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New tropical cyclone products on the web

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New tropical cyclone products on the web

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The ECMWF tropical cyclone (TC) products are designed to provide probabilistic information to the users. Those products comprise, amongst others, the strike probability forecast of a TC up to 5 days ahead based on data from the Ensemble Prediction System (EPS) and seasonal forecasts of the tropical storm activity.

The continuous development of the forecasting systems at ECMWF has improved the ability to predict the formation of TCs in the medium and extended ranges. Following user requests, a new range of products has been designed to display TC activity (including genesis) throughout the EPS forecast range up to a month ahead. The tracking of existing (named) TCs has been extended from 5 to 10 days into the forecast. The TC identification and tracking algorithms for all forecast ranges have been unified (up to now medium-range and seasonal forecasts used different tracking software). In addition, technical changes made last July allow the TC track forecasts for the deterministic model to be disseminated about one hour earlier than previously.

This article introduces the new products and illustrates these with some examples. Also some results concerning the verification of TC forecasts during the testing period are presented. The dissemination of the new TC products is planned to commence in the first quarter of 2012.

Tropical cyclone tracker

Previously, TC products at ECMWF included only the prediction of tracks of TCs already present in the initial conditions for the medium-range deterministic and EPS (*van der Grijn et al.*, 2005) forecasts and for seasonal forecasts of tropical storm activity (*Vitart et al.*, 2007). These two products used different TC trackers.

It is desirable to have a single TC tracker at ECMWF for predictions at various time ranges (medium-range, monthly and seasonal) and for various types of products (genesis location and tropical cyclone track). Consequently a new tracker has been developed which is a combination of the previous two trackers – see Box A for more details. All the TC products described in this article use this new tracker.

Tropical cyclone products for existing storms

Whenever a tropical cyclone is observed and is present in an EPS forecast, a set of products is generated automatically using the observed position reported via the Global Telecommunications System (GTS) in near real time. The current TC products are being replaced at ECMWF. To date, these products are available from the web at:

- http://nwmstest.ecmwf.int/products/forecasts/d/tccurrent

The next generation of products includes the extension of the tracking and strike probability maps from 5 to 10 days ahead and probabilistic information of the storm intensity. The definition of a TC 'strike' was introduced by the National Weather Service in early 1980s (Sheets, 1985): a strike occurs whenever the centre of a storm moves through an area represented by a circle with radius of 62.5 nautical miles. An approximate threshold (120 km) has been used to construct the strike probability maps at ECMWF since 2003. This is computed using the EPS forecast tracks which are present in the forecast up to 10 days.

Strike probabilities and tracks

Figure 1 shows the strike probability map for Irene from the 10-day EPS forecast from 00 UTC on 22 August, one day after being named a tropical storm. The high-resolution model (T1279) and the ensemble mean tracks are represented by solid and dotted lines respectively, with the symbols placed at 24-hour intervals. With this type of information the forecaster gets valuable guidance of the timing of a hit, especially for the storm to make landfall at a particular location. The forecaster might also want to look at the full set of tracks as well as the derived strike probabilities.

Figure 2 shows the individual tracks based on the same forecast as depicted in Figure 1. The tracks are identified with different colours at 24-hour intervals to emphasize the uncertainties of the motion of the storm with forecast lead time. This can be particularly useful when landfall is expected to occur at a particular location.

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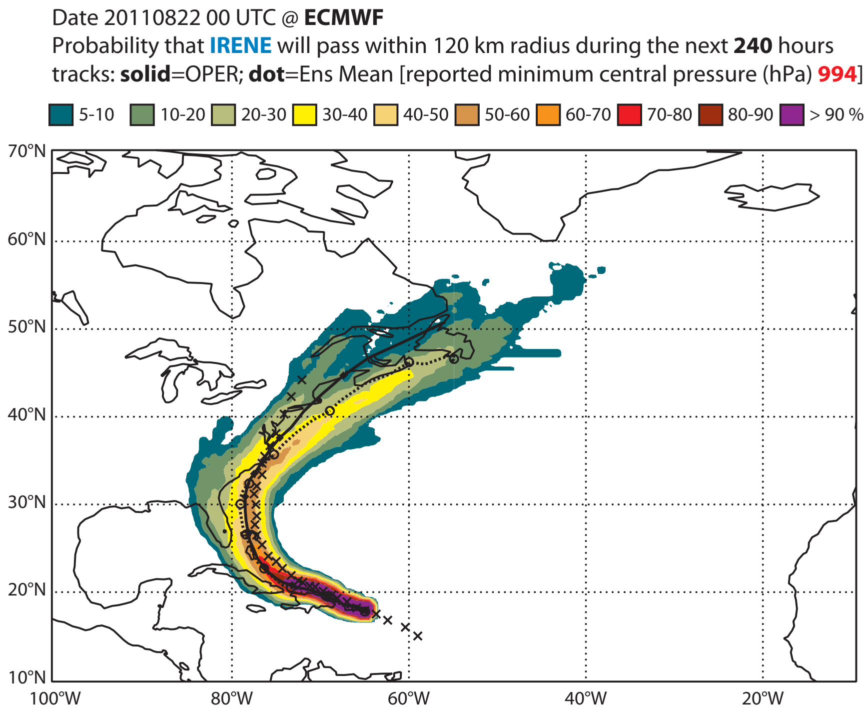

