International EUFAR Workshop: "Combining Upcoming Satellite Missions and Aircraft Activities: Future Challenges for the EUFAR Fleet" Paris, 13-15 September 2006

Report of the major outcome of the workshop

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Supported by the workshop participants

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Within the framework of EUFAR, the Cloud and Aerosol EUFAR Working Groups have proposed to organize a joint workshop on the topic of "Combining upcoming satellite missions and aircraft activities: Future challenges for the EUFAR fleet". The workshop was held at the Paris Observatory from Wednesday 13th to Friday 15th September 2006. The workshop was sponsored by EUFAR, NASA, and ESA.

Altogether 30 people attended (France 9, Germany 7, USA 7, UK 3, Italy 1, The Netherlands 1, Belgium 1, Switzerland 1). A photo of the workshop participants is shown below.

The major objective of the workshop was to summarize the state of the art in the area of aerosol, cloud, and radiation measurements using aircraft as instrument platforms and to discuss how to use/develop the available capabilities of the EUFAR fleet to support satellite remote sensing validations in this area. Therefore we brought together scientists from the satellite and the aircraft communities. During the workshop these experts have reviewed current and planned activities in the two fields and debated requirements, possible developments and common activities. Furthermore, numerical modellers have been invited to the workshop, in order to assess how models can support combined aircraft/satellite field experiments and how field experiments shall be designed for model validation.

The time table of the workshop is attached in the Appendix. After three review-type introductory talks on observation (in situ and remote sensing) as well as modelling of clouds and aerosols, we have established three sessions on clouds, aerosol particles and combined aerosol-cloud studies. Within these sessions, short talks (10 minutes) were given and followed by lively discussions. Each session was lead by two chair persons. They gave a summary of the main outcome of each session during the round table discussion which was held on the last day of the workshop.

During the round table discussion, major gaps in the current knowledge on aerosols and clouds, and our capability of observing them, were identified and the further proceeding was agreed on. A set of recommendations for needed developments for the European fleet was outlined as follows:

(a) Recommendations to the **Funding Agencies**:

- Steady funding is a prerequisite for successful science especially in the field of airborne research. Interruptions or serious cuts in funding have long-term, problematic implications. Continuous aircraft operation is the only way to assure that available know-how is maintained and further developed.
- Aircraft in-situ measurements will continue to provide a necessary means of linking the different and numerous methods of retrieving cloud and aerosol properties from satellites (and ground-based observations).
- Aircraft measurements cannot be replaced by satellite observations in the future. Both approaches have their own strengths and weaknesses and will be needed further on as a synergic tool. Models to link the satellite approach with airborne validation programs should be included in the funding.
- The EUFAR fleet is missing a long-endurance, heavy payload aircraft which can also operate at low altitudes for multidisciplinary (aerosol, cloud and radiation) large scale field campaigns in oceanic and remote areas.
- The satellite community should always be encouraged to consider airborne validation experiment of the atmospheric retrieved parameters as part of their projects. Funding agencies should also promote airborne/satellite projects that are synchronized with ship cruises (e.g., Polarstern).

(b) Recommendations to the **Aircraft Operators**:

- Airborne experiments will increasingly require a multi-platform approach, for example in order to obtain simultaneous cloud and remote-sensing observations within a particular cloud system. Aircraft operators should try to cooperate with

air traffic control to establish suitable and generally agreed rules for multi-aircraft operations.

- Airborne experiments should take particular note of the observing path/sensitivity of the satellite system and its footprint in designing flight tracks since the range of satellite observations now extends from traditional passive nadir imaging systems to active, nadir-sounding radars/lidars and passive limb sounding techniques.
- There is a set of crucial devices for aerosol and cloud studies that should be part of the extended base-instrumentation of each aircraft of the EUFAR:
    - suite of microphysical probes to measure aerosol, drops and ice crystals size distributions (0.1 to at least 1000 µm)
    - filter and impactor sampling to study the particle chemical composition (bulk and single-particle) and shape
    - passive and active remote sensing instruments that replicate satellite measurements
    - lidar and millimeter-wave radar to place the in-situ measurements into at least a 2-d context within the cloud system. Such systems also provide more statistically-significant sampling over short spatial scales of large particles in the size spectrum.
    - particle absorption and scattering coefficients with separation of sub-micron and total contributions.

