Met Office
Hadley Centre

Met Office tropical storm forecast for the North Atlantic

July to November 2009

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Contents

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Executive Summary

The Met Office coupled ocean-atmosphere seasonal prediction system (known as GloSea) is used to forecast the number of tropical storms (including hurricanes) and Accumulated Cyclone Energy (ACE) index for the Atlantic sector in the period July to November 2009. Recent research has shown that the skill of dynamical systems such as GloSea is challenging or even overtaking that of statistical prediction methods – which to date have formed the basis of most published predictions.

The GloSea model is a physical-dynamical representation of the ocean-atmosphere system, and the number of storms developing in the prediction can be counted to form the basis of the forecast. An ensemble forecasting approach is used in which many parallel predictions are made that sample the forecast uncertainty. This allows a detailed breakdown of the probability of various ranges of storm activity, an advantage that is not readily available from statistical methods.

The forecast is presented in two ways: a 'best estimate' and two-standard-deviation range, and a detailed graphical and tabulated breakdown of the probability of activity ranges and thresholds.

For the 2009 season a best estimate of 6 storms is predicted for the July to November period, with a two-standard-deviation range of 3–9. The detailed breakdown indicates a very high probability (~100%) of 15 or fewer storms (15 were observed last year), and a high probability (85.4%) of 9 or fewer storms (9, observed in 2006, is the lowest number observed in any of the last 5 years).

The best estimate for the ACE index is 60, with a two-standard-deviation range of 40–80. The predicted probabilities that the ACE index will be lower than observed last year and in any of the last 5 years are 97.6% and 78% respectively.

Important features of this year's GloSea forecast are the development of weak-to-moderate El Niño conditions, and the maintenance of below-normal sea-surface temperature in the tropical North Atlantic. Both these factors will contribute to the raised probabilities for an inactive season. The dynamical prediction models of most other international centres also predict an El Niño-type development in the tropical Pacific, adding confidence to the predicted raised probability of below-normal activity for the North Atlantic 2009 season.

1. Introduction

The prediction tool used for this forecast is the Met Office Global Seasonal forecasting system (GloSea). GloSea uses a dynamical numerical model of the climate system with full interactive coupling between the ocean and atmosphere. The number of tropical storms developing in the GloSea seasonal predictions can be counted, and this forms the basis of the forecast. Importantly, GloSea is skilful at predicting the evolution of large-scale ocean-atmosphere processes and interactions that drive the degree of tropical storm activity, and this gives rise to skilful forecasts of tropical storm numbers. Use of dynamical prediction systems represents a new departure in operational tropical storm forecasting. Traditionally such forecasts have been made using statistical prediction methods. Statistical methods do not model atmospheric processes, but are based on past relationships between storm numbers and preceding observed conditions (e.g. pre-season sea surface temperature (SST) patterns).

Recent research has shown that, for predictions of tropical storm frequency, the skill of dynamical systems such as GloSea is now challenging or even overtaking that of some well-known statistical methods (Vitart, 2006 and Vitart *et al.*, 2007). In particular, GloSea successfully predicted 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.

This report presents a forecast of North Atlantic tropical storm numbers and Accumulated Cyclone Energy (ACE) index (Bell *et al.*, 2000) for the period July to November 2009. The forecast is presented in two ways: a ‘best estimate’ and two-standard-deviation range, and a detailed breakdown of the probability of activity ranges and thresholds.

Last year the Met Office seasonal forecast was for 15 storms in the July to November period, with a 70% probability range of 10–20; in the event, 15 storms were observed to occur.

2. Method outline

The GloSea seasonal prediction model is initialised with an analysis of the global oceans, land and atmosphere (see Appendix A for more details). The analysis provides the model with a description of the current climate state, an important factor in obtaining realistic predictions. The forecast presented here is derived from a GloSea prediction initialised on 1st June 2009, and run to 6 months ahead – allowing prediction of the number of storms occurring in the July to November period. The starting conditions are varied slightly to make 41 individual predictions. The 41 predictions are collectively called an ‘ensemble’ and each individual prediction is called an ensemble ‘member’. 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 single ‘best estimate’ forecast that is the basis of our public forecast. The ‘best estimate’ is a simplification that does not take full account of the forecast uncertainties addressed by probability forecasts such as those provided in this report.

Because the dynamical model grid does not fully resolve relatively small features such as tropical storms, a calibration procedure is applied which adjusts the number of detected storms. The calibration factor is derived by comparing the number of predicted storms with the number of observed storms over a series of retrospective forecasts.

Probabilities that the number of storms will be within ranges or ‘categories’ (e.g. 10 to 12 storms) can be derived by counting the proportion of the 41 ensemble members that predict the number of storms to fall in that range. Probabilities that the number of storms will exceed a threshold (e.g. the forecast probability for more than 12 storms) can be derived in a similar way.

An important index of seasonal tropical storm activity is the Accumulated Cyclone Energy (ACE) index, which is a measure of the collective intensity and duration of tropical storms during the season (Bell *et al.*, 2000). Forecasts of ACE index are also presented here in addition to forecasts of tropical storm numbers. The forecasts of ACE index are derived using model-predicted wind speeds, and include a calibration procedure similar to that applied for the forecasts of storm numbers (based on comparing predicted and observed ACE index values over a retrospective forecast period). Probability forecasts for categories of ACE index are presented in a similar way to the forecasts for storm numbers.

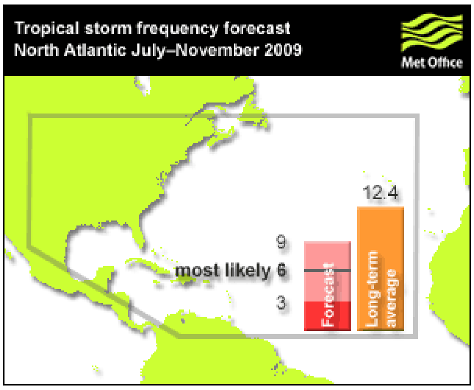
The forecast probabilities are based purely on the forecast ensemble distribution, without any adjustment to take account of biases in predicted probabilities noted in retrospective forecasts. Experience has shown that unadjusted probabilities show the predicted skews (relative to the climate distribution) more clearly than bias-adjusted probabilities. However, because the predicted probabilities are likely to have biases, the precise values should be treated with caution.

Because of small changes in the calibration method since last year's forecast, re-forecasts for the 2005, 2006, 2007 and 2008 seasons have been made using the same method used for the 2009 season and are provided for comparison with the 2009 forecast in Appendix B.

