TroCCiBras

TROPICAL CONVECTION and CIRRUS EXPERIMENT BRAZIL

> A MULTI-INSTITUTIONAL BRAZILIAN RESEARCH PROJECT <

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STUDY OF THE INTERACTION BETWEEN METEOROLOGICAL, ATMOSPHERIC CHEMISTRY AND LIGHTNING PARAMETERS IN TROPICAL CONVECTION BETWEEN GROUND LEVEL AND THE LOWER STRATOSPHERE IN THE STATE OF SÃO PAULO

TroCCiBras

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NOTE

This proposal can be downloaded from the **TroCCiBras Website:**

http://www.ipmet.unesp.br/troccibras/

1. INTRODUCTION

Research in atmospheric sciences and related topics often relies heavily upon observations in regions of the atmosphere which are inaccessible to many of the in situ observational systems, and even to remote sensing performed by instrumentation restricted to coverage at relatively close ranges. On the other hand, measurements effected by satellites or ground-based remote sensing tools, like wind, cloud and precipitation radars, as well as Lidars, always have to be validated before they can be declared of the quality-level required for research, or even for operational practices. Another fundamental issue refers to the in situ sensors, which are remotely operated, as is the case with conventional radiosondes. This sounding system, which has been the primary tool of validation for the atmospheric profiling both from space – with satellites – and from the ground as, for instance, through synergistically combined radio-acoustic, radiometer and GPS measurements, is known to be inaccurate for measurements of humidity in the upper troposphere and lower stratosphere, thus itself requiring independent verifications by other in situ sensors in that atmospheric layer.

High-flying aircraft and balloons then come into the scene as alternatives for the validation of measurements from both radiosondes and the variety of other satellite-borne, and ground-based remote sensing instruments. Commonly, such measurements are only performed during major field experiments, from which a number of ongoing or proposed research projects and validation campaigns in the area can profit.

The present proposal aims at taking advantage of the measuring capacity of two planned European Commission (EC) projects, designated “TROCCINOX” (Tropical Convection, Cirrus and Nitrogen Oxides Experiment) and “HIBISCUS” (a project on “Impact of tropical convection on the upper troposphere and lower stratosphere”), for effecting observations, which are vital to specific phases of research projects in Brazil. Those measurements are intended to explore vertically the environment throughout the troposphere, extending into the lower stratosphere; they will be centered in the State of São Paulo with a nominal coverage of a radius of up to 750 nautical miles (NM). The following section on “Background” details the need for such measurements, as well the European projects themselves. It will be followed by individual summaries of the Brazilian projects. For the sake of better comprehensibility, the projects are classified within three groups (“umbrella projects”) under the general titles of “Meteorology, Atmospheric Physics and Forecasting”, “Atmospheric Chemistry” and “Validation of Satellite-borne and Ground-based Remote Sensors”. The inclusion of the “Validation” project as a separate group is done on the grounds that this is an activity basic to any research effort.

2. BACKGROUND

Many of the science and technology projects in atmospheric sciences and related areas, developed or based in the State of São Paulo, rely heavily upon observational systems, either those constituting operational networks or specific arrays of instrumentation dedicated to research projects and, eventually a blend of both. While the horizontal spatial domain and the lower- to mid-tropospheric layer – to about 6 km – are within reach of a substantial amount of in situ sensing systems which are available in the State, or whose implementation is feasible in both economic and logistic terms, direct measurements in the mid to upper troposphere and in the lower stratosphere, are possible, in the foreseeable future, only through international cooperative programs. These are the measurements typically effected with aircraft and balloons, and commonly involve substantial manpower and funds. They are usually the cornerstone of large field campaigns and are, by nature, transitory, gathering much observational power provided by instrumentation-platforms eventually pulled from different parts of the world.

During the development of the so-called Radasp (Radar in Sao Paulo) project (Calheiros, 1985), active field campaigns have taken place in the State in the 80's, demonstrating the crucial role that measurements play in providing key insights on typical local/regional atmospheric phenomena, which otherwise would not materialize. These insights are often those that allow outstanding improvements both in statewide weather forecasts and in scientific knowledge of the meteorological systems spanning the region.

With the implementation of Doppler weather radars in the early 90's and the consolidation of mesoscale modeling practices, the demand on more accurate observations with more resolving power in time and space in the State of São Paulo has been steadily increasing. Eventually, the measurements extend to neighboring regions adjacent to the State of São Paulo, to accommodate requirements of the research and/or operations. Such is the case with some mesoscale modeling practices and studies involving, for instance, transport phenomena. This prompted the community to enhance the efforts regarding field campaigns based in the State, either developed individually with "in-house" capabilities or jointly with national and/or international partners. The experiment for assessing the capabilities of the Bauru radar in wind profiling in clear air is a good example of the former (Calheiros *et al.*, 1998); the balloon campaigns focusing on ozone measurements by means of high-flying balloons in the tropics, primarily a French effort, but in close collaboration with IPMet (Appendix 2), is emblematic regarding the latter.

Specific needs for direct measurements throughout the troposphere have been building up as research on subjects listed below began to intensify -

- severe storm dynamics in nowcasting;
- modeling of the complex interactions between cloud formation processes and aerosols;
- transport of aerosols and trace gases through cloud processes that impacts on the climatology of temperature and rainfall;
- effect of clouds on the composition and dynamic structure of the lower stratosphere;
- lightning genesis and contribution to the nitrogen oxides ($NOx = NO+NO_2$) budget;
- local/regional modeling of the atmospheric chemistry;
- validation of measurements from remote sensors, mainly satellite and ground-based weather radars, involving the matching of measurements from different sensors;
- assessment of clear air detection and cloud boundary determination, as well as rainfall quantification by microwave radiometry from space.

Two of these topics can, to a certain extent, be considered new in the State of São Paulo, with regards to specific measurements to be performed in order to meet the existing requirements. The first deals with the connection between lightning activity and the resulting NOx production, while the second relates to the validation of remote sensing measurements by both space- and ground-based sensors.

One very important question, which is specifically related to this project, is the ozone (O_3) budget throughout the vertical extension of the atmosphere, from the surface to about the lower stratosphere. In fact, the strong absorption of the earth's IR radiation by ozone turns this atmospheric component into a major issue in climate studies. In the troposphere, NOx is closely related to the O_3 chemistry. This relation involves two separate processes: 1) in the regions of high concentrations of NOx, ozone is produced in the transformation of NO to NO_2 through a photochemical process – this is facilitated by peroxy radicals formed during oxidation of carbon monoxide (CO), methane and volatile compounds, and 2) in the regions of low NOx concentrations, O_3 is destroyed catalytically. On the other hand, the abundance of nitrogen oxides regulates the atmospheric oxidizing power and global biogeochemical cycles. In this sense, they are intricately linked to the hydroxyl radical ($OH^\bullet$), which is another key atmospheric oxidizing species. And, through reaction between NO_2 and $OH^\bullet$, relatively stable nitric acid (HNO_3) is generated which, through rain down-washing, provides fixed nitrogen for the biosphere.

The sources of NOx can be of anthropogenic origin, e.g., fossil fuel, or generated naturally, like biomass burning, oxidation of atmospheric ammonia and lightning, injecting NOx into the atmosphere. However, transport from the stratosphere and aircraft emissions could also be significant sources.

Due to its relevance, NOx has been the object of much research, among which stands out the assessment of the relative importance of the sources. A recent study (Zhang *et al.*, 2003) on this issue focuses on the continental United States, dealing with the tropospheric chemistry processes through the use of the 3D numerical model MOZART (Model of Ozone and Related Chemical Tracers). By running the model with and without the lightning source, the lightning impact was determined: *Run i:* with both lightning and surface (including anthropogenic, biomass burning and soil release) emission sources of NOx; *Run ii:* without the lightning source; and *Run iii:* without the surface emission sources within the boundaries of the continental U.S. Lightning data spanning a 5-year period (1995-99) were used. Comparisons of the output of the model runs against aircraft observations, taken as averages from different field campaigns in summer over the US, show a good agreement. In all cases, the model results (with all sources included) were within the standard deviation of the aircraft observations and near the average values (Figure 1). Such an agreement validates the method used by the authors in dealing with the different NOx emissions.

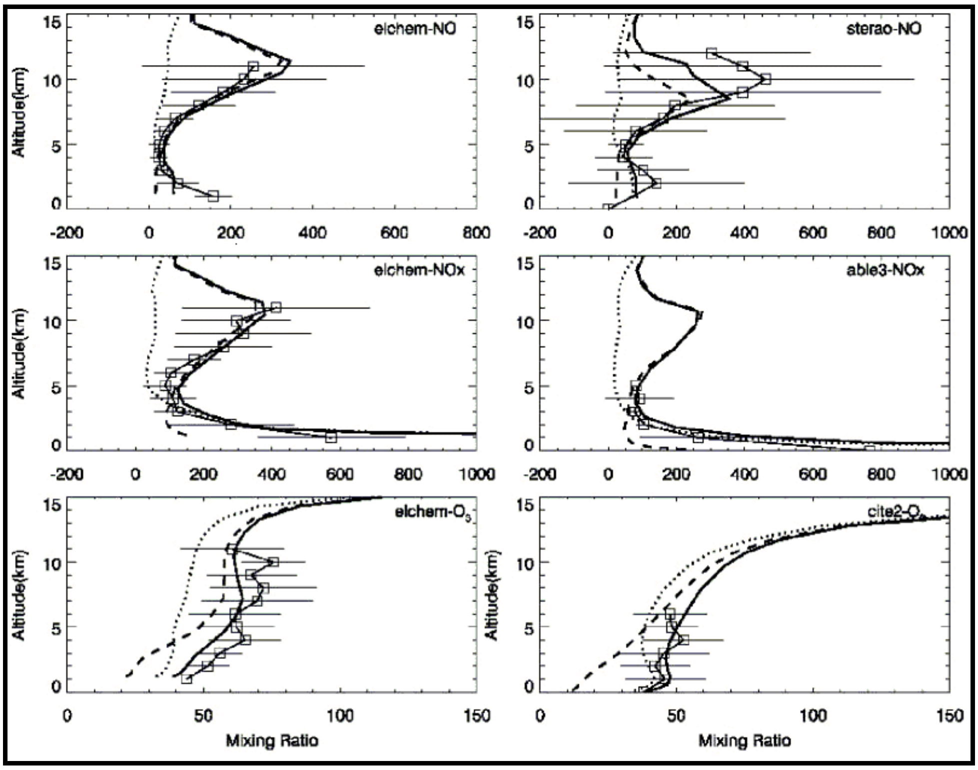

Figure 1. Vertical mixing ratio profiles of NO, NOx, and O_3 from model results and aircraft observations. The solid line with symbols shows the averages of concentrations observed from aircraft during the field studies. The horizontal lines represent the standard deviations of the observations. The solid line without symbols shows the concentrations calculated in model *Run i*, the dotted line represents model *Run ii*, and the dashed line corresponds to model *Run iii* (after Zhang *et al.*, 2003).

Outstanding among the results is the finding that summer lightning plays a surprising dominant role in the control of NOx and O_3 concentrations in the middle and upper troposphere, in spite of the fact that fossil-fuel burning represents the largest source of NOx over the US. Zhang *et al.* (2003) also verified, that the effect of lightning in the US propagates through vast areas of the northern hemisphere through atmospheric circulation (Figure 2). It can be noted in this figure, that at the 250 hPa level in July, the changes in the average concentrations of NOx are controlled by lightning over the US and other large areas of the northern hemisphere. It can also be seen that lightning in the US has a significant influence on O_3 concentrations over much of the northern hemisphere.

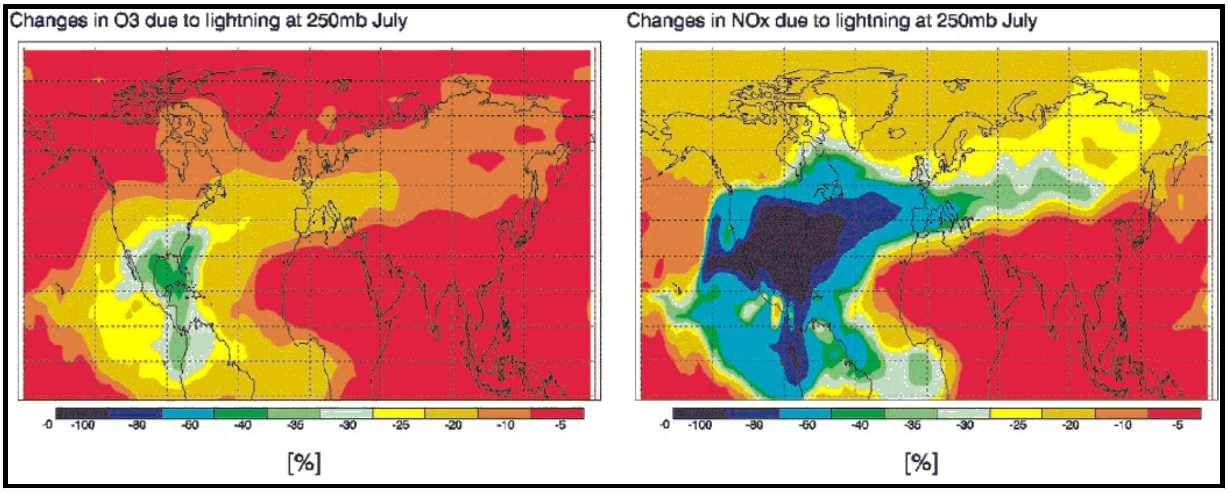

Figure 2. Horizontal extent of the influence exerted by U.S. lightning, in percentage changes in O_3 (left) and NOx (right) concentrations at the 250 hPa level, averaged for the months of July (after Zhang *et al.*, 2003).

Another important point to be considered here is that, in addition to O_3 production caused by NOx, transport and chemical processing – including stratospheric injection, horizontal advection and local chemical production/destruction - also strongly affect the O_3 concentrations in the troposphere. The results presented by Zhang *et al.* (2003) add significantly to the bulk of motivation for the deployment of field campaigns to measure NOx and O_3 in areas where lightning is concentrated, as is the case for the State of São Paulo and surroundings.

Much more pronounced effects, as compared to those found in the US study, are to be expected for the area focused in this proposal. In fact, in a recent study by Fehr and Pinto (2003), it is shown that for summer around Bauru, lightning density reaches 50 flashes $km^{-2}.yr^{-1}$ during the month of January, a figure about 5 times the maximum of 11 $km^{-2}.yr^{-1}$ occurring in Germany.

On the other hand, a simulation covering the whole earth with the global climate chemistry model ECHAM, for the months of December to January in a 5-year period, found a peak of lightning NOx production at approximately the SW quadrant of Bauru, which is near the geographic center of the State of São Paulo. Only a few other relative maxima are existing, i.e., in south-western Africa and north-western Australia (IPA/DLR, Appendix 1; see also Figure 3). While for the whole globe, lightning NOx production values generally vary from about <0.5 to 2.0 nanograms of nitrogen per second per square meter [$ng(N).s^{-1}.m^{-2}$], the above mentioned peak reaches a value $\geq 4.0\ ng(N).s^{-1}.m^{-2}$. Those measurements, by providing a comprehensive assessment of the sources of atmospheric NOx emissions will contribute essentially for the elaboration of control strategies for regional, as well global, air pollution.

The second topic relates to the validation of remote sensing measurements by both space- and ground-based sensors. Among the validation issues, the recent launching of the Aqua satellite carrying onboard a new generation atmospheric profiler, integrating the HSB (Humidity Sounder for Brazil), can be pointed out. This created a crucial need for accurate measurements of, for instance, humidity in the upper troposphere and lower stratosphere, where corresponding conventional radiosonde measurements are relatively inaccurate. As a result, an effort begun in the search for means through which as many of the required validation measurements as possible could be performed.

The TROCCINOX (Tropical Convection, Cirrus and Nitrogen Oxides) project was approved by the European Commission in 2002, to provide a multitude of atmospheric measurements from a tropical region (Appendix 1). Brazil was considered an option, amongst several others, for conducting these measurements, which is a unique opportunity to obtain very valuable data for many of the projects now being carried out in the State of São Paulo. The measurements to be performed during the project campaign fit well within many specific requirements of the State projects.

The main objectives of TROCCINOX, which is an RTD Program of the European Commission, DG RTD-I.2, “Energy, environment, and sustainable development“ (Key Action: 2 - Global Change, Climate and Biodiversity), can be summarized as follows:

- to improve the knowledge about lightning-produced NO_x (LNO_x) in tropical thunderstorms by quantifying the produced amounts, by comparing it to other major sources of NOx and by assessing its global impact, and
- to improve the current knowledge on the occurrence of other trace gases (including water vapor and halogens) and particles (ice crystals and aerosols) in the upper troposphere and lower stratosphere in connection with tropical deep convection as well as large-scale upwelling motions.

Thus, the project TROCCINOX will perform first measurements of the combined properties of convection, aerosol and cirrus particles and chemical air composition (nitrogen oxides in particular) in the tropics over oceanic and continental regions (State of São Paulo and adjoining areas) in the upper troposphere and lower stratosphere, including troposphere-stratosphere exchange. Bauru was identified as the ideal base point, due to its proximity to observed high lightning frequencies over the South American continent. A modeling component aims in providing improved descriptions of processes relevant to global climate problems (e.g., the production of NOx by lightning, as shown in Figure 3, which is based on a five-year simulation by the ECHAM model).

Another project with the participation of the European Commission, HIBISCUS, investigates the impact of tropical convection on the upper troposphere and lower stratosphere (Appendix 2). It is an essentially French effort conducted jointly with IPMet and built upon the previous experience with many campaigns of long-duration stratospheric balloon flights released from IPMet’s balloon launch facility in Bauru (Central São Paulo State). The HIBISCUS Pre-Campaign was realized during February 2003, when new balloon launch methods and newly developed payloads were tested ahead of the main campaign in 2004. For obvious reasons, it is coordinating its HIBISCUS Main Campaign in Brazil with the planned TROCCINOX activities in the country.

