Integrating and Blending Diverse Observing Platforms to Assess Observations and Forecasts of Tropical Cyclone Genesis, Wind Structure, and Intensity Change

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Executive Summary:

This work will focus on blending and integrating relevant NASA observing platforms with conventional and adaptive measurements to help identify the topical cyclone intensity changes from genesis through landfall. NASA satellite observing measurements include surface wind and rainfall from QuikSCAT, the TRMM Microwave imager, and AQUA AMSR-E platforms. These data will be integrated with measurements from NOAA and other sources including the research aircraft (two P3's, Gulfstream 4), GPS sondes, the stepped frequency microwave radiometer (SFMR), as well as GOES cloud drift and SSM/I winds and conventional data from drifting and moored buoys, ships, and coastal stations. During the TCSP field program, a near-realtime component will involve preparation of daily mesoscale (1000 km) kinematic surface analyses on tropical systems with in the TCSP area of interest as identified in the operational Automated Tropical Cyclone Forecast System (ATCF). Named tropical cyclones will undergo mesoscale analysis on a 6 h basis. Analyses will be used to document genesis, current intensity, intensity change, and evaluate model forecasts of intensity and wind structure as well as to demonstrate the capability of blending and integrating NASA measurements with those of other land, air, space, and marine observing platforms. Comparisons of various observation platform measurements to each other, to models, and to H*Wind analyses will document the performance of NASA platforms and model forecasts.

1. Introduction

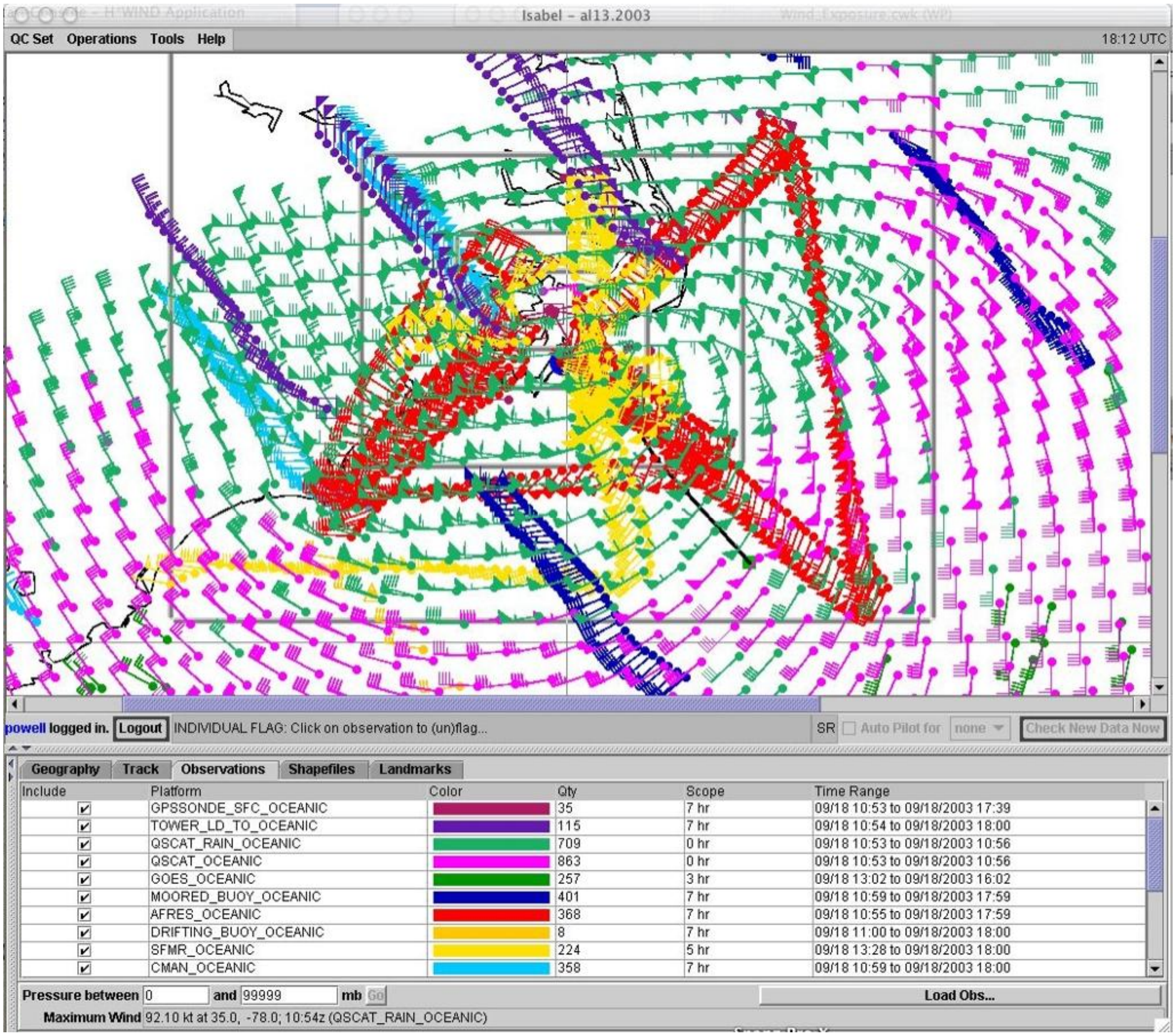
Previous Convection and Moisture Experiments (CAMEX) focused on observing and modeling rapid intensification and storm movement, while contributing to improving remote sensing techniques in tropical cyclones. The TCSP program extends the accomplishments of that work to focus on why such a small percentage of tropical systems develop into storms and hurricanes, and when storms do form, what factors lead to changes in intensity. It has long been known (Malkus and Riehl 1956) that the ambient atmosphere is not able to support the pressure drops observed in tropical cyclones unless surface energy fluxes can be augmented by stronger winds and lower pressures. In their seminal work, Charney and Eliassen (1964) envisioned tropical cyclones forming as a result of a feedback process initiated through a cooperative process in which low-level horizontal convergence of moisture acted to enhance and organize small-scale cumulus convection resulting in release of latent heat in the cyclone center. Burpee (1974) identified African Easterly Waves (AEW) as propagating vorticity disturbances that can act as a trigger to conditions favorable to cyclogenesis, but very few of these systems actually develop further, suggesting the need for additional mechanisms and processes.

