Cirrus Clouds Over the Amazon

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Objectives

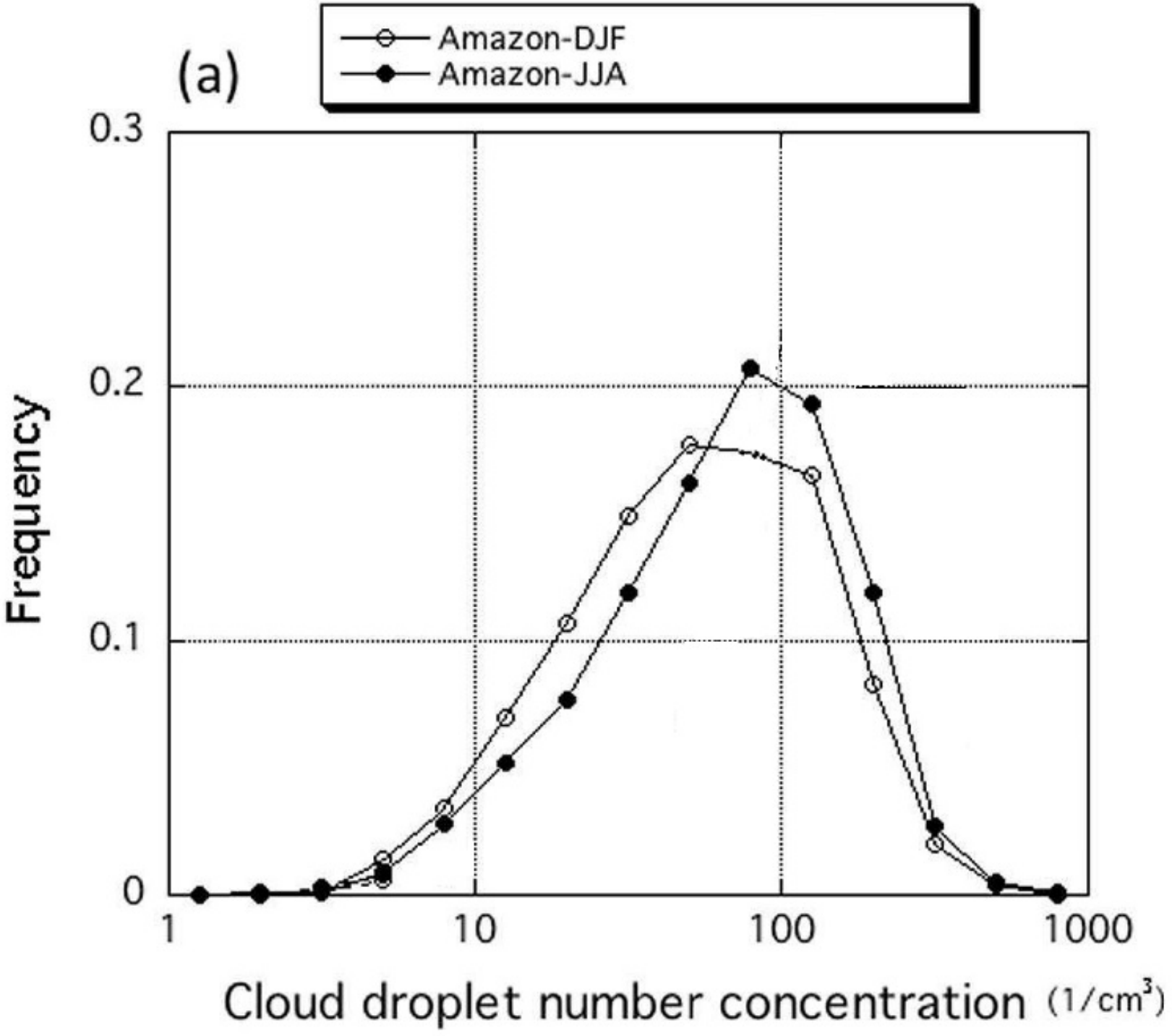
- Identify microphysical properties and frequency of occurrence of cirrus clouds in and around the Amazon
- Analyze satellite data
- Parameterize numerical models used to estimate radiative transfer and cirrus cloud forcing and influence on climate.
- Discuss cirrus clouds and global climate sensitivity

