Integrated Land Ecosystem – Atmosphere Processes Study

iLEAPS Newsletter

http://www.ileaps.org

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iLEAPS is a core project of IGBP

GLOBAL IGBP CHANGE

Special Issue on Aerosols – Clouds – Precipitation – Climate

iLEAPS Science Plan and Implementation Strategy is available in English and in Chinese.

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iLEAPS IPO GUEST SCIENTISTS

iLEAPS welcomes collaboration and interaction between the International Project Office (IPO) and the many researchers from a multitude of disciplines involved in iLEAPS activities. We welcome guests from professors and senior researchers to postdocs and PhD students.

A guest scientist can host a workshop, edit a book or journal special issue related to iLEAPS activities, guest-edit the iLEAPS Newsletter, develop new initiatives, plan and enhance national iLEAPS activities, construct a website.

This is an opportunity for close collaboration with an international research program with a view of the activities all over the world, also an opportunity to develop new interactions and lines of research, obtain new contacts, and spend a shorter or longer time period in new surroundings.

Although budget constraints usually limit our ability to fund visitors, we provide for the office and computational needs of visitors who come with independent salary support.

If you are interested in spending a sabbatical, a shorter of longer period at iLEAPS IPO, please contact (ipo@ileaps.org).

INSTRUCTIONS TO CONTRIBUTORS

The iLEAPS Newsletter informs on iLEAPS-related scientific activities. The theme of contributions should be relevant to iLEAPS and integrated land-atmosphere research. The Newsletter is published twice a year and it is released both in printed and on-line versions. For the paper version the specified word length according to these instructions is enforced. The author may provide additional material to be used on the iLEAPS web page.

SCIENTIFIC ARTICLES

Articles are 700–1000 words and cover 1–2 pages with accompanying 2–3 pictures or figures. Articles can contain the following:

- RESULTS of scientific research
- SUMMARIES presenting synthesis of recent scientific development in land-atmosphere research
- POSITION PAPERS stating views and directions in scientific research
- REPORTS presenting key scientific outcomes of programmes, workshops, or meetings.

EDITORIAL

Editorials are around 500 words with or without one accompanying figure. Editorials are by invitation and feature a personal interpretation and evaluation on the theme of the issue.

NEWS

Other than strictly scientific contents will be max 200 words and can be for

- **PEOPLE** presentation
- **ACTIVITIES** report and commentaries
- **ANNOUNCEMENTS** of coming events, job vacancies or short news.

Text and graphs should be provided in separate files. Please do not send graphs, figures, logos, photos or other graphical material inserted into Word documents.

Text should be in Word doc or plain text.

Graphs and figures should be in its original format or else as high resolution .eps vector images. If you do not have the possibility to save the graph as an ÉPS file, save it as a very large pixel graph, minimum 300 dpi (TIF, TIFF or JPEG).

Photographs should be in TIF format, minimum 300 dpi. When you take photos, save them using the best possible resolution and quality available in your camera settings, with as little compression as possible. Generally digital cameras (and photo scanners) save photos in RGB format. Send the photos in the format saved by the camera, do not make any transformations. If you use Photoshop or some other program to edit the photo, the save the file in EPS format with resolution 300 dpi, no compression. If the program forces you to compress the file, select the best possible quality. Even .tif and a very little compressed JPEG formats are applicable. In addition to EPS format, a good format for sending all kinds of photos is PDF, with resolution at minimum 300 dpi (in the size it will be printed in) and as little compression as possible.

The contributors are kindly requested to handle potential **copyright issues** of the material.

Contributions should be e-mailed to the Executive Editor at the iLEAPS IPO.

Cover photo

Haboob (dusty convective outflow) in Hombori, Mali, 23 August 2005. Photo taken during the AMMA (Analyses Multidisciplinaires de la Mousson Africaine) field campaign by Françoise Guichard and Laurent Kergoat, CNRS copyright.

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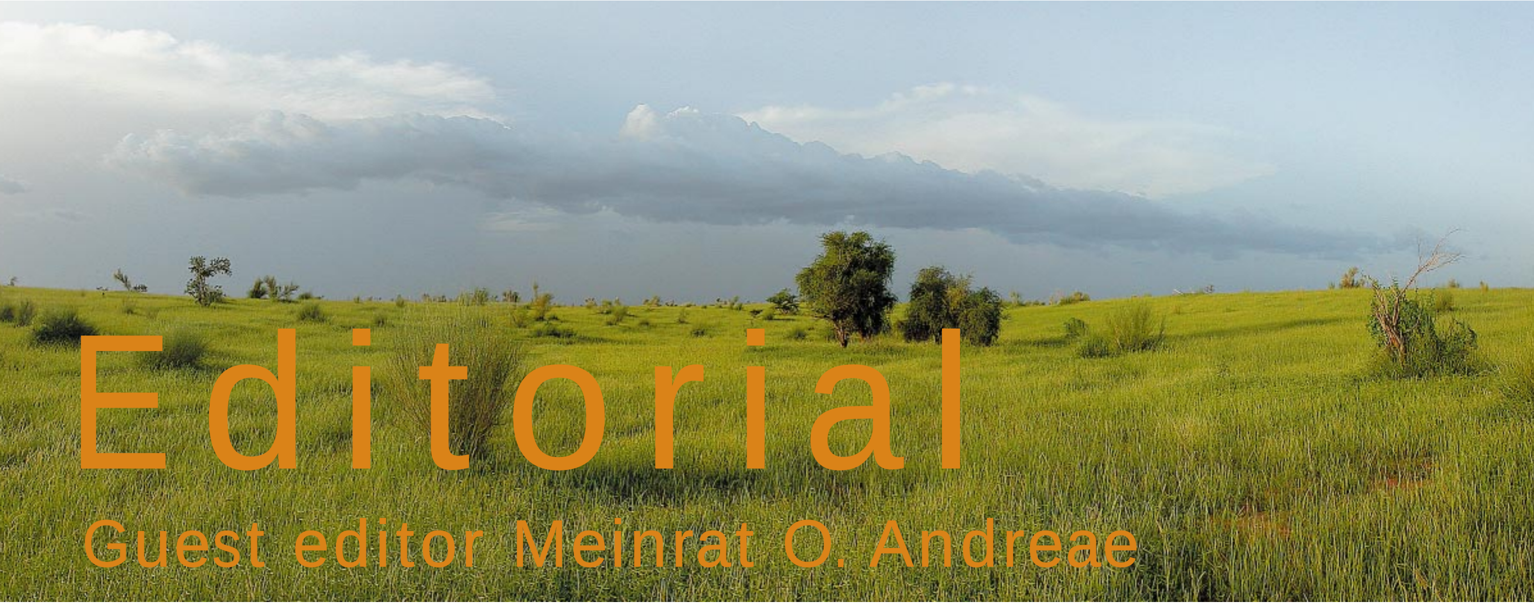


Editorial

Guest editor Meinrat O. Andreae

A low-level cloud line formed in the late afternoon hour above Agoufou, Mali 15 August 2005, this line then dissipated quickly at sunset. Photo by Françoise Guichard & Laurent Kergoat, CNRS copyright.

Aerosol–cloud–precipitation–climate interactions are the focus of this issue of the iLEAPS Newsletter. As in previous issues, however, the science articles are not limited to this theme but illustrate the importance of land-atmosphere interactions showing the wide spectrum of iLEAPS-related research.

The Intergovernmental Panel of Climate Change (IPCC) published the Fourth Assessment report in 2007, stating that aerosols, clouds and precipitation—and their complex and tightly coupled interactions—remain as the largest uncertainties in our current understanding of the climate system.

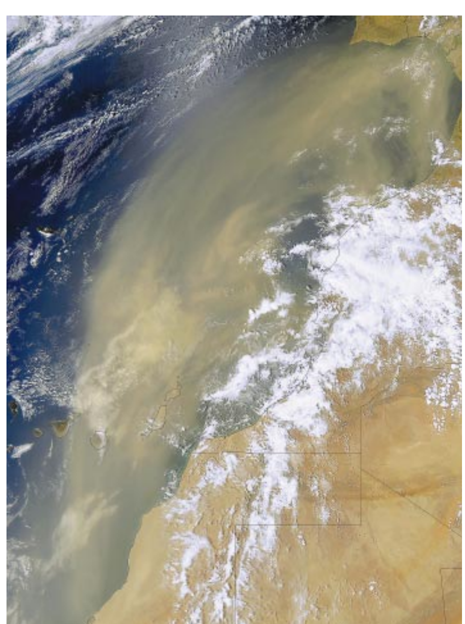
A recent publication by the International Aerosol Precipitation Science Assessment Group (IAPSAG), a panel of international experts appointed by the World Meteorological Organization (WMO) and the International Union of Geodesy and Geophysics (IUGG), focused on reviewing the state of the science and indentifying the areas requiring further study. The panel was lead by Zev Levin and William Cotton, co-authors of an article in this issue summarizing the results of the report.

The Aerosols, Clouds, Precipitation, Climate (ACPC) initiative by iLEAPS in collaboration with the International Global Atmospheric Chemistry (IGAC) core project of IGBP and the Global Energy and Water Experiment (GEWEX) of WCRP organized a specialist workshop in October 2007 in Boulder, Colorado, USA. The aim of the workshop was to develop the ACPC research agenda and strategy in the short and long run.

In this newsletter, Bjorn Stevens and co-authors summarize the outcome of the workshop, the issues of importance, and a strategy for a research program.

The main authors of the ACPC-related scientific articles from among the invited specialists and planning group members: V. Ramanathan, Bjorn Stevens, Bill Lau, Ulrike Lohmann, Danny Rosenfeld, Maria Assunção F. Silva Dias, Cynthia Twohy and Sandro Fuzzi. Other invited speakers were Graeme L. Stephens and Brian Soden.

The workshop hosted by Guy Brasseur and the National Center for Atmospheric Research gathered 57 participants (mainly from the US, but also from Europe, Brazil, Israel and Australia), specialists in aerosol physics and chemistry, cloud dynamics and microphysics, atmospheric radiation and climate dynamics.



Dust storm over Marocco, 20 April 2004.
Photo provided by Meinrat O. Andreae.

iLEAPS has established web pages and a mailing list for the ACPC initiative. The ACPC web pages http://www.ileaps.org/acpc/ can be reached through the iLEAPS website at http://www.ileaps.org and the members of the mailing list through the email address: acpc@ileaps.org

Volatile organic compounds from vegetation surpass the anthropogenic emissions of volatile hydrocarbons on a global scale, playing an essential part in atmospheric chemistry as well as in the formation of aerosol particles. Ülo Niinemets stresses that the reliable prediction of biogenic emissions, or deposition onto vegetation, based on knowledge of the processes involved and also the effects of environmental conditions, is essential in predicting atmospheric constitution on a regional scale and imperative to improve emission and atmospheric chemistry models.

In this fifth issue, an article by Chris Taylor elaborates the importance of feedbacks between soil moisture and precipitation in a hotspot, the drought-prone Sahel at the southern border of the Sahara, where a negative feedback was observed locally with development of storms over dry soil. This is of considerable interest to the weather and climate modelling communities; any feedbacks between soil water and precipitation could either amplify or suppress climatic anomalies such as drought, depending on the sign of the feedback. ■

MARIE CURIE ACTIONS

Marie Curie Actions are part of the European Commission initiatives to facilitate mobility of researchers and Marie Curie – iLEAPS is part of this programme. A number of travel grants are available for each event. Read criteria for eligibility, detailed information and updates at

www.atm.helsinki.fi/ileaps/marie-curie-ileaps

Marie Curie ● iLEAPS

Training course Marie Curie – iLEAPS, Model-Data Assimilation

Physics and chemistry of air pollution and their effects: field course and data analysis

10–19 March 2008, Hyytiälä Field Station, Finland. 3 ECTS.

Organizers: Prof. Timo Vesala, Prof. Markku Kulmala and Prof. Pertti Hari from the University of Helsinki

During the course following subjects will be covered

- Introduction to SMEAR II station, www.atm.helsinki.fi/SMEAR/
- Introduction to atmospheric physics and chemistry as well as boundary layer meteorology
- Biosphere - atmosphere interactions
- Formation of atmospheric aerosol particles
- VOC emissions
- Modelling the nitrogen cycle
- Tropospheric transport and inversion models
- Analysis of data from SMEAR II station
- Data analysis and assimilation into global models
- Statistical methods

The course is organized in cooperation between

- iLEAPS (*Integrated Land Ecosystem-Atmosphere Processes Study*)
- The Graduate School "Physics, Chemistry, Meteorology and Biology of Atmospheric Composition and Climate Change"
- Atmosphere-Biosphere Studies (ABS) Master's Degree Programme
- EUCAARI (*European Integrated project on Aerosol Cloud Climate and Air Quality Interactions*)
- EUSAAR (*European Supersites for Atmospheric Aerosol Research*).

The course involves 2–3 lectures per day, but the main emphasis is on intensive group work, and writing a scientific report on the group work after the course. The course is aimed to MSc and PhD students of atmospheric sciences. In the course the students will utilize 12 year aerosol, gas and meteorological data measured at Hyytiälä station to learn some basic data treatment and data analysis methods.

The main tools are MATLAB and IDL programming language.

Deadline for application submission to this event has expired.

Conference Marie Curie – iLEAPS, Feedbacks Land-Climate Dynamics – Key Gaps

Current understanding of how integrated land ecosystem atmosphere processes influence climate dynamics

Fall 2008, La Badine, France.

Organizer: Dr. Nathalie de Noblet, CEA-CNRS, France

Science

on aerosols, clouds, precipitation, climate

Anni Reissell

ACPC – The evolution of a joint initiative

Recognition of the potential climate impacts of anthropogenic aerosols has led to a large body of research assessing the aerosols' role in the Earth's radiative balance. Much less is known about their effects on precipitation, and the consequences for the climate system and the water cycle.

This is also stressed in the 4th Assessment report of the Intergovernmental Panel of Climate Change (IPCC 2007, see Noone et al, in this issue). Existing knowledge and research needs have been summarized in the report by the WMO/IUGG International Aerosol Precipitation Science Assessment Group (IAPSAG; see Cotton and Levin, in this issue).

The initiative on Aerosols, Clouds, Precipitation and Climate (ACPC) is intended to develop an integrated research program to investigate the interactions and feedbacks among aerosols, cloud processes, precipitation, and the climate system (ACPC Boulder Specialist Workshop report, see Stevens at al, in this issue).

Ideas for a broad project to study the linkages between aerosols, clouds, precipitation and climate had been circulating informally though the community for a few years, and in fact were part of the original iLEAPS Science Plan.

They came into a clearer focus during discussions at the 3rd iLEAPS Scientific Steering Committee meeting in Boulder, Colorado, 20–21 January 2006, where it also became obvious that better coordination with current and proposed WCRP/GEWEX aerosol-cloud-climate activities was warranted.

Just prior to the SSC meeting, Danny Rosenfeld had given the presentation "Thermodynamic responses to precipitation changes as induced by surface and aerosol impacts on cloud processes—Implications for the Earth's energy budget and the hydrological cycle" at the 18th GEWEX SSG meeting in Dakar, Senegal (9–13 January 2006), which stimulated lively discussions in that community.

Subsequently, a first outline describing the initiative was presented at the joint IGBP and WCRP Steering Committee meeting in Pune, India, (2–7 March 2006), where the special focus was to advance collaboration and discussion on common scientific questions and new initiatives between the two programs and also within ESSP.

The discussions indicated that, while we are far from understanding aerosol-climate connections, there is already underused data that can still provide new information.

This can be addressed by better coordination with current and proposed WCRP/GEWEX aerosol-cloud-climate activities within GRP (GEWEX Radiation Panel), GCSS (GEWEX Aerosol and Cloud Research, GEWEX Cloud Systems Studies), HAP (Hydrological Application Project), and other programs such as THROPEX (Predictability and mitigation of natural disasters) and GWSP (Global Water System Project).

But besides mining existing information and gaining access to data from ongoing programs, the importance of the impact of aerosols on precipitation patterns - and therefore on the thermodynamic and radiative energy budget of the Earth - calls for an international, coordinated project of dedicated field campaigns.

Following the joint IGBP/WCRP meeting in Pune, the scientific steering committees of

Rain shower from a cumulonimbus praecipition over downtown Helsinki as seen from the Kumpula campus, University of Helsinki, 31 August 2007. The mast of the SMEAR III station can be seen at the right. Photo by Timo Nousiainen.

Arrival of gust front associated with a decaying mesoscale convective system in the late morning, in Agoufou, Mali, 11 August 2006. Photo by Francoise Guichard and Laurent Kergoat. Copyright CNRM-GAME & CESBIO (CNRS).

iLEAPS, IGAC and GEWEX appointed ACPC representatives for each core project to produce separate white papers describing the scientific issues of relevance to the foci of the projects.

After the 4th iLEAPS SSC meeting on 17–18 January 2007 in Wageningen, the Netherlands, a small ACPC planning group consisting of representatives from iLEAPS, IGAC and GEWEX was established.

The planning group representatives from iLEAPS are M.O. "Andi" Andreae, Markku Kulmala and Daniel Rosenfeld, from IGAC Sandro Fuzzi, Graciela Raga, and Colin O'Dowd (also representing SOLAS), and from GEWEX Tom Ackerman, Bill Lau, Ulrike Lohmann and Pier Siebesma.

The group met at the end of March to compile a joint white paper and to plan a larger science workshop to take place in October 2007. The joint white paper is published in iLEAPS Newsletter (iLEAPS Newsletter 4/2007) and also available at the ACPC website (http://www.ileaps.org/acpc/).

This white paper formed the starting point for the iLEAPS-IGAC-GEWEX ACPC Specialist Workshop, which was held 8–10 October 2007, at NCAR in Boulder, Colorado, USA. The meeting was hosted by Guy Brasseur, Director of Earth and Sun Systems Laboratory, and the National Center for Atmospheric Research (NCAR).

The workshop was sponsored also by the European Network of Excellence on Atmospheric Composition Change (ACCENT). The workshop was organized by iLEAPS, IGAC (International Global Atmospheric Chemistry) and GEWEX (Global Energy and Water Cycle Experiment), core projects of IGBP and WCRP.

In all, 57 participants attended from the US (41 participants), Australia (1), Brazil (2), Finland (2), France (1), Germany (1), Israel (2), Italy (1), Mexico (1), Netherlands (1), Switzerland (2), and United Kingdom (2). The event gathered specialists from aerosol physics and chemistry, cloud dynamics and microphysics, atmospheric radiation, and climate dynamics.

The workshop presentations (available at http://www.ileaps.org/acpc/) were as follows:

Andi Andreae,
Background for ACPC initiative, part I

Markku Kulmala,
Background for ACPC initiative, part II

V. Ramanathan,
Aerosol-Cloud-Climate Interactions:
Outstanding Issues

Bill Cotton,
Results of the WMO/IUGG international Aerosol Precipitation Science Assessment Group (IAPSAG)

Graeme L. Stephens,
Remote sensing of aerosol, cloud, precipitation, climate interactions:
A-Train capabilities

Bjorn Stevens,
Quantifying aerosol effects
on cloudiness, as mediated by rain

Sandro Fuzzi,
Aerosols as CCN,
IN and their effects on CDNC

Maria Assunção F. Silva Dias,
Can the slowing of auto-conversion result in increasing precipitation? part I

Danny Rosenfeld,
Can the slowing of auto-conversion result in increasing precipitation? part II

Brian Soden,
Aerosols, Precipitation and
the Energetics of the Climate System

Cynthia Twohy,
How do Aerosol-Precipitation Interactions affect the Energetics of the Climate System

Bill Lau,
What are aerosol-precipitation
impacts on the larger scales?
Aerosol-climate and water cycle
(precipitation, clouds, winds) interactions

Ulrike Lohmann,
How do Aerosol-Precipitation Interactions affect the Energetics of the Climate System?

We submitted a proposal to the International Space Science Institute, ISSI (http://www.issibern.ch/), to provide support for the further development of ACPC. The main task of ISSI is to contribute to the achievement of a deeper understanding of the results from space-research missions, adding value to those results through multi-disciplinary research in an atmosphere of international co-operation.

Our proposal was approved, and the planning group morphed into an "ISSI Team", getting together at ISSI in Bern, Switzerland for three meetings in 2008–9 to write scientific articles and an ACPC Science and Implementation Plan. The first such meeting was in 28–30 January 2008 and the second one will be on 7–9 October. Bjorn Stevens will join the Team at the second meeting.

The ACPC mailing list (email address is acpc@ileaps.org) was established in the beginning of 2008 and is aimed at those interested in and working on issues related to aerosol-cloud-precipitation-climate interactions.

This mailing list was proposed at the ACPC workshop in Boulder by Jingfeng Huang from the Rosenstiel School of Marine and Atmospheric Science (RSMAS), University of Miami, Florida.

The aim is to strengthen the communication among researchers from a variety of disciplines and to encourage collaborations on ACPC-related research worldwide.

Two moderators are taking care of the mailing list: Jingfeng Huang and Amato Evan from the Cooperative Institute for Meteorological Satellite Studies at the University of Wisconsin-Madison, Wisconsin, USA.

The purpose of this mailing list is to facilitate discussions and debates on scientific questions, to provide a means for the rapid exchange of each other's publications within the ACPC community, to give information about upcoming events and conferences, and to establish a weblog.

By spreading the word quickly through the mailing list, it will help to stimulate research interests, attract global attention, and encourage potential collaborations.

