European Science Foundation
Standing Committee for Life, Earth and Environmental Sciences (LESC)

ESF LESC EXPLORATORY WORKSHOP

Microbiological Meteorology:
Working at the Intersection of Biology, Physics and Meteorology to Understand and Regulate the Microbial Component of Weather

INRA, Avignon Research Center
Avignon, France,
28 February - 4 March 2006

Convened by:

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FINAL REPORT

1. Executive summary

This workshop brought together 25 scientists from the biological and physical sciences for three days to identify important research questions concerning the origin, characteristics and fate of biological particles in the atmosphere, their impact on atmospheric processes that define climate, and their role in atmospheric chemistry. These scientists were from research institutes and universities in 6 European countries, in the US and in Israel* and represented expertise in atmosphere physics and chemistry, meteorology, modeling of atmospheric processes, bioclimatology, environmental microbiology and plant pathology. The first part of the workshop consisted of a series of tutorials to bridge knowledge gaps between different scientific disciplines represented by the participants. Cloud physics, modeling of weather, microbial quantification, genetics of microbes, atmospheric chemistry, and agricultural practices were all presented conceptually and technically in terms of standard methods. It became obvious that 1) a great deal of collaboration would be needed to knit the participants into a cohesive problem solving entity and 2) microorganisms are an understudied and possibly critical component of atmospheric processes. After the initial cultural shock of finding out how interrelated these disparate fields might be, the group started defining essential collaborations that could lead to finding out just what role microorganisms currently have or might conceivably have in meteorological processes. We identified research priorities and proposed a thematic structure to guide our future work. Working groups were established. We also made preliminary work plans for writing and publishing a prospective article to widen interest in this field.

*Two additional participants from Canada and Austria had to cancel their participation due to health problems.

1.1 Workshop objectives

For decades, microbiologists and atmosphere scientists have suspected that air-borne micro-organisms, abundant in the atmosphere up to high altitudes, play critical roles in atmospheric processes. For example, some air-borne bacteria are highly effective ice nuclei and they are suspected to be involved in processes leading to the formation of rain and snow. There is also growing evidence that, while air-borne, micro-organisms have significant metabolic activity that could modify the chemistry of the atmosphere. As physical particles, micro-organisms might also have effects on reflectivity and other physical properties of the atmosphere. Furthermore, a large proportion of air-borne bacteria and other micro-organisms are emitted from cropped lands and the dynamics of emission is influenced by agricultural and other land-use practices. The objective of the workshop was to bring together the necessary competence to examine this **interplay between vegetation, bio-aerosols, atmospheric processes and air quality**. This competence represented a very broad spectrum of physical and biological sciences including microbiology, agronomy, atmospheric chemistry and physics, meteorology and modeling. One of the fundamental objectives of the meeting was to create the initial momentum for new interdisciplinary research programs. Hence, an essential task was to address the following questions:

- Are there cohesive and original research questions that require the combined expertise of the workshop participants?
- Are these research questions based on premises that can be substantiated?
- Is there a critical mass of scientists interested in these questions?

A second goal of the workshop was then to identify research priorities, research settings and collaborations, and possible sources of funding.

2. Scientific Content

The workshop was oriented around several approaches to generating interdisciplinary discussion. These included 1) general presentations about the long term potential impacts of research on interactions of bio-aerosols and the atmosphere, 2) tutorials to bridge knowledge gaps across disciplines, 3) discussions focused on how to address several specific research questions and 4) general brainstorming and prospecting. The program did not involve any formal presentations of participants' research *per se*.

2.1 Summary of the topics covered

The full content of the general and tutorial presentations is available on the workshop website (described below). A short summary of each topic is presented here.

Long term interest in understanding the interaction of air-borne biological particles with the atmosphere - 4 points of view:

Agriculture (*D. Sands, Montana State University, USA*)

A large proportion of micro-organisms in the atmosphere originates from plant production. Agricultural practices are one of the few environmental parameters that we can modify on a large scale. If agriculture is in fact the source of bacteria that could influence atmospheric processes leading to rainfall, could we change agricultural practices in ways that could have a significant and durable impact on rainfall?

