# Regional Aerosol-Chemistry-Climate Observatories for the Indo-Asia-Pacific Region

***Proposal Submitted to NOAA***

***March 11, 2003***

*Via the Joint Institute for Marine Observations*
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**PROJECT SUMMARY**

The Atmospheric Brown Cloud (ABC) Project is an international research effort initiated by the United Nations Environment Program (UNEP). Its first region of focus is Asia and the Pacific (EAP-AP). The ABC science team consists of scientists from China, Europe, India, Japan, Korea and the USA (see the ABC concept paper by *Ramanathan and Crutzen*, 2001; available at http://www-asianbrowncloud.ucsd.edu/ABCconceptfinal23May01.pdf). The ABC secretariat for science is located at the Center for Clouds, Chemistry and Climate (C4) at the Scripps Institution of Oceanography at the University of California, San Diego (UCSD). The ABC secretariat for policy is located at the UNEP EAP-AP headquarters at Bangkok. The project addresses the major environmental challenges facing the Indo-Asia-Pacific region in the coming decades; i.e., the climate and other environmental consequences of rising levels of greenhouse gases, aerosols and other related air pollutants. The two main components are observations and regional impacts modeling. The present proposal to NOAA is to set up regional aerosol-chemistry-climate observatories. The major goal of these observatories is to estimate the aerosol radiative forcing and to relate the forcing to anthropogenic emissions from the region. The specific objectives of the observatories are consistent with those of the National Aerosol Climate Interaction Program (NACIP) (*Ramanathan et al*., 2002; available at http://www-NACIP.ucsd.edu). We require 10 new observatories in the Indo-Asia-Pacific region, half of which will be funded by NOAA and the other half by the governments of China, India, Japan, and Korea and Sweden. When these are combined with 3 existing observatories in the region, we will have adequate coverage to meet the goals and objectives of the ABC project. The PIs and the management team have demonstrated experience in conducting field research with international funding for INDOEX which was led by C4 with major funding from NSF, NOAA, DOE, NASA and European and Indian funding agencies. It is our goal and expectation that these observatories will become an integral part of other global and regional observing systems such as WMO-GAW, UNEP-EANET, APEX (Japanese Network), NOAA's, NASA's and DOE's regional networks amongst others. One of the major outcomes of this study is a reliable and observationally based estimate of the aerosol radiative forcing for the Asian region which will be used for IPCC studies and as model input for GCM simulations of climate change. Regional capacity building, training of young scientists and students, impact analysis and integration with

health impact studies, agriculture impact studies and policy makers will be the hallmarks of this program.

It should be noted that the Brown cloud is a worldwide phenomenon. While ABC's first emphasis in on Asia, we envision the program articulated by the ABC science team will become a template for other regions of the world including Africa, America and Europe.

The major scientific objectives of the observatories are:

- To establish continuous chemical and microphysical aerosol observations at key locations in the Indo-Asian-Pacific region with a particular emphasis on black carbon, organics and cloud condensation nuclei. A major thrust of these observatories will be characterization of the sources of these aerosols based on the analysis of aerosol filters for molecular markers and single particle analysis. The identified sources from the molecular markers will include bio-fuels and other forms of biomass burning; coal combustion; diesel and two-stroke engines. The source characterization will be used by UNEP and the regional governments to develop future strategies to mitigate the impact of Asian air pollution on climate, human health, and the environment.
- To use regional scale source-receptor models in conjunction with the data from observatories and validated satellites to identify the relative contribution of the various Asian regions to the observed aerosol loading.
- To determine direct short-wave and long-wave aerosol radiative forcing at the surface and top of the atmosphere based on aerosol data in conjunction with comprehensive in situ and remote radiometric measurements.
- To relate the aerosol forcing to regional sources of aerosol emissions.

The proposed new observatories will be located in: S. Asia (Maldives; the Andamaan Island in India; and Nepal); SE Asia (Sabah in Malaysia, with alternate site in the Mekong Delta); East Asia (Hefei and Hebei in China); the Western Pacific Rim (Amami-Oshima/Hateruma in Japan, Gosan/Inmyon Island in S. Korea); the Western Pacific (Minamitorishima); and the Central Pacific (Midway). ABC will also use existing observatories (funded outside of this proposal) in Momote in the Western Pacific (DOE-ARM site), Mauna Loa in Hawaii (by NOAA) and Trinidad Head in west coast of USA (AGAGE site operated by SIO and NOAA). Two of the sites (Maldives and Gosan) will serve as super observatories and

will become the main training and calibration facilities of the proposed ABC surface observation network. The funding requested under this NOAA proposal includes the manpower required for processing, management and distribution of the collected data. The proposed observations and the integration of ground based observations with satellites and models will be based on experience gathered during the Indian Ocean Experiment (INDOEX) and ACE-Asia.

It should be noted that, in addition to the aerosol-climate observatories described here, ABC would also be establishing aerosol - air pollution - health - agriculture related observations under separate funding. These observation sites to be located in urban and rural locations will be funded by governments in Asia. For example, Ministry of Science of Technology in China has funded ABC investigator (M. Fang) in China to set up air pollution observations in several sites with in China.

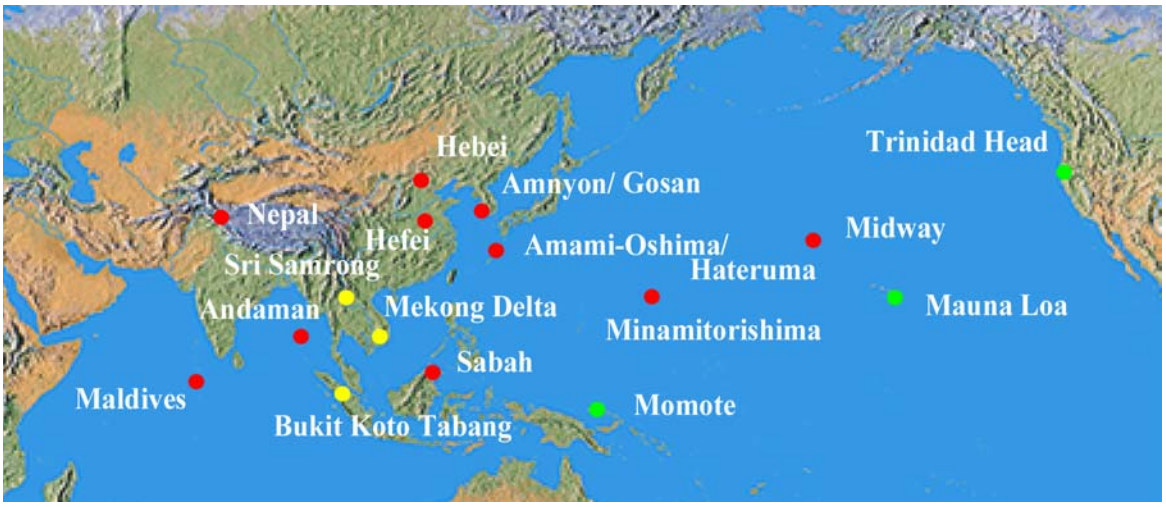



Figure 1a. Proposed locations for ABC observatories (red dots). Green dots indicate existing observatories to be used as is. The yellow dots indicate locations under consideration.

Figure 1b: A Proof of concept for ABC observatory. This figure shows a Super Observatory built by C4 at Maldives for INDOEX.

**List of Acronyms**

| | |
|---|---|
| ABC | : Atmospheric Brown Cloud |
| ACE-Asia | : Aerosol Characterization in East Asia Experiment |
| AERONET | : AErosol RObotic NETwork |
| APEX | : Asian Atmospheric Particulate Environment Change Studies |
| APN | : Asia-Pacific Network for Global Change Research |
| AGAGE | : Advanced Global Atmospheric Gas Experiment |
| BSRN | : Baseline Surface Radiation Network |
| C4 | : Center for Clouds, Chemistry and Climate |
| DOE | : Department of Energy |
| DOE-ARM | : DOE-Atmospheric Radiation Measurement program |
| EAP-AP | : Environment Assessment Program for Asia and the Pacific |
| EANET | : East Asian Network on Acid Deposition |
| GAW | : Global Atmospheric Watch |
| GCM | : General Circulation Model |
| GFDL | : Geophysical Fluid Dynamic Laboratory |
| ICIMOD | : International Center for Integrated Mountain Development |
| INDOEX | : INDian Ocean EXperiment |
| IPCC | : Intergovernmental Plan on Climate Change |
| NACIP | : National Aerosol Climate Interaction Program |
| NASA | : National Aeronautics and Space Administration |
| NOAA | : National Oceanic and Atmospheric Administration |
| NORAD | : Norwegian Agency for Development Co-operation |
| NSF | : National Science Foundation |
| SIDA | : Swedish International Development Cooperation Agency |
| SIO | : Scripps Institution of Oceanography |
| START | : SysTem for Analysis, Research and Training |
| UCSD | : University of California in San Diego |
| UNEP | : United Nations Environment Program |
| UNEP RRC.AP | : UNEP Regional Resource center for Asia and the Pacific |
| WMO | : World Meteorological Organization |

# TABLE OF CONTENTS

## PROJECT DESCRIPTION

### *Atmospheric Brown Cloud (ABC) Project: An Overview*

The most visible impact of air pollution is haze, a layer of pollutants and particles from biomass burning and industrial emissions. This cloud of pollution at times has a brownish color (e.g., the Denver Brown Cloud or the LA smog, see Fig. 2) and this brown cloud phenomenon is a common feature of industrial and rural regions around the world (Fig.2). Due to long-range transport, the mostly urban (fossil fuel related) or rural (biomass burning related) phenomenon is transformed into a regional haze (or cloud) that can span an entire continent or even the entire N. Pacific (see Fig. 3). In the context of this study, the phrase "Atmospheric Brown Cloud" is used in symbolic context referring to all manmade particulates and pollutants, including desert dust influenced or coated by pollutants. It is now becoming clear that the brown cloud can have large impacts on climate and health.

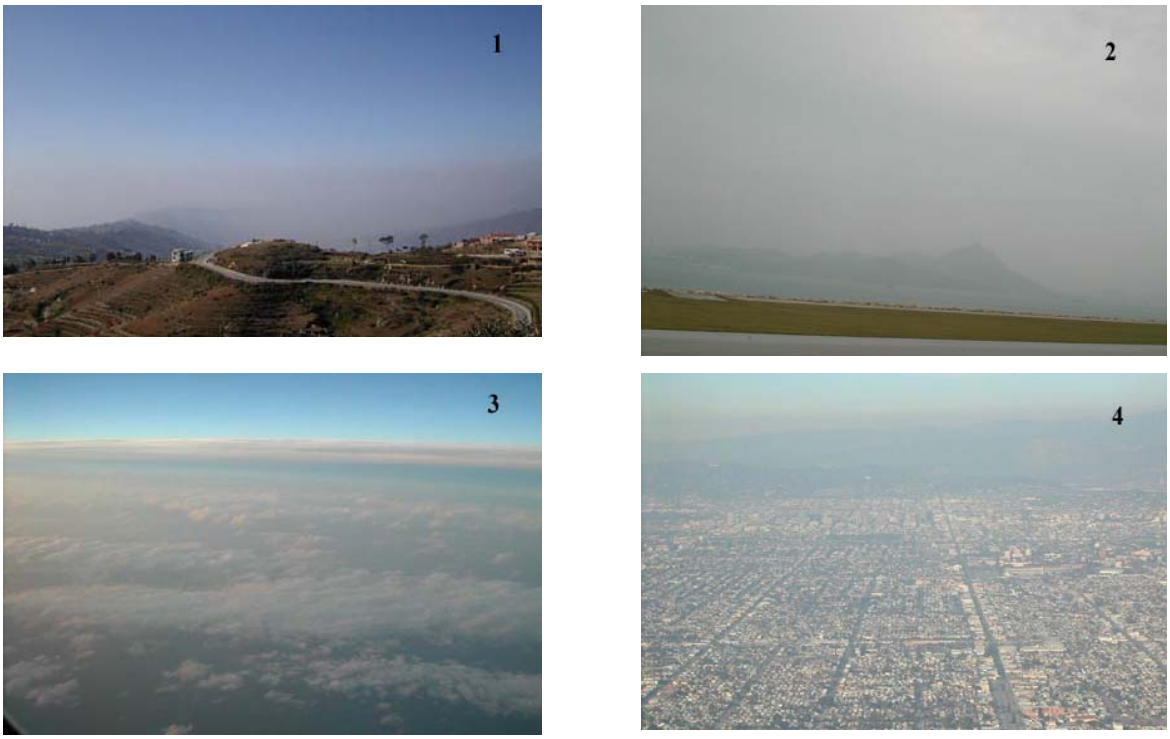



Figure 2. Airborne images of brown clouds: Katmandu Valley, Nepal, Dec. 21, 2002 (1), Hong Kong Airport, Dec. 25, 2002 (2), Western Central Pacific, Dec. 24, 2002 (3), Los Angeles, Dec. 27, 2002 (4). Photos taken by V. Ramanathan

A recent international study, the Indian Ocean Experiment (INDOEX), has revealed (*Rajeev et al., 2000; Ramanthan et al.,* 2001a, *Lelieveld et al*, 2001) that this haze is transported far beyond the source region, particularly during the dry season. The discovery of the so-called

Asian haze by INDOEX scientists, a 3 kilometers thick brownish layer, hovering over most of the tropical Indian Ocean and South Asia is a clear evidence of the magnitude of the problem (*Ramanathan et al*, 2001a; hereafter referred to as R-2001a). The haze consists of sulfates, nitrates, organics, black carbon and fly ash amongst several other pollutants (*Sathessh et al*, 1999; *Lelieveld et al*, 2001; R-2001a). Its most direct effects include a significant reduction in the solar radiation reaching the surface (*Jayaraman et al*, 1998; *Satheesh and Ramanathan*, 2000); a 50 to 100% increase in solar heating of the lower atmosphere (R-2001a); suppression of rainfall; reduction in agricultural productivity; and more importantly adverse health effects.

