National Aeronautics and Space Administration

Exploiting Spatio-Temporal Dependence in Multi-Footprint Remote Sensing Retrievals

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Program: FY21 SURP **Strategic Focus Area: Uncertainty Quantification**

Objectives

- Develop statistical methodology and efficient computational tools for multi-footprint joint retrievals of atmospheric and surface properties from remote-sensing data
- Applicable to multiple current and future Earth science missions
  - Trace gas retrievals from Orbiting Carbon Observatory-2/3 (OCO-2/3)
  - Joint surface/atmosphere retrievals for Surface Biology and Geology (SBG)
- Science objectives for these and other Earth-observing missions focus on quantities of interest (QOIs) that exhibit correlation in space and/or time

Approach and Results

- Multi-footprint approach uses a multivariate spatial statistical model as prior distribution
  - Spatial correlation can be state-dependent
- Within-footprint correlation for OCO-2/3 exhibits block structure for state vector groups (Fig. 2)
- Team has enabled forward model evaluation and simulation experiments with ReFRACtor retrieval software package (Fig. 3)
- In FY22, retrieval simulation experiments are planned using spatially-correlated states
  - Results to be compared with linear model case of [3] (Fig. 4)
  - Enable multi-footprint retrieval capability for OCO-2 small areas

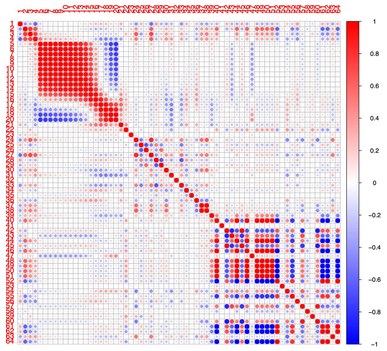

Figure 2: Estimated within-footprint correlation structure for OCO-2 retrieved states. Strongest correlations (in red) in top left block correspond to the vertical profile of atmospheric CO_2.

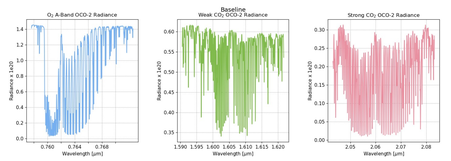

Figure 3: Example OCO-2 spectra produced from a forward model evaluation with the Reusable Framework for Retrieval of Atmospheric Composition (ReFRACtor). Panels depict the three spectral bands observed by OCO-2.

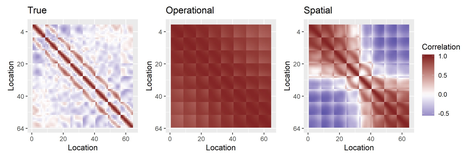

Figure 4: Spatial correlation of retrieval errors for total column CO_2 under three retrieval strategies, from [3]. The operational one-at-a-time retrieval (center) yields strongly correlated retrieval errors.

Background

- Geophysical QOIs (e.g. atmospheric CO_2) are inferred (retrieved) from satellite spectra
- Modern retrieval methods often use Bayes' theorem, assuming a *prior distribution*, for atmospheric state
- Single-footprint retrieval errors are often spatially correlated [1,2]
- Multi-footprint strategy allows simultaneous inference for a small area of footprints (Fig. 1).

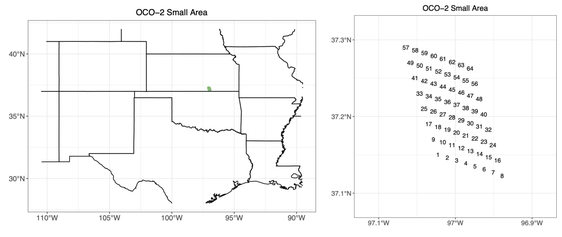

Figure 1: Example multi-footprint scenario for OCO-2. Left: A small portion of an individual OCO-2 orbit (in green) over southern Kansas with m = 64 footprints. Right: A zoomed-in view of the locations of the nearby footprints.

Significance/Benefits to JPL and NASA

- Enhance relationship between JPL, co-I Katzfuss research group, and connected academic statisticians
- Methodology can inform next-generation retrieval approaches, enabling improved precision and accuracy
- Reduce challenges introduced by spatio-temporal correlation of retrieval errors in higher-level products and science investigations

References

[1] Anthony Torres, Gretchen Keppel-Aleks, Scott Doney, Michaela Fendrock, Kelly Luis, Martine De Mazière, Frank Hase, Christof Petri, David Pollard, Coleen Roehl, Ralf Sussmann, Voltaire Velazco, Thorsten Warneke, and Debra Wunch, "A Geostatistical Framework for Quantifying the Imprint of Mesoscale Atmospheric Transport on Satellite Trace Gas Retrievals," Journal of Geophysical Research **124** (2019). doi: 10.1029/2018JD029933
[2] John Worden, Gary Doran, Susan Kulawik, Annmarie Eldering, David Crisp, Christian Frankenberg, Chris O'Dell, and Kevin Bowman, "Evaluation and attribution of OCO-2 XCO2 uncertainties," Atmospheric Measurement Techniques **10** (2017): pp. 2759–2771. doi: 10.5194/amt-10-2759-2017
[3] Jonathan Hobbs, Matthias Katzfuss, Daniel Zilber, Jenný Brynjarsdóttir, Anirban Mondal, and Veronica Berrocal, "Spatial Retrievals of Atmospheric Carbon Dioxide from Satellite Observations," Remote Sensing **13** (2021). doi: 10.3390/rs13040571

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