A Q&A Session on Radar Remote Sensing

(or Everything You Always Wanted to Know About SAR)

This Session is created in partnership with Franz Meyer (ASF Chief Scientist/NASA/UAF).

In recent years, the Earth Observations community has seen an increase in the availability and application of synthetic aperture radar (SAR) data for mapping and monitoring disasters, water, and land cover applications such as deforestation, crops, flooding, and earthquakes. Previous ARSET online webinar series focused on building the skills needed to acquire and understand SAR data, including polarimetric and interferometric SAR (PolSAR and InSAR), as well as potential applications. The demand for guidance using SAR is extensive. The goal of this live, 2 hour question and answer session is to provide participants with the opportunity to ask questions of a panel of experts. The session will be provided twice, once in English and once in Spanish.

This Q&A-type training builds on ARSET's previous webinars: Introduction to Synthetic Aperture Radar and Advanced Webinar: Radar Remote Sensing for Land, Water, & Disaster Applications. The session is also designed to prepare participants for future advanced SAR trainings. Attendees will be allowed to ask the panel of experts questions about SAR so we will have assumed you have gone through the suggested reading. Some initial questions may be answered by previous ARSET trainings, so we are assuming you have watched these or have equivalent experience.

English panel experts:
Erika Podest, NASA ARSET Trainer, NASA/JPL
Franz Meyer, ASF Chief Scientist, NASA/UAF
Paul Rosen, Project Scientist, NASA/JPL
Eric Fielding, Principal Scientist, NASA/JPL
Naiara Pinto, UAVSAR Science Coordinator, NASA/JPL
Eric Anderson, Research Scientist, SERVIR, NASA/UA

Question 1: The critical baseline for interferometry is dependent on the bandwidth of the system. But higher bandwidth would mean more data rate and development challenges, In principle, can we also change the center frequency of the system in the repeat measurement of the area rather than keeping a large bandwidth ? If yes then what are the challenges associated with it and has it been implemented in any mission current or future ?
Answer 1: Yes, longer wavelength means a longer critical baseline for a fixed range bandwidth or range resolution. However, longer wavelength typically means a larger antenna in the elevation direction. Larger antennas usually lead to higher cost.
Live Answer: (Paul) So, for - in terms of this being implemented in any mission, it turns out NISAR and ALOS which are L-band systems 24 cm wavelength systems can operate with a very large critical baseline along the order of 20 km with a very modest bandwidth. That allows us to get good interferometric performance for the mission we can control the baseline well with this system and keep the correlation high because the critical baseline is so much larger than our actual baseline. In the NISAR case, we have a very large antenna - it's a 12 m diameter circular reflector. It's a challenge to build, there's a 9 m boom associated with it and a 12 m mesh reflector that has to deploy in space. And there's quite a bit of complexity and cost associated. For that size aperture, we believe the NISAR costs are much lower than they would be if we tried to build the same thing using the conventional black planar technology. You can think of a resolution element in a SAR image on the ground - the resolution element as effectively being a little antenna. You illuminate with the radar the ground and with that energy that scatters off the ground re-radiates back to the radar - that's like a little antenna. If you've studied SAR in ARSET classes, you know antennas have a beam width proportional to the wavelength divided by the size of the antenna. Here the size is the resolution element, so that's the resolution. You can see the size of that radiation pattern from the resolution element is proportional to the wavelength/resolution. THe longer the wavelength the longer that radiation pattern is. That pattern is proportional to the critical baseline. If you have finer resolution, you have a bigger critical baseline. It relates to Q2 with PSI, it's like something with fine resolution. It's the only element in a given resolution cell with significant energy so the resolution of that pixel is effectively much much finer, so you have an infinitely large critical baseline you can see no matter the observation.

Question 2: Could you please describe PSI technique? And is there a suitable & free software for processing PSI?

Answer 2: PSI (persistent scatterer interferometry) is using a method to measure very small surface deformation signals using interferometric SAR observations. PSI specifically uses long-term stable point-like scatterers for this approach. PSI is particularly popular for monitoring deformation of infrastructure and urban environments.

There are few public domain software packages. One of the few available is the StaMPS software package (https://homepages.see.leeds.ac.uk/~earahoo/stamps/). For an overview of other similar tools, please look at the Github RadarCode repository which curates a list of available public-domain software packages (https://github.com/RadarCODE/awesome-sar)

Additional Live Answer: (Franz) InSAR is capable to measure the deformation of the ground at the fractions of a wavelength. Typically radar wavelengths are somewhere between 1-10 cm and that shows you that through inSAR you can observe surface deformations v accurately. In many cases, the technique is so powerful, we are trying to observe surface deformation that's very small and they're developing slowly over time. Mm to cm per year type of rate. This kind of deformation may be related to groundwater extraction under urban environments. Small deformations we'd like to extract. In order to give the earth enough time to deform enough so we can measure it, we need to create interferograms that span long time scales. Over the long time, the environment changes too much for the measurement to still make sense. There are some exceptions, and those are these PSIs. These are often point-like objects on the ground (rocks, corners of buildings, pieces of mostly man-made structure) that remain the same over long time spans. If we can extract their information we can use them to measure scattering over time spans with high accuracy.

