Questions & Answers Part 3

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 Erika Podest (erika.podest@jpl.nasa.gov) or Abhishek Chatterjee (abhishek.chatterjee@jpl.nasa.gov).

Question 1: Can you please elaborate on the relation and connection between OCO and AIRS? What is AIRS, how does it measure GHG and carbon and how does it compare or compliment OCO measurements?
Response 1: First, let me remind everyone how we measure CO2 from space. The basic idea is that we are looking at the high resolution spectra of sunlight reflecting from, or the thermal radiation emitted by, the Earth's surface in the atmosphere. This spectra is carrying information about the structure and composition of the atmosphere. We look at the spectra from the orbiting spacecraft and then analyze it with different algorithms to extract information about the atmosphere including the distribution of CO2 and other greenhouse gasses.

The AIRS instrument was one of the first multi-purpose instruments that we had in space. It uses the thermal infrared band to retrieve the CO2 concentration in the atmosphere. OCO on the other hand looks at the near infrared spectra. These two instruments are looking at two different spectral bands - AIRS CO2 measurements are more representative of CO2 concentrations in the middle and upper troposphere of the atmosphere. It also has a pretty large footprint and in general the initial attempts in trying to do CO2 retrievals yielded precisions that were not better than 1% to 2%. Because these measurements are not very sensitive to the surface but rather to the mid to upper troposphere, it was not giving us much information about the fluxes that were occurring near the surface.

This was sort of a great first demonstration of how we could make CO2 measurements from space, however, scientists that were looking at the data quickly realized that it wasn't really providing a great constraint on the flux exchange happening between the surface and the atmosphere.

This is where the newer sensors like OCO-2, which is looking at the near infrared band, come in. OCO-2 and OCO-3 provide greater information and greater constraint on the exchange of fluxes that are occurring near the surface. It also provides measurements with higher spatial resolution. Right now the errors in the retrievals are 1ppm or even lower. That is the difference between AIRS and OCO. There are still algorithm improvements that are happening on the AIRS retrievals. However, because of the fundamental differences between the spectra that the instruments look at, we end up with two different pieces of information about CO2 in the atmosphere. There are also studies that are trying to combine the information from the two missions and provide a greater constraint. Those studies however are still ongoing.

Question 2: Is NBE, in the terms of inverse modeling, the same as the NEE (Net Ecosystem Exchange) measured by the eddy covariance technique?
Answer 2: They are similar, but not identical. NEE from eddy covariance towers looks at flux exchanges occurring at very small footprints, typically around 1km. NBE is derived from atmospheric measurements that span the total atmospheric column, which are indicative of the natural exchange that is happening such as photosynthesis and respiration.

However, other processes occurring within that domain for example, land use change, deforestation or biomass burning will be integrated into the signal. This is because the atmosphere integrates all of that information together and provides us information of the flux exchange occurring across all carbon cycle processes. If we could for example take each retrieval by itself and then just do an inversion over a particular tower and there are no other processes occurring within that domain other than photosynthesis and respiration, then in theory the NBE will be equal to NEE. In practical terms there is a difference between those two terms.

Question 3: Question. In slide 16, why is cement separated from "Fossil Fuel and Cement Emissions (FF)"? What Fossil Fuel emissions are used in the inverse model? Are they spatially gridded data or national-level data?
Answer 3: There is a historical reason why we report fossil fuel and cement emissions separately. Currently the information that we get about fossil fuels are primarily compiled from inventories, which are based on data obtained from production, consumption and trade of fossil fuels. This is different from the processes associated with the decomposition of carbonate, e.g., the production of cement. Cement

manufacture is often included in CO2 inventories because it is the largest industrial process leading to CO2 emissions that *does not* involve fossil fuel combustion.

A large number of these inventories and reports are provided by different countries or international organizations and as of a few years ago a lot of them reported production of fossil fuel that just involved fossil fuel combustions (e.g. oil and gas burning, etc.). They would not include any kind of information about the exchange of bunker fuels or for example cement production, which is actually not due to fossil fuel combustion.

Primarily because of this we started with a fossil fuel production database and a different cement production database, which are then combined. Many of the newer inventories that are being produced gather data from fossil fuel and cement emissions together and all of that data is reported together in the recent inventories. Here I have included two different inventories that we look at. The first one is the Open Source Data Inventory for Anthropogenic CO2 (ODIAC) emission data product, available at https://odiac.org/index.html. It is gridded to 1°x1° km and contains anthropogenic total carbon emissions due to fossil fuel emissions, cement production and gas flaring.

For specific regions and countries of the globe, there is even data at 1km. You can also obtain country-level fossil fuel CO_2 emission estimates from CDIAC-FF. Please see Gilfillan, D. and Marland, G.: CDIAC-FF: global and national CO_2 emissions from fossil fuel combustion and cement manufacture: 1751–2017, Earth Syst. Sci. Data, 13, 1667–1680, https://doi.org/10.5194/essd-13-1667-2021, 2021.

Question 4: What is BBE in Philip et al., 2022, on slide #20?
Answer 4: BBE = Biomass Burning Emissions.

Question 5: Can we use OCO-2 and OCO-3 data to map data on carbon stocks & fluxes in four mangrove carbon pools (aboveground biomass, belowground biomass, soil, and dead organic matter)?
Answer 5: OCO-2 and OCO-3 data will provide information about the net exchange of fluxes that are occurring above the mangrove carbon pool. For example, you can get an estimate of the flux exchange occurring over a large mangrove area such as the Everglades in the U.S. or the Sundarbans in India and Bangladesh. In theory if you are able to map the exchange of fluxes, it refers to the net change in carbon stocks. Those

carbon stocks are then related to the four pools that you mention here. The data by itself will give you an understanding of the net flux exchange but then you would need another framework or other ancillary data to convert that exchange of net flux to net changes in carbon stocks.

