White Paper for the HALO (High Altitude and Long Range Aircraft) Mission ACRIDICON

Aerosol, Cloud, Precipitation, and Radiation Interactions and Dynamics of Convective Cloud Systems
(ACRIDICON)

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Version of 14 December 2012

Photo D. Rosenfeld

1 Introduction and Motivation

The effects of aerosol particles and clouds on atmospheric dynamics, weather, climate, and public health are among the central topics in current environmental research. Aerosol particles and clouds influence the Earth's radiative energy budget by scattering, absorption and emission of solar and terrestrial radiation. Furthermore, they play key roles in the hydrological cycle and in the formation of precipitation. Moreover, aerosol, cloud and precipitation particles affect the abundance of trace gases via heterogeneous chemical reactions and other multiphase processes (ACPC 2009; Heintzenberg and Charlson 2009; Kolb et al. 2010; Boucher 2012; Stevens 2012).

Aerosol effects on the formation of clouds and precipitation can lead to profound modifications in the dynamics and radiative properties of convective cloud systems. These processes may influence the vigor and organization of heavy weather events like hail and rainstorms and cascade all the way to changing the global circulation of the atmosphere and the Earth's energy budget (Rosenfeld et al. 2008; ACPC 2009; Heintzenberg and Charlson 2009).

The quantitative understanding and predictability of aerosol, cloud, and precipitation properties, interactions, and effects in the climate system are, however, very limited. The lack of simultaneous in-situ measurements of cloud microphysical properties, chemical tracer compounds and aerosol characteristics within deep convective clouds has been a serious obstacle to evaluate detailed cloud-resolving models that can be used for obtaining a more comprehensive understanding of aerosol-cloud interaction and convective tracer transport. The major bottleneck has been the difficulty to investigate and characterize these properties and interactions by in-situ and remote sensing observations. This applies especially to the regime where aerosol-cloud-precipitation interactions play a particularly important role, i.e., the challenging environment of deep convective clouds, from the cloud base through the mixed phase levels all the way up to the anvils (Rosenfeld et al. 2008; ACPC 2009; Heintzenberg and Charlson 2009). The complex interaction between cloud and aerosol strongly depends on the thermodynamics. Williams et al. (2002) compare distinct meteorological regimes in the Amazon region which has enabled to evaluate the aerosol hypothesis for cloud electrification. The results for two distinct months of the most electrically active pre-monsoon regime, one dominated by boundary layer smoke and another with low CCN concentration, casts doubt on a primary role for the aerosol in enhancing the electrification. Recent results also show that the aerosol-cloud interaction strongly depends of the atmosphere instability; during high unstable atmospheric conditions black carbon enhances precipitation formation and contrarily, during stable days, precipitation is reduced as black carbon concentration increases (Gonçalvez and Machado, 2012).

Aerosol cloud interaction can potentially modify cloud microphysical properties and consequently the rainfall, cloud life cycle and lightning activity. The improvement in knowledge of this interaction can be used to validate and improve high resolution model and climate change simulations.

2 Aims

2.1 General objectives

The HALO mission ACRIDICON is aiming at the elucidation and quantification of aerosol-cloud-precipitation interactions and their thermodynamic, dynamic and radiative effects in convective cloud systems by in-situ aircraft observations combined with indirect measurements (aircraft, satellite, X Band dual Pol radar, and ground based) and numerical simulations. Here we summarize the general scientific issues (Section 2.2) that will be addressed and the specific scientific and technical questions (Section 2.3) that shall be answered within the HALO mission ACRIDICON.

2.2 General scientific questions

- Does the interaction of natural and anthropogenic aerosols with clouds and precipitation significantly influence the cloud microphysics, the formation, evolution and dynamics of convective cloud systems and the vigor of heavy weather events (hail and rainstorms)?
- Can these effects induce substantial changes in the global circulation of the atmosphere, the Earth's energy budget, and climate?
- What are the characteristic physical and chemical properties of aerosol and cloud particles in convective cloud systems (inflow, in-cloud, outflow), and how do they change in the course of cloud evolution?
- What are the effects of convective cloud systems on the solar and terrestrial radiation budget, and how can the three-dimensional microphysical structure of convective clouds be considered?
- (For the long range flights one of the goals would be) - Are the cloud processes over forest and deforested regions statically different?
- (For the long range flights one of the goals would be) - Are the cloud processes over polluted and non polluted regions statically different?

2.3 Specific scientific and technical questions

- Can we achieve comprehensive in-situ characterization of the microphysical and chemical properties of aerosol, cloud, and precipitation particles in convective clouds? What are the particle characteristics (number concentration, size distribution, structure, phase, composition, mixing state, cloud condensation and ice nucleation activity) as a function of depth above cloud base and cloud base temperature?
- Do the aircraft indirect measurement instruments and the available radar and satellite data allow determining microphysical profiles of convective clouds as measured in situ by instruments mounted on the aircraft?
- Can we observe characteristic differences in the microphysical properties, dynamics, and radiative effects of convective cloud systems in polluted and unpolluted air? What are these differences (updraft velocities, turbulence, hydrometeor types, cloud electrification, precipitation intensity, proportions and particle size distribution of liquid cloud droplets

and ice crystals, cloud areal and vertical extent, cloud lifetime, cloud albedo, liquid water and ice water profiles, deep of mixed layer and eletrification)?

- Do air pollutants, in particular anthropogenic aerosols, significantly change the height and time for onset and properties of precipitation in convective cloud systems?
- How do deep convective clouds influence the aerosol (particles and gas) in the free and upper troposphere (transport, source, and sink)?

3 Mission Types

In order to investigate these topics, five general types of flight missions are proposed for ACRIDICON. All the missions are performed in both clear and polluted conditions preferably under comparable thermodynamic conditions (i.e., cloud base temperature, humidity fields, wind shear) and also under contrasting thermodynamic situations. The five missions are called:

- 3.1 Cloud vertical evolution and life cycle (cloud profiling)
- 3.2 Aerosol processing (in and outflow)
- 3.3 Satellite and Radar validation (cloud products)
- 3.4 Vertical transport and mixing (artificial tracer)
- 3.5 Clouds formed over forest/deforested areas in polluted/pristine conditions

3.1 Cloud vertical evolution and life cycle (cloud profiling):

3.1.1 Scientific objectives

The major purpose of this mission is to document the vertical evolution (from cloud base to anvil) of the cloud microstructure during the different phases of the cloud life cycle and to follow the initiation of hydrometeors in growing convective cloud elements, under various thermodynamic conditions downwind Manaus (Manaus polluted plume) and upwind Manaus (pristine conditions). The aerosol conditions range between pristine and highly polluted atmosphere, containing small and large concentrations of CCN (Cloud Condensation Nuclei). Importance is given also to the concentration of giant CCN that potentially counteract the effects of small CCN. The ice nucleating (IN) capability of the aerosols is also potentially affecting the mixed and ice phase processes. The thermodynamic range of conditions is mostly captured by cloud base temperatures and CAPE (Convective Available Potential Energy). Warmer cloud base means greater vertical distance for development of warm rain below the freezing level. Differences in the sensible heat flux is also important in determining the intensity of the turbulence in the boundary layer and the cloud base updrafts, which in turn determine the fraction of CCN that actually gets activated into cloud drops. Cloud fraction also plays an important role in the cloud - aerosol interaction, high cloud fraction is normally associated with less intense vertical motion in contrast to more isolated thunderstorm. Also the humidity and wind field have certain influences which will be studied during ACRIDICON. Specific science questions are the determination of the following cloud properties as a function of the various aerosol and thermodynamic conditions:

- Cloud base drop size distribution (DSD).
- The evolution of DSD with depth above cloud base.
- The cloud life cycle from the DSD , liquid and ice content and the mixed layer point of view for pristine and polluted conditions.
- The required DSD properties and height above cloud base for onset of warm rain.
- The height and temperature to which warm rain can reach in a supercooled state before freezing.
- The extent of rainout of warm rain in clouds before freezing and hence avoidance of releasing the latent heat of freezing.
- Amount of cloud water below and above the height of onset of warm rain.
- Amount of supercooled cloud water as a function of temperature and updraft speed, down to the ultimate temperature of homogeneous ice nucleation (-38ºC).
- The main mode of raindrop initiation: coalescence of the modal size of the DSD into drizzle and further into rain drops and/or rain embryos formed on isolated giant CCN.
- The mode of initiation of convective ice hydrometeors: Freezing rain drops or riming of nucleated ice crystals.
- When and where do snow aggregates form in the convective clouds?
- Extent of cloud electrification.
- How much and what type of hydrometeor growth can occur in the anvil?
- What is the typical cloud ice vertical structure for polluted and pristine condition.
- What is the CAPE effect on the precipitation and cloud strucutre.

3.1.2 Measurement strategy

The ground radar will identify the first echoes of cloud formation in the polluted and pristine regions. Specific flights will follow the cloud structures to measure the vertical cloud characteristics during the life cycle. Some specific flights will be coordinated with the G1 airplane. These flights will be designed to follow the clouds near Manaus downwind/upwind, for low/high CAPE and in isolated and more organized cloud systems.

For a complete vertical documentation of the microphysical evolution of the convective clouds, typical flights shall start by probing the aerosols below cloud base, and then ascend through the young cloud elements in the upshear growing stages of the convective cloud, all the way to the level of the anvil (see Figures 1a and 1b). Thus, this mission would start with a characterization of the boundary layer below cloud base in its developing stage (couple of minutes, leave sufficient time for conducting a full CCN supersaturation spectrum if not measured at several supersaturations simultaneously) with regard to aerosol particles, trace gases, dynamics. The cloud base would be penetrated. Further occasional penetrations will be performed during climbing at the young upshear side, with a roughly 300 m vertical spacing. The penetrations should be such that ambient air and aerosols will be sampled as well, including the air that is detrained from the cloud at the various levels. In the cloud-free regions radiation reflected by cloud edges is measured to obtain vertical information about the cloud droplet effective radius. Subsequently the outflow region (exhaust of the cloud) would be sampled to look at cloud-processed aerosol particles. Finally HALO would fly well above cloud (500 m) for radiation measurements. This over-flight will be along the wind shear, so that the cloud cross section will document the cloud from its young growing elements at the upshear and their maturation towards the downshear side.

The conduct of a vertical cross section should take about an hour. Several such profiles shall be taken at conditions with similar thermodynamic conditions but contrasting aerosol content to the maximum possible extent.

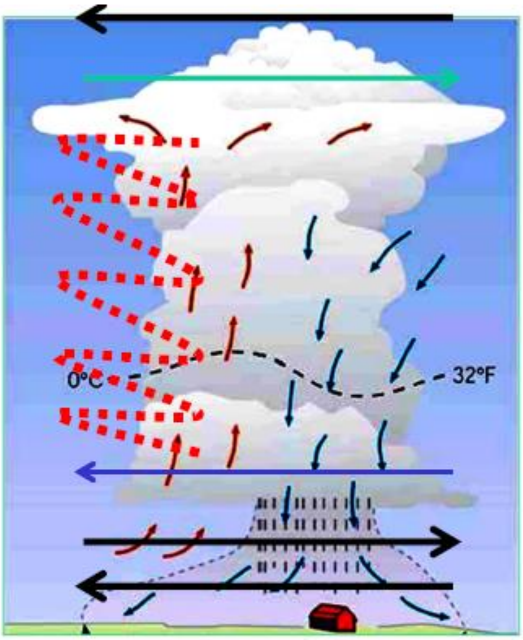
3.1.3 Key instruments (by priority, first 6 are a must, but all are important)

(a) In-situ

- CCP (Cloud Combination Probe), a combined sonde containing CIP (Cloud Imaging Probe) 30-1000 µm and CDP (Cloud Droplet Probe) 2-47 µm.
- Nevzorov probe: Hot wire liquid water and ice content instrument.
- NIXE/CAPS: Cloud imaging probe 25-1500 µm.
- Dual chamber CCN counter.
- PIP: Precipitation imaging probe, 0.1-6.2 mm.
- Ice nuclei counter.
- SID-3: Small ice (particle) detector, phase discrimination, 1-100 µm.
- UHSAS-A: 50-1000 nm dried aerosol size distribution.
- CVI (Counterflow Virtual Impactor)
- Mini-DOAS: UV, VIS, NIR, limb/nadir spectrometers for water phase (g,l,s) and trace gas paths.

(b) Indirect measurements

- SMART-PRO: Spectral Modular Airborne Radiation measurement sysTem for cloud PROfiling, 0.4 – 2.0 µm wavelength to obtain cloud droplet effective radius.



Profile 3000-46000 ft: 1.5 hours

Figure 1a: Suggested schematic flight pattern to document the microphysical evolution of convective cloud.

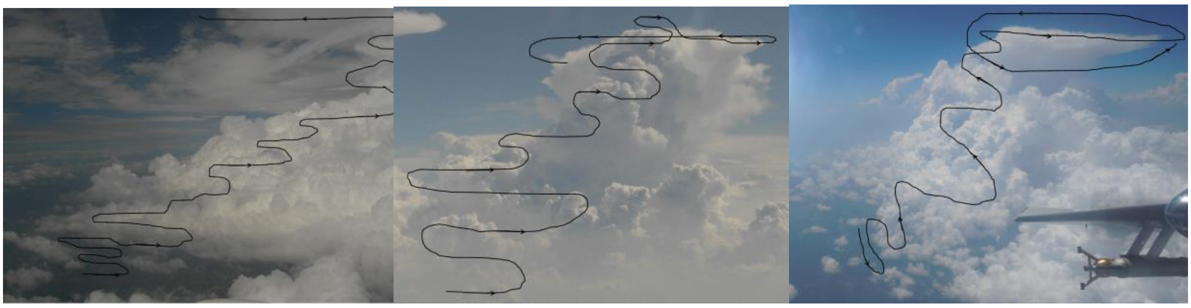


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Figure 1b: Sketches of suggested flight pattern.