Atmospheric Physics (*P. DeMott, Colorado State University, USA*)

Bio-aerosols need to be brought to the forefront of concepts concerning atmospheric aerosols, if it can be proven that they are important. Basic data on their concentrations, distributions and cloud-activation behaviors are needed. Numerical modeling exercises would be useful for demonstrating the potential role of these aerosols on clouds and climate.

Atmospheric Chemistry (*A. Flossman, Université Blaise Pascal / CNRS, France*)

Cloud drops contain numerous chemical species (formaldehyde, acetate, etc.) significant for the oxidizing capacity of the troposphere. Cloud drops also contain numerous different micro-organisms that can have metabolic activity even at cold temperatures (ca. 5°C, for example). These micro-organisms can degrade (or produce) chemicals that play an important role in atmospheric chemistry.

Microbial Ecology (*R. Psenner, University of Innsbruck, Austria*)

About 200 years ago, the ocean bottom below about 500 m depth was considered to be a desert. We are all aware of the considerable change in our understanding of the ecology of this habitat since then. More recently, our eyes are also being opened to the abundant and diverse microbes that inhabit ice and snow. The atmosphere (cloud droplets, aerosols, etc.) is the next frontier to be explored as a microbial habitat. This will lead to knew paradigms concerning the biology of micro-organisms are their interaction with the environment.

Tutorials from the core part of the program

Capturing and characterizing atmospheric aerosols (*R. Jaenicke, Universität Mainz, Germany*)

- Size distribution of particles of biological origin in the atmosphere.
- Problems of aerodynamics of particle samplers: particle intake, transport, impaction.

Chemical analysis of atmospheric aerosols (*H. Bauer, Vienna University of Technology, Austria*)

- Samplers: high volume samplers, impingers, impactors.
- Chemical analysis: polar and non-polar organic tracers, cellulose and anhydrous sugars, carbon, humic substances.
- Results of chemical composition studies at urban and peri-urban sites.

Single particle analysis of atmospheric aerosols (*M. Posfai, University of Veszprem, Hungary*)

- Principles of operation and specific applications of transmission electron microscopy, scanning electron microscopy, atomic force microscopy and aerosol mass spectrometry.

Origins and properties of ice nucleation active organisms in the atmosphere (*C. Morris, INRA, France*)

- Biological origins of atmospheric ice nuclei.
- Habitats for proliferation of organisms with ice nucleation activity.
- Properties of INA organisms that could confer properties of air-borne particles.
- Detection of micro-organisms, of traces of micro-organisms and of traces of INA bacteria in environmental samples.

Properties of the ice nucleation active protein of bacteria (*D. Georgakopoulos, Agricultural University of Athens, Greece*)

- Characteristics of the gene for ice nucleation activity in bacteria.
- Structure and stability of the ice nucleation active protein.
- Environmental conditions favoring expression of the gene for ice nucleation gene and protein production.

Snow, ice and clouds as habitats for micro-organisms (*R. Psenner, University of Innsbruck*)

- Presence, abundance and characteristics of organisms in ice ecosystems.
- Global and regional importance of these ecosystems.
- Research deficits and needs; targets for future research.

The physical states of water (*O. Möhler, Forschungszentrum Karlsruhe, Germany*)

- Basic properties of water and ice
- Vapour pressure of ice.
- Vapour pressure of (supercooled) liquid water.
- Phase transition: liquid to ice (homogeneous freezing).
- Consequences of ice formation in liquid clouds.

Heterogeneous ice nucleation (*G. Vali, University of Wyoming, USA*)

Physical principles underlying the process of water going into a solid state including:

- size distribution of (nucleation) germs
- nucleation rate
- deposition
- freezing

in the context of different modes of nucleation:

- deposition
- immersion freezing
- condensation freezing
- contact freezing
- evaporation
- memory effect
- haze freezing

All about clouds (*P. DeMott, Colorado State University, USA*)

- What is a cloud?
- What is its origin?
- What makes it rain?
- What can we predict and model about a cloud's destiny?

