Remote sensing of clouds and calibration using Fujifilm Finepix S1 digital camera

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1 Introduction

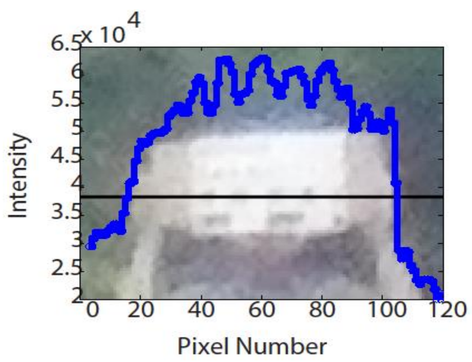
- Clouds exert important radiative effects on climate.
- Clouds are commonly characterized by cloud fraction in measurements and models.
- We undertook high resolution photography from the surface to examine cloud structure at high resolution.

2 Camera Specs

Fujifilm Finepix S1 digital camera specifications		
Focal length = 215 mm , f# = 5.6, Effective aperture diameter = 38.4 mm, 35 mm Equivalent focal length = 1200 mm		
Output: 3456 x 4608 pixels; 16 bit of red green and blue		
	λ = 450 nm	λ = 532 nm	λ = 650 nm
Rayleigh criterion, μrad (mm @ 1 km)	29	34	41
Pixel FOV, μrad (mm @1 km)	6.3		

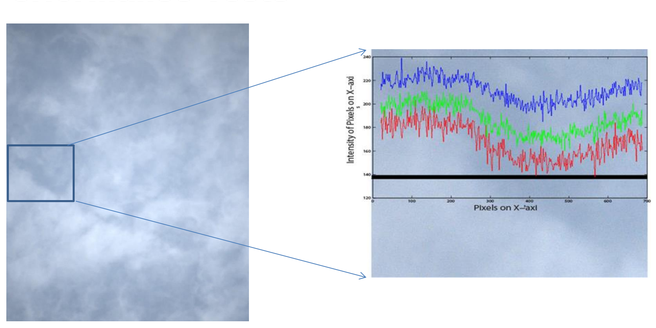
Resolution Tests

Set up of camera for the resolution test.



Target at 1 km, line profile of red channel intensity over the 4 cm bars of target at 1 km.

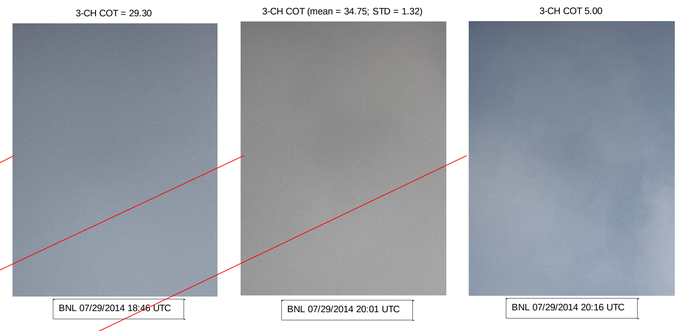
Performance Tests

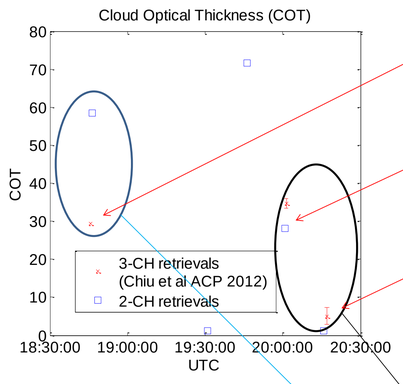


- Field of view of each image is 22 x 29 mrad. (22 x 29 m at cloud height of 1 km)
- Can resolve cloud images at small scale with each pixel (29-41 μrad from table)!
- Shown with line profile of red, green and blue channels of an enlarged sample cloud image taken with the Fujifilm digital camera.

