Geophysical Research Abstracts
Vol. 16, EGU2014-14477-2, 2014
EGU General Assembly 2014

Strategies for satellite-based monitoring of CO_2 from distributed area and point sources

Florian M. Schwandner, Charles E. Miller, Riley M. Duren, Vijay Natraj, Annmarie Eldering, Michael R. Gunson, and David Crisp

Jet Propulsion Laboratory, California Institute of Technology, Pasadena, United States (florian.schwandner@jpl.nasa.gov)

Atmospheric CO_2 budgets are controlled by the strengths, as well as the spatial and temporal variabilities of CO_2 sources and sinks. Natural CO_2 sources and sinks are dominated by the vast areas of the oceans and the terrestrial biosphere. In contrast, anthropogenic and geogenic CO_2 sources are dominated by distributed area and point sources, which may constitute as much as 70% of anthropogenic (e.g., Duren & Miller, 2012), and over 80% of geogenic emissions (Burton et al., 2013). Comprehensive assessments of CO_2 budgets necessitate robust and highly accurate satellite remote sensing strategies that address the competing and often conflicting requirements for sampling over disparate space and time scales.

Spatial variability: The spatial distribution of anthropogenic sources is dominated by patterns of production, storage, transport and use. In contrast, geogenic variability is almost entirely controlled by endogenic geological processes, except where surface gas permeability is modulated by soil moisture. Satellite remote sensing solutions will thus have to vary greatly in spatial coverage and resolution to address distributed area sources and point sources alike.

Temporal variability: While biogenic sources are dominated by diurnal and seasonal patterns, anthropogenic sources fluctuate over a greater variety of time scales from diurnal, weekly and seasonal cycles, driven by both economic and climatic factors. Geogenic sources typically vary in time scales of days to months (geogenic sources *sensu stricto* are not fossil fuels but volcanoes, hydrothermal and metamorphic sources). Current ground-based monitoring networks for anthropogenic and geogenic sources record data on minute- to weekly temporal scales. Satellite remote sensing solutions would have to capture temporal variability through revisit frequency or point-and-stare strategies.

Space-based remote sensing offers the potential of global coverage by a single sensor. However, no single combination of orbit and sensor provides the full range of temporal sampling needed to characterize distributed area and point source emissions. For instance, point source emission patterns will vary with source strength, wind speed and direction. Because wind speed, direction and other environmental factors change rapidly, short term variabilities should be sampled. For detailed target selection and pointing verification, important lessons have already been learned and strategies devised during JAXA's GOSAT mission (Schwandner et al, 2013).

The fact that competing spatial and temporal requirements drive satellite remote sensing sampling strategies dictates a systematic, multi-factor consideration of potential solutions. Factors to consider include vista, revisit frequency, integration times, spatial resolution, and spatial coverage. No single satellite-based remote sensing solution can address this problem for all scales. It is therefore of paramount importance for the international community to develop and maintain a constellation of atmospheric CO_2 monitoring satellites that complement each other in their temporal and spatial observation capabilities:

1. Polar sun-synchronous orbits (fixed local solar time, no diurnal information) with agile pointing allow global sampling of known distributed area and point sources like megacities, power plants and volcanoes with daily to weekly temporal revisits and moderate to high spatial resolution. Extensive targeting of distributed area and point sources comes at the expense of reduced mapping or spatial coverage, and the important contextual information that comes with large-scale contiguous spatial sampling.

2. Polar sun-synchronous orbits with push-broom swath-mapping but limited pointing agility may allow mapping of individual source plumes and their spatial variability, but will depend on fortuitous environmental conditions during the observing period. These solutions typically have longer times between revisits, limiting their ability to resolve temporal variations.

3. Geostationary and non-sun-synchronous low-Earth-orbits (precessing local solar time, diurnal information possible) with agile pointing have the potential to provide, comprehensive mapping of distributed area sources such as megacities with longer stare times and multiple revisits per day, at the expense of global access and spatial coverage.

An ad hoc CO_2 remote sensing constellation is emerging. NASA's OCO-2 satellite (launch July 2014) joins JAXA's GOSAT satellite in orbit. These will be followed by GOSAT-2 and NASA's OCO-3 on the International Space Station as early as 2017. Additional polar orbiting satellites (e.g., CarbonSat, under consideration at ESA) and geostationary platforms may also become available. However, the individual assets have been designed with independent science goals and requirements, and limited consideration of coordinated observing strategies. Every effort must be made to maximize the science return from this constellation. We discuss the opportunities to exploit the complementary spatial and temporal coverage provided by these assets as well as the crucial gaps in the capabilities of this constellation.

References

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