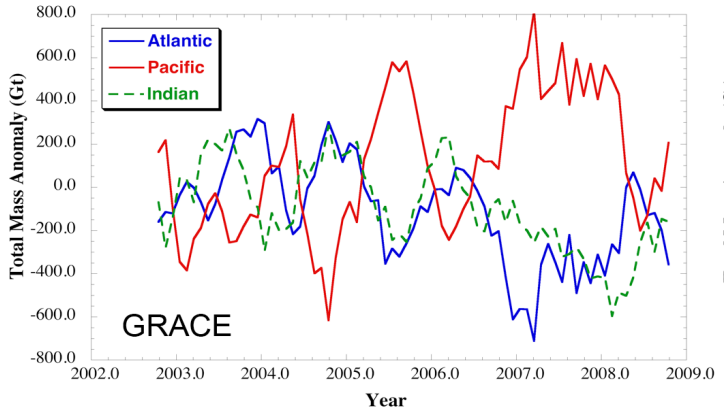
GRACE Reveals Long-Term Mass Redistribution within the Ocean

Gravity and Mass redistribution in the Earth system: The Earth's gravity field is the result of the mass distribution in the complete Earth system, including solid Earth, oceans, atmosphere, ice, land, and biosphere. Redistributing this mass in any of the Earth sub-systems changes the gravity field. The largest gravitational variations are caused by moving water mass from one place on the Earth to another, such as from the ice sheets of Greenland into the ocean.

The **Gravity Recovery And Climate Experiment (GRACE)** provides unprecedented measurements of temporal changes in the Earth's gravity field. This mission has a designed lifetime of 5 years, although it is currently in its 8th year of operation. GRACE has demonstrated that satellite gravity missions have a *unique* capability to measure ice-sheet and glacier mass loss or accumulation, terrestrial water storage change, and ocean mass variations. Measurement of net decreases in the masses of ice stored in Greenland, certain regions of Antarctica, and corresponding increases in ocean mass are examples that directly provide evidence of climate change impacts on global sea level rise. Satellite gravimetry is the only technology able to directly weigh the oceans and measure the variations in its mass. In addition to measuring a mean mass (sea level) increase of about 1.5 mm/year during the 8-year period, GRACE has demonstrated for the first time that there are large exchanges of water mass between the Atlantic, Indian, and Pacific Oceans on periods of 2-years and longer. The mass exchanges are the same size, or larger, than the yearly mass loss from Greenland and Antarctica, and as a consequence can make local sea level change significantly higher (or lower) over shorter periods than the long-term mean increase.

Internal Ocean Mass Redistribution: An Unknown Quantity in Long-Term Climate Change. The GRACE observations allow us to directly measure long-term mass exchanges between ocean basins for the first time. Such exchanges are driven by variations in atmospheric winds and ocean currents, which are expected to change significantly in a warming climate. While scientists have accepted that there are seasonal exchanges of mass between basins like the Atlantic and Pacific Oceans, there has been little evidence that these exchanges can be sustained for longer periods. Chambers and Willis (2009) have used GRACE data to demonstrate that these mass exchanges can last for 2-years and longer, and have peak amplitudes as high as the seasonal exchange. This internal mass redistribution can amplify or partially cancel local sea level rise compared to the global mean. With the short record from GRACE, it is too early to tell if these mass exchanges can last longer than 3 to 4 years, although some ocean models suggest they can last for several decades.



From early 2006 until early 2008, 700 Gigatonnes (Gt) of mass were transported from the Atlantic and Indian Oceans to the Pacific. This is enough to make sea level rise over this period nearly twice the mean rate in the Pacific, with a corresponding drop in the Atlantic sea level that completely masks the mean rate.

Reference: Chambers, D. P., and J. K. Willis ,2009, *J. Geophys. Res.*, **114**, C11008, doi:10.1029/2009JC005518.