National Aeronautics and Space Administration

FY23 Strategic Initiatives Research and Technology Development (SRTD)

Foundations of Data Fusion for Future PBL Missions

Principal Investigator: Amy Braverman (398); **Co-Investigators:** Margaret Johnson (398), Marcin Kurowski (329), Matthew Lebsock (329)

Strategic Focus Area: Next Earth Science Decadal Survey: Technology & Architecture for Planetary Boundary Layer (PBL)/ Surface Topography & Vegetation | **Strategic Initiative Leader:** Rashmi Shah

Objectives

A. Develop, implement, and test prototype algorithms for fusing data from two notional future JPL PBL missions identified in the PBL Report (a sounder and a radar/lidar modeled on the DIAL and DAR instrument concepts).

B. Demonstrate that we can evaluate accuracies, uncertainties, and computational costs of fused data products that will result from different design choices.

Background

1. One the most important conclusions of a recent NASA study on future PBL observation is that no single instrument can observe the PBL adequately, and that *"...the production suite of a spaceborne PBL mission...should combine each component's information content in and optimal manner..."*

2. Statistical methods for combining such heterogeneous data are based on spatial statistical models.

3. These methods are purely data driven. A physical model can be used incorporated to drive temporal dynamics (this is data assimilation), but that is not our objective here.

4. In this project, we built a spatial statistical model to quantify the relationship between the (three-dimensional) PBL spatial field and notional observations of it by two instruments: a sounder-like instrument and a radar-like instrument flying down the center of the sounder swath.

5. The PBL variable studied here is water vapor.

Significance

This is crucial data processing technology for future PBL missions. Instead of performing trade studies for individual instruments in formulation, data fusion allows us to do so for combinations of instruments that provide complementary data. These results provide proof-of-concept for methods to simulate basic observing characteristics, perform data fusion, and evaluate results quantitatively.

Approach and Results

1. Basic idea: We postulated a probabilistic model that describes the behavior of a full, 3D water vapor field. Then we added a probabilistic specification of how observed data relate to the full field, and finally used basic rules of probability to obtain the conditional probability distribution of the true-but-not-directly-observed field, given the observed data.

2. Data: We used data from a sequence of progressively more complex Large Eddy Simulations (LES's) which we called "Dry", "LBA", and "Gate", representing three canonical PBL regimes: dry, mid-latitude conditions, marine with some convection and self-organization, and tropical deep convection.

3. Pseudo-observations from the two instruments were constructed as overlapping spatial aggregates of the full-resolution field endowed with random, normally-distributed independent measurement errors. Nine cases radar-like instrument with vertical resolution fixed at 15 hPa, along-track varies at 1, 5, and 10 km vs sounder-like instrument with horizontal resolution fixed at 1 km, vertical varies at 45, 90, and 150 hPa.

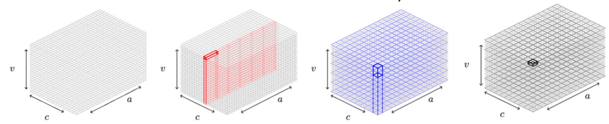

Figure 1. Left: Full-resolution LES grid (100m horizontal resolution and 7.5 hPa vertical resolution for LBA). Center-left: Pseudo-observations for radar-like instrument. Center-right: Pseudo-observation for the sounder-like instrument. Horizontal resolution fixed at 1 km. Right: target resolution.

4. Statistical model:

$$\mathbf{Z} = \mathbf{F}\mathbf{Y} + \epsilon,\ \epsilon \sim \mathcal{N}(\mathbf{0}, \mathbf{V}_\epsilon), \quad \mathbf{Y} = \mathbf{H}\boldsymbol{\eta} + \boldsymbol{\delta},\ \boldsymbol{\delta} \sim \mathcal{N}(\mathbf{0}, \mathbf{V}_{\boldsymbol{\delta}}), \quad \boldsymbol{\eta} \sim \mathcal{N}(\mathbf{0}, \mathbf{K}).$$

Observation vector; Aggregation matrix; Vector of all voxels' "true" values; Vertical basis matrix; Coefficient vector; errors: $\epsilon, \boldsymbol{\delta}$

5. Estimate mean vector and covariance matrix of ``True" vector given "Observation" vector => fused estimate and uncertainty at "target" resolution. Estimate vertical basis matrix from radar-like pseudo-observations, and model parameters from all pseudo-observations.

6. Nine experiments (3 horizontal resolutions for radar-like instrument vs 3 vertical resolutions for the sounder-like instrument) for each Dry, LBA, and Gate LES runs. 3 shown below for LBA: best, intermediate,

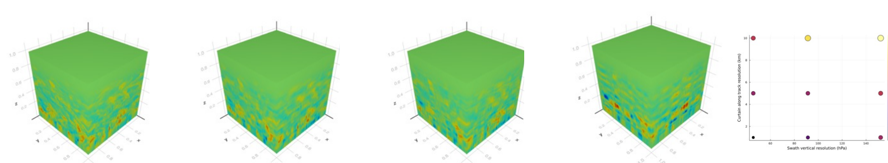

Figure 2. Left: Full-resolution LES grid (100m horizontal resolution and 7.5 hPa vertical resolution for LBA). Center-left: fused estimate for radar-like instrument at 1 km along-track and 15 hPa vertical and sounder-like instrument at 1 km horizontal and 45 hPa vertical (best case). Center-middle: fused estimate for radar-like instrument at 5 km along-track and 15 hPa vertical and sounder-like instrument at 1 km horizontal and 90 hPa vertical (intermediate case). Center-right: fused estimate for radar-like instrument at 10 km along-track and 15 hPa vertical and sounder-like instrument at 1 km horizontal and 150 hPa vertical (worst case). Summary root-mean-squared-errors for all nine LBA experiments.

7. As expected, root-mean-squared error (RMSE; far right panel of Figure 2) decreases with higher resolution. RMSE calculated over whole cube at target resolution. RMSE differs depending on across-track "curtain position" in the cube. See Figure 3

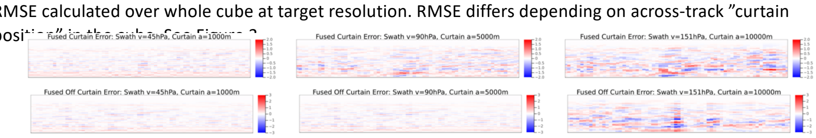

Figure 3. RMSE plots for along-track slices through LBA cube. Top row: center along-track slice (used to learn vertical basis matrix) for best, intermediate and worst cases. Bottom row: off-center along-track slice.

National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

www.nasa.gov

Clearance Number: **CL#23-5043**
Poster Number: RPC#107

PI/Task Mgr. Contact Information:
818-793-4606, Amy.Braverman@jpl.nasa.gov