Figure 1 Strike probability (%) that TC Irene will pass within 120 km for the next 10 days for the EPS forecast starting at 00 UTC on 22 August 2011. The lines correspond to T1279 (solid) and ensemble means (dot) tracks with symbols placed at 24-hour intervals. Cross symbols correspond to observed positions of hurricane Irene during the same period.

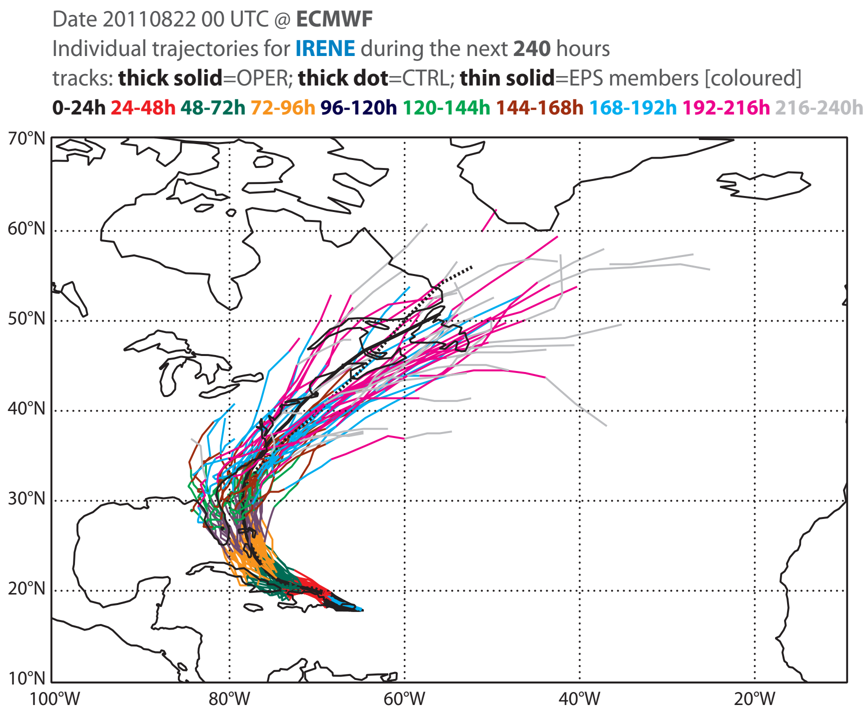

Figure 2 As Figure 1 but for the individual tracks from the EPS for TC Irene using various colours to indicate tracks over 24-hour intervals out to 240 hours. Black lines represent the T1279 (solid) and T699 control (dot) model tracks.

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The new tracker

A

At ECMWF, the medium-range prediction of tropical storm tracks has used the tracker described in *van der Grijn et al.* (2005) to detect features with characteristics of TCs in the analysis and forecast whenever a storm is observed. However, the seasonal forecasts of tropical storms are based on the *Vitart et al.* (1997) algorithm, which not only identifies low pressure systems, but also checks the presence of a warm core above the centre of the storm in the upper troposphere. The presence of a warm core is an important criterion, particularly for genesis detection, since it helps to distinguish tropical cyclones from extra-tropical cyclones.

In order to have a single TC tracker at ECMWF for predictions at various time ranges and for various types of products, the *Vitart et al.* (1997) tracker has been modi- fied so that the detection of cyclones for each model time step remains the same as before. But the trajectory building now uses the same algorithm as in *van der Grijn et al.* (2005), which was more accurate than the one that was used in *Vitart* (2007). Therefore, the new tracker is a combination of the previous two trackers and can be used for seasonal forecasting as well as for the medium- range. For the deterministic forecast and EPS, the maximum wind speed criteria for a tropical storm are set to 17 m/s as for observations, but the criterion is set to a lower value for seasonal forecasts (about 13 m/s) because of the lower horizontal resolution of System 4, the seasonal forecasting system.

