A study of the influence of Chinese pollution on air quality in Japan

Project Summary

In the latter part of the 20th Century, China began its emergence from a primarily agrarian economy to become a major political and economic force. At the same time, and not coincidentally, China has also had a major impact on the environment, with soaring pollution levels (e.g., Irie et al., 2005; Richter et al., 2005), and greenhouse gas emissions that will exceed those from the United States by 2010 (World Energy Outlook, 2006). Numerous studies have revealed that air quality, like climate change, is not just a local, but also a regional and global issue that recognizes no political boundaries (e.g., Morris et al., 2006; Wotawa and Trainer, 2000), a fact that presents challenges for international relations. For example, ozone levels over Japan rose 11 – 20% from the 1970’s to 1990’s as a result of China’s enhanced NOx emissions (Naja and Akimoto, 2004), and pollution from China is projected to significantly impact the U.S.A. in the 21st century (Yienger et al., 2000). Global climate change will further exacerbate these problems. How will the international community address and solve such complicated environmental issues?

The Olympics in Beijing during August 2008 provide an unprecedented opportunity to examine and quantify the impact of China’s air pollution regionally and globally. China has promised cleaner air for the games, meaning at least temporary emissions reductions. I propose to examine ground-based, balloon-borne, and satellite observations of pollution made before, during, and after the Olympics. Through direct comparisons, I will quantify the impact of Chinese pollution on Japan and beyond.

Naja and Akimoto (2004) identify Kagoshima as an ideal location for this study. This site in Western Japan is regularly influenced by pollution from China and provides an excellent base from which to make observations. Japan has a long record of environmental monitoring data that will be useful for comparison with the data gathered in this study. In addition, since many of the world’s leading experts on East Asian pollution live in Japan, I hope to work closely with them, residing in Japan while conducting this research.

The proposed research will lead to an improved scientific understanding of regional and long-range pollution transport and to improved air quality forecast models, useful for personal and urban planning. The study leverages and will enhance my current research program of pollution transport within the U.S.A. Data from this study will enable scientists to more accurately quantify local and remote sources of pollution, thereby assisting government environmental agencies to better tailor plans for improving air quality. Furthermore, this project will provide critical information to policymakers in Japan, the U.S.A., and the international community that could shape international relations, help refine international law, and inform future international environmental agreements.

Objectives:
1) Review the impact of Chinese pollution on Japan’s air quality from historical measurements.
2) Determine the effectiveness of Chinese air pollution controls implemented during the Olympics.
3) Determine Chinese contributions to air pollution in Japan.
4) Demonstrate the effectiveness of new, ground-based air quality monitoring equipment from NASA.

Specific Tasks:
1) Evaluate historical pollution measurements in Japan to establish a pollution baseline.
2) Deploy NASA O3 lidar and NO2 instruments in Kagoshima before the Olympics.
3) Make pollution measurements in Japan before, during, and after the Olympics in 2008 and 2009.
4) Examine satellite data and use transport models to track pollution to source regions.
5) Compare data with air quality forecast model predictions.
6) Evaluate differences in NO2, O3, SO2, and aerosols measured in Japan before, during, and after the Olympics to evaluate China’s contribution to Japan’s air quality.
Project Statement

Background:

Ozone (O\textsubscript{3}) is an important trace gas species in the Earth’s atmosphere in concentrations at the part-per-million level. It is extremely effective at filtering energetic ultra-violet (UV-B) radiation from the Sun. While most O\textsubscript{3} is found in a stratospheric layer (20 – 30 km), ozone that affects air quality is generated by reactions of pollutants near the surface when nitrogen oxides (NO\textsubscript{x}) and hydrocarbons react in the presence of sunlight. Numerous studies have demonstrated the negative impacts on human health caused by both acute high-level and prolonged low-level exposures to O\textsubscript{3} (e.g., McConnell et al., 2002; Bell et al., 2004). Persistently elevated surface O\textsubscript{3} levels also reduce crop yields (e.g., Kobayashi, 1995), with impacts already observed in China (Chameides et al., 1999) and future losses projected for Japan due to enhanced East Asian pollution (Pochanart et al., 2002).

Emissions of NO\textsubscript{x} in East Asia have increased by over 125% since 1975 (Streets et al., 2003), mostly due to China’s industrialization. Such anthropogenic activity has altered regional O\textsubscript{3} pollution. Balloon data from Japan showed significant increases in tropospheric O\textsubscript{3} during the 1970’s and 1980’s, with increases in the lowest layer of the atmosphere over Western Japan of ~6 (±4)%/decade (Oltmans, et al. 2006). Asian pollution also has impacted North America (e.g., Jacob, et al., 1999; Berntsen et al., 1999) and was the subject of a recent international campaign (INTEX-B, the Intercontinental Transport Experiment B). Asia already has a bigger impact on the global emissions budget than the U.S.A. (Bey et al., 2001) and will play a dominant role in future global environmental change (Intergovernmental Panel on Climate Change, IPCC, 2001). The current IPCC report (2007) suggests that more intense, longer lasting, and more frequent heat waves during the summer in East Asia are very likely in the future (Christensen et al., 2007), resulting in conditions that further will exacerbate regional pollution.

