3D Error Assessment and Cloud Climatology from MODIS

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Extend 3D retrieval capabilities for both passive (Terra and Aqua) and active (THOR lidar) remote sensing

1. Multiple-instrument Cloud-Aerosol I3RC Cases and 3D Toolkit
   [I3RC = (International) Intercomparison of 3D Radiation Codes
2. **3D Error Assessment and Cloud Climatology from MODIS**
3. *3D Cloud Retrieval from MISR*
4. *Cloud Retrievals from THOR (Thickness from Offbeam Returns)*

Task I: Multiple-instrument Cloud-Aerosol I3RC Cases and 3D Toolkit

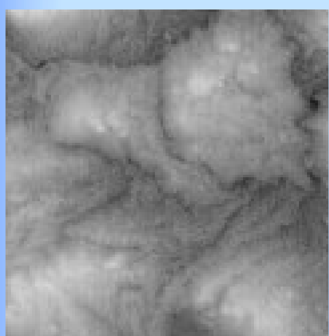
Expected results

- Cloud cases from collocated MODIS, MISR and ASTER data
  - such cases are based directly on observed cloud fields;
  - all multi-instrument observed radiances are computable by "I3RC-certified" 3DRT codes;
  - the cases provide a basic for development of improved 3D retrievals.

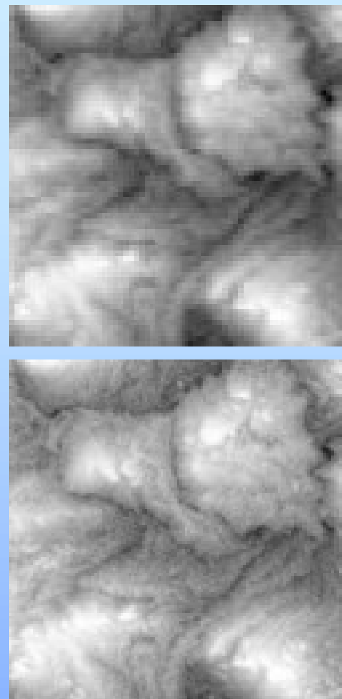
- Open Source Toolkit (led by Robert Pincus)
  - publicly documented MC Fortran code for 3DRT;
  - complements to widely used SHDOM.

- Educational pages on I3RC website (http://climate.gsfc.nasa.gov/I3RC/)
  - case studies of different degrees of 3D complexity (from pp marine Sc to broken Cu) where students can learn about 3D RT and understand where and how pp approaches break down

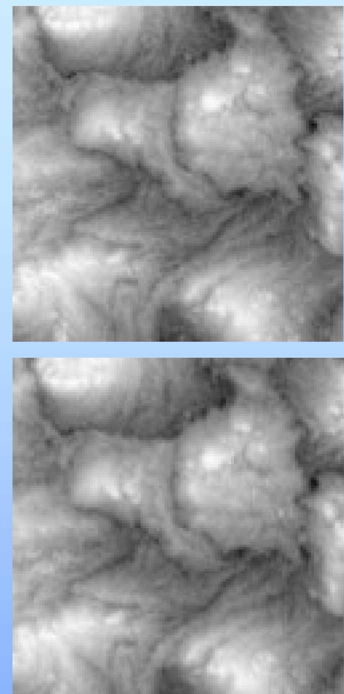
Multiple-instrument Cloud-Aerosol Cases
case I: marine Sc (led by T. Varnai)



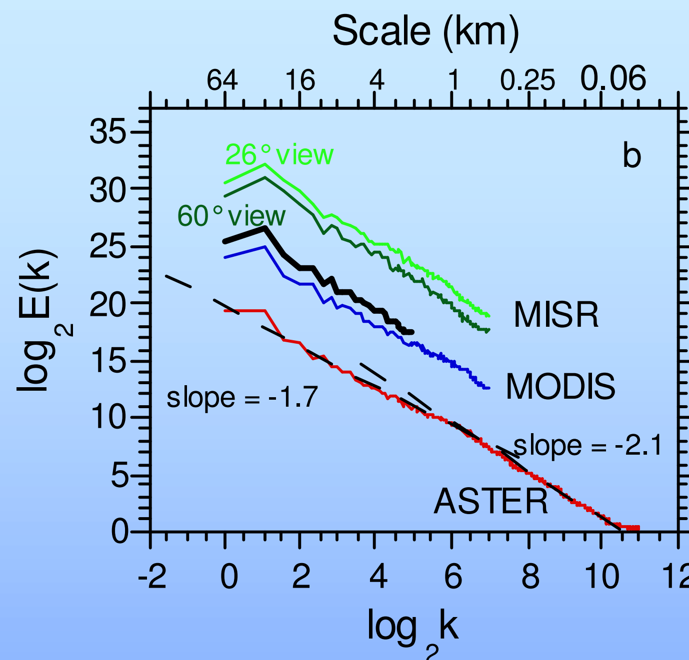
60 by 60 km **ASTER** image (nadir view, 15 m resolution)



60 by 60 km **MODIS** image (1 km and 250 m resolution)



60 by 60 km **MISR** image (275 m resolution, 26° and 60° viewing zenith angles)

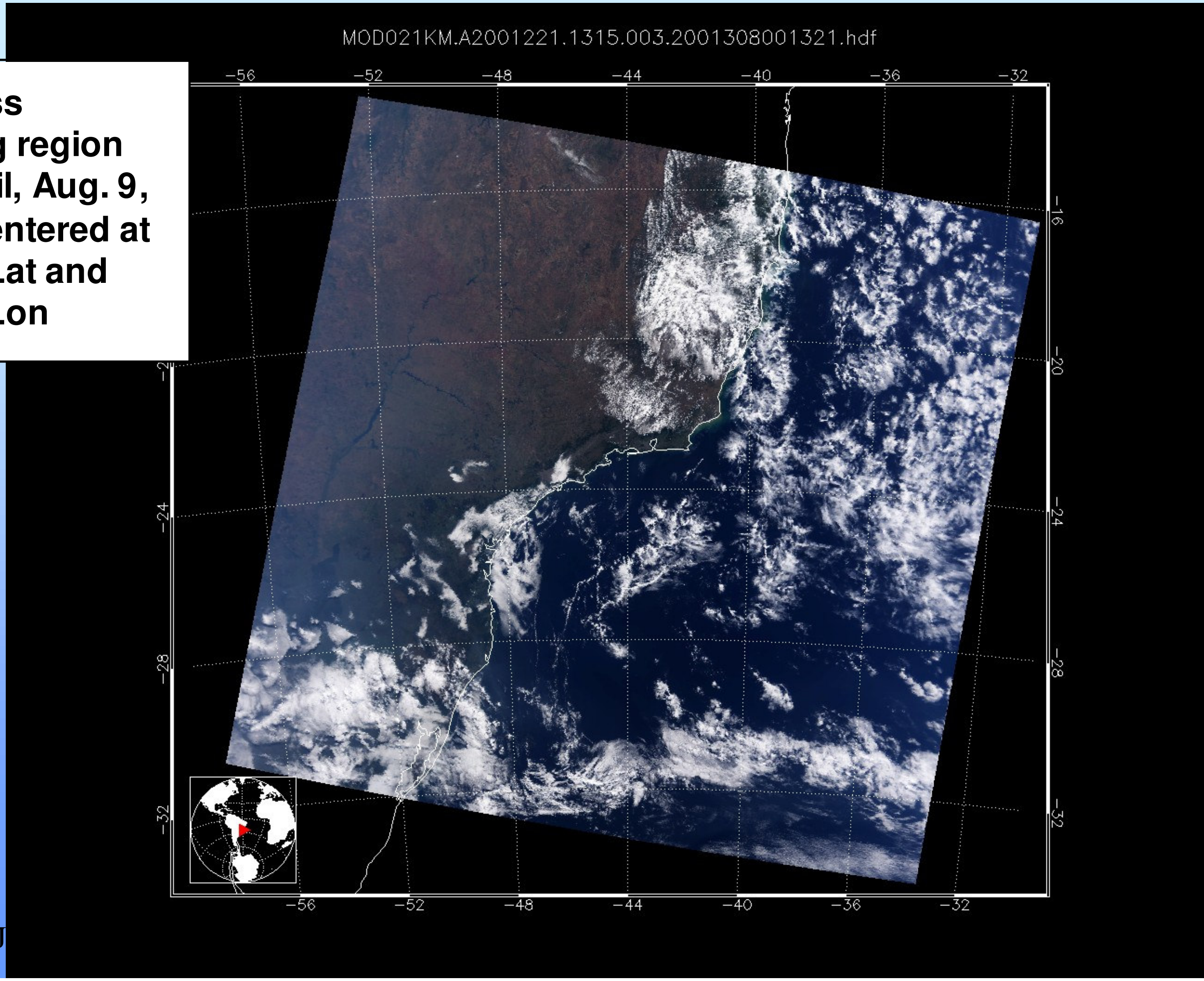


Wavenumber spectrum of variations in all five images

Images of the same marine Sc cloud from ASTER, MODIS and MISR taken on board of Terra on May 21, 2001 at 19:41 UTC over the Pacific Ocean