Cirrus Clouds

- Cirrus generally appears white or light gray in color. It forms when water vapor undergoes deposition.
- Altitudes above 5,000 m.
- Formed mainly by non spheric ice crystals, lifetime can go from hours to a few days.
- Despite being relatively transparent to incoming solar radiation, they are opaque to outgoing infrared radiation, and thus may have a **positive radiative forcing.**
- The global cirrus cover is 20-25%, 70% over the tropics.

Microphysical Properties
Cloud Droplet Concentration

- Derived from the CloudSat satellite data, 2006-2010
  - Cloud Profiling Radar (CPR)
- Active vs Passive- 94 GHz
- Provides vertical cloud structure information on different sized particles
- Used to analyze:
  - Cloud to precipitation transitional process
  - Relationships among cloud droplets, drizzle, and rain
  - ~1500 km of 7 S and 60 W over Amazon

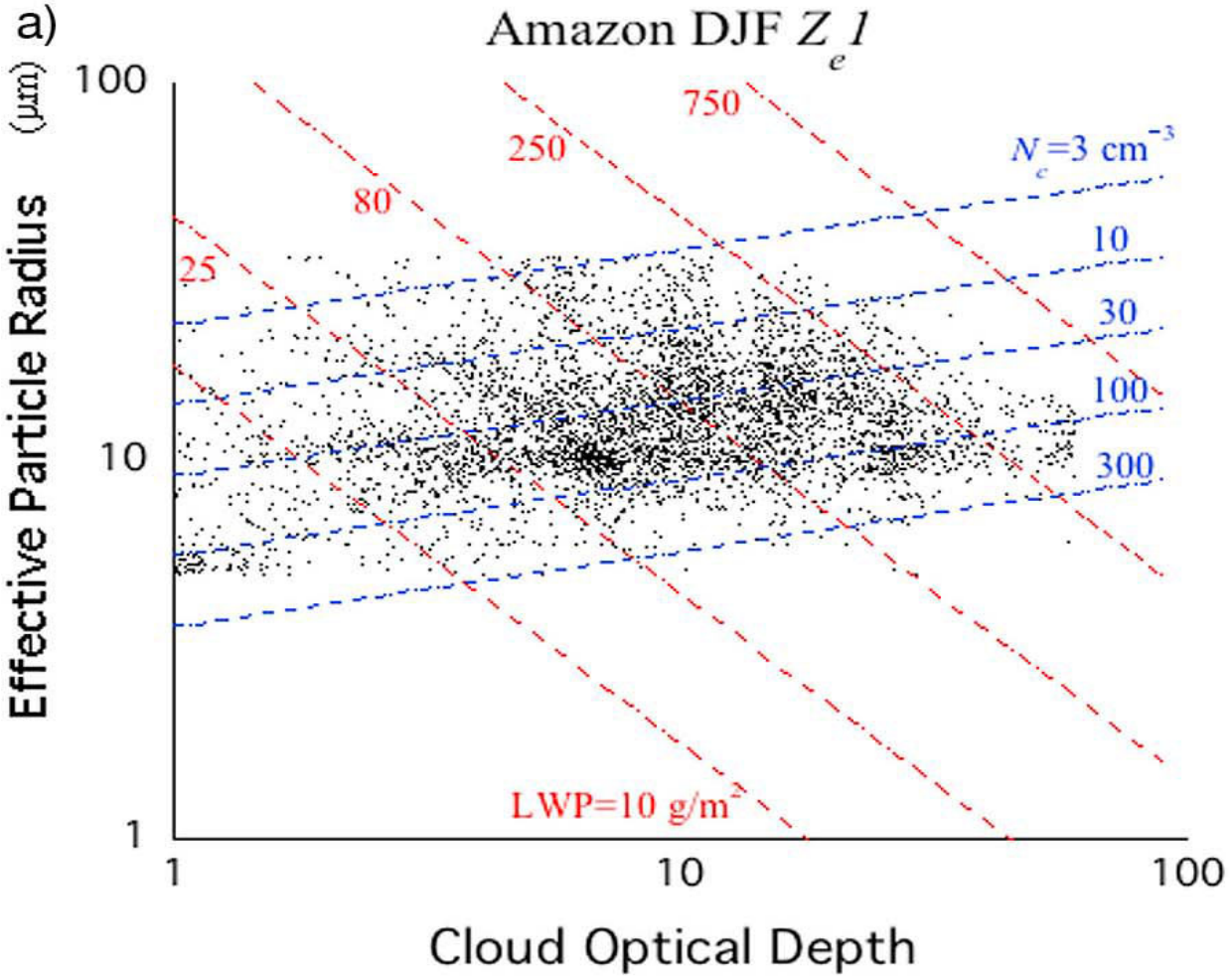


Frequency distribution for cloud droplet number concentration over the Amazon
(Modified from KAWAMOTO, 2012)

