ENVISAT ASAR: A SPEED-GUN IN SPACE

J.A.Johannessen[1,2], B. Chapron[3], F. Collard[4], A. Mouche[4], M. Rouault[5] and J. Tounadre[3]

[(1)] *Nansen Environmental and Remote Sensing Center, Bergen, Norway*
Thormoehlensgate 47, N-5006, Bergen Norway
[(2)] *Geophysical Institute, University of Bergen, Norway*
[(3)] *Institute Francais de Recherche pour l´Exploitation de la Mer, Plouzané, France*
[(4)] *CLS – Direction of Radar Applications, Plouzané, France*
[(5)] *Council for Scientific and Industrial Research, Ecosystem Earth Observations, Cape Town, South Africa*

ABSTRACT

Regular access to Doppler shift measurements from Envisat Advanced Synthetic Aperture Radar (ASAR) Wide Swath Mode (WSM) images is now possible. An increasing data set of the radar-detected ocean surface roughness velocities inverted from the Doppler shifts has therefore emerged dating back to mid 2007. This offers an innovative capability to establish time series and gridded maps of Doppler-derived ocean surface velocities. Building on more than 1000 acquisitions from the greater Agulhas Current, the robust results give confidence that the Envisat ASAR can be used as a speed-gun from space. Combined with surface drifter data and altimeter measurements, these new products strengthen the routine monitoring of the intense current regimes.

1. INTRODUCTION

Direct global spaceborne measurements of surface current are not straightforward. Satellite altimeters such as JASON and Envisat RA2 are measuring the along-track ocean surface topography with high precision (1-3 cm over 25 km). The strength of the across-track surface current is then calculated from the geostrophic balance. Utilizing satellite along-track interferometry, the instantaneous sea surface scatter velocity can be estimated from the phase difference as successfully demonstrated during the Shuttle Radar Topography Mission (SRTM) (Romeiser et al., 2005). However, this technique has hitherto not been available on a regular basis from orbiting satellites (Romeiser et al., 2010).

Frequency shift determination from the instantaneous phase history analysis of single antenna Synthetic Aperture Radar (SAR) returns has also been used to derive an estimate of the range directed surface velocity as suggested by Chapron et al. (2005). Using the Envisat ASAR wave mode and wide swath mode (WM, WSM) images, Johannessen et al. (2008) further showed that Doppler anomalies can be determined with an r.m.s. error of 5 Hz (equivalent to 0.2 m/s) at a spatial resolution of 8 km by 4 km. This Doppler anomaly is associated with an overall range directed bulk velocity corresponding to the mean motion of the radar detected scatterers at the ocean surface including the desired ocean surface current.

2. APPROACH

Since the European Space Agency´s (ESA) upgrading of the ground segment in mid 2007, regular access to Envisat ASAR WSM Doppler grid information has led to the creation of a comprehensive data set. This has supported generation of an empirical relationship to explain the observed wind dependence of the C-band Doppler shifts for both VV and HH polarizations (Collard et al., 2008; Johannessen et al., 2008). Based on access to reliable estimate of the local wind speed and direction it is thus possible to quantify and systematically remove the expected wind contribution. Consequently, a residual Doppler shift anomaly can be retrieved for more direct comparison to the radial surface current as shown in Figure 1.

This new emerging capability to map range directed surface velocities corresponding to intense surface current is demonstrated in this paper. More than 1000 ASAR WSM acquisitions have been individually processed to produce mosaic maps of the mean residual radial Doppler-derived velocities from ascending (descending) satellite tracks of the Agulhas Current (Figure 2).