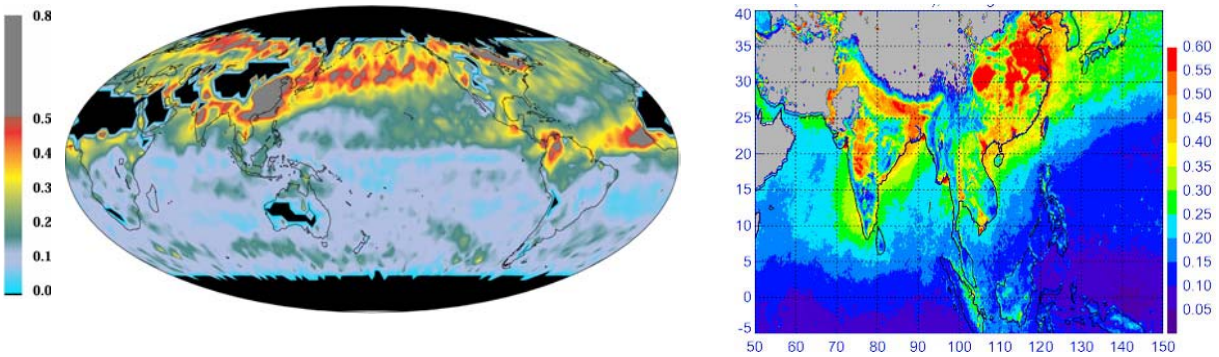



Figure 3: Global (left panel) and regional (right panel) distribution of natural and anthropogenic aerosol optical depth at 0.55 μm derived from Moderate Resolution Imaging Spectroradiometer (MODIS) instrument onboard the Terra satellite.

The first focus of the ABC project is Asia, hereafter referred to as ABC-Asia. About 60% of the world's population of 6 billion lives in Asia. The recent decades witnessed impressive economic development in the region. Fueled by growing population, globalization and the information technology revolution, this development has resulted in higher demands for energy, mobility and communications. The scope and magnitude of the environmental consequences of these demands are far reaching, especially with respect to air pollution at local and regional levels. These far reaching environmental effects have raised major questions about sustainability of the rapid development in the region.

The ABC project (*Ramanathan and Crutzen*, 2001) articulates a strategy to understand the air pollution issue in this broader context and help policymakers arrive at informed decisions. We build on the strengths of the INDOEX science team (of over 200 scientists around the world), which has established a record in conducting big-science that cuts across national and

disciplinary boundaries. The ABC project is coordinated with UNEP to translate scientific findings into policy options for action.

On the scientific side, ABC-Asia broadens the scope of the research by considering the entire Asian region and the adjacent tropical Indian Ocean and western Pacific Ocean. We will begin with a new framework (Fig. 4), which recognizes both the regional and the global nature of the aerosol radiative forcing as well as the impact of aerosols on regional and global scales (Fig. 4). The science component of ABC-Asia consists of two components, namely observatories and impact studies (See the top two green circles in Fig. 5).

***Observatories***: Develop regional air-quality and climate observatories to establish baseline measurements of pollutant gases, particulates and column burden of aerosols from a combination of in-situ, remote soundings and satellite measurements systems. These sites will facilitate observations needed for estimating impacts on air chemistry, radiative forcing and climate including temperature, solar energy, cloudiness, rainfall and water budget. These observatories in combination with satellites will be used to track the haze and the plumes on regional scales. Lack of such high quality data is the major reason for the uncertainties in environmental impact assessment.

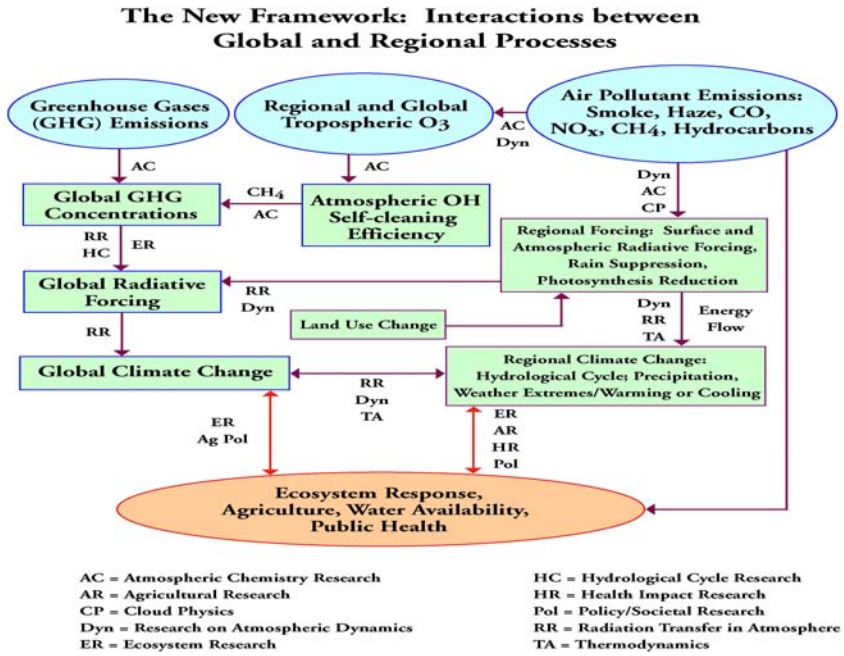



Figure 4: The new framework calls for a regional focus. Air pollution and aerosols exert a large regional radiative forcing which can have direct impact on regional climate. Both the regional forcing and regional climate change can aggregate to influence global climate change. Global climate change, in turn, can lead to regional climate changes. We have to understand the impact of human activities on regional as well as global climate change.

***Impact Studies***: Develop an integrated modeling approach that combines data assimilation techniques with predictive models that will estimate the impact of pollution on climate, atmospheric chemistry, agriculture and water budget. To maximize its policy-relevance, the model will need to be able to predict how changes in emissions in one area (a country or portion of a country) affect ambient air quality in other areas. This requires a level of disaggregation beyond that found in typical climate change models. We will use the meteorological and chemical data from the observatories and crop models to assess the effects of the haze, ozone and greenhouse gases on water budget, soil moisture and agricultural productivity; we will initiate epidemiological studies to assess the health impacts and assess the global climatic impacts of the haze.


Figure 5: ABC has 4 components: **Observatories** collect new data on chemistry, aerosols and radiative fluxes. The data require careful **scientific** analysis to infer the aerosol radiative forcing. The radiative forcing is used to perform **impact studies**, which then lead to **policy** analysis. The science and observations are coordinated at the ABC Science secretariat at C4 in La Jolla; the impact studies are jointly coordinated by C4 and UNEP Bangkok office; while the policy is coordinated by UNEP at Bangkok. Funding for the science will be obtained by the science agencies in the respective countries. Observations will be supported by NOAA and similar agencies in the participating Asian countries. UNEP will also seek private foundation grants.

***Policy Studies***: UNEP will have the primary responsibility for policy related ABC studies. Through UNEP we will invite environmental economists to join the project and explore various policy options for the region. The economics research will build on the biophysical research and will have as its chief objectives: a) the quantification of pollution damages in monetary terms, b) the estimation of the costs of alternative strategies for improving air quality, c) the evaluation of alternative instruments for implementing those strategies (e.g. command-and-control vs. market-based), and d) the design of international emissions reductions agreements.

The fundamental goal of this ambitious and unifying effort is to avert a potential environmental catastrophe in the region and enable an environmentally sustainable development for this region whose population is expected to reach 5 billion in the coming decades. We are also committed to regional capacity building. It is our goal to help train future Asian environmental scientists, agronomists, health experts and economists through exchange of students and post-doctoral scientists between the participating institutions. The climate observatories are critical components of this education outreach by serving as regional education and training facilities where regional students and other professionals will help operate the observatories, analyze data and hold joint authorship on scientific publications. The Center for Clouds, Chemistry and Climate (C4), Scripps Institution of Oceanography (SIO) at the University of California at San Diego (UCSD), will collaborate with UNEP and other international organizations, such as WMO-GAW program and SysTem for Analysis, Research and Training (START), to conduct this education outreach program.

Overall, C4 with its international INDOEX universities and research institutions will coordinate all aspects of this program in collaboration with UNEP/Regional Resource Center for Asia and the Pacific (UNEP RRC.AP).

**The Scientific Thrusts of the NOAA Component of ABC-Asia:**

The primary focus of this proposal is the characterization of the regional distribution of black and organic carbon aerosols, single scattering albedo and radiative forcing and the assessment of the contribution of the Indo-Asian-Pacific region to global aerosol forcing (*Takemura et al*, 2002, 2001; *Nakajima et al*, 1999). On regional scales the aerosol radiative forcing at the surface is very large, and in magnitude, an order of magnitude larger than the radiative effect of the greenhouse gases. Recent field measurements (*Jayaraman et al*, 1998, 2001; *Satheesh and Ramanathan*, 2000) have shown that absorbing and scattering aerosols within the haze lead to a very large reduction in the diurnally and monthly averaged solar radiation absorbed by the atmosphere and the surface, by as much as –70 $Wm^{-2}$ per unit optical depth (*Satheesh and Ramanathan*, 2000). Direct measurements have also shown that S. Asian aerosols absorb as much 45 $Wm^{-2}$ solar energy per unit optical depth (*Satheesh and Ramanathan*, 2000). The primary reason for the large surface reduction is black carbon aerosols, without which the surface reduction will be smaller by about 50%. In addition, aerosols also lead to appreciable reduction in the solar radiation at the surface by enhancing the albedo of clouds (so-

called indirect effect; *Penner et al*, 2001; *Nakajima et al*, 2001). A similar story has emerged from the NSF-NOAA funded Aerosol Characterization in East Asia Experiment (ACE-Asia), conducted in East Asia (*Huebert et al*., 2003). Asia contributes about 50% or more to the worldwide emissions of $SO_2$ and black carbon. Clearly, it is difficult, if not impossible, to come to grips with the impacts of aerosols on global warming without understanding the role of Asian aerosols on global radiative forcing. In addition, the aerosols can also have large regional impact on Asia. The aerosol optical depths in many Asian regions routinely exceed 0.3 (*Xu*, 2001); these high aerosol regimes persist on seasonal to annual time scales (Fig. 6a). Several recent global modeling studies have suggested that the radiative forcing of such absorbing aerosols can have a perceptible impact on the regional precipitation, including the monsoonal rainfall (*Xu*, 1999; *Chung et al*, 2002; *Menon et al*, 2002; *Chung and Ramanathan*, 2003).

