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OCEANOGRAPHY AND CLIMATE CHANGE USING REMOTE SENSING AND GIS

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Abstract

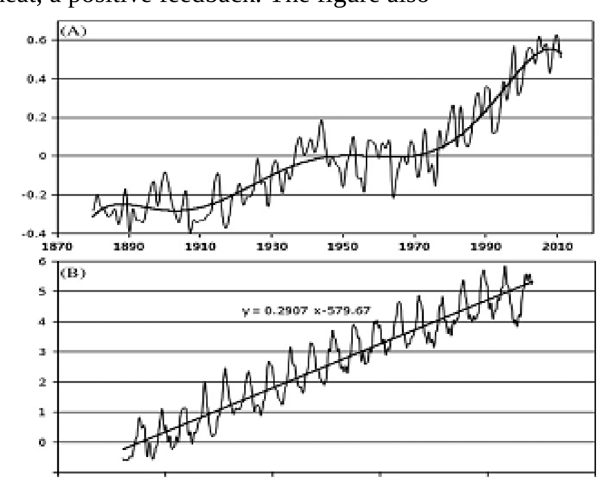
RS & GIS are vital tools in the present monitoring of frequent measurements of the Earth over decades with significantly high spatial resolution. Protectorate measurements of sea surface high temperature are a key component in the analyses of global warming and its effects. Altimeters and gravity missions such as GRACE are used to measure sea level rise at global and regional scales. A variety of satellite sensors (microwave and visible radiometers, scatterometers, SAR, gravity sensors, altimeters, etc.) are used for tracking the melting of sea ice and continental ice over the Polar Regions and Greenland. GIS techniques are used to monitor large scale natural climate oscillations such as El Niño and the influence of atmospheric teleconexions such as NAO. The present issue is the first one of a series of issues updating our knowledge of the RS & GIS observed variability related to climate change.

Introduction

What do we understand here about climate change? In this issue we focus on the rapid changes that have taken place during the last decades due to the increase of global temperature, mainly as a result of the increase in the concentration of greenhouse gases. This is also called contemporary climate change. Fig. 1(A) shows for example the increase of global temperature during the last century (Hansen et al., 2010). Since 1900, the temperature has experienced a net increase of _0.85 1C and about two-thirds of that amount has taken place since 1980. This means a warming rate two times more rapid than the secular mean. This period of rapid global warming is coincident with the beginning of satellite Oceanography (1978/79) and so there is an important record of satellite observations about climate change and its evolution. We analyze here the satellite observations of global warming and of two of the more important consequences over the physical ocean: (i) the sea level increase, observed using altimeters and gravity remote sensing (20 yr of observations); (ii) and the melting of the Polar Regions observed with passive microwave sensors and other type of sensors (33 yr of measurements). SMOS (2009) and Aquarius (2011) are able to measure salinity and evaporation/ precipitation, but do not provide long time series yet and are left out of this initial analysis. Our aim is not to review the subject exhaustively but to give the reader an introduction with updated measurements to this exciting and relevant topic, Satellite-observed Climate Change.

A. Global warming

Fig. 1(A) shows the global change of temperature since 1880 to present (2012). The time series is compiled and analyzed on a yearly basis by NASA-GISS using SST measurements from satellites, ships and buoys along with air temperature from meteorological stations (NASA, 2012; and references therein). Notable in the figure is the rapid warming that has taken place during the last 30yearsgivingameanratecloseto 0.2 10C per decade. Since 2000 we have seen in the GISS records nine of the ten warmest years (Table 1) which highlights the importance of the long term trends over the natural inter annual fluctuations.2010 is the warmest year and shows a positive anomaly of 0.61 1C (1200 km) with respect to the mean of the period 1951–1980. Fig. 2 presents the 2010 global distribution of temperature anomalies. The more pronounced increases take place in Polar Regions where the loss of ice by global warming increases the absorption of solar heat, a positive feedback. The figure also



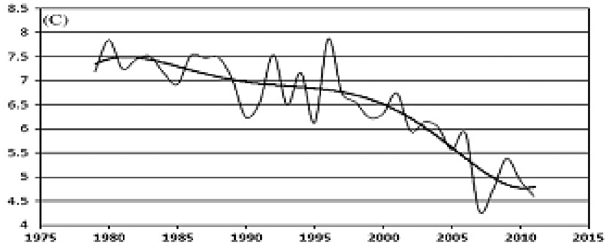


Fig. 1. Time series of (A) global land-ocean temperature e anomaly (C), (B) global sea level change (cm) and (C) Arctic Sea ice extent (millions km2) during September (non-seasonal sea ice). The figures have been elaborated using combined satellite and in-situ data from NASA-GISS, altimetry data from AVISO, and data from satellite microwave sensors from NSIDC.

