GLOBCURRENT: SENTINEL-3 SYNERGY IN ACTION

J.A. Johannessen[1], B. Chapron[2], F. Collard[3], M.-H. Rio[4], J.-F. Piollé[2], G. Quartly[5], J. Shutler[6], R. Escola[7], C. Donlon[8], R. Danielson[1], A. Korosov[1], R. P. Raj[1], V. Kudryavtsev[1], M. Roca[7], J. Tournadre[2], G. Larnicol[4], S. Labroue[4], P. Miller[5], F. Nencioli[5], M. Warren[5] and M. Hansen[1]

[(1)]NERSC, Thormøhlens gate 47, N-5006 Bergen, Norway; email: johnny.johannessen@nersc.no
[(2)]Ifremer, Technopole, Pointe du Diable 29280 Plouzané, Brest, France
[(3)]OceanDataLab, Pointe du Deolan, Plouzané, Brest, France. Email: dr.fab@oceandatalab.com
[(4)] CLS, Toulouse, France
[(5)]Plymouth Marine Laboratory, Prospect Place, The Hoe, Plymouth, Devon, PL1 3DH, UK
[(6)]University of Exeter, Penryn, UK
[(7)]isardSAT UK
[(8)]ESA ESTEC, Noordwijk, The Netherlands

ABSTRACT

The ESA Data User Element (DUE) funded GlobCurrent project (http://www.globcurrent.org) aims to: (i) advance the quantitative estimation of ocean surface currents from satellite sensor synergy; and (ii) demonstrate impact in user-led scientific, operational and commercial applications that, in turn, will improve and strengthen the uptake of satellite measurements.

Today, a synergetic approach for quantitative analysis can build on high-resolution imaging radar and spectrometer data, infrared radiometer data and radar altimeter measurements. It will further integrate Sentinel-3 in combination with Sentinel-1 SAR data. From existing and past missions, it is often demonstrated that sharp gradients in the sea surface temperature (SST) field and the ocean surface chlorophyll-a distribution are spatially correlated with the sea surface roughness anomaly fields at small spatial scales, in the sub-mesocale (1-10 km) to the mesoscale (30-80 km). At the larger mesoscale range (>50 km), information derived from radar altimeters often depict the presence of coherent structures and eddies. The variability often appears largest in regions where the intense surface current regimes (>100 - 200 km) are found. These 2-dimensional structures manifested in the satellite observations represent evidence of the upper ocean (~100-200 m) dynamics. Whereas the quasi geostrophic assumption is valid for the upper ocean dynamics at the larger scale (>100 km), possible triggering mechanisms for the expressions at the mesoscale-to-submesoscale may include spiraling tracers of inertial motion and the interaction of the wind-driven Ekman layer with the quasi-geostrophic current field. This latter, in turn, produces bands of downwelling (convergence) and upwelling (divergence) near fronts.

A regular utilization of the sensor synergy approach with the combination of Sentinel-3 and Sentinel-1 will provide a highly valuable data set for further research and development to better relate the 2-dimensional surface expressions and the upper ocean dynamics.

1. INTRODUCTION

From a purely physical point of view, the ocean surface current can be characterized as a coherent horizontal and vertical movement of water – in contact with the surface and representative over a specific depth range – with a given velocity that persists over a specific region and given time period. Our ability to monitor ocean surface currents and to understand the fundamental processes that influence their strength and variability has evolved during the last decades. Historically, the motivation for understanding the global ocean circulation originally emerged from traditional maritime activities like transportation and shipping. Today, on the other hand, both climate change monitoring and projections as well as operational oceanography, air-sea interactions and coupled physical and biogeochemical interactions are demanding distinct and accurate knowledge of the ocean surface currents. For example, search and rescue operations, monitoring of sediment transport, pollution dispersal and prediction of fish egg and larvae drift all require precise estimates of surface currents at a broad range of temporal and spatial scales. As such, the modern definition of an ocean surface current now needs to encompasses smaller scales and their associated three-dimensional flows, with manifestations at the surface that are just beginning to be resolved and interpreted.

The ESA Data User Element (DUE) funded GlobCurrent project (http://www.globcurrent.org) aims to:

- advance the quantitative estimation of ocean surface currents using a satellite sensor synergy approach;
- demonstrate impact in user-led scientific, operational and commercial applications;
- improve and strengthen the uptake of satellite measurements for upper ocean research and application.