The PSI technique was really one of the first methods to monitor deformation at the cm-mm scale over long times. And it's particularly used for urban environment deformation, relating to infrastructure installations, like levees and dams. Not as possible for natural environments where the likelihood of having these objects that are very bright in the image and are stable are not that likely to exist. There are a lot of software packages that can do PSI processing, but many are not public domain. There are a few exceptions: StaMPS (above) and RadarCode

(Paul) The ISCE package we're building for NISAR has some workflows that are prototypes that will be available (maybe in 6 months or so).

(Franz) If you're working on fairly limited extent areas - interested in understanding deformation, there's a package called SARPROZ. The software isn't free for commercial use, but you may be able to get a license for personal or academic use from the PI.

Question 3: How is the velocity of the sensor platform utilized to get a higher resolution? Actually, I wanted to know how specifically it's utilized for better spatial resolution in a specific mode.
Answer 3: The resolution in the direction of the flight track is proportional to the antenna length - L/2 for strip-mode Synthetic Aperture Radar (SAR). The distance to the ground and the velocity do not factor into the resolution. The Doppler bandwidth is higher but that just means the time resolution is finer. But since the
(Paul) For those of you who studied standard SAR theory, the resolution in the long track dimension is the antenna length divided by 2. The velocity will affect the doppler bandwidth (higher v is higher bandwidth). Since velocity is faster, the spatial resolution will be the same. What really matters is how the spatial extent at a given point in the ground is in the beam. The beam width isn't determined by velocity, but by size of the antenna and the wavelength. In spotlight mode, resolution is also determined by illumination extent not velocity. Not sure I can think of any specific radar modality where the velocity matters.
(Franz) So - the velocity of the sensor itself only matters in the sense that it dictates the pulse repetition frequency that needs to be used by the system to sample the system correctly. The beam width defines the resolution.
(Paul) Yes and no. You can do the point and shoot method with no real velocity and still get a synthetic aperture.
(Eric F) Does the velocity affect the track of motion on the ground? The velocity of the platform?
(Paul) Yes, it does impact your ability to measure moving targets - that's true, but I don't think that's the question. Also, the moving target indication - accuracy is a function of velocity and signal to noise ratio and a bunch of technical factors, which might be too much to get into here.

Question 4: How to minimize the effect of wave in flood/water mapping? I found that Sentinel-1 seems to be affected by the windy wave in large water surface. This reduces the accuracy of the water mask using SAR data. Or is there a better approach to improve the flood mapping or water mask?
Answer 4: This is a good question. Depending on polarization, SAR is sensitive to surface roughness, and hence, is affected by the small ripples that are caused by wind

on a water surface. Luckily, the sensitivity to roughness (and hence wind on water) is not equally strong for different polarizations. Cross pol data (e.g., HV and VH) are much less affected than
(Franz) Depending on polarization, the brightness of a water body to SAR is dependent on wind that may blow over the water and ripples that may happen. One of the things SAR is good at seeing is surface roughness. If you have wind, wind interacting with the water surface creates capillary waves that increase the roughness of the water. It makes the water appear much brighter if there is no wind. In terms of the application, when people attempt to do things like flood mapping, the approach is usually that one assumes water bodies are much darker than the surrounding environ. In the absence of wind, water is smooth and it's a very specular reflector. It's very dark in SAR fields. This isn't true when significant wind comes into play. It makes it harder to discern from the surrounding environment. This is true for SAR in general, but the effective roughness depends on polarization. For instance, Sentinel 1, depending on whether you work on land or water. Over land, it provides 2 polarizations, one is the so called co-polarized VV and is emitted and received in vertical polarization. The component sent in V is sent back in V. In addition to VV, Sentinel-1 also provides VH polarization. The component sent in vertical is received in horizontal polarization. If you have both available, the cross term (this VH term) is much less sensitive to wind and the brightness on the water will go much more slowly. Work off the VH dataset for water detection for flood mapping in windy conditions. Other approaches are to work off polarization ratios to improve the detection of water surfaces. One of the easiest ways is to switch from the VV to the VH channel.
(Eric Fielding) and it also strongly depends on the radar wavelength
(Franz) This q was directed at Sentinel-1 and the C band is roughly at 5 cm scale. Future missions like NISAR working in L band which is 25 cm scale will be less affected by wind effects.

Question 5: Is it possible to rely on radar images to classify agricultural crops with good accuracy, and if possible, can you give some links to explain more.
Answer 5:
We'll be covering some of this is an upcoming ARSET Advanced SAR training in August/September
(Franz) There are methods - especially overall, if you look at vegetative environments, the more success for detecting/classifying agriculture will come from future missions that operate at longer wavelengths. There are some things you can do with C band, but

the performance of radar to characterize vegetation will improve with the lengthening of the wavelength. A C-band sensor like sentinel 1, its penetration into vegetation is limited, so it will be less capable than an L band sensor which has more penetration capabilities. There are some radar methods, esp time series of radar datasets. To at the very least to get at the area where agriculture activities are happening. One method is the coefficient of variation - looks throughout a growth season the radar environment changes dramatically - no vegetation, growth of vegetation, harvest. It makes it easier to detect because of the changes with SAR. Both their signature and with polarimetric information you can do more toward classification of crops. We can track down more info, I don't have a link handy, there's a paper we can place here later that has C-band and L-band data that tries to get to classification of different crops.

