CLIMATE-RELATED CHANGE OF SEA LEVEL OBSERVED WITH SATELLITE ALTIMETRY

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Long-term changes of sea level cause challenging concerns for people living in coastal areas. These changes occur mainly due to the variations of the seawater density and the amount of water in the ocean. Recent advances in satellite altimetry provided high-accuracy regular and nearly global measurements of sea level. Due to earth rotation, large-scale surface currents (gyres) in the open ocean away from the equator are determined by the spatial distribution of sea surface heights (so-called geostrophic currents) which can be derived from satellite altimetry data. Our results show that the sea levels and the associated velocities of the surface geostrophic circulations in the subtropical and subpolar gyres of the North Atlantic and North Pacific Oceans varied out of phase with each other in the decade 1992-2002. This is probably a natural phenomenon.

The evolution of satellite altimetry from Seasat (1978) to TOPEX/Poseidon (1992) and Jason-1 (2001) has led to the present ~5 cm state-of-the-art overall accuracy in determination of the sea surface height (SSH). SSH can be measured by estimating the range R from the satellite to the sea surface (Fig. 1). Radar altimeters onboard the satellites transmit a short pulse of microwave radiation at high frequency towards the sea surface. A part of this pulse is reflected back to the altimeter after hitting the sea surface. The round trip time t for the pulse to travel from the satellite to the sea surface and back to the satellite scaled by the speed of light c (at which electromagnetic waves travel in vacuum) yields the range $R=ct/2$. After correcting the range measurements for atmospheric refraction and sea state biases, SSH is obtained by subtracting the range from the satellite altitude, which is precisely determined relative to a reference ellipsoid. Subtracting from SSH an equipotential surface called the geoid (detemined by mass distribution of earth and sea

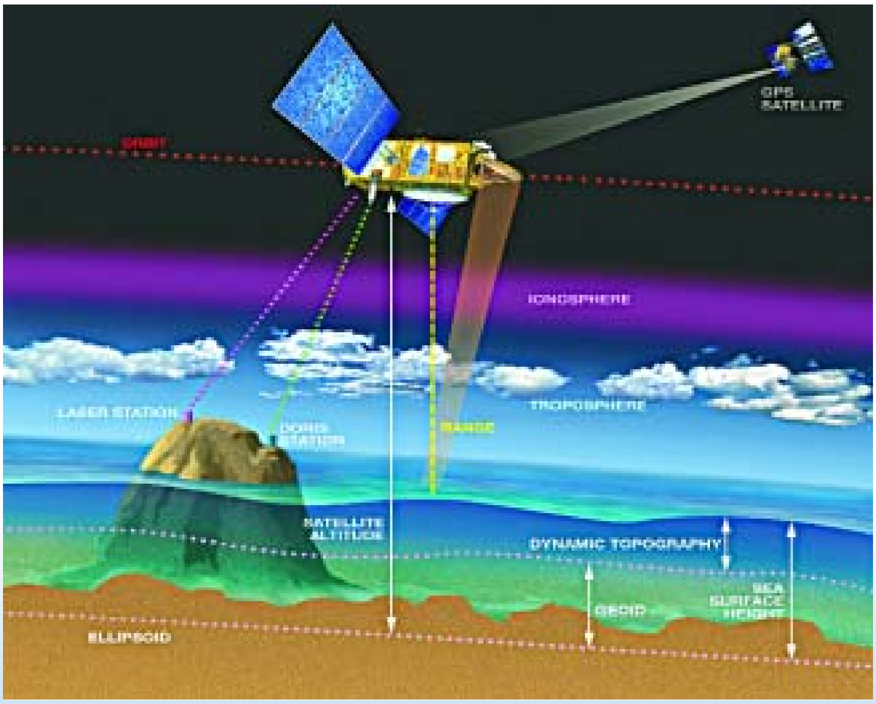

Fig. 1: Principle of sea surface height measurements with satellite altimetry. The picture is borrowed from http://www.aviso.oceanobs.com.

