SAR Detection Capabilities, Interpretation and Application

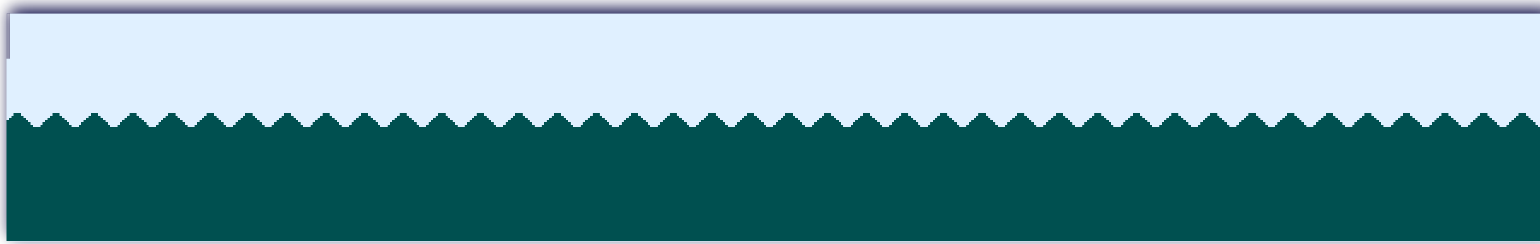
J.A. Johannessen and F. Collard

SAR CONTRIBUTION TO MARINE MONITORING

Operational Surveillance	Emerging New 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

SAR Signatures of Ocean Waves

- 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



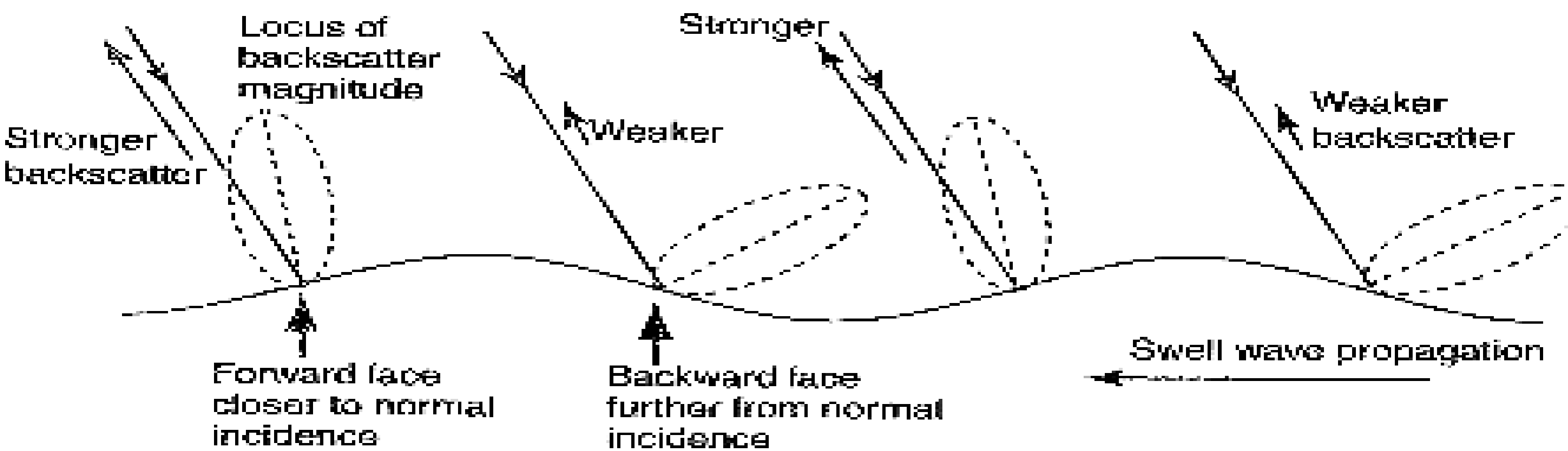
Courtesy Roland Romeiser

SAR WAVE IMAGING MECHANISMS

- 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

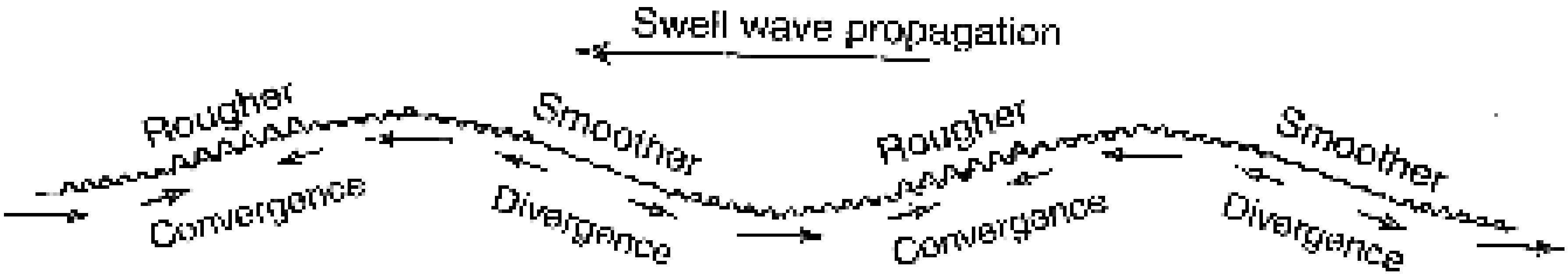
$$T_t(k) = \left(\frac{1}{\sigma^o} \cdot \frac{\partial\sigma}{\partial\theta}\right)_{\theta = \theta_0} \cdot ik_r$$



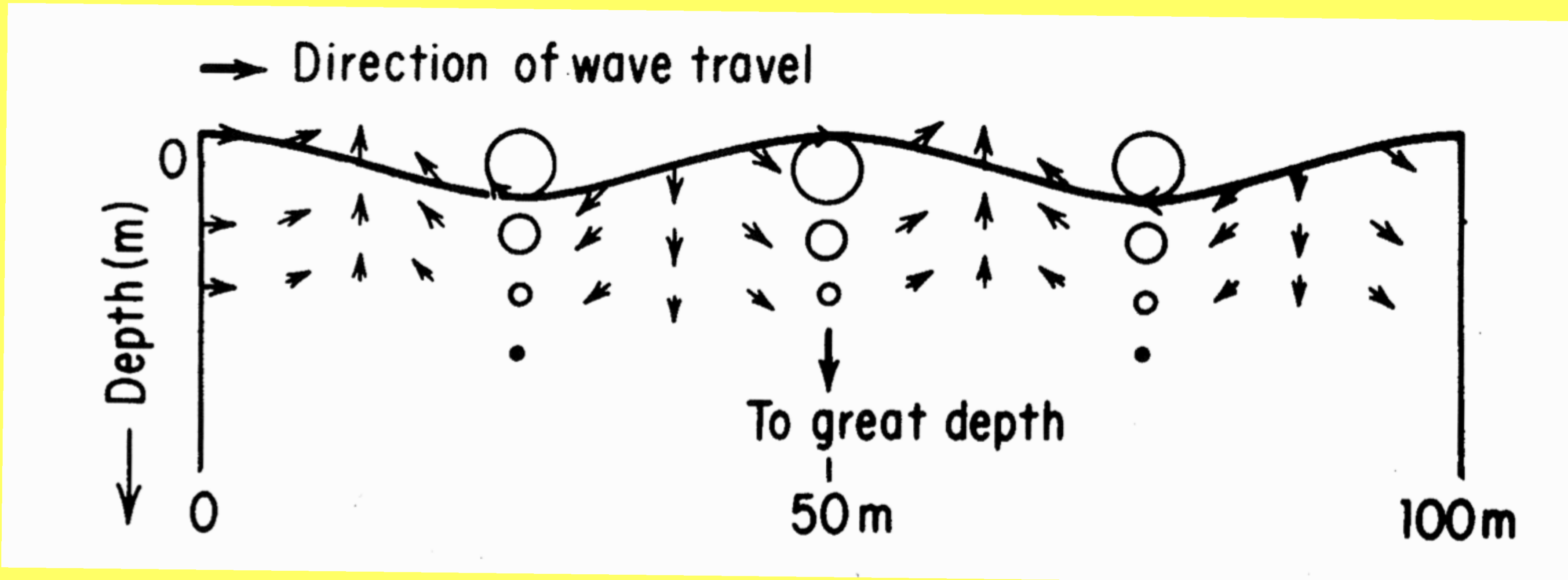
SAR WAVE IMAGING MECHANISMS

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

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

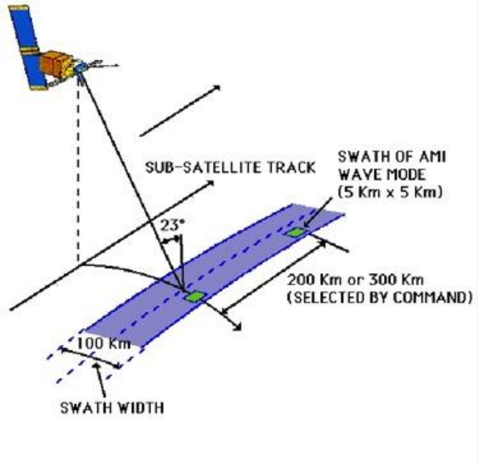


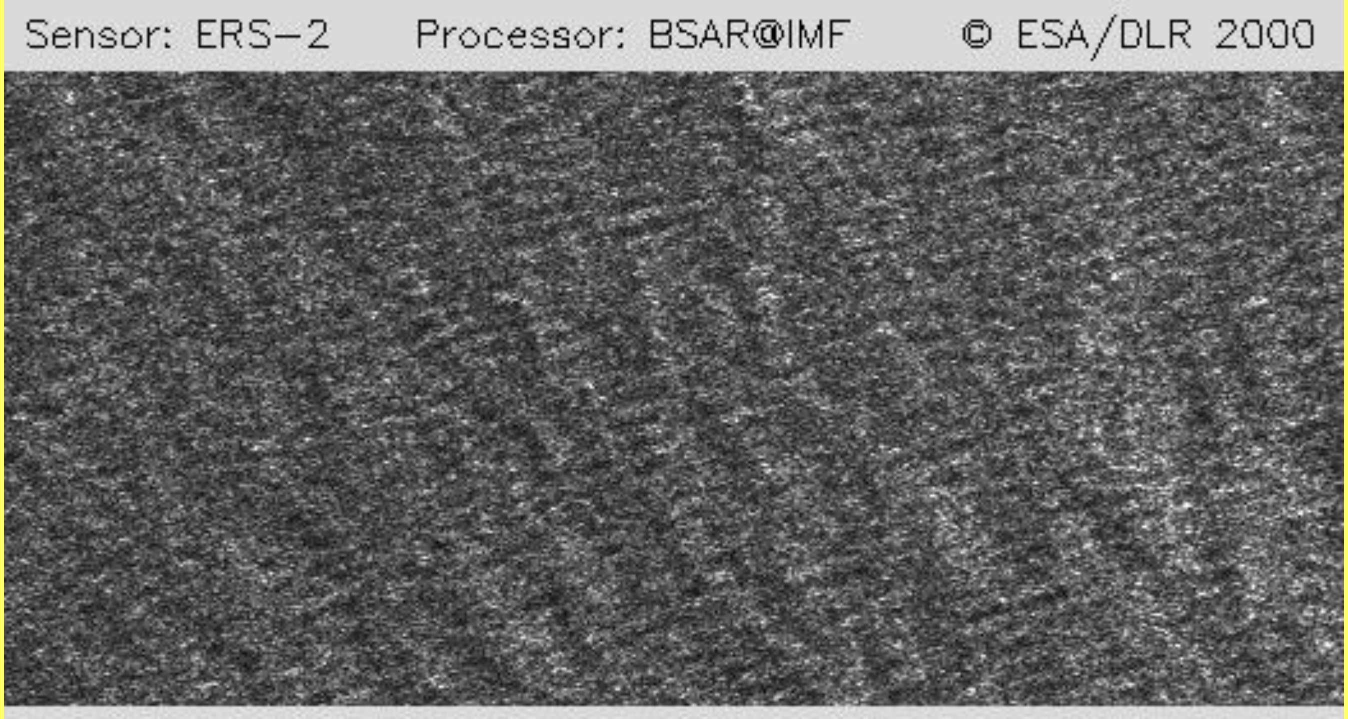
PARTICLE MOTION DUE TO TRAVELLING WAVES

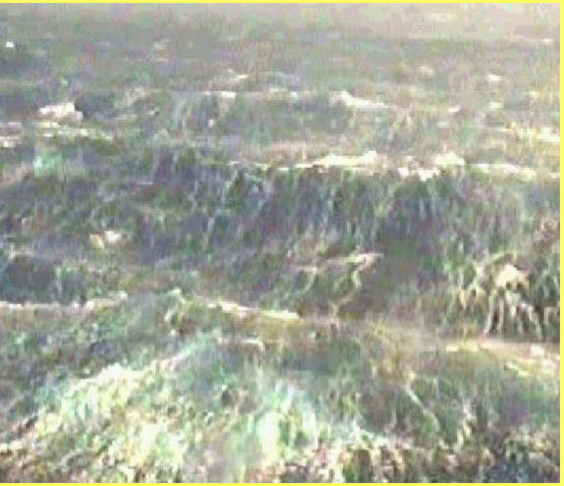


After Neumann and Pierson

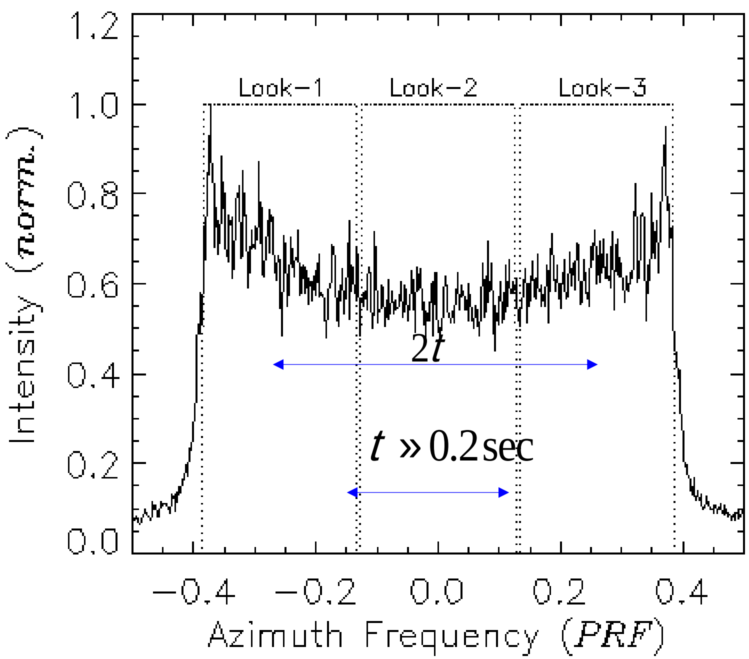
SAR wave imaging: What is the travel direction

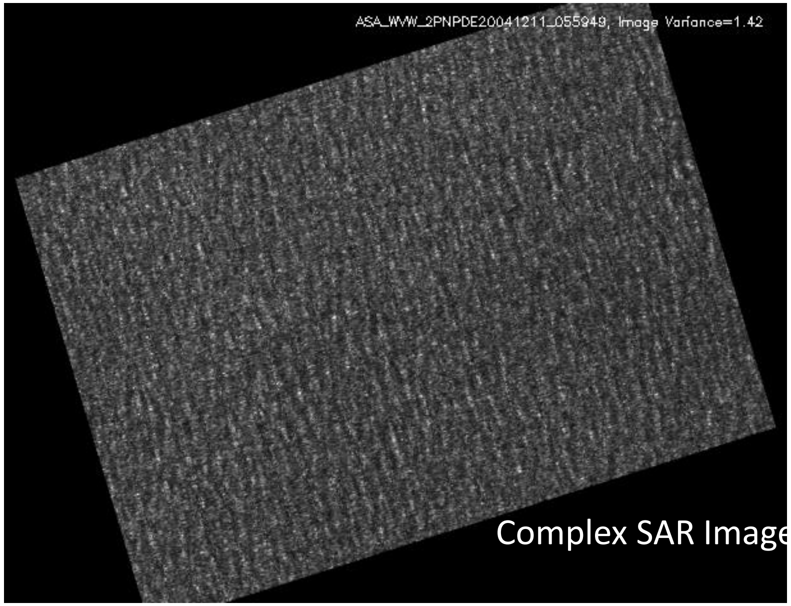






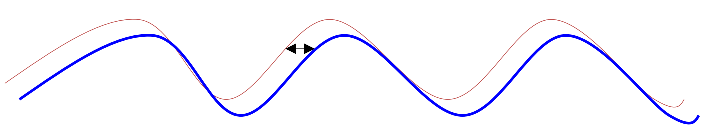
om Co- to Cross-Spectra Estimation: Ambiguity Removal





