Observations of 3D Radiative Effects in MODIS Cloud Optical Thickness Retrievals

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Outline

Introduction
Importance of 3D effects

Pre-MODIS study of 3D effects
LANDSAT, AVHRR, POLDER

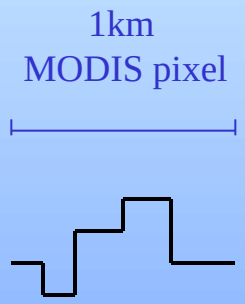
Theoretical simulations of MODIS images
Uncertainties based on stochastic models

MODIS observations and products
Statistical asymmetry
Effect of view angles
Effect of sub-pixel variability
Wavenumber spectra

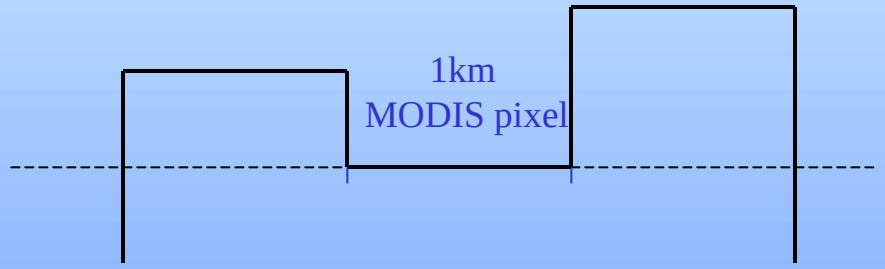
Conclusions

What are 3D Radiative Effects?

