Met Office Consulting

Met Office dynamical climate model forecasts of tropical storms in the Atlantic Sector

June forecast of July to November 2007

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Prepared by:
Dr Matt Huddleston, Principal Consultant, Climate Change
Dr Richard Graham, Climate Applications Manager

Reviewed by:
Dr Julian Heming, Tropical Prediction Scientist

Authorised for issue by:
Cathy Durston, Head of Met Office Consulting

Executive summary

This article describes a new system for forecasting Atlantic tropical storm activity, providing information about the methodology and details of the latest forecast for 2007.

Forecasts of the number of named storms for the Atlantic tropical storm season have been made using a new dynamical method based on seasonal climate models. The method allows an assessment of the risk of above normal tropical storm activity, as well as providing more detailed information on the likelihood of specific numbers of named storms. The method is unique in the sense it is not based on a historical-statistical or "analogue" method, and has no subjective component.

For 2007, ten named storms have been predicted for July to November. It has been assessed that there is an 80% chance that there will be 12 or less named storms. The climate model signal is associated with a predicted cooling trend in sea surface temperatures in the Pacific and tropical North Atlantic that influence storm activity.

To assess the accuracy of the new system, similar forecasts have been run retrospectively for previous years using only data that would have been available had the forecasts been made operationally in real-time (i.e. allowing no knowledge of the future). These have proved to be highly skilful relative to forecasts from other providers who use historical statistical relationships. Significantly, the forecast for 2005 gave good guidance for the very active season that year. For the below-normal activity in 2006, the forecast gave more neutral guidance but, unlike a number of published statistical forecasts, did not show a strong signal for above-normal activity. The climate model has also been shown to be skilful at predicting sea surface temperatures in both the tropical Pacific and Atlantic Oceans.

Introduction

At the start of the North Atlantic season (which usually runs from June to November) the Met Office now forecasts the number of tropical storms expected throughout the period. This is done using a dynamical seasonal prediction computer model of the global atmosphere-ocean system developed in the Met Office's climate research division, the Hadley Centre. The seasonal prediction model is based on a Met Office Hadley Centre climate model.

The seasonal prediction model is initialised with a complete analysis of the global oceans, land and atmosphere. The analysis provides the model with best available description of the current climate state, an important factor in obtaining realistic predictions. The starting conditions are varied slightly to make 41 individual forecasts out to six months ahead. The 41 forecasts are collectively called an 'ensemble' and each forecast an ensemble member. The ensemble procedure allows estimation of the probability of various outcomes and of the forecast uncertainty. The frequency of tropical storms in each of the 41 ensemble members is processed to create a probability distribution for the expected number of storms. In addition, the average number of storms over all ensemble members (the ensemble mean) is derived to provide a 'bottom line' forecast.

The seasonal model includes representation of the physical and dynamical processes characteristic of tropical storms, allowing the number of storms developing in the model to be counted. To correct for any systematic bias in the model the predicted number of storms is adjusted by comparing observed and predicted numbers in past forecasts over the period 1987-2006. The forecast process also includes predictions of the sea surface temperature (SST) anomalies. This season, a cooling trend in SST is expected in the tropical North Atlantic, and this favours fewer tropical storms than seen in recent years prior to 2006.

Recent studies have shown that Met Office's model and other European models have considerable in skill predicting the number of tropical storms, for example successfully predicting the change from the exceptionally active season of 2005 to the near-normal activity of the 2006 season. This marked difference between seasons was missed by a number of statistical prediction methods, which have traditionally formed the basis of most published forecasts.

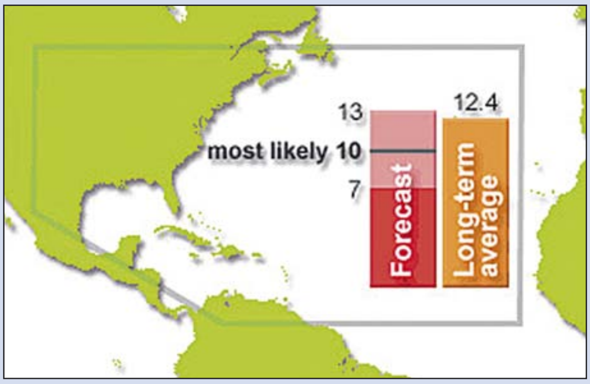
Full details of the forecasting methodology and verification of forecasts can be found in Appendix B.

