Doppler at C-Band for Ocean Remote Sensing:

Detecting the motion of the ocean surface

Alexis Mouche, CNRS/Ifremer/IRD

together with
Bertrand Chapron & Jean Tournadre LOPS CNRS/Ifremer/IRD
Harald Johnsen & Geir Engen Norut
Fabrice Collard, Ocean Data Lab

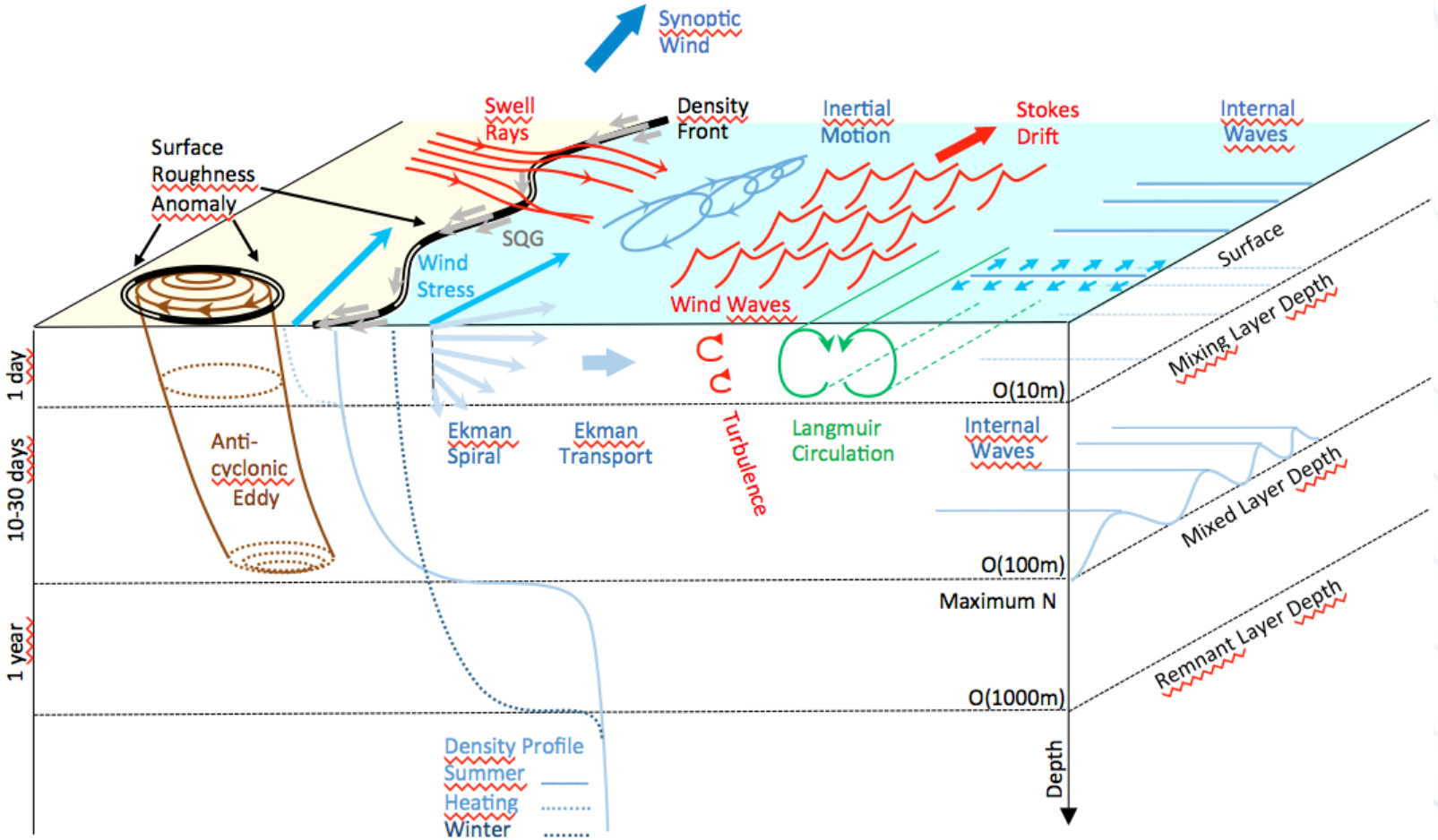
and

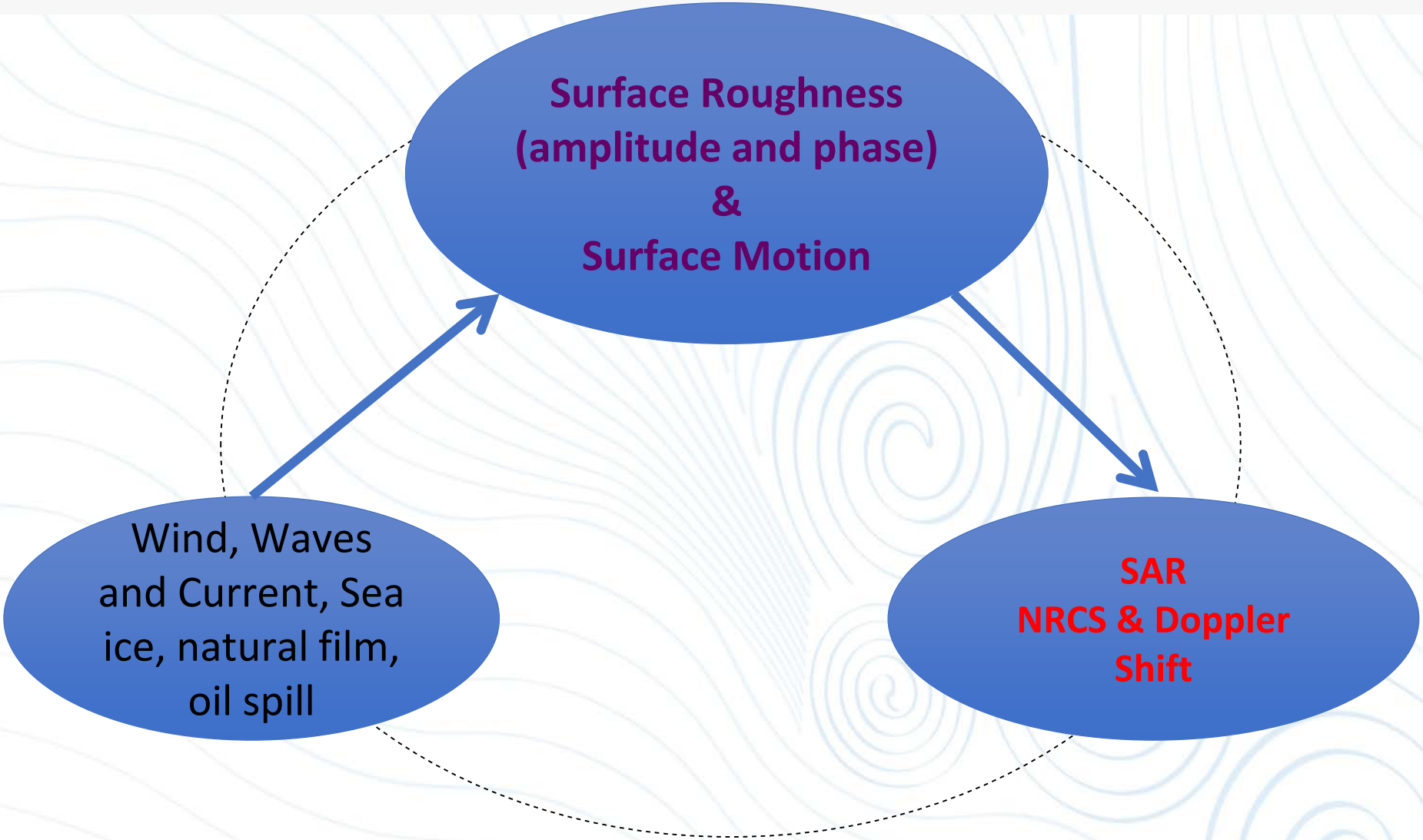
Johnny A. Johannessen (NERSC)

Content

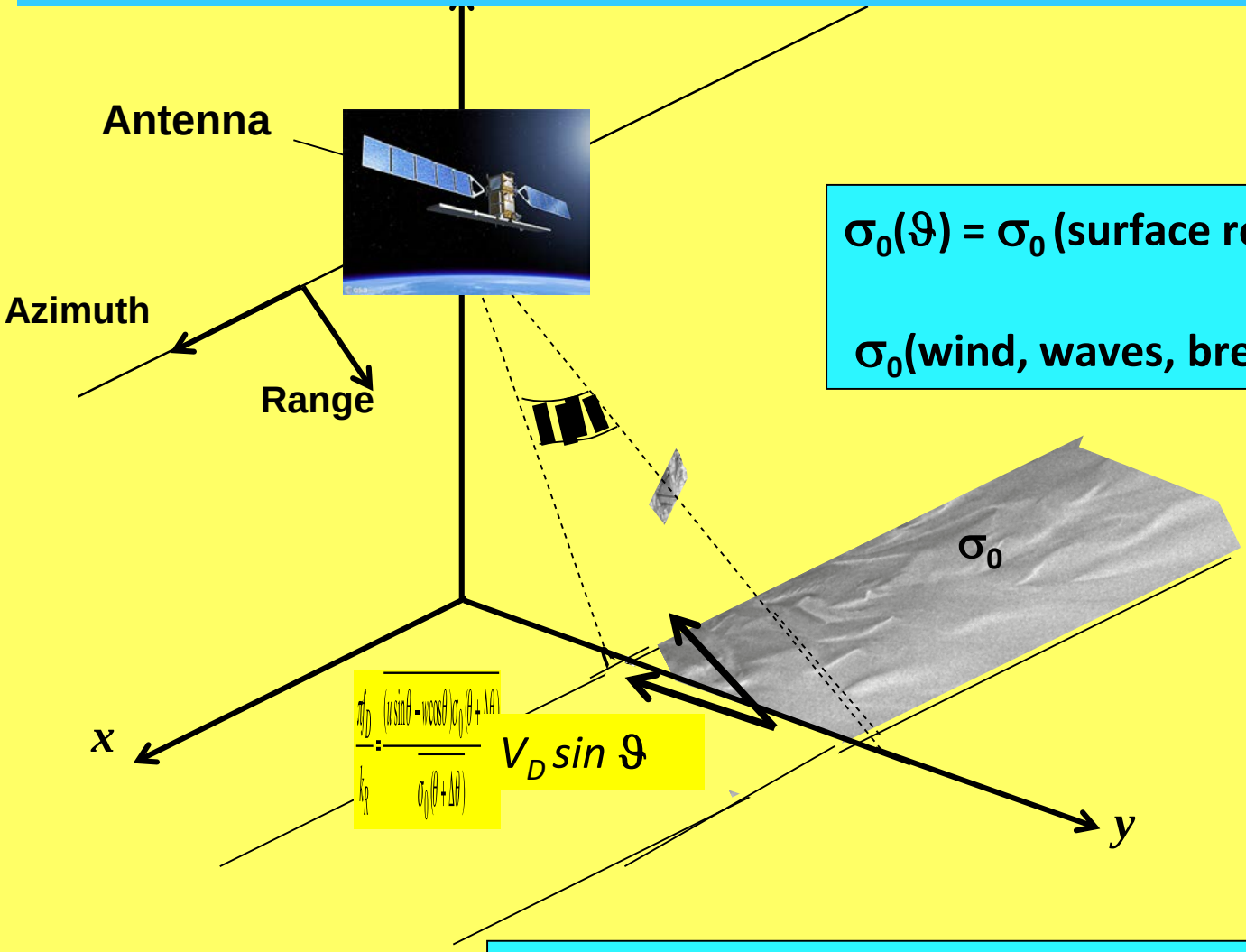
- Background to Doppler shift observations
- Inversion to surface motion
- ENVISAT/ASAR Experience
  - Global monthly equatorial currents
  - Gulf Stream
  - Ahulhas Current
  - Mean dynamic topography
  - Atmospheric fronts
- Summary

THE OCEAN SURFACE AND MOTION PHENOMENA




Surface Roughness
(amplitude and phase)
&
Surface Motion
Wind, Waves
and Current, Sea
ice, natural film,
oil spill
SAR
NRCS & Doppler
Shift

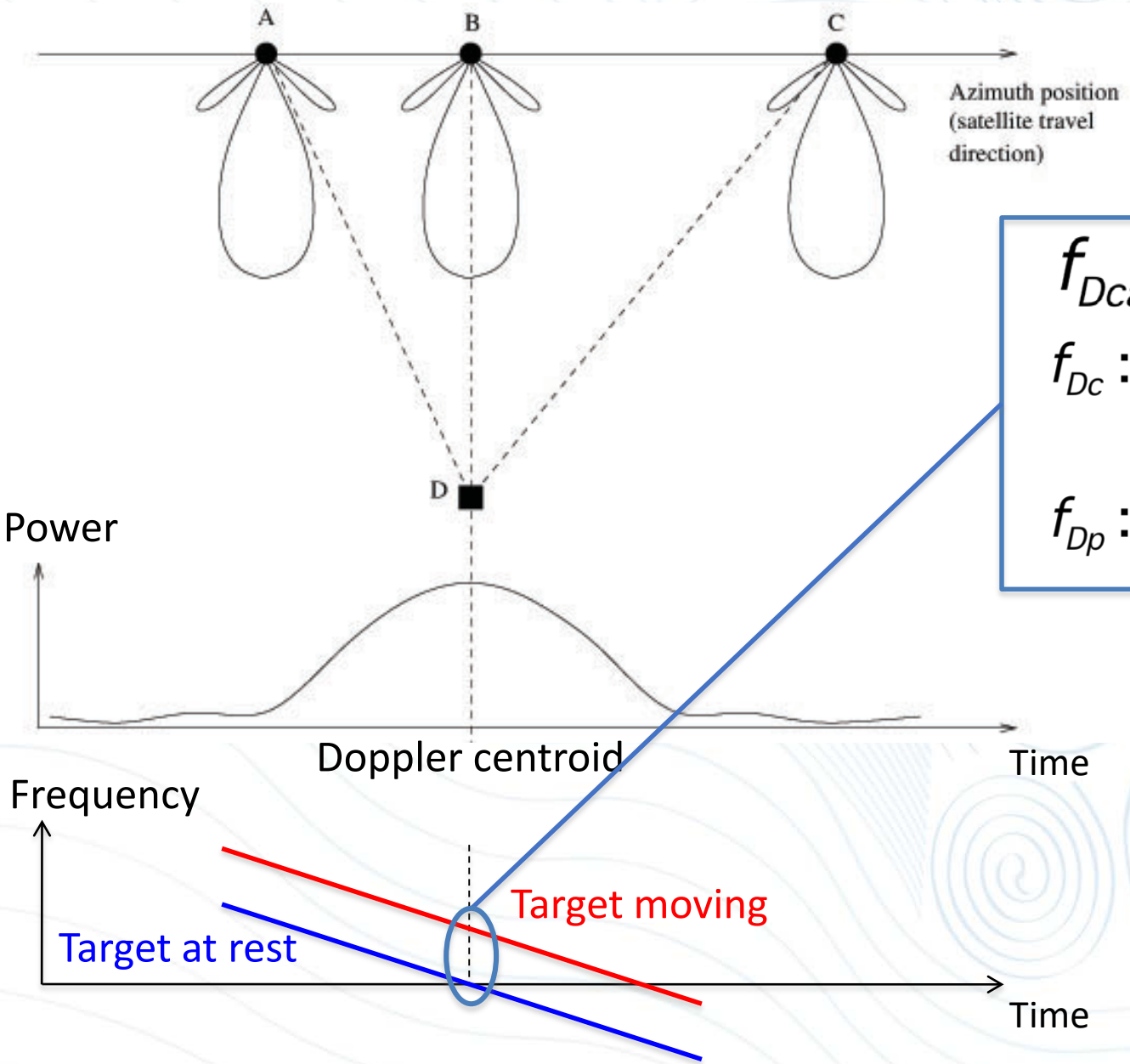
APPROACH: SAR Imaging of Roughness and Doppler Shift



$\sigma_0(\vartheta) = \sigma_0$ (surface roughness) =

σ_0(wind, waves, breaking, current

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



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

f_{Dc} : estimated Doppler cen
frequency shift

f_{Dp} : predicted Doppler shift

Chapron et al. (2003, 2005)

Doppler Centroid estimated from SAR data can be decomposed as follow:

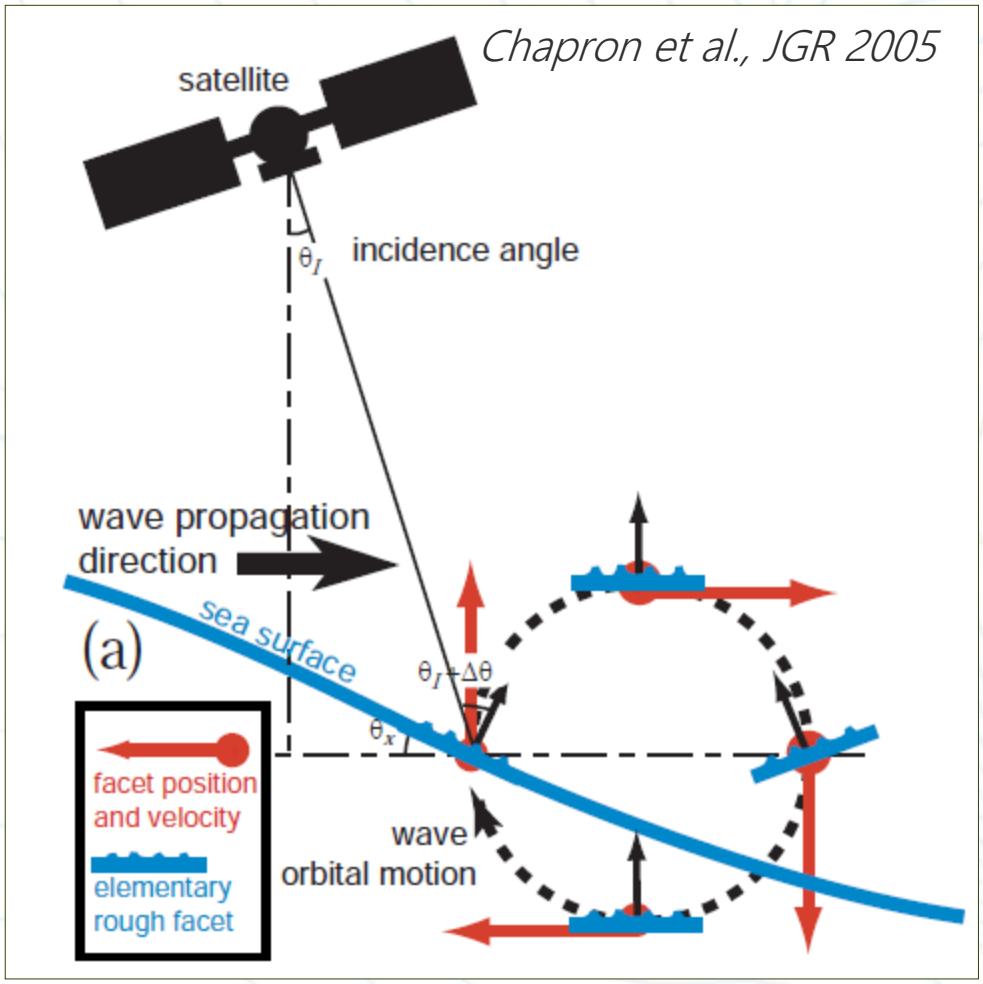
$$F_{SAR}^{DC} = F_{Att}^{DC} + F_{Ant}^{DC} + F_{Geop}^{DC}$$, where

F_{SAR}^{DC} is estimated from the SAR data

F_{Att}^{DC} is estimated from the geometry knowledge (quaternions based)

F_{Ant}^{DC} is the antenna contribution related to TRM drifts, failures, misalignements, etc

$F_{Geophys}^{DC}$ is the contribution of the ocean surface scatterers displacements



$F^{DC}_{Geophys} = F^{DC}_{Curr} + F^{DC}_{Waves} + I$, where

F^{DC}_{Curr} is due to underlying current

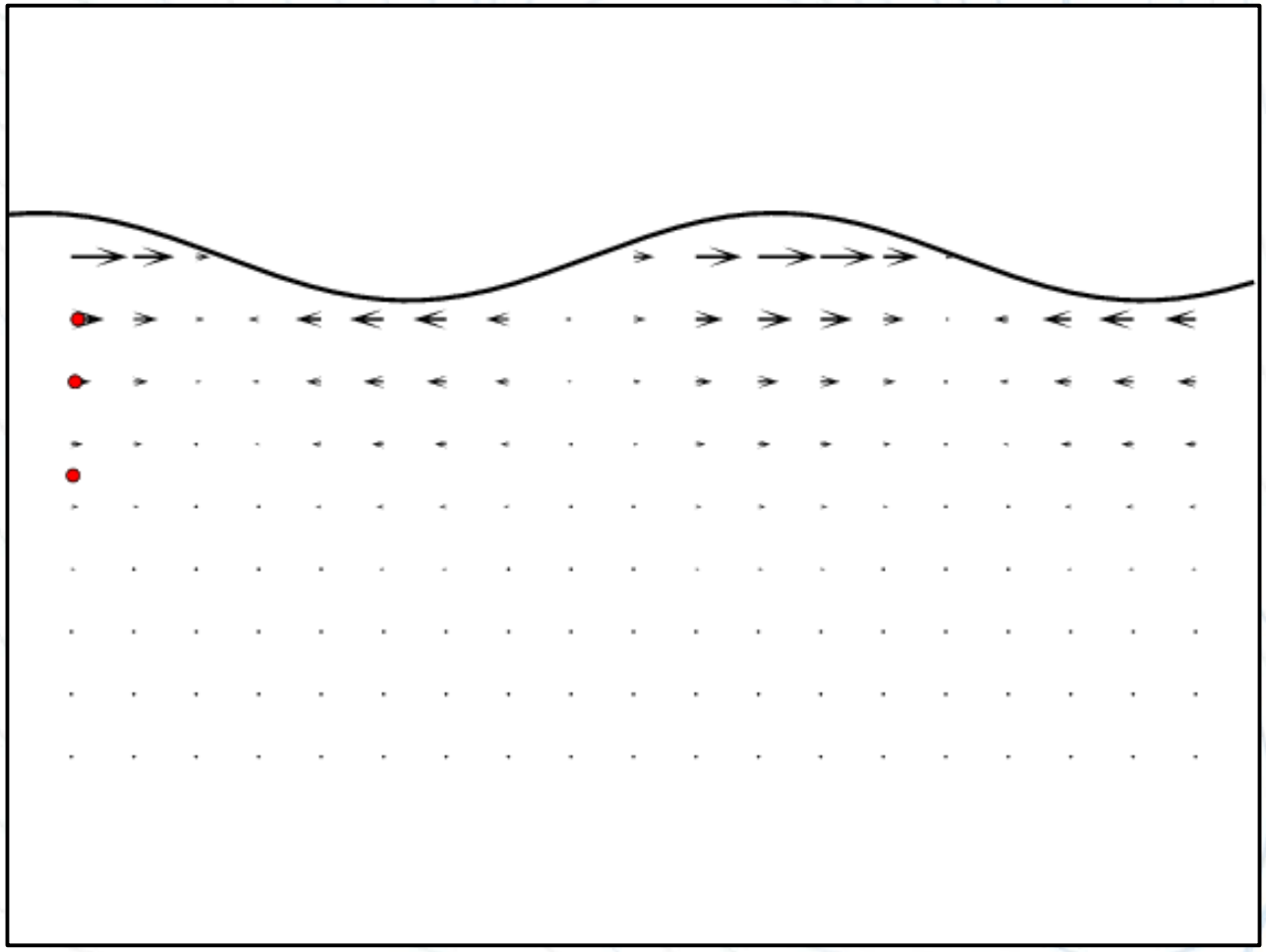
F^{DC}_{Waves} is due to background sea state

F^{DC}_{wxc} is due to waves-current interactions

- First order : underlying current + background sea state

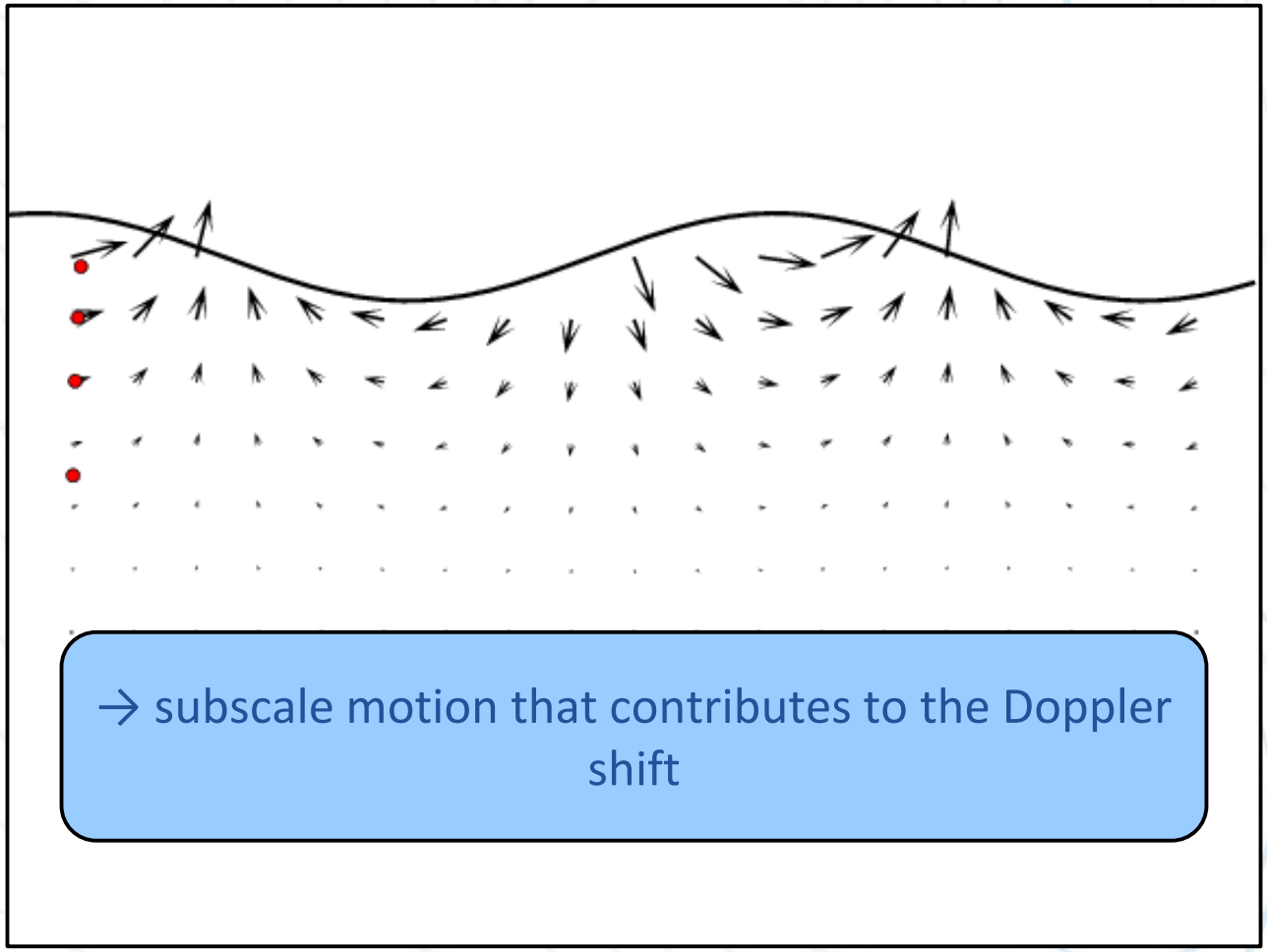
- Second order : sea state perturbated by surface current. Advanced models
- such as Doprim are needed to take into account modification of wave spectrum by
- surface current gradients.

The Stokes Drift



Courtery Johannes Rohrs, MET.NO

The Stokes Drift



Courtecy Johannes Rohrs, MET.NO

Ifremer

Inversion to surface motion:

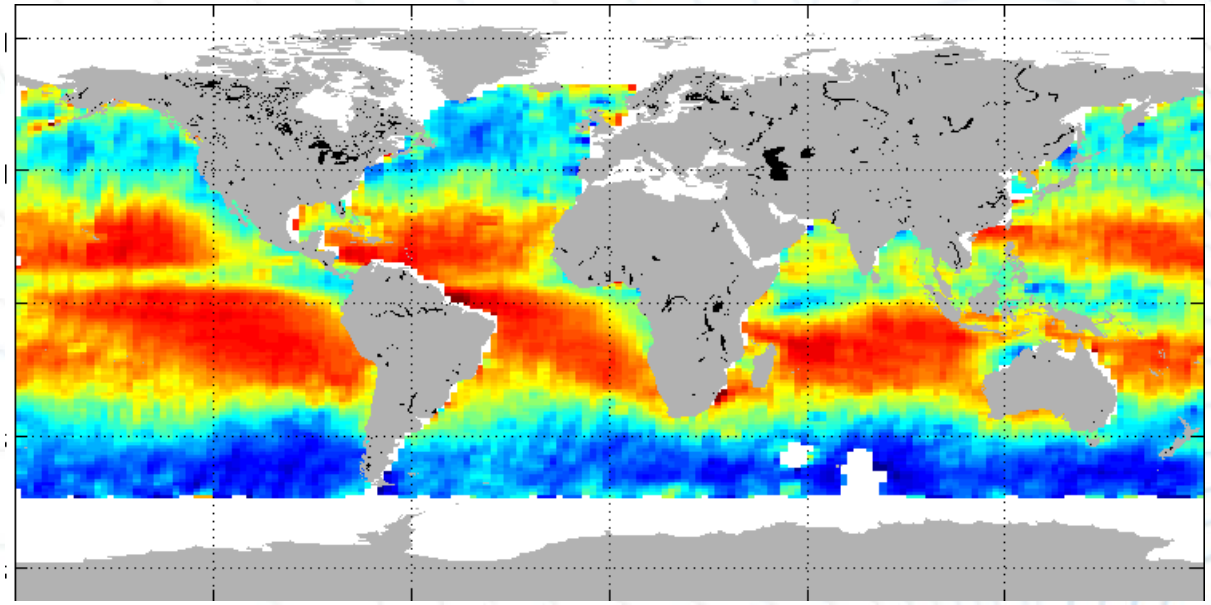
ENVISAT/ASAR Experience

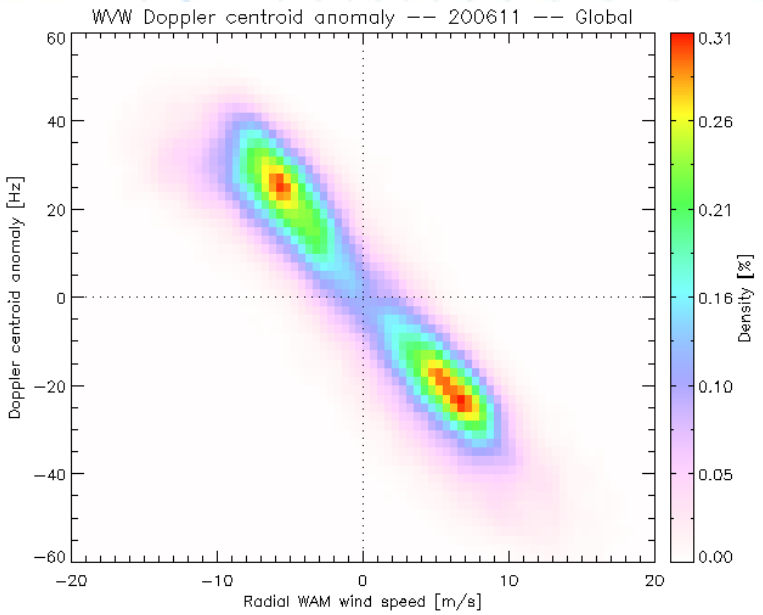
Ocean Surface Current Retrieval

Global Scale

Ifremer

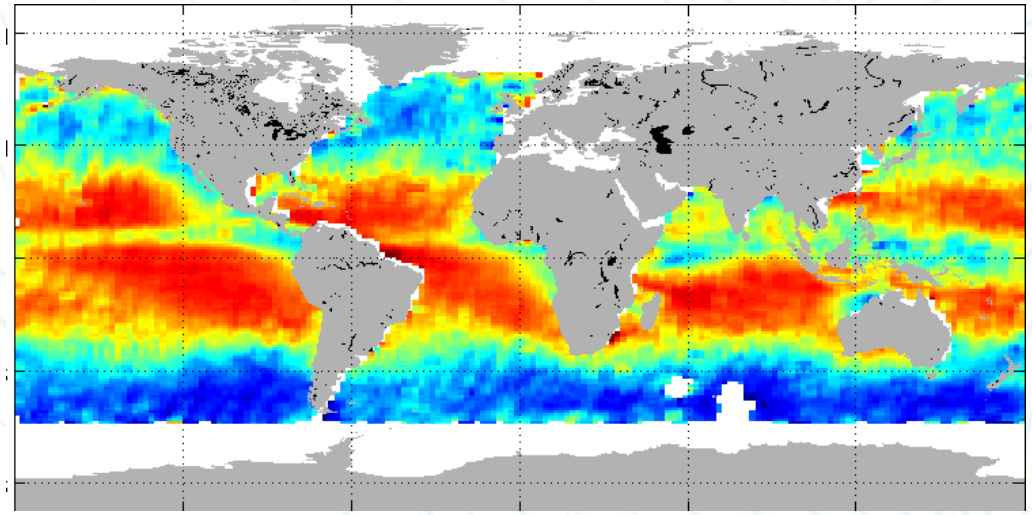
Monthly Mean of Doppler

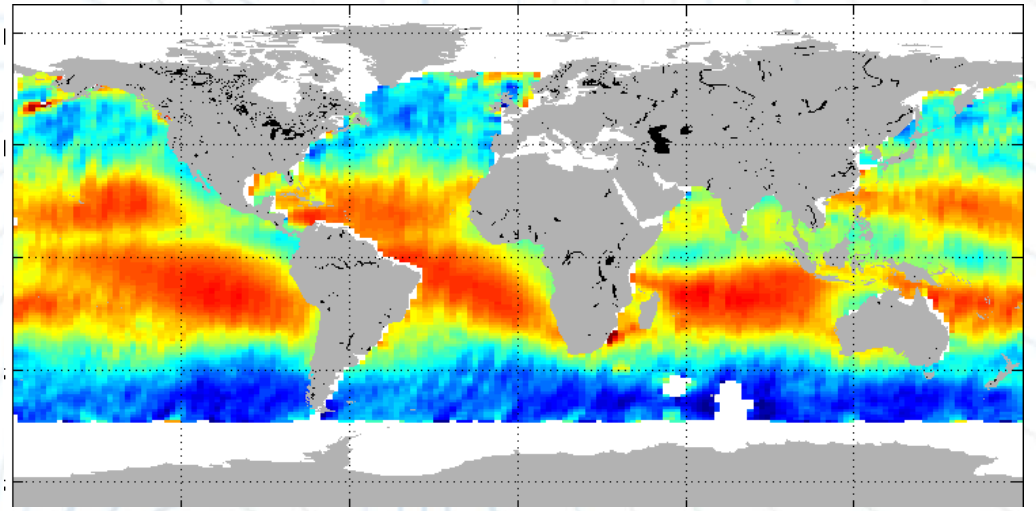




- First presented at ENVISAT Cal-Val review in 2002, published in JGR 2005 using wave mode at 23° incidence angle.
- There is a large correlation with the wind speed.

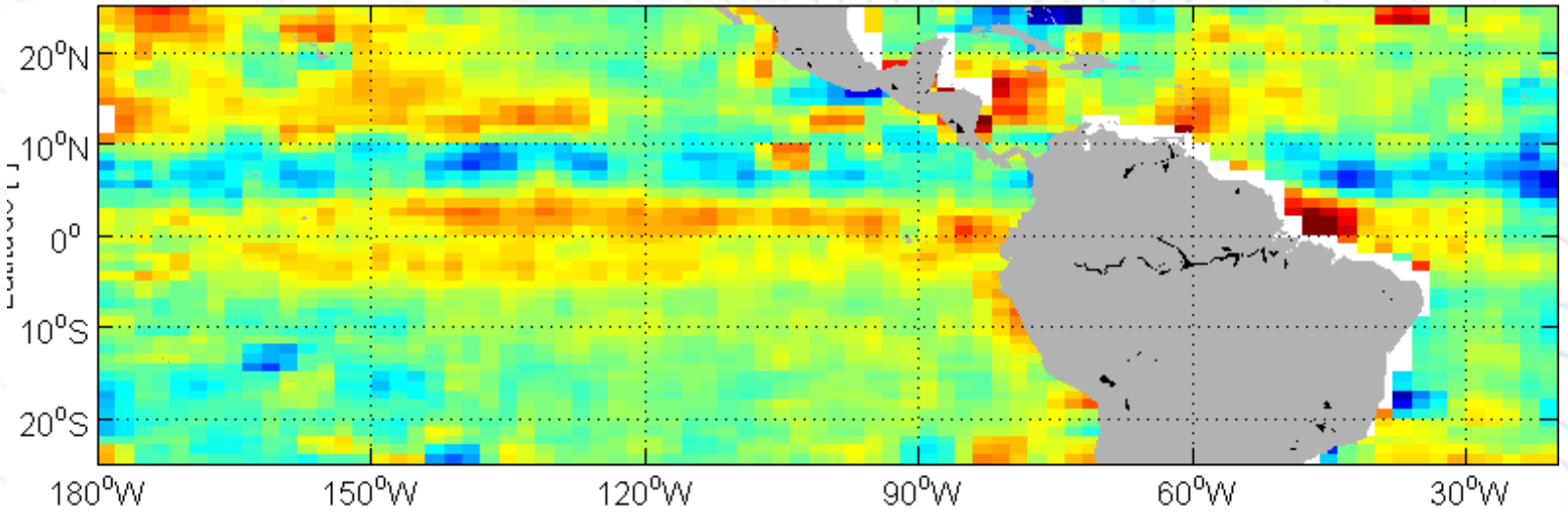
Monthly Mean of Doppler and Radial Wind speed





Doppler Anomaly/Velocity
(ASAR WM)

Radial Wind Speed
(ECMWF)



Radial Current Velocity (sea state effect removed)

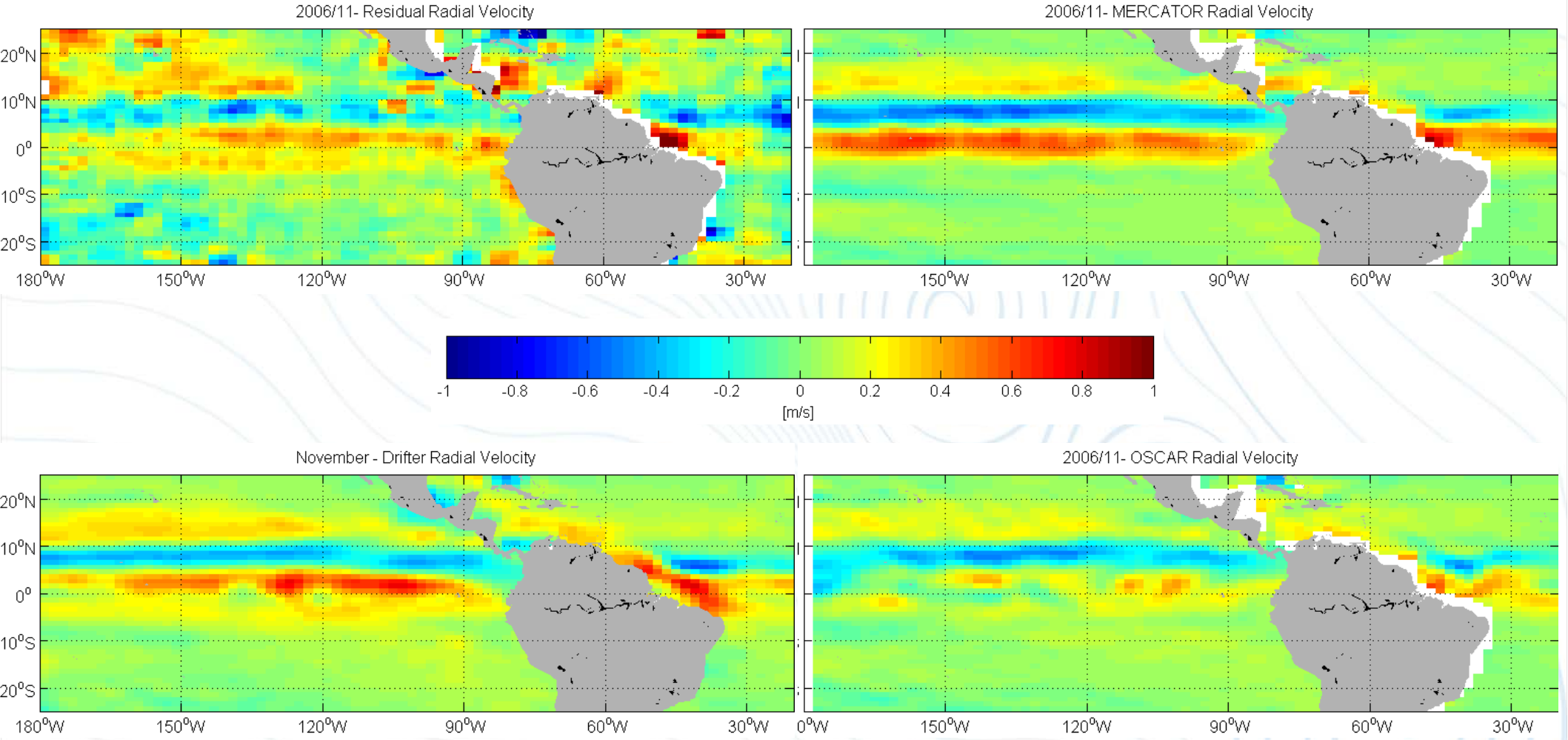
Collard et al., SEASAR 2008

Simple Methodology to remove sea state contribution
Application to Equatorial Pacific Ocean
Monthly analysis

$$F_{Curr}^{DC} = F_{Geophys}^{DC} - F_{Waves}^{DC} - F_{\cdot}$$

neglected

$$F_{waves}^{DC} = CDOP\left(\theta, U_{10}^{model}, \Phi\right)$$

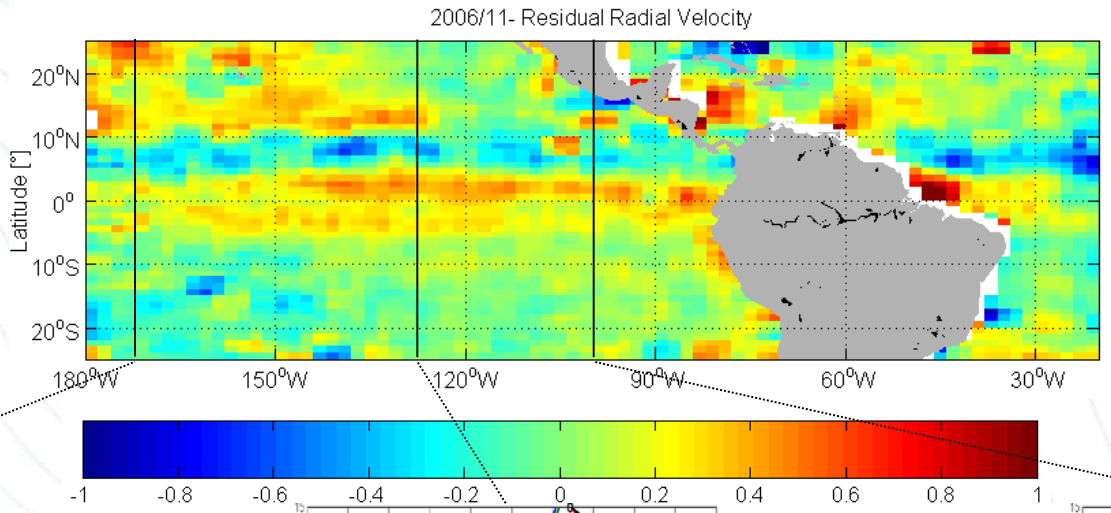


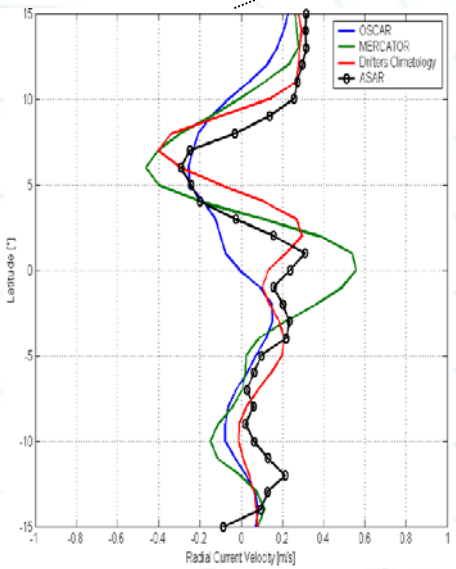
Collard et al., SEASAR 2008

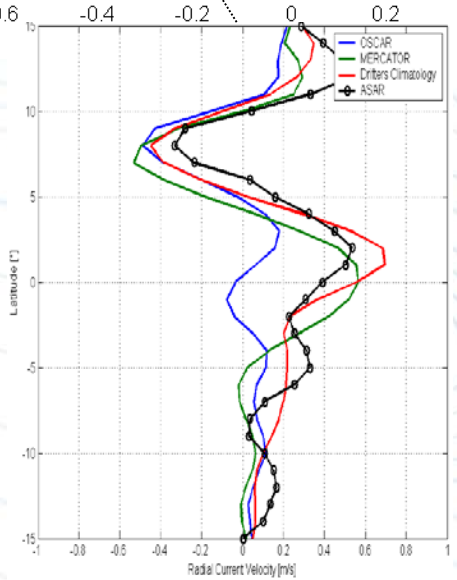
Simple Methodology to remove sea state contribution
Application to Equatorial Pacific Ocean

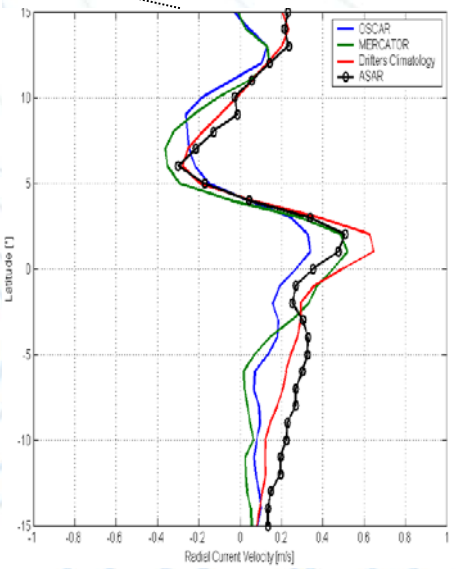
$$F_{Curr}^{DC} = F_{Geophys}^{DC} - F_{Waves}^{DC} - F_{\text{neglected}}$$

