# Accounting for gravitational attraction and loading effects on altimeter data and state estimates

**Rui M Ponte[1], Katherine J Quinn & Christopher G Piecuch[2]**

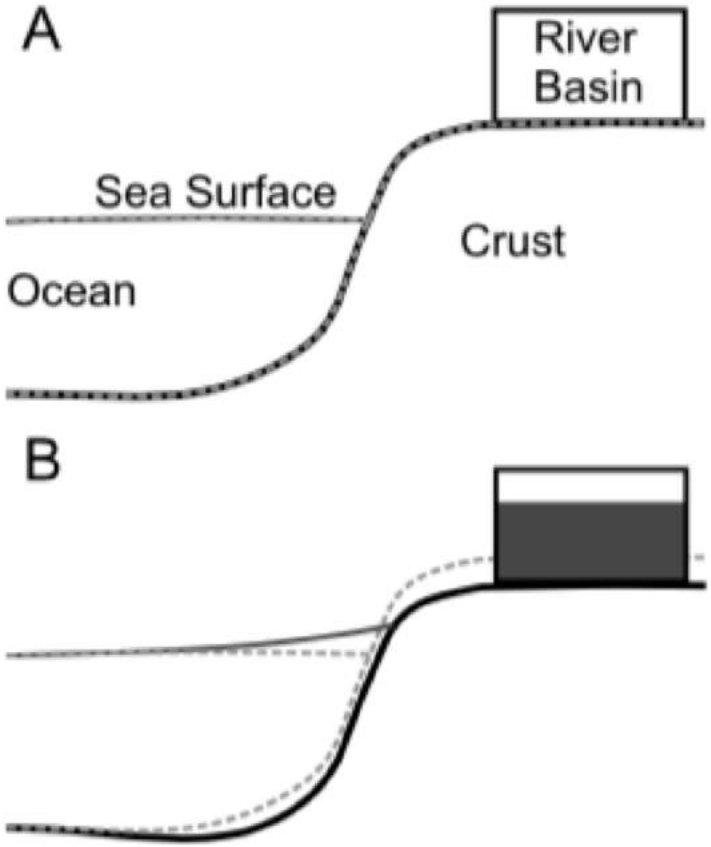
[1]Atmospheric and Environmental Research, Inc., USA

[2]Woods Hole Oceanographic Institution, USA

**ECCO Project Meeting**

**University of Texas at Austin, October 29-31, 2018**

# Gravitational and loading effects




Tamisiea et al. (2010, JGR)

- **Changes in the mass field over land, even without involving mass transfer to the oceans, affect sea level through the physics of gravitational attraction and loading (GAL):**
  - **Surface atmospheric pressure and distribution of air mass over land**
  - **Terrestrial water storage**
  - **Land ice (glaciers and ice sheets)**

# Motivation and outline

**At monthly and longer time scales, response to gravitational forcing associated with GAL effects is expected to be nearly static in nature, i.e., gradients in sea surface height (SSH) caused by GAL carry no dynamic significance**

- **How important are these static signals associated with GAL effects and what are potential problems for physical inference if not corrected for?**
- **Can one provide useful estimates of GAL effects on SSH and at what level of uncertainty?**

**Examine long-term trends associated primarily with changes in land ice at high latitudes, possible ways of properly accounting for GAL static signals when using altimeter data in state estimation**

