GRACE-FO: science results, project status & outlook

GRACE-FO STM 2024
Potsdam, Germany

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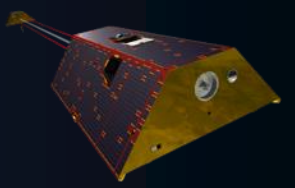
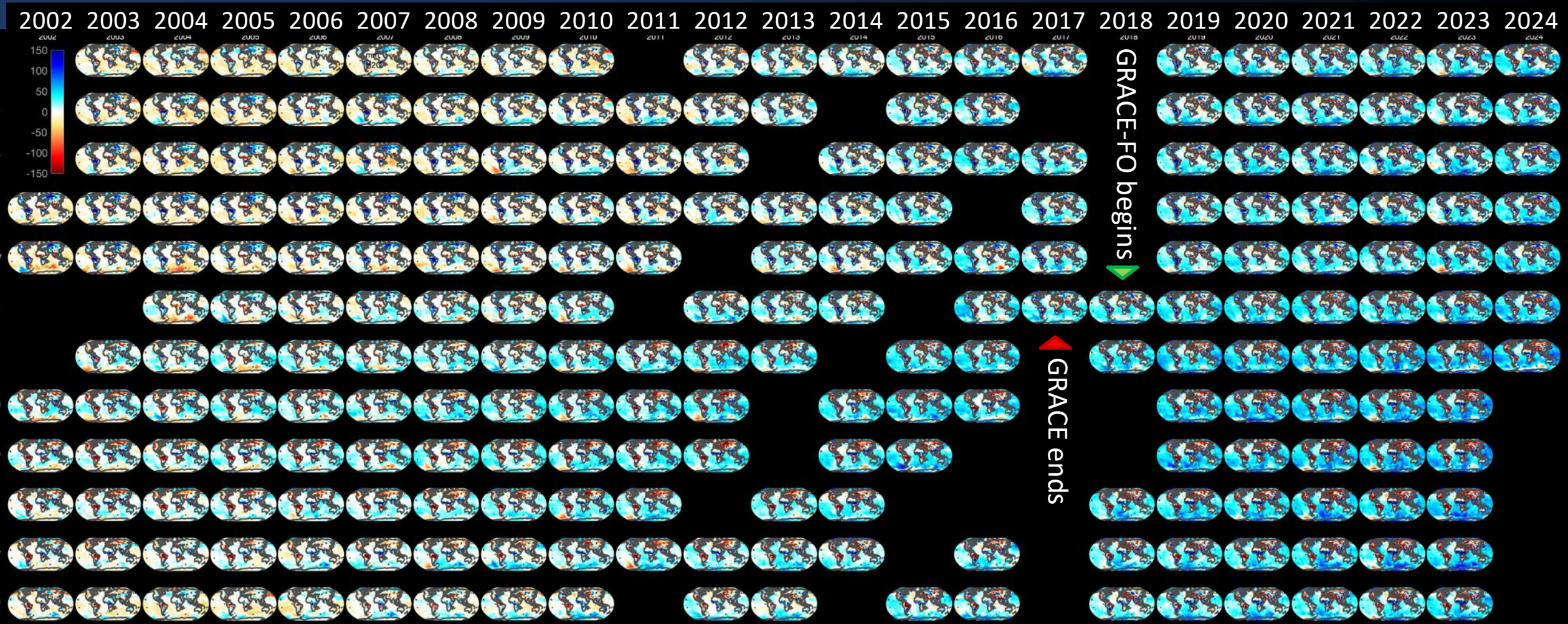
Science Data System Teams

GRACE and GRACE-FO: 22+ years of Scientific Discoveries and Expanding Societal Applications



- Uninterrupted science data collection & processing
- Continued climate data record extension & impactful results



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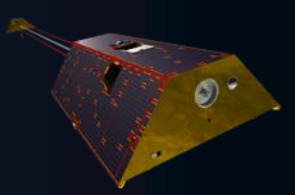

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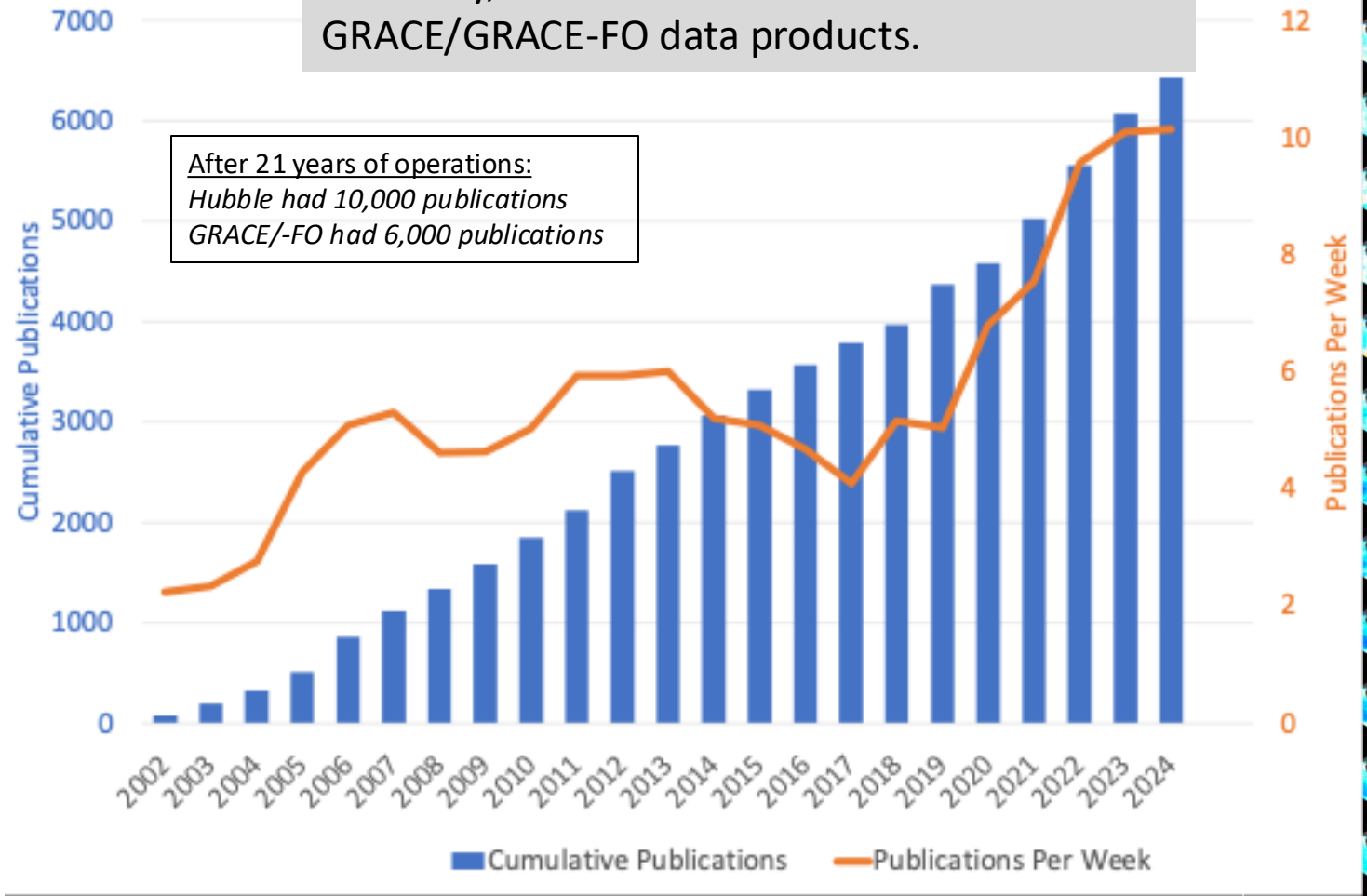
Highlights:

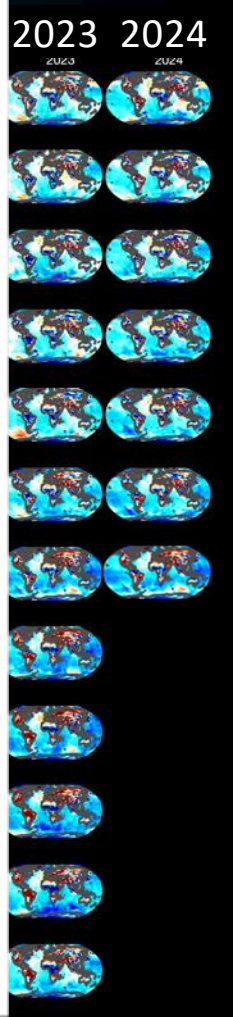
Publications: **6500 (Sep/'24)**

2nd most cited NASA instrument/observable in the **Intergovernmental Panel on Climate Change (IPCC) AR6 report.**

Terrestrial Water Storage (i.e., Mass Change) has recently become a **Global Climate Observing System Essential Climate Variable** and **contributes to 14 of 54** additional GCOS Essential Climate Variables.