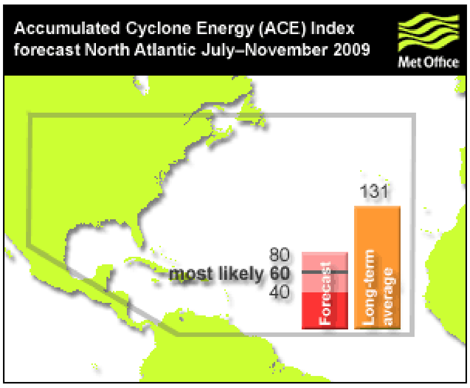
3. The public forecast issued on 18th June 2009

The public forecast is based on the ensemble-mean prediction, with a range defined by plus and minus one standard deviation of the 41 ensemble members about the ensemble mean (referred to hereafter as the two-standard-deviation range). This yields 6 tropical storms as the 'best estimate' for the number occurring in the North Atlantic during the July to November 2009 period, with a range of 3 to 9. Six storms represents below normal activity relative to the 1990–2005 long-term average of 12.4 (Fig. 1a). The last time the seasonal total was as low as 6 storms was in 1992. There has been no season in the period 1987–2008 with fewer than 6 storms (1987–2008 is the period used as baseline for the analysis in section 4).

For the ACE index (Fig. 1b) the ensemble-mean prediction is 60 (units are 10^4 knots^2) with a two-standard-deviation range of 40 to 80 which, consistent with the low number of predicted storms, represents below normal activity relative to the 1990–2005 long-term average of 131.



a)



b)

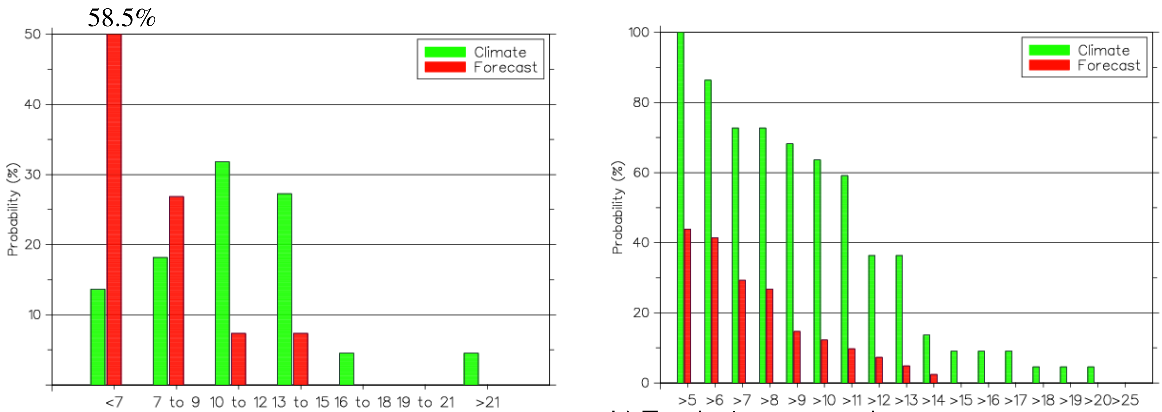
Figure 1*: Met Office publicly issued tropical storm forecasts for the North Atlantic sector, July–November 2009. a) predicted number of storms, b) predicted ACE index*

4. Forecast detail
4.1 Tropical storm numbers

Figures 2a and b and Table 1 show probability forecast information, derived from the 41-member ensemble, and provide additional detail on the ensemble mean forecast and two-standard-deviation range (Fig. 1). Figure 2a provides the forecast probability that the number of storms will be within given ranges, while Figure 2b and Table 1 provide forecast probabilities for exceeding a given number of storms. The equivalent observed frequencies, based on the 1987–2008 period and taken from the NOAA HURDAT dataset (Jarvinen *et al.,* 1984), are also shown. The forecast and observed probabilities are based directly on counts of storms and the distribution is not smoothed or fitted to a functional form. The main features of the forecast probabilities are summarised below.

- The forecast probability distribution (red) is strongly shifted to the less active categories relative to the climate distribution (green). The <7 category is the mode of the forecast distribution, whereas the 10–12 category is the mode in climatology (the mode is the category with the highest probability). The <7 category includes the ensemble mean (6).

- The skew in the forecast distribution to the less active categories is compensated by reduced probability (relative to climatology) of all categories from 10–12 and higher. The predicted probability of the 16–18 category and higher categories is technically zero, as none of the 41 ensemble members predicts more than 15 storms. However, as the model ensemble does not fully capture all the prediction uncertainties, there may be a finite but very small probability of the occurrence of these categories.
- The predicted probability of 15 storms (the number observed last year) or fewer is very high (100%, compared to a climate chance of 90.9% - but see comment above). The predicted probability of 9 storms (as observed in 2006 and the lowest number observed in the last 5 years) or fewer is 85.4%, compared to a climate chance of 31.8% (Table 1).
- Predictions suggest better than even odds (approximately 55/45) of 5 storms or fewer (Table 1).



a) Tropical storm numbers b) Tropical storm numbers

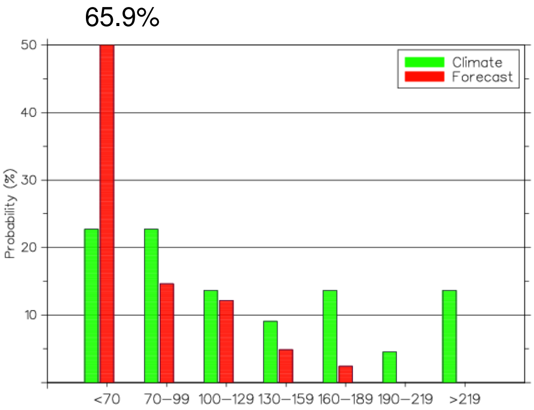
***Figure 2**: a) Probability that the number of Atlantic sector tropical storms, in the July to November 2009 period, will lie within given ranges: red bars = forecast probabilities for 2009; green bars = climatological frequencies (1987–2008) derived from the NOAA HURDAT dataset. b) as a), but showing the probability that the number of tropical storms will exceed a given number. Note: the forecast and climatological probabilities appear 'stepped' because they are based directly on storm counts, the distribution has not been smoothed or fitted to a functional form.*

