EFFECTS OF EMISSIONS ON CURRENT AND FUTURE RAINFALL PATTERNS IN SOUTHEAST BRAZIL

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FAPESP

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Necessary conditions for precipitation:

Nucleation of cloud droplets

- aerosols
- water vapour saturation
  – depends on aerosol composition and hygroscopicity

↓

Cloud droplet growth and coagulation

↓

Rain

Effects of pollution aerosols

- Fine particles (industrial, combustion etc) → increased cloud droplet population

  - Reduces cloud water vapour supersaturation
  - Inhibits droplet growth
  - Increasing cloud lifetime

    → reduced precipitation initially?

    → heavier rainfall later?

- Inhibition of cloud formation with absorbing aerosols?

- Initiation of precipitation by injection of soil dusts?

Observation-based investigation of the relationships between atmospheric aerosols, cloud formation and precipitation in agricultural regions

Economy based on agro-industry: Sugar cane production; oranges; processing plants; transport networks; infrastructure; urban development

Evidence for a diminishing frequency of rain events in the dry season, with total precipitation concentrated into a smaller number of more intense events

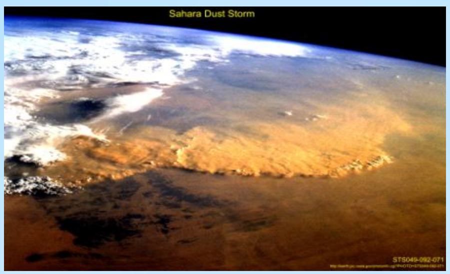
- Reduced soil water content
- Increased run-off
- Increased need for irrigation
- Affects hydroelectric power generation

Future changes in the nature of the region’s atmospheric aerosol due to:

- less biomass burning
- less natural biogenic emissions
- more urban / transport / industrial emissions

Sources of aerosols in rural São Paulo State

Biomass burning



Wind-blown dusts

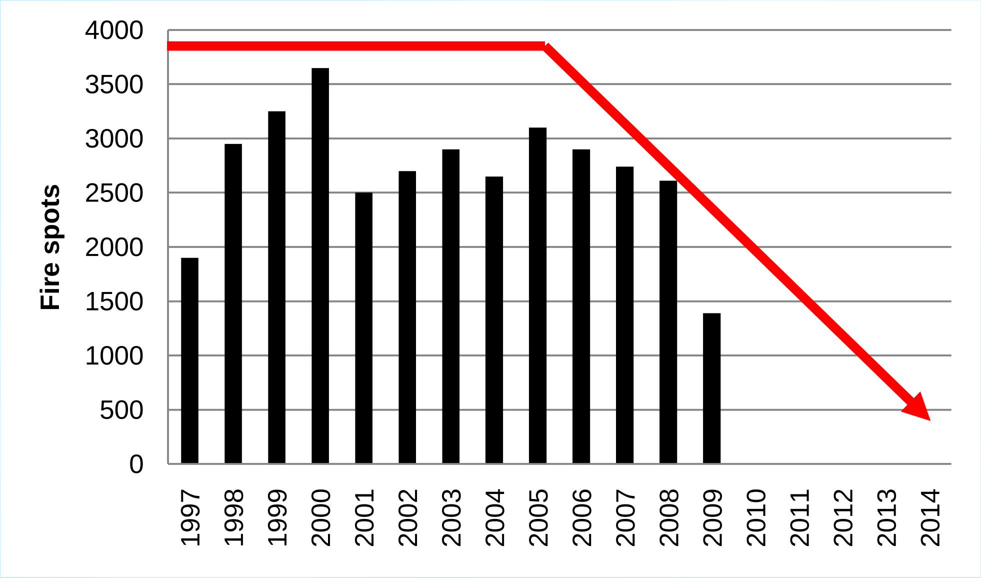
Industry

Transport

Secondary aerosols - LRT

Fire spots detected in São Paulo State (hot pixel data, AVHRR detector on board NOAA satellites)

Phasing-out of sugar cane burning = altered aerosol composition
⇒ affects cloud droplet nucleation
⇒ alters rainfall patterns



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2014-2017 AD

OBJECTIVES

1. Identify the relationships between:

- frequency, distribution and intensity of precipitation
- aerosol number concentrations and size distributions
- aerosol chemical composition
- cloud droplet effective radius
- frequency of cloud to ground electrical discharges

2. Use aerosol compositional measurements to identify the sources of particles, and the likely consequences of changes in emission source strengths on precipitation patterns

Questions:

1. Do aerosols emitted, or formed, within the region influence the region's precipitation regime?

2. What is the influence of long-range transported aerosols?

3. Which aerosols, or their chemical constituents, are important?

    Soluble sulphates and nitrates?

