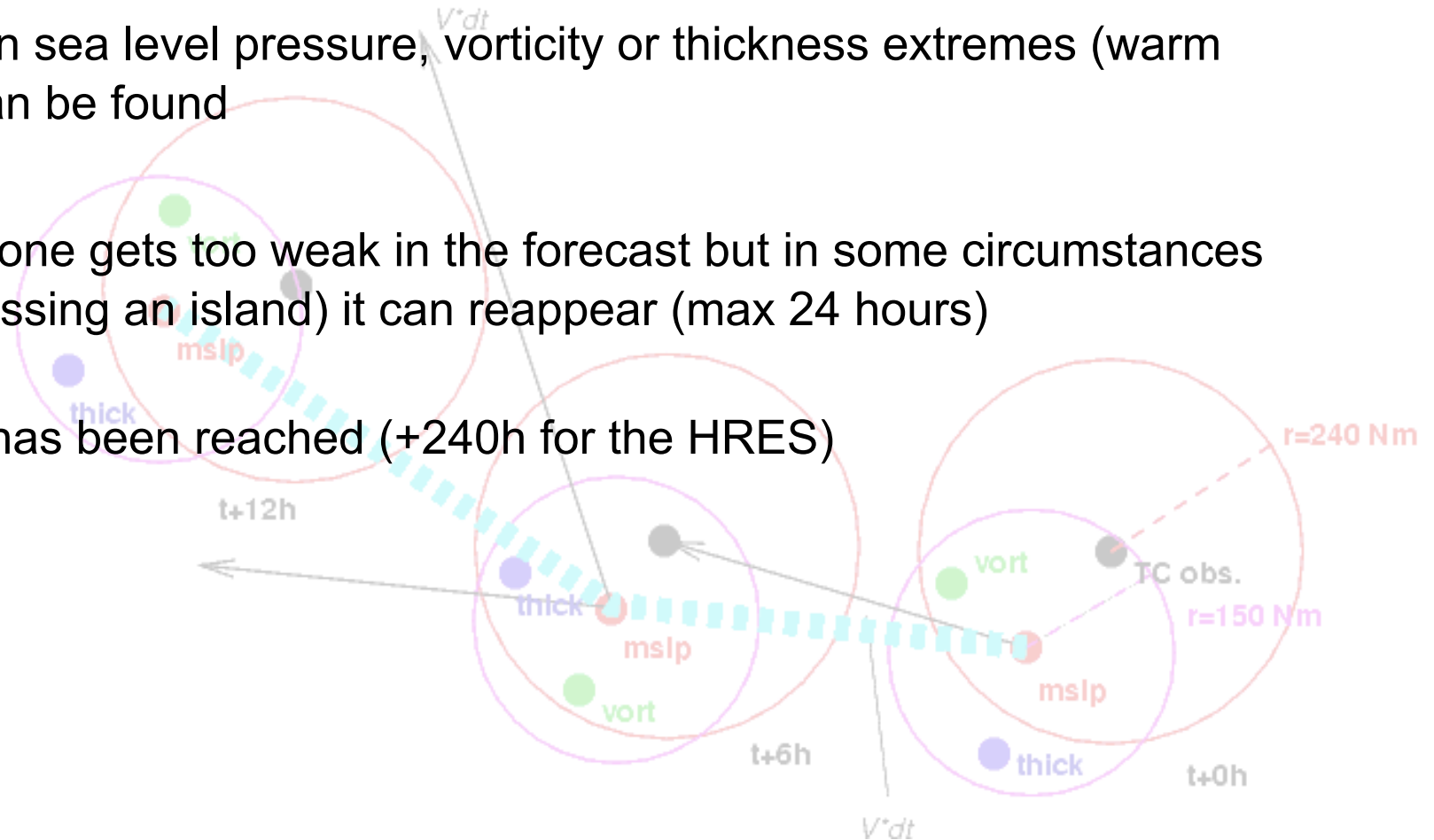vort 850hPa   *V* 850,700,500,200 hPa

warm core 500-200 hPa
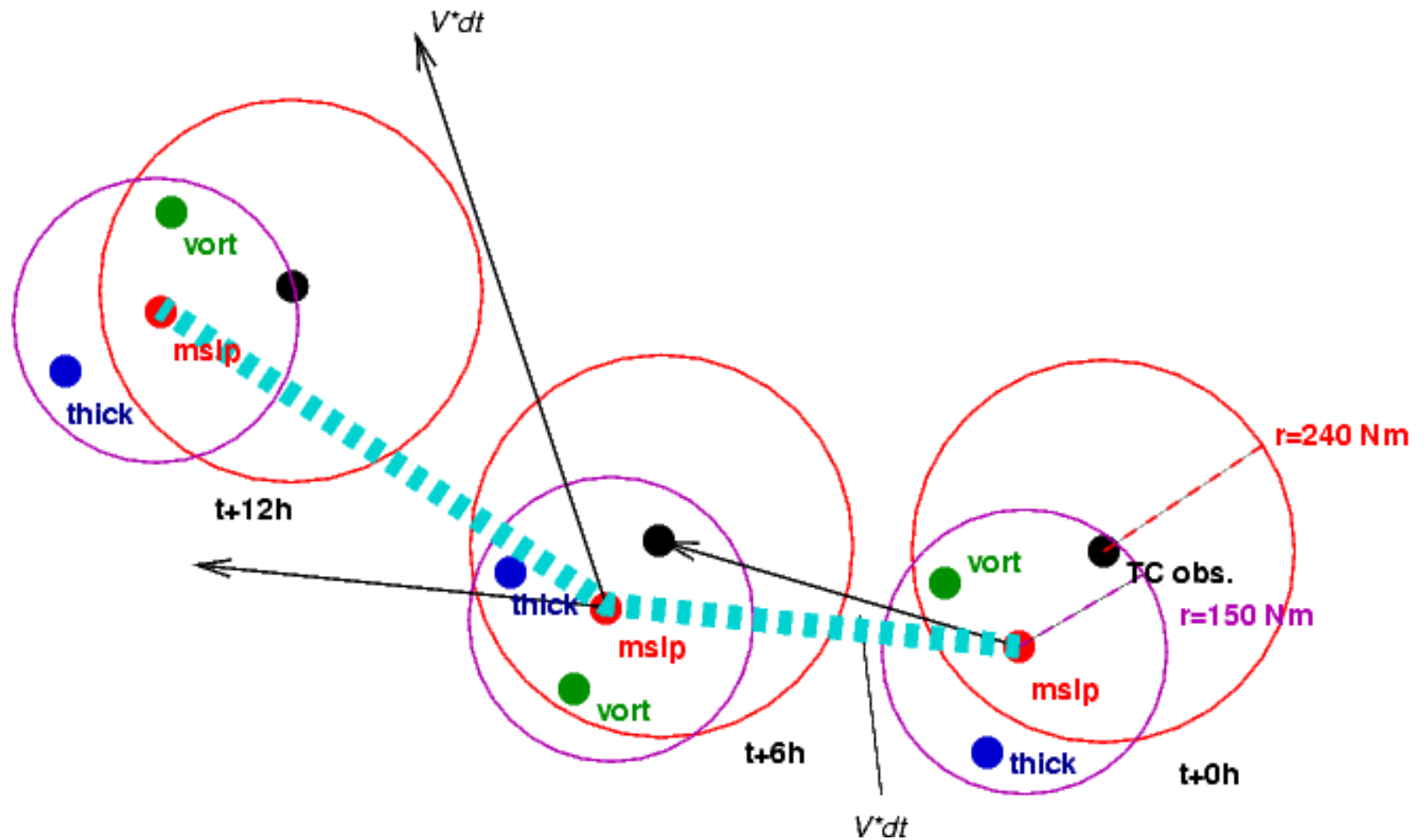
ECMWF TC Tracker – How it works

