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Tropical Cyclone Intensity and Structure Changes due to Upper-Level Outflow and Environmental Interactions

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LONG-TERM GOALS

The long-term goals of this project are to investigate the hypotheses that changes in tropical cyclone intensity and structure depend on: i) characteristics of the upper-level environment, ii) TC structure, iii) phasing of the TC and the environmental features, and iv) feedback of the TC onto the environment. The hypotheses are to be addressed via observations of the interactions between a a tropical cyclone over tropical, subtropical, and midlatitude regions in the context of increasingly complex upper-level environments. The spatial and temporal variations in tropical cyclone outflow and its interaction with the environment are examined with respect to impacts on changes in tropical cyclone intensity, strength, and size. Results will lead to improvements in understanding, modeling, and analysis of tropical cyclone intensity and structure changes in support of improved prediction of potentially high-impact weather that impacts shore- and sea-based operations over the western North Atlantic and Pacific Ocean basins.

OBJECTIVES

Structure and intensity changes occur throughout the life cycle of a tropical cyclone (TC) due to asymmetries in lower boundary conditions, internal factors related to dynamics and convection, and environmental interactions. Environmental influences on a mature TC are known to be most critical at upper levels where the inertial stability of the vortex is reduced. As a TC moves poleward and approaches recurvature, the upper-level environment becomes increasingly complex such that interactions may ensue due to the proximity of a TC to semi-permanent mid-ocean troughs, midlatitude troughs and ridges, and upper-level jet systems. While the poleward movement of a TC eventually leads to weakening and transition to an extratropical cyclone, the initial poleward movement is often associated with intensification and structure changes (i.e., expansion of the radius of maximum winds or expansion of the total wind field) that can occur rapidly.

The objective of this project is to examine the role of tropical cyclone outflow as a key factor by which the large-scale environment relates to changes in the internal structure of the tropical cyclone. Internal

structure is defined as intensity, strength, and size. Based on the framework of the three primary categories of environmental interaction, which are defined as upper-level troughs, vertical wind shear, and the upper-level outflow of the tropical cyclone itself, specific objectives are to examine the hypotheses in the framework of the large-scale environment of the North Atlantic and western North Pacific. The environments are partitioned into regions that are: a) equatorward; b) along; and c) poleward of the subtropical ridge axis.

APPROACH

In the context of the project objectives, the approach is to examine tropical cyclone interactions with three primary environments. Outflow characteristics equatorward of the subtropical ridge axis, where tropical cyclones form and undergo initial intensification are examined relative to convective activity and the large-scale environment that dictates whether the convection-outflow system can lead to TC formation or decay (e.g., when upper-level flow contributes to excessive ventilation that disrupts the warm core. The interaction between environmental factors and the tropical cyclone convection along the subtropical ridge axis is examined where recurvature may occur and the interactions among environmental and TC processes are sensitive to a variety of factors (i.e., upper-level trough characteristics, TC intensity and/or size). Finally, outflow characteristics poleward of the subtropical ridge axis are examined where the impact of the environment on the TC intensity and structure defines the process of extratropical transition (ET). Furthermore, over this region poleward of the subtropical ridge, the process of weakening may lead to TC outflow impacting the midlatitude jet stream and downstream waveguide across the entire North Atlantic or North Pacific basins.

Tropical cyclone – environment interactions over the three regions are examined in a combined climatological, observation, and modeling framework. Analysis of historical cases over each region define typical patterns of outflow – environment interactions. Observations are examined from potential aircraft and satellite platforms for possible cases during previously scheduled field campaigns and the operational hurricane reconnaissance program over the North Atlantic. Finally, modeling studies will examine the processes related to tropical cyclone outflow – environment interactions as forcing tropical cyclone intensity and structure changes.

WORK COMPLETED

To examine the processes associated with upper-level tropical cyclone – environment interactions, simulations of the formation and rapid intensification stages of Typhoon (TY) Sinlaku (2008), which occurred during the Tropical Cyclone Structure-2008 (TCS-08) field program. This case was chosen not only for the rapid intensification and structural changes but also because there are several sets of aircraft data avaliable. These data range from low-level observations from the WC-130J in the inner core, and mid- to upper-level observations from the Taiwan DOTSTAR aircraft and German DLR Falcon aircraft. Previous studies have been conducted on the relative value of the three sets of aircraft observations to forecast track skill using the ECMWF, NCEP-GFS, and JMA Global Spectral Model.