    Water-soluble organic carbon?

    Mineral dusts?

    "Biomass burning" material?

4. How do the "aerosol effects" compare with:

    (a) changes in large-scale circulation,

    (b) altered heat and moisture fluxes associated with land use change,

in determining precipitation patterns?

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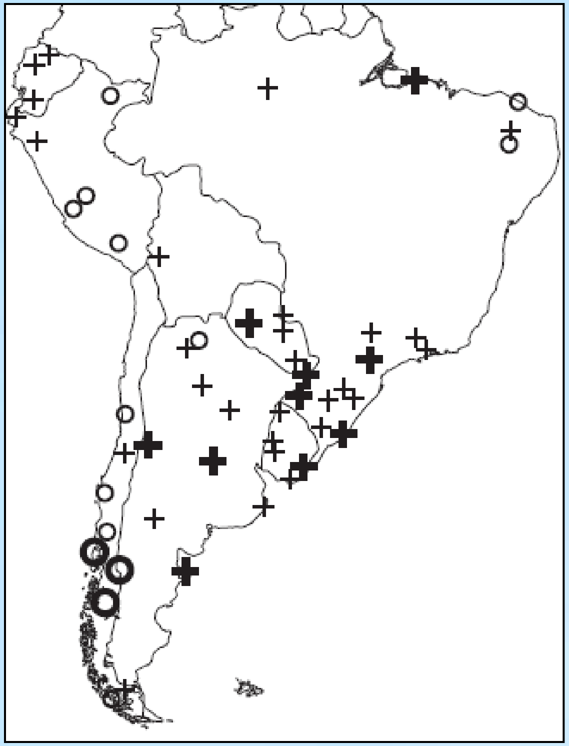
Precipitation trends, 1960-2000

+ = Increase

+ = Significant increase

o = Decrease

O = Significant decrease



Source: Haylock et al., 2006

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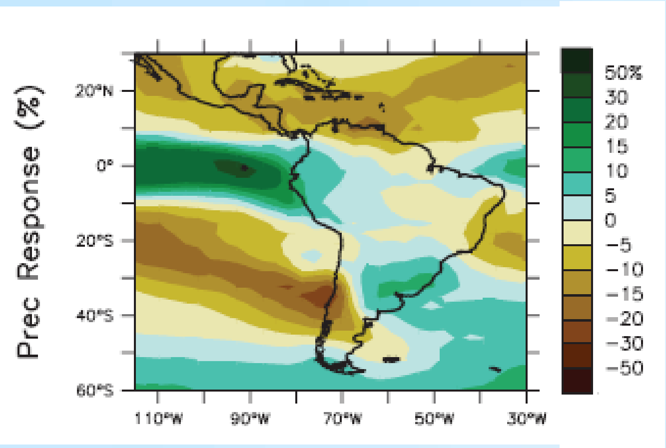
Changes in precipitation predicted for 1980/1999 – 2080/2099



Source: IPCC AR4, WG1, Ch.11

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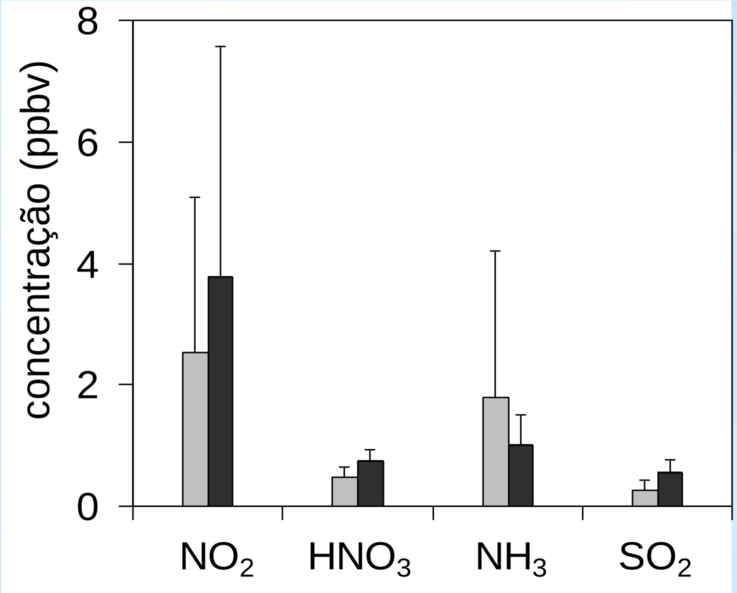
Progressive elimination of sugar cane burning