Multiple-instrument Cloud-Aerosol Cases
case II: biomass burning (led by G. Wen)

Biomass burning region in Brazil, Aug. 9, 2001 centered at -17.10 Lat and -42.16 Lon



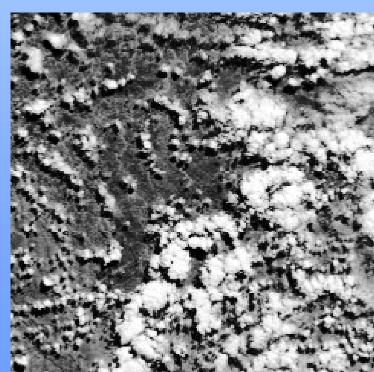
Multiple-instrument Cloud-Aerosol Cases
case II: biomass burning (led by G. Wen)

ASTER
(VNIR 15 m and SWIR 30 m)

60 km

MODIS
RGB = 2.2, 0.86, 0.55 μm

1 km resolution



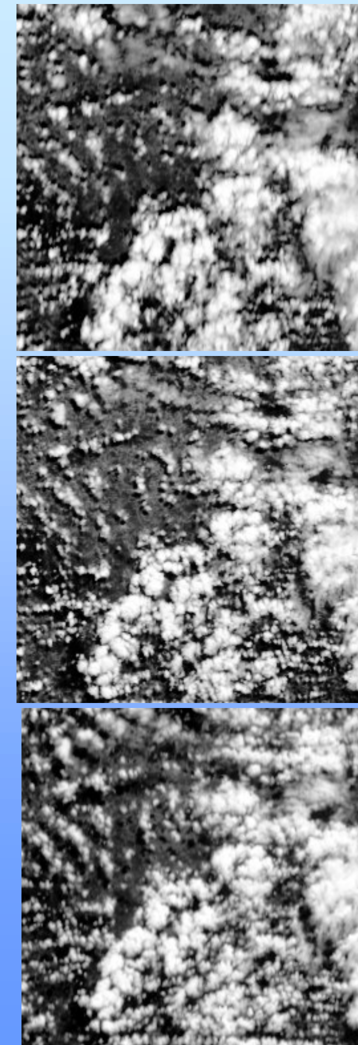
0.25 km resolution

MISR (0.67 μm)
0.275 km resolution (in nadir)

Cf (60^o)

An (0^o)

Ca (60^o)



Biomass burning region in Brazil, Aug. 9, 2001 centered at -17.10 Lat and -42.16 Lon

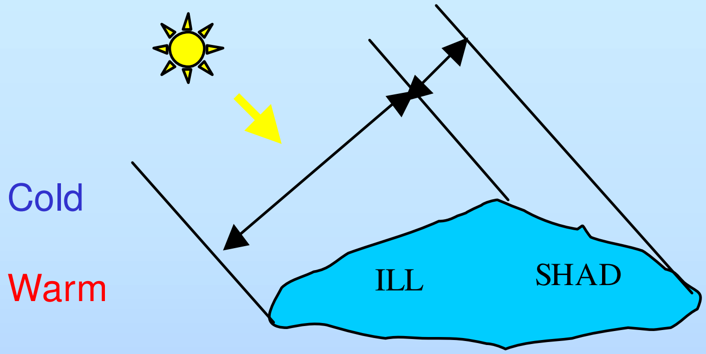
Task II: 3D Error Assessment and Cloud Climatology from MODIS

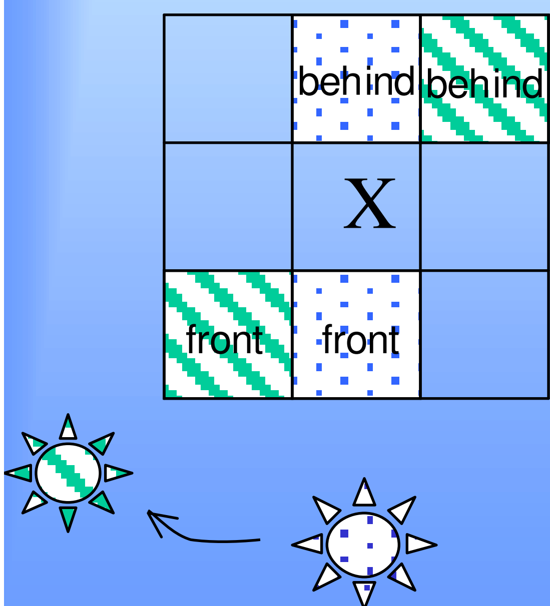
Expected Results

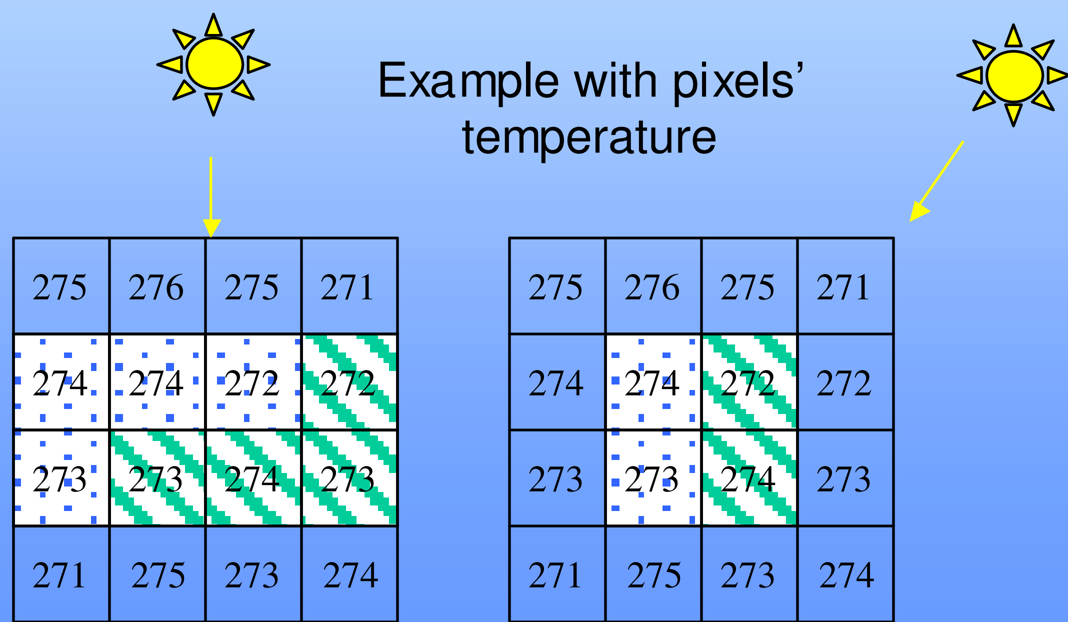
- Error bounds that cloud horizontal variability introduces into retrievals
- Climatic distribution of 3D effects

Illustration of "illuminated" and "shadowy" pixels

(led by Tamas Varnai)