The tracker will stop if…

- no mean sea level pressure, vorticity or thickness extremes (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 model

ECMWF

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/**
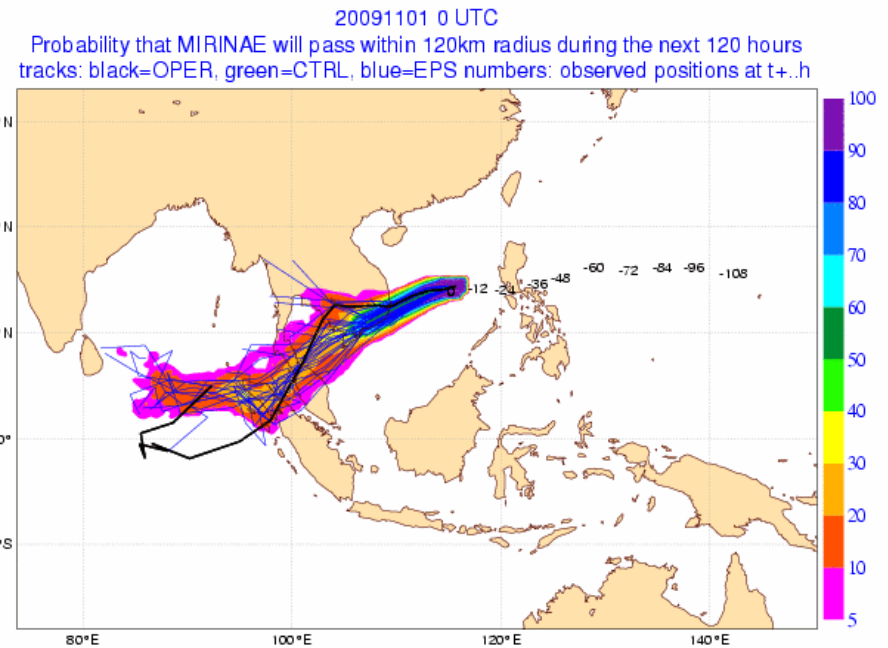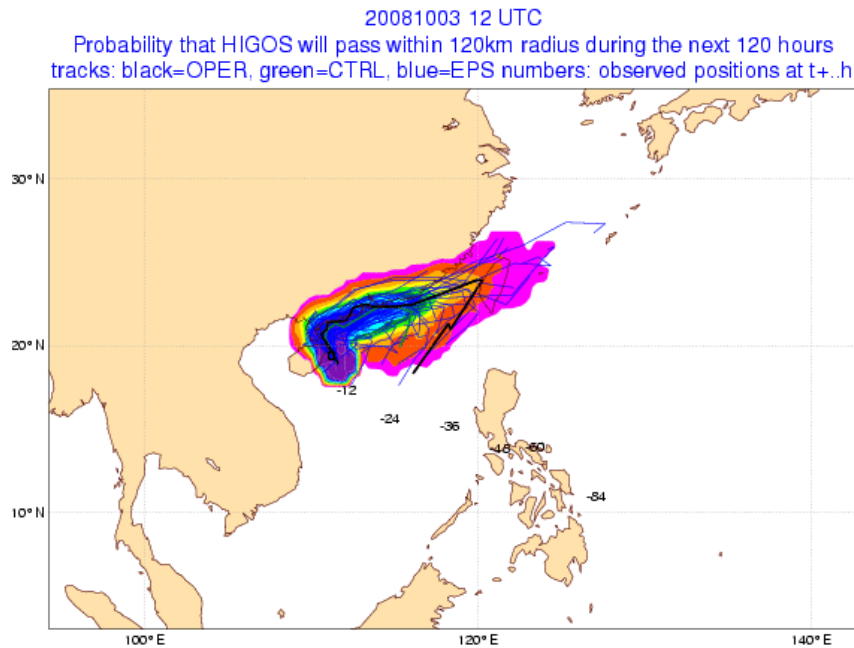
Click me to jump to the
next slide
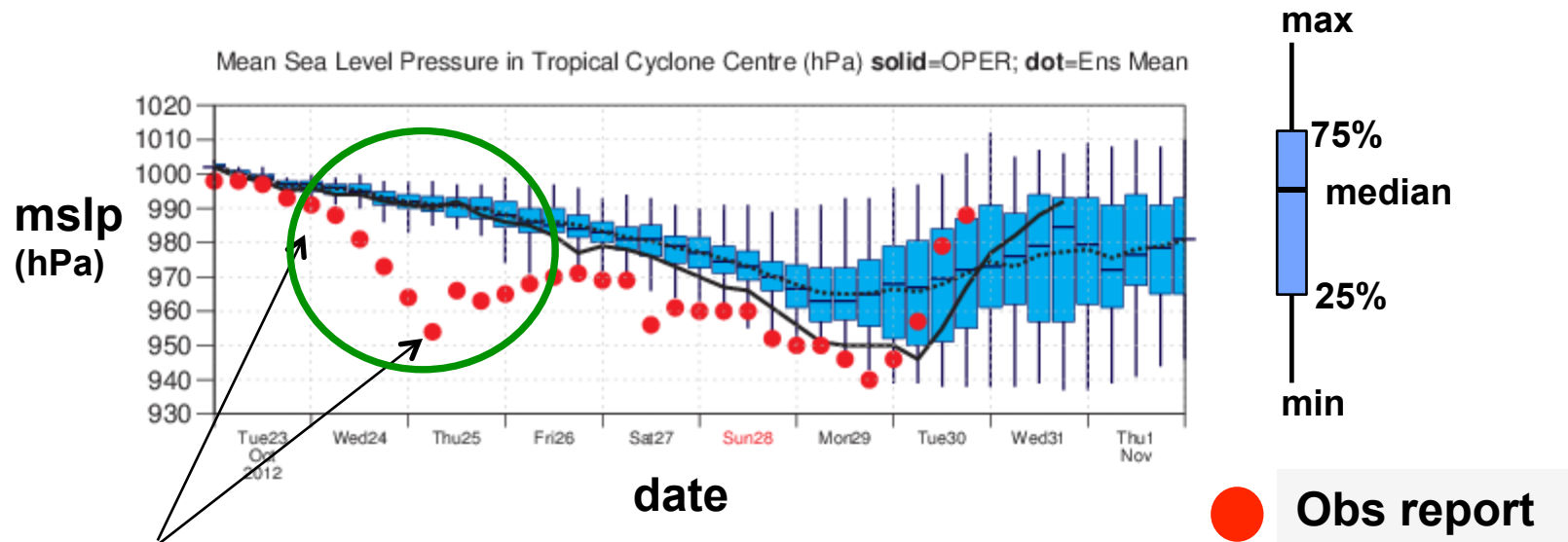
ECMWF

