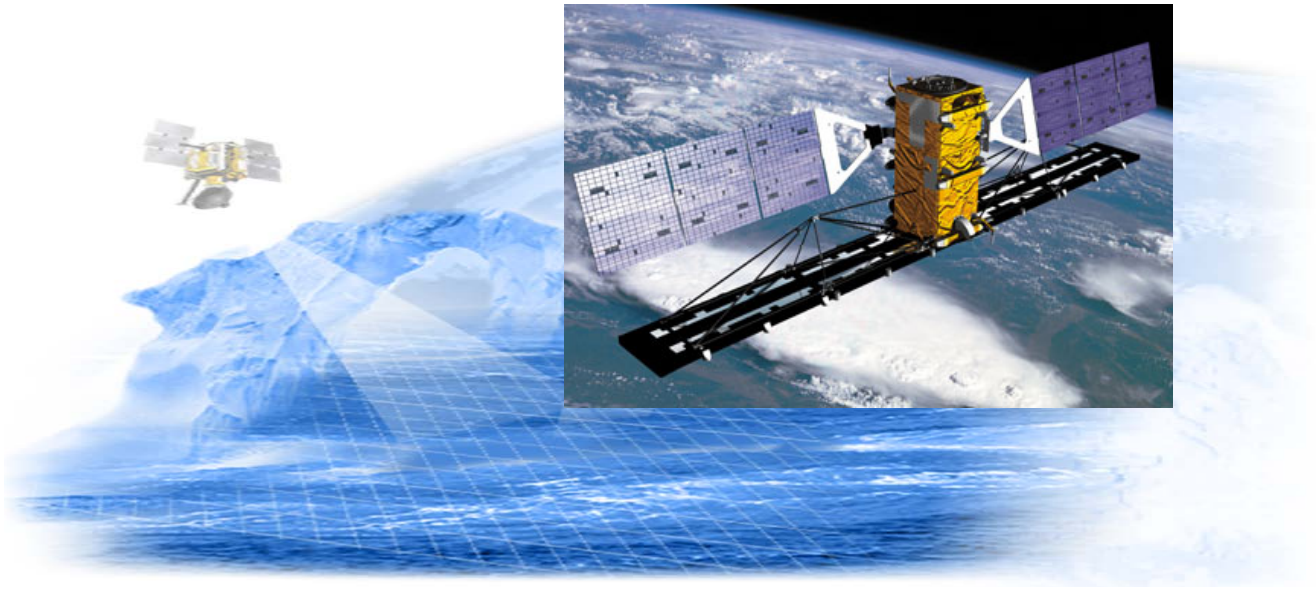


Cross-Polarized Synthetic Aperture Radar: A New Potential Measurement Technique for Hurricanes

[1]William Perrie, and [2]Biao Zhang

[1]Bedford Institute of Oceanography, Dartmouth, CANADA
[2]Nanjing Information Science and Tech University, China

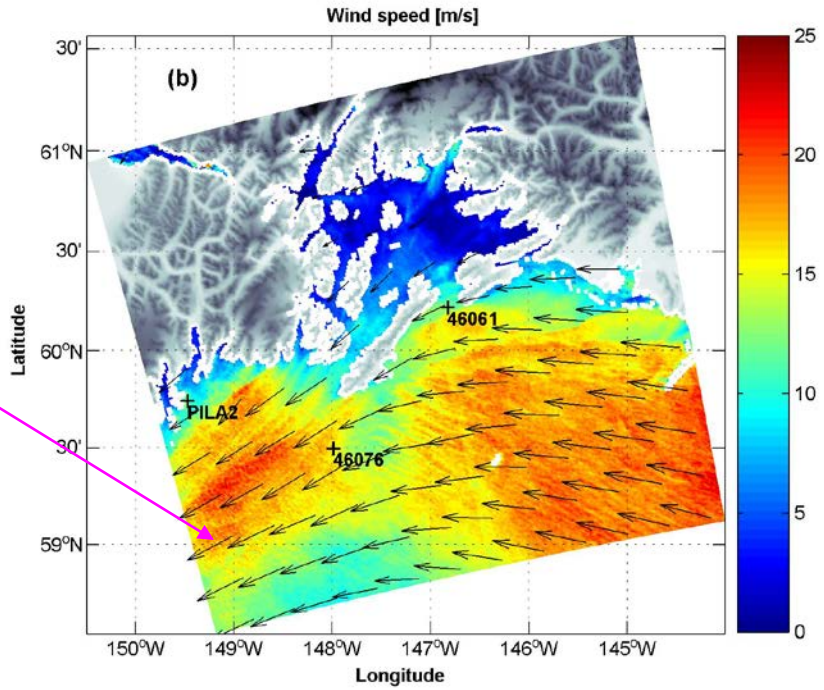
Contents .1.2.3

Movitation

SAR wind speed retrieval

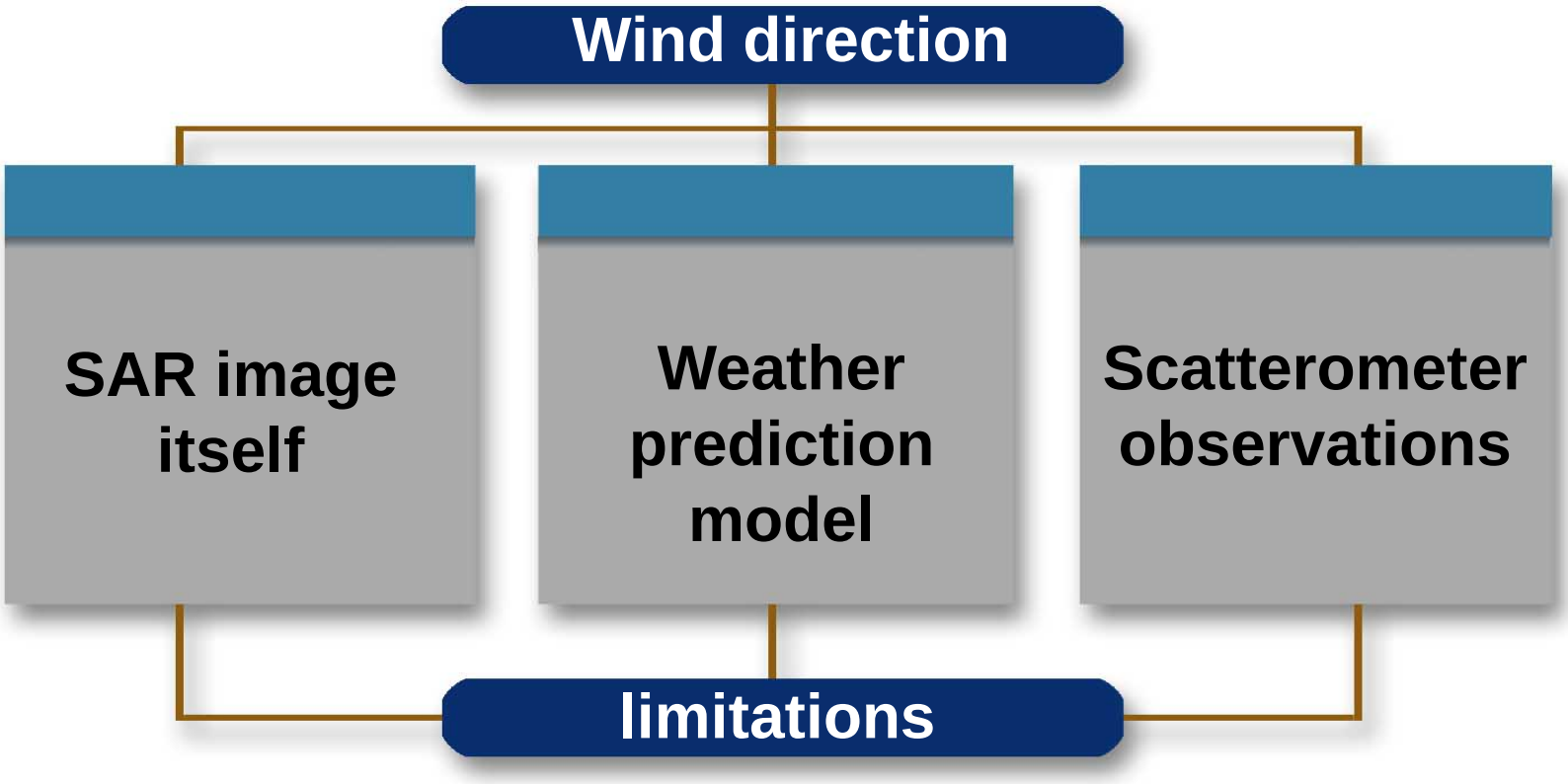
U_{10} ϕ

CMOD



$$\sigma_0(\theta, U_{10}, \phi) = A_0(\theta, U_{10})[1 + A_1(\theta, U_{10})\cos\phi + A_2(\theta, U_{10})\cos(2\phi)]^{1.6}$$

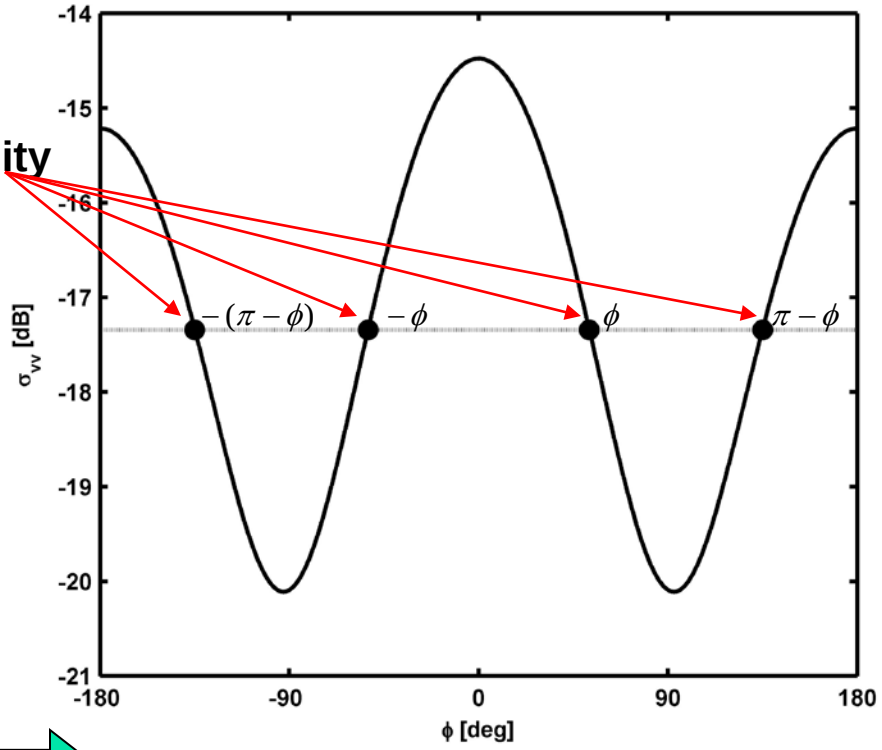
Movitation

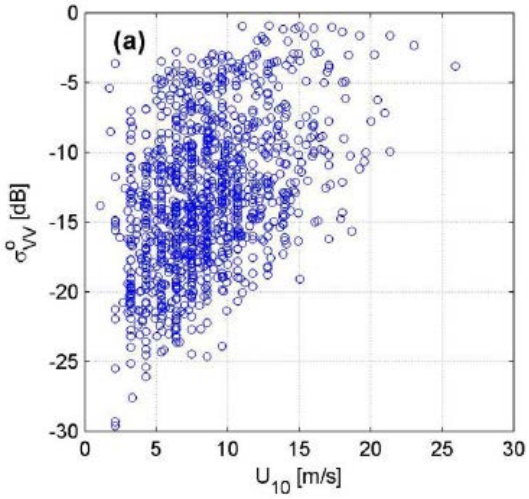

Wind direction
SAR image itself
Weather prediction model
Scatterometer observations
limitations

Movitation

CMOD

wind direction ambiguity





NRCS_VV → dependent on incidence angle and wind direction

RADARSAT-1 → "the past"

only HH-polarization data...

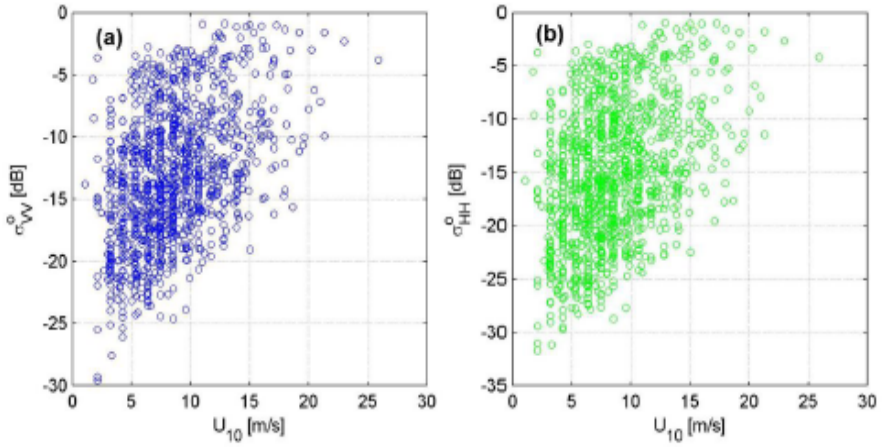
2. Wind blending for conventional algorithms

Co-Polarization Model: CMOD5.N

$$\sigma_0^{(m)} = \mathrm{B0}(1 + \mathrm{B1}\cos\phi + \mathrm{B2}\cos 2\phi)^{1.6}$$

$$\mathrm{B1} = \frac{c_{14}(1+x) - c_{15}v(0.5 + x - \tanh[4(x + c_{16} + c_{17}v)])}{1 + \exp(0.34(v - c_{18}))} t_2 v, s_0)^{\gamma}$$

$$\mathrm{B2} = (-d_1 + d_2 v_2)\exp(-v_2)$$

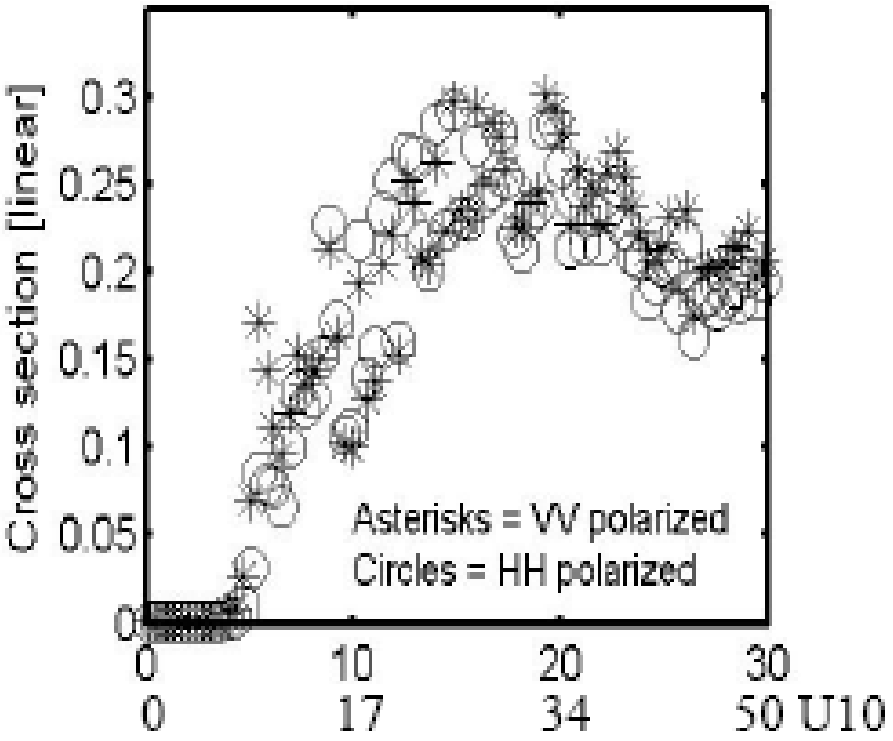


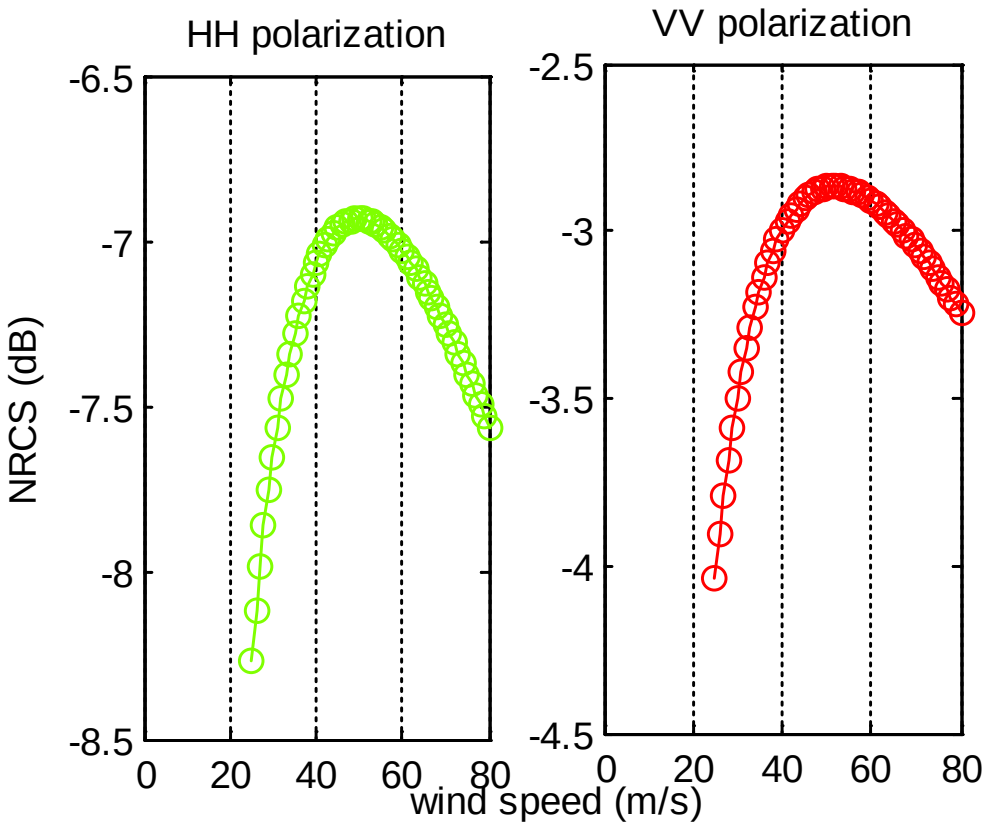
1:wind **speed**, wind **direction** and radar **incidence angle** dependence.
2: NRCS_VV **saturates** at **high winds**.

- the wind speed ambiguity problem in **SAR Imagery**

NRCS under high winds

Donelan et al.