Land-atmosphere exchanges, the relationship between land-use and climate (*D. Courault, INRA, France*)

- Introduction: the main processes involved in the relationship between land use and climate at a regional scale.
- The different parameters of the energy balance and the models involved.
- Examples of surface - atmosphere exchanges at the scale of small agricultural regions.
- Effect of cultural practices on microclimatic variables.
- The turbulence phenomenon near the surface: large eddies.

The influence of micro-organisms on atmosphere chemistry (*L. Deguillaume, Faculté des Sciences et Technologie, France*)

Speculative and substantiated discussion about these questions:

- Are micro-organisms in the atmosphere able to transform chemical compounds such as organic functional groups, heavy metals, etc?
- What is the relative importance of atmospheric chemistry driven by contact among molecules versus microbiological degradation?
- Which environmental factors dictate the importance of airborne taxa on transformation of atmospheric chemical species?
- What is the impact of bioaerosols on SOA degradation?
- Does the modification of the chemical composition of organic aerosols along with particle size and density influence significantly their CCN efficiencies?
- Can processes at the air/snow interface represent a significant source of VOCs in the atmosphere?

Modeling atmospheric processes (*B. Vogel, Universität Karlsruhe, Germany*)

- Why do we need models of atmospheric processes?
- How do these models work?
- What are their limits and what are the prospects for refinement and improvement?
- How are the models validated?
- Some specific illustrations of available atmospheric models.

Introduction to PCR for detection and characterization of micro-organisms (*J. Nowoisky, Max Plank Institute for Chemistry, Germany*)

- What is DNA?
- How DNA is extracted and amplified for further characterization.
- How the sequence of the nucleotides in DNA is determined ("DNA sequencing").
- Searching data bases to identify the source of DNA from the environment based on its sequence ("Blasting").

Real time PCR for the quantification of micro-organisms (*T. Hill, University of East London, UK)*

- Theory behind quantification.
- DNA stains: Sybr Green I for enumeration of Pseudomonads.
- DNA probes: Scorpion to quantify ammonia oxidizers.
- Potential for enumeration of ice nucleation genes.

Probes for 16S ribosomal RNA for detection and characterization of micro-organisms (*R. Psenner, University of Innsbruck, Austria*)

- What is ribosomal RNA and how is the rRNA from bacteria different from that of higher organisms?
- How does this RNA tell us about the identity of an organism?
- How can we combine phylogenetic taxonomy with bacterial counts, activity assessment and biomass estimation? For instance, by using CARD-FISH or fluorescent in situ hybridization with isotope techniques.

Abundance and transformation of proteins in air particulate matter (*U. Poeschl, Max Plank Institute for Chemistry*)

- Aerosol processes and effects on climate and human health.
- Aerosol feedback loops.
- Aerosol multiphase processes.
- Protein abundance.
- Protein nitration.
- Protein hydration
- Salt hydration
- Deliquescence phase transition.

2.2 Group discussion of research questions

2.2.1 Role of micro-organisms and bio-particles in processes leading to precipitation (discussion leader: P. DeMott, Colorado State University, USA)

Here we identified two main hypotheses to be tested:

- Ice nucleation active (INA) bacteria have an active role in creating precipitation in some types of clouds.
- Natural sources exist that provide concentrations of INA bacteria of significance to precipitation.

Tests of the first hypothesis would require seeding experiments in clouds, experiments with snow canons and cloud chamber experiments. For cloud seeding experiments, orographic clouds would be the best candidates. The INA material could be a mixture of IN-active and IN-inactive strains that could be traced independently. Determining the amount of real precipitation resulting from cloud seeding could be complicated; chamber and canon experiments would permit more targeted observations of resulting crystallization and precipitation.

To evaluate the second hypothesis, it would be important to determine the aerosol abundance and size distribution and to identify the biological component. Detailed information concerning the spatial (vertical and horizontal) and temporal distribution of atmospheric particles and their abundance relative to suspected sources is lacking. Specific field sites that offer little turbulence would be needed for such measurements. Examples of such sites are listed below. Particles should then be further characterized for their properties relative to processes involved in precipitation (cloud condensation nucleation capacity; ice nucleation activity). This type of study would require concerted efforts among multiple laboratories (multiple field sites) and is likely constrained at present by the lack of widely-available equipment for field measurements of aerosol abundance, particle size and properties (CCN and INA).