Tracking spurious features during the forecast Examples

20081003 12 UTC
Probability that HIGOS will pass within 120km radius during the next 120 hours
tracks: black=OPER, green=CTRL, blue=EPS numbers: observed positions at t+..h

20091101 0 UTC
Probability that MIRINAE will pass within 120km radius during the next 120 hours
tracks: black=OPER, green=CTRL, blue=EPS numbers: observed positions at t+..h

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

ECMWF

TC intensity forecast

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

HR Sandy (18L)

Mean Sea Level Pressure in Tropical Cyclone Centre (hPa) **solid**=OPER; **dot**=Ens Mean

Rapid intensification
~40 hPa in 30 hrs

CCECMWF

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

Run 05@00   ● reported obs   Run 06@00

0-24h 24-48h 48-72h 72-96h 96-120h 120-144h

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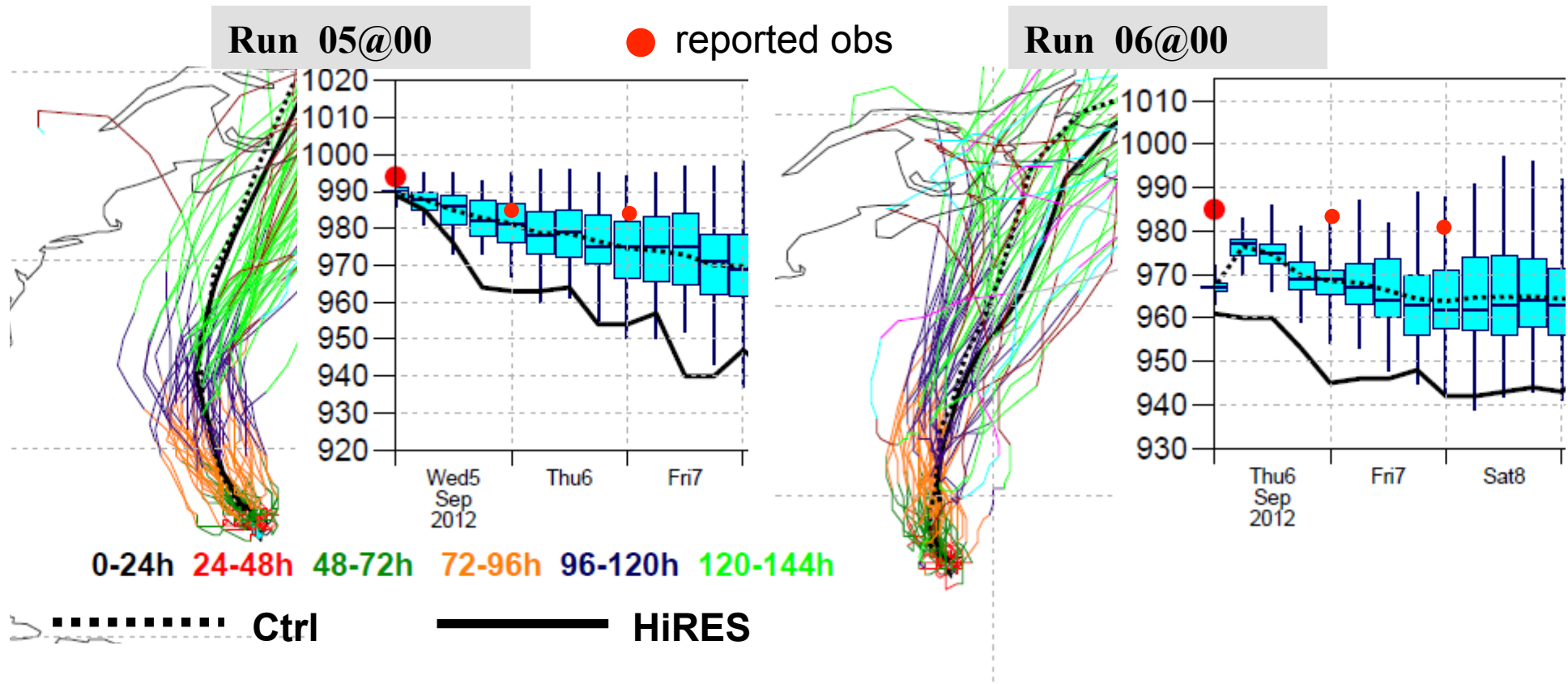
Each line represents an individual TC track ENS member (colours change every 24h forecast)
The individual tracks suggest a very slow moving storm during the first days
The HiRes analysis shows a too deep storm between 6 and 8th September

ECMWF

Coupled ocean and atmosphere (cont...)
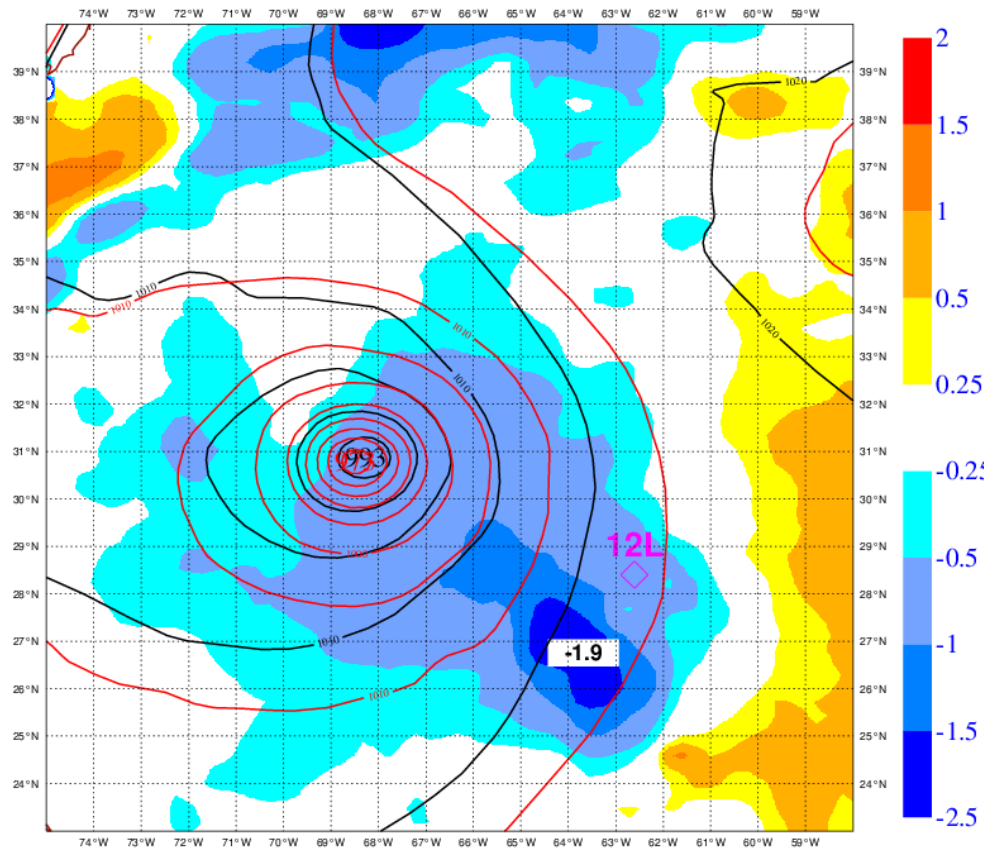
Control: operational T639 (constant SST anomaly)

Experiment: coupled ocean-atmosphere model

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

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

03 Sep 12 UTC   +120h VT: 08 Sep 12 UTC

ECMWF

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 %

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)

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]

ECMWF

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]

