SIXTH INTERNATIONAL WORKSHOP on TROPICAL CYCLONES

Topic 4.3 : **Short-term Climate (Seasonal and Intra-seasonal) Prediction of Tropical Cyclone Activity and Intensity**

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4.3.1 **Seasonal Tropical Cyclone Forecasts**

4.3.1a**. Statistical Seasonal Tropical Cyclone Forecasts**

Seasonal tropical cyclone forecasts are currently produced using statistical and dynamical methods in various centers and for different regions. Statistical seasonal tropical cyclone prediction was first conducted in the Atlantic basin (Gray 1984a, 1984b) at Colorado State University using statistical relationships between Atlantic tropical cyclone activity and predictors such as the El Niño – Southern Oscillation (ENSO), the Quasi-Biennial Oscillation (QBO) and Caribbean basin sea level pressures.

Statistical forecast techniques have continued to develop since these early forecasts (e.g. Gray et al. 1992, Klotzbach and Gray 2004). Additional groups since then began issuing statistical seasonal hurricane forecasts for the Atlantic including the Institute of Meteorology of Cuba (1996), NOAA (1998) and Tropical Storm Risk (1999).

Currently, the Cuban seasonal forecast is based on the solution of a regression and an analogue method which gives various hurricane parameters, such as the total number of named storms, hurricanes and hurricane destruction potential for the entire Atlantic region, as well as separated numbers of named storms for the Caribbean Sea and the Gulf of Mexico, and the first and last day of the hurricane season (Ballester et al. 2004a, 2004b).

The NOAA (National Oceanic and Atmospheric Administration) Atlantic Outlook is based on the state of the Atlantic multi-decadal signal (Goldenberg et al. 2001, Bell and Chelliah 2006) and the ENSO conditions. The NOAA outlook gives tercile probabilities for tropical cyclone activity level for various parameters (number of named storms, hurricanes, and major-hurricanes, and ACE [accumulated cyclone energy]). Since 2003 NOAA has also been issuing similar outlooks for the Eastern Pacific hurricane season, first experimentally, and operationally since 2005.

Johnny Chan and colleagues at the City University of Hong Kong have issued seasonal forecasts for the Northwest Pacific basin (number of tropical cyclones, tropical storms and typhoons) since 1997 utilizing various environmental conditions, the most prominent ones being ENSO and the extent of the Pacific subtropical ridge (Chan et al. 1998, 2001, Liu and Chan, 2003).

The Tropical Storm Risk (TSR) issues statistical forecasts for tropical cyclone activity in the Atlantic, western North Pacific and Australian regions. In the case of the western North Pacific, the seasonal predictability of ACE index has been computed (Lea and Saunders 2006). The seasonal prediction model uses Niño 3.75 (5°S-5°N, 180°-140°W) forecasts (Lloyd-Hughes et al. 2004) to predict the NW

Pacific ACE index. The NW Pacific ACE index is forecast with positive skill at the 95% confidence level over a 41-year period from early May.

Owens and Landsea (2003) examined the skill of Gray's operational Atlantic seasonal tropical cyclone forecasts relative to climatology and persistence. Their analysis indicated that for the analyzed period (1984 - 2001) both the statistical and the adjusted forecasts demonstrated skill over climatology and persistence. There is also evidence that the adjusted forecast was more skillful than the statistical model forecast. The TSR forecast in hindcast and operational mode is also skillful (Lea and Saunders, 2006) using as skill measure the mean square skill score (percentage reduction is mean square error compared to a rolling prior 10 year climatology).

4.3.1b**. Landfall Probability Forecasts**

Seasonal forecasts of landfall probabilities for the Atlantic have been issued by Colorado State University since August 1998. These probabilities are based upon a forecast of tropical cyclone activity and a measure of North Atlantic SSTs. In general, when an active season was predicted, the probability of landfall was increased. The CSU forecast team has recently also calculated landfall probabilities for 11 regions, 55 sub-regions and 205 coastal and near-coastal counties from Texas to Maine (Klotzbach, 2006).

The Cuban Meteorological Institute also issues statistical landfall forecasts of tropical cyclones in Cuba, based on a discriminant function methodology.

