

What do we need from the next generation of geophysical models, and their future use in geodetic data analysis and reference frame?

2026 GGOS Unified Analysis Workshop

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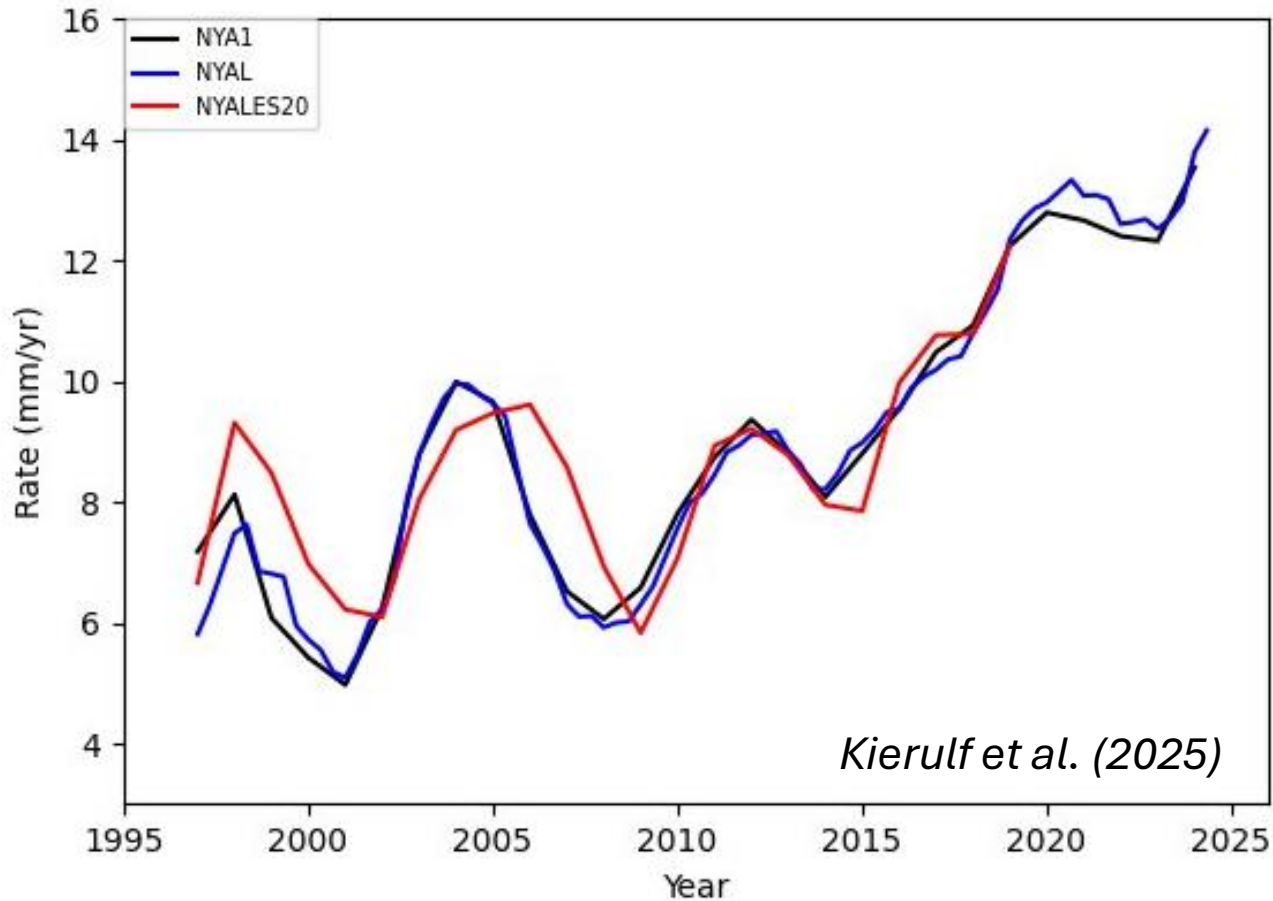
Outline

- In particular, models for loading caused by mass variations
- Scale of observed variability, in particular interannual -> trend
 - Cryosphere
 - Terrestrial Hydrology
 - Impacts
- What would we do differently if we had accurate models?