Bracken and Bosart (2000) presented a strategy for identification of areas favorable to tropical cyclogenesis. They suggested foremost that a mechanism for "persistent and organized deep mesoscale convection" must first be present before other factors could act. Such a mechanism would involve a flow pattern that would force synoptic scale ascent by vorticity advection, eventually creating a favorable environment by destabilizing the lower troposphere, removing the trade wind inversion, and enhancing convergence through Ekman pumping. Once an environment favorable to ascent is present, other factors such as vertical wind shear, low-level vorticity, and warm sea surface temperatures may help to intensify the system.

In the Eastern Pacific, terrain factors come into play. Zehnder and Farfan (1997) identified cyclogenesis in the Eastern Pacific, suggesting that the mountains of Central America act to block the low-level flow associated with AEW's leading to an easterly jet acting with a north easterly jet near the Gulf of Tehuantepec and existing convergence to produce a closed circulation that eventually became a hurricane. Molinari et al. 2000 reasoned that strong AEW's could focus sufficient low-level vorticity for cyclogenesis, provided that wind shear was already low and sea surface temperatures were already favorable. Simpson et al. (1997) suggested another cyclogenesis process brought on by mesoscale convective vortices that develop in mid levels within stratiform rain areas trailing mesoscale convective systems. Such vortices, in the presence of a monsoon low, may interact to develop into a tropical cyclone.

While these studies help to understand what factors are typically associated with cyclogenesis, once a storm has developed, the same quantities may also help control intensity change. Current forecast models have little skill in predicting intensity, making it difficult to use traditional methods for data assimilation in which a short term forecast field is combined with data to create an analysis field to initialize the model. Further complicating the prospects for improved intensity forecasting is the fact that in-situ measurements of peak winds in the extreme hurricane environment are very difficult to obtain, so new and sometimes unproven indirect methods are often used to measure surface winds within the inner core. An example of inner core hurricane data coverage is shown in Fig. 1 for Hurricane Isabel of 2003.

The various estimates of intensity from these platforms (Fig. 2) vary from 76-101 kts, suggesting an apparent uncertainty of at least 25% even with good data coverage. However, by conducting analyses on a regular basis, an experienced scientist is able to make decisions on which techniques work best under different situations, perhaps lowering the uncertainty estimate to near 10% if ideal platforms are available to meet the given situation. In the situation depicted in Figs. 1 and 2, the reconnaissance aircraft measurement adjusted to the surface with the PBL model was chosen because it proved a better match with nearby GPS sondes and SFMR measurements in other parts of the storm, and was known to perform well for storms of similar intensity. While intensity forecasts are validated, it is through comparison to a subjectively determined "best track" peak sustained surface wind speed. Wind radii are extracted from model analysis and forecast fields and are available from the Automated Tropical Cyclone Forecast (ATCF) System. However, no systematic objective validation program exists for regular comparisons of official or model forecast wind radii to observations. Recent work by Wu et al., suggest that because the scale of a tropical cyclone is much less than the Rossby radius of deformation, the pressure field responds by geostrophic adjustment to the wind field, and therefore future data assimilation methods should focus on the wind field. If the model forecast surface wind fields are to eventually contribute to modern data assimilation systems in the next generation of hurricane models (such as HWRF), the errors of short-term forecasts should be random and relatively small. If differences are large and/or biases exist, the model forecast field would be a poor first guess and result in a poor initialization of the model (Hoffman 1984, Daley 1991).



powell logged in. INDIVIDUAL FLAG: Click on observation to (un)flag...

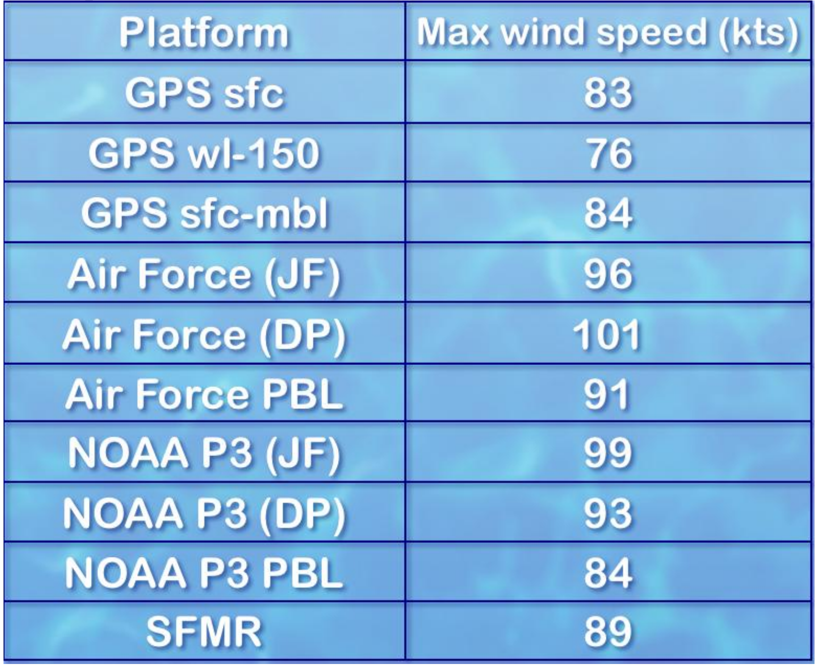
Include	Platform	Color	Qty	Scope	Time Range
☑	GPSSONDE_SFC_OCEANIC	🟥	35	7 hr	09/18 10:53 to 09/18/2003 17:39
☑	TOWER_LD_TO_OCEANIC	🟪	115	7 hr	09/18 10:54 to 09/18/2003 18:00
☑	QSCAT_RAIN_OCEANIC	🟩	709	0 hr	09/18 10:53 to 09/18/2003 10:56
☑	QSCAT_OCEANIC	🟪	863	0 hr	09/18 10:53 to 09/18/2003 10:56
☑	GOES_OCEANIC	🟩	257	3 hr	09/18 13:02 to 09/18/2003 16:02
☑	MOORED_BUOY_OCEANIC	🟦	401	7 hr	09/18 10:59 to 09/18/2003 17:59
☑	AFRES_OCEANIC	🟥	368	7 hr	09/18 10:55 to 09/18/2003 17:59
☑	DRIFTING_BUOY_OCEANIC	🟧	8	7 hr	09/18 11:00 to 09/18/2003 18:00
☑	SFMR_OCEANIC	🟨	224	5 hr	09/18 13:28 to 09/18/2003 18:00
☑	CMAN_OCEANIC	🟦	358	7 hr	09/18 10:59 to 09/18/2003 18:00

