Hurricane Force Extratropical Cyclones Trends from ECMWF and Ocean Prediction Center Analysis

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Abstract:

While much has been studied concerning tropical cyclones, comparatively less is known about the behavior, climatology, trends, and contribution to heat, moisture and momentum budgets of extratropical cyclones (ETC). The most extreme ETCs that reach Hurricane-Force (HF) intensity, can be just as deadly if not more so to vessels at sea. This work attempts to address the gap in knowledge of the most explosive ETCs. The frequency and size of ETC's suggests that they should be a significant contributor to the exchange of energy between the atmosphere and ocean. However, the characterization of the full impact of ETCs on the ocean – atmosphere system was not possible to define before QuikSCAT, which was able to consistently and accurately sample the full range of winds in these powerful storms. Imagery interpretation techniques such as Dvorak, used to estimate tropical cyclone intensity, are not applicable for ETCs. This effort will for the first time allow for an accurate accounting of the contribution of most extreme ETCs to the earth's climate energy balance computation.

Science Question:

- What are the Decadal trends of hurricane force extratropical cyclones (ETC) and what is the resulting impact on Oceanic and Atmospheric forcing?
  - Address the gap in knowledge of the most explosive ETCs as compared to tropical cyclones
  - Investigate trends and impacts of cyclonic wind stress, curl, divergence and sea surface temperatures (SST' s) associated with HF ETCs on ocean forcing;
  - Study the difference in trends and characteristics of HF ETCs resulting from QuikSCAT and ASCAT scatterometer observations of these extreme conditions in order to develop analysis techniques that will help improve the use of different scatterometer data in an operational environment.

Wind Data and Processing Methodology

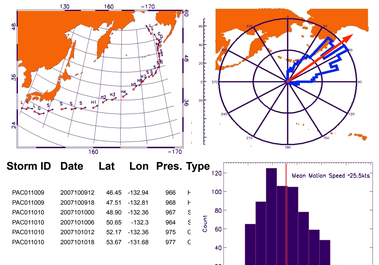

Fig.1 Ocean Prediction Center hurricane force extratropical cyclone database information

- **Estimate cyclone motion speed and direction**
- **Extract all hurricane force 6-h cycles per month**
- **Extract hurricane force events during 6h, 12h 18h, 24h and >24h**
- **Perform statistical analysis of these events**
- **Select QuikSCAT files that correspond to each chosen event**

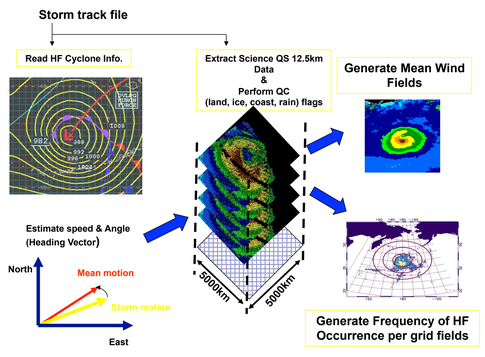

Fig.2 Schematic of extratropical cyclone wind and hurricane force frequency composite processing

Comparison of QuikSCAT, WindSat and ASCAT HF Observations

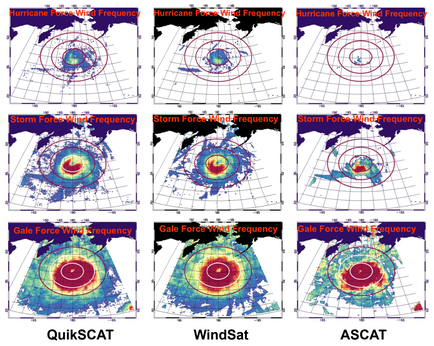

Fig.3 Comparison of frequency of hurricane force occurance within extratropical cyclones in Pacific ocean for 2007-2009 period

To study suitability of different ocean surface vector wind products to study hurricane force winds within extratropical cyclones we compared Jet Propulsion Laboratory 12.5km QuikSCAT, Remote Sensing Systems 25km WindSat and NOAA 12.5km ASCAT products. Fig.3 shows comparison of probabilities of hurricane force occurrence within extratropical cyclones in North Pacific for period of 2007-2009. RSS WindSat and JPL QuikSCAT products show very similar performance within all three wind categories (gale 17-24m/s, storm 24-32.5m/s, hurricane force >32.5m/s) and therefore are complementary for this type of study. The ASCAT product compares well to QuikSCAT and WindSat at gale and storm wind force categories. The hurricane force observations with ASCAT instrument are less frequent due to smaller measurement swath and somewhat less sensitivity on V-pol C-band measurement to winds higher than 30m/s.

