Part 1 Questions & Answers Session A

Please type your questions in the Question Box. We will try our best to answer all your questions. If we don't, feel free to email Amita Mehta (amita.v.mehta@nasa.gov) or Dr. Matthew Rodell (matthew.rodell@nasa.gov). This document will be shared to the training webpage within one week.

Question 1: Does the distance between both sensors change sometimes?
Answer 1: Yes it does. It can vary by 10s of km over the course of the mission.

Question 2: How can multi-source satellite data be combined to reduce uncertainty in groundwater estimation, and what are the limitations of this approach for decision-making?
Answer 2: GRACE/FO data are the only that provides a measurement directly related to changes in groundwater. Other satellites can give an idea such as NISAR can provide supporting information on ground surface deformation that is associated with aquifer compaction, but there is not a direct relationship with groundwater storage levels. Other water cycle observations are critical for interpreting GRACE/FO data.

Question 3: Is the GRACE satellite mission suitable for monitoring terrestrial water storage changes in archipelagic countries such as Indonesia?
Answer 3: No, the problem is the islands are smaller than the spatial resolution of GRACE.

Question 4: How can uncertainty in satellite-derived groundwater estimates be effectively communicated to policymakers, and are there probabilistic or machine learning approaches—such as mixture density networks—that can better characterize the multi-source uncertainty inherent in groundwater estimation?
Answer 4: We found you have to speak the policy maker's language to be actionable. Working with stakeholders to develop products tailored to their specific needs. We are just starting to use AI/ML to develop products for these stakeholders

Question 5: Does vegetation contribute to these anomalies or depletion that we see, for example, in the Himalayas (North India)? And maybe the mountain glacier retreat?

Answer 5: Glacier retreat, yes. We can see a component of GRACE data resulting from reduction of glacial mass. Vegetation: those changes (<0.5 mm/year) are below the uncertainty range of GRACE

Question 6: I would like to know what the observation depth of GRACE data is in the subsurface. In other words, is it useful for evaluating, for example, anomalies in deep, confined aquifer systems?
Answer 6: 1) GRACE is not limited by depth because it is measuring changes in mass. 2) In a confined aq, there is not a 1 to 1. Water pressure measured in a piezometer cannot be easily translated to change in mass storage.

Question 7: Has anyone investigated GW storage changes in areas experiencing "mysterious" earthquakes not related to fault zones, like in the Great Plains or Louisiana?
Answer 7: We are not aware of research in this area.

Question 8: How can we design a unified probabilistic data fusion framework that integrates multi-scale satellite observations and hydrological models to robustly estimate groundwater under uncertainty?
Answer 8: This could be a proposal for research.

Question 9: Given the archipelagic nature of the Philippines, how useful would GRACE data be? Is there a way to overcome the pixel limitation for island nations?
Answer 9: As with the answer to a previous question, the coarse spatial resolution prevents distinguishing mass variations in the island from those in the ocean.

Question 10: How do you practically go about deseasoning? Illustrate it so well that anyone can do that.
Answer 10: Estimate the monthly seasonal cycle and subtract the mean January from each January, etc.

Question 11: To what extent can groundwater depletion, inferred from GRACE-based terrestrial water storage anomalies, act as a predictor or amplifier of compound climate extremes such as heatwaves and wildfires?
Answer 11: When terrestrial water storage is lower, the land is drier, veg is not as moist as it could be. Those conditions make it more likely for a wildfire. This is an active area of research.

Question 12: In the charts section for GRACE-FO, why not replace no data with nulls?
Answer 12: We will provide this feedback to the developers.

Question 13: What does deseason mean?
Answer 13: Deseason means that you have a time series of GRACE, you will see a natural seasonal cycle. To deseason, we use a stats approach to estimate and remove that cycle to see non-seasonal changes. That way we can more easily see anomalies relative to normal for a given time of year.

Question 14: How can you get the actual value of TWS in water volume rather than water equivalent thickness?
Answer 14: You multiply the WET by the area. You will have to convert the units.

Question 15: Hi, great talk. I am interested in the analysis tool and I have a couple of questions. 1) The option detrend data, how is it detrending the dataset? 2) There are 2 datasets: JPL water equivalent and CSR water equivalent. I see that CSR has better spatial resolution, but can you expand on the differences of these datasets? 3) I have never used GRACE but I am interested in using it. I was wondering if these results would be the same/similar as downloading the mascons and plotting the data myself?
Answer 15: CSR provides data on a finer grid for convenience, but the effective spatial resolution remains the same. You still must average the pixels over a sufficiently large region (>150,000 km2) for the results to be meaningful. The centers process GRACE data in different ways, each with benefits and drawbacks, so comparing is problematic. I recommend choosing one and focusing on the science.

