OCEAN REMOTE SENSING DATA INTEGRATION - EXAMPLES AND OUTLOOK

Bertrand Chapron[(1)], A. Bingham[(2)], Fabrice Collard[(3)], Craig Donlon[(4)], Johnny A. Johannessen[(5,6)], Jean-François Piollé[(1)] and Nicolas Reul[(1)]

[(1)] IFREMER, Centre de Recherche et d'Exploitation Satellitaire, 29280 Plouzané, France,
Email: Bertrand.Chapron@ifremer.fr, jean.francois.piolle@ifremer.fr, Nicolas.Reul@ifremer.fr
[(2)] Jet Propulsion Laboratory, NASA, 91109 Pasadena, California, USA, Email: andrew.w.bingham@jpl.nasa.gov
[(3)] Collecte Localisation Satellite, Radar Division, Brest, France, Email: dr.fab@cls.fr
[(4)] European Space Agency, ESTEC, Keplerlaan 1, NL-2201 AZ Noordwijk, The Netherlands,
Email: craig.Donlon@esa.int
[(5)] Nansen Environmental and Remote Sensing Center, Thormoehlensgate 47, N-5006, Bergen, Norway
[(6)] Geophysical Institute, University of Bergen, Norway
Email: johnny.johannessen@nersc.no

ABSTRACT

Satellite remote sensing has emerged as an essential and necessary observing system to acquire global information about the state of the ocean. Complemented with in situ observing networks, the ultimate goals are to be able to make accurate estimates of selected key sets of geophysical variables, with the intention of either making operational predictions across time and spatial boundaries, or advancing fundamental knowledge through development of empirical relationships and theoretical models. For satellite oceanography, improvements are then constantly being sought in our understandings of the geophysical processes, the sensor physics, the electromagnetic and microwave properties and interactions at the complex air-sea interface. Challenges appear as unlimited as the variety of sea surface dynamics and boundary layer meteorological conditions with their broad range of spatial and temporal scales across the globe. To face these challenges, numerous efforts took places over the passed decade to build an ever-increasing quality, quantity, duration and integration of ocean observations. In parallel, simulation capabilities largely improved. All these efforts are then all critically calling for improved methodologies to better structure the wealth of information that is made readily accessible. This latter aspect is a very demanding new component for future multidisciplinary scientific research. Major innovations to consolidate sensor data repositories, to automate tailored queries, to extract, reveal and quantify relationships will then closely associate computer science developments and applied statistics with comprehensive theoretical and experimental thematic studies.

1. INTRODUCTION

Global Earth Observation systems have already demonstrated significant applications in our current way to understand and manage the Earth's environment. Specifically for satellite oceanography, altimeters, scatterometers, radiometers and ocean color imagers can be stated as revolutionary developments in the study and view of the state of the global upper ocean. As reported during the OceanObs'09, relatively long time and consolidated series of these sensor measurements have been consistently processed. Obtained from different platforms since the beginning of the nineties, Level 2 geophysical products to Level 3 and 4 advanced products are readily available. Numerous investigations are now common to efficiently merge the complementary Level 2 geophysical products using multiple sensor sources to define gridded Level 3 and 4 products. These include merged global ocean surface topography using the different available altimeter missions (http://www.aviso.oceanobs.com/) high-resolution sea surface temperature using multi-sensor and platforms measurements (http://www.ghrsst.org/) (Donlon et al., 2010), the combined ocean colour data (http://www.globcolour.info/), blended wind products (http://www.ncdc.noaa.gov/oa/rsad/seawinds.html) or ftp://ftp.ifremer.fr/cersat/products/gridded/mwf-blended) (Bourassa et al., 2010), as well as near-real time ocean surface current derived from satellite altimeter and scatterometer data (e.g. http://www.oscar.noaa.gov).

Accordingly, analysis can now be carried out to more precisely characterize the variability in the global ocean, at scales of tens to hundreds of km and tens to hundreds of days. The homogenized observations and efficient data integrations often successfully help to reveal very complex interplays, associations and feedbacks between variables. With the improved in situ networks in place (Pouliquen et al., 2010), the advanced satellite products clearly paved the way for an efficient global data integration. As now routinely assimilated by numerous forecast systems (Balmaseda et al., 2010), these efforts serve both research and applicative interests. Operational oceanography is then emerging to address major challenges and applications (global monitoring, disaster management support, climate change issues, etc). As developed, the global data integration also helps consistent retrospective analysis using a wide range of inter-calibrated observations (in situ, satellite), with targeted objectives to build robust representations of ocean environmental and climate indices and predictors.

However, implementation and operation of a routine ocean monitoring system is highly demanding, with respect to the sustainable long-term observations and the real-time interpretations that never seem fully adequate. The wide range of spatial scales (from millimeters to kilometers) may certainly not be matched, even using the broad spectrum of sensor technologies that have the optimum capabilities based on their electromagnetic frequency, polarization, incidence angle, coherence, Doppler characteristics and spatial/time resolution. Moreover, strengths and weaknesses of the different observing methods are not always fully characterized under all environmental conditions, leaving questions about the use of the observations for predicting the intensity, the frequency and the tendency of particular events as well as extremes. In particular, designs and operations of global ocean measurements inevitably involve compromises between empirical retrieval algorithms and spatial and temporal resolutions. While numerous geophysical processes and various oceanic phenomena with very short spatial scales are recognized as key contributions to horizontal and vertical fluxes of momentum, heat and tracers, most satellite observations do not resolved fine spatio-temporal structures. This certainly hampers our ability to better understand and precisely quantify the role of the smaller scale phenomena for the upper ocean dynamics.

But, when new high-resolution measurements will be more systematically available, these observations may also directly question our ability to better understand and model the small-scale features in terms of both ocean processes and sensor physics. Consequently, these needs for an increased spatio-temporal resolution not only ask for new instrument designs, but also include new opportunities to refine the use of existing observations, the algorithms to interpret the data, as well as to look for potential synergies between measurements.