This tracker is applied to model output every 6 hours and allows a tropical cyclone to 'disappear' for 24 hours (a tropical cyclone may weaken for a short period of time when crossing an island for instance). The presence of a warm core is required only once during the full tropical cyclone lifetime, so that the trajectory contains the early part of the life of the cyclone, when it is a tropical depression, and also the later part (extra-tropical transition, after landfall). This tracker can detect any tropical storm that develops during the forecast even though it might not be present in the initial conditions. To be detected a storm needs to be present for a minimum of two time steps. The tracker is applied to each individual EPS and seasonal forecast member.

Ensemble members

To have a clear perception how the EPS forecast is handling the feature during the forecast, a list of the EPS members in which the storm was tracked, together with intensity, can be viewed at 24-hour intervals. An example is shown in Figure 3 for Irene. The first column indicates the forecast interval; subsequent columns show the intensity for the high-resolution 'hr' and EPS control 'ct' forecasts followed by the list of ensemble members. They are coloured according to one of the five predefined intensity categories: tropical depression, tropical storm, and hurricane categories 1, 2 and 3. The attribution is made using the maximum 10-metre wind speed assigned to each member. If the storm disappears from the forecast a blank space replaces the number of the member in that list. Those gaps are not necessarily permanent. Note that the storm is missing in members 6 and 37 at 192 hours but not at 216 hours. This behaviour is quite common in the new tracker because it can stop and then restart the tracking of the same feature some hours later in the forecast, under specific circumstances (see the main characteristics of the tracker described in Box A).

Despite of the continuous improvement in the EPS forecasts in the last few years, the ensembles still have difficulties representing rapid intensity changes. This could be explained by the lack of spatial resolution and description of the inner-core processes in TCs (long-term statistics for intensity forecast errors show differences between the high-resolution and EPS control models with the later showing worse results). Even so, the current forecast system offers a far better distribution of the intensity probability when compared with the previous model configurations.

Intensity probabilities

With the new TC product, it is feasible to represent the uncertainty of strength of a TC during the forecast especially when a rapid development is under way. The intensity probability forecast represents the number of EPS members falling into five predefined categories (as described earlier), each one having equal weight.

Figure 4 shows the probability of storm intensity forecast at 6-hour intervals up to 10 days for hurricane Irene. The most likely category is 'tropical storm' for the whole forecast period. Note that there is a small chance of Irene becoming 'hurricane 1' force on 27 August, which coincides with landfall of the storm accordingly to the position from the ensemble mean (see Figure 1).

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

Figure 3 Numbers of ensemble members that tracked TC Irene at 24-hour intervals up to 10 days based on the same EPS forecast used for Figures 1 and 2. Each ensemble number is coloured accordingly with the strength of the storm in the forecast at the same time intervals.

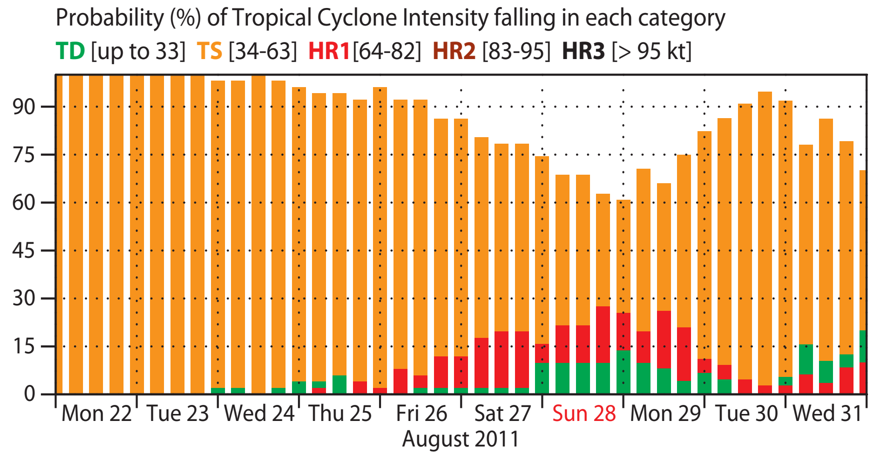

Figure 4 Intensity probability forecast (%) for TC Irene for the next 10 days based on the same EPS forecast used for Figures 1, 2 and 3. The landfall was predicted to occur during 27 August.

