Reference Frame and Identifying Localized vs Regional Deformation: Examples from Hawaii and the North Atlantic

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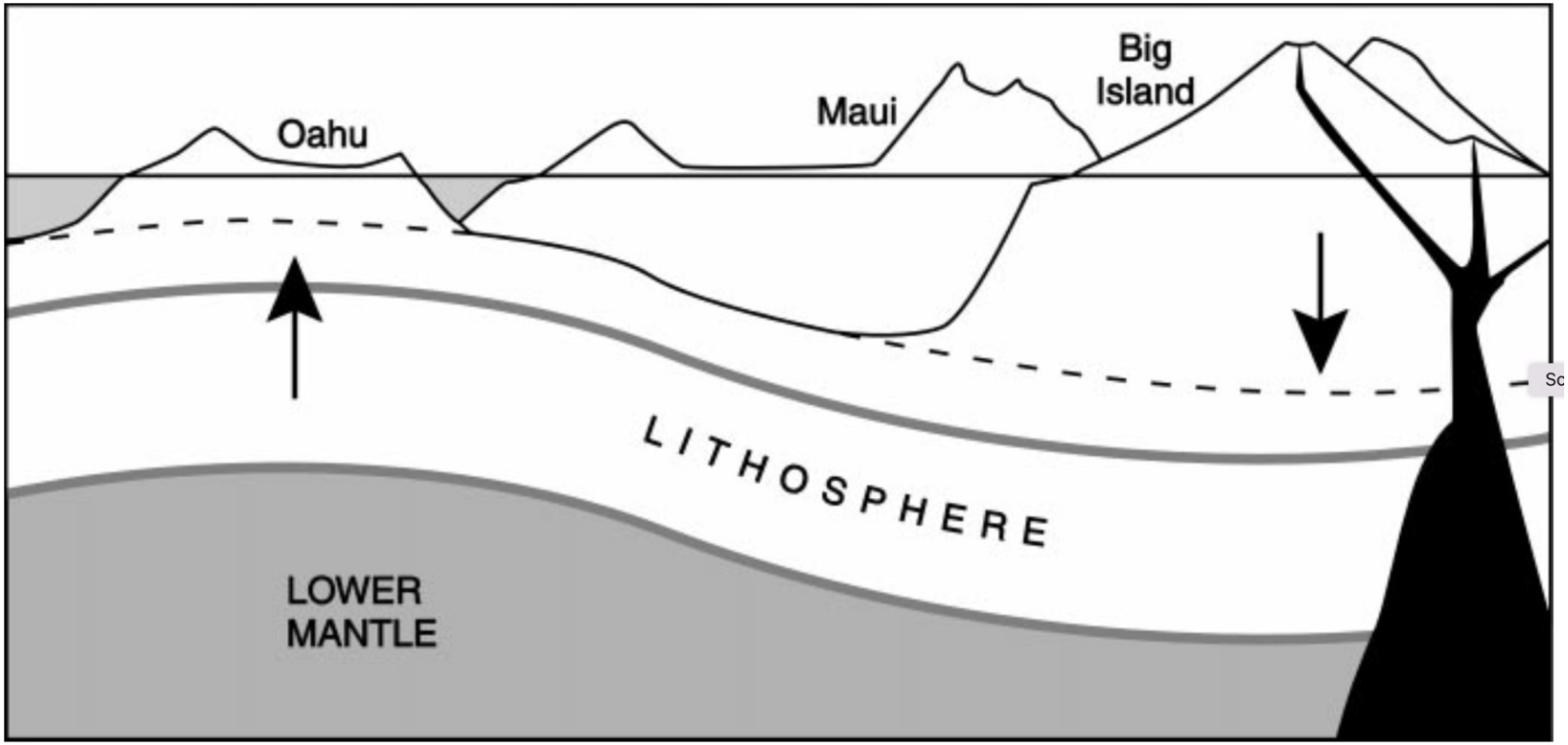
The Geophysical Problem

- On islands like Hawaii and Iceland, we want to isolate and model multiple geophysical signals, and some of these affect an area larger than the island.
  - Pressurization of shallow magma bodies
  - Tectonic motions and active faulting
  - Surface loading
- Small vertical motions can be very important for distinguishing competing deformation models
- How to ensure that we are accurately measuring these displacements?

