# Advanced Satellite-Derived Wind Observations, Assimilation, and Targeting Strategies During TCS-08 for Developing Improved Operational Analysis and Prediction of Western Pacific Tropical Cyclones

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## LONG-TERM GOALS

Forecasts of tropical cyclone (TC) formation and intensity change in the north-western Pacific basin are often lacking in skill, in part due to the paucity of conventional oceanic observations that are assimilated into the operational models. This lack of observations has also constrained our understanding of how TC formation is governed by environmental processes. Recently, remotely-sensed observations from satellites have become a routine and important input to the global data assimilation systems. These data can provide critical environmental data for the testing of hypotheses of TC formation and development, and improving our understanding of how environmental influences on TC structure evolve up to landfall or extratropical transition. In particular, winds derived from geostationary satellites have been shown to be an important component of the observing system in reducing TC model track forecasts. However, in regards to TC formation, intensity change, and extratropical transition, it is clear that a dedicated research effort is needed to optimize the satellite data processing strategies, assimilation, and applications to better understand the behavior of the near-storm environmental flow fields during these evolutionary TC stages. To our knowledge, this project represents the first time anyone has tried to evaluate the impact of targeted *satellite* data on TC forecasts using an automated dynamic targeted observing strategy. TCS-08 will afford us the opportunity to employ specially-processed satellite data along with observations collected in situ by the NAVY P-3, and other platforms, to investigate these objectives as they apply in the western north Pacific TC basin. The development of successful real-time strategies to optimally assimilate wind data from satellites will ultimately lead to the provision of improved initial and boundary conditions for the Navy's envisioned mesoscale coupled ocean-wave-atmosphere forecast model.

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**Forecasts of tropical cyclone (TC) formation and intensity change in the north-western Pacific basin are often lacking in skill, in part due to the paucity of conventional oceanic observations that are assimilated into the operational models. This lack of observations has also constrained our understanding of how TC formation is governed by environmental processes.**

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## OBJECTIVES

The ultimate objective of this project is the development and refinement of a capability to supplement the contemporary atmospheric observation network with advanced satellite wind observations to improve high-resolution operational analyses and medium-range forecasts of western North Pacific typhoons.

One primary research goal will be to evaluate and diagnose the impact of assimilating the advanced satellite wind observations on global Navy model forecasts, and high-resolution forecasts of structure change. We aim to better understand how to utilize the satellite wind data in the context of numerical model assimilation and forecast impact. Optimizing the assimilation of the experimental satellite winds will involve a continued investigation of the satellite data quality control indicators, prescribing improved observational error covariances, and utilizing 4DVAR approaches.

## APPROACH

During the field phase of TCS-08, experimental satellite-derived wind observations were produced by UW-CIMSS using state-of-the-art automated methods. Hourly datasets were routinely derived from operational images provided from the Japan Meteorological Agency (JMA) MTSAT geostationary satellite. In addition, special rapid-scan (r/s) images from MTSAT-2 were provided by JMA for extended periods (24-48hrs) over specific regions, and including parts of selected typhoon life cycles. UW-CIMSS also processed these images into wind fields (higher resolution). These special satellite-derived wind observations complemented those data collected by the NRL P-3 aircraft during TCS-08, by providing unique time-continuous environmental data in locations that were deemed important to tropical cyclone formation and development.

The project uses the 2008/9 versions of NAVDAS and NOGAPS, the Navy's current operational data assimilation and global forecast model systems, so that the research results may be easily transitioned to improve the Navy's operational predictions. The DA approaches will be extended to the new NAVDAS 4DVAR system that is expected to be ready for use very soon. We expect that the 4DVAR assimilation will provide an improved analysis, since its temporal continuity better exploits the asynoptic satellite winds than 3DVAR, in which the observations are assimilated at discrete 6-hour intervals. Upon completion of the experiments, the resulting global analyses and forecasts will be made available to investigators involved in developing and testing the Navy's coupled ocean-wave-atmosphere model.

Existing adaptive observing strategies such as the Ensemble Transform Kalman Filter (ETKF) and NOGAPS Singular Vectors have been used to identify regions in which numerical forecasts are most likely to benefit from the assimilation of additional satellite wind data. A new 'synthetic observation ensemble' will also be devised to answer this question more directly. Via the observation sensitivity method (for forecasts up to 24h) and data denial in the Navy forecast system (for forecasts up to 5 days), the impact of assimilating targeted high-density (hourly and rapid-scan) satellite winds on global model forecasts of tropical cyclone track and high-resolution forecasts of tropical cyclone structure will be evaluated and analyzed.

