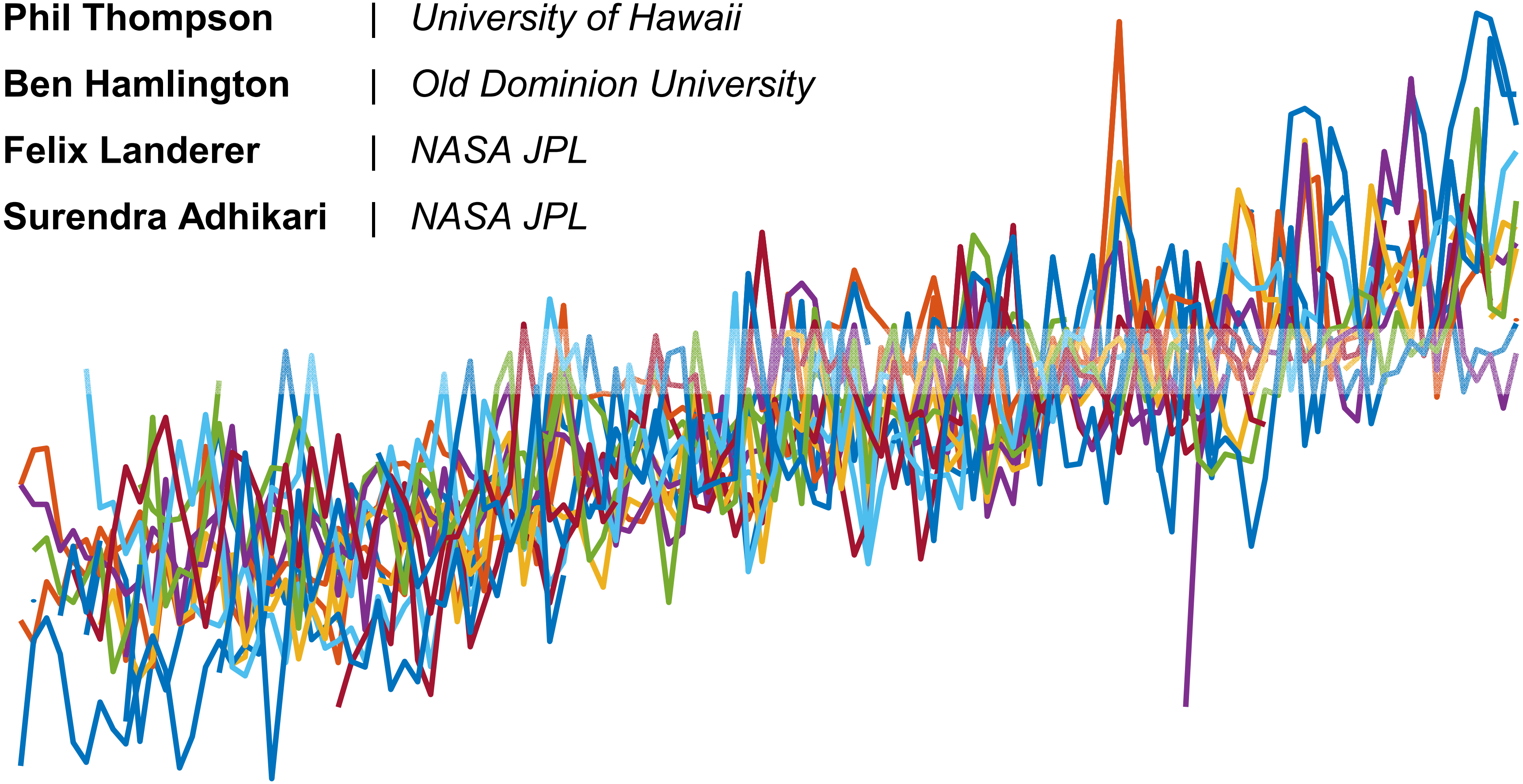
Are long tide gauge records in the wrong place to measure global mean sea level rise?

Phil Thompson | *University of Hawaii*

Ben Hamlington | *Old Dominion University*

Felix Landerer | *NASA JPL*

Surendra Adhikari | *NASA JPL*



November 1, 2016 | 2016 Ocean Surface Topography Science Team Meeting, La Rochelle, France

Background and motivation

- Averaging 20th century trends from small sets of long, high-quality TG records results in mean rates of rise around 1.5-1.8 mm/yr [e.g., *Douglas*, 1997, *Holgate*, 2007, *Spada and Galassi*, 2012].
  - EOF reconstructions produce similar 20th century global trends [e.g., *Church and White*, 2011; *Ray and Douglas*, 2011].

