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

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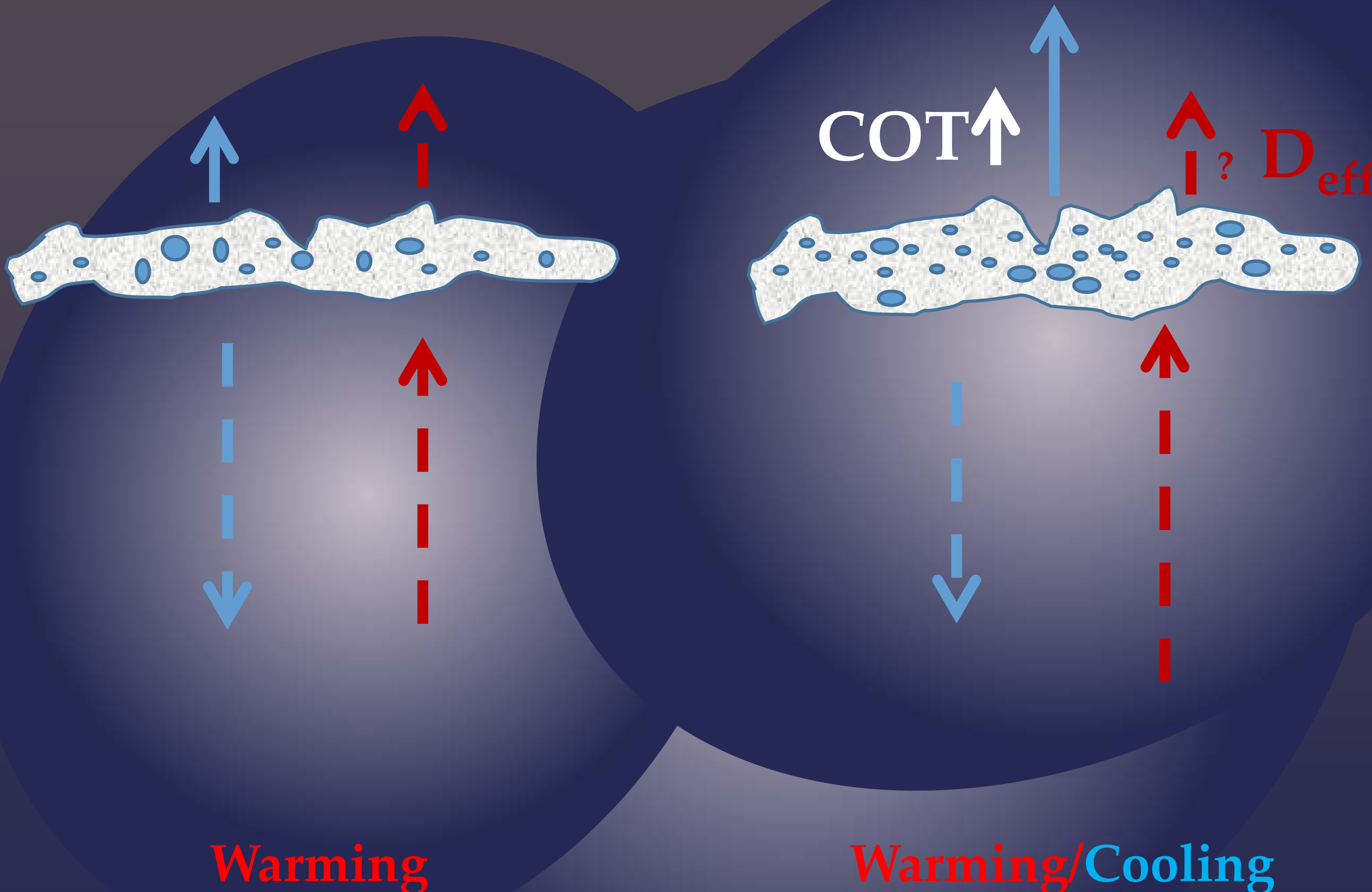
- 30% cover over the globe [Liou, 1986; Rossow and Schiffer, 1999]

- 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]

Mauna Loa Observatory, Hawaii, Dec 14, 2012


COT
? D_{eff}
Warming
Warming/Cooling

AERONET Sunphotometer Global Network

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

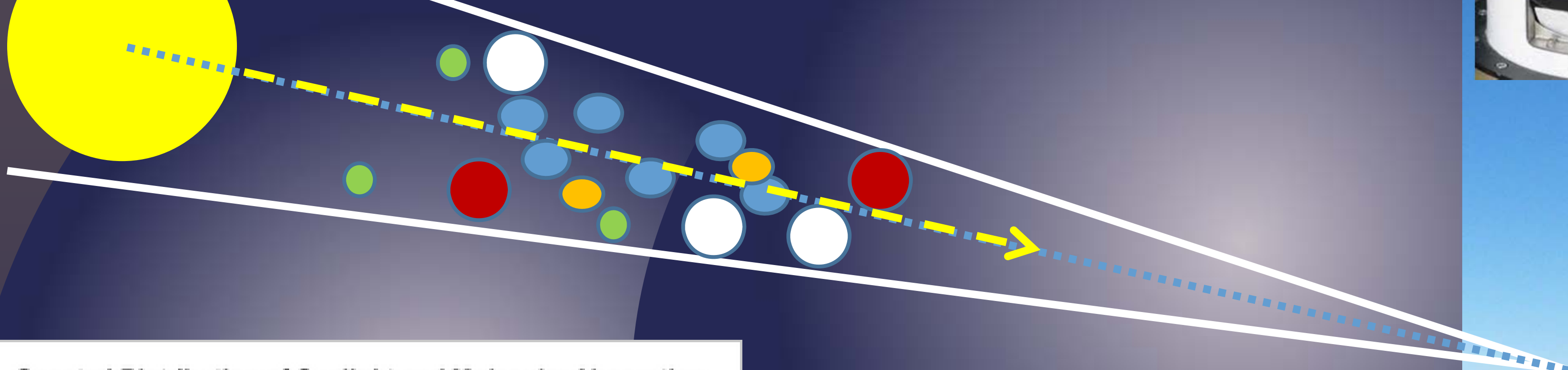
↓

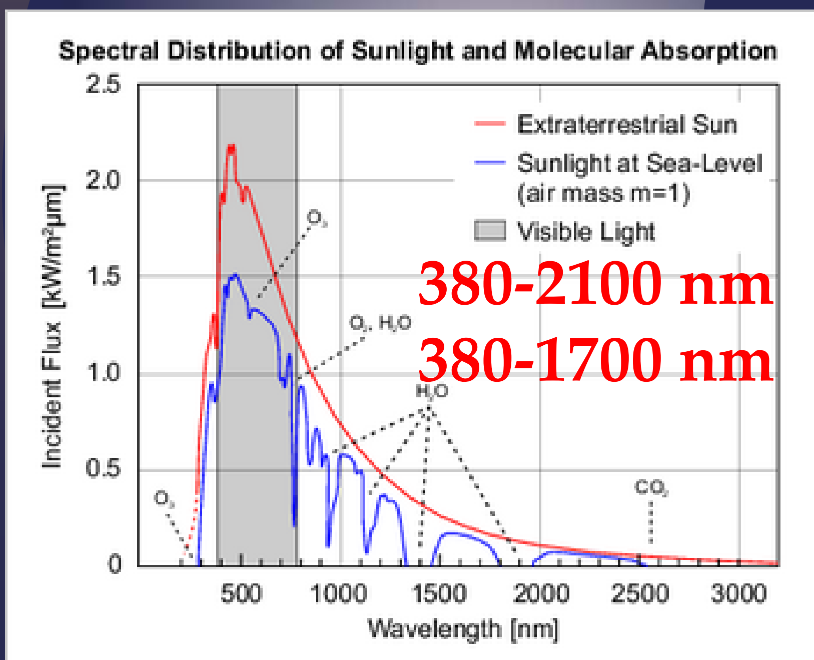
Retrieve cloud properties

λ dependent approach: need SWIR channel

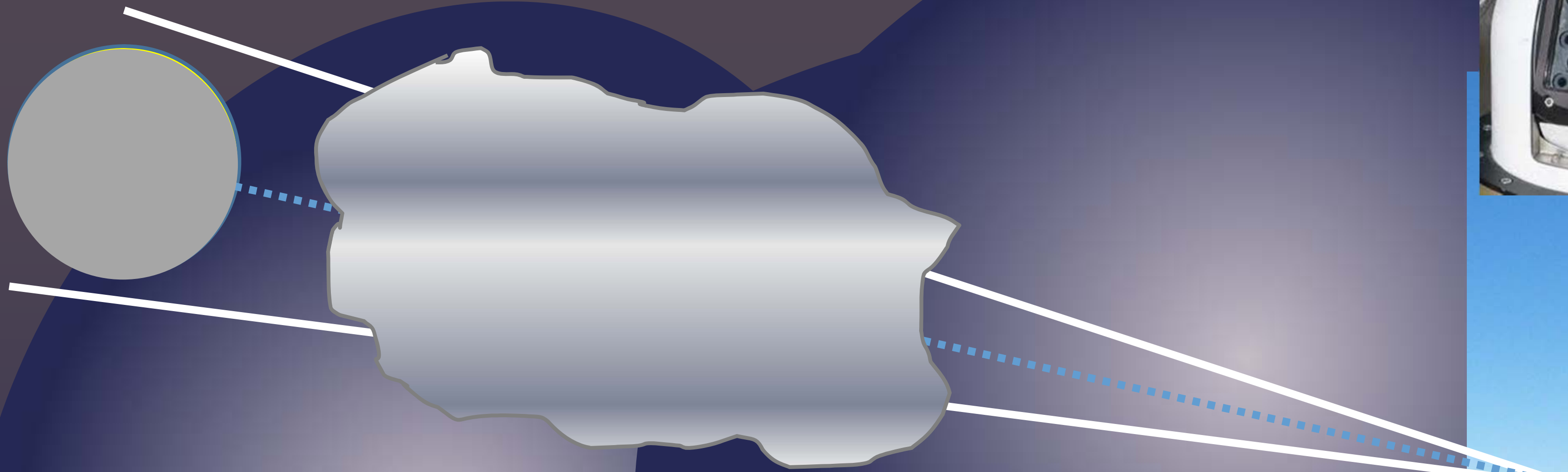
Sunphotometry basics

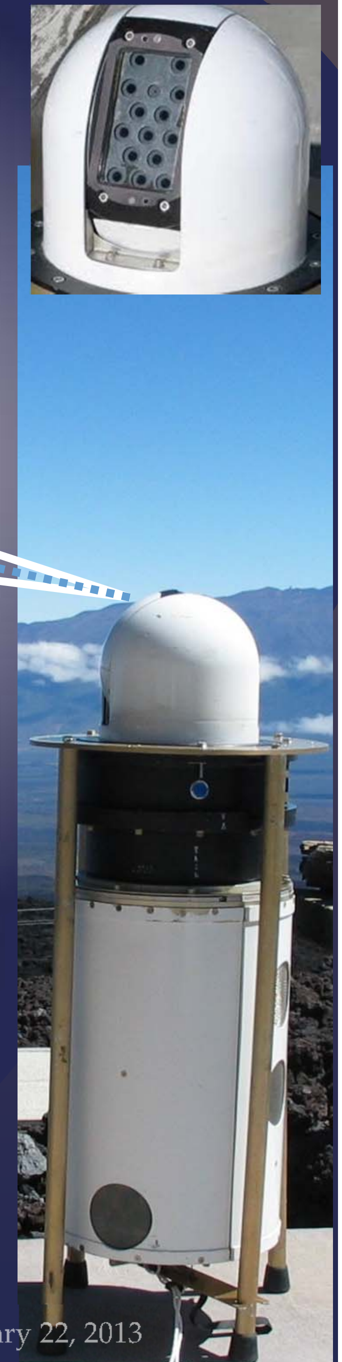
$$T = I/Io = \exp\left[-(\tau_a+\tau_g)/\mu\right]$$