Flexural Deformation

- Over the last 3000-4000 years, uplifted shorelines show that O‘ahu has uplifted by 1.5-2 meters, a rate of ~0.5 mm/yr (Grossman and Fletcher (1998)

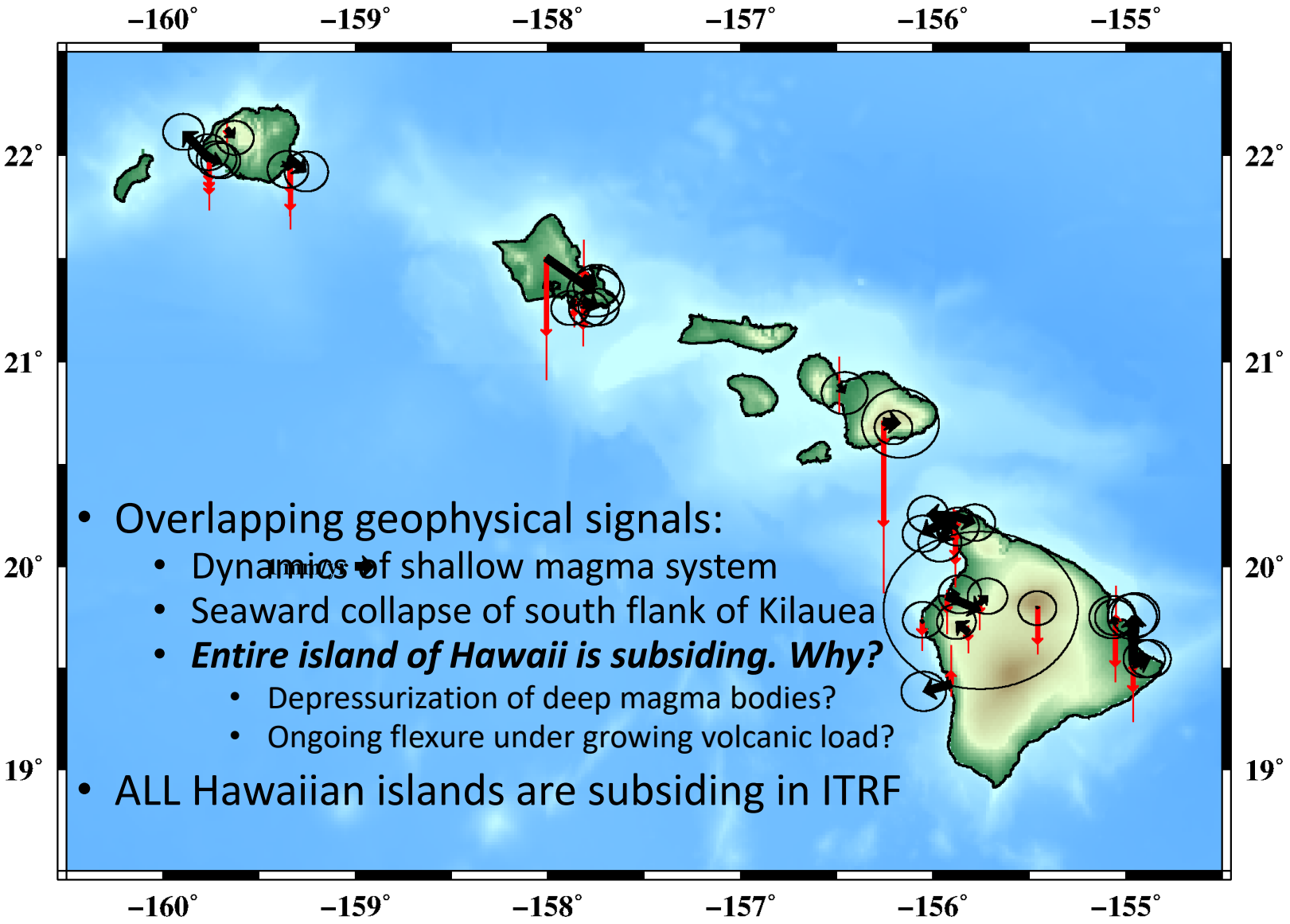


Grossman et al. (1998)

