

Hurricane Imaging Radiometer (HIRAD) Wind Speed Retrievals and Assessment Using Dropsondes

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Tropical Meteorology*

Acknowledgments

- Funding from Office of Naval Research Tropical Cyclone Intensity (TCI) program
- HDSS dropsonde data from Yankee Environmental Systems (YES), quality-controlled by Michael Bell and TCI colleagues
- Idealized model output provided by Dave Nolan

HIRAD (Hurricane Imaging Radiometer)

NASA MSFC Earth Science Office

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Objectives:

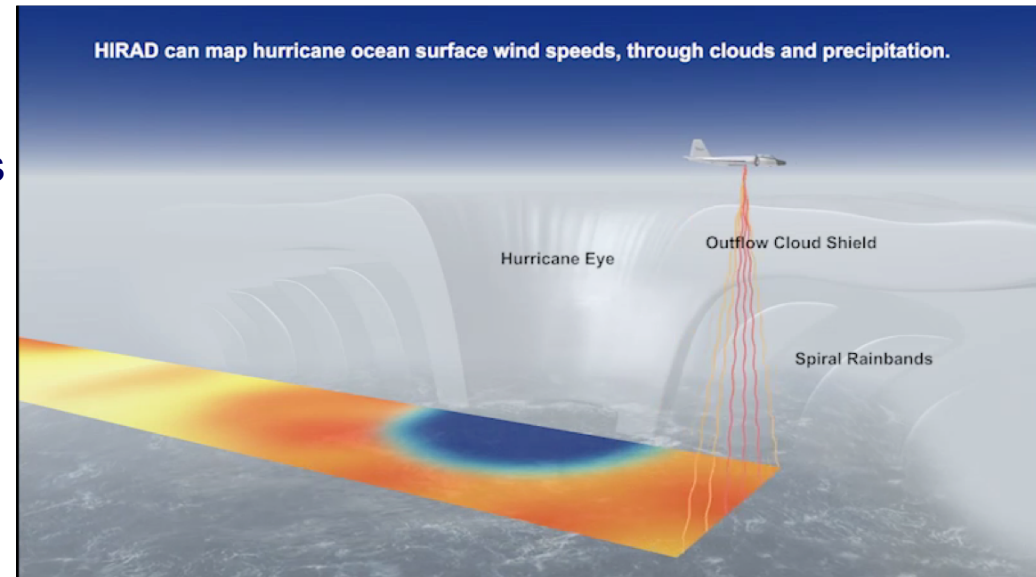
- Map surface wind speed *over wide swath* (~50 km, for aircraft > FL600) in hurricanes
- Provide research data for understanding hurricane structure, intensity change
- Enable improved predictions, decision support

Technical Approach:

- Retrieval approach similar to operational SFMR (C-band frequencies respond to foam on ocean surface), but HIRAD adds wide swath instead of nadir trace
- Stronger wind -> more foam -> warmer brightness temperatures
- Minimum detectable wind speed ~30 kt (below tropical storm force; ~ 15 m s⁻¹)

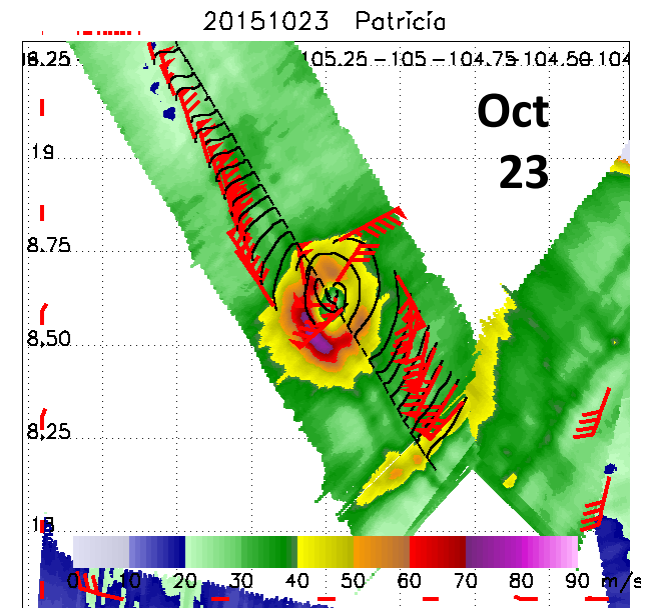
Future Goals:

- Upgrade to add wind direction
- More robust 2nd-generation instrument(s)



Hurricane Patricia (2015) at Cat 5 intensity, with dropsonde wind barbs overlaid.

For a small storm like Patricia, one aircraft pass maps the entire eyewall.



