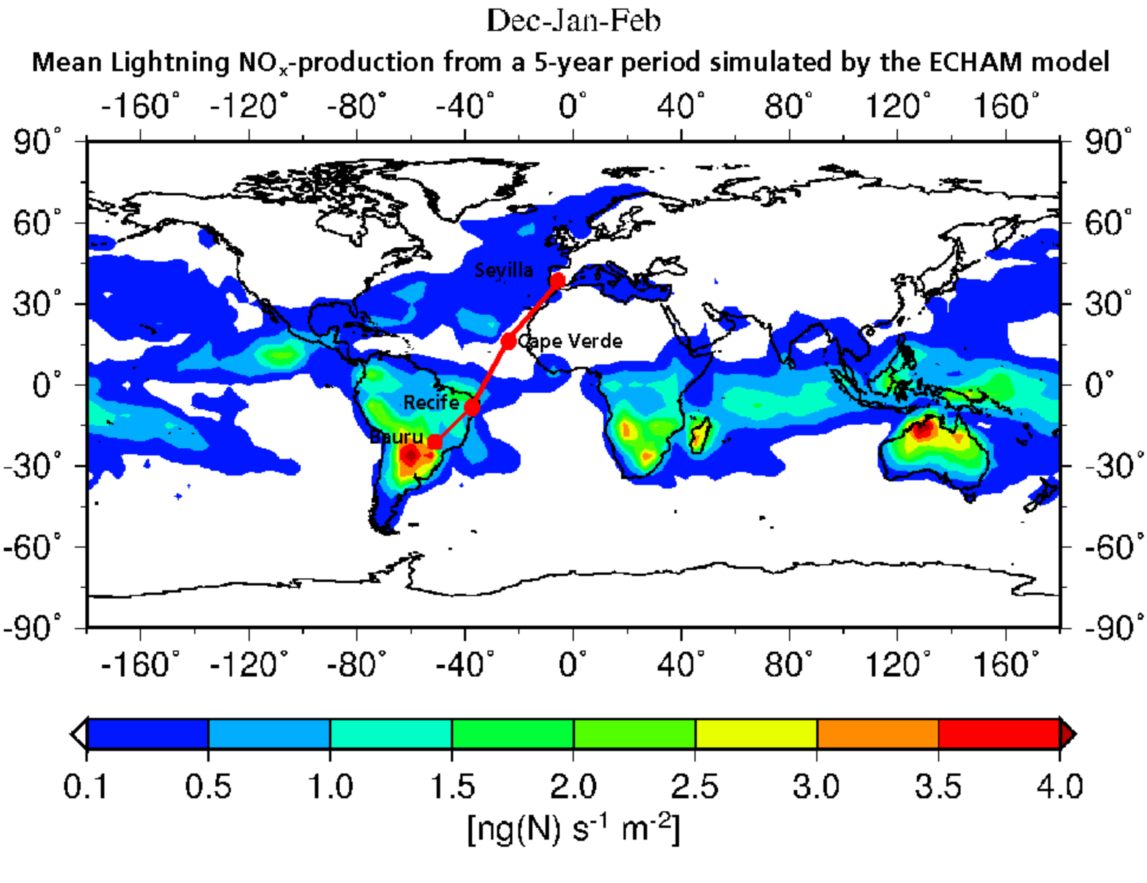
Tropical Convection, Cirrus, and Nitrogen Oxides Experiment

TROCCINOX

A short description of a project under the RTD Programme of the
European Commission, DG RTD-I.2,
“Energy, environment, and sustainable development“,
Key Action: 2 (Global Change, Climate and Biodiversity)



Project duration:

1 June 2002 – 31 May 2005

(July 2002)

Partners:

Partner No.	Full name	Abbreviation	Country code
1	Deutsches Zentrum für Luft- und Raumfahrt	DLR	D
2	Eidgenössische Technische Hochschule Zürich	ETHZ	CH
3	University of Lancaster	ULANC	UK
4	Central Aerological Observatory, Moscow	CAO	RU
5	Stratosphere-M, Ltd., Moscow	STM	RU
6	Instituto di Fisica Atmosferica di CNR	CNR-IFA	I
7	Forschungszentrum Jülich, Institut für Stratosphärenchemie	FZJ-ICG1	D
8	Université Paul Sabatier / Laboratoire d'Aérologie	UPS/LA	F
9	Universität Mainz, Institut für Physik der Atmosphäre	IPA-UMZ	D
10	J. W. Goethe Universität Frankfurt, Institut für Meteorologie und Geophysik	JWG-IMG	D
11	University of Leeds	UNIVLEEDS	UK
12	Istituto Nazionale di Ottica Applicata	INOA	I
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Figure on the Title Page:
The Figure shows the mean lightning NO_x-production for the period Dec/Jan/Feb computed for a 5 year simulation by the ECHAM model. Envisaged measuring site at Bauru (Brazil) and transfer flight route of the involved research aircraft are shown in red.

