Further Development of PCRTM in Solar Spectral Region Under Multiple-Layer Cloudy Conditions

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CLARREO SDT Meeting, University of Michigan, MI, May 10-12th, 2016

Outline

- Overview of previous PCRTM-SOLAR
- Results in Last CLARREO SDT Meeting
- Goal After Last CLARREO Meeting
- New Strategy to Accelerate PCRTM-SOLAR
- Main Results of the New PCRTM-SOLAR
  - Training
  - Validation
- Conclusion

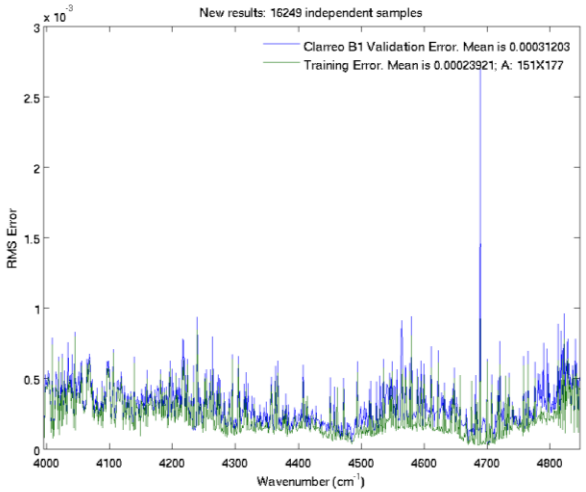
Our Previous Work: PCRTM-SOLAR

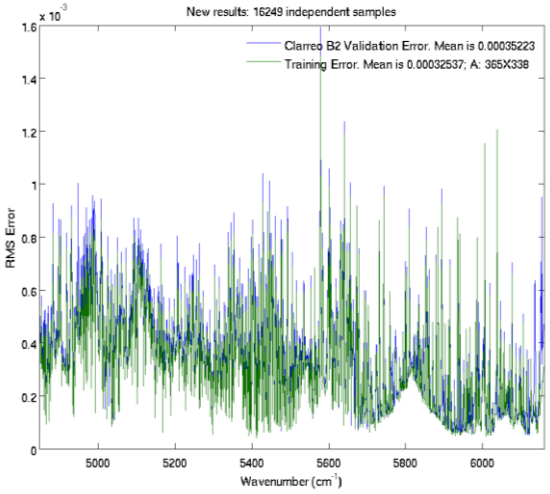
- CLARREO Reflected Solar (RS) spectrum from 300 nm to 2.5 μm with 1 cm^{-1} resolution (29,311 channel frequencies).
- MODTRAN: need radiances at 259,029 mono frequencies
  - Real Example: qsub to CLARREO machine at NASA LaRC, 16-stream, one spectrum)
    - CPU TIME = 2 hours 39 minutes = 9540 s
- PCRTM-SOLAR: need radiances at only 1,359 mono frequencies for land surface
  - Real Example: qsub to CLARREO machine at NASA LaRC, 16-stream, one spectrum)
    - CPU TIME = 67.736237 (radiance at 1359 mono frequencies)
    - PCRTM TIME = 8.00094604E-02 (convert rmono to rchan)

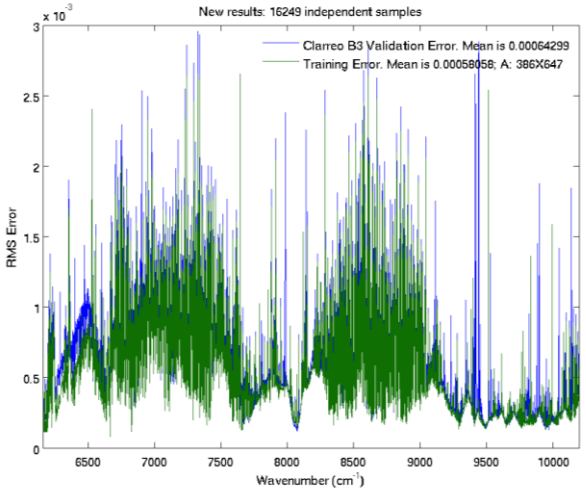
0.3-2.5 μm	PCRTM-SOLAR	MODTRAN	SPEED UP
Ocean 1 cm^{-1}	956	259029	270
Land 1 cm^{-1}	1359	259029	190
Ocean 4 nm	279	259029	928
Land 4 nm	354	259029	731

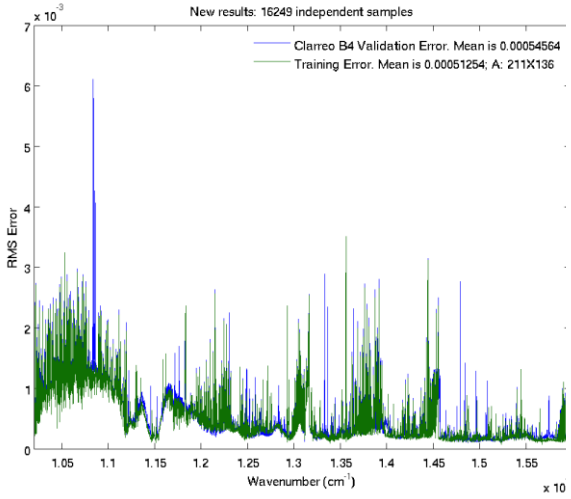
- PCRTM-SOLAR is able to treat multi-layer cloud/aerosol