Numerous studies have examined the seasonal variation of O\textsubscript{3} pollution in Japan. Although the seasonal cycle of surface O\textsubscript{3} in Japan has an annual minimum during summer due to an enhanced maritime meteorology, East-Asian sources account for the largest fraction of pollution (up to 60%) in summer (Yamaji et al., 2006). Fishman et al. (2003) found the largest tropospheric column O\textsubscript{3} amounts in East Asia during summer, while Tie et al. (2007) found strong outflows of industrial NO\textsubscript{x} and resulting O\textsubscript{3} from China and Japan during summer. Naja and Akimoto (2004) studied over 30 years of balloon data from 4 Japanese stations and found that regional ozone pollution peaks in western Japan in late spring and summer, with concentration enhancements of up to 36 ppb found at Kagoshima during August due to Chinese pollution. “The region between about 28°N and 34°N is the best place to capture the continental outflow from both northern and southern China throughout the year,” (Naja and Akimoto, 2004), making Kagoshima an ideal site for deployment of the NASA ground-based instruments. During August (the Olympic period) air masses arrive in Kagoshima from China every 3 – 5 days (Naja and Akimoto, 2004).

In August 2008, Beijing will host the Olympics. As part of its Olympic bid, China promised to improve air quality before the games (Beijing 2008, Official Olympics Website; Oster, 2007). By making pollution measurements before, during, and after the Olympics in 2008, then returning in the summer of 2009 to make additional measurements with the same instrument suite for comparison, we have a unique opportunity to examine the efficacy of China’s pollution control strategy and to quantify China’s contribution to regional and global pollution budgets.

Methodology – Instruments and Models:

NASA recently has developed two new portable instruments useful in the proposed research. First a spectrometer system based on Cede et al. (2006) measures trace gases (NO\textsubscript{2}, H\textsubscript{2}O, O\textsubscript{3}, SO\textsubscript{2}, HCHO) and aerosol amounts in the spectral range 280 to 525 nm. Developed with a NASA research grant by Dr. Jay Herman, this instrument has been successfully deployed at Goddard Space Flight Center (GSFC) in Greenbelt, Maryland; Thessaloniki, Greece; and Table Mountain, California. Second, NASA and ITT Industries have developed a portable, eye-safe differential absorption lidar (DIAL) system using optical
parametric oscillators (OPO) (Chyba et al., 2001; Richter et al., 2000). The instrument yields high-resolution vertical profiles of O₃ and aerosols (Profitt and Langford, 1997; Reichardt, et al., 2000). Such systems have been successfully applied to retrieve O₃ in the troposphere (e.g., Veselovskii et al., 1997).

Both NASA instruments will be deployed in Kagoshima, site of a monitoring station in far western Japan that regularly launches balloons to measure ozone (ozonesondes). Because both instruments are small and mobile, we can relocate them if we find conditions more advantageous elsewhere. Continuous monitoring of O₃ and NO₂ profiles will provide data on the vertical distribution and the diurnal cycle of these important trace gases, and will enhance our opportunities to measure air pollution arriving from China.

Ozonesondes are launched regularly from 4 sites in Japan (Kagoshima, Naha, Sapporo, and Tsukuba). These in situ data are helpful in identifying transported pollution plumes, both anthropogenic and stratospheric in origin (e.g., Naja and Akimoto, 2004) and will be leveraged in this research.

The Ozone Monitoring Instrument (OMI) on the Aura satellite has made daily global measurements of column O₃, NO₂, SO₂, and aerosols since July 2004. Dr. Edward Celarier and Dr. Nickolay Krotkov of the NASA GSFC will provide special high-resolution OMI data over East Asia to aid this study. Data from the Moderate Resolution Image Spectrometer (MODIS), the Atmospheric Infrared Sounder (AIRS) instrument, and weather satellites will also be employed to track and diagnose source regions for pollution plumes detected in Japan, as has been done in previous studies (e.g., Morris et al., 2006).

The NASA Goddard Trajectory Model (Schoeberl and Sparling, 1995) driven by winds from the Goddard Earth Observing System (GEOS-4) assimilation (Bloom et al., 2005), and the Community Multi-Scale Air Quality (CMAQ) model (Byun, et al., 1999) will be employed to assist in identifying the origins of polluted air masses. These models have been used successfully in previous long-range transport pollution studies (Morris et al., 2006; Colarco et al., 2004; Yamaji et al., 2006).