Specifically, NOAA funds are requested to provide the American contribution to the aerosol-climate observatories in the Asian region. The locations of the proposed aerosol-climate observatories are shown in Fig. 1a. In addition to these observatories, the countries involved in ABC will initiate more urban and rural observatories that meet their specific objectives such as measuring visibility, gaseous pollutants and documenting the impacts of the haze on health, agriculture. Here we restrict our attention to the aerosol-climate observatories that are needed for the aerosol radiative forcing.

The NOAA funds will be used to contribute to the following specific objectives:

- Establish continuous chemical and microphysical aerosol observations and radiometric observations at key locations in the Indo-Asian-Pacific region with a particular emphasis on organic and black carbon aerosols and dust,
- Determine short-wave and long-wave aerosol radiative forcing at the surface and top of the atmosphere directly from radiometric observations at the sites of the observatories and integrate these with satellite data and regional aerosol assimilation models to produce regional estimates and,
- Relate the aerosol forcing to regional sources of aerosol emissions based on analysis of molecular markers in aerosol filter samples, aerosol single particle analysis, and regional aerosol assimilation models

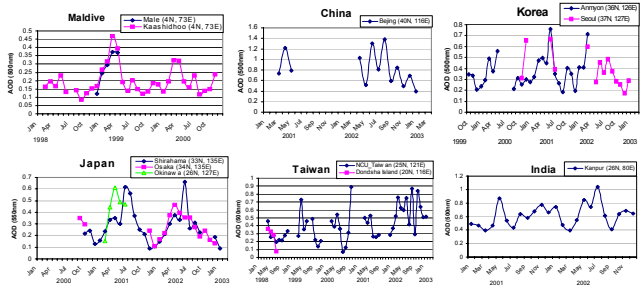
The ABC observatories and the follow on analysis outlined next will produce for the first time an end-to-end set of data, beginning from time series of aerosol properties (Fig. 6a and 6b), vertical distribution of aerosols (Fig. 6c), source characterization (Fig. 6d), relative contribution of various aerosol species to the forcing (Fig. 6e), a composite of single scattering albedo values for the surface and for the column (Fig. 6f), surface and TOA forcing (Fig. 6g), an assimilated and integrated data set of regional aerosol forcing and finally the contribution of the various Asian regions to the global forcing (Fig. 6i). By funding this activity, NOAA would contribute in a major way to reducing the current uncertainties in global warming projections, for this proposal would lead to the determination of an observationally constrained estimate of the aerosol radiative forcing and emissions of black carbon and organic carbon for the Indo-Asian-Pacific region.

**Results from Previous Support/Research**

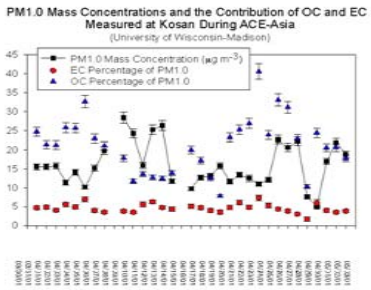
**INDOEX**: NOAA provided partial funding (through Ron Brown) for the Indian Ocean Experiment (INDOEX) designed to study the complex influence of aerosols transported from the south Asian region and carried out in the years of 1998 and 1999 [*Ramanathan et al*., 1996; 2001a; 2001b; *Mitra*, 2001; *Moorthy et al*, 1999; *Jayaraman et al*, 2001; *Lelieveld et al*, 2001]. INDOEX was a multinational effort led by $C^4$ and NSF was the lead agency for INDOEX with substantial additional funding from NOAA, DOE and European and Indian institutions. The US coordinator and Co-Chief scientist (with P. J. Crutzen) for INDOEX was V. Ramanathan, Director of C4, and Principal Investigator (PI) of this proposal. The results by PI from INDOEX are illustrated in the text and references. As part of INDOEX, we set up an aerosol-chemistry-radiation observatory in the Maldives (*Lobert et al*, 2001; *Satheesh et al*, 1999), which will serve as a model for the proposed ABC observatories.

INDOEX results have been published extensively (www-INDOEX.UCSD.Edu) including two special issues of Journal of Geophysical Research & the Indian journal Current Science; and to conserve space and meet the page limitation of NOAA proposal we refer to reader to these publications. A summary of the INDOEX results and its implications can be found in R-2001b. We note that INDOEX was restricted to the dry season and furthermore, did not adequately account for many regions of south and Southeast Asia.

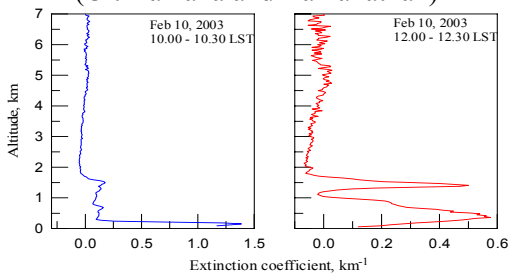
**(a)**: Time series of AOD (Holben et al., 2001)



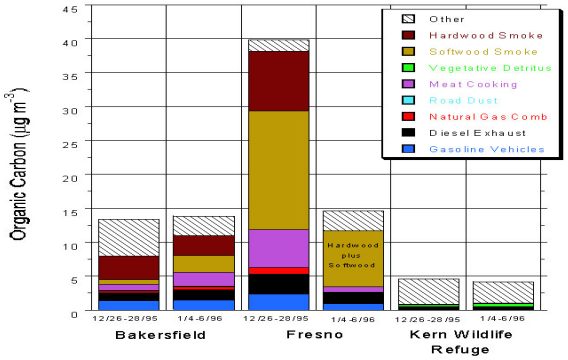

**(b)**: Time series of BC and OC in S.Korea - J.Schauer



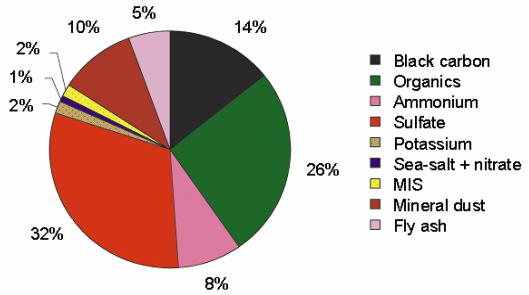

**(c)**: Vertical aerosol profiles over Nepal ($C^4$: Ramana and Ramanathan)



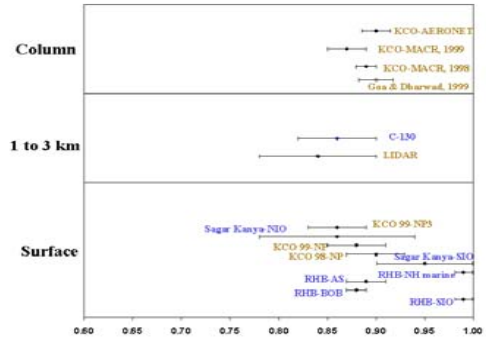

**(d)**: Source Characterization (Schauer et al., 2002)



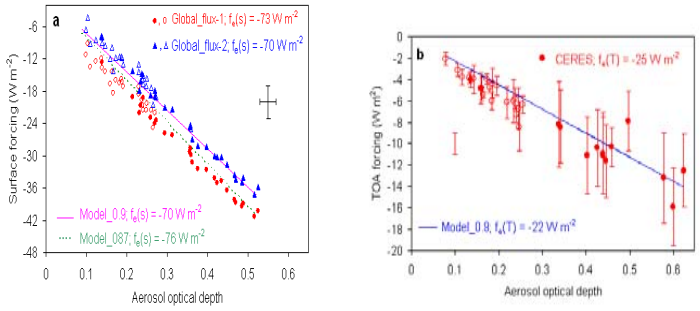

**(e)**: Relative contributions of the various chemical species to AOD at 0.5 μm (Ramanathan et al., 2001a)



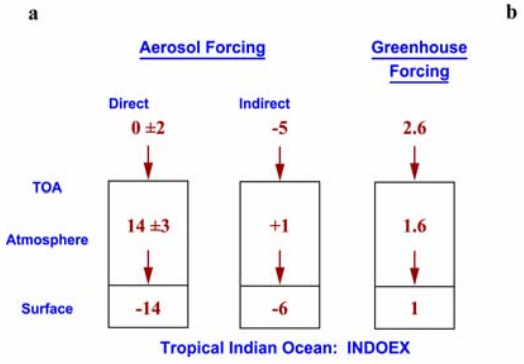

**(f)**: Aerosol Single Scattering Albedo: INDOEX (Ramanathan et al., 2001a)




**(g)**: Aerosol forcing from radiometers (Satheesh and Ramanathan, 2000)




**(h)**: Regional forcing (Ramanathan et al., 2001a)




**(i)**: % Contribution by region (STEM2K1, Carmichael)

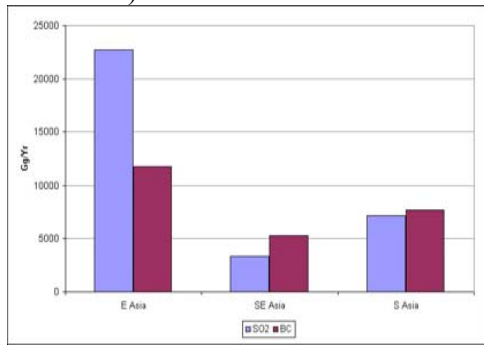



Figure 6: An example of how data from the ABC observatories will be integrated to yield regional radiative forcing and attribute this forcing to regional aerosol sources.

**ACE-Asia**: NOAA also provided funds (through the (Ron Brown) to support the ACE-Asia experiment. In an approach similar to that used in INDOEX, the ACE-Asia science team made simultaneous measurements of aerosol chemical, physical, and optical properties and their raidative impacts in a variety of airmasses, often coordinated with satellite overpass. Three aircraft, two research ships, a network of lidars, and many surface sites gathered data on Asian aerosols. Several of the co-investigators of this proposal participated in the ACE-Asia experiment. The results from ACE-Asia will appear in a special issue of Journal of Geophysical Research.

**Science Plan (Statement of Work)**

***Observation Technologies – ABC Indo-Asia-Pacific Network***

**Principal Criteria for site selection***:*

i) Should be indicative of emissions from a large region; ii) Should include regions representative of various Asian regions that are major sources of aerosols; iii) Should be indicative of long range transport.

Amongst the sites that satisfy the above criteria, preference was given to the locations that satisfied one or more the following requirements: An established GAW facility at the location; an ongoing regional facility at the location; is part of the NASA-AERONET network; has a continuous aerosol measurement record.

Table 1 lists the sites chosen for the ABC observatories and their current status. It should be noted that some of the sites are in existence and are being supported by the government in the region where the site is located or by funding agencies in the US. Three of the 13 sites (Momote, Mauna Loa and Trinidad Head) are run by ongoing programs at NOAA, NASA and DOE and do not require funding from this proposal. For the remaining 10 sites, NOAA funding will be the main funding source (providing 40% to 75% of the total) for six and partial funding source (20% to 40%) for 4. The proposed ABC observatories will be operated in close cooperation with the GAW (WMO), AERONET (NASA), EANET (UNEP), BSRN (WMO) and observational networks operated by NOAA or DOE. AERONET is the NASA funded Aerosol Robotic Network (*Holben et al*., 2001).

**There are three categories of sites**: Super Observatory (SO); Main Observatory (MO); and Complementary Site (CS). Super Observatories will be located at two sites, Main observatories

will be located at 7 sites and complementary sites will be located at 4 locations. The observations to be undertaken under these three categories are listed below within brackets. It should be noted that not all of the measurements will be undertaken at all of the observatories, at all times.

- Aerosol optical depth (AOD) and column average single scattering albedo, SSA, at all observatories (SO, MO, CS). We will use AERONET (NASA) or PRIDE (JAPAN) sun-photometer network and do not require NOAA funding. AOD is the fundamental measurement of column average aerosol loading and column average SSA is the fundamental indicator of aerosol absorption.
- Mass in two size fractions (SO, MO, CS). A basic and fundamental indicator of sub-micron (basically anthropogenic) and super micron aerosol amount at the surface.
- Major chemical components including ions, BC and OC concentrations (SO, MO, CS); Molecular marker analysis of filter samples will also be undertaken to characterize the sources of aerosols (i.e., coal combustion; diesel; bio fuel; bio mass combustion; etc). This information is needed to identify the anthropogenic fraction of aerosols; to calibrate and validate regional aerosol assimilation model; and to model aerosol radiative effects.