-Look Extraction
-Intensity Detection

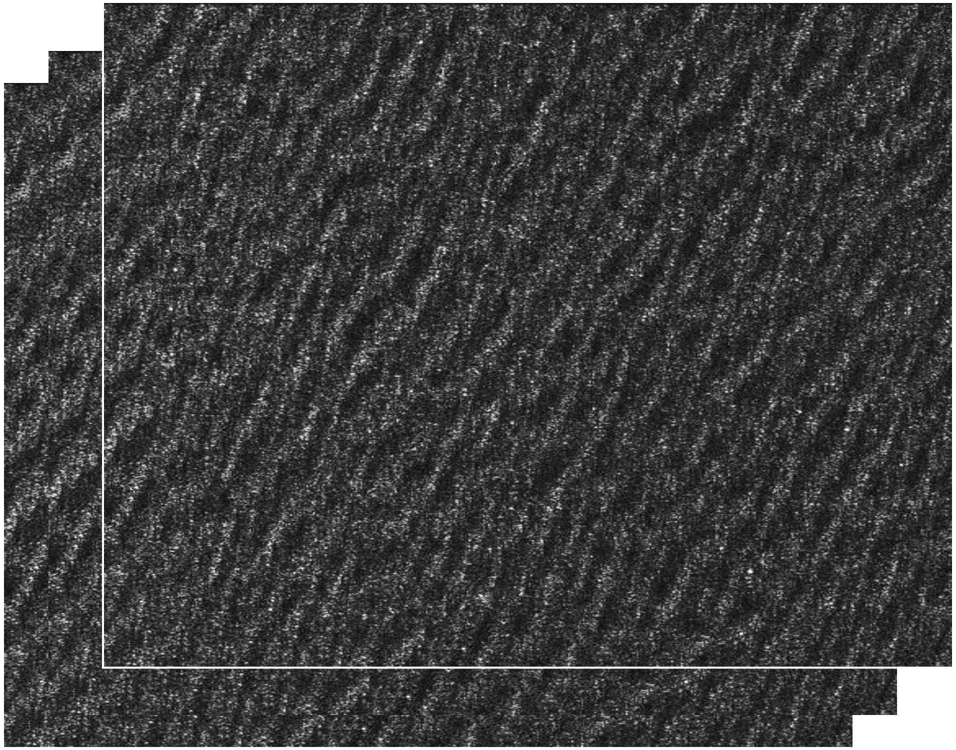
$$\Delta\varphi = \omega_k \cdot \tau \approx 10^o$$



phase term resolves wave propagation direction

Ambiquity removal

3 look intensity images

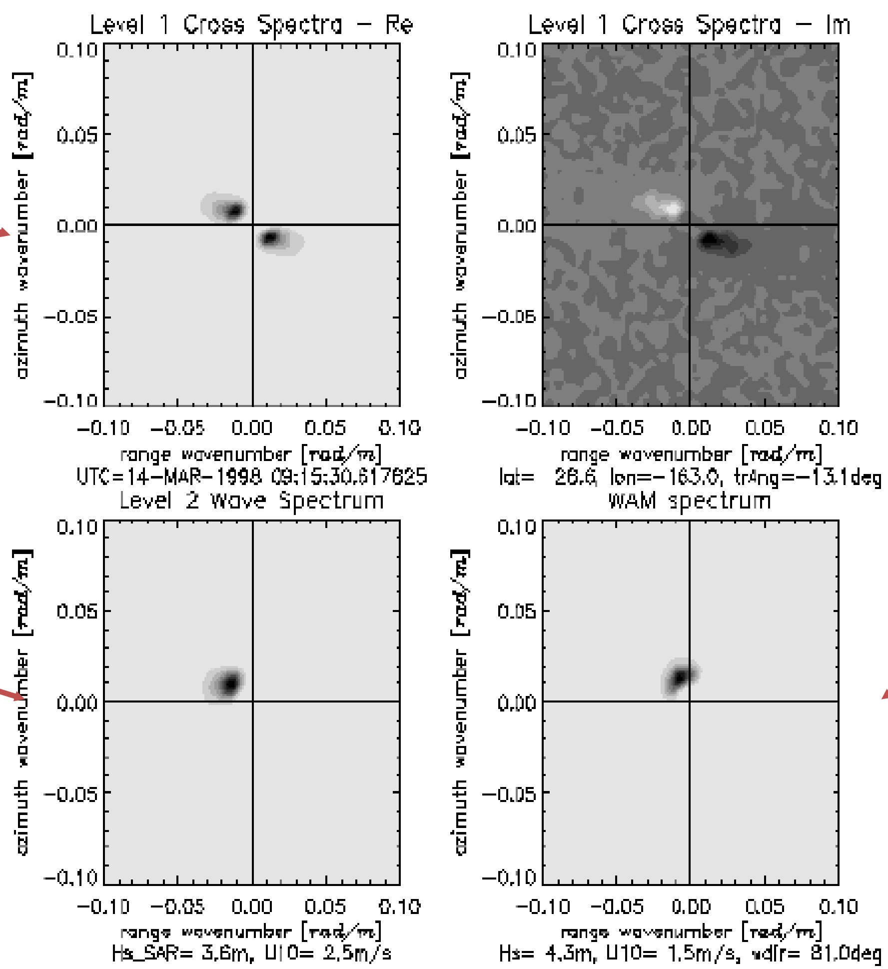


Spectral Estimation

Inversion to SAR Ocean Wave Spectra

SAR image cross-spectra

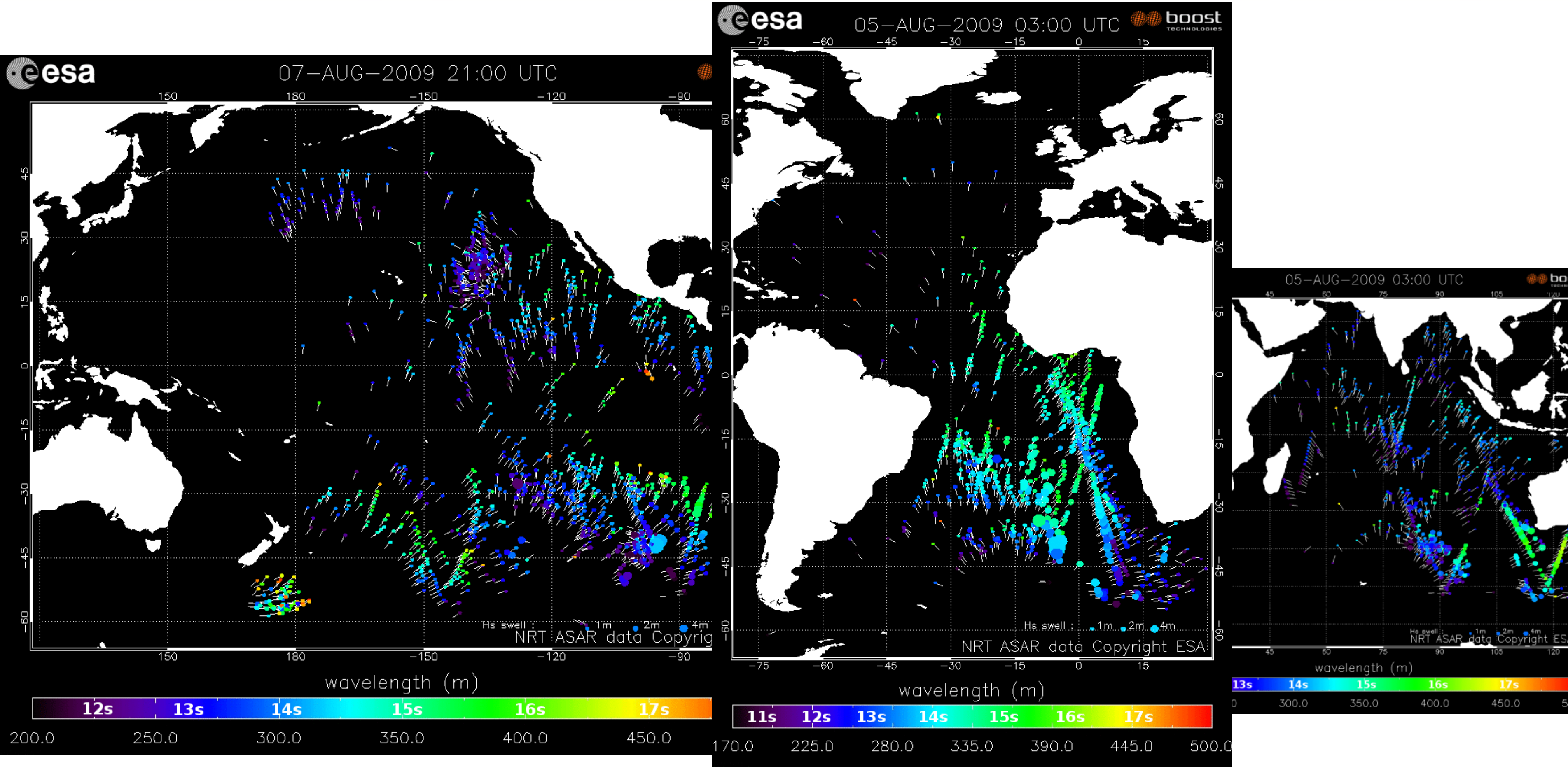
SAR ocean wave spectra



WAM (for comparison)

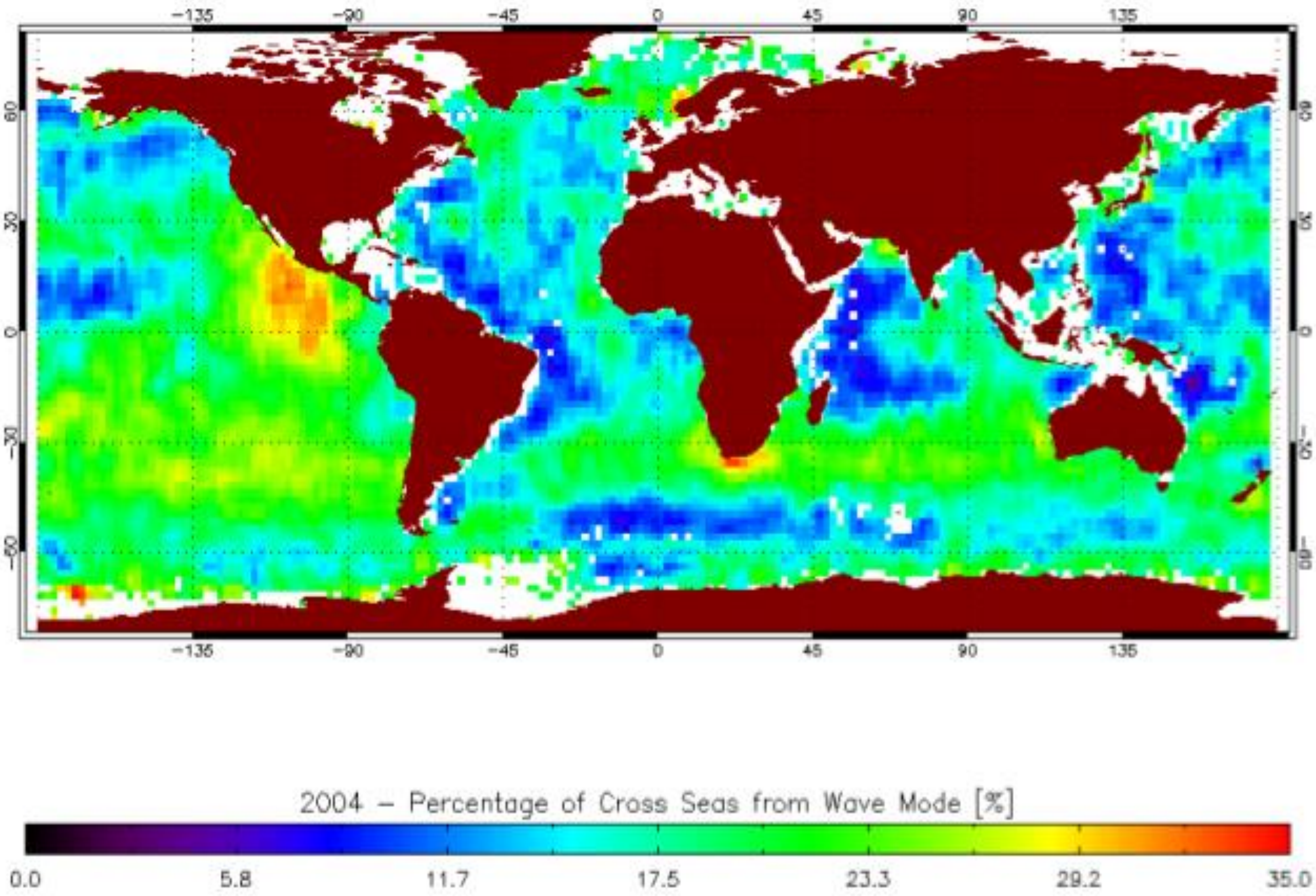
Courtesy NORUT

Swell propagation



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

Higer Order Products - Crossing Seas



CourtesyCLS-NORUT

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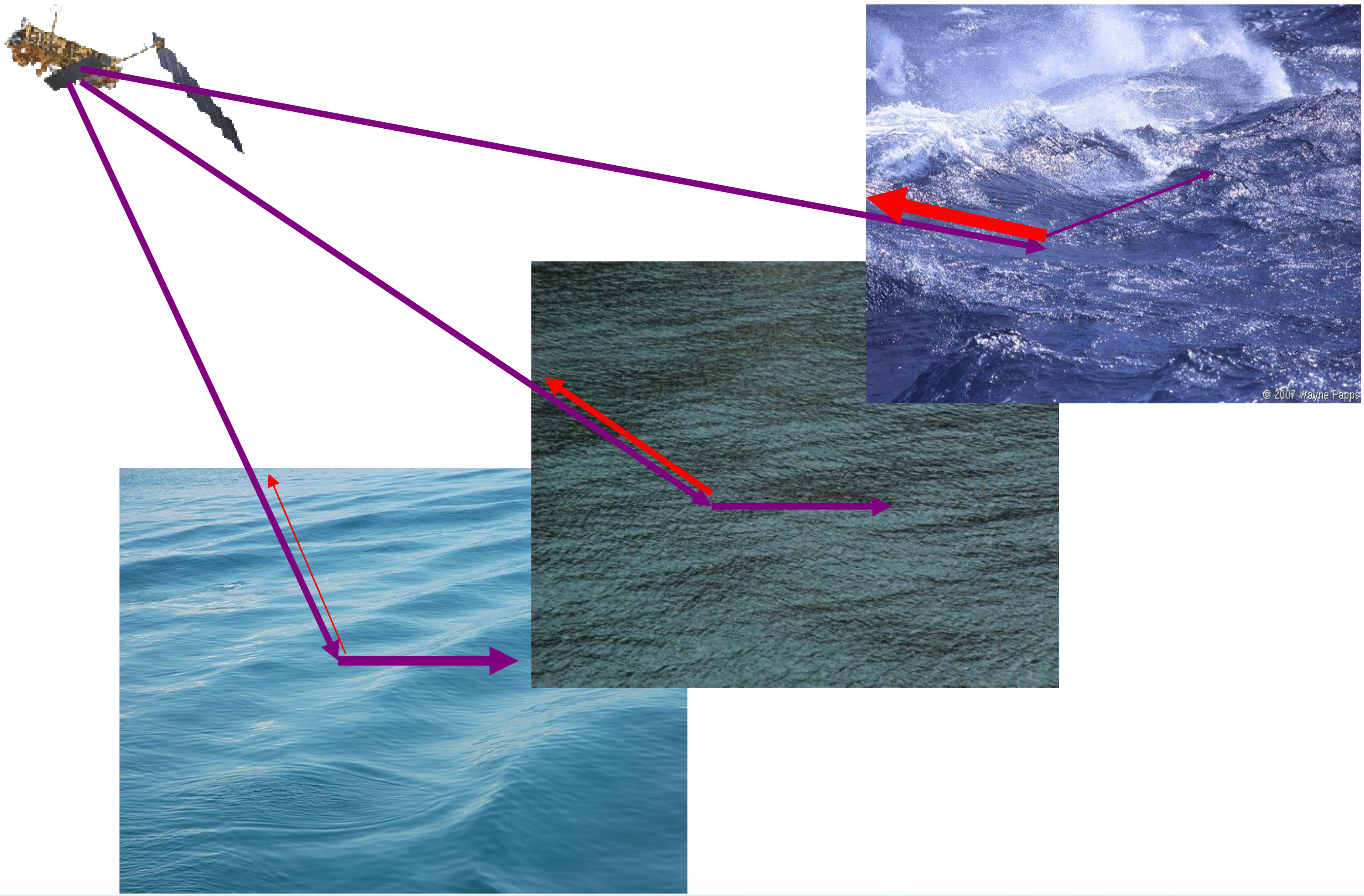
Radar backscatter increases with wind speed