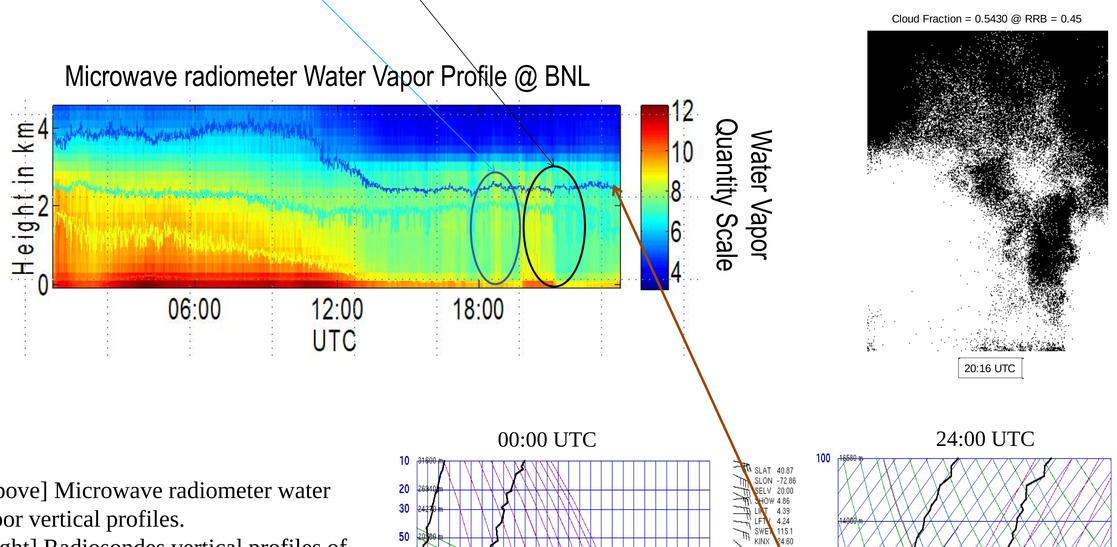
3 Example of Cloud Analysis

True Color Cloud Images



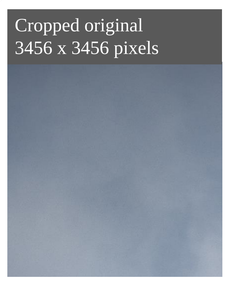


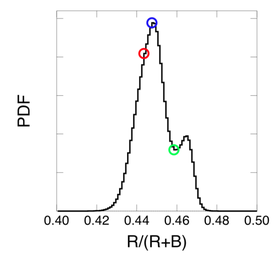
[Left] Cimel sky photometry cloud-mode 3 channel and NASA's 2 channel Cloud Optical Thickness retrievals on 07/29/2014 at Brookhaven National Laboratory (BNL), Upton, Long Island, NY. [Lat: 40° 49' 20" N Lon: 72° 52' 24" W]
[Above] Cloud images at times of COT data.
[Below] Sample cloud mask and fraction at 20:16 UTC.
(Local Standard Time = UTC – 5 hours)

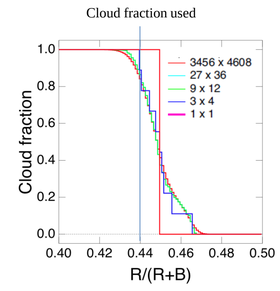


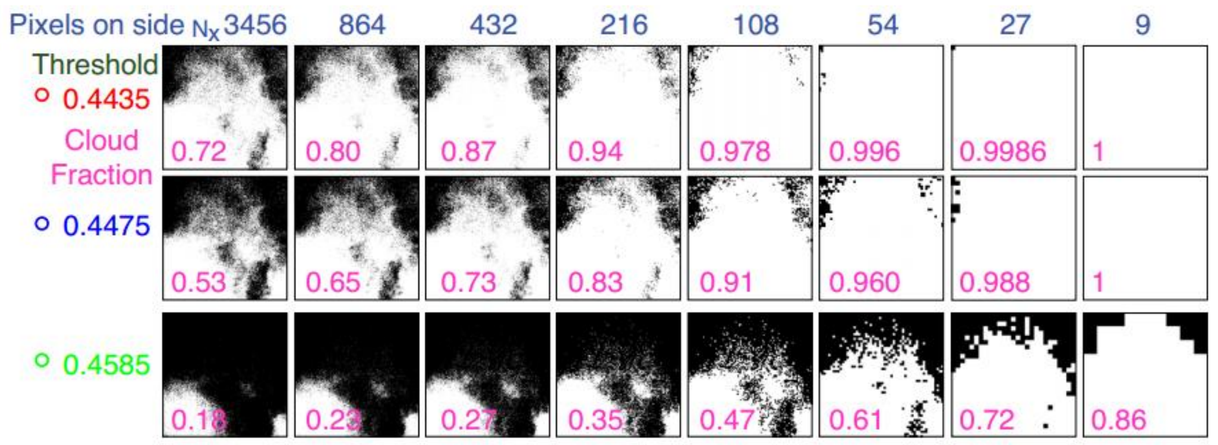
- [Above] Microwave radiometer water vapor vertical profiles.
- [Right] Radiosondes vertical profiles of temperature and dew point temperature; launched at 00 UTC and 24 UTC.
- High water vapor concentration from Microwave radiometer shows clouds at ~2 km from ~13 -24 UTC and is inconsistent around 20 UTC.
- Close temperature and dew point temperature of radiosonde confirms cloud formation at ~2 km.

