Tropical Cyclone Intensity

1 Describe the physical, chemical, or biological measurements upon which this indicator is based. Are these measurements widely accepted as scientifically and technically valid? Explain.

This indicator is based on measurements of tropical cyclones over time. The data set used for this indicator is maintained by the National Oceanic and Atmospheric Administration's (NOAA's) National Hurricane Center, and is referred to as HURDAT (HURricane DATa). HURDAT compiles information on all tropical cyclones occurring in the North Atlantic, including parameters such as wind speed, barometric pressure, storm tracks, and dates. Field methods for data collection and analysis are documented in official NOAA publications (Jarvinen et al., 1984). This indicator is based on sustained wind speed, which is defined as the one-minute average wind speed at an altitude of 10 meters.

Data collection methods have improved since HURDAT began. When the data series began, ships and land observation stations were used to measure and track storms. Since then, organized aircraft reconnaissance, the coastal radar network, and weather satellites with visible and infrared sensors have improved accuracy in determining storm track, maximum wind speeds, and other storm parameters such as central pressure. A re-analysis of early HURDAT data was initiated to improve both random and systematic error present in data from the beginning of the time series. Information on HURDAT re-analysis is available at on the NOAA Web site at: www.aoml.noaa.gov/hrd/data_sub/re_anal.html.

2 Describe the sampling design and/or monitoring plan used to collect the data over time and space. Is it based on sound scientific principles? Explain.

The HURDAT data series is composed of observations of tropical cyclones and hurricanes in the North Atlantic Ocean. HURDAT does not include data for storm systems that are classified as extratropical. However, it does include data from storms classified as subtropical, meaning they exhibit some characteristics of a tropical cyclone but also some characteristics of an extratropical storm. Subtropical cyclones are now named in conjunction with the tropical storm naming scheme, and in practice, many subtropical storms eventually turn into tropical storms. HURDAT is updated annually by NOAA and data are available from 1886 through 2009.

Early in the data set there is a high likelihood that storms went undetected, as observations of storms were made only by ships at sea and land-based stations. Storm detection improved in 1944 with the use of aircraft reconnaissance (Jarvinen et al., 1984), but it was not until 1970, when global satellite coverage became nearly complete, that tropical cyclone detection rates reached close to 100 percent.

Weather satellites were first used in 1960 to detect the initial position of a storm system; reconnaissance aircraft would then fly to the location to collect precise measurements of the

wind field, central pressure, and location of the center. Data collection methods have since improved with weather satellites. The mission catalogue of data sets collected by NOAA aircraft is available at: www.aoml.noaa.gov/hrd/data_sub/hurr.html.

This indicator covers storms occurring in the Atlantic Ocean north of the equator, including the Caribbean Sea and the Gulf of Mexico.

3 Describe the conceptual model used to transform these measurements into an indicator. Is this model widely accepted as a scientifically sound representation of the phenomenon it indicates? Explain.

Two separate indices were used for the Tropical Cyclone Intensity indicator: NOAA's Accumulated Cyclone Energy Index (ACE Index) and the Power Dissipation Index (PDI).

Figure 1:

This indicator uses NOAA's ACE Index to describe the combined strength and duration of tropical storms and hurricanes each season. As described by Bell and Chelliah (2005), "the ACE Index is calculated by summing the squares of the estimated 6-hourly maximum sustained wind speed in knots for all periods while the system is either a tropical storm or hurricane." A system is considered at least a tropical storm if it has a wind speed of at least 39 miles per hour. The ACE Index is preferred to other similar indices such as the Hurricane Destruction Potential (HDP) and the Net Tropical Cyclone Index (NTC) because it takes tropical storms into account and it does not include multiple sampling of some parameters. The ACE Index also includes subtropical cyclones, which are named using the same scheme as tropical cyclones and may eventually turn into tropical cyclones in some cases.