- More recently, a probabilistic estimate [*Hay et al.*, 2015] produced a 20th century global rate of approximately 1.2 mm/yr.

- If the lower global mean rates are correct, then the long, high-quality TG records must be in the “wrong place”.
  - Can this conclusion be supported?
  - What physical processes are responsible?

Tide gauge selection

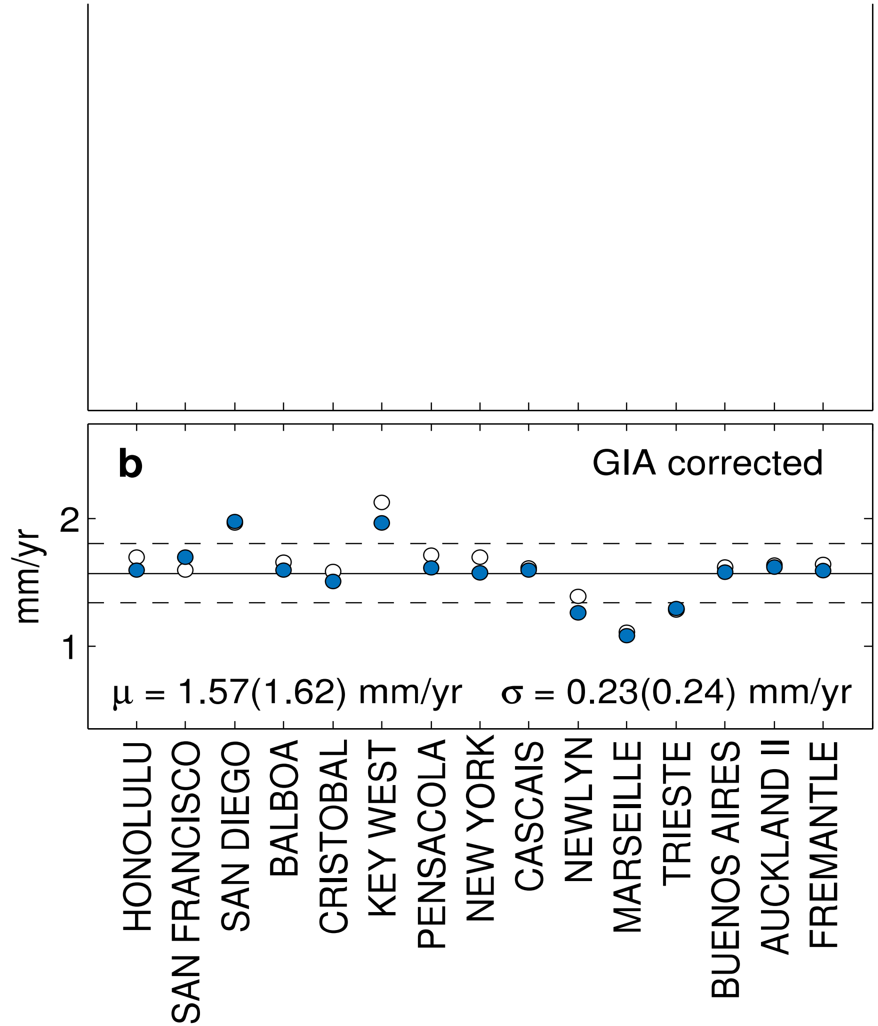
- Read more in the *GRL* article (doi:10.1002/2016GL070552)
- We selected 15 records that satisfy the following criteria:
  - At least 70 valid annual values during 1901-2000,
  - GIA corrections that are consistent across GIA models [Spada and Galassi, 2012],
  - No documented evidence of substantial non-GIA vertical land motion (VLM).

Tide gauge selection

- The set used here overlaps with sets of gauges used in similar analyses of long, high-quality records:
  - *Douglas* [1997] and *Mitrovica et al.* [2001] used 15 records with ≥70 valid annual means during 1901 – 2000; 13 included here.
  - *Holgate* [2007] used 9 records; all 9 included here.
  - *Spada and Galassi* [2012] used 11 non-Baltic/Black Sea records with ≥70 valid annual means during 1901 – 2000; 9 of them are included here.
- Is this the "best" or "optimal" set?
  - Even if not, this is certainly a set of very high-quality records.
  - We should be able to identify specific physical processes capable of reconciling the local observed rates with reconstructed global rates.