Pressure between 0 and 99999 mb

Maximum Wind 92.10 kt at 35.0, -78.0; 10:54z (QSCAT_RAIN_OCEANIC)

Fig. 1. H*Wind interface showing observation panel with different observation platforms shown in various colors as described in the lower panel. Shown are Hurricane Isabel data for the time period of landfall, 1300-1800 UTC on 18 September 2003.

By integrating various observing platforms and blending them into an analysis after careful quality control, it is possible to compare the observations to each other and to analyses and model forecast winds in the same general storm-relative location. By evaluating many cases in a scaled, storm-relative coordinate system, an ensemble of storm wind field instances may be constructed and maps of the relative performance characteristics of various observing platforms and forecasts will begin to emerge. We propose to use the intensive observation period of the TCSP field program to produce regular assessments of model wind field forecasts. The official and model forecasts of the peak wind and radii of tropical storm, 50 kt, and hurricane force winds may also be compared to those determined from observations.

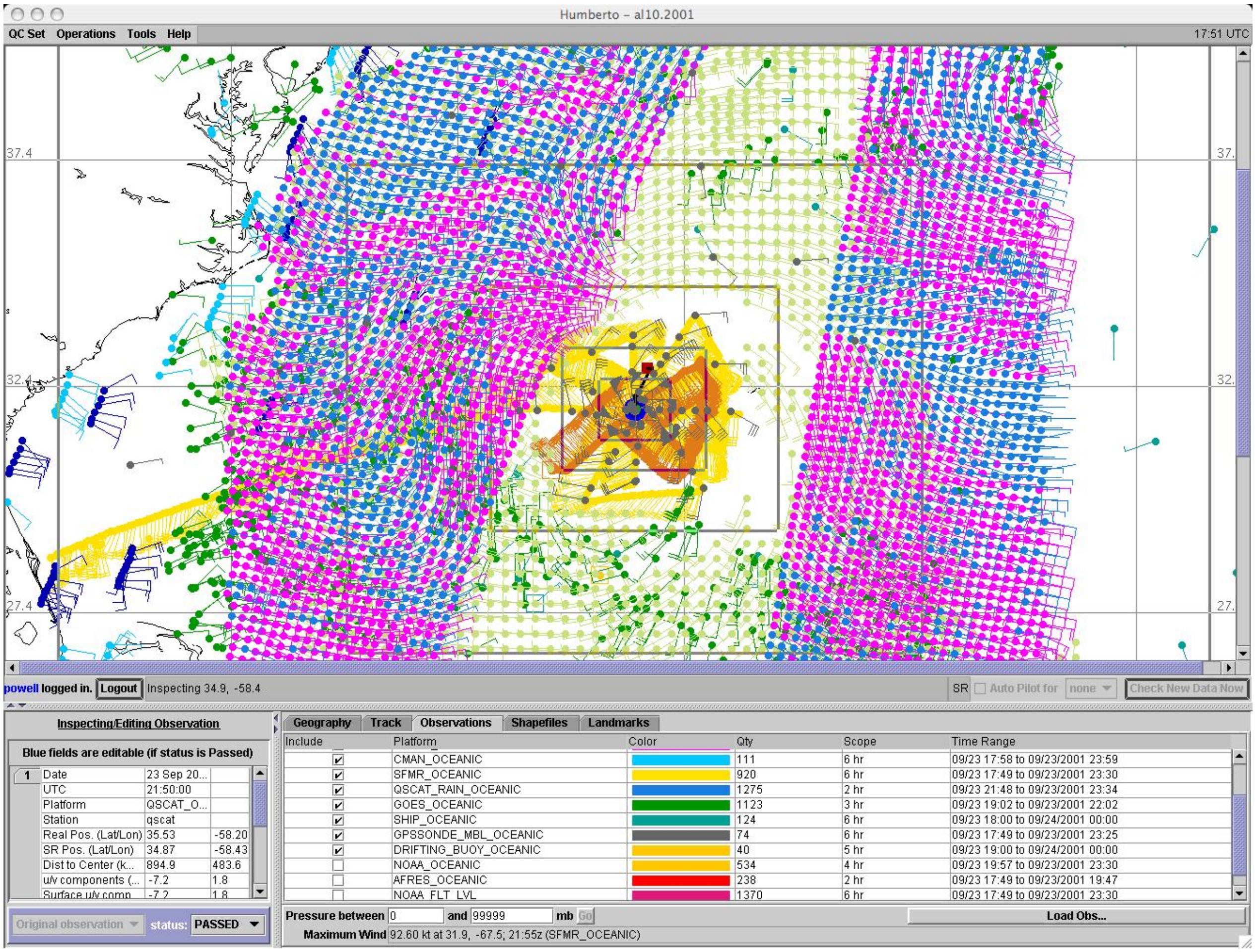


Platform	Max wind speed (kts)
GPS sfc	83
GPS wl-150	76
GPS sfc-mbl	84
Air Force (JF)	96
Air Force (DP)	101
Air Force PBL	91
NOAA P3 (JF)	99
NOAA P3 (DP)	93
NOAA P3 PBL	84
SFMR	89

Fig. 2. Estimates of the maximum sustained wind of Hurricane Isabel based on observation platform information depicted in Fig. 1. Based on the experience of the analyst, the Air Force Planetary Boundary Layer (PBL) estimate was considered most representative of the peak wind in the hurricane over this time period.

