Sentinel-1 A: Status & Opportunities

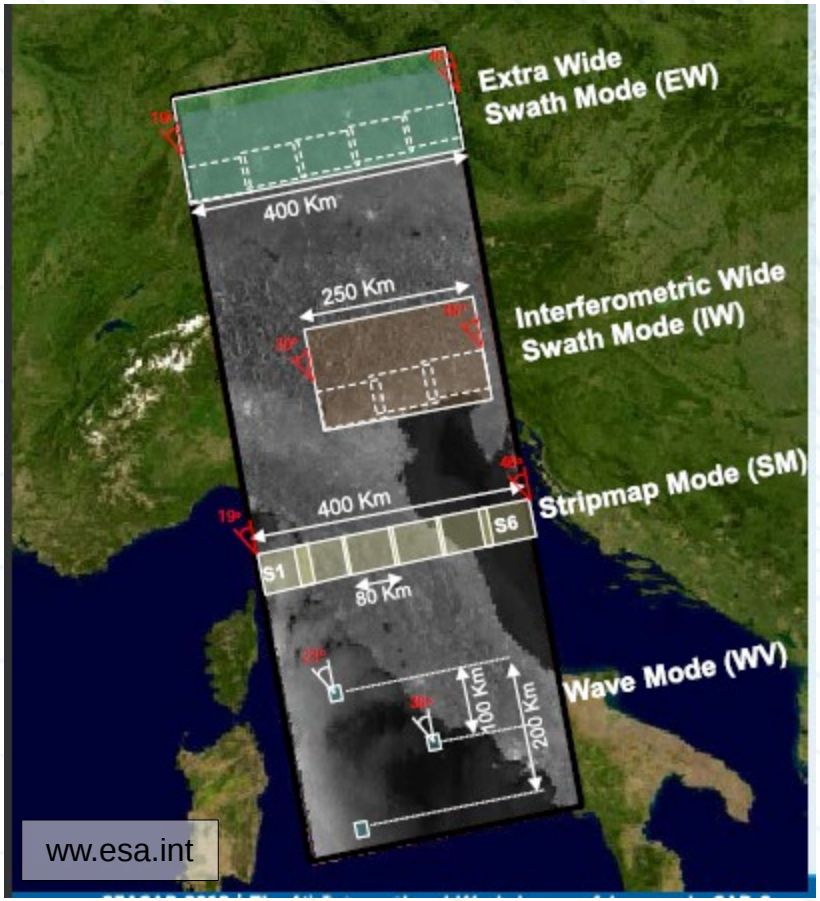
A. Mouche, Ifremer

in collaboration with
Sentinel-1 ESL Team
(Aresys, BAES, CLS, ESA, NORUT, ODL & UZH)
Ifremer, Laboratoire Océanographie Spatiale Team
(B. Chapron, P. Queffeulou, F. Paul, A. Grouazel)
W. Alpers (UH)

MetOp-SG Scatterometer Science Advisory Group 2nd Meeting, 16-17 June 2015

- Sentinel-1 A Cal/Val (L2)
- Sentinel-1 A, Doppler and Cross-Polarization
- Sentinel-1 A and Rain

- Sentinel-1 A Cal/Val (L2)
  - **S-1 Acquisitions Modes**
  - S-1 MPC Strategy & CAL/VAL Time line
  - Results for WM
- Sentinel-1 A, Doppler and Cross-Polarization
- Sentinel-1 A and Rain

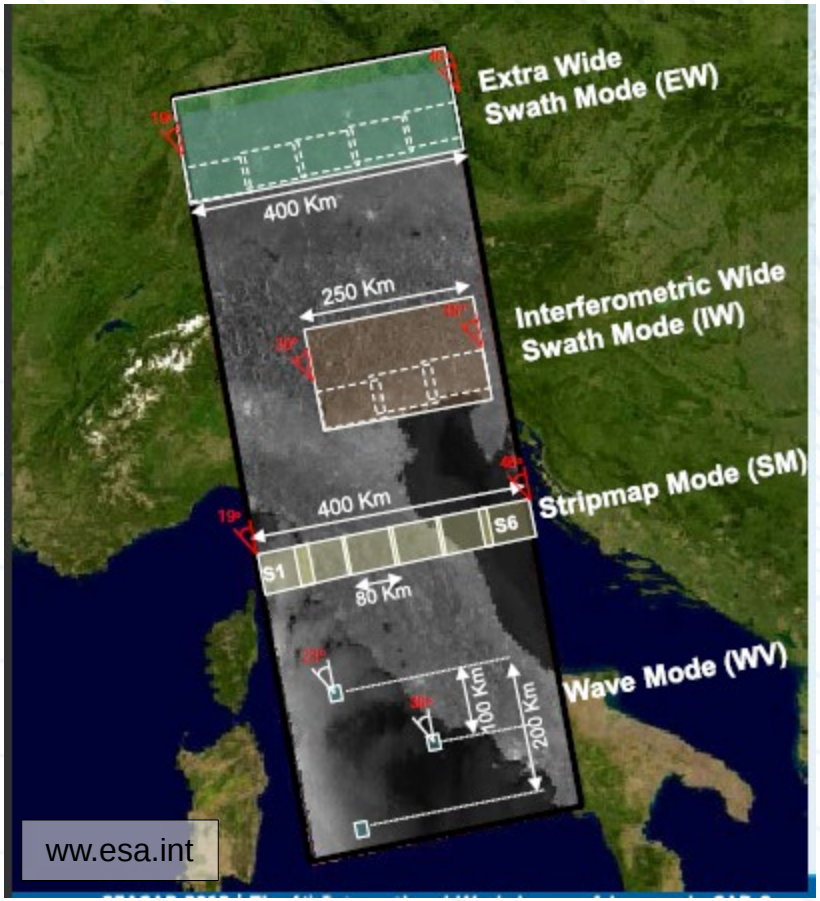


- 4 exclusive operational modes.

High Bit Rate (HBR)	IW [19°-46°]
	EW [19°-46°]
	SM (S1->S6)
Low Bit Rate (LBR)	WV [23° ; 36°]

- Polarisation schemes for IW, EW and SM:
  - single polarisation: HH or VV
  - dual polarisation: HH+HV or VV+VH

- Single polarization VV (or HH), for WV



- 4 exclusive operational modes.

High Bit Rate (HBR)	IW [19°-46°]
	EW [19°-46°]
	SM (S1->S6)
Low Bit Rate (LBR)	WV [23° ; 36°]

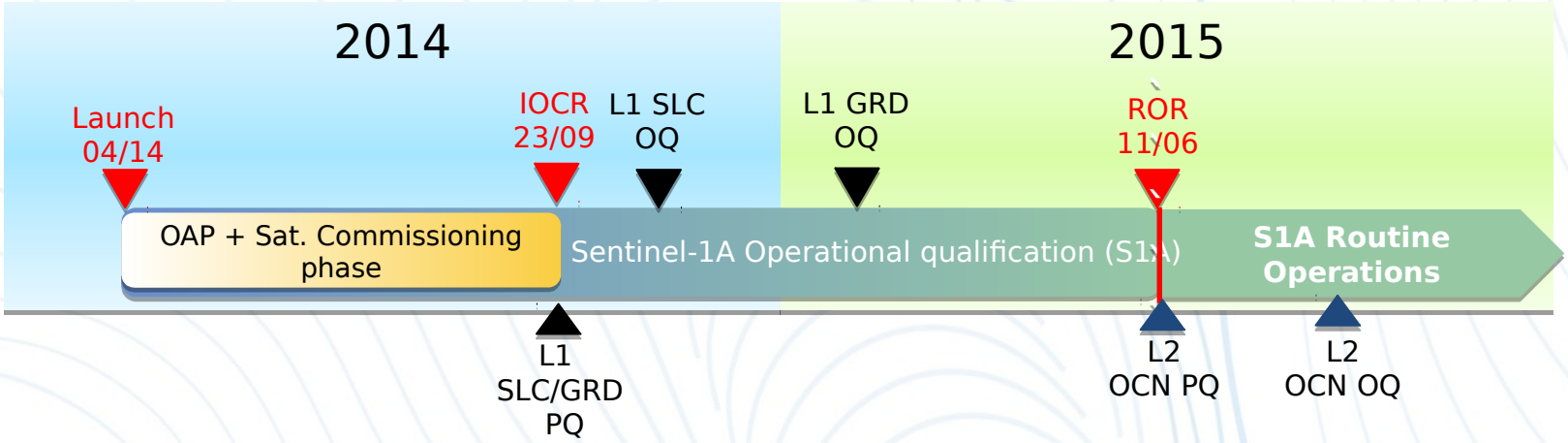
- Polarisation schemes for IW, EW and SM:
  - single polarisation: HH or VV
  - dual polarisation: HH+HV or VV+VH

- Single polarization VV (or HH), for WV

Range of incidence angles and polarization configurations for Extra Wide Swath Mode (EW) are close to next SCAT. IW is also interesting.

- Sentinel-1 A Cal/Val (L2)
  - S-1 Acquisitions Modes
  - **S-1 MPC Strategy & CAL/VAL Time line**
  - Results for WM
- Sentinel-1 A, Doppler and Cross-Polarization
- Sentinel-1 A and Rain

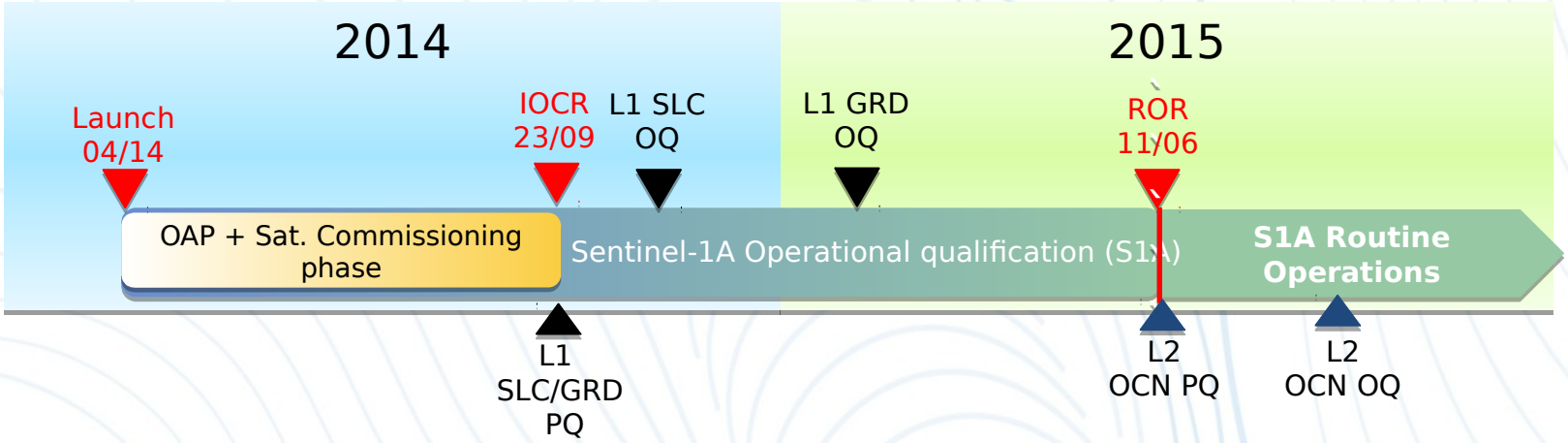
Sentinel-1 Cal/Val (L2): S-1 MPC Strategy & CAL/VAL Timeline



- Verification of the S-1A product was foreseen in a staggered approach L0 -> L1 ->L2
- Verification of the L1 and L2 products is made in two steps:
  - **P**artially **Q**ualification: Products mature enough to support exploitations although with quantified limitations
  - **O**perational **Q**ualification: Product meeting the requirements
- Full qualification of the L1 has been completed in March 2015 with the full qualification of the GRD
- Qualification of the Level 2 is on-going. Partial qualification of the L2 OCN WV is achieved for **R**outine **O**perations **R**eview. Full qualification is expected in the coming months

Courtesy of N. Miranda, ESA, EOP-G

Sentinel-1 Cal/Val (L2): S-1 MPC Strategy & CAL/VAL Timeline



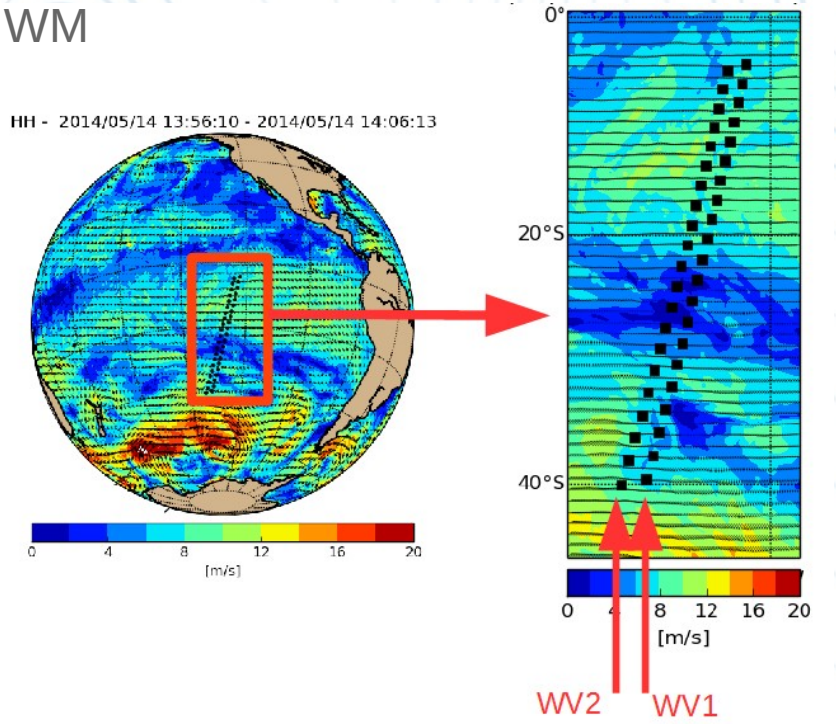
- Verification of the S-1A product was foreseen in a staggered approach L0 -> L1 ->L2
- Verification of the L1 and L2 products is made in two steps:
  - **P**artially **Q**ualification: Products mature enough to support exploitations although with quantified limitations
  - **O**perational **Q**ualification: Product meeting the requirements
- Full qualification of the L1 has been completed in March 2015 with the full qualification of the GRD → **Ready for radiometry studies (GMF)**
- Qualification of the Level 2 is on-going. Partial qualification of the L2 OCN WV is achieved for **R**outine **O**perations **R**eview. Full qualification is expected in the coming months

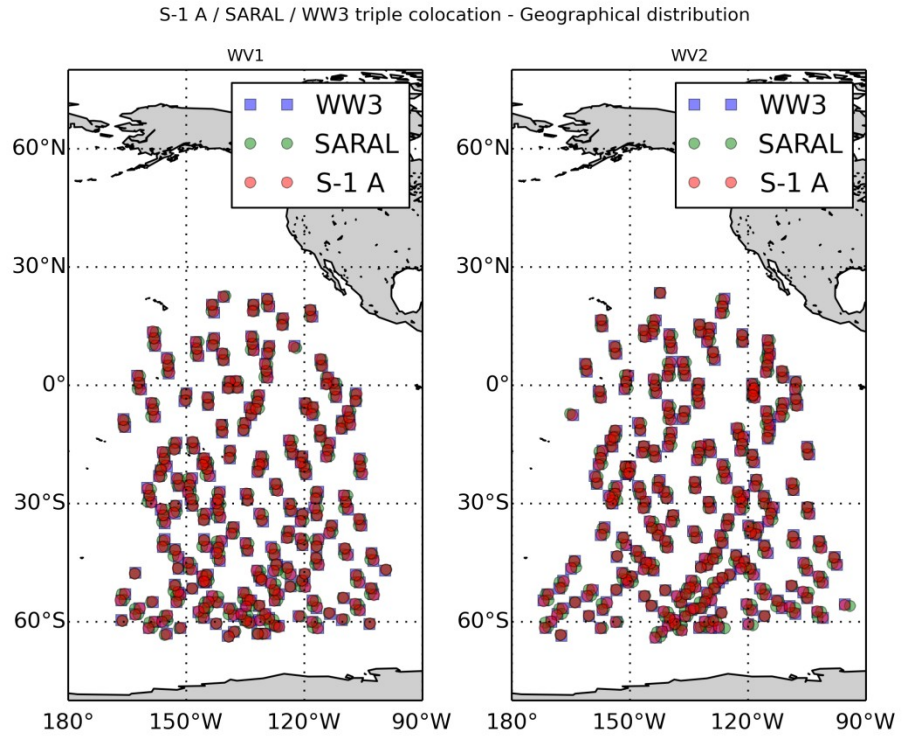
Courtesy of N. Miranda, ESA, EOP-G

- Sentinel-1 A Cal/Val (L2)
  - S-1 Acquisitions Modes
  - S-1 MPC Strategy & CAL/VAL Time line
  - **Results for WM**
- Sentinel-1 A, Doppler and Cross-Polarization
- Sentinel-1 A and Rain

Sentinel-1 Cal/Val (L2): Results for WM

- WaVe (WV) mode is the default operational mode over open ocean
- WV images the ocean at high resolution but with a discrete spatial sampling
  - Small imagettes of 20x20Km at 100Km interval
  - Alternates two swath (WV1, WV2) – leap frog
  - Polarisation can be HH or VV
- L2 WV OCN contains wave, wind speed and radial vel.
- Full WV OCN validation encompasses the performance verification of all components, for all polarisation and incidence angle
- Validation relies on massive collocation with NWM, buoys or external data (Scatterometers, Altimeters)
- Validation limited to a portion of the Pacific ocean, for now

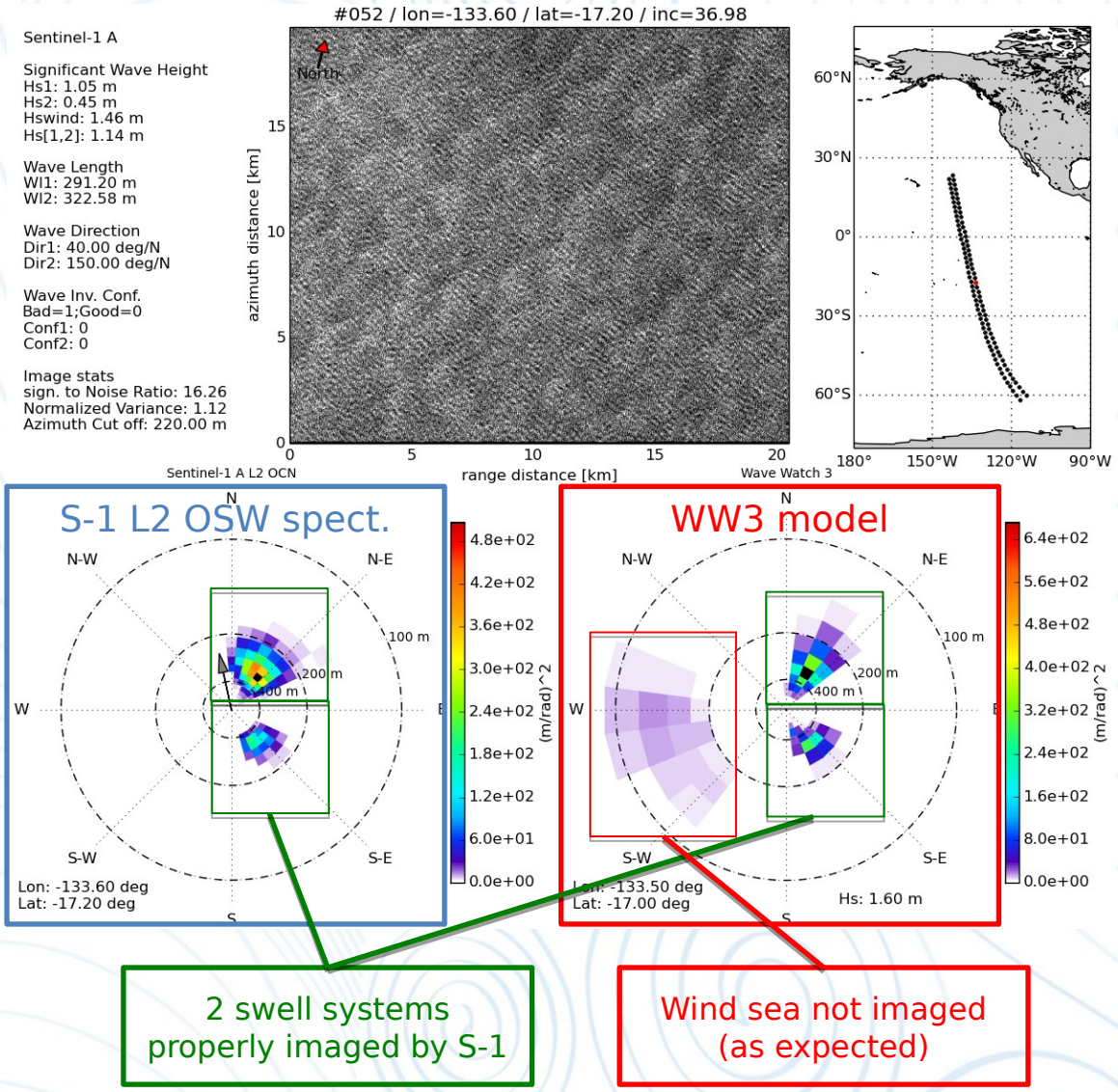




Sentinel-1 Cal/Val (L2): Results for WM

OSW validation encompasses the verification of the:

- swell spectra against Wave models and buoys
- Spectra partitioning
- Integral parameters:
  - Significant Wave Height
  - Wave direction
  - Wavelength
- Wind speed and direction



Comparison of swell spectra S-1A vs. WW3 model

Sentinel-1 Cal/Val (L2): Results for WM

- Integral parameters have been statistically assessed over ~ 3 months of data against model and other EO data

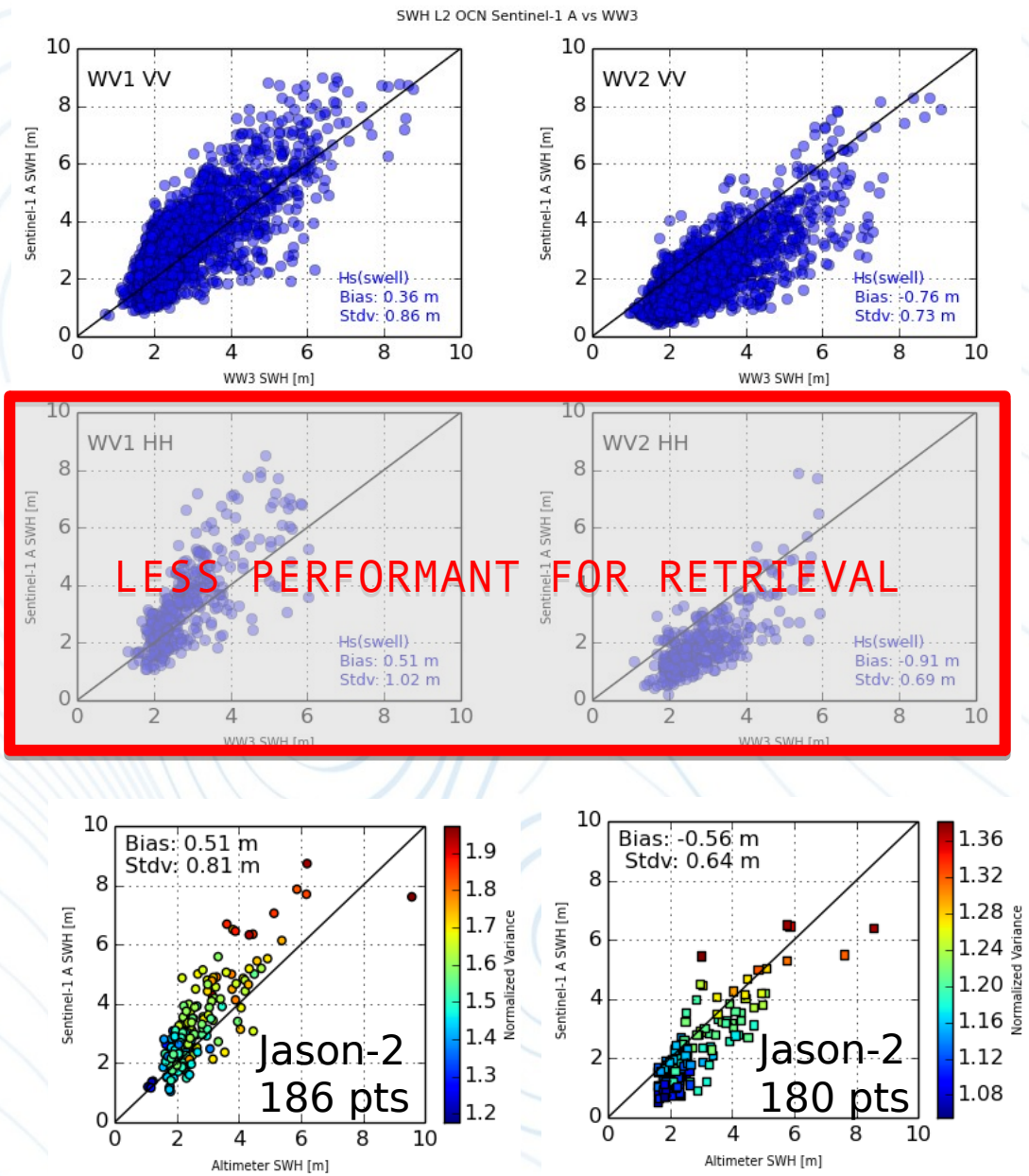
- HH data has worst performance
  - VV will be the polarisation used for operational use

- SWH current performance:
  - Bias >0.3m [<0.1m Rqt]
  - RMSe > 0.7m [<0.5m Rqt]

  → Modification of the MTF is requested and will be achieved in 1-2weeks

- Similar conclusions are obtained from co-location with other radar altimeter (e.g. SARAL/Altika)

- Similar conclusions are obtained when doing partitions validation



Sentinel-1 Cal/Val (L2): Results for WM

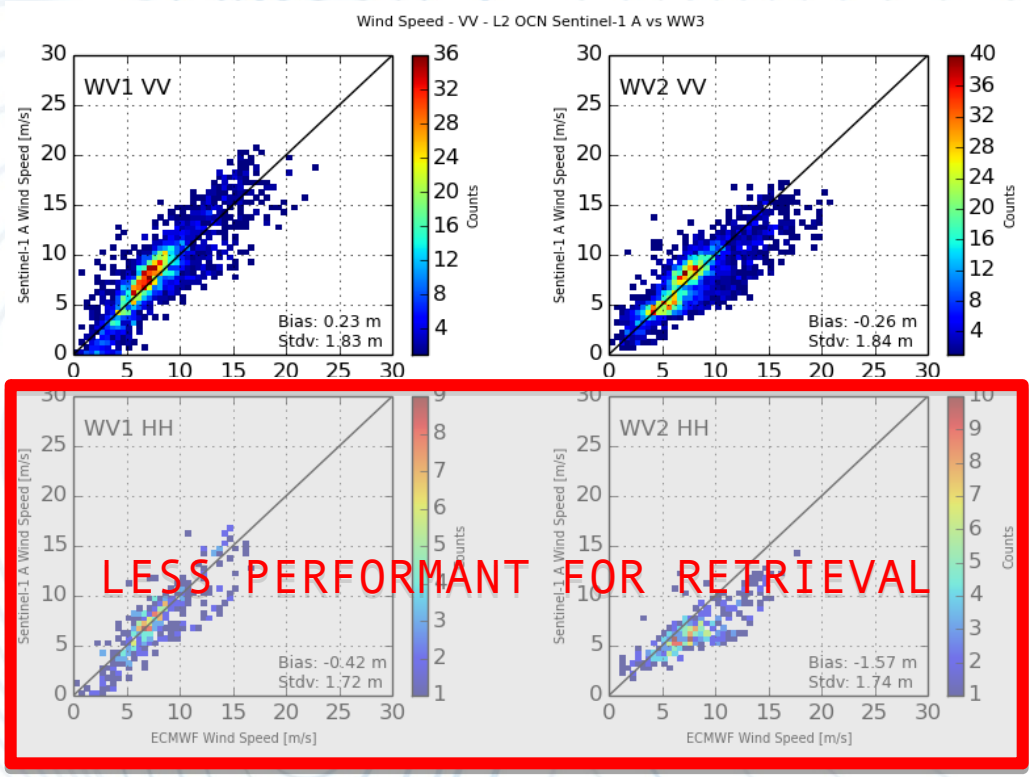
- Wind speed is compared against ECMWF model for polarisation and swath performance verification
  - VV will be used as main operational mode

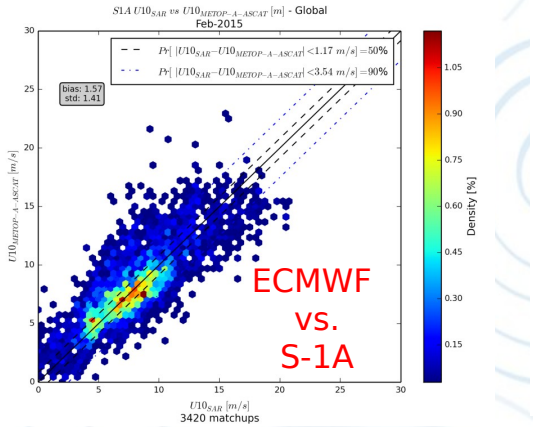
- Good results are achieved for wind speed:
  - Bias is >1.5 m/s for all polarisation but < 0.26m/s for VV **[0 m/s Rqt.]**
  - RMSe is <1.84 m/s **[<2 m/s]**

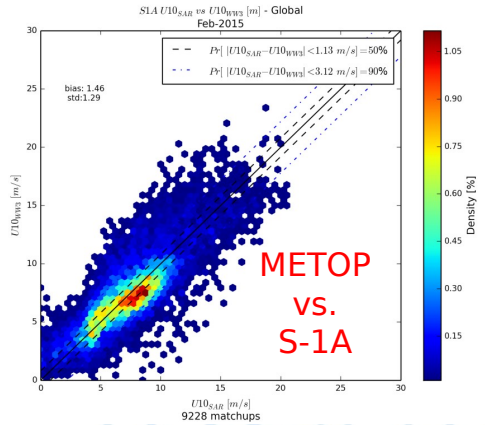
- Way forward
  - Bias will be further improved by using the wind direction from model (default 45deg is used)

    IPF version in 2-3weeks
  - Residual bias will be fine tuned using global acquisition (started on 15/05)

- Validation against other sensors is consistent with results obtained with model

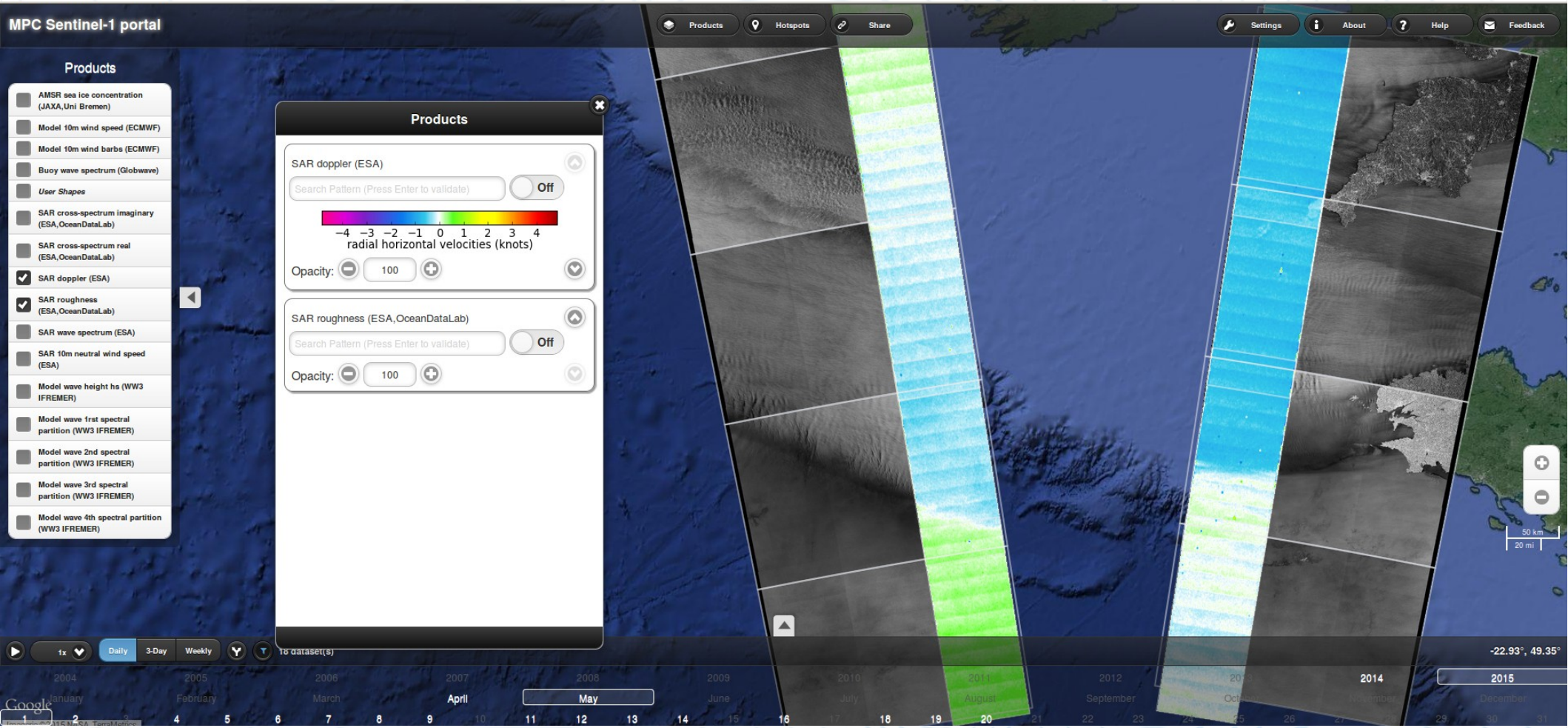






- Sentinel-1 A Cal/Val (L2)
  - S-1 Acquisitions Modes
  - S-1 MPC Strategy & CAL/VAL Time line
  - Results for WM
- Sentinel-1 A, Doppler and Cross-Polarization
  - **Doppler**
  - Cross-Polarization
- Sentinel-1 A and Rain

Sentinel-1 A, Doppler and Cross-Polarization: Doppler

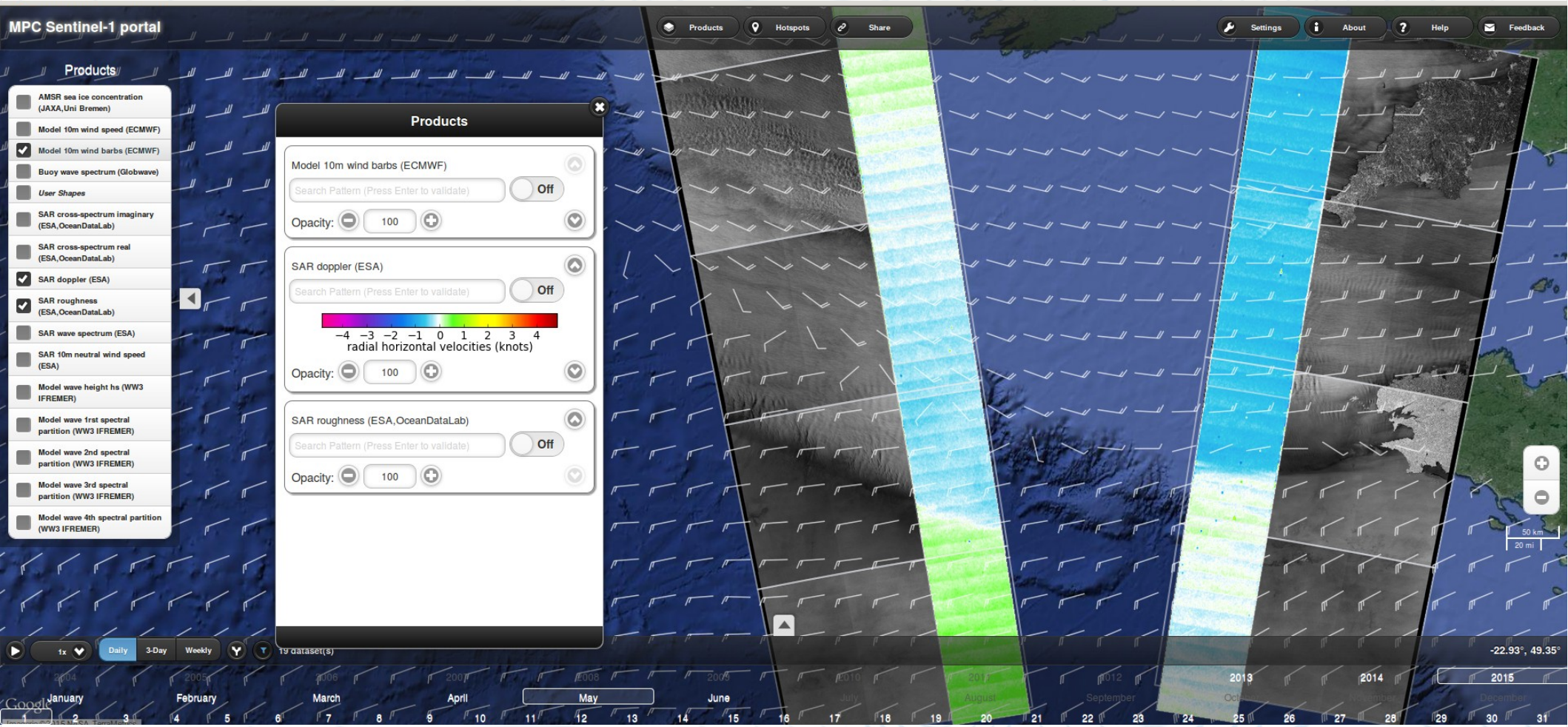


Geophysical Doppler assessment is mostly qualitative for now

- scalopping (0.3 m/s amplitude)

Courtesy of F. Collard, OceanDataLab

Sentinel-1 A, Doppler and Cross-Polarization: Doppler



Geophysical Doppler assessment is mostly qualitative for now

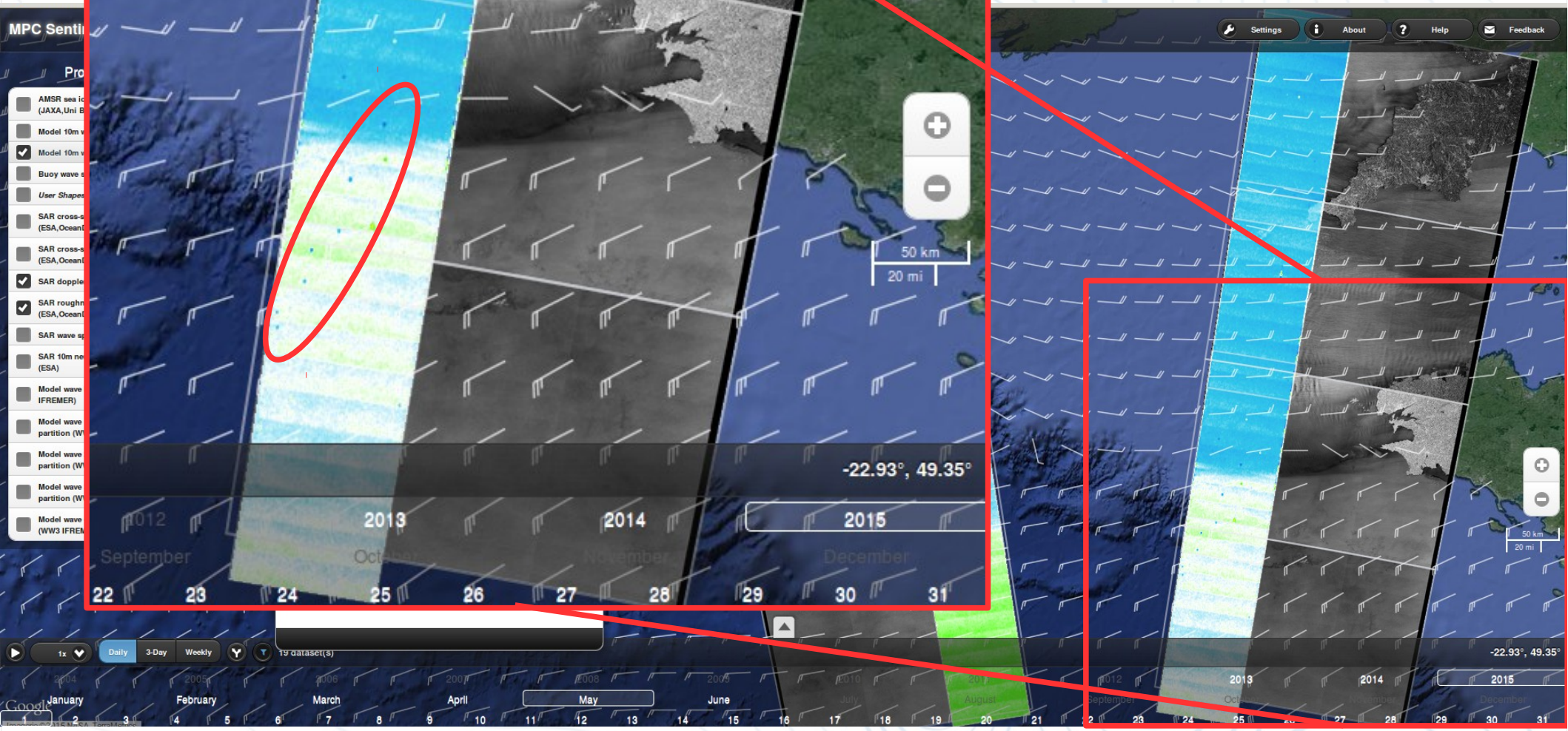
- scalopping (0.3 m/s amplitude)

Sometimes it is encouraging:

- main patterns consistent with wind direction

Courtesy of F. Collard, OceanDataLab

Sentinel-1 Doppler and Cross-Polarization: Doppler



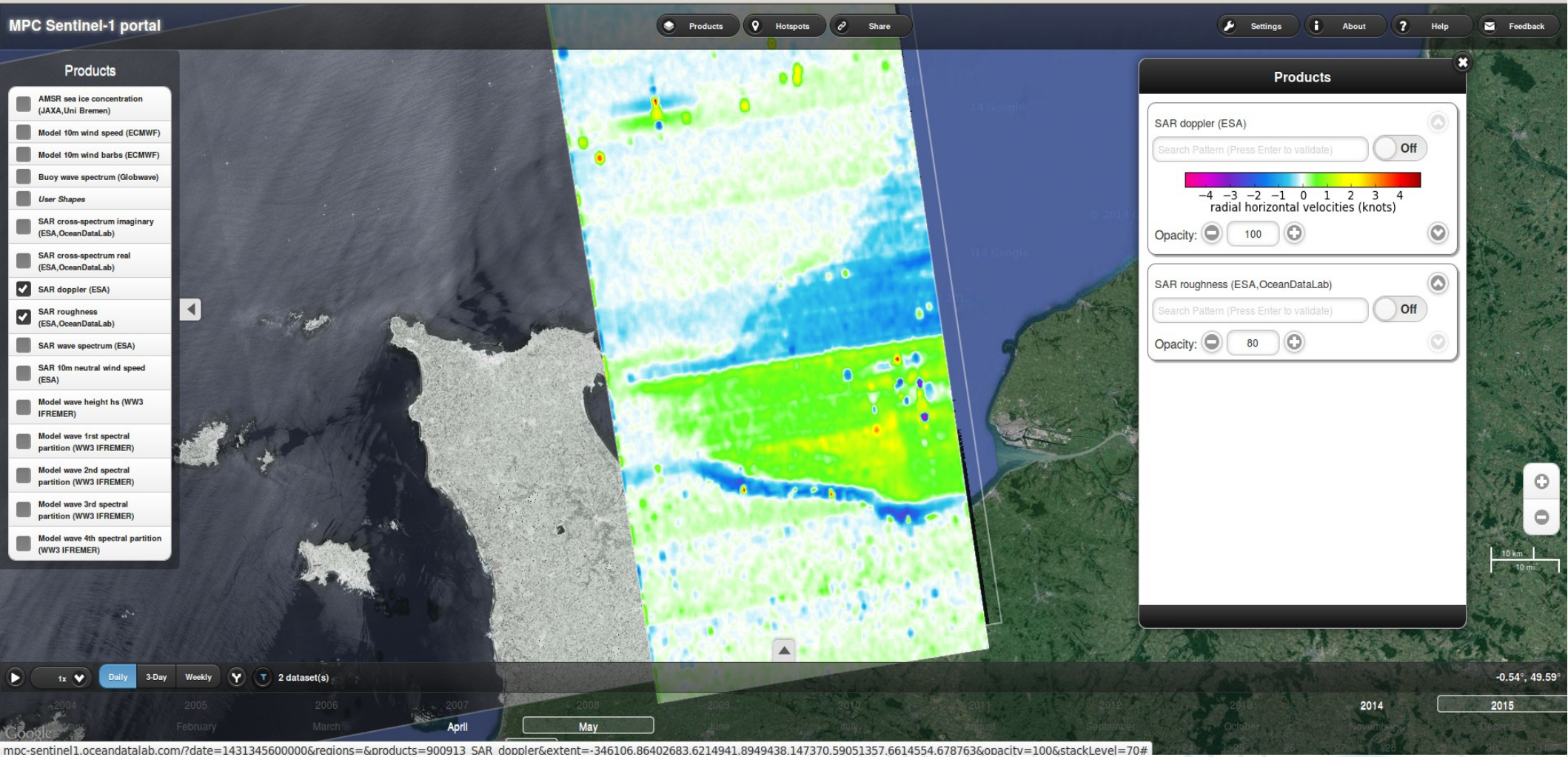
Geophysical Doppler assessment is mostly qualitative for now

- scalopping (0.3 m/s amplitude)

Sometimes it is encouraging:

- main patterns consistent with wind direction
- Doppler from ships consistent with marine traffic

Courtesy of F. Collard, OceanDataLab

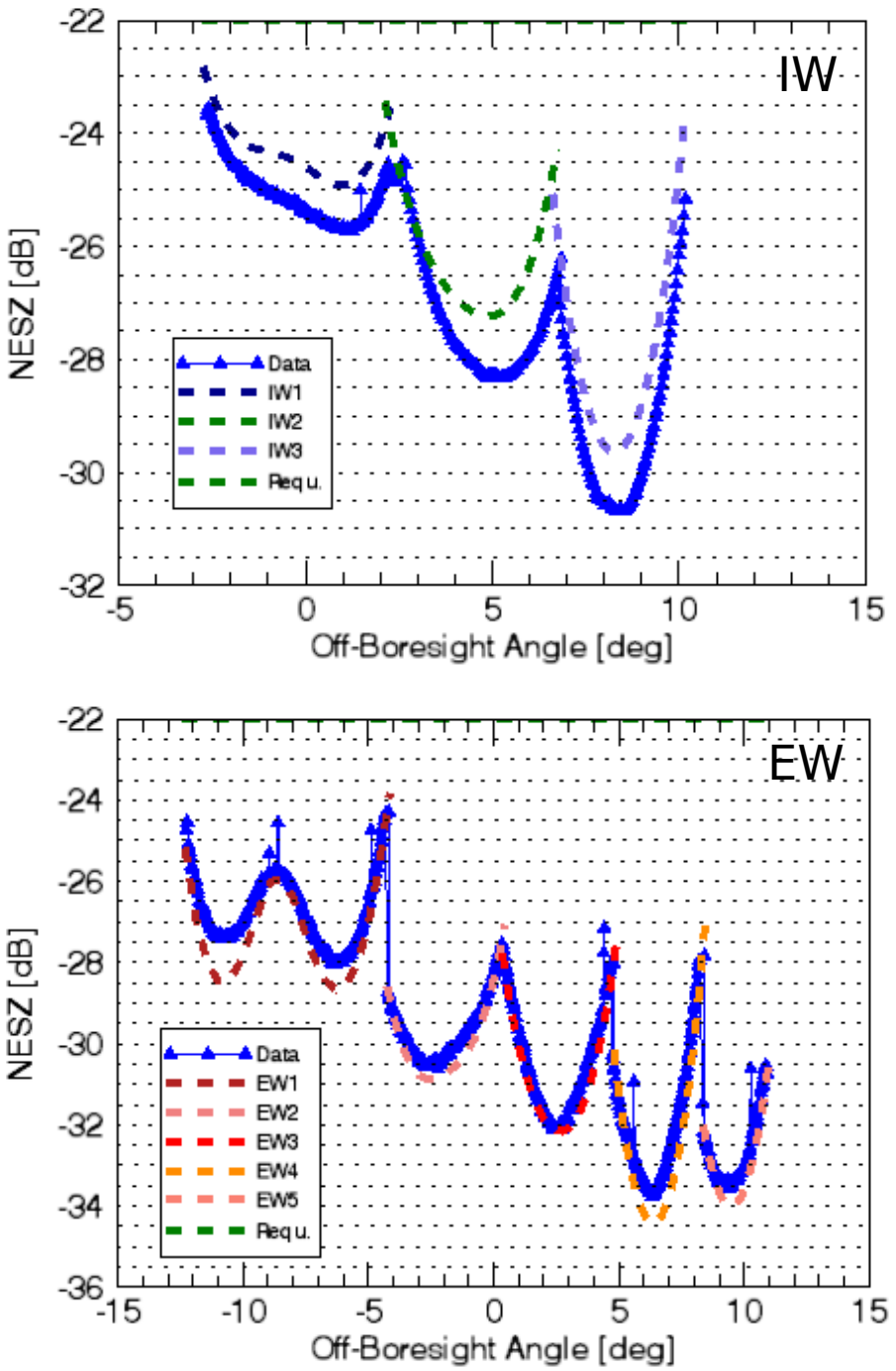


Sometimes it is bad !

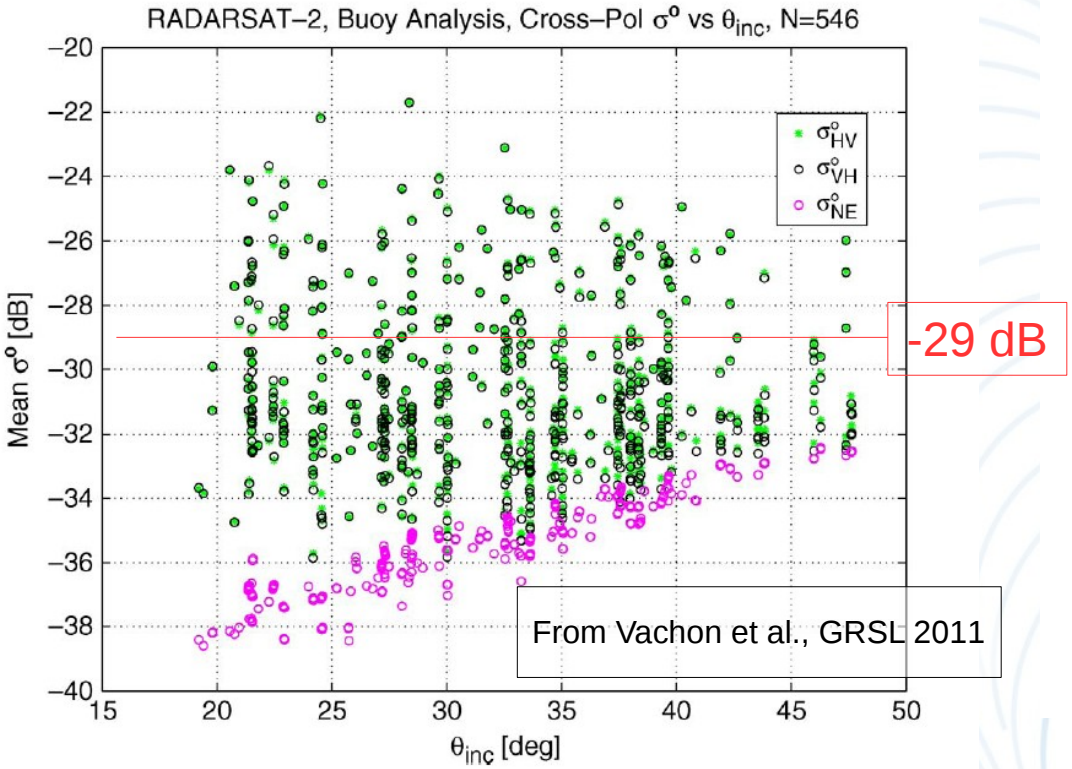
Courtesy of F. Collard, OceanDataLab

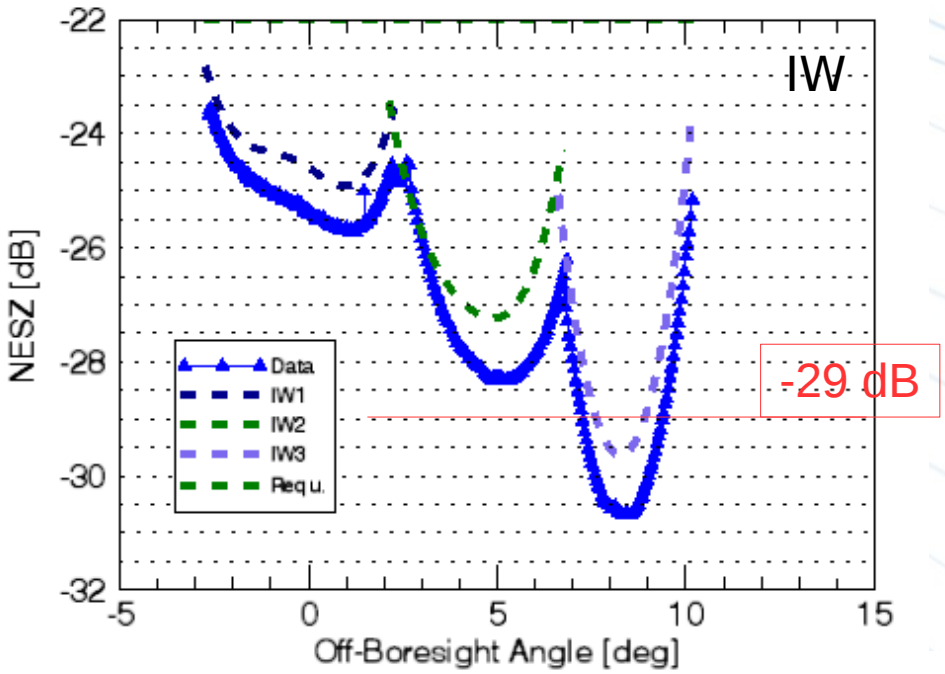
- Sentinel-1 A Cal/Val (L2)
  - S-1 Acquisitions Modes
  - S-1 MPC Strategy & CAL/VAL Time line
  - Results for WM
- Sentinel-1 A, Doppler and Cross-Polarization
  - Doppler
  - **Cross-Polarization**
- Sentinel-1 A and Rain

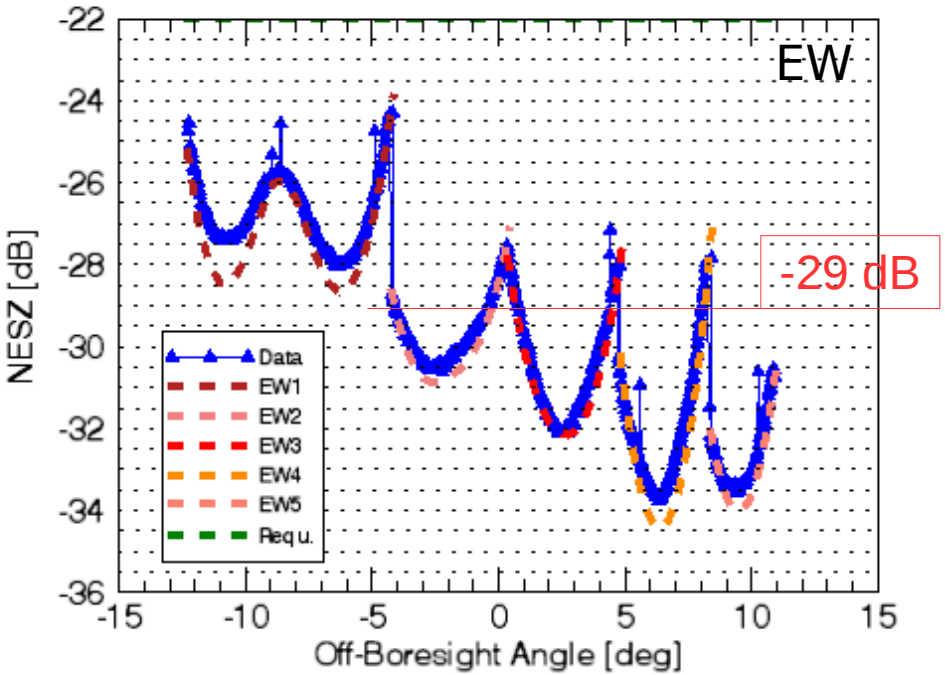
- NESZ is measured over area of low backscatter (e.g. ocean under low wind speed) and compared with theoretical profiles (dashed line)
- Mission requirement is -22dB (- - -)
- NESZ is within the requirement and following very well the theoretical profile if not better than it



Sentinel-1 A, Doppler and Cross-Polarization: Cross-Polarization





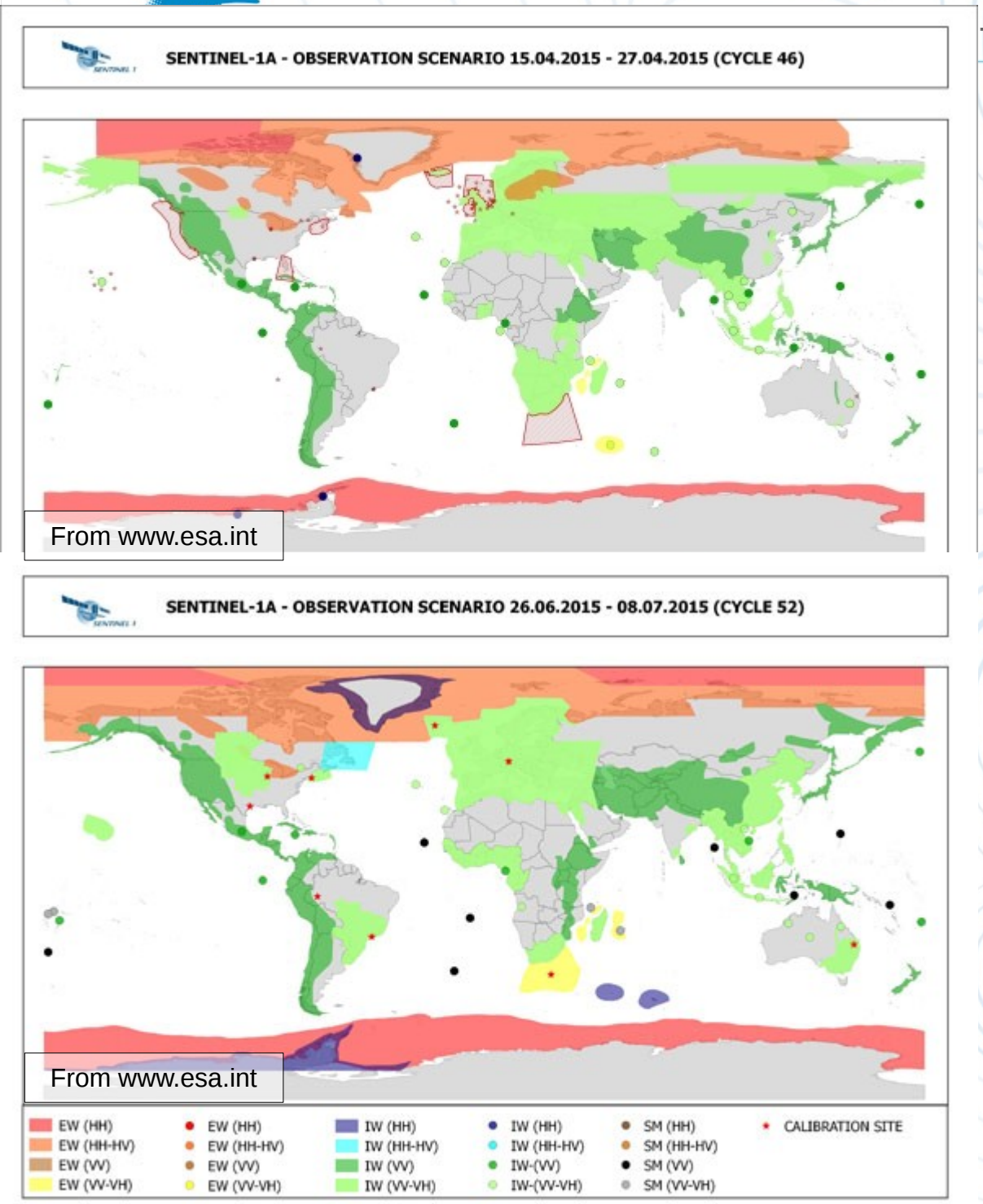


For Sentinel-1 A,
NESZ < -29 dB for largest incidences

EW Mode is close to RS-2 Quad-Pol
NESZ for largest incidence angles

→ Low values of NESZ for Sentinel-1 seems suitable for preparing VH GMF

-Polarization: Cross-Polarization

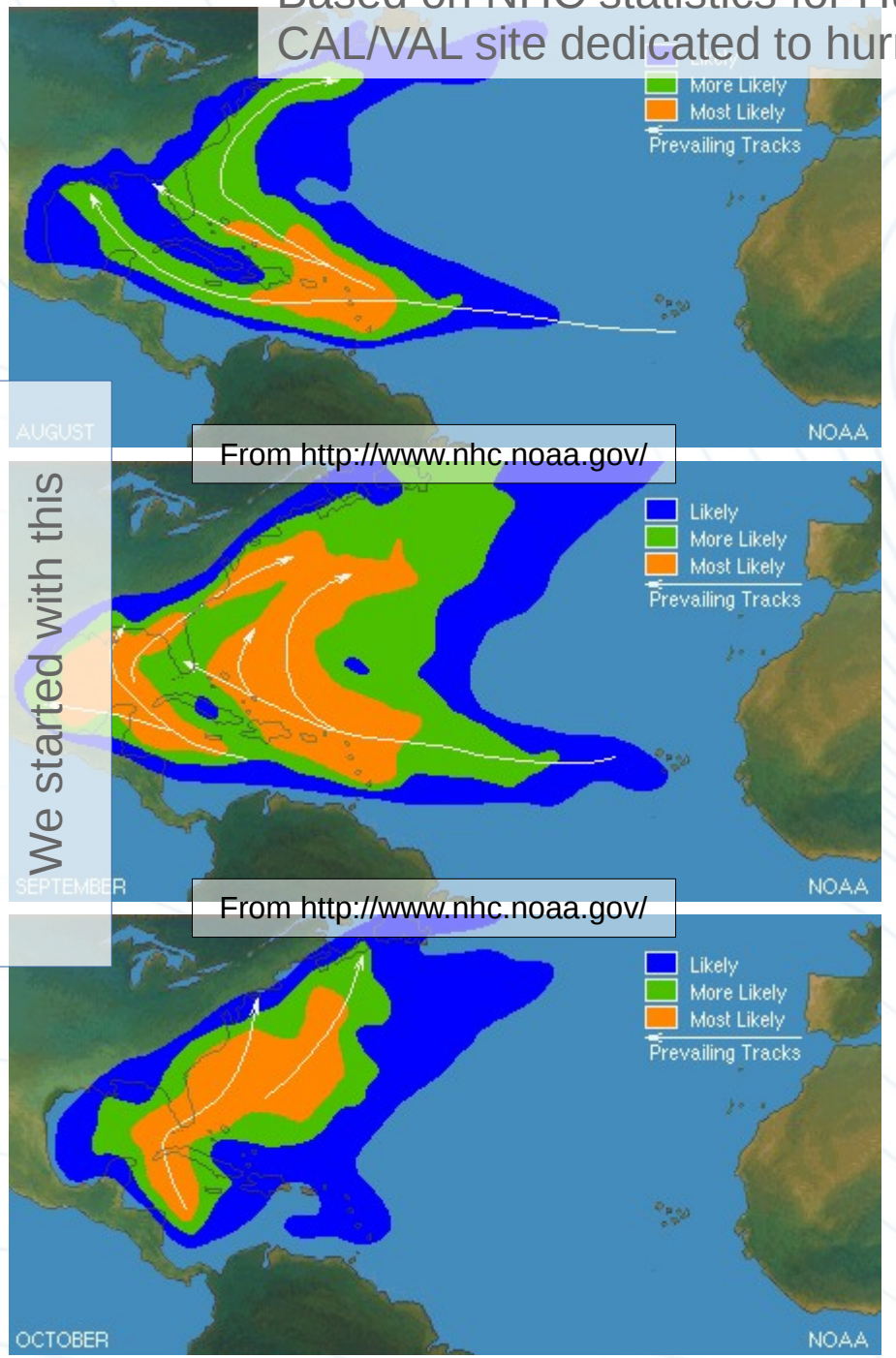


- Volume of planned acquisition is higher than with ASAR/ENVISAT
- EW in dual-pol mode is not used a lot over buoys and ocean
- EW (HH-HV) may be the most interesting. It is used for Copernicus ice service at very high latitudes, where low pressure systems are located

