Exploring Local Variability of Thin Cirrus using Sunphotometry: A Mauna Loa Case Study

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30% cover over the globe [Liou, 1986; Rossow and Schiffer, 1999]

5-10% are thin cirrus clouds → hard to detect and quantify by space-borne platforms [Jin et al., 1996; Stubenrauch et al., 1999; Lou et al., 2002]

Still large uncertainty in space-borne [Zhang et al., 2009] and ground-based [Comstock et al., 2007] quantification of COT

Uncertainty in warming/cooling effects [Nazaryan et al., 2008; DeMott et al., 2010]
Sunphotometers have the potential to increase our global capability to quantify relatively thin cirrus (up to COT of ~4) COT and $D_{eff}$

0.03-0.06 AOD positive bias in measurements “contaminated” by cirrus

[Chew et al., *Atm. Env.*, 2011]
A new perspective on an old issue:

So far:
Aerosols + cirrus

Filtered out,
Not archived in general
Non-filtered instances can cause AOD bias

New approach:
Aerosols + cirrus

Model $T_{\text{tot}}(\lambda, \text{COT}, D_{\text{eff}}, \eta)$

Retrieve cloud properties

$\lambda$ dependent approach: need SWIR channel
Sunphotometry basics

\[ T = \frac{I}{I_0} = \exp \left[ -\frac{(\tau_a + \tau_g)}{\mu} \right] \]
\[ T = \frac{I}{I_0} = \exp\left[\frac{-\tau_a + \tau_g}{\mu}\right] \]
$T = \exp\left[-\frac{(k\tau_c + \tau_a + \tau_g)}{\mu}\right]$

$k(\eta, \lambda, D_{\text{eff}}) = 1 - \varpi(\lambda, D_{\text{eff}}) \int_0^\eta P(\theta, \lambda, D_{\text{eff}}) \sin \theta d\theta$

[Shiobara and Asano 1994]
Calculated Transmittance values for various COT and $D_{\text{eff}}=10 \, \mu m$ (dashed) and $D_{\text{eff}} = 120 \, \mu m$ (solid)

(Segal-Rosenheimer et al. [2013], *JGR*, accepted)
Mixture Recipe of Particle Habits used to derive optical properties database (GHM) and which was used to derive $k_{pre}$ factor.

(Baum et al. [2011], *J. Appl. Met. Clima.*, 50, 1037-1056)
Asymmetry Parameter derived from models

![Graph showing Asymmetry Parameter as a function of D_{eff} (μm)]

- Smooth model - 670 nm
- Smooth model - 2100 nm
- SR model - 670 nm
- SR model - 2100 nm
LUT for Smooth GHM Model

Transmittance $\lambda = 670$ nm

Transmittance $\lambda = 2138$ nm

Deff = 10 $\mu$m
Deff = 15 $\mu$m
Deff = 30 $\mu$m
Deff = 50 $\mu$m
Deff = 80 $\mu$m
Deff = 100 $\mu$m
Deff = 120 $\mu$m

LUT for Smooth GHM Model

NASA Ames Research Center
LUT for Severe Roughened GHM Model

Transmittance $\lambda = 670$ nm

Transmittance $\lambda = 2138$ nm

Deff $= 10\mu$m
Deff $= 15\mu$m
Deff $= 30\mu$m
Deff $= 50\mu$m
Deff $= 80\mu$m
Deff $= 100\mu$m
Deff $= 120\mu$m

$\tau_{\text{cloud}}$
Spectral fit comparing GHM with SR and Smooth parameterization of ice particles

In the following cases Smooth model yielded better fit and more valid retrievals relative to SR
Implications later on...

NASA Ames Research Center
Results from Ground-Based Measurements in Mauna Loa Hawaii
Filtering of Aerosol instances from Cirrus instances on a dual-transmittance plot

Transmittance at $\lambda = 675$ nm

Transmittance at $\lambda = 2138$ nm

AATS AOD at 675 nm

AATS AOD (cloud-flagged instances)
Smooth GHM: \( \tau_{\text{err}} = \pm 5 \times 10^{-3} \)

Deff\(_{\text{err}} = \pm 20 \)
End cirrus period

20121214 2300 UT
Evidence for increasing COT with time.
Cirrus clouds were detected continuously from 17:30 (07:30 local time) to 18:30.
The fit on this day were not as good as other days; this is being investigated with using a single particle habit that might fit better to this type of cirrus

**Bullet Rosettes**

Retrieval results using GHM Smooth model parameterization for 12-12-19
Implications of ice particle model used in retrieval:

Formerly [Segal-Rosenheimer et al. 2013, JGR, accepted] we have shown that for COT~1 difference between SR and Smooth models are ~12% and SR yield better fits. For COT between 1-4.

Comparison between MODIS (Smooth) and POLDER (Roughened) COT Differences were found to be ~32% for COT>2 [Zhang et al., 2009].

In current case studies COT<~0.5 Smooth model yield better fits and difference with SR model was up to 25%. Consistent with former observations that Smooth models Yield better fit for optically thinner cirrus (COT<1).

MODIS new Retrievals: COT ↓ D_{eff} ↑ Sunphotometers can increase sensitivity to optically thin COT and their retrieved D_{eff}

Severe Roughened Aggregates of Solid Columns
Derived Ice Water Path (IWP) values for the various case studies

Large variations within thin cirrus (COT<1) cases were observed. Can exert a radiative effect in infra-red, where magnitude and effects on global mean still not fully established [IPCC, 2007]
SUMMARY & OUTREACH

We have demonstrated our capability in detection of thin cirrus clouds, with good correlation with observed temporal variability and geostationary satellites with their high temporal and spatial resolution. Such thin cirrus are usually overlooked with MODIS and are difficult to quantify above land with IR imagers.

All the three days investigated are under the category of thin cirrus clouds but showed large variations between days and even within a short period when in-situ formation was observed. How this variability propagates through models and CRT (shortwave and longwave) calculations if at all?

We have found differences when retrieving 2 different cirrus cases on different days. What is the role of the specific cirrus particle habit model in that? How this relates to cirrus origin and formation? We are still investigating this...
Utilization of the method is possible for other sunphotometers extending to the SWIR spectral range. Deploying such instruments around the globe (e.g. AERONET) can contribute to our understanding of very thin cirrus, their microphysical properties (COT and $D_{eff}$) and local climatology and trends of such clouds.

Assessment of local variability of cirrus COT/$D_{eff}$ under clean conditions (e.g. MLO cases) and under polluted atmosphere at the same locations (e.g. MLO at periods affected by Asian Dust ~March-May) can assist global modeling in understanding the resultant cloud formation properties under these distinct cases.
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Thanks for your attention!