Finally, another crucial factor is the daily stream of large amounts of satellite data; we are talking about "Terabytes" to "Petabytes" of data to download, transform from electromagnetic to geophysical and biological quantities, analyze and understand. The increasing number and resolution of the sensors, the upcoming shift from exploratory satellite missions to fully operational and sustained missions, the raise of new space agencies (China, India) all contribute to dramatically increase the amount of data to be collected, stored and explored. Oceanographers and end-users can thus often be deluged with data, and besides assimilation strategies (Rienecker et al., 2010, Bahurel et al., 2010), the gap between data collections and analysis will grow in absence of dedicated tools.

As mentioned above, fifteen to thirty years long time series of satellite-retrieved parameters such as sea surface temperature, waves, sea surface height, surface wind vectors, sea-ice extent, concentration and drift, surface layer phytoplankton chlorophyll concentration, are now readily available and provide an ever-growing massive archive that still has to be fully explored. This again emphasizes the highly needed research efforts to better understand the different sensor physics and capabilities, to demonstrate and explore in more details the combined uses of the different observations, to propose and test improved dynamical and statistical integration strategies to be used to guide the developments for innovative, efficient and thematically driven data-mining methodologies.

In the following, examples are used to further highlight some of these aspects, and more specifically to insist on potential data synergies to take full benefit of global satellite products.

2. CHARACTERIZING EXTREME WIND EVENTS

Satellite-measurements are quite unique and often critical for short term forecasting of extreme weather events such as tropical cyclones or explosive mid-latitude storms and polar lows. In addition, the long time series are becoming highly important in the context of validation and assimilation in seasonal-to-decadal climate predictions. Moreover, the available long-term measurements also offer means to better examine the role of extreme conditions for the state of ocean at local and global scales (Goni et al., 2010). In particular, the global and integrated observations can help to reveal some aspects of the air-sea couplings associated with storm-tracks, and their associated impact on the ocean circulation and heat transport.

As demonstrated by radiometers onboard the DMSP (Defense Meteorological Satellites Program) satellite series, WindSat (joint NOAA Integrated Program Office/Department of Defense/NASA demonstration project) and TRMM (Tropical Rainfall Measuring Mission), as well as by scatterometers onboard the ERS (European Remote-sensing Satellite), ADEOS (Advanced Earth Observing Satellite), QuikSCAT (Quick Scatterometer) and ASCAT (Advanced Scatterometer) satellites, unprecedented synoptic observations of surface wind and atmospheric water content are possible and reveal the storm structures with impressive details (see Fig. 1). However, the satellite observations are not direct measurements of geophysical parameters such as the surface wind speeds, and can further suffer from limitations linked to the sensors characteristics and

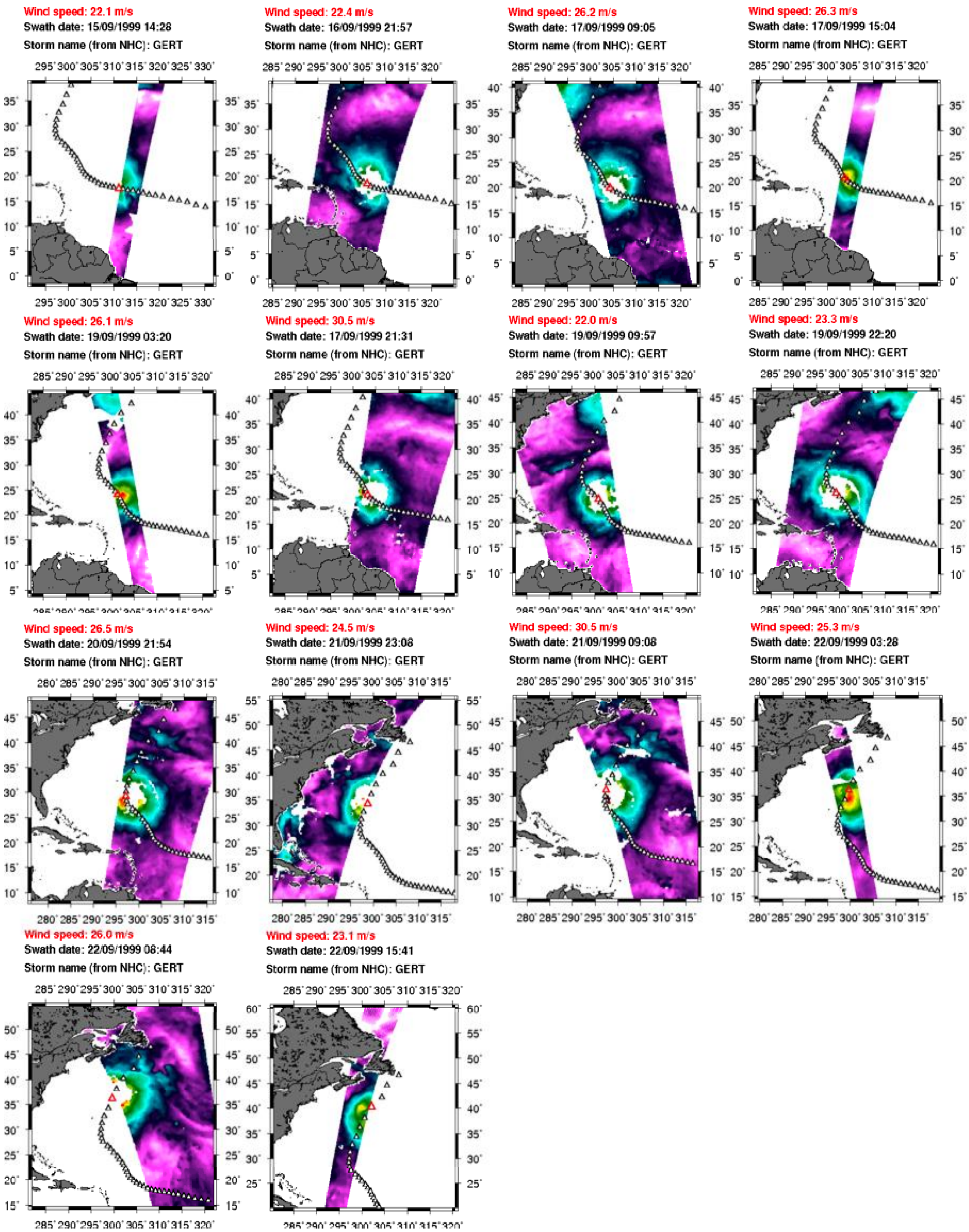


Figure 1. *The track of the hurricane Gert (1999) overlaid wind field observations from different scatterometers (ERS and QuikScat) illustrating the strength in sensor synergy. Note that the central area of the hurricane sometimes is occluded due to heavy rain effects (represented in white).*

deficiencies in retrieval algorithms and empirical relationships under extreme environmental conditions.