Proc. 'Sentinel-3 for Science Workshop', Venice, Italy
2–5 June 2015 (ESA SP-734, December 2015)

The GlobCurrent project follows an analysis and interpretation framework for ocean surface current estimates as outlined in [1]. The project has a 3-year duration and will end in December 2016. The following tasks forms the core of activities in the *GlobCurrent* project:

- Federate the international user community for ocean surface currents to develop scientific and end-user consensus on technical and scientific requirements relevant to the project.
- Undertake research and development activities to define, evolve, and maintain Algorithm Theoretical Baseline Descriptions (ATBD) for all the *GlobCurrent* ocean surface current products and validate the performance of each algorithm.
- Define and document a Technical Specification for each evolving version of the *GlobCurrent* system.
- Implement and qualify each successive version of the *GlobCurrent* system and operate each system to produce the required outputs.
- Support user-led application case studies to encourage the appropriate development of the *GlobCurrent* system and uptake of *GlobCurrent* products and demonstration services.

A brief summary of the present availability of the global data products is provided in section 2, complemented with an emphasis of the relevance and importance of the Sentinel-3 data. Section 3 addresses the ongoing development of regional climatology products with examples from the Agulhas Current region, while section 4 proceeds with synoptic snapshot examples for the same region. The summary and outlook follows in section 5.

2. DATA PRODUCTS AND RELEVANCE OF SENTINEL-3

The first GlobCurrent global data products cover a 3-year period from 2010 to 2012. The data include geostrophic current (at the surface), Ekman current (at the surface and 15 m depth) and surface Stokes drift components. The two former products are produced from a combination of satellite data (altimetry, GOCE, GRACE, scatterometers) and in-situ data (Argo floats, surface drifter data), whereas the latter is derived from the Wave Watch III model. The data are interpolated to a common grid with a temporal resolution of three hours and a spatial resolution of about 10 km. An example of the global product is shown in Figure 1. The readers are referred to [2] for further explanation on how this product is derived.

The expected Sentinel-3 provision of data and information products in support of the global, regional and local surface current estimations is illustrated in Figure 2. From the radar altimeter, infrared radiometer and imaging spectrometer (including sun glint) one can obtain 6 geophysical variables, notably: small scale roughness anomalies, ocean color, sea surface height (SSH), significant wave height, near surface wind speed and sea surface temperature (SST). These variables and their spatial and temporal changes contain direct or indirect manifestations and signals related to the surface current conditions. Example of signals include: surface current boundaries; surface tracer velocity; surface Ekman current; inertial motion; surface current vorticity; surface geostrophic current and Stokes drift.

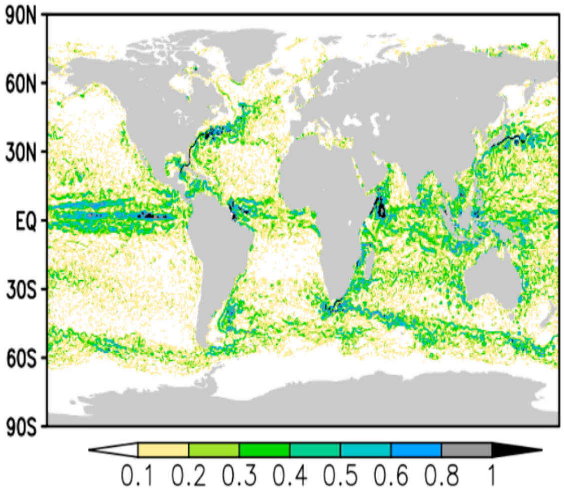

Figure 1. *Map of global surface geostrophic current (in m/s) at mid-night on 1st September 2012. Speeds below 0.1 m/s are removed (white) while speeds above 1 m/s are black.*

Further invoking data and information products from Sentinel-1 and other existing complementary satellite missions jointly with data from in-situ observing systems will increase the number of derived ocean variables. These will enable more reliable information on the surface current conditions and the uncertainties (Figure 2). This suggests that systematic use of satellite sensor synergy combined with in-situ data will strengthen our ability to obtain high quality and consistent information on surface current conditions and their relationship to the upper ocean (~100 m) dynamics and processes. In the following this is further illustrated by some selected examples for satellite sensor synergy, notably:

- drifter data climatology together with climatology of SSH, SST and range Doppler velocity fields;
- snapshot SST, surface geostrophic current and surface drifter data;