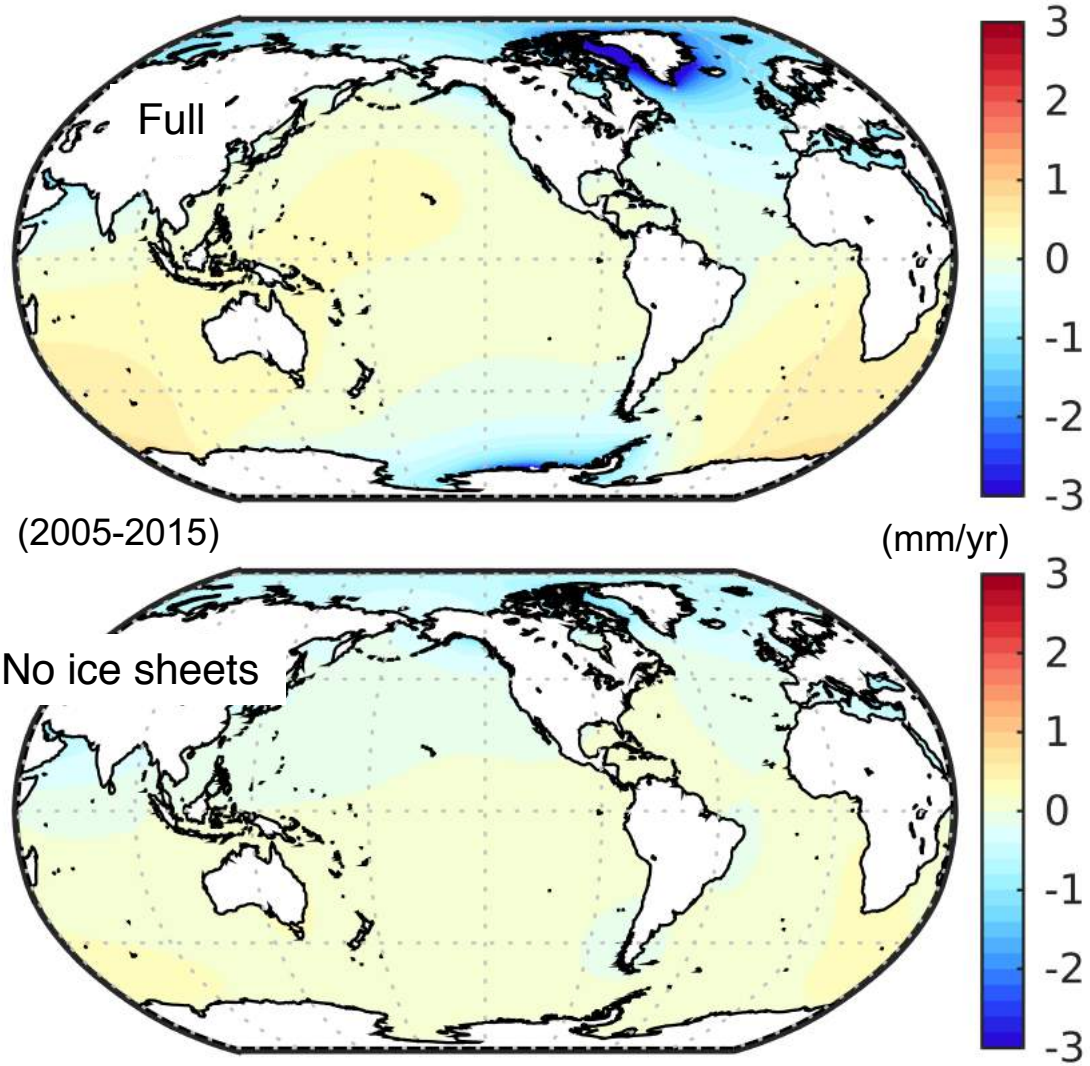
# Methodology

- Effects of land hydrology/ice from GRACE data (JPL mascon solutions)
- Effects of atmosphere based on ECMWF fields
- Sea Level Equation including rotational feedback to estimate changes in SSH (or absolute sea level, as seen by altimeter)
- Steric sea level estimates from Argo data (Scripps gridded product)
- Altimetric 1x1 degree grids from CSIRO with IB and GIA corrections
- Other ancillary fields (bottom pressure, deep steric height) from ECCO ocean state estimates

Details on calculations and results provided in

Ponte, Quinn & Piecuch (2018, *J. Atmos. Oce. Tech.*)