1. Summary

Tropical Convection, Cirrus, and Nitrogen Oxides Experiment (TROCCINOX)

Problems to be solved

The composition of the atmosphere, the stratospheric ozone layer, and the state of the global climate depend crucially on processes in the tropical regions, in particular at the tropical tropopause. Potential changes in ozone and climate are of relevance for all of the Member States of the European Union and are topic of international protocols such as the Kyoto Protocol, the long-range Transboundary Air Pollution convention, and the Montreal protocol. For assessments of anthropogenic contributions to the nitrogen oxides budget (such as from air traffic), the natural sources need to be known. The global budget of nitrogen oxides is very uncertain mainly because of unknown sources of nitrogen oxides from lightning, most of which occurs over the continents in the tropics. Besides nitrogen oxides formation, deep convection contributes to aerosol formation, transports water vapour and tracers, contributes to cirrus formation, and may contribute to the activation of halogen compounds in tropical cirrus clouds. All these processes are far from being understood. TROCCINOX enhances our knowledge for future preservation of ecosystems, by contributing detailed information on tropical atmospheric processes.

Scientific objectives and approach

An improved understanding of the chemical and physical processes of the tropical tropopause is needed for predicting future ozone and climate changes. The first scientific objectives is to improve the knowledge about lightning-produced NO_x in tropical thunderstorms by quantifying the amounts produced in well-characterised cloud formations, by scaling up the results of the mission to provide global estimates of lightning NO_x, by comparing it to other major sources of NO_x, and thereby assessing its global impact. The second scientific objective is to improve the current knowledge on the occurrence and transport of other trace gases (including water vapour and halogens) and particles (ice crystal and aerosol particles) in the upper troposphere and lower stratosphere in connection with tropical deep convection as well as large scale upwelling motions. The scientific objectives of TROCCINOX will be addressed by performing a field experiment in the tropics including measurements on different spatial scales. Two fully instrumented research aircraft, an M55 Geophysica and a Falcon will probe the large scale structure of the upper troposphere and lower stratosphere during transfer flights to a tropical destination. During an intense measuring campaign at the tropical site the aircraft operations will be co-ordinated with detailed ground-based and space borne systems. Numerical modelling of the observed processes will be carried out to improve understanding and quantification of the observed processes and assessments of their global impacts.

Expected impacts

The data analysis and the modelling component will provide improved descriptions of processes relevant to global climate problems (e.g. the production of NO_x by lightning). This will serve to reduce the large degree of uncertainty in our understanding of the climate system, within the limits of the problems addressable in the present study. The results will be published and provided for advice in ongoing assessment and decision processes. Potential users of the research carried out will benefit from the TROCCINOX data base, which will be available at the end of the project for further exploitation. This will further improve the understanding of the chemical and physical processes at the tropical tropopause as well as the assessment of future ozone and climate changes.

2. SCIENTIFIC/TECHNICAL OBJECTIVES AND INNOVATION

Climate change and changes of the atmospheric composition are major global environmental problems. The atmospheric composition, including the stratospheric ozone layer, and the state of the global climate depend crucially on processes in the tropical regions, in particular at the tropical tropopause. The tropopause altitude in the tropics is typically between 16 and 18 km, too high to be reached by most research aircraft. The lack of measurements in the tropics in general, and the specific difficulties associated with undertaking any kind of focused measurement campaign in the tropics, means that a fundamental understanding of chemical and physical processes is lacking. We have access to two instrumented research aircraft, one reaching higher than 21 km in altitude, which are used together with satellite data, ground based observations and modelling tools to perform the project: "Tropical convection, cirrus clouds and nitrogen oxides experiment" (TROCCINOX).