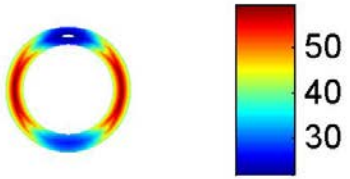
Incident angle=35º

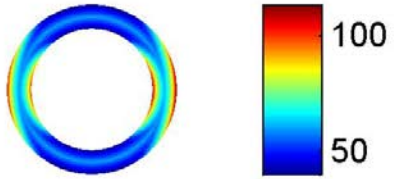
Incident angle=31º

- Donelan et al. (2004)
- Fernandez et al. (2006)

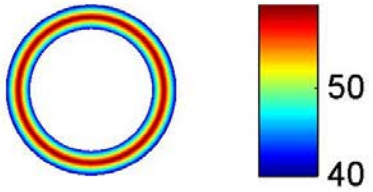
Wind retrieved from self-simulated NRCS VV polarization

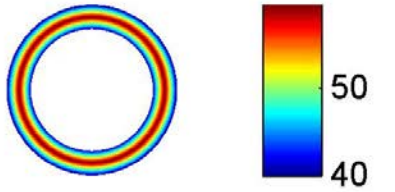
CMOD5



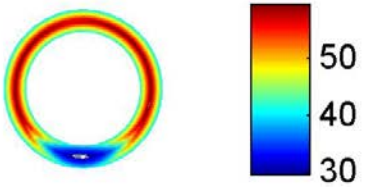


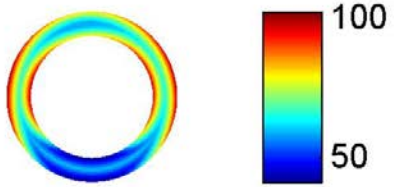
COMD4HW



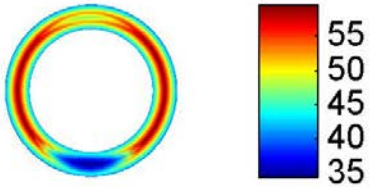


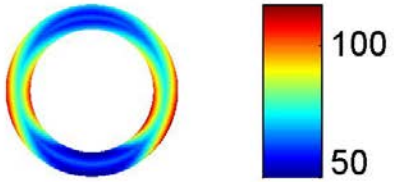
HWGMF_V





HWGMF_H





smaller solution

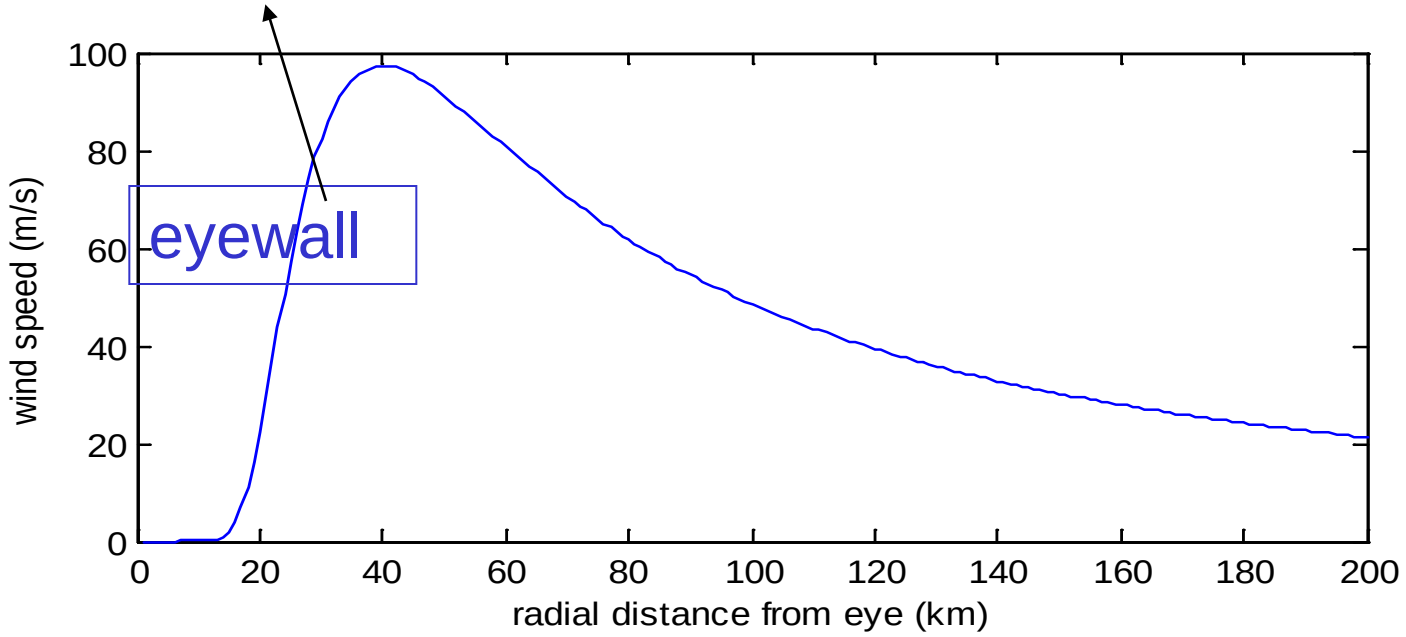
bigger solution

How to remove speed ambiguity?

- Neither smaller solution OR bigger solution can be taken directly as the real wind.

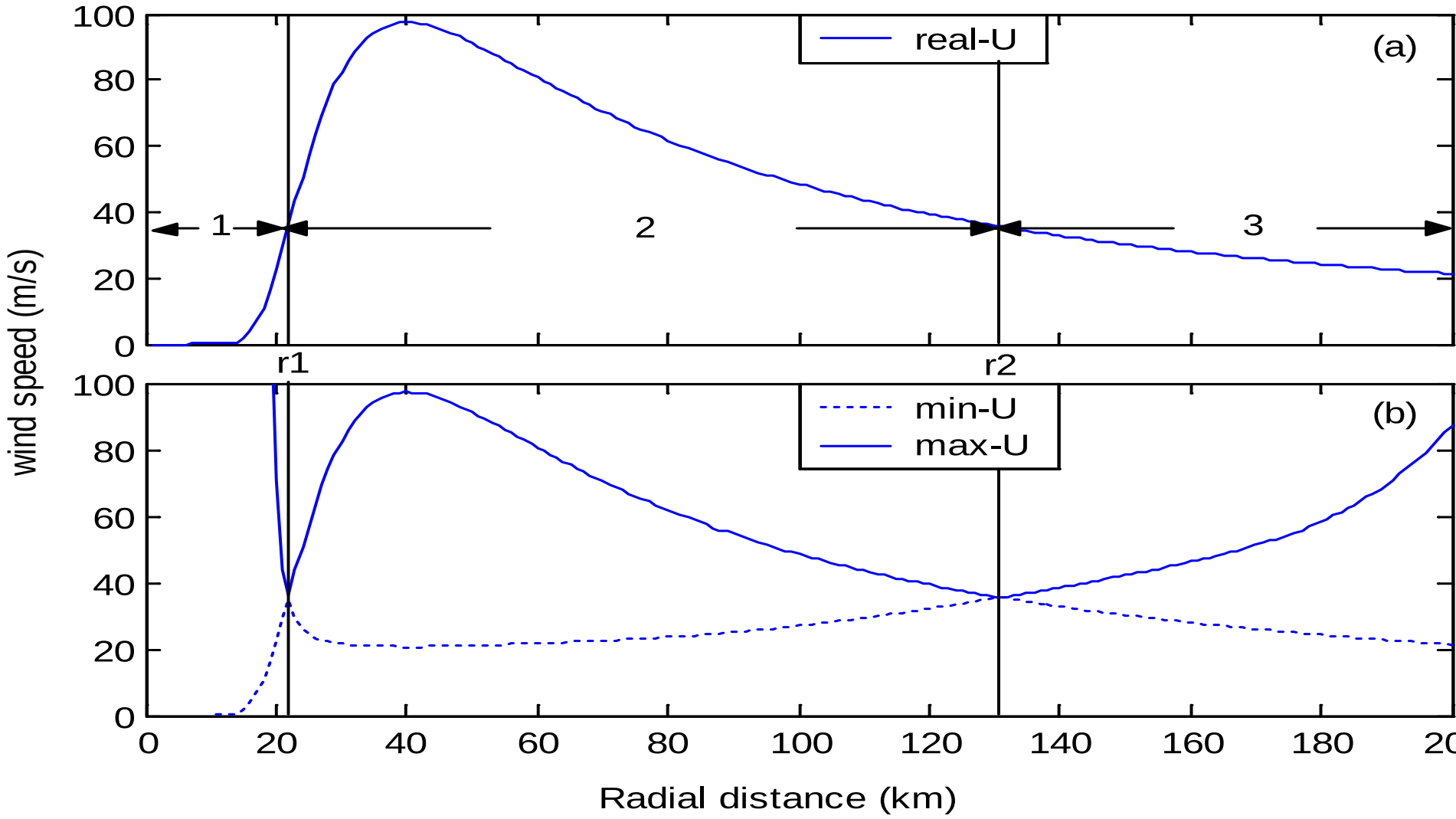
Speed ambiguity removal for hurricanes

- A typical hurricane wind profile

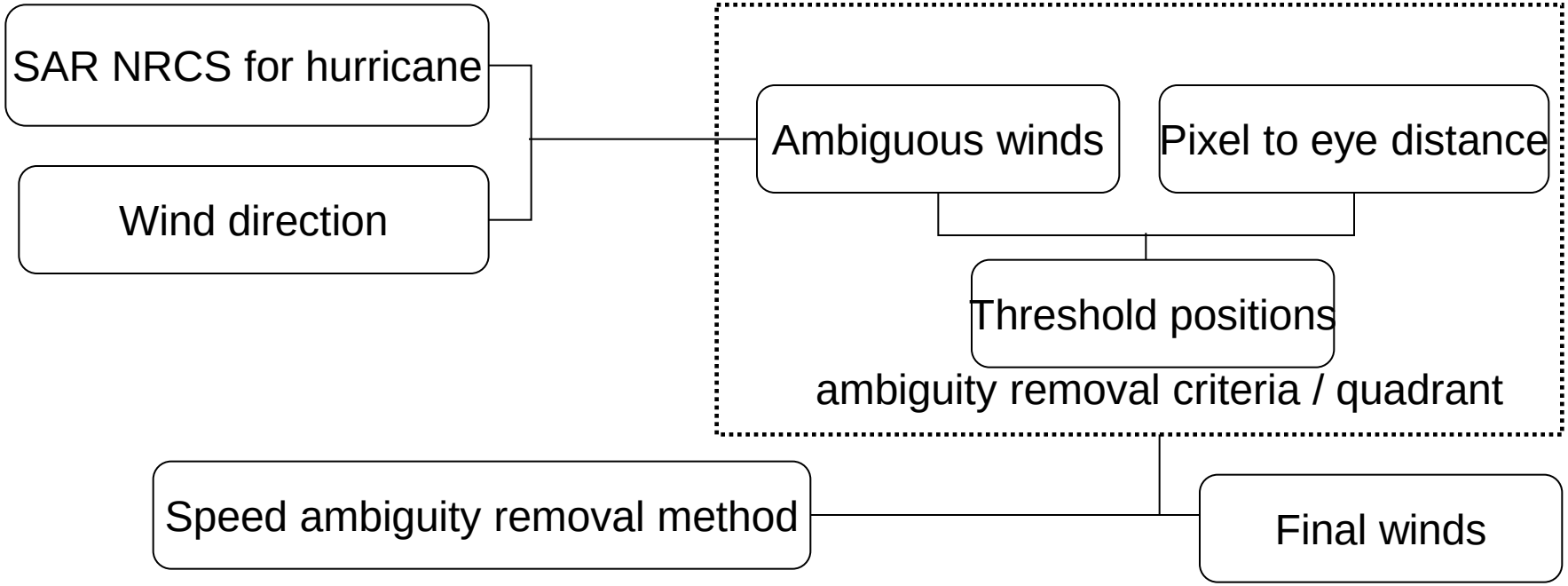


from Holland (1980) profile

Ambiguity in hurricane speed profile

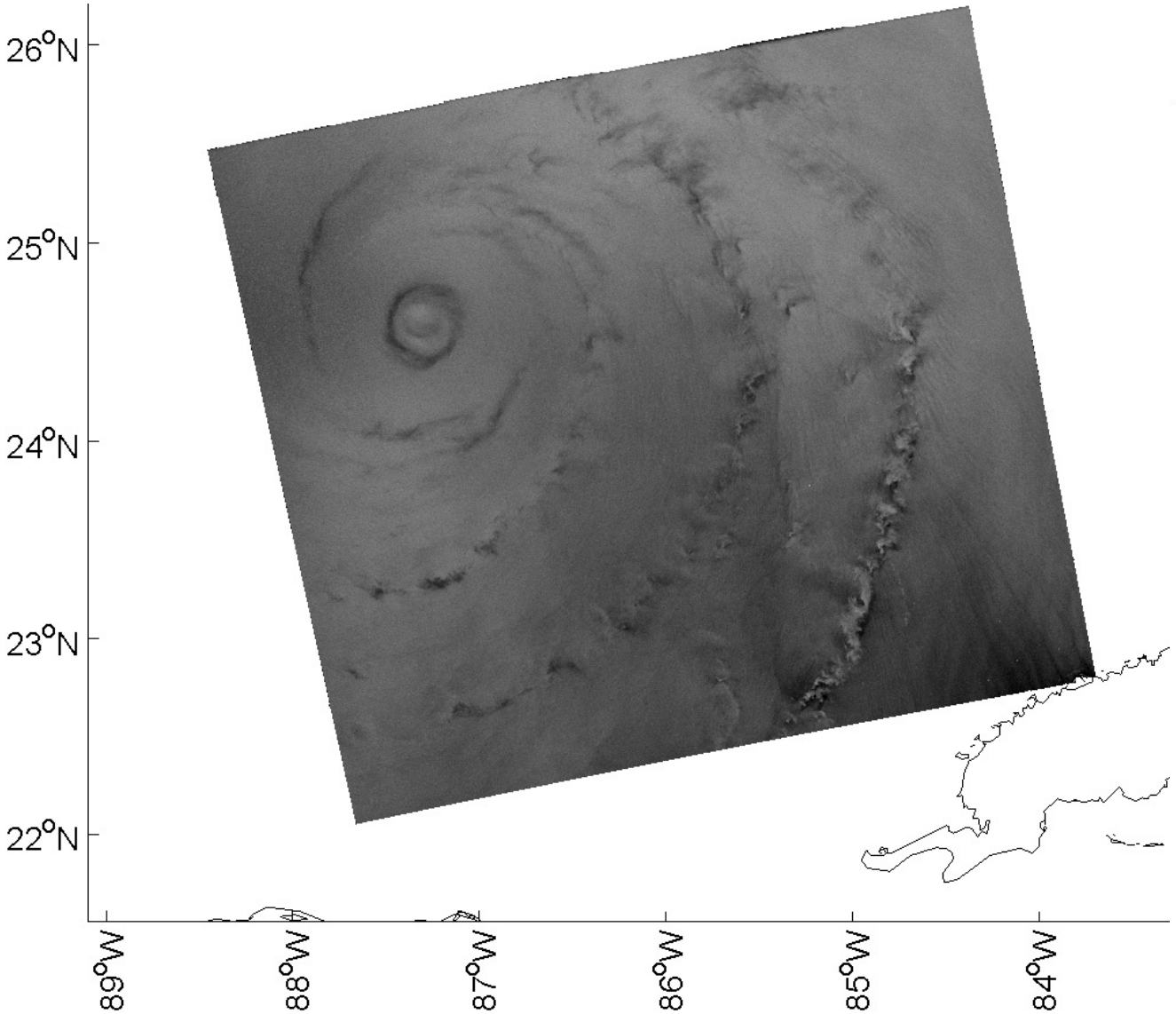


Speed ambiguity removal



Speed ambiguity removal for Rita

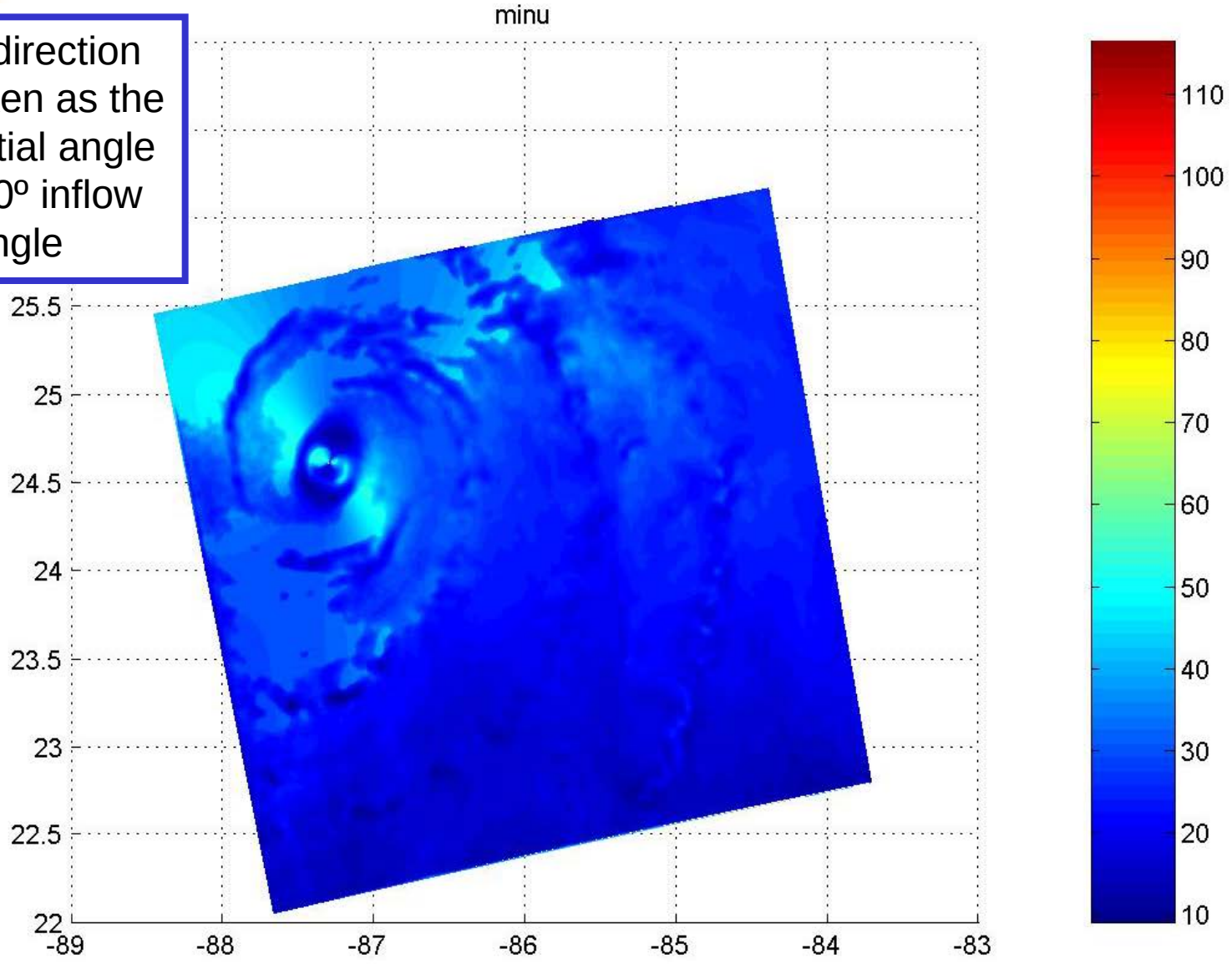
→Envisat ASAR image (Sep 22 03:22 2005)