# GAL-driven trends in SSH

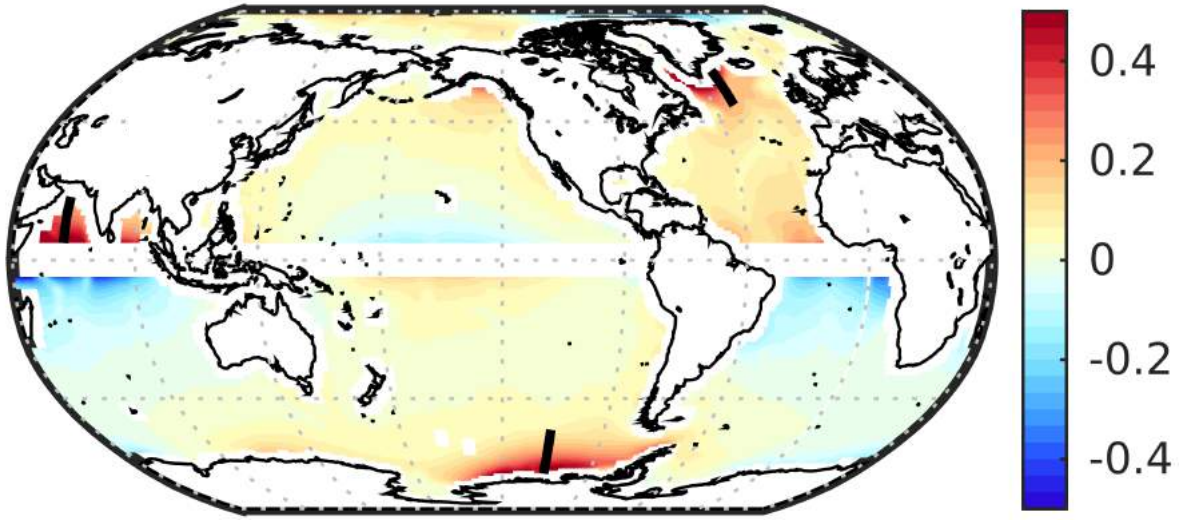



- **Typical effects of order 1mm/yr**
- **Larger (negative) trends near the ice sheets**
- **Strongest spatial gradients near Greenland**
- **Effects of atmospheric mass redistribution weaker (not shown)**

**Implications for geostrophic transports?**

# Errors in geostrophic transports

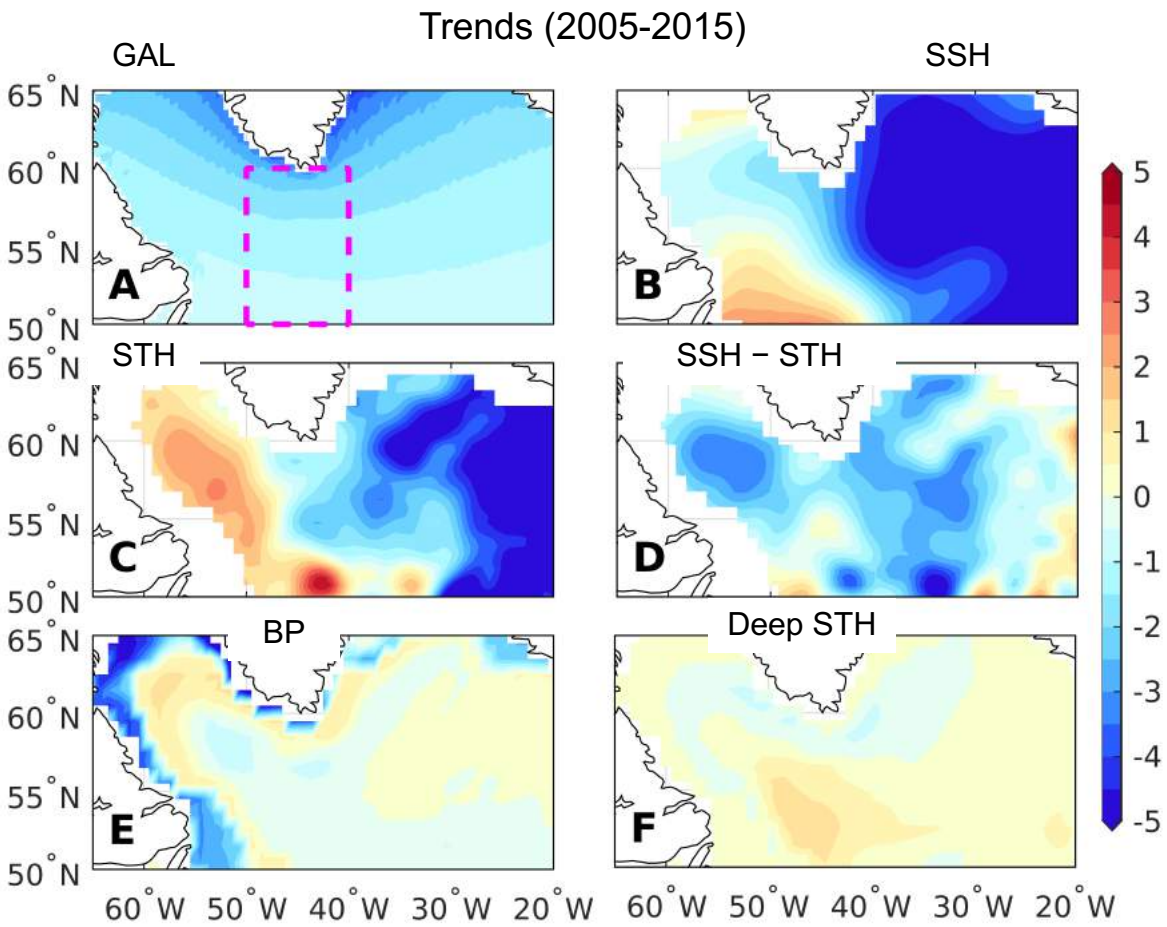
Decadal changes in zonal geostrophic transport per degree latitude (Sverdrups)




