Multi-platform Tropical Cyclone Surface Wind Analysis (MTCSWA) Blended Product

Presented by John Knaff

J. Dostalek (CIRA), L. Ma (OSPO)

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Outline

- Team Members and Affiliations
- Blended Product Development
- Identified Issues/Risks/Mitigations
- Future Algorithm Improvements
- Product Outreach
- Summary and Path Forward

MTCSWA Blended Product Team

Algorithm Team Members

Name	Organization	Major Task
John Knaff	STAR	Lead Developer
Liqun Ma	OSPO	Lead OSPO
Jack Dostalek	CIRA	Software/implementation support
ASSISTT	STAR	NDE implementation

Input Needs for the Blended Product Algorithm

- Blended Product Name: **MTCSWA**

Required Satellite and Ancillary Input Data Products

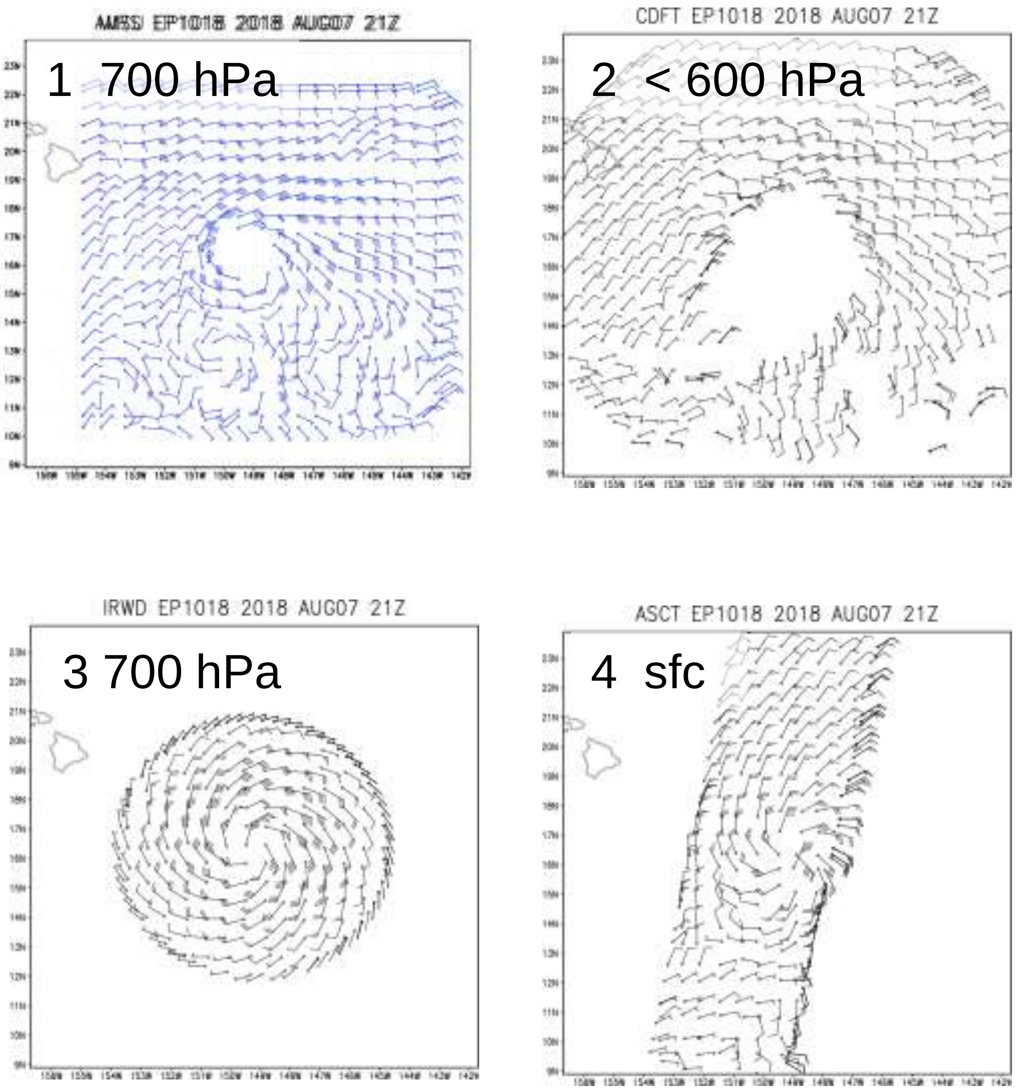
	Data Product Name (Inputs)	Input Data Type (Satellite/Model Forecasts/*In-situ*)	Temporal/ Spatial Resolution, Format	Source(s)
1	Wind Scatterometry	METOP-A/B	12-hrly/25 km	OSPO
2	Wind (850, 700 hPa) AMSU	MIRS Retrievals METOP-A/B, NOAA-18/19	12-hrly/50 km	OSPO
3	Wind (850, 700 hPa) ATMS	MIRS Retrievals SNPP	12-hrly/25 km	OSPO
4	IR-proxy-wind (700 hPa)	GOES-15/16, Metosat-8/11, Himawari-8	3-hrly/4 km x 10^o	OSPO
5	AMV winds	GOES -15/16	3-hrly/variable	OSPO
6	AMV winds	Himawari-8/Metosat	3-hrly/variable	Navy/OSPO
7	TC location/intensity	ATCF (text)	6-hrly	JTWC/NHC

MTCSWA Technical Approach

1. MTCSWA **blends four satellite-based wind estimates** compiled over 9 hours
   - **AMVs** below 600 hPa (NESDIS, EUMETSAT, JMA)
   - **AMSU/ATMS** – sounding based **winds** (solves the balance equations on pressure levels) (Bessho et al. 2007)
   - **Advanced Scatterometer**
   - **IR-Based flight-level proxy winds** (given intensity, motion and location estimates the 2-D wind field at 700 hPa) (Knaff et al. 2015, Mueller et al. 2006)

2. Technical Approach
   - Moves wind data to a **storm-motion-relative framework** valid at analysis time.
   - Adjust winds to a **common pressure level** (Franklin et al. 2003)
   - **Adjust for lack of frictional inflow** for surface winds (Zhang and Ehlhorn 2012)
   - A variational **data fitting** approach in polar coordinates
   - **Adjusts winds** to 10-m oceanic exposure or land (Franklin et al. 2003)
   - **Applies** appropriate frictional **inflow angles** (Zhang and Ehlhorn 2012).

