Towards optimal estimation retrieval of cirrus cloud optical and microphysical properties using hyperspectral shortwave instruments and a fast radiative transfer algorithm

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Introduction

- **Purpose** – We are developing a cirrus cloud retrieval of cloud optical depth (τ_{Cloud}), cloud effective diameter (D_{eff}), and cloud top pressure (P_{Top}) for hyperspectral ultraviolet, visible, and near-infrared (UV-Vis-NIR) instruments that uses a state of the science ultrafast radiative transfer model. *Work is ongoing*

- **The importance of cirrus clouds:**
  - Cirrus clouds are high altitude ice clouds.
  - Cirrus clouds have a global frequency of occurrence with higher frequency in the tropics and lower frequency at the poles.
  - They are strong modulators of atmospheric radiation.
    - Reflect incoming solar radiation
    - Absorb longwave radiation emitted by the Earth
  - Scattering properties difficult to model.
  - Poor representation in weather and climate models necessitates more robust global satellite retrievals.

- **Hyperspectral instruments:**
  - Measure spectrally resolved signals in each pixel.
  - Contain highly information dense measurements.
    - Hundreds to thousands of channels.
  - Premise – using all the channels of a hyperspectral instrument will maximize the information content over current multispectral instruments that measure in similar spectral regions.

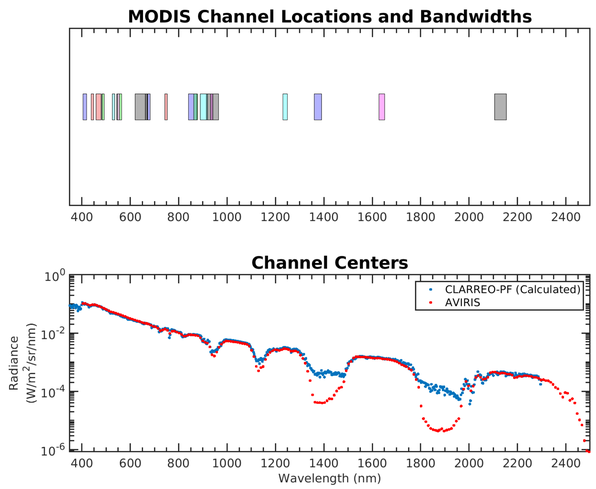


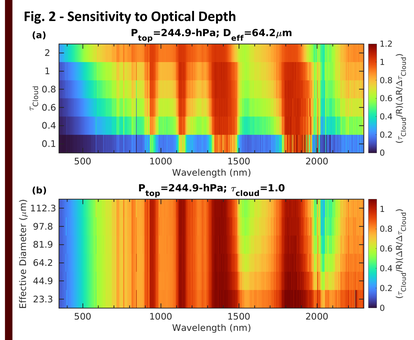
Fig. 1 - Comparison of instrument channel locations. Upper plot: location of MODIS channel bands with box widths corresponding to spectral response function full width at half maximum (FWHM). Lower plot: measured clear sky AVIRIS (red) and synthetic CLARREO-PF spectrum (blue). The points denote locations of the hyperspectral channel centers.

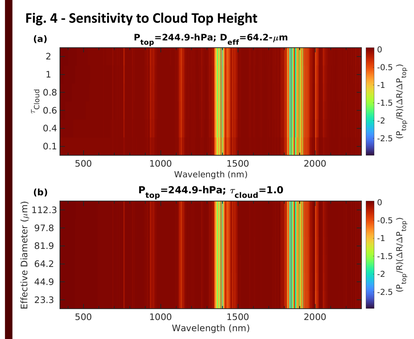
Rationale for the retrieval development

- Rationale 1 – Much of the UV-Vis-NIR spectrum sensitive to retrieval variables of interest $(\tau_{Cloud}, D_{eff}, P_{Top})$, especially in the water vapor absorption, ice absorption, and O_2 bands.