- Mode ~80cm^-3
- Comparing seasons, JJA higher than DJF

Microphysical Properties

Optical Depth



$$N_C = \sqrt{2} B^3 \Gamma_{eff}{}^{1/2} LWP^{1/2} r_e{}^{-3}$$

Microphysical Properties
Optical Depth

$$\tau_c = \int_{z_b}^{z_t} \alpha_{par}(z')dz'$$

- Z is the height of cloud bottom and top
- α is the extinction coefficient
- Optical Depth accuracy dependent on:
  - Accuracy of molecular backscattering and extinction coefficients
  - Correct determination of Zb and Zt

Microphysical Properties
Summary

	τ_c	r_e (μm)	N_c (cm^{-3})	LWP (g/m^2)
Amazon Z_e1	11.8 (15.4)	13.7 (14.7)	88.6 (119.2)	89.7 (117.1)
Amazon Z_e2	18.3 (21.5)	16.0 (17.1)	85.5 (124.2)	152.1 (173.1)
Amazon Z_e3	15.7 (19.1)	15.8 (16.8)	75.4 (108.6)	135.3 (162.9)
Amazon Z_e4	14.3 (16.4)	17.3 (18.3)	56.9 (76.9)	143.3 (175.0)

- Average τ smallest for Z1, Largest for Z2, then decreases
- LWP similar with larger deviations
- Inverse correlation between effective radius and concentration
- Smaller the concentration, the bigger the radius

For Amazon Z1 data:

$$N = 88.6\ cm^{-3}$$

$$r_e = 13.7\ \mu m$$

$$W_l = 89.7\ g.m^{-2}$$

$$\sigma_{ext} = \int_0^{\infty} n(r)\pi r^2 Q_{ext} dr$$

$$\sigma_{ext} = 0.1044\ \mu^{-1}$$

$$\tau_{ext} = \frac{3W_l}{2\rho_l \overline{r_e}}$$

$$\tau_{ext} = \frac{3*89700}{2*1000*13.7}$$

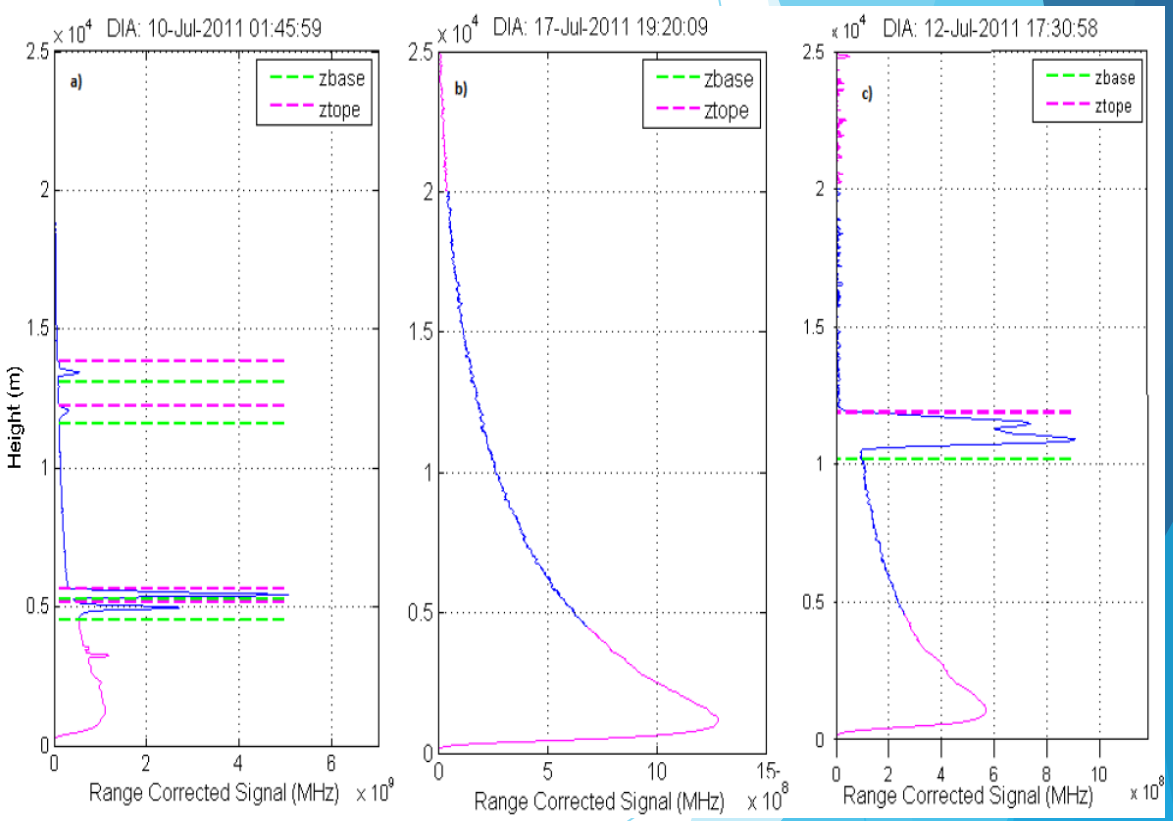
$$\tau_{ext} = 9.82$$

Ground based Lidar

- Lidar-Raman system was used to detect and determine the occurrence of cirrus clouds over the Amazon in a study accomplished by Gouveia (2014).
- The LIDAR (Light Detection and Ranging) is an active remote sensing system, a pulse of laser light is emitted to the atmosphere and interacts with particles and molecules.
- As the pulse of electromagnetic radiation travels through the atmosphere, a fraction of the pulse is attenuated due to scattering and absorption, and the light that is backscattered (scattered with an angle of 180 to the direction of propagation) is collected by a telescope and measured in high temporal resolution.