Input data



1. Microwave Sounder – based winds (Bessho et al. 2006)
2. Atmospheric Motion Vectors
3. IR-based flight-level proxy winds (Knaff et al. 2015)
4. Scatterometery

Special treatment of A-SCAT wind speeds

A hurricane specific bias correction is applied to A-SCAT data based on Chou et al (2013).

Results based on collocated dropwindsonde observations

Increases observed winds, especially above 17.5 ms^{-1} (35 kt)

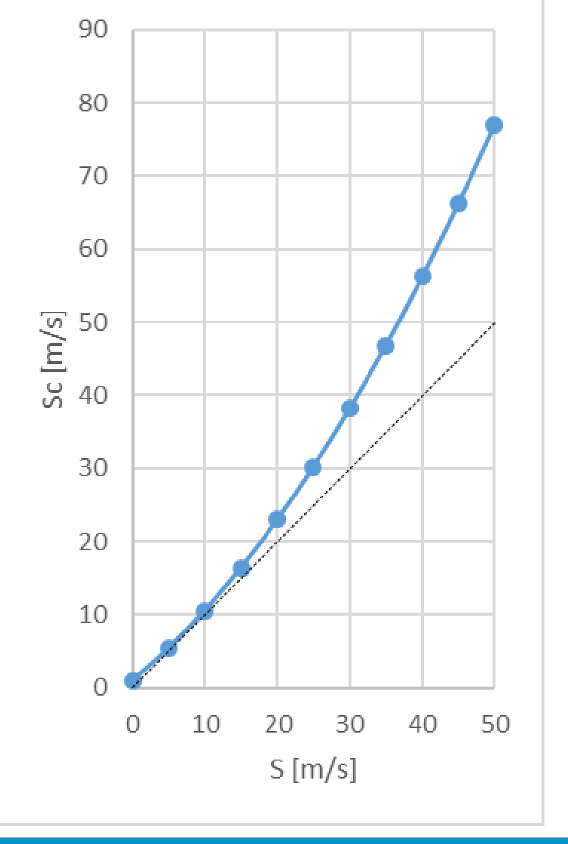
Form of the bias correction

S ≡ observed A-SCAT wind speed

S_c ≡ bias corrected A-SCAT wind speed,

Where S has units of ms^{-1}

$$S_c = 0.014S^2 + 0.821S + 0.961$$



A motion-relative/common level framework

INPUTS:

1. Current position and intensity (ATCF)
2. Past position and intensity (ATCF)
3. Forecast Position/Intensity, if available
4. Observed and Proxy winds (last 9 hours)

PROCEEDURE:

1. Spline Latitude (t)
2. Spline Longitude (t)
3. Move observations from their observed time to the analysis time using these estimates for positions
4. Calculate r, ϴ coordinates based on the analysis center
5. Bias correct ASCT
6. Adjust winds/inflow angles to a common analysis level (700 hPa)

RESULT:

Observations (9h worth) are in a motion relative framework
Observations on a polar grid
Observations at a common level (gradient level/ 700 hPa)

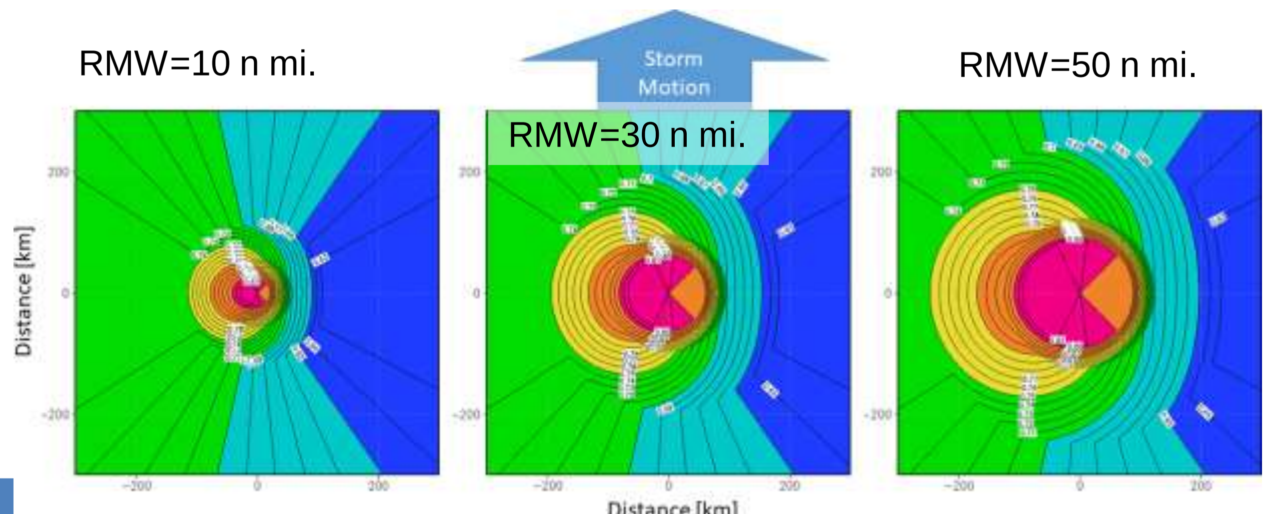
These are ready for blending in the analysis

Adjusting winds to common levels (speed)