One potentially useful reference by Whelen and Siqueira (2018): Time-series classification of Sentinel-1 agricultural data over North Dakota (https://www.tandfonline.com/doi/full/10.1080/2150704X.2018.1430393)

Coefficient of variation for use in crop area classification across multiple climates by Whelen and Siqueira (2018): https://www.sciencedirect.com/science/article/pii/S0303243417303318

(Erika) In adding to what Franz said, radar is sensitive to structure and water content. Optical is sensitive to the chemical composition of your plants. It's two different measurements with SAR you can ID different types of crops as long as they're structurally different. The structure changes throughout the season, so if you have time series you can better ID the crops. If you have polarimetric information it helps to ID different types. There was an ARSET training specifically on this - the Advanced SAR training in 2018 (https://arset.gsfc.nasa.gov/disasters/webinars/advanced-SAR-18), I believe it was Part 2 in the 4 part webinar series focused on SAR for agriculture, specifically identifying different types of crops and looking at soil moisture. That was done by Heather McNairn, and she used C-band. C-band, again - the wavelength will determine the amount of penetration through the canopy and c-band has a shorter wavelength than L-band. C-band will provide adequate data depending on the size of your crop. It will provide data to identify different types of crops based on their structure. I can dig up a couple of papers as well that talk about classifying crop types with radar, as well as the link to the last training (above)

Question 6: Kindly explain the main differences between coherent and noncoherent decompositions in SAR polarimetry? Considering the applications such as oil spill which decomposition should be used for better results?
Answer 6: (Paul) Coherent decompositions mean that the scattering matrix itself is broken into canonical scattering matrix components, like diagonal matrices that could be trihedrals, dihedrals, or slightly rough surfaces, or off diagonals like dipoles. Noncoherent decompositions rely on the covariance focus on the statistical properties of surfaces and are therefore better suited to surfaces that are randomly oriented, or collections of coherent scatterers that behave like a random collection. So for oil spills, where one would not expect to have any coherent oriented scatterers, noncoherent is the way to go.
(Franz) In a way, I wonder - maybe that's - the coherent methods, particularly used the full information, amplitude and phase, in their - in the analytics. While non-coherent methods rely on amplitude only or not all the phase info available in the covariance matrix
(Paul) It doesn't have to be that way.

Question 7: Using interferometry to determine water surface elevation in rivers, I know it can be done in wetland to determine double bounceback. Besides wetlands, what other types of vegetation can we obtain the double bounceback?
Answer 7: certain stages of growing irrigated rice may show double bounce. Consider a 4 step "phenology": 1) open or bare soil, to 2) smooth water (single bounce), to 3) vertical stalks or shoots beginning to come through water with very little foliage (double bounce), and finally 4) very leafy vegetation (volume scattering) - it can be applied to mangrove forests too, especially if longer wavelength data are available.

We should also mention the SWOT mission will use single-pass interferometry to measure surface water elevations.
(Eric A) Good comment on standing vegetation in flat water. Irrigated rice is a similar situation as a SAR instrument may see a wetland. Think about a few stages of growing irrigated rice (4 step phenology above).
(Eric F) I'm not an expert on SWOT, but I wanted to mention the other NASA mission that JPL is building at the mission is called the Surface Water and Ocean Topography mission (SWOT) and that mission will use interferometry to measure surface water elevation in rivers, lakes, and the ocean. They will be using single pass interferometry

by using two antennas on the radar satellite to get the elevation from the two antennas rather than repeat pass interferometry that Eric Anderson and others were discussing.
(Franz) SWOT can do it (ideally) globally, other vegetation (rice, it has been shown to work in mangrove forests, esp if longer wavelength data are available
(Eric A) Thinking of stalk-y vegetation. What do you think of stages of forest plantations.
(Erika) You can detect inundated vegetation - water under vegetation under pretty much any type of vegetation as long as the signal can penetrate through the canopy. It isn't the type of vegetation that's the limiting factor, it's the biomass. If you have a lot of biomass, you won't get the double bounce scattering mechanism, even though you might have standing water beneath the vegetation. We can detect inundated vegetation that represents different vegetation types. As Eric A. mentioned, there can be rice at different stages of growth, it could be mangroves, it could be tropical wetlands, it could be inundation that's flooded during a specific event. It's the biomass that's the limiting factor.

Question 8: While working with PolSARpro, I encountered Shannon Entropy and Entropy as different images. kindly explain what is the difference between the two?
Answer 8:
(Franz) I'm assuming, not having PolSARpro in front of me - the entropy term relates to the entropy variable that comes out of the algorithm that particular version of entropy is a way of deciding how many [] scattering mechanisms are present in a particular SAR pixel. It first performs a form of eigenvalue composition on the pixel to arrive at a conclusion whether there is only one dominant scattering present. For a dense forest, it might be mostly vegetation-type scattering, or whether there are multiple scattering mechanisms at play. Shannon entropy I can't say much about - I will have to - I don't know the details of how that's used in SAR.
(Paul) Similar question posted on the web, basically PolSARpro will produce a Shannon entropy and an entropy estimate, but it is presumably defined somewhere in PolSARpro
(Franz) It may be in the documentation. Or talk to the main developers behind PolSARpro.

