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Real-Time Prediction of Tropical Cyclone Intensity Using COAMPS-TC

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Introduction: The demand for more accurate tropical cyclone (TC) forecasts with longer lead times is greater than ever due to the enormous economic and societal impact of these storms. There has been spectacular improvement in TC track prediction; a three-day hurricane track forecast today is as skillful as a one-day forecast was just 30 years ago. However, there has been little progress in improving TC intensity and structure forecasts due to a variety of reasons, ranging from a lack of critical observations under high wind conditions and in the TC environment, to inaccurate representations of TC physical processes in numerical weather prediction (NWP) models. Advances in high-resolution TC modeling and data assimilation are thought to be necessary to significantly improve the performance of intensity and structure prediction. To this end, the Naval Research Laboratory in Monterey, California, has developed the Coupled Ocean/Atmosphere Mesoscale Prediction System for Tropical Cyclones (COAMPS-TC™), a new version of COAMPS® designed specifically for high-resolution tropical cyclone prediction.

COAMPS-TC System: The COAMPS-TC system is comprised of data quality control, analysis, initialization, and forecast model subcomponents. A TC version of the Navy Atmospheric Variational Data Assimilation System (NAVDAS) has been developed to blend the available atmospheric observations from a plethora of sources, along with synthetic observations that define the TC structure and intensity. The COAMPS-TC atmospheric model uses the nonhydrostatic and compressible form of the dynamical equations; and includes physical parameterizations of cloud microphysical processes, convection, radiation, boundary layer processes, and surface layer fluxes.[1] The COAMPS-TC system allows for moving nested grid families that independently follow individual tropical cyclone centers. The COAMPS-TC system has the capability to operate in a fully coupled air–sea interaction mode using the Navy Coastal Ocean Model (NCOM) and the Simulating WAves Nearshore (SWAN) model.[2] The Navy Coupled Ocean Data Assimilation (NCODA) system is used to initialize the ocean.

Real-Time Demonstration of COAMPS-TC: Real-time COAMPS-TC forecasts have been conducted using U.S. Department of Defense High Performance Computing (HPC) platforms over the past several years. An example of the intensity forecast performance of COAMPS-TC for a large number of cases (more than 450 cases at the 24 h forecast time) in the W. Atlantic region for the 2010 and 2011 seasons is shown in Fig. 1 (homogeneous statistical sample). The COAMPS-TC model had the lowest intensity error of any dynamical model for the 36 to 120 h forecast times, which is an important period for forecasters and decision makers. Other numerical models included in this analysis are operational models run by NOAA (HWRF, GFDL), and the Navy's current operational limited area model (GFDN).

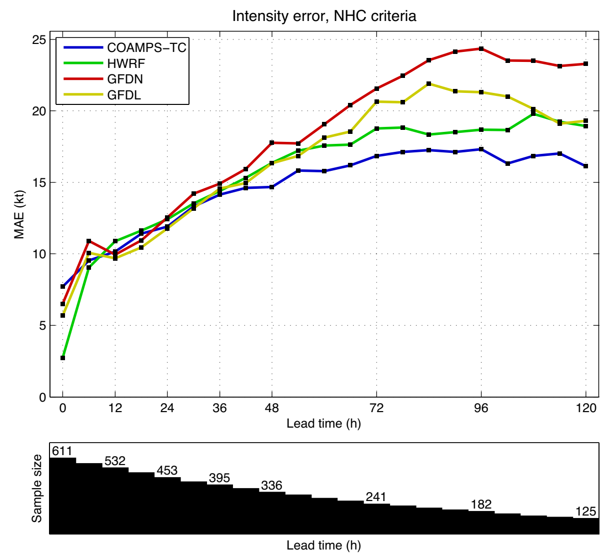

FIGURE 1
Wind speed mean absolute error (MAE) (knots; 1 knot = 0.514 m s^{-1}) as a function of forecast time for the 2010 and 2011 seasons in the Atlantic basin for a homogeneous statistical sample. The numerical models included in this analysis are the Navy's COAMPS-TC, operational models run by NOAA (HWRF, GFDL), and the Navy's current operational limited area model (GFDN). The number of cases is shown at the bottom. (NHC = National Hurricane Center).