2. Work to be undertaken

Since many studies suggest the importance of the low level vorticity and convergence fields for cyclogenesis we propose to monitor these fields during the TCSP field program with twice per day mesoscale kinematic surface analyses. Once a system has developed, we propose to monitor the intensity in real-time with daily surface wind field analyses. The daily analyses will be available to assist with mission planning and will also comprise measurements obtained during the missions and made available in real time. The HRD Realtime Hurricane Wind Analysis System (H*Wind) (Powell et al., 1996, 1998) will be used to blend, integrate, evaluate, and analyze observations from available space, air, land, and sea-based platforms. H*Wind provides a JAVA graphical front end to an Oracle database, providing interactive quality control (QC) that requires the experience of the analyst to decide which data are representative of the current situation.



powell logged in. Inspecting 34.9, -58.4

Inspecting/Editing Observation

Blue fields are editable (if status is Passed)

1			
	Date	23 Sep 20...	
	UTC	21:50:00	
	Platform	QSCAT_O...	
	Station	qscat	
	Real Pos. (Lat/Lon)	35.53	-58.20
	SR Pos. (Lat/Lon)	34.87	-58.43
	Dist to Center (k...	894.9	483.6
	u/v components (...	-7.2	1.8
	Surface u/v comp...	-7.2	1.8

status: PASSED

Include	Platform	Color	Qty	Scope	Time Range
☑	CMAN_OCEANIC	🟦	111	6 hr	09/23 17:58 to 09/23/2001 23:59
☑	SFMR_OCEANIC	🟨	920	6 hr	09/23 17:49 to 09/23/2001 23:30
☑	QSCAT_RAIN_OCEANIC	🟦	1275	2 hr	09/23 21:48 to 09/23/2001 23:34
☑	GOES_OCEANIC	🟩	1123	3 hr	09/23 19:02 to 09/23/2001 22:02
☑	SHIP_OCEANIC	🟩	124	6 hr	09/23 18:00 to 09/24/2001 00:00
☑	GPSSONDE_MBL_OCEANIC	⬛	74	6 hr	09/23 17:49 to 09/23/2001 23:25
☑	DRIFTING_BUOY_OCEANIC	🟧	40	5 hr	09/23 19:00 to 09/24/2001 00:00
☐	NOAA_OCEANIC	🟧	534	4 hr	09/23 19:57 to 09/23/2001 23:30
☐	AFRES_OCEANIC	🟥	238	2 hr	09/23 17:49 to 09/23/2001 19:47
☐	NOAA_FLT_LVL	🟪	1370	6 hr	09/23 17:49 to 09/23/2001 23:30

Pressure between 0 **and** 99999 **mb**

Maximum Wind 92.60 kt at 31.9, -67.5; 21:55z (SFMR_OCEANIC)

Fig. 3. Distribution of surface wind observations displayed in H*Wind for the CAMEX mission into Hurricane Humberto on 23 September 2001 for a six hour time window from 1749 – 2400 UTC. Lower left panel shows result of analyst inspection of a data point. Lower right panel show checked observing platforms that are displayed above.

To improve data coverage we incorporate a time-to-space conversion within a storm-relative coordinate system with a time window that may be adjusted to provide sufficient data for analysis. All observations are preprocessed to a consistent framework for height (10m), exposure (marine or open terrain over land), and averaging time (maximum 1 min sustained wind speed). This framework is consistent with the terminology used in National Hurricane Center forecasts and warnings as well as wind loading provisions used by many building codes (ASCE 2002). The distribution of observations shown in Fig. 3 for the CAMEX mission into Hurricane Humberto of 2001 is similar to what might be expected in a TCSP mission. H*Wind provides a comprehensive set of tools to allow an experienced scientist to conduct graphical interactive QC and objective analysis. The overlaps of various platforms provide numerous opportunities to compare observing platforms to each other and the analysis. However, the quantity of information to be compared is relatively large, nearly 10,000 individual observations in this case. A low-weight background field from a model or a prior analysis may be incorporated to provide continuity and help fill in data voids. Once these data pass scrutiny, they are objectively analyzed with a nested "mechanical" interpolation approach (Ooyama1987, Lord and Franklin

1987). The analysis consists of a two-dimensional least squares fitting algorithm combined with a derivative constraint, originally developed by Ooyama for GATE. The analyzed field is represented by series of local basis functions (cubic B splines) centered at each nodal point. Coefficients of the splines are chosen to minimize the differences between observations and the analysis, subject to a constraint that acts as a low-pass filter to control resolvable scales. Analysis filters and homogeneous boundary conditions are selectable for each of 5 nested meshes, and subjective weights may also be assigned by platform. The wind analysis is constrained to match the maximum observed wind location and magnitude. It is also constrained such that the coastline represents a discontinuity where flow in equilibrium with open-terrain and marine exposure immediately respond to the new underlying surface. In reality such transitions occur on a scale of a few kilometers. Because the resulting analysis is continuous and twice differentiable, it is well suited to computation of derived fields such as vorticity and divergence, and is also readily determined at observation points as well as any specified model grid. Comparisons between the analysis and observations indicate root mean square differences on the order of 2-3 m/s. Analyses are made available in graphic and gridded form on the web (http://www.aoml.noaa.gov/hrd/data_sub/wind.html), where they are used for a variety of applications including experimental forecast/warning guidance, and damage assessment. Frequency is typically 6 h (or ~ 3h at landfall). Several enhancements to H*Wind will enable generation of kinematic quantities derived from the wind field analysis. These analyses will then be compared to available observations, and to model analysis and forecast fields to help assess the accuracy of observations from various platforms as well as intensity forecast errors. Models of interest include COAMPS and the GFDL. Global models are too coarse to resolve the inner core of the hurricane and even the COAMPS and GFDL "bogus" the tropical cyclone circulation or relocate the coarse model circulation to the observed position of the cyclone rather than incorporate a data assimilation scheme. The resolution of the inner core of the GFDL model is 1/6 degree or about 18 km while that of COAMPS can be 27, 18, or 9 km, depending on the application. This resolution should be capable of resolving many details of the inner core of a mature tropical cyclone but may have difficulties with small, intense systems. When working with model wind fields the framework must be considered to make sure the height, exposure and averaging times are equivalent (Powell and Houston 1999).