Image collocations with the ECMWF wind products were used to remove the wind contribution to the Doppler velocity. The maps display comparable locations of the core of the Agulhas Current, suggesting strongest current upstream from 25°E. In both maps, moreover, the structure of the radial Doppler velocities suggest that the separation from the coast occur slightly north of 33°S, and with similar growing distances from the coast in the downstream direction. This is in agreement with the topographic steering of the Agulhas Current (Gründlingh, 1983). Whereas the shallow continental shelf widens towards southwest the shelf

Proc. 'SeaSAR 2010', Frascati, Italy,
25–29 January 2010 (ESA SP-679, April 2010)

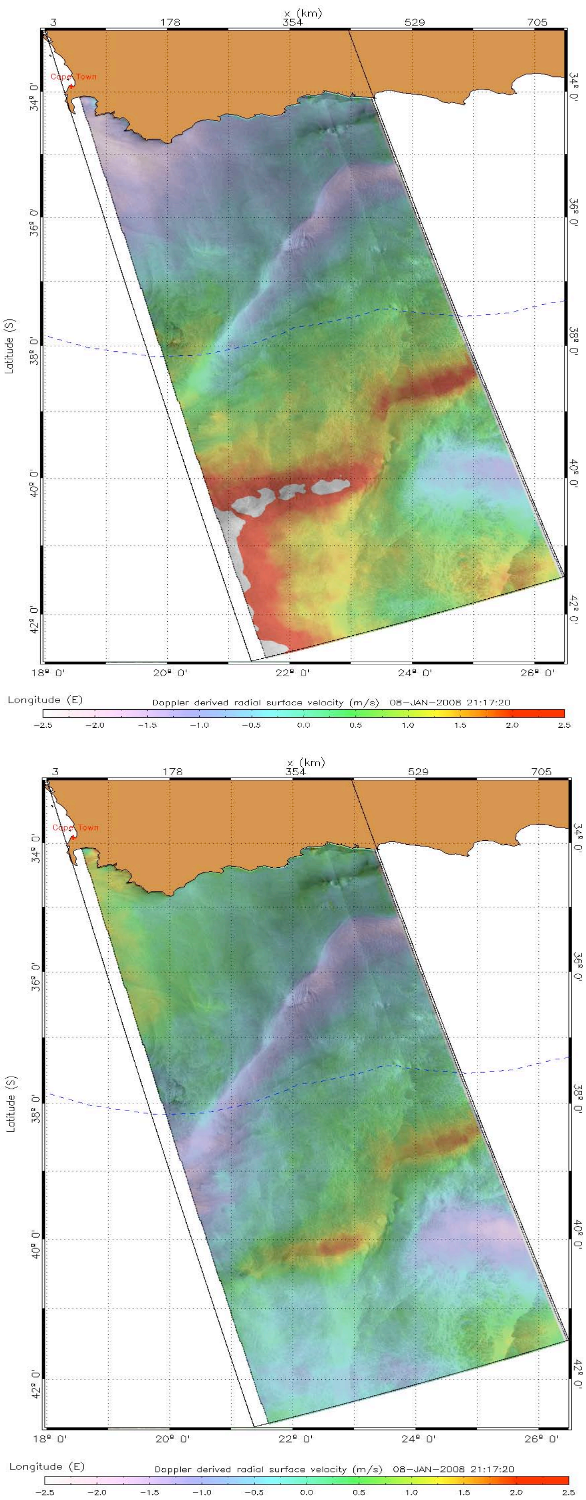

Figure 1. *Range Doppler velocities before wind removal (upper) and after wind removal (lower).*

break, which is very steep in this area, stabilizes the Agulhas Current and inhibit meander growth. Consequently estimation of the surface geostrophic current from altimeter derived sea level anomalies are largely suppressed compared to the range Doppler

