An overview of the Satellite Coastal and Oceanic Atmospheric Pollution Experiment (SCOAPE) Cruise along the Louisiana Coast. A partnership between NASA and the U.S. Department of the Interior’s Bureau of Ocean Energy Management shows that satellites can monitor emissions from the Gulf of Mexico energy industry. Both satellites and coastal trace gas measurements during a Spring 2019 research cruise found more pollution over land than the Gulf.
In 2017, NASA’s Goddard Space Flight Center (GSFC) and the U.S. Department of the Interior’s Bureau of Ocean Energy Management (BOEM) began a partnership to assess the usefulness of satellite data for monitoring air quality (AQ) over the U.S. coast and Outer Continental Shelf (OCS). The OCS of the Gulf of Mexico west of 87° 30’ West longitude is a major territory over which BOEM has jurisdiction to ensure that its offshore oil and natural gas (ONG) operations do not significantly affect the AQ of any state. The initial focus of the GSFC-BOEM study was in the Gulf of Mexico south of the Louisiana coastline, due to its high density of energy operations.

Nitrogen dioxide (NO₂), the primary pollutant of interest, is measured by well-documented satellite and ground-based remote sensing technologies. In May 2019, NASA and BOEM conducted an oceanographic cruise in the Gulf of Mexico focused primarily on observing NO₂ and ozone (O₃) with a suite of trace gas analyzers deployed on the University of Southern Mississippi’s Research Vessel (R/V) Point Sur out of the Louisiana Universities Marine Consortium (LUMCON; http://lumcon.edu) Cocodrie, LA, facility. The cruise has been designated as Satellite Coastal and Oceanic Atmospheric Pollution Experiment (SCOAPE), with a sampling strategy designed to answer the following questions:

- What do pollutant levels measured by satellite over the Gulf of Mexico look like, and how do they compare to coastal Louisiana?
- Can satellite observations detect emissions from offshore ONG operations and are the measurements accurate?
- Can satellite and other remote sensing data be used to measure offshore pollutant levels at the surface, inasmuch as the latter is the metric for human exposure?

**Sampling Strategy**

BOEM’s emissions reports of 2014 and 2017, complemented by AQ models and meteorological considerations, guided the experimental cruise track design. Satellite NO₂ instruments and NASA’s surface-based Pandora spectrometer systems used for “ground truth” operate in the ultraviolet/visible spectrum, requiring clear skies. Onshore wind flows, which bring pollution from the OCS toward the coastline, were the primary reason for selecting May 2019 for the SCOAPE cruise. BOEM wanted measurements near deepwater platforms far from shore, as well as among the higher-density small emitters closer in.

Figure 1 shows that on Day 1 (May 10) the R/V Point Sur headed east/northeast through the eastern Heavy Density Area (HDA) of operations offshore of Louisiana and Mississippi before heading south through a large platform area. The cruise sampled the southern areas on May 12 and 13 and revisited the HDA-East on May 15. Sampling on days May 16 and 17 took place in the HDA-West region and involved circling the Louisiana Offshore Oil Port (LOOP).

Routine meteorological parameters (temperature, relative humidity, winds) and continuous O₃, NO₂, methane (CH₄), and carbon dioxide (CO₂) data were collected on the R/V Point Sur, along with column NO₂ measurements from a Pandora spectrometer instrument. Canister samples for a large suite of volatile organic compounds (VOCs) and carbon monoxide (CO) analyses performed post-cruise were collected 2–3 times each day. Ozone sondes and radiosondes were launched for midday satellite overpasses.
Pollution Contrasts: Land and Sea

Fine-tuning of cruise plans while at sea took advantage of satellite maps, near-real-time cloud imagery, meteorological forecasts, and AQ models. The NASA GEOS-CF (composition forecasting) CO forecast for May 12, 2019, appears in Figure 2a. The clean marine air regime in which the R/V Point Sur had been sampling May 10–12 appears in blue, indicating model predictions of CO ~100 parts per billion by volume (ppbv), somewhat higher than shipboard CO (not shown), which was as low as 69 ppbv, suggesting tropical air origins. O₃ during May 10–12 was often 10–20 ppbv (Figure 2b), also tropical values. By midday on May 13, a cold front-induced sudden wind shift brought more polluted air to the ship; mean values of CO were 130 ppbv. After May 13, O₃ measured on R/V Point Sur averaged 45 ppbv, more than a two-fold jump from May 10–12.

Figure 2b also displays CH₄ concentrations. Pre-May 13 air averaged CH₄ ~1.90 parts per million by volume (ppmv); this was followed by a 0.1-ppmv jump in the continentally influenced air. At natural

Figure 2. Illustrations of two air quality regimes: (a) CO Forecast, showing continental-marine boundary. Surface CO NASA GEOS-CF forecast valid at 13:00 CDT on May 12, 2019; (b) Quality-assured (ship exhaust effects eliminated) surface O₃ (red) and CH₄ (black) from R/V Point Sur during SCOAPE cruise.

Figure 3. TROPOMI Tropospheric Column NO₂ (in DU) over SCOAPE Cruise region on (a) May 13, 2019, and (b) May 15, 2019. White open circles are the locations of the top 500 NOₓ-emitting platforms from BOEM’s 2014 inventory and the white solid line marks the track of the R/V Point Sur.

