Considerations when using Tropical Cyclone products

Overall Performance

In general, analysis of IFS model performance suggests:

- HRES errors in forecast positions of tropical cyclones are on average less than 200km at Day3 and less than 350km at Day5.
- Broadly, the IFS models tend on average to move tropical cyclones rather too slowly (by about 1-2km/hr).
- Strike probabilities seem to be a little high. This applies to TCs in existence at T+0, but in view of some conflicting results this topic is currently undergoing further investigation (Nov 18). ECMWF plans to start verifying the 'activity' product soon.
- The IFS models handle rapid intensification of tropical cyclones rather poorly. It is quite common to see an under-estimate of the speed of intensification during periods of intensification.
- HRES errors in central pressure are erratic but have a relatively small average bias though tend to over-deepen the central pressure. The ENS Control run is generally not deep enough by around 15hPa.
- There is on average an under-estimation of maximum winds in the circulation, particular during periods of rapid intensification.

The first and second points partly relate. The fist and third points together mean that although intensification might not occur quickly enough, the depth reached at the end of it can often be too great, implying in turn that the intensification period is too long.

Characteristics regarding Forecast Movement

It has been found that the errors in forecast position and movement of tropical storms are:

- for analysed location - on average about 50km.
- for speed - on average 1.0-1.5kph slow.
- for direction - tending to the right of track

If the steering flow is:

- moderate or strong - the tropical storm moves realistically.
- weak - the tropical storm moves slowly and more erratically, and especially so if a deep tropical storm.

Forecast Error Statistics for Pre-existing Tropical Cyclones

The figures below provide verification examples, over multiple or single cases, illustrating typical IFS model characteristics, be they strengths or weaknesses. Key points for the forecast user are highlighted in the captions.
Fig 8.1.10.3.1A: Reliability diagram of tropical cyclone strike probabilities, at day 10, for TCs in existence at T+0, for year July to June (years indicated by colours) showing reasonably good reliability (plots are near the diagonal), but a tendency towards over-confidence (plots to right of diagonal).

Fig 8.1.10.3.1B: Relative operating characteristics (ROC) diagram for tropical cyclone strike probabilities, at day 10, for TCs in existence at T+0, for year July to June (years indicated by colours) showing high ROC score (plots lie towards left and upper axes) with low False Alarm Rate and high Probability of Detection.
Fig 8.1.10.3.3: An illustration of what can happen when the model resolution is increased. HRES model performance Aug-Nov 2015 using test runs (~9km resolution - Red; ~16km resolution - Blue), both without ocean coupling. On average, ~9km resolution forecast location error is slightly better to about Day5 but marginally worse from Day5 to Day7. However, beyond about Day5 the low sample size makes statistics unreliable and ~9km resolution is unlikely to be significantly different to ~16km resolution. Users should note that this diagram is included to illustrate that resolution changes have a significant impact. With the introduction of ocean-atmosphere coupling in HRES in cycle 45r1, introduced in June 2018, characteristics of the behaviour of HRES have changed somewhat. For example a tendency to over-deepen, which is very apparent here, has been reduced. New plots will be added to the User Guide once we have a large enough sample.

Analysis Aspects

Interpretation of Increments near Tropical Cyclones

Large vector increments suggest a sensitivity to observations and hence the possibility of fast growing errors. Wind increments also impact upon the thermal structure of the model atmosphere. Users should consider the potential for increased uncertainty in the subsequent evolution.
It should be remembered that the analysis process seeks to maintain dynamic and thermal balance within the IFS. To do this, it is possible that valid observations may be given low weight or be rejected near sharp upper troughs, or in the vicinity of deep active weather systems. Users should consider the potential for increased uncertainty in the subsequent evolution while bearing in mind the observations marked by increment vectors have, at least partially, been accepted and incline the analysis to better reflect the true structure of the atmosphere.
Fig8.1.10.3.4: Tropical cyclone strike probability for Hurricane Florence from 12UTC 6 Sep 2018 (left). Large upper troposphere increments are evident near the location of the hurricane during data assimilation (centre) and the related modifications to the IFS model atmosphere will have had some impact upon the subsequent forecast run at 00UTC 7 Sep 2018 (right).

There are distinct changes in the forecast track of the hurricane between the two forecasts. On the later forecast:

- the threat area in eastern USA is broadened.
- there is less chance that the hurricane track will curve northwards off the eastern seaboard.
- the southern flank of the threat extends southward into Florida.
- HRES (and ENS mean) make more progress westwards into USA.

Users should consider the potential for increased uncertainty in the forecast (perhaps beyond that shown by the ENS) when large increments are indicated.

