EVALUATION OF MULTI-SATELLITE MAPPING CAPABILITIES FOR OPERATIONAL MESOSCALE MONITORING

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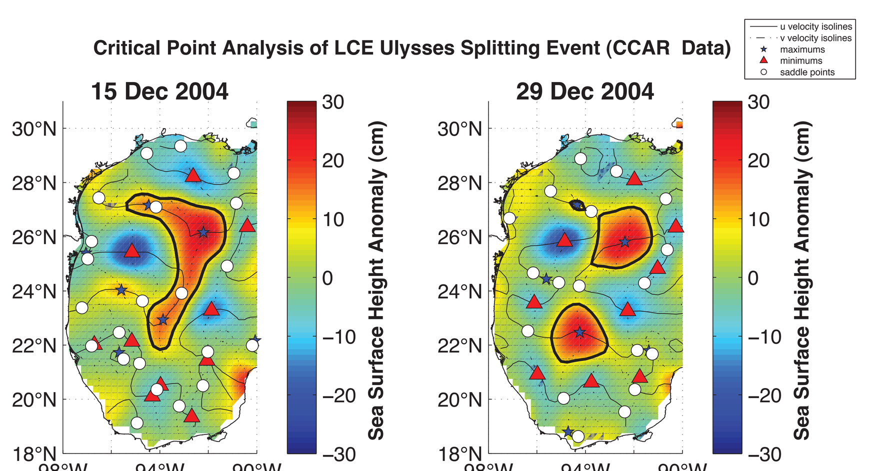
Abstract

Since the launch of TOPEX/Poseidon(T/P) in August 1992, nearly continuous two-satellite altimetric sampling has been available from the T/P, Jason-1, and Jason-2 in combination with the ERS-1&2 and Envisat missions. Tandem sampling has allowed unprecedented mapping of the ocean mesoscale. Nevertheless, mesoscale signals at wavelengths of up to 300 km, corresponding to eddies with characteristic diameters of up to 150 km, are not fully resolved by this sampling. Mesoscale mapping can be improved with additional sampling. This motivated the T/P and Jason-1 tandem mission in which the satellites were flown in an interleaved 10-day repeat ground track pattern with a track separation half that of the T/P mission. Jason-1 and Jason-2 are in a similar tandem configuration, although the temporal phasing is different. As a result, nearly continuous four-satellite altimetric sampling (T/P, Jason-1, GFO, and Envisat) was available from October 2002 through September 2005. Three-satellite altimetric sampling (Jason-1, Jason-2, and Envisat) has been available since February 20, 2009 when Jason-1 became operational in the interleaved orbit. In an effort to better understand the mesoscale mapping capabilities afforded by multi-satellite sampling, we compare CCAR and AVISO 2-satellite and 4-satellite products. These studies will be used to better understand the limitations of current products at mesoscale wavelengths and to develop improved altimeter products with better depiction of the ocean mesoscale eddy field.

Data and Methods

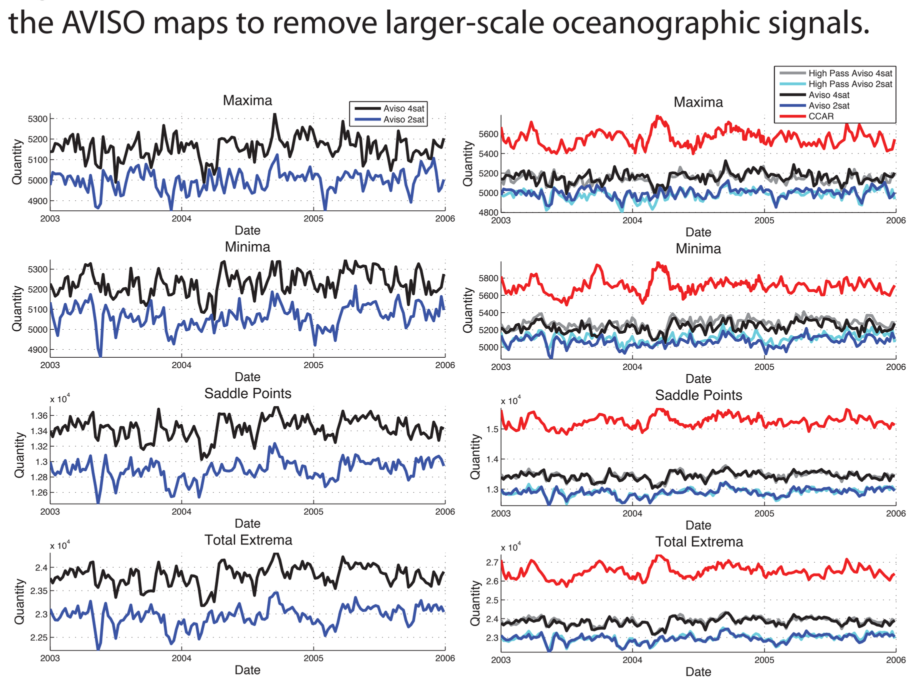
Qualitative and quantitative evaluations are used to assess the population, structure, distribution, and interaction of mesoscale circulation features as resolved in the current generation of altimeter products. A variety of comparisons are made using global eddy censuses based on critical point analyses. More detailed regional comparisons are made using simulated drifter tracks and eddies resolved by a feature intensity index based ocean color and sea surface temperature imagery.