Public forecast as issued 19 June 2007

Forecast for July to November 2007
Issued 19 June 2007

Ten tropical storms are predicted as the most likely number to occur in the North Atlantic during the July to November period, with a 70% chance that the number will be in the range seven to 13. This represents below normal activity relative to the 1990-2005 long-term average of 12.4.

Note: The forecast is for the five full months remaining in the June-November Atlantic tropical storm season. There have already been two named storms – Andrea and Barry.



2007 forecast detail

Due to the probabilistic nature of the forecasts, more detailed assessment of the risks of different numbers of storms is possible. The forecast can be presented in a categorical sense showing the likelihood of different ranges of storm numbers (e.g. 7-9 storms, 10-12 storms etc.), or in terms of cumulative probability distributions.

The forecast probability of the storm-number categories can be compared against the climatological frequency of the category, to determine whether the chance of a particular category occurring is greater or lower than the usual chance. For the 2007 forecast we have used the 20 year period 1987-2006 to define the observed frequency of the categories. This period has been active on average, relative to the 1950-2006 period (for 1987-2006 the mean number of tropical and sub tropical storms was 11.8, relative to the 1950-2006 period mean of 9.8 storms).

Due to the relatively short nature of the time series from 1987, the frequency distributions are inherently under-sampled leading to somewhat noisy statistics. Even so, good results from the use of 3-category probabilistic forecasts have been demonstrated and validated (e.g. Vitart et al. 2007, see appendix B).

Figure 2 provides a six category representation of the June 2007 forecast where the green bars show the climatologically probability of the categories and the red bars show the forecast probability. The figure shows that forecast probabilities are substantially enhanced for 7-9 tropical storms in the Atlantic sector from July to November. Near normal climatological chances are expected for 10-12 storms, and less than normal chances of 13-15, 16-18 or >18 storms are expected. The probability distribution is consistent with the public forecast of 10±3 storms, but indicates a skew in the probabilities towards the negative side of the range. The observed category for some notable recent years is also indicated on Figure 2 for perspective.

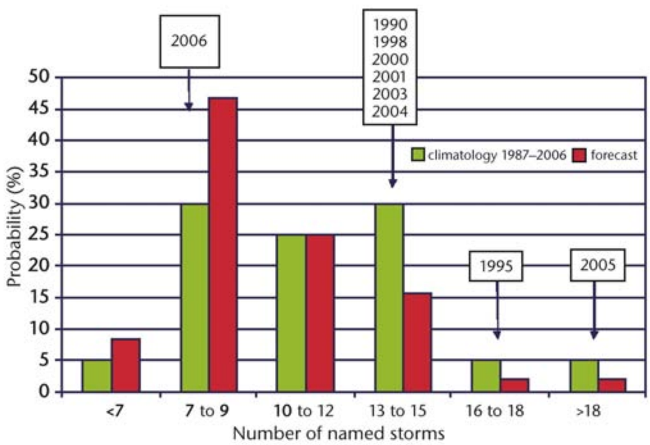


Figure 2: Probability forecast of the number of Atlantic sector named storms for July to November 2007. Bars in green represent climatological frequencies derived from 1987-2006 observations. Bars in red are forecast probabilities for 2007 derived from an ensemble of 41 climate model forecasts.

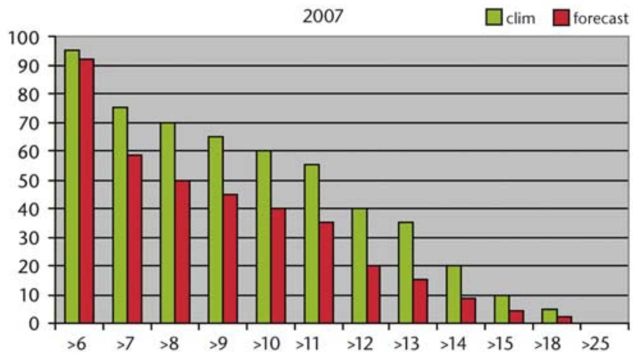


Figure 3: Cumulative probability forecast of the number of Atlantic sector named storms for July to November 2007. Bars in green represent climatological frequencies derived from 1987-2006. Bars in red are forecast probabilities derived from an ensemble of 41 climate model forecasts.