Figure 1 of the indicator shows annual values of the ACE, which are determined by summing the individual ACE Index values of all storms during that year. The index itself is measured in units of wind speed squared, but for this indicator, the index has been converted to a numerical scale where 100 equals the median value over a base period from 1951 to 2000. A value of 150 would therefore represent 150 percent of the median, or 50 percent more than normal. NOAA has also established a set of thresholds to categorize each hurricane season as "above normal," "near normal," or "below normal" based on the distribution of observed values during the base period. The "near normal" range extends from 75 to 117 percent of the median, with the "above normal" range above 117 percent of the median and the "below normal" range below 75 percent.

Figure 2:

For additional perspective, this indicator also presents the PDI. Like the ACE Index, the PDI is also based on wind speed, but it uses a different calculation method that places more emphasis on storm intensity. Emanuel (2005, 2007) provides a complete description of how the PDI is calculated. Emanuel (2007) also explains adjustments that were made to correct for biases in the quality of storm observations and wind speed measurements early in the period of record. The PDI data in Figure 2 of this indicator are in units of 10^{11} m^3/s^2, but the actual figure omits this

unit and simply alludes to “index values” in order to make the indicator accessible to the broadest possible audience.

The PDI trend line in Figure 2 has been smoothed using a five-year weighted average applied with weights 1, 3, 4, 3, and 1. This method applies greater weight to values near the center of each five-year window. Data are plotted at the center of each window; for example, the five-year smoothed value for 1949 to 1953 is plotted at year 1951. Sea surface temperature (plotted for reference) has also been smoothed over five-year periods.

The PDI includes all storms that are in the so-called “best track” data set issued by NOAA, which can include subtropical storms. Weak storms contribute very little to power dissipation, however, so subtropical storms typically have little impact on the final metric.

4 What documentation clearly and completely describes the underlying sampling and analytical procedures used?

Figure 1:

ACE Index computation methods and seasonal classifications are described by Bell and Chelliah (2006). This information is also available on the NOAA Web site at: www.cpc.noaa.gov/products/outlooks/background_information.shtml.

Figure 2:

Emanuel (2005, 2007) describes methods for calculating the PDI and deriving the underlying power dissipation formulas. Analysis techniques, data sources, and corrections to raw data used to compute the PDI are described in the supplementary methods for Emanuel (2005), with further corrections addressed in Emanuel (2007).

Underlying data:

Sampling and analysis procedures for the HURDAT data are described by Jarvinen et al. (1984) for collection methods up to 1984. Changes to past collection methods are partially described in the supplementary methods from Emanuel (2005). Other data explanations are available at: www.nhc.noaa.gov/pastall.shtml#hurdat.

5 To what extent is the complete data set accessible, including metadata, data-dictionaries, and embedded definitions? Are there confidentiality issues that may limit accessibility to the complete data set?

Figure 1:

An overview of the ACE Index is available at: www.cpc.ncep.noaa.gov/products/outlooks/background_information.shtml. The data for this

indicator are published in the form of a bar graph in NOAA's annual "North Atlantic Hurricane Season: A Climate Perspective" (2009 edition available at: www.cpc.noaa.gov/products/expert_assessment/hurrsummary_2009.pdf). The numbers were obtained in spreadsheet form by contacting Dr. Gerry Bell at NOAA.

Figure 2:

Emanuel (2005, 2007) gives an overview of the PDI, along with figures and tables. This indicator reports on an updated version of the data set (through 2009) that was provided by Dr. Kerry Emanuel at the Massachusetts Institute of Technology.

Underlying data:

Wind speed measurements and other HURDAT data are available in various formats on NOAA's Atlantic Oceanographic and Meteorological Laboratory site: www.aoml.noaa.gov/hrd/data_sub/data_format.html. Definitions for the original HURDAT data format are available at: www.aoml.noaa.gov/hrd/data_sub/hurdat.html. Information on HURDAT re-analysis for historical values that may have been changed to reduce systematic and random error is available at: www.aoml.noaa.gov/hrd/data_sub/re_anal.html.

6 Are the descriptions of the study or survey design clear, complete, and sufficient to enable the study or survey to be reproduced? Explain.

Using raw HURDAT data and descriptions of HURDAT re-analysis, discussion of the ACE Index available in Bell and Chelliah (2006) would allow for the reproduction of ACE Index values. Explanation and formulas given by Emanuel (2005, 2007) would allow for the reproduction of PDI values using the raw data.