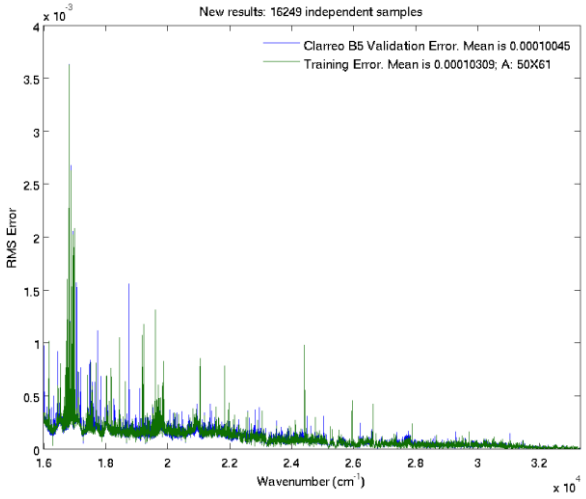
Our Previous Work: Accuracy of PCRTM-SOLAR











- 1359 mono frequencies were selected from training.
- The validation results indicate that the accuracy of PCRTM-SOLAR is very high, mean over wavenumber of the RMS is $1x10^{-4}$ to $6.5x10^{-4}$.

Previous Results in Last CLARREO SDT Meeting

- We developed a ultrafast high accuracy PCRTM-SOLAR model for one-layer of cloud/aerosol (One-Layer-Cloud/Aerosol PCRTM-SOLAR):
  - Look up tables (compressed)
  - No need to call DISORT
  - Independent of stream number
  - Orders faster than previous PCRTM-SOLAR
- Disadvantage:
  - Hard to expand to multiple-layer cloud/aerosol cases

Goal After Last CLARREO SDT Meeting

- To develop a new PCRTM-SOLAR for multiple-layer cloud/aerosol cases:
  - Need to be faster than previous PCRTM-SOLAR
  - Need to be with very high accuracy (comparable to previous PCRTM-SOLAR)
  - Able to treat all cases the previous PCRTM-SOLAR can treat.

Speed and Accuracy Dilemma

- Speed and accuracy dilemma in MODTRAN/DISORT
  - The accuracy depends on stream number N. Larger N usually gives higher accuracy.
  - The computation time is approximately proportional to N^3.
- Do we have to compromise between accuracy and speed? (We want both!!!)

New Strategy: 4-Stream to N-Stream

- What we need:
  - Speed: 2-stream or 4-stream
  - Accuracy: N-stream (N >> 2)
- The link between 4-stream and N-stream (Land surface, 1 cm^{-1} resolution case):

$$r_{Nstr}^{1359} = r_{4str}^{1359} + (r_{Nstr}^{1359} - r_{4str}^{1359}) = r_{4str}^{1359} + \Delta r^{1359}$$

They are highly related!

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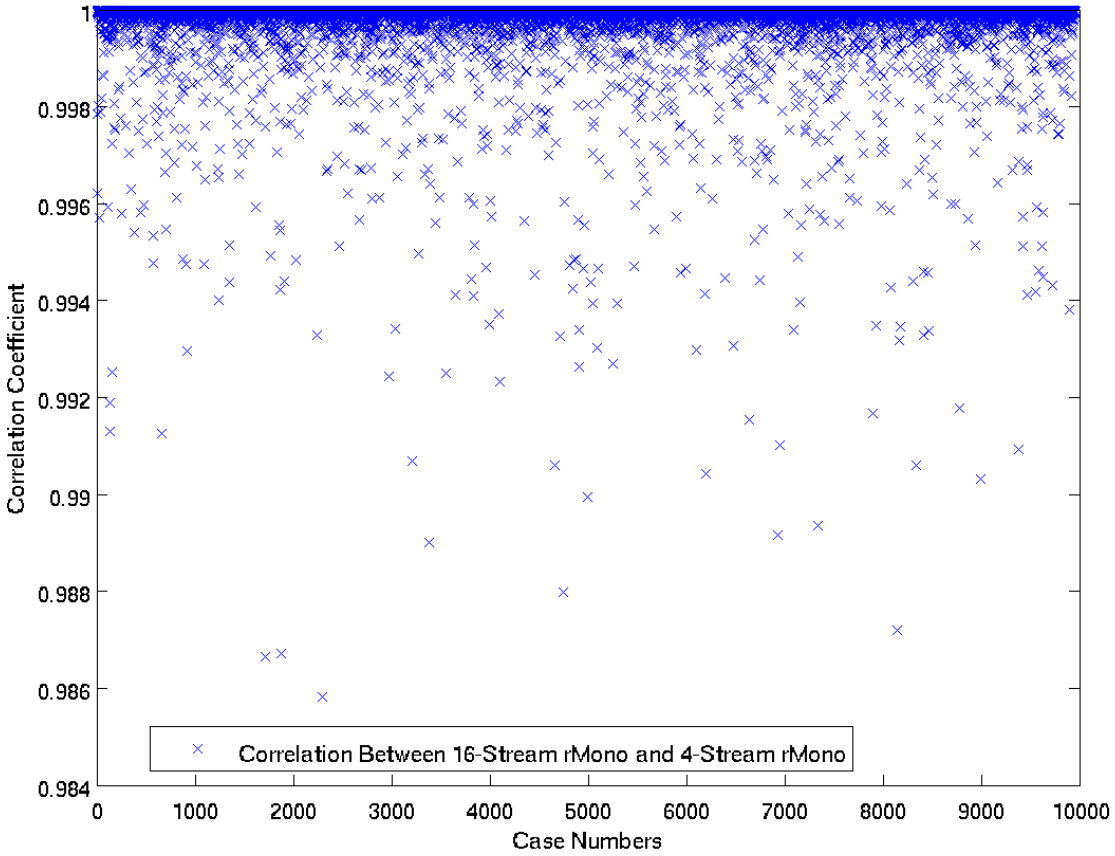

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New Strategy: 4-Stream to N-Stream

- Training the small difference:

$$\mathrm{D}r^{1359} = B^{1359\times M} \cdot \mathrm{D}r^{M}$$

With M << 1359.

