Characterization of cirrus clouds at São Paulo Metropolitan Region (SPMR) studied with Systematic Elastic Lidar Measurements

ELIANE G. LARROZA,
C. Hoareau, W. Nakaema, E. Landulfo , R. Boareau, P. Keckhut

elarroza.ipen@gmail.com

IPEN Brazil, LATMOS-IPSL, UVSQ, Guyancourt, France

Outline

Motivation

Introduction

Material and methods

Results

Conclusions

Perspectives

Motivation

Use of one methodology for characterization and classification of cirrus cloud at Sao Paulo city (RMSP) by lidar system, building up a cirrus cloud data base.

Inovation → Currently cirrus cloud climatology in Brazil is new

↓

→ Lidar Ratio (LR) is calculated for each observation (literature uses constant LR = 18 sr)

Introduction

What is?

Cirrus Clouds

1) Generally fibrous-like appearance;

2) Predominantly temperature below -40^{o}C;

3) Composed basically by ice crystals;

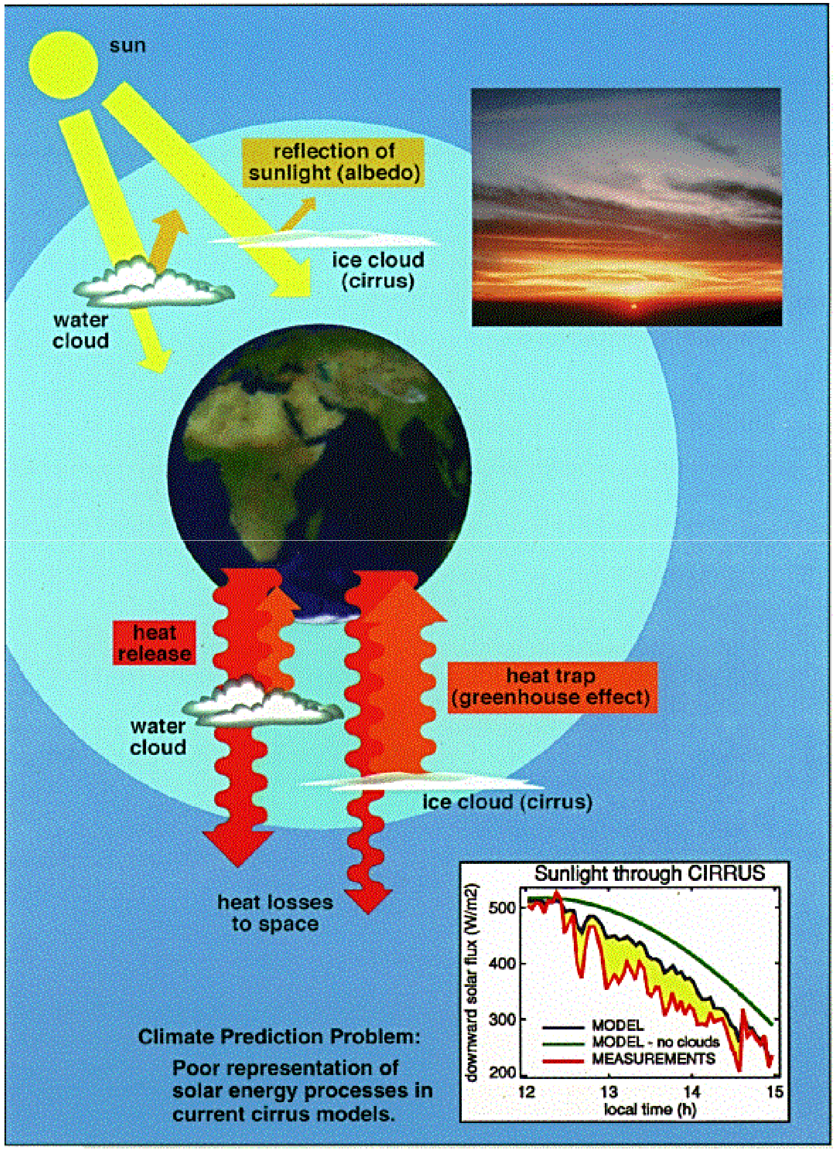
4) Altitudes ~ 7-20 km (tropics), near the tropopause.

5) Optical Depth (τ_C):

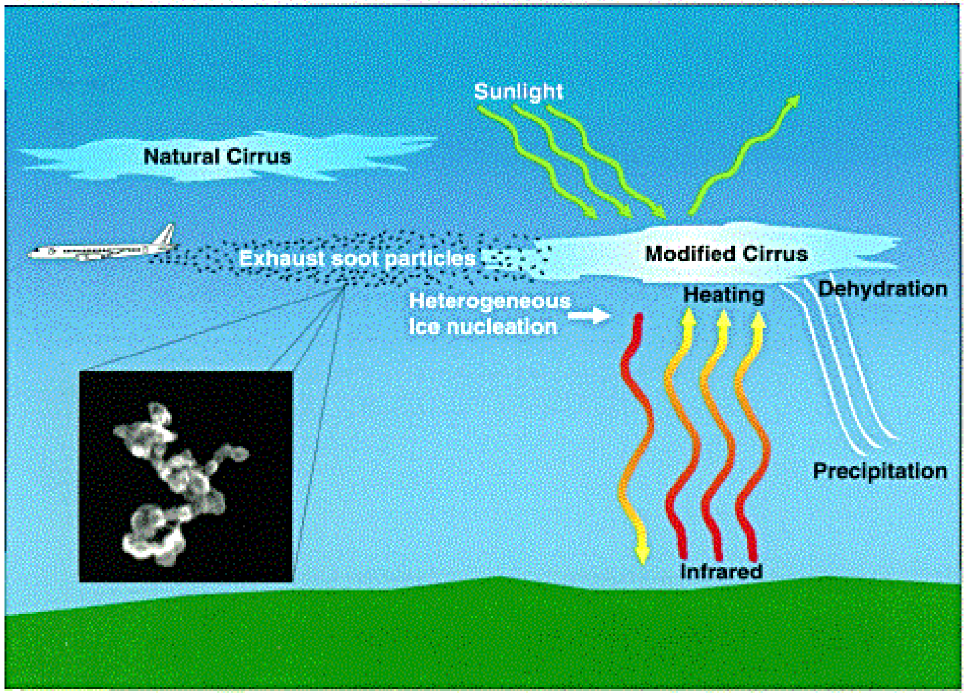
- τ_C<0.03 - sub-visible cirrus (SVC) clouds
- 0.03 <τ_C< 0.3 - thin cirrus clouds
- τ_C>0.3 - cirrus opaque

Introduction

Why?