→ Good chances to get high wind speed values for GMF preparation

Based on NHC statistics for Hurricanes occurrences, ESL L2 proposed a CAL/VAL site dedicated to hurricanes to secure acquisitions in EW Dual-Pol

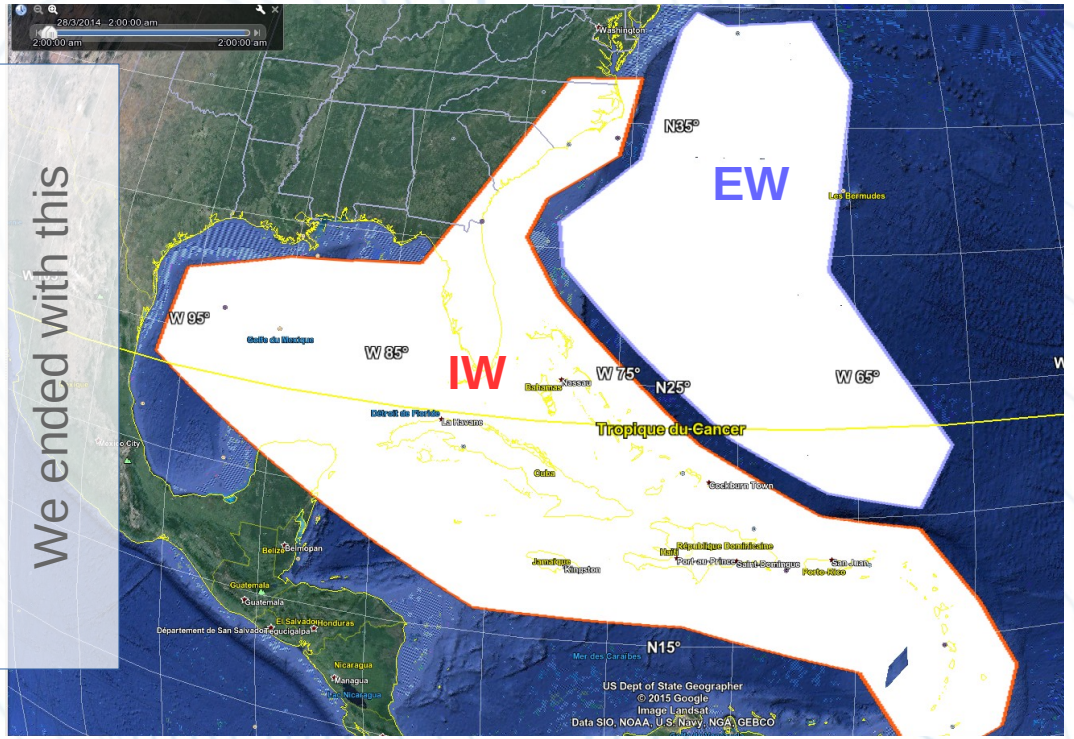
We started with this



From http://www.nhc.noaa.gov/

From http://www.nhc.noaa.gov/

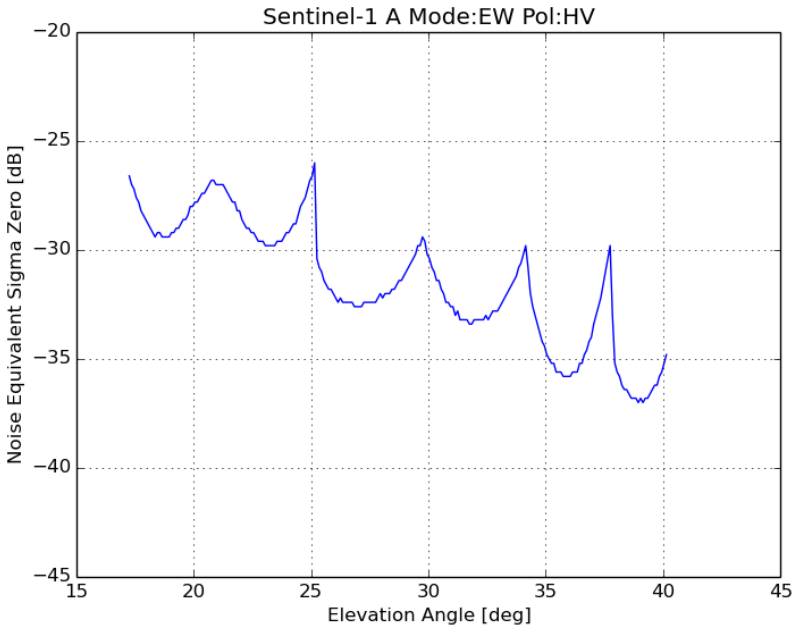
We ended with this



Good chances to get high wind speed values for GMF preparation

Preliminary CP NRCS Analysis

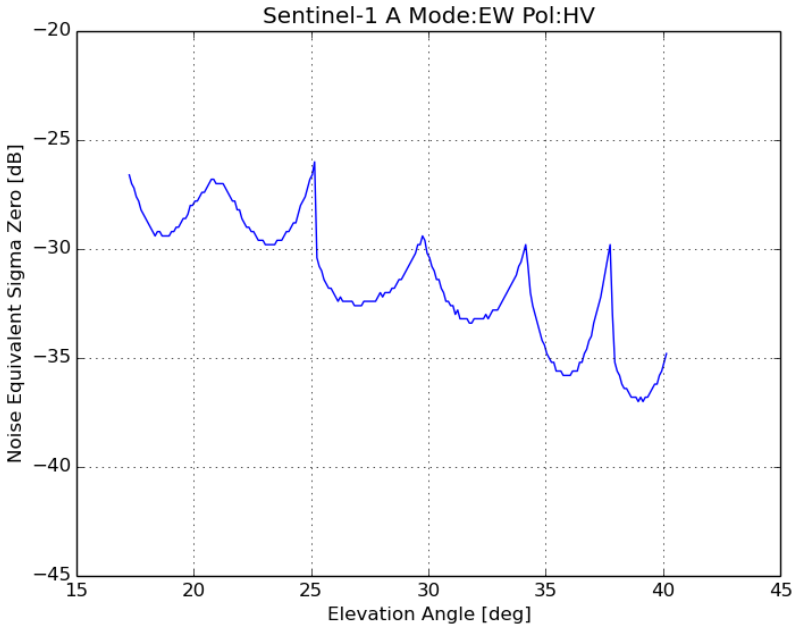
- All Sentinel-1 A data acquired in cross-polarization have been processed up to Level-1 FR GRD by ESA PDGS using Terrain Observation with Progressive Scans SAR (TOPSAR).
- EW swath is 400 km wide and covers incidence angles from 19 to 46 degrees.
- NESZ is derived from the data set.
- NRCS are corrected from the NESZ.

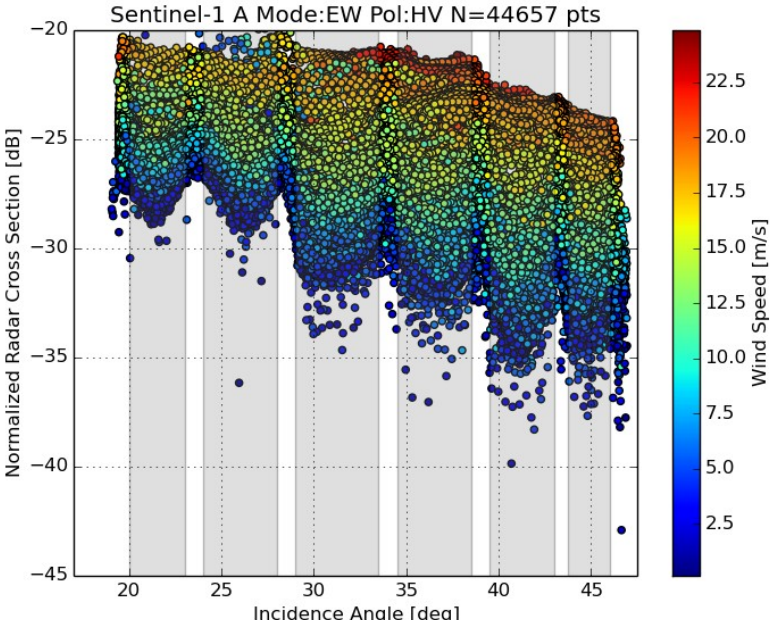


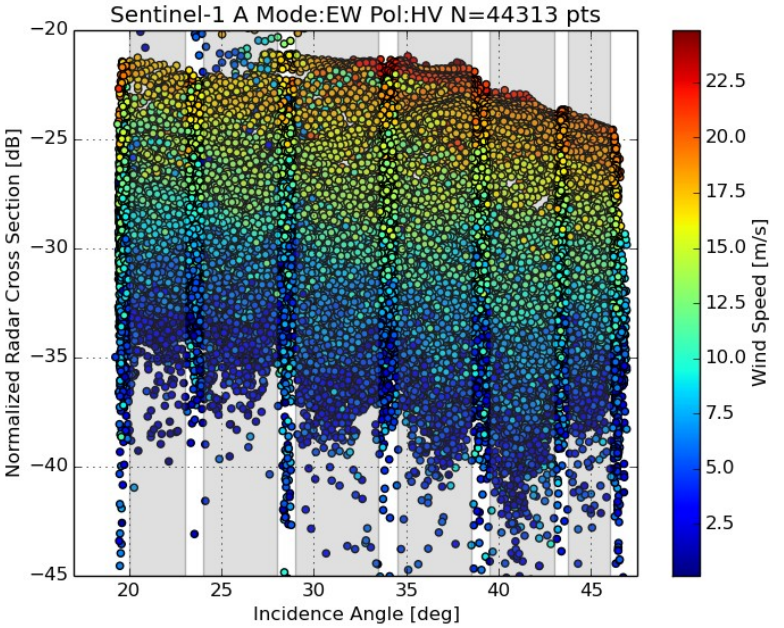
Sentinel-1 A, Doppler and Cross-Polarization: Cross-Polarization

Preliminary CP NRCS Analysis

- All Sentinel-1 A data acquired in cross-polarization have been processed up to Level-1 FR GRD by ESA PDGS using Terrain Observation with Progressive Scans SAR (TOPSAR).
- EW swath is 400 km wide and covers incidence angles from 19 to 47 degrees.



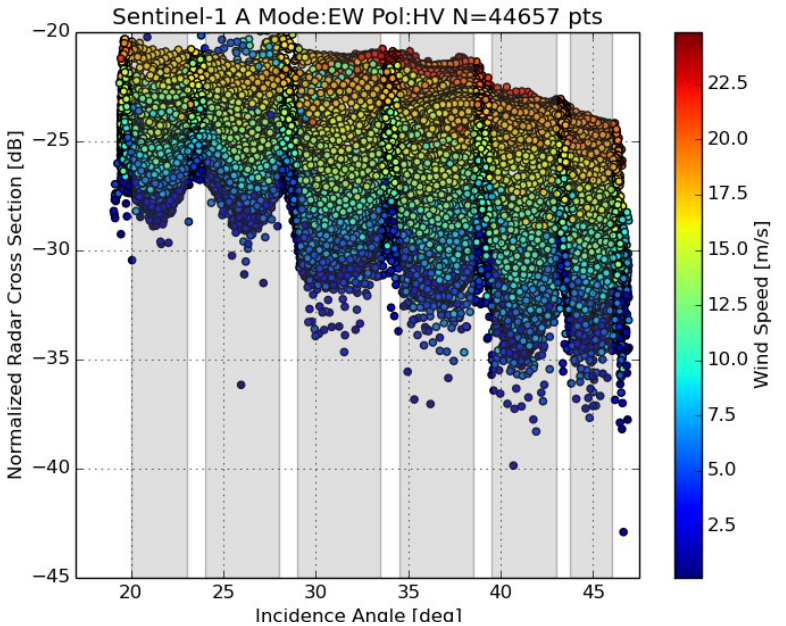


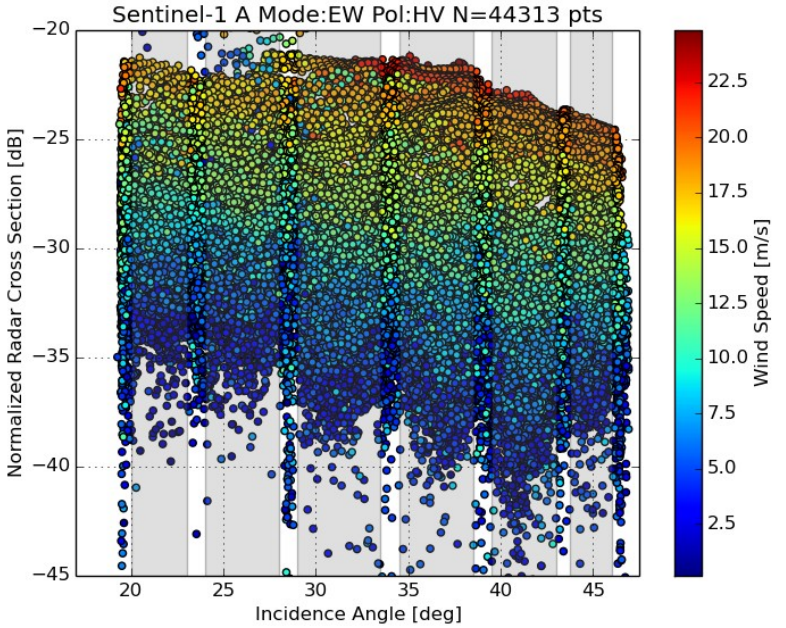


Sentinel-1 A, Doppler and Cross-Polarization: Cross-Polarization

Preliminary CP NRCS Analysis

- All Sentinel-1 A data acquired in cross-polarization have been processed up to Level-1 FR GRD by ESA PDGS using Terrain Observation with Progressive Scans SAR (TOPSAR).
- EW swath is 400 km wide and covers incidence angles from 19 to 47 degrees.
- NESZ correction significantly impacts the results
- Dependence of NRCS with wind speed is observed from 2 to 22 m/s
- Dependence of NRCS with incidence angle is observed for this range of wind speeds

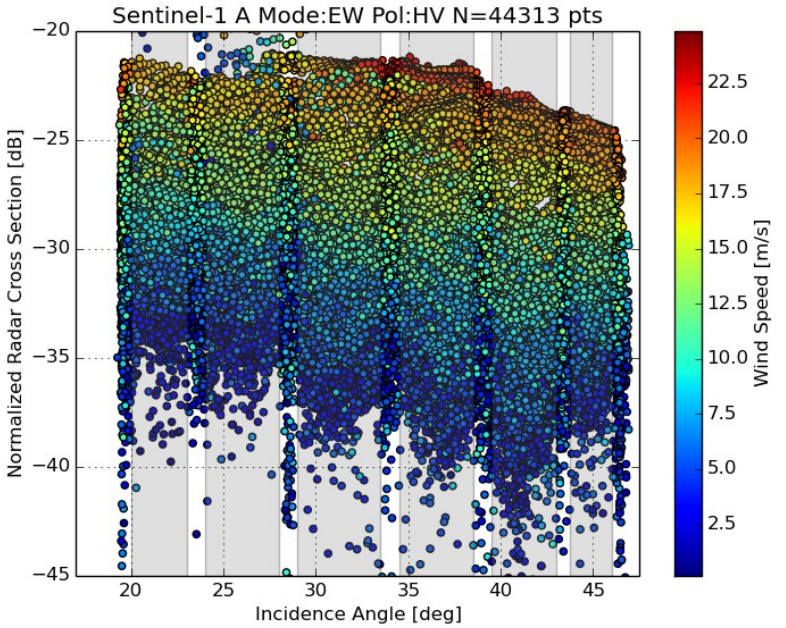


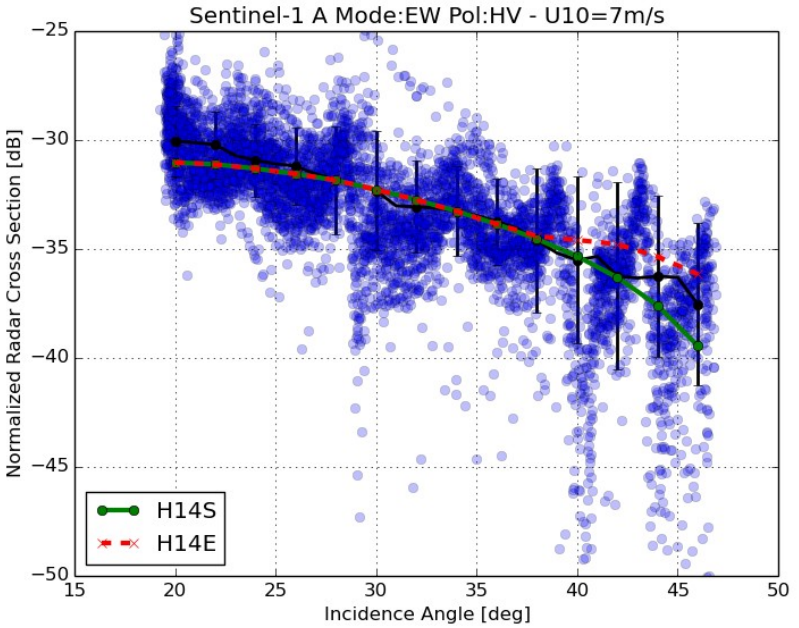


Sentinel-1 A, Doppler and Cross-Polarization: Cross-Polarization

Preliminary CP NRCS Analysis

- All Sentinel-1 A data acquired in cross-polarization have been processed up to Level-1 FR GRD by ESA PDGS using Terrain Observation with Progressive Scans SAR (TOPSAR).
- EW swath is 400 km wide and covers incidence angles from 19 to 47 degrees.
- NESZ correction significantly impacts the results
- Dependence of NRCS with wind speed is observed from 2 to 22 m/s
- Dependence of NRCS with incidence angle is observed for this range of wind speeds. In line with last RS-2 study at 7 m/s

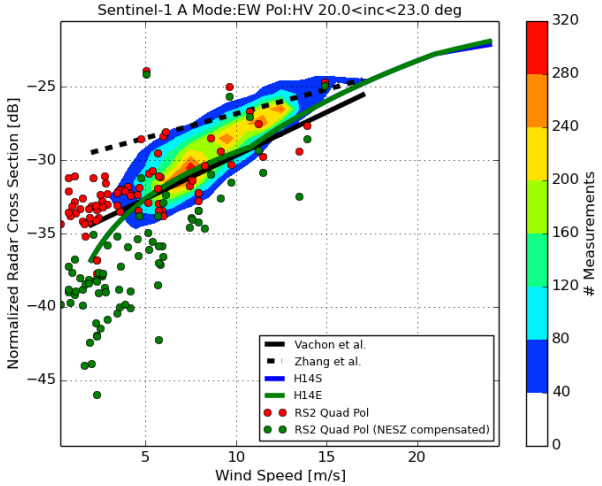


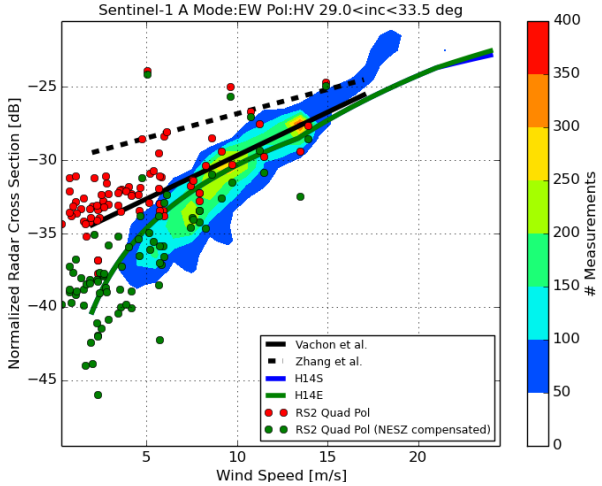


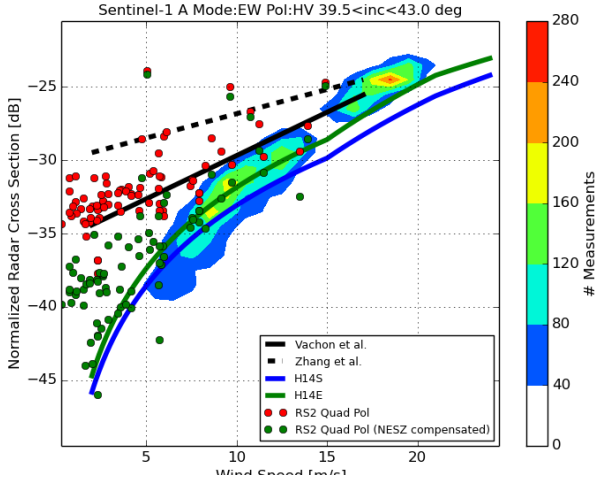
Preliminary CP NRCS Analysis

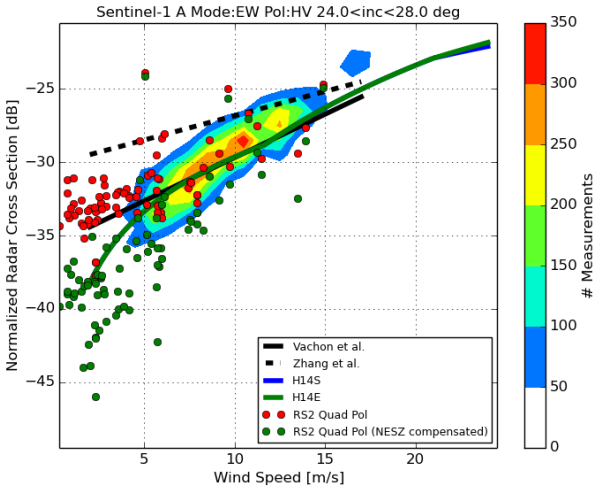
- Dependence of NRCS with wind speed has been observed for several incidence angles from light to medium wind speeds.