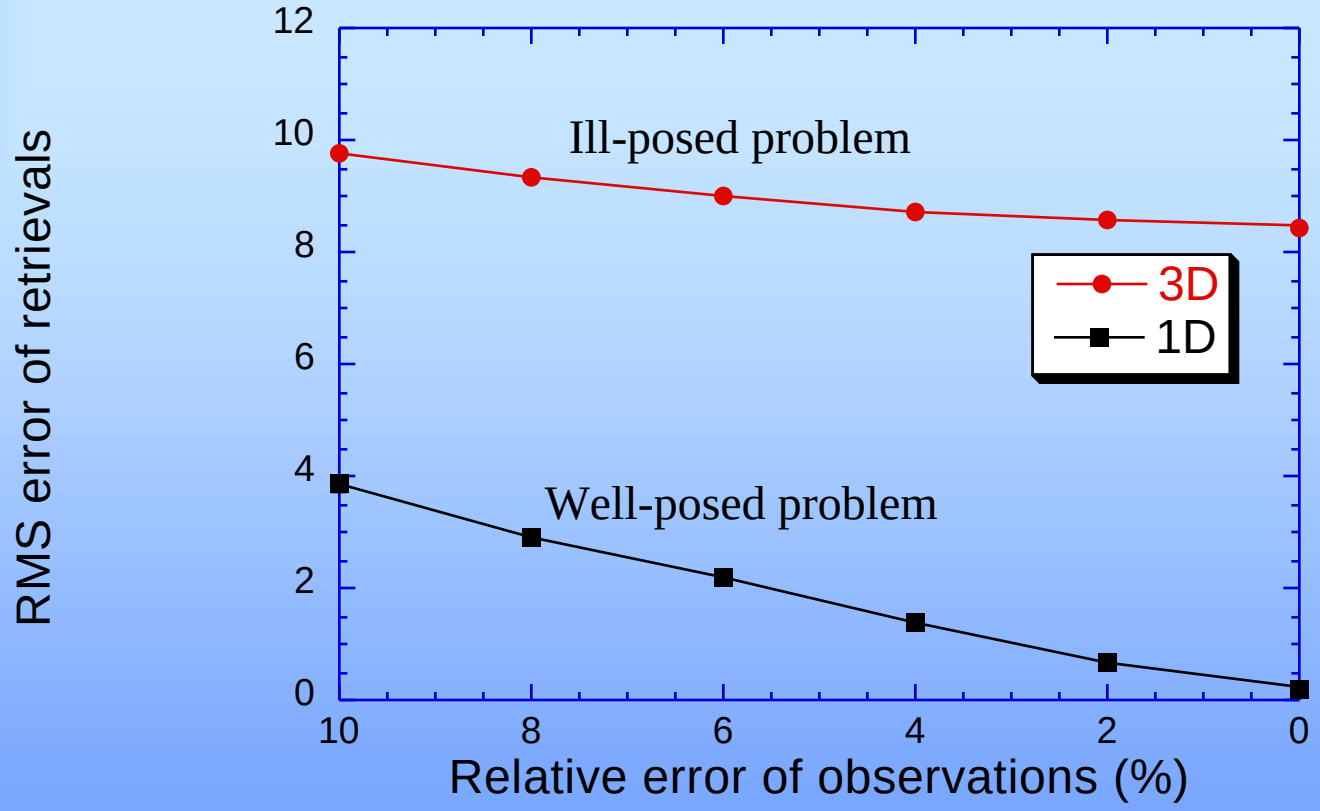
Sub-pixel variability



Effects of neighboring pixels (e.g., shadowing)



Importance of understanding 3D effects

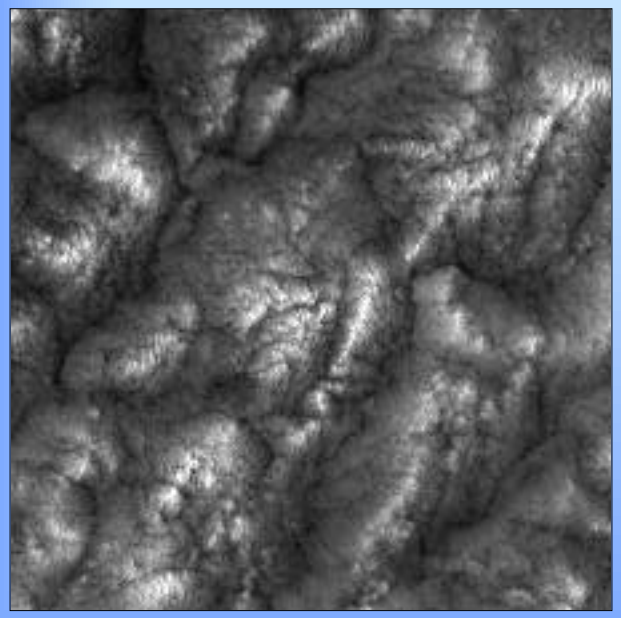


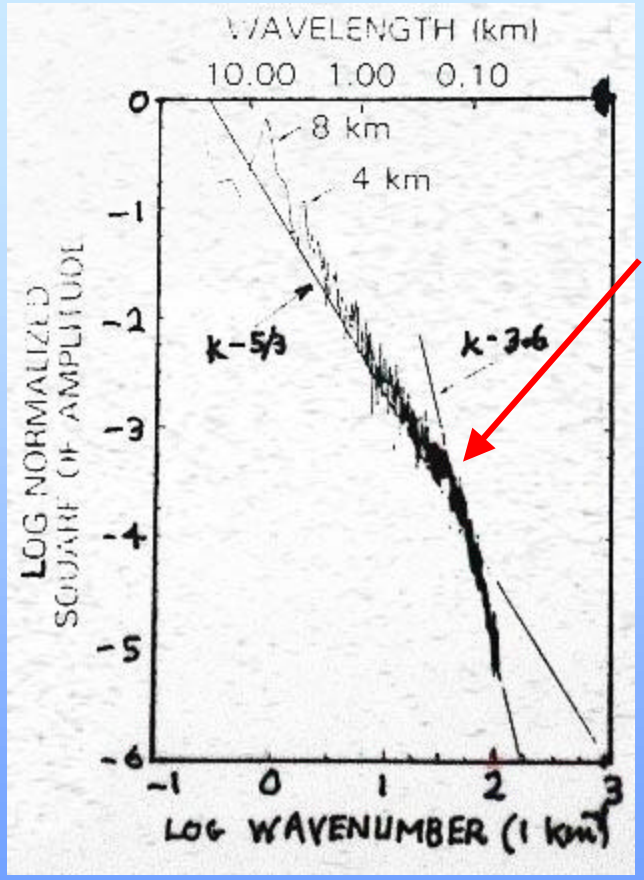
Based on a sample set of RT calculations carried out at 250-m resolution for SZA=60^{o}