Finally, in order to extend and evaluate targeting hypotheses specific to high-resolution predictions of tropical cyclone structure, new perturbation experiments in the Weather Research and Forecasting

(WRF) modeling framework are being designed. This framework allows for the direct diagnosis of how modifications to the initial wind field in the synoptic environment lead to altered forecasts of tropical cyclone structure. The software is designed such that it can be transferred to the developing COAMPS-TC framework at the Naval Research Laboratory, Monterey.

**WORK COMPLETED**

In Year 2, the UW-CIMSS team collected and provided the EOL TPARC/TCS-08 data management team with the MTSAT-1R satellite-derived wind datasets provided hourly in real time during the TCS-08 field phase (Year 1). These datasets were also made available to scientists at NRL-MRY working with NOGAPS to conduct data impact studies. The special rapid-scan MTSAT-2 images provided by JMA at selected times during the experiment were used to study optimized data processing approaches to achieve maximum quantity and quality of vectors. Once achieved, the datasets were made available to the EOL TPARC/TCS-08 data management team.

The primary task of the U. Miami team in Year 1 had been to provide real-time guidance for targeting in support of the TCS-08 and T-PARC field programs. In Year 2, the focus has turned to the detailed investigation of the synoptic sensitivity associated with one long-lived cyclone during TCS-08: Typhoon Sinlaku, and the evaluation of hypotheses for optimal areas for targeting satellite wind data. In order to accomplish this, the U. Miami team installed a 2-km resolution version of the Weather Research and Forecasting (WRF) model, including a new bogus vortex initialization and nesting within global models such as NOGAPS. This high-resolution model offers the new flexibility to investigate questions about the modification to numerical predictions of tropical cyclone *structure* (and not just track) by assimilating targeted satellite wind data. A graduate student funded on this grant, William Komaromi, was trained on the usage of the WRF framework, and is now conducting the numerical experiments for his thesis research.

**RESULTS**

A unique satellite-derived dataset was produced during TCS-08 consisting of hourly wind fields (important for testing 4DVAR assimilation methods), and occasionally enhanced with higher-resolution rapid-scan winds (important for resolving details of tropical cyclone circulations and interacting targeted features). To date, only the hourly datasets have been considered for data assimilation experiments with NOGAPS. Results from the first set of trials, for Typhoon Nuri, were mixed. The hourly MTSAT AMVs did not result in a track or intensity forecast improvement. However, neither did special aircraft dropsonde data available during parts of the event. The investigation continues, and plans are to next run experiments with Typhoon Sinlaku, and to include the rapid-scan datasets in the NOGAPS trial runs.

In terms of targeting approaches for the satellite-derived wind data, it is possible to modify features such as shortwaves via vorticity inversion in a layer, and then analyze their influence on the evolving TC structure in WRF. Using the initial condition, the horizontal and vertical scales of the shortwave are first determined subjectively. Inversion of the shortwave vorticity results in the streamfunction field and geopotential field (via geostrophy). Using the hydrostatic relationship, the shortwave temperature perturbation is then determined. Removal of the wind, geopotential, and temperature perturbations from the total fields yields a reasonably balanced, shortwave-free base state.

An example of a hypothesis on optimal target areas for satellite wind data is illustrated below. Based on intuitive reasoning and targeting strategies, it is proposed that the numerical forecast of Typhoon Sinlaku is sensitive to the representation of a shortwave to its north-northwest. Figure 1 illustrates the removal of this shortwave via this method, while maintaining consistency and balance in the environmental flow.

