Proposal in response to FY 2013 Joint Hurricane Testbed funding opportunity

07 December 2012

Project title: Verification of HWRF Intensity Forecasts using a Novel Multi-Scale Intensity (MSI) Metric

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Project duration: Two years

Proposed budget: $62.8K (year 1), $64.1K (year 2)

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Verification of HWRF Intensity Forecasts using a Novel Multi-Scale Intensity (MSI) Metric

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B. Abstract

Although the requirement for predicting the extreme value of hurricane near-surface wind speed is well justified based on potential damage concerns, and that the observation based estimates of the maximum wind used for operations are generally accepted, the current metric of TC intensity -- the maximum one-minute sustained wind speed at 10 m above surface anywhere in the storm -- is not optimal for the purposes of dynamical forecast verification and assessment of forecast system changes on forecast accuracy. The standard intensity metric refers to a subjective estimate of an extreme value in a highly turbulent, convectively driven, and spatially-extensive wind field. This quantity is practically unobservable and inherently un-resolvable by the dynamical forecast models, including the high-resolution regional models. Consequently, the intensity forecast verification in terms of the difference from the Best Track value includes difficult-to-quantify representativeness errors both from the forecast and Best Track quantity. We propose a new metric – dubbed the Multi-scale Intensity (MSI) -- that would enable verification based on quantities that are explicitly resolvable by both the observations and dynamical models, which assumes the maximum wind in a hurricane may be represented by a sum of a resolved, deterministic, low-wavenumber component and a stochastic quantity containing all higher wavenumber contributions. The low-wavenumber (i.e., symmetric mean plus wavenumber-1 asymmetry) structure is explicitly resolved by SFMR surface wind measurements from a typical aircraft reconnaissance mission, and the residual contribution has a well-defined probability distribution function relative to the Best Track intensity. Thus, we propose to develop real-time processing applications to compute low-wavenumber analyses from SFMR observations and HWRF surface wind forecasts. Following this, we propose to evaluate HWRF TC-intensity forecasts under this new metric. This proposal addresses JHT goals: NHC-2, NHC-3, NHC-10, and EMC-3.4.

C. Statement of Work

C.1 Project duration: 2 years

C.2 Project description

Introduction

Although the requirement for predicting the extreme value of hurricane near-surface wind speed is well justified based on potential damage concerns, and that the observation-based estimates of the maximum wind used for operations are generally accepted, the current metric of TC intensity -- the maximum one-minute sustained wind speed at 10 m above surface -- is not optimal for the purposes of dynamical forecast verification and assessment of forecast system changes on forecast accuracy. The standard intensity metric refers to an extreme value determined subjectively, often based on several quasi-independent data sources. This quantity is practically unobservable and inherently un-resolvable by the dynamical forecast models, including the high-resolution regional models. Consequently, the intensity forecast verification in terms of the difference from the Best Track estimate includes difficult-to-quantify representativeness errors both from the forecast and Best Track quantity. We propose a new metric that would enable verification based on data that are explicitly resolvable by both the observations and dynamical models. A recent study (Vukicevic et al., 2012) has demonstrated the properties and benefits of the new metric using the operational and research aircraft reconnaissance SFMR (Stepped-Frequency Microwave Radiometer) measurements and numerical forecast data from the near-real-time experimental Hurricane-WRF (HWRF) model.

In the following we present the formulation of the metric, the evaluation using the SFMR and Best Track observations and the application to forecast verification .

Formulation of the MSI metric

<u>MSI metric</u>

Using a polar coordinate (θ, r) reference frame that is centered on the TC vortex at a height of $z = 10\,\text{m}$ (meters), the wind speed for each radius r may be represented by the following expression:

$$V(r,\theta) = V_0(r) + V_1(r)\cos[\theta - \alpha_1(r)] + \varepsilon(r) \quad , \qquad (1)$$

where V_0 and V_1 are the amplitude of axisymmetric (wavenumber 0) and first harmonic (wavenumber 1) component of the wind speed, α_1 is the asymmetry phase, and ε is the total contribution from the remaining higher-order harmonics. This expression is exact and follows directly from the azimuthal Fourier decomposition of wind field. At the radius of maximum wind (RMW) and azimuth $\theta = \alpha_1$, Eqn. (1) represents the hurricane intensity, $V = V_{max}$. Assuming the averaging time scale of 1 minute, the expression (1) represents a multi-scale decomposition of the standard TC intensity (the intensity as defined by the Best Track value) into the low wavenumber structure (V_0+V_1) and a residual (ε).