$$F_{waves}^{DC} = CDOP\left(\theta, U_{10}^{model}, \Phi\right)$$

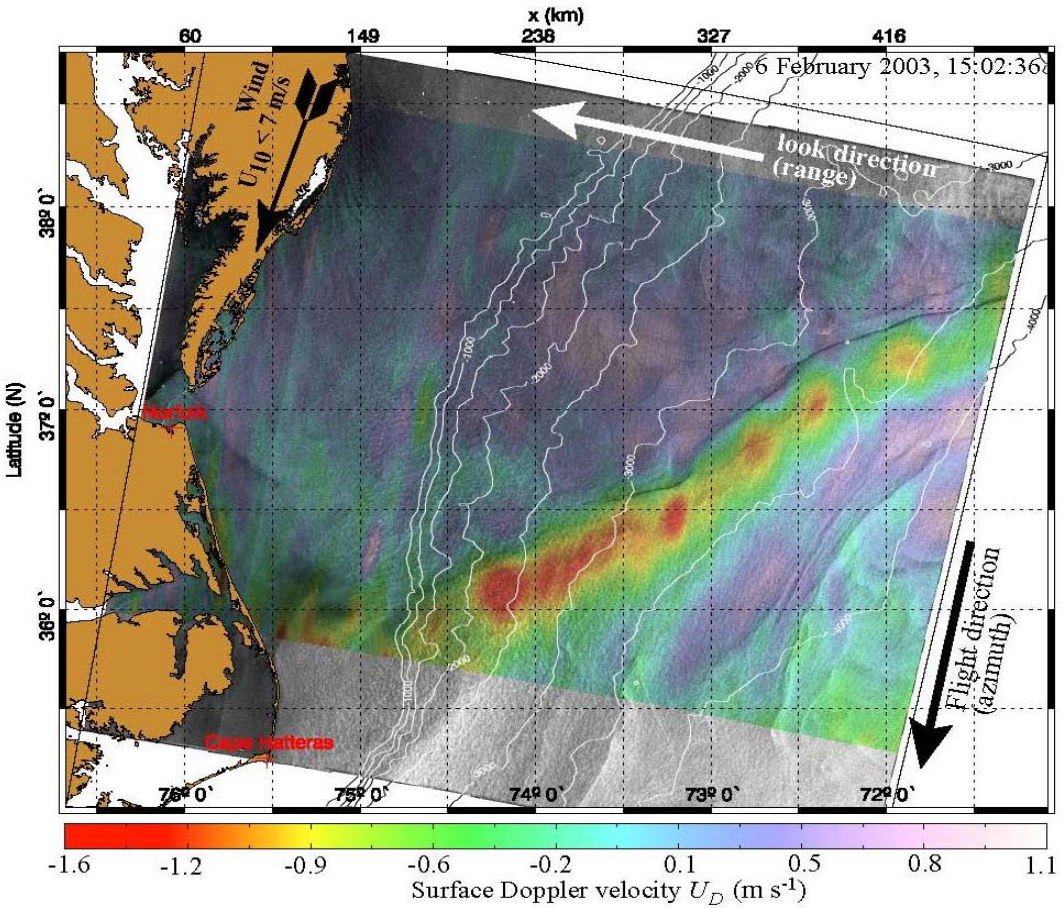








Collard et al., SEASAR 2008



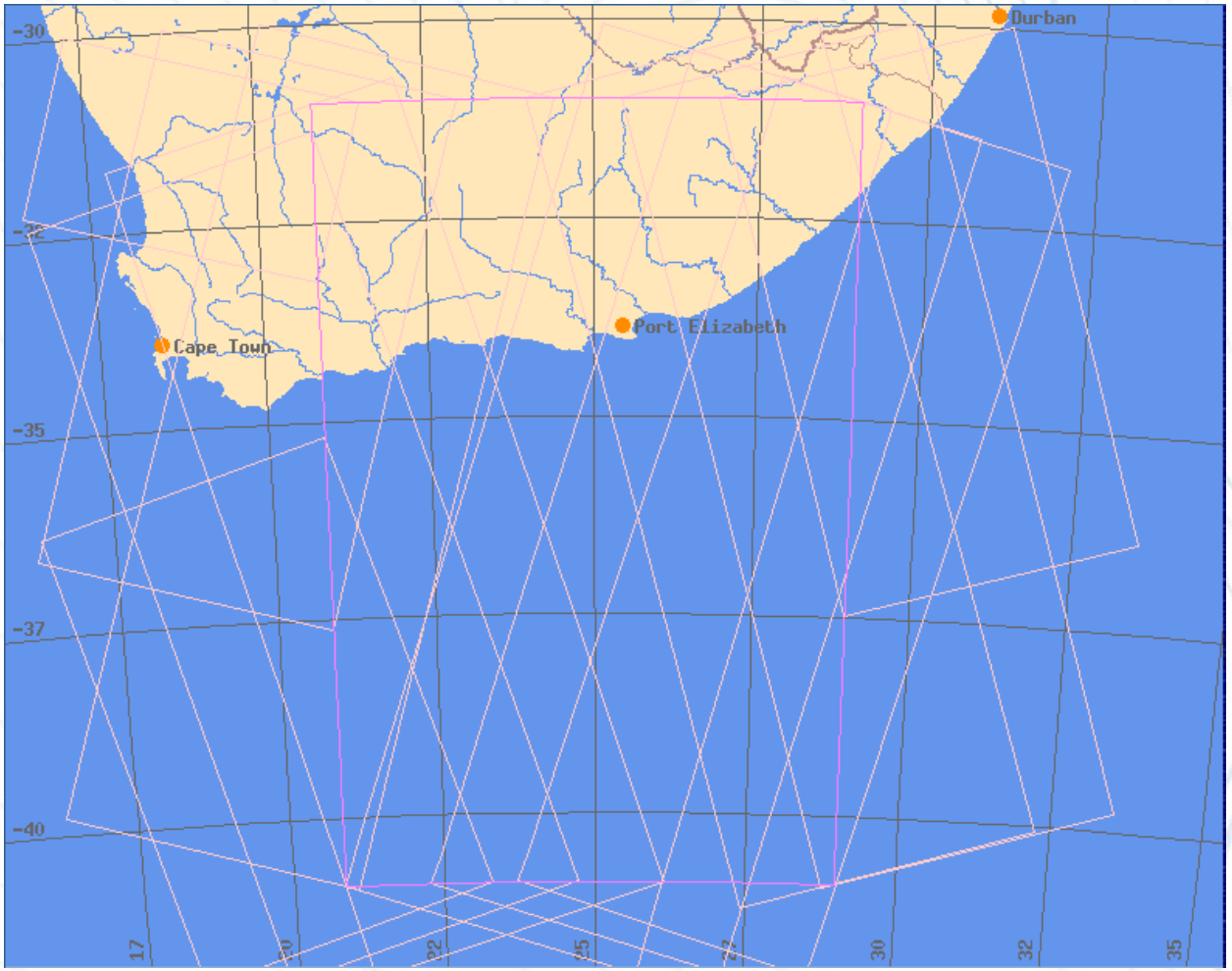
•First presented at ENVISAT Cal-Val review in 2002, published in JGR 2005 using wave mode at 23° incidence angle.

•Image mode acquisitions exhibit a significant signature over areas with large and strong ocean surface current such as Gulf Stream