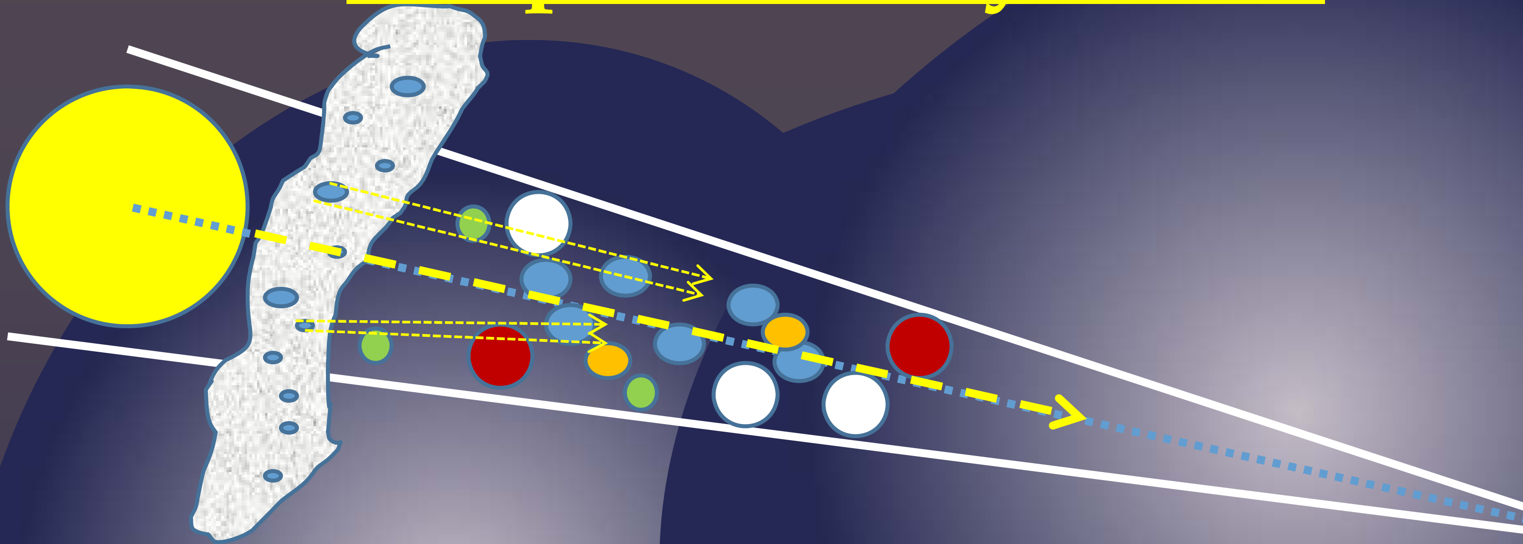
Sunphotometry basics

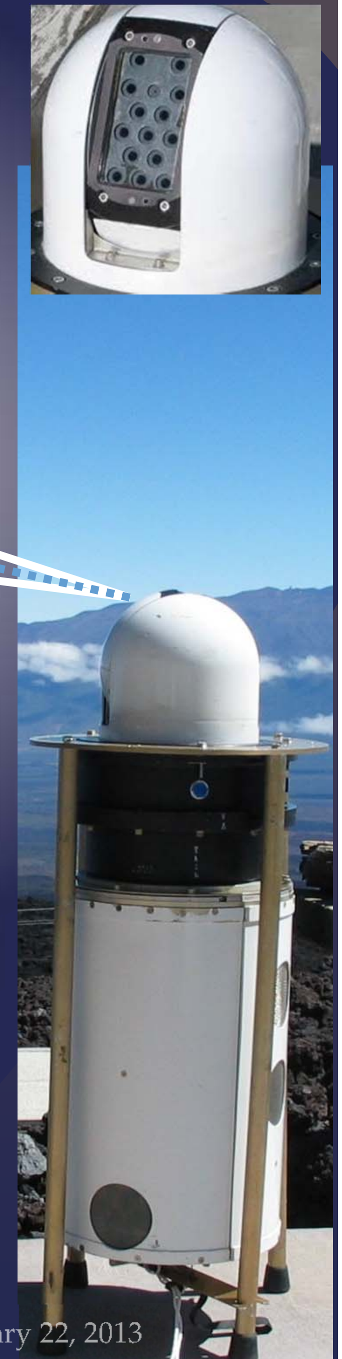




$$T = I/Io = exp\ [-\tau_a+\tau_g)/\mu]$$

Sunphotometry basics



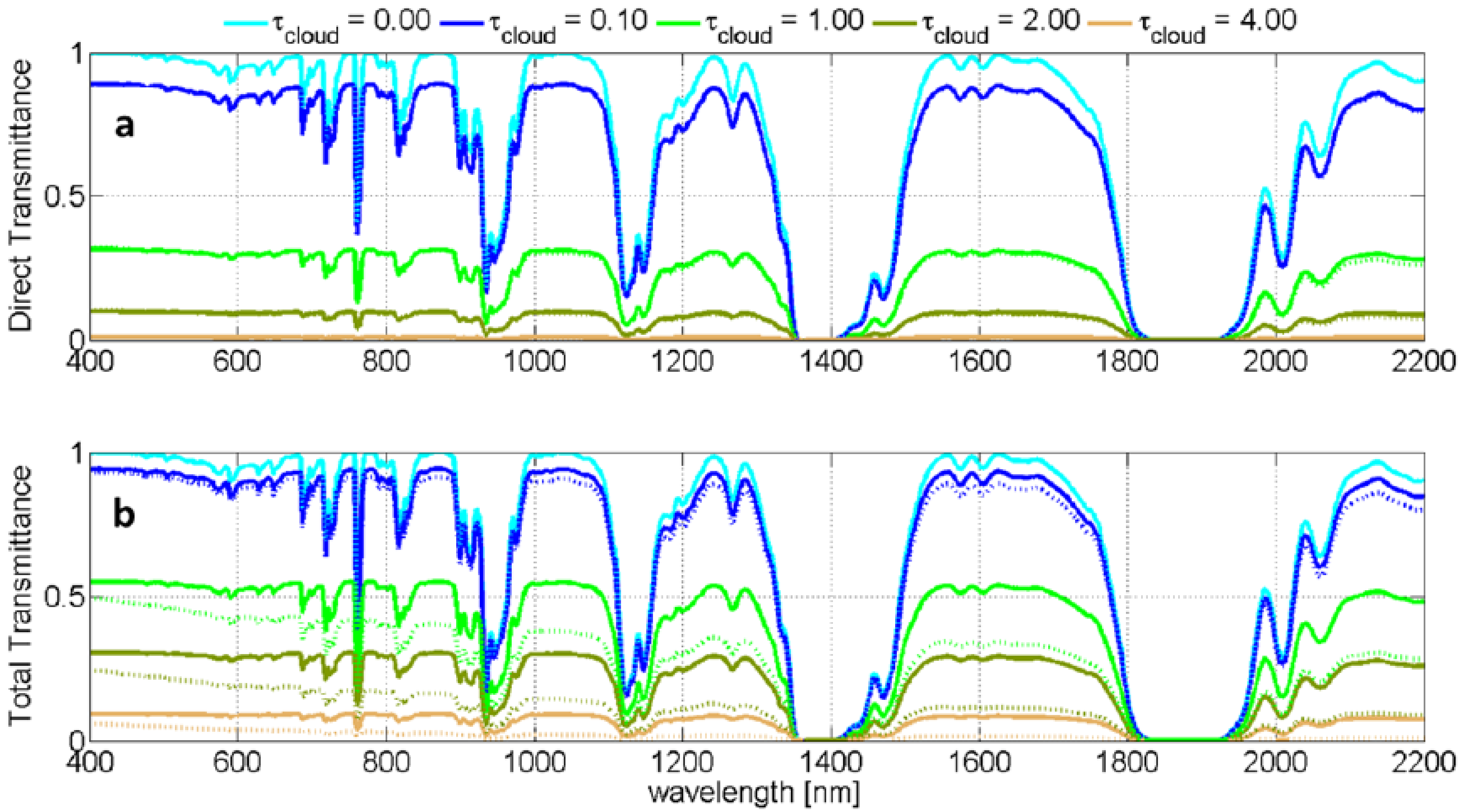


$$T = \exp\left[-(k\tau_c + \tau_a + \tau_g)/\mu\right]$$

$$k(\eta, \lambda, D_{eff}) = 1 - \varpi(\lambda, D_{eff}) \frac{\int_0^{\eta} P(\theta, \lambda, D_{eff}) \sin\theta \, d\theta}{2}$$

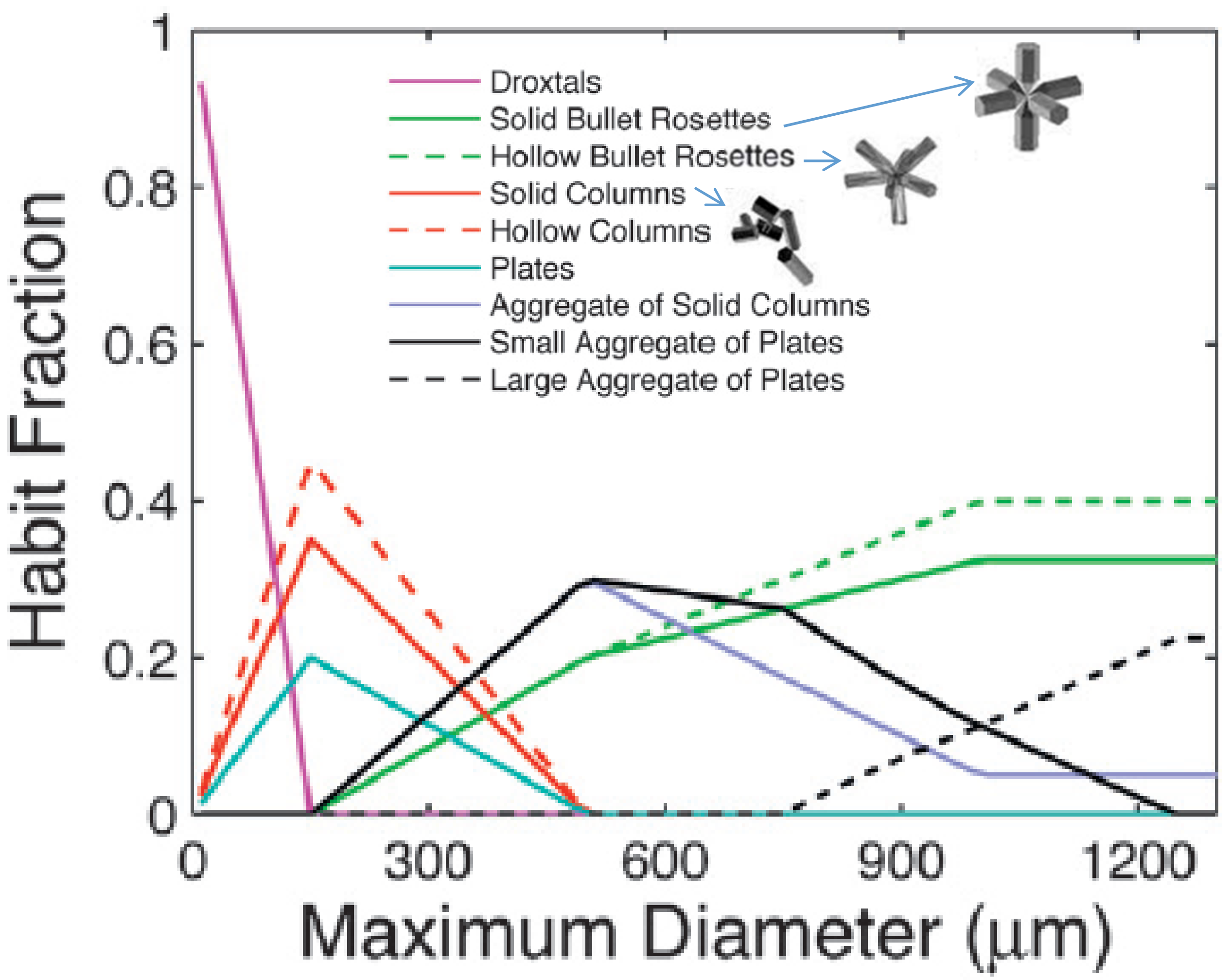
[Shiobara and Asano 1994]

Calculated Transmittance values for various COT and D_{eff}=10 μm (dashed) and D_{eff} = 120μm (solid)



