

SATELLITE-DERIVED SST/OCEAN COLOUR AND THE NORTH ATLANTIC OSCILLATION: A CASE STUDY FOR THE NE ATLANTIC REGION

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Background

The North Atlantic Oscillation (NAO) is one of the most prominent and recurrent patterns of atmospheric variability in the mid to high latitudes of the Northern Atlantic (Hurrell et al., 2003). Since mid-latitude SST is mainly governed by atmospheric forcing, NAO is probably the main source of inter-annual variability of SST in the region.

Fluctuations in temperature and salinity, vertical mixing, circulation patterns and ice formation of the North Atlantic Ocean influenced by variations in the NAO have a demonstrated effect on marine biology through both direct and indirect pathways.

Data Source

Data was collected from Satellite images of Sea Surface Temperature (SST) and Ocean Colour (OC) from MODIS (Aqua);

- Monthly averages were determined for 12 areas (3x3 km²) in the NE Atlantic (Fig. 1):

- Aveiro
- Azores Current
- South Azores Current
- North Channel Faial – Pico
- South Channel Faial – Pico
- Condor
- Faial-Flores
- Gibraltar Offshore
- North Azores Current
- NW Faial
- S. Miguel - Santa Maria
- S. Miguel - Terceira

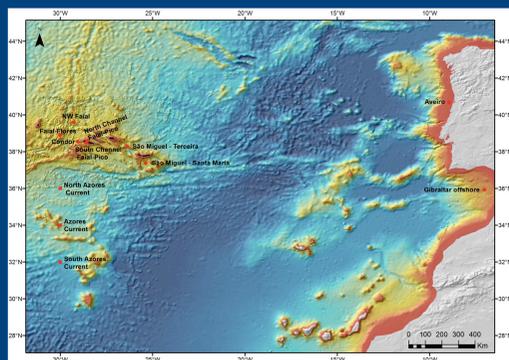


Figure 1: Bathymetry map of NE Atlantic, showing the Azores Archipelago, mainland Portugal and North of Africa. The continental shelf above 200 m depth is highlighted in red. Red dots indicate the areas of the masters chosen for the study (image courtesy by Ricardo Medeiros 2011 @ImagDOP).

The North Atlantic Oscillation (NAO) index used in this study was the NAO Station Based (DJFM), which is a winter (December through March) index of the NAO based on the difference of normalized sea level pressure (SLP) between Lisbon, Portugal and Stykkisholmur/Reykjavik (UCAR, 2011).

Sea Surface Temperature Time Series

In the Azores region the SST (Fig. 2) varies between 15 and 24 °C while in the mainland Portugal (mPT) it varies between 14 and 21 °C. Monthly mean SST peaks during August/September. The lowest temperatures are achieved during March in the Azores, and in February in the mPT. During the warm season, waters around the Azores are in average about 2 °C higher than around the mPT, and in some years (e.g. 2002, 2005, 2007, 2008) this difference can reach almost 4 °C. The average difference of 2 °C between the regions maintained during the cold season, can also slightly exceed 2 °C (like in 2004, 2005, 2006, and 2009).

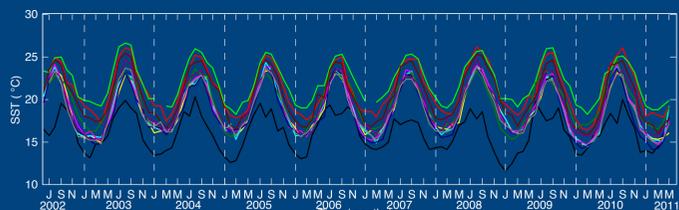


Figure 2: MODIS-derived SST monthly average variation for the 12 areas in study.

During 2010-2011, particularly during the cold season, the water temperatures dropped by about 1 - 2 °C in the Azores, while in mainland Portugal both the minimum and the maximum temperatures slightly increased.