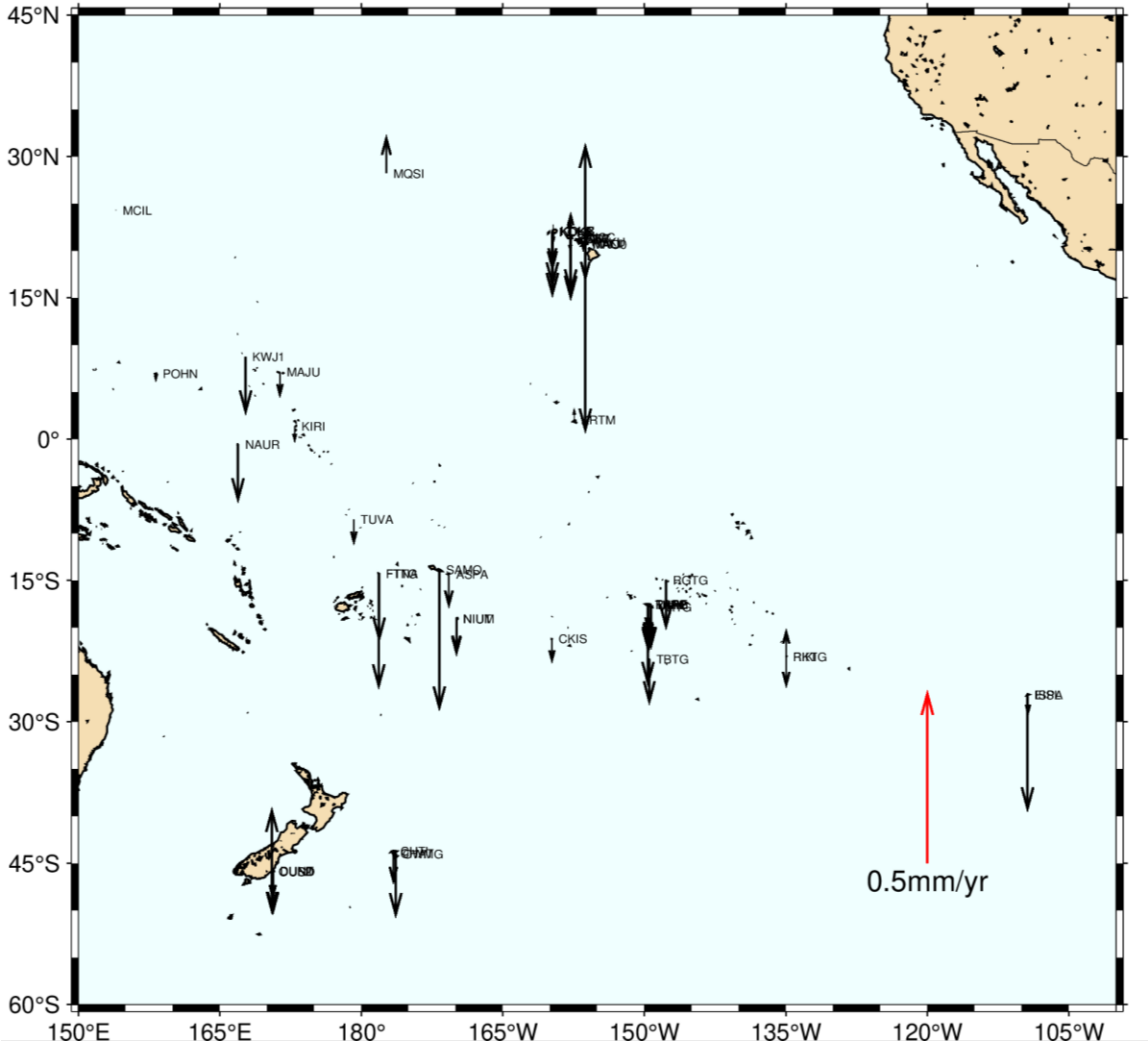
GPS Velocity Data

- GIPSY goa-6.5 PPP solutions 1996-2022
- Aligned to ITRF2014 globally
  - Katarina Vance will present an update at AGU, planned to use ITRF2020.
- Velocities estimated using a colored noise model
- Sites with long time series usually have velocity uncertainties well under 1 mm/yr
  - ~0.1-0.2 mm/yr horizontal
  - ~0.3-0.5 mm/yr vertical

Hawaii

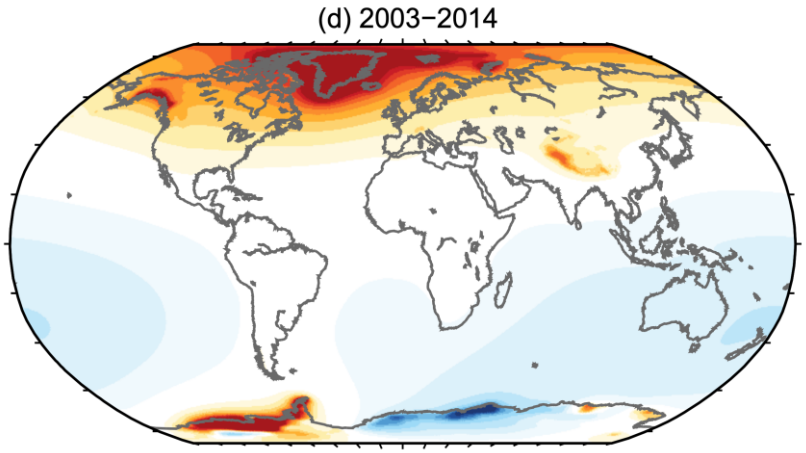

−160°
−159°
−158°
−157°
−156°
−155°
22°
21°
20°
19°
• Overlapping geophysical signals:
• Dynamics of shallow magma system
• Seaward collapse of south flank of Kilauea
• ***Entire island of Hawaii is subsiding. Why?***
• Depressurization of deep magma bodies?
• Ongoing flexure under growing volcanic load?
• ALL Hawaiian islands are subsiding in ITRF