An example of a real-time COAMPS-TC forecast for Hurricane Irene (2011) is shown in Fig. 2. The composite National Weather Service (NWS) radar reflectivity (a proxy for the rainfall distribution and intensity) is shown in the top panel near the time of landfall in North Carolina at 1148 UTC 27 August 2011, and the COAMPS-TC predicted radar reflectivity at 36 h valid at 1200 UTC is shown in the bottom panel. The COAMPS-TC forecast shown in Fig. 2 is for the model second grid mesh (15 km horizontal resolution). The model prediction was accurate in the track, eventual landfall location, and storm intensity, as well as the

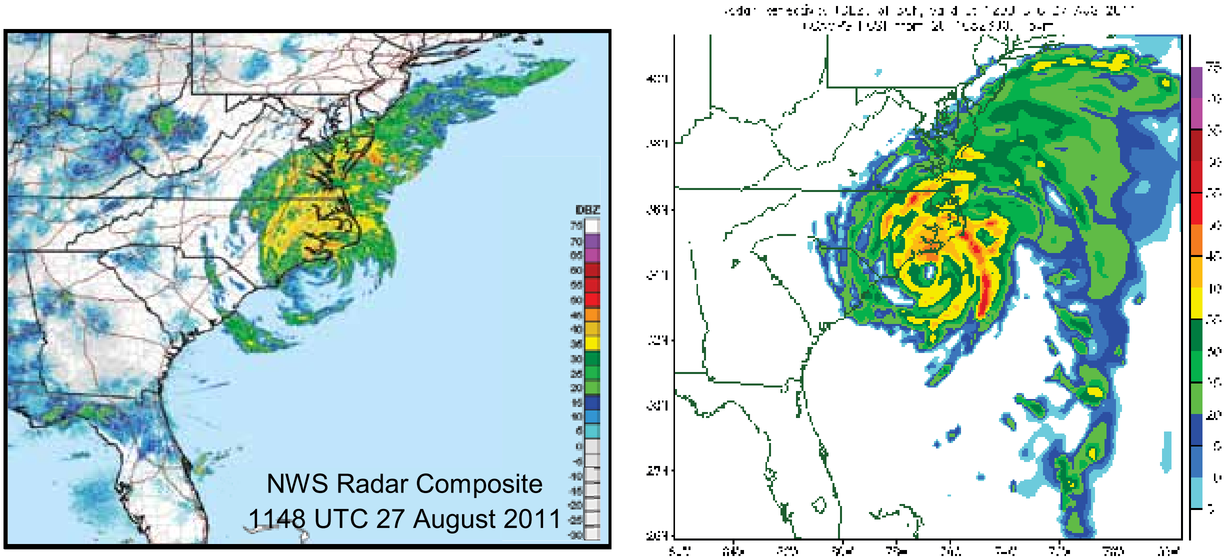

FIGURE 2
The NWS composite radar reflectivity valid at 1148 UTC 27 August 2011 (left panel) (source NOAA) and the COAMPS-TC 36 h forecast radar reflectivity performed in real time and valid at 1200 UTC 27 August (right panel) for Hurricane Irene. The COAMPS-TC reflectivity is shown for the second grid mesh, which has a horizontal resolution of 15 km.

structure and size, especially important characteristics of this particular storm in such close proximity to the U.S. East Coast. The COAMPS-TC prediction captures the large areal extent of the precipitation field, as well as its asymmetry about the TC center (most of the precipitation is north and east of the center). This large shield of heavy precipitation caused severe river flooding as it slowly moved north through the mid-Atlantic and northeast United States. Overall, the Navy's COAMPS-TC real-time intensity predictions of Hurricane Irene outperformed other leading operational governmental forecast models, as shown in Fig. 3. All the available models except COAMPS-TC had a tendency to over-intensify Irene, often by a full storm category or more. These real-time COAMPS-TC forecasts were used by forecasters at the National Hurricane Center (NHC) as part of an experimental NOAA multi-model ensemble. The COAMPS-TC consistently provided accurate real-time intensity forecasts during the period of August 23 through 28, 2011, when critical decisions, including decisions on evacuations, were made by forecasters and emergency managers.

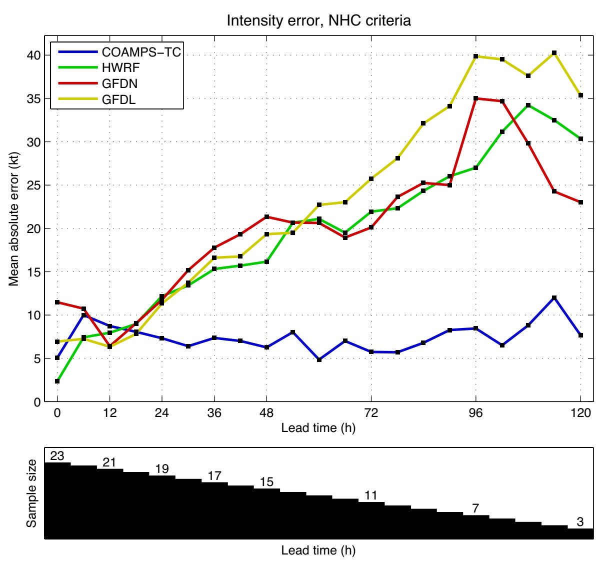

FIGURE 3
Wind speed mean absolute error (MAE) (knots) as a function of forecast time for Hurricane Irene for a homogeneous statistical sample. The numerical models included in this analysis are the Navy's COAMPS-TC, operational models run by NOAA (HWRF, GFDL), and the Navy's current operational limited area model (GFDN). The number of cases is shown at the bottom. Only forecasts after Irene has moved away from Hispaniola are shown here.