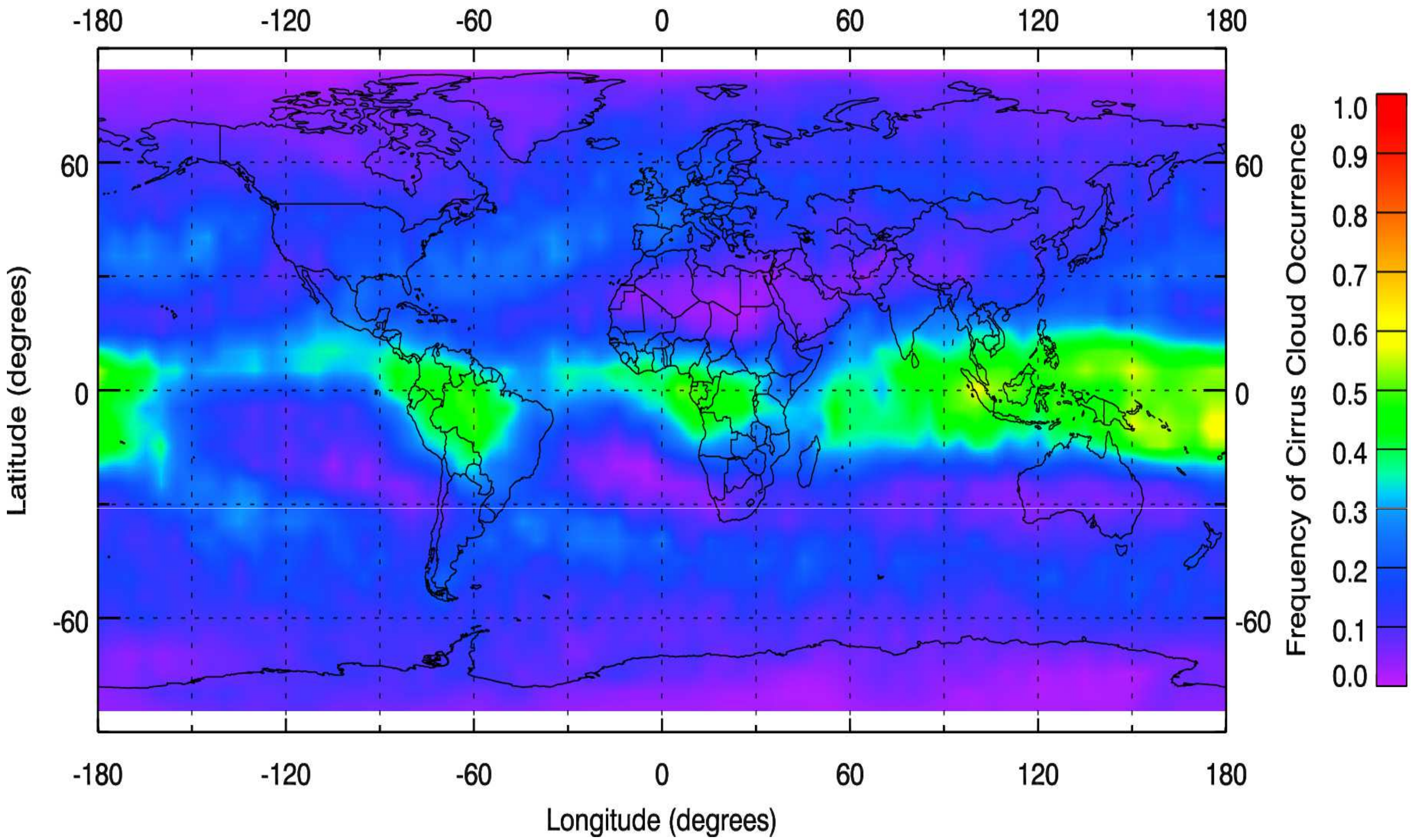


http://geo.arc.nasa.gov/sge/jskiles/fliers/all_flier_prose/cirrusclimate_kinne/cirrusclimate_kinne.html



Introduction

Why?



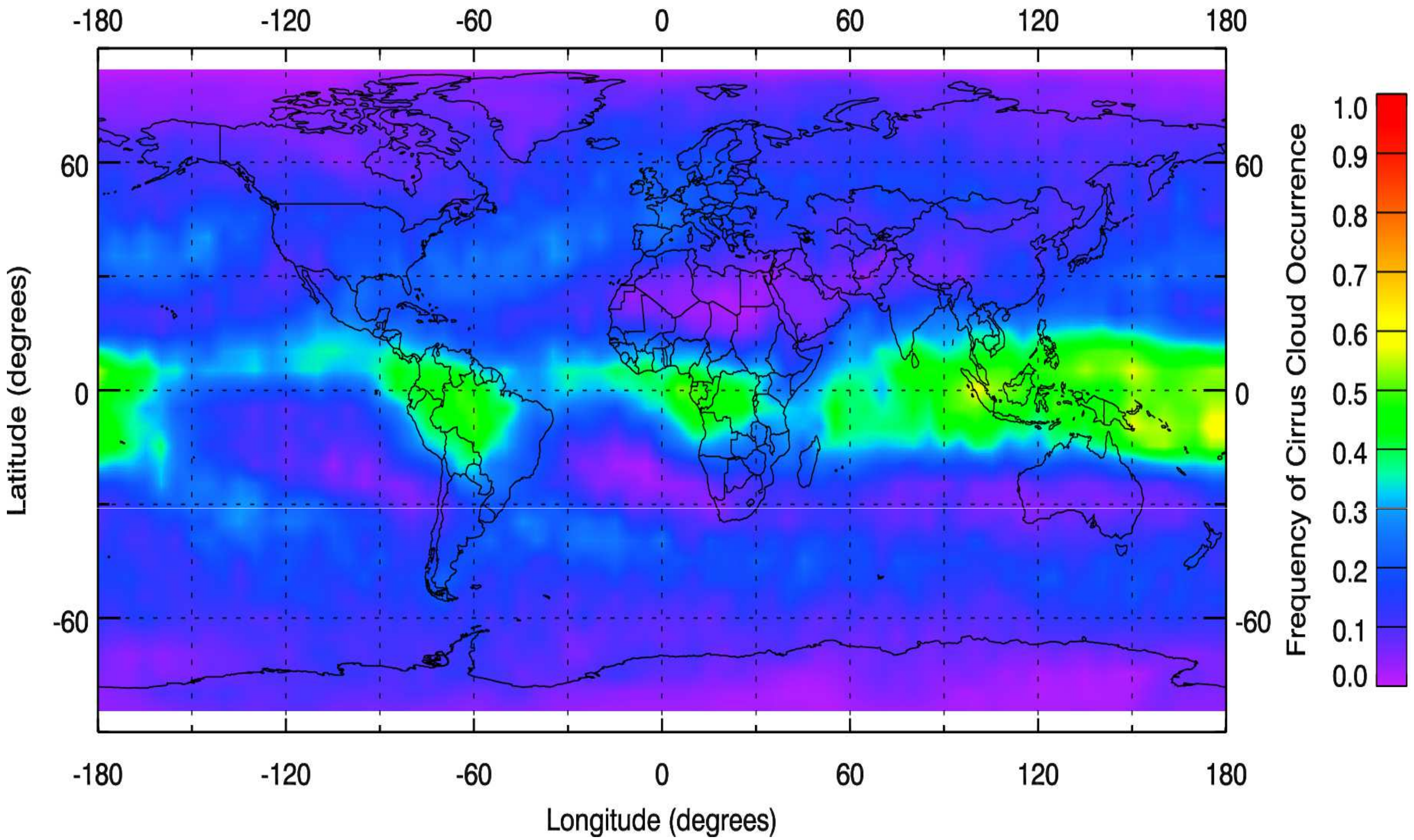
Global distribution of average frequency of occurrence of cirrus clouds identified by the Cloudsat/CALIPSO of 1-year average of daylight and nighttime measurements by Sassen et al., 2008.

Global Coverage

- Mid-Latitudes 20-30%
- Tropics 50% - 60%

Introduction

Why?



Global distribution of average frequency of occurrence of cirrus clouds identified by the Cloudsat/CALIPSO of 1-year average of daylight and nighttime measurements by Sassen et al., 2008.

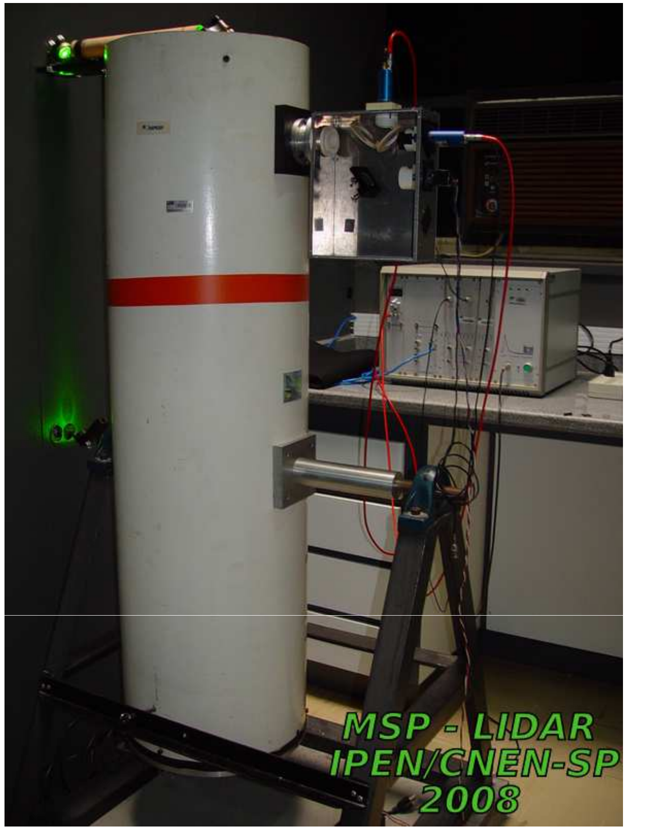
- Information of the optical and microphysical properties of thin cirrus are essential to the understanding of atmospheric radiation budget and climate, particularly over the tropics.