Forecast period of enhanced Hurricane Activity, 9 days ahead

GOES-EAST VISIBLE - SEP 16 10 18:45 UTC
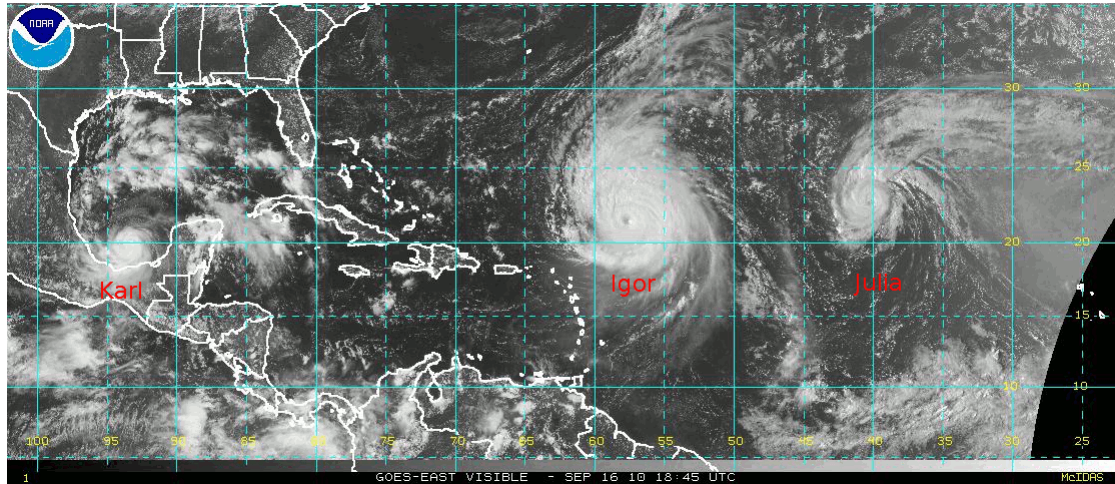
Goes-East visible image
16 September 18 UTC

Wednesday 8 September 2010 00UTC ECMWF Forecast t+210 VT: Thursday 16 September 2010 18UTC Surface: Mean sea level pressure
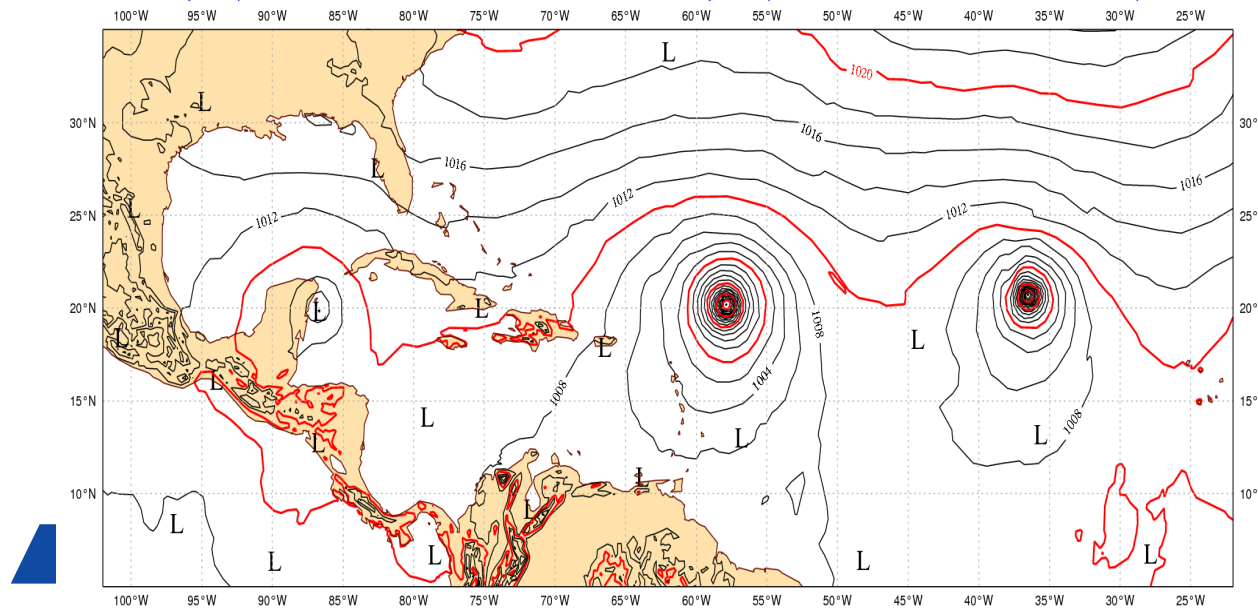
T+210 h T1279 Forecast MSLP

Tropical Cyclone Activity Medium Range EPS

Selected forecast steps covering the next 12 days

Maps: global view and 7 additional TC basins

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

Strike probability for TC/TS/HR

Forecast runs covering the last 10 days
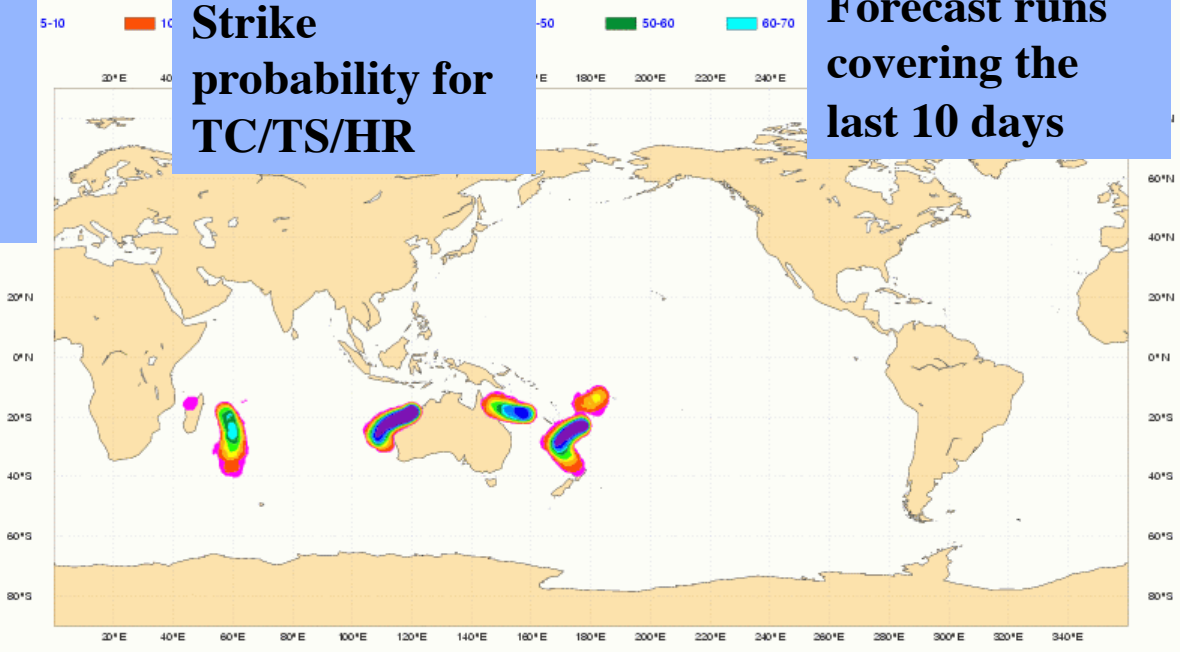
Forecast performance