Question 9: Why does NISAR L band have both hybrid pol and full pol?
Answer 9: Hybrid has many features of full polarization data but has half the data rate. Also, for NISAR full pol has less than optimal ambiguity performance across the entire

swath because the pulse rate is so high. Therefore the full pol is best suited for selected areas and applications, whereas the dual-pol modes in general have better uniform performance across the swath.
(Paul) You might think if you have full polarization you should use it all the time- as with every practical system there are limitations on the performance. If you operate on full polarization, you go from H to V on the next pulse and receive both polarizations. In order to get images at the 2 polarizations to get images properly sampled, you have to pulse the radar at twice the rate to get twice the data. For NISAR we're trying to make global measurements on ascending and descending over all land and ice surfaces. Over 50% of the time that the radar is orbiting, it is imaging *something*, land or ice. And even some oceans. If we did that at full pol all the time, we would have more data than we could get to the ground. Hybrid pol has many of the characterizations of full pol - not quite as rich but rich. We don't have to pulse the radar at double that rate. The other issue with full pol - there are some noise properties, called ambiguities, that are a little higher than one would like in best case at certain parts of the swath. For some applications it's fine, but for others it's not. We've decided to operate mostly in dual-pol mode to get data to the ground and have optimal imaging performance. Radar is mostly operated in dual-pol of transmitting H and receiving Horizontal and Vertical except over India and surrounding reasons, they have baseline a number of these compact hybrid modes. The reason most of the earth is in traditional polarizations is because the scientists using the imagery have developed algorithms based on polarizations from more traditional bases. To do this globally in hybrid, they'd have to redesign all those algorithms.

Question 10: Thank you for the SAR handbook. Do you plan on producing anymore like that?
Answer 10: Thanks for your feedback! You can download the handbook here: https://www.servirglobal.net/Global/Articles/Article/2674/sar-handbook-comprehensive-methodologies-for-forest-monitoring-and-biomass-estimation?utm_source=dlvr.it&utm_medium=twitter

Access to SAR Handbook website to download individual chapters and one pagers: https://www.servirglobal.net/Global/Articles/Article/2674/sar-handbook-comprehensive-methodologies-for-forest-monitoring-and-biomass-estimation

We are working with our new partners in the SERVIR-Amazonia network to look into co-producing new case studies with tutorials, scripts, example data and results. Provisionally, our focus for these cases studies are forest monitoring and forest change monitoring in Amazonia, as well as mangrove mapping with blended optical-SAR techniques. We are targeting early 2020 to make these new materials available.
(Franz) When you read through this document, the link above to the handbook - it's a free and open book. It's also a living document so hopefully over time we'll expand the content as things change. If you click on this link, you can either download the book as a PDF
(Eric) Also getting some info from Africa Flores (editor) and Franz was an author. There are some 1-pg quick reference guides - about 3. We're working on developing a few more quick reference guides for SAR pre-processing, vegetation indices, different ways to access SAR, etc.

Question 11: Could you please discuss ROC curve for interpretation in SAR and what are possible methodologies to apply it on SAR image for Classification? Any related resource materials and softwares to work on? Currently working on Oil Spill Spatial Extent Assessment and wishing to use ROC curve for this scenario.
Answer 11: ROC stands for Receiver Operating Characteristic and is a way of describing the performance of a classifier as the classification threshold is varied. ROCs are used a lot in SAR especially when trying to develop new classification algorithms, determining their performance, and comparing to the performance of other techniques. To calculate ROCs, you ideally need to know the statistical properties of both your image background, and of the signal (change, water bodies …) you try to detect.
(Franz) ROC is a technical term used when you try to describe the performance of a classifier, whether that's an image or other datasets. If you're classifying data into subclasses, you can try to derive a ROC that will describe the number of false alarms, or percentage of false alarms and missed hits you might incur for a given threshold. It tells you how the performance varies as you change the classification threshold. Used extensively in SAR classification, esp when using statistical classification methods. If you wanted to create ROC curves to describe your classifier, in the performance of the classifier, you need to know both the properties of the background-the thing you aren't interested in, and the statistical properties of the component you want to detect. In your case, you want the statistical properties of the ocean not covered in oil and compare that to the properties of the oil-covered ocean. Once you know those, you

can calculate the performance of your detection algorithm and contrast/compare that to other algorithms available in the literature. That's what it's most useful for. We've done a couple papers where we use ROC curves to compare our methods to other methods. I don't know if anyone else on the panel knows more technical resources.

Question 12: Do we need to take any kind of ground measurements for PSI for any step?
Answer 12: Yes, you always need at least one ground control point as a reference for the InSAR measurements, with PSI or any other technique, if you want to convert to absolute displacements. Otherwise the PSI measurements will be only relative to an arbitrary location.
(Eric F) PSI and all other type of inSAR measurements are always relative measurements and you need to have a ground - at least one ground control point in the area of your measurements if you want to determine what the absolute displacement of the ground surface is. You have to have some type of ground control or be able to assume you know some place is not moving in the scene.

