NOAA Quadrennial Review
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Charge to Reviewers: Review of Presented Projects

Hurricane Research Division

Presentations (and posters) on Key HRD Research Thrusts :

1. Physical Processes: **Jason Dunion**, John Kaplan, Joe Cione, John Gamache, Eric Uhlhorn, Jun Zhang, Sim Aberson, Gustavo Goni (PhOD)
2. Impacts: **Mark Powell**, Robert Rogers, Peter Dodge, Sylvie Lorsolo, Shirley Murillo, John Kaplan, Eric Uhlhorn
3. Track: **Sim Aberson**
4. Model Sensitivity and Evaluation: **Robert Rogers**, John Kaplan
5. Model Improvements: **Sundararaman Gopalakrishnan**, John Gamache

Physical Processes

Jason P. Dunion

Improvements in tropical cyclone (TC) intensity forecasts are currently lagging 15-20 years behind those for track. Understanding and predicting TC intensity represents a significant challenge for several reasons: 1) there are numerous atmospheric and oceanic factors that can influence TC intensity; 2) the accuracy of a given TC intensity forecast is directly affected by the accuracy of the associated track forecast; 3) the factors influencing TC intensity are multi-scale, ranging from the surrounding synoptic scale environment to sub-vortex phenomenon in the TC inner core to microphysical processes. NOAA/AOML/HRD is conducting research to address these key issues related to TC intensity change using a combination of theoretical studies, in situ and remotely sensed observations collected in the field, satellite data and numerical modeling experiments.

HRD is currently involved in several research areas related to TC intensity change:

- Understand and predict TC rapid intensification;
- Investigate the ocean response to TCs and associated impacts on TC intensity change;
- Improve the understanding of the four-dimensional ocean response to TCs using aircraft-deployed drifting buoy arrays;
- Investigate the impact of the Saharan Air Layer's (i.e. Saharan dust storm's) dry air, enhanced vertical wind shear and suspended mineral dust on TC intensity change;
- Observe and understand the processes of TC eyewall replacement cycles and associated changes in TC intensity;
- Understand and describe eye-eyewall mixing processes and how small-scale features found in the TC eyewall can affect TC intensity;

Relevance to NOAA Strategic plan: Improving the understanding and prediction of TC intensity supports the Weather and Water Mission Goal to serve society's needs for information by developing and infusing research results and technologies, and providing research mission support to multiple disciplines.

Societal Relevance: Hurricanes produce annual losses averaging over $5B. The public has a need to understand the risk of storm threats as well as an understanding of the storms that have affected them. Improving our understanding and prediction of TC intensity can help address those needs.

Technology Transfer: A rapid intensity index has been developed to aid forecasters in forecasting TC rapid intensification and was recently transferred to operations under NOAA's Joint Hurricane Testbed project. An inner-core sea surface temperature cooling algorithm was recently developed for integration into the Statistical Hurricane Intensity Prediction Scheme (SHIPS) forecast model and was also successfully transferred to operations under the NOAA Joint Hurricane Testbed.

Evidence of collaboration: The research areas related to TC intensity discussed here have occurred in collaboration with numerous government, university and private industry organizations that including NOAA GFDL, NOAA EMC, NOAA NESDIS, NASA, NRL-

Monterey, CIRA, SCRIPPS, the U.S. Air Force, University of Wisconsin-Madison, University of Miami, and AAI Corp.

Who would miss this work if not done?: The research being conducted at NOAA/AOML/HRD related to TC intensity change is an integral part of NOAA's Hurricane Forecast Improvement Project (HFIP). The main objective of HFIP is to implement a unified approach to guide and accelerate improvements in TC forecasts, with emphasis on TC rapid intensity change, and reduction in uncertainty. If these research projects were not being carried out, certain advancements in our understanding of TC intensity would not occur and improvements in the prediction of TC intensity change would be slower to occur.