20th century rates from long, high-quality TG records

- Observed local rates show substantial scatter.
- Correcting for GIA substantially reduces the scatter and reduces the mean rate by ≈0.1 mm/yr.
  - ICE6G (blue), ICE5G (white)
- Can we reconcile the GIA-corrected local rates (mean ≈1.6 mm/yr) – on a physical basis – with a global mean rate substantially less than the mean rate from these observations?



Reconciling local and global rates

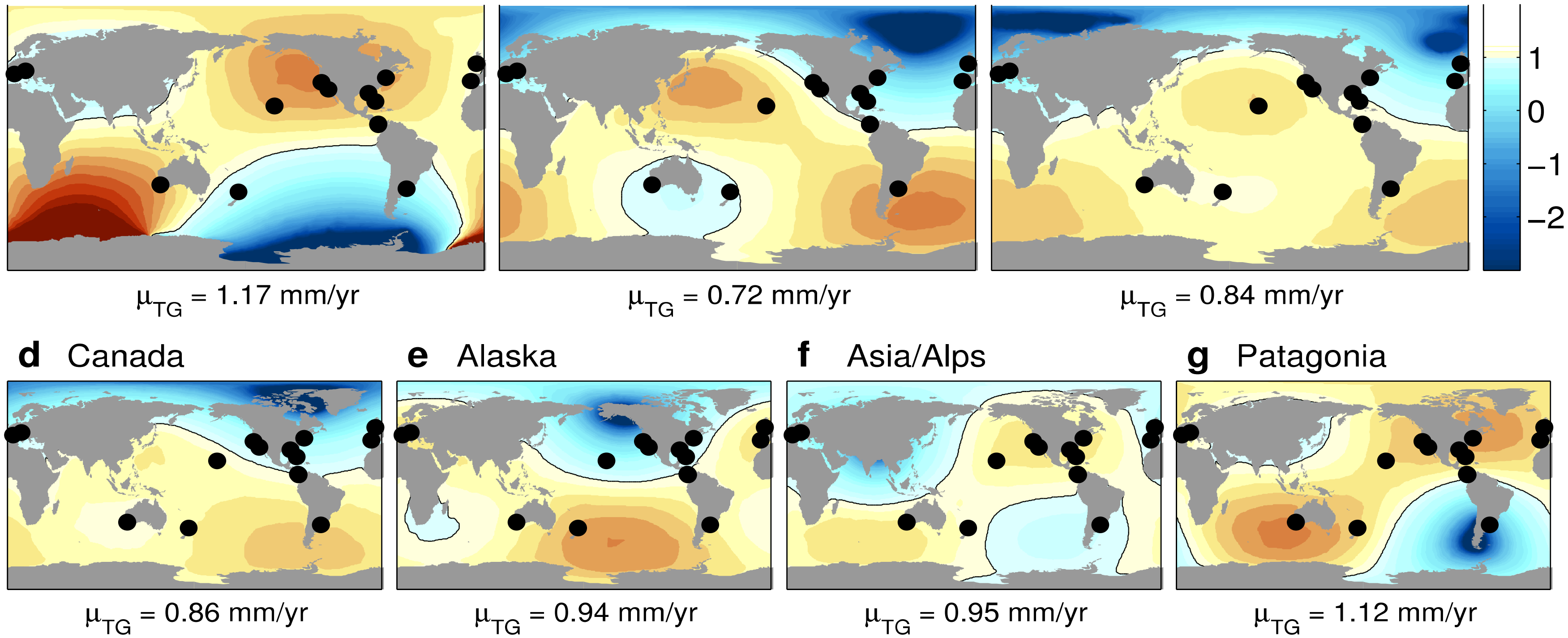
- Three leading-order processes that can account differences between local and global 20th century rates:
  1) Ice melt fingerprints
  2) Wind and ocean dynamics
  3) Non-GIA vertical land motion (VLM)

- VLM is the most difficult to address. In our paper, we …
  – address VLM issue by simply selecting gauges with no documented evidence of substantial non-GIA VLM.
  – focus on the effect of melt fingerprints and ocean dynamics.

- In this talk, I'll briefly discuss a more quantitative approach to VLM using GPS rates at the tide gauge locations.

Effect of ice melt fingerprints

- We used melt fingerprint produced by Surendra Adhikari at JPL (doi:10.5194/gmd-9-1087-2016) for the two major ice sheets and five groupings of glaciers and ice caps.
  - Normalized to 1 mm/yr mean; each affects TG mean differently.