ENVISAT/ASAR Experience

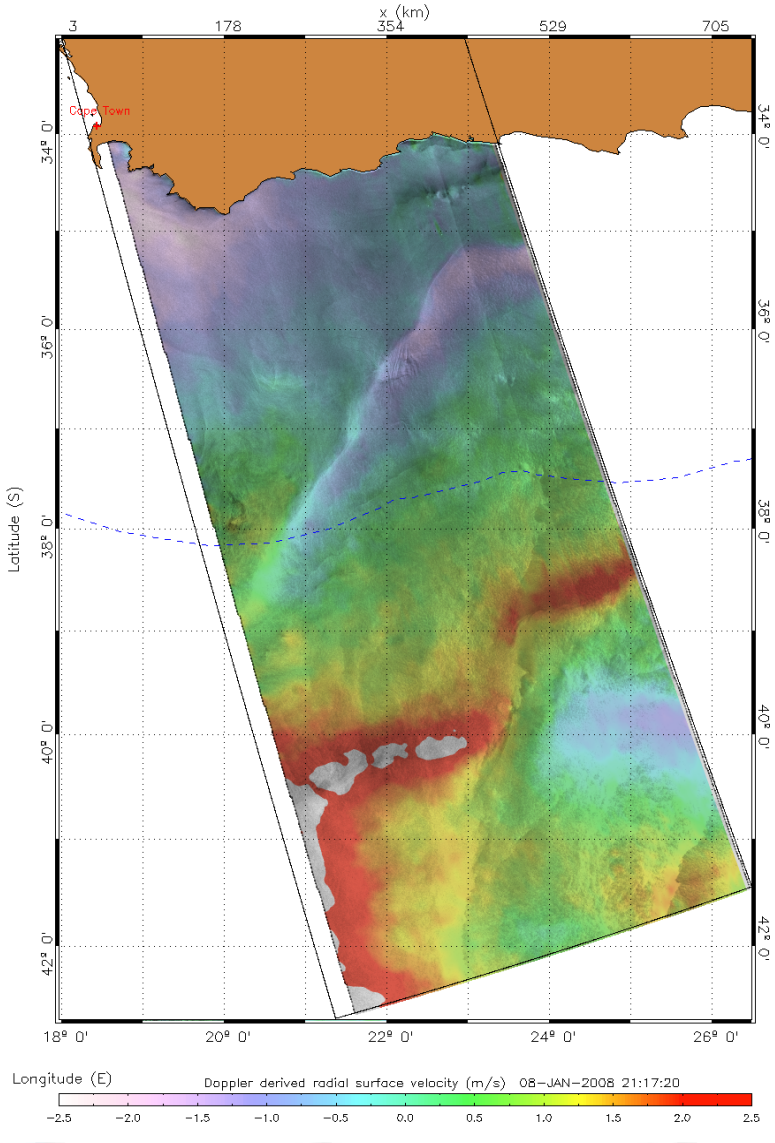
Ocean Surface Current Retrieval

In the Agulhas Current

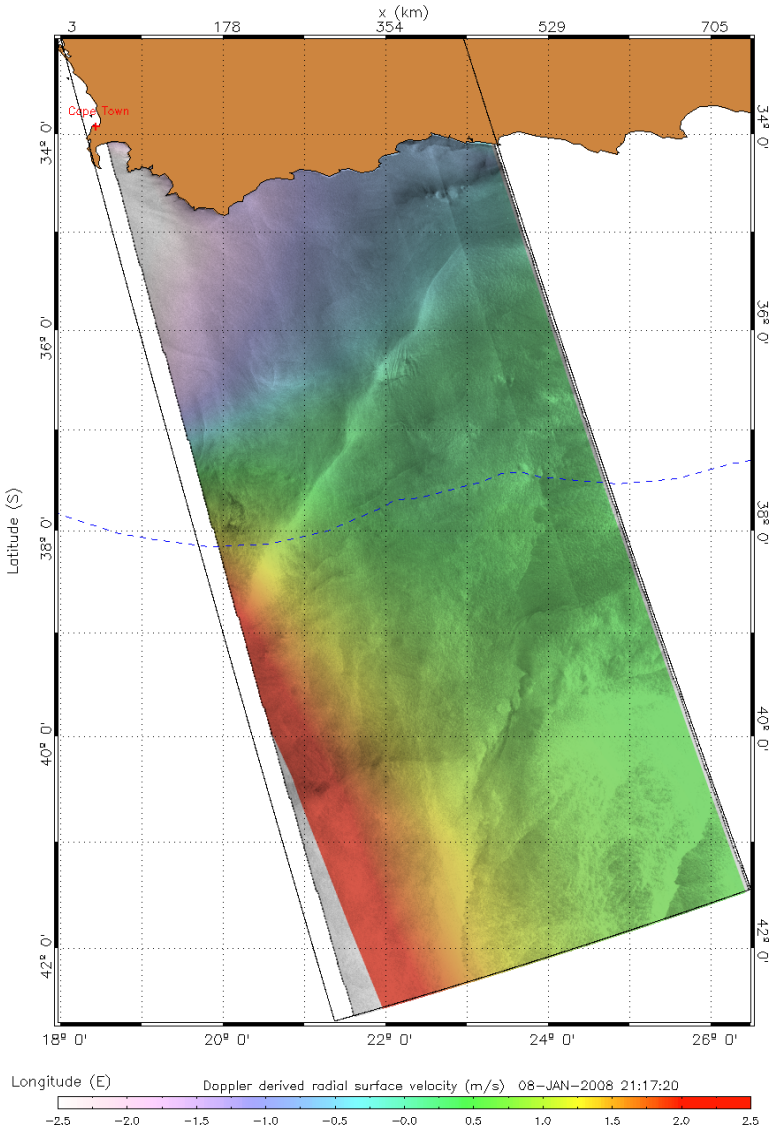


Doppler and Sea surface Current from Wide Swath

Total velocities

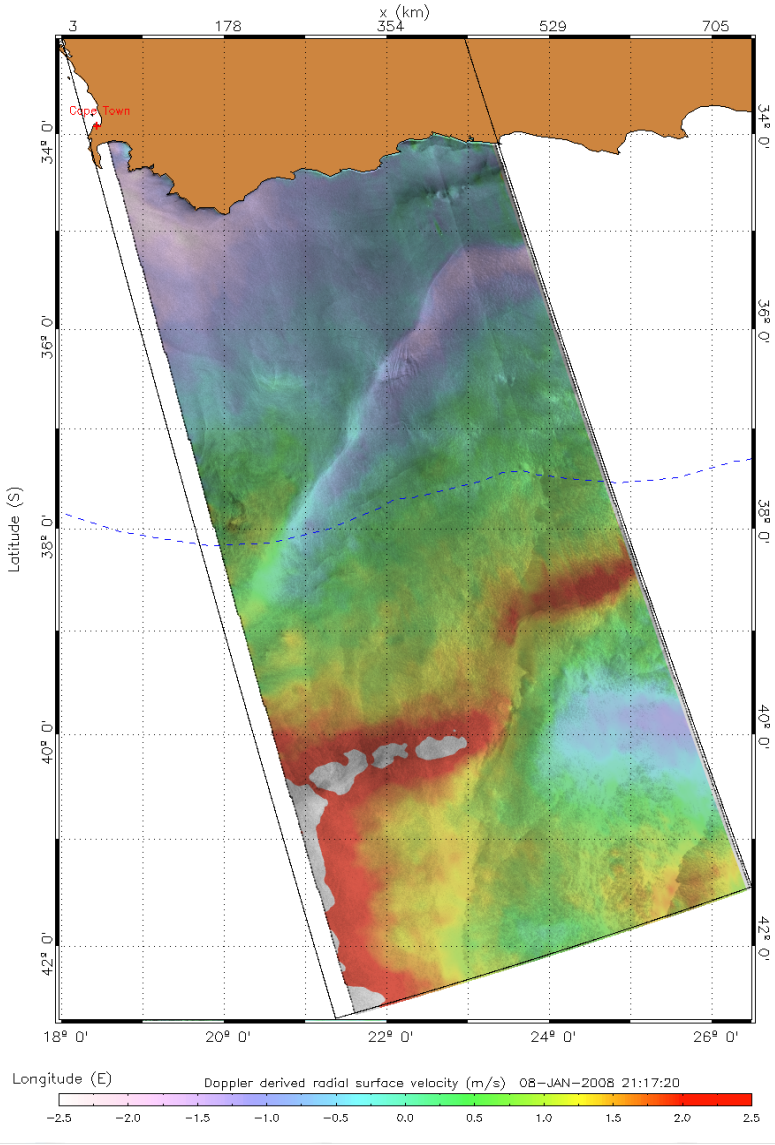


CDOP velocities

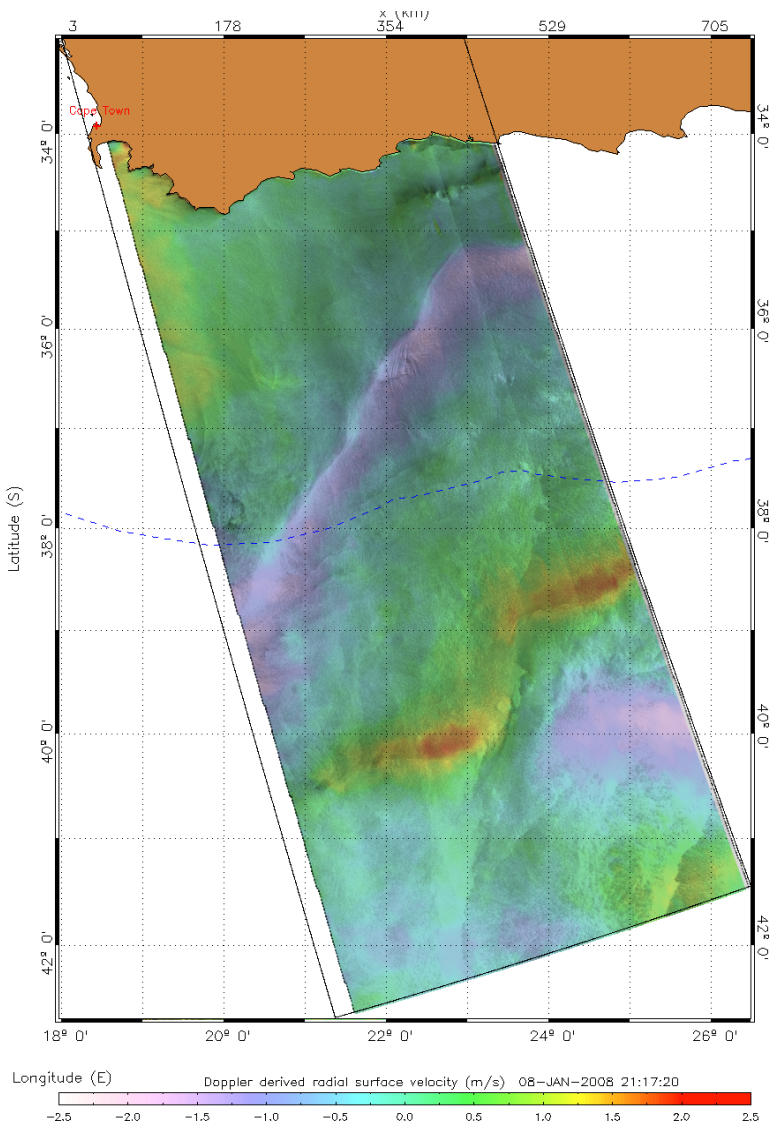


Doppler and Sea surface Current from Wide Swath

Total velocities

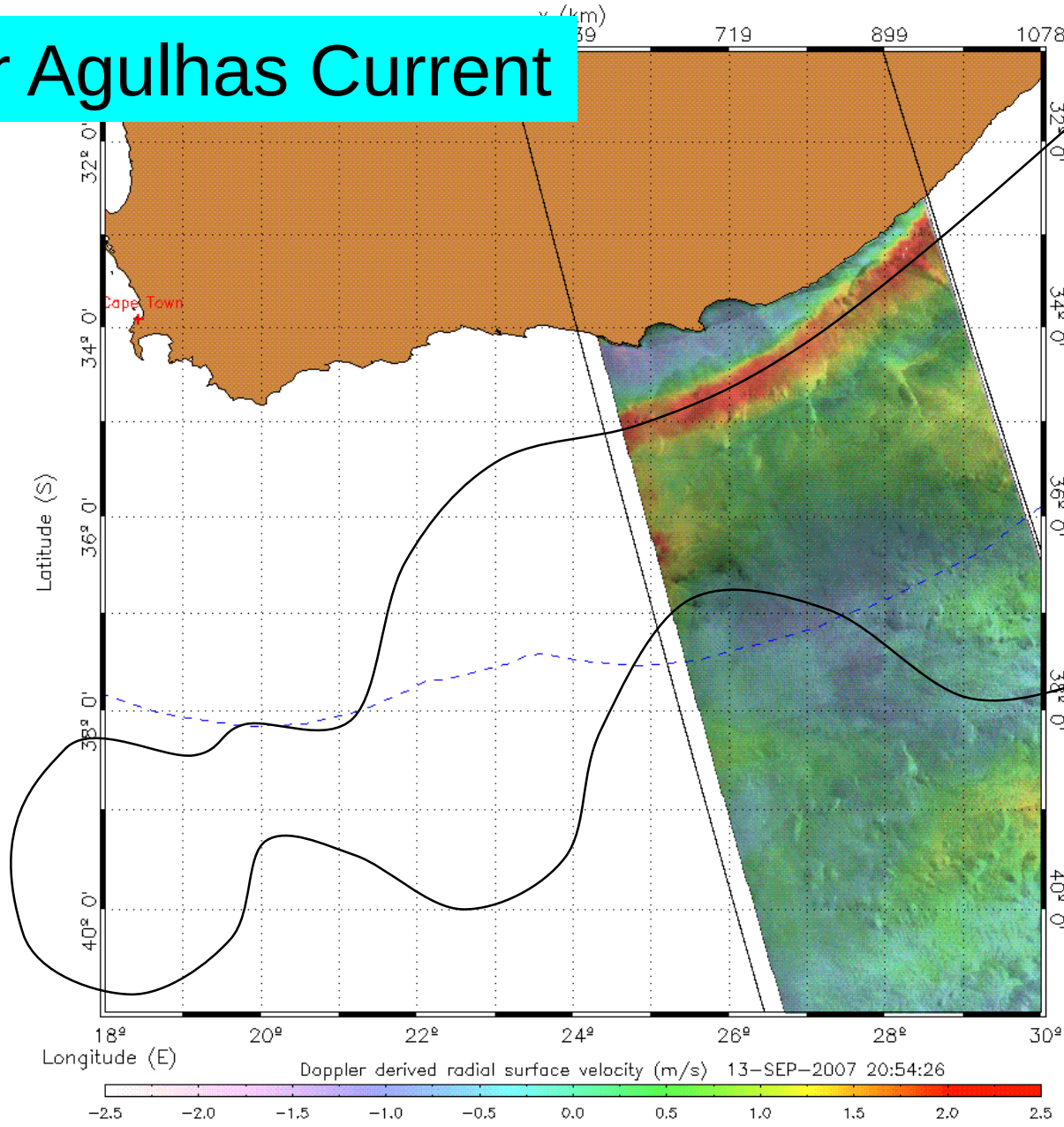


Residual velocities



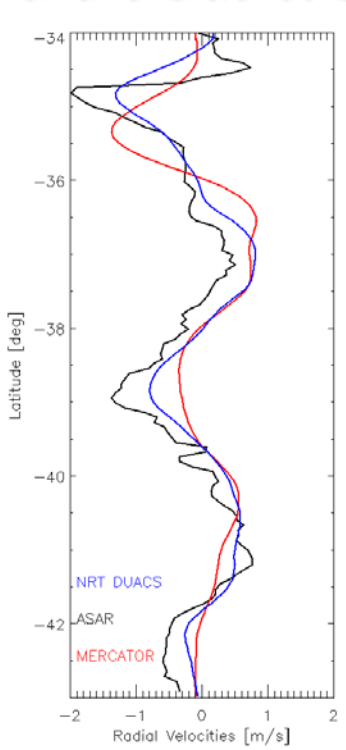
The greater Agulhas Current

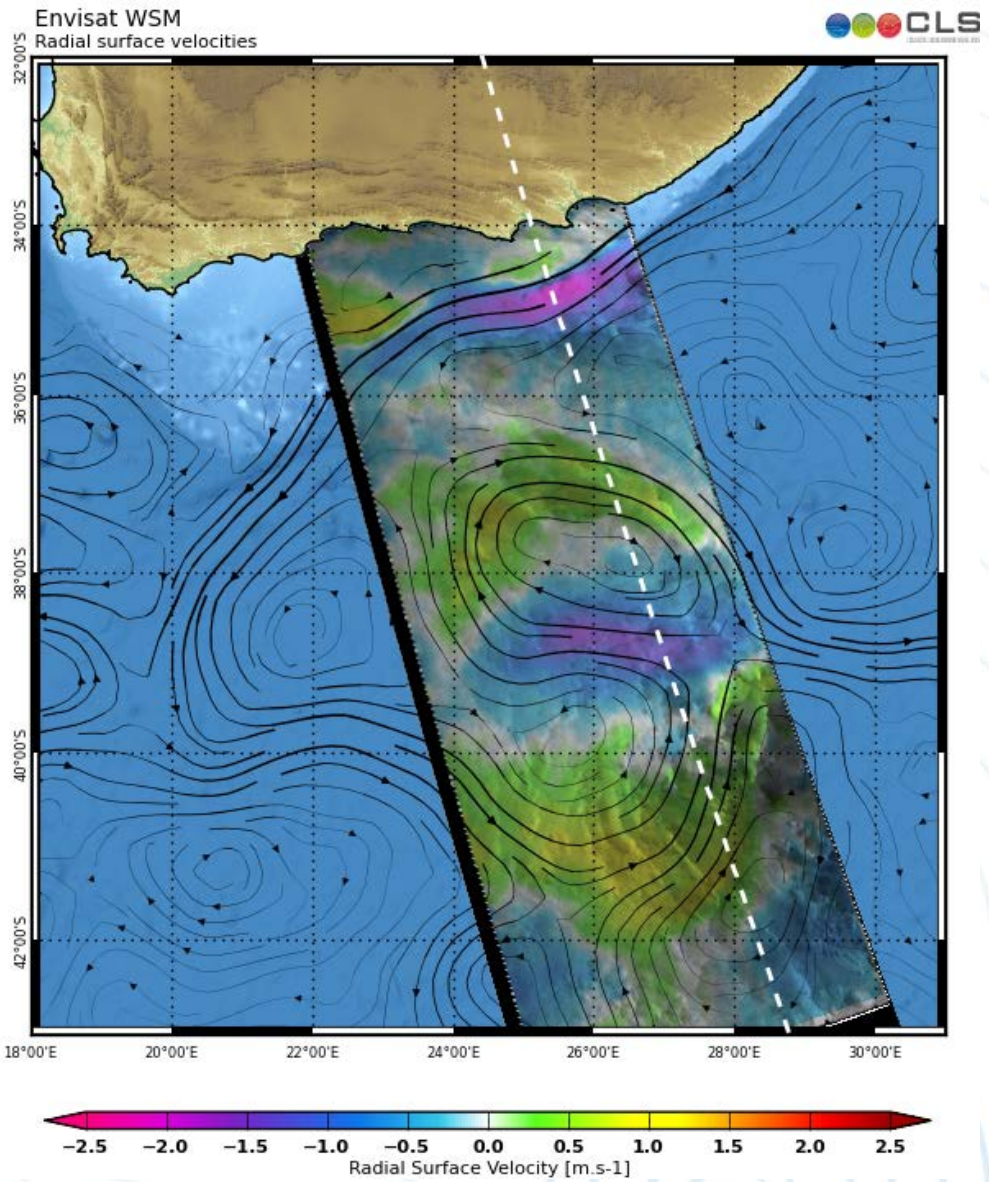
Direct measurements of surface flow of the Greater Agulhas Current as obtained from ASAR Wide Swath Mode on 13, 16, 19 and 22 September 2007. The radial surface velocity is marked in the colour bar in metres per second.



Doppler and Sea surface Current from Wide Swath

- Image-by-image analysis
  - **Comparison with Altimetry**
  - Comparison with Drifters
  - Comparison with S





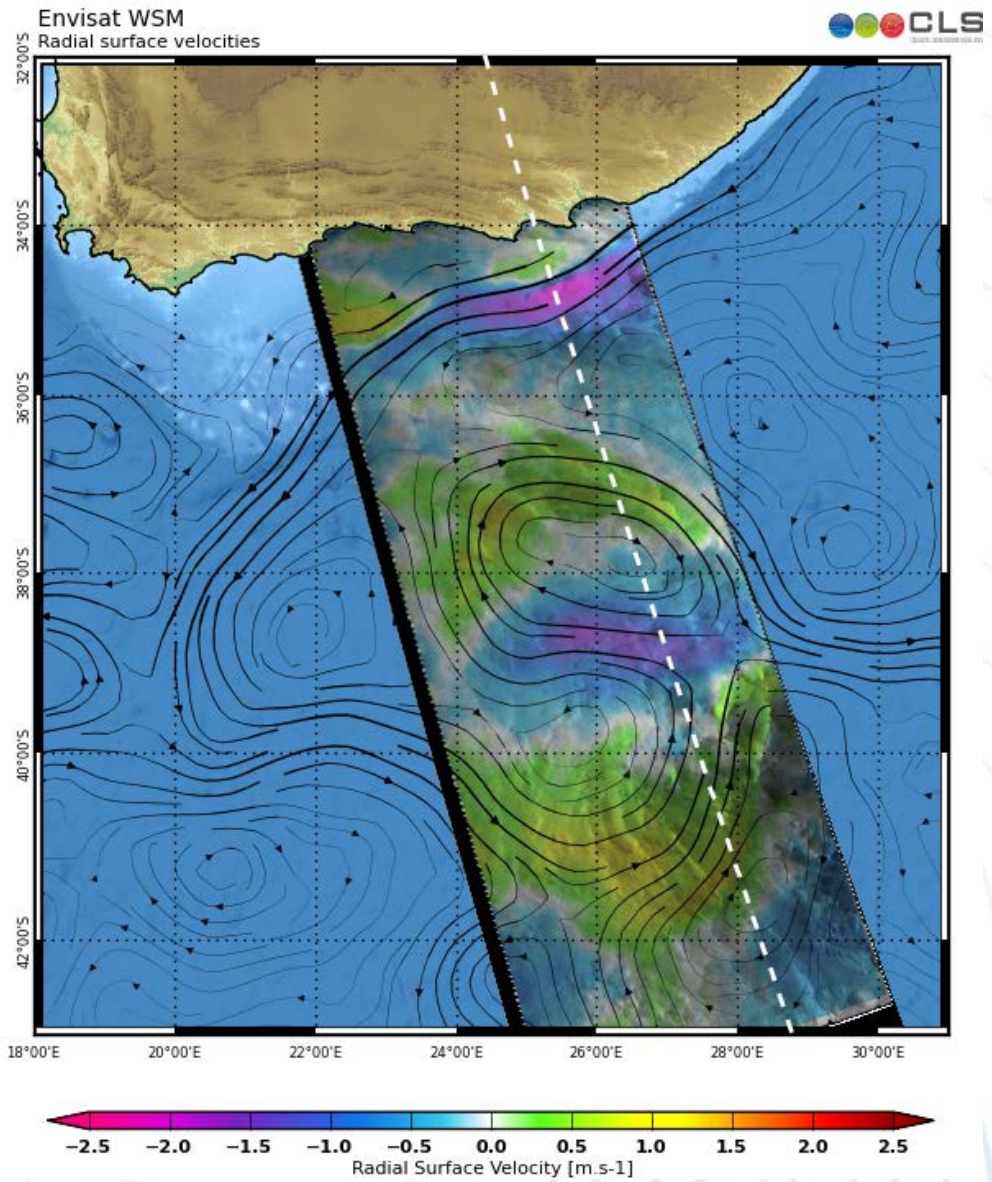
Doppler and Sea surface Current from Wide Swath

- Image-by-image analysis

  - **Comparison with Altimetry**

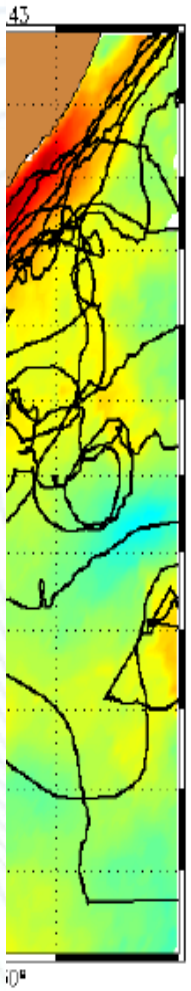
  - Comparison with Drifters

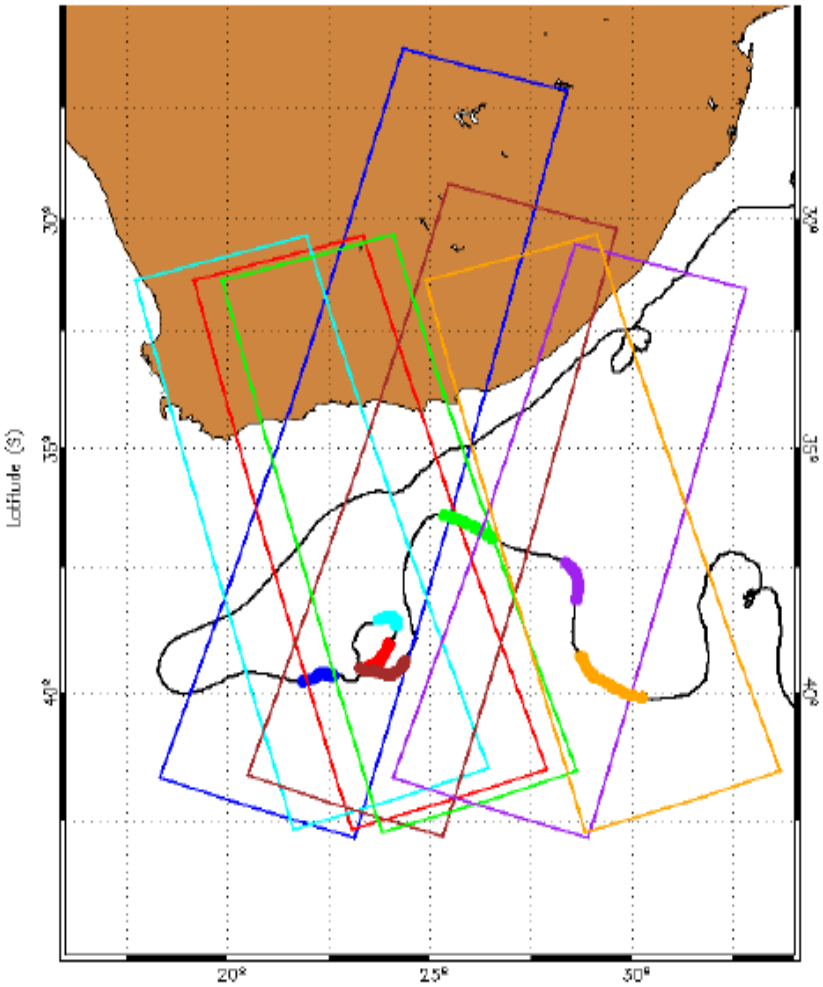
  - Comparison with SST

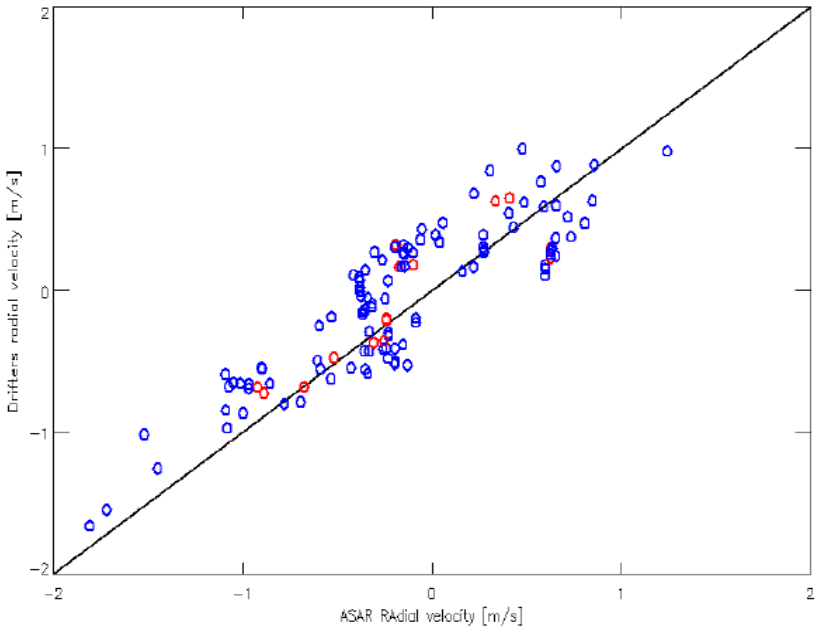


Doppler and Sea surface Current from Wide Swath

- Image-by-image analysis
  - Comparison with Altimetry
  - **Comparison with Drifters**
  - Comparison with SST

