Exercise 2 - Remote sensing of the ocean

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1 Exercise 1: El Niño and La Niña

In this exercise we want to study an important oceanic and climatological phenomenon known as *El Niño*. To this end, we will look at the annual variability of sea surface temperature and chlorophyll concentrations obtained by remote sensing.

1.1 SST anomalies

Open QGIS and load all GeoTIFF files in the EXO1/SST subfolder of your DATA folder. These data provide global (worldwide) observations of sea surface temperature (SST) in °C performed by the Moderate Resolution Imaging Spectroradiometer (MODIS) instrument aboard the Aqua (EOS PM) satellite. Aqua (launched in 2002) is a satellite with a heliosynchronous orbit aimed at the study of the water cycle. The data contain December monthly-averaged SST observations taken between 2002 to 2017. The coordinate system is WGS84 (standard lat/lon coordinates).

1. Look at the current specification of the MODIS instrument on Aqua. a) Explain how sea surface temperature can be derived from these measurements.

To make it easier to study the annual variability, we will start by creating a map of the average monthly SST in December through all years of observations. Use the *r.series* function in the GRASS section of your Processing Toolbox[1], on the right of your QGIS window (see Figure 1). In *r.series*, indicate that you want to use all 16 layers, and that you want to perform the average. In the *Advanced Parameters* section, it is possible to bound the valid range of values that will be taken into account when computing the average. Save the computed monthly SST December climatology into a file named *sst_dec_avg.tiff*.

Now that we know the climatological monthly SST for December, we will compute the monthly SST December anomalies in the years 2011 and 2015. The anomalies are defined as the difference between the observed values and the climatological average. You can compute these anomalies with the *Raster calculator* in the *Raster menu* on top of your

[1] If you do not see the *Processing Toolbox*, you must first make it visible by activating it in the View menu (on top of your QGIS window) under *Panels*, or alternatively by clicking on *Processing* menu, and then selecting *Toolbox*.

QGIS window (Figure 2). Call the output anomaly layers *sst_anomaly_dec_2011.tiff* and *sst_anomaly_dec_2015.tiff*.

To correctly visualize the anomalies, define an appropriate diverging colormap (i.e. "spectral" or "RdBu") centered around 0.[2] Specify symmetric minimum and maximum values (i.e. -3.5 °C , 3.5 °C). In the context of temperature anomalies, the reddish colors are usually employed to highlight positive anomalies (warmer than usual temperatures), while bluish colors are used to characterize cooler periods (negative anomalies).

You can save the colormap so that it can be reused to display also the other SST anomalies fields, by clicking on the *Export colormap to file* button on the right side of the *Classify* button. You can then reload such colormap when setting the style of another anomaly field layer by clicking on the left-adjacent button *Load colormap from file*. Alternatively, after having defined the colormap of a layer, you can *Copy Style* and *Paste Style* onto the other layer.

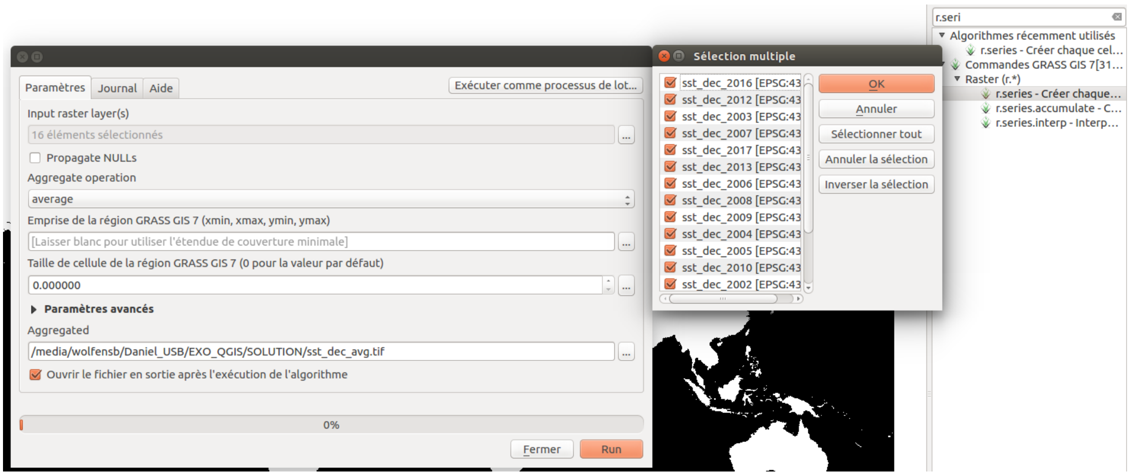

Figure 1: Using *r.series* to compute the climatological monthly SST of December.

December 2015 corresponded to a strong *El Niño* event, whereas December 2011 was characterized by a *La Niña* event, which can be considered as the opposite condition to *El Niño*.

2. Take a look at the SST anomalies in December 2011 and 2015 and focus on the Pacific coast of Peru. What can you say about these particular months? In particular, what do you observe during the strong *El Niño* event of December 2015?