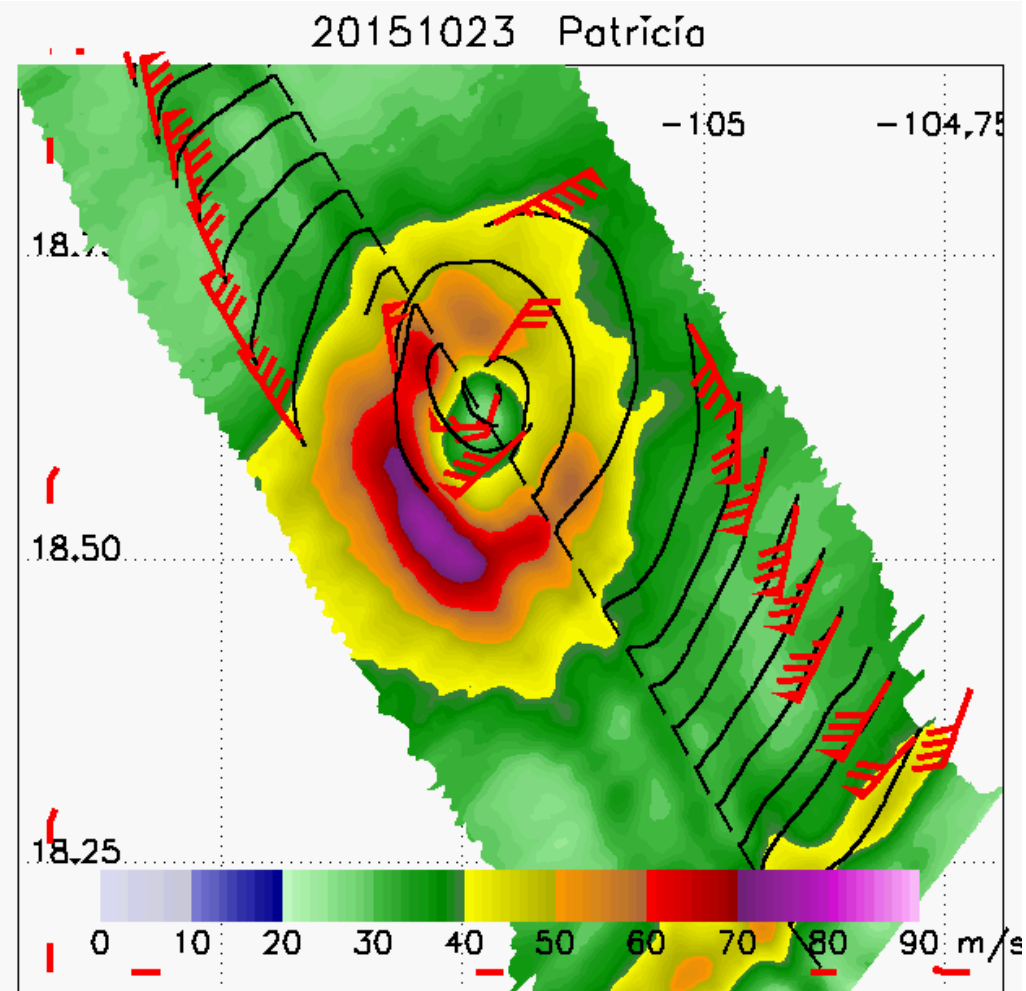
Tropical Cyclone Intensity (TCI) Experiment

■ TCI

- Sponsored by Office of Naval Research
- HIRAD and High Density Sounding System (HDSS) on NASA WB-57 in 2015
- Hurricanes Joaquin, Patricia, Marty, and remnants of TS Erika
- Aircraft based in Houston, but forward-deployed to Warner-Robins, GA for half the flights and Harlingen, TX for half the flights
- Datasets available through NCAR EOL archive

■ This presentation:

- Quantitatively compare HIRAD retrievals to ~600 point estimates of surface wind speed, based on HDSS dropsondes
- Dropsonde surface wind speed estimated from WL150 or MBL, following Uhlhorn et al. 2007 and Franklin et al. 2003