SAR sensing of wind speed

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

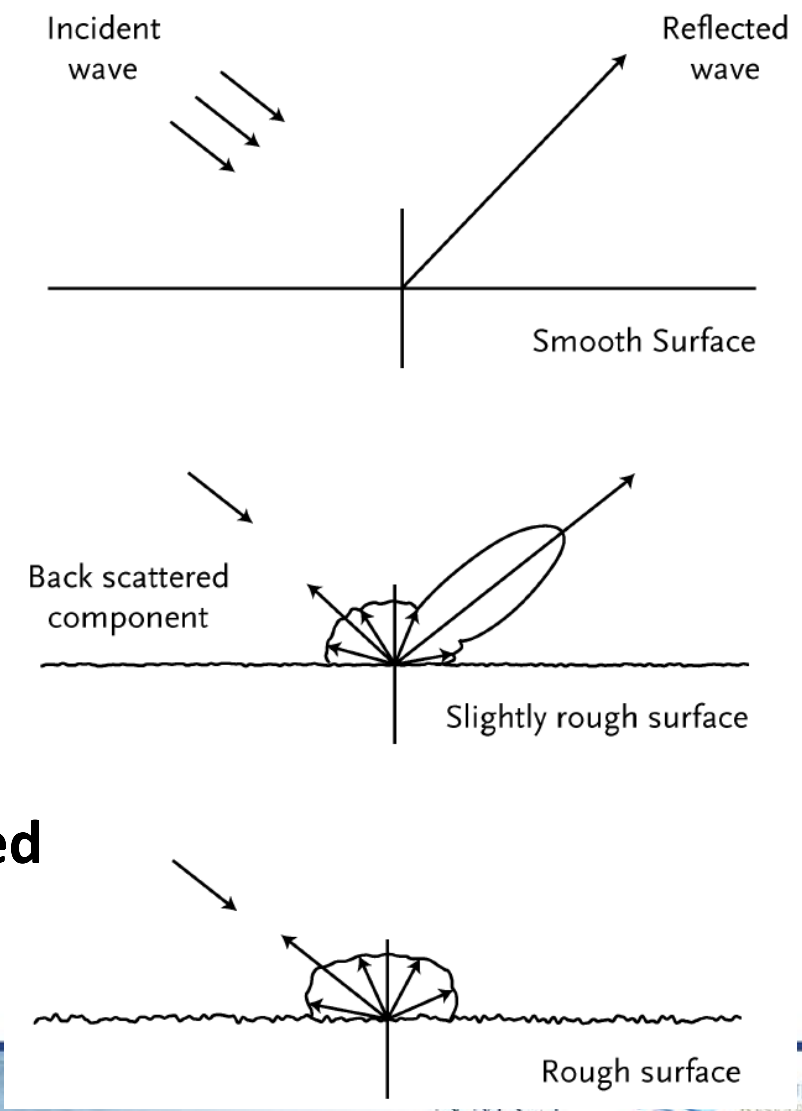
$$P_r = (P_t/4\pi R^2)\, G\, (\sigma/4\pi R^2)\, A$$

measured = incident x reflected

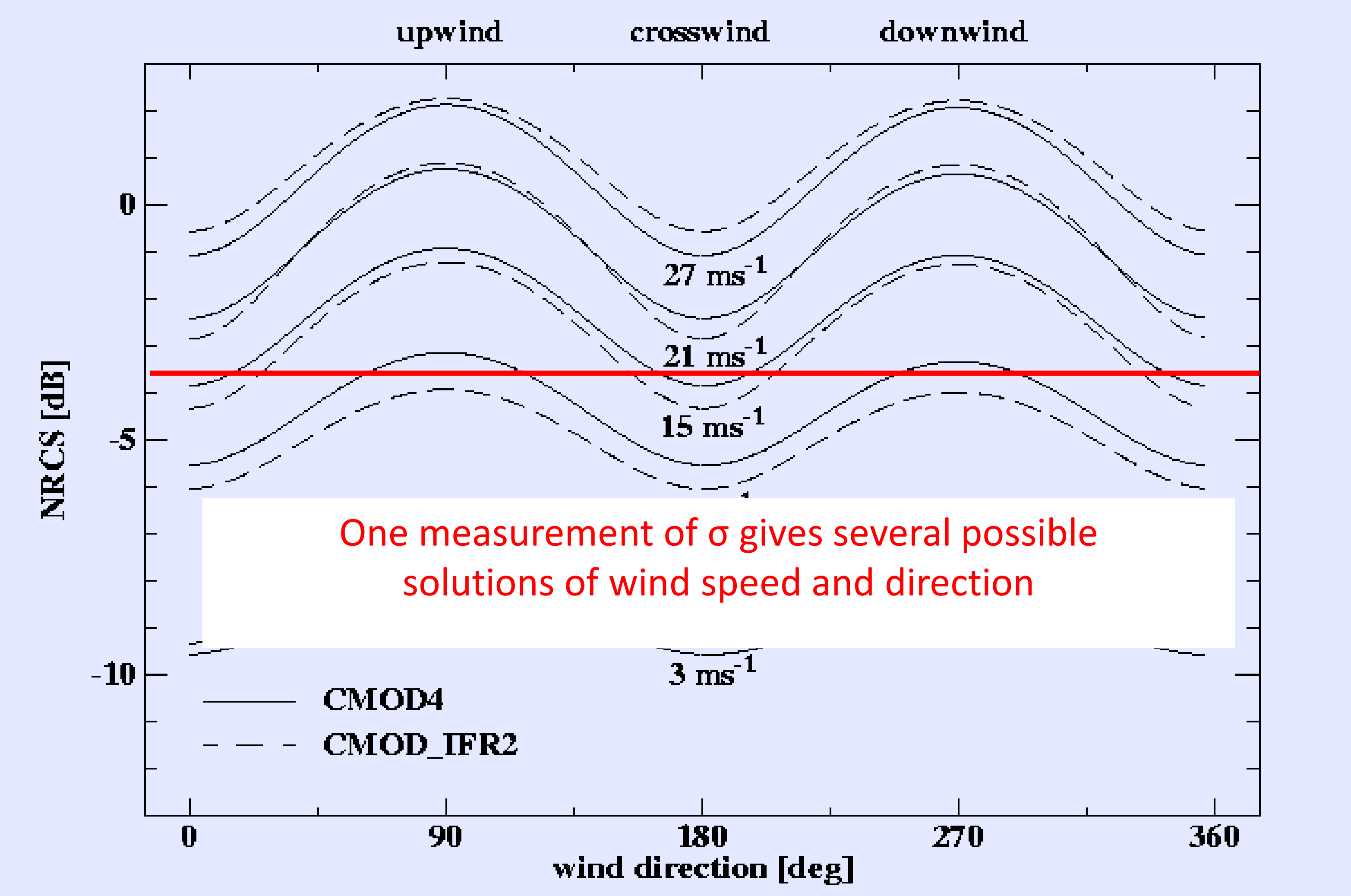
G = antenna gain, A = antenna area,
σ = radar cross section, R = range distance

σ is a measure of the surface roughness

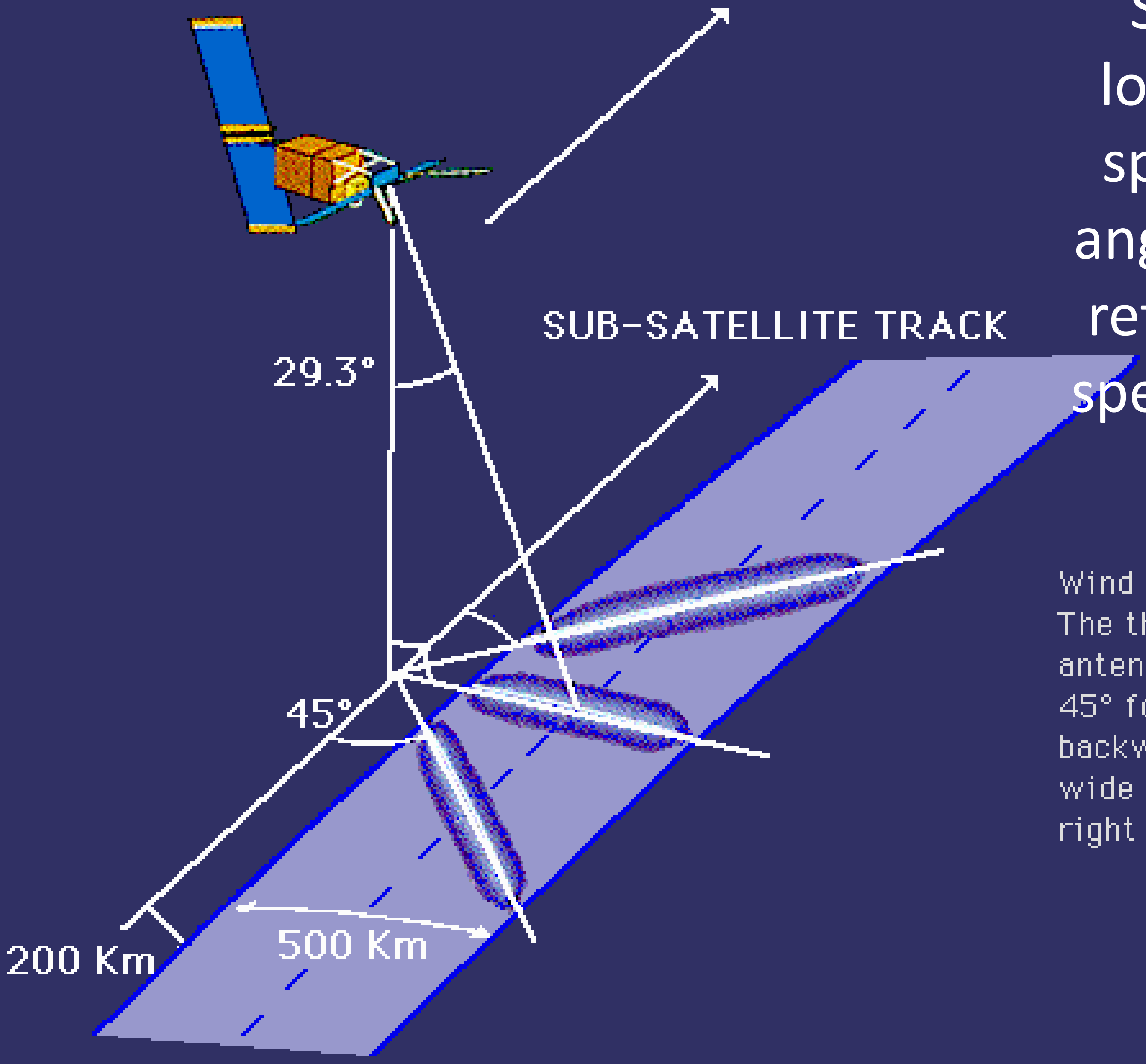
σ is well correlated with wind speed



σ as function of wind direction for various wind speeds



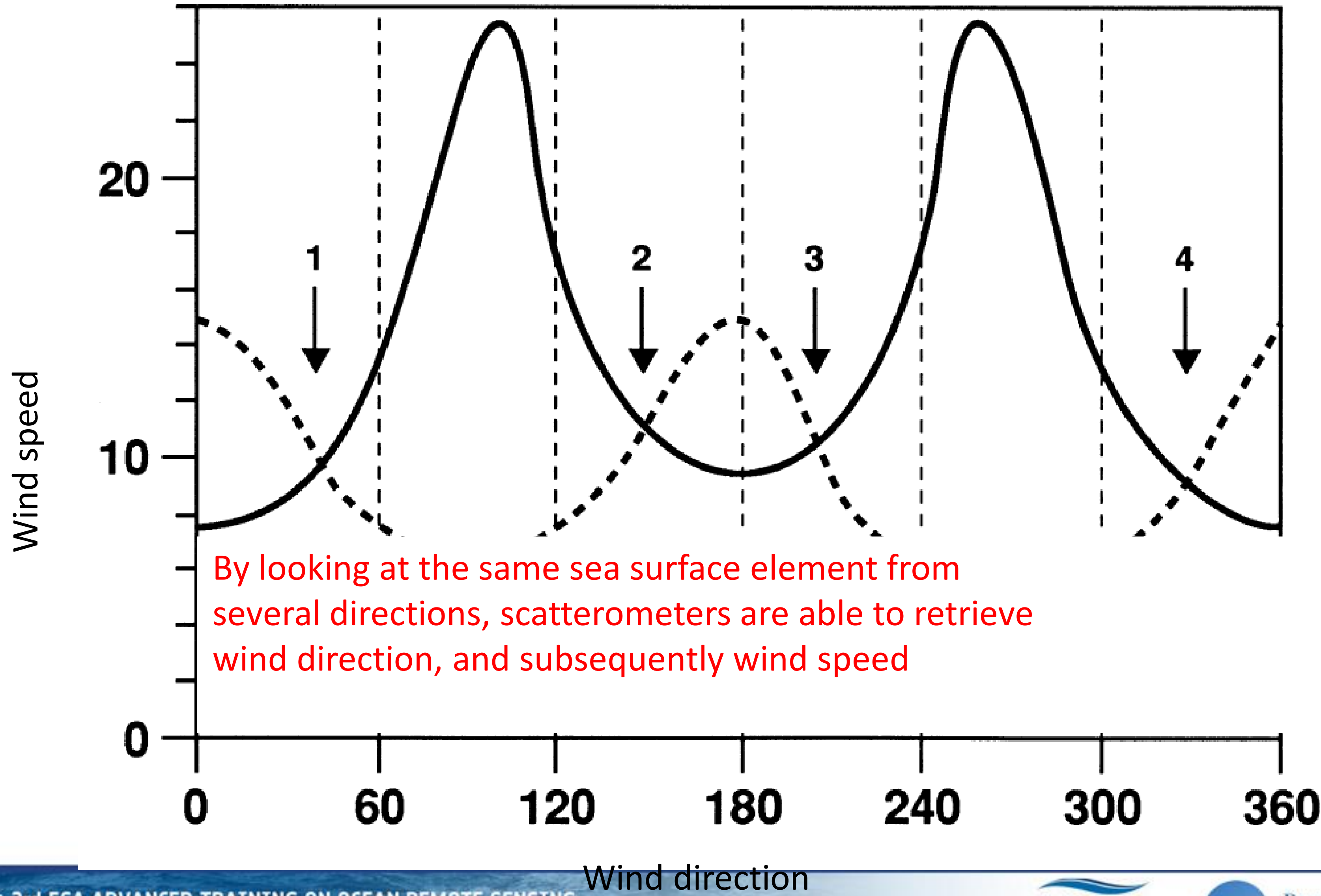
Wind Scatterometer Geometry



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.