Ground based Lidar

Lidar-Raman station in the Amazon



Plots generated by Lidar output

Ground based Lidar

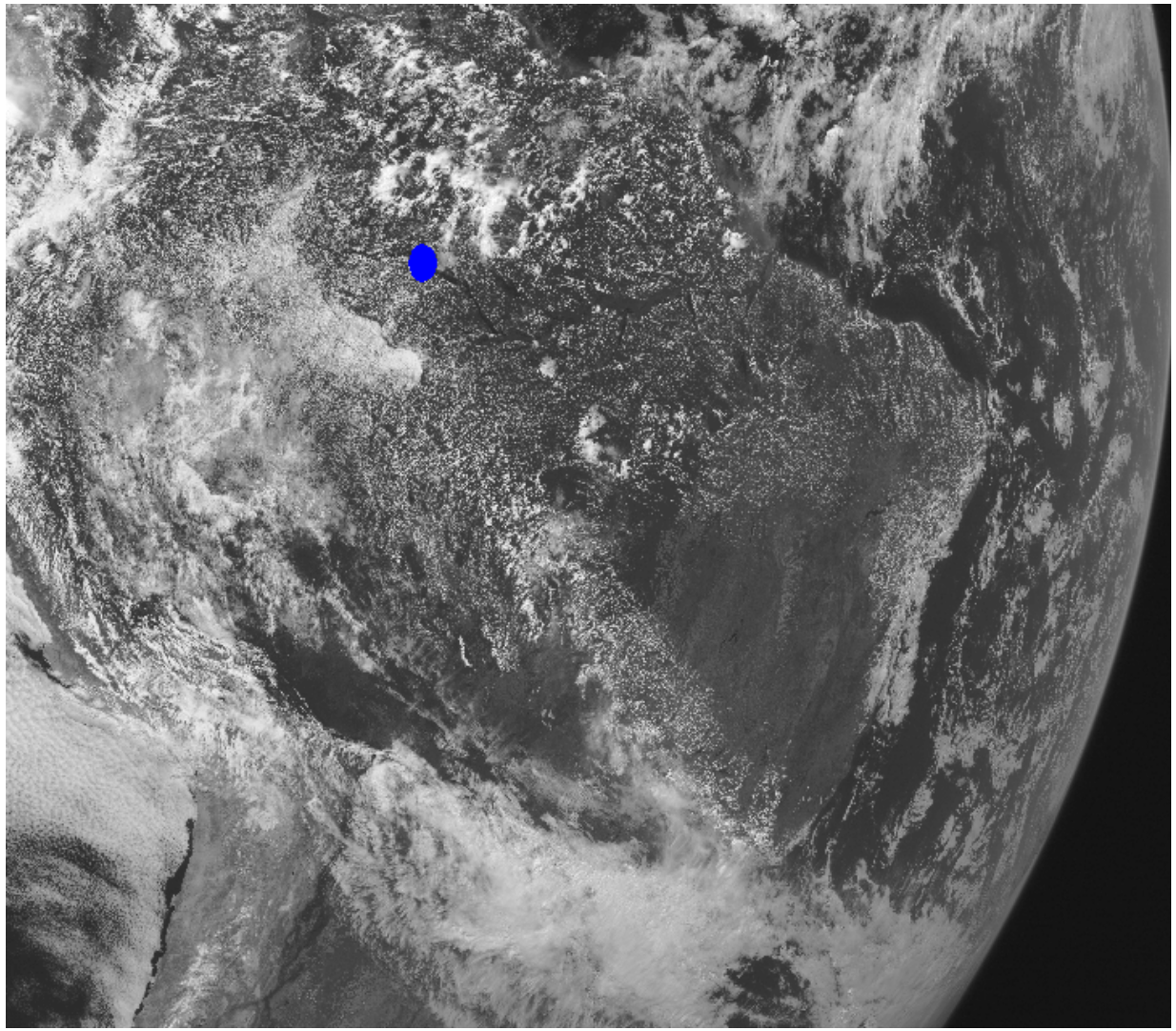
	Total	DJF	MAM	JJA	SON
Frequency of temporal occurrence (%)	71.0	78.1	82.8	52.0	77.3
Cloud bottom height (km)	12.5	12.5	12.6	12.6	12.4
Standard deviation	2.4	2.7	2.5	2.1	2.3
Cloud top height (km)	14.3	14.1	14.4	14.1	14.4
Standard deviation	2.2	2.4	2.2	1.8	2.3
Maximum backscattering height (km)	1.82	1.61	1.87	1.52	2.00
Standard deviation	1.53	1.30	1.62	1.30	1.63
Subvisual Cirrus (%)	24.2	25.0	21.4	37.9	18.9
Thin Cirrus (%)	40.7	34.4	38.0	43.6	42.1
Cirrus Stratus (%)	35.1	40.6	40.5	18.5	39.0

