University: **University of Hawai‘i at Manoa**

Name of University Researcher Preparing Report: Yi-Leng Chen

NWS Office: National Weather Service Honolulu Forecast Office

Name of NWS Researcher Preparing Report: Robert Ballard

Partners or Cooperative Project: Partners Project

Project Title: Hindcasts of TC Lane (2018) and TC Wutip (2019) with a New TC Initialization Scheme with Data Assimilation to Improve Intensity Forecasts

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Section 1: Summary of Project Objectives:

The proposed project has three components:

1) Perform data assimilation to provide better mesoscale environment to spin up tropical cyclones (TCs) in the high-resolution model domain;

2) Test the performance of the new TC dynamical initialization scheme proposed by Nguyen and Chen (2011; 2014) (NC2014) with data assimilation in simulating the track, intensity, and structure of TC Lane (2018) and TC Wutip (2019), especially during the periods with rapid intensity changes; and

3) Compare our model performance with operational models, e.g., HWRF and COAMPS and rain gauge, surface, satellite and radar observations. The University of Hawai‘i (UH) team will focus on modeling and hindcasts. The Central Pacific Hurricane Center/National Weather Service (CPHC) team will focus on providing input on the challenges faced in operational forecasts and the usefulness and value of our model results in real-time operational settings. The National Weather Service Honolulu Forecast Office (NWS-HFO) is collocated with the Department of Atmospheric Sciences in the Hawai‘i Institute of Geophysics Building on the University of Hawai‘i campus. In the future, we will conduct experimental real-time TC forecasts over the Hawaiian Islands, CNMI/Guam, and the Western Pacific.

Section 2: Project Accomplishments and Findings:

a) Update of the high-resolution WRF-ARW model over the Hawaiian Islands: (i) shifting the initial conditions from GFS to FV3GFS; (ii) upgrading the once daily high-resolution 72-h forecasts to twice daily; (iii) replacing the U.S. Geological Survey (USGS) land use data compiled by Zhang et al. (2005a,b) with the recently updated land cover from the Coastal

Change Analysis Program (C-CAP, NOAA 2019) (Hsiao et al., 2020) due to the recent urbanization of the Ewa Plain and City of Kapolei.

b) Bring twice daily high-resolution WRF-ARW and WRF-NMM experimental 72-h forecasts to the numerical model suite at NWS Honolulu. The WFO Honolulu continues to evaluate the usefulness of experimental high-resolution daily forecasts for graphical forecast products with a grid-size of 2.5 km, with feedback provided to the UH team.

c) The NC2014 TC initialization scheme considers the interaction between TCs and the open ocean environment to improve TC initial intensity and structure. With data assimilation, we included unconventional data [GPS Radio Occultation (RO) refractivity, atmospheric motion vectors (AMVs) from Geostationary satellites (GOES-WEST and HIMAWARI), radiance from polar orbiters, etc.] in our regional domain to provide better initial conditions for TC Lane (2018) and TC Wutip (2019). For TC Lane, dropsondes and flight-level data from hurricane hunters were also used.

d) Similar to our previous studies, in addition to better resolution of winds, pressure, and size, the initial TC structure for both Lane (2018) and Wutip (2019) includes hydrometeors in the eyewall and spiral rainbands with asymmetric/symmetric structure, which are consistent with microwave images observed by polar orbiting satellites.

Our findings are as follows.

a) TC Lane (2018)

We did two 5-days test runs (Control, Spin-up, and 12-h Data Assimilation plus spin up) for TC Lane (0000 UTC, 21 August and 1200 UTC 21 August).

The initial TC structure from 12-h Data Assimilation (3-h cycles) plus spin-up (DA-SPIN) performs the best as compared with the control run (CTRL; initialized using GFS) and SPIN (using GFS as the environment fields to spin up TC) (Nguyen and Chen, 2011, 2014; Chen et al., 2014). The initial TC structure is validated against microwave observations from polar orbiters. DA-SPIN also provides the best track and intensity forecasts among three test runs.

In comparison with HWRF and COMAPS, DA-SPIN also provides favorable initial TC structure consistent with aircraft observations in the literature (e.g., Hawkins and Rubsam, 1968) with a maximum warm core above the 400-hPa level with sinking motion within the inner core region, especially in the upper atmosphere. One of the strengths is that the TC at the model initial time from DA-SPIN is well adjusted to the mesoscale environment with well defined eyewall and spiral rainbands. With a 12-h DA every 3 hours, the mesoscale environment for the DA-SPIN runs at the model initial time has merit when compared to the CTRL runs using GFS data.

The 0000 UTC 21 August HWRF run predicted a direct hit on Oahu. The best track data for both 0000 UTC, 1200 UTC showed that in the coastal waters of Hawai‘i under strong vertical windshear and relative cold SST, TC Lane made a sharp turn and moved westward without making landfall. Our DA-SPIN runs suggest that the best track data might overestimate the TC

intensity as it moved toward the coastal waters of Hawai‘i or the intensity might be too strong for the environment it was embedded.