- Algorithm is based on the findings of Franklin et al. (2003) who defined reductions to the surface in two regions and four pressure layers.
  1. Eyewall (within 2 * RMW)
  2. Outer vortex
  3. There is also 4% and 17% differences as a function of azimuth in Eyewall and outer regions

Level (hPa)	Eyewall	Outer Vortex
600-800	0.88	0.83
800-900	0.78	0.78
900-990	0.73	0.73
990-Sfc	0.77	0.77

Examples: Reduction Factors (R) from 700 hPa



$R < 0.65$ | $0.75 \leq R < 0.80$
$0.65 \leq R < 0.70$ | $0.80 \leq R < 0.85$
$0.70 \leq R < 0.75$ | $R > 0.85$

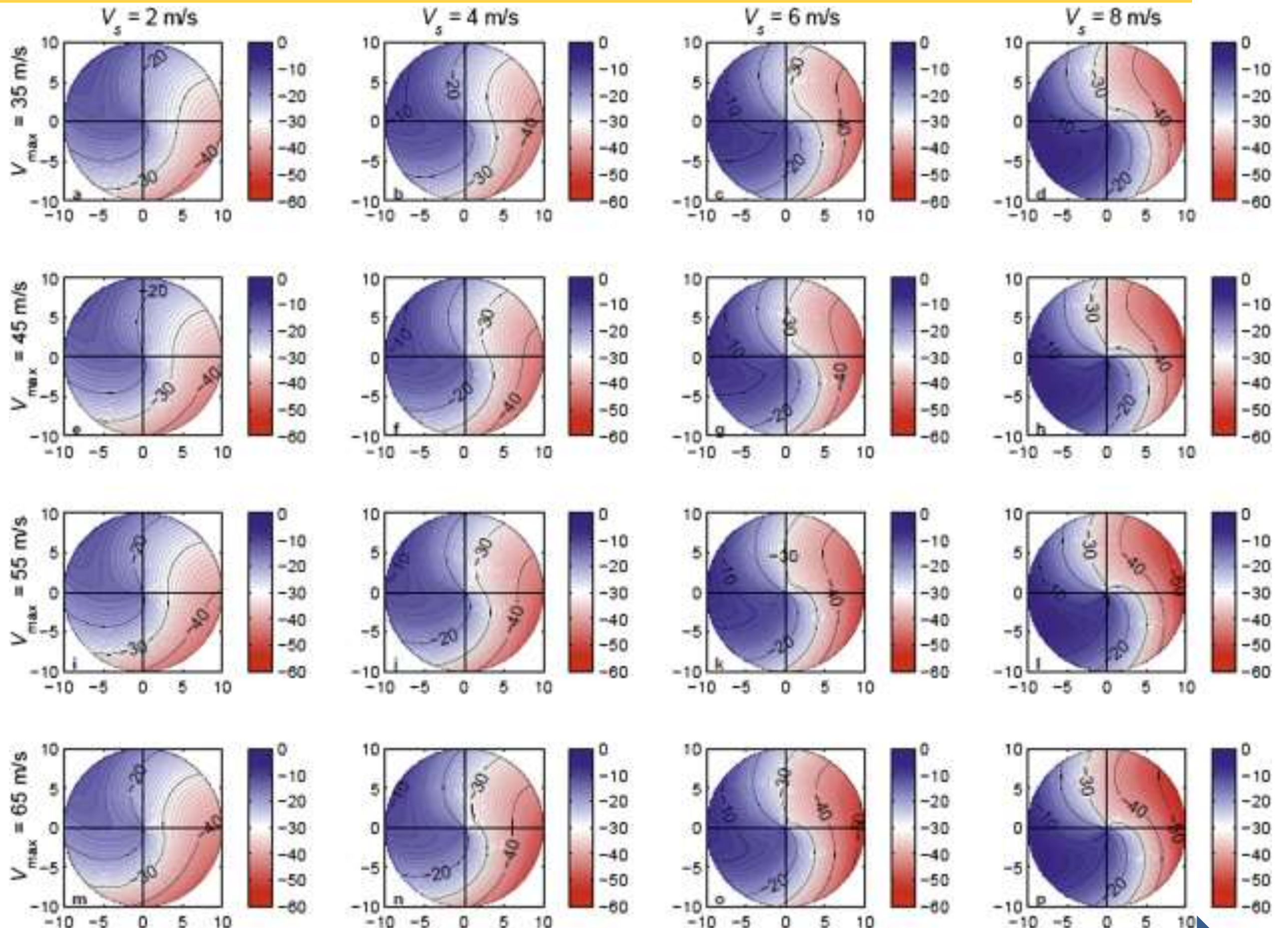
This algorithm allows for
1. **Adjustment of the wind speeds to a common level**
2. **Adjustment from the analysis level to the surface following analysis**

Adjusting winds to common levels (angles)

- Algorithm is based on the findings of Zhang and Ehlhorn (2012) who developed a parameterization for surface inflow angles in hurricanes as a function of radius, translation speed, and intensity

Storm motion

- Intensity +



(slower) Translation Speed (Faster)

This algorithm allows for

1. **Adjustment of the inflow angles from the surface to a common level**
2. **Estimation of surface inflow angles for analyzed wind speeds adjusted to the surface**

The Analysis Scheme

- Based on Thacker (1988) – a data fitting method
- Variational (Minimize *C*)
- Data fitting
- Allows for scalar wind estimates
- Allows for weighting of observation types
- Has adjustable filter weights (r, ϴ)
- On a polar grid 4.5 km x 10^o (i.e., Makes circles rather than squares)
- Solved iteratively via steepest decent

$$C = \frac{1}{2}\sum_{k=1}^{K} w_k\left[(u_k - U_k)^2 + (v_k - V_k)^2 \right]$$

Wind vectors Measures misfit

$$+ \sum_{m=1}^{M} w_m (s_m - S_m)^2$$

Wind speeds Measures misfit

$$+ \sum_{i=1}^{I}\sum_{j=1}^{J} \left\{ \begin{array}{l} \alpha\left[(\delta_{xx}U_{ij})^2 + (\delta_{xx}V_{ij})^2\right] \\ + \beta\left[(\delta_{yy}U_{ij})^2 + (\delta_{yy}V_{ij})^2\right] \end{array} \right\}$$