3. Objectives and expected significance

This work will focus on blending and integrating NASA's remote wind sensing platforms with conventional and adaptive observing systems to help identify tropical cyclone intensity changes from genesis through landfall. NASA satellite remote wind observing platforms include QuikSCAT Seawinds, the TRMM Microwave imager, and AQUA AMSR-E. These data will be integrated in near real time with measurements from NOAA and other sources including the research aircraft (two P3's, Gulfstream IV), reconnaissance aircraft operated by the U. S. Air Force Reserves, GPS sondes, the stepped frequency microwave radiometer (SFMR), as well as GOES cloud drift and SSM/I winds and conventional data from drifting and moored buoys, ships, and coastal stations.

A. Diagnose mesoscale surface kinematic structure during the TCSP Field Program

Subject to data availability, mesoscale wind, vorticity, and divergence field analyses will be conducted for suspect development regions in the TCSP field program area of interest. Suspect development areas will be identified from the ATCF, an analysis will be scheduled in near real time if sufficient data are available. For example, if an "Invest" reconnaissance flight is scheduled in the reconnaissance aircraft "Plan of the Day" product, or if a TCSP mission is scheduled into a suspect area, an analysis will be scheduled to take advantage of maximum data availability. Once a system has been classified as a depression, topical storm or hurricane, the frequency of analysis will increase to accommodate aircraft sampling blended with QuikSCAT, AQUA, or TRMM overpasses. Such sampling may be sufficient to conduct 1- 4 analyses daily, depending on operational requirements or TCSP mission planning. Aircraft observations or indirect measurements from the aircraft platforms are key to determining the wind field, especially in the inner core of mature systems. During the TCSP field program, analyses will be made available on the web within 1 h of the analysis time except during late evening and early morning hours (after which analyses will be available the following morning). When mature tropical cyclones are active in the Atlantic basin west of 60 degrees west longitude, our experience has indicated data coverage is sufficient for analyses at hours 00, 06, 12, and 18 UTC. During TCSP, analysis times can be flexible to accommodate specific experiments. A series of graphical and gridded products, similar to those on our web site (http://www.aoml.noaa.gov/hrd/data_sub/wind.html), will be made available to all TCSP investigators. These products are valuable for mission planning and will also help document the development, intensification and weakening stages of tropical systems in the TCSP areas of interest. They will also become the basis for evaluation of NASA platforms and model forecasts.

B. Evaluate the performance of NASA's remote wind measurement platforms in tropical cyclones

All observations, and storm track information related to an analysis are stored and may be examined in a scaled, storm-relative coordinate system. Surface winds will be scaled by the maximum observed surface wind contained in the quality controlled H*Wind objective analysis data set. All information will be mapped to a storm centered cylindrical grid oriented in the direction of storm motion with a radial extent of 5 times the radius of maximum surface wind as determined by the analysis (Rmax), a radial resolution of 0.1 R/Rmax, and an azimuthal resolution of 45° (Fig. 4). The radial gradients in a tropical cyclone are far greater than those in the azimuthal direction so reconnaissance aircraft typically fly repeated "figure 4" flight patterns that are oriented along cardinal directions and sample the wave number one and two asymmetries in the flow field. Research missions may sample in the same manner or rotate the pattern to sample different azimuths. We orient the system along the storm motion vector over the time window for the analysis, and assign a relatively low resolution to the azimuthal direction consistent with typical inner core sampling but a very high resolution radial grid so that near-horizontal homogeneity may be assumed within a grid cell. We also assume that conditions within a cell are near stationary by using shortest possible time window that provides sufficient data coverage for an analysis while minimizing changes in storm. Typical time windows for an analysis are 4-6 hours, during which an aircraft may complete one or more "figure 4" flight patterns.

Surface wind observations contained within the same grid cells will be scaled by the maximum surface wind speed (as determined from the analysis) and compared by platform. For example, the scaled mean wind speed, mean inflow angle, and standard deviation of QuikSCAT observations within a grid cell for a particular storm and analysis time will be compared to similar quantities from all other platforms within the cell, as well as the objective analysis resulting in a set of differences that will be stored in our database along with position and storm information.