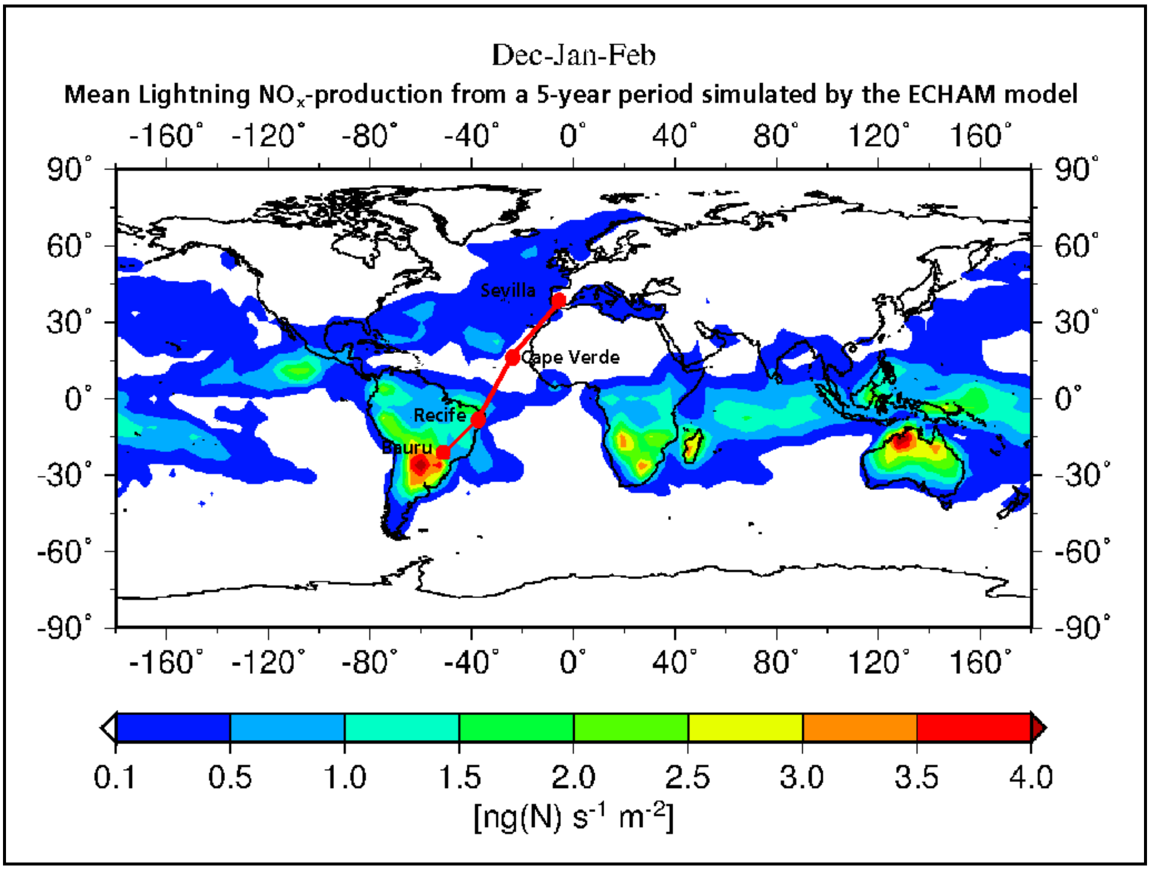

Figure 3. Mean lightning production from a five-year period simulated by the ECHAM model. The envisaged measuring site at Bauru, S.P., and transfer flight route of the involved research aircraft are shown in red (IPA/DLR, Appendix 1).

The general objective of the HIBISCUS project is to investigate the impact of tropical convection on the stratosphere at global scale. Thus, more specific objectives of the HIBISCUS project can be summarized as follows:

- Past and present meteorological analyses
- Vertical and horizontal transport
- Clouds and microphysics
- Source of stratospheric water vapor
- Chemistry, impact of lightning and pollution
- Satellite validation (ENVISAT, SAGE-III)

Further specific objectives will characterize the impact of convection on the tropical upper troposphere and lower stratosphere, the transport pattern, radiation, microphysics and atmospheric chemistry.

By its turn the TROCCINOX researchers, after analyzing the worldwide lightning activity and verifying that a region in the mid-western Brazil and Central Africa show the highest concentration, and taking into account crucial logistic aspects, concluded that Brazil offered the best conditions for an experiment on deep convection and associated lightning activity to take place. Also, the coordination with HIBISCUS, which is based in Bauru, contributed, to a certain extent, to that decision.

2.1 REFERENCES

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3. GENERAL OBJECTIVES

During the International TROCCINOX Workshop, initiated by the TROCCINOX coordinators (IPA/DLR) and their Brazilian partners (IPMet/UNESP), and realized in February 2003 at IPMet in Bauru, the interest of Brazilian research groups in participating in a joint multi-disciplinary research project, which would exploit unique data provided by the TROCCINOX and HIBISCUS campaigns, was tested. This Workshop was also joined by the HIBISCUS team, which was then engaged in the Pre-HIBISCUS 2003 Campaign, in preparation for the 2004 Main-Campaign. The Workshop was attended by about 35 delegates and most Brazilian research groups, specialized in Atmospheric Sciences, were represented.

It was proposed, that all relevant research organizations and University Departments be invited to submit a brief proposal, indicating intended activities during the joint campaign. The Lead Institution, IPMet/UNESP, would coordinate these short proposals and subsequently invite for complete proposals, including limited budgets, to be submitted. These were then organized into the current TroCCiBras Proposal for submission to the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) to authorize a “Scientific Expedition”, through which TROCCINOX could be invited to participate. On the other hand, HIBISCUS is an already ongoing joint project between CNRS and CNES on the European side and IPMet/UNESP in Brazil, and thus does not need the special status of “Scientific Expedition”.

The general objective of the TroCCiBras project is thus to obtain a set of special measurements throughout the troposphere and the lower stratosphere, to meet specific research needs of Brazilian research institutions, through the realization of the EU project TROCCINOX and the joint Brazilian / European project HIBISCUS in Brazil. Both projects are described in Appendices 1 and 2.

The different research sub-projects, although classified into three main topics, viz., “Meteorology, Atmospheric Physics and Forecasting”, “Atmospheric Chemistry” and “Validation of Satellite-borne and Ground-based Remote Sensors”, constitute in fact a comprehensive ensemble. In this sense, the validation represents a quality-controlled source of data for the meteorology and chemistry research topics of the project, e.g.

satellite profiles of temperature and relative humidity for the models (e.g., Eta, MOZART, etc), while interactions among different research sub-projects are often mentioned explicitly in the respective sections. However, some connections, as detailed in the sequence exemplify the comprehensive nature of the ensemble of sub-projects.

Thus, the estimates of cloud tops as characterized in the topic on clear air detection and cloud boundaries in the Validation research proposal link the investigations on echo top heights (especially those penetrating the tropopause), integrating the research line on Meteorology, Atmospheric Physics and Forecasting. Another example of interactions is the research on the dependence of chemical reactions in the stratosphere, which can seriously impact climate, on the quantities of pollutants and time-scales of the transport, which clearly involves both meteorological and chemical issues. In particular, the sub-project on “Air Pollution, Cloud and Climate Interactions” (Section 5.7) and the “Atmospheric Chemistry” Chapter show an intense interaction component with respect to that dependence. Yet, the investigation on nitric acid (HNO_3), which is a photochemical oxidation product of NOx, leading to the formation of organic and inorganic nitrates (which constitute cloud condensation nuclei – CCN) interacts with the sub-project on Cloud Physics Studies, which will deploy a Cloud Condensation Nucleus Counter (CCNC).

In conclusion, it can be stated that all sub-projects will contribute major milestones to the overall knowledge of the atmosphere over the State of São Paulo and thus facilitate the achievement of the two primary goals of TroCCiBras, viz., the validation of satellite-derived measurements (especially those of the HSB) and the improvement of Nowcasting methods.

4. INFRASTRUCTURE

4.1 IPMet’s PARTNER ORGANIZATIONS IN THIS STUDY

Lead Scientists are indicated for each group/organization.

- Centro de Previsão do Tempo e Estudos Climáticos (CPTEC) / Instituto de Pesquisas Espaciais (INPE) - Dr Carlos Nobre
- Centro de Lasers e Aplicações (CLA) / Instituto de Pesquisas Energéticas e Nucleares (IPEN) - Dr Eduardo Landulfo
- Centro da Química e Meio Ambiente (CQMA) / Instituto de Pesquisas Energéticas e Nucleares (IPEN) - Dr Luciana Vanni Gatti
- Centro de Ensino e Pesquisas em Agricultura (CEPAGRI) / Universidade Estadual de Campinas (Unicamp) - Dr Hilton Pinto
- Centro Técnico Aeroespacial (CTA) / Instituto de Aeronáutica e Espaço (IAE) - Dr Gilberto Fisch & Dr Luiz Augusto Machado (current affiliation CPTEC)
- Embraer, Gavião Peixoto Unit - Mr Paulo Urbanavicius
- Grupo de Eletricidade Atmosférica (ELAT) / Instituto de Pesquisas Espaciais (INPE) - Dr Osmar Pinto Junior (in collaboration with Dr Mike Taylor of Utah State University, USA, and Prof Paul R. Krehbiel of the New Mexico Institute of Mining & Technology, USA)

- Instituto Agronômico de Campinas (IAC) - Dr Orivaldo Brunini
- Instituto de Astronomia, Geofisica e Ciências Atmosféricas (IAG) / Universidade de São Paulo (USP) - Prof Maria Assunção F. Silva Dias & Prof Pedro Silva Dias
- Instituto de Física (IF) / Universidade de São Paulo (USP) - Prof Paulo Artaxo (in collaboration with Prof Meinrat O. Andreae of the Max Planck Institute for Chemistry, Mainz, Germany)
- Instituto Nacional de Meteorologia (INMET) - Dr Alaor Moacyr Dall'Antonia Jr.
- Universidade Estadual do Ceará (UECE) - Dr Alexandre Costa

4.2 AVAILABLE INSTRUMENTATION

In addition to the satellite sensors, as well as TROCCINOX & HIBISCUS instrumentation detailed in Appendices 1 and 2, respectively, the following instrumentation infrastructure will be available to conduct the proposed study, some of which is already in place -

- IPMet's S-band Doppler radars at Bauru & Presidente Prudente
- 3 Joss-Waldvogel Disdrometers (IPMet, Bauru)
- 2 Vaisala Radiosonde System (IPMet & CTA, Bauru)
- Lightning Detection Network (will be expanded over the State of São Paulo by INPE during 2003)
- High-sensitive cameras to observe sprite lightning (will be imported temporarily for the Jan/Feb 2004 experiment by ELAT/INPE in collaboration with the Utah State University)
- Backscattering Lidar to provide aerosol profiles of up to 10 km from the interior of the State (operated by CLA/IPEN)
- Ground-based air quality monitors (operated by CQMA/IPEN)
- Monitors for airborne measurements of aerosols & trace gases (supplied by IF/USP & M-P-I, to be installed in INPE's Bandeirante aircraft)
- UECE's Bandeirante aircraft fully instrumented for cloud physics measurements
- Remtech PA2 Sodar (IAG/USP)
- Sonic anemometer (CTA)

4.3 ADDITIONAL DATA

The following observations will be made available during the campaign period by collaborating organizations -

- Surface observations (possibly also intra-cloud flashes) of lightning supplied by ELAT/INPE
- Surface and Radiosonde observations within the study area supplied by INMET
- All on-line data (e.g., satellite pictures, RAMS Model output, Radiosonde Tephigrams, etc) available from “Master” of IAG/USP
- Automatic Weather Station data supplied by CEPAGRI/Unicamp & IAC
- Global Circulation & Prediction Models; Regional & Meso Eta Models operated by CPTEC/INPE, with specific, customized & project-related outputs issued during the Jan/Feb 2004 campaign
- Full set of high-resolution satellite observations during the Jan/Feb 2004 campaign provided by CPTEC/INPE

4.4 RESEARCH AREA

The primary area of research or “intense observation area” (IOA) will be in the State of São Paulo and neighboring states, within the range of the Bauru and Presidente Prudente S-band radars (Figure 5). More specifically, detailed studies of individual tropical clouds and storms will be conducted on the mesoscale within the 240 km range of the radars, for which volume scans will be available every 7.5 min, but could also be extended to within the 450 km radar range. Both these areas are well covered by lightning observations from the Brazilian network.

In order to also document the regional, as well as continental flow and life-time of NOx, especially the portion generated by lightning, various aerosols and other trace gases, including water vapor, it is vitally important to also fly missions along the south-eastern, eastern and north-eastern regions of the continent. This will primarily be done on the in-bound flight after a refuelling stop in Recife, en route to Gavião Peixoto (GPX, Figure 4), as well as on the return transfer flight. The outflow plume from the Amazon region (Silva Dias, 2003) could be best captured by transversal flights across north-eastern Brazil, before making a re-fueling stop at Recife. These measurements would be of great importance to the LBA studies by providing data which have so far been unreachable for Brazilian scientists. However, the feasibility of such a cross-section would largely depend on a suitable synoptic situation prevailing on the day of the return transfer flight from GPX to Recife.

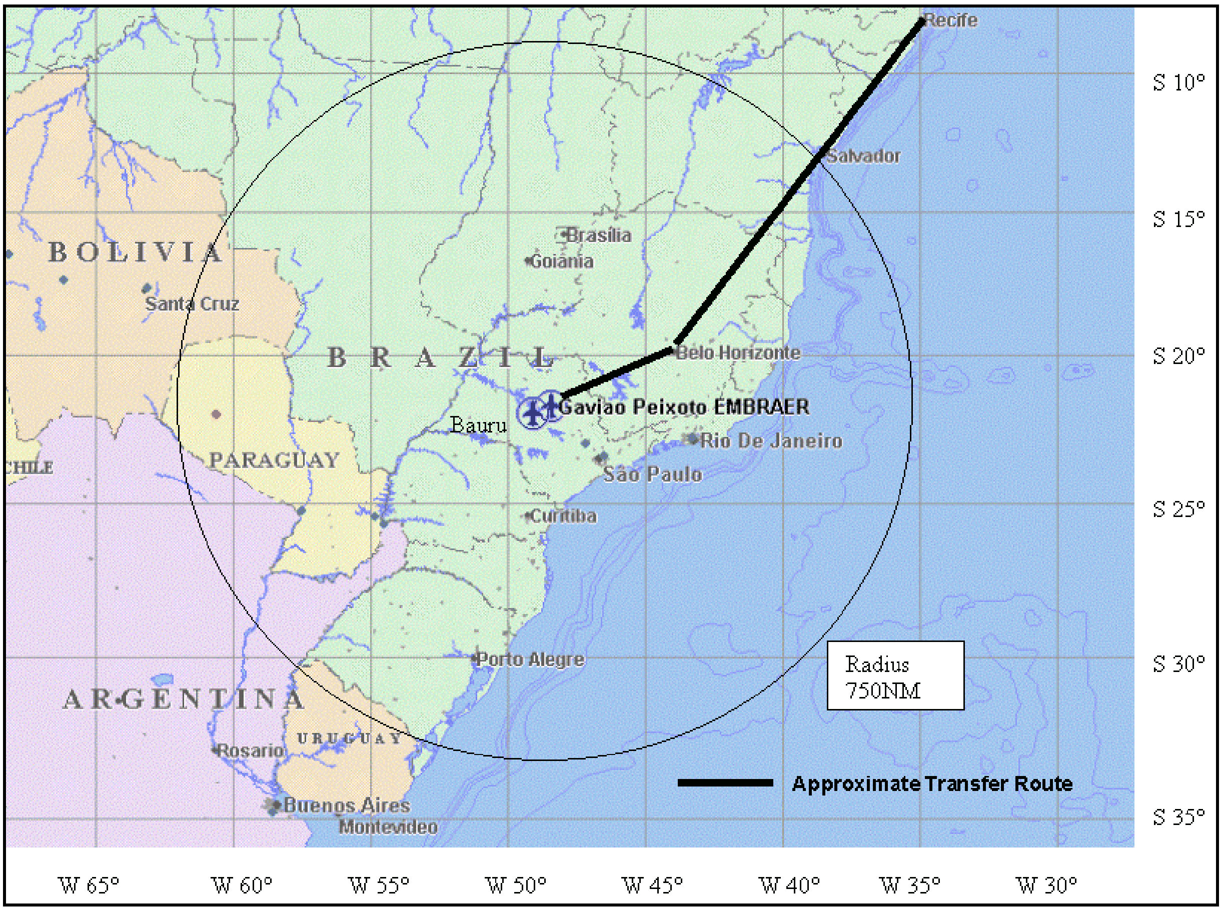

Figure 4. Operational range of the Geophysica M55 and Falcon 20 E-5 aircraft (750 NM) from Gavião Peixoto Airport (GPX) without re-fuelling stop (Source: H. Finkenzeller, DLR, 2003). The approximate route of the transfer flights is also indicated. Detailed flight routes and patterns will strongly depend on daily meteorological conditions and will have to be decided on a day-by-day basis.

4.5 REFERENCES

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5. METEOROLOGY, ATMOSPHERIC PHYSICS AND FORECASTING

5.1 INTRODUCTION

The analysis and interpretation of the weather phenomena and its related kinematics structure has been demonstrated in the literature focusing on extra-tropical cyclones and severe storms, while equivalent information on the tropics is still relatively sparse. In particular, the so-called ground validation programs including field campaigns for specific data acquisition would result in a unique data set that could be deployed for cloud studies and rainfall processes in tropical and subtropical areas, such as the central area of the State of São Paulo.

A combined set of measurements will provide an opportunity for the atmospheric science community to characterize the microphysical, kinematic and electrical structure of tropical convection over the central regions of the State of São Paulo. The Bauru (BRU) and Presidente Prudente (PPR) S-band Doppler radars (Figure 5) will provide the storm kinematic structure information of the precipitation systems as they evolve through their life cycle. These radar parameters will be supplemented by additional ground-based rain gauges, disdrometers and in-situ measurements by four aircraft.