Penalty term Acts as a filter

$$\delta_{xx}U_{ij} = (U_{i+1,j} + U_{i-1,j} - 2U_{ij}) / \Delta x^2$$

$$\delta_{yy}V_{ij} = (V_{i+1,j} + V_{i-1,j} - 2V_{ij}) / \Delta y^2$$

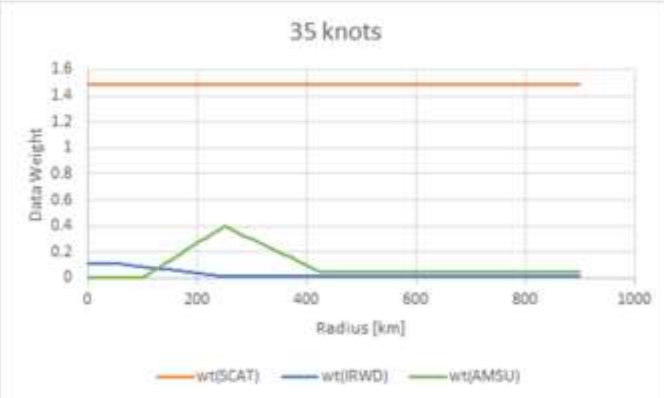
Filter weights	Data weights
α	w_k
β	w_m

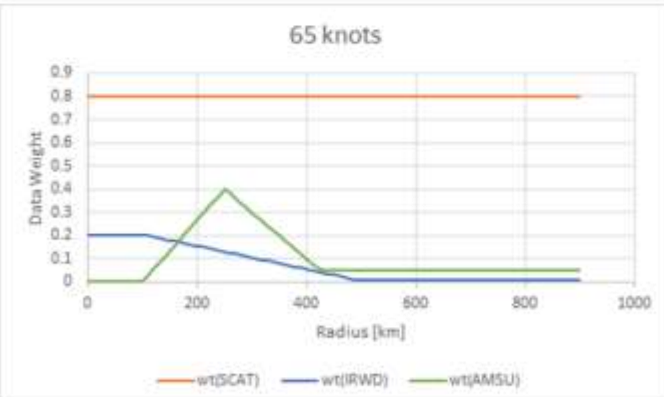
response function F (k) of the filter weights

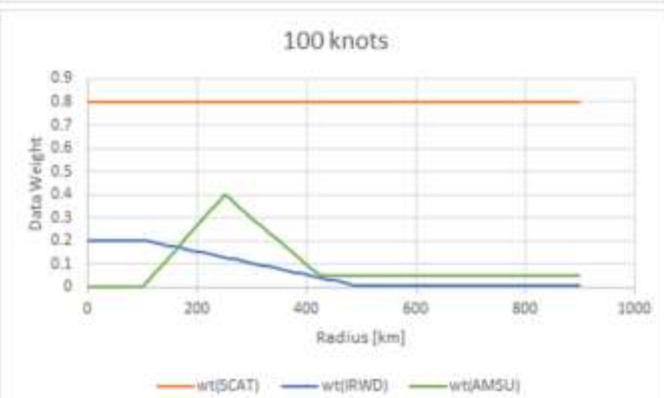
$$F(k) = 1/\{1 + 8\alpha[1 - \cos(k\Delta x)]^2\}$$

Where x can be r or θ and α = β

Data weights







To help overcome the shortcomings of each input data weights are used to weight data selectively as a function of radius, current intensity and data type.

- Weights were tuned using aircraft-based analyses
- Weights are a function of intensity
- Weights are a function of the number of points in the analysis.