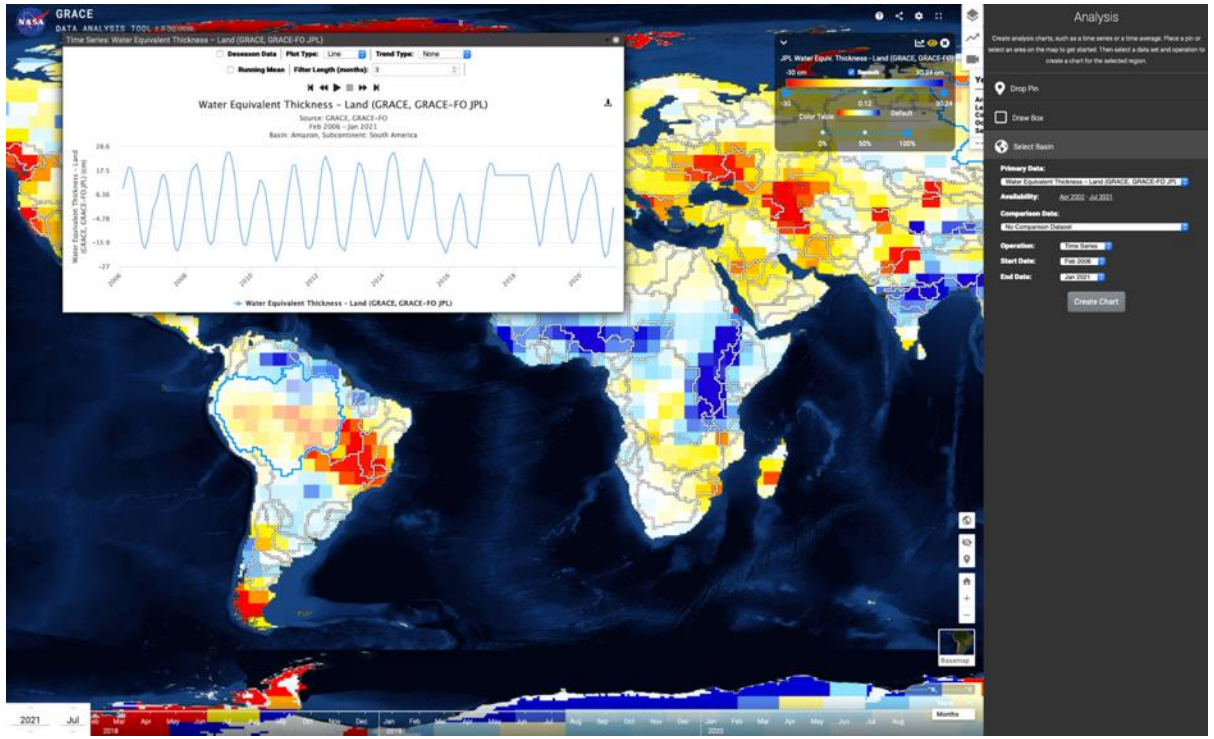
Currently, ~70% of users download Level-3 & 4 GRACE/GRACE-FO data products.



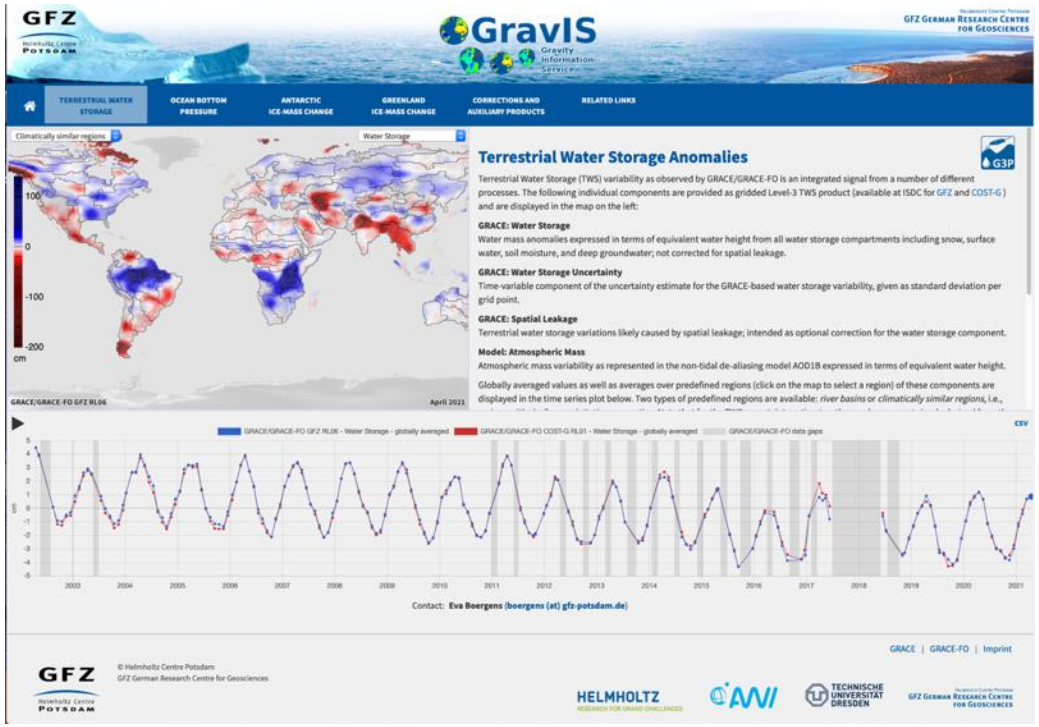


GRACE / GRACE-FO Data Portals are popular access point for many new users.

- Main archives: NASA-PO.DAAC and GFZ ISDC for L1, L2 and L3 data (open access)
- Interactive web portals greatly reduce ‘entry barrier’ for new users (science and application use cases)
- ~70% of users download Level-3 & 4 GRACE/GRACE-FO data products
- Many L3/L4 users don’t interface directly with the data generators / providers



https://grace.jpl.nasa.gov/data-analysis-tool



http://gravis.gfz-potsdam.de

New Knowledge Transfer & Outreach initiatives provide an ‘on-ramp’ for new users & stakeholders.