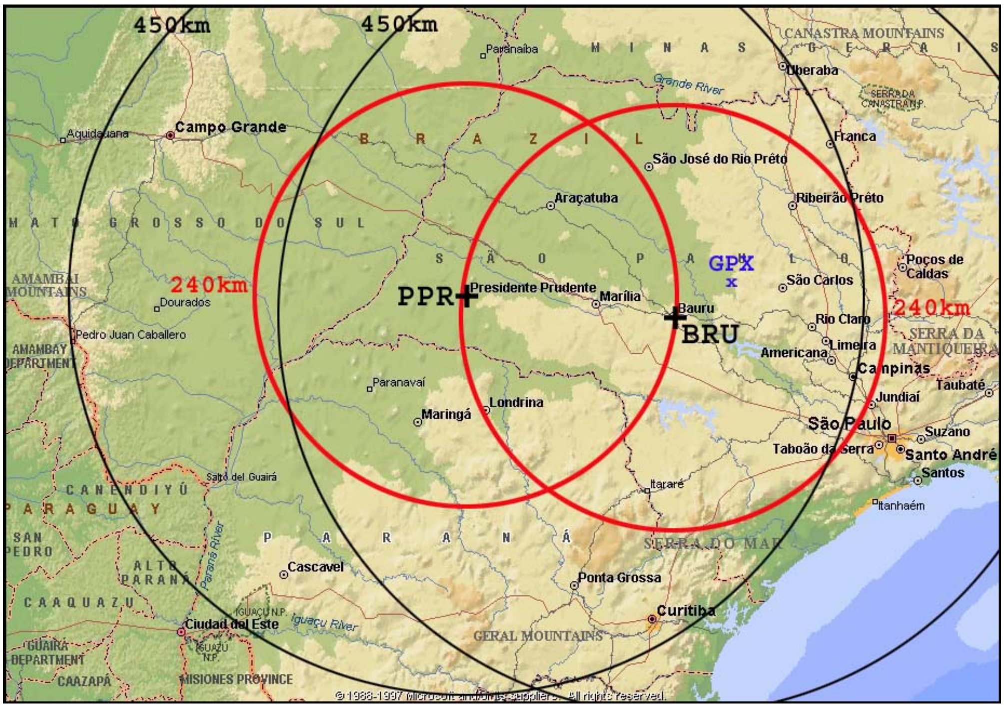

Figure 5. IPMet's Radar Network (PPR & BRU), showing 240 and 450 km range rings, as well as the location of Gavião Peixoto Airport (GPX).

In terms of vertical transport of aerosols and trace gases within convective systems, especially for those cases where the updrafts penetrate through the tropopause into the lower stratosphere, it is vitally important to document the relationship between echo tops (e.g., 10 dBZ) as measured by the S-band radars and actual cloud top as measured by the Geophysica (M55) aircraft and satellites. Depending on the quantities of pollutants and time-scales of the transport, different chemical reactions may take place in the stratosphere, which could have serious impacts on the global climate.

Observations of intra-cloud (IC) and cloud to ground (CG) lightning frequencies and properties will provide unique information regarding the precipitation formation, updraft structure and strength, as well as the electrical nature of the convection. This will complement the other radar- and aircraft-derived parameters and thus enhance the value of these measurements and their impact on forecasting procedures.

Finally, a pilot study for 8 February 2001, when relatively small and isolated storms caused a major flooding event in Bauru, resulting in 8 fatalities through drowning and collapsing structures or landslides, as well material damage exceeding USD 1.5 million (Held and Nachtigall, 2002), demonstrated that the Meso Eta model running in a non-hydrostatic configuration, centered over Bauru with a 10x10 km resolution, predicted the development of potentially severe storms in the Bauru area and accumulated rainfall very well 48 hours ahead (Held and Gomes, 2003). Thus, it is proposed to run this model operationally during the TROCCINOX experiment in collaboration with CPTEC and use the project data for validation and fine-tuning.

The more developed areas in Southeast and South Brazil are highly dependent on the hydrometeorological resources and are also recognized as important sources to the atmosphere of aerosol and trace gases derived from biomass burning and urban air pollution. Understanding and modeling the complex interactions of the underlying physical processess involved in cloud formation in the presence of aerosol, the cloud transport of aerosol and trace gases, and the ultimate effect on rainfall and surface climatology, will form the main thrust of the sub-project entitled “Air Pollution, Cloud and Climate Interactions“. This project will then also provide the link between meteorology and atmospheric chemistry, which is the second umbrella project within the framework of this Proposal.

5.2 RADAR OBSERVATIONS, INTEGRATION OF LIGHTNING OBSERVATIONS, NUMERICAL MODELS & NOWCASTING

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Co-Investigators:	**Ana Maria Gomes Held (IPMet/UNESP)** **Roberto Vicente Calheiros (IPMet/UNESP)** **Maria Andrea Lima (IPMet/UNESP)** **Jorge Luís Gomes (CPTEC/INPE)** **Maurício de Agostinho Antonio (IPMet/UNESP)** **Osmar Pinto Jr. (ELAT/INPE)**

INTRODUCTION

IPMet’s two S-band Doppler radars (Figure 5) are well situated in Bauru (Lat: 22° 21’ 28” S, Lon: 49° 01’ 36” W, 624 m amsl) and Presidente Prudente (Lat: 22° 10’ 30” S, Lon: 51° 22’ 22” W, 460 m amsl) to observe and track storms developing in tropical air masses being circulated from the Amazonia region, through Goiás / Mato Grosso do Sul into the western State of São Paulo. The common mechanism for this type of synoptic situation is governed by the upper air cyclonic vortex (Vórtice Ciclônico em Altos Níveis; VCAN) over Northwest Brazil or just off the coast and the Bolivian High (Alta Boliviana; AB) above the western part of the continent, creating a north-westerly air flow (Held *et al.*, 2003). It had been found, that during the past 8 years (1996 – 2003) on 33% of the days in February at least one, or more storms would penetrate through the tropopause into the lower stratosphere, but this frequency can increase up to 52% in some years (Held *et al.*, 2003). It is exactly this type of storm complex, which is of prime interest to the TROCCINOX community.

OBJECTIVES

The specific objectives of this sub-project are to:

- Describe the morphological characteristics of the convective systems in south-east Brazil (with emphasis on the central area of the State of São Paulo);
- Describe the physical characteristics of the rain systems reaching Bauru in terms of rain drop size distributions;
- Analyze the convective features of the central region of the State of São Paulo, including storm life cycles, rainfall intensity, thermodynamic structures and the interaction with electrical activities of the storms;
- Identify and compare similarities between tropical and subtropical convective systems as observed by radars;
- Verify echo top heights, especially in cases where they penetrate the tropopause, using observations from the Geophysica (M55) aircraft by comparing the radar echo contour at different thresholds with actually observed cloud tops;
- Investigate the vertical transport pattern and frequency of aerosols and trace gases reaching the lower stratosphere (this is directly relevant to research conducted under the sub-project discussed in Section 5.7, as well as in the “Atmospheric Chemistry” umbrella project);
- Relate lightning observations (network data of CG and IC flashes, magnitude, polarity, etc, but especially SPRITES, if they occur) with 3-D reflectivities and airflow, as well as the resultant NOx production measured by the Falcon and Geophysica aircraft (this will be done jointly with research conducted under the sub-project discussed in Section 5.6);
- Use data from the lightning network to improve nowcasting, since the occurrence of intra-cloud activity is indicative for the intensification of existing cells and the development of new ones.
- Use all available meteorological data to validate and later fine-tune the Meso Eta model, centered over Bauru and operated with a 10x10 km resolution at 3-hour time steps, to improve the prediction of potentially severe storm development and issue preliminary warnings to Civil Defense Authorities and other interested parties up to 48 hours ahead. This would form a significant contribution to the “Integrated Hydrometeorological System of the State of São Paulo” (SIHESP) Project.

OBSERVATION AND METHOD

- Routine weather forecasting will be provided by IPMet in collaboration with output from CPTEC, Master of IAG/USP and INMET.
- The Bauru and Presidente Prudente radars will be operated continuously (24 hours per day) in surveillance mode (450 km range), recording a 0º elevation PPI every 30 minutes. As soon as precipitation is detected within the 240 km range, the radar scanning mode will be changed to continuous volume scans, completing and recording a volume scan every 7.5 min.
- One Joss-Waldvogel Disdrometer (RD-80) will be operated continuously (24 hours per day), recording the precipitation over Bauru with a one-minute accumulation period.
- The Meso Eta Model (in non-hydrostatic mode) will be run by CPTEC with a 10x10 km grid, centered over Bauru, issuing 3- or 6-hour outputs (Held and Gomes, 2003).
- A consolidated “MET-INFO” page will be provided by IPMet via Intranet to all Campaign Participants, interactively, and updated automatically on-line.
- The research aircraft of TROCCINOX and TroCCiBras will be based at Embraer’s Gavião Peixoto Airport (GPX, just west of Araraquara; Figure 5), where an Operations Center with a direct Internet link to IPMet will be installed, providing immediate access to all on-line information required for flight planning.
- The storm climatology during the experimental period will be analyzed in detail.
- The relatively high sensitivity of IPMet’s S-band radars will be utilized to detect convergence areas, where future storm development is expected, by means of “clear air radar signals” *prior* to the occurrence of rain echoes; this study is limited to the “near-range” of up to 30-50 km (Lima, 2002).
- Storm complexes selected by TROCCINOX for aircraft measurements will be fully analyzed with 3-dimensional fields of radar reflectivity and radial velocities. These will be merged with aircraft measurements, lightning observations and ground monitoring results.
- A detailed characterization of the convective and stable boundary layer (CBL & SBL, respectively), as well as of the troposphere and lower stratosphere will be performed by means of 4-6 radiosonde ascents from Bauru and continuous Sodar wind profiles up to about 1.0 – 1.5 km above ground level.

PREVIOUS EXPERIENCE

The PI’s experience in radar meteorology and severe convective storms goes back to the early 70s, when he was contracted by the then Council for Scientific and Industrial Research in South Africa to establish a radar research meteorology group, using their newly acquired S-band radar near Johannesburg (Held, 1977; Carte and Held, 1978; Held, 1978; Held 1982). This research was also closely linked to hail and lightning being produced by severe storms (Held, 1973; Held, 1974; Held, 2002). During summer 1976 he spent one month with the National Hail Research Experiment (NHRE) in Colorado (USA). Subsequently, he was responsible for the implementation of the triple Doppler radar installation in South Africa (Held and Gomes, 1991; Gomes and Held, 1992).

The PI's experience in terms of boundary layer meteorology and atmospheric chemistry includes a leading participation in the SAFARI'92 project (Southern African Fire-Atmosphere Research Initiative; Held, 1996; Zunckel *et al.*, 1996), which is an international collaborative project and together with TRACE-A falls under the umbrella of STARE, which itself is part of the IGAC (International Global Atmospheric Chemistry) project and IGBP (International Geosphere-Biosphere Programme). Furthermore, he has initiated and coordinated several field campaigns, involving airborne pollution sampling (Held *et al.*, 1999), rain quality analysis (Held and Mphepya, 2000; Galpin and Held, 2002), transboundary transport of pollutants, dispersion modelling and drought cycles risk analysis (using various meteorological and hydrological models; Held *et al.*, 2002). He was editor of a book on air pollution in South Africa and is also lead author of two of its Chapters (Held *et al.*, 1996). Furthermore, he was a key participant and Regional Steering Committee Member of the international co-operative SAFARI 2000 project (Southern African Land-Atmosphere-Biosphere Interactions; Website: http://safari.gecp.virginia.edu/). More recently, he has participated in the last campaign of the Large-scale Biosphere Atmosphere Experiment in Amazonia – LBA ("Dry-to-Wet Season Campaign - LBA"; September/October 2002) as field coordinator for part of the campaign deploying the meteorological radar.

One of the co-investigators was instrumental in the Software Development and storm analysis of single and multiple Doppler radars in South Africa (Gomes and Held, 1990; Held and Gomes, 1991; Gomes and Held, 1992), as well as the implementation of EVAD for the S-band Doppler radar (Held and Gomes, 1991). All co-investigators have also participated in the "Amazon Boundary Layer Experiment" and various LBA campaigns (Silva Dias *et al.*, 2000; Silva Dias *et al.*, 2002), as well as in other, short field experiments (winter & summer 1996), that have been initiated and organized by IPMet (Calheiros *et al.*, 1997; Calheiros *et al.,* 1998). During recent years, the whole team was concentrating on the analysis of severe storms and nowcasting in the State of São Paulo in preparation for the SIHESP (Sistema Hidrometeorológico do Estado de São Paulo) Project (Gomes *et al.*, 2000; Held *et al.*, 2001; Held and Nachtigall, 2002; Held and Gomes, 2003), including the early detection of preferential areas for storm development (Lima, 2002). Rain drop size distributions were studied during short periods at IPMet, mostly to determine the local relationship between disdrometer and radar (Zawadzki and Antonio, 1988; Moraes *et al.*, 2002)

5.3 VALIDATION OF ATMOSPHERIC AND CHEMISTRY NUMERICAL MODELS

Principal Investigator: Carlos Nobre

Co-Investigators:	**Chou Sin Chan (CPTEC/INPE)** **Karla Longo Freitas (CPTEC/INPE)** **Jorge Luís Gomes (CPTEC/INPE)** **Josiane Bustamante (CPTEC/INPE)** **Leila Maria Mercê A. Martins (CPTEC/INPE)** **Saulo Ribeiro de Freitas (CPTEC/INPE)** **Paulo Artaxo (IF/USP)** **Maria de Fátima Andrade (IAG/USP)**

INTRODUCTION

The studies will broaden our knowledge base regarding tropical convection. The observations undertaken during the TROCCINOX field campaign are expected to serve as an important validation data set to be used to evaluate the performance of the atmospheric models (Eta) routinely implemented at CPTEC verifying its convection representation from the statistical point of view, as well as to validate and calibrate parts of the MOZART model, which will be implemented jointly with the Max-Plank-Institute (Hamburg, Germany). This project will interact closely with the “Atmospheric Chemistry” umbrella project (Chapter 6).

Furthermore, the Meso Eta model will be running during the TROCCINOX Experiment, centered over Bauru, with a resolution of 10x10 km, for operational forecasting (48 hours has proved so far to be the optimum window; Held and Gomes, 2003). This part of the project will be executed in direct collaboration with and support of the sub-project discussed in Section 5.2.

SCIENTIFIC BASIS AND METHODOLOGY

The Meso Eta model is a grid-point model that uses the vertical eta coordinate and can run in non-hydrostatic mode (Rogers *et al.,* 2001). It includes a cloud microphysics scheme to represent the grid-scale cloud and precipitation (Ferrier *et al.*, 2002). This cloud scheme predicts condensate in the form of cloud water, ice crystals, rain, snow, graupel and sleet. The campaign version of the model will parameterize the deep convective clouds by the Betts-Miller-Janjic scheme (Janjic, 1994). The Kain-Fritsch convective scheme is also available and will be run in parallel mode for validation and fine-tuning. Although these two schemes use different approaches and their results in the Eta model have shown similar satisfactory scores, the Kain-Fritsch scheme can provide information about the intensity of the updraft (Kain *et al.,* 2001). Short and long wave radiation processes are parameterized by the GFDL radiation package. The aircraft and radar measurements will be used to validate major cloud properties, particularly the deep convective cloud features such as cloud depth (top and base), cloud mass fluxes, cloud trajectory, cirrus anvil formation, condensation nuclei concentration and rain production.

To assess the importance of NOx production by lightning in the tropics, the global chemical transport model – MOZART (Model of Ozone and Related Chemical Tracer, Hamburg version; Horowitz *et al.*, 2003) will be used. This version of the model includes updates and improvements to the chemistry emissions and transport. Surface emissions of chemical species in MOZART include those from fossil fuel burning and other industrial activities, biomass burning, biogenic emissions from vegetation and soils, and oceanic emissions. Lightning is distributed in the model according to the location of the convective clouds (Rasch *et al.*, 1997) scheme. The MOZART is designed to take chemical species and reactions as input. The aircraft measurements of NOx emission by lightning and of NO_2 photolysis will be used to calibrate the chemical mechanism of MOZART.

Subsequently, all available data will be used for validation and fine-tuning of the atmospheric Meso Eta model and the MOZART model.

Backward and forward air parcels trajectories from the experiment area will also be calculated operationally during the experiment in order to provide flight planning and real time data analysis support. An air parcel trajectory model, following the methodology developed by Freitas *et al.* (2000) will be running using the wind fields from the operational ETA model. These trajectories, referred to as 3D kinematics convective trajectories, have a term to reinforce the effect of the convection on the vertical velocity at the model-resolved scale. The cloud covered fraction area **(*a*)** and the average vertical velocity at the cloud scale **(w_c)** are determined from a 1D cloud model and the convective trajectories are calculated using the wind fields given by **($u;v;aw_c+(1-a)w$)**, where **(u,v,w)** are the wind fields at the model-resolved scale. Trajectories following this methodology were ran during the LBA-CLAIRE experiment in the Amazon basin and proved to give much more reliable results in the presence of convective systems than the conventional 3D trajectories (Freitas *et al.*, 2000; Andreae *et al.,* 2001).

Thereafter, it is planned to use the trace gases and aerosol data collected during the experiment to validate a very recent implementation of shallow and deep convective transport modules, including aerosol wet removal, in a tracer transport model. Freitas *et al.* (2003) describe an in-line Eulerian tracer transport coupled to RAMS (BATTRAM, Brazilian Atmospheric Tracer Transport Model) originally developed to simulate the transport of biomass burning emissions. Basically, BATTRAM solves the mass conservation equation, including the grid scale advection, the sub-grid turbulent transport in the PBL, the sub-grid transport associated with deep and shallow convection, the convective wet-removal and dry deposition, providing the 3D tracer distribution. The convective transport modules are linked to a mass flux cumulus scheme (Grell and Devenyi, 2002). The idea is to use BATTRAM to study the transport and deposition of passive species such as CO and aerosol particles due to convective activity. An example of the model performance on simulating convective activity can be seen in Figure 6, which shows a comparison of 24-hour (on 7 September 2002) accumulated rainfall (mm) as observed by the Tropical Rainfall Measuring Mission (TRMM) and as simulated by the model. Figure 7a is a vertical cross section at latitude 13° S showing the high CO concentration (biomass burning production) in the Planetary Boundary Layer (PBL) and the CO vertically transported to the high troposphere by convective systems associated with the cold front. Figure 7b shows the plume of CO at the 10700 m (~250 hPa) level being advected by the zonal flow. These simulations agree very well in general pattern and apparently in magnitude with the MOPITT CO estimated for the day. For PM2.5, as it is mainly scavenged by rainfall, the main effect is its deposition over the continent and Atlantic Ocean (Figure 7c).

