

Estimating Winds From Synthetic Aperture Radar in Typhoon Conditions

Chris Wackerman¹, Jochen Horstmann², Ralph Foster³, Hans Graber⁴, Mike Caruso⁴

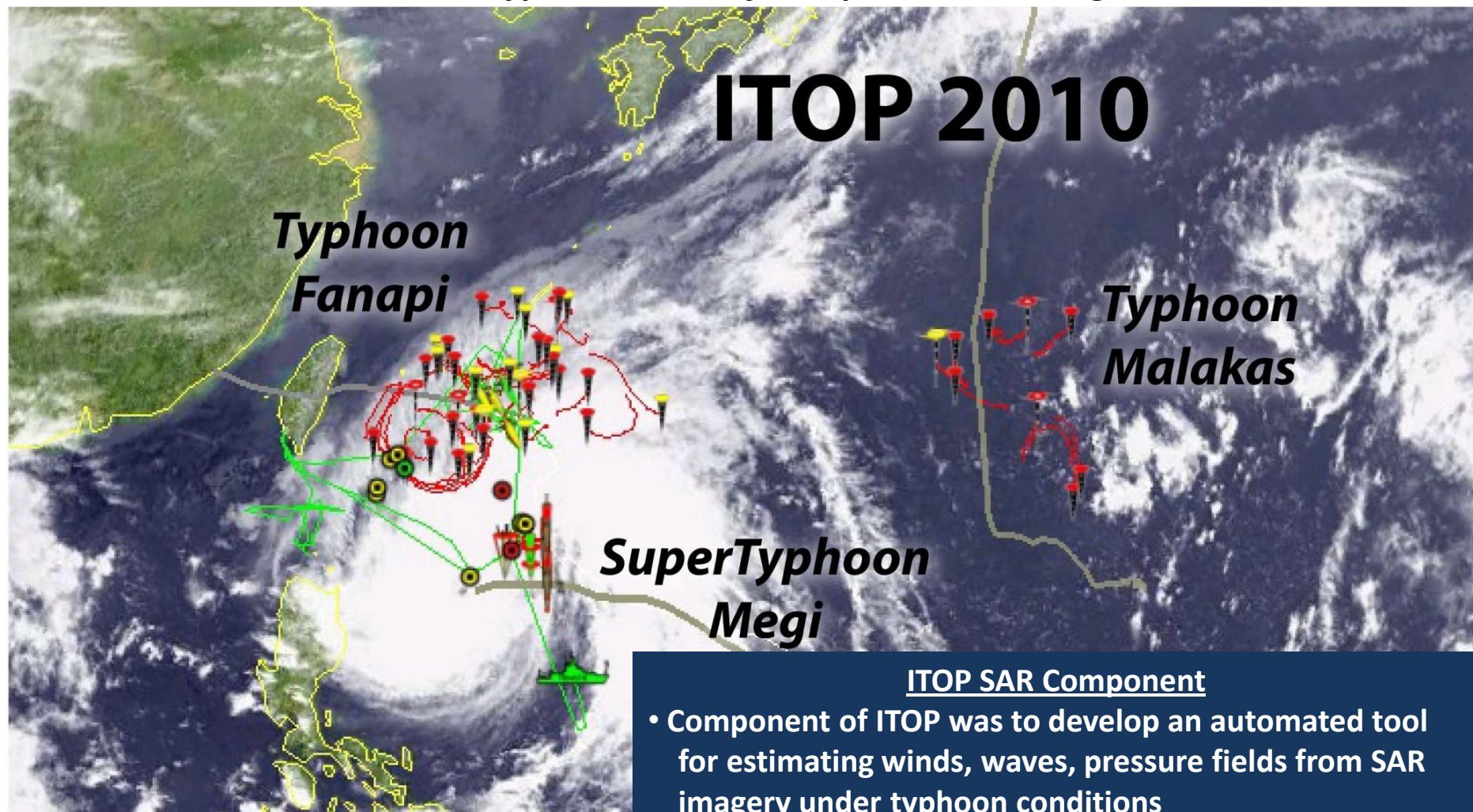
¹General Dynamics AIS, ²NATO/NURC, ³APL/UoW, ⁴CSTARS/UoM

SeaSAR 2012, 18-22 June 2012, Tromso Norway

Background

ONR Impact of Typhoons on the Ocean in the Pacific (ITOP) Program

Joint ONR-Taiwan large scale campaign to measure environmental properties during the 2010 typhoon season for improved modeling



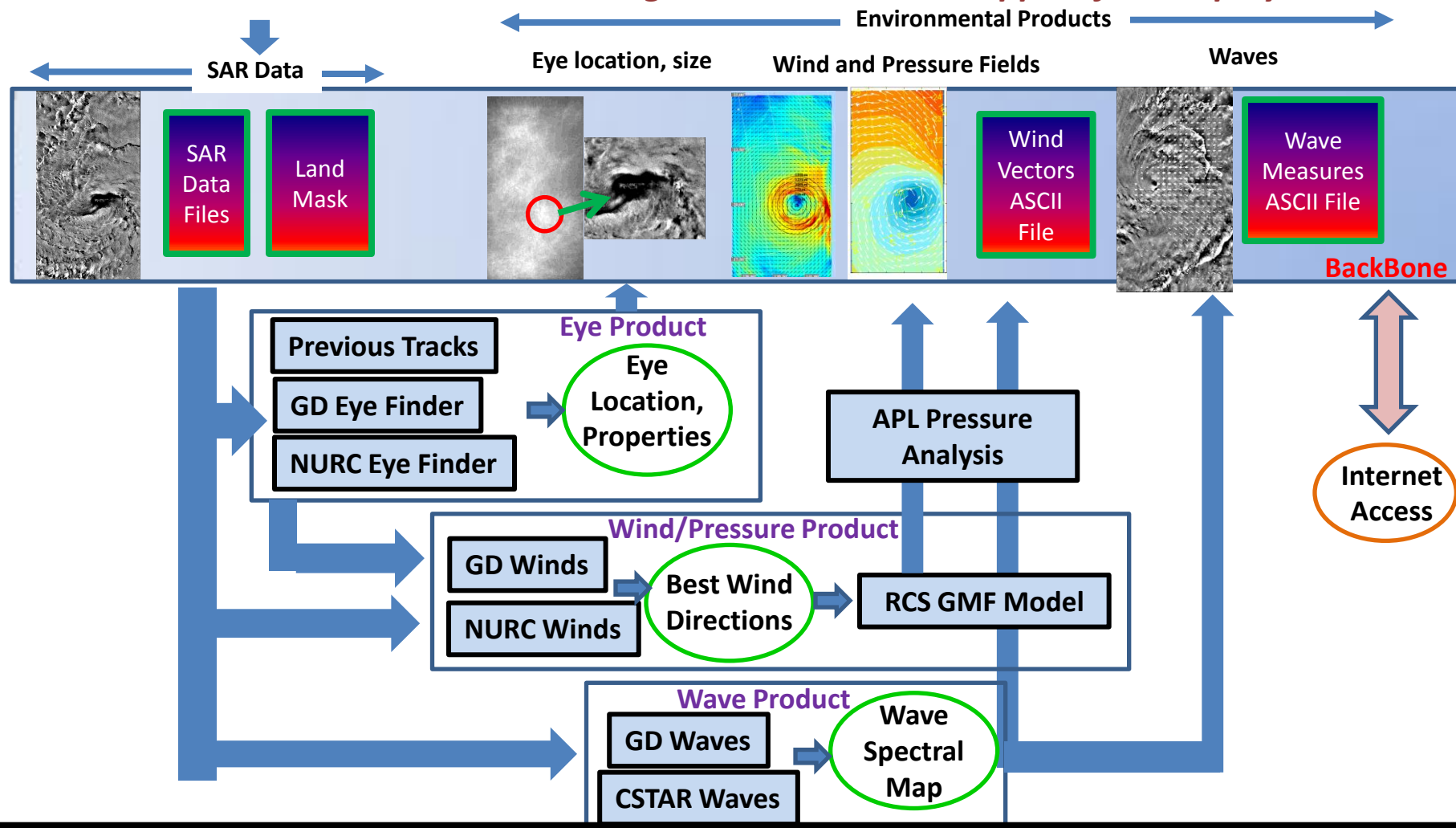
ITOP SAR Component

- Component of ITOP was to develop an automated tool for estimating winds, waves, pressure fields from SAR imagery under typhoon conditions
- Purpose is to use SAR estimate to initiate models to prediction storm path/strength

SAR Typhoon Processing System (SARTyPS)

CSTARS SAR Backbone
Processing System

*Real-time SAR environmental product generation system
being built at CSTARS to support field deployment*

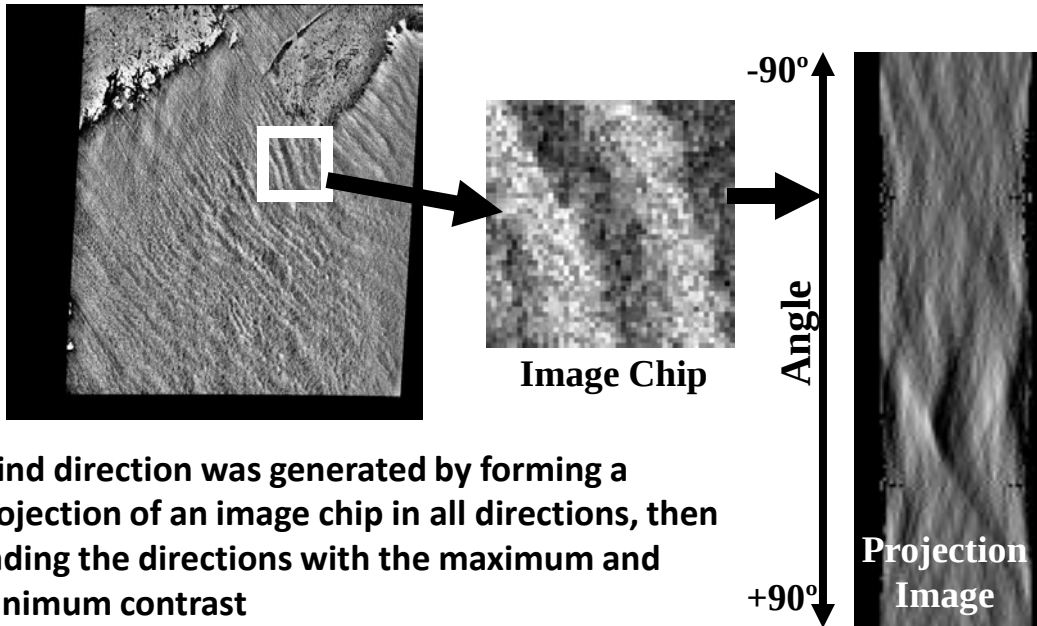


ITOP SAR Working Group

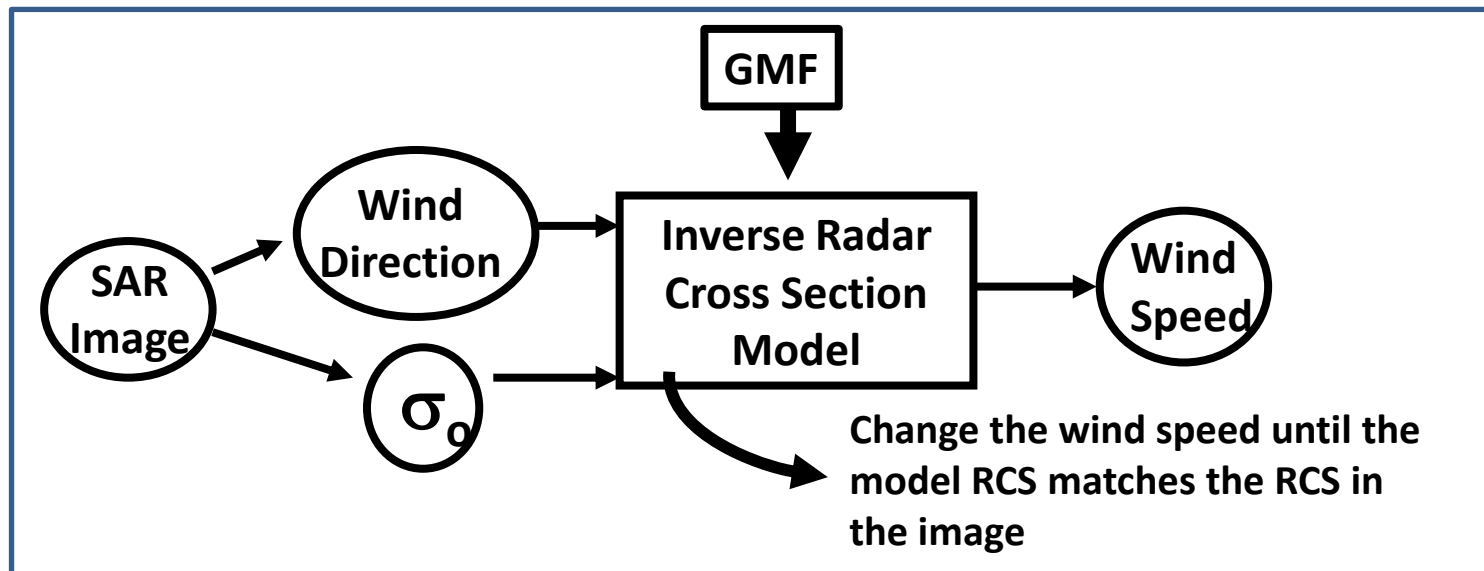
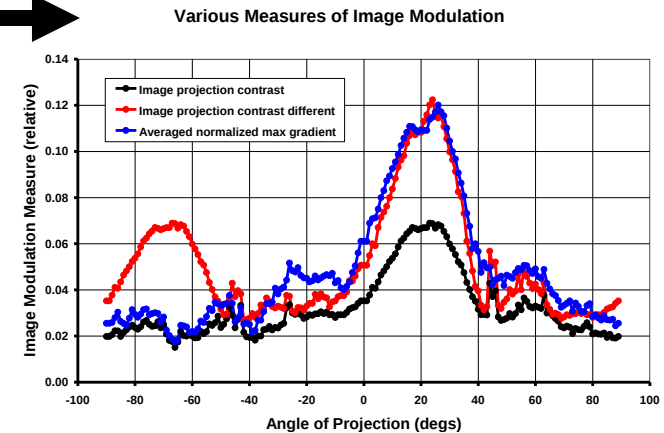
Dr. Hans Graber – CSTARS UoM; SAR Tasking, Processing
Mr. Mike Caruso – CSTARS UoM: SAR Tasking, Processing
Dr. Roland Romeiser – CSTARS UoM: Wave Estimation

Dr. Jochen Horstmann – NATO/NURC: Wind Estimation
Dr. Ralph Foster – APL/UoW: Wind, Pressure Estimation
Dr. Chris Wackerman – GDAIS: Wind, Wave Estimation

GD SAR Wind Algorithm



Wind direction was generated by forming a projection of an image chip in all directions, then finding the directions with the maximum and minimum contrast



SAR Data Sets

From RADARSAT AO, Processed at CSTARS

7 Historical Pacific storms (2004-2007): RS1 CHH QSCAT GT

4 Historical Atlantic storms (2005 Katrina, 2006 Helene):

RS1 CHH: 4 QSCAT, 2 SFMR GT

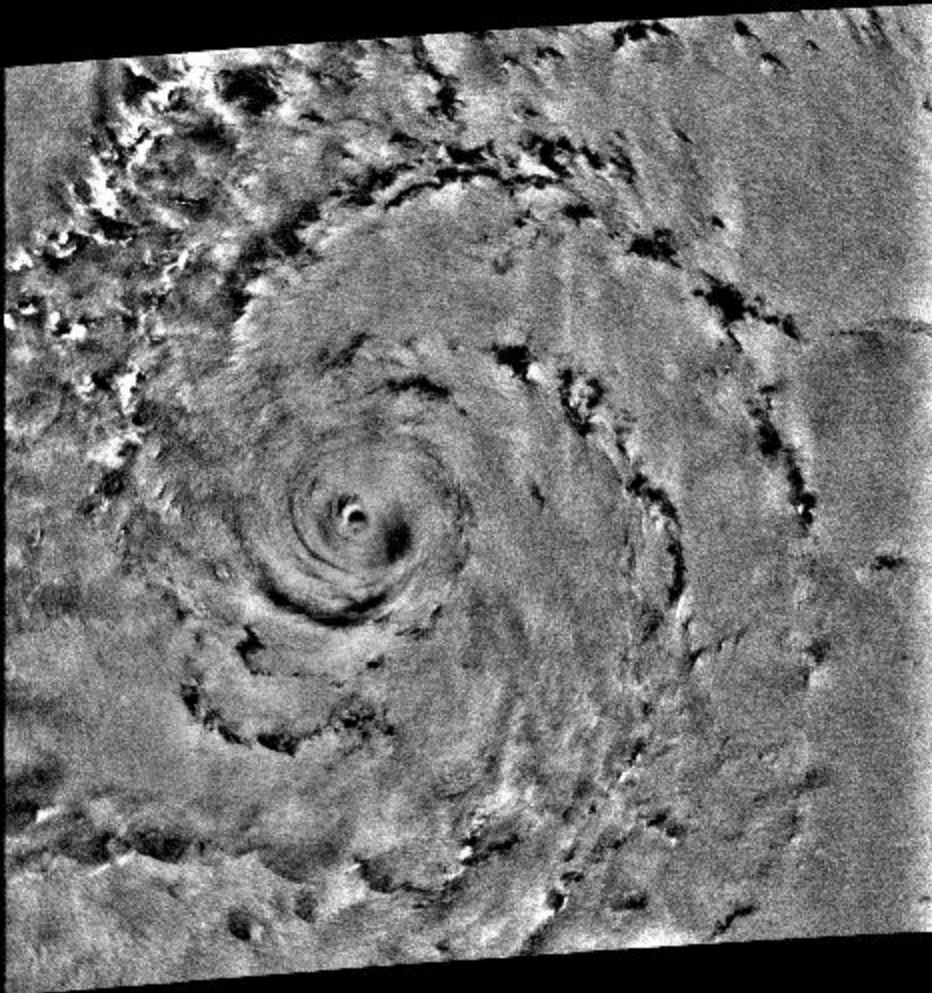
Ground Truth Processing

- Location corrected to be storm relative, then shifted to SAR eye
- Dropsonde U10N from fitting 10-40m winds to mean flow profile
- SAR ws *1.1 to compare to SFMR (instantaneous vs. sustained winds)

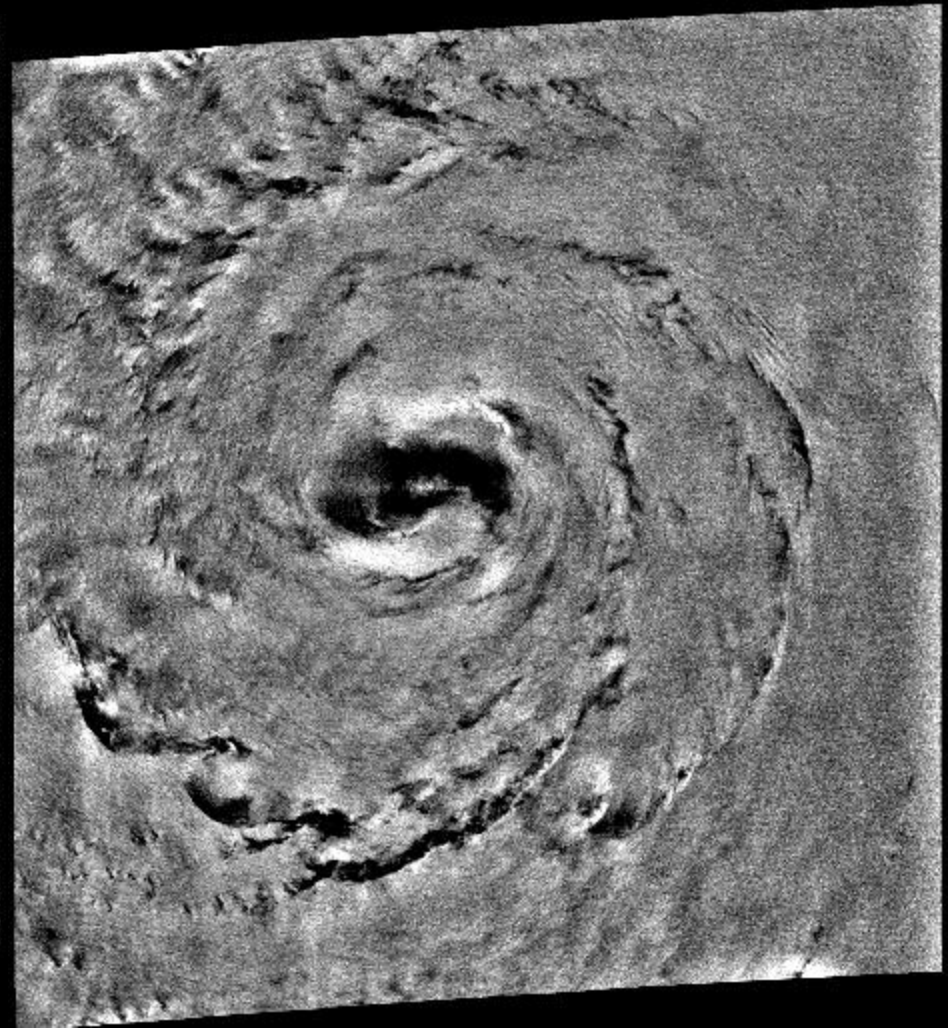
ONR ITOP SAR Collections: Tasked, Processed by CSTARS

ITOP 2010 SAR Eye Hits and Near Misses							
Storm	Date (UTC)	Time (UTC)	Satellite	Band	Polarization	Comments	C130 flight
Fanapi	20100912	20:23	RSAT-2	C	VV	Near Miss	1009121741
Fanapi	20100913	09:08	RSAT-2	C	HH/HV	Near Miss	1009131807 (+9 hrs)
Fanapi	20100917	21:14	RSAT-2	C	HH/HV	Near Miss	1009171805
Malakas	20100922	22:03	RSAT-2	C	HH/HV	Eye	1009221742
Malakas	20100924	08:49	RSAT-2	C	HH/HV	Near Miss	1009241329 (+6 hrs)
Malakas	20100929	08:27	Cosmo-SkyMed-3	X	VV	Cold Wake	1009291223 (+5 hrs)
Megi	20101014	09:02	RSAT-2	C	HH/HV	need to orde	1010132253 (-5 hrs)
Megi	20101014	20:58	Cosmo-SkyMed-3	X	VV	Miss	1010141745
Megi	20101014	21:17	Cosmo-SkyMed-2	X	VV	Miss	1010141745
Megi	20101015	21:00	RSAT-2	C	VV	Eye	1010151846
Megi	20101016	09:17	Cosmo-SkyMed-3	X	VV	Eye	1010151846 (-5 hrs)
Megi	20101017	01:27	EnviSAT	C	VV	Eye	1010161740
Megi	20101017	09:35	Cosmo-SkyMed-3	X	VV	Eye	1010170650 (in route)
Megi	20101017	21:41	RSAT-2	C	VV	Eye	1010170650 (-6 hrs); 1010172347(+7 hrs)
Megi	20101017	21:53	Cosmo-SkyMed-3	X	VV	Eye	1010170650 (-6 hrs); 1010172347(+7 hrs)
Megi	20101018	22:12	Cosmo-SkyMed-3	X	VV	Eye	no flights available
Megi	20101019	09:41	Cosmo-SkyMed-1	X	VV	Eye	no flights available
Megi	20101019	22:30	Cosmo-SkyMed-3	X	VV	Eye	no flights available