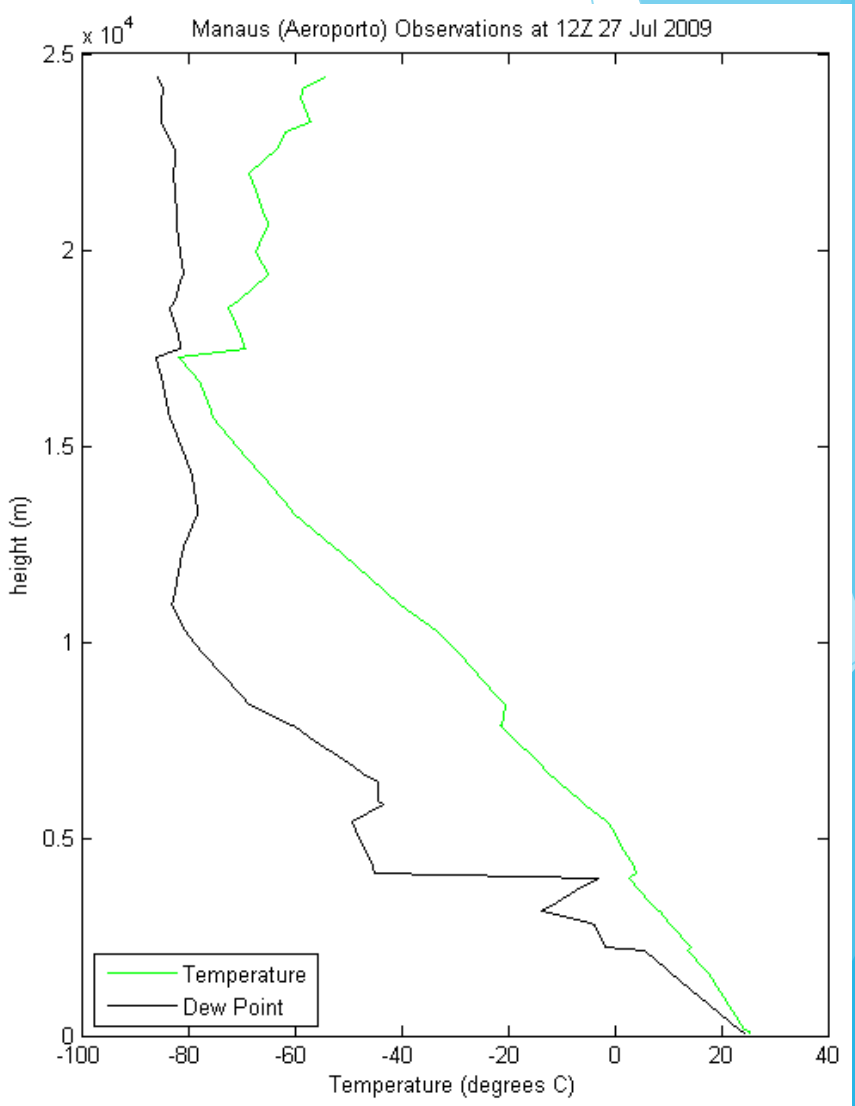
Table 2. Summary of average values for cirrus clouds properties (modified from GOUVEIA, 2014).