{The above three items will be critical for providing a baseline to understand changes in the distribution of carbonaceous aerosols over the next several decades; they are also needed as input for aerosol-radiation forcing models}

- Monthly inexpensive passive samplers for sulfur dioxide ($SO_2$), ammonia ($NH_3$) and ozone ($O_3$) will be undertaken to help interpret and use the radiation and aerosol measurements (SO, MO, CS).
- Light scattering and absorption coefficients at various wavelengths (SO, MO, CS); fundamental quantities needed to develop and validate aerosol-radiation models used for forcing estimates.
- Aerosol number concentration (SO); needed for detailed aerosol and radiation modeling for aerosol forcing estimates.
- Cloud condensation nuclei number concentration at 0.5% super-saturation (SO); needed to develop aerosol-cloud microphysical models used for indirect forcing effect estimates.

- Diffuse, global and direct solar radiation (SO, MO); will be used to estimate the aerosol forcing directly and the column integrated aerosol solar absorption for clear skies.
- Lidar back-scattering measurements to document the aerosol vertical profile (SO, MO). These data are critical for obtaining the correct sign (heating or cooling) of the direct forcing. For example an aerosol with SSA of 0.9 (typical value for Asian aerosols) will cause cooling if confined to first 1 km (below clouds) but will cause heating if aerosol is above 2 km (above low clouds). The vertical profile is also needed for indirect radiative forcing estimates and for validating satellite aerosol retrievals.
- Single particle mass spectrometer analysis will be performed for one month every year at only SO to: 1) determine the internally and externally mixed state of the aerosol which is critical data needed for radiation modeling of aerosols; and 2) to link aerosol pollution measured at ABC sites to specific human activities (e.g., coal combustion, bio-fuel, diesel, two-stroke engines, etc for source attribution)

The above list overlaps with the core measurements recommended by the World Data Center for Aerosols (http://www.ei.jrc.it/wdca) for the GAW global stations.

***Super Observatories (SO)*:** The super sites will serve as hubs for calibration, standardization, intense observing periods and training of students and new scientists from the participating nations. The primary criteria for the super observatories are: sampling air masses from large regions in Asia; accessibility; good infrastructure; ability for any or all members of the ABC science team to operate their instruments on the site and access their data in real time. Two of the thirteen will serve as super observatories, one each in the N. Indian Ocean (Maldives) and the W. Pacific ocean (Gosan in S. Korea). The Maldives and the Gosan sites have been approved as super sites by the ABC science team. The Maldives sample air from S. Asia during the dry season, pristine southern hemisphere air (at low levels), as well as dust from Saudi Arabia and Sahara (*Li and Ramanathan*, 2002) during the wet season (JJA) and the ITCZ during the transition months. The Gosan site in S. Korea will sample air from China and other regions in East Asia. Thus, between the two super sites, we will capture aerosols from India and China. These two stations have been successfully used as super-sites during recent aerosol campaigns (INDOEX and ACE-Asia, respectively).

During special observing periods (about 1 month every year) investigators from the Asian region (S. and SE Asian for Maldives; and East Asian for Gosan) will be invited to the super sites to bring their instruments and aerosol samplers to inter-compare aerosol chemical and physical and radiation measurements. We will also arrange, with the help of WMO and UNEP, for training and tutorial sessions during these observing periods for students and new scientists as well as Video lectures by members of ABC science team. Radiometric instruments at the super sites will also be calibrated once every year. In addition, special efforts will be undertaken to examine the aerosol indirect effect at the super sites. Toward this goal routine cloud condensation nuclei measurements will be undertaken at the super sites and we also envision aircraft campaigns (funded outside of this proposal; R. Schnell, private communication).

***Main Observatory (MO) and Complementary Site (CS)***: The criteria for the MO are the same as mentioned above and the MOs will share the same core observations as the super sites. At the complementary sites, we are mainly interested in estimating the long-range transport of Asian aerosols and hence we will undertake only surface filter samples for aerosol chemical composition and passive gas phase samplers, except for the Midway site where we will also deploy AERONET for AOD and SSA.

Table 1 – Proposed ABC Surface Observation Network

| **Location and Type**<br>SO: Supper Observatory<br>MO: Main Observatory<br>CS: Complementary Site | **Attribute** | **Current Measurements**<br>$\sigma_s$: Aerosol scattering coefficient; $\sigma_a$: Aerosol absorption coefficient; $\sigma_s(z)$: vertical profiles using Lidar; $n_a(r)$: size distribution; $n_a$: aerosol number concentration; $Fs_B$: solar broadband radiation; $Fs_V$: solar visible radiation; Fsuv: solar ultravilot radaion; BC/OC:Black carbon /organic carbon; ions: $SO_4$, $NO_3$; etc., SSA: single scattering albedo | **Funding Sources**<br>[Funding: Main-M; Partial-P; Limited-L]; M denotes 40 to 75%; P for 20 to 40%; and L is for 0 to 20%. |
|---|---|---|---|
| **S. Asia/ N. Indian Ocean** | S. Asia air mass | | |
| Maldives [SO] | Samples S. Asian air during dry season, marine air and Arabian dust during wet season (SW monsoon). | BSRN site; APN site; GAW site; No such observatory in this region | M-NOAA; L-UNEP, Maldives, NASA, SIDA |
| Andamaan [MO] | Samples S., SE Asia and Saudi Arabian air during dry and wet season. | 4 Indian institutions have begun aerosol and chemistry measurements. | M-India; P-NOAA; L-UNEP; SIDA |
| Nepal [MO] | Samples Himalayan, W. Asian and Mediterranean air mass during dry season and SW monsoon flow during wet season. | Limited observations were initiated in winter 2003 using NOAA & NSF funds. | M-NOAA; P-UNEP; L-Nepal, SIDA, NASA |
| **East Asia** | East Asia air mass | | |
| Hefei [MO] | Samples air pollution in the rapidly developing areas, and uplifted dust from Loess Plateau (in northern China) and Gobi dust transported by northwesterly cold front activities. | $Fs_B$, $Fs_V$, AOD, $\sigma_a$, $\sigma_s$, $O_3$, CO, $\sigma_s$ (z) and Sondes. | M-China; P-Japan & NOAA; Co-ordinated through China-Japan joint programs (GEWEX /GAME/HUBEX/ Radiation, NASDA/ GLI and ADEC). |
| Hebei [MO]<br>Shangdianzi | About ~75km north of Beijing and samples unpolluted dust from Gobi and Loess Plateau. | GAW site; TOMS surface validation site for $O_3$. | M-China, NOAA; L-UNEP; NASA, NOAA |
| Or<br>Xianghe | Samples polluted dust during dry season and anthropogenic aerosols during wet season. | AERONET, $O_3$, Fsuv and Sondes, GAW site. | |
| **SE Asia**<br>Sabah [MO] Malaysia | samples biomass burning from SE Asia. | GAW site is under construction (To be established) | M-NOAA; L-UNEP, NASA, Malaysia, SIDA |

| | | | |
|---|---|---|---|
| **Western Pacific Rim** | | | |
| Gosan/Anmyon-do [SO] | Samples air from East Asia and yellow sand from Mongolia & China deserts; may be used as twin-site or single site in Gosan. | Gosan: GAW site ($CO_2$, $N_2O$);<br>Anmyon: GAW site ($CO_2$, $N_2O$); $\sigma_s$, $\sigma_a$, $n_a(r)$, $\sigma_s(z)$, PM2.5 and PM10; AERONET site | M-Korea, NOAA; P-NASA; L-SIDA |
| Amami-Oshima/ Hateruma [MO] | Samples long range transport of aerosols from E. Asia / Samples E. Asia air during winter & spring, marine and biomass burning aerosols during summer; may be used as twin-site; Radiation and aerosol in Amami-Oshima and Chemistry in Hateruma. | Amami-Oshima: $\sigma_s(z)$, Japan-SKYNET, $Fs_B$, $Fs_V$, SSA, $n_a(r)$, Phase function, $\sigma_s$, $\sigma_a$, CCN, aerosol sampling, gas sampling. (http://duckbill.ccsr.u-tokyo.ac.jp/WORKSP/miyazaki/Sohn.APEX-5th.pdf)<br>Hateruma: GAW site ($CO_2$, $CH_4$, $N_2O$); AGAGE site. | M-Japan; P-NOAA; L-SIDA/UNEP |
| Momote [MO] | Samples biomass burning aerosols from Indonesia during spring and marine air during other seasons. | $Fs_{.B}$, $Fs_{.V}$; $\sigma_s(z)$; Sondes; AERONET site (more information at www.arm.gov) | DOE-ARM site. Does not require NOAA funding. |
| **Central and East Pacific** | Long range transport from East Asia/ Downstream sampling | | |
| Minamitorishima [CS] | Samples long range transport from SE Asia. | GAW site ($CO_2$); AOD. | M-Japan; P-NOAA |
| Midway [CS] | Samples long range aerosol transport from E Asia. | GAW site ($CO_2$; $CH_4$; CO); 20 years record of aerosol ions exists for this site. | M-NOAA; US forest service, Maintained by NOAA, R. Schnell |
| Mauna Loa [CS] | Samples Asian air mass during spring, Pacific and American air masses during other seasons. | GAW site ($CO_2$; $CH_4$; CO; $O_3$; $H_2$; $N_2O$; CFCs; HCFCs; HFCs; $CH_3CCl_3$; $C_2Cl_4$; $CH_2Cl_2$; $SF_6$; $CCl_4$), AOD, $\sigma_s$, $\sigma_s(z)$ and $n_a$ (R.Schnell). | NOAA, non-ABC |
| Trinidad Head [CS] | Samples Asian air mass during spring, Pacific and American air masses during other | GAW site ($CH_4$; $N_2O$; CFCs; $CF_4$; $CCl_4$; $CHCl_3$; $CH_3CCl_3$, $SF_6$, $O_2$, $CO_2$); $O_3$ sondes; AGAGE site maintained by SIO and NOAA (R. Weiss). | NOAA, non-ABC/NASA |

C4 and the NOAA funded investigators of this proposal will have the primary responsibility for the following sites: 1) Maldives (C4); 2) Nepal (C4); 3) Malaysia (C4) and 3) Midway (U. Miami). In addition, other NOAA or NASA funded (Non-ABC) scientists will have the primary responsibility for the sites in Mauna Loa (R. Schnell) and Trinidad (R. Weiss of SIO). With respect to all other sites, scientists from the nation (selected from the ABC science team listed in this proposal as collaborators) where the site is located will have the primary responsibility to operate the site. Details are given under the management section. Our immediate objective for Year-1 (August of 2003) is as follows:

We will start observations in Maldives, Nepal, Gosan (Gosan and Anmyon-do as the alternate site) and Midway. The aerosol climate observatories in the Republic of Maldives and Gosan, Republic of Korea will be reactivated to subsequently become the main training and calibration facilities of the proposed ABC surface observation network. We aim to establish a full-fledged super observatory in the Maldives (using n`ew funds from NOAA and existing funds and facilities from NSF to Ramanathan's lab). Some of the instruments needed for this site have been purchased as part of the INDOEX activity using NSF funds. The Korean ABC team (see discussion later) will establish the Gosan site with funding from Korea and from NOAA. The Anmyon-do site (a GAW site) is already operating with aerosol filter samples and CIMEL (NASA funds) for nearly two years. We will install radiometers to measure the radiative forcing. Our objectives in Nepal, Gosan and Midway are modest for year-1. With NOAA and NSF funds, C4 (in collaboration with ICIMOD of Nepal) started some initial aerosol and radiation observations in Nepal (at two sites, one in Katmandu and another at Nagarkot) beginning November of 2002. We will continue these observations during 2003 with the expectation that it will lead to an ABC main observatory in 2004. In Midway, we will fund the Miami group to continue their filter sampling and analysis that has been going on for about 20 years and NASA (B. Holben) funds will be used to set up a CIMEL instrument for aerosol optical depth and single scattering albedo measurements.

The Maldivian Climate Observatory (MCO) will be the principal site for collecting aerosol and radiometric ground-based data in South Asia and is being established at the northern part of the island of Hanimaadhoo, Republic of Maldives (6.47° N, 73.11° E). MCO has recently become an ecological reserve, represents a perfect site for long-term aerosol observations and monitoring environmental impacts of the South Asian Haze, and is receiving strong support from the Maldivian government. C4 ran a comprehensive aerosol-climate observatory in this region

from 1998 to 2000. The construction of a new observatory building and the establishment of basic radiometric and meteorological measurements (carried over from INDOEX) are being funded by NSF and the Ministry of Home Affairs, Housing and Environment (MHAHE).