AMVs weights = 5.0 for all intensities

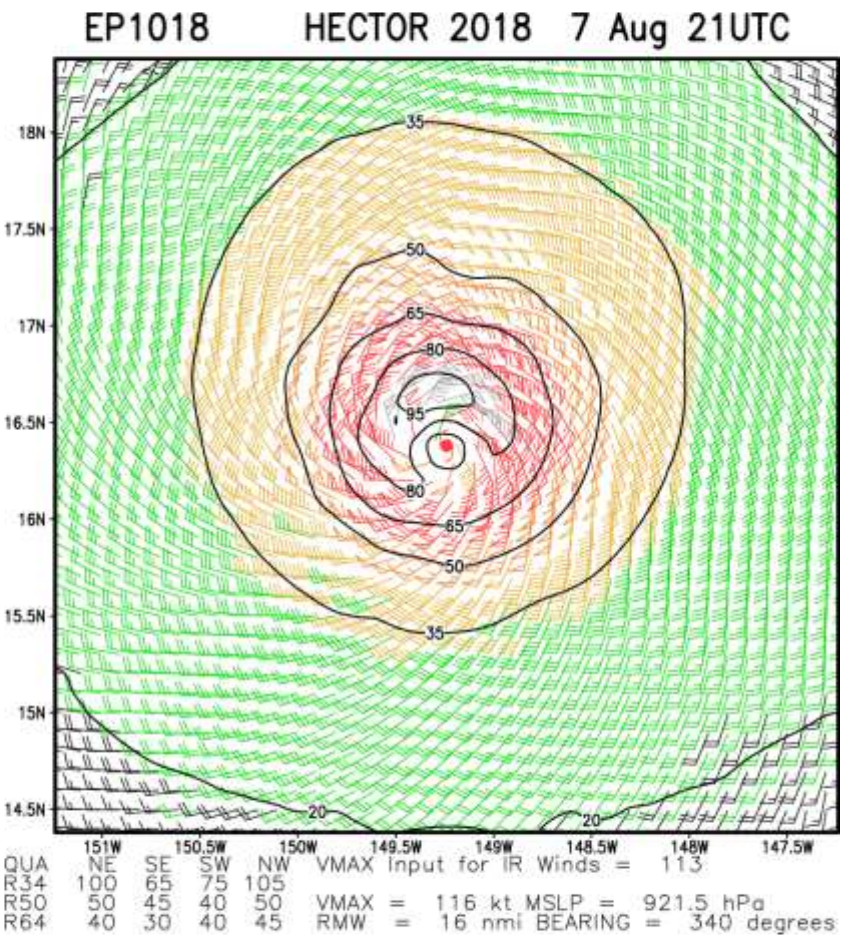
MTCSWA Examples/Outputs

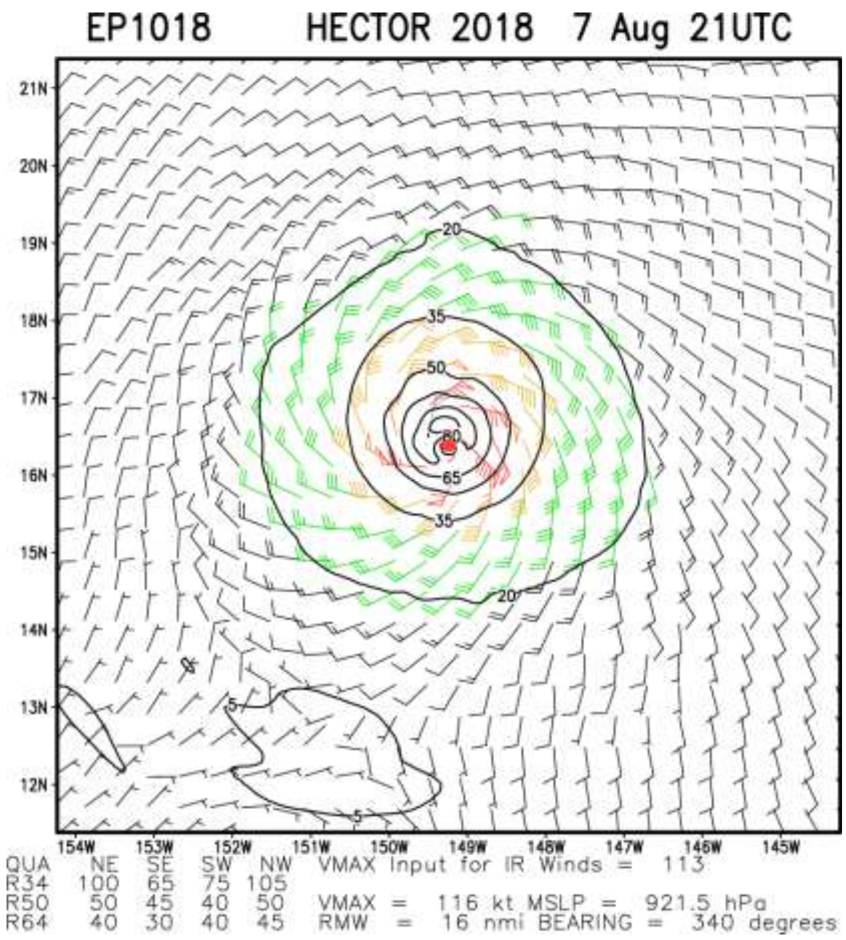
Output Data Products

	Blended Data Product Name (Outputs)	Output Data Type (Satellite; Model Forecasts; In-situ)	Spatial, Temporal Resolution, Format	Source(s)
1	TC Surface Wind Analysis	GOES/Met-op/Metosat/POES/SNPP/H8	10km, 3-hourly, NETCDF	STAR Enterprise NDE
2	TC ATCF-Fix	GOES/Met-op/Metosat/POES/SNPP/H8	Wind Radii, RMW, MSLP, 3-hourly, ASCII	STAR Enterprise NDE

MTCSWA Examples/Outputs

Output Data Products





MTCSWA Examples/Outputs

Output Data Products

ATCF Fix

EP, 10, 201808072100, 70, ANAL, PR, , **1638N, 14924W**, 10 , 2, , 2, **922**, 2, MEAS, **34, NEQ, 100, 65, 75, 105**, , , , , 2, 16, , E, CIRA, MPS, MPS, 201808070900, 201808080046, , , AMSU CD WV IR ASCT , CIRA Combined Multi-Platform Satellite Analysis

EP, 10, 201808072100, 70, ANAL, PR, , **1638N, 14924W**, 10 , 2, , 2, **922,** 2, MEAS, **50, NEQ, 50, 45, 40, 50**, , , , , 2, 16, , E, CIRA, MPS, MPS, 201808070900, 201808080046, , , AMSU CD WV IR ASCT , CIRA Combined Multi-Platform Satellite Analysis

EP, 10, 201808072100, 70, ANAL, PR, , **1638N, 14924W**, 10 , 2, , 2**, 922**, 2, MEAS, **64, NEQ, 40, 30, 40, 45**, , , , , 2, 16, , E, CIRA, MPS, MPS, 201808070900, 201808080046, , , AMSU CD WV IR ASCT , CIRA Combined Multi-Platform Satellite Analysis

