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An analysis of SST gradients off the Peruvian Coast: The impact of going to higher resolution

Jorge Vazquez-Cuervo [a,*], Boris Dewitte [b], Toshio M. Chin [a], Edward M. Armstrong [a], Sara Purca [c], Edward Alburqueque [d]

[a] Jet Propulsion Laboratory/California Institute of Technology, Pasadena, USA
[b] LEGOS/IRD, Toulouse, France
[c] Instituto del Mar del Peru, Callo, Peru
[d] Universidad Nacional Mayor de San Marcos, Peru

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ABSTRACT

The Peruvian Coastal Upwelling System (PCUS) is one of the most productive fisheries in the world. Upwelling events are associated with changes in the magnitude and location of frontal structures. SST gradients from four different data sets, NCDC, REMSS, OSTIA, and MUR are compared in two test areas off the PCUS: Païta (5°S) and Pisco (14°S). In both areas gradients derived from the MUR data set show greater magnitudes, as well as larger seasonal cycles. Off Pisco, the magnitude of the seasonal cycle of 2.2 °C/100 km in MUR is larger than the one derived from the lower resolution data sets. All data sets at Pisco exhibit a seasonal cycle that peaks in late Austral summer and early fall. Hovmöller diagrams calculated at 5.5°S, 10.5°S, and 14.5°S show clearly defined offshore maxima in the cross-shore gradients for all the data sets. Upwelling scales determined by the distance to the first maxima vary depending on the data set used. At 5.5°S upwelling scales vary from 10 km for MUR to 50 km for NCDC. At 14.5°S the scales vary from 20 km for MUR to 40 km for OSTIA. All four data sets show similar large-scale structures associated with the Peruvian upwelling. However, MUR shows finer scale structures that are most likely due to submesoscale to mesoscale eddies. Sub-sampled MUR 1 km data at the 25 km, 9 km, and 4 km resolutions compare well in magnitude and phase with the lower resolution products. Agreement in gradient magnitude between the lower resolution data sets and the MUR sub-sampled at their respective resolutions implies that the pixel-to-pixel analysis noise in MUR is at a similar level as the other data sets.

1. Introduction

The Peruvian Coastal Upwelling System (PCUS) stands out in terms of exploitable fisheries of the major Eastern Boundary Upwelling Ecosystems (EBUS) of the world's ocean (Chavez et al., 2008). Still, it experiences the most variable environmental physical forcing in particular through the connection with the equatorial variability at a wide range of frequencies, i.e. from intraseasonal to interannual timescales (Pizarro et al., 2002; Dewitte et al., 2011, 2012). Despite this highly variable environmental forcing, the PCUS is also exceedingly efficient in the transfer of primary production to fish (see Fig. 1 of Chavez et al. (2008)). The reason for this remains unclear although it might be related to the relatively high eddy activity (Chaigneau et al., 2009) that can extend the area of high biological productivity offshore (Correa-Ramirez et al., 2007) and actively participate in the cross-shore transport of coastal water properties, forming a link with the open ocean environment. Although satellite altimetry has been proven very useful for documenting some aspects of the Eddy Kinetic Energy (EKE) in the PUCS (Chaigneau et al., 2009), it only allows documenting the variability scale on the order of 50–100 km. Only sea surface temperatures (SST) derived from infrared satellite sensors have sufficiently high resolution to determine the scales associated with coastal upwelling. Most studies of upwelling regions have in fact addressed these limitations in the resolution of the satellite data. For instance, QuikSCAT data does not allow resolving the wind drop-off at the coast which is influential on the upwelling (Capet et al., 2004; Renault et al., 2012), whereas TMI data tend to have a warm bias along with a blind zone of ~25 km at the coast. The 25 km blind zone is inherent to microwave measurements. Considering the fine cross-shore structure of the upwelling cells in most Eastern boundary current systems, there is a need for higher resolution products in order to better document and study upwelling dynamics in these regions. Although satellite analyzed SST products that use infrared sensors can provide the resolution, they are limited by cloud coverage. Microwave sensors can retrieve SSTs during cloudy conditions, but are limited to 25 km in resolution. Current strategies attempt to merge SST data from different sensors in an optimal way that takes advantage of each sensor.