Critical Point Analysis: Since we are interested in the basic patterns of the eddy fields rather than rigorously defined vortex kinematics and dynamics, we use a simple critical point analysis of the SSHA extrema to evaluate the altimeter data products. Critical points are geostropic velocity stagnations points in the flow where the local velocity is zero, corresponding to the maxima, minima, and saddle points in SSHA maps. These points are associated with anticyclonic and cyclonic eddies at small scales and Rossby waves or gyres at larger scales. We have identified the points associated with elliptic and hyperbolic critical points, which are related to the topology of the sea surface height. At eddy scales, elliptic points denote the centers of eddies and are associated with strong vorticity, while hyperbolic points are found in regions between interacting eddies or within deforming eddies and are where deformation dominates.

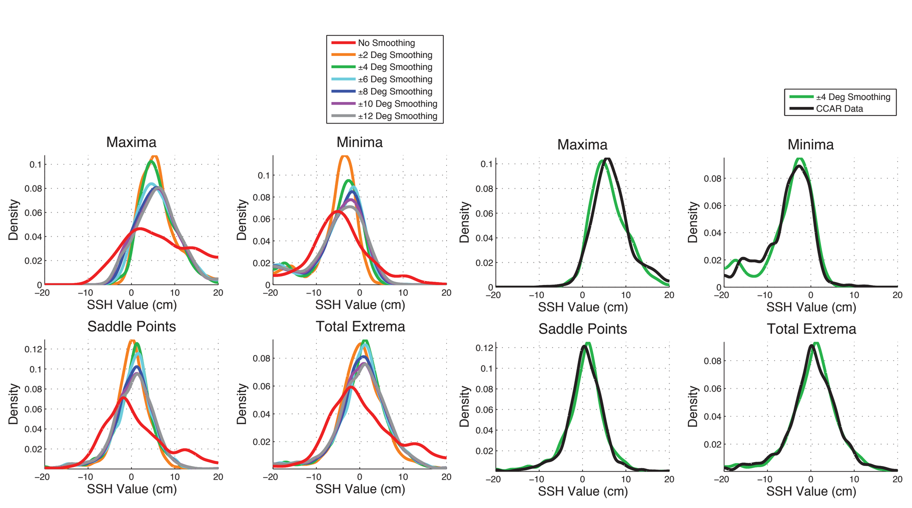


Eddy deformations and changes in the sea surface topology are clearly seen in the splitting of Loop Current Eddy (LCE) Ulysses in the western Gulf of Mexico, which shown in the CCAR SSHA maps to the left. The maps highlight the splitting of LCE Ulysses into two large anticyclones and one small anticyclone in Dec 2004. A 9-cm SSHA eddy-tracking contour is also shown. The small anticyclonic eddy jettisoned by LCE Ulysses during the splitting event is resolved in the northwest corner of the Gulf. This eddy was well observed by an MMS deepwater study array (Donohue et al., 2008), and was associated with the only time that a clear signature of Loop Current water was observed in the array during the 14-month study program.