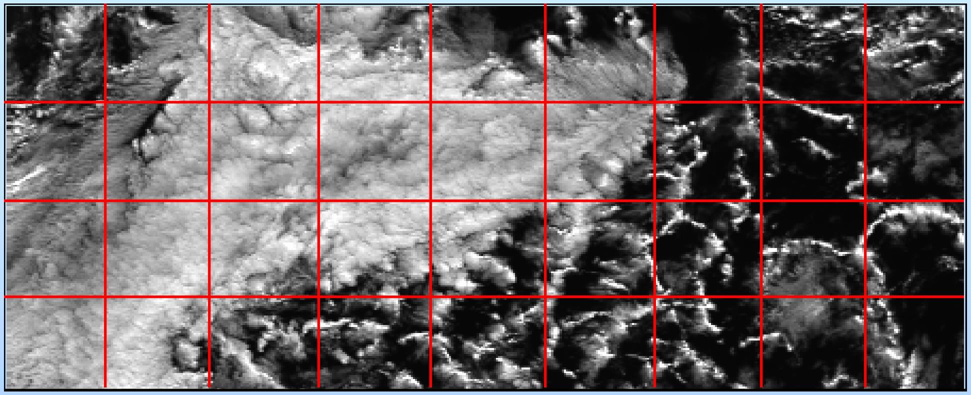




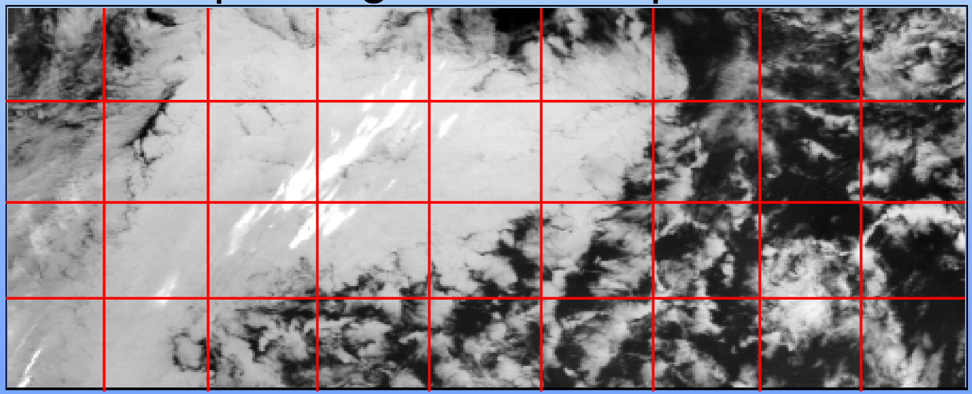


3D Error Assessment: Example

0.86 µm reflectance

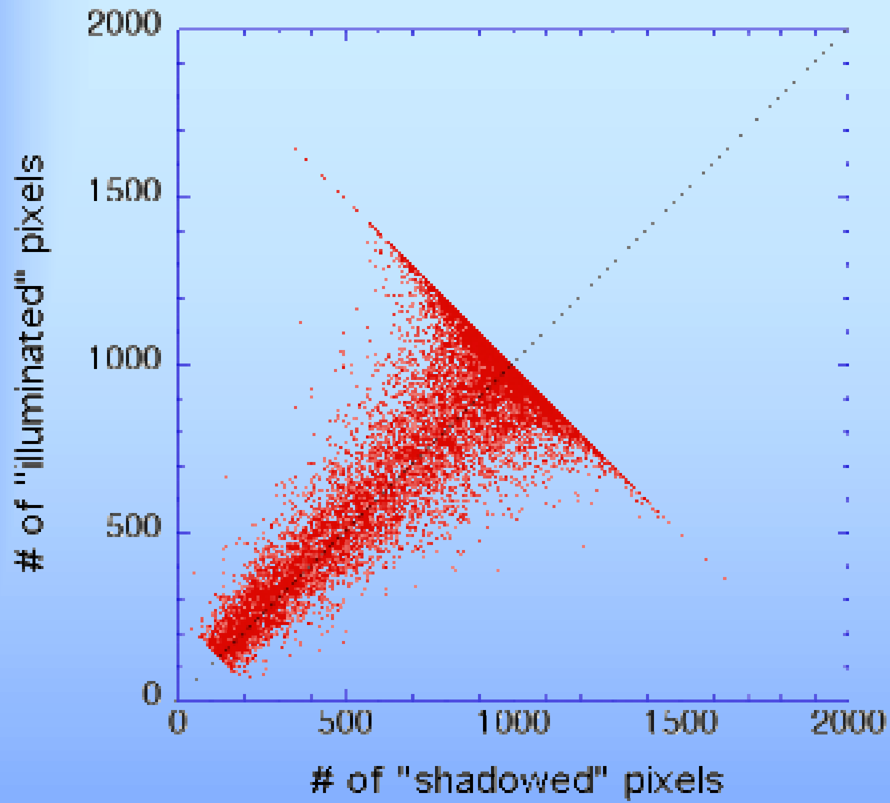


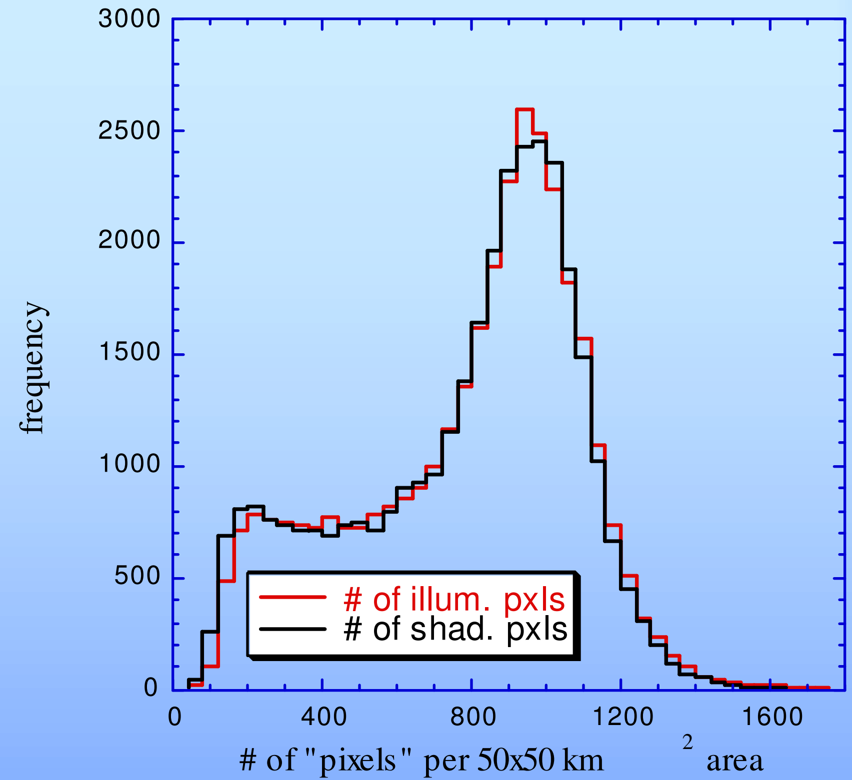
11 µm brightness temperature



An example of 450x200 km^2 area observed by MODIS with VIS and IR channels. The area has been divided into 36 areas of 50x50 km^2 each.