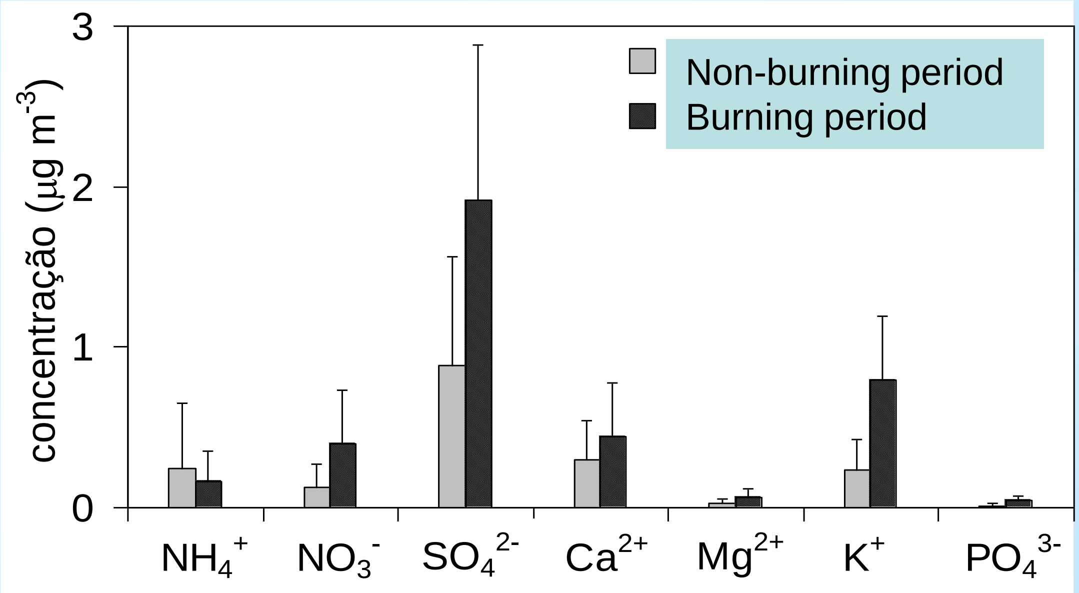
4

Further increases in precipitation?

Influence of sugar cane burning

Average concentrations of NO_2, HNO_3, SO_2 and NH_3 (ppbv), and the ions NH_4^+, NO_3^-, SO_4^{2-}, Ca^{2+}, Mg^{2+}, K^+ and PO_4^{3-} during the sugar cane burning period (May to November) and during the non-burning period (December to April). The error bars indicate the standard deviation