Other developments

The traditional Lagrangian meteograms (i.e. following the centre of the storm as it moves in the forecast) for the 10-metre wind speed and minimum mean sea level pressure were kept in the new product. However, the time series for the control model was replaced by the ensemble mean in the new meteograms.

The observed TC position and minimum central pressure (when available) are also included in the new TC product. With this the user can have a perception of the position and 'intensity' errors at the analysis time.

Tropical cyclone activity (including genesis)

With the new tracker running (pre)-operationally, a set of new products has been designed to synthesize the information in the EPS forecasts for TCs. These products are available in graphical form at:
- www.ecmwf/products/forecasts/d/charts/medium/eps/genesis/ta_genesis/

for the twice daily EPS integrations.
- www.ecmwf.int/products/forecasts/d/charts/mofc/forecast/tcyc/

for the 32-day extension of the EPS every Thursday and Monday.

Strike probabilities from the medium-range forecasts

Figure 5 shows the strike probability for the occurrence of TCs (storms with maximum wind speeds >8 m/s) that will pass within 300 km of a given location in the two-day period 20–22 August for the EPS medium-range forecast from 00 UTC on 17 August 2011. No observed TCs were present at the analysis time. Using this product, forecasters would immediately notice a very active period predicted for the Caribbean Sea and West Atlantic regions; more than 70% probability that a tropical storm may develop for the next days can be seen over Honduras and the region northeast of the islands of Antigua and Barbuda. Verifying data is shown in the same figure.

Tropical cyclone Harvey formed on 19 August offshore of Honduras and made landfall in Belize the following day, whilst Irene materialized east of the Lesser Antilles on 21 August. Irene became the first hurricane of the 2011 Atlantic season reaching category 3 (>49 m/s). It moved north-westward towards Florida before turning northwards on the 25 August. Landfall occurred two days later in North Carolina as hurricane category 1 (>33 m/s), crossing New York the next day; heavy floods caused widespread disruption in some east coast states. For both storms the observed initial positions were not far from the location of the maximum forecast probability of tropical cyclone genesis given in Figure 5. Equivalent strike probability maps are also generated for cyclones with maximum wind strength above tropical storm (>17 m/s) or hurricane (>33 m/s) thresholds. This allows the forecaster to evaluate the potential activity for more intense systems. All these TC activity products are available as global maps and for seven ocean basins for forecast ranges up to 12 days ahead.

Strike probabilities from the monthly forecasts

Equivalent activity products are produced for monthly forecasts twice a week using exactly the same methodology as for the medium-range forecasts. For these longer lead times, the strike probabilities are computed for the standard 7-day periods corresponding to the calendar weeks (for instance days 5–11, days 12–18, days 19–25 and days 26–32 for the Thursday forecasts) used for monthly forecast products.

Figure 6 shows an example of the monthly forecast strike probabilities. The starting date is 4 August 2011 and the forecast range is days 12–18 (same case as for Figure 5). At this time range, the probabilities are much lower than in the medium-range, but this forecast indicates probabilities up to 30% for a tropical cyclone to occur in the areas that were affected by Irene and Harvey. These probabilities are higher than in other areas of the North Atlantic basin and also higher than climatology.

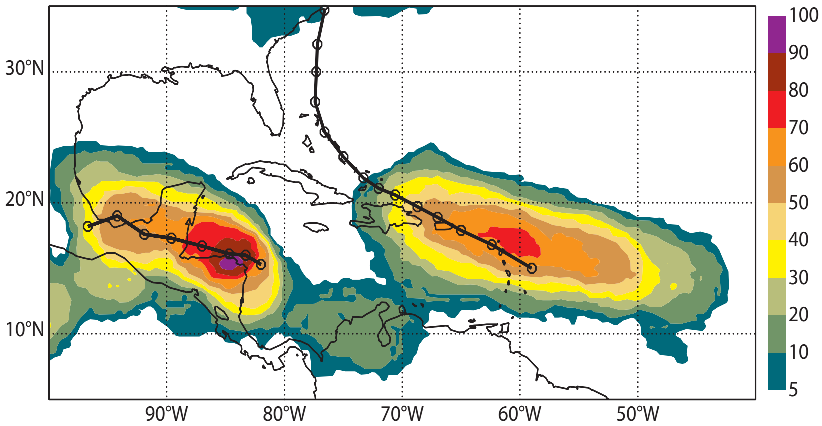

Figure 5 Strike probability (%) for tropical cyclone activity within 300 km (systems with maximum wind speed >8 m/s) for the two-day period 20–22 August based on the EPS forecast from 00 UTC on 17 August 2011. Solid lines and open circles represent the observed tracks of tropical storm Harvey (to west) and hurricane Irene (to east) between 20 and 24 August.