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 over continental regions in the upper troposphere and lower stratosphere, including troposphere-stratosphere exchange. A modelling component aims in providing improved descriptions of processes relevant to global climate problems (e.g. the production of NO_x by lightning). The general objectives are:

1. 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 NO_x and by assessing its global impact, and
2. to **improve the current knowledge on the occurrence of other trace gases** (including water vapour 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

More specifically, TROCCINOX will address the following questions:

1. **What is the impact of tropical deep convection on the balance and distribution of NO_x and other trace gases?** Nitrogen oxides play a key role in stratospheric and tropospheric ozone formation and ozone losses. There are still large uncertainties in the knowledge of the different sources of reactive nitrogen (ground traffic, biomass burning, microbial activity, aircraft) for the atmosphere. Estimates of the global production of NO_x from lightning (LNO_x) in thunderstorms still differ by about one order of magnitude. Recent satellite observations (OTD) have demonstrated that, on the global scale, lightning activity is highest over tropical continental areas. But it is still not known how much NO_x is produced by these storms and how this production relates to cloud parameters like particle phase, updraft strength, cloud top height, or flash rate, which all would be useful for parameterisations of NO_x-production. These questions will be addressed in TROCCINOX by an integrated observational strategy including different measuring systems (ground based weather radar and lightning detection, airborne measurements and satellite observations). These issues have been investigated recently during the EU-sponsored RTD-project EULINOX (under the 4th framework program) for mid-latitude thunderstorms over Europe. TROCCINOX will extend these investigations to the global scale by concentrating on tropical storms. This will contribute to an improved assessment of the global LNO_x source.

2. **How do troposphere-stratosphere exchange processes contribute to the amount of water vapour entering the stratosphere?** The tropical tropopause is now recognised to comprise a region some 4 km deep, where the influence of stratospheric dynamics (the Brewer-Dobson circulation) and the influence of tropospheric dynamics (particularly the most energetic convection) are of comparable importance. This ‘tropical tropopause layer’ (TTL) plays a crucially im-

portant role in determining the water vapour mixing ratio in the stratosphere. It is important to understand processes controlling stratospheric water vapour because of the enormous sensitivity to humidity of important stratospheric chemical processes, and hence the budget of ozone in the entire stratosphere. New observations of the water vapour distribution will be made around convective systems and associated cirrus outflows as well as in the lower stratosphere. These measurements will allow an improved quantitative understanding of many aspects of the dehydration process.

3. **What is the effect of tropical deep convection on the formation and distribution of aerosol particles?** By measuring condensation nuclei with high time resolution, we will learn more about their ability to serve as the nuclei for the formation of aerosols in the tropical upper troposphere (UT) and lower stratosphere (LS). These measurements will establish whether the tropical upper troposphere is the primary source of aerosol nuclei for the whole stratosphere, as suggested by Brock et al. (1996). Enhanced aerosol concentrations have indeed been observed around clouds, although their origin is not been explained. Understanding such particle formation processes in the UT/LS region is a necessary step in quantifying the overall aerosol budget of this region of the atmosphere.

4. **What are the origins of cirrus clouds in the tropics and how do cirrus clouds affect air composition?** Cirrus clouds influence the radiative and photochemical balance of the whole atmosphere but particularly in the tropics, where insulation is high and where persistent cirrus sheets, extending for several hundred kilometres, have been observed close to, and at large distances from, convective regions. Although the occurrence of high tropical cirrus clouds is well documented, processes controlling their origin and evolution remain poorly understood. In situ and remote (lidar) measurements during TROCCINOX will concentrate on better defining the processes responsible for cirrus formation.

5. **How do tracer correlations across the sub-tropical barrier look like quantitatively and what does that mean for transport between the tropical and mid-latitudinal stratosphere?** TROCCINOX will offer unique opportunities to: i) extensively probe the transition zone between subtropical and tropical air from the tropopause to 21 km; ii) explore a longitudinal section of the subtropical barrier region; iii) observe filaments of extratropical air being mixed across the subtropical barrier into the tropical pipe and characterise the spatial scale and depth of penetration into the tropics of such events; iv) investigate whether the subtropical barrier extends below altitudes of 400 K and if so, how it blends with the tropopause; v) investigate how tropospheric convection systems connect with the stratospheric tropical pipe; vi) evaluate whether most air injected into the stratosphere by very deep convection indeed mixes there irreversibly or descends back into the troposphere.

The tropopause region in the tropics is one of the most poorly investigated and understood regions of the atmosphere, although it is well known that this is where greenhouse gases, water vapour, and particles mainly enter the stratosphere. **TROCCINOX will include the first comprehensive European field study in the tropopause region over continental tropical regions** using a high-flying Geophysica M55 (ceiling 21 km) and a high-flying Falcon-20 (ceiling 13 km) research aircraft, ground-based observation systems, and satellite data. With these measurements and supporting model simulations for local, regional and global scales, TROCCINOX will investigate the impact of deep convection on the chemical composition, cloud structure and aerosol nucleation in the tropical upper troposphere and lower stratosphere.

