

SIXTH INTERNATIONAL WORKSHOP on TROPICAL CYCLONES

Topic 4 : **Climate Variability and Seasonal Prediction of Tropical Cyclone Activity/Intensity**

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Incorporating:

Topic 4.1 **Variability of tropical cyclone activity/intensity on intraseasonal and interannual scale**
Rapporteur: Chang-Hoi Ho (SNU, South Korea)

Topic 4.2 **Possible relationships between climate change and tropical cyclone activity**
Rapporteur: Tom R. Knutson (GFDL, USA)

Topic 4.3 **Short-term climate (seasonal and intra-seasonal) prediction of tropical cyclone activity and intensity**
Rapporteur: Suzana J. Camargo (IRI, USA)

4.0.1: **Introduction**

In this section, an overview of variability of tropical cyclone activity on timescales from intraseasonal and interannual in Topic 4.1 to multidecadal and millennial in Topic 4.2 is given. Predictions on the intraseasonal and interannual time frames are the focus of Topic 4.3. Additionally, a review of how anthropogenic greenhouse gas increases are impacting tropical cyclones today and in the future is discussed Topic 4.2.

Previously, climate variability of tropical cyclones on scales from intraseasonal to millennial time frames was not in the mainstream of tropical cyclone research. However, interest in better understanding and prediction of relatively short-term (intraseasonal and interannual) fluctuations as well as longer (decadal, multidecadal, centennial, and millennial) variations has grown tremendously in the past several years. Additionally, there has been an explosion in publications and research into how the impacts of manmade "global warming" may be changing tropical cyclone characteristics both today and decades into the future. It is estimated that the tropical cyclone climate variability and change publications have increased by a factor of five to ten compared with just a decade ago, as the extensive literature review in these three topics demonstrate.

While there has been an amazing growth within the field, there are numerous questions that remain which need to be addressed by further research, such as: 1) Is there sizable and useable skill present for intraseasonal tropical cyclogenesis on the scale of a few days to a few weeks in advance?; 2) Can seasonal tropical cyclone predictions be regionalized with skill over and above just downscaling basin-wide predictions?; 3) What role, if any, does the stratospheric quasi-biennial oscillation have for dictating tropical cyclone activity and, if so, what is the physics involved?; 4) Given the climate surprises that occur on an interannual timescale (e.g., the unpredicted El Niño of 2006), what is the practical limit of predictability of seasonal forecasts?; 5) Are there naturally occurring significant multidecadal tropical cyclone oscillations?; 6) What are the trends in tropical cyclone frequencies and

intensities, after accounting for increasing monitoring during the last few decades?; 7) Given the wide disparity between global warming impacts on numerical modeling/theory (small impact on tropical cyclone intensity in the future) versus recent observational studies (large impact on tropical cyclone intensity already occurring today), which of these two conclusions is correct or are both in need of revision?; 8) What can tropical cyclone historical archival reconstructions and paleotempestology tell us about today's climate and how changes may be manifested because of global warming and natural climate variability? All of these important issues are currently open ones that further study in theoretical, numerical modeling, and observational studies are needed to provide objective guidance for the future.

4.0.2 Variability of tropical cyclone activity/intensity on intraseasonal and interannual scale

Topic 4.1 reviews the current status of the understanding on variability of tropical cyclone activity/intensity on intraseasonal to interannual time scales around the globe. Annually, approximately 80–90 tropical cyclones occur over the tropical oceans. The tropical cyclone activities depend on thermodynamic parameters (e.g., sea surface temperature (SST), atmospheric stability, and mid-tropospheric moisture) and dynamic parameters (e.g., low-level vorticity and vertical wind shear). In many cases, thermodynamic parameters are closely linked with each other in the tropics; the atmosphere overlying high SSTs tends to be humid, and humid air with high atmospheric temperature inevitably becomes unstable.

Over the tropical oceans prone to frequent tropical cyclones, the thermodynamic factors for tropical cyclone formation are most often satisfied. Also, the dynamic parameters—positive low-level vorticity and weak vertical wind shear—give rise to environments favorable for the generation of tropical cyclones. In the case of changes in the large-scale circulation in the tropical oceans, the thermodynamic and/or dynamic parameters may be modified. These modifications, in turn, may alter the tropical cyclone activity/intensity.

The variation of the tropical cyclone activity is to some extent associated with the El Niño–Southern Oscillation, quasi-biennial oscillation, Arctic Oscillation, North Atlantic Oscillation, Antarctic Oscillation, Madden–Julian Oscillation, etc., depending on ocean basins. Subsequently, the discussion will be involve several ocean basins such as the western North Pacific, the North Atlantic, the eastern and central North Pacific, the Indian Ocean, and Australia and South Pacific.

4.0.3 Possible relationships between climate change and tropical cyclone activity

Topic 4.2 reviews the current science on possible relationships between climate change and tropical cyclone activity/intensity on different time scales.