Product Evaluation/Validation/Tools

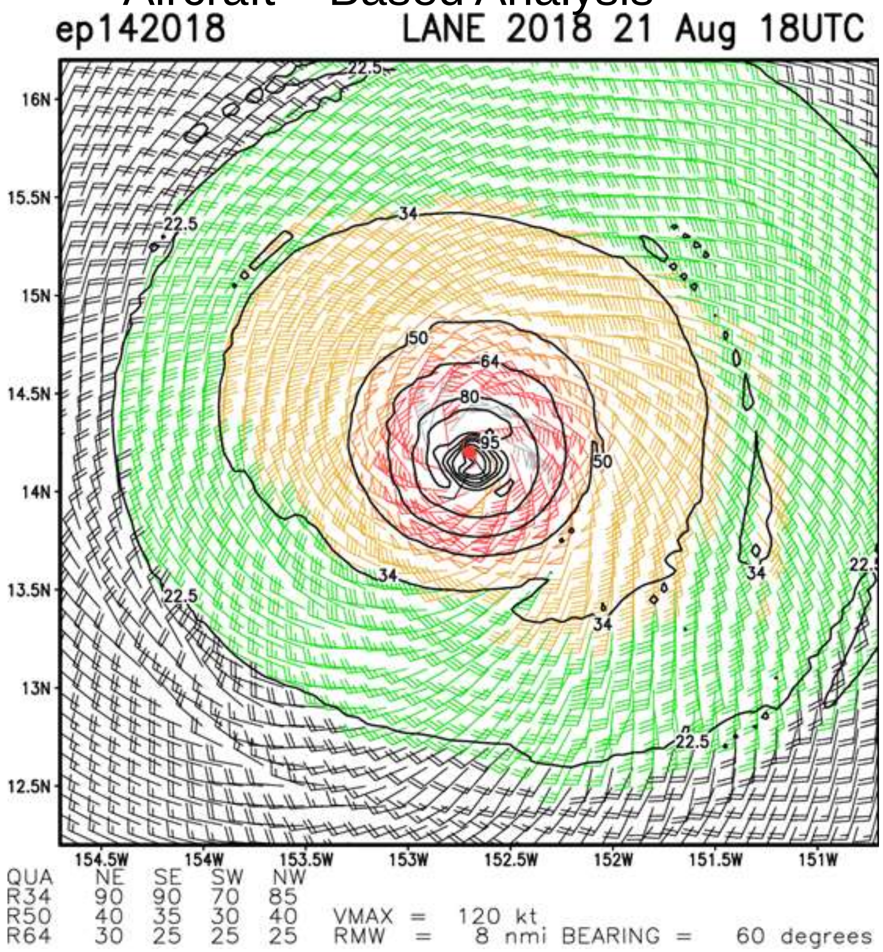
- Product Evaluation/Validation
  - Initial validation and training was based on aircraft-based H*Wind (Powell et al. 1998) surface wind analyses
  - Current evaluation is based on an in-house aircraft-based surface wind analysis developed for the Joint Hurricane Testbed and final best track estimates or 34-, 50- and 64-kt winds.

- Validation show that the largest errors (~ 5 ms-1) are in the vicinity the radius of maximum winds. Elsewhere errors are typically less than 2 ms^{-1}

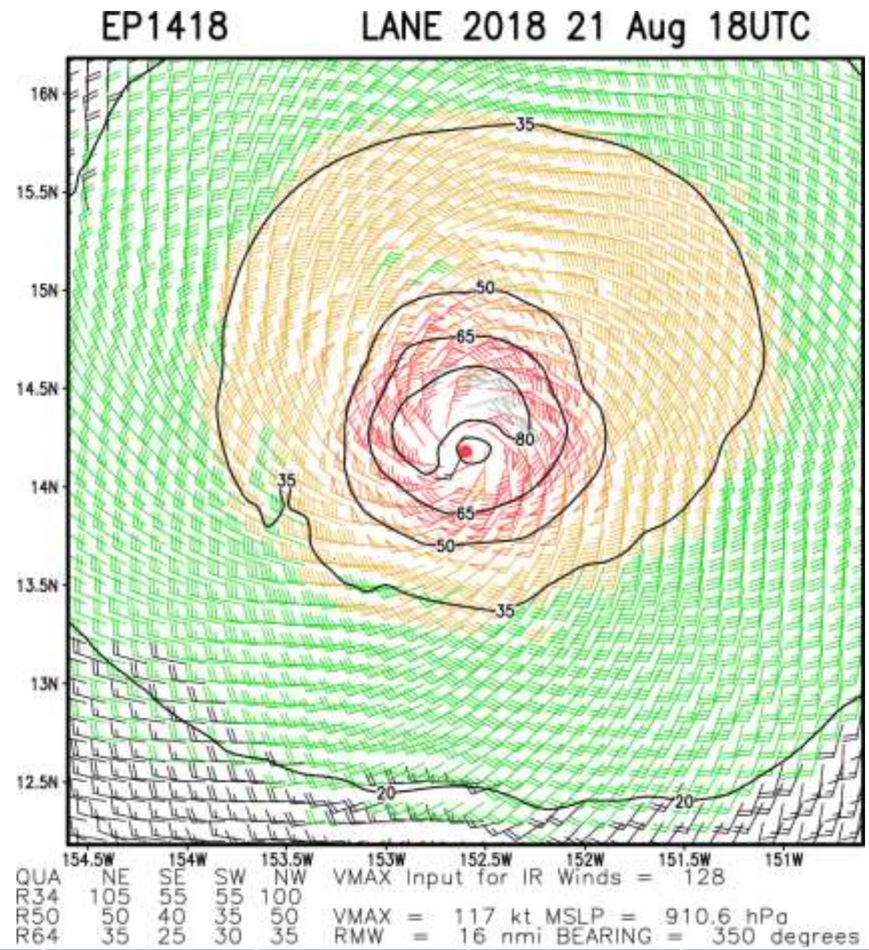
Recent example Hurricane Lane (next slide)

Hurricane Lane (small, compact, and intense)

Aircraft – Based Analysis



MTCSWA



Working Best Track

Vmax = 135 kt

CP = 941 hPa

RMW = 20 nmi.