Example SAR Images: Historic Pacific Storms

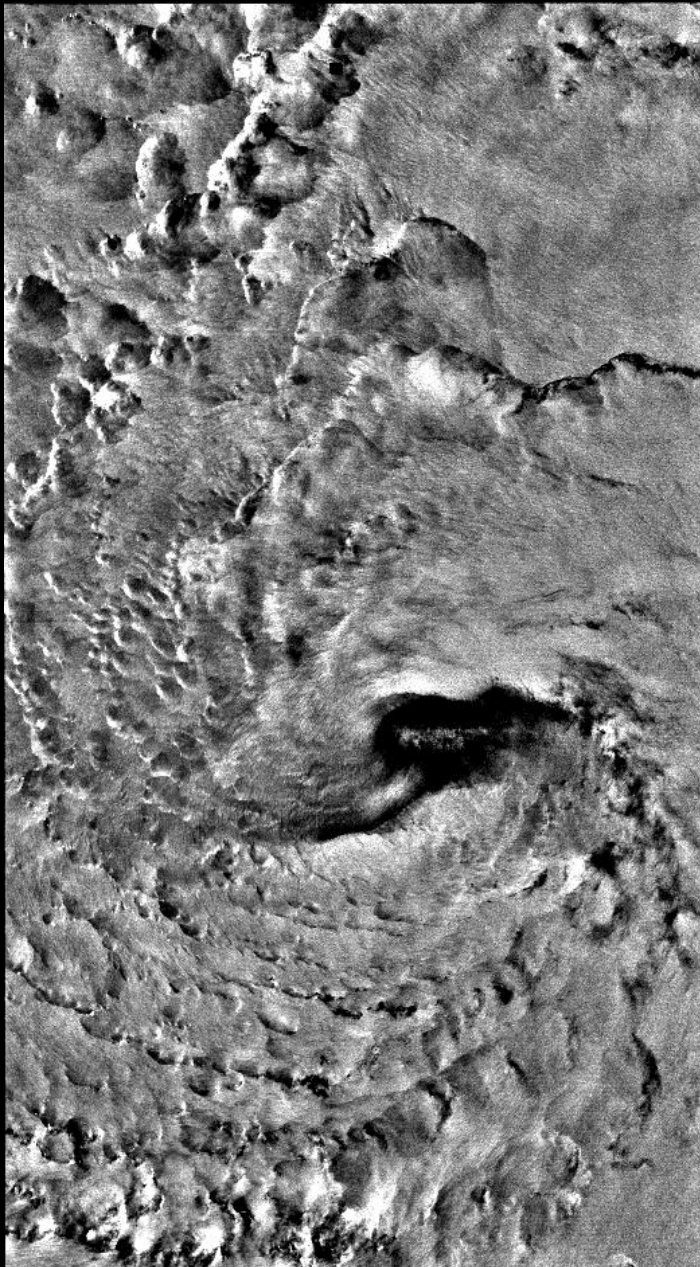


Typhoon Ewiniar July 2006: RS1 CHH

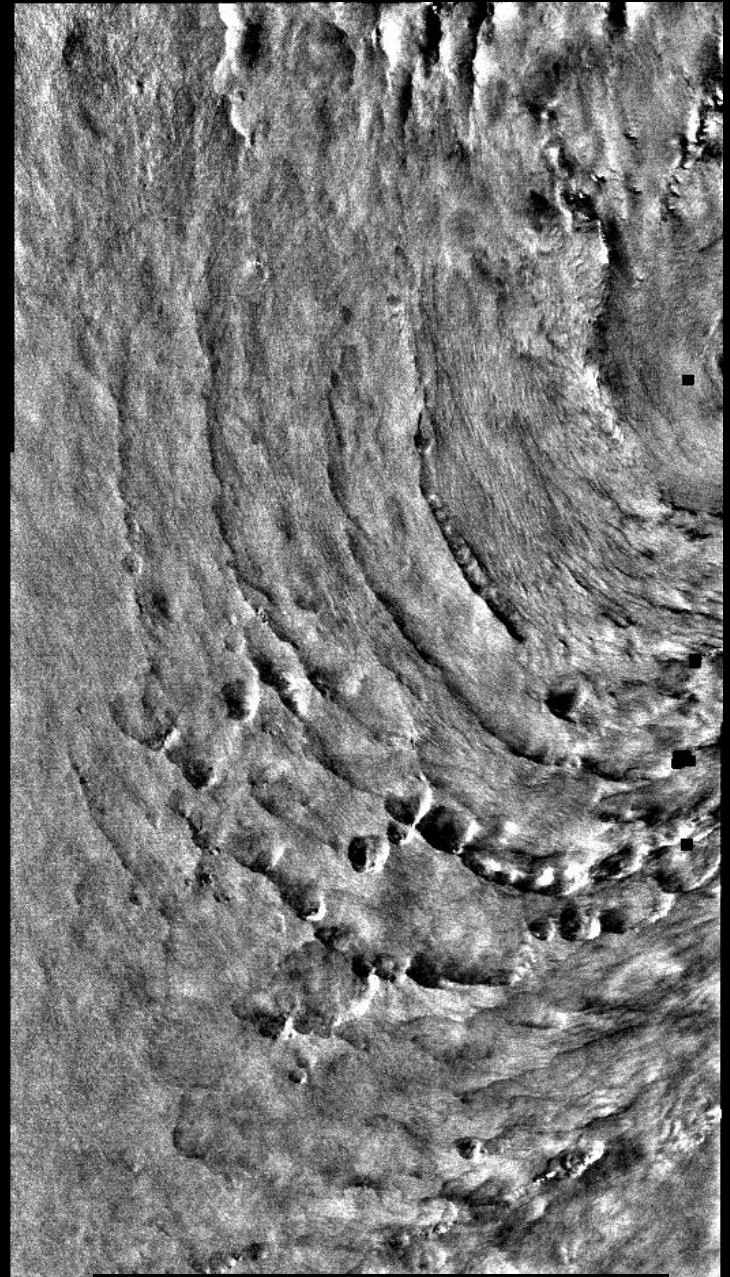


Typhoon Fitow August 2007: RS1 CHH

Example SAR Images: ITOP 2010 Storms

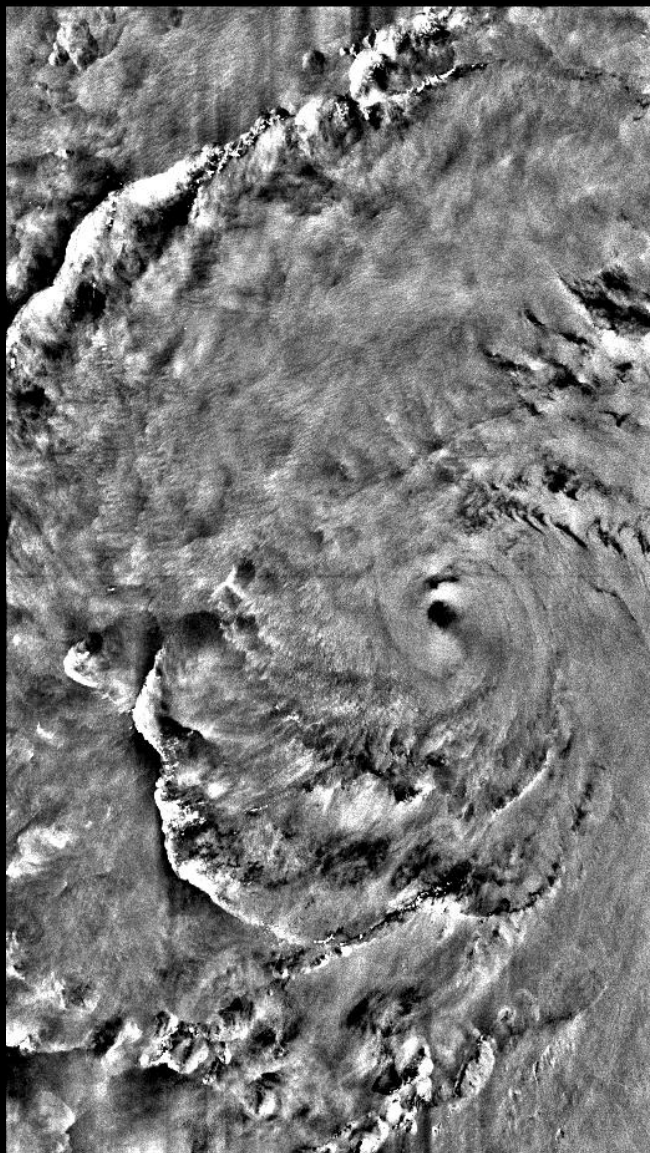


Malakas 9/22/10: RS2 C-HH

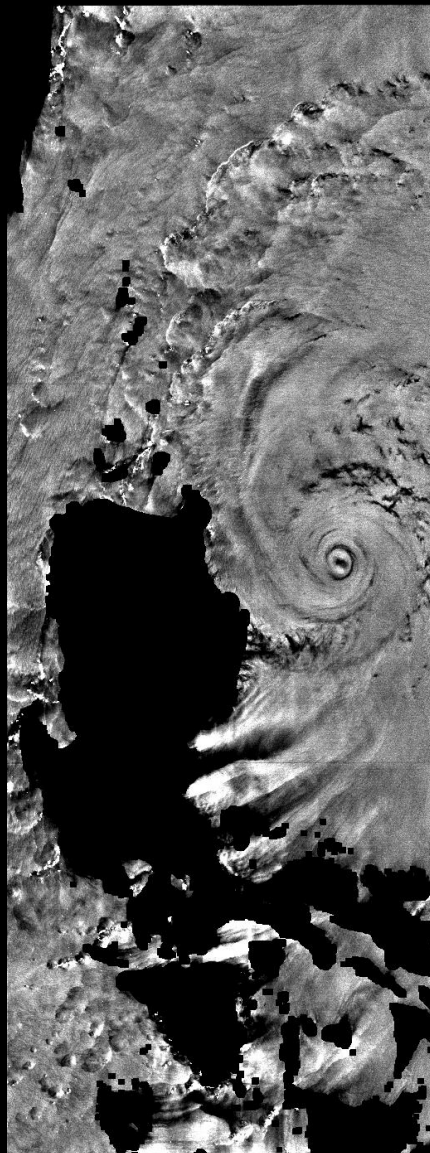


Malakas 9/24/10: RS2 C-HH

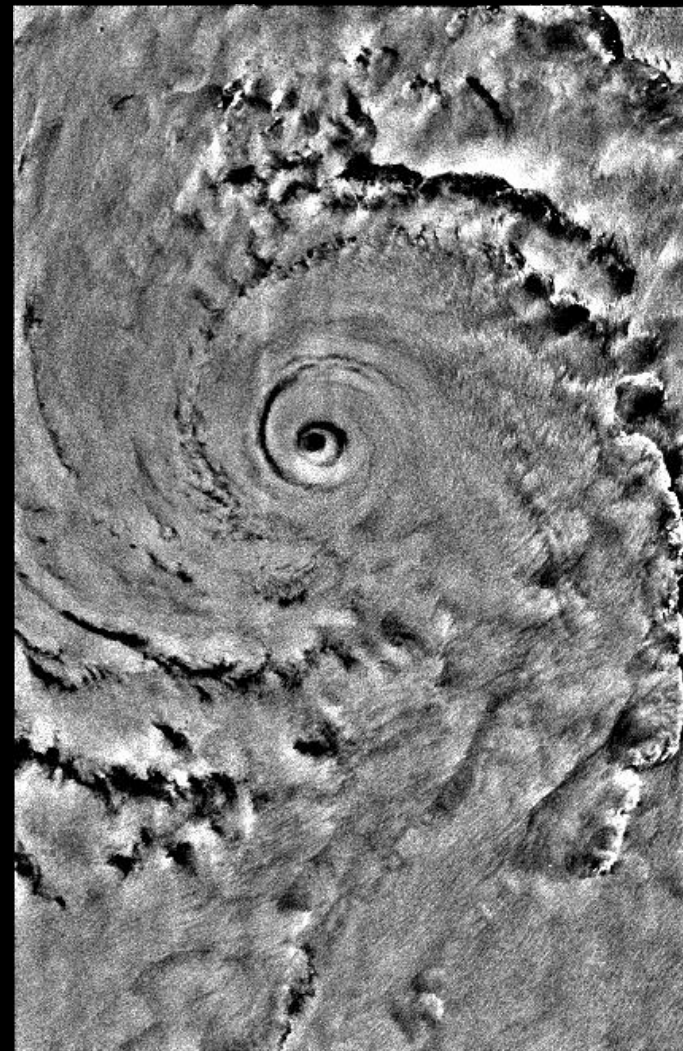
Example SAR Images: ITOP 2010 Storms



Megi 15 Oct 2010: RS2 CVV

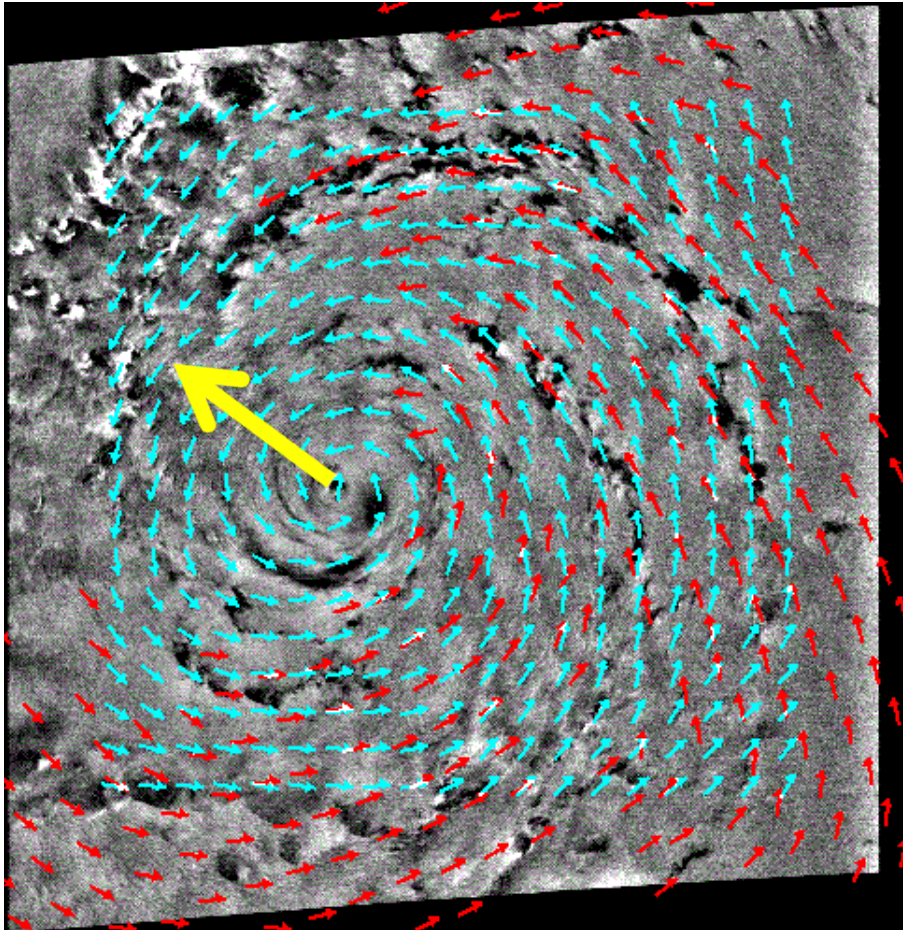


Megi 17 Oct 2010: RS2 CVV

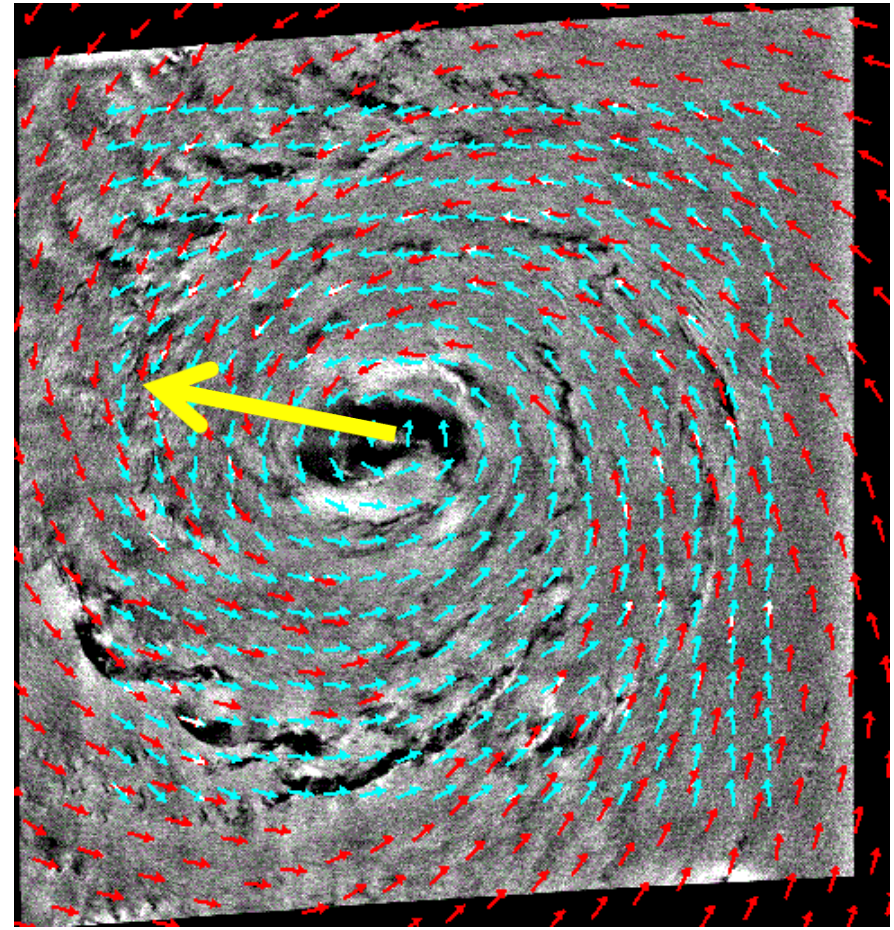


Megi 17 Oct 2010: Envisat CVV

Evaluating SAR Wind Direction Estimation



Ewinar, Pacific Typhoon, July 2006



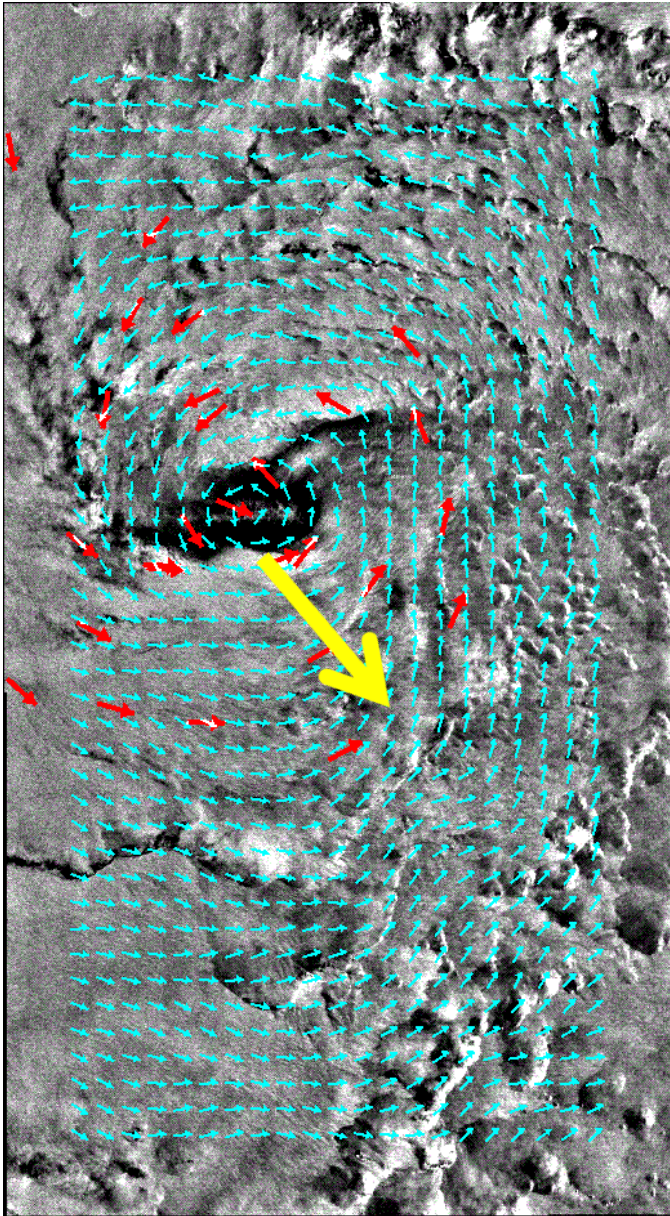
Fitow, Pacific Typhoon, August 2007

Red arrows = QSCAT wind direction
Blue arrows = SAR wind direction
Yellow arrow = storm propagation direction

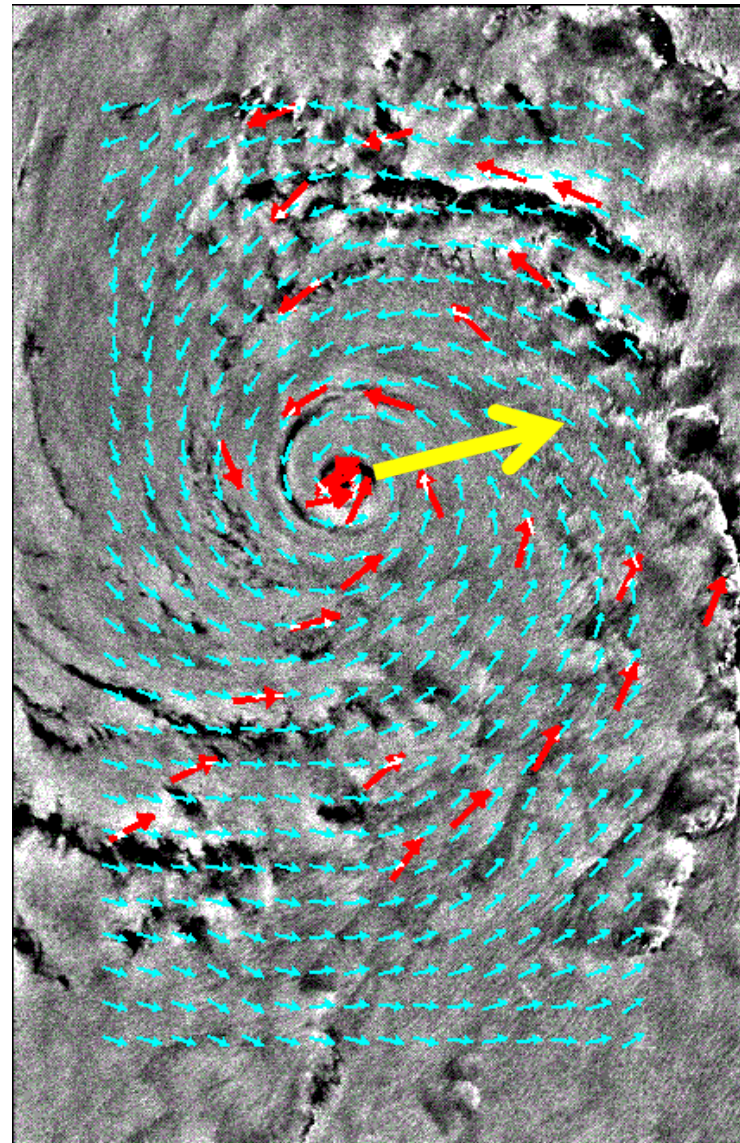
Only used QSCAT wind directions that were not rain-flagged for the direction analysis

Evaluating SAR Wind Direction Estimation

Red arrows = Dropsonde wind direction
Blue arrows = SAR wind direction
Yellow arrow = storm propagation direction