Material and methods

LIDAR: *Light detection and Ranging*

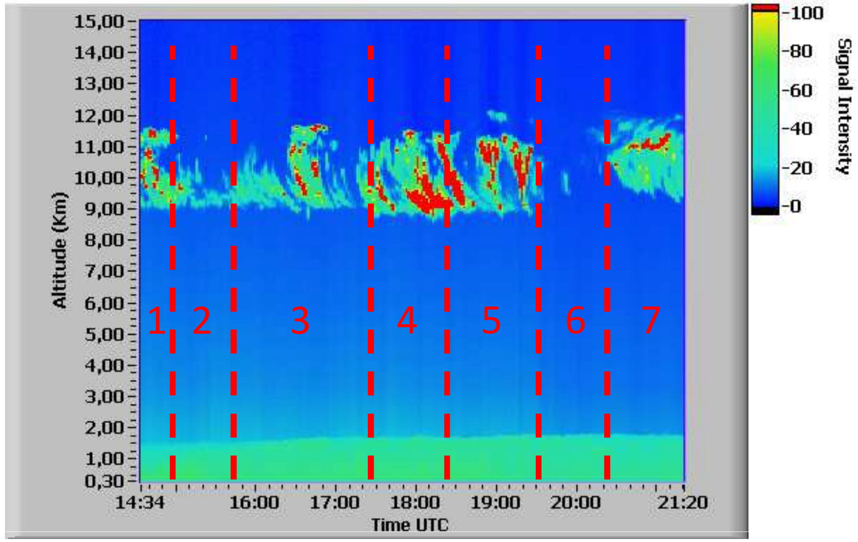
Configuration (2007):

- Coaxial and vertical pointing
- Laser Nd:YAG @ 532 nm
- Telescope: diameter 30 cm & focus = 1.5 m
- Backscattered light collection: Photomultiplier + interference filter (1nm FWHM) to reduce background
- Acquisition: dual system *(analogic and foton counting)*
- Range: 15 km/30 km with 15 m vertical resolution
- Temporal Resolution: 100ns, file acquisition each 2 minutes
- Channel: elastic backscattering (*Rayleigh* and *Mie*)

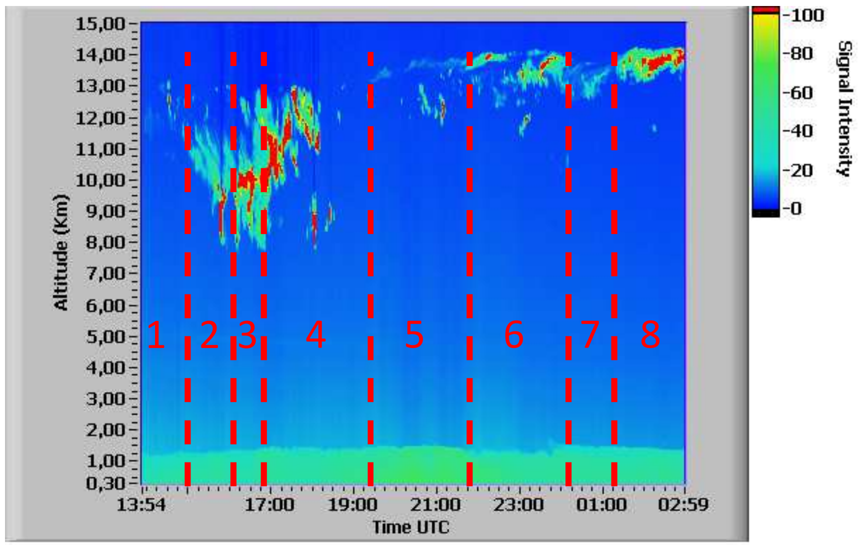


All cirrus clouds similar?

12 June 2007



14 June 2007



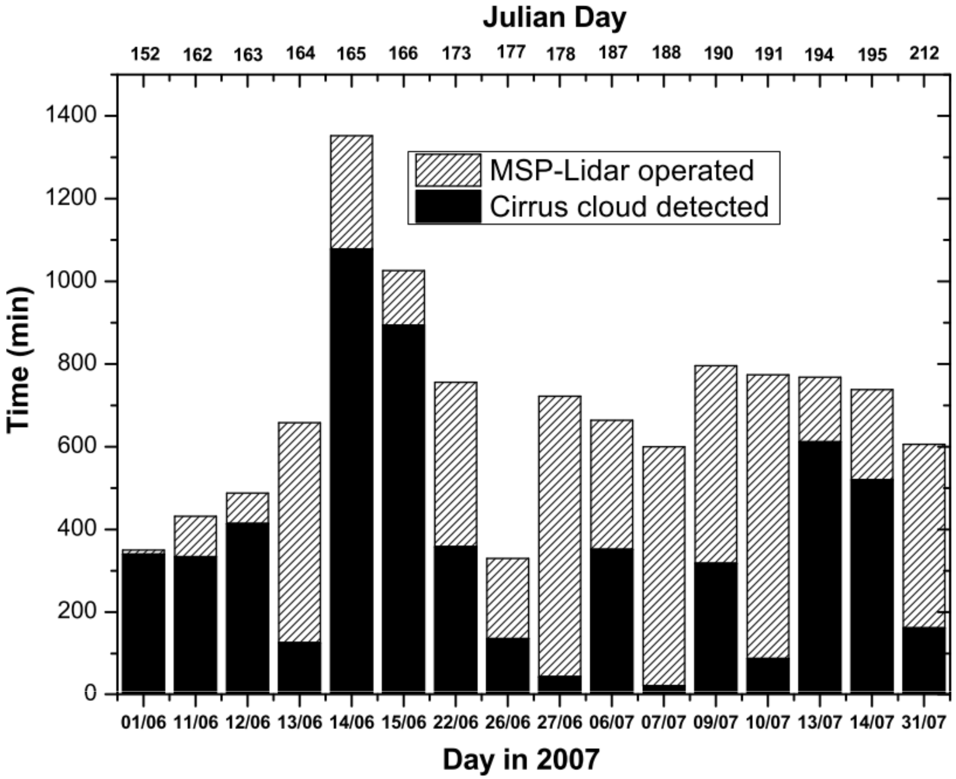
Derived geometric parameters from lidar

- Top height
- Bottom height
- Thickness
- temperature from radiosonde

Derived optical properties from lidar

- Transmittance
- Optical Depth
- Lidar Ratio

Data



Basic information about the underlying lidar data set of this study on June-July 2007.	
Months	June/July
No. of meas. days	34
No. of meas. min.	10710
No. of cirrus day	16
No. of cirrus observations (stationary period)	104
Cirrus detected (min)	5798
Cirrus detected (%)	54

Material and methods

Scattering Ratio(SR)
Goldfarb et al, 2001

Optical Depth(τ_c)

z_{top}

$$SR(\lambda,r) = \frac{\beta_{Rayleigh}(\lambda,r) + \beta_{cirrus}(\lambda,r)}{\beta_{Rayleigh}(\lambda,r)}$$

Raw Lidar signal
(corrected for the Background
and the altitude square dependence)