Wind retrieval

- Smaller ambiguous solutions

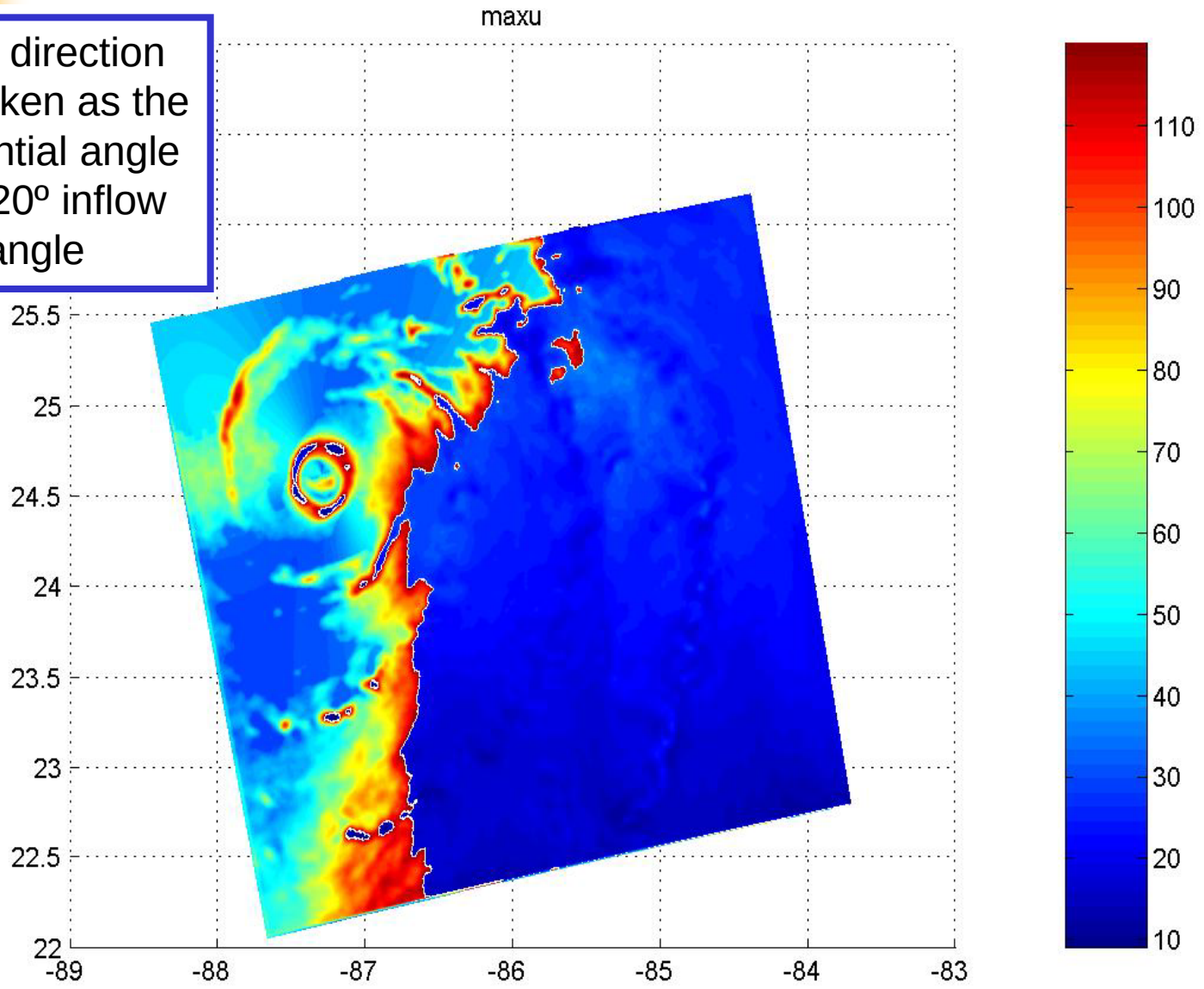
Wind direction was taken as the tangential angle with 20º inflow angle



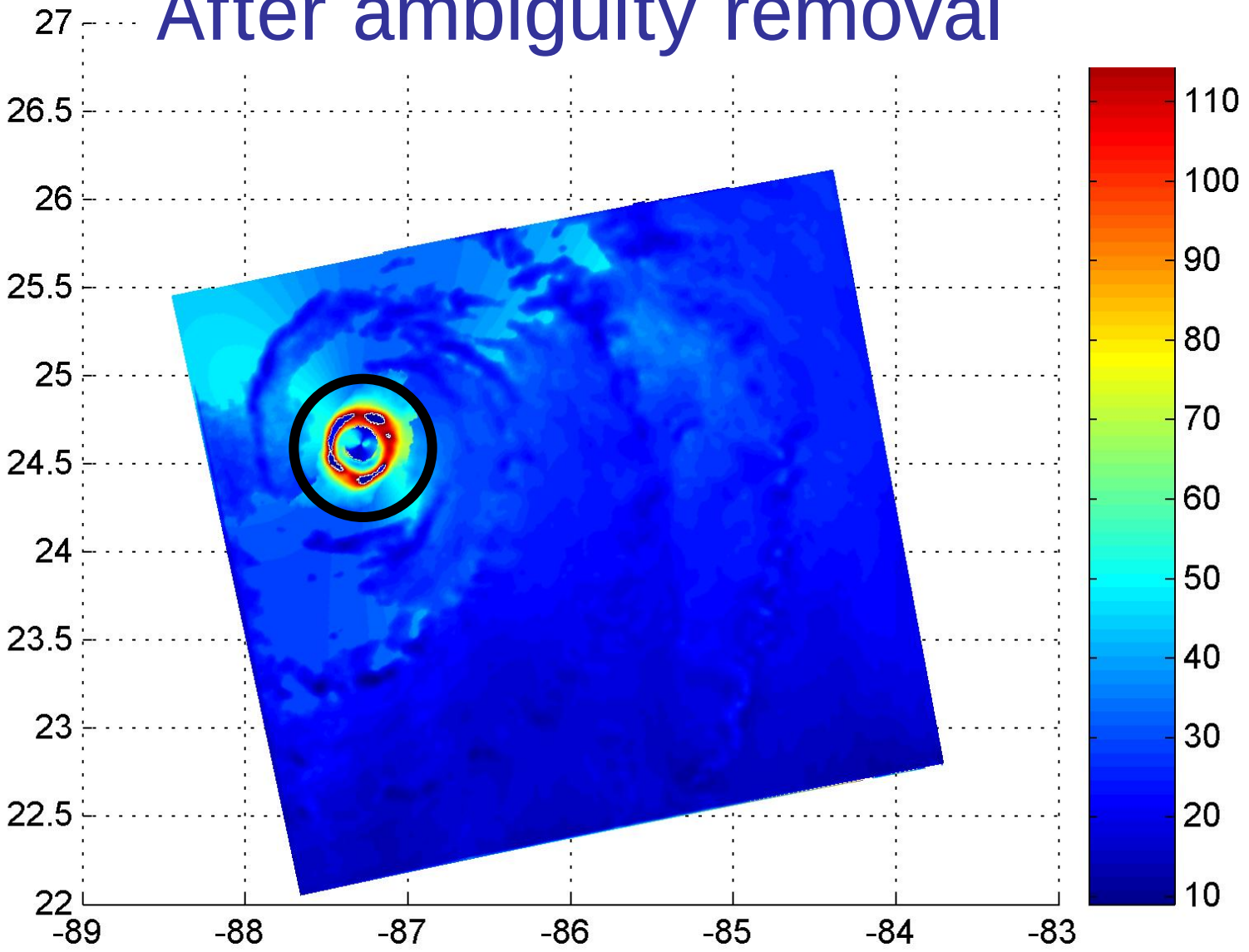
Wind retrieval

- Bigger ambiguous solutions

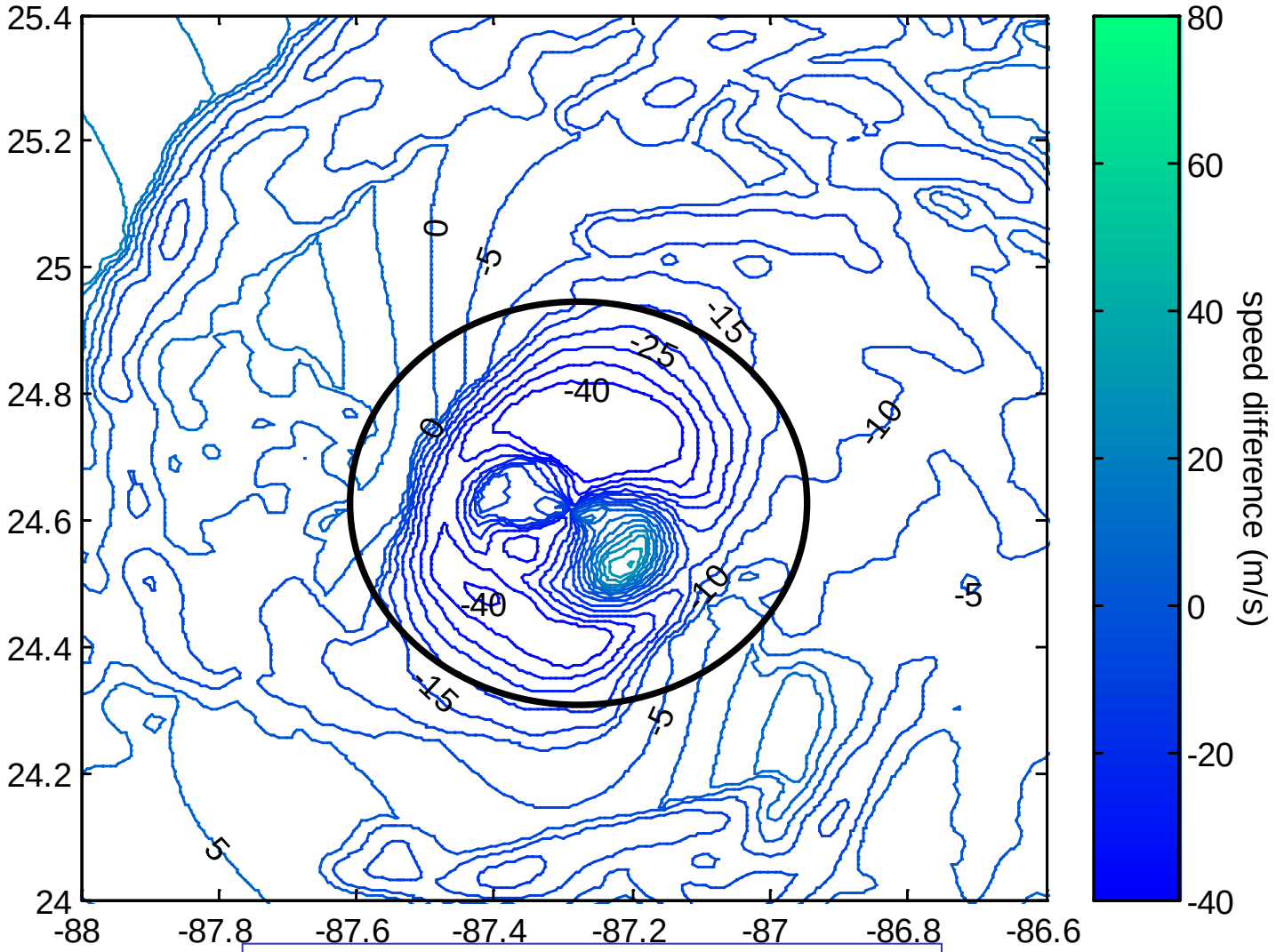
Wind direction was taken as the tangential angle with 20º inflow angle



After ambiguity removal

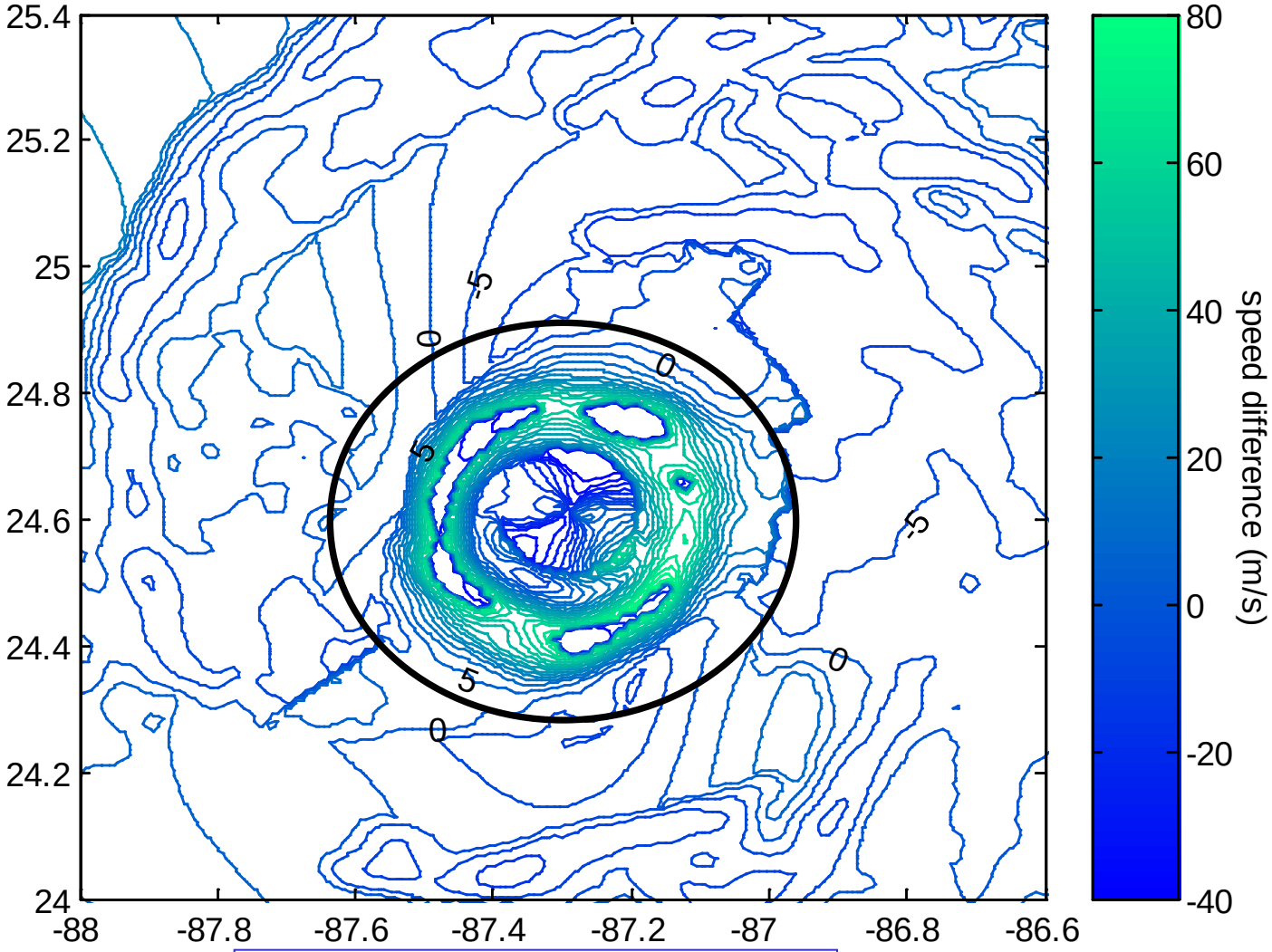


Speed difference with NHC winds



Smaller solution - NHC winds

Speed difference with NHC winds



Final solution - NHC winds

Conclusions to here -1

1) ambiguity exists in high wind SAR retrievals, more severe at near side of SAR range
2) based on typical cyclone structure, a speed ambiguity removal method is developed
3) method can maybe be generalized and adopted to other GMFs to give improved SAR retrieved winds.

Shen, H., Perrie, W., and He, Y. 2006: A new hurricane wind retrieval algorithm for SAR images, *Geophys. Res. Lett.*, 33, L21812, doi:10.1029/2006GL027087

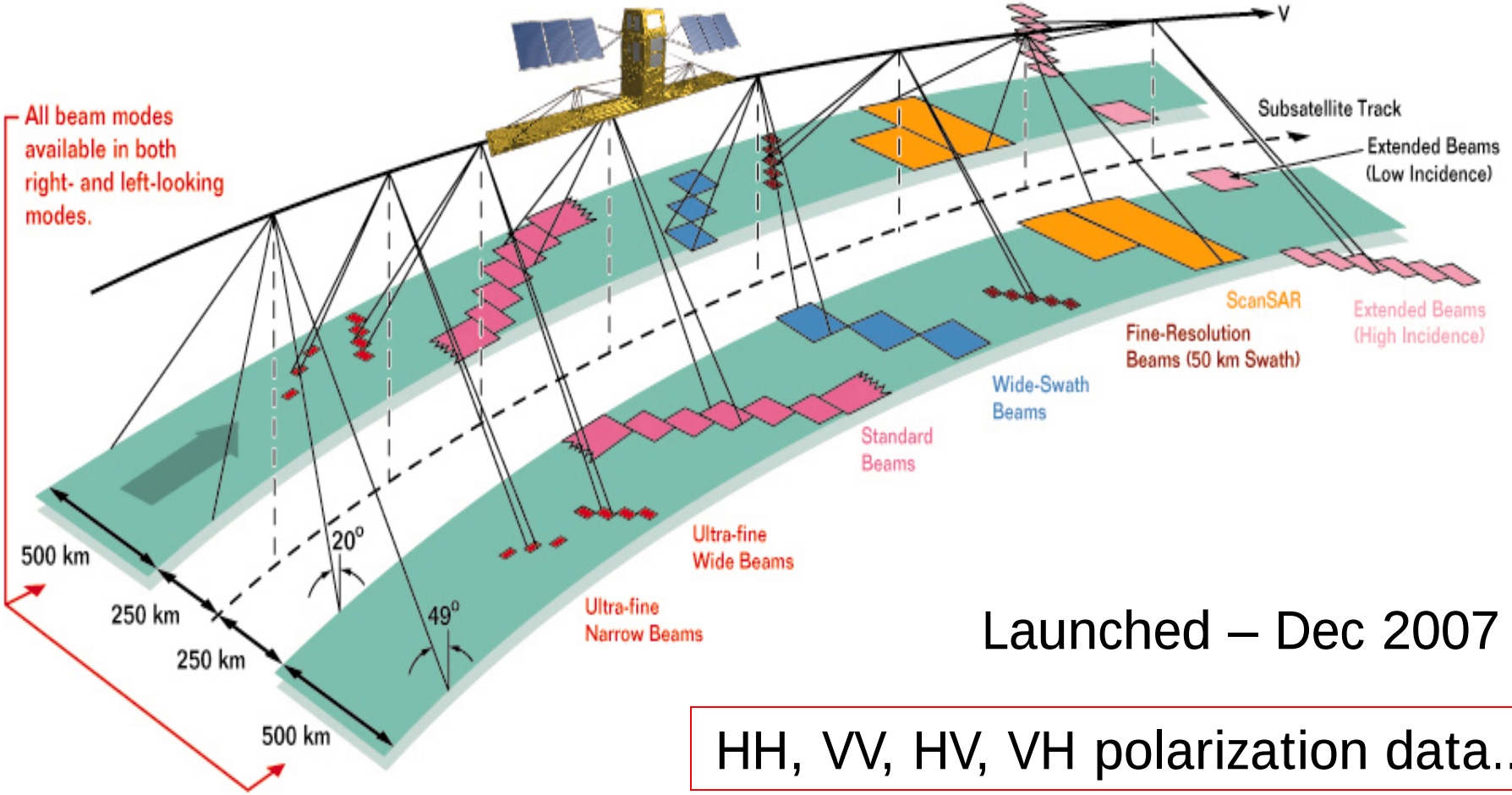
Shen, H., Perrie, W., and He, Y., 2007: Correction to "A new hurricane wind retrieval algorithm for SAR images", *GRL*, 34, L01811, doi:10.1029/2006GL029089.