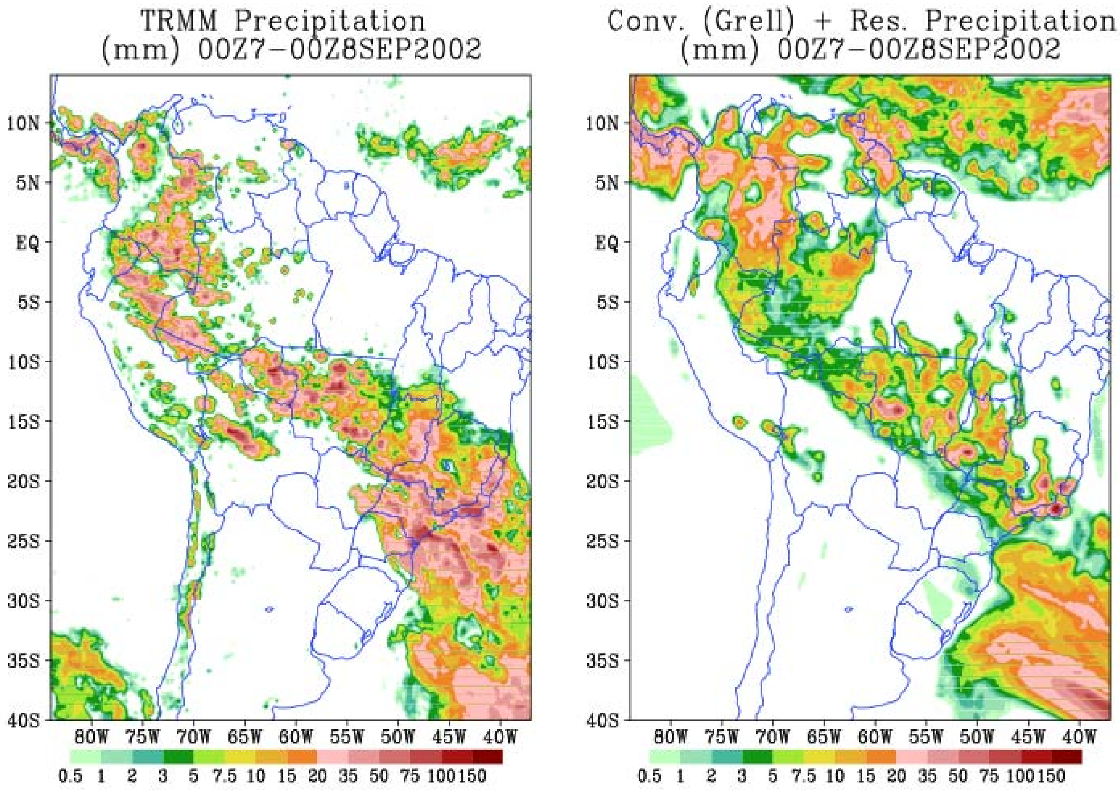


Figure 6. Left: 24-hour accumulated rainfall (mm) on 7/8 September 2002, as observed by the Tropical Rainfall Measuring Mission (TRMM); **Right:** model simulated (convective (Grell *et al.*, 2002) plus resolved) rainfall for the same period.

PREVIOUS EXPERIENCE

All members of the CPTEC Modeling Group have many years of experience, not only in running operational climate and forecasting models, ranging from global scale (NCEP Analysis), through regional scale (operational Eta) to mesoscale (Meso Eta), but also in verifying, fine-tuning to local conditions in Brazil, and developing of new modules for the various models. They have been specializing through post-graduated or post-doctoral studies in the USA, United Kingdom, Italy and Germany. They will be supported by members of USP, who have many years of experience in air quality measurements in the context of major Brazilian field experiments, like the various LBA projects.

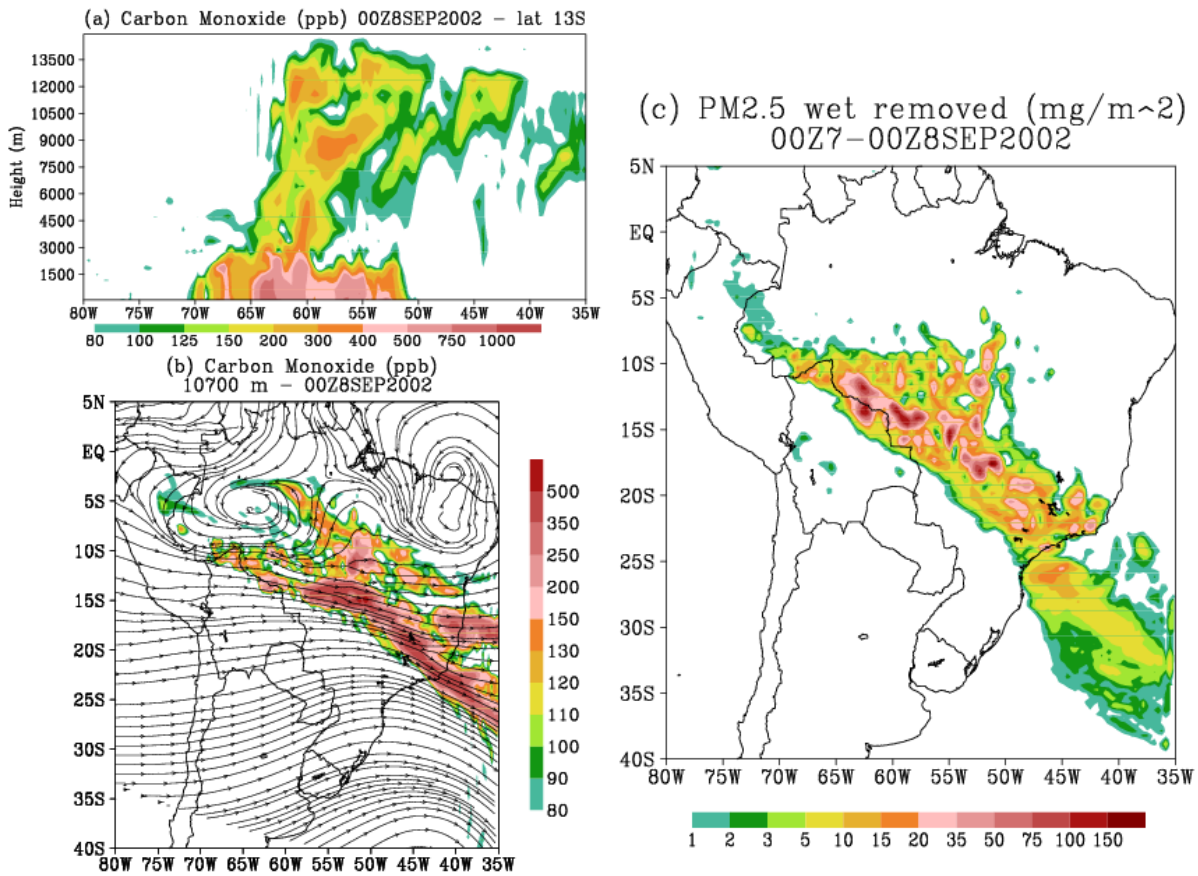


Figure 7. (a) Vertical cross section at latitude 13 S of CO (ppb) concentration in the PBL and the CO vertically transported to the high troposphere on 00Z September 8. **(b)** Plume of CO at level 10700 m (~250 hPa) being advected by the zonal flow. **(c)** Accumulated PM2.5 wet removed (mg.m^{-2}) between 00Z 7 – 00Z 8 September.

5.4 THE COUPLING BETWEEN THE BOUNDARY LAYER AND THE ONSET AND VIGOR OF MOIST CONVECTION

Principal Investigators: **Gilberto Fisch (CTA)**
Luis Augusto Machado (CPTEC/INPE)

Co- Investigators: **Marcus Oyama (CTA)**
Rosa Marques (CTA)
Jorge Luís Gomes (CPTEC/INPE)
Gerhard Held (IPMet/UNESP)
Ana Maria Gomes Held (IPMet/UNESP)

INTRODUCTION

The main source of water vapor to the clouds during the summer in the State of São Paulo is through surface evaporation. The water vapor is transferred to the atmosphere by turbulent processes (which characterize the convective boundary layer) producing clouds and heavy rain in the late afternoon. The surface conditions (both thermodynamic and dynamic) modulate the characteristics of the convection, producing cumulus clouds (which may or may not develop during the day). The vigor of the convective forcing indicates the time and space scale of the convective cloud organization. The area of the cloud shield of the convective system changes in association with the upper level wind divergence and with the condensation/ evaporation process. A rapidly growing convective system is a cloud cluster with strong liquid water condensation and strong vertical mass flux. The area increase in the initial stage is mainly due to the condensation process and thereafter, in the mature stage, it is due to the upper air wind divergence. The upper air divergence is a signature of the mass flux inside the convective towers that had previously contributed to the condensation process. The Planetary Boundary Layer (PBL) controls the mass flux inside the cumulus cloud and probably can control the spatial and time scale of the convection.

First profiling of the lower troposphere in the central State of São Paulo was done by IPMet in 1981 during intensive field campaigns, using frequent radiosonde ascents (Silva Dias and Silva Dias, 1982). However, this current sub-project goes much further, by also deploying a tethered balloon, which provides a detailed profile of the temperature, humidity and wind direction in the first few hundred meters above ground level, as well as a sodar, which provides continuous profiles of the u, v and w components of wind (in addition to wind direction and speed) up to 1000 – 1500 m above ground level. These parameters are essential inputs for the modeling groups of HIBISCUS, TROCCINOX and CPTEC, as they provide the basic information to calculate the heat flux from the earth‘s surface.

A pilot study (Held and Gomes, 2003) clearly showed the potential of the non-hydrostatic Meso Eta model to predict most of these parameters reasonably accurately, but more case studies would be required before one could generalize this.

This sub-project aims to study this interaction by means of regular observations in the PBL during the TROCCINOX experimental period and subsequently transfer the knowledge to modeling strategies, thus allowing for fine-tuning of the mesoscale models.

OBJECTIVES

The overall objective of this sub-project is to investigate the role of the PBL in triggering the moist convection during the summer in the State of São Paulo. The scientific questions to be answered are:

- What is the structure of the PBL over the Bauru area?
- What is the coupling mechanism between thermodynamic conditions at the surface and the structure of the PBL to trigger the moist convection?
- How and when does the boundary layer control the vigor and lifetime of the convective cells, with special emphasis on storms penetrating into the lower stratosphere?
- How well does the non-hydrostatic Eta model, centered over Bauru with 10x10km resolution, predict favorable boundary layer conditions for the development of severe storms?

- How long before precipitation echoes are observed by the IPMet S-band Doppler radars can they identify the convergence areas and how is this linked to the PBL conditions?

METHODOLOGY

- Radiosonde ascents: 4 standard soundings per day (at 00, 06, 12 and 18 UTC) and 2 extra soundings (at 15 and 21 UTC) during 20 days (January / February 2004, coinciding with the TROCCINOX intensive operations), yielding a total of up to 6 soundings per day at 03:00, 09:00, 12:00, 15:00, 18:00 and 21:00 LT. These soundings will have to be coordinated with HIBISCUS and TROCCINOX operational requirements. Some of the ascents will also carry ozone sondes, using larger balloons to reach the stratosphere, which will be transmitting for >4 hours. This will necessitate the use of multi-frequency radiosondes.
- Measurements with the tethered balloon up to 500 m in the early morning and noon.
- Continuous measurements of the wind profile with a SODAR equipment.
- Additional measurements with aircraft (turbulent fluxes at the entrainment zone) will complete the data-set.
- Radar operation generating volume scans every 7.5 minutes (provided by IPMet).
- Satellite GOES and MODIS images (provided by CPTEC/DSA).
- Model runs of the Meso Eta model (in non-hydrostatic mode, centered over Bauru, reolution 10x10km) provided by CPTEC.

PREVIOUS EXPERIENCE

The pricipal investigators have been key scientists in all major Brazilian field experiments, with special involvements in the various LBA projects, as well as the South American Low Level Jet Project (SALLJ), all of which are international collaborative projects. The experience of some of the Co-Investigators has been listed in Sections 4.2 and 4.3.

Team: Scientists (3), Technicians (4) from CTA, and PhD and MSc students from INPE (2).

5.5 CLOUD PHYSICS STUDIES

Principal Investigator: Alexandre Costa (UECE)

Co-Investigators:
José Carlos Parente de Oliveira (UFC)
Gerson Paiva Almeida (UECE)
Carlos Jacinto de Oliveira (UECE)
João Bosco Verçosa Leal Jr. (UECE)

INTRODUCTION

In order to link detailed radar observations with the airborne measurements from the Falcon (mid-troposphere) and Geophysica (upper troposphere and lower stratosphere) aircraft, it is essential to also measure simultaneously cloud physics parameters and air pollutants (aerosols and trace gases, cf "Atmospheric Chemistry", Chapter 6) between ground level and the mid-troposphere.

OBJECTIVES

This project has the following objectives:

- Investigating microphysical properties (hydrometeor concentration, mean diameter, size distribution and shape, in case of ice particles) in order to provide a better understanding of cloud electrification;
- Evaluating how different aerosol sources influence cloud microphysics and their ability in producing lightning discharges;
- Finding representative distribution-functions of hydrometeors (particularly cloud droplets and raindrops) as a basis for development and/or calibration of physical parameterizations in atmospheric models, including electrification processes and lightning generation;
- Investigating possible cloud microphysics feedbacks involving nitrogen oxides, such as interactions between NOx and sulfur compounds to produce sulfates in clouds (via hydrogen peroxide) and clear air (via hydroxyl radical), which may alter aerosol processing by clouds.

STATE OF THE ART AND AVAILABLE METHODS

Cloud microphysics measurements have received increased attention by atmospheric scientists from a diversity of fields, as knowledge on cloud particle concentration, type and size distribution are very important for calibrating remote instrumentation, such as the ones installed on satellites, as well modeling studies of the climate system. From that perspective, *in situ*, airborne measurements are still the most reliable means to collect aerosol and cloud microphysics data, by using aerosol and hydrometeor counters/sizers.

State-of-the-art airborne aerosol and cloud microphysics instrumentation include very sophisticated equipments that count and classify cloud particles by size. In addition, capturing cloud particle images, which is fundamental for ice-phase and mixed-phase cloud studies, is now possible.

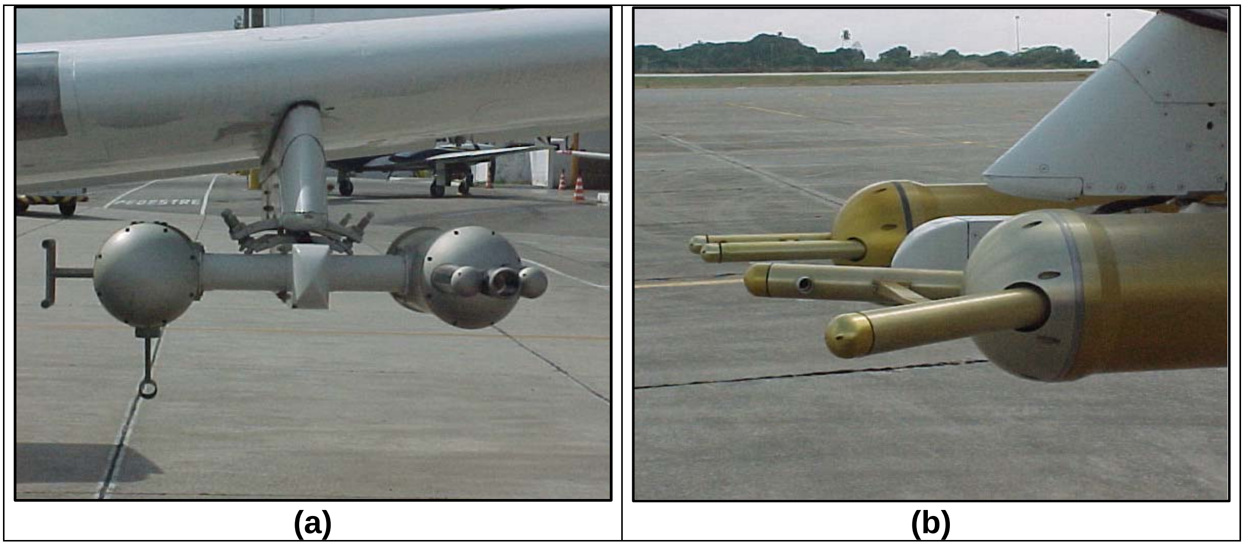
A very comprehensive platform for cloud microphysics studies – particularly in the warm phase – is already available for the atmospheric science community in Brazil, viz. the UECE's ALPA (Portuguese acronym, which stands for Airborne Laboratory for Atmospheric Research).

ALPA (Figure 8) is a Bandeirante, modified for research, which has reinforced wings and landing gear, as well as underwing hardpoints. It is equipped with a Global Positioning System (GPS), sensors for static and dynamic pressure, temperature, humidity and liquid water content, a cloud condensation nucleus counter (CCNC), and three spectrometer probes (Forward-Scattering Spectrometer Probe FSSP-100 with the Signal Processing Package SPP-100, Optical Array Probe OAP-200X, and Optical Array Probe OAP-200Y, Figure 9) that allow particle counting and sizing in the ranges of 2-47 μm (FSSP), 30-450 μm (200X) and 300-4500 μm (200Y). In other field experiments, ALPA has temporarily received a variety of other instruments, such as a Passive Cavity Aerosol Spectrometer Probe (PCASP), a CN counter, an aethelometer and a nephelometer.

Figure 8. UECE's Airborne Laboratory for Atmospheric Research (ALPA/UECE).

WORK PLAN

A combination of different flight strategies will be used, aiming at a detailed description of aerosols and cloud microphysics during the field campaign. Of course, there must be flexibility in choosing flight strategies during the campaign, and multiple procedures may be used during the same flight to achieve multiple objectives. The final decision on the combination of flight strategies will be taken in collaboration with the TROCCINOX flight plans and based on day-to-day meteorological conditions.



(a) (b)

Figure 9. Sensors installed on ALPA's **(a)** left wing (LWC sensors and FSSP-100) and **(b)** right wing (OAP-200X and OAP-200Y).

AEROSOL VERTICAL PROFILING

Spiral flight trajectories, as the one depicted in Figure 10 will be used to investigate how atmospheric aerosols are distributed in the vertical, within and above the boundary-layer.