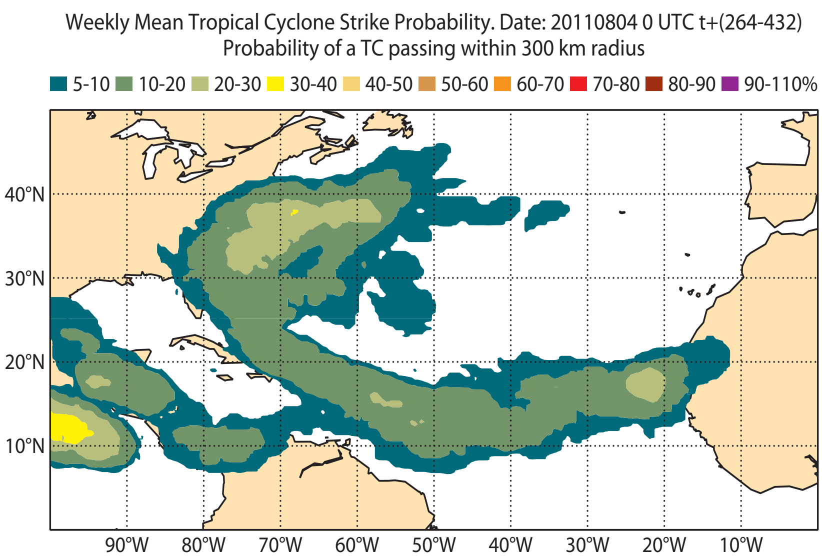

Figure 6 Strike probability (%) for tropical cyclone activity (>8 m/s) for the seven-day period 16–22 August (time range: day 12–18) based on the EPS forecast from 00 UTC on 4 August 2011.

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Seasonal forecast products
The new tracking algorithm is also used to track TCs in the seasonal forecasts (System 4). At this time range, the TC products include the number of tropical storms, number of hurricanes, accumulated cyclone energy (ACE) over a basin (North Atlantic, eastern North Pacific, western North Pacific, South Indian Ocean, Australian Basin and South Pacific), tropical storm density anomaly and standardized tropical storm density for a six-month period. The seasonal forecasts of TCs are available at:

- www.ecmwf.int/products/forecasts/d/charts/seasonal/forecast/seasonal_range_forecast/

Figure 7 shows an example of the verification of the hurricane frequency over the North Atlantic for past forecasts from System 4 starting on 1 July for each year from 1990 to 2010. This shows that, overall, the System 4 has some skill in predicting the in the Atlantic basin for this period. On the seasonal time scale, the predictability of tropical storms comes mostly from the predictability of sea surface temperatures and vertical wind shear in the tropics, which are strongly modulated by the El Niño and La Niña phenomena.

Verification
Verification is performed routinely to assess the performance of both the deterministic and EPS forecasting systems. This is of major importance, particularly when there is an important model development to be implemented in operations such as the increase of resolution or changes in the physical parametrizations, both of which are known to have a significant impact on the quality of TC forecasts.

Deterministic forecasts
The extension of the forecast tracks beyond five days has permitted, for the first time, the assessment of the model's ability to track TCs out to 10 days. To evaluate the forecast accuracy, the observed position and minimum central pressure of the storm (available from the bulletins disseminated via the GTS) are used as independent data.

Figure 8 shows the mean position and intensity errors as a function of the forecast time range up to 7 days for a period of ten months starting on 11 November 2010. For comparison the statistics are given for both the new and old trackers. Out to 120 hours the position errors of the new tracker are similar to those of the old tracker (Figure 8a): the position error is around 450 km and almost double this value 2½ days later. Thereafter position errors increase linearly with the forecast time range between 72 and 168 hours. However, the verification period is still too short to provide enough cases to compute scores with sufficient statistical significance for longer forecast lead times (up to 10 days).

For the mean absolute intensity errors of the minimum central pressure (Figure 8b) the results are similar, but slightly better for the old tracker. The mean absolute error obtained from the new tracker increases linearly with the forecast lead time up to 168 hours. Differences are more significant for the bias. With the new tracker the bias is smaller in the first 72 hours whilst, for longer lead times, the tracker tends to emphasise the systematic negative bias in the forecast system for tropical storms (i.e. the forecast tends to predict too strong storms, on average, when compared with observational data).