	NE	SE	SW	NW
R34	110	95	50	120
R50	70	40	30	80
R64	35	25	25	30

MTCSWA Implementation Status

- Implementation
  - Previous version running at NSOF (degraded)
  - This version is running experimentally at CIRA
  - Planned in late 2018.
  - ATCF fix files are already getting to NHC, CPHC and JTWC
  - NetCDF output should help with use on AWIPS-II, ATCF
- Will be run on NDE
- Help coming from ASSISTT

Identified Issues/Risks/Mitigations

Identified Risk/Issues	Action/Mitigation
Transition to operations (NDE)	Working with ASSISTT personnel
Himawari access	Plans for moving to operations
Failure of ASCAT	None
Metop-C products replacing A	Plans for moving to operations

Future Algorithm Improvements

- Improvements
  - Incorporation of ASCAT from Metop-C
  - Possible use of SMAP and SMOS winds (experimental)
  - Improved estimation of radius of maximum winds from satellite (ongoing work)
  - Work to improve central pressure estimates in intense storms.
- Future Validation Plans
  - Continue to use aircraft-based data for inner core
  - SMAP and SMOS wind speeds and TROPICS non-linear balance winds as independent assessment of outer winds

Summary and Path Forward

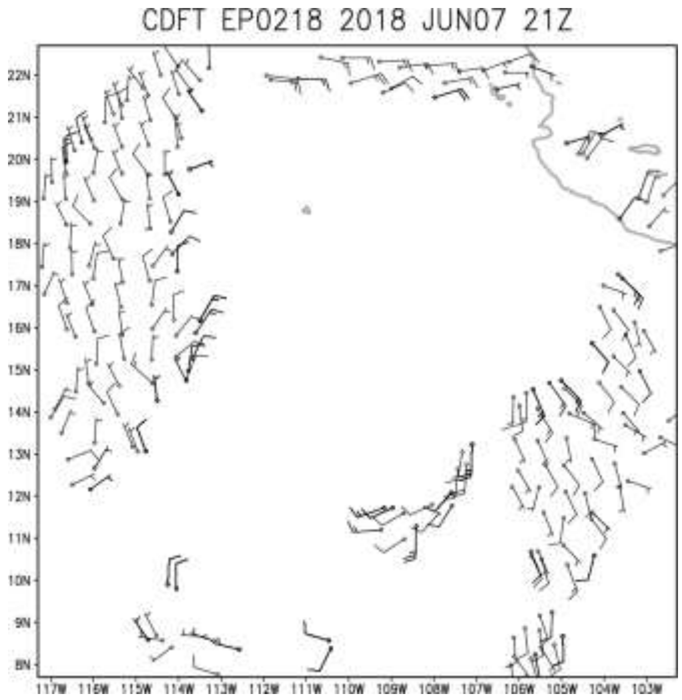
- MTCSWA provides **unique** and important information regarding the **real-time surface wind structure** in **global** tropical cyclone
- The **satellite-only-based** information provides key information in regions where routine aircraft reconnaissance is not performed
- Surface wind structure estimates support NWP (e.g., Bender et al. 2017), wind probabilities, watch/warnings, and wave forecasts (various methods) and thus impact TC impacts and forecasts.

Path Forward:

1. Get these updates in operations
   - mitigate the GOES-16 and soon GOES-17 degradation
   - Improved known shortcomings of the legacy analyses.
2. Continue to improve the inputs and methodology as part of StAR base or other funding opportunities

Backup Slides

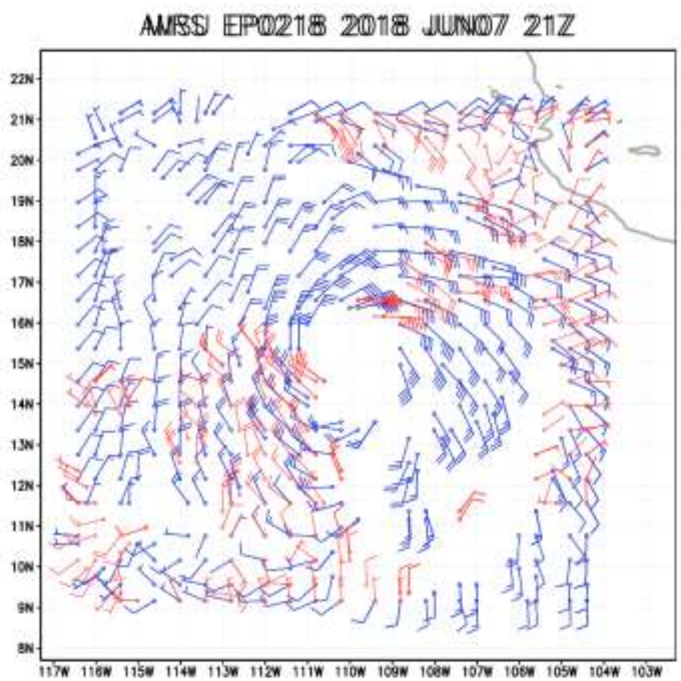
Input 1: AMVs



- Source (NESDIS & US Navy)
- All AMVs below 600 hPa (IR, Vis,WV)
- Each data point is compiled in a storm-motion relative framework valid at the analysis time
- Each are adjusted to 700 hPa as a function of pressure, azimuth and radius
- Provides environmental winds

