Non-seasonal fluctuations of the Arctic Ocean mass observed by GRACE

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1. Outline
The non-seasonal signals are obtained by subtracting the monthly mean climatology. As suggested by an ECCO2 ocean data synthesis product, the non-seasonal variability of the mass-related sea level (bottom pressure or Ocean Mass - OcM) in the Arctic Ocean explains a large portion of the non-seasonal sea surface height variance (Figure 2). Time variable gravity observations from the GRACE satellites reveal strong non-seasonal fluctuations of bottom pressure in the Arctic Ocean with periods from 2 to 6 months and a record-high bottom pressure anomaly in February of 2011 (Figure 2). To examine the nature and driving forces behind these fluctuations we have (i) coupled GRACE measurements to concurrent wind forcing (Figures 3 and 4), (ii) revealed atmospheric and ocean circulation patterns characteristic for low and high Arctic OcM anomalies (Figure 5), and (iii) identified the sources of mass input responsible for large anomalies in 2011 (Figures 6-8).

2. Arctic Ocean Mass Changes in Relation to Wind Forcing
- The coupled Empirical Orthogonal Functions (EOF) analysis shows that the non-seasonal variability of the Arctic Ocean mass is strongly coupled to wind forcing (Figures 3 and 4). The first coupled zonal wind stress and OcM EOF mode (Figure 4) explains 56% of the covariance and the correlation between the corresponding principal component (PC) time series is 0.57.
- The first coupled meridional wind stress and OcM EOF mode (Figure 4) explains 73% of the covariance and the correlation between the corresponding PC time series is 0.68.
- The zonal wind pattern is related with a di-pole pattern of Arctic Ocean mass changes (Figure 3). Consistent with Ekmans dynamics, westerly wind intensification over the North Atlantic at about 60°N and over the Russian Arctic continental shelf breaks the ocean mass to decrease in the Nordic seas and in the central Arctic, and to increase over the Russian Arctic shelf. The time evolution of the zonal wind pattern is significantly correlated with the Arctic Oscillation index (r=0.52).
- Basin-wide Arctic Ocean mass fluctuations are correlated with northward wind anomalies over the northeastern North Atlantic and Nordic seas, and over the Bering Sea (Figures 4 and 5).

3. Atmospheric and Oceanic Circulation Patterns
- Positive (negative) Arctic Ocean mass anomalies are associated with anticyclonic (cyclonic) anomalies of the large-scale ocean circulation pattern (Figure 5b).
- Southward (northward) wind anomalies over the Nordic seas favor southward (northward) anomalies of the Ekmans slope current across the region and through the Fram Strait.
- Sverdrup dynamics over the Nordic seas does not explain the Arctic OcM variability, but it can be relevant south of 65N (see wind stress curl in Figure 5a).

4. Where does the water come from?
- Using the ECCO2 model, we show that the observed non-seasonal Arctic Ocean mass variability is mostly explained by the net horizontal wind-driven transports, and the contribution of freshwater fluxes is negligible (Figure 6a).
- The variability of the net inflow into the Arctic Ocean is mostly determined by the variability of the inflow through the Atlantic sector (Figure 6b). The correlation between the total inflow and the Atlantic sector inflow is 0.77, while the correlation between the total inflow and the Bering Strait transport is 0.1.
- The Atlantic sector and Bering Strait net transports partly compensate each other (Figure 6b). Correlation between them is -0.49.
- Transport anomalies across both the Atlantic and Pacific gateways were equally important for generating large Arctic OcM anomalies in February and November 2011 (Figure 7). The associated anomalies in atmospheric circulation are shown in Figure 8.

Acknowledgements. The ECCO2 model runs have been carried out at Jet Propulsion Laboratory, California Institute of Technology. GRACE ocean data were processed by Don P. Chambers, supported by NASA MEASURES Program, and are available at http://grace.jpl.nasa.gov. This research was funded by NASA Physical Oceanography program (grant number NNX11AE27G) and carried out at the NDAA Atlantic Oceanographic and Meteorological Laboratory and at Jet Propulsion Laboratory, California Institute of Technology.