* Corresponding author at: JPL/Caltech M/S 300/323, 4800 Oak Grove Dr., Pasadena, CA 91109, USA. Tel.: +1 818 354 6980; fax: +1 818 393 6720.
E-mail address: Jorge.Vazquez@jpl.nasa.gov (J. Vazquez-Cuervo).

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Using satellite-derived SST products has historically been difficult in areas such as the PCUS where persistent cloud cover can severely limit the feasibility of using infrared sensors. Historical results (Belkin & Cornillon, 2003) do show that fronts can be determined from the NOAA Pathfinder SST data. Infrared sensors such as the Advanced Very High Resolution Radiometer (AVHRR) and the Moderate Resolution Imaging Spectroradiometer (MODIS) can provide SSTs at high spatial resolutions of 1–2 km. Microwave sensors provide near all-weather capability for deriving SSTs, but at a lower 25 km resolution (Wentz et al., 2000). Upwelling regions such as the PCUS are associated with gradients in SST that are defined by frontal structures smaller than 25 km (Marchesiello & Estrade, 2010). It is important to document such structures from observations in order to provide useful materials for the validation of high-resolution regional models and to better understand the mesoscale to submesoscale dynamics that are influential on a number of biogeochemical and biological properties (Gruber et al., 2011), and improve our knowledge of the air–sea interaction at mesoscales (Chelton & Xie, 2010; Chelton et al., 2007). The objective of this paper is to take advantage of various SST products to infer the horizontal gradients, taken here as a proxy of the frontal structures. Results have shown that the PCUS is an area of frontal structures that vary in both space and time (Belkin & Cornillon, 2003). The focus is on two regions of the PCUS characterized by two different upwelling regimes: the Païta region around 5°S which is highly connected to the equatorial circulation and the Pisco region around 15°S that experiences the seasonality of the upwelling favorable winds (Dewitte et al., 2011). The gradients are calculated in these regions using SST data sets with different spatial gridded resolutions (25 km, 9 km, 5 km, and 4 km). The objective is for the first time to quantify the annual cycle of gradient magnitudes off the PCUS, and examine the consistency between the magnitude of the gradients and resolution. An additional goal is to determine whether any of the gradient variability could be due to mesoscale and submesoscale variability. In particular, we wish to examine the potential disadvantages/advantages in utilizing AVHRR and MODIS in blended SST products based on their respective coverage off the PCUS and investigate to which extent higher-resolution products can be useful to infer physically relevant parameters for describing upwelling dynamics, which includes the upwelling scale. In particular, the latter is often confused with the Rossby radius of deformation which defines the length scale over which rotational effects are felt. Off the Peruvian Coast, the baroclinic Rossby Radius of deformation (Croquette et al., 2007; Pickett & Paduan, 2003; Smith, 1994) is about 200 km (Chelton et al., 1998) and only describes the geostrophic adjustment of the upwelling front. Estrade et al. (2008) and Marchesiello and Estrade (2010) show that the actual upwelling scale is associated with the length of the frictional inner shelf zone where surface and bottom Ekman layers overlap. Off Central Chile, characterized by steep and narrow shelves, this scale can be no more than 5 km (Marchesiello & Estrade, 2010). Overall, issues to be addressed in this paper are whether there are features that can be identified more clearly or seen at higher resolutions that are not seen in the lower resolution data sets. Other points to be discussed are the magnitude of the annual cycle in SST gradients and how the variability of the gradients might be associated with movements of the upwelling front associated with mesoscale to sub-mesoscale activities.