The recently announced "Korean ABC Project" (Seoul National University, Korea University; and Hankuk University of Foreign Studies) will contribute to the ABC surface observatories in Korea by reactivating and maintaining a surface observatory in Gosan, Cheju Island and Anmyon-do island which will be the principal sites for collecting aerosol and radiometric ground-based data for air mass from East Asia. The proposed measurements funded by Korean agencies will include chemical components ($CO_2$, $CH_4$, CFCs, NOx, CO, wet/dry deposition), aerosol and radiometric observations. The observatory was fully operational during the intensive phase of the recent ACE-Asia aerosol campaign and represents a perfect site for monitoring BC and dust outflow from East Asia to western Pacific. NOAA funds will be used to augment the capability of this site.

We will establish ~2 new observatories and one complementary site each year such that by year-3 all ABC observatories will be operational. Specific plans will be submitted at the end of Year-1 for NOAA approval. As can be seen from Table 1, three of the sites have two possible locations:

Gosan/Anmyon-Do: While Gosan will be our main site, Anmyon-Do (on the western boundary of S. Korea) is a GAW site, has an AERONET CIMEL instrument for AOD funded by NASA and radiometers and a Lidar funded and maintained by Korean scientists, and samples air from China before it passes through Korea. We consider these two sites as twin-sites and both will be used for ABC studies.

Amami-Oshima/Hateruma: We are considering both these sites. They both sample similar air masses. The Japanese project, APEX (Chief scientist: Dr. Nakajima) has started a major field study on aerosols and has set up a surface measurements site at Amami-Oshima with aerosols microphysical and radiation measurements, while Hateruma is a GAW site with emphasis on air chemistry. Thus one scenario is that Amami-Oshima would be an aerosol site for ABC and Hateruma a chemistry site for ABC. The decision will be taken at the next ABC meeting in Japan in September 2003.

Hebei Province: Shangdianzi / Xianghe: While the Korean and Japanese observatories of ABC will sample downstream air mass from East Asia, we need an upstream site to sample

unpolluted dust from Gobi. Shangdianzi (a GAW site) or Xianghe (AERONET site) will serve this purpose. The actual location will be decided at the ABC meeting in China during early 2004.

**Regional Estimates of the Forcing**: The data from the observatories will yield aerosol forcing and source information, over the observatory sites. We are also interested in the regional distribution of the forcing. For this purpose, we will employ a data integration scheme (described in *Ramanathan et al*, 2001a) that will integrate surface and column measurements with satellite data (AVHRR and MODIS) and aerosol assimilation models (the regional STEM-2K1 model). This scheme yields the regional aerosol forcing due to direct and indirect effects and their relative contributions similar to those shown in Fig. 6i. This part will leverage funds to V. Ramanathan from NSF (Contact: Dr. J. Fein) and to Carmichael through an NSF center for regional modeling. The assimilation techniques for STEM-2K1 are presently being developed under a new NSF Information Technology Research (ITR) grant. This 5-year project begun in August 2002 is devoted to aerosol and chemical data assimilation in regional and global models. These developments will take place with the NSF funding, and only the application to Asia for the ABC analysis will be funded by this proposal. The assimilation techniques will be focused not only on providing optimally constrained estimates of AOD, but also on improving the regional emission estimates. More details of the integration scheme and the model are given in the next section.

**Observation Technologies: Specific Details**

***Gas Phase Chemistry Measurements (G. Carmichael):*** At the ABC sites sulfur dioxide ($SO_2$), ammonia ($NH_3$), $NO_2$ and ozone ($O_3$) will be monitored monthly by deploying inexpensive (about $1500 per site per year) passive samplers. Passive samplers present a means of addressing many measurement issues in air pollution and atmospheric chemistry, in that they provide a cost effective way to monitor specific species at urban, regional and global scales, and offer broad capacity building opportunities. NOAA funded 2 years ago a GAW pilot project on passive samplers ($50K) (*Carmichael et al*., 2003). We realize the critical need for additional air chemistry measurements and precipitation chemistry (for acidity and vertically integrated black carbon measurement). At a later stage, to be covered from other resources, time-resolved measurements of several gas phase chemical species that play important roles in atmospheric chemistry and/or human health will be added. Precipitation chemistry measurements will be covered by Dr. H. Rodhe through grants from SIDA.

***Fine Particle Mass and Trace Element Composition (J.Schauer)***: Particle mass measurements along with selective trace elements analysis will also be conducted at each observatory site. Samples for these measurement will be collected with the sampler used for the collection of the fine particle carbonaceous and ions measurements. In order to facilitate collaboration with the local scientist and help build capacity for aerosol measurements, the fine particle mass and trace element measurements will be conducted by local collaborators. In regions where these capabilities do not already exist, the project team will work with local scientist and environmental agencies to establish the capabilities for mass and trace elements analysis of atmospheric particulate matter. To assure high quality data is collected by local laboratories project QA/QC procedures will be adopted for all observatory measurements, which will include intercomparison samples with the project team members that extensive expertise in these measurements. In addition, collaborators will be invited to visit the project team's laboratory for training and consultation.

***Organic and Black Carbon Measurements (J. Schauer)****:* In order to better understand the composition, origin, and properties of the carbonaceous fraction of the aerosols distributed across the Asian region, samples of particulate matter will be analyzed for black and organic carbon (BC & OC) and will be analyzed by gas chromatography mass spectrometry (GCMS) techniques to quantify the distribution of organic compounds present in particulate matter samples. These measurements will be employed to understand the sources of carbonaceous aerosols in Asia. The development of methods to speciate particle-phase organic compounds in atmospheric and source samples over the past decade (*Rogge*, et al., 1993; *Schauer* et al., 1999a; *Schauer et al*., 1999b; *Schauer et al*., 2001; *Schauer et al*., 2002c; *Schauer et al*., 2002b) has lead to the development of molecular marker source apportionment models (*Schauer et al*., 1996; *Schauer and Cass*, 2000; *Schauer et al*., 2002a; *Zheng et al.,* 2002) that use unique organic compounds emitted from source as tracers to quantify the contribution of air pollution sources to atmospheric concentrations of carbonaceous particulate matter and the mass of particulate matter. Although these models have been predominately developed in the context of the United States urban atmosphere, recent emissions tests have measured profiles for Asian Biomass combustion, which includes cow paddies, rice straw, jack fruit branches, and coconut leaves (*Sheesley et al*., 2003). In addition, source profiles have been developed for residential coal combustion in China and are currently being used in conjunction with atmospheric

measurements made in Beijing, Hong Kong, and Cheju Island (South Korea), as part of the ACE-Asia project, to quantify the source of carbonaceous aerosols in Asia. The analysis typically will produce the sort of results as shown in the figure 6d.

It is important to recognize that the molecular markers quantified in particulate matter samples using GCMS techniques have very high specificity due to the fact that the molecular marker have chemical structures that are directly related to materials consumed in the source. As an example is the high concentration of levoglucosan in biomass combustion aerosols that result from the degradation of cellulose present in biomass (*Sheesley et al*., 2003). Similar molecular markers have been identified for coal combustion, motor vehicle exhaust, food cooking emissions, resuspended agricultural dust, vegetative detritus, cigarette smoke, and variety of other sources.

As part of ABC, daily samples will be collected at the observatory sites throughout the calendar year and monthly composites will be analyzed for molecular markers. These results will be used to obtain a semi-quantitative analysis of the spatial and temporal distribution of carbonaceous aerosol sources in Asia using methods previously presented by *Rogge et al*., (1993). It is expected that the organic speciation data will also provide insight into the chemical nature of the organic aerosols that can provide important information to predict the hygroscopic behavior and optical properties of these organic aerosols for indirect forcing estimates.

The method that will be used for BCOC analysis will follow the protocol established as part of the ACE-Asia study (*Schauer et al*., 2003). In this study, each group measuring organic and elemental carbon employed the same analysis protocol. This study further confirmed, however, that all existing elemental and organic carbon analysis techniques have problems but that the method adopted by the ACE-Asia study appears to be better suited for climate and source attribution studies. For these reasons, the ACE-Asia ECOC method will be used for the Atmospheric Brown Cloud - Asia Study.

The chemical measurements of carbonaceous aerosols will be conducted at the University of Wisconsin by Dr. Schauer. This laboratory has extensive facilities for these measurements and maintains a comprehensive quality assurance and quality control program. He is currently employing these techniques to study the composition, origin and impact of carbonaceous aerosols on climate change, human health and the ecosystem.

***Observation of Ions: Sulfates, Nitrates and Dust (D. Savoie):*** Continuous 2-day (48-hr) high-volume (ca 1 $m^3$ $min^{-1}$) bulk aerosol samples will be collected on 20×25 cm Whatman-41 filters. Sampling will be controlled by wind sensors, which activate pumps only during periods when surface winds are off the ocean sector at speeds greater than 1 m $sec^{-1}$, thereby minimizing the potential for island effects. UMia will be responsible for construction of these sampling systems and for training collaborators in their use and maintenance. The sampling systems are comparable to those that have been used by the UMia aerosol group at a variety of stations for several decades. These systems have proven to be reasonably inexpensive and very reliable with minimum maintenance required.

All of the bulk samples will be analyzed by UMia for $SO_4^{2-}$, $Cl^-$, $NO_3^-$, $NH_4^+$, $Na^+$, and K using established procedures (e.g., *Savoie et al*., 1989, 1992, and 2002). Quarter sections of each high-volume bulk filter are extracted with 20 mL of 18 MΩ $cm^{-1}$ Milli-Q water. The full 25-mm low volume filter is extracted in 10 mL of Milli-Q water. In each of the extracts $SO_4^{2-}$, $Cl^-$, and $NO_3^-$ concentrations are measured with 1σ uncertainties of ±5% using suppressed ion chromatography (IC) with Dionex columns and suppressor. $NH_4^+$ is measured with a 1σ uncertainty of ±5% using an O-I-Anaytical FS3000 automated colorimeter. $Na^+$, and $K^+$ are measured with 1σ uncertainties of ±2% and ±5% by flame atomic absorption spectrophotometry. For the purposes of this discussion, "mineral" aerosol is defined, as the refractory portion of the aerosol that remains after the water-insoluble fraction is ashed in a muffle furnace overnight at 500°C. In areas such as the tropical North Atlantic, this fraction is dominated by soil dust from arid and semi-arid regions. However, in other areas such as downwind of India, flyash from combustion processes also contributes and may frequently dominate.

***Single Particle Analysis (K. Prather, UCSD)***: These analyses will be undertaken at only the super observatories and that too for only one month per year. In order to obtain real-time information and a rapid picture of the particle chemistry and sources in the Asian-Pacific, a transportable aerosol time-of-flight mass spectrometer (ATOFMS) will be used (*Gard*, 1997) to continuously monitor the size and chemical composition of individual particles. As demonstrated during previous international field campaigns including ACE-Asia and INDOEX, information at the single particle level provides unique insight into the sources of the particles as well as chemical reaction (aging) processes particles undergo in the atmosphere.

ATOFMS data complement traditional filter-based techniques, which have been used to obtain useful information on aerosol composition as well as some information on particle sources. Our group has developed aerosol time-of-flight mass spectrometry (ATOFMS), which provides real-time information on the size and chemical composition of individual particles. One of the major strengths of single particle mass spectrometry technique lies in their unparalleled ability to detect unique fingerprints of particles from different sources. ATOFMS has been used to characterize the size-resolved composition of particles produced from a variety of sources including biomass, vehicles (gasoline and diesel), soil, and coal combustion. As demonstrated during INDOEX, these fingerprints can be used to track and apportion particles from biomass burning versus fossil fuel combustion. An excellent correlation was shown between ATOFMS measurements of K-rich particles and acetonitrile, a unique gas phase biomass marker measured using a co-located PTR-MS. This was the first demonstration showing the use of ATOFMS for source apportionment, and illustrated the power of combining gas and particle phase measurements.