Some earlier (pre-MODIS) studies

at high resolution, diffusion smoothes images

60 km by 60 km Landsat scene





Smoothing scale= (mfp*cloud thickness)$^{1/2}$

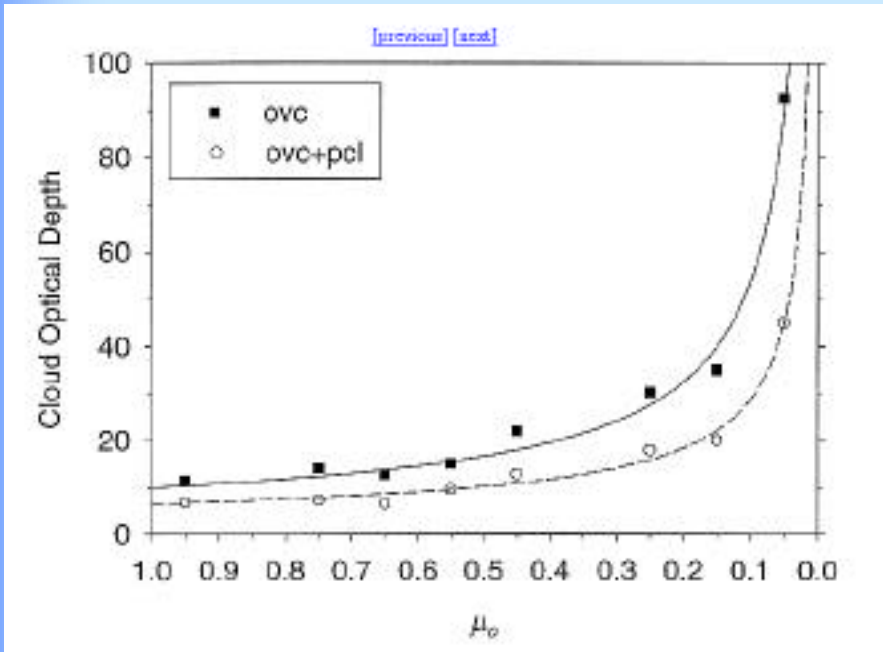
from Marshak et al. (1995) and Davis et al. (1997)

from Cahalan and Snider (1989)

Earlier studies

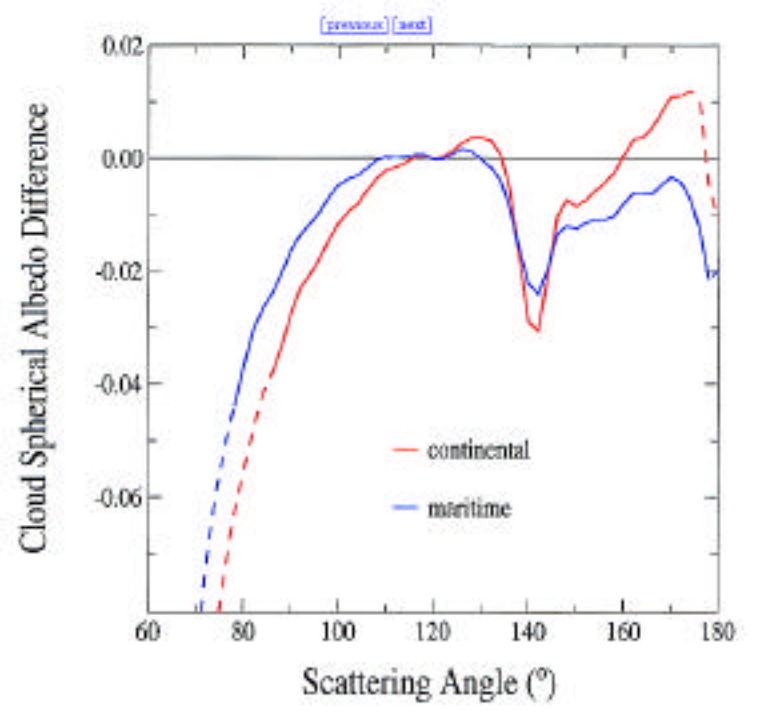
For oblique sun,

clouds appear too thick & forward reflection is too low



Based on AVHRR data

from Loeb and Coakley (1998)



