Long-range transport of Asian dust and its effect on oceanic ecosystem: summary, scientific plan and challenge to ADOES

1. Background

Dust storm is a natural phenomenon. A historical record of dust storm events in China can be tracked back one thousand year ago (Zhang, 1984; Shi et al., 2003). Dust storm is not only the result of a natural process, but also, in some extent, it is enhanced by human activity such as estrepement, over grazing, biomass denudation and abuse of water resources. Dust storm carrying a huge amount of mineral dust from desert and Gobi is of considerable scientific importance because of its role on human health and climate, e.g., its influences on global radiation balance, cloud processes, atmospheric chemistry (Arimoto, 2001; McKendry et al., 2007). The huge amount of mineral dust deposits in ocean and would impact upon ocean biogeochemical cycling and ecosystem, improve marine primary productivity and exert direct and indirect influences on regional and global climate (Jickells et al., 2005).

Since 1980s, a variety of studies associated with dust events have been performed, including mineralogy, chemical composition, geologic processes, transport, deposition, optical properties, particle size distributions of globally transported dust and the linkage between dust and atmospheric environment and climate change (Arimoto et al., 2001; Shi et al.,, 2003). The main sources of globally distributed dust are figured out, including the Sahara-Sahel region of Africa, Taklimakan and Gobi deserts of Asian, Australian deserts and Northern America (Zhang et al., 2003). Soil-derived particles account for a large fraction of atmospheric particles, with radii ranging from less than 0.1μm to 100 μm (Arimoto et al., 1997; Prospero et al., 2002). Particles larger than 5 μm are present only in source regions while particles in the size range from 0.1 to 5 μm have a lifetime from hours to weeks, allowing long-range transport over thousands of kilometers from their sources (Arimoto, 2001; Prospero, 2001, 2003). Dry and wet deposition of these particles leads to a large gradient of dust concentrations and deposition fluxes that vary substantially on time scales of ～1 day（Jickells et al., 2005）.

There have been a number of investigations in the literature regarding the transport of aerosols from the continents to the ocean (Bergametti et al., 1989; Arimoto et al., 1995; Gong et al., 2003;

Zender et al., 2003; Zdanowicz et al., 2006). They reported the existence of Saharan dust even over the remote areas of the Atlantic and Pacific Oceans, and some studies reported that trans-Pacific Asian dust can be often detected in the subarctic and tropical Pacific oceans. In recent years, the dusts event from South America and their effect on the South Atlantic Ocean have been found (Erickson et al., 2003; Gasso et al., 2007).

Dust sources in East Asia are also the major dust sources on the earth. Asian dust generates at high latitude and high elevation while it is not case for other dust sources. The characteristics of Asian dust in morphology, soil texture, and dust storm activities are unique (Xuan al., 2000; 2002; 2004). Asian dust is driven by the synoptic condition different from others. For example, Asian dust, particularly in the source region of East Asia, frequently occur in spring (Littmann, 1991) while Sahara Desert and most other sources frequently occur in summer (Prospero et al., 2002).

Deserts in Middle Asia, Northwestern China and the boundary area of China and Mongolia are the major source regions of Asian dust. Studies show that dust storm in different extents actually occur in any season including in summer and fall in the proximity to the source area, although the regional outbreak mainly occur in spring.

Although the data and analysis methods used in those studies are different, both the frequency of dust storm (include blowing dust and dust storm) and dust storm days are found to vary greatly year-by-year since 1950's. There is an evidence to suggest that the frequency and magnitude of Asian dust storms has been on the decline since the late 1970s until recently, has a slight increase in 2000-2002, and 2006-2007(Qian et al., 2002; Ding et al.,2003； Shao et al., 2006; Chen et al., 2007). This is probably a result of the combination of human effort on environment protection and climate variability, but the explanation need more evidences.

The regions affected by the Asian dust storm include not only China and Mongolia but also the downwind Korea, Japan, the Pacific ocean, Hawaii, the west coast of America, even the subarctic region and Europe (Duce et al., 1980；Husar et al., 2001; Fang et al., 2002；Zdanowicz et al., 2006). The Asian dust storm is obviously a hemispheric scale phenomenon.

Annually, 10 to >10^2 Tg of soil-derived mineral aerosol are transported from the arid East Asian, contributing to 5%～40% of the global dust release estimated (Zhang et al., 1997；Luo et al.，2003; Ginoux et al., 2004; Tanaka et al., 2006). Asian dust can also deposit large amounts of nutrients (e.g. nitrogen, iron) into the coastal and Pacific Oceans, and impacting surface biological productivity and the air–sea exchange of CO_2 associated (Bishop et al., 2002; Yuan.,2006；Zhang et al, 2007). For the subarctic Pacific, an important HNLC (high nitrate low chlorophyll) region in the northern hemisphere, transport and deposition of mineral dust from Asia appears to be the major source of Fe (Duce et al., 1991). Phytoplankton growth in this region has been shown to be stimulated by increasing Fe concentration of the surface waters in the region, but it is still difficult to establish a cause-effect relationship between Asian dust passages and phytoplankton bloom events (Bishop et al., 2002; Yuan et al., 2006).