Summary of my REFAG Talk

- Interannual variability is common
 - Distinct patterns, often consistent over a few to several years, temporarily looks like a secular trend
 - There are variations in magnitude of ~annual cycle
 - Changes in hydrological regime can change uplift rates at the level of a few mm/yr
 - Changes in glacier mass balance can be larger, ~several mm/yr
- Other examples
 - Southwestern US drought cycle (Borsa et al., 2014)
 - California and Cascadia, USA (Argus et al., 2014; Argus et al., 2017; Fu et al., 2015)
 - Southern Africa (Mielke et al., 2025)

Cryosphere: Ny Alesund

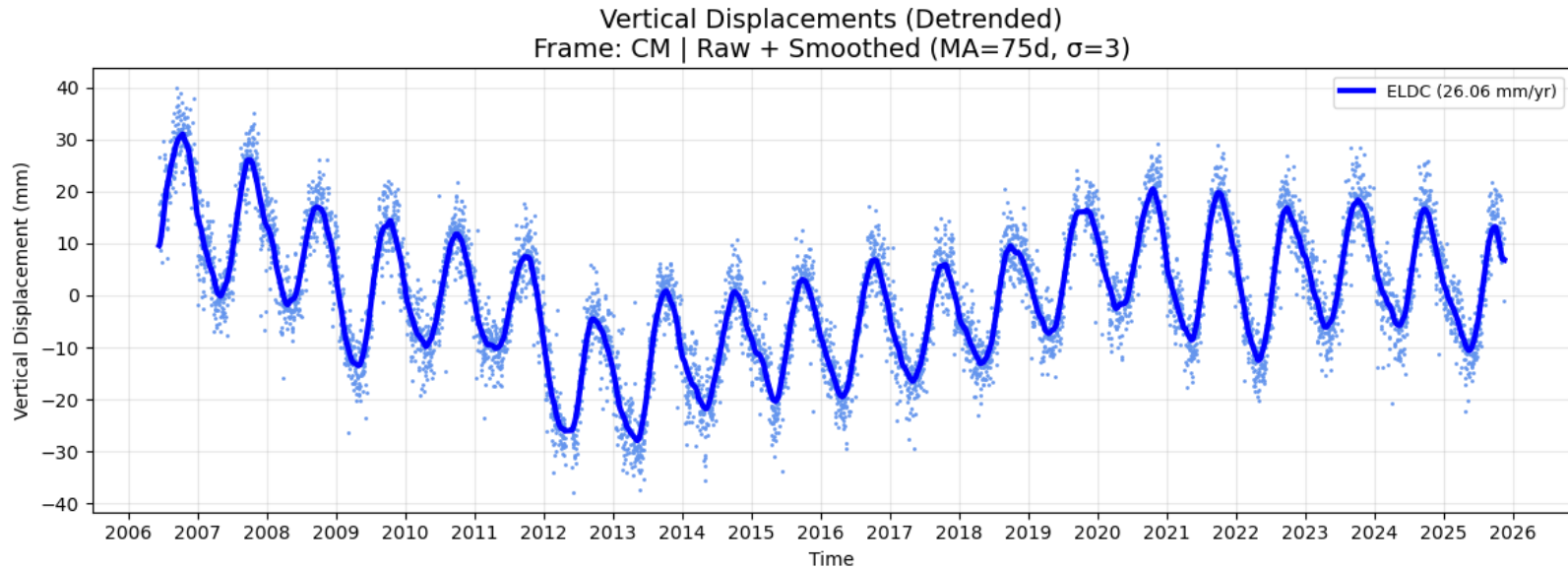


Kierulf et al. (2022)
Kern et al. (2025)
Kierulf et al. (in review)

