Determination of Cloud Liquid Water Distribution with 3D Cloud Tomography

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Can we “X-ray” clouds?

microwave radiometers

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Tomography is a method for imaging the interior of an object from its projections.

**CAT scanner**

Computed Tomography

**GROUND PENETRATING RADAR**

Transmitted waves → Reflected waves

Buried tank

GEOSPHERE INC

**Tree root distribution**

Tomography
What if the patient is a cloud?

Warner et al., 1985

Transmission Tomography

Emission Tomography

Forward model

Inverse model
The simulated brightness temperatures are proportional to the length of the lines radiating from each radiometer.
Regularization helps obtain optimal solution for ill-posed inverse problem

Original space  \[ \text{functions} \]  Reduced space

Regularization

Impose constraints, e.g., smoothness, non-negativity

“Ill-posedness” is characterized by condition number; e.g.,

\[ 10000 \rightarrow \text{badly ill-posed,} \quad 10 \rightarrow \text{slightly ill-posed} \]

A smoothness constraint is added to Lawson and Hanson’s non-negative least squares algorithm using the method of (Liu et al., 1998).
Standard least squares method corresponds to the case in which no constraints is used.

\[ \text{Condition number: 2217} \]

RMSE of brightness temperature

Regularization parameter (increasing smoothness)
Error of least squares method is 5 times as large as smoothn’s constrained regularizat’n

Min errors of LWC and $T_B$ do not occur at same point.
8 radiometers well capture the spatial pattern of cloud liquid water at 20x20 resolution.

**Stratocumulus**
- max(LWC)=0.97
- mean(LWC)=0.31
- RMSE=0.06

**Broken cumulus**
- max(LWC)=1.0
- mean(LWC)=0.04
- RMSE=0.006
Radiometer noise and number of scan angles trade off against each other

More scan angles means less dwell time and hence higher noise at each angle.
Reconstruction error declines when ...

Number of radiometers increases

Output resolution decreases

Relative error of LWC

Condition number

2 radiometers, Warner's setup
Future: improve reconstruction through data fusion, retrieve vapor and ice water.

We need to talk!
Summary: cloud tomography is able to retrieve LWC within 5% of the max LWC

... at resolution of a few hundred meters with a 4-radiometer setup.

The passive microwave tomographic reconstruction of cloud liquid water is ill-posed.

Regularization with non-negativity and smoothness constraints helps obtain the optimal solution.

Reconstruction accuracy depends on:

- Radiometer noise level
- Total number of scan directions
- Output resolution
- Number of radiometers