



Waves

Near Surface Wind

Internal Waves

Surface Current

Ship detection

Oil spill

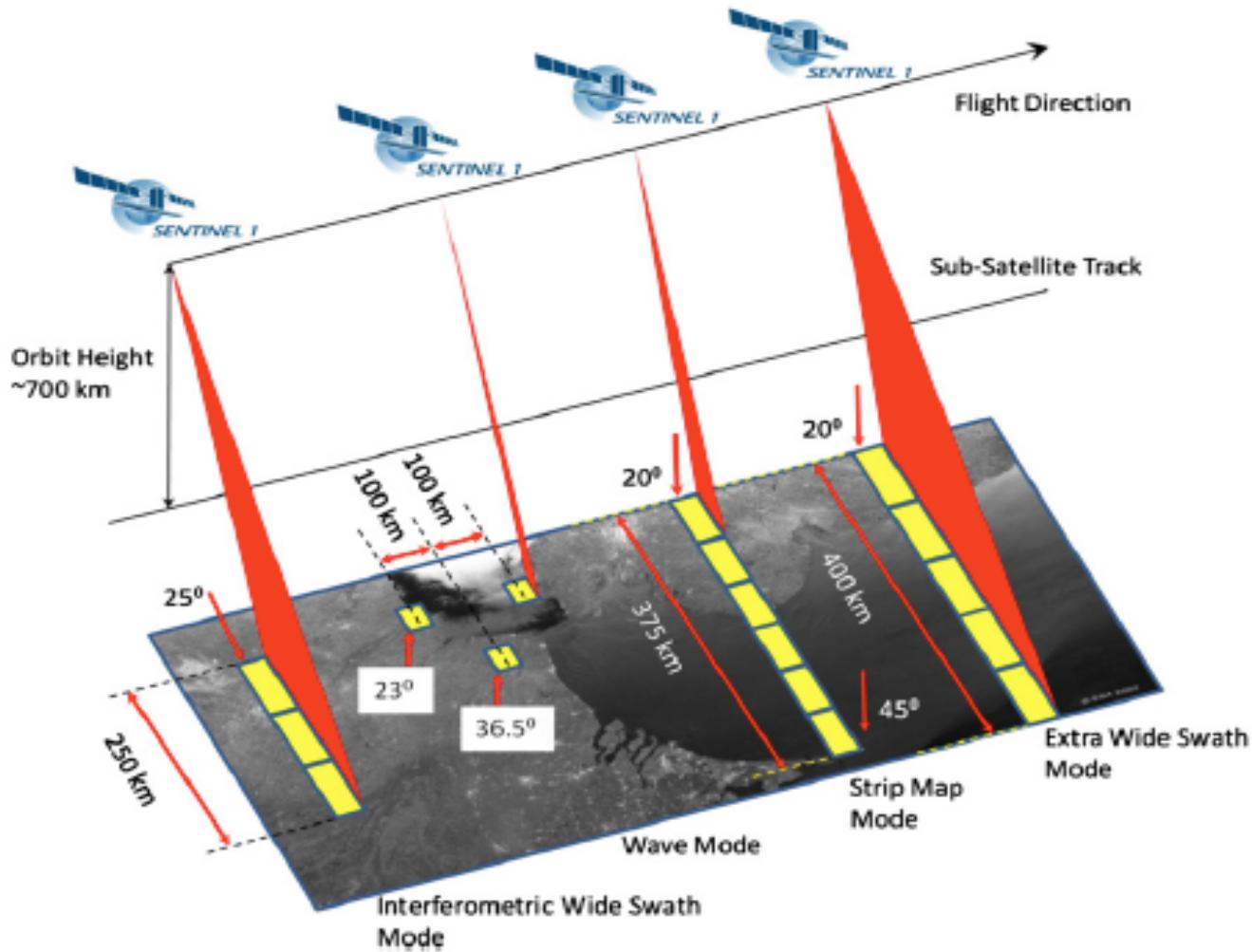
Sea ice

Sentinel-1 Launched 3 April 2014



- Air-sea interaction, thermodynamics and mixing in the atmospheric boundary layer – upper ocean mixed layer;
 - Wind field interaction and coupling to surface waves, current, Stokes drift, Ekman current and mixing – momentum exchange between the air-upper ocean;
 - Physical based explanation for the surface roughness at all scales from cm to 100 of km.
-
- SAR imaging by Bragg scattering, specular and wave breaking in response to cm waves, coupled with modulation by longer waves, wind field variations and surface current variations and damping material. SAR is unique for this!!!

Sentinel-1 Operating Modes for Wind-Wave-Current detection





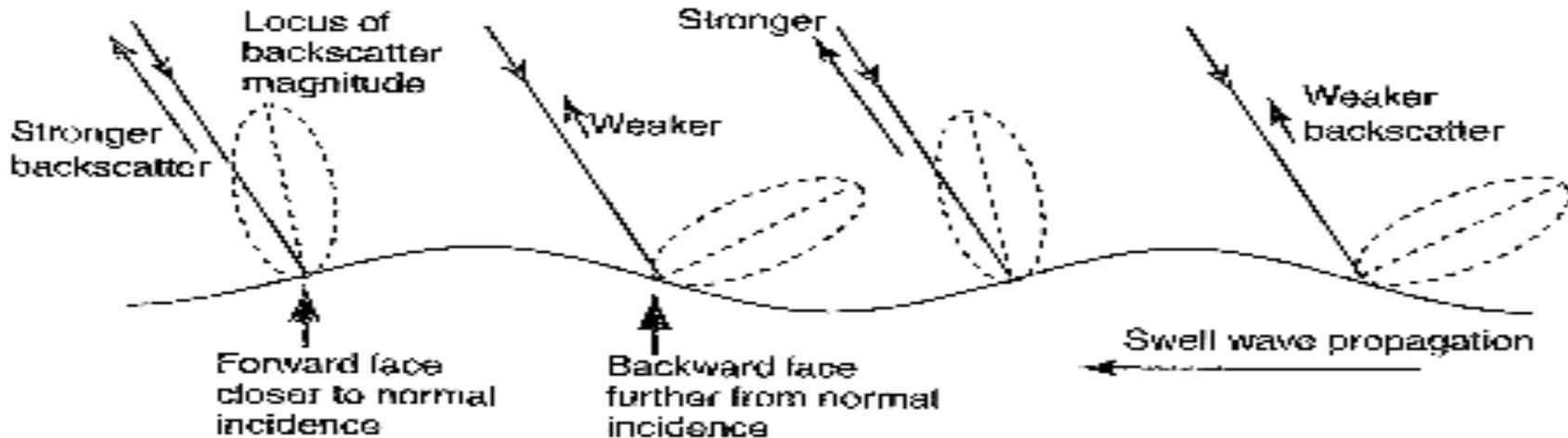
Parameter	Interferometric Wide-swath mode (IW)	Wave mode (WV)
Polarisation	Dual (HH + HV, VV + VH)	Single (HH, VV)
Access (incidence angles)	31°–46°	23°–37° (mid incidence angle)
Azimuth resolution	<20 m	<5 m
Ground range resolution	<5 m	<5 m
Azimuth and range looks	Single	Single
Swath	>250 km	Vignette 20×20 km
Maximum NESZ	–22 dB	–22 dB
Radiometric stability	0.5 dB (3σ)	0.5 dB (3σ)
Radiometric accuracy	1 dB (3σ)	1 dB (3σ)
Phase error	5°	5°
Parameter	Strip Map mode (SM)	Extra Wide-swath mode (EW)
Polarisation	Dual (HH + HV, VV + VH)	Dual (HH + HV, VV + VH)
Access (incidence angles)	20°–47°	20°–47°
Azimuth resolution	<5 m	<40 m
Ground range resolution	<5 m	<20 m
Azimuth and range looks	Single	Single
Swath	>80 km	>410 km
Maximum NESZ	–22 dB	–22 dB
Radiometric stability	0.5 dB (3σ)	0.5 dB (3σ)
Radiometric accuracy	1 dB (3σ)	1 dB (3σ)
Phase error	5°	5°

SAR CONTRIBUTION TO MARINE MONITORING

Operational Surveillance	Emerging new Operational application	Routine Product and partly used in NWP	Research Dominated
Ship detection Oil spill detection Sea Ice Shallow water Bathymetry	Wind field retrievals	Ocean Waves and Ocean Spectra	Surface current fronts and eddies Internal Waves Atmospheric boundary layer Processes Film damping

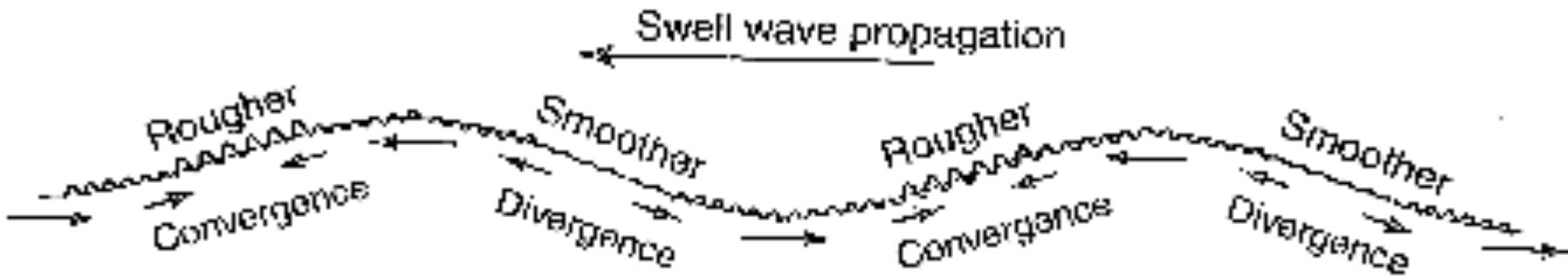
- Longer waves locally modify the exact plan of incidence to produce a contrast corresponding to the local change in cross section
 - **Tilt Modulation** : a priori knowledge of the gradient of the relative cross section as a function of the small incidence angle deviation

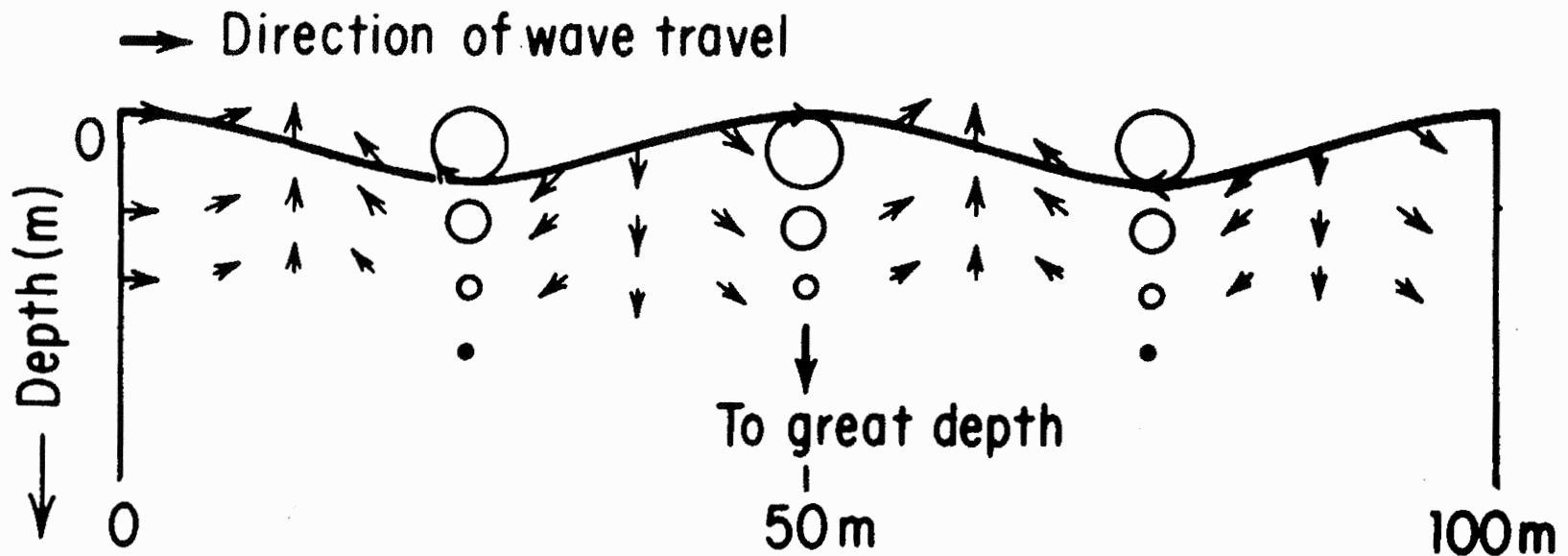
$$T_t(k) = \left(\frac{1}{\sigma^0} \cdot \frac{\partial \sigma}{\partial \theta} \right)_{\theta = \theta_0} \cdot ik_r$$



→ **Hydrodynamic Modulation** : a priori knowledge of the gradient of the relative cross as a function of the phase of the long wave

$$T_h(k) = \left(\frac{1}{\sigma^0} \cdot \frac{\partial \sigma}{\partial \varphi} \right) \cdot ik_r$$



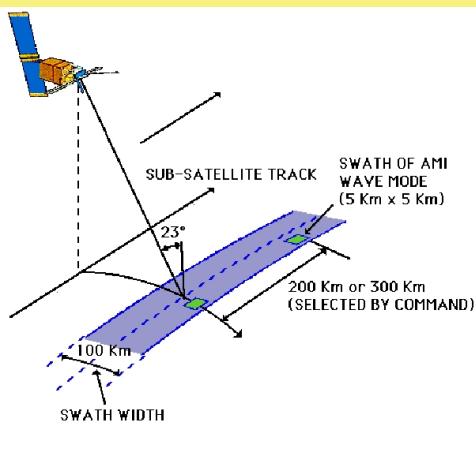


After Neumann and Pierson

- Bragg scattering: NRCS \propto Bragg wave intensity; relation depends on incidence angle
- Longer waves modulate the NRCS
 - Tilt modulation affects incidence angle
 - Hydrodynamic modulation affects Bragg wave energy



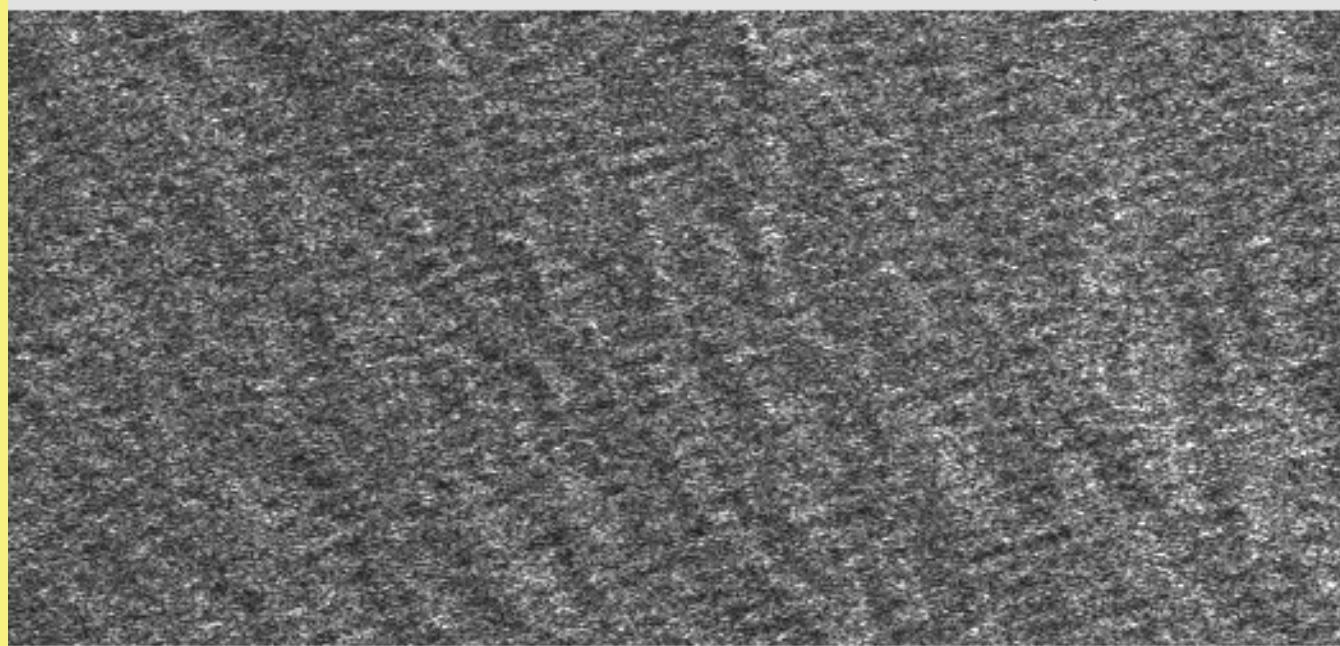
Courtesy Roland Romeiser

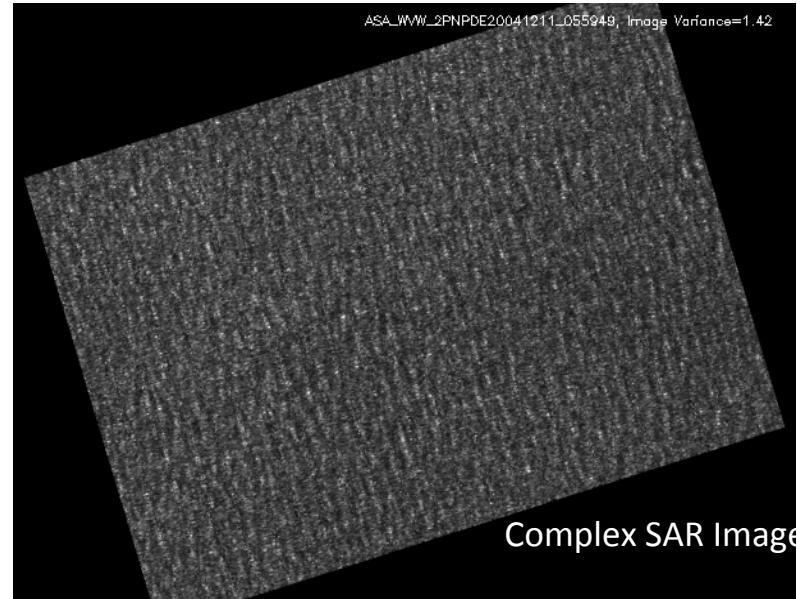
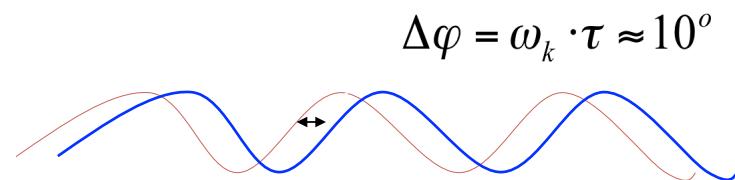
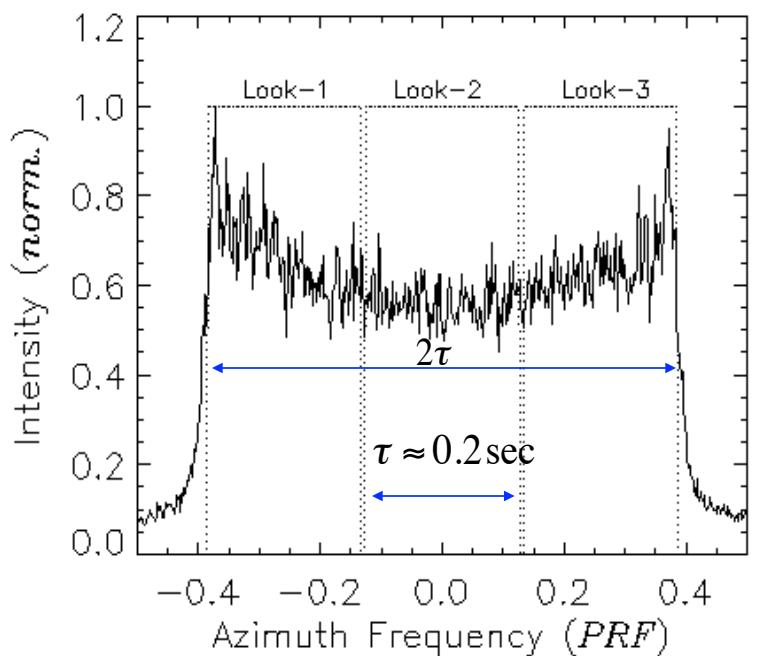


Sensor: ERS-2

Processor: BSAR@IMF

© ESA/DLR 2000

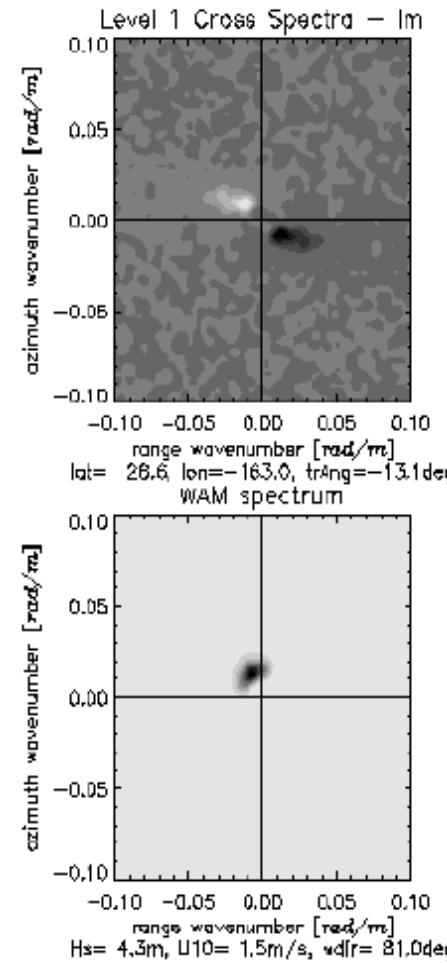
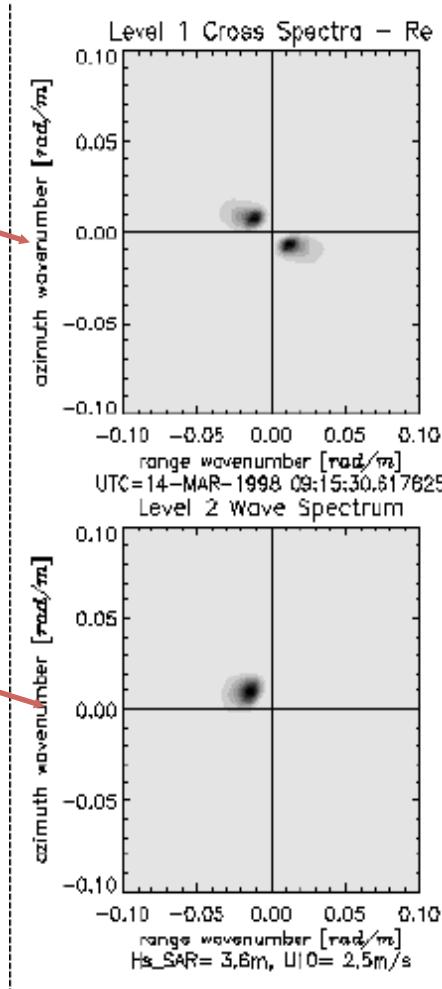