Question 16: Could a GRACE-like mission detect temporal mass changes on Mars, and what magnitude of water movement would be required for detection?
Answer 16: If there were significant mass changes on Mars, a GRACE like mission could detect those. If water is not moving (most likely it is not moving on Mars), then there would be no value in such a measurement.

Question 17: Can I find the GWT depth through this, in a 20 sq km area?
Answer 17: Not with GRACE alone. GLDAS 2.2, which integrates GRACE and other data, are available on a .25 degree grid.

Question 18: How do you get the GWT data from this TWT?

Answer 18: To isolate GW storage changes from TWS, one must either (1) subtract independent estimates of soil moisture, surface water, and snow/ice storage changes from TWS, or (2) use a data assimilating land surface model, e.g., GLDAS 2.2.

Question 19: Can you please help me regarding how to create or get started to prepare such interactive web browsers?
Answer 19: We will provide reference material.

Question 20: Is it possible to upload our own basin in a shapefile format? Or is there another way to download the data more systematically and more locally?
Answer 20: We will cover this in Part 2 of this series. You cannot upload your own shapefile. But downloading and using it in a GIS where you can use your shapefile for analysis.

Question 21: Do we need the newest QGIS version for the next exercise?
Answer 21: The procedure is based on the newest version.

Question 22: For identification of a regional signal: Can you recommend practices for combining multiple mascons for a single product or for multiple products (JPL, CSR, GSFC) to estimate TWS and the uncertainty of TWS? E.g., if you calculate a mean time series should some weighting be applied to de-emphasize mascons at the edge of the basin? Or: would you say that the full range of all mascons across all products represents the uncertainty for a region?
Answer 22: There's not much value in combining mascons from different centers. It could have the unintended consequence of damping the mass change signals. Mascon products attempt to account for and minimize leakage. Weighting interior mascons higher than edge mascons could potentially reduce errors slightly but I can't advise it.

Question 23: What does water thickness mean?
Answer 23: WT is used to explain a mass change (kg of water) and equate that to eq height of water. Imagine if you took all the water from the aquifers, soil, snow, ice, and surface water and ponded it on the surface. Changes in the depth of that pond would be equivalent to the water thickness changes reported by GRACE.

Question 24: Do Level 3 products account for regional earthquakes (such as the 2023 Turkiye-Syria earthquake)? If studying a region like this for groundwater depletion, should the impact of seismic events be taken into account?
Answer 24: We have seen that the EQ has to have a magnitude of at least 8 for it to have a significant effect on the recovered mass change signal. In those cases, GRACE

processing attempts to account for and remove the earthquake signal, but it is not perfect.

Question 25: How good is the GRACE data if I want to check the correlation between levee subsidence and groundwater. Or is it good when analyzing a large area?
Answer 25: Mass change associated with levee subsidence is likely too small to detect using GRACE. GRACE can detect the filling of very large reservoirs such as the Three Gorges Dam reservoir in China.

Question 26: The tool indicates that the information is water thickness. Does it mean the thickness of the water above and below the ground? Is it ignoring the layers of soil in between?
Answer 26: All water on and below the surface and combine into one. Yes, it would be ignoring the soil layers because soil mass is not changing.

Question 27: Does this exercise have to be done now? I mean in the live session or there is a deadline to it?
Answer 27: It is not due today. You will have between April 30th and May 15th (when the homework is due).

Question 28: There is a question in the exercise that says to move the month year to July 2021 and then it follows with a question regarding July 2022; should we use July 2022?
Answer 28: You are checking all the years so you will.

Question 29: Could you please repeat what the vertical line on the plot was?
Answer 29: It is the place for multi-year, it shows the month and year and the TWS anomaly.

Question 30: Are there any attempts made to downscale the grace data for smaller watersheds or high-resolution impact studies?
Answer 30: There are efforts with GLDAS 2.2 that incorporates precip, soil types, and other high-resolution data. ML approaches are being explored.

Question 31: Could GRACE data be used in water budget preparation for HUC 8 (subbasin) scale to compare/ground truth with well data collected locally? For example, could ET, Precip, Soil Moisture, and Snow Water Equivalent from other

satellite data/models be combined to get change in groundwater to compare with local wells?
Answer 31: HUC 8 basins are too small for GRACE data to be useful. GRACE data assimilation products, e.g., GLDAS 2.2, may be useful.

Question 32: Can you plot multiple data (model) on the same chart for comparison?
Answer 32: You should have to download from 2 different timeseries and combine.

Question 33: When will the present data (March/April 2026) be available?
Answer 33: 3-4 months after real time due to the degree of processing needed.