Note: These figures display the tropospheric column, whereas Figure 4 shows Total Column (TC) NO₂ for both satellite and Pandora.
The Pandora time-series compared to the R/V Point Sur shipboard NO₂ measurements are illustrated in Figure 4a, along with surface–Pandora–satellite comparisons for the cruise period. Just as observations for the in-situ trace gases show a discontinuity at the May 13–14 transition, Total Column (TC) NO₂ also increases by ~30%; compare the position of the horizontal lines in Figure 4a. However, a close-up of the May 15 comparisons (Figure 4b) shows a fairly large range of TC NO₂ from 0.15 DU up to 0.30 DU. These TC NO₂ amounts are indicative of low to moderate pollution. Pandora measurements in Maryland during OWLETS-2 (see Sullivan et al., elsewhere in this issue) were as high as 0.40 DU for TC NO₂. Median TC NO₂ was > 1.0 DU at several sites in and near Seoul (Korea) in 2016 during the KORUS-AQ campaign.

The Pandora instrument has been developed for AQ monitoring and validation of operational satellite instruments (e.g., Aura’s Ozone Monitoring Instrument [OMI]) as well as TROPOMI. The mean agreement between TROPOMI and Pandora TC NO₂ (Figure 4a) during the cruise is ~14%, with the Pandora higher than the satellite under the more polluted conditions. For the OMI satellite instrument, with ~6–8 times coarser resolution than TROPOMI, the Pandora offset is also ~14%, but with higher offsets than TROPOMI after May 14. Coincident TROPOMI and Pandora TC NO₂ observations have a higher correlation (R~0.9) than for OMI (R~0.6); TROPOMI appears to do a better job capturing the shift to a more polluted Gulf of Mexico regime.

Remote Sensing and Ambient Pollution

From an AQ viewpoint, the SCOAPE cruise offered a chance to address two issues about ambient pollution. First, the Gulf of Mexico sampling was the first opportunity to observe Pandora–surface NO₂ relationships near ONG platforms. Second, with the new Pandora sensor incorporating upgraded optics and a more reliable sun-tracker, we were able to study the instrument as a proxy for measuring ambient pollution in coastal waters.

Figure 4b displays Pandora data on a clear sampling day, May 15, when the R/V Point Sur was in the vicinity of deep-water platform Petronius (Figure 1). In the morning, there are small surface NO₂ spikes and, marked in the ellipses, Pandora TC NO₂ spikes with increases greater than a factor of 2, from ~0.15 to 0.35 DU. In general, over the course of the day, the Pandora TC NO₂ increases ~50% to a mean ~0.22 DU, but with several spikes above 0.25 DU near platform clusters (Figure 4c) as the R/V Point Sur travels west from Petronius. The surface analyzer records a mean NO₂ mixing ratio ~10 ppbv but also displays transient peaks greater than 25 ppbv; the latter continue post-sunset when the Pandora is no longer making measurements.

The reason for the apparent surface-column disconnect in NO₂ observations is the lower height of the morning mixed boundary layer; Pandora TC NO₂ is evidently capturing platform emissions near Petronius above the marine boundary layer that the analyzer does not. By afternoon, the boundary layer height has increased to 1.5 km, and the Pandora responses are more reflective of the near-surface levels of NO₂. Thus, the answer to the question of Pandora data as an indicator of AQ is that, although the continuous column NO₂ information responds to local pollution and can serve as a substitute for satellite monitoring, it may not be sufficient for measuring ambient (i.e., “nose-level”) NO₂ exposure.

Conclusions

Below is a summary of our responses to the questions the SCOAPE cruise set out to answer.

What do pollutant levels measured by satellite over the Gulf of Mexico look like, and how do they compare to coastal Louisiana?

Satellite measurements of NO₂, used as our AQ proxy, are accurate over coastal Louisiana and the Gulf of Mexico. Our limited cruise measurements show larger pollutant values over the continent than the Gulf of Mexico. However, both in-situ and Pandora sampling display prominent NO₂ spikes near platform ONG operations.

Can satellite observations detect emissions from offshore ONG operations and are the measurements accurate?

Although satellite measurements can detect regions of elevated NO₂ associated with ONG operations, more analysis of the SCOAPE cruise data using chemical tracers (CH₄, CO₂, VOCs), trajectories, and chemical-transport models, is required to establish uncertainties. The Pandora–TROPOMI and OMI comparisons show that the satellite column NO₂ readings are accurate to ~14%, with the satellite values biased low under more polluted conditions.
Figure 4. (a) Overpass comparisons of TROPOMI (gold diamonds) and all Pandora readings (green circles) each day. TROPOMI and Pandora average 14% agreement in TC NO₂ (DU); (b) Closeup of Pandora (TC, DU) and surface NO₂ analyzer (ppbv) on R/V Point Sur, May 15, 2019. Spikes in NO₂ originate from sampling plumes near Petronius; (c) SCOPE track (white) with Pandora TC NO₂ on May 15. Orange-red boxes are platform locations.
Can satellite and other remote sensing data be used to measure offshore pollutant levels at the surface, inasmuch as the latter is the metric for human exposure? Neither satellite nor Pandora column amounts provide ambient concentrations of NO₂. Case studies can establish statistics for the conditions under which the column–surface NO₂ relationship is strongest. NASA will continue this type of analysis in preparing for the 2022 launch of a geostationary O₃ and NO₂ satellite, TEMPO, which is designed for hourly pollution monitoring over North America and its coastal waters.

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