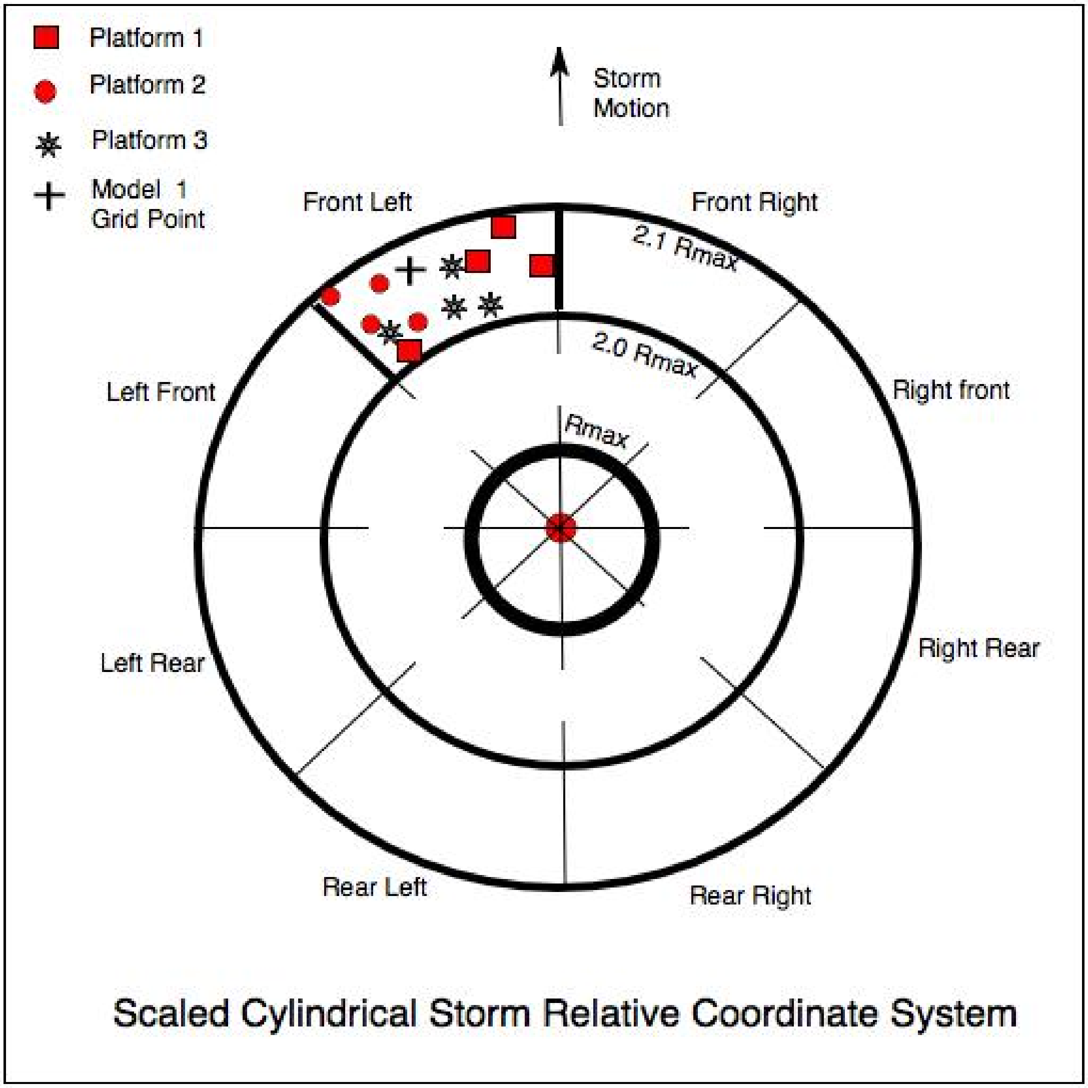


Figure 4. Coordinate system for comparison of observing systems and model forecast winds. All platforms within the grid cell are evaluated against each other, the analysis, and model forecasts.

An ensemble of storms sampled during TCSP will enable the creation of a series of storm-centered maps depicting the differences between QuikSCAT winds and winds from each platform, as well as the analysis. These maps could also be examined to see whether differences are dependent on storm translation speed and intensity. It should be stressed that while the wind analyses represent an objective analysis of observations that have passed interactive quality control by an experienced analyst, the observations used for the platform comparisons will undergo no quality control other than gross checks for obvious biases and errors. Hence a subset of observations that did not contribute to the analysis could be compared to the analysis for an independent assessment. For example, the QuikSCAT rain flagged wind vector observation platform may not necessarily pass QC for the analysis, but it will still be compared to all other observations relevant to the time period and to the analysis. Studies have demonstrated how NASA observation platforms like Seawinds (through data denial experiments) may impact a forecast (Atlas et al 2001). NASA platforms typically undergo evaluation by a calibration/validation team, by comparison to individual platforms but many of the platforms specific to tropical cyclones (Table 1) may not have been considered.

An advantage of this approach over conventional platform comparisons is the storm relative framework and the ability to compare to specialized platforms that are only available when tropical cyclones are sampled by aircraft.

Surface Observing Platform	**Measurement Concept**
NASA QuikSCAT SeaWinds	Scattering off capillary waves
NASA AQUA AMSR-E	Sea Sfc roughness emission
NASA TRMM microwave imager	Sea Sfc roughness emission
SSM/I	Sea Sfc roughness emission
GOES	Cloud tracking adj. To sfc
Aerosonde (see Cione proposal)	In situ from onboard navigation system
NOAA FL Adj. To sfc 1	PBL model adj FL to sfc
NOAA FL Adj. To sfc 2	Empirical (.9) adjustment of FL wind in eyewall, .8 elsewhere
NOAA FL Adj. To sfc 3	Empirical adjustment of FL wind based on tilt method
NOAA FL Adj. To sfc 4	Empirical based on peak FL wind
GPS sonde Sfc	Tracking sonde to 10 m
GPS sonde Sfc MBL	Empirical based on lowest 500 m mean wind
GPS sonde Sfc WL150	Empirical based on lowest 150 m mean wind
NOAA Moored buoys	In situ anemometer measurements

Table 1. List of selected observing platforms for which comparisons will be conducted. Air Force reconnaissance aircraft would have the same properties as those listed above for the NOAA research aircraft.

In particular the ability to compare to the Stepped Frequency Microwave Radiometer (SFMR) aboard the NOAA research aircraft and GPS sondes in the core of the storm and other platforms like drifting buoys, the Aerosonde (see Cione proposal), moored buoys, C-MAN stations, METAR stations, and cloud drift winds typically on the periphery. The SFMR (Uhlhorn and Black 2002) measures the emissivity of the sea surface foam and has the advantage of not saturating out at high wind speeds; the SFMR also is not contaminated by rain or cloud. However, measurements in regions where foam may be contributed by current interactions, shoaling waves, or small landmasses may cause high biases. Typically such regions are readily recognized during H*Wind's interactive quality control process. Three different GPS sonde wind measurements are available in H*Wind. The 10 m level wind, the mean boundary layer derived surface wind, and the lowest 150 m layer derived surface wind. In strong wind speeds, for reasons related to signal-to-noise ratio of the receiver, the sonde wind computation may fail before the sonde is able to sample the wind near 10 m. In addition the 10 m wind is representative of whatever feature the sonde falls through so there is large variability in the measurement. Alternative estimates of surface winds based on the lowest 500 m layer mean wind (MBL) or lowest 150 m layer (WL150) show much less variability and provide estimates even if the sonde wind computation fails near the surface.