The low wavenumber forecast has spatial scales equivalent to RMW and may be directly verified against observations such as SFMR. In contrast, the residual is practically unobservable and inherently un-resolvable. It is unobservable because it results from the superposition of high frequency waves and turbulence that is convectively driven and spatially extensive, and is inherently un-resolvable because the forecast model's grid spacing is greater than that required to capture the 1-min mean wind (Rotunno et al. 2009). These properties suggest that the residual, high-wavenumber component is best represented as a stochastic quantity with the associated empirical probability density function (PDF). From the definition $V_{max} \geq V_0$, the following condition results: $\varepsilon \geq -V_1$, implying that the probability distribution function of ε (PDF[ε]) is a left-bounded and non-Gaussian distribution. Based on this analysis, we define the MSI metric consisting of deterministic $(V_0 + V_1)$ and stochastic (ε) wind components. The metric allows for verification of the intensity forecasts at the resolvable scales in terms of standard deterministic error norms, such as the bias and standard deviation, and at the un-resolvable scales in terms of properties of PDF[ε].

SFMR surface wind analysis

Like aircraft flight-level winds, surface winds measured by SFMR are obtained along a flight track. A typical hurricane reconnaissance pattern consists of flight legs radially toward and away from the storm center. Thus, data sampling is dense in the radial direction, but comparatively sparse in the azimuthal direction. A semi-spectral representation of the wind field is well suited based on this type of sampling pattern, with the radial dimension represented in physical space and the azimuthal dimension in wavenumber space.

As an example, observations from Hurricane Katrina on 28 Sept. 2005 are used to develop an analysis (Fig. 1). For an individual flight, each radial leg (inbound or outbound from the center) is identified. In this example the flight consists of five total penetrations (the first four are used for demonstration here), as shown in Fig. 1a. For each leg, a radius of maximum wind (RMW) is found, and is used to normalize the observed distance from the center of the storm. Also, an average RMW is computed for all legs. Each radial leg of wind data is then interpolated to a normalized grid ($r^* = r$/RMW), whose spacing depends on the average RMW to maintain consistency with the 3 km model resolution. In this example, an average surface RMW = 25 km results in $\Delta r^* = 0.12$. The maximum surface wind speed for each radial leg will always be found at r^*=1. Based on the storm center found for each pass from the wind speed minimum, the azimuth angle relative to storm motion direction is computed for each observation. The angles are also interpolated to the same radial grid; thus, at each radius, a set of $u(\theta)$ observations are obtained, corresponding to each radial leg.

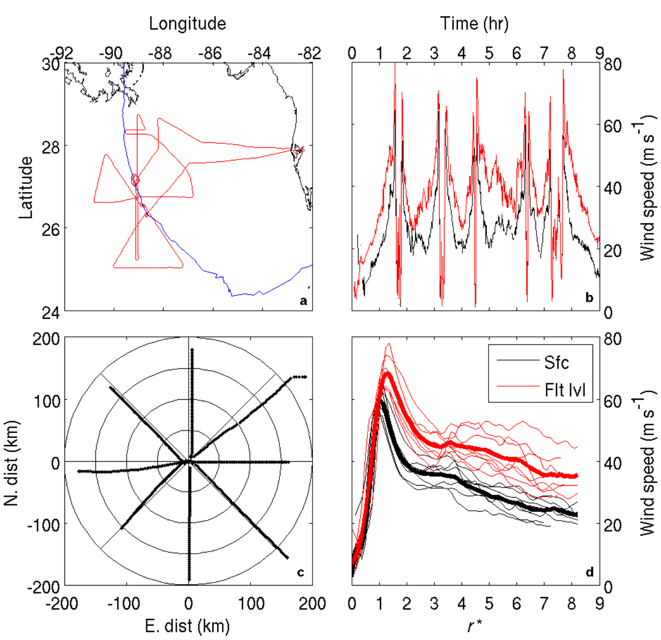

Figure 1: Observations from Hurricane Katrina (28 Aug. 2005). Shown are (a) flight track (red) and storm track (blue); (b) time series of surface and flight level winds; (c) storm-center referenced radial flight legs; (d) normalized radial profiles of surface and flight level winds, along with symmetric means.