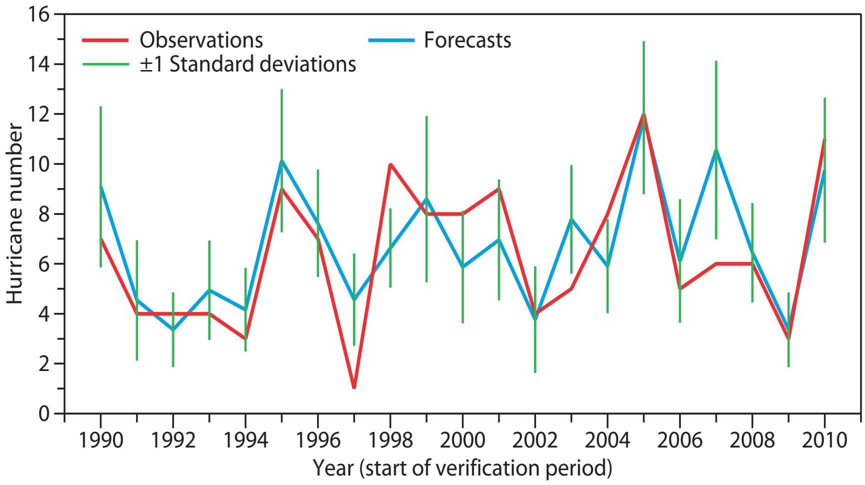

Figure 7 Interannual variability of the number of hurricanes from August to January predicted by System 4 hindcasts starting on 1 July for each year from 1990 to 2010 (blue line) and observed (red line). The vertical green bars represent 2 standard deviations from the model ensemble distribution.

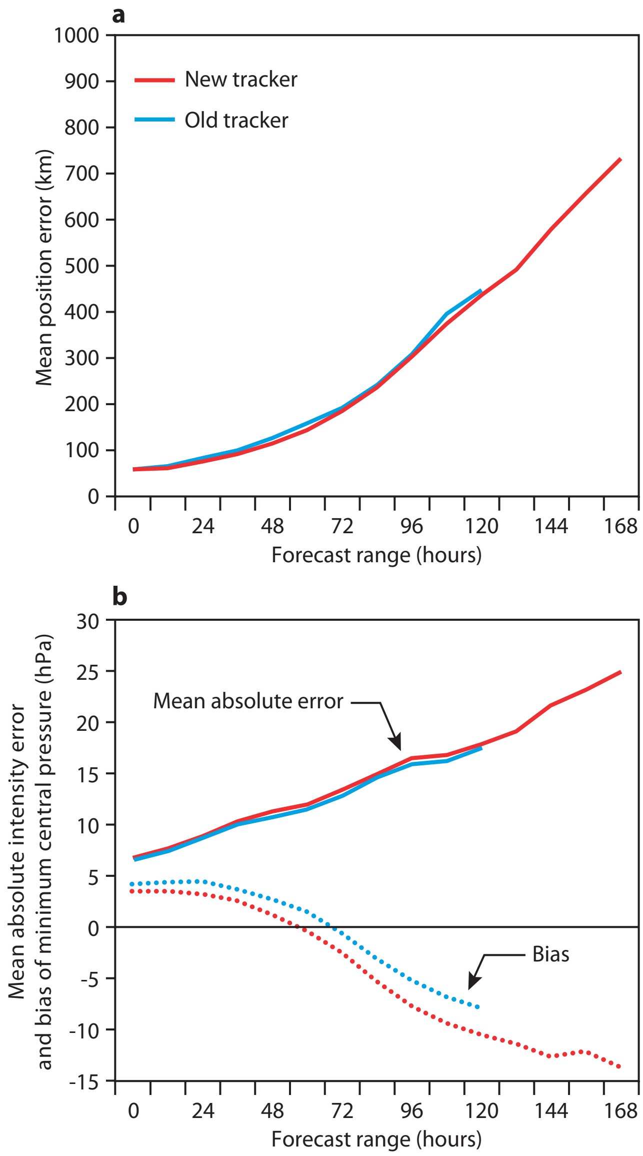

Figure 8 Verification of tropical cyclone forecast from the T1279 model. (a) Mean position errors based on the new (red) and old (blue) trackers for a period of 10 months starting in mid-November 2010. (b) As (a) but for the mean absolute intensity errors and bias of minimum central pressure; solid lines for the mean absolute error and dotted lines for the bias.

Probabilistic forecasts

The verification of probabilistic products is also part of the verification package developed at ECMWF. Recently this has been expanded to include the assessment of the new product – the strike probability of TC activity during the forecast.