Multi-antenna solution

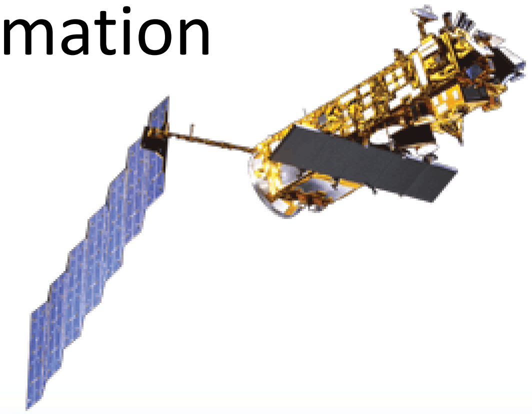


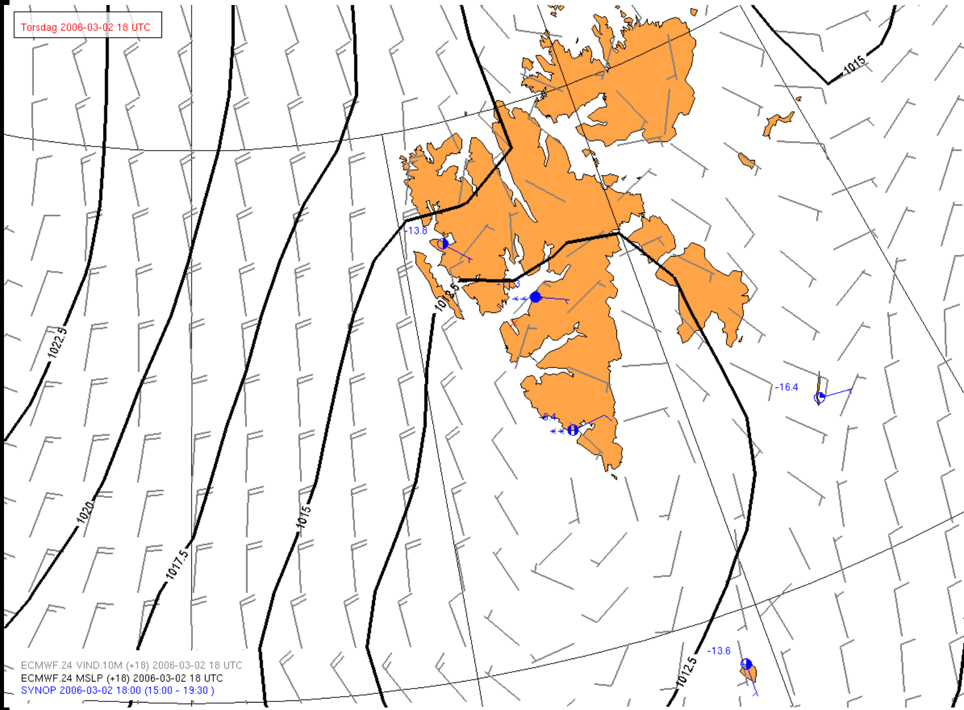
By looking at the same sea surface element from several directions, scatterometers are able to retrieve wind direction, and subsequently wind speed

SAR's have only one antenna

- 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

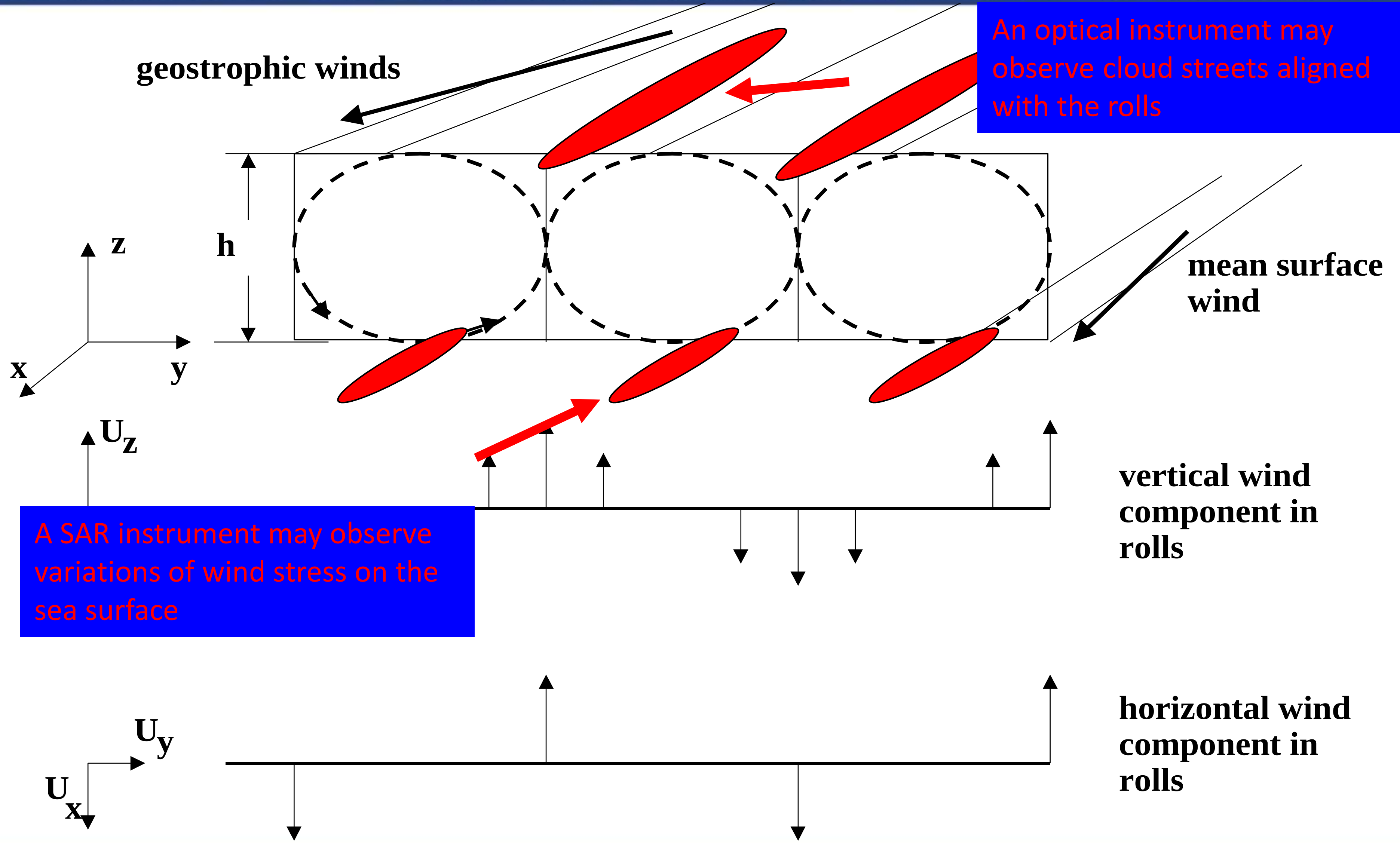




Envisat ASAR V/V ASCENDING

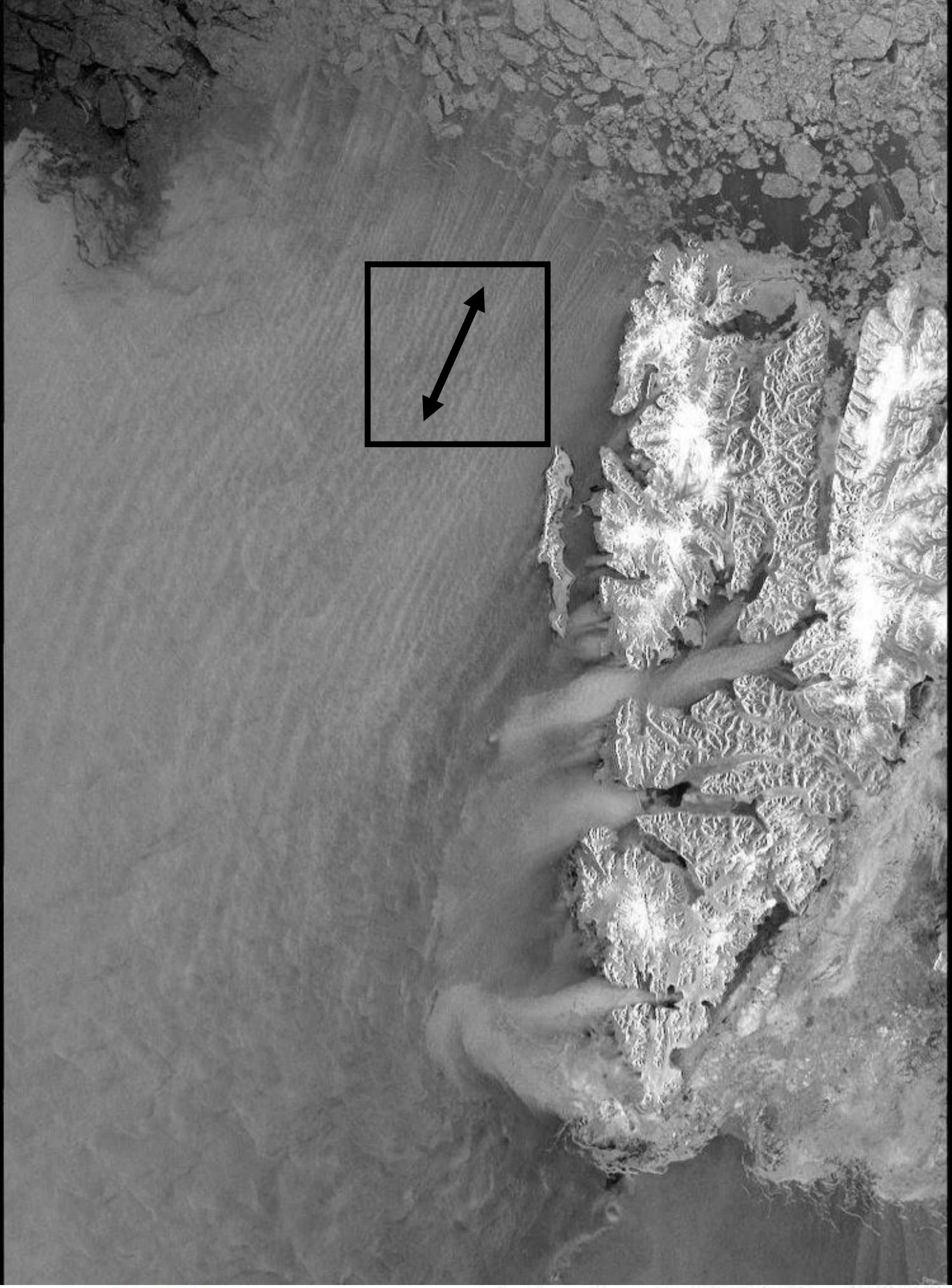
02-MAR-2006 19:43:49

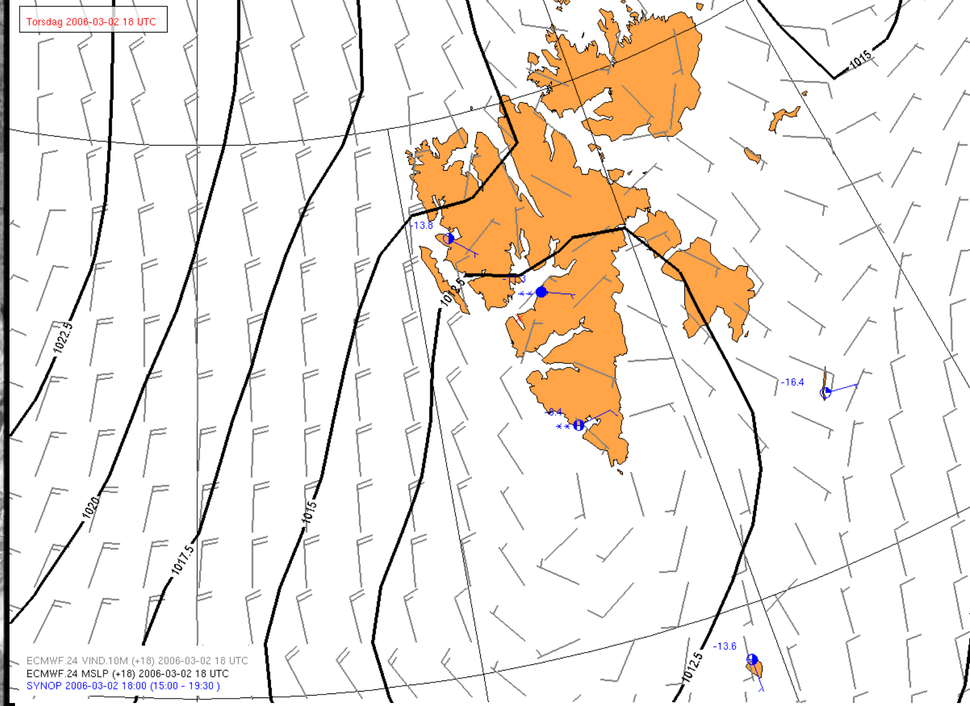
Atmospheric Boundary layer rolls

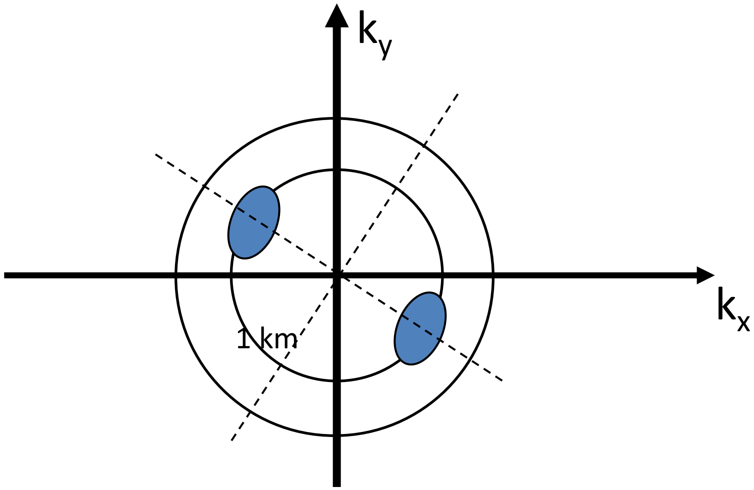


An optical instrument may observe cloud streets aligned with the rolls

A SAR instrument may observe variations of wind stress on the sea surface







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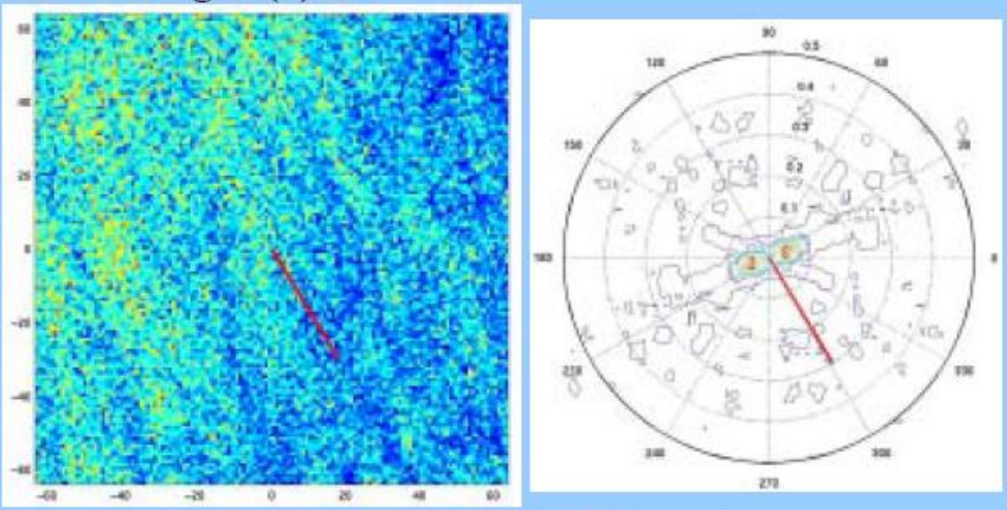
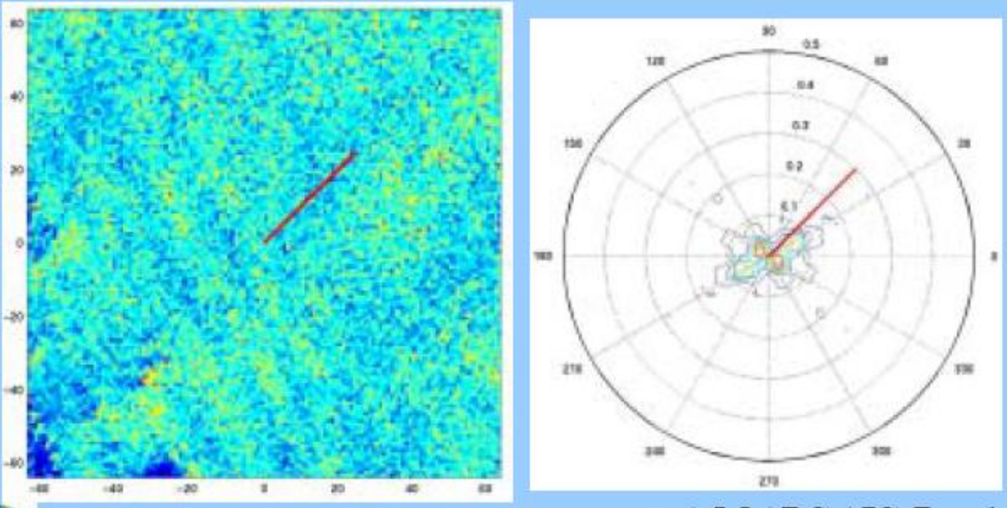
High-Resolution Wind Fields from SAR Imagery