Using the melt fingerprints

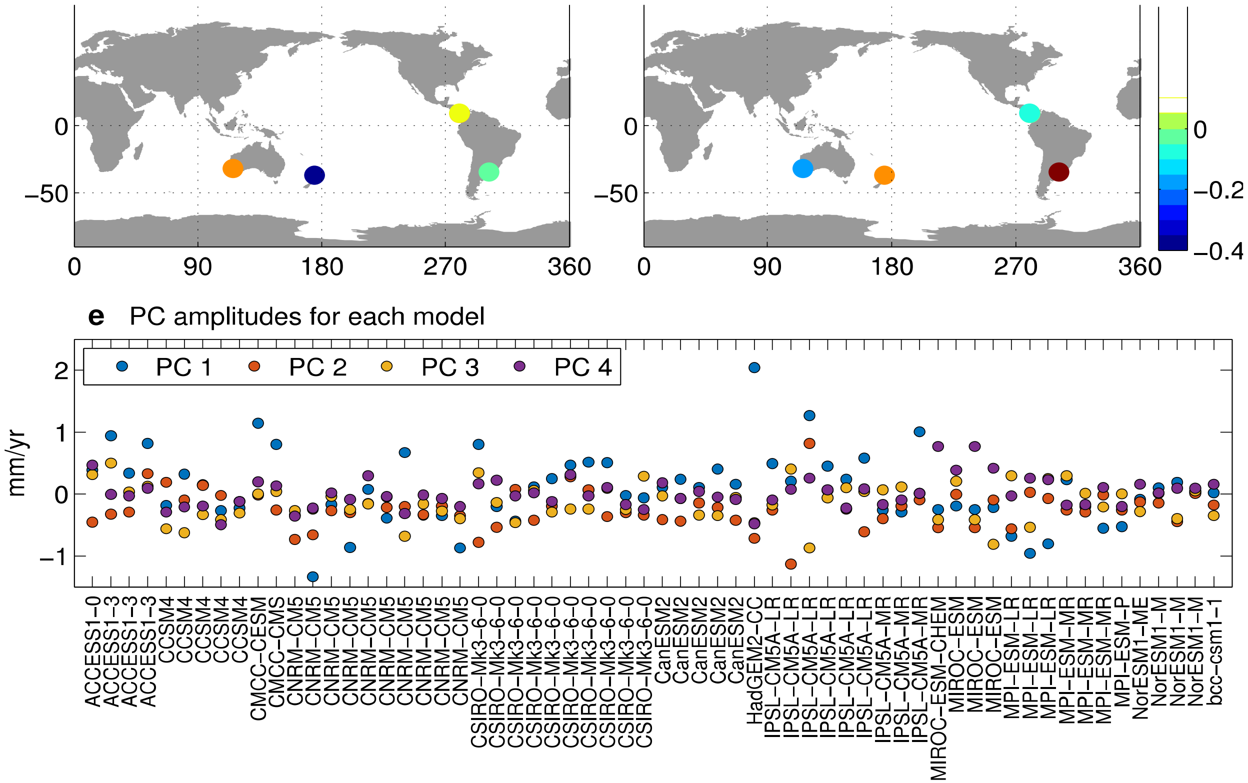
- We do not know *exactly* how much these sources melted during the 20th century, but there are some observational and model-based constraints (e.g., IPCC AR5, *Gregory et al.*, 2013, etc.).
  - More detail in the article.
- We used these constraints to create Gaussian probability distributions for the amplitude of each fingerprint pattern.
- We used the distributions in a Monte Carlo simulation.

Effect of ocean dynamics

- Lack of hydrographic observations early in the 20th century prevents robust estimates of spatial structure in dynamic sea level change during 1901 – 2000.

- Since we cannot know the *true* pattern of dynamic change, we use CMIP5 ensemble members to provide possible patterns.
  - We calculated dynamic sea level trends (the local trend minus the global mean trend) at the grid points closest to the 15 TG locations during 1901–2000 for 63 CMIP5 historical runs.
  - We then calculated EOFs of these trends using the ensemble member as the independent variable.
  - Creating linear combinations of all 15 spatial EOFs with randomized amplitudes effectively provides access to an infinite number of realizations for 20th century internal climate variability.