Kierulf et al. (2025)

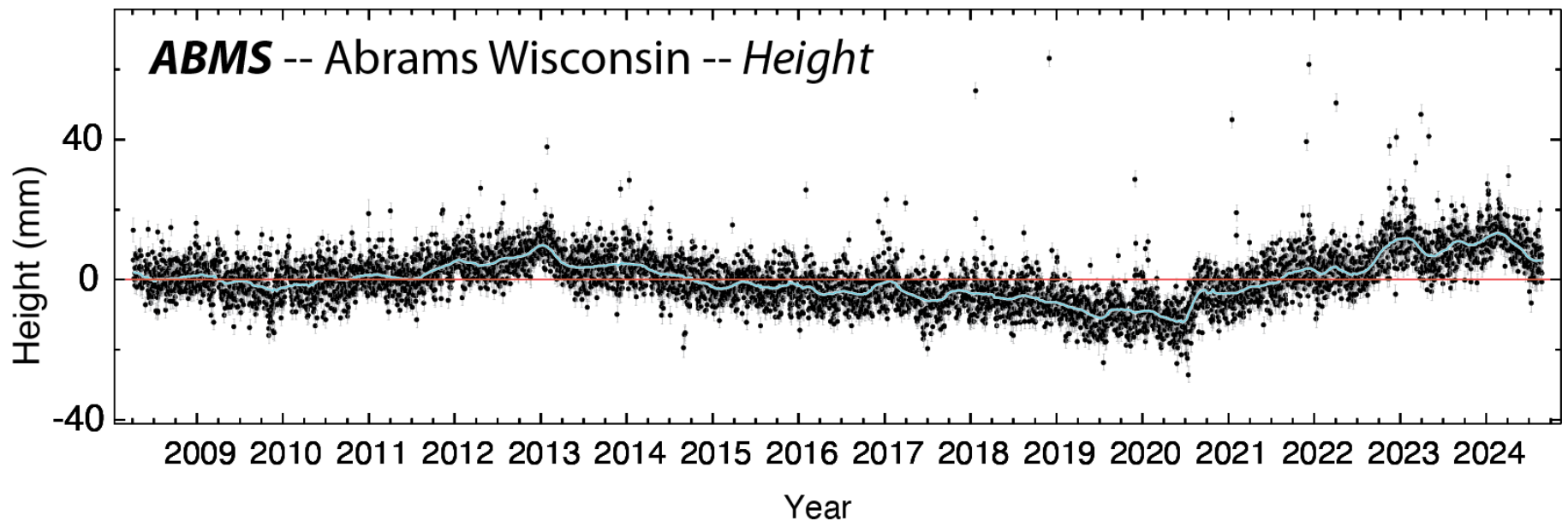
- Uplift rate continuously variable, can impact VLBI scale
- Elastic loading models (cryosphere) explain ~50% of variability

Cryosphere: Southeast Alaska



- Multi-year periods of consistent vertical motion, but with rates that vary by 3-4 mm/yr
- Cryosphere models (e.g., Copernicus) match timing of variability but underestimate magnitude

Motions are Close to Secular, within each Temporal Regime



Cause of variations:

- *Elastic deformation of the solid Earth due to the changing load (weight) of water in the Great Lakes (plus other surface water and groundwater)*

Why a Reference Frame Issue?

- Aliasing
 - Observed motions not described in reference frame coordinate model are aliased into frame alignment => alter values of all estimates
 - Even alignment of solutions to ITRF + empirical seasonals gives distinctly different time series
 - If we try to force data to fit a mathematical model that lacks needed non-linearity, non-linear motions are aliased into some parameter estimates
- Data Strength, Stability and Predictability
 - One long linear segment is more powerful than 2-3 shorter segments
 - Hydrologic/cryospheric changes spatially correlated

Some Open Questions

- If it is useful to account for seasonal periodic motions, why just annual + semi-annual?
 - Which frequencies? And periodic functions are just a useful approximation, not the reality
- What are potential affects on datum definition?
- How to ensure future predictability?