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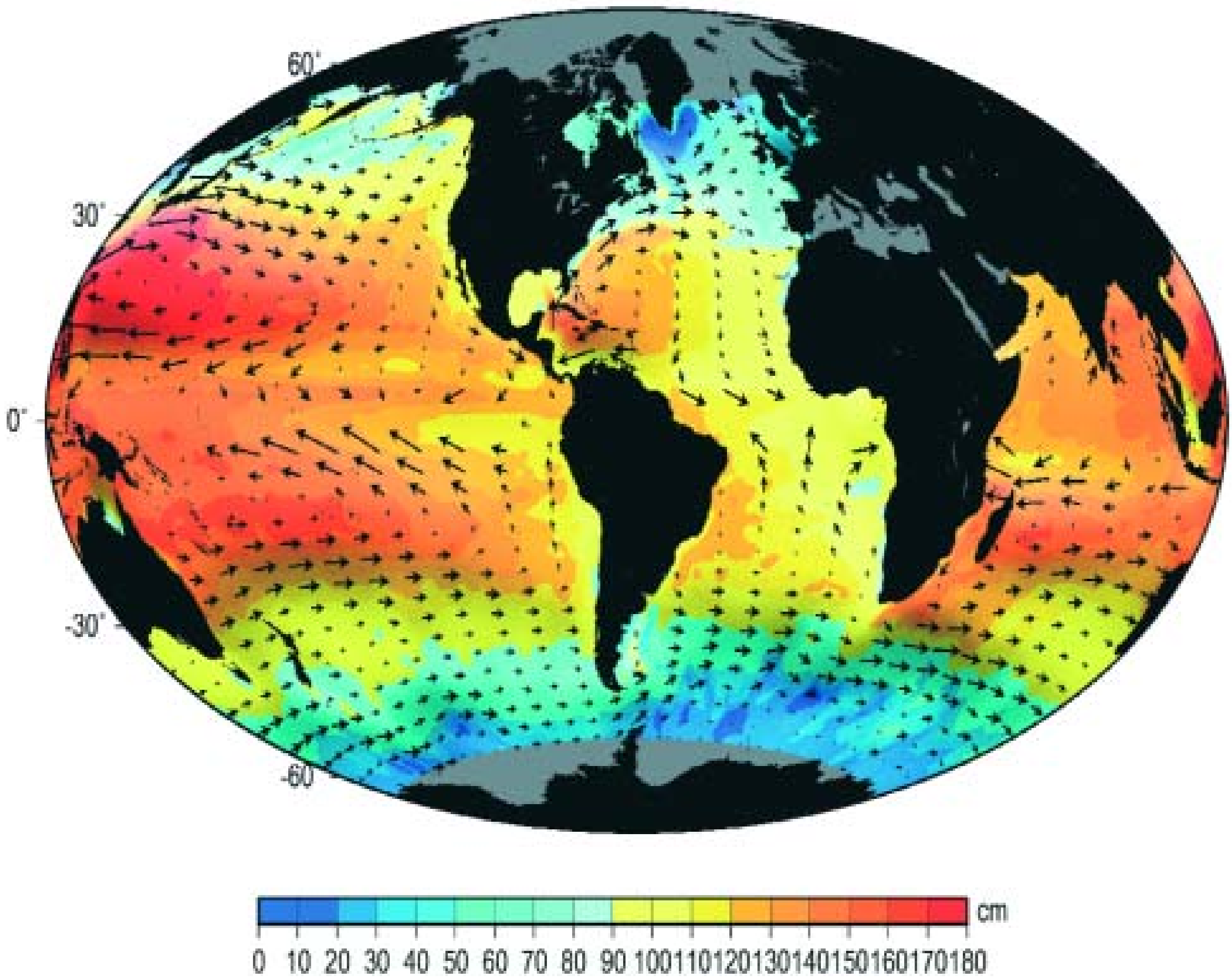

Fig. 2: Global mean dynamic topography and surface geostrophic circulation. Colors indicate mean sea level, see legend. The picture is borrowed from http://www.aviso.oceanobs.com.

floor) gives dynamic topography - the sea surface made up by dynamic effects in the ocean (Fig. 2): wind stress, geostrophic currents, effects of the earth's rotation, seasonal changes, etc. The advantage of satellite altimetry over in situ measurements is that satellites provide nearly global observations every 10 days. This allows studying oceanic processes with spatio-temporal scales from oceanic eddies with diameters in the order of 50 km and larger phenomena.

