Dealing with 3D issues in cloud-vegetation interactions

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Clouds with Low Optical (Water) Depth ("CLOWD")

- Over 50% of the warm liquid water clouds at the SGP site have LWP < 100 g m^{-2}

- MWR’s uncertainty is 20-30 g m^{-2} (i.e., errors of 20% to over 100%)

- Aerosol indirect effect research needs accurate measurements of LWP and effective radius

courtesy of Dave Turner, PNNL
Presentation at the ARM STM 2004
Intercomparison between different retrievals of cloud LWP
(easy case: Variable Thickness Stratus Case)

Results from 14 Mar in the ARM 2000 Cloud IOP at the ARM SGP site, a day (esp. around 21 UT) when the cloud was particularly stratiform and uniform

courtesy of Dave Turner, PNNL
Presentation at the ARM STM
Retrieval of cloud optical depth

Common approach is to use downward fluxes:

• broadband pyranometers
  (Leontieva & Stamnes, 1994; Boers, 1997)

• narrowband radiometers
  (Min and Harrison, 1996, Min et al., 2003)

computed by DISORT:
g=0.85, \( \omega_0 = 1 \), \( \rho_{surf} = 0.2 \)
Three major problems with inferring cloud optical depth:

(i) lack of one-to-one relationship even for “plane-parallel” 1D clouds;
(ii) a strong influence of 3D cloud structure on measured radiance;
(iii) no retrieval for 3D values larger than max of 1D.
AERONET

AERONET is a ground based monitoring network that consists of identical multi-channel Cimel radiometers for assessing aerosol optical properties.

Cimel at GSFC, Roof of the Bld.
33
1.2° FOV

Clouds

Aerosol optical thickness

Data from MAR/22, 2000

- AOT_1020 : <0.056>
- AOT_870 : <0.057>
- AOT_670 : <0.082>
- AOT_500 : <0.132>
- AOT_440 : <0.158>
- AOT_380 : <0.217>
- AOT_340 : <0.286>

Cordoba-CETT, S 31 31’, W 64 27’, Alt 730 m,
PI: Brent_Holben, brent@spamer.gsfc.nasa.gov

9/23/1999
Objectives

• to exploit the sharp spectral contrast in vegetated surface reflectance between 0.67 and 0.87 µm to retrieve cloud properties from measurements of zenith radiance;

• to study possibility of simultaneous retrieval of droplet effective radius from measurements of zenith radiance at 0.87 and 1.64 µm spectral regions
Cimel radiance measurements (GSFC, Bld. 33): four channels (440, 670, 870, and 1020 nm)

- **(a) Atmosphere dominates:**
  \[ I_{440} > I_{670} > I_{870} > I_{1020} \]
  Aerosol optical properties can be retrieved

- **(b) Surface and Clouds dominate:**
  \[ I_{440} \approx I_{670} < I_{870} \approx I_{1020} \]
  Cloud optical properties can be retrieved

- **(c) Transition between (a) and (b):**
  - sharp changes in \( I_\lambda \) around cloud edges;
  - the “order” of \( I_\lambda \) between all four channels rapidly changes from cloudy to clear and back.
Two-Channel Narrow Field of View (NFOV)

September 29, 2004; ARM SGP

Normalized radiance vs. time (UT)

673 nm
870 nm

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Two-channel cloud retrievals

Satellite retrieval of $\tau$ and $r_e$
from Nakajima-King, JAS 1990

Surface retrieval of $\tau$ and $A_c$
from Marshak et al., JAS 2004

Satellite retrieval of $\tau$ and $r_e$
from Nakajima-King, JAS 1990

Surface retrieval of $\tau$ and $A_c$
from Marshak et al., JAS 2004
2D Look-Up Tables
“NIR vs. RED” plane

\[ I_{\text{RED}} = I_{\text{RED}}(\tau, A_c) \]
\[ I_{\text{NIR}} = I_{\text{NIR}}(\tau, A_c) \]

\( \tau \) is cloud optical depth
\( A_c \) is “effective” cloud fraction
Where are Cimel data-points?

July 28, 2002 ARM CART site in OK

Cimel measurements taken around 13:45, 13:58 and 14:11 UT

\[ A_c = 0.85 \text{ is not a visual cloud fraction but a "radiatively effective" one that also compensates for cloud horizontal inhomogeneity not accounted for by 1D RT.} \]
Retrieval examples

Cloud optical depth retrieved from:

- **Cimel** (spectral zenith radiance)

- **MWR** (Microwave Radiometer) assuming $r_e = 7 \, \mu m$

- **MFRSR** (Multi-Filter Rotating Shadowband Radiometer)

August 8, 2002; 18:00 UT CART site

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Retrievals

LUT with Cimel data-points

July 3, 2002

MFRSR data is courtesy of Q. Min

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Retrievals from broken Cu clouds

Show MOVIES
Local climatology
(Santa Barbara, CA: 2003)

Cloud optical depth

“Effective” cloud fraction

Frequency

Frequency
Local climatology

(ARM CART cite, OK: 2001-2003)

Cloud optical depth

"Effective" cloud fraction
Cloud droplet effective radius from Cimel

- LUT for two wavelengths: 870 and 1640 nm;
- Cimel measurements $I(870)$ and $I(1640)$;
- Surface albedo from MODIS/MISR

Difficulties (Platnick, 2000):
- less sensitive to droplet size;
- canceling effect of $\omega_0$ and $g$. 