2.2.2 What are the obstacles to long distance aerial dissemination and survival of micro-organisms? (discussion leaders: T. Hill and B. Moffett, University of East London, UK)

To list the full spectrum of processes involved in aerial dissemination and survival of micro-organisms, we likened their aerial dissemination to airplane transport of passengers. Micro-organisms would take off from some surface. Mechanisms of take-off would be related to the nature of the vehicle (microbes associated with soil, debris, spores, aggregates with other microbes, on insects, etc.). Take-off would occur from either terrestrial or water surfaces (forests, grasslands, tundra, semi-arid and desert regions, crops, pastures, urban areas, animal bodies, sea water, fresh water, snow and ice) and would likely have temporal variability as a function of temperature, relative humidity, wind, rain, convection, turbulence in seasonal and annual cycles. The duration and destiny of the flight would depend on the aerodynamic properties of the vehicle and on the prevailing meteorological conditions. These properties and conditions would also influence the survival of the microbial "passengers", certain vehicles being better protectors against desiccation, UV radiation, low pH, oxidative stress, etc.

Mechanisms of landing could be passive (sedimentation, scrubbing by precipitation) or active if the INA or CCN activities of the microbes contributed to the formation of rain or snow. Upon landing, the microbes might be successful immigrants if they arrive in a hospitable environment or one to which they can adapt quickly. Priority questions about this process that emerged were:

- Given a source, what proportion of micro-organisms take off?
- How high and how far do they normally go (500 km per day like water)?
- Is the residence time in the atmosphere days or weeks (can we compare to other aerosols)?
- What proportion survives and what proportion of them lands in a suitable location?
- How much time do they spend in air *vs*. in water droplets?
- Are they metabolically active on the journey?

2.2.3 The impact of micro-organisms on rainwater quality, air pollution and other aspects of air quality. (discussion leaders, H. Bauer, Vienna University of Technology, Austria)

We focused on two hypotheses:

- Bacteria can alter the organic compounds in cloud droplets (either actively or passively).
- Micro-organisms are altered chemically by polluted air and this has a subsequent effect on their involvement in atmospheric processes.

The first hypothesis revealed a point of controversy among the atmospheric chemists. This concerns the relative importance of gas phase chemical reactions vs. liquid phase chemical reactions in defining the chemistry of the atmosphere. Gas phase chemistry concerns the bulk of the atmosphere. However, some participants argued that 1% of aerosol and cloud drops contain bacteria and this might be sufficient to affect atmosphere chemistry given that reactions in the liquid phase are more efficient.
Nitration of tyrosine residues in proteins was discussed as an example of the possible effect of the atmosphere on bacterial INA. Tyrosine is in the octapeptide repeat of the INA protein and is part of the structure of the protein critical for ice nucleation activity. We speculated if exposure of *Pseudomonas syringae*, for example, to reactive nitrogen species in the atmosphere (nitrate radicals, nitric and nitrous acid, etc.) would reduce the INA of this bacterium and devised experiments to test this hypothesis.

2.2.4 Identifying priority questions from the "potpourri" of questions listed in the program. (discussion leaders, D. Sands, Montana State University, USA; B. Moffett, University of East London, UK; and U. Poeschl, Max Plank Institute for Chemistry, Germany).

Prior to their arrival at the workshop, participants contributed 150 questions about bioaerosol-atmosphere interactions that were included in the program. We grouped the questions and identified those of greatest research priority. For each theme, the questions are grouped by the type of approach (laboratory and chamber experiments (**Lab**), or field experiments and remote sensing (**Field**)) best suited for investigation.

- **Emission and deposition of particles**

  <u>Lab</u>

  - How do biological aerosol inputs to the atmosphere vary by region and season?

  <u>Lab & Field</u>

  - What are the main processes for the entrainment/deposition of micro-organisms into/from the atmosphere?