Based on SSH trends from GAL assuming they represent a depth-independent pressure gradient

- **Largest transport changes (~0.5 Sv) found near ice sheets and also in the tropics (e.g. Arabian Sea)**
- **Large spatial scales imply substantial accumulated errors (~ 5 Sv) across latitudinal sections in Southern Ocean, subpolar North Atlantic, Arabian Sea**
- **Magnitudes similar to decadal changes in circulation inferred from altimetric studies (e.g., Häkkinen and Rhines 2004; Hogg et al. 2015)**

# A closer look at subpolar NA



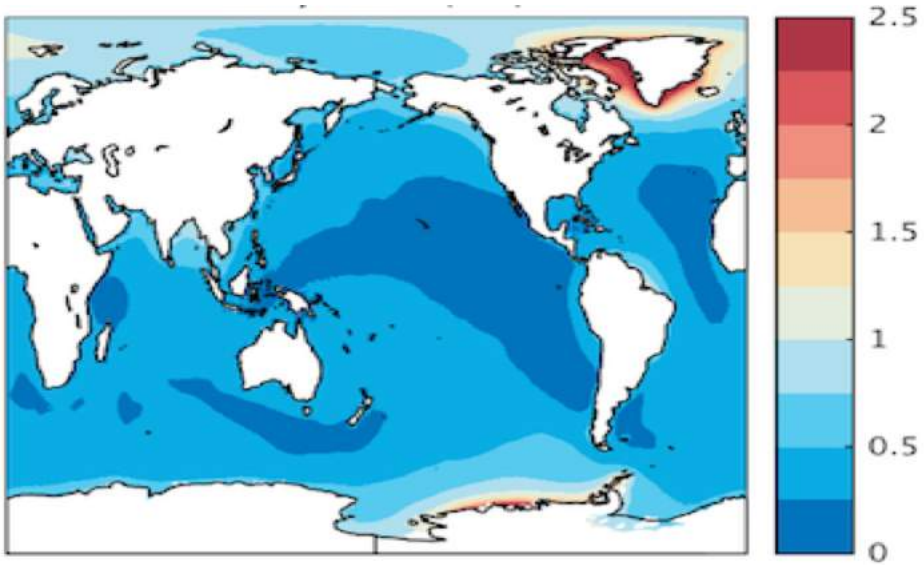

STH (steric height/Argo)
Deep STH (ECCO)
BP (bottom pressure/ECCO)

- **Trends in altimeter minus steric height residual (SSH − STH) have magnitudes comparable to GAL trends, even in presence of considerable noise**

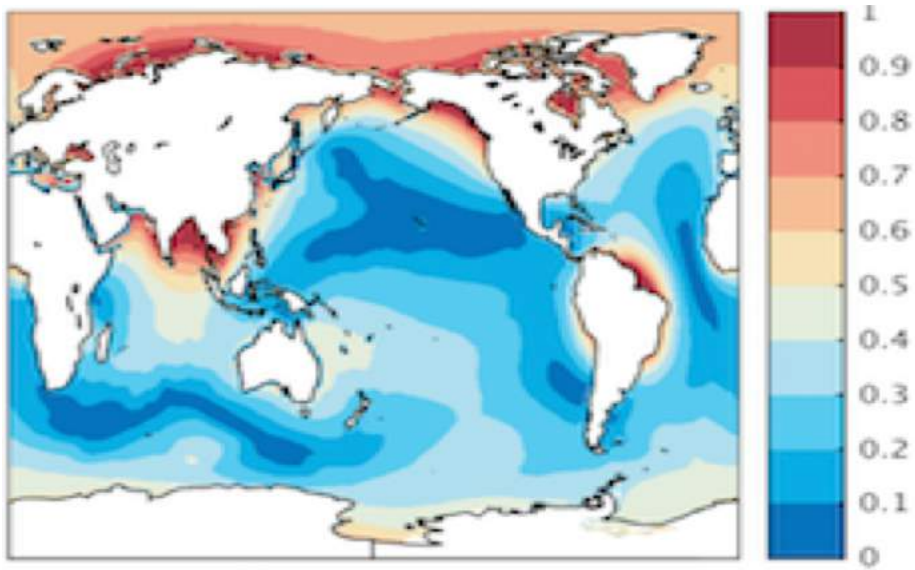
- **For mass, heat budget purposes, GAL trends are as large as deep steric or dynamic bottom pressure trends**