Relevant Papers & Reports:

Knaff, J., M. DeMaria, and J. Kaplan, 2007: Improved Statistical Intensity Forecast Models, NOAA/Joint Hurricane Testbed project: http://www.nhc.noaa.gov/jht/05-07reports/final_Knaffetal_JHT07.pdf

Cione, J.J., and E.W. Uhlhorn, 2003: Sea surface temperature variability in hurricanes: Implications with respect to intensity change. *Mon. Wea. Rev.,* **131(8)**, 1783-1796.

Niiler, P., W. Scuba, and D. Lee, 2004: "Performance of minimet wind drifters in hurricane Fabian". *Sea Journal of Korean Society of Oceanography*, **9(3)**, 130-136.

Dunion, J.P., and C.S. Velden, 2004: The impact of the Saharan Air Layer on Atlantic tropical cyclone activity. *Bull. Amer. Meteor. Soc*., **85 no. 3**, 353-365.

Montgomery, M.T., M.M. Bell, and M.L. Black, 2003: Hurricane Isabel (2003): New insights into the physics of intense storms. Part I: Mean vortex structure and maximum intensity estimates, *Bull. Amer. Meteor. Soc*., **87(10)**, 1335-1347.

Aberson, S.D., M.T. Montgomery, M.M. Bell, and M.L. Black, 2003: Hurricane Isabel (2003): New insights into the physics of intense storms. Part II: Extreme localized wind, *Bull. Amer. Meteor. Soc*., **87(10)**, 1349-1354.

Impacts

M. Powell

AOML hurricane impact research focuses on using conventional and unique hurricane measurement systems to improve understanding and modeling of the forcing that produces rainfall and storm surge flooding, damaging waves, and winds.

Several advances on impacts are:

- Discovery that, as winds increase to hurricane force, the marine drag coefficient flattens out and then decreases as winds continue to increase. This result is now influencing numerical weather prediction, storm surge, and wave modeling.
- Development of a new metric for hurricane destructive potential based on integrated kinetic energy.
- Experimental products from the Hurricane Wind Analysis system (H*Wind), a tool to integrate diverse observations from space-, sea-, air-, and land-based measurement platforms.
- A rainfall flooding model that incorporates storm motion, wind shear, and terrain slope.

Relevance to NOAA Strategic plan: Hurricane impacts research supports the Weather and Water Mission Goal to serve society's needs for information by developing and infusing research results and technologies, and providing research mission support to multiple disciplines.

Societal Relevance: Hurricanes produce annual losses averaging over $5B. The public have a need to know the risk of storm threats as well as an understanding of the storms that have affected them.

Technology Transfer: Transition to the National Hurricane Center of new models for the prediction of rainfall flooding and inland wind decay. H*Wind research products in use by the insurance industry.

Evidence of collaboration: 17 peer-reviewed papers since 2006 have used H*Wind products. 55 peer-reviewed papers have cited the 2003 drag coefficient research published in Nature. AOML leads the development of the atmospheric component of the State of Florida Public Hurricane Loss Model.

Who would miss this work if not done? The work is an integral part of current research on the carbon footprint of hurricanes, endangered species response to hurricanes, development of models to predict forest harvest loads after hurricanes, insurance industry loss model validation, hurricane model wind and rain structure validation, emergency management research on real-time damage and loss estimation, initial fields for storm surge and wave modeling.

Outstanding Papers:

Powell, M. D., and T. A. Reinhold, 2007: Tropical cyclone destructive potential by integrated kinetic energy. *Bull. Amer. Meteor. Soc*., **87**, 513-526.

Lonfat, M., **R. Rogers**, **F. Marks, Jr.**, and T. Marchok, 2007: A Parametric Model for Predicting Hurricane Rainfall. *Mon. Wea. Rev.,* **135**, 3086-3097.

Powell, M.D., P.J. Vickery, and T.A. Reinhold, 2003: "Reduced drag coefficient for high wind speeds in tropical cyclones" *Nature,* **422**, 279-283.