3. PROJECT WORKPLAN

a) Introduction – Overall Methodology and Structure of the Workplan

For meeting the objectives described above, TROCCINOX applies the following **two-component strategy**:

1. TROCCINOX will conduct a **field study** in order to examine the effects of tropical deep convection on chemical, aerosol and cirrus-cloud processes in the upper troposphere and lower stratosphere, including troposphere-stratosphere exchange.
2. A **modelling component** that aims to improve on current descriptions of the processes studied (e.g. the production of NO_x by lightning), and to assess their relevance to global climate problems.

The **field study** will address these problems on different spatial scales. Two aircraft will probe the atmosphere during the transfer flights (large scale) to a tropical destination. During an intense measuring campaign at the tropical site(s) the aircraft operations will be co-ordinated with detailed ground-based observations of thunderstorms or other relevant atmospheric parameters on a local scale. Satellite data will serve to establish the link between local and global-scale parameters.

TROCCINOX will perform a co-ordinated field study with the HIBISCUS project (5th FP of EU). Using balloon-borne instrumentation instead of aircraft measurements, HIBISCUS investigates similar issues as TROCCINOX.. As in past field experiments, the starting point for the balloon flights will be located at Bauru in Brazil. Short duration balloons will probe the chemical structure of the troposphere and lower stratosphere on a scale similar to the TROCCINOX local aircraft operations. The large scale aspects are investigated by long duration balloons able to travel around the globe several times.

The large range of scales addressed in the proposed study requires a variety of **models** to be applied to the inherent problems, each to a special aspect of the project. Modelling will cover the growth of ice crystals and aerosol particles, the effects of clouds on the radiative transfer, chemistry and transport of trace gases, precipitation formation, lightning and the related NO_x-production, and the global scale climatic impacts of deep tropical convection. As TROCCINOX, HIBISCUS will also include a strong modelling component.

b) Project Planning and Time Table

b-1. Preparation of the Field Campaign

TROCCINOX envisages to perform an extensive field measuring campaign with final destination in the tropics in early 2004. The project is planned for a duration of 36 months starting on 1 June 2002.

The **central region of South-America** is considered for investigation area. It is centred around the Bauru region in the State of Sao Paulo. Strong support from local institutions is provided there. The IPMET (Instituto de Pesquisas Meteorológicas) as the local Institute of Meteorological Research is highly interested in questions of tropical convection, weather forecast and hydrological research. It operates a network of weather radars thus providing good information on thunderstorms. The IPMET is part of the UNESP (University of the State of São Paulo).

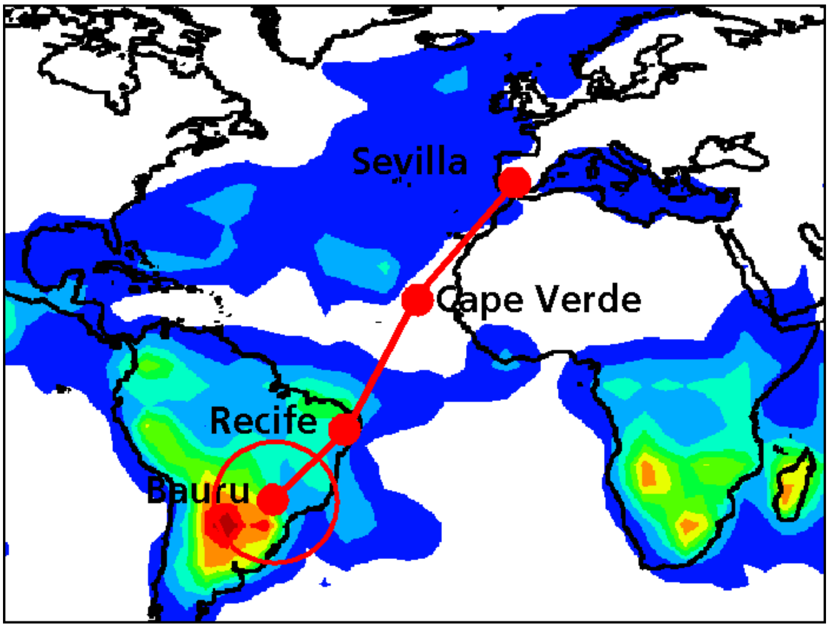

***Figure 1**: Map of locations and flight route planned for the TROCCINOX field campaign. Set-up of the aircraft will be in Seville (Spain). Transfer flights to and from Recife via the Cape Verde Islands will provide meridional cross-sections. Bauru in Brazil is envisaged as location for an IOP with ground-based observing systems involved. The circle indicates the approximate range of local aircraft operations. Colour contours (see title figure for units) show mean lightning NO_x-production for the period Dec/Jan/Feb computed for a 5 year simulation by the ECHAM model.*