Interpolated over
Radiosonde profile

$\beta_p = 0$; SR $\rightarrow 1$

Scattering by particles
SR > 1

Lidar Ratio (LR)
Klett J, D, (1981,1983,1985-86)

$$LR = \frac{\alpha_p(\lambda,r)}{\beta_p(\lambda,r)}$$

$$\tau_C = (LR)\times\sigma_{Rayleigh}\int_{z_{base}}^{z_{top}}\eta_{ar}(z)\left(SR(z)-1\right)dz$$

$$\beta_m = \sigma_{Rayleigh}(z)\times\eta_{ar}(z)$$

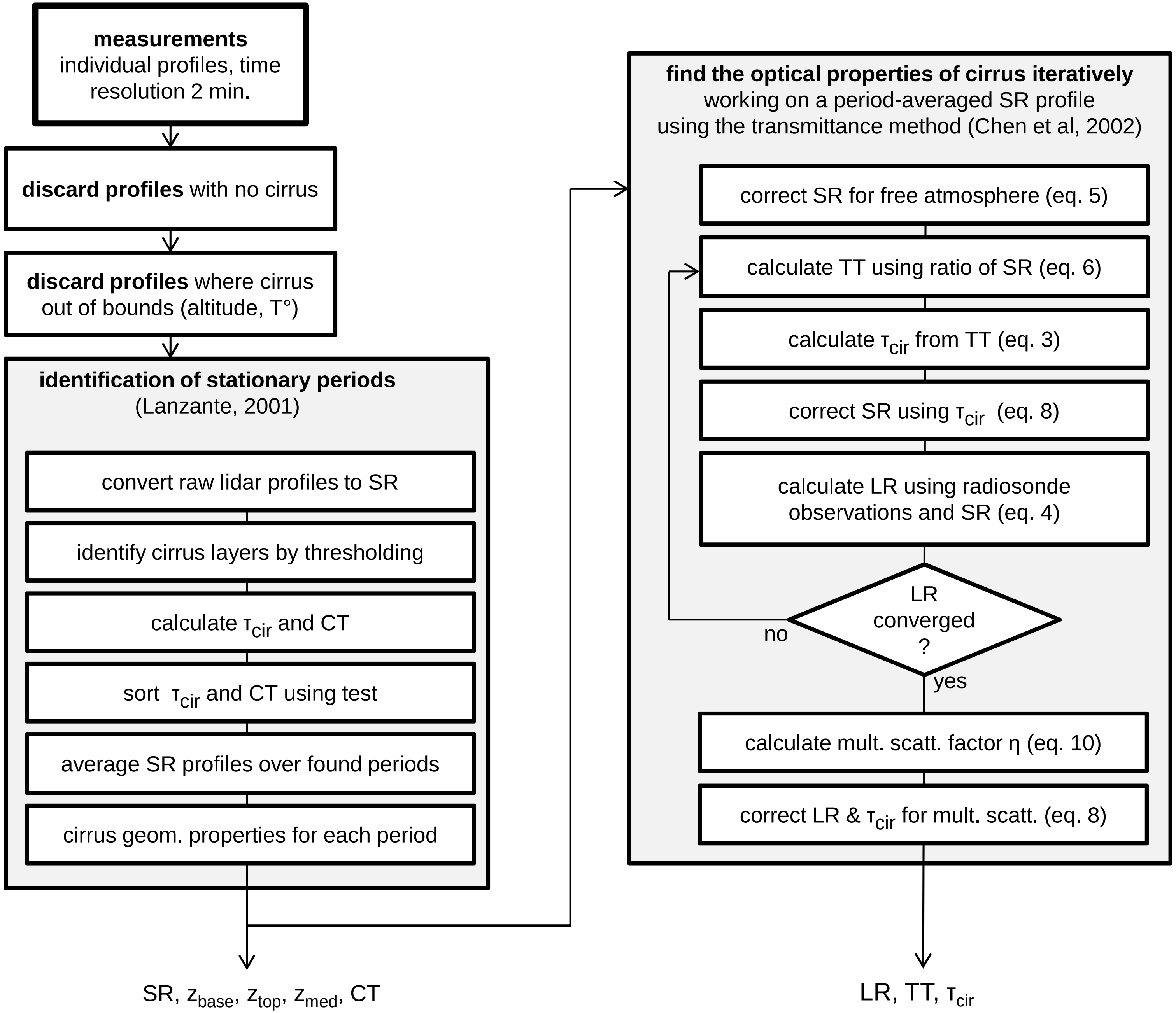
Rayleigh
Backscattering
cross section
per molecule

Refractive index for standard air

$$\sigma_{Rayleigh} = \frac{\pi^2(n^2-1)}{\eta_{ar}^2\lambda^4}F_k$$

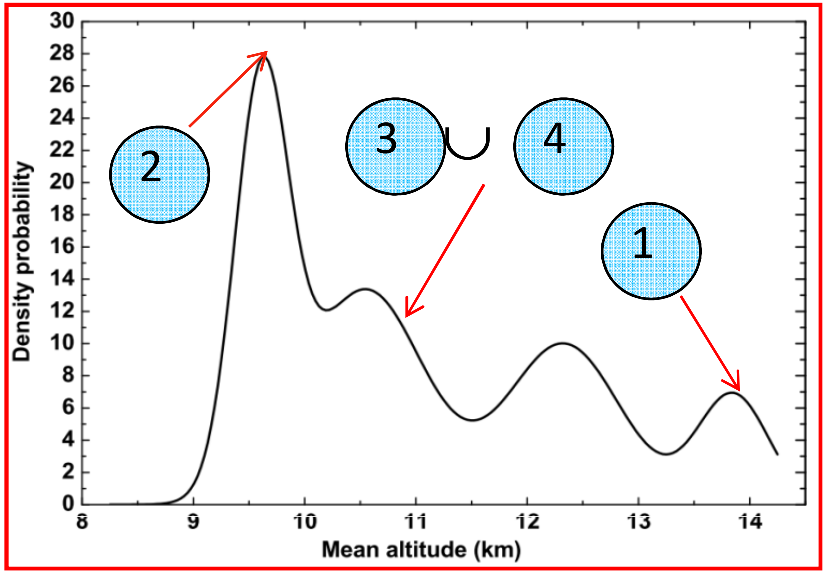
King Factor:
- Depolarization (Measures, 1984)
- Depend on the gas mixture

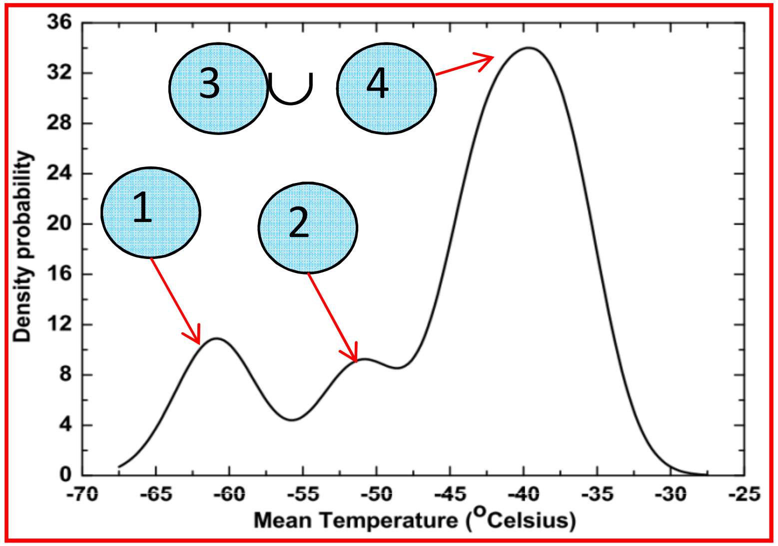
Molecular number density
(radiosonde or Standard Atmosphere)

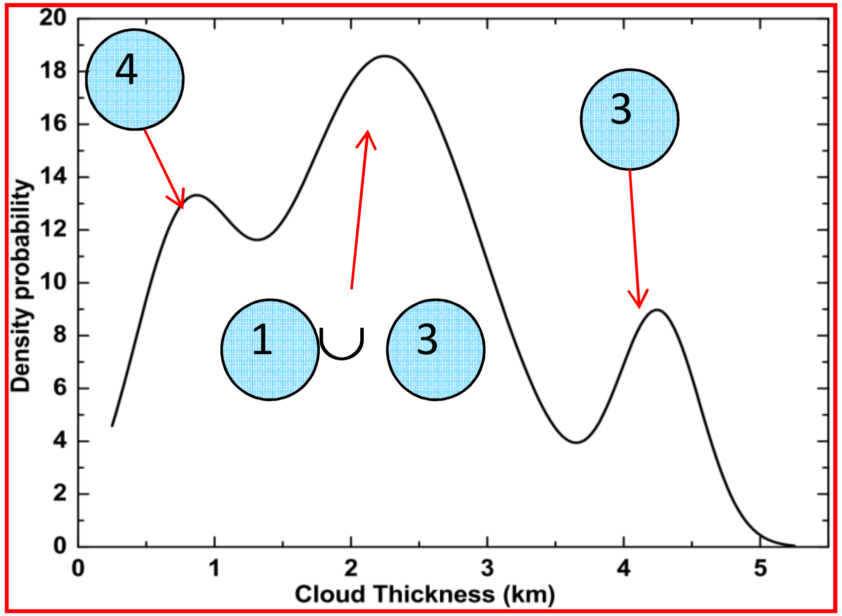


Elaborated by R. Bourayou

Non-gaussian distributions a sign of different cloud types?