Based on Polder data

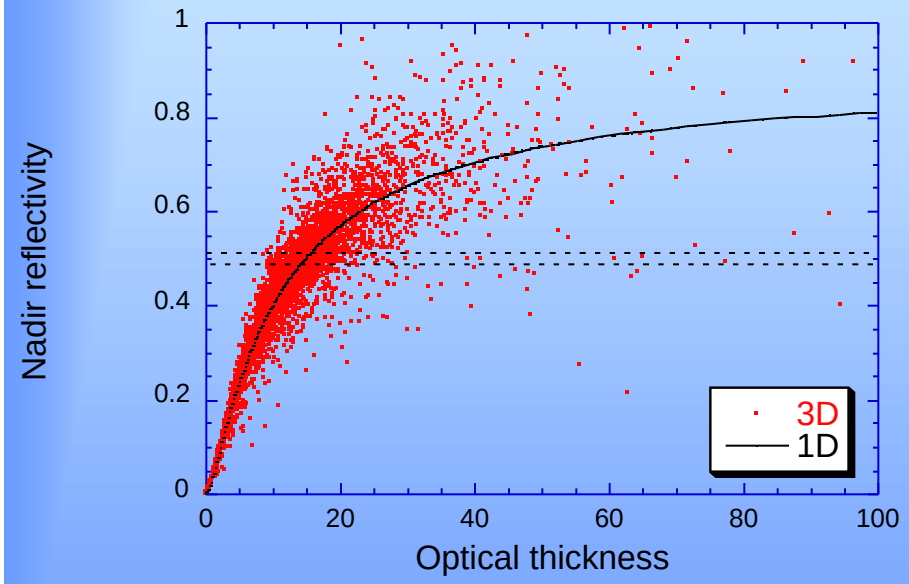
from Buriez et al. (2001)

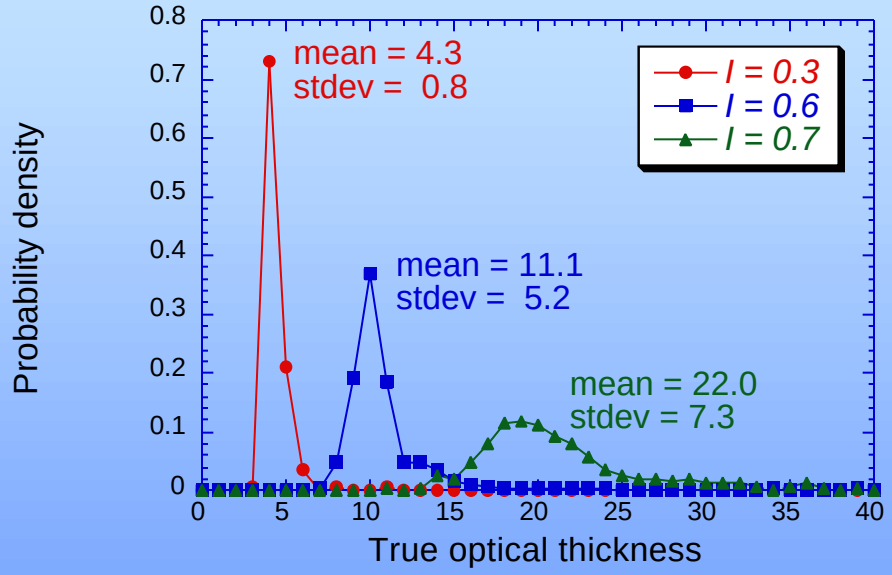
How are 3D effects studied?

- Theoretical simulations of horizontally inhomogeneous clouds and application of 3D radiative transfer;
- Statistical analysis of satellite data and products;
- Combination of theoretical simulations with a statistical analysis of satellite data.

Theoretical simulations

Test datasets are realizations of “realistic” stochastic cloud models

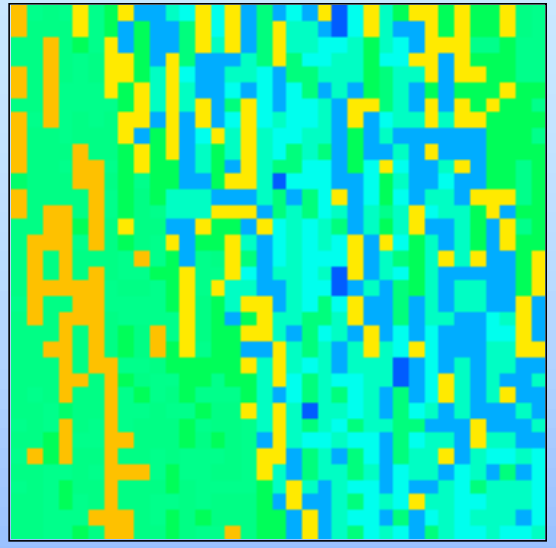


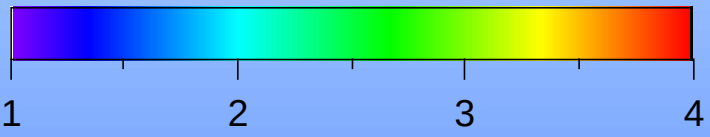


$$\tau_{\text{mean}}(I) = E(\tau \mid \text{reflectivity} = I)$$

Theoretical simulations (cont.)