Cumulative probabilities assist the user in making risk based decisions. By identifying either their own appetite for risks on decisions (e.g. the probability threshold for a given number of storms that must be exceeded before one acts), or by looking at the risks associated with key event thresholds (e.g. the probability of more than 12 named storms) one can decide whether to take action. Figure 3 and table 1 detail forecast probabilities in this format for the 2007 Atlantic tropical storm season.

As an example, it can be seen that the chance of exceeding 12 named storms is 20% whereas the (1987-2006) climate probability is 40%. Thus the forecast indicates we are half as likely as normal to get more than 12 named storms in 2007.

Conversely, if appropriate action is taken only when the forecast probability exceeds 80%, then it can be seen that there is an 80% chance that there will be 12 or less storms according to this forecast.

Threshold of number of storms	Climate probability 1987-2006	Forecast probability 2007
>6	95	91.7
>7	75	58.3
>8	70	50.0
>9	65	45.0
>10	60	40.0
>11	55	35.0
>12	40	20.0
>13	35	15.0
>14	20	8.6
>15	10	4.3
>18	5	2.1
>25	0	0.0

Table 1: Cumulative probabilities for the exceedance of threshold numbers of storms for the North Atlantic sector for July-November 2007. Note: forecast probabilities are given to 1 decimal point to help preserve a smooth distribution. Accuracy to 1 decimal point is not implied.

2007 global forecast ocean conditions

Year to year variability in seasonal climate is strongly influenced by evolving patterns in global sea surface temperature (SST). Reliable estimation of the future state of global SST is therefore crucial in seasonal prediction. The SST evolves through complex interactions between the ocean and atmosphere. These interactions are represented in the Met Office coupled ocean-atmosphere seasonal climate model, enabling explicit prediction of both the SST evolution and the impact of SST on seasonal conditions.

The El Niño phenomena is the best known example of the influence SST anomalies can exert on seasonal climate. El Niño is associated with seasonal anomalies over many parts of the tropics with teleconnections extending to the extra-tropics. A great deal of scientific effort has been undertaken to increase the reliability of dynamical climate model predictions of El Niño, and current levels of skill are competitive with those of traditional statistical prediction methods.

In June 2007, neutral / weak La Niña conditions (anomalously cold SST in the tropical east Pacific, in contrast to the warm anomalies associated with El Niño) are evident. However, SST has been predicted to cool sharply by some dynamical models – indicating a substantial chance of a stronger La Niña event occurring through the remainder of 2007 and into 2008. A current consensus view is offered by the International Research Institute for Climate and Society (IRI) (http://iri.columbia.edu) which states that there is about a 50% chance of La Niña conditions developing further.

The Met Office dynamical model forecast indicates development of a very significant cooling in the central Pacific (figure 4). The signal for a La Niña event is thus strong though the precise amplitude of the predicted SST anomalies (which reach about -2.5˚C) is thought to be too large and must be viewed with caution.

In broad support of the Met Office forecast, all other coupled models including that of the European Centre for Medium-Range Weather Forecasting also signal cooling of SST in the tropical east Pacific (figure 5). In terms of its impact on tropical storm frequency, La Niña events are sometimes implicated in an enhanced tropical storm season in the Atlantic (as presumably picked up by the 2007 NOAA / CSU forecasts). However, the atmospheric response to La Niña (or El Niño) events varies from case to case. An advantage of the dynamical prediction method is that, through representation of complex non-linear feedbacks in the physical processes at work, it is not tied to a typical response, which is a weakness of some statistical prediction methods.