Indicates that the 2010 warming took place during a transition in the Pacific from El Niño to the cool phase of La Nin˜ a. NASA has estimated that the El Niño of 1998 (El Niño of the Century) contributed globally to an increase of 0.2 1C (NASA, 2010). 2010 is therefore a notable year because it presents the highest increase of global temperature of the last 131 years when a major factor of natural variability (El Niño Southern Oscillation or ENSO) is in a cooling phase.

The consequences of global warming are diverse. Over the globe it is changing the water cycle and the patterns of precipitation, it is affecting the survival of species and it is spreading the distribution of tropical diseases. In the oceans, it is bleaching the coral reefs and it is displacing to higher latitudes the distribution of many fishery species. In the physical ocean it is melting the ice in Polar Regions and it is raising the level of the sea.

Table 1

Global Temperature Anomaly (°C)					
Smoothing radius: 250 km			*Smoothing radius: 1200 km*		
Order	*Year*	*Anomaly*	*Order*	*Year*	*Anomaly*
1	2010	0.58	1/2	2010/2005	0.61
2	2005	0.57	3/4	2007/1998	0.57
3	1998	0.54	5/6	2006/2002	0.56
4/5	2009/2002	0.52	7	2009	0.55
6	2003	0.51	8	2003	0.54
7	2006	0.50	9	2011	0.50
8	2004	0.47	10/11	2004/2001	0.48
9	2001	0.46	12	2008	0.43
10	2011	0.44	13	1997	0.40
11	2008/1997	0.41	14	1995	0.38
12	1995	0.37	15	1990	0.35
13	1990	0.34	16/17	2000/1991	0.34
14	1999	0.33	18/19	1999/1988	0.32
15	2000	0.32	20	1996	0.29
16/17/18	1991/1990/1988	0.30			
19	1987	0.26			
20	1996	0.24			

Top 20 warmest years in the NASA GISS records by rank for the period 1880–2011. The table has been elaborated using GISS Global Maps from GHCN v3 Data with a smoothing radius of 250 km and 1200 km (see Fig. 2). The global temperature anomalies (1C) are relative to the mean of the base period 1951– 1980 and are calculated from January to December. When considering the rank between years, we have to take into account that the uncertainty of the measurements (0.05 1C; Hansen e tal., 2010) can be larger than the difference adjacent anomalies.

B. Sea level rise

Fig. 1(B) presents the global sea level rise since 1993 to present (2012). It has been estimated using combined data from the altimeters Topex-Poseidon (1992–2005), Jason-1 (since 2002) and Jason-2 (since 2008) provided by AVISO (CLS). The altimeters allow measuring the sea level and its variation not only in coastal regions, as with tidal gauges, but all over the planet, thanks to the global coverage of satellites (Cazenave and Nerem, 2004; Cazenave and Llovel, 2010). The altimetry results, before and after removing the seasonal signal, gives a mean sea level increase of 2.9 mmyr_1. The rate increases to 3.2 mmyr_1 after applying the correction of 0.3 mmyr due to the earth deformation caused by glacial isostatic adjustment (GIA; Peltier, 2009). There are several reasons behind the sea level rise, and the relative importance of each contributing factor changes with time. The contribution of the thermal expansion for the period 1993–2007 has been estimated to be 30% of the total sea level rise, and the contribution of the melting of land ice _55% (Cazenaveetal.,2009; Cazenave and Llovel, 2010; Church et al., 2011). These authors indicate that the recent acceleration of glacier melting and the loss of ice from ice sheets have increased the melt of land ice to 80% of the total rise of sea level. The analyses include not only altimetry measurements but also temperature/salinity profiles (measuring the thermosteric and the halosteric contributions) and gravimetric measurements from GRACE (measuring the mass variation and GIA)[11].