In a recent paper (Saunders and Lea 2005), TSR describes their new forecast model for issuing in early August skilful seasonal predictions of hurricane landfall activity for the coast of the United States. The new prediction model uses wind patterns to predict the U.S. ACE index (effectively the cumulative wind energy from all U.S. striking tropical storms during the main hurricane season). The July height-averaged winds in these regions are indicative of atmospheric circulation patterns that either favor or hinder evolving hurricanes in reaching U.S. shores. The model gives forecasts from 1 August. 97% of all intense hurricane strikes on the U.S. and 87% of all hurricane hits on the U.S. occur after this date. The model correctly anticipates whether US hurricane losses are above-median or below-median in 74% of the years between 1950 and 2003. It also performed very well in 'real-time' operation in 2004 and 2005. For these damaging hurricane seasons the model predicted U.S. landfalling hurricane activity in the upper quartile (2004) and upper decile (2005) of years historically.

4.3.1c **Dynamical Tropical Cyclone Seasonal Forecasts**

The IRI (International Research Institute for Climate and Society) and ECMWF (European Centre for Medium-Range Weather Forecasts) issue seasonal forecasts of tropical storm frequency based on dynamical models. The ECMWF forecasts are based on coupled ocean-atmospheric models (Vitart and Stockdale 2001). In contrast, the IRI forecasts are obtained in a two-tier procedure, by first forecasting various possible scenarios for the sea surface temperatures (SST) using statistical or dynamical models and then forcing the atmospheric models with those predicted SSTs. Tropical cyclone-like vortices are then identified and tracked in the atmospheric model outputs (e.g. Vitart 1997; Camargo and Zebiak 2002). The IRI also issues ACE forecasts based on dynamical models for a few Northern Hemisphere regions.

The skill of some dynamical models to predict the frequency of tropical storms over the Atlantic can be comparable to the skill of statistical models. Over the other ocean basins, dynamical models can also display some robust skill in predicting the frequency of tropical storms, but they usually perform poorly over the North and South Indian oceans (e.g. Camargo et al. 2005a). It is not clear if this due to model errors or to a lack of predictability. Combining different model forecasts (multi-model ensemble forecast) seems to produce overall better forecasts than individual ensemble forecasts (Vitart 2006). The skill of various climate models for seasonal tropical cyclone activity in hindcast mode is discussed in Camargo et al. (2005a) and Vitart (2006).

The seasonal prediction of the risk of tropical storm landfall still represents a challenge for dynamical models. The tropical storm tracks in seasonal forecasting systems are usually unrealistically too poleward due to the too coarse horizontal resolution of the models. Either finer resolution or the use of statistical techniques such as clustering (Camargo et al. 2005b) would be needed to predict the risk of tropical storm landfall.

4.3.2 **Sub-seasonal Tropical Cyclone Forecasts**

Interest in the prediction of atmospheric variability on the intra-seasonal timescale has recently blossomed (e.g., Schubert et al 2002, Waliser et al. 2006). On this timescale, the Madden-Julian oscillation (MJO), with its 30- to 80-day period, provides the greatest prospects for tropical prediction. Concurrent with the developments in MJO prediction, the modulation of TC activity by the MJO has been shown for many of the world's major TC formation regions (e.g., Liebmann et al. 1994, Maloney and Hartmann 2000, Molinari and Vollaro 2000, Hall et al. 2001, Bessafi and Wheeler 2006). Thus there exists hope for practical application of the MJO for TC activity forecasting in the near future.

MJO prediction has so far been approached using mainly empirical methods (see review by Waliser (2005)), owing to the difficulty that global numerical models have in its simulation and prediction (e.g., Jones et al. 2000, Lin et al. 2006). Useful predictive skill from empirical methods has been quoted in the range of 15 to 20 days for large-scale fields in the tropics. The crux of the empirical problem is the extraction of the MJO's frequency-limited signal from observational data in real-time. Empirical methods then evolve this signal in a way that is consistent with the statistics of past MJO events.

The first empirical method to be implemented in real time involves Fourier wavenumber-frequency filtering of daily updated outgoing longwave radiation (OLR) data (Wheeler and Weickmann 2001), available online since 2000. Filtered fields constructed for times after the end of the dataset are used as a skilful forecast, as applied to the MJO and other tropical waves as well. Despite being a forecast of large-scale OLR only, and not of TC activity, it has gained a broad awareness amongst tropical forecasters.

The use of empirical orthogonal functions (EOFs) to extract the MJO's signal has also gained common usage. The NOAA Climate Prediction Center produces ten indices for monitoring the different longitudinal stages of the MJO. The Australian Bureau of Meteorology computes the daily projection onto the leading pair of EOFs of the combined fields of equatorially-averaged OLR, 850-hPa zonal wind, and 200-hPa zonal wind, producing a two-component index of the MJO (Wheeler and Hendon 2004). WWW-sites provide the daily-updated indices as well as their historical values (back to the 1970s), and have been applied to the study of TC activity modulation (e.g., Wheeler and McBride 2005, Harr 2006) and prediction (Leroy et al. 2004).