Number of storms	Climate Probability 1987–2008	Forecast Probability 2009
>5 (≤5)	100.0 (0.0)	43.9 (56.1)
>6 (≤6)	86.4 (13.6)	41.5 (58.5)
>7 (≤7)	72.7 (27.3)	29.3 (70.7)
>8 (≤8)	72.7 (27.3)	26.8 (73.2)
>9 (≤9)	68.2 (31.8)	14.6 (85.4)
>10 (≤10)	63.6 (36.4)	12.2 (87.8)
>11 (≤11)	59.1 (40.9)	9.8 (90.2)
>12 (≤12)	36.4 (63.6)	7.3 (92.7)
>13 (≤13)	36.4 (63.6)	4.9 (95.1)
>14 (≤14)	13.6 (86.4)	2.4 (97.6)
>15 (≤15)	9.1 (90.9)	0.0 (100.0)
>16 (≤16)	9.1 (90.9)	0.0 (100.0)
>17 (≤17)	9.1 (90.9)	0.0 (100.0)
>18 (≤18)	4.5 (95.5)	0.0 (100.0)
>19 (≤19)	4.5 (95.5)	0.0 (100.0)
>20 (≤20)	4.5 (95.5)	0.0 (100.0)
>25 (≤25)	0.0 (100.0)	0.0 (100.0)

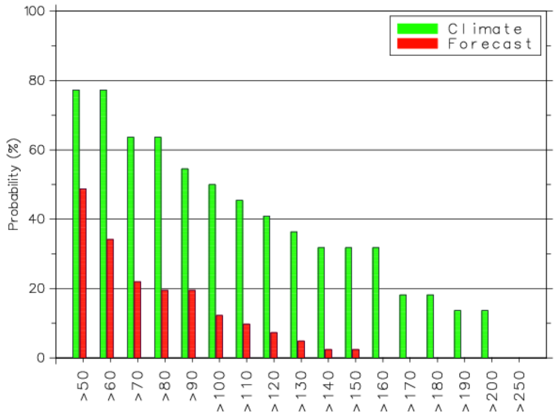
***Table 1**: The climate and forecast probabilities that the number of Atlantic sector tropical storms will exceed a given threshold. The complementary event and its climate and forecast probabilities are given in brackets. Note: probabilities are given to one decimal place to help preserve a smooth distribution. Accuracy to one decimal place is not implied.*

4.2 Accumulated Cyclone Energy (ACE) index

For the July to November 2009 period the predicted ensemble-mean ACE index is 60 (units are 10^4 $knots^2$) with a two-standard-deviation range of 40–80, which represents below-average activity relative to the 1990–2005 long-term average of 131. The probability distributions (Figs. 3a and b) show similar skew characteristics to those of the storm number probabilities (Figs. 2a and b), with a strongly enhanced probability of a particularly inactive season (ACE index <70) and reduced probability (relative to climatology) of all other categories. The forecast probability that the ACE index for the July to November 2009 period will be equal to or lower than last year's value (141) is ~97.6%, compared to a climate chance of ~68.2% (based on nearest tabulated values, Table 2). The predicted probability of an ACE index equal to or lower than the lowest observed value in the last 5 years (71) is ~78% compared to a climate chance of ~36.4% (based on nearest tabulated values, Table 2).



a) ACE index



b) ACE index

***Figure 3**: a) Probability that the Accumulated Cyclone Energy (ACE) index, in the July to November 2009 period, will lie within given ranges: red bars = forecast probabilities for 2009; green bars = climatological frequencies (1987–2008) derived from the NOAA HURDAT dataset. b) As a) but showing the probability that the ACE index for the July to November 2009 period will exceed a given value.*

ACE index	Climate Probability 1987–2008	Forecast Probability 2009
>50 (≤50)	77.3 (22.7)	48.8 (51.2)
>60 (≤60)	77.3 (22.7)	34.1 (65.9)
>70 (≤70)	63.6 (36.4)	22.0 (78.0)
>80 (≤80)	63.6 (36.4)	19.5 (80.5)
>90 (≤90)	54.5 (45.5)	19.5 (80.5)
>100 (≤100)	50.0 (50.0)	12.2 (87.8)
>110 (≤110)	45.5 (54.5)	9.8 (90.2)
>120 (≤120)	40.9 (59.1)	7.3 (92.7)
>130 (≤130)	36.4 (63.6)	4.9 (95.1)
>140 (≤140)	31.8 (68.2)	2.4 (97.6)
>150 (≤150)	31.8 (68.2)	2.4 (97.6)
>160 (≤160)	31.8 (68.2)	0.0 (100.0)
>170 (≤170)	18.2 (81.8)	0.0 (100.0)
>180 (≤180)	18.2 (81.8)	0.0 (100.0)
>190 (≤190)	13.6 (86.4)	0.0 (100.0)
>200 (≤200)	13.6 (86.4)	0.0 (100.0)
>250 (≤250)	0.0 (100.0)	0.0 (100.0)

***Table 2**: The climate and forecast probabilities that the ACE index for July to November 2009 will exceed a given threshold. The complementary event and its climate and forecast probabilities are given in brackets. Note: probabilities are given to one decimal place to help preserve a smooth distribution. Accuracy to one decimal place is not implied.*

5. Sea surface temperature predictions for the 2009 season

A large proportion of the inter-annual variability in North Atlantic tropical storm activity is linked to sea-surface temperature (SST) variability in the tropical Pacific Ocean (associated with the El Niño Southern Oscillation – ENSO) and in the tropical North Atlantic. The success of the dynamical model forecasts is rooted in good prediction skill for SST in these regions and also in an ability to correctly translate predicted SST variability into variability of tropical storm frequency – through representation of ENSO impacts on Atlantic vertical wind shear and through local SST impacts (Vitart *et al.*, 2007).

The GloSea ensemble-mean SST forecast for the August-September-October period, encompassing the climatological peak of the tropical storm season, is provided in Fig. 4. The forecast indicates above-normal SST in the tropical Pacific – indicating development of El Niño-type conditions. In contrast, below-normal SST is predicted in the so-called Main Development Region for tropical storms in the tropical North Atlantic (10˚N to 20˚N; 20˚W to 60˚W). El Niño conditions and below-normal SST in the tropical North Atlantic both tend to suppress North Atlantic tropical storm activity. Thus predicted SST anomalies in both regions favour suppressed North Atlantic tropical storm activity, and this is consistent with the strongly enhanced probability of a particularly inactive season seen in Figs. 2 and 3.