Info portal:
www.globalwaterstorage.info

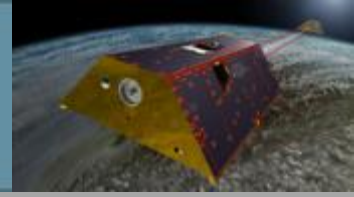
COP28: *Passage of Water* art project with Google and NASA, using data GRACE-FO & SWOT satellites

NYC Natural History Museum (photo: Steve Nerem)

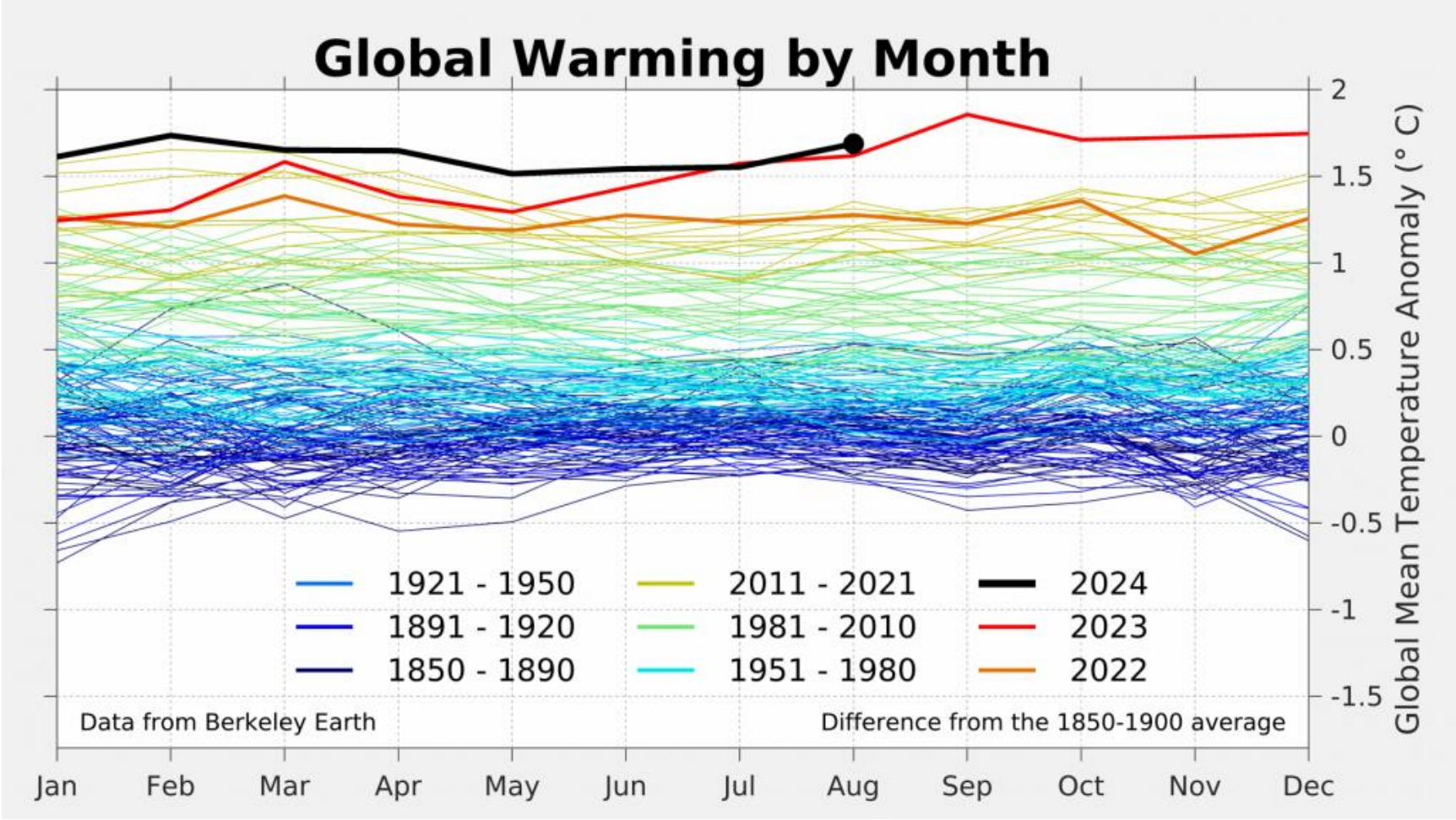
GRACE-series data and visuals play a vital role for understanding & communicating our changing climate.

NASA’s *Earth Information Center* at the National Museum of Natural History, DC

The GRACE-missions series provides Essential Climate Variables, tracking mass and water cycle changes.



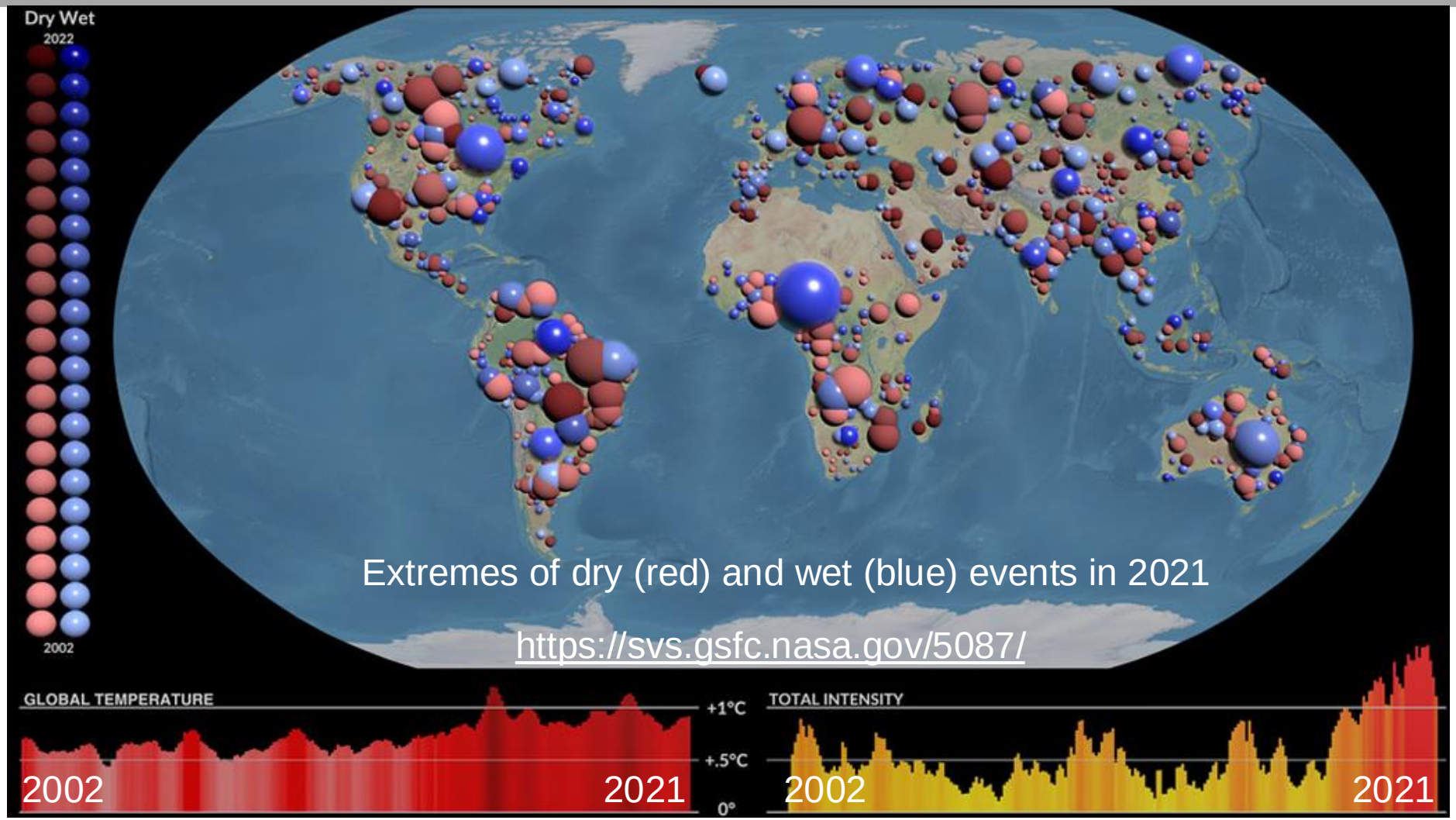
State of the Climate: It's been hot in 2023 – 2024, partly due to El Niño.



