FINAL REPORT

University: University of Hawaii at Manoa

Name of University Researcher Preparing Report: Yi-Leng Chen

NWS Office: NWS WFO Honolulu Office

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Partners or Cooperative Project: Partners Project

Project Title: Applications of Satellite Data for Model Initialization and Verifications to Improve Weather Forecasting in Hawaii

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Section 1: Summary of Project Objectives

The main objective of this outreach proposal is to improve model initial conditions through data assimilation in the regional domains and validate high-resolution model output using available GOES and MODIS data to improve forecasting over the Hawaiian Islands. In addition to daily model runs, we would like to study the following weather phenomena: 1) a small-scale trade wind disturbance that made landfall on Oahu on 24 September 2013; 2) trapped lee wave events on the lee side of the Island of Oahu; and 3) a Kona storm that developed to the northwest of the Hawaiian islands on 10 December 2008. High spatial and temporal resolution GOES-R data in the future and high resolution numerical model forecasts offer the promise of possible detection and timely model guidance for small-scale trade wind disturbances and trapped lee waves both during the daytime and at night, as well as improvement of heavy rainfall monitoring and QPF during the winter storm season.

Section 2: Project Accomplishments and Findings

Describe the research/development activities and accomplishments carried out to date. These accomplishments may relate specifically to the original project objectives, or they may be ones that arose during the course of the project (e.g., development of an innovative method for accomplishing the objective or insight into a related problem). Highlight any major changes to the scope of work. If the project involved separate research topics, please list each separately

I. Application of satellite products in numerical weather prediction

The WRFDA 3DVAR data assimilation system (Baker et al., 2012; MWR) system is used to assimilate satellite derived wind vector and unconventional data to improve our model initial conditions for our daily run for Hawaii using the WRF-ARW model.

Dr. Chen collaborated with Dr. Chuan-Chi Tu, a former PhD student who now works at the National Central University, on re-assimilating unconventional data in improving the initial conditions provided by the NCEP GFS analysis and subsequent forecasts of a coastal heavy rainfall event during the early summer rainy season in Taiwan using the WRFDA 3DVAR data assimilation system through a 36-h cycling run to stuidy an extreme heavy rainfall case in Taiwan. Assimilated data include observations from satellite-derived winds,TIROS Operational Vertical Sounder (TOVS) temperature profile (SATEM), Quick Scatterometer (QuikSCAT) ocean surface winds, aircraft, ship and buoy, manned and automated weather stations, and upper-air soundings. In addition, GPS Radio Occultation (RO) refractivity profiles from the Constellation Observing System for Meteorology, Ionosphere, and Climate (COSMIC) satellites and special soundings are also assimilated. The results show that the cold pool (rain evaporative cooling effect) generated by the antecedent rains one day earlier and orographic effects can be captured in the initial conditions in the high resolution (3 km) domain. Furthermore, the subsynoptic features (moisture tongue and low-level jets) are also better depicted at the model initial time after data assimilation, based on error statistics and comparison s with ECMWF YOTC analysis with a 0.25 degrees grid. The results were published in the Monthly Weather Review (Tu et al., 2017) (http://www.soest.hawaii.edu/MET/Faculty/chen/CC_Tu_2017.pdf).

II. Improving basic understanding of local mesoscale forecasting problems in Hawaii

a. A Trade-Wind Disturbance:

A rare small trade-wind disturbance, which originated from a weak, dissipating frontal clouds over the Eastern Pacific on 22 September, made landfall in Oahu on 24 September 2013. Once formed, it was advected southwestward forward the Hawaiian Islands by the trade-wind flow. Our preliminary model results suggest that the vortex circulation is mainly confined below the trade-wind inversion and completely washed out in the synoptic analysis at the surface. Nevertheless, the cyclonic circulation associated with this disturbance is clearly evident from visible satellite pictures and radar data. Radar observations are only available over the coastal waters. We expect this type of event could be detected and monitored by GOES-R ABI data throughout the entire life cycle during the day and at night. This event is successful simulated by our high resolution WRF model with a 2-km grid. We are analyzing our model data to gain more insights on the dynamics of this trade-wind disturbance.

b. Trapped Lee Waves:

A MS student (Ms. L. Li) completed her thesis by studying the conditions favorable for the occurrence of trapped lee wave events downstream of the Island of O‘ahu (27 January, 2010—TRAP1; 24 January, 2003—TRAP2; and 25 August, 1977) using soundings, weather maps, satellite images and the high resolution (~ 1 km) WRF model. The common factors for these trapped mountain wave events over O‘ahu are: 1) presence of an inversion above the ridge tops; 2) presence of an inversion above the ridge top; 3) abundant low-level moisture; 4) strong low-level winds with a Froude Number ($Fr=U/Nh$) > 1 impinging on the mountain ranges, where U is the upstream speed of the cross-barrier flow, N is stability, and h is the mountain height; and 5) increasing wind speed with respect to height through the inversion. A strong pre-frontal southwesterly flow is the typical synoptic setting for the occurrence of trapped mountain waves in winter. During the summer event, the large-scale flow is characterized by the presence of an upper-level disturbance with easterly winds aloft and strong northeasterly trade winds in low levels. The high-resolution (1 km grid) WRF model successfully simulates the onset, development, and dissipation of these events. These events could possibly be predicted and monitored using satellite data (visible, fog product at night), sounding data, synoptic maps, and high resolution models in real-time operational settings. The results were accepted by the Journal of applied Meteorology and Climatology with minor revisions suggested by the Editor (Li and Chen 2017).