- The obtained radiance with N-stream accuracy is thus given by:

$$r_{Nstr}^{1359} = r_{4str}^{1359} + B^{1359\times M} \cdot \mathrm{D}r^{M} = r_{4str}^{1359} + B^{1359\times M} \cdot (r_{Nstr}^{M} - r_{4str}^{M})$$

- **Don't need N-stream calculation at all 1359 frequencies;**
- **Need N-stream calculation at M frequencies among the 1359 frequencies. (M << 1359)**
- **Need 4-stream calculation at all 1359 frequencies.**

New Strategy: 4-Stream to N-Stream

- Estimated speed using the new strategy:

$$\text{time ratio} = \frac{\text{time for N-stream (all 1359 frequencies)}}{\text{time for 4-stream (all 1359 frequencies)} + \text{time for N-stream (M << 1359 frequencies)}}$$

For 16-stream accuracy: N = 16. Assume M = 35

Method	Number of frequencies	Speed Up
MODTRAN	259,029	1
PCRTM-SOLAR	1359	190
MODIFIED PCRTM-SOLAR	1359 (4 stream) + 35 (16 stream)	4560

M = 35

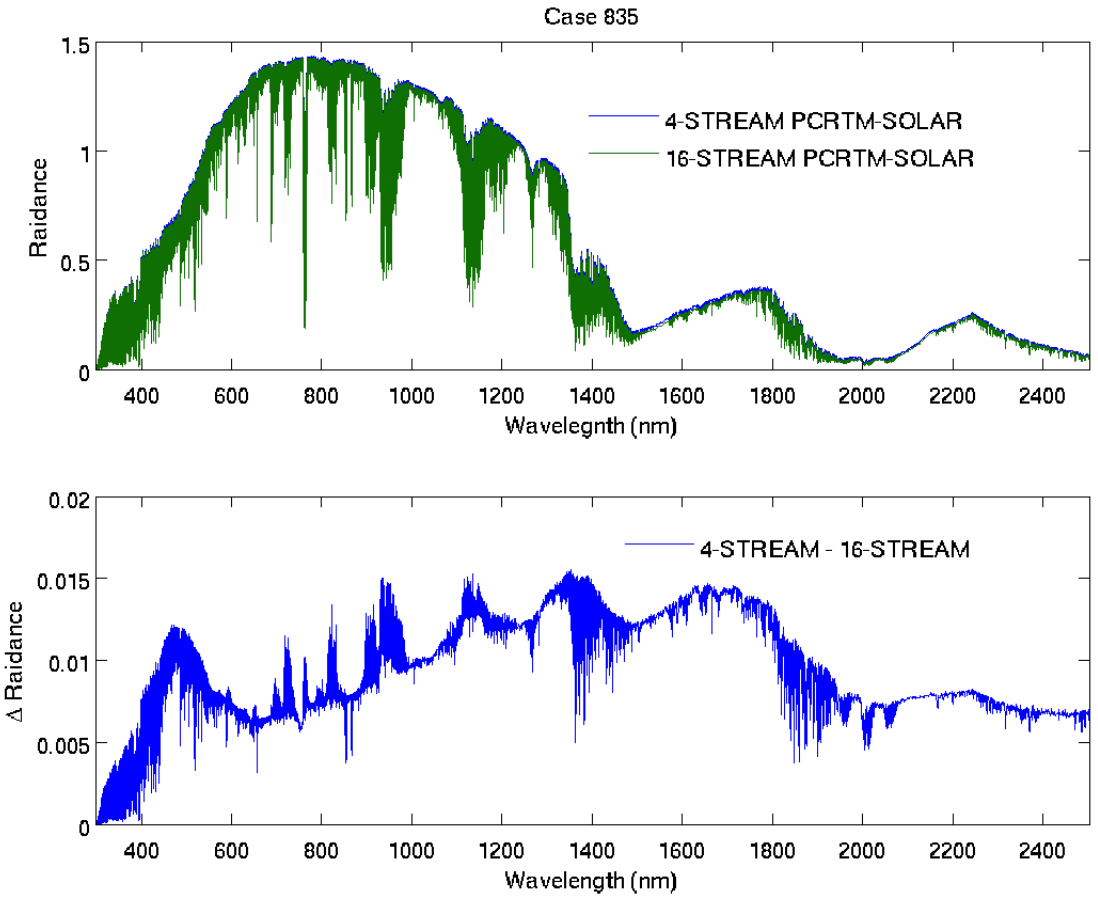
The modified PCRTM-SOLAR may complete one spectrum calculation in ~ 3 seconds, rather than ~ 3 hours (MODTRAN).