In this study, the intent was to simulate observations that may be taken using a Global Hawk unmanned aerial vehicle (UAV). Observations from a Global Hawk would be obtained near 60,000 feet and over longer temperal periods and larger spatial domains than a piloted conventional aircraft. The numerical experiments were conducted using the Advanced Weather Research Forecast (A-WRF) model. A series of four experiments were conducted that progressed from being initialized with current forecasts from the ECMWF, assimilating convential observations, assimilating WC-130J

observations, assimilating pseudo observations representative of being from a Global Hawk. The pseudo observations were constructed from ECMWF analyses valid at the pseudo observation time. The observations were constructed to represent dropwindsondes released from 60,000 feet over a region where the outflow from Sinlaku was impinging on the midlatitude jet stream ahead of a progressive midlatitude trough. For all experiments that included an assimilation of data, a ensemble-based assimilation scheme was used with 48 ensemble members.

Other work completed focused on finishing previously started analyses of structure changes in a tropical cyclone under strong vertical wind shear (Foerster et al. 2014), the interaction of a tropical cyclone and midlatitude baroclinic zone and jet stream (Quinting et al. 2014), the impact tropical cyclone outflow on the midlatitude flow patterns (Keller et al. 2014), and the role of a tropical upper-tropospheric trough in the nondevelopment of a tropical convective cloud cluster (Penny et al. 2014).

RESULTS

The various forecasts of the track of TY Sinlaku during its movement northward prior to recurvature were compared with the Joint Typhoon Warning Center best track, the track as defined in the ECMWF analyses captured from the Year of Tropical Convection (YOTC) data set, and a WRF simulation in which the ECMWF analyses were used as boundary conditions (Fig. 1). A WRF simulation initialized using ECMWF forecasts with no assimilation (blue track in Fig. 1) was too far equatorward of the best track (black line in Fig. 1), the ECMWF forecast (green line in Fig. 1), and the A-WRF using the ECMWF analyses (magenta line in Fig. 1). When the A-WRF is run in forecast mode assimilating the pseudo observations meant to be representative of the Global Hawk, all the ensemble members are poleward of the A-WRF forecast track without assimilation. Initial inspection of the resulting forecast fields (Mitchell 2014) indicate that the pseudo observations improved the forecast of the outflow-jet stream interaction and contributed to a track that was more poleward than the originally forecast. Continued inspection of the fields will provide increased details with respect to the value added by potential observations at high altitude and over regions remote from the tropical cyclone center.

To examine the role of vertical wind shear due to the presence of a strong midlatitude jet, a unique situation was analyzed in that TY Sinlaku moved to near 35°N lat. as a typhoon that had not yet begun the process of extratropical transition (ET). High-resolution airborne Doppler radar observations together with flight-level aircraft data, and dropwindsondes provided analyses of the detailed structural characteristics of the evolution of the mid- and upper-levels of the typhoon. The analysis of Foerster et al. (2014) was conducted in shear-relative coordinates to document the evolution in eyewall convection that became rotated from downshear, matured and transformed to stratiform cells on the upshear side of the storm center. These modifications to the eye convection were related to the start of the transformation stage of ET.

As Sinlaku tracked eastward of Japan it began to interact with the primary midlatitude baroclinic zone and jet stream. Again, high-resolution airborne Doppler radar observations provided measurements of the interaction of the storm outflow, an upstream midlatitude trough, and the downstream jet stream (Quinting et al. 2014). Quasi-geostrophic diagnostics were applied to examine the processes related to the linkages between the midlatitude and tropical environments.