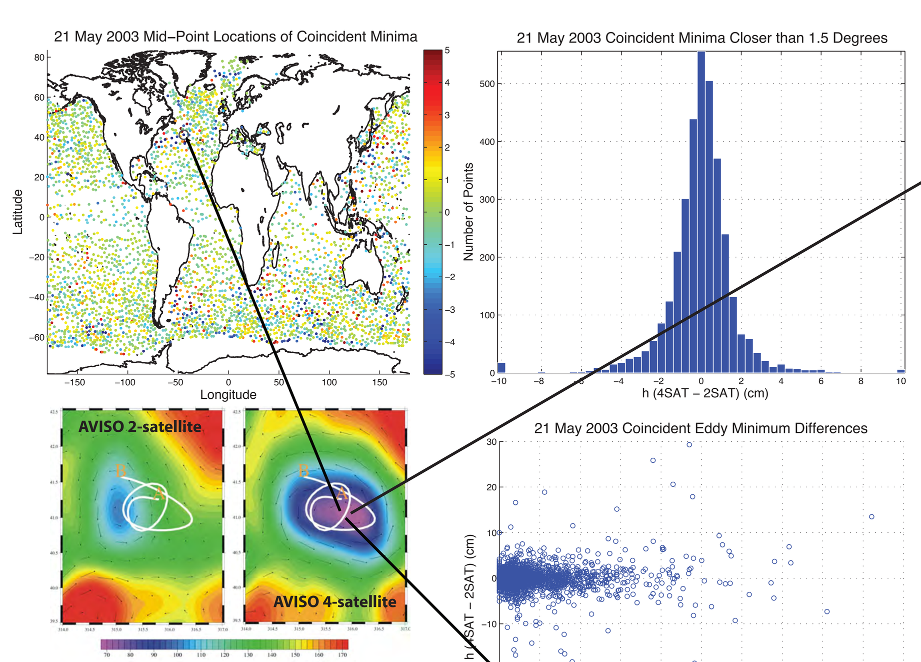
Global Comparisons of AVISO 2-Satellite and 4-Satellite Data Products: Applying the critical point analysis to the Aviso 2-satellite, AVISO 4-satellite, and CCAR data products over the global oceans, we find the results plotted in the figures below for critical points in waters deeper than 1000 meters. Only relatively small differences are seen in the total number of maxima, minima, and saddle points between the AVISO two- and four-satellite mapped products. Overall there was an average increase of about 4% in the total number of critical points mapped by the AVISO products when using four satellites versus two satellites. The difference between the CCAR four-satellite product versus the AVISO two-satellite product was about 15%. We are currently investigating the difference in the distributions of the extrema between the CCAR and AVISO mesoscale products after high pass filtering the AVISO maps to remove larger-scale oceanographic signals.