3.2 Aerosol processing (inflow and outflow)

This mission focuses on aerosol characterization in the inflow and outflow of convective clouds.

3.2.1 Scientific objectives

The major scientific objectives of this mission are:

- to characterize particle properties and trace gas composition in the inflow and outflow of convective clouds,
- to study the vertical redistribution of aerosols by convective systems,
- to investigate particle formation processes and the evolution of aerosol properties (size distributions, chemical processing) in the fresh and aged outflow of convective cells, and
- to assess the cloud processing of aerosol particles, in particular black carbon containing particles in thunderstorm systems.

Some of the specific scientific questions to be addressed are the following:

- How do particle size distribution, mixing state, and particle chemistry change between inflow and outflow regions?
- How does the pollution level in the boundary layer (inflow region) affect particle properties found in the outflow region?
- Under which conditions is wet removal of particles controlling outflow aerosol properties ("clean" outflow case)? Under which conditions is upward transport of boundary layer aerosol controlling the outflow properties (“polluted” outflow case)?
- Which percentage of black carbon particles acts as CCN and which percentage is deposited by wet deposition?
- Is deposition of black carbon by ice crystals an important removal process?

Furthermore, one of the general topics addressed in this mission is the question of aerosol indirect and semi-direct effects (burn-off of clouds by black carbon absorption/heating) and in how far observations made during ACRIDICON can help to confine understanding and calculations of these effects.

3.2.2 Measurement strategy

Two slightly different approaches are necessary to characterize convective outflow on all relevant time scales (outflow ages):

(a) Isolated cloud study

(b) Long-range outflow survey

(a) Isolated cloud study (2-3 flights)

The aerosol will be characterized by in-situ measurements mainly in the boundary layer (inflow) and in the outflow region (inside and outside the anvil), and, with lower priority, also in intermediate levels in the vicinity of an isolated convective cell. Cloud penetrations close to the convective hot spots are not essential, but anvil penetrations at high altitudes are mandatory (Figure 2).

To study aerosol ageing in the outflow, it is important to devote enough flight time for an extensive probing of the outflow region. Under suitable meteorological conditions flying upwind along the convective cloud track (away from the cloud path) allows to cover a range of outflow ages from "fresh" outflow to that of several hours age.

Depending on how fast the convective system develops, the endurance of HALO, one of the key improvements of this measurement platform, might allow surveying the outflow at several altitudes and several directions from the convective core. Alternatively, in a separate mission, flight time can be prioritized to investigate the entrainment and detrainment in the altitude regions between inflow and outflow (by "circling" around the cell in different altitude levels).

Several case studies should be attempted (1-2 per flight; at least 2-3 flights), in coordination with measurement tasks for other mission topics. In particular, this type of mission could presumably be combined with the artificial tracer mission described in Sec. 3.4.

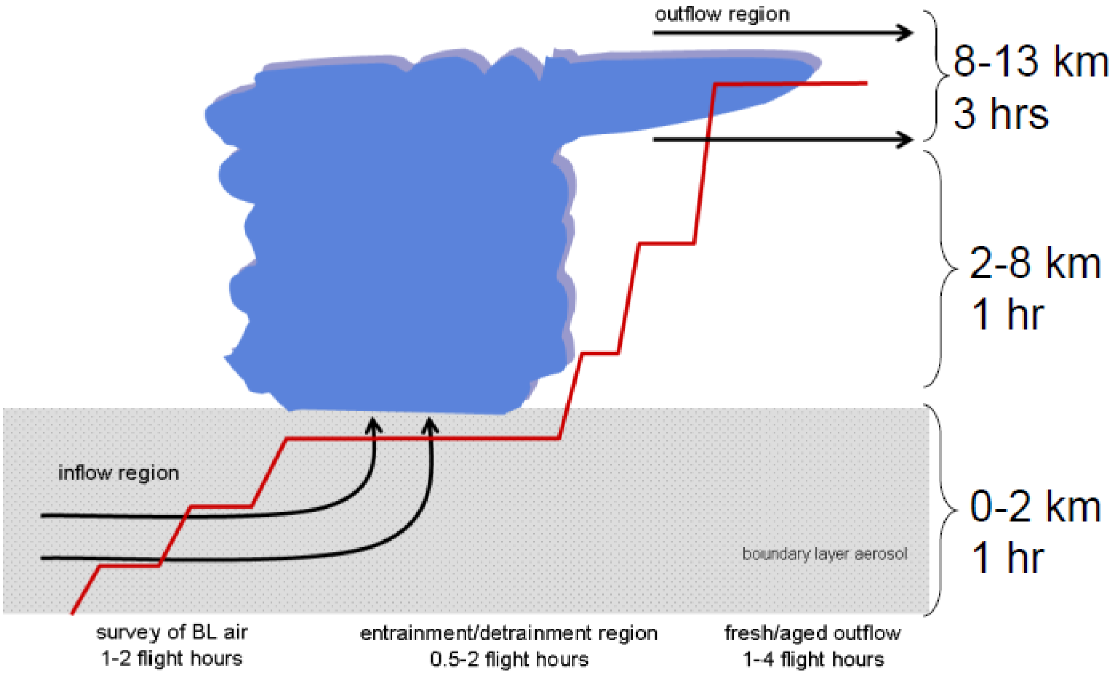

Figure 2: Schematic diagram of the flight pattern for aerosol characterization in inflow/outflow of a deep convective single cell system.

(b) Long-range outflow survey (1-2 flights)

During a single case study mission as described in the previous section probing of convective outflow of tens of hours age or more will be difficult to achieve. Therefore, a separate flight mission is needed in a situation where convective activity occurs over a large region (example in Figure 3). In this case the flight will be mainly devoted to survey the upper troposphere for "aged" outflows of a larger number of thunderstorm systems. This will cover in a rather statistical sense many different cases of convective outflow (different outflow ages) and allow to access the difference and transition to "background" properties of the upper troposphere.