-Look Extraction
-Intensity Detection

phase term resolves wave propagation direction

SAR image
cross-spectra

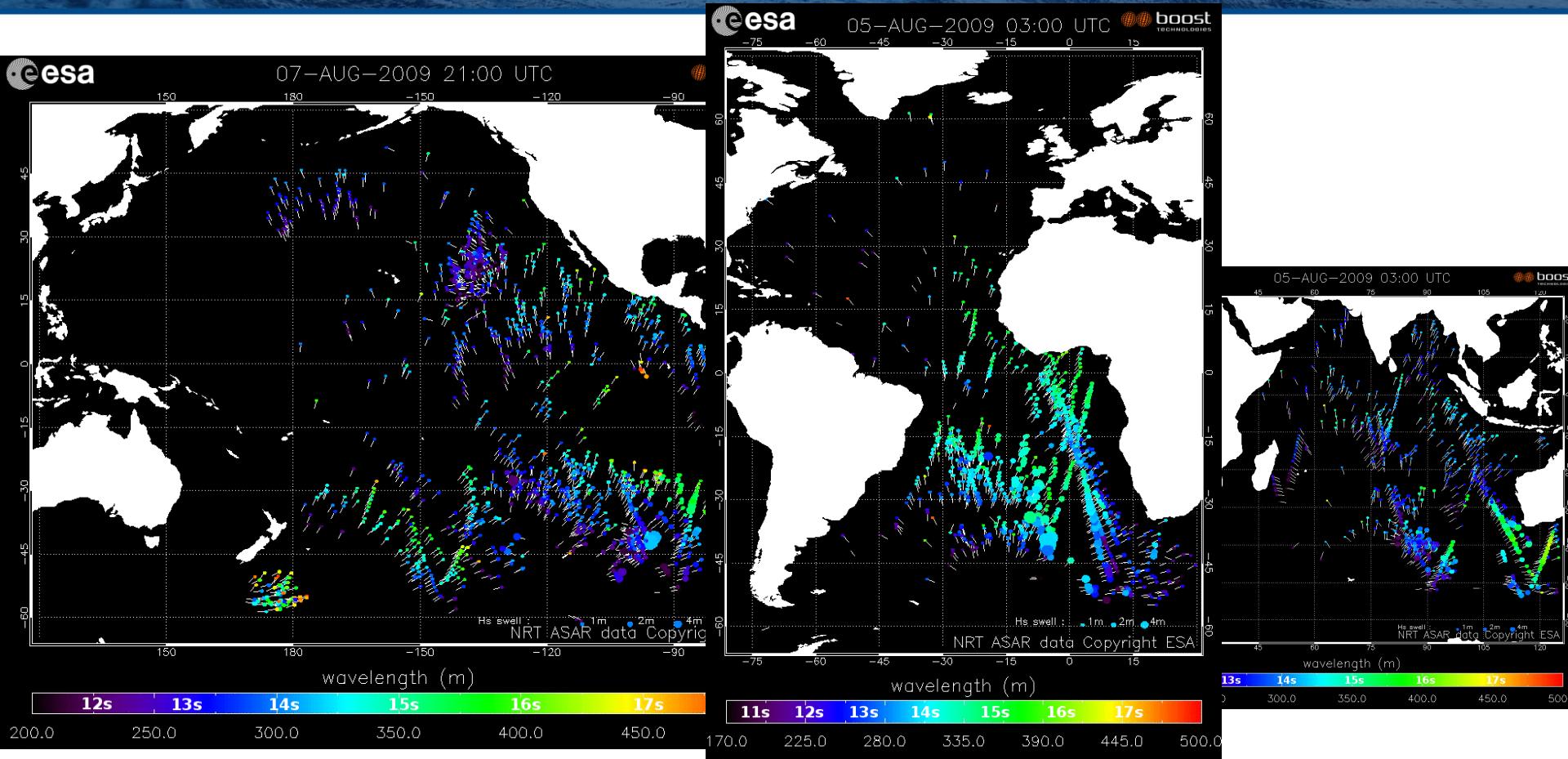


SAR ocean
wave spectra

WAM
(for comparison)

Courtesy NORUT

Swell propagation

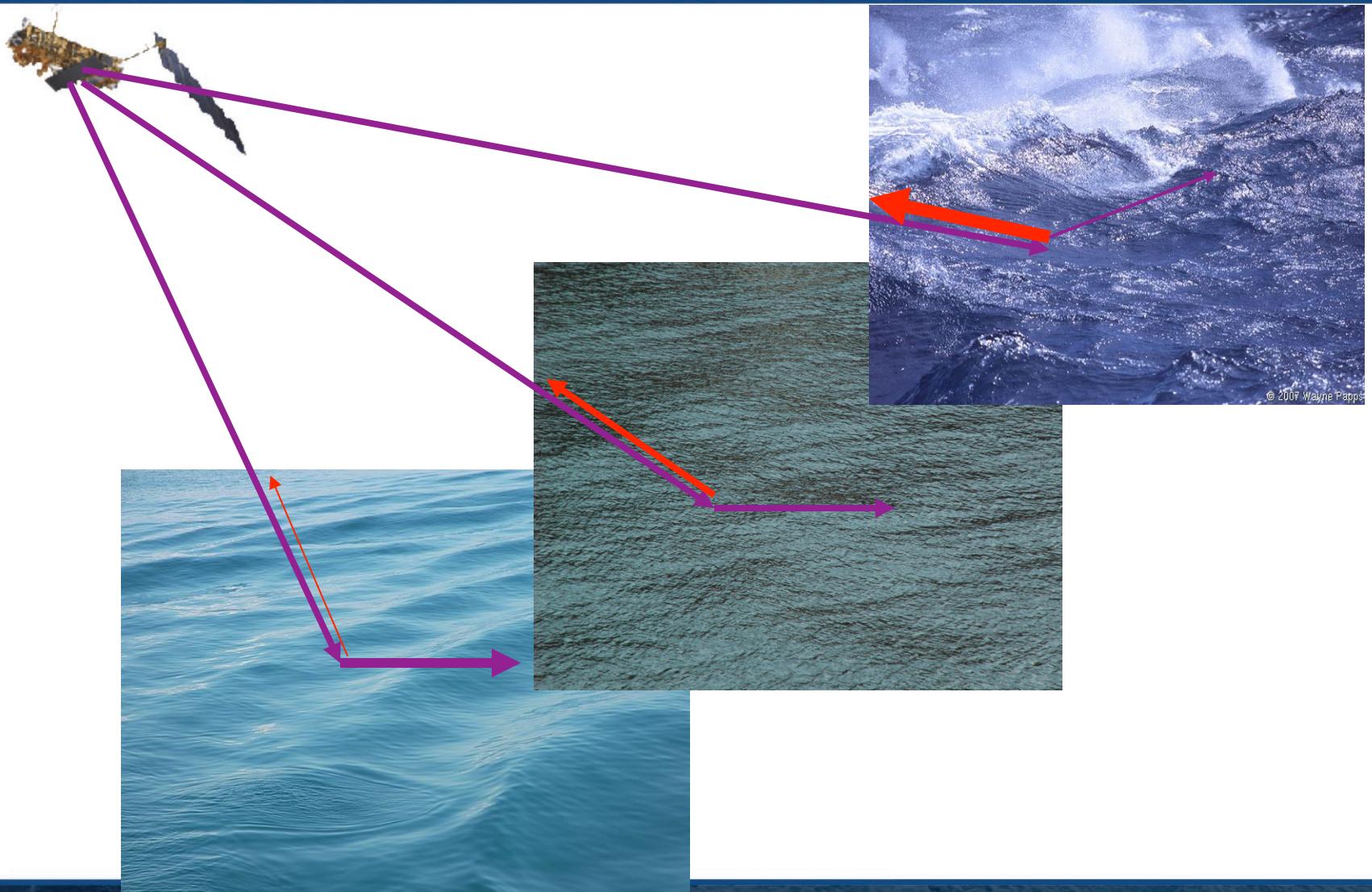


Courtesy Collard, Chapron (ESA WVC study) <http://soprano.cls.fr>

SAR CONTRIBUTION TO MARINE MONITORING

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Radar backscatter increases with wind speed



- Transmits a puls of microwave radiation
- Measures the fraction that comes back

$$P_r = (P_t/4\pi R^2) G (\sigma/4\pi R^2) A$$

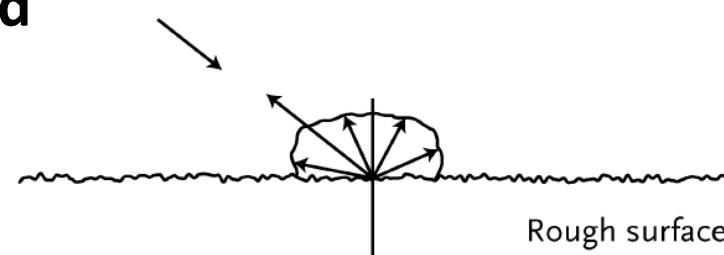
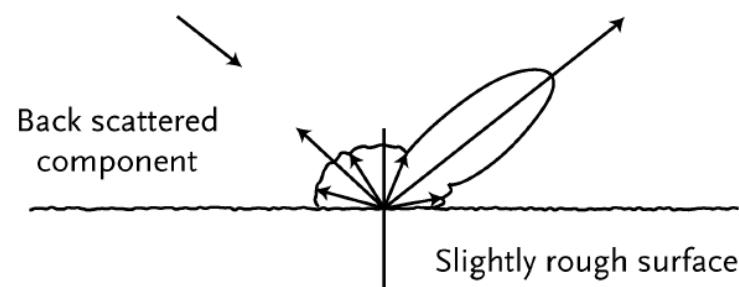
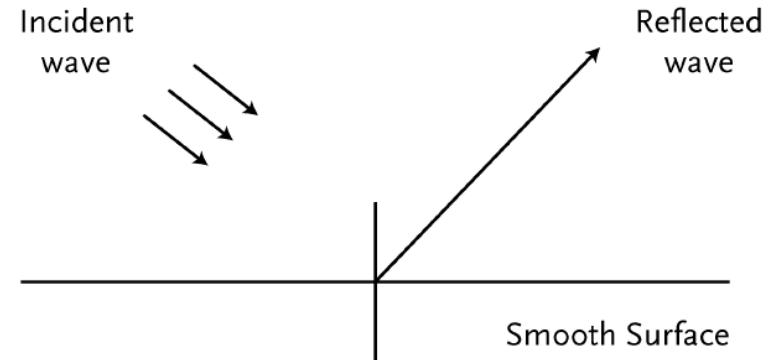
measured = incident x reflected

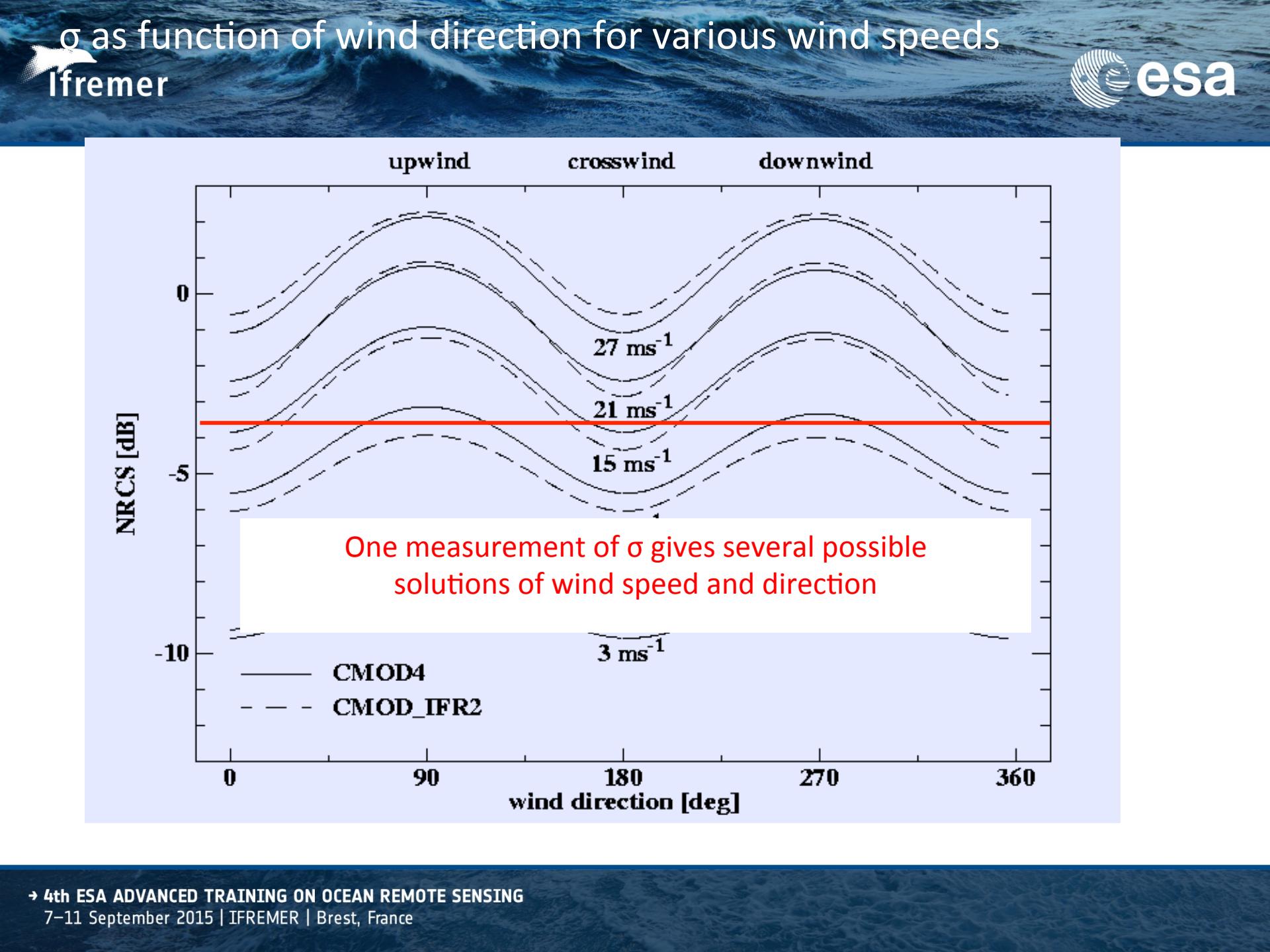
G = antenna gain, A = antenna area,

σ = radar cross section, R = range distance

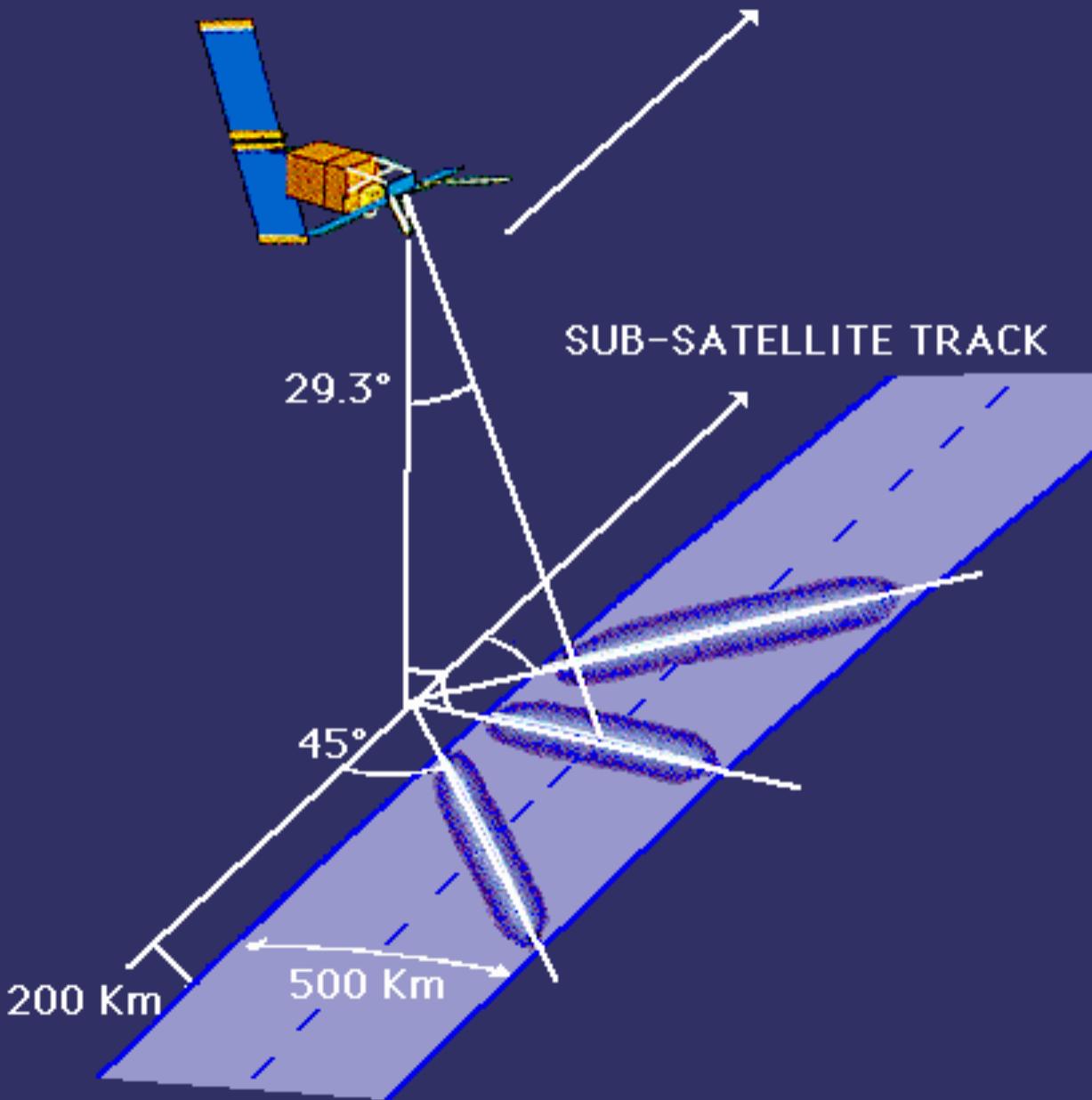
σ is a measure of the surface roughness

σ is well correlated with wind speed



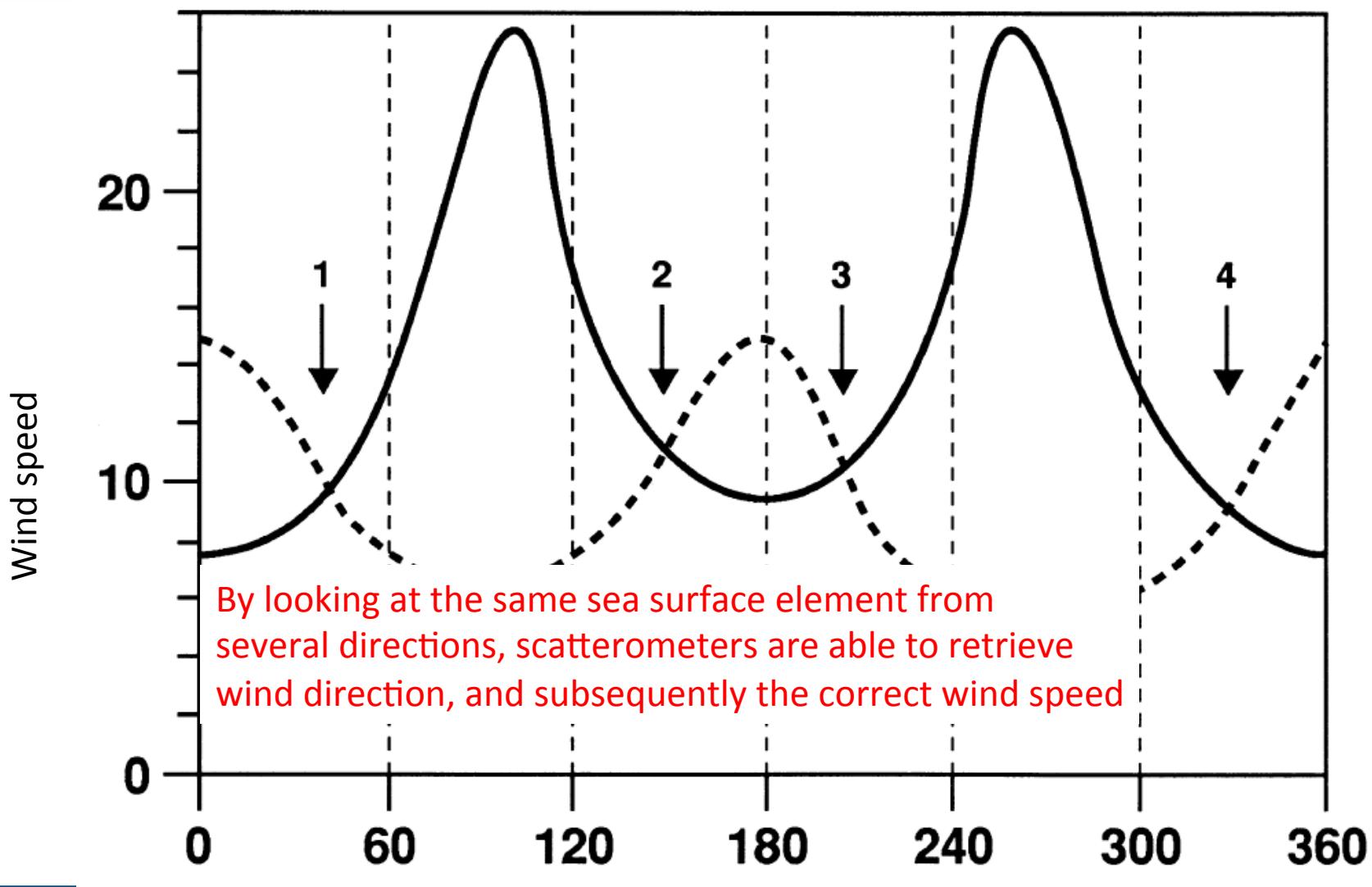


Wind Scatterometer Geometry

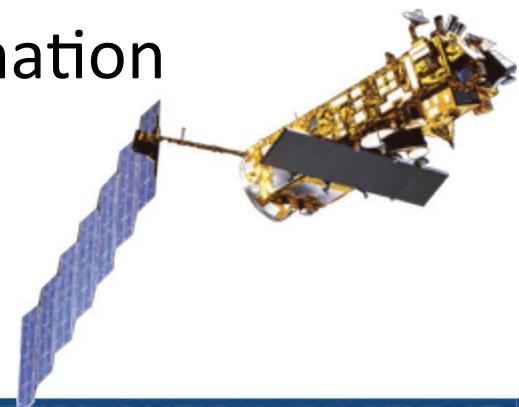


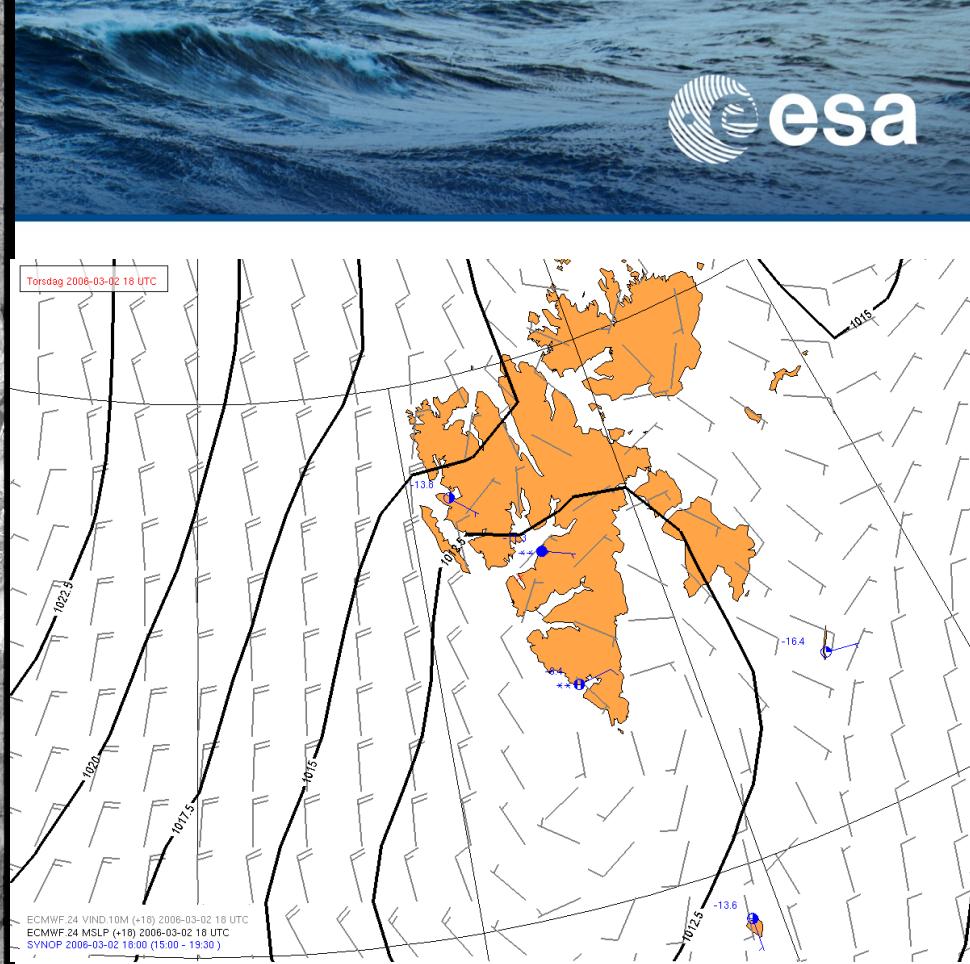
Scatterometers looks at the same spot from several angles to be able to retrieve both wind speed and direction