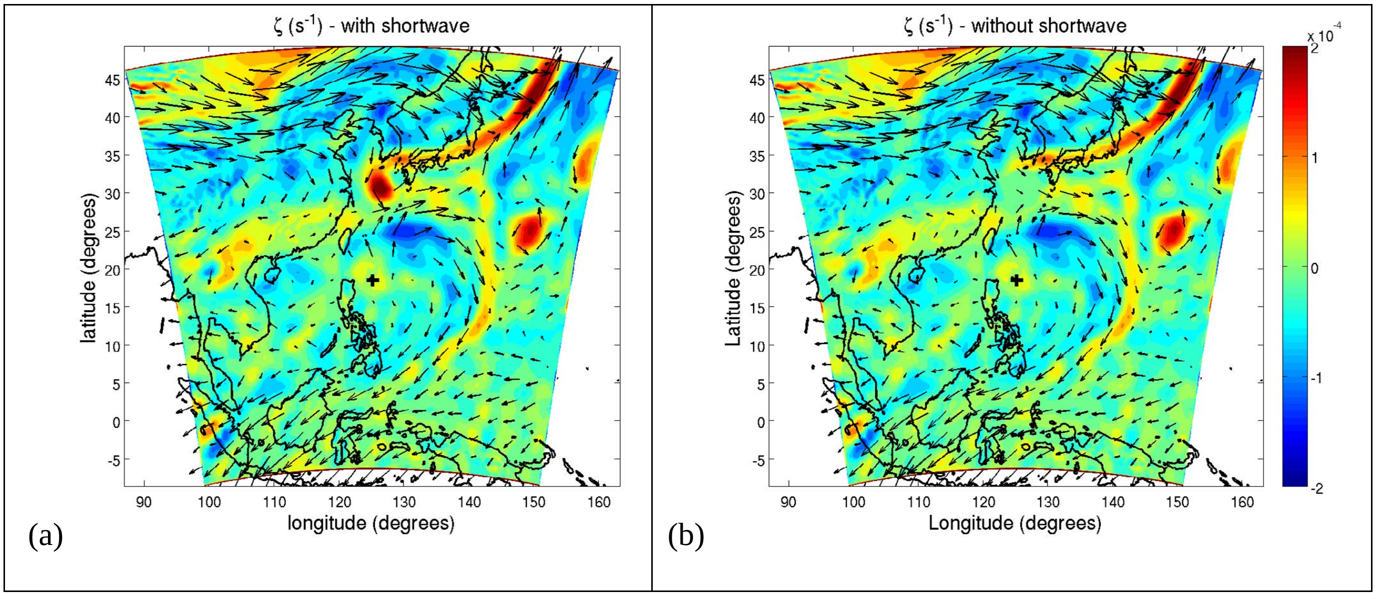
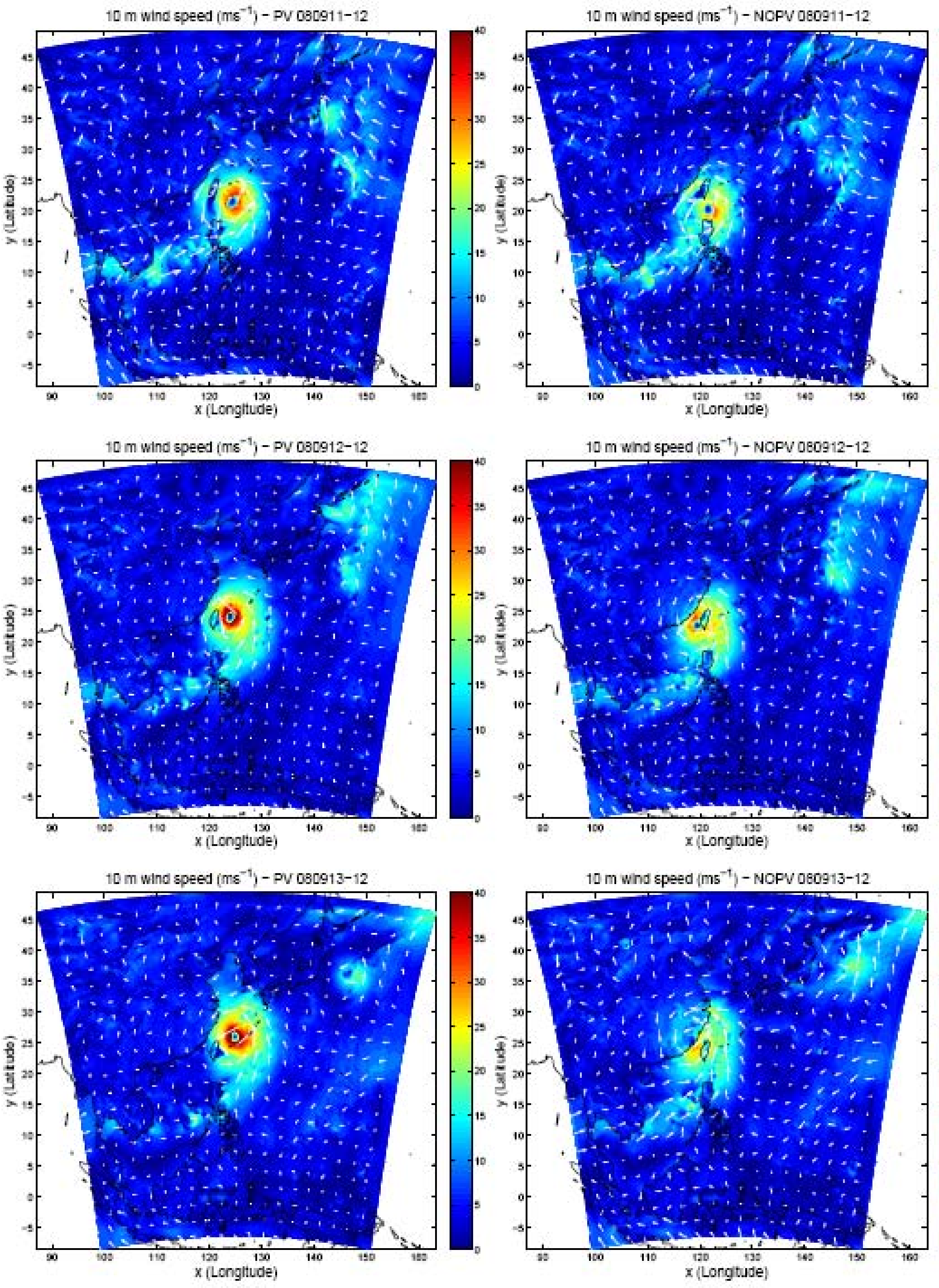