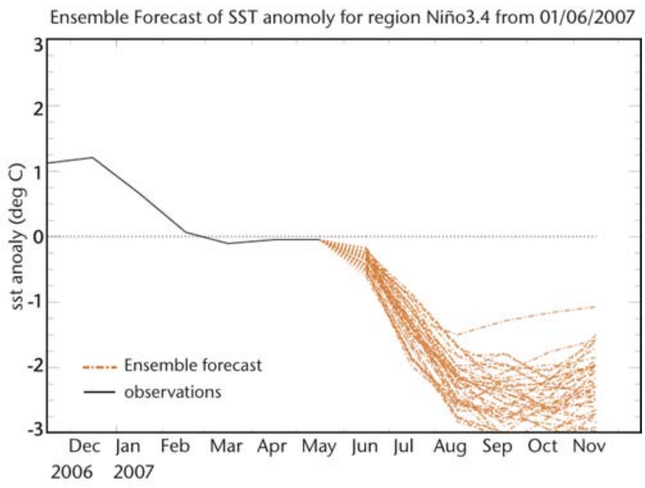


Figure 4: Central Pacific sea surface temperature anomaly plume forecast from the Met Office dynamical coupled seasonal forecast model from June 2007. Each red line is from one ensemble member of the coupled climate model. The black line represents observed conditions.

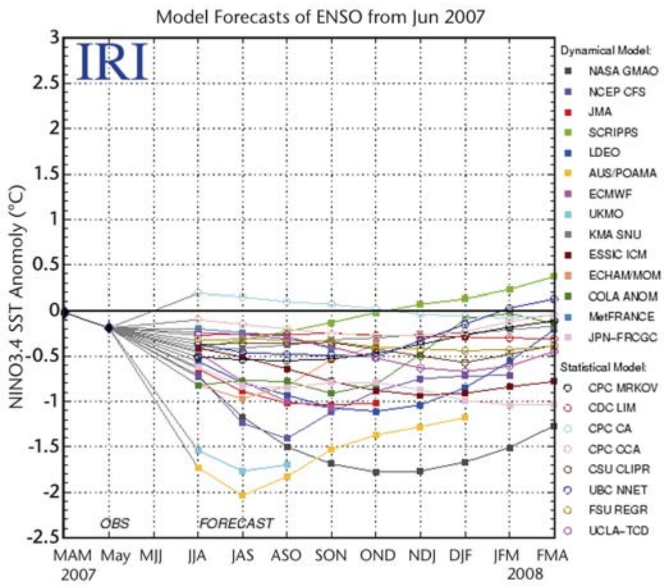


Figure 5: The global consensus on Pacific sea surface temperature anomalies for forecasts started in May 2007 (from IRI, USA).

SST in the tropical North Atlantic has a direct impact on tropical storm formation. Years with above normal SST are generally associated with above normal numbers of storms (e.g. 2005). The latest forecast from the dynamical model indicates development of below normal SST in the tropical North Atlantic (Figure 6 shows the ensemble mean forecast for the August-October period). The prediction of below normal SST in this region is consistent with the dynamical model prediction of lower than normal or near normal tropical cyclone activity in 2007. Analysis of retrospective forecasts shows that forecasts of tropical North Atlantic SST do have significant skill, as is explained in the next section on model performance.

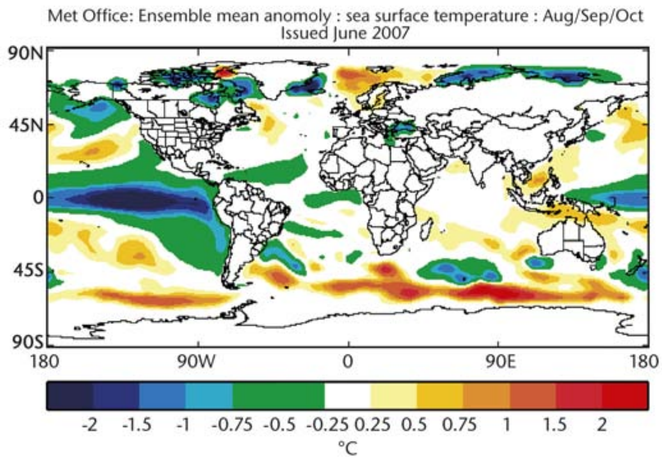


Figure 6: Ensemble-mean forecast of August-September-October 2007 sea surface temperature anomaly, from June 2007. Anomalies are expressed relative to the 1987-2001 period. Note the negative anomalies are predicted for both the equatorial Pacific and the tropical North Atlantic.

Forecast verification and model performance

Verification of tropical storm predictions

The mean number of storms from all 41 ensemble members (the ensemble mean) provides a summary statistic from the probability distribution that may be used as a predicted 'most likely' single value. The ensemble mean prediction has been verified against the observed number of storms in retrospective forecasts for the slightly shorter period 1993-2006 (Vitart el al., 2007). Performance statistics for this period are shown in table 2.

