Part 3 Questions & Answers Session

Please type your questions in the Question Box. We will try our best to get to all your questions. If we don't, feel free to email Carl Malings (carl.a.malings@nasa.gov) or Melanie Follette-Cook (melanie.cook@nasa.gov).

Question 1: Is GEMS also a hyperspectral instrument?
Answer 1: Yes; the Geostationary Environment Monitoring Spectrometer (GEMS) is part of a new constellation of geostationary hyperspectral instruments for observing atmospheric composition. GEMS covers Korea and East Asia; several Pandora instruments have been deployed to support evaluation of GEMS data. The constellation also includes TEMPO over North America, and will eventually also include Sentinel-4 over Europe and North Africa.

Question 2: Are there any examples where the solar energy industry has used Pandora instrument data? I get asked this question often.
Answer 2: No, we have not been in communication with the Solar Power Industry. That is a good question, we could provide real time hyperspectral solar flux to better optimize panel design.

Question 3: How do I join the Pandora network?
Answer 3: The PGN is a network of Pandora instruments, not people. Instruments can be purchased from SciGLob. NASA and ESA will calibrate the instrument and coordinate the membership application. You can learn more at the PGN site.

Question 4: Given that the Pandora spectrometer is ground-based, what is the approximate area it samples (in terms of distance from the instrument's location)? I'm asking to understand the difference in coverage compared to satellite instruments.
Answer 4: For direct-sun observations, the footprint of the column measured by Pandora is a function of the solar zenith angle (SZA) – it is very small for small SZAs and reaches spatial scales (of the order of 1-2 km) close to that of high-resolution satellites for SZA>70 degrees. In MAX-DOAS mode, the distance sampled in the horizontal direction depends on the aerosol loading at the instrument location–cleaner

conditions are associated with larger sampling distances. Given this aerosol dependence, the horizontal (and vertical) distances sampled are estimated by the retrieval.

Question 5: What factors go into the placement of PGN sites? There seem to be a high density of sites in the Eastern US. Why is this?
Answer 5: The US EPA is very interested in using the Pandora Ground Network for their air quality studies. The EPA purchased several instruments and installed them at EPA sites along the heavily populated “I-95” corridor along the East Coast of the USA. High densities in Japan and Korea were associated with evaluation of the GEMS instrument. Norwegian groups have purchased instruments for examining Polar regions. The placements are determined by the priorities of the instrument owners.

Question 6: Why use this method rather than FTIR?
Answer 6: Fourier transform spectrometers could also be used to measure trace gasses in a manner similar to that of the Pandora. We have several Pandoras co-located with FT spectrometers: for example, Pan68 Wrightwood (Table Mountain) alongside the JPL FTUV spectrometer, Pan74 Armstrong also a TCCON site, Pan142 Mexico City-UNAM alongside several different spectrometers including FT, and Pan204 Boulder-NCAR alongside the NCAR FT spectrometer. The FT spectrometers tend to be a bit more expensive and larger, and they require more infrastructure.

Question 7: How do I check quality control on the AOD data from the AERONET Level 2?
Answer 7: Level 2 AERONET data have already gone through some quality control. Please refer to Parts 1 and 2 of the training for more details. Recordings of these are posted on the training website.

Question 8: Is there any project to assess coherence between AERONET and Pandora measurements? They use different instruments and methods, but retrievals would not differ so much, right?
Answer 8: AERONET instruments’ radiometric characteristics are calibrated in absolute terms (i.e., for a given level of measured counts, solar irradiance at the instrument can be accurately calculated), while the Pandora radiometric calibration is relative. This difference is relevant to what data can be retrieved by either instrument. However, research efforts to retrieve aerosol products using Pandora instruments are underway

and the robustness of these retrievals will be assessed against colocated AERONET measurements.

Question 9: What is the next level of AERONET derived data following the current ones (such as AOD, SSA, etc.) in advancing aerosol characterization and air pollution assessment?
Answer 9: Currently, Level 2 data are the most processed products provided by AERONET. For more information, please refer to Part 1 and Part 2 of this training, posted on the training webpage.

Question 10: What about the AOD from the direct component of solar radiation? Could the procedure for Cimel be applied for the retrieval?
Answer 10: Research efforts to retrieve aerosol products using Pandora instruments are underway and the robustness of these retrievals will be assessed against colocated AERONET measurements.

Question 11: What does it mean when you have a level 2 data product from Pandora, but it says 'data are unvalidated'?
Answer 11: Some Level 2 data products are not considered mature because they have not yet been thoroughly compared with data from other sources (satellites, in-situ, non-Pandora ground based measurements), and may be labeled as ‘unvalidated’. This is a subjective and qualitative assessment. The ‘unvalidated’ tag does not imply that the data products are not quality controlled by the PGN or that there are any instrument malfunction issues.