***FIGURE 1. (a) Relative vorticity field and flow, averaged in a 650-150 hPa layer, with no removal of the shortwave. (b) As in (a), but with the shortwave removed just south of Korea. Typhoon Sinlaku is marked by "+".***

Figure 2 illustrates the modification to the track and wind field of Typhoon Sinlaku due to the removal of the shortwave illustrated in Fig. 1. With the shortwave included, the WRF forecast takes Sinlaku close to NE Taiwan, where the typhoon actually made landfall. With the shortwave excluded, the ridge to the east of the model typhoon increases its strength, thereby inducing a more westward track with the storm making a false landfall in China. Therefore, Fig. 2 indicates that there is sensitivity in the WRF forecast to the shortwave to the north of Sinlaku. We are applying such principles to identify relative sensitivities of forecasts to features near to and far from the TC in its formation and structure change phases, based on NOGAPS Singular Vectors and other sensitivity methods. The key target areas for satellite wind data throughout the life cycle of Sinlaku will therefore be revealed.

| SHORTWAVE | NO SHORTWAVE | |
|---|---|---|




2-day fcst

3-day fcst

4-day fcst

***FIGURE 2. Left column: WRF forecast for Typhoon Sinlaku initialized on 12 UTC, 09 September 2008. Right column: As for the left column, but with the shortwave removed from the initial conditions.***

## IMPACT/APPLICATIONS

A quantitative understanding of the influence of improved representations of the synoptic environment and outflow in the tropical cyclone will lead to new scientific conclusions on environmental interactions and modifications to tropical cyclone track and structure. The longer-term impact will be derived from the improved assimilation of targeted satellite wind observations in Navy (and other) models.

## TRANSITIONS

None in this reporting period.

## RELATED PROJECTS

This project is related to that funded by the TCS-08 grant N000140810250: "Using NOGAPS Singular Vectors to Diagnose Large-Scales on Tropical Cyclogenesis" (PI Majumdar; Co-PIs Peng and Reynolds of NRL Monterey). A supplement to the budget on that grant has enabled the further development of the WRF vortex initialization and inversion software for easy use by students and collaborators. This software will also be used in the new NOPP collaboration between Velden and Majumdar. Additionally, the same software is being employed by Majumdar on a new collaboration with the NOAA National Hurricane Center.

This project is also related to that funded by the NSF grant ATM-0735892: "Extratropical transition of tropical cyclones over the western North Pacific: Physical characteristics, downstream impacts, and predictability" (PI Velden, Co-PIs Harr and Elsberry of NPG).

## REFERENCES

None in this reporting period.

## PUBLICATIONS

No refereed publications in this reporting period.

## PATENTS

None in this reporting period.

## HONORS/AWARDS/PRIZES

PI Velden elected to the AMS Hurricane Scientific and Technical Advisory Committee, and as Co-Chair of the next WMO International Workshop on Tropical Cyclones to be held in 2010.