Here we present decadal trends of sea level and surface geostrophic circulation in the extra-tropical North Atlantic (NA) and North Pacific (NP) estimated by linear regression from satellite altimetry data for the period from December 1992 to November 2002 (Fig. 3). The observed trends in the NA are substantially different from those in the NP. In the subpolar and eastern areas of the NA sea level was rising while in the areas of the Gulf Stream and the North Atlantic Current (NAC) it was decreasing. In the NP the decadal increase of sea level occurred in the Kuroshio extension, in the North Pacific Current (NPC), and in the Western Subarctic Gyre. At the same time sea level decreased in the Bering Sea, Alaska gyre and near the Californian coast. The decadal trends in geostrophic velocities in the NA suggest that the anticlockwise circulation in the subpolar gyre (Labrador Sea and Irminger Basin) and clockwise circulation in the subtropical gyre declined between 1992 and 2002. The geostrophic currents in the Labrador Sea and Irminger Basin decelerated with 2 – 3 cm/s. A slowdown of the geostrophic velocities also occurred in the NAC and in the Gulf Stream. The northern wall of the NAC associated with the Subarctic Front as well as the NAC flow around the Newfoundland Rise decelerated with 2 – 4 cm/s. In contrast to the NA, the decadal trends in geostrophic velocities in the NP showed a strong intensification of the geostrophic flow of the Kuroshio extension around 35°N with 10 cm/s and a 2 – 8 cm/s increase of geostrophic velocities in the NPC. The anticlockwise circulation in the subpolar Alaska gyre intensified with an increase in geostrophic velocities in the Alaskan Current of about 2 cm/s. Intensification also took place in the California Current where the southward geostrophic flow increased by about 1 – 2 cm/s. An anomalous clockwise geostrophic flow developed in the Western Subarctic Gyre suggesting a deceleration of the Alaskan Stream along the Aleutian Islands and its possible deviation south-westwards.

Thus we conclude that throughout the decade 1992-2002 the subtropical and subpolar gyres of the NA decelerated while the subtropical and subpolar gyres of the NP intensified. A deceleration of a subtropical gyre is associated with a decrease in sea level, an intensification with an increase in sea level. The reverse is the case for the subpolar gyres; i.e. a deceleration of the subpolar gyre is associated with an increase of sea level (intensification with a decreasing sea level). Previous studies have shown that from 1955 to 1996 sea level was decreasing in the subpolar NA and subtropical NP while it was rising in the subtropical NA and subpolar NP. Therefore, we propose that decadal trends observed in 1992-2002 may be a part of gyre-scale interdecadal oscillations that are not necessarily related to the anthropogenic global change, and thus may be of a natural origin. Based on our observations, we suggest that the subtropical and subpolar gyres of the NA may vary out-of-phase with the subtropical and subpolar gyres of the NP. When the former spin down (sea level rises in the subpolar gyre and decreases in the subtropical gyre), the latter spin up (sea level rises in the subtropical and decreases in the subpolar gyres) and vice versa. We look forward to confirm or refute this hypothesis with longer altimetry records in the future .