Central Pacific Velocities



Global Surface Loading Models

- Riva et al. (2017) average rate (vertical) 2003-2014, CM frame
- Coulson et al. (2021) time series of 3D rates over 2003-2013, CE frame
- Long-term GIA (e.g., ICE-6G)



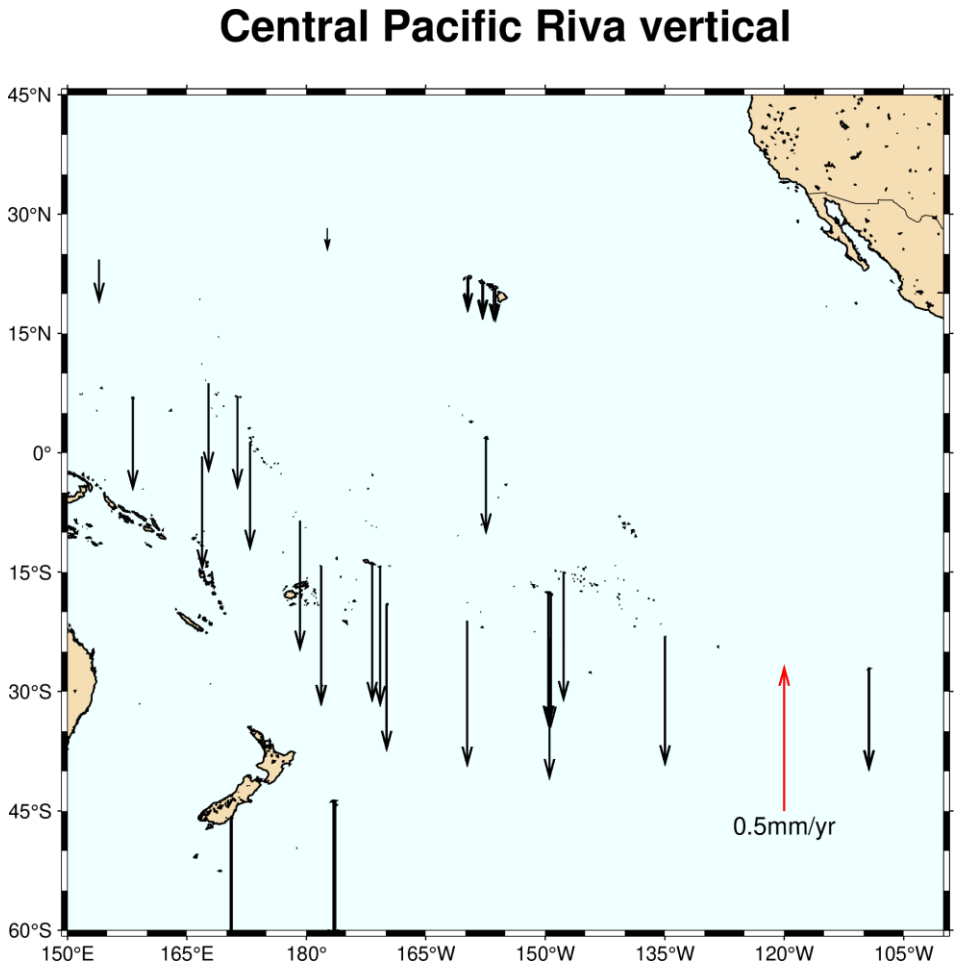
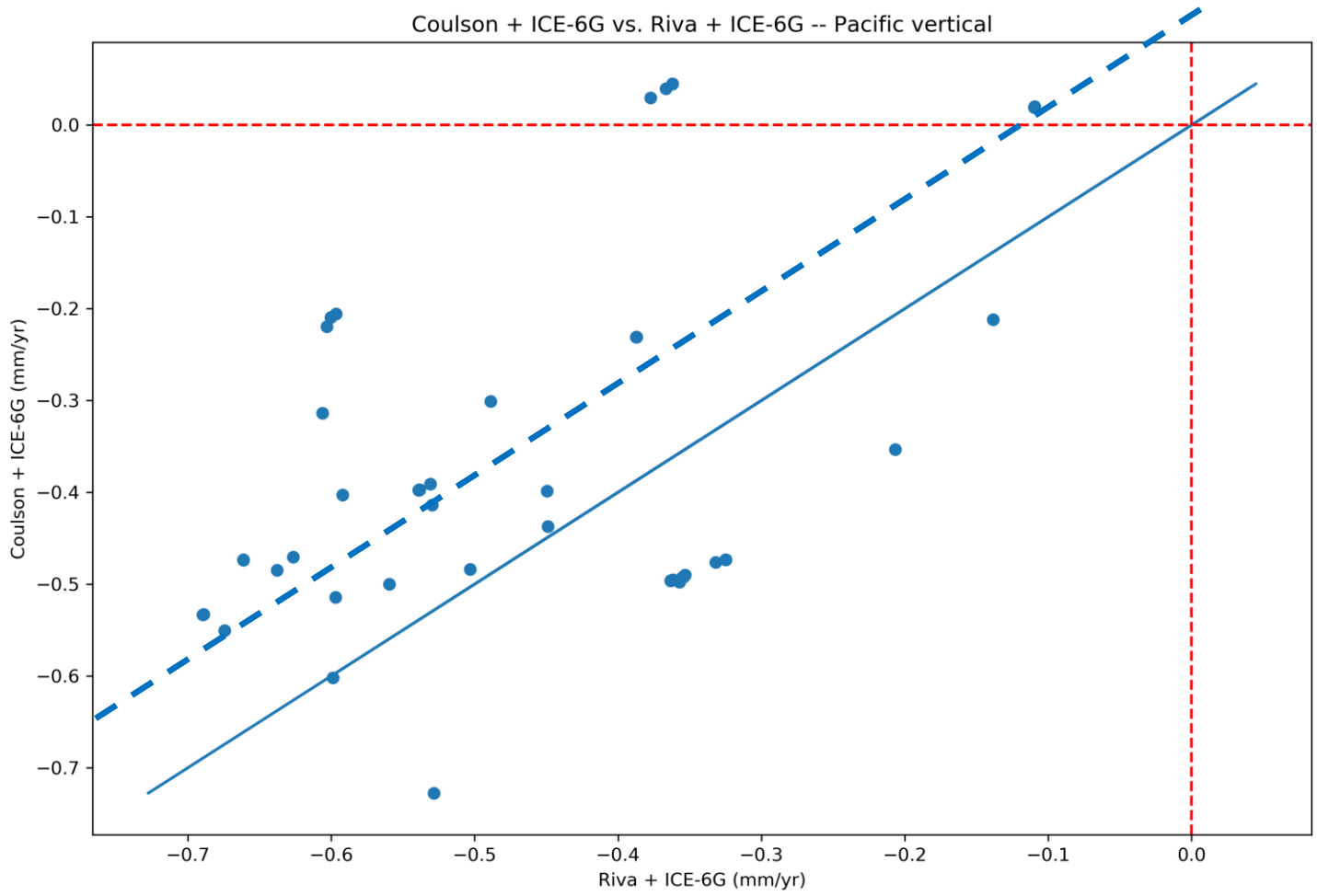