Data: Simulation High Resolution RS Spectrum

- Channel radiances as well as mono radiances of 9957 cases were simulated for land surface with different
  - ATM ID, SZA, VZA, AZA, AOD, Water Vapor, Absorption, Scattering, Cloud (1-layer, 2-layer, 3-layer, ice, water, clear sky), Surface BRDF, etc.
- 9000 cases were used for training
- 957 cases were used for validation

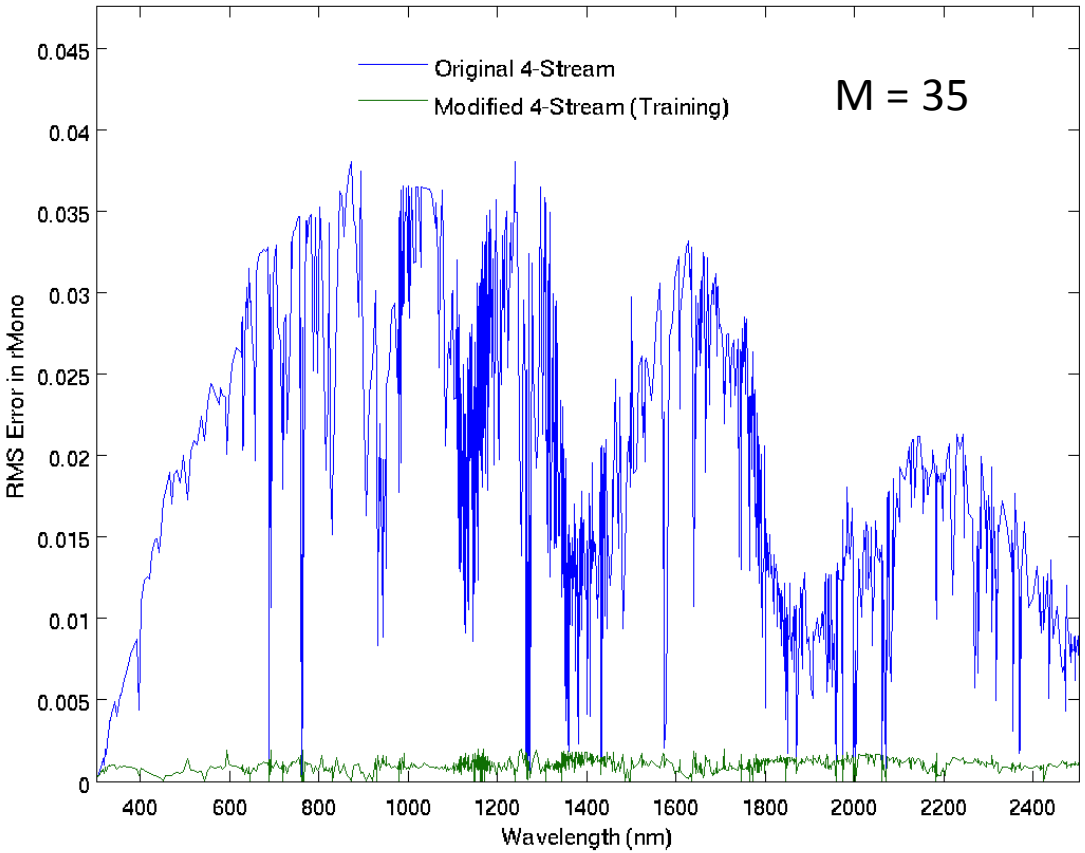
The Difference Between 16-Stream and 4-Stream Results in PCRTM-SOLAR

Typical difference between 4-stream radiance and 16-stream radiance:



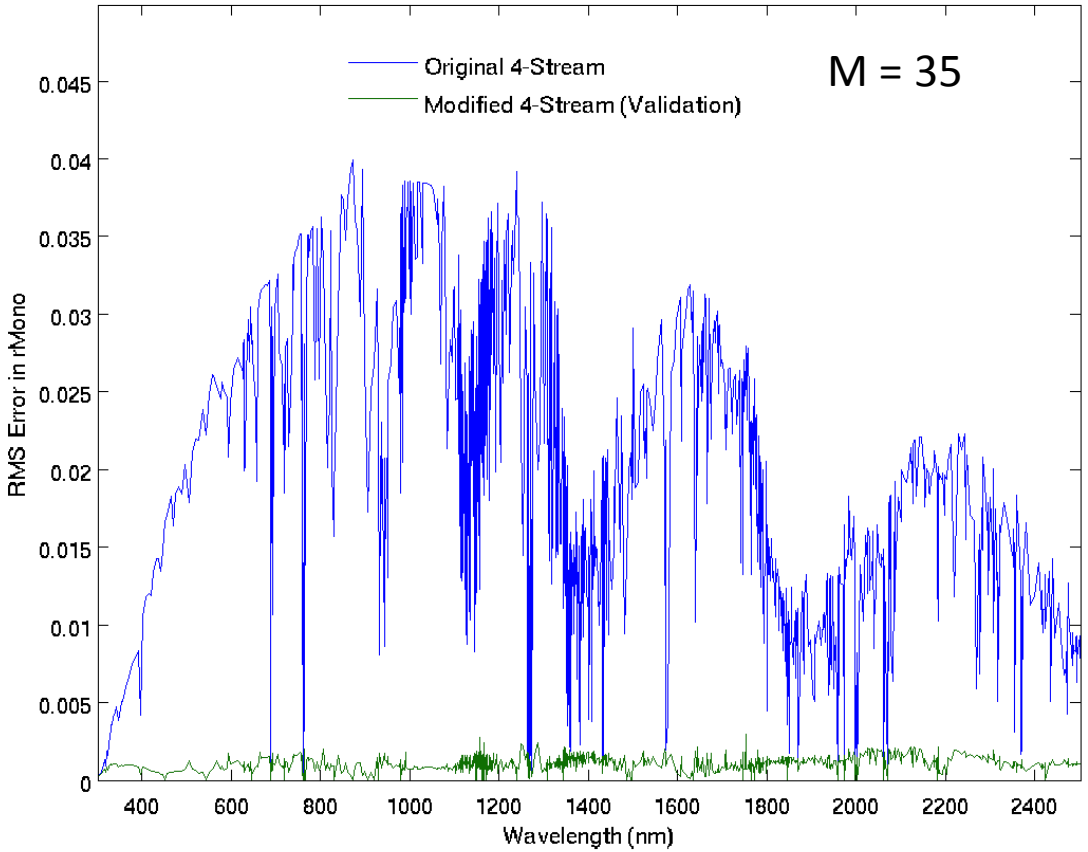
New Strategy: rMono Training

$$r_{16str}^{1359} = r_{4str}^{1359} + B^{1359\times M} \cdot \mathrm{D}r^{M} = r_{4str}^{1359} + B^{1359\times M} \cdot (r_{16str}^{M} - r_{4str}^{M})$$