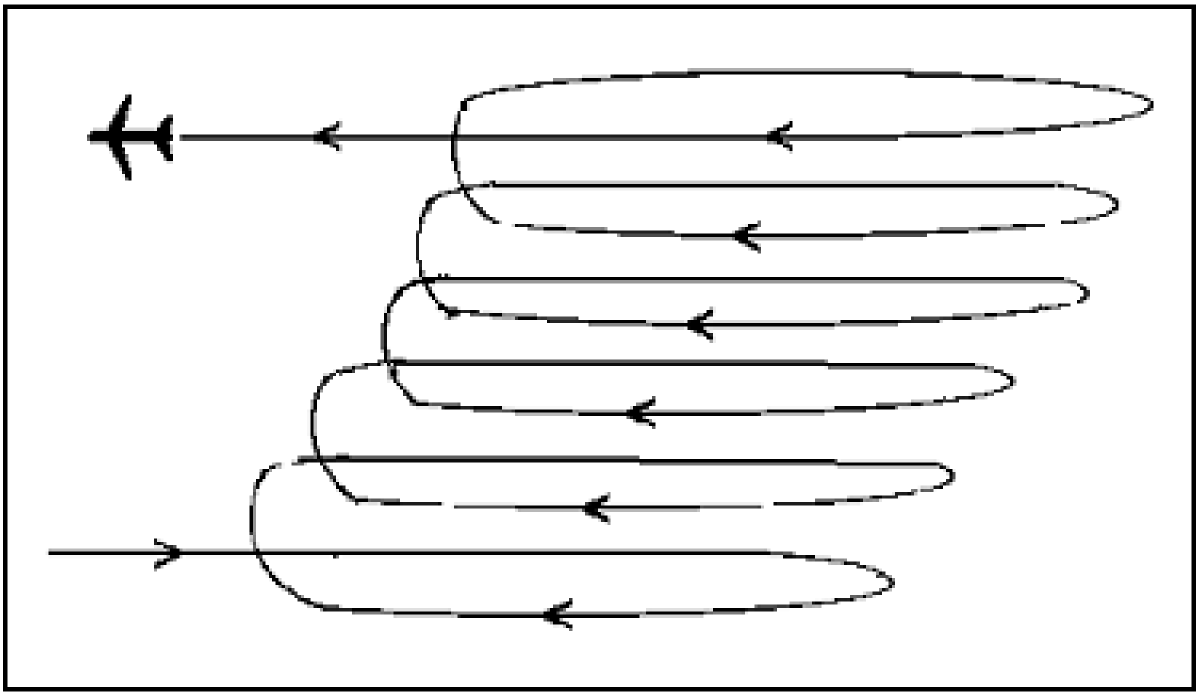


Figure 10. Flight strategy for aerosol vertical profiling.

NUCLEATION PROCESS IN CLOUD BASES

Associated with diverse conditions of aerosol transport and/or emission, different cloud microphysics regimes are commonly established in may regions of the world (an extreme example is the Amazon, in which very polluted conditions due to fires occur during the dry season, whereas a much cleaner environment is found during the wet season).

In order to verify how CCNs are activated into cloud droplets in different microphysical regimes, a flight procedure can be used, in which the aircraft alternates constant-height passes below the cloud field with penetrations inside non-precipitating clouds, just above their bases, as in Figure 11. Hence, a relationship is found between the CCN spectra and the newly-formed cloud droplet spectra.

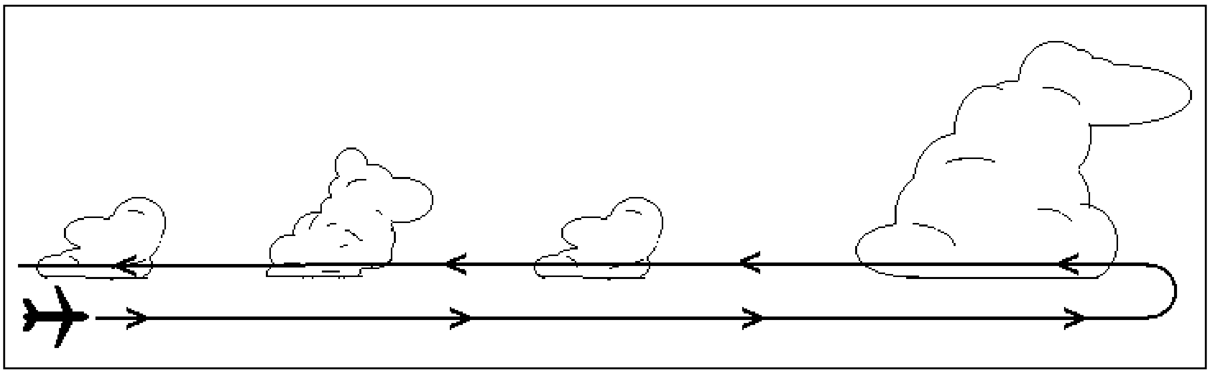


Figure 11. Flight procedure used to investigate the nucleation process.

VERTICAL PROFILES IN CONVECTIVE CLOUDS

Deep convection often evolves from towering cumulus at the *congestus* stage, in which warm-phase processes (droplet growth via condensation and collision-coalescence) prevail.

Many characteristics of convection’s life cycle, including its precipitation efficiency and its predisposition for lightning production, are greatly influenced by the vertical structure of cloud droplet spectra. Hence, vertical profiles in developing convection must be conducted, as shown in Figure 12. Of course, this is the case for an isolated convective cell, which is not always the case (often, convection develops in cloud clusters). Based on the assumption that all cells in the same cloud system have approximate microphysical characteristics, penetrations at different levels may be carried out in different towers, instead as shown in Figure 12.

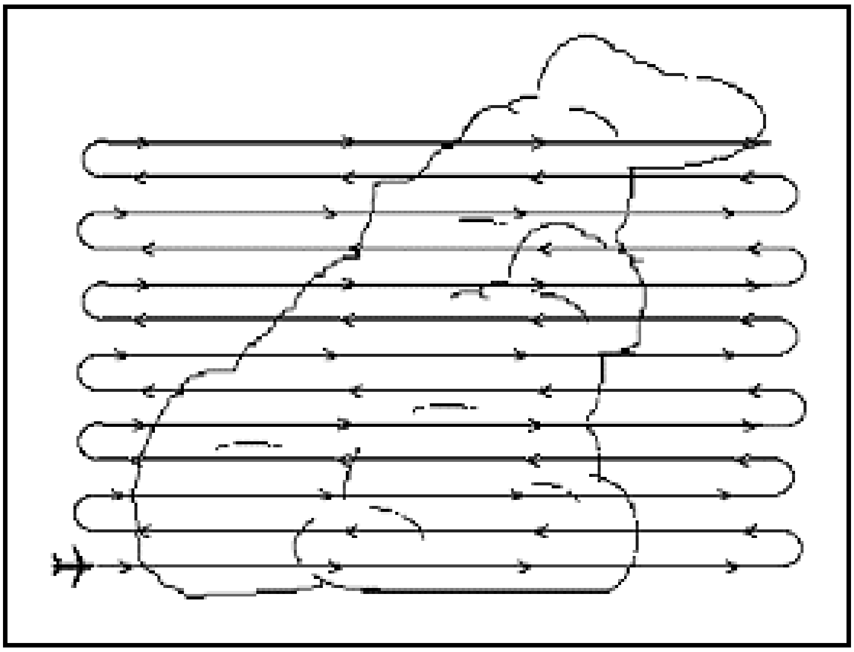


Figure 12. Flight procedure to sample towering cumulus vertically.

PREVIOUS EXPERIENCE

UECE's cloud microphysics group, which includes affiliates from partner institutions (FUNCEME, Fundação Cearense de Meteorologia e Recusos Hídricos, and UFC, Universidade Federal do Ceará) has conducted and/or participated in a number of field projects involving aircraft measurements with distinction to the "Ceará Experiment", carried out in 1994 (Costa *et al.,* 2000), the EMfiN!-ESN-Ceará (*Experimento de Microfísica de Nuvens / Experimento de Semeadura de Nuvens do Ceará* or Cloud Microphysics Experiment / Cloud Seeding Experiment in Ceará) and the SMOCC-EMfiN!-LBA (Smoke Aerosols, Clouds, Rainfall and Climate – Cloud Microphysics Experiment – Large-scale Biosphere-Atmosphere Experiment in Amazônia), both conducted in 2002.

Team: Currently, the group comprises 5 researchers at the Ph.D. level, 2 researchers at the M.S. level, 2 pilots, 1 mechanic, and a number of graduate and undergraduate students.

COOPERATION

To carry out the project, there is a demand for upper-level measurements, which will be supplied by the TROCCINOX aircraft measurements. All TROCCINOX flights will be supported by cloud physics and atmospheric chemistry flights in the lower part of the troposphere, using the specially instrumented Bandeirantes from UECE and INPE. However, since only about six TROCCINOX flights are planned, the two Bandeirantes will also perform measurements in the lower troposphere on suitable days between TROCCINOX flights. This project will be conducted in close cooperation with sub-projects discussed in Sections 5.2 and 5.6, as well as in Chapter 6 on "Atmospheric Chemistry".

5.6 LIGHTNING AND SPRITES STUDIES

Principal Investigator : **Osmar Pinto Jr. (ELAT/INPE)**

Co-Investigators: **Marcelo M. F. Saba (ELAT/INPE)**
Mike Taylor (Utah State University, USA)

Besides providing the above-mentioned information from the lightning network (cf. Section 5.2), this project will concentrate on SPRITES, as observed with a set of highly sensitive cameras, to be loaned by the Utah State University.

SPRITE is a new phenomenon observed in the United States in the beginning of the 1990s (Sentman *et al.*, 1995), right above thunderstorms. They extend from the upper troposphere to the mesosphere, with a maximum intensity around 60-80 km. Recent research has indicated that, in general, they are associated with positive CG flashes (Boccippio *et al.*, 1995). The first observations of SPRITES in south-eastern Brazil, carried out in 2002 by the ELAT group, indicate that the phenomenon seems to be more common than it was expected. SPRITES were observed in association with local thunderstorms on several days during the summer season. This adds a new perspective to this project and suggests that the SPRITES may have a significant role in the physical and chemical processes in the upper atmosphere.

The measurements at the upper troposphere and lower stratosphere will be crucial for the above-mentioned studies, taking into account the levels at which the SPRITES occur. It would be the first time that the NOx production of SPRITES could be quantified, which will add an important parameter in the chain of atmospheric chemistry processes in the stratosphere. This would be directly relevant to research conducted under the sub-project discussed in Section 5.7.

The observational campaign includes full nighttime observations with at least one high-sensitive camera during the period of airplane observations (roughly one month), located at a site between 100-200 km from Bauru.

The specific scientific objectives of this sub-project are to -

- confirm SPRITE rates just observed in this region of Brazil;
- study in more details the relationship between sprites and parent lightning flashes;
- investigate the NOx production associated with SPRITES and thunderstorms producing SPRITES;
- study the radar-observed characteristics of thunderstorms producing SPRITES.

PREVIOUS EXPERIENCE

- Operation of the “triggered lightning” installation of INPE at Cachoeira Paulista, S.P.
- Integration of Brazilian Lightning Network jointly with several institutions.
- First field experiment to observe SPRITES in Brazil, jointly with R. Holzworth (University of Washington, USA), in 2002.

5.7 AIR POLLUTION, CLOUD and CLIMATE INTERACTIONS

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INTRODUCTION

The more developed areas in Southeast and South Brazil are highly dependent on the hydrometeorological resources and are also recognized as important sources to the atmosphere of aerosol and trace gases derived from biomass burning and urban air pollution. Understanding and modeling the complex interactions of the underlying physical processess involved in cloud formation in the presence of aerosol, the cloud transport of aerosol and trace gases and the ultimate effect on rainfall and surface climatology remain one of the important scientific challenges for the next decades.

The present proposal aims at the documentation of clouds and their effect on the physical and chemical environment and is built upon the results of previous projects (including some supported by FAPESP as will be seen later) and, mainly on the preliminary results obtained during LBA, the Large-scale Biosphere Atmosphere Experiment in Amazônia. It is also based on a strong partnership with project TROCCINOX (supported by the European Commission). Based on these foundations, this proposal is focused on the local and regional cloud transport of aerosol produced by biomass burning and urban air pollution, their radiative effect on surface climate as represented by rainfall and air temperature and the cloud effect on lower stratosphere composition and thermodynamic structure.

The proposal is based on a broad up-to-date methodology, which prioritizes special data collection, its conceptual analysis and integrated modeling of the physical system.

SCIENTIFIC BASIS

Among the biogenic aerosol and trace gases produced by vegetation, primary or secondary, available throughout the year, there are also those produced by biomass burning (Crutzen *et al.,* 1985; Crutzen and Andreae, 1990) . Biogenic aerosol and aerosol produced by biomass burning have a direct role on the surface and troposphere energy budget due to their capacity to scatter and absorb solar radiation (Martins *et al.*, 1998; Artaxo *et al.*, 1998; Echalar *et al.*, 1998). This aerosol can also impact atmospheric thermodynamic stability in as much as they tend to cool the surface (by scattering radiation that would otherwise be absorbed at the surface) and by warming atmospheric layers above by absorption. Modeling the aerosol effect on climate depends fundamentally on the microphysical and optical properties of these particles. Jacobson (2001) and Andreae *et al.* (2001) suggest that particles produced by biomass burning may have a very important role in the global greenhouse effect with a potential heating impact of about 1/3 of that of CO_2 being more efficient than CH_4, which is considered the second most important gas in the anthropogenic part of the greenhouse effect. Besides the radiative processes (Schaefer *et al.*, 2002), this aerosol may act as CCN – cloud condensation nuclei – depending on their composition (Eagan *et al.*, 1974; Roberts *et al.*, 2001). The impact of aerosol, from the radiation or cloud formation point of view (Rosenfeld, 1999; Silva Dias *et al.*, 2002; Wiliams *et al.*, 2002), affects the regional energy budget and has an impact on the atmosphere dynamics, producing a local impact and indirectly also a global impact.

Clouds are directly linked to the surface processes (Betts *et al.*, 1996) through the turbulent fluxes of sensible and latent heat, and to the atmosphere composition defined by trace gases and aerosol. Clouds may also alter the surface fluxes and the transport of trace gases and aerosol on regional and global scales, depending on the cloud depth (Swap *et al.*,1996; Freitas *et al.*, 1996, 2000, 2001; Longo *et al.*, 1999; Andreae *et al.*, 2001).

SCIENTIFIC QUESTIONS AND OBJECTIVES

The scientific objectives of the present proposal are based on an integrated view of the environment and the causes and effects of deep convection in southeast Brazil.

The specific objectives are to:

- describe the impact of deep convection on the regional surface climate;
- describe the impact of deep convection on the lower stratosphere thermodynamic structure;
- describe the rainy season in terms of cloud pattern evolution and aerosol concentration;
- describe the weather systems and air mass evolution during the rainy season;
- analyze the several convective features of the region including cloud life cycle, rainfall intensity, lightning, dynamics and thermodynamics;
- describe the temperature inversion equilibrium in the presence of a mixed layer with aerosol and its evolution after the major rainfall events;
- improve the ability to model the different processes in an integrated view of climate and regional weather.

The specific objectives above involve different observational activities and numerical modeling strategy in different scales.

The present proposal will certainly represent a big step towards understanding of the physical processes.

ATMOSPHERIC MESOSCALE CAMPAIGN

The research strategy has been based on a large observational component during the TOCCINOX Campaign to be conducted in 2004 in the rainy season. Parallel to the campaign and the data analysis, the analysis of operational historical data and of data from previous field campaigns will be carried out, as well as the interpretation of remote sensing data from meteorological radars, satellite-borne sensors and surface sensors.

The following activities are essential for the succesful completion of the present project:

- Measurements of cloudiness, lightning and rainfall with weather radar, satellite and lightning network.
- Radiossonde profiles reaching the lower stratosphere.
- Vertical profiles of aerosol and trace gases in the troposphere and lower stratosphere - by means of instrumented aircraft.
- Identification of surface sources from satellite and ground measurements.

The weather radars of IPMet in the State of São Paulo and the Brazilian Air Force and SIVAM radars elsewhere in Brazil provide the basic information about cloudiness and rainfall, to be completemented with the satellite information of the TRMM radar and with GOES-8 imagery. The Brazilian radiosonde network can be used and just incremented with a special station with more frequent launches (Bauru; cf Section 5.4). The international partner has the capability to bring two instrumented aircraft for middle troposphere and lower stratosphere measurements of trace gases and aerosol, while in Brazil the INPE aircraft is available for lower troposphere measurements and a microphysics aircraft (Almeida *et al.*, 1992) for warm clouds can also be used.

The data will be analysed to achieve the goals stated in the previous section and will also be used to validade model simulations. The model used is RAMS (Pielke *et al.*, 1992; Walko *et al.*, 1995).

PREVIOUS EXPERIENCE

The PIs have coordinated several field campaigns in São Paulo and in the Amazon region and have actively participated in the Large-scale Biosphere Atmosphere Experiment in Amazonia (LBA). The data base generated in the Amazon field campaigns may be seen in http://www.master.iag.usp.br/lba while the modeling efforts in day to day activities may be seen in http://www.master.iag.usp.br.

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(No page 41 due to the shortening of Chapter 5.6)

6. ATMOSPHERIC CHEMISTRY

6.1 INTRODUCTION

The balance of the sources of nitrogen oxides (NOx) and aerosols in the mid-troposphere and lower stratosphere has not yet been fully quantified (Crutzen, 1995). Biomass burning and urban/regional air pollution lead to enhanced concentrations of several key chemical species that where thought to be restricted to the troposphere. Recently, the role of cloud transport of aerosol and trace gases to the mid-troposphere and lower stratosphere - where their concentrations are very low – has been identified (Peter, 2003). The contribution of lightning produced NOx adds another term to the budget of NOx within the cloud and to the amount of NOx ultimately ejected at the cloud top. Aerosol particles change the radiation balance in significant ways, altering the radiation fluxes that drive many photochemical reactions in the atmosphere, such as the formation of ozone and other key species that influence the NOx budget.

The impact of trace gases and aerosols exported to the mid-troposphere and lower stratosphere on atmospheric chemistry and cloud microphysical processes is a reason for growing concern and the incentive for our research. Additionally, trace gases and aerosols exported to these high altitudes are subject to long-range transport and may, thus, affect chemistry and microphysics far from their origin.

Measurements performed by the DLR-Falcon and the Geophysica will only cover the mid-troposphere and lower stratosphere, i.e. heights where aerosols and trace gases are transported. Information on their concentrations in the inflow region of cloud systems at low altitudes is critical to close the budget of the trace gas fluxes within the whole column. This is especially important in that measurements in the boundary layer and lower troposphere will help to separate anthropogenic from biogenic emissions of aerosols and trace gases. Not only emissions, but also chemical reactions and interconversion of trace gases and aerosols define the actual concentrations in the lower troposphere. One exemplary process is the formation of nitric acid (HNO_3) as an oxidation product of NOx photochemistry. Via HNO_3, inorganic and organic nitrates are formed, that ultimately participate in cloud formation as hygroscopic cloud condensation nuclei (CCN).