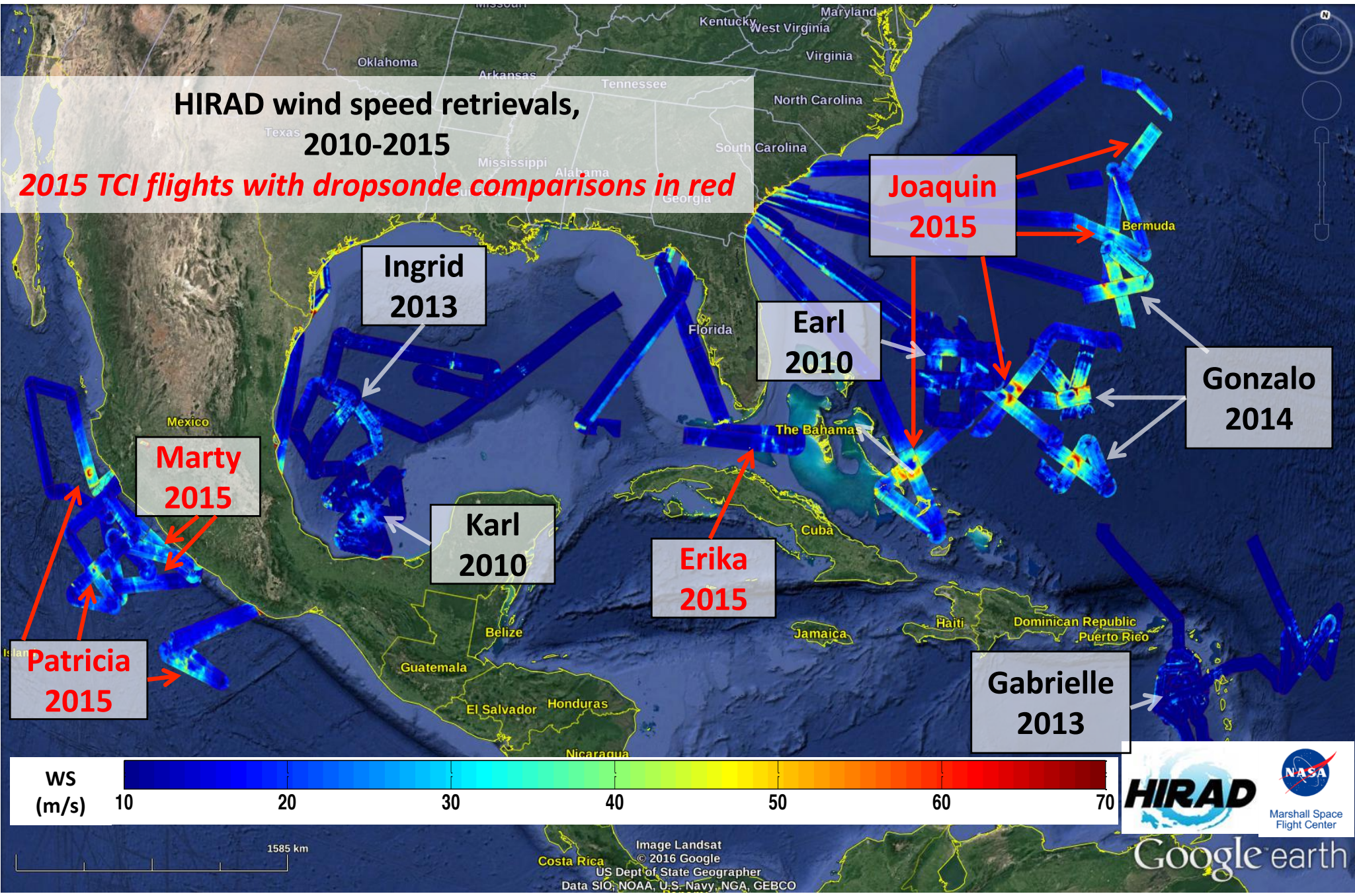


Hurricane Patricia (2015) at Cat 5 intensity, with dropsonde wind barbs overlaid.

For a small storm like Patricia, one aircraft pass maps the entire eyewall.

HIRAD wind speed retrievals, 2010-2015

2015 TCI flights with dropsonde comparisons in red



**Marty
2015**

**Ingrid
2013**

**Karl
2010**

**Erika
2015**

**Earl
2010**

**Joaquin
2015**

**Gonzalo
2014**

**Patricia
2015**

**Gabrielle
2013**

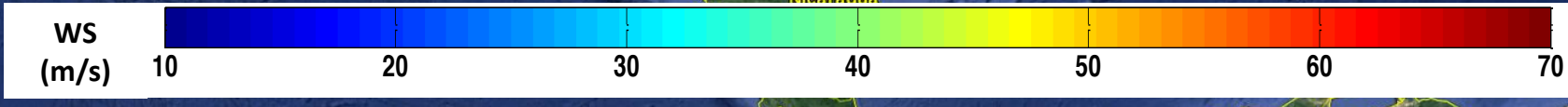
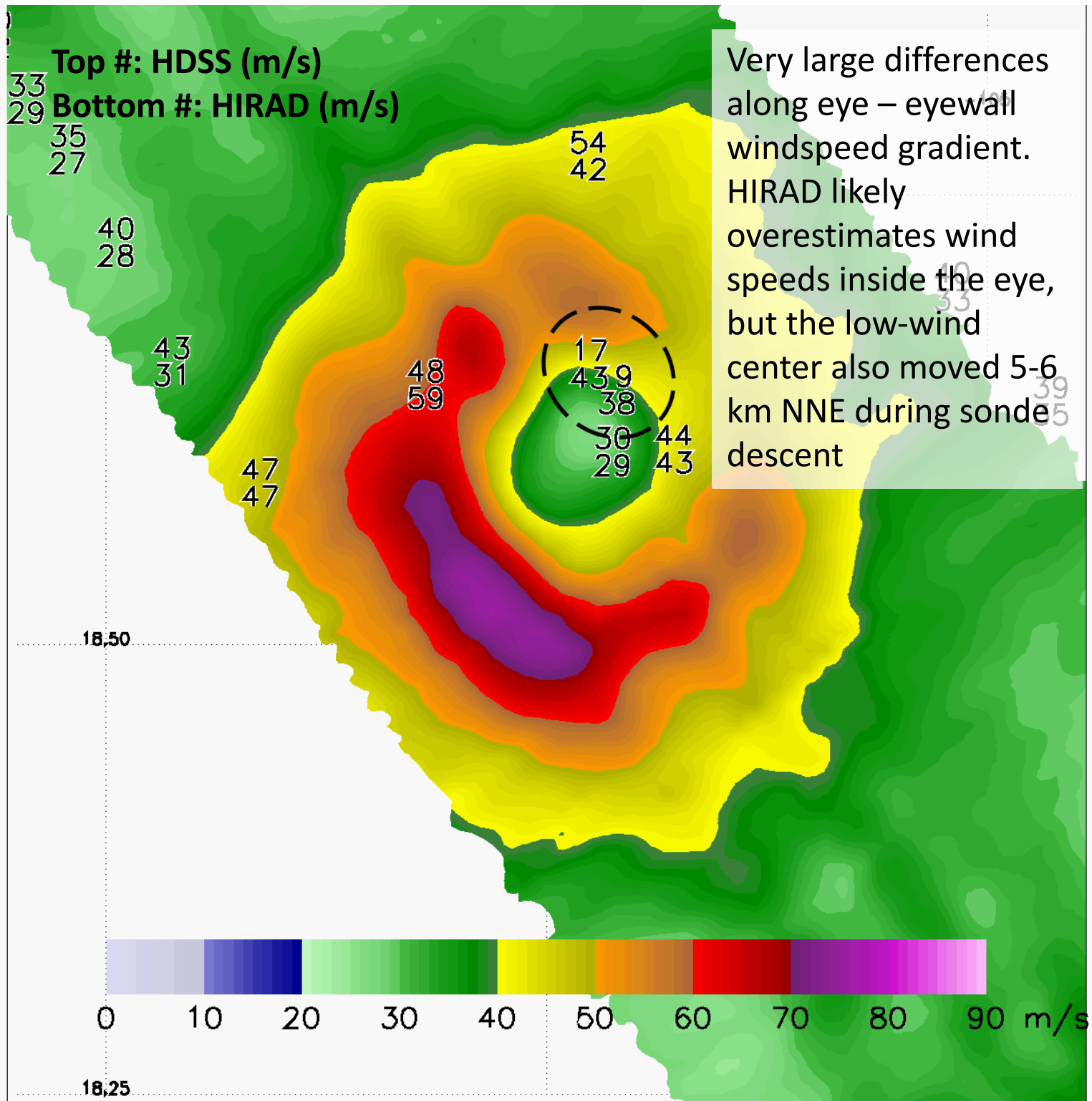