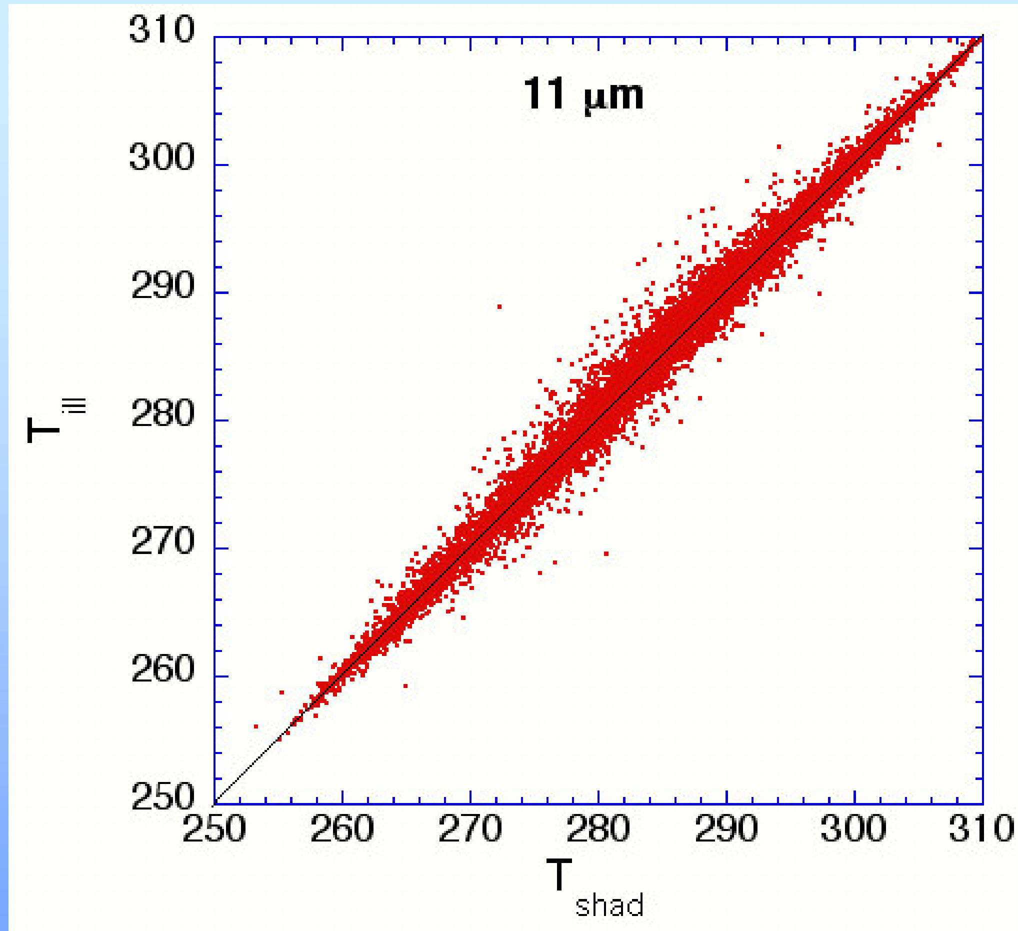
Number of pixels





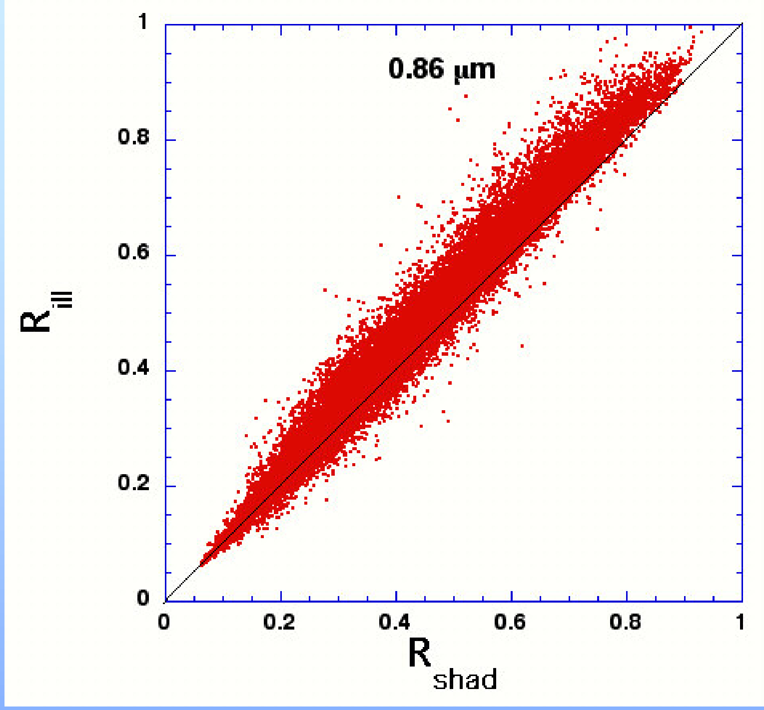
of “illuminated” and “shadowed” pixels (total #: 10^7+) in 50x50 km^2 areas are statistically equal

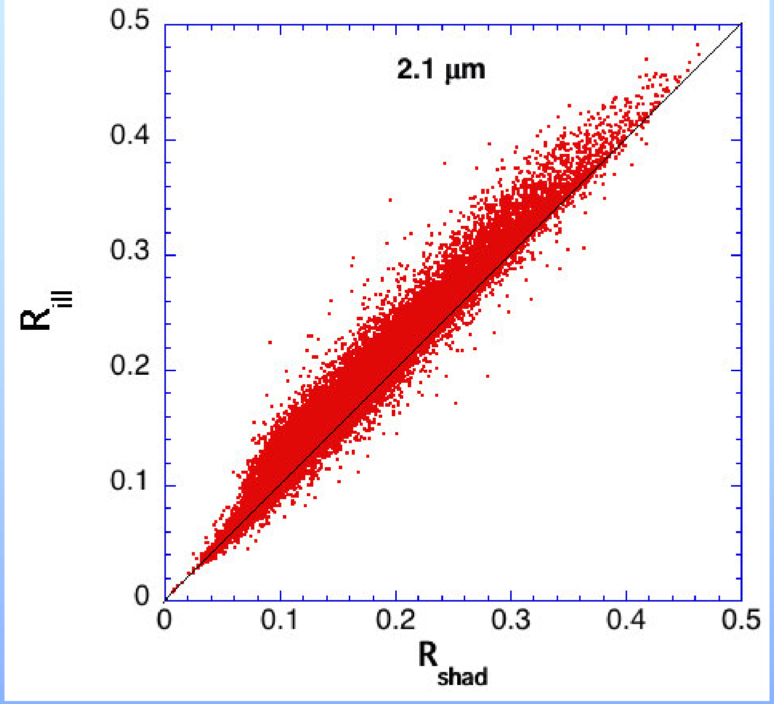
Symmetry at 11 μm



So is IR brightness temperature

Asymmetry at 0.86 and 2.1 μm

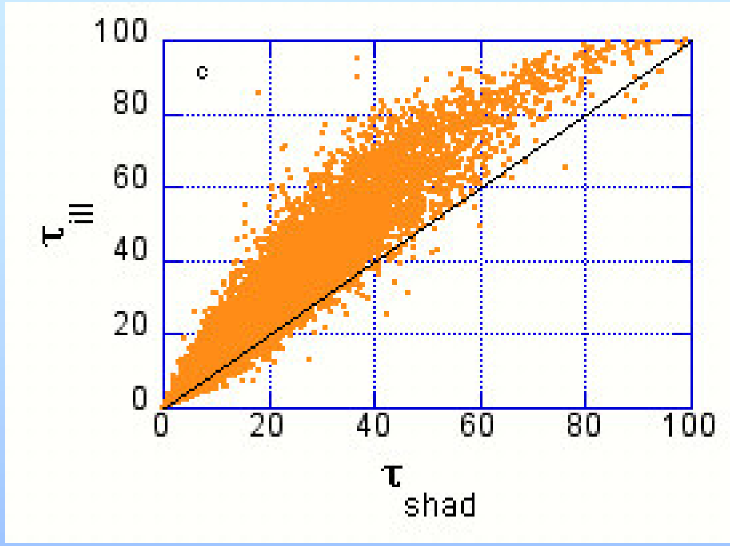


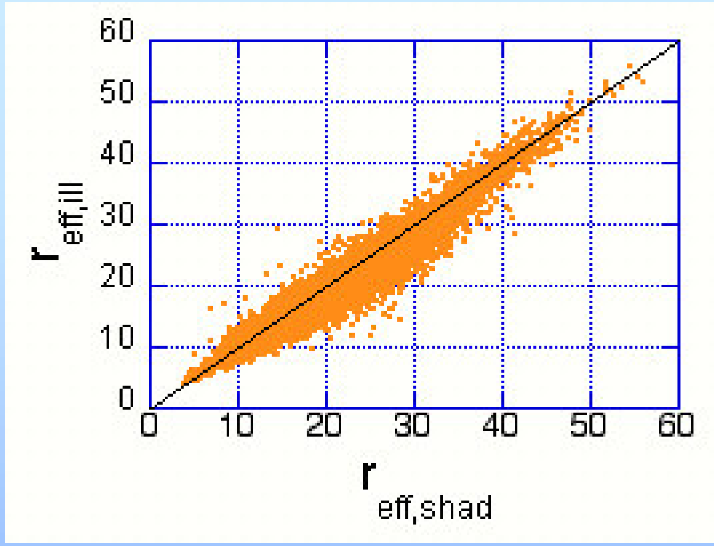


Each dot corresponds to a 50x50 km^2 area. Averaged reflectancies over "illuminated" pixels are plotted vs. "shadowed" ones.

The ill. slopes are much brighter than the shad. ones!