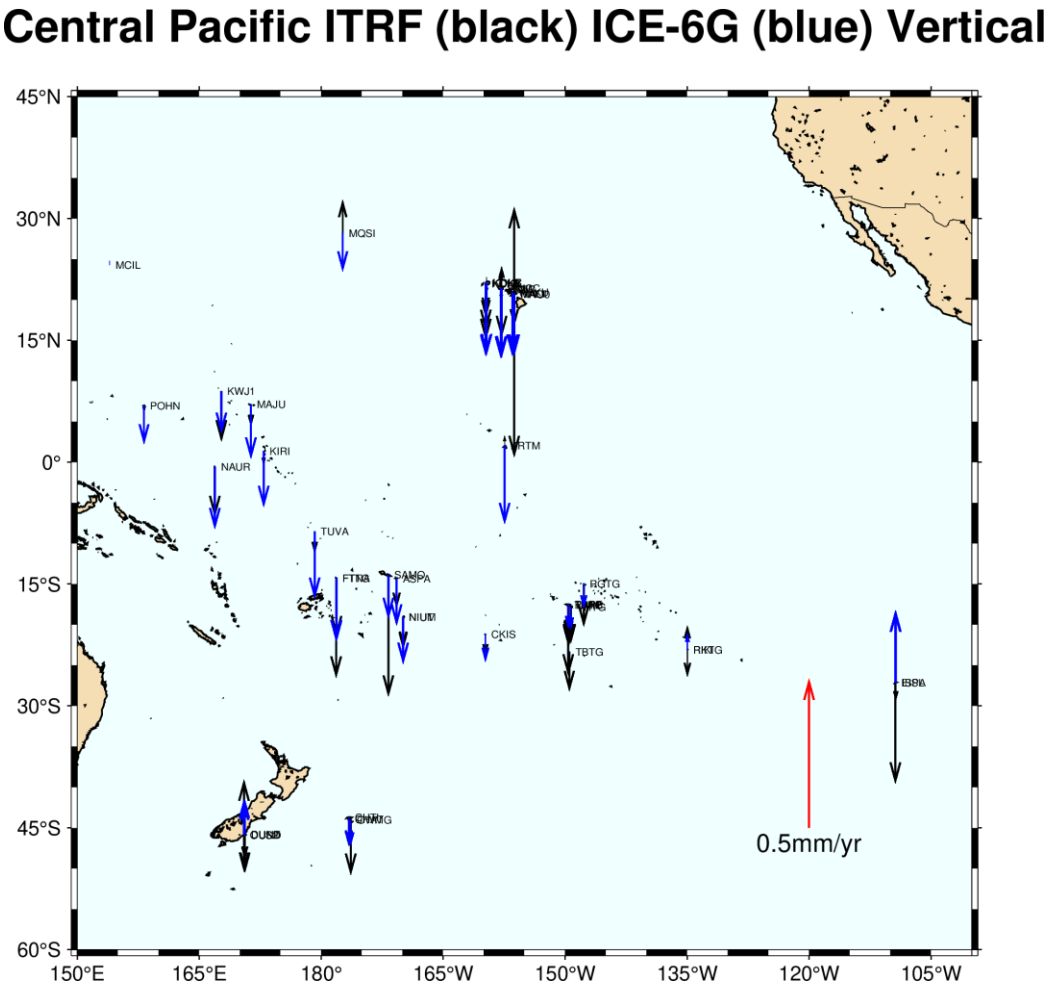
Figure and model values from Riva et al. (2017)