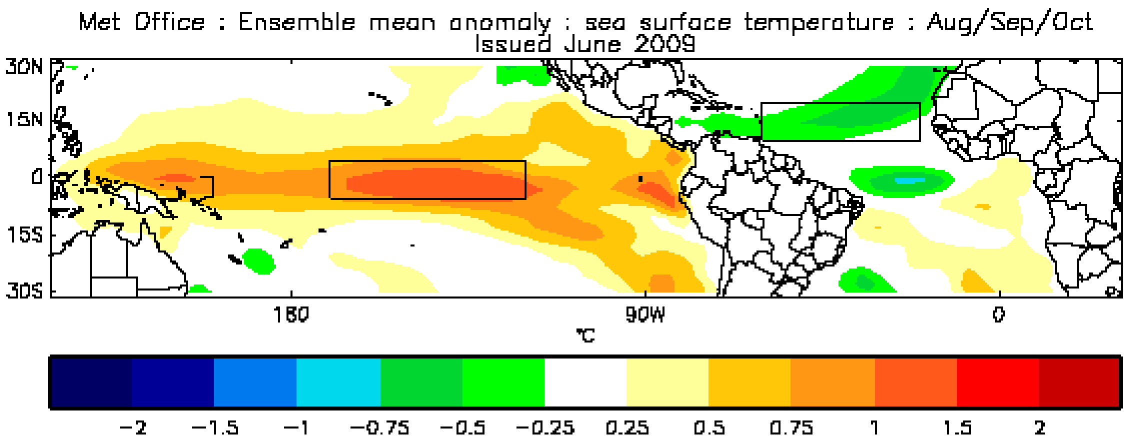


Figure 4*: Ensemble-mean sea-surface temperature anomalies for August-September-October predicted from June 2009. Anomalies are expressed relative to the 1987–2001 period. Note positive anomalies are predicted in the eastern tropical Pacific (the boxed area shown is the Niño3.4 region (5˚S to 5˚N; 120˚W to 170˚W) often used to monitor El Niño/La Niña development), and predominantly cool anomalies in the Main Development Region (shown boxed – 10˚N to 20˚N; 20˚W to 60˚W) in the tropical North Atlantic.*

The GloSea-predicted temporal evolution of tropical Pacific SST anomalies is shown in Fig. 5. GloSea predicts a warming of SST in the Niño3.4 region (often used to monitor El Niño development) with a peak in August, after which there is a slight cooling, but with ensemble members still centred around an anomaly of about +1.0˚C for September and later months (Fig. 5). The GloSea forecast may be compared with a range of other dynamical and statistical predictions of tropical Pacific SST in Fig.6, from the website of the International Research Institute for Climate and Society (IRI). Figure 6 shows that all the dynamical models considered predict a warming of SST with a median anomaly of about +1.0℃ for the August-September-October period. Some statistical models also predict a warming of SST consistent with that of the dynamical models, although three statistical models suggest maintenance of near-neutral conditions.

An international consensus, coordinated by the World Meteorological Organisation (WMO) and which includes interpretation of dynamical output from many prediction models, currently favours a substantially enhanced probability of El Niño-type conditions developing in the latter half of 2009. This consensus supports the GloSea prediction, and adds confidence to the predicted raised probabilities for below-normal North Atlantic tropical storm activity.

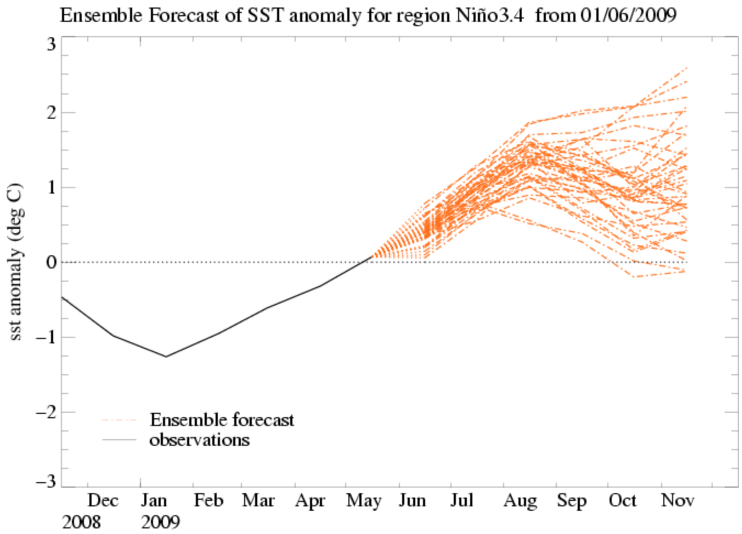


***Figure 5**: GloSea forecast for Niño3.4 (5˚S to 5˚N; 120˚W to 170˚W) monthly SST anomalies initialised 1st June 2009. Anomalies are relative to the 1987–2001 period. Red lines show the predicted SST evolution of the individual GloSea ensemble members. The black line shows observed anomalies. The spread in the ensemble 'plume' provides a measure of the prediction uncertainty.*

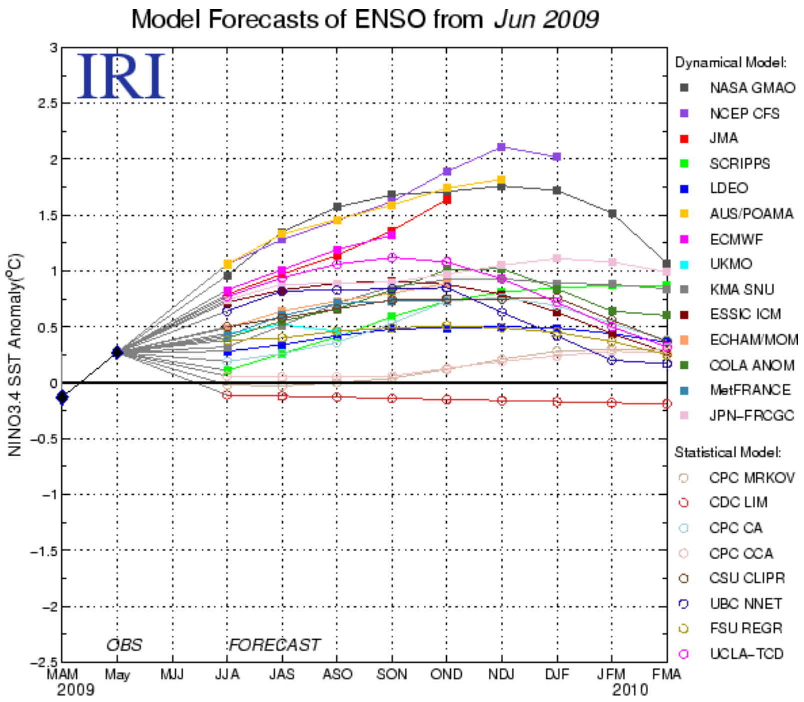


***Figure 6**: Forecasts of tropical Pacific SST anomalies from a range of dynamical and statistical prediction systems (from IRI).*