- August '24 is the 15th consecutive month to set or tie the monthly global temperature record
- In addition, August '24 marks the fourteenth consecutive month at least 1.5 °C warmer than the corresponding pre-industrial (1850-1900) average.
- Relative cooling is expected with the end of El Niño, possibly transitioning into La Niña in the coming months.

https://berkeleyearth.org/july-2024-temperature-update/

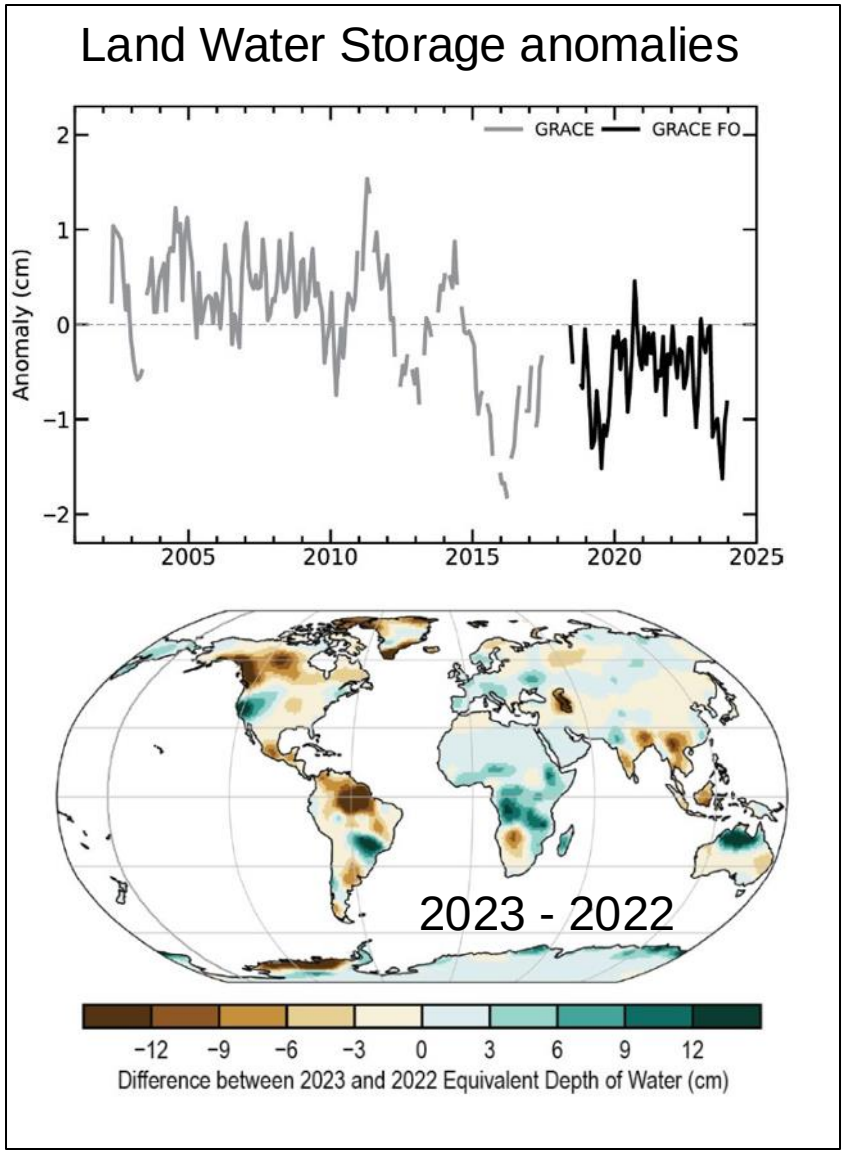
Global total intensity of extreme events increased from 2002 to 2021, mirroring Earth's rising temperatures over this period.



Extremes of dry (red) and wet (blue) events in 2021 .The volume of the sphere is proportional to the intensity of the event. The plots at the bottom of the figure show that the total intensity of extreme events increased as global temperatures increased (Rodell & Li, 2022).

State of the Climate 2023:
It's been mostly dry over land in 2023 (rel. to 2022)

https://doi.org/10.1175/BAMS-D-24-0116



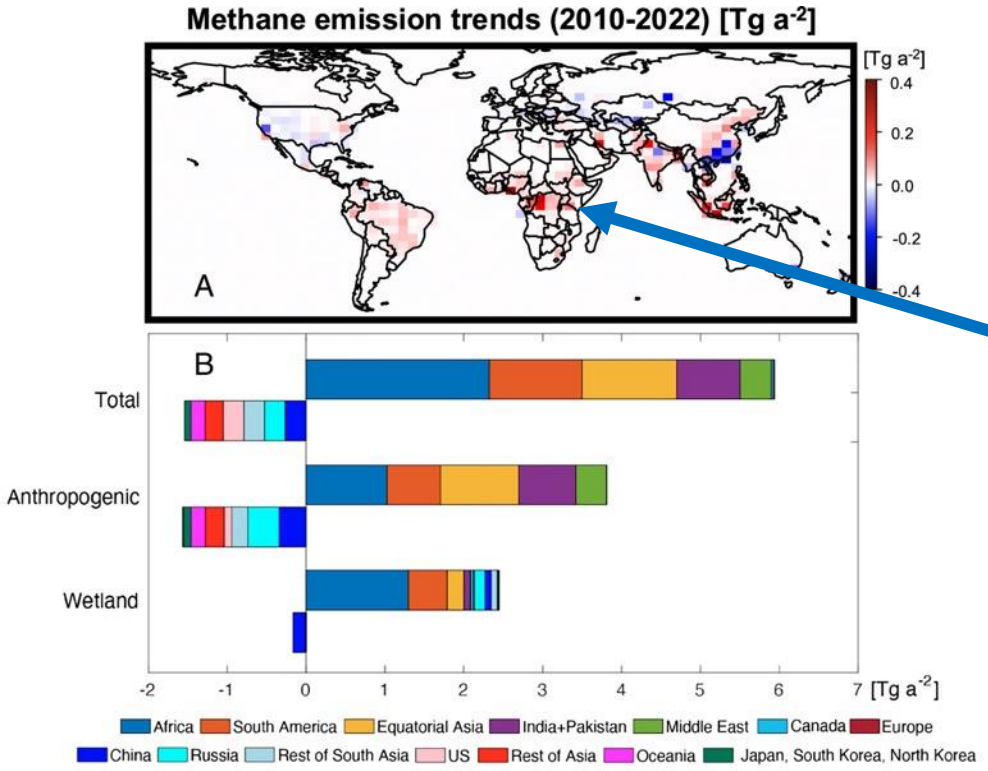
Land:

- Lower global mean precipitation total over land for the year, with 2023 being one of the driest years since 1979
- However: *intensity* of the rain that did fall *increased*, as expected under warmer conditions
- Total Land Water Storage in 2023 reached its second-lowest point since 2002
  - the first time that over 7% of land area was in most-severe drought category

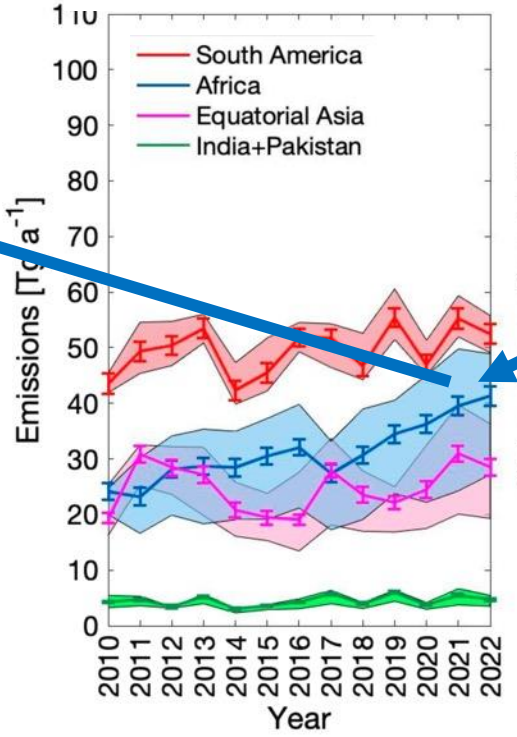
Atmosphere:

- total column water vapor showed the wettest year on record globally, with over 1 kg of water vapor extra per square meter across Earth's surface