Sub-image 1(a): ERS-2 SAR 22 June 1996



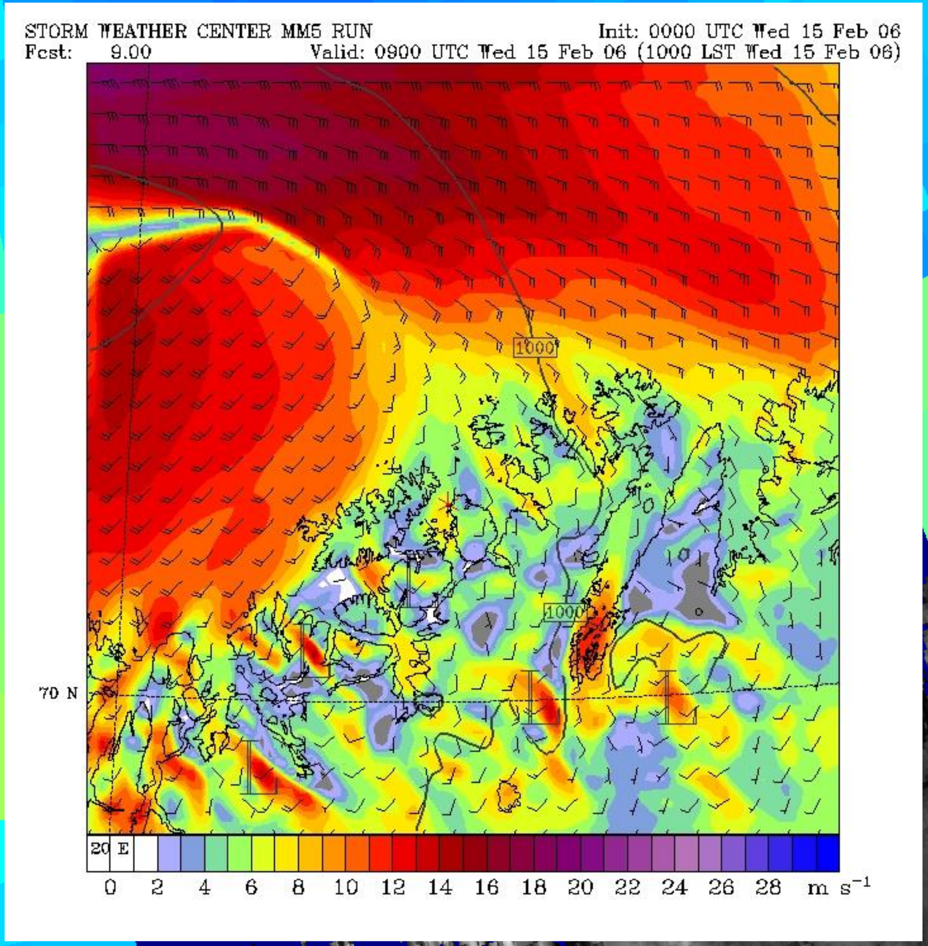
SUCCESS: The wind direction from the algorithm is correctly chosen along the direction of the wind streaks.

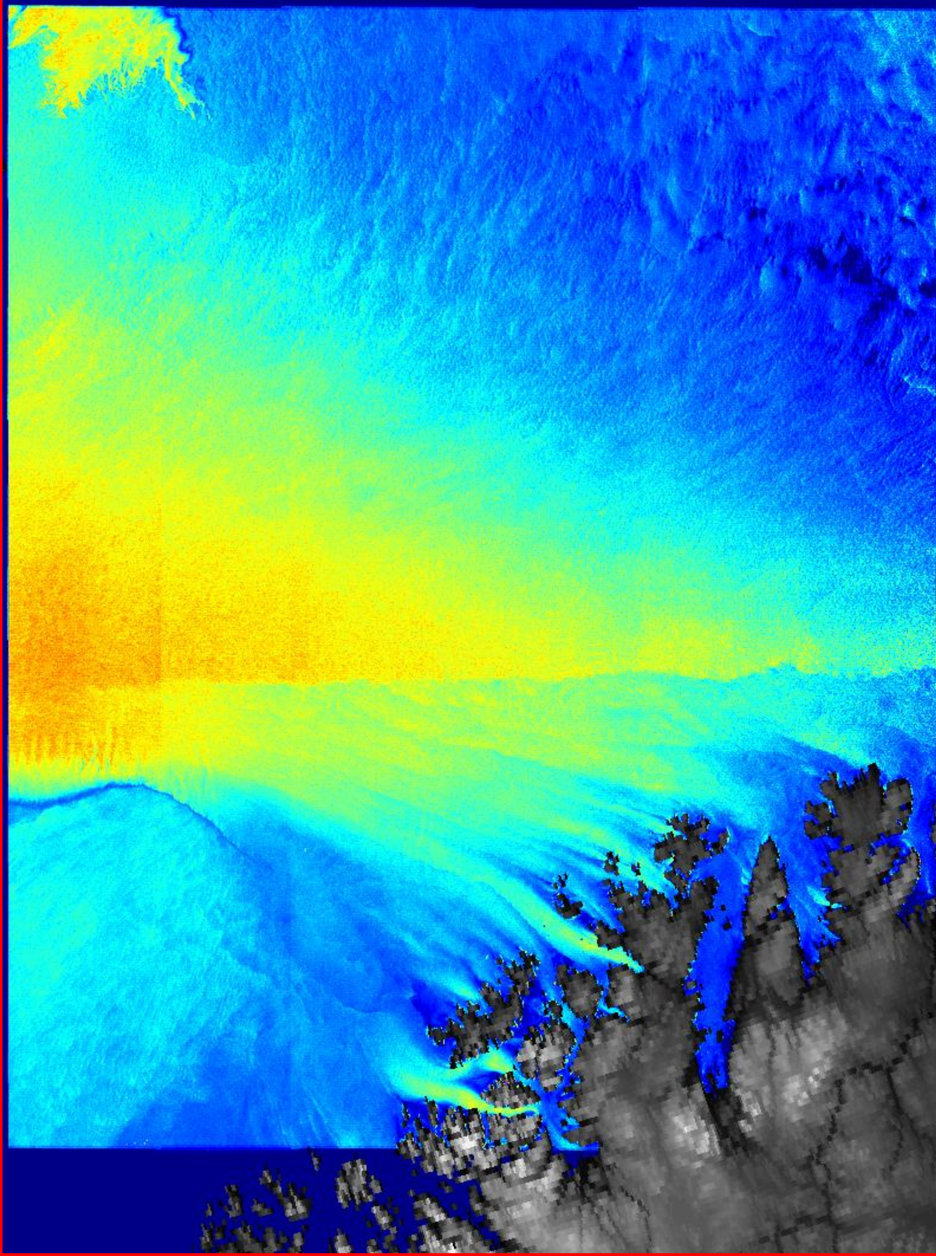
Sub-image 1(b): ERS-2 SAR 22 June 1996



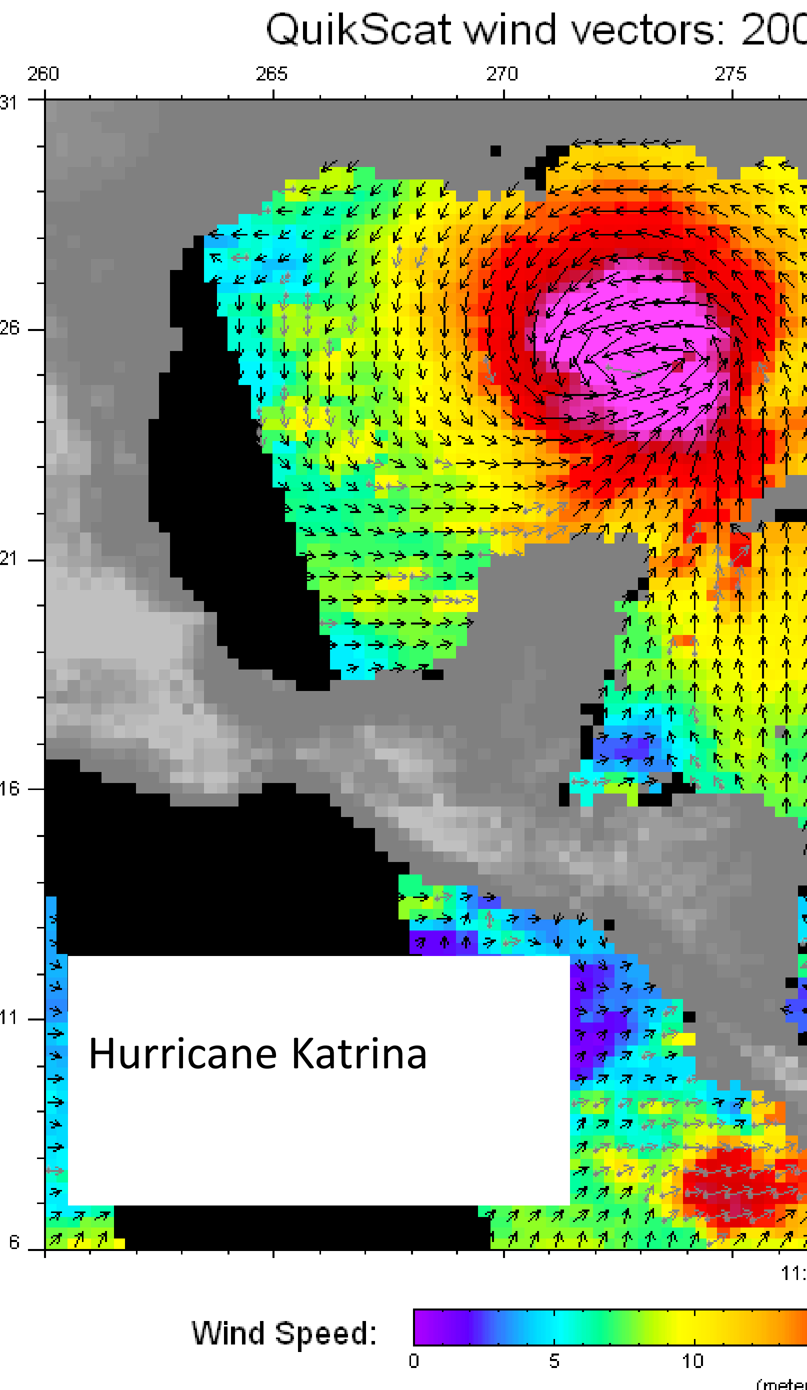
FAILURE: In this area, atmospheric gravity waves and atmospheric boundary layer rolls give two different maxima perpendicular to each other in the image spectrum. The wind direction automatically chosen by the algorithm is parallel to the gravity waves. This is corrected by an operator before the final wind map is produced.

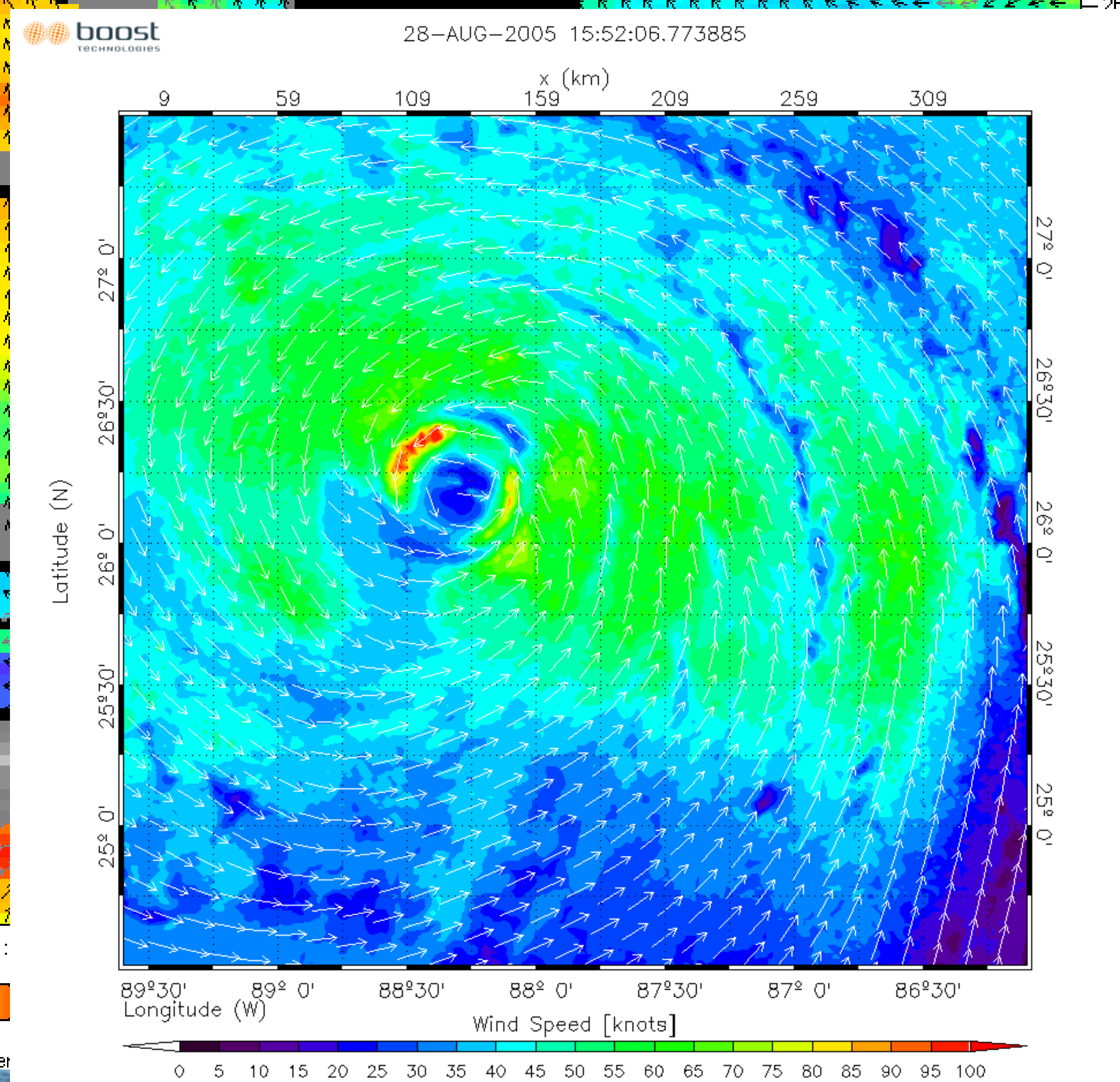
A MARSAIS Product


STORM WEATHER CENTER MM5 RUN
Init: 0000 UTC Wed 15 Feb 06
Fcst: 9.00
Valid: 0900 UTC Wed 15 Feb 06 (1000 LST Wed 15 Feb 06)
1000
1000
70 N
20 E
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 m s-1