- **Atmospheric abundance of particles**

  Field

  - How to demonstrate that ice nuclei or cloud condensation nuclei active in the atmosphere have a significant component from biogenic sources? The potential is there for this to be the case, yet the proof is elusive.
  - What do we know about the sources, concentrations, sizes and kinds of biological aerosol particles in the atmosphere?
  - Where in the world could the bioprecipitation cycle be occurring naturally where it could be demonstrated?
  - Do clouds which are formed by bacteria hamper or facilitate precipitation?
  - Is the diversity of bacteria in the atmosphere known, how variable is it, does it depend on the ecosystem on the ground?
  - Do bacteria which belong to different species have a different behaviour in the atmosphere? If so, which effects are equal, which are different?
  - What are ice nucleation bacteria (INB) like (single particles or clusters, shape) when they are airborne?
  - What are the concentrations of biotic particles in the atmosphere?

- **The relationship between ice nucleation activity, cloud condensation nucleation activity and precipitation**

  Lab

  - At which temperatures do biological ice nuclei form ice in the atmosphere? What do we really know about the ice nucleation efficiency of bacteria and other biogenic particles?
  - What is the molecular-scale mechanism of ice nucleation on bacteria? Is there a certain crystallographic plane of the structure of ice templated by functional groups on the cell wall?
  - Is there a potential role for biosurfactants in bubble bursting, coalescence and in altering vapour pressure of water droplets?

  Field

  - Do clouds which are formed by bacteria hamper or facilitate precipitation?
  - Do bacteria which belong to different species have a different behaviour in the atmosphere? If so, which effects are equal, which are different?

- **Measurement of biological aerosols**

  Field

  - What techniques are available to identify biological aerosol particles? Are any of the real-time measurements amenable to flying on aircraft?
  - Do we have instruments to detect the ice nucleation bacteria in the atmosphere at different altitudes?

- **Biology and chemistry**

  Lab

  - What atmospheric conditions permit the viability of micro-organisms during atmospheric transport?
  - Do airborne bacteria reproduce in the atmosphere (or is the atmosphere just a conveyor)?

  Lab & Field

  - Do atmospheric agents (radiation, reactive gases etc.) modify bacterial pathogenicity (make them more toxic or enhance the allergic effects)?

3. Results

One of the main results of the workshop was a clear recognition of the importance of research concerning the role of bioaerosols in atmospheric processes and their fate in the atmosphere, a meeting of partners and establishment of a critical mass for this research, and identification of priorities for research and the development of methods. We might be so bold as to state that this workshop marks the beginning of a new field of research. Furthermore, we identified themes around which we should structure future research in this field. These themes are:

- **Field measurements and observations, sampling strategies and data assimilation.**
- **Methods for characterizing particles in aerosols that take into account their biological properties and their ice nucleation at temperatures just below 0°C.**
- **Seeding and cloud chamber experiments for investigating bioaerosol-atmosphere interactions**
- **Characterization of the main processes for entrainment/deposition of micro-organisms into/from the atmosphere.**
- **The possible effect of atmospheric chemicals on microbial survival and nucleation activity.**

This workshop highlighted the great diversity of particles of biological origin in the atmosphere and enlightened participants to the need to take into account that atmospheric particles may indeed be biological and not simply physical entities. The possibility that biological particles multiply and/or metabolize makes them distinct from abiotic atmospheric particles. Nevertheless, we wonder if we can apply the concepts and methods for studying microbial ecology in other habitats to the study of the atmosphere. If this is conceivable we anticipate a major step in our understanding of the atmosphere. There will be need for adapted methods, appropriate scales of study and open minds about new paradigms.

3.1 Working groups and collaborations.

This workshop led to the establishment of new working groups and collaborations. Furthermore, it re-enforced the pertinence of some of the existing collaborations that were represented. These include:

- Working group on the taxonomic identification and characterization of biological properties of air-borne micro-organisms (*University of East London, University of Innsbruck, INRA-Avigon, Agricultural University of Athens, Max Planck Institute for Chemistry*).
- Collaboration concerning cloud chamber experiments to characterize the process of nucleation of atmospheric water by ice nucleation active bacteria (*Forschungszentrum Karlsruhe, Agricultural University of Athens, INRA-Avignon).*
- Collaboration concerning the effect of nitration on bacterial ice nucleation activity (*Max Plank Institute for Chemistry and INRA-Avignon*).
- Collaboration concerning the effect of cloud seeding with marked strains of INA bacteria (*University of Wyoming, USA, Montana State University, USA, Agricultural University of Athens, INRA-Avignon*).
- Collaboration to model plant disease spread and the dissemination of fungal spores (*Universität Karlsruhe and INRA-Avignon*).
- Collaboration concerning interactions of biological particles and ice particles and their effects on atmospheric chemistry and physics (*INRA-Avignon, Max Planck Institute for Chemistry, and University of Mainz – ongoing German Research Foundation Project "Tropospheric Ice Phase", DFG-SFB-TROPEIS*).