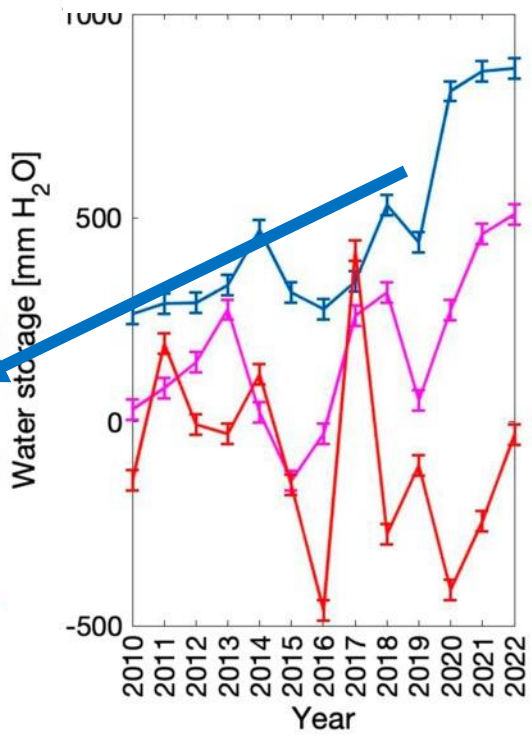
GRACE-FO impact: Inverse modeling of satellite observations shows inundation in wet tropics led to 2020–2022 methane surge



Regional trends of methane emissions



Regional water storage changes from GRACE and GRACE/FO

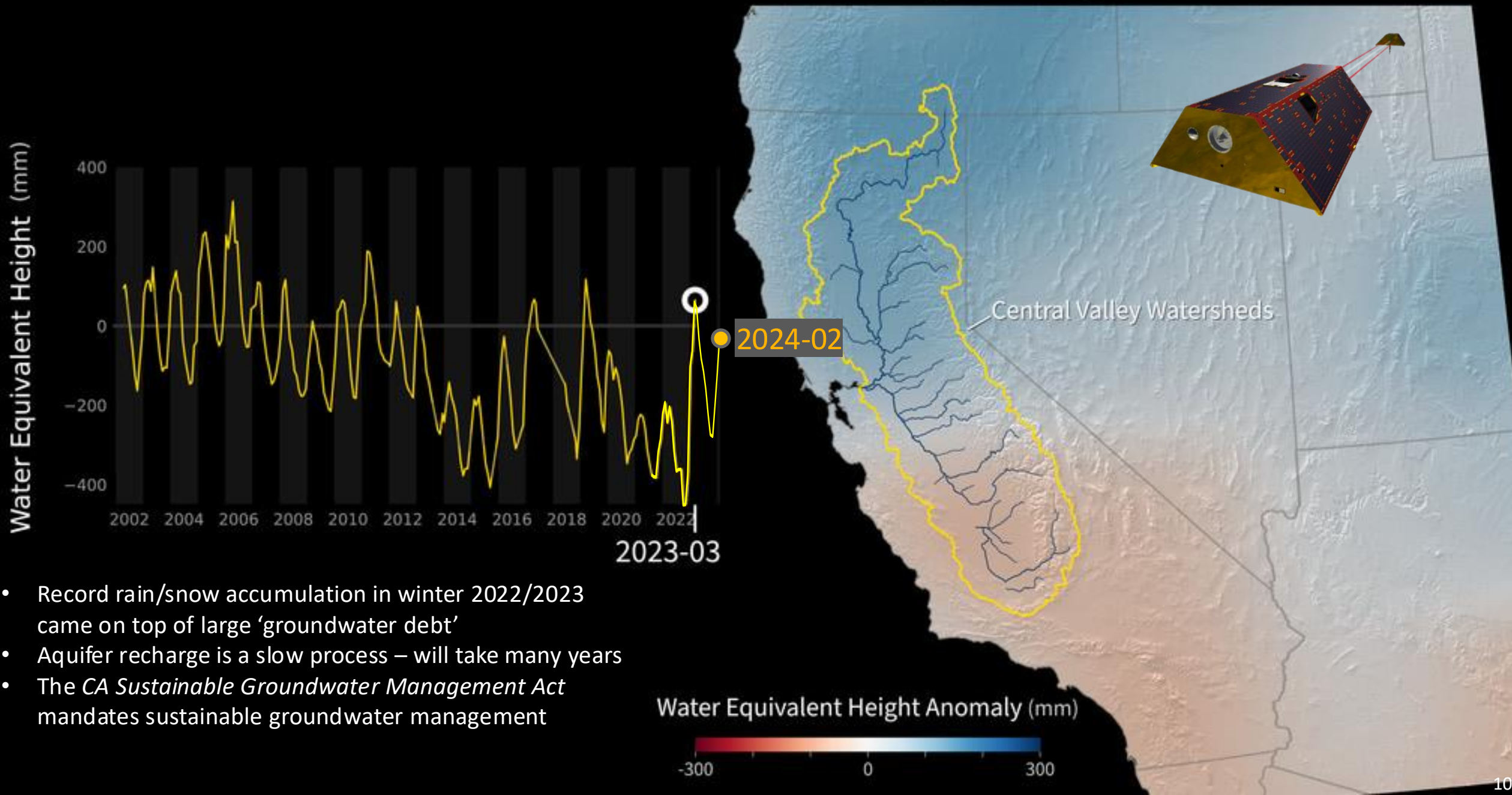


Question: What drove growth of methane, an extremely potent greenhouse gas?

Answer:
1. Decadal methane growth has been driven by the wet tropics
2. The 2020–2022 methane surge was due to large-scale wetland inundation in Africa and Equatorial Asia associated with La Niña conditions, derived from GRACE-FO observations

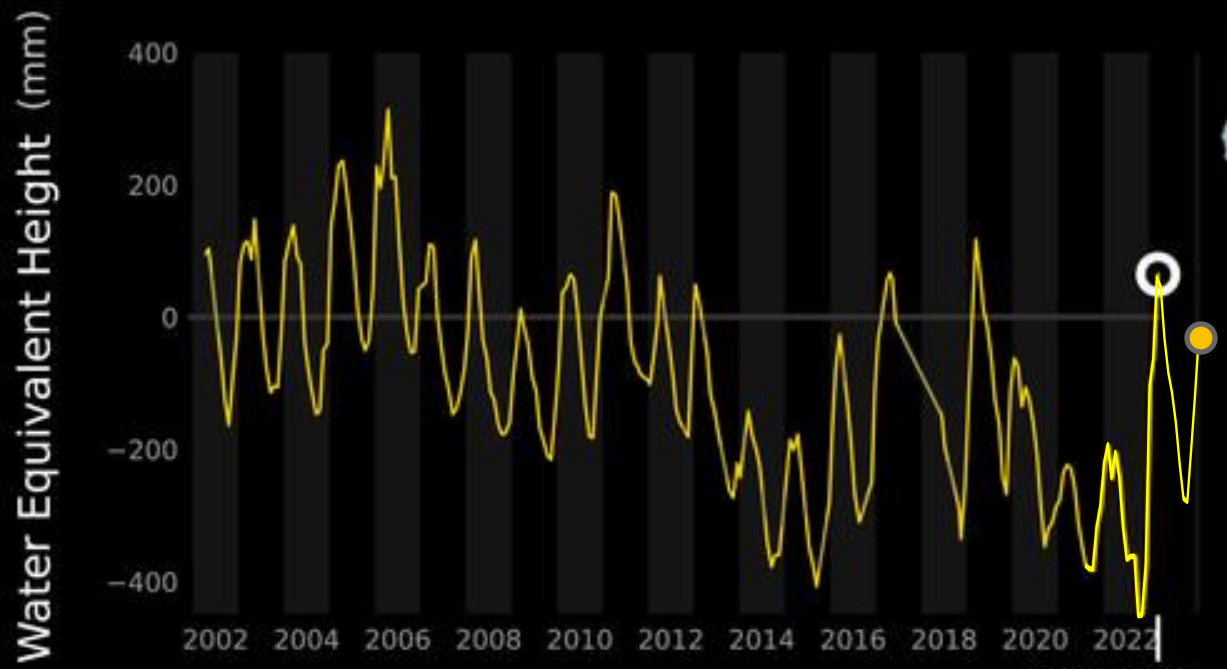
Qu et al., 2024, PNAS: https://doi.org/10.1073/pnas.2402730121