To promote the study on Asian dust and its effect on ocean ecosystem, ADOES (Asian Dust and Ocean EcoSystem) is proposed to be a new ad hoc task team under the frame of international SOLAS (Surface Ocean-Lower Atmosphere Study). The goal of ADOES is: To quantitatively understand the deposition flux and bioavailability of Asian dust, and its impact on biogeochemical processes in ocean ecosystem. This will provide scientific bases for the study of eolian dust-ocean ecosystem-radiative gases-climate change.

2. Scientific topics of ADOES

ADOES is initially proposed in the SOLAS open science meeting held in Halifax, in Oct., 2004. From 2005 to 2009, four international workshops have been held in China and Korea to address the scientific questions and to draft the scientific plan, all the studies on Asian dust, including outbreak mechanism, transport path, deposition flux, bioavailability and its comprehensive effects on ocean ecosystem, are in the scope of ADOES. In the next 5 to 10 years since 2010, we will focus on the topics, which are related to various SOLAS activities, particularly 1.4(Iron and Marine Productivity), 1.5 (Ocean-Atmosphere Cycling of Nitrogen), 2.1(Exchange Across the Air-Sea Interface) and 3.3(Air-Sea Flux of N_2O and CH_4).

The objective and research scope of each topic in ADOES are as follows:

2.1 Physical and chemical variations of dust aerosol during its downwind transportation

Objectives:

This activity aims to investigate and interpret the physical and chemical variations of dust aerosol during the transportation from the arid areas to the ocean. We are particularly interested in the interaction of dust participles with air pollutants from mega cities.

Scope of the study:

The knowledge and understanding of dust outbreak, transportation, dry and wet removing process remains rough and uncertain in a great degree and needs to be improved. This is because of lack of long-term, systematic and synthetic observational data, especially lack of studies of physical and chemical changes of dust during its transportation. For example, the particle concentration spectrum, distribution and shape etc. are variable, depending on their sources. These parameters may change significantly because of dry or wet removing; Dust particles can capture gases or coagulate solid particles and react with each other, leading to a change in chemical constituent. The overall purpose of the activity is to determine temporal-spatial distribution of dust aerosol, and quantitatively understand the changes of physical and chemical characters of dust particles during the transportation process.

- Main sources of Asian dust which can be transported to the Pacific Ocean.
- The probability of Asian dust reaching the coastal and open oceans.
- Physical variations (e.g. spectrum, hygroscopy) of Asian dust during its transportation from arid areas to the Pacific Ocean.
- Chemical composition change(e.g. carbon, sulfur, nitrogen, iron) of Asian dust during its transportation from arid areas to the Pacific Ocean

2.2 Transport pathway and layer distribution of dust and its deposition flux to northern Pacific Oceans

Objectives:

The objective of this activity is to investigate the transport pathway of dust from source to ocean and quantify dry and wet deposition flux of Asian dust to northern Pacific Oceans.

Scope of the study:

Asian dust affects over a broad areas of ocean in the northern hemisphere, including the coastal oceans such as the Bohai sea, Yellow sea，East China Sea, South China sea and Japan Sea, the tropical Pacific and subarctic Pacific. Transport passage of dust to coastal oceans could extend to the open ocean in some strong dust storm events, depending on atmospheric circulation system and latitude of dust sources and vertical distribution of dust. Atmospheric deposition is an important source of the nutrients, especially for the main limiting elements in oceanic system such as nitrogen and iron. Asian dust has a significant contribution to the nutrient structure of ocean through its dry and wet deposition. By means of field observation and model simulation, this plan will systematically investigate the processes of the transport and deposition of dust aerosols to seas; examine the transport path of dust aerosols to coastal oceans and the Pacific.

- Transport passages of dust from source to the ocean and their factors associated.
- Vertical distribution of Asian dust during the long-distance transport, and the horizontal fluxes across Chinese and Japan coast.
- Factors determining deposition fluxes of dust and the chemical composition over ocean (e.g. ABL, wave, cloud/rain microphysics and chemistry).
- Relative contributions of dry and wet deposition of dust and its chemical compositions over different ocean areas.

2.3 Impacts of dust on biogeochemistry and ocean ecosystem

Objectives:

The objective of this activity is to improve understanding of the role of dust on biogeochemistry processes in ocean ecosystem, particularly those occurring at the interface between atmosphere and ocean.

Scope of the study:

The aerosols originated from East Asia contain plenty of mineral elements such as iron and nitrogen, the deposition of which can stimulate the activity of the sea organism, change the transparent layer of the sea and increase the ocean production. The increase of photosynthesis in the seas also increases the air-sea exchange fluxes of active radiation gases. Through field studies, laboratory experiments and model simulations, we will focus on our research on the following aspects:

- Solubility and bioavailability of dust from different sources.
- Impacts of dust on Fe and nitrogen biogeochemistry between atmosphere and ocean.
- The role of dust input on marine primary production and dominant species of phytoplankton; episodic response of species composition and structure to the extreme dust storm deposition input.
- Effects of dust input on the air-sea exchange fluxes of active radiation gases (e.g. CH_4, N_2O,

DMS, CO_2).