The report first discusses observed tropical climate trends and multi-decadal variability that are relevant to tropical cyclone activity, including in SSTs, water vapor, atmospheric stability, and atmospheric circulation. Investigations into observed trends and low-frequency variability of tropical cyclone activity are reviewed, which cover all tropical cyclone basins but most focus upon the Atlantic tropical cyclone records. An overview is provided of paleotempestology – the study of pre-historic tropical cyclones using geological proxy evidence or historic documents – which provides localized estimates of tropical cyclone variations on the order of century and millennium timescales. Theoretical studies and numerical models (both coupled global climate models and downscaled regional models) have been utilized extensively to research past tropical cyclone behavior (climatology, seasonal cycles, interannual, decadal and multidecadal variability). These tools have also been instrumental in making projections of future greenhouse gas warming impacts (into tropical cyclone frequency, intensity, and rainfall) as well as allowing assessments of how these changes compare with studies of recent tropical

cyclone observations. Finally, the role that tropical cyclones may have in actively forcing the climate system is discussed.

There are substantial roadblocks both in making reliable future projections about tropical cyclone activity and in determining whether a trend can be detected in historical tropical cyclone data. For the climate change detection problem, a large hurdle is the quality of the tropical cyclone historical databases. Several recent studies report strong increasing trends in several tropical cyclone metrics. However, the databases used in these studies were unfortunately populated over time without a focus on maintaining data homogeneity, a key requirement for databases which are to be used to assess possible climate-related trends. Additionally, improved understanding of the causes of past variations or trends in tropical cyclone activity will depend on the existence of reliable climate-quality data sets for related variables, such as SST, atmospheric temperature, moisture, wind shear, etc. However, data quality and data inhomogeneity issues with datasets such as the NCAR/NCEP and ERA reanalyses remain as an important roadblock for further advancement. Climate (global and regional) models are another important tool for investigating tropical cyclone climate variability and change. These contain hypotheses for how the climate system works in a framework which allows experiments to be performed to test various hypotheses or compare the model's historical simulations against historical observations. Nonetheless, there are important uncertainties in climate models and the radiative forcings used for such experiments. Finally, in contrast to the theory of potential intensity of tropical cyclones, which is more well-established, a comparable theory of tropical cyclone frequency is not well-developed at this time. The lack of theoretical underpinning of tropical cyclone genesis and frequency of occurrence remains as an important roadblock to progress in this area, apart from global model limitations.

In general, hurricane-climate research is expected to progress most rapidly when a combination of theory, modeling, and observations are brought to bear on the problem. The need for improved climate-quality tropical cyclone databases seems clear. These will provide better information for assessing future changes, and more reliable statistical assessments of past changes in hurricane activity, including landfall, in all basins. Tropical cyclone/climate modeling studies will benefit from efforts to improve global climate modeling in general. In addition, studies which focus on simulation or downscaling of tropical cyclones could benefit from more rigorous testing of model performance with simulating a wider range of tropical cyclone metrics. Finally, exploration of empirical approaches, such as seasonal genesis parameters, should be encouraged, including testing/evaluation and improvements aimed at reproducing characteristics of historical tropical cyclone activity in different basins from both observations and climate model simulations. Based on these results, these approaches may be useful for making climate change projections of tropical cyclone activity.

4.0.4 Short-term climate (seasonal and intra-seasonal) prediction of tropical cyclone activity and intensity

Topic 4.3 discusses the state of the science in seasonal and sub-seasonal tropical cyclone prediction.

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 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 began in the mid-1980s and have spread to several tropical cyclone basins. Some groups are issuing seasonal forecasts up to almost a year in advance of the season. Verifications of some of the seasonal prediction efforts have demonstrated that substantial skill exists, especially at the shortest lead times. Additionally, recent statistical predictions have been attempting to regionalize the forecasts to impacts along specific coastal zone.

Two groups are now issuing seasonal forecasts of tropical storm frequency based on dynamical models. 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. The seasonal prediction of the risk of tropical storm landfall still represents a challenge for dynamical models, as track produced tend to be unrealistically poleward in most modeling systems

Interest in the prediction of atmospheric variability on the intra-seasonal timescale has recently blossomed. On this timescale, the Madden-Julian Oscillation (MJO), with its 30- to 80-day period, provides the greatest prospects for tropical prediction given its large scale, tendency to persist for at least an additional cycle, and its moderate to strong relationship to tropical cyclone activity in some basins. MJO prediction has so far been approached using mainly empirical methods, owing to the difficulty that global numerical models have in its simulation and prediction. While there is much room for improvement in the skill and application of empirical/statistical methods of intra-seasonal tropical cyclone 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, indicate useful predictability of the MJO may extend to 25-30 days, 10 days longer than that currently derived from empirical methods.