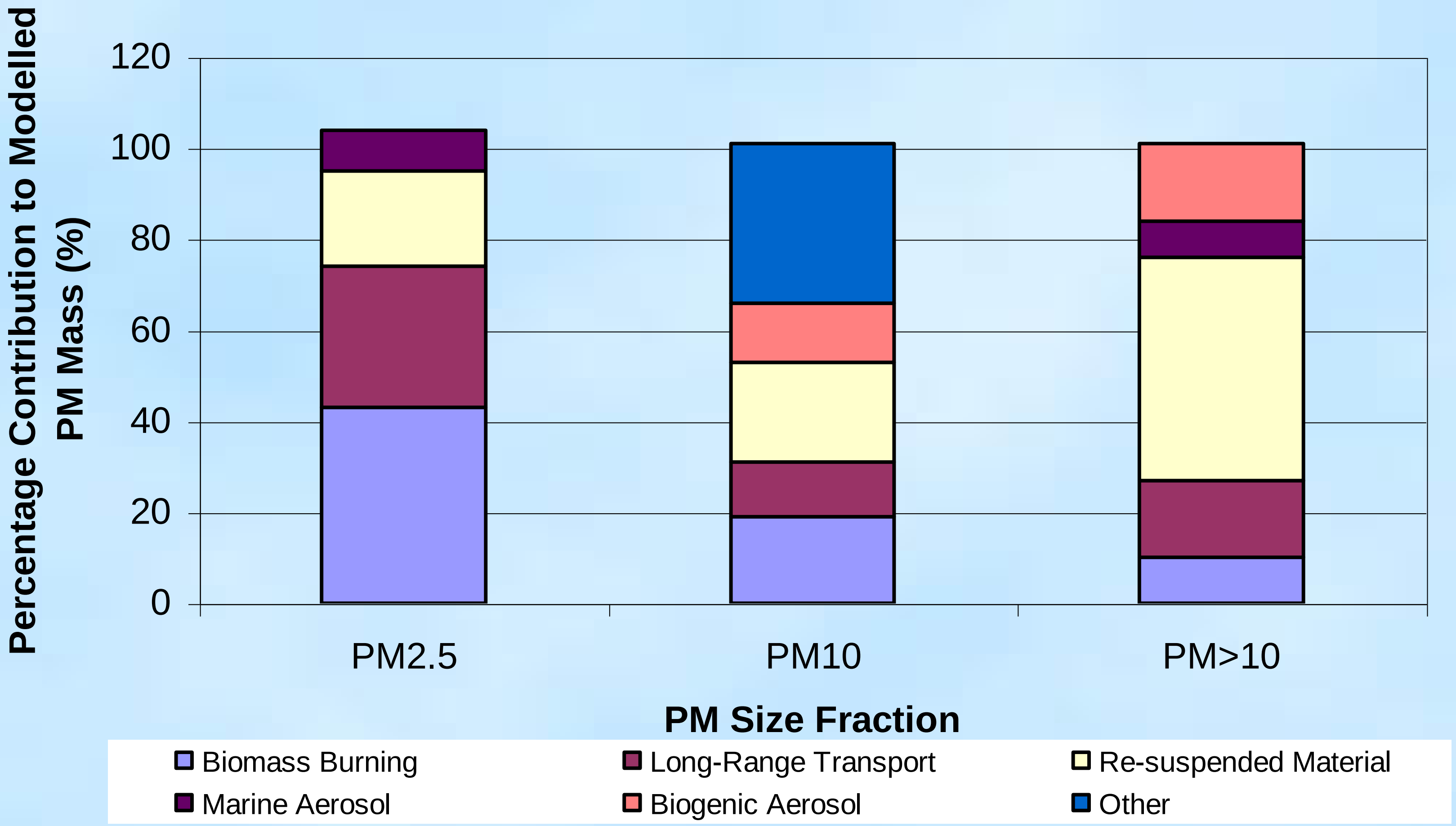




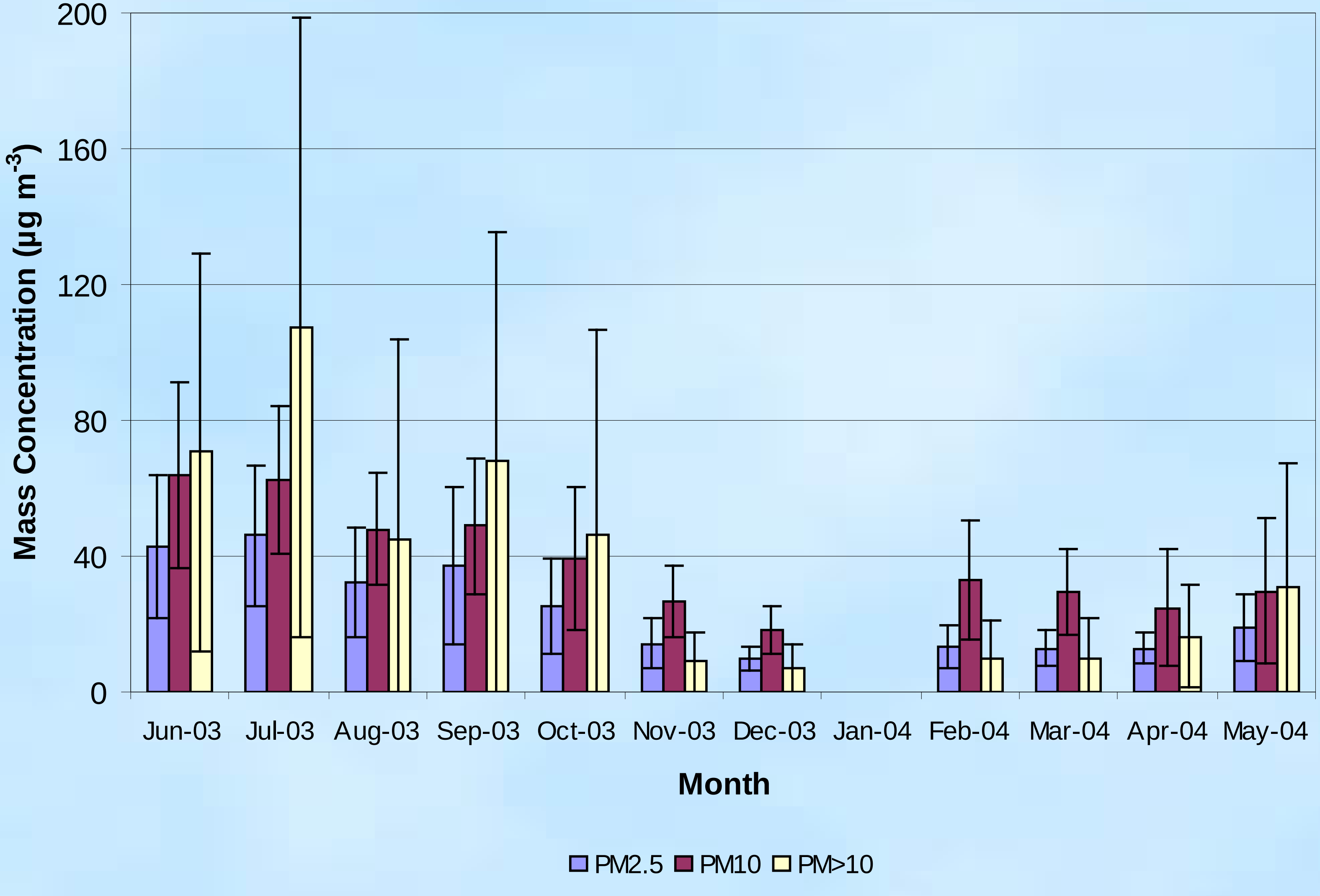
Percentage of total attributable to sugar cane burning: N and S (~30 %); K and P (~50 %)