A project of the size and importance of TROCCINOX justifies careful consideration of the site and season of the IOP. The convective season at Bauru lasts from December until February. Favourable conditions for the HIBISCUS bolloon flights also prevail during this season. According to the present planning the IOP (intense observation period) is scheduled for January of 2004.

b-2. The Field Campaign

b-2.1 Operation Centre

The field operations will be guided by an Operation Centre. The Operation Centre will provide an experimental mission diary summarising all relevant information on forecasts, flight decisions, quick-looks, maps, scientific findings, and notes from science meetings. Archiving of data will already start during the campaign (e.g. archiving of forecasts) and will contribute to the project's data base.

b-2.2 Aircraft, Measuring Strategy

The project will deploy two research aircraft.

M55-Geophysica: Length 22.9 m, wing span 37.5 m, max speed 750 km/h, record altitude 21830 m, operative radius about 3500 km at 17 km altitude, max take-off weight 24700 kg, max payload 1500 kg, max payload volume 11.83 m^3, two turbofan engines, requiring 1800m runway (asphalt).

Falcon 20-E5/D-CMET: Length 16.3 m, wing span 17.15 m, cruise speed about 720 km/h, max operative altitude about 13 000 m, operative radius about 3000 km, max duration about 4:45 h, max take-off weight 13 200 kg, max payload about 1200 kg, two turbofan engines, requiring 2000 m runway (asphalt).

The M-55 Geophysica will carry a suite of in-situ instruments to measure ozone, water vapour, reactive trace gases (NO, NO_y), tracer species (including CO, CO_2), condensation nuclei and ice particles. These in-situ measurements will be complemented by on-board scatterometers and microjoule lidars. The Falcon aircraft will measure aerosol and water vapour fields using a lidar. This enables it to act as a pathfinder for the M-55 aircraft, i.e. it offers the unique possibility

(a) to detect the (100 m thick) visible/sub-visible cirrus decks and to direct the Geophysica into such clouds which it would miss otherwise, and
(b) to advise the Geophysica to penetrate cumulonimbus anvils at certain locations and thus perform scientifically relevant flight-manoeuvres that the M-55 otherwise would have to avoid for safety reasons.

These aircraft have previously worked in tandem to make detailed observations of the tropical tropopause. This strategy will be followed in TROCCINOX during the transfer flights from Europe to the Tropics and during the long range flights between different campaign sites. Vertical profiles will be taken during take off and landing phases.

Locally, i.e. within the measuring range of the ground based systems available at a main experimental site, the aircraft will perform anvil penetrations of thunderstorms guided by the ground based observations. Measurements at different heights and at different distances from the storm centre will reveal the spatial structure of anvil outflows. Measurements in the lower stratosphere above the anvil will be performed in order to study ST-exchange processes.