4 Cloud Fraction









- Cloud fractions of the same image are highly arbitrary and depend on the Red/(Red+Blue), RRB, threshold.
- Cloud fraction of Δ54% with Δ0.015 threshold.
- As resolution decreases, cloud fraction tends to increase if the threshold is below the mean, and vice versa.

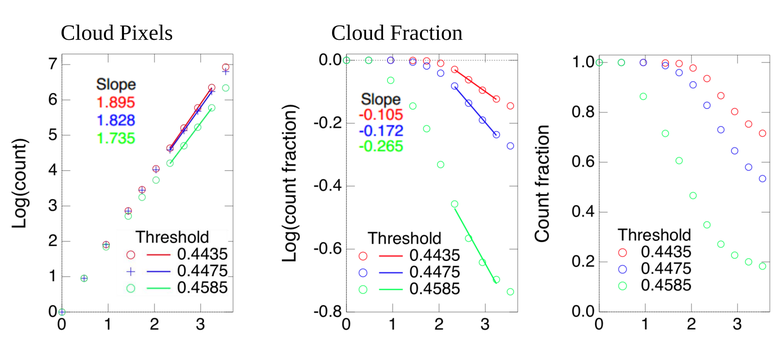
5 Fractal Analysis

Goal:
- Measure fractal dimensions to associate with clouds and its cloud fraction.

Fractal dimension:

$$\frac{d \log(\#\text{ of exceeding threshold element})}{d \log(\#\text{ of boxes on the side})}$$

- Pixel with **any** cloud is considered cloud.

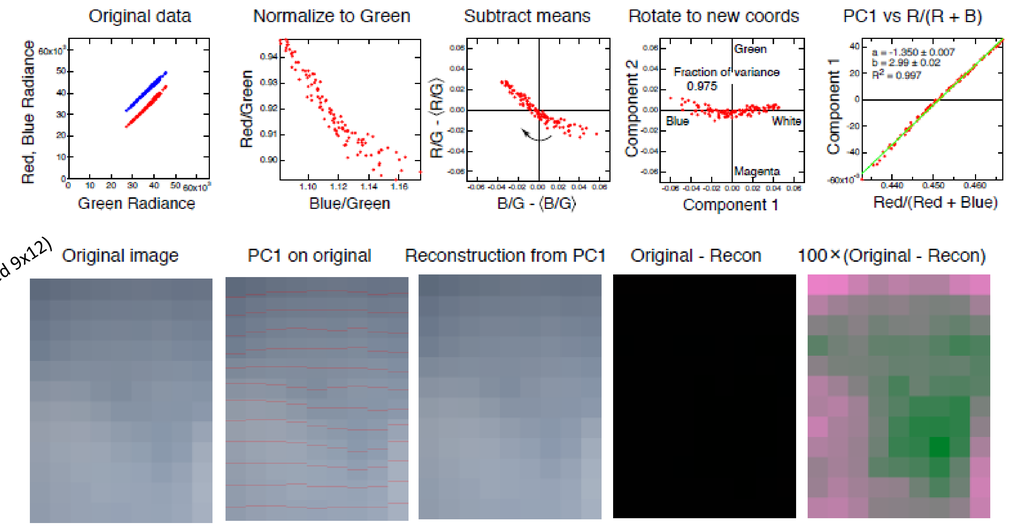


Results:
- Slopes in log(count) versus log(dimensions) being near 2 shows fitting of the data. The slope of log(cloud fraction) versus log(dimensions) shows that the data is distinctly different.
- Cloud fractal dimension still varies on the threshold; fractal dimensions almost double with Δ0.0040 threshold.
- This shows that cloud fraction cannot be uniquely defined or measured.

Method	Threshold	Slope	Uncertainty
Box counting	0.4435	1.895	0.003
	0.4475	1.828	0.005
	0.4585	1.735	0.029
Fractional area	0.4435	-0.105	0.003
	0.4475	-0.172	0.005
	0.4585	-0.265	0.029

- Conventional box-counting method versus fractional method.
- Uncertainties are same for either method.
- Both methods are equivalent.

6 Principal Component Analysis



- The color of the degraded 9x12 original image is accurately reconstructed by a single component.
- The first principal component is linearly related to Red/(Red + Blue), which thus serves as a quantitative measure of cloud contribution to zenith radiance.

7 Conclusions

- Surface-based high resolution photography provides a new and interesting view of clouds.
- Cloud fraction cannot be uniquely defined or measured: Inherently depends on threshold and resolution.
- As resolution decreases, cloud fraction tends to increase if the threshold is below the mean, and vice versa.
- These findings raise concerns over ability to characterize clouds by cloud fraction or fractal dimensions.
- Principal component analysis may lead to a robust means of quantifying cloud contribution to radiance.

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