7 To what extent are the procedures for quality assurance and quality control of the data documented and accessible?

Jarvinen et al. (1984) describe quality assurance/quality control procedures for each of the variables in the HURDAT data set, including storm track, wind speed, and central pressure. Corrections to early HURDAT data are made on an ongoing basis through the HURDAT re-analysis project to correct for both systematic and random errors identified in the data set. Emanuel (2005) provides a "supplementary methods" document that describes both the evolution of more accurate sample collection technology and further corrections made to the data. Emanuel (2007) describes additional bias corrections for the PDI to account for some of the limitations of observations collected early in the period of record.

8 What statistical methods, if any, have been used to generalize or portray data beyond the time or spatial locations where measurements were made (e.g., statistical survey inference, no generalization is possible)? Are these methods scientifically appropriate?

Wind speed was recorded four times daily in the early part of the data set. Wind speeds were measured from various sources including estimation of wind speeds over the ocean by ships, measurements from ship anemometers, measurements from aircraft reconnaissance, and calculations from observed pressure values. Analysts compiled all available wind speed observations and all information about the measurement technique to determine the wind speed for the four daily intervals for which the storm track was recorded.

9 What uncertainty measurements or estimates are available for the indicator and/or the underlying data set?

The ACE Index and the PDI are calculated directly from wind speed measurements; thus, the main source of possible uncertainty in the indicator is uncertainties within the underlying HURDAT data set. Uncertainty measurements do not appear to be readily available for HURDAT data. Because the determination of storm track and wind speed requires some expert judgment by analysts, some uncertainty is likely, although methodological improvements suggest that recent data may be somewhat more accurate than earlier measurements.

10 To what extent do uncertainty and variability impact the conclusions that can be inferred from the data and the utility of the indicator?

Because uncertainty varies depending on observation method, and these methods have evolved over time, it is difficult to make a definitive statement about the impact of uncertainty on this indicator. All observations are carefully reconstructed by analysts, however, meaning this indicator should be considered reasonably accurate.

Because of the greater uncertainties inherent in earlier data, this indicator excludes data prior to 1950. For the PDI, Emanuel (2007) employed a bias correction process for the early part of the period of record (the 1950s and 1960s), when aircraft reconnaissance and radar technology were less robust than they are today—possibly resulting in missed storms or underestimated power. These additional corrections were prompted in part by an analysis published by Landsea (2005).

11 Describe any limitations or gaps in the data that may mislead a user about fundamental trends in the indicator over space or over the time period for which data are available.

Limitations to this indicator include the following:

1. As described in the response to Question 8, wind speeds are measured using several observation methods with varying levels of uncertainty, and these methods have

improved over time. The wind speeds recorded in HURDAT should be considered the best estimate of several wind speed observations compiled by analysts.

2. Many different indices have been developed to analyze storm duration, intensity, and threat. Each index has strengths and weaknesses associated with its ability to describe these parameters. The two indices used in this indicator (ACE Index and PDI) are considered to be among the most reliable.

12 References

Bell, G.D., and M. Chelliah. 2006. Leading tropical modes associated with interannual and multidecadal fluctuations in North Atlantic hurricane activity. J. Climate 19:590–612.

Emanuel, K. 2005. Increasing destructiveness of tropical cyclones over the past 30 years. Nature 436:686–688. Supplementary methods available with the online version of the paper at: <www.nature.com/nature/journal/v436/n7051/full/nature03906.html>

Emanuel, K. 2007. Environmental factors affecting tropical cyclone power dissipation. J. Climate 20(22):5497–5509. <ftp://texmex.mit.edu/pub/emanuel/PAPERS/Factors.pdf>

Jarvinen, B.R., C.J. Neumann, and M.A.S. Davis. 1984. A tropical cyclone data tape for the North Atlantic Basin, 1886–1983: Contents, limitations and uses. NOAA Technical Memo NWS NHC 22.

Landsea, C.W. 2005. Hurricanes and global warming. Nature 438:E11–E13. <www.aoml.noaa.gov/hrd/Landsea/landseanaturepublished.pdf>