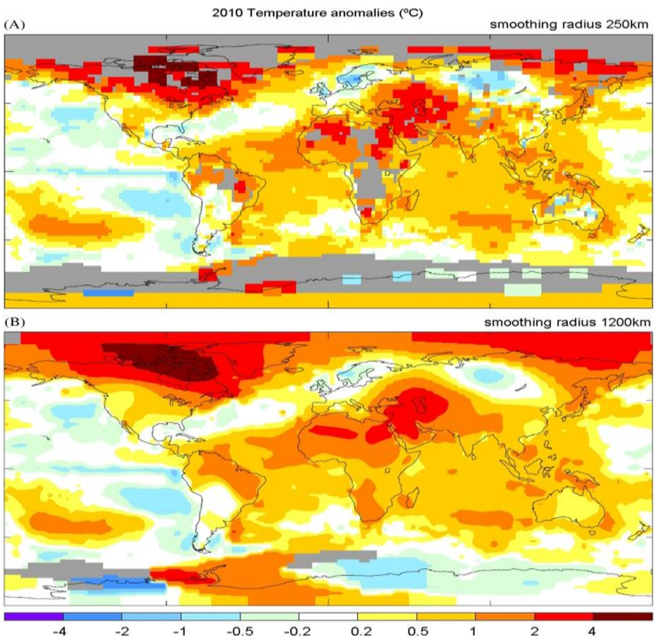


Fig. 2 Global map of temperature anomalies

The global coverage of the satellites allows elaborating global maps of sea level tendency that have shown that the increment is not uniform (Lombard et al., 2005, 2009). In some regions there are pronounced increases while in others there are decreases. A pronounced decrease has been described for example in the central Mediterranean Sea. The sea level has increased above average in the southern Indian Ocean, the western region of the Pacific, the North Atlantic around Green- land and the Southern Ocean (Fig. 3). The major contributor to these differences is non-uniform thermal expansion though other processes like salinity variations and ocean circulation changes also give rise to regional differences (Cazenave and Meyssignac, 2012; Willis and Church, 2012). The melting of the glaciers and ice sheets is also leading to an uneven sea level rise (Mitrovica et al., 2009). Parts of the observed regional patterns are due to the natural climate variability that fluctuates with time making part of the regional trends transient (Meyssignac et al., 2012). We have analyzed in Table 2 the mean sea level trends for the different oceanic regions during the period 1992– 2011 (_20 years). The largest departures from a linear trend take place in the Black Sea and the Mediterranean Sea, two semi-enclosed seas. In these regions the 20 yr altimeter record (Fig. 4) shows an oscillation with a maximum near 2000 and a minimum near 2007.

The consequences of sea level rise for the coastal regions include periodic flooding, salinization of the estuaries, contamination of water, erosion of beaches and storm surges.

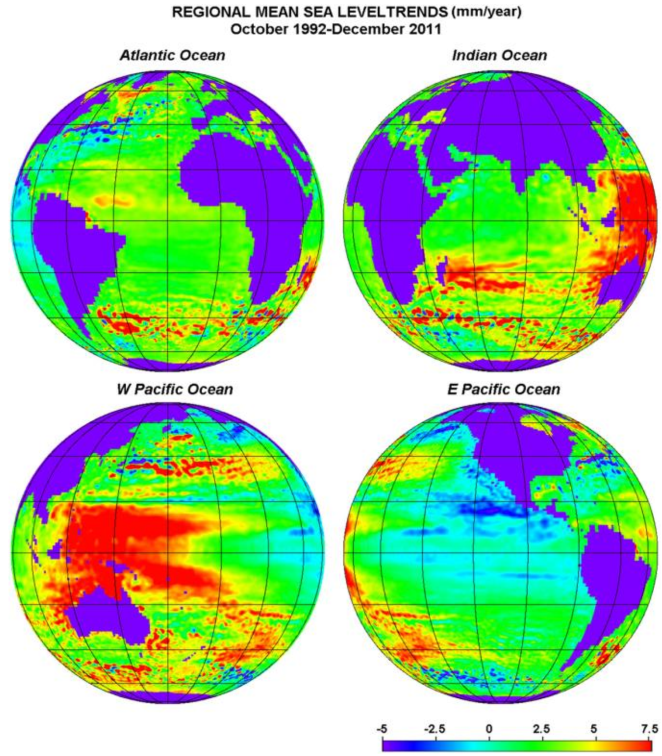


Fig. 3: Regional Mean Sea Level Trends

Nicholls et al. (2011) have analyzed the global distribution of land and population in relation to the rise of the sea level. According to these authors a rise of 2 m could displace globally 187 million people. Sea level rise has created a new type of refugees, the climate change refugees as reported in the Pacific islands of Vanuatu by UNEP (2005). In the Kiribati islands, more than 110,000 people will need to be reallocated. The Maldives, in the Indian Ocean, with a population over 300,000 people is also extremely sensitive to sea level rise. In the highly populated. Atlantic coast of North America a hotspot of accelerated sea level rise has been described recently. Here sea level rise superimposed on storm surge and