Sources of Aerosols (SP- Rural)

Method: Principal Components Analysis + Multiple Linear Regression



Monthly Mean $PM_{2.5}$, PM_{10} and $PM_{>10}$ Concentrations

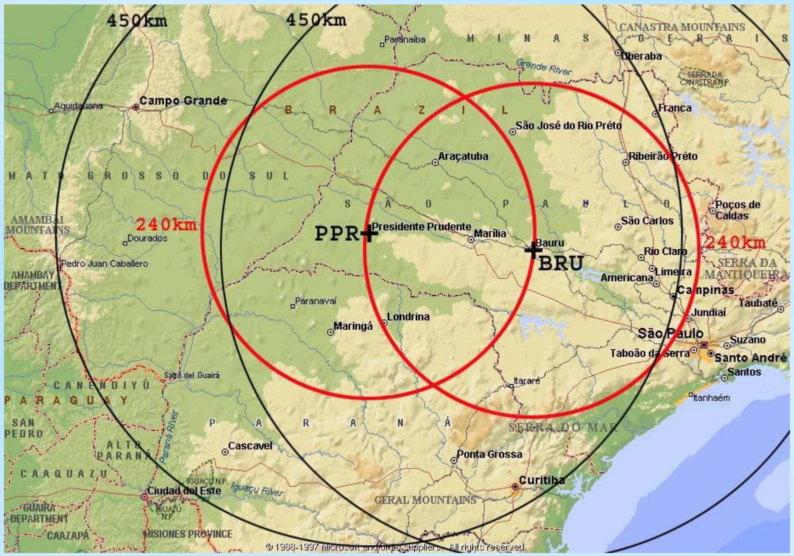


CONTINUOUS MEASUREMENTS

- **Frequency, distribution and intensity of precipitation**
- **Aerosol number and mass concentrations, and size distributions**
- **Cloud droplet effective radius**
- **Frequency of cloud to ground electrical discharges**

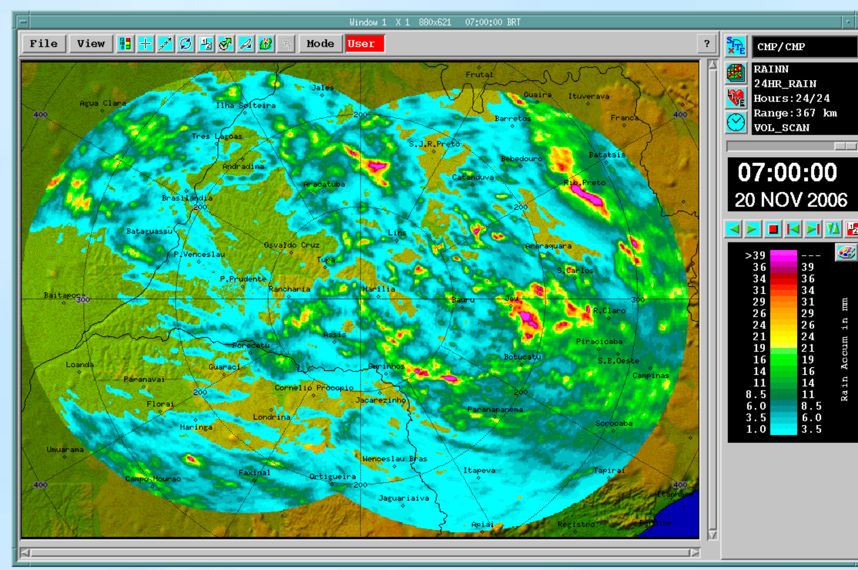
Frequency, distribution and intensity of precipitation

(S-band Doppler radars)



The IPMet radar network (BRU = Bauru; PPR = Pres. Prudente), indicating the 240 km and 450 km ranges, corresponding to quantitative and qualitative measurements, respectively