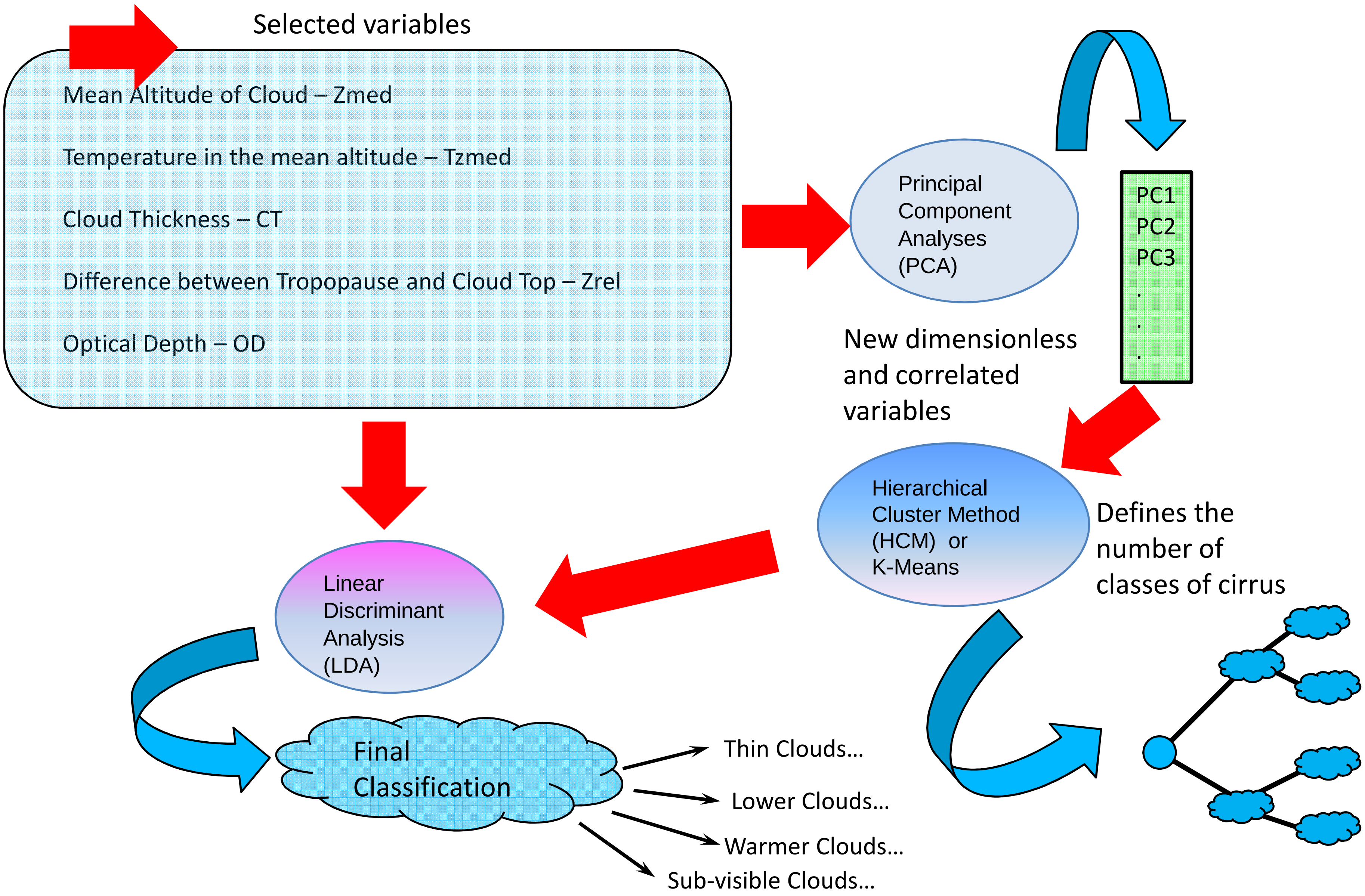






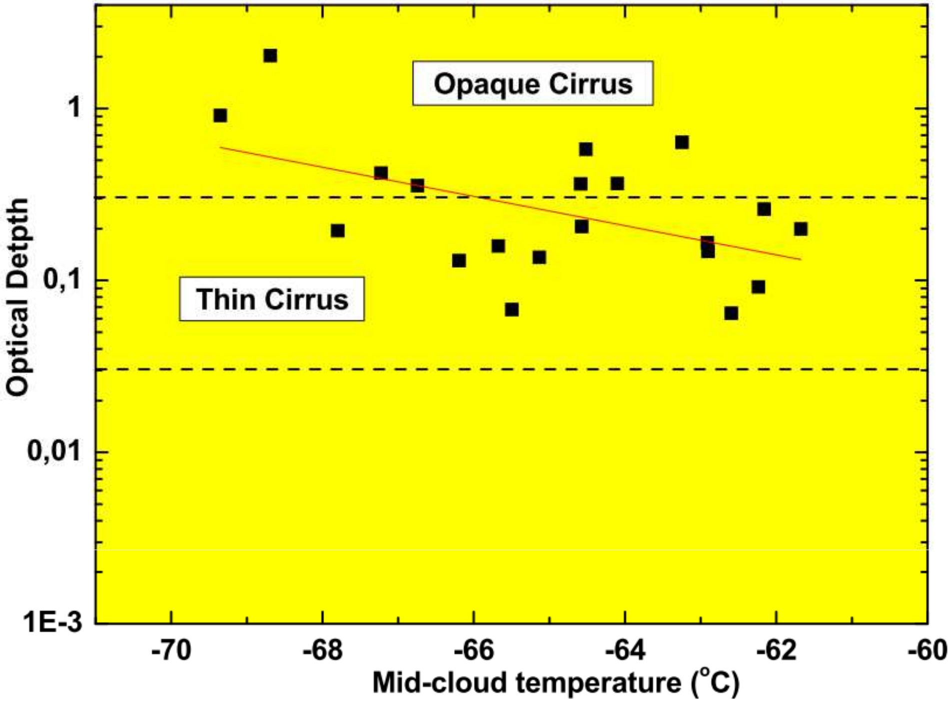
Material and methods

Next step: Multivariate Analyses to determine the class of cirrus



Results

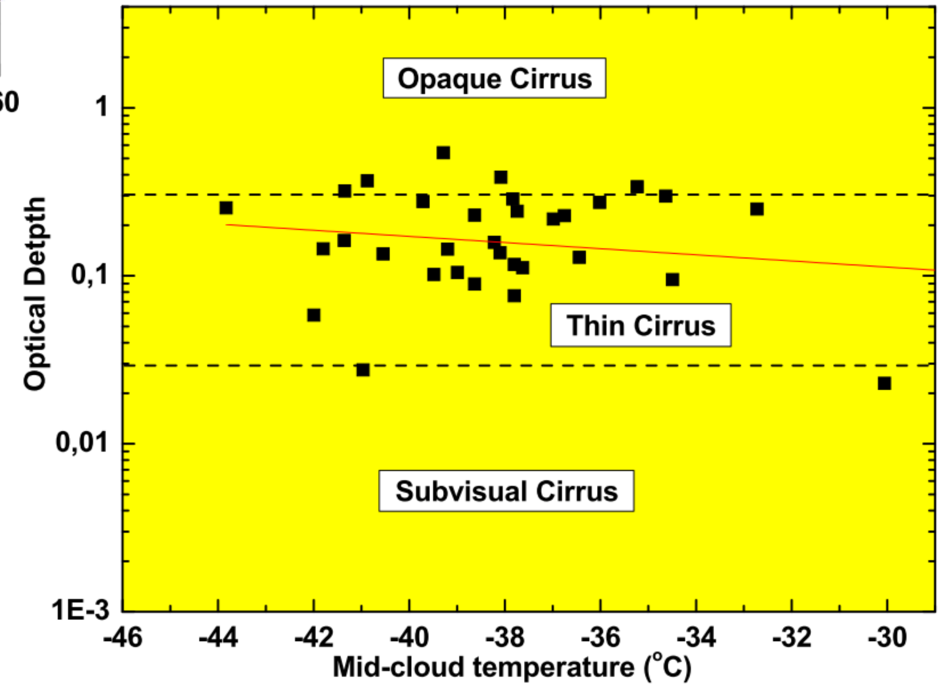
Class 1



A scatter plot of optical depth (τ_C) versus mid-cloud height . PeríodJune-July 2007.