MAS 35x35 km^2 field of marine Sc measured at 50-m resolution





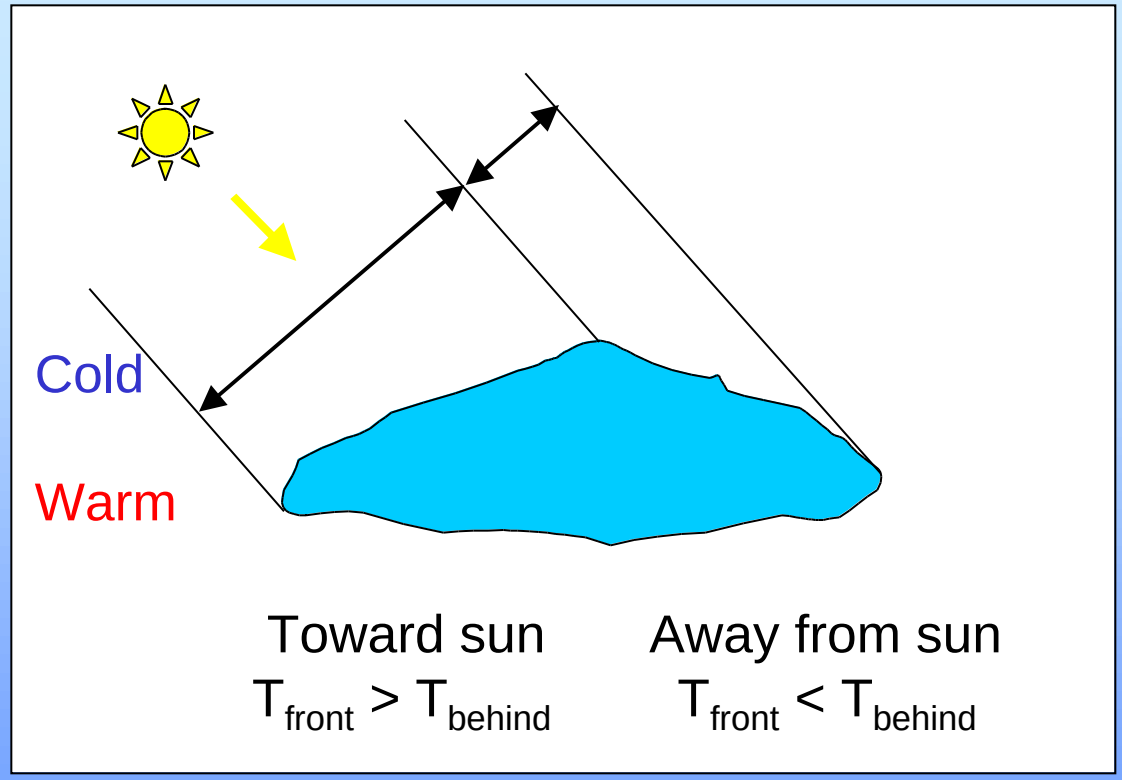
Estimated error bounds for optical thickness retrieved at 1-km resolution

MODIS data

Examine MODIS data: how frequently 3D effects influence the measured radiances and the retrieved cloud properties:

- Optical thickness
- Particle effective radius
- Cloud water path

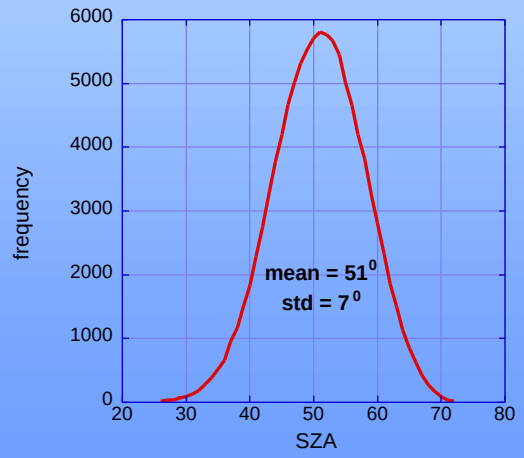
Statistical asymmetry in clouds



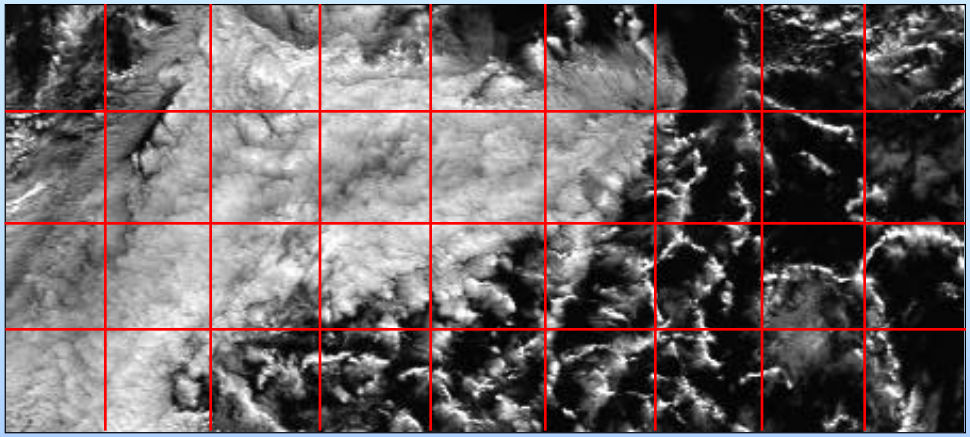
"illuminated" "shadowed"

Procedure for MODIS images

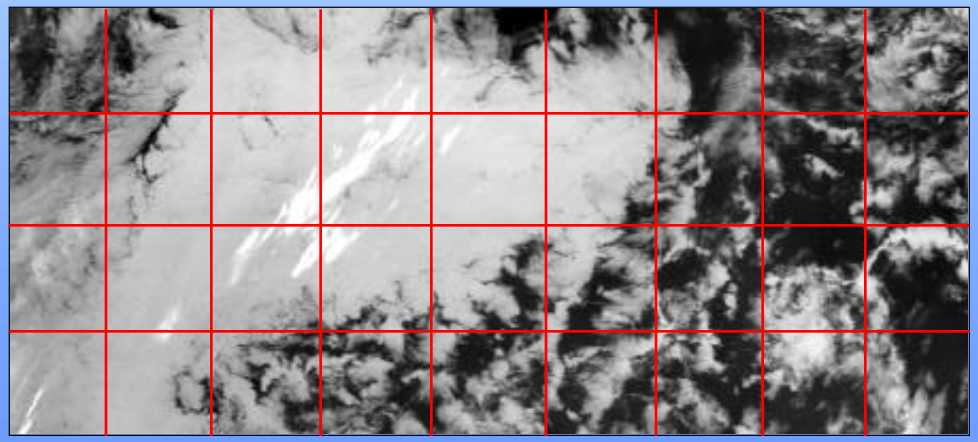
March & Sept. 2001
NH & SH, Latitude ≈ 45°
120 images (10^7+ pixels)
2000 km x 450 km
Solar zenith angle ≈ 40°-60°
1 km radiance, cloud products
All clouds (e.g., ice & liquid)