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

ECMWF

Lead Time of ACC 60% winds 850 hPa
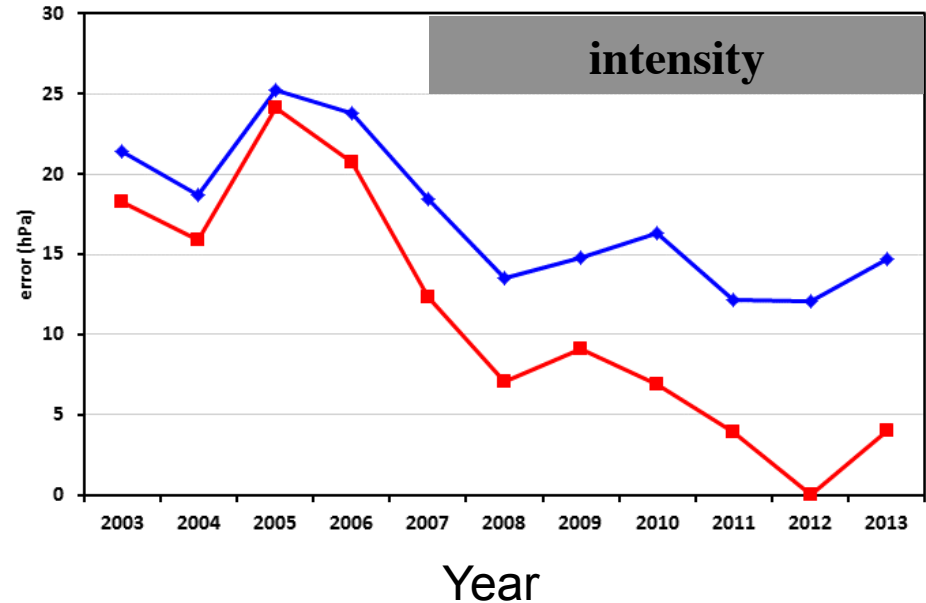# RMS winds 200 hPa (against observations)
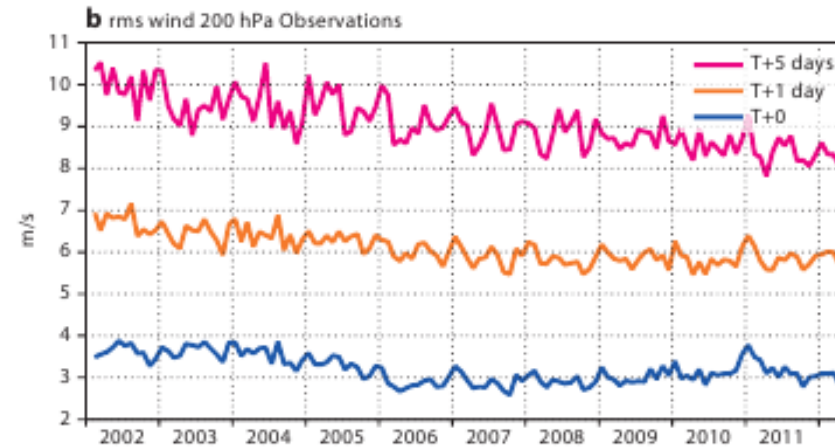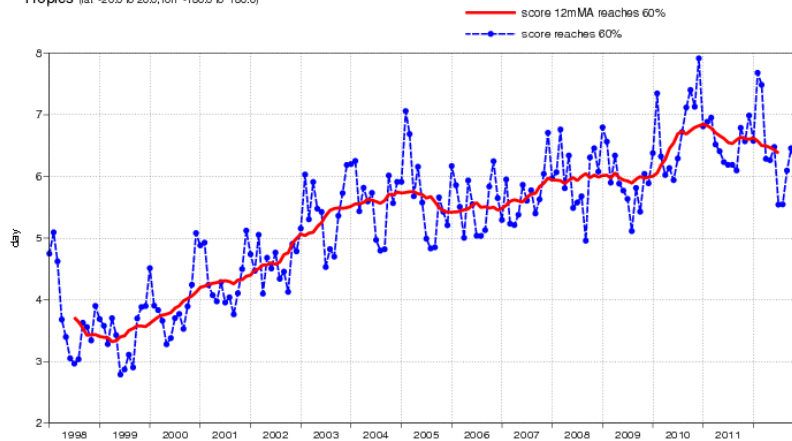
A performance gain of ~2.5 days since early 2000 for winds at 850 hPa

Verification HRES (12 month means ending on 30 November)

Mean position error D+5 & D+3 Deterministic model
(annual mean ending on 30th June)