Prediction of tropical cyclone track and particularly intensity remains one of the greatest challenges in meteorology today. The results of this research highlight the promising capability of COAMPS-TC. While COAMPS-TC accurately predicted the evolution of Irene and other tropical cyclones in real time, it has not predicted all TCs equally well. The data collected during the life cycle of these storms provide opportunities to study and obtain a greater appreciation of the complex physics and interactions that occur in these systems, and to use this information to improve our COAMPS-TC modeling system.

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Cirrus Cloud Seeding by Stratospheric Volcanic Aerosol Particles

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Introduction: Lower stratospheric (LS) volcanic incursions can indirectly perturb upper tropospheric (UT) cloud fields (i.e., cirrus clouds) long after the initial eruption cycle from gradual particle settling and re-entrainment back into the troposphere. Volcanic sulfur dioxide and hydrogen sulfide vapor molecules are photo-oxidized in the LS, forming gaseous sulphuric acid, which in turn increases sulfate-based aerosol particle concentrations through nucleation, condensation, and coagulation (i.e., hydrated sulfuric acid solution droplets). These particles, combined with any embedded silicate ash aloft, are highly efficient ice nuclei.

NRL scientists, in collaboration with colleagues at NASA Goddard Space Flight Center (GSFC), have collected the most compelling observations to date unambiguously linking cirrus cloud seeding to aged stratospheric volcanic particles.[1] The August 7 and 8, 2008, Mt. Kasatochi eruption injected gases and ash into the LS over the Aleutian Islands of southwestern Alaska, nearing 17.0 km (all heights above mean sea level). Ten days downwind over south-central Maryland, Kasatochi aerosols were profiled by ground-based lidar mixing into the UT near a tropopause fold. Driven by enhanced ambient water vapor concentrations, cirrus clouds and ice crystal fallstreaks emerged from within the volcanic layer, likely induced by either homogeneous freezing of sulfate solution droplets or their heterogeneous activation by ash. NASA and NOAA satellite observations add contextual evidence supporting these findings.

Kasatochi Particles and Cirrus Cloud Seeding over Maryland: On August 17 and 18, or just a week after the Kasatochi eruption, LS aerosol particles were profiled in zenith-oriented 0.532 μm lidar measurements collected at the NASA Micropulse Lidar Network (MPLNET) field site on the GSFC campus in Greenbelt, Maryland (Fig. 4). Lidar backscatter is proportional to particle number concentration and cross-sectional area. The LS layer depicted in Fig. 4 thus represents scattering by newly formed sulfate solution droplets and any ash debris aloft. The cold-point tropopause height measured at nearby Sterling, Virginia, during this period varied between 12.0 and 12.5 km.

Hyperspectral ultraviolet composite retrievals of sulfur dioxide concentration over the eastern United States at 1815 UTC on the 17th shown in Fig. 5(a), derived from NASA Ozone Monitoring Instrument (OMI) measurements, depict transient Kasatochi LS filaments approaching central Maryland. Regional water vapor imagery collected concurrently from a NOAA geostationary satellite (6.47 to 7.02 μm broadband channel) is shown in Fig. 5(b). Subsidence associated with a tropopause fold, marking the intrusion of stable stratospheric air into the baroclinic region beneath the jet stream propagating along the base of a geopotential height trough apparent over the east-central United States, is interpreted from a relatively dark band stretching from Nebraska to Maryland. Tropopause folds are turbulent, thus inducing UT/LS exchange.

Beginning 2000 UTC on the 17th, with maximum SO_2 concentrations reaching the area, increased backscatter was measured with the MPLNET instrument above 13.0 km, lasting through 0100 on the 18th. Simultaneously, a segment of the layer was displaced downward into the UT, reaching below 11.0 km by 0500. From 2200 until 0400, strong and transmissive signals characteristic of cirrus clouds and ice crystal fallstreaks were profiled from 10.0 to 11.5 km, with tops embedded within the UT-entrained layer. A regional true-color composite image derived from NASA Moderate Resolution Infrared Spectroradiometer (MODIS) measurements collected at 1805 UTC on the 17th, in sequence ahead of OMI, is shown in Fig. 6. A relatively narrow band of cirrus clouds and fallstreaks, corresponding with those profiled by the MPL, were oriented from northwestern Virginia across the Chesapeake Bay and extending northeastward over the western Atlantic.

Two scenarios for cirrus cloud seeding likely reconcile this event. First, regional temperatures above 10.0 km were colder than 235 K, or the approximate threshold for homogeneous freezing of water that in solution is believed a function of water activity as opposed to