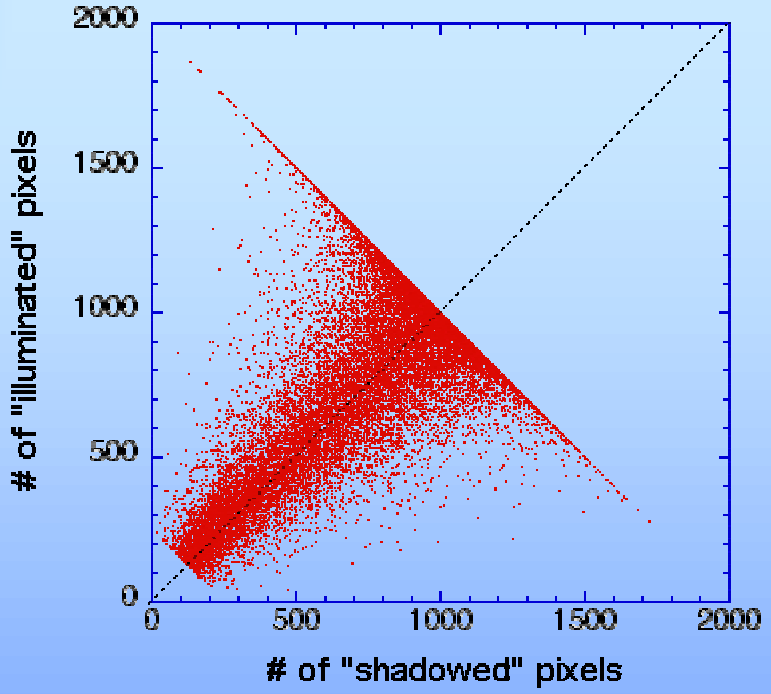
0.86 μm reflectance

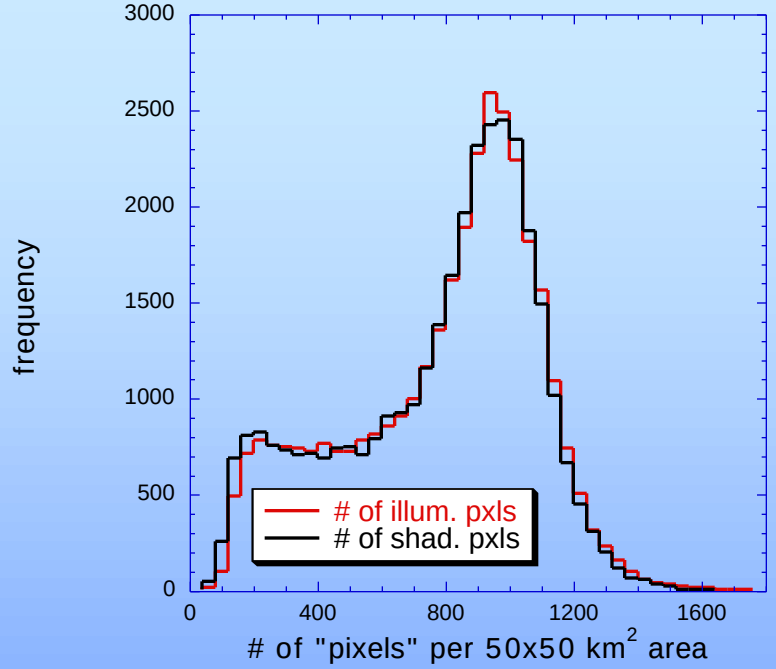


11 μm brightness temperature



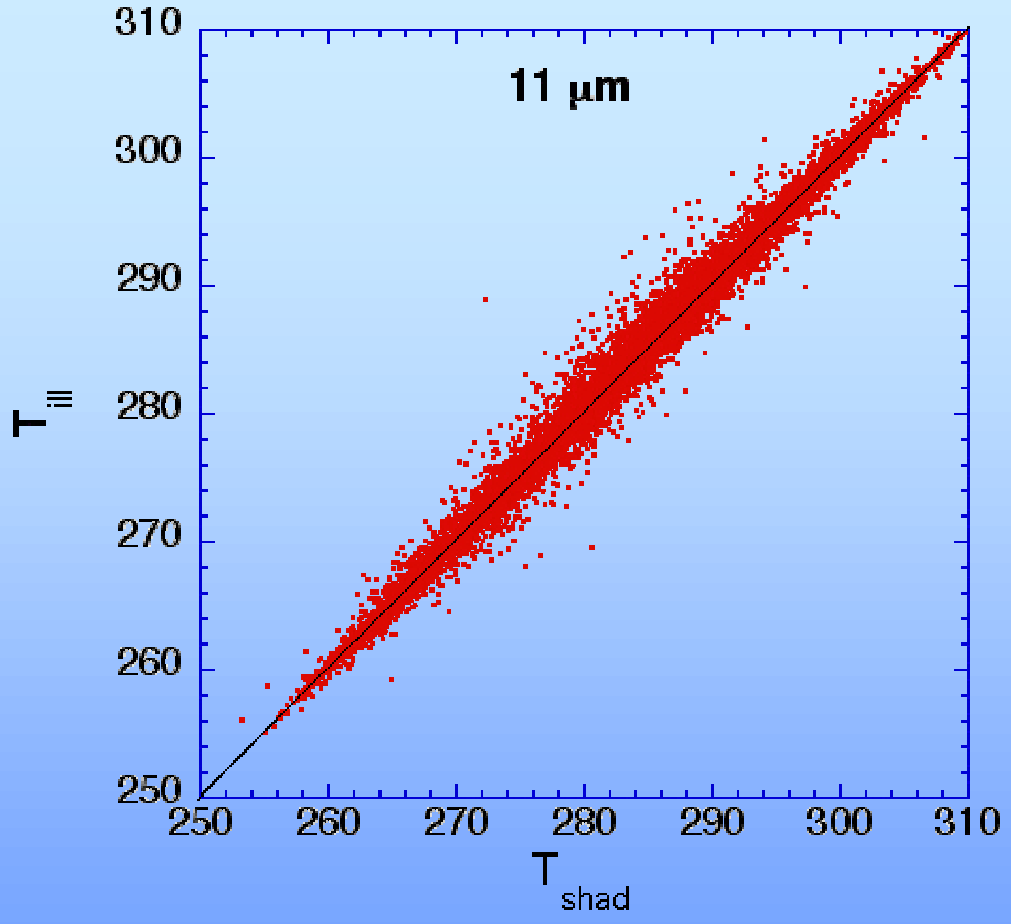
Number of pixels