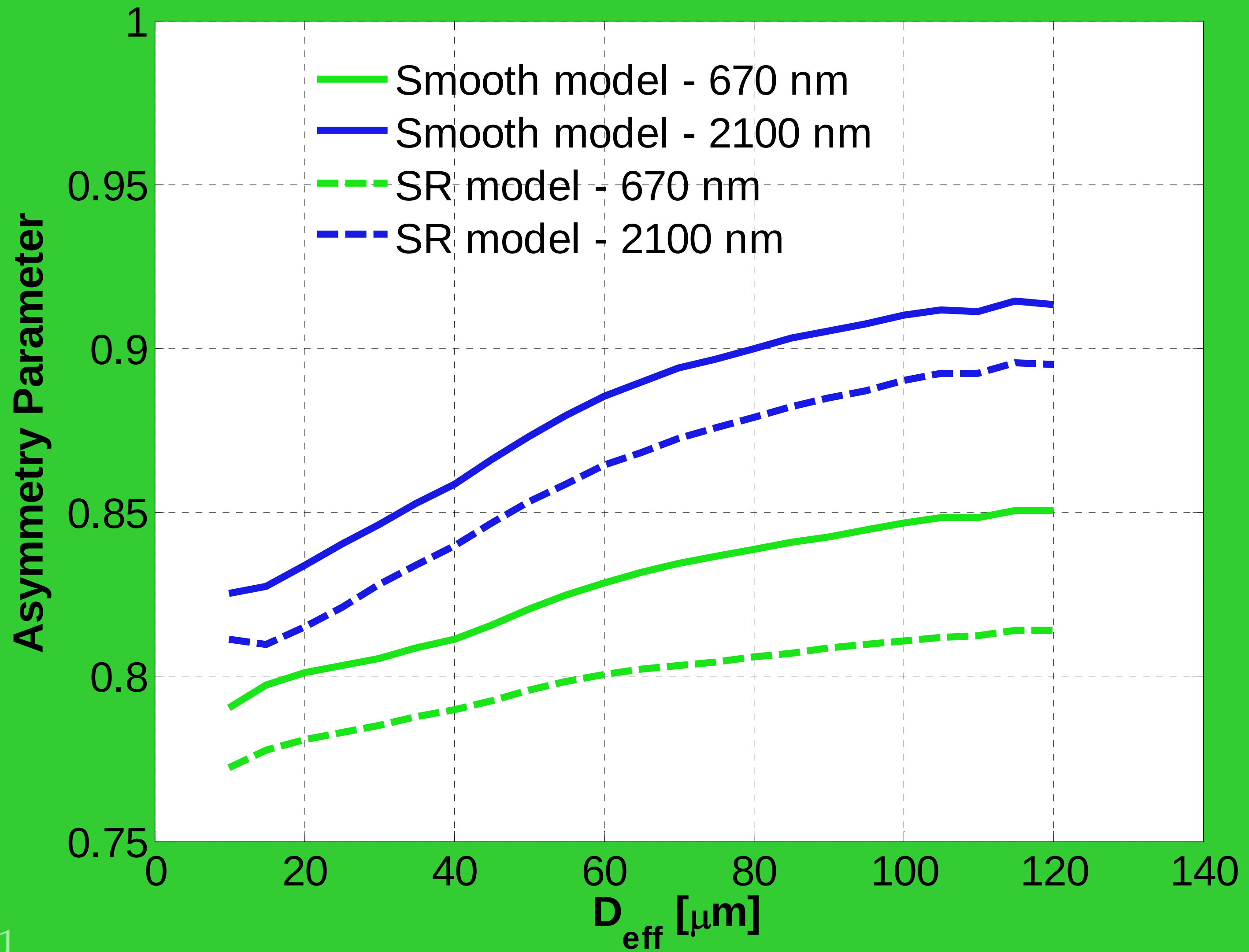
(Segal-Rosenheimer et al. [2013], *JGR*, accepted)

Mixture Recipe of Particle Habits used to derive optical properties database (GHM) and which was used to derive k pre-factor

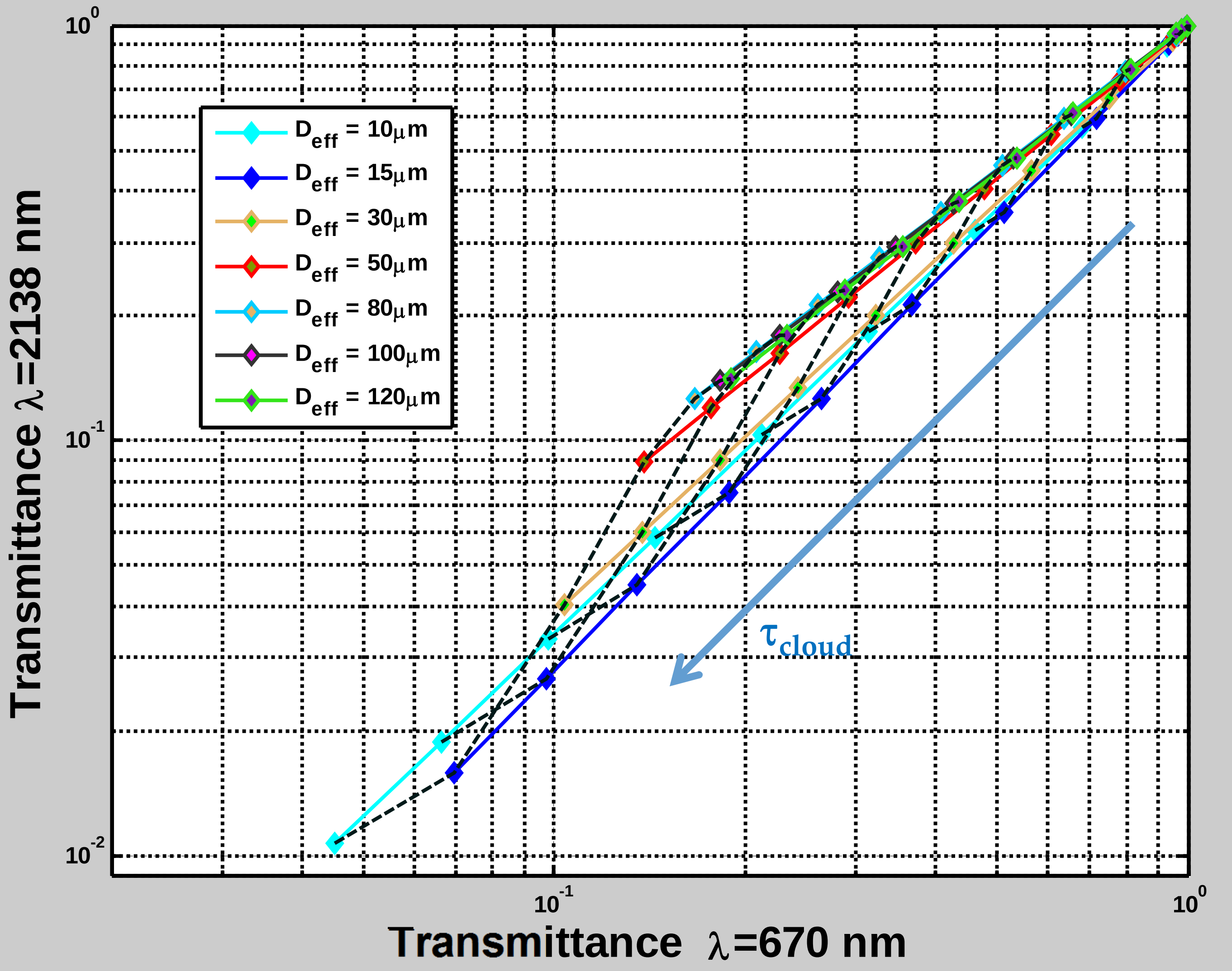


(Baum et al. [2011], *J. Appl. Met. Clima.*, 50, 1037-1056)