Shen, H., He, Y., and Perrie, W. 2008: Speed ambiguity in hurricane wind retrieval from SAR imagery. In *International Journal of Remote Sensing* as of Sept. 15.

Shen, H., Perrie, W., He, Y., 2009: On SAR wind speed ambiguities and related geophysical model functions. *Canadian J. Remote Sensing.* Vol. 35, No. 3, pages 310-319.

The present – RADARSAT-2

Imaging Modes



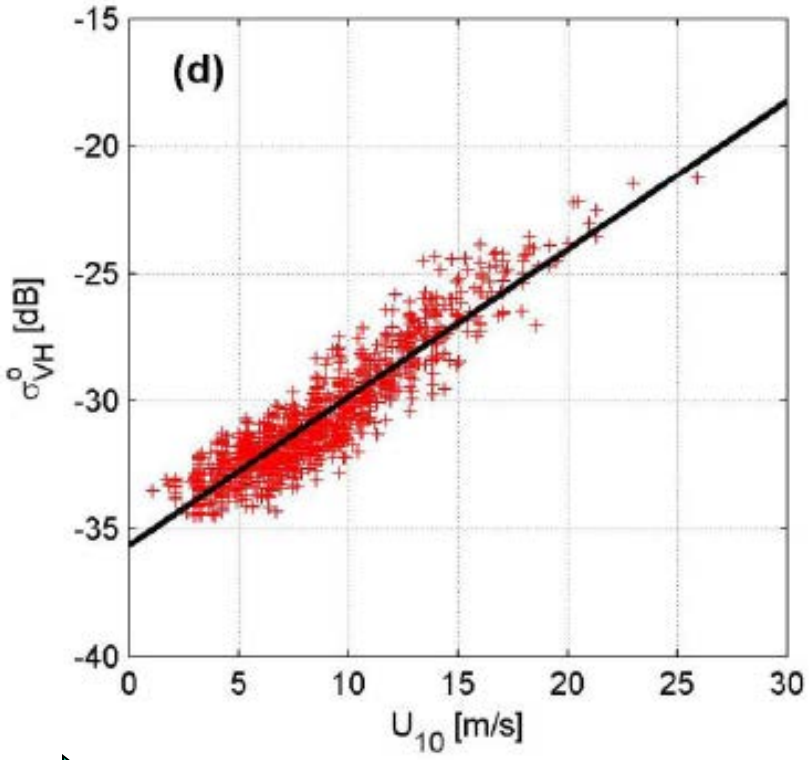
Launched – Dec 2007

HH, VV, HV, VH polarization data...

The present – RADARSAT-2

Movitation

C-2PO



NRCS_VH → Independent of incidence angle and wind direction

Method

Polarimetric correlation coefficient between VV and HV

$$\rho_{VVHV} = \frac{< S_{VV} \cdot S_{HV} >}{\sqrt{< |S_{VV}|^2 >< |S_{HV}|^2 >}}$$

Scattering matrix

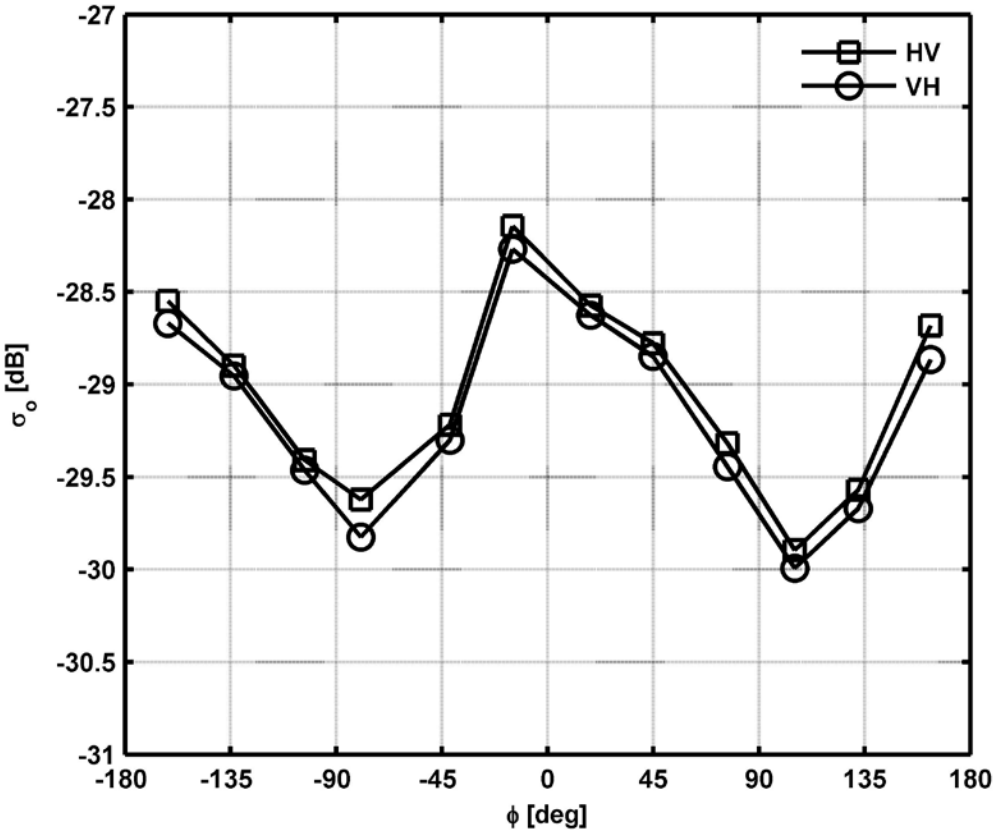
$$S = \begin{bmatrix} S_{hh} & S_{hv} \\ S_{vh} & S_{vv} \end{bmatrix}$$

RS - 2 Fine Quad-Polarization

Results

NRCS in cross-polarization versus relative wind direction

even

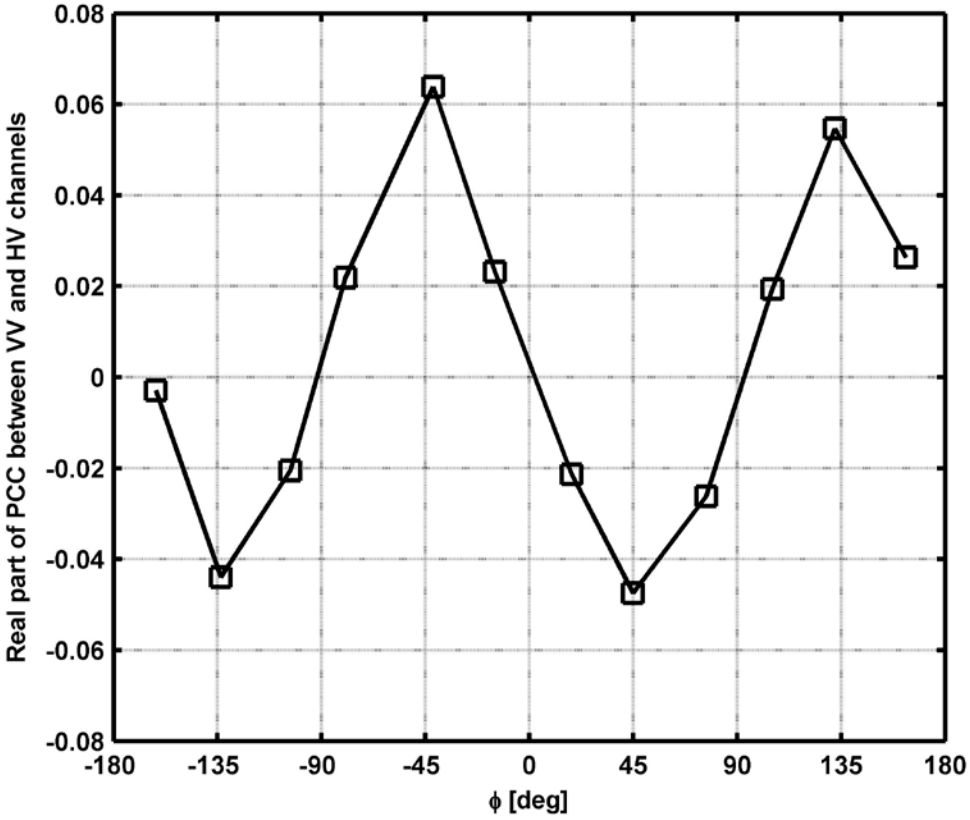


symmetry

Results

Real part of Polarimetric correlation coefficient (PCC)

odd

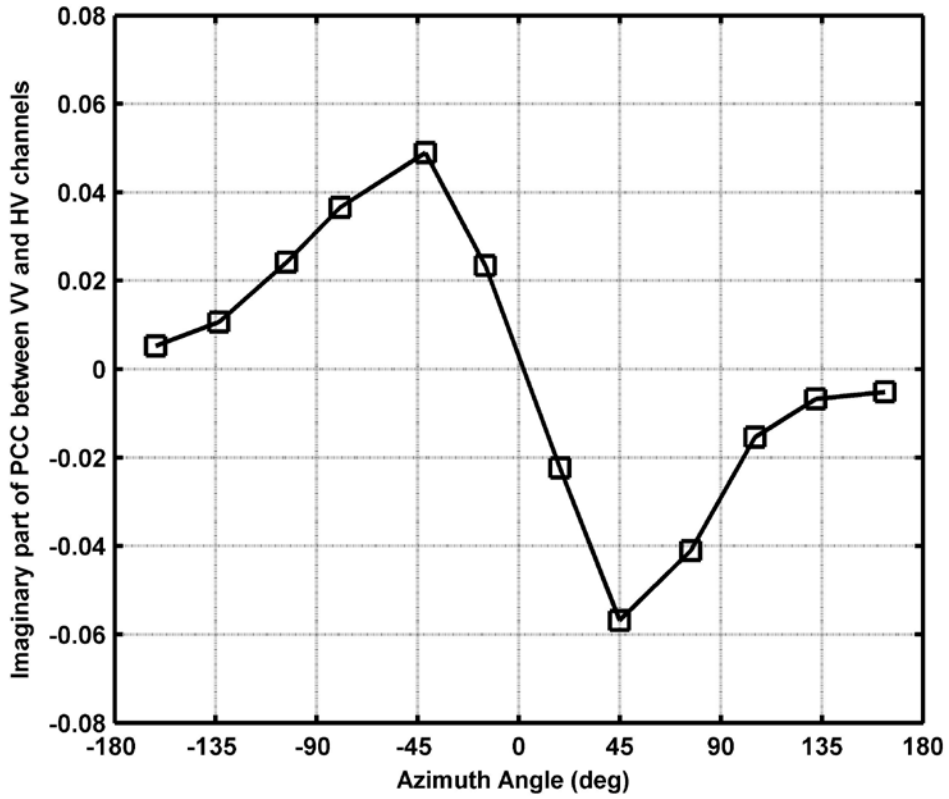


symmetry

Results

Imagery part of Polarimetric correlation coefficient (PCC)

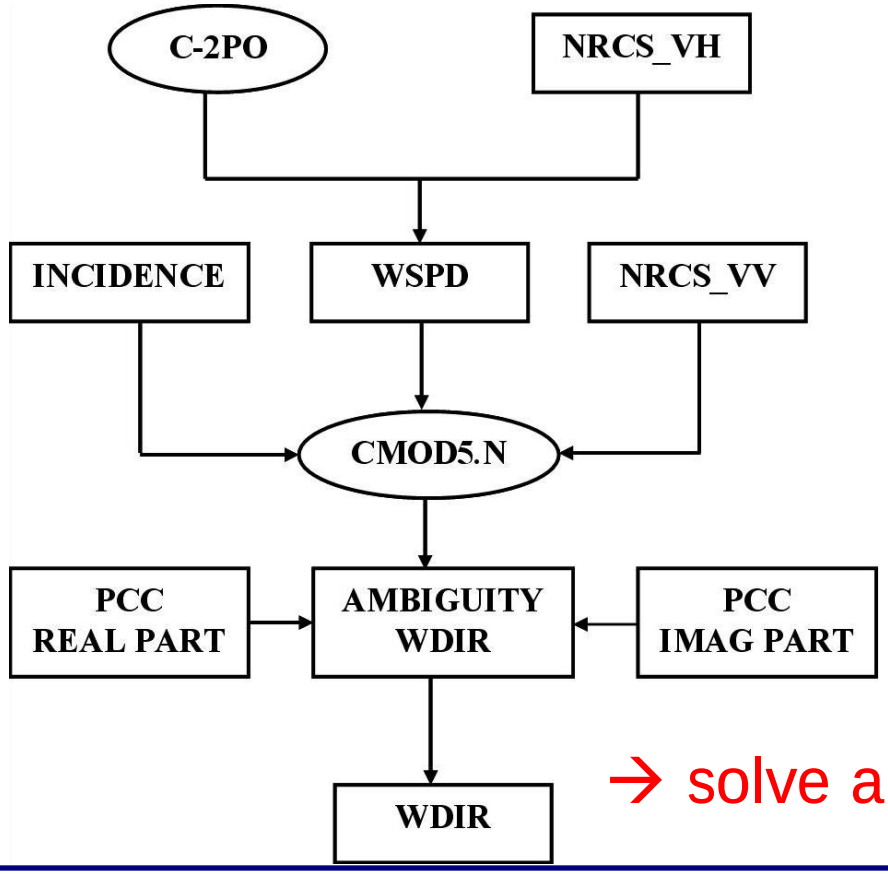
odd



symmetry

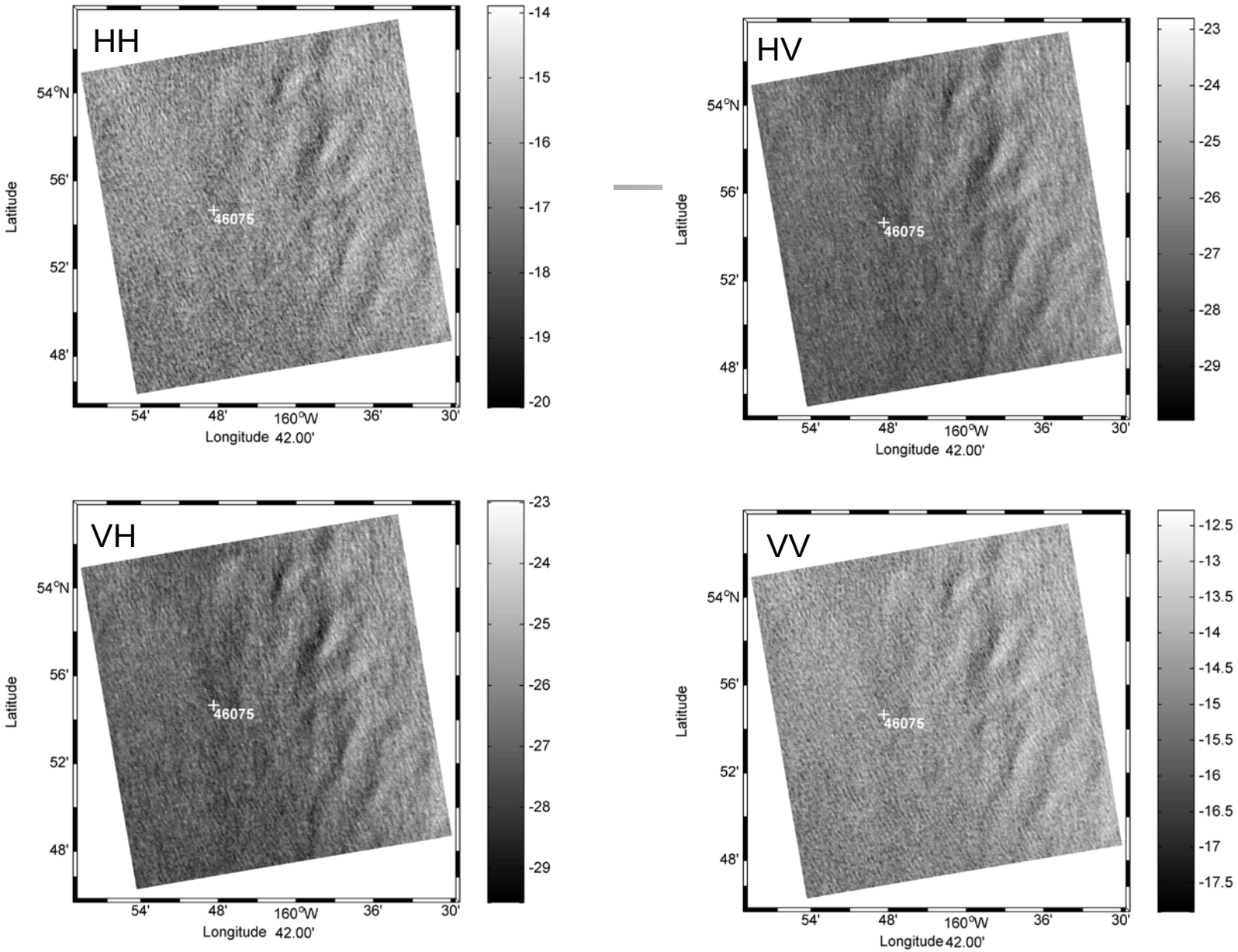
Method

Wind-vector retrieval algorithm (our idea)