Question 13: Are there any alternatives to Polsar Pro, since it's not available for download on the web?
Answer 13:
(Franz) For people not familiar with Polsar Pro, we talked a little about SAR polarimetry before - SAR datasets provide info not only in one polarizations, but in multiple polarizations. It's one of the big benefits of an active sensor like SAR where we have full control over transmitted and received information, so we can use polarization to understand more of the environment than we could for a single polarized measurement. There's a lot of theory on how to use polarization in SAR data to do image classification or information mining and a lot of this sophisticated theory is coded up in a software package released by ESA called Polsar Pro that has been available for a number of years. Currently, and not sure if it's still true, the tool isn't available online. But as far as I know, the team is planning to publish the next version fairly soon. In terms of alternatives, I personally am not aware of right now an alternative that has all the functionality Pulsar Pro has offered and the full breadth of themeatics available. There's some polarimetric capabilities in other tools. A little embedded in ESA's Sentinel-1 SNAP toolbox

(https://step.esa.int/main/toolboxes/snap/). I can track down the link to download SNAP. Paul can maybe talk to JPL effort called Plant
(Paul) Plant is mostly for polarimetrically related time series analysis, or multi-baseline. Don't know it has all the decompositions in it. I'm sure it isn't as complete as Polsar Pro, but it is an open source tool and expandable. I think the authors (Marco Lavalle) at JPL are interested in other people contributing to it. It's probably a good way to go for building a community. It's Python based. Python with NumPy is a relatively straight-forward way of interacting with data.
(Franz) It's true a little thin on the market in terms of capabilities, but we can follow up and find out what the latest plans are. My understanding is it will come available fairly soon.
(Paul) Do you know why it was removed?
(Franz) I recall a reason, but not sure enough about it to speculate.
(Paul) Plant is on github.
(Naiara) PolSARPro v6 is now available: https://www.ietr.fr/polsarpro-bio/

Question 14: I was wondering if we can use short-time-spanning SAR interferometry for detecting these systematic changes (line-shaped changes in relative humidity). Is it feasible to use such as system as it can penetrate in cloudy conditions which also predominated in front borders?
Answer 14:
(Paul) I think the question is asking if you have short time span interferometry where you know there's no surface deformation, can you use the phase signature in the interferogram to say something about what's going on in the atmosphere. Esp if regular features like a linear storm front - since it penetrates clouds, you're looking at wet and dry tropospheric changes from one time to the next. The answer to that question is yes, you can look at it. You can certainly see features. We see atmospheric turbulence, water vapor variability, changes in the path length due to topographic effects even from the dry troposphere. We see gravity waves propagating across mountain fronts. Many people have proposed using interferograms in an operational way to update weather models. So far there hasn't really been sufficient data to do so. Because SAR systems tend to be in any given spot, they don't sample the atmosphere very often. Every 1-2 weeks. Understanding the signature has been difficult. But it's a rich area for the future, and many people have proposed systems like Sentinel with regular acquisitions, or like NISAR with near-global acquisitions. Integrate signals over time and integrate them in the context of weather models.

(Eric F) I can add I know a geophysicist at CalTech has been trying to study ground deformation in Western Pakistan and one of the problems he has there is that there are these huge signals of water vapor in fronts that overwhelm some of the interferograms he's trying to analyze for ground deformation. So there can be a large signal from these weather fronts. It's very clear in places where we have good ground conditions for InSAR like Pakistan.

Question 15: Is there any study evaluating biomass with a combination of X-Band and L-Band (P would be better but I think we still have to wait for it with NISAR!) images?
Answer 15:
(Paul) I'm not sure I have the answer, but if I interpret the question right, it's indicating NISAR will create P band images. I want to clarify NISAR has an L-band sensor (24 cm radar) and an S-band sensor around 9 cm wavelength. Closest I think would be GeoSAR airborne mission in the 90s that was X-band and P-band a dual-aperture interferometer. X-band and P-band - measured height of X-band and P-band with X-band seeing closer to the height of the canopy and P-band seeing closer to the ground. Measuring both height and structure of the forest, with single-pass interferometry (two antennas). Don't know if that data is available for use, but there was a lot of data.

Question 16: Is there a reason behind banding and scalloping in SAR images? In addition, which is the most efficient method for speckle removal from SAR images as many speckle filters are available?
Answer 16: Scalloping is an image property that mostly related to burst-mode type SAR data such as ScanSAR images or the TOPS-mode data that's currently used by the Sentinel-1 mission. It can have different origins. In ScanSAR it is caused by the fact that not every point of the ground receives the same energy from the sensor during the imaging process. In ScanSAR, every point on the ground is only illuminated by a fraction of the full antenna beamwidth. As transmitted power varies across the beamwidth, the different areas receive different amounts of energy
(Franz) Scalloping is a specific artifact that comes from burst mode - not every point receives the same amount of energy from the sensor during imagery. In the uncalibrated dataset, this causes different patches of the ground to have slightly different brightness. This is corrected during calibration. There's an antenna pattern applied that corrects for the difference in brightness. But what happens at the same time, in darker areas, the radar brightness is increased to have a flat image. We also

increase the noise in the dataset at the same time. If you have datasets with a fairly dark background (e.g., ocean scenes) you can sometimes see an elevated noise floor where the brightness of the image has to be increased to see a calibrated flat scene. This is often called scalloping and mostly observable in places where the radar cross section of the ground itself is fairly low, so the noise has measurable impact on the appearance of the scene. On banding, there's a second artifact that can happen in these burst-mode. In order to increase swath width/coverage of one scene, we use burst mode to illuminate several swaths. Sometimes when these swaths are put together, they don't fully line up at the seams of the burst. These should become rarer as techniques improve.
(Paul) for large area mosaics, you're looking at the scene from different angles, maybe adjacent pixels are being seen from different angles and the surface scatter characteristics are different at different angles. So there can be unavoidable banding issues in a large scene.
(Franz) Second part was about speckle and most effective way to do speckle removal. There's a library of speckle filters you can pick from. I think the optimal filter will depend on your scene and application. I don't know that there's one filter I would recommend. For a while, speckle methods based on non-local mean filters - filters that try to identify image shapes with similar content were fairly popular for a while. There are other methods that perform similarly, so I don't know if I have a favorite.
(Erika) I agree - it's a matter of trying out the different filters and it depends on what you're trying to do. I've personally found applying a mean filter is what I prefer because I like to retain the original statistics of the data as close as possible to what they originally were. Some of the filters - I'm not sure what's being applied and how the original data is changing.
(Paul) the advantage of something like the non-local means looks at the statistics and seems to preserve features that most people want to see preserved. But it's true you don't always know the output statistics from those applications.

Question 17: Can SAR data be used in mapping soil salinity? Is there a theoretical relationship between SAR and salinity?
Answer 17: Backscatter from soils is the result of surface roughness, subsurface volume scattering, soil moisture, salinity, and other dielectric properties of the soil. It is difficult to tease out salinity from the other dielectric signals. In general, soil moisture seems to be the dominant separable signal, especially at L-band. The aquarius mission measured salinity of the oceans at L-band using radiometry and radar backscatter, but

there obviously the moisture is well known - it is water - so the dielectric properties are attributable to salinity.
(Paul) SMAP and SMOS are using the L-band to measure soil moisture. I would say that the likelihood of being able to pull salinity out of SAR is fairly low. But maybe others have better experience.
(Erika) I agree with what Paul said. There is a relationship between SAR and Salinity. Ulaby, who wrote sort of the "Bible of SAR" - . Here is a reference to a publication: https://www.semanticscholar.org/paper/Analysis-of-the-Backscattering-Coefficient-of-Soils-Aly-Bonn/11ad641b7c7ad99f23ce4bdab12443892c3e71fd

Question 18: Is it possible to use any SAR index for monitoring crops (stages, etc.)?
Answer 18: time-series SAR backscatter can help distinguish single-, double-, and triple-cropped rice areas. This paper demonstrates how backscatter behaves in response to different stages of rice growth (see Fig 1). Knowledge of these trends can help "count" the number of crop cycles in a year over a region (https://www.mdpi.com/2072-4292/7/12/15808/htm). Another good summary of SAR use for rice mapping is in section 1.2 of this paper. Aside from backscatter, others have seen that HH/VV polarization ratios behave in response to rice phenology; you could think of this ratio as a type of index.
(https://www.mdpi.com/2072-4292/6/11/10773/htm).
(Eric A) Caveat: not an agriculture expert. A lot of the research around SAR for crops seems to be focused on rice. There's several reasons why they might focus on rice for SAR. We were discussing how backscatter can behave in different stages. The paper shows images with how signals rise and fall. One of the ways you can use knowledge of that trend is to classify areas that are single, double, or triple rice crops. This is important for understanding potential yields or yield deficits, greenhouse gas emissions. There's another good summary in the second paper. In addition to backscatter, others have looked at ratios of HH/VV polarization. It may not be an index like Normalized Diffference Vegetation Index (NDVI), but you can think of it as an index that can characterize phenology in rice.

Question 19: My question pertains to Vertical line of sight looking down on a Heritage building. What is the smallest SAR payload that can be mounted to a UAV?

Answer 19: This is an area of very active development by commercial and academic groups. Because SAR requires transmitting the radar with significant power, SAR payloads are always larger than optical sensors that only receive light.
(Eric F) SAR payloads for UAVs are an active area of development. A key thing about SAR is the radar must be transmitted with a significant amount of power, which requires a large antenna and batteries. So SAR payloads are always larger than optical payloads. I think some typical numbers I've heard are on the order of 20-100 kg.
(Paul) It depends on your application, of course, if you're willing to fly low and hover you can maybe get away with it. But for practical applications, you're right.

Question 20: Could you please explain the effect of the ionosphere in the SAR backscatter?
Answer 20: The ionosphere can rotate the polarization of the electromagnetic SAR signal called Faraday rotation, so it can lead to imagery that have amplitude variations unrelated to the surface backscatter level, which potentially could lead to misinterpretation of the image. In addition, the ionosphere can have plasma structures at a fine scale that can lead to refractive bending and differential delay of the radar signal. This can lead to amplitude and phase distortions that can be quite pronounced at times. These effects are usually stronger for long wavelength SARs (such as P- or L-band SAR) but are also often observable at C-band and X-band
(Franz) Both the Faraday rotation effect - which can change the signal on the ground over time - and the distortion (along-track displacements of parts of the image) - those are typically more pronounced for long wavelength SAR, but they can be observed at C-band. If you've worked on pixel or feature tracking methods - a lot of people use C-band radar to look at things like glacier motion. In that, what you often do is track the movement of a certain piece of ground over time through several SAR images. When you do that, you may see some artifacts in your tracking result that come from a distortion of the image that comes from the atmosphere. It's more pronounced in P- and L-band, but can show up in C- and X-band. The effect is on amplitude, but also the phase, and can be more pronounced on the phase. Future missions like NISAR will try to correct for atmospheric distortions. NISAR will provide mission-process interferograms and will have a correction layer.

Question 21: Do you have a plan to introduce a cloud computing system or having lectures on big data processing, machine learning analysis and taking advantage of open platform such as Google Earth Engine?

Answer 21: Yes. There are teams at JPL and the ASF DAAC right now that are thinking about and developing technology that allows users to process data in the cloud - or better near the archive. We have some prototype systems (https://opensarlab.asf.alaska.edu/) in place right now and are currently scoping their functionality and cost implications with beta testers.
(Franz) SAR data is becoming more available and the data is getting bigger in size. We have regular sampling now, which allows us to do things we couldn't do in the past. But it comes with problems - it becomes more and more difficult for a regular end-user to deal with the information given storage and processing needed. So the answer is: yes, at least in the NASA world we've been thinking about cloud-based computer resources for quite some time. NISAR's data system will likely rely on the cloud and has been designed to run cost effectively and computationally effectively in cloud systems like the AWS cloud. We've also started prototyping systems that have allowed the users to come in and do their analysis in web-based environments. We've developed a thing called the Open SAR Lab that we're currently testing with selected beta testers. We try and figure out whether the functionality is useful, what the cost implications are, and making sure the environment is secure so no one can use the environment to attack other scientists or do harm to the data centers or anybody else. Link is above. Other activities are going on at JPL, and there is increased usage of GEE. It has ingested - or is ingesting Sentinel-1 data into the environment. There is a growing community to do GEE for analysis of SAR data.
(ARSET will offer a training in Aug/Sep that looks at using GEE for SAR data)
(Paul) We do give a SAR/inSAR class at a place called UNAVCO every summer that is being developed using a methodology called Jupiter notebooks, similar to what Franz has implemented in his open SAR paradigm. Ours is not yet cloud enabled. However, we could take all our jupyter notebooks as designed and convert them to something like open SAR and they'd be useable. In the next year or so, it will be cloud-enabled. And I think Franz and I both believe the future is using cloud-enabled where you can take your tools to where the cloud resides. There's another development being done between ESA and NASA in the data center development area called MAAP the Multi Analysis Platform (or something like that). This is geared to data from NISAR and BIOMASS mission (launching and operating on roughly the same timeframe) and from GEDI, the ISS lidar sensor. The idea is to provide tools not just for processing but for algorithm development on the cloud collocated with the data. They've had some prototype demonstrations and they're focusing on ecosystems, biomass estimation,

disturbance estimation, and related topics. That should be publicly available within a year or so.
(Franz) Wanted to mention something - ESA has an ongoing effort to use this called the ESA Thematic Exploitation Platforms (https://tep.eo.esa.int/). Allows users to go in to platforms and are available. I'm mentioning them because they could be useful now. It would also be useful for us to hear if you have experience the things you like about these platforms - what you don't like. So while we're developing our own tools, it's useful to know how to fit into the landscape and how to fit into previous efforts.

(Erika) ARSET will have another advanced SAR training at the end of Aug/early Sep. One of the parts will look at looking at flood trainings using GEE. The announcement for that training should be coming out later this week!

Preliminary connections between SAR and GEE: Training trainers in Hindu Kush-Himalaya region:
https://servir.icimod.org/events/training-trainers-workshop-synthetic-aperture-radar-and-google-earth-engine
Demonstrating a fusion of SAR and optical signals to characterize and monitor surface water bodies https://www.sciencedirect.com/science/article/pii/S2211379718303048
Developing and testing some workflows for Sentinel-1 pre-processing in GEE, (initially oriented toward forest change monitoring in Amazonia) sort of "translating" some of the tutorials in the SAR Handbook.
(Eric A) How quickly can we drill through a temporal archive of images? We're in exploratory stages and driven by a lot of questions that need the entire - need to be addressed by the entire time series of images. A few initial things. SERVIR often uses a train the trainers approach. Our hub in ICIMOD that serves Hindo Kush-Himalaya region will provide additional trainings or demonstrations of combining Sentinel-1 or optical and SAR data are out there in the recent literature. Focused on water quality detection. Going back to some of the needs and demands from the SERVIR Amazonia hub - we've started to translate some of the SAR handbook materials from Python into a GEE environment, noting the similarities and differences.

Question 22: What is the best given between radar images and lidar data for the estimation of biomass and carbon in tropical forests?

Answer 22: “best” is in the eye of the beholder. If we have both and our study area is large (more than 100s of hectares), we should think about using it all. If we have the resources to acquire fly airborne lidar or even capture ground-based lidar to create point clouds to estimate biomass, then we can get amazing data. A few caveats are that those data represent one time period and come at a high cost. If our study area is vast, very cloudy, and if the biomass and carbon are in great states of flux (i.e., deforestation, degradation, etc), radar images may give you more bang for the buck. Paul Siquera notes in Ch 4 of the SAR Handbook that “Forest Stand Height can be used an indicator of the age of a forest stand, plant and animal habitats, and the amount of Above Ground Biomass (AGB) held in the forest stand. FSH can be measured through the use of terrestrial and/or airborne lidar, with airborne lidar being especially useful due to its wide area coverage and direct measurement of forest height. A difficulty with airborne measurements, however, is that while these measurements work well at the *tens- to hundreds-of-hectares-level*, they are difficult to scale beyond that.” Another way to consider this question is that lidar data can be a useful input for “training” SAR-derived FSH models (either interferometric or coherence-based). We should also note that spaceborne and free lidar data are becoming more available (ICESAT-1 and -2, and NASA GEDI on ISS -- expected to become available this October-- and Land, Vegetation, and Ice Sensor or "LVIS”). Sassan Saatchi also blends lidar, SAR, and ground-based measurements for global biomass estimation, but relationships between “no universal model to convert the lidar height measurements into AGB on a continental scale, and by acquiring data in different forest types and calibrating the lidar data with ground forest inventory plots, new models are being developed…” (Ch 5 of the SAR Handbook).
We should use lidar data to build confidence in the radar data, which will continue to be freely available, while lidar data are not as regularly available.

Question 23: As far as polarimetric calibration of SAR image is concerned, for the compact polarimetric mode esp. CTLR (circularly transmit and linearly receive) mode, if we correct for the relative phase and ellipticity of polarisation ellipse, what should be the ideal other stokes derived parameters?
Answer 23: (We can ask around and will post an answer here later)

Question 24: Can you please suggest a resource that deals with the basics of the intricate process of SAR Image formation, involving the signal processing aspects with programming? A very beginner resource?

Answer 24: Oh, that's a difficult question. There probably is not a perfect resource for everybody but let me suggest a few papers or books to start from:

- SAR Handbook Chapter 2: Spaceborne Synthetic Aperture Radar: Principles, Data Access, and Basic Processing Techniques (https://gis1.servirglobal.net/TrainingMaterials/SAR/Chp2Content.pdf)
- A. Moreira: A tutorial on synthetic aperture radar https://ieeexplore.ieee.org/abstract/document/6504845
- ARSET has an Introduction to Synthetic Aperture Radar: https://arset.gsfc.nasa.gov/disasters/webinars/intro-SAR
- Look at the resources on: https://radar.community.uaf.edu/
- SAR-EDU / EOCollege: https://eo-college.org). https://eo-college.org/landingpage/

(Paul) Developing a jupyter notebook that goes through the fundamentals of image formation. Can't give it out yet - it still needs some vetting, but within a month or two, it should be ready for distribution. DLR has also created a similar jupyter notebook, but I don't know if it's freely available. In principle, since they've used it for teaching, it should be available. So, within a few months, there will be relatively straight-forward beginner resources, but you will need a jupyter installation and some experience with Python or MatLAB.
(Franz) Have you tried it on the Open SAR lab?
(Paul) I have - it works beautifully.
(Franz) Growing library of resources - in addition to ARSET, there's a page I maintain for a class that has a full semester's worth of information on microwave remote sensing. Slide decks, training materials, all available for anyone interested and more coming along all the time.

Question 25: What trends in radar remote sensing (e.g., sensors, processing) would you expect in the future?
Answer 25: There will be many many commercial X-band radar systems under development (some already launched) that will likely provide useful scientific remote sensing data with latencies approaching hours rather than days or weeks. There are also likely to be a number of additional L-band systems beyond ALOS and NISAR. ESA is considering an L-band pair of satellites in the Sentinel-1 orbit, and DLR is working toward a dual satellite Tandem L-band mission.

Beyond the sensors, we have noted above that processing will likely be on the cloud to avoid transporting large volumes of data. Missions (such as NISAR) will deliver higher level products as part of their standard products rather than just the Single Look Complex Imagery, and geocoded also, including interferograms which will make the data much more usable. Further, given the prevalence and ubiquity of SAR data, there will be an enormous number of higher level algorithms vetted by the community and large scale data record projects producing regional or global maps in a variety of disciplines, from ice sheets to forest biomass and cover, surface water extent, crop activity, and surface deformation.

(Paul) Just as Planet Labs optical data are becoming more and more used with anchors like Sentinel-2 and Landsat, the commercial SARs will be anchored by bigger systems like Sentinel-1 and NISAR and will be usable in that context. Sentinel-1 will be there for the next 30 years or so.

We've had Sentinel-1 for 4 years or so, and it's the first time SAR has had a prevalent, ubiquitous dataset available to many people. Just at the beginning of exploitation of these datasets. Going to see an explosion of algorithms and products being produced that we can all choose from. And I can imagine projects sponsored by agencies like NASA or NSF in the U.S. where they are creating data records on a regional or global scale. I can imagine these easily happening given what's coming up in the future (ice sheet maps, biomass, etc.) At the beginning of seeing the true utility of SAR data.

(Franz) SAR is popular and with all the sensors coming up - there's going to be more trends emerging as time comes along and people get more and more excited about the dataset.

(Eric F) I wanted to reiterate that Sentinel-1 was the first fully open access SAR dataset with systematic acquisitions. That is a big change in the accessibility of SAR - that will be continued with NISAR.