Effects on τ and r_{eff}

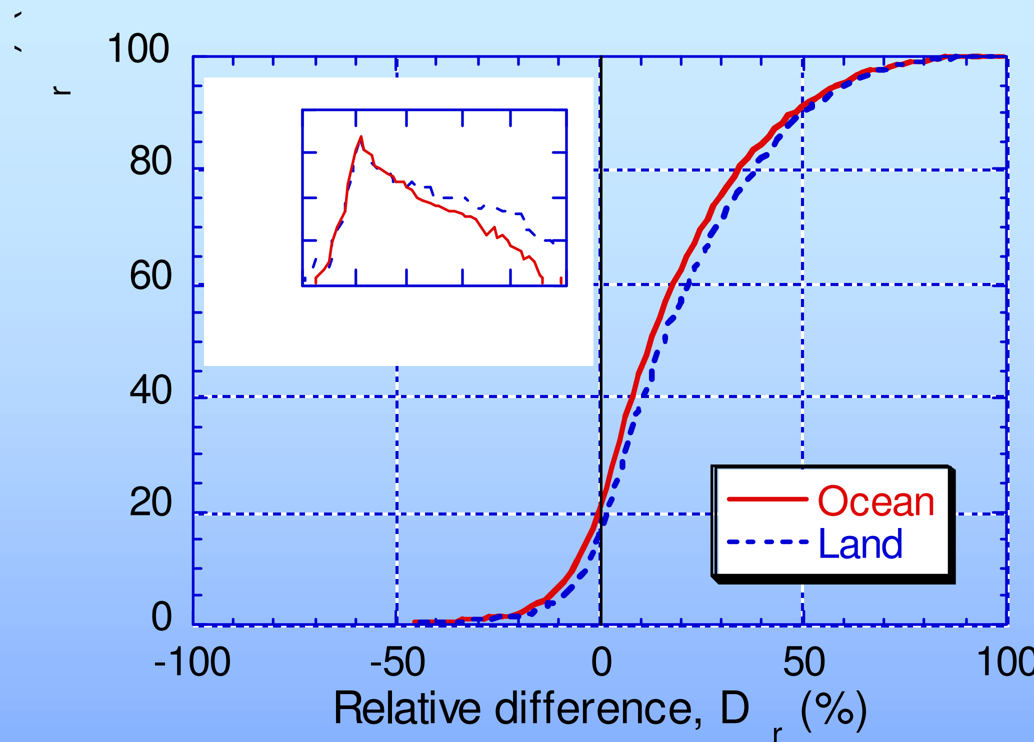




Comparison of mean optical depth, τ, and mean effective radius, r_{eff}, at the illuminated and shadowed portion of 50 by 50 km areas

3D effects may have a strong influence!

Example of climatic distribution of 3D effects

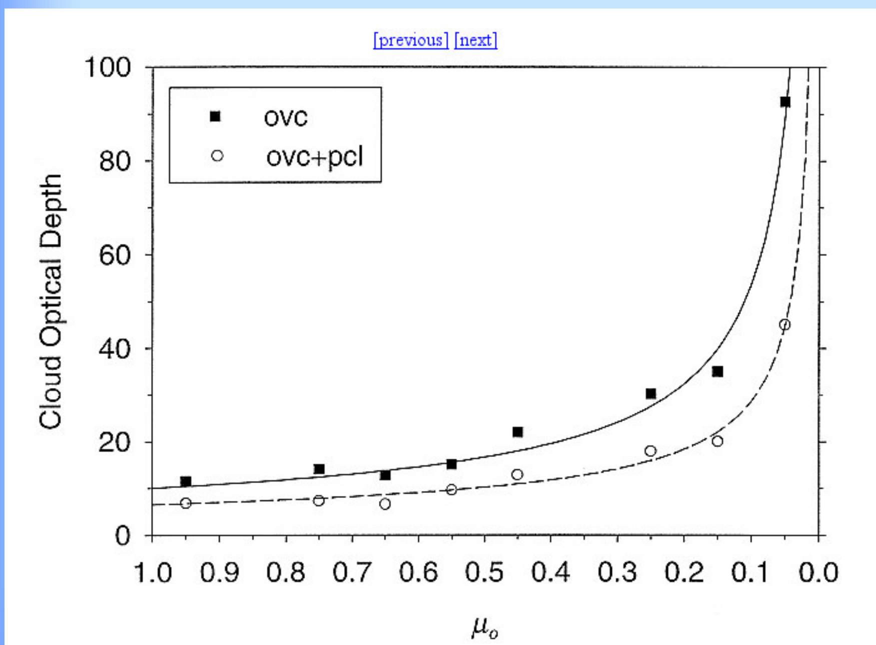


Comparison of the histograms of the cloud asymmetry in optical depth retrieved from clouds over **land** and **ocean**. The inset shows the histograms of the asymmetry vs. differences between average optical depths of illuminated and shadowed pixels, τ_{TS} and τ_{AS}, respectively.

“Forward” vs. “Backward” scattering

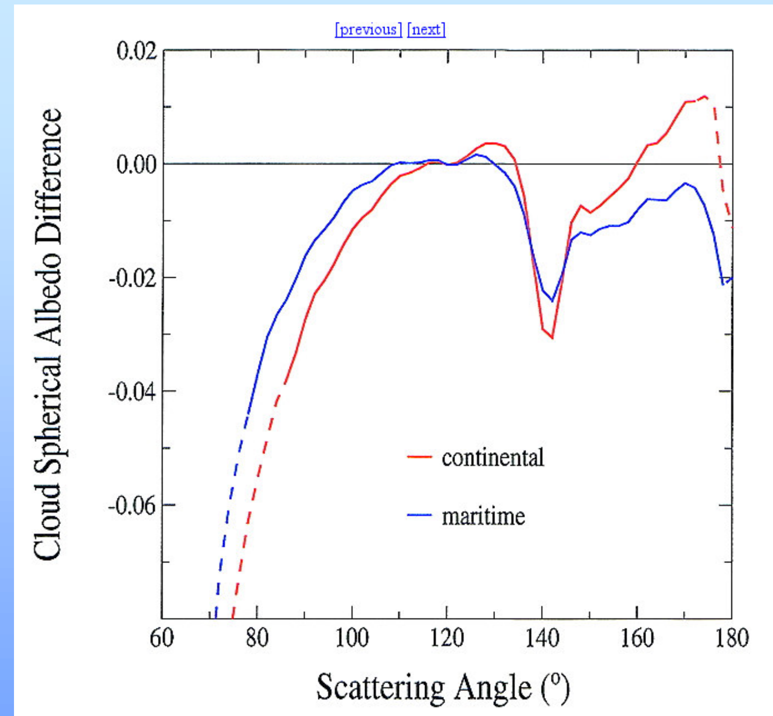
Earlier studies on 3D effect:

For oblique sun, clouds appear too thick & forward reflection is too low



Based on AVHRR data

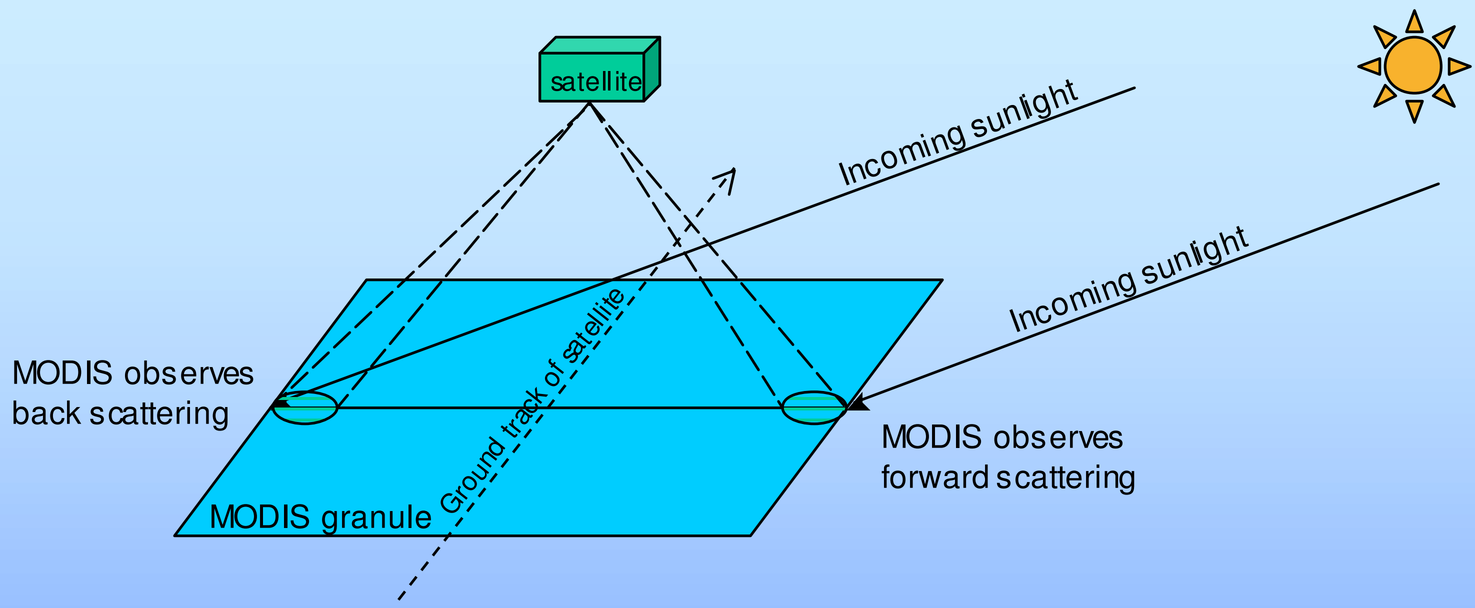
from Loeb and Coakley (1998)