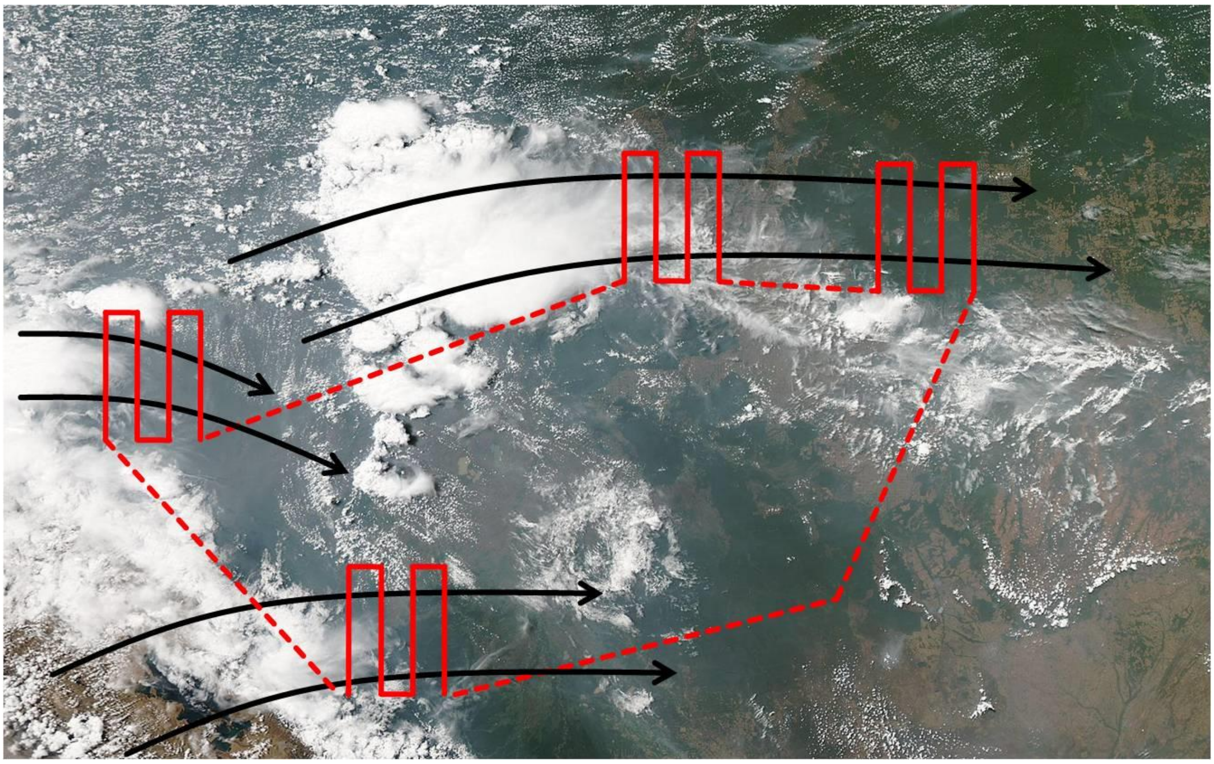

Figure 3. Schematic diagram of the flight track (mainly in upper troposphere) for a long-range survey of the outflow of different convective systems

3.2.3 Key instruments

In-situ measurements of aerosol properties are essential for this mission. This includes size distribution in all relevant size modes, mixing state and chemistry. Relevant instruments include: Aerosol microphysics by AMETYST (size distribution of total and non-volatile aerosol) and the wing probe UHSAS-A, the cloud wing probes CAS-DPOL, NIXE/CAPS, CCP (consisting of CIP & CDP) (to determine coarse mode aerosol and, in this context, for in-cloud/out-of-cloud discrimination), aerosol mass spectrometers ALABAMA & C-TOF-AMS (aerosol chemical composition), particle impactor sampling and Tandem-OPC (aerosol composition and growth factor). Black carbon characterization by SNOOPY and the 2nd SP2 connected to the CVI inlet in combination with measuring the residual particle size distribution by a UHSAS is essential. CVI connected measurements are of particular importance for in-cloud measurements in the anvil. Furthermore, trace gas measurements (CO, ozone, possibly SO_2, and also an artificial tracer during selected missions, see section 3.4) are essential for air mass and inflow/outflow characterization. A Lidar will monitor the vertical distribution of aerosols in the inflow and outflow regions, and in background conditions.

3.3 Satellite and Radar validation (cloud products):

3.3.1 Scientific objectives

The remote sensing and in situ instrumentation suggested for ACRIDICON provides a detailed view on the properties of convective cloud systems. The cloud satellite validation mission aims to compare these airborne data to equivalent data retrieved from space-borne instruments.

(a) The suggested strategy will compare the quantities directly measured by satellite and airborne instrumentation (solar radiance, microwave radiance, radar reflectivity and Lidar backscatter, upper level out flow, penetrative clouds), Radar hydrometeor classification to estimate uncertainties in the satellite calibration. In this regard, deep convective clouds are ideal targets. With high optical thickness the contribution of the surface to the emitted or reflected radiation is minimal and with high cloud top altitude only a small atmospheric column between target and satellite instrument is affecting the radiation measurements.

(b) In a second step cloud products such as cloud optical thickness, particle diameter, liquid and ice water path, and phase derived by retrieval algorithms applied to both airborne and satellite data will be validated, incorporating in situ measurements. Knowing the potential uncertainties in the satellite measurements gives the opportunity to validate the cloud products and retrieval algorithms.

(c) Strong convective clouds show ring U/V shape in the cloud top when observed by IR radiometers. These flights are an opportunity to better understand the formation of these patterns. Also the area expansion in the cloud top of convective system is related to the upper level divergence and can be indirectly related to the updrafts inside the clouds. These flights are also an opportunity to test and adjust quantitative relationship between these parameters.

(d) The co-located flights with the GPM satellite will allow the combinations of dual frequency radar and microwave radiometer (GMI) with airplane measurements. Parameterizations from satellite, radar and passive microwave and ground radar will allow to test and adjust algorithms to retrieval precipitation, ice size, ice integrated content and hydrometeor classification

(e) Aqua, Terra, NPP, Metop and GOES-13 are satellites carrying multispectral sensors, and the co-located airplane and satellite data will make possible the intercomparison between ice/water, particle size, penetrative clouds retrieval and measured,

3.3.2 Measurement strategy

A direct comparison along the satellite track for ranges longer than 25 km (2 minutes flight time at 200 m s^{-1} aircraft ground speed) will be not feasible due to the fast development of the convective clouds. Therefore, stochastic approaches will be applied. Above the cloud top flight legs in random directions will be flown to provide data which can statistically be interpreted. In this regard, e.g., the clout top temperature (altitude) – particle diameter relationship, water phase, will give one basis for a comparison.

Additionally, in situ measurements of cloud properties will be used for the comparison with airborne and space borne remote sensing data. Thus this mission can partly be combined with the cloud vertical evolution (profiling) mission. The detailed flight strategy suggested for this particular mission is shown in Figure 4 and listed below.

1 (1/2h) Characterization of the surface albedo along the predicted satellite track. Simultaneous measurements of boundary layer aerosol possible.

2 (1h) Slow ascent to altitudes above cloud top; including measurements of vertical profile of background aerosol and cloud properties.

3 (1h) Flight synchronized with satellite overpass time. Several flight legs above the target cloud in random direction.

4 (1h) In situ characterization of cloud top (anvil).

5 (1/2h) Descent with measurements of aerosol profile

+ ice and water content - . inside the cloud.