Image Landsat © 2016 Google
US Dept of State Geographer
Data SIO, NOAA, U.S. Navy, NGA, GEBCO



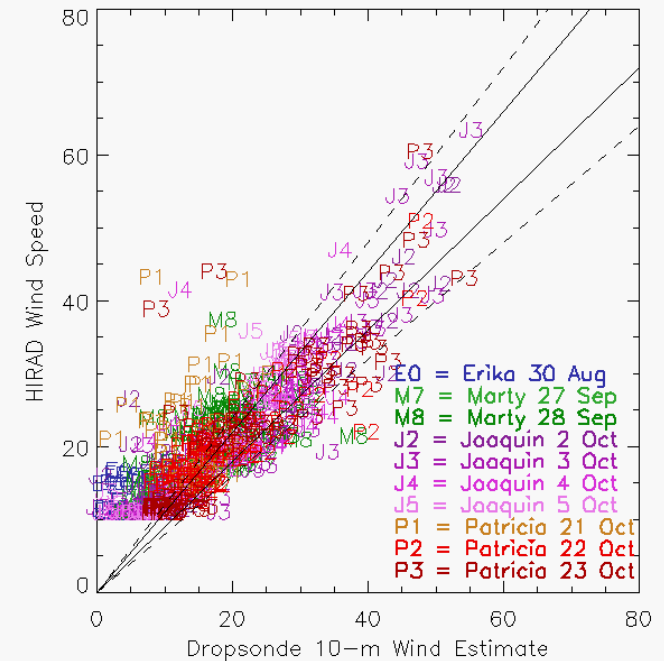
Point-by-point comparisons of surface wind speed using 636 sondes.

Adjusted wind to surface using WL150 or MBL, following Uhlhorn et al. 2007 and Franklin et al. 2003

Did not account for storm moving a few km during 10-15 minute dropsonde descent

HIRAD – HDSS Differences by Flight

HIRAD Wind Speed	Sample size	Bias (m s^{-1})		RMSD (m s^{-1})		MAD (m s^{-1})	
Post-Erika 30 Aug	46	5.7	47%	6.7	54%	5.7	47%
TS Marty 27 Sep	50	2.0	13%	4.4	28%	3.8	24%
Hurricane Marty 28 Sep	68	1.7	8%	5.8	28%	4.4	22%
Hurricane Joaquin 02 Oct	73	1.6	12%	5.7	30%	4.2	23%
Hurricane Joaquin 03 Oct	64	-0.1	2%	5.8	34%	4.7	26%
Hurricane Joaquin 04 Oct	73	0.0	2%	5.8	29%	4.0	21%
Hurricane Joaquin 05 Oct	65	2.5	17%	4.2	30%	3.1	20%
TS Patricia 21 Oct	57	5.5	21%	9.4	36%	6.5	28%
Hurricane Patricia 22 Oct	71	0.0	0%	4.4	23%	3.4	18%
Hurricane Patricia 23 Oct	69	-0.4	-3%	6.7	23%	4.1	17%
All	636	1.6	11%	6.0	31%	4.3	24%
<i>Excluding 30 Aug, 21 Oct</i>	<i>533</i>	<i>0.9</i>	<i>6%</i>	<i>5.4</i>	<i>28%</i>	<i>4.0</i>	<i>21%</i>



Most flights had bias $< 2 \text{ m s}^{-1}$

Erika and Patricia (21 Oct, during TS stage) had larger biases than the other flights

Also a few large outliers from eye-eyewall windspeed gradient in Patricia (23) and Joaquin (04)