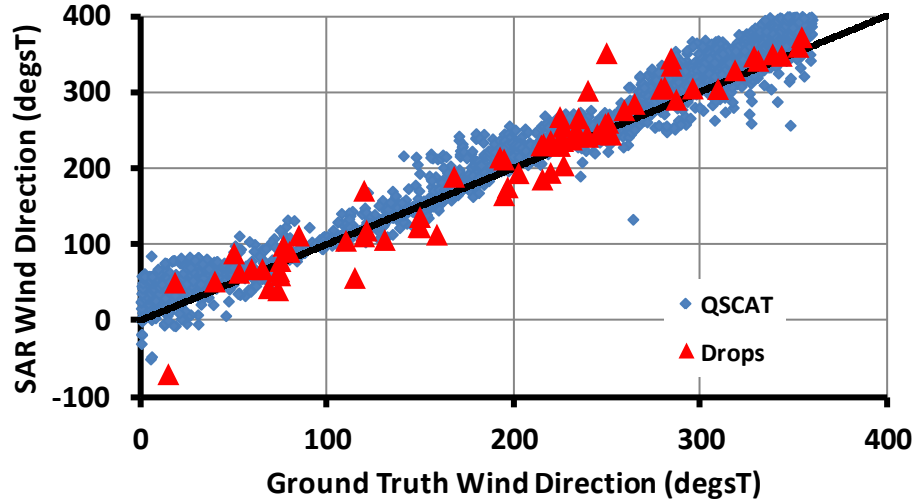
Malakas, Sept. 22, 2010: RS2 C-HH



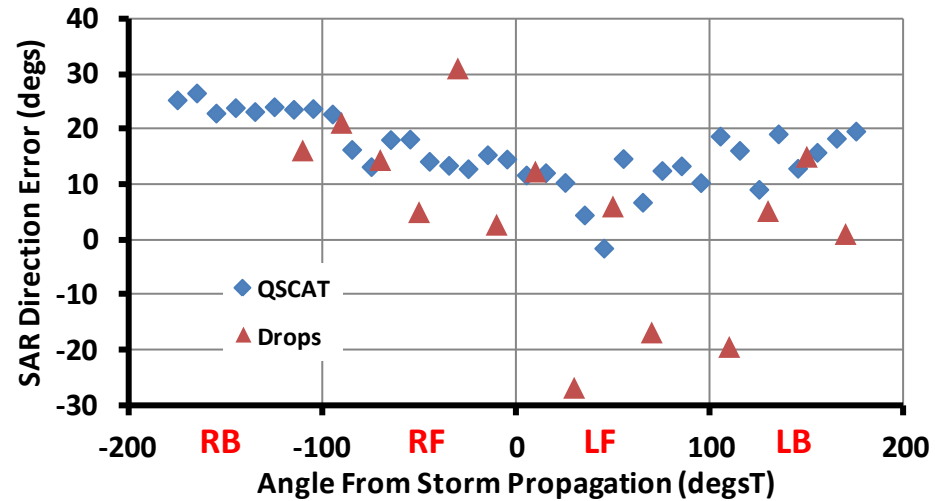
Megi, Oct. 17, 2010; Envisat C-VV

Evaluating SAR Wind Direction Estimation

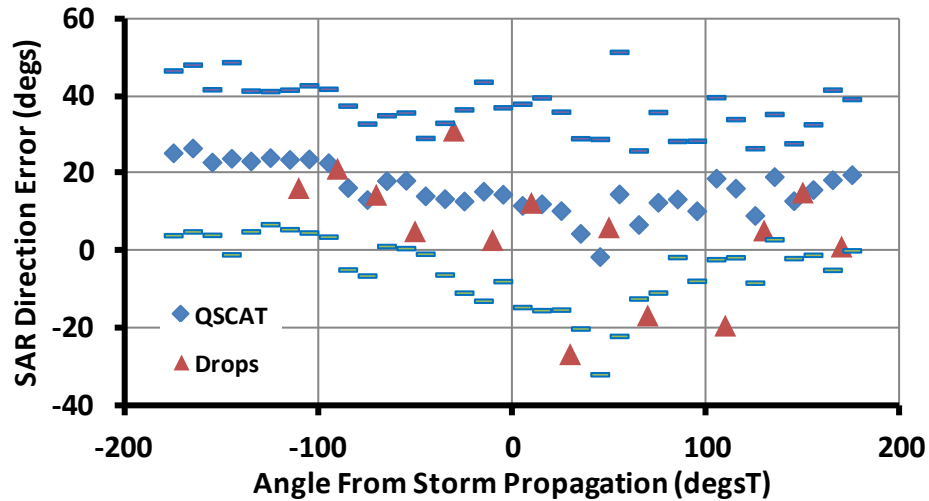
Wind Direction Estimation



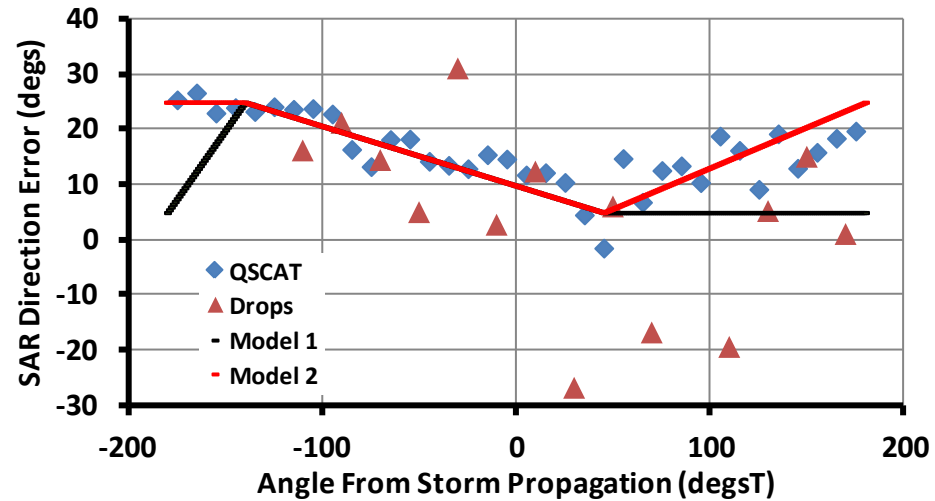
SAR Direction Error



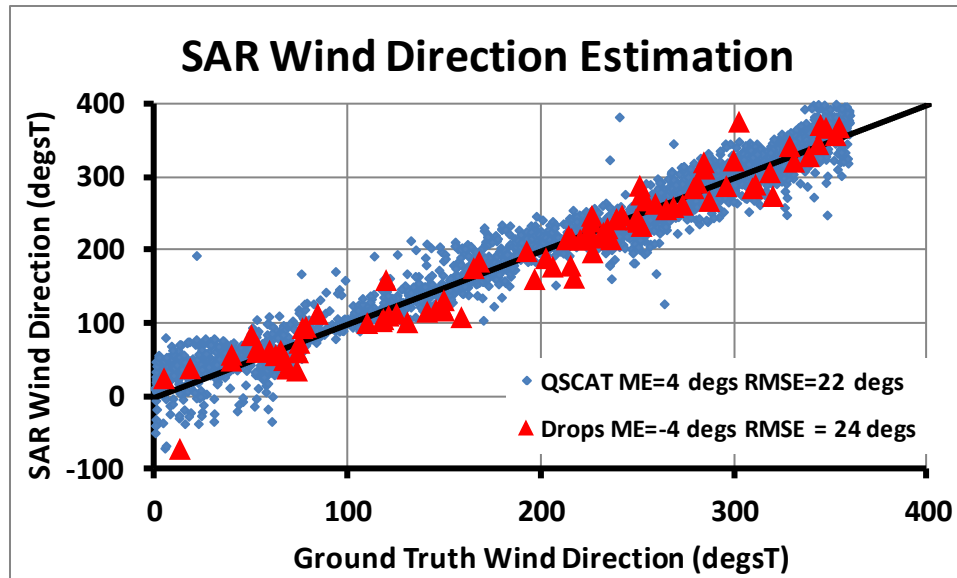
SAR Direction Error



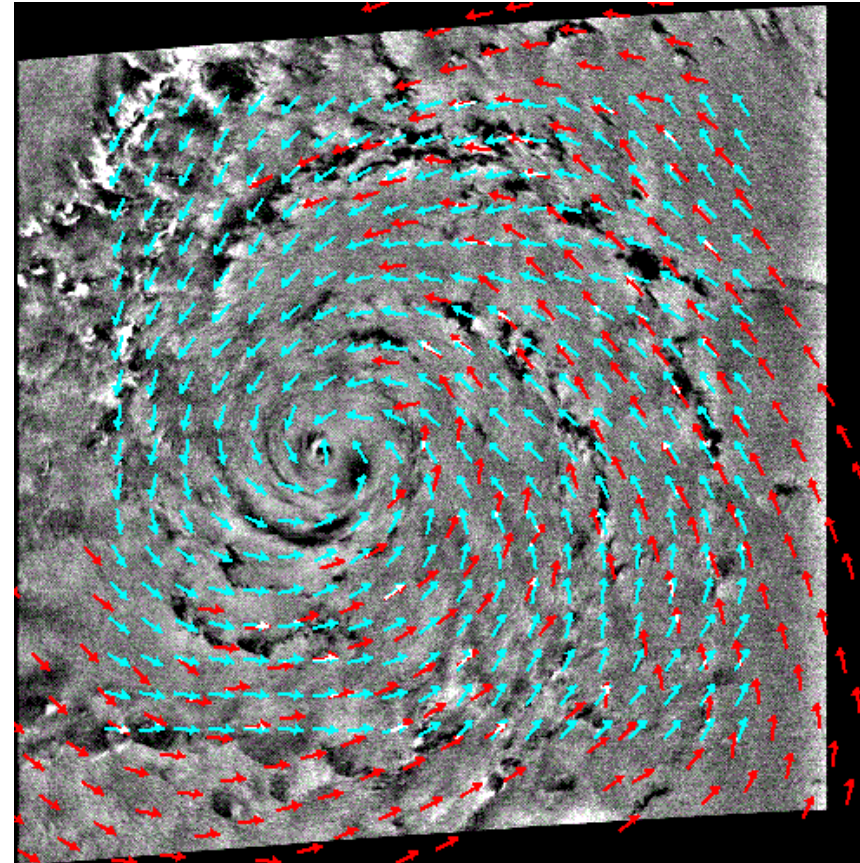
SAR Direction Error



Evaluating SAR Wind Direction Estimation

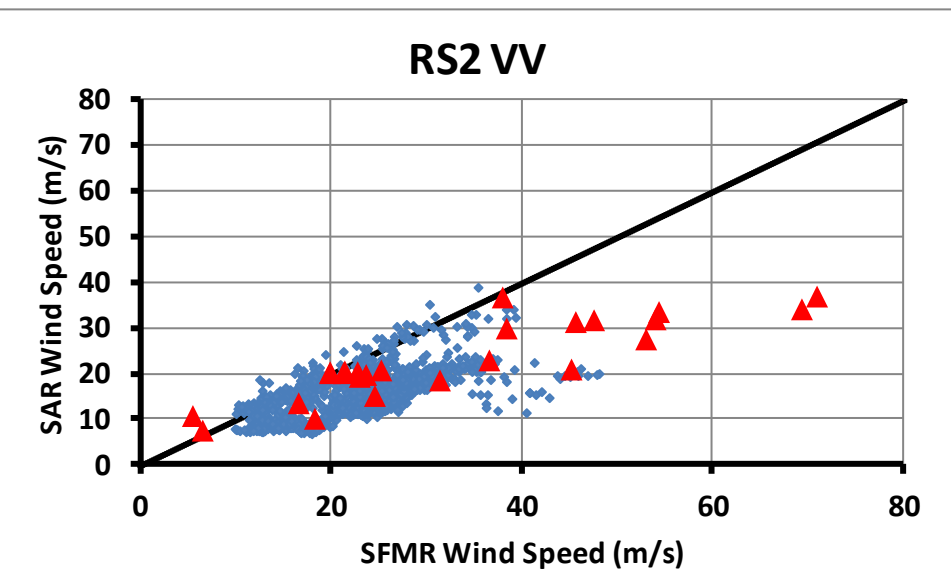
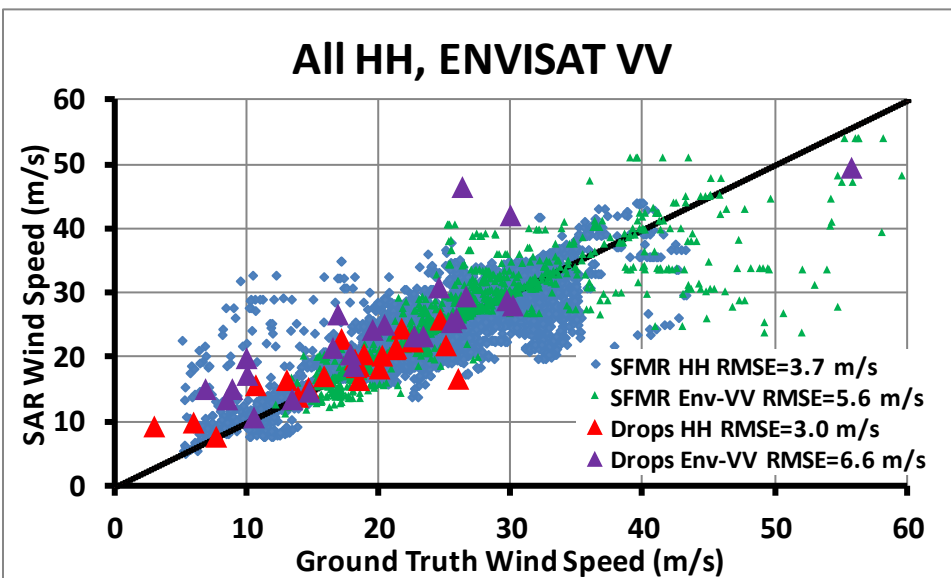
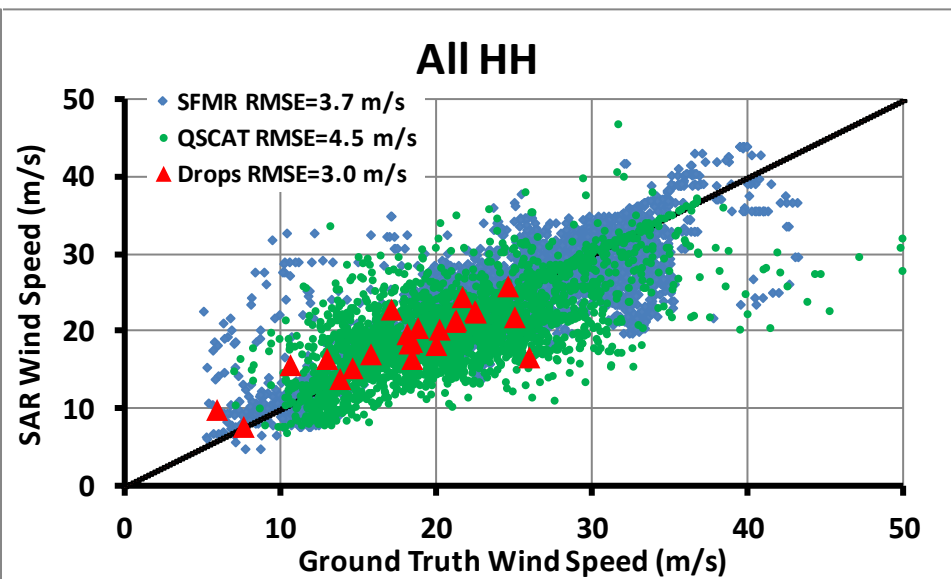
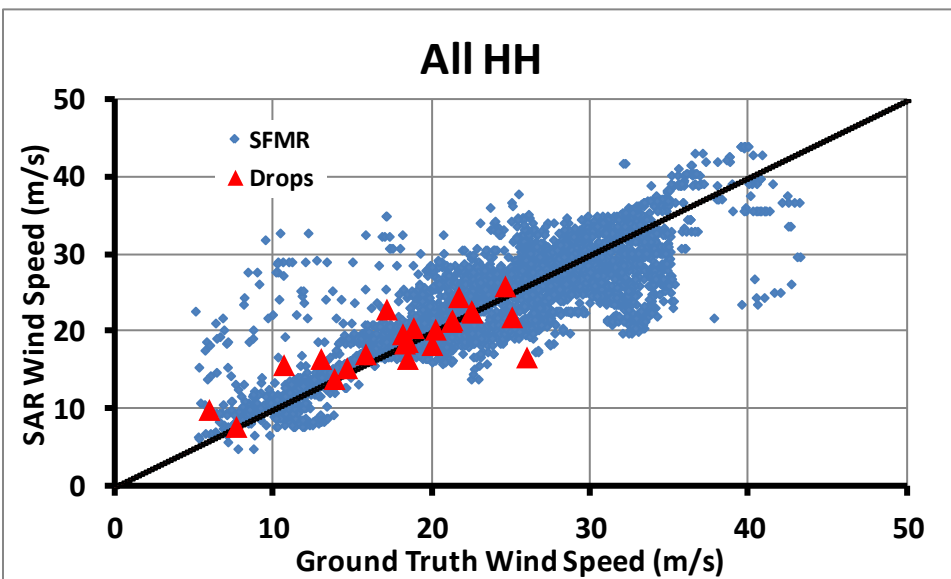


Rotation helps with QSCAT wind speed estimate (RMSE = 4.7 vs. 5.4 m/s), Drops (RMSE = 3.0 vs. 3.5 m/s), and the same for SFMR



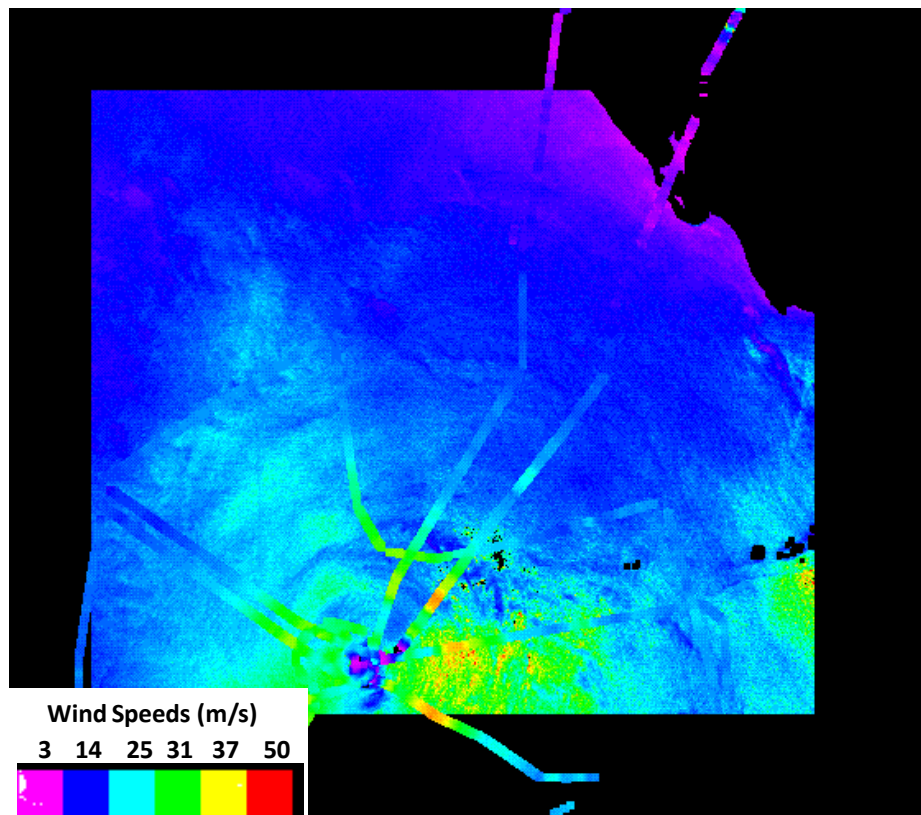
Ewinar, Pacific Typhoon, July 2006
Rotated SAR wind directions

Evaluating SAR Wind Speed Estimation

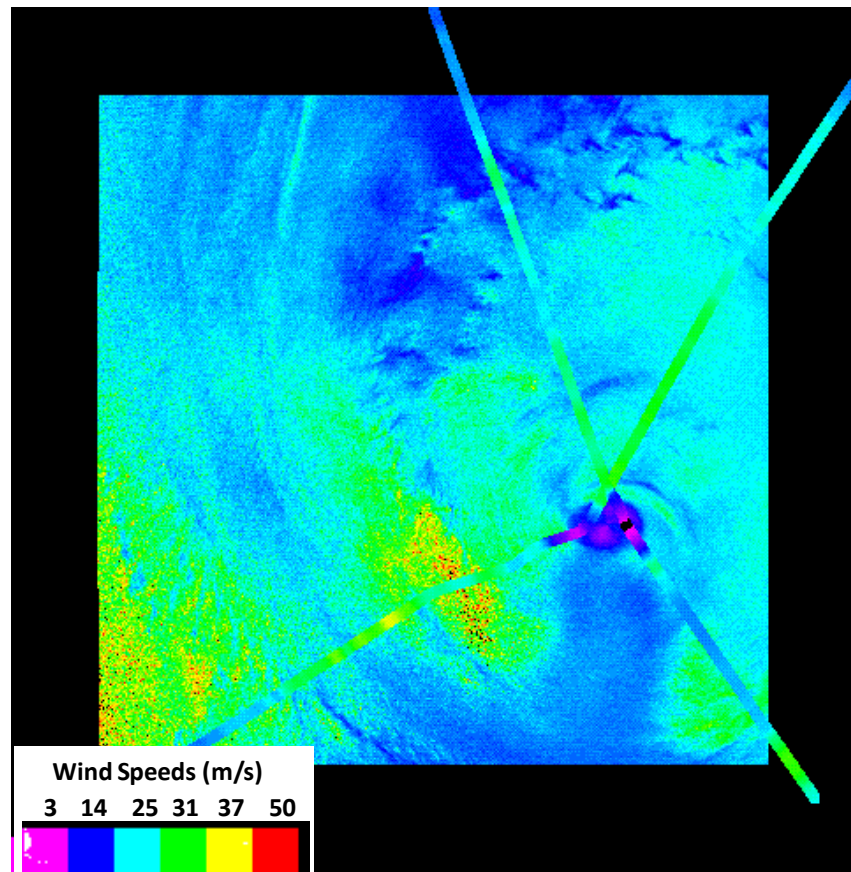


C-band GMF = CMOD5N, Thompson Model ($a=0.8$) for HH: low-windspeed ± 2 km jitter allowed in locations; SAR ws*1.1 to compare to SFMR; All QSCAT pts

Evaluating SAR Wind Speed Estimation



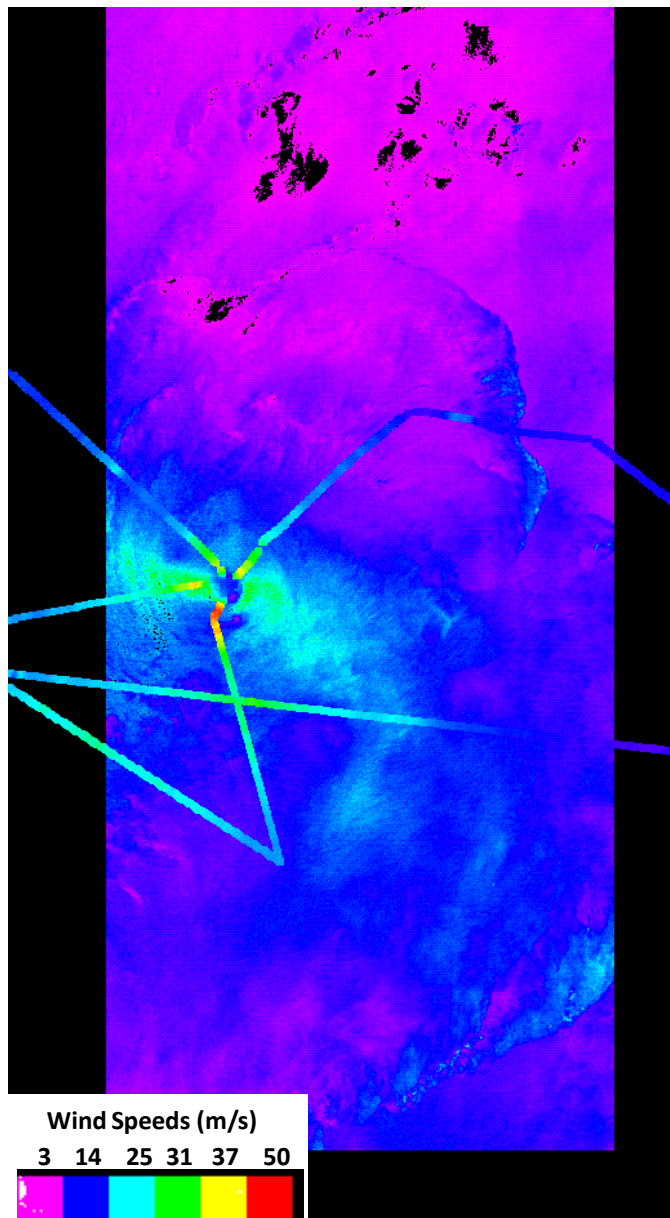
**Katrina, Aug 27 2005: RS1 CHH
With SFMR Wind Speeds**



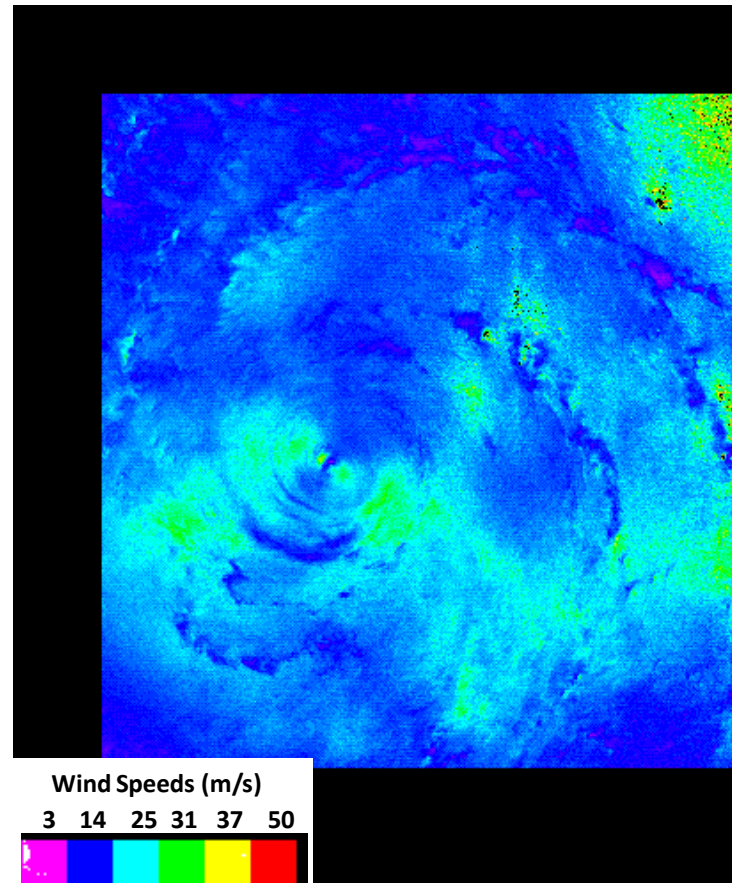
**Helene, Sep 20 2006: RS1 CHH
With SFMR Wind Speeds**

Evaluating SAR Wind Speed Estimation

Sometimes appears to have an “hourglass” wind speed shape around the eye

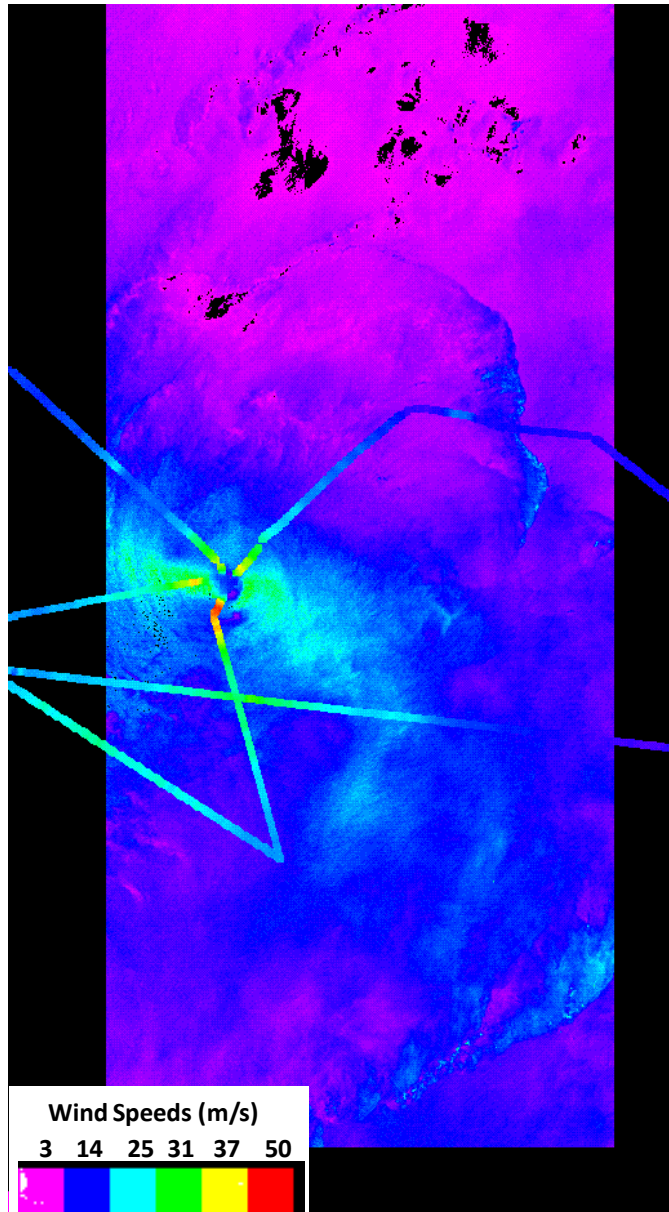


Megi, Oct. 15 2010: RS2 CVV

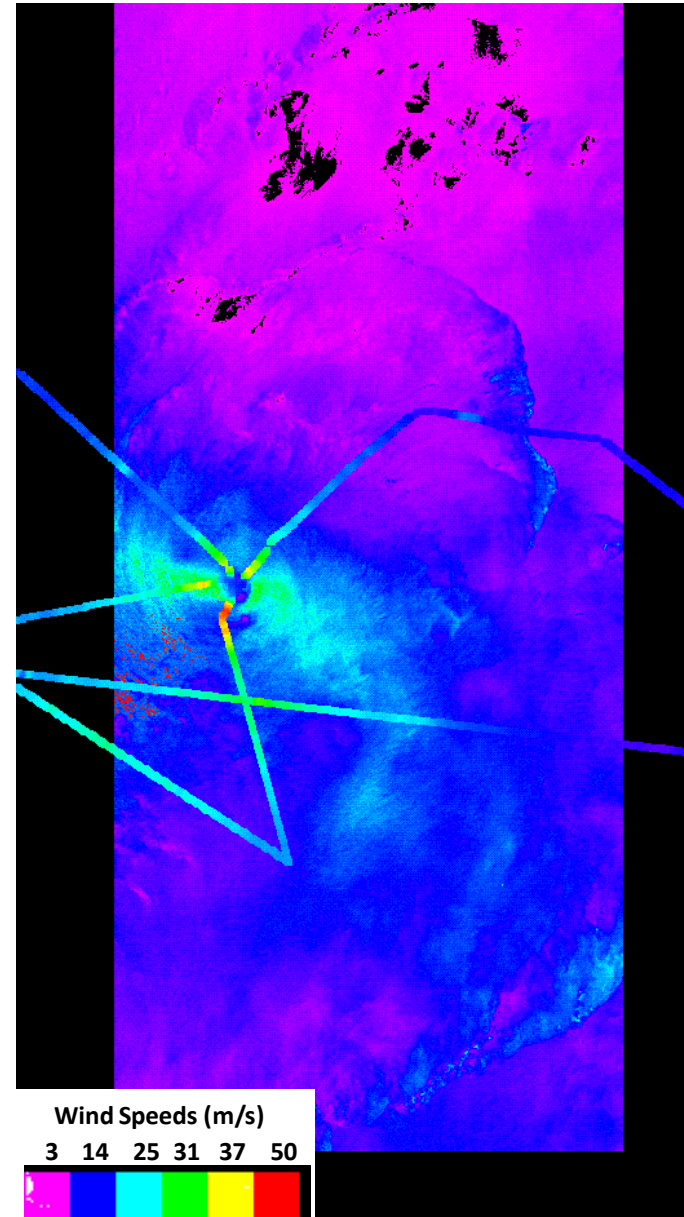


Ewinia July 2006: RS1 CHH

Low Wind Speed Solution



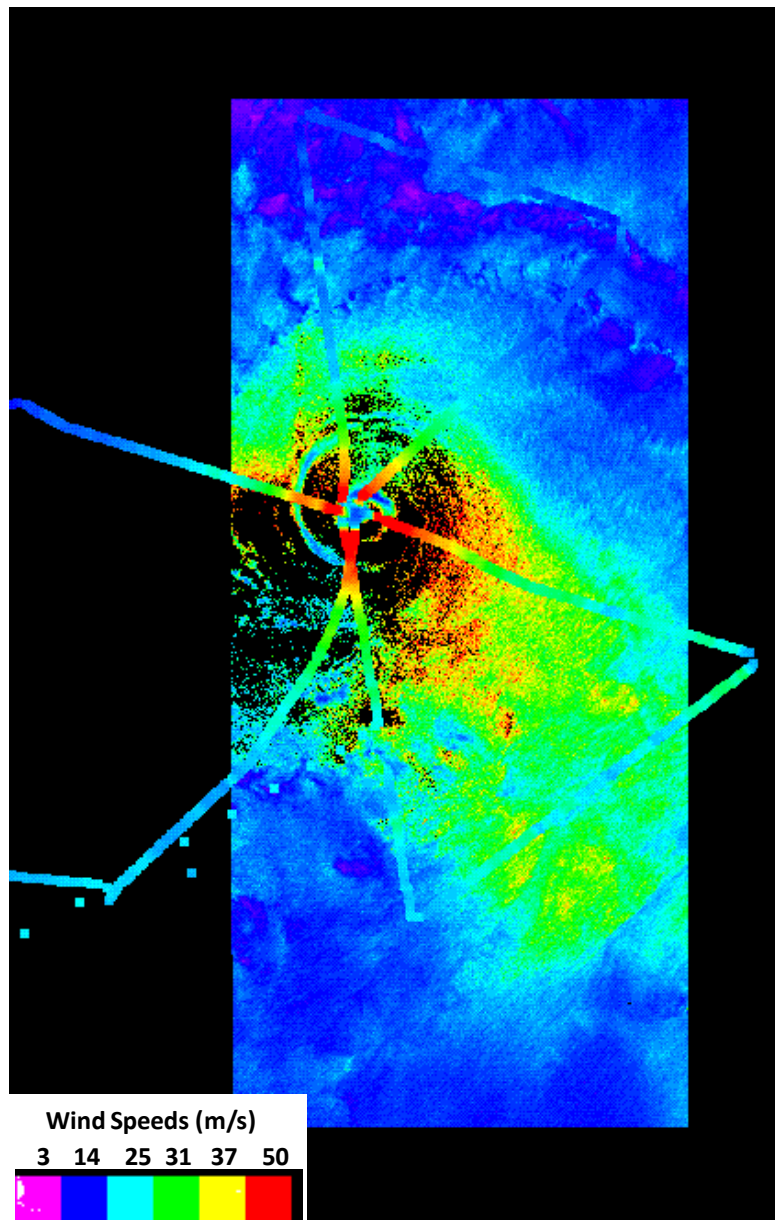
High Wind Speed Solution



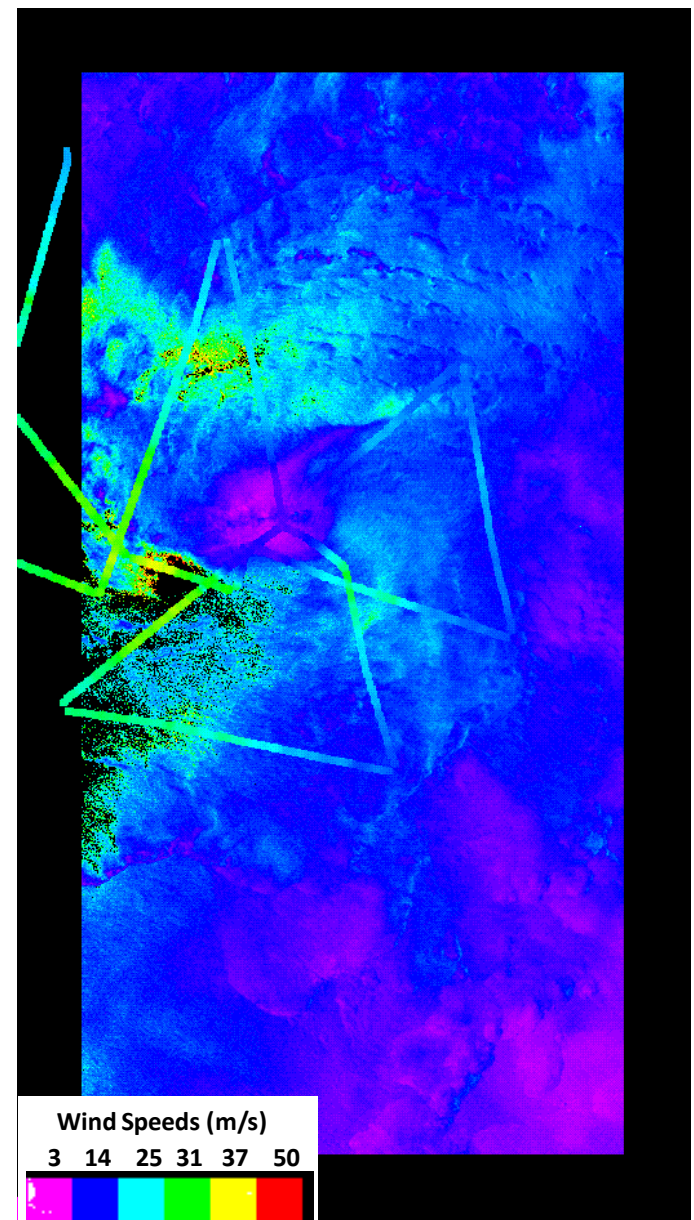
Evaluating SAR Wind Speed Estimation

Black regions
are areas
where the SAR
RCS was too
high for any
wind speed
put into the
CMOD5N GMF

