Part 3 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. Eric Fielding (eric.j.fielding@jpl.nasa.gov). This document will be shared to the training webpage within one week.

Question 1: Is downscaling important for looking at groundwater drought index in a particular region?
Answer 1: The NOAA Drought Index is estimating the drought of surface water and shallow soil moisture. It does not directly measure groundwater, but areas of drought are often places where cities or farms will extract groundwater. The drought index is based on the weather, including precipitation and temperature.
For meteorological drought index, groundwater changes may be less significant. Downscaling would be possible.

Question 2: What happens during a storm if OPERA has difficulty due to distance to capture data?
Answer 2: The OPERA surface water extent and disturbance products that are based on the Harmonized Landsat-Sentinel2 (HLS) optical image products will be blocked by cloud cover and won't have a measurement for those dates and pixels. The OPERA products based on SAR images from Sentinel-1 (and soon NISAR) are not affected by clouds and will have measurements for every pass.

Question 3: Can we apply OPERA DISP anywhere (for example, the Middle East)?
Answer 3: NASA only has funding to process the OPERA DISP products over North America, but all the software is open so others could use the same software to process other areas.

Question 4: I want to process Sentinel-1 data into displacement for small AOIs in different regions outside North America. Since OPERA DISP is limited geographically, how difficult would it be to build a similar workflow?
Answer 4: All the OPERA software is open source and available on GitHub, so processing a small area should be relatively easy. The main time-series program is called "dolphin." It can be used with S1 or other SAR data. The OPERA displacement workflow has extra sophistication to enable continent-scale processing, but this is not necessary for small areas.

Question 5: If we generate SBAS InSAR time series for a region using tools like PyGMTSAR, MintPy, or LiCSBAS, how can we distinguish groundwater-driven deformation from other processes like oil and gas extraction, tectonics, earthquakes, or snow loading? How should we handle intercomparison and validation, and how do OPERA products ensure consistency between C-band Sentinel-1 and L-band NISAR for long-term monitoring?
Answer 5: The separation of different geophysical or groundwater effects is beyond the scope of this training, but the time-series data provided by OPERA DISP can help to distinguish effects within the Earth. The seasonal displacements that are typical in groundwater extraction is one way to see the difference from tectonic effects.
The OPERA displacement (DISP) products are processed separately for each Sentinel-1 and soon NISAR track. There is no additional processing to ensure consistency between tracks. The future OPERA Vertical Land Motion (VLM) products will be a level 4 product where the separate OPERA DISP-S1 tracks are combined with local GNSS (GPS) data to make a consistent map of the vertical and horizontal land motion.

Question 6: For the Python demonstration, what is the velocity accuracy of this result? 5 mm/yr?
Answer 6: The OPERA DISP-S1 products have been validated to meet the requirement for a velocity accuracy of 5 mm/year, where the data has high quality. Some areas with low InSAR coherence due to farm activities, flooding, or dense vegetation will be marked as unreliable in the “recommended mask” included with the DISP products and will not have a useful velocity measurement.

Question 7: For the Python demonstration, are subsidence and depletion equal?
Answer 7: The relation between the volume of groundwater extraction and the surface subsidence is determined by the characteristics of the groundwater reservoir that vary greatly. The situation can be especially complex in some areas with groundwater reservoirs at different depths. They are not equal but closely related and require some advanced hydro modeling to better understand what the reservoir characteristics and response are.

Question 8: I am seeing some missing monthly data while working with the ASF data. What is the reason for this?
Answer 8: The OPERA products are only available when the source data was acquired. The various satellites (especially Sentinel-1) sometimes miss a few acquisitions or change their acquisition plans, especially the Sentinel-1 constellation where they have

time periods with two satellites and other periods with only one satellite. S1B stopped working in 2021. S1C was operational in 2025. S1D is now operational.

Question 9: When we download the DISP files, what is the best way to assign the reference (based on a point or border of the bounding box)? How is a reference point selected for measurement of displacement? Is there any specific point we should select?

Answer 9: The best reference point location is one where you know that the ground surface is stable. For groundwater studies, this is typically a point outside of the sedimentary basin. The reference point also needs to be coherent in all the dates of the InSAR time series, so not covered with dense vegetation for Sentinel-1.

Question 10: What is the difference between LOS velocity, Deformation Along slope, Horizontal and Vertical deformation? And how are they estimated using SAR?

Answer 10: The fundamental measurement from InSAR is the line-of-site (LOS) velocity. A single LOS velocity from one track of data is not sufficient to separate horizontal and vertical displacements. Combining two or more LOS measurements can be used to estimate what component of the displacement for each point is vertical and horizontal. The horizontal component can only be estimated in the East-West direction with two LOS measurements.

Question 11: Is there any atmospheric correction applied to the level 3 or raw results? When analyzing the displacement time series, should we apply corrections like ionosphere delay, solid earth tides, etc.?

Answer 11: The OPERA DISP raw products do not have the atmospheric corrections applied, but they do include layers in the files of ionospheric delay and solid earth tides. These effects are small for the C-band Sentinel-1 data, so they are not necessary for most purposes. The OPERA project is providing a separate tropospheric estimation product that can be used to apply tropospheric delay corrections, which are much larger than the ionosphere or solid earth tide corrections for C-band. The file for the exercise has these layers.

Question 12: In the displacement portal, there are many pixels over a waterbody. Why were the pixels not removed by the water mask?

Answer 12: The ASF Displacement Portal shows the data with a water mask and a mask for areas of low InSAR coherence. Unless you have a lake that is dry at times.

Question 13: In the time series that you showed, does each point represent deformation with respect to the reference date or to the date immediately before? If we have deformation in times t1, t2, t3, the shown deformation in t3 is deformation with reference to t2 or t1 (assuming t1 is the reference date)?
Answer 13: The OPERA products are processed in stacks. The notebook ties together the reference dates for the ministack. Please see the documents provided for nomenclature.

Question 14: When analyzing displacement time series data, should we use unfiltered displacement or shortwave displacement?
Answer 14: For almost every analysis, use the unfiltered displacement.

Question 15: Is the displacement time series comparable with SBAS derived displacement time series?
Answer 15: Yes, it should be comparable. OPERA time series analysis
But the fundamental result should be like the SBAS.

Question 16: What algorithm uses OPERA to create the time series, PSI or SBAS?
Answer 16: OPERA algorithm is phase linking using both PSI and SBAS. They are combined for each 30mx30m pixel.

Question 17: I received this message: Timeseries Service Error
No OPERA-S1 burst frame ids were found over the given aoi:
POINT(35.08880147340745 29.44513006398394). What should I do?
Answer 17: This is outside of North America so you will not find a measurement.

Question 18: Are the velocity maps an average or total for the years?
Answer 18: The notebook shows the average over the time interval. Average velocity from 2019 - 2022 (dry years). 2022-2024. Maps are included that show the total, cumulative displacement.

Question 19: Is the velocity map still in LOS direction or does the script download both directions and decompose the vertical element?
Answer 19: The analysis is still in the line of sight. There is no decomposition.

Question 20: What should be the minimum time window to measure surface displacement for groundwater applications?

Answer 20: It will depend on how fast the GW displacements occur. Slower (1 cm/yr) displacement will require 2 or 3 years to analyze.

Question 21: Why are there positive subsidence points?
Answer 21: 2022-2024 interval, where the CA received a huge amount of rainfall resulting in recharge.

Question 22: While exploring the ASF portal in my region, I am seeing localized pockets of subsidence a few hundred meters/yards across. Is it reasonable to interpret this as subsidence? What sort of factors should we be wary of for misinterpretation at fine scales?
Answer 22: Displacement products are indicating ground motion. Subsidence, landslides moving, earthquakes, etc. but most measurements should be useful. You will have to interpret what is causing the displacement. Some displacement for former landfills, the materials are compacting over time.

Question 23: Land displacement can be caused by multiple factors, such as erosion. Do we separate them from groundwater subsidence in the DISP datasets?
Answer 23: Land to surface due to erosion will become incoherent in the DISP so it will not be a measurement. InSAR cannot measure erosion.

Question 24: Could you provide key references documentations that could guide us to produce OPERA (land displacement, VLM, etc.) output dataset for study area located in Africa, for example?
Answer 24: OPERA algorithm is open and online on GitHub. A paper coming out shortly will show the methodology.

Question 25: Is there a way to enter the coordinates of my point of interest directly into the OPERA DISP search bar?
Answer 25: The portal does not have that capability. NASA Earthdata allows for this.

Question 26: How can OPERA DISP time series be quantitatively integrated with GRACE and GLDAS data to improve groundwater storage estimation, considering their different spatial and physical sensitivities?
Answer 26: You must consider the total response. Spatial resolution has a big effect so modeling and data assimilation techniques. There are papers on combining these datasets.

Question 27: Since OPERA-DISP uses InSAR radar from satellites, does the radar beam actually penetrate underground and see the water table directly?
Answer 27: No, the radar does not see the water table. It penetrates at most a few cm.

Question 28: When OPERA data is processed, are there different reference points for the North America region or is there a unique point? Can we know the location of such a point?
Answer 28: DISP are not processed to any global ref point. Each frame has its own local reference point. You will need to provide your own.

Question 29: For InSAR, what are some best practices if studying groundwater related subsidence in a seismically active area? In addition to analyzing both ascending and descending datasets, do you have further recommendations?
Answer 29: Earthquakes are gradual fault motions and are a concern. An additional effect where the GW reservoirs have an edge at the location of a fault resulting a variation. We have seen this in the Santa Clara Valley in California.

Question 30: InSAR measures displacement relative to a reference point, but no point is truly stable due to tectonic strain and other factors. In a basin with both regional tectonics and groundwater pumping, what minimum temporal baseline is needed to separate these signals?
Answer 30: In some cases, you may have a GPS station to get the full absolute 3D displacement time series as a reference point. You would have to do your own analysis. A local reference point says it has zero displacement.

Question 31: What if we want to do groundwater temporal changes as one of the environmental factors to demonstrate a causal relationship to the lake Geohazard? Which dataset is the best available option? GRACE has its own limitations.
Answer 31: InSAR gives you the higher spatial resolution to tie to local effects. GRACE will only give you a regional scale.

Question 32: If the area of selection is bigger than one frame, does the disp Jupyter script mosaic them and fix the phase jump in between?
Answer 32: No, this script only works with one frame.

Question 33: Won't OPERA process Canada even by removing wintertime data? Is there a limitation in processing 6 months of data every year?

Answer 33: They decided not to process parts of Canada more than 200m north of the border. See Alaska displacement data, and you will see gaps due to snow cover.

Question 34: How can OPERA DISP data be used at the local scale to assess groundwater level variations linked to vegetation evapotranspiration, particularly in comparing water use between fast-growing and slow-growing forest tree species?

Answer 34: The products are measured with the S1 data, so it depends on the available acquisitions. In some places, such as the West Coast of the USA, they acquired data every 6 days. Other areas every 12 days or even every 24 days. NISAR will be every 12 days. The Sentinel-1 satellite constellation has varied over time. Initially, they had only the Sentinel-1A satellite until Sentinel-1B joined it in late 2016 and they had two satellites operating. The Sentinel-1B satellite stopped operating in December 2021, so they went back to having only one satellite until early 2025, when Sentinel-1C began operations. During the times with only one Sentinel-1 satellite, they could only acquire half as much data, so the coverage was reduced and the minimum interval was 12 days. When they have two Sentinel-1 satellites, they acquire data over more area and acquire data every 6 days in some places, especially over Europe and tectonically active areas, including the West Coast of the USA.

Question 35: What is the cause of the positive artifacting around bodies of water in the ASF DAAC?

Answer 35: It is due to the ways they calculate the Short-wavelength displacement. A window of 25 miles across the center of the sub but the areas nearby will have an uplift.

Question 36: When calculating the linear recurrence/velocity of pixels, what is the improvement to accuracy of using a polynomial fitting instead, at least over smaller areas where computation time is not a major concern?

Answer 36: Higher order polynomial data but you will see noise. Tropospheric corrections can be used. You don’t want to overfit which is why we use averages over a few months.

Question 37: It is commonly known that Mexico City is sinking due to the compression of the clay beneath it. In our exercise, this negative land displacement was surrounded by a ring of positive displacement. Why is this?

Answer 37: Due to the way the short-wavelength filter was applied, it appears to have uplift around the edges. Look at the unfiltered and you will not see the uplift around the edges.

Part 3 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. Eric Fielding (eric.j.fielding@jpl.nasa.gov). This document will be shared to the training webpage within one week.

Question 1: How do we know the phase change is from the change of distance of the same object instead of reflected signal from another object?
Answer 1: The phase for a SAR pixel or resolution element is the weighted average of all the objects in the pixel. The phase change is then the average of the objects in a pixel. If objects within a pixel move in different directions, then the phase becomes incoherent, which is the reason that the C-band InSAR in areas of heavy vegetation is often incoherent. The individual trees and branches within each pixel move in different directions. In certain cases, there is one object such as a building that reflects the radar much more strongly than other objects in the pixel. The persistent scatterer InSAR (PS-InSAR) method tries to find the pixels with one very strong and persistent radar scatterer.

Question 2: On the ASF portal, is the time series also short wavelength filtered? What is the kernel size used? How does the filtering affect the absolute magnitude of displacement measurements? Are corrections (solid earth tides, ionospheric delay, tropospheric delay) applied to the time-series displayed in the Displacement Portal?
Answer 2: The data shown in the ASF Displacement portal is the short-wavelength filtered data. The kernel size is 25 km. In the filtered data, the data values at each point are the original value minus the weighted average of the points in the kernel or filter window, so the displacement values are changed. There are no corrections applied.

Question 3: What is the difference between the groundwater products derived from GRACE and SAR? How should we choose between them?
Answer 3:
The GRACE and GRACE-FO satellites measure the changes in mass over large areas, roughly 200 to 400 km across. They also provide products downscaled to spacings of about 50 km. The mass change is largely due to groundwater changes, but changes in mass to snow accumulation or water in surface reservoirs are also included. Due to the coarse spatial resolution, the GRACE measurements are best used for regional analysis of groundwater changes. The InSAR measurements from the OPERA displacement

(DISP) products are much higher spatial resolution (30 meters), but they measure the surface displacement and not the mass or volume change of groundwater storage. Additional groundwater hydrological modeling is necessary to determine the groundwater mass or volume changes from the InSAR data. Choosing what data to use depends on what you want to achieve.

Question 4: Do we need Python to run these steps, or will they also work in R?
Answer 4: The Jupyter notebook that we used here and provided on GitHub is written in Python. It uses some OPERA utilities that are written in Python, so the notebook will only run with a Python kernel created as explained in the beginning of the notebook. It would be a significant effort to convert the OPERA utilities for downloading the data to R, but the calculations done inside the notebook are relatively simple and could be converted to R.

Question 5: In the areas you presented during the demonstration, the displacement scale shows symmetrical values of +6 and -6 for uplift and subsidence zones respectively. Is it physically plausible for both phenomena to exhibit identical magnitudes, or does this indicate a scaling or processing artifact?
Answer 5: This was just a choice made subjectively when choosing the color scale, so that the white on the blue-white-red color scale was at zero displacement.

Question 6: Which NASA groundwater or terrestrial water storage products would be most suitable for detecting drought-related stress in forest ecosystems at regional scale?
Answer 6: At regional scales, GLDAS and GRACE/FO would be more effective.

Question 7: Are there plans to expand the OPERA DISP high-resolution products beyond North America to provide global coverage for developing regions facing critical groundwater crises?
Answer 7: NASA only has funding to do OPERA products for North America. The European Copernicus program has a similar Sentinel-1 displacement product available for Europe, called the European Ground Motion Service. It is at https://egms.land.copernicus.eu/.

Question 8: Given that many groundwater products are coarse in spatial resolution, what is the best way to integrate them with high-resolution Sentinel-2 variables for local-scale forest fire risk mapping?
Answer 8: I am not an expert in this subject.

Question 9: Can OPERA-DISP displacement data be used as an indirect indicator of groundwater depletion or land subsidence in mountainous or forested regions, and could such information support forest fire vulnerability monitoring by identifying areas experiencing long-term water stress?
Answer 9: The OPERA displacement date measures the surface defamation. It turns out mass displacement in mountains can cause uplifting effects, but it is a small effect. There are several studies that show how GNSS data can be used to measure the seasonal and long-term loss of mass in mountainous areas that is due to decreases in water stored in the snow, ice, soil, and groundwater.

Question 10: Ionospheric noise has been removed using Jupyter Notebook. Is there a filter code available for tropospheric noise as well, or should it be addressed separately by applying the Tropospheric Zenith Delay product?
Answer 10: Yes, the OPERA products do include an ionospheric layer but it is a separate layer that you can apply. The OPERA Tropospheric Zenith Delay product is a separate product that can be applied to the OPERA DISP analysis or other InSAR analysis, but this is an advanced topic not shown in this notebook.

Question 11: How do you recognize subsidence from groundwater depletion from other surface displacement types?
Answer 11: The subsidence due to groundwater depletion often has a seasonal variation especially for agriculture during the growing season. The winter seasons it may slow. The time series can provide information about the displacement. The groundwater extraction effects in steep slope or hard rock areas it is almost likely to be other effects like landslides or tectonic activity.

Question 12: Are VLM data correlated with local well and surface water delivery data?
Answer 12: Vertical Land Motion (VLM) is a product that is usually made from InSAR data. OPERA is a line of site displacement. OPERA is working on calibrating with other data for Level 4 data.

Question 13: Is there a link between groundwater changes and earthquakes, and can this information be used to forecast them?
Answer 13: Yes, we have seen cases where large extractions of water changing their size and mass has changed the state of stress in the Earth’s crust associated with earthquake activity.

Question 14: What workflow do you recommend for combining the 3 tools we saw in the course in a study on groundwater in central Mexico?
Answer 14: It is not easy to combine the datasets, as all three datasets introduced in this training have different characteristics. As we saw, the GRACE/FO data provide total terrestrial water storage changes globally on a monthly basis at a low resolution (~300 km²), while OPERA provides surface displacement related to groundwater changes at a very high resolution (30m), limited to North America with varying temporal coverage (6 to 24 days), and GLDAS 2.2 provides global groundwater changes at a 0.25-degree resolution on a daily basis.

However, GLDAS 2.2 already assimilates GRACE/FO data in the model, so there is no need of further combining them. You may want to examine GRACE/FO assimilated - GLDAS 2.2 data (maps and time series) in your area of interest, and then, within that area examine DISP maps and time series — depending on the size of the area and your application, you can choose the appropriate dataset(s).

Question 15: Where in the NASA ecosystem can local annual GNSS Subsidence Monitoring Program Campaign data (groundtruth) be shared?
Answer 15: The University of Nevada Reno processes the GNSS time series for many thousands of GNSS stations around the world and provides the time-series products on their web site.

Question 16: I require access to freely available groundwater datasets for the Murray–Darling Basin, Australia. Could you recommend suitable data sources (e.g., bore data, groundwater levels, salinity, hydrochemistry) and outline the best approach for accessing and integrating these datasets into a remote sensing-based water quality and health risk framework?
Answer 16: This question is outside the scope of this training. Other local agencies may have this information.