24-h accumulated rainfall (combined Bauru and Presidente Prudente radars, coverage of central and western regions of São Paulo State)



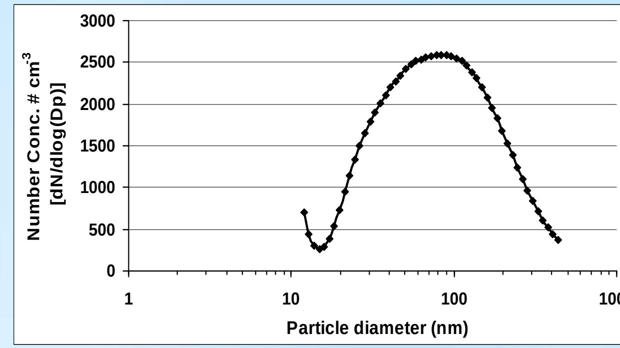
Aerosol number concentrations and size distributions

Scanning Mobility Particle Sizer (SMPS) + optical particle counters

Location: Ground station in Araraquara

TSI SMPS M3080L+M3775

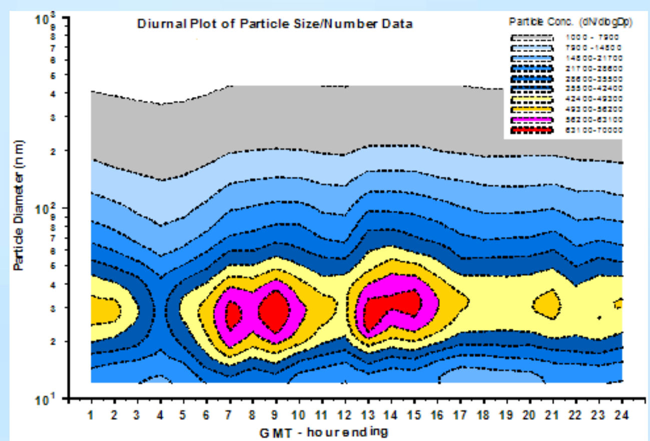
Aerosol size distribution: Multiple channels, 5 nm to 0.457 µm



Example of SMPS aerosol size distribution scan

TSI Aerotrak M9310

Aerosol size distribution: 6 channels, 0.3 µm to 20 µm



Example of diurnal plot of aerosol size distribution scans

Cloud droplet effective radius

MODIS (Moderate Resolution Imaging Spectroradiometer) spectral profiles near-infrared channels (1.6 μm, 2.1 μm, 3.7 μm)

AQUA / TERRA satellites

Data reprocessed for the geographical area with boundary coordinates (UL = -21.0 S, -49.0 W; LR = -22.75 S, -47.25 W)

(Software: MODIS Swathe Tool / HDF Explorer)

http://ladsweb.nascom.nasa.gov/

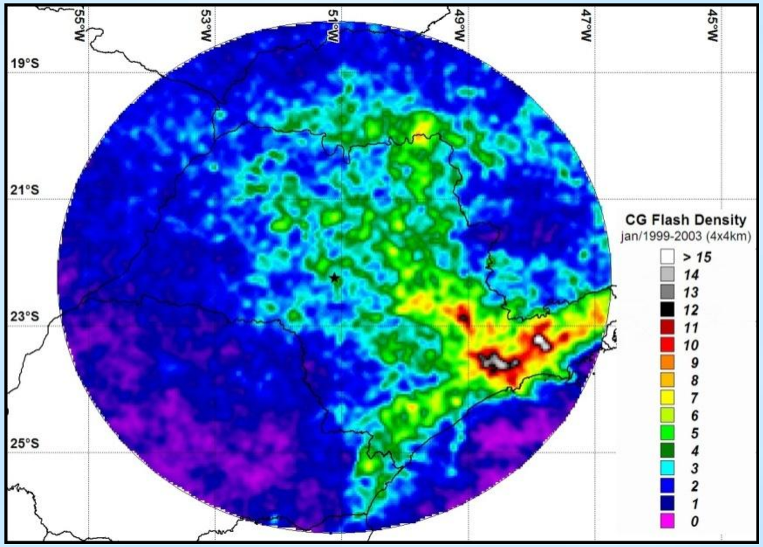
Frequency of cloud to ground electrical discharges

Brazilian Lightning Detection Network (BrasilDAT)

* Strong correlations between the frequency of cloud-to-ground lightning discharges, precipitation intensity and atmospheric aerosol loadings

(Naccarato et al., 2003; Naccarato et al., 2004)

Density of electrical discharges (cloud – ground) in January; mean for 1999-2003, within the range of the Bauru radar (Naccarato et al., 2004)