6.2 VERTICAL DISTRIBUTION OF AEROSOLS AND TRACE GASES BETWEEN THE GROUND AND THE MID-TROPOSPHERE

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In order to compile vertical profiles and an inventory of natural and anthropogenic aerosols and trace gases of the whole atmosphere, it is absolutely essential to also measure their concentrations in the lower troposphere. This is where ground-level emissions of aerosols and trace gases, both from natural and anthropogenic sources, are ingested into cloud systems. Through deep convection they are then efficiently transported to the mid-troposphere and eventually to the lower stratosphere. These measurements will be performed by INPE´s Bandeirante aircraft, fitted with air quality monitors from IF/USP and the Max Planck Institute for Chemistry (Mainz, Germany). They will be complemented by the measurements of the Falcon aircraft in the mid-troposphere and the Geophysica M55 above it up to the lower stratosphere ($\leq$ 20 km).

Further supportive measurements will be made by UECE’s Bandeirante, equipped with cloud physics instrumentation (cf umbrella project on “Meteorology, Atmospheric Physics and Forecasting”, Section 5.5), as well as the ground-based Lidar of IPEN, which will be deployed in or near Bauru (to monitor aerosol profiles in the central State). Ground-level concentrations of the various pollutants will be provided by IPEN.

For the above-mentioned reasons, this sub-project aims at quantifying the amount of aerosols and trace gases ingested by subtropical/tropical, well-characterized cloud systems by deploying the INPE Bandeirante aircraft in the lower troposphere (0-3 km). As estimates on NOx produced by lightning in individual cloud systems still differ by one order of magnitude, information on the complete vertical profile of trace gases and aerosols is needed to close their budgets and to provide chemical and cloud models with the respective boundary conditions. In order to model the NOx production and distribution of a column, measurements throughout the whole column are needed, directly for NOx, as well as for its precursors and decomposition products.

SCIENTIFIC BASIS

Nitrogen oxides play a key role in the balance of ozone in the atmosphere. In the troposphere, as well as in the stratosphere the concentrations of NOx define whether ozone (O_3) is produced or destroyed. Chameides *et al.* (1992) described a transition from O_3 destruction to O_3 production at NOx concentrations of 30 ppt. This threshold implies that O_3 is mainly destroyed in low NOx conditions and that there is a significant production of O_3 if sugar cane burning emissions are present, since NOx is emitted in significant amounts from sugar cane and biomass burning. Furthermore, in the dry season the oxidation products of NOx are scavenged from the atmosphere less efficiently with suppressed rainfall. Studies of NOx and O_3 in Amazonia have recently shown interesting properties in terms of convection and long range transport (Cordova *et al*., 2003a, 2003b).

In view of the crucial role of NOx, biogenic and anthropogenic sources and their balance need to be assessed in the wet, as well as in the dry season. In this regard, it is very informative to perform NOx measurements in Southeast Brazil, where anthropogenic emissions play an important role in the budgets of the compounds mentioned. In a previous airborne campaign in Amazonia (LBA-CLAIRE 2001) the potential for the calculation of ground fluxes for trace gases (CO_2 and even NOx, as a reactive gas) has been shown (Thielmann *et al.*, 2003). It is intended to use the measurements in the State of São Paulo to further validate the method, to compare the fluxes of trace gases derived over Amazonia to those derived from the measurements in more developed regions of Southern Brazil. In this way, the impact of anthropogenic versus biogenic emitted NOx on the formation or destruction of ozone (on the oxidative capacity of the atmosphere) will be elucidated. Carbon monoxide (CO) and O_3 measurements could help in the data interpretation, being tracers for photochemical processes or sugar cane or industrial combustion emissions. The ratio of CO to aerosol particles can also help to differentiate sugar cane burning emissions from regional industrial emissions. Air mass trajectories will be produced using the RAMS model, and will be integrated in the flight plan (Freitas *et al.*, 1997)

SCIENTIFIC QUESTIONS AND OBJECTIVES

The scientific objectives of the present proposal are:

- Extend the measurements of aerosols and NOx to the lower troposphere (including the boundary layer) to get complete profiles from 0-22 km together with the DLR Falcon (3-12 km) and the Geophysica (12-20 km).
- Compare NOx, O_3, CO and aerosol concentrations in the updraft and downdraft regions of cloud systems to get an insight on the processes inside the clouds.
- Derive trace gas ratios and ratios between trace gases and aerosol physical parameters to separate NOx ingested by the cloud from lightning-produced NOx. This information is crucial for models, as they intend to link lightning-produced NOx to cloud parameters, like flash rate, cloud height and/or updraft strength, to get a means to parameterize lightning-produced NOx.
- Make use of the trace gas ratios together with trajectory information to identify anthropogenic and biogenic sources of the air ultimately transported upwards in the clouds.
- Perform boundary layer budgeting to derive ground fluxes of NOx and other species.
- Assess whether these fluxes differ from those measured over Amazonia.

AIRCRAFT FLIGHT STRATEGY

The INPE aircraft for TroCCiBras will be instrumented for measuring several trace gases continuously, such as CO_2, O_3, CO, NO_x, as well as to collect gas canisters for laboratory analysis of several volatile organic compounds. A full array of aerosol properties will also be measured. The GPS installed on the aircraft will give accurate positioning data. Flight tracks will be planned on short-term based operational weather forecasts provided by IPMet/UNESP and CPTEC/INPE, in close cooperation with the flight planning of the DLR Falcon and the Geophysica. The focus of the INPE Bandeirante flights will be low altitude, with strong synchronization with the Falcon measurements. Measurements of trace gases and aerosols onboard the INPE Bandeirante aircraft will include:

- Nitric oxide (NO) and nitrogen dioxide (NO_2) by chemiluminescence (and previous photolysis in the case of NO_2) - loaned by M-P-I
- Photolysis rate of NO_2 (J_{NO2}) by filter radiometry - loaned by M-P-I
- VOC: gas canisters followed by GC-MS and GC/FID analysis

- Ozone by UV absorption - loaned by M-P-I
- Carbon monoxide (CO) - loaned by M-P-I
- Carbon dioxide (CO_2) - Licor (infrared) analyzer loaned by M-P-I
- Aerosol size distribution trough Scanning Mobility Particle Sizer
- Black Carbon measurements using an Aethalometer
- Light scattering measured using a Nephelometer
- Total aerosol particle number by Condensation Particle Counter
- Aerosol chemical composition trough filter sampling

Figure 13 shows the INPE Bandeirante aircraft equipped for atmospheric chemistry measurements.

Figure 13. INPE Bandeirante aircraft instrumented for trace gases and aerosol measurements.

Studies of vertical aerosol profiles will be based on measurements effected with an elastic backscattering Lidar, providing aerosols backscattering profiles of up to 10 km in height, every 3 to 5 minutes. This height could be increased by adding a transient recorder, operating both in analog and photo-counting mode. Polarization measurements might be available, also contributing a Nitrogen-Raman signal, if the equipment ordered arrives before the TROCCINOX field campaign. The Lidar will be operated in or near Bauru (to monitor aerosol profiles in the central State) and measurements will be complemented to above the 10 km ceiling by both the FALCON and M-55 measurements. Furthermore, a backscatter diode laser (LABS), an aerosol scattering probe (0.2 – 3 μm) and a micro-lidar will be flown on short-duration HIBISCUS balloons (Appendix 2), complementing and verifying the aerosol profiles derived from the ground-based Lidar at Bauru up to 22 km (ZL balloons up to 30 km). Also, 15 O_3 / backscatter sondes will be released from Bauru (cf. Section 5.4).

To carry out the project, there is a demand for upper-level measurements, which will be supplied by the TROCCINOX aircraft measurements. All TROCCINOX flights will be supported by cloud physics and atmospheric chemistry flights in the lower part of the troposphere, using the specially instrumented Bandeirantes from UECE and INPE. However, since only about six TROCCINOX flights are planned, the two Bandeirantes will also perform measurements in the lower troposphere on suitable days between TROCCINOX flights. This project will also be conducted in close cooperation with sub-projects under the umbrella of “Meteorology, Atmospheric Physics and Forecasting” (Sections 5.2, 5.5 and 5.6).

PREVIOUS EXPERIENCE

The INPE aircraft has been deployed in several field campaigns in the State of São Paulo and in Amazonia within the frame of the Large-scale Biosphere Atmosphere Experiment in Amazonia (LBA) (Artaxo *et al.*, 2002, Andreae *et al.*, 2002). It is well suited for measurements in the lower troposphere and may be equipped with the instrumentation mentioned at short notice. All instruments are already available at IPEN and IF/USP, and are fully operational, and calibration facilities are first rate. Synchronization with weather forecasts was well done in previous campaigns, and with the help of the IPMet radars, it will provide an optimum operational scheme. Regional atmospheric modeling with integration of flight patterns was successfully done in Amazonian conditions, that are much more difficult than in the State of São Paulo (Andreae *et al.*, 2002).

The CLA of IPEN was established in 2000 and is not only involved in the development of new materials for lasers and optical spectroscopy, but also concentrates on the application of lasers. It has installed the first LIDAR (LIght Detection And Ranging) system in São Paulo in 2002 to monitor vertical profiles of pollutant concentrations, being part of an international cooperation program.

Training Activities

Graduate students and postdoctoral researchers will implement much of the research conducted during TRroCCiBras. It is anticipated that a large proportion of these will come from Brazil and will be trained for measurement techniques and data analysis at the European partner institutions, wherever appropriate. These junior researchers are also expected to play a major role in the post-campaign data interpretation phase, where they will be instrumental in maintaining an active flow of information and ideas between the European and Brazilian partners.

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7. VALIDATION OF SATELLITE-BORNE AND GROUND-BASED REMOTE SENSORS

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7.1 INTRODUCTION

Validation is a fundamental procedure for remote sensing measurements and the quality attained in carrying it out is a major factor in determining the usefulness of the data for research and many operational practices. However, it is surprising that it is only more recently, that this matter has been receiving due attention from space agencies, even in the more developed countries, in spite of being a mandatory link in the chain from the signal impinging on the sensor to the data being assimilated in models and algorithms, particularly in research projects, but also in certain operational activities.

Hilsenrath *et al.* (2001) focus this basic issue in a distinctively appropriate way, when dealing with observations related to O_3 in the atmosphere.

While validation spans a large range of applications of satellite measurements in Brazil, it was the recent availability of sounding of the atmosphere with a quality compatible with that of conventional radiosondes, provided by the NASA EOS platform Aqua, that brought a clear picture of demand for the pertinent validation practices, and the resulting implementation of projects. In its infancy here, so to say, validation presently combines both participation in field experiments and development of specific topics, mainly on applied research, but also some on fundamental research. Along those lines, three main topics of investigations have emerged at the IPMet/UNESP regarding validation.

Identified as outstanding issues under the broad validation umbrella, those topics approach, in general: 1) Proper matching of observations from different sensors, 2) Rainfall quantification through microwave radiometry from space, and 3) Clear air & cloud boundaries.

This umbrella project, “Validation of Satellite-borne and Ground-based Remote Sensors”, in the present Proposal aims specifically at profiting from the rare opportunity represented by specialized measurements to be effected during fields experiments centered in the State of São Paulo as part of two scientific projects of the EC, i.e., TROCCINOX and HIBISCUS, briefly discussed in Chapter 2 of this Proposal, with details being provided in Appendices 1 and 2. It should be emphasized that the measurements mentioned above are unique in the sense that they can only be made with the main observational tools to be deployed by the involved EC countries during the field experiments, i.e., high-flying aircraft and stratospheric balloons.

Comprehensive by itself, this sub-project is a well-defined segment of the general efforts on the validation issue being developed by IPMet, per se or in cooperation with other organizations, including some from foreign countries.

7.2 RESEARCH TOPICS

MATCHING MEASUREMENTS FROM DIFFERENT SENSORS

Objectives

- Formulate procedures for pre-processing data from different sensors, to make them readily comparable for validation purposes.
- Derive statistically tuned relationships between satellite soundings of the atmosphere and matching remote sensing measurements from ground-based or airborne (balloons or aircraft) sensors.

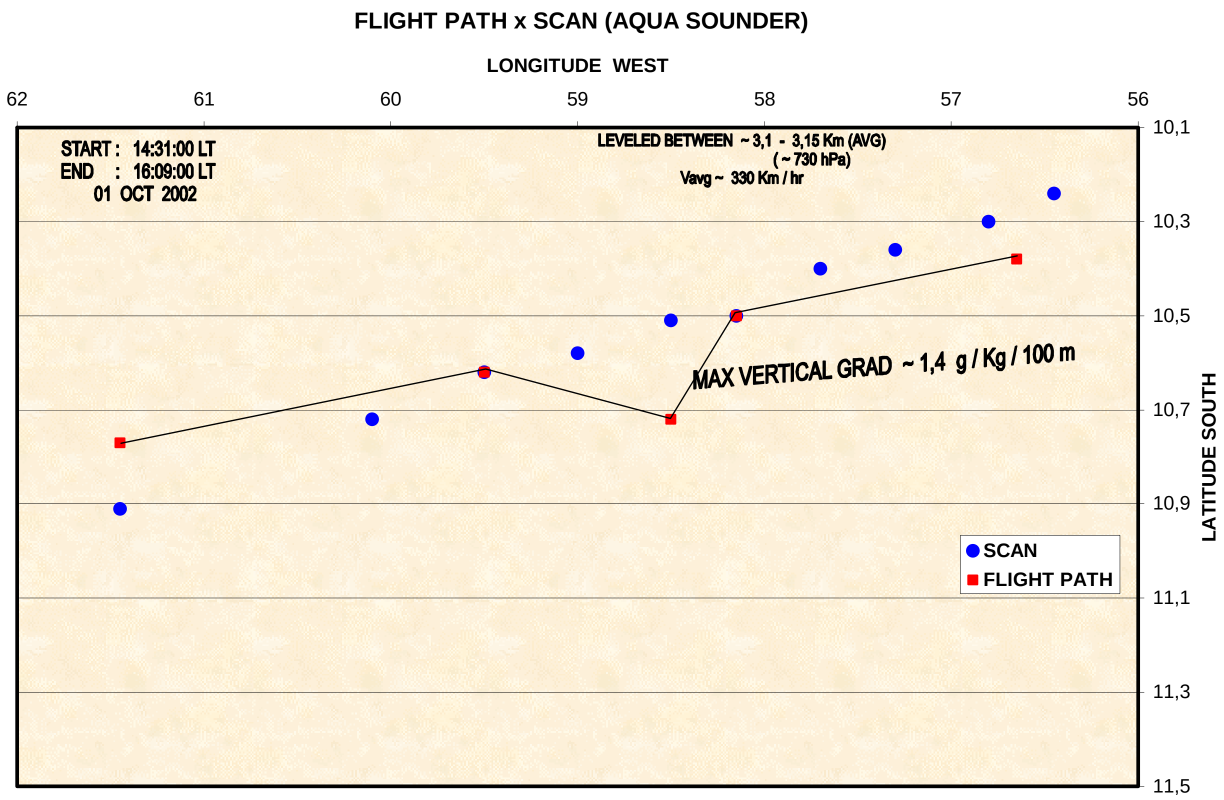
Scientific Basis

Similarly to the validation question, to the extent of our knowledge this fundamental issue is not, surprisingly, being considered to the level of its relative importance. This in spite of, however, being clearly mentioned lately in many programmatic, or even in topic-specific works. In at least two main programs this subject has been brought to the attention of the respective science teams, i.e., in the Gvap/GEWEX/WCRP, and in the AIRS/Aqua contexts. In the Gvap, Dr. Jens Bösenberg from the Max Planck Institute (Germany) pointed out the complex question of comparing radiosonde data, essentially point measurements, with the “volumetric” kind of measurements provided by remote sensors, like satellites and ground based radiometers. Similarily, during many meetings of the AIRS science team, this same question has been raised at different occasions, mainly by Professors David Staelin from the MIT Lincoln Radiation Laboratory and William Smith from Langley’s NASA Research Center, the principal investigator for this sub-project. Prof. Staelin points out this problem in one of his works on precipitation retrievals through satellite microwave radiometry (Staelin and Chen, 2000). His observations are expended when dealing with the difficulties faced in the retrievals involving such complex phenomena as precipitation. He recalls that within one single satellite footprint of 15 km there are “varied hydrometeor types, densities and sizes as well as varied vertical velocities and cell-top altitudes”. Prof. Smith presented several examples of aircraft observations of temperature (T) fields where large gradients through distances smaller than satellite “Field Of Views” (FOVs) would make the space-based radiometry for T severely impaired. Since accuracies of 1 K, or better are being sought for in the Aqua profiling of T, the smoothing imposed by the FOV (about 50 km for Aqua) is critical. A model for the T variation within the FOV was suggested by members of the Science Team assigned to the validation effort, but questions like the degree to which a certain model reproduces the actual gradients must be addressed.

As part of the Validation efforts in Brazil, specifically devoted to the atmospheric sounder onboard the Aqua spacecraft, radiosonde ascents and aircraft flights were performed within the context of the Large-scale Biosphere Atmosphere Experiment (LBA) “Dry-to-Wet Season Campaign” (LBA, 2002), during September and October 2002 in Rondônia (Amazonia). Validation-dedicated flights were operated with an

EMBRAER Bandeirante turbo-prop twin-engine aircraft. Flight paths followed the satellite cross-track atmospheric scan at the ground, leveling at about 3000 m ±100 m. The average cross-track distance was about 500 km of the nominal 825 km half-cross-track distance. Measurements of T and Td (dew point) were performed. The derived water vapor (WV) mixing ratio variation through the flight path was compared to the satellite-measured mixing ratio, for some selected segments along the cross-track scan: one near nadir, another one at the western extreme of the aircraft path and a third in-between. The flight path and scan position are shown in Figure 14.

Figure 14. Approximate positions of the flight path (magenta) and the center of the IFOVs for the corresponding portion of the cross-track scan on 01 October 2002. Maximum vertical gradient for the mixing ratio is indicated, as well as basic flight information.