6. Forecast verification

Ensemble mean retrospective forecasts ('re-forecasts') for the period 1987–2008 are compared with observations in Fig. 7 for both storm numbers and ACE index. The re-forecasts are made with the same method used for the 2009 forecast, except that a smaller 15-member ensemble is used. The so-called cross-validation procedure is employed in which no observed information for the year being predicted is used in the calibration process – in order that the re-forecasts are consistent with the constraints of an operational environment. More detailed re-forecast information is provided for 2005–2008 in Appendix B. The inter-annual variability of storm numbers (Fig. 7a) and ACE index (Fig. 7b) is generally well predicted by GloSea; correlations with observations are 0.63 and 0.70 respectively (Note: higher correlations for GloSea predicted storm numbers are found for the shorter period, 1993–2006 – see Table 3). The improved calibration method used this year has increased the correlation for ACE index (which was 0.62 with the previous method). The active seasons of 1995 and 2005 are generally well signalled in the forecast storm numbers (Fig. 7a). The observed number in 2005 (24) is underestimated by the ensemble mean (18), but is within the predicted range (8 to 29) (see Appendix B, Table 5). Relatively high values of ACE index are successfully identified for 1989, 1995 and 1998 (Fig. 7b), but the ensemble-mean ACE index forecast for 2005 is less successful, showing a substantial under-prediction (but see the detailed analysis in Appendix B).

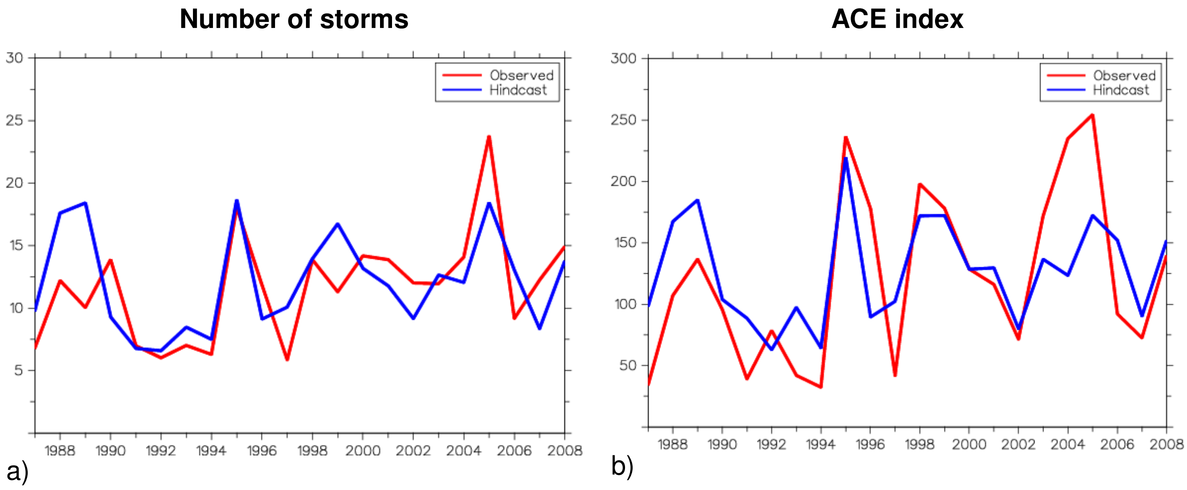


Figure 7*: Ensemble-mean forecasts (blue) and observations (red) of a) tropical storm numbers and b) ACE index for July to November periods 1987–2008. Forecasts are initialised in June. Observed values are from the NOAA HURDAT dataset.*

The GloSea ensemble-mean forecasts of tropical storm numbers perform well in comparison with the statistical forecasts of the Colorado State University (CSU) and University College London's Tropical Storm Risk (TSR). A published comparison of scores for the period 1993–2006 (Vitart *et al.*, 2007) is shown in Table 3. The GloSea correlation score in Table 3 was calculated using a slightly different calibration method in use at the time, however a very similar value (0.76) is achieved with the revised calibration method used for the 2009 forecast. The higher GloSea correlation score (relative to the statistical methods) 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 in closer accord with observations.

	Met Office (GloSea)	Tropical Storm Risk	Colorado State University
Correlation (Best = 1.0)	0.78	0.65	0.39
RMS error (Best = 0.0)	3.65	4.70	4.76

***Table 3**: Correlation and root mean square error (RMS) performance measures for the number of Atlantic tropical storms predicted by the Met Office dynamical seasonal model, TSR and CSU, compared with the observed number of tropical storms during the whole Atlantic season over the period 1993–2006. Adapted from Vitart et al., 2007. Note: the GloSea correlation score for this period obtained with the revised calibration method used for the 2009 forecast is 0.76.*

The baseline period is too short to allow a meaningful verification of probability forecasts for each of the 7 categories of activity used (e.g. Fig. 2a) – since the sample size for each category is small. However, verification has been performed for broader categories defined as fewer than 10 storms and more than 13 storms. Relative Operating Characteristic (ROC) scores for events defined by these thresholds are shown in Table 4. The ROC score is a standard verification measure recommended by the World Meteorological Organisation for assessment of probabilistic forecasts. The value of the ROC score may be interpreted as the frequency with which the forecasts correctly discriminate between the event and the non-event (e.g. years with fewer than 10 storms from years with 10 storms or more). Thus a ROC score of 1.0 indicates perfect skill (100% success rate), while a score of 0.5 indicates no skill (no better than random guessing). The ROC scores (Table 4) indicate a strong ability to discriminate for the two events, with best skill for the relatively inactive years which are correctly discriminated in 84% of cases.