Distribution of Extrema as a Function of High Pass Filtering

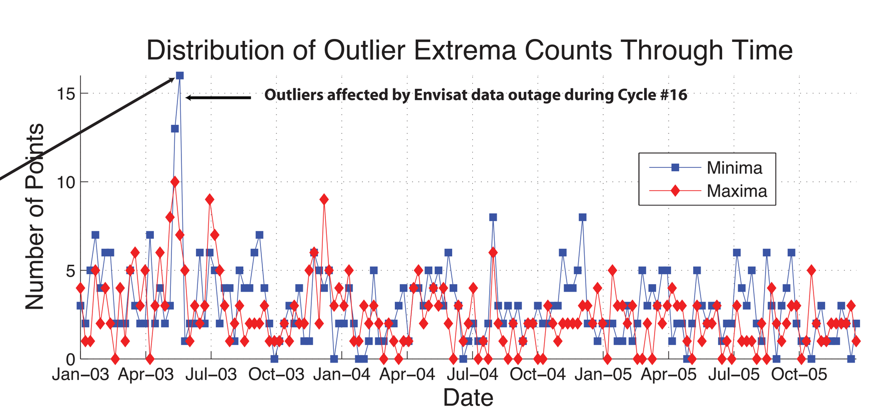


Additional analyses are performed on the critical points to calculate the height differences associated with nearly collocated extrema in the weekly AVISO 2- and 4-satellite maps. Height differences at these points help to quantify the changes in the mesoscale eddy field and their variation. Examples for cyclonic eddies (minima) from the 21 May 2003 maps are shown below left. The AVISO maps on that date (Pascual et al., 2006) are frequently cited as an example of improved mapping afforded by 4- versus 2-satellite sampling. Counts of the cyclonic and anticyclonic (minima and maxima) extrema through the 3-year time period (2003-2005) show that this date was an extreme in the number of eddies exhibiting an increase in amplitude of 10 cm causing displacements of the extrema by less than 1.5 degrees. Further investigation, however, showed that the anomalous values were in part caused by Envisat data outages during cycle 16. Nevertheless, inspection of the T/P and GFO alongtrack data over the time period shows that T/P and GFO contributed significantly to energetic mesoscale mapping throughout the 3-years with T/P contributing about 30% more frequently than GFO.



"The Canonical 4-Satellite Sampled Cyclonic Eddy"

Comparison of altimetry and drifter data in a Gulf Stream cyclonic eddy: The white line represents the trajectory followed by a surface float between (A) 14 May 2003 and (B) 28 May 2003. The vector arrows correspond to the absolute velocity field (geostrophy + Ekman) and the background color field is the SLA + MDT (in cm) on 21 May 2003 from the (left) 2 satellite (T/P/Envisat) and (right) 4-satellite (T/P/Jason/Envisat/GFO) configurations. (figure from Pascual et al, 2006)