- Rationale 2 – Changing properties of atmosphere, surface, or scattering angles changes the locations of the most informative channels.

- Rationale 3 – New ultrafast radiative transfer models allows using the complete hyperspectral spectrally resolved measurement.
  - Previously, channels were chosen to maximize information content and minimize computational burden.





Figures 2, 3, and 4 – Modeled sensitivity of CLARREO-PF measured reflectances to perturbations of proposed retrieval variables [8]
- **Fig. 2** - Sensitivity to τ_{Cloud}
- **Fig. 3** - Sensitivity to D_{eff}
- **Fig. 4** – Sensitivity to P_{Top}

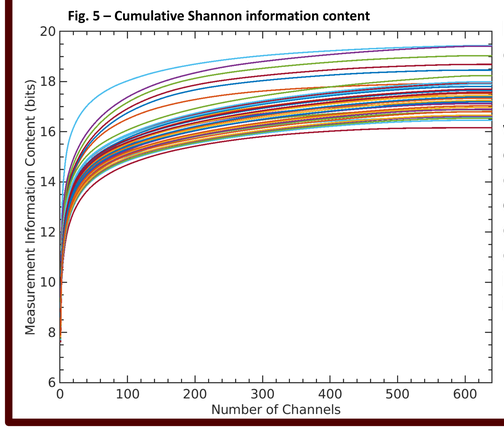


Fig. 5. This figure shows the cumulative sum of the Shannon information content of modeled cirrus cloud scenes over ocean water. Each curve is for a different cirrus cloud. The cumulative sum is performed over all 640 CLARREO-PF channels starting with the channel with the most information content to least information content. [8]

Data, Models, and Methodology

- **Retrieval methodology:**
  - Optimal estimation [1] methodology allows easy integration of hyperspectral channels and quantification of uncertainties.

- **Instruments:**
  - Airborne Visible/Infrared Spectrometer ([2], AVIRIS) – 224 channels, 400 to 2300 nm, 10 nm spectral resolution. Flown on NASA aircraft.
  - Earth Surface Mineral Dust Source Investigation ([3], EMIT) – 328 channels, 500 to 2500 nm, 7.5 nm resolution

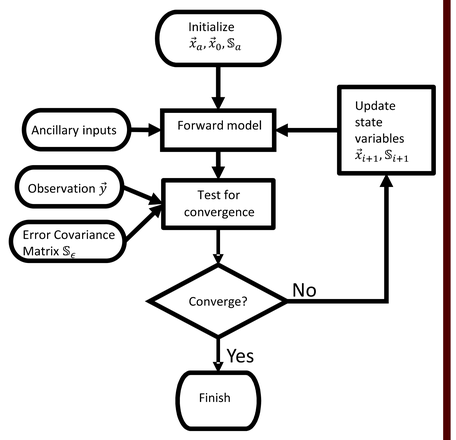


Fig. 6 - Flowchart of basic optimal estimation retrieval format.

- **Radiative Transfer Models**
  - Principal Component Radiative Transfer Model for solar spectrum ([4], PCRTM-Solar) – Very fast radiative transfer model developed for efficient hyperspectral calculations with scattering.
  - VLIDORT [5] – Vector radiative transfer model for plane-parallel multiscattering radiative transfer calculation with polarized light. This is used to train PCRTM-Solar for the possible atmosphere states that will be encountered.

- **Ice optical property Model**
  - Two-Habit Model [6] – State of the science ice particle scattering model. Used to construct bulk cloud layers.

- **Validation datasets**
  - MODIS Collection 6 [7] – Most recent published ice cloud dataset, contains τ_{Cloud}, D_{eff}, P_{Top}.

References

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8. Figs. 2-5 are from authors Ph.D. dissertation: J. C. Mast, "Toward hyperspectral remote sensing of cirrus clouds and aerosol mineral dust," Ph.D., Atmospheric Sciences, Texas A&M University, Texas, United States, 2023.