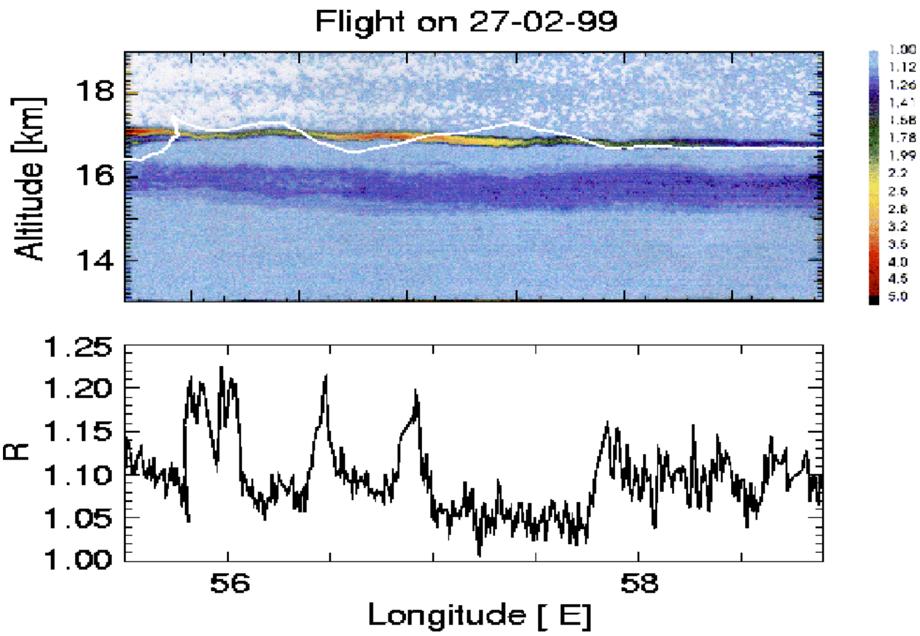

Figure 2: First planned in situ measurements of sub-visible cirrus clouds. Colour: backscattering ratio of sub-visible cirrus layer at the tropical tropopause measured by the aerosol lidar on board of the Falcon. Thin white line: flight course of the Geophysica as commanded by the science officer on board of the Falcon. Lower panel: results from scattersonde on board of Geophysica clearly revealing the traversal of the layer.

For measurements in the upper troposphere and lower stratosphere the high-flying M55-Geophysica aircraft (Figure 3) will be instrumented for in-situ measurements of trace gas species, ice crystal and aerosol particles, and will have remote sensing capabilities for aerosol and cloud particles. Similar types of measurements will be carried out by a Falcon jet aircraft (Figure 4) in the lower and middle tropical troposphere. Figures 3 and 4 show the two aircraft in flight indicating the position of the instrumentation.

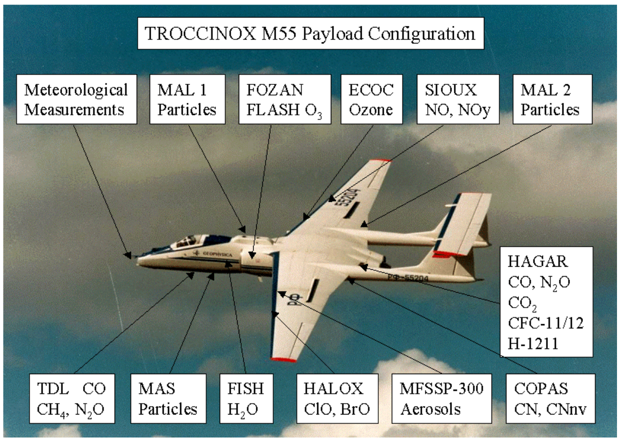

Figure 3: *View of M55-Geophysica aircraft with position of instrumentation as indicated*

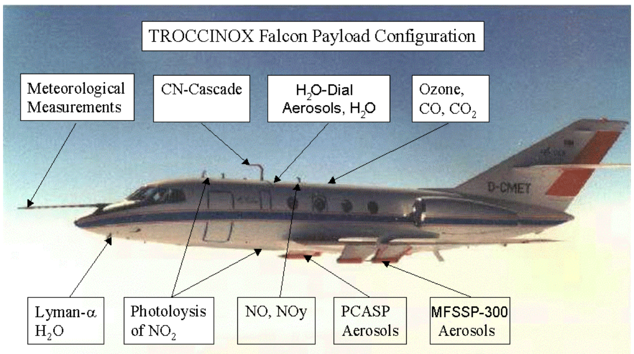

Figure 4: *View of Falcon aircraft with position of instrumentation as indicated*

A description of the major instrumentation of the two aircraft is available on request.

Tables 1 and 2 give an overview of the instrumentation planned for the aircraft. The techniques used are listed including averaging characteristics and accuracy of the measurements. The measuring tasks and the expected outcomes from the systems will be described in more detail in the Workpackage descriptions.