3. CLIMATOLOGY OF DRIFTER DATA, SST, SSH AND RANGE DOPPLER VELOCITY

Satellite data record lengths that are now nearing more than 30 years (in some cases 40 years) are gradually becoming highly valuable for generation of multi-decadal climatology, in particular, for global and regional application with a spatial resolution of about 100 km. Such a satellite-based climatology can now often be combined with a climatology derived from comparable long records of in-situ data as shown in Figure 3. The climatology representation for the greater Agulhas Current regime displays the surface trajectory pattern from surface drifter data (left) together with the combined sea surface temperature (SST) and sea surface height (SSH) fields representing the austral summer (middle) and austral winter (right) conditions.

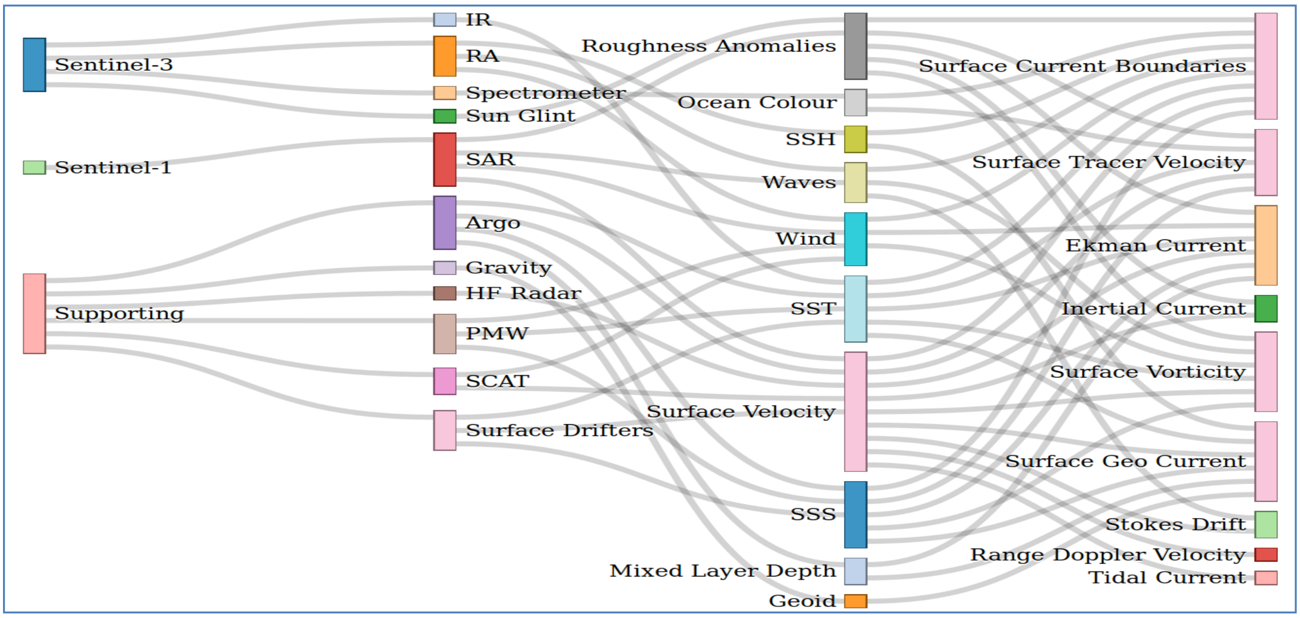

Figure 2. *Illustration of Sentinel-3 provision of data and information products in support to the global, regional and local surface current estimations. Additional provision of complementary data and information from Sentinel-1 and other supporting missions and in-situ data further demonstrates the importance and strength of sensor synergy.*