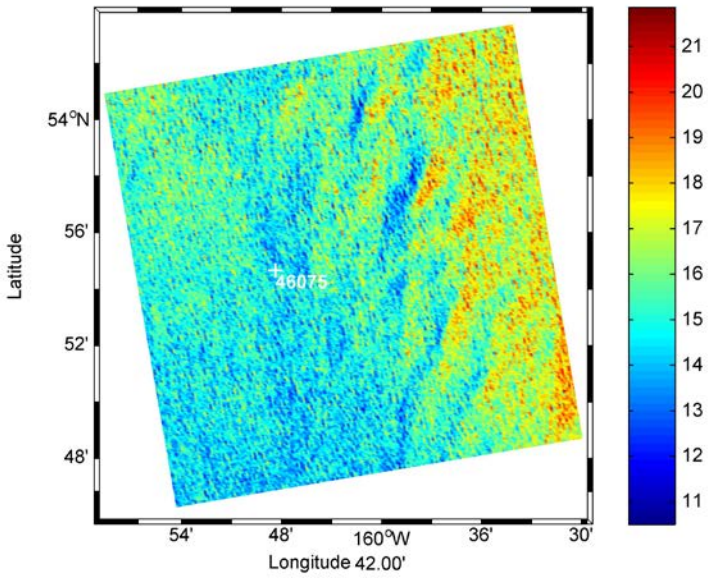


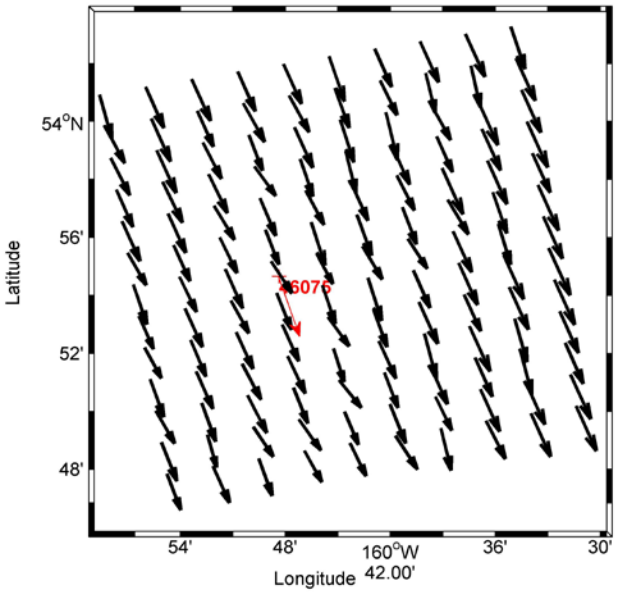
→ solve ambiguity problem

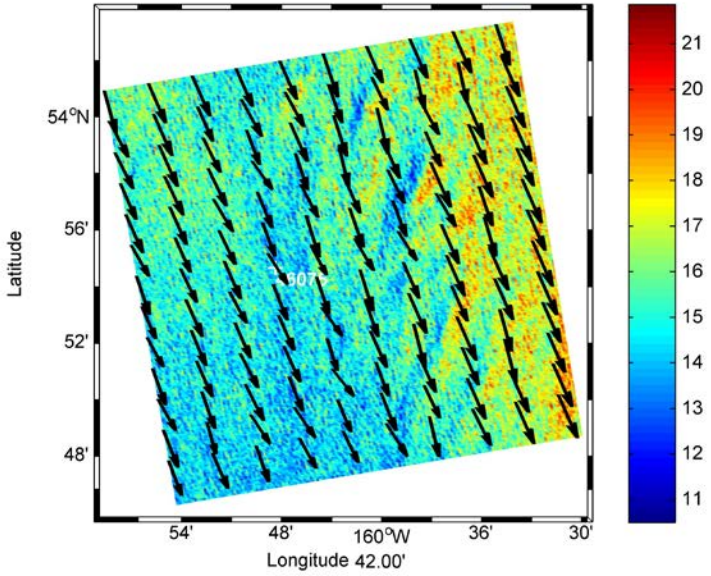
Wspd=15.7 m/s Wdir=169°



Mar 20, 2010 04:33 UTC



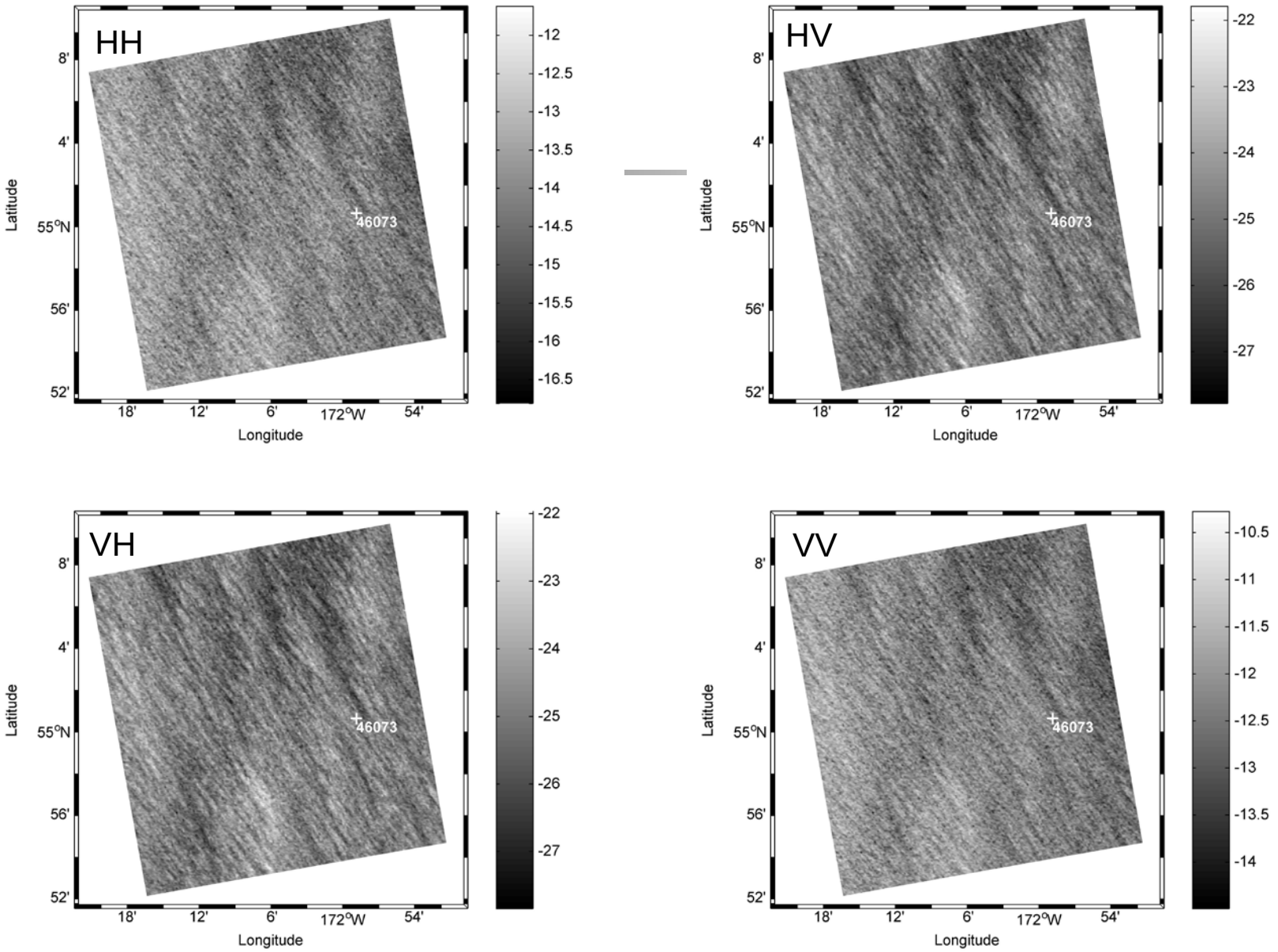




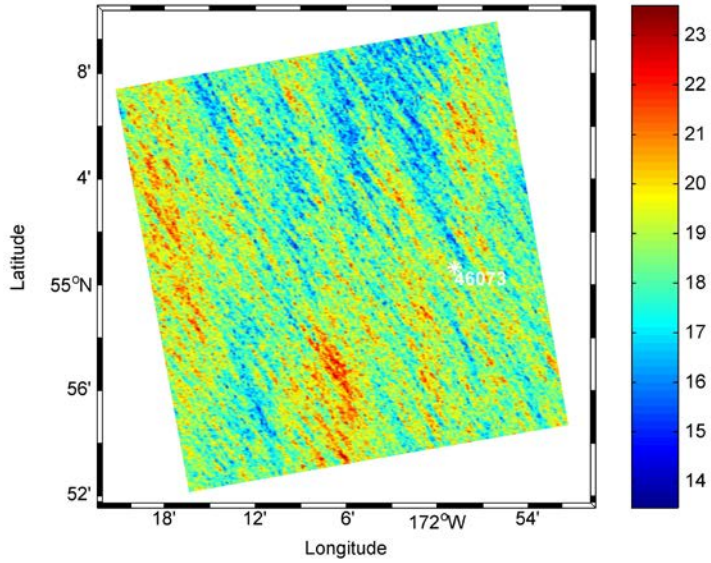
Buoy-measured wdir=169°
Our Retrieved wdir=151°

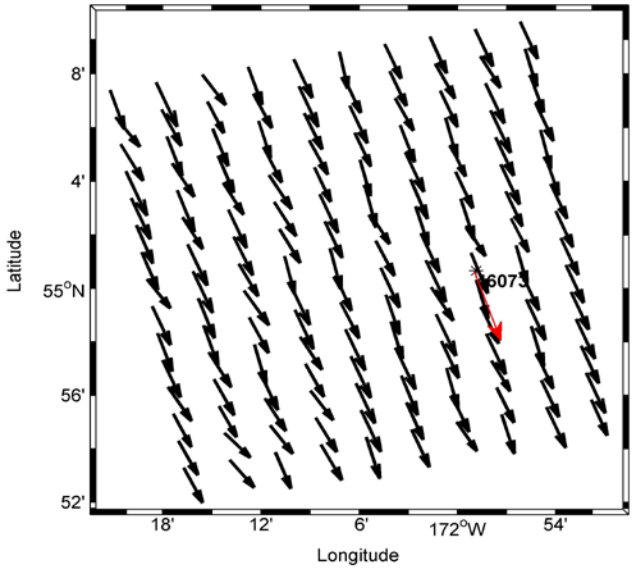
Buoy-measured wspd=15.7m/s
Our Retrieved wpsd=13.7 m/s

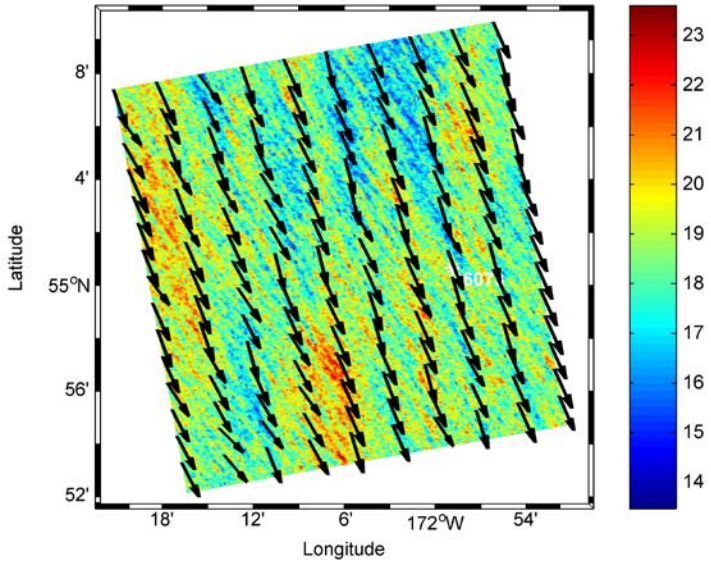
Wspd=19.0 m/s Wdir=142°



Jan 09, 2011 05:15 UTC



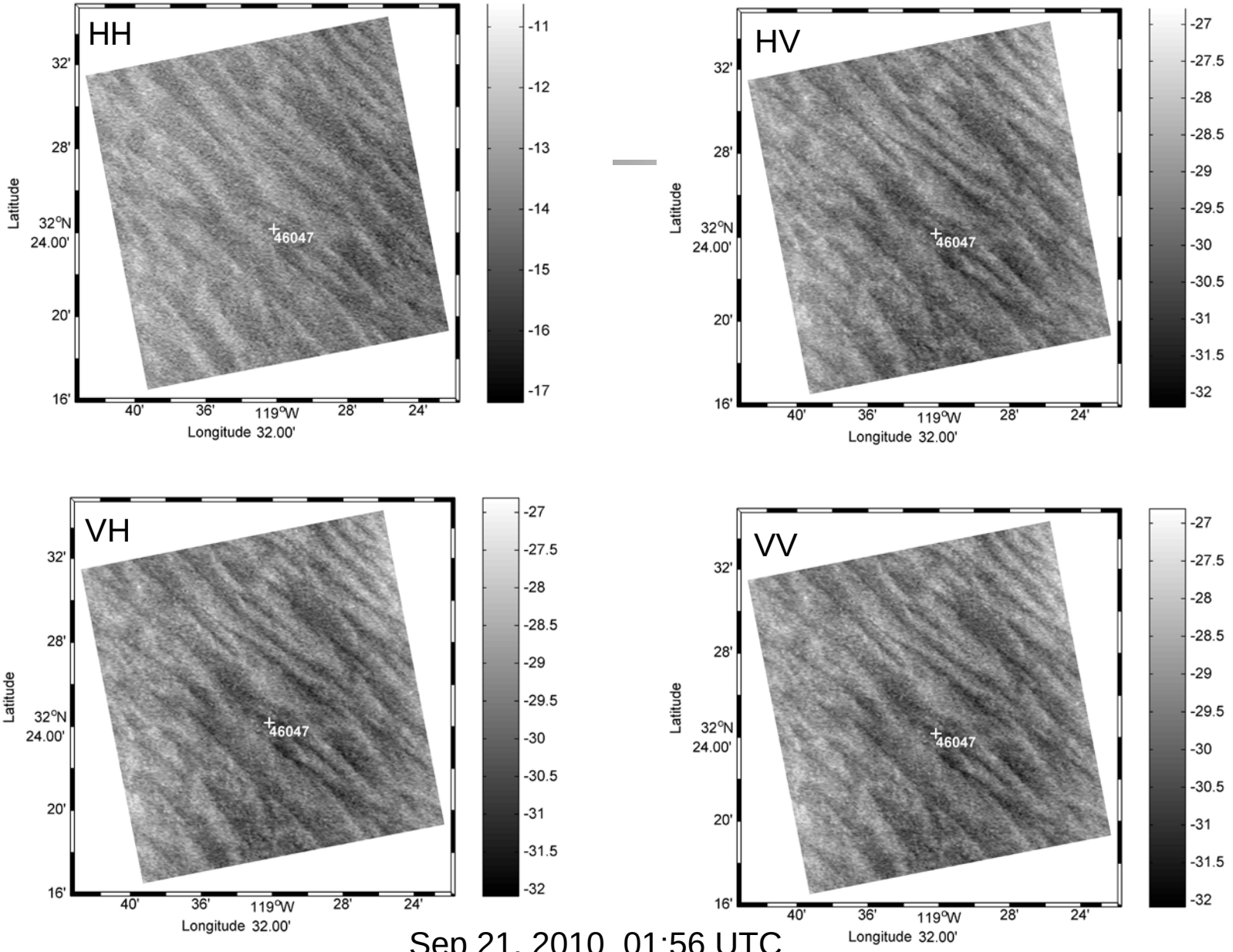




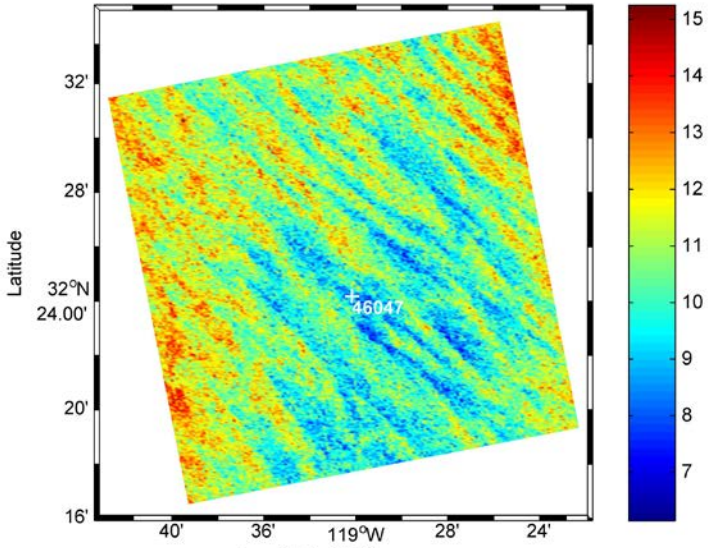
Buoy-measured wdir=142°
Our Retrieved wdir=152°

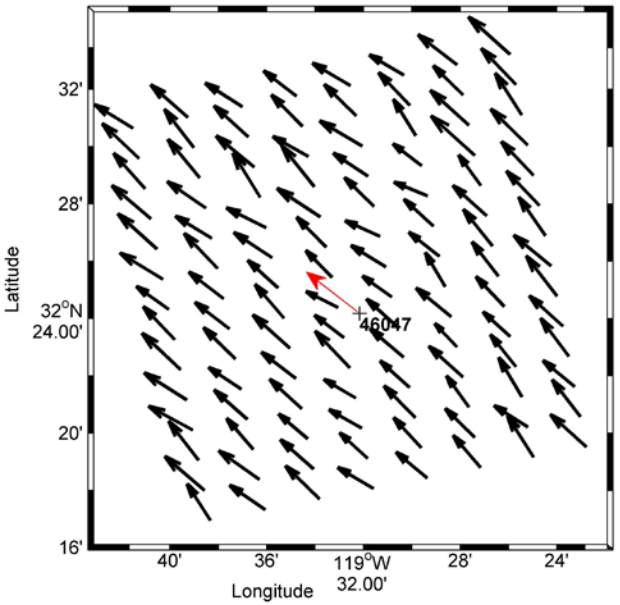
Buoy-measured wspd=19.0m/s
Our Retrieved wpsd=17.8 m/s

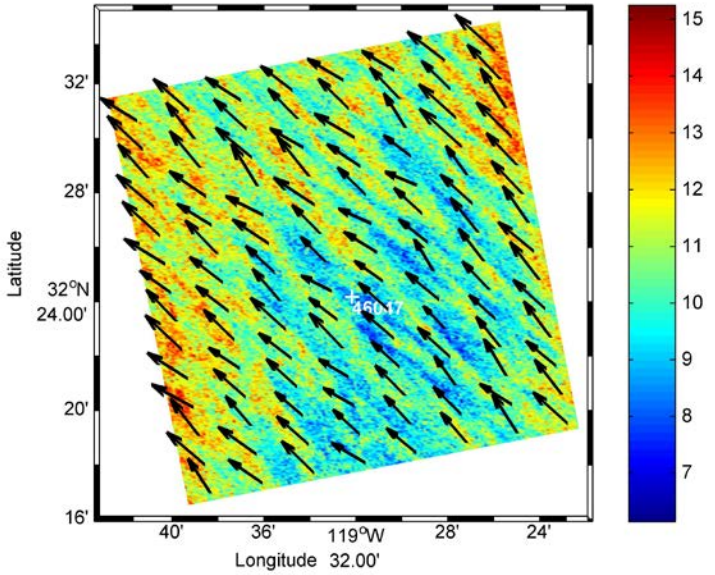
Wspd=11.1 m/s Wdir=311°



Sep 21, 2010 01:56 UTC







Buoy-measured wdir=311^{o}
Our Retrieved wdir=323^{o}

Buoy-measured wspd=11.1m/s
Our Retrieved wpsd=10.3 m/s

Conclusions to here -2

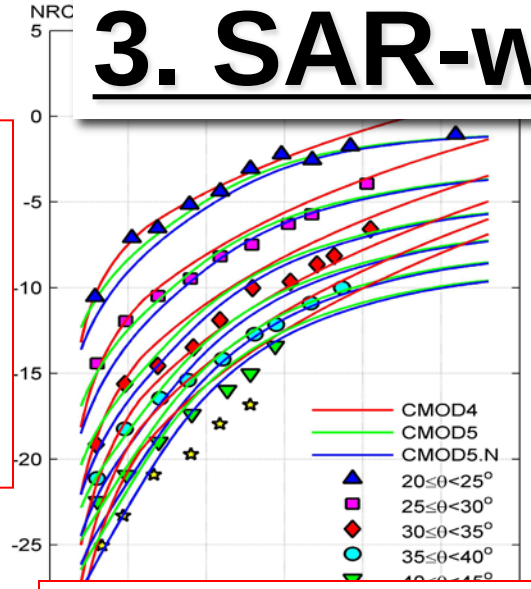
- odd / even symmetries of polarimetric correlation coefficients (PCC) for co- / cross-polarizations → remove wind ambiguity.

