National Aeronautics and Space Administration

FY23 Strategic University Research Partnership (SURP)

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

Principal Investigator: Jonathan Hobbs (398)**; Co-Investigators:** Amy Braverman (398), James McDuffie (398), Vijay Natraj (329), David Thompson (382), Otto Lamminpää (398), Matthias Katzfuss (Texas A&M University), Anirban Chakraborty (Texas A&M University)

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

Background

- Single-footprint retrieval errors are often spatially correlated
- Multi-footprint strategy allows simultaneous inference for a small area of footprints (Fig. 1).

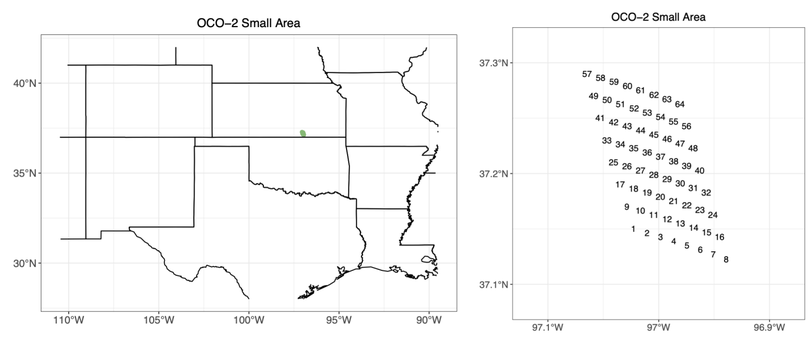


Figure 1: Example multi-footprint scenario for OCO-2. Left: A small portion of an individual OCO-2 orbit (in green) over southern Kansas with m = 64 footprints. Right: A zoomed-in view of the locations of the nearby footprints.

Approach, Results, Significance

- Within-footprint correlation for OCO-2/3 exhibits block structure for state vector groups (Fig. 2)
- Team enabled retrieval simulation experiments with ReFRACtor retrieval software package (Fig. 3)
- Multivariate spatial factor model provides variable range of spatial correlation for different state vector constituents (Fig. 4)
- Retrieval simulation experiments with spatially-correlated states and forward-model discrepancy
  - Result in retrieval errors with nonzero mean and modest spatial correlation
  - Team developed and archived notebooks documenting examples

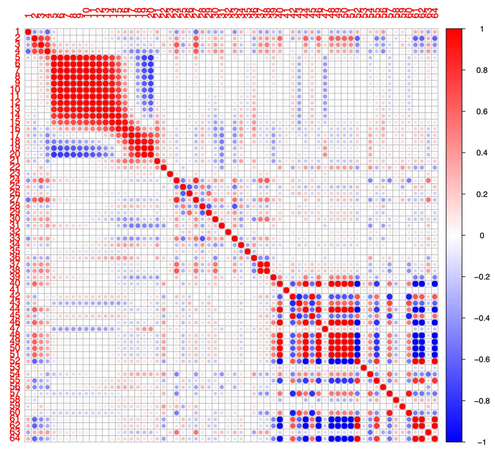


Figure 2: Estimated within-footprint correlation structure for OCO-2 retrieved states. Strongest correlations (in red) in top left block correspond to the vertical profile of atmospheric CO_2.

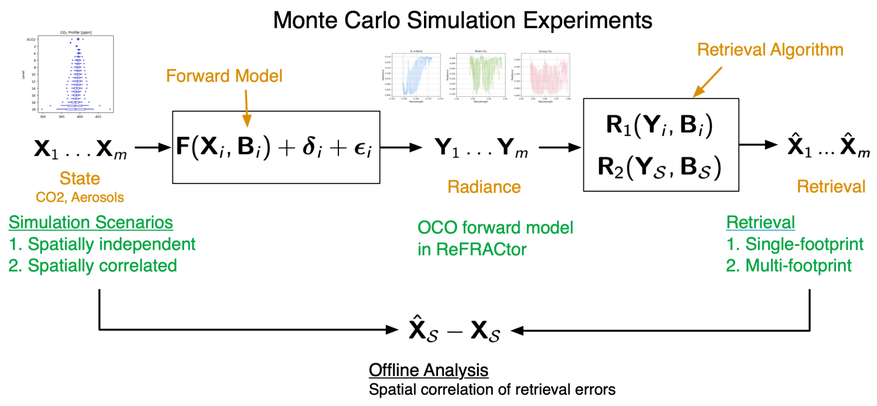
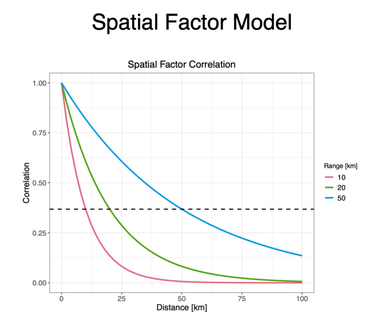


Figure 3: Schematic diagram of simulation experiment framework for single and multi-footprint retrievals. Collections of spatially independent or correlated states are generated and used in the OCO forward model in the ReFRACtor software.



$$\mathbf{X}_j = \mathbf{\Lambda}\,\mathbf{W}_j + \boldsymbol{\eta}_j$$

$$Cor(\mathbf{W}_{jk}, \mathbf{W}_{j'k'}) = \exp\left\{\frac{2||\mathbf{s}_j - \mathbf{s}_{j'}||}{\lambda_k + \lambda_{k'}}\right\}$$

Figure 4: Spatial factor model for OCO-2/3 state vectors. A small collection of spatially-correlated latent factors $\mathbf{W}_j$ each have a unique spatial correlation length. Within-footprint correlations are induced through a data model for the state vector $\mathbf{X}_j$.

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Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

www.nasa.gov

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References:

[1] 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

PI/Task Mgr. Contact Information:

Email: Jonathan.M.Hobbs@jpl.nasa.gov