6 (1/2h) Return to airbase

Total duration = 4.5 h

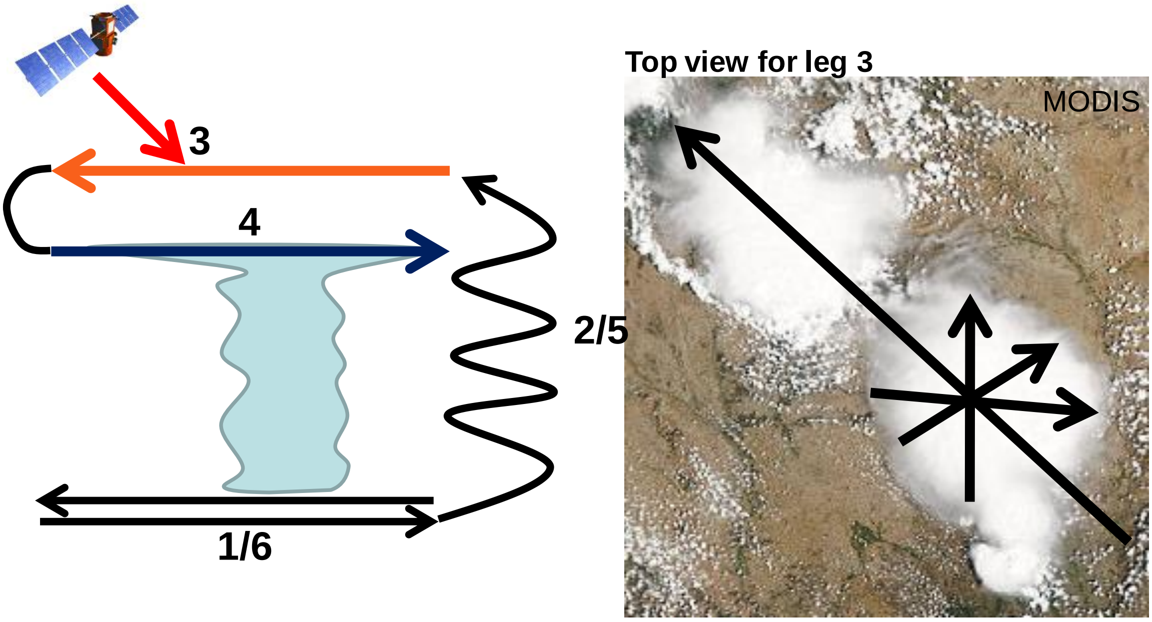

Figure 4: Flight pattern suggested for satellite validation mission.

3.3.3 Key instruments

Key instruments comprise all remote sensing techniques suggested for ACRIDICON which are similar to adequate satellite instruments (SMART Albedometer, HALO-SR, HAMP Microwave Radiometer, HAMP Cloud Radar). In situ probes (CCP, SID-3, CAS-DPOL, NIXE-CAPS). In situ probes (CDP, SID-3, CIP, CAPS) are necessary to obtain independent information on the cloud particle properties. Additional remote sensing instruments applied to derive vertical cloud and aerosol properties during ascents or descents of the aircraft (DOAS, Vertical Cloud Scanner) will complete the data set. Aerosol properties needed for radiative transfer simulations and studying cloud-aerosol interactions are measured in situ and by remote sensing.

The main satellite instruments comprise the A-Train satellites and Geostationary Operational Environmental Satellites (GOES): MODIS, AMSR-E and CERES on Aqua, CPR on CloudSat, CALIOP on Calipso, and SEVIRI on MSG. Table 1 illustrates which quantity derived by satellite instruments is covered by the airborne instrumentation. Additional operating and upcoming satellites missions such as the Suomi National Polar-orbiting Partnership NPP or the Global Precipitation Measurement (GPM) mission will be included.

	Quantity	**Airborne Instrument**					
		In Situ	**SMART**	**HALO-SR**	**MWR**	**Cloud Radar**	**DOAS**
Primary	**Spectral Solar Radiance (1,6,7)**			🟩			🟩
	Spectral Solar Irradiance (6)		🟩				
	Radar Reflectivity (4)					🟩	
	Microwave Radiation (2,3)				🟩		
Product	**Cloud Top Alt./Pressure/Temp. (1,2,3,4,5,6,7,8)**	🟩		🟩	🟩	🟩	🟩
	Cloud Optical Thickness (1,7)	▨	🟩	🟩			🟩
	Cloud Particle Diameter (1,7)	🟩	🟩	🟩			
	Cloud Liquid Water Path (2,3,4)				🟩	🟩	
	Cloud Ice Water Path (4)					🟩	
	Cloud Phase (1,5,7,8)	🟩	🟩	🟩		🟩	🟩
	Vertical Distribution (2,3,4,8)	🟩			🟩	🟩	▨
	Aerosol Properties (1,5,7)	🟩		🟩			
	Energy Budget (6)		🟩				

Table 1: Quantities measured by satellite instruments and their coverage by the airborne instrumentation. Satellite instruments are labeled by numbers: ***A-Train:*** *MODIS (1), AMSR (2), AMSU (3), CloudSat (4), CALIPSO (5),, CERES (6).* ***GOES-East:*** *Imager (7), Sounder (8)*

3.4 Vertical transport and mixing (artificial tracer):

The objective of this mission is to distribute an artificial tracer below the cloud, wait for almost half an hour (to let the tracer distribute homogeneously), and then to measure again below cloud. After one or two hours the outflow would be sampled. The waiting time could be filled with investigating the entrainment regions of the cloud.

3.4.1 Scientific objectives

- To study vertical mass transport associated with deep convection
- To characterize the type and degree of pollution in the air masses where convection occurs
- To quantify redistribution of air pollutants and their scavenging by clouds

Specific tasks are:

- To prepare and guide a tracer experiment for investigation of transport and scavenging in an isolated thundercloud
- To release and sample artificial tracer (perfluorocarbons)
- To measure the air mass tracer SO_2, CO, O_3.

3.4.2 Measurement strategy

The tracer experiment will be performed for an isolated thundercloud. Figure 5 shows a sketch of the measurement strategy. The inflow air will be tagged using a perfluorocarbon tracer (e.g. C_6F_{12}). This can be conducted by two different technique: a) tracer release from HALO or another aircraft in the inflow air during thundercloud activity using a device installed in the back of the aircraft, b) tracer release from a small truck operating in the investigation area where thundercloud formation is occurring.

The outflow air will be sampled with HALO during multiple penetrations of the anvil and transects through cloud free outflow air downwind of the anvil. In addition, vertical profiles will be flown before, during and after the thundercloud activity to study the vertical redistribution and modification of trace species and the detrainment of air at levels in the middle troposphere.

For quantification of scavenging of trace species in the thundercloud, the concentration ratios of the trace gases and aerosols of interest relative to the inert artificial (PFC) and ambient (CO) tracer need to be measured in the inflow air as well as outflow air. Therefore, the inflow air has to be characterized after release, dispersion and mixing of the PFC tracer.

In addition, it is planned to perform an experiment where SO_2 is co-released with the PFC providing a known initial SO_2/PFC ratio in the inflow air. The wet removal of SO_2 in the cloud is then inferred from the observed reduced SO_2/PFC ratios in the anvil outflow. Such an experiment can be performed during conditions with low SO_2 concentrations in the investigation area with thundercloud activity.