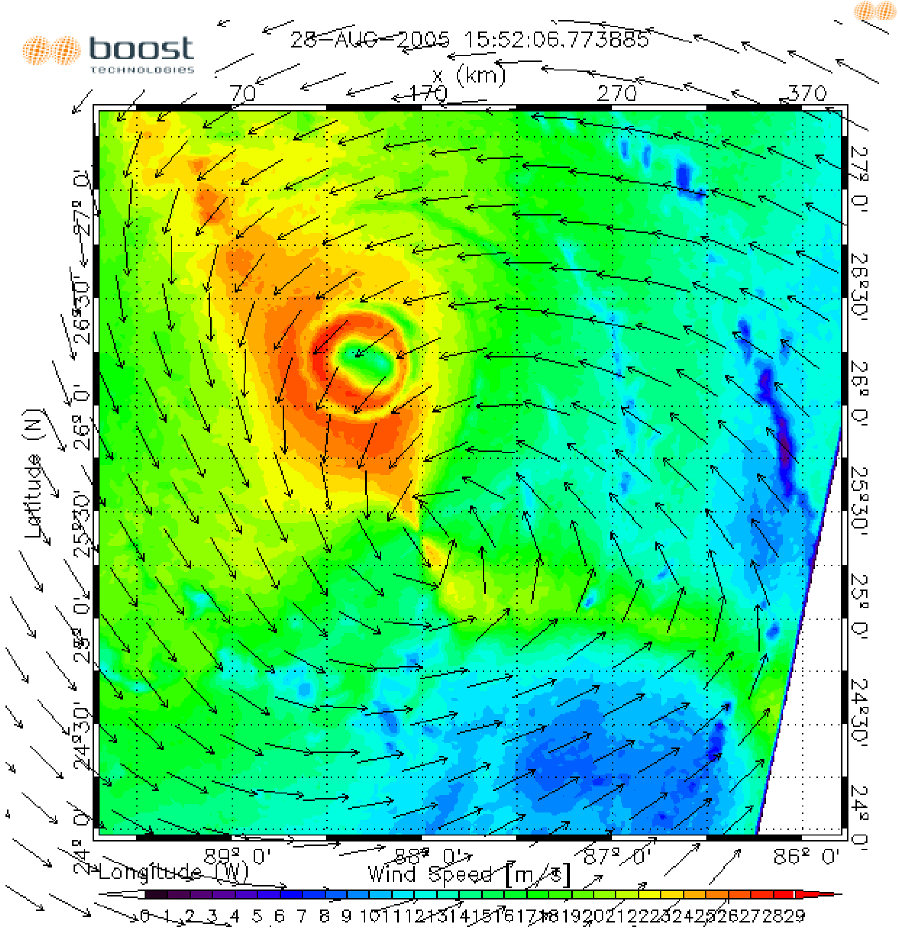


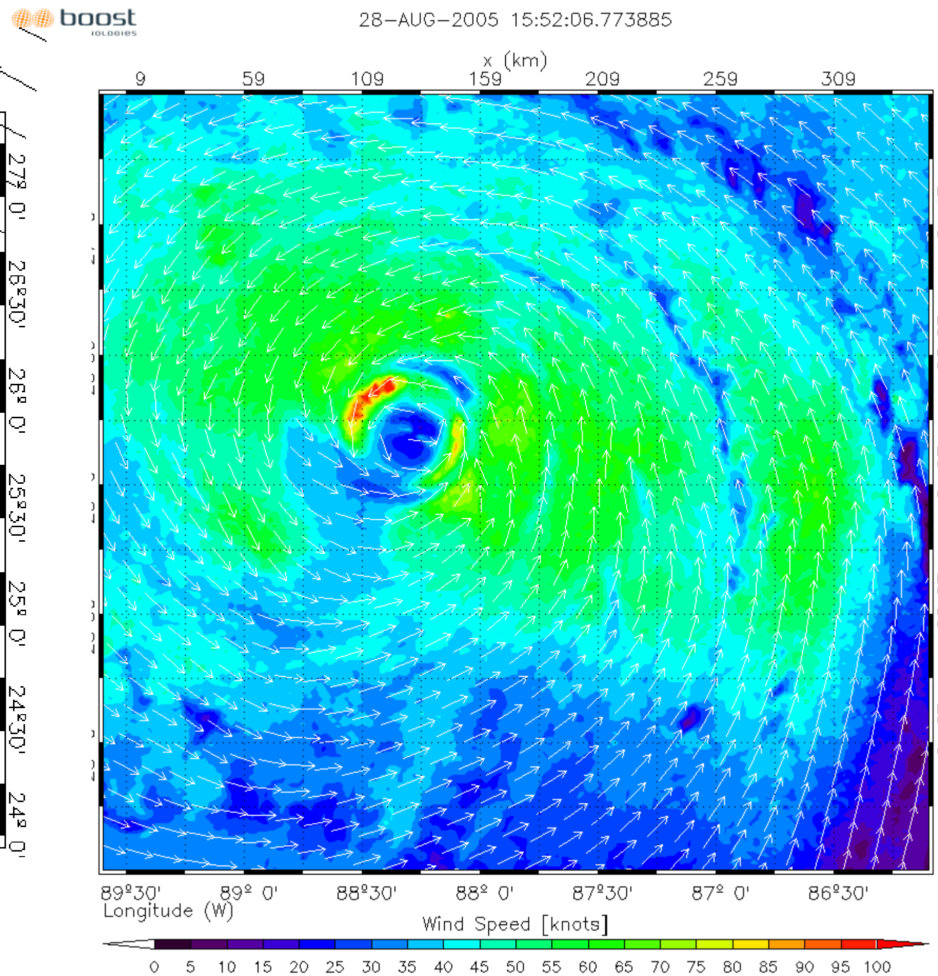
Hurricane Katrina





Hurricane Katrina, 28 Aug 2005
Importance of using correct wind direction





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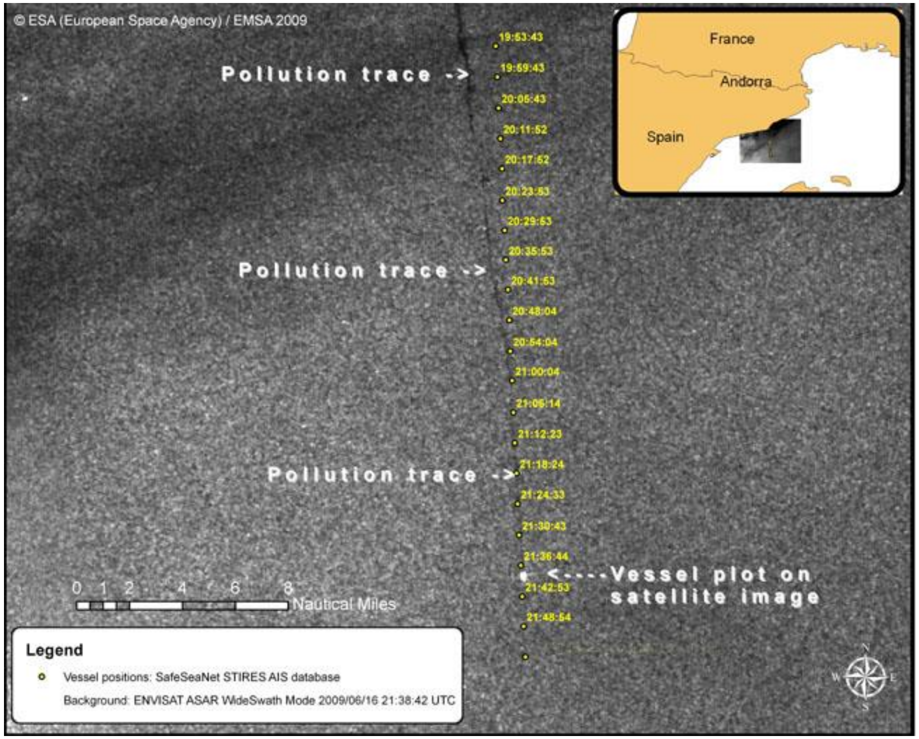
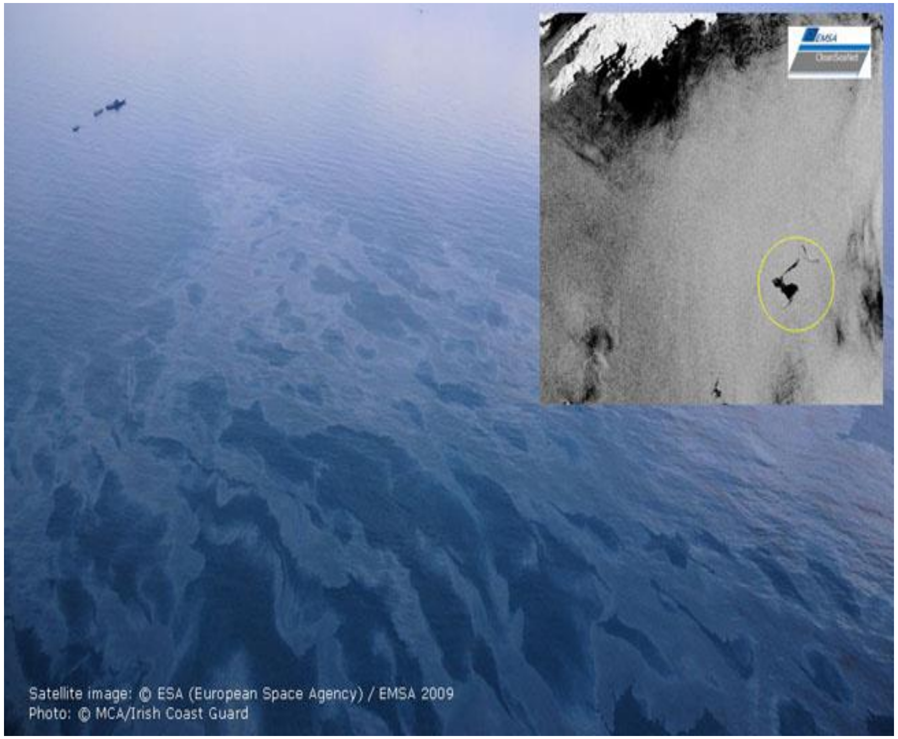
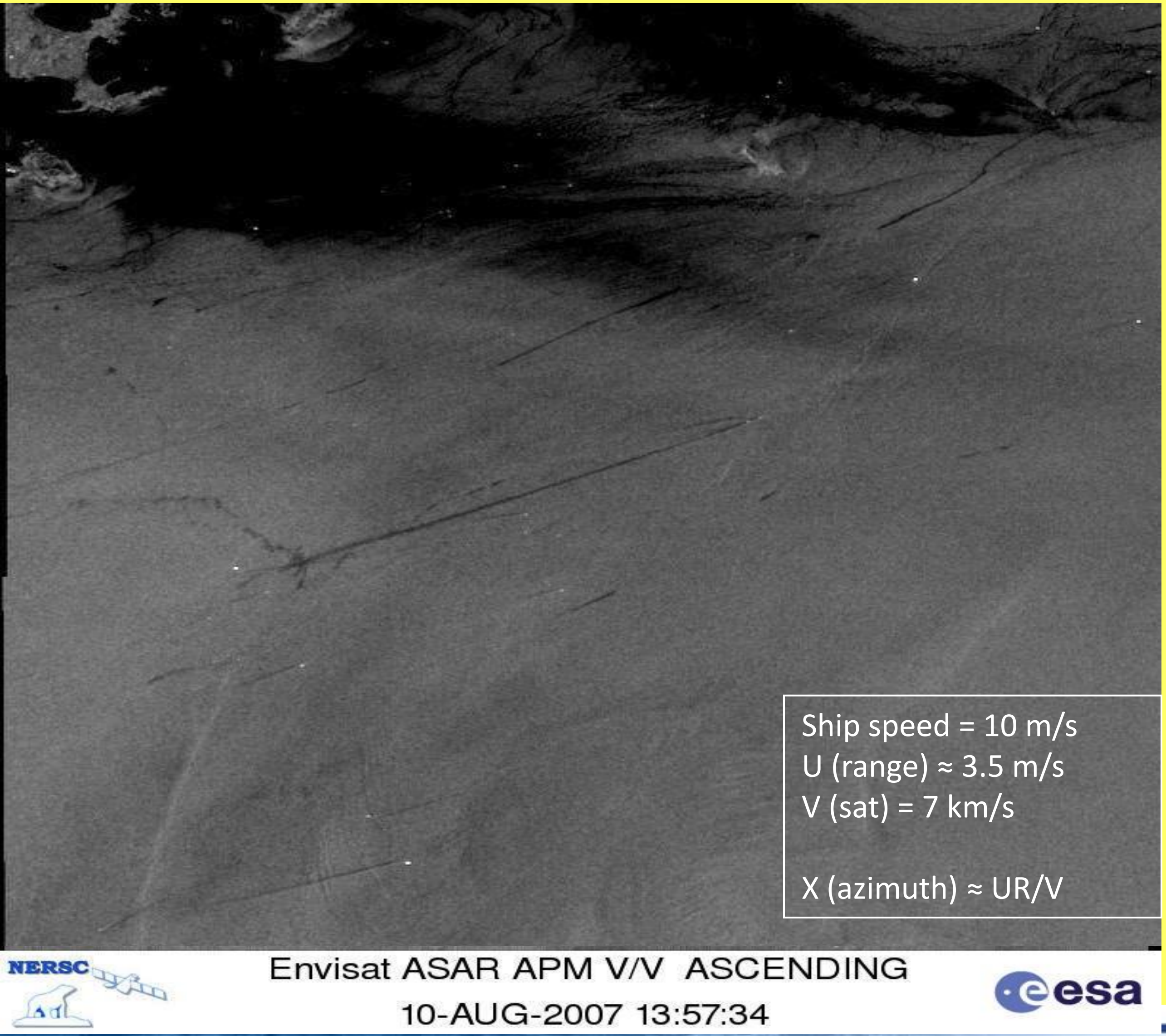
OIL SPILLS


© ESA (European Space Agency) / EMSA 2009
Pollution trace ->
Pollution trace ->
Pollution trace ->
<----Vessel plot on satellite image
France
Andorra
Spain
Nautical Miles
Legend
Vessel positions: SafeSeaNet STIRES AIS database
Background: ENVISAT ASAR WideSwath Mode 2009/06/16 21:38:42 UTC

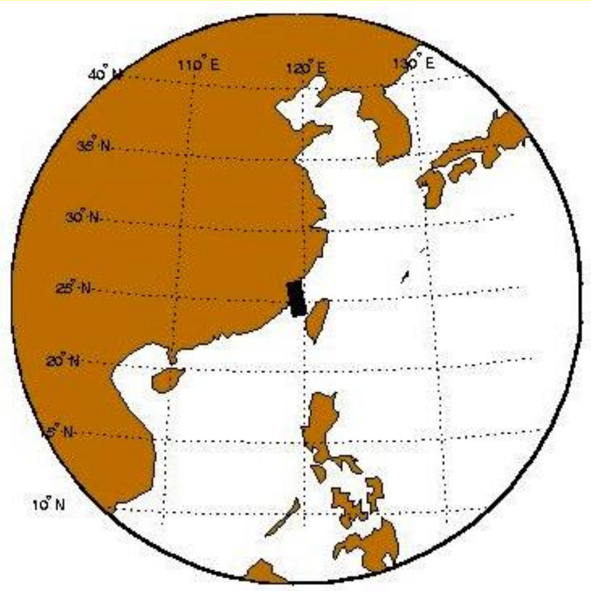

Satellite image: © ESA (European Space Agency) / EMSA 2009
Photo: © MCA/Irish Coast Guard

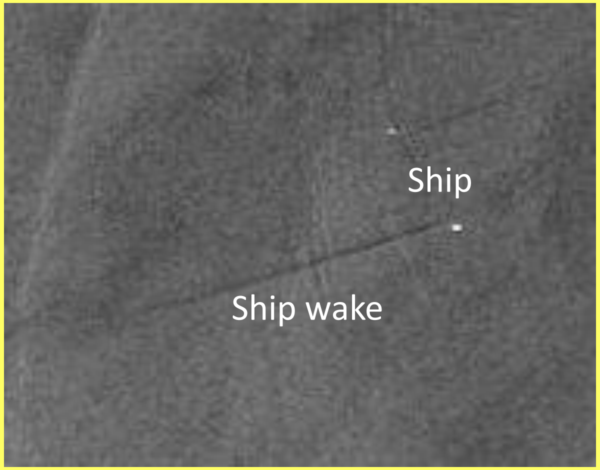
Ships and Ship Wakes - Oil spill?