ATOFMS will be used at the ABC sites, periodically (and not continuously because of the cost) to gain a rapid snapshot of particle chemistry in these regions. Using ATOFMS, information can be obtained on virtually all species present in the particles including organic carbon, elemental carbon, metal species, sulfates, nitrates, etc (*Gard*, 1998; *Bhave*, 2001; *Bhave*, 2002a). Furthermore, it is these chemical couplings (e.g., internally versus externally mixed) that ultimately impact the radiative properties of the particles. For example, during INDOEX, it became evident that pure sulfate particles did not occur, but instead sulfate was internally mixed with organic carbon and elemental carbon in sub-micron particles and dust and sea salt in super-micron particles (*Guazzotti*, 2001). Our goal in ABC will be to merge the particle types present during time periods dominated by particular sources with radiative measurements to begin to assess the impact of specific aerosol sources on climate. These data will ultimately be used as inputs for chemical transport and radiative models to further our understanding of aerosols in various regions of the world.

***Cloud Condensation Nuceli Counter (G. Roberts; SIO)****:* We have designed a light-weight continuous-flow thermal gradient diffusion chamber to improve our measurements of cloud condensation nuclei (CCN) (*Roberts and Nenes*, 2003). This instrument was developed for autonomous operation in airborne studies employing a novel technique of generating a

supersaturation along the streamwise axis of the instrument. Although similar in design to CCN instruments developed by *Hoppel et al*. [1979], *Leaitch and Megaw*, [1982] and *Chuang et al*., [2000], our instrument establishes a linear temperature profile along the streamwise axis to maintain a quasi-uniform supersaturation along the streamwise axis of the chamber. Model simulations suggest that direct measurements in the climatically important range of supersaturations of less than 0.1% are possible.

We have successfully tested the instrument during airborne experiments – Instrument Development and Education in Airborne Science (IDEAS) project at NCAR in April 2002 and the Cirrus Regional Study of Tropical Anvils and Cirrus Layers - Florida Area Cirrus Experiment (CRYSTAL-FACE) in July 2002. The results from the CRYSTAL-FACE campaign have yielded a remarkably good aerosol/CCN closure at 0.2% supersaturations shown in Fig. 7. Another instrument employing the same technique also operated successfully at 0.8% supersaturation. CCN concentrations were measured with a sampling resolution of 1Hz at a fixed supersaturation and compared to dry aerosol size distributions on one-minute intervals.

We have applied for a patent on this new design (*Roberts, G., A Nenes*; UCSD Disclosure #SD2002-186) and are working with Droplet Measurement Technologies in Boulder, CO to develop a commercial version of this instrument. Such an instrument will be vital in understanding the link between aerosols and cloud formation.

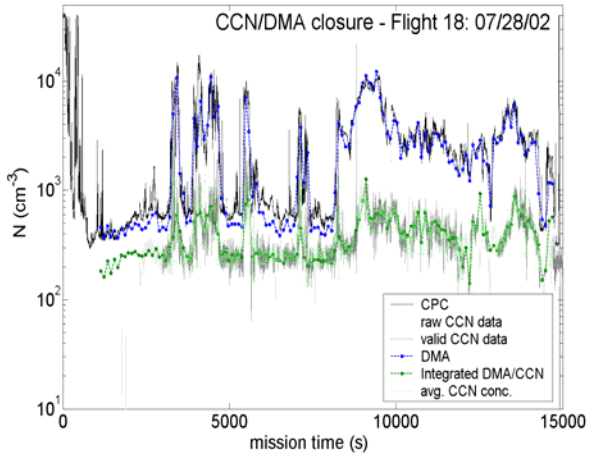



Figure 7: Time series of CCN and size distribution closure during a research flight on 28 July 2002 during CRYSTAL-FACE. The blue and black lines show the total aerosol concentration, and the green lines show the predicted and measured CCN concentrations assuming an ammonium bisulfate aerosol.

***Aerosol Absorption, Single Scattering Albedo and Radiative Forcing (D. Savoie; B. Holben and V.Ramanathan*):** One of the most important goals of the radiometric observations is to determine the aerosol absorption near the surface and for the column.

*Aerosol absorption and Single Scattering Albedo (D. Savoie):* The near-surface aerosol absorption will be determined by 3-wavelength nephelometer and PSAP and high spectral resolution radiometer. In addition, bulk filters will additionally be analyzed for spectrally resolved aerosol absorption (from 300 to 1100 nm wavelength at 10 nm intervals). Aerosol absorption measurements are calculated from the total diffuse reflectances from 25-mm diameter punches from the bulk filters as measured with an Optronics OL 740A Spectroradiometer with an OL 740-70 Diffuse Reflectance Attachment (integrating sphere). The remainder (about one-half) of each filter sample will be archived. UMia will analyze these samples first for spectrally-resolved aerosol absorption and then for the major water-soluble ions. Previous test at UMia have shown that there is no significant contamination of the samples during the absorption measurements. Comparisons with results from the bulk samples will, by difference, additionally yield information regarding the composition and light absorption properties of the supramicron particles. Supramicron size fractions are typically dominated by mechanically produced sea-salt and soil dust aerosols. In contrast, sub-μm fractions are typically dominated by compounds produced primarily by gas-to-particle conversion and are highly acidic (pHs from <2) (e.g., *Huebert et al*., 1996; *Keene et al*., 2002).

Spectrally-resolved light absorption by aerosols between 300 to 1100 nm at 10 nm intervals with a 5 nm bandwidth will be quantified by Total Diffuse Reflectance (TDR) Spectroradiometer coupled to an OL 740-70 Diffuse Reflectance Attachment (DRA) (*Ball et al*., 2002; *Savoie et al*., 2003). At each wavelength, reflected light intensity is automatically monitored until three successive readings fall within ±0.5%. The average of these three readings is then recorded. Absorption is determined by comparing the reflectance of a sample ($R_S$) to the corresponding reflectance of a blank filter ($R_B$). The aerosol absorption coefficient ($Abs_{Coef}$) is given by:

$$Abs_{Coef} = \ln(R_B/R_S)/(V_S/A_S)$$

where $Abs_{Coef}$ is in terms of $Mm^{-1}$, $V_S$ is the sampled air volume and $A_S$ is the active area of the sample filter. Results from previous analyses using Whatman-41 sampling substrates shows that the spectra of "black soot" are consistent with Mie estimates based on a constant index of refraction (both real and imaginary parts) and a reasonable particle size. Comparisons

during a National Institute for Global Environmental Change (NIGEC) campaign in North Carolina and during INDOEX aboard the R/V Ron Brown showed that the magnitude of the absorbance at 565 nm for "black soot" by this technique is virtually identical to that obtained from a PSAP (Particle Soot Absorption Photometer).

In contrast, the results obtained during the Puerto Rico Dust Experiment (PRIDE) depart sharply, with the PSAP yielding only about 40% of the total absorption measured with TDR. In this latter experiment, the major absorbing species was supramicron Saharan dust. These results suggest that the PSAP was undermeasuring the soil dust absorption by a factor of about 2.5 during PRIDE. The difference is attributed to a substantial loss of supramicron soil dust particles within the PSAP as a consequence of a sharp turn in the air stream prior to the sample filter. Given the need to accurately correct total aerosol absorbance for that due to soil dust in order to estimate BC absorbance, it is imperative that the soil dust absorbance be accurately measured. The column average single scattering albedo will be determined by the solar-aureole data from CIMEL (*Dubovik et al*, 2002). This technique was validated in INDOEX with in-situ aircraft data.

***Radiometric Measurements:*** One of the fundamental results from the ABC observatories is the direct determination of the aerosol forcing at the surface and the energy absorbed by the aerosols within the atmosphere. Solar radiation broadband and visible fluxes will me measured at the surface to determine the aerosol surface forcing as per the method of *Satheesh and Ramanathan*, (2000; see figure 6g). Accuracy and precision (i.e., reproducibility) of the radiometric measurement is vital to the study since we are concerned with changes of the order of several watts per square meter. Kipp & Zonen group Pyranometers and pyrheliometers are more reliable radiometers and commonly used to measure irradiances at the surface in a long-term, monitoring mode (*Satheesh et al*, 1999; *Satheesh and Ramanathan*, 2000). These instruments are characterized by its high sensitivity, low impedance, low temperature response, and low nonlinearity.

The ventilated Kipp & Zonen pyranometer (CM21 type) is designed for measuring irradiance (0.3-2.8 μm) on a plane surface, which is a measure of both the direct and diffuse radiation. This instrument does not exhibit tilt dependence thus it can measure solar radiation at high solar zenith angels as well. It has an absolute accuracy of about ± 2%. The error in the total pyranometer due to directional response (that is, the detector responds differently to radiation

depending on the incident angle) is ±10 $Wm^{-2}$. Kipp & Zonen pyrheliometer (CH1 type) measures direct solar flux (0.28–4.0 μm), which results from the radiant flux from a solid angle of 5°. The absolute accuracy of this instrument is ±3 $Wm^{-2}$, with a precision of about 1% per year. Sun tracker and shadow ball arrangement measures diffuse component by shielding the pyranometer (direct component). Diffuse radiation when added to the direct solar flux from the pyrheliometer, gives us the global solar flux.

The total mount of solar radiation absorbed within the atmosphere by aerosols will be determined by the aerosol-forcing efficiency technique of *Satheesh and Ramanathan* (Fig. 6g). In this method, time series of downward radiation fluxes are correlated with visible aerosol optical depth (AOD) to determine the surface forcing efficiency, i.e., the rate at which aerosols decrease the solar flux at the surface. Likewise, the top-of-atmosphere (TOA) forcing efficiency is determined by correlating satellite measured upward flux at TOA (by TERRA and AQUA) with AOD (see the right hand panel of Figure 6g). The difference between the TOA efficiency and surface efficiency is the absorbed energy per unit optical depth. For the INDOEX region, the atmospheric absorption increased at the rate of 50 $Wm^{-2}$ per unit AOD. This technique provides a powerful constraint for models.

**Quality Assurance Statement**

A quality system for the project measurements will be put in place that meets or exceeds the data quality objectives of the ABC monitoring program and the other end users of the data generated by the project. Through a process of continual improvement and in cooperation with NOAA and the Global Atmosphere Watch (QAW) QA/SAC at the State University of New York in Albany, quality assurance and quality control procedures will be developed for the monitoring program that will help establish a foundation for future climate monitoring efforts. Throughout the monitoring effort emphasis will be placed on the technical accuracy of the work done. This applies not only to the actual sampling, analytical work, modeling, as well as written and verbal reports. In order to maintain and develop personnel capabilities, people involved in the project will undergo continuing training. The project will also provide a work environment based on the integrity and professionalism of its staff. Such an environment will help ensure that the work is performed with a dedication to excellence and continuous improvement. Since the measurements that will be produced by the ABC monitoring program are already being conducted by the project team for other projects sponsored by NOAA and other federal agencies, including EPA,

DOD, NSF, and DOE, the QA/QC efforts of the project will directly parallel these existing projects.

***Criteria for determining acceptability of data quality*:** A key aspect of the acceptability criteria for the data generated as part of the project will be an accurate reporting of the uncertainty of all reported measurements. The uncertainties of these measurements will be based on field blanks, analytical and procedural blanks, calibration standards, spiked samples and standard reference materials. In addition, the accuracy of the measurements will be evaluated and quantified through intercomparison studies for both field instruments and laboratory analyses. The project team will not only participate in intercomparison studies but will also lead such efforts. An example of such effort by the project team is the ACE-Asia intercomparison study for organic and elemental carbon in atmospheric particulate matter samples (Schauer et al., 2003), which was lead by Dr. Schauer. The project will help to facilitate intercomparison studies of this nature through collaboration with other research teams and Global Atmosphere Watch (GAW) QA/SAC at the State University of New York in Albany

***Procedures for the handling and custody of samples*:** Acquisition of meaningful aerosol chemical and microphysical data at atmospheric monitoring sites requires strict adherence to "clean" protocols and rigorous quality control (QC). We will assign unique IDs to every sample and maintain sample records from field collection to final data reduction.

***Methods, calibration and performance evaluation*:** Standard operating procedures (SOPs) with detailed QA protocols for all methods used in the project will developed and will be provided to the NOAA. Instruments are calibrated with blanks and standards. A series of blanks and standards are run to bracket the expected range of samples. The sensitivity of the instruments is monitored throughout by running check standards and blanks with samples. For organic and elemental carbon, as well as molecular markers in aerosols samples, certified standards are not currently available. To this end, the standards used in the project were prepared and checked in collaboration with the EPA NRMRL lab. As new standards and standard reference materials are developed over the course of the project, these standards and reference materials will be intergrated into the project. In cases where standards are not available, the identification and quantification of these compounds will be clearly noted and the basis for identification and quantification will be clearly provided in all data reports and manuscripts.