	No. of storms < 10	No. of storms > 13
ROC score	0.84	0.73

***Table 4**: Relative Operating Characteristic (ROC) scores for GloSea probabilistic forecasts for the events: 'fewer than 10 storms', and 'more than 13 storms' in the July–November period. A ROC score of 1.0 indicates perfect skill, while a score of 0.5 indicates the forecasts are no better than random guessing. Scores are calculated using retrospective forecasts for 1987–2007.*

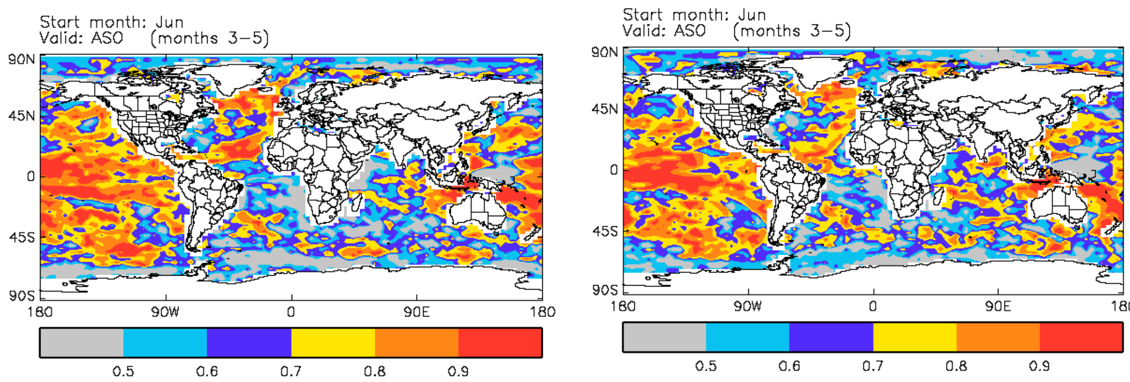
As mentioned previously, the success of the dynamical model forecasts is rooted in good prediction skill for SST in the equatorial Pacific and tropical North Atlantic oceans. Measures of prediction skill for June forecasts of August-September-

October SST anomalies are provided for ensemble-mean forecasts in Table 5 and for probability forecasts in Fig. 8.

	Equatorial Pacific (Niño3.4 region)	Tropical North Atlantic
Correlation Best = 1.0	0.84	0.88
RMS error Best = 0.0	0.67˚C	0.13˚C

Table 5: C*orrelation and root mean square error performance measures for ensemble-mean predictions of August-September-October SST in the equatorial Pacific* (5˚S to 5˚N; 120˚W to 170˚W) *and tropical North Atlantic* (10˚N to 30˚N; 5˚W to 85˚W). *Results are from retrospective forecasts for the 1987–2005 period.*

Ensemble-mean forecasts and observations have a correlation exceeding 0.8 in both regions (Table 5). Probability forecasts for SST anomalies, based on the ensemble distribution, also show good skill. This is illustrated in Fig. 8, which provides a global assessment of retrospective probabilistic forecasts for August-September-October SST below the lower tercile ('cold' SST events – Fig. 8a) and above the upper tercile ('warm' SST events – Fig. 8b). The skill measure used is the ROC score calculated and plotted at each model ocean grid-point. ROC scores of 0.7 and above are shaded yellow to red, and correspond to regions with relatively high skill levels. It may be seen that the equatorial Pacific and tropical North Atlantic, where the seasonal model predicts, respectively, warm and cold anomalies for the 2009 season, are both regions where the model has demonstrated a good performance track record (ROC scores exceed 0.7) for both warm and cold SST events. Note that skill in the tropical North Atlantic is highest and most widespread for 'cold' SST events – consistent with the higher ROC scores for prediction of inactive (compared to active) tropical storm seasons (Table 4).



a) b)

Figure 8*: Relative Operating Characteristic (ROC) scores for June probability forecasts of August-September-October SST (a) below the lower tercile, (b) above the upper tercile. Scores are evaluated using retrospective forecasts for the 1987–2002 period. 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 (perfect forecasts would attain a ROC score of 1.0). 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 – where in this case the event is SST in a given tercile category).*

7. Future forecasts and feedback

Long-range tropical storm forecasts are important for many market sectors. Given this, the Met Office is committed to developing a full range of tropical-storm forecast products in a way that best meets its customers' needs. Scientific rigour is key – 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, due to its operational weather and climate responsibilities. Forecasts from the Met Office's global short-range model predicted the formation of sub-tropical storm Andrea in May 2007 a full 60 hours before any other model. The short-range model has also proved its worth in predicting hurricane landfall (accurately predicting the landfall of Katrina in 2005 12 hours ahead of other models). Track forecast accuracy for the North Atlantic, in 2007 and 2008 combined, was better than in any previous two year period.

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 Met Office Hadley Centre has developed new dynamical climate prediction models for the Intergovernmental Panel on Climate Change assessment, and these are now being tested on timescales from seasons to decades – all with a risk-based probabilistic and verifiable approach. In this way, the full range of climate change impacts will increasingly be included in Met Office forecasts in the future.

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 – please contact: **consulting@metoffice.gov.uk**

Appendix A – GloSea: the Met Office global seasonal dynamical prediction system

The GloSea seasonal prediction system uses a coupled ocean-atmosphere General Circulation Model (GCM), similar to the HadCM3 climate version of the Met Office Unified Model, 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*. (2000). A performance assessment for temperature predictions using GloSea may be found in Graham *et al*. (2005).

The atmospheric component of the system (see Pope *et al*. (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, east-west grid spacing at 1.25°, and north-south 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 which enables specification of the land-sea mask at the ocean resolution, rather than the coarser atmosphere resolution. This allows a relatively detailed representation of the land-sea boundaries – which can be important in the evolution of SST anomalies. Like HadCM3, the seasonal coupled GCM contains no flux corrections or relaxations to climatology.

Each forecast requires initial ocean, land and atmosphere conditions. The 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 GCM component of the system. To generate the ocean analyses, the ocean GCM is run using surface fluxes of momentum, heat and water prescribed from atmospheric analyses, while assimilating sub-surface ocean observational data, with temperatures in the top layers constrained to be close to surface observations.

GloSea forecasts to 6 months ahead are made each month using initial conditions valid for the beginning of the month. The initial conditions are perturbed to create starting conditions for the 41-member ensemble. The perturbations are created during the construction of the ocean analysis by varying the surface momentum fluxes by amounts that represent the observed uncertainty in this quantity. Perturbations are additionally applied to SST, again to represent the observed uncertainty in observation of SST. Over the 6-month forecast the evolution of the 41 individual members will diverge. The spread in the forecast represents the prediction uncertainty arising from uncertainty in the initial conditions.