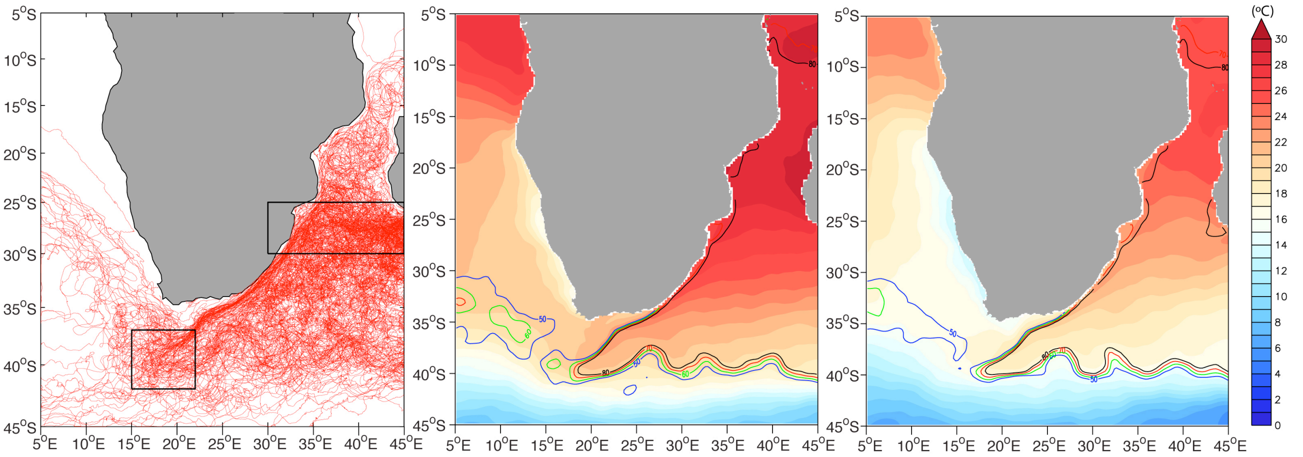

Figure 3. *(left) Climatology of surface drifter data for the period 1992 to 2014. Note that only those surface drifters passing the rectangular box in the Southern Mozambique Channel are plotted. The retroflection region is represented by the square box. The climatology of SST (colour) and SSH (contours) representing the period 1993 to 2012 for January (middle) and July (right). The contours range from 50 to 80 cm with an interval of 10 cm. The color bar to the right gives the SST in degree Celsius.*

The satellite-tracked drifters of the Global Drifter Program (GDP) now provide a large homogeneous data set of global near-surface current observations [3]. These observations can be decomposed to derive the global distribution of time-mean near-surface ocean currents, but also their seasonal cycle, and the variance of eddy fluctuations. All drifters have a drogue (sea anchor) centered at a depth of 15 m to reduce the downwind slip to ~0.1% of the wind speed for winds up to 10 m/s, in order to follow the water within the mixed layer. When this drogue is lost, the downwind slip largely increases to ~1–1.5% of the wind speed. This allows one to identify and remove unwanted drift estimates from un-drogued data. Surface drifter analysis moreover often first consists of a low-pass filter in time of the observations to best remove tidal and near-inertial components of the upper flow. The filter is a 2-point Butterworth filter with half-power cutoff at five days. The spatial mapping is reaching 0.5°x 0.5°, using data within ellipses set from the variance of eddy fluctuations, evaluated from the data and starting with 2°x 2° bins.

The surface drifters reveal the clear signal of the narrow (~100 km wide) and strong core of the Agulhas Current with the well known distinct bending in the main flow direction due to topographic steering at about 22° E. In the retroflection region the trajectories spread out in response to the more complex dynamic conditions in this area. Of the 163 drifters passing through the rectangular box in the southern Mozambique Channel 65 were also passing through the box in the retroflection region. Evidence of eddy shedding and drift into the South Atlantic are also seen as well as the large meandering pattern of the eastward flowing Agulhas Return Current, although the boundary of this current are less pronounced in the drifter data. In comparison the SST field and SSH field display frontal features and meandering structures that are consistent with the drifter trajectories in the Agulhas Current and the Agulhas Return Current (Figure 3). This consistency between SSH and SST fronts is the basis of the "Velocity Projection" technique being developed in GlobCurrent to use SST or ocean colour imagery to add directional information to the currents derived from individual altimeter transects. This is being evaluated for the flow of the East Madagascar Current to the south of Madagascar [4]. The January climatology displays transport of warmer surface waters out of the Indian Ocean and hence reveals larger contrast in the SST field than for July, whereas there is little difference in the SSH field between January and July, except in the retroflection region where the 50 cm height-contour extends much further westward in January. At the spatial scale (~100 km) of this climatology the structural agreement displayed in the 3 fields results from the fact that they to a large extent obey the surface geostrophic balance.