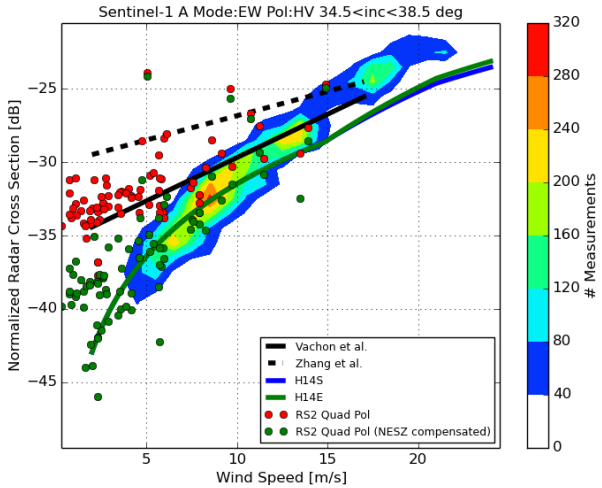
- Results are consistent with latest RS2 analysis from Hwang et al., 2014
- **To be continued...**

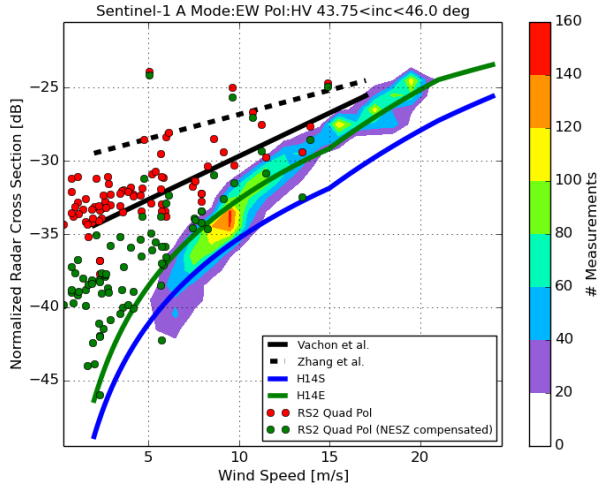




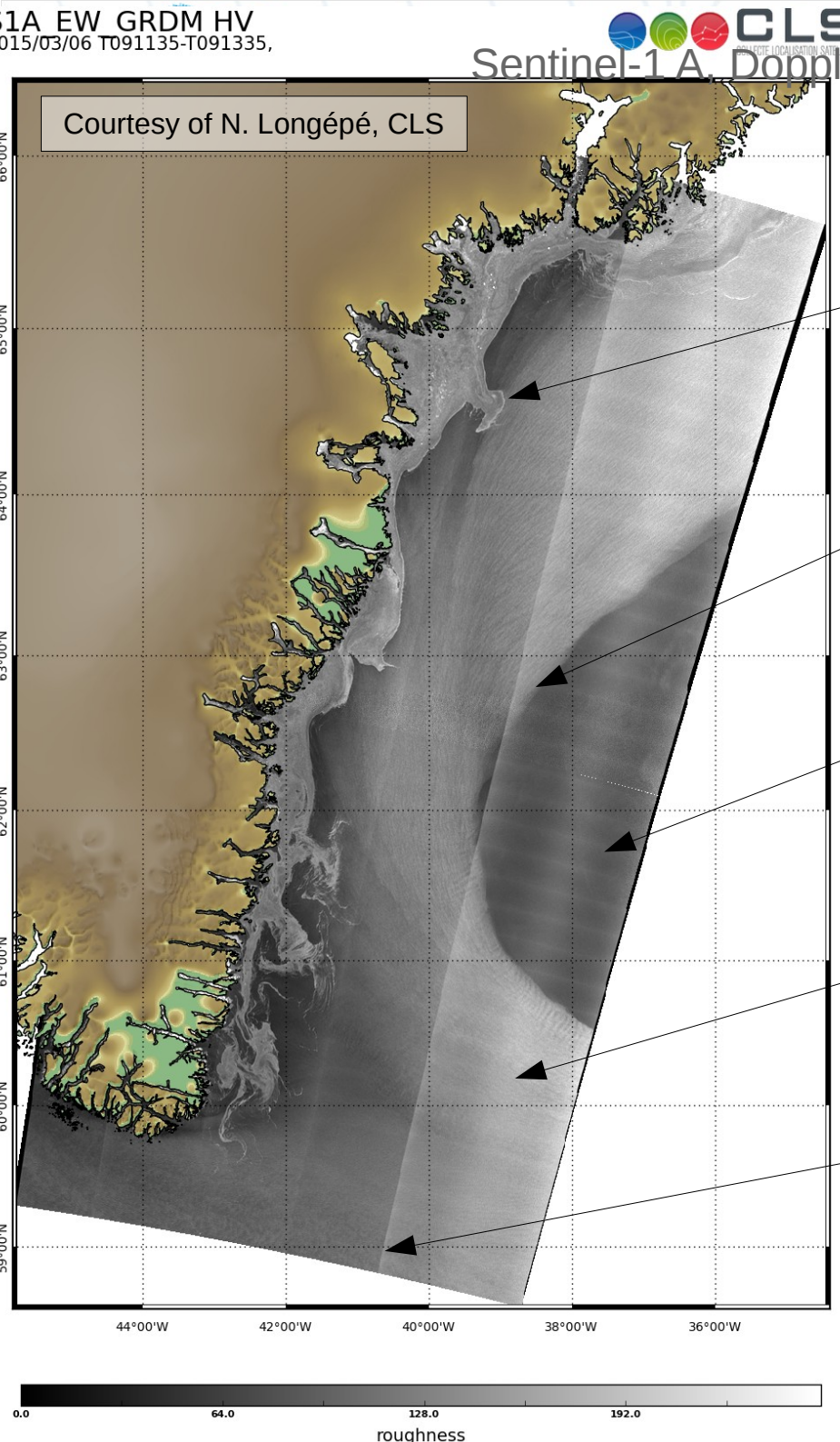








Sentinel-1 A, Doppler and Cross-Polarization: Cross-Polarization



Sea Ice and Open Sea frontier

Strong Wind speed and Direction gradient

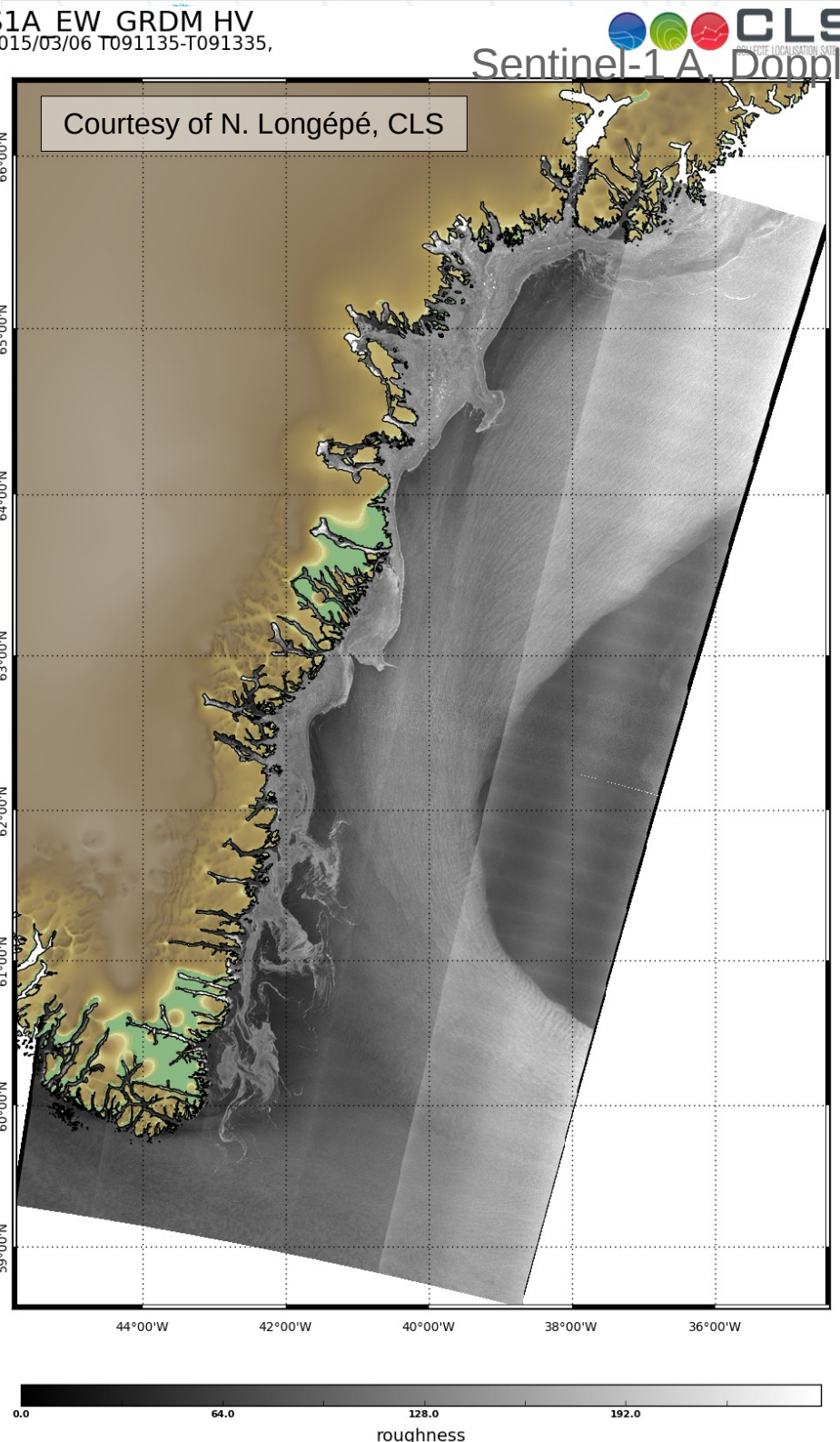
Low wind Area. Noise can be seen (in azimuth and range directions)

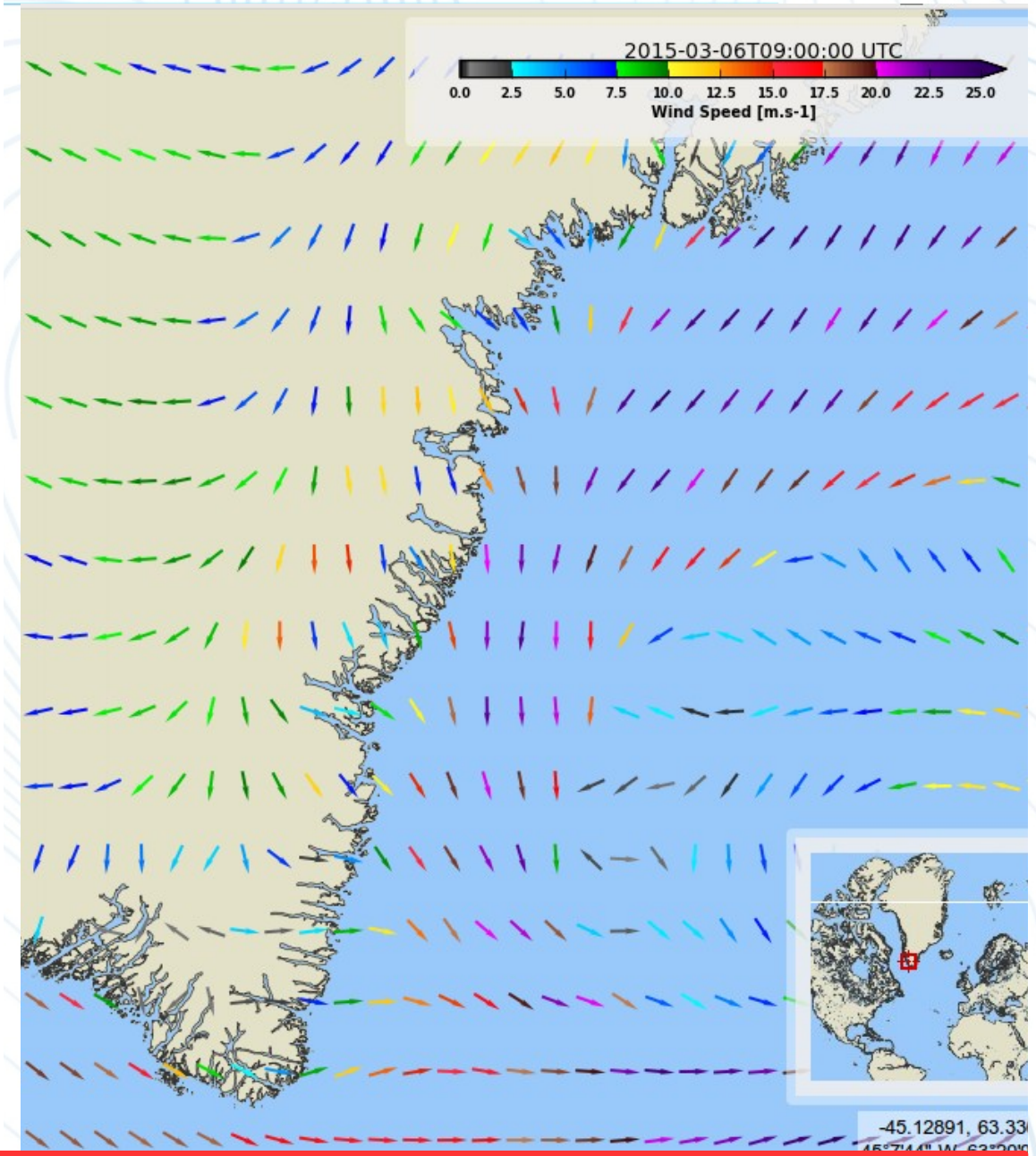
Strong wind Area.

Sub Swath Jump

Exemple of
Sentinel-1 A EW Product in HV polarization

Sentinel-1 A, Doppler and Cross-Polarization: Cross-Polarization



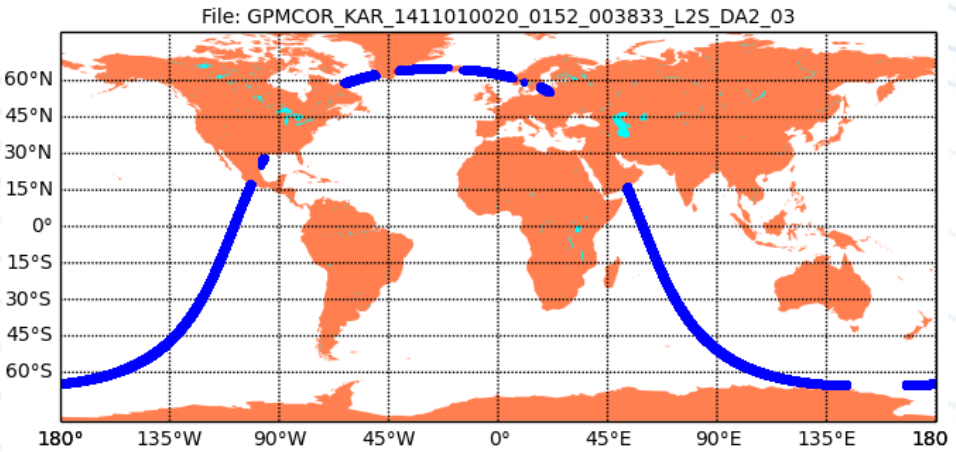


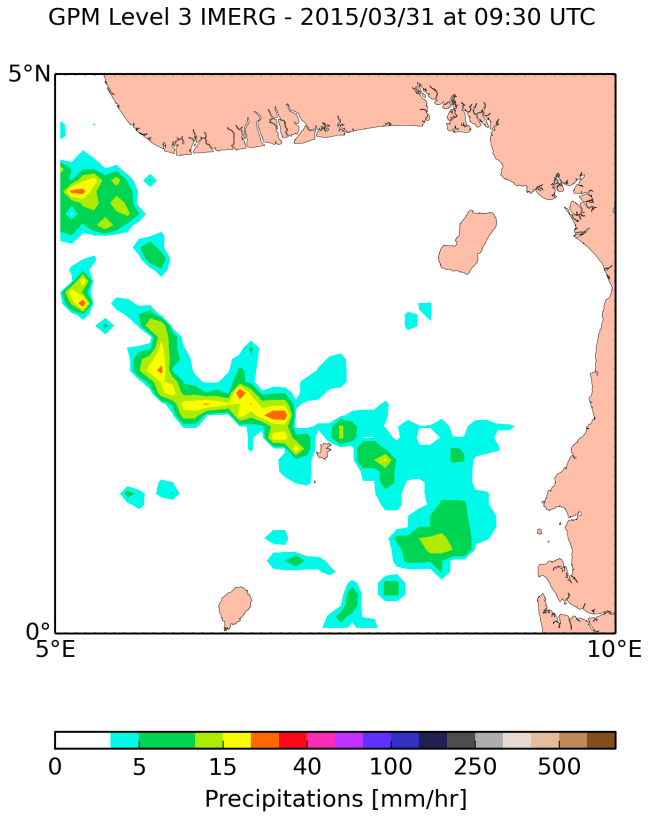
Exemple of
Sentinel-1 A EW Product in HV polarization

- Sentinel-1 A Cal/Val (L2)
  - S-1 Acquisitions Modes
  - S-1 MPC Strategy & CAL/VAL Time line
  - Results for WM
- Sentinel-1 A, Doppler and Cross-Polarization
  - Doppler
  - Cross-Polarization
- **Sentinel-1 A and Rain**