Based on Polder data

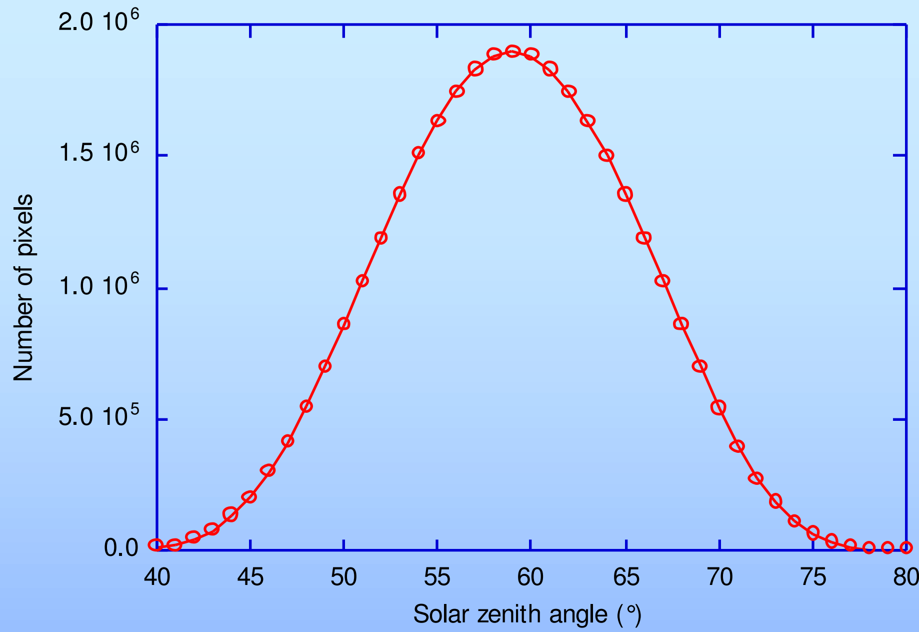
from Buriez et al. (2001)

"Forward" vs. "Backward" scattering MODIS geometry



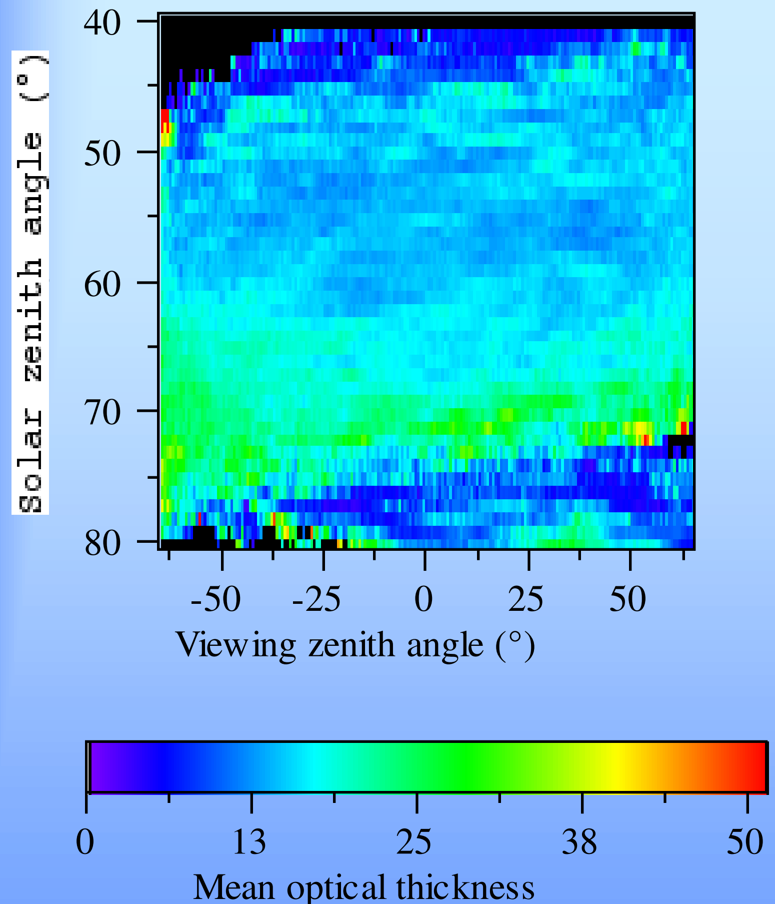
At 40° latitude, clouds are not viewed from the exact forward and backward directions but rather 50° off the plane of solar azimuth

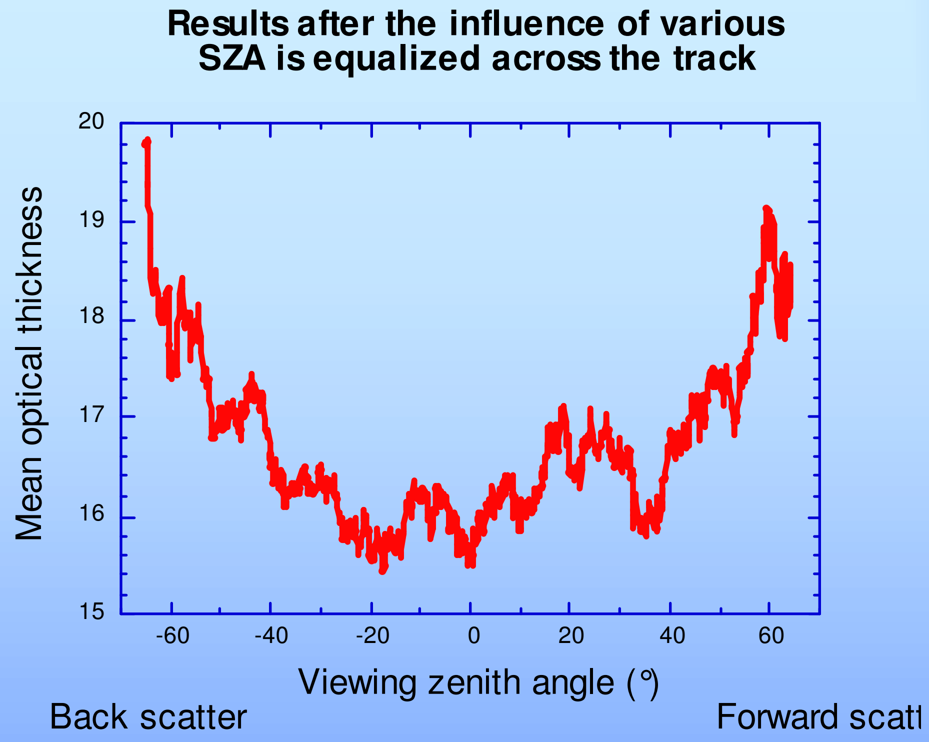
"Forward" vs. "Backward" scattering MODIS data



Nov. 1, 8, 15, 22, 29 in 2000, 2001, 2002, 2003.
10 MODIS granules from **Terra** in 2000 and 2001 and from both **Terra** and **Aqua** in 2002 and 2003. Total: 300 granules. Form a ring around the Earth at roughly 40° North. Liquid clouds only with $\tau > 2$.