Dynamic trend EOFs from CMIP5



Standard deviation of the PCs

↓

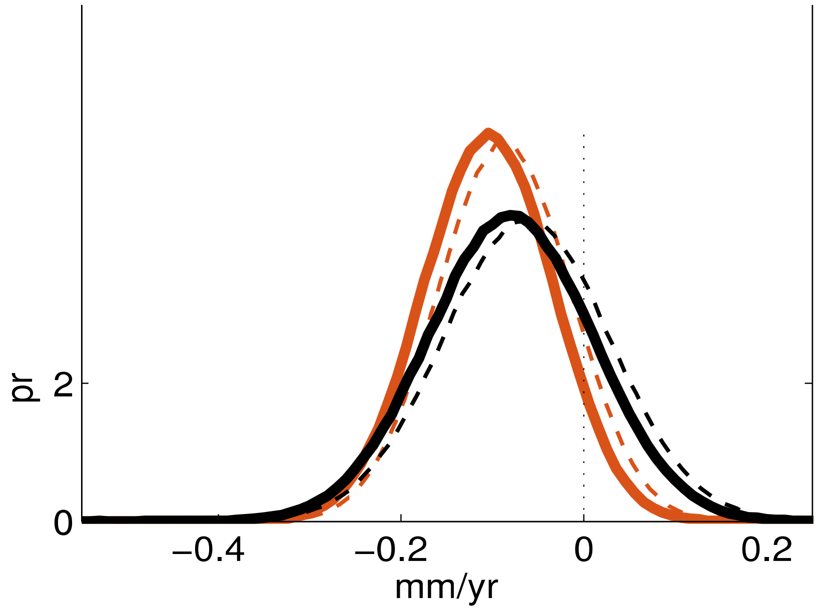
Probability distributions for the amplitude of each EOF.

Quantifying bias due to fingerprints and ocean dynamics

- We performed a Monte Carlo simulation (10^6 iterations):
  1) Draw values from the probability distributions for all 7 fingerprint patterns and all 15 dynamic EOFs.
  2) Create linear combinations of these patterns at the TG locations based on the random amplitudes.
  3) Calculate how much sampling bias occurs due to each individual realization of spatial structure in sea level change.

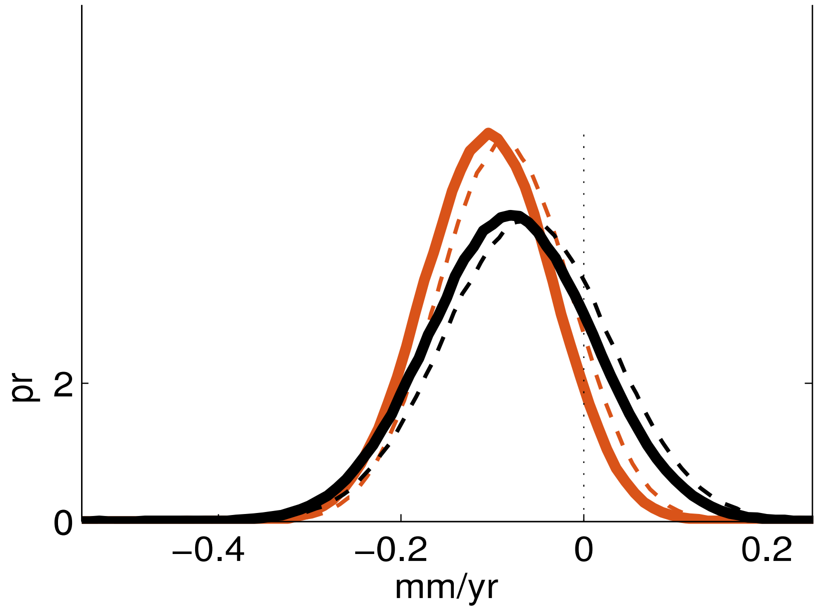
Probability of sampling biases

- Simulation for both GIA models
- Central value is −0.08 mm/yr for ICE-6G.
  - sign indicates the 15 TG records tend to under-estimate the global trend
- This conflicts with lower estimates of global mean sea level rise that suggests these gauges overestimate the global rate.