  Aircraft operators should be prepared to lay the foundations (hardware mountings, inlets, and certification) to run these instruments.

(c) Recommendations to the **Scientific Community**:

- Cloud research should focus on cloud life cycle studies as a priority. This research includes the time as a new variable. In this way we proceed from the relatively simple cloud state characterization to dynamical studies. Furthermore cloud edge effects have been identified as urgent and rather new issue to be studied. The same statement holds for mixed-phase clouds and drizzle/precipitation processes in clouds.
- In aerosol science two major gaps are the inadequate definition (thus knowledge) of the anthropogenic aerosol fraction and the characterisation of mineral dust. The role of absorbing aerosol particles over clouds has been indicated as a new urgent subject of investigation.
- Quality control issues are very important. It is an obvious necessity to always relay the magnitude and nature of uncertainties of the measurements to the modellers. This holds for both in situ aircraft measurements and satellite retrievals. The retrieval assumptions for satellite projects should also be given. The domain of validity of in situ aircraft measurements should be also provided.
- The development of new or improved airborne instrumentation is required to measure the following properties:

- Aerosol particles: Spectral optical depth (sun photometer), asymmetry parameter (*g*-meter), size-resolved chemical composition (refractive index), real-time particle imaging to quantify particle shape (especially for mineral dust, 0.003 to 40 µm size), spectral absorption coefficient of particles, cloud condensation and ice nuclei concentrations, humidity effects on particles (growth/shrinking, modifying refractive index and shape)
- Cloud droplets and ice crystals: Size distribution measurements and imaging in the 30-100 µm diameter range, polarization properties of ice crystals, scattering phase function. Development of instrumentation for cloud water/ice collection for chemical analysis should also be pursued.
- Optical extinction coefficient: Whilst this is in principle derivable from measurements of the complete particle size distribution, this may be distorted by systematic measurement errors and uncertainties in merging the partial distributions measured by different instruments. High Spectral Resolution Lidar (HSRL) and differential airborne sunphotometry provide reliable independent measurement. One or both of these techniques ought to be included in all EUFAR campaigns where satellite coordination is being attempted.

- The design of a combined aircraft/satellite field experiment shall involve numerical modelling activities (aerosol transport and transformation models) that are presently necessary to provide missing information on aerosol origin and composition.

One additional recommendation that came out of the meeting was for this particular EUFAR working group to meet again, perhaps within 6 to 12 months in order to follow up before momentum is lost.

The focus on the follow up meeting should be to probe into how we plan to achieve some of the measurement recommendations that came out of this first meeting. This implies that there is potential to examine, discuss, and recommend specific experiments, specific observations strategies, and to make recommendations for new airborne sensor development to directly measure or derive the needed variables. To answer the question "how" will require a detailed discussion of what satellite sensors measure (radiance at specific wavelengths) and what is derived from those data as well as some understanding of inherent information content in the data and how measurement uncertainty propagates into the derived quantities. It will also require a larger representation of the in situ aerosol and cloud aircraft communities, which for timing reasons was rather unrepresented at the first meeting.

The validation of the AERONET aerosol products – size distribution and single scattering albedo in particular – through a specifically designed multi-aircraft experiment was subject of lively debate during and after the workshop. The AERONET aerosol retrievals are routinely used as ground-based truth in satellite validation programs. Whilst the discussion is still ongoing at the time this report is submitted, it seems like the need for this specific validation experiment, and challenges involved, can be unambiguously indicated as one recommended topic of discussion for the possible follow-up workshop.