C. Evaluate the ability of current hurricane forecast models to predict intensity and wind structure

The same storm centered, scaled, cylindrical coordinate system will be used to evaluate model wind field forecasts at 0, 12, 24, 36, 48, 72, 96, and 120 hours, every 6 hours. Only model analysis fields and forecasts at valid times within 1.5 h of analysis times will be evaluated. The GFDL and possibly also COAMPS models will be evaluated by comparison of grid points to observing platforms and analysis values in the same scaled storm centered cylindrical grid cells. Since we are only evaluating intensity forecasts, we need not be concerned about track errors. Hence, model gridded fields will be transformed to the storm relative system (Fig. 2) for comparison. In addition to the comparisons of the model fields to measurements by observation platform, we may also evaluate the peak model wind speed and tropical storm, 50 kt, and hurricane force wind radii in each quadrant compared to the observation-based analysis.

It should be stressed that to our knowledge, no systematic evaluation (relative to observations) of hurricane model initial and forecast surface wind fields has ever been attempted. This is especially needed now since it is apparent that ocean waves (Walsh et al., 2002) have a specific storm relative distribution that can impact air sea interaction parameterizations. In addition, the surface drag coefficient over the open ocean may level off or actually decrease as surface winds increase above hurricane force (Powell et al., 2003) in contrast to parameterizations used in many models. Limitations of model parameterizations may cause biases that are more prevalent in extreme wind conditions, but these are difficult to determine at present due to lack of a systematic objective model wind field analysis and forecast validation program. Evaluations are a necessary first step if data assimilation methods are to be applied to future models such as the Hurricane Weather Forecast Model (H-WRF). Data assimilation systems assume that errors of short-term forecasts of models that might be used as background or first-guess fields should be small and random (Tallagrand 1997). After an ensemble of storms and forecasts for each forecast time, maps will be constructed depicting how the models compare to each observation platform as well as the analysis. The database created in this effort will be well suited for support of future data assimilation studies for evaluation of model background error covariance.

D. Document landfall situations

Accurate diagnosis of the location of the peak surface winds is critical for modeling storm surge and waves as well as assessing damage after landfall. In the event of a land falling hurricane or tropical storm within the TCSP area of interest, H*Wind analyses will be conducted on a 3-6 h frequency, subject to data availability. We will also attempt to analyze the system after landfall but such analyses are dependent on availability of observation exposure information (Powell et al., 2004) and the reliability of the observing system. For example, the Automated Surface Observing System (ASOS) used in the U. S. has experienced data losses due to power failures. Typically fewer data are available over land in the core of the storm since aircraft do not continue to monitor hurricanes after landfall and remote microwave sensing systems are designed for marine conditions. Work is ongoing to derive low-level wind fields from land-based Doppler radars but these data are not yet regularly available. If a land falling storm subsequently moves out over water again, we will also continue to conduct analyses, subject to availability.

4. Plan of work

Year 1

Make arrangements to regularly download available NASA observing platforms capable of observing surface winds. TRMM and QuikSCAT winds are currently available to us courtesy of NESDIS. We will also need to arrange with NASA and/or NESDIS for access and delivery of AMSR-E surface winds in near real time if available. Make contacts with Navy and NOAA scientists to obtain GFDL and COAMPS inner mesh gridded surface wind field analyses and forecasts out to five days, four times per day. Secure necessary server and disk space to accommodate storage of model data and new observing platforms. Make changes to H*Wind to enable kinematic synoptic and storm-relative analysis of generalized scalars, radial and tangential components, and inflow angle. Make changes to H*Wind to allow creation of super-obs for platforms that provide high density, partially redundant observations. Provide coding to allow additional kinematic products to be designed and made available. Conduct near real-time analyses of invest and officially classified tropical cyclones within the TCSP area of interest. Make analysis products available on the web to all TCSP investigators in graphical, gridded, and shape file format. Collect observing platform, analysis, and model wind comparison data for performance calculations. Work on analysis and design of an interface to provide examination and analysis of evaluation results.

Year 2

Conduct additional analyses as needed. Continue developing an interface for performance comparisons of observing platforms, analyses and forecasts. We will consult with Dr. Jeff Kepert, an internationally known expert on tropical cyclone surface winds who is currently working in the Data Assimilation group of the Australian Bureau of Meteorology. Dr. Kepert will serve as an unfunded collaborator but part of our travel funds will pay for him to visit AOML for consultation purposes. With his guidance, we will design and develop a prototype of the evaluation system for one storm from Year 1, evaluating both observing platforms and forecasts. Additional year 2 activities include presenting results at a conference and preparing a journal article summarizing genesis, intensity, and intensity change based on analyses conducted on mature and developing tropical systems during the TCSP field program.

Year 3

Make improvements to evaluation system based on experience with prototype. For all TCSP tropical cyclones, complete performance evaluation computations for observing platforms relative to each other, to the analysis, and to models. Compare model winds to analysis winds over an ensemble of cases from TCSP. Prepare journal articles describing observing system, analysis, and model performance, respectively.

BUDGET SUMMARY

For period from 2005 to 2006

		NASA USE ONLY	
	A	**B**	**C**
1. Direct Labor (salaries, wages, and fringe benefits)	236.6		
2. Other Direct Costs:			
a. Subcontracts			
b. Consultants			
c. Equipment	7.0		
d. Supplies	3.3		
e. Travel	5.0		
f. Other	6.0		
3. Indirect Costs*	112.9		
4. Other Applicable Costs			
5. SUBTOTAL--Estimated Costs	370.8		
6. Less Proposed Cost Sharing (if any)	192.8		
7. Carryover Funds (if any)			
a. Anticipated amount: _______			
b. Amount used to reduce budget			
8. Total Estimated Costs	178.0		XXXXXXX
9. APPROVED BUDGET	XXXXXX	XXXXXXX	