Next year's tropical storm forecast will be produced using an upgraded version (version 4) of the seasonal prediction system. The new system, GloSea4, is a fundamental change on the present system. It uses HadGEM3, the new Met Office Hadley Centre (MOHC) climate model, which has improved flow dynamics and improved representation of physical processes. In recognition of the growing importance of seasonal prediction, the new system is fully integrated within the development cycle of the Met Office family of models covering prediction on all timescales. This means that the development and performance of GloSea4 forecasts will benefit from improvements in the models for other timescales, and vice versa – giving good potential for improving the skill of seasonal forecasts, including tropical storm forecasts.

Some key facts on GloSea4 are summarised below.

GloSea4:

- uses HadGEM3, the new MOHC coupled ocean-atmosphere climate model (the present system uses HadCM3)
- has enhanced atmospheric horizontal resolution relative to the current system: 1.875° east-west and 1.25° north-south (compared, respectively, to 3.75° and 2.5° for the present system)
- has enhanced atmospheric vertical resolution relative to the present system (38 levels vs 19 levels).

Appendix B – Equivalent detailed retrospective forecast information for 2005–2008

Re-forecasts for the last four Atlantic seasons (July to November) are provided here for comparison with the 2009 forecast. The re-forecasts have been made using the same method as for the 2009 forecast, with the exception that a smaller 15-member ensemble is used for the 2005 forecast, rather than the 41-member ensemble used since 2006. Only information that would have been available in an operational real-time environment has been used. Because of small changes to the calibration method this year, the values differ in some instances from those provided in last year's report and in the 2007 and 2008 operational forecasts.

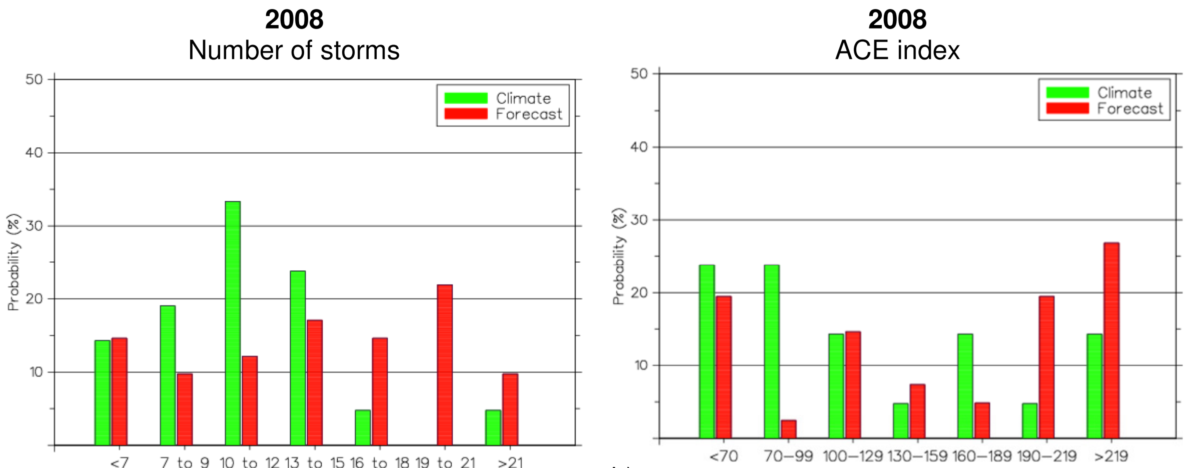
For 2008 the ensemble-mean prediction of 15 storms exactly matches the number of observed storms. In contrast, the ensemble-mean prediction for ACE index is too high, with the observed value of 141 below the predicted range of 154–201 (Table 6). The probability forecasts give accurate guidance in favouring activity greater than the climate mode, both for tropical storm numbers and for ACE index (Figs. 9a and b). However, the most likely category overestimates the observed activity in both cases.

For 2007 the observed number of storms (12) was within the two-standard-deviation forecast range of 6–13 (Table 6). The 2007 season was notable for the relatively low ACE index considering the near-normal number of storms that occurred – resulting from a predominance of relatively weak short-lived storms. The observed low ACE index (71) was within the predicted range of 61–102 (Table 6), and the potential for a low value was clearly indicated in the probability forecast for ACE index (Fig. 10b), which showed an enhanced probability (nearly twice the climatological chance) of an ACE index of less than 70.

The contrast between the exceptionally active 2005 season (24 storms observed) and the near-average 2006 season (9 storms observed) was well captured by the forecast probability distributions. For 2005 the peak in forecast probability distribution is in the >21 category (Fig. 12a), while for 2006 the peak forecast probability is for the 7–9 category (Fig. 11a). Thus in both years the category predicted as most likely was observed. The observed difference between the 2005 and 2006 seasons is also captured, to a degree, in the ACE index forecasts. For 2005 (Fig. 12b), the largest predicted probability is for the 100–129 ACE index category, but there is a strong secondary peak for the >219 category (the observed value was 257). In contrast, predicted probabilities for the 2006 season (Figs. 11b) show little skew and the 70–99 category (which contains the observed value of 91) had the highest predicted probability (and largest predicted enhanced chance over the climatological chance).

	Number of storms			ACE index		
	EM	2 sd range	Observed	EM	2 sd range	Observed
2008	15	11–19	15	180	154–206	141
2007	9	6–13	12	81	61–102	71
2006	13	10–17	9	136	112–161	91
2005	18	8–29	24	174	114–235	257

***Table 6**: Ensemble mean (EM) forecasts and observations for 2005–2008 July to November tropical storm numbers and ACE index. Forecasts are initialised in June and are made using identical methods to those used for the 2009 forecast. (Note the 2005 forecast used a smaller ensemble of 15 members.) Also, the ensemble-mean values and two-standard-deviation ranges for 2007 and 2008 differ, in some cases, from the values issued operationally because of small changes to the forecast calibration. Storm numbers and ACE index are derived from the NOAA HURDAT dataset and may differ from values published with our public website forecast.*



a) b)

***Figure 9**: a) Forecast probability that the number of Atlantic sector tropical storms, in the July to November 2008 period, will lie within given ranges. Red bars indicate the forecast probabilities for 2008; green bars the climatological frequencies derived from the NOAA HURDAT observation dataset, 1987–2007. b) As a), but for ACE index.*