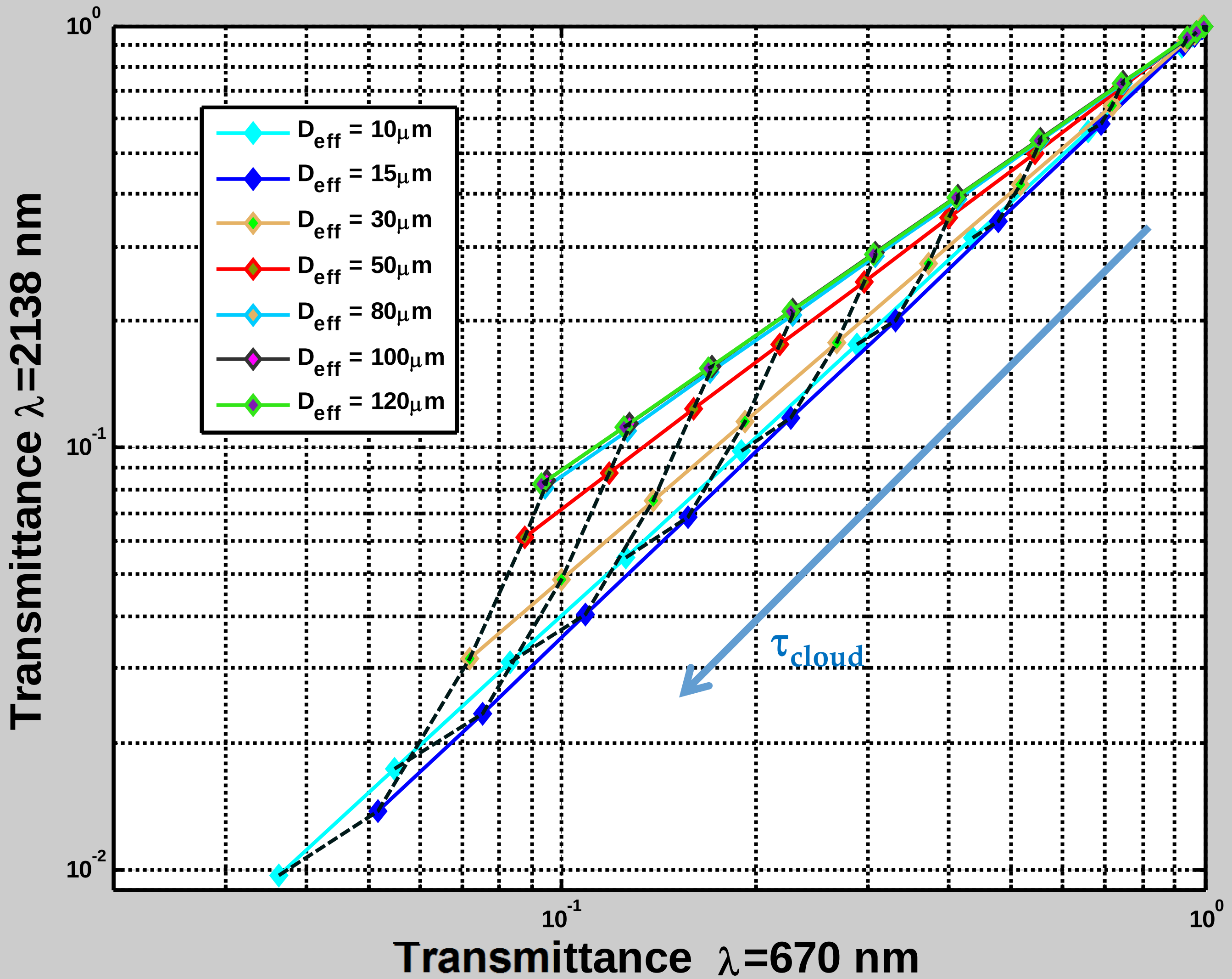
Asymmetry Parameter derived from models



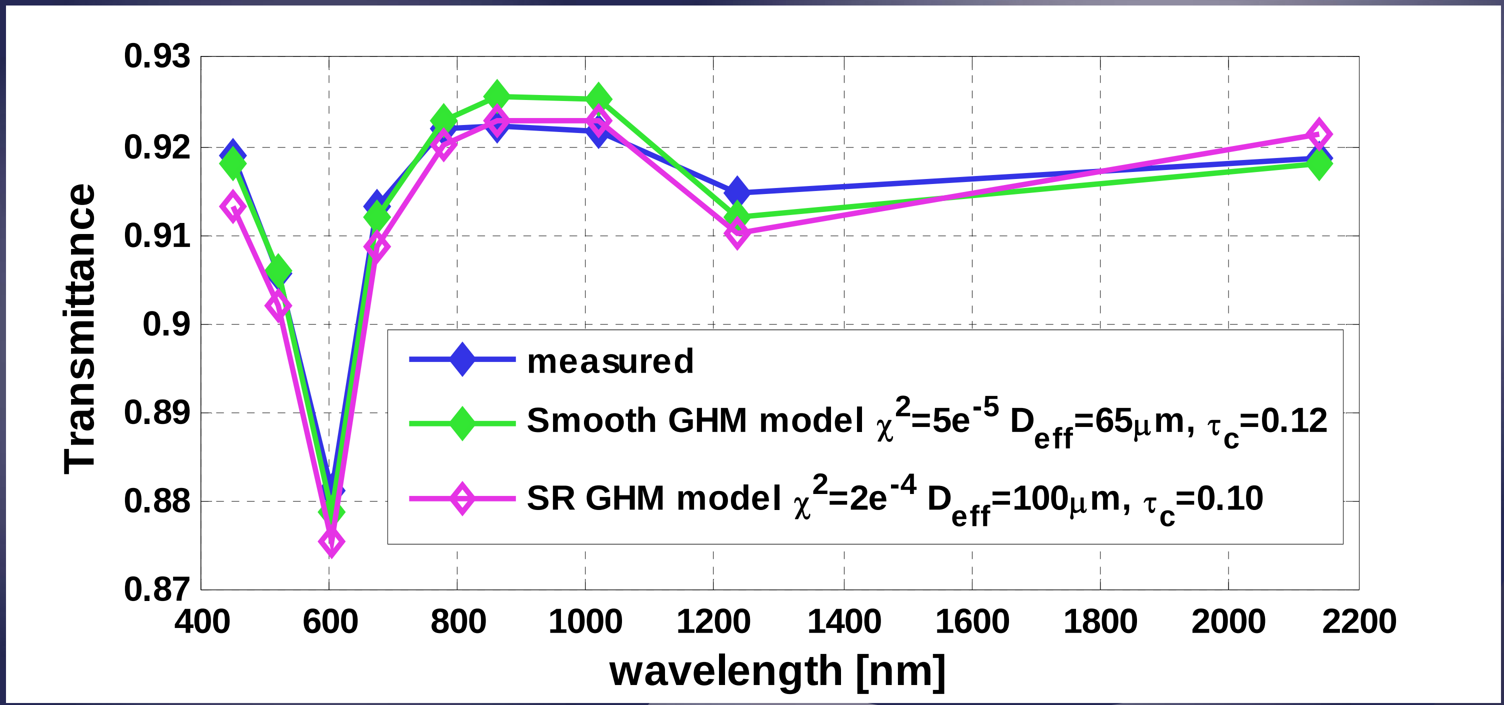
LUT for Smooth GHM Model



LUT for Severe Roughened GHM Model



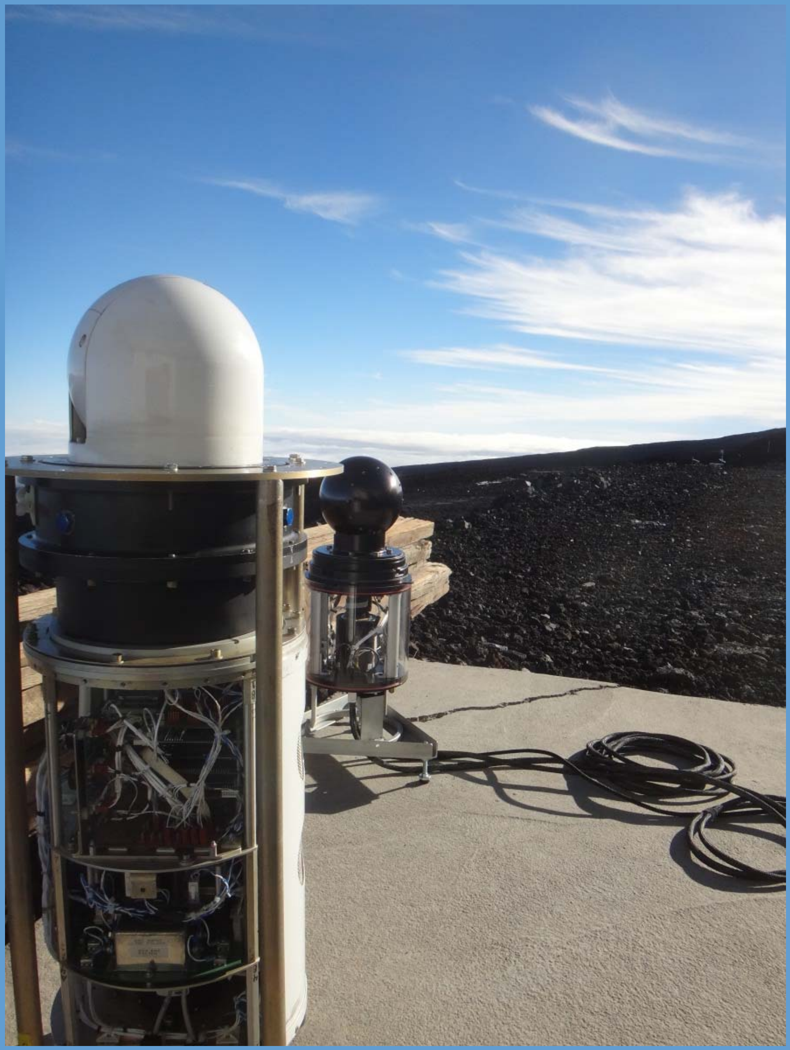
Spectral fit comparing GHM with SR and Smooth parameterization of ice particles

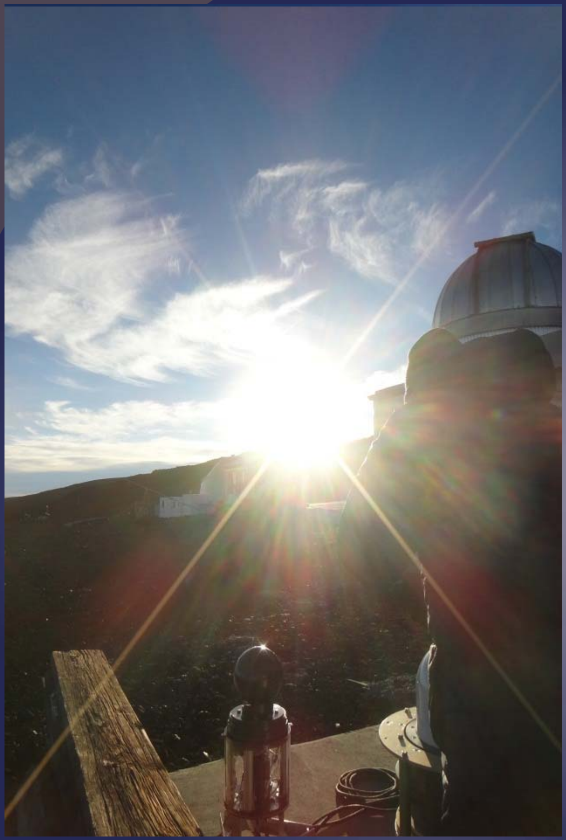


In the following cases Smooth model yielded better fit and more valid retrievals relative to SR