Next, a harmonic function of the form: $U(r^*,\theta)=\hat{U}_0(r^*)+\hat{U}_1(r^*)\cos[\theta-\hat{\phi}_1(r^*)]+\hat{\varepsilon}(r^*)$

Iis fit to the observations using least-squares, with the carets indicating that the quantities are estimates of the true parameters. Thus for each radius, a set of three parameters (wavenumber-0 mean U_0, wavenumber-1 amplitude U_1 and phase ϕ_1) describe the (V_0+V_1)

surface wind field structure, with an associated residual error (ε), as shown in Fig. 2 for the Katrina example. The maximum wavenumber 0+1 (WN0+1) wind speed is found at ($r^* = 1$, $\theta = \phi_1$). Note that this is generally not found at the same location as the maximum observed wind speed over a single flight. For this example, the estimated maximum $(V_0 + V_1)_{SFMR} = 62.9 \pm 1.4$ m s^{-1} is found, as compared to the corresponding Best Track intensity estimate of 74.7 m s^{-1}. From this simple structure, a scale-consistent 2-D wind field analysis may be reconstructed (not shown).

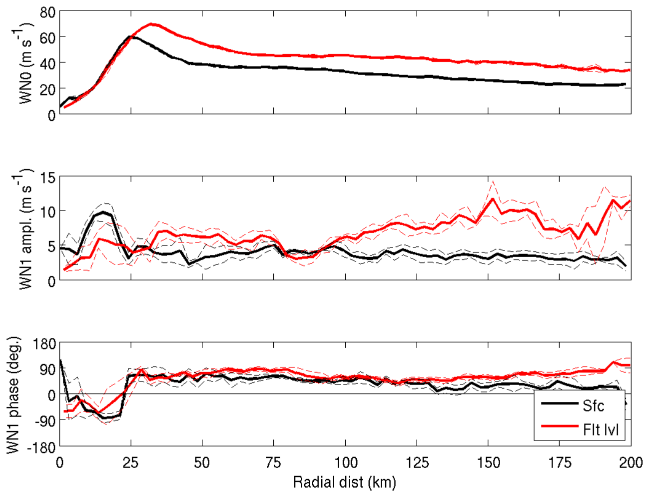

Figure 2: Surface wind low wavenumber structure computed from observations in Hurricane Katrina. The three panels are radial profiles of wavenumber-0 mean (top), wavenumber-1 amplitude (middle), and phase angle measured clockwise-relative to north (bottom). Dashed lines are 1 standard deviation error bounds on the parameter estimates.

<u>MSI decomposition from observations</u>

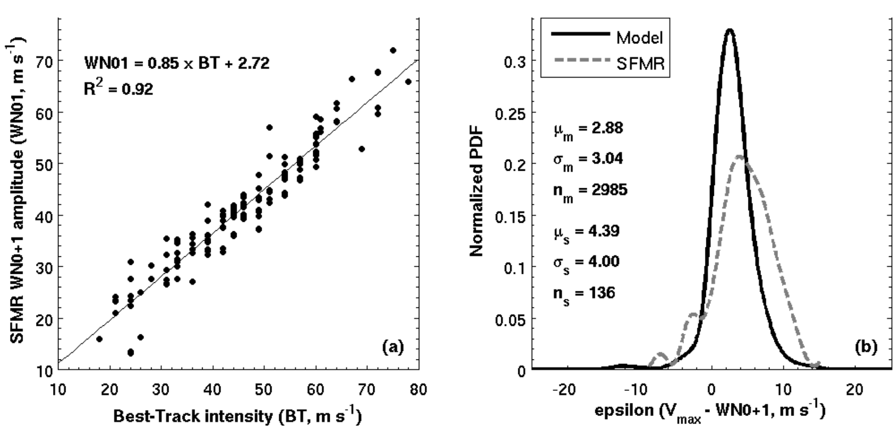

Figure 3: (a) Best-track intensity vs. SFMR-based low wave number analysis for 136 observed cases in years 2001-2011; and (b) PDF of observed residual intensity (Best-Track maximum wind minus $(V_0+V1)_{SFMR}$), plotted as the grey dashed curve.

The semi-spectral analysis method was applied to SFMR measurements from the operational and research aircraft reconnaissance for 136 TC cases for years 2001-2011. The resulting $(V_0+V_1)_{SFMR}$ and the corresponding BT intensity values are displayed in Figure 3a.
It is evident that the low-wavenumber intensity is well-correlated with BT intensity values (r^2 = 0.92). In fact, this correlation is stronger than for the relationship between the maximum observed SFMR wind and the BT intensity (r^2 = 0.90, not shown). The corresponding PDF[ε] in Figure 3b (dashed gray curve) shows that the observation-based residual intensity is a stochastic quantity with a small mean and standard deviation of 4.4 and 4.0 m s^{-1}, respectively. Consistent with the above theoretical analysis, the distribution is left bounded and non-Gaussian. The mean and standard deviation of the residual intensity are well within the BT intensity uncertainty of ~5 m s^{-1} (Torn and Snyder 2012; Landsea, 2012).

