Lessons Learned and Initial Assessment of Small Satellite for Data Assimilation: Part I - TEMPEST-D

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1. Overall Goals

Explore quick and agile methodologies to entrain small-satellites that have limited lifetimes into the NOAA processing stream. Develop workflows that would allow NOAA, once it has identified in-space assets, to ingest, calibrate, validate, and exploit these data in a minimum amount of time. The specific goals are the following:

- Assimilate TEMPEST-D radiances into FV3GFS and assess impact, focusing on regions and time periods of high uncertainty in FV3GFS that coincide with TEMPEST-D data.
- Address, in coordination with JCSDA, the required flexibility and agility of the GSI system.
- Address, in coordination with STAR, potential improvements in the O2R and R2O workflows and support systems.

2. TEMPEST-D Technical Info and Cal/Val

The Community Radiative Transfer Model (CRTM) is used by the NOAA operational GSI data assimilation system as the forward operator for the assimilation of the top-of-atmosphere (TOA) satellite radiances. In order to compute TOA radiances from the forecast model and compare with data as part of an assimilation algorithm, the satellite zenith, satellite scan angle, and satellite azimuth angles are required by the CRTM. Although the satellite scan angle and satellite zenith angle are available in the original TEMPEST-D HDF5 file, satellite azimuth angle is not. As a result, the three angles were recomputed for a given pixel of TEMPEST-D using spherical trigonometry.

A spherical triangle is formed by the intersection of three great circles. Thus, side_a (scan angle), side_b (latitude to satellite), and side_c (co-latitude to the footprint) are arcs of great circles in radians. In addition, angle B is the satellite bearing/azimuth angle where

\[ \cos B = \cos \alpha - \cos \beta \cos \gamma, \]

Knowing side_a, side_b, and angle B, side_c can be calculated as follows:

\[ \text{side}_c = \cos^{-1}(\cos \text{side}_b \cdot \cos \text{side}_c), \]

Given \( \beta = \text{azimuth}, \gamma = \text{azimuth}, \) and \( \alpha = \text{scan angle}, \)

a. satellite scan angle
b. satellite zenith angle
d. earth incident angle

The CRTM-TEMPEST-D radiance field can be calculated in GNU-F90 using the following equations:

\[ \begin{align*}
\text{side}_a &= \cos^{-1}(\cos \text{side}_b \cdot \cos \text{side}_c) + \sin \text{side}_b \cdot \sin \text{side}_c \cdot \cos \text{angle}_{\alpha-eta} \\
\text{angle}_{\alpha-eta} &= \cos^{-1} \left( \frac{\sin \text{side}_a}{\sin \text{side}_b \cdot \sin \text{side}_c} \right) \\
\end{align*} \]

An example of the computed scan angle from four TEMPEST-D orbits between 0800 UTC and 0900 UTC of December 8, 2018. Along each orbit, scan angle on the forward left side is negative, while scan angle on the forward right side is positive. The computed scan angles varies between approximately -55 degrees and +55 degrees, which is close to the scan angle from the original TEMPEST-D HDF5 file.

3. Data Quality Control (QC) and BUFHR Format

The following tests are applied to consecutive satellite latitude and longitude as QC parameters:

\[ \text{Values of satellite orientation yaw, pitch, and roll must be less than 0.1 degrees} \]

4. Satellite Angles/Geometry for the CRTM

5. Initial Assimilation using GSI with FV3GFS

As an initial attempt to assimilate TEMPEST-D radiances into FV3GFS using GSI, the following procedures are considered:

- Use the MHS QC procedure in GSI to identify and remove cloudy pixels of TEMPEST-D from being assimilated (clear-sky radiation assimilation).
- Apply mass bias correction but no angle dependent bias correction (GSI uses a linear function to calculate scan angle, while the scan angle is provided by TEMPEST-D).
- 145 km thinning is used to be consistent with other satellite instruments assimilated in FV3GFS.

6. Key Lessons Learned and Future Work

- Small satellites may not have the level of data availability required for long-term assimilation (e.g., because of downlink issues, competing scientific priorities, or satellite design), which is essential to appropriately address bias that usually requires seasonal to annual assessment.
- Small satellite data products often do not natively contain all data fields required for data assimilation experiments and fields will need to be generated from the data that is available.
- Because small satellite missions do not have engineering and Cal/Val teams characterizing the data, the required quality control for data assimilation experiments must be discovered and applied through trial and error or connections to the instrument teams.
- Small satellite data will be provided in a variety of data formats, each of which will need to be uniquely converted to BUFHR files for assimilation into GSI prior to running experiments.
- Incorporate the TEMPEST-D PWV retrieval algorithm to the GSI procedure.
- Extend current work to all-sky radiation assimilation of TEMPEST-D.

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