For instance, scatterometer measurements are strongly affected by rain when using Ku-band instruments (e.g. QuikSCAT), and even when using C-band (e.g., ASCAT). It has also been reported that passive microwave radiometer resolution is often too coarse to delineate the fine scale structures associated with extreme conditions. it is often the combined use of these different sensors that offers the best solution for retrieval of extreme wind conditions. Moreover, while certainly limited by its relatively coarse across-track sampling, the altimeter (Jason-like) dual frequency radar cross-section measurements can add strength to these observations. Altimeter signals can indeed be processed using specialized algorithms to retrieve the surface wind speed and significant wave height, along with the rain rate in extreme weather events. Quite surprisingly, winds up to 50 m/s have been estimated in hurricane conditions using altimetry, matching airborne local measurements (Quilfen et al., 2010).

Combined with scatterometer and radiometer measurements, the altimeter measurements directly provide integrated sea state information, i.e. the significant wave height (SWH) which is related to the intensity and history of the surface winds. Altimeter measurements can thus provide key data to help to describe the sea state structures in the wake, near the center, and ahead of storms.

Very far from the area of most intense storms, distinctive swell systems appear. These energetic swells are very long and well organized surface waves that rapidly outrun the propagation of its source, and radiate across the ocean basins in different directions. As wavelength and celerity also directly scale with the generating wind speeds, the longest swells become the fingerprints of the most powerful ocean storms. Swells can then be very persistent with energy e-folding length scales exceeding 30,000 km (Ardhuin et al., 2009), and can propagate for many days almost unchanged in wavelength and direction. Munk et al. (1963) already proposed an elegant heterodyning technique to push the spatial resolution for the estimation of storm location using buoy swell data.

Using such an approach, recent works demonstrated that it is indeed possible to combine different satellite measurements, e.g. the altimeter significant wave height measurements and the ENVISAT ASAR (European Space Agency Environmental Satellite-Advanced Synthetic Aperture Radar) Wave Mode measurements, to fully reconstitute the history of the longer swell waves propagating over thousand of kilometres across entire ocean basins. Backward and forward geometrical idealized propagations (Collard et al., 2009) are used to distinguish the different swell systems observed over a 10-day period. Once separated, the swell systems are tracked back to their initial sources (Fig. 2). The longer the waves, the faster they travel along great-circle paths. A prescribed co-located match-filter space-time analysis can be used to more precisely evaluate the source intensity. As demonstrated, this quasi-linear dynamical approximation for the swell propagation is a very robust tool to optimally combine the different satellite observations (http://soprano.cls.fr/L3/fireworks.html). Moreover, the analysis of remotely generated swell systems can further build on all available in situ buoy measurements (Swail et al., 2010).

Together with available standard wave forecasts, these results highlight the potential to combine dynamically many different sensor data to derive a more consistent view of the storm intensity and its related wave field. Using the different satellite sensors, this strategy tends to overcome the individual sensor intrinsic limitations, and directly helps filling gaps in space and time in between the orbit cycles of observations. Such a combined consistent analysis can be essential to identify more precise rules for storm intensity estimations, as well as to provide refined wind field errors.

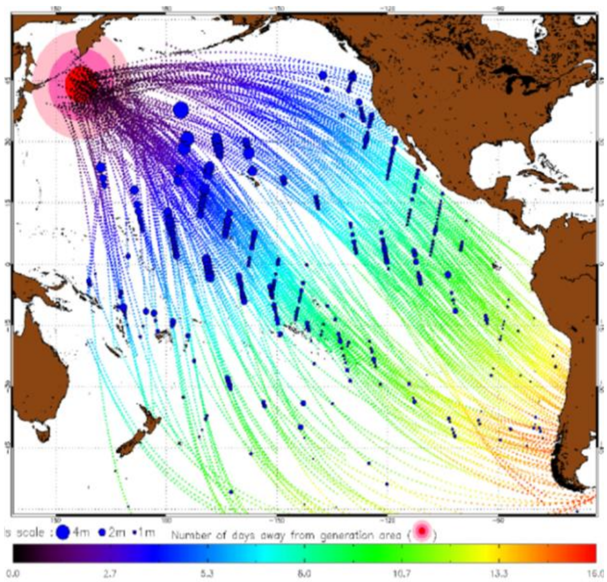


Figure 2. Great-circle trajectories of swell systems in the Pacific Ocean with periods between 10 s and 17 s. The selective space-time match-filter is built according to the selected group velocity and estimated swell propagation directions from ENVISAT SAR measurements at locations indicated by blues circles. The size of the circles is related to the computed significant wave height. Trajectories are color-coded as a function of the propagation time (in number of days) since the swell generation at the source located with the red circle. Accordingly, altimeter and scatterometer measurements (not shown) can be consistently co-located, and in situ buoy measurement selected.

3. FINER AND FINER RESOLUTION

Since the first images from space, the attention of both theoreticians and remote sensing scientists has been triggered by the abundance of various ocean patterns and signatures in the mesoscale and submesoscale ranges. As observed, very small features, such as frontal zones or spiraling eddies, at the 10 to 30 km scales are usually manifested in IR (infrared) based SST (Sea Surface Temperature) variability maps and Chlorophyll concentration fields, which are observable under favourable cloud conditions, with typical resolutions of 250 m to 1 km. In addition to the usual SST and reflectance images indicative of upper layer dynamics, related signatures of roughness variations are also often reported (Munk et al., 2000). Short scale spatial roughness variations often precisely delineate the convergence and divergence zones in the upper layers of the ocean (Kudryavtsev et al., 2005, Johannssen et al., 2005). These small oceanic features are likely associated with mixed-layer dynamics and surface current gradients. Contemporaneous manifestations in sea surface temperature and roughness variation measurements are expected to reveal zones of strong convergence/divergence associated with downwelling and upwelling. Figure 3 illustrates such observations.