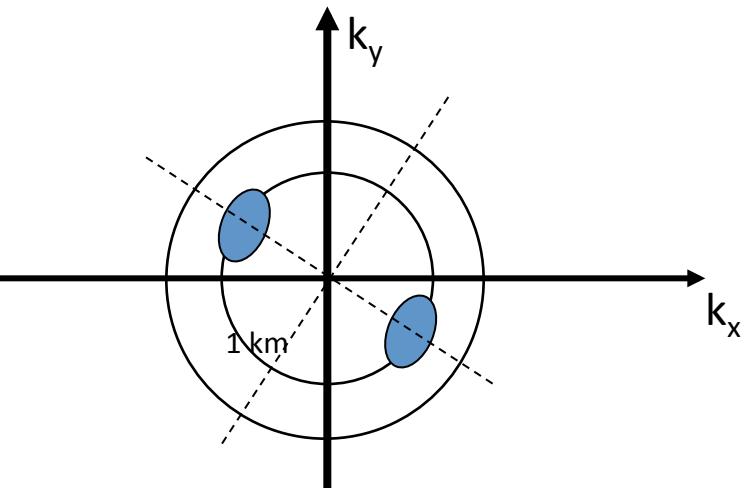
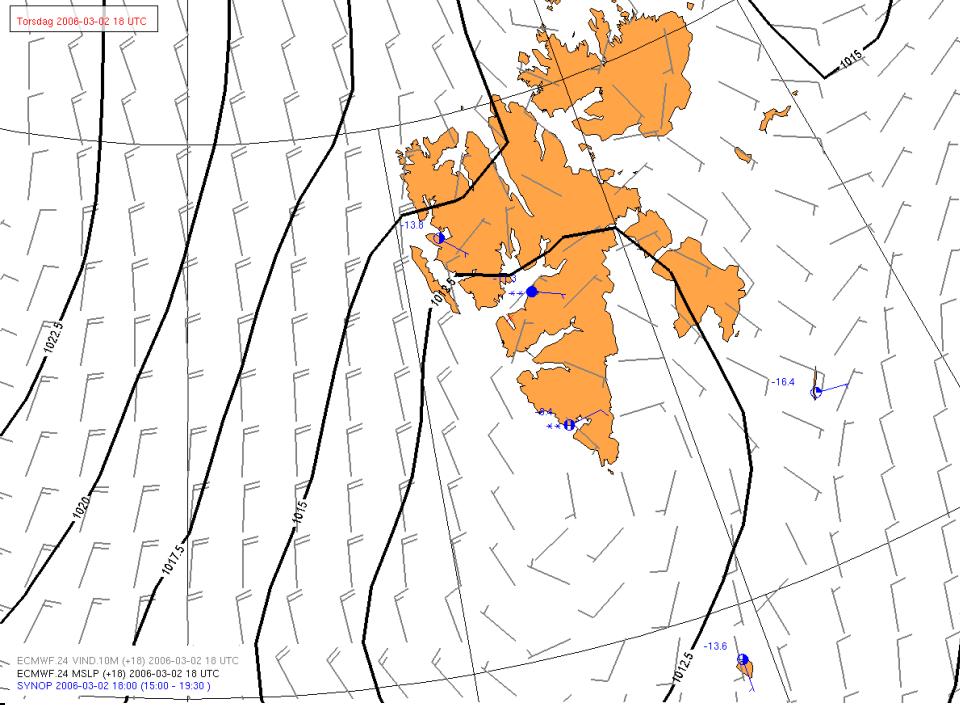
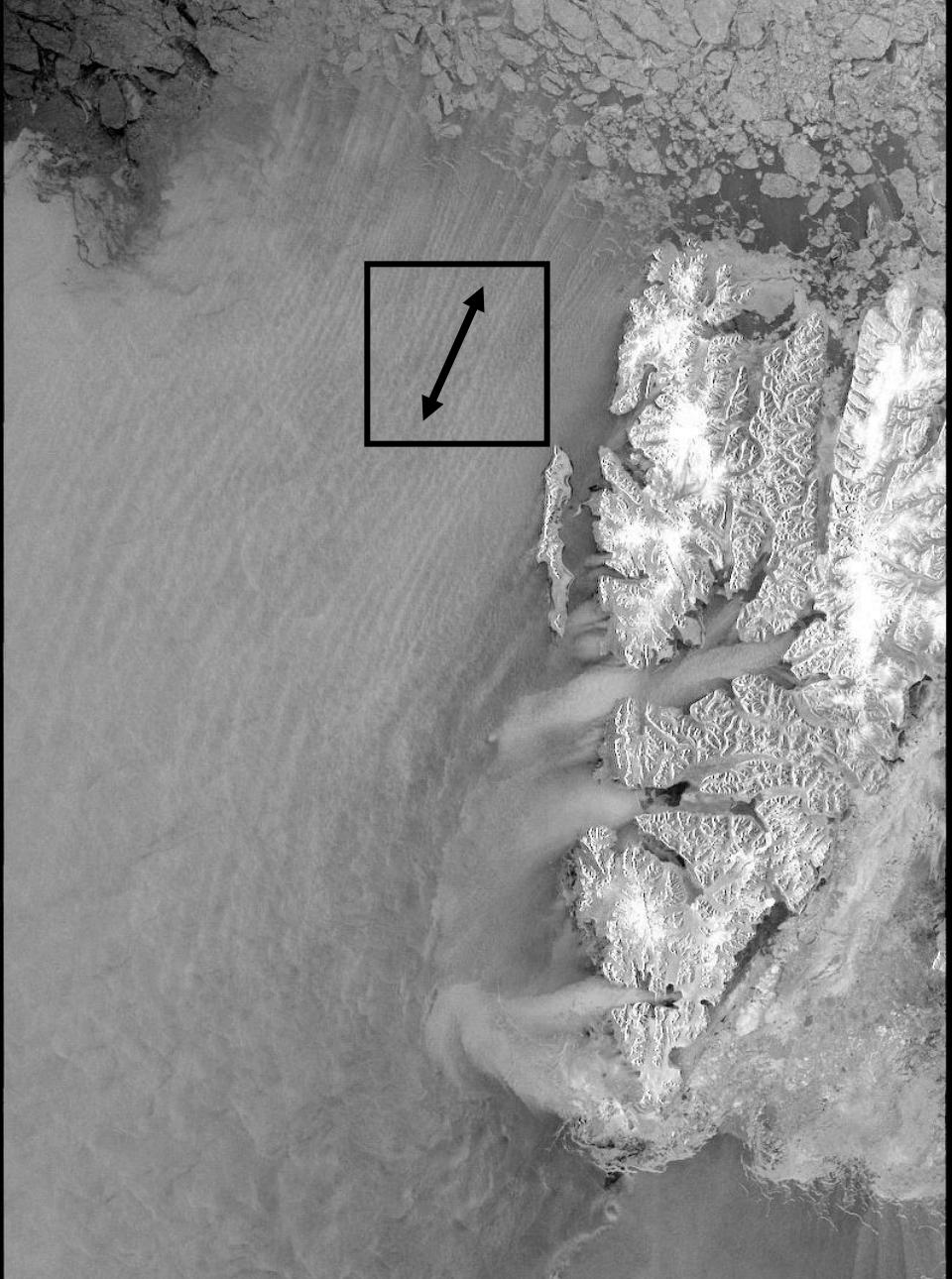
Wind Scatterometer geometry. The three Wind Scatterometer antennae generate radar beams 45° forward, sideways and 45° backwards across a 500 Km wide swath, 200 Km to the right of the sub-satellite track.

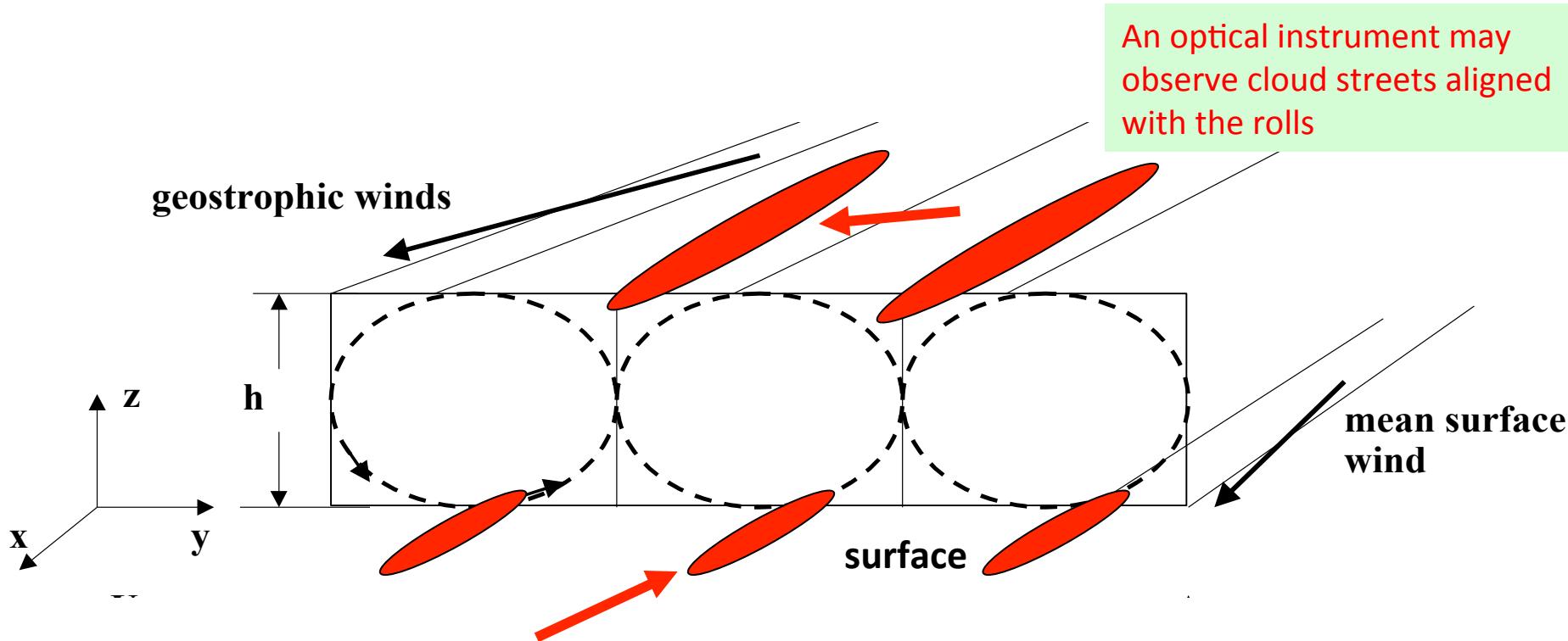


- Wind direction information must be taken from another source
 - Numerical model
 - Scatterometer (if colocated in time and space)
 - From wind streaks in the SAR-image
 - New resource: SAR Doppler information









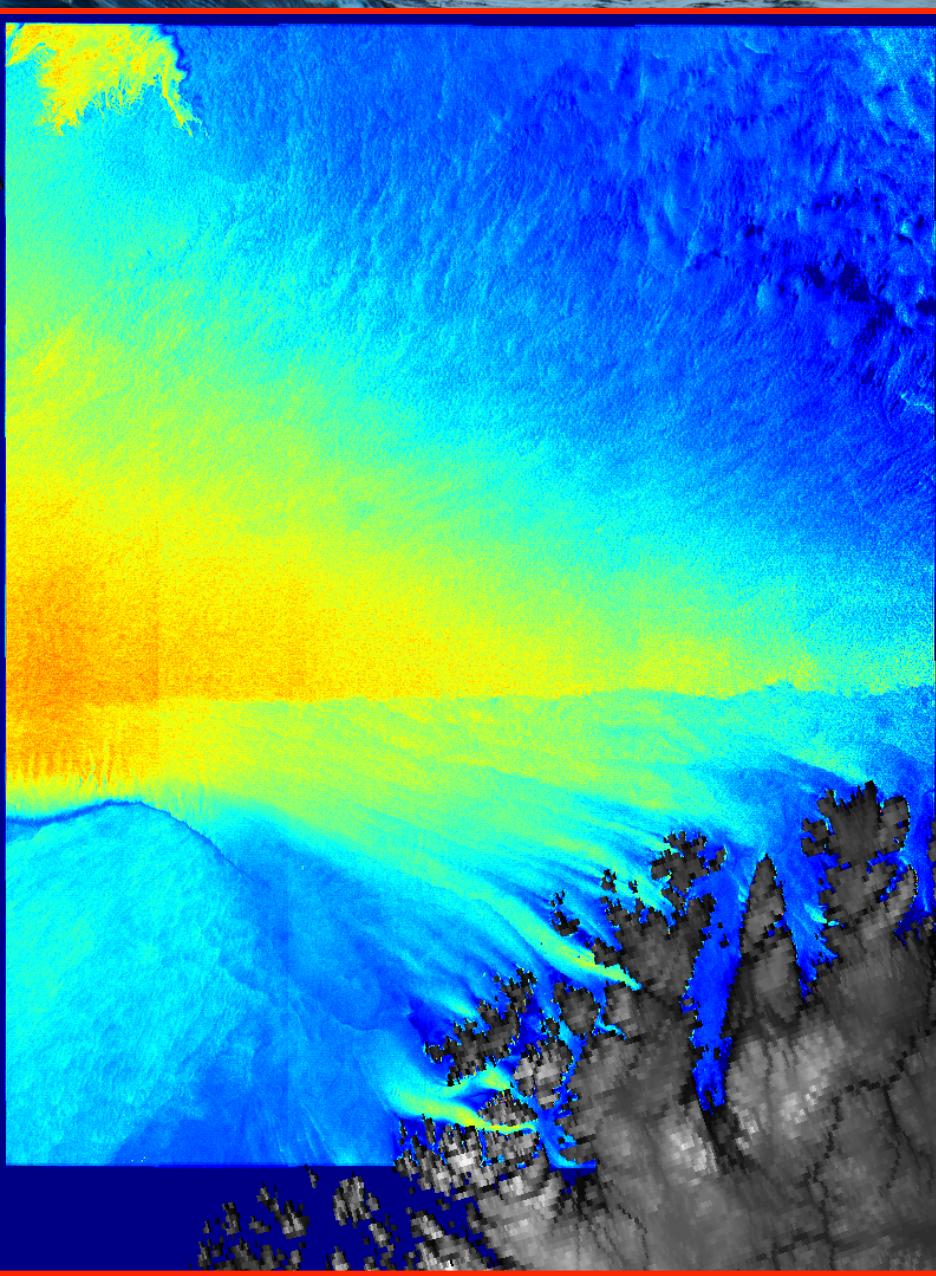
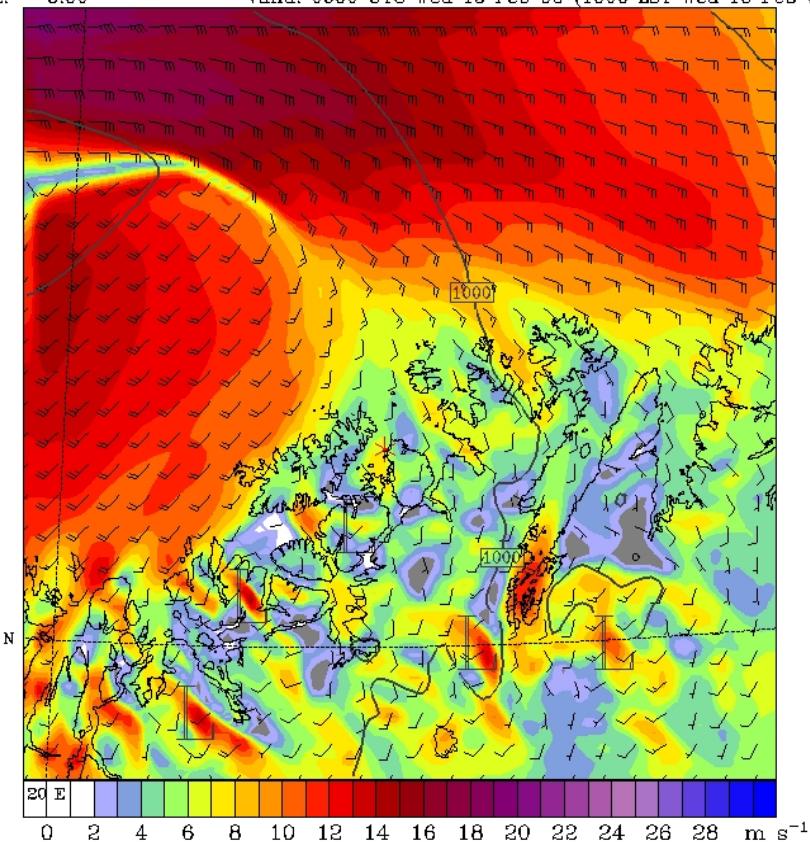


STORM WEATHER CENTER MM5 RUN

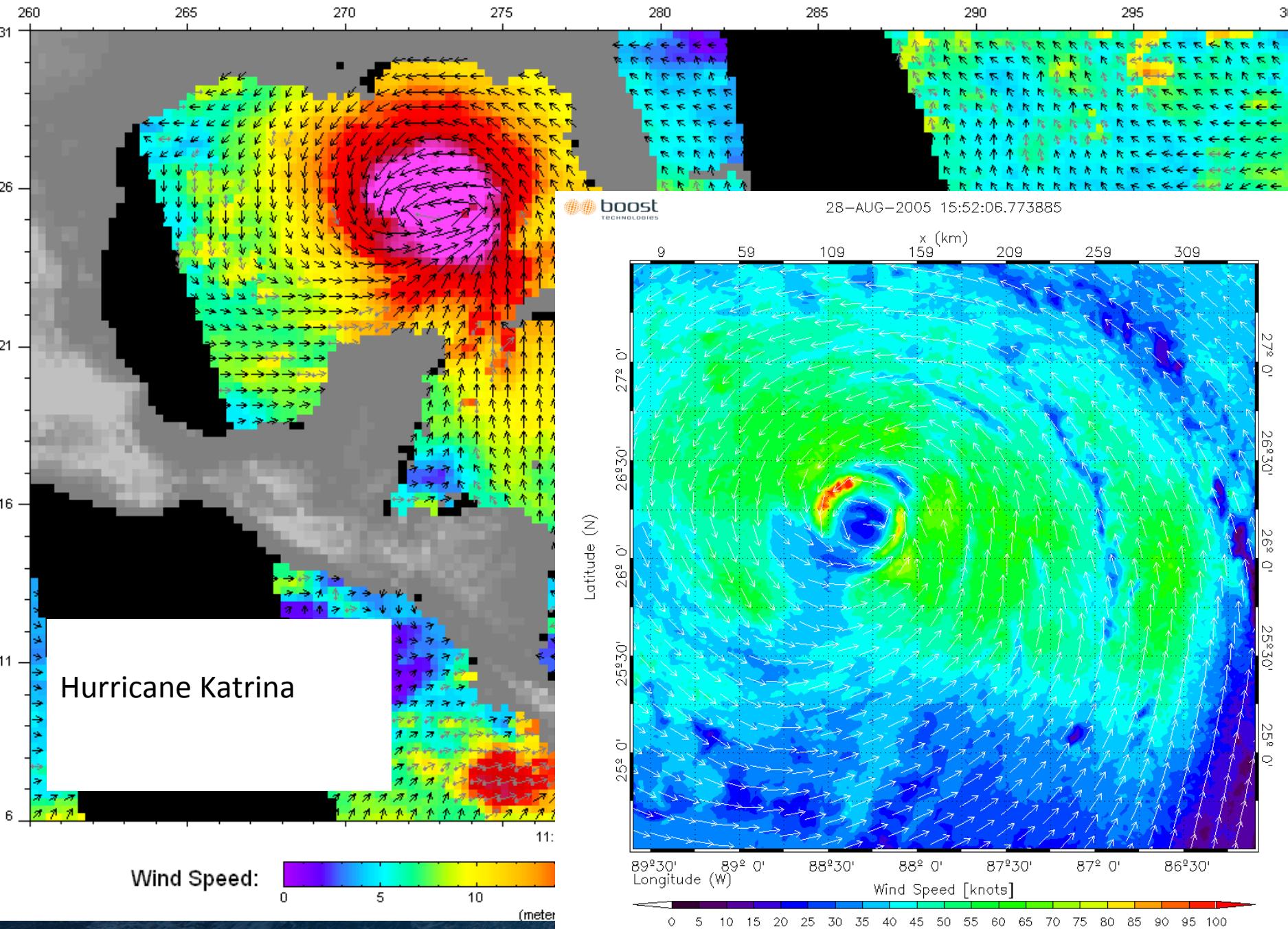
Fest: 9.00

Init: 0000 UTC Wed 15 Feb 06

Valid: 0900 UTC Wed 15 Feb 06 (1000 LST Wed 15 Feb 06)