Table 1 TROCCINOX Measurement Characteristics of Geophysica Instrumentation and their contributions to answer questions 1 to 5 stated in Section 2 (+ important, X essential) (1 ppmv = μmol/mol, 1 ppbv = nmol/mol, 1pptv = 1 pmol/mol)

Species / Parameter	**Technique**	**Partner**	**Δt**	**Accu racy**	**Preci-sion**	**1**	**2**	**3**	**4**	**5**
Remote Aerosol Profile (up to 2km from aircraft)	Microjoule-Lidar (MAL-1 and MAL-2)	ON	30-60 s	10 %	10 %			X	X	
Ozone	Electrochemical cell (ECOC)	CAO	10 s	0,01 ppmv	5 %	X	X	+	+	X
Ozone (fast)	Dye chemiluminescence (FOZAN)	CAO	1 s	0,01 ppmv	8 %	X	X		+	X
H_2O (total)	Lyman-α photo-fragment flourescence (FISH)	FZJ-ICG1	1 s	0.2 ppmv	4 %	+	X	X	X	X
H_2O (gas phase)	Lyman-α (FLASH)	CAO	8 s	0.2 ppmv	6 %	+	+	+	+	+
NO	Chemiluminescence (SIOUX)	DLR	1 s	2 pptv	3 %	X	+	+		+
NO_y	Chemiluminescence + Au-converter (SIOUX)	DLR	1 s	5 pptv	5 %	X	+	X	+	X
CO	TDL	INOA	5 s	5 %	2 %	X	+	+	X	+
CO	GC/ECD (HAGAR)	JWG-IMG	120 s	5 ppbv	5 ppbv	X	+	+	X	X
ClO	Chemical-conversion resonance fluorescence (HALOX)	FZJ-ICG1	20 s	20 % or 5 pptv	5 %			X	+	
BrO	Chemical-conversion resonance fluorescence (HALOX)	FZJ-ICG1	100 s	35 % or 3 pptv	20 %			X	+	
CO_2	Non-dispersive IR (HAGAR)	JWG-IMG	10 s	0.2 ppmv or 0.05 %	0.2 ppmv or 0.05 %	X	+	+	X	X
N_2O CFC-11/-12 H-1211	GC/ECD (HAGAR)	JWG-IMG	90 s	0.5 % 1 % 4%	1.5 % 1.5 % 4 %		+	+		X
N_2O	TDL	INOA	5 s	5 %	2 %	+	+		+	X
CH_4	TDL	INOA	1 s	4 %	1 %	+	+		+	X
Condensation nuclei (CN-total , CN-non-volatile)	2-channel CN counter (COPAS)	IPA-UMZ	1 s	10 %	5 %		+	X	X	+
Size speciated aerosols (0.4-40µm)	MFSSP-300	IPA-UMZ	20 s	20 %	10 %			X	X	
Aerosol optical properties	Multi-wavelength Scattering (MAS)	CNR-IFA	10 s	5 %	5 %				X	
Temperature	Standard	CAO	0.1 s	0.5 C	0.1 C	X	X	X	X	X

Table 2 TROCCINOX Measurement Characteristics of Falcon Instrumentation and their contributions to answer questions 1 to 5 stated in Section 2 (+ important, X *essential)*

Species / Parameter	Technique	Partner (No.)	Averaging time	Accuracy	Precision	1	2	3	4	5
Remote Aerosol Profile	LIDAR	DLR	1 sec	10 %	2 %	X	X	X	X	+
Remote H_2O Profile	DIAL	DLR	1 min	10 %	10 %	+	X	X	+	X
Ozone	UV absorption	DLR	5 sec	5 %	1 %	X			X	
H_2O	Lyman-α	DLR	1 sec	0.3 g/m^3	0.01 g/m^3	X	+	+	X	
NO	Chemiluminescence	DLR	1 sec	2 pptv	3 %	X			+	
NO_y	Chemiluminescence + Au converter	DLR	1 sec	5 pptv	5 %	X			+	
CO	VUV fluorescence	DLR	5 sec	3 ppbv	1ppbv	X			X	
CO_2	IR absorption	DLR	2 sec	0.5 ppmv	0.1 ppmv	X			X	
Condensation nuclei (CN)	Butanol CN counter	DLR	1 sec	10 %	5 %	+		+	X	
Size speciated aerosols	PCASP, FSSP300	DLR	20 sec	20 %	10 %	+			X	
Position, wind	INS, GPS, 5-hole probe	DLR	1 sec	200 m (horiz.) 1 m/sec (horiz.) 0.3 m/sec (vert)	0.1 m/sec (h) 0.05 m/sec (vert.)	X	+	+	X	+
Temperature	Rosemount	DLR	1 sec	0.5°	0.1°	X			X	
NO_2 photolysis $J(NO_2)$	Filter radiometer	DLR	1 sec	5 10^{-4}	1 10^{-4}	X				

b-2.3 Ground based and spaceborne systems

Detailed investigations of individual thunderstorms and large storm clusters during TROCCINOX greatly benefit from ground-based and spaceborne observational capabilities. These comprise Doppler radar systems, lightning detection networks, vertical profilers and meteorological stations. Satellite observations will allow for local studies and will also help with the interpretation of the large-scale meteorological phenomena.