To date, global direct quantification of horizontal dispersion and mixing at such scales is not available. Significant progress has certainly been made, and a key sensor to obtain precise measurements of the ocean topography is the radar altimeter. Satellite altimetry is now a very mature and fully operational satellite remote sensing technique with an extensive body of literature. Yet, the ocean's mesoscale (10-50 km) and submesoscale (< 10 km) variability and energy are very difficult to map with conventional radar altimeters because of the narrow illuminated swath, regardless of the orbital configuration. To adequately resolve mesoscale eddies requires observations with the finest possible space-time resolution. As a natural strategy, the use of multiple satellites bearing identical high-class altimeters (ERS, TOPEX (Topography Experiment), GFO (GEOSAT (Geophysical/Geodetic Satellite) Follow-On), JASON, ENVISAT) could then map the mesoscale ocean features if their orbits were all very precisely (~ 1 cm) known. Accordingly, multiple payload launches can potentially successfully address this so-called “altimetry gap” (Scott, et al., 2010, Cippolini et al., 2010, Wilson et al., 2010). Improved technology solutions can also be sought to develop new altimeters with multi-beam illumination patterns and/or interferometric capabilities, e.g. the SWOT (Surface Water and Ocean Topography) instrument (Fu et al., 2010). It is also interesting to gain resolution by trying to better exploit existing data, and to combine the lower resolution altimeter products with all available higher-resolution observations.

As a first strategy to obtain high-resolution surface currents from non-altimetric measurements, the sequences of high-resolution IR images have already been proposed and successfully used (e.g. Matthews and Emery, 2009). Among different techniques, the Maximum Cross Correlation (MCC) method to identify pattern displacements is by far the most widely used. These techniques rely on the availability of cloud-free images with short-time intervals between acquisitions, and favours sampling from geostationary rather than polar-orbiting satellites.

More recently, the possibility to derive small-scale structures and so-called, Lagrangian coherent structures, from the coarser SSH (Sea Surface Height) and SST global observations has been explored. Indeed, using a Lagrangian-dynamical framework, a larger-scale microwave-detected SST field can be advected using SSH-derived velocities on higher-resolution grids, generating much smaller-scale patterns by 2D chaotic advection.

In particular, the 2D particle separation statistics (d'Ovidio et al., 2009, Beron-Vera et al., 2008, Waugh and Abraham, 2008), i.e. the Lyapunov exponent and vector fields, are known to provide powerful theoretical and practical frameworks for the analysis of the instabilities. As well, the advected reconstructed fields can be compared to clear-sky observations to determine exact locations of gradients. Thus, the characterization of the instantaneous geometry of the tracer fields (Turiel et. al., 2009), and Lagrangian diagnostics can build on low resolution data and help to better assess mesoscale activity related to 2D turbulence. Figures 4 and 5 illustrate the findings and results of these new analyses tools.

Further theoretical developments and numerical experiments can also be invoked. Indeed, it has been recently put forward a new dynamical framework which leads to anticipate that, under favorable environmental conditions, upper layer ocean dynamics is mostly driven by the distribution of surface density anomalies (Klein et al., 2008). This dynamical framework significantly departs from 2D turbulence, and suggests an interesting new perspective to guide analysis and interpretation of the very high-resolution observations. One important outcome of these efforts would imply that the 3D dynamics of the upper ocean could be recovered from high resolution SST and SSH measurements (Isern-Fontanet et al., 2008, Klein et al., 2009). Demonstrations using existing satellite data have already been carried out with encouraging results (Isern-Fontanet et al., 2006). This can explain the often-revealed high degree of correlations between altimeter SSH and SST in areas associated with fronts and mesoscale variability.

These different techniques complement routine access to an ever-increasing population of high quality in situ