QuikScat wind vectors: 2005/08/28 - morning passes - Gulf of Mexico

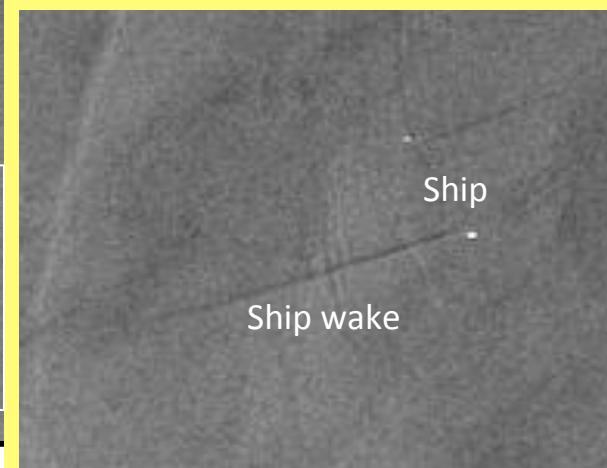
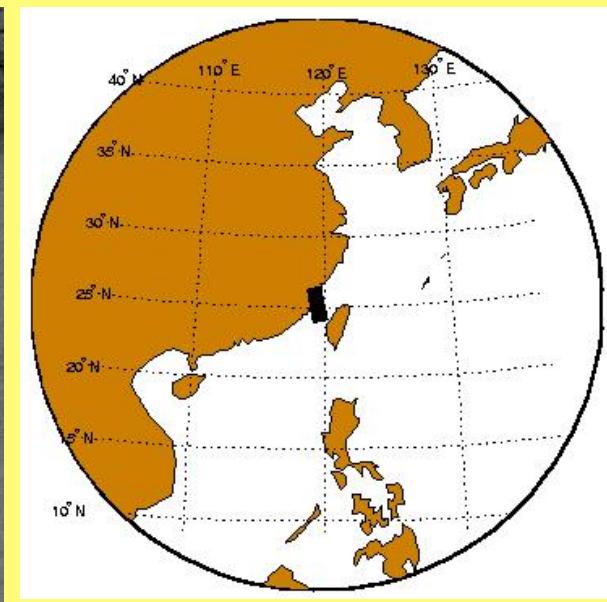
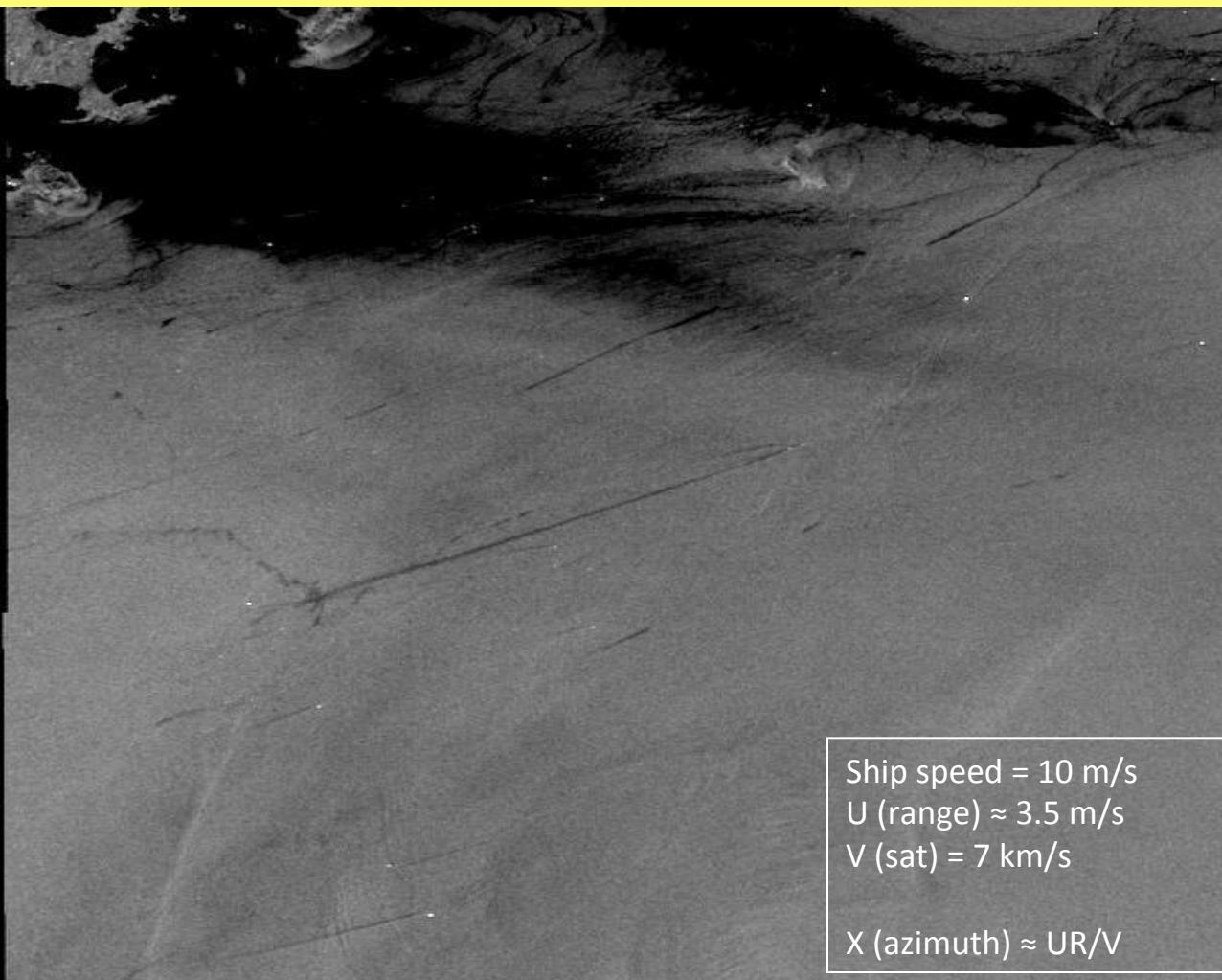


SAR CONTRIBUTION TO MARINE MONITORING

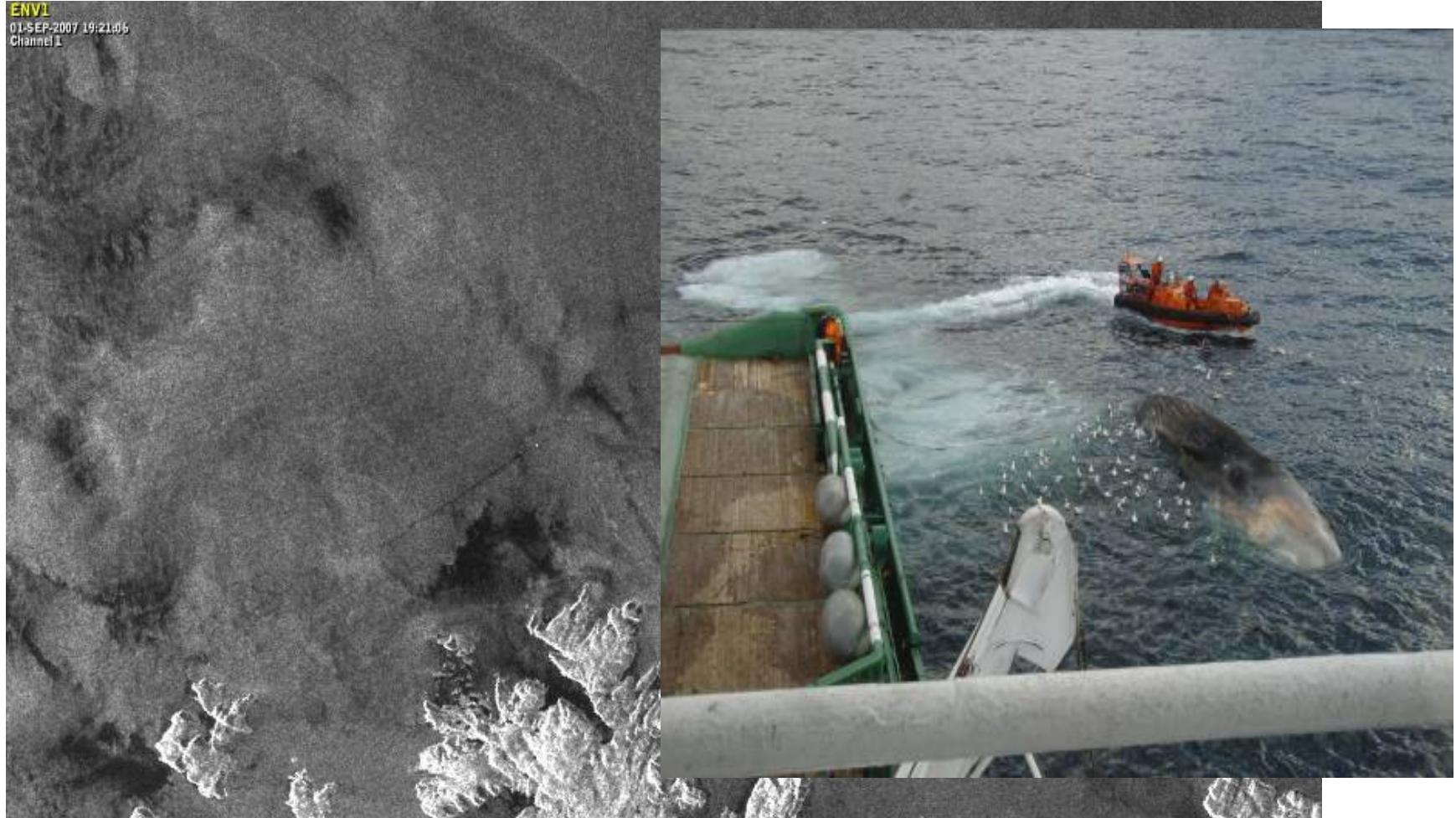
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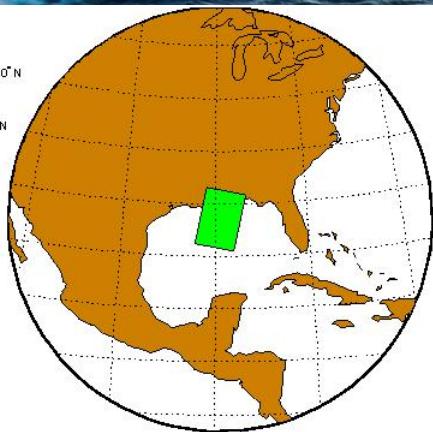


Ships and Ship Wakes - Oil spill?

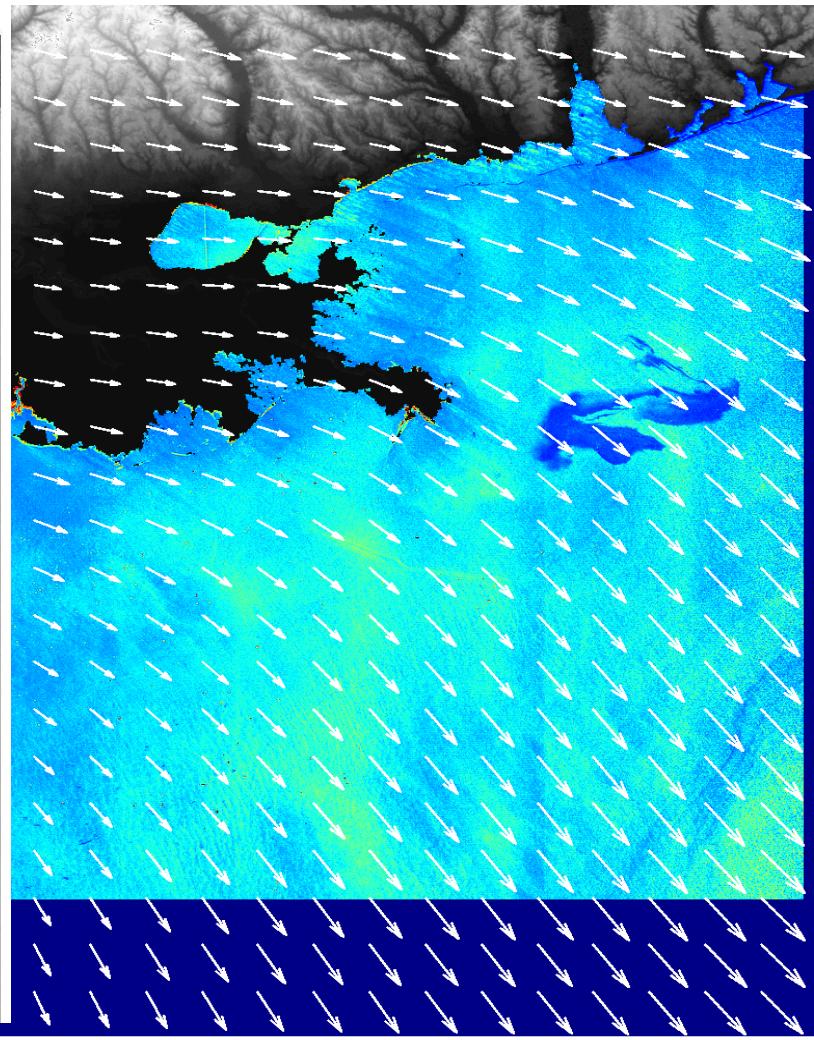
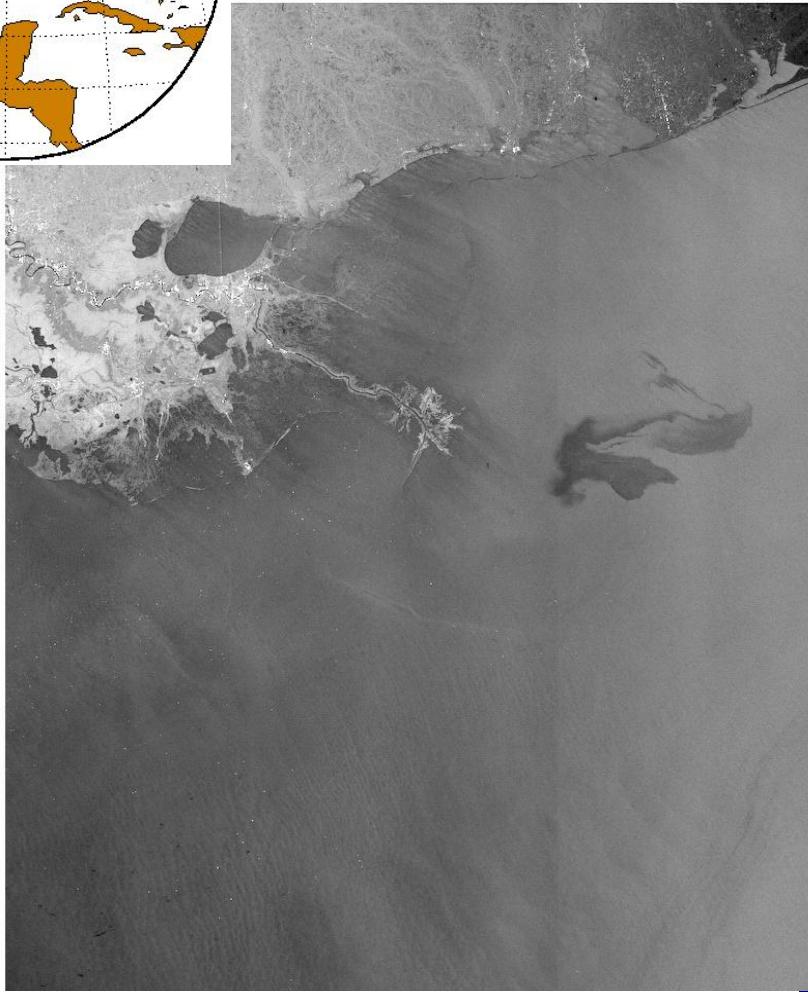


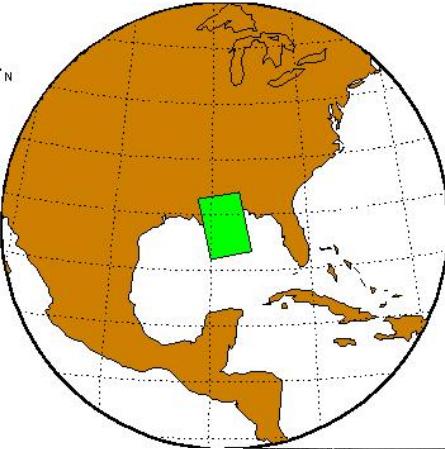
Black tail – but not always a real pollution



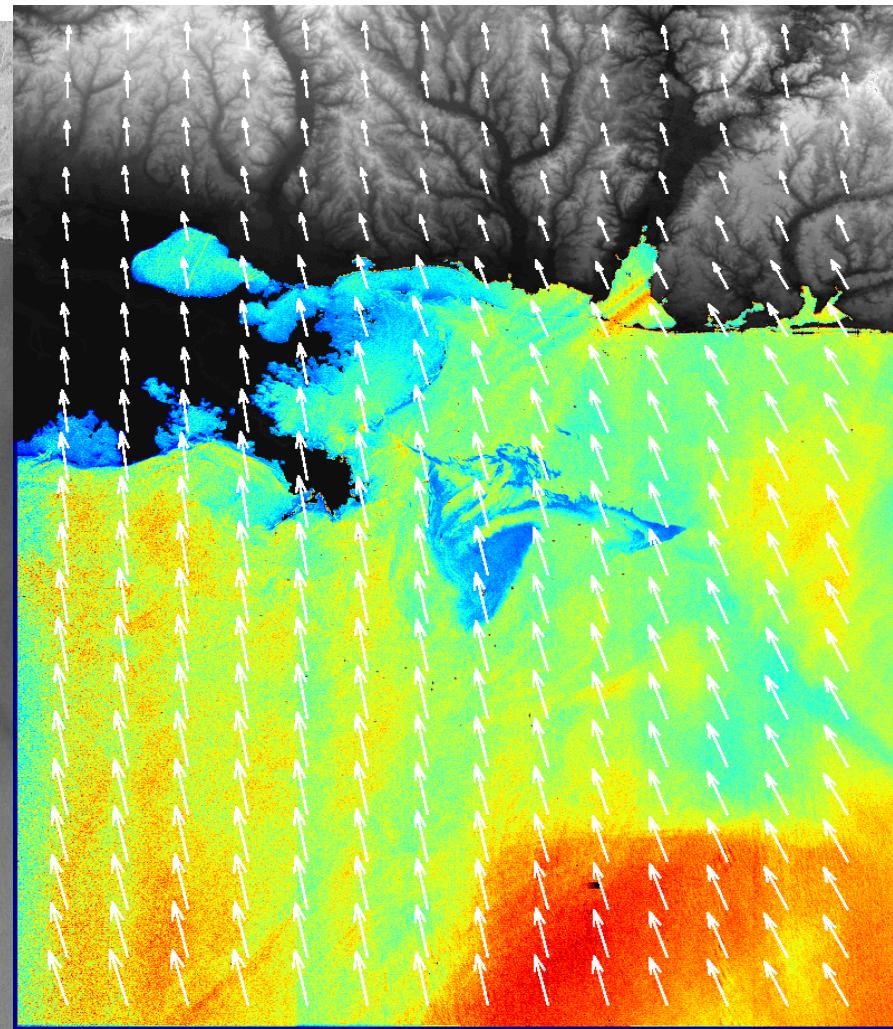
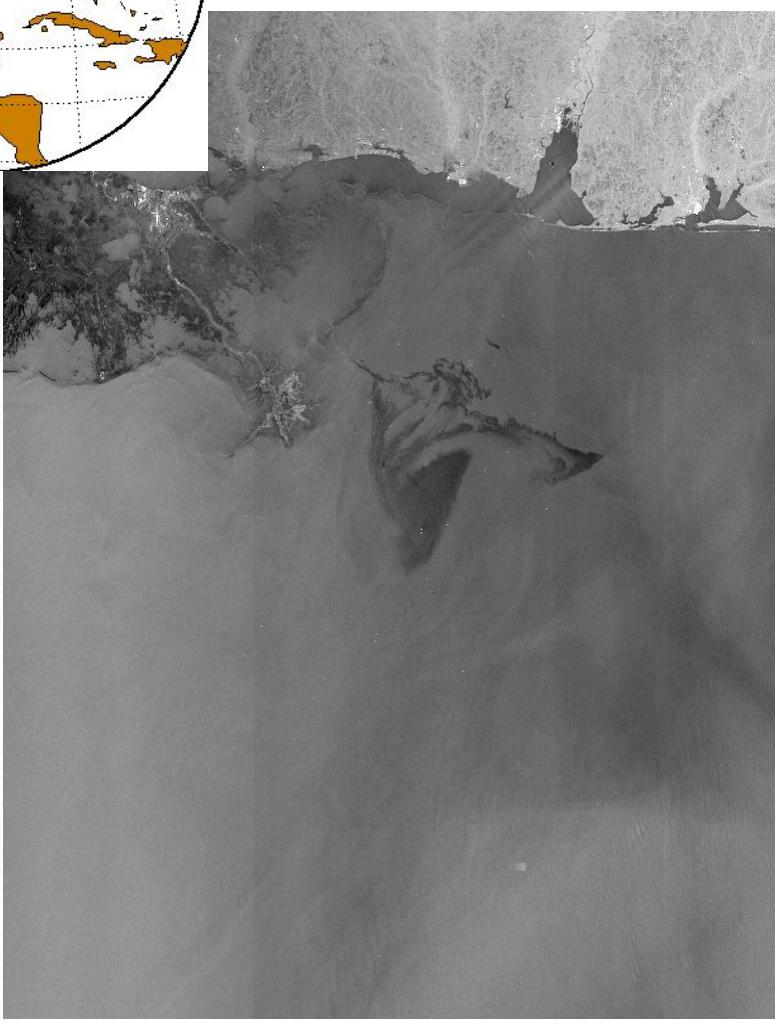