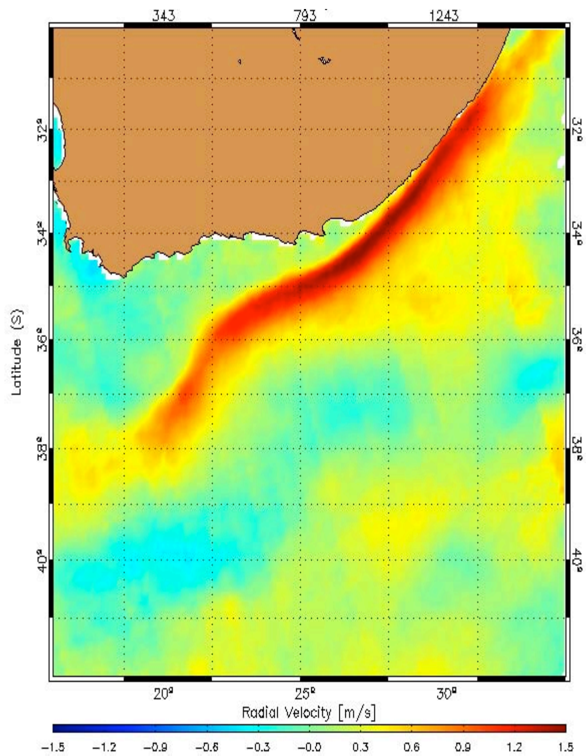

Figure 2. *Mean range Doppler velocities of the Agulhas Current derived from more than 500 ascending Envisat ASAR WSM acquisitions. The color bar mark the speed in m/s with "warm" ("cold") colors being directed towards west (east).*

velocities as reported by Johannessen et al. (2008).

The ascending tracks yield a more favorable imaging geometry with respect to the core flow direction. Accordingly, the maximum mean radial Doppler velocity reaches about 1.5 m/s with a distinct mean current width reaching about 100 km east of 22°E . In comparison, the mean radial velocity obtained from the descending tracks (not shown) is only about 0.8 m/s with a mean width of 80 km. However, these velocity differences almost entirely vanish when the ascending and descending components are rotated into the distinct pathway of the Doppler velocity signal. With such a projection an estimate of the maximum speed of the Agulhas Current at 33°S and 28.5° E, for instance, is found to reach about 1.75 m/s.

The map reveal that the Agulhas Current undergoes an apparent shift in strength and flow direction centered at about 36°S and 22.5°E. Downstream from this region the gradual weakening and discontinuity in the mean Doppler velocity pattern suggests that the Agulhas Current evolves into a less energetic flow towards the retroflection region centered at 38-39°S, 18°E. Sign shifts of the range Doppler velocities followed by the gradual manifestation of a moderately weaker and broader eastward velocities are manifesting the retroflection region and the semi-permanent meandering of the Agulhas Return Current (Boebel et al, 2003).

The robust manifestation of these Doppler velocity signatures of the Agulhas Current is striking. Although the Doppler velocity is not a direct surface current measurement, it inevitably suggests that the use of Doppler observations can help to derive new and innovative estimates of mesoscale dynamics provided the wind contribution is reliable removed.

Quantitative investigation of the surface drifter data (http://www.aoml.noaa.gov/phod/dac/gdp.html) allow these results to be further assessed. The drift trajectory of buoys from the same averaging period is inserted on top of the range Doppler velocity in Figure 3.

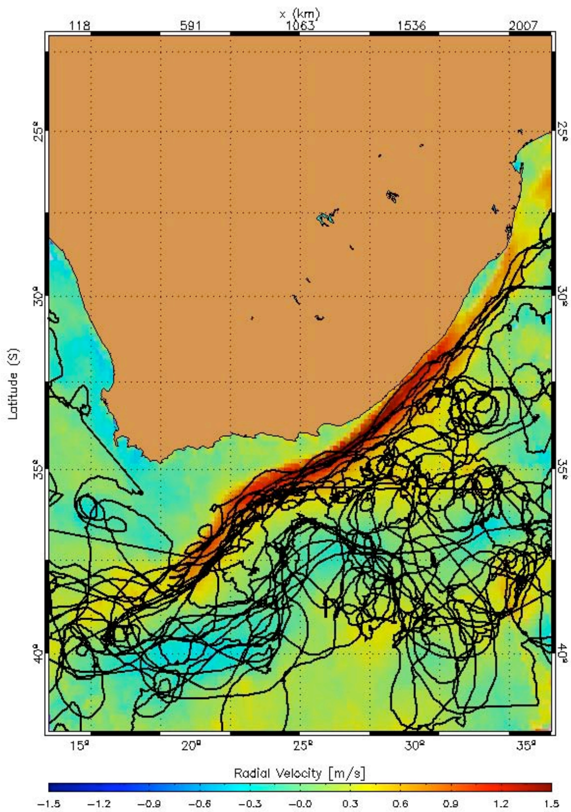

Figure 3. *Surface drifter trajectories ("spagulhas") overlaid the mean radial Doppler velocities shown in Figure 2.*

