Exercise 2 - Solution
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LTE, EPFL, Switzerland

1 Exercise 1

Question 1

Sea surface temperatures (SST) are derived by relating radiance measurements in specific portions of the infrared (IR) spectrum through the help of the Planck law. The overall principle is simple: the warmer the water, the higher the IR surface emissivity and the higher the signal (radiance) recorded by the MODIS passive radiometer. Since large portions of the IR/thermal radiation emitted by the surface are absorbed by the gaseous species in the atmosphere, to retrieve SST it is necessary to sense IR radiation in specific narrow bands of the electromagnetic spectrum (known as IR atmospheric window bands), where atmospheric absorption is very limited.

Question 2

December 2015 corresponds to a strong *El Niño* event, which is characterized by a band of warm ocean water that develops in central and east-central equatorial Pacific.

Usually, high temperatures off the coast of South America lead to an increase of evaporation and an increase in atmospheric humidity. Normally, the trade winds[1] of the Southern Hemisphere tend to blow this warm water to the west. However, during *El Niño* these winds weaken or even reverse, for reasons that are not yet well known, and all this warm seawater and atmospheric humidity stays in place or gets transported towards the coast, leading to high SST and high precipitation. This warm water displaces the cooler water that is normally found near the surface of the eastern Pacific, setting off atmospheric changes that affect weather patterns in many parts of the world.

December 2011 corresponds to a *La Niña* event, which can be seen as the opposite of *El Niño*. It is characterized by rather cool SST. In the case of *La Niña*, strong westerlies tend to move the warm water in the Pacific towards the west, which causes an upwelling of cold, nutrient-rich deeper water to the surface along the Peruvian coasts.

[1] Alizés in French

2 Exercise 2

Question 3

There are two currents that can be identified.

In the northern hemisphere, there is a strong warm surface current which flows from the Gulf of Mexico up to the Canadian coast. This is the *Gulf stream*. As the water moves northward the water cools down and gets more and more dense. This change in density is essentially wind-driven as wind passing over the water causes evaporation which cools the water and increases its salinity. Moreover at high latitudes, the formation of sea-ice also increases the salinity of sea water[2]. In the North Atlantic Ocean, the water becomes so dense that it begins to sink down through less salty and less dense water and the current becomes a deep water current.

As the Gulf stream moves away from the Atlantic coast into the North Atlantic, it starts to form meanders or eddies at the interface with cold water (Figure 2). These meanders show a strong temporal variability and can create warm and cold core rings, when the meanders are bypassed[3].

In the southern hemisphere, there is a cold current called *Falklands current* which flows northward along the Atlantic coast of Patagonia as far north as the mouth of the Rio de la Plata. Unlike the Gulf stream, this current extends all the way to the sea-floor.

Figure 1: Gulf stream and Falkland currents locations on the map of SST in January 2015.

Question 4

The plume of warm water with low salinity (and hence less dense) water, which can be observed near the Brazilian/Guyana coast, originates from the mouth of the Amazon rivers and gets displaced northwards by the South Equatorial current, which flows from central Africa to Central America. The plume is almost absent in January and very visible in August. This can be explained by the fact that January is preceded by a period of low-

[2]This is known as brine exclusion: salt is expelled from the forming ice, because it doesn't fit into the crystal structure of water ice

[3]The analogy for rivers would be the formation of oxbow lakes (or "Bras mort" in French)

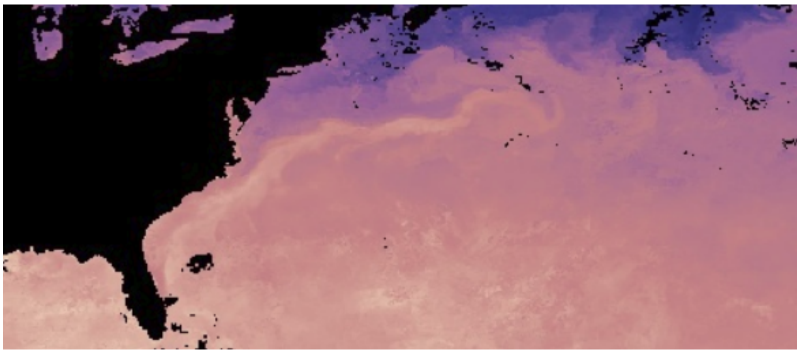

Figure 2: Example of Gulf stream eddies at the cold/warm SST interface, during Summer 2017.

flow in the Amazon (Nov-Dec), whereas August is preceded by a period of high flow (Jun-Jul).

Other similar (though not as strong) signatures can be seen e.g. in Eastern India at the mouth of the Ganges (plume visible in August at the end of the monsoon season) and in Western Africa (mouth of the Congo and Niger), this time with the plume visible in January.

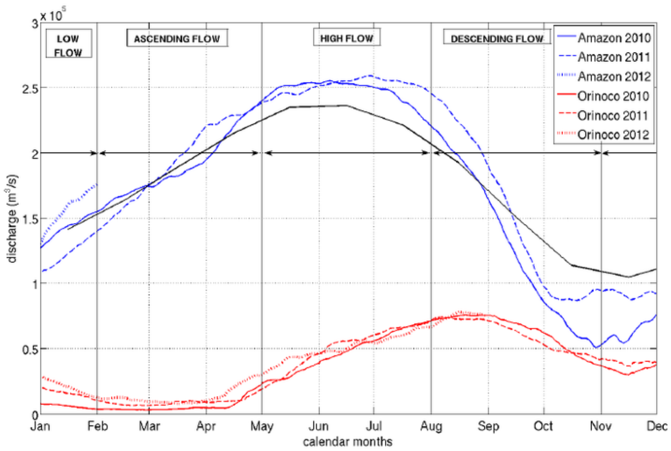

Figure 3: Monthly discharges in the Amazon (in blue) during 3 years of observations. Source: https://www.researchgate.net/profile/Nicolas_Reul/publication/255954490/figure/fig3/AS:297684989693956@1447985040771/Figure-5-Amazon-blue-and-Orinoco-red-River-discharge-cycles-measured-respectively.png

Question 5

Sea surface salinity follows mainly the global evaporation and precipitation patterns. In the subtropical regions, evaporation rates are high because of high temperatures and strong solar radiation. These latitudes also correspond to weak precipitation. High evaporation and low precipitation implies that salt gets more and more concentrated within the surface sea water. Near the equator, evaporation rates decrease because of the decreasing solar radiation caused by extensive cloud cover. Instead, precipitation rates strongly increase because most of the moisture evaporated in the subtropical regions is advected towards the equator. This cause salinity to increases in the tropics. At temperate latitudes, the same reasoning can be applied.

Then density is influenced not only by salinity, but also by temperature. As sea surface temperature covaries with latitude, the first order trend is decreasing temperature and increasing density with increasing latitude. The range in temperature change is larger than the range in salinity change, allowing this effect to dominate. In addition, regions with sea ice experience brine exclusion, which increases the salinity of the water.

Question 6

As MODIS is a passive remote sensing instrument, it can only perceive radiance emitted by the surface. Additionally, observations in the visible or infrared bands are strongly limited by cloud cover. The Aquarius/SAC-D mission relied on a radiometer sensitive to longer wavelengths in the microwave range, where cloud cover impact less strongly the signal emitted by the surface water. Concerning the monitoring of subsurface waters, passive and active sensors provide no/limited information. Only active sensors with very long wavelengths in the microwave spectra can penetrate the first upper meters of the oceanic surface. The monitoring of the ocean layers is still an open scientific challenge.