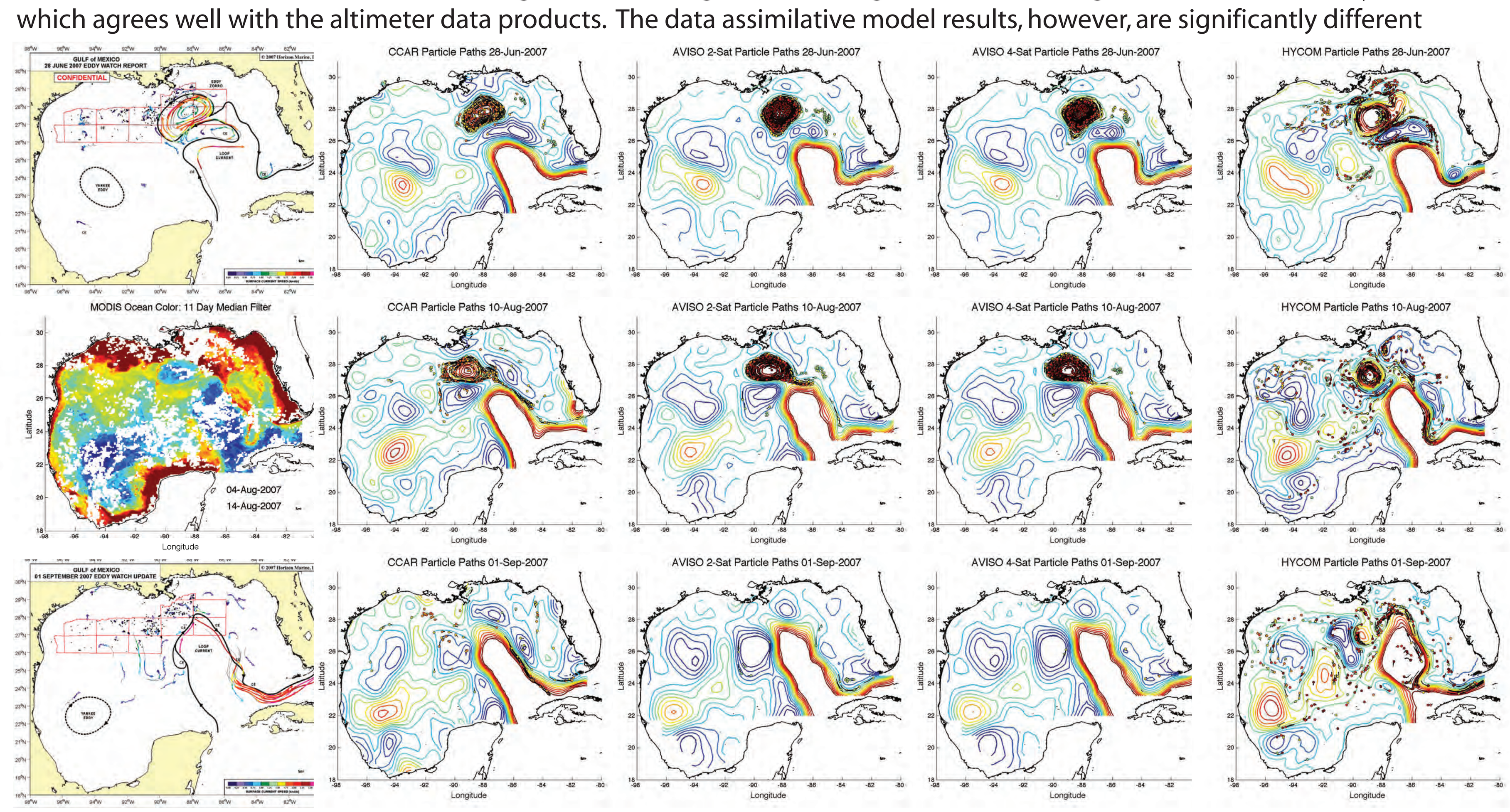


Number of Extrema Amplified by 10+ cm	Maxima Field Count	Maxima % of Total	Minima Field Count	Minima % of Total
0	21	13.4	9	5.7
1	31	19.7	25	15.9
2	41	26.1	45	28.7
3	32	20.4	25	15.9
4	11	7.0	20	12.7
5	11	7.0	15	9.6
6	4	2.5	11	7.0
7	2	1.3	3	1.9
8	1	0.6	2	1.3
9	2	1.3	0	0.0