Figure 9 shows the reliability curves for the probability forecast that a tropical storm or hurricane will pass within 300 km during a 2-day period for two basins in the northern hemisphere and two for the southern hemisphere. The forecast does not perform equally well in all basins. This result is expected since the number of storms per season and basin can vary significantly from year-to-year which in turn is influenced by the main sources of predictability for TCs (e.g. Madden-Julian Oscillation and El Niño).

Overall, the probability forecasts tend to indicate too high confidence at all probability levels. In the northern hemisphere the forecasts are more reliable in the North Atlantic than in the West Pacific. In the Atlantic basin the forecast reliability has improved in the last year, particularly for low probability forecasts. The forecast reliability for the South Indian Ocean is higher than in the North Australia region. In the South Indian basin the reliability curve for the 2011 season has deteriorated when compared with the previous seasons, especially for low probabilities. This might be related with the fact that the 2011 season was the least active since the records began in 1923.

The skill of the ECMWF 32-day EPS to predict tropical storm strike probabilities over weekly periods has been evaluated from a research experiment because there was not a big enough sample from real-time monthly forecasts. In this experiment, 15-member ensemble forecasts using the same configuration as

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the operational monthly forecasts, but with a version of the IFS which was operational from November 2010 to May 2011, have been produced starting on the first day of each month from 1989 to 2008. The probability of a tropical storm strike has been computed over a 10°×5° box for each forecast and compared to the observations from the National Hurricane Center (NHC) over the North Atlantic and eastern North Pacific and to observations from the Joint Typhoon Warning Center (JTWC) for the other ocean basins. The dimension of the tropical storm strike domain (10°×5°) for the verification was chosen so that it is large enough to make the verification statistically robust. The Brier skill score has been computed for the northern and southern hemisphere seasons.

Figure 10 shows that the 32-day EPS displays skill in predicting tropical storm strike probabilities for the first three-weekly periods (positive Brier skill score). It also indicates that the model shows more skill over the southern hemisphere than over the northern hemisphere in the sub-seasonal time range. This could be explained by the major role the Madden Julian Oscillation (MJO) plays in modulating TC activity. Since the MJO is more intense during the southern hemisphere tropical cyclone season (winter and spring) than during that of the northern hemisphere (summer and autumn), it is expected that the predictability of TC activity should be higher over the southern hemisphere than over the northern hemisphere in the sub-seasonal time range.