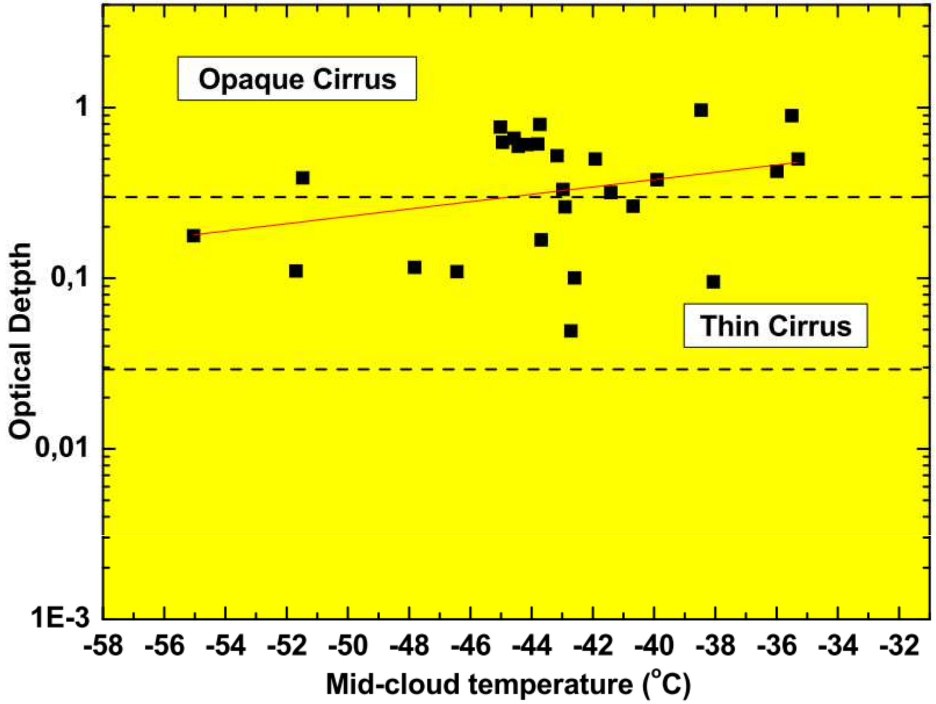
- Decrease optical depth with increase temperature ;
- Basically composed of thin cirrus cloud.

Class 2



Results

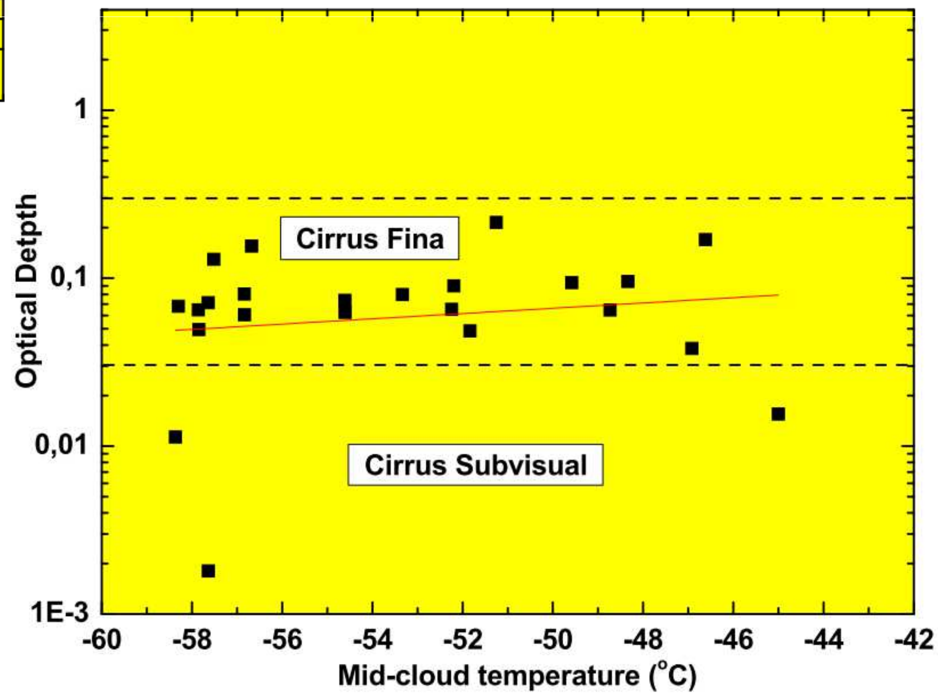
Class 3



A scatter plot of optical depth (τ_C) versus mid-cloud height . PeríodJune-July 2007.

- Increase optical depth with Increase temperature .

Class 4

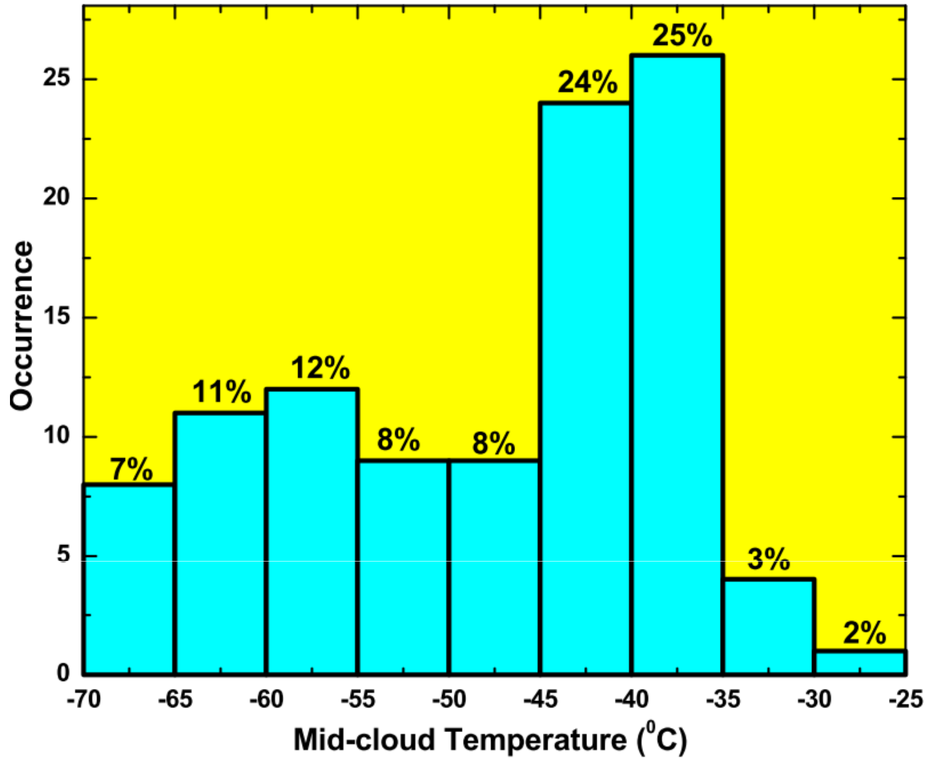


Clustering analyses: 4 classes at São Paulo (sub-tropical region)