July 28, 2004, GSFC, Bld. 33
Combined retrieval of
optical depth $\tau$, 
(effective) cloud fraction $A_c$, and 
droplet effective radius $r_e$

Assuming that surface albedos: $\alpha_{670}$, $\alpha_{870}$, $\alpha_{1640}$ are known,

we have

\[ I_{670} = I_{670}(\tau, A_c, r_e) \]
\[ I_{870} = I_{870}(\tau, A_c, r_e) \]
\[ I_{1640} = I_{1640}(\tau, A_c, r_e) \]

MODIS surface refl. around Bld. 33 at GSFC averaged over 8 days starting from July 27, 2004. Data are 11 by 11 km with 500 m resolution (22 by 22 pixels).
Two-step retrieval of optical depth $\tau$, (effective) cloud fraction $A_c$, and droplet effective radius $r_e$

1st step:
\[ I_{670} = I_{670} (\tau, A_c, r_e) \]
\[ I_{870} = I_{870} (\tau, A_c, r_e) \]

2nd step:
\[ I_{870} = I_{870} (\tau, A_c, r_e) \]
\[ I_{1640} = I_{1640} (\tau, A_c, r_e) \]
August 2, 2004; GSFC

Optical depth

Effective radius

Cloud fraction

Effective radius (um)

time (UTC)

MODIS overpass

GSFC

08/02/2004

data ok rate ~ 50%

time

retrieval rate = 86%

MODIS overpass

optical depth and sza

08/02/2004

data ok rate ~ 50%

retrieval rate = 86%

MODIS overpass

I3RC 14 Oct, 2005

time

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Some theory behind the RED vs. NIR method

(Marshak et al., 2004)

\[
I = I_o + \frac{\rho I_s T_o}{1 - \rho R}
\]

\[
T_o = 1 - A_c + A_c \cdot T_{o,pp}
\]

\[
I_{RED}(\tau, A_c) = I_{o,RED}(\tau) + \frac{\rho_{RED} I_{s,RED}(\tau) \cdot [1 - A_c + A_c T_{o,pp,RED}(\tau)]}{1 - \rho_{RED} R_{RED}(\tau)}
\]

\[
I_{NIR}(\tau, A_c) = I_{o,NIR}(\tau) + \frac{\rho_{NIR} I_{s,NIR}(\tau) \cdot [1 - A_c + A_c T_{o,pp,NIR}(\tau)]}{1 - \rho_{NIR} R_{NIR}(\tau)}
\]
Some theory behind the COUPLED method

(Barker and Marshak, 2001, Knyazikhin and Marshak, 2005)

\[ I = I_o + \rho I_s \frac{T_o}{1 - \rho R} \]

\[ I_{\text{RED}} = I_{o,\text{RED}} + \rho_{\text{RED}} T_{\text{RED}} I_{s,\text{RED}} \]

\[ I_{\text{NIR}} = I_{o,\text{NIR}} + \rho_{\text{NIR}} T_{\text{NIR}} I_{s,\text{NIR}} \]

Assumptions:

\[ I_{o,\text{NIR}} = I_{o,\text{RED}} \]

\[ I_{s,\text{NIR}} = I_{s,\text{RED}} = I_s \]

\[ I_{\text{NIR}} - I_{\text{RED}} = (\rho_{\text{NIR}} T_{\text{NIR}} - \rho_{\text{RED}} T_{\text{RED}}) I_s (\tau) \]

\[ I_s (\tau) = \frac{I_{\text{NIR}} - I_{\text{RED}}}{F_{\text{NIR}} - F_{\text{RED}}} \]

\[ I_{\text{NIR}} (x) - I_{\text{RED}} (x) = \int_{x' \in S} \left[ F_{\text{NIR}}^\uparrow (x') - F_{\text{RED}}^\uparrow (x') \right] \cdot J (x, x') dx' \]

\[ r_{\lambda} (x) = \frac{\int_{x' \in S} F_{\lambda}^\uparrow (x') J (x, x') dx'}{F_{\lambda}^\uparrow (x')} \]

\[ r_{\lambda} (x) \approx \eta (J) = BF \bigg|_{F=1} = \int_{x' \in S} J (x, x') dx' \]

where \( \eta (J) \) is the max eigenvalue

\[ \eta (J) \approx \frac{I_{\text{NIR}} (x) - I_{\text{RED}} (x)}{F_{\text{NIR}}^\uparrow (x) - F_{\text{RED}}^\uparrow (x)} \]

\[ I_s (x, \tau) \approx \frac{I_{\text{NIR}} (x) - I_{\text{RED}} (x)}{F_{\text{NIR}}^\uparrow (x) - F_{\text{RED}}^\uparrow (x)} \]
Summary

The Main Ideas

• use three wavelengths:
  one in RED (670 nm) where vegetation albedo is low
  one in NIR (870 nm) where vegetation albedo is high
  one in MIR (1640 nm) where cloud droplets absorb

• retrieve cloud optical depth and effective cloud fraction using the NIR vs. RED plane and then effective radius using NIR vs. MIR plane

The Results (so far)

• looks promising; it largely removes 3D effects;
• it is not the final answer but a big improvement against any single-wavelength retrievals;
• it can
  – fill (cloud) gaps in AERONET aerosol optical depth retrievals
  – estimate (effective) cloud fraction and
  – droplet effective radius
  even for broken clouds
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Seasonal applicability

\[ NDVI = \frac{NIR - RED}{NIR + RED} \]

ARM CART site, OK

Bondville, IL

NDVI = \( \frac{NIR - RED}{NIR + RED} \)