3.4.3. Key instruments

PFC tracer release unit:	Tracers are released from two liquid PFC reservoirs using a spray atomizer nozzle outlet. The release rate can be varied depending on the experimental requirements. During the release from a truck, SO_2 gas can be co-released with the PFC from a gas bottle for specific cases.
PFC measurements:	PFC will be measured with two technique covering different concentration ranges and time resolutions: a) sampling of PFC on adsorption tubes (80) in-flight followed by analyses with a GC-MS/MS system in the laboratory (detection limit: 10 ppq, time resolution: 20s), b) on-line measurements of PFCs using a chemical ionization mass spectrometer (detection limit: 1ppt, time resolution: 1s).
Sulfur dioxide (SO_2):	SO_2 will be measured continuously with a chemical ionization mass spectrometer including on-line calibration using isotopically labeled $S^{34}O_2$. The CIMS instrument is also able to measure additional trace species, e.g. HNO_3.
Cabon monoxide (CO):	CO is detected with VUV fluorescence (AEROLASER).
Ozone (O_3).	O_3 is measured using UV absorption (modified TE 49C).

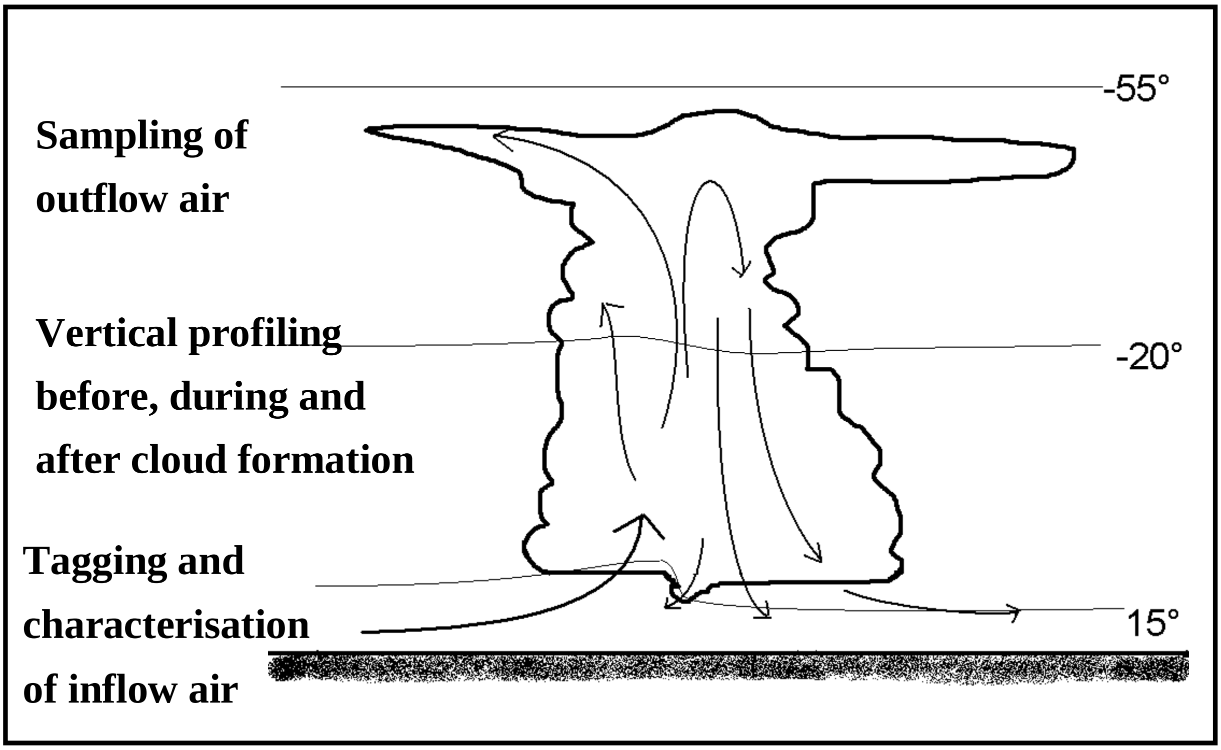

Figure 5: Measurement strategy for "Tracer Mission"

The instruments proposed have been prepared already for the HALO ML-CIRRUS mission. Presently, the certification for use on the HALO aircraft is ongoing. The instruments are grouped in racks as follows:

Rack AMTEX:	includes CO, O_3, and PFC adsorption tube sampler
Rack PERTRAS-R:	includes PFC release module
Rack ITMS:	includes a chemical ionization ion trap mass spectrometer for simultaneous measurements of SO_2, HNO_3 and PFC.

The AMTEX and ITMS racks have a weight of 150 kg each and should be integrated in the

HALO main cabin (e.g. position 17 and 18). The PERTRAS-R rack has a weight of 100 kg and will be integrated in the HALO baggage compartment.

3.5 Clouds formed over Forest/deforested areas in polluted/pristine conditions

3.5.1 Scientific Objectives

Changes in the land use lead to changes in the latent and sensible heating fluxes between surface and atmosphere and can directly affect the local precipitation pattern There are several studies discussing the effect of vegetation pattern in the precipitation, some are controversial and show how complex the impact of vegetation in cloud development is (Duirieux et al. 2003, Negri et al. 2010, Wang 2010). These studies employ satellite and modeling data. The planned flights during ACRIDICON will allow a statistical description of the clouds over forest and deforest regions oi both polluted and clear environments.

3.5.2 Measurement Strategy

The flights will be defined considering measurements over forest and deforest regions.

Three layers will be measured: cloud base, middle and top. Some forest/deforested regions will be selected for these specific flight; out of these specific regions the flight will be just below the zero degree layer to measure the warm clouds. Two flights will be scheduled, one for more clear conditions and another for more polluted clouds. In this way it will be possible to classify clouds as associated with forest (high and low aerosol concentration) and deforested (high and low aerosol concentration) areas. Figure 6 illustrates an example of the suggested flight pattern.

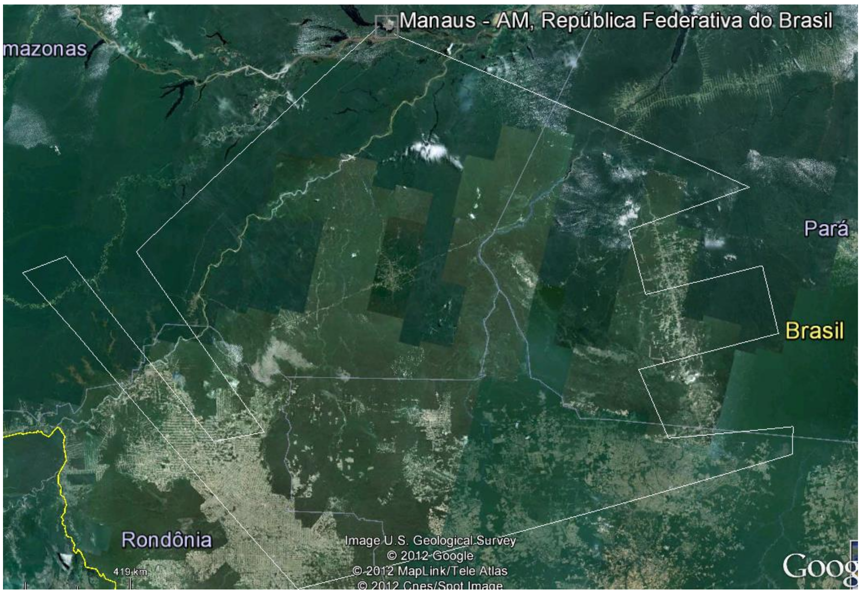

Figure 6: Suggested flight pattern for Mission 5.