- more of a
problem at low
incidence angles
- more of a
problem for VV

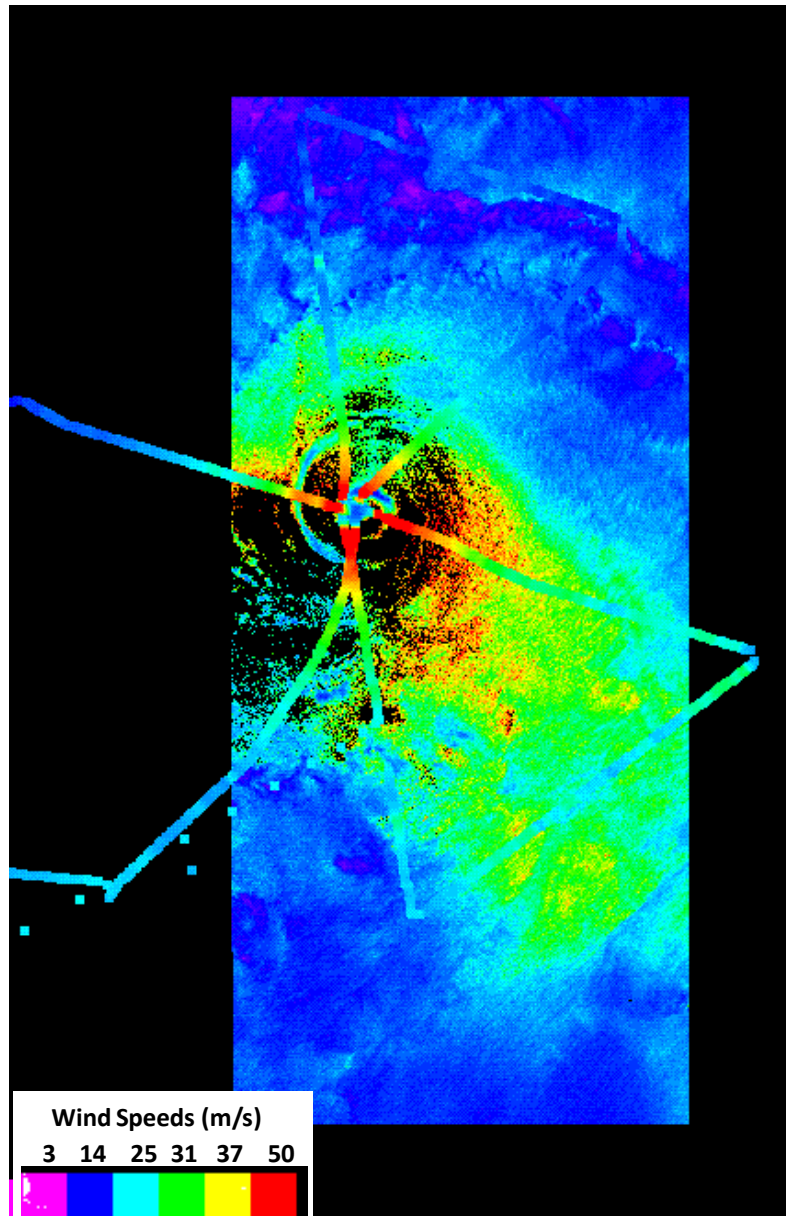


Megi, Oct. 17 2010: Envisat CVV

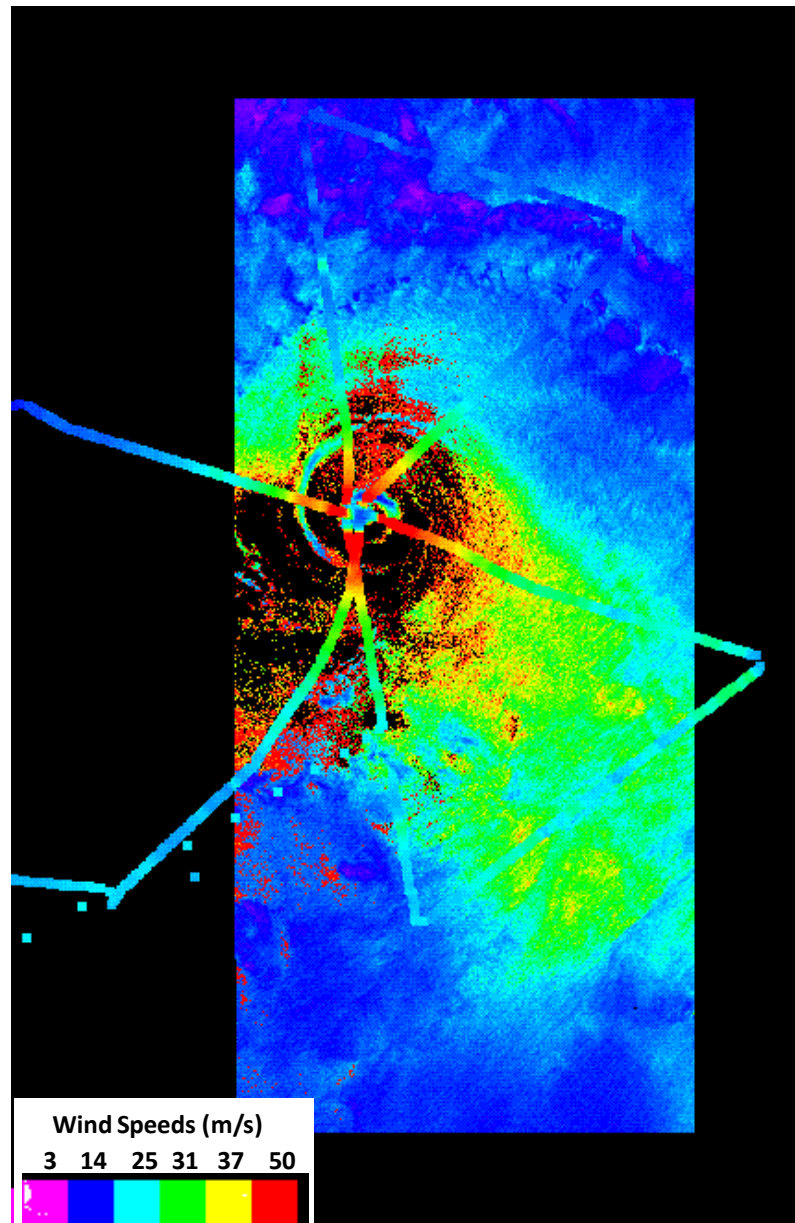


Malakas, Sept. 22 2010: RS2 CHH

Low Wind Speed Solution



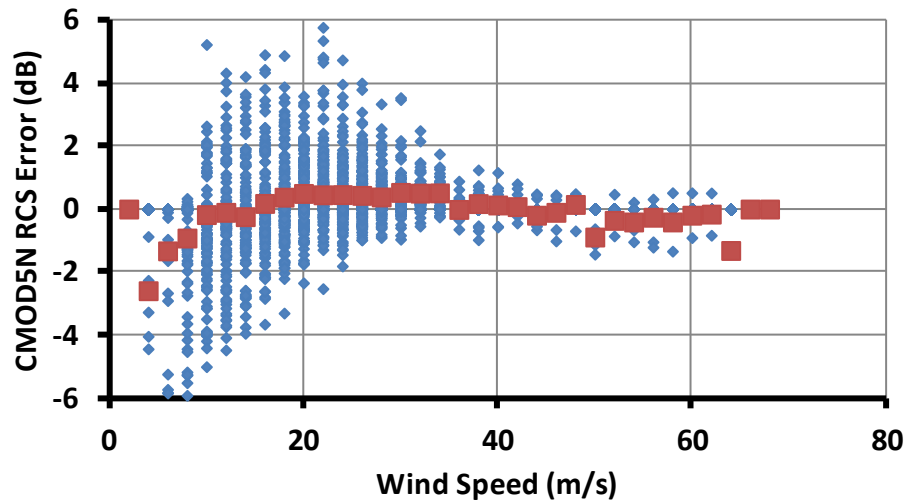
High Wind Speed Solution



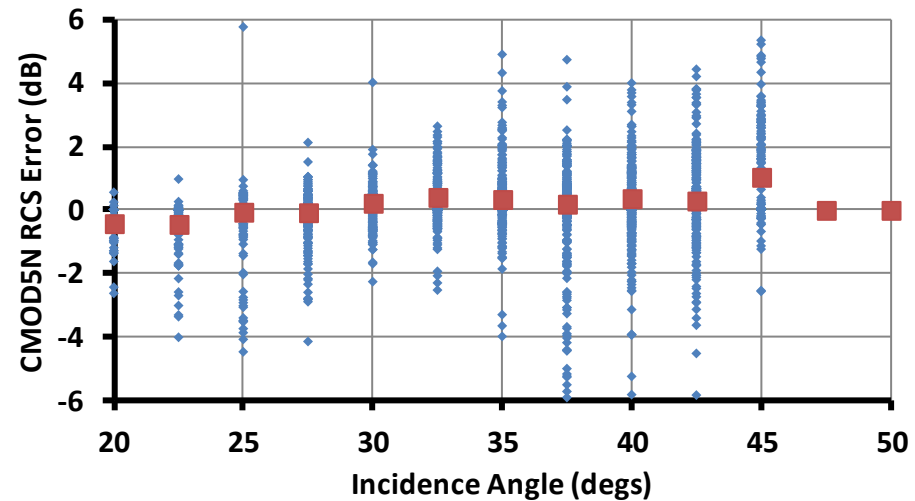
Megi, Oct. 17 2010: Envisat CVV

Re-Scaling CMOD5N

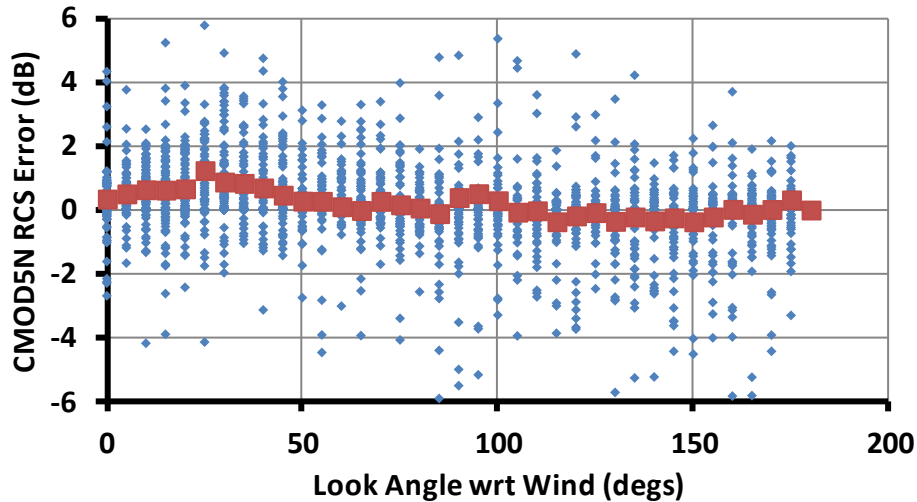
CMOD5N Error Trends



CMOD5N Error Trends



CMOD5N Error Trends



Wind Speed binned every 2 m/s
Incidence Angle binned every 2.5 degrees
Look Angle binned every 5 degrees

Using SAR HV Imagery to Estimate Wind Speed

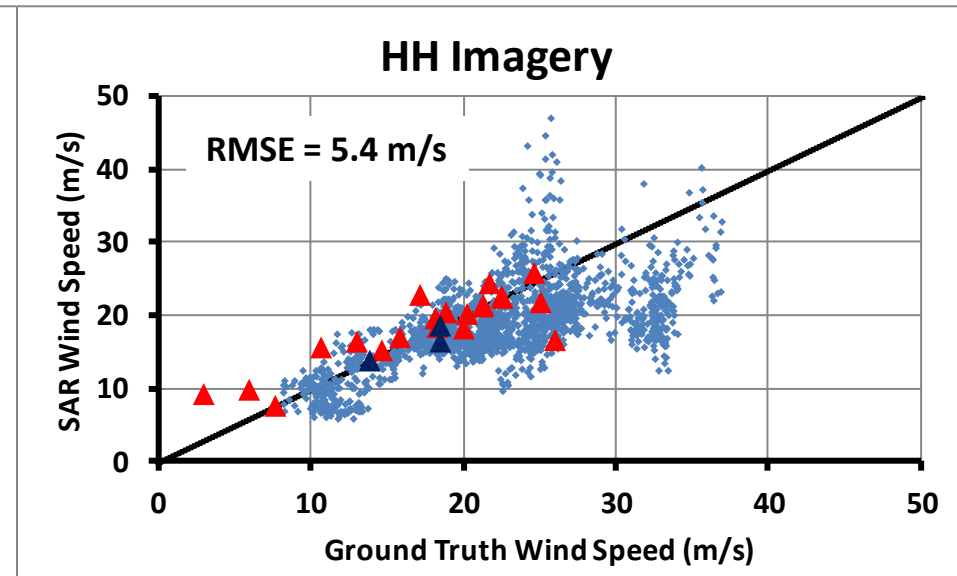
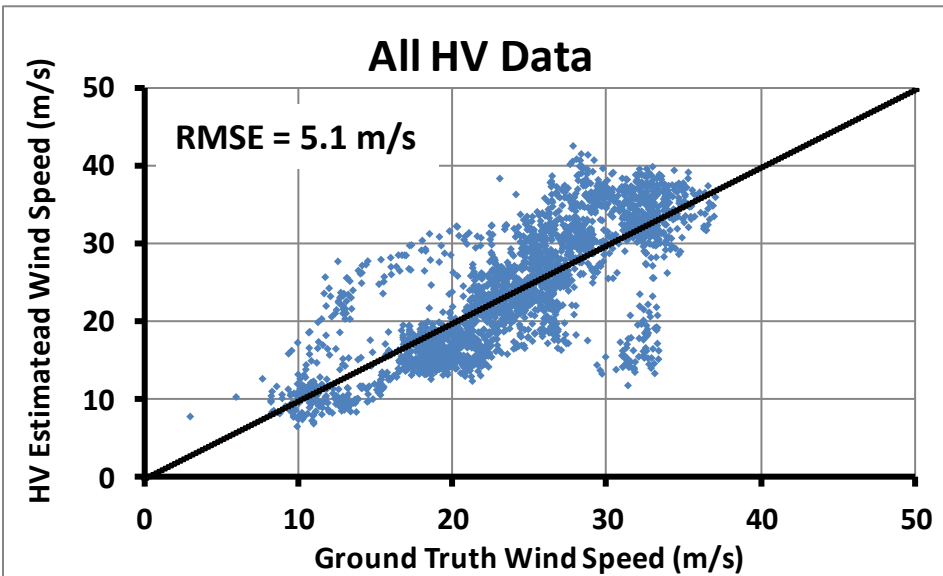
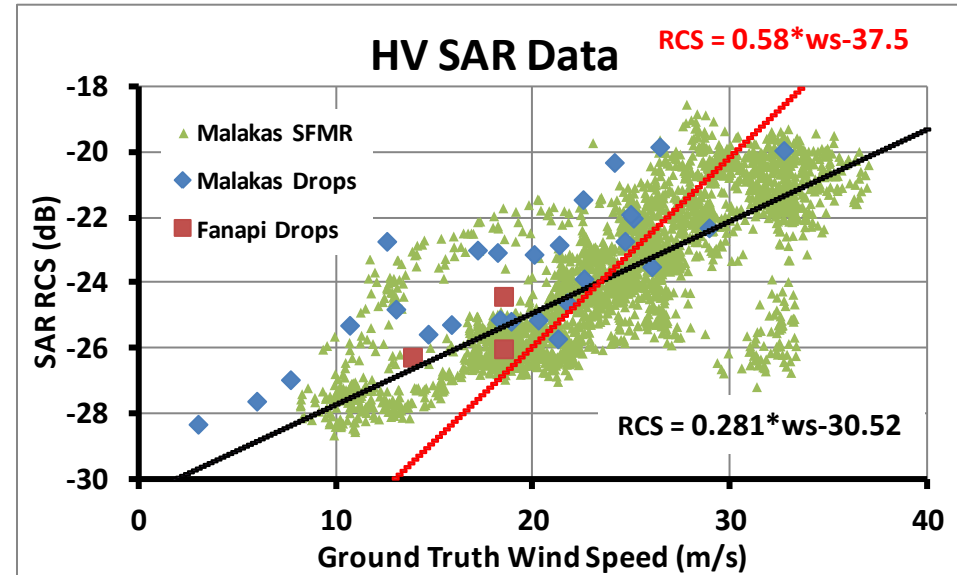
Data Sets

Fanapi 13 : no GT

Fanpi 17: 3 drops

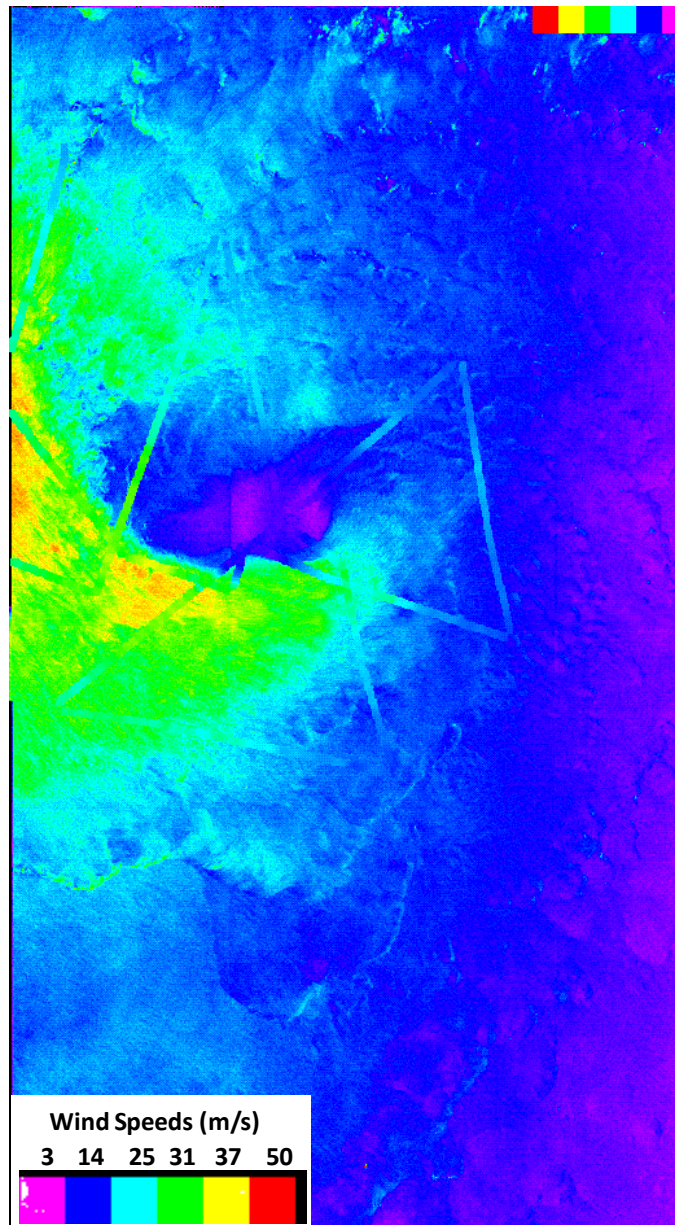
Malakas 22: SFMR and drops

Malakas 24: no GT

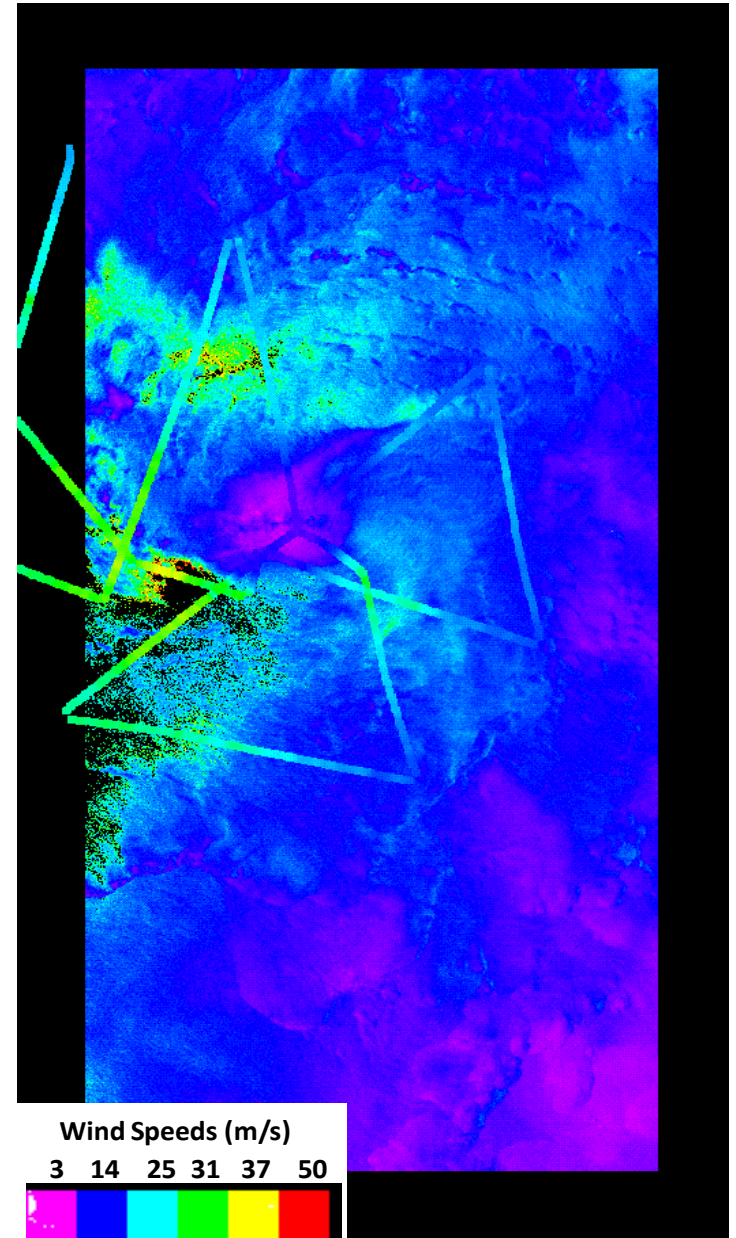


Malakas 22 C-HH RS2: With SFMR Wind Speeds

HV winds do
not suffer from
the drop-outs
(obviously)