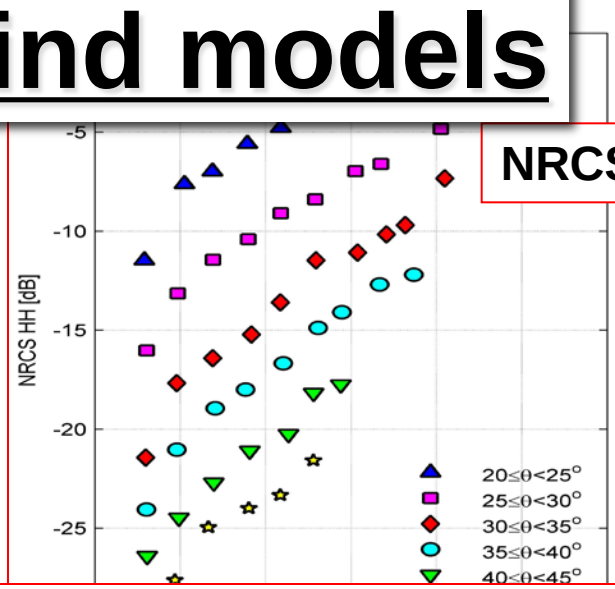
- we propose a retrieval algorithm for wind speed + direction simultaneously based on C-2PO, CMOD5.N for quad-pol data.

1) Zhang, B., Perrie, W., Vachon, P. Li, X., Pichel, W., 2012: Ocean Vector Winds Retrieval from C-band Fully Polarimetric SAR Measurements. In press *IEEE TGRS*
2) Zhang B., W. Perrie, and Y. He, 2011: Wind speed retrieval from RADARSAT-2 quad-polarization images using a new polarization ratio model. *J. Geophys. Res.*, **116**, doi:10.1029/2010JC006522.

3. SAR-wind models

NRCS_VV, NRCS_HH **depend on** incidence angle, wind direction

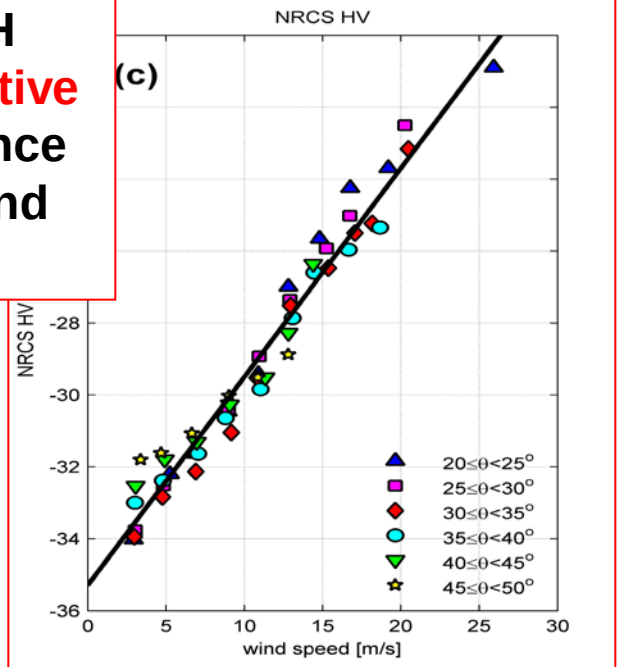


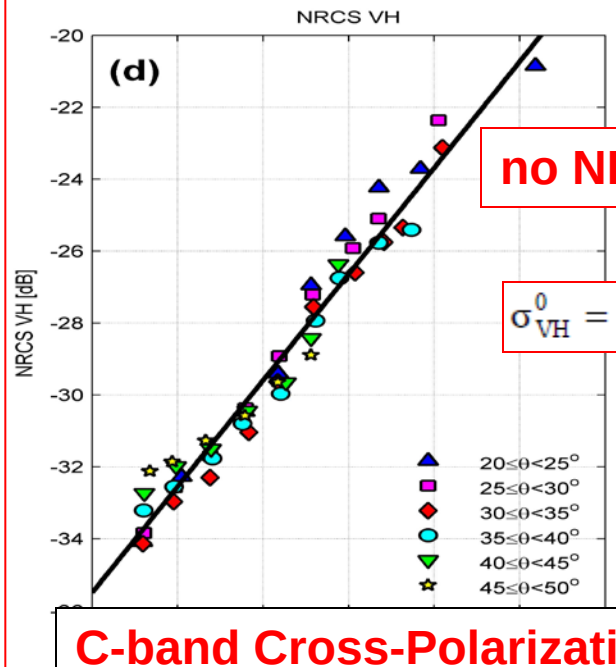


NRCS_VV saturates

Quad-Polarization Ocean Backscatter data

NRCS_HV, NRCS_VH **not sensitive** to incidence angle, wind direction



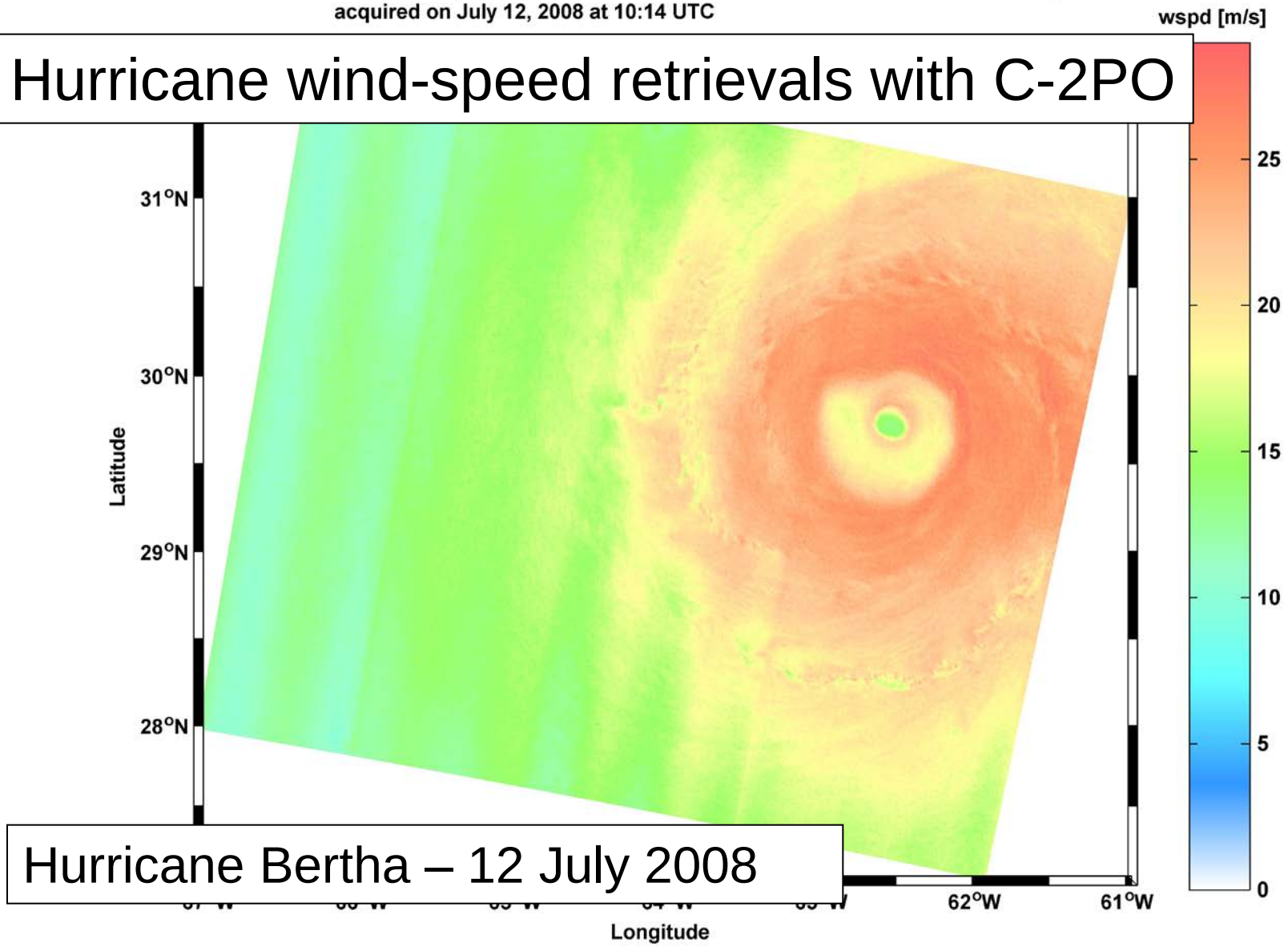


no NRCS_HV saturation

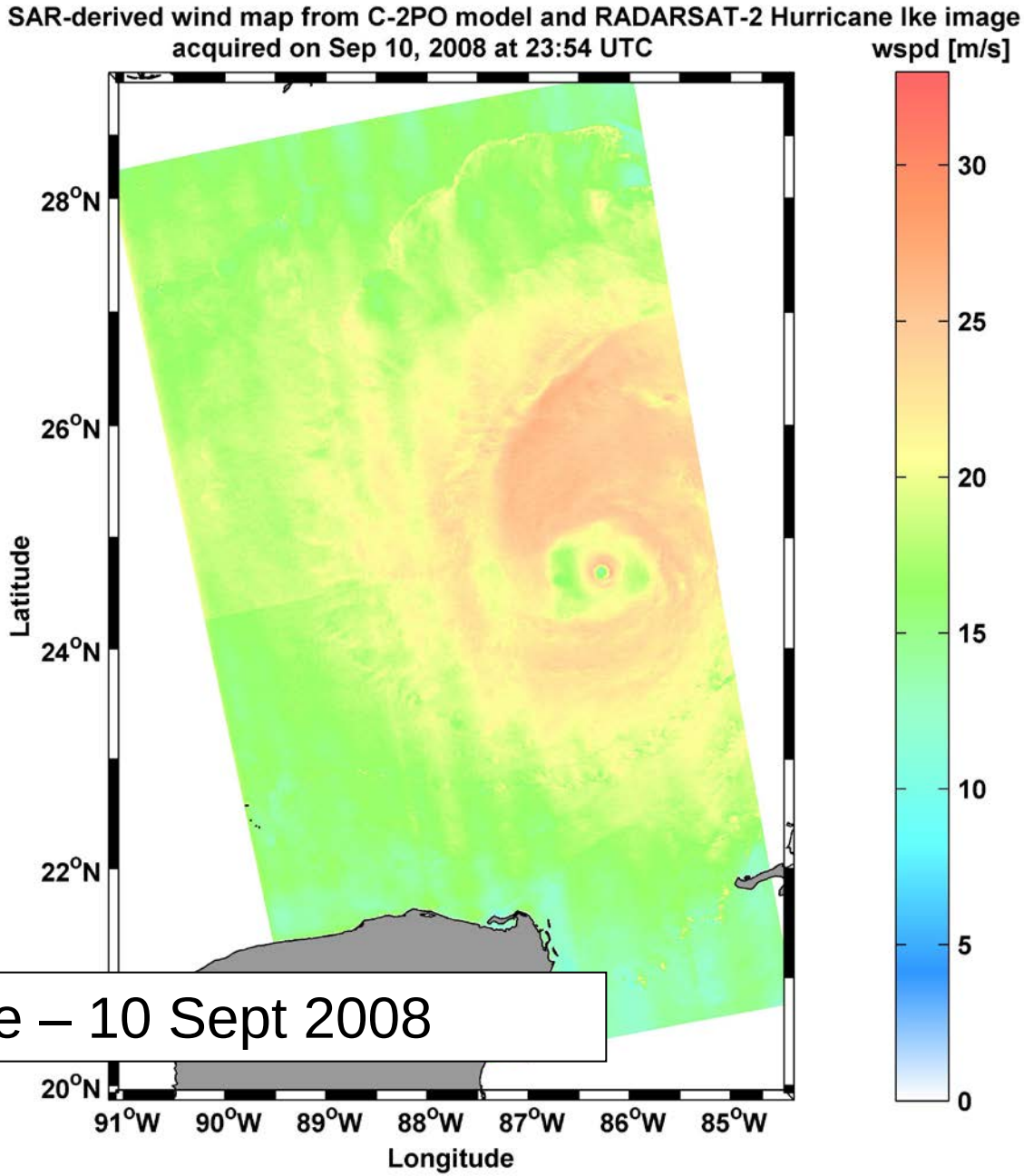
$$\sigma^0_{VH} = 0.580 * U_{10} - 35.652$$

C-band Cross-Polarization model: C-2PO

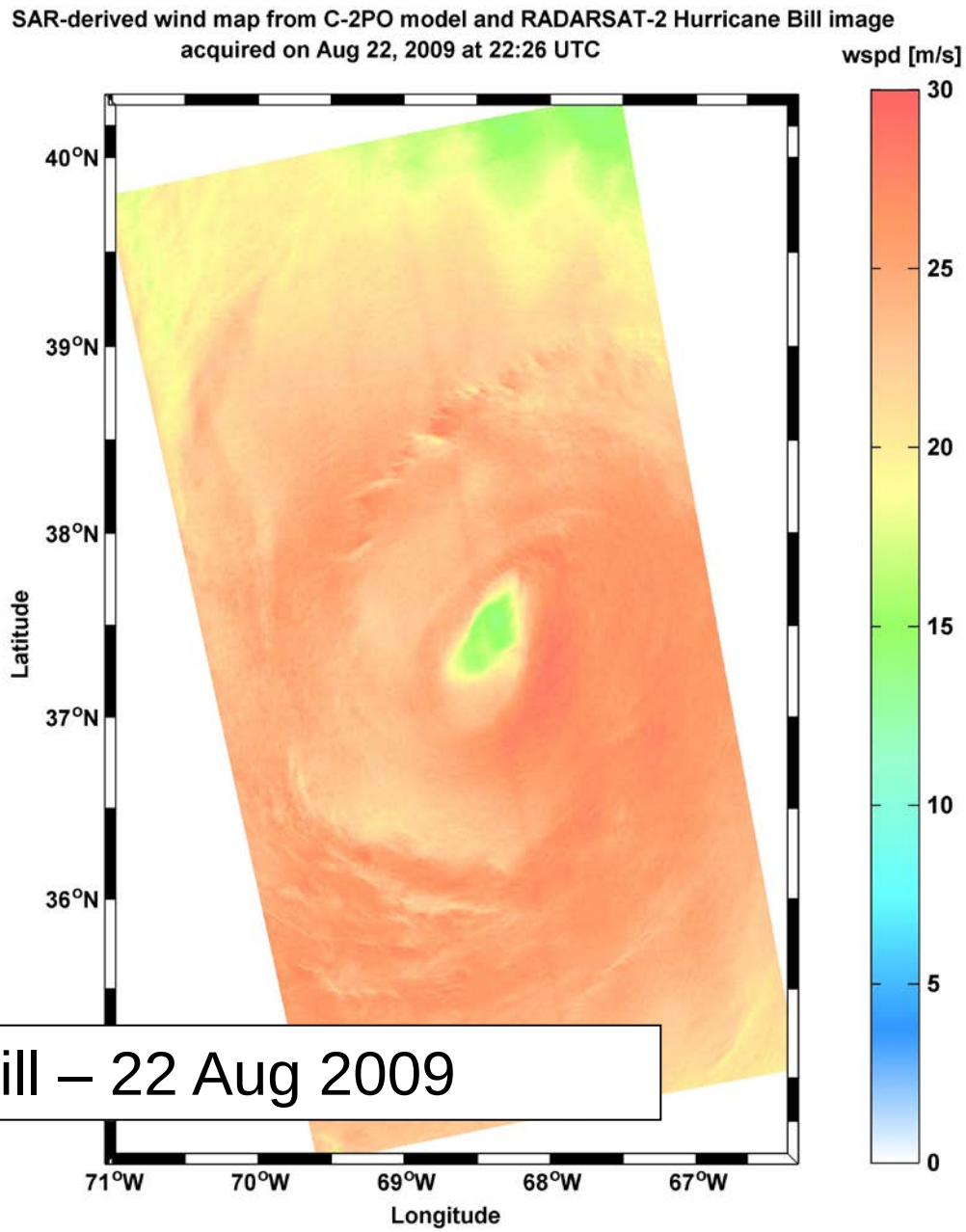
Hurricane wind-speed retrievals with C-2PO