[2]To define the style/colors of a layer, go to the layer *Properties-Symbology* tab.

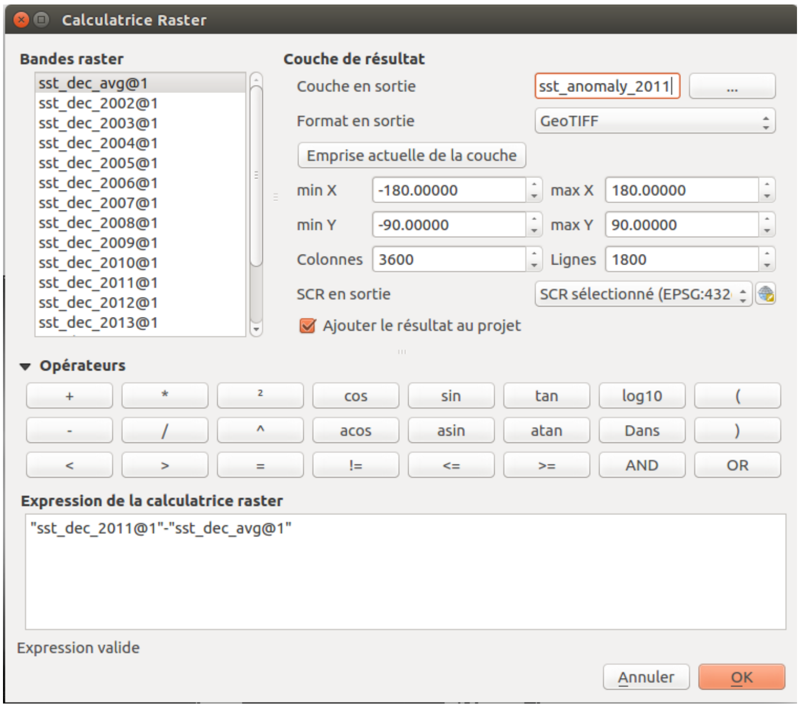

Figure 2: Computing the monthly SST anomaly for December 2011.

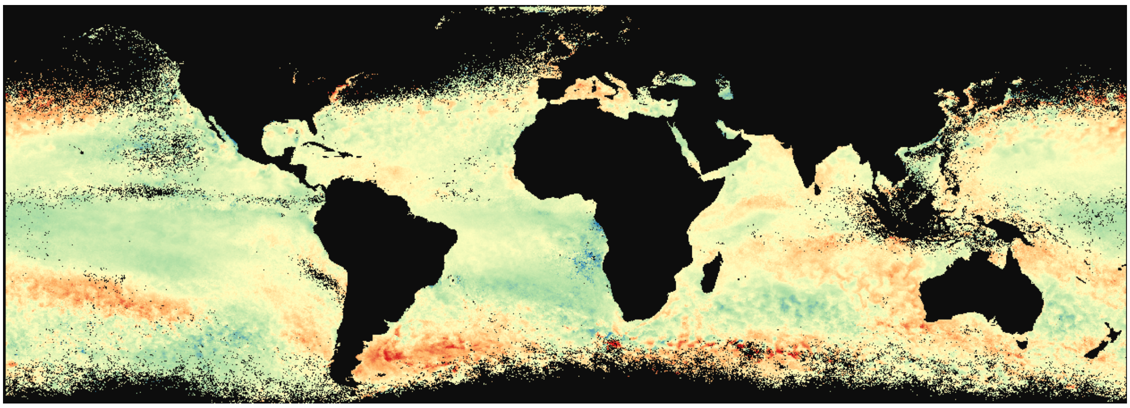

Figure 3: SST anomaly in December 2011 during La Nina event.

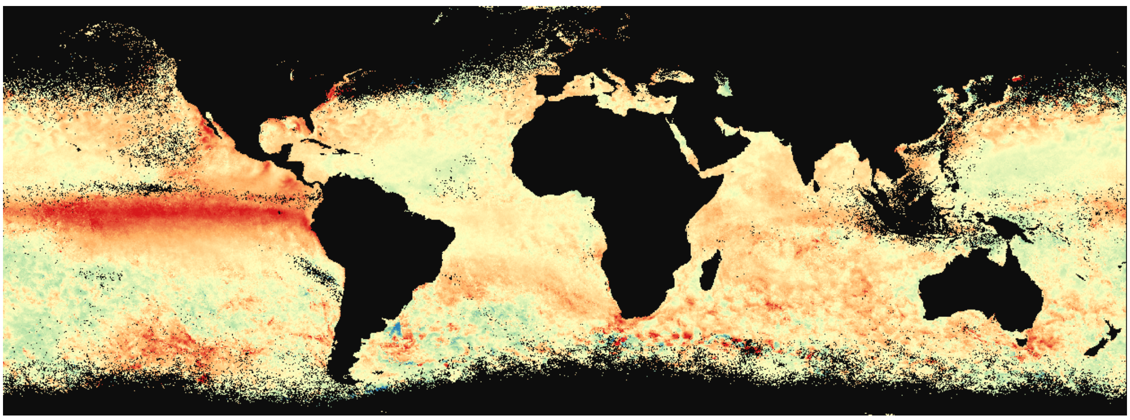

Figure 4: SST anomaly in December 2015 during El Nino event.