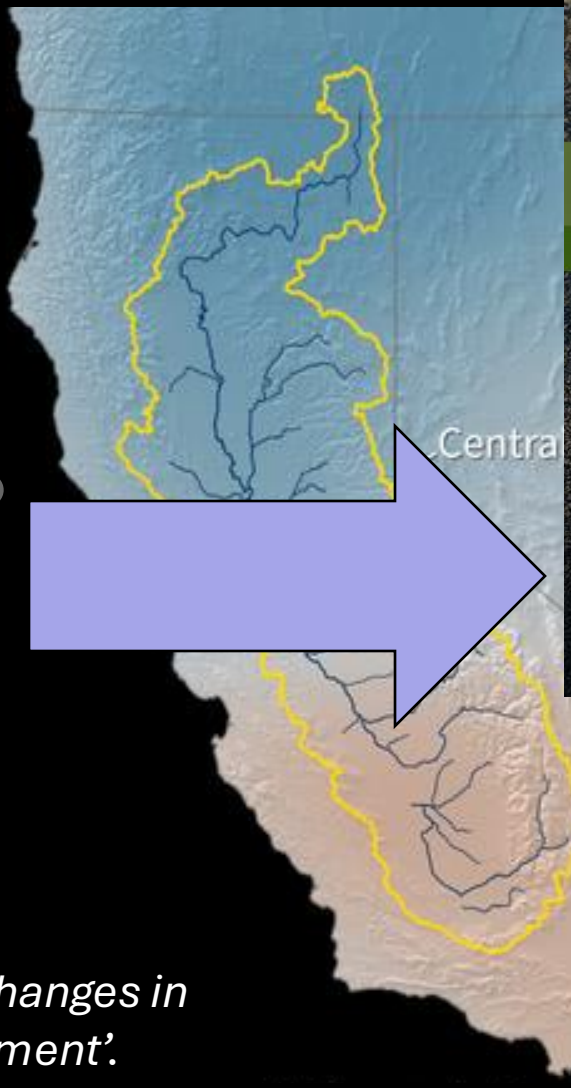
GRACE Observations of Terrestrial Water Storage Changes in California

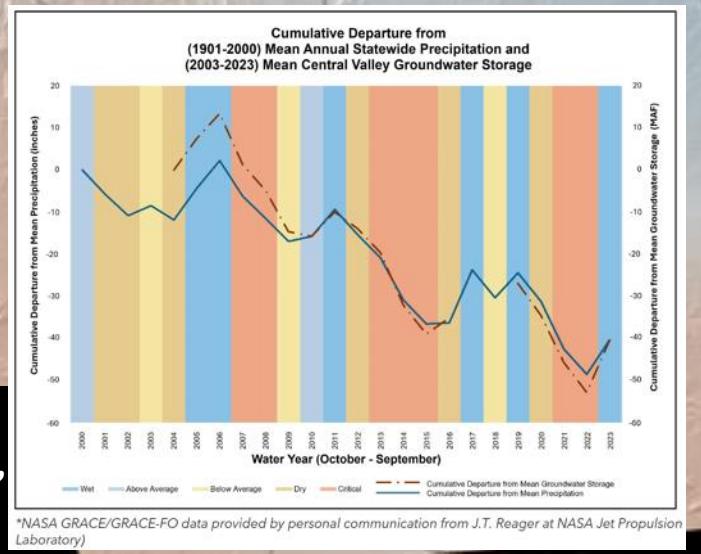


- Record rain/snow accumulation in winter 2022/2023 came on top of large ‘groundwater debt’
- Aquifer recharge is a slow process – will take many years
- The *CA Sustainable Groundwater Management Act* mandates sustainable groundwater management

GRACE-missions inform Groundwater Management by California's *Department of Water Resources (DWR)*







*NASA GRACE/GRACE-FO data provided by personal communication from J.T. Reager at NASA Jet Propulsion Laboratory)

Earth Science in Action:

On a semi-annual basis, provides '*insight for the regional changes in groundwater',* and *'to help inform science-backed management'*.

GRACE(-FO) observations address their crucial need '*for sustainable groundwater management practices to ensure water resiliency amidst ongoing climate challenges [...].'*

Mission Updates since last STM (10/2023)

GRACE-FO:

- Programmatic & Mission Events
- Science Data Performance & Quality
- Near-term Plans & Outlook

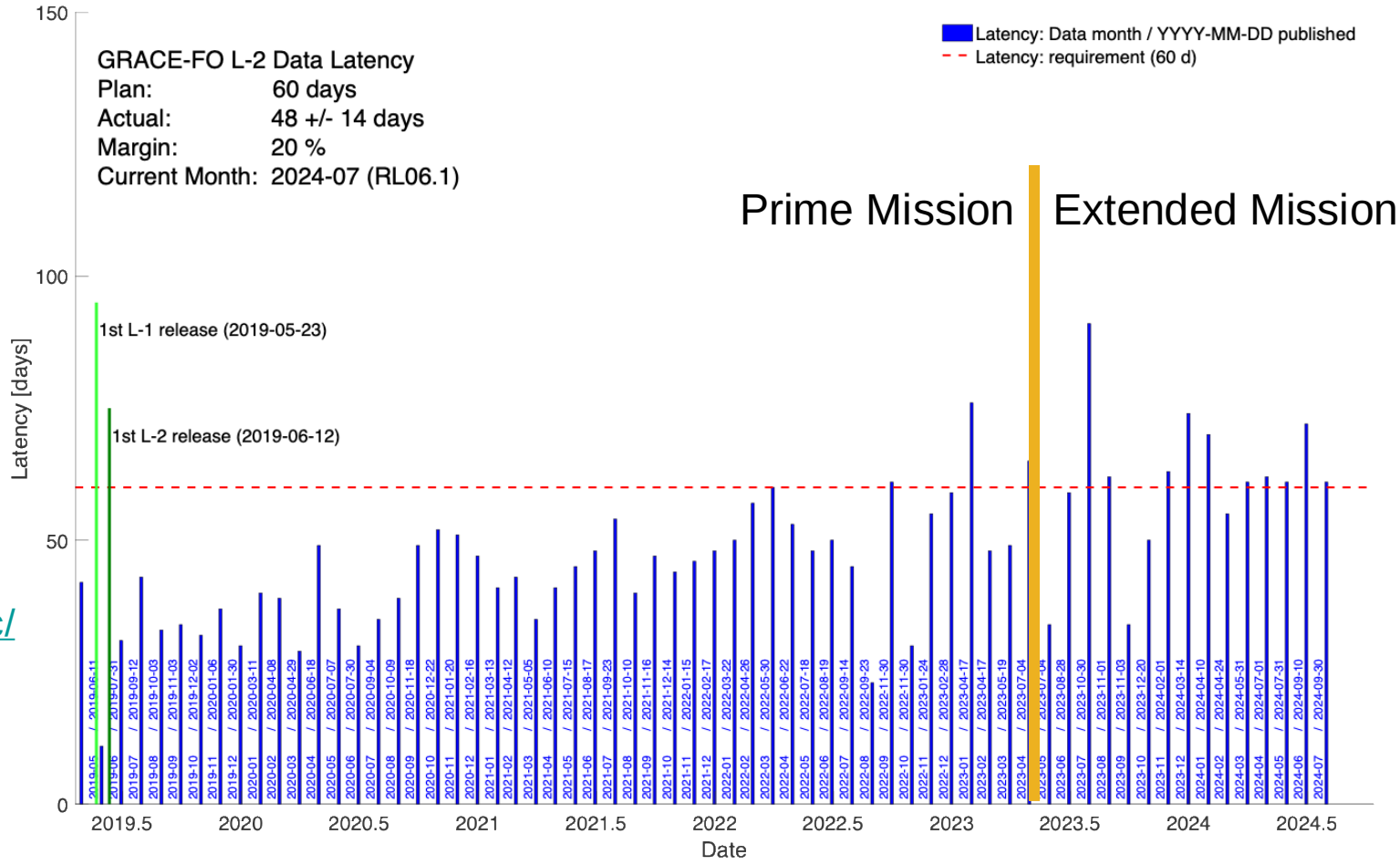
Mission Updates since last STM (10/2023)
Bottom line: GRACE-FO is healthy and delivering good science data!

- Mission is in its ‘extended mission’ phase (since 6/2023)
  - Mission operations at GSOC are secured by GFZ funding till May 2026; proposal for continuation till December 2029 was requested by GFZ
- Uninterrupted science data collection / processing for climate data record continuity
  - Since mission start, delivered 72 monthly gravity/mass change data products at a level consistent with GRACE (see Level-2 talks in this session)
  - Wide-pointing mode continuously enabled since 07/2023 has prevented further AOCS thruster leak growth (no LRI data in this mode)
  - Further improved accelerometer ‘hybrid-transplant’ can deal effectively with high-drag environments (talk by Chris McC) -> SDS talks on new data releases RL06.3
  - Currently going through a repeat-orbit altitude range (Sep/Oct 2024; 4-day repeat 472-468.5 km) leads to reduced quality of gravity fields during this period
- No major issues with operations, spacecraft & science instruments
  - Nominal activities (see MOS talk for details)
- Solar Cycle 25 is peaking at high levels as expected (SOM talk)

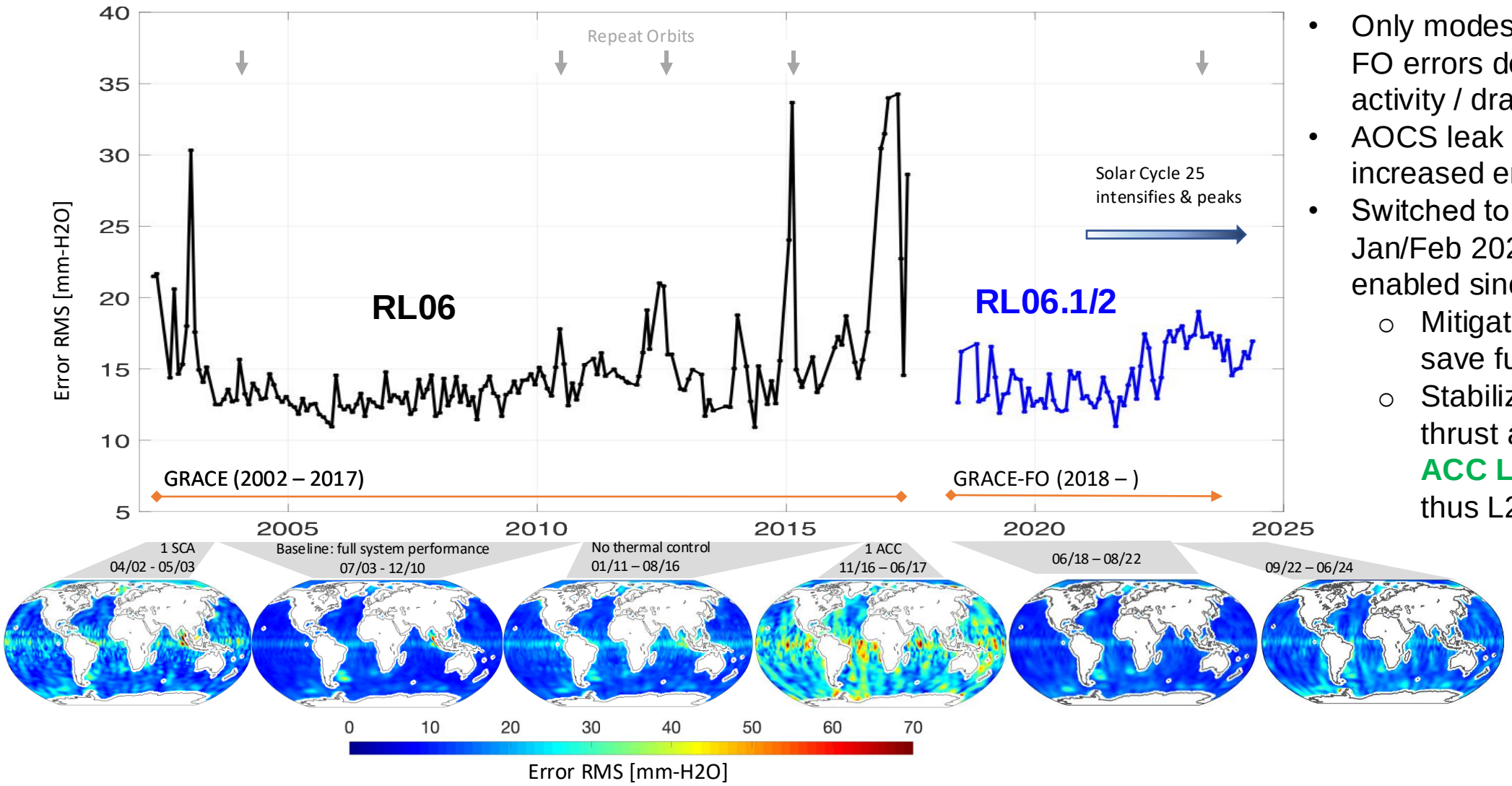
GRACE-FO: SDS Data Product Status

- Steady delivery of:
  - L-1 (weekly bundles)
  - L-2 (monthly)
  - L-3 (monthly)
  - L-4 (monthly)

- SDS data portals:
  - GFZ ISDC
    - https://isdc.gfz-potsdam.de/grace-fo-isdc/
  - JPL PO.DAAC
    - https://podaac.jpl.nasa.gov/GRACE-FO

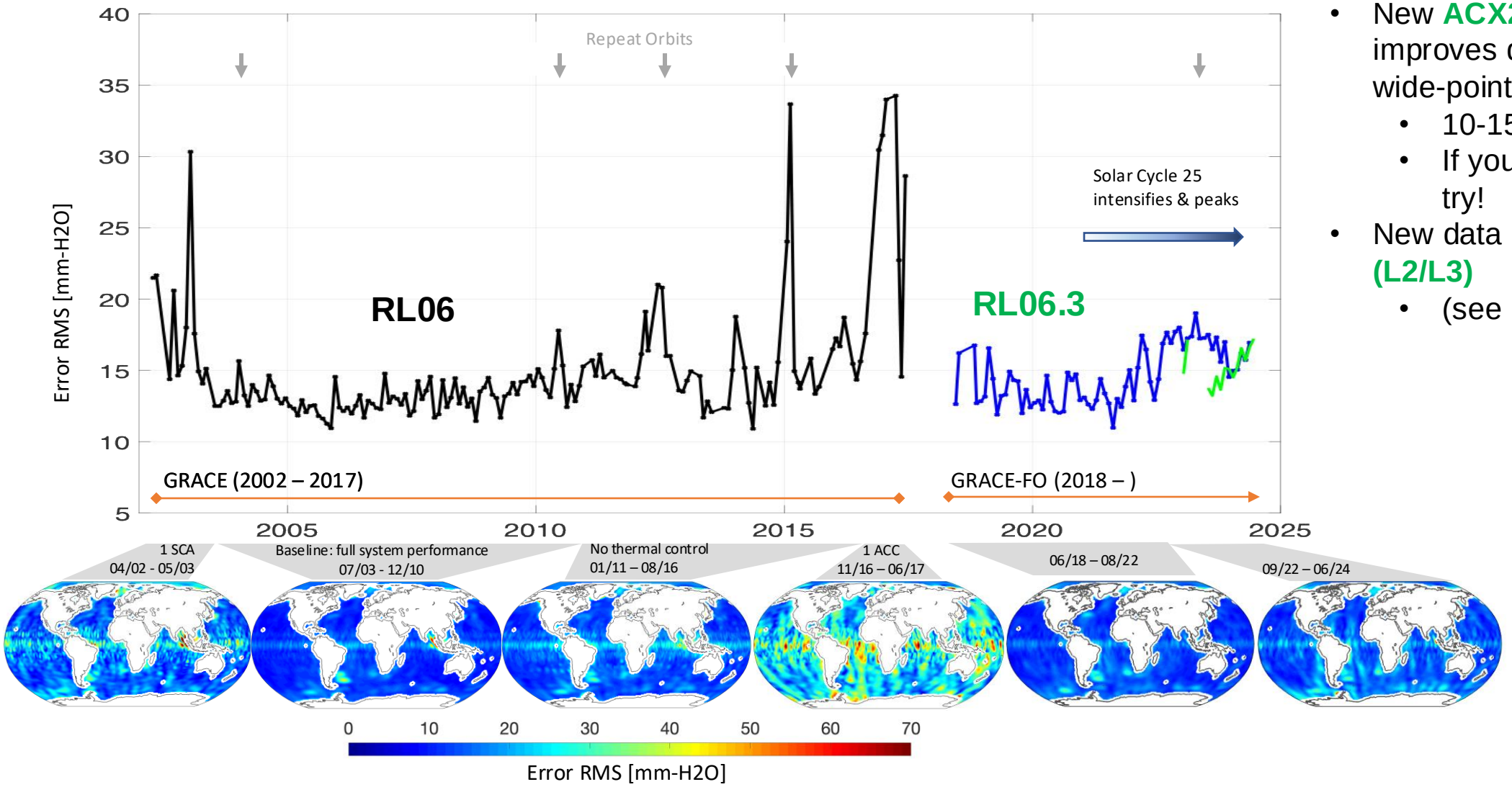


Science Performance & error levels: Ocean RMS is stable in recent very high drag environment



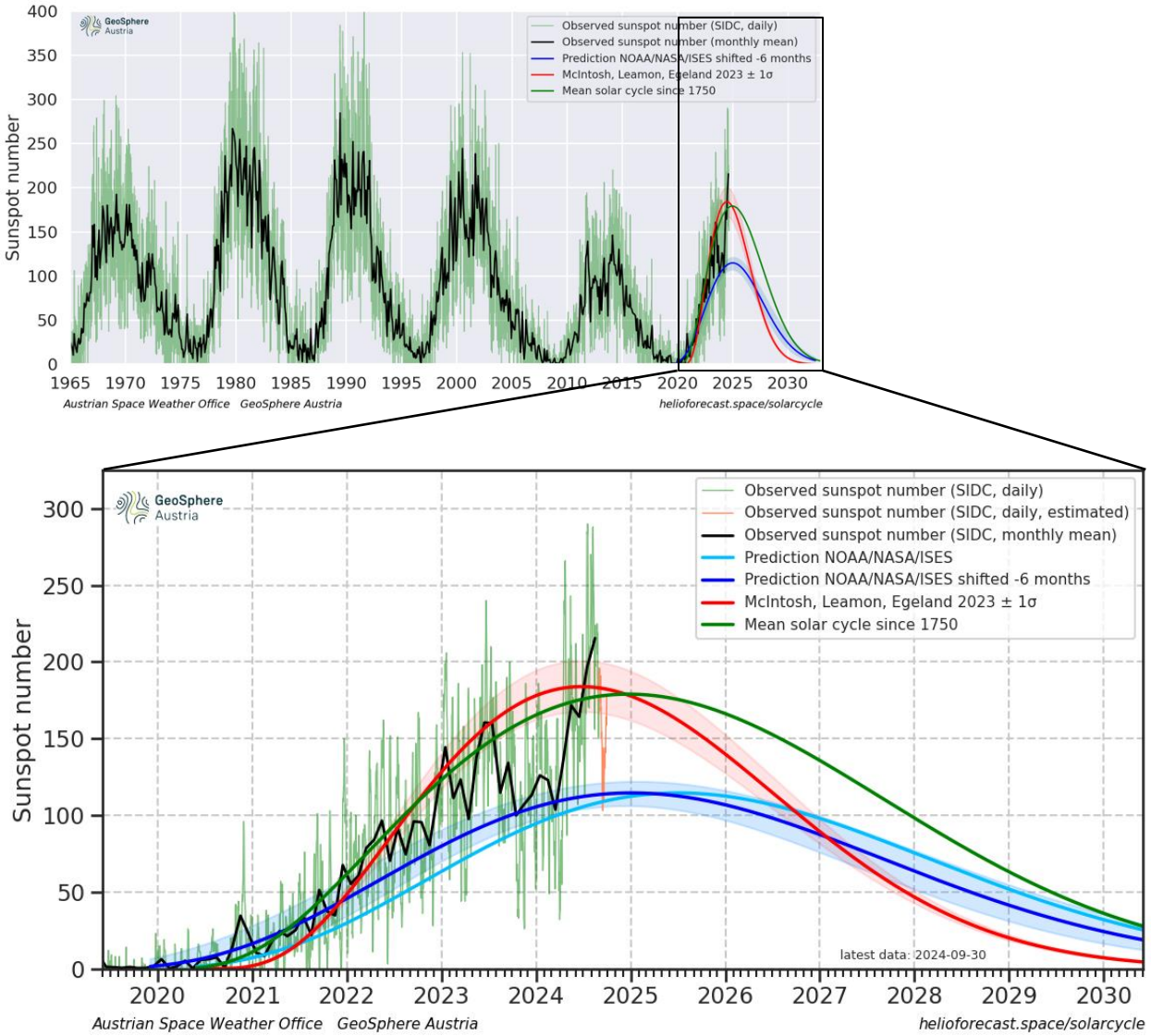
- The data record between GRACE and GRACE-FO is consistent
- Only modest increases in GRACE-FO errors despite very high solar activity / drag since late 2021
- AOCS leak at thrusters also increased error levels in 2022
- Switched to ‘wide pointing’ mode in Jan/Feb 2023, continuously enabled since Jul-2023
  - Mitigates leak increase to save fuel & increase lifetime
  - Stabilizes leak and lowers thrust actuations, **improving ACC L1 calibrations**, and thus L2 / L3 data quality

Science Performance & error levels: Ocean RMS is stable in recent very high drag environment



- New **ACX2 ACC calibration** improves data performance in wide-pointing mode:
  - 10-15% RMS reduction
  - If you haven't yet – give it a try!
- New data released as **RL06.3 (L2/L3)**
  - (see L1 talk later)

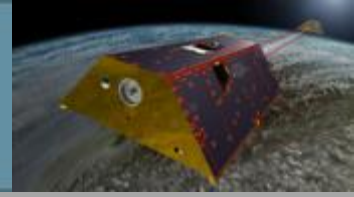
Outlook: Solar Cycle #25 is peaking – challenging space craft drag environment will persist



- High SC25 activity impacts science data quality (mainly through accelerometer-transplant errors)
- Elevated SC activity (i.e., above mid-2022 levels) expected for another 2-3 years
- Despite high solar activity, science data quality is good & stable
- Orbit raises currently not planned; project team will assess orbit raises as SC25 quiets down

(https://helioforecast.space/solarcycle)

Laser Ranging Instrument: several teams have done lots of new analysis of the existing LRI data (2018 – 2023)



Instrument:

- LRI experience 2018-2023: very stable, very low operational overhead
- While LRI link cannot be maintained in wide pointing mode, instrument is ON in diagnostic mode (No life limiting parts, LRI still accumulating lifetime)
- All LRI components are healthy (i.e., LRI link can be re-enabled in relative fine-pointing mode)
- GRACE-C will feature the LRI as the only ranging instrument (with added redundancy) – see talk by F. Flechtner, Thur)

Science Data:

- LRI range measurements are well characterized, performing better than required
- LRI and MWI geophysical signal content very consistent (2018 - 2023)

Several talks in this meeting will discuss new LRI results & insights – stay tuned!

GRACE-FO Mission Status - Summary

- Achievements 2023/2024:
  - Uninterrupted collection of high-impact gravity, mass change & GPS-RO observations, producing excellent science results & applications across all Earth system domain & extending the GRACE data record
  - SDS team further advanced the ACC data calibrations, yielding improved L-1/2/3/4 science data products (released as ACX2, RL06.3)
  - Switch to 'wide-pointing' mode halted thruster leak-growth, benefitting data performance & lifetime
- Outlook & Plans:
  - Nominal spacecraft operations (wide-pointing mode for now with LRI in diagnostic mode)
  - Reprocessing of GRACE and GRACE-FO (RL07) is on track for 2025 release
  - Fuel budget and orbit decay outlook is favorable for overlap with NASA / DLR *GRACE-Continuity* mission, targeted to launch 12/2028

Next GRACE-FO Science Team Meeting: *(likely)* 7-9 Oct, 2025 @ TBD, US.