Only 7 of these buoys transected in the core of the Agulhas Current across the meridional section at 26°E bounded by 33-35°S. However, none of them were collocated in space and time with the SAR acquisitions in the core region. The corresponding trajectories of the drifters converges and follows very nicely the pathway of the core of the Agulhas Current as depicted by the Doppler range velocities (Figure 3). On several occasions in the northeastern region the maximum speed of the drifter reaches more than 1.7 m/s in very good agreement with the projected Doppler velocities. It is also noteworthy to see the distinct bending of the drifter trajectories that occur at about 36°S and 22.5°E in agreement with the pattern of the radial Doppler velocities. Consequently this Doppler shift technique offers the ability to infer valuable estimates of surface current in energetic ocean current regimes. There is also agreement in the location of the apparent merging of the drifters in the Agulhas Return Current and the range Doppler velocity.

Routine monitoring of the seasonal to interannual transport variability of the greater Agulhas Current regime is hitherto rare and not adequate to quantify the transports in the retroflection region partitioned between the eddy shedding into the South Atlantic Ocean and the Agulhas Return Current. In view of the need to establish a more comprehensive monitoring system for the Indo-Atlantic inter-ocean mass and heat exchanges connected with the greater Agulhas Current, it is therefore tempting to incorporate this radial Doppler velocity estimation method. Complemented with routine merged satellite sea surface temperature (SST) products (Figure 4) derived from the Ifremer ODYSSEA global SST analyses products (http://*cersat.ifremer.fr)* such a satellite based monitoring system component would clearly be very powerful as demonstrated in this paper.

3. SUMMARY

Although a dedicated validation campaign is yet to be executed, the long-term persistence displayed in the Doppler velocity maps adds significant confidence in the retrieval method. Combined with surface drifters, SST fields, altimeter-derived surface geostrophic current and in the near future a new improved geoid from the GOCE satellite, it should strengthen the capacity for quantitative monitoring of the dynamics of intense current regimes and advance the possibility to estimate the maximum surface current. Systematic production and establishment of long time series of the surface range Doppler velocities is therefore proposed for selected intense current regimes in view of the space agencies approved continuity of SAR missions in this decade. Among these current regimes are, in addition to the greater Agulhas Current, the Gulf Stream, the Kuroshio Current, the Malvinas Current and the North Brazilian Current. Ideally such routine provision of Doppler velocities converted to reliable radial surface currents would support establishment of new climatology and could become invaluable for model validation and assimilation. Further documentation of the feasibility of this range Doppler retrieval method can be evidenced at http://soprano.cls.fr and/or from the excellent expression obtained on 7 March 2010 http://soprano.cls.fr/L2/currentProducts/details/9649.