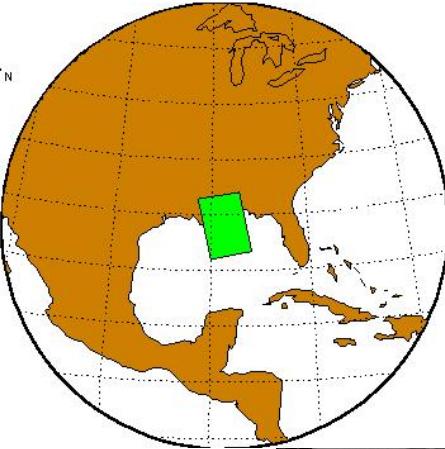
Oil spill in the Gulf of Mexico



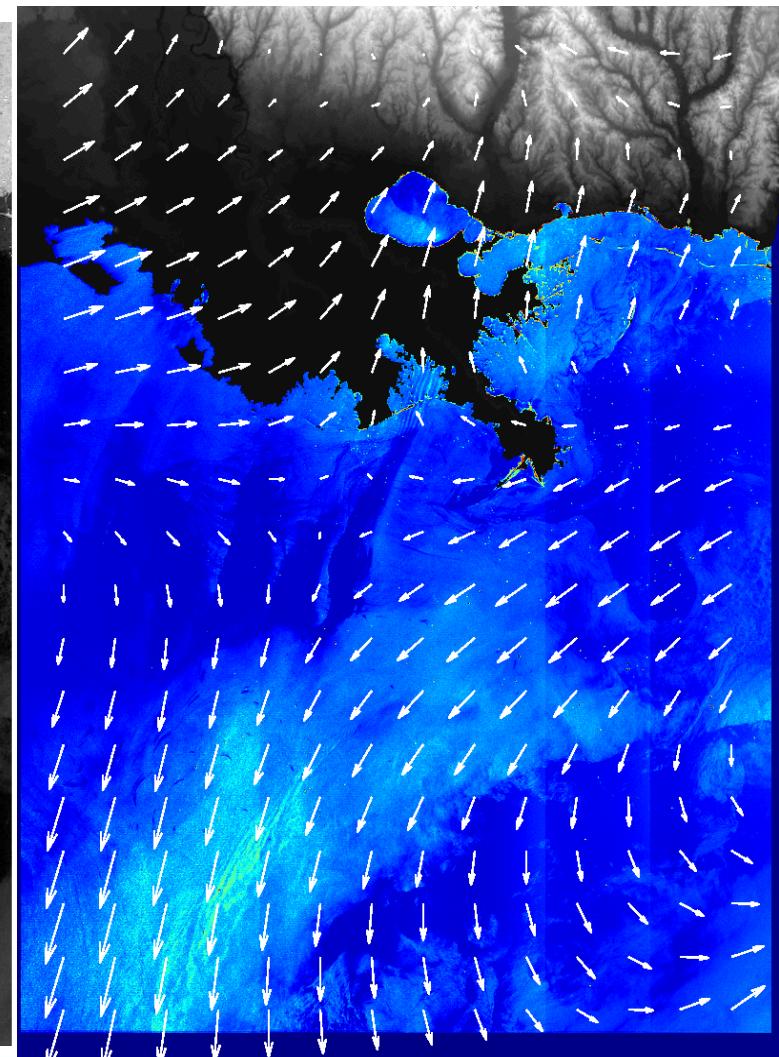
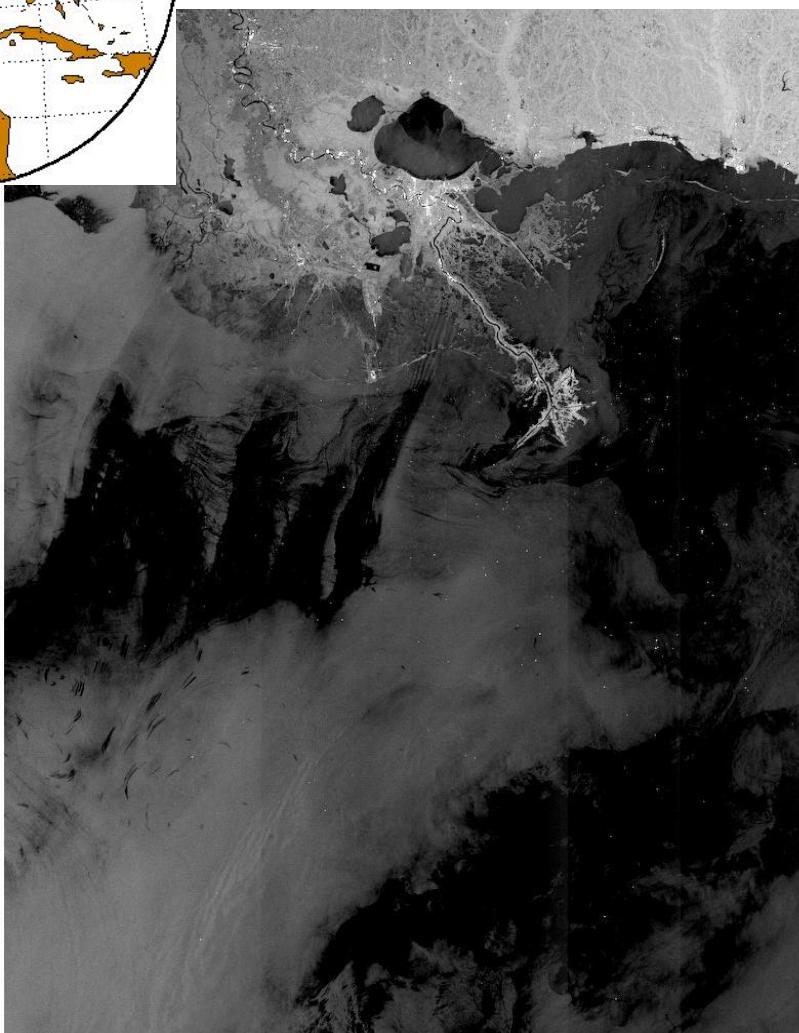


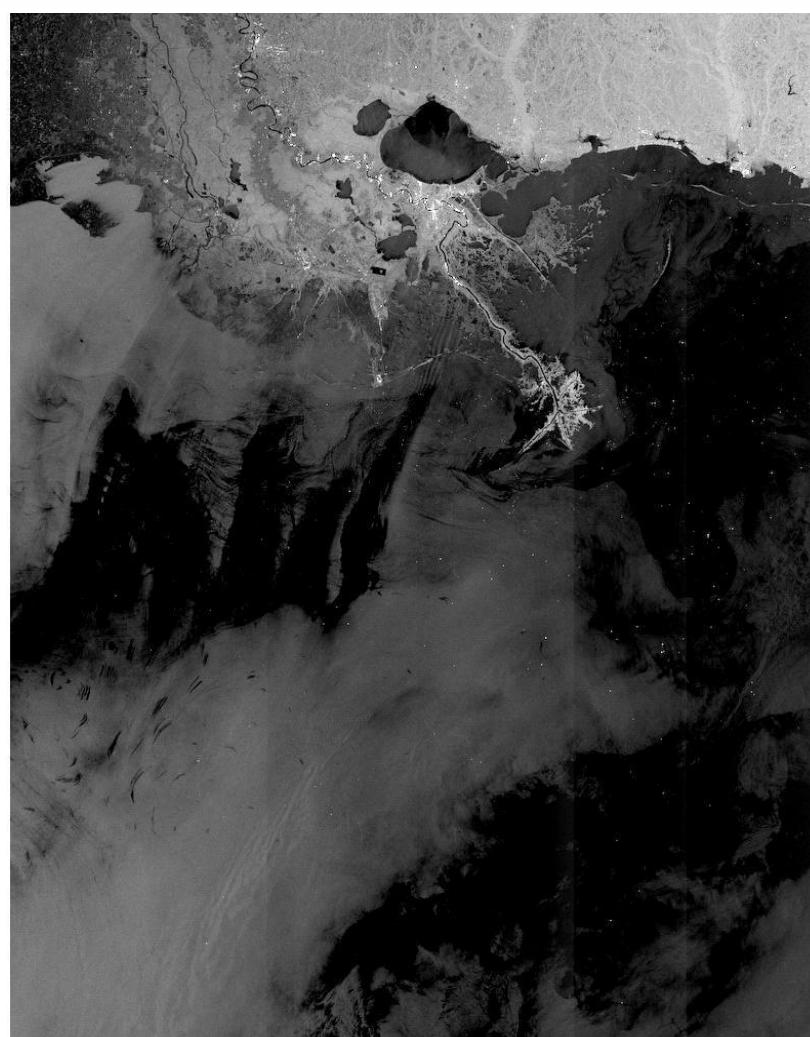
Oil spill in the Gulf of Mexico





Oil spill in the Gulf of Mexico





Quad-polarization SAR for
ocean feature classifications

Decompose images in
Pol diff., Pol ratio, non-polarized,
Cross polarized

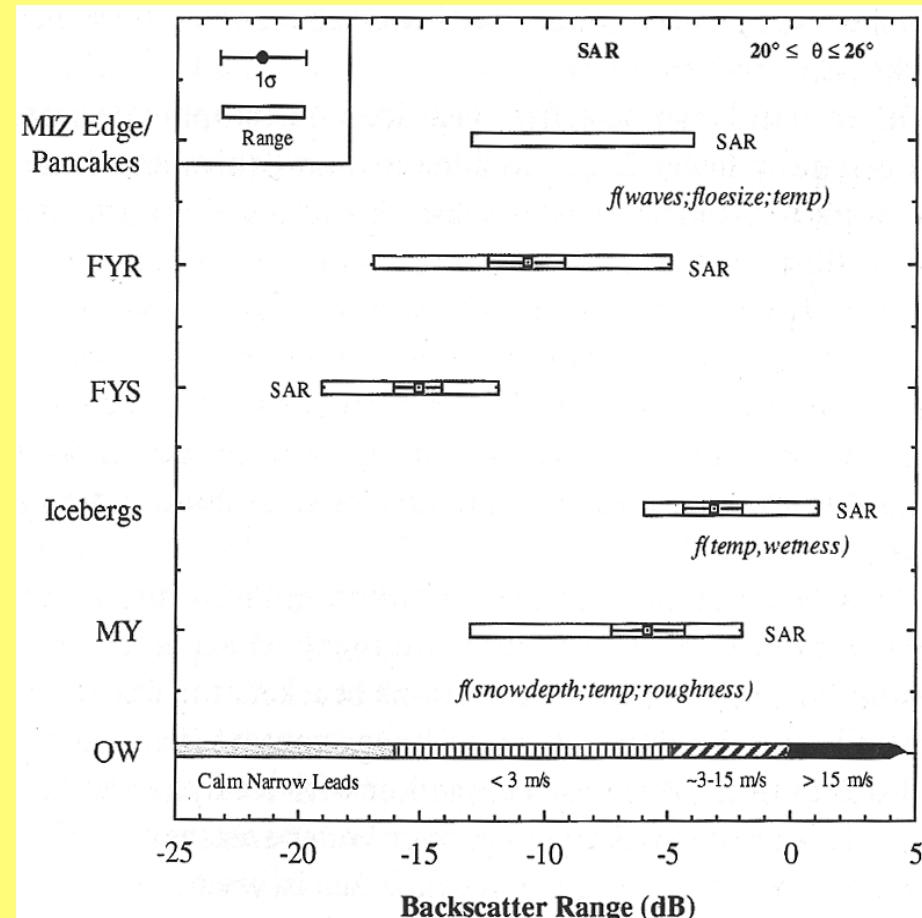
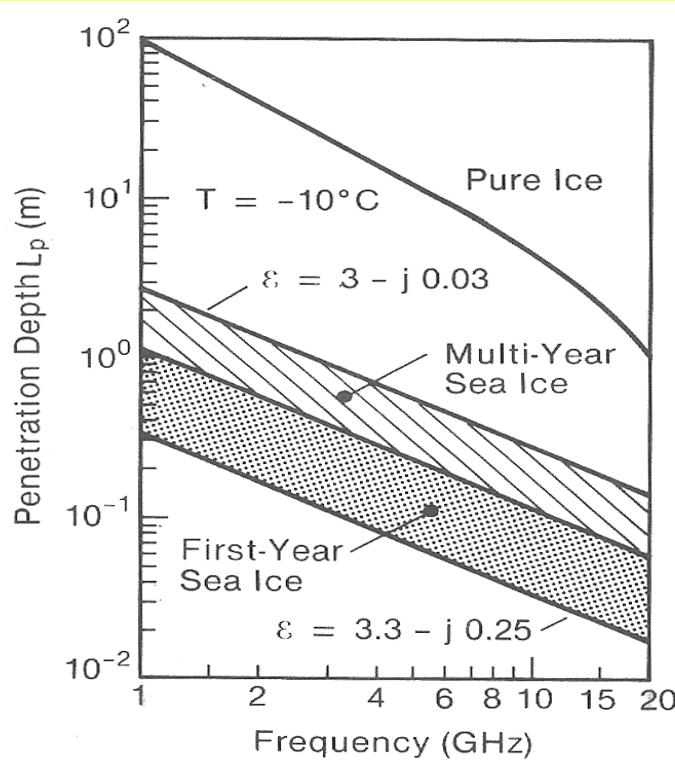
SAR CONTRIBUTION TO MARINE MONITORING

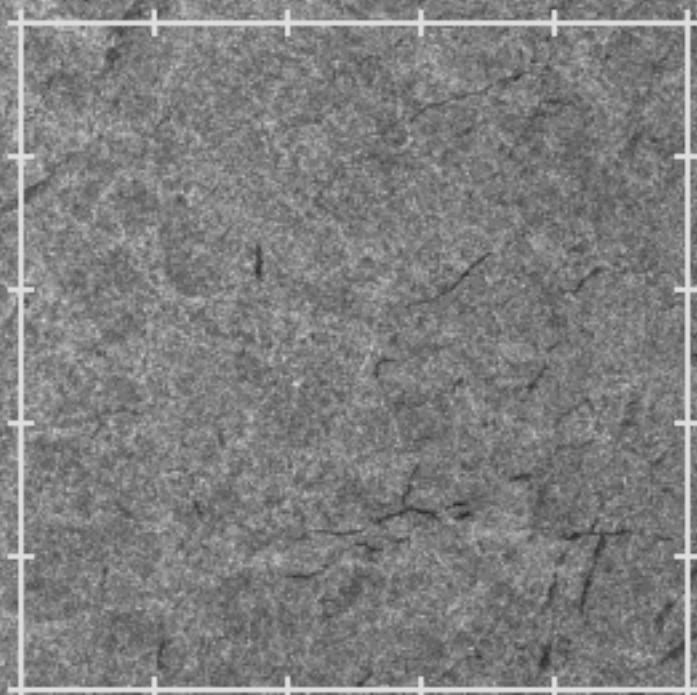
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The importance of volume scattering is governed by the dielectric properties (dielectric constant) of the material:

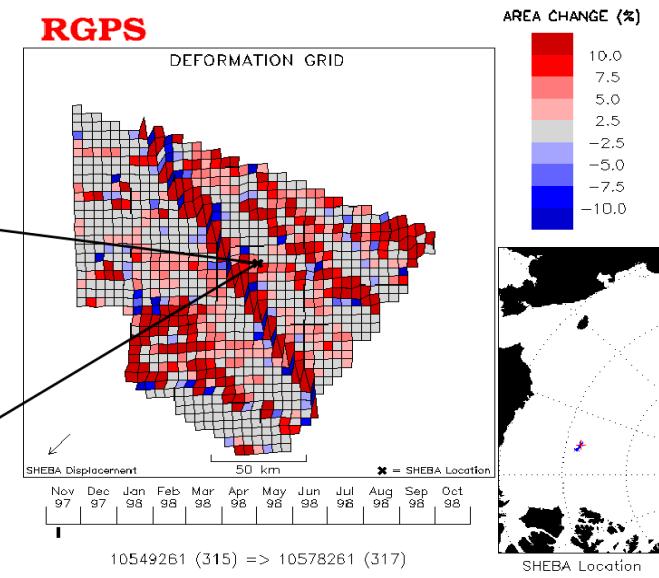
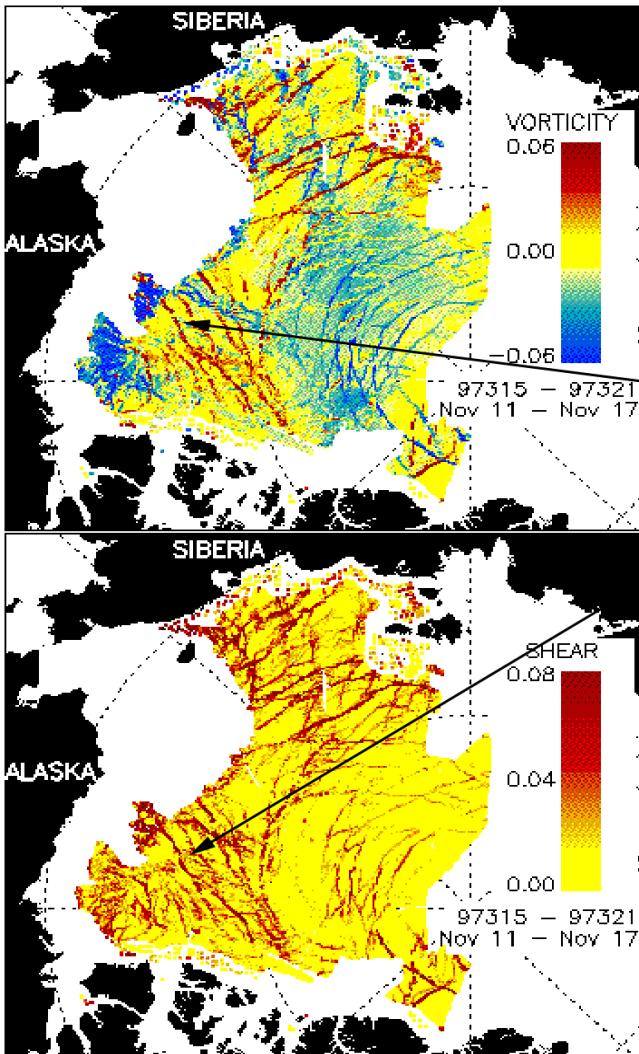
High DE: surface scattering dominates

Low DE: volume scattering dominates





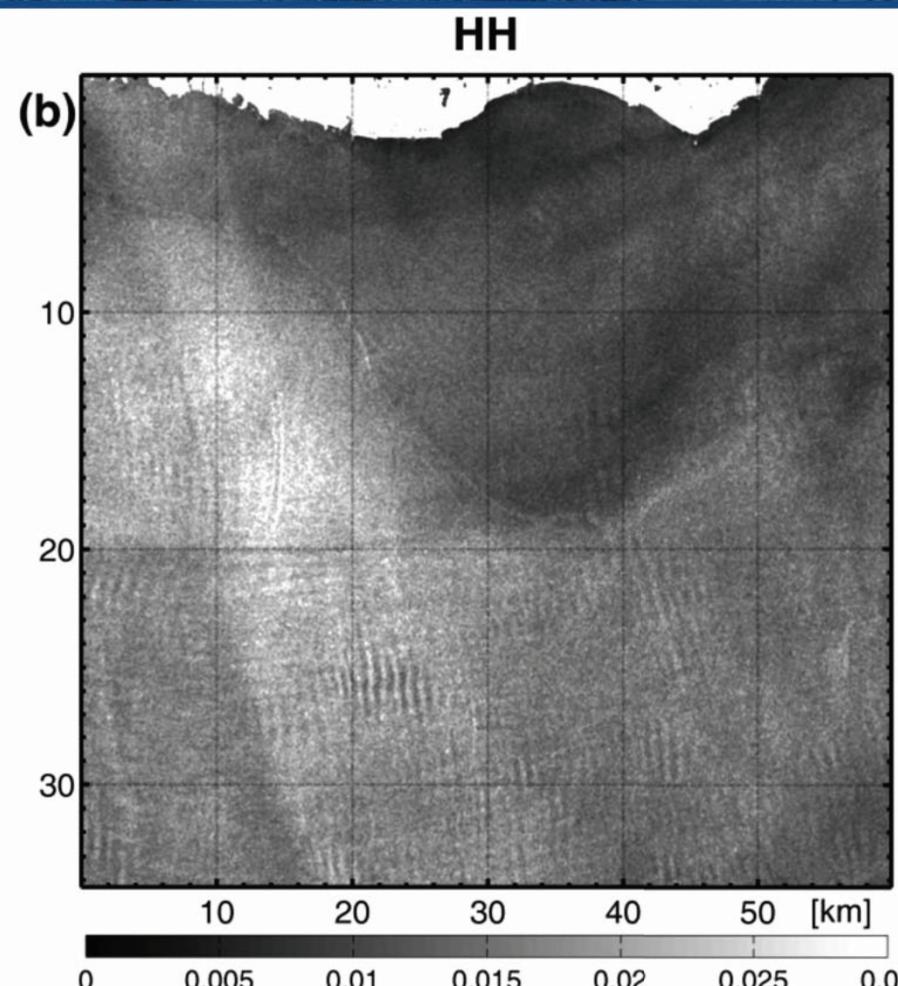
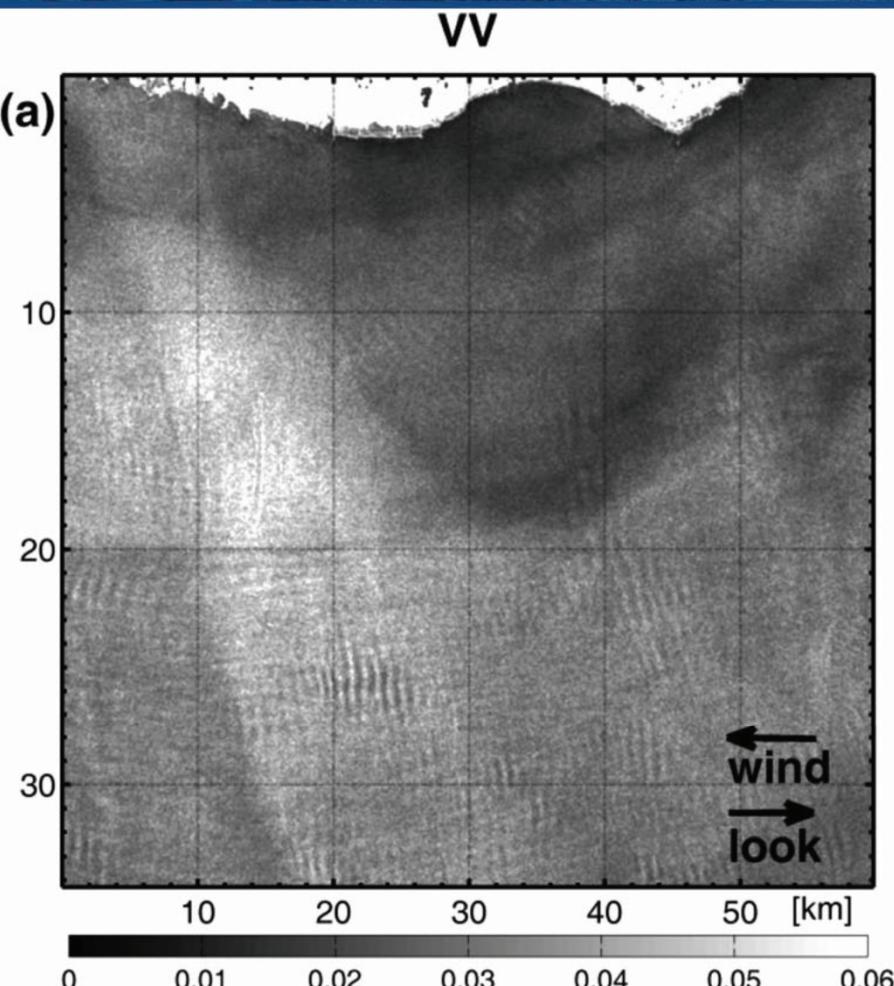
Location of SHEBA, Nov 97



**Large-scale Visualization
Of Cell Deformation**

SAR CONTRIBUTION TO MARINE MONITORING

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Kudryavtsev et al., 2014

Quad-polarization SAR for ocean feature classifications

Decomposed NRCS in
Polarized and non-polarized
signals

$$\sigma_0^{pp} = \sigma_{0B}^{pp} + \sigma_{wb}.$$

Polarization difference (PD)

$$\Delta\sigma_0 \equiv \sigma_0^{vv} - \sigma_0^{hh} = \sigma_{0B}^{vv} - \sigma_{0B}^{hh}.$$

Polarization ratio (PR)