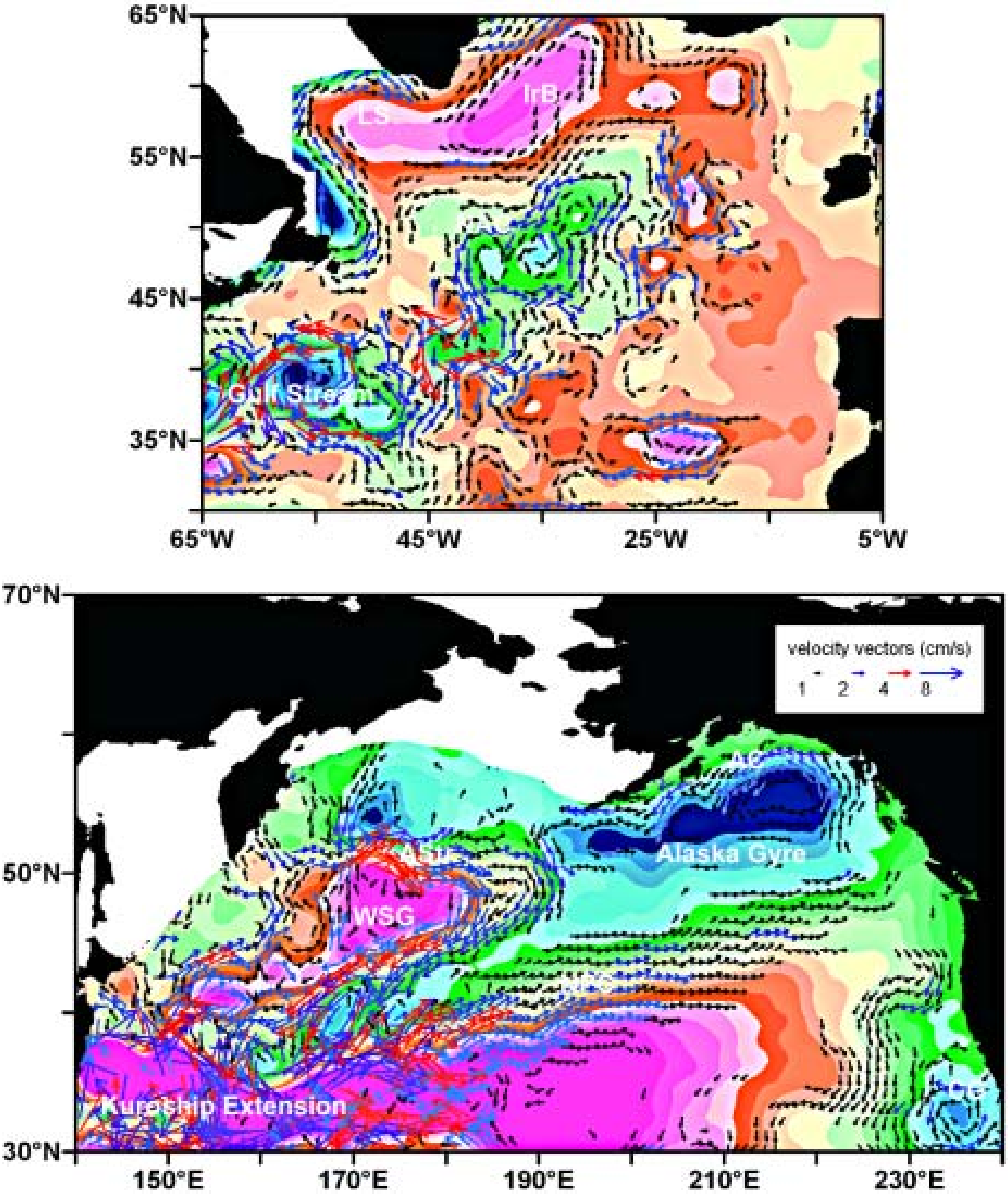

Figure 3: Maps of the geographical distribution of sea level trends (cm) and the derived geostrophic velocity trends (cm/s) over December 1992 – November 2002 in the North Atlantic Ocean (top panel) and in the North Pacific Ocean (bottom panel). The colors indicate the difference in height in cm. Arrows indicate the directions of the surface currents.
Abbreviations: North Atlantic: NAC – North Atlantic Current, IrB – Irminger Basin, LS – Labrador Sea
North Pacific: NPC – North Pacific Current, CC – California Current, AC – Alaska Current, AStr – Alaskan Stream, WSG – Western Subpolar Gyre.