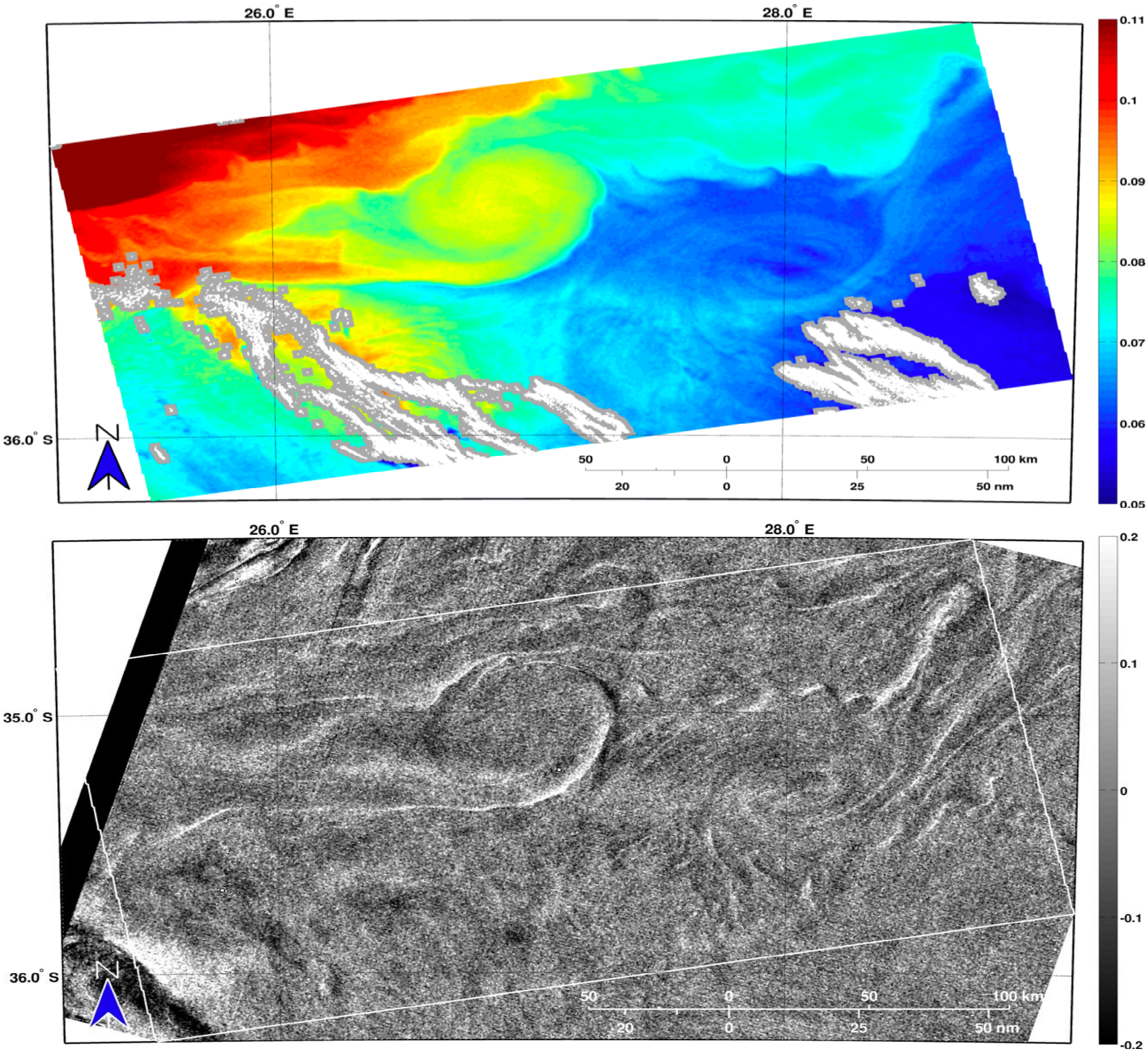


Figure 3. *Distinct expression of mesoscale and submesoscale features in the Agulhas Current region. (top) Brightness temperature (indicated by the color code) from the MODIS instrument obtained on November 17 2007. (bottom) Near coincident sea surface roughness measurements obtained with the Envisat ASAR wide swath sensor. In both images the resolution is around 250 m.*

drifting buoy (surface and subsurface) measurements (http://www.aoml.noaa.gov/phod/dac/gdp.html) (e.g., Griffa et al., 2008) and reconstructed geoid estimates. In turn, a refined mean dynamic topography (MDT) is now available http://aviso.oceanobs.com/en/data/products/auxiliary-products/mdt/index.html. Further global improvement of the MDT will become available after release of the GOCE (Gravity and Steady State Ocean Circulation Explorer) data (launched in March 2009) foreseen in second half of 2010. As well, emerging new analysis capabilities from imaging radars (Johannessen et al., 2008; Chapron et al, 2005) are also promising with respect to reconstruction of high-resolution MDT, in particular in areas of strong topographic steering. At present, the imaging radars, better known as Synthetic Aperture Radars (SARs), are the best way to obtain all-weather high resolution (~ 100 m) measurements of the ocean surface, and the possibility to use single and/or dual-antenna radar interferometric techniques are demonstrating capabilities to provide radar line-of-sight sea surface motion information at very high spatial resolution (Romeiser et al., 2010). Advanced polarization capabilities are also currently developed to improve the radar image contrast analysis. Thus, an extremely large quantity of high-resolution observations will readily become available in the coming years. This is again certainly challenging our ability to

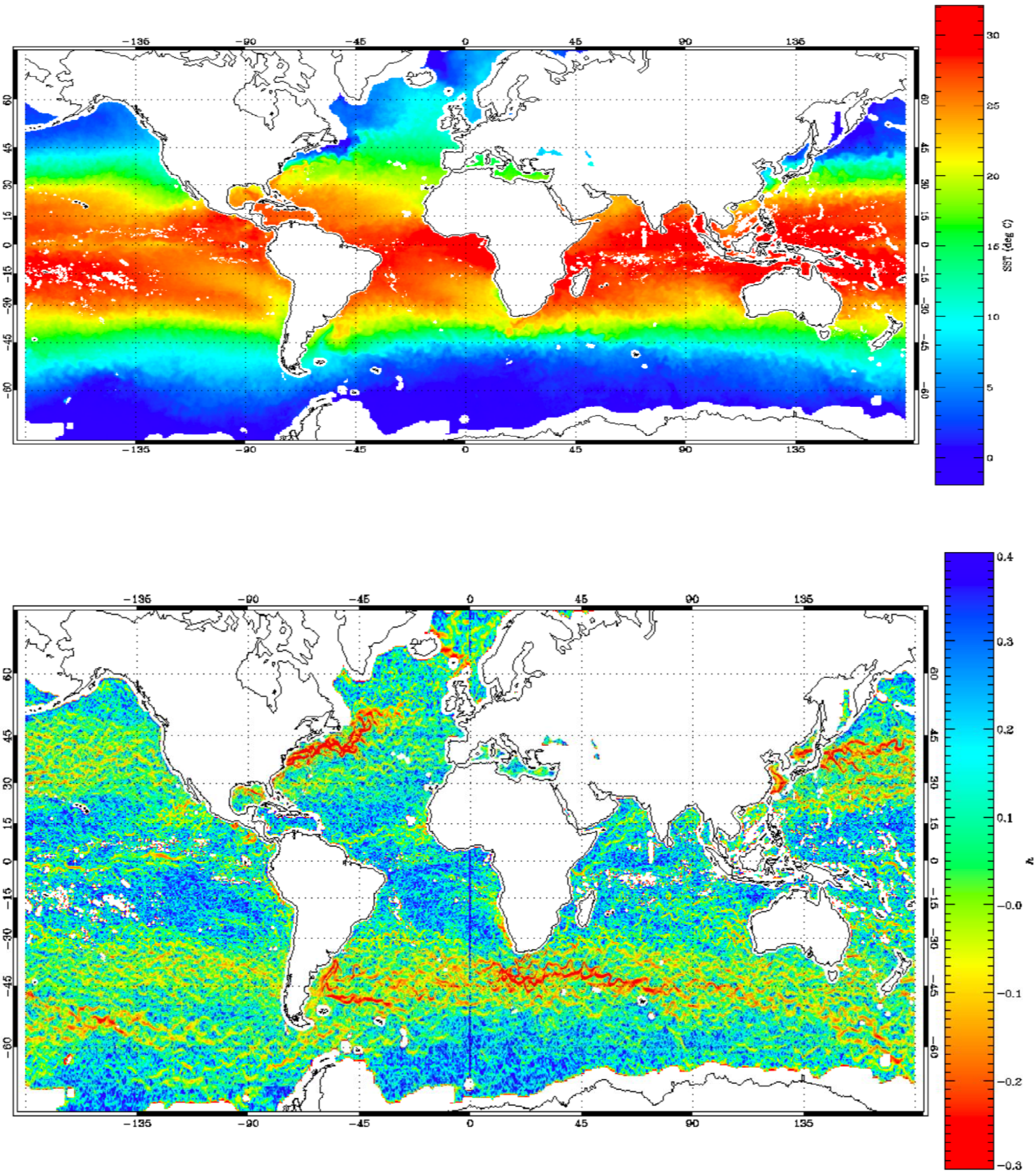


Figure 4. *Global SST field (top) and singularity map (bottom). Areas associated with large scale current fronts and intense mesoscale variability are very well delineated. See Turiel et al., 2009 for more details.*