3.2 Network and website

A website was created for the workshop on the INRA-Avignon server and will be maintained to transmit the presentations and summary from the workshop: http://www.avignon.inra.fr/internet/unites/pathologie_vegetale/Bacteriology/Microbiological%20Meteorology/version_index_html

A network is being established based on the mailing list for the workshop participants and additional colleagues who have expressed their interest in the website.

3.3 Links to other networks

To achieve characterization of the abundance and size distribution of biological aerosols, appropriate sampling sites are necessary. One strategy to find such sites would be to explore the list of sites currently used for aerosol studies and to attempt to collaborate with the working groups responsible for these sites. Such sites include:

- Indonesia: A UK NERC consortium of investigators is leading a project called OP-3 at a site in Danum Valley Malaysia.
- Manaus, Brazil: the LBA BARCA project includes tower measurements in the Amazon basin.
- Pelleston, Michigan: the University of Michigan runs a long term forest site. See http://data.engin.umich.edu/PROPHET/default.htm.in
- Department of Energy, Atmospheric Radiation Measurement program operates atmospheric radiation measurement sites on the California coast, in Oklahoma, on the North Slope of Alaska, in Darwin Australia and they have a mobile facility that they have shipped for studies most recently in Niamey, Niger
- Sites in the context of the FP6 program "Organics over the Ocean Modifying Particles in both Hemispheres (OOMPH)". The aim of this program is to study ocean-atmosphere interactions. The Air Chemistry Group at the University of Veszprem, Hungary is involved in this project. For details, see pp 38-39 of the document at: http://europa.eu.int/comm/research/environment/pdf/european_research_climate_change_en.pdf

3.4 Follow ups.

Two principle follow-ups are foreseen:
A special issue in the journal "Biogeosciences" dedicated to the interaction of biological aerosols with the atmosphere. C. E. Morris will contact the editors of this journal to open a special issue (open archive, on-line journal). As the leading article, we will submit a prospective paper concerning future research in this field based on the discussions at this workshop. The article will be authored by all the workshop participants and a few additional colleagues who have requested to participate. This paper will then be followed by primary scientific publications from participants and from the growing network.

A session on "Biological Ice Nucleators in the Atmosphere – at the Crossroads of Physics and Biology" during the 2007 annual meeting of the International Union of Geodesy and Geophysics to be held in Perugia, Italy. The conveners of this session are G. Vali and C.E. Morris. Publicity for this session will go out to the network established from the workshop.

Furthermore, many of the participants will have the occasion to transfer information from the workshop to their respective fields or to be invited to present novel information outside their fields. An example of this will happen during the 2008 meeting of International Congress on Plant Pathology where D. Sands, R. Psenner and C.E. Morris have been invited to give talks about interactions of micro-organisms and the atmosphere during a session on air-borne plant pathogens. These invitations arise from the contacts established via this workshop.

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Avignon, France, 28 February - 4 March 2006

