LA-UR-08-0354

Case for a Climate-Driven Synergy Between 3D Cloud Tomography Using Radar or Microwaves and Fine-Resolution Oxygen A-band Spectroscopy

Context

The DOE Atmospheric Radiation Measurement (ARM) Program is investing significant resources into cloud distribution and characterization in all three spatial dimensions (and time) using tomographic techniques, both active (radar-based) and passive (microwave-based), scanning from a few stations in either case. This investment in cutting-edge observational technology will support three important mission areas:

1/ 3D cloud-resolving model validation;
2/ assessment of space-based cloud remote sensing products;
3/ input for 3D forward radiative transfer models targeting remote sensing signals as well as radiation budget estimation over a wide range of scales.

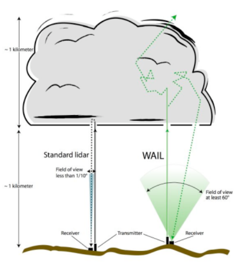
It is of paramount importance to bridge the gap across scales—as well as across wavelengths—between this 3D cloud tomography focused, by definition, on small details and key radiation properties in climate modeling: short-wave heating rate and long-wave cooling rate profiles that are meaningful for the large domains of interest in GCMs (1 gridcell ~ 100 km).

Proposition

We claim that high-resolution O_2 A-band spectroscopy can close this double gap for the solar spectrum from the standpoint of cloud impacts. Indeed, this new observational diagnostic has proven to be highly sensitive to 3D (e.g., multi- and/or broken layered) structure in cloudiness from the particularly relevant perspective of atmospheric absorption processes; see list of references. Concerning the wavelength gap, A-band data exploitation does not require any assumptions about cloud microphysics, as does radar and microwave cloud probing (to get back to short- and long-wave properties). Wisely, ARM is also investing instrument development funds into an operational (all weather) A-band spectrometer with sufficient resolving power.

Part of the return on this investment will be new remote sensing capability delivering accurate cloud properties in the case of a single/unbroken layer. Finally, all of this ground-based spectro-radiometry (of cloud-transmitted sunlight) will be complemented by NASA's powerful A-band spectrometer on the Orbiting Carbon Observatory (OCO), and we already know that this cloud-reflected sunlight is even more information rich.

N.B. Because O_2 is an abundant well-mixed absorbing gas in which all the scattering particles are immersed, *A-band spectroscopy has the essentially the same signal physics as lidar*, namely, space-and-time radiative transfer. Algorithms for aerosol profile retrieval have been proposed, and cloud boundaries are readily detected (laser ceilometry), when single-scattering dominates because time delay can be translated into range. **Inside dense clouds, multiple-scattering dominates and the 1-to-1 time-range connection is lost; new "off-beam" lidar techniques then enable accurate cloud property retrievals.** [papers available upon request]



Schematic of LANL's Wide-Angle Imaging Lidar

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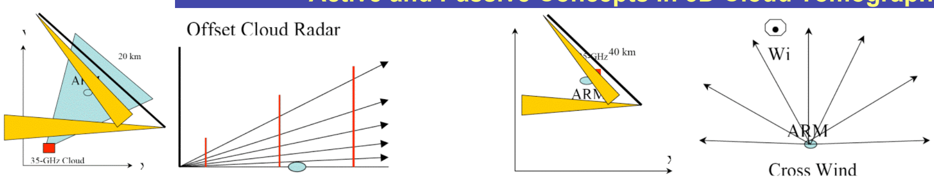
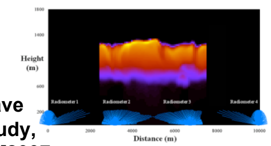
Active and Passive Concepts in 3D Cloud Tomography:

Two possible spacing and scanning configurations for the ARM Volume-imaging Array (AVA):

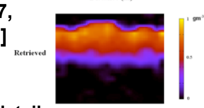


(a) Offset the 35-GHz radar from the ARM SGP site and scan a 3D sector centered at the vertically pointing radars (right); the two 9.4-GHz radars are spaced 20-30 km apart and provide 3D surveillance coverage and supplementary coverage for areas where the offset 35-GHz radar will have difficulty providing coverage (at very short and very long range from the radar location). (b) Place the 35-GHz at the Central Facility, make simple cross-wind 180º scans, and use the wind to map the 3D structure of clouds (right); for this mode, the two 9.4-GHz radars would conduct autonomous volume scans independently from the 35-GHz radar.