Linear tendency lines of Sea Level change in the different oceanic regions of the world for the period 1992- 2011(20 years).Produced using AVISO altimetry data corrected for seasonality without GIA adjustment The largest departures from a linear trend takes place in the Black Sea and the Mediterranean Sea, two semi-enclosed seas(r2:0.08and0.18respectively).

Table 2

Oceanic region	*Linear tendency line*	*Mean sea level increase*
N Atlantic Ocean	$y=0.239x-1.136\ r^2=0.78$	$2.39\ mm\ yr^{-1}$
S Atlantic Ocean	$y=0.316x-1.414\ r^2=0.85$	$3.16\ mm\ yr^{-1}$
N Pacific Ocean	$y=0.237x-0.755\ r^2=0.78$	$2.37\ mm\ yr^{-1}$
S Pacific Ocean	$y=0.264x-0.753\ r^2=0.76$	$2.64\ mm\ yr^{-1}$
Indian Ocean	$y=0.368x-1.751\ r^2=0.87$	$3.68\ mm\ yr^{-1}$
Black Sea	$y=0.389x-2.428\ r^2=\mathbf{0.08}$	$3.89\ mm\ yr^{-1}$
Mediterranean Sea	$y=0.236x-1.298\ r^2=\mathbf{0.18}$	$2.36\ mm\ yr^{-1}$

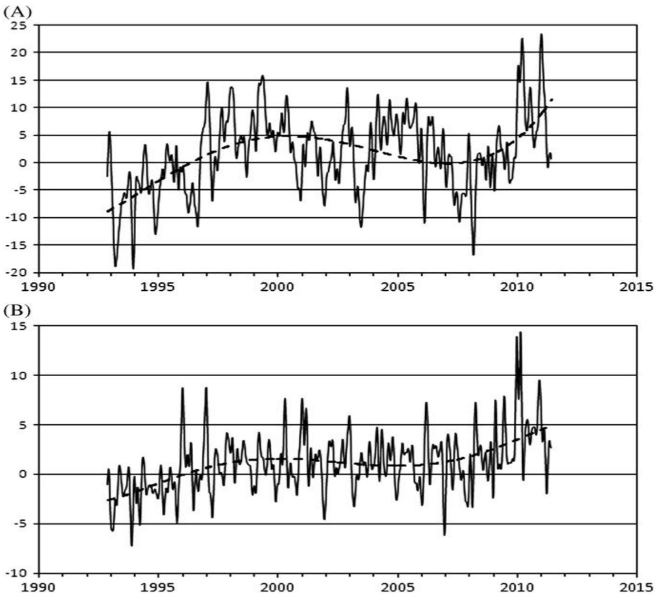


Fig.4: Sea Level Change (cm) in (A) The Black Sea and (B) The Mediterranean Sea (1992- 2011).
wave run-up will increase the vulnerability of coastal cities to flooding (Sallenger et al., 2012).

Melting of the Polar Regions and Greenland

The Polar Regions are among the most sensitive regions to climate change. Fig. 1(C) shows the drastic reduction in the extent of the perennial sea ice of the Arctic region from 1979 to present. The figure has been elaborated using satellite micro wave data from the National Snow and Ice Data Center (NSIDC; Fetterer et al., 2002). The extent of the non-seasonal sea ice of the Arctic region is decreasing at a mean rate of 0.85 million km2 or12% extents per decade. The minimum extents took place in September 2007 when it decreased to 4.30 million km (Fig. 5). That represented are duction of 40% with respect to the mean extent of the period 1979–2000 (pink line). The extent of the thickness or multi-year component of the sea ice is declining even faster (15%perdecade) making more vulnerable the non-seasonal sea ice cover as revealed also by satellite measurements (Comiso, 2012). Some researchers believe that the region could be free of sea ice during summer in 25 years (Wang and Overland, 2009).