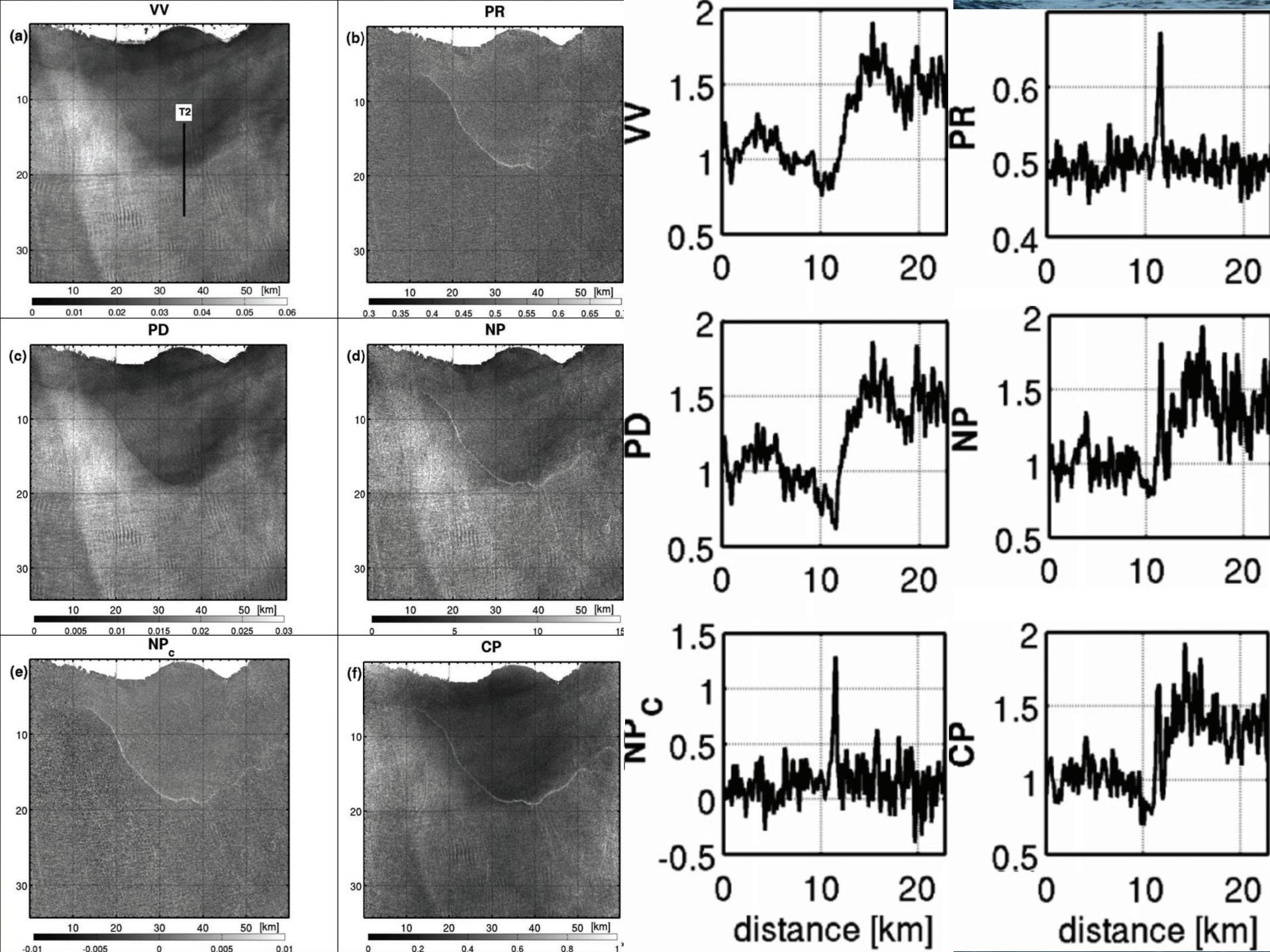
$$P = \frac{\sigma_{0B}^{hh} + \sigma_{wb}}{\sigma_{0B}^{vv} + \sigma_{wb}}.$$

Non-polarized signal (NP)

$$\sigma_{wb} = \sigma_0^{ww} - \Delta\sigma_0 / (1 - P_B).$$

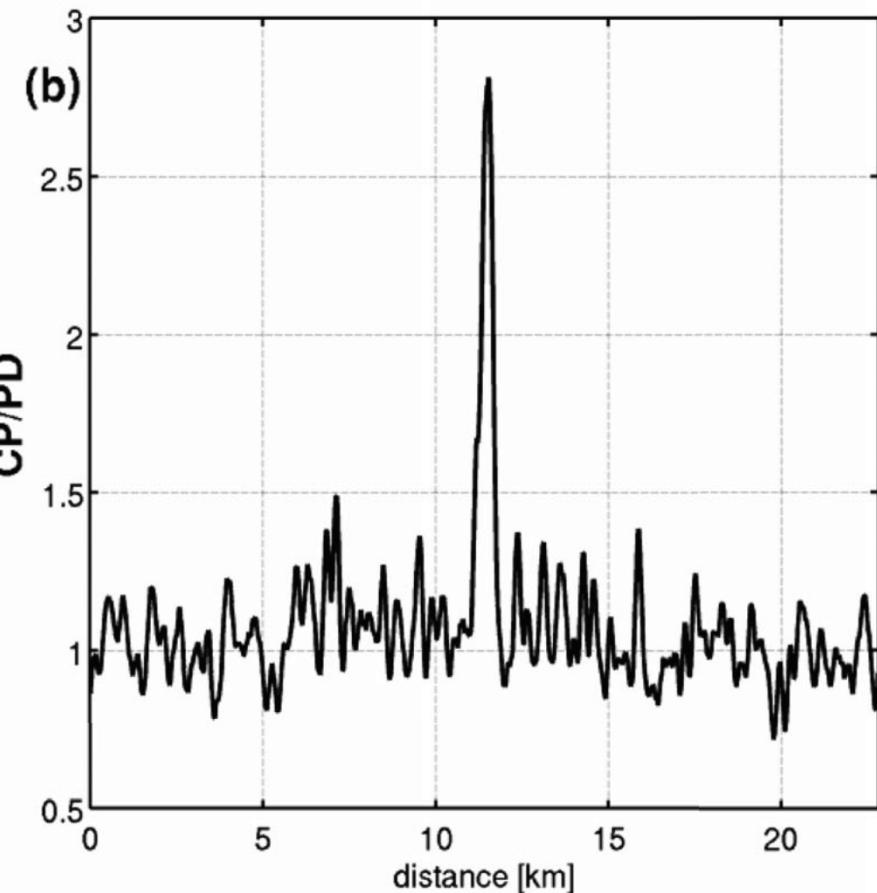
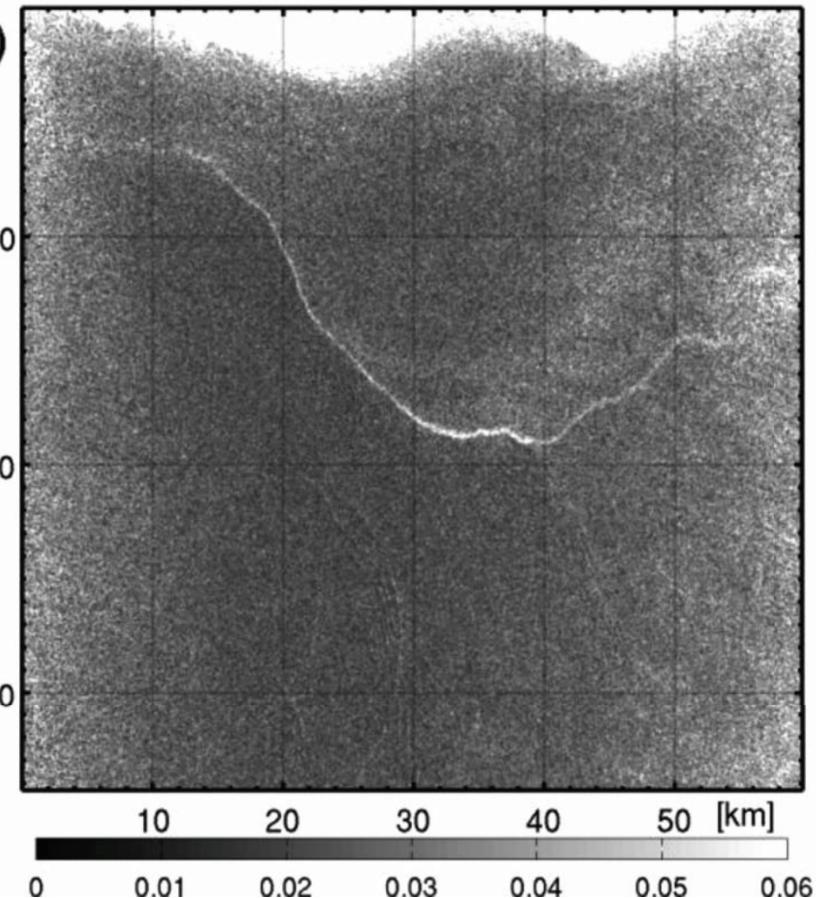
Cross polarized signal (CP)

$$CP = (\sigma_0^{vh} + \sigma_0^{hv}) / 2,$$



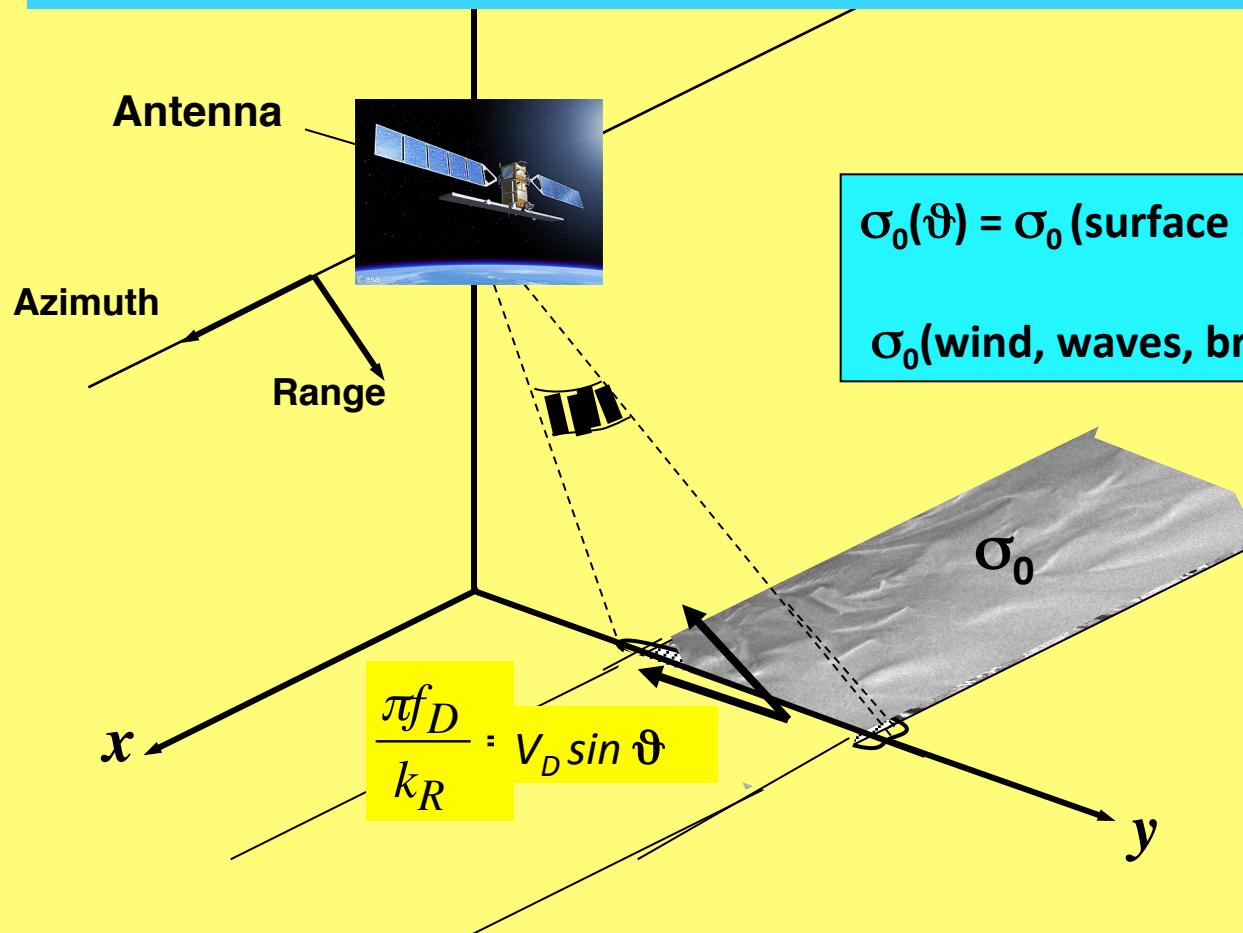
CP/PD

(a)



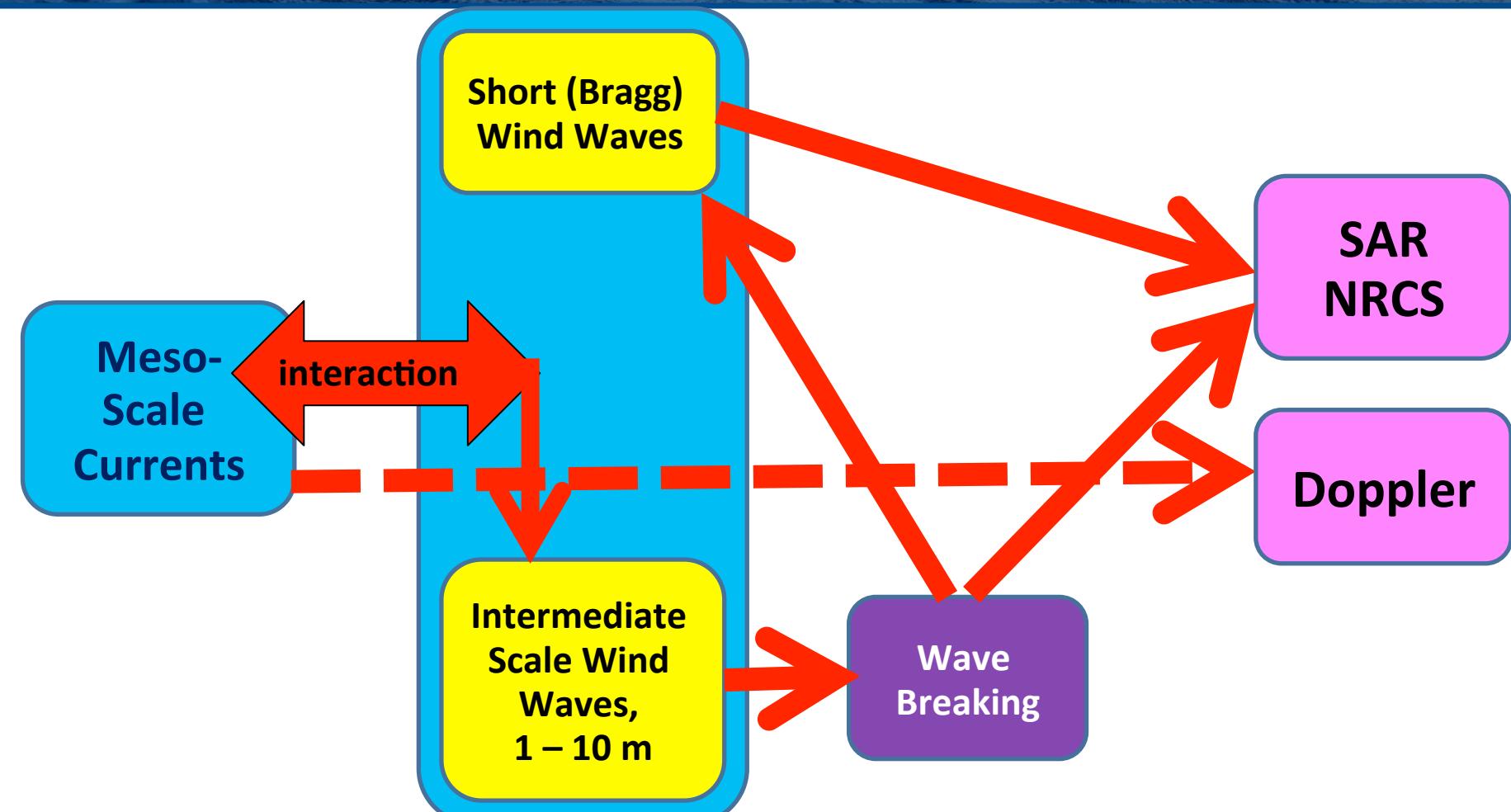
Both the wind variability and the wave-current interaction contribute to the CP signal. The first contribution is primarily removed by considering the ratio of the cross-polarized NRCS and the polarization difference.

SAR Imaging of Roughness and Doppler Shift



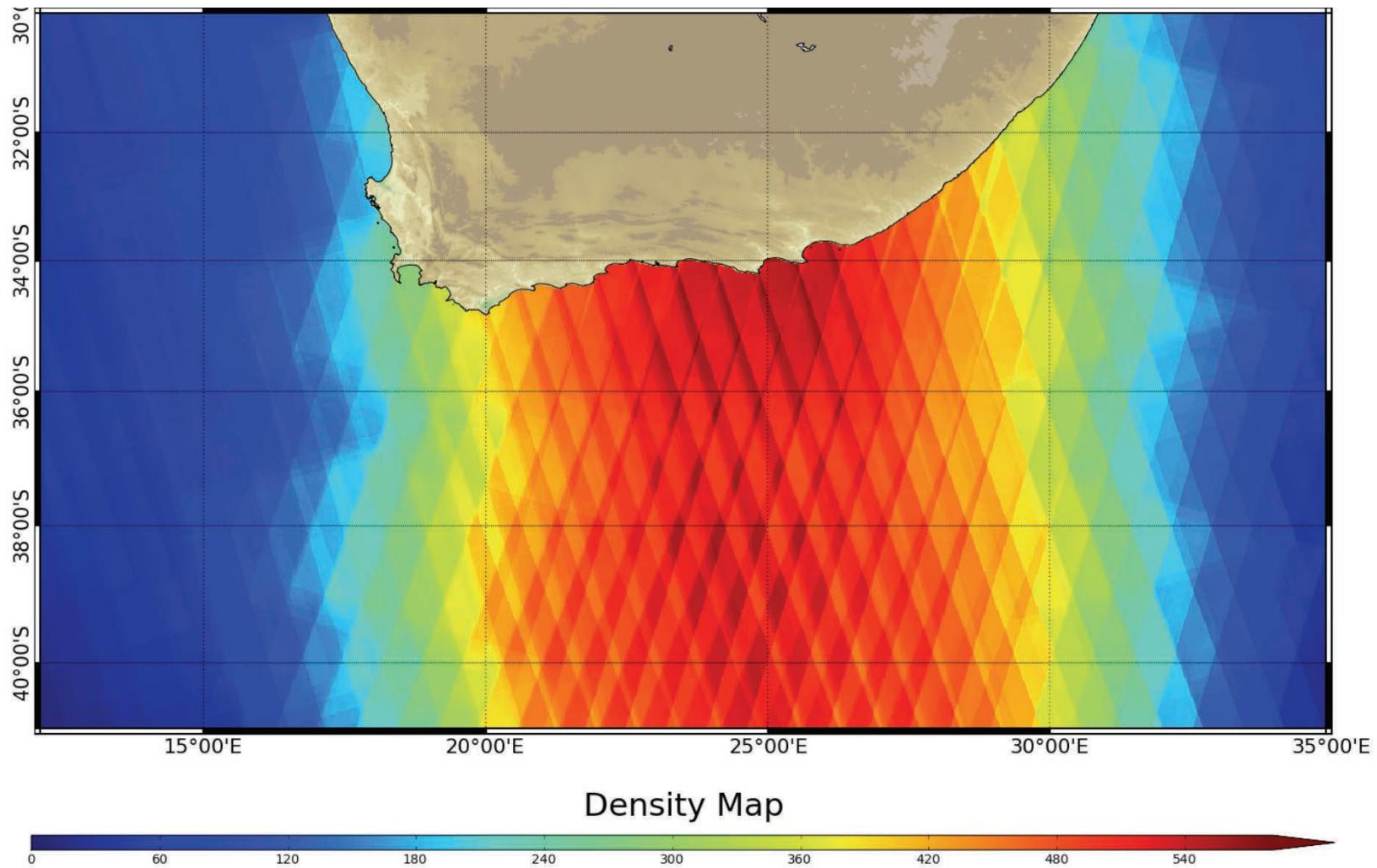
$V_D = V_D$ (wind driven scatterer, waves, breaking, current)

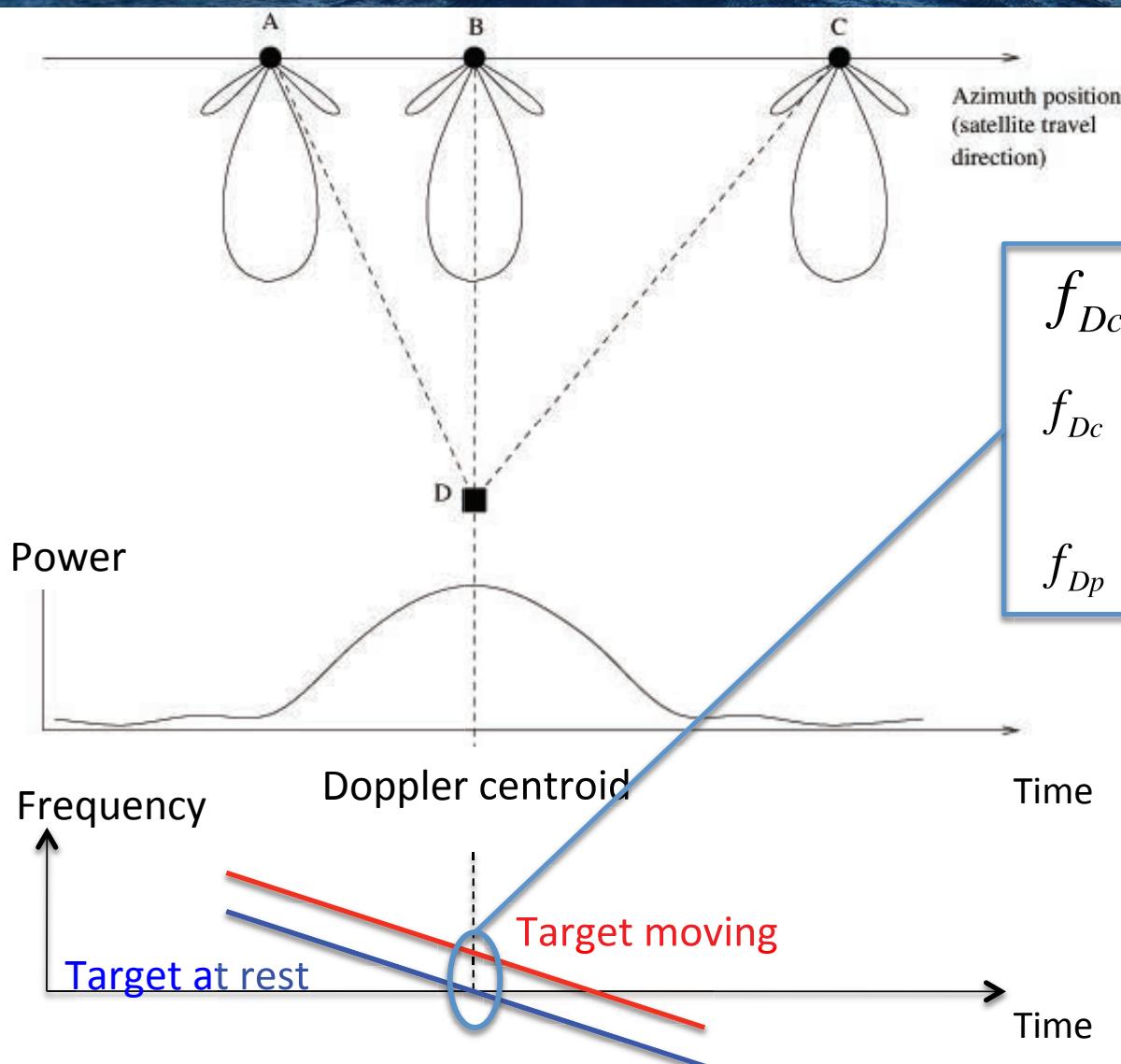
SAR Imaging Observations & Simulation Modelling