What Should We Do Differently?

If we had accurate models, I think we should...

- Incorporate model loading time series into the reference frame definition
 - Requires definition of a “climatic average” mean load
 - Requires a parametric model for future projection
 - Requires a reanalysis process for updates
- Know how inaccurate motion models alias into derived quantities that other sub-disciplines use
 - Re-check current practices
 - Monitor future load changes and their impacts

Questions for Discussion

- Assuming models are accurate, what are the advantages and disadvantages of including a time series representation of loading deformation in our reference frame definition and coordinate model?
 - What issues will have to be worked out? (For example, impact on datum definition)
- How could (or should) models be applied in other analyses? Are we using them consistently?

Our Panel Will Discuss

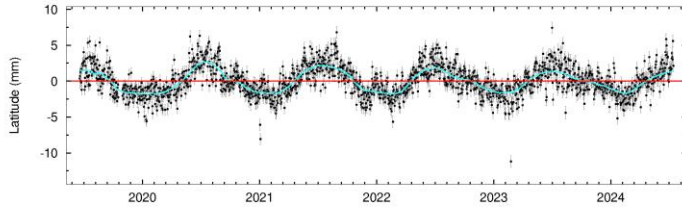
- Assuming models are accurate, what are the advantages and disadvantages of including a time series representation of loading deformation in our reference frame definition and coordinate model?
- How could (or should) models be applied in other analyses? Are we using them consistently?
- Are we waiting for the perfect model, or can we use what's available? What improvements are needed for this to be done?
- How can we assess the long-term stability and the **mean field** of reanalyses, which is not ensured (more and more satellite data are assimilated through time)?
 - For example, air tides (S1 and S2) are significantly changing in ERA5, which is not seen in ground barometric stations .
- If models are never perfect, how can we describe the uncertainties and take them into account in processing?
- How can geodetic products (station coordinates, gravity fields, EOPs) be defined independently of the reduced models?

ITRF2020 linear vs CM

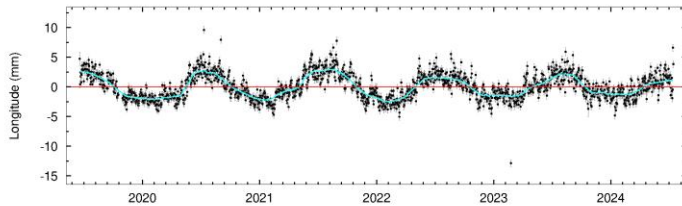
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1834 Daily Solutions (2019.47 - 2024.53)
Relative to best-fitting line. Motion rates are in ITRF.

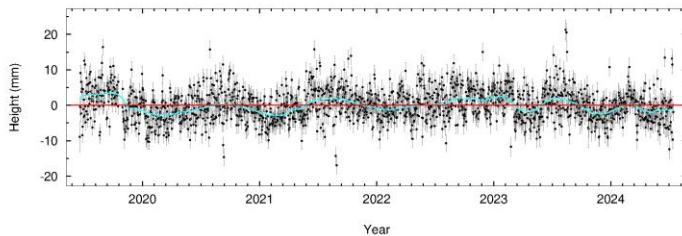
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Motion rate -15.6 +- 0.0 (mm/yr) Repeatability 2.1 (mm)