The melting of the Polar Regions has other consequences in addition to the rise of the sea level. For example the decrease of the Arctic ice can decrease the population of the polar bears that live and rear over the Arctic sea ice. The reduction of Arctic ice can also have consequences over the currents of the North Atlantic. In the seas of Greenland, Norway and Labrador the sinking of dense and salty waters link the warm waters of the Gulf Stream with the cold deep waters of the thermohaline circulation.

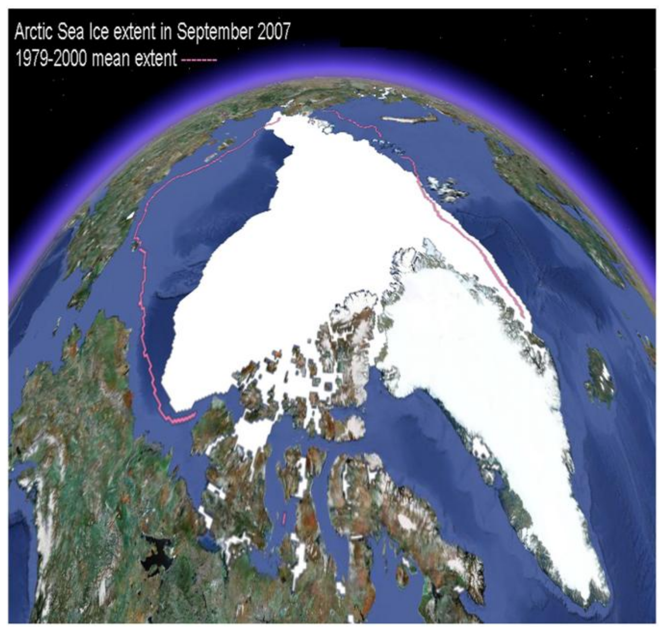


Fig.5: Extent of the non seasonal Arctic Sea ice during September 2007 produced using data from NSIDC (National Snow and Ice Data Center).

The increased melting of Arctic ice could increase the amount of fresh water in the region slowing the sinking of the waters and thus slowing the thermohaline circulation. Satellites measuring sea surface salinity (SSS) such as SMOS and Aquarius/SAC-D could be expected to measure the freshwater flux in key areas of the North Atlantic.

Natural climate variability

The global increase of temperature, the rise of the sea level and the melting of ice in the Polar Regions are also influenced by the natural variability that needs to be considered in order to quantify the anthropogenic signal of the climate. The role of the natural variability is observed for example in the Arctic region where researchers have shown with remote sensing a response of the sea ice to the Arctic Oscillation (AO, Rigor et al., 2002). In Antarctica, El Niño/La Niña cycle redistributes the regional sea ice (Kwok and Comiso, 2002; Rind et al., 2001). Away from the Polar Regions, Fig. 6 shows for example the extraordinary change in sea surface temperature and sea level anomaly for the North Atlantic Ocean following an abrupt change of the North Atlantic Oscillation or NAO (Garcia-Soto and Pingree, 2012). The natural variability is not only relevant in relation to how much climate change is attributed to anthropogenic or to other factors, but the anthropogenic warming itself can also influence the natural variability making the separation more difficult. Yeh et al. (2009) has predicted for example a five-fold increase of the Central-Pacific-El Niño with respect to the Eastern-Pacific-El Niño under global warming due to a flattening of the Equatorial Pacific thermocline. In this special issue we have therefore added a final section that analyzes with satellite measurements large-scale oceanic oscillations such as El Niño and the influence of atmospheric teleconections like AO and NAO.

New research

The topics of this and subsequent issues include but are not limited to the following ones:

a) Global warming and its effects on regional weather patterns.
b) Melting of ice over the Polar Regions and Greenland.
c) Sea level rise and changes of ocean circulation.
d) Climate change effects on biological productivity.
e) Natural climate fluctuations and multidecadal variability.

Conclusion

In this paper the change between the Central Pacific El Niño and the Eastern Pacific El Niño flavors using satellite measurements and a model and show that the different flavors (CP and EP El Niño) relate to a contrasted Equatorial Kelvin Wave (EKW) activity. A variety of satellite sensors (microwave and visible radiometers, scatterometers, SAR, gravity sensors, altimeters, etc.) are used for tracking the melting of sea ice and continental ice over the Polar Regions and Greenland. GIS techniques are used to monitor large scale natural climate oscillations such as El Niño and the influence of atmospheric teleconexions such as NAO.

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