Impact of Scatterometer Winds on Tropical Cyclone Analyses

Scatterometer winds are only incorporated into analyses at low resolution. Moreover correct interpretation of wind direction ambiguities relies upon a correct background wind pattern derived from earlier forecast runs which of course may differ from reality. In consequence an erroneous forecast can potentially be "reinforced" if incorrect wind directions are assigned. In turn this can degrade the analysis quality for tropical storms (or conceivably also intense depressions). Viewed separately, scatterometer winds can give the user an indication of the true severity of winds associated with low pressure features (but note that there is an upper limit for their utility).

General Forecast Information

HRES versus ENS

One of the consequences of the high spatial resolution of HRES is that, compared to the ENS, it responds more readily to the changes in the evolving structure of the modelled atmosphere. This can be especially evident when there is extensive active convection, and the mean sea level pressure in the vicinity can often be forecast to fall, sometimes steeply, with a consequent increase in the low altitude wind circulation (for developing tropical storms). The track of these low pressure centres can vary significantly from run to run according to variations in the low pressure structure. Users should always compare HRES forecasts with corresponding ENS member forecasts. Nevertheless, HRES should generally be considered as a more probable member of the ensemble, particularly with regard to central pressure, and should not be discarded just because of major differences in intensification rates or in the subsequent low track. Indeed HRES can often give early indication of the development of small or vigorous circulations and the associated strong and potentially dangerous winds.
Fig8.1.10.3.5: Tropical cyclone strike probability for Hurricane Florence (left, date and time given above). HRES forecast values are shown by a black line in the graphs on the right of the charts. Plots for the central pressure HRES (black line) are lower than the lowest values from ENS (box and whisker plot) with winds correspondingly greater than indicated by ENS. This can be attributed, at least in part, to the finer resolution of HRES leading to more detailed (perhaps more active) forecast convection. It is noticeable the effect stops or is reversed as the hurricane is forecast to make landfall on Friday 14 Sep, significantly reducing convection. Winds decrease due to the weakening of the hurricane and also because of the increased surface friction over land which may be better modelled by HRES. Similar effects can be seen in the forecast pressures and winds associated with Typhoon Mangkhut (right).

Forecast Consistency

Tropical storms are highly energetic and small differences between the analyses and background fields in sequential runs, or small perturbations developed by the IFS models in the circulating flow, can have a major impact on the forecast evolution. This is especially true with the higher resolution of the HRES which can show major differences in depth and track of the tropical storm, particularly later in the forecast, when compared with previous HRES runs or ENS. It is important therefore to monitor the progress of forecasts of tropical storms and assess critically changes over a series of runs. Some possible problems are illustrated below.

The forecast central pressure and track of a tropical storm can show quite large run-to-run variations. The example below shows HRES and ENS forecasts from two runs (data times 12UTC 30 July 2017 and 12UTC 1 August 2017) to illustrate the differences that can occur. In fact none of the HRES or ENS mean forecasts were correct. The weakening tropical storm actually moved northeast through central Japan. Outlying ENS members proved the better guidance in each case.
Extratropical Transition

Fig 8.1.10.3.6A (Left): Strike probabilities for NORU up to 12 UTC 8 August 2017 (T+240) based on ENS and HRES forecast, data time 12 UTC 30 July 2017.

Fig 8.1.10.3.6B (Right): Strike probabilities for NORU up to 10 August 2017 (T+240) based on ENS and HRES forecast, data time 12 UTC 1 Aug 2017.

ENS mean track shown as dotted line and HRES track as solid line. Crosses mark previous positions of NORU.

Note the large net change between forecasts from these two data times, in HRES and ENS mean tracks, and in the strike probabilities:

- The earlier forecast has a 30% threat to coastal central eastern Japan and Tokyo, 10%-20% threat to the islands south of Kyushu, but little threat to the Sea of Japan.
- The later forecast has <10% threat to eastern Japan and Tokyo but 30%-40% threat to the Sea of Japan (and 40%-50% in the south), and 70%-80% threat to the islands south of Kyushu.
Extratropical transition of tropical storms is, in general, difficult for NWP models to deal with. NWP models often show large run-to-run variability in forecast track, movement and depth of a tropical depression as it moves into the mid-latitudes. Small differences between the analyses and background fields in sequential runs, or small perturbations developed by NWP models in the circulating flow, can have a major impact on the forecast evolution. The higher resolution of the HRES can induce spurious developments not indicated by lower resolution models (e.g. ENS). This is especially so with energetic systems such as developed tropical storms and can make some forecast aspects unsafe later in the forecast period (say beyond Day5).
Fig 8.1.10.3.7A (Left): Strike probabilities for tropical cyclone 17W up to 10 August 2017 (T+240) based on ENS and HRES forecasts, data time 12UTC 1 August 2017. It is notable that the ENS mean track (dotted line) and the tracks of the majority of ENS members veer eastwards towards mid-Pacific as extratropical transition occurs while HRES (solid line) and a few ENS members curve the low pressure centre westwards towards Japan.