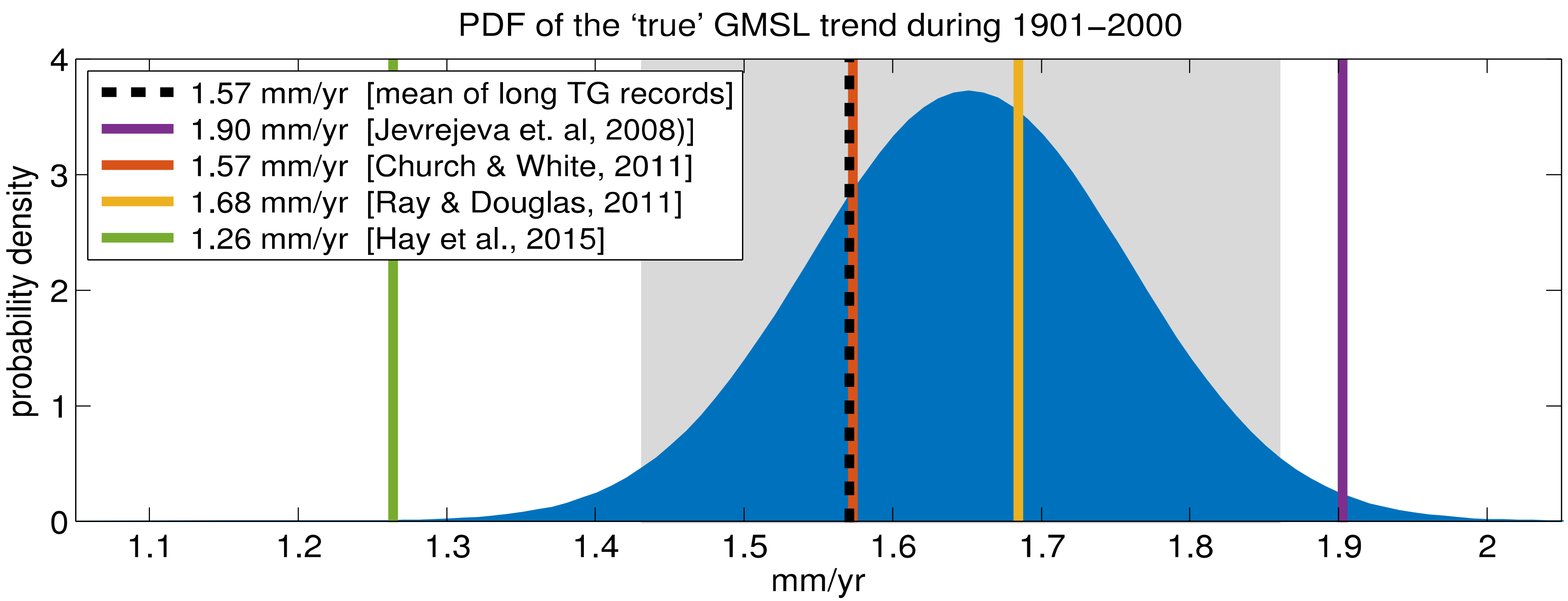
Probability of sampling biases

- Probability of overestimating the global rate by
  - more than 0.1 mm/yr is ≈2%.
  - more than 0.2 mm/yr is small.
- Excluding the ice sheets:
  - Distributions shifts toward even more negative values.
  - Zero chance of overestimat-ing by more than 0.2 mm/yr.
- IF the TGs do substantially over-estimate the global rate, it is likely due to AA/GR fingerprints.



Implications for the 20th century global mean rate

- A distribution for the "true" global mean trend (1.66 ± 0.22 mm/yr):
  - Subtract the sampling bias from the arithmetic mean of the 15 GIA-corrected TG rates.
  - Propagate the standard error in the mean and the uncertainty in the sampling bias.