c. A Winter Storm:

A rapidly intensifying winter-time cyclone impacted the Hawaiian Islands from 11 to 15 December 2008 was studied by Ms. Jie Chen as her MS thesis. She graduated in summer 2016. The storm brought heavy rains, high winds, and extensive flooding to the western part of the island chain and caused an estimated $50 million in damages. A detailed case study of this "bomb" was conducted using National Centers for Environmental Prediction (NCEP) Climate Forecast System Reanalysis (CFSR) data, synoptic maps, satellite data, and a high resolution WRF model. The analysis showed that the rapid development of the cyclone was caused by upper-level forced ascent interacting constructively with a low-level baroclinic region. The latent heat release provided a positive feedback to intensify the surface cyclone and contributed to the rapid cyclogenesis in a baroclinic environment with a marked vertical tilt. Contributions from ocean fluxes are only of secondary important. When the synoptic settings are no longer favorable without a marked vertical tilt, the latent heat release has a negative feedback on maintaining the cyclone. Favorable conditions for the occurrence of the two widespread heavy rainfall periods associated with this storm include: (i) moisture tongue rooted in the deep tropics extending northeastward over the Hawaiian Islands; (ii) synoptic forced ascending motions; and (iii) feedback effects from latent heat release. Total precipitable water (TPW) observed by satellites in conjunction with high resolution model output are very useful in monitoring the timing of widespread heavy rainfall periods associated with this type of event.

III. Deliver twice daily high-resolution (< 3 km) 72-h forecasts using WRF-NMM for all major islands over the State of Hawaii to the NWS HNL Forecast Office for evaluation and assessment in real-time operational settings.

IV. Related Accomplishments

One of the PhD students (Mr. F. Hsaio) is working on afternoon heavy local showers over central Oahu as part of his PhD dissertation. A MS student (Ms. Y.-F. Huang) completed her MS thesis in Spring 2016. She studied summer trade-wind rainfall maximum on the western Kona lee side of the Island of Hawaii using the archive of our historical daily forecasts. Based on a MS thesis (T. Winning), we have completed a study on the climatology of trade-wind inversion (spatial and seasonal variations) over the Hawaiian Islands using GPS Radio Occultation (RO) data during 2007-2012. Our results show that the trade-wind inversion height determined by the sounding data are affected by orographic lifting, especially the Hilo soundings during the summer under persistent trades. The results were published in the Atmospheric Research (http://www.soest.hawaii.edu/MET/Faculty/chen/YLChen_2016_AtmRes.pdf) (Winning et al., 2016).

Section 3: Benefits and Lessons Learned: Operational Partner Perspective

List the benefits to the NWS office from the collaboration and any significant lessons learned during the study. Please be as specific as possible, particularly in regard to any improvements in forecasting resulting from the COMET project. Identify any major problems encountered and describe their resolution.

In addition to aiding in day-to-day weather predictions, the UH-WRF nested domains are the only ones which do an adequate job capturing some significant local wind and orographic effects. For example, these model runs show much improved skill over other models at forecasting the placement and intensity of sea breeze/upslope-forced afternoon convection over the islands and downwind convergence plumes which can result in flash flooding and cloud-to-ground lightning hazards. They also show skill at capturing terrain-induced wind effects near brushfires. The improved handling of sea-breeze/land breeze circulations aids forecasters in the preparation of airport aviation forecasts which determine takeoff and landing configuration for the day. The increased vertical and horizontal resolution of this model allows us to view the potential for damaging downslope windstorms better than any other guidance we currently receive, via both cross sections and plan view. The larger state domain, when used with the local island domains, assists forecasters during situations when a tropical cyclone is approaching the islands by doing a much better job in depicting significant and sometimes extreme local wind effects caused by terrain accelerations. This model also correctly depicted the small but significant, sub-synoptic motion that brought Hurricane Ana closer to the islands in 2014 than was depicted by the large scale guidance.

Section 4: Benefits and Lessons Learned: University Partner Perspective

Describe the benefits to the University resulting from the collaboration and any significant lessons learned during the study. Identify any major problems encountered and describe their resolution.

The main benefits to the university are the exposure of the students to operational forecasting and better understanding of forecast challenges in the operational environment. The National Weather Service Honolulu Forecast Office is collocated with our department in the same building on campus, which enables close interactions between both groups. For example, our students, faculty and staff are able to participate in twice weekly weather briefings at the NWS Honolulu Forecast Office.

