IMPACTS OF NATURAL AND ANTHROPOGENIC AEROSOLS ON THE STRATOCUMULUS DECK OFF CHILE

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The world's most extended and persistent stratus deck around the world is that located under the Pacific high off the coast of Chile and Southern Peru. This cloud deck has a large impact on the regional and global circulations (e.g., Hartmann et al, 1992; Hartmann, 1994). In this region, large emissions of oxidized sulfur occur, both due to anthropogenic processes (Lefhon et al, 1999), mainly copper smelting, and natural processes, mainly biogenic emissions along the Humboldt current system, and perhaps also volcanic emissions (e.g., Scholes et al, 2003; Andres & Kasgnoc, 1998). Despite the relevance of these processes for the regional and global climate, our quantitative understanding and our predictive capabilities to assess potential future changes are scarce.

Altogether, given the large emissions of oxidized sulfur that take place in Northern and Central Chile, the circulation and cloud patterns in the area, and the potential effects of sulfur aerosols on clouds, we started in 2002 a collaboration to assess the regional distribution of oxidized sulfur and its radiative effects over Central and Northern Chile. Here we propose a collaboration intended to better understand the aerosol-cloud-climate interactions and to provide tools for assessing and predicting these effects by means of global and regional scale modeling. Also, we aim at strengthening the links with other research activities, particularly remote sensing of aerosols and clouds and dynamical modeling of the marine boundary layer over the Eastern Pacific.

1) INTRODUCTION

In addition to impacts of oxidized sulfur on human health, various other impacts on climate, clouds and precipitation have been widely recognized by the scientific community (e.g., Twomey, 1974; Charlson et al, 1987; Albrecht, 1989; Charlson et al, 1991; Kiehl and Brigleb, 1993; Boucher and Lohmann, 1995; Nemesure et al, 1995; Jones and Slingo, 1996; Chuang et al, 1997; Haywood and Boucher, 2000; IPCC, 2001; Wilson et al, 2001; Lohmann, 2002). Acidic deposition in connection with sulfate aerosols was pointed out in the early 60's and 70's as a regional issue of concern in Europe and North America. Nowadays, acidic deposition by sulfur and other species has become an issue in developing countries, particularly over Southeast Asia (e.g., Rodhe et al, 1995; Rodhe et al, 2002). The scattering effects of aerosols in general, and of sulfate aerosols in particular, are daily experienced by inhabitants of polluted urban areas all over the world as reflected in hazy conditions and low visibility. On the regional and global scales, it has been shown that the main contributors to the scattering of solar radiation are sulfate and some organic aerosols with a net global average direct forcing of about –0.5 W/m^2 (e.g., IPCC, 2001). The quantification of the impact of sulfate aerosols due to their role as cloud condensation nuclei (CCN) has been more elusive. Nevertheless, anthropogenic sulfate aerosols are thought to make clouds brighter and more long-lived (e.g., Ramanathan et al, 2001).

Chile has a long tradition of exploiting mineral resources, particularly copper. The copper smelters in Chile stand for about 1 % of the ca. 70 TgS/yr oxidized sulfur (SO_x) emitted worldwide. In addition, in the coast of Central and Northern Chile exchanges of biogenic trace species are significant, particularly dimethylsulfide (DMS), which is an important precursor of natural aerosols and cloud condensation nuclei (CCN). Volcanoes may also be a significant source of aerosols, sulfate aerosols in particular. Finally, Santiago, one of South America's megacities is also a significant source of polluted air, containing both organic and inorganic aerosols that also may affect the properties of clouds.

An outstanding feature of Central and Northern Chile is the persistent stratus clouds off the coast out over the ocean under the Pacific High. This cloud deck has a large impact on the regional and global circulations. Therefore, given the large emissions of oxidized sulfur, both anthropogenic and natural, that take place in Northern and Central Chile, the circulation and cloud patterns in the area, and the potential effects aerosols on clouds, particularly sulfur aerosols, we aim at establishing a long-term collaboration with European researchers to assess the regional distribution of oxidized sulfur and its direct and indirect radiative effects over Central and Northern Chile.

2) OBJECTIVES

Hence, given the large emissions of oxidized sulfur that take place in Northern and Central Chile, the circulation and cloud patterns in the area, and the effects of sulfur aerosols on clouds and precipitation, we find it necessary to provide the basis for a long-term collaboration to quantify these effects. In particular, we aim at establishing the modeling tools require to provide quantifications and scenarios for such impacts. From this, the following objectives are extracted.