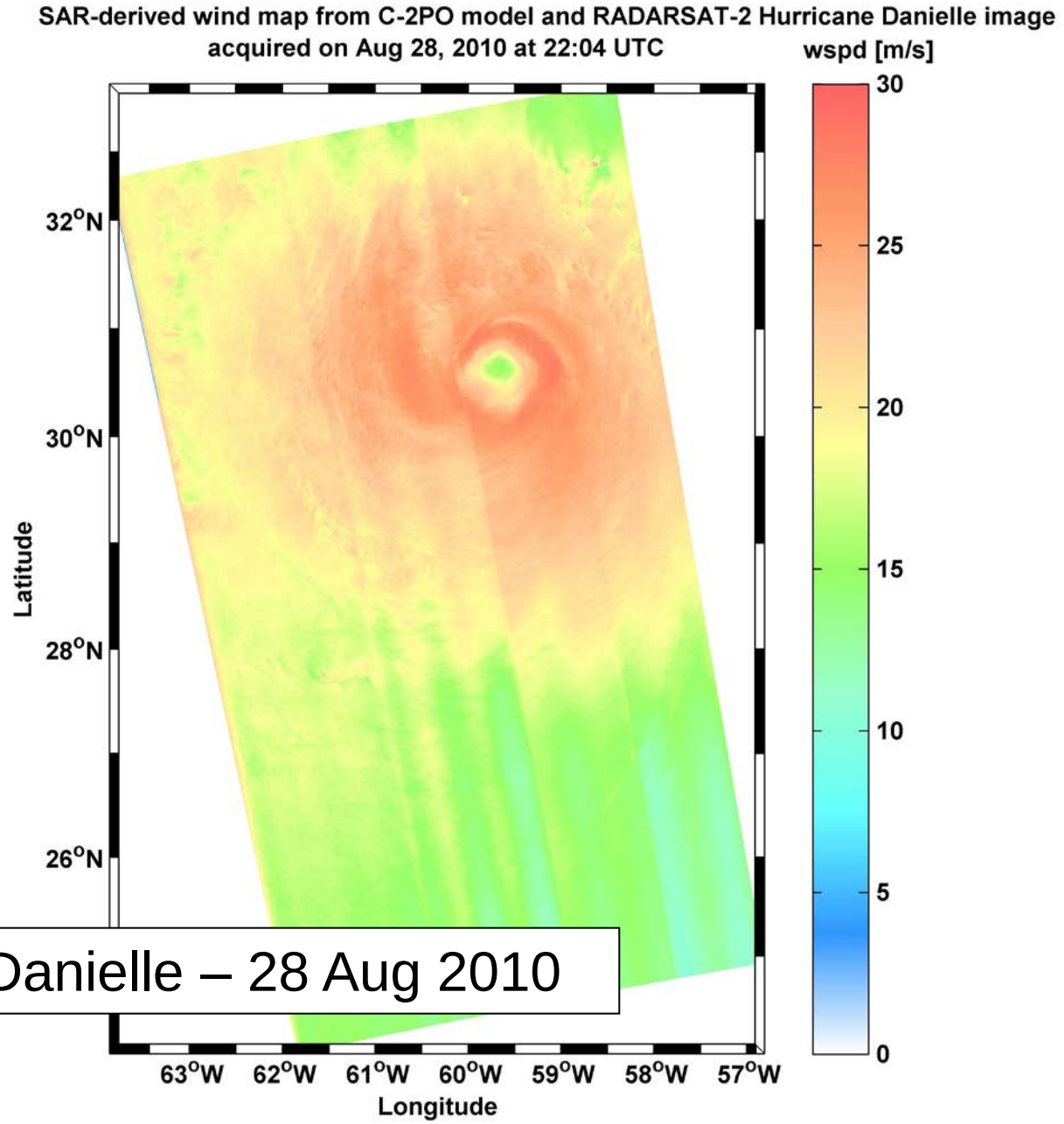
Hurricane Bertha – 12 July 2008



Hurricane Ike – 10 Sept 2008

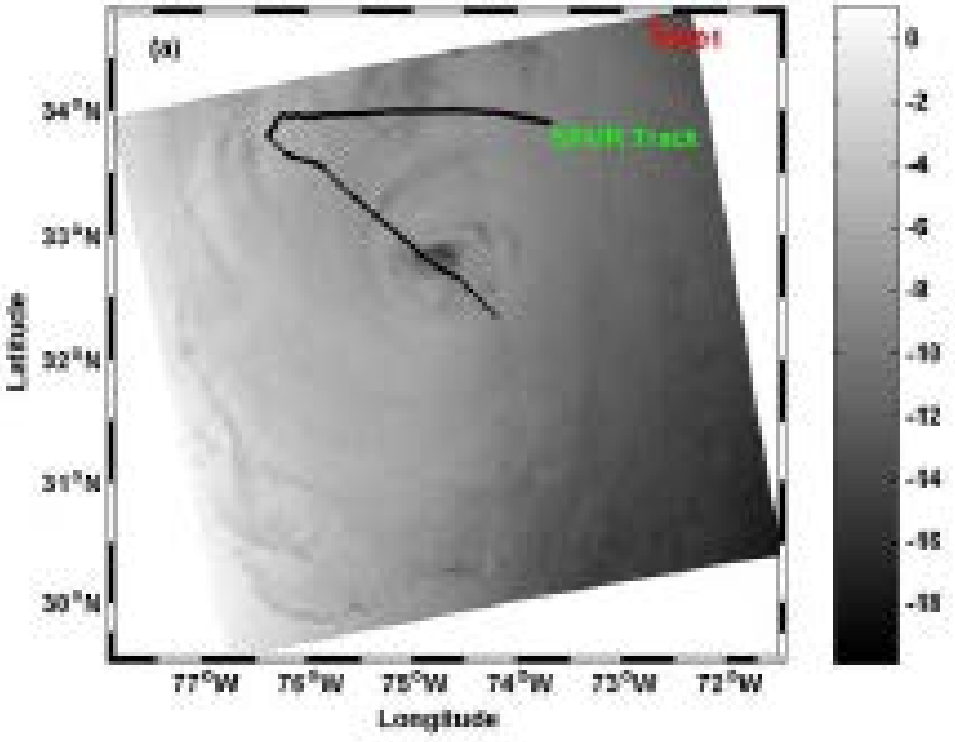


Hurricane Bill – 22 Aug 2009

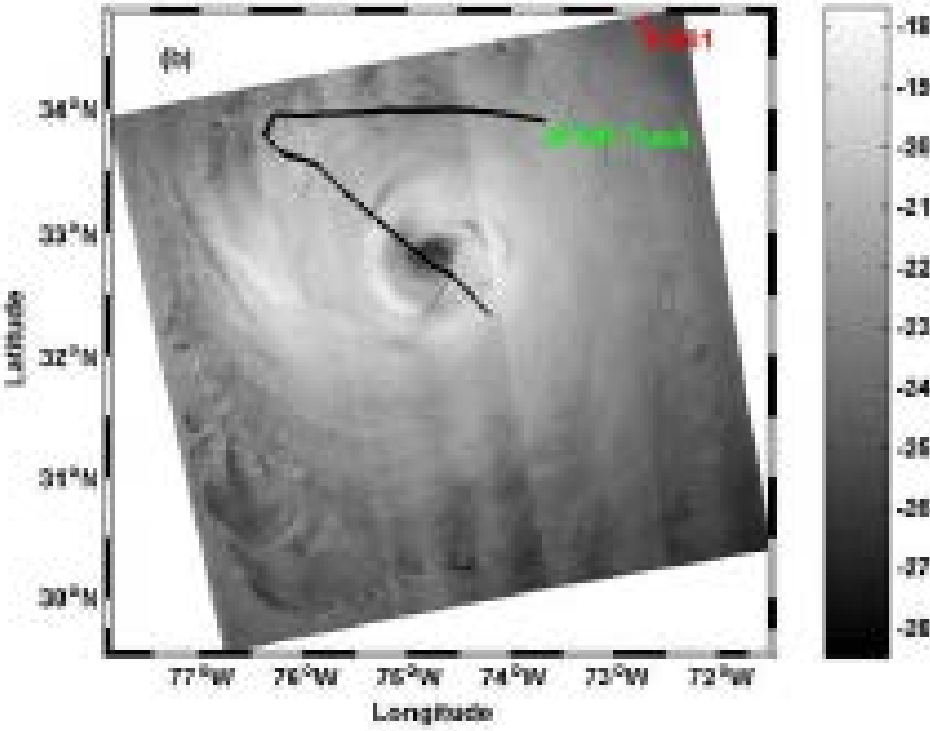


Hurricane Danielle – 28 Aug 2010

Hurricane Earl on Sep 02, 2010 at 22:59 UTC



VV polarization



VH polarization

RADARSAT-2 dual-polarization SAR image

Hurricane Earl on Sep 02, 2010 at 22:59 UTC

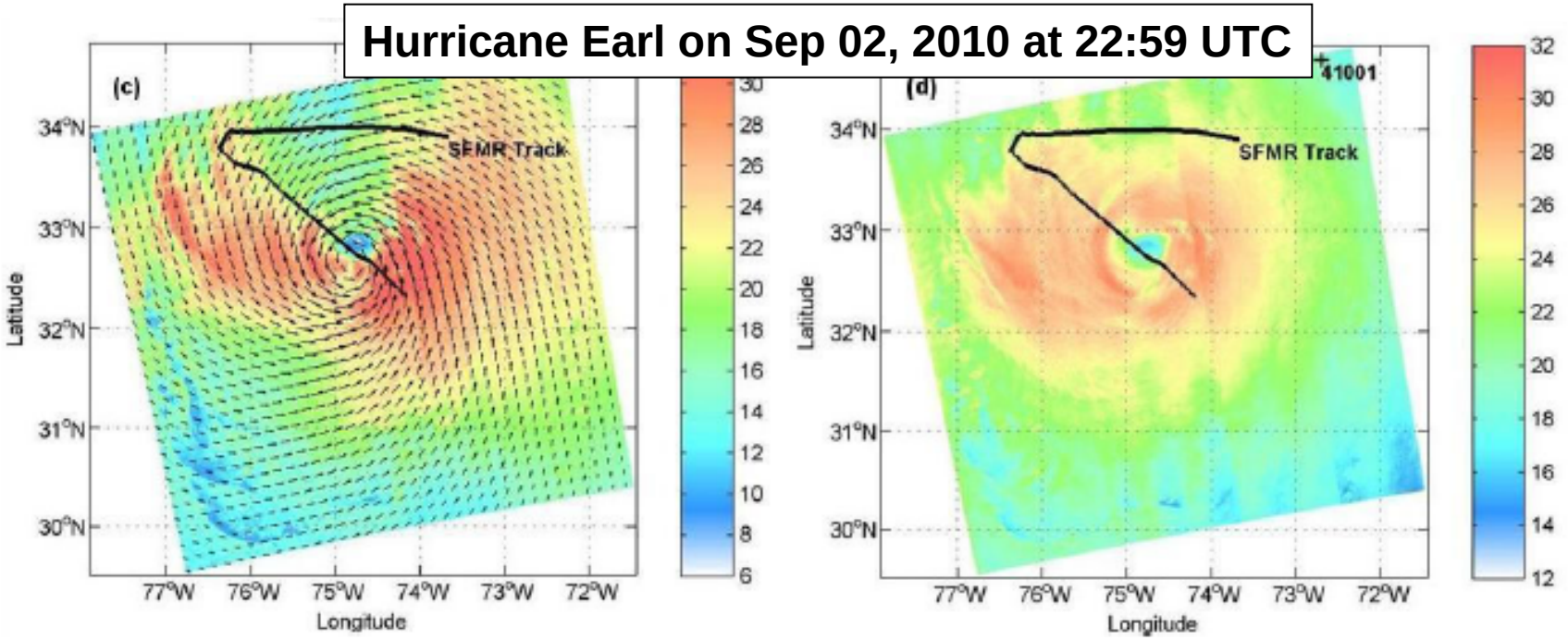
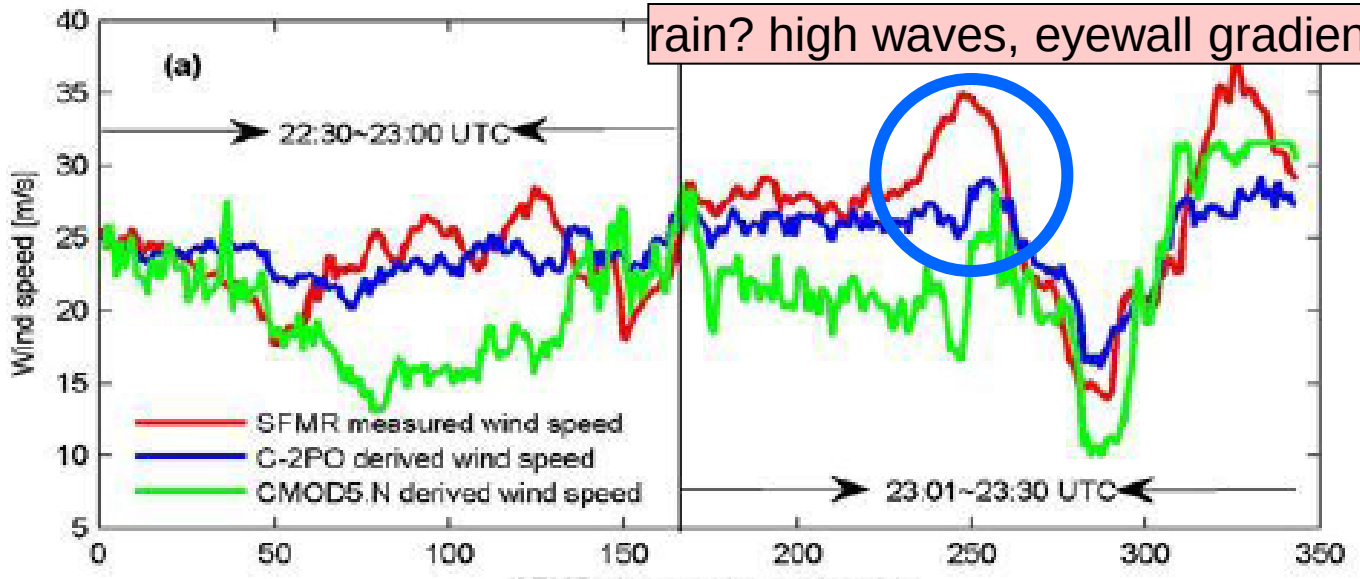


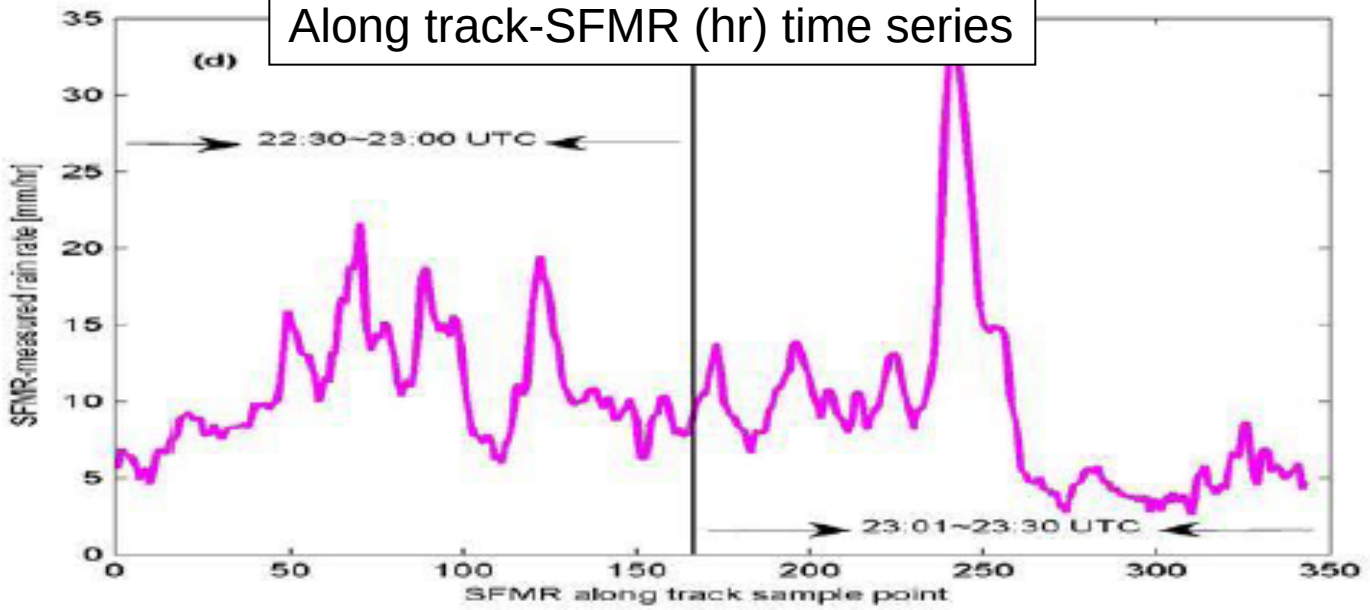
Fig. 3. One RADARSAT-2 dual-polarization SAR image acquired over Hurricane Earl at 22:59 UTC on September 2, 2010, (a) VV polarization and (b) VH polarization. Colorbar show sigma-naught in VV polarization (σ^0_{VV}) and in VH polarization (σ^0_{VH}) in dB, respectively. SAR-retrieved wind speeds from (c) the CMOD5.N model and σ^0_{VV}, with external wind directions from NOAA HRD H*Wind are overlaid, and (d) from the C-2PO model and σ^0_{VH}. Colorbar shows wind speeds at 10-m height (U_{10}) in m/s. RADARSAT-2 Data and Products © MacDonald, Dettwiler and Associates Ltd, - All Rights Reserved.

Comparison of C-2PO and CMOD5. SAR wind retrievals

rain? high waves, eyewall gradients…?