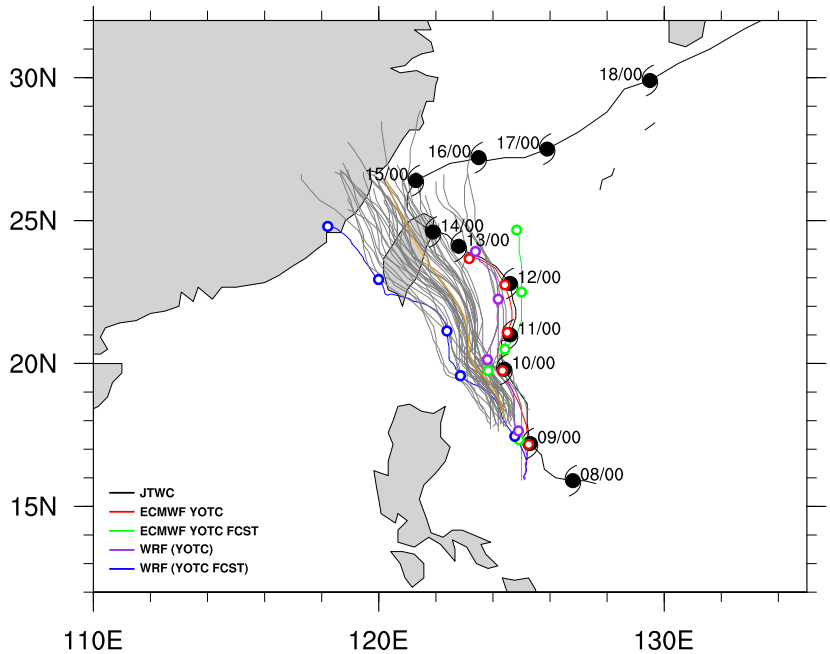

Figure 1. The best track (black line) of Typhoon Sinlaku (2008) and the position in the ECMWF analysis (red line) with forecasts initialized at 0000 UTC 9 September from the ECMWF (green line), the A-WRF using ECMWF analyses (magenta line), the A-WRF using ECMWF forecasts (blue line), and ensemble members from the A-WRF with ensemble data assimilation of pseudo Global Hawk observations. The orange line defines the ensemble mean track.

The interactions between a tropical cyclone outflow and a midlatitude jet were examined in relation to changes in the tropical cyclone structure and the downstream jet characteristics (Keller et al. 2014). The changes in both tropical and midlatitude systems were examined using eddy kinetic energy as framework to define the processes associated with the tropical-extratrpopical interactions. In the cases examined, the role of barcolinic conversion of eddy available potential energy contained in the tropical circulation to eddy kinetic energy of the midlatitude jet was determined to be the key process related to the phasing between the tropical and midlatitude circulations.

IMPACT/APPLICATIONS

The research being conducted on the interactions among a tropical cyclone and the upper-level environments equatorward of the subtropical ridge, along the subtropical ridge, and poleward of the subtropical ridge will result in increased accuracy associated with the prediction of tropical cyclone intensification and structural changes. These improvements will be defined in part through improved numerical simulations using high-resolution models such as the Coupled Ocean Atmosphere Mesoscale Prediction System – Tropical Cyclone (COAMPS-TC). Additionally, the unique observations of the upper-level environment of mature tropical cyclones over the western North Pacific provide a unique capability to identify the relative roles of environmental factors on tropical cyclone intensity change.

TRANSITIONS

Following the compilation and analysis of the wide range of cases and model results, research results that identify factors responsible for the variability in tropical cyclone – environment interaction as they relate to tropical cyclone intensification and structure change will transition into a variety of products that will benefit operational forecasting of these tropical cyclone characteristics. These may be stand-alone products, satellite-based products, improvements to numerical models, etc. Final transition of the research will result in increased predictability associated with tropical cyclones that impact operations of the U.S. Navy across the western North Pacific

RELATED PROJECTS

The analysis of tropical cyclone sturcture and intensity changes is being conducted in relation to several other projects sponsored by ONR Marine Meteorology. One project titled NASA Hurricane and Severe Storm Sentinel (HS3) Observations for Testing Environmental Control of Hurricane Formation and Intensification is examining data obtained during Hurricane and Severe Storms Sentinel experiment.

PUBLICATIONS

Foerster, A. M., M. M. Bell, S. C. Jones, and P. A. Harr, 2013: Observations of the eyewall structure of near-extratropical Typhoon Sinlaku (2008) in vertical wind shear. *Mon. Wea. Rev.,* **142**, 3372 – 3392. (refereed)

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