IGBP and WCRP on ACPC initiative

Kevin Noone[1], Carlos Nobre[2], John Church[3] and Ann Henderson-Sellers[4]

1. International Geosphere – Biosphere Programme Secretariat, Royal Swedish Academy of Sciences, Stockholm, Sweden
2. Weather Research and Climatic Studies Center (CPTEC) of the National Space Research Institute (INPE), Cachoeira Paulista, São Paulo, Brazil
3. Antarctic Climate & Ecosystems Cooperative Research Centre (CRC) and Australian Commonwealth Scientific and Industrial Research Organisation (CSIRO) Marine Reseach, Hobart, Tasmania, Australia
4. World Climate Research Programme, World Meteorological Organization, Geneva, Switzerland

Professor **Kevin Noone** is Executive Director of the International Geosphere – Biosphere Programme (IGBP) Secretariat

Professor **Carlos Nobre** is Chair of the IGBP Steering Committee

Dr. **John Church** is Chair of the World Climate Research Programme (WCRP) Joint Steering Committee

Professor **Ann Henderson-Sellers** was Director of WCRP Joint Planning Staff in 2006–2007

Once again, the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) has identified aerosols, clouds and precipitation as one of the largest uncertainties in our current understanding of the climate system. As shown in the Table 1, this same conclusion has extensive historical baggage.

One reason that aerosol and cloud processes remain so uncertain is because the processes linking aerosol-cloud interactions, precipitation development, and the dynamical processes that drive convection are complex and tightly coupled.

This issue was also highlighted at a recent workshop in Sydney, Australia jointly organized by the Global Climate Observing System (GCOS), the World Climate Research Programme (WCRP) and the International Geosphere-Biosphere Programme (IGBP) as one that is central to the research and observational strategies for all three organizations.

As with any complex issue, there is no single approach that by itself will lead to rapid advances in understanding. Indeed the IPCC Assessments have always highlighted the physics of convection and convective cloud formation as being a serious challenge. Improving understanding of the importance of CCN couple these outstanding 'physics' questions with newer and equally challenging 'chemistry' ones.

In this regard, the Aerosols, Clouds, Precipitation and Climate (ACPC) initiative is a very exciting opportunity to gather together the breadth and depth of expertise that will be needed to make progress in this area.

ACPC brings together scientists from several IGBP and WCRP projects, led by iLEAPS and IGAC within IGBP and GEWEX within WCRP. This initiative will create a focus for a new and expanded community of sci-

Decaying remnants of a cumulonimbus mamma that slowly drifted over eastern Helsinki, 3 September, 2007. Photo by Timo Nousiainen.

entists to look at all the various dynamical, microphysical and chemical processes that underlie ACPC.

As with any endeavor to address a difficult issue, there are debates within the scientific community about what issues are of greatest importance in terms of determining the climatic effects of aerosols and clouds, and about how to prioritize research efforts to address them.

Besides the inherent scientific difficulty of the subject, another reason that aerosols and clouds "remain the dominant uncertainty in radiative forcing" is because our communities are still working out the most effective ways to collaborate on this issue. This new constellation will enable a great step forward to be taken in our ability to look at these processes in an integrated fashion, instead of within separate communities with different priorities and approaches.

ACPC links directly with the joint IGBP-WCRP Atmospheric Chemistry and Climate activities (AC&C) and with our joint climate modeling work conducted by IGBP's AIMES and WCRP's Working Group on Coupled Modelling (WGCM).

Beyond addressing key science issues, an additional positive result of this new initiative is the benefit it will have for the parent programmes—IGBP and WCRP—in terms of showing concrete ways in which the programmes can pursue a closer working relationship across the board to address complex scientific issues of common interest.

IGBP and WCRP are fully supportive of the ACPC initiative, and are looking forward to exciting progress and results. We are confident that because of the work done in ACPC, the conclusions about uncertainty in the *next* IPCC Assessment Report will be very different! ■

GLOBAL IGBP CHANGE

WCRP World Climate Research Programme

IPCC Second Assessment Report (1995)

Many factors currently limit our ability to project and detect future climate change. In particular, to reduce uncertainties further work is needed on the following priority topics:

- Estimation of future emissions and biogeochemical cycling (including sources and sinks) of greenhouse gases, aerosols and aerosol precursors and projections of future concentrations and radiative properties.
- Representation of climate processes in models, especially feedbacks associated with clouds, oceans, sea ice and vegetation, in order to improve projections of rates and regional patterns of climate change.
- Systematic collection of long-term instrumental and proxy observations of climate system variables (e.g., solar output, atmospheric energy balance components, hydrological cycles, ocean characteristics and ecosystem changes) for the purposes of model testing, assessment of temporal and regional variability, and for detection and attribution studies.

IPCC Third Assessment Report (2001)

Since the Second Assessment Report, significant progress has been achieved in better characterising the direct radiative roles of different types of aerosols. Direct radiative forcing is estimated to be –0.4 W m^{-2} for sulphate, –0.2 W m^{-2} for biomass burning aerosols, –0.1 W m^{-2} for fossil fuel organic carbon and +0.2 W m^{-2} for fossil fuel black carbon aerosols. There is much less confidence in the ability to quantify the total aerosol direct effect, and its evolution over time, than that for the gases listed above. Aerosols also vary considerably by region and respond quickly to changes in emissions.

IPCC Fourth Assessment Report (2007)

Anthropogenic contributions to aerosols (primarily sulphate, organic carbon, black carbon, nitrate and dust) together produce a cooling effect, with a total direct radiative forcing of –0.5 [–0.9 to –0.1] W m^{-2} and an indirect cloud albedo forcing of –0.7 [–1.8 to –0.3] W m^{-2}. These forcings are now better understood than at the time of the TAR due to improved in situ, satellite and ground-based measurements and more comprehensive modelling, but remain the dominant uncertainty in radiative forcing. Aerosols also influence cloud lifetime and precipitation.

Table 1. Compilation of statements from the summaries for policymakers of the Second (SAR), Third (TAR) and Fourth IPCC Assessment Reports.

Bjorn Stevens is a Professor of dynamic meteorology at the University of California Los Angeles. In 1996 he received his PhD from Colorado State University, and in collaboration with William R. Cotton, his advisor, and Graham Feingold he used and developed large-eddy simulation with explicit microphysics to elucidate the mechanisms whereby precipitation suppresses the growth of the marine boundary layer. He was Post-doctoral Fellow of the Advance Study Program at the National Center for Atmospheric Research, where he worked with Chin-Hoh Moeng and Peter Sullivan and developed interests in both larger-scale modeling, and field measurements.

His large-scale interests were nurtured by Humboldt Fellowship spent visiting the group of Erich Roeckner at the Max Planck Institute for Meteorology in Hamburg Germany. His field interests were explored further after arriving as an assistant professor at UCLA in 1999. At UCLA he developed and led the DYCOMS-II (in collaboration with Don Lenschow and Gabor Vali) and the RICO (in collaboration with Robert Rauber, Charles Knight and Harold Ochs) field studies. The DYCOMS-II measurements placed the first definitive bounds on entrainment at the top of stratocumulus-topped boundary layers as well as quantified the rates and effects of precipitation from stratocumulus.

The RICO data are providing new insights into the role precipitation plays in the development of shallow cumulus, and the possible role (or lack thereof) of the atmospheric aerosol. In recognition of his "pioneering advances in understanding and modeling of cloud-topped boundary layers" Dr. Stevens was awarded the 2002 Clarence Leroy Meisinger Award of the American Meteorological Society.

Bjorn Stevens, the ACPC Planning Team and participants of the ACPC workshop in Boulder

Aerosols, Clouds, Precipitation, Climate (ACPC): Outline for a new joint IGBP/WCRP initiative

Background

Environmental hazards in the form of air pollution, floods and droughts affect a large portion of the world's population. Increases in atmospheric aerosol associated with industrialization have caused health-related problems associated with worsening air quality, while floods and droughts result in major losses in lives and property, displacing millions from their homes every year.

Recent studies suggest that the increased aerosol loading may have changed the energy balance in the atmosphere and at the Earth's surface [1] and altered the global water cycle in ways that make the climate system more prone to precipitation extremes.

As yet, we do not fully understand how the aerosol affects the development of precipitation, nor the extent to which it affects the cycles of water and radiant energy in the climate system as a whole. Hence, achieving a better understanding of how the aerosol affects clouds and precipitation, and consequently large-scale circulations is not only a major scientific challenge, but is also important to policy makers and stakeholders for making decisions on mitigation strategies.

Over the past decades new measurements from satellite-based remote sensors have revealed conspicuous associations amongst aerosols, clouds and precipitation [2, 3]. In accord with expectations based on *in situ* measurements, clouds forming in a polluted environment appear to have smaller droplets, which, in the absence of other effects, may suppress the formation of rain by shallow clouds [4].

Correlations between aerosol and cloud fraction and cloud liquid-water (both positive and negative) have been demonstrated ([5], and ref therein), with commensurate effects on the amount of solar radiation reflected back to space.

In deep clouds the low-level suppression of warm rain appears to be associated with modified microphysical pathways, enhanced ice precipitation aloft, and invigoration of the convection.

It appears that both the radiative and cloud-mediated aerosol effects induce large changes in precipitation patterns, which in turn may change not only regional water resources, but also the horizontal and vertical distribution of diabatic heating that propels the regional and global circulation systems that constitute the Earth's climate.

This has been the impetus for large observational, modeling, and theoretical efforts that have focused mainly on the radiative components of these aerosol-cloud interactions and their impact on the climate system [e.g., 6]. While this has led to a much deeper understanding of the interactions between aerosols, radiation, and precipitation, much remains still to be learned about these radiative effects.

On the other hand, there has not yet been a comparable research effort concerning the microphysical effects of aerosols on clouds and precipitation, and the consequences for the water cycle and large scale circulation. Scientific understanding in this realm therefore remains very incomplete, hampering our ability to make projections of future climate change and to propose mitigating actions.

Much of the energy that drives the climate system is infused into the troposphere by deep convective rain clouds. However there are no quantitative measurements of the impact of the aerosol on deep convective clouds, their propensity to precipitate, the vertical distribution of heating, and the subsequent modulation of circulation systems and rainfall distribution.

The SMOCC92 campaign in the Amazon Basin—M O Andreae and D Rosenfeld with the research aircraft at Cruzeiro do Sul airport. Inthe back a deforestation fire with a pyrocumulus cloud building above it.

For this reason, and because the effects of the aerosol on shallow cloud systems is a topic of much existing effort, it makes sense to initially focus any proposal for a new program on questions that affect deep, precipitating convection. Such a program, which we call the Aerosols, Clouds, Precipitation and Climate (ACPC) program, is outlined below.

A first step towards this program was taken with a previous article in this Newsletter [7]. The present paper outlines the scientific justification, fundamental questions, and general implementation concepts for ACPC. A detailed science and implementation plan is under development by the ACPC planning team and will be presented in the near future.

Scientific Issues

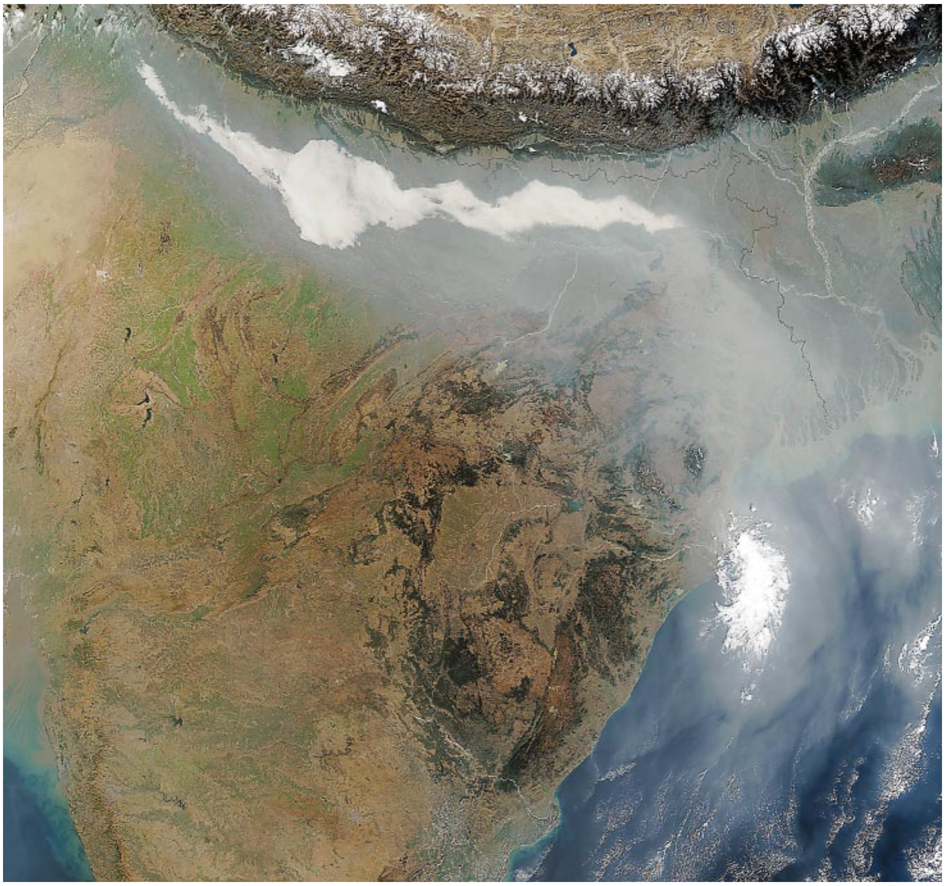
Many of the important questions can be cast in broad categorical terms:

- What is the relationship between surface rain and cloud microstructure, i.e., the number of activated cloud droplets or nucleated ice crystals? To the extent that they exist, are such relationships modulated by meteorological conditions?
- Looking toward smaller scales, what is the relationship between cloud microstructure and the ambient aerosol? How will aerosol dynamics together with atmospheric chemistry affect cloud microphysics?
- If changes in the development of precipitation can be attributed to perturbations to the aerosol, how do changes in the vertical structure of latent heating affect the subsequent development of circulations systems on scales ranging from that of the cloud or cloud-system to the regional and beyond?
- Likewise, to what extent do radiative perturbations (including those mediated by the surface) attributable to the varying physicochemical and optical properties of the aerosol, impact circulation systems across these many scales?
- In closing the loop, to what extent do changes in clouds, precipitation, and circulation systems regulate the distribution of the aerosol itself?
- And ultimately, how well can (or do) we represent existing understanding of the above respects in our theories and models of the climate system?

It has proven difficult to extract a harmonized view of the relationships of the type articulated above for a variety or reasons [8]. Foremost, in many situations we simply have not been listening, which is to say that significant gaps in the observational record are apparent.

But even when we have been paying attention, it has been difficult to extract a signal, with confounding factors being: the background roar of the ambient meteorology; a narrow focus on individual clouds for which the noise of circumstance is often loudest; consonance between the background aerosol and the meteorological conditions making it difficult, and often impossible, to isolate one from the other; and dissonance amongst myriad processes embodied by any categorical relationship.

As an example of this dissonance we note that the relationship between cloud microstructure and rain may depend on many factors, ranging from microscale processes such as the local intensity of turbulence in the cloud, to larger-scale processes such as the efficacy of cold-pool development, distribution of cloud-top heights, or the relative humidity of the cloud environment.



MODIS image of mixture of smoke, haze, fog and bright clouds trapped by the topography of the Indo-Gangetic Plain.

Likewise, the various ice-nucleation processes and the myriad microphysical pathways via which rain forms in mixed-phase clouds have thwarted attempts to quantitatively relate the character of the aerosol to the microphysical properties of glaciated clouds, and surface rainfall.

Given the history of attempts to draw demonstrable links of the type we seek, it seems natural to ask, what is new? To some extent we are more knowledgeable. In part, because the maturation of Earth System science has increased the discourse amongst diverse intellectual communities, questions such as ours are no longer the domain of scientists drawn from a single discipline, but are now being embraced by a diverse community.

This discourse has been facilitated and accelerated by the relatively recent realization that climate change, and associated effects on the hydrological cycle, are a problem of immense importance. In the present context these include experts in land-surface processes, aerosol and cloud physics, chemistry, radiative transfer and remote sensing, fluid simulation, and large-scale modeling, among others.

Such intermingling is giving birth to new experimental designs. In particular our understanding of the aerosol, and its relationship to the microstructure of warm-phase clouds has advanced significantly [9, 10] over the past decade, both as a result of advances in aerosol instrumentation, but also as a product of the deployment of such instruments in a series of field studies spanning the globe. Some of these experiments have also helped expand our imagination in terms of where to look for relationships between aerosols, clouds and precipitation.

Deliberate burnings in near tropical regions such as the South African Savannah, rain forests of the Amazon, or the sugar cane fields on subtropical islands provide opportunities for exploring these questions; these are natural laboratories in which one can hope, for the first time, to separate the effects of meteorology and the aerosol on large scales.

The empirical and conceptual progress in our understanding parallels other advancements in measurement science. Tremendous advances in remote sensing, using both space- and surface-based sensors, means that characterization of cloud microphysical and optical properties from spaceborne active and passive sensors, together with surface networks of multi-parameter and multi-wavelength radars, lidars and microwave radiometers, now provide an unprecedented opportunity to quantify both cloud structure, water content, and surface rain rates at a range of scales.

Such opportunities are amplified by a number of other developments: the emergence of new classes of autonomous vehicles (unmanned aerial vehicles, UAVs); new radar-scanning technologies, such as phased arrays; a satellite observing system in the form of the A-Train (the satellite constellation; e.g., CALIOP/CALIPSO and CPR/CloudSat), providing data of unprecedented quality, whose capabilities are unlikely to be improved upon in the coming decade; a new fleet of modern aircraft capable of deploying large-payloads with great endurance and at tremendous altitude; and modeling simulation/assimilation systems capable of synthesizing diverse and rich data streams on the one hand, and parsing the conceptual landscape on the other.

These developments lead to new opportunities. For instance the emergence of strategies for untangling aerosol perturbations from meteorological ones, e.g., by focusing on areas well downwind of deliberately set fires.

The articulation of questions, such as: how do clouds and precipitation modify the size and composition of aerosol? Can changes in profiles in the convective heating/drying, long measured by sounding arrays, be related to aerosol effects? How does aerosol modification of the surface heat budget affect convection and precipitation?

Likewise, advancements in measurement science offer the possibility to statistically characterize differences in the life-cycle of convective complexes as a function of the aerosol, or to begin thinking about parsimonious descriptions of the joint distribution of aerosol properties and cloud microphysical structure.

Strategy

To realize these opportunities and make progress in understanding physical relationships among aerosols, clouds and precipitation we propose a coordinated international effort encompassing a strategy that embodies the following elements: (i) isolation of, and focus on systems where there are strong indications of aerosol effects on deep

Passage of a line of low-level cumulus clouds on the Mont Hombori, in the morning of 16 August 2005. These clouds are the last remnants of an MCS which propaged throughout the previous night. Photo by Francoise Guichard and Laurent Kergoat. Copyright CNRM-GAME & CESBIO (CNRS)

convection; (ii) an emphasis on statistical characterizations of aerosol-cloud-precipitation interactions; (iii) the development of approaches that leverage past and ongoing activities; (iv) thorough integration of modeling and observational activities; (v) a hierarchical approach to both modeling and data collection/analysis.

Systems with strong indications of aerosol effects on deep convection

Item (i) above, focuses attention on tropical or monsoonal regions over the Amazon, Africa, South and East Asia and the Maritime Continent. These regions are known for very high anthropogenic aerosol loading from mega-cities and industrial complexes, and/or biomass burning aerosols, and dust, which in the case of the latter can sometimes also be traced to land-use practices.

Regions of biomass burning, particularly within a season, are a particularly attractive target for more intensive study; because, to the extent fires reflect seasonal (rather than day-to-day) variations in the meteorology, one stands a chance of decorrelating the biomass burning aerosol and the meteorology.

In this respect the Amazon is particularly attractive as past experience (The Large Scale Biosphere-Atmosphere Experiment in Amazonia, LBA field study) suggests that meteorology and aerosol loading may indeed decorrelate on subseasonal timescales [4].

Already planned activities in South and East Asia such as JAMEX (Joint Aerosol-Monsoon Experiment [11) as part of the planned Asia Monsoon Year (AMY 2008-2012), and the recent AMMA2006 (African Monsoon Multidisciplinary Analyses [12]) program over West Africa also provide unique opportunities that should be further developed prior to renewed commitment of resources elsewhere.

While AMMA concentrated mainly on the radiative and dynamic aspects and SMOCC [4] on the microphysical impacts of the aerosols, an integrated approach is needed to make further progress.

Statistical characterizations of aerosol-cloud-precipitation interactions

The second element of the strategy, which emphasizes the development of statistical relationships, can be implemented by studies that consider extended ranges in space and/or time, such as remote sensing studies at basin scales and long term measurements at potentially sensitive locations worldwide.

Statistical relationships are most likely to arise from large samples in homogeneous conditions, thus favoring observational regions that maximize the observational area while minimizing the heterogeneity in both the underlying surface and the expected composition of the aerosol.

Of the monsoon and tropical regions discussed above, the Amazon and Equatorial Africa satisfy this constraint better, both because of more homogeneous land-surface features, but also because of the perception that they are more locally forced, i.e., large-scale factors associated with the reorganization of monsoonal circulations are still poorly understood [13].

Smallish late-summer cumulonimbus as seen from Viikki, Helsinki, Finland, 30 August 2007. Photo by Timo Nousiainen.

Also, past experience suggests that it is important to first evaluate the likelihood of observations being able to test a particular statistical hypothesis. Such an evaluation is critical to both the framing of the hypotheses, and the design of the observational network intended to test them. Hence initial work incorporating simulation studies of cases from past, and ongoing, field work should focus on such an evaluation.

Preparatory work of this type may usefully be performed in the context of the GEWEX Cloud Systems Studies (GCSS) working group activities, although it could also be carried out by individual groups.