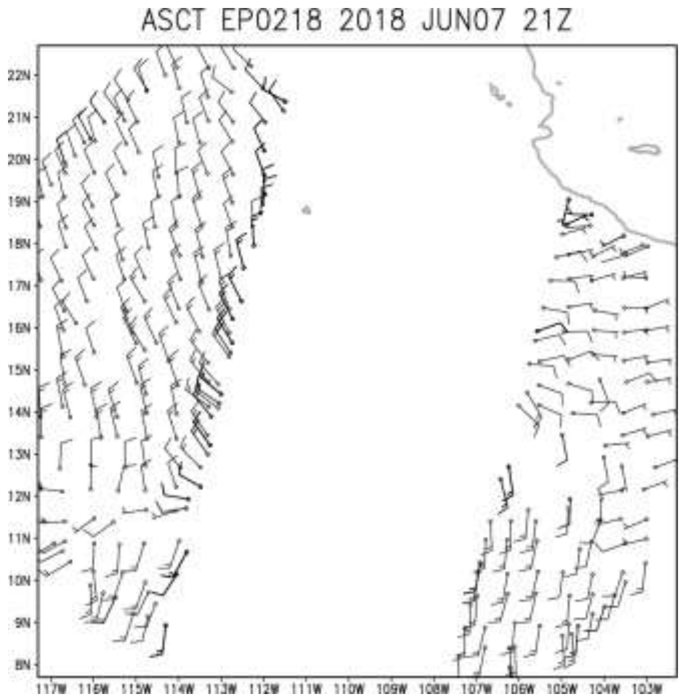
Input 2: AMSU/ATMS Sounder-based winds

Statistical
MIRS



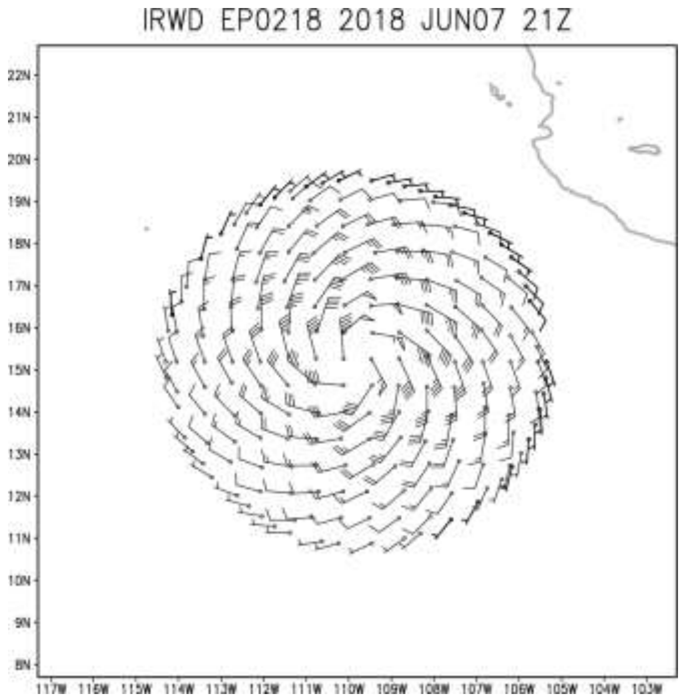
- Method of Bessho et al. (2006) that solves the non-linear balance equations on pressure surfaces
- Winds are compiled in a motion relative framework
- Winds are adjusted to 700 hPa
- By product of the Hurricane Intensity and Structure Algorithm (HISA)
- Statistical (NCEP) and MIRS (OSPO) based inputs
- Provides asymmetries r=200 - 400

Input 3: A-Scat



- Source: OSPO MCADDE server
- Winds are compiled in a motion relative framework
- Winds are adjusted to 700 hPa, speed (Franklin et al. 2003), angles (Zhang and Uhlhorn 2012), bias (Chou et al. 2013)
- Provides environmental and near core winds, when availalbe

Input 4: IR-based flight-level proxy winds



- Winds are based on the algorithm discussed in Knaff et al. (2015) that related intensity, motion and IR patterns to the flight level winds (wavenumbers 0-2)
- Winds are compiled in a motion relative framework
- Winds are adjusted to 700 hPa as a function of pressure, azimuth and radius
- Provides winds near the core and the radius of maximum winds

References used in this talk

Bessho, K., M. DeMaria, and J. A. Knaff, 2006: Tropical Cyclone Wind Retrievals from the Advanced Microwave Sounder Unit (AMSU): Application to Surface Wind Analysis. *J. of Applied Meteorology.* **45**(3), 399-415.

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Thacker, W. C., 1988: Fitting models to inadequate data by enforcing spatial and temporal smoothness. *J. Geophys. Res.*, **93**(C9), 10655–10665, doi: 10.1029/JC093iC09p10655.

Zhang, J.A. and E.W. Uhlhorn, 2012: Hurricane Sea Surface Inflow Angle and an Observation-Based Parametric Model. *Mon. Wea. Rev.,* **140**, 3587–3605, https://doi.org/10.1175/MWR-D-11-00339.1

Importance/Benefits/Users

- In tropical cyclone regions without routine aircraft reconnaissance the surface wind estimates efficiently provide critical information about the surface wind structure associated with TCs.
  - Initial wind structure estimates influence watch/warning, TC conditions of readiness
  - Initial wind structure estimates are provided to NWP
  - Initial wind structure influence output of the wind speed probability product, which are inputs to watch/warning and significant wave height guidance
- No current funding for maintenance or future development (out of hide)

Name	Organization	Application	User Feedback
Mark Demaria	NHC	Wind Radii Estimation	Experimental and older operational versions fixes in ATCF Viewed on web-site
Brian Strahl	JTWC	Wind Radii Estimation	Older operational versions in fixes at JTWC Technical exchange occurring this week. Viewed on web-site

Documentation/website links

(Provide this information in your back-up slides)

- For experimental products
  http://rammb.cira.colostate.edu/products/tc_realtime/
- For legacy/operational product (degraded)
  http://www.ssd.noaa.gov/PS/TROP/mtcswa.html

Output Product(s) Specifications

- Blended Product Name: **MTCSWA**
- Output Data Type(s): Wind (netCDF), ATCF-fix (ASCII)

Output Product(s) Attributes	Threshold	Observed/validated
Latency	1h	35m
Geographic coverage	Global	Global
Vertical Coverage	N/A	N/A
Vertical Cell Size	N/A	N/A
Horizontal Cell Size	10 km	10 km
Mapping Uncertainty	50km	~20 km
Measurement Range	0-100 m/s	0-75 m/s
Measurement Accuracy	5 m/s	5 m/s
Measurement Precision	5 m/s	5 m/s
Measurement Uncertainty	5 m/s	5 m/s