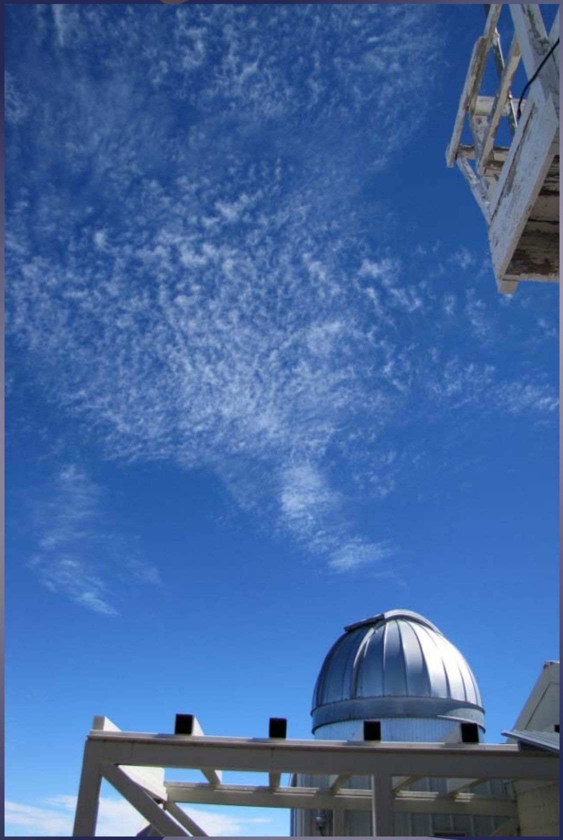
Implications later on…

Results from Ground-Based Measurements in Mauna Loa Hawaii





12-12-12



12-12-14

12-12-19

12-12-12

12-12-14

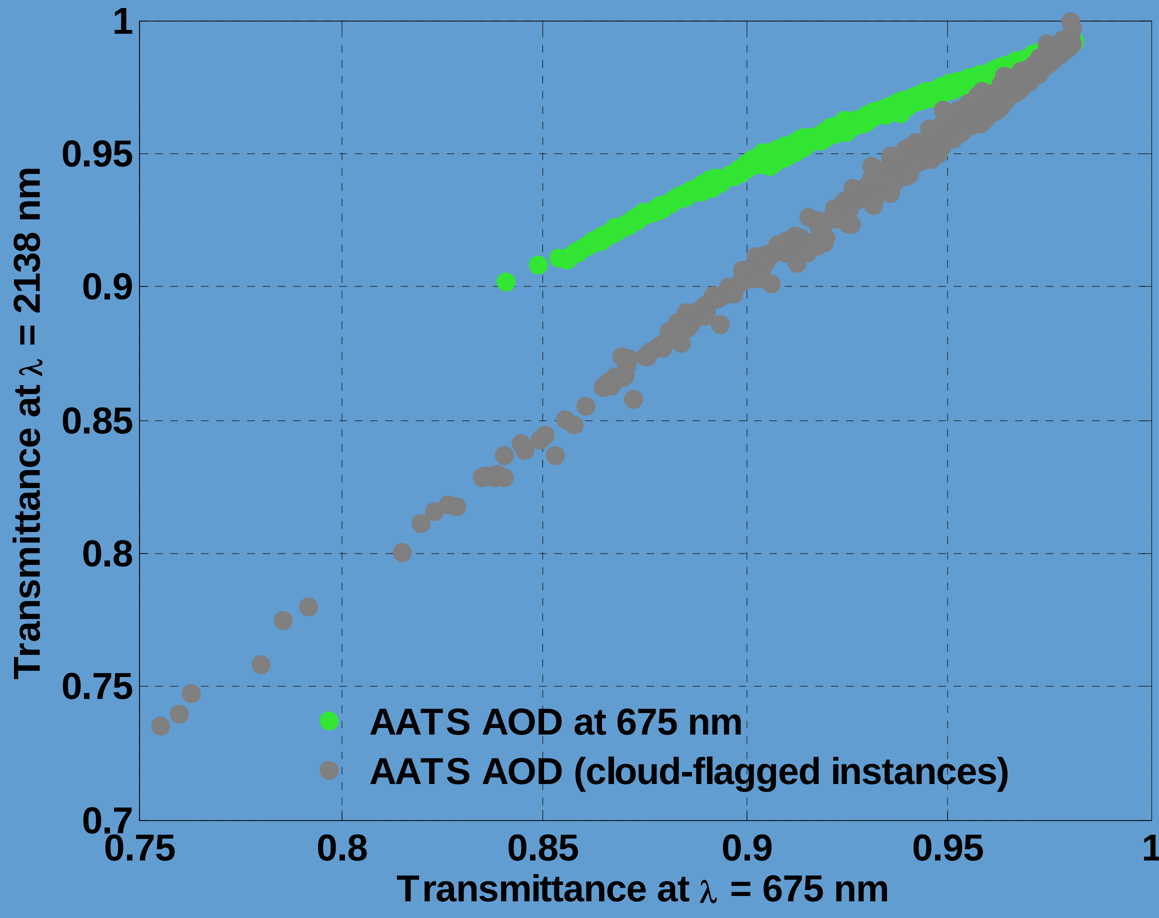
12-12-19

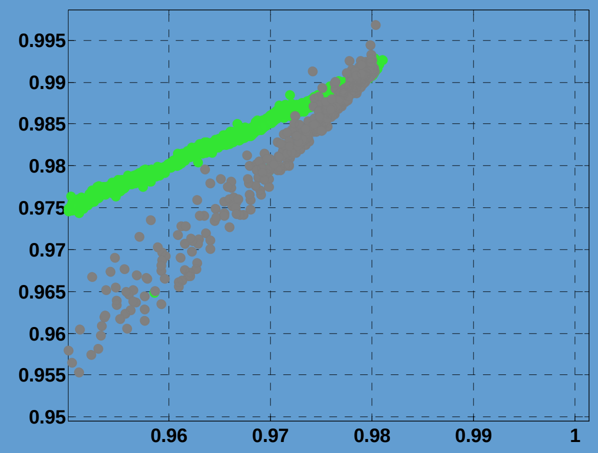
12-12-12

12-12-14

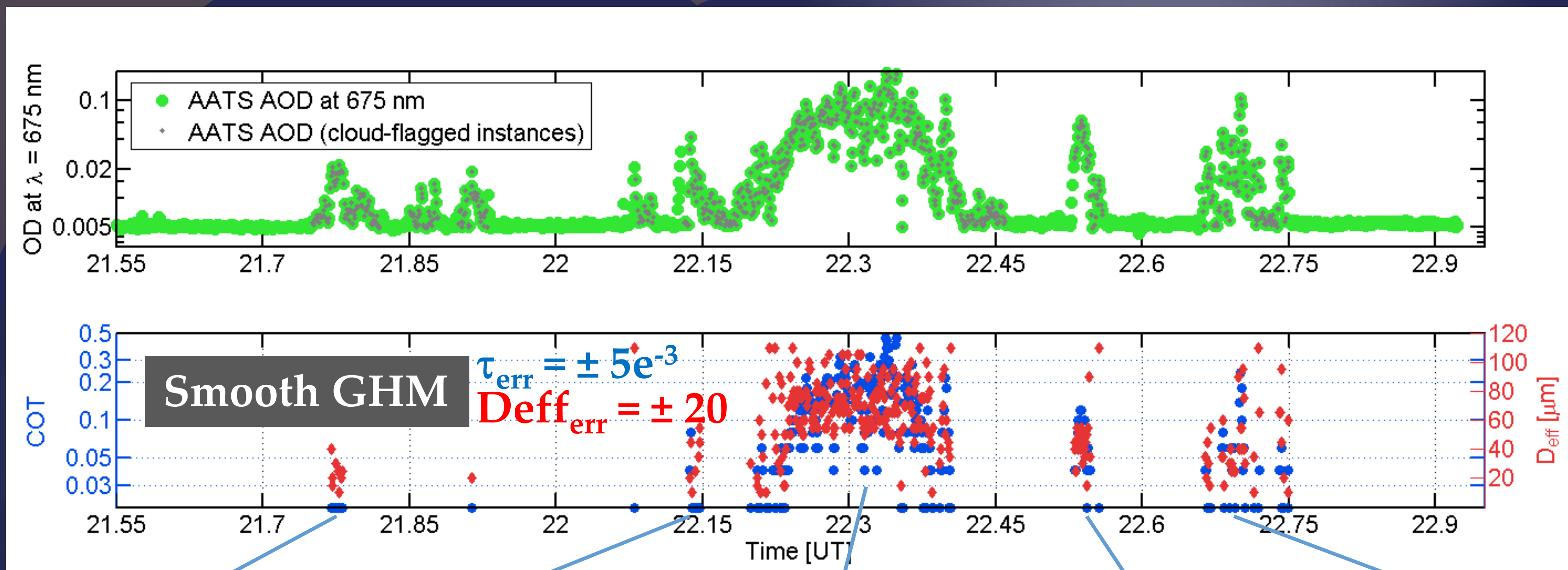
12-12-19

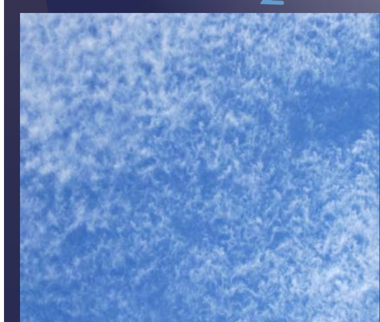
Filtering of Aerosol instances from Cirrus instances on a dual-transmittance plot

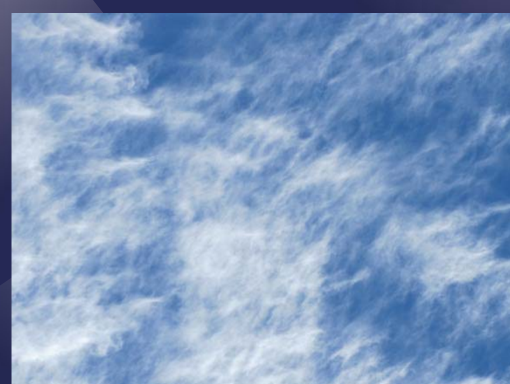




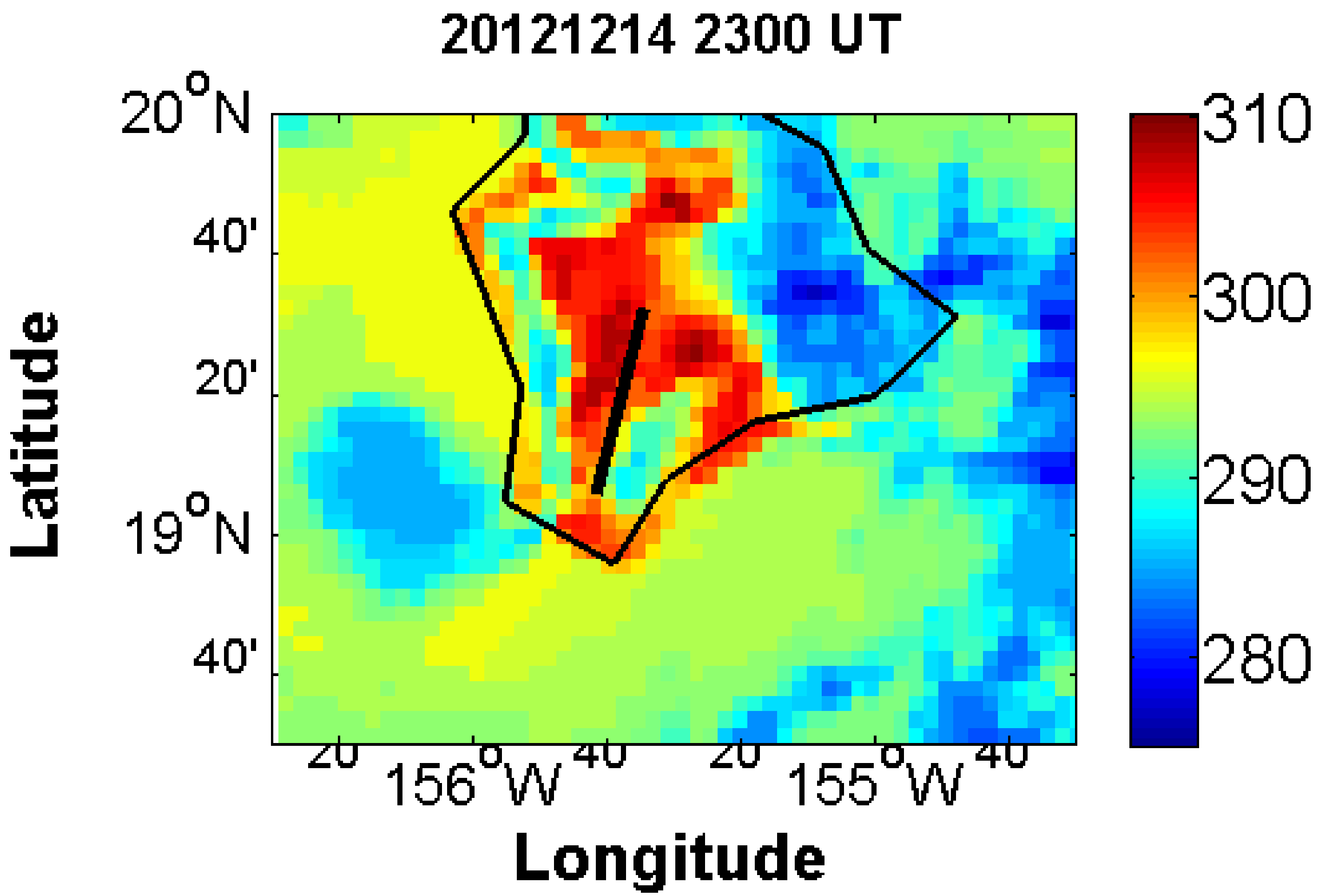
Representation of cirrus variability with time for 12-12-14

