



Part 2 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: How does the assimilation work daily when GRACE and GRACE-FO are monthly?

Answer 1: We use an ensemble Kalman smoother data assimilation approach that compares the monthly anomalies from the observation with those in the model and then adjusts the model incrementally over that month using information on the relative uncertainty in both estimates. See [this article](#).

Question 2: I derived reservoir surface area from Sentinel-1 SAR imagery. Can this be extended to estimate reservoir volume, and under what assumptions would this be valid?

Answer 2: This training is focused primarily on groundwater data. But to answer your question, additional data will be needed to estimate reservoir volume, such as bathymetry. If you are interested in the volume of water in the reservoir, water level height will also be required.

Question 3: How well does RZSM from GLDAS represent seasonal soil moisture dynamics in agricultural regions, considering differences between summer and winter crops and the impact of irrigation?

Answer 3: GLDAS 2.2 does not simulate irrigation, thus there could be substantial differences between on the ground soil moisture and GLDAS 2.2 where and when there is irrigation.

Question 4: Is there a reference to look up the formula to convert well data using specific yield to compare this with GLDAS?

Answer 4: Finding the specific yield data will be the more difficult part. It changes from location to location, availability, etc. Sand or gravel will have a higher yield. Clay or sandstone the yield will be low. Formula: $dGW = -Sy * dDTW$, where dGW is the change in groundwater storage in cm, Sy is the specific yield (unitless), and $dDTW$ is the change in depth to water measured in a well. Sy typically ranges between 0.02 and 0.50. This formula only works for measurements in unconfined aquifers.



Question 5: Does terrestrial water storage data also include information on water pollutants, and does it vary based on differences in geographic location?

Answer 5: It does not have information on pollutants.

Question 6: When groundwater elevations drop, eventually stream base flow drops, then "disappears" and the stream runs dry. This has been observed in western and central Kansas. Has anyone looked at time series of streamflow data, looking for gauges transitioning from perennial to intermittent flow regimes, with base flow as an indicator of drought/climate change/human impacts?

Answer 6: Google Scholar would be the best place to investigate this further.

Question 7: When we calculate anomalies in GLDAS 2.2, what years do we use for normalization?

Answer 7: You can use any baseline period by averaging the GLDAS 2.2 data over that period and subtracting that average from the GLDAS 2.2 time series.

Question 8: If we want monthly estimates of soil moisture change for the CONUS that include conditioning on remotely sensed soil moisture, should we use GLDAS2.2 or a version of NLDAS?

Answer 8: If CONUS, NLDAS has the higher spatial resolution and typically better input meteorological forcing data.

Question 9: I'm looking to analyze drought patterns across southern Alberta and would like to compare GRACE-based drought indicators with existing groundwater well records in the province. Are there any guidelines you can suggest for the best types of wells to use for such an exercise? Do I need to select between active and inactive wells for such analysis?

Answer 9: 1) it should be a well in an unconfined aquifer. 2) The longer the data record the better. Active wells for current conditions. 3) You don't want to use one that is actively pumping or close to a water supply well, as it will not represent large scale ambient groundwater conditions.

Question 10: I am unsure if I understood the reach of GLDAS. Is it a model that incorporates different datasets? Are the outputs only for the US territory? If that is the case, can we modify the code to use in other areas? Do we have to provide the input data (e.g., groundwater levels)?



Answer 10: GLDAS is a Global Land Data Assimilation System. It is global and incorporates numerous input datasets.

Question 11: For the assignment are we supposed to use Giovanni only or can we use a dataset from Google Earth?

Answer 11: For this exercise, you will just use Giovanni and QGIS.

Question 12: As lakes don't really flow, is it easy to capture its decrease in volume?

Answer 12: Most lakes are too small to influence GRACE observations, though they can have a collective effect on observed TWS changes in regions like Minnesota and parts of Canada where lakes dominate the landscape or over very large lakes like the Great Lakes. GLDAS 2.2 does not simulate lakes specifically.

Question 13: How can we interpolate to the extent to all river basin cover?

Answer 13: QGIS has a function to interpolate data within a mask.

Question 14: What is the latency of GLDAS 2.2? Can it be used for early warning?