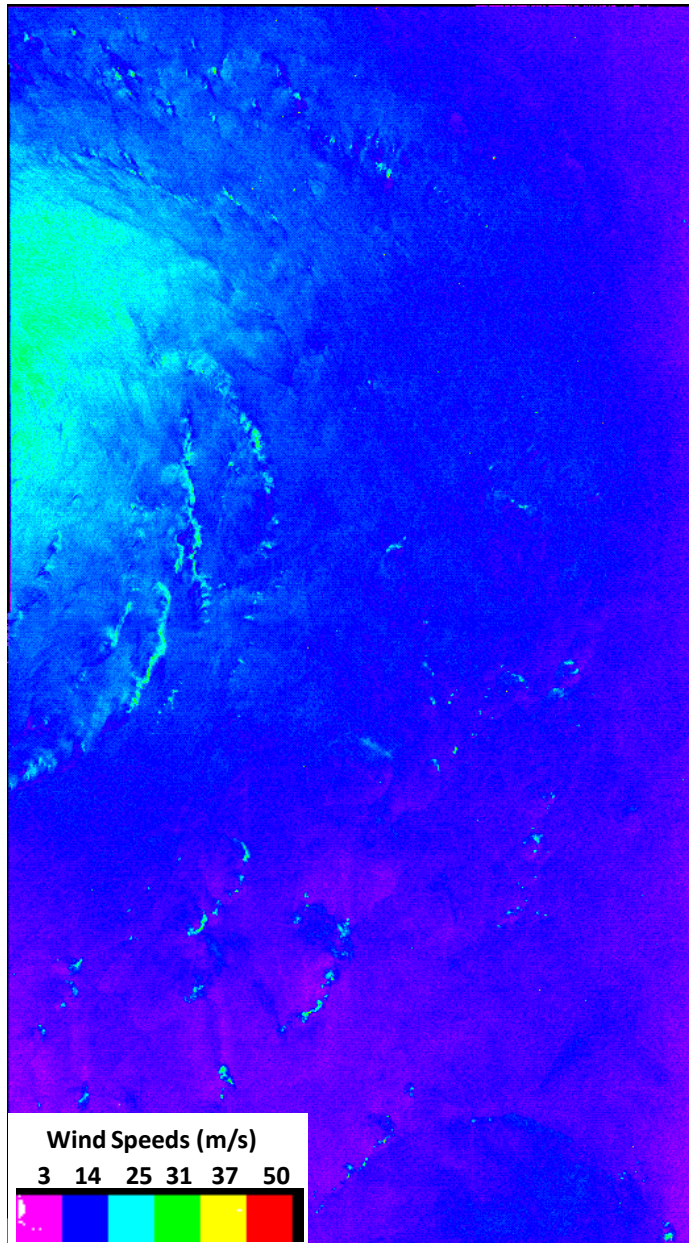


HV Wind Speeds

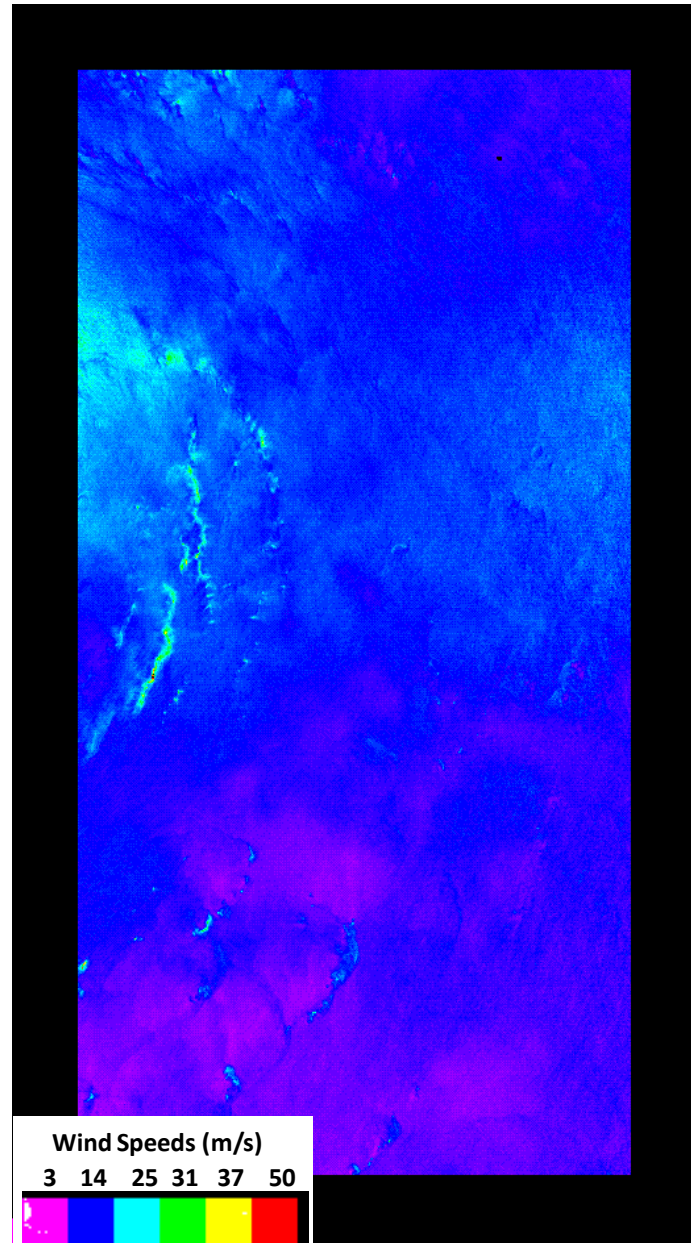


HH Wind Speeds

Fanapi 17 C-HH RS2

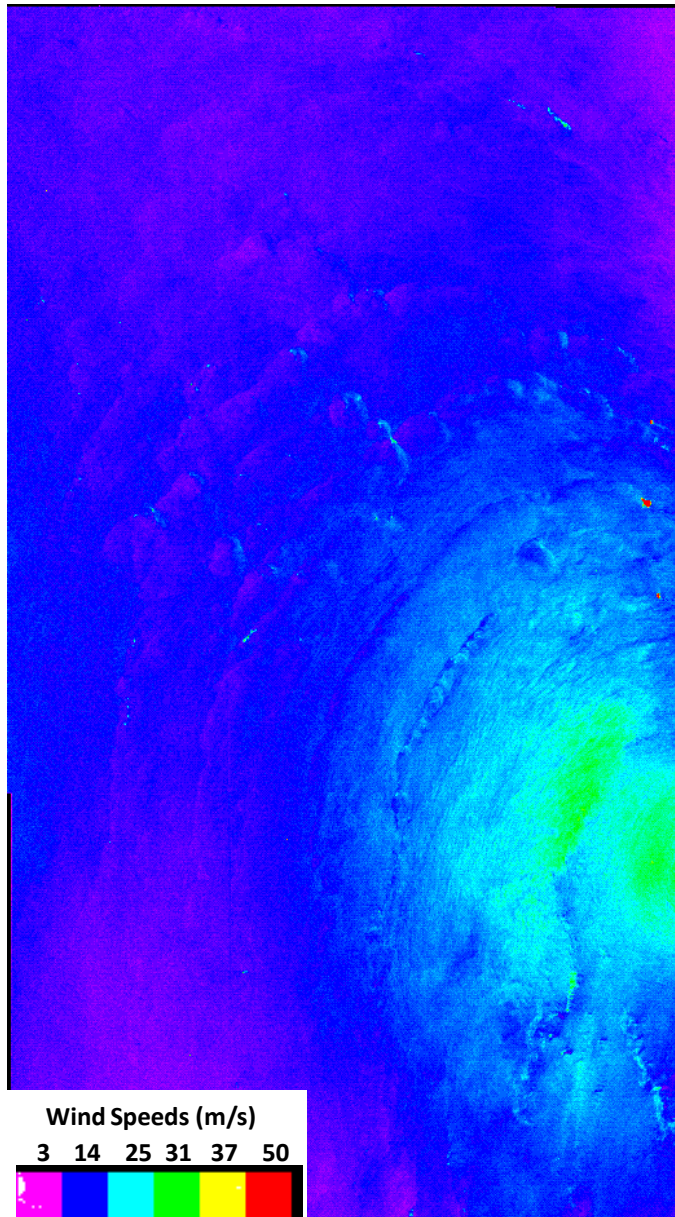


HV Wind Speeds

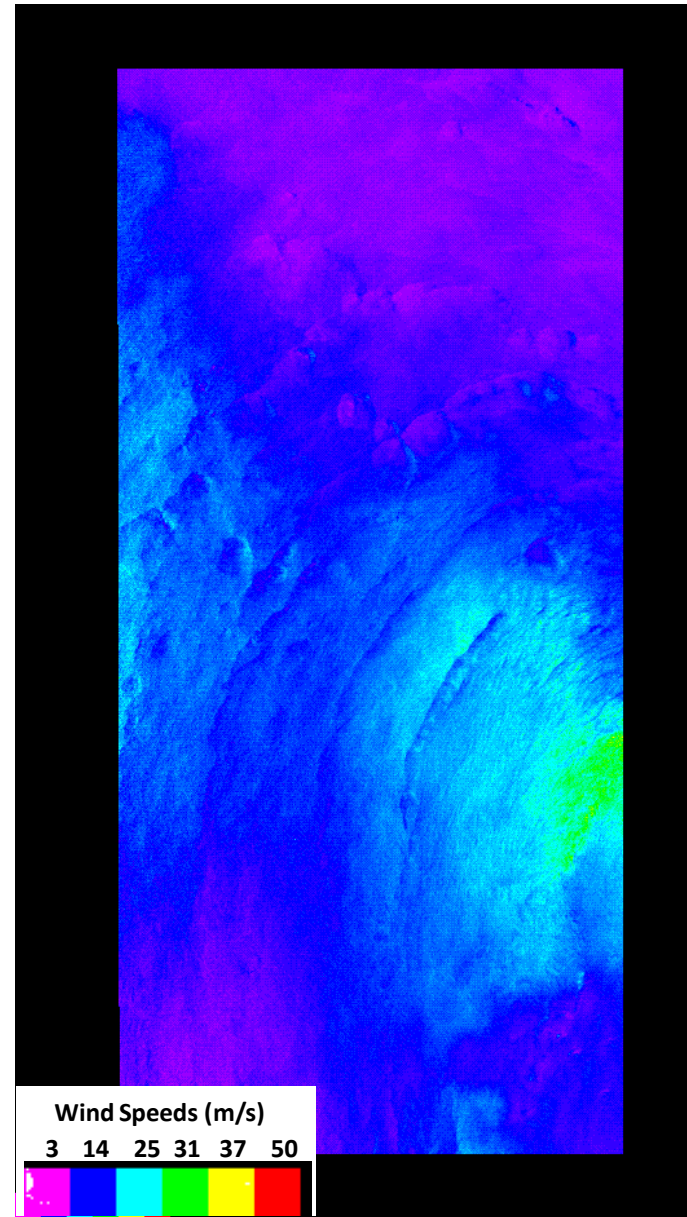


HH Wind Speeds

Malakas 24 C-HH RS2



HV Wind Speeds

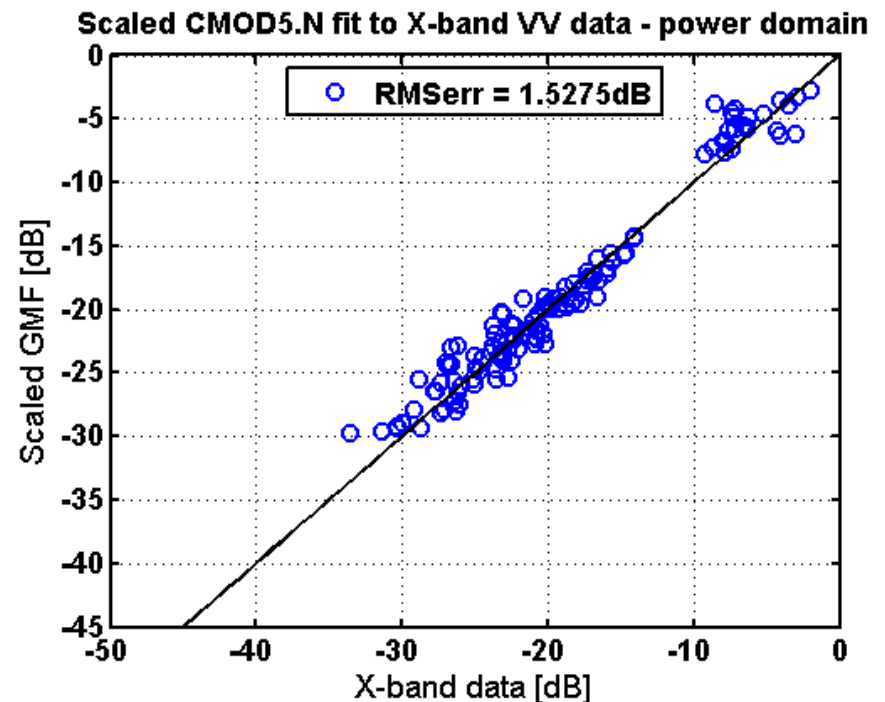
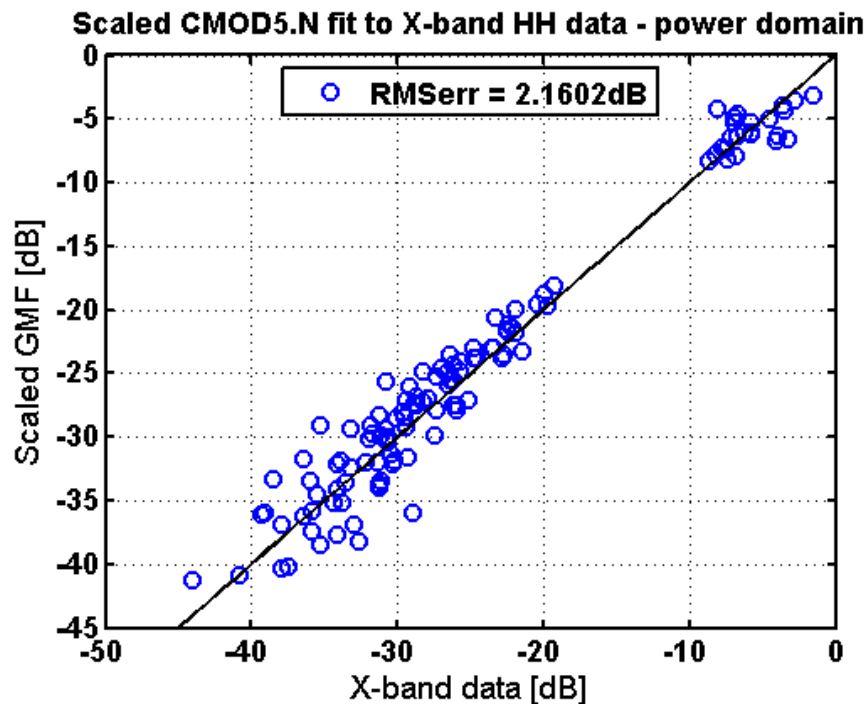


HH Wind Speeds

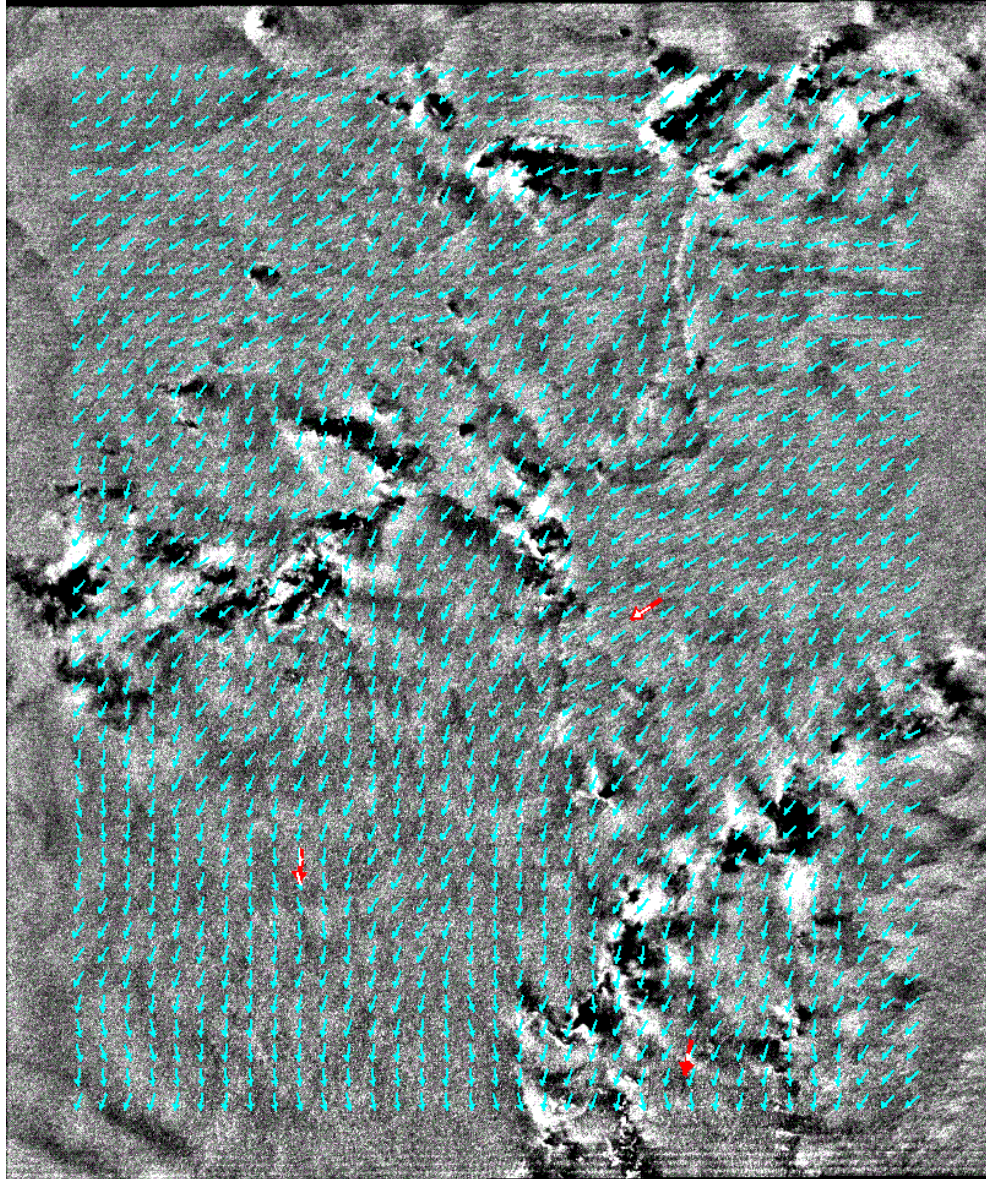
SAR Winds From CSM X-VV

Currently examining a X-band GMF derived from scaling CMOD5N

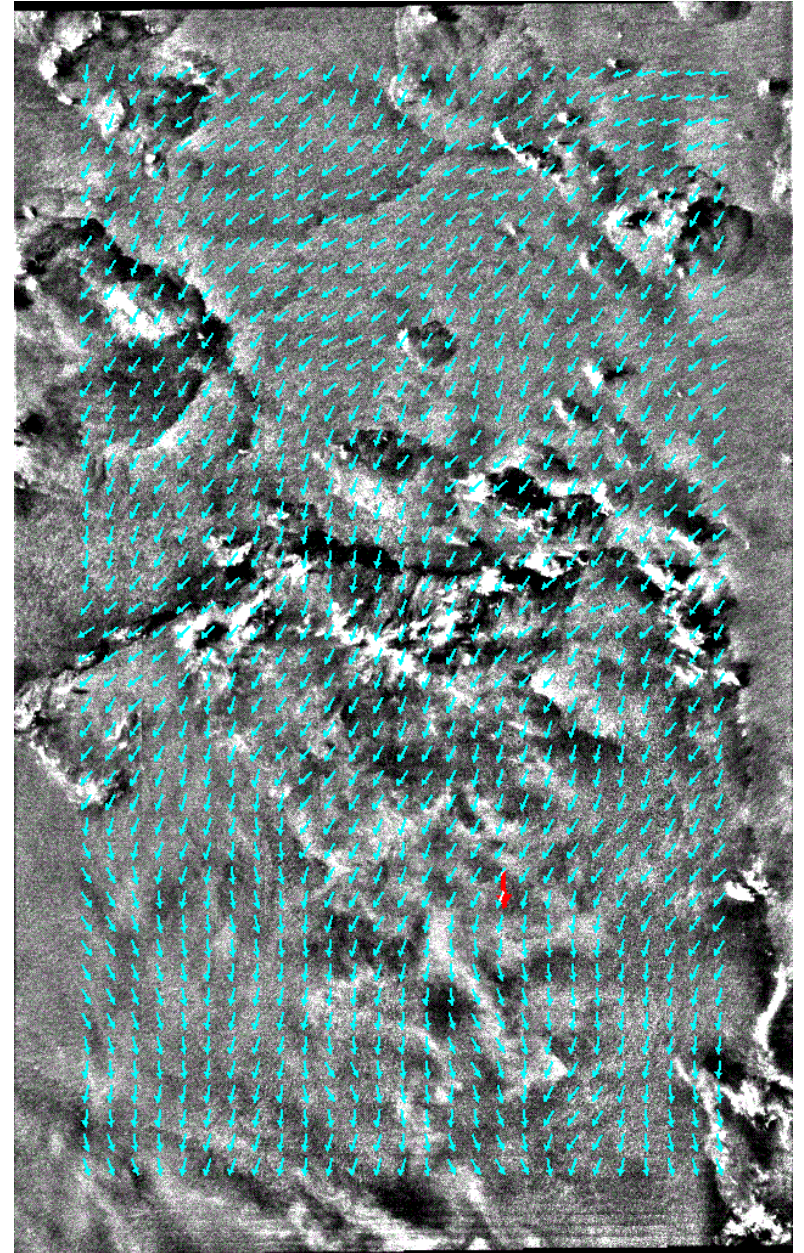
- Using airborne X-VV, X-HH data to provide the scaling (wind speeds are all < 12 m/s)
- Provided better results than interpolating between C- and Ku-band GMFs



SAR Winds From CSM X-VV

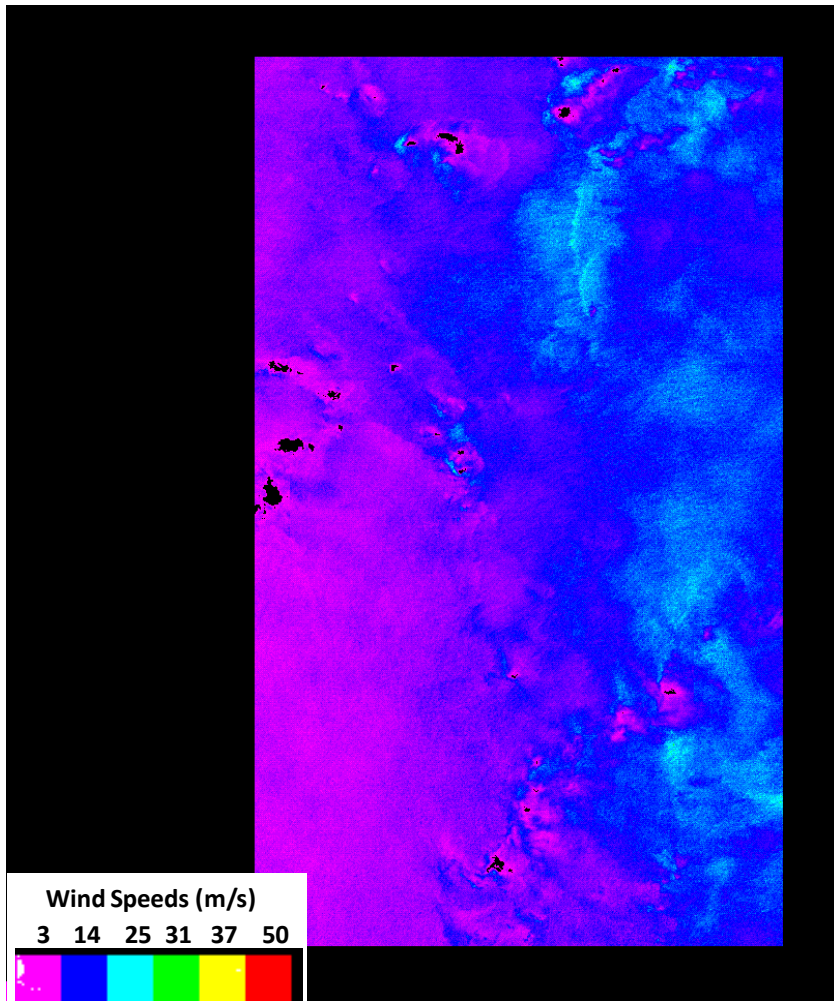


Megi 10/14 20:58 CSM3 XVV

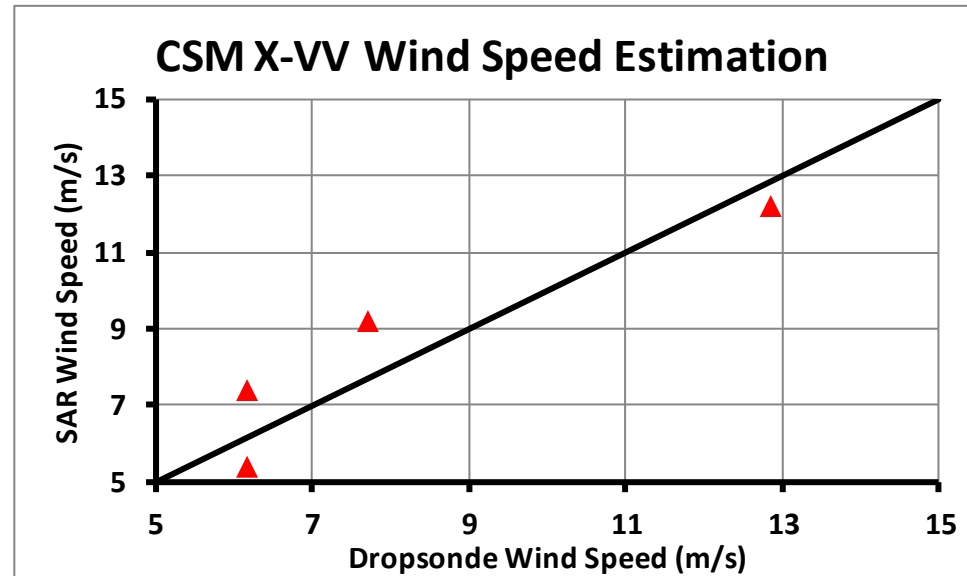
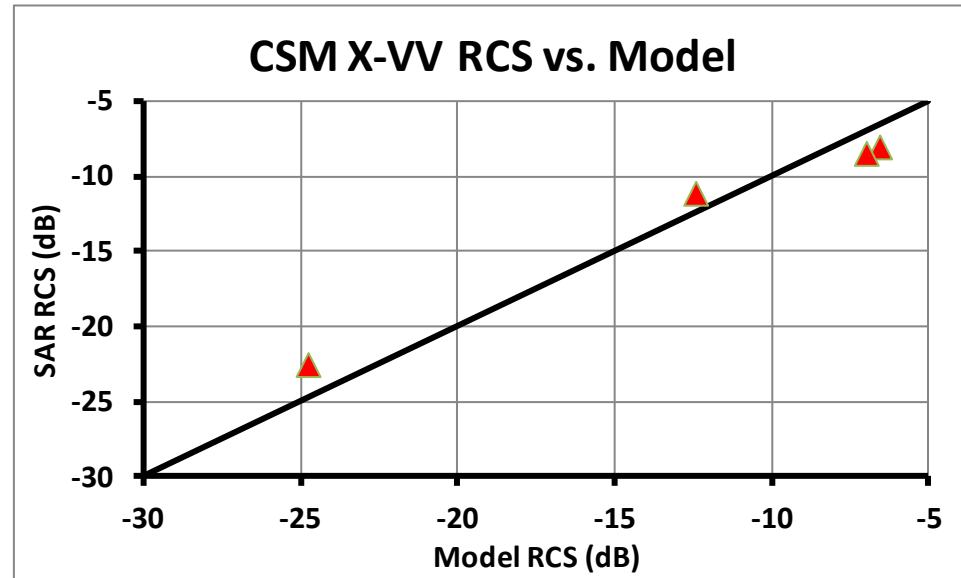


Megi 10/14 21:17 CSM2 XVV

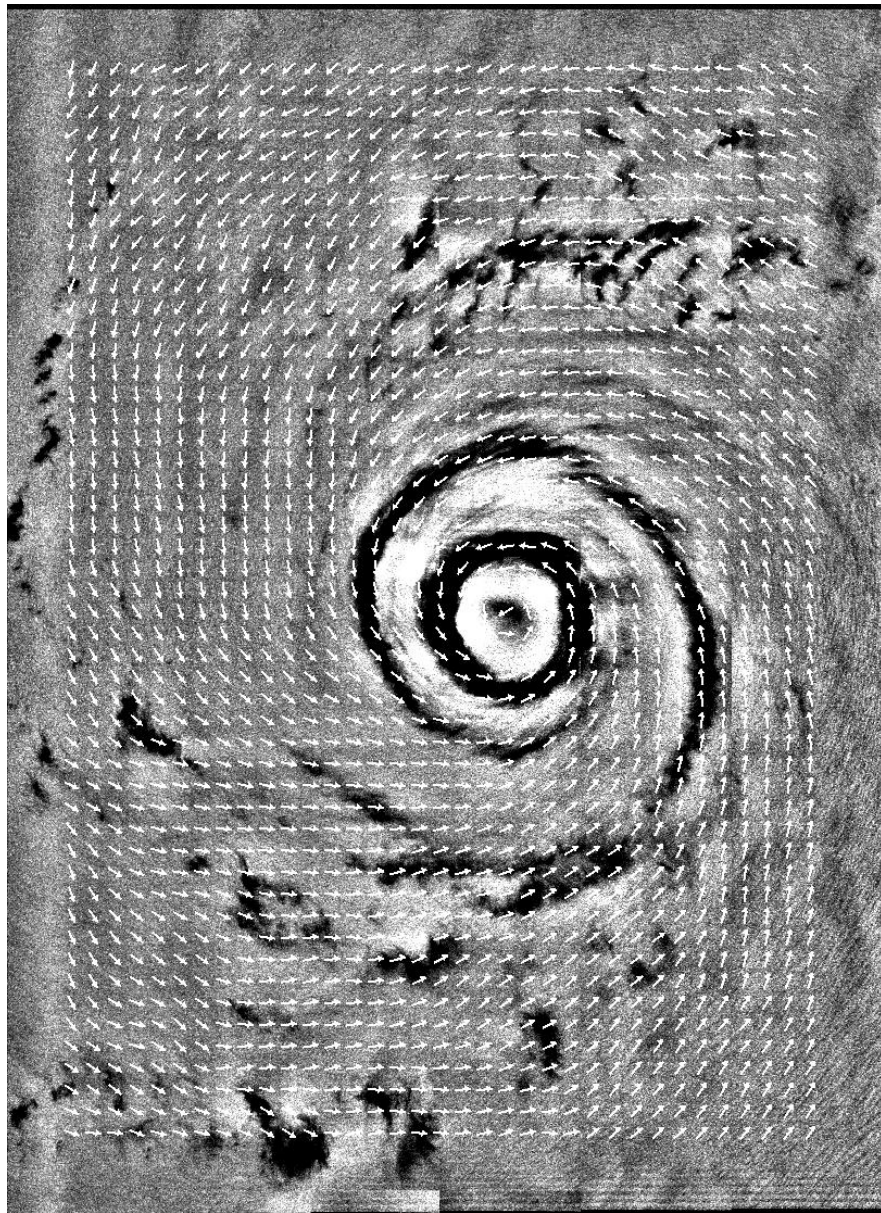
SAR Winds From CSM X-VV



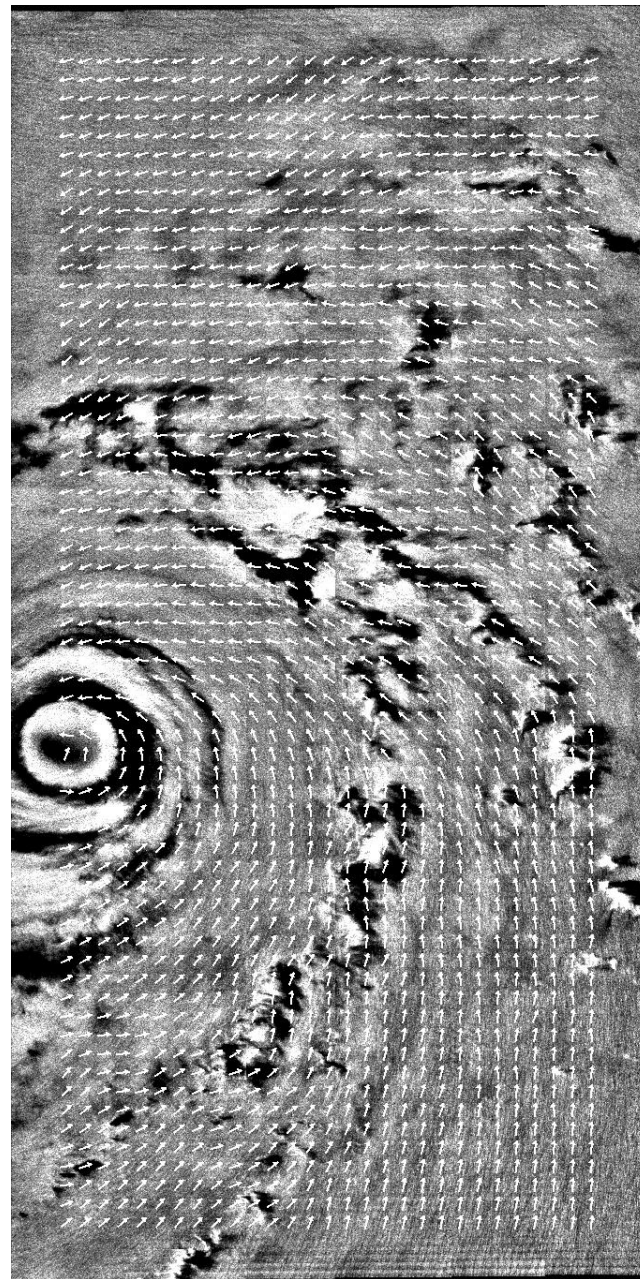
Megi 10/14 20:58 CSM3 XVV



SAR Winds From CSM X-VV

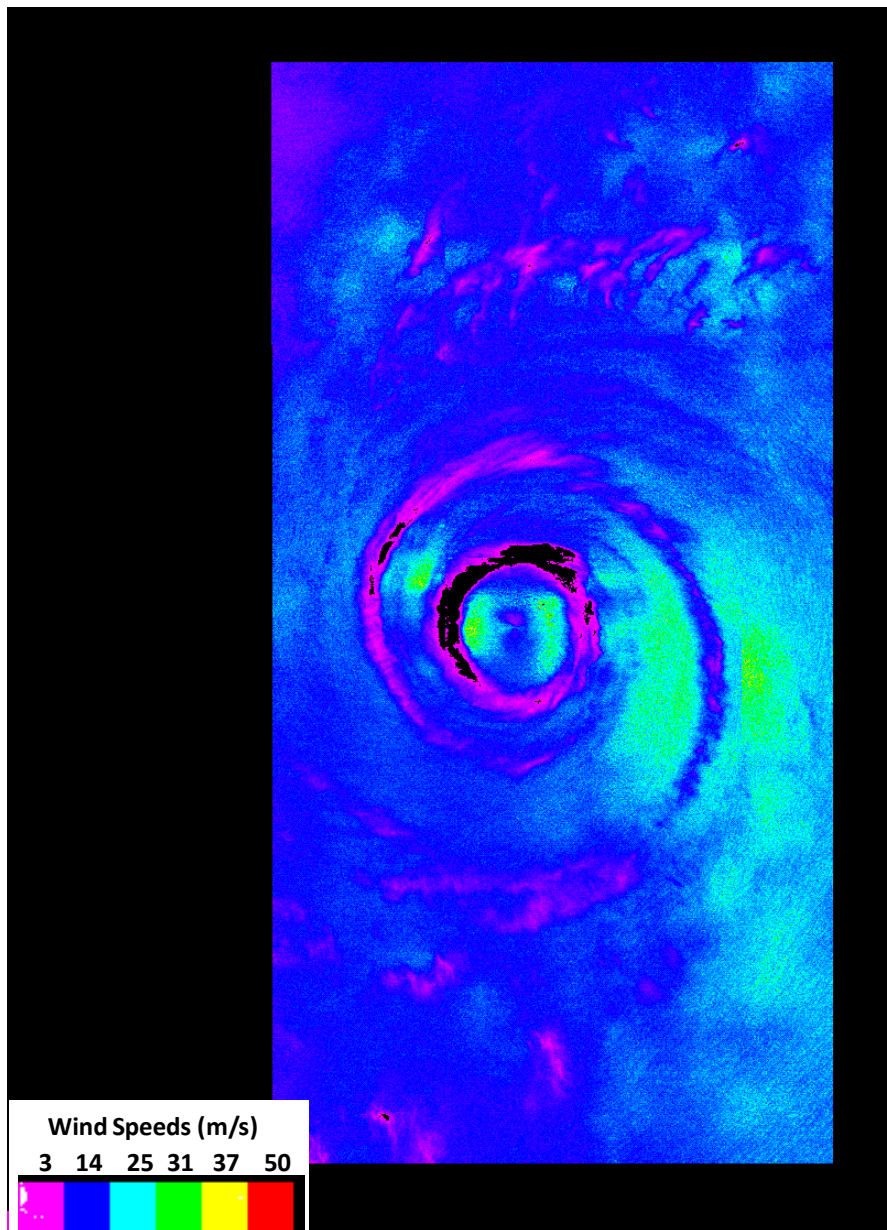


Megi 10/17 09:00 CSM3 XVV

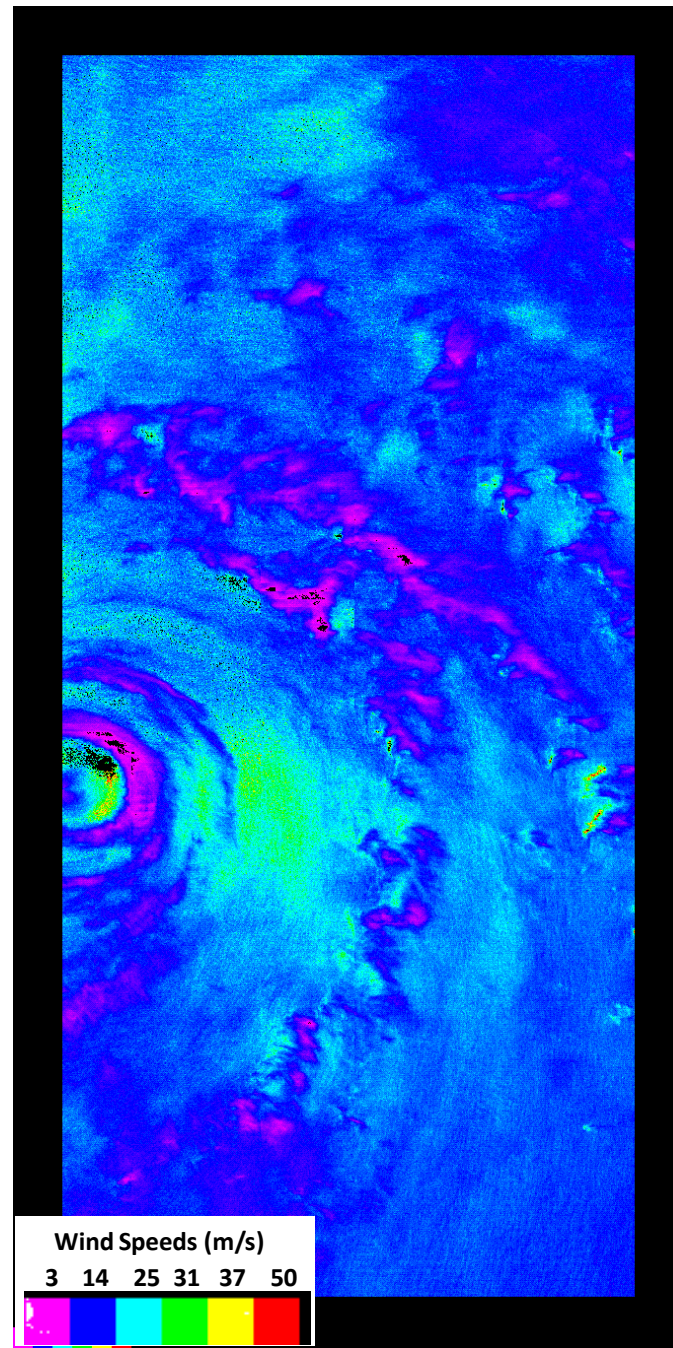


Megi 10/17 21:00 CSM3 XVV

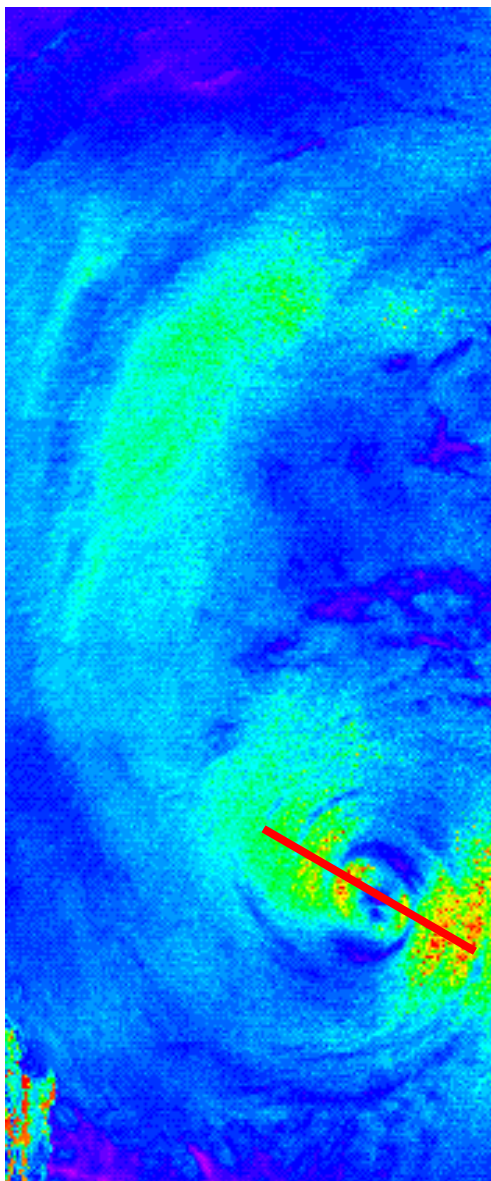
SAR Winds From CSM X-VV



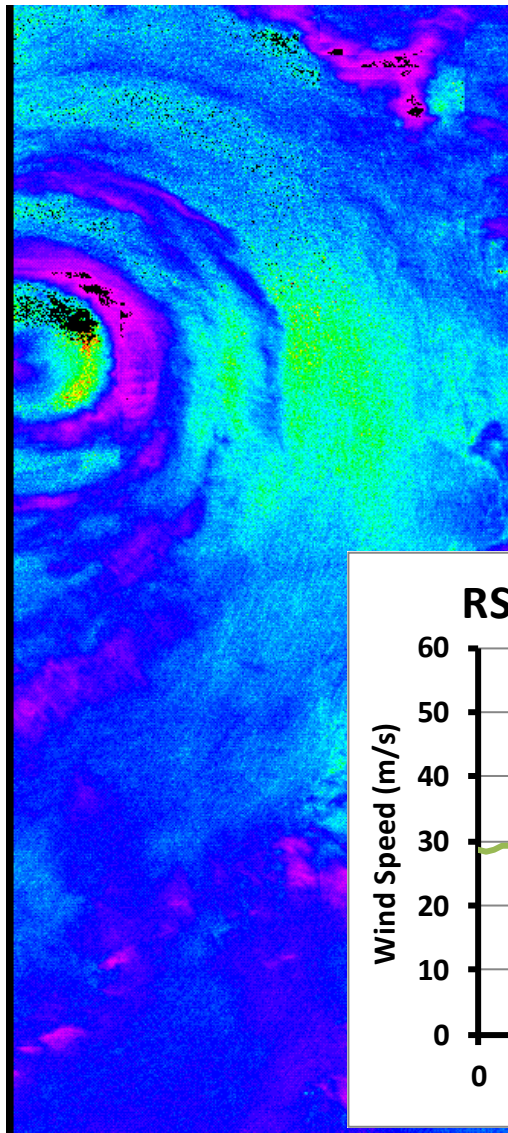
Megi 10/17 09:00 CSM3 XVV



Megi 10/17 21:00 CSM3 XVV



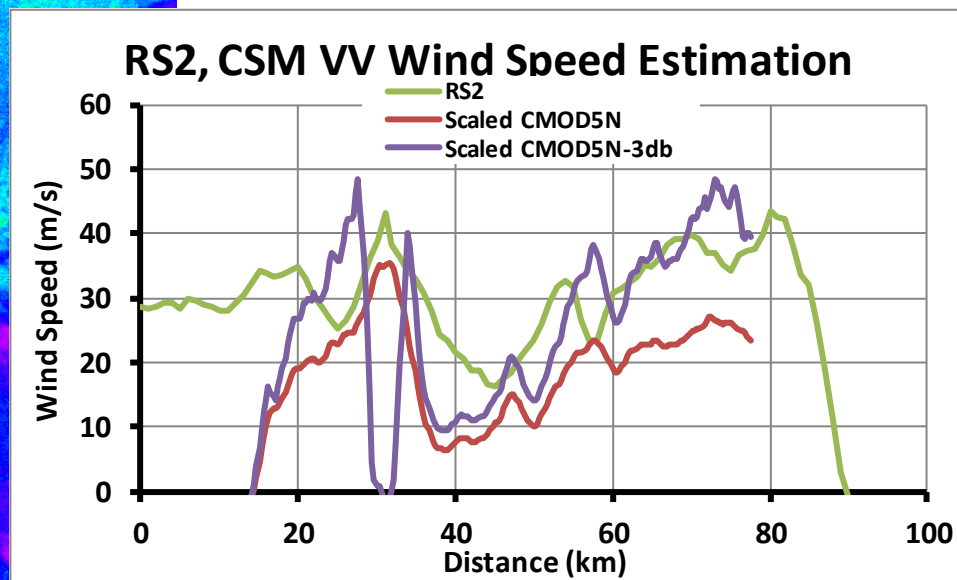
Megi 10/17 21:41 RS2 CVV



Megi 10/17 21:00 CSM3 XVV

SAR Winds From CSM X-VV

Comparison of Simultaneous RS2 and CSM C-VV Winds



Estimating Winds From Synthetic Aperture Radar in Typhoon Conditions

Summary and Conclusions

- Under ONR ITOP program, we are developing an automated system to estimate wind, waves, pressure fields from SAR imagery of typhoons
- It appears that the orientation of features in the SAR image that surround the eye are rotated outward by 5-20 degrees from the surface wind direction
 - more rotation on the right side of the storm, most in right-back quadrant
 - applying the rotation decreases the wind speed estimation error
 - Final wind direction have mean error = +/- 4 degs, RMSE = 22 degs
- CMOD5N does a good job of estimating wind speed for HH and winds $< \sim 40$ m/s
 - RMSE for HH imagery is 3 -4 m/s (compared to QSCAT, SFMR, Drops)
 - RMSE for VV is 6 m/s (compared to SFMR, Drops), *but see next bullet*

Estimating Winds From Synthetic Aperture Radar in Typhoon Conditions

Summary and Conclusions (cont)

- CMOD5N has some problems
 - “hourglass” shape in the wind speed around the eye
 - “drops-outs” for high wind regions
 - both worse at smaller incidence angle, VV
 - Does not appear to be a high/low wind speed issue
 - Does not appear to be solved by a simple re-scaling of CMOD5N
 - May need to research additional RCS sources (e.g. spray) in these regions
- Cross-pol (HV) shows promise in estimating wind speeds
 - Slightly better RMSE (5.1 m/s vs. 5.4 m/s), appears to have some better spatial results with SFMR
 - no “drop-outs”
 - slope term is approximately half the published value (0.281 vs. 0.58)?

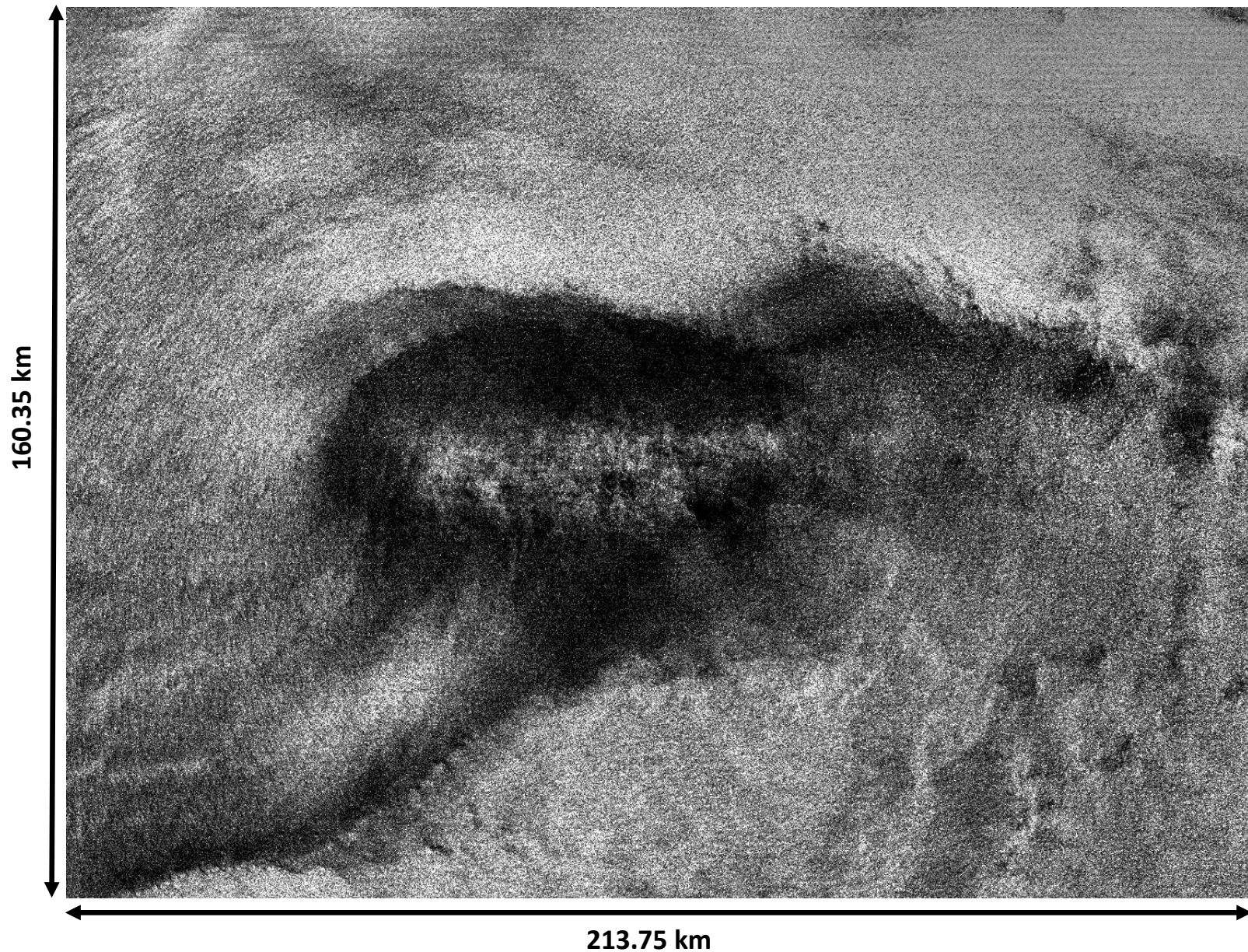
Estimating Winds From Synthetic Aperture Radar in Typhoon Conditions

Summary and Conclusions (cont)

- **Performing initial work on X-band GMF and wind retrievals**
 - **wind direction algorithms appears to work well as is compared to dropsondes**
 - **scaled CMOD5N model appears to work on both airborne and CSM data for lower wind speeds (< 15 m/s)**
 - **appears to need additional decrease for higher wind speeds (approximately -3dB)**

Back-Up

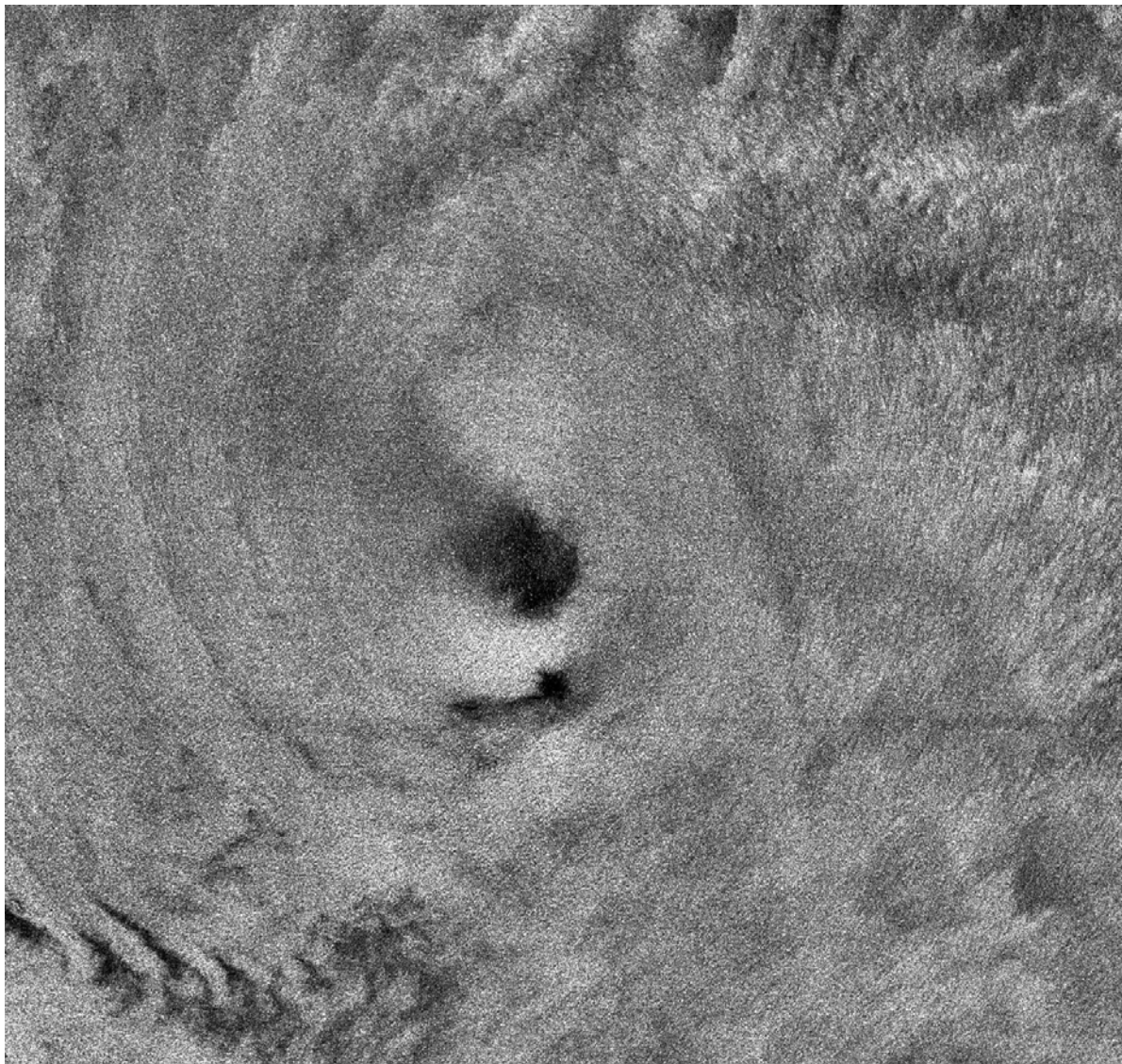
Malakas 9/22



Megi 10/15

216.45 km

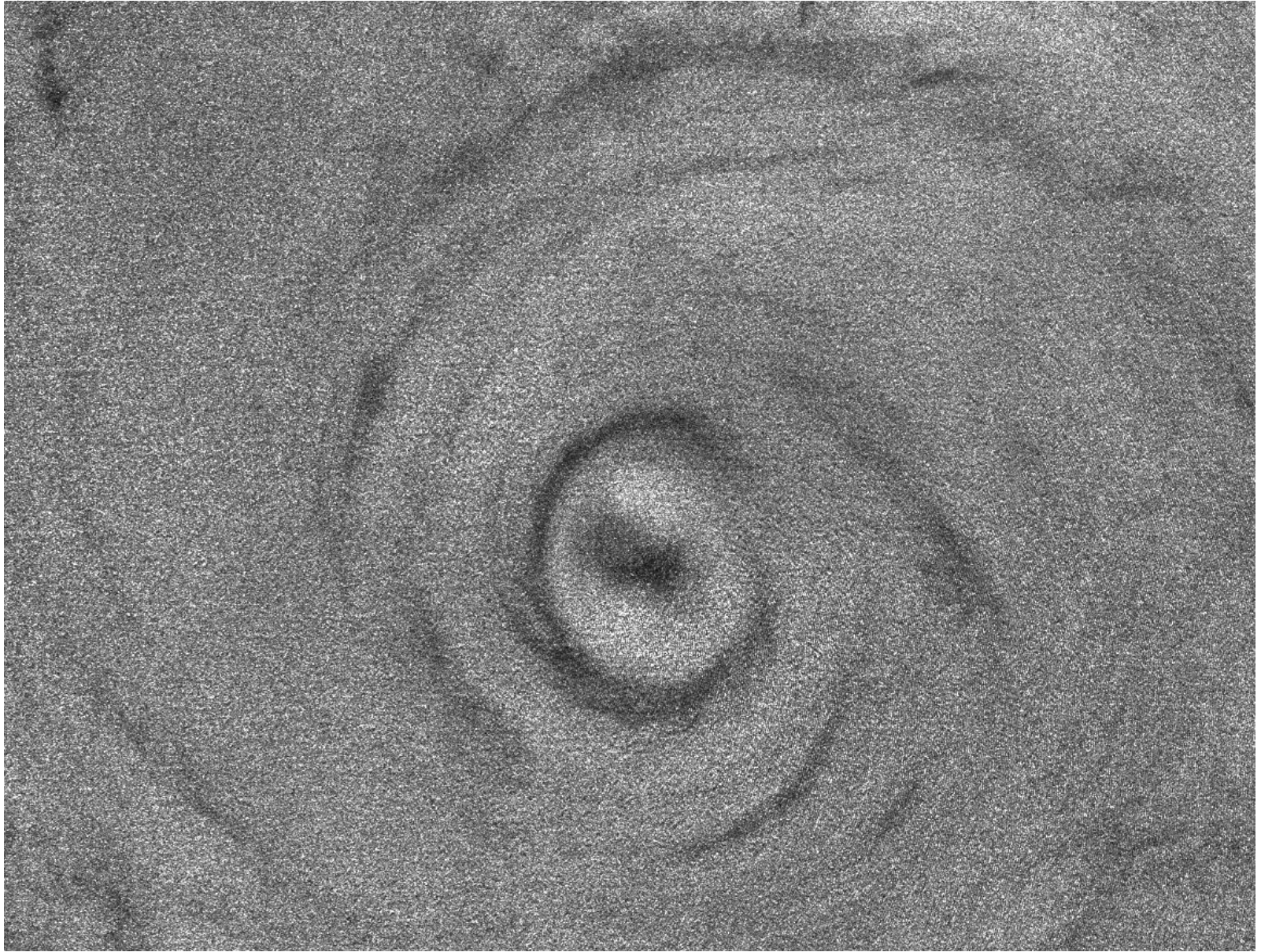
204.15 km

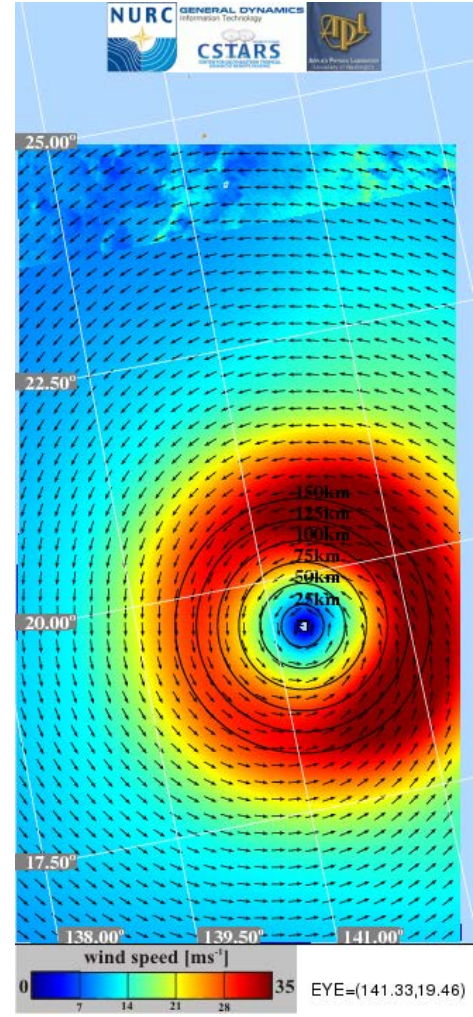
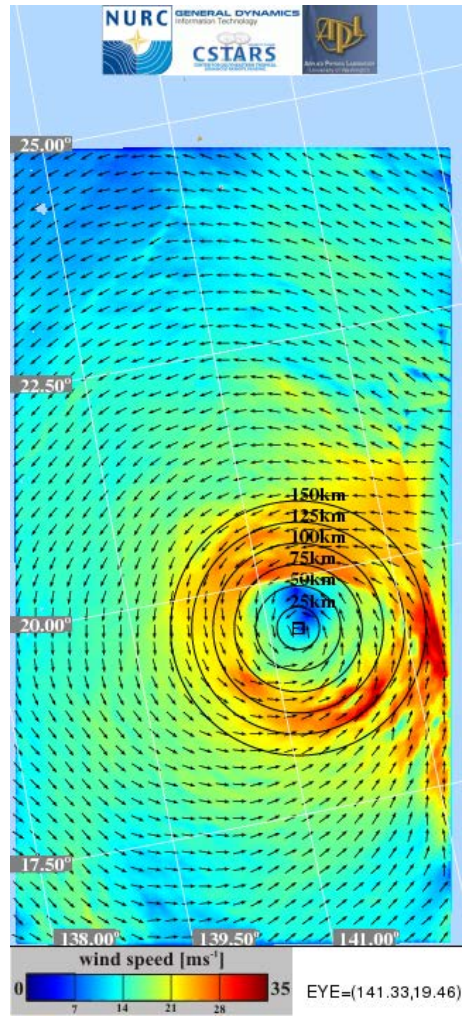
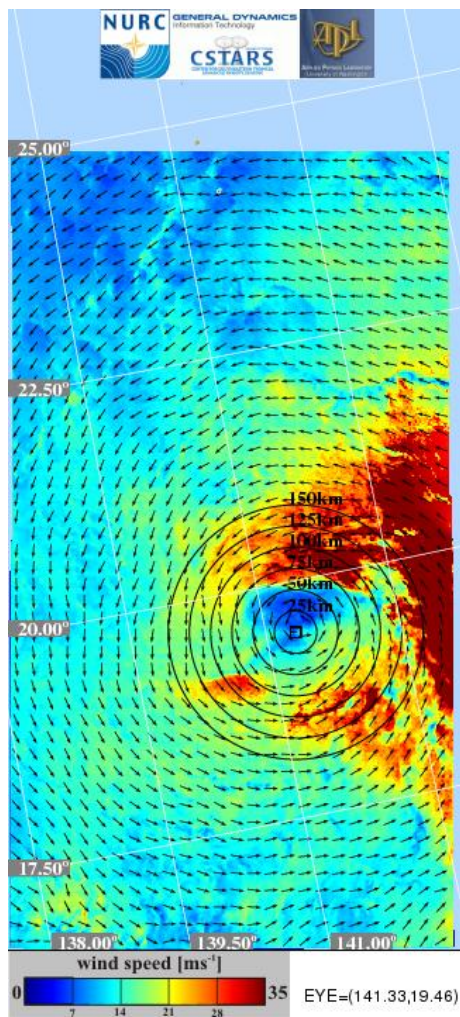


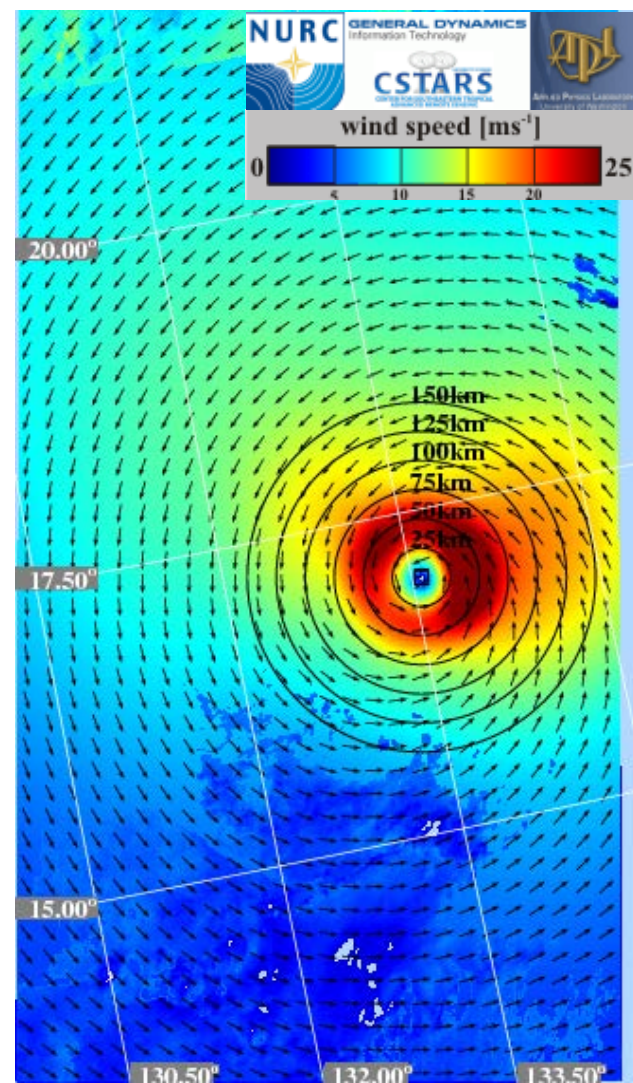
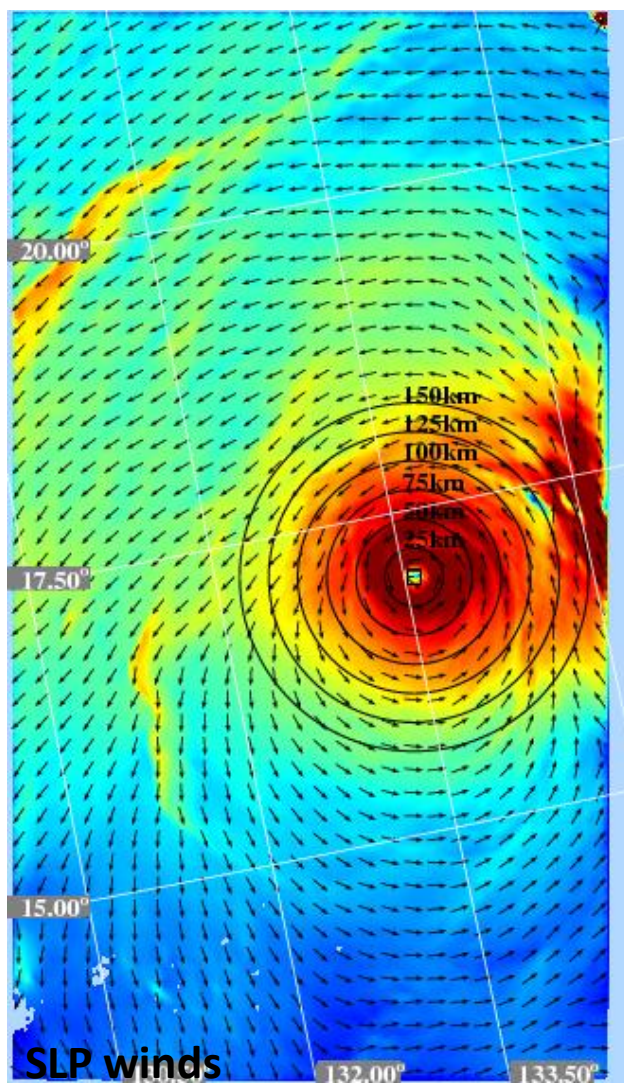
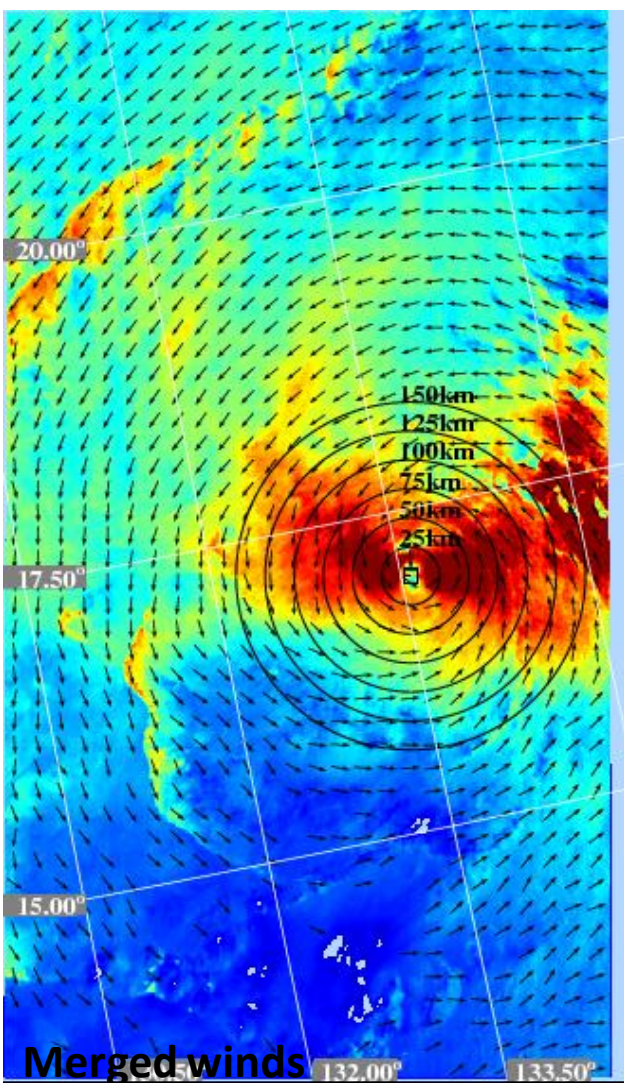
172.96 km

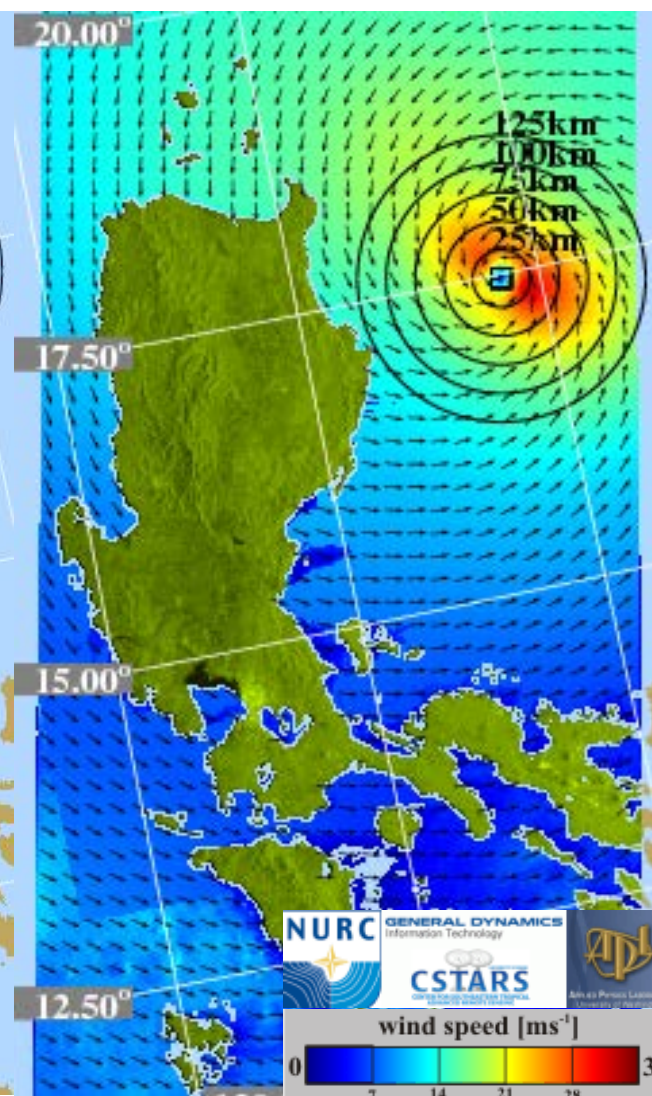
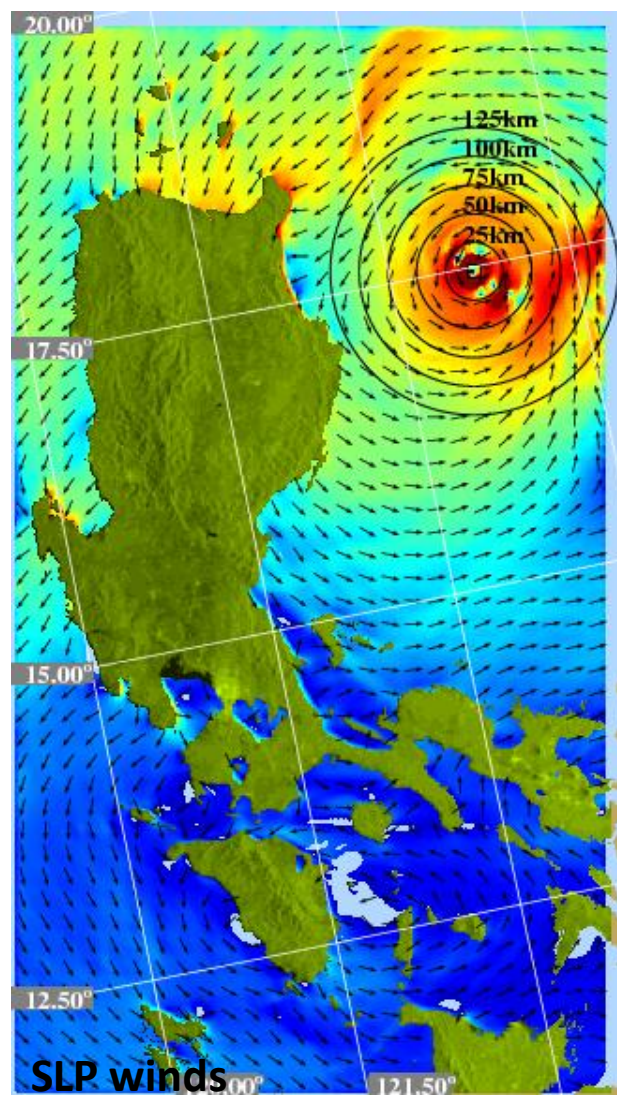
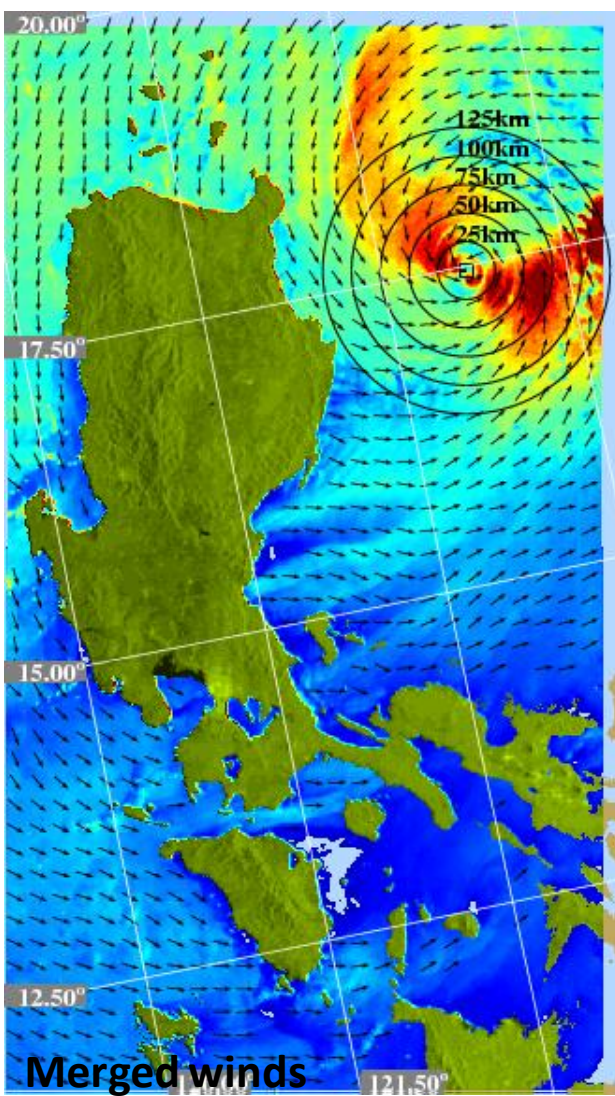
Megi 10/17

131.40 km

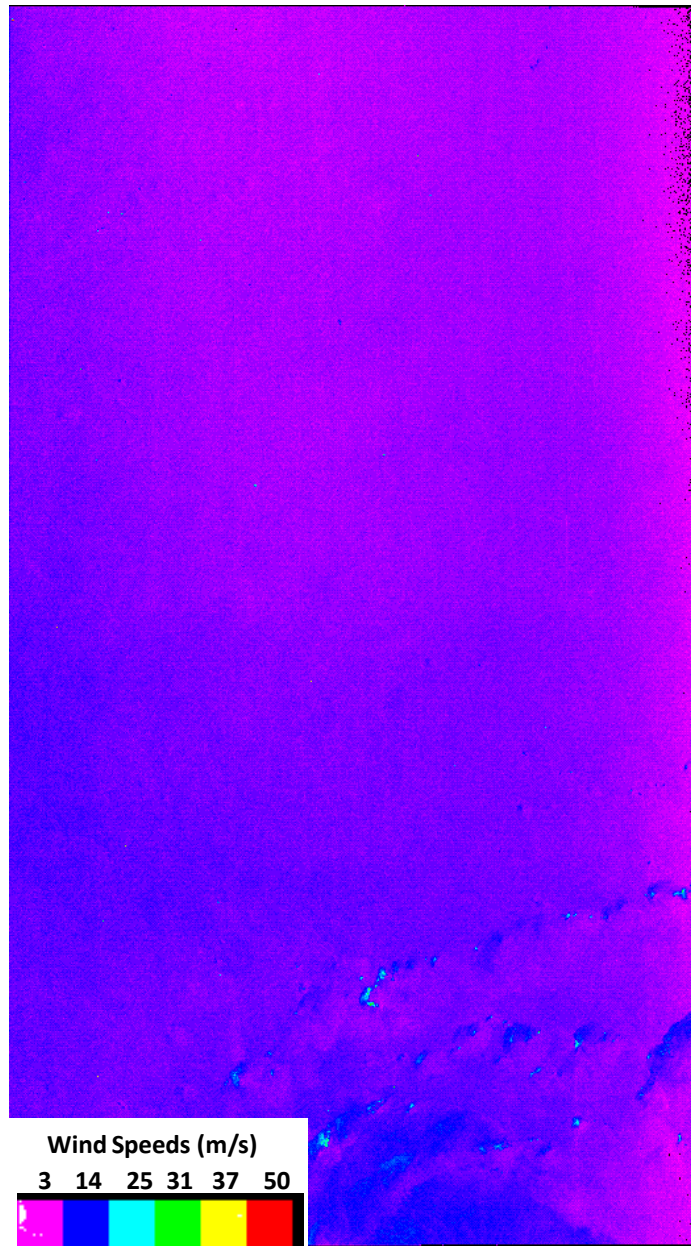




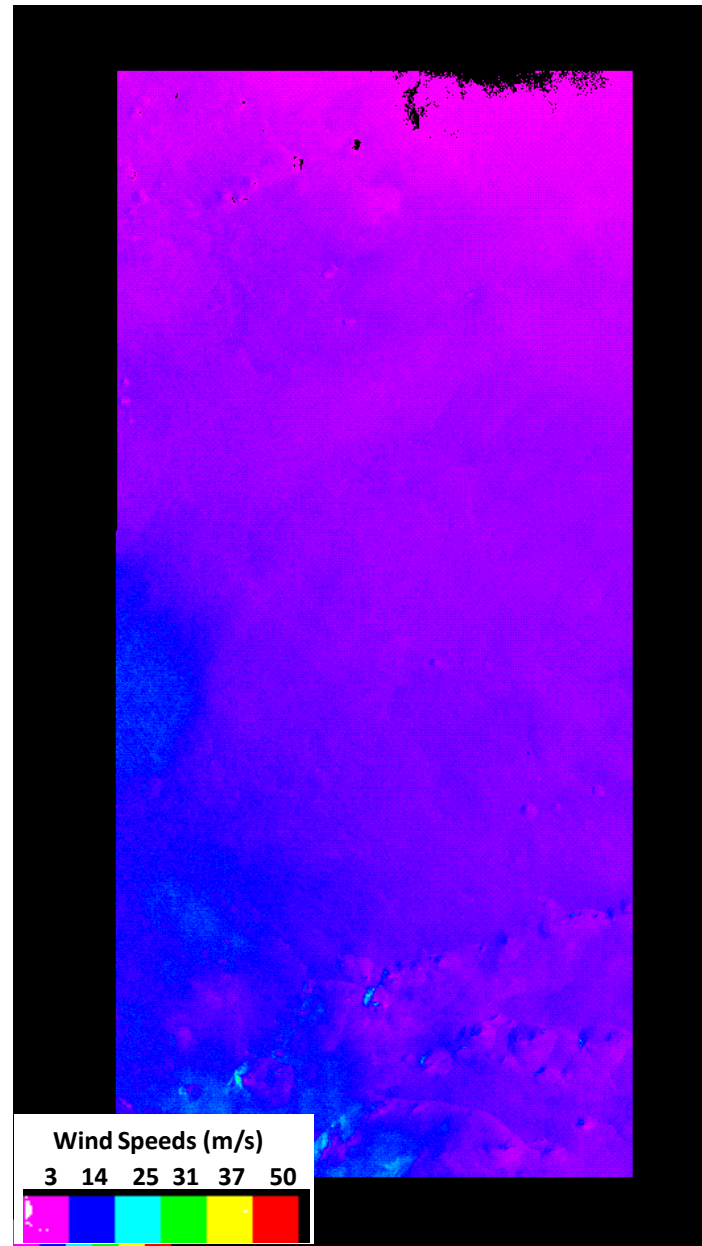




Fanapi 13 C-HH RS2



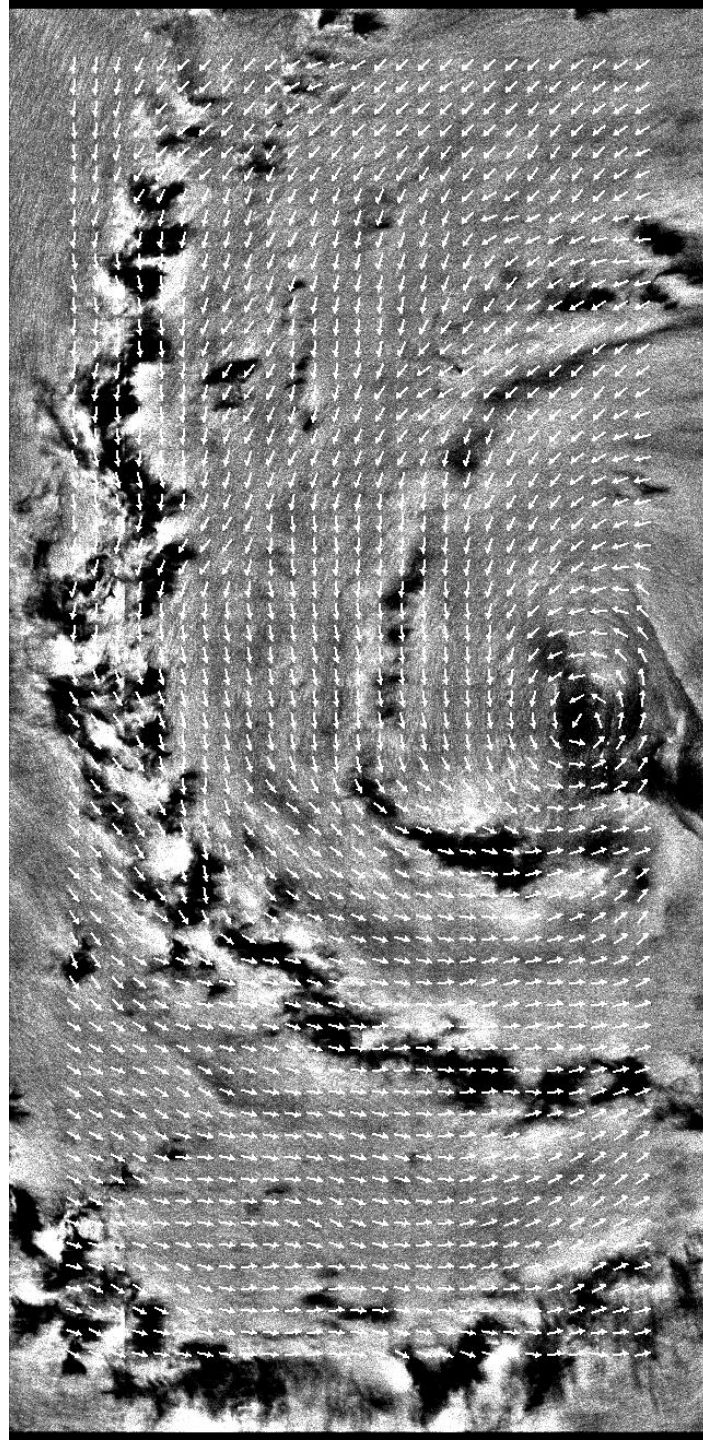
HV Wind Speeds



HH Wind Speeds

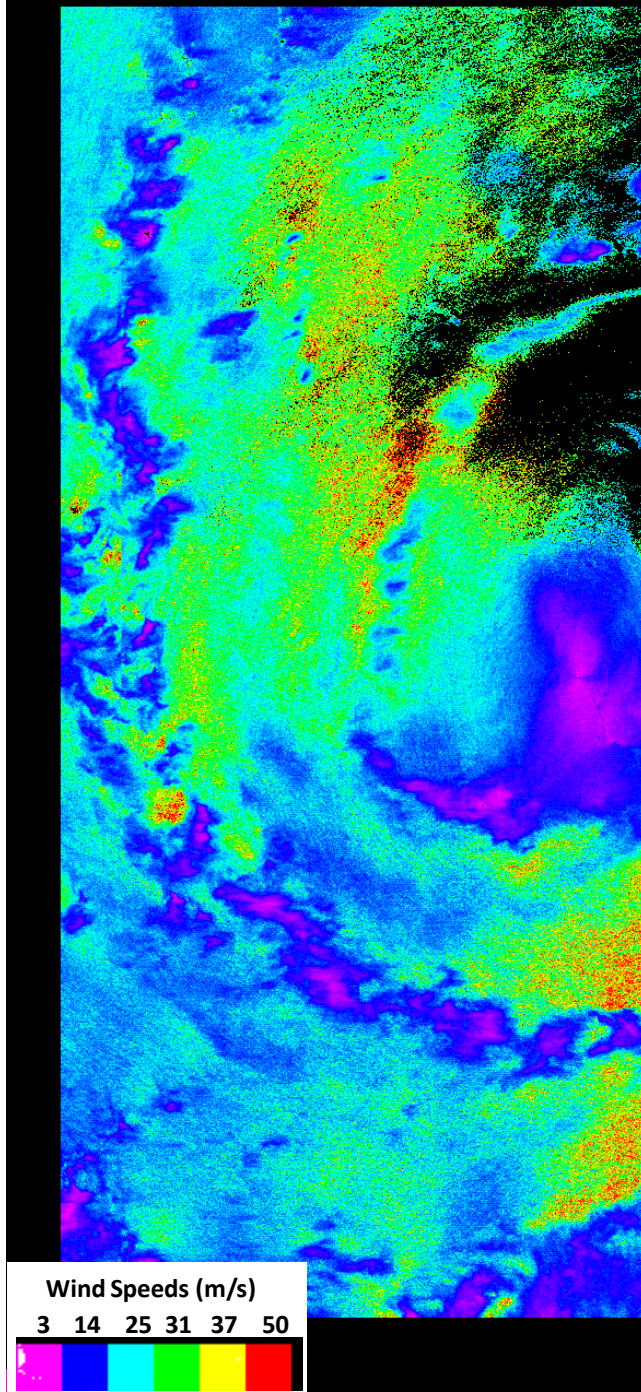
SAR Winds From CSM X-VV

Megi 10/19 22:00 CSM3 XVV

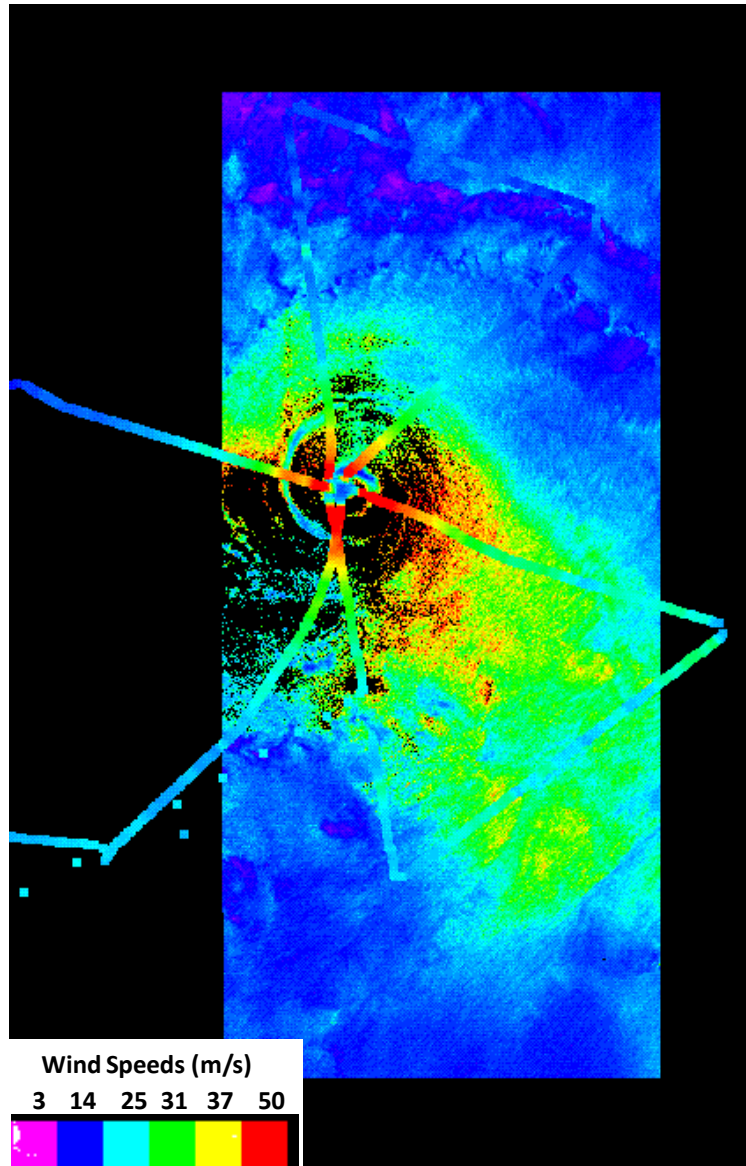


SAR Winds From CSM X-VV

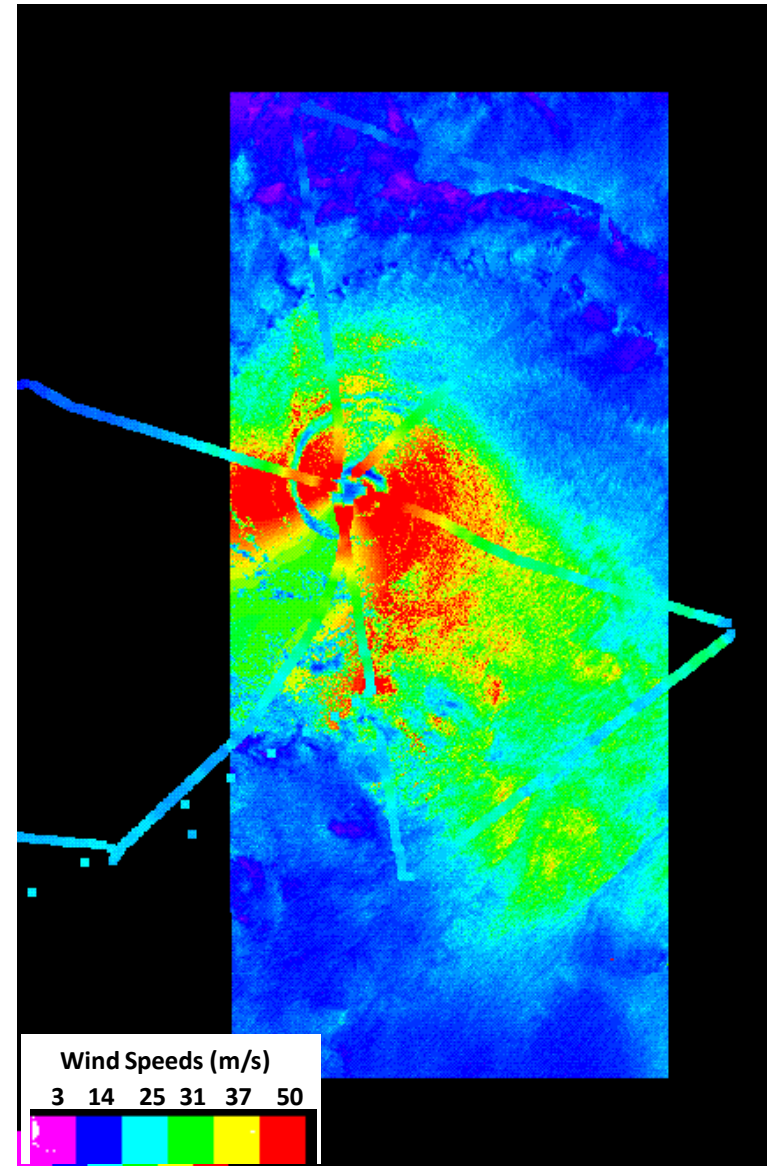
Megi 10/19 22:00 CSM3 XVV



Evaluating SAR Wind Speed Estimation



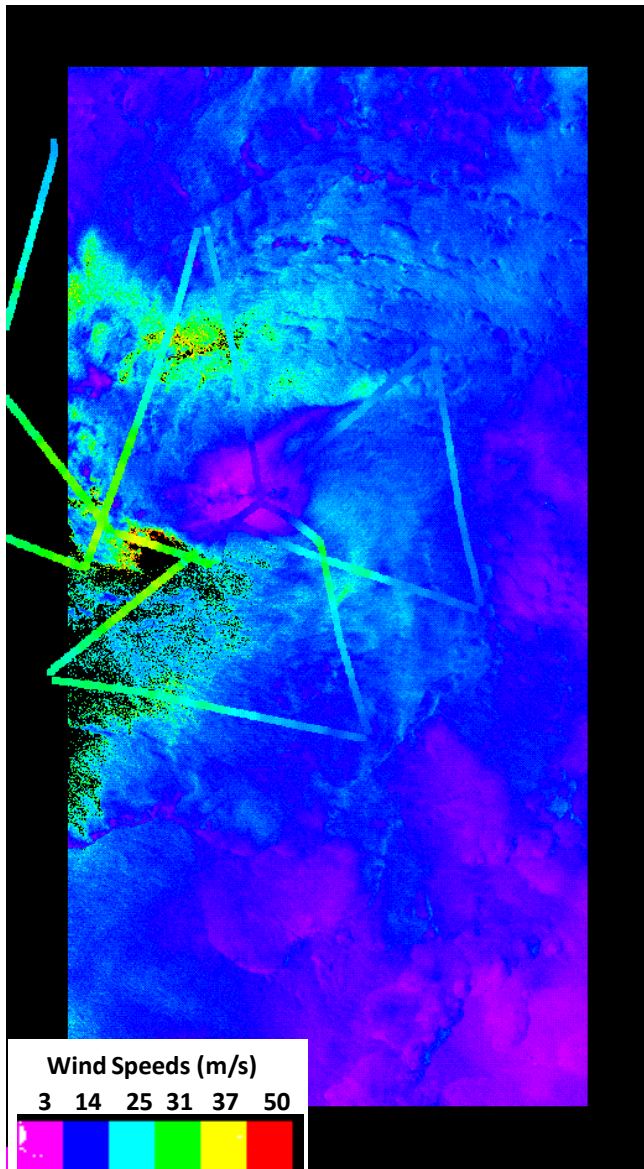
Black if all wind speeds give CMOD5N
RCS lower than SAR RCS



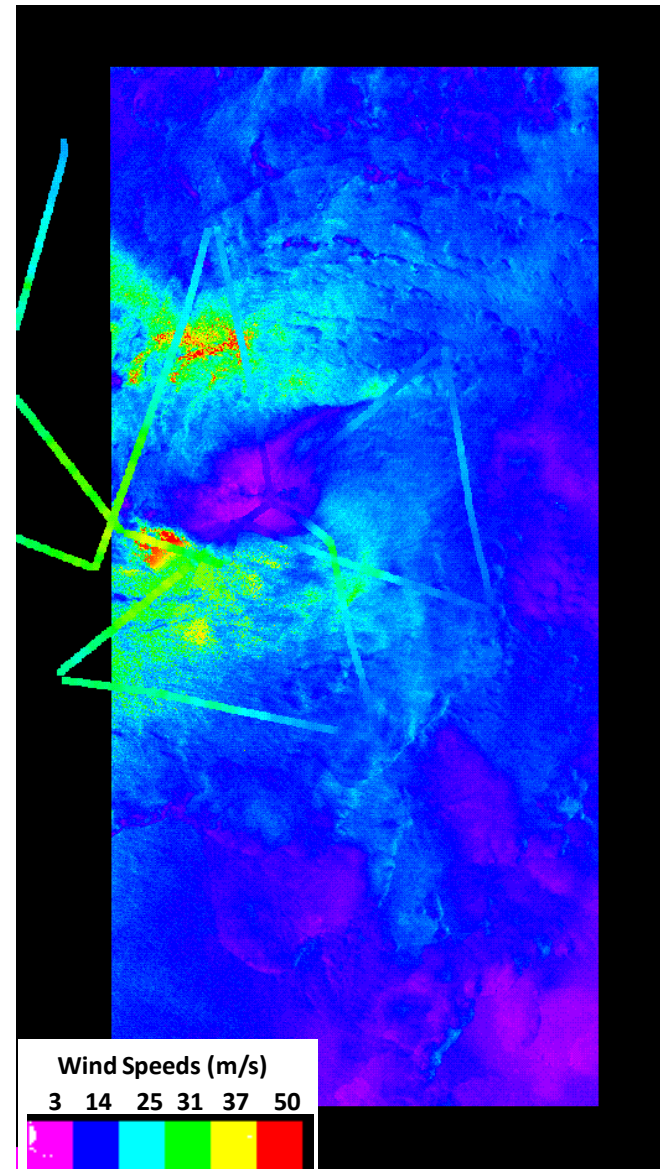
Pick wind speed that generates closest
RCS

Megi, Oct. 17 2010: Envisat CVV

Evaluating SAR Wind Speed Estimation

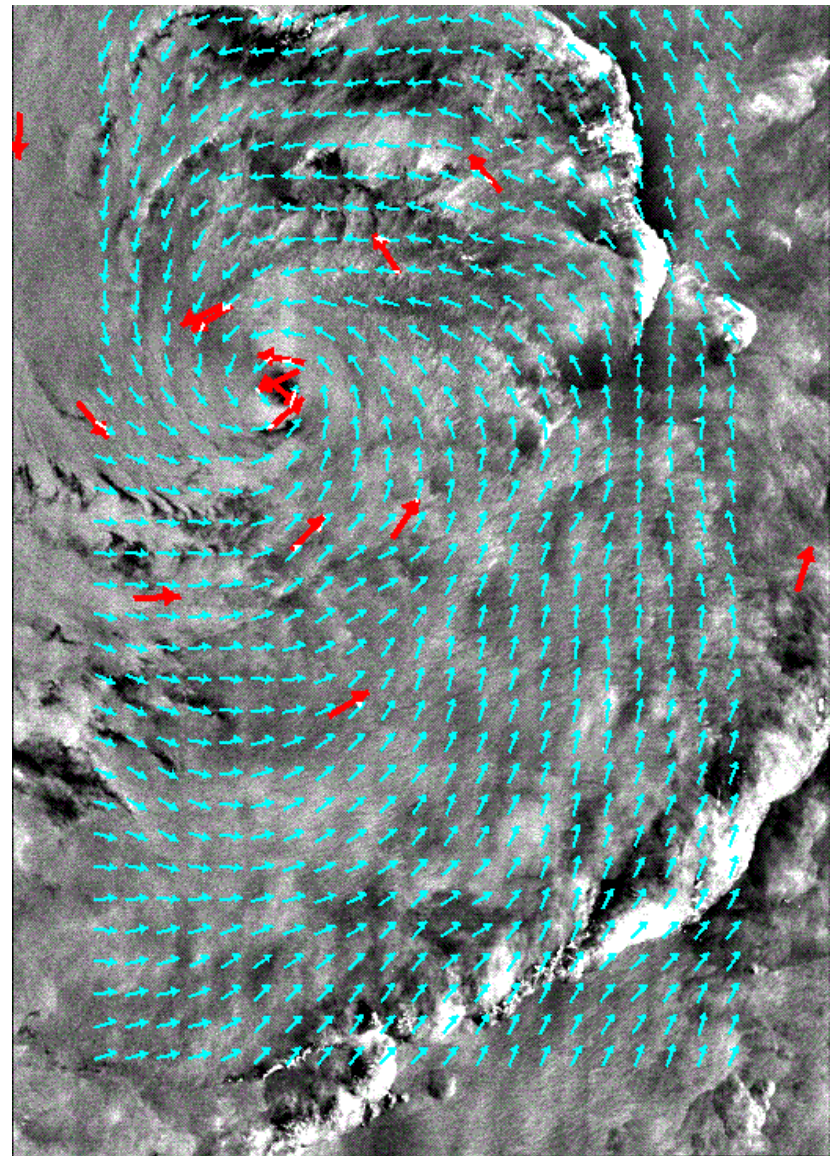
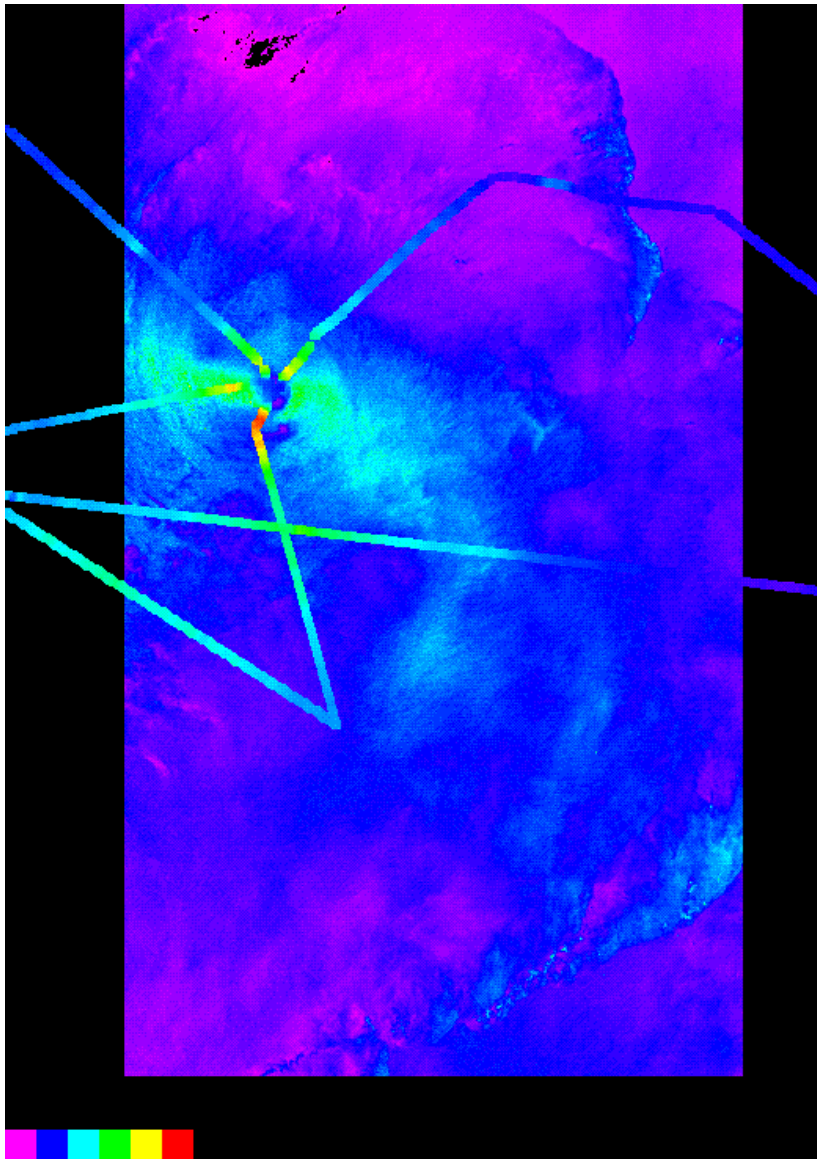


**Black if all wind speeds give CMOD5N
RCS lower than SAR RCS**



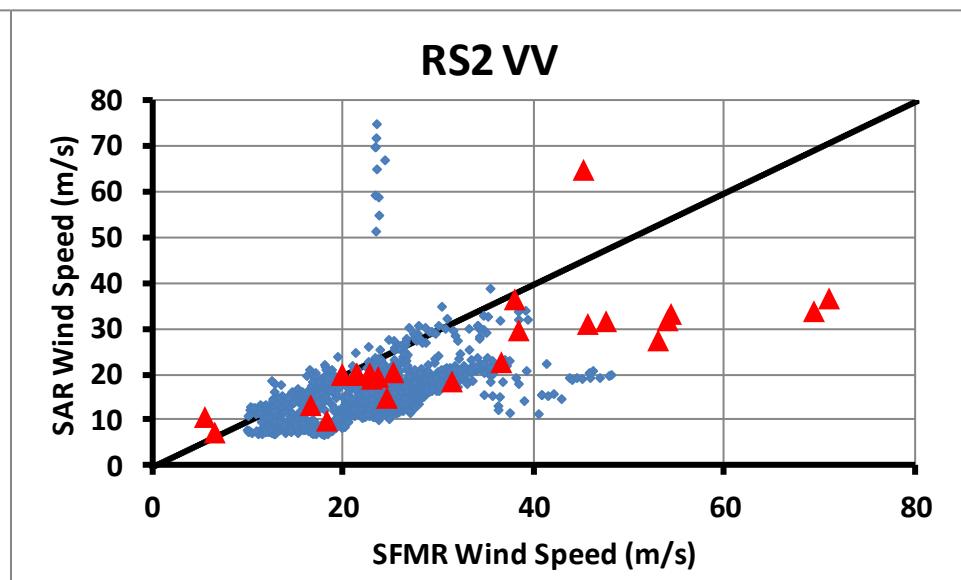
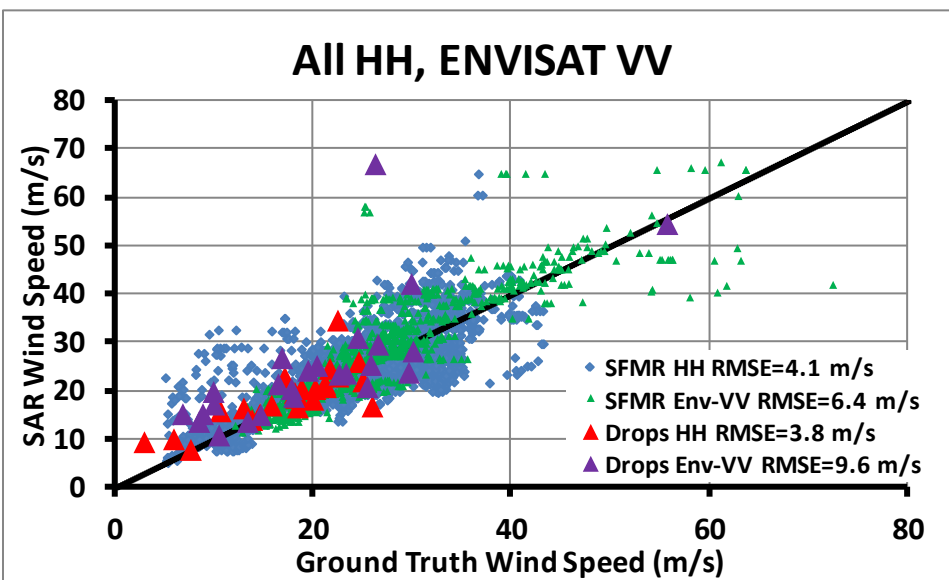
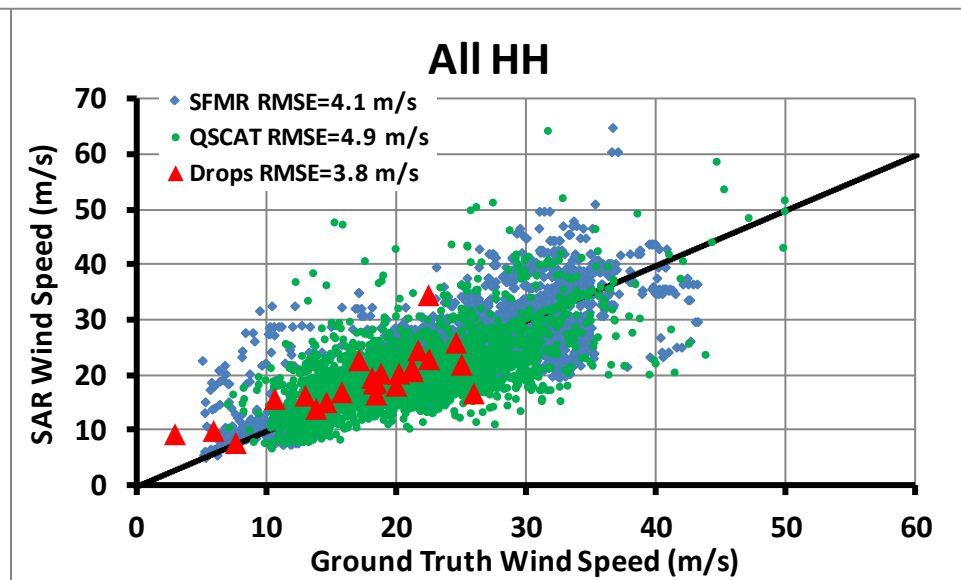
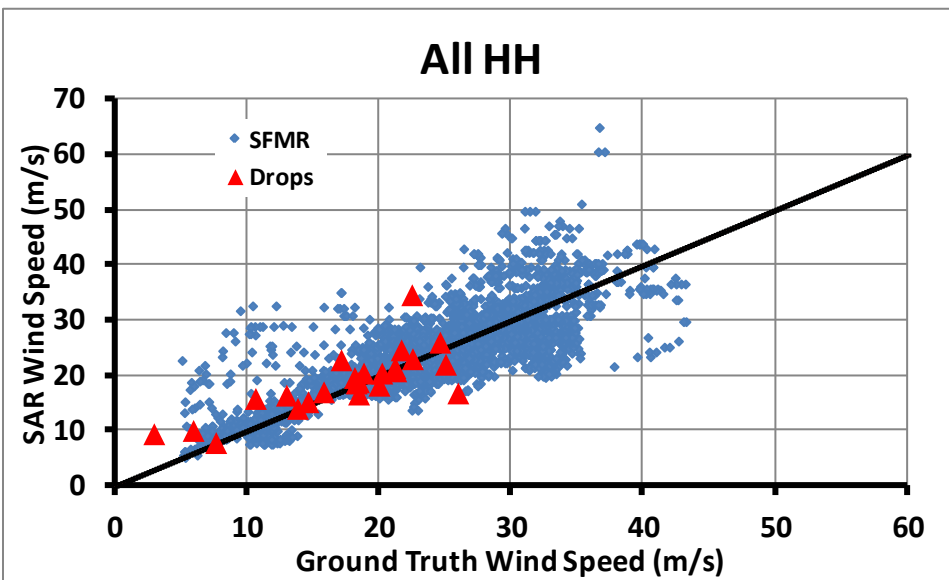
**Pick wind speed that generates closest
RCS**

Evaluating SAR Wind Speed Estimation



Megi, Oct 15 2010: RS2 CVV

Evaluating SAR Wind Speed Estimation



C-band GMF = CMOD5N, Thompson Model ($a=0.8$) for HH: hi-windspeed ± 2 km jitter allowed in locations; SAR ws*1.1 to compare to SFMR; All QSCAT pts