HIRAD – HDSS Differences by Wind Speed

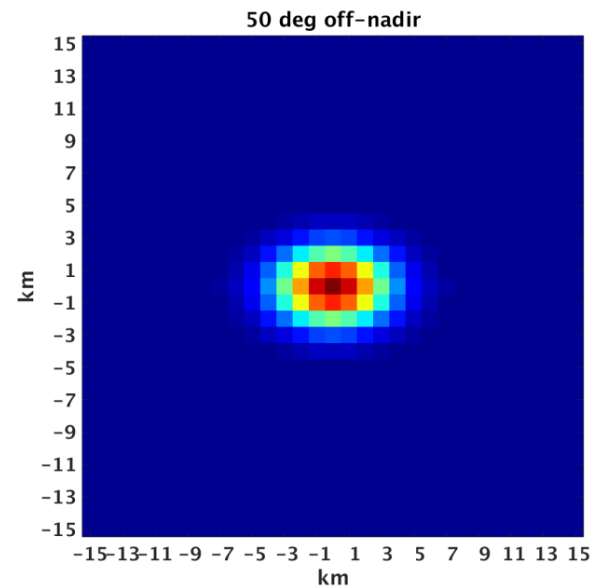
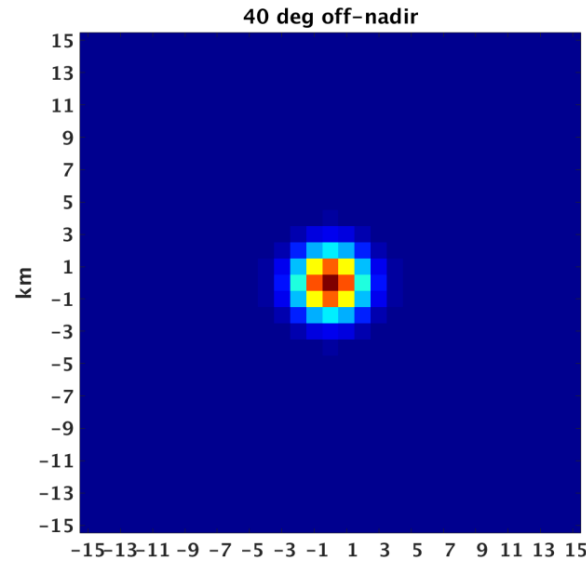
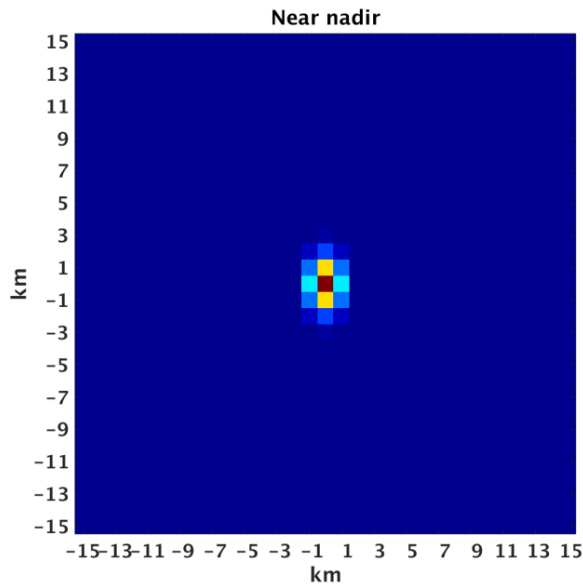
Using 636 sondes from 10 flights

HIRAD Wind Speed	Sample size	Bias (m s^{-1})		RMSE (m s^{-1})		MAD (m s^{-1})	
< TS: < 17.5 m s^{-1}	304	2.2	18%	4.5	36%	3.5	27%
TS: $17.5 - 33.0 \text{ m s}^{-1}$	279	0.8	3%	6.2	27%	4.7	21%
Hurricane: > 33.0 m s^{-1}	53	3.2	7%	10.7	26%	7.2	18%
<i>All</i>	<i>636</i>	<i>1.6</i>	<i>11%</i>	<i>6.0</i>	<i>31%</i>	<i>4.3</i>	<i>24%</i>

Omitting Erika, TS Patricia 21 Oct, and 3 dubious points from eye-eyewall gradient

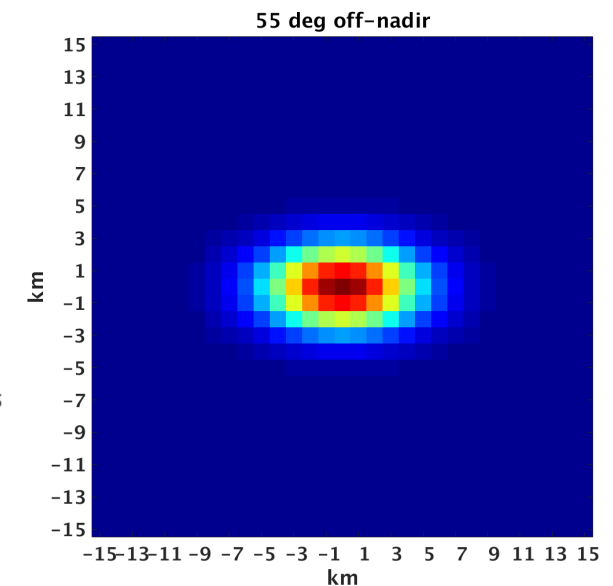
HIRAD Wind Speed	Sample size	Bias (m s^{-1})		RMSE (m s^{-1})		MAD (m s^{-1})	
< TS: < 17.5 m s^{-1}	235	1.7	14%	4.1	33%	3.2	25%
TS: $17.5 - 33.0 \text{ m s}^{-1}$	248	-0.1	-1%	5.6	25%	4.3	19%
Hurricane: > 33.0 m s^{-1}	47	0.3	0%	6.3	16%	4.8	12%