Chlorophyll-a Time Series

The same pattern is not evident on Chlorophyll-a concentrations (Fig. 3). The Azores waters are clearly less productive than the upwelling regions at the mainland Portugal. Satellite-derived monthly Chlorophyll-a concentrations vary in the Azores region between 0.08 and 0.3 mg m⁻³ and in the mPT between 0.2 and 0.75 mg m⁻³ (up to 1.4 mg m⁻³ in March 2009). In both regions, the highest Chlorophyll-a concentrations are observed during spring, while the lowest are observed during summer. In the Azores region the second (autumn) bloom is often observed, which is not characteristic for the mPT. Instead, at the mPT a weak summer increase in Chlorophyll-a is often detected.

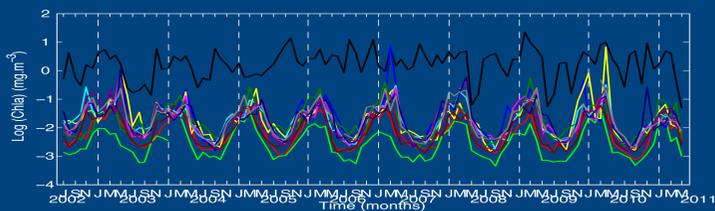


Figure 3: MODIS-derived Chlorophyll-a monthly average variation for the 12 areas in study.

SST and Chlorophyll-a Anomalies

During the ten-year period, positive and negative SST anomalies have been alternating, with a periodicity of around 2 years. For the last 12 months, all areas in the Azores region have showed consistently the most negative SST anomalies in the period of study (Fig. 4 – top) although the same pattern is not observed in the continental regions (Aveiro and Gibraltar).

Between 2006-2007 and 2008-2009 periods, SST anomaly was not interchanged with a negative anomaly. Both times showed two positive anomaly periods in a row, coinciding precisely with strong shifts in the NAO index (the first being from a negative NAO phase to the most positive NAOI observed in the period of study and the second from that period to what end up by being the lowest NAOI for the whole period).

As for Chl a, alternate positive and negative anomalies are also observed although not as evident as in SST. Continental regions (Fig.4 – bottom left) show higher monthly variability while the Azores region (Fig. 4 bottom middle and right) seasonal variation is most evident.

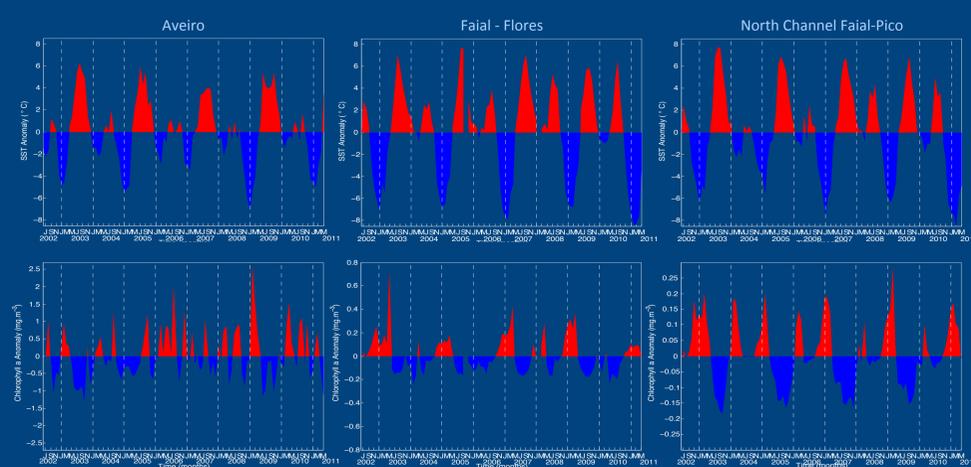


Figure 4: MODIS-derived SST (top) and Chlorophyll-a (bottom) monthly anomalies for the 3 areas in study: Aveiro (left), Faial-Flores (middle) and North of the Azores Current (right).

Apart from the 2 periods mentioned above, there is a agreement between negative Chl-a anomalies and positive SST phases. The opposite is also verified.

Intra-annual variations

Spectral analysis showed SST variability to be dominated by the annual and semi-annual cycles (Fig. 5 – left), the amplitudes increasing to the north. At mainland Portugal the amplitudes of both cycles are low. On an annual time-scale this is a result of reduction of the summer temperature peak by seasonally intensified coastal upwelling, which, in turn, is a result of the northward shift and local intensification of the trade winds in summer.