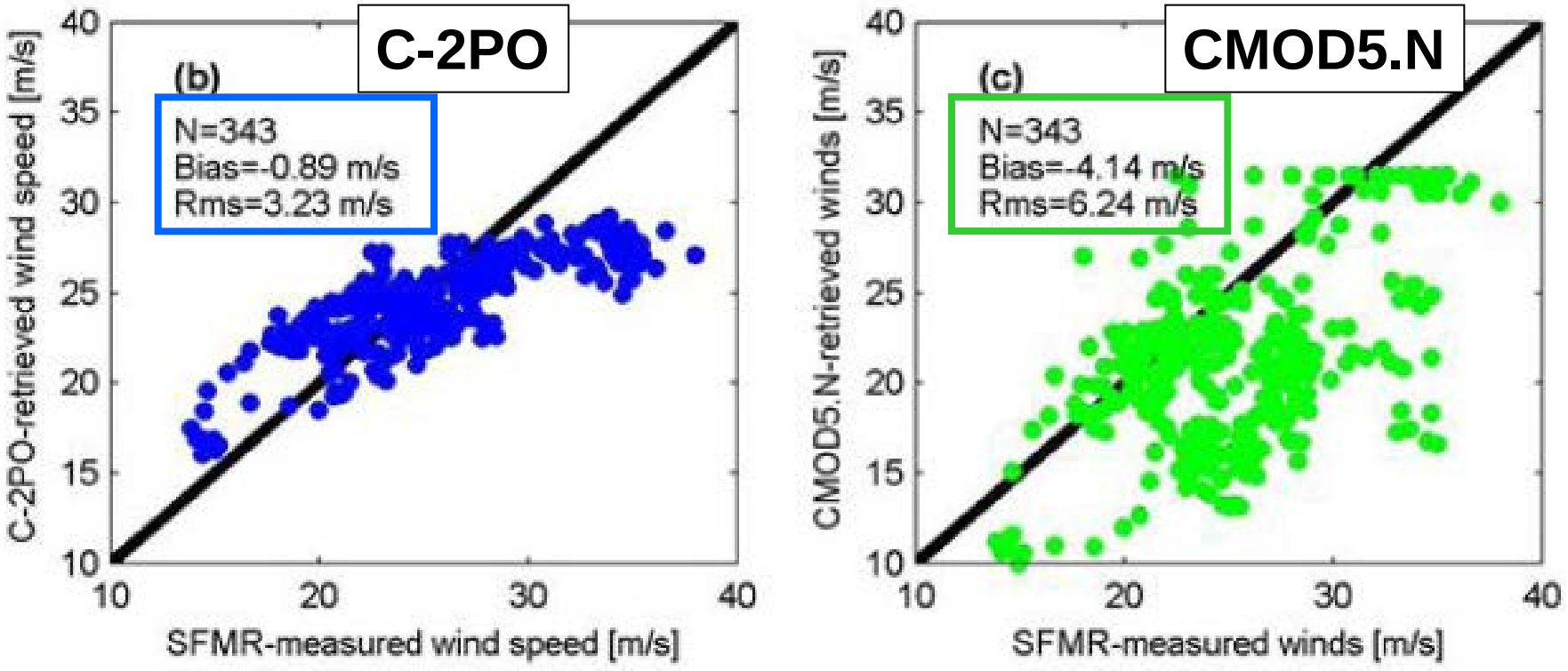


Along track-SFMR (hr) time series



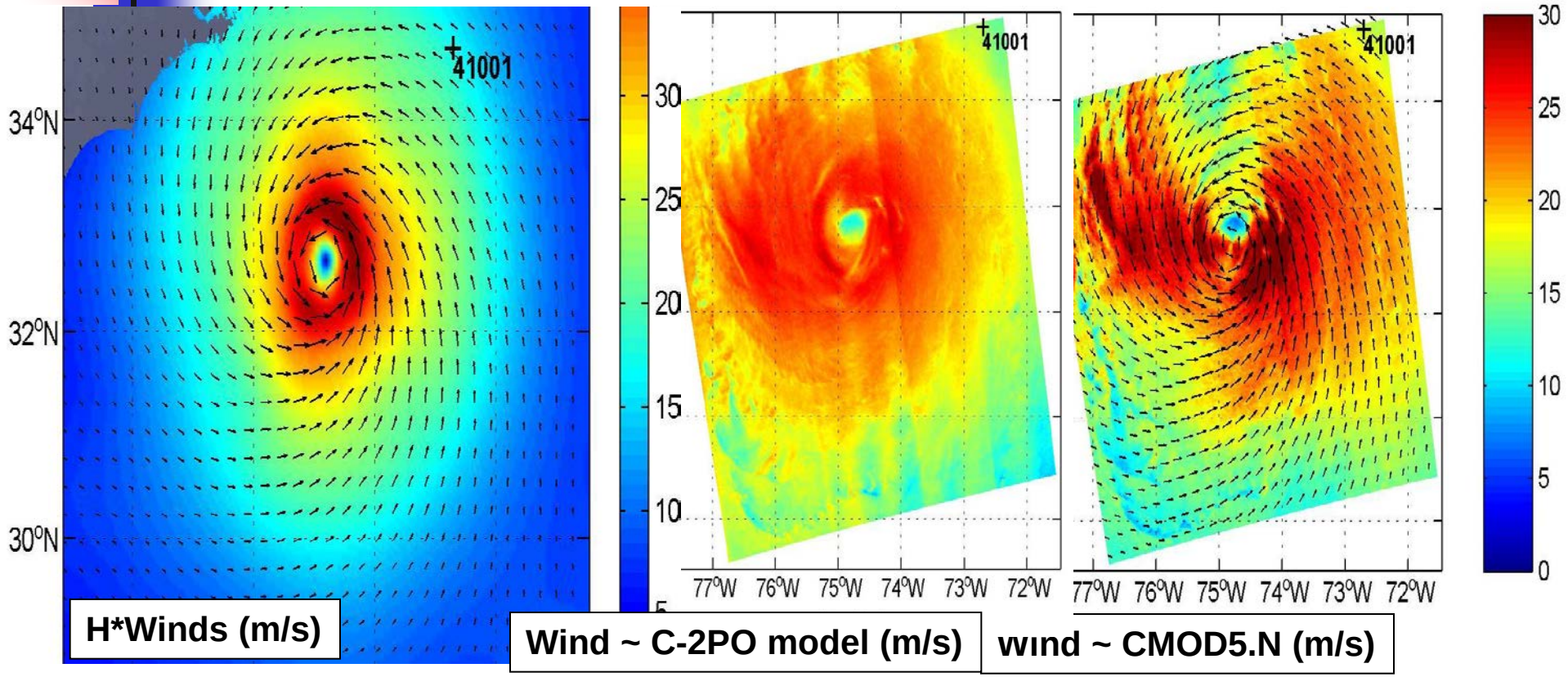
SFMR-measured 10s rain rates (mm/hr) time series (hr)

Hurricane Earl



Comparisons of C-2PO and CMOD5.N SAR-retrieved winds U10 (Sep 02, 2010 at 22:59 UTC) with collocated H*Wind

Hurricane Earl on Sep 02, 2010 at 22:59 UTC



H*Winds (m/s)

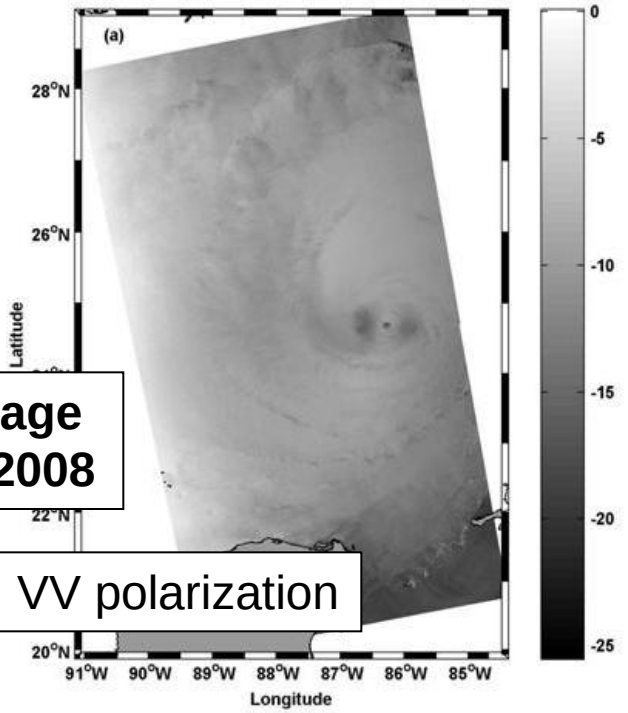
Wind ~ C-2PO model (m/s)

wind ~ CMOD5.N (m/s)

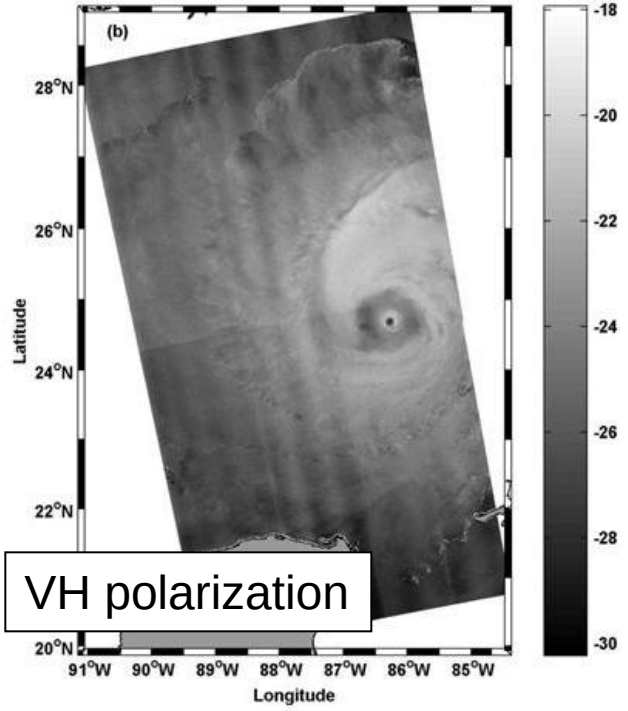
Wind speed from NDBC buoy #41001 is	18.1 m/s
from C-2PO model is	16.0 m/s
from CMOD5.N is	17.4 m/s
from H*Wind is	16.8 m/s

Hurricane Ike

dual-polarization SAR image at 23:56 UTC on Sep 10, 2008

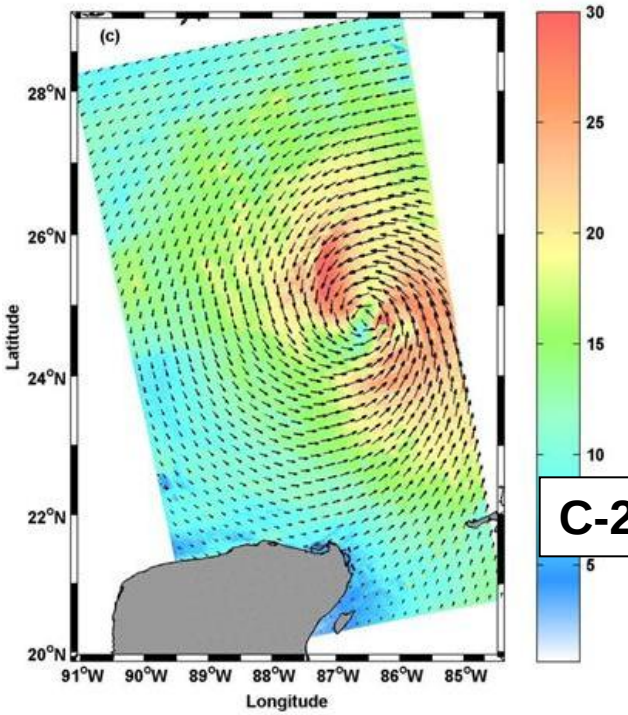


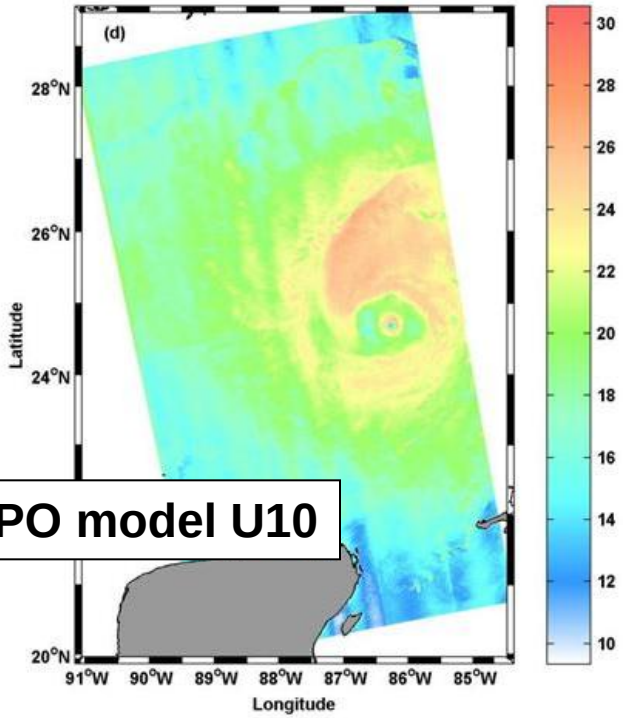
VV polarization



VH polarization

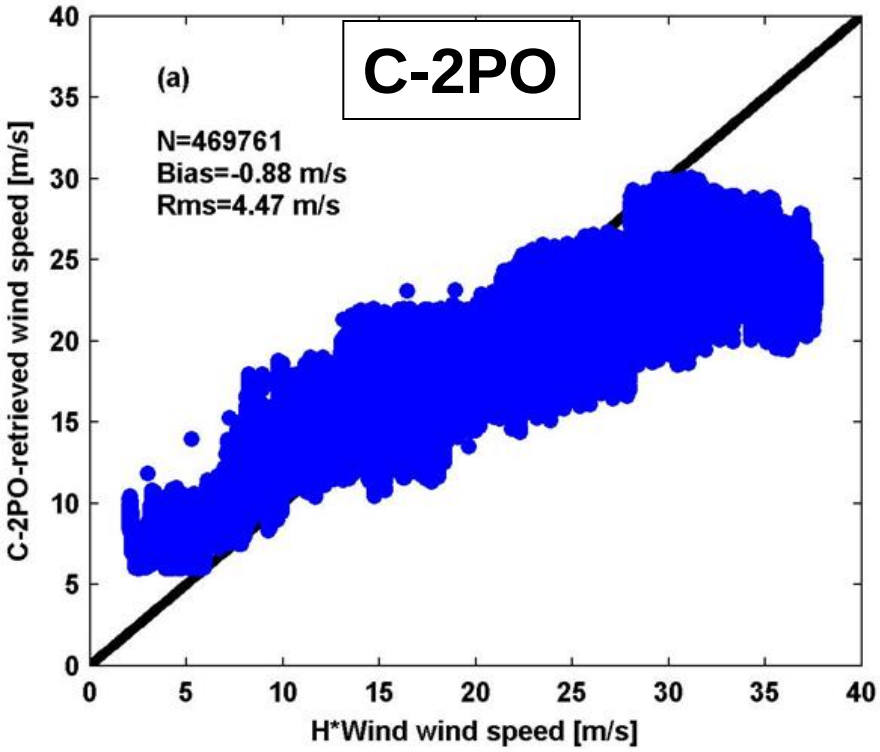
CMOD5.N + wind directions via H*Wind

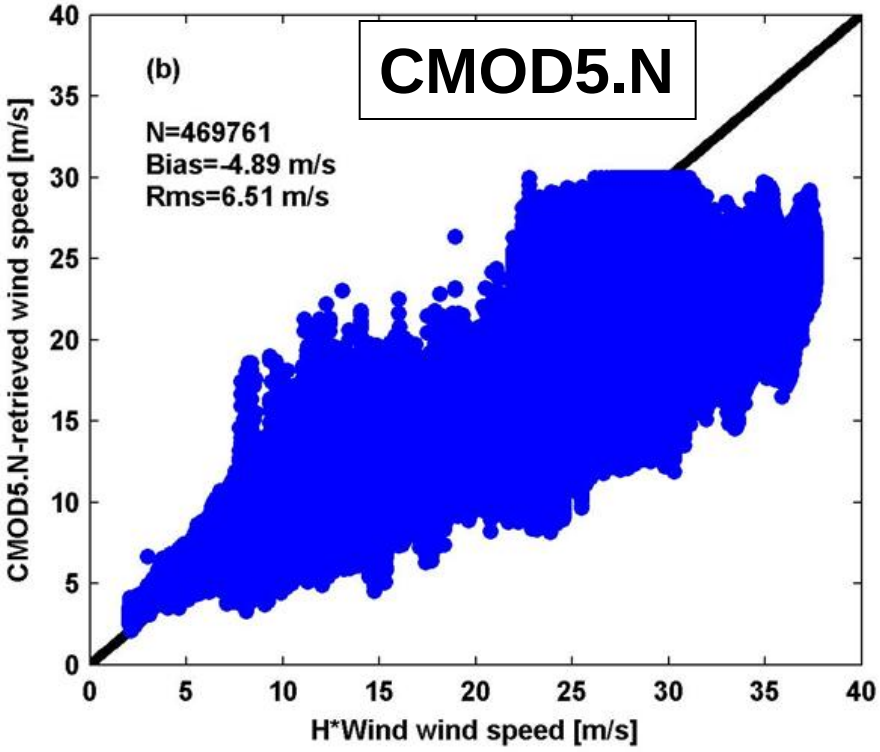




C-2PO model U10

Hurricane Ike

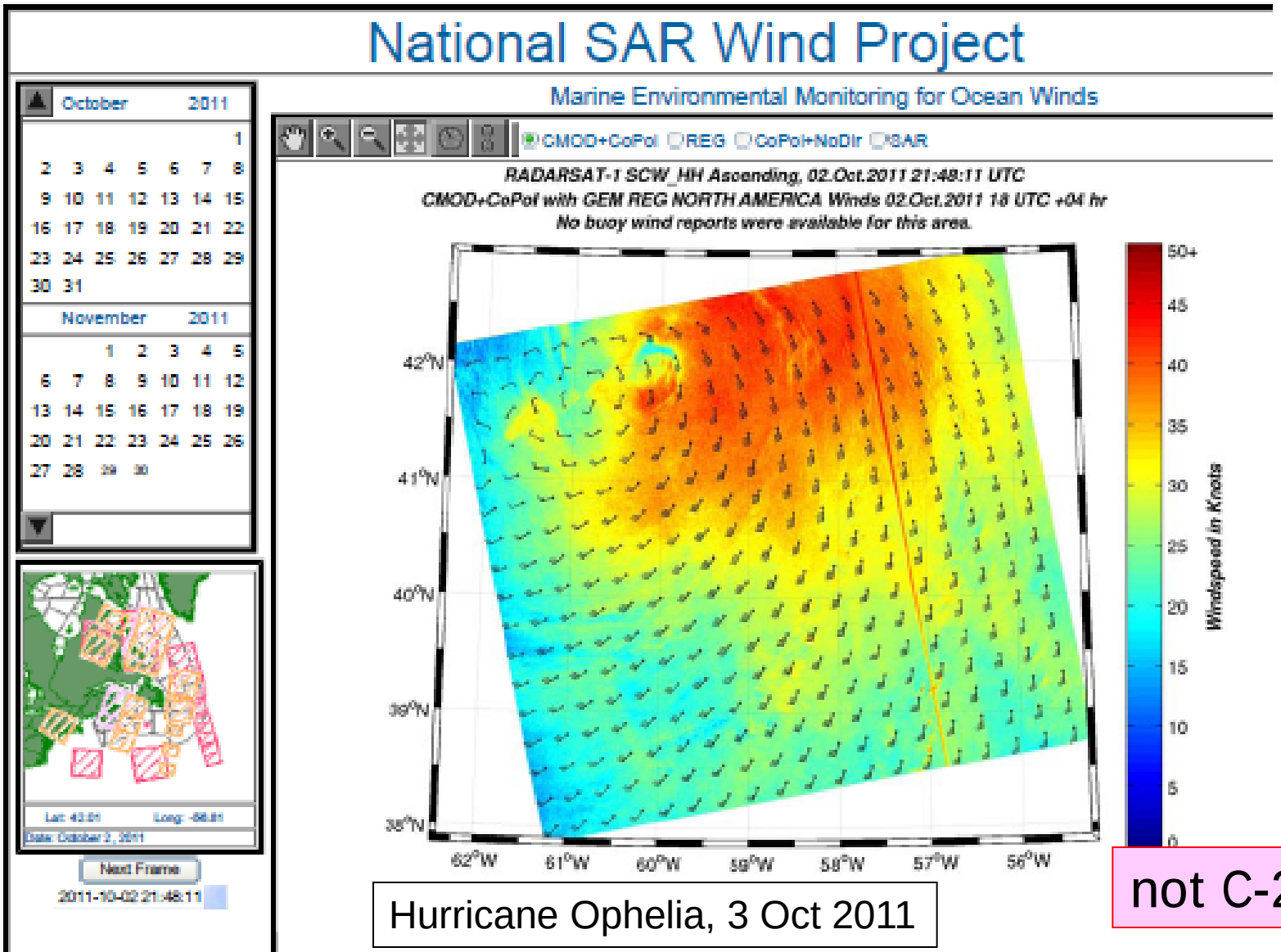




Comparisons of C-2PO and CMOD5.N SAR-retrieved winds U10 (23:56 UTC, on September 10, 2008) with collocated H*Wind

CMOD5.N → bias of -4.89 m/s and RMS error of 6.51 m/s
C-2PO → bias of -0.88 m/s and RMS error of 4.47 m/s

The future – coordinated international constellation of SAR Winds satellites ?



Hurricane Ophelia, 3 Oct 2011

not C-2PO

Conclusions – part 3

- C-2PO model presented
- insensitive to wind direction, radar incidence angle
  - easy mapping of observed cross-pol NRCS to wind speed
- avoids errors in wind speed retrievals that occur in CMOD5.N
- in quad-pol data, C-2PO does not seem to saturate
  - → potential for hurricane wind retrievals
- dual-pol Earl: high wind verification of R2 SAR – airborne SFMR

Zhang, B., W. Perrie (2011), Cross-polarized synthetic aperture radar: a new measurement technique for Hurricanes, in press - *Bulletin of the American Meteorological Society* (BAMS).