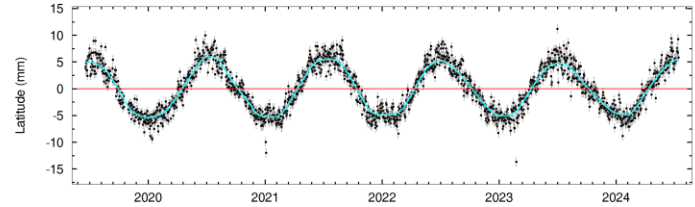
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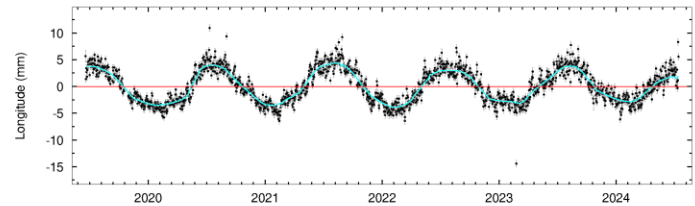
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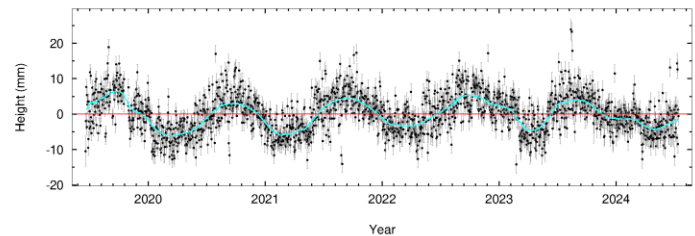
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Motion rate 0.3 +- 0.0 (mm/yr) Repeatability 5.5 (mm)

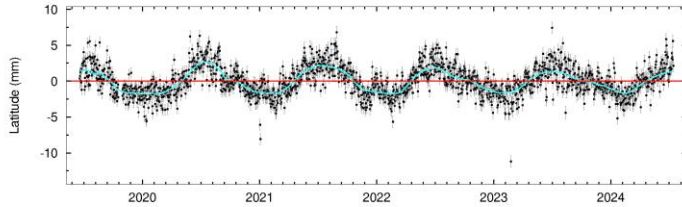


ITRF2020 linear vs CF

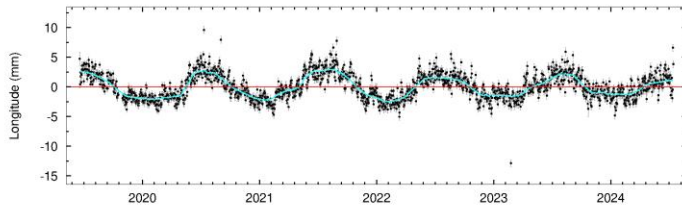
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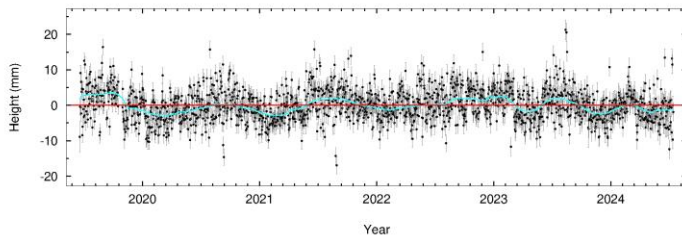
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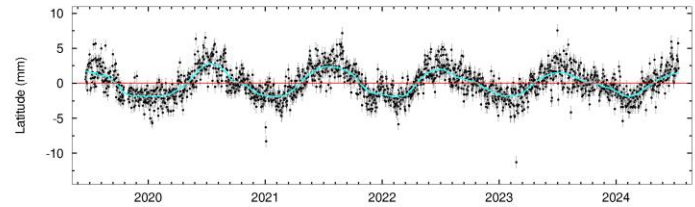
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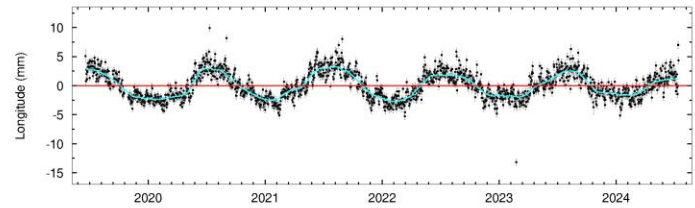
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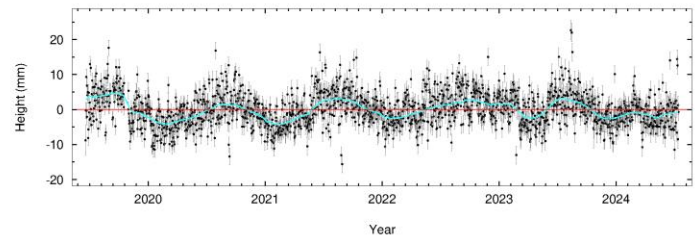
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Motion rate 0.4 +- 0.0 (mm/yr) Repeatability 4.7 (mm)