MEASUREMENTS DURING INTENSIVE CAMPAIGNS

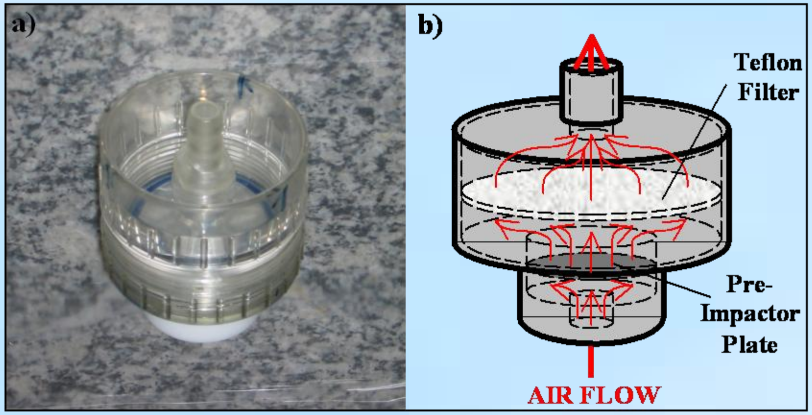
- **Aerosol chemical composition – use of source signature species**

  SOLUBLE IONS
  WATER-SOLUBLE ORGANIC CARBON
  ORGANIC COMPOUNDS
  - **Levoglucosan**
  - **PAHs**
  - **Nitro-PAHs**
  - **Carbonyls**

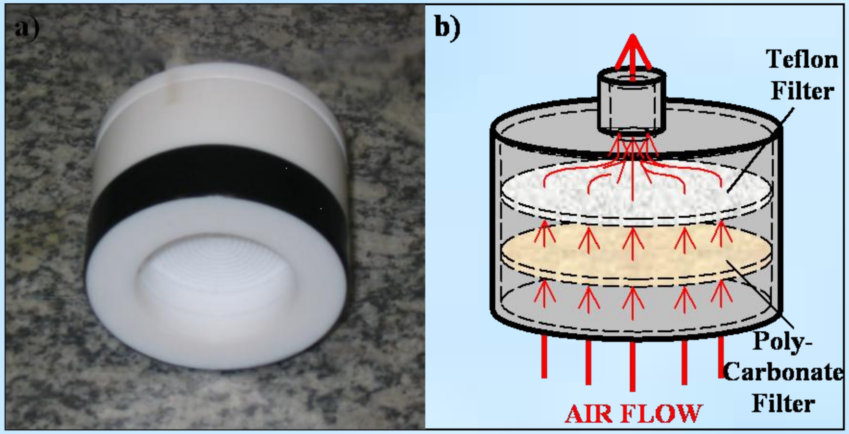
  TRACE ELEMENTS
  - **^{23}Na, ^{24}Mg, ^{27}Al, ^{39}K, ^{44}Ca, ^{51}V, ^{52}Cr, ^{54}Fe, ^{55}Mn, ^{59}Co, ^{60}Ni, ^{63}Cu, ^{66}Zn, ^{88}Sr, ^{111}Cd, ^{118}Sn, ^{133}Cs, ^{138}Ba, ^{140}Ce, ^{202}Hg, ^{208}Pb**

- **Hygroscopic growth characteristics of different aerosol classes**

Aerosol Sampling Techniques – Filters (low volume)



- PM_{10}
- Steel pre-impactor plate
- 50 % cut-off at flow rate of 8.5 L min^{-1}
- Teflon filter



- $PM_{2.5}$ / $PM_{>2.5}$
- Nuclepore pre-filter (12 µm pore size)
- 50 % cut-off at flow rate of 30.0 L min^{-1}
- Teflon filter

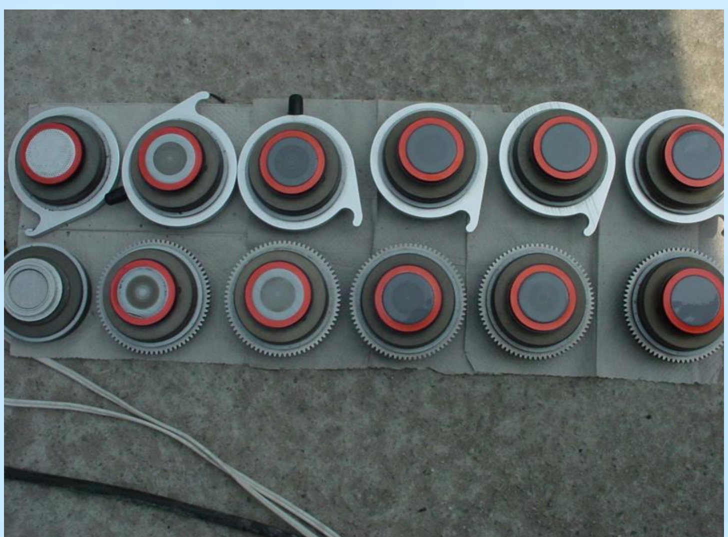
Aerosol Sampling Techniques – High volume samplers