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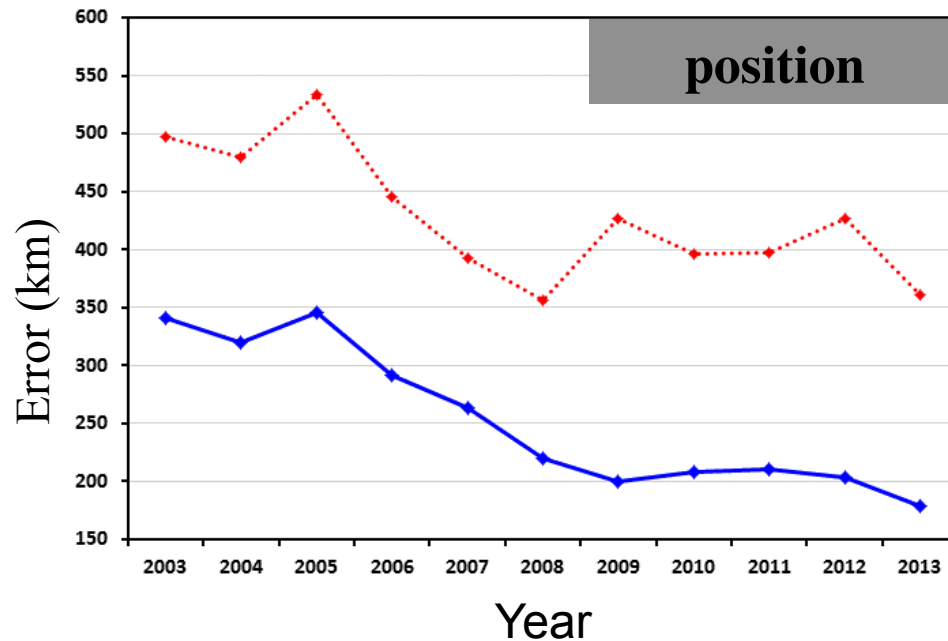
Mean absolute intensity & Bias error D+3 Deterministic model
(annual mean ending on 30th June)

intensity

Error = Forecast – Obs
Obs from the best track reports

ECMWF

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")**
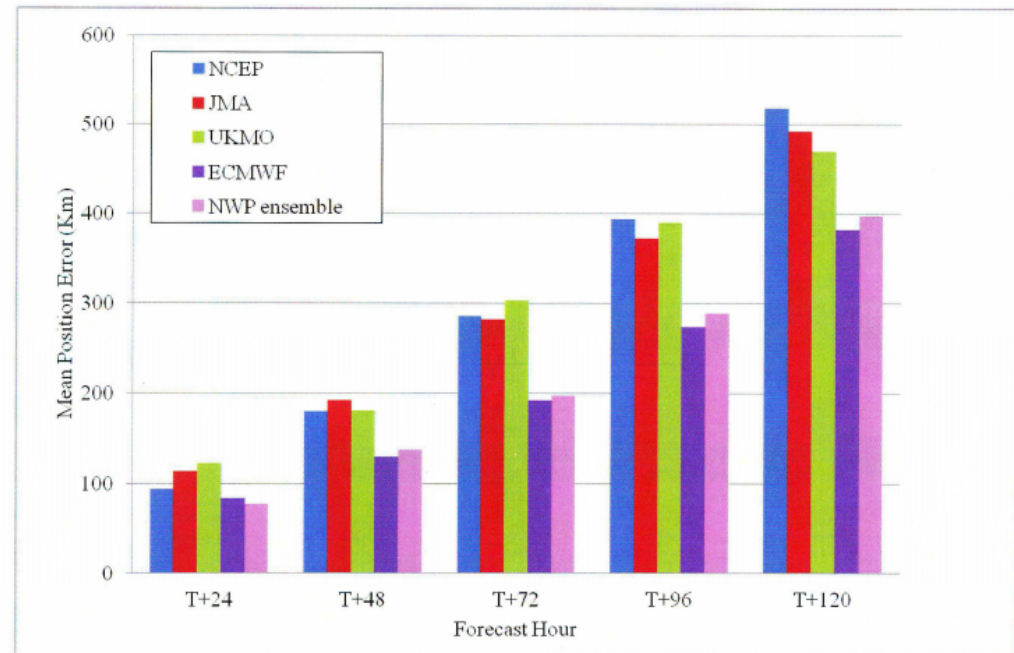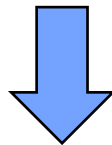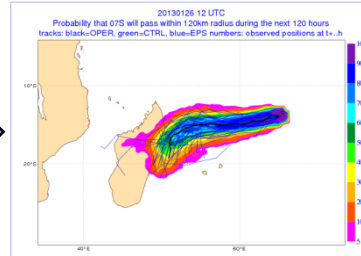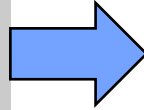

Figure 7. Mean position errors of forecasts from the NWP ensemble and the respective member models for T+24 to T+120 in 2011.
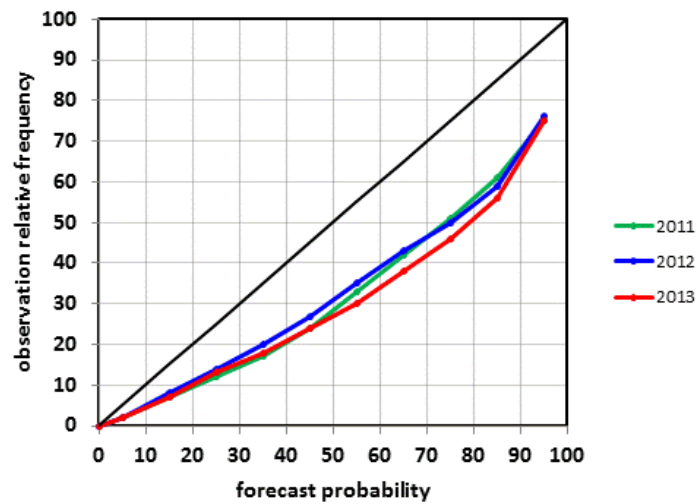
14