Development of approaches that leverage past and ongoing activities

The importance of leveraging past and ongoing work is essential to both the observational and the simulation components of the ACPC program.

In terms of simulations, GCSS has a rich history of using observations to evaluate models and, in cases where existing observations have been insufficient, designing entire field campaigns (for instance the phase two of the Dynamics and Chemistry of Marine Stratocumulus, DYCOMS-II and Rain in Cumulus over the Ocean, RICO) centered on specific questions that emerge from the modeling.

In terms of ongoing and past field work, AMMA2006 provides a unique opportunity to explore how enhancements to the observational network better constrain tropical clouds.

Likewise, AMY2008-2012 provides new chances to test components of an emerging experimental strategy, and perhaps, through modest augmentation of the already planned resource deployment, begin developing the basis for better exploring the affects of the aerosol on deep convection in the context of the Asian Monsoon [14].

Apart from the deployment of additional instruments during the AMY2008-2012, one idea that addresses many aspects of the above, would be to use GCSS to develop case studies from the AMMA2006 or AMY2008-2012 field data, with an eye toward better framing the issues for a possible future Amazon field study.

So doing would ensure the thorough integration of simulations and observations, thereby addressing both the third and fourth elements of the strategy outlined above.

Thorough integration of modeling and observational activities

The integration of models and measurements also places demands on the models. The physics of current models, particularly general circulation models (GCM), inadequately (if at all) represent relevant processes for aerosol effects on precipitation.

Traditionally, cloud microphysical processes are only included in GCM parameterizations of stratiform clouds but not in convective clouds [15]. Also, most GCMs only allow one convective cloud type per grid cell instead of the whole spectrum of convective clouds.

Options to be exploited include the development and implementation of different (more detailed) representations of parameterized convective clouds, the multiscale-model framework (MMF), and global (or very large-scale) cloud resolving models.

In terms of the latter, the emphasis on AMMA2006 by the Cascade project (at the University of Reading), provides a unique opportunity to explore issues pertaining to aerosols, clouds, and precipitation in the context of very large-scale cloud resolving modeling studies.

Hierarchical approach to both modeling and data collection/analysis

Finally, the development of a systematically multi-tiered, or hierarchical approach is of paramount importance.

In terms of the modeling this involves the careful design of test cases that link the full range of relevant models: (1) detailed physicochemical models of aerosol-cloud interactions (perhaps in parcel models); (2) microphysical models of the precipitation formation process; (3) fine-scale models that explore cloud and boundary layer-scale interactions associated with the effects of a changing aerosol on cloud radiative or microphysical properties; (4) cloud-system resolving models that can explore the effects of aerosol mediated changes to the radiative forcings and/or precipitation on the scale of cloud systems; and (5) regional or global scale models capable of both feeling the global constraints that may restrict the effects of perturbations seen on smaller scales, and extending the effects of such perturbations remotely (through teleconnections).

In terms of observations, a multi-tiered approach means that the observational strategy must be refined through the exploration of existing data-sets, particularly from a whole range of satellite sensors and consolidated meteorological data sets (e.g., AMMA2006), strategic partnerships in ongoing or planned experiments (e.g., JAMEX/AMY, but ongoing plans for a 'year of tropical convection' provide another opportunity), and the development of base-line longer-term measurements in an area targeted for more intensive study.

Additionally, periods of more intensive study should be repeated in two or more seasons and in ways that afford the best opportunity to extrapolate local findings to regional and even global scales using the current generation of earth observing satellites.

In this context advanced data assimilation techniques are essential, which in practice means active collaboration with the European Center for Medium Range Weather Forecasting (ECMRF), whose state of the art data assimilation system is essential to integrated assessment activities spanning a wide range of scales.

Summary

We encourage the development of a new initiative focused on quantifying aerosol-cloud-precipitation interactions in regions of deep tropical convection.

Such an initiative should build on ongoing and past activities, and include long-term monitoring in strategic locations (perhaps the Amazon), the enhancement of observational networks for already planned field studies, further analysis of existing and emerging data sets, coordinated modeling studies that span a range of scales (perhaps in the context of GCSS), building toward a period of more intensive field work spanning one or more seasons. Preliminary work suggests that the Amazon has many features that would lend itself well to such a study.

At the very least, such a study stands to significantly advance our understanding of deep, precipitating, convective systems, long a meteorological enigma. There is also reason to believe that such an effort could provide bounds on the susceptibility of such systems to changes in the atmospheric aerosol; both would be a great leap forward.

The transfer of knowledge gained from such an effort to regional weather forecasting centers to improve weather and climate prediction will be of substantial benefit to society. ■

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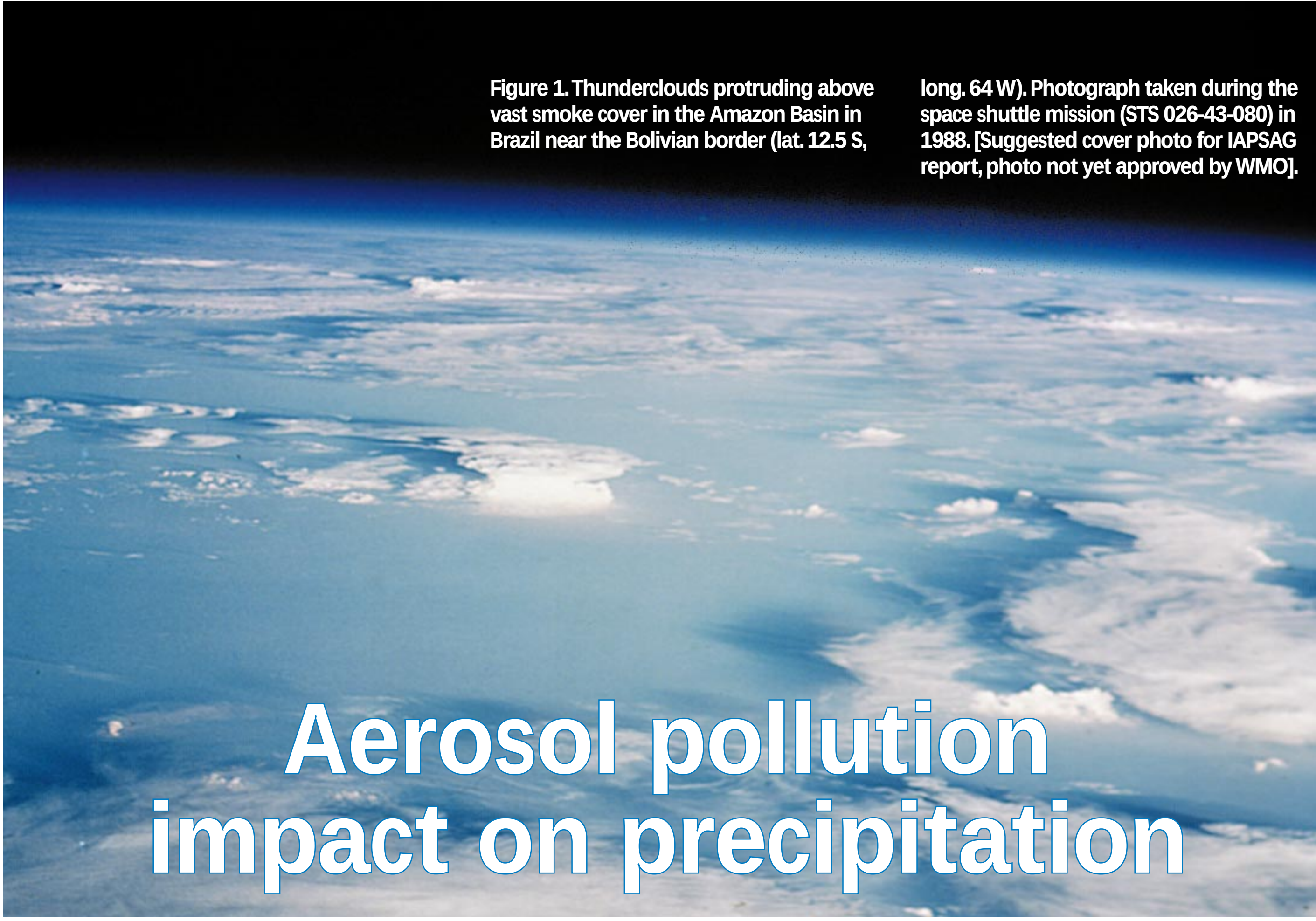

Figure 1. Thunderclouds protruding above vast smoke cover in the Amazon Basin in Brazil near the Bolivian border (lat. 12.5 S, long. 64 W). Photograph taken during the space shuttle mission (STS 026-43-080) in 1988. [Suggested cover photo for IAPSAG report, photo not yet approved by WMO].

Aerosol pollution impact on precipitation

William R. Cotton[1] and Zev Levin[2]

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This is a summary of the report by the World Meteorological Organization (WMO) and the International Union of Geodesy and Geophysics (IUGG) International Aerosol Precipitation Science Assessment Group (IAPSAG) entitled "Aerosol pollution impact on precipitation: a scientific review" [1].

Increasing concentrations of anthropogenic aerosol particles have an effect on the amount as well as the spatial and temporal distribution of clouds and precipitation affecting the hydrological cycle. The complex interactions between meteorological parameters, aerosols, cloud microphysics and dynamics make it difficult to assess the effect on precipitation change and climate.

Clouds are known to play a major role in climate through their direct interactions with solar radiation. In addition, precipitation from clouds is the only mechanism that replenishes ground water and completes the hydrological cycle. Changes in either the amounts and/or the spatial and temporal distribution of rainfall will have dramatic impacts on climate and on society. Increases or decreases in rainfall in one region could affect rainfall downwind. Similarly, changes in rainfall distribution will strongly affect semi arid regions that are of dire need of water.

Among the factors that could contribute to cloud and rain modification are the effects of air pollution from various sources such as urban air pollution and biomass burning. In 2003 the WMO and the IUGG recognized the potential danger from such effects and passed resolutions aimed at focusing attention to this issue. As a follow up to this resolution the WMO formed an international forum composed of a number of experts to review the state of the science and to identify areas that need further study.

The IAPSAG panel was chaired by Zev Levin and William Cotton served as vice chair. The manuscript is 482 pages and was prepared by 13 lead authors, 27 contributors, and 17 reviewers. The report has now gone through a technical editing stage and is being published by the WMO (Fig. 1). During the three-year process of compiling this report, Peter Hobbs who served as the original chair of the panel, Yoram Kaufman who served as a lead author, and Brian Ryan who was one of the reviewers passed away.

The report begins with an overview chapter of the principles of cloud and precipitation formation. This is followed by a chapter on the sources and nature of atmospheric aerosols, and then followed by a chapter on the distribution of aerosols, including their transport, transformation, and removal. There is also a chapter on in situ and remote sensing techniques for measuring aerosols, clouds, and precipitation and two chapters that review the state of knowledge on the effects of pollution and biomass aerosols on clouds and precipitation; one from an observational perspective and the other a modeling perspective. These are followed by a chapter on parallels and contrasts between deliberate cloud seeding and aerosol pollution effects. A summary and conclusions is given in the final chapter.

It is concluded that both observations and modeling studies show that pollution aerosols increase cloud drop concentrations and reduce average drop size. However, the effects on precipitation on the ground are much more difficult to quantify as once the precipitation process is altered, the dynamics of clouds and mesoscale systems also change in a nonlinear way. Thus the effects of aerosols on precipitation become much less predictable.

The clouds exhibiting the strongest signal are orographic clouds where both observations and modeling studies suggest an appreciable reduction in precipitation by aerosol pollution. These clouds are more susceptible to aerosol pollution owing to their modest liquid water contents, the limited time that drops and ice particles stay within them, and if they are downwind of major pollution sources their temporal and spatial persistence makes them highly vulnerable to pollution. However, orographic precipitation downwind of polluted urban regions may also be modified by changes in urban land-use (e.g. urban heat island, changes in surface roughness) and thus both increases or decreases in precipitation are possible.

In the case of deep convective clouds, models give mixed evidence whether aerosol pollution increases or decreases precipitation. For less intense cumulonimbus clouds, aerosol-pollution appears to decrease precipitation. For more intense multicell storms, the suppression of warm cloud precipitation processes can lead to more supercooled water thrust aloft where it can freeze, thereby releasing more latent heat of freezing and increasing the storm intensity and rainfall. However, the situation gets more complicated when one considers the impacts of secondary convection forced by cold-pools. There, increased primary storm intensities can lead to weaker or stronger secondary convection and therefore increase or decrease rainfall on the ground depending on stability, windshear, and interactions with larger-scale circulations like sea-breeze or urban heat island circulations.

In the immediate vicinity of polluted urban areas, observations suggest increased precipitation downwind of cities in several regions. Modeling studies, however, indicate that urban land-use is the dominant source of those precipitation anomalies. Aerosol pollution, however, can still have important impacts but those impacts will vary depending on the background aerosol supply and probably the specific locations of the urban centers relative to local physiography (Fig. 2).

Atmospheric general circulation models (AGCMs) coupled to mixed-layer ocean models suggest that the direct and indirect effects of aerosols can cool ocean sea surface temperatures and thereby slow down the hydrological cycle in contrast to greenhouse warming. The implication is that pollution aerosols could have far greater consequences to precipitation than previously thought and that there are many knowledge gaps and uncertainties related to aerosol pollution effects on precipitation. ■

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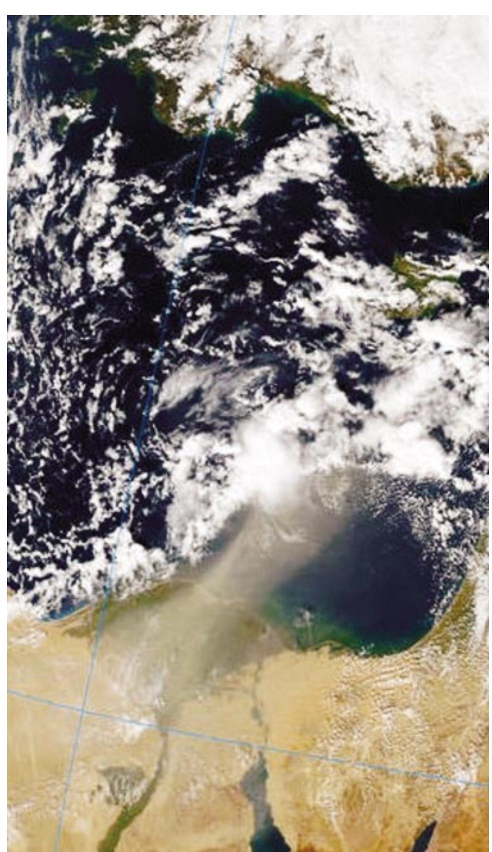

Figure 2. ➤ MODIS (Moderate Resolution Imaging Spectroradiometer) satellite image of a dust storm interacting with a cold front over the Mediterranean. Image taken on January 28, 2003 during the last flight of the Colombia space shuttle. Photo from the National Aeronautics and Space Administration (NASA).

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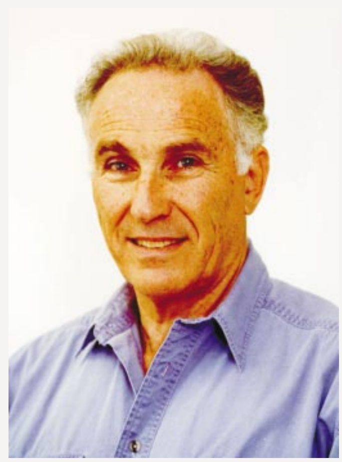

Zev Levin is a Chair Professor in Atmospheric Physics at Tel Aviv University where he has been since 1971. He received his PhD from the University of Washington in 1970 and spent one year at University of California, Los Angeles (UCLA), working on experimental cloud physics. He was the Chairman of the Department of Geophysics and Planetary Science, then the Dean of Research and Vice President for Research and Development of Tel Aviv University. He was nominated as the first director of the newly formed Porter School of Environmental Studies of Tel Aviv University. Prof. Levin is the President of the International Commission on Clouds and Precipitation, ICCP. He is the author of about 150 peer reviewed papers. He was the Chair of the WMO/IUGG International Aerosol Precipitation Science Assessment Group.

V. Ramanathan is Distinguished Professor of Atmospheric and Climate Sciences and the founding director of the Center for Clouds, Chemistry and Climate at the Scripps Institution of Oceanography, University of California, San Diego, California, USA. In the mid 1970s he discovered the greenhouse effect of CFCs and numerous other manmade trace gases. Among others, he has shown that the greenhouse effect can be monitored from space, and clouds have a large natural cooling effect on the planet. He has led the Indian Ocean Experiment (INDOEX) with Dr PJ Crutzen; the project discovered the wide spread South Asian Atmospheric Brown Clouds (ABCs). He currently chairs the United Nations Environment Programme (UNEP) sponsored ABC Project and the US academy panel that provides strategic advice to the US Climate Change Science Program. His current research focuses on the use of miniaturized instruments on unmanned aircraft to understand long range transport of aerosols and how they regulate the planetary albdo.

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Why is Earth's albedo 29% and was it always 29%?

Earth scientists have elegant and testable theories for the evolution of CO_2 and other greenhouse gases over the Earth's history. Earth scientists can also explain the amount and distribution of the dominant natural greenhouse gas, water vapor, in the atmosphere from thermodynamics and dynamics.

Using Newtonian dynamics, scientists can account for the large scale circulation of the atmosphere. Given the large scale circulation, scientists can understand the geographical locations of deserts, rainforests, etc.

From the solar insolation at the top-of-the-atmosphere, these theories enable researchers to determine the global mean climate of the Earth-atmosphere system, but for one missing link. Earth scientists have no sound physical basis or theory for constraining the influence of clouds on the amount of solar radiation reflected by the planet, the planetary albedo.

Modern day satellites have constrained the Earth's albedo to be about 29% (±2%). The albedo of the Earth's clear sky region is about 15% (±2%). Thus the presence of clouds enhances the albedo of a cloud-free Earth by about a factor of about two, from 15% to 29%. Why is the lack of a theory for constraining the role of clouds in planetary albedo a major problem and why is this relevant to iLEAPS Aerosols, Clouds, Precipitation, Climate initiative?

I The albedo questions

Why is the global albedo about 29%?

Two following examples illustrate why this is an important question. A global albedo of 32% would plunge the Earth into a climate similar to that of the last ice-age; while an albedo of 27% would be comparable to a seven-fold increase in the CO_2 concentration, close to the values required to bring the planet to the warm cretaceous. Given this state of the field, and given the fact that clouds exert a large global cooling effect (about –15 to –20 W m^{-2} globally), scientists need to understand the processes that constrain the Earth's albedo to be around 29%.

There is no obvious physical constraint for the albedo to be 29%. For example, is there a microphysical or optical constraint on the cloudy sky albedos to limit the planetary albedo to be about 29%? There is no such constraint, because for an overcast sky with very deep clouds, the limit on the albedo is 70% to 80%, as indeed, observed over the deep cumulonimbus regimes of the western Pacific warm pool or other warm oceans in the tropics.

Was the global albedo always 29%?

Most if not all geological and geochemical studies on the evolution of the Earth's climate have implicitly or explicitly assumed the albedo to be 29%. While some have accounted for ice sheet and land surface variations on the albedo, the clouds have implicitly been assumed to be the same as today. Is there any justification for this assumption?

The albedo of our neighboring planet Venus is about 70% or more, while that of Mars, the other neighboring planet, is about 17% (Fig. 1). Venus is overcast, i.e, 100% cloud-covered but Mars is nearly cloud-free. It is remarkable that although the solar insolation at top-of-the-atmosphere of Venus is about twice as large as that on Earth, the actual solar energy absorbed by Venus is slightly less than that of Earth.

Clearly, clouds and albedo feedbacks have played a major role in the evolution of the climates of these three planets. There is

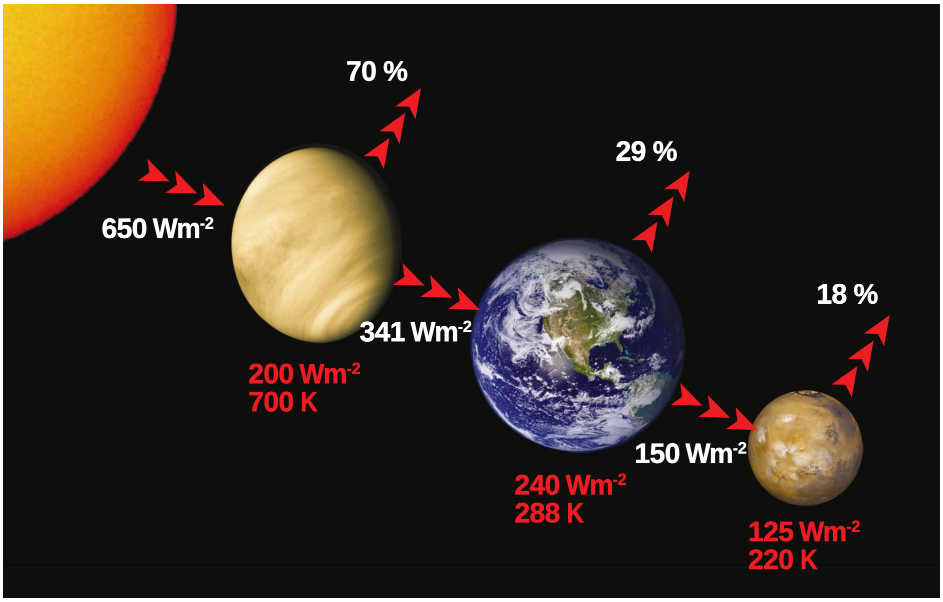

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Figure 1. Solar radiation budget of Venus, Earth and Mars. For each of the 3 planets, the number next to the arrow pointing towards the planet shows the incoming solar radiation; the number next to the arrow pointing away from the planet shows the percent of incoming solar radiation that is reflected by the surface-atmosphere system, i.e, albedo; the numbers in red below each planet are the absorbed solar radiation and the surface temperature. All of the numbers are globally-annually-diurnally averaged values. The figure is adapted from Ramanathan 2006 [8].

one hypothesis, however, which proposes albedo-climate feedback as a regulator of the planetary climate. The GAIA hypothesis [1] invokes black daisies (greenhouse gases) and white daisies (clouds and aerosols [2])

Why is this issue relevant to iLEAPS issue of aerosol-cloud-precipitation interactions?