***Facilities and Administrative Costs.**

BUDGET SUMMARY

For period from 2006 to 2007

		NASA USE ONLY	
	A	**B**	**C**
1. Direct Labor (salaries, wages, and fringe benefits)	176.4		
2. Other Direct Costs:			
a. Subcontracts			
b. Consultants			
c. Equipment	1.0		
d. Supplies	0.4		
e. Travel	5.0		
f. Other	8.0		
3. Indirect Costs*	80.2		
4. Other Applicable Costs			
5. SUBTOTAL--Estimated Costs	271.0		
6. Less Proposed Cost Sharing (if any)	115.9		
7. Carryover Funds (if any)			
a. Anticipated amount: _______			
b. Amount used to reduce budget			
8. Total Estimated Costs	155.1		XXXXXXX
9. APPROVED BUDGET	XXXXXX	XXXXXXX	

***Facilities and Administrative Costs.**

BUDGET SUMMARY

For period from 2007 to 2008

	A	NASA USE ONLY B	NASA USE ONLY C
1. Direct Labor (salaries, wages, and fringe benefits)	188.2		
2. Other Direct Costs:			
a. Subcontracts			
b. Consultants			
c. Equipment	1.0		
d. Supplies	0.4		
e. Travel	5.0		
f. Other	8.0		
3. Indirect Costs*	86.1		
4. Other Applicable Costs			
5. SUBTOTAL--Estimated Costs	288.7		
6. Less Proposed Cost Sharing (if any)	122.9		
7. Carryover Funds (if any)			
a. Anticipated amount: _______			
b. Amount used to reduce budget			
8. Total Estimated Costs	165.8		XXXXXXX
9. APPROVED BUDGET	XXXXXX	XXXXXXX	

***Facilities and Administrative Costs.**

		Budget Year 1				Budget Year 2				Budget Year 3			
		NOAA		NASA		NOAA		NASA		NOAA		NASA	
		Cost Sharing		Requested		Cost Sharing		Requested		Cost Sharing		Requested	
		mm	Amount	mm	Amount	mm	Amount	mm	Amount	mm	Amount	mm	Amount
Personnel													
AOML	Powell	2.0	21.0			2.0	22.2			2.0	23.6		
AOML	Murillo		0.0	3.0	12.3		0.0	3.0	13.1		0.0	3.0	13.8
AOML	Dorst	3.0	17.7			3.0	18.7			3.0	19.8		
AOML	Soukup	8.0	55.0			2.0	14.6			2.0	14.6		
CIMAS	Dunion		0.0	2.0	9.6		0.0	2.0	10.2		0.0	2.0	10.8
CIMAS	Carrasco		0.0	4.0	14.4		0.0	4.0	15.3		0.0	4.0	16.2
CIMAS	Otero		0.0	6.0	27.0		0.0	4.0	19.1		0.0	4.0	20.2
CIMAS	Morisseau		0.0	3.0	24.6		0.0	2.0	17.4		0.0	2.0	18.4
CIMAS	St Fleur		0.0	3.0	4.3		0.0	4.0	6.1		0.0	4.0	6.5
Subtotal			93.6		92.2		55.5		81.1		58.0		86.0
Fringe Benefits	NOAA		23.4		3.1		14.4		3.4		15.7		3.7
	CIMAS		0.0		24.3		0.0		22.0		0.0		24.8
Total Salaries and Fringe Benefits			117.0		119.6		69.9		106.5		73.7		114.5
Indirect Costs	NOAA		75.8		10.0		46.0		10.8		49.2		11.7
	CIMAS		0.0		27.1		0.0		23.4		0.0		25.2
Total Labor Costs			192.8		156.7		115.9		140.7		122.9		151.4
Equipment			0.0		7.0		0.0		1.0		0.0		1.0
Supplies			0.0		3.3		0.0		0.4		0.0		0.4
Travel	Meetings		0.0		5.0		0.0		5.0		0.0		5.0
Other	Publications		0.0		0.0		0.0		2.0		0.0		2.0
	IT Infrastructure (hardware/software maintenance)		0.0		6.0		0.0		6.0		0.0		6.0
Total			192.8		178.0		115.9		155.1		122.9		165.8

Budget Justification:

1. Direct labor includes costs for near real-time kinematic analyses by experienced analysts during the TCSP field program. Also included are development costs for enhancements to H*Wind software to enable kinematic analysis, and the ability to super ob partially redundant observations. Further development costs will include analysis and design of the observation platform and evaluation system.

2c. Equipment costs include a low cost server to assist with data storage and additional disk space to handle storing model forecast and analysis fields.

2d. Software costs include a Matlab license with toolset for database connectivity.

2e. Travel costs will contribute to PI participation in conferences and visits for consultation with Dr. Kepert.

2f.. Other costs: Computer infrastructure costs of $6000 per year are requested to contribute to hardware and software maintenance. Costs of $2k in years 2 and 3 are for refereed journal publication charges.

3. Indirect costs use a rate of 64.8% (NOAA) and 26% (CIMAS/UM) with a projected increase of 1% a year for the NOAA rate.

6. Cost Sharing: Labor for the PI and some of the development and analysis costs is provided by NOAA.

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PhD, Meteorology, 1988 Florida State University,
MS, Meteorology, 1978 Pennsylvania State University,
BS, Meteorology, 1975 Florida State University

Professional Certification: AMS Certified Consulting Meteorologist (#475)

Employment: 1978 - present: Atmospheric scientist, NOAA Hurricane Research Division, AOML

Awards:
Department of Commerce Gold Medal, 1992 (Unit Award for performance in Hurricane Andrew)

Special Recognition Award, 1996: Scientific Operations Officer for the NOAA Olympic Marine Forecast Team

NOAATech 2000 Conference "Best JAVA Implementation Award", for "A distributed Real-time Hurricane Wind Analysis System."

NOAATech 2002 "Best Transition to Operations Award" to the H*Wind team.

Selected Refereed Journal Publications:

Powell, M.D., D. Bowman, D. Gilhousen, S. Murillo, N. Carrasco, and R. St. Fleur, 2004: Tropical Cyclone Winds at Landfall: The ASOS-CMAN Wind Exposure Documentation Project. Bull. Amer. Met. Soc., 85, in press.

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