The value and strength of the sensor synergy approach can be further explored and systematically applied as demonstrated in Figure 4 where the Envisat ASAR range Doppler velocity climatology of the Agulhas Current is displayed together with the SST climatology for the same 5 years time integration from 2007 to 2011 [5]. The spatial resolution is about 15-20 km. Evidently there is a striking consistency in the manifestation of the Agulhas Current between the velocity field and the SST field. The structure of SST maxima represented by the 22° C isoline is clearly collocated and oriented with the mean range Doppler velocity maxima of about 1.5 m/s from the separation point of the Agulhas Current from the coast to about 22° E. The gradual southward turning and spreading of the SST field southwestward from this region is also consistent with the pattern in the velocity map, as is the meandering SST contours representing the Agulhas Return Current eastward from the retroflection point to about 28° E. The combined effect of the strong surface current and SST front implies that significant modification of the surface stress (up to 25–30%) will occur across this sharp and coupled front in the surface current and temperature in agreement with [6]. It is moreover clearly a good agreement with the overall pattern of the greater Agulhas Current regime depicted in Figure 3.

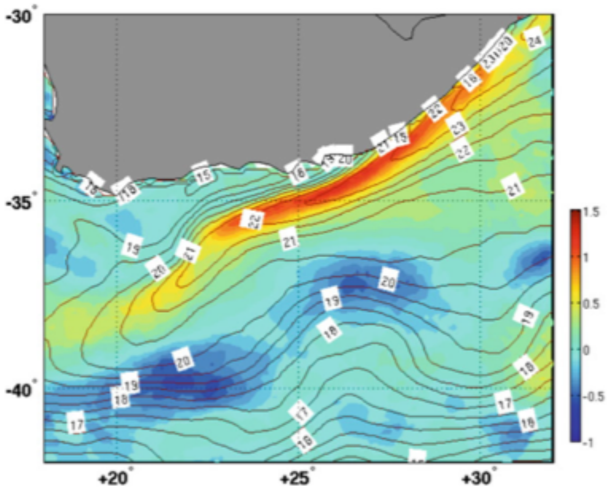

__Figure 4.__ Mean SST field (isolines) in Celsius derived from the ODYSSEA global SST analysis products for the period mid-2007 to mid-2011 overlaid the mean range Doppler velocity field (colour). Contour interval is every 0.5° from 14 to 24° C. The colour bar indicate surface speed in m/s.

4. SNAPSHOT SST, SURFACE GEOSTROPHIC CURRENT AND SURFACE DRIFTER DATA

The snapshot surface geostrophic current pattern overlaid on the SST field shown in Figure 5 further documents the relationship of these two quantities at a daily timescale and spatial resolution of about 25 km. Again the core of the Agulhas Current with the characteristic bending at about 22° E is clearly depicted both in the SST field and the surface geostrophic current. At the same time the retroflection region appears more diffuse with the westernmost position of the main return flow (compared to climatology) located at about 15° E. Evidence of the northward flowing Cape Good Hope current is also depicted just to the west of

15° E. The surface drifter trajectories further support these findings.

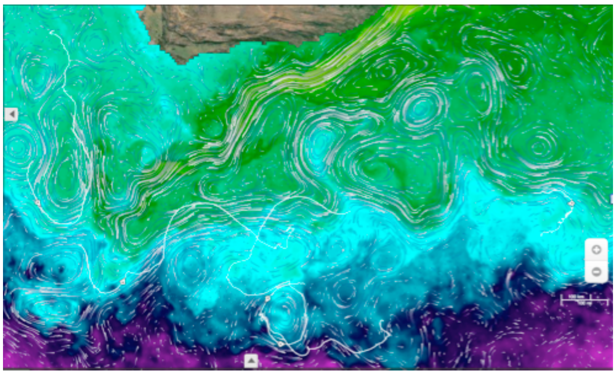

Figure 5. Synoptic snapshot showing the combined SST (colour) and surface geostrophic current (white stippled lines) obtained on 6 September 2012 together with the trajectory of the surface drifting buoys (white lines) with a symbol marking the position on 6 September.

As expected there is distinct relationship of the SST anomalies to the orbital geostrophic flow associated with the many cyclonic (cold SST) and anticyclonic (warm SST) eddies with diameters ranging from 50-400 km. The collocation of these eddy features with the rising Argo profiling floats will furthermore provide valuable opportunity for comparison of the vertical structure of the watermasses within the cyclonic and anticyclonic eddies [7].