Section 5: Publications and Presentations

Provide complete citations using the AMS bibliographic format for each thesis, dissertation, publication or presentation prepared as part of this project.

I. Thesis

Li, L., 2015: Conditions favorable for the occurrence of trapped mountain lee waves downstream of O‘ahu. MS Thesis, Dept. of Atmospheric Science, Univ. of Hawaii, Honolulu, HI 96822. 102pp.

Chen, J., 2016: A Rapid Cold-Front Cyclonegenesis over the Central Pacific Ocean. MS Thesis, Dept. of Atmospheric Science, Univ. of Hawaii, Honolulu, HI 96822. 101pp.

Huang, Y.-F., 2016: A Study of Summer Lee-side Rainfall Maxima over the Island of Hawaii and the Rainfall on the Lee-side of Oahu. MS Thesis, Dept. of Atmospheric Science, Univ. of Hawaii, Honolulu, HI 96822. 84pp.

II. Publications:

Winning, T., Y.-L. Chen, F. Xie, 2016: Estimation of the Marine Boundary Layer Height Over the Central North Pacific Using GPS Radio Occultation. *Atmos. Res.*, **183**, 362-370. (doi:10.1016/j.atmosres.2016.08.005).

Tu, C.-C., Y.-L. Chen, S.-Y. Chen, Y.-H. Kuo, and P.-L. Lin, 2017: Impacts of including rain evaporative cooling in the initial conditions on the prediction of a coastal heavy rainfall event. *Mon. Wea. Rev.,* **145**, 253-277.

Li, L., and Y.-L. Chen, 2017: Conditions favorable for the occurrence of trapped mountain lee waves downstream of Oahu. *J. Appl. Meteor. Climate* (accepted pending minor revisions).

III. Conferences and Workshops

Chen, Y.-L., 2016: Initialization of High Resolution Models for Simulations of Extreme Weather Events in the Subtropics. 2016 OCONUS Technical Interchange Meeting, 26-30 June, University of Hawaii at Manoa, Honolulu, HI 96822.

Hsiao, F., and Y.-L. Chen, 2016: Numerical Simulations of Two Local Thunderstorms over Central Oahu during the Warm Season. 2016 OCONUS Technical Interchange Meeting, 26-30 June, University of Hawaii at Manoa, Honolulu, HI 96822.

Chen, Y.-L., C.-Y. Chen, H. V. Nguyen and F. Hsiao, 2016: Applications of a New Tropical Cyclone Initialization Scheme on Improving Intensity, Structure and Track Forecasts. 48th Annual Session of the UNESCAP/WMO Typhoon Committee on Feb 22-25, 2016, Honolulu, HI.

Huang, Y.-F, and Y.-L. Chen; 2016: Summer Leeside Rainfall Maximum over the Island of Hawaii. 2016 AGU Fall Meeting, 12-16 December, San Francisco, California.

Chen, Y.-L., C.-Y. Chen and H. V. Nguyen, and F. Hsiao, 2016: Is the TC Storm-Scale Circulation and the Large-Scale Flow in Quasi-Equilibrium? The 2nd US-Taiwan Extreme

Precipitation Workshop, Hawaii, September 6-8 2016, University of Hawaii at Manoa, Honolulu, HI 96822.

Hsiao, F., and Y.-L. Chen, 2016: Numerical Simulations of Two Local Thunderstorms over Central Oahu during the Warm Season. The 2nd US-Taiwan Extreme Precipitation Workshop, Hawaii, September 6-8 2016, University of Hawaii at Manoa, Honolulu, HI 96822.

Huang, Y.-F. and Y.-L. Chen, 2016: A Study of Summer Leeside Rainfall Maxima over the Island of Hawaii. The 2nd US-Taiwan Extreme Precipitation Workshop, Hawaii, September 6-8 2016, University of Hawaii at Manoa, Honolulu, HI 96822.

Tu, C.-C., Y.-L. Chen, S.-Y. Chen, Y.-H. Kuo and P.-L. Lin; 2016: Impacts of Including Rain Evaporative Cooling in the Initial Conditions on the Prediction of a Coastal Heavy Rainfall Event during TiMREX. The 2nd US-Taiwan Extreme Precipitation Workshop, Hawaii, September 6-8 2016, University of Hawaii at Manoa, Honolulu, HI 96822.

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

Describe the responsibilities of the various project participants over the course of the entire project.

The UHM team is responsible for providing twice daily 72-h high resolution (with grid size as small as 1.5 km) (http://www.soest.hawaii.edu/MET/Faculty/mm5/WRF/index.html) experimental high resolution forecasts to the NWS Honolulu Forecast Office. Our students also work on case studies of significant weather events based on model simulations and observations as their thesis topics.

The National Weather Service in Honolulu is creating and utilizing post-processed output from the various UH-WRF domains in its preparation of gridded forecasts for wind and probability of precipitation, as well as to aid in situational awareness during the potential for high impact events (either statewide or for spot forecasts for particular partners, for example, the fire weather community. The NWS in Honolulu evaluates the output and provides feedback to UH regarding suggestions for improvements to the model.