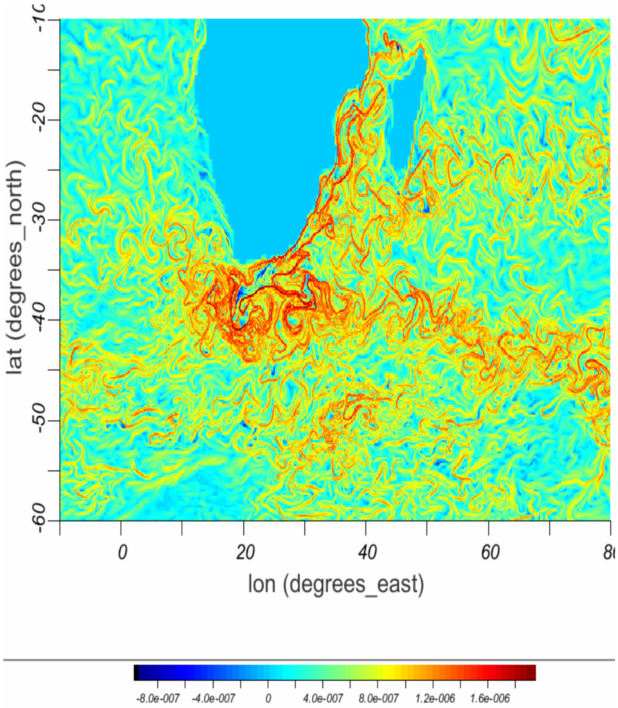


Figure 5. Lyapunov exponents and vectors provide a very powerful theoretical and practical framework for the analysis of the instabilities that can develop in a dynamical system. The 1/4 degree Mercator ocean model that assimilates ocean measurements is used to compute 2D particle separation statistics to better reveal finer structures and mesoscale turbulence in the greater Agulhas Current region.

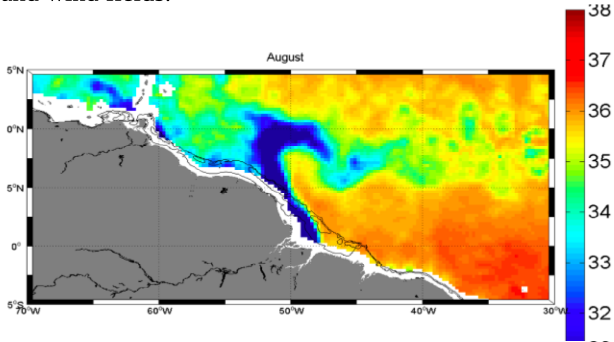
quantitatively interpret these data, but will also allow new developments and strategies.

As already mentioned above concerning extreme phenomena, improved interpretation of the abundant and rich manifestations of the mesoscale and submesoscale ocean dynamics shall also build on new dynamical frameworks and synergies between different sensors. This appears essential to provide the oceanographic community with more accurate estimates of horizontal and vertical fluxes of kinetic energy and tracers (Scott et al., 2010).

4. A NEW CHALLENGE: SEA SURFACE SALINITY FROM SPACE

Measurement of sea surface salinity (SSS) from space poses numerous engineering and scientific challenges that also push the boundaries of ocean remote sensing capabilities (Lagerloef et al., 2010). They involve precise determination of the dielectric characteristics of seawater through low-noise passive microwave (MW) radiometer measurements of the ocean brightness temperature (Tb). Optimally to retrieve SSS, the measurements must be performed at a low frequency near 1.4 GHz (L-band). Unfortunately, there are numerous stringent error sources stemming from the characteristics of the L-band sensor hardware, as well as the development of SSS retrieval algorithms ESA SMOS mission launched in November 2009; NASA (The National Aeronautics and Space Administration) Aquarius ESSP (Earth System Science Pathfinders) mission to be launched in 2011).

SSS from space also imposes a great challenge since science requirements are aiming at a precision of the order of 0.1 psu (practical salinity units). This requirement means that all contributing terms to the ocean Tb measurements, foremost being sea surface temperature and ocean surface roughness, must be accounted for in a very consistent manner. More specifically, it is necessary to develop an electromagnetic/geophysical inversion scheme for the expected surface roughness and foam emissivity signatures at L-band. Models must also be capable to correct for sun glint and galactic electromagnetic radiation reflected towards the sensors. In that context, the SSS retrieval shall heavily rely on the quality and use of auxiliary fields, including the key SST, sea state and wind fields.



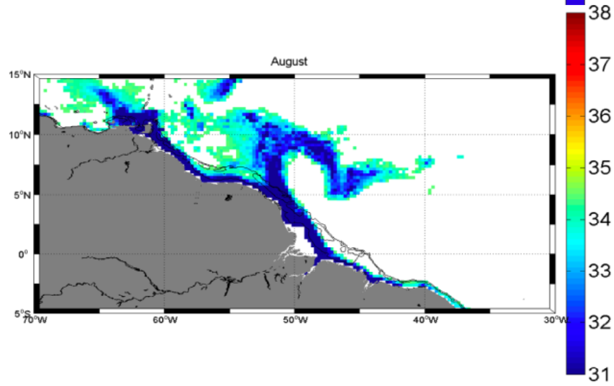


Figure 6: (top) Monthly averaged sea surface salinity in the Amazon region retrieved from AMSR- E and (bottom) SSS derived from CDOM (Colored Dissolved Organic Matter) absorption coefficient obtained with the GSM (Generic Sensor Model) model and the SeaWiFS)Sea-viewing Wide Field of View Sensor) and MODIS (Moderate Resolution Imaging Spectroradiometer) sensors for August 2004.