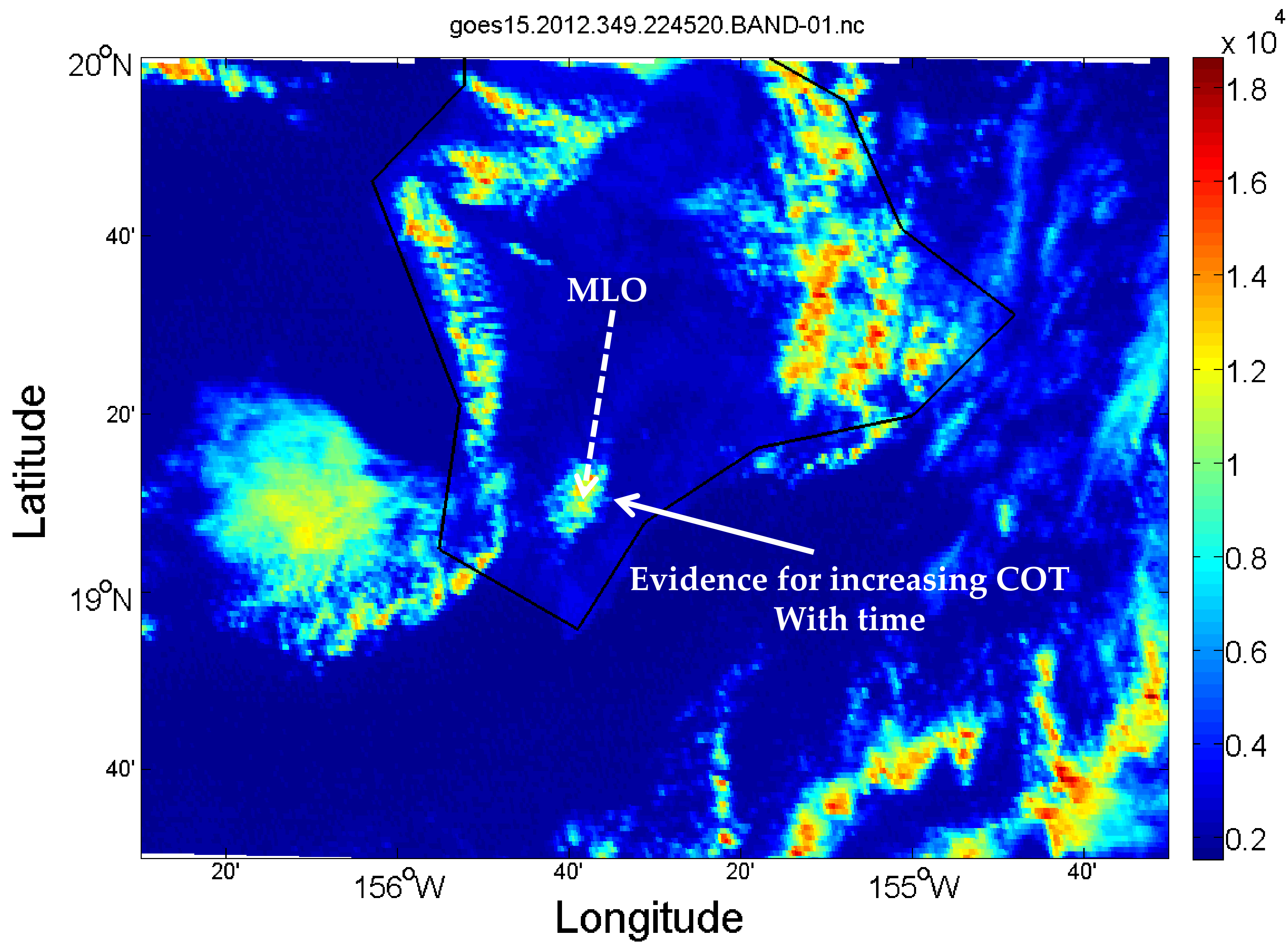






End cirrus period

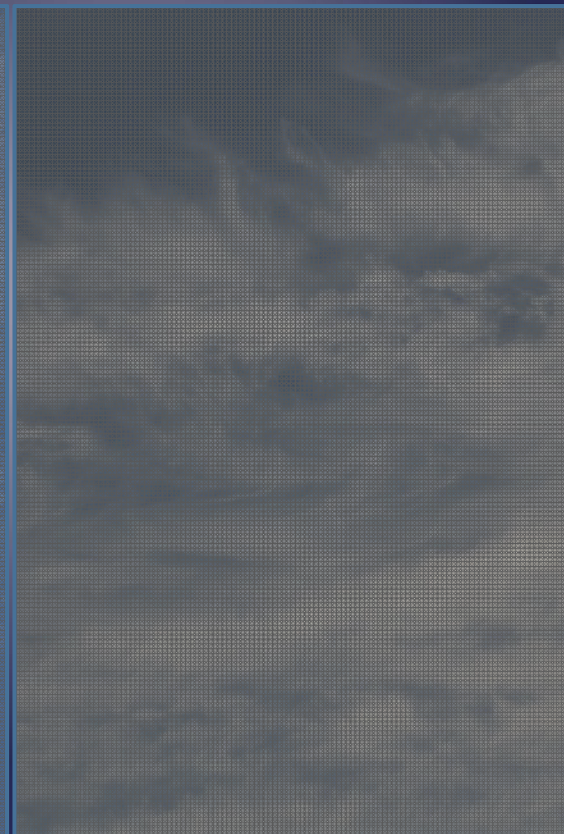




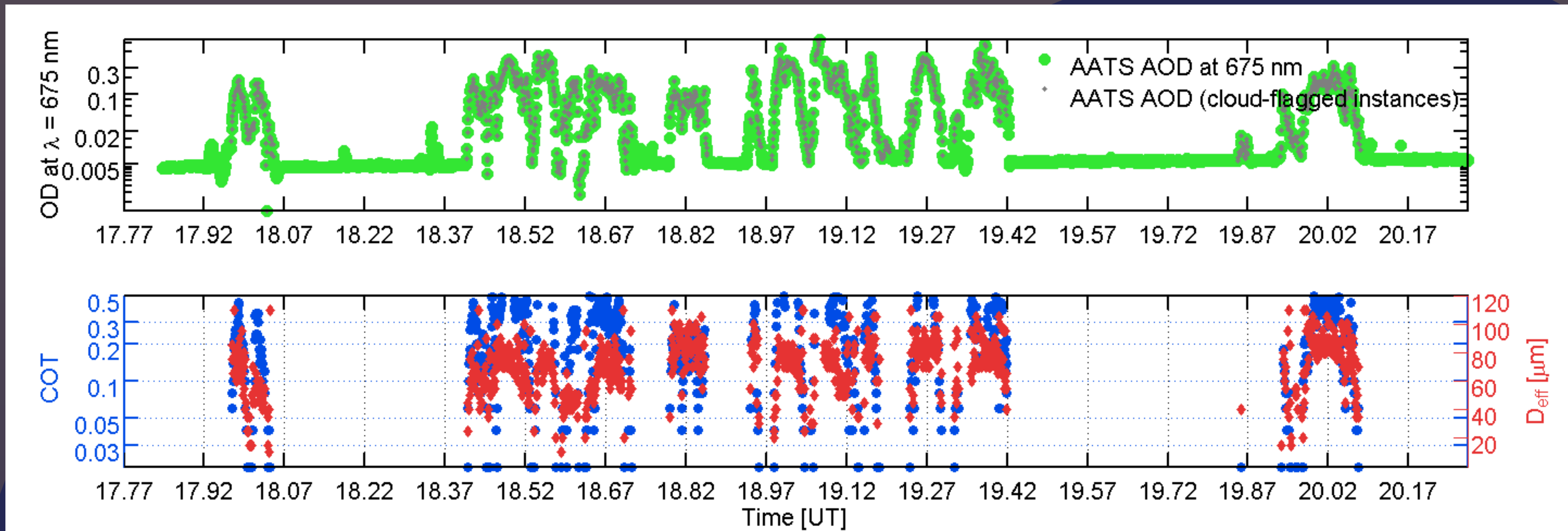
goes15.2012.349.224520.BAND-01.nc
x 10^4
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
20°N
40'
20'
19°N
40'
Latitude
20'
156°W
40'
20'
155°W
40'
Longitude
MLO
Evidence for increasing COT
With time

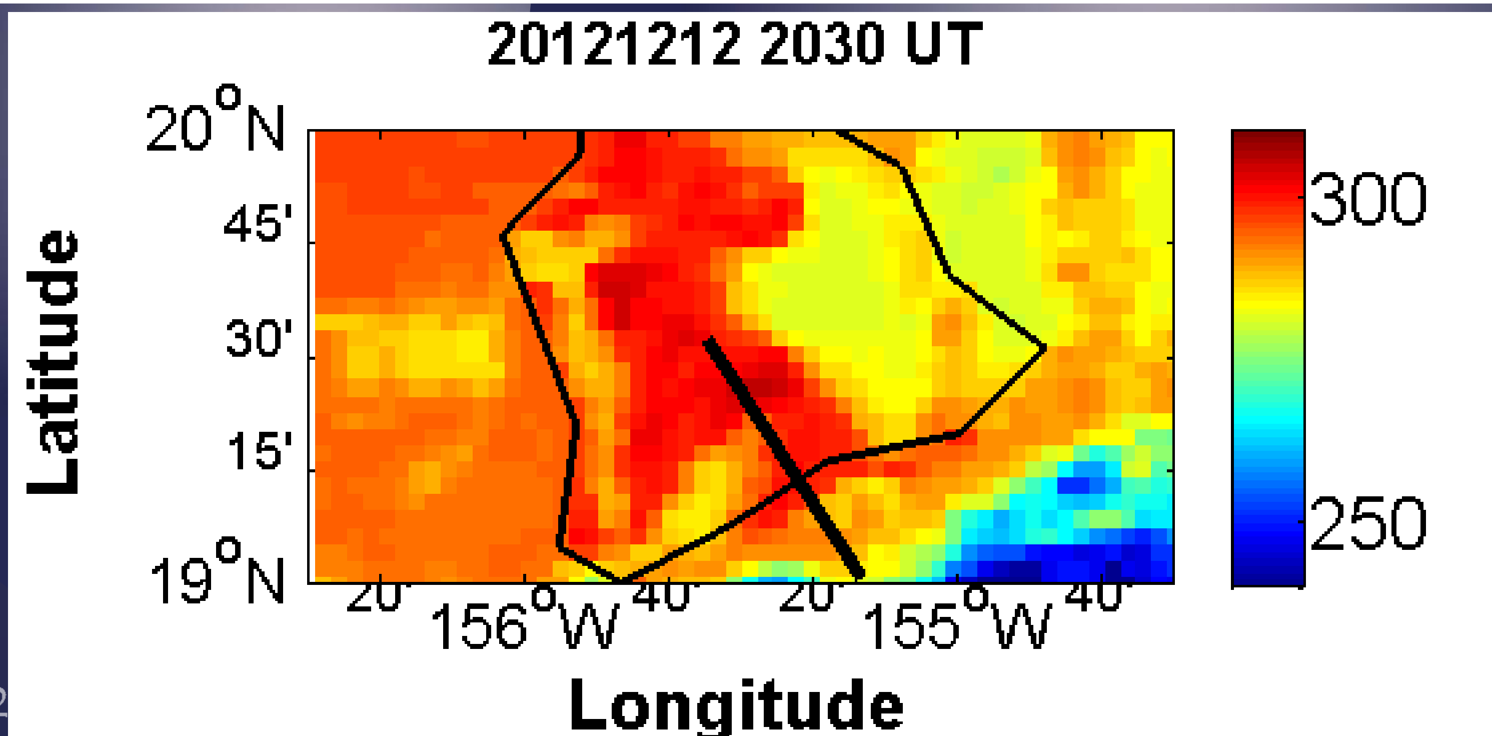
12-12-12

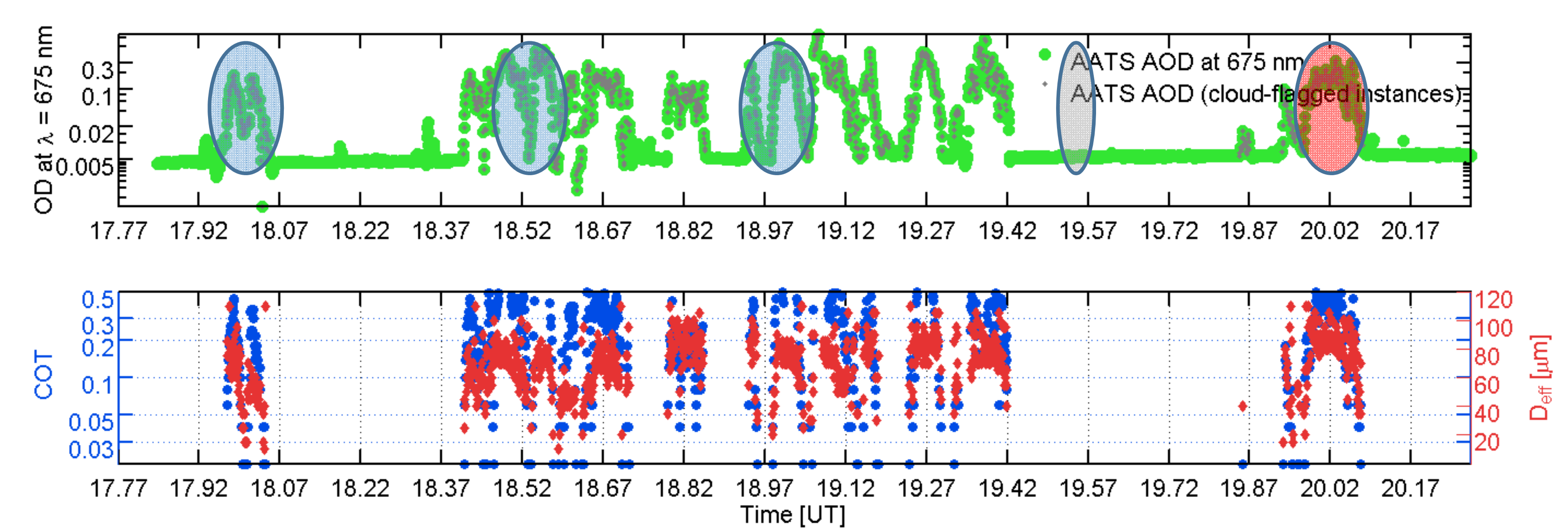
12-12-14



12-12-19


OD at λ = 675 nm
0.3
0.1
0.02
0.005
AATS AOD at 675 nm
AATS AOD (cloud-flagged instances)
17.77 17.92 18.07 18.22 18.37 18.52 18.67 18.82 18.97 19.12 19.27 19.42 19.57 19.72 19.87 20.02 20.17
COT
0.5
0.3
0.2
0.1
0.05
0.03
120
100
80
60
40
20
Deff [μm]
17.77 17.92 18.07 18.22 18.37 18.52 18.67 18.82 18.97 19.12 19.27 19.42 19.57 19.72 19.87 20.02 20.17
Time [UT]


20121212 2030 UT
20°N
45'
30'
15'
19°N
Latitude
20' 156°W 40' 20' 155°W 40'
Longitude
300
250