As can be seen, the dynamical model performs well in comparison with the statistical / analogue forecasts of the Colorado State University and University College London Tropical Storm Risk forecasts. In particular, the higher correlation score highlights the model's ability to get the phase of year-on-year fluctuations in the number of storms correct, whilst the lower root mean square (RMS) error highlights that the size of those fluctuations is also more in accord with observations.

	Met Office	Tropical Storm Risk	Colorado State Uni.
Correlation Best = 1.0	0.78	0.65	0.39
RMS error Best = 0.0	3.65	4.7	4.76

Table 2: Linear correlation and root mean square error between the number of Atlantic tropical storms predicted by the Met Office dynamical seasonal model, TSR and CSU and the observed number of tropical storms during the whole Atlantic season (taken from the US National Oceanic & Atmospheric Administartion National Hurricane Center http://www.nhc.noaa.gov) over the period 1993-2006.

Verification of SST predictions

As discussed previously, North Atlantic tropical storm frequencies are correlated with SST anomalies in both the tropical Pacific and tropical North Atlantic. Forecasts of sea surface temperature in the Pacific are relatively skilful: from June forecasts performed retrospectively for 1987-2005 of August-October mean sea surface temperatures in the equatorial Pacific NINO3.4 region (160°E-150°W, 5°S – 5°N), the forecast vs. observed temperature correlation is r=0.84 with a 0.67°C mean RMS error. Forecasts of sea surface temperature in the Atlantic are also skilful: in the tropical Atlantic formation region (5°-85°W, 10°N– 30°N), the forecast vs. observed temperature correlation is r=0.88 with a 0.13°C mean RMS error.

Verification of probabilistic forecasts for global SST anomalies has been performed using retrospective forecasts for the 1987-2002 period. The probability of five categories of temperature is predicted (warmest 5th to coldest 5th of events), with probability determined by the proportion of the 41 ensemble members with temperature in the range defined by the category. The Relative Operating Characteristic skill measure recommended by the World Meteorological Organisation for assessment of probabilistic forecasts is used.

Relative Operating Characteristic (ROC) scores for probabilistic predictions of episodes of well-below normal sea surface temperature in August-October are provided in Figure 7. ROC scores of 0.7 and above are shaded yellow to red, and correspond to regions with significant skill levels. It may be seen that the tropical Pacific and tropical North Atlantic, where the seasonal model predicts cold anomalies for the 2007 season, are both regions where the model has demonstrated a good performance track record (ROC scores exceed 0.7).

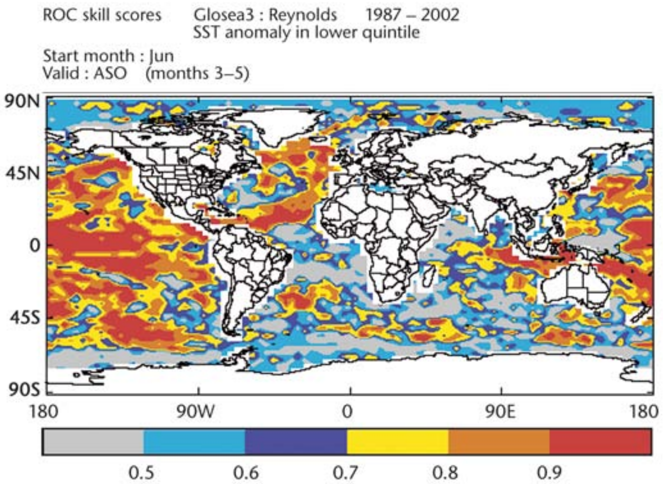


Figure 7: Relative Operating Characteristic scores for lower-quintile (predictions of coldest 5th of events) sea surface temperature. Regions with ROC score equal to or greater than 0.7, 0.8 and 0.9 are coloured yellow, orange and red respectively - and indicate regions with relatively good seasonal prediction skill. Regions with ROC score between 0.6 and 0.7 show skill at lower levels but still better than guessing or use of climatology. Grey or light blue shading is used when scores are below 0.6, suggesting forecasts in these regions are currently little better than guesswork. (Note: a ROC score of 0.5 or below indicates no forecast skill in detecting the event – in this case the coldest 5th of events).