Ship speed = 10 m/s
U (range) ≈ 3.5 m/s
V (sat) = 7 km/s

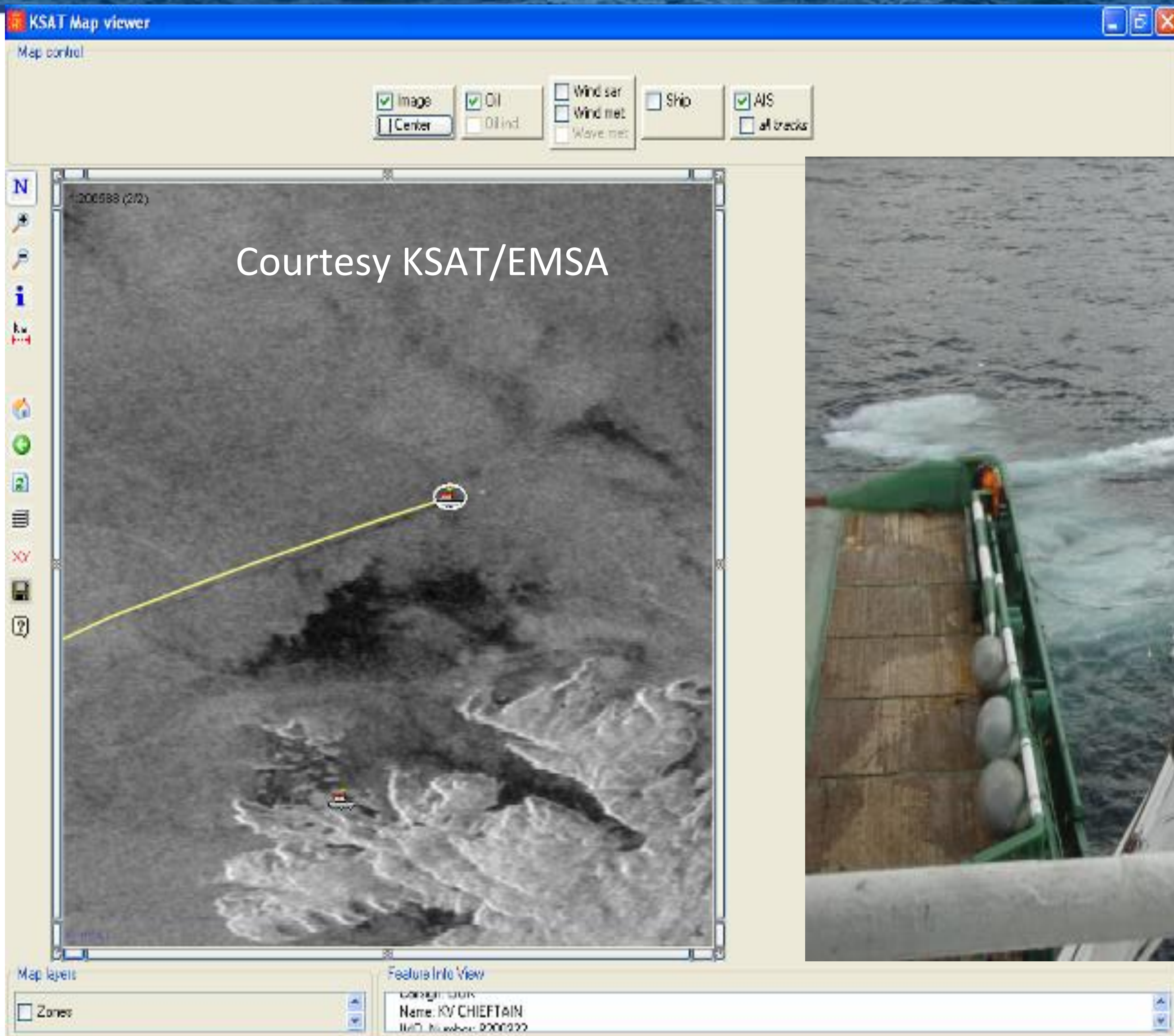
X (azimuth) ≈ UR/V



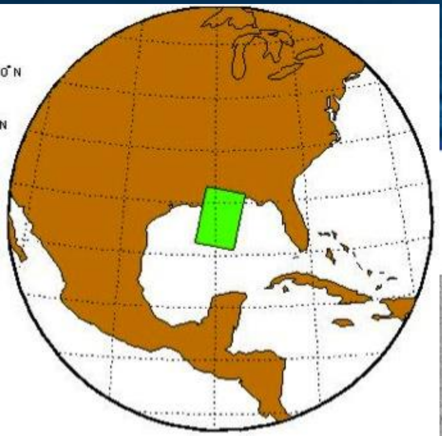


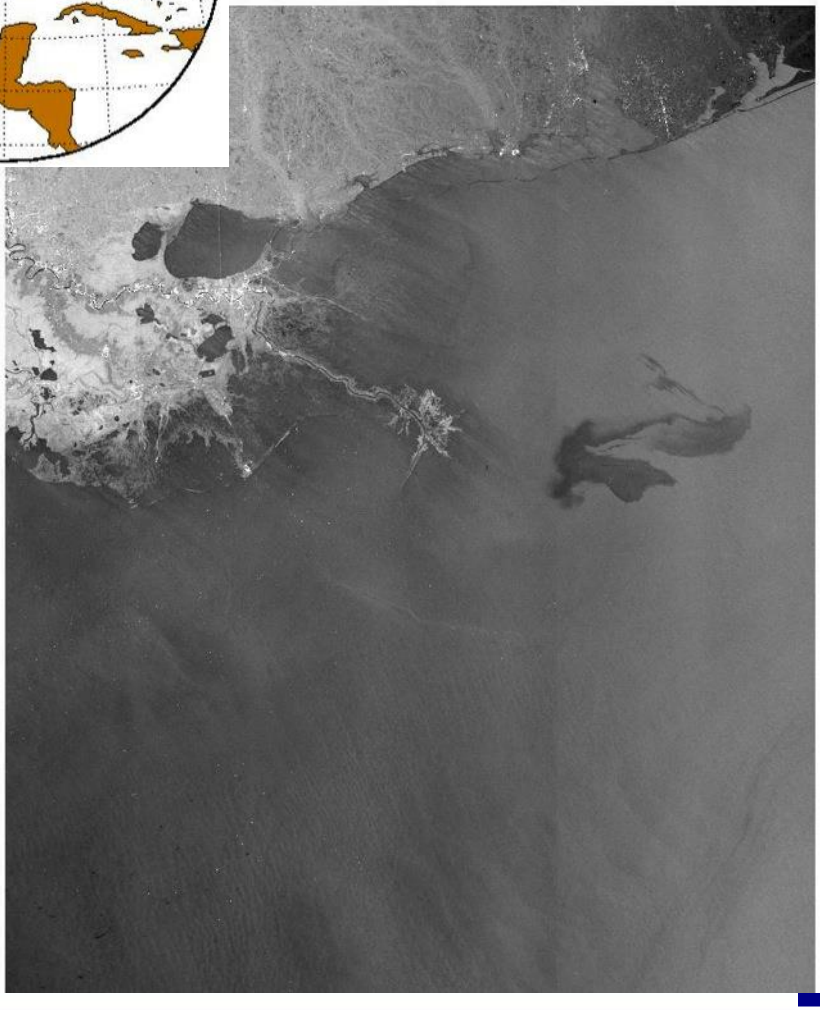
Black tail – but not always a real pollution