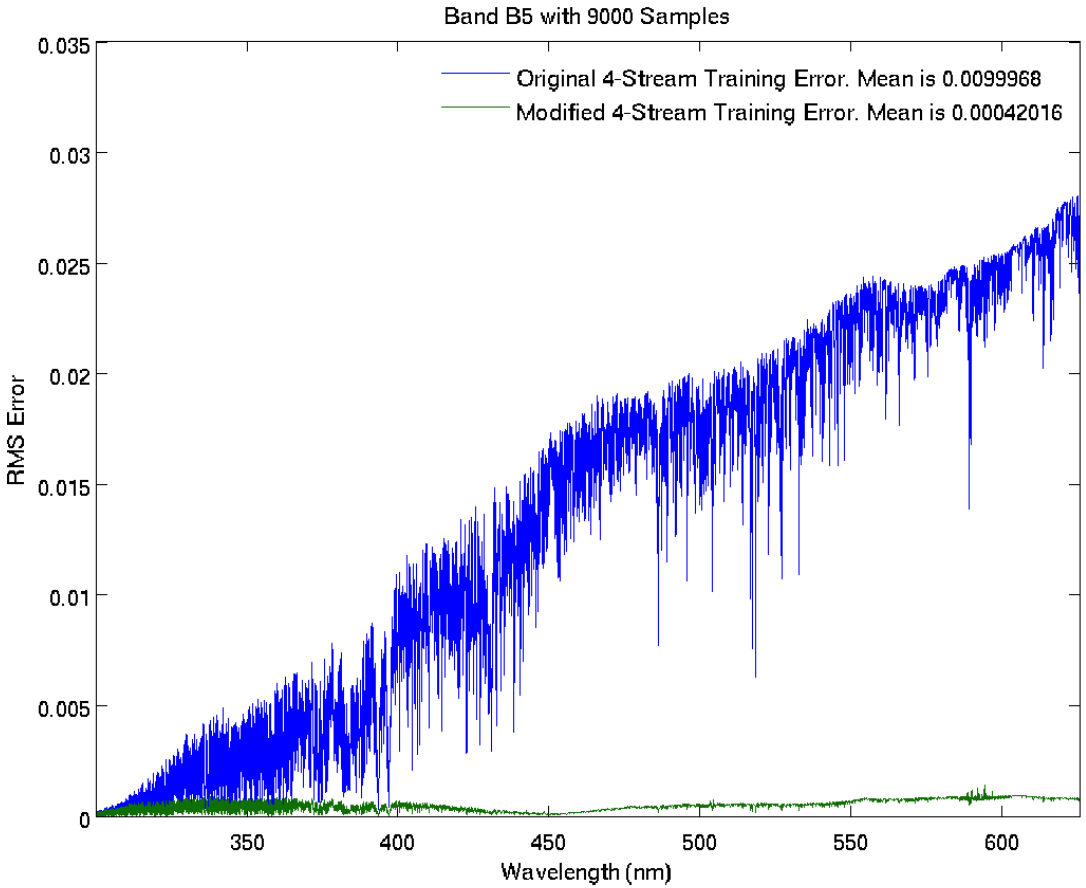


New Strategy: rMono Validation

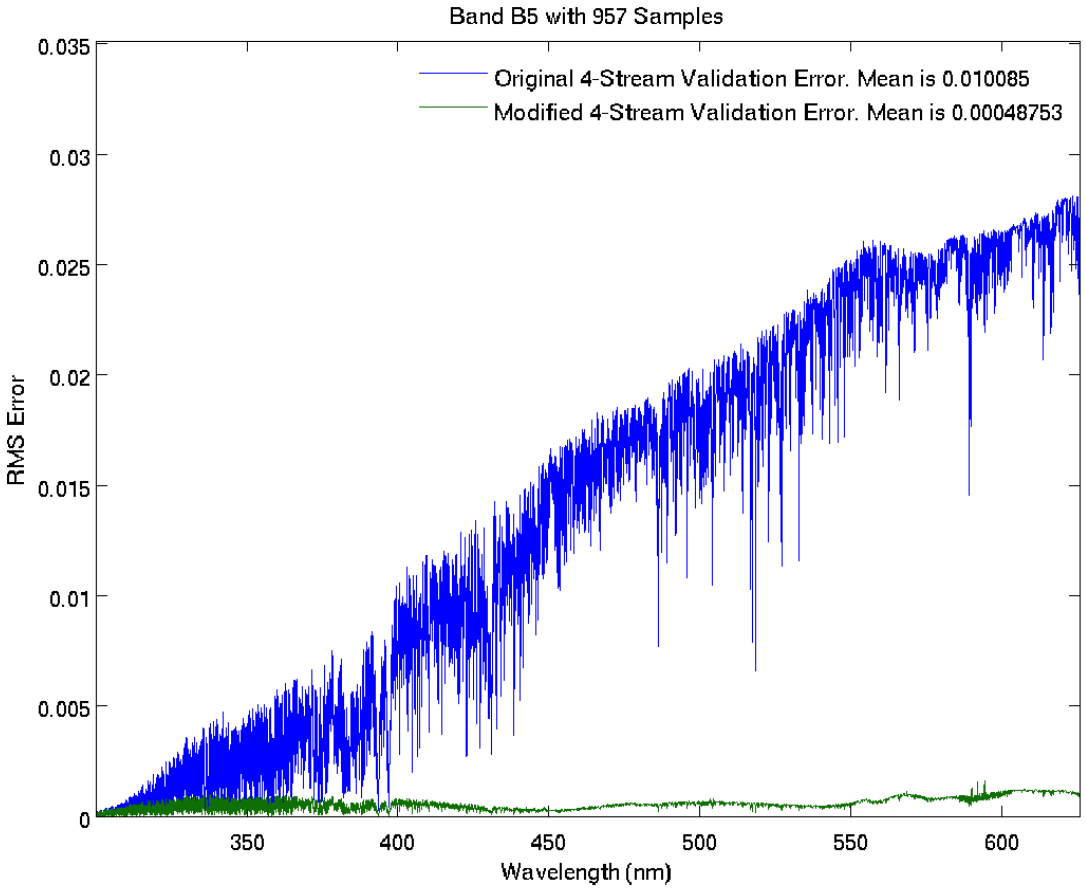
957 independent cases:



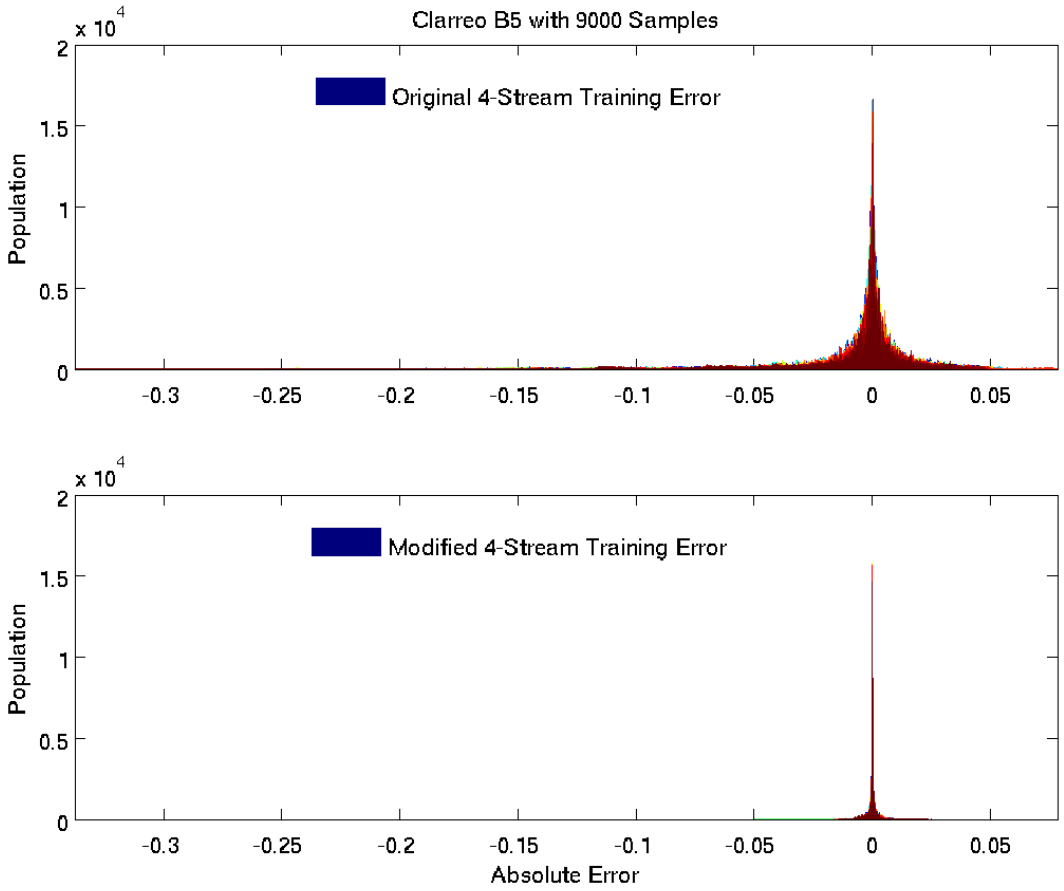
New Strategy: rChan Training Error



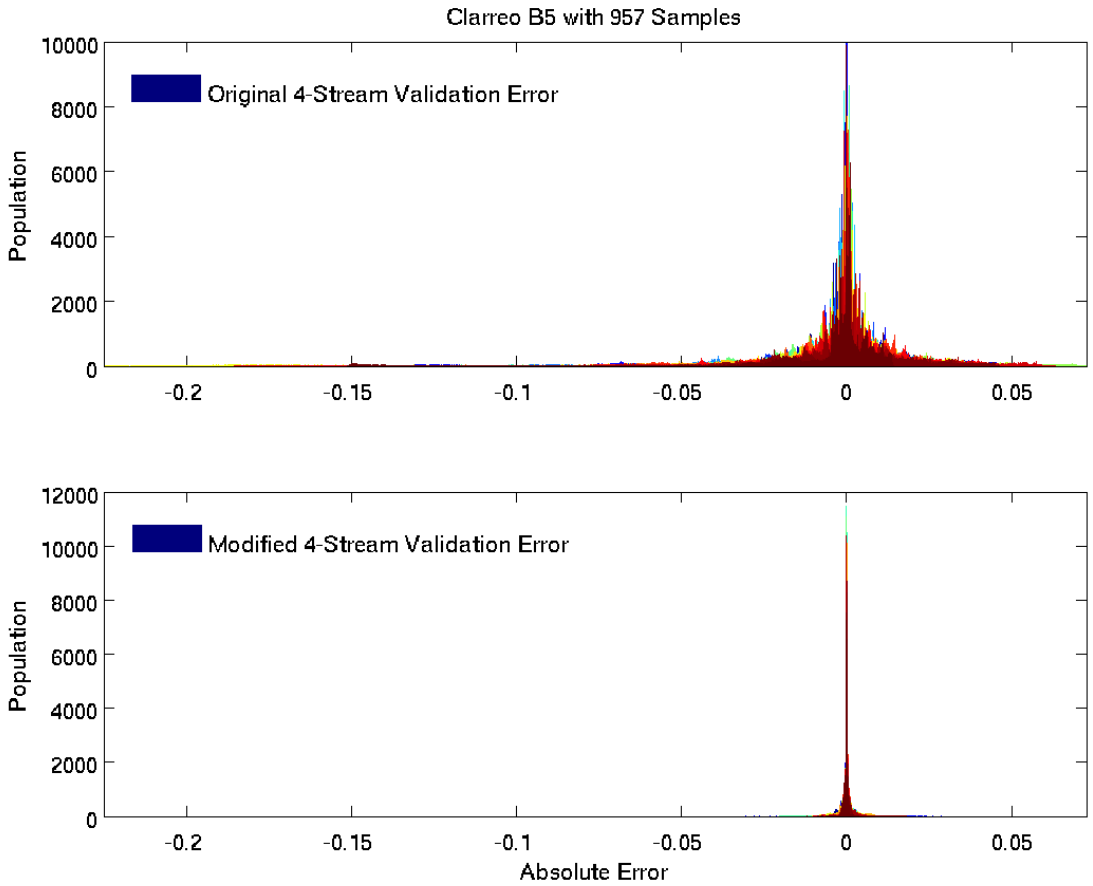
