The Retrieval of Atmospheric Profiles from Satellite Radiances for NWP Data Assimilation

W. Smith Sr., E. Weisz, H. Revercomb, N. Smith

University of Wisconsin Space Science and Engineering Center - Madison

The 20th International TOVS Study Conference (ITSC-20)
28 October – 3 November
Lake Geneva, Wisconsin, US
Poor Sounding Vertical Resolution Causes Problem with Direct Assimilation of Satellite Profiles

**Filter Sounders (e.g., HIRS)**

- Weighting Function
- $\Delta v = 15 \text{ cm}^{-1}$

---

**Interferometer Sounders (e.g., CrIS)**

- Weighting Function
- $\Delta v = 0.5 \text{ cm}^{-1}$

---

**Resolution Function**
The vertical resolution and accuracy increases greatly with the number of spectral channels. The improvement is proportional to the square root of the number of channels (i.e., S/N).
**The Problem**

- Satellite profile retrievals exhibit vertical structure biases toward the a-prior profile (i.e., either the initial guess profile or the mean of the statistics used for regression) due to the low vertical resolution (i.e., “null space”) of the radianc observations.
- This bias was large for retrievals from low spectral resolution filter radiometers (e.g., TOVS) causing vertical resolution aliasing when assimilated into NWP models causing negative impact.
- Direct assimilation of the radiances, rather than retrievals, was employed to avoid vertical resolution aliasing and to achieve positive impact.
- However, for hyperspectral sounding instruments, which contain thousands of spectral channels, radiance assimilation of all the spectral radiances is currently too time consuming for operational use. As a result, only a small subset of spectral channel radiances are assimilated limiting the vertical resolution, which is maximized by utilizing “ALL” the spectral channels in the retrieval process.
- Here, a simple and time efficient method for de-aliasing full spectral resolution hyperspectral sounding retrievals is presented.
"Dual-Regression" Retrieval Algorithm* Overview

Global clear soundings

Radiances (clear FM)

Clear-trained regression coefficients

Global cloudy soundings

Radiances (cloudy FM)

Cloud height classes

Cloud-trained regression coefficients

Theoretical Statistics

Radiances Observations

Clear-trained EOF regression retrieval

Cloud-trained EOF regression retrieval

Cloud Top Altitude

Level where $T_{\text{cloudy}} > T_{\text{clear}}$ for $p > p_{\text{clld}}$

Final Profile

Clear-trained above and cloud-trained Cloud Top

Temperature, Humidity and Ozone profiles, Surface and Cloud parameter at single FOV (0-2-km) resolution

How Can We Estimate the Forecast Model Alias Produced by Assimilating Satellite Profile Retrieval?

- RTM simulate radiances from a model forecast profile co-located with the satellite observation
- Produce a profile retrieval from the RTM simulated satellite radiances using exactly the same algorithm used to retrieve profiles with real satellite observations
- The vertical resolution alias is simply the difference between the model radiance profile retrieval and the forecast model profile used to simulate the radiance observations used for that retrieval
- Eliminate the satellite retrieval alias by subtracting the model forecast estimated vertical resolution alias from the real satellite observation profile retrieval
De-aliasing Algorithm

Model Profiles → Sfc $\varepsilon_v$ → Tskin → CLR RGN CLDY RGN → CLR RGN CLDY RGN → CLR STATS CLDY STATS → Cloud Pressure → Real Observation DR RTVL → Real Obs. DR RTVL + DA Correction → De-aliased Dual-Regression RTVL

Model RTVL → CLR RGN CLDY RGN → Model RTVL → DA Correction Model Prof. – Model RTVL

Clr RTM Rad Spectrum → Observed Spectrum
Regression Vs. De-aliased Retrieval
DOE SGP ARM-Cart-site (May 20, 2013)
SNPP-2 Arctic (Summit Greenland) CrIS Sounding Validation
March 23, 2015

---

[Graph showing temperature and relative humidity profiles with various lines indicating different data sources and times.]
The “Environmental” GH

**Airborne Vertical Atmospheric Profiling System (AVAPS)**
- 89 Dropsondes / flight
- Temperature, Pressure, wind, humidity vertical profiles

**Scanning High Resolution Infrared Sounder (S-HIS)**
- Upwelling thermal radiation at high spectral resolution between 3.3 and 18 microns.
- Temperature, water vapor vertical profiles

**Cloud Physics Lidar (CPL)**
- 532/1064 nm Lidar Reflection
- Cloud structure and depth
DA S-HIS Vs. Dropsonde Statistics (HS3-2014)

N = 655 comparisons

For Large GDAS – Drop Differences
CrIS Coverage ~19 UTC
May 20 2013

11 micron (i.e., 900 cm^{-1}) Radiance
Clear Retrieval Radiance Residuals

De-aliased Profile Retrievals Possess Smaller Obs. – Calc. Radiance Residuals than Do the Forecast Model and Regression Profiles Used for the De-aliasing Process
Regression Vs. De-aliased Vs. GDAS Lifted Index (May 20 2013)

Model \frac{dLI}{dt} (19:08–16:53)
Time Tendencies of Lifted Index (May 20 2013)

LI RGN CrIS (19:08) - LI RGN IASI (16:53) (K/hr)

LI DA CrIS (19:08) - LI DA IASI (16:53) (K/hr)

GDAS LI (19:08 UTC)

SPC Storm Reports for 05/20/13

TORNADO REPORTS... (37)
WIND REPORTS/HI.... (281/5)
HAIL REPORTS/LG..... (129/9)
TOTAL REPORTS...... (447)

National Weather Service
Storm Prediction Center
Norman, Oklahoma
Summary

• Poor vertical resolution of satellite soundings can cause a vertical alias within the NWP models that assimilate them.

• The vertical alias can be determined using NWP simulated radiances and removed from the real radiance retrieval.

• It is shown that the de-aliased profile retrieval is an improvement of the model profile that was used for the de-aliasing process.

• Analyses of time consecutive (2-hr interval) satellite retrievals (i.e., from Metop-B IASI and S-NPP CrIS), antecedent to a Tornadic storm outbreak, indicates that the assimilation of de-aliased satellite profile retrievals will improve the forecast of the location and timing of severe weather events.

• This hypotheses now needs to be proven through the time assimilation of de-aliased hyperspectral soundings obtained from the system of Metop-A, Metop-B, S-NPP, and Aqua satellites.