While the atmospheric circulation determines the location and extent of clouds and water content, aerosols are the nuclei for cloud drops and thus determine the size and number distribution of cloud drops. The aerosol properties, in turn, are determined by the chemistry (e.g. oxidation of sulfur dioxide) and the biology (dimethyl sulfide and organics). The aerosol-cloud interactions in turn determine the precipitation efficiency of clouds and thus regulate lifetimes and spatial extent of clouds. All of these parameters including the aerosol concentration and composition undergo significant temporal (minutes to years) and spatial (meters to planetary scales) variations.

It is remarkable that general circulation climate models (GCMs) are able to explain the observed temperature variations during the last century solely through variations in greenhouse gases, volcanoes and solar constant. This implies that the cloud contribution to the planetary albedo due to feedbacks with natural and forced climate changes has not changed during the last 100 years by more than ±0.3%; i.e, the cloud forcing has remained constant within ±1 W m^{-2}. If indeed, the global cloud properties and their influence on the albedo are this stable (as asserted by GCMs), scientists need to validate this prediction and develop a theory to account for the stability.

Largest source of uncertainty inpredicting anthropogenic climate change

The link between aerosols and cloud albedo determines the so-called indirect effect of anthropogenic aerosols. Many models and some field observations, for example, the Indian Ocean Experiment (INDOEX [3]) has shown that an increase in anthropogenic aerosols can nucleate more cloud drops and enhance the cloud albedo and lead to a cooling effect.

The IPCC 2007 report [4] shows that this cooling effect may be large enough to offset 50% of the radiative heating due to the build up in greenhouse gases. This indirect effect is acknowledged to be the largest source of uncertainty in understanding the human impact on the global climate.

II Cloud Radiative Forcing: Regional Puzzles

Cloud radiative forcing

Cloud radiative forcing (CRF) is defined as the difference between the radiation budget (net incoming solar radiation minus the outgoing long wave) over a cloudy (mix of clear and clouds) sky and that over a clear sky. If this difference is negative clouds exert a cooling effect, while if it is positive, it denotes a heating effect. Five-year average of the cloud radiative forcing [5] is shown in Fig. 2. The global average forcing is about –15 to –20 W m^{-2} and thus clouds have a major cooling effect on the planet. Two major puzzles posed by this data are germane to the topic of this paper.

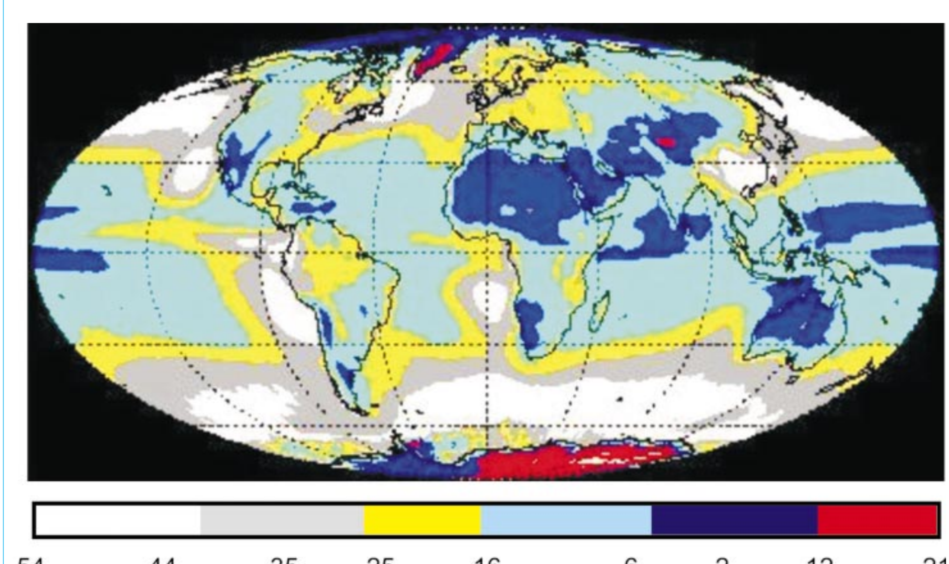

Figure 2. Net cloud radiative forcing from the Earth radiation budget experiment, ERBE [5].

The enormous cooling effect of extra-tropical storm track cloud systems

Extra-tropical storm track cloud systems provide about 60% of the total cooling effect of clouds [6]. The annual mean forcing from these cloud systems is in the range of –45 to –55 W m^{-2} and effectively these cloud systems are shielding both the northern and the southern polar regions from intense radiative heating. Their spatial extent towards the tropics moves with the jet stream, extending farthest towards the tropics (about 35 deg latitude) during winter and retreating polewards (polewards of 50 deg latitude) during summer. This phenomenon raises an important question related to past climate dynamics.

During the ice age, due to the large polar cooling, the northern hemisphere jet stream extended more southwards. But have the extra tropical cloud systems also moved southward? The increase in the negative forcing would have exerted a major positive feedback on the ice age cooling. There is a curious puzzle about the existence of these cooling clouds. The basic function of the extra tropical dynamics is to export heat polewards.

While the baroclinic systems are efficient in transporting heat, the enormous negative radiative forcing (Fig. 2) associated with these cloud systems seems to undo the poleward transport of heat by the dynamics. The radiative effect of these systems is working against the dynamical effect. Evidently, we need better understanding of the dynamic-thermodynamic coupling between these enormous cooling clouds and the equator-pole temperature gradient, and greenhouse forcing.

Land-atmosphere-ocean coupling in the Tropics

Another major interesting feature in Fig. 2 is the smaller forcing over the highly reflective (high albedo) tropical cloud systems. It is well known that over the western tropical Pacific, equatorial Africa, South America, and the monsoon regions of Asia, deep cumulonimbus-cirrus systems give rise to extensive high albedo clouds, but Fig. 2 does not show this cooling effect.

The fundamental reason is that the greenhouse effect of these cloud systems are very large (because their tops are located in the cold upper troposphere) and the large positive forcing from the cloud greenhouse effect nearly cancels out the large negative forcing from the high albedo of these clouds. There is one intriguing feature of the equilibrium albedo of these deep cumulonimbus-cirrus cloud systems.

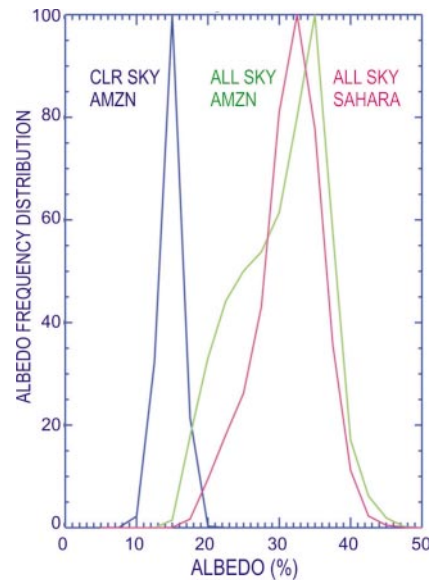

Figure 3. Frequency distribution of top-of-atmosphere broad band albedo based on data from Earth radiation budget experiment, ERBE.

The frequency distribution of clear sky albedos over Sahara and the clear and cloudy sky albedos over the Amazon region in South America are shown in Fig. 3. The striking feature is the near similarity in the albedo between the all-sky (clear and clouds) albedo over the Amazon (magenta) and the clear sky albedo of Sahara. The all sky value of Saharan albedo is not shown because it is very similar to its clear sky albedo values.

Although the clear sky albedo of Amazon is less than 15% (compared with Sahara value of 34%), the clouds even out the albedo differences and hence Amazon all sky values are close to Saharan values. This similarity cannot be attributed to a limiting value of Amazon albedo to, say, a value close to 30%. The annual mean albedo of Amazon is most likely determined by land-atmosphere-ocean interactions limiting the cloud fraction and its thickness by the availability of cloud water and nuclei. However, it is intriguing why the mean albedo of this region over a longer time period is close to 30%. Similar annual mean and large scale average values are found over the other tropical cloud systems as well.

The GAIA hypothesis has remained untestable [7]. We need a more testable hypothesis that not only addresses the questions raised here but also explains the albedo puzzles posed in this paper.

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Integrated Land Ecosystem Atmosphere Processes Study
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iLEAPS Session

BG2.1 Interactions of Land Cover and Climate
Convener: Reissell, A.
Co-Convener: Andreae, M.; Kabat, P.

Land cover both responds to the climate and affects the climate, and these interactions are a major focus of the IGBP core project Integrated Land Ecosystem - Atmospheric Processes Study (iLEAPS). Changes in land cover are now recognized as a factor that has contributed to changes in climate on all scales from local to regional and even global. This symposium invites papers on the full range of topics relating to the interactions of changes in land cover and condition and in climate, including changes relating to deforestation, agriculture, and other development; feedbacks relating to albedo, roughness, carbon storage and fertilization, trace gas fluxes, and other biogeochemical cycles; and impacts relating to ecosystem shifts, melting of permafrost, and water resources and soil moisture.

iLEAPS organized/co-sponsored/related sessions

BG2.7 Land - atmosphere Interactions and human activity in Monsoon Asia
Convener: Fu, C.
Co-Convener: Kabat, P.; Reissell, A.

BG2.8 Land-atmosphere interactions in Northern Eurasia (co-listed in CR)
Convener: Groisman, P.
Co-Convener: Kabat, P.; Hibbard, K.

BG2.11 Synthesis efforts from the global network of ecosystem-atmosphere CO_2, water and energy Exchange (FLUXNET)
Convener: Reichstein, M.
Co-Convener: Papale, D.

BG2.6 Methane fluxes and carbon cycle of permafrost ecosystems
Convener: van Huissteden, K.
Co-Convener: Christensen, T.

BG4.1 Biogeochemical feedbacks on global climate change
Convener: Friend, A.
Co-Convener: Betts, R.; Poulter, B.; Lenton, T.

AS1.14 African Monsoon Multidisciplinary Analysis (AMMA) (co-listed in BG, CL, OS & SSS)
Convener: Taylor, C.
Co-Convener: Janicot, S.; Marticorena, B.

AS3.21 The dry deposition process at the substrate- to global scale (co-listed in BG & OS)
Convener: Ganzeveld, L.
Co-Convener: Altimir, N.

CL22 Land-climate interactions from models and observations: Implications from past to future climate
Convener: Seneviratne, S.
Co-Convener: van den Hurk, B.; Ciais, P.

CL15 Physical and biogeochemical feedbacks in the climate system
Convener: Jones, C.
Co-Convener: Alexeev, V.

We warmly welcome you to participate in the sessions!

European Geosciences Union General Assembly, 13-18 April, 2008. Vienna, Austria

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Absorbing aerosols enhance Indian summer monsoon rainfall

Aerosols can affect precipitation through radiative effects of suspended particles in the atmosphere and/or by modulating the cloud formation processes. This article deals only with precipitation and large-scale changes induced by radiative effects of aerosols.

Based on radiation properties, aerosols can be classified into two types: those that absorb solar radiation, and those that do not. Both types of aerosols scatter sunlight and reduce the amount of solar radiation that reaches the Earth's surface, causing it to cool. However, absorbing aerosols, in addition to cooling the surface, can heat the atmosphere. The heating of the atmosphere produces a rising motion and low-level moisture convergence, which lead to increase in rainfall. The latent heating from enhanced rainfall may produce feedback processes in the large-scale circulation, further amplifying the initial response to aerosol radiative forcing.

Figure 1. A space shuttle view of the Indo-Gangetic Plains shrouded in haze, against the partially snow-covered foreground of the Tibetan Plateau.

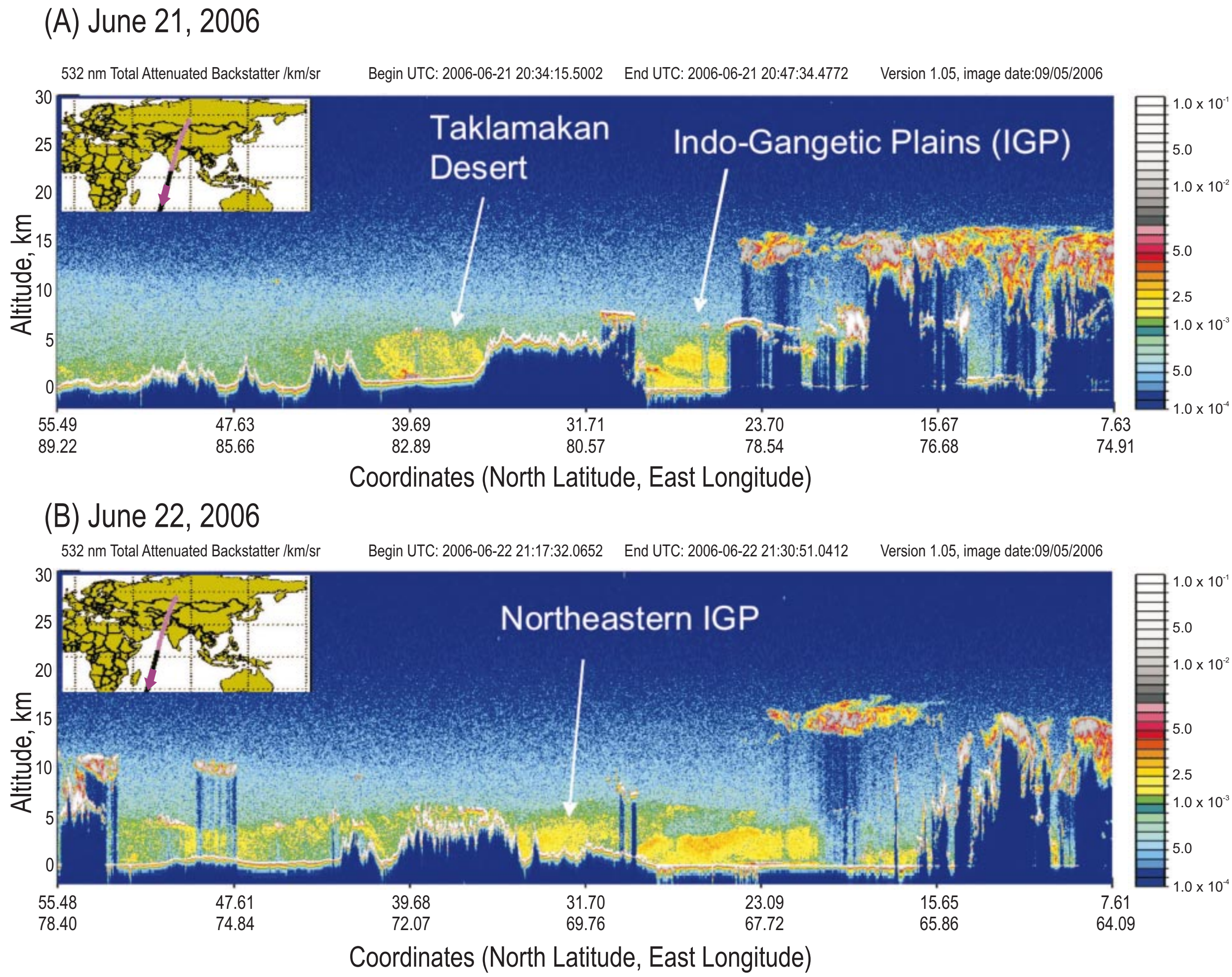

Figure 2. Color-coded near-meridional vertical cross-sections of CALIPSO satellite's lidar back-scatter signal (532 nm) across India and the Tibetan Plateau. The green, yellow and red color shows low, medium and high aerosol concentrations of aerosols respectively. Deep convection and high cirrus are shown from yellow to grey showing increasing concentration of ice-scattering. Aerosols under high clouds cannot be detected by CALIPSO.

The aerosol-induced atmospheric feedback effects are likely to be most effective in aerosol "hotspots" which are characterized by heavy aerosol loading over large areas with abundant atmospheric moisture. The Indo-Gangetic Plains (IGP) in northern India is an aerosol "super-hotspot" due to high population density and concentration of industrial plants. Most of the aerosols in the IGP region are absorbing species—black carbon from coal, biofuel, and biomass burning, as well as dust transported from the Middle East and the Thar Deserts. During the northern spring and early summer, these aerosols are found in large quantities piling up against the southern slopes of the Tibetan Plateau, visible in the form of a thick layer of haze shrouding the entire region (see Fig. 1).

Recent studies have shown that the radiative heating perturbations induced by absorbing aerosols, i.e., dust and black carbon, in the atmosphere-land-ocean system may, through dynamical feedback processes, increase or decrease monsoon rainfall depending on the relative importance of the atmospheric heating and the surface cooling effects [1, 2, 3, 4]. With regard to the role of topography in further enhancing the initial response to aerosol radiative forcing, Lau et al [3] introduced the "Elevated Heat Pump" (EHP) hypothesis, which suggests that dust and black carbon accumulated over the Indo-Gangetic Plains (IGP), by wind transport against the foothills of the Himalayas, act as an elevated heat source that spurs anomalous warming of the middle and upper troposphere over the southern Tibetan Plateau. The tropospheric heating subsequently leads to an enhancement of monsoon rain over northern and central India. Lau and Kim [4] have provided preliminary observational evidence of the EHP effects.

CloudSat and CALIPSO satellites, which were launched in 2006, have provided vertical profiles of aerosols and clouds to allow further testing of the EHP hypothesis. The accumulation of absorbing aerosols against the slopes of the Tibetan Plateau during the summer monsoon season is evident in Fig. 2, which shows two vertical near-meridional cross-sections of lidar backscatter signal from CALIPSO across the India subcontinent and the Tibetan Plateau during the onset phase of South Asian monsoon.

On June 21, 2006, monsoon convection has already set in over northeastern India, and the Bay of Bengal, as indicated by the high-level clouds abutting thick layers of aerosols in the IGP (Fig. 2a). The aerosol layer over the IGP rises to 4.5 – 5 km against the foothills of the Himalayas. Preliminary analysis of AERONET (AErosol RObotic NETwork) optical thickness data (not shown) indicates that the aerosols are composed of large-size particles, with high absorptivity, most likely composed of dust particles, coated with black carbon from local sources.

Dust aerosols over the Taklamakan desert also accumulate to great heights against the northern slopes of the Tibetan Plateau. During the onset phase, there is large east-west contrast in the distribution of rain and dust over the IGP. The eastern por

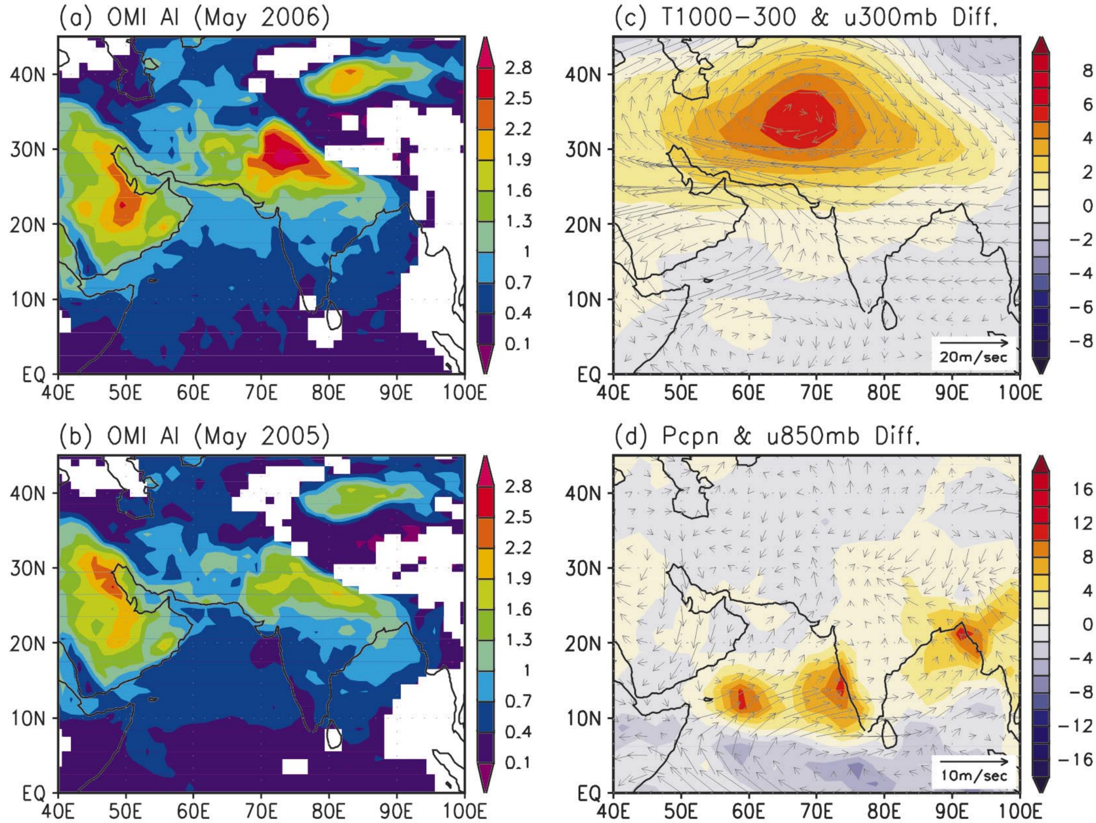

Figure 3. (a) and (b): Aerosol distribution from Ozone Monitoring Instrument (OMI) Aerosol Index (AI) data over the South Asian monsoon and adjacent deserts, for (a) May 2006 and (b) May 2005. Unit is non-dimensional. (c) and (d): Distribution of anomalous (May 2006 minus May 2005) large-scale circulation states; (c) upper level (300 hPa) winds and column averaged tropospheric temperature (1000–300 hPa), and (d) lower level (850 hPa) winds and rainfall. Magnitudes of wind arrows are as shown. Temperature is in ℃ unit and rainfall in mmday^{-1}.

tion is mostly covered with precipitating deep convection, which washes out some of the dust aerosols advected from the west. However, the western portion of the IGP remains mostly dry, and dust covered.