PROGRAMME

Tuesday	28 Feb. 2006				*Arrival of participants*
Wednesday	1 Mar. 2006	08:00			*Departure of bus from hotel in Avignon*
		08:30	duration		*Arrival at INRA research center*
		08:30	0:20	08:50	Get settled and transfer files to the computer linked to video projector
		08:50	0:15	09:05	**Welcome remarks**, **C. Morris** Around-the-table brief introduction of each participant.
		09:05	0:10	09:15	Welcome to the INRA Avignon Research Center **J. Guerif** (President of Center)
		09:15	0:15	09:30	**Presentation of the European Science Foundation (ESF), tba** (Standing Committee for Life, Earth and Environmental Sciences)
		09:30	1:10	10:40	**The Vista: Why is "Microbiological meteorology" interesting?** This is a discussion of the potential long term interest of understanding how air-borne particles of biological origins impact atmospheric phenomena. These particles include vital and non vital cells of bacteria, fungi, algae, pollen, etc. and remnants of a wide range of single- and multi-cellular organisms. From the viewpoint of four different scientific disciplines we will consider: What are the potential long term environmental and socio-economical consequences of understanding the impact of bio-aerosols on the atmosphere and the underlying mechanisms? What expertise do we have to offer and what expertise do we need to reveal this impact and mechanisms? The discussion should be relatively light in terms of scientific jargon so as to help establish a common language that will foster efficient communication throughout the workshop and that will enhance collaboration.
	Details, Vista	09:30	0:10	09:40	Point of view 1: Agriculture – **D. Sands**
		09:40	0:10	09:50	Point of view 2: Atmosphere physics – **P. Demott**
		09:50	0:10	10:00	Point of view 3: Atmosphere chemistry – **A. Flossman**
		10:00	0:10	10:10	Point of view 4: Microbial ecology – **R. Psenner**
		10:10	0:20	10:30	General discussion
		10:30	0:10	10:40	*Coffee/Tea break*

	10:40	2:05	**12:45**	**Tutorial:** To elucidate the impact of air-borne biotic particles on atmospheric phenomena, we will need to comprehend certain concepts outside of our own disciplines. The objective of this session is to provide answers to technical questions about microbiology, atmosphere physics, meteorology and modeling that are comprehensible for scientists outside of those respective disciples. Via concise presentations (not more than half of the allotted time) and question/answer periods, this session will provide answers to some basic technical questions.
Details, Tech.	10:40	0:30	11:10	Atmospheric aerosols: sampling, collection and results. **Discussion leader: R. Jaenicke**
	11:10	0:30	11:40	Chemical analysis of atmospheric aerosols. **Discussion leaders: H. Puxbaum** & **H. Bauer**
	11:40	0:30	12:10	Single particle analysis of atmospheric aerosol particles: Methods and examples. **Discussion leader: M. Posfai**
	12:10	0:35	12:45	Air-borne ice nucleation-active organisms: where do they proliferate, how abundant are they and how do we detect and recognize them? **Discussion leader: C. Morris**
	12:45	1:15	**14:00**	*Lunch break*
	14:00	4:00	**18:00**	**Tutorial, cont.**
Details, Tech.	14:00	0:45	14:45	Ice nucleation-active proteins: what is their structure and stability? When and how are they produced? **Discussion leader: D. Georgakopoulos**
	14:45	0:20	15:05	*Bona fide* microbial habitats: are snow, ice and cloud water habitats for micro-organisms? **Discussion leader: R. Psenner**
	15:05	0:15	15:20	*Coffee/Tea break*
	15:20	0:30	15:50	The physical states of water: what is ice, how do we characterize it and how is it different from vapor and liquid water? **Animator: O. Moehler**
	15:50	0:45	16:35	Heterogeneous ice nucleation: how does it happen and by what techniques can we determine the potential for it to happen? **Discussion leader: G. Vali**
	16:35	0:30	17:05	A look at clouds: what is a cloud, what is its origin and what can we predict and model about its destiny? **Discussion leader: P. Demott**
	17:05	0:30	17:35	Land-atmosphere exchanges: what is the relationship between land use and climate? **Discussion leader: D. Courault**
	17:35	0:25	18:00	Discussion
	18:00			*Departure for Avignon*
	19:30			*Group dinner, downtown Avignon*