Future forecasts and feedback

Long-range tropical storm forecasts are likely the most important environmental forecast for many market sectors, beyond climate change. Given this, the Met Office is committed to developing a full range of tropical storm forecast products in a way that best meets its customer's needs. Scientific rigour is a key aspect of our heritage – and we look forward to improving and developing the science with our business and public customers.

The Met Office is ideally placed to provide risk based forecast information on tropical storms on a full range of timescales from hours to decades ahead. Global weather forecasts in 2007 predicted the formation of sub-tropical storm Andrea, May 2007, a full 60 hours before any other model. The dynamical weather models have also proved their worth in predicting hurricane land fall (accurately predicting the landfall of Katrina 12 hours ahead of other models).

This same technology is used on seasonal timescales through our integrated Unified Model – where both weather and climate scientists work together to improve both short term and long term predictions. The Hadley Centre for Climate Prediction has developed new dynamical models for the Intergovernmental Panel on Climate Change process, and these are now being tested on timescales from seasonal to decadal ranges – all with a risk-based probabilistic and verifiable approach. In this way, the full range of climate change impacts will be included in our forecasts – whether they are for the year 2100 or for tomorrow.

To assist in this process, we would like to develop long-standing and supportive relationships with our commercial clients to ensure that the forecasts are suitable for business as well as public use. Any feedback is welcome – contact details are below.

Appendix A – Equivalent detailed forecast information for 2005 and 2006

The 2005 and 2006 forecasts were made in an operational mode – i.e. with no knowledge of future information at the time of the forecast.

2006 forecast detail

The forecast for 2006 is presented in a similar way to the 2007 forecast for comparison. The forecast was made in an operational environment, with no use of observed data beyond 1 June 2006. It can be seen from figures 8 and 9 that the forecast showed that probabilities were close to the climatological expectation for storm numbers with a slight skew to active i.e. there was not a strong signal for an active or a quiet season. The climatological average for the 1987-2005 period is 11.9 tropical storms. Table 3 shows the predicted chance for more or fewer storms than average was approximately 50/50.

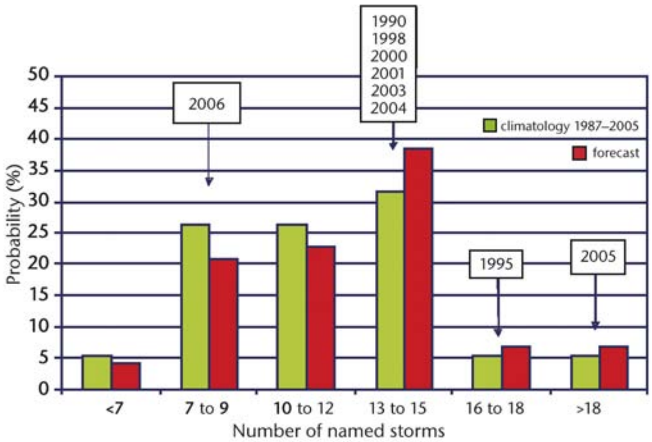


Figure 8: Probability forecast of the number of Atlantic sector named storms for July to November 2006. Bars in green represent climatological frequencies derived from 1987-2005. Bars in red are forecast probabilities from an ensemble 41 climate model forecasts. The forecast suggests near climatological probabilities, with a slight skew to the higher categories. The observed number of storms was nine.

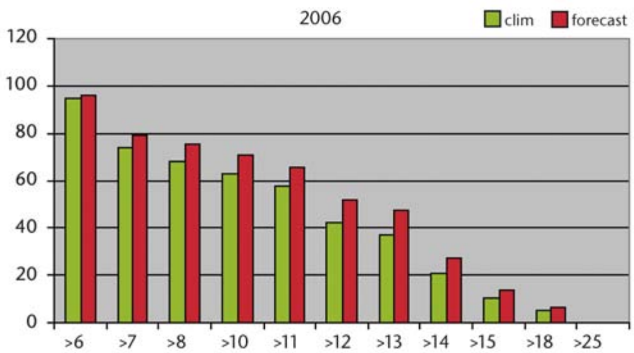


Figure 9: Cumulative probability forecast of the number of Atlantic sector named storms for July to November 2006. Bars in green represent climatological frequencies derived from 1987-2005. Bars in red are forecast probabilities from an ensemble 41 climate model forecasts. Note there is no ">9" category as this frequency was not observed in the climatological period – this implies the same probability as for ">8" storms.