Sentinel-1 A and Rain

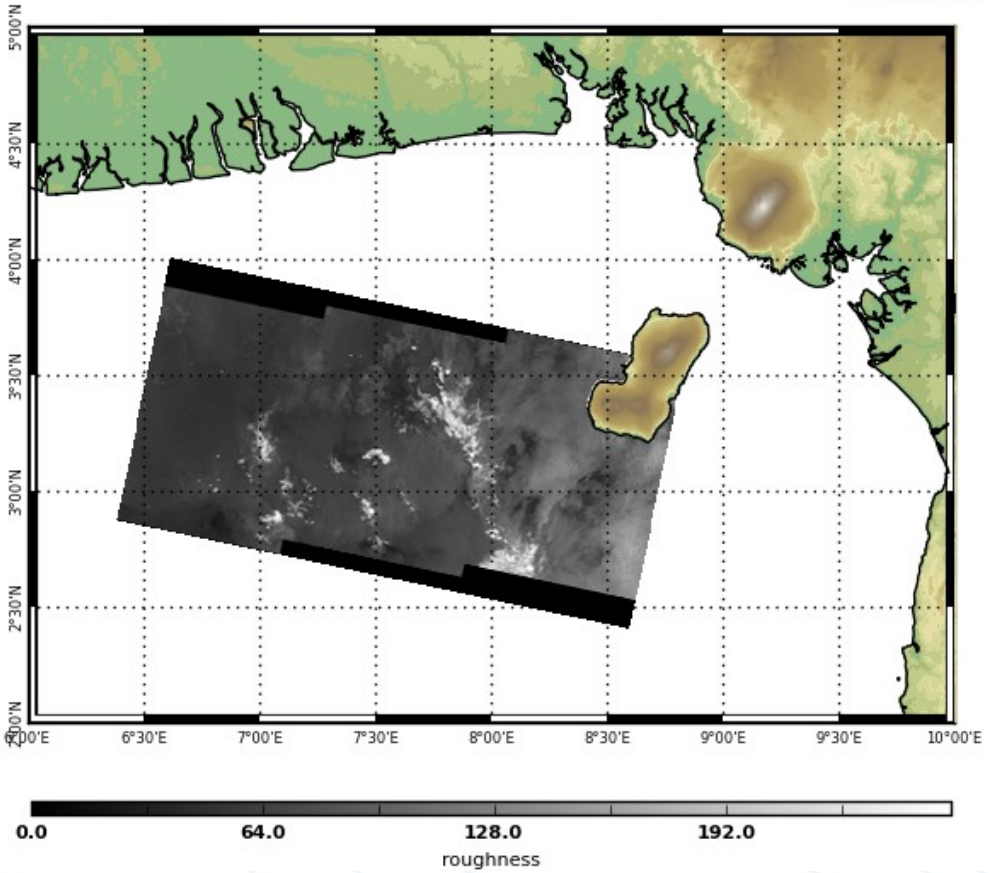
- Sentinel-1 A launch date is 2014/04/03
- Global Precipitation Measurement (TRMM follow-on) launch date 2014/02/27
  - Orbit modifications to get measurements up to 60°N/S (instead of 30°N/S with TRMM)
  - L2 Rain products (5kmx5 km)
  - New L3 IMERG product (0.1°x0.1°, 30 min)

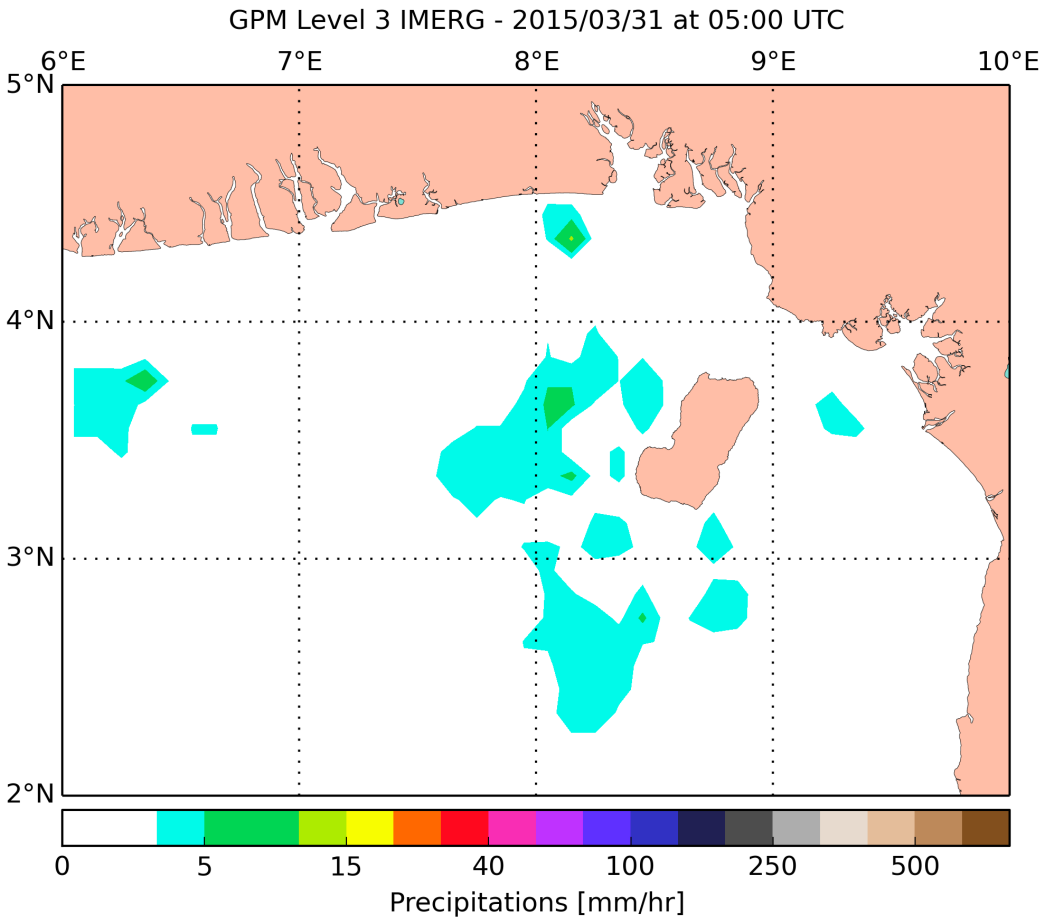




Possibility of joint study between C-Band cross section in co- and cross-polarization, Doppler and rain measurement

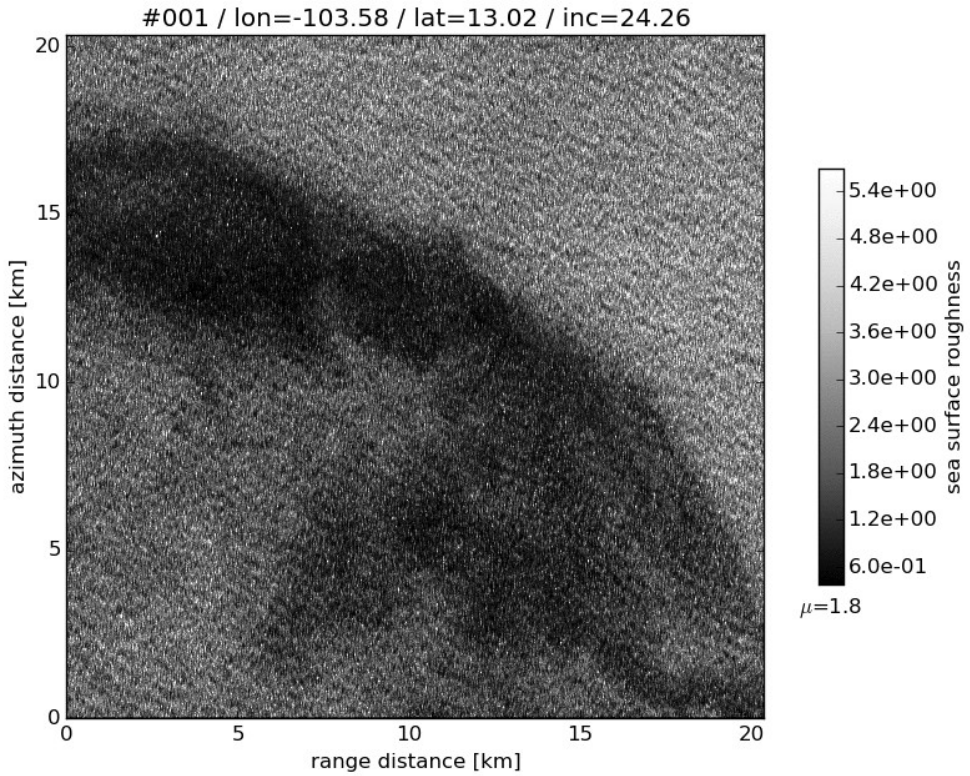
05:13: UTC

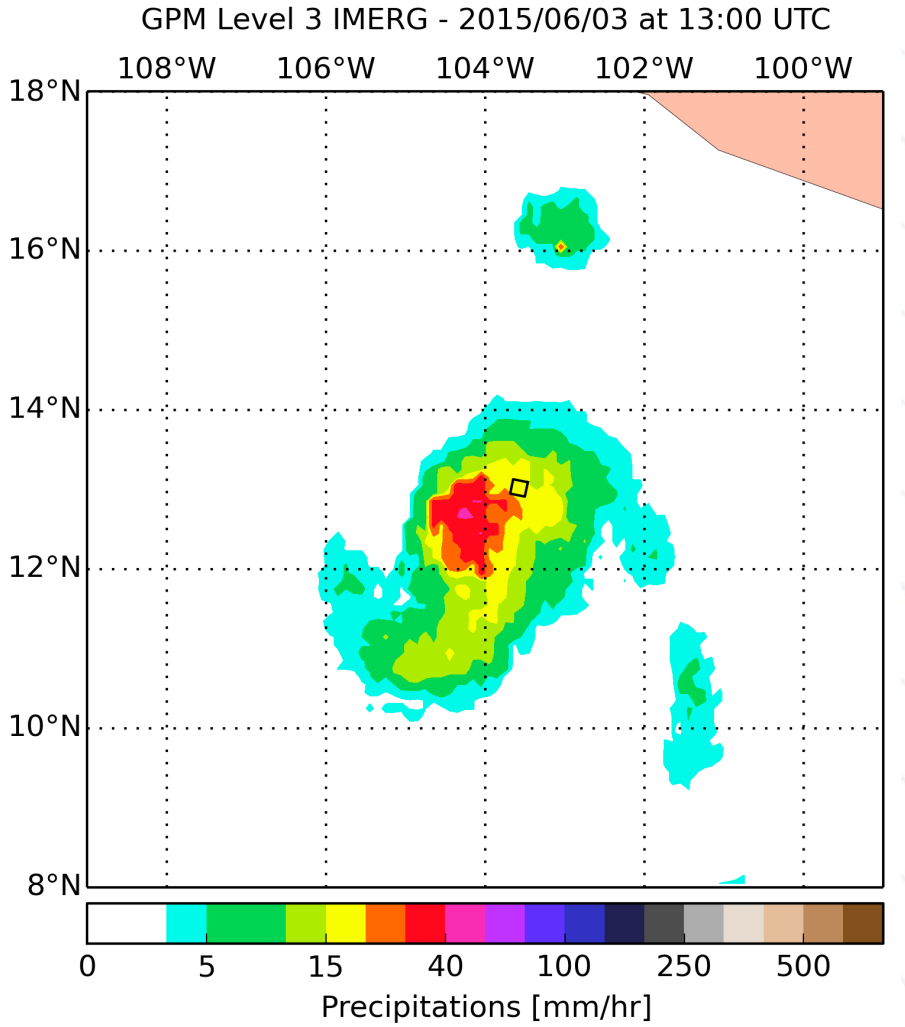




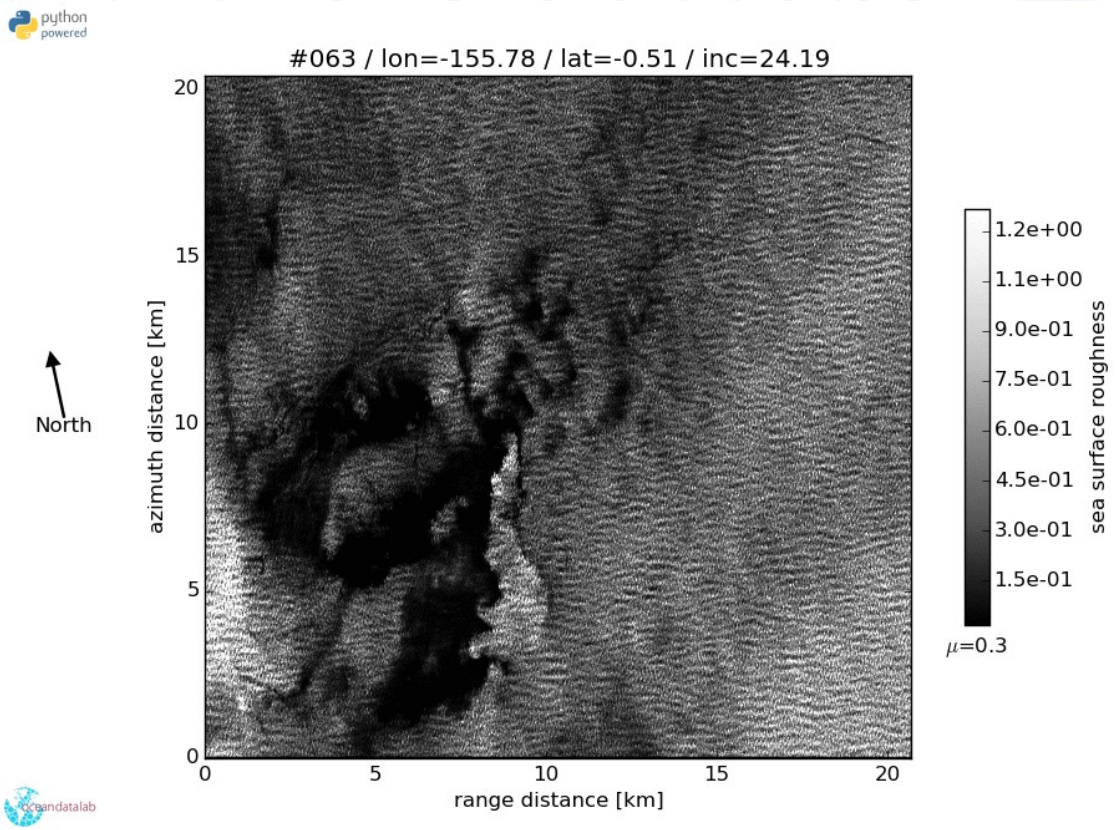
Exemple of Squall line as observed by
Sentinel-1 A in co-polarization and L3 IMERG

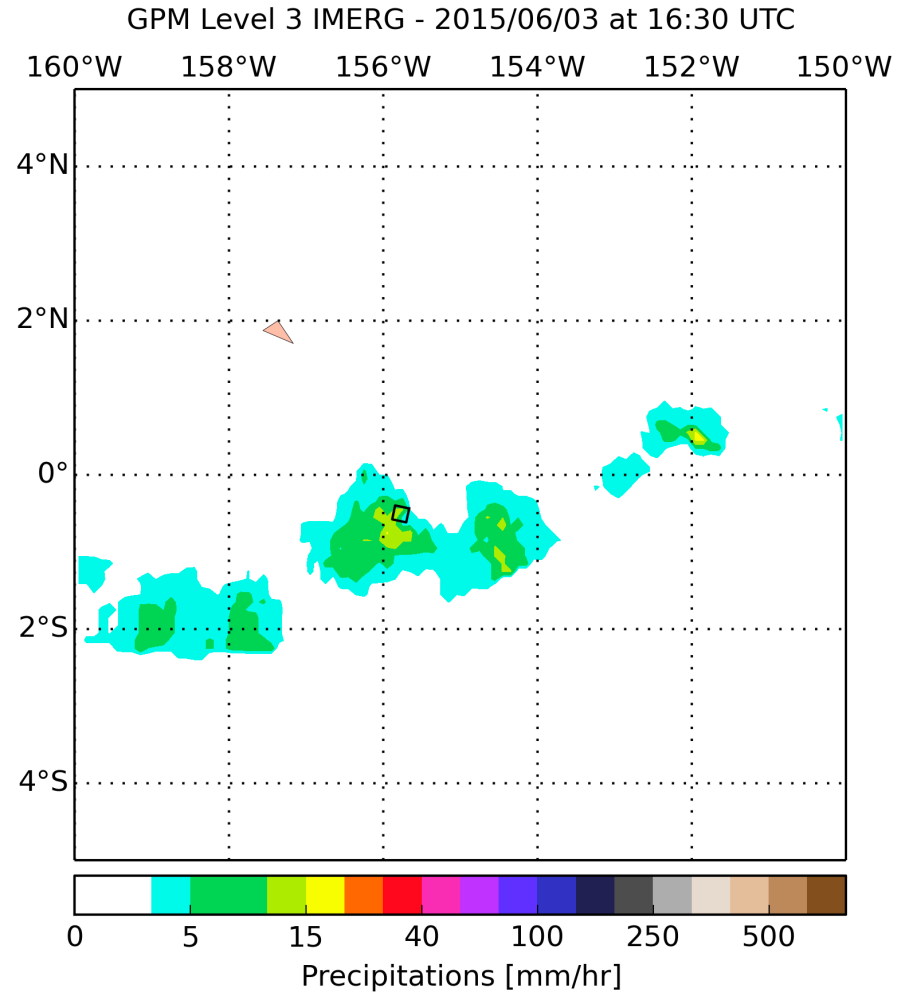
Massive co-locations is possible with Wave Mode



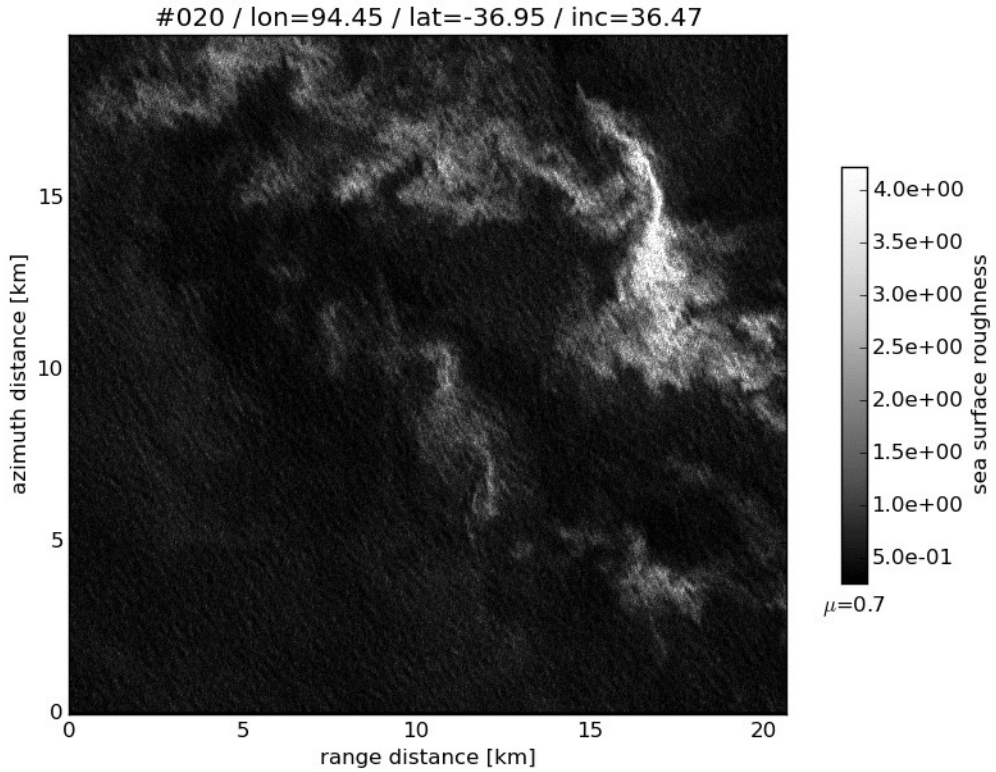


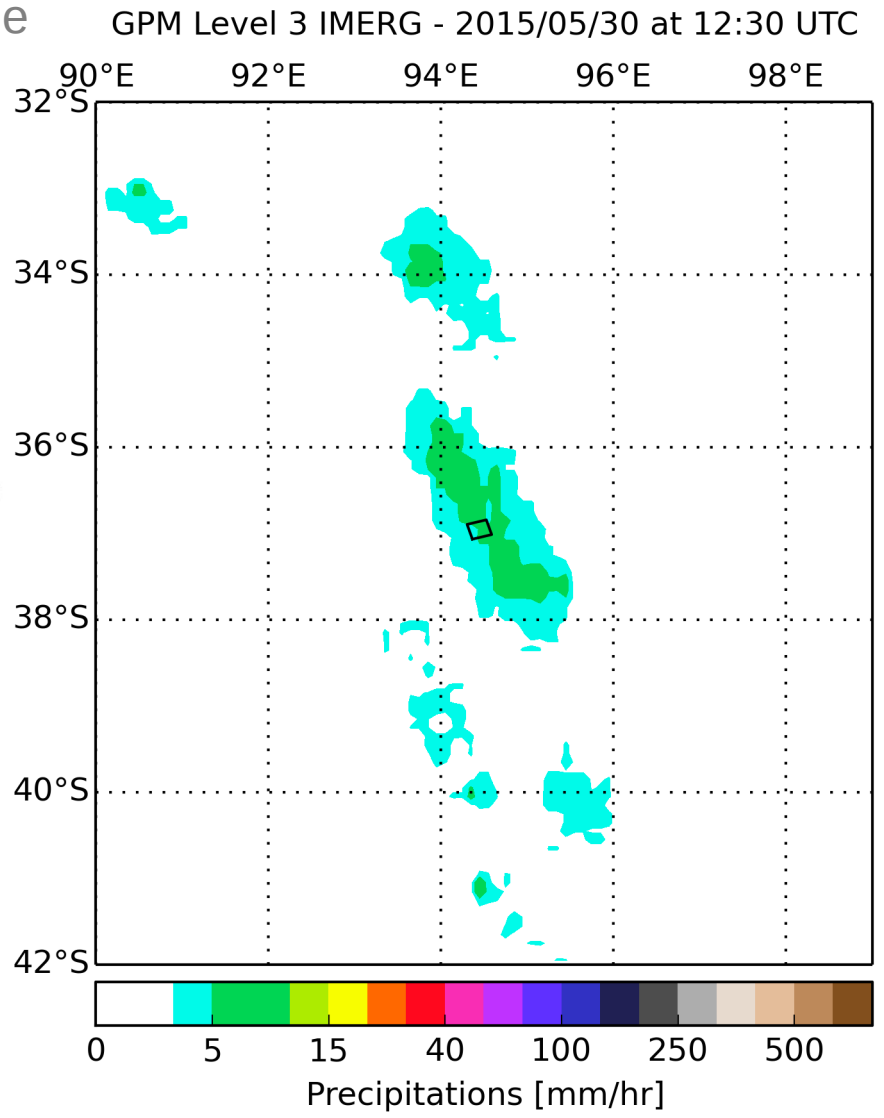
Massive co-locations is possible with Wave Mode