The segments appear in Figure 15 as SC, SE and SW, respectively. In the eastern flight segment, SE, the mixing ratio varied between 8.8 and 11.5 $g.kg^{-1}$, in an approximate linear fashion, resulting in a gradient reaching about 0.14 $g.kg^{-1}.km^{-1}$. The latter value was the maximum space gradient found during the flight. Mixing ratios for the three segments are shown in Figure 15. Compared to the single (constant for the IFOV, “Instantaneous Field Of View”) value given by the satellite, these measurements indicate that a substantial smoothing took place. Such smoothing might, for instance, prevent the utilization of satellite estimates of mixing ratio as input to mesoscale models applied to that area.

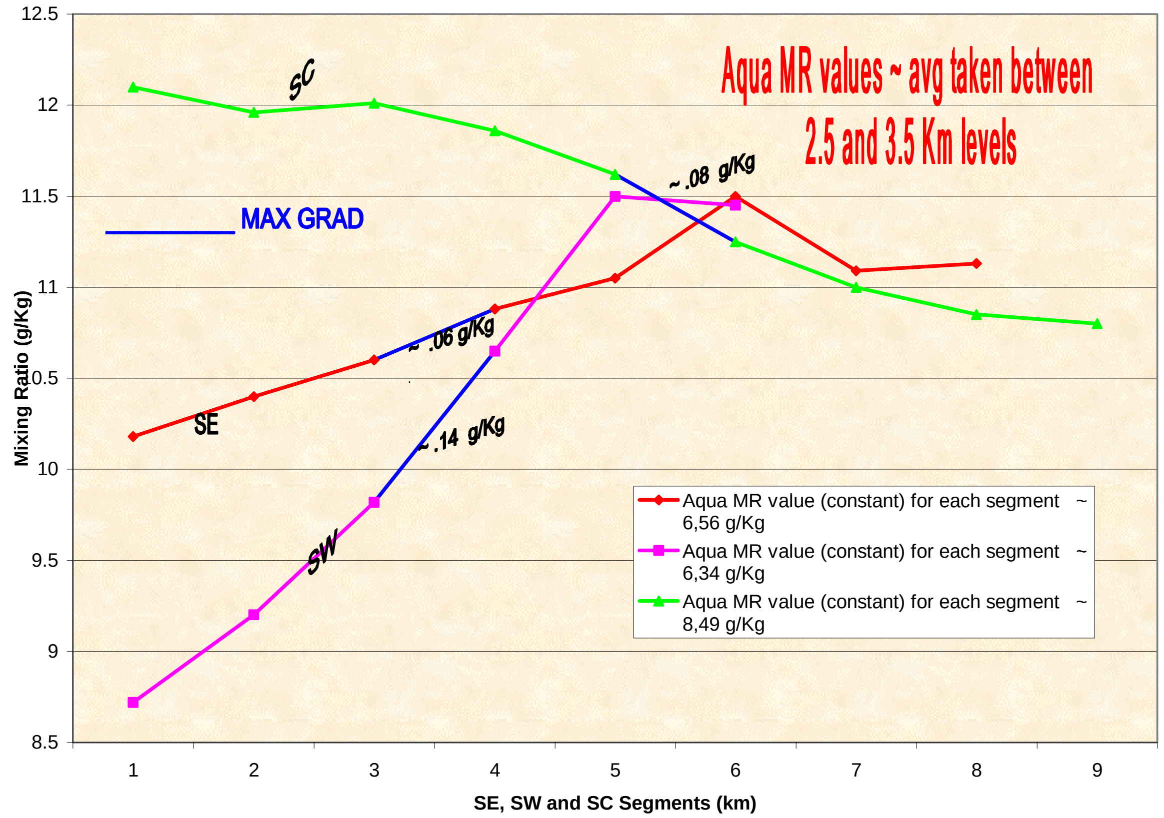


Figure 15. Evolution of the mixing ratio along selected segments of the cross-track scan, each with a length comparable to the satellite resolution on 01 October 2002. SE, SC and SW are the eastern (near nadir), central and western segments, with reference to the cross-track scan.

This topic aims at obtaining observations of the variation of humidity fields at the upper troposphere and lower stratosphere, with the relatively high spatial resolution, which is attainable by the TROCCINOX and HIBISCUS instrumentation (Appendices 1 and 2). Those measurements, only possible with the high flying aircraft and balloons of the EC projects, will give crucial information on the humidity gradients in the higher atmospheric layers. This will be the first time that such information, deemed important, for instance, for weather forecasting, is available in our regions. While world-widely very relevant, it is in the tropical areas – such as in Brazil – that the humidity field information is particularly important. In addition, another quite important issue will benefit essentially from the data, i.e., the radiosonde's poor performance in the upper troposphere & lower stratosphere. This is a well known problem associated with today's operational radiosonde network, and must be appropriately addressed so that radiosondes can play the role of a basic validation function for remote profiling of the atmosphere.

Regarding this problem with radiosondes, IPMet has been receiving the contribution of Dr U. Leiterer and his group from the Linderberg Meteorological Observatory in Germany. He developed algorithms to correct the radiosonde humidity profiles and his support is an important asset for this topic (Leiterer and Naebert, 1997).

The methodology to be applied is the now widely disseminated approach of Calheiros and Zawadzki (1987), which was originally developed for radar - raingage comparisons, in the estimate of rainfall. Essentially, probability distributions of both involved variables are matched to generate the required pair of values for correlation. Analytically:

$$\int p(Z)dZ = \int p(R)\, dR,$$

where Z stands for radar reflectivity and R for rainrate.
Proper adjustments to the methodology will be implemented in the use of the technique for comparisons between the other variables considered here, to take into account the differences in the way the observations are effected.

Focusing the humidity field as derived from satellite sensors, and from in situ measurements controlled by ground-based systems, probabilities will be computed and matched through a procedure similar to that previously described for the Z vs R relationship. It can be expressed as:

$$\underbrace{\int p(H)d(H)}_{\text{remote sensing}} = \underbrace{\int p(H)\, d(H)}_{\text{in situ}}$$

The equality of integrands means that the number of events in incremental intervals, for each variable, are the same.

One approach to be explored, by similarity with the radar-raingage application, will be to compare the radiosonde point value for each layer of the satellite (IFOV), with the corresponding satellite value. Initially a layer of 2 km will be used for the Aqua sounder and 4 –5 km for the NOAA satellites, for compatibility with the respective resolutions.

Methodology

The approach will be first, to elaborate probability density functions (PDFs) of the variables, as measured by each of the observing sensors. Those PDFs will be stratified basically by region, season and daily interval. This procedure will be performed for layers oriented in a direction normal to the axis of the approximate solid cone of observation of the satellite, at nadir. Layer thickness will be defined by resolution along the vertical (nadir) axis of the illumination volume. For the sensors performing in-situ measurements, both remotely surveyed (e.g., radiosondes) or flown through the illuminated volume (e.g., aircraft) the set of observations will be that falling within the resolution volume.

ASSESSING CLEAR AIR DETECTION AND CLOUD BOUNDARIES

Objectives

- Assess the relative importance of coherent vs incoherent scattering processes within clouds and of temperature vs humidity, in determining clear air returns, and to investigate cloud boundaries and rain/no-rain thresholds;

- Determine the structures of the Liquid Water Content (LWC) and dry (clear) air of clouds, mainly in situations of intense convection;
- Analyze the temperature and humidity fields in the clear air and at the cloud-free air interface.

Introduction

Clouds exert a large influence on climate, through its interference with the radiative transfer through the atmosphere. The cloud feedback is the largest source of uncertainties in climate-change calculations in current climate models (Kattenberg *et al.*, 1996). By reflecting solar radiation clouds have a cooling effect, on the one hand, while, by trapping heat at the surface it has a warming effect, on the other hand.

The proper understanding of these effects requires an insight into cloud processes, both at the macro and micro scales. Height of the cloud at its top and base, and the associated depth, cloud fraction and cloud overlapping are all macro-physical properties of clouds, while the state of the cloud particles (solid, liquid) and the size distribution of those particles are important microphysical cloud properties. For assimilation in models, the “Particle Size Distribution” (PSD) is parameterized by its number density, average drop size, width of the PSD, LWC or its optical depth.

Actually, water is present in clouds in relatively small amounts. In fact, LWC in large cumulus clouds, for instance, amounts to a few grams in a cubic meter, a figure that depends on height. Values between about 0.05 to 0.25 $g.m^{-3}$ are typical for stratus clouds.

Thus, most of a cloud is clear air and only the large number of droplets present makes the cloud visible. Due to the small size of the drops and their high number density, clouds present a large total area with a low LWC. This makes clouds an important element for the transfer of solar and heat radiation through the atmosphere. On the other hand, the partition between clear air and hydrometeors within clouds has direct implication in the total value of radar reflectivity.

Radar plays a unique role in cloud research, since it is the only remote sensing instrument that can penetrate into dense clouds. In this sense, radar can provide two crucial parameters, i.e., reflectivity profiles and cloud boundaries. Its use for the retrieval of cloud properties – and other quantitative applications of radar observations – requires, however, an accurate determination of the reflectivity, Z. In general, Z is computed under the assumption that the underlying process of microwave scattering by the particles is incoherent. Notwithstanding, recent research has been indicating the occurrence of significant coherent scattering, pointing out that when coherent scattering by particles occurs in a dominant fashion, the cloud properties retrieved can be in larger error, if only the incoherent process is taken into account (Venema, 2000).

The coherent particle scattering derives from spatial structures present in the liquid water portion of the clouds. Arguments offered by Venema (2000) question the common believe that this coherent scattering, while existing, is negligible in comparison to the variations in humidity, which would have a much larger influence in the refractive index than equal variations in liquid water content. In fact, the arguments sustain that a much smaller fluctuation of the water vapor mixing ratio in clouds is likely, as compared to the liquid water mixing ratio. Recent work based on radar dual-frequency observations of clouds and smoke (Knight and Miller, 1998; Rogers and Brown, 1997) has shown a correlation between reflectivities at both frequencies, which could not be explained by incoherent particle scattering and coherent scattering by air. Coherent particle scattering, however, could cause the detected correlation. Subsequently a total radar reflectivity factor is proposed, in the research works referred to above, which takes into account both incoherent and coherent terms.

Some results with the Bauru radar will be re-analyzed, involving the issue of coherent particle scattering. Those results (Lima *et al*., 2002) indicate that a combination of Bragg (coherent) air scattering and Raleigh (incoherent) particle scattering was acting to compose the final reflectivity values. The occurrence of coherent particle scattering is a clear possibility in this case, and should be thoroughly verified. One of the results, as shown in Figure 16, presents a profile of Z in which the enhancement of reflectivity at the top of the layer can be distinctively noted.

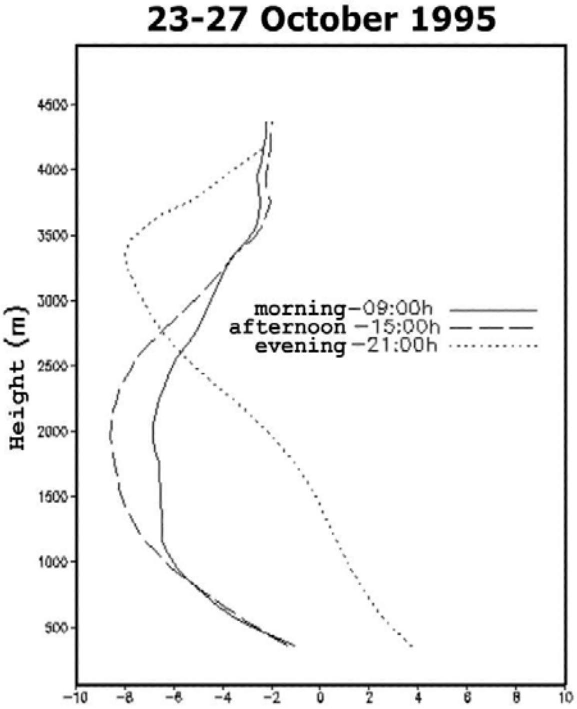


Figure 16. Profiles of mean reflectivity (dBZ) for the period 23-27 October 1995 and times of day as indicated (from Lima *et al.,* 2002).

On the other hand, Figure 17, shows a radar cross section of reflectivity, for 23 October 1995, i.e., within the period used to obtain Figure 16. It can be noted how the thermal plumes develop vertically, above the fire spots, providing relatively high Z values aloft. The possibility that particulate matter taken to the upper region of the plume might present a pattern compatible with coherent scattering should be investigated.

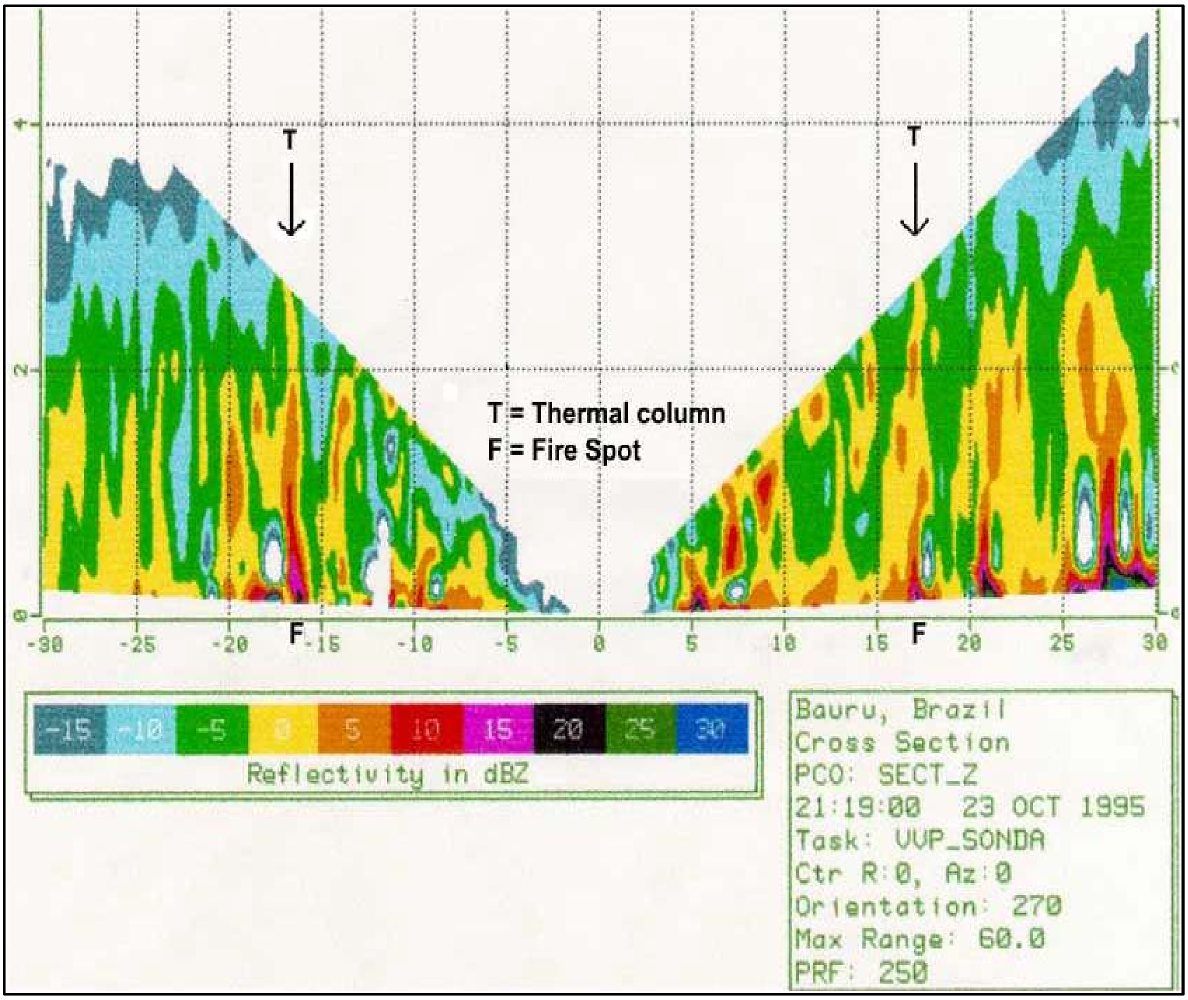


Figure 17. Vertical cross-section (W-E) on 23 October 1995, 21:19, featuring fire spots and thermal columns. Only fires which could be identified with Doppler data are shown. Relatively high values of Z (>10dBz) near the surface are ground echoes.

The appropriate assessment of the different scattering mechanism effects is crucial for validation of remote sensing measurements. Examples are the Aqua microwave precipitation radiometry, and the determination of cloud boundaries involved in cloud clearing algorithms, which support the retrieval of temperature and humidity profiles, from satellite observations. Regarding rainfall validation, the process of correlating brightness temperature, Tb, and radar reflectivity, Z, involves all factors contributing to the total Z. In particular, the results from Skofronic-Jackson *et al*. (2003) on the similarities of the evolution of Z and Tb at the 183.33 ±7 GHz satellite sensor channel will be investigated.

Another recent result, in this case relevant for the underlying humidity in air scattering processes is that of Sohn *et al.* (2003). They developed a method for retrieving upper and mid-tropospheric water vapor burden from the 183.33 ±1, ±3 and ±7 GHz. These are 3 of the 4 channels of the Brazilian Humidity Sounder (HSB) on board the Aqua platform.

With respect to the determination of cloud boundaries, one problem is rain, because the observation of the small cloud droplets is difficult in the presence of raindrops.

These small droplets are the most important in radiative terms. On the other hand, the presence of only a few large particles below cloud base will impair the observation of the base. Also, at the base of water clouds, or in large regions of ice clouds, the small particles determine a low value for Z. These problems led to the search for additional sensors and, as of now, the main advancement achieved was the synergetic use of radar and lidar, in an attempt to minimize the limitation of each sensor, for cloud boundaries determination.

Radar can help crucially in the identification of the rain/no-rain boundaries in satellite images. The satellite problem has been dealt with by Xu *et al.* (1999), who considered the problems associated with uncertainties in the determination of those boundaries. On the other hand, radar sensitivity restricts the capacity of detecting light rain. The problem of the rain area delineation may become an important issue in many applications such as numerical weather forecasting. In fact, if due to a poor MDZ (Minimum Detectable Reflectivity), light rain, significant in terms of the energy flux generated by LHR (latent heat release) equivalent to that amount of rain, goes undetected, there will be a negative impact in the forecasting model performance. An assessment of that effect has been made (Calheiros and Lima, 2001) involving the Bauru radar, and the TOGA radar while operating in Rondonia (Calheiros *et al.*, 2001).