Characteristics of the four cirrus classes				
Class type	1 Thick upper troposphere or near tropopause cirrus	2 Mid-upper troposphere thin cirrus	3 Thick mid-upper troposphere cirrus	4 Thin upper troposphere cirrus
Ocurrence (%)	19	32	27	22
Mean altitude of Cloud (km)	13.38 ± 0.56	9.67 ± 0.45	10.36 ± 0.65	11.77 ± 0.77
Thickness (km)	2.31 ± 0.71	1.86 ± 0.81	3.85 ± 0.83	1.14 ± 0.67
Relative height (km)	0.16 ± 1.74	6.54 ± 1.14	2.53 ± 2.17	4.53 ± 0.86
Optical Depth	0.37 ± 0.45	0.19 ± 0.11	0.42 ± 0.26	0.08 ± 0.05
Top altitude	14.52 ± 0.64	10.59 ± 0.60	12.27 ± 0.96	12.33 ± 0.67
Mean temperature inside of the cloud (ºC)	-64.89 ± 2.25	-37.94 ± 3.24	-43.21 ± 4.61	-53.51 ± 4.87

Results

Type of crystals according to the range of temperature



Frequency distribution of cirrus with Mid-cloud temperature (km) on June-July 2007

Wang e Sassen, 2002 (Mid latitude) : T_{med} -40 ^{0}C and -55 ^{0}C;

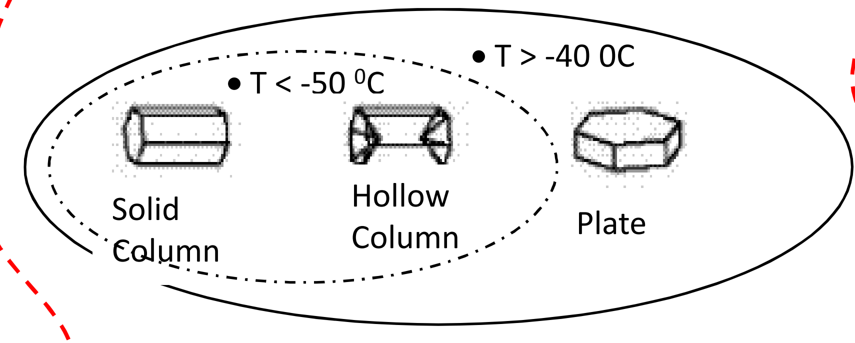
Reichardt ,1999 (Geestack, Germany): T_{med} -55 ^{0}C and -60 ^{0}C;

Platt et al., 1987 (Darwin, Australia): Tmed -60 ^{0}C and -70 ^{0}C;

Seifert et al., 2007 (Maldivas): Tmed -50 ^{0}C and -70 ^{0}C

Heymsfield and Platt, 1984
(predominance of crystals):

Hexagonal



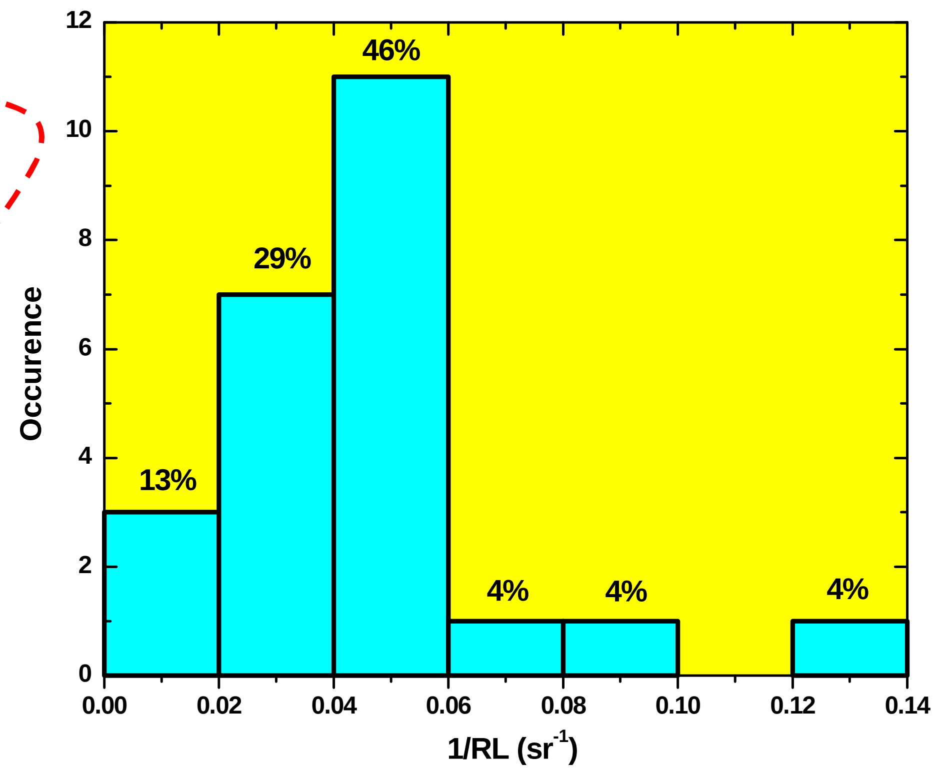
• ”convective” cirrus are dominated by spatial crystals forms while “Stable” cirrus are dominated by hollow columns.

•-30 ^{0}C < T < -40 ^{0}C - long crystals

Results

Table 1: Comparison of LR from MSP-lidar with literature. The <RL> is calculated between 11-14 June 2007.

	LR (sr)
Giannakaki et al., 2007 (Mid latitude)	**28 ±17**
Sassen and Comstock, 2001	**24±38**
Seifert et al., 2007 (Maldivas)	**32±10**
MSP-lidar (<LR>)	**26 ±12**

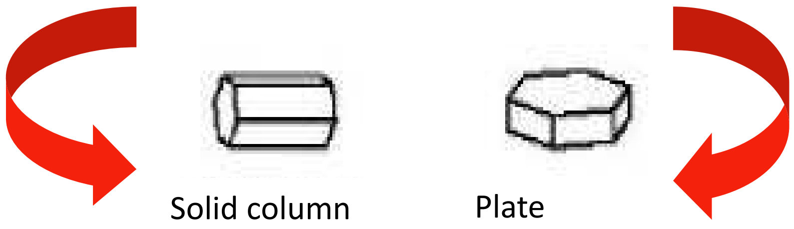


Frequency distribution of 1/LR (sr^{-1}) for 29 observations.

Table 2: Classification of crystal ice by Sassen and Dodd, 1989.

Crystal ice	1/LR (sr^{-1})
hexagonal	**0,026**
Thin plates	**0,086**
Thick plate and columnss	**0,0838**

<1/LR> = 0,048 ±0,025 sr^{-1}



Hexagonal crystal ice

Conclusions

Methodology

Robust and consistent statistic to determine macro-pysical parameters and optical properties as a classification of cirrus cloud.

Zmed and TZmed

Key parameters to cirrus clouds formation and the multivariate approach showed to beefficient and objetive to decide whetherdifferent classes (clusters) can be identified and discriminated using theavailable data.

Depolarizationratio

It would be valuable to add the depolarization as a cloud parameter in the classification analysis because it provides information on the shape of the cirrus crystals (Noel et al., 2002; Keckhutet al. 2006)

Lidar Ratio

Agreement and consistence with the literatures caracterized the solid hexagonal crystal ice (column and plate) presents in the cirrus cloud observed byMSP-Lidar system

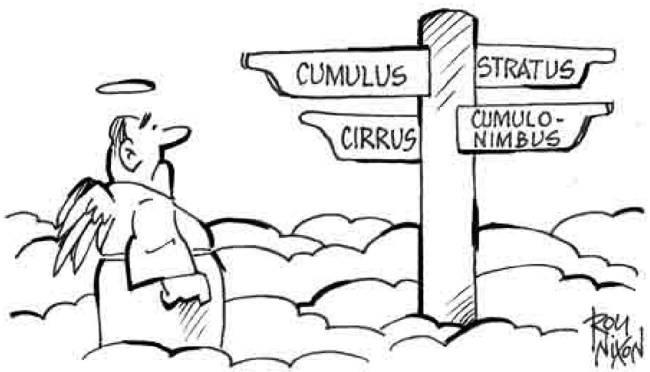
Perspectives

To extend the methodology application on the MSP-lidar data measurements since 2004 with the goals to obtain a cirrus cloud climatology at Sao Paulo region.