- To estimate the distribution of oxidized sulfur, both natural and anthropogenic, over the stratatocumulus area over the Eastern Pacific
- To estimate the potential impact on the properties of the persistent stratus deck (direct and indirect effects)
- To estimate the relative importance of natural and anthropogenic sources on the burden and distribution of oxidized sulfur
- To evaluate the sensitivity of the estimates with respect to model resolution with emphasis on relevant weather conditions such as coastal lows and cut-off lows.
- To improve, in close collaboration with other research groups, the accuracy of the simulations by means of assimilation of satellite data.
- To improve, in collaboration with concurrent research the parametrizations of Sc clouds in current models

3) PARTICIPANTS

- Chile/ Center for Mathematical Modeling (CMM)
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    - Framework project FONDECYT 1030809, 2003-2006: *Stratosphere-Troposphere Exchange (STE) processes and their impact on the ozone balance in the subtropics of the Southern Hemisphere: A multi-scale integrated study based at Cerro Tololo (30ºS, 70ºW, 2200 m.a.s.l).*
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4) OVERALL OBJECTIVES

- To better grasp the regional distribution of oxidized sulfur, both natural and anthropogenic, and to evaluate their potential impact on the properties of the persistent stratus deck over the ocean under the Pacific high
- To strength the links with other research activities and communities particularly those related to remote sensing of aerosols and clouds in France, dynamical modeling of the marine boundary layer over the Eastern Pacific and modeling of ocean-atmospheric interaction in Chile

5) HYPOTHESES

We assume that both of our group's research activities will gain in depth and perspective by complementing our expertises un global climate modeling and regional scale dispersion. Further, we assume that available atmospheric models can provide estimates of the atmospheric distribution of oxidized sulfur emitted from biotic and abiotic processes, and their subsequent impacts on the radiative balance, and that the accuracy of these simulations can be improved.

6) METHODOLOGY

The distribution of oxidized sulfur (SO_x) and its radiative effects could be assessed by means complementary model simulations.

- High-resolution (0.1º) SO_x fields will be estimated using the off-line Multiscale Atmospheric Transport and Chemistry (MATCH) model (Robertson et al, 1999) already implemented in Chile. It has been applied to assess dispersion of oxidized sulfur and arsenic over Northern and Central Chile (e.g., Gallardo et al, 2002; Huneeus et al, 2003). This model would be fed with semi-climatological outputs provided by a three-dimensional numerical weather prediction (NWP) model, the High Resolution Limited Area Model (HIRLAM, Undén et al, 2002) and outputs for specific situations provided by a regional climate model and the NWP model at use the Chilean Weather Office within the framework of ongoing research at the CMM (FONDECYT 1030809).
- The General Circulation model LMD-ZT (Cosme et al, 2002) will be used to study the dispersion of oxidized sulfur and to estimate the corresponding radiative forcings. By comparing the global and regional simulations we will explore the sensitivity of the estimates to model resolution.
- The simulations will provide estimates of the direct and indirect forcing by oxidized sulfur. These forcings will be evaluated by comparing with observations. . We will then jointly explore the assimilation of satellite data to improve the simulations over this area of the world that is in an appalling lack of observations and where strong signals can be detected by remote sensors providing an opportunity for validation of retrieval algorithms. (This is the theme of Nicolás Huneeus PhD work at LOA). In general, we expect to better constrain aerosol transport to Pacific Ocean.
- On the basis of observational data provided from complementary projects (e.g., Rutllant et al, 2003; FONDECYT 1020833) we expect to improve the parameterizations of Sc in the models we apply.

In addition to the modeling work, workshops and symposia will be organized in connection with the visits of the scientists. Also, short-term (1-3 months) stays of graduate students will be promoted. We expect to be able to establish co-guided graduate theses for students in Atmospheric Science, Mathematics and Informatics.

7) MISSIONS DURING THE FIRST YEAR OF THE PROJECT

France to Chile: None during the first year, the missions should take place during the second year of the cooperation

Chile to France:

- Laura Gallardo, January 2004, 20 days, Gathering and synthesis of results. Also, learning about the type of aerosol data intended to be assimilated in the climate model and eventually in a regional-scale model.
- José Rutllant, June 2004, 15 days, Acquaintance with the stratocumulus parameterizations in the model and comparisons with sounding data collected through complementary projects in the Sc area

8) RESULTS

- Increased