Question 12: What is the typical timeline from L0 to L2 retrievals, for example for NO_2, for an individual Pandora instrument?
Answer 12: Typically, an instrument will start producing all L2 products within 3-6 months of collecting L0 data. This timeline largely depends on the quality of data collected (~2 months of good weather data) and availability of a PGN scientist to perform a full field calibration. Some L2 products that do not require a full field calibration, such as the NO_2 MAX-DOAS products, will be available within 1-2 weeks of L0 files being generated.

Question 13: Are there any examples of K-12 engagement using Pandora? The instrument we operate is on the roof of a high school. Ideally, this would benefit

the high school students through formal curricular use, science club use, or co-location of other light, sky, or met sensors near Pandora. But building such a program from scratch is difficult – and any templates or examples would be appreciated.
Answer 13: Yes, the University of Iowa has Pan246 installed at West High School in Iowa City, Iowa. NASA has the Pan254 instrument installed at Greyhills Academy of the Navajo Nation in Tuba City, Arizona. Currently, we do not have K-12 programs, but NASA is working to develop curricula with universities through the IPMSI program.

Question 14: What is the cost of a Pandora instrument? I would like to compare the Pandora O_3 parameter with a dobson instrument (TOC). Can you suggest some papers to study the process to convert the pandora units to D.U.?
Answer 14: A 1-Spectrometer pandora costs somewhere around $50,000 and a 2-spectrometer system costs around $70,000 in 2024. The exact pricing needs to be obtained from the manufacturer, SciGlob. In order to convert the Pandora units of mol/m^2 to D.U. one would just need to divide the Pandora units by a factor of 4.4615×10^{-4}
Relevant Papers and Reports:
https://amt.copernicus.org/articles/9/5747/2016/
https://earth.esa.int/eogateway/documents/20142/37627/TD6.2-report-on-the-comparison-of-the-TCO-with-Dobson-Brewer.pdf
https://www.sciencedirect.com/science/article/pii/S135223101730167X

Question 15: Is it possible to link the AERONET-derived parameters to the PANDORA data to obtain more fascinating analysis especially in air pollutant assessments? Can this be done?
Answer 15: Absolutely! We have several co-located Pandora and Cimel instruments. Pandora can potentially provide hyperspectral aerosol optical depth. This is an active area of research and not ready for operational use.

Question 16: Why do some species have both multi-axis and direct Sun retrievals, while some (e.g., O_3) only have direct Sun retrieval?
Answer 16: The main reason is that the sky measurement determines the tropospheric amount of the species. In the case of O_3, most of the O_3 is in the stratosphere and only a few percent is in the troposphere. It is very difficult to accurately determine tropospheric O_3 amounts from the weak absorption signal.

Question 17: What are the wavelengths, or wavelength range, at which Pandora instruments measure?
Answer 17: Pandora UV instruments (the typical configuration) measure in the 290-540 nm range. Dual spectrometer Pandoras also include a visible measurement in the 430-960 nm wavelength range.

Question 18: Could you explain what 'out-of-the-box data products' means?
Answer 18: Certain PGN retrievals are possible using just a laboratory calibration. These retrievals become operational as soon as an instrument is installed and formally added to the PGN network, and are termed ‘out-of-the-box’. Other data products (direct sun NO_2, formaldehyde, and SO_2) require a PGN calibration analyst to generate a reference spectrum and perform field calibration.

Question 19: Could you please expand on how the field calibration is performed? Maybe briefly describe the steps?
Answer 19: The goal of the field calibration is to produce a trace gas absorption-free reference instrument for use in the retrievals. The advantage of using an instrument-specific reference spectrum versus an external reference spectrum is that it can better offset instrumental characteristics that may not have been fully characterized by laboratory analysis alone. The first step to produce the spectrum involves selecting a single noontime period on a clear day for use as the initial reference spectrum. From here, a month’s worth of L0 data is ingested and a modified Langley extrapolation is used to determine and subtract the absorption of each trace gas of interest from the reference spectrum.

Question 20: What is the temporal and spatial resolution of the instrument? Can it detect emission sources far from the location of the instrument?
Answer 20: The duration for direct Sun measurement is typically 30s-1min, while profile scans in the MAX-DOAS mode typically take 10 minutes. Typical measurement ‘schedules’ for Pandora instruments go back and forth between these two modes to maximize the availability of both types of measurements but instrument PIs have some flexibility to choose measurement modes that they are interested in. For direct-sun observations, the footprint of the column measured by Pandora is a function of the solar zenith angle (SZA) – it is very small for small SZAs and reaches spatial scales (of the order of 1-2 km) close to that of high-resolution satellites for SZA>70 degrees. In

MAX-DOAS mode, the distance sampled in the horizontal direction depends on the aerosol loading at the instrument location–cleaner conditions are associated with larger sampling distances. Given this aerosol dependence, the horizontal (and vertical) distances sampled are estimated by the retrieval.