“Forward” vs. “Backward” scattering MODIS data

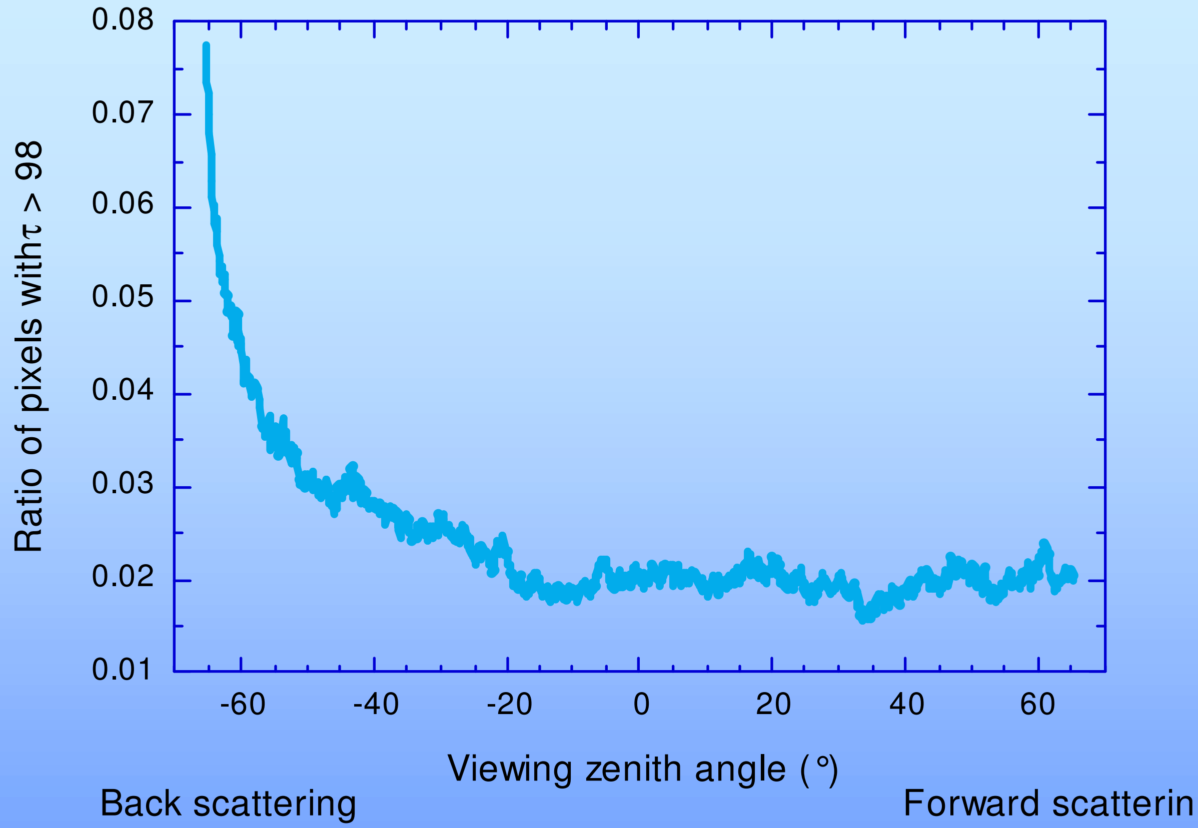




Mean optical depth as a function of SZA and VZA

Mean optical depth (normalized by SZA) as a function of VZA

"Forward" vs. "Backward" scattering MODIS data: saturated pixels



Fraction of "saturated" pixels as a function of VZA

Climatic distribution of 3D effects

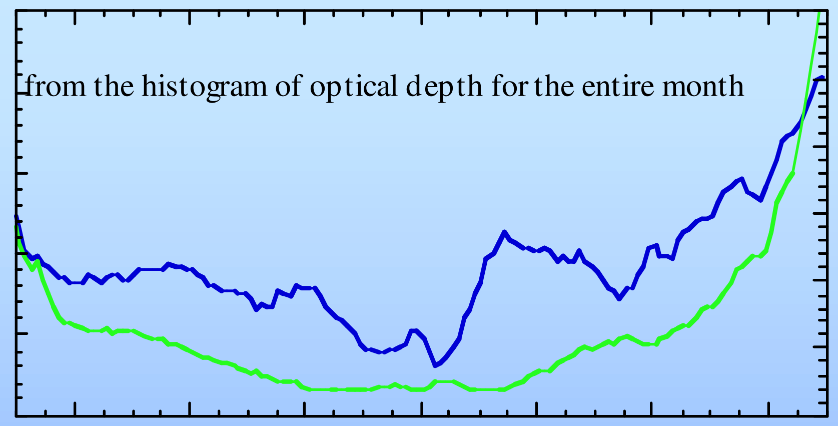
(led by Lazaros Oreopoulos)

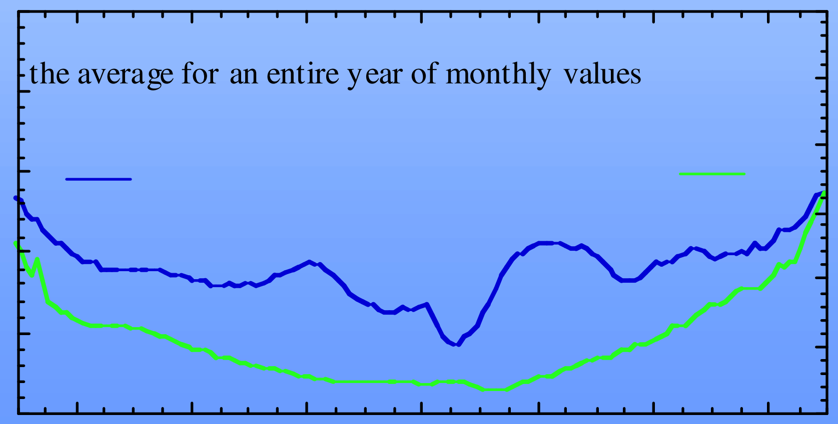
• Latitudinal variation (-70° to 70°) of inhomogeneity parameter χ of Cahalan (1994) and optical depth τ for water clouds from MODIS data.

• Variations of optical depth are possibly exaggerated due to biases in optical depth retrievals under oblique illumination.

• 3D retrievals are needed to remove such biases.

$$\chi = \frac{\exp(\overline{\ln \tau})}{\overline{\tau}}$$





Task II: Conclusion

• Statistical asymmetry is a direct signature of cloud 3D structure that cannot be taken into account in 1D retrievals:

- Estimate the errors that horizontal cloud variability introduces into retrievals of cloud properties;

- Study the climatology of 3D effects by analyzing how cloud 3D structure varies with geographical region, season and climatic conditions.