"Radar Imaging of meso-scale current features" ---- Kudryavtsev et al., JGR, 2005 (Part 1);
Johannessen et al., JGR, 2005 (Part 2); Chapron et al, 2005; Johannessen et al., JGR, 2008

Envisat ASAR Coverage of the Greater Agulhas Current





$$f_{Dca} = f_{Dc} - f_{Dp}$$

f_{Dc} : estimated Doppler centroid frequency shift

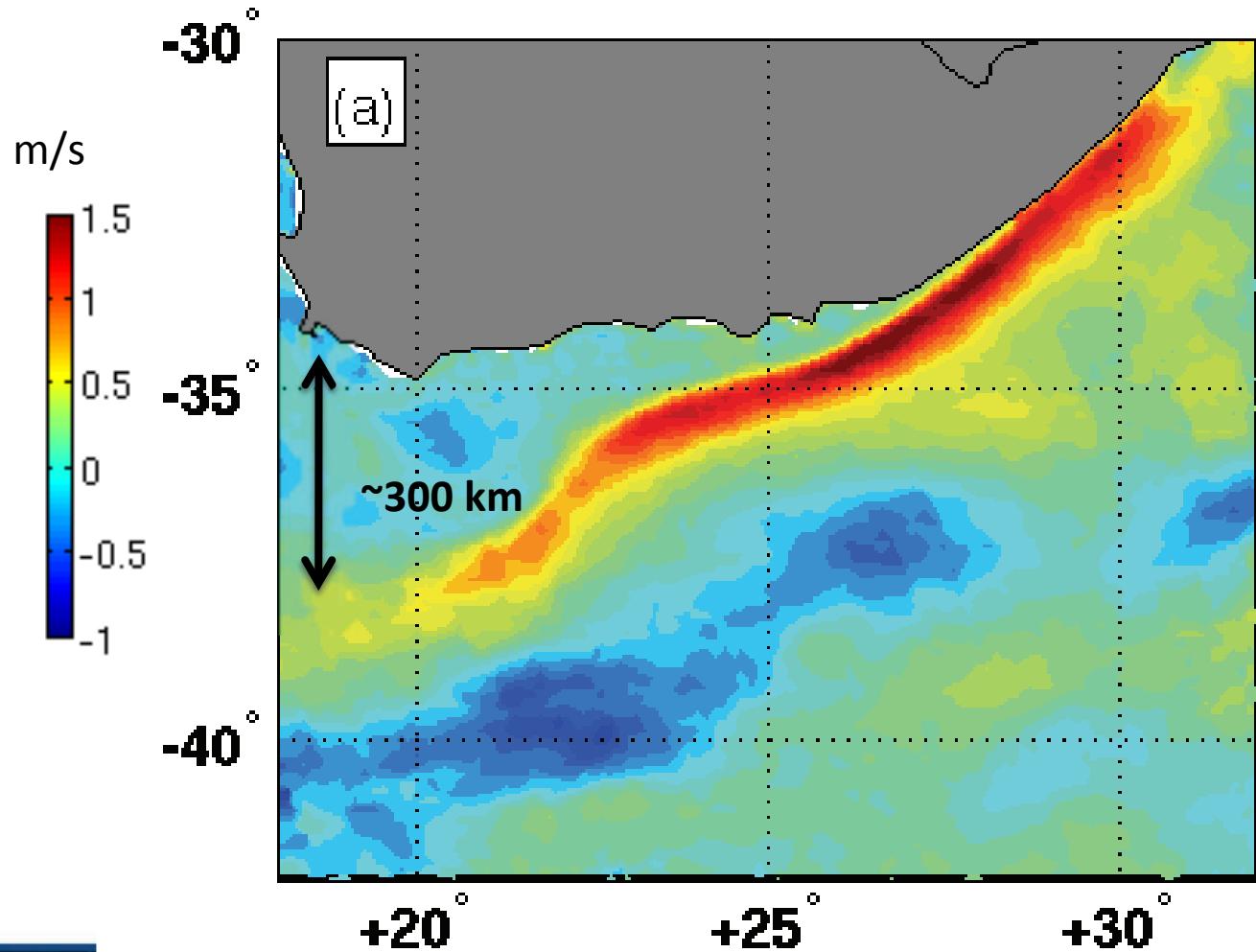
f_{Dp} : predicted Doppler shift

Chapron et al. (2003, 2005)
Hansen et al 2012

Doppler Centroid Frequency Shift



Range Doppler Velocity Map – mean of ~600 asc. Aq.



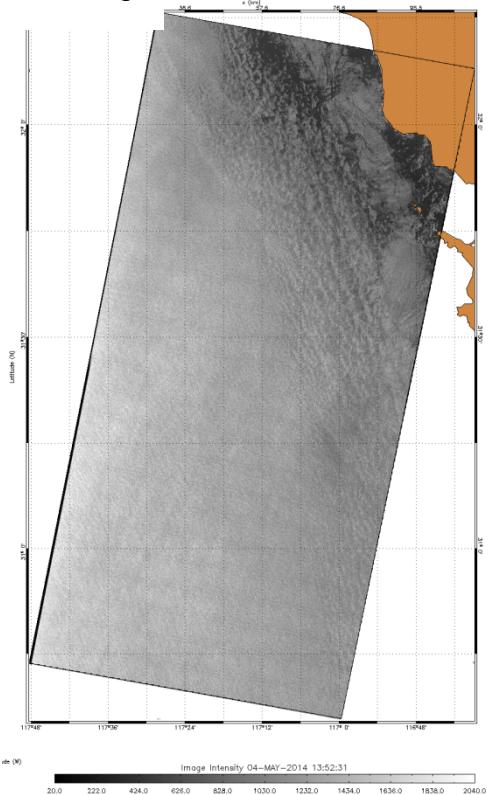
Accuracy about
2-4 cm/s

Johannessen et al., 2014

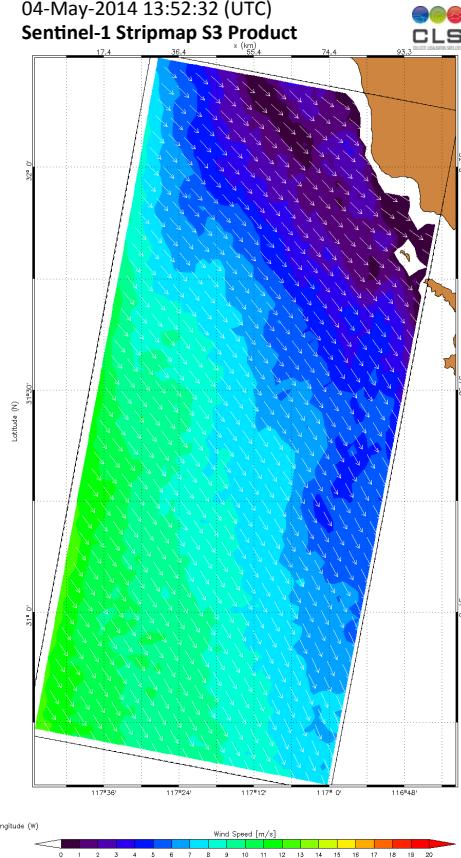
FIRST DEMONSTRATION WITH SENTINEL-1A DATA

First Wind measurement with S-1 A

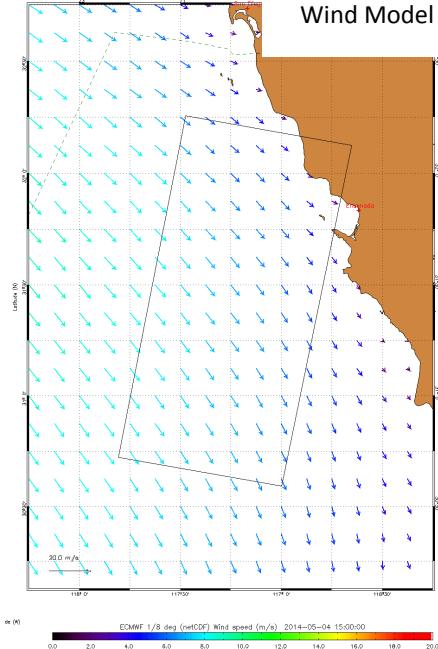
S-1 A SM Image



04-May-2014 13:52:32 (UTC)
Sentinel-1 Stripmap S3 Product

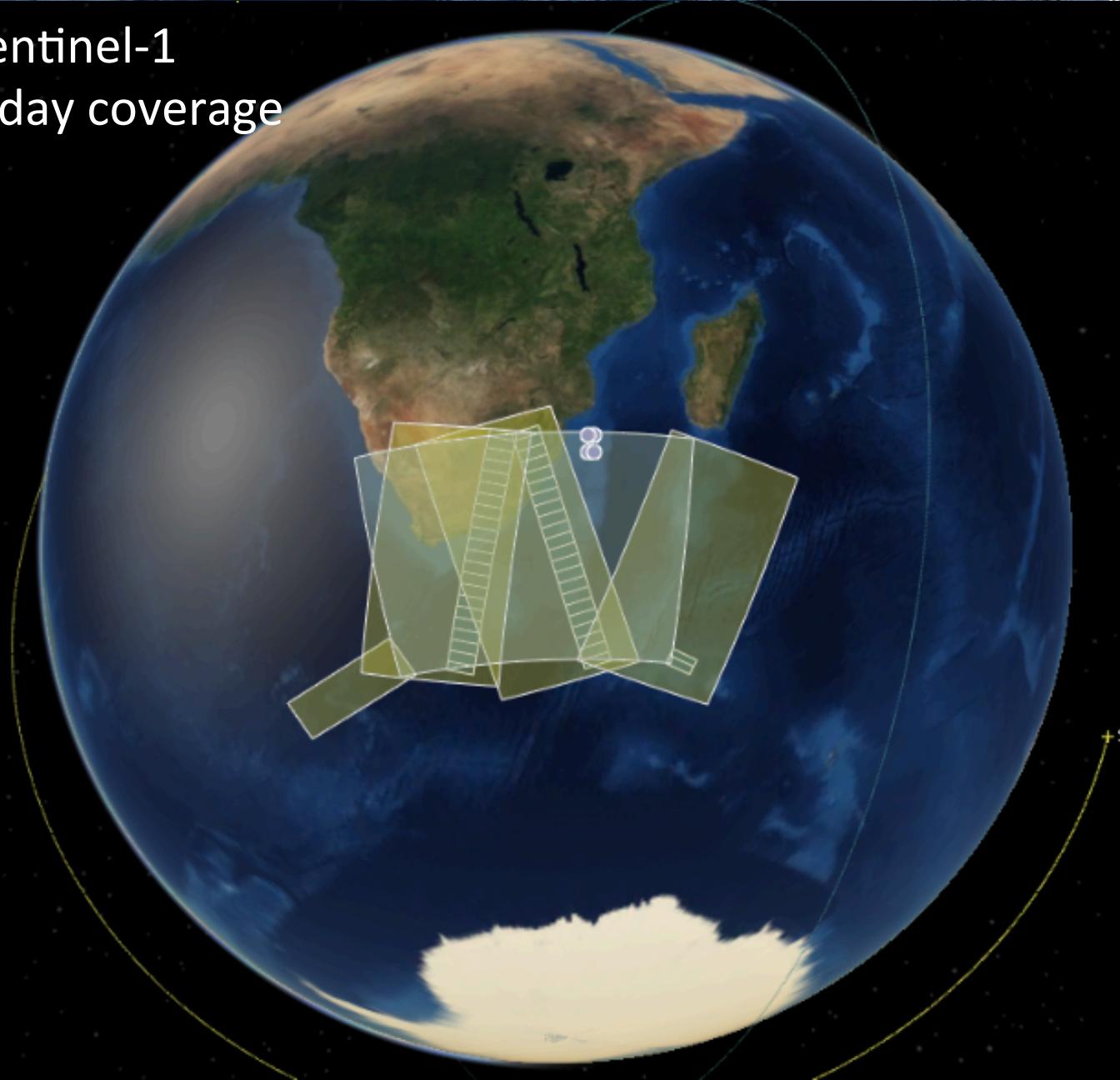


Wind Model

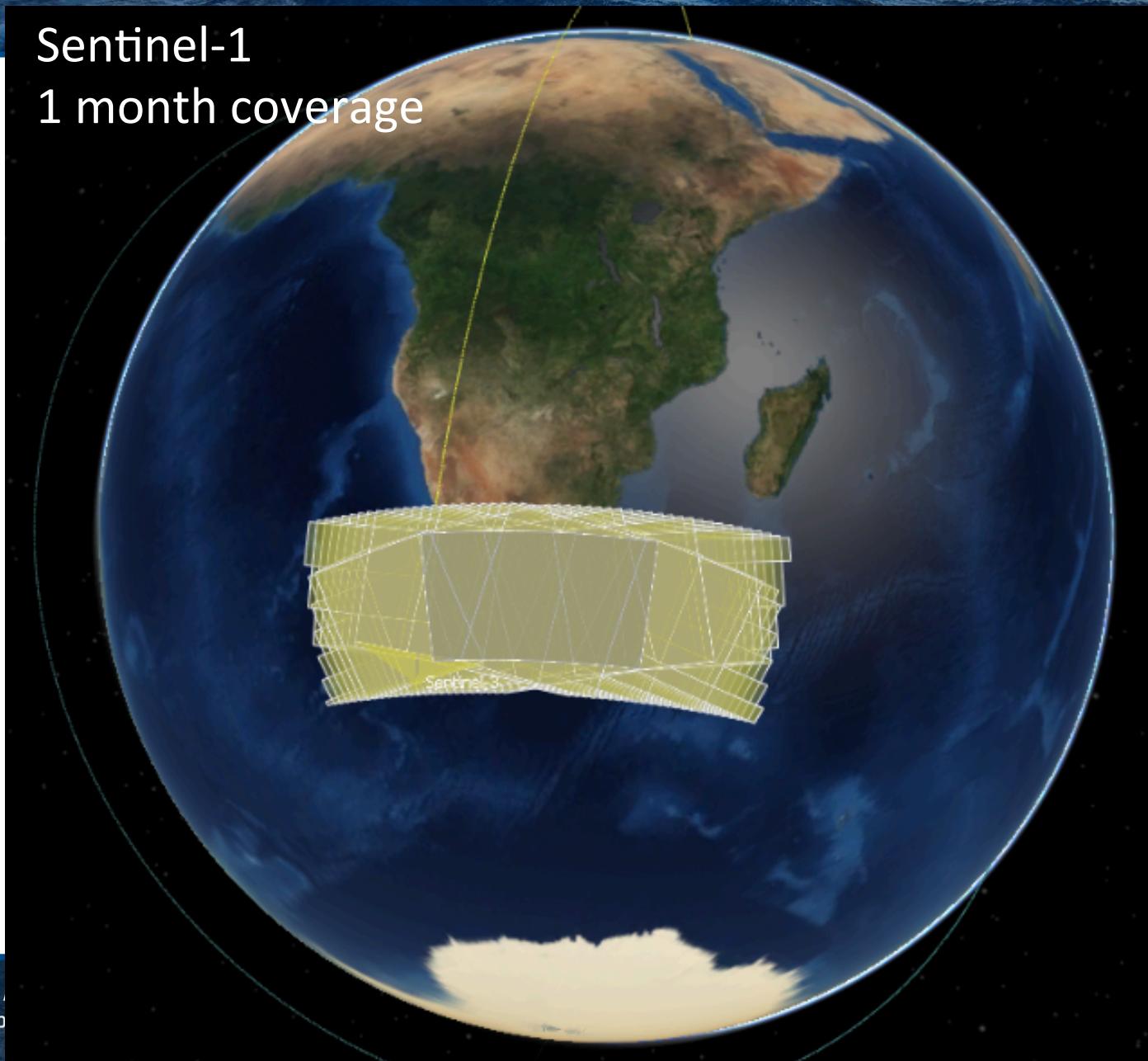


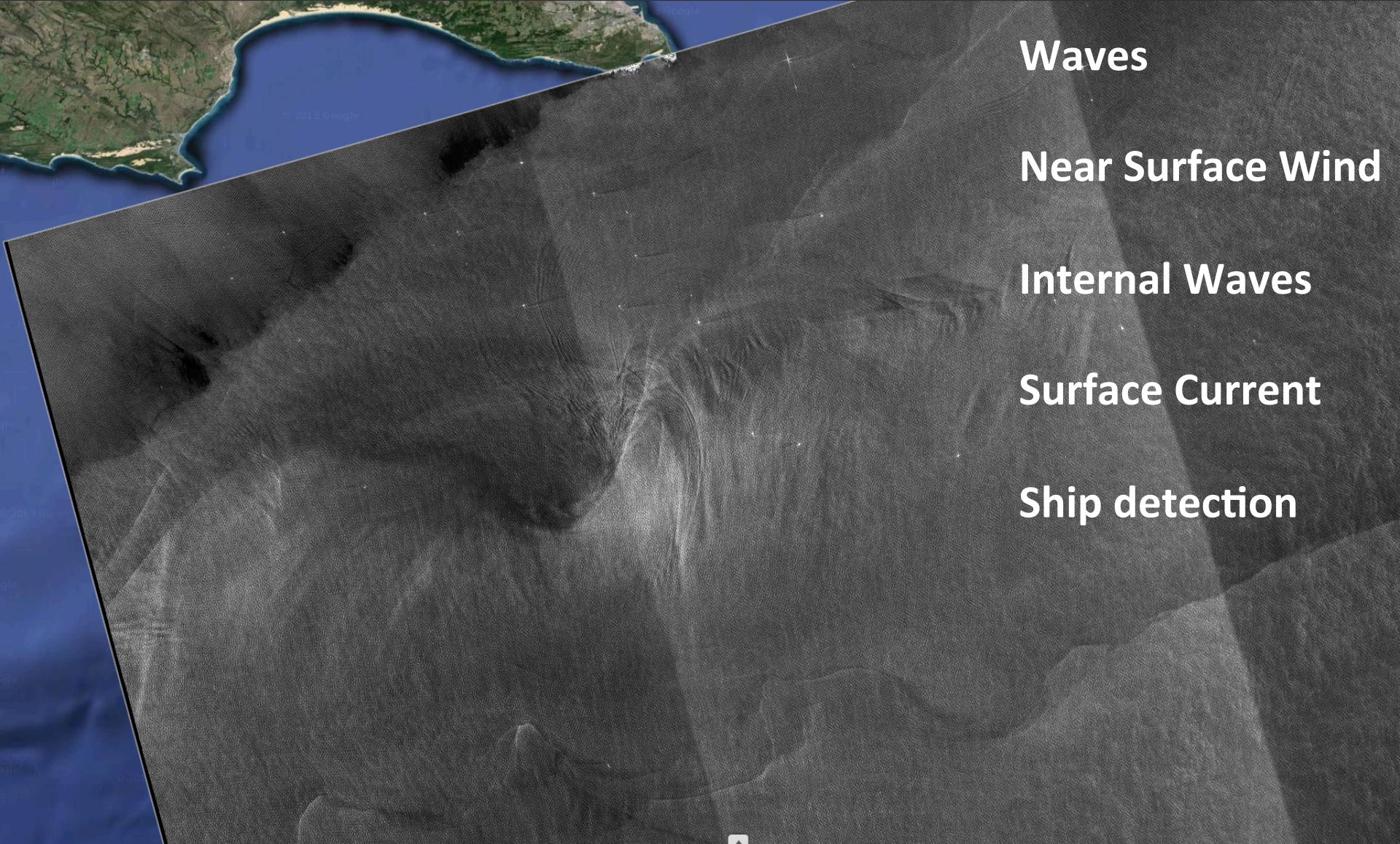
- S-1 A is able to measure relative wind variations at very high resolution (1 km here)
- Wind fields estimates will benefit from dual polarization for extreme events such as hurricanes.