Comparison of Riva vs Coulson Models



Impact of GIA

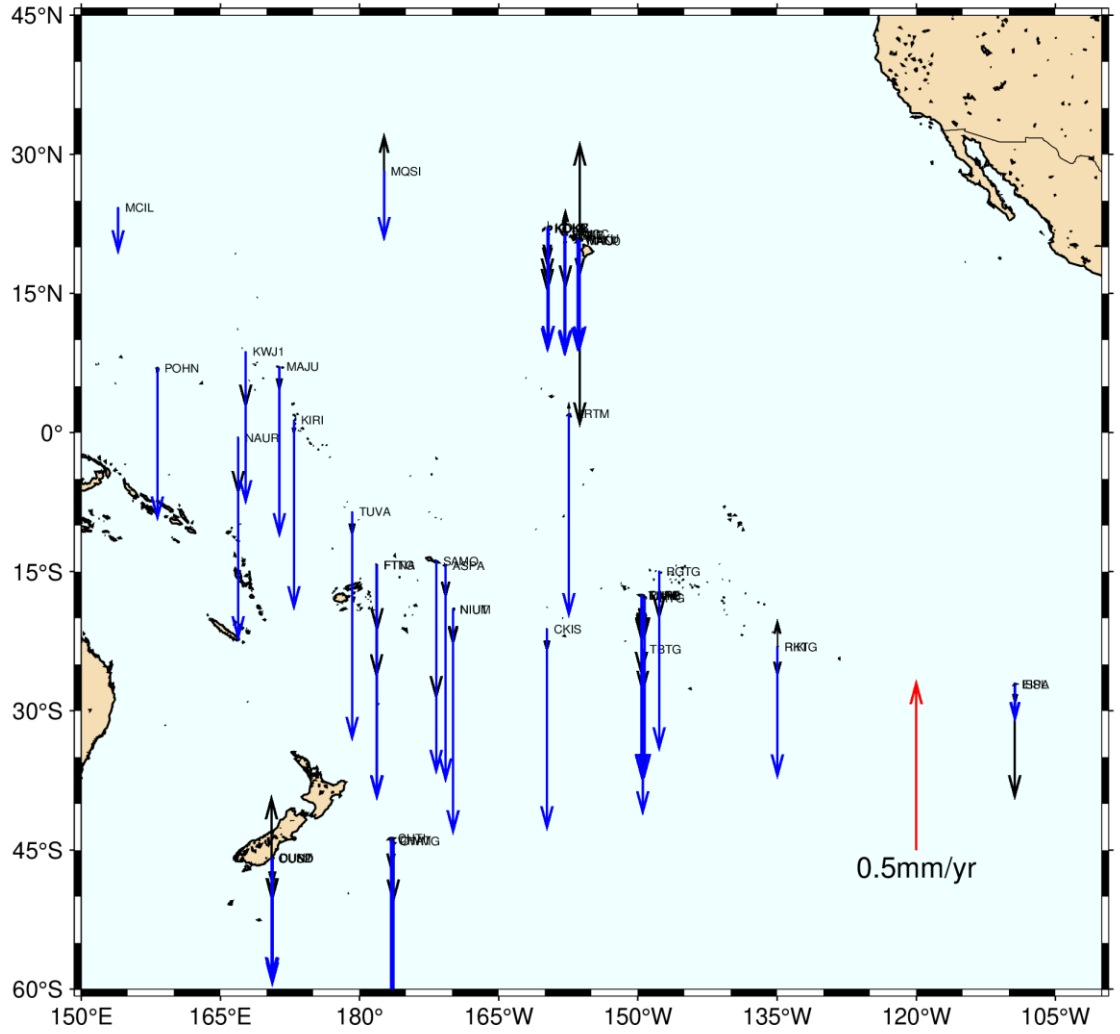
- ICE-6G/VM5a predicts subsidence 0.2-0.3 mm/yr
- What about other ice/viscosity models?
- Steffen et al. (2021) computed many combinations
- Subsidence rates in Pacific similar across GIA models, but sensitive to lower mantle viscosity