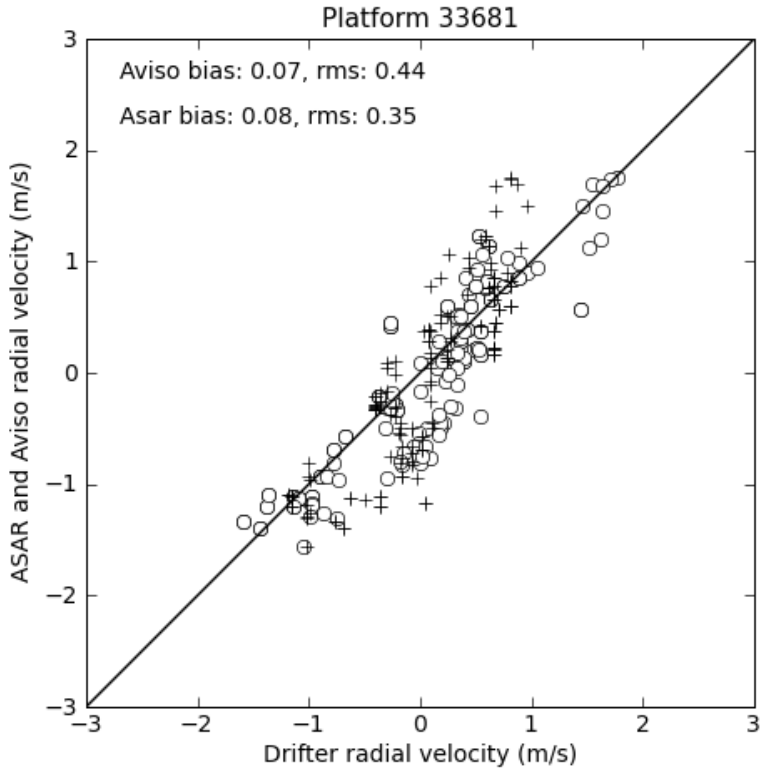




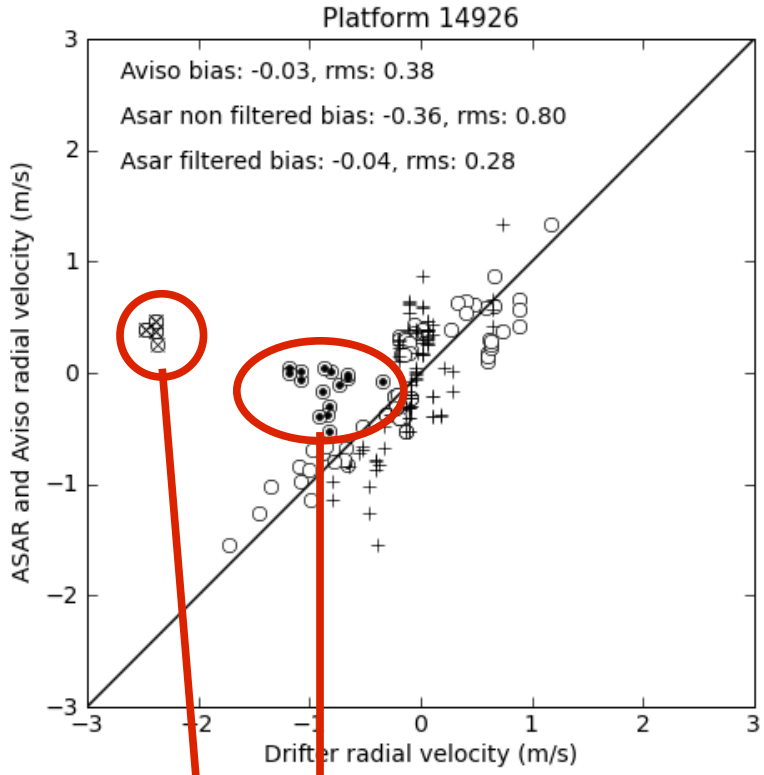


rms:0.28 m/s

ASAR and drifter compare well



Asar and drifter radial velocity compare well except for:



Errors linked to differences between winds at measurement location and ECMWF winds used in processing the radar surface velocities

◆Rain cell

◆Low radar incidence angle

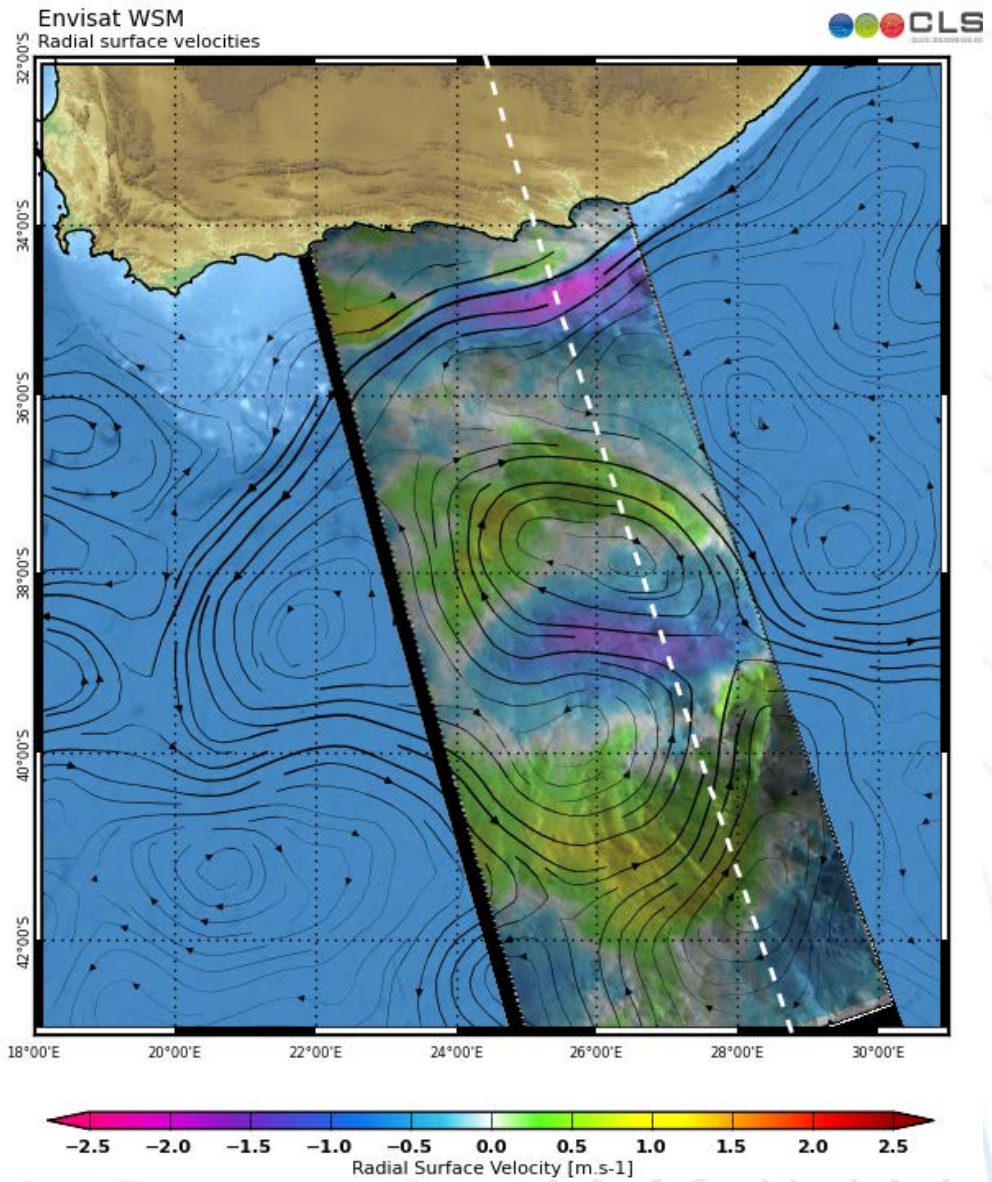
Doppler and Sea surface Current from Wide Swath