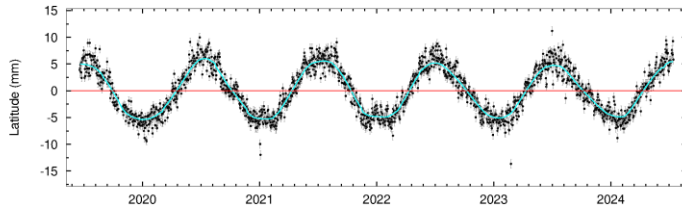


ITRF2020 CM vs CF

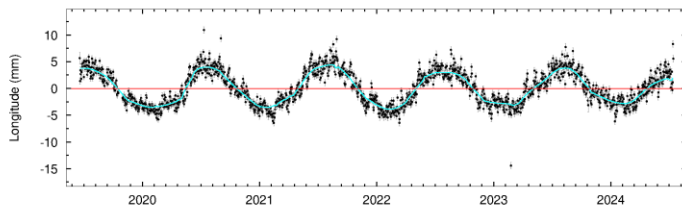
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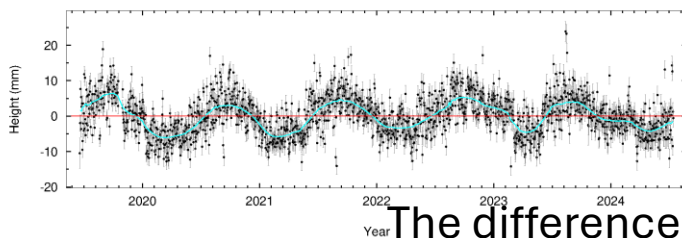
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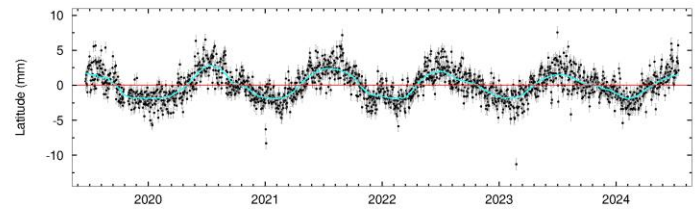
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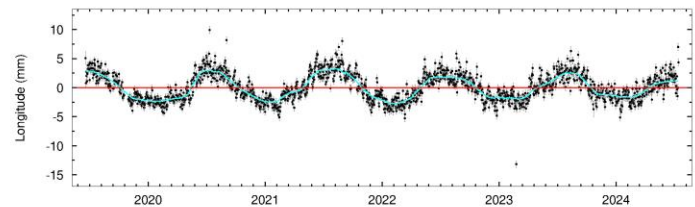
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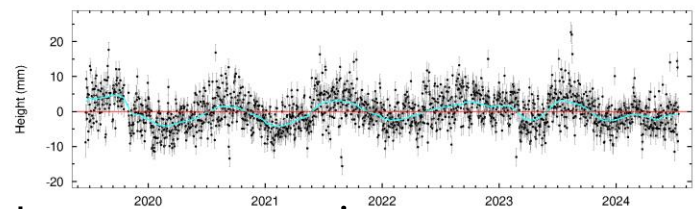
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The difference is a seasonal geocenter motion