The large east-west asymmetry in aerosol loading and convective cloud distribution can be seen in Fig. 2b, which shows a thick extensive aerosol layer stretching from the Thar Desert to northern Arabian Sea on June 22, 2006. On June 22, 2006, the deep clouds were more restricted to the south over the Arabian Sea. This aerosol layer most likely consisted of dust particles from the Thar Desert, as well as dust transported from the Middle East deserts.

One of the "projections" of the EHP is that the aerosol-induced large-scale circulation feedback may enhance rainfall over India in the late spring and early summer season. Fig. 3 shows the distribution of Aerosol Index (AI - an index detecting the presence of UV-absorbing aerosols) from the Ozone Monitoring Instrument (OMI) of Aura satellite for May 2006 and 2005 respectively. Three major hotspots are noted: the IGP, the Taklamakan, and the Saudi Arabian Desert.

Excessive aerosol loadings are clearly seen over the IGP in May 2006 in comparison to May 2005, for reasons yet to be determined. The corresponding anomalous (May 2006 minus May 2005) large-scale features show an upper level anticyclone, engulfing a warmer upper troposphere, with strong easterlies stretching from Bay of Bengal, through northern India to the Arabian peninsula (Fig. 3c).

Coupled with the upper level anomalies are low-level westerlies from the Arabian Sea across southern India, ending in a cyclonic circulation over the Bay of Bengal, with upslope southeasterly along the foothills of the Himalayas (Fig. 3d). Rainfall is enhanced in the Arabian Sea, the western Ghats, and the Bay of Bengal. These features are consistent with an advance of the monsoon rainy season, and enhanced monsoon circulation in May initiated by atmospheric heating by absorbing aerosols as postulated by the EHP hypothesis. ■

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Aerosol Clouds Precipitation Climate

Atmospheric aerosols have profound impacts on the thermodynmic and radiative energy budgets of the Earth. Recognition of the potential climate impacts of anthropogenic aerosols has led to a great deal of research to assess their role on the Earth's radiative balance. Much less is known about the effects of aerosols on precipitation, and the consequences for the climate system. The Aerosols, Clouds, Precipitation and Climate (ACPC) initiative is intended to develop an integrated research program to investigate the interactions and feedbacks among aerosols, cloud processes, precipitation, and the climate system.

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What are the aerosol-precipitation effects at larger scales?

Anthropogenic aerosol particles such as sulfate and carbonaceous aerosols have substantially increased the global mean burden of aerosol particles from pre-industrial times to the present day. Aerosols can interact with clouds and precipitation by acting as cloud condensation nuclei or ice nuclei. The series of possible impacts of aerosols through the modification of cloud properties are called indirect effects [1]. The cloud albedo effect, that is, the distribution of the same cloud liquid water content over more, hence smaller, cloud droplets leading to higher cloud reflectivity, is a purely radiative forcing. It is estimated to range between –0.3 and –1.8 W m^{-2} [2].

The other effects involve feedbacks in the climate system. Feedbacks due to the cloud lifetime effect, semi-direct effect or aerosol-ice cloud effects can either enhance or reduce the cloud albedo effect. Moreover, the albedo effect cannot be easily separated from the other effects; in fact, the processes that decrease the cloud droplet size per given liquid water content also decrease precipitation formation, presumably prolonging cloud lifetime. In turn, an increase in cloud lifetime also contributes to a change in the time-averaged cloud albedo.

Climate models estimate the sum of all anthropogenic aerosol effects (total indirect plus direct) to be a –1.2 W m^{-2} ranging from –0.2 to –2.3 W m^{-2} change in the top-of-the-atmosphere net radiation since pre-industrial times [1]. Inverse estimates from simple or intermediate climate models that use the observed increase in land temperature and ocean heat content constrain the indirect aerosol effect to be between –0.1 and –1.7 W m^{-2} [3].

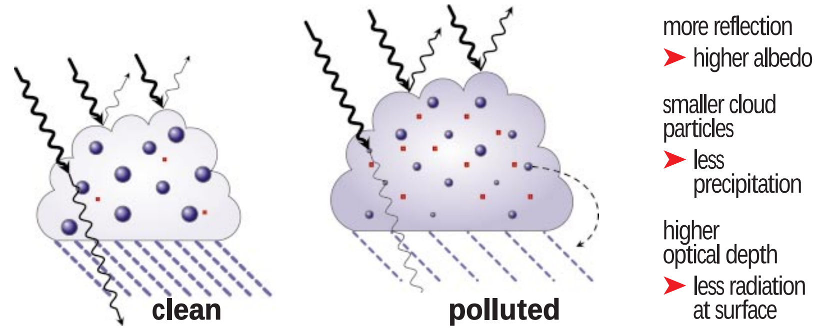
As shown in Fig. 1, the glaciation effect refers to an increase in ice nuclei resulting in a rapid glaciation of a super-cooled liquid water cloud due to the difference in vapour pressure over ice and water. Unlike cloud droplets, these ice crystals grow in an environment of high super-saturation with respect to ice, quickly reaching precipitation size, with the potential to turn a non-precipitating cloud into a precipitating cloud. The thermodynamic effect refers to a delay in freezing by the smaller droplets causing super-cooled clouds to extend to colder temperatures. In addition to aerosol-induced changes at the top-of-the-atmosphere, aerosols affect the surface energy budget with consequences for convection, evaporation and precipitation (Fig. 1).

When aerosol effects on warm convective clouds are included in addition to their effect on warm stratiform clouds on a global scale, the overall indirect aerosol effect and the change in surface precipitation can be larger or smaller than if just the aerosol effect on stratiform clouds is considered [e.g. 4]. In simulations where greenhouse gases and aerosol emissions are increased since pre-industrial times, accounting for microphysics in warm and cold convective clouds matches the observed increase in precipitation better than if only aerosol effects on warm and cold stratiform clouds were considered [5].

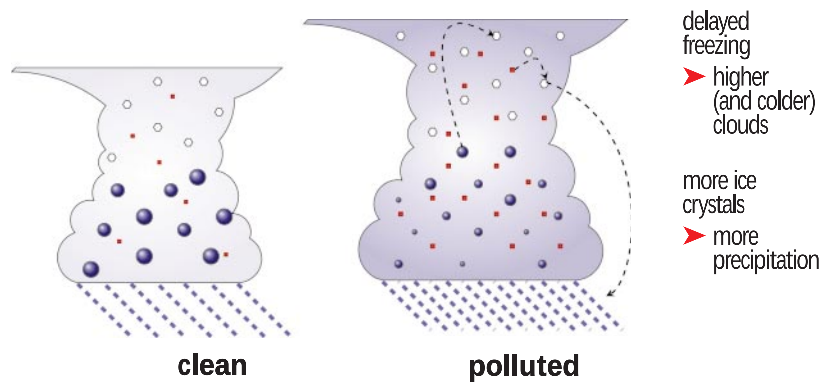
By increasing aerosol and cloud optical depth, anthropogenic emissions of aerosols and their precursors contribute to a reduction of solar radiation at the surface. Transient simulations and GCMs (general circulation models) coupled to mixed-layer ocean equilibrium simulations suggest that the decrease in solar radiation at the surface resulting from increases in optical depth due to the direct and indirect anthropogenic aerosol effects is more important for controlling the surface energy budget than the greenhouse gas induced increase in surface temperature.

The other components of the surface energy budget (thermal radiative flux, sensible and latent heat fluxes) decrease in response to the reduced input of solar radiation. As global mean evaporation must equal precipitation, a reduction in the latent heat flux in the model leads to a reduction in precipitation. This is in contrast to the observed precipitation evolution in the last century and points to an overestimation of aerosol influences on precipitation. The simulated decrease in global mean precipitation from pre-industrial times to the present day may reverse into an increase of about 1% during the period 2031–2050 as compared to the period 1981–2000, because the increased warming due to black carbon and greenhouse gases then dominates over the sulphate cooling [6].

Global climate model estimates of the change in global mean precipitation due to the total aerosol effects are summarised in Fig. 2. Consistent with conflicting results from



Cloud albedo and lifetime (negative radiative effect for warm clouds at TOA and less precipitation); solar dimming (less radiation at the surface)



Glaciation effect (positive radiative effect at TOA and more precipitation); thermodynamic effect (precipitation can decrease or increase)

Figure 1. Schematic diagram of the aerosol effects discussed in Table 1. TOA refers to the top-of-the-atmosphere. Adopted from Denman et al. [1]. ➤

Table 1. Overview of the different aerosol indirect effects and their sign of the net radiative flux change at top-of-the-atmosphere (TOA) (top 5 rows), for the global mean net shortwave radiation at the surface, F_{sfc} and for precipitation (bottom 5 rows). Adopted from Denman et al. [1]. ➤

Effect	Cloud Types Affected	Process	Sign of Change in TOA Radiation	Potential Magnitude	Scientific Understanding
Cloud albedo	All clouds	For the same cloud water or ice content more but smaller cloud particles reflect more solar radiation	Negative	Medium	Low
Cloud lifetime effect	All clouds	Smaller cloud particles decrease the precipitation efficiency thereby presumably prolonging cloud lifetime	Negative	Medium	Very low
Semi-direct effect	All clouds	Absorption of solar radiation by absorbing aerosols affects static stability and the surface energy budget, and may lead to an evaporation of cloud particles	Positive or negative	Small	Very low
Glaciation indirect effect	Mixed- phase clouds	An increase in ice nuclei increases the precipitation efficiency	Positive	Medium	Very low
Thermodynamic effect	Mixed- phase clouds	Smaller cloud droplets delay freezing causing super-cooled clouds to extend to colder temperatures	Positive or negative	Medium	Very low

Effect	Sign of Change in F_{sfc}	Potential Magnitude	Scientific Understanding	Sign of Change	Potential Magnitude	Scientific Understanding
Cloud albedo effect	Negative	Medium	Low	n.a.	n.a.	n.a.
Cloud lifetime effect	Negative	Medium	Very low	Negative	Small	Very low
Semi-direct effect	Negative	Large	Very low	Negative	Large	Very low
Glaciation indirect effect	Positive	Medium	Very low	Positive	Medium	Very low
Thermodynamic effect	Positive or negative	Medium	Very low	Positive or negative	Medium	Very low

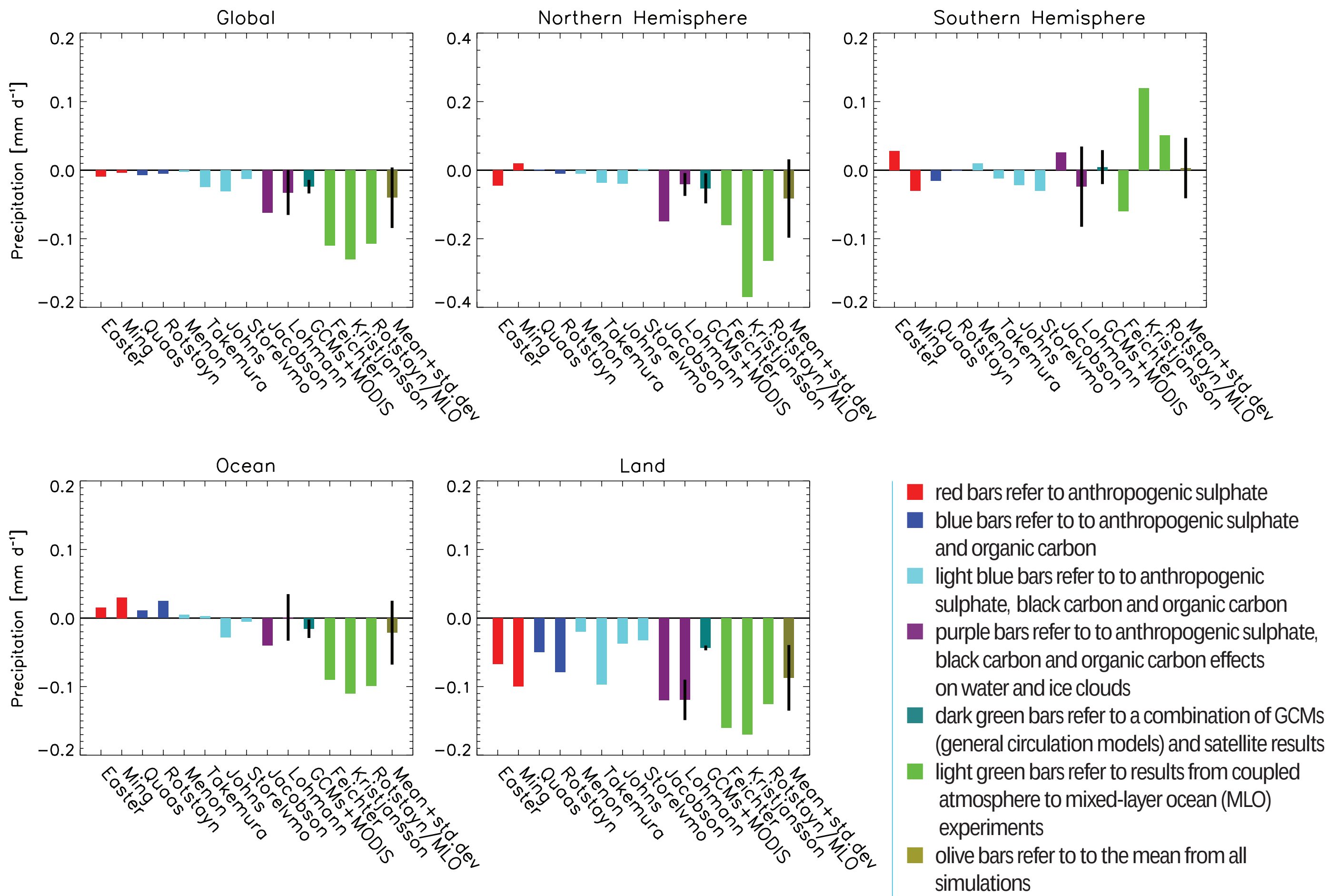


Figure 2. Global mean change in precipitation due to the total anthropogenic aerosol effect (direct, semi-direct and indirect cloud albedo and lifetime effects) from pre-industrial times to the present day and its contribution over the Northern and Southern Hemisphere, over oceans and over land. Vertical black lines refer to ±1 standard deviation. Adopted from Denman et al. [1].

detailed cloud system studies, the change in global mean precipitation varies between 0 and –0.13 mm day^{-1}. These differences are amplified over the Southern Hemisphere, ranging from –0.06 mm day^{-1} to 0.12 mm day^{-1}. In general, the decreases in precipitation are larger when the atmospheric GCMs are coupled to mixed-layer ocean models (green bars), where the sea surface temperature and, hence, evaporation are allowed to vary (Fig. 2).

In summary, the impact of anthropogenic aerosols on cloud properties has been demonstrated in a number of different field studies and in satellite data and agrees with model simulations. It has, however, proven much harder to detect a signal of anthropogenic aerosols in changes in precipitation both in observations and modelling studies. This is one reason for the new aerosol-cloud-precipitation-climate (ACPC) initiative as discussed in this newsletter. ■

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Can the slowing of auto-conversion result in increasing precipitation?

The iLEAPS-IGAC-GEWEX joint white paper on Aerosols, Clouds, Precipitation and Climate [1] presents the concept of "thermodynamic forcing" by aerosols changing the energy pathways in convective systems due to the impact of aerosols on cloud composition and precipitation forming processes. The aerosols do that by serving as cloud drop condensation nuclei (CCN).

Smoke particles act as good CCN, so that clouds forming in smoky air are composed of large concentration of small drops, which are slow to coalesce into raindrops. The slowing of the conversion of cloud water into precipitation leads to suppression of precipitation in shallow and short lived clouds, such as form during winter over topographical barriers, and so decreases water resources in semi-arid regions. Absorbing aerosols, such as smoke, were observed to suppress small scale convection by intercepting the solar radiation from heating the surface. The evidence for that was reviewed in iLEAPS Newsletter Issue 2 [2].

While these aerosols might reduce precipitation from small clouds, they can lead to the invigoration of deep tropical clouds as illustrated in Fig. 1.

The white paper presents the hypothesis that the slowing down of the rate of the drop coalescence into rain drops (i.e., auto-conversion) delays the precipitation of the cloud water, so that more water can ascend to the altitudes where the temperature is colder than 0 ºC.

By not raining early, the condensed water would then form ice precipitation particles that release the latent heat of freezing aloft, and reabsorbing heat at lower levels where they melt. The result would be more upward heat transport for the same amount of surface precipitation. The consumption of more static energy for the same precipitation amount would then be converted to equally greater amount of released kinetic energy that could invigorate the convection and lead to a greater convective overturning, more precipitation and deeper depletion of the static instability [2].

This modification of the exchange rate between the amount of surface precipitation and the heating of the mid and upper troposphere is a fundamental "thermodynamic forcing" with possible far-reaching ramifications, which needs to be better understood.

This conceptual model is supported by satellite observations, which have shown increase in cloud top heights for convective clouds over the Atlantic Ocean [3]. Model simulations suggested that the association between the increased cloud top heights and aerosols could not be explained solely by the alternative explanation, meteorology. Lin et al. [4] found even stronger association between aerosol optical depth and cloud top height over the Amazon (see Fig. 2).

Numerical simulations were used by Martins et al. [5] to test the hypothesis of aerosol impact on cloud development under given atmospheric conditions in the southwestern Amazon region. The Brazilian regional atmospheric models software (*RAMS*) climate model data was run at a 4 km resolution with 2 moment microphysical bulk scheme on a nested domain of 488 km x 488 km.

Different aerosol loadings from biomass burning were imposed by introducing different CCN concentrations and corresponding shape parameters of the cloud droplet size distribution in accordance with the observations reported by Andreae et al. [6].

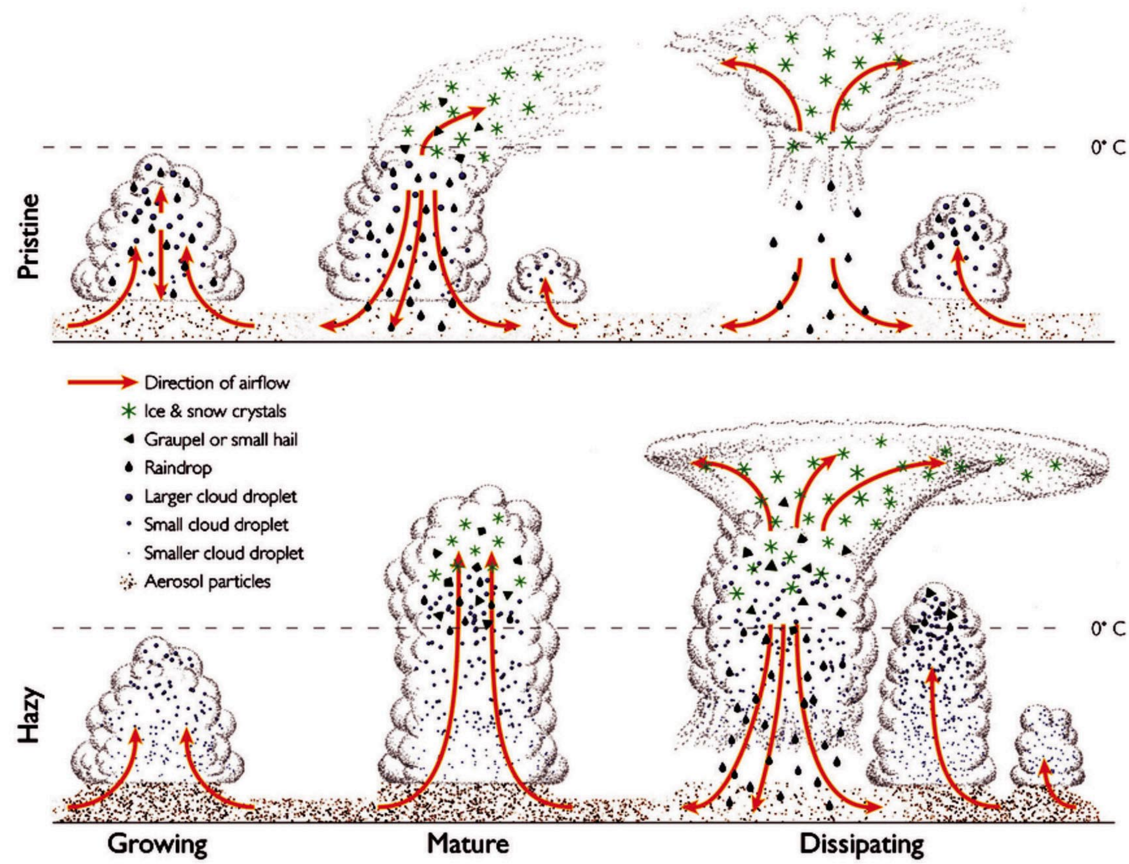

Figure 1. Deep convective clouds developing in pristine (top) and smoky (bottom) atmosphere. The cloud water coalesces into raindrops that rainout from the pristine clouds. The smaller drops in the smoky air do not precipitate until reaching the supercooled levels, where they freeze onto ice precipitation that fall and melt at lower levels. The additional release of latent heat of freezing aloft and reabsorbed heat at lower levels by the melting ice implies greater upward heat transport for the same amount of surface precipitation in the more smoky atmosphere. This means consumption of more instability for the same amount of rainfall. The inevitable result is invigoration of the convective clouds.