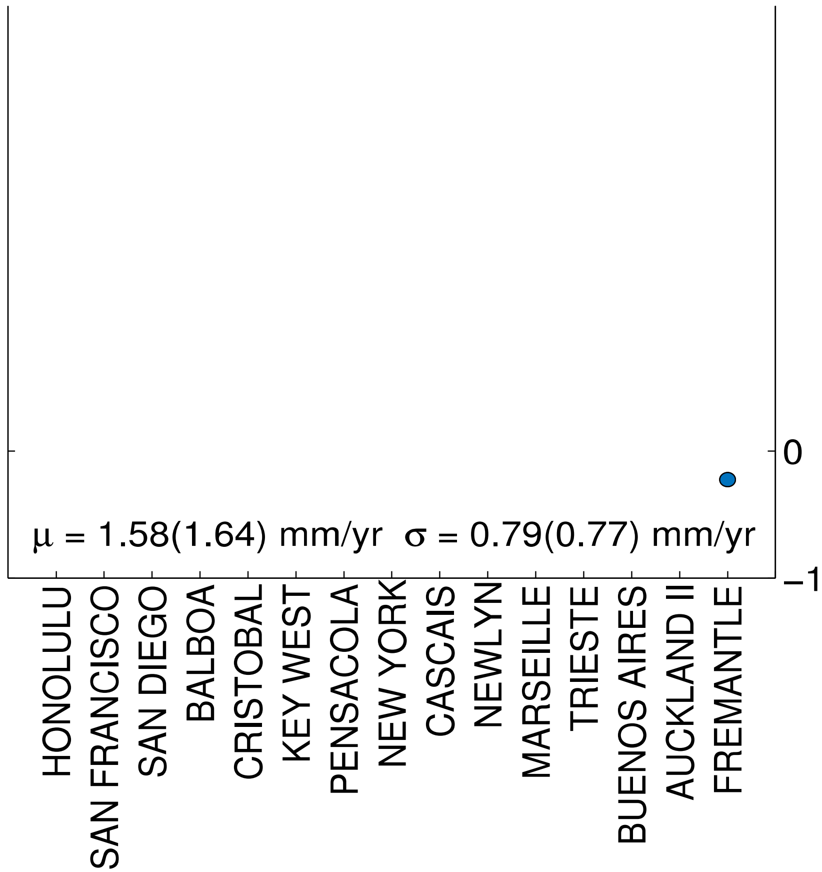
Applying VLM estimates from GPS

- Our paper ends with the conclusion that neither melt fingerprints nor ocean dynamics are likely to reconcile observed TG rates with a global mean rate less than 1.4 mm/yr.

- Another possibility is non-GIA VLM.
  - We can test this by looking at GPS rates of VLM.
  - SONEL provides two files that make this calculation possible:
    1) ULR6a_Vertical-Velocities_Tablehttp://www.sonel.org/IMG/txt/vertical_velocities_table.txt.
    2) A survey of GPS stations co-located with TG stationshttp://www.sonel.org/spip.php?page=cgps.

Applying VLM estimates from (

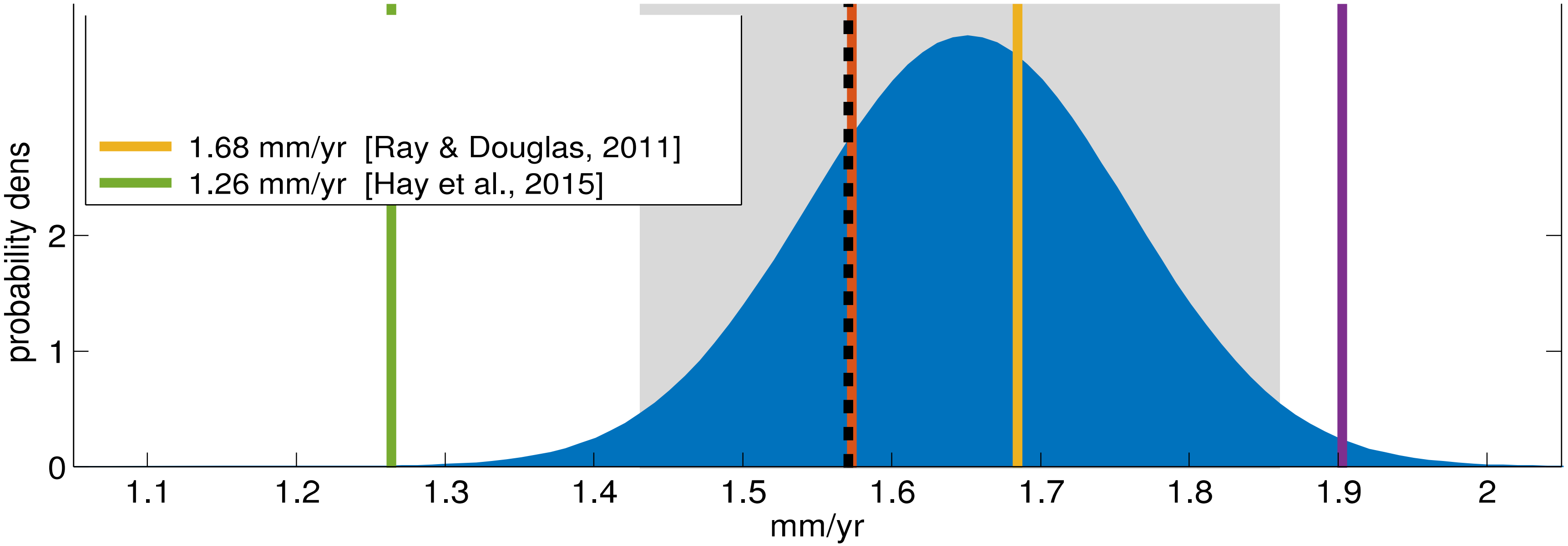
- Corrected TG rates for GIA-geoid plus GPS-VLM in two ways:
  1) Using nearest GPS in the SONEL survey.
  2) Using a weighted average of the GPS rates in the SONEL survey with weights based on amount of GPS data available.