Finally, it was agreed to head for a joint publication of the workshop findings in *EOS* or *Bull. Amer. Meteorol. Soc.* A first draft shall be circulated amongst the participants by the end of 2006.

APPENDIX

Workshop Agenda

Wednesday, 13 September 2006

1200-1300 Registration

INTRODUCTION
Chair Persons: Manfred Wendisch, Paola Formenti

1300-1310: Jean-Marie Flaud (LISA, Paris): Welcome.

1310-1325: Phil Brown (MetOffice, Exeter) and Jean-Louis Brenguier (Meteo France, Toulouse): Introduction to EUFAR and activities of the Expert Working Groups.

1325-1340: Manfred Wendisch (IFT, Leipzig) and Paola Formenti (LISA, Paris): Objectives of the workshop, logistics.

1340-1410: Steven Platnick (NASA Goddard, Greenbelt): Satellite measurements of cloud properties: Overview and needs for validation.

1410-1440: Tad Anderson (University of Washington, Seattle): A review of aerosol measurements: Extending to the global scale.

1440-1510: Ina Tegen (IFT, Leipzig): How can modelers fill the gaps of the aerosol and cloud measurements?

1510-1530: Coffee/Tea Break

CLOUDS
Chair Persons: Steven Platnick, Bernhard Mayer

1530-1550: Alain Protat (CESBIO, Paris): The investigation of cloud processes from ground, airborne and space borne active remote sensing in France: the SIRTA, RALI, CALIPSO, and CloudSat projects.

1550-1610: Filip Vanhellemont (BISA): Stratospheric aerosols, PSCs and subvisual cirrus clouds as observed by GOMOS on ENVISAT.

1610-1630: Jürgen Fischer (Free University, Berlin): Observation of clouds with SEVIRI and MERIS.

1630-1650: Coffee/Tea Break

1650-1710: John Remedios (ESA, Univ Leicester): Validation of cloud/aerosol information from the MIPAS-ENVISAT.

1710-1730: Bernhard Mayer (DLR, Oberpfaffenhofen): Uncertainties in cloud remote sensing and how aircraft observations can help to reduce them.

1730-1750: Andreas Macke (IFM-GEOMAR, Kiel): Modeling and observing the radiation budget of the cloudy atmosphere.

1750-1810: Peter Pilewskie (Colorado University, LASP, Boulder): Validation of satellite cloud remote sensing via airborne spectral irradiance.

Thursday, 14 September 2006

AEROSOL PARTICLES
Chair Persons: Irina Sokolik, Ina Tegen

1000-1020: Gerrit de Leeuw (TNO, The Hague): Retrieval of aerosol properties from satellite data: Needs for algorithm development and validation.

1020-1040: Didier Tanre (LOA, Lille): Validation of CALIOP and PARASOL aerosol products by means of spectral airborne photometry.

1040-1100: Andreas Petzold (DLR, Oberpfaffenhofen): Combining aerosol lidar and in-situ methods for the validation of current and future satellite-borne aerosol instruments: Lessons learned from LACE 98, ITOP 2004 and SAMUM 2006.

1100-1120: Coffee/Tea Break

1120-1140: Manfred Wendisch (IFT, Leipzig): Parameterization of aerosol solar radiative forcing using CALIOP lidar data.

1140-1200: Olivier Boucher: Recent findings on the aerosol direct effect.

1200-1220: Irina Sokolik (GeorgiaTech, USA): Remaining and emerging challenges in measuring and modeling mineral dust aerosol.

1220-1400: Lunch

1400-1420: Oleg Dubovik (NASA Goddard, Greenbelt): Application of inverse modeling for retrieving global aerosol emissions form satellite observations: Potential and issues.