Fig. 3 shows cloud vertical development at the time of maximum extent in each of the four CNN categories. The simulated cloud vertical development increased with greater CCN concentrations, in accordance with the observational results of Lin et al. [4], shown in Fig. 2.

Fig. 4 implies that the accumulated rainfall averaged over the simulation domain increases with increasing aerosol loading, as well as the total column cloud liquid plus ice averaged in space and time. Fig. 3 also shows a shift towards upper levels of the maximum in liquid plus ice, which is consistent with more intense convective updrafts with greater CCN concentrations. The magnitude of these results may be exaggerated due to the relatively poor resolution of the model, but at least their direction is consistent with the observations and conceptual model.

Raupp and Silva Dias [7] demonstrated that atmospheric circulation responds to tropical convection in the Amazon in the form of travelling Rossby-gravity waves with periods of the order of 4 days. Low level heating leads to a more confined tropospheric response, as opposed to deep heating that exhibits a stronger remote effect (teleconnections) according to DeMaria [8].

Silva Dias et al. [9] simulated such changes for enhanced convective heating that was arbitrarily changed as a sensitivity study, during the wet season in the same Southwest Amazon region. It is therefore useful to regard the Amazon region as a tropical heat source occuring in two modes of convection, one with latent heat released

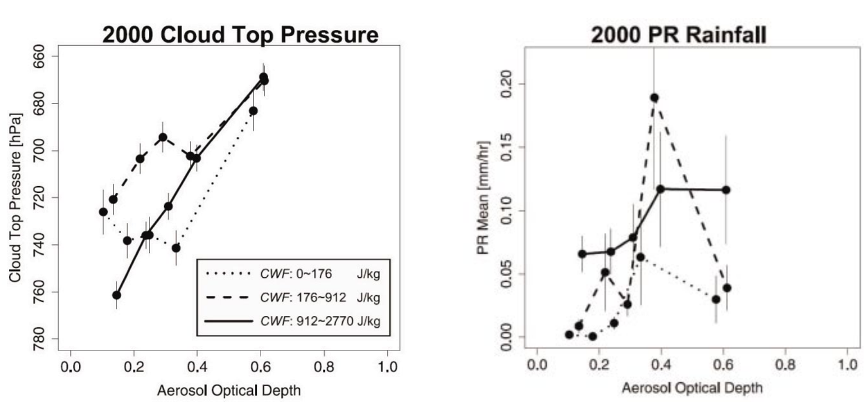

Figure 2. Convective cloud top pressure (left) and measured rainfall (right) in relation to aerosol optical depth (τ_a) over the Amazon in 2000. The convective cloud top pressure was measured by the moderate resolution imaging spectroradiometer, MODIS; the measured rainfall was determined using tropical rainfall measuring mission precipitation radar; and aerosol optical depth was derived from MODIS data. The data are binned by τ_a with each bin spanning 20 percentile of the τ_a values and further stratified into different cloud work function (CWF, similar to available potential convective energy) regimes. Note that the cloud top heights (decreased cloud top pressure) and rainfall amounts increased with increased τ_a, and even more strongly for the more convective situations as indicated by the greater atmospheric instability, which is depicted by greater CWF. After Lin et al. [4].

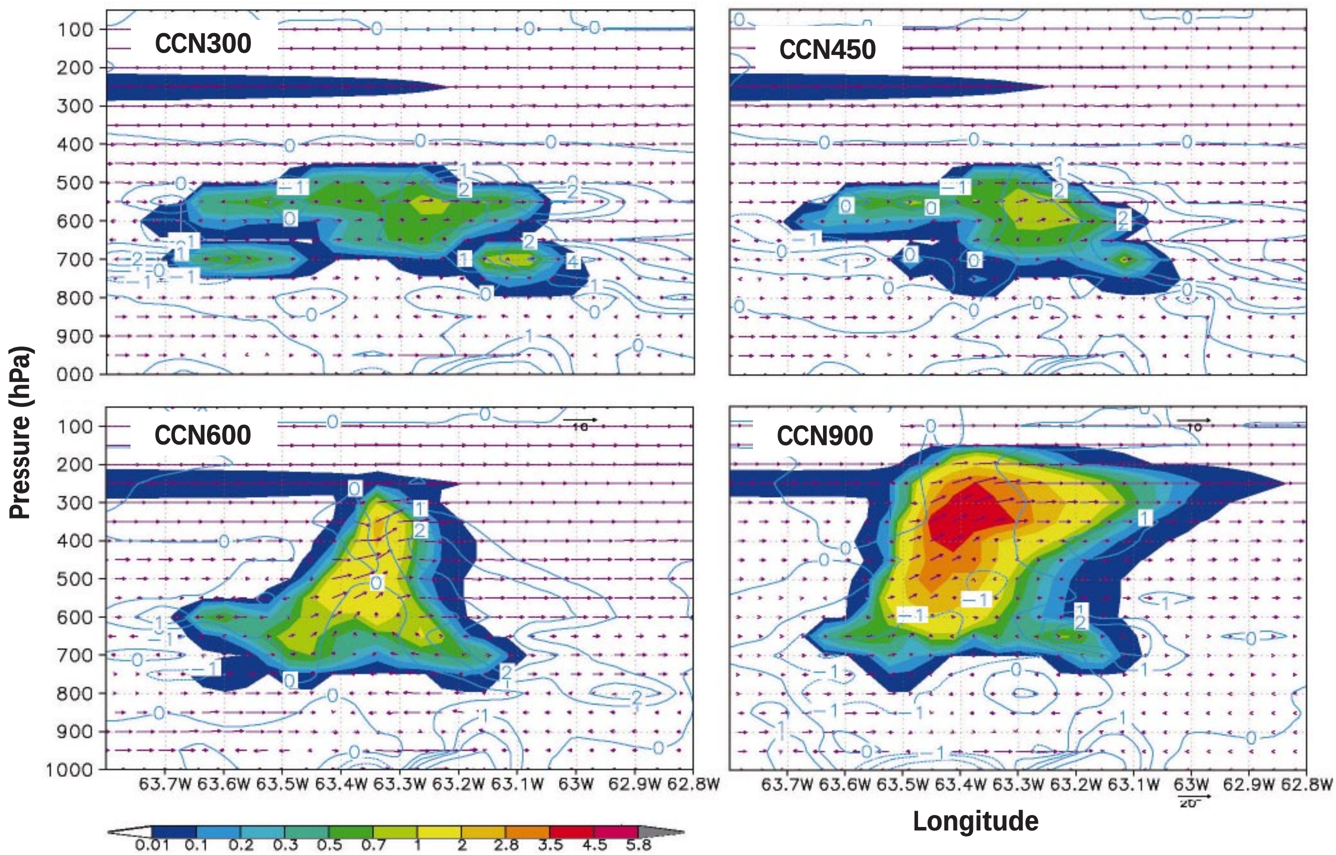

Figure 3. Simulation of the response of cloud development to changing concentrations of cloud condensation nuclei (CCN). Vertical structure of cloud and ice water mixing ratio (g kg^{-1}) observed at the time of maximum liquid water path for 300 CCN cm^{-3} (a), 450 CCN cm^{-3} (b), 600 CCN cm^{-3} (c) and 900 CCN cm^{-3} (d). The CCN concentration and cloud droplet distribution with appropriate shape parameters are used to represent the varying aerosol loadings due to biomass burning within the same atmospheric conditions. Contour lines represent the temporal variation of water vapor mixing rate (g kg^{-1} h^{-1}). Numerical simulations with 4 km x 4 km horizontal resolution using the Brazilian regional atmospheric models software (BRAMS) for 23 September 2002 in Southwest Amazon region. After Martins et al. [5]

in low levels – the clean case – and the other where vigorous convection is associated with a maximum of latent heat released in upper levels – often the case with more aerosol loading. A stronger remote response—or teleconnections—is favored by the deep heating, whereas the low level heating leads to a more confined tropospheric response.

Andreae et al. [6] suggested that invigoration also induces more hail from the clouds. This hypothesis was tested in the Sixth EU Framework Programme ANTI-STORM (Anthropogenic Aerosols Triggering and Invigorating Severe Storms) project. Using a combination of models and observations, the conceptual model shown in Fig. 1 was refined.

The main new insights are: (a) even moderate amounts of air pollution, such as normally occur in large areas in Europe, can have a large impact on the hail potential of warm base storms; (b) there is an "optimal" aerosol concentration level, where in very high levels (e.g., CCN concentrations > 3000 cm^{-3}) the amount of hail and storm intensity starts to decrease, but not to the low level of the pristine storms; (c) the potential impact of aerosols on hail formation becomes greater for clouds that form in more moist atmosphere with warmer cloud base.

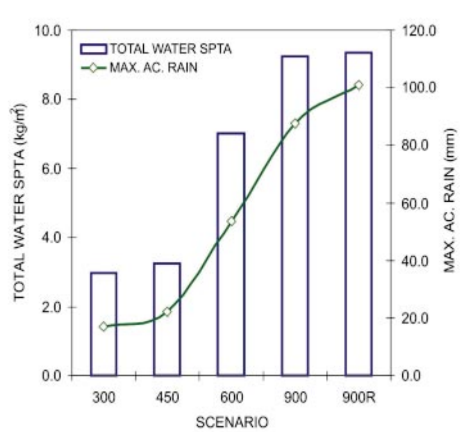

Figure 4. Total simulated rainfall and condensates in response to increased CCN concentrations. Total water spta is the space peak time average of total water in a column and max ac rain is the maximum accumulated rainfall at the surface. Fig. 3 shows one cloud within this simulation domain. Figure after Martins et al. [5].

The enhanced and delayed aerosol-induced release of latent heat may lead to regional scale enhancement and re-distribution of convection, low level moisture convergence and precipitation, as described in the joint white paper [1]. Additional observational evidence that supports the hypothesis of DeMaria [8] and Silva Dias et al. [9] was obtained by analysis of the weekly cycle of aerosols, precipitation and convergence patterns over the USA and the adjacent oceans [10].

Fig. 5 shows that the observed mid-week maximum in aerosol concentrations over the USA is associated with a maximum in sur-

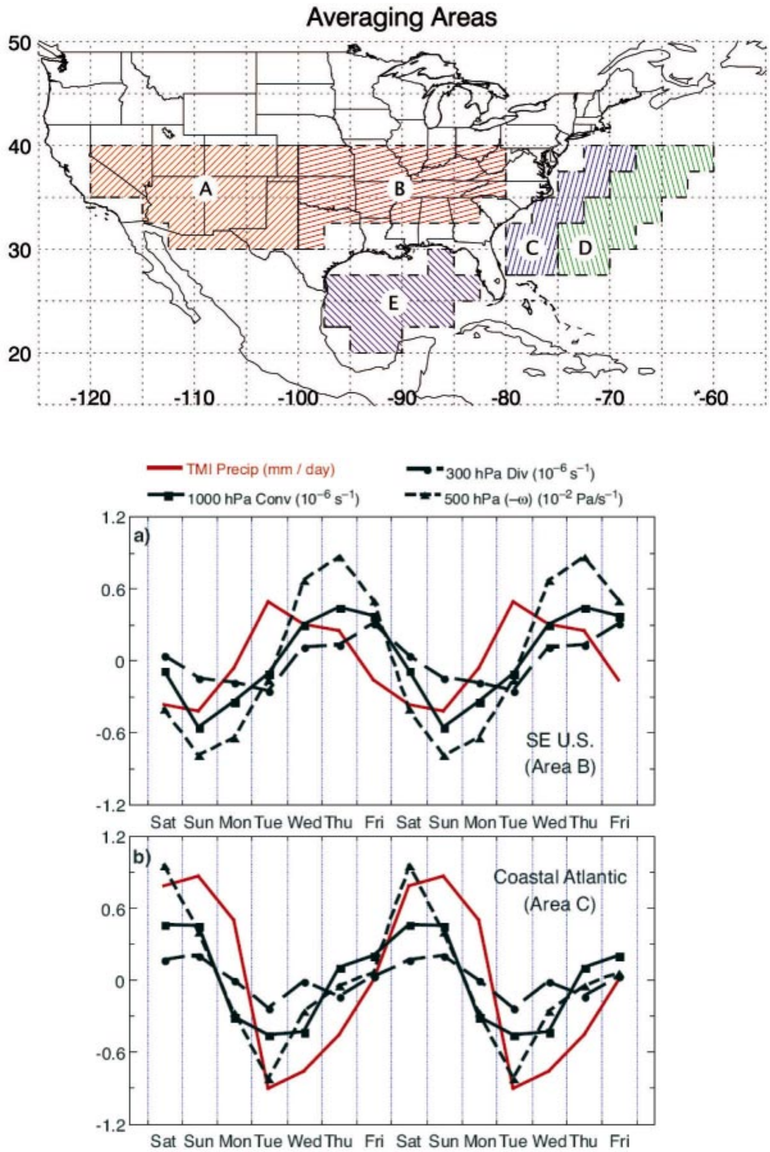

Figure 5. Day of the week modulation of surface convergence and precipitation during summer (JJA) in the Southeast USA (area B) coupled with divergence over the adjacent ocean (area C) that occur with the weekly cycle of air pollution. Average wind convergence over the area at 1000 hPa indicates net inflow into the area near the surface. Average divergence at 300 hPa indicates net export of air out of the area at altitudes typical of storm tops. Mid-atmosphere average vertical velocity at 500 hPa is represented by $-\varpi$, the time rate of change of air pressure of an air parcel (sign reversed). Daily tropical rainfall measuring mission (TRMM) measured rainfall anomalies are superimposed for comparison. Differences from time means are plotted for each quantity, and tested to be statistically significant. Wind-field statistics (summer, 1998–2005) are obtained from National Centers for Environmental Prediction-National Center for Atmospheric Research reanalyses 2 (NCEP2 reanalysis) over Southeast USA (area B) and the costal Atlantic (area C) in the map at the top panel, as a function of the day of the week. From Bell et al. [10].

face convergence, upward air motion and precipitation in the Southeast USA, with compensating effects over the adjacent ocean. Hence the weekly cycle of the pollution aerosols affects warm base subtropical clouds that prevail over the Southeast USA during summer (area B), but not the cool base clouds over the southwestern USA (area A), in agreement with the conceptual model in Fig. 1 and with model simulations [11].

The reported highlights here illustrate the processes that are included in the joint white paper. The examples in this communication underline the importance and the challenges that the ACPC program is aimed at. ■

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Toward the understanding of indirect aerosol effects and precipitation

Aerosol particles originating from both natural and anthropogenic sources have the potential to influence cloud microphysical properties through their action as cloud condensation nuclei (CCN) and ice nuclei (IN). Subsequent changes in droplet and ice crystal concentrations and sizes therefore impact radiative forcing and climate. These effects are called indirect aerosol effects [1].

Since precipitation development is related to droplet and ice crystal concentration and size, aerosol particles may also influence how efficiently clouds precipitate. While the cloud albedo effect [2] has received the most scientific attention, effects of aerosols on cloud lifetime and thermodynamics are discussed in this paper.

The cloud lifetime effect is based on the same initial hypothesis as the cloud albedo effect, i.e., that more CCN result in more droplets but the droplets are smaller. In addition to increasing cloud albedo, these smaller droplets may result in less precipitation and, potentially, longer cloud lifetimes [3].

Measurements from satellites have determined that aerosol optical depth is positively correlated with regional cloud cover (extent), and some [4, 5, others] have attributed this to longer cloud lifetimes associated with increased CCN number concentrations. Based on satellite data, the magnitude of this lifetime effect has been calculated to be potentially larger than the albedo effect [5].

Aerosol burdens and cloud cover, however, can increase together due to a number of physical processes. The processes listed below may all result in apparent or real increases in aerosol optical depth near clouds. These changes will be more pronounced as cloudiness increases, but are not necessarily caused by aerosols impacting cloud microphysical properties. In addition, satellite observations have poorly quantified errors in the partly cloudy environments often used in cloud-aerosol interaction studies. The processes together with errors in satellite retrievals probably affect the interpretation of cloud-aerosol interaction studies based on satellite observations [6].

Processes that may impact detection of the cloud lifetime effect:

1. Residual cloudiness (cloud contamination) of imagery pixels identified as cloud-free that lie within broken cloud systems.
2. Enhanced reflectivity of cloud-free columns due to the scattering of sunlight reflected by nearby clouds.
3. Hygroscopic growth of particles resulting from the elevated relative humidity of the near-cloud environment.
4. Enhanced particle size resulting from the chemical processing of solutes within clouds that subsequently dissipate.
5. New particle production in detraining regions of clouds.

In situ data of cloud penetrations can be used to help understand these processes. For example, Fig. 1 shows relative humidity and droplet concentration measured by the US National Science Foundation's C-130 aircraft during two different level flight legs through small cumulus clouds over the Indian Ocean. As the aircraft approached the first cloud cluster, relative humidity increased and remained elevated with values between 85% and 100% throughout most of the cloudy region. Fig. 1b depicts a second region where humidity was also elevated near clouds, but the level of enhancement is less and there is a large amount of natural variability in both regions.

Fig. 2 shows relative lidar backscatter data, corresponding to the time period given in Fig. 1b, from an aerosol lidar instrument aboard the aircraft. The lidar data show a substantial increase in backscatter near clouds. Compositing of *in situ* humidity data from over 100 different cloud passes revealed a mean increase in relative humidity of a few percent in the last kilometer prior to cloud entry. While these changes from the clear-sky humidity are not very large, the growth response of aerosols is non-linear and increases rapidly in this high humidity regime. Therefore, significant changes in aerosol optical thickness may occur in the near-cloud region, even without invoking enhanced number concentrations of aerosols.

Aerosol effects on mixed-phase clouds, which yield the majority of global precipitation, are even less well understood than aerosol effects on warm clouds. Additional complexity is introduced when precipitation is formed by ice-phase processes. Increased numbers of aerosols acting as CCN and IN may reduce droplet and ice crystal size, an effect that is expected to reduce precipitation. On the other hand, higher concentrations of small droplets (and, therefore, less removal of water through warm rain processes) in polluted clouds can result in increased latent heat release as droplets freeze at higher altitudes in clouds. This process can actually invigorate clouds and produce enhanced precipitation through ice phase processes. Evaporation of additional rain in the sub-cloud layer can produce cold dense air and convergence that can stimulate neighboring cloud development.

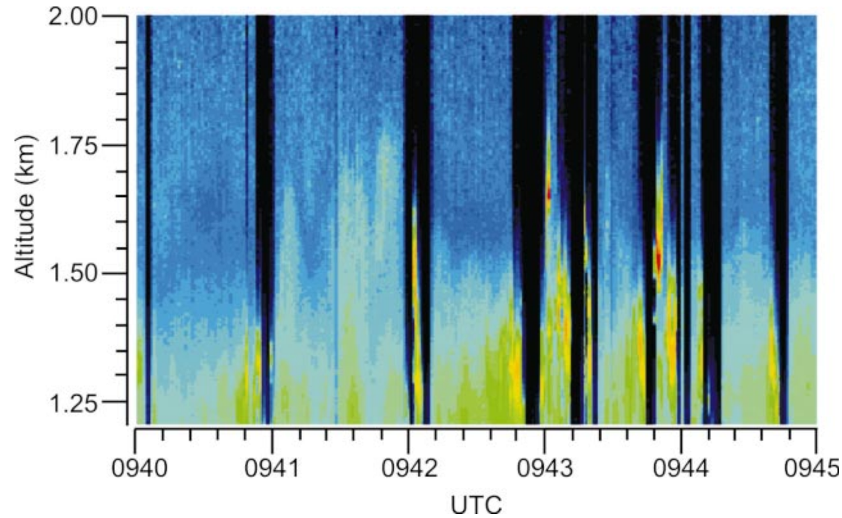

Figure 2. Scanning aerosol backscatter lidar (SABL) range-corrected backscatter when the C-130 aircraft was flying in the cloud layer with SABL pointed upwards for the time period shown in Fig. 1b. Low values are shown in blue, and highest values are orange and red. The black regions showing no returns indicate cloud penetrations by the C-130. Altitude in km is on the vertical axis.