# GAL (other variability)

Standard deviation (cm)




Annual amplitude (cm)



# Dealing with GAL effects

**At the data level:**

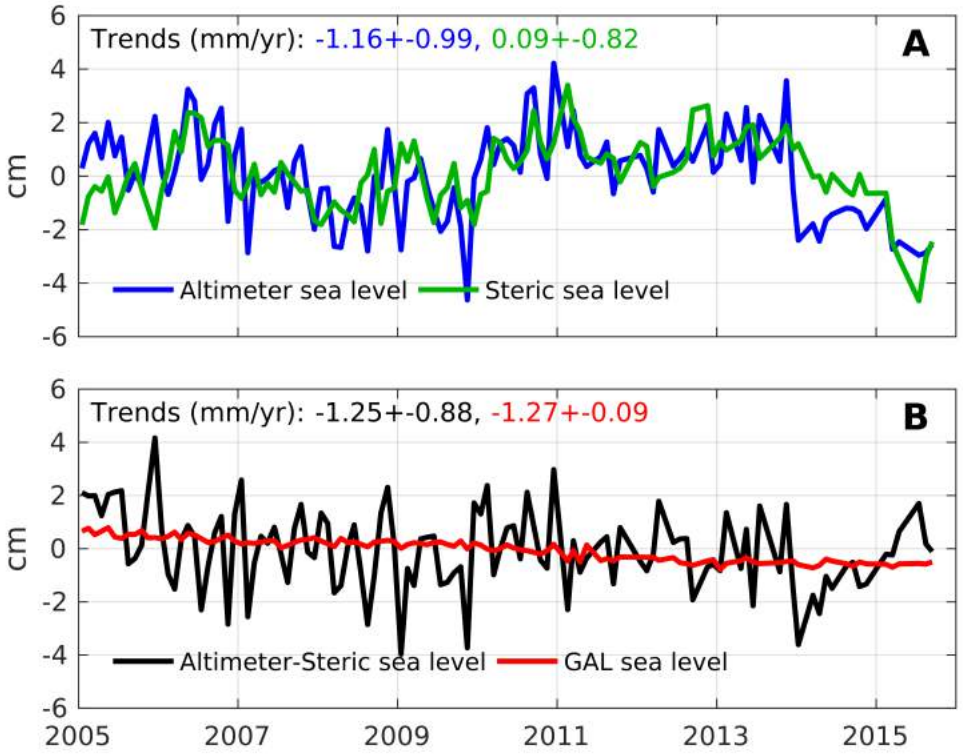
- **Calculate various estimates of GAL SSH variability (different input, model assumptions,…)**
  - **Satellite gravity (gaps, only since GRACE launch)**
  - **Hydrology models (omission errors)**
  - **Atmospheric effects weak but reasonably well determined**
- **Compare and assess underlying uncertainty in GAL fields**
- **Provide GAL correction, apply it to altimeter data, and constrain to corrected fields**

# Dealing with GAL effects

**At the model level:**

- **Account for missing physics and forcing in the model**
  - **Calculate gravitational forcing**
  - **Provide consistent freshwater flux forcing**
  - **Include self-attraction and loading physics in the model**
- **Constrain to uncorrected data**
- **Possible to include GAL forcing as a control field (as for other forcing controls)**

# Time series in subpolar NA




Time series of fields averaged over box south of Greenland (40-50W, 50-60N)

Annual cycles removed

- **Trends from GAL effects important for correct interpretation of altimeter, steric height records and sea level budgets**
- **GAL effects at monthly time scales weak compared to other variability**