Relevance of my teaching and professional experience:

My multi-dimensional research career has prepared me well for a collaborative research environment and has included analysis of remote sensing data, the development and implementation of models of the Earth’s atmosphere, and participation in numerous field campaigns in the U.S.A., Panama, and Antarctica. Every summer from 1992 – 2006, I worked at the NASA GSFC as a visiting faculty member, post-doctoral researcher, or graduate student. Projects included research on the impact of subsonic and supersonic aircraft on the stratosphere (Schoeberl and Morris, 2000) and the use of a chemical box model to assess episodic and localized stratospheric O₃ loss (Morris et al., 1998). My NASA projects continue to provide me access to many satellite data sets, including the Upper Atmosphere Research Satellite, the Earth Energy Budget Satellite, the Nimbus satellite series, and currently, the Aura satellite instruments.

My field research experiences have prepared me for working in new and overseas environments. As a graduate student, I was sent to Antarctica to repair an instrument designed to measure the atmospheric electrical conduction current. During the summer of 2004, just before taking my current position at Valparaiso University (VU), I began an ozonesonde research project at Rice University in Houston. The project has flourished, with over 200 ozonesonde launches from 4 sites in Texas, over 30 from three sites in Indiana and Michigan, and 20 from Panama. The very first summer of our project, we observed the impact of forest fire smoke from Alaska and Canada on ozone levels in Houston (Morris et al., 2006). During the spring of 2006, we participated in INTEX-B, a campaign designed to study long-distance pollution transport from Asia and Mexico. Our data from Houston have been linked to sources in Mexico City (Thompson et al., 2007, in preparation). These studies have positioned me to conduct the long-distance pollution transport research outlined in this proposal.

Significance:

Air quality forecasting is becoming a standard part of meteorological forecasts. Poor air quality has led to increased asthma in children (McConnell et al., 2002) and increased mortality (Bell et al., 2004). The
reduction of the Chinese pollution burden during the Olympics will provide an unprecedented test of the models (e.g., Yamaji, et al., 2006), which should result in improved air quality model forecasts, important for both human health and urban planning. Since air pollution respects no political boundaries, negative impacts resulting from long-range and global pollution transport do not fit neatly into existing international law, yet clearly affect international relations. Data from this study will improve our understating of pollution transport and help policymakers craft new international environmental agreements.

**My professional development:**

To this point in my career, I have worked mainly in full-time teaching positions, which at VU means teaching four courses per semester. While I have had the opportunity to travel internationally for conferences and a fluid dynamics summer school at Cambridge University, I have not spent an extended period conducting research outside of the U.S.A. I would relish the opportunity provided by this project to conduct air quality research full-time in Japan. Working with regional pollution experts in Japan, I will develop further my expertise in air quality. As Asia continues to grow and industrialize, its importance to the global environment will grow as well. Completing this research project, therefore, will position me well for future air quality studies and collaborations with my colleagues in Japan. Furthermore, results from this study may be applicable to my current research on regional pollution within the U.S.A., in which it appears that pollution from mid-western states is regularly impacting pollution levels in Houston, Texas.

**Motivation for working in Japan:**

Japan provides an ideal site from which to observe emission outflow from China. Ozonesondes have been launched from four sites in Japan for 30+ years, providing an extended record against which measurements taken during the time of this project can be compared, and Kagoshima provides an ideal location from which to study imported Chinese pollution. Using trajectory models and satellite observations, I will be able to track air masses back to their source regions.

Important to this study is the opportunity to work in close collaboration with the numerous, world-renowned experts in East Asian air quality. My first choice would be to work at the Frontier Research Center for Global Change (FRCGC) in Yokohama, Japan. Members of this group have published numerous studies identifying industrial (Akimoto et al., 2006; Akimoto and Narita, 1994) and biomass burning sources in China (Yan et al., 2006) and examining modeling predictions (Yamaji, et al., 2006).

**Value of this project to Japan:**

Results from the project will be valuable to the Japanese air quality research community, environmental agencies in Japan, and to the Japanese government. The project will debut two new NASA instruments (a tropospheric O₃ lidar system and a NO₂ profiling instrument). Should they prove effective in this study, a surface network of such instruments could be deployed in the future to provide a 3-D picture of pollution that could identify polluted air masses before they arrive in populated areas and provide data to models that might greatly improve air quality forecasts. The project will also provide access to special, high-resolution NASA satellite data sets that should prove useful to the modeling community within Japan. By quantifying the impact of China’s pollution on Japan, this study will better position the Japanese government and the international community to negotiate environmental treaties with China as it continues to industrialize and its pollution burden continues to grow.

**Affiliation arrangements and collaboration:**

I have identified several potential collaborators within Japan, including Hajime Akimoto (FRCGC), Kondo Koike (University of Tokyo), Masato Shiotani (Kyoto University), and Masatomo Fujiwara (Hokkaido University). I am hopeful soon to have a letter of invitation from one or more of them.

I also have 4 collaborators in the USA at NASA GSFC. Dr. Thomas McGee and Dr. Jay Herman will provide the lidar and NO₂ profiling instruments respectively. Dr. Edward Celarier and Dr. Nickolay Krotkov will provide high-resolution NO₂ and SO₂ column data sets from OMI for East Asia.
Timeline for the project:

<table>
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<tr>
<th>Dates</th>
<th>Task</th>
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<tr>
<td>1 July 2008</td>
<td>Arrive in Yokohama at FRCGC to establish a base for operations</td>
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<tr>
<td>8 July 2008</td>
<td>Deploy NASA instruments at Kagoshima</td>
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<tr>
<td>15 July – 30 Sept. 2008</td>
<td>Take measurements of NO2 and O3 in field with NASA instruments.</td>
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<td></td>
<td>Olympics in Beijing 8 – 24 Aug. 2008</td>
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<td>1 Oct. – 31 Dec. 2008</td>
<td>Return to FRCGC to begin data reduction and analysis; work with</td>
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<td></td>
<td>FRCGC scientists on historical data review and modeling studies</td>
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<tr>
<td>1 Jan. 2009</td>
<td>Return to USA</td>
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<tr>
<td>1 June – 31 Aug. 2009</td>
<td>Return to Japan; redeploy instruments; take additional measurements</td>
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<td></td>
<td>to compare with 2008 data; identify impacts of China’s pollution</td>
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<tr>
<td>Aug. 2009</td>
<td>Present preliminary results at FRCGC in Japan</td>
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<tr>
<td>1 Sept. 2009</td>
<td>Return to USA</td>
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<tr>
<td>Fall 2009</td>
<td>Present preliminary results at NASA GSFC</td>
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<tr>
<td>Fall 2009</td>
<td>Present preliminary results at a conference on air quality</td>
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<tr>
<td>May 2010</td>
<td>Submit at least one manuscript to a peer-reviewed journal</td>
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Language competency:

Although knowledge of Japanese is not required and I have no working knowledge of Japanese, I took Mandarin Chinese for 5 years in high school and college, which should help me to learn enough written Japanese to navigate everyday life. Since almost all research presentations and publications in my field are in English, I should be able to communicate scientifically with my Japanese colleagues.

Dissemination plan:

Results from my research will be presented in multiple venues. I will share my results first with my Japanese and NASA colleagues before more broadly sharing it with the scientific community. I will then present reports to the environmental agencies in Japan and the U.S.A., highlighting the impact of China’s pollution on air quality in Japan. Finally, I will submit at least one manuscript for publication in a peer-reviewed journal. Below is one possible research dissemination plan:

- Research presentation of preliminary findings at FRCGC (Yokohama), August 2009
- Research presentation of preliminary findings at NASA GSFC (Greenbelt, MD), Fall 2009
- International Conference on Modeling, Monitoring and Management of Air Pollution, Fall 2009
- Manuscript submission(s) by May 2010 (e.g., Atmospheric Environment, Science)

Possible lecture topics:

I would enjoy the opportunity to provide lectures to Japanese colleagues and students, and to the general public. The following is a sample list of talks: (1) The impact of Alaskan and Canadian forest fires on O3 pollution levels in Houston; (2) Deriving tropospheric O3 from satellite observations; (3) Using peer-learning techniques in introductory physics; (4) An introduction to stratospheric O3 and the ozone hole.

Personal qualities:

I am an outgoing, friendly, adaptable individual with a genuine interest in the people and cultures around me. My experiences in numerous academic and research environments, including at the South Pole and in a remote area of Panama, have fostered flexibility and resourcefulness. Identified by my peers as someone with leadership potential, I was nominated to and took part in the Project Kaleidoscope Faculty 21 Leadership Institute (2006). I believe strongly in undergraduate participation in research. As a result, I have enjoyed working closely with numerous undergraduate students on my research and have presented conference papers and published journal articles with them. I am grateful for the opportunities I have enjoyed to this point in my career and am truly excited by the possibilities presented by this proposed Fulbright research project in Japan.
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References

Akimoto, H., and H. Narita, Distribution of SO\textsubscript{2}, NO\textsubscript{x} and CO\textsubscript{2} emissions from fuel combustion and industrial activities in Asia with $1^\circ \times 1^\circ$ resolution, Atmos. Env., 28, 213 – 225, 1994.