Powell, M. D., **G. Soukup**, S. Cocke, S. Gulati, **N. Morisseau-Leroy**, S. Hamid, **N. Dorst**, and L. Axe, 2005: State of Florida hurricane loss projection model: Atmospheric science component. *J.Wind Engineer. and Indust. Aerodyn*., **93**, 651-674.

Track

S. D. Aberson

Hurricane track research is focused on accelerating improvements to numerical and operational forecasts of tropical cyclone tracks.

Several advances from the observations are:

• Sampling regions of large ensemble deep-layer-mean (850-200 hPa) wind spread with regularly-spaced dropwindsondes provides a statistically significant larger improvement to numerical tropical cyclone track forecasts than sampling symmetrically around a storm with more dropwindsondes.

• Sampling regions which objective techniques, such as the Ensemble Transform Kalman Filter (ETKF), suggests are most important for track forecasts provides forecasts as good as those from the ensemble variance technique.

• Sampling regions which Total Energy Singular Vectors (TESVs) from other numerical model systems provides better forecasts than other techniques in a small sample.

• Data must be properly assimilated into numerical models:

1. As the resolution of the models increases, the location and time information provided with observations must be improved, or the data will degrade model forecasts.
2. One bad observation can severely degrade model forecasts, quality control systems must continue to be improved.
3. Current data assimilation techniques (3DVAR/SSI and GSI) allow for spread of data globally. The use of next-generation (ensemble-based) techniques may alleviate this problem and provide better forecasts.

Relevance to NOAA Strategic plan: Hurricane track research helps NOAA to service the public's need for weather and water information; to support the nation's commerce with information for safe, efficient, and
environmentally sound transportation; and to protect, restore, and manage the use of coastal and ocean resources through an ecosystem approach to management.

Societal Relevance: All other tropical cyclone forecasts (intensity, structure, waves, rainfall, etc.) depend upon track forecasts. Warning of the average mile of coastline now costs more than $1 million per mile; because of inherent inaccuracies of track forecasts, U. S. coastlines must be overwarned. Decreasing uncertainty in the numerical guidance used to make official decisions can save $1 million per mile, as well as improving the ability of the nation to mitigate damage from tropical cyclones.

Technology Transfer: Targeting, optimal flight track, quality control and data assimilation techniques described above have all been transitioned to operations at the National Weather Service/National Centers for Environmental Prediction (NCEP). In addition, Taiwan/Republic of China has duplicated and expanded upon this work with their own airborne sampling to improve typhoon track forecasts in their area. During 2008, a multi-national research program based upon much of this work will take place in the Western Pacific basin.

Evidence of collaboration: The annual operational surveillance program is a collaborative effort between AOML, NCEP, and the NOAA/Aircraft Operations Center. The government of Taiwan and National Taiwan University have worked with AOML scientists to develop an airborne sampling system for the Western Pacific basin. The Japanese Meteorological Agency is using optimal flight track software developed at HRD for their own planning. AOML has worked with the University of Miami, the University of North Carolina-Charlotte, the Naval Research Laboratory-Monterey, the European Centre for Medium-Range Weather Forecasting, and National Taiwan University to improve targeting and data assimilation techniques. AOML is collaborating with these agencies and the Japanese, German, Korean, and United Kingdom weather services, along with Yonsei University and the Air Force, in cooperation with the United Nations World Meteorological Organization to further improvements to track forecasts globally.

Contributions of data to national and GEOSS-related data bases: All dropwindsonde data from this program is kept available to the wider community via AOML's website.

Who would miss this work if not done? Though track forecasts have improved substantially during the last few decades, theoretical studies of the predicability limit show that there remains room for improvement. If the current research is not done, improvements to track forecasts (and subsequent improvements to forecasts of other factors) will slow or stop.