Frequency of cirrus clouds

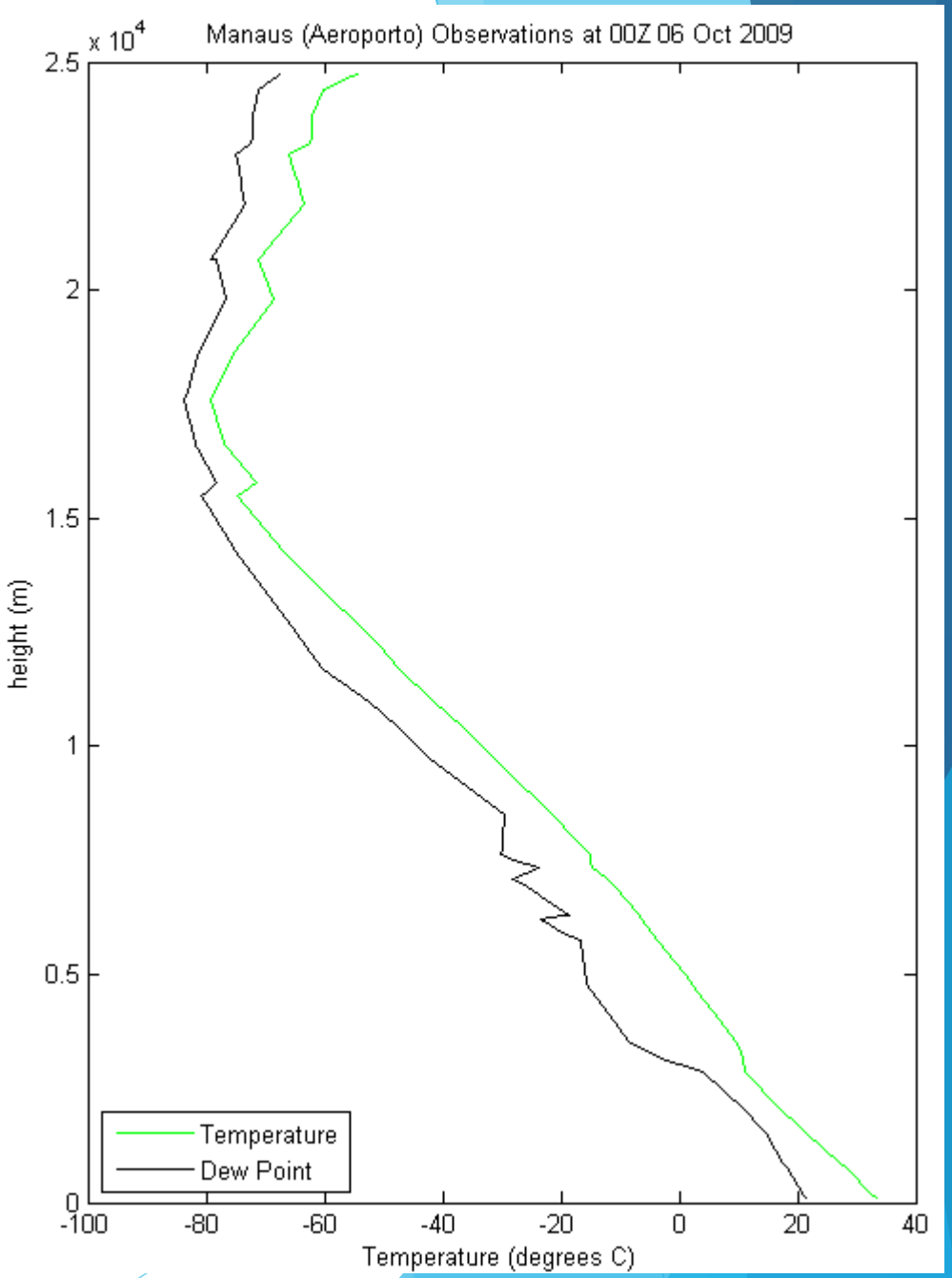
- Determined by Lidar-Raman system
- Difference between the frequency of occurrence for winter (JJA, 52.0%) and summer (DJF, 78.1%). Can be explained by the formation and transport mechanisms of cirrus clouds.
- Also observed in the CloudSat datasets analyzed by Kawamoto (2012)

Infrared satellite image obtained from Geostationary Operational Environmental Satellite (GOES-14), with the Amazon region highlighted.





Photography taken at the International Space Station in October 6th, 2009, showing tropical storms over the Western Amazon (GOUVEIA, 2014).



Conclusions

- The CloudSat active remote sensing and ground-based Lidar-Raman detection methods were very successful in determining microphysical properties and frequency of occurrence of cirrus clouds in and around the Amazon.
- Such properties are of extreme importance for better parameterization of numerical models used to estimate radiative transfer and cirrus cloud forcing and influence on climate.
- The Lidar-Raman system operating continuously in the Amazon region generates high quality data on cloud properties, not only for Cirrus but also for other cloud types.
- Clouds in the Amazon are a very important part of the climate system, and the understanding of cirrus clouds and convective processes in the region is useful when modeling climate change in global scale.

References

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