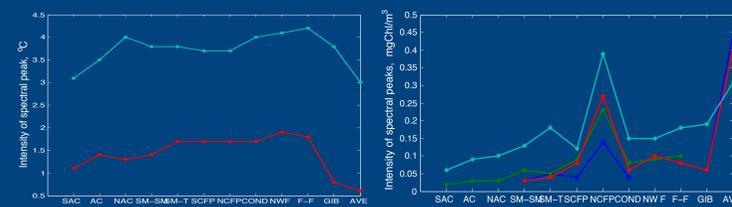


Figure 5: Intensity of Spectral Peaks for SST (left) and Chlorophyll-a (right) for the 12 masters. Areas are South of Azores Current (SAC), Azores Current (AC), North of Azores Current (NAC), S. Miguel – Santa Maria (SM-SM), S. Miguel – Terceira (SM-T), South Channel Faial-Pico (SCFP), North Channel Faial-Pico (NCFP), COND, NWF, F – F (Faial-Flores), Gibraltar, Aveiro. Lines correspond to 2-3 month (darker blue), 4-month (green), semi-annual (red) and annual (cyan) variability observed for the areas in the study.

In Chlorophyll-a (Fig. 5 – right), besides the annual and semi-annual cycles, 4-months and 2/3-months cycles are observed. All those cycles show clear intensification in the upwelling region of mainland Portugal. The observed intensification of the cycles north of Faial is presumably also generated by variations in the intensity of local upwelling.

Inter-annual Variations of SST and Chlorophyll-a vs. NAOI

Correlation (r) of SST and Chlorophyll-a winter averages vs. the North Atlantic Oscillation index (NAOI) are significant for some of the areas in study. The highest correlation between winter (JFMA) Chlorophyll-a and the NAOI is observed in the areas of Faial – Flores (Fig. 6 - top), NW Faial (Fig. 6 – middle) and S. Miguel (Fig. 6 – bottom): $r = 0.75, 0.63$ and 0.64 , respectively, all significant at a 95% level. The highest SST and NAOI winter months correlation was attained in the areas of NW Faial and of Faial – Flores ($r = 0.69$ and 0.76 , respectively, both significant at a 95% level).

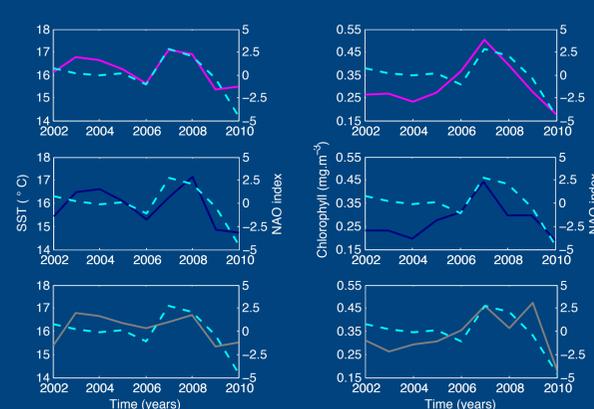


Figure 6: Comparison between Winter SST (left) and Chlorophyll-a (right) averages and NAOI for 3 areas: Faial – Flores (pink), NW Faial (dark blue) and S. Miguel – Terceira (grey). Winter averages were calculated for December through March (DJFM) and January through April (JFMA) for SST and Chlorophyll-a, respectively using monthly data. Dashed cyan line represents winter NAOI index.

High correlation is also observed in the areas of Faial – Pico Channel (North and South, with $r = 0.6$, significant at a 90% level). In mPT the highest correlation is observed not during winter months but on the annual averages of NAOI and Chlorophyll-a. For all other areas, no evident correlation among these two parameters was found.

Conclusions

- Besides a seasonal cycle, both SST and Chlorophyll-a show pronounced half-year peaks. Chlorophyll-a also varies at time-scales of 2-3 and 4 months.
- Intra-annual cycles in SST are reduced, while those in Chl are intensified in the upwelling regions.
- In the Azores region winter atmospheric forcing should play a significant role in inter-annual variation of SST and Chl, while in the mPT summer atmospheric forcing is also important.

References

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