Ocean Prediction Center HF Extratropical Storm Best Track Cyclone Database 2000-2009

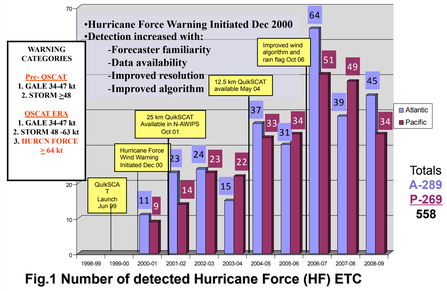

Fig.1 Number of detected Hurricane Force (HF) ETC

Since December 2000 OPC started issuing HF warnings for ETCs in North Pacific and Atlantic Ocean. The HF cyclones best track database was created based on OPC's 6-hourly surface analyses. This database contains the storm center latitudes and longitudes for each 6 hour analysis period, as well as the observed central surface pressure and the cyclone maximum wind speed based on the Beaufort wind speed scale (gale 34-47 kts (17.2-24.4 m/s), storm 48-63 kts (24.5-32.6 m/s) and hurricane force (HF) 64 kts or greater (32.7 m/s or greater).

This database is an excellent start for this study, but the database is incomplete. As the forecasters' familiarity and understanding of QuikSCAT data grew through the years, the identification of HF winds within the OPC analysis was increasing. The increasing trend in the number of HF cyclones shown on Fig 1 therefore is not necessarily a climatological trend but probably just an indication of forecaster familiarity.

Since we cannot go back in time and just have the OPC forecasters redo their forecasts from the beginning of the QuikSCAT mission, another approach is required to construct a complete a HF extratropical cyclone best track data base.

Development of an Automated Cyclone Tracking Scheme

The first step in studying cyclone life cycle characteristics such as deepening rate, central pressure, and velocity of motion and length of lifecycle is the identification and evaluation of cyclone tracks.

Lim and Simmonds (2002) developed a relative central pressure normalized deepening rate parameter (NDR_r) to be used in characterizing explosive developers

$$NDR_r = \Delta p_r \sin 60 \,/\, 24 hPa \sin\phi$$

where Δp_r is relative central pressure change of a system over 24h obtained as the difference between the central pressure of a cyclone and the climatological pressure at the cyclone location at that time of year, and φ is latitude. Using this method they assembled a 21-year long (1979-1999) database of explosive ETCs in the SH based on the NCEP-DOE reanalysis-2 and developed a method for detecting and tracking of these extreme cyclones.

Following method of Lim and Simmonds (2002) and Patoux at al (2009) we extended cyclone tracking algorithm to Northern Hemisphere and applied it on ECMWF 6hr analysis for period of 9 years (2000-2009). Tracks produced with this tracking method in Northern Atlantic were compared with OPC ETC 2000-2009 database (Fig. 1). During this time period ECMWF model produced only 24 cyclones that reached hurricane force winds (>63kts) based on maximum wind within storm radius tracked with automated scheme. Therefore wind speed variable alone could not be used as reliable parameter to identify all HF ETC's. In order to use this database to expand upon OPC database we first matched ECMWF tracks and OPC tracks. Using minimun surface pressure, deepening rate and maximum surface wind within cyclone search radius we developed probability function that ECMWF cyclone reached HF winds.

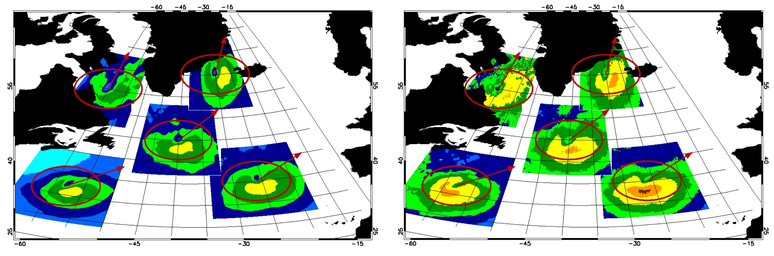

Fig.2 Spatial wind speed distribution within hurricane force extratropical cyclones using ECMWF analysis (a) and QuikSCAT wind observations (b)