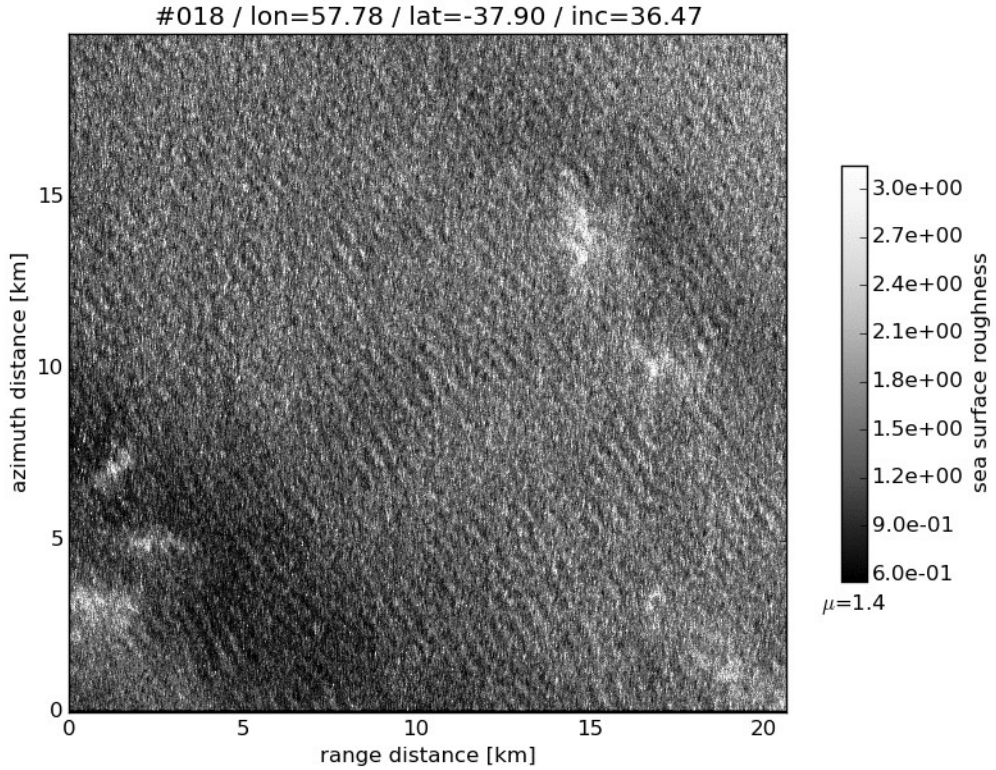


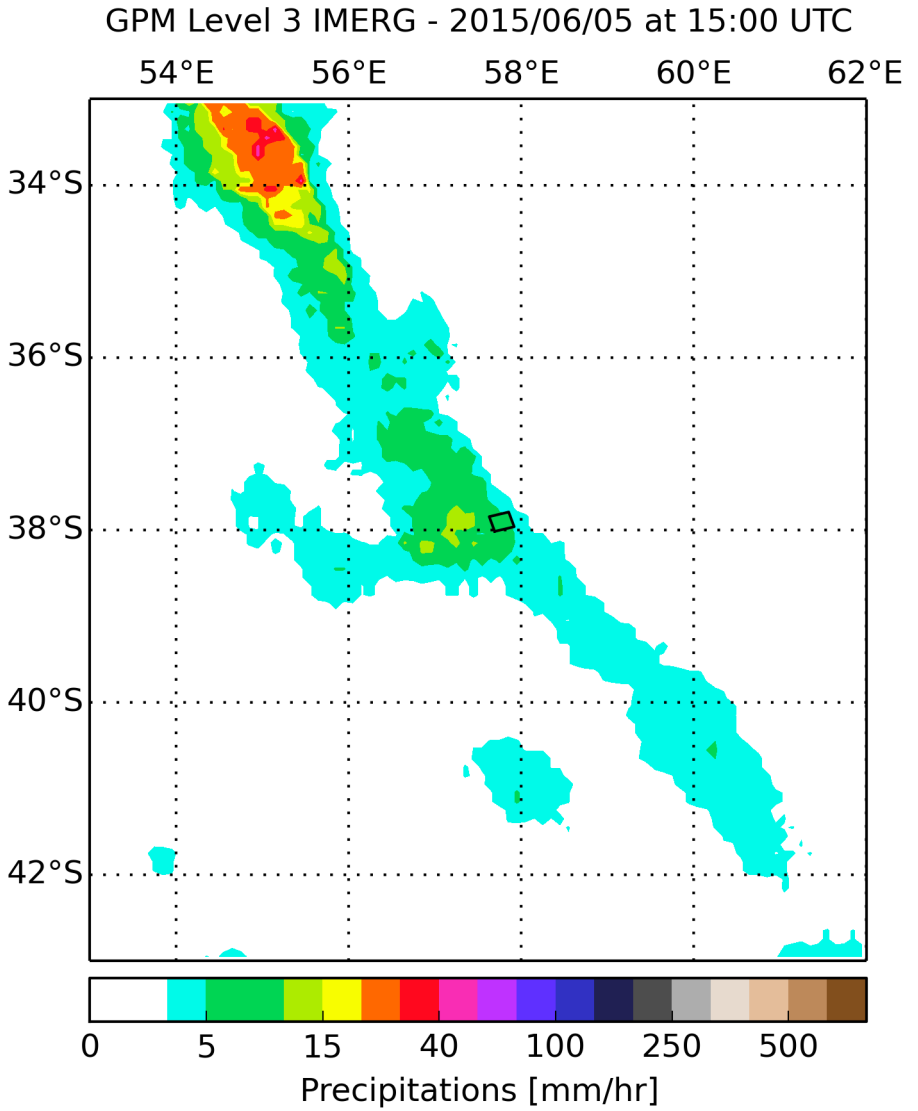
Massive co-locations is possible with Wave Mode





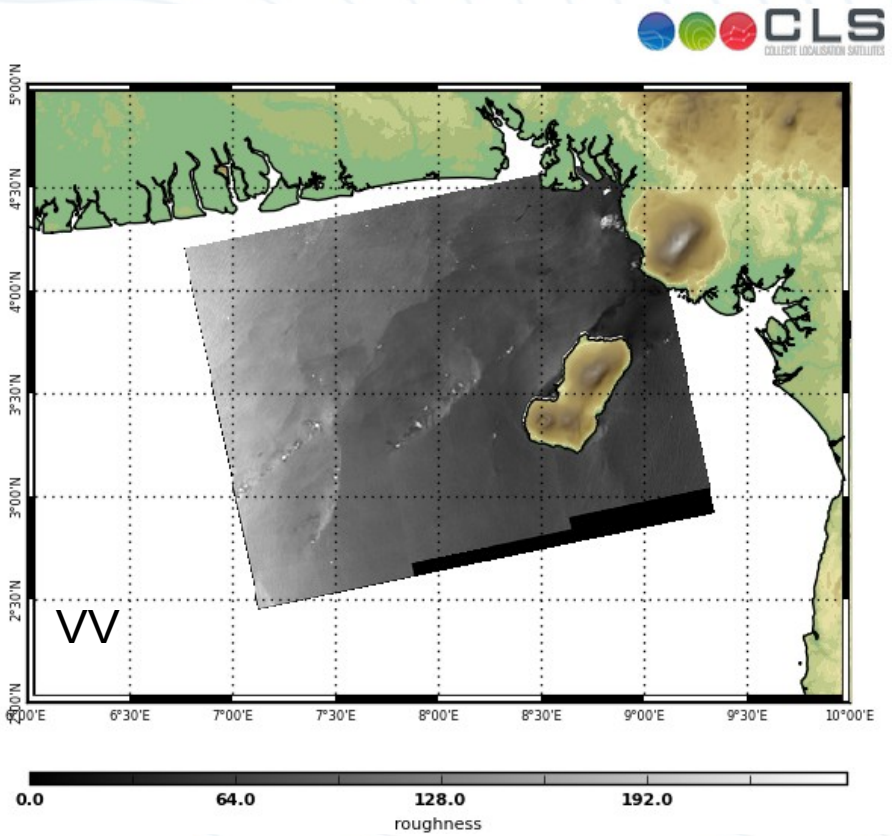
Massive co-locations is possible with Wave Mode

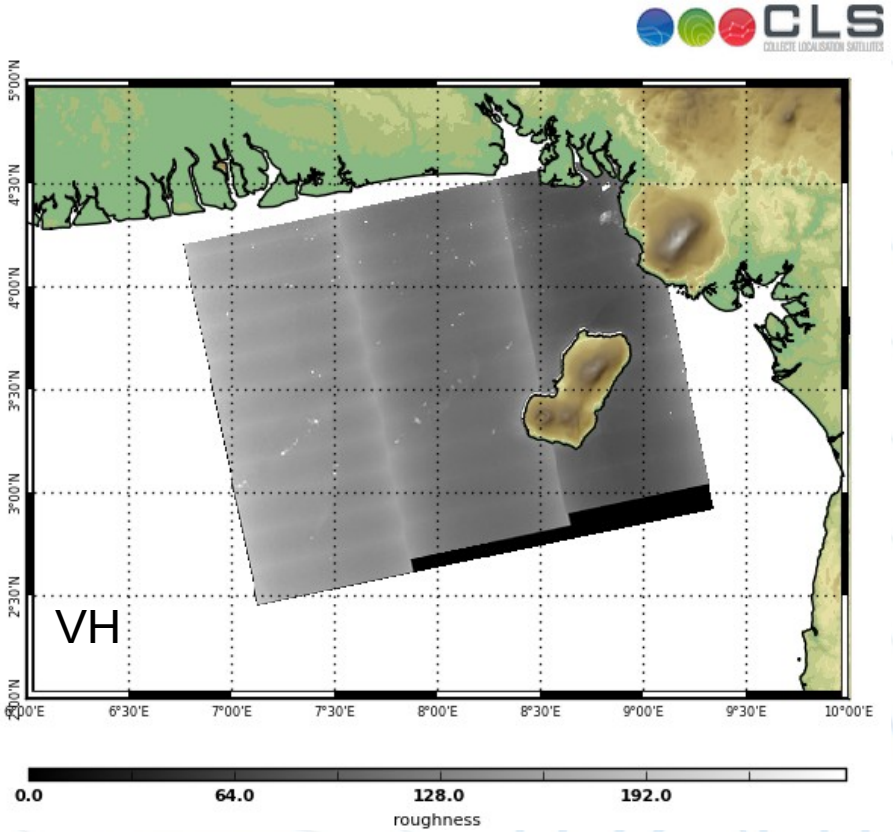


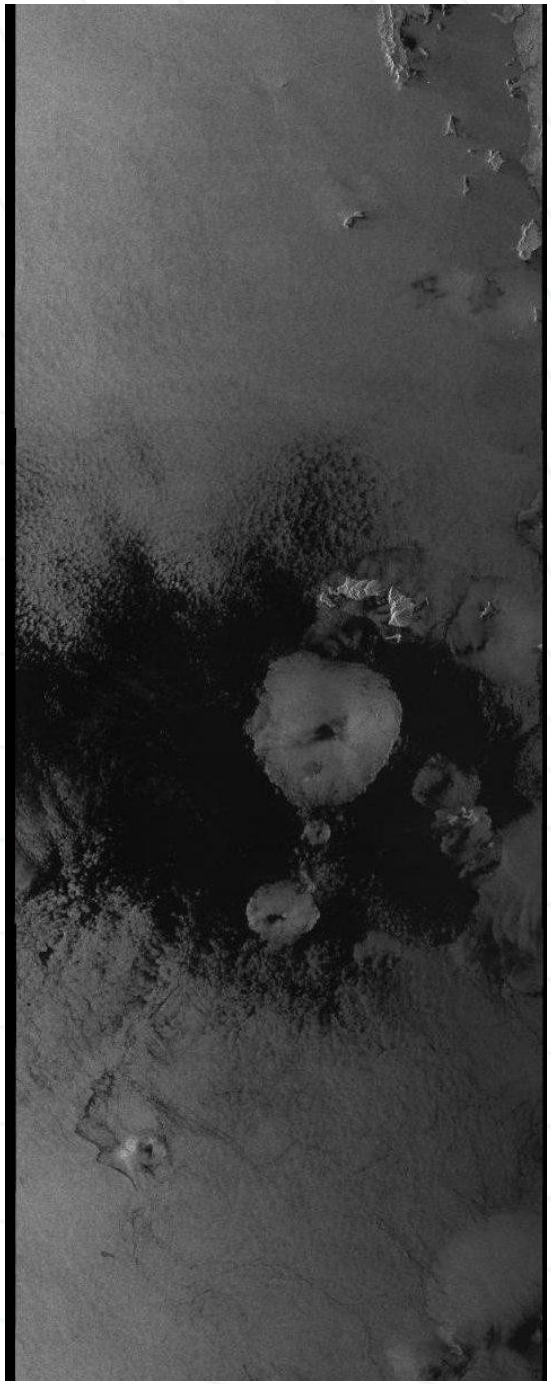


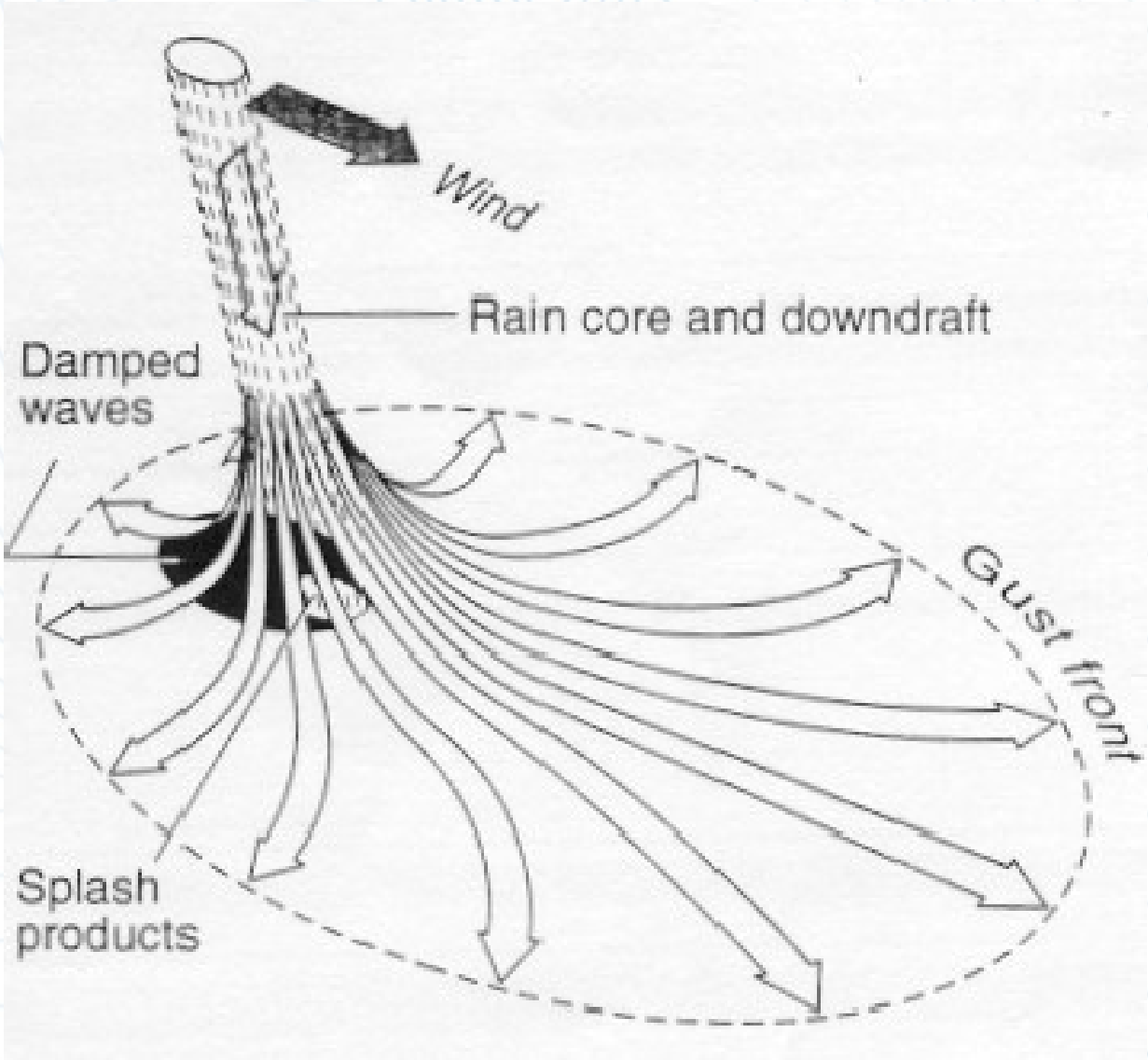
High wind speed situations and heavy rains often happen concurrently

Sentinel-1 A dual polarization data will allow to investigate NRCS cross-polarization signature in cases of rain.



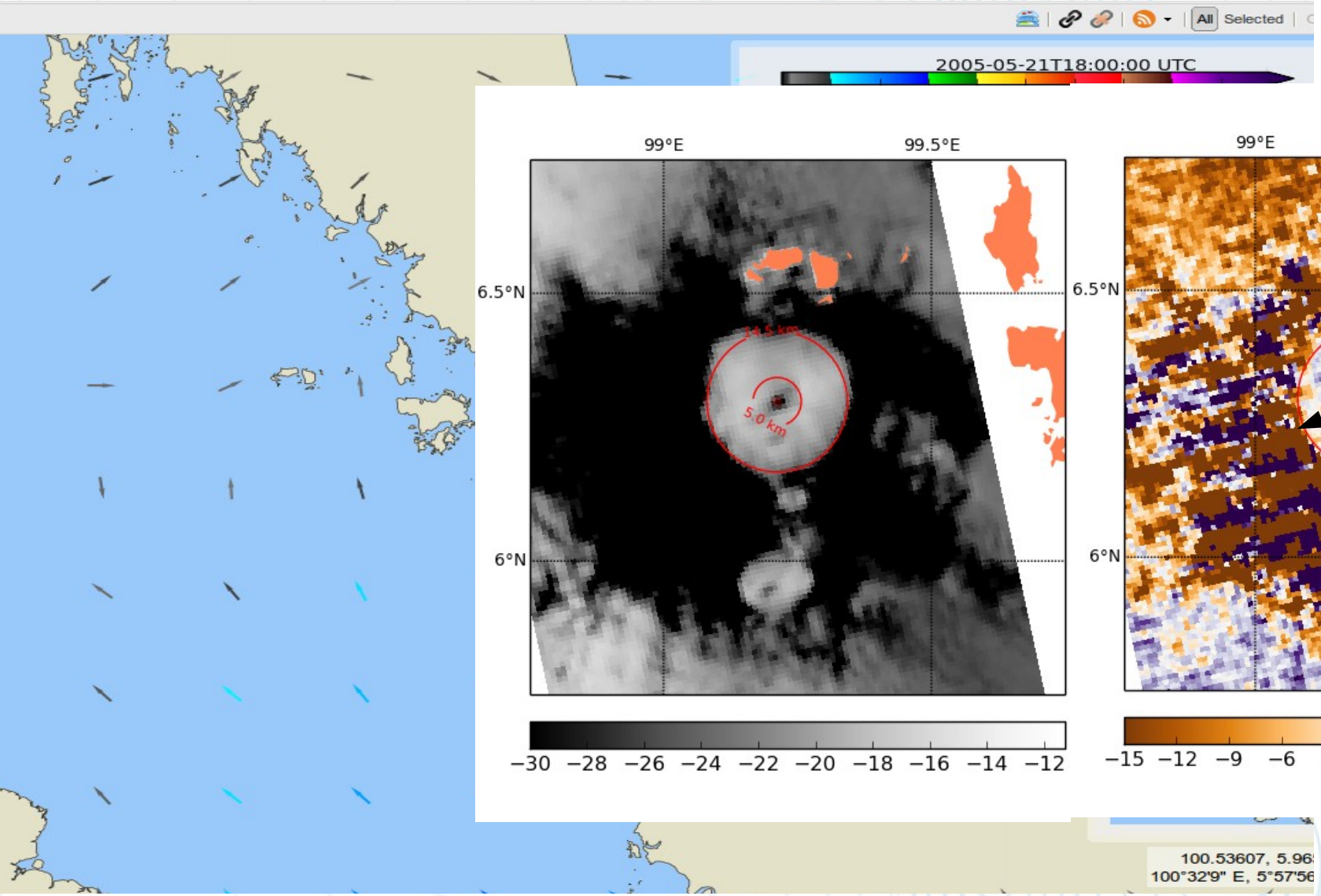




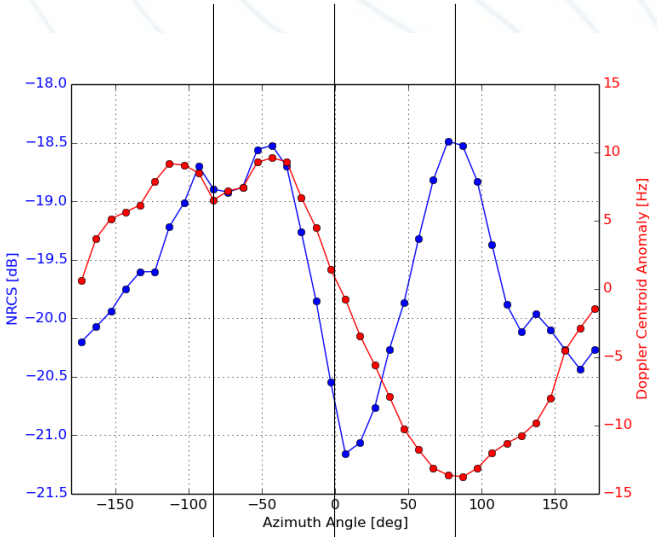


Schematic sketch of the **downdraft of a rain cell,** spreading over the sea surface and causing roughening of the sea surface; (adapted from Atlas, 1994b).