A network of two operational Doppler radars is operated by the IPMET at Bauru and Presidente Prudente. It offers good opportunities to observe thunderstorm growth including precipitation formation and the outflow into the anvil at the tropopause which is of special interest for the proposed project. Such information will help to guide the aircraft operations.

Satellite observations will be used for the forecasts during the field campaign, and also for comparison with the measurements taken by the ground-based systems and the model calculations.

b-3. Scientific Analysis of the Campaign, Modelling

Modelling work is an integral part of corresponding Workpackages. The characteristics of the models extend from micro-scale processes of aerosol and cirrus formation, via meso-scale cloud processes describing thunderstorm related processes (including flow characteristics, microphysics, lightning and NO_x-production) to global scale climate processes.

The interpretation of measurements of trace gas concentrations (water vapour, NO_x/NO_y, ClO_x, long-lived tracers, etc) and particles in the upper troposphere/lower stratosphere (UTLS) and specifically in the Tropical Tropopause Layer (TTL) depends crucially on our knowledge of the dynamics and of the microphysical processes of that region. The tropical band between West Africa and South America is characterised by a wide variety of dynamical and cloud processes, both having key roles in the interpretation of the TROCCINOX observations for data sampled during the local mission flights as well as during the transfer flights. Conversely, many of the dynamical processes in this region are poorly understood, for example the return of stratospheric filaments into the stratosphere, or the return of tropospheric convective overshoots into the troposphere, and it is expected that the high resolution measurements obtained during the mission will greatly benefit our understanding of these processes.

The dynamics include large scale air motions (e.g. upper tropospheric westerlies, the tropical easterly jet near the tropopause), equatorial waves in the LS, transport barriers at the tropical/subtropical tropopause and in the subtropical LS, and processes that can induce transport across these barriers (e.g. Rossby wave breaking and subsequent filamentation of stratospheric air into the UT, or the deep convection of tropospheric air into the LS). Microphysics and cloud dynamics involve large-scale advective or slow convective transport and small-scale deeply convective motions in the TTL, which lead to the formation of extended cirrus layers or to cumulonimbus formation, respectively. Both clouds types, though drastically different in appearance, contribute in as yet not quantified ways to dehydration. In addition, cumulonimbus clouds are often electrified, and the resulting lightning activity leads to NO_x production, a major focus of TROCCINOX.

Evidently, modelling for TROCCINOX must address vastly different scales, ranging from hemispheric or inter-hemispheric (several 10^3 km), via regional (several 100 km) to cloud-scale (several 10 km) in the horizontal, and from tropospheric-stratospheric (30 km) to cloud-scale (1 m) in the vertical. This is reflected by the following hierarchy of interlinked models.

A summary of the characteristic features of the models is given in Table 3. The inter-relation with the Workpackage structure is also indicated explaining the specific contribution of each model to the respective Workpackage.

Table 3 Summary of Model characteristics and their contributions to answer questions 1 to 5 stated in Section 2 (+ important, X *essential)*

Model Name	*Features relevant to TROCCINOX objectives*	*Contribution*	**1**	**2**	**3**	**4**	**5**	*Partner*
MesoNH	mesoscale, 3D storm dynamics, explicit cloud scheme and detailed radiative-transfer	forecasts during campaign, storm scale transport	X	X	X	X	X	UPS/LA
ECHAM	global climate model, implications of lightning NO_x-parameterizations esp. on Europe	assessment of climatic implications of field campaign results	X			X	X	DLR
3D trajectories	trajectory data interpretation, synoptic scale studies	H_2O-T-O_3 data interpretation, participation in flight planning	X	X	X	X	X	ULANC
2D axi-symmetric cloud model	deep convective model that calculates trace gas transport to the UT	coupling with chemical box model, aerosol formation in storm outflow, anvil microphysics, participation in flight planning	+	X	+			UNIV-LEEDS
1D cirrus model	Cirrus cloud modelling, nucleation, particle growth/evaporation, radiative properties	Lidar data interpretation, participation in flight planning		+	X	+		ETH
MM5	mesoscale, thunderstorm simulation, cloud and precipitation microphysics, flashes, lightning NO_x	interpretation of airborne NO_x measurements, quantification of LNO_x production	X	X				DLR