The paper is organized as follows: Section 2 presents the six SST data sets, Section 3 identifies the magnitudes of the seasonal SST gradient signal from the different data sets, Section 4 discusses the results in terms of the upwelling scales off Peru, and Section 5 concludes with the significance and future direction of the work.

2. SST data sets and method's description

Six daily SST data sets, both level 3 (with data gaps) and level 4 (no data gaps due to objective interpolation) are used to compare SST gradient magnitudes for 2009. The level 3 data are used as reference data sets for comparisons with the derived SST gradients from the level 4 SST products. All level 4 data sets are distributed through the Group for High Resolution Sea Surface Temperature (GHRSST) (Donlon et al., 2007). These data are available in near real time and as historical data can be retrieved through the Global Data Assembly Center (GDAC) located at NASA's Physical Oceanography Distributed Active Archive Center (PO.DAAC) (http://ghrsst.jpl.nasa.gov) and the Long Term Stewardship and Reanalysis Facility (LTSRF) located at NOAA's National Oceanographic Data Center (NODC) (http://ghrsst.nodc.noaa.gov). The gridded resolution of the different SST products ranges from 25 km to 1 km. The following is the description of the four level 4 (no gaps) SST data sets in the order of decreasing resolution.

2.1. Multi-scale ultra-high resolution sea surface temperature (MUR)

The MUR SST analysis is globally gridded at 1 km resolution by merging data from MODIS, AMSR-E, and AVHRR. An objective interpolation technique based on a wavelet decomposition (Chin et al., 1998) is used to process each retrieval data set with respect to its inherent resolution. More information can be found at http://mur.jpl.nasa.gov/. Data descriptions may also be found at: http://podaac.jpl.nasa.gov/dataset/JPL-L4UHfnd-GLOB-MUR.

2.2. Operational Sea Surface Temperature and Sea Ice Analysis (OSTIA)

The Operational Sea Surface Temperature and Sea Ice Analysis (OSTIA) is a 5 km gridded global SST product. Data are available from April of 2006 as daily 5 km gridded global SSTs. More information may be found in Donlon et al. (2012) along with a data description at: http://podaac.jpl.nasa.gov/dataset/UKMO-L4HRfnd-GLOB-OSTIA.

2.3. Remote Sensing Systems microwave infrared merged SST analysis (REMSS)

Remote Sensing Systems (REMSS) microwave infrared merged product consists of globally gridded 9 km daily fields. Data used in this product consist of derived SSTs from the MODIS instrument on board the NASA Terra and Aqua platforms, as well as the Advanced Microwave Spectroradiometer-Earth Observing System (AMSR-E) on board the Aqua platform. The GHRSST product name embedded in the file name refers to the mw_ir_OI data set. More information may be found in Gentemann et al. (2009) along with data descriptions at: http://podaac.jpl.nasa.gov/dataset/REMSS-L4HRfnd-GLOB-mw_ir_OI.

2.4. Reynolds (NCDC)

This product is available in daily files from June 1 of 2002 until present day. SSTs are the result of an objective interpolation of satellite derived SST data from the Advanced Very High Resolution Radiometer (AVHRR), the Advanced Microwave Scanning Radiometer on board the NASA Earth Observing System Aqua Platform (AMSR-E) as well as in-situ data. The GHRSST product name embedded in the file name refers to the AVHRR_AMSR_OI data set. More information on the interpolation may be found in (Reynolds & Smith, 1994; Reynolds et al., 2002), along with data descriptions at http://podaac.jpl.nasa.gov/dataset/NCDC-L4LRblend-GLOB-AVHRR_AMSR_OI.

The following is the description of the two level 3 data sets (with gaps) used as a reference for comparison.

2.5. Level 3 4 km MODIS Aqua SSTs (MODIS)

Nighttime and daytime SSTs from MODIS Aqua are produced as globally gridded fields at a 4 km spatial resolution. All data are available through the PO.DAAC. This is considered a level 3 product and not objectively interpolated. Thus data gaps still exist due predominately to