The implication of the MSI analysis' results using the observations to the forecast verification, is that the forecasts with accurate low-wavenumber intensity alone would have the maximum skill achievable with respect to the standard BT intensity metric, because the mean and absolute mean error of such forecasts would be equal to the mean and absolute mean of the PDF[ε]. This conclusion further implies that practical predictability is determined by the skill of the low-wavenumber intensity forecast. The need for verification of the forecast skill in terms of the low-wavenumber intensity is, therefore, well justified.

Demonstration of MSI utility

Model wind field decomposition

An example of the MSI metric's use for verification of a dynamical model forecast and comparison with the standard intensity metric is presented. The forecast data were obtained using the results of data assimilation and forecast experiments with the experimental version of the HWRF dynamical model for 83 cases from years 2008-2011 (Aksoy et al., 2012; Gall et al., 2012). The data included output with 1-h frequency for each 120-h long forecast (some outputs included less than 120 hours of TC vortex parameters, because of vortex dissipation or the presence of land). The low-wavenumber wind structure was computed for each forecast output time using the high resolution (3 km) inner grid wind speed data at 10-m height. To decompose the wind field, the model grid was transformed into the polar coordinate grid (θ, r), with origin at the forecast vortex center, with radial and azimuthal grid spacing of 2 km and 1 degree, respectively. A wind field Fourier decomposition was then applied in θ for each r, although the decomposition was not performed for radii that included land anywhere within the corresponding circle. As in the observation-based analysis, the RMW was determined using the axisymmetric wind speed. The values of V_{max} were obtained from the standard "ATCF" model forecast output.

<u>Forecast verification</u>

The model forecast PDF[ε] was computed using the forecast values of V_{max} and (V_0+V_1). As compared to the observation-based distribution, the model PDF[ε] is more symmetrical and has smaller mean and standard deviation values of 2.9 and 3.0 m s^{-1}, respectively (solid curve in Figure 3b). The difference indicates the forecast tendency toward underestimating the residual intensity.

As is customary for the standard metric using BT intensity, the forecast errors for low-wavenumber maximum wind as function of forecast lead time were evaluated by computing the sample mean (the bias) and absolute mean value of the instantaneous differences for the forecast times for which the observation data were available. These mean errors are displayed in Figure 4 together with the corresponding errors using the BT metric. Several important properties are evident: First, the mean errors (Figure 4a) of the forecast maximum with respect to the BT intensity are extremely well-correlated with the bias of combined low-wavenumber intensity with respect to the SFMR-based values (i.e., the corresponding curves are virtually parallel). Second, the difference between these biases was about -4 m s^{-1}, indicating the systematic underestimate of the residual intensity. This result is consistent with the differences between the observation- and forecast- based statistical distributions. Third, for the given sample (the time matched cases) the forecast error bias was of the opposite sign for V_0 and V_1 for forecast lead times longer than 36 hours. These properties combined indicate that error compensation occurred both between the individual errors of V_0 and V_1, and with the residual intensity when using the standard metric. Because the residual intensity had almost constant negative bias, whereas the sign of the low-wavenumber error bias varied, the total error bias using the standard BT metric was reduced whenever the low- wavenumber bias was positive. The results suggest that the using the standard intensity metric could lead to an underestimate of the actual intensity forecast errors. The effect of error compensation was also evident in the mean absolute error measure, as the errors using the standard metric were significantly smaller than the sum of the absolute errors of the contributing components for several forecast times (Figure 4b). Further analysis (not shown) indicated that the axisymmetric intensity was the dominant error in the forecast.