10	1	0.6	0	0.0
11	0	0.0	0	0.0
12	0	0.0	0	0.0
13	0	0.0	1	0.6
14	0	0.0	0	0.0
15	0	0.0	0	0.0
16	0	0.0	1	0.6
Total Fields				

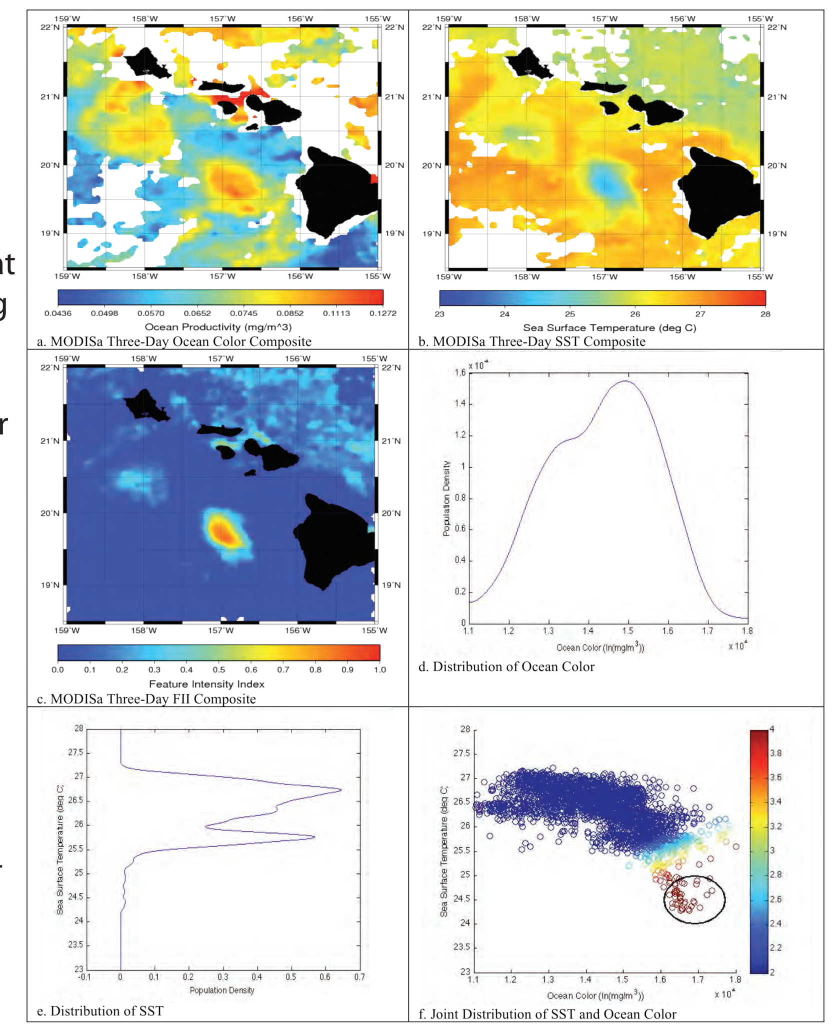
Satellite	Pass	Maxima	Minima
Topex	Ascending	97	126
	Descending	117	147
	Total	214	273
GFO	Ascending	89	95
	Descending	79	109
	Total	168	204