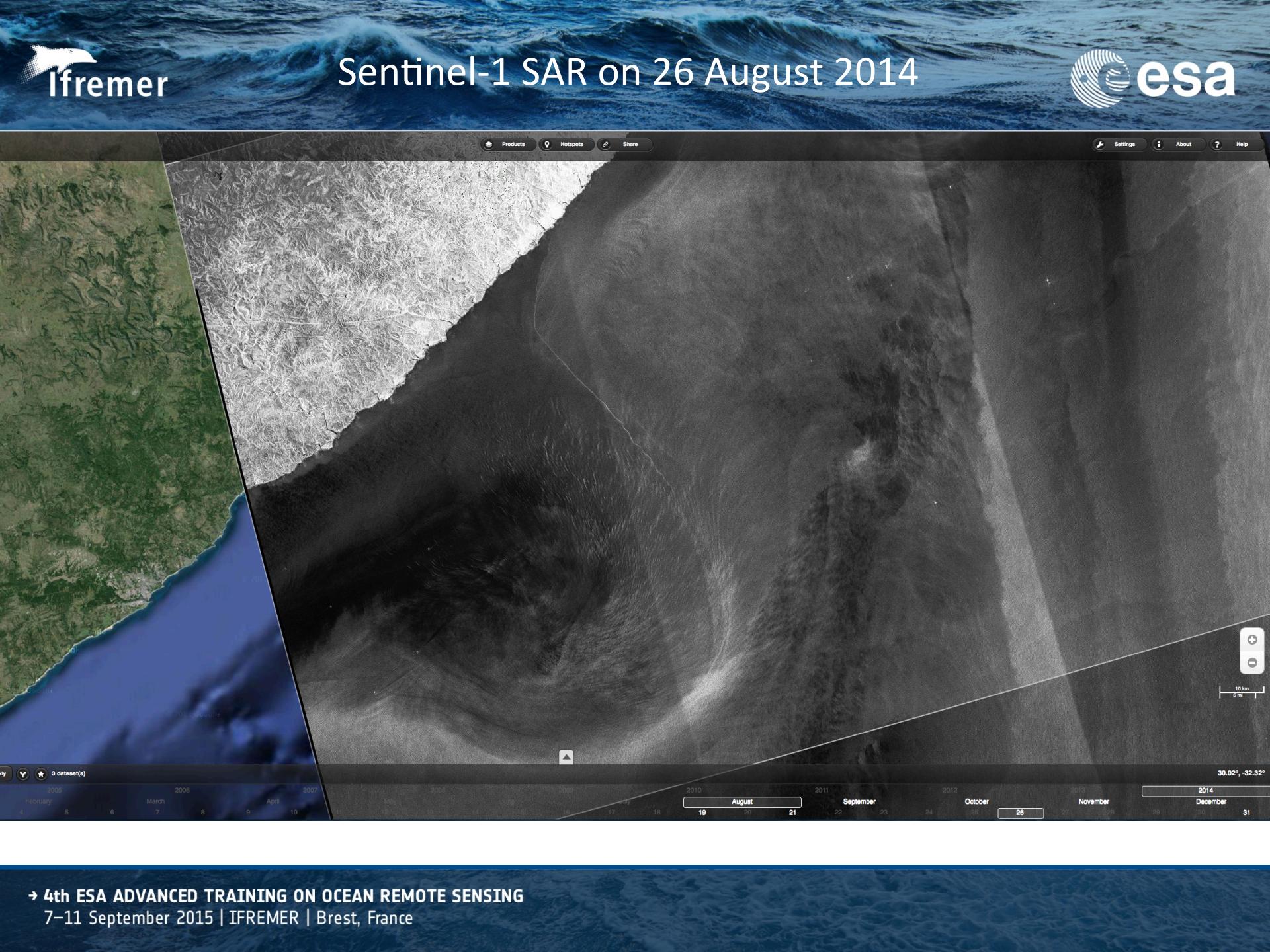
Sentinel-1 1 day coverage



Sentinel-1
1 month coverage







+

-

Mthatha

100 km

Min SST: 14

Max SST: 25

Show HH 100

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**NANSEN-CLOUD
SST
SAR**

2014-10-15
GHRSST / JPL
SENTINEL-1

+

-

Mthatha

100 km

Min SST: 19

Max SST: 23

Show HH 100

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**NANSEN-CLOUD
SST
SAR**

2014-10-15
GHRSST / JPL
SENTINEL-1

+

-

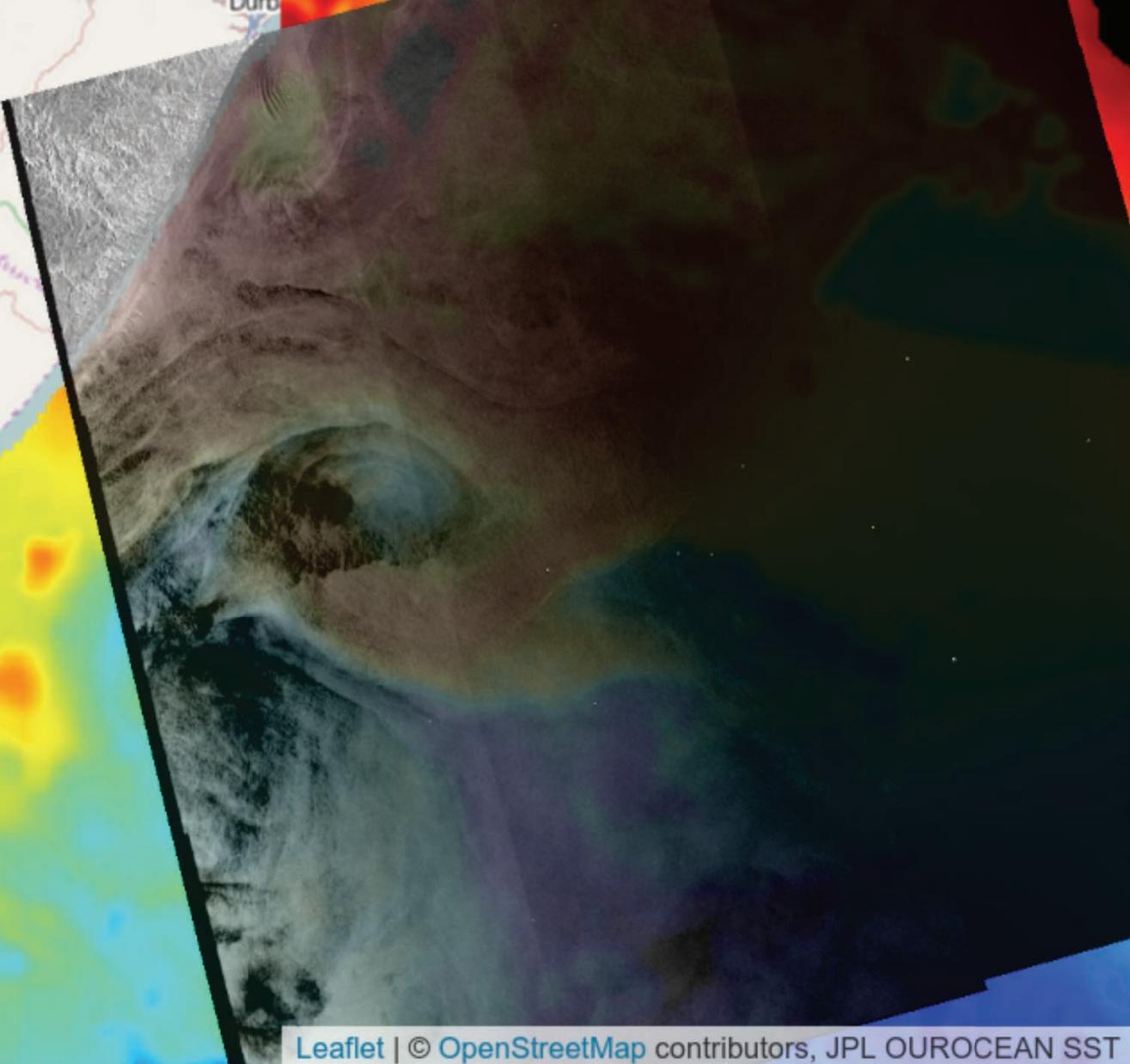
Mthatha

100 km

Min SST: 19

Max SST: 23

Show HH 90



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**NANSEN-CLOUD
SST
SAR**

2014-10-15
GHRSST / JPL
SENTINEL-1

+

-

Mthatha

100 km

Min SST: 19

Max SST: 23

Show HH 80

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**NANSEN-CLOUD
SST
SAR**

2014-10-15
GHRSST / JPL
SENTINEL-1

+

-

Mthatha

100 km

Min SST: 19

Max SST: 23

Show HH 70

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**NANSEN-CLOUD
SST
SAR**

2014-10-15
GHRSST / JPL
SENTINEL-1

+

-

Mthatha

100 km

Min SST: 19

Max SST: 23

Show HH 60

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**NANSEN-CLOUD
SST
SAR**

2014-10-15
GHRSST / JPL
SENTINEL-1

+

-

Mthatha

100 km

Min SST: 19

Max SST: 23

Show HH 50

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**NANSEN-CLOUD
SST
SAR**

2014-10-15
GHRSST / JPL
SENTINEL-1

+

-

Mthatha

100 km

Min SST: 19

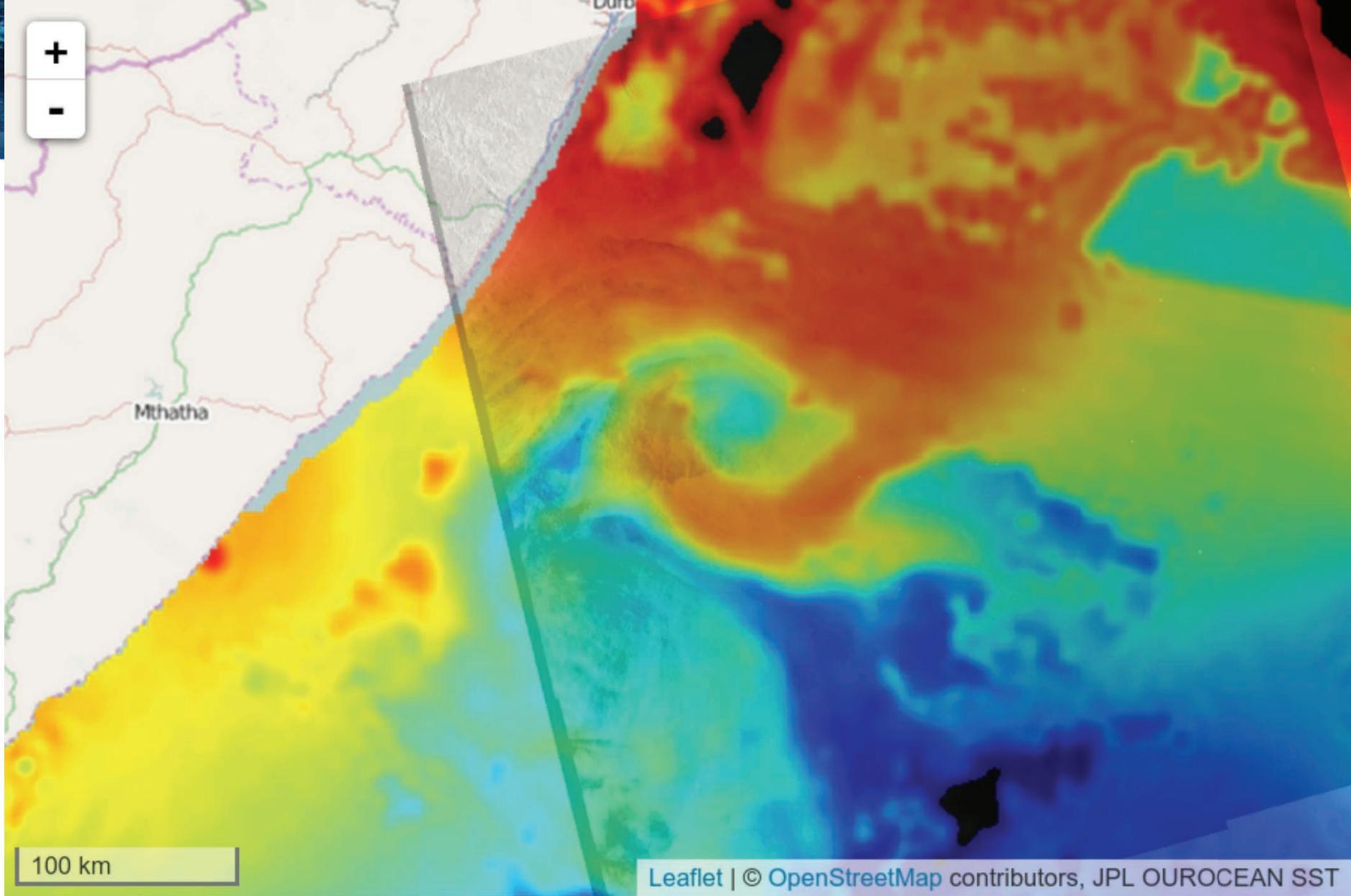
Max SST: 23

Show HH 40

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**NANSEN-CLOUD
SST
SAR**

2014-10-15
GHRSST / JPL
SENTINEL-1



100 km

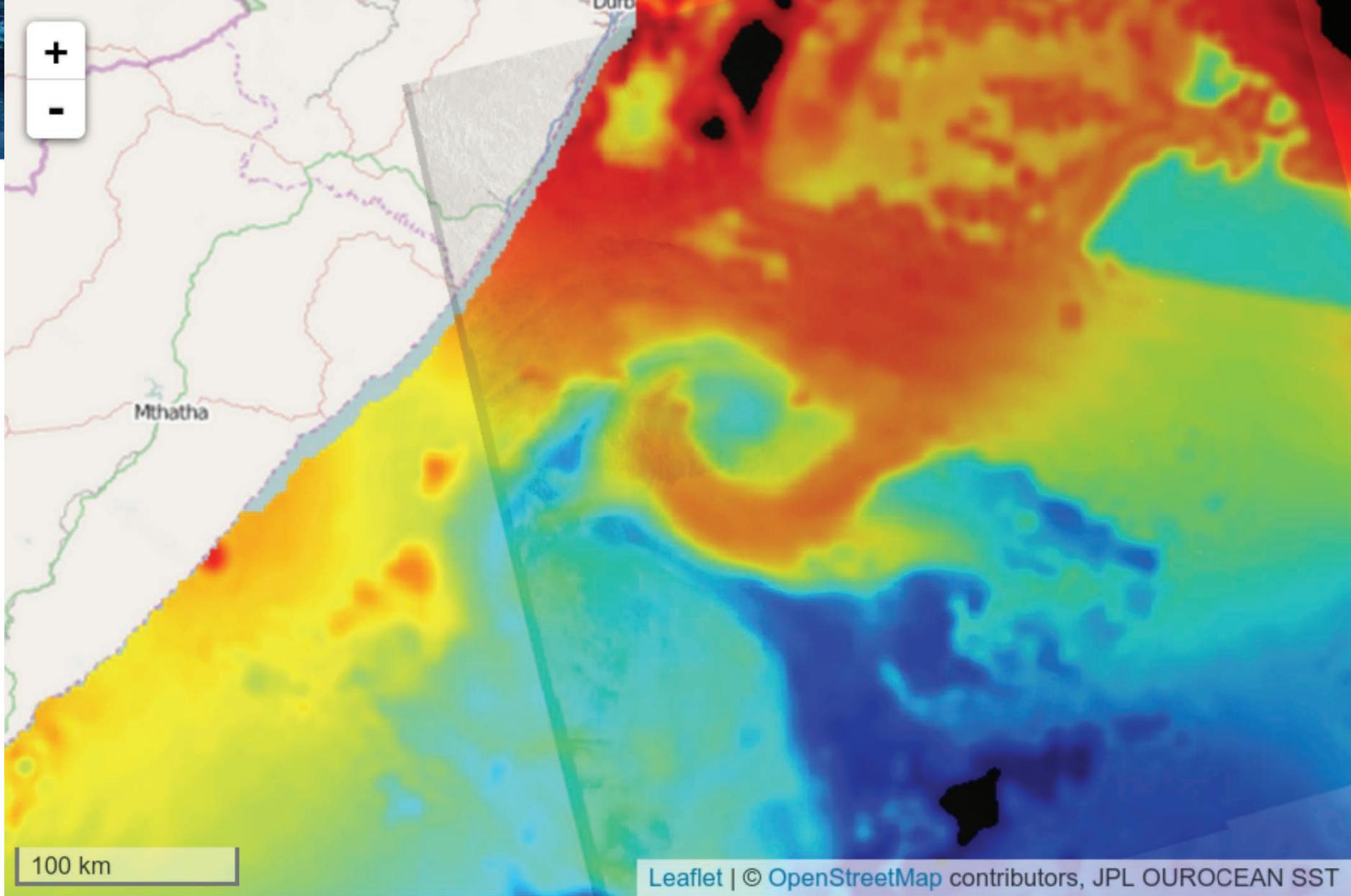
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Min SST: 19 Max SST: 23

Show HH 30

**NANSEN-CLOUD
SST
SAR**

2014-10-15
GHRSST / JPL
SENTINEL-1



100 km

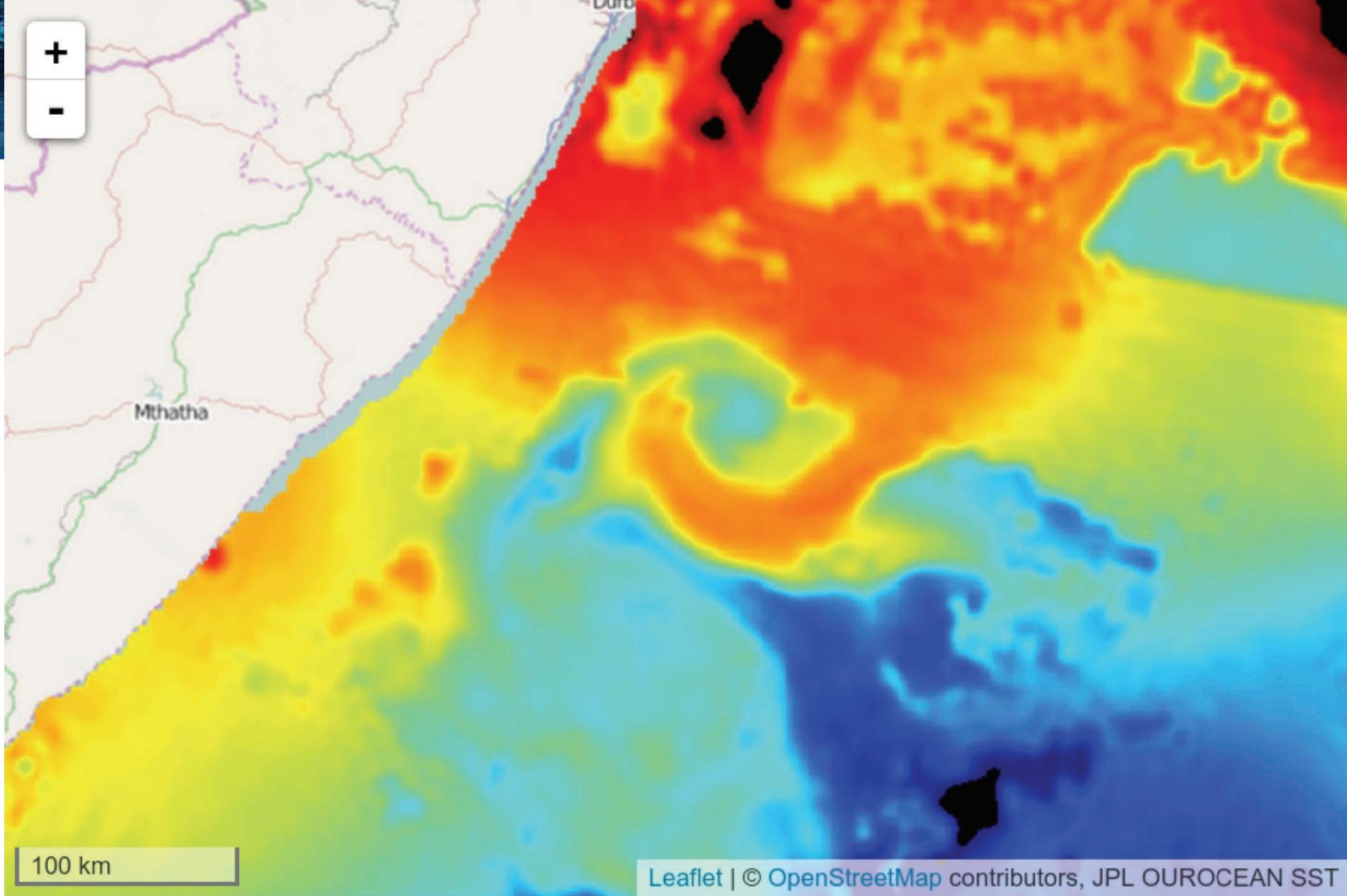
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Min SST: 19 Max SST: 23

Show HH 20

**NANSEN-CLOUD
SST
SAR**

2014-10-15
GHRSST / JPL
SENTINEL-1



100 km

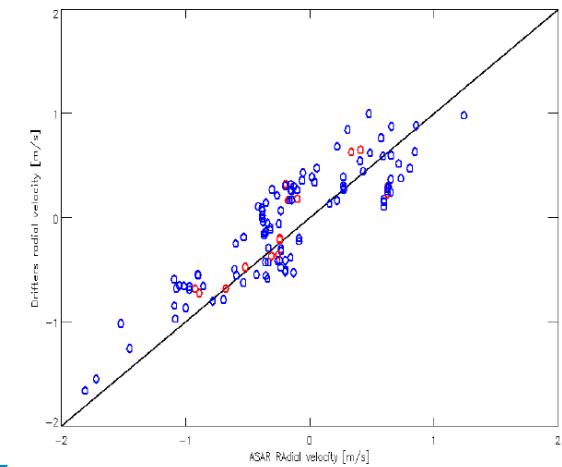
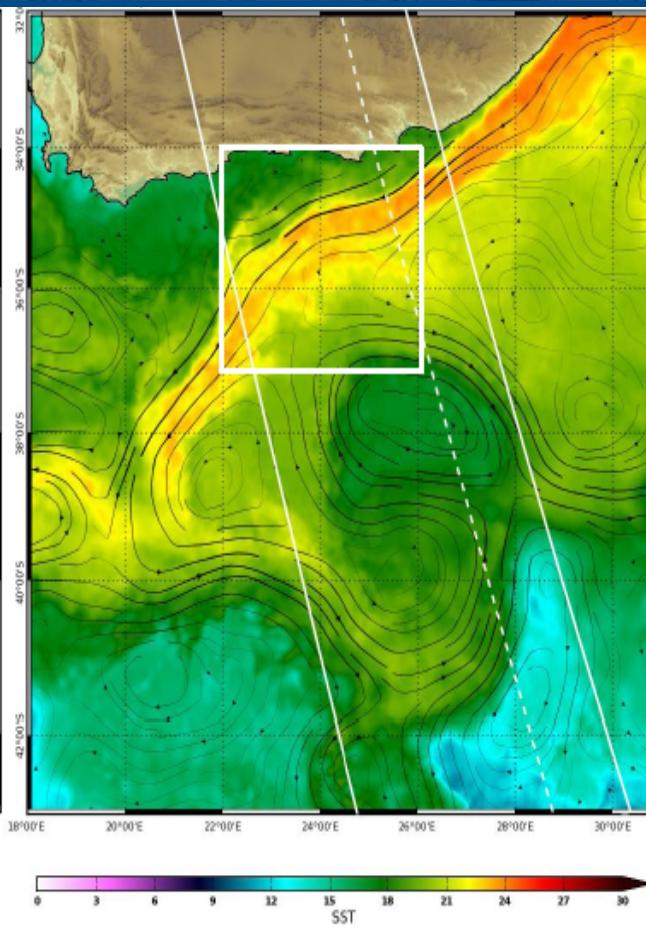
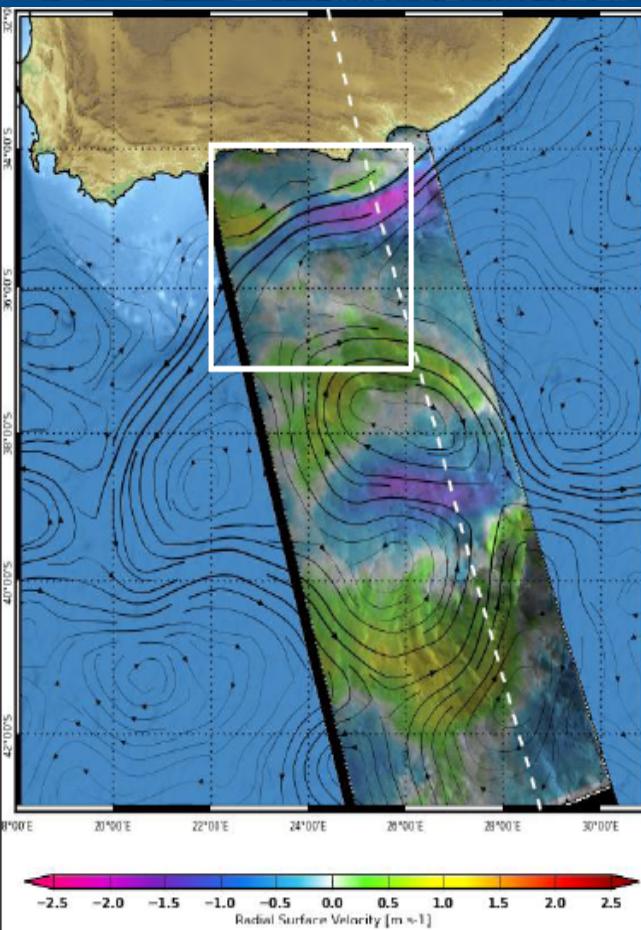
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Min SST: 19 Max SST: 23

Show HH 0

**NANSEN-CLOUD
SST
SAR**

2014-10-15
GHRSST / JPL
SENTINEL-1



GlobCurrent

<http://www.globcurrent.org>