OD at λ = 675 nm
0.3
0.1
0.02
0.005
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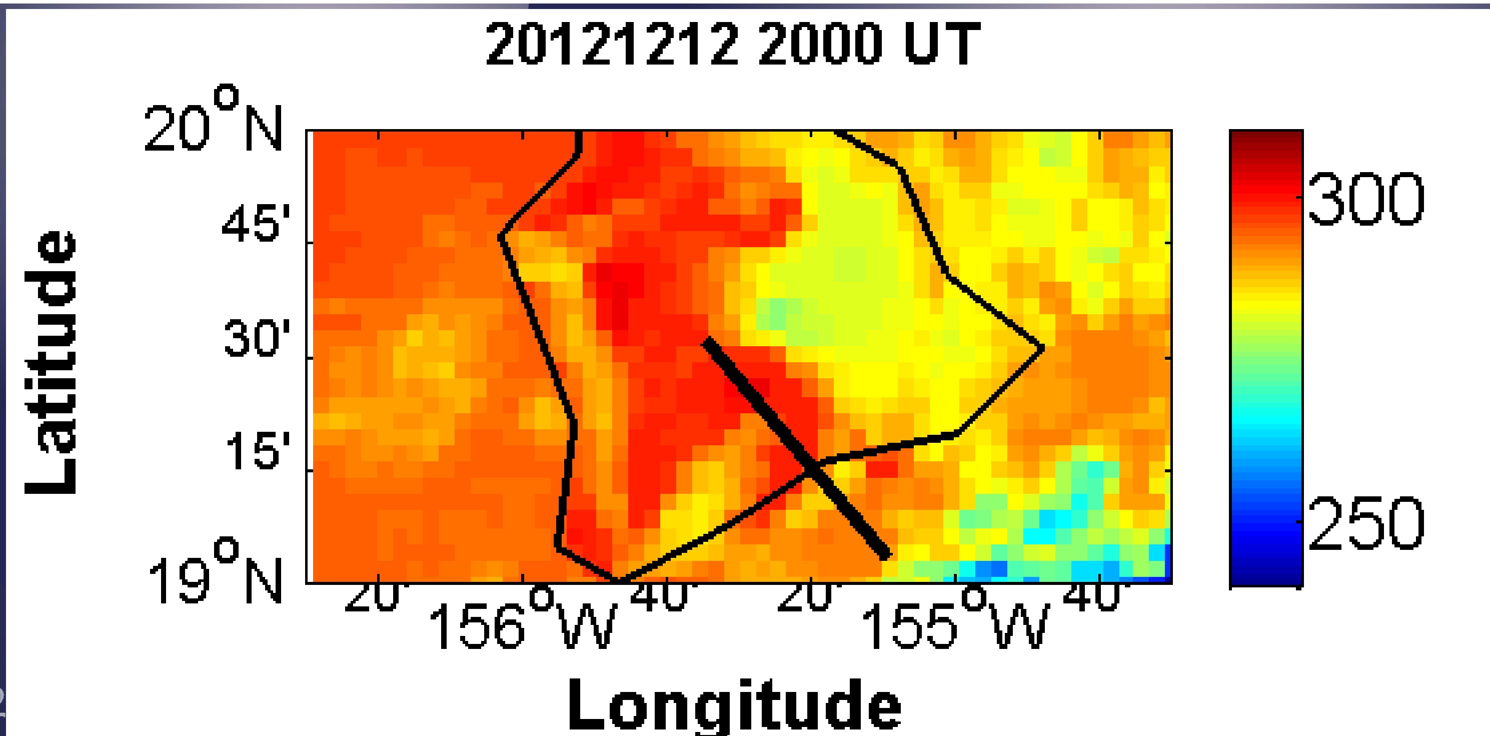
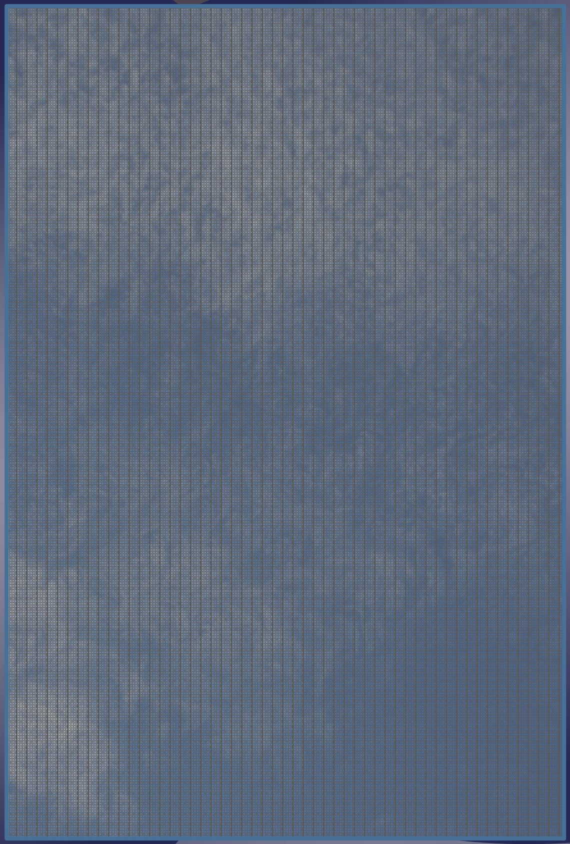
17.77 17.92 18.07 18.22 18.37 18.52 18.67 18.82 18.97 19.12 19.27 19.42 19.57 19.72 19.87 20.02 20.17
COT
0.5
0.3
0.2
0.1
0.05
0.03
120
100
80
60
40
20
D_eff [μm]
Time [UT]


20121212 2000 UT
20°N
45'
30'
15'
19°N
Latitude
20'
156°W
40'
20'
155°W
40'
Longitude
300
250