Question 34: I wonder if we have options for downscaling this GRACE data so it can fit for analysis in an archipelago and whether there are some approaches to mitigate the leaked signal problems on the edge of land.
Answer 34: Please see the answer to question 3. An island must be at least 150,000 km2 for GRACE to isolate a mass change signal, and even then, signal leakage from the ocean would create large uncertainty

Question 35: Can we interpret Water Equivalent Thickness (WET) data to identify regional wet and dry periods influenced by flood events?
Answer 35: If you have a flood, there is more water so you should see an increase. Flash flooding will not be detected because it typically lasts significantly less than a month.

Question 36: For oil and gas basins, is it possible to measure changes in mass due to water levels vs. changes in oil and gas levels?
Answer 36: Even in regions with the most oil production, the resulting mass changes are much smaller than water storage changes.

Question 37: I am not quite sure which sea basin to use for California: San Francisco Coast or California Gulf? Can you give a hint, please?
Answer 37: Not for a basin, just the state of California.

Question 38: Given the coarse resolution of GRACE data, what is the best way to apply it to small basins? Is it better to use mascon products or combine GRACE with hydrological models?
Answer 38: Combining GRACE with hydrological models via data assimilation can improve the spatial resolution. See next week's GLDAS 2.2 training.

Question 39: Could water pollution be masking something?
Answer 39: No, chemical constituents of the water are irrelevant for mass change detection.

Question 40: What is the unit for the ΔGW? Does it show us the changes in the volume of the Groundwater or the water table changes?
Answer 40: Units are cm (or sometimes mm) equivalent height of water. Multiply those by the area of the region to get volume (after making units consistent)

Question 41: Does the tool accept a shapefile of a study area?
Answer 41:

Question 42: I want to create a mathematical model of an aquifer in the city where I live (Huanuco, Peru). I want to know if I can derive the boundaries of the aquifer I will be using from the Grace Mission?
Answer 42: GRACE cannot tell you the boundaries of an aquifer.

Question 43: What methods or assumptions are required to estimate agricultural water withdrawal from GRACE total water storage signals, and how reliable are these estimates at seasonal versus annual scales?
Answer 43: One would need to know the other inputs and outputs to the water budget (precipitation, runoff, etc.) and compute agricultural water usage as a residual.

Question 44: So Grace is basically measuring the land movement that we can generate using SAR Interferometry?
Answer 44: No. GRACE measures mass changes based on their influence (via gravity) on the orbits of two satellites. SAR interferometry measures changes in surface elevation.

Question 45: For regional studies like the Ganges-Brahmaputra basin, what is the best approach to 'downscale' the coarse GRACE-FO resolution (~300km) using Python or Machine Learning to make it actionable for local water resource management?
Answer 45: There is no way to downscale GRACE data without auxiliary information, such as one would get from a land surface model.

Question 46: What methods or assumptions are required to estimate agricultural water withdrawal from GRACE total water storage signals, and how reliable are these estimates at seasonal versus annual scales?

Answer 46: One would need to know the other inputs and outputs to the water budget (precipitation, runoff, etc.) and compute agricultural water usage as a residual.

Part 1 Questions & Answers Session B

Please type your questions in the Question Box. We will try our best to answer all your questions. If we don't, feel free to email Amita Mehta (amita.v.mehta@nasa.gov) or Dr. Matthew Rodell (matthew.rodell@nasa.gov). This document will be shared to the training webpage within one week.

Question 1: Is there some kind of geoid model that GRACE & GRACE-FO use?
Answer 1: Yes, more information can be found here.

Question 2: What is the speed of the GRACE/GRACE-FO satellites? Also, it covers one region once in a month or satellites can cover one region more than 1 time in a month?
Answer 2: 7K per second to remain in orbit at that altitude. There are images on spacing of the tracks.

Question 3: Are GRACE data used in hydrological studies at the drainage-basin scale after downscaling?
Answer 3: We will address downscaling in Part 2. Data integration allows you to get down to 25 x 25 km.

There are efforts with GLDAS 2.2 that incorporates precipitation, soil types, and other high-resolution data. Machine learning (ML) approaches are being explored.

Combining GRACE with hydrological models via data assimilation can improve the spatial resolution. See next week's GLDAS 2.2 training.

There is no way to downscale GRACE data without auxiliary information, such as one would get from a land surface model.

Question 4: At the start of the presentation you noted that GRACE data is a total gravity change. When working with the Data Analysis Tool has the total gravity been "corrected" to just the groundwater portion of the change?
Answer 4: Total Terrestrial water storage is shown in the analysis tool. It detects changes from month to month in mass (redistribution of terrestrial water storage).