It's estimated that Asian dust storms can carry more pollutants than African ones due to the greater densities of population and more industrial emissions on the transport pathway of dust. During transportation, dust particles can be modified physically and chemically through reactions with anthropogenic gaseous and particulate pollutants. These pollutants such as acidic gases and POPs (persistent organic pollutants) and microorganisms carried by dust are of considerable importance to the environmental change in the ocean system (Prospero et al., 2004). This modified-dust deposition into the ocean can exert chemical and biological effects on the surface ocean, although a quite uncertain remains. In addition, some of these pollutants may act as a tracer to identify the source of dust and route of dust transport.

3. Methodology and related programs

Field measurements, laboratory experiments, satellite data retrieval, and modeling studies will be combined to service ADOES scientific plan. Intensive observations will be performed to obtain reliable database, including time series of physical/chemical characters of Asian dust at multiple sites from source areas to depositional areas over continent and the Northern Pacific Ocean.

Field measurements and modeling studies both suggest that 30- 95% of total removal of dust is by wet deposition, but in considerable uncertainties. Wet deposition also exhibits a high spatial variation, depending on meteorological condition, aerosol size distribution and transport altitude of dust (Jickells, et al., 2005). An integrated dust transport model, which includes a wind erosion sub-model, dust ABL sub model, long-range dust transport sub-model, dry deposition sub-model and wet removal sub-model will be developed. The wet removal sub-model is necessary not only for the estimation of indirect cloud radiative forcing induced by dust, but for the estimation of dust and chemical composition deposition flux into the ocean.

Laboratory experiments will be an important part in ADOES. These experiments will include the laboratory incubation and mesocosm perturbation experiments on board of research vessel or special device in the surface ocean. The objective of these experiments is to provide first-hand data of the impact of dust chemical composition on primary production and ecosystem in coastal and open ocean.

Satellite data is the valuable resource for ADOES study, which can be used to identify the transport route of dust, and to estimate the dry deposition flux of dust and Chl.a concentration in the surface ocean.

ADOES is a research plan through source areas in northern west China to acceptation sites, e.g., coastal seas and open oceans in the Pacific Ocean, west coast of United States and Canada. To fully understand the impact of Asian dust on climate and ocean eco-system, international strategy and cooperation among Asian countries and the scientists from America and Europe are essential. An agreement has been signed by China SOLAS and Canada SOLAS in 2006 for a cooperative study on Asian dust and its effects on Pacific ecosystem. The preliminary discussion based on comparative study of Sahara dust and Asian dust has been presented by the scientists from Germany and China.

The research projects related to Asian dust have been conducted in the last decade, including Asian-Pacific Regional Aerosol Characterization Experiment(ACE-Asia)(Huebert et al.,2003), the NASA Global Tropospheric Experiment Transport and Chemical Evolution Over the Pacific(TRACE-P) (Christopher, 2003), the Asian Atmospheric Particle Environment (APEX)(Nakajima et al.,2003), The Aeolian Dust Experiment on Climate Impact(ADEC) (Mikami et al., 2006), the East Asian Studies of Tropospheric Aerosols: an International Regional Experiment (EAST-AIRE)(Li et al., 2007). These studies mainly focused on the climate effects and feedback of Asian dust. ADOES builds on these studies and attempts to improve understandings of impact of Asian dust on ocean ecosystem.

There are several on going researches related to ADOES such as China SOLAS program (Surface ocean - lower atmosphere study: biogeochemical and physical process coupling) Japan SOLAS program (W-PASS, Western Pacific Air-Sea interaction Study), Chinese CHOICE-C program (Carbon cycling in China Seas - budget, controls and ocean acidification), the Strategic Japanese-Chinese Cooperative Program on “Climate Change” (Response of marine ecological system in the marginal seas to open ocean of the western North Pacific to climate change), Sino-Canada joint program (Biogeochemical impacts of Asian dust on the North Pacific ecosystem and climate).

4. Task team co-ordination and members

One of the task co-coordinators, Prof. Huiwang Gao (College of Environmental Science and Engineering, Ocean University of China, E-mail: hwgao@ouc.edu.cn) will lead the study "Impacts of dust on biogeochemistry and ocean ecosystem", Prof. Mitsuo Uematsu (Center for International Cooperation Ocean Research Institute, University of Tokyo, uematsu@ori.u-tokyo.ac.jp) will lead the study "Transport path and layer of dust and its deposition flux to northern Pacific Oceans" and Prof. Guanyu Shi (Institute of Atmospheric Physics, Chinese Academy of Sciences, shigy@mail.iap.ac.cn) will lead the study "Physical and chemical variations of dust aerosol during its downwind transportation".

To promote and effectively implement ADOES, we propose to create a task team. The members represent key participating countries and critical scientific areas, and take a responsibility to provide scientific guidance for ADOES, and disseminate information about activities falling within this field, and to encourage international collaboration and national relevant activities.

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