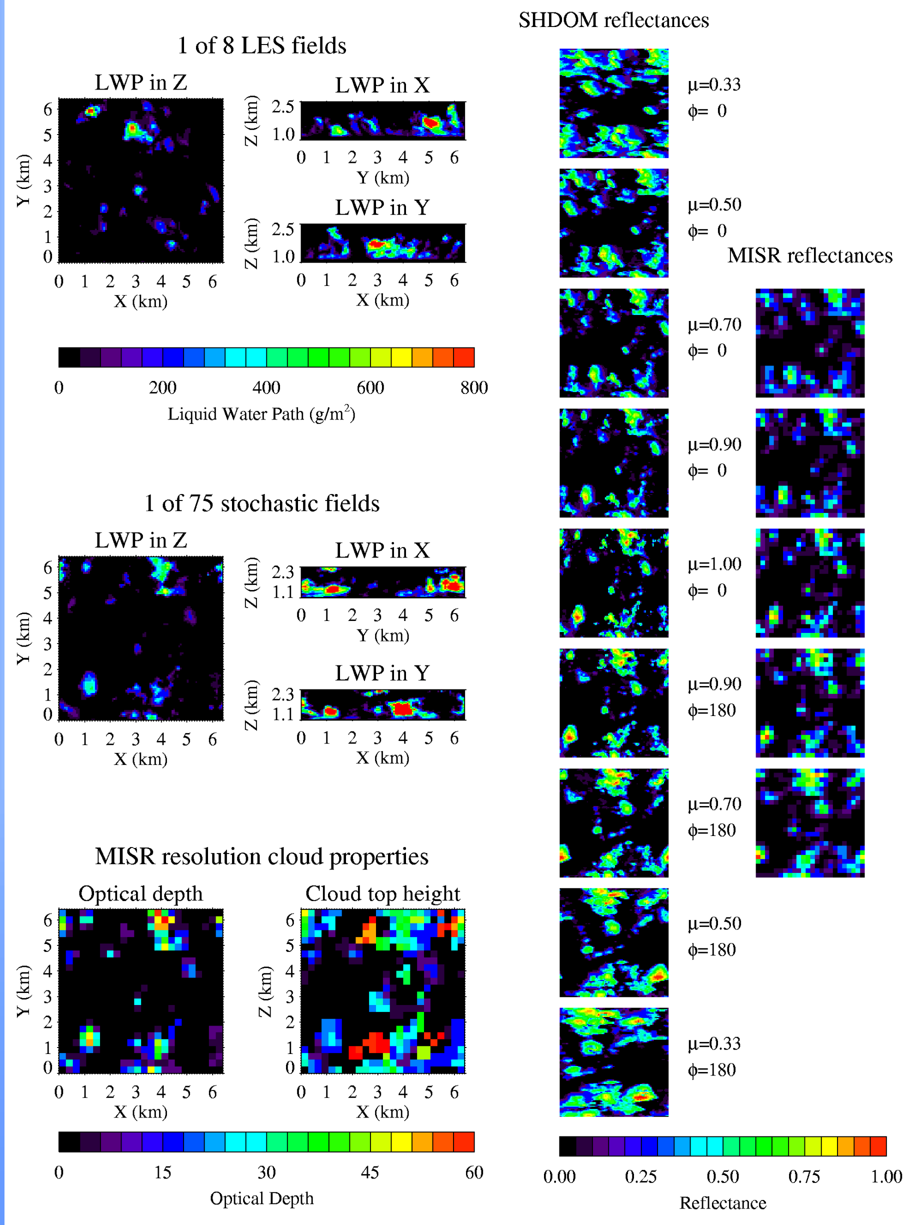
Task III: 3D Cloud Retrievals from MISR

(led by Frank Evans)

Expected results

- 3D algorithm for cloud optical depth and top height retrievals
- Importance of textural and angular parameters for optical depth and height
- Estimates of improvements

3D Cloud Retrievals from MISR



3D cloud retrieval algorithm

The liquid water path (LWP) from LES cloud fields is shown in the **upper left**.

The **middle left** has the LWP fields for one of the stochastic fields generated with statistics of the 8 LES fields.

The stochastic field with a grid spacing of 67 m is averaged 4x4 columns to obtain the MISR nadir resolution optical depth and cloud top height shown in the **lower left**.

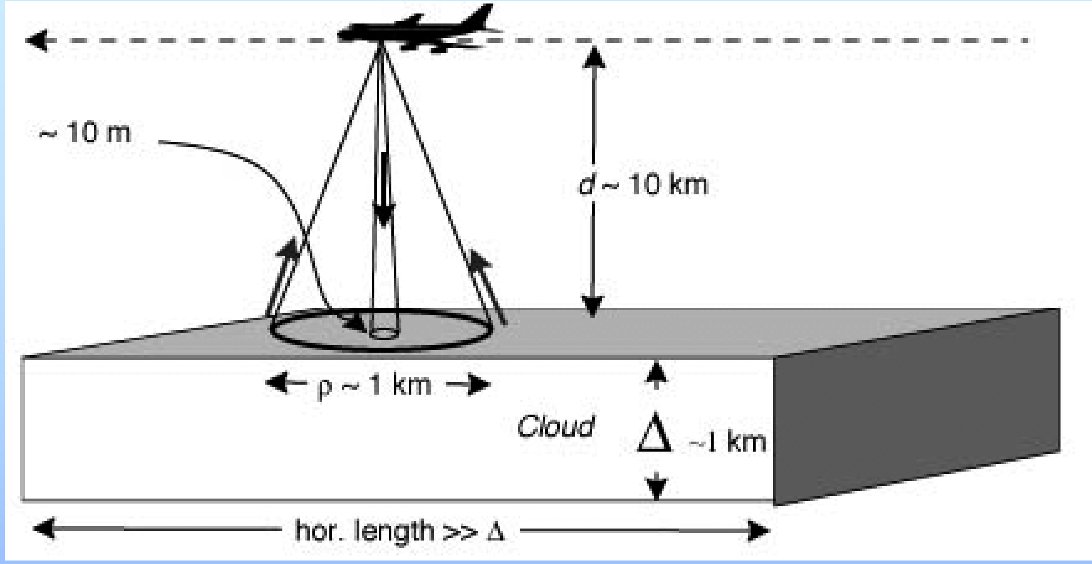
Reflectances at the nine MISR angles are computed with the SHDOM 3D radiative transfer code.

The reflectances at MISR resolution for the five angles used in the retrieval simulation are shown in the **right column**.

Marshak

Task IV: THOR Lidar Retrievals

(led by Bob Cahalan and Tamas Varnai)

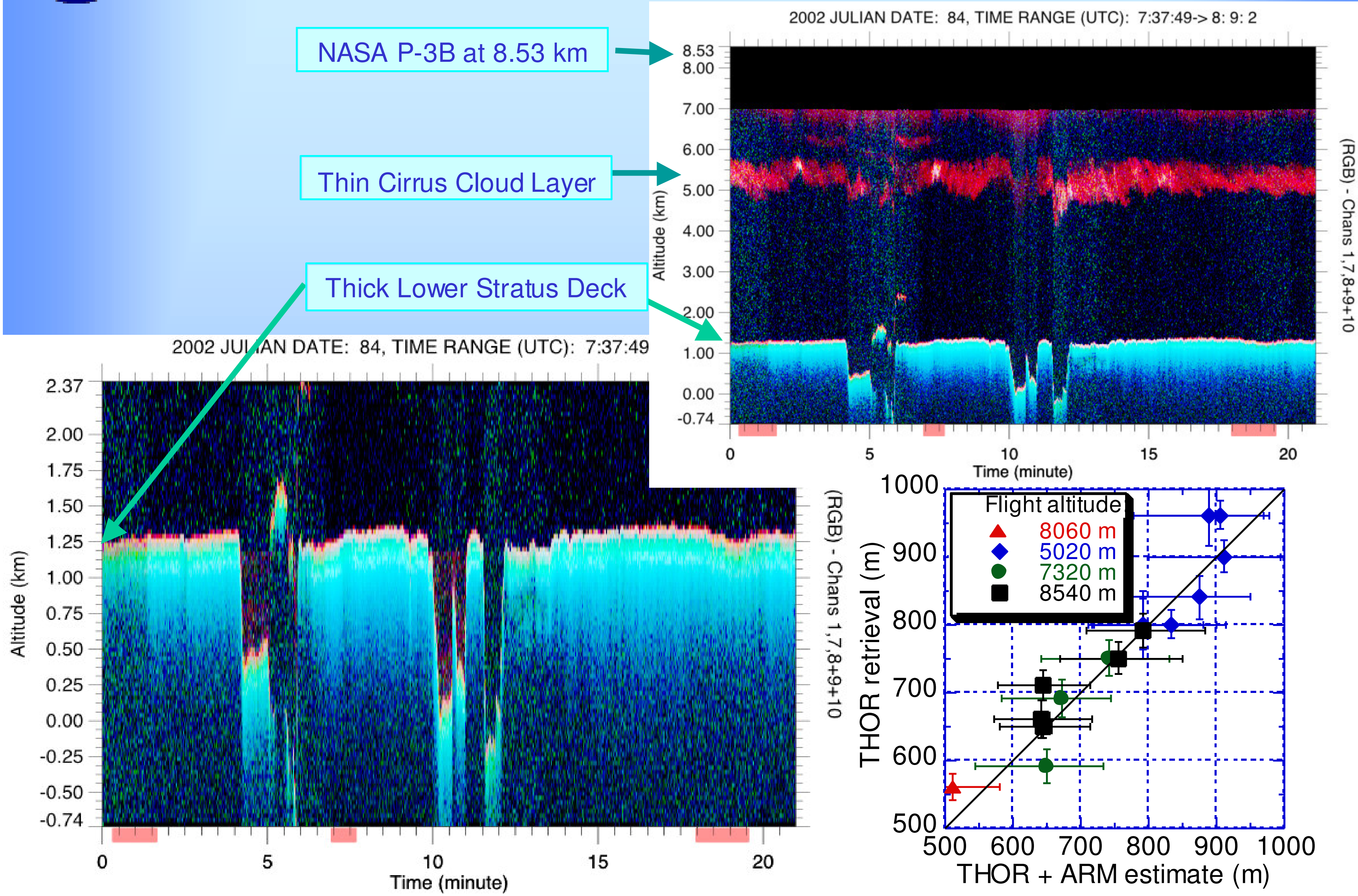


•**Objectives -** ***Measure geometrical thickness of optically thick clouds***

•**Accomplishments -** ***Measured cloud geometric thicknesses: 500–1000 m ± 30 m, τ > 25***

•**Exp. results** ***- algorithms for cloud geometrical thickness and extinction retrievals***

THOR Color Composite (R,G,B) = (1,7,8)



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