Fig 8.1.10.3.7B (Right): The same case as in Fig 8.1.10.3.7A. Top: Probability from ENS members for tropical cyclone 17W to fall into each of the 5 tropical cyclone intensity categories shown at 6hr intervals to 10 days. Centre and Bottom: Lagrangian meteograms of distribution of the ENS for the 10m wind (kt) and MSLP (hPa) at tropical cyclone 17W centre. Tropical cyclone 17W is considered to have become extratropical by Day9 and central pressure and wind information is discontinued at that time. HRES central pressure and winds diverge from the ENS beyond Day5 and forecasts cease as winds fall below the threshold for a tropical cyclone to exist and the depression effectively transitions to become extratropical (or even non-existent) sooner than it appears to in most (~80%, see top row) of the ENS members.

Misleading Indications of Threat areas.

The strike threat areas sometimes appear shifted away from the track of the centre shown by the ENS mean (dotted line) and the HRES (solid line). This appears to be a plotting problem and can occasionally be very misleading. The problem will be rectified in future updates.
Fig8.1.10.3.8: Strike probabilities of NORU up to 17 August 2017 (T+240) based on ENS and HRES forecast, data time 00UTC 7 August 2017. ENS mean track (dotted line) and HRES track (solid line). Crosses mark previous positions of NORU. The strike threat area is shifted to the northwest of the forecast track of the centre shown by the ENS mean (dotted line), and the HRES (solid line), whereas the strike threat should be approximately centred on the ENS mean track.

**Genesis: Tropical Cyclone Activity charts**

Although often very useful it should be remembered that these are an experimental product based upon identification of the warm-core circulation during the forecast period. The technique can mis-identify as a tropical cyclone a high-latitude circulation containing something of a warm core (e.g. a well occluded frontal depression with cooler air encircling some warm, moist air remnants near the centre). The result will be spurious probabilities of tropical storm strikes. Future improvements to the technique will aim to remove this problem.

**Potential error in tracking TCs:**

Once official reports signify the existence of a tropical cyclone, it is automatically tracked. The tracking algorithm uses HRES output and is based on using the extrapolation of past movement and the mid-tropospheric steering flow to obtain a first-guess position 6 hours into the future. The actual forecast position is then determined by searching for mean sea level pressure (MSLP) and 850hPa vorticity extremes around the first-guess position. In some circumstances the thickness maximum, the central MSLP, surface winds, and the orography are also considered in the evaluation. This process repeats at 6 hour intervals through the forecast until either the tropical cyclone dies or the end of day10 is reached.

Rarely two Tropical Storms are relatively close the possibility arises that the tracking algorithm may jump from one to another - e.g. if one is decaying. This seems to be a very rare occurrence and which is under investigation, but users should be aware of the potential for this error.
Ocean Waves in association with Tropical Cyclone forecasts

A limit is placed on the roughness length scale parameter in order to avoid the effect of too much drag from the sea surface in the lower atmosphere and enable more realistic (stronger) winds to be forecast in the vicinity of relatively intense tropical cyclones. It should also be noted that tropical cyclone development with strengthened winds has only a limited effect upon the size and character of waves developed by the Wave model. The model change to limit the roughness length scale at very high speeds was introduced in cycle 47r1 in June 2020. See Section on Waves near tropical storms.
RSMC official forecasts of tropical cyclones take precedence

Note: IFS products on these pages regarding tropical cyclones are generated automatically without any editing by forecast experts. RSMCs (Regional Specialized Meteorological Centres) have ultimate responsibility for official forecasts of tropical cyclones within their respective regions (ECMWF is one of a number of centres that provide data to them). Up-to-date information is available by direct access to official RSMC forecasts through the WMO Severe Weather Information Centre. For up-to-date forecast information for their own local area users should refer to forecasts from their own National Meteorological Service.

Additional Sources of Information

(Note: In older material there may be references to issues that have subsequently been addressed)

- See ECMWF Newsletter, Summer 2020 issue for further explanatory information regarding Tropical Cyclone Wind Forecasts.
- Read more about tropical cyclone products (Pages 17-23).
- Read more about tropical cyclone activity (including genesis) from medium range and extended range ENS.
- Read information on ECMWF performance regarding tropical storms (pages 11, 12 and 43).
- Read more about forecasting tropical cyclones in the medium-range.
- Watch a webinar on tropical products and skill (30sec delay before start)

Updated/Amended 28/04/20 - Added Potential Error in Tracking.

Updated/Amended 06/07/20 - Added Ocean Waves section; modified Overall Performance.

Updated/Amended 25/10/20 - amended chart links to open access.