Continue of the work and cooperation with Dr. Philippe Kechut from LATMOS/IPSL: use the same methodology applied atSao Paulo in the Isle Réunion located ~ same latitude (21^{o}S)

Implement a depolarization channel on the MSP-lidar system

Acknowledgments



CNPq
Conselho Nacional de Desenvolvimento Científico e Tecnológico

CLA

Special thanks to:

- Dr. PHILIPPE KECKHUT (LATMOS/IPSL)

- Dr. EDUARDO LANDULFO (CLA/IPEN)

- Dr. WALTER NAKAEMA (CLA/IPEN)

-Dr. RIAD BOURAYOU

-CNPq

LATMOS

Sciences de l'environnement
Institut Pierre Simon Laplace

ipen

cnrs

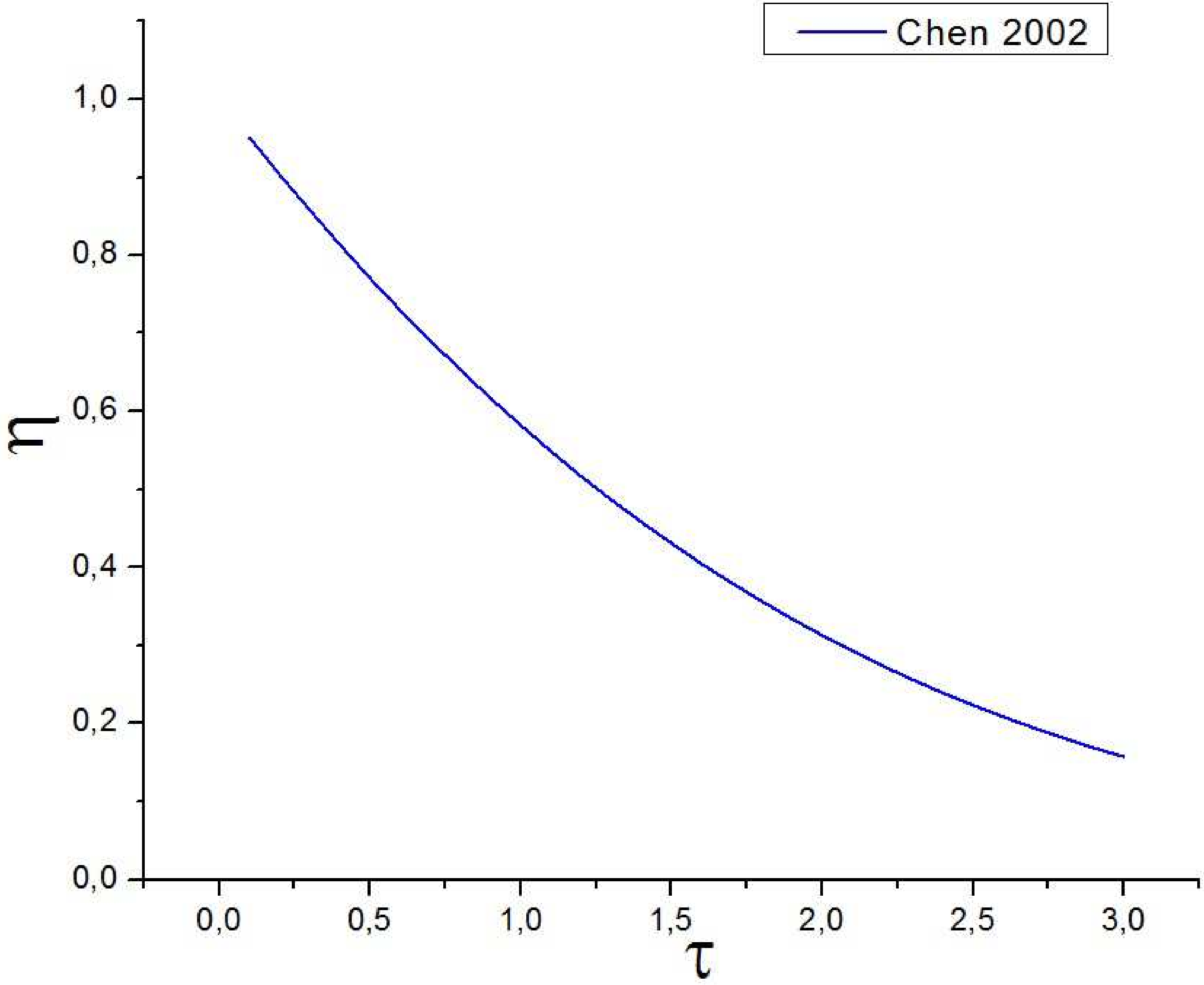
UNIVERSITÉ DE VERSAILLES
SAINT-QUENTIN-EN-YVELINES

Table 1 – Macro-physical properties of cirrus observed over São Paulo city from 11th June 2007.

Periods	z_{base} (km)	z_{top} (km)	z_{med} (km)	T_{zbase} (°C)	T_{ztop} (°C)	T_{zmed} (°C)	CT (km)
			Multi-layer cloud – First Layer				
1	8.05	9.47	8.76	-26.77	-37.76	-32.47	1.42
2	7.75	9.56	8.65	-24.08	-38.50	-31.58	1.81
3	7.69	9.40	8.54	-23.61	-37.17	-30.74	1.70
4	7.85	9.01	8.43	-25.02	-34.49	-29.92	1.15
			Multi-layer cloud – Second Layer				
1	9.79	11.19	10.49	-40.52	-52.87	-46.66	1.4
2	9.84	11.12	10.48	-41.01	-52.24	-46.59	1.28
3	10.05	10.89	10.47	-42.99	-49.98	-46.56	0.84
4	10.09	11.01	10.49	-43.33	-51.15	-47.2	0.91
			Mono-layer cloud				
5	7.51	10.76	9.13	-21.88	-48.91	-35.47	3.27
6	8.44	10.74	9.59	-30.09	-48.8	-39.17	2.32
7	8.73	10.83	9.77	-32.19	-49.39	-40.64	2.12

Table 2. Optical properties of cirrus observed over São Paulo city from 11th June 2007.

Periods	TT	τ_{cir_app}	τ_{cir_eff}	LR_{app} (sr)	LR_{eff} (sr)
Multi-layer cloud – First Layer					
1	0.76 ± 0.03	0.14 ± 0.02	0.13 ± 0.02	28 ± 4	26 ± 4
2	0.65 ± 0.02	0.21 ± 0.01	0.19 ± 0.01	22 ± 1	19 ± 1
3	0.83 ±0.03	0.09 ± 0.02	0.09 ± 0.02	25 ± 4	24 ± 4
4	0.84 ± 0.03	0.09 ± 0.02	0.08 ± 0.02	35 ± 5	33 ± 5
Multi-layer cloud – Second Layer					
1	0.58 ± 0.04	0.28 ± 0.03	0.24 ± 0.03	37 ± 4	32 ± 4
2	0.5 ± 0.02	0.35 ± 0.02	0.29 ± 0.02	39 ± 3	32 ± 3
3	0.65 ± 0.02	0.22 ± 0.02	0.19 ± 0.02	38 ± 4	34 ± 4
4	0.76 ± 0.02	0.14 ± 0.02	0.13 ± 0.02	74 ± 13	69 ± 12
Mono-layer cloud					
5	0.16 ± 0.01	0.92 ± 0.01	0.56 ± 0.01	20 ± 1	12 ± 1
6	0.34 ± 0.01	0.54 ± 0.01	0.41 ± 0.01	20 ± 2	15 ± 2
7	0.48 ± 0.01	0.37 ± 0.01	0.30 ± 0.01	19 ± 1	16 ± 1


Chen 2002
1,0
0,8
0,6
0,4
0,2
0,0
η
0,0
0,5
1,0
1,5
2,0
2,5
3,0
τ