***Procedures for data reduction and reporting*:** Unique IDs will be used throughout this study to track samples. Electronic copies (Excel spreadsheets) of all data will be made and verified from original field notebooks, analytical bench sheets and integrator printouts. Once accuracy of electronic files is ensured, sample concentrations will be calculated using computer programs that are fully documented. For sample comparisons, an appropriate test will be run depending on the particular question as summarized in the below table. The assumption of normality will be tested and if necessary, data may be log transformed. If data are not normally distributed, non-parametric tests will be employed.

*Statistical methods for data evaluation:*

| ***Data comparison*** | Parametric | ***Non-Parametric*** |
|---|---|---|
| comparison of 2 variables | Pearson Correlation | Spearman Rank Correlation |
| comparison of means from two groups | t-test | Wilcoxon Rank Sum Test |
| comparison of means from multiple groups | Analysis of Variance (ANOVA) | Kruskal-Wallis Test |

***Quantitative and/or qualitative procedures used to evaluate success of the project, peer review*:** The success of this project will be evaluated on the basis of whether sample collection and laboratory studies answer the main project hypothesis listed in the project summary. Through our previous work and collaborations detailed in the proposal, we have refined our sampling and analysis approach. For new analytical methods, we will consult with others conducting similar research and share samples for comparisons of techniques. We plan to meet with other researchers conducting similar measurements and plan to participate in laboratory intercomparisons to ensure the quality and transferability of results among other related projects.

**Calibration of Radiometric Instruments**: We will conform to or exceed the BSRN standards and work closely with Dr. E. Dutton (NOAA) to develop our procedure. All of the radiation instruments namely, Kipp & Zonen Pyranometers and Pyrheliometes will be calibrated under the protocol of BSRN and NOAA (E. Dutton) once a year. The radiation instruments at super observatories (SO) will be calibrated once a year using NOAA facilities. In addition one set of instruments will be calibrated and they will be taken to each and every MO and CS to check and correct the calibration at the site itself. BSI instruments will be calibrated at the BSI Company, which is located in San Diego. Based on our experience at the Kaashidoo Climate Observatory (KCO) that radiation instruments needs calibration once in a year on a regular basis.

## Data Assimilation and Model Development

***Regional Aerosol Radiative Forcing and Source Apportionment - Integration of Observations, Satellite Data and Modeling (V. Ramanathan)***: INDOEX (R2001a) successfully integrated field measurements with satellite and models to estimate the regional aerosol forcing. We will adopt the INDOEX approach for integrating surface observations with models and satellite data (Fig. 8).

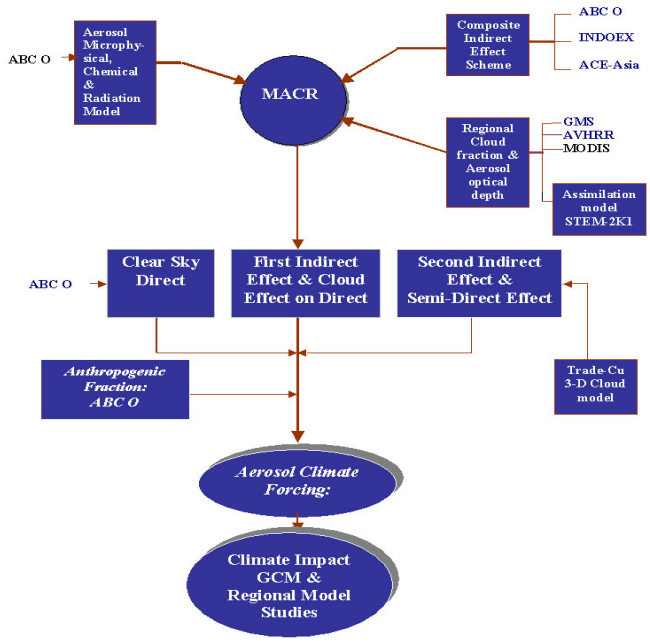



Figure 8*:* Adapted from the INDOEX data integration scheme taken from *Ramanathan et al* [2001a]. Ground based data are measured by the ABC observatories and ship/aircraft campaigns, if any. Field data from INDOEX, Ace-Asia and CCN data from ABCO (observatories) will be used to develop indirect effect scheme. CERES (Clouds and Earth's Radiant Energy System), a radiation budget instrument onboard the TERRA and Aqua satellites provides the TOA forcing and surface radiometers will provide surface forcing. These data along with satellite and the regional assimilation model STEM-2K1 output will be injected in MACR to produce regional forcing. The filter sample chemical data will be used to estimate the anthropogenic fraction of this forcing. This will be used in climate impact studies using GCMs.

The focal point of the data integration scheme is the Monte Carlo Aerosol-Cloud-Radiation (MACR) model, a numerical algorithm allowing a careful analysis of the relative contribution of aerosol species to the aerosol direct and indirect forcing [*Podgorny et al*., 2000; *Podgorny and Ramanathan*, 2001]. MACR includes:

- A model for the natural and anthropogenic aerosols (hybrid mixing of inorganic, organic and black carbon species) over the oceanic regions impacted by Asian outflow (e.g., *Satheesh et al*., 1999, 2002),
- Satellite aerosol retrieval models constrained by the surface INDOEX observations (*Rajeev et al.*, 2000; *Rajeev and Ramanathan*, 2001; *Li and Ramanathan*, 2002).
- 3D Monte Carlo (MC) radiative transfer model for computing aerosol radiative forcing in the atmosphere (*Podgorny et al*., 2000; *Ramanathan et al*., 2001a; *Podgorny and Ramanathan*, 2001, and references therein).
- An indirect effect scheme developed from aircraft data (R-2001a). This scheme will be modified with CCN data collected from the ABC observatories.

The MACR will be driven by data from the following components: ABC observatories; Satellite data for regional AOD and cloud distribution and STEM-2k1 model for aerosol chemical components and vertical distribution. Fig. 6f exemplifies various sources of data on aerosol single scattering albedo during INDOEX. MACR as well as the data integration scheme have been documented extensively (R-2001a). Another key ingredient of the integration scheme is the regional aerosol assimilation model described next.

***Linking the Source to the Forcing: Chemistry –Transport Modeling and Data Assimilation (G.Carmichael):*** The regional transport and chemistry modeling will be carried out using the STEM-2K1 model. The objectives are to provide realistic estimates of the spatial and temporal distributions of aerosol optical and chemistry information (which will be used as inputs to the MACR model to estimate aerosol radiative forcing) and assess the relative importance of coal combustion, diesel emissions and fossil fuel combustion on the observed absorbing aerosols. The STEM-2K1 model has been used extensively in Asia, and recently was applied in the design and execution of the NASA TRACE-P, the NSF ACE-Asia, and the NOAA ITCT-Y2K2 intensive field experiments. A detailed description of the model and a rigorous evaluation of the model performance using the Trace-P and Ace-Asia observational data is available in *Uno et al.,* (2002) and *Carmichael et al.*, (2002). Figs 9-10 are illustrative examples of model results for BC and dust. The calculated BC is compared to surface observations at the four sampling sites located along ~140°E (the time series are arranged so that the top is the most northern site etc.). These results show that the model (and emissions) is able to capture many of the important features in the observed time series.

The STEM-2K1 model will be used to estimate aerosol distributions over Asia with a horizontal resolution of 60 km (same as the RCM). Size-resolved aerosol distributions of BC, wind blown soil dust, OC, nss-sulfate, sea salt, nitrate, and primary in-organic particles due to fly ash, cement manufacturing and the like, for the Asian domain that spans Pakistan to Japan, and Indonesia to Mongolia will be produced. The emissions inventories needed for this study will build upon those that have already been developed and used in the analysis of the Trace-P, Ace-Asia and ITCT-Y2K2 experiments. Anthropogenic emission inventories (SOx, NOx, CO, CO2, NH3, Black Carbon, Organic Carbon and Hydrocarbons) were prepared specifically for the Trace- P and ACE-Asia experiments and were based on year 2000 grided annual emissions. A unique aspect of this bottom-up inventory is that it is driven by regional-specific information on fuels and activity. Biofuels and fossil fuels can be tracked separately, as can emissions from

various economic sectors (e.g., domestic, transport, power generation, industrial). Emissions from specific regions and even megacities can be isolated. The details of the inventory are presented in *Streets et al.,* and *Woo et al.,* (2002). A summary of the combustion (fossil, biofuel and in-field biomass) emissions and details on the methodology can be found on the ACESS web site http://www.cgrer.uiowa.edu/EMISSION_DATA/index_16.htm. These inventories will be modified during the course of this study as new information becomes available.

Special emphasis will be placed on the attribution of ambient BC levels to source categories including biomass burning, biofuel, diesel, coal, etc. The regional aerosol model will be driven by the meteorological fields provided by the regional climate model operated in a data assimilation mode. The meteorological data assimilation will be performed by Leung and colleagues at PNNL. An important element of the regional aerosol modeling analysis will be related to the assimilation observed AOD to improve the 4-dimensional representation of aerosol distributions in Asia. The assimilation techniques for STEM-2K1 are presently being developed under a new NSF Information Technology Research (ITR) grant. This 5-year project begun in August 2002 is devoted to aerosol and chemical data assimilation in regional and global models. These developments will take place with the NSF funding, and only the application to Asia for the ABC analysis will be funded by this proposal. The assimilation techniques will be focused on not only on providing optimally constrained estimates of AOD, but also on improving the regional emission estimates.

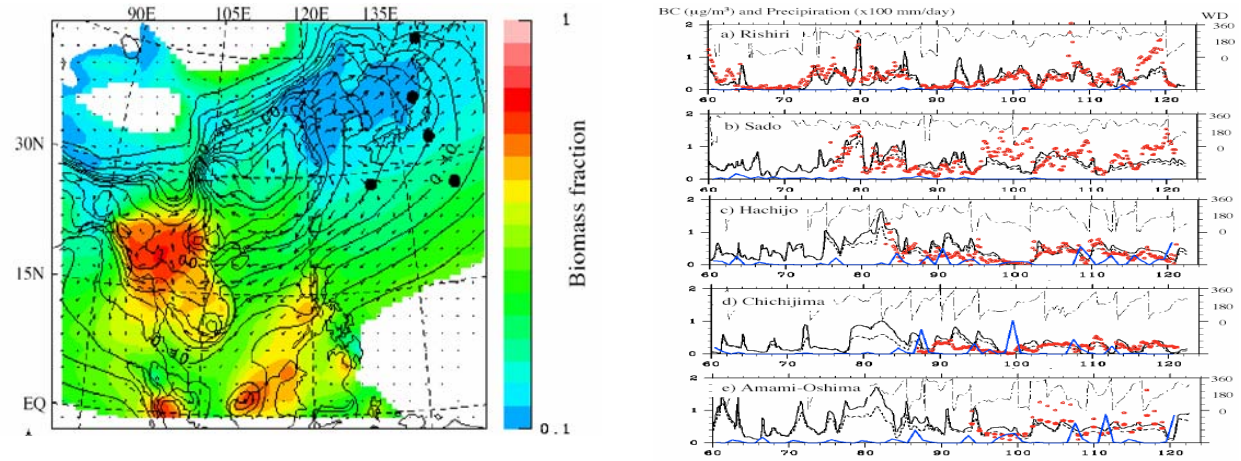



Figure 9. Left: Spatial distribution of BC concentration in ug/m$^3$ (line), biomass burning fraction (color), and horizontal flux of BC in ug/m$^2$/s (vector) averaged over March and April 2001. Right: Comparison of simulated BC with observation at the four sampling sites located along ~140E (the time series are arranged so that the top is the most northern site, etc, as shown on the left).