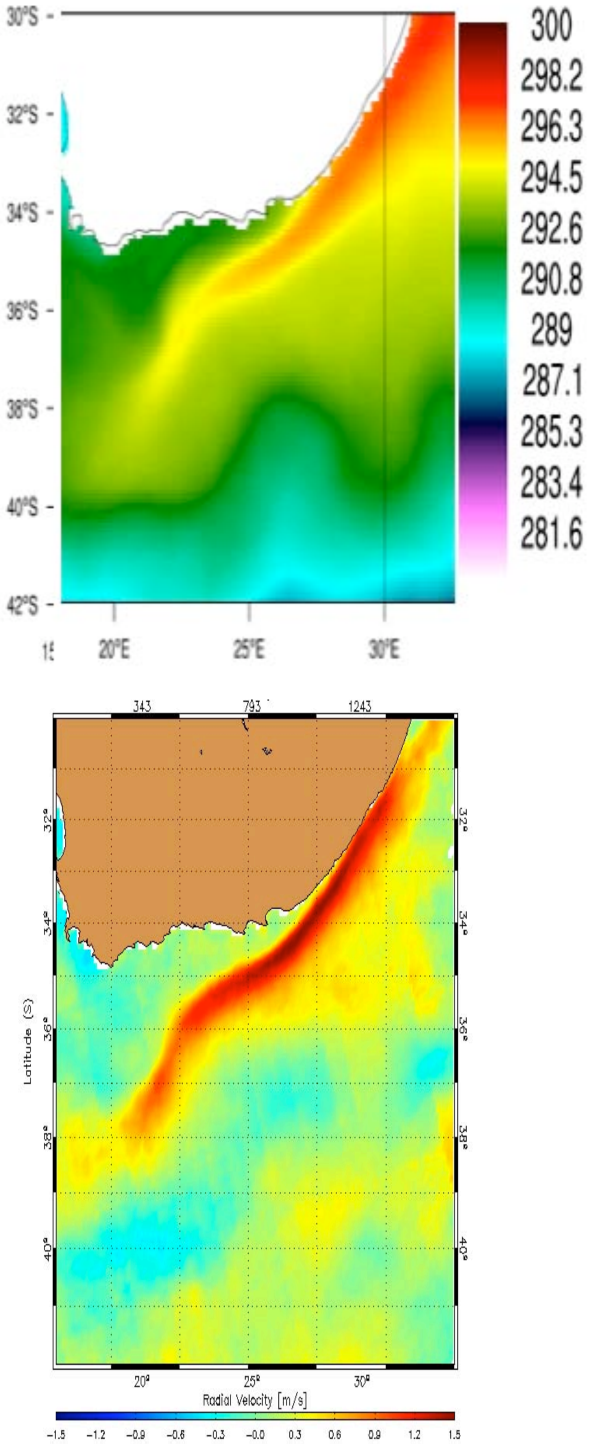

Figure 4. *(upper) Mean SST field in degree Kelvin derived from the ODYSSEA global SST analyses products at http://*cersat.ifremer.fr/. *(lower) Mean range Doppler velocity field shown in Figure 2.*

References

Boebel, O., T. Rossby, J.R.E. Lutjeharms, W. Zenk and C. Barron (2003), Path and variability of the SAgulhas Return Current, *Deep Sea Research*, 50, 35-56, 2003.

Chapron, B., F. Collard, and F. Ardhum, (2005), Direct measurements of ocean surface velocity from space: Interpretation and validation, *Journal of Geophysical Research*, 110, C07008.

Collard F, A. Mouche, B. Chapron, C. Danilo, J.A. Johannessen (2008) Routine high resolution observation of selected major surface currents from space. *In Proc SeaSAR 2008, 8 pp, ESA Communication Production Office,* ESTEC, Noordwijk, Netherlands.

Gründlingh, M.L. (1983), On the course of the Agulhas Current, *South African Geographical Journal*, 65(1), 49-57, 2003.

Johannessen, J.A., B. Chapron, F. Collard, V. Kudryavtsev, A. Mouche, D. Akimov and K.-F. Dagestad, A model of combined backscatter and Doppler shifts for surface velocity estimation from SAR images, *Geophysical Research Letter*, 28 November, 2008.

Romeiser, R., H. Breit, M. Eineder, H. Runge, P. Flament, K. de Jong, J. Vogelzang, Current measurements by SAR along-track interferometry from a Space Shuttle, *IEEE Transactions on Gescience and Remote Sensing*, Vol. 43, No. 10, October 2005.

Romeiser, R., J.A. Johannessen, B. Chapron, F. Collard, V. Kudryavtsev, H. Runge, and S. Suchandt, Direct surface current field imaging from space by along-track InSAR and conventional SAR. In Oceanography From Space, Revisited, V. Barale, J.F.R. Gower, and L. Alberotanza (eds.), 20 pp., *Springer Science and Business Media*, in press, 2009.

Acknowledgements. This work was supported by the Research Council of Norway, project number 177441/V30 and by ESA through the study contract no. 18709/05/I-LG. ESA is also acknowledged for implementing systematic ASAR wide swath acquisitions over the greater Agulhas Current making this study possible. We are also grateful to the Global Drifter Program at their server at AOML in Miami http://www.aoml.noaa.gov/phod/dac/gdp.html.