Sentinel-1 A and Rain



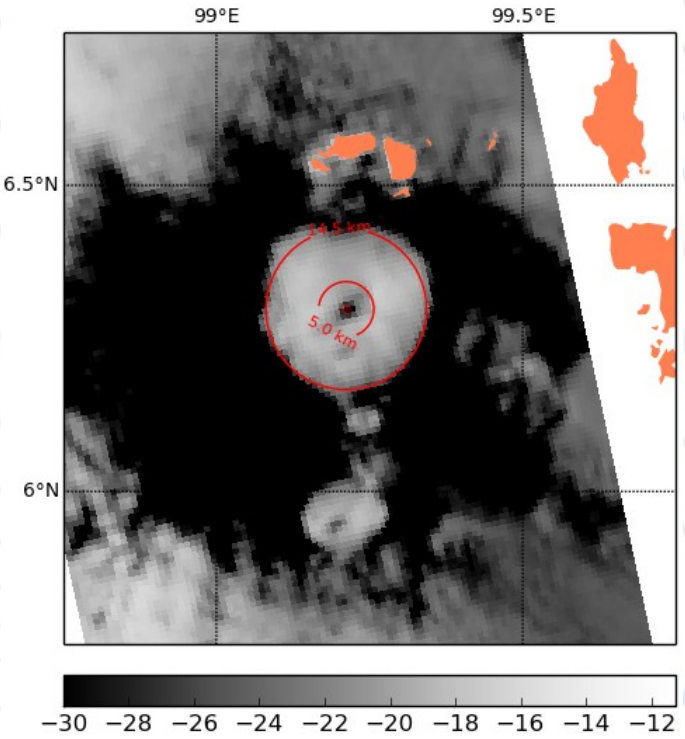
Outside the rain cells, Doppler variation is consistent with model wind
Inside the rain cells, Doppler sign is consistent with downdraft with circular gust front

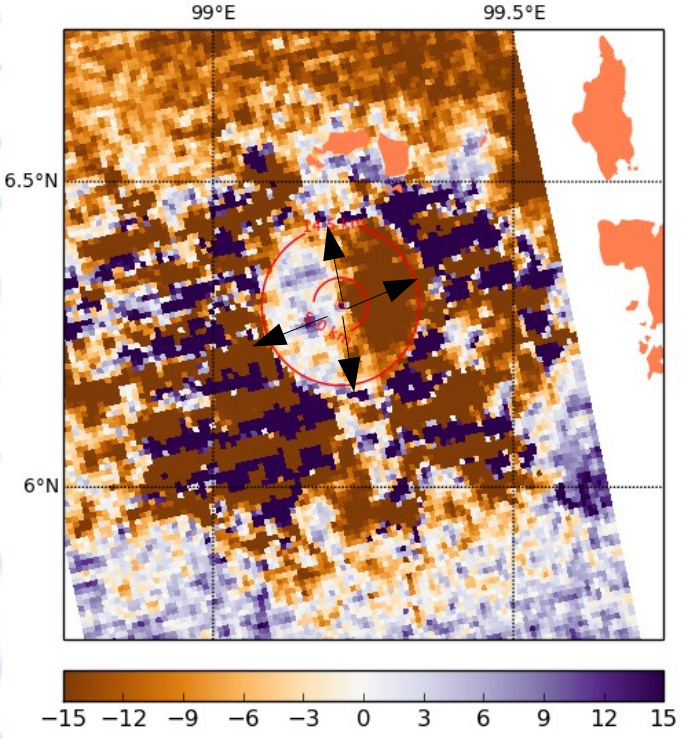


Downwind

Crosswind

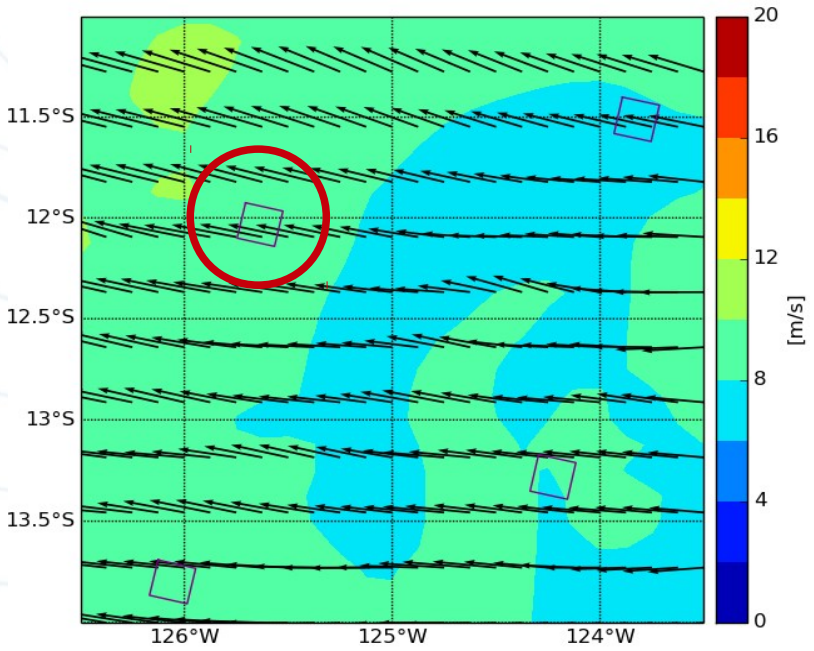
Upwind

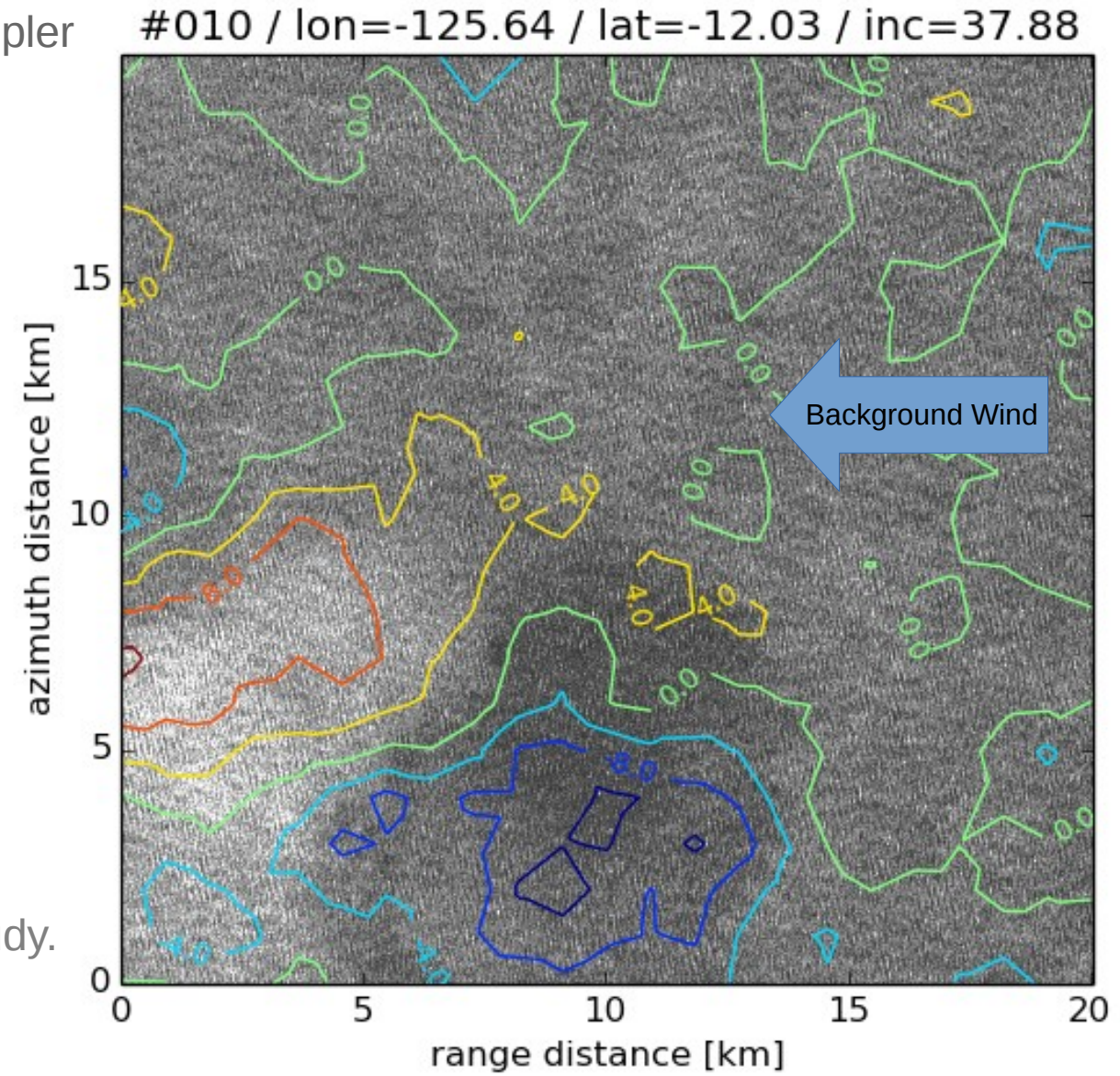




Inside the rain cells, Doppler & NRCS variation are consistent
They can be used together for wind vector inversion, divergence estimate

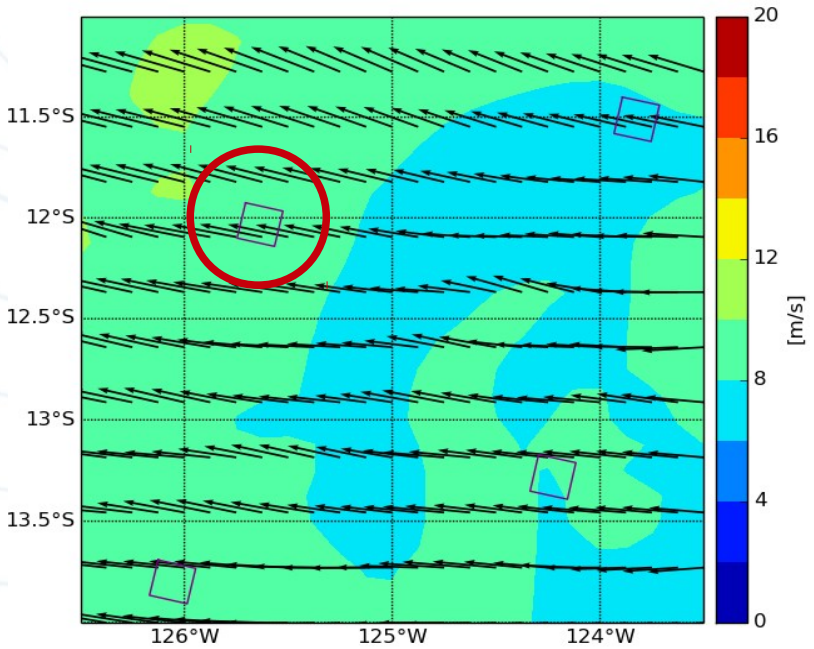
Downdraft, Wave mode, NRCS & Doppler

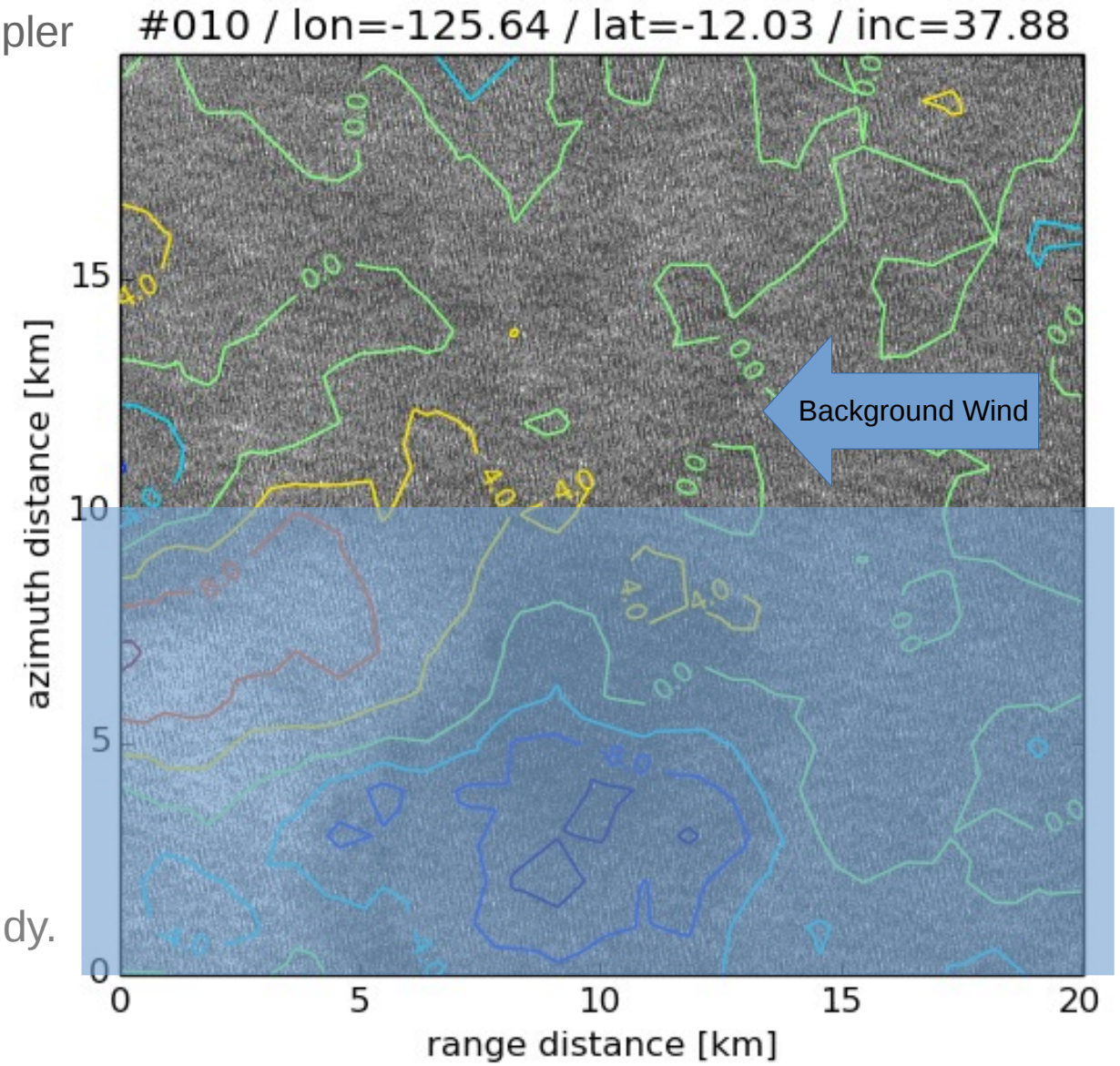




- Imagette #10 is considered for this study.
- Incidence angle is 37.88 degrees
- Polarization is HH
- Wind is blowing in range direction

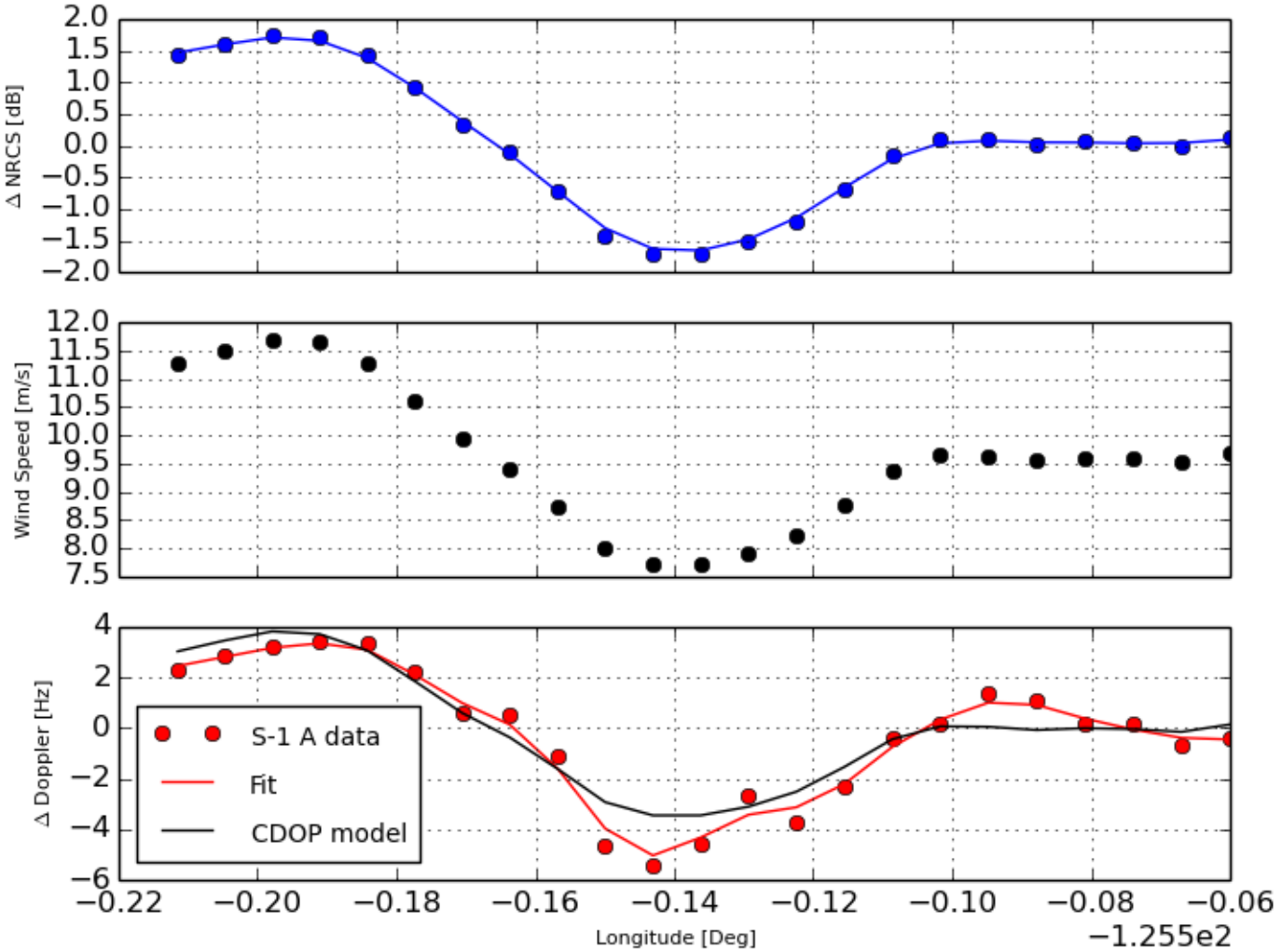
Downdraft, Wave mode, NRCS & Doppler





- Imagette #10 is considered for this study.
- Incidence angle is 37.88 degrees
- Polarization is HH
- Wind is blowing in range direction

Downdraft, Wave mode, NRCS & Doppler



wind speed variations retrieved from NRCS for a constant wind direction according to CMOD-5.

When applying these wind spee values into our Doppler GMF (CDOP), we are able to reproduce the Doppler variation inside the rain cell.

This confirms that both NRCS and Doppler are affected by win effect

Conclusions

- Sentinel-1 A L1 products are now fully qualified according to ESA criteria.
- Sentinel-1 A acquisition plan should allow a significant amount of dual-polarization data in Extended Wide or Interferometric Wide Swath.
- Dedicated site to allow acquisitions in Dual-Pol EW during the hurricanes period over West Atlantic has been requested to ESA via Sentinel-1 MPC.
- NESZ for Extended Wide Swath is
  - Better than -26 dB
  - Better than -29 dB (RS-2 Dual-Pol) for medium incidence angles (~25-33 deg)
  - Better than -32 dB for large incidence angles.
- Preliminary study shows that Sentinel-1 A data acquired in EW mode enables to describe the expected (from RS-2 experience) behaviour of CP NRCS with respect to incidence angles and wind speed - for light to moderate wind.
- GPM and Sentinel-1 A co-existence offers a unique potential to study NRCS at High resolution with respect to rain in both co- and cross-polarization.
- Doppler is encouraging. Work needs to be done before any further geophysical exploitation.
- Sentinel-1 B will follow soon (2016) with the same capabilities !

→ Next C-Band SCAT may certainly benefit from Sentinel-1 constellation