Question 5: One quick question—since GRACE satellite mission measures total water storage, how can we distinguish between layers like the shallow aquifer

and the Memphis Aquifer? Also, does GRACE have a depth limit, or does it integrate over the full subsurface column?
Answer 5: There is no depth limit because it is changes to the gravitational field. You will need additional data. GRACE is not limited by depth because it is measuring changes in mass.

Question 6: Is there a color scale somewhere? I don't see it.
Answer 6: It is on the upper right corner. It is a continuous scale.

Question 7: Is it necessary to take into account the surface water storage change for large basins, eg. Amazon or Paraná basin, to get water balance and/or water storage components disaggregation?
Answer 7: Wet tropical basic, TWS changes tend to be more dominated by SWT. SWOT mission used radar to measure height of surface waters that can be used in higher precision. Using that with GRACE data

Question 8: How is TWS used to measure droughts?
Answer 8: When we look at deseasoned data you are left with the non-seasonal anomalies so when it goes negative, you are seeing drought conditions.

Question 9: How are grid values handled in the analysis when the river basin boundary only partially overlaps a grid cell?
Answer 9: They are weighted according to the grid area of the basin.

Question 10: Why are Level 3 data significantly different between products? For example, JPL vs. CSR. How do you best decide which product to use?
Answer 10: Please view this resource. Most basins over a long period the differences between the two products. They are processed in diff ways so comparing is problematic. I choose one and focus on the science.

CSR provides data on a finer grid for convenience, but the effective spatial resolution remains the same. You still must average the pixels over a sufficiently large region (>150,000 km2) for the results to be meaningful. The centers process GRACE data in different ways, each with benefits and drawbacks, so comparing is problematic.

Question 11: Is it possible to use GRACE data for basins as small as 18000km2? What methods would you recommend to process or 'downscale' the data for use at that scale?

Answer 11: There is no way to downscale GRACE data without auxiliary information, such as one would get from a land surface model.

Question 12: Does el Niño and la Niña affect the changes in Global TWS?
Answer 12: Yes, you can find maps online showing the correlation between TWS and precipitation.

Question 13: Question to Matthew: Is there a dataset obtained with a study dealing with filling the data gap between the successive GRACE missions that you consider reliable?
Answer 13: GLDAS 2.2 can be used to fill that gap. It is far from perfect. Machine learning (ML) approaches have been used as well.

Question 14: What is the difference between the normal data and the deseason data? What method is used to deseason the time series? Can you explain the deseason data? What is it and how is it different from the standard data and how do you apply it?
Answer 14: Deseason means that you have a time series of GRACE, you will see a natural seasonal cycle. To deseason, we use a stats approach to remove that cycle to see non-seasonal changes. That way we can see anomalies relative to normal. (Drier or wetter seasons).

Question 15: What is the planned lifecycle of the GRACE-FO mission? Will there be a successor after decommission?
Answer 15: GRACE FO has an issue with an onboarding accelerometer. GRACE-C (Continuity) should launch in 2028.

Question 16: Beyond resolution what are the differences between JPL data and CSR data? Why is the resolution way better for CSR?
Answer 16: The grids these centers provide are not the same as the effective resolution. CSR is just provided at a finer grid. CSR provides data on a finer grid for convenience, but the effective spatial resolution remains the same. You still must average the pixels over a sufficiently large region (>150,000 km2) for the results to be meaningful. The centers process GRACE data in different ways, each with benefits and drawbacks, so comparing is problematic. I recommend choosing one and focusing on the science.

Question 17: Please summarize for us how underground water can be quantified and monitored using GRACE? how many satellites are involved in the process and what about the in-situ data are they required ?
Answer 17: GRACE is not limited by depth. It monitors the change in gravity. There are 2 satellites associated with GRACE.

Question 18: About the exercise, is there any website or email to submit? Where will we upload our answers to the questions?
Answer 18: You will submit your answers in the homework assignment after the training. It will be posted under Part 3.

Question 19: I would like to know how to interpret the values shown in the JPL website. Are those time series TWS anomalies? If so, which is the time base period?
Answer 19: Yes, they are anomalies - or change in TWS compared to 2004-2009 period. We will confirm this.

Question 20: Just wanted to reiterate the questions whether we could download data in .csv format for further analysis. Can we get the GRACE data in excel or CSV files for further analysis?
Answer 20: Yes, you can download and use in a GIS for analysis. In part 2 of this series. You cannot upload your own shapefile. But downloading and using it in a GIS where you can use your shapefile for analysis.

Question 21: Is there no data for 2017/2018?
Answer 21: Yes, that is correct.

Question 22: How can we validate downscaled GRACE data?
Answer 22: Validation relies upon in situ observations. Groundwater well data (unconfined aquifers).