The modulation of TC numbers by the phase of the MJO has been quoted to be as high as 4:1 in some locations (e.g., Hall et al. 2001; Maloney and Hartmann 2000). TC genesis tends to preferentially occur near, and a little westward, of the longitude of maximum MJO convective activity. These are regions of enhanced low-level cyclonic vorticity associated with the near-equatorial convective forcing. Application of such information by TC forecasters has so far been mostly subjective. One objective method, however, is that developed by Leroy et al. (2004), which provides predictions of weekly probabilities of TC activity within large zones. Predictors are the MJO indices of Wheeler and Hendon (2004), large-scale patterns of SST as indicators of ENSO and interannual Indian Ocean variability, and the climatological seasonal cycle of TC activity. Verification statistics show that incorporation of the MJO predictor increases skill out to 2-3 weeks. Greatest skill is achieved during times when the MJO is strong, and little improvement is gained when the MJO is weak. Further increases in skill would be expected through the incorporation of information from equatorial Rossby (ER) waves, and potentially other convectively-coupled equatorial waves as well (Leroy et al. 2004, Bessafi and Wheeler 2005, Frank and Roundy 2006), but given their lower explained variance and higher frequency, the predictability and lead-time they provide is less (Wheeler and Weickmann 2001).

An empirical method that has sought to include the effects of a wide variety of wave modes and climate signals to forecast local daily probabilities of TCs has recently been developed by Paul Roundy at CIRES. It is based on research showing the relationships of the waves to TCs (Frank and Roundy 2006), and the wave's self-consistent patterns of propagation and interaction (Roundy and Frank 2004a, 2004b). The method, employing logistic regression, fits a hyperbolic tangent function to the relationship between these modes and time series representing the local presence of TCs. The optimum subset of available predictors is found for each region and time lag. The method shows improvement of roughly 10-40 percent over climatological probabilities at one-week lead times, depending on location. Regions where skill tends to be highest include the Northeast Pacific, the Northwest Pacific, and the Bay of Bengal. This method acts like an analogue forecast because probabilities of a TC occurring in a given wave state depend on how often they formed in similar states in the past. Consequently, if a TC forms within a unique wave state or a wave state that has not often been associated with TCs in the past, high probabilities might not be forecast. The method is skillful because many TCs form within similar large-scale wave and climate states.

While there is much room for improvement in the skill and application of empirical/statistical methods of intra-seasonal TC prediction, the greatest hope for improvement lies with dynamical/numerical models. Indeed, numerical studies using twin-experiment methodology in which the model employed is assumed to be perfect (Waliser et al. 2003), indicate useful predictability of the MJO may extend to 25-30 days, 10 days longer than that currently derived from empirical methods. Empirical methods are limited in the totality of the weather/climate system they can predict, their ability to adapt to arbitrary conditions, and their ability to take advantage of known physical constraints (Waliser 2005). Given the inadequacy of the representation of the MJO, and other tropical waves, in current numerical prediction models, however, much work remains to achieve their theoretical potential.

A recent development in statistical tropical cyclone prediction in the Atlantic is the prediction of an individual month's tropical cyclone activity by the Colorado State University team. These shorter-term (than seasonal) predictions are issued due to the fact that inactive seasons can have active months and active seasons can have inactive months. Individual monthly prediction began with a prediction of August-only activity issued with the 1 August seasonal forecast in 2000. Following the success of the August-only forecast (Blake and Gray, 2004), September-only (Klotzbach and Gray 2003) and October-only forecasts were developed.

4.3.3 **Conclusions**

Statistical seasonal tropical cyclone forecasting has come a long way since it began in the early 1980s. Along with predictions of total seasonal activity, several forecasts now include individual monthly forecast and predictions of probability of landfall. As the availability of global datasets such as the NCEP/NCAR and ECMWF Reanalysis continue to be improved, so will statistical forecasts of tropical cyclone. An updated and homogenous quality best-track dataset globally would also contribute for more skilful forecasts.

Dynamical seasonal tropical cyclone forecasts are now currently issued for various regions. Increasing model resolution should help improve the skill of these forecasts. In order to be able to forecast landfall probabilities using dynamical models, systematic biases in the tracks of model tropical cyclones need to be examined and explained. Some of the biases are probably not only due to low-resolution, and more research is needed in understanding the atmospheric models' ability to forecasts tropical cyclones.

On sub-seasonal time scales, with the improvement of the dynamical and statistical models in forecasting MJO and other large-scale waves, forecasting tropical cyclone activity should be possible operationally at short lead times in the near future, as already occurs experimentally in a few cases.

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