2 Exercise 2: Ocean currents and seawater density

In the second part of this exercise, we will study the seasonal variability of seawater density and how it affects surface currents.

2.1 Salinity

Close all layers of the previous exercice and open all GeoTIFF files present in the DATA/EXO2 subfolder. These raster files correspond to the monthly average SST and salinity measurements taken in January and August 2014. Whereas the SST data is obtained as before with the AQUA/MODIS instrument, the salinity data is obtained from the newer but short-lived Aquarius/SAC-D satellite (launched in 2011 and failed in 2015). The power received by the SAC-D radiometer antenna is governed by the microwave emissivity and temperature of the ocean surface. When salt dissolves in water, it creates charged cations (Na+) and anions (Cl-), leading to an increase in conductivity, which is negatively correlated to the microwave emissivity. Based on knowledge of the SST, it is possible to relate a decrease in the received power at the instrument to an increase in salinity of the surface water. The units of salinity are expressed in units of ppt (parts per thousands = grams of salt per kg of water).

2.2 Seawater Density

The density of seawater is governed by the pressure, the salinity and the temperature of the water. It is usually expressed as:

$$\rho^{\text{sea}} = \rho^{\text{fresh}} + \sigma \tag{1}$$

where $\rho^{\text{fresh}} = 1000\text{kg m}^{-3}$ is the standard density of fresh water and σ is the seawater excess density.

At the surface, the atmospheric pressure is more or less constant, so a simplified expression for the seawater excess density (σ) is:

$$\sigma = -0.175 \cdot \text{SST} + 0.7718 \cdot S_a \tag{2}$$

where S_a is the salinity in ppt. As the equation suggest, cold saline waters are more dense than warm fresh waters.

Now, based on the data provided, use the QGIS *Raster Calculator* to compute a rough estimate of σ with Equation 2 for both January and August. Use an appropriate colormap to display your images (for example the *Blues* colormap) as in Figure 5.

3. Take a look at the density and SST images for January 2014. Identify a cold and a warm ocean current. Describe their direction and flow features, and name them.

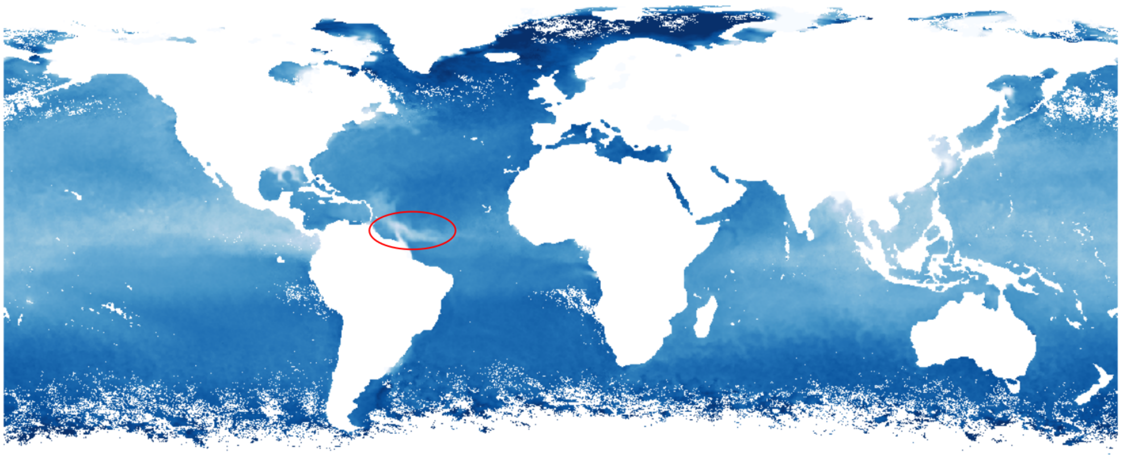

Figure 5: Seawater excess density (σ) in August 2014. Dense waters are shown in dark blue. The red circle corresponds to the area mentioned in Question 5.

4. In August, as seen in Figure 5, near the Brazilian/Guyana coast (red circle), there is a strong plume of seawater with low density. Explain why this is the case and why this plume is almost absent in January. Identify two more regions with similar phenomena.

5. Explain why the salinity tends to be largest in subtropical regions and tends to be lower near the Equator and at temperate latitudes. In turn, explain why the density increases with latitude despite the salinity distribution.

6. What are common limitations when utilizing remote sensing to monitor the ocean? What advantages are there when comparing the Aquarius/SAC-D sensor to TERRA/AQUA MODIS?