Over the 3-year time period from 2002 through 2005, T/P contributed sampling 487 times that increased an eddy extrema by 10-cm in amplitude in the weekly AVISO maps while changing the location less than 1.5 degrees. This compares to a total count of 372 instances for GFO over the same time period. Thus, T/P in the interleaved orbit contributed about 30% more to energetic eddy sampling than did GFO in the 4-satellite sampling configuration.

Simulated Drifter Tracks: Differences in the SSHA maps, and the mean fields used to estimate total SSH, affect the trajectory of simulated drifter paths in the mapped eddy fields. This is seen in the trajectories of simulated drifters released in Loop Current (LC) Eddy Zorro near the time when it reattached to the Loop Current in August 2007, shown in the panels below for the CCAR, AVISO two-satellite, AVISO four-satellite, and HYCOM data assimilation data products. Eddy Watch reports, based on satellite-tracked drifters, show the bulk of the drifters orbiting in Zorro exiting the Gulf along the northern margin of the LC as the eddy reattaches, which agrees well with the altimeter data products. The data assimilative model results, however, are significantly different

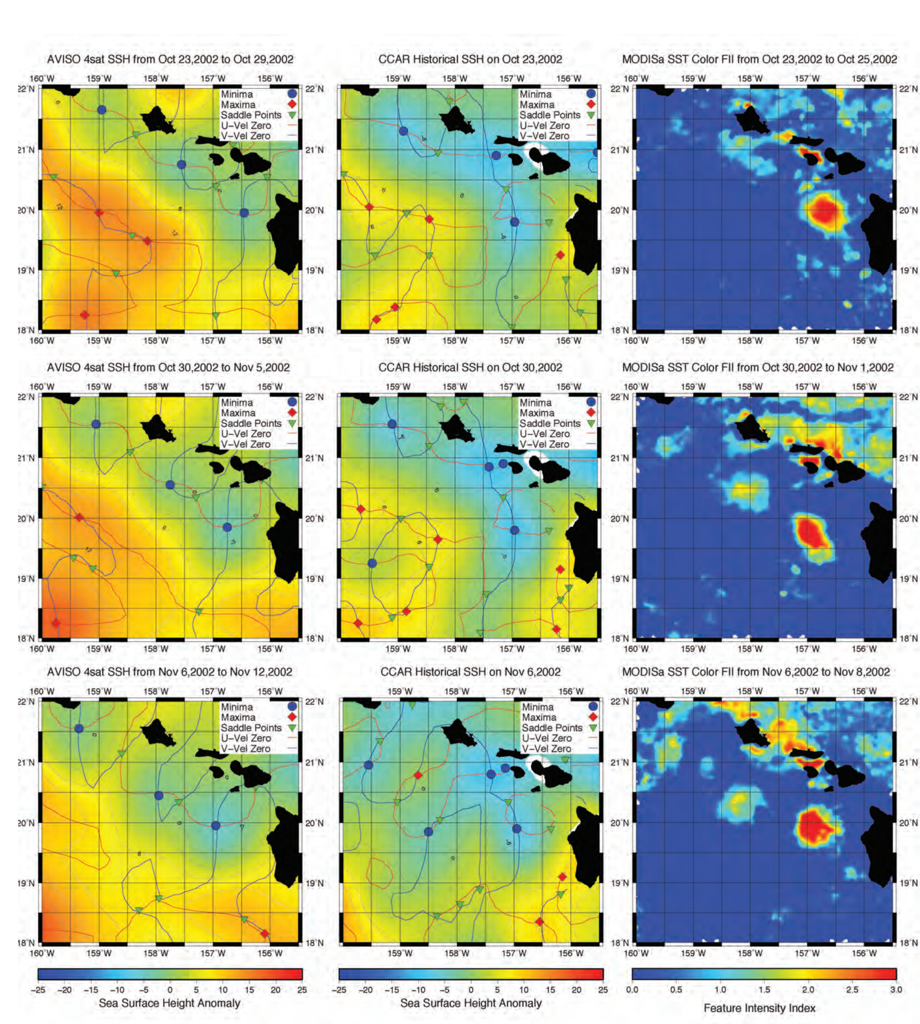


Feature Intensity Index: Corroborative evidence of mesoscale eddies over the global oceans for validating altimeter mesoscale products is difficult to acquire. Recently, we have developed a "Feature Intensity Index" (FII) derived from MODISa imagery that was used to track individual cyclonic eddies in the lee of the Big Island of Hawaii over time periods of up to four months (Joy et al., submitted). The index is calculated by subtracting standardized SST from standardized color values at each pixel location. Standardized values were calculated by subtracting the regional mean and dividing by the standard deviation.



Representative 3-day composite images from October 23-25, 2002 over the region are shown to the left. The individual SST and color distributions have very few values that are cold or productive, respectively, so isolating eddy signatures from either product alone is difficult. In contrast, the difference of the color minus the SST is a well-defined cluster of collocated cold and productive pixels highlighted in the joint distribution. This clustering of the data is robust enough through time so that the FII feilds can be used to automatically track cyclonic eddies.

The cyclonic eddies in the lee of the Big Island are typically only about 50 km in diameter and represent a significant challenge to altimetric mapping. The FII composite maps in this region, therefore, provide ancillary and synoptic information on the mesoscale eddy feild useful for evaluating the mesoscale mapping capabilities of multi-satellite altimeter data products at smaller time and space scales.



In the panels to the left, we compare the AVISO 4-satellite and CCAR mesoscale products with the FII images in the lee of the Big Island of Hawaii. The contoured SSHA maps are shown overlaid with the zero velocity lines and critical points to aid in the identification of mesoscale eddies. The FII images show a row of three cyclones along a northwest-oriented line to the southwest of the archipelago. The large eddy in the lee of the Big Island is well represented in both altimeter data products with the minima well collocated with the strong FII eddy signatures over the two weeks. The weaker cyclones are better represented in the AVISO 4-satellite altimetry maps than in the CCAR maps.

More systematic comparisons will be made in the region to understand the sampling of small scale eddies by comparing altimeter-tracked eddies to eddy tracking using FII images. Cyclonic eddies have been automatically tracked using FII images over a six-year time period from July 4, 2002 to July 4,2008. A total of twenty-four distinct features were found in this time span that endured for more than five days and were separated from other events by at least five days. This data set will serve as a benchmark to evaluate the altimeter-derived mesoscale products and to develop products with greater temporal and spatial resolution to fully exploit the denser sampling afforded by the T/P/Jason-1 and Jason-1/Jason-2 tandem missions.

Summary

Selected analyses have been presented to highlight a variety of tools useful for evaluating the population, structure, distribution, and interaction of mesoscale features as depicted in the current generation of altimeter products. Preliminary comparison of the AVISO 2- and 4-satellite products show only a small (4%) increase in the number of extrema mapped with the additional sampling. This modest increase is primarily a result of using the same correlation time and space scales in the objective interpolation procedure for both the 2- and 4-satellite maps. The CCAR mesoscale maps show about 15% more features; however, this increase may not necessary reflect better performance and needs to be investigated carefully with comparison to ancillary observations of the ocean mesoscale. The objective eddy census tools and analysis techniques provide useful information to better understand the limitations of current altimeter products at mesoscale wavelengths and to develop improved products for the operational and scientific communities. In the next phase of our work, mesoscale products will be developed and tested with the goal of producing a new generation of operational and research quality datasets with improved depictions of the ocean mesoscale eddy field. Robust processing improvements will be incorporated into the CCAR operational system to improve operational monitoring of mesoscale circulation in the Earth's oceans.

References:

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