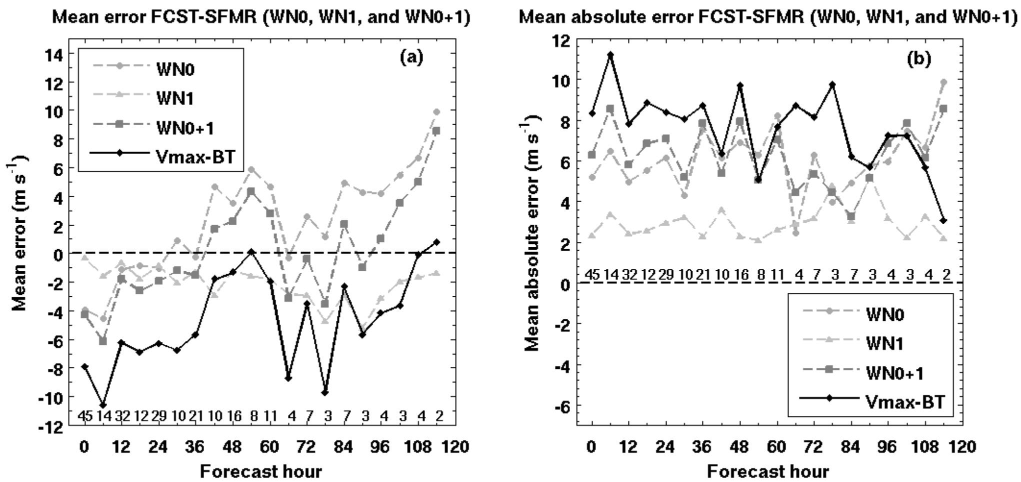

Figure 4: Comparison of intensity forecast errors as function of forecast time using the MSI (gray curves) and BT metrics (black curve). (a) is for bias (the mean error) and (b) is for mean absolute error measure. The results include all overlapping time instances between the aircraft observations and forecast for years 2008-2011.

Assessment of forecast system change

The differences between the verification results using the standard and MSI metrics was further analyzed by evaluating the impact of forecast system changes on the intensity forecast skill. The errors of a new and old version of the HWRF model were compared for 11 cases of Hurricane Earl that were observed by NOAA-P3 aircraft reconnaissance in 2010. Using the standard metric, a significant improvement of the forecast skill was observed, whereas the opposite conclusion was derived using the MSI metric (Figure 5). Specifically, the bias of wavenumber-0 increased in amplitude and changed sign from negative to positive from the old to new version of the model, whereas no change of the negative biases in wavenumber-1 and residual occurred. This condition resulted in significant net bias reduction using the standard metric (dashed and solid black curves in Fig.5), although the skill was degraded for the low-wavenumber intensity (dashed and solid gray curves in Fig.5) and was not improved for the residual intensity. The amplitude of the residual bias is the difference between corresponding black and gray curves (almost unchanged from old to new version).

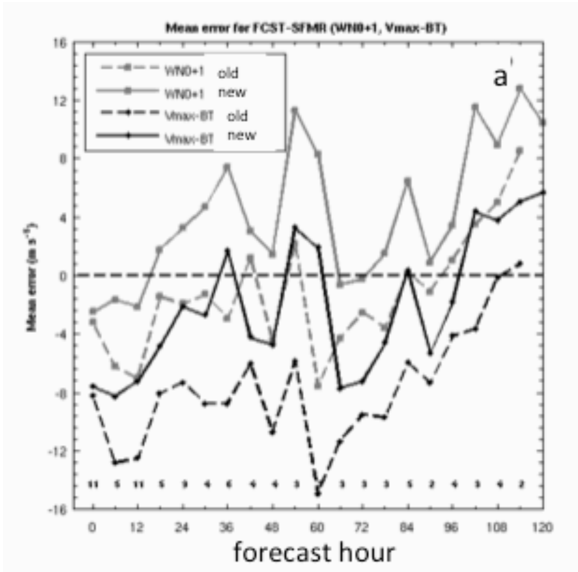

Figure 5: Mean forecast error with respect to BT (black curves) and using the MSI metric (gray curves) for the old and new version of the forecast model (old-dashed and new-solid). The low-wavenumber errors are for (V_0+V_1) with respect to SFMR analysis.

In summary, the study results demonstrate that the verification using the MSI metric would provide more revealing information about the intensity forecast errors for the dynamical model(s), which could significantly contribute to future forecast system improvements.

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C.3 Work plan

First year efforts would be devoted primarily to developing the real-time processing of observation and model fields. In particular, the SFMR field analysis and implementation of model field decomposition would be addressed. Also, during the first year, verification for the 2013 hurricane season would be presented at the 2014 Interdepartmental Hurricane Conference. In the second year, real-time processing would be tested, including making the real-time products available to NHC Hurricane Specialists.