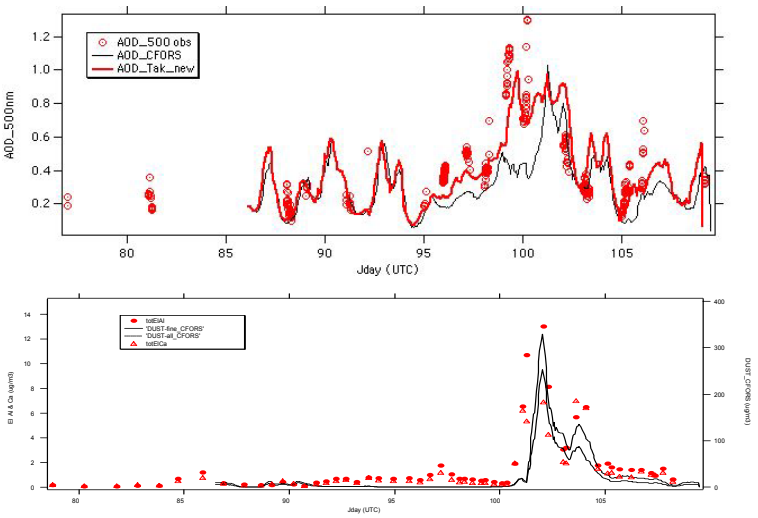



Figure 10. Comparison of observed and simulated AOD (upper) and dust (lower). For the upper panel, open circles represent observed AOD, black line represents the *a priori* simulation, and red line represents simulation with adjusted (crude assimilation) emissions from the TaklaMakan desert. The observations were taken on board from the research vessel "Ron Brown".

***Scientific Users and Uses of the Data*:** The ABC international science team, the aerosol assimilation modeling groups, the general circulation modeling community and the IPCC - aerosol radiative forcing groups will be the initial users of the data. The National Aerosol Climate Interactions Program (NACIP), a group of about 50 American aerosol and climate modeling researchers, will be entrained into the use of the data. We fully expect our international collaborators to do the same in their respective nations.

***Data Archival*:** The data from all of the ABC observatories will be archived at C4, the UNEP regional center at Bangkok and WMO-GAW program, using common format and protocol recommended by WMO. In addition, C4 will maintain the C4 data integration scheme (CIDS) developed for the CEPEX and INDOEX field campaigns since this scheme facilitates integration of surface and aircraft data with satellite data and model output. One full time programmer will be designated at C4 for this purpose.

***Sustainability of the Observatories*:** The current proposal is for five years. At the end of four years, we will assess the success of the observatories. If our scientific objectives are accomplished, we will then recommend a reduced set of long-term observations (for monitoring purposes only) for another five years that can be sustained through NOAA funds and commitments from regional governments. We also anticipate that, by the end of the first five years, the operation of the observatories will become the major responsibility of WMO-GAW program and the governments in the region where the sites are located with C4 and the ABC science team serving in an advisory capacity and as users of the data.

**Project Management**

The Atmospheric Brown Cloud-Asia (ABC) Project is an international research effort initiated by the United Nations Environment Programme (UNEP) for Asia and the Pacific (EAP-AP). The ABC science team consists of scientists from China, Europe, India, Japan, Korea and the USA. The ABC secretariat for science is located at the Center for Clouds, Chemistry and Climate ($C^4$) at the Scripps Institution of Oceanography (SIO) at the University of California, San Diego (UCSD). The ABC secretariat for policy is located at the UNEP EAP-AP headquarters in Bangkok.

The two main components are observations and regional impacts modeling. The present proposal to NOAA is to set up regional aerosol-chemistry-climate observatories. Of the 10 new proposed ABC observatories in the Indo-Asia-Pacific region, about half of the total funding will be requested from NOAA while the rest by the governments of China, Japan, Korea and India. In addition, UNEP has also initiated contacts with research foundations in Scandinavia (SIDA and NORAD) to fund European participation in the observatories. The PI and his management team have demonstrated experience in conducting field research with international funding for INDOEX which was led by C4 with major funding from NSF, NOAA, DOE, NASA, European and Indian funding agencies. It is our goal and expectation that these ABC observatories will become an integral part of other global observing systems such as WMO-GAW, UNEP-EANET, NOAA's, NASA's and DOE's regional networks amongst others. Regional capacity building, training of young scientists and students, impact analysis and integration with impact studies in agriculture, health, and policymaking will be the hallmark of this ABC program. The funding requested under this NOAA proposal includes the manpower required for processing, management and distribution of the collected data.

C4 and the NOAA-funded investigators of this proposal will have the primary responsibility for the following sites: 1) Maldives; 2) Nepal; 3) Malaysia and 4) Midway. In addition, other NOAA-funded scientists (other than in this proposal) will have the primary responsibility for the sites in Mauna Loa (R. Schnell) and Trinidad (R. Weiss of SIO and NOAA Lab). With respect to all other sites, scientists from the nation where the site is located will have the primary responsibility to operate the site. These scientists are included here as international collaborators. We have begun work with the scientists responsible for each of the other sites in: China (Guangyu Shi for Beijing and Mao Jei Tai for Hefei), Andamaans in India (R. Pachauri; A. Jayaraman of PRL; K. Krishnamoorthy of SPL; and A. P. Mitra), Japan (H. Akimoto and T.

Nakajima), Korea (K. Kim and B. J. Sohn for Gosan and Jiyoung Kim for Anmyon), Nepal (B. Shrestha of ICIMOD Institute), USA (R. Schnell for Mauna Loa; J. Prospero and D. Savoie for Midway and R. Weiss for Trinidad). NOAA funds through this proposal will be used to augment the observations in these sites by providing the instruments, calibration and training facilities. We anticipate one of the two following structure to facilitate ABC participation in these sites: each site will have an international steering committee chaired by a scientist from the nation where the site is located with members from the ABC team; or each region will have its own steering committee and an ABC member will represent ABC in this steering committee.

Specific surface laboratory management will be modeled after the successful Kaashidhoo Climate Observatory established in the Maldives during 1998-2000 for INDOEX. For each station, NOAA-funded or otherwise, the intricate and delicate negotiation will have taken place prior to the signing of a Memorandum of Understanding (MOU). This document set forth the legal relationship between Project ABC (represented by SIO/UCSD, home institution of the PI and the ABC Science Secretariat) and the cognizant agency representing the host nation where the observatory is located. At the existing sites that ABC will supplement with instruments, the MOU could be a tri-party (ABC, host country and third national funding organization) document in case ABC instruments will be located within the immediate facility operated by a specific organization or agency.

For the NOAA-funded sites, beside the aforementioned Site Steering Committee, there will be a Science Team (consisting of all instrument PIs), a scientist-in-residence (chosen from the region where the site is located) to coordinate the daily operations, a site scientist (located in C4) who will take the responsibility for calibration, quality control, quality assurance, and data analysis, a government liason/manager (local personnel) and the site manager (H. Nguyen located in C4) who will be working closely with the Project PI to ensure smooth daily operations, meeting all business contractual obligations as well as national and international obligations. The MOU also speculates the terms of collaboration including construction of the facilities and the instrument tower(s), supply of electricity, instrument and lab operations, import and export of instruments and equipment, site security, data collection, analyses and access, and training of local and regional personnel. The MOU also establish final disposition of the real estate, or the lab building and the instrument tower (while titles of the instruments and equipment remain vested in the original owners). At the end of an agreed upon period, titles can be transferred from SIO/UCSD and/or NOAA (and other future funding agencies) to a regional

consortium of interested parties led by the appropriate agency in the host country. The host country is encouraged to incorporate the transferred facility into the nation's research infrastructure while the site to remain scientifically part of the Global Climate Observing System.

**Schedule and Interim Milestones**

Year-1:

Initiation of 4 observatories in the Maldives, Nepal, Midway and Gosan. The first emphasis will be to start the super observatory at Maldives. Aerosol chemistry, radiation and lidar measurements will be started in Nepal and Gosan. At Midway, the U. Miami group will resume the filter samples for major ions and mineral dust; and NASA will deploy the AERONET sun photometer. Undertake single particle analysis at Nepal.

Establish the monthly mean time series of aerosols, black and organic carbon content, single scattering albedo and direct forcing.

Year 2: Update Nepal into Main Observatory (MO), Gosan into a SO. Also, initiation of limited observations in Andamaans (LIDAR and aerosol filter analyses of BC/OC and major ions), Amami-Oshima/Hateruma (aerosol BC/OC and major ions) and Hefei (aerosol BC/OC, major ions, radiometers and Lidar). Undertake single particle analysis in Gosan and Amami-Oshima.

Year 2: Establish the time series of quantities mentioned above; determine source characterization using the molecular markers; validation of the regional source-receptor model; integration of local (in situ) measurements with satellite data and regional aerosol assimilation model.

Year 3: Update Andamaan, Amami-Oshima/Hateruma and Hefei into MOs. Initiate MO in Malaysia & Hebei; and CS (aerosol filter samples and aerosol absorption) in Minamitorishima. Undertake single particle analysis at Hefei and Hebei.

Year 3: The first estimation of the regional distribution of black carbon, organic carbon, single scattering albedo and aerosol forcing will be completed. We will also characterize the

forcing with regional emission sources. The regional data will used to validate the aerosol assimilation model of NCAR and GFDL's GCM simulation of aerosols forcing.

An IPCC-style aerosol forcing will be published along with the contribution of the Asian region to global radiative forcing. We will compare this forcing with estimates from about 10 GCMs from around the world.

A major review of the performances (science and Managerial) of the observatories will be conducted with a review committee chosen in consultation with UNEP and NOAA.

Years 4: Simultaneous measurement of temporal evolution of aerosol composition and optical properties in all the 13 observatories will be available for comparison with model simulation. Undertake single particle analysis at Andamaans and Minamitorishima.

Monthly average distribution of all aerosol species for all sites will be available for comparison with model output.

Regional model of aerosol sources and distribution: completion of characterization of the sources; production of regional maps of BC, OC, ions and single scattering albedo.

We will start impact studies of Asian aerosols with GFGDL and NCAR GCMs.

Year 5: Baseline estimates of averages of all quantities and their seasonal and inter- annual variability will be established; aerosol forcing and its anthropogenic fraction will be established; a first detailed description of the source apportionment will be completed.

We will update the IPCC-style aerosol forcing published during Year-3.

We will compare this forcing with estimates from several GCMS from around the world.

**Performance Measures**

Year 1: Successful operation of the Super observatory in Maldives and supplementary observations in S. Asia and Indian ocean, and preliminary data of seasonal distribution of black carbon, organic carbon, major ions and single scattering albedo. Currently, such observationally constrained regional distribution of black and organic carbon, single scattering albedo does not exist. In principle, this constitutes a 100% improvement in our knowledge of black carbon in S. Asia.

Year 2: Currently, such observationally constrained regional distribution of black and organic carbon; single scattering albedo and aerosol radiative forcing estimates do not exist. In principle, this constitutes a 100% improvement in our knowledge of aerosol black carbon and forcing for the Indo-Asia-Pacific region.

By comparing these observed forcing, aerosol absorption and single scattering albedo with climate models (e.g. GFDL or NCAR), we expect at least a factor of 2 improvement in their accuracy.

Year 3: The regional forcing estimates provided by this project will contribute significantly to IPCC estimates of global mean aerosol forcing. Currently even the sign of the direct forcing for absorbing aerosols in the tropics is open to question. Thus a reliable estimate of the forcing for the Asian region will make a major improvement (about 50%) in our estimates of the forcing.

Year 4 & 5: The surface forcing estimates provided by this study is fundamental to understanding of the impact of aerosol on the hydrological cycle. In addition the characterization of the aerosol sources by integrating data with satellite and assimilation model (STEM-2K1) will also produce first time information on the aerosol sources. Such observationally constrained aerosol sources and the forcing estimates on climatologically relevant time scales (1 to 5 year average) and space scales (the entire Indo-Asian-Pacific region) are currently not available. This data product would constitute a quantum improvement in our understanding of the impact of aerosols on climate.

**Anticipated Research Results**

- Baseline data for aerosols, black and organic carbons, single scattering albedo and radiative forcing
- Baseline data for aerosol sources including natural, fossil fuel and biomass burning
- Validation of satellite retrieval of aerosol AOD and absorption
- Regional distribution of aerosol species including black and organic carbon and single scattering albedo for input to GCMs.
- Regional distribution of anthropogenic aerosol forcing for IPCC-style forcing estimates

**Relevance of Work and Synergistic Activities**:

- Will make a significant improvement on the IPCC estimates of aerosol forcing;
- Will make a significant improvement in the finger printing of anthropogenic climate changes;
- Will aid the Asian region in better policy actions to curb the impacts of air pollution on health, agriculture and climate.
- Will closely integrate these data with NOAA's-GFDL GCM. We are collaborating with Dr. V. Ramaswamy's group to enable this collaboration.
- The observatories will also become part of WMO-GAW, BSRN, AERONET and EANET networks and thus leverage these activities.

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