Hurricane Force ETC's from ECMWF and OPC Tracks Trends in North Atlantic

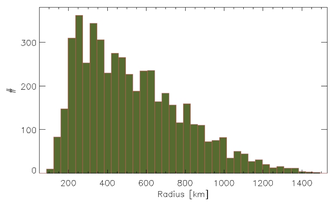

Fig 3. HF ETC radius distribution from automated cyclone tracking scheme

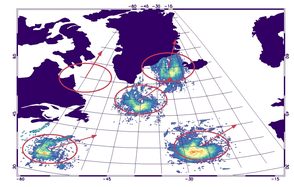

Fig 4. Spatial distribution of hurricane force winds in ETC's from QuikSCAT observations

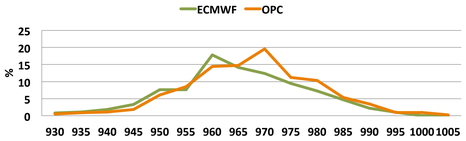

Fig 5. Histogram of minimum central pressure during HF stages in North Atlantic ETC's from ECMWF 6-hourly analysis fields (green) and OPC HF ETC database (orange). The peak of ECMWF cyclone distribution is ~960mbar while the peak of OPC cyclone database is ~970mbars.

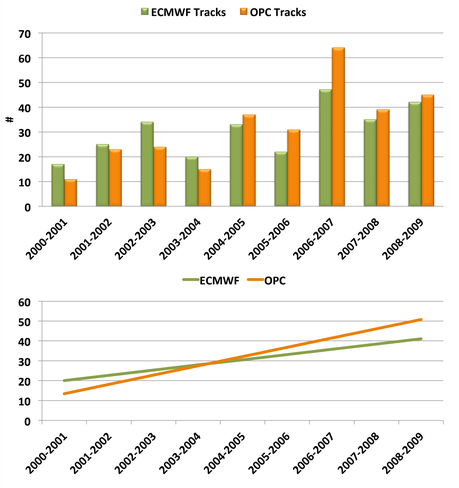

Fig.6 Number of HF ETC's in North Atlantic as detected by automated cyclone tracking scheme using ECMWF analysis (green) and OPC HF ETC database (green) The OPC HF cyclones are the same as those plotted in earlier chart. The ECMWF HF ETCs were determined utilizing the automated cyclone detection and tracking scheme, which are independent of forecaster training and satellite wind retrieval algorithm changes. The ECMWF HF ETC tracks show a higher number of HF cyclones than OPC in the first several years when QuikSCAT was first introduced in OPC, which is expected.

Fig.7 HF ETC trend in terms of number of cyclones per year during study period in North Atlantic. The ECMWF HF ETC tracks also indicate an increasing trend in HF cyclone count in North Atlantic during the study period (Fig.. The increase rate from OPC database is 4.66 cyclones/year while the increase rate from ECMWF database is 2.63 cyclones/year

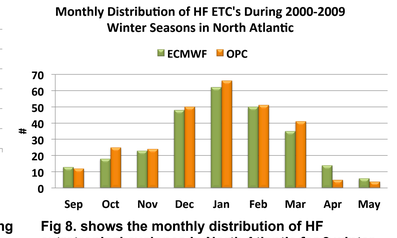

Fig 8. shows the monthly distribution of HF extratropical cyclones in North Atlantic for 8 winter seasons. Both the OPC and automated dectection/ tracking method using ECMWF exhibit a similar distribution showing the maximum cyclone activity during month of January.

Conclusions:

- Automated cyclone tracking scheme using combined Lim and Simmonds and Patoux et al methods was developed and applied in North Atlantic for period between 2000-2009
- Probability of cyclone reaching HF stage using matchup dataset between ECMWF and OPC database was developed and applied on ECMWF cyclones. Using this probability ECMWF HF ETC database was developed and analyzed.
- Number of hurricane force extratropical cyclones in North Atlantic show an increasing trend both from Ocean Prediction ETC database and ECMWF automated cyclone tracking database. The rate of increase in 2.63 cyclones/ year from ECMWF and 4.66 cyclones/year from OPC

References:

Lim E-P, Simmonds I (2002) Explosive cyclone development in the southern hemisphere and a comparison with northern hemisphere events. Mon Wea Rev 130:2188–2209

Patoux J.,Yuan1,X., Li1,C., Satellite-Based Midlatitude Cyclone Statistics Over the Southern Ocean. Part I: Scatterometer-Derived Pressure Fields and Storm Tracking. *Geophys. Res*., vol 114, D04105, doi:10.1029/2008JD010873, 2009