Outstanding Papers:

Aberson, S.D., and J.L. Franklin, 1999: Impact on hurricane track and intensity forecasts of GPS dropwindsonde observations from the first-season flights of the NOAA Gulfstream-IV jet aircraft. *Bull. Amer. Met. Soc.*, **80**, 421-428.

Aberson, S.D., 2002: Two years of operational hurricane synoptic surveillance. *Wea. Forecasting*, **17**, 1101-1110.

Aberson, S.D., 2003: Targeted observations to improve operational tropical cyclone track forecast guidance. *Mon. Wea. Rev.*, **131**, 1613-1628.

Wu, C.-C., P.-H. Lin, **S.D. Aberson**, T.-C. Yeh, W.-P. Huang, K.-H. Chou, J.-S. Hong, G.-C. Lu, C.-T. Fong, K.-C. Hsu, I.-I. Lin, P.-L. Lin, and C.-H. Liu, 2005: Dropsonde observations for typhoon surveillance near the Taiwan region (DOTSTAR): An overview. *Bull. Amer. Met. Soc.*, **86**, 787-790.

Aberson, S.D., and B. Etherton, 2006: Targeting and data assimilation studies during Hurricane Humberto (2001). *J. Atmos. Sci.*, **63**, 175-186.

Majumdar, S. J., **S.D. Aberson**, C. H. Buizza, M.S. Peng, and C. A. Reynolds, 2006: A comparison of Adaptive Observing Guidance for Atlantic Tropical Cyclones, *Mon. Wea. Rev.*,

134, 2354-2372.

Aberson, S.D., 2007: Large forecast degradations due to synoptic surveillance during the 2004 and 2005 hurricane seasons. *Mon. Wea. Rev.,* in print.

Reynolds, C.A., M.S. Peng, S.J. Majumdar, **S.D. Aberson**, C.H. Bishop, and R. Buizza, 2007: Interpretation of adaptive observing guidance for Atlantic tropical cyclones. *Mon. Wea. Rev.,* in print.

Wu, C.-C., K.-H. Chou, P.-S. Lin, **S.D. Aberson**, M.S. Peng, and T. Nakazawa, 2007: The impact of dropsonde data on typhoon track forecasting in DOTSTAR. *Wea. Forecast.,* in print.

Model Sensitivity and Evaluation

R. Rogers

Improvements in tropical cyclone (TC) intensity forecasts have lagged improvements in track forecasts. Numerical model guidance can be key contributor to intensity forecasts, but limitations in numerical models present a barrier to improvements in intensity forecasts. These limitations include: 1) inadequate specification of the TC vortex in the initial conditions; 2) deficient representation of physical processes; 3) insufficient horizontal and vertical resolution. Evaluating numerical models by comparing them with observations in a robust manner can identify deficiencies in the models and lead to improvements in them. AOML is uniquely positioned to contribute to this effort through a combination of data collection and analysis and numerical model experiments.

Several deficiencies identified in numerical models through model evaluation include:

- Surface wind field that is too broad and more azimuthally symmetric than observed
- TC boundary layer that is warmer and with stronger surface fluxes than observed
- Inadequate specification of moisture fields in initial conditions
- Higher rainfall, weaker vertical motions than observed
- Inaccurate inner-core rainfall distributions

Relevance to NOAA Strategic plan: Evaluating TC numerical models supports the Weather and Water Mission Goal to serve society's needs for information by developing and infusing research results and technologies, and providing research mission support to multiple disciplines.

Societal Relevance: Hurricanes produce annual losses averaging over $5B. The public have a need to know the risk of storm threats as well as an understanding of the storms that have affected them. Improving numerical models through model evaluation can assist in that goal.

Technology Transfer: Transition to the Hydrological Prediction Center of new validation TC rainfall validation metrics and statistics has occurred. Modifications to numerical models based on rainfall and vertical motion evaluations ongoing.

Evidence of collaboration: The evaluations discussed here have occurred in collaboration with numerous government and university organizations, including NOAA GFDL, NOAA EMC, NOAA NESDIS, NASA, NCAR, University of Miami, and Howard University.