Modeling studies suggest that the sign and magnitude of these thermodynamic effects on convective clouds are dependent on environmental variables like humidity, wind shear, and static stability [7]. Additionally, CCN, giant CCN, and IN may have competing effects on cloud lifetime and precipitation development. Thus, aerosol physicochemical properties such as size, shape, and hygroscopicity that influence their propensity to act as different nuclei types need to be quantified. These examples show that understanding of aerosol effects on precipitation and climate is a challenge that requires not only global, long-term observations, but also focused field experiments and comprehensive modeling studies. ■

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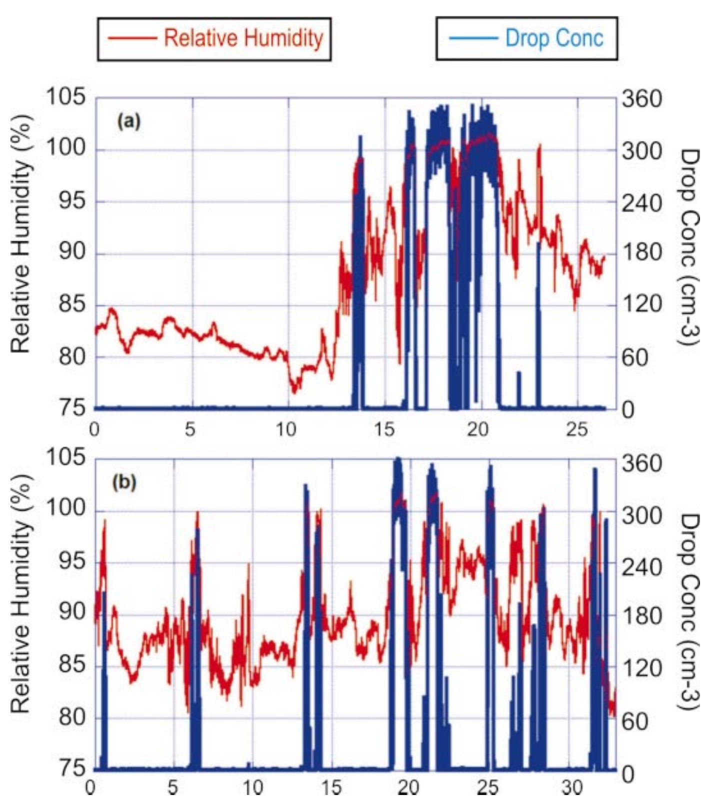

Figure 1. Relative humidity calculated from the Lyman-alpha absorption hygrometer (red) and droplet concentration from the forward scattering spectrometer probe (FSSP–100) (blue) aboard the C-130 aircraft for two different time periods in broken cumulus clouds over the Indian Ocean.

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Spatial and temporal variability of aerosol physical and chemical properties and effects on cloud microphysics and precipitation

Over the past few years, many atmospheric observational and modelling studies have shown that changes in precipitation in different parts of the world are linked to aerosol properties [e.g. 1, 2, 3, 4]. Several factors control the physical and chemical properties of aerosols: sources (primary emissions and secondary formation, natural and anthropogenic sources), transport, removal (dry and wet deposition, sedimentation), transformation (heterogeneous and aqueous chemical reactions, gas and water condensation), for example.

Consequently, aerosol properties are highly variable, both in space and time, as shown in Fig. 1, which illustrates the size-segregated mass and chemical composition of aerosols in different areas of the world, characterised by different sources and levels of pollution.

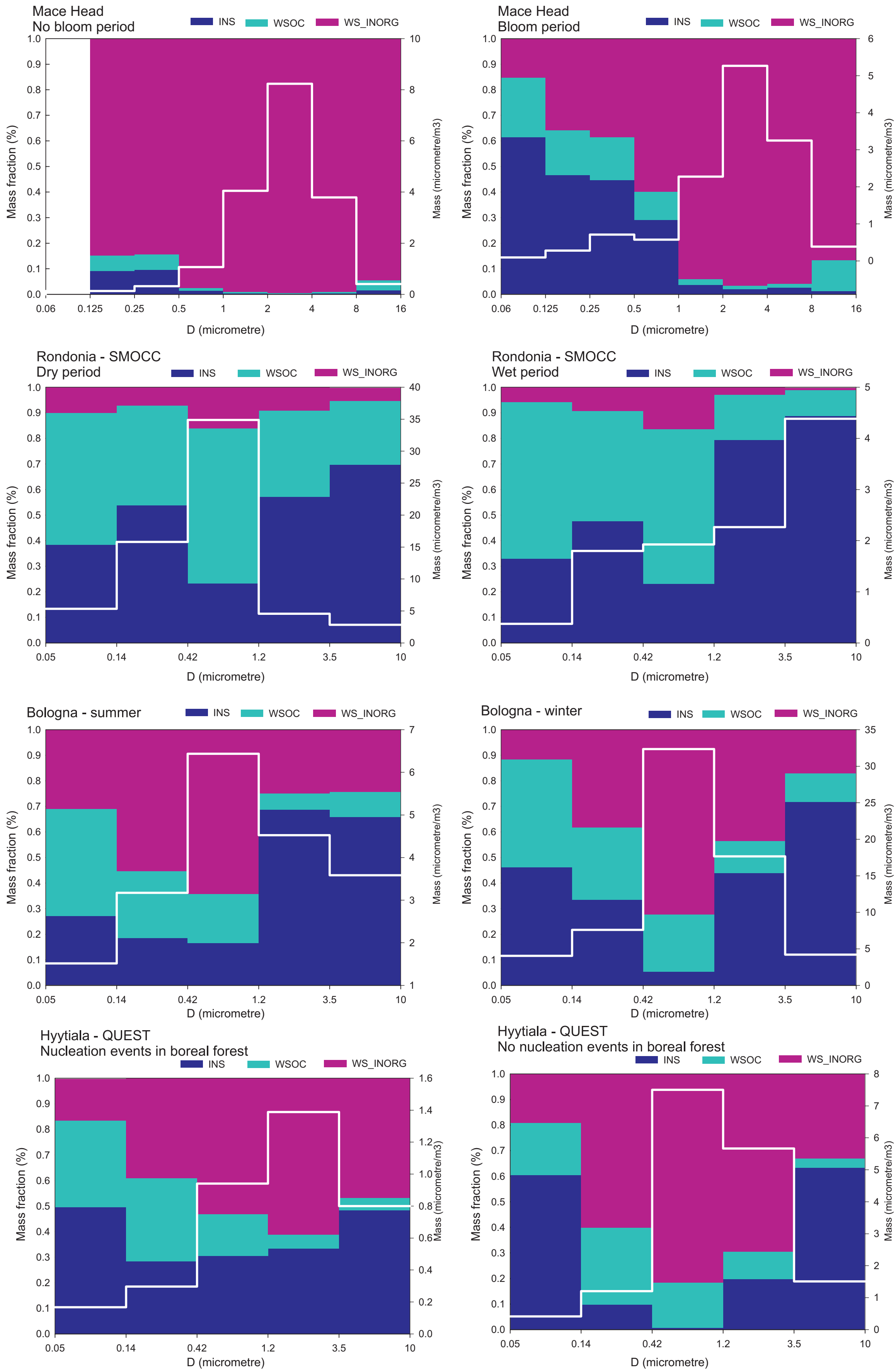
Three main components of chemical composition of the aerosols are shown in the figure; water-soluble inorganic species (WS_INORG), water-soluble organic carbon (WSOC) and insoluble material (INS). In the submicron fraction, most of the insoluble material is also organic. This description is certainly oversimplified, in particular for the organic component (soluble and insoluble), which contains hundreds (or even thousands) of species, but, nevertheless, clearly shows the large contribution of organic species to aerosol composition. In particular, knowledge about the chemical composition and properties of the organic portion is still inadequate.

The observations from the measurement sites show that the characteristics of the aerosol properties also vary as a function of time. For example the aerosol loading in Po Valley, Italy, is lower in summer than in winter (Figs. 1e, f) with higher WSOC in the fine fraction during winter due to enhanced contribution of combustion sources [5].

On the other hand, in the Amazon the aerosols originating from biomass burning (Figs. 1c, d) have similar relative composition during dry and wet periods, but the total aerosol loading differs by one order of magnitude between periods [6]. In the case of marine aerosol (Figs. 2a, b), the fine fraction is dominated by organic insoluble species only during the periods of high biological activity (spring and summer), while the sea salt component is dominant during the rest of the year [7, 8].

Figure 1. Mass size distribution (right axis) and size-segregated chemical composition (left axis) of aerosols at different locations and in different time periods. Mace Head, Ireland – marine aerosol during periods of: a) low biological activity and b) high biological activity; Rondonia, Brazil – biomass burning aerosol during c) dry season and d) wet season; Po Valley, Italy – continental urban aerosol during e) summer and f) winter; Hyytiälä, Finland – boreal forest aerosol during periods of: g) no new fine particle formation (nucleation), and h) nucleation. WS_INORG = water-soluble inorganic compounds; WSOC = water-soluble organic compounds; INS = insoluble fraction. ➤

Such highly variable aerosol populations undergo complex interactions with clouds, as schematically shown in Fig. 2. The aerosols have a direct influence on cloud microphysics, and thus on precipitation, through cloud condensation nuclei (CCN) and ice nuclei (IN) activation. Understanding how aerosol properties affect CCN activation is essential for improving the representation of cloud formation in models and, eventually, formation of precipitation [9].


Mace Head
No bloom period
INS
WSOC
WS_INORG
Mass fraction (%)
Mass (micrometre/m3)
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Mace Head
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INS
WSOC
WS_INORG
Mass fraction (%)
Mass (micrometre/m3)
D (micrometre)
Rondonia - SMOCC
Dry period
INS
WSOC
WS_INORG
Mass fraction (%)
Mass (micrometre/m3)
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Mass (micrometre/m3)
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Bologna - summer
INS
WSOC
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Mass fraction (%)
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Bologna - winter
INS
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Hyytiala - QUEST
Nucleation events in boreal forest
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WSOC
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D (micrometre)
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No nucleation events in boreal forest
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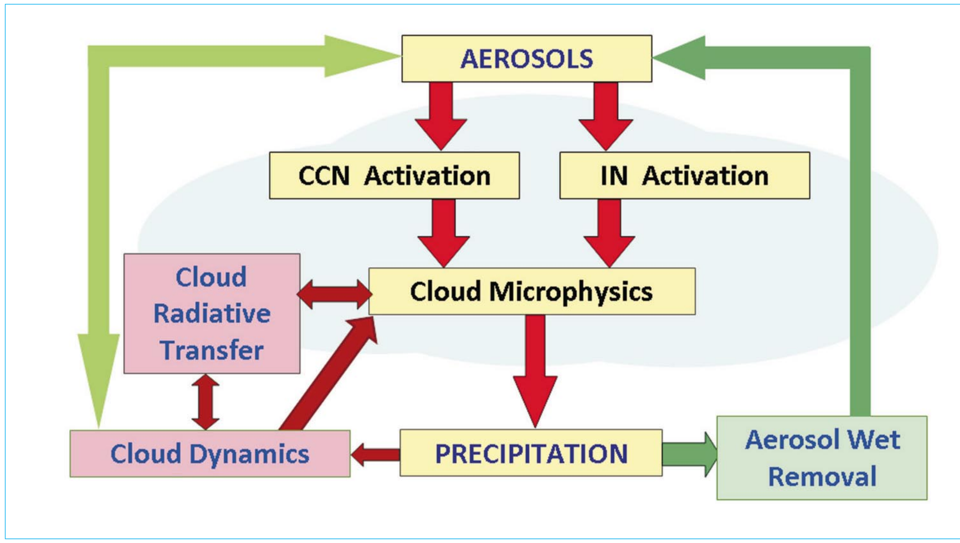

Figure 2. A schematic diagram of aerosol-cloud-precipitation interactions. CCN = cloud condensation nuclei and IN = ice nuclei. ➤

In addition to their direct effect as CCN, aerosols also affect clouds and precipitation indirectly by modifying cloud radiative properties and cloud dynamics (see the left side of the scheme in Fig. 2). Moreover, aerosol removal from the atmosphere by precipitation is a feedback mechanism which also needs to be taken into account.

Regarding the CCN activation and their impact on cloud microphysics, for example, the knowledge of the WSOC fraction of biomass burning aerosols is necessary to predict CCN activation in the models [10]. For marine aerosol, also the mixing state of the aerosol (the way in which the different chemical compounds are mixed within the particles) is important for predicting aerosol activation [7]. On the other hand, Medina et al. [11] have stressed the importance of knowing both the size-resolved chemical composition of the aerosol and their mixing state to reach CCN closure for continental urban aerosol. In any case, the relative importance of aerosol size distribution versus chemical composition in determining CCN concentrations has not yet been solved unequivocally [see e.g. 12, 13]. Even less is known about the effect of aerosol properties on ice nuclei activation.

In conclusion, linking aerosol and precipitation, and disentangling changes in precipitation due to dynamical effects from changes resulting from altering aerosol properties is a continuing task which requires a strong coordinated effort such as the Aerosols, Clouds, Precipitation and Climate (ACPC) initiative, which involves field measurements, long-term monitoring, satellite measurements and modelling studies at a variety of scales. ■

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Science
from the iLEAPS recognized projects

Ülo Niinemets is Professor of Plant Physiology at Estonian University of Life Sciences (Chair of the Estonian Academy of Sciences). He is a steering committee member of several international programmes, including the European Science Foundation - VOCBAS (Volatile Organic Compounds in Biosphere Atmosphere System) and NinE (Nitrogen in Europe). He has conducted experimental work on plant stress physiology from Northern to Mediterranean Europe, in Australia, New Zealand, continental US and Hawaii, and currently collaborates in several worldwide plant science networks. His present research focuses on physiological and physico-chemical controls on plant VOC emissions.

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Getting hold of terpene emissions from vegetation

Plants form a huge range of volatile organic compounds (VOC) called terpenes - hydrocarbons consisting of isoprene (five carbon atoms, C5) building blocks. Volatile terpenes – monoterpenes (two isoprene units, C10) and sesquiterpenes (three units, C15) are emitted in large quantities by vegetation and play a paramount role in atmospheric reactivity and secondary aerosol formation. Therefore, reliable prediction of terpene emissions with high temporal (0.5-1 h) and spatial (0.5-1 km^2) resolution is a key issue in predicting atmospheric constitution on a regional scale.

Simple robust approaches have been proposed to simulate terpene emissions from vegetation. In plant species with large storage pools of terpenes such as found in conifers, where terpenes are stored in specialized organs, resin ducts, emissions have been predicted on the basis of temperature only, while in plant species lacking specialized storage, terpene emissions have been simulated in dependence of light and temperature using the “isoprene algorithm” (standard Guenther et al. [1] models).

VOCBAS is a European Science Foundation (ESF) Scientific Programme (2004–2009). It supports interactive multi- and cross-disciplinary research addressing the fundamental study of VOC synthesis while supplying information useful for ecological and physiological studies, emission modelling, and understanding of VOC impact on tropospheric chemistry in a changing environment. Particularly, VOCBAS contributes to training programmes aimed at creating young researchers able to integrate expertise currently available in the different disciplines.

Typically, emission models are parameterized based on leaf cuvette measurements and scaled up to the canopy level. This approach requires information of emission potentials for each emitting species and detailed estimates of species coverage. Alternatively, the emission potential of vegetation can be estimated using flux measurements at ecosystem scale and inverting the canopy model.

However, recent work has shown several major quantitative and qualitative uncertainties related to plant terpene emissions, questioning the overall reliability of conventional modelling approaches. There is a large body of recent evidence demonstrating that a major part of terpenes is emitted in a light-dependent manner in plant species with specialized storage pools as well, such that the use of only temperature in predicting terpene emissions from vegetation leads to biased estimates of daily emission dynamics [2].

On the other hand, non-oxygenated monoterpenes are highly soluble in leaf lipid phase and there is always a certain non-specific storage capacity of terpenes within the leaves, even in species not possessing any specialized storage structures for monoterpenes, such as the Mediterranean oak *Quercus ilex*. While the rates of terpene synthesis respond quickly to modifications in light and temperature, non-specific storage dampens the response kinetics and also results in different daily emission dynamics (Fig. 1).

Although the rate of monoterpene synthesis is essentially zero in the absence of light in these species, a conspicuous outcome of non-specific storage is the significant nocturnal monoterpene emission from species without specialized storage structures. Nighttime emission fluxes cannot be predicted by conventional models and can hardly be measured by flux towers due to difficult nighttime meteorological conditions (for example Fisher et al. [3] for problems in assessing nighttime fluxes). Yet, nocturnal emissions can play a significant role in determining the overall hydroxyl radical ($OH^{\cdot}$) concentration and atmospheric reactivity during morning hours.

An important consequence of the high lipid solubility of terpenes is the considerable terpene uptake and deposition on foliage surface by non-emitting species growing intermixed with emitting species (Fig. 2) [4]. Monoterpenes taken up when ambient air concentrations are relatively high can later be released from the leaves to ambient air when the air concentrations of monoterpenes decrease. Such uptake and release of terpenes dampens the response of emissions to environmental modifications. Terpene emissions from a mixed plant canopy consisting of emitting and "non-emitting" plants are expected to respond more slowly to environmental changes than can be predicted on the basis of cuvette measurements of emitting plant species.

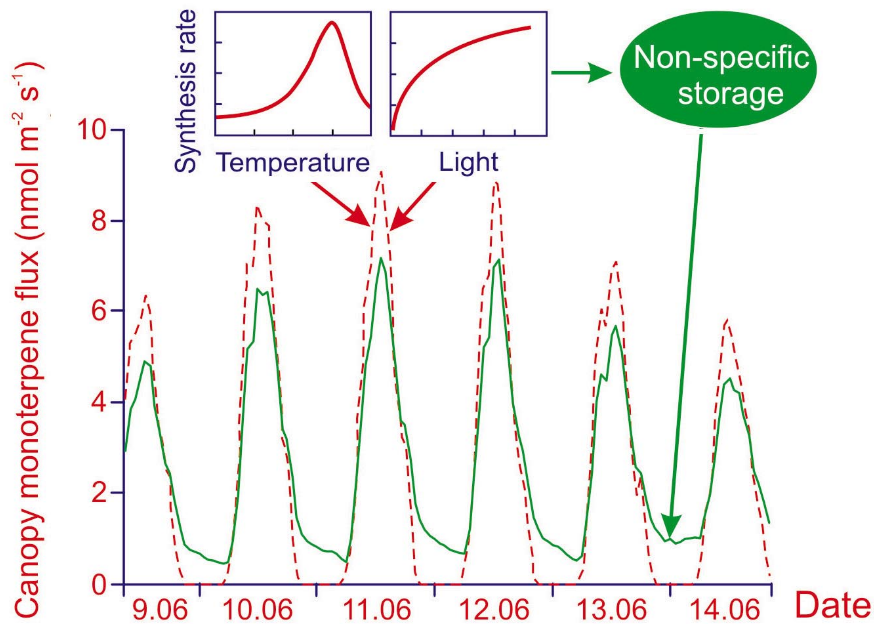

Figure 1. Canopy monoterpene emissions from a Mediterranean broad-leaved evergreen forest dominated by evergreen oak *Quercus ilex* (Castelporziano, Italy) during six days in June simulated using the standard Guenther et al. [1] model (dashed line) and a model considering the non-specific storage of monoterpenes in leaf liquid and lipid pools (solid line) (modified from Niinemets and Reichstein [9]). According to the standard model, the emission rate responds instantly to changes in light and temperature. However, non-specific storage of monoterpenes within the leaves introduces time-lags in emission responses to environmental modifications. One important outcome of the non-specific storage is also a significant nocturnal emission of monoterpenes.

The non-specific storage, particularly relevant for highly lipid-soluble monoterpenes, can also be important in interpreting methane fluxes from vegetation in aerobic conditions. As ambient air methane concentrations are very high compared to other VOC, on the order of 2 ppm, part of the methane released by plants into methane-free air and in response to temperature fluctuations can be due to the non-specific storage of methane in equilibrium with ambient air [5].

The second uncertainty in predicting terpene emissions is that the emission potential of many important plant species is not known, and stress- and time-dependent modifications of emission potentials are poorly understood. Uptake and release of monoterpenes from plant species not constitutively producing terpenes can partly explain the contrasting observations of terpene emission potentials for some species (e.g., the extensive VOC emission database at *http://bai.acd.ucar.edu/Data/BVOC/index.shtml*).

Furthermore, practically every plant species can be triggered to emit terpenes in response to biotic stress such as herbivory or pathogen attack or in response to some abiotic stress factor such as elevated ozone concentrations [e.g., 6]. Such induction of monoterpene emissions is currently not considered when predicting terpene emissions from vegetation, but can potentially significantly alter the ecosystem fluxes.

Finally, high reactivity of some of the plant monoterpenes and most sesquiterpenes, with atmospheric lifetimes on the order of minutes, imposes significant difficulties in determining whole canopy terpene emission fluxes using micrometeorological techniques. The shorter observed lifetime of OH-radicals than expected on the basis of measured VOC emission fluxes has been used to calculate the "missing atmospheric reactivity" above forested areas [7]. "Missing reactivity" estimated this way scales with air

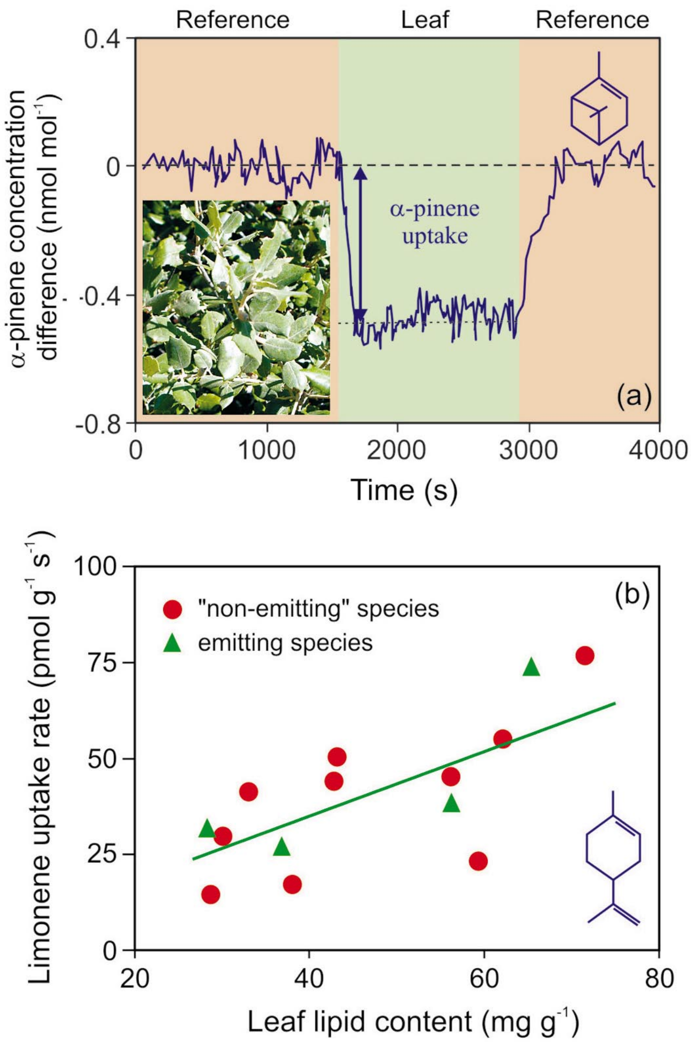

Figure 2. Illustration of the uptake of monoterpene α-pinene by leaves of evergreen oak *Quercus ilex*: a) data modified from Copolovici et al. [10] and dependence of monoterpene limonene uptake rate on foliage lipid content; b) data modified from [4]. Non-oxygenated monoterpenes are highly soluble in leaf lipid phase and are taken up from ambient air in both species constitutively emitting monoterpenes and in non-constitutive emitters. In a), endogenous monoterpene production was inhibited by fosmidomycin, a potent inhibitor of plastidic isoprenoid synthesis pathway.

temperature according to a simple exponential relationship similar to the temperature response of terpene emissions from specific leaf storage structures. On the basis of this similarity, missing reactivity has been interpreted to result from biogenic processes, most likely from emissions of highly reactive terpenes.