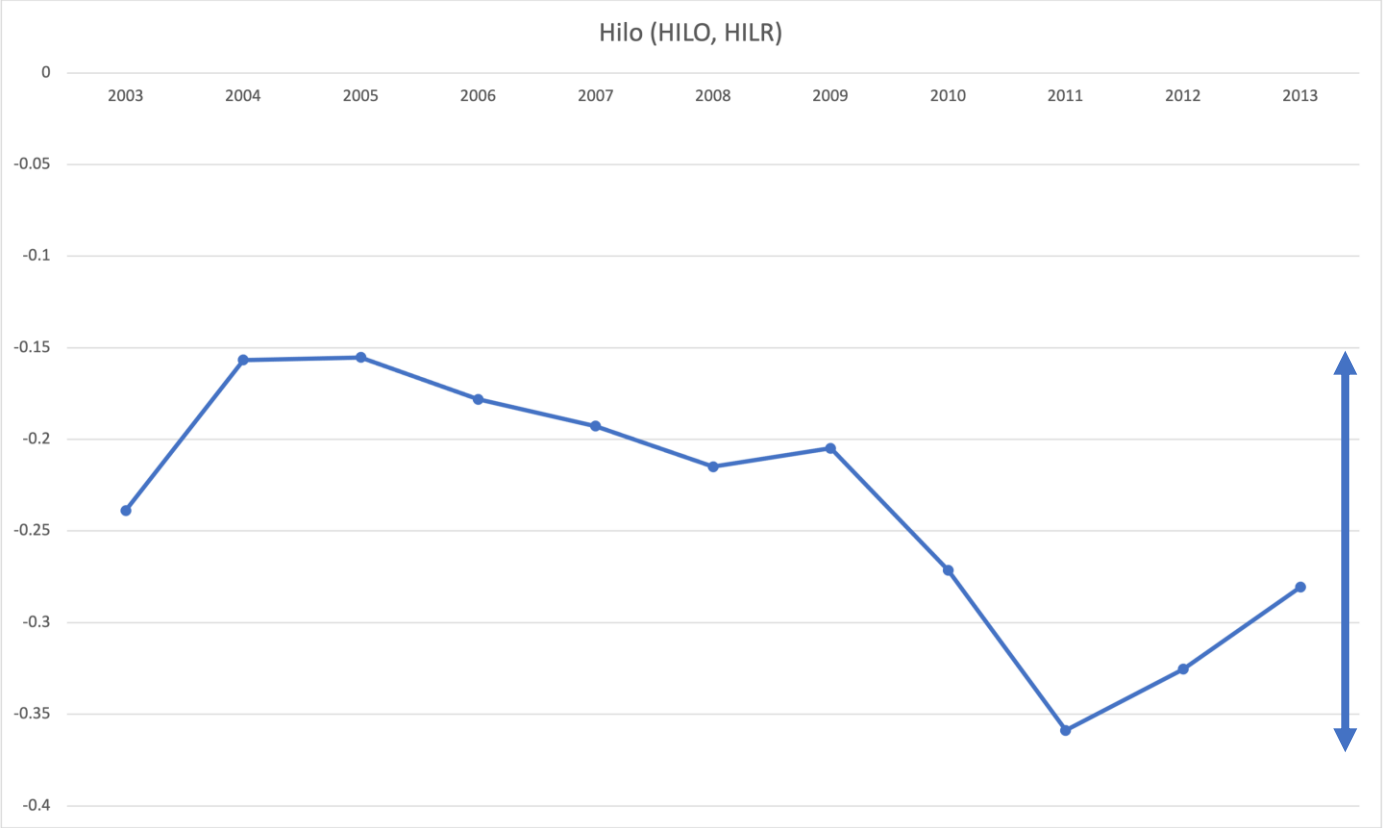
Higher/Lower lower mantle viscosity => higher subsidence rate