3.5.3 Key Instruments

The airplane configuration is the same for all flights. The most important parameters are the same as described in Table II.

4. Implementation

4.1 Measurement region and time

Measurements shall be conducted in the Amazon region during the biomass burning season, where intense convective activity can be expected and where clean background air and polluted air from extensive biomass burning can be found. The high relevance of the Amazon region for the global climate system and the great importance and opportunities of aerosol-cloud interaction studies in this region are well documented in the scientific literature (e.g., Andreae et al. 2004; ACPC 2009; Pöschl et al., 2010; GOAmazon 2011). Flights probing the vertical structure of convective clouds as well as their inflow and outflow regions should be conducted in clean and adjacent polluted air masses. The mission is scheduled for September/October 2014 in close collaboration with the 2nd Intensive Operation Period (IOP) of the GOAmazon2014 project taking place in Manaus (Brazil) throughout 2014 with extensive ground-based and airborne research activities (GOAmazon 2011). Due to the highly complementary nature of ACRIDICON and GOAmazon2014, both projects and scientific communities are expected to benefit greatly from the intended joint operations.

4.2 Aircraft measurement parameters and instrumentation

Comprehensive in-situ characterization and remote sensing of aerosol, cloud, and precipitation particle properties, cloud dynamics, and radiative properties shall be accompanied by trace gas measurements helping to identify the extent and sources of air pollution influencing the investigated convective cloud systems.

An overview of prospective measurement parameters and instrumentation is given in Appendix D. Some of the core measurement parameters shall be covered by more than one instrument, which allows efficient quality control of the applied inlet and measurement systems and data. If required, however, redundancies could be flexibly reduced and individual instruments or packages could be omitted for compliance with the final demo mission payload restrictions. A large proportion of the instrumentation for ACRIDICON is already operational and has been applied successfully on the Falcon and other research aircrafts. Several new and improved instruments for deployment in the ACRIDICON demo mission and subsequent follow-up missions are currently under development. Depending on the progress and results of these developments, as well as on the final payload and certification constraints of the aircraft platform, the actual volume and composition of individual instruments and instrumentation packages may still undergo some change.

4.3 Satellite remote sensing

Satellite remote sensing, especially from GPM, NPP, METOP, GOES 13 (5 channels) offers a unique opportunity to combine in-situ and remote sensing measurements with high spatial and temporal resolution along the trajectory of convective cloud systems. The following parameters can be retrieved: aerosol optical depth, Angstrom coefficient, particle size & type (sulfates, dust, smoke, sea salt); cloud & precipitation effective radii, phase, optical depth, liquid water path; trace gas distributions for CO, CH_4, O_3, NO_x, etc. (FU Berlin, HU Jerusalem, Uni Heidelberg, MPIC-S).

4.4 Ground-based remote sensing

Evolution of the various types of hydrometeors in the clouds which are investigated by the aircraft (conventional and polarimetric radars, DLR) should be complemented by respective ground based observations which will be performed during the ground-based component of GoAmazon2014. This includes S Band radar and X band dual polarization, microwave radiometer, micro rain radar, didrometer and raingauge.

4.5 Off-line particle analysis

Aerosol and cloud residual particles collected on filters and/or impaction substrates will be analyzed by advanced analytical techniques (electron, atomic force, and optical microscopy; laser desorption ionization and secondary ion and mass spectrometry; biochemical assays; evolved gas analysis; Uni Frankfurt, Uni Darmstadt, MPIC-B).

4.6 Data assimilation and numerical simulations

Assimilation of the measurement data and numerical simulations of the processes at a hierarchy of scales, from the individual particle through the individual cloud scale, the regional scale to the global circulation and climate scales (HU Jerusalem, U Stockholm, U Cambridge).

High resolution (1 km) BRAMS simulations will be performed each day. Model simulations combined with radiative transfer models will be applied to create satellite and radar fields.

4.7 Flight planning

Scientific flight planning will be based on a number of forecasting and now casting tools. A mission planning flight tool is currently under development which will implement access to and visualization of a wide range of ECMWF-based forecast products. CPTEC will provide dedicated weather forecast to the campaign, using global and regional models. Besides, a specific visualization system, called SOS-CHUVA Manaus will be developed to support flight planning and coordination. SOS is a Geographical information system to visualize several overlays of geographical information and real time weather data as satellites, radars and models output.

A local operation center will be established in collaboration with SIPAM, INMET, UEA and INPA. For instance, access to local near real-time radar data is essential to guide the aircraft to the most promising convective cells during the missions.

5 Education and training

This is an important component of the whole project. The topic of cloud-aerosol interaction, the instrumentation and techniques proposed to be employed during the field campaign will provide new insights, an unprecedented dataset for testing new theories. The project will involve a large community of scientists and students, therefore it is very important to exchange knowledge and to make this new measurement techniques and science available to local students.

We plan to perform a one-week training session in Manaus during the field campaign, exchange students and researchers. The project coordination will identify mutual interests and potential collaborations for researcher and students exchange. From the Brazilian side, the "sandwich scheme" (usually promoted by CAPES and CNPq) can be used. Recently, the Federal Government of Brazil, through the Science and Technology Minister (MCT) has launched a new program ("Ciência Sem Fronteiras - Science without Frontiers) that can distribute and sponsor scholarships for short duration courses (up to 1 academic year) outside of Brazil.

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Appendix A: Project partners

A.1 Universities

Hebrew University of Jerusalem (Atmospheric Physics)
Ludwig-Maximilians-Universität (LMU), München (Meteorology)
Universidade de São Paulo (IAG and IFUSP)
Universidade federal do ABC
Universidade Estadual do Amazonas (Meteorology)
Universidade Federal do Pará (Meteorology)
Universidade Estadual do Ceará (UECE- Physics)
University of Cambridge (Geography)
University of Darmstadt (Electron Microscopy)
University of Frankfurt (Atmospheric Physics/Meteorology)
University of Heidelberg (Environmental Physics)
University of Köln (Meteorology)
University of Leipzig (Meteorology)
University of Mainz (Atmospheric Physics)
University of Stockholm (Meteorology)

A.2 Research institutes

Instituto de Pesquisa da Amazônia (INPA)
Instituto de Pesquisas Espaciais (INPE/ CPTEC and CCST).
DLR Oberpfaffenhofen (Atmospheric Physics, Flight Operations)
FZ Jülich (ICG 1)
Sistema de Proteção da Amazônia (SIPAM)
EMBRAPA
TROPOS Leipzig (Physics Department)
MPIC Mainz (Biogeochemistry, Particle Chemistry, Satellite)
MPIM Hamburg (Climate Processes)
KIT Karlsruhe (IMK-AAF)