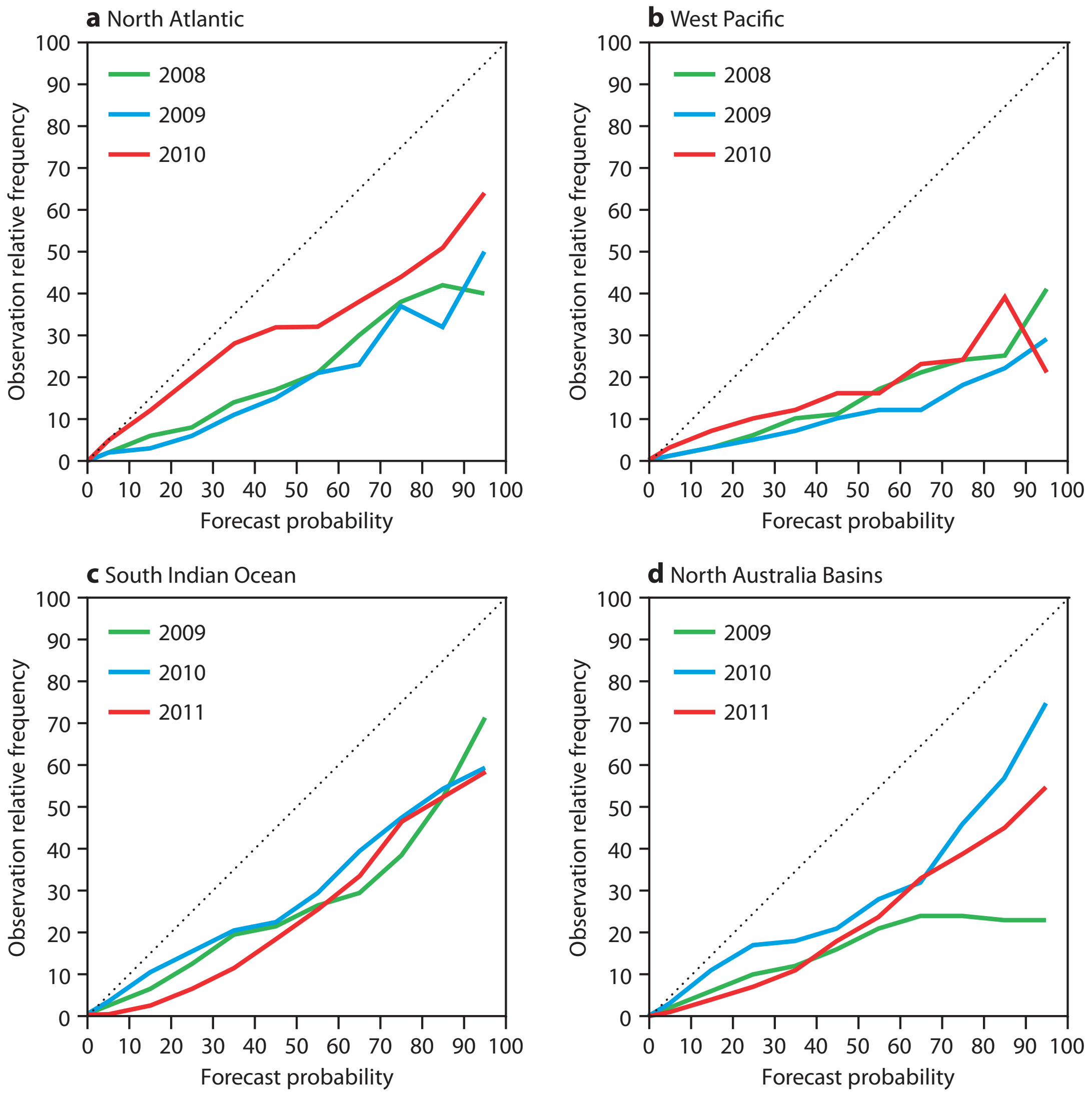

Figure 9 Reliability diagrams for the strike probability of tropical storm strength (and above) activity within 300 km in two-day period for the forecast range 48–96 hours for the last three hurricane seasons for (a) North Atlantic, (b) West Pacific, (c) South Indian Ocean and (d) North Australia basins.

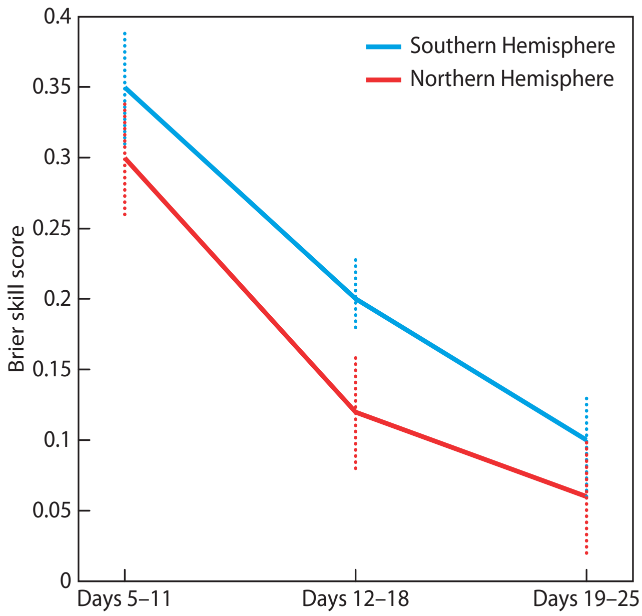

Figure 10 Brier skill scores of the strike probability of tropical storms in the ECMWF monthly forecasts for days 5–11, days 12–18 and days 19–25 for all the tropical storm basins over the northern (red line) and the southern (blue line) hemispheres. The dotted line represent the level of confidence computed using a 10,000 re-sampling bootstrap technique.

Concluding remarks

A new set of probabilistic products for TCs for the medium-range and monthly forecasts has been introduced. For the medium range the strike probability forecast product for existing TCs has been extended from 5 to 10 days. The new TC product, also represents the uncertainty in the strength of a TC during the forecast which is especially of interest when a rapid development is under way. Also, the strike probability for the TC activity (including genesis) during the forecast for the medium and extended ranges is now available to the users via the web.

The accuracy of the new tracking algorithm has been confirmed as being at least as good as the current operational one and will soon replace it. In addition, this new tracking algorithm is being used for the detection of TCs at all time ranges (medium-range, monthly and seasonal). Graphical products are available via the web. There are plans to make the corresponding binary products available to users through the MARS archive in the first quarter of 2012. Recent technical changes in the operational suite have allowed the TC track forecasts from the deterministic model to be disseminated one hour earlier.

Further reading

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