- Image-by-image analysis

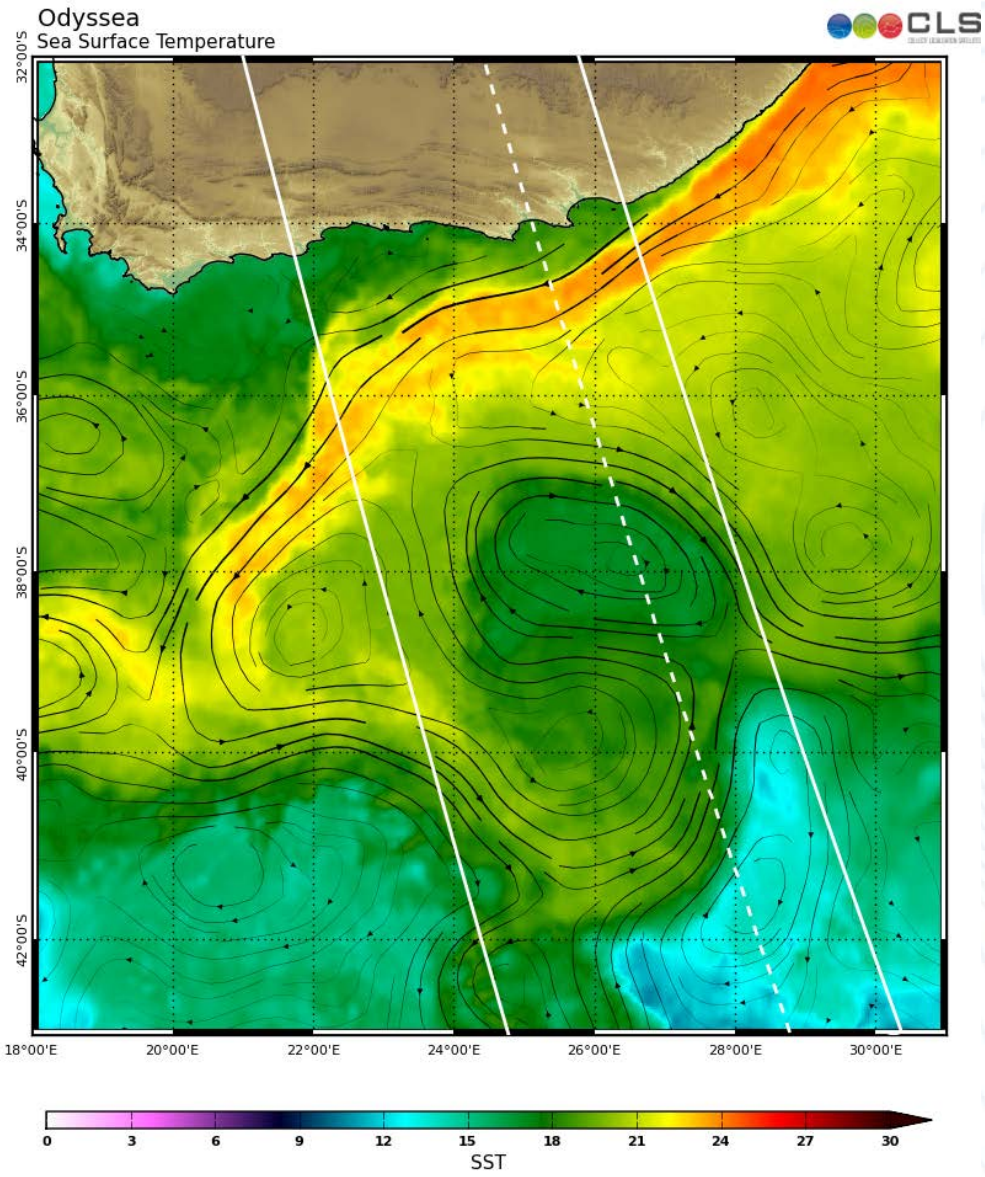
  - **Comparison with Altimetry**

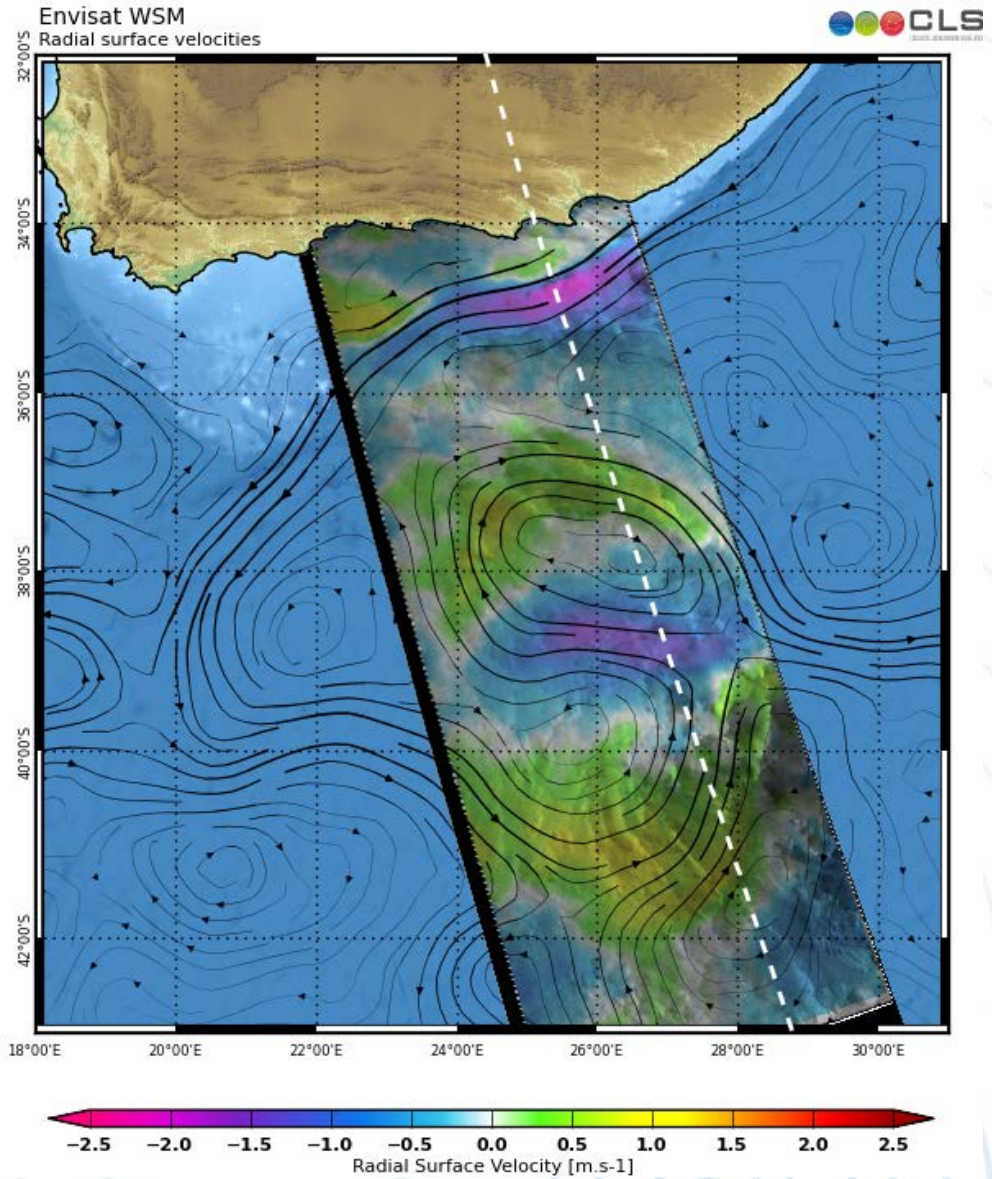
  - Comparison with Drifters

  - Comparison with SST



Doppler and Sea surface Current from Wide Swath



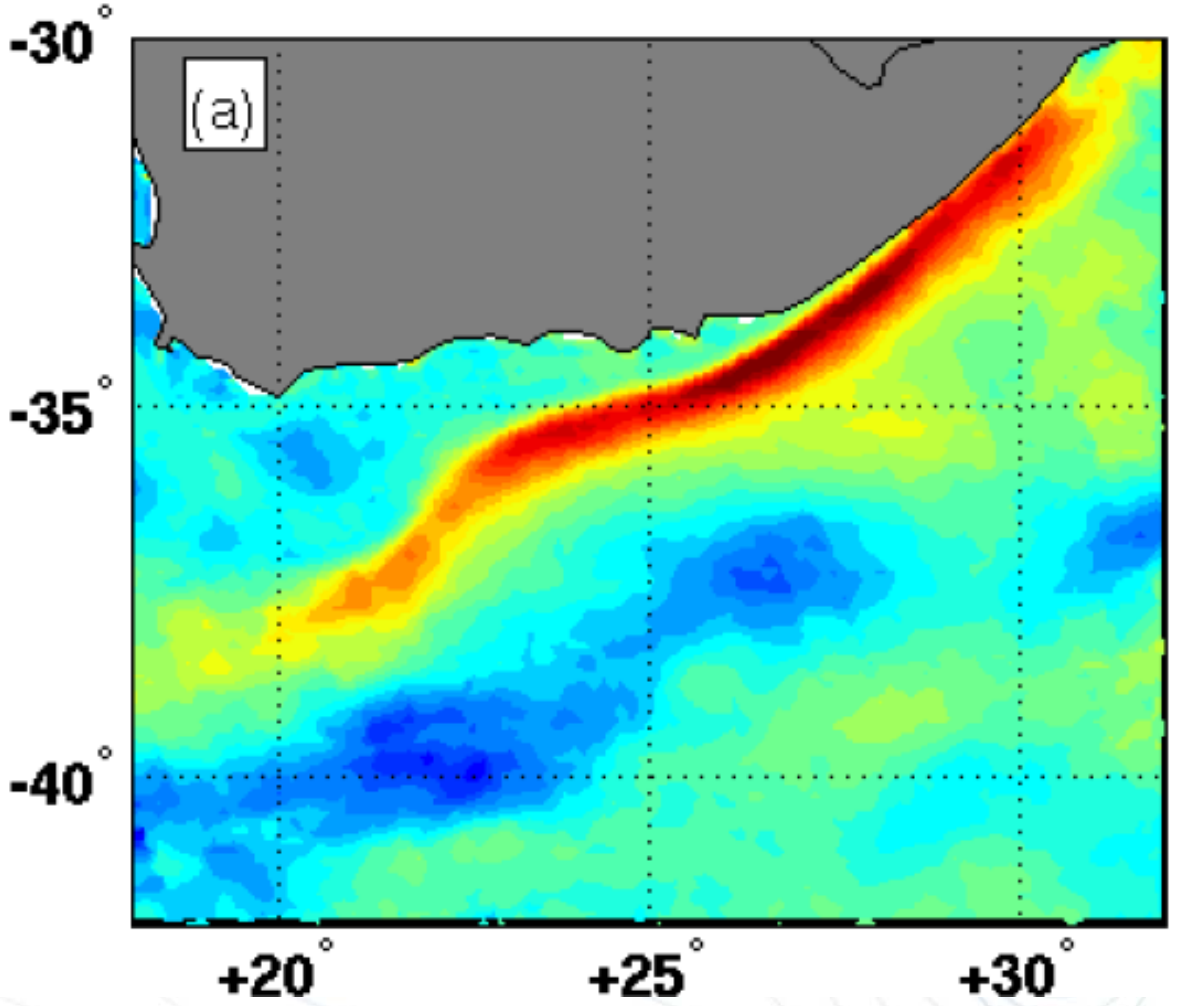


ENVISAT/ASAR Experience

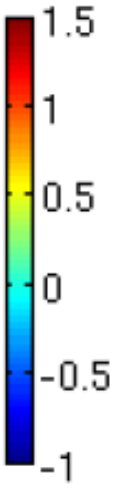
Ocean Surface Retrieval

High Resolution Mean Dynamic Topography

Mean Radial Velocities & MDT

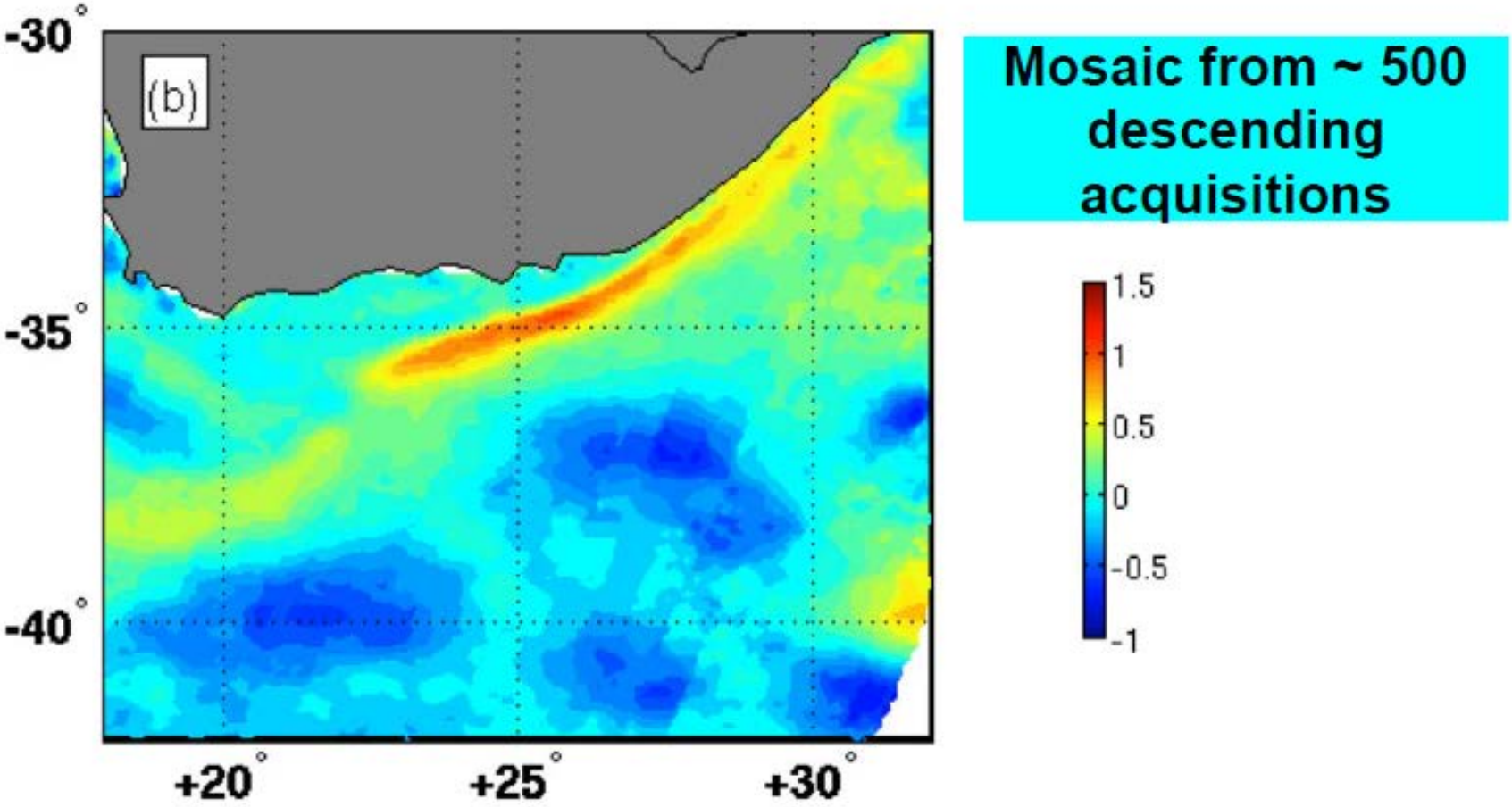


Mosaic from ~ 600 ascending acquisitions



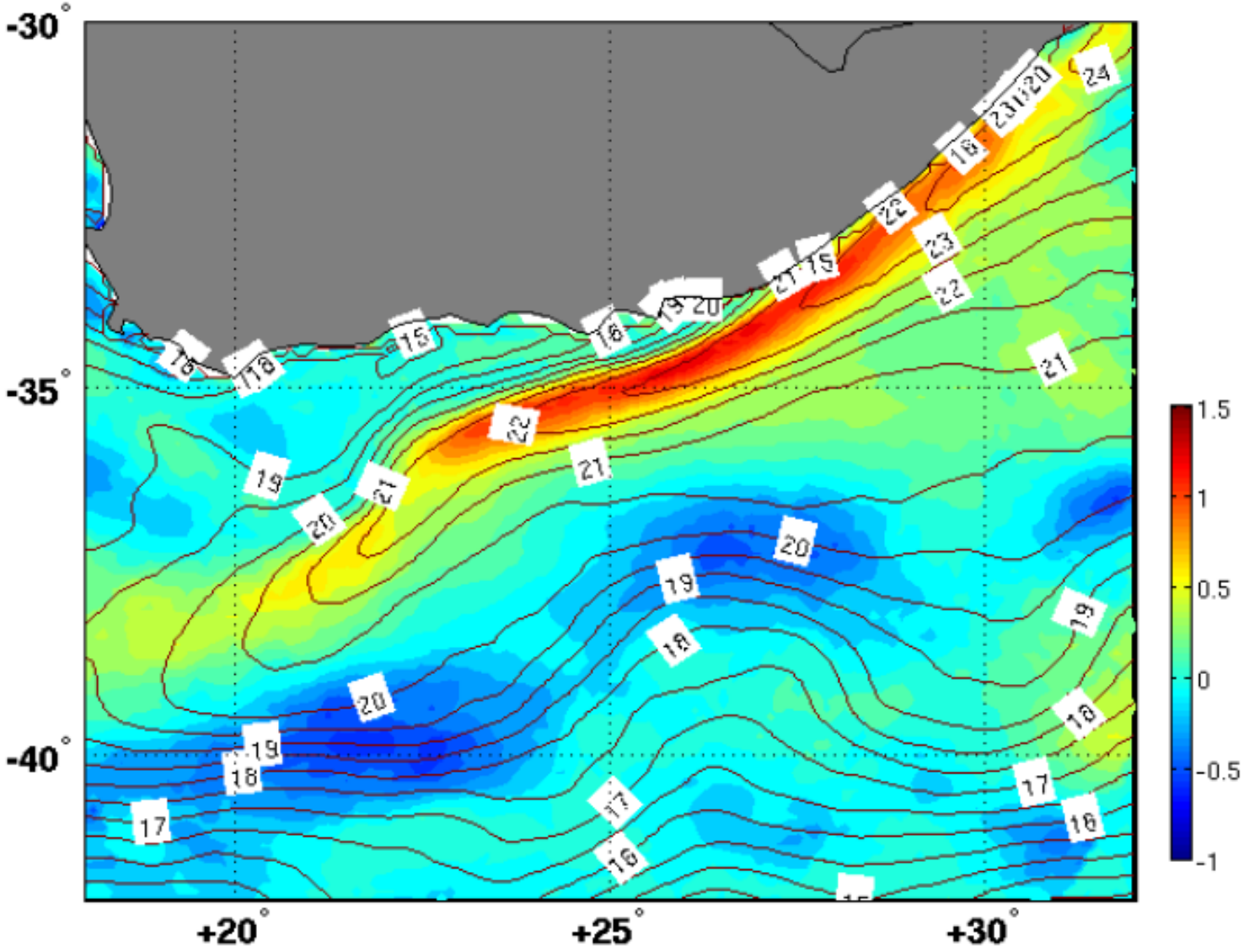
Ifremer

Mean Radial Velocities & MDT



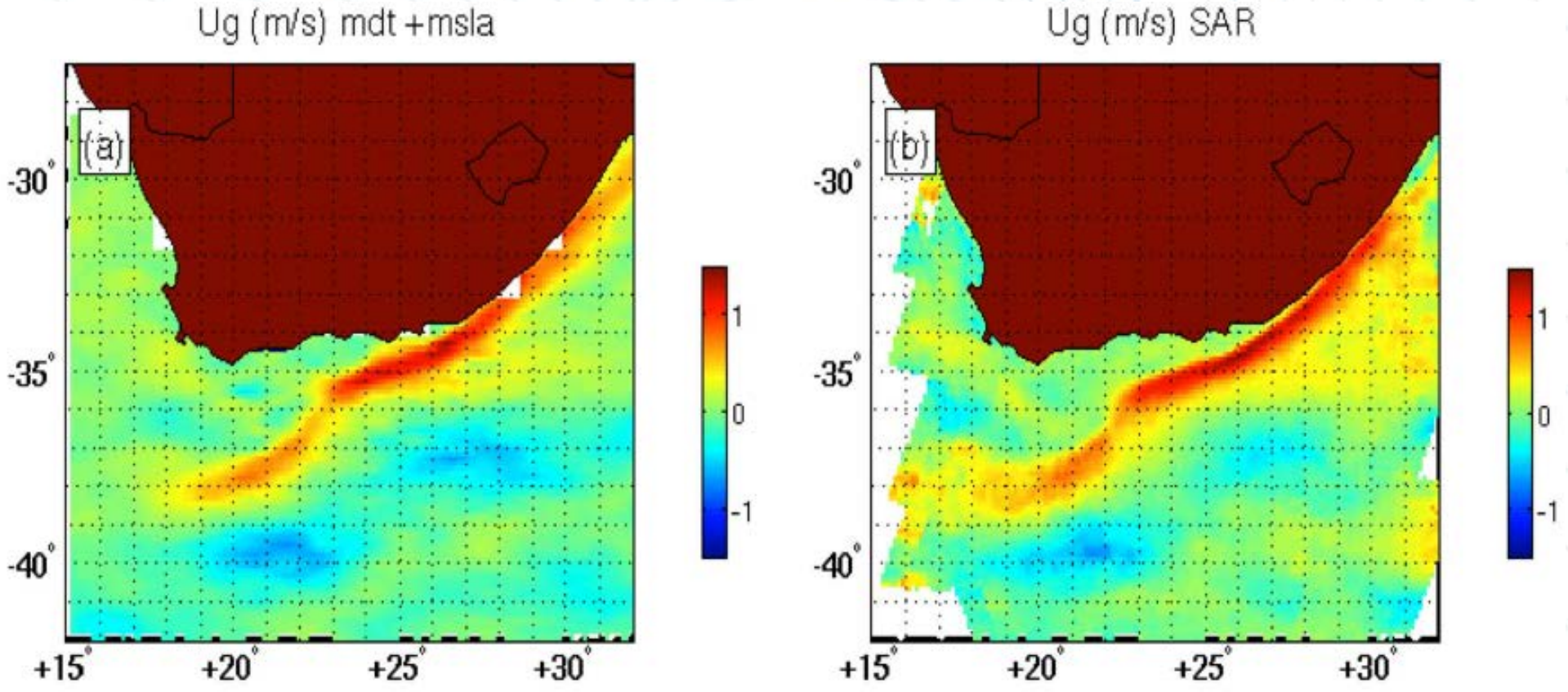
Ifremer

Mean Radial Velocities & MDT

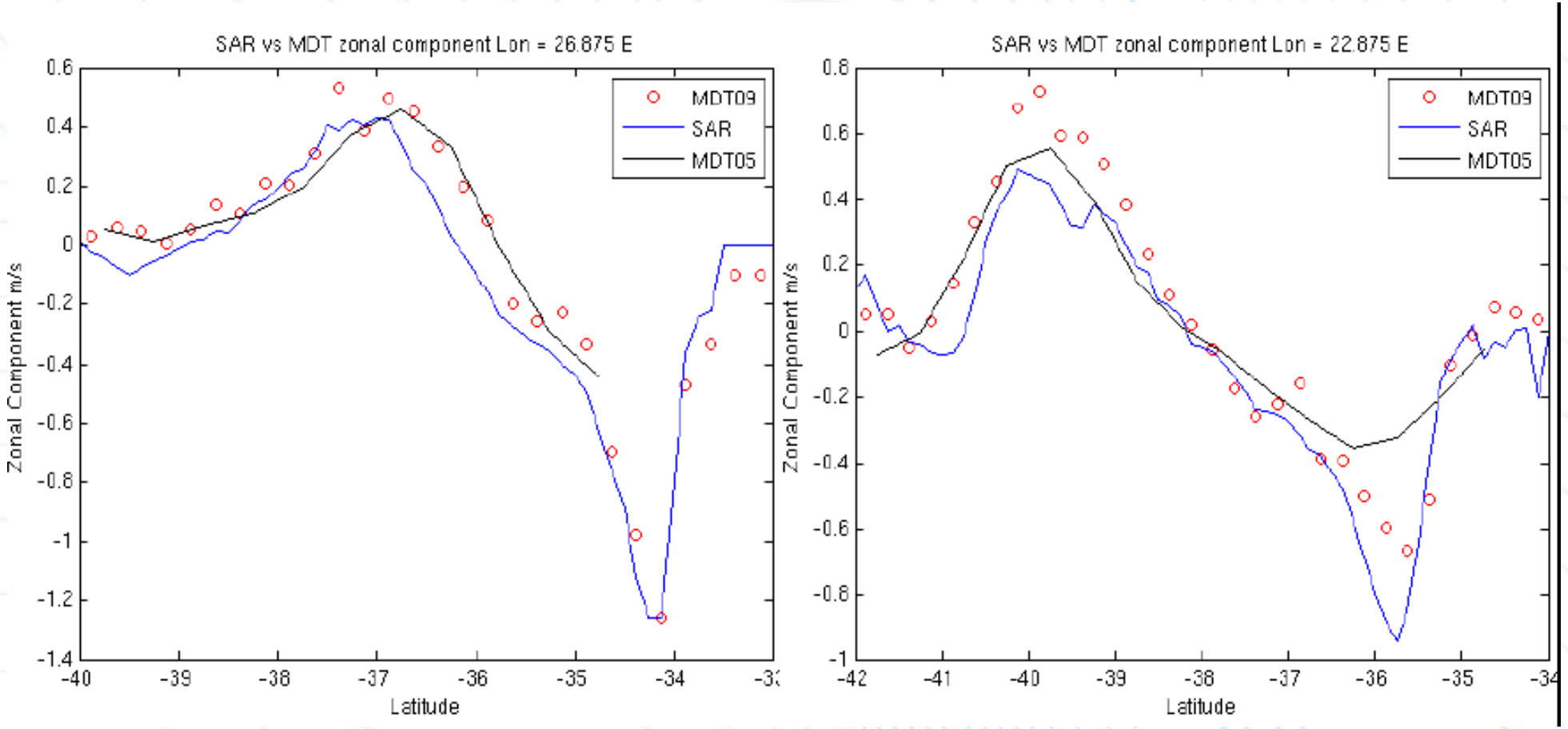


Ifremer

Mean Radial Velocities & MDT



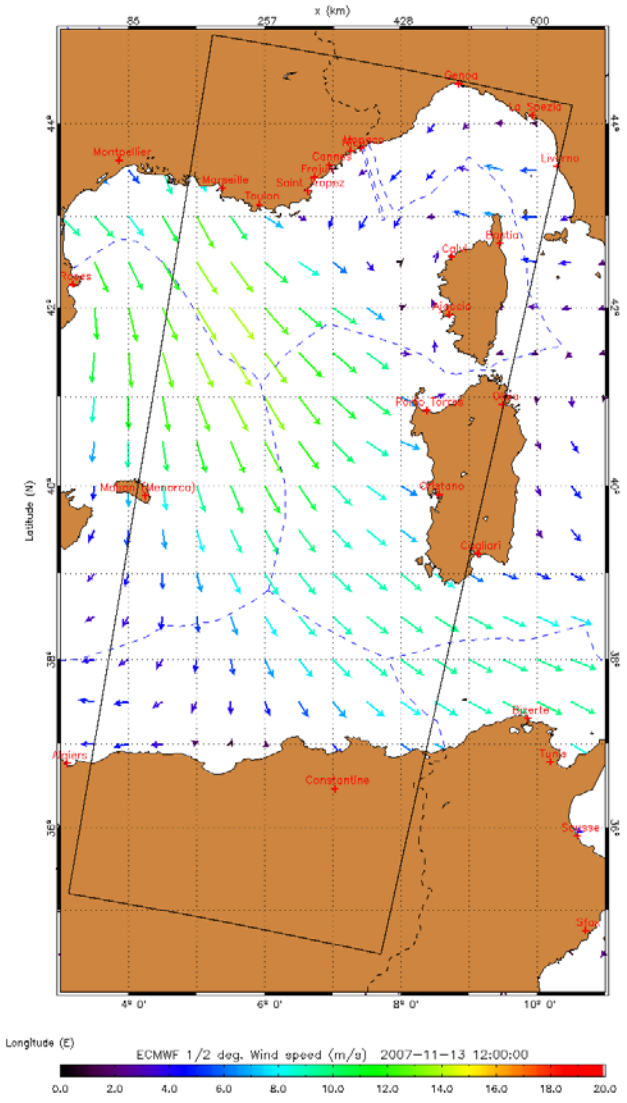
Mean Radial Velocities & MDT

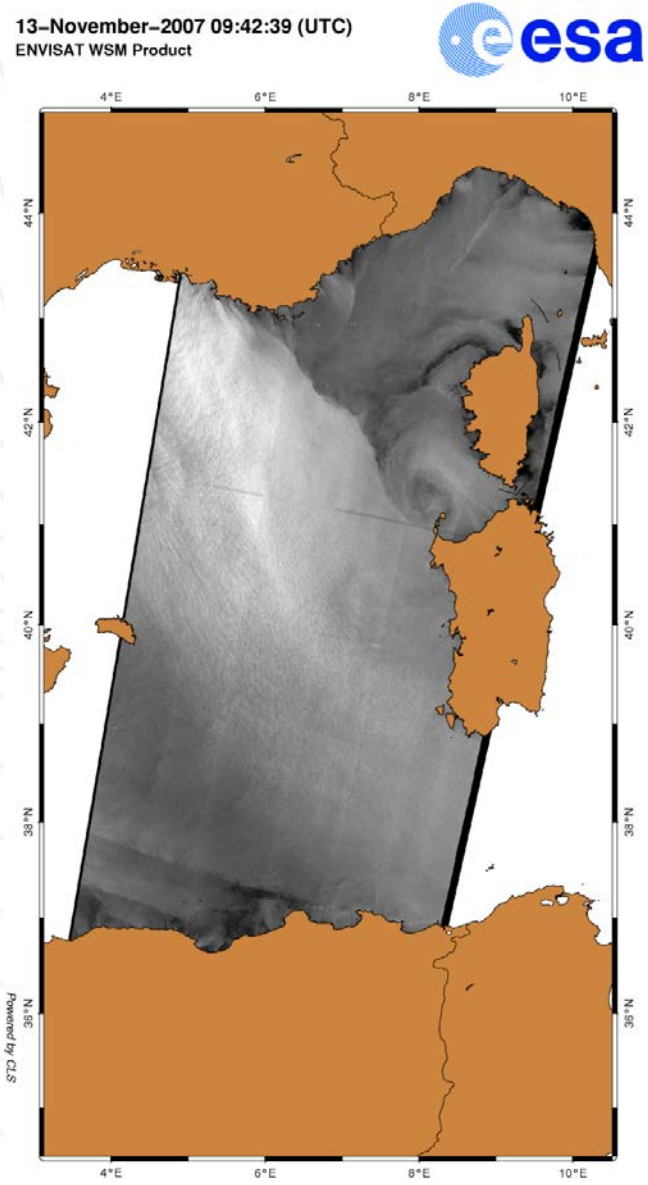


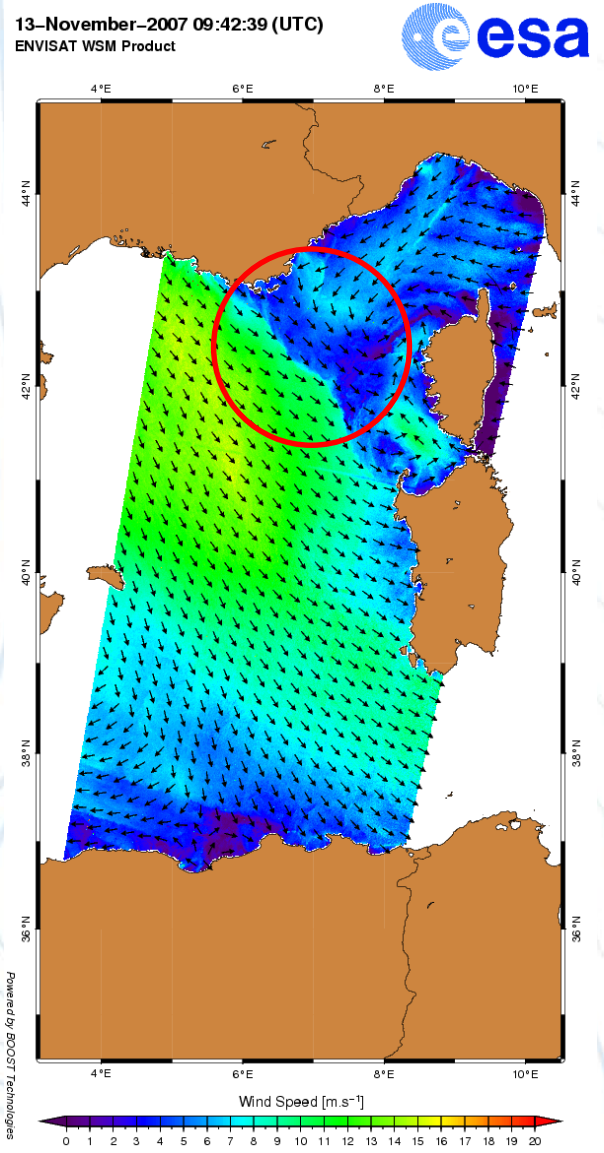
A new MDT is being developed by M.H. Rio and will incorporate SAR Doppler (see Rio et al. 2016)