New Strategy: rChan Validation Error



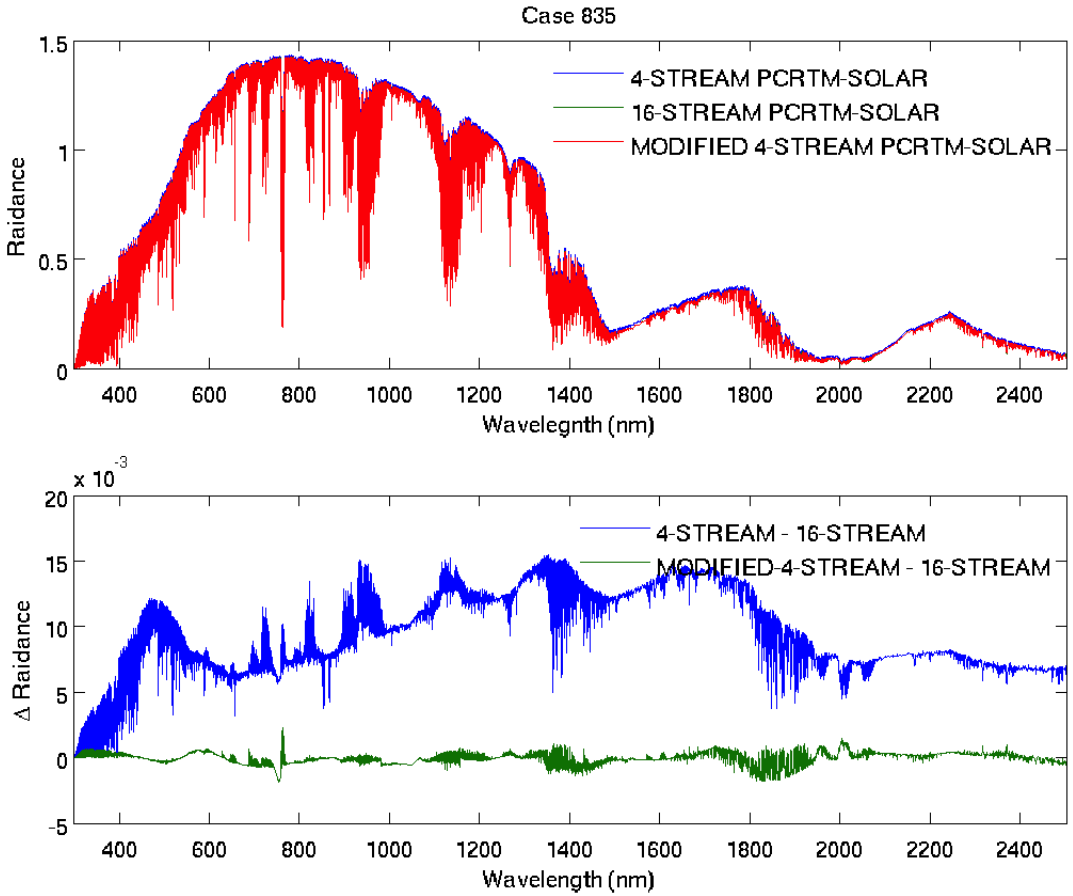
New Strategy: rChan Training Absolute Error