Model vs Data

Central Pacific ITRF (black) and Riva + Ice6G (blue) vertical



Time Variations



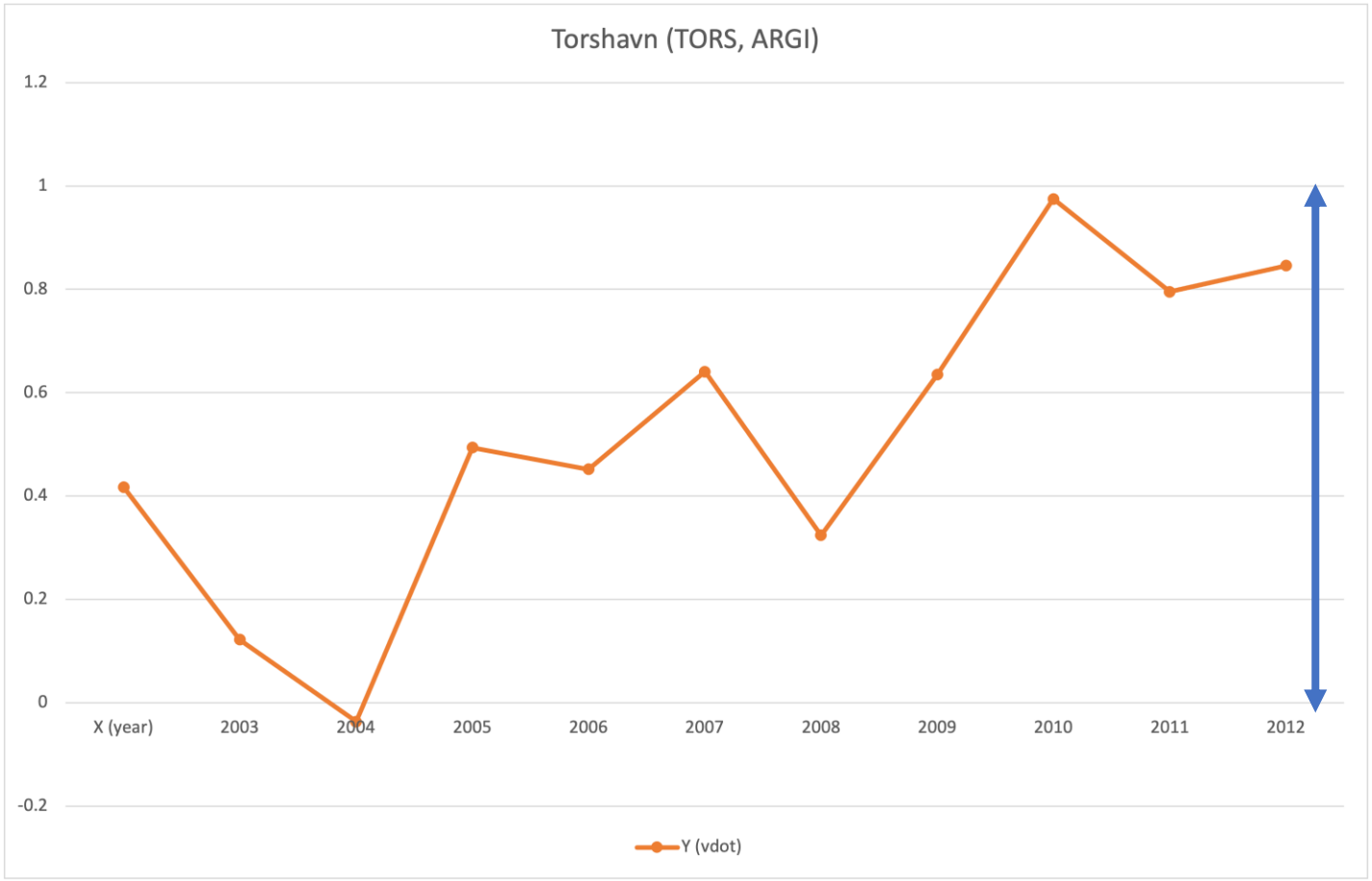
- Time variations in present-day surface loading are significant
- Coulson: range of predicted uplift rates spans ~0.2 mm/yr over 2003-2013

Model from Coulson et al. (2021)

Takeaway Points (Pacific)

- GPS sites across the Pacific basin mostly subside at rates of 0.2-0.4 mm/yr
- Present day surface loading causes the Pacific basin to subside by ~0.3-0.5 mm/yr
  - Time variations in present day surface loading are at the level of ~0.2 mm/yr
- Sum of surface loading + GIA overpredicts observed subsidence by ~0.5 mm/yr
- ***Errors in models? Or small error in frame origin definition of ITRF? Or both?***
  - ***It is not easy to identify the cause of this differenceh.***
- ***More model development is needed, but assessing sub-mm/yr effects should be feasible***

North Atlantic: Greater uplift rate variability



Model from Coulson et al. (2021)

Conclusions

- Present-day surface loading deforms the entire planet.
- Even away from the major loads the rate variations can be larger the velocity measurement capability.
- This challenges a purely velocity-based reference frame as motions at the sub-mm/yr level are likely not linear in time.
- We need better models for global present-day loading to account for these effects.