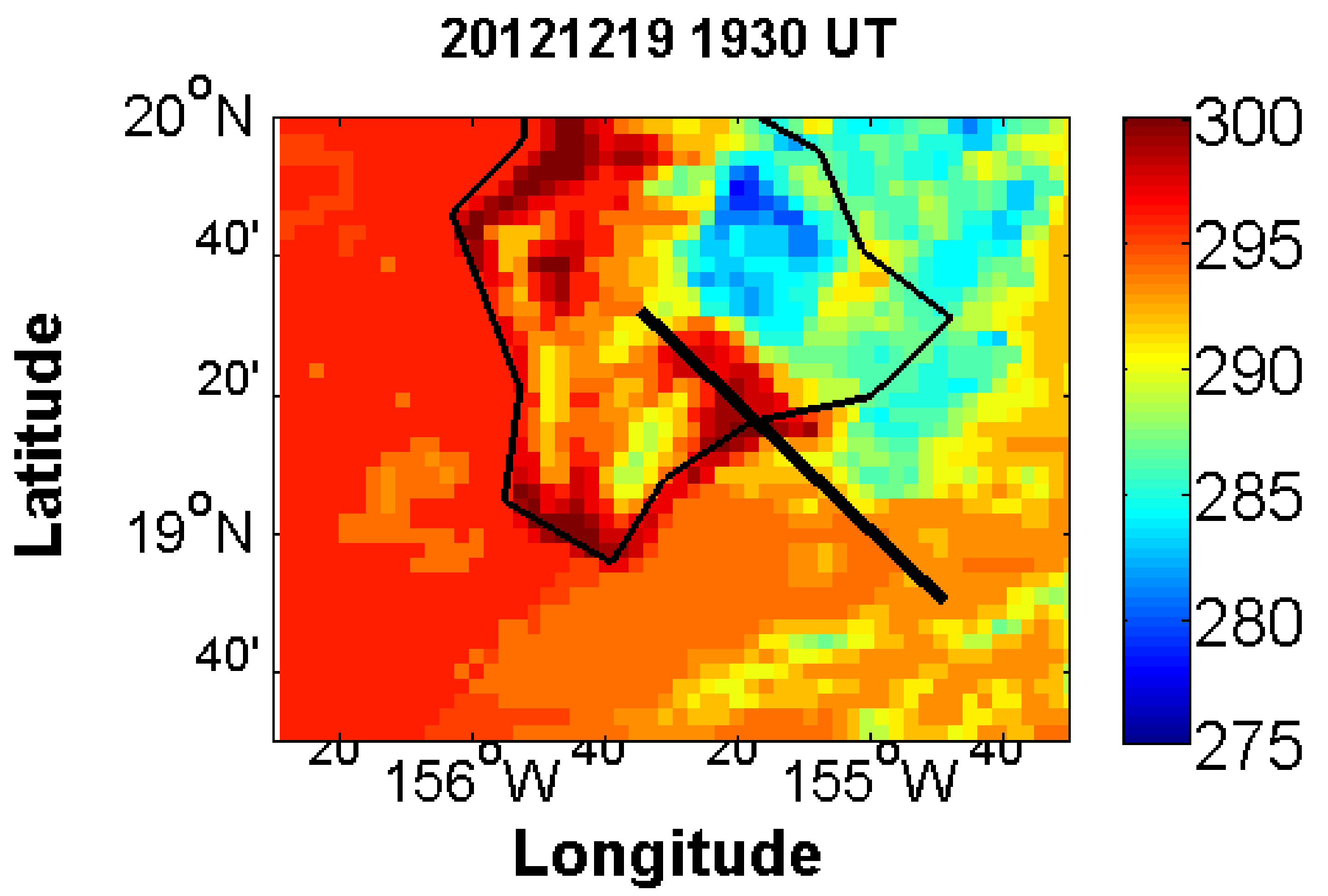
12-12-12



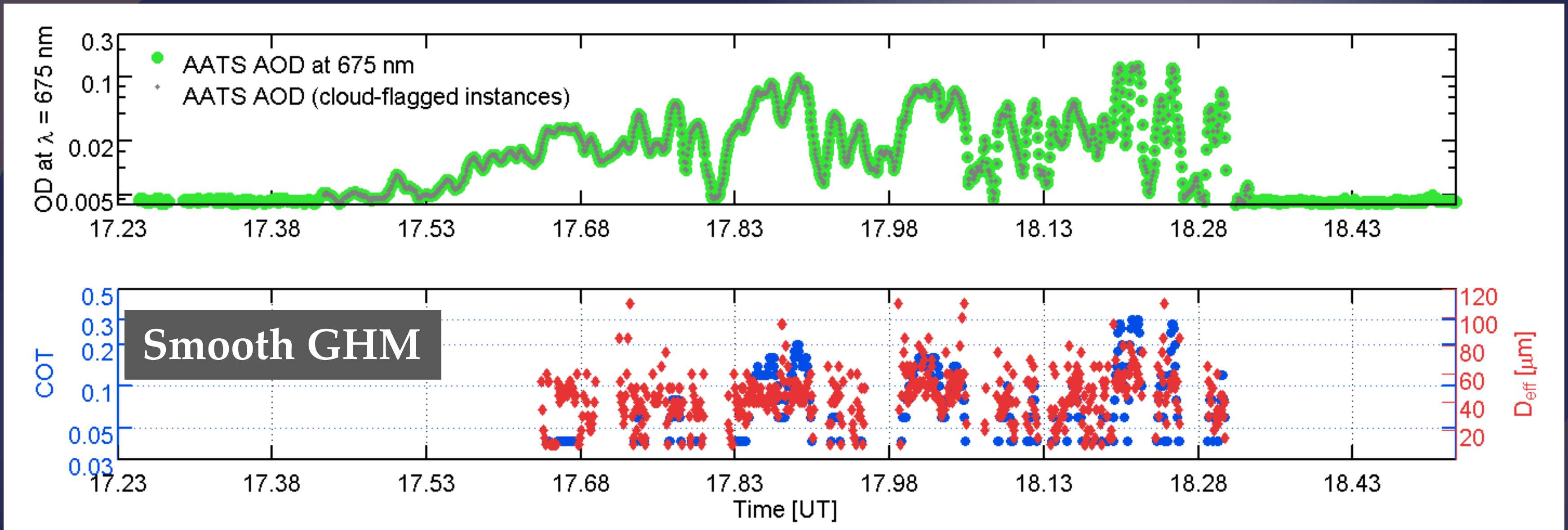
12-12-14

12-12-19

Cirrus clouds were detected continuously from 17:30 (07:30 local time) to 18:30

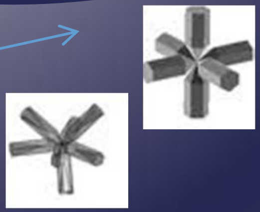


Retrieval results using GHM Smooth model parameterization for 12-12-19



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



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} ↑

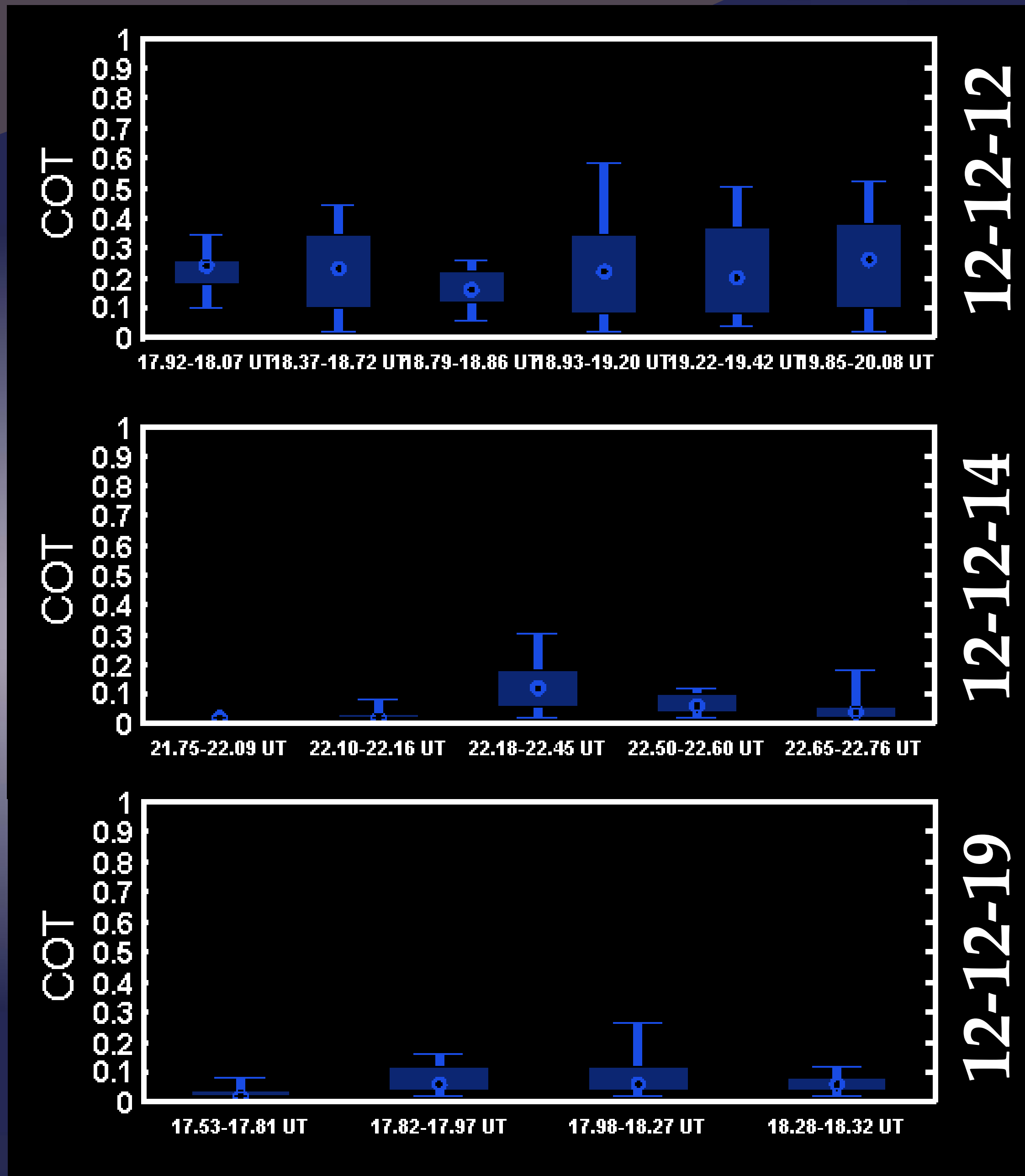
Severe Roughened Aggregates of Solid Columns

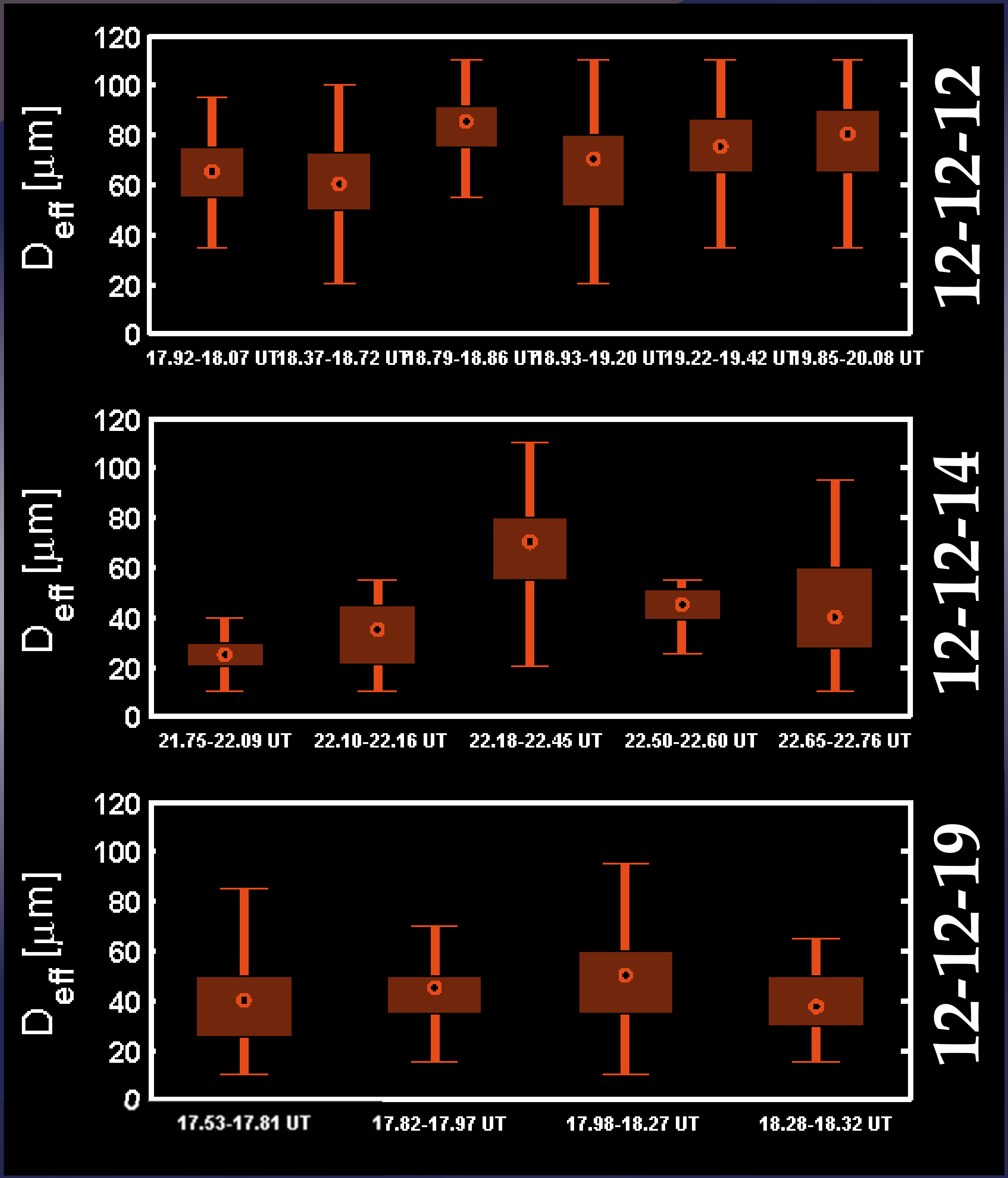
Sunphotometers can increase sensitivity to optically thin COT and their retrieved D_{eff}

12-12-12

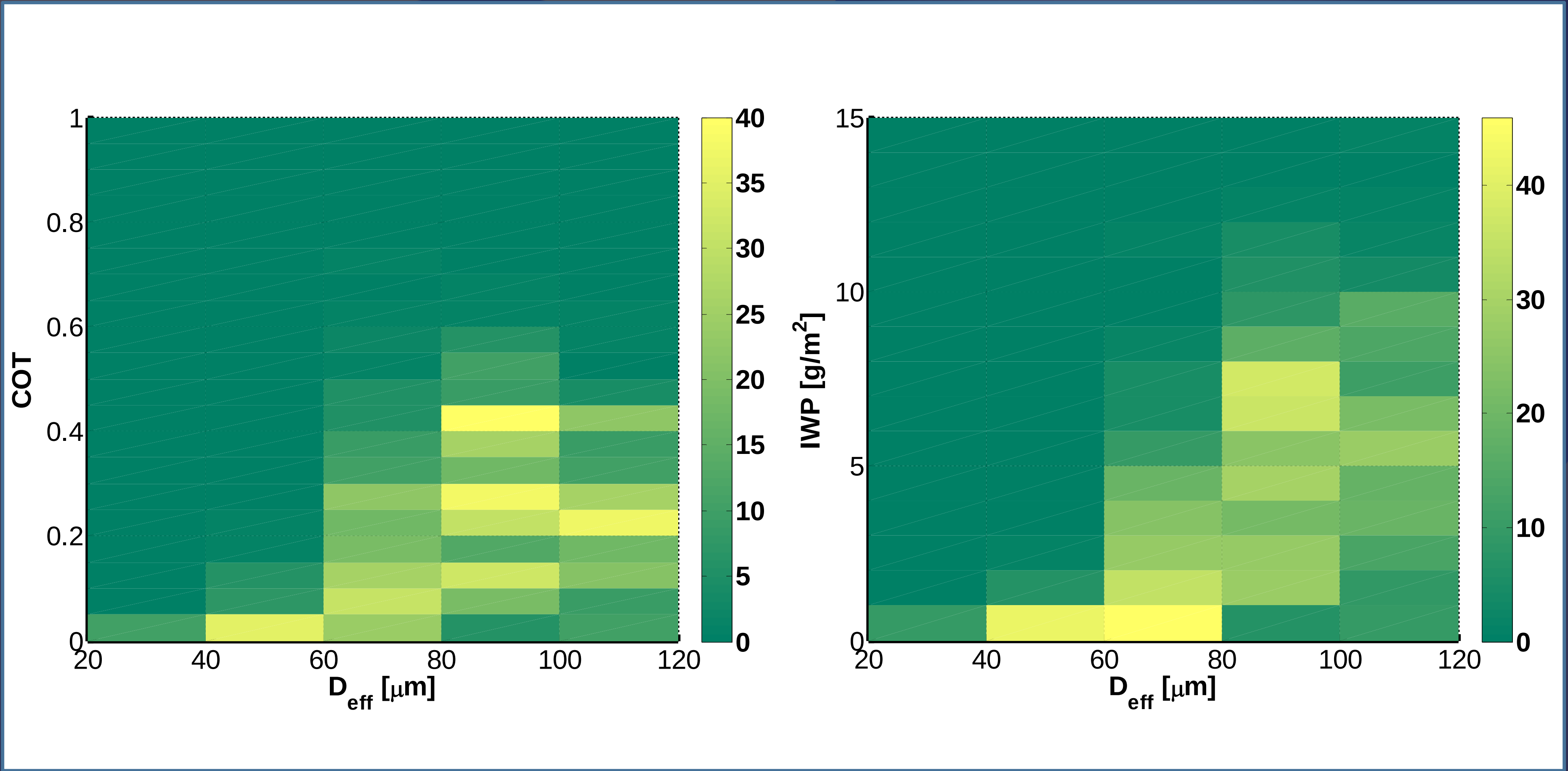
12-12-14

12-12-19


COT
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
17.92-18.07 UT
18.37-18.72 UT
18.79-18.86 UT
18.93-19.20 UT
19.22-19.42 UT
19.85-20.08 UT
12-12-12
21.75-22.09 UT
22.10-22.16 UT
22.18-22.45 UT
22.50-22.60 UT
22.65-22.76 UT
12-12-14
17.53-17.81 UT
17.82-17.97 UT
17.98-18.27 UT
18.28-18.32 UT
12-12-19


120
100
80
60
40
20
0
D$_{eff}$ [μm]
17.92-18.07 UT
18.37-18.72 UT
18.79-18.86 UT
18.93-19.20 UT
19.22-19.42 UT
19.85-20.08 UT
12-12-12
21.75-22.09 UT
22.10-22.16 UT
22.18-22.45 UT
22.50-22.60 UT
22.65-22.76 UT
12-12-14
17.53-17.81 UT
17.82-17.97 UT
17.98-18.27 UT
18.28-18.32 UT
12-12-19

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…

SUMMARY & OUTREACH

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.


Thanks:
John M. Livingston – SRI International
Bryan A. Baum – University of Wisconsin
Co-authors:
Phil Russell, John Livingston,
S. Ramachandran, Jens Redemann,
Bryan Baum


Thanks for your attention!