1420-1440: Christiane Textor (IPSL, Paris): Results from the AeroCom model intercomparison

1440-1500: Francesco Cairo (ISAC, Rome): The M55 Geophysica aerosol payload: instrumentation and results

1500-1520: Coffee/Tea Break

COMBINED AEROSOL AND CLOUD STUDIES
Chair Persons: Tad Anderson, Jens Redemann

1520-1540: Chip Trepte (NASA Langley, Hampton): Requirements for validation of CALIPSO cloud/aerosol measurements.

1540-1600: Alexander Kokhanovsky (ESA, Uni Bremen): Aerosols and clouds studied using MERIS and SCIAMACHY on ENVISAT

1600-1620: Peter Spichtinger (ETH Zurich): Aerosol cloud interactions - experiments and simulations.

1620-1640: Jean-Louis Brenguier (Meteo France, Toulouse): What are satellites missing to assess the impact of aerosols on the hydrological cycle: Potential of airborne measurements.

1640-1700: Jens Redemann (BAERI, Sonoma): Simultaneous satellite and airborne aerosol remote sensing in the vicinity of clouds.

20:00-… Joint Dinner at the Ambassade d'Auvergne (a map will be provided).

Friday, 15 September 2006

ROUND TABLE DISCUSSION
Chair Persons: Paola Formenti, Manfred Wendisch

0900-1200: Discussion and Conclusions

Questions to be discussed:

a) Review of current and planned satellite activities for measurements of aerosol, cloud, and radiation parameters and the currently planned concurrent airborne validation studies.
b) Summarize the available capabilities, gaps and future needs (new instruments, measurement strategies) for validation of these space borne measurements using the EUFAR fleet.
c) Discuss how the detailed airborne in situ and global satellite data can be combined to investigate man-made global climate changes. To which extent will models be useful for interpreting and integrating the measurements? Which accuracy of cloud and aerosol measurements is required in order to narrow climate predictions?

Reporting: Do we publish a summary of the meeting? What should it contain (a summary only or abstracts as well)? What forum do we use?

List of acronyms

AERONET	Aerosol Network
BAERI	Bay Area Environmental Research Institute
BISA	Belgian Institute for Space Aeronomy
CALIOP	Cloud-Aerosol LIdar with Orthogonal Polarization
CALIPSO	Cloud Aerosol Lidar and Infrared Pathfinder Satellite Observations
CESBIO	Centre d'Etudes Spatiales de la Biosphère
DLR	Deutsches Zentrum für Luft- und Raumfahrt
ENVISAT	Environmental Satellite
ESA	European Space Agency
ETH	Swiss Federal Institute of Technology
EUFAR	European Fleet for Airborne Research
GOMOS	Global Ozone Monitoring by Occultation of Stars
IFM-GEOMAR	Leibniz-Institut für Meereswissenschaften an der Christian-Albrechts Universität zu Kiel
IFT	Institute for Tropospheric Research
IPSL	L'Institut Pierre-Simon Laplace
ITOP	Intercontinental Transport of Ozone and Precursors
LACE	Lindenberg Aerosol Characterization Experiment 1998
LASP	Laboratory for Atmospheric and Space Physics
LISA	Laboratoire Interuniversitaire des Systèmes Atmosphériques
LOA	Laboratoire d'Optique Atmosphérique
MERIS	Medium Resolution Imaging Spectrometer
MIPAS	Michelson Interferometer for Passive Atmospheric Sounding
NASA	National Aeronautics and Space Administration
PARASOL	Polarization and Anisotropy of Reflectances for Atmospheric Sciences coupled with Observations from a Lidar
RALI	Radar-Lidar
SAMUM	Saharan Mineral Dust Experiment
SCIAMACHY	Scanning Imaging Absorption Spectrometer for Atmospheric Carthography
SEVIRI	Spinning Enhanced Visible and Infra-Red Imager
SIRTA	Site Instrumental de Recherché par Télédétection Atmospherique
TNO	Nederlandse Organisatie voor toegepast-natuurwetenschappelijk onderzoek