Appendix B: List of acronyms

ACRIDICON	Aerosol, Cloud, Precipitation, and Radiation Interactions and Dynamics of Convective Cloud Systems
AEROLASER	Company name
ALABAMA	Aircraft-based Laser Ablation Aerosol Mass Spectrometer
AMSSP	Airborne Multi- Spectral Sunphoto- & Polarimeter
AQUA	Satellite name
A-Train	Afternoon Train (Nickname for satellite flight formation)
BC	Black Carbon
CALIPSO	Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations
CAPE	Convective Available Potential Energy
CAS-DPOL	Cloud Aerosol Spectrometer
CAPS	Cloud, Aerosol, and Precipitation Spectrometer
CCN	Cloud condensation nucleus
CCNC	Cloud condensation nucleus counter
CCP:	Cloud Combination Probe
CDP	Cloud Droplet Probe
CIMS	Chemical Ionization Mass Spectrometry
CIP	Cloud Imaging Probe
CPC	Condensation Particle Counter
C-ToF-AMS	Compact Time-of-Flight Aerosol Mass Spectrometer
CVI	Counterflow Virtual Impactor
CWC	Cloud Water Content
DMA	Differential Mobility Analyzer
DMT	Droplet Measurement Technologies, Inc.
DOAS	Differential Optical Absorption Spectroscopy
DSD	Drop size distribution
ENVISAT	Environmental Satellite
FINCH	Fast Ice Nucleus Chamber
FSSP	Forward Scattering Spectrometer Probe
GC-MS/MS	Gas chromatography- tandem mass spectrometry
HALO	High Altitude and Long Range Research Aircraft
HAMP	Cloud Radar and Microwave
IN	Ice nucleus
INC	Ice nucleus counter
ITMS	Ion Trap Mass Spectrometer
MAAP	Multiangle Absorption Photometer
MAI	Micrometer Aerosol Inlet
MERIS	Medium Resolution Imaging Spectrometer Instrument
METEOSAT	Meteorological satellite
MPIC-PC	Max Planck Institute for Chemistry, Particle Chemistry Department
MPIC-B	Max Planck Institute for Chemistry, Biogeochemistry Department
MSG	Meteosat Second Generation
NASA	National Aeronautics and Space Administration
NIXE/CAPS	The New Ice eXperimEnt – Cloud Aerosol Precipitation Spectrometer
OPC	Optical Particle Counter
PARASOL	(Polarization and Anisotropy of Reflectances for Atmospheric Sciences coupled with Observations with a Lidar
PCASP	Passive Cavity Aerosol Spectrometer Probe
PERTRAS-R	Perfluorocarbon tracer system for Lagrangian aircraft experiments

PFC	Perflourocarbon
PIP	Precipitation Imaging Probe
POLDER	Polarization and Directionality of the Earth's Reflectances
PSAP	Particle Soot Absorption Photometer
PVM-100	Particle Volume Monitor
SID3	Small Ice Detector 3
SMART	Spectral Modular Airborne Radiation Measurement System
SMART-PRO	Spectral Modular Airborne Radiation measurement sysTem for cloud PROfiling
SP2	Single Particle Soot Photometer
TOPC	Tandem Optical Particle Counter
UHSAS-A	Ultra-High Sensitivity Aerosol Spectrometer, Airborne
UT	Upper troposphere
VUV	vacuum ultraviolet

Appendix C: Aircraft instrumentation and measurement parameters (A: cabin and small wingpods, B: belly pod and large wind pods)

Maybe add Brazilian Co-PIs (e.g., Paulo Artaxo with U. Pöschl on CCN/Abs./Soot)

- ➔ **I agree! Would you make a suggestion of which Brazil PI could be grouped whit which German PIs??? Thanks.**

Principle Investigator	**Institute**	**Measurement Parameter und Instruments**
Hermann	TROPOS	Aerosol size distribution and hygroscopicity (aerosol particle number concentration, size distribution and hygroscopic growth factors, tandem optical particle counter)
Hermann	TROPOS	MAI: micrometer aerosol inlet (micrometer aerosol sampling)
Mertes	TROPOS	CVI inlet: Cloud particle sampling (drops, ice particles)
Mertes	TROPOS	Analysis of cloud particle residues: number concentration (CPC), number size distribution (UHSAS), black carbon (PSAP), condensed water content (Lyman-alpha hygrometer)
Weigel	Uni Mainz	PMS wing pod: In-situ aerosol and cloud particle size distribution: CCP[CIP+CDP], PIP
Krämer	FZJ	**PMS wing pod:** Ice crystal size distribution: NIXE-CAPS
Schnaiter	KIT	**PMS wing pod:** Phase, shape, and size of cloud particles, 1–100 µm: SID-3
Hannemann	DLR	**PMS wing pod:** MTP (Microwave Temperature Profiler)
Minikin	DLR	**PMS wing pod:** Aerosol size distribution accumulation mode (0.07-1.0 µm) (UHSAS-A)
Minikin	DLR	**PMS wing pod:** Aerosol size distribution coarse mode and cloud elements (0.5-50 µm); depolarization (CAS-DPOL)
Schneider, Curtius	MPI Mainz Uni FFM	Aerosol mass spectrometer (aerosol and CPN ensemble composition, C-TOF-AMS)
Schneider, Curtius	MPI Mainz Uni FFM	Single Particle Composition (ALABAMA)

Minikin	DLR	Aerosol microphysics (Aerosol number concentration and size distribution (0.003-2 µm), separately for total and non-volatile aerosol; derived: mixing state, AMETYST consisting of 4 x CPC, 2 x DMPS, 2 x Grimm-OPC, TD)
Weinzirl	DLR	BC mass and size distribution (SNOOPY consisting of SP2 and 3-wavelength-PSAP)
Minikin	DLR	Submicrometer Aerosol Inlet (HASI)
Pöschl	MPI Mainz	CCN & Optics (cloud condensation nuclei, CCNC: DMT-200, dual column)
Pöschl	MPI Mainz	Aerosol light absorption, water vapor (PAS: Photo-acoustic spectrometer)
Pöschl	MPI Mainz	Soot (behind CVI, SP-2: Single particle soot photometer)
Bundke	Uni FFM	Ice nuclei (FINCH: IN counter)
Schlager	DLR	Trace gases (CO, O3, AMTEX: optical spectrometers)
Schlager	DLR	Trace gases (SO2, HNO3, PFC, ITMS: ion trap mass spec.)
Schlager	DLR	Trace gases (PFC tracer, PERTRAS-R: PFC release)
Ziereis	DLR	Trace gases (NOy, NO, chemiluminescence)
Pfeilsticker	Uni Heidelberg	NO2, HONO, BrO, ClO, OClO, IO, OIO, HCHO, C2H2O2, SO2, O3, O4, H2O (l,g,s) (UV/VIS/nearIR Mini DOAS)
Wendisch	Uni Leipzig	SMART Albedometer (spectral radiance and irradiance)
Crewell	Uni Köln, MPI Hamburg	liquid water path, temperature and humidity, profiles, cloud snow and rain water path (microwave radiometer)
Ament	Uni Hamburg	Profiles of radar reflectivity, depolarisation ration and vertical velocity (Cloud Radar)
Jäkel	Uni Mainz	SPARM-PRO: Radiation