Who would miss this work if not done? The work is an integral part of current research on model evaluation and improvement. If it were not done, identification of model deficiencies would not occur and improvements to the models would be slower to occur.

Outstanding Papers:

Rogers, R.F., M.L. Black, S.S. Chen, and **R.A. Black**, 2007: An Evaluation of Microphysics

Fields from Mesoscale Model Simulations of Tropical Cyclones. Part I: Comparisons with Observations. *Journal of the Atmospheric Sciences*, **64**, 1811-1834.

Marchok, T., **R. Rogers**, and R. Tuleya, 2007: Validation Schemes for Tropical Cyclone Quantitative Precipitation Forecasts: Evaluation of Operational Models for U.S. Landfalling Cases. *Weather and Forecasting,* **22**, 726-746.

Model Improvements

S.G.Gopalakrishnan

The modeling program is focused on improving forecasts of rapidly intensifying tropical storms by (i) improving the existing high-resolution modeling capabilities at NOAA, (ii) advancing hurricane inner core data assimilation techniques, (iii) enhancing our understanding of the physical processes that control the rapid intensity changes in tropical cyclones using the high-resolution model simulations.

Relevance to NOAA Strategic plan: While 48-hr track forecasts have improved at the rate of 3.5% per year, the intensity forecasts have only improved about 0.8% per year. The Hurricane Forecasting Improvement Project (HFIP) is aimed at advancing NOAA's ability to predict tropical cyclones intensity, structure and rainfall distribution.

NOAA's modeling and observational capabilities: The Weather Research Forecasting Model (WRF) is a general purpose, multi-institutional mesoscale modeling system. A version of the WRF model called the HWRF/WRF-NMM modeling system, developed at the NOAA's National Center for Environmental Protection (Gopalakrishnan et al, 2006) was recently adopted for operational hurricane forecasting. At AOML we wish to combine our existing strength in procuring unconventional observations down to the vortex scale in hurricanes and our expertise in understanding of the inner core physical processes in tropical cyclones to advance this modeling system.

Evidence of collaboration: The program is expected to have a legacy of operation, yet without missing the important components of basic hurricane research. Consequently it is expected that AOML would be the pivotal node for hurricane model development and research. University collaboration is very important. Work has started in this direction. We are working with University of Miami, Texas A & M, and international universities like the Indian Institute of Technology, New Delhi, India. We are also developing strong collaborations with National Center for Atmospheric Research (NCAR), WRF-Development Testbed Center (DTC) at Boulder and with several NASA labs. Other NOAA labs such as Earth System Research Laboratory (ESRL), Geophysical Fluid Dynamical Laboratory (GFDL), Princeton and National Severe Storm Laboratory (NSSL), and National Center for Environmental Prediction (NCEP) are our strategic partners.

Who would miss this work if not done? Improving the NOAA's abilities of predicting the tropical cyclones will help the forecasters, and consequently, the general public.

Challenges: Although steady progress has been made with numerical models for guidance, much needs to be done for improving intensity forecast. Nevertheless, the hurricane modeling research community has progressed quite rapidly in terms of understanding the inner core processes of the storm by conducting advanced numerical simulations at 1-3 km horizontal resolution and comparing the modeled results with observations whenever possible. Given, fidelity and timely forecast being the two most important criteria in operational models, it is not clear if all hurricane model development and results may improve numerical models for real-time guidance. At AOML we need to strike the right balance between research and operation. Although AOML is well positioned to do this task, transition of modeled products to operation may be the biggest challenge ahead.

Outstanding Papers:

Gopalakrishnan, S.G., N. Surgi, R. Tuleya, and Z. Janjic, 2006 : "NCEP's Two-way-Interactive-Moving-Nest NMM-WRF modeling system for Hurricane Forecasting", *27th Conference on Hurricanes and Tropical Meteorology*, 24-28 April 2006, Monterey, California.