Atmospheric chemistry models have been further inverted to predict the emission rate of reactive terpenes [8]. However, we currently lack information on reaction rate constants for a multitude of terpene reactions, and also on how these reaction constants vary with air humidity and temperature, complicating the overall assessment of the contribution of reactive terpenes. Typically, the chemical reaction rate also increase exponentially with temperature. Hence, the observation that the "missing reactivity" depends exponentially on temperature not necessarily implies that biological processes are involved.

In conclusion, reliable prediction of terpene emissions constitutes a challenge for experimentalists and modellers. More information on terpene synthesis induction mechanisms, physico-chemical characteristics of terpenes and terpene reaction rate constants in the atmosphere is clearly needed to improve the emission and atmospheric chemistry models. ■

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RESEARCH CONFERENCES

ESF-FMSH Entre-Sciences Conference on
Interdisciplinary Environmental Sciences

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IGeSA, Porquerolles • France
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With support from

This interdisciplinary conference will present the new advances in the modelling of the Global Change that combines Geosciences and Economics, with a perspective view from history - given the novelty of their interrelations – and from political science – given the impact of the model outputs in the public sphere. The conference will gather together speakers and attendees from Europe and North America in Porquerolles, one of the most beautiful islands of the French Riviera. About 150 participants are expected to attend. Its originality and attractiveness will lie in the mixing of scientists concerned with the same topics but coming from disciplines far apart (from Physical and Natural Sciences to Social and Human Sciences). Speakers will use clear and understandable language while maintaining a high scientific level. This conference, lasting 5-days will facilitate contacts and stimulate intellectual exchanges, especially among the young researchers, and future collaborations.

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Wolfgang Cramer, ecologist, Potsdam Institute (PIK), DE
Michel Déqué, climatologist, Meteo-France, FR
Romain Duval, economist, OECD, FR
Ottmar Edenhoffer, economist, Potsdam Institute (PIK), DE
Hughes Goosse, climatologist , Univ. Catholique de Louvain, BE
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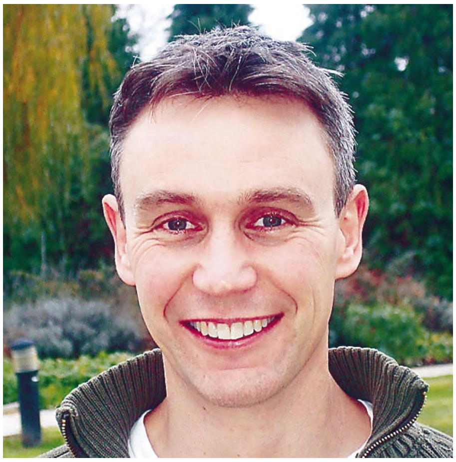

Chris Taylor is a research scientist at the NERC (Natural Environment Research Council) Centre for Ecology and Hydrology in Wallingford, UK. He obtained his PhD at Reading University in 1996 on mesoscale modelling of the Hydrology-Atmosphere Pilot Experiment in the Sahel 1990-1992 (HAPEX-Sahel). His scientific interests lay in land surface-atmosphere interaction using a combination of models and observations, with a particular geographical focus on the Sahel in Africa. He has been involved in the African Monsoon Multidisciplinary Analyses (AMMA) project since its early days.

AMMA is based on a French initiative and is a major international project funded by a large number of agencies particularly from France, UK, US and Africa, and by the European Union.

Christopher M. Taylor

Centre for Ecology and Hydrology, Wallingford, United Kingdom

Observing soil moisture – rainfall feedbacks

It is well-known that land surface features can affect local weather, as an example the preferential development of clouds over hills and along coast lines associated with sea breezes. These are well-observed and well-understood phenomena apparent often to the naked eye. In recent decades, meteorologists have become increasingly interested in how other, more subtle land surface features influence the development of clouds and storms.

Land surface – atmosphere fluxes of heat, water and momentum differ, for example, between forest and agricultural land. We might expect that approximately the lowest kilometre of the atmosphere, the Planetary Boundary Layer (PBL), will respond to these differences in fluxes, provided the surface features are large enough that the horizontal wind does not completely mix out the effect of the spatial variability in fluxes.

Mesoscale modelling studies show that around forests of several tens of kilometres, weak sea-breeze type effects can occur [1].

There is surprisingly little observational evidence of the many idealised modelling studies, perhaps reflecting the scarcity of strong mesoscale contrasts in land surface properties. In one example, Negri et al. [2] identified an enhancement of moist convection during the afternoon over deforested areas in Amazonia compared to the surrounding forest, though this effect was only detectable during the dry season, when the atmosphere is relatively quiescent.

The impact of soil moisture on precipitation is of considerable interest to the weather and climate modelling community. Soil moisture is a dynamic component of the land-atmosphere system, and any feedbacks between soil water and precipitation could either amplify or suppress climatic anomalies such as drought, depending on the sign of the feedback.

Soil moisture, and its control on surface fluxes, is not well simulated by atmospheric models, and there is a large potential range

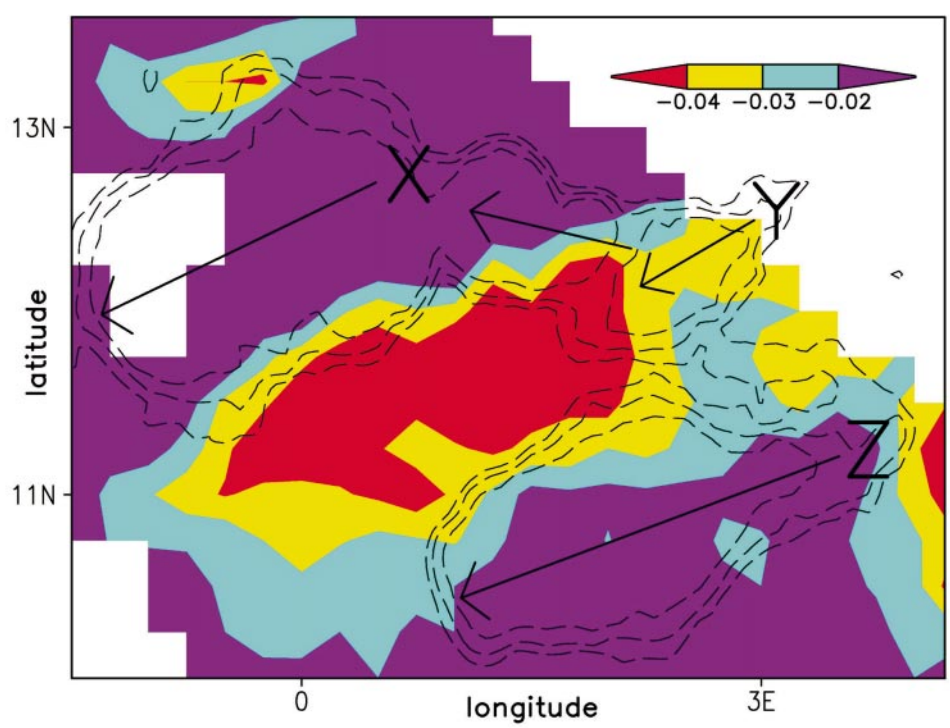

Figure 1. ➤ An example of convective cloud development (dashed lines) in a flat region of Burkina Faso, where previous storms have produced a landscape characterised by patches of high soil moisture (red shading). The patches are identified from anomalies in microwave polarisation ratio. Three storms develop (at X, Y and Z) and propagate in the direction of the arrows.

of feedback strengths produced by different models [3]. Due to the scarcity of appropriate observations at length scales where feedbacks operate, we cannot be certain which feedback processes dominate in the real world, or even their sign. Observational studies which capture key aspects of soil moisture – precipitation feedbacks therefore provide an important piece of the jigsaw in understanding the role of the land surface in current and future climate.

Precisely because soil moisture is very dynamic, knowledge of its spatial pattern is more limited than that of vegetation. Soil moisture is extremely heterogeneous, depending on spatial variations in soil and vegetation properties as well as climate, notably rainfall. Current satellites offer some possibilities to detect soil moisture by microwave, thermal and other sensors. In a recent study, we used passive microwave data to examine how mesoscale moisture patterns in the top centimetre of the soil affect the development of deep convection in the Sahel [4].

The Sahel, located at the southern border of the Sahara, is an ideal place for such studies as during the wet season, intense travelling convective storms are frequent, producing swaths of wet soil beneath their paths, often hundreds of kilometres in length on an otherwise dry surface. With only sparse vegetation, the fluxes are rather sensitive to the availability of near surface moisture for evaporation directly from the exposed soil. For a day or two after rainfall, passive microwave data shows where the evaporation rates are high and sensible heating is low.

From analysis of thermal imagery of deep (and cold) convective clouds, a strong impact of soil moisture on the development of storms during the afternoon and early evening was identified. It appears that storms tend to initiate and propagate preferentially over dry soil, at least during the initial stages of their life cycle. An example of such behaviour is shown in Fig 1. This implies a negative feedback locally, i.e. rain develops over dry soils, and contrasts with previous results showing enhanced rainfall over wet soils for mature storms [5].

The Special Observing Period of the African Monsoon Multidisciplinary Analyses (AMMA) in 2006 provided a unique opportunity to investigate the atmospheric response to soil moisture patterns. The research aircraft of the UK National Centre for Atmospheric Science targeted wet and dry features identified from near real time surface temperature data from the Meteosat satellite [6].

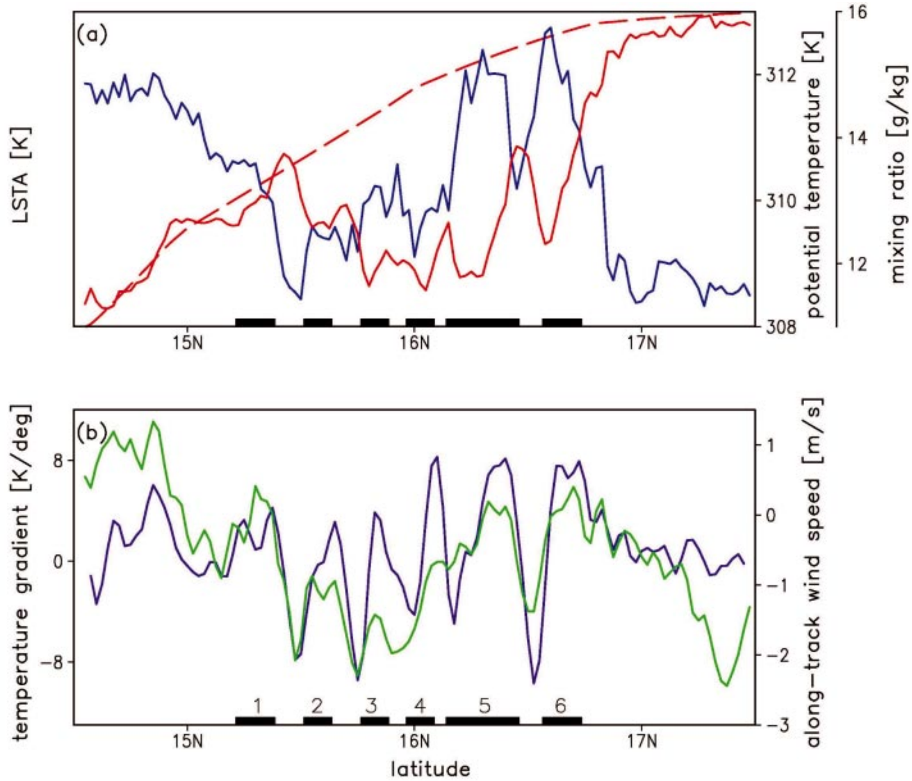

Figure 2. Measurements from an aircraft flying north-west at 170 m above a sequence of 6 wet patches identified from satellite imagery [6]. (a) The observed Planetary Boundary Layer (PBL) temperature (red solid line) increases towards the Sahara in the north, consistent with the large scale temperature gradient (red dashed line). Over the wet soils, however, air temperatures fall sharply, accompanied by an increase in humidity mixing ratio (blue). This is due to the strongly contrasting land surface fluxes. (b) The surface-induced gradients in air temperature (green) are strong enough to induce changes in the speed and direction of the wind (purple).

The aircraft data showed a strong response of PBL temperature and humidity to soil moisture (Fig. 2), even when flying over wet patches of less than 10 kilometres in width. The study showed that typical mesoscale soil moisture features produced daily by storms in the Sahel produce contrasts in sensible heating strong enough to induce sea-breeze type circulations. The convergence over the dry soil produces ascent, and this trigger for convection is thought to play an important role in the negative feedback detected from satellite data.

How soil moisture influences rainfall at other time and space scales in this sensitive and drought-prone region remains at the top of the agenda in the AMMA research programme. Understanding of the strength, and even the sign, of soil moisture – rainfall feedbacks, is crucial for improving weather and climate predictions for this, and also for other soil moisture "hotspots". ■

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Activities

National Activities

iLEAPS–Japan

The country of Japan is an archipelago consisting of some 6,000 islands that stretch from latitude 45ºN to 25ºN along the Pacific coast of Asia. Because the country is located at the northeastern edge of the Asian monsoon climate belt the humidity is fairly high with average rainfall ranging, depending on area, from 1,000 to over 2,500 mm.

The weather is under the dual influence of the Siberian weather system and the patterns of the southern Pacific, resulting in four distinct seasons in a year. However, due to its wide range of latitude, Japan has a variety of climates. The average annual temperature ranges from 17℃ in the southern parts to 9℃ in the extreme north.

66% of the land is covered by forests and is characterized by numerous mountains which form a complex topography along with small basins and plains around short and turbulent rivers.

The population, over 127 million, is heavily concentrated in the plains, especially in the large cities along the Pacific coastline. Heavy urbanization with the development of economy in the country over the last century has significantly influenced biogeochemistry and hydrology of land ecosystems as well as atmosphere processes.

The interactions over the country are closely linked with adjacent regions, where human activities associated with rapid economic development may be having a detectable impact on the monsoon ecosystems.

National science

A series of seminars has been organized to inform Japanese scientists about the iLEAPS program and to encourage them to join. The activities within the iLEAPS network in Japan are currently being planned. However, many of the participants in the network are focusing on and contributing to ongoing iLEAPS-related activities of other IGBP core projects, WCRP projects or regional projects. iLEAPS–Japan will promote these activities together with the collaborative partners, such as IGAC, GLP, GEWEX etc. Some specific objectives of the iLEAPS activities in Japan are:

- study of exchange of carbon dioxide, water vapor, and energy between terrestrial ecosystems and the atmosphere across daily to inter-annual time scales (AsiaFlux)
- monitoring and modeling of trace gas (CH_4, N_2O, NO_x, NH_3, others) emissions from agriculture and forest ecosystems
- study of the contribution of pollutant emissions from megacities to local and regional (including Asian Pacific) air quality and to the radiation budget (in collaboration with IGAC Mega-Cities: Asia)
- research on effects of changing atmospheric environment, such as elevated CO_2 and ozone concentrations on soil-plant systems
- establishment of a hydro-meteorological prediction system, particularly up to seasonal time-scale, to increase scientific understanding of Asian monsoon variability interactions between climate and vegetation (in collaboration with GEWEX-MAHASRI).

iLEAPS–Japan organization

Similar to other IGBP core projects and WCRP projects, iLEAPS–Japan sub-committee will be established under the joint IGBP/WCRP committee of the Science Council of Japan. Dr. Kazuyuki Yagi was appointed the chair of the iLEAPS–Japan sub-committee.

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Funding agencies

- Ministry of Education, Culture, Sports, Science and Technology
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Research institutes

- National Institute for Agro-Environmental Sciences (NIAES)
- Forestry and Forest Products Research Institute (FFPRI)
- National Institute for Environmental Studies (NIES)
- National Institute of Advanced Industrial Science and Technology (AIST)
- Meteorological Research Institute
- Tohoku University
- The University of Tokyo
- Tokyo Institute of Technology
- Nagoya University
- Tottori University

and other institutes and universities

Meetings

iLEAPS-IGAC-GEWEX Expert Workshop on Aerosols, Clouds, Precipitation, Climate (ACPC) Interactions, NCAR, Boulder, Colorado, USA, 8–10 October 2007

The specialist workshop with 57 participants was held in order to develop the ACPC research agenda. The meeting was hosted by Guy Brasseur, Director of Earth and Sun Systems Laboratory, and National Center for Atmospheric Research (NCAR), and sponsored also by ACCENT (European Network of Excellence on Atmospheric Composition Change).

The workshop was organized by iLEAPS, IGAC (International Global Atmospheric Chemistry) and GEWEX (Global Energy and Water Cycle Experiment), core projects of IGBP and WCRP.

The workshop report by Bjorn Stevens, the ACPC Planning Group and the workshop participants is presented in this Newsletter. Workshop presentations, info on ACPC mailing list and more at

iLEAPS website: http://www.ileaps.org

ACPC webpages: http://www.ileaps.org/acpc/

iLEAPS-ACCENT-QUEST Expert Workshop "On the relevance of surface and boundary layer processes for the exchanges of reactive and greenhouse gases", Wageningen, Netherlands, 9–12 October 2007

The workshop aimed at reviewing our current knowledge of physical and chemical processes and their impact on the larger spatial and temporal scale distribution of atmospheric compounds.

Particular emphasis was on promoting the interaction between the atmospheric physics and chemistry communities, and also on whether the new observation and modelling techniques are suited to address the key questions in surface and boundary layer processes.

The expert workshop attended by 40 participants was organized by Laurens Ganzeveld (Department of Earth System Sciences, Wageningen University and Research Centre, WUR, Netherlands), Jordi Vilà (Meteorology and Air Quality Section, WUR), and Cor Jacobs (Alterra, WUR).

Workshop presentations are available at iLEAPS website: http://www.ileaps.org

Marie Curie-iLEAPS Workshop – Models: Towards a process-based description of trace gas emissions in land surface models, Helsingborg, Sweden, 16–19 October 2007

The second event in the series of four Marie Curie-iLEAPS events was organized by Almut Arneth (Department of Physical Geography and Ecosystems Analysis, Lund University, Sweden) in Helsingborg, Sweden and co-sponsored by VOCBAS.

With 70 participants, the workshop brought together modellers and experimentalists who study the surface - atmosphere exchange of a range of compounds (e.g., biogenic volatile organic compounds, carbon dioxide, methane, nitrogen oxides).

The meeting provided a forum to discuss the processes underlying their emissions and how well (if at all) these are represented in terrestrial surface models, particularly in dynamic global vegetation models.

The next iLEAPS Newsletter will include scientific articles from the workshop.

Palaeofires workshop, Totnes, UK, 22–26 October 2007

The palaeofire workshop co-sponsored by University of Edinburgh, QUEST, University of Oregon, PAGES, iLEAPS and University of Bristol brought together 14 international experts on palaeofire science with different perspectives and investigative techniques for reconstructing late Quaternary fire histories.

The first phase of the Global Palaeofire Working Group (GPWG), following the Dartington I workshop in October 2006, resulted in a reconstruction of global fire regimes since the Last Glacial Maximum.

The rapid growth of the Global Charcoal Database (GCD) and the growing interests by the international palaeofire community, including a palaeo-component of the new International Geosphere Biosphere Program (IGBP) cross-project FIRE activity (endorsed by the IGBP Scientific Steering Committee in March 2007 and hosted by iLEAPS) necessitated bringing together members of the GPWG to identify the state-of-the-art science in palaeofire research and to initiate the operational plan that utilizes the GCD as a research tool.

The next iLEAPS Newsletter will include a report on the palaeofires workshop.

ACPC ISSI Team meeting, Bern, Switzerland, 28–30 January 2008

The Aerosols, Clouds, Precipitation, Climate (ACPC) initiative Planning Group is also an ISSI Team, proposal approved by the International Space Science Institute (ISSI, http://www.issibern.ch/) in 2007.

In January 2008 at the ISSI Team meeting, first out of three meetings, the Team finalized the Boulder ACPC Expert Workshop report and started working on a scientific article.

The second ISSI Team meeting will be held 7-9 October 2008 for writing the ACPC Science and Implementation Plan. Bjorn Stevens will join the Team in the second meeting.

The Team members from iLEAPS are Andi Andreae, Markku Kulmala, Danny Rosenfeld; from IGAC Sandro Fuzzi, Colin O'Dowd, Graciela Raga; from GEWEX Tom Ackerman, Bill Lau, Ulrike Lohmann, Pier Siebesma.

iLEAPS

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iLEAPS RECOGNIZED PROJECTS