Can the Doppler shift have value for wind retrievals?

Wind inversion exemple, where the atmospheric front is misplace due to the use of not enough precise ancillary wind information

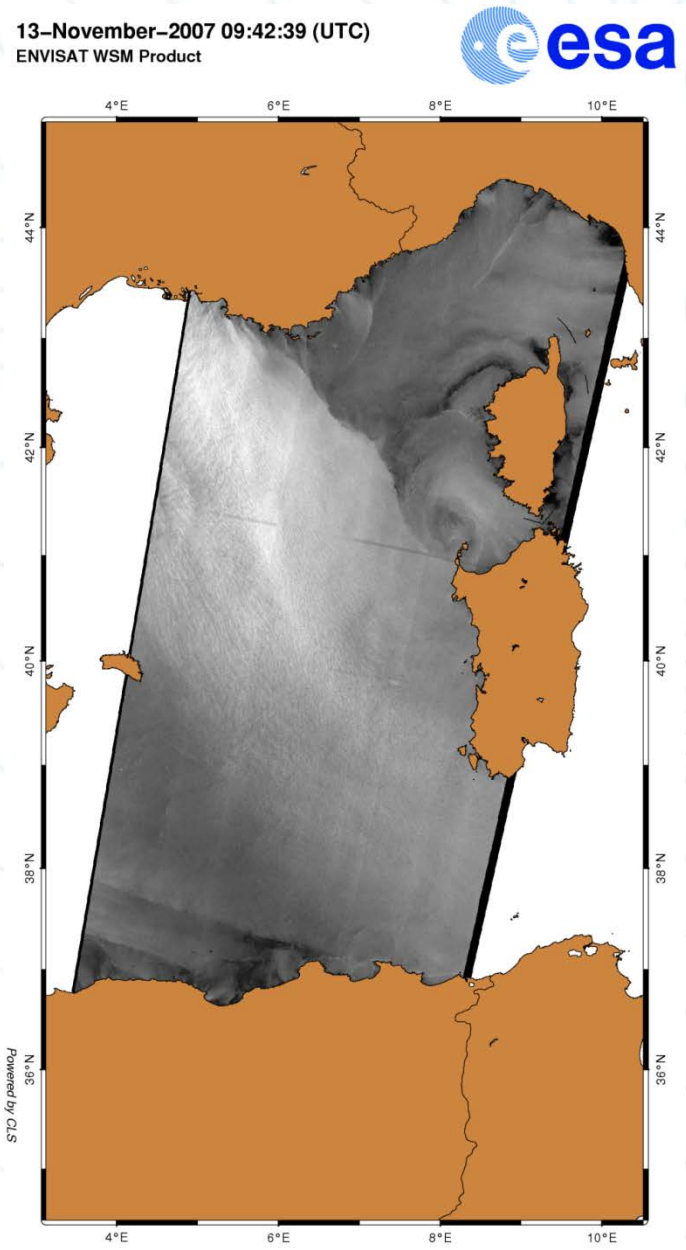


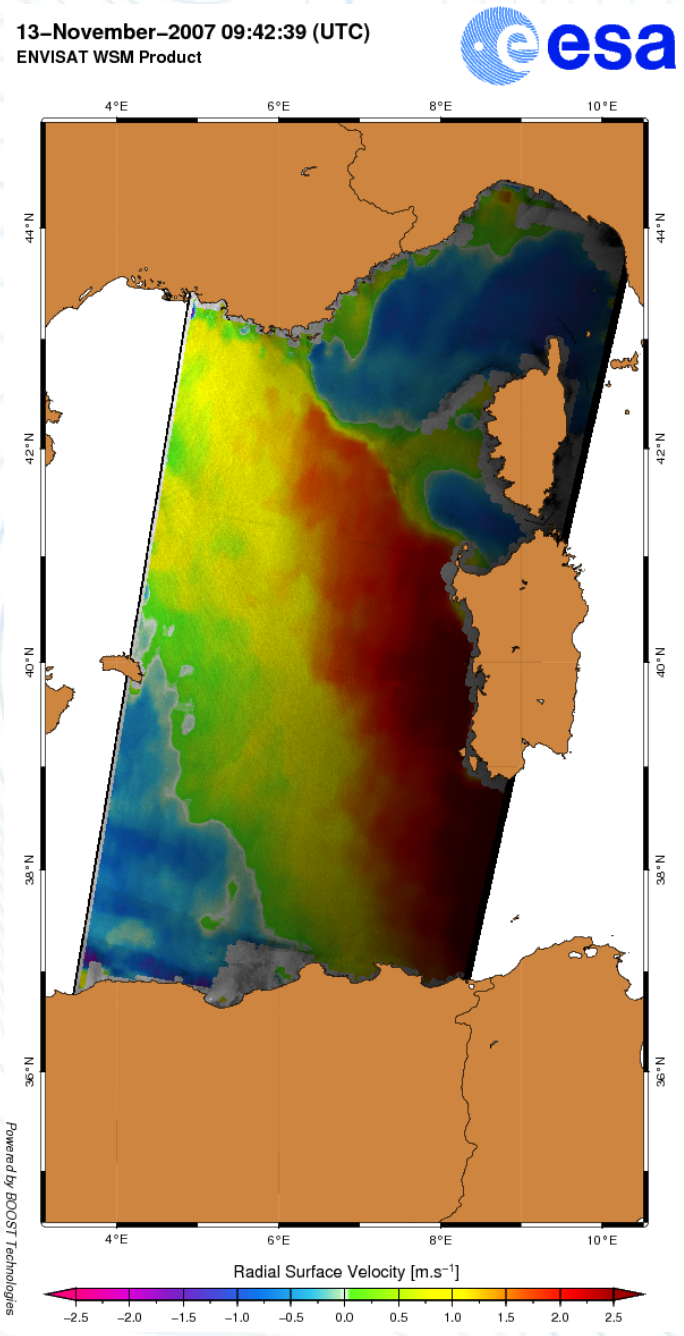




Mouche et al., IEEE TGRS 2012

As for NRCS, Doppler and ocean wind speed are strongly related.





Mouche et al., IEEE TGRS 2012

Summary

- Doppler is affected by both Sea state and Sea surface current
- Doppler response to sea state is higher in HH than in VV
- Doppler response to sea state decreases when incidence angle increases
- In cases where wind is dominating the Doppler contribution, Doppler can be used to constrain wind inversion. In particular for wind direction

Perspectives

- The Sentinel-1 SAR data will soon provide Doppler information on a regular basis
- Combination of Doppler and NRCS for wind retrieval from several antenna may be of interest for future satellite scatterometer concepts