However, these challenges are faced with promising expectations. Indeed, in preparation for use of SMOS (ESA's (European Space Agency) Soil Moisture and Ocean Salinity) and Aquarius SSS data, an example of a successful data integration using existing high quality data from the EOS AMSR-E (Earth Observing System Advanced Microwave Scanning Radiometer-Earth Observing System) satellite radiometer has already been demonstrated. For the warm tropical Atlantic Ocean having large salinity gradients of the order 2-4 psu, the sensitivity of brightness temperature to sea surface salinity change is well captured (Reul et al., 2009). It has also already been documented that ocean color data can be used to infer salinity in large river plume regions (Del Vecchio et al., 2002, Salisbury et al., 2001). This is shown in Fig. 6 with the SSS retrievals from the AMSR-E C- and X-band channel Tb measurements and the SeaWiFS and MODIS observations.

While these AMSR-E channels have significantly lower SSS sensitivities than that at L-band, persistent high salinity contrasts in areas of large-river plumes can confidently be extracted. Links between SSS and coloured dissolved matter absorption coefficients are also clearly evidenced, and such a combined products can further help to derive new satellite-based SSS climatologies of river plumes as well as characterize the seasonal cycles and interannual variability of their associated large-scale SSS structures. Consequently, high quality ancillary data products and integration will thus significantly contribute to the new era of global monitoring of SSS over the ocean.

5. OUTLOOK

An area of unfilled promise in ocean surface remote sensing is the development of consistent inversion of sea surface characteristics via the ever-increasing complement of microwave and optical techniques. During the past few years, there have been considerable efforts in more precisely understanding the mechanisms by which surface expressions of oceanic and atmospheric phenomena are possibly detected by remote sensing instruments. Such investigations must urgently continue and stem largely from the great and sometimes hidden potential of the different measurements to provide invaluable synoptic information at improved temporal and spatial resolution. As emphasized in this paper, intrinsic individual sensor limitations may often be minimized using such adequate data synergies.

Satellite remote sensing techniques and data acquisitions always present challenges but are at the same time unique means to better decipher the very complex interplay between crucial parameters and processes controlling air-sea interaction and physical-biological coupling, as well as to support both near-real time monitoring needs and climate studies. Besides new measurements and new technologies, future challenges will certainly be dedicated to more thoroughly analyze methods of present and passed data sets to derive advanced multi-sensor geophysical products. At the OceanObs'09 meeting, Level 3 and Level 4 data products are already strongly emerging to serve wider science and application communities, and efforts will continue to push towards resolving ocean processes at finer time and space scales. Improved dynamical frameworks will help to advance the design and development of space- and time-evolving estimations methods, while in situ measurements will provide the highly necessary reference measurements for validation and model refinements. An ambitious target must be to develop innovative tools to unambiguously relate satellite based 2D information with 3D upper ocean dynamics.

More advanced identification techniques to find self-similar and coherent structures have also been presented and discussed during the meeting. With the development of new tools, geometric, spatial and temporal characteristics can be more systematically extracted and efficiently mined to answer queries in an objective data-driven or dynamically-driven manner. Such advanced developments can be applied to both Level 2 and 3 data products and simulated data to further help statistical analysis on large multi-dimensional archives. Already, a great deal of efforts has been undertaken and presented at OceanObs'09 to provide an homogeneous access to satellite data, relying on common standards (Open Geographic Standard, OGC) and technologies for metadata, data content, format (NetCDF) and access (ftp, OpenDAP). These efforts are still to be strengthened when considering the optimization of the data flow. For instance, full resolution swath data are still very voluminous, bandwidth consuming and complicate to manage, due to their sampling pattern, especially when focusing on very regional areas. With available ocean circulation model outputs, this is opening new ways to integrate, interpret and disseminate the data. It will lead to the definitions of thematically-driven search engines to recognize that users have disparate needs when assessing the data, but that common and collaborative ways to search, process, visualize, analyze the data can be more optimally shared between agencies and interested communities.

6. REFERENCES

1. Ardhuin, F., Chapron, B. and Collard, F. (2009). Observation of swell dissipation across oceans, *Geophys. Res. Letter, Vol*. 36, L06607, doi:10.1029/2008GL037030.

2. Bahurel, P. & Co-Authors (2010). "Ocean Monitoring and Forecasting Core Services, the European MyOcean Example" in these proceedings (Vol. 1), doi:10.5270/OceanObs09.pp.02.

3. Berron-Vera, F.J., Olascoaga, M.J. and Goni, G.J. (2008). Oceanic mesoscale eddies as revealed by Lagrangian coherent structures, *Gephys. Res. Letter, Vol*. 35, L12603, doi:10.1029/2008GL033957.,

4. Berron-Vera, F.J., Olascoaga, M.J. and Goni, G.J. (2008). Oceanic mesoscale eddies as revealed by Lagrangian coherent structures, *Gephys. Res. Letter, Vol*. 35, L12603, doi:10.1029/2008GL033957.

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

6. Collard, F., Ardhuin, F. and Chapron, B. (2009). Monitoring and analysis of ocean swell fields from space: New methods for routine observations, *J.*

Geophys. Res., Vol. 114, C07023, doi:10.1029/2008JC005215.

7. Bourassa, M. & Co-Authors (2010). "Remotely Sensed Winds and Wind Stresses for Marine Forecasting and Ocean Modeling" in these proceedings (Vol. 2), doi:10.5270/OceanObs09.cwp.08.

8. Cipollini, P. & Co-Authors (2010). "The Role of Altimetry in Coastal Observing Systems" in these proceedings (Vol. 2), doi:10.5270/OceanObs09.cwp.16.

9. Del Vecchio, R. and Blough, N.V. (2002). Photobleaching of chromophoric dissolved organic matter in natural water: kinetics and modelling, Marine Chemistry, 78, 231-253.

10. Donlon, C. & Co-Authors (2010). "Successes and Challenges for the Modern Sea Surface Temperature Observing System" in these proceedings (Vol. 2), doi:10.5270/OceanObs09.cwp.24.

11. Fu, L. & Co-Authors (2010). "The Surface Water and Ocean Topography (SWOT) Mission" in these proceedings (Vol. 2), doi:10.5270/OceanObs09.cwp.33.