- We conclude that non-GIA VLM cannot reconcile the observed TG trends with lower estimates of 20th century GMSL rise.

Conclusions (1 of 2)

- The central value of this distribution is an estimate of the average rate of global mean sea level rise during the 20th century.



Conclusions (2 of 2)

- This result also serves as a reality check:
  - If the "true" global mean rate is substantially different from the observed local rates in the best TG records, then we should be able to identify specific physical processes with the potential to account for the differences.
- Our results show that neither melt fingerprints nor ocean dynamics are likely to produce a sampling bias large enough to reconcile observed local rates with global mean rates less than 1.4 mm/yr.
- Another possibility is non-GIA VLM, but we did not find evidence from GPS rates that non-GIA VLM causes substantial bias in the trends from TG records examined here.

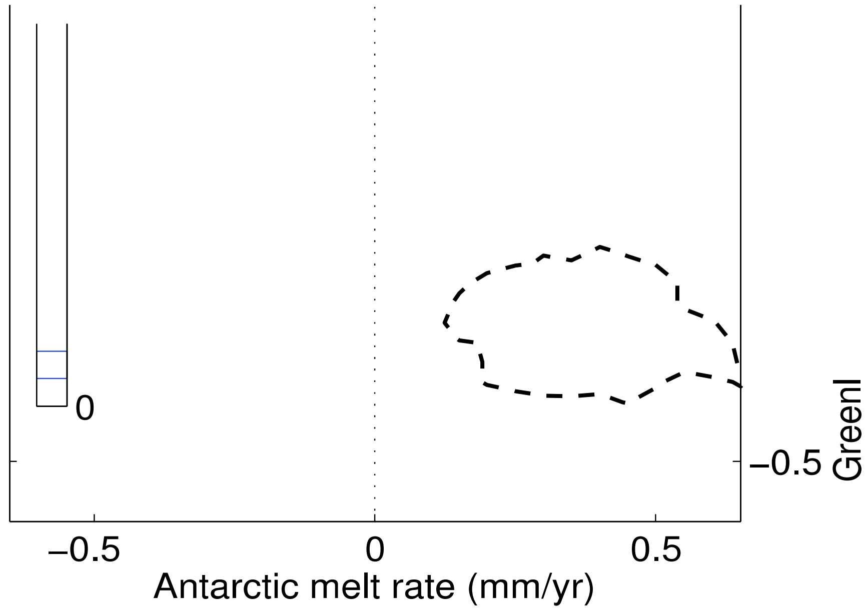
Tide gauge selection

ID	Name	Lat (°N)	Lon (°E)	Span	Years
155	HONOLULU	21.3	202.1	1905–2000	96
10	SAN FRANCISCO	37.8	237.5	1901–2000	100
158	SAN DIEGO	32.7	242.8	1906–2000	92
163	BALBOA	9.0	280.4	1908–2000	92
169	CRISTOBAL	9.3	280.1	1909–1979	71
188	KEY WEST	24.6	278.2	1913–2000	87
246	PENSACOLA	30.4	272.8	1924–2000	76
12	NEW YORK	40.7	286.0	1901–2000	98
52	CASCAIS	38.7	350.6	1901–1993	82
202	NEWLYN	50.1	354.5	1916–2000	85
61	MARSEILLE	43.3	5.4	1901–2000	92
154	TRIESTE	45.6	13.8	1901–2000	94
157	BUENOS AIRES	-34.6	301.6	1905–1981	76
150	AUCKLAND II	-36.8	174.8	1904–1998	92
111	FREMANTLE	-32.1	115.7	1901–2000	89

Distribution of ice sheet melt rates

- M
  s

- If
  o
  ra
  - a large positive AA melt rate, and …
  - a negative GR melt rate (i.e., GR gaining mass)



Applying VLM estimates fro