Answer 14: GLDAS 2.2 EP (extended period; includes the model simulation after the most recent GRACE-FO is available) is delivered to GES DISC within 1-2 weeks of present. So, depending on the application, it can be used for early warning. Earthdata search can provide lower latency data.

Question 15: Why is GLDAS data available up to January 2026?

Answer 15: There is a 1–2 month data latency on Giovanni. GLDAS 2.2 EP products can be downloaded from GES DISC with a 7–14 days latency.

Question 16: Do we need to reproject the data before adding to QGIS?

Answer 16: Not necessary.

Question 17: The map visualization part can also be done using ArcGIS right? Are there any advantages of using QGIS for this?

Answer 17: Yes, you can use ArcGIS. We use QGIS as it is open source and free.

Question 18: For the demonstration, I am a little confused about what I am seeing. I selected my region of interest close to the coastline. There are some areas that do not have information. Can you explain why some areas may not have info? Secondly, the results show the time averaged groundwater storage, in



an area where the aquifer system has several layers, is this average the total of all the layers or does it go only to a certain depth?

Answer 18: If you are talking about the GRACE interactive browser, it is possible that some coastal areas are missing due to GRACE/FO data resolution. Averaged groundwater storage is total over all depths, not a particular layer.

Question 19: I see data for up to 2014 for time averaged maps. How do I access up to the current date?

Answer 19: You can change the year/month/day in the Giovanni time selection window.

Question 20: Are there corrections for "development," such as urban buildout, mining, etc.?

Answer 20: Mass changes associated with urban development are much smaller than TWS mass changes are well below the uncertainty level of the data.

Question 21: I got this message: Error: Sorry, but the visualizer may be taking too long. Please select a smaller spatial region or time range. How do I fix this?

Answer 21: Please try it in a few minutes. It should work for the region and time range given in the exercise.

Question 22: Can we use this groundwater data to calculate the velocity or rate of change of groundwater of any area?

Answer 22: Yes, you can compute the rate of change from a time series of TWS in a given region.

Question 23: Is this data available on Google Earth Engine? If yes, then it shouldn't be a problem reducing the entire time-series to a single mean image.

Answer 23: Some GLDAS is available on GEE; not sure about 2.2.

Question 24: Is it better to correlate change in ground with Sentinel-1 InSAR of the same location to determine the reason for uplift or subsidence? I'm asking this while considering injection wells.

Answer 24: GLDAS does not simulate injection wells and their effects on mass would be too small to be distinguished in GRACE-FO observations.

Question 25: How long does it usually take to plot data?

Answer 25: Depending on the spatial domain and temporal range, it may take from a few seconds to a few minutes.



Question 26: Do we need to upload our output somewhere or exercise questions based on this task?

Answer 26: You will not be uploading any output, though homework questions will be based on these tasks.

Question 27: Referring to the Key Limitations on Slide 31, it is noted that GLDAS 2.2 does not simulate groundwater pumping. In the context of Indonesia, particularly in regions dominated by massive localized pumping for large-scale mining operations, how severely does this limitation skew the GRACE/FO downscaled data? Does the model misinterpret this localized anthropogenic depletion as a broader climate-driven anomaly?

Answer 27: It is a significant limitation. Pumping is not simulated by the model. Further, GRACE observations are too coarse for Indonesian islands, so that uncertainty due to improperly accounted ocean mass variations will be an issue.

Question 28: Is it possible to have the time series from each pixel in the area? There are big changes in the same region, it would be interesting to see each.

Answer 28: Yes, you can enter single pixel coordinates in the Giovanni, and you can get a time series for that pixel.

Question 29: Are you still available for questions after the last session if we have problems with the homework?

Answer 29: Yes, we will be available to answer questions after the last session.

Question 30: From Part 1, TWS data means the water thickness data that we take from the GRACE interface and have plotted. Is that correct?

Answer 30: Yes, that is correct.

Question 31: This multi-year average map is great for long-term trends. But let's say that last year was a drought year. Can this product tell me if last year was unusually bad compared to normal conditions? Or is it only useful for decadal stuff?

Answer 31: Yes, drought monitoring is one of the main applications of GLDAS 2.2.

Question 33: When you say 'groundwater storage' in this model, are we actually measuring groundwater, or are we just calculating whatever is left over after we subtract soil, snow, and plants from the GRACE satellite?



Answer 33: Those factors and many more. We are calculating using a model simulation. See [this article](#).

Question 34: How do we actually do the data assimilation? What are the data sources?

Answer 34: See [this article](#).

Question 35: I am looking for groundwater anomalies on the East Coast of James Bay. Unfortunately, there is no observation or any kind of well. What is your suggestion for the validation and the comparison? What can I do for downscaling?

Answer 35: Over most of the globe there is not in situ data available. GLDAS 2.2 downscales GRACE-FO data to 0.25 degree resolution. Further downscaling would require information about aquifer properties and other fine scale information.



Part 2 Questions & Answers Session B

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Question 1: How can we move from using GRACE as a historical monitoring tool to an active forecasting tool? Are there specific data assimilation techniques you recommend for integrating GRACE-FO (Follow-On) data into local hydrological models?

Answer 1: 2.2 GLDAS 2.2 output is available within 1–2 weeks of present, so more information (such as meteorological forecast data) would need to be integrated to create a forecast. I have no experience integrating GRACE-FO or GLDAS 2.2 data into local forecast models.

Question 2: GRACE has a coarse spatial resolution. If I am looking at a smaller basin, what 'downscaling' methods or supplemental data should I pair with GRACE to make the data actionable at a local level?

Answer 2: GLDAS 2.2 downscales GRACE data to 0.25 degree resolution. For smaller scales, additional fine scale data would need to be integrated.

Question 3: Based on the criteria, how did the selection for areas that there is no observed data for groundwater get integrated into the data assimilation (i.e. places in Latin America)?

Answer 3: GLDAS 2.2 incorporates meteorological data, soil properties, slope, land cover, and other globally available information and then assimilates GRACE/FO data. No groundwater observations are included.

Question 4: Why can't I use a confined aquifer for GRACE validation?

Answer 4: Piezometer measurements in confined aquifers represent pressure head, which do not correlate directly with changes in mass.

Question 5: What correlation can be considered acceptable for validating downscaled GWSA (1km)?

Answer 5: That would depend upon the specific application, but a correlation coefficient greater than 0.5 is generally considered to be good.



Question 6: I am curious how GRACE can be practically integrated with land surface or groundwater simulation models. Given its coarse resolution and storage-based measurements, what are the biggest limitations for local-scale groundwater studies?

Answer 6: Limitations of GRACE data include the coarse resolution and 3–4 month latency. For information on GRACE integration in land surface models, see [this article](#), [this article](#), or [this article](#).

Question 7: What applications do you feel the GLDAS 2.2 groundwater storage data is best suited for? Do you feel the data is of high enough quality to be used in settings which lack groundwater storage data (e.g., water budgets or modeling in international basins)?

Answer 7: It is best suited for medium to longer term applications (e.g., drought monitoring; estimating aquifer depletion trends) and interannual variability. Where groundwater data are lacking, GLDAS 2.2 groundwater provides a fair representation of large-scale groundwater conditions.

Question 8: What is the key difference between data assimilation (DA) and model calibration? In other words, why was GRACE data not directly used as a calibration data set to optimize LDAS model parameters?

Answer 8: Calibration is more of a one-time event to improve the model parameters, but because TWS is an integrated quantity (as opposed to a measurement of surface soil moisture or snow water equivalent, for example), it is not well suited for calibration. GRACE data assimilation provides a continuous constraint on the simulated TWS.

Question 9: Given that basins smaller than 20,000 km² are well below the native resolution of GRACE, to what extent does the GLDAS 2.2 output reflect actual local hydrogeological processes versus physical model interpolation? For a hydrogeologist, is the product robust enough to derive physical values for storage and recharge at this scale, or should its use be strictly limited to analyzing trends and temporal anomalies?

Answer 9: For aquifer properties, it will not be robust enough. Also, where there are groundwater pumping or injections, GLDAS 2.2 will not capture those effects. In other regions it provides a fair representation of ambient groundwater conditions.

Question 10: Is there a minimal allowable box size in Giovanni?

Answer 10: You can display one grid point – that is the smallest size.



Question 11: How can we disaggregate GRACE total storage into individual storage components?

Answer 11: By using data assimilation, as with GLDAS 2.2, or by using independent measurements of soil moisture, snow water equivalent, and surface water storage changes, for example if one wanted to isolate groundwater storage changes.

Question 12: Is it possible to query the Level 3 GRACE data with Python instead of using GUI?

Answer 12: Yes, we will share where the data (netCDF format) can be downloaded from. You can then use Python to read and analyze the data.

Question 13: When discussing remotely sensed groundwater storage estimates, the community's focus is very much on GRACE (despite it being a TWSA). Why is there not more discussion of the GW storage estimate in GLDAS 2.2? Lack of awareness or something else?

Answer 13: GLDAS 2.2 is a derived product where GRACE is a direct observation. People tend to trust direct observations more.

Question 14: Is there any rule on programmatically requesting data from NASA's server? I am not sure how many concurrent requests I can use now.

Answer 14: There should not be a rule about concurrent requests, but it may take time to get all the data you request.

Question 15: Up to what depth can the GRACE satellite detect TWS? Are there any limitations?

Answer 15: There are no limitations to the depth of the observations. The effect of gravitation is what is being measured and depth does not matter.

Question 16: Can GRACE satellite detect TWS changes twice in a month for the same region or it passes one time only in a month?

Answer 16: Geodesists can create biweekly gravity and TWS anomaly fields from GRACE/FO, but the uncertainty is larger.

Question 17: I know there are older versions of GLDAS (2.0, 2.1), speaking in general terms, how would you describe the difference of 2.2 from the older model versions?

Answer 17: They are different versions, not necessarily older versions. Temporally consistent 1948–2014 forcing data is used in version 2.0. Version 2.1 uses higher quality forcing data for 2001–present. Both of those provide a choice of three different



land surface models, whereas GLDAS 2.2 only has one. GLDAS 2.2 is the only version that assimilates GRACE/FO data.

Question 18: What's the speed of the GRACE satellites? How many days does it take to complete one orbit around the globe?

Answer 18: GRACE-FO satellites are in a polar orbit, with a velocity of about 7.5 km/s, orbiting Earth ~15 times per day.

Question 19: What do you think about GLDAS2.2-DA's suitability to obtain a good estimate of the groundwater "reserve" of any river basin?

Answer 19: GLDAS 2.2 cannot tell you about the total amount in storage, it only tells you how storage is changing over time. You can look at the long-term range of variability of TWS from GRACE/FO or GLDAS 2.2 and estimate how much water remains above the lowest level in the data record as an indicator of how much water remains, but that lowest level is probably nowhere near the driest a region could possibly be.

Question 20: Do we separately download the different water storage components from Giovanni and subtract them from the terrestrial water storage from GRACE to obtain the groundwater component? Is this correct?

Answer 20: You already have groundwater data from GLDAS 2.2 that you can access using Giovanni.

Question 21: I was able to downscale GRACE GWSA up to 1km, and correlation coefficient (R) came out to be 0.56 on a point data of wells. Is it acceptable for a very small area (2700 km²)?

Answer 21: That's a pretty good result for downscaling to that scale, but it's difficult to know if that was luck or skill, i.e., whether it could be repeated in other locations.

Question 22: What will be the different applications or where we can use GLDAS in groundwater studies as groundwater is very dynamic and has a nonlinear behavior?

Answer 22: Drought monitoring and aquifer depletion studies are two examples.

Question 23: Can I download GRACE information on Google Earth Engine?

Answer 23: GRACE data is not available in GEE as far as we know.



Question 24: Is QGIS the primary data visualization platform used in remote sensing applications? Are there other widely used applications which fulfil the same purpose?

Answer 24: Any GIS will work. Python and R allow you to visualize as well. IDL, NCL, Matlab are other options.

Question 25: I thought there were some known gaps in GRACE data between the end of the GRACE mission and GRACE-FO start. Did this have an impact on the GLDAS 2.2 derived GW storage estimate?

Answer 25: GLDAS 2.2 bridges gaps in GRACE/FO data by running the model without data assimilation. Between mid-2017 and mid-2018 is one of those periods. Uncertainty is greater during those times.