Effects of footprint size



Antenna Pattern Smoothing Weights

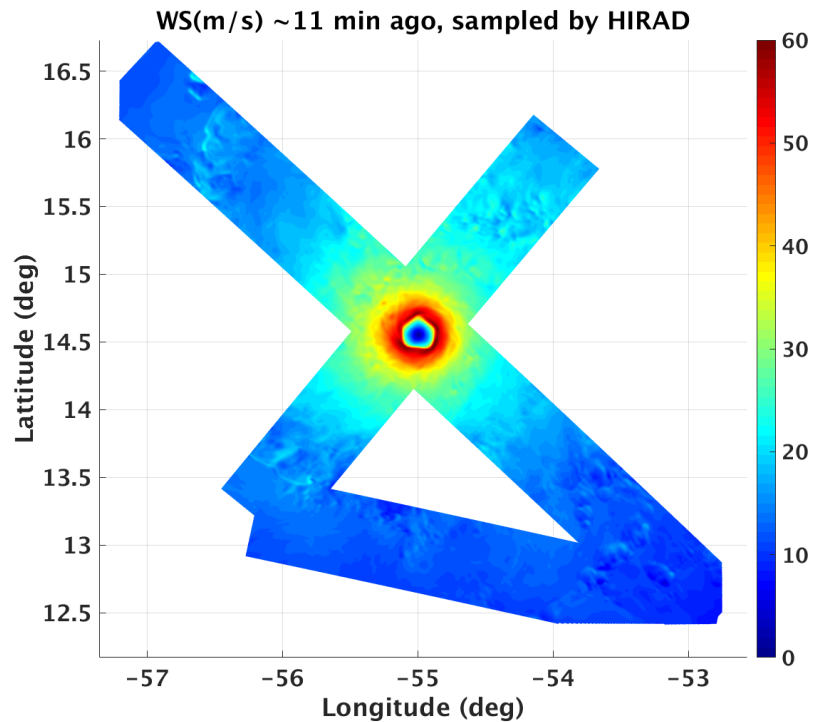
The shape changes from an along track oriented ellipse (\sim near nadir) to a circle (\sim 40 deg) and then back to an ellipse whose semi-major axis oriented along the xtrack direction.



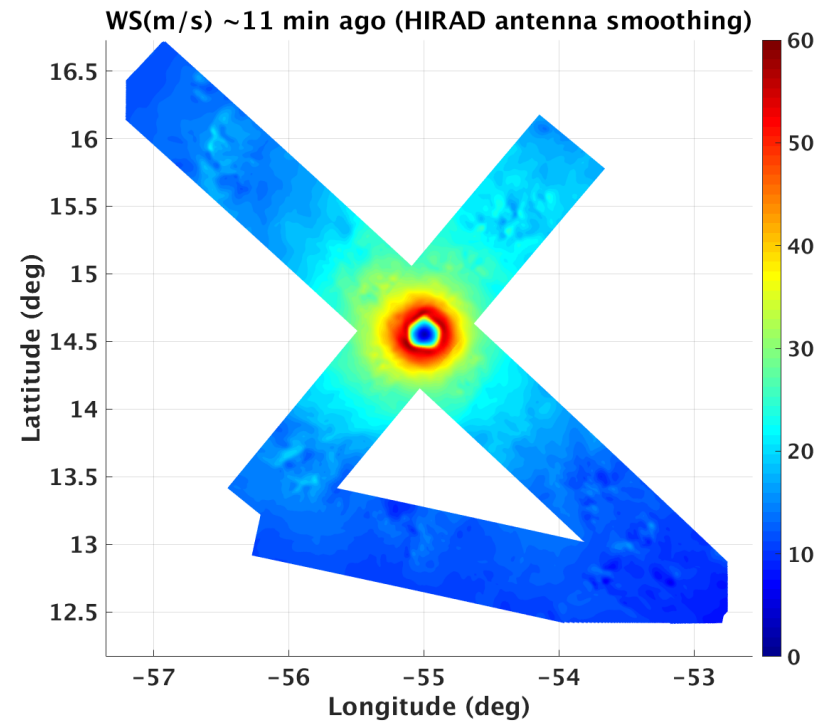
Near circular footprint
(40 deg off-nadir)

Effects of footprint size

Take a 1-km idealized simulation from Nolan, and subset a $\pm 60^\circ$ HIRAD swath:

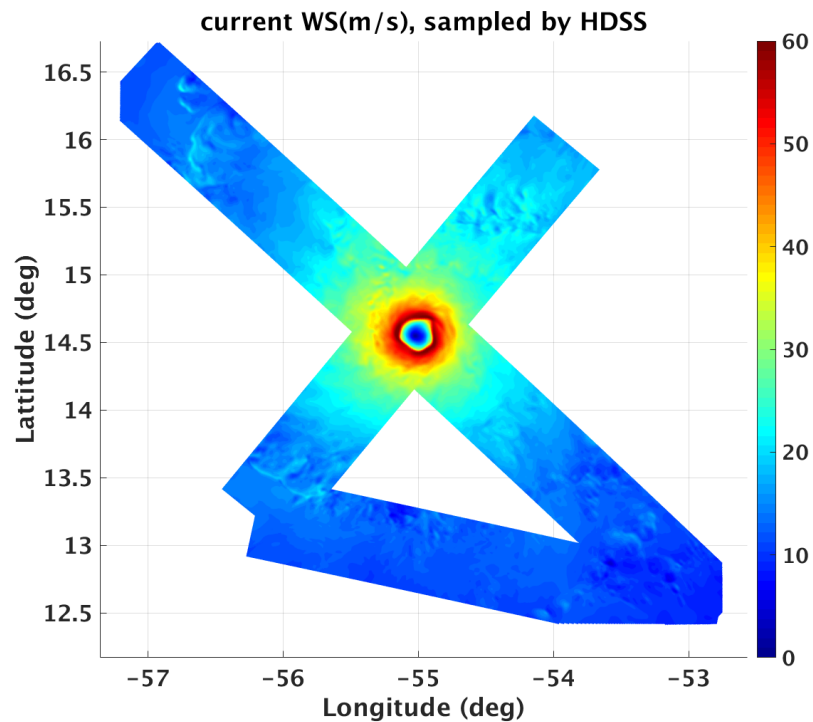


Apply smoothing to match HIRAD's footprint sizes at different incidence angles across a swath:



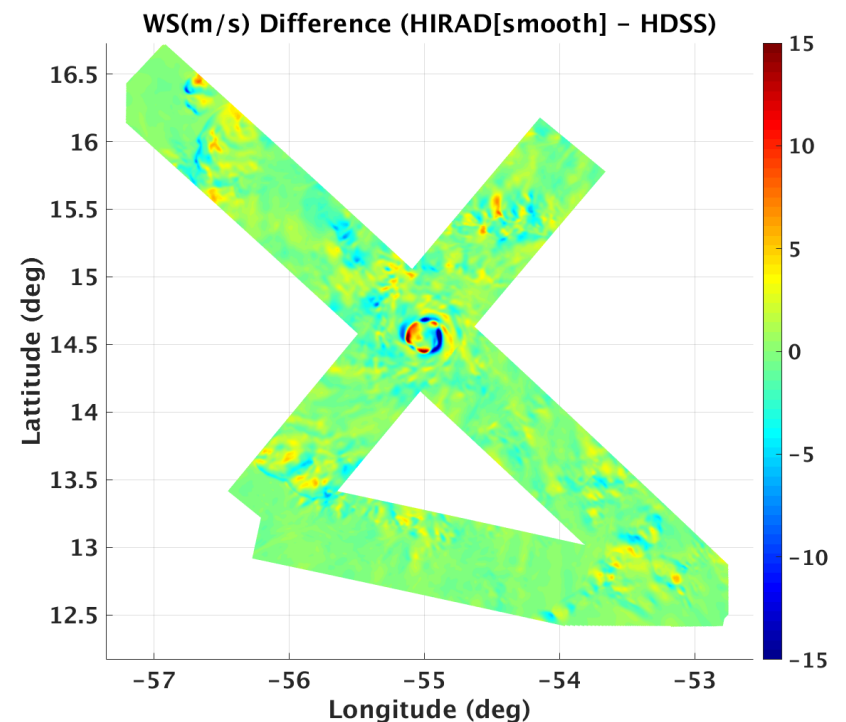
Effects of footprint size & temporal mismatch

Take idealized surface wind field 10 minutes later, simulating the conditions a dropsonde would fall into:



Dropsondes typically took 10-15 minutes to descend from WB57 flying near 60,000 ft

Compute difference, accounting for HIRAD beam smoothing and temporal evolution during dropsonde descent:



Differences range from -22 to + 19 m s⁻¹

HIRAD – HDSS Differences by Wind Speed

- Even perfect measurements & perfect retrievals would have some differences exceeding 20 m s^{-1} , when compared against dropsondes
- The idealized model output suggests $\sim 2\text{-}3 \text{ m s}^{-1}$ RMS Difference would be expected even with perfect measurements from both HIRAD and dropsondes
- Estimating HIRAD error requires accounting for that, and accounting for uncertainty in dropsonde-based estimate of surface wind

$$\text{RMSE}_{\text{HIRAD}} \sim \left(\text{RMSD}_{(\text{HIRAD-SONDE})}^2 - \text{RMSD}_{\text{SONDE}}^2 - \text{RMSD}_{(\text{spatio-temporal mismatch})}^2 \right)^{0.5}$$

$$\text{RMSE}_{\text{HIRAD}} \sim \text{sqrt} \left((6.0 \text{ m s}^{-1})^2 - (3.1 \text{ m s}^{-1})^2 - (2.0 \text{ m s}^{-1})^2 \right)^{0.5}$$

$$\text{RMSE}_{\text{HIRAD}} \sim 4.7 \text{ m s}^{-1}$$

From Uhlhorn et al. 2007 evaluation of using WL150 to get surface wind speed

Summary

- HIRAD surface wind speed retrievals evaluated using HDSS dropsonde intercomparison for 636 sondes, 10 flights during 2015 TCI project
- Performance looks good across all incidence angles
- Bias $< 2 \text{ m s}^{-1}$; near zero for most flights
- RMS Difference about 6 m s^{-1}
- Largest differences likely associated with motion of the eyewall during the dropsonde's 10-15 minute descent (*the wind scene is imaged by HIRAD before the dropsonde reaches the surface*)

Summary

- RMSE Error estimated to be $\sim 4\text{-}5 \text{ m s}^{-1}$, accounting for uncertainties in dropsonde surface wind speed estimates *and* spatio-temporal mismatches in the comparisons
- Simply eliminating the most dubious HIRAD-dropsonde matchups reduces the RMSD to $\sim 5 \text{ m s}^{-1}$, computed across all intensities