The following products would be delivered:

- Real-time surface wind analyses of SFMR observations for each in-storm aircraft mission, including (V_0+V_1) and an estimate (with error bounds) of V_{max} based on sample statistics of PDF[ε]; also, estimates of RMW and significant wind radii by quadrant, including uncertainties, would be produced.
- HWRF intensity forecasts in terms of (V_0+V_1), ε and, V_{max}.
- HWRF forecast verification statistics based on surface wind analyses for diagnosing predictability at resolvable scales using retrospective data.

C.4 Timeline

Year 1

- Develop the software for real-time wind analysis of SFMR that would produce (V_0+V_1), an estimate (with error bounds) of V_{max} based on sample statistics of PDF[ε], estimates of RMW and significant wind radii by quadrant, including uncertainties.
- Develop the software for real-time filed decomposition of HWRF model forecasts of 10 m wind speed that would produce the equivalent parameters
- Provide on-line capability for comparison of the forecast and analysis via a web-portal

Year 2

- Make archive of the low-wavenumber analysis products for retrospective verification
- Produce HWRF forecast verification statistics based on the analyses for diagnosing the skill improvements and predictability at resolvable scales using the retrospective data

C.5 Schedule and needs for expected travel

Travel costs are requested for PI T. Vukicevic to attend the annual Interdepartmental Hurricane Conference. Other coordination meetings with designated JHT contacts are at no cost to JHT.

C.6 JHT staff requirements : None

D. Budget

				Budget Year 1				Budget Year 2		
			NOAA Requested		JHT Requested		NOAA Requested		JHT Requested	
			mm	Amount	mm	Amount	mm	Amount	mm	Amount
Personnel										
AOML	T. Vukicevic		1.0	$ 10,704	0.0	$ -	1.0	$ 11,239	0.0	$ -
AOML	E. Uhlhorn		1.0	$ 7,493	0.0	$ -	1.0	$ 7,867	0.0	$ -
AOML	P. Reasor		1.0	$ 8,933	0.0	$ -	1.0	$ 9,380	0.0	$ -
AOML	B. Barry		0.0	$ -	0.5	$ 4,965	0.0	$ -	0.5	$ 5,214
CIMAS	B. Koltz		0.0	$ -	6.0	$ 28,073	0.0	$ -	6.0	$ 29,476
Subtotal				$ 27,130		$ 33,038		$ 28,486		$ 34,690
Fringe Benefits		AOML		$ 8,410		$ 1,539		$ 9,116		$ 1,668
		CIMAS		$ -		$ 10,387		$ -		$ 11,201
Total Salaries and Fringe Benefits				$ 35,540		$ 44,964		$ 37,602		$ 47,560
Indirect Costs		AOML		$ 18,125		$ 3,317		$ 19,553		$ 3,579
		CIMAS		$ -		$ 10,000		$ -		$ 10,576
Total Labor Costs				$ 53,666		$ 58,281		$ 57,155		$ 61,714
Equipment						$ -				$ -
Supplies						$ -				$ -
Travel	Meetings					$ 2,000				$ 2,000
Publications						$ -				$ -
Other (i.e. software costs etc...)						$ 2,500				$ 375
Total				$ 53,666		$ 62,781		$ 57,155		$ 64,089

JHT costs include salary, benefits, and overhead costs for B. Klotz (6 mo.), IT support for B. Barry (0.5 mo), travel to IHC for T. Vukicevic, and software support (Matlab license):

- Year 1 $62.8K
- Year 2 $64.1K

Leveraged costs: Salary support for T. Vukicevic, E. Uhlhorn, and P. Reasor (1.0 months each year for each) is provided by NOAA/HFIP.

F. Curriculum Vitae

Abbreviated CV for Tomislava Vukicevic

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Education

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M.S. 1986 University of Utah, Department of Meteorology
Ph.D. 1989 University of Utah, Department of Meteorology

Employment

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Head of Data Assimilation Group
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2009- date: Adjunct Professor
Rosenstiel School of Marine and Atmospheric Sciences, University of Miami, Miami

2009- 2011: Adjunct Professor
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2008-2009: Senior Scientist
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2004- 2009: Associate Professor, Research
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1997-1998: Scientist II
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1993-1996: Scientist I
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1991-1992: Visiting Scientist
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1989-1991: Postdoctoral Fellow

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Recent and Relevant Publications

Vukicevic, T., A. Aksoy, P. Reasor, S. D. Aberson, K. Sellwood, and F. Marks, 2012: Joint impact of short-term tendency and state forecast bias in ensemble Kalman filter data assimilation of high-resolution tropical cyclone observations. In revision , *Mon. Wea. Rev.*

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Education

- Ph.D., Meteorology and Physical Oceanography, University of Miami, May 2008.
- M.S., Physical Oceanography, Florida Institute of Technology, Dec. 1996.
- B.S., Meteorology, Florida State University, May 1993.

Employment

- Research Meteorologist, NOAA/AOML/Hurricane Research Division, Miami, FL, July 2006 – present.
- Senior Research Associate III, University of Miami/Cooperative Institute for Marine and Atmospheric Studies (AOML), Miami, FL, Mar. 2000 – July 2006.

- Systems Analyst, Booz-Allen and Hamilton (AOML), Miami, FL, Nov. 1998 – Mar. 2000.
- Research Associate, SSAI, Inc., Greenbelt, MD, July 1997 – Nov. 1998.
- Graduate Research Assistant, Florida Institute of Technology, Melbourne, FL, June 1994 – July 1997.
- Systems Analyst, PRC, Inc., Reston, VA, May 1993 – June 1994.

Recent and Relevant Publications

Uhlhorn, E. W. and L. K. Shay: Loop current mixed layer energy response to Hurricane Lili (2002). Part II: Idealized numerical simulations. *J. Phys. Oceanogr.*, in review.

Cione, J. J., E. A. Kalina, J. Zhang, and E. W. Uhlhorn: Observations of air-sea interaction and intensity change in hurricanes. *Mon. Wea. Rev.*, in review.

Winterbottom, H. R., E. W. Uhlhorn, and E. P. Chassignet (2012): A design and an application of a regional coupled atmosphere-ocean model for tropical cyclone prediction. *J. Adv. Modeling Earth Sys.*, **4**, M10002, 17pp.

Zhang, J. and E. W. Uhlhorn (2012): Hurricane sea-surface inflow angle and an observation-based parametric model. *Mon. Wea. Rev.*, XX, xxxx-xxxx.

Uhlhorn, E. W. and L. K. Shay (2012). Loop current mixed layer energy response to Hurricane Lili (2002). Part I: Observations. *J. Phys. Oceanogr.*, **42**, 400-419.

Uhlhorn, E. W. and D. S. Nolan (2012). Observational undersampling in tropical cyclones and implications for estimated intensity. *Mon. Wea. Rev.*, **140**, 825-840.

El-Nimri, S. F., W. L. Jones, E. W. Uhlhorn, C. Ruf, J. Johnson, P. Black (2011): An improved C-band ocean surface emissivity model at hurricane-force wind speeds over a wide range of incidence angles, *Geosci. Rem. Sens. Lett.*, **7**, 641-645.

Powell, M. D., E. W. Uhlhorn, and J. D. Kepert (2011): Reply to comments on Estimating maximum surface winds from hurricane reconnaissance measurements, *Wea. Forecasting*, **26**, 777-779.

Shay, L. K., B. Jaimes, J. Brewster, P. Meyers, C. McCaskill, E. Uhlhorn, F. Marks, G. R. Halliwell Jr., O.-M. Smedstad, and P. Hogan (2011): Airborne ocean surveys of the Loop Current complex from NOAA WP-3D in support of Deepwater Horizon oil spill. Liu, Y. A, et al. (Eds.). Monitoring and modeling of the Deepwater Horizon oil spill: A record-breaking enterprise. *Geophys. Monogr. Series*,**195**, AGU, Washington DC, 271 pp.

Powell, M. D., E. W. Uhlhorn, and J. D. Kepert (2009): Estimating maximum surface winds from hurricane reconnaissance measurements, *Wea. Forecasting*, **24**, 868—883.

Halliwell, G. R. Jr., L. K. Shay, S. D. Jacob, O. M. Smedstad, E. W. Uhlhorn (2008): Improving ocean model initialization for coupled tropical cyclone models using GODAE nowcasts, *Mon. Wea. Rev*., **136**, 2576—2591.

Uhlhorn, E. W., P. G. Black, J. L. Franklin, M. Goodberlet, J. Carswell and A. S. Goldstein (2007). Hurricane surface wind measurements from an operational stepped-frequency microwave radiometer. *Mon. Wea. Rev.*, **135**, 3070-3085.

Jiang, H., E. Zipser, P. Black, F. Marks and E. Uhlhorn (2006): Validation of rain rate measurements from the Stepped-Frequency Microwave Radiometer. *J. Atmos. Sci*., **63**, 252-267.