Methodology

Performing dedicated measurements, both at single frequency in the S-band and/or dual-frequency, at S- and X-bands, in different weather conditions, will be the first activity. Those weather conditions will include clear air with the presence of smoke/pollutants (e.g., the environmental conditions shown in Figure 17). During the period of dedicated measurements, radar will be submitted to an intense calibration effort. In addition to this special period, past events of smoke/thermals will undergo a reanalysis. The distribution of cloud particle sizes (PSD) will be made with aircraft and the conventional reflectivity values will be computed. Comparisons between values of both Z from radar measurements and retrieved from PDS will be made. Discrepancies eventually resulting will be evaluated as an indicator for the presence of coherent particle scattering. Cloud boundaries, i.e. base and top, and contours of horizontal slices at selected levels, will be determined as a function of different Z thresholds. The results will then be verified against the corresponding boundaries as determined with cloud clearing algorithms, used for T and RH retrievals. Similarly, from data acquired by the Aqua and the NOAA series satellites, rain/no-rain thresholds will be estimated, using the HSB channel 4 (183.33 ± 7 GHz) and similar sensors onboard other satellites and aircraft measurements. They will then be compared with radar-indicated thresholds. Corrections for the radar-determined cloud and rain boundaries will be retrieved.

RAINFALL QUANTIFICATION BY SATELLITE MICROWAVE CHANNELS

Objectives

- Obtain precipitation estimates in tropical Brazil, through observations of satellite sensors operating in the microwave band.
- Derive relationships between brightness temperature (Tb), primarily from the HSB channel 4 (183.33 ± 7 GHz) with an eventual complementation of data from the 54 GHz (O_2 band) channels from AMSU-A, onboard the NASA platform Aqua, and the corresponding reflectivities from the Bauru (22^o 21’ S, 49^o 16’ W) and the Presidente Prudente (22^o 07’ S, 51^o 23’ W) radars in Sao Paulo, Brazil (Figure 5).

Introduction

The precipitation estimate with satellites has been a current practice for years now, with varying degrees of success. The use of satellites for that reasonably meets the requirements of time sampling, which is compatible with the scale of evolution of most of the precipitating systems, except for situations in the tropical areas when intense convective systems show a very fast change in the associated rainfall fields. However, the observations from geostationary orbits are restricted to sensors operating in the VIS and IR channels, since the proven technology available nowadays does not allow the implementation of microwave instruments in geosynchronous orbits. On the other hand, the rainfall quantification through methods based on the VIS and IR channels is significantly limited; for instance, a serious ambiguity exists in delineating the rain/no-rain borders in the images. With the advent of space-borne microwave sensors – until now only in polar orbits – a new perspective arose regarding precipitation estimates. One example in this sense is the rainfall field derived from the SSM/I (Satellite Sensor Microwave/Image) and the SSM/T1 and T2 onboard the DMSP (Defense Meteorological Satellite Program) US satellites, from which a sensible improvement of the rain estimates was obtained when compared with those based on VIS and IR.

The access to the DMSP satellite in real-time and the distribution of the data it collects, are restricted, but with the recent NOAA meteorological satellites (NOAA 15, 16 and 17) – which carry SSM/T1 and T2 similar instruments, i.e., the AMSU-A and the AMSU-B, respectively – a new possibility for the operational use of space-borne microwave radiometry for rainfall estimates was created. Of course, the quasi-polar orbits prevent that a high rate of time sampling of the same area be performed, since there are only two observations each day covering approximately the same region.

Notwithstanding, one alternative solution, drawing growing attention, is the utilization of a “blending” scheme, with the interval between the polar satellite observations of an area being filled with VIS and/or IR images from geosynchronous orbits. Recently, researchers with the Mesoscale Alpine Experiment in Europe (Bougeault *et al.,* 2001) have adopted such an approach for precipitation retrievals. Also, with the future implementation of the joint US - EU polar orbiters, at least three satellites will be performing microwave observations reducing the time sampling interval by a factor of three (from 12 to 4 hours). In May of 2002, the NASA polar platform Aqua was injected into an orbit similar to those of the operational NOAA meteorological satellites. Aqua carries an hyperspectral VIS/IR instrument, the AIRS (Atmospheric IR Sounder), and two microwave sounders: the AMSU-A in the lower microwave band (15 channels from about 22 to 89 GHz) and the HSB (Humidity Sounder for Brazil) in the upper portion of the microwave spectrum (4 channels at 150GHz and 183.33 ±1, ±3 and ±7 GHz; Lambrigtsen and Calheiros, 2003). The Aqua atmospheric sounder allows, for the first time, the profiling of the atmospheric temperature and humidity from space, with the same accuracy as that provided by the conventional radiosondes. Also, the HSB presents a low noise level as compared to the AMSU-B (about 4 dB below; Grant and Calheiros, 2000). These two characteristics will contribute substantially to the issue of rainfall estimates. In the context of the AIRS Science Team, which is constituted by a group of researchers and supporting experts based at the NASA's JPL, Staelin and Chen (2000) from MIT have performed a first work on the use of microwave observations at 54 GHz and 183.33 ±1 and ±7 GHz, from the respective instruments onboard NOAA 15, to estimate precipitation. They used a neural network trained with the US NEXRAD radars and verified that retrievals of instantaneous precipitation rates agreed "surprisingly well" with the radar data. This is partially supported by recent research develop at IPMet (Machado and Calheiros, 2003; Calheiros and Machado, 2003).

A quick look verification of the microwave absorption spectrum for oxygen and water vapor shows regions where oxygen absorption prevails, and which are suitable for temperature soundings; while in other regions of the spectrum water vapor absorption dominates. Those water vapor regions are appropriate for humidity retrievals. The Aqua (in similarity with the NOAA instruments) AMSU-A (primarily a temperature sounder) microwave sensors are grouped near the 60-GHz oxygen band. The Aqua HSB (like the NOAA AMSU-B, which is primarily an humidity-sounder) channels are grouped around the 183 GHz water vapor line and just below it, where oxygen absorption is not significant. The water vapor absorption lines are superimposed on the so-called "continuum", i.e. the underlying background in which absorption increases as the square of frequency. Liquid water, on the other hand, has no spectral lines and its absorption effect increases as the square of the frequency in the AMSU-A spectral range, and about linearly in the HSB range. Considering water vapor and non-precipitating clouds, and taking those characteristics into account, the retrieval algorithms for T and the relative humidity (RH) have been developed. However, when precipitating clouds are involved, scattering will prevail over absorption and much more complex retrieval methods are required (see, for instance, Lambrigtsen and Calheiros (2003), for a concise discussion on this).

In their work, Staelin and Chen (2000) have presented a preliminary discussion on the physical basis of precipitation retrievals using radiometry at 54 and 183 GHz. It is much elucidative, and is summarized below.

The 183-GHz spectral region:

In the absence of hydrometeors, each 183 GHz channel would penetrate a water vapor burden, which is dependent on the frequency, and sound the average temperature in the corresponding atmospheric layer. Each layer is characterized by the corresponding water vapor weighting function.

Considering an ideal atmosphere, saturated at all altitudes, a fixed relation between the water vapor burden and the temperature would exist. Since each frequency (in the 183 GHz region) penetrates a fixed water vapor burden, the idealized brightness temperature observed near each channel is also fixed (for such saturated atmospheres). Also, for such atmospheres, if there are no microwave observable hydrometeors present, Tb near 183 GHz would be largely independent of temperature at the surface and latitude (second-order effects, due to pressure-dependence of water vapor absorption, are small).

Hydrometeors will contribute to both microwave absorption and scattering, lowering Tb below its nominal value for saturated atmospheres. This cold precipitation signature (frequency-dependent) is unique in the sense that a Tb value below that corresponding to saturation generally cannot be generated otherwise. A physical relationship between rain-rate and the 183-GHz spectrum arises, in part, because the equilibrium precipitation rate approximately equals the rate at which convective updrafts transport saturated water vapor into regions of low temperature, that dehumidify the air, and greater updraft velocities produce greater hydrometeor populations, altitudes and sizes. All these properties coherently impact the 183 GHz emission spectrum.

However, Staelin and Chen (2000) warn about the difficulties involved, stemming from the complexity of the precipitation process. Difficulties include variable hydrometeor types, sizes and densities within the satellite sensor resolution (15 km for the HSB/AMSU-B), and varied vertical velocities and cell-top altitudes; fallout times of the smaller hydrometeors longer than the growth times of strong convection; hydrometeors changing their form as they fall; and variations in available potential energy, natural aerosol content, surface type (e.g. ocean versus land), gravity wave effects, wind shear and electrification state, which all can modulate the results. They conclude that, notwithstanding, those problems do not impact strongly the basic observation that higher vertical velocities in saturated atmospheres (which characterize the convective precipitation environment) generally yield higher precipitation rates and stronger precipitation signatures near 183 GHz. This is demonstrated by data presented later in their work.

The region near 54 GHz :

Above about 53.6 GHz channels are largely surface blind due to oxygen absorption. The 54 GHz region samples tropospheric temperature and hydrometeors in broad layers at altitudes, which increase with frequency. All solid, liquid or mixed-phase hydrometeors absorb and scatter the electromagnetic waves, typically introducing cold spots in the AMSU-A surface radiance images.

In this spectral region, liquid and solid hydrometeors above 4 km are generally visible against the warmer opaque atmosphere background below. This contrasts with the tendency of window channels over land to respond to both liquid hydrometeors and random surface variations. Hydrometeors at very high altitudes produce cold spots across all tropospheric AMSU-A channels; low altitude hydrometeors impact primarily AMSU-A at the lower, more transparent radio frequencies which see down to those atmospheric depths. Through that frequency dependent penetration, 54 GHz spectra reveal altitudes of precipitation cell-tops even when hidden under thin cirrus or light clouds. In addition, the more transparent 54 GHz channels measure cloud albedo, which depends also on the hydrometeors' particle-size spectrum and type (ice clouds have substantially higher albedo than water clouds). The observed cloud top altitudes of convective cells generally correspond to the top of the graupel cloud thrust aloft, where the average graupel sensed near 183 GHz is typically much smaller than that sensed at 54 GHz. Both graupel size populations are much larger, and fall out much more rapidly, than typical cloud particles sensed at infrared wave lengths. For such convective cells, the rain-rate is closely related to the vertical velocity and the absolute humidity of the saturated air. This velocity is also directly related to the cell-top altitude; the humidity can be estimated from nearby non-precipitating spots. Since higher vertical wind velocities are able to sustain larger hydrometeors better for longer periods, they permit growth of water droplets and ice particles to sizes sufficient to perturb 54 GHz and lower frequencies. This relation between cell-top altitude and precipitation rate has been observed, e.g., by Calheiros and Santos (1996) and Vicente *et al*. (1998), through comparisons of IR geostationary data and ground weather radar rain rate estimates. In fact, AMSU is better than, e.g., GOES sensors in such aspects like the ability to retrieve temperature and humidity profiles near precipitation, and the ability to see through overlying cirrus down to the more substantive graupel (information on cirrus can be provided by TroCCibras during the field campaign). Also, because larger hydrometeors strongly affect both 54 GHz and 183 GHz, while smaller hydrometeors affect primarily only 183 GHz, differences in microwave responses near both frequencies provide information about graupel size distribution. Particle size is a particularly good indicator of vertical updraft velocities, since only larger velocities can sustain larger particles aloft. These larger velocities are also directly conveying saturated air into low temperature zones, where the humidity is condensed, generating precipitation. As a consequence, a simple relationship may be expected, linking vertical velocities and the height of cell-tops in convective processes to precipitation rates.

These discussions give a good indication of the formidable scientific challenge represented by the retrieval of precipitation from space-based microwave radiometry. Because of the nature of the problem, an approach based on the probability matching method (Calheiros and Zawadzki, 1987) is in order. Calheiros and Santos (1996), working with the Meteosat 5 geostationary VIS and IR channels and Bauru radar data, produced relationships between temperatures, or count numbers, and rainfall for the area of the State of São Paulo covered by the Bauru radar data. Applied to satellite independent data in relation to the basic set used for derivation of the relationships, they provided rainfall values compatible with corresponding radar measurements. Back in 1993, Turner and Austin (1993) used 3-D radar data from Florida as input to a microwave radiation transfer model, which simulated the Tb brightness observations of a 19 GHz space-borne radiometer, at nadir. They checked the potential accuracy of different sensor systems for different footprint sizes, employing various rainfall-retrieval algorithms to three Florida convective storms.

The complexity associated with frozen hydrometeors, as observed by microwave radiometers – in synergy with radars, in this case - has again been pointed out recently by Skofronic-Jackson *et al.* (2003). The paper provides retrieval estimates of precipitation profiles and frozen hydrometeor profiles with the use of wide band (10-340 GHz) radiometry and radar observations. It is shown that high-frequency microwave channels (frequencies above 150 GHz) provide information, which allows the definition of characteristics of frozen hydrometeors appearing in the upper layers of clouds. Results for the 183.33 ±7 GHz channel (Skofronick-Jackson *et al*., 2003; Figure 3, p.482) indicate a good relationship between Z at the top of the cloud and the corresponding Tb. This accumulates evidence to the finding by Staelin and Chen (2000) on Tb vs R, as discussed above.

The probability matching was chosen as a suitable method for obtaining the required Tb vs R relationships. The preliminary information being now obtained from the first calibrated set of data from the Aqua atmospheric sounder shows that a correspondence between the radar images from Bauru, SP, Brazil, and the HSB channel 4 (183.33 ±7 GHz) corresponding satellite images is apparent in a visual inspection. Also, a quick-look verification of the Tb and rainfall ranges indicates that they are compatible and reproduce, to a good extent, previous results.

The issue of the ice scattering at the higher (over about 100-150 GHz) microwave frequency range is key to a successful establishment of the Tb vs R relationship. As discussed above, this will require knowledge about the scatterers at or near the top of the storm. This knowledge can only be reliably obtained with airborne measurements, such as those to be performed by TROCCINOX.

Methodology

The basic procedure to be adopted will follow the steps below -

- Selection of radar events in the coverage areas of the Bauru and Presidente Prudente radars from different yearly periods. These periods will be:
  a) of intense convective activity, from December to February;
  b) of frontal activity with embedded shallow convection, from May to August;
  c) of the rainy-to-dry transition period, from March and April; and
  d) of the dry-to-rainy transition period, from September to November.

The basic selection criterion will be the interval of intensities contained in the rainfall field, which will prevail over that of area of rain coverage:

- Extraction, from the general satellite data storage, of the granules containing the radar areas and corresponding to the selected radar images;
- Correction of the brightness temperatures in the areas of radar coverage for the zenith angle increase along the cross track swath;
- Spatial matching analysis of the pairs of radar & satellite images for optimum area cell correlation between the two sensing systems;
- Computation of the cumulative probability files, with day/night and seasonal stratification, for both satellite and radar, and tests for the statistical stability of the obtained probability curves;
- Matching of the P(Tb) and P(Z) probability curves, and derivation of the Tb vs R regression;
- Application of the Tb-R relationships to independent satellite images and validation with both radar and gage observations;
- Comparative analysis of the relationships for Bauru and Montreal, including the respective climatic differences support;
- Modeling of the scattering process (Tb), and validation with TROCCINOX observations;
- Verification of the possible acting mechanisms on the rainfall retrieval and their relative role in the final results;
- Vicarious validation of the Aqua rainfall estimates with the corresponding NOAA data, for both AMSU and HSB/AMSU-B data.

7.3 TROCCINOX AND HIBISCUS: ESSENTIAL MEASUREMENTS FOR THE PROJECT

Many of the measurements to be performed during the above mentioned experiments constitute essential data for relevant segments of the present project. However, some are crucial for the research proposed in this sub-project and could not be obtained otherwise. They include the in-situ water vapor measurements, as well as the observations to be performed with the lidars (lidar & microlidar) onboard the aircraft and balloons. In particular, the aircraft lidars - the M-55 from above and the Falcon from below – will cover regions of the space around clouds in an exclusive way. All and every of the three research topics on Validation will make intensive use of those measurements in a pioneer experiment. Also, during the transfer flights, very long-distance spatial profiles of the vertical structure of WV will be effected, providing a set of data hardly found in experiments around the world. This quite long cross-section of WV is unique in terms of knowledge of the humidity structure over large distances in Brazil. It will be a much valuable contribution to the knowledge of the Brazilian atmosphere. On the other hand, cirrus observations to be effected in the field campaign play a fundamental role, e.g., in the retrieval of the atmospheric profiles and provide basic information in the process of estimating rainfall with IR from the geostationary satellites. These IR rainfall estimates will be used as interpolation values in the precipitation retrievals from microwave channels in polar orbit satellites.

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8. CLOSURE

The policy of data availability adopted by TroCCiBras entails full data sharing among partners. Disclosing data to third parties is the sole responsibility of the involved partners and is subject to the clauses established in the respective Data Protocols – or similar agreements – existing among the participants.

The version of this proposal to be submitted to, e.g., financing agencies, will include the appropriate documentation as required by each agency, such as chronograms and detailed budgets. This refers specifically to Brazilian supporting organizations and does not imply submittals to any foreign agencies connected or not, to both TROCCINOX and HIBISCUS projects. There are a number of supporting partners, i.e., institutions not directly involved in the experimental activities of the project, but because of their interest in the results to be obtained from the realization of the project and recognizing its importance for the country, they agreed to provide relevant information for TroCCiBras. As of now, these are INMET (National Institute of Meteorology), IAC (Agronomical Institute of Campinas), and CEPAGRI (Center for Agricultural Research), contributing with meteorological surface and upper air observations during the field campaign and developing activities to make use of the project results in selected practices, like weather forecast for INMET and Agriculture/Modeling for IAC and CEPAGRI. CPTEC/INPE will provide the operational forecasting base through outputs from its numerical models, as well as high-resolution satellite imagery. Operational satellite images will be downloaded directly from NASA, while lightning observations and upper air soundings (tephigrams) are sourced from ELAT/INPE and “Master” of IAG/USP, respectively.

The State of São Paulo Secretariat involving science and technology is providing executive support to TroCCiBras, by assisting with obtaining the required permissions from the Federal Government, as most of the research sub-projects are led by institutes from the State of São Paulo and the project is also based there. In addition, TroCCiBras may benefit substantially from the SIHESP (Integrated Hydrometeorological System of the State of São Paulo) now being implemented. While only a limited number of equipment is expected to be already deployed when the Field Experiment takes place in early 2004, they will incorporate the latest technology and should provide particularly accurate data to TroCCiBras.