In general if you want to get data on carbon stocks, there are other space-based instruments that you can use such as GEDI, which is a LIDAR flying on the ISS, or the Landsat mission that has a long history.

Please see - Hamilton, S. E., Castellanos-Galindo, G. A., Millones-Mayer, M., and Chen, M. (2018). *Remote Sensing of Mangrove Forests: Current Techniques and Existing Databases. Threats to Mangrove Forests: Hazards, Vulnerability, and Management*, eds C. Makowski and C. W. Finkl, (Cham: Springer International Publishing), 497–520.

Question 6: How do the OCO-2 products work with wildfire, as mentioned in the earlier slide about Australia wildfire?
Answer 6: Wherever a wildfire is happening, there will be a large emission of smoke or ash plumes. When OCO-2 flies over that area, typically because there is such a thick cloud or smoke cover, we are not able to directly get any retrievals where that fire is occurring. However, we can make observations downwind from that fire where the air is somewhat clearer. At this downwind location, there will be an enhancement in atmospheric CO_2 concentrations, and other species like carbon monoxide that is co-emitted during fires.

We then use information of that enhancement in CO_2 and CO to back out the emissions coming from the fire. That is one of the main principles that was used in the Byrne et al paper. Other studies have looked at wildfires in other locations (for e.g., California in the US), obtained enhancements in XCO_2 due to a fire and then developed an understanding of how much CO_2 emissions actually happened.

Question 7: Can you please share how we can access the ground measurements data and sensors (i.e., in slide 20: measurements from ground-based sites, the in-situ network)?
Answer 7: Yes, our colleagues at NOAA Global Monitoring Laboratory in Colorado, USA are in charge of collecting data from various ground-based measurement networks,

checking them and then packaging them for ease-of-use. You can access these data packages here - https://gml.noaa.gov/ccgg/obspack/
In addition to CO2, they have data packages for methane and other greenhouse gasses. This is a great resource for getting all of this type of data from one place.

Question 8: What is sounding in OCO-2 data? Is this analogous to a radiosonde sounding?
Answer 8: In our satellite columns, sounding refers to one retrieval or one measurement over a specific point. A single sounding means a single retrieval happening over a particular spot.

Question 9: Can you please clarify how OCO identifies CO2 plumes from large source points - what is the accuracy and granularity, which example sources were detected and over what time scale?
Answer 9: The way we identify CO2 plumes from large point sources, such as a power plants or over an urban area or megacity is in general very similar to what I mentioned about how we calculate the CO2 enhancement from the wildfire example. For example, if we went over a power plant emission and obtained a measurement of the total CO2 concentration, we would then compare it to the retrievals taken close by but not directly over that power plant.

By differencing the two retrievals we would get a sense of the enhancement in CO2 concentration and then we use an atmospheric transport model to obtain an understanding of the winds. We use these two pieces of information to back out how much of the CO2 emissions can be attributed to that particular source. In terms of which sources can be detected, the accuracy in general for OCO-2 is typically less than 1ppm. When we fly over a power plant or any large CO2 source, the enhancement in XCO2 over those sources is much larger than 1ppm and hence we can definitely detect that change. Right now, OCO-2 and OCO-3 studies are indicating that typically we are able to easily see emissions from any of the large thermal power plants across the globe.

Also see Chevallier, F., et al. (2022). Large CO_2 emitters as seen from satellite: Comparison to a gridded global emission inventory. GRL, 49, e2021GL097540. https://doi.org/10.1029/2021GL097540

Question 10: What is the temporal and spatial resolution of the CO2 raster layer?
Answer 10: In regards to the Level 3 product shown in the presentation, this is a global product. The spatial resolution is 0.5 degrees, which is roughly about 50 km grid boxes along the tropics. The temporal resolution of these products are daily but they are also aggregated and available at monthly resolution.

Question 11: Does OCO-2 provide separate Level-4 NBE and NCE products? How are the two set apart given that they are products of an integrated atmosphere?
Answer 11: Please refer to the slide on terminology in the presentation for the difference between NBE and NCE. There are separate Level 4 NBE and NCE products. In general, we go from NBE to NCE by adding the fossil fuel emission term. The ARSET Global Stocktake training has further information about those terms and what data products are being made available from the OCO-2 mission - https://appliedsciences.nasa.gov/join-mission/training/english/arset-atmospheric-co2-and-ch4-budgets-support-global-stocktake

Question 12: Can you please elaborate on the ability to monitor town-scale or city-scale CO_2 emissions?
Answer 12: We are able to monitor, detect, and quantify emissions that are occuring over large cities or megacities. For example, the entire Los Angeles metropolitan area or over Riyadh in Saudi Arabia or Paris, France. The next session from this training will discuss monitoring and quantifying urban anthropogenic CO2 emissions. There will be case studies shown and discussed in that session.

In short, we are able to monitor cities very well. The constraints for space-based measurements are always cloud cover. For example, if it is very cloudy, as occasionally happens over Mumbai, India during the monsoon season - during that period we see a large amount of missing retrievals. In that case a Level-3 product comes into play where we can use prior information from models along with any limited retrievals that we might obtain from the satellite to generate a gap filled map over the domain.

Question 13: Any hands on for downloading and processing Level-3 & Level-4 data?
Answer 13: Right now, we do not have that in our plans. We will take this into consideration for future higher level training. We do appreciate the feedback! Also send your feedback to the trainers and fill out the survey you will receive during the final part of this webinar series.