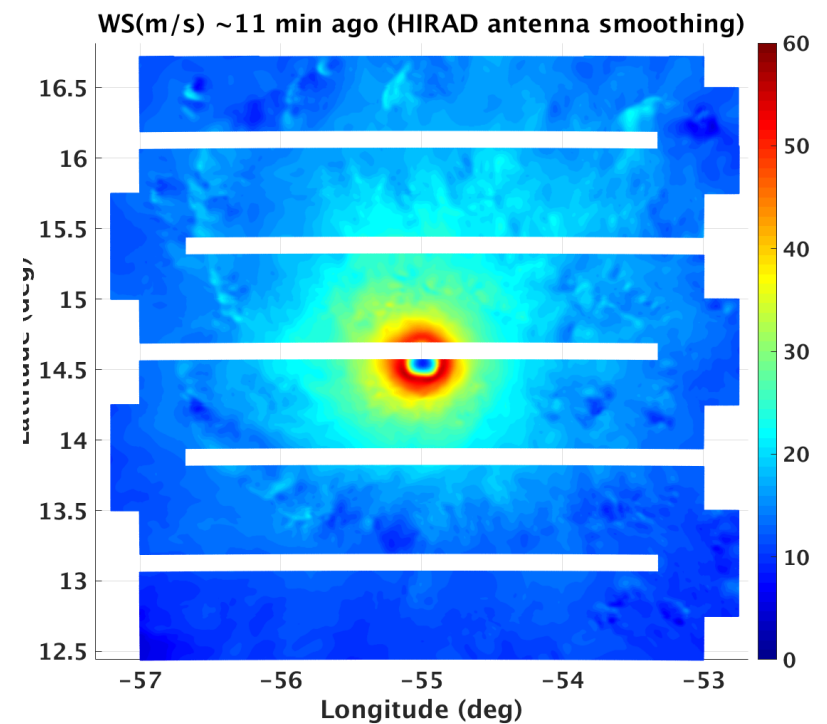
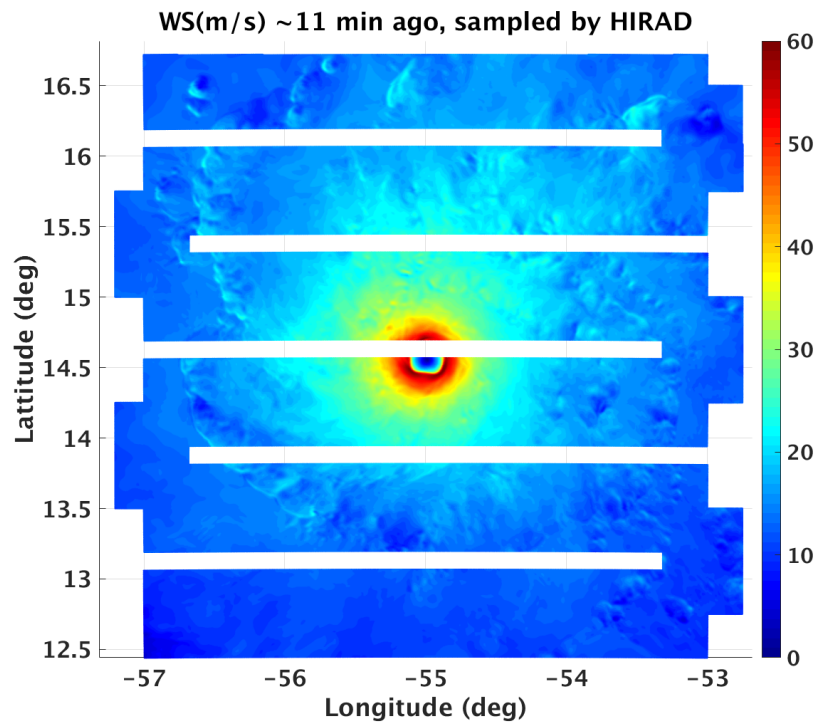
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Lawnmower pattern applied to idealized simulation (~4 – 4.5 hr duration for ~400 kt aircraft at FL600)

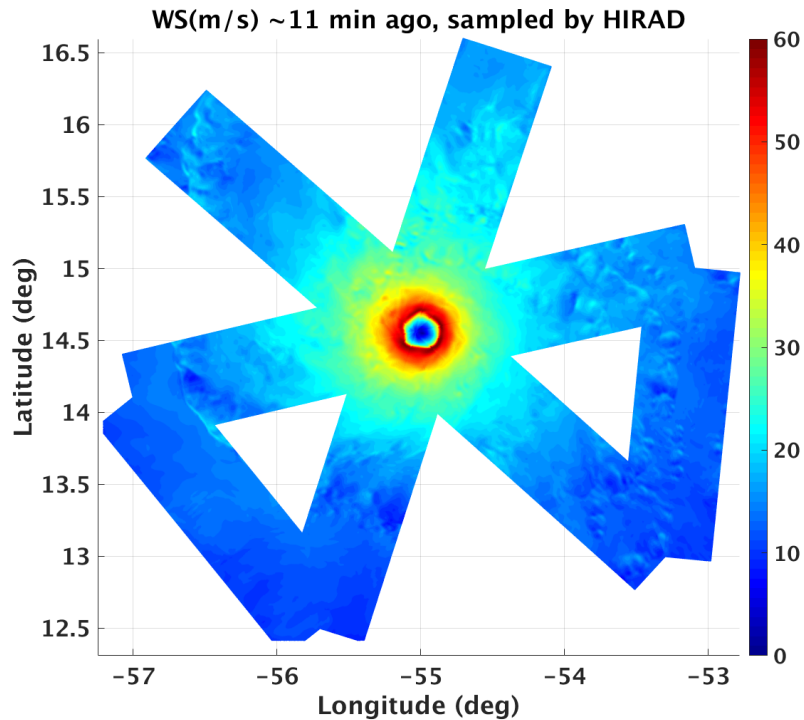
Take a 1-km idealized simulation from Nolan , and subset a +/-60° HIRAD swath :

Apply smoothing to match HIRAD's footprint sizes at different incidence angles across a swath:



Backup – Butterfly Pattern

Take a 1-km idealized simulation from Nolan, and subset a $\pm 60^\circ$ HIRAD swath:



Apply smoothing to match HIRAD's footprint sizes at different incidence angles across a swath:

