SAR Hurricane Observations Campaign, Preliminary Results

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Content

- Motivations,
- SAR Hurricane Observations Campaign,
- Normalized Radar Cross Section, over Hurricanes,
- NRCS and Ocean Surface Wind Speeds,
- Tropical Cyclone Parameters,
- Conclusions

Motivations

- Ocean Remote Sensing
  - Investigate the benefit of having High Resolution & Synoptic C-Band radar measurements in co- and cross- polarization

1. SAR is the only sensor able to provide an High Resolution (space) observation of Hurricane at synoptic scale.

   ⇨ Impact of the resolution on the hurricane observations

2. SAR is only space sensor able ot measure NRCS in both co- and cross- polarization

   ⇨ Impact of the choice of polarization on hurricane observations

3. Sentinel-1 SAR can be co-located with Passive measurements

   ⇨ Role of breaking waves and/or foam on active & passive measurements

Motivations

- Ocean Remote Sensing
  - Investigate the benefit of having High Resolution & Synoptic C-Band radar measurements in co- and cross- polarization
  - Use the new capabilities of SAR for geophysical parameters measurements to

    1. measure new geophysical parameters or improve existing ones

       ➢ In the context of Copernicus, ESA processes and delivers in NRT a operational ocean surface wind product based on co-polarization.

    2. Prepare future missions

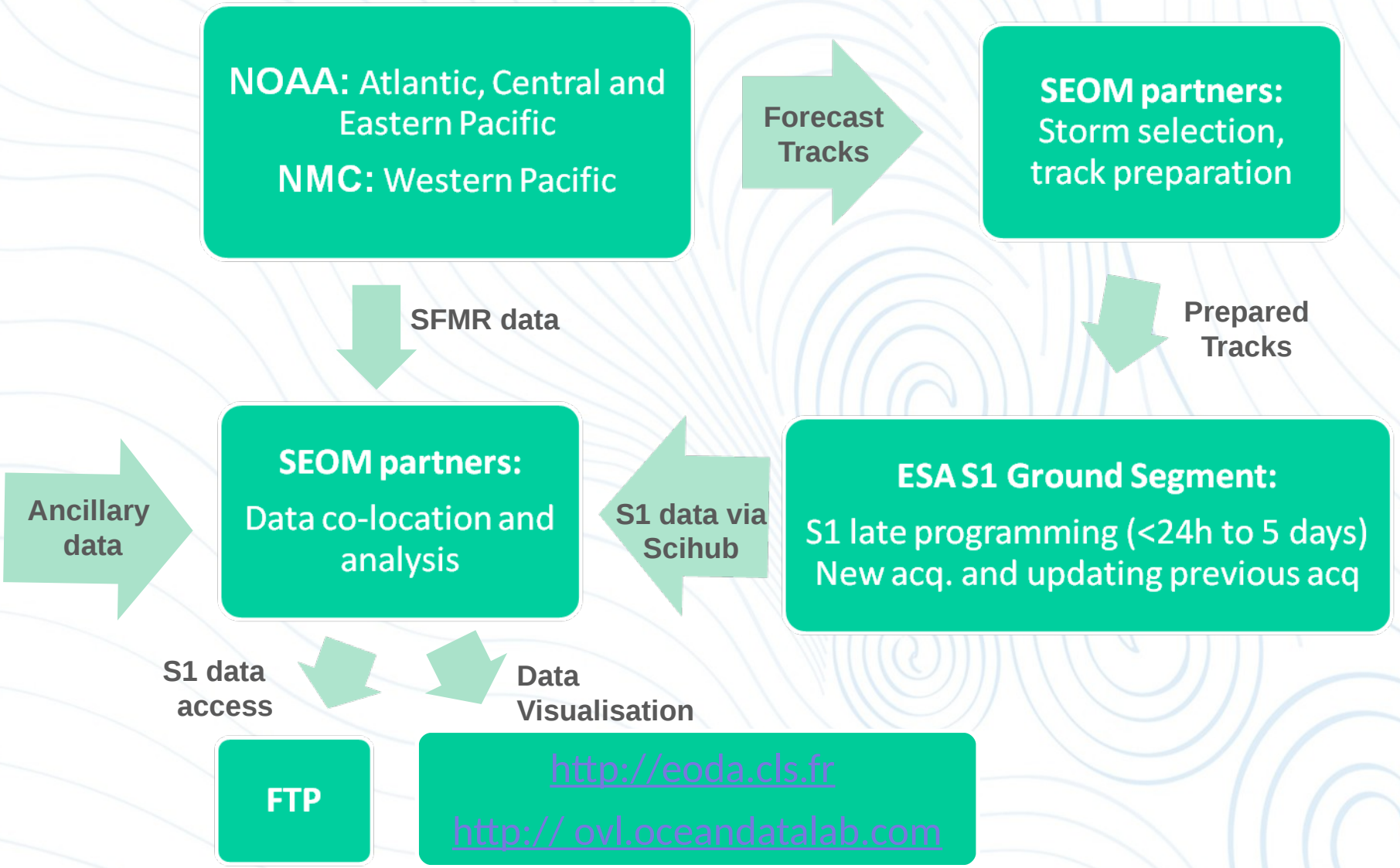
       ➢ Metop-SG (2019) should get the ability to measure NRCS in co- and cross-polarizations

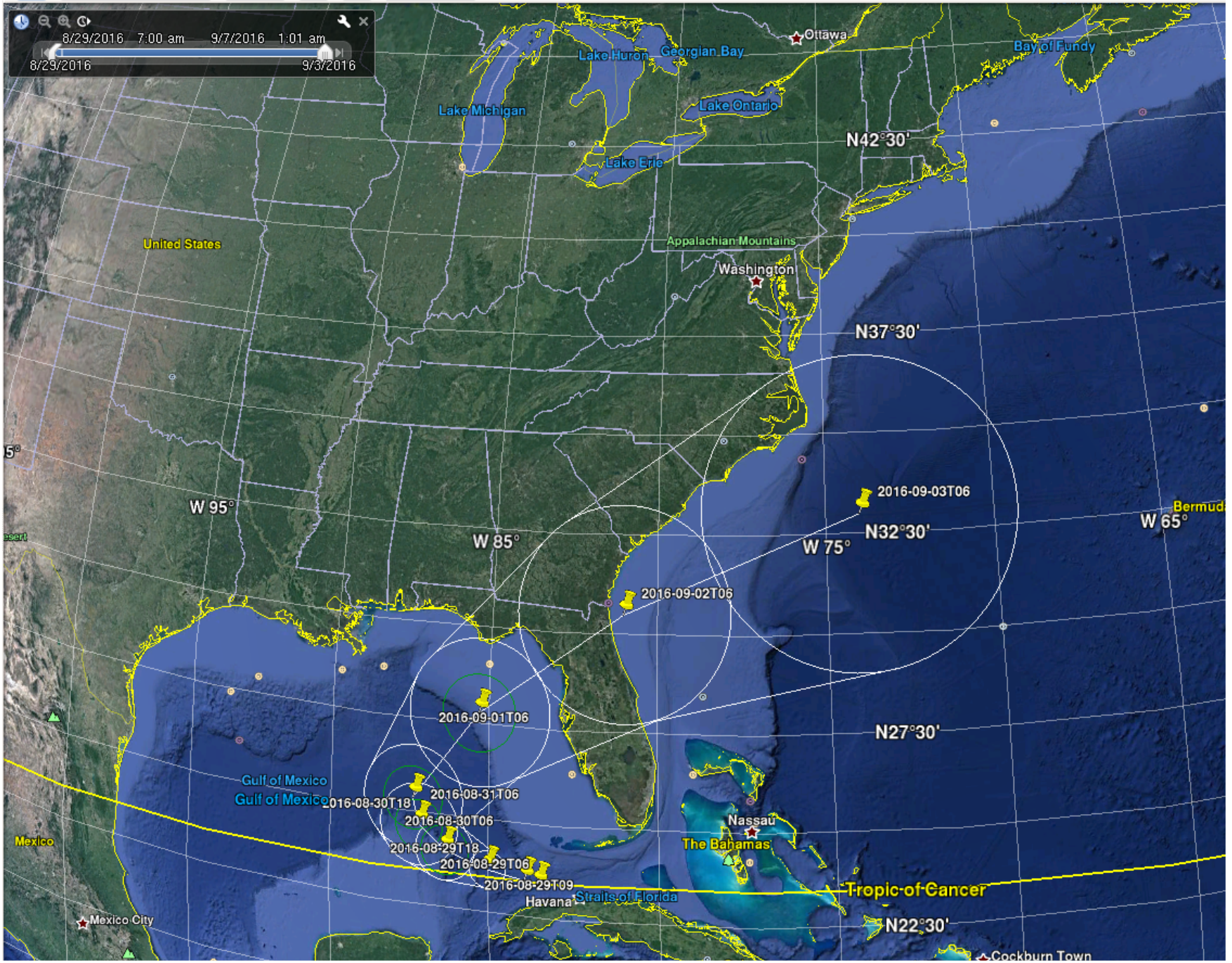
Motivations

- Tropical Cyclone Study
  - Derive T.C. « standard » geophysical parameters such as Maximum Sustained Wind, radius of maximum wind speed or 34-,50- and 64- wind radii
  - Provide consistent analysis between hurricane wind (wind extent, wind speed) and the hurricane generated waves
- SAR-Based services
  - SHOC could be seen as a demonstration service for EU to provide SAR observations as part of the Copernicus Program.
    Notre that there is an emergency management (geohazards) service

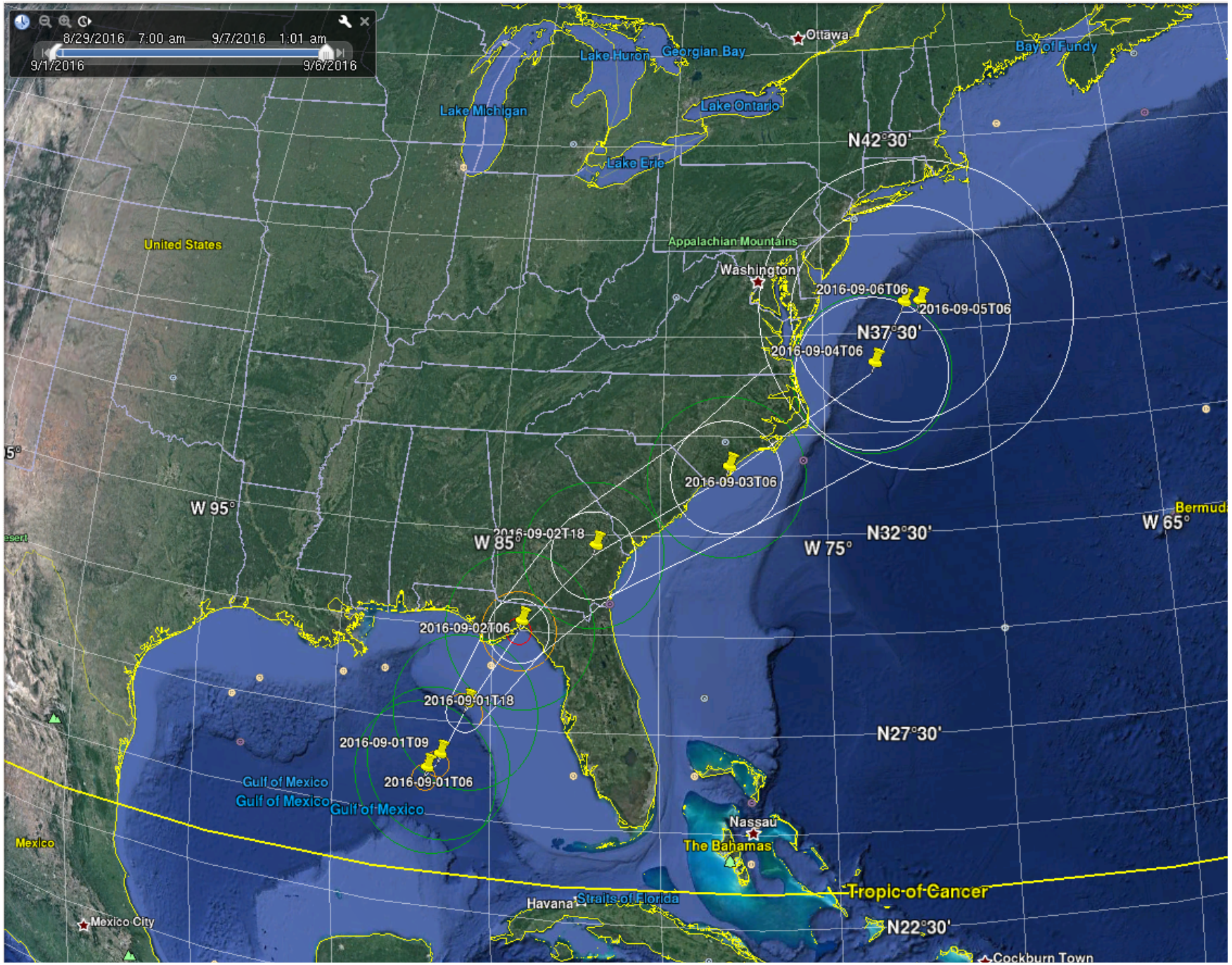
Satellite Hurricane Observations Campaign

- Principle

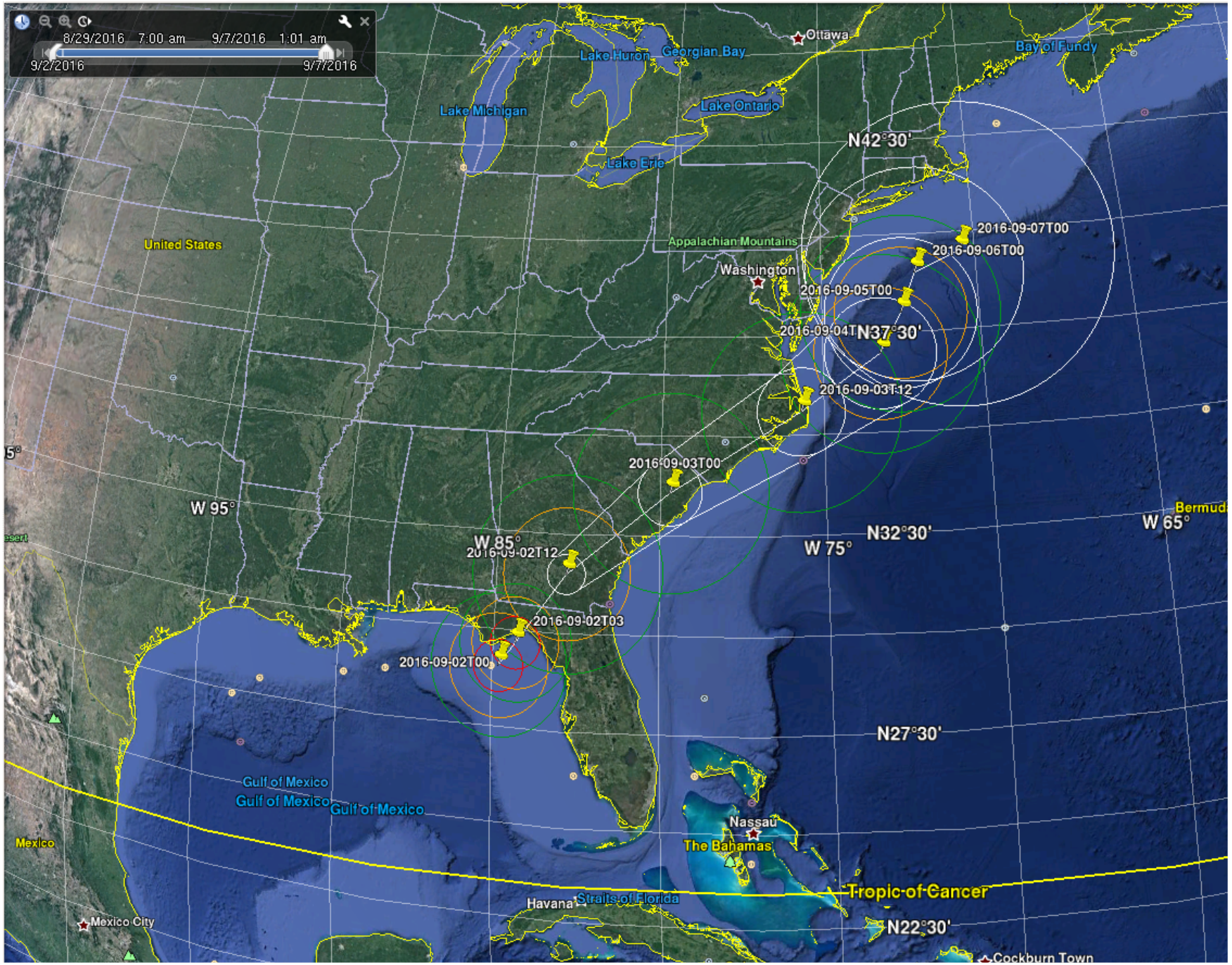

NOAA: Atlantic, Central and Eastern Pacific
NMC: Western Pacific
Forecast Tracks
SEOM partners: Storm selection, track preparation
SFMR data
Prepared Tracks
Ancillary data
SEOM partners: Data co-location and analysis
S1 data via Scihub
ESA S1 Ground Segment: S1 late programming (<24h to 5 days) New acq. and updating previous acq
S1 data access
Data Visualisation
FTP
http://eoda.cls.fr
http:// ovl.oceandatalab.com



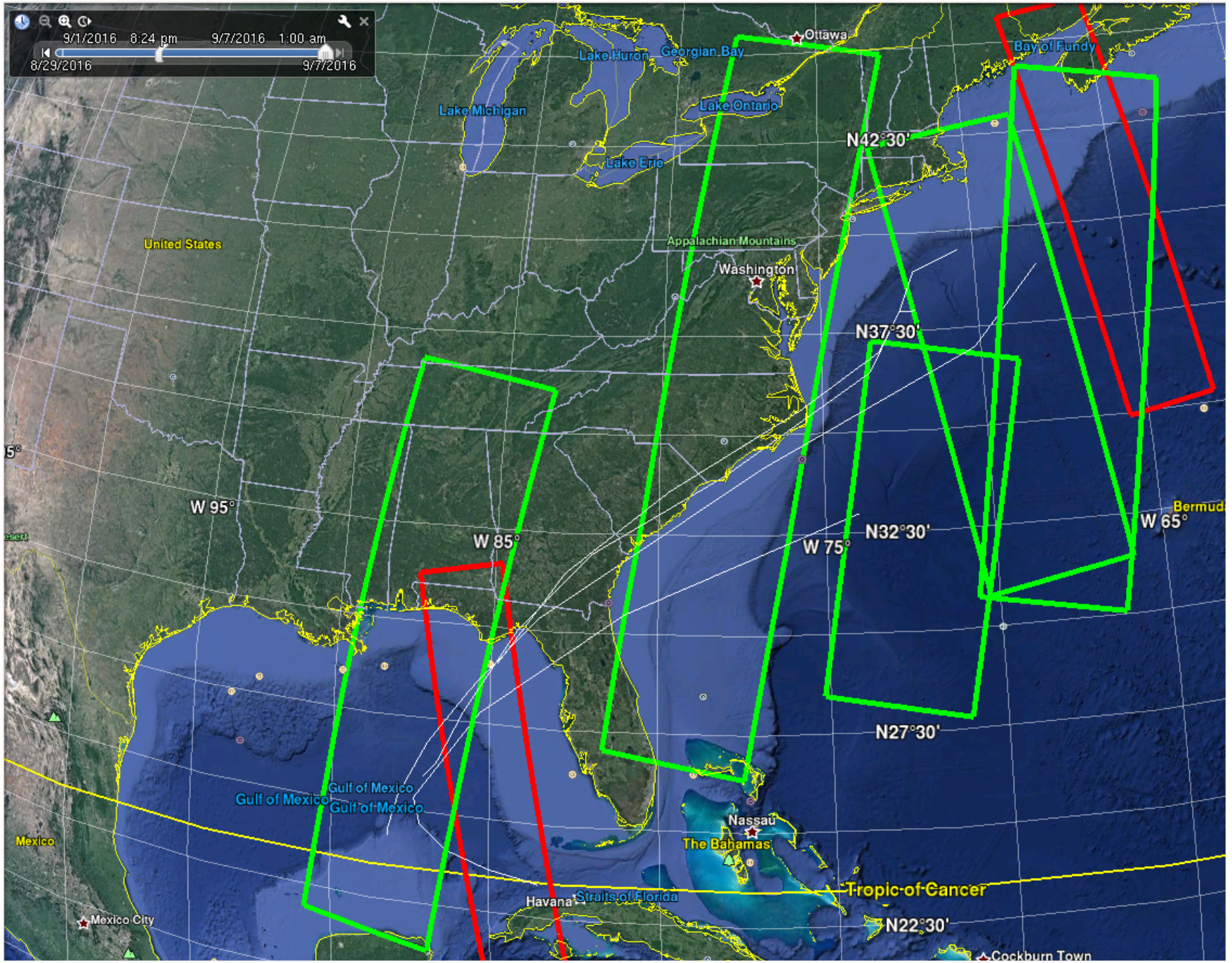
Example of successive trajectories for Hurricane Hermine provided to S1 ground segment to plan acquisitions the Hurricane center – V0



Example of successive trajectories for Hurricane Hermine provided to S1 ground segment to plan acquisitions the Hurricane center – V1

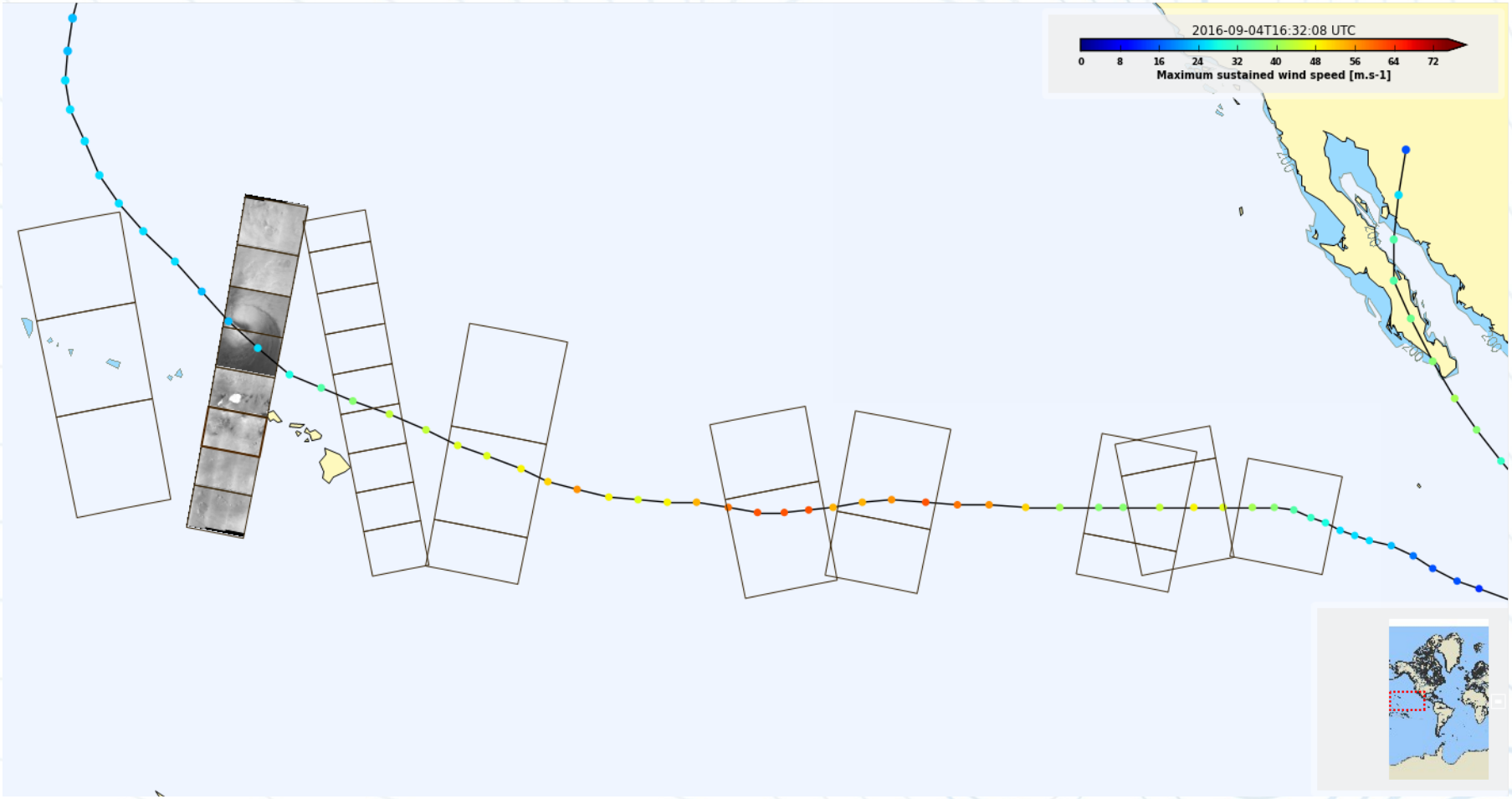


Example of successive trajectories for Hurricane Hermine provided to S1 ground segment to plan acquisitions the Hurricane center – V2

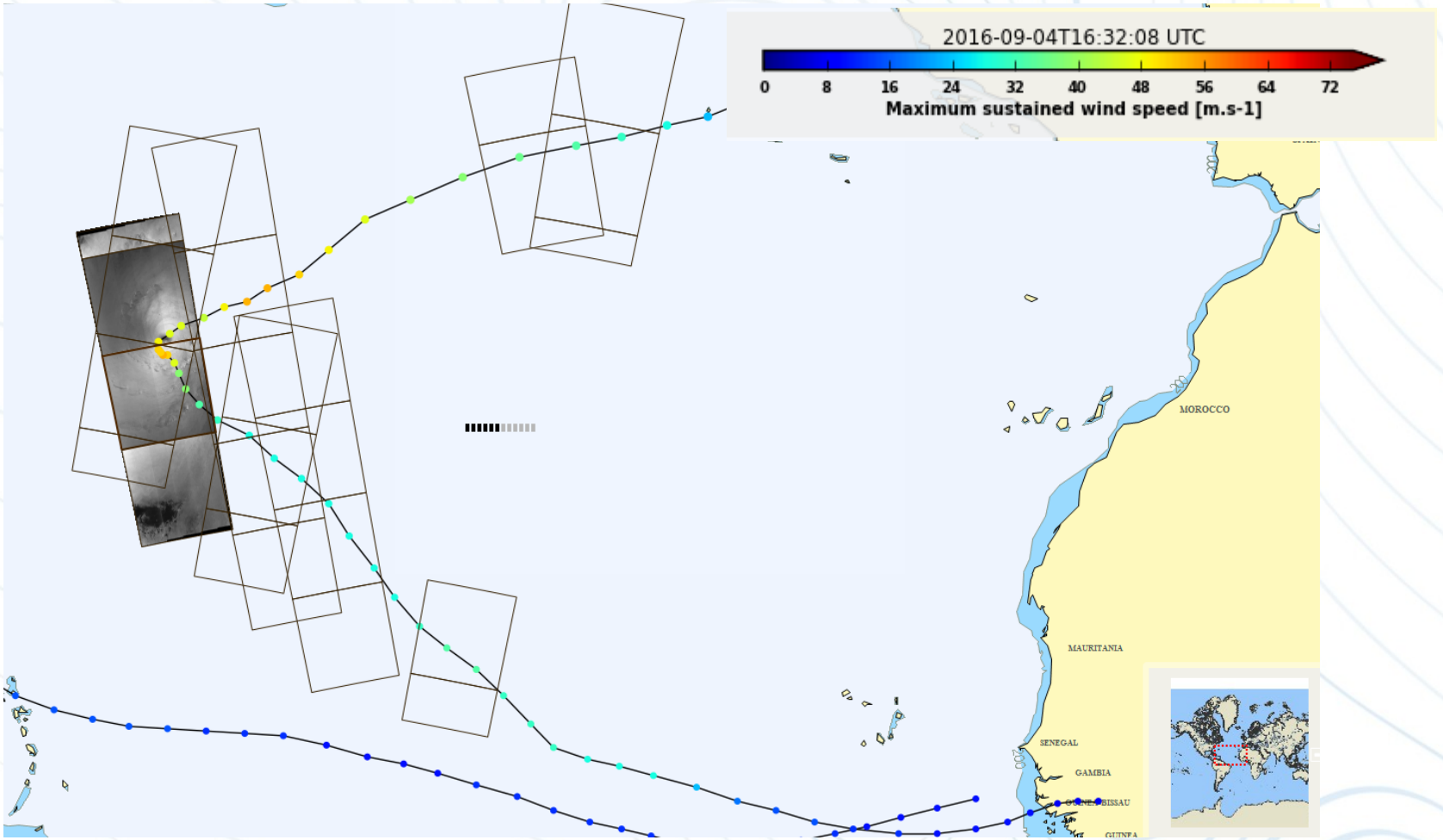


All S1 acquired acquisitions over Hurricane Hermine (green for EW, red for IW) with successive forecast trajectories

Sentinel-1A acquisition over Lester along its path



Sentinel-1A acquisition over Gaston along its path



#	Name	Nbr of Acq	SMFR	Eye
1	Kay	1		
2	Lyonrock	4		3
3	Gaston	10		6
4	Lester	10		4
5	TS8	3		
6	Hermine	6	1	2
7	Madeline	4		
8	Namtheum	2		1
9	Orlene	2		
10	Meranti	1		
11	Malakas	4		
12	Karl	5	3	2
13	Lisa	10		
14	Megi	3		2
15	Hulika	6		

- 20 acquisitions with eye captured in SAR images (~30 %)

- Very few co-locations with SFMR (3)

No co-location during most intense regimes of the T.C.

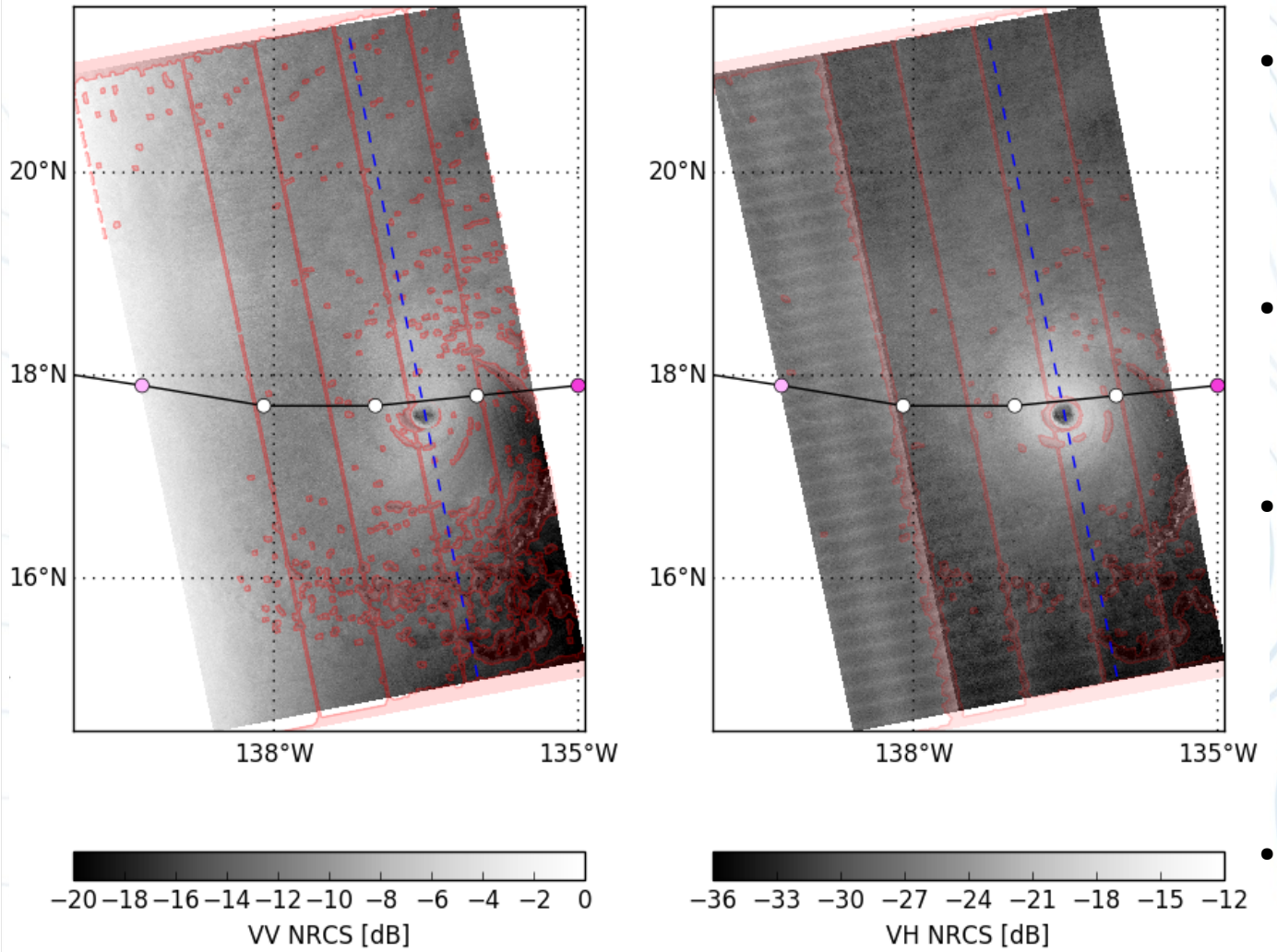
20 acquisitions with eye captured in SAR images (~30 %)

S1 acq over most extreme winds:

- Typhoon **Lionrock**: 2 acq. in Cat 3, both at **105 knots** max. sustained winds
- Typhoon **Megi**: 1acq. in Cat 3, **100 knots** max sustained winds
- Hurricane **Lester**: 2 acq. in Cat 3 and 4, **105 and 120 knots** max sustained winds

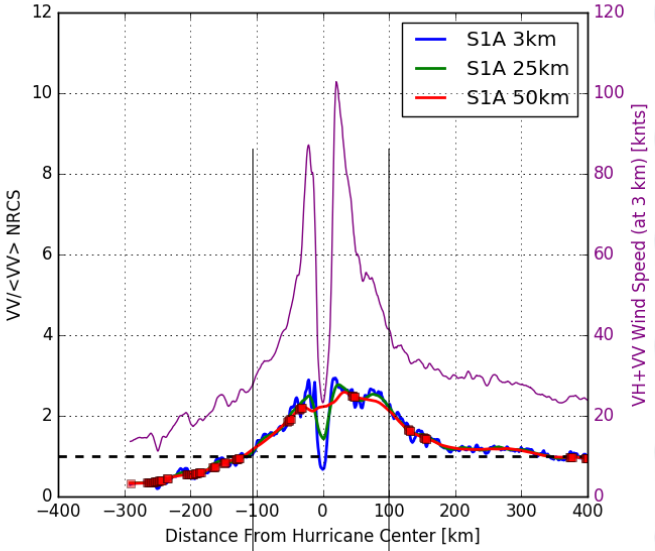
NRCS Sensitivity to the response of the ocean surface during hurricanes events

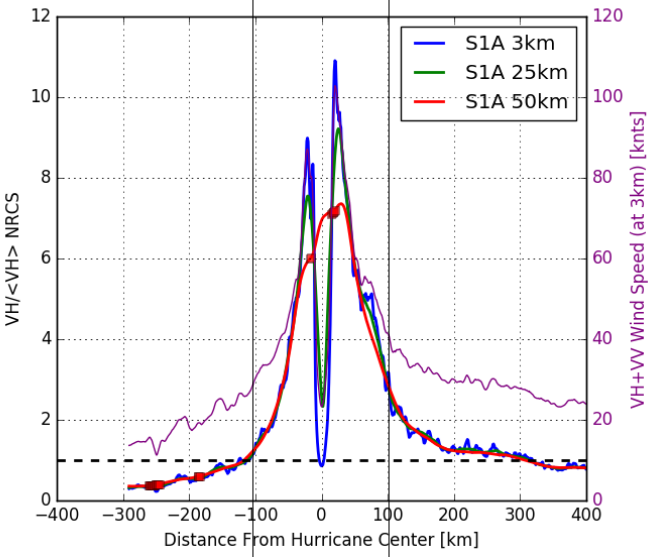
NRCS



- Both VV and VV captures hurricane features (eye, rain impact, wind acceleration)
- VV-NRCS is much higher than VH-NRCS
- VH is significantly affected by noise.
  - In Near range, SNR is very low
  - Far from the eye the SNR is very low.
- LG gradient method can be applied to filter out heterogeneities in the images

Koch, W. "Directional Analysis of SAR Images Aiming at Wind Direction." IEEE Transactions on Geoscience and Remote Sensing 42, no. 4 (April 2004): 702–10. doi:10.1109/TGRS.2003.818811.





Background Background

- Difference of NRCS sensitivity is analyzed with respect to the background signal :

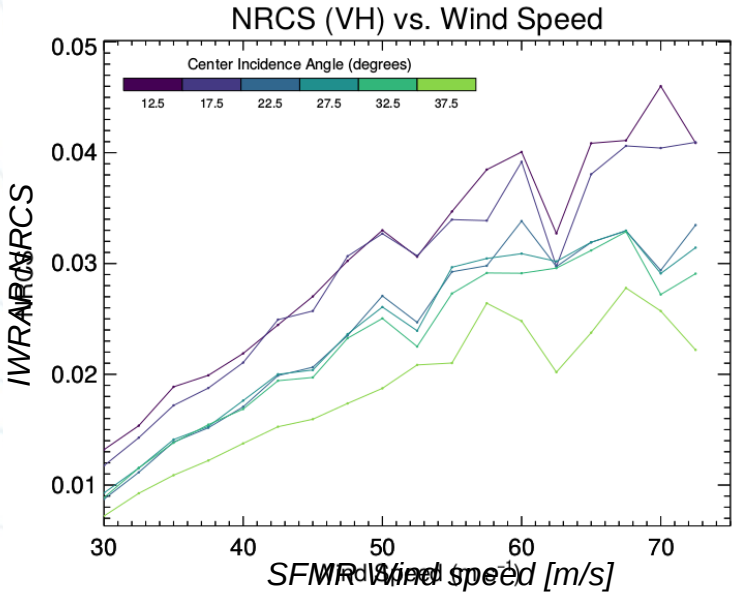
  C_pp = NRCS_pp/<NRCS_pp>

- Sensitivity of VV-NRCS is found to be much lower (up to 3 times) than in VH-NRCS

- Sensitivity of NRCS decreases when resolution increases ; but remains much higher in VH.

- Resolution changes impacts more VH than VV.

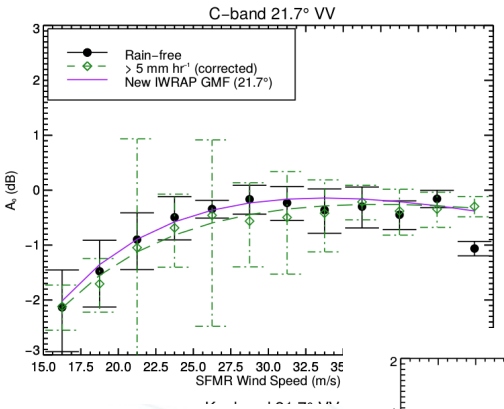
NRCS & Ocean Surface Wind

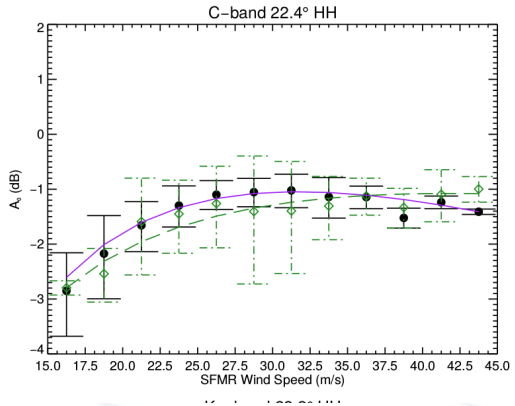


Airborne measurements

- Sensitivity of VH NRCS does not decrease over hurricane.

Sapp et al., IGARSS 2016

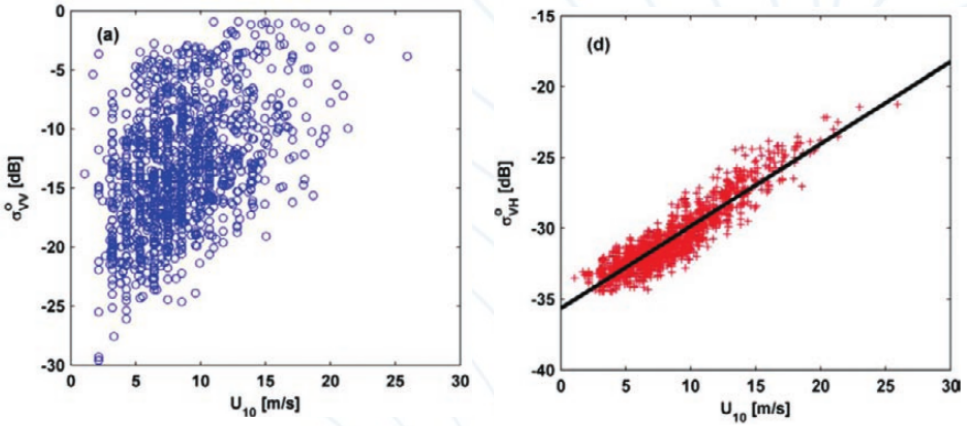




- Sensitivity of VV & HH NRCS is much lower than VH

Sapp, PhD Thesis

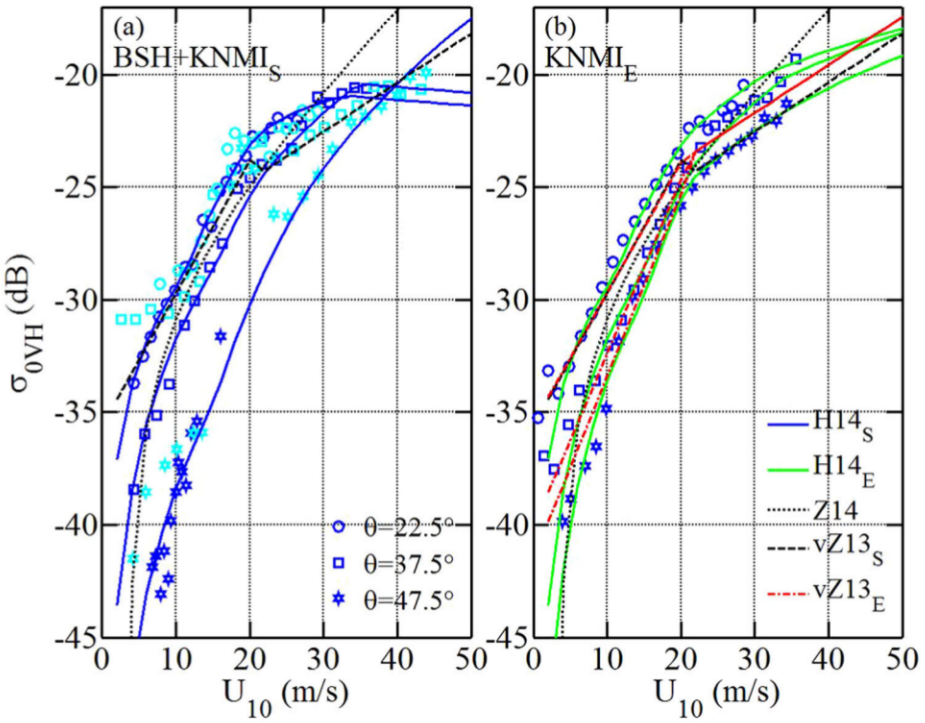
Satellite measurements



Buoys Wind Speed [m/s]

- RadarSat-2 SAR confirmed this sensitivity of NRCS in VH

Zhang & Perrie, BAMS 2012



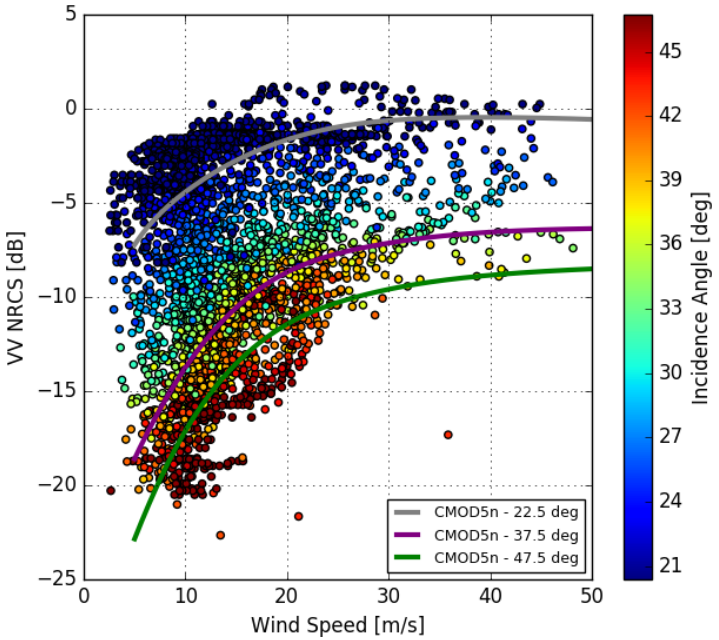
- Few existing measurements over hurricanes have been accurately documented

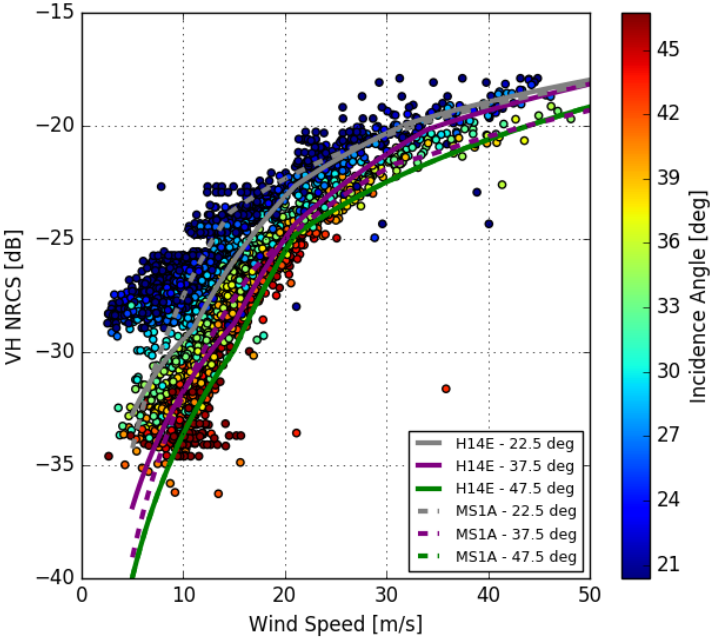
Hwang et al., JGR 2015

- Reference data used for wind are SMAP processed by RSS.
  - No saturation is expected at high wind
  - Resolution is about 40 km
  - It provides more than 8500 co-locations
- Too few co-locations available with SFMR.

NRCS & Wind

- Reference data used for wind are SMAP processed by RSS.
  - No saturation is expected at high wind
  - Resolution is 40 km
  - It provides more than 8500 co-locations
- Too few co-locations available with SFMR.
- Analysis from Sentinel-1 data versus SMAP winds
  - confirms the lost of sensitivity at VV when wind increases
  - confirms the highest sensitivity of VH
  - confirms the noise contamination for low winds.
  - An ad-hoc modification of the Hwang et al., GMF coefficients is proposed to take into account for new data at high wind and noise at low winds.





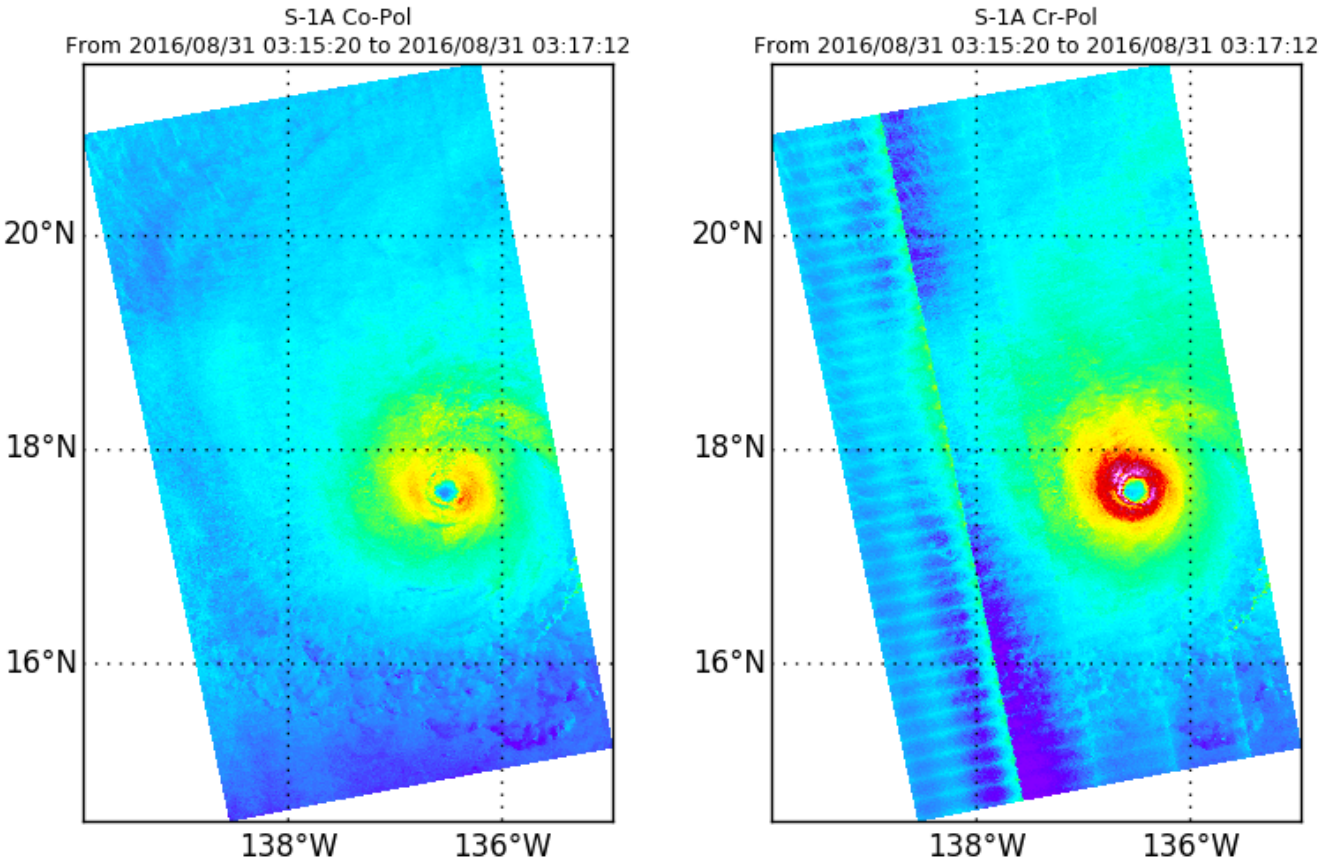
- VV-NRCS is used together with apriori wind vector from ECMWF to get 3-km wind speed and direction using CMOD5n GMF

$$J(\boldsymbol{u}) = \underbrace{\left(\frac{\sigma^0 - (\mathrm{CMOD})(\boldsymbol{u})}{\Delta\sigma^0}\right)^2}_{\text{NRCS term}} + \underbrace{\left(\frac{\boldsymbol{u} - \boldsymbol{u}_B}{\Delta\boldsymbol{u}}\right)^2}_{\text{A priorimodel term}}$$

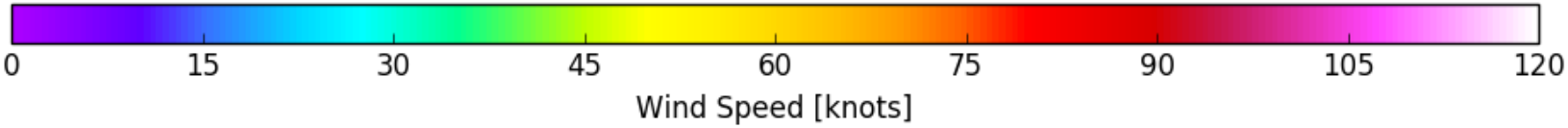
- VH-NRCS is used to get 3-km wind speed from VH CMOD GMF

$$J(\boldsymbol{u}) = \underbrace{\left(\frac{\sigma^0 - (\mathrm{CMOD})(\boldsymbol{u})}{\Delta\sigma^0}\right)^2}_{\text{NRCS term}} +$$

NRCS & Wind



- VV-wind speeds are lower than VH winds near the eye
- VH-winds speeds are not geophysical where SNR is too low.
- VH-Wind speeds reach 115 knts near the eye in agreement with track files



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- VH-NRCS is used to get wind speed from VH CMOD GMF

$$J(\boldsymbol{u}) = \underbrace{\left(\frac{\sigma^0 - (\mathrm{CMOD})(\boldsymbol{u})}{\Delta\sigma^0}\right)^2}_{\text{NRCS term}} +$$

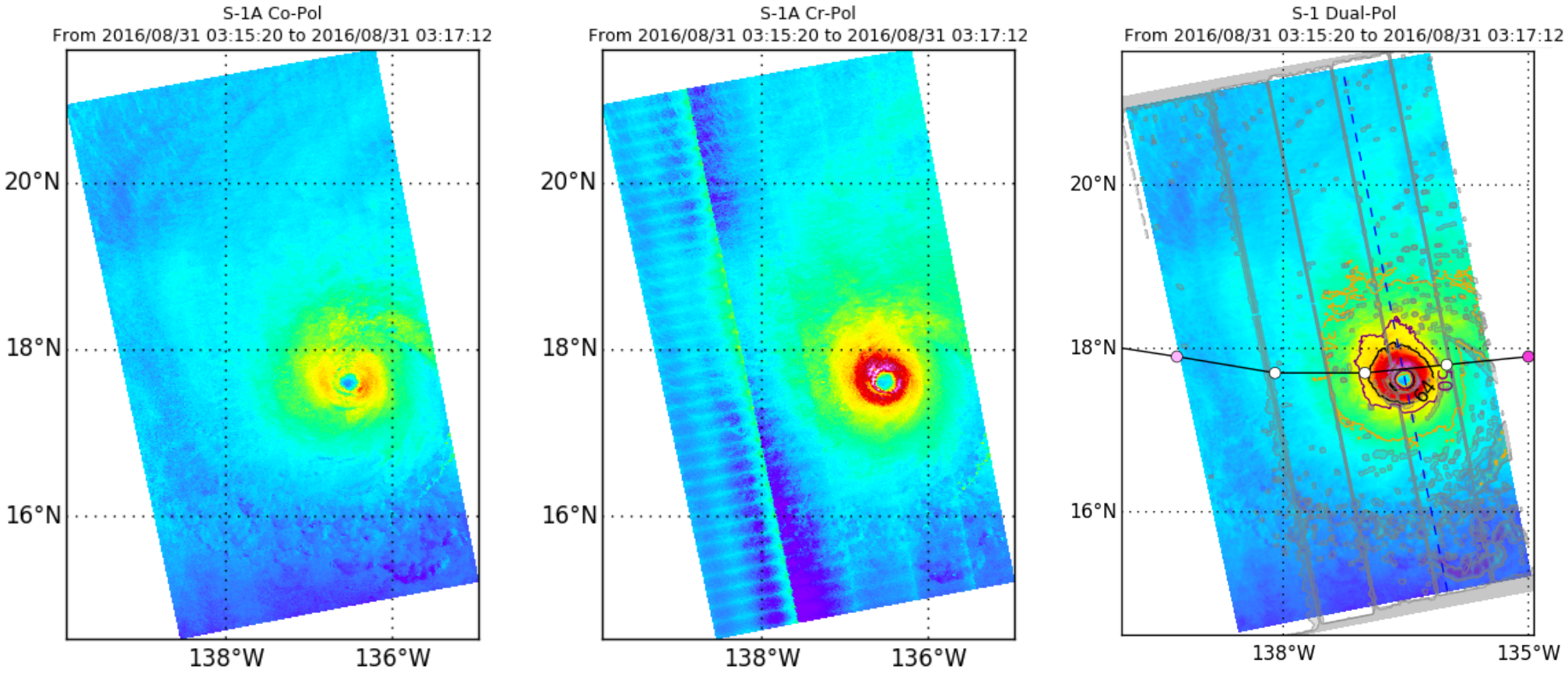
- VV-wind is used as apriori wind vector and combined with VH-NRCS.
  VH-NRCS is used when SNR is good.

$$J(\boldsymbol{u}) = \underbrace{\left(\frac{\sigma^0 - (\mathrm{CMOD})(\boldsymbol{u})}{\Delta\sigma}\right)^2}_{\text{NRCS term}} + \underbrace{\left(\frac{\boldsymbol{u} - \boldsymbol{u}_B}{\Delta\boldsymbol{u}}\right)^2}_{\text{A priorimodel term}}$$

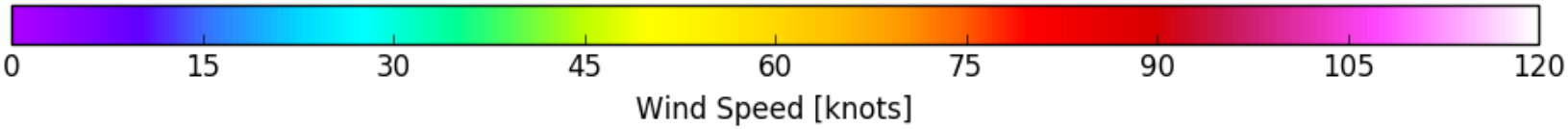
= f(NRCS,NESZ)

= Wind vector from VV-NRCS

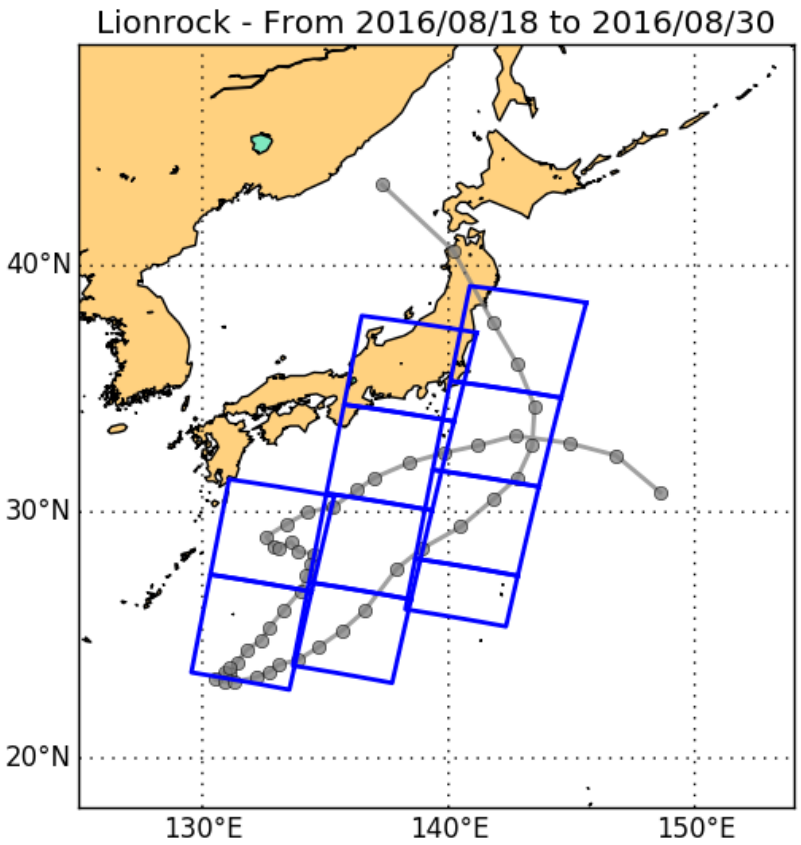
NRCS & Wind

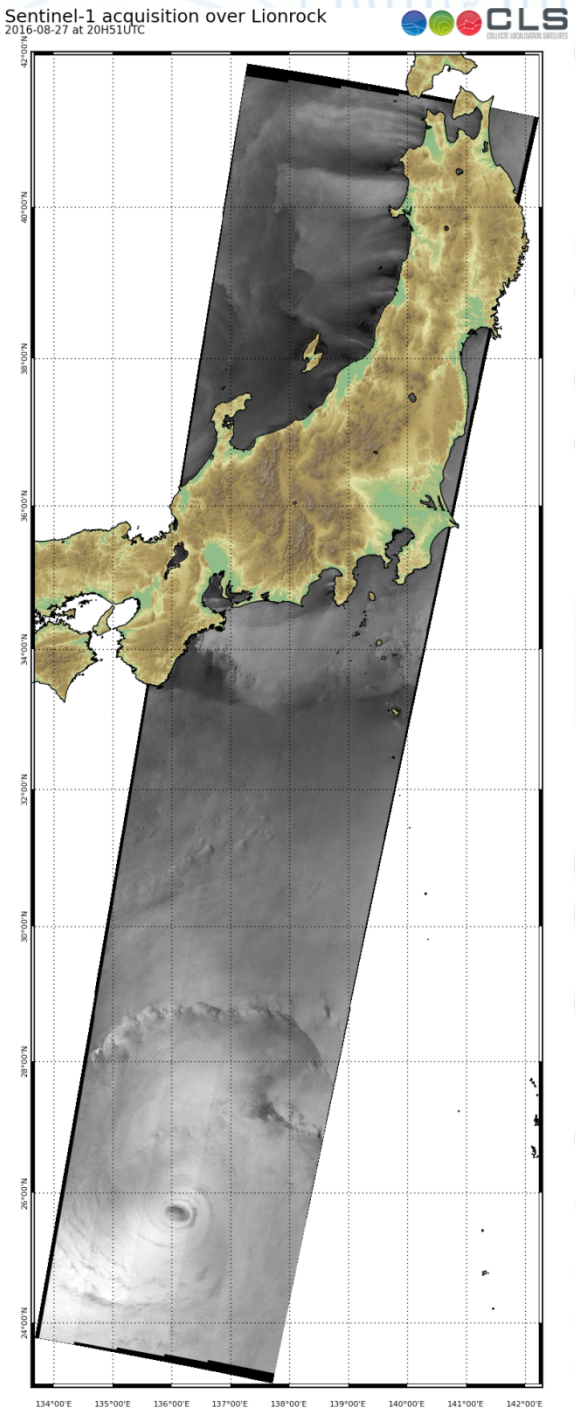


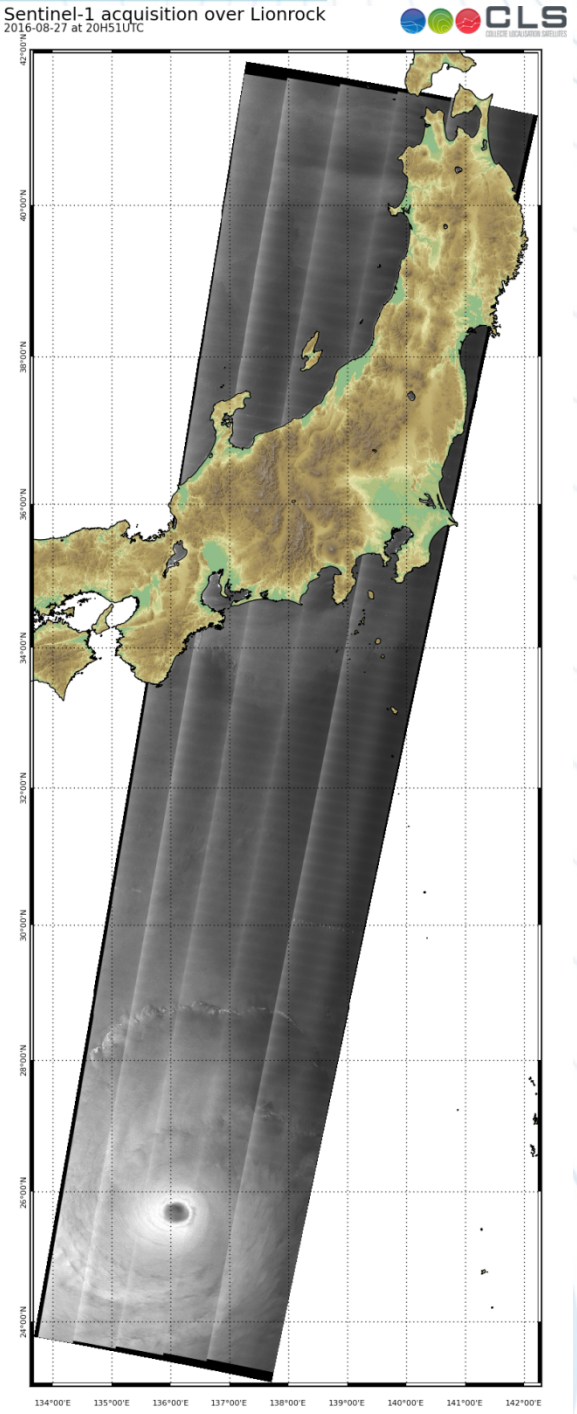
Combination of VV-and VH NRCS enables to take benefit of VV-NRCS for low to strong (<35 m/s) wind speeds and VH-NRCS for extreme winds (>35 m/s).

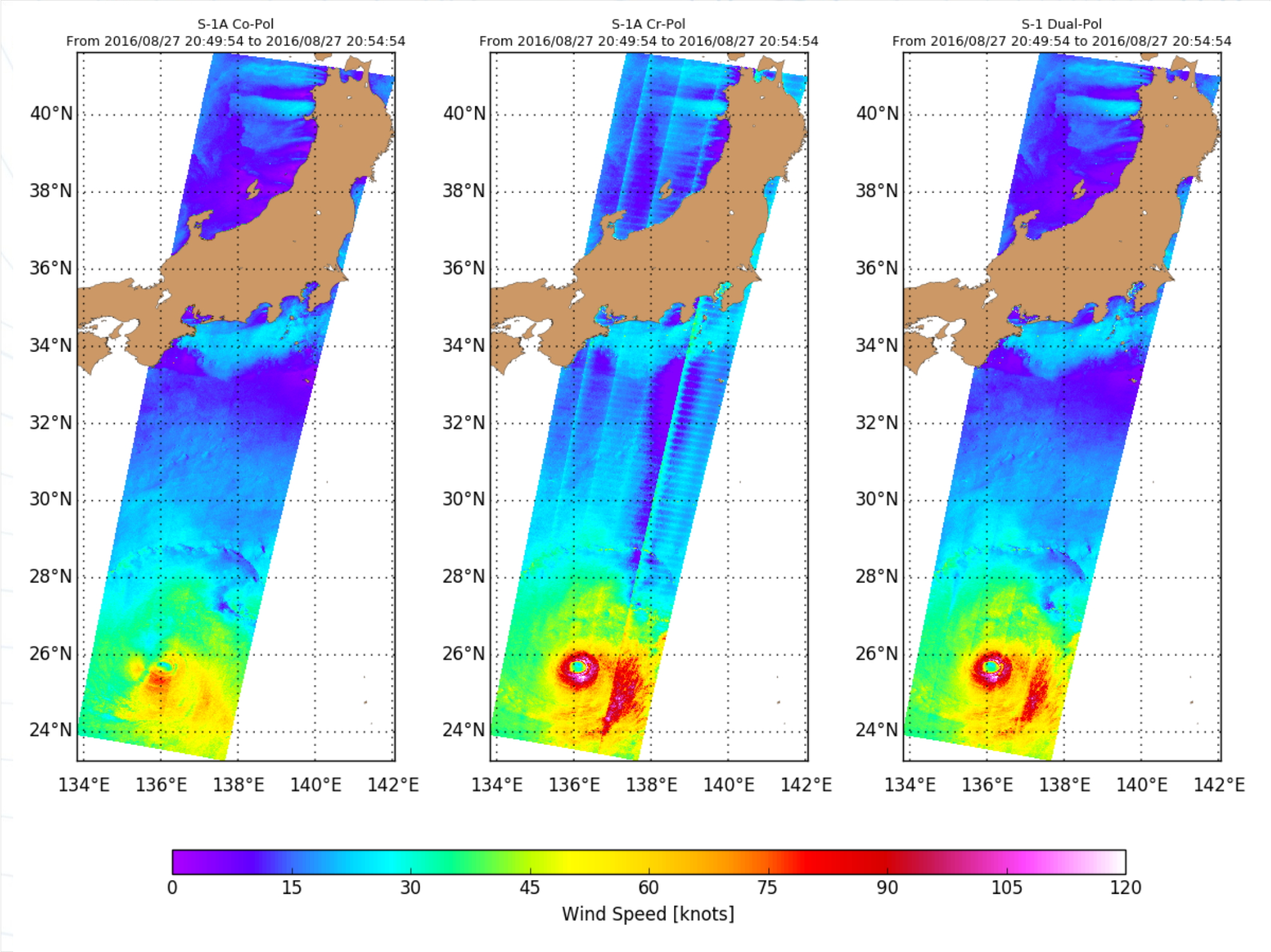


NRCS & Wind

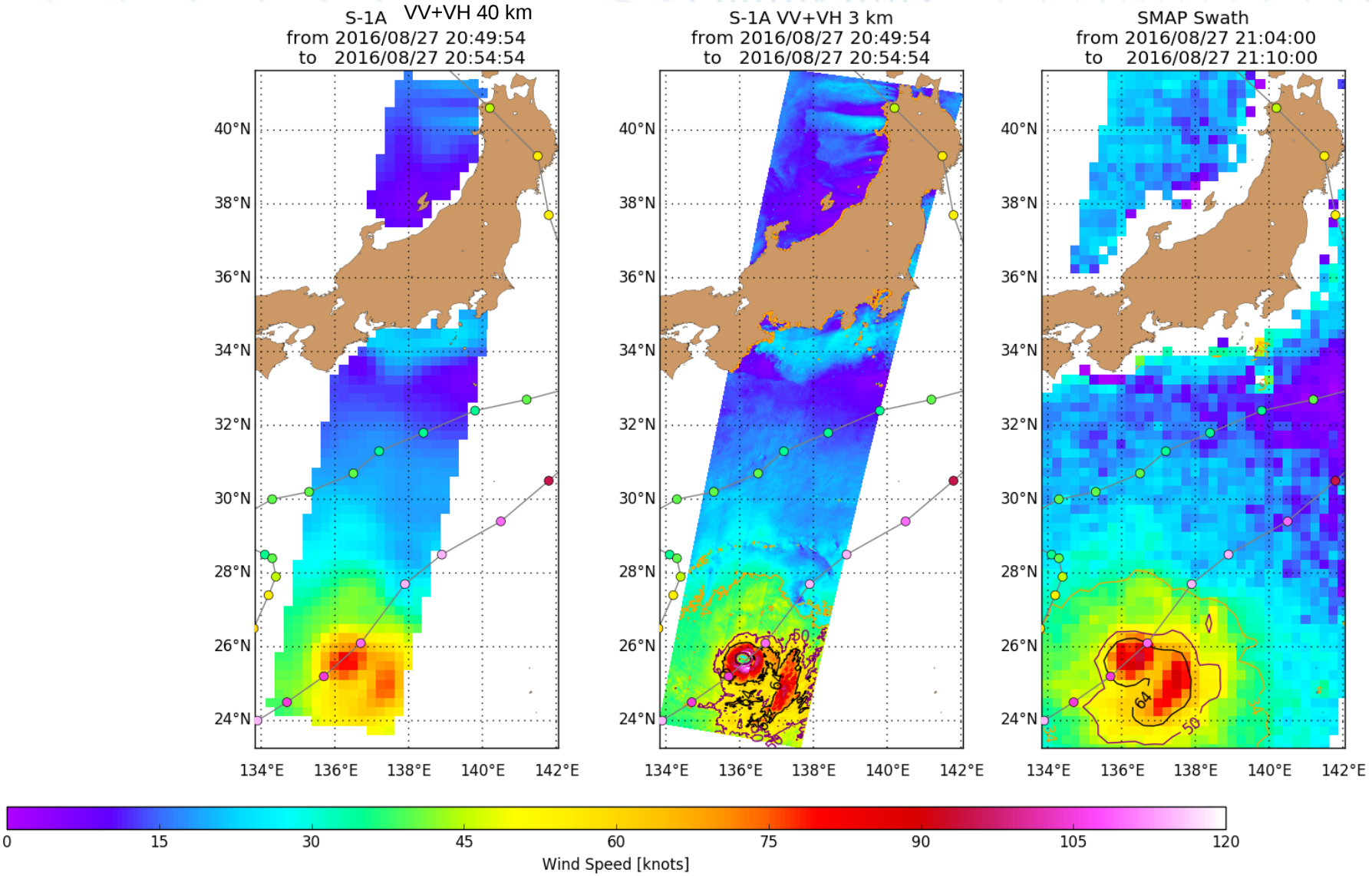

Lionrock - From 2016/08/18 to 2016/08/30
40°N
30°N
20°N
130°E
140°E
150°E


Sentinel-1 acquisition over Lionrock
2016-08-27 at 20H51UTC
CLS

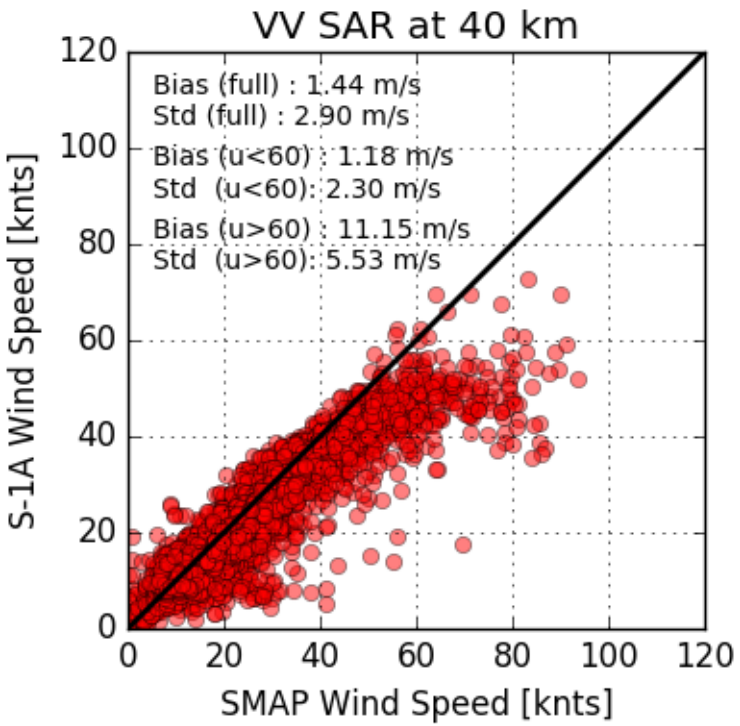

Sentinel-1 acquisition over Lionrock
2016-08-27 at 20H51UTC
CLS

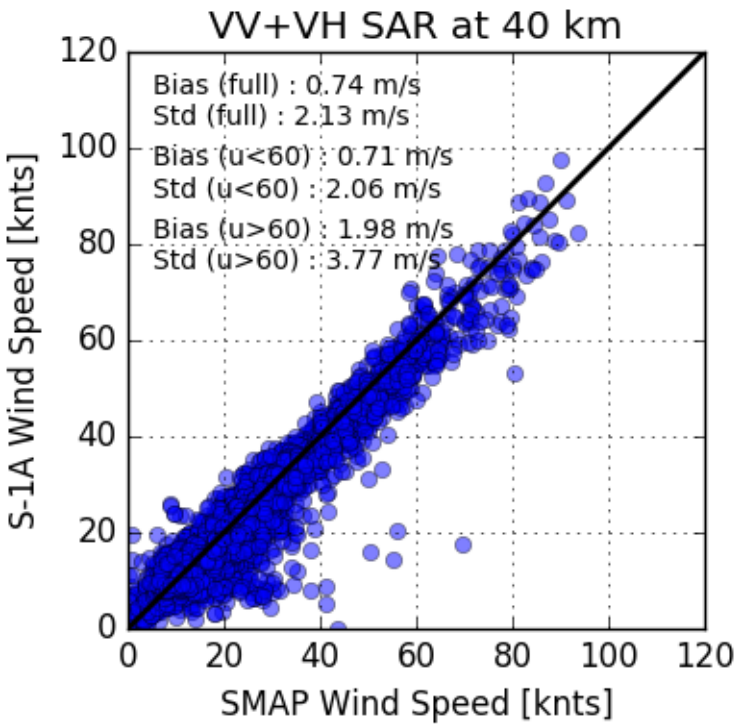

S-1A Co-Pol
From 2016/08/27 20:49:54 to 2016/08/27 20:54:54
S-1A Cr-Pol
From 2016/08/27 20:49:54 to 2016/08/27 20:54:54
S-1 Dual-Pol
From 2016/08/27 20:49:54 to 2016/08/27 20:54:54
40°N
38°N
36°N
34°N
32°N
30°N
28°N
26°N
24°N
134°E
136°E
138°E
140°E
142°E
0
15
30
45
60
75
90
105
120
Wind Speed [knots]

NRCS & Wind



- VV+VH derived from SAR at 40 km can be directly compared to SMAP winds.
- 3-km resolution SAR winds enable finer description of wind speed gradients near the eyes in situation of very intense T.C. where eye radius is small.

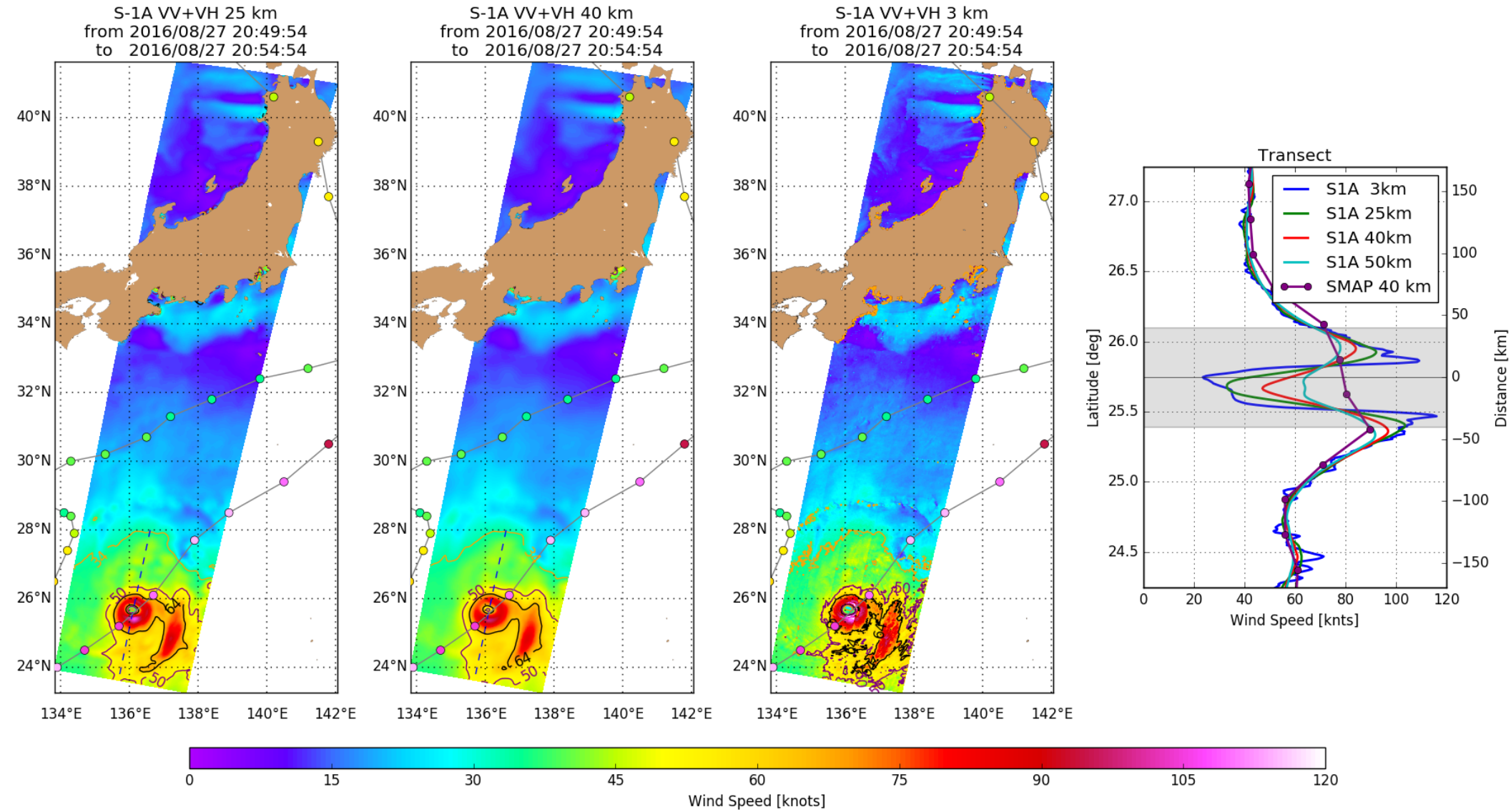




- VV+VH derived from SAR at 40 km can be directly compared to SMAP winds.

⇨ The use of VV+VH allows measuring higher wind speeds in agreement with SMAP winds.

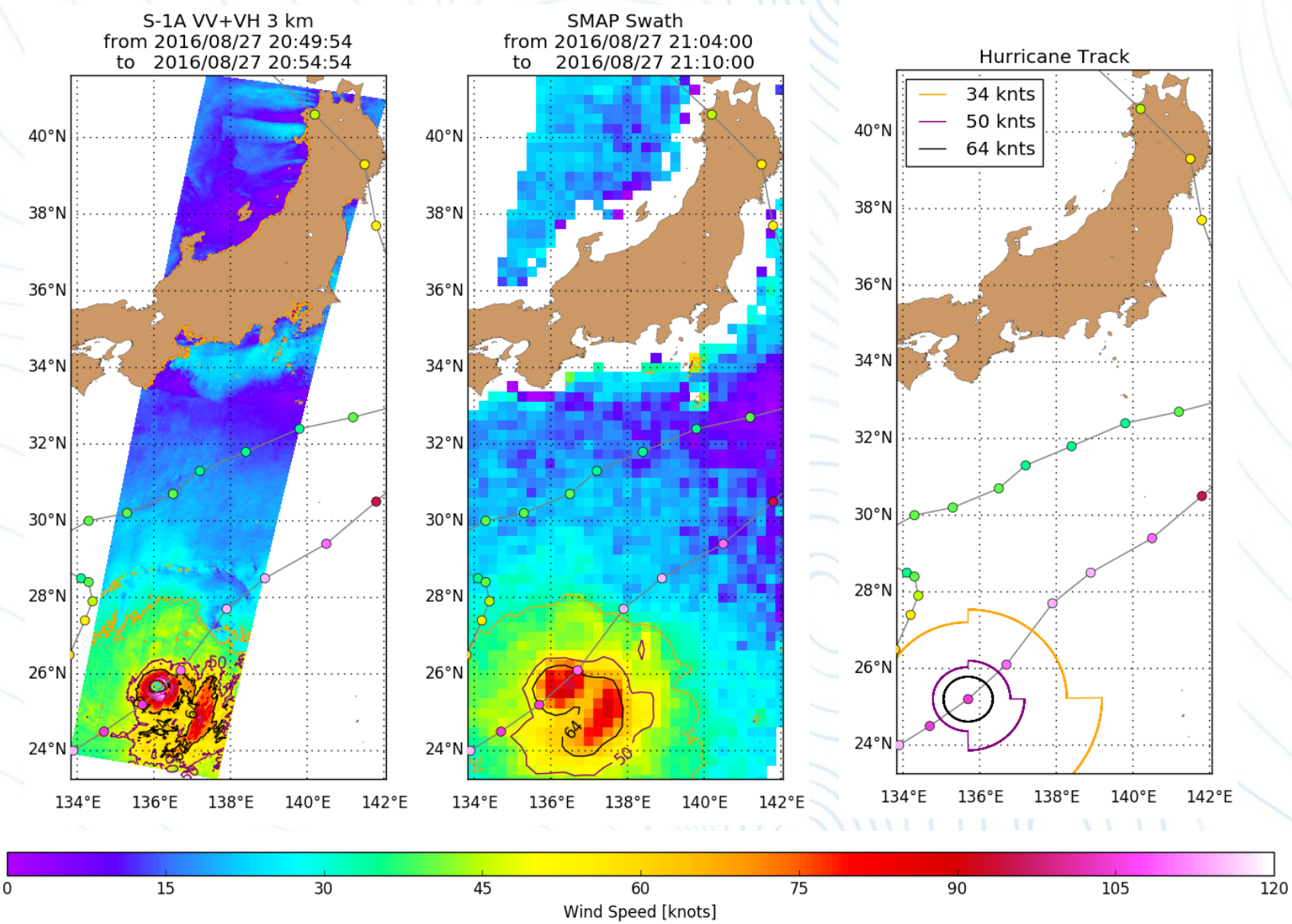
NRCS & Wind



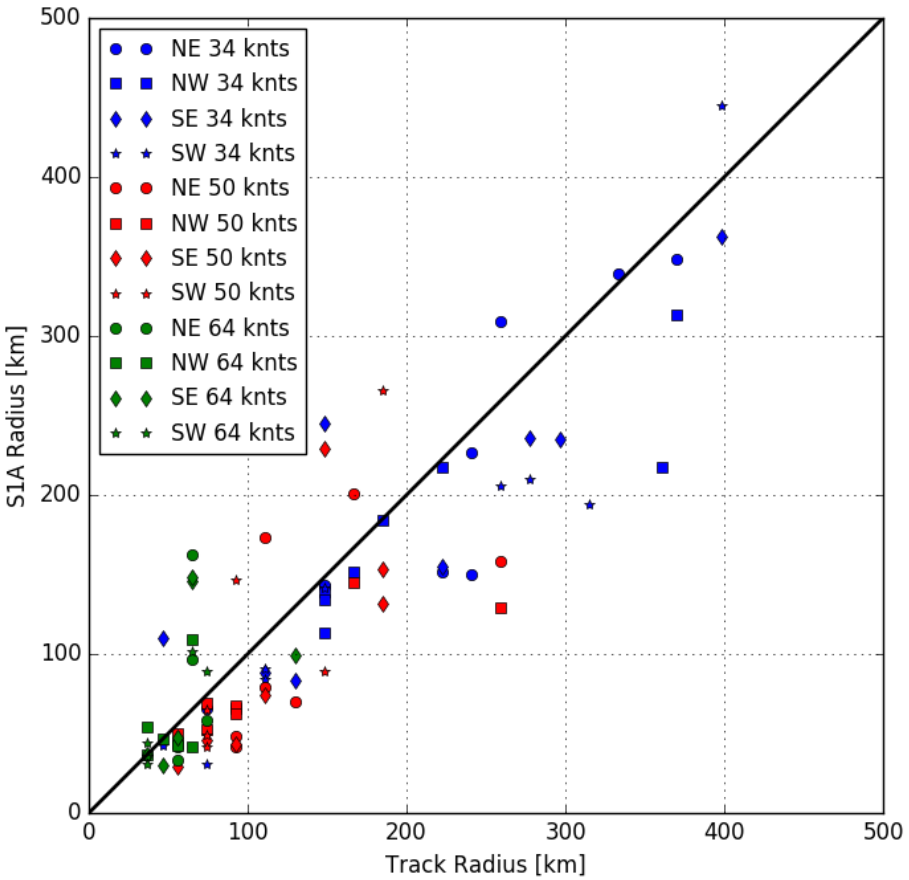
- SAR winds at multi-resolutions enables evaluating the resolutions impact on the wind speed as compared to 1-min MSW as given in Best tracks.

- Here for Δx >25 km and eye radius ~60 km, VV+VH SAR winds hardly reaches 95 knts where tracks and 3-km VV+VH SAR winds gives wind speeds higher than 105 knts.

Tropical Cyclone Parameters
Wind Radii



- 3-km resolution SAR winds allow measuring 34-, 50- and **64**-knots wind radii.



		NE	NW	SW	SE
R34	N	9	9	8	9
	Bias [km]	-17.72	-1.45	-14.40	-32.94
	Relative Error [%]	-7.83	-0.72	-7.07	-17.03
	Standard Deviation [km]	39.11	103.88	56.61	44.18
R50	N	8	8	7	6
	Bias [km]	-27.26	-33.26	-20.77	1.70
	Relative Error (%)	-20.66	-29.32	-17.06	1.57
	Standard Deviation [km]	48.94	37.57	42.61	49.43
R64	N	6	6	6	5
	Bias [km]	11.21	4.26	18.06	10.31
	Relative Error (%)	18.15	8.37	27.21	20.61
	Standard Deviation [km]	42.42	21.96	46.30	15.31

- First assessment of wind radii from SAR against track wind radii are performed. SAR is able to provide a wind radii in 96 % of the cases.

Conclusions & Summary

- 2 Sentinel-1 SAR exists and no dedicated EU service for hurricane observations exists so far.
  - SHOC shows that the use of forecast tracks by the ESA Mission Planning can allow to maximize hurricane observations in SAR in both co- and cross-polarizations.
  - Acquisitions obtained in the framework is certainly not enough.

- VH-NRCS quality for Sentinel-1 is dominated by noise
  - This prevents for any accurate geophysical analysis when backscattering is low.
  - Over hurricanes, VH-NRCS SNR can be used and is found much more sensitive to the response of the ocean surface than VV-NRCS

- A strong relationship between VH-NRCS and SMAP winds or SFMR winds has been found
  - This can be used for hurricane wind measurements in areas where SNR is good.
  - The combination of VH-NRCS with VV-NRCS can be used to measure 3-km ocean surface wind speeds from 2 m/s up to 65 m/s

- The high resolution capabilities of SAR **AND** the VH polarization allows to measure very high wind speeds consistent with MSW as given tracks.
  - Metop-SG should directly benefit from VH – even if HR will not be achieved