Thursday	**2 Mar. 2006**	**08:15**			*Departure of bus from hotel in Avignon*
		08:45			*Arrival at INRA research center*
		08:45	0:15	**09:00**	*Get settled*
		09:00	1:15	**10:15**	**Tutorial cont.**
	Details, Tech.	09:00	0:30	09:30	Atmosphere chemistry: what is the influence of micro-organisms on the chemistry of the atmosphere, what are they metabolizing and what are they transforming? **Discussion leader: L. Deguillaume**
		09:30	0:45	10:15	Models of atmospheric processes: why model, what can be modeled and how are the models validated? **Discussion leader**: **B. Vogel**
		10:15	0:20	**10:35**	**General discussion**: summary presentation of the discussion questions submitted by participants before the meeting. Discussion of those that we have not yet touched upon. **Discussion leader: D. Sands**
		10:35	0:10	**10:45**	*Coffee/Tea Break*
		10:45	2:00	**12:45**	**Prospecting: What do we want to know and how close can we get?** Here we will identify ideal scientific goals. These goals will be useful in building research programs or setting up activities around the steps needed to achieve these goals. This is a session of informal discussion focused around several broad subjects. Each discussion leader will put together a comprehensive list synthesizing the ideas that emerge from the discussion.
	Details, Prosp	10:45	2:00	12:45	***Subject 1***: The role of microorganisms and other biological particles in atmospheric processes leading to precipitation. **Discussion leader: Paul Demott**
		12:45	1:15	**14:00**	*Lunch break*
					Prospecting, cont.
	Details, Prosp	14:00	2:00	16:00	***Subject 2***: The impact of microorganisms on rainwater quality, air pollution and other aspects of air quality. **Discussion leader: H. Bauer**
		16:00	1:30	17:30	***Subject 3:*** Microbial air-borne voyages: obstacles and means to departure, to distant trajectories and to survival. **Discussion leaders: B. Moffett** & **T. Hill**
		17:30	0:30	**18:00**	General discussion
		18:00			*Departure for Avignon*
		20:00			*Group dinner, downtown Avignon*

Friday	**3 Mar. 2006**	**08:30**			*Departure of bus from hotel in Avignon*
		09:00			*Arrival at INRA research center*
		09:00	0:15	**09:15**	*Get settled*
		09:15	2:00	**11:15**	**Team building, part 1: 'Round the table suggestions'.** Each participant (or group of participants who are currently working together) will propose and briefly describe a hypothesis they would like to test that would require the competence of other participants, particularly those from disciplines outside their own.
		11:15	1:00	**12:15**	**Funding sources**: During this session we will compile a list of possible funding sources on regional, national, and international levels that could support research concerning the impact of microorganisms on atmospheric processes and related subjects. Participants are asked to bring information on specific sources and to present how this could be useful for this research subject.
		12:15	0:30	**12:45**	**Team building, part 2:** During this session we will consider the possibility of breaking up into functional groups that will work together in the afternoon to set up the initial details of collaborative work and/or requests for funding.
		12:45	1:15	**14:00**	*Lunch break*
		14:00	1:30	**15:30**	**Team work, part 1:** We will try to establish as many preliminary details as possible concerning collaborative research projects that can be conducted within existing research programs and concerning funding that we will solicit to establish new research programs. For this discussion, we will divide up into the teams identified in the previous session, or the entire group will remain together if this option is considered by the group as the optimal approach for this work.
		15:30	0:30	**16:00**	**Team work, part 2**: Each group will present a synopsis of the status of their planning. If all participants stayed together for the "Team work" discussion, there will be only one synopsis. In either case, the synopsis(es) should indicate who will take responsibility for future action.
		16:00	0:15	**16:15**	**Announcements:** Information about upcoming meetings, etc. from any of the participants.
		16:15	0:15	**16:30**	Discussion about activities of participants staying in Avignon on Saturday 4 March
		16:30	0:30	**17:00**	**Workshop summary:** Comments, questions, remarks and criticisms about the organization, etc. by all participants. We will also discuss how to maintain our interactions and how to expand our network.
		17:00			*Departure for Avignon*
		19:30			*Wine and cheese reception at Hôtel d'Angleterre*

ESF LESC Exploratory Workshop:

Microbiological Meteorology: Working at the Intersection of Biology, Physics and Meteorology to Understand and Regulate the Microbial Component of Weather
Avignon, France, 28 February - 4 March 2006

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Statistical Information on Participants

Distribution by country:

Austria	2
France	10
Germany	5
Greece	1
Hungary	1
Israel	1
United Kingdom	2
United States	3

Distribution by gender:

Female	6
Male	19

Data on age distribution was not available.