Exceedance of number of storms	Climate probability 1987-2005	Forecast probability 2006
>6	94.7	95.8
>7	73.7	79.2
>8	68.4	75.0
>10	63.2	70.4
>11	57.9	65.8
>12	42.1	52.1
>13	36.8	47.5
>14	21.1	27.1
>15	10.5	13.6
>18	5.3	6.8
>25	0.0	0.0

Table 3: Cumulative probabilities for the exceedance of threshold numbers of storms for the North Atlantic sector for July-November 2006. Note there is no ">9" category as this frequency was not observed in the climatological period – this implies the same probability as for ">8" storms. Forecast probabilities are given to 1 decimal point to help preserve a smooth distribution. Accuracy to 1 decimal point is not implied.

2005 forecast detail

The forecast for 2005, unlike 2006, had a very strong signal for an active season. The forecast was made in an operational environment with no use of observed data beyond 1 June 2005.

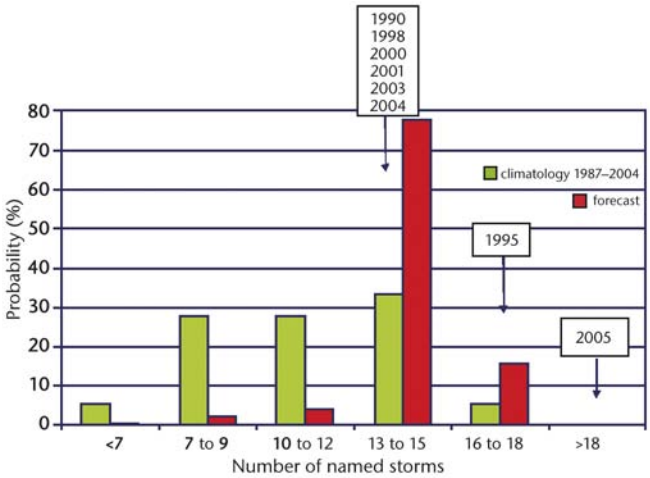


Figure 10: Probability forecast of the number of Atlantic sector named storms for July to November 2005. Bars in green represent climatological frequencies derived from 1987-2004. Bars in red are forecast probabilities from an ensemble 41 climate model forecasts. The forecasts indicate a strong bias towards the higher frequency categories, with a marked peak for the range 13-15 storms. The observed number was 25.

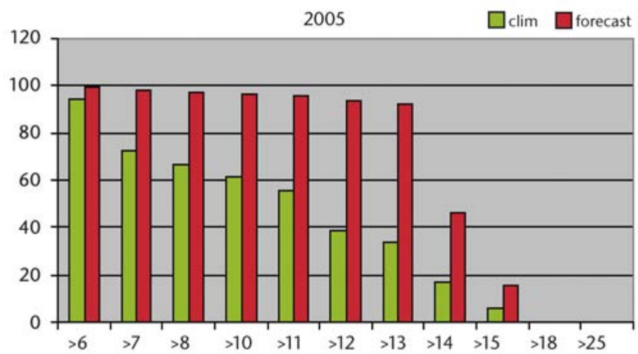


Figure 11: Cumulative probability forecast of the number of Atlantic sector named storms for July to November 2005. Bars in green represent climatological frequencies derived from 1987-2004. Bars in red are forecast probabilities from an ensemble 41 climate model forecasts. Note there is no ">9" category as this frequency was not observed in the climatological period – this implies the same probability as for ">8" storms.

Exceedance of number of storms	Climate probability 1990-2004	Forecast probability 2005
>6	94.4	99.6
>7	72.2	97.9
>8	66.7	97.5
>10	61.1	96.7
>11	55.6	95.8
>12	38.9	93.3
>13	33.3	92.5
>14	16.7	46.3
>15	5.6	15.4
>18	0.0	0.0
>25	0.0	0.0

Table 4: Cumulative probabilities for the exceedance of threshold numbers of storms for the North Atlantic sector for July-November 2005. Note there is no ">9" category as this frequency was not observed in the climatological period – this implies the same probability as for ">8" storms. Forecast probabilities are given to 1 decimal point to help preserve a smooth distribution. Accuracy to 1 decimal point is not implied.