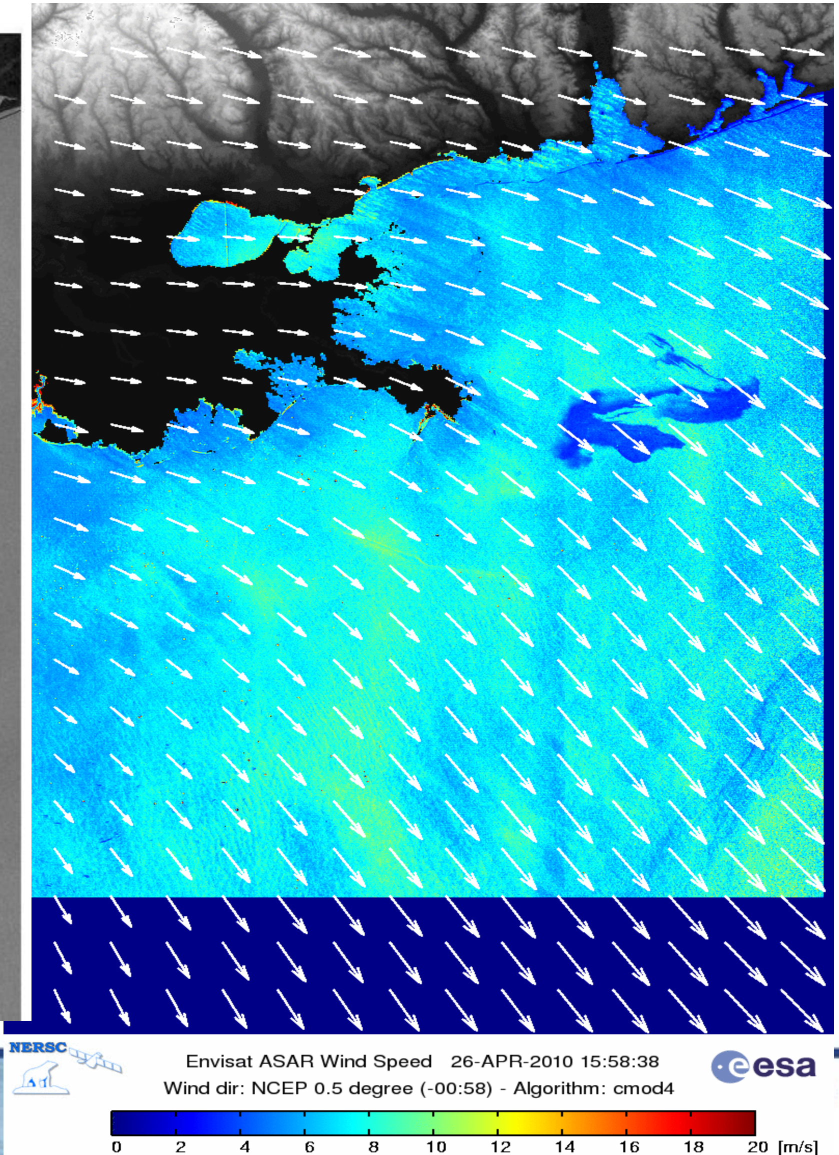
Towing of a dead whale



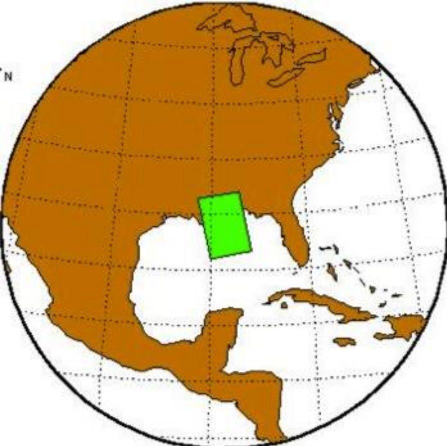
Oil spill in the Gulf of Mexico

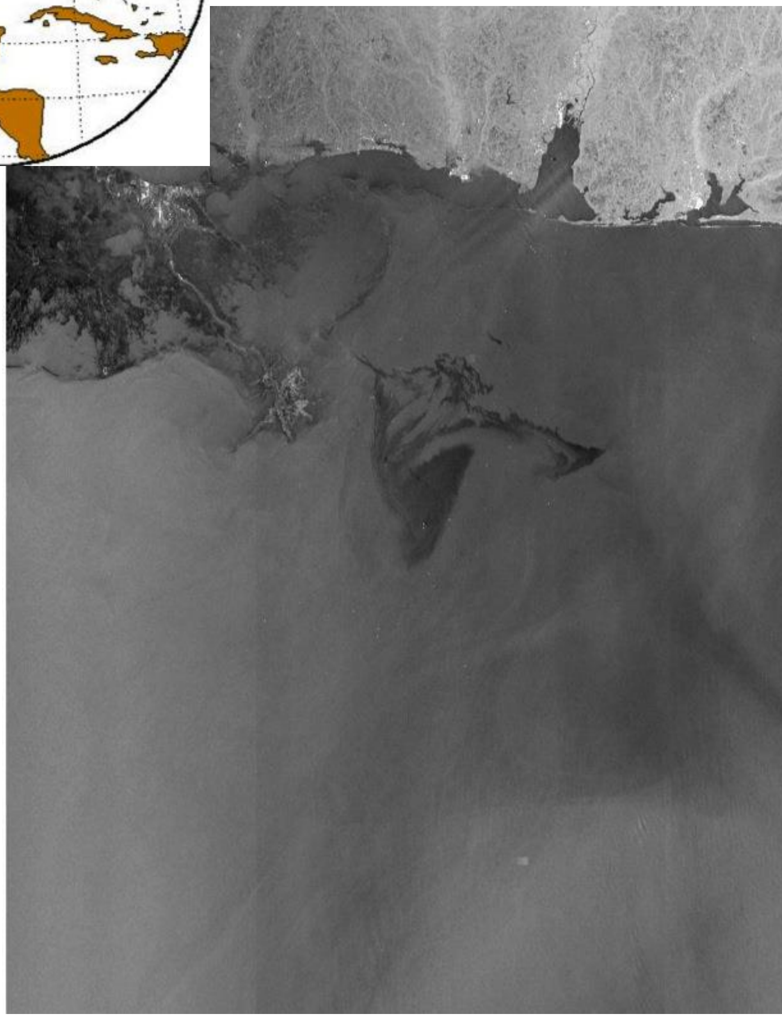


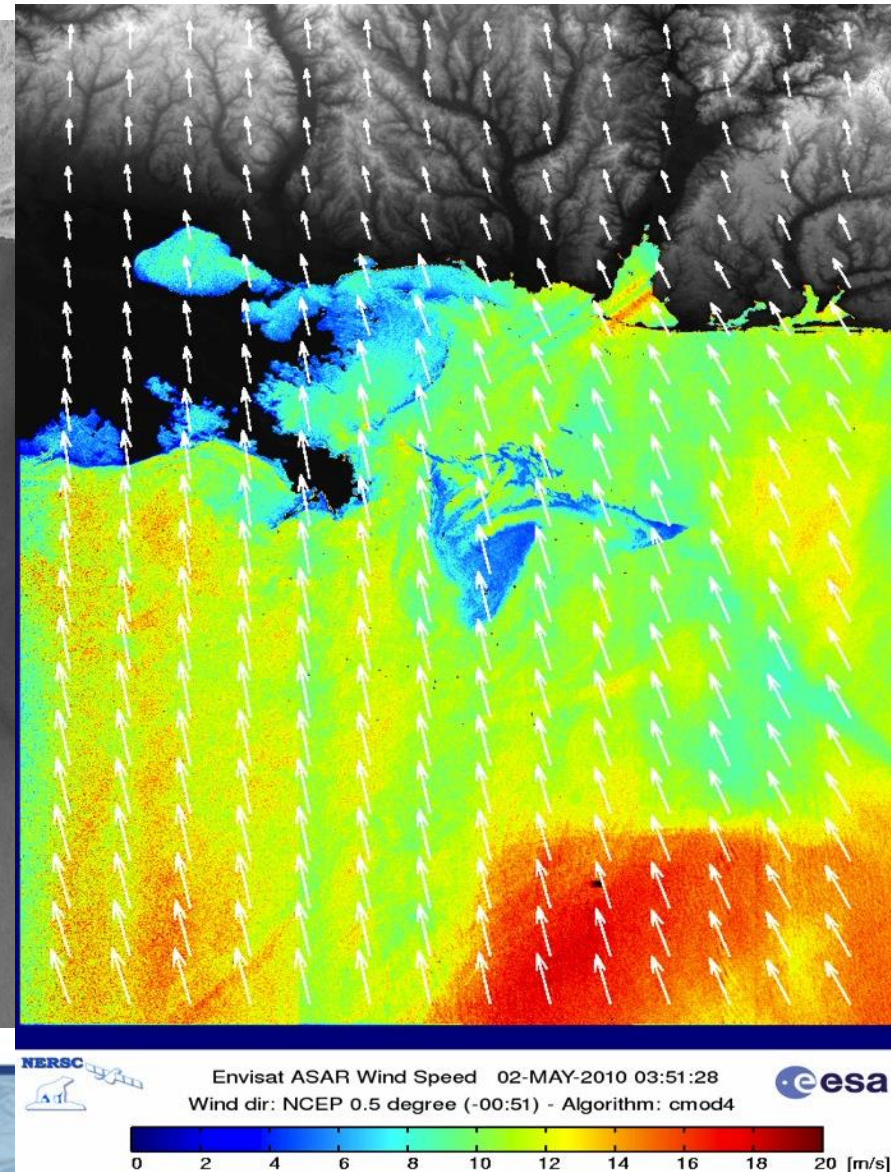




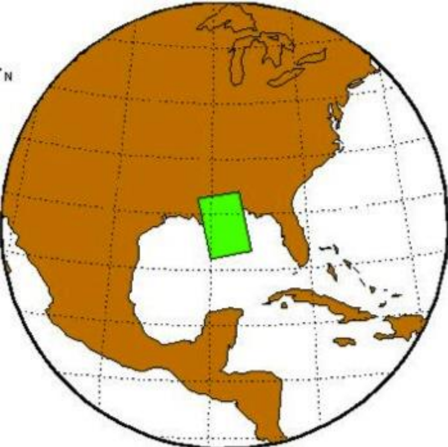
Oil spill in the Gulf of Mexico

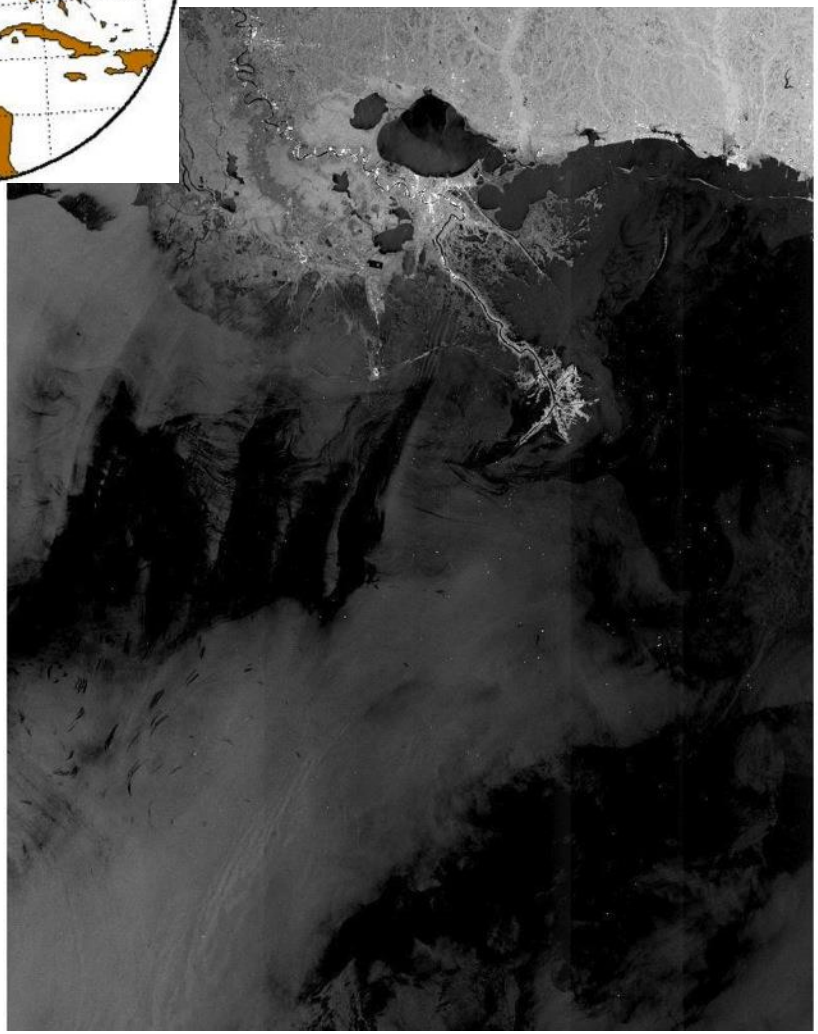


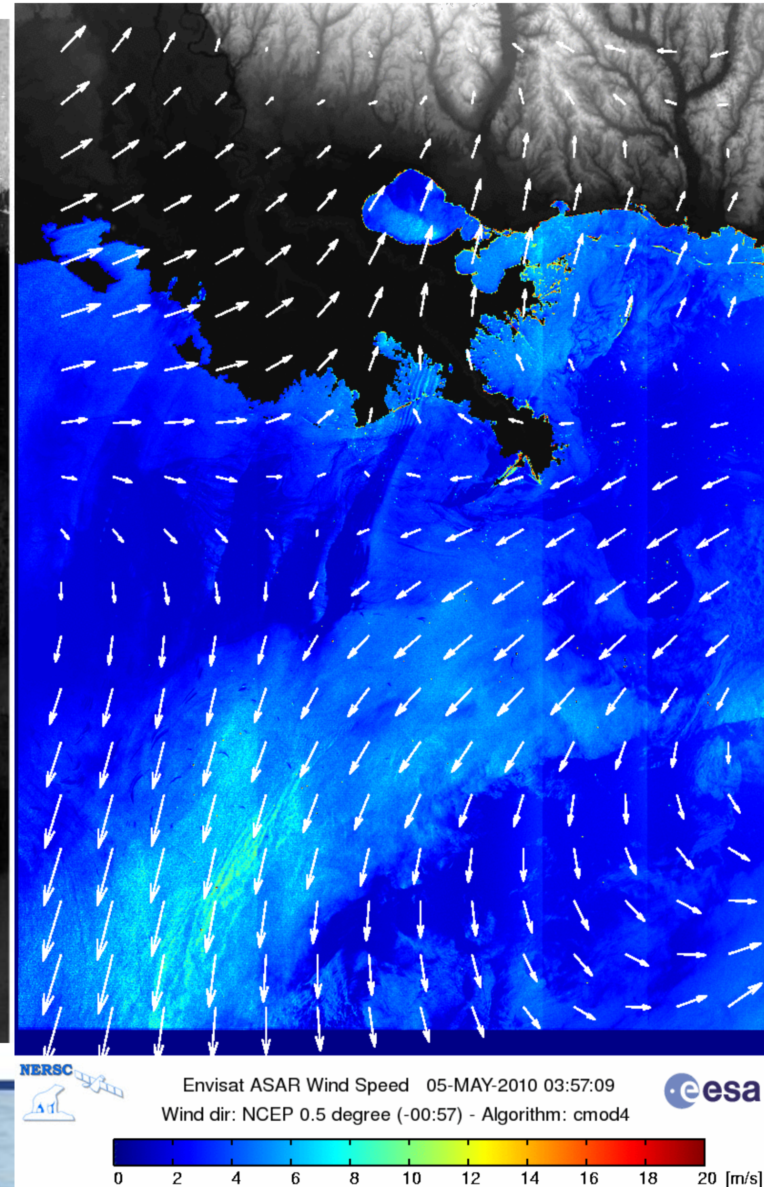




Oil spill in the Gulf of Mexico







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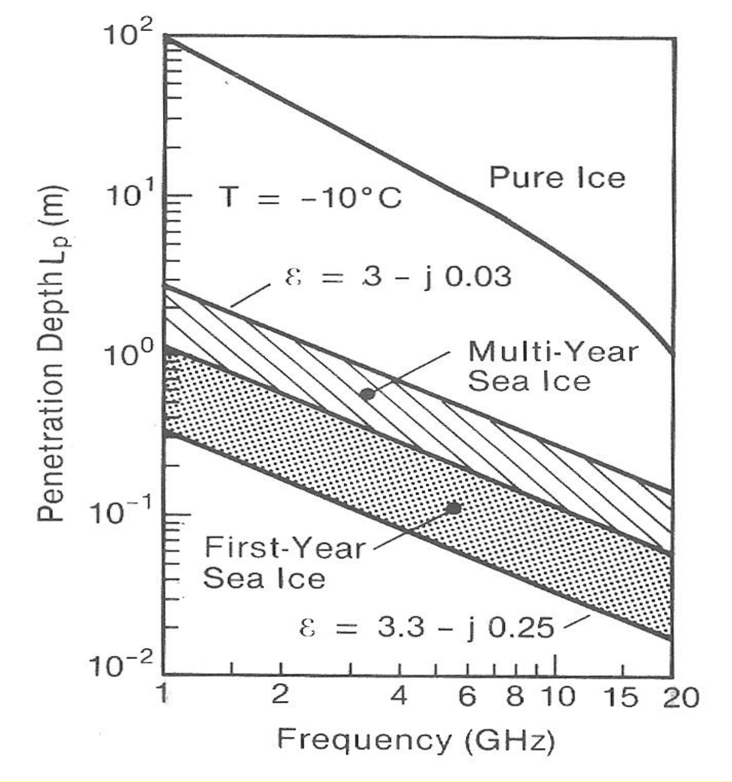
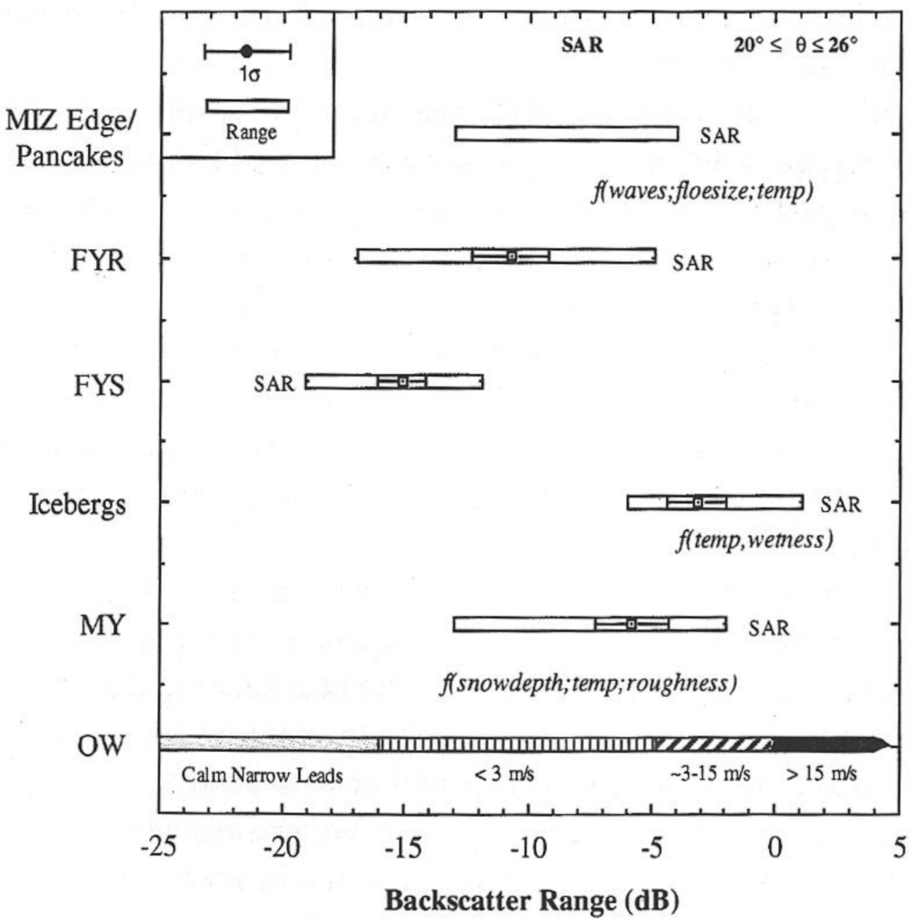
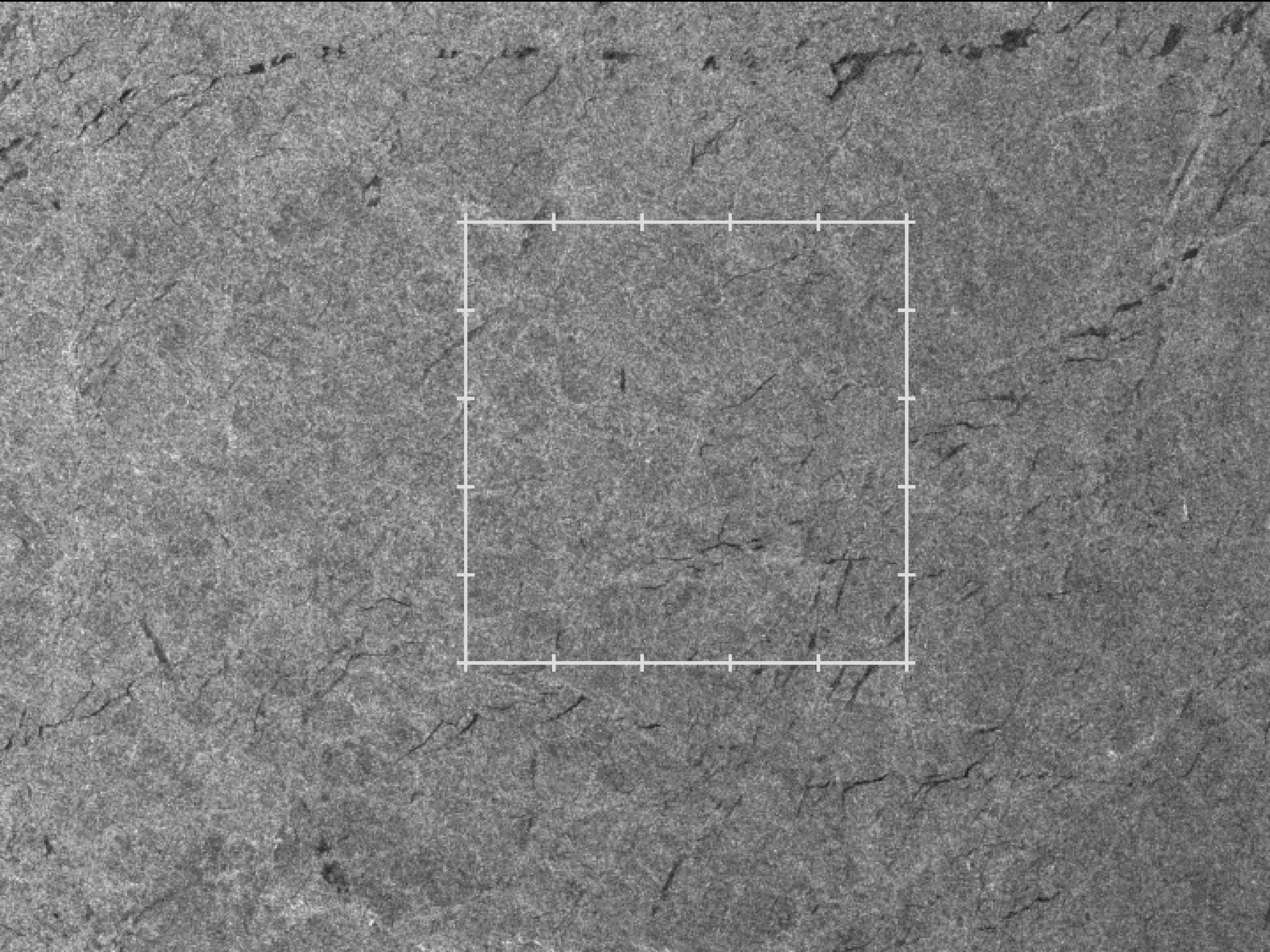
Surface and volume scattering

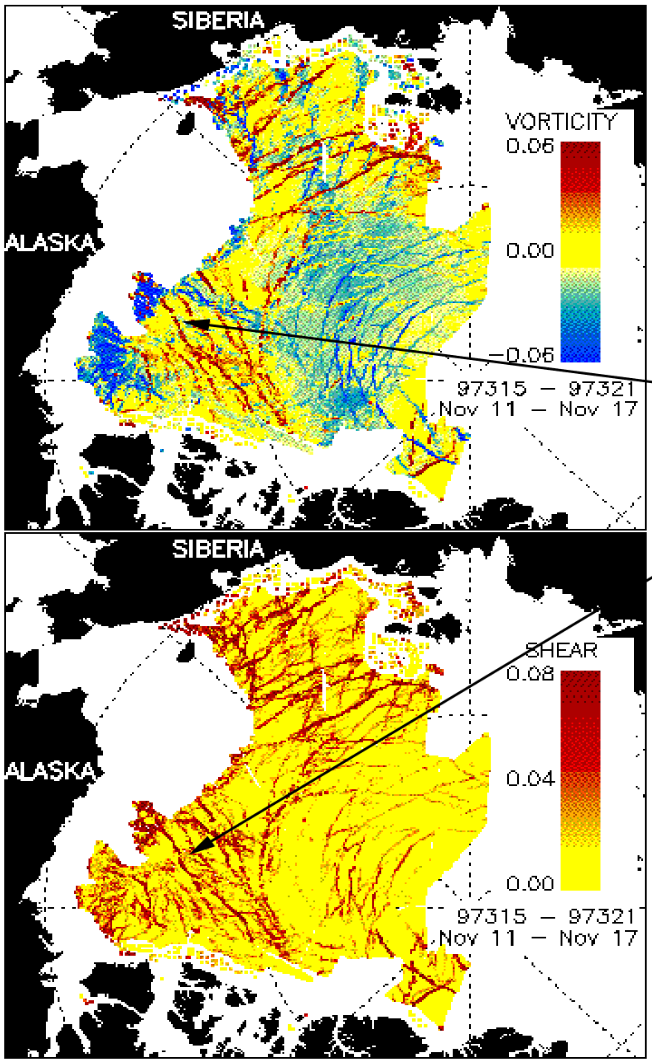
The importance of volume scattering is governed by the dielectric properties (dielectric constant) of the material:
High DE: surface scattering dominates
Low DE: volume scattering dominates

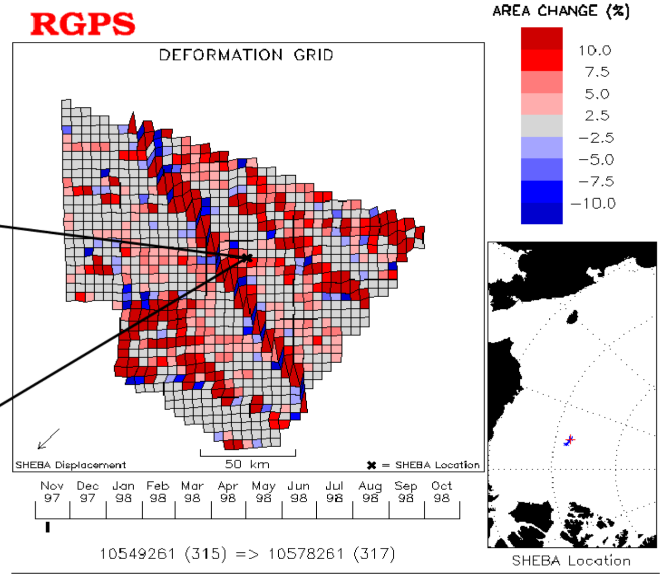






Location of SHEBA, Nov 97





Large-scale Visualization
Of Cell Deformation