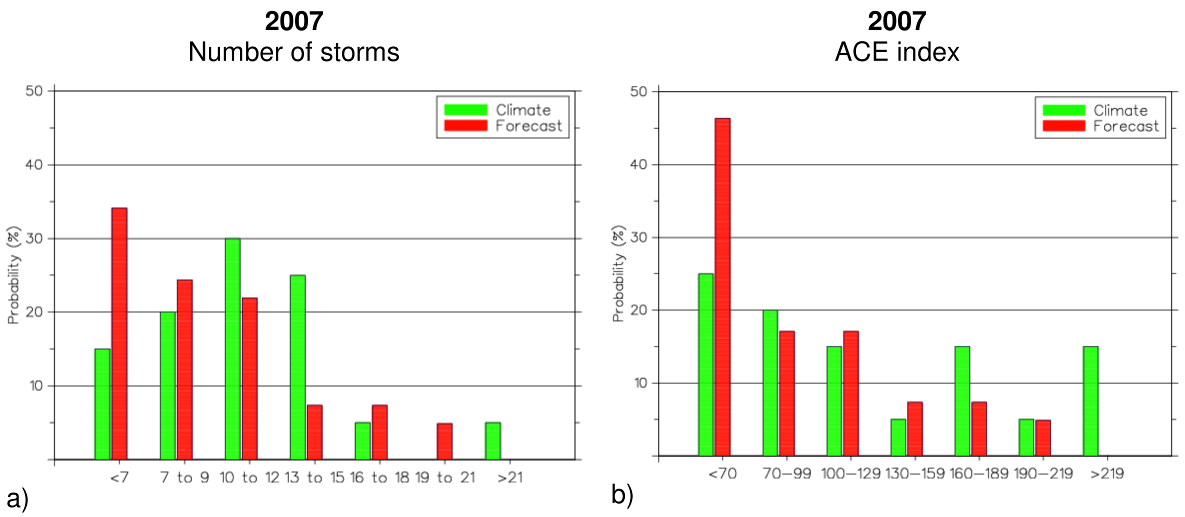


Figure 10*: As Fig. 9, but for 2007. Climatological frequencies are based on 1987–2006.*

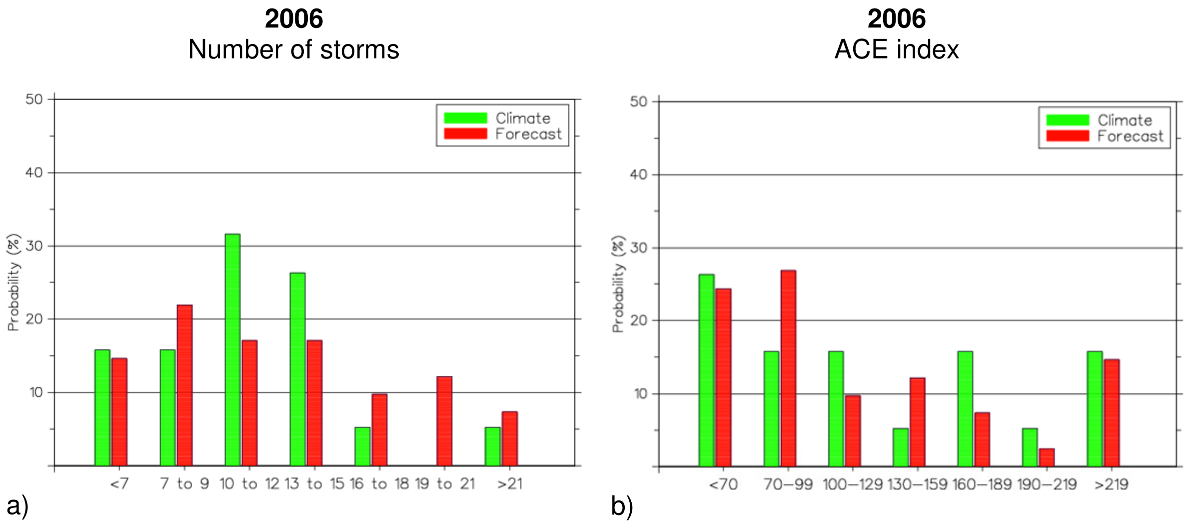


Figure 11*: As Fig. 9, but for 2006. Climatological frequencies are based on 1987–2005.*

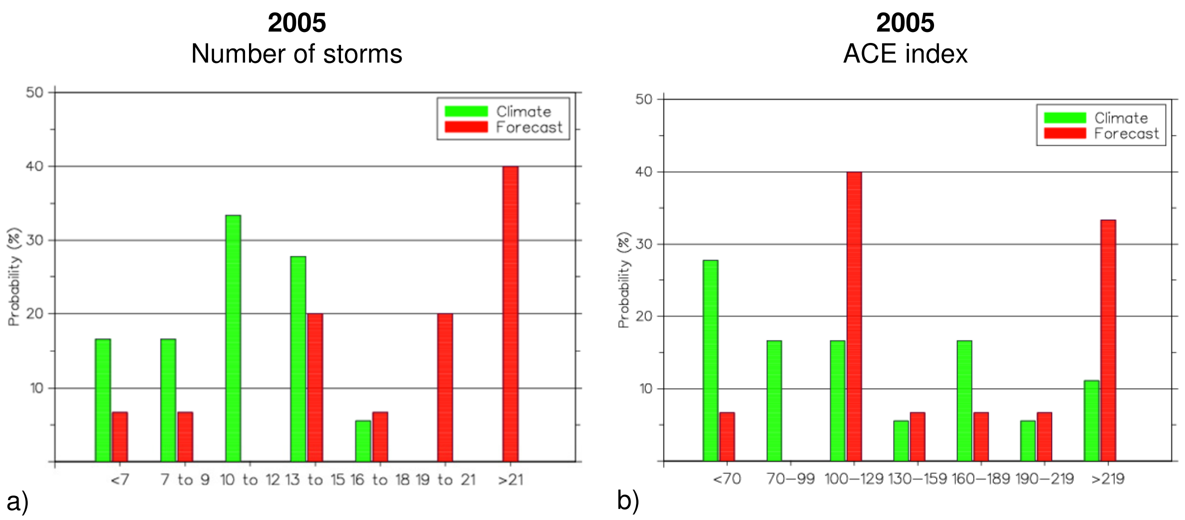


Figure 12*: As Fig. 9, but for 2005. Climatological frequencies are based on 1987–2004.*

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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.

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