Appendix B - forecast method and model details

Global seasonal forecasts are made each month to six months ahead using the Met Office seasonal prediction model. http://www.metoffice.gov.uk/. Each forecast starts from the observed state of the ocean, land and atmosphere on the first day of the month of issue - the 'initial conditions'. Unfortunately, the initial conditions are not known precisely (one reason is that observing stations/instruments are sparsely distributed in some regions), and individual forecasts can be very sensitive to small uncertainties in the initial conditions. The sensitivity to initial conditions is taken into account by making a number of predictions each with slight variations to the starting conditions which reflect our uncertainty in the initial state. This technique generates an 'ensemble' of forecasts with each individual forecast referred to as an ensemble 'member'. The forecast products are created by analysing the output from all the ensemble members.

The Met Office seasonal dynamical prediction system

The seasonal prediction system is a coupled ocean-atmosphere General Circulation Model (GCM), similar to the HadCM3 climate version of the Met Office Unified Model (UM), with a number of enhancements for seasonal forecasting purposes. Details of the model physics and discussion of the performance of HadCM3 can be found in Gordon et al. Climate Dynamics (2000).

The atmospheric component of the system (see Pope et al. Climate Dynamics (2000) for a description), has a horizontal resolution of 3.75° east-west and 2.5° north-south, and 19 vertical levels. The oceanic component has 40 vertical levels (compared to 20 in HadCM3), zonal grid spacing at 1.25°, and meridional grid spacing of 0.3° near the equator increasing to 1.25° poleward of the mid-latitudes (compared to 1.25° resolution east-west and north-south in HadCM3). A coastal tiling scheme has been included, to enable specifications of the land-sea mask at the ocean resolution. Like HadCM3, the seasonal coupled GCM contains no flux corrections or relaxations to climatology.

Each forecast requires initial ocean, land and atmosphere conditions. Land and atmosphere conditions are specified from atmospheric analyses that are produced separately for weather prediction purposes. The ocean initial conditions are taken from ocean analyses generated specifically for seasonal forecasting, using the ocean Global Climate Model component of the system. The ocean Global Climate Model is run using surface fluxes of momentum, heat and water prescribed from atmospheric analyses, while assimilating sub-surface ocean obervational data, with temperatures in the top layer(s) constrained to be close to surface observations.

Each month, forecasts are run with starting conditions at the beginning of the month, to create a 41-member ensemble. The different ensemble members are created by perturbing the ocean state, through windstress perturbations throughout the ocean analysis stage and initial sea surface temperature perturbations.

Tropical storms prediction

In addition to seasonal forecasts of temperature and precipitation, the seasonal prediction model (GloSea) is used to forecast the number of tropical storms forming over each of the tropical ocean basins out to six months ahead.

The predictions are based on GloSea representation of dynamical and physical processes characteristic of tropical storms, and are achieved by counting the frequency of tropical storms in the model forecasts.

As the dynamical model grid does not fully resolve tropical storms, numbers are calibrated using behaviour in retrospective forecasts for past years. The method used is identical to that in Vitart et al. 2007 wherein GloSea is referred to as model 2.

Studies have shown that GloSea and other European models have substantial skill in predicting the number of tropical storms during the North Atlantic season, nominally June to November (see e.g. Vitart et al. 2007 where GloSea is model 2). Importantly, the models distinguished between the exceptionally active season of 2005 and the below-normal activity of the 2006 season. This marked inter-annual change was missed by a number of statistical prediction methods, which have to date formed the basis of most issued predictions.

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For further details or feedback, please contact:
consulting@metoffice.gov.uk

Please note that our Hurricane predictions are inexact; they are based upon the evolving knowledge of the weather and climate research community at the time they are made and their accuracy cannot be guaranteed.

Met Office FitzRoy Road Exeter EX1 3PB United Kingdom
Tel: +44 (0)1392 885680 Fax: +44 (0)1392 885681
Email: consulting@metoffice.gov.uk www.metoffice.gov.uk/consulting