In the CTRL runs, with no well defined TC structure predicted, the TC drifted with the low-level northeasterly flow. It appears that the tracks of the HWRF and COMAPS are significant affected by the upper-level steering flow after the storm entered the coastal waters of Hawai‘i, whereas the tracks from CTRL runs with a weak TC structure are affected mostly by the low-level northeasterly winds.

When we compared the TC structure in the model before turning for all three runs (CTRL, SPIN and DA-SPIN) initialized at 0000 UTC and 1200 UTC, 21 August, it is apparent that the track is affected by the TC structure and intensity. It also explains why the TC made a sharp turn in DA-SPIN runs after entering the coastal waters and weakening. Our DA-SPIN runs have better initial TC structure (size, warm core, winds, RH) in the inner core region and subsequent forecasts. The figures for CTRL, SPIN and DA-SPIN runs are given in http://www.soest.hawaii.edu/MET/Faculty/chen/Lane_Figs.pdf

b) TC Wutip (2019)

The model track forecasts for TC Wutip (2019) is very challenging. We ran tests for TC Wutip (2019) and, again, the DA-SPIN provides better initial TC structure and subsequence forecasts than CTRL and SPIN. It also has apparent merits when compared to operational models from our national centers (HWRF and COAMPS). The figures for our model runs are given in http://www.soest.hawaii.edu/MET/Faculty/chen/Wutip_Figs.pdf.

More tests and research are needed to better understand the factors affecting structure, intensity and track forecast over Hawai‘i and the western Pacific.

Section 3: Benefits and Lessons Learned: Operational Partner Perspective

Gradients of wind shear and sea surface temperature often lead to difficult-to-forecast changes in intensity and track of tropical cyclones. Improved mesoscale assimilation and forecasts of mesoscale changes within the system should lead to better forecasts in these challenging situations. The main Hawaiian Islands lie near climatological gradients of wind shear and sea surface temperature, which make tropical cyclone forecasting particularly challenging. Tropical Cyclone Lane is just one example of a system that underwent rapid structural, intensity, and track changes very near the main Hawaiian Islands. High resolution modeling can offer forecasters more information about specific impactful outcomes that they would not otherwise have using lower resolution models. More work needs to be done to study what can improve assimilation and model physics to better simulate smaller scale changes in the tropical cyclone environment and internal structure, in order to achieve more reliable guidance for forecasters who need to communicate impacts to the public.

Section 4: Benefits and Lessons Learned: University Partner Perspective

The main benefits to the university are the exposure of students to operational forecasting and better understanding of the forecast challenge in the operational environment. During the fall 2019 semester, Dr. Chen was the Instructor for ATMO 405, Synoptic Satellite Meteorology. His class attended the weather briefing at NWS-HFO every Friday morning. A forecaster (Norman Hui) and David Hitzl also taught a few classes on GOES-R ABI images when Dr. Chen was on travel attending conferences. Mr. Hitzl is an instructor with the NWS Pacific International Training Desk and a part-time PhD student under the supervision of Dr. Chen. Those interactions are invaluable learning experiences for our students.

Section 5: Publications and Presentations

a) Publications

Hsiao, F., Y.-L. Chen, D. E. Hitzl, H. V. Nguyen, and R. Ballard: Effects of trade wind strength on airflow and weather over O‘ahu. *Mon. Wea. Rev*. (submitted).

Hsiao, F., Y.-L. Chen and D. E. Hitzl, 2020: Numerical simulations of local afternoon heavy rainfall events over Central Oahu under weak wind conditions during the warm season. *Mon. Wea. Rev*. **148**, 4117-4141.

Hitzl, D.E., Y.-L. Chen and F. Hsiao, 2020: Wintertime easterly and southeasterly airflow in the 'Alenuihaha Channel, Hawai‘i. *Mon. Wea. Rev*., **148**, 1337-1362.

b) Presentations during the second webinar in the Pacific Training Desk Webinar series on Island Mesoscale Meteorology (September 17, 2020) hosted by David Hitzl

Li, L. and Y.-L. Chen: Conditions favorable for the occurrences of trapped mountain lee waves downstream of Oahu.

Hsiao, F., Y.-L. Chen, D. E. Hitzl, H. V. Nguyen, and R. Ballard: Effects of trade wind strength on airflow and weather over O‘ahu.

Section 6: Summary of University/Operational Partner Interactions and Roles;

Part 2(b) and (c) are joint efforts between UH and NWS. R. Ballard participated in the preparation of the manuscript that was submitted to the *Monthly Weather Review*.

References:

Chen, C.-Y., Y-L. Chen and H. V. Nguyen, 2014: The spin-up process of a cyclone vortex in a tropical cyclone initialization scheme and its impact on the initial TC structure. *SOLA*, **10**, 93-97.

Nguyen, H.V., and Y.-L. Chen, 2014: Improvements to a tropical cyclone initialization scheme and impacts on forecasts. *Mon. Wea. Rev*., **142**, 4340-4356.

Nguyen, H. V., and Y.-L. Chen, 2011: High resolution initialization and simulations of typhoon Morakot (2009). *Mon. Wea. Rev*., **139**, 1463-1491.