Equipped with a 5-stage impactor with particle size cut-offs from >7.2 to <0.49 µm

Collection of aerosols for analysis of:

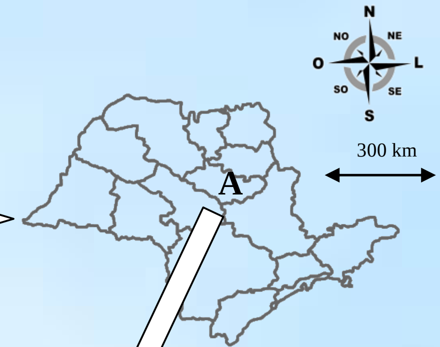
- Organic compounds
- WSOC
- Trace metals

Aerosol Sampling Techniques - Impactor



MOUDI Stage Number	*50 % Cut-off Particle Diameter (μm)*
Inlet	18.00
Stage 1	10.00
Stage 2	5.60
Stage 3	3.20
Stage 4	1.80
Stage 5	1.00
Stage 6	0.56
Stage 7	0.32
Stage 8	0.18
Stage 9	0.10
Stage 10	0.06
Backup or Stage 11	0

Sampling site – UNESP campus (Araraquara)



DATA STATISTICAL ANALYSIS AND INTERPRETATION

AIMS:

- Identification and quantification of aerosol sources
- Relationships between aerosol physical and chemical variables and (a) cloud droplet r_e, (b) precipitation parameters

METHODS:

- Principal components analysis (PCA)
- Factor analysis
- Simple and multiple linear regression routines

Input parameters:

Aerosol properties: Number size distributions; mass; water soluble ions (NH_4^+, Na^+, K^+, Mg^{2+}, Ca^{2+}, Cl^-, NO_3^-, SO_4^{2-}, CH_3COO^-, $HCOO^-$, $C_2O_4^{2-}$); elements (^{23}Na, ^{24}Mg, ^{27}Al, ^{39}K, ^{44}Ca, ^{51}V, ^{52}Cr, ^{54}Fe, ^{55}Mn, ^{59}Co, ^{60}Ni, ^{63}Cu, ^{66}Zn, ^{88}Sr, ^{111}Cd, ^{118}Sn, ^{133}Cs, ^{138}Ba, ^{140}Ce, ^{202}Hg, ^{208}Pb); organic tracer compounds

Cloud properties: Effective droplet radius

Precipitation: depth; frequency; intensity
Electrical discharge density

Preliminary results: Relationship between aerosol number concentrations and r_e

Aerosol size fraction (µm)	April (n=18) r	April (n=18) p	May (n=47) r	May (n=47) p	June (n=24) r	June (n=24) p
0.3-0.5	0.344	0.162	**0.503**	**0.000**	-0.261	0.218
0.5-1.0	0.395	0.105	**0.409**	**0.004**	-0.054	0.801
1.0-3.0	0.214	0.393	**0.458**	**0.001**	-0.325	0.121
3.0-5.0	0.164	0.515	**0.490**	**0.000**	0.125	0.559
5.0-10.0	0.149	0.555	**0.531**	**0.000**	0.305	0.147
>10	0.051	0.840	**0.349**	**0.016**	-0.199	0.352

- Positive correlations could be explained by hygroscopic particle growth – more information needed concerning smaller particles
- June – drier conditions, reduced hygroscopic growth, and r_e is negatively correlated with aerosol number concentrations in these size fractions

For cloud cover >20 %:

Significant inverse correlations:

r_e vs.1.0-3.0 µm (r = -0.88, p = 0.002)

r_e vs. 3.0-5.0 µm (r = -0.85, p = 0.003)

r_e vs. 5.0-10.0 µm (r = -0.76, p = 0.018) (n = 9)

- Greater consistency in the cloud-aerosol relationship during periods of more extensive cloud cover can be explained by a lesser influence of ephemeral or anomalous clouds (such as pyrogenic clouds, or clouds formed locally close to water bodies)

Concluding comments: progress to date

Current observations:

- Aerosol number concentrations (0.3 – 10.0 µm size range)
- Cloud r_e retrievals
- Precipitation data
- Aerosol collection (low volume, Hi-vol)
- Analyses of major ions, WSOC and levoglucosan

Measurements needed:

- Aerosol number concentrations (0.05 – 0.5 µm size range)
- Analyses of organic compounds and trace metals

Acknowledgements

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