12. Goni, G. & Co-Authors (2010). "The Ocean Observing System for Tropical Cyclone Intensification Forecasts and Studies" in these proceedings (Vol. 2), doi:10.5270/OceanObs09.cwp.36.

13. Griffa, A., Lumpkin R. and Veneziani, M. (2008). Cyclonic and anticyclonic motion in the upper ocean, Geophyc. *Res. Letter, Vol. 35, L01608*, doi:10.1029/2007GL032100.

14. Isern-Fontanet, J., Chapron, B., Lapeyre G. and Klein, P. (2006). *Geophys. Res. Letter, Vol. 33, L24608,* doi:10.1029/2006GL027801.

15. Isern-Fontanet, J., Lapeyre, G., Klein, P., Chapron, B. and Hecht M. W. (2008), Three-dimensional reconstruction of oceanic mesoscale currents from surface information, *J. Geophys. Res.,* 113, C09005, doi:10.1029/2007JC004692.

16. Johannessen, J.A., Kudryavtsev, V., Akimov, D., Eldevik, T., Winther, N. and Chapron, B. (2005). On Radar Imaging of Current Features; Part 2: Mesoscale Eddy and Current Front detection. *Journal of Geophysical Research,* Vol. 110, C07017.

17. Johannessen, J. A., Chapron, B., Collard, F., Kudryavtsev, V., Mouche, A., Akimov, D. and Dagestad K.-F. (2008). Direct ocean surface velocity measurements from space: Improved quantitative interpretation of Envisat ASAR observations, *Geophys. Res. Lett.,* 35, L22608, doi:10.1029/2008GL035709.

18. Klein, P., Hua, B., Lapeyre, G., Capet, X., Le Gentil, S. and H. Sasaki, (2008). Upper ocean turbulence from high 3-D resolution simulations, *J. Phys. Oceanogr*., 38, 1748–1763.

19. Klein, P., Isern J., Fontanet, Lapeyre, G., Roullet, G., Danioux, E., Chapron, B., Le Gentil, S. and Sasaki, H. (2009). Diagnosis of vertical velocities in the upper ocean from high resolution sea surface height, *Geophys. Res. Lett.,* 36, L12603, doi:10.1029/2009GL038359.

20. Kudryavtesv V., Akimov, D., Johannessen, J. and Chapron, B. (2005). On radar imaging of current features: 1. Model and comparison with observations, *J. Geophys. Res., 110, C07016*, doi:10.1029/2004JC002505.

21. Lagerloef, G. & Co-Authors (2010). "Resolving the Global Surface Salinity Field and Variations by Blending Satellite and In Situ Observations" in these proceedings (Vol. 2), doi:10.5270/OceanObs09.cwp.51.

22. Balmaseda, M. & Co-Authors (2010). "Role of the Ocean Observing System in an End-to-End Seasonal Forecasting System" in these proceedings (Vol. 1), doi:10.5270/OceanObs09.pp.03,

23. Matthews D. K. and Emery, W. J. (2009). Velocity observations of the California Current derived from satellite imagery, *J. Geophys. Res., 114, C08001*, doi:10.1029/2008JC005029.

24. Munk, W. H., Miller, G. R., Snodgrass, F. E. and Barber, N. F. (1963). Directional recording of swell from distant storms, Philos. Trans. R. Soc. London, Ser. A, 255, 505–584.

25. Munk, W.H., Armi, L., Fischer, K., Zachariasen, F. (2000). Spirals on the Sea, Proc. Roy. Society, London, A, 456, 1217-1280.

26. Pouliquen, S. & Co-Authors (2010). "The Development of the Data System and Growth in Data Sharing" in these proceedings (Vol. 1), doi:10.5270/OceanObs09.pp.3.

27. d'Ovidio, F, Isern-Fontanet, J., Lopez, C., Hernandez-Garcia, E., Garcia-Ladona, E. (2009). Comparison between Eulerian diagnostics and the finite-size Lyapunov exponent computed from altimetry in the Algerian Basin, *Deep Sea Res.* I, 56, 15-31.

28. Quilfen Y., Chapron, B. and Tournadre, J. (2010). Satellite microwave surface observations in tropical cyclones, Monthly Weather Review, doi:10.1175/2009MWR3040.1.

29. Reul, N., Saux-Picart, S., Chapron, B., Vandemark, D., Tournadre, J. and Salisbury, J. (2009). Demonstration of ocean surface salinity microwave measurements from space using AMSR-E data over the Amazon plume, *Geophys. Res. Lett.,* 36, L13607, doi:10.1029/2009GL038860.

30. Rienecker, M. & Co-Authors (2010). "Synthesis and Assimilation Systems - Essential Adjuncts to the Global Ocean Observing System" in these proceedings (Vol. 1), doi:10.5270/OceanObs09.pp.31.

31. Romeiser, R., Johannessen, J.A., Chapron, B., Collard, F., Kudryavtsev, V., Runge, H. and Suchandt, S. (2010) 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.), 73-91, Springer Science+Business Media.

32. Salisbury, J.S., Campbell, J.W., Meeker, L.D. and Vorosmarty. C.J. (2001). Ocean Color and River Data

Reveal Fluvial Influence and Coastal Waters, EOS Transactions, Vol 82, 221-227.

33. Scott, R. & Co-Authors (2010). "Satellite Altimetry and Key Observations: What We've Learned, and What's Possible with New Technologies" in these proceedings (Vol. 2), doi:10.5270/OceanObs09.cwp.76.

34. Swail, V. & Co-Authors (2010). "Wave Measurements, Needs and Developments for the Next Decade" in these proceedings (Vol. 2), doi:10.5270/OceanObs09.cwp.87

35. Turiel A., Nieves, V., Garcia-Ladona, E., Font, J., Rio, M.-H. and Larnicol. G. (2009). The multifractal structure of satellite sea surface temperature maps can be used to obtain global maps of streamlines, *Ocean Sci*., 5, 447–460.

36. Waugh D. K. and Abraham, E. R. (2008). Stirring in the global surface ocean, *Geophys. Res. Lett*., 35, L20605, doi:10.1029/2008GL035526.

37. Wilson, S. & Co-Authors (2010). "The Ocean Surface Topography Constellation: The Next 15 Years in Satellite Altimetry" in these proceedings (Vol. 2), doi:10.5270/OceanObs09.cwp.92.