For more details: http://science.arm.gov/wg/cpm/scm/scmic5/docs/AVA_plan.v3.pdf



Passive μwave simulation study, cf. Huang et al. [2007, submitted to JGR-D]



For more details:
http://www.arm.gov/science/research/content.php?id=MTMz

Primer in Differential Absorption Spectroscopy:

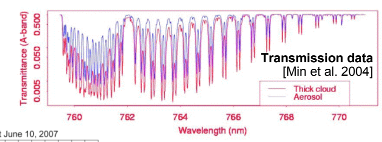
$$I_\nu / I_{L=0} = \exp[-\overbrace{\sigma_\nu}^{\text{cross-section}} \times \overbrace{n}^{\text{density}} \times \overbrace{L}^{\text{path length}}]$$ **Application :**

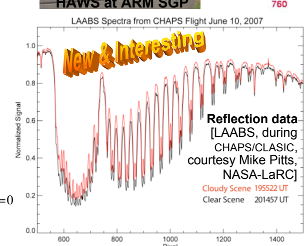
(e.g., CO_2 with OCO)

$$\textbf{known / not :} \left\{ \begin{array}{llll} ? & \surd & \surd & \text{estimating molecular cross-sections, normally in a laboratory} \\ \surd & ? & \surd & \text{monitoring amounts of chemical effluent in situ or remotely} \\ \surd & \surd & ? & \text{scattering/reflection diagnostics of media permeated with gas} \end{array} \right.$$

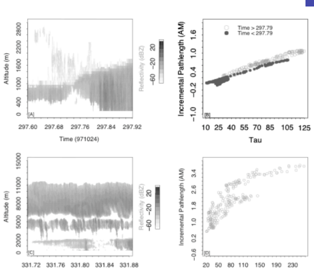
$$I_\nu \equiv I(k_\nu) = I(0)\langle \exp[-k_\nu L]\rangle = \boxed{I(0)\int_0^\infty p(L)}\exp[-k_\nu L]\mathrm{d}L \quad \Rightarrow \quad \langle L^q \rangle = \int_0^\infty L^q p(L)\mathrm{d}L = \frac{1}{I(0)} \times \left(-\frac{\mathrm{d}}{\mathrm{d}k_\nu}\right)^q I \Bigg|_{k_\nu=0}$$

Impulse Response Function of cloud from "3+1 D" RT equation ➔LT➔ $I(k_\nu)$



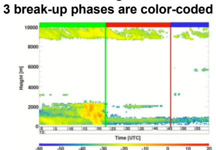


Path Length Statistics from A-Band Spectroscopy Under Cloudy Skies:

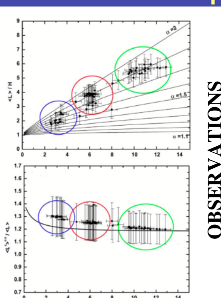


Mean pathlength - τ stats from A-band
Min et al. [2001]

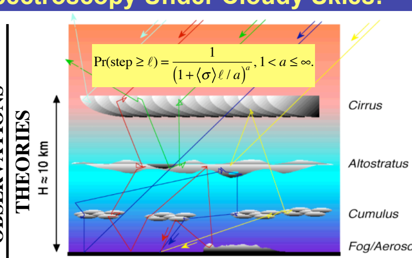
Millimeter-wavelength cloud radar
3 break-up phases are color-coded



2-moment pathlength - τ statistics from A-band
Scholl et al. [2006]



OBSERVATIONS
THEORIES



Anomalous transport/diffusion schematic:
Notice the small steps in clouds and the large jumps between them and/or the ground.

Anomalous diffusion model (i.e., asymptotic trends)

(E(step^q) = ∞ for $q \geq \alpha$):
$T \sim \tau_{tr}^{-\alpha/2}$ and $\langle L\rangle_T \sim H \times \tau_{tr}^{\alpha-1}$,
$1 < \alpha \leq 2$, as $\tau_{tr}=(1-g)\tau \to \infty$
[Davis & Marshak'97]
$R = 1-T$ and
$\langle L^q\rangle_R^{1/q} \sim H \times \tau_{tr}^{(1-1/2q)\alpha-1}$
as $\tau_{tr}=(1-g)\tau \to \infty$
[Davis'07, in preparation].

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