In the GlobCurrent project these daily fields of SST, and surface geostrophic current will moreover be regularly combined and blended with ocean colour data, sunglint observations and Sentinel-1 SAR roughness anomaly and range Doppler velocity data and other Level 2 to 4 products. This will allow further investigation of the multiple types of 2-D surface signal expressions and relationship to mesoscale processes and the upper ocean dynamics as demonstrated by [8] and [9]. Systematic availability of these combined data will moreover be highly attractive with respect to model validation and assimilation as also demonstrated by [5].

5. SUMMARY AND OUTLOOK

The GlobCurrent project looks forward to ingesting new data into the observation-based analysis of currents. In particular there will be global coverage of delay Doppler altimetry from Sentinel-3, giving improved resolution and precision in the retrieval of SSH. Also the Korean sensor GOCI provides hourly ocean colour images of the East China Sea and Sea of Japan from a geostationary vantage point; GlobCurrent is investigating the potential of the Maximum Cross Correlation technique to produce reliable currents from sequences of shortly-spaced images.

Global and regional observation-based and model-based surface currents are now available at a spatial resolution of about 10 km, often as weekly analyses and daily forecasts. An important objective of the GlobCurrent project is the validation and the estimation of the data quality using independent observations and or information. Assessment of the GlobCurrent surface current (component and or combined) can also be performed in part using assimilation systems (e.g., MyOcean) as a reference. However, because assimilation systems also depend on ocean models that have limited vertical resolution near the surface, they are not expected to be a reference for all the fast current variations that the GlobCurrent project aims to resolve. A complementary assessment of current including fast variations is also possible using independent in situ observations (e.g., Argo and surface drifters), and high-resolution remote sensing (e.g., satellite optical glitter and land-based high frequency radar). User led case studies provide opportunities to pursue this objective at the GlobCurrent supersites such as the Agulhas Current region.

With the expected Sentinel-1 A and Sentinel-3 A joint operation from mid 2016 such type of climatological fields will be re-established and further improved with the inclusion of the B-satellites. With the growing data record this will moreover open up for the opportunity to look into seasonal variability.

6. REFERENCES

[1] Chapron, B., and the GlobCurrent Team, January 2015, GlobCurrent Analyses and Interpretation Framework, Technical Report available at http://www.globcurrent.org

[2] Rio, M.-H., S. Mulet, *and* N. Picot, 2014, Beyond GOCE for the ocean circulation estimate: Synergetic use of altimetry, gravimetry, and in situ data provides new insight into geostrophic and Ekman currents, *Geophys. Res. Lett.*, 41, 8918–8925.

[3] Lumpkin, R., *and* G. C. Johnson, 2013, Global ocean surface velocities from drifters: Mean, variance, El Nino–Southern Oscillation response, and seasonal cycle, *J. Geophys. Res. Oceans*, 118, 2992–3006.

[4] Nencioli, F., G. Quartly, and P. Miller, 2015, Exploring multi-sensor satellite synergies to provide direction to high-resolution along-track altimtery currents, *This Proceedings* (6pp).

[5] Johannessen, J. A., B. Chapron, F. Collard, B. Backeberg, 2014, Use of SAR data to monitor the Greater Agulhas Current, *In Remote Sensing of the African Seas,* edited by V. Barale and M. Gade, ISBN 978-94-017-8007-0, Springer.

[6] Chelton D.B., M.G. Schlax, M.H. Freilich, R.F. Milliff, 2004, Satellite radar measurements reveal short-scale features in the wind stress field over the world ocean. *Science* 303: 978–983.

[7] Kudryavtsev, V. N. A. Myasoedov, B. Chapron, J. A. Johannessen, F. Collard, 2012, Imaging mesoscale upper ocean dynamics using SAR and optical data, *Journal of Geophysical Research,* Vol. 117, C04029, 2012.

[8] Quartly, G. D., J. Georgiou, and M. A. Srokosz, 2010, Estimating the Indo-Atlantic salt flux from ARGO and altimetry. In, *ESA Living Planet Symposium, Bergen, 28th Jun-2nd July 2010.* Noordwijkerhout, NL, European Space Agency ESA SP-686. (5pp)

[9] Lapeyre G. and P. Klein, 2006, Dynamics of the Upper Oceanic Layers in Terms of Surface Quasigeostrophy Theory. *J. Phys. Oceanogr.*, **36**, 165–176.