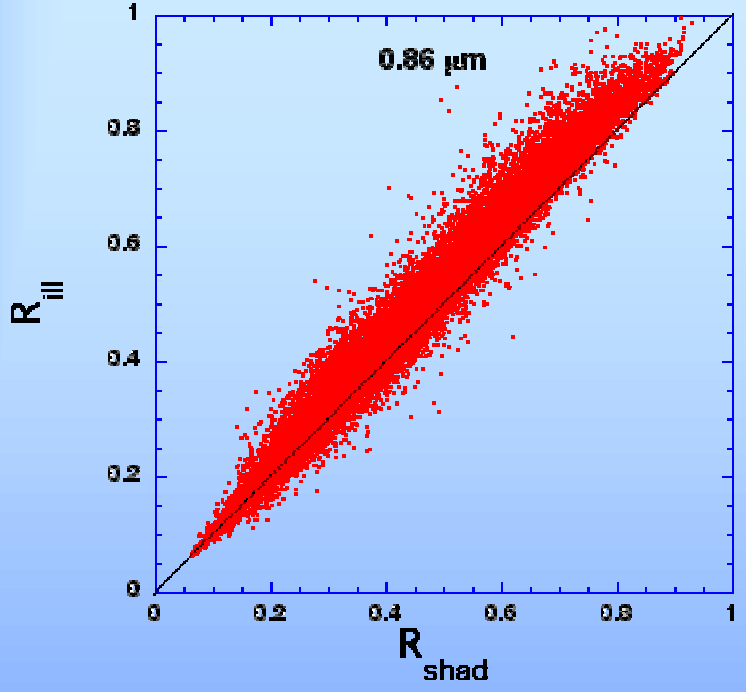
of “illuminated” and “shadowed” pixels in 50x50 km^2 areas are statistically equal

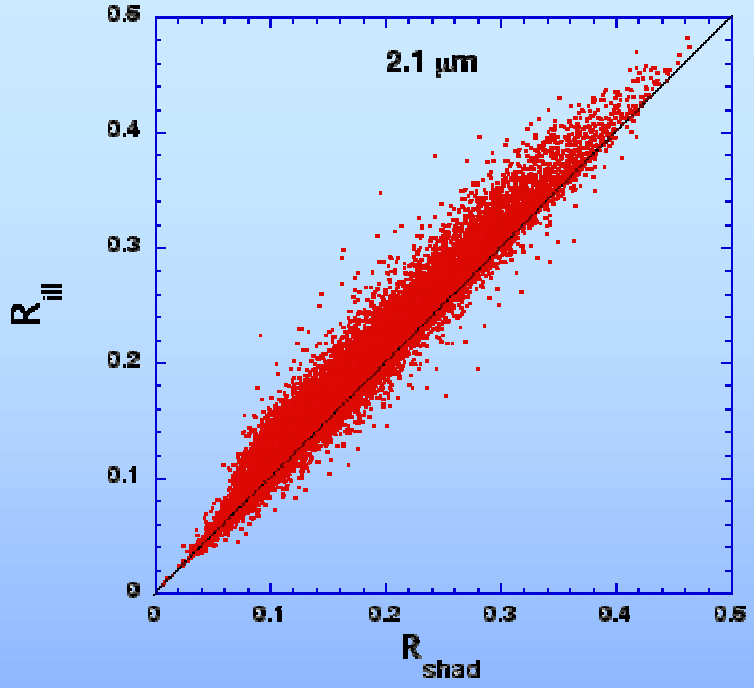
Symmetry at 11 μm



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!