Sea level budget study of the Japan Sea: GRACE, Argo, and Satellite altimetry

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In this study, we confirm the closure of sea level budget coming from barystatic (increase of the water mass due to inflow of land water) and steric (thermosteric and halosteric change of sea water density) variations, using the three sensors, i.e. GRACE (Gravity Recovery and Climate Experiment) satellite gravimetry for barystatic changes, Argo floats for steric changes, and satellite altimetry (TOPEX/POSEIDON and Jason series satellites) for total sea level changes.

Sixteen years have passed since the launch of GRACE by NASA/DLR in 2002. GRACE has been used mainly for studying water redistribution on land, but it is becoming possible to discuss the time-variable gravity in the ocean. Here, we focus on the seasonal gravity change of the Japan Sea. To analyze the gravity changes, we used of the Stokes' coefficients with degrees and orders complete to 60 from the Level-2 RL-5 data released by CSR, University of Texas, and applied the de-striping filter and the Gaussian filter to reduce short-wavelength noises. We added back the coefficients in GAD files to GSM files to restore oceanic and atmospheric mass changes. The time series of gravity at the center of the Japan Sea showed that there is clear gravity drop in summer months with the amplitude of ~5 cm. We are going to justify this by using the other two sensors, Argo and satellite altimetry.

Nearly 4,000 Argo float buoys have been deployed in the world-wide ocean, and they have been providing temperature and salinity profiles down to the depth of 2,000 meters. We downloaded the monthly profile data at grid points from the Met Office Hadley Center observation datasets (www.metoffice.gov.uk), and calculated thermosteric sea level changes of the Japan Sea since 2005, when they deployed enough number of the floats in the worldwide ocean. For the altimetry data, we downloaded the average monthly sea level of the Japan Sea from the data center of NOAA (www.star.nesdis.noaa.gov).

Tide gauge data at the Tobishima and Okushiri (both in Japan Sea) observatories are known to show the amplitude ~4 times as large (~20 cm amplitude) as GRACE with the maximum occurring in August and September. This is nearly consistent with the satellite altimetry data since in the Japan Sea. The discrepancy between the observed sea level changes and the GRACE barystatic changes reflects the steric changes. Thermosteric changes inferred from the Argo data also indicate seasonal changes reaching ~20 cm in amplitudes. This suggests that the substantial part of the sea leve changes comes from thermal expansion of warm water above the thermocline. By comparing the Argo and satellite altimetry data, we found that the thermosteric peak comes slightly earlier than the satellite altimetry peak. Therefore, by subtracting the Argo data from the altimetry data, we get a minimum barystatic sea level in early summer. This is consistent with the GRACE data, i.e. seasonal sea level budget closes in the Japan Sea. This also demonstrate the robustness of the observed seasonal barystatic sea level changes there.
As reported earlier, the occurrences of disastrous earthquakes along the eastern margin of the Japan Sea concentrate in summer months. Considering that diurnal ocean tides have small amplitudes in the Japan Sea, this clear seasonality may reflect the annual change of ocean bottom pressure and subsequent change of the Coulomb Failure Stress of the plate boundary thrust faults along the eastern margin of the Japan Sea.

Figure caption: Comparison between the seasonal mass change of the Japan Sea by combining the satellite altimetry and in-situ thermosteric changes from Argo float (left), and GRACE gravimetry (right). Their coincidence suggests the closure of the seasonal sea level budget of the Japan Sea.

Keywords: GRACE, Argo float, Satellite altimetry, Japan Sea, Seasonal change