New Strategy: rChan Validation Absolute Error



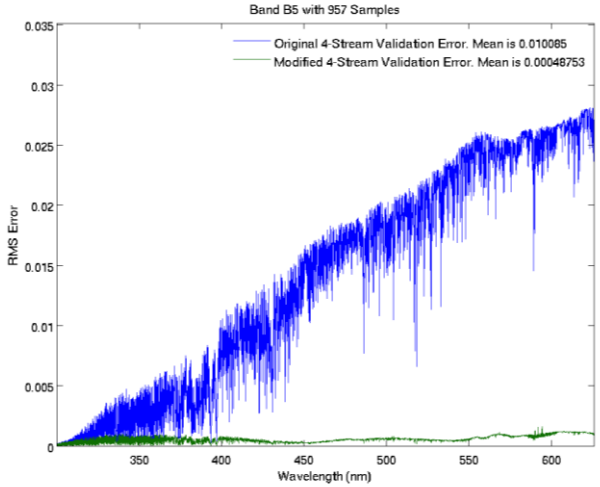
New Strategy: Typical Channel Radiance

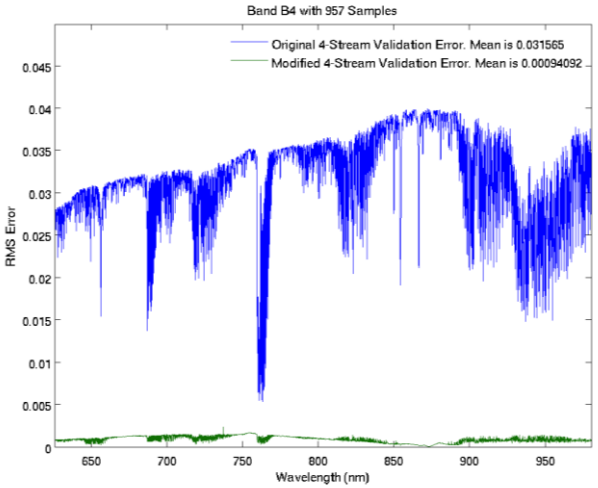


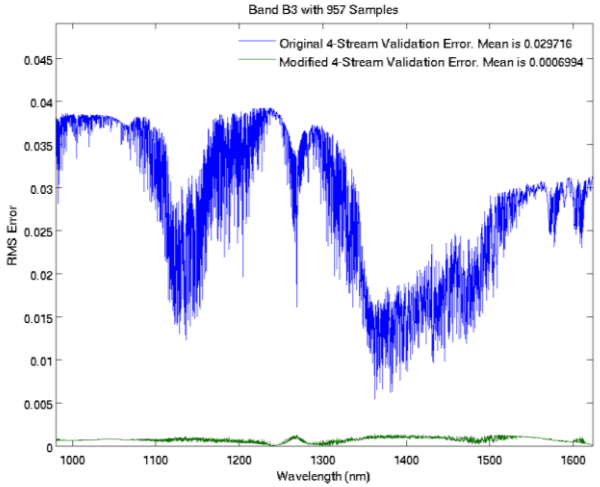
The modified 4-stream PCRTM-SOLAR provides results comparable to previous 16-stream PCRTM-SOLAR.

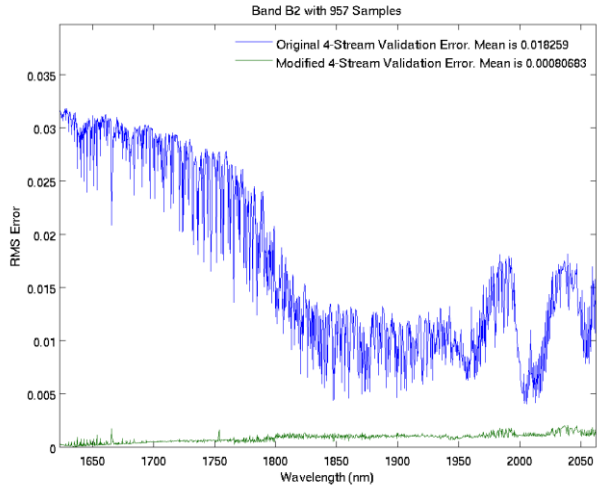
16-stream accuracy at a 4-stream cost.

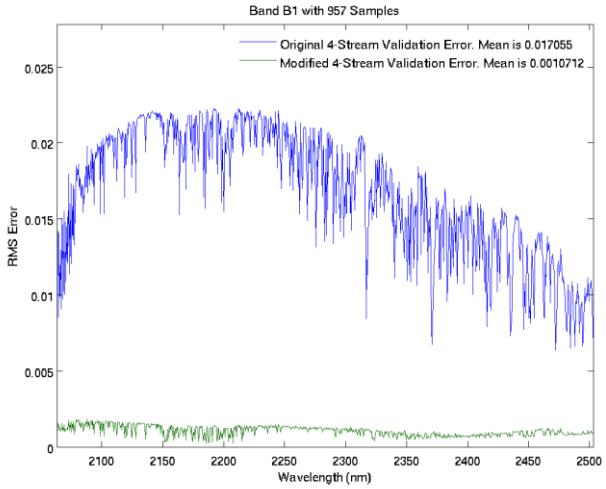
Results for Whole CLARREO RS Spectral Region











- 35 mono frequencies were selected from training.
- The validation results indicate that the accuracy is high, mean over wavenumber of the RMS is 4.8×10^{-4} to 1.0×10^{-3}.

Conclusion

- A new method was developed to simulate RS spectrum for multi-layer cloud/aerosol condition in the range of 300 nm to 2.5 μm.
- Fast speed was achieved by calculating mono radiance with 4-stream MODTRAN at 1359 preselected frequencies.
  - 4560 times faster than 16-stream MODTRAN
  - 24 times faster than 16-stream previous PCRTM-SOLAR
- Accuracy was greatly improved by calculating mono radiance with 16-stream MODTRAN at only 35 preselected frequencies.
  - RMS is ~10^{-4} to 10^{-3} (comparable to previous 16-stream PCRTM-SOLAR)
- May be easily expanded to higher accuracy
  - Using higher stream number to compute mono radiances in MODTRAN
  - Fellow the same procedure to train the data
- Further works
  - Ocean surface
  - Integrated into linearized radiative transfer model