Uhlhorn, E.W., and P.G. Black (2003): Verification of remotely sensed sea surface winds in hurricanes. *J. Atmos. Oceanic Tech.*, **20**, 99-116.

Awards and Honors

- American Meteorological Society Special Award, 2010.
- NOAA/OAR Best Paper, nominated, 2008, 2009, 2011.
- NOAA bronze medal award, 2008.
- American Meteorological Society Banner I. Miller award, 2008.
- NOAA bronze medal award (Group), 2007.

Field Research Experience

- NOAA Intensity Forecasting Experiment (IFEX) Director, 2009.
- NOAA Intensity Forecasting Experiment (IFEX) 2005-present.
- ONR/Coupled Boundary Layer and Air Sea Transfer (CBLAST) 2002-2004.
- NOAA/NSF Hurricane Air-Sea Interaction (HARSIN) Experiment 2002.
- NOAA/HRD Hurricane Field Program 1998-Present.

Professional

- Member, American Meteorological Society, 1995-present.

Abbreviated CV for Paul Reasor

Paul D. Reasor

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(i) Professional Preparation

University of California, Berkeley	B.A.	199 3	Physics
Colorado State University	M.S.	199 6	Atmospheric Science
Colorado State University	Ph.D.	200 0	Atmospheric Science

(ii) Appointments

2009-present	Research Meteorologist, NOAA/AOML/HRD
2003-2009	Assistant Professor, Department of Meteorology, The Florida State University
2002–2003	Research Scientist, Department of Atmospheric Science, Colorado State University
2001–2002	Research Associate, Hurricane Research Division, NOAA/AOML, Miami, FL
2000–2001	NRC Postdoc, Hurricane Research Division, NOAA/AOML, Miami, FL

(iii) Recent Relevant Publications

Reasor, P. D., and M. D. Eastin, 2011: Rapidly Intensifying Hurricane Guillermo (1997). Part II: Resilience in shear. *Mon. Wea. Rev.*, **140**, 425-444.

Reasor, P. D., M. D. Eastin, and J. F. Gamache, 2009: Rapidly Intensifying Hurricane Guillermo (1997). Part I: Low-wavenumber structure and evolution. *Mon. Wea. Rev.,* **137**, 603-631.

Reasor, P. D., M. T. Montgomery, and L. F. Bosart, 2005: Mesoscale observations of the genesis of Hurricane Dolly (1996). *J. Atmos. Sci.,* **62**, 3151-3171.

Reasor, P. D., M. T. Montgomery, and L. D. Grasso, 2004: A new look at the problem of tropical cyclones in vertical shear: Vortex resiliency. *J. Atmos. Sci.*, **61**, 3–22.

(iv) Recent Synergistic Activities

Member: American Meteorological Society

Member: NASA Tropical Cloud Systems and Processes (TCSP) Science Team (2005-2008)

Associate Editor, *Journal of the Atmospheric Sciences* (2006 – 2009)

Reviewer: *J. Atmos. Sci., Mon. Wea. Rev., Quart. J. Roy. Met. Soc., Dyn. Atmos. Ocean, Wea. and Forecasting, J. Atmos. Ocean. Tech., Geophys. Res. Let., NSF*

Graduate student thesis advisor: 6 M.S. and 3 Ph.D. (2003-2009)

G. Current and Pending Support

Investigator	Status	Project title	Funding Source	Total amount	Time (months per year)
T. Vukicevic PI Co-I T. Greenwald, CIMSS	Current	Validation of HWRF forecasts with satellite observations	JHT	$89.4K (combined AOML and CIMSS) Second year of 2 year	1.0 in kind
T. Vukicevic PI	Current	Improving Prediction of Precipitation by Objective Estimation of Bulk Effects of Cloud and Precipitation Microphysical Processes	NSF Explanation: Hosted at RSMAS/UM; Transferred from CU to continue supporting PhD student when PI Vukicevic accepted position with AOML	$534.17K for 3 years Currently in 4-th year with no - cost extension and is near completion , (April 2013).	1.0 in kind
E. Uhlhorn (PI)	Current	Improved SFMR surface wind measurements in intense rain conditions	JHT	$80.4K (2nd of 2 year)	1.0 (in-kind)
E. Uhlhorn (co-PI)	Pending	Guidance on Observational Undersampling over the Tropical Cyclone Lifecycle	JHT	$184.4K (2 years)	1.0