ECMWF

ENS Skill

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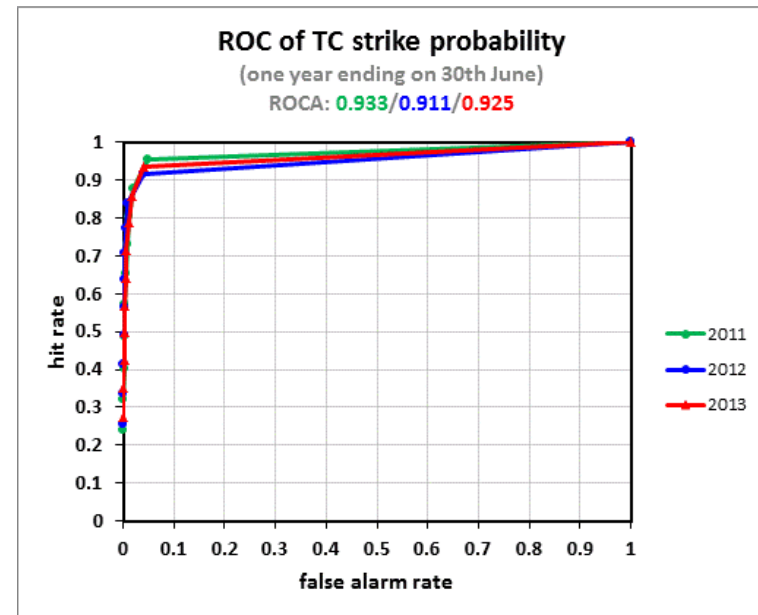

Reliability of TC strike probability
(one year ending on 30th June)
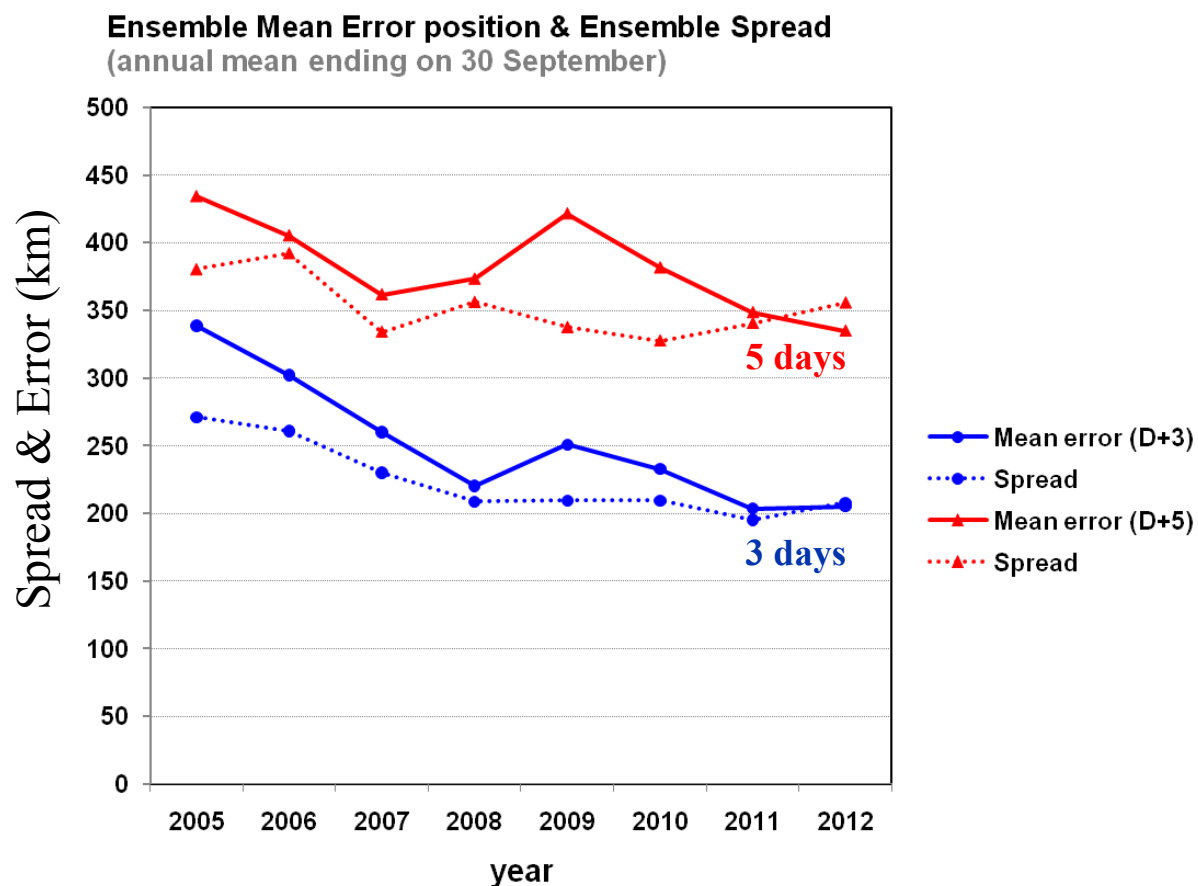

ROC of TC strike probability
(one year ending on 30th June)
ROCA: 0.933/0.911/0.925

CECMWF

ENS SPREAD & EM ERROR

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

Ensemble Mean Error position & Ensemble Spread
(annual mean ending on 30 September)

QUESTIONS?

ECMWF