Question 21: I wanted to use the data from 2000 for all atmospheric parameters. Where can I get that?
Answer 21: PGN was not operational in 2000; although the instrument was developed earlier, they were not used operationally until formal network observations began in 2019.

Question 22: Is the field calibration data (clear sky, noon) from one day or multiple? Is that repeated over time to monitor for drift? We have a new instrument installed this month in the Arctic that we monitor remotely. Should we be documenting cloud conditions at the noon hour as monitored by a webcam?
Answer 22: The field calibration picks only one single clear sky day to use for the reference spectrum, but needs about a month of good weather days to finalize the field calibration. Yes, the field calibration is repeated and quality assured over time – depending on drift some instruments require a new field calibration yearly, while some instruments in the PGN have only required one field calibration over their full measurement period. While it is always helpful to have a local weather record available on the instrument PC, it is not required for the field calibration to be performed. But it is very useful for the PGN team to know which days are clear days as seen by webcam!

Question 23: Where can I find the data for a specific location I choose?
Answer 23: Visit the website: https://data.pandonia-global-network.org/.

Question 24: For total column measurements, besides satellite comparison, what other instruments can be used to compare with Pandora?
Answer 24: This was briefly answered above. Individual instruments can be compared with colocated FTIR and other UV-vis DOAS instruments. In the case of ozone, Pandora columns could be compared with those from Brewer and Dobson instruments.

Question 25: I would like to know how many Pandonia instruments are located in Africa.

Answer 25: This can be found on the website linked above. There are only a few – a couple in South Africa. We hope to add a few more in the upcoming year or two via the satellite needs working group.

Question 26: Why not distribute all instruments globally, instead of having dozens of instruments in already very well-monitored regions (USA, Western Europe)? It seems that the effort of making the instrument mostly "autonomous" (e.g., by adding solar panels and satellite comm.) would be paid well by the value of having new and more interesting data.
Answer 26: This was addressed above. Many locations have been chosen with other satellite missions in mind like GEMS. Finding a location to host the instrument is challenging due to various factors like trees, electricity, etc.

Question 27: For Pandora retrievals, is it possible to download the total optical depth at certain wavelengths (similar to the AERONET Total Optical Depth file)?
Answer 27: No, but you can download the L1 data. This is calibrated spectral radiance. This could be scaled and compared to AERONET as addressed above.

Question 28: How do I transfer the counts against pixels into concentration of specified trace gasses?
Answer 28: This requires development of a retrieval code, or r-code, as discussed in the presentation. For more details on how these codes are developed, please refer to the publications related to the PGN. The L2 data will give the abundance at different altitudes.

Question 29: How do you cope with low-quality data? I mean, if you need to use low-quality measurements because you don't have an alternative, is there a way to know the uncertainty with which you are dealing? Or a way to confirm whether or not you can rely on that data?
Answer 29: There are two answers to this question. The PGN senses this and provides data quality flags of the retrievals, such as clouds and low light levels. This can only do so well at determining data quality. Scientists also look at the data and compare it to what is expected. Irregularities may demonstrate issues. We do provide our best estimates of measurement uncertainty, as well as a variety of quality diagnostics that scientists may use to decide whether the data are good enough for their purposes.

Question 30: How much does a PGN instrument cost?
Answer 30: A base model 1-Spectrometer Pandora costs somewhere around $52,500 in 2024. The exact pricing needs to be obtained from the manufacturer, SciGlob.

Question 31: Can Pandora tell the altitude of a tropospheric column it detects during one scan? Is this the same as the altitude of the highest layer in the max-doas scan?
Answer 31: Yes, it is the same. The uncertainty goes up with altitude.

Question 32: Can Pandora data be downloaded for any city, or only for cities where Pandora instruments are located?
Answer 32: Data will only be available where Pandora instruments are located.

Question 33: When Pandora uses the Moon as a source of light, does it use the reflectance from the ROLO model?
Answer 33: The lunar retrievals are still under development. The ROLO model was not used.

Question 34: How should we go about comparing Pandora NO_2 tropospheric columns to model simulations? With satellites, there are usually averaging kernels that can be used, but I am not sure about Pandora. Would it be recommended to calculate the column up to a certain height?
Answer 34: There is some uncertainty in the height determination, but recognizing that uncertainty I would recommend building this into the calculation.

Question 35: How many lower tropospheric levels (at what heights) are available in the Pandora datasets?
Answer 35: The number of layers can be 11 or 13, typically. The heights vary; these will be reported in the dataset.

Question 36: What is the spectral resolution of the hyperspectral instruments used to calibrate the Pandora instruments?
Answer 36: We do not use hyperspectral instruments to calibrate. We use light sources. They are typically below a nanometer.

Question 37: How are the surface concentrations in the Pandora data products derived?
Answer 37: This is addressed in the presentation (Slide 34) and also above, for the answer to Question 4.

Question 38: For Pandora (and I suppose the prior two days for AERONET), questions about the spatial frameworks. The slide just showed lat/long in DD to 4 digits of precision and an elevation. But what is the grade of the location data (mapping, survey, etc.), why only 4 decimals of precision, and what is the spatial framework reference for these networks? I keep running into challenges with the spatiotemporal position accounting across products.
Answer 38: We use Google maps to get the latitude and longitude of our instrument locations. We don't need a very high level of precision for these, since we only need to know where the Sun is in relation to the instrument.

Question 39: How many PANDORA stations are co-located with AERONET stations?
Answer 39: Around 15. We are currently working to increase the number of co-located instruments. In addition, we are working towards using a similar naming convention to make the identification of colocated instruments easier.

Question 40: How is retrieval different in the case of using the moon as a source of light as compared to using the sun as a source of light? Also, does it do the sky measurement at night? If yes, how do you take care of low signal to noise ratio?
Answer 40: We do not do sky measurements at night.

Question 41: Does PGN have any sites in India?
Answer 41: Yes, two. Pan250 Haldwani-ARIES and Pan251 Nainital-ARIES. These are new as of 2024. We hope to add more as opportunities arise.

Question 42: How can we access the PANDORA network data?
Answer 42: Visit: https://data.pandonia-global-network.org/.

Question 43: Is there any website describing some case studies using one or many of these ground-based networks?
Answer 43: Please see a list of publications related to PGN data.

Question 44: What is the detection limit of Pandora HCHO retrievals?
Answer 44: It depends on the instrument. It can depend on the age of the instrument.

Question 45: How are these PANDORA derived parameters validated?
Answer 45: See the response to question 11; Pandora data are validated by scientists through comparisons with satellites, in-situ, and non-Pandora ground based measurements.

Question 46: NO_2 measurements are utilized for the mixed layer height estimation; are there other factors considered along with it like local or meteorological effect or measurements of the other gasses as well? How is this done?
Answer 46: You can refer to the paper for specific details.

Question 47: How often do researchers take advantage of the portability of the Pandora instrument? Does it make sense to move an instrument around a city or does one more often want simultaneous measurements from nearby sites?
Answer 47: Mobile instruments are difficult to operate because we need to track the Sun dynamically using a camera for feedback. We have deployed ship-borne instruments for field campaign support. These are special cases that require substantial effort to operate, so we limit the use of mobile instruments.

Question 48: Is it possible for Pandora to retrieve other gasses that have UV-Vis absorption? Can users do retrieval by themselves?
Answer 48: Yes and Yes. It is possible to retrieve H_2O, NO_3, BrO, and HONO, maybe some others depending on the local abundance. These gasses have been retrieved by some Pandora users in special cases. For example, the LuftBlick team has retrieved NO_3 from Lunar measurements. The L1 files are available for you to try your own retrievals. The L2_fit files will show some species that are not officially retrieved. A caution: these species are not officially retrieved because the retrievals are still for research only. They are not high enough quality to be produced operationally by the PGN.

Question 49: Have any instruments been intentionally deployed as a stereo pair versus co-location?

Answer 49: Yes. We operated Pan58 and Pan31 Charles City at the VCU Rice River Center in stereo. We can see gradients in NO_2 in the East vs. West views.

Question 50: Are you aware of any attempt to use this instrument as an active sensor by pairing with a distant light (laser?) source?
Answer 50: No, but it is common practice to use a white light laser and spectrometer for long-path measurements.

Question 51: Why does the number of top heights of layers in the L2 data profile (MAX-DOAS mode) vary over time?
Answer 51: The number of layers in the MAX-DOAS L2 data vary for two reasons: (1) each set of layer data corresponds to a measurement routine that is designed for a specific purpose. For example, a fast sky-scan using only 5 angles can provide the tropospheric column amount and the near-surface concentration. This scan will show up as a 4 layer set in the L2 file and is not usable as a trace gas profile. (2) Some of the observations in an elevation scan might encounter clouds and get discarded in the L2 data because of high uncertainty.

Question 52: Does Pandora provide an averaging kernel? If not, does it influence the comparison with satellites, especially if the satellite is sensitive to higher altitude while Pandora is more sensitive to the surface?
Answer 52: Total columns from direct Sun Pandora measurements are independent of the vertical distribution of trace gasses in the atmosphere, so these can be easily compared with satellite total column measurements.

Question 53: Can we study SIP and SP using Pandora in agro climatic places?
Answer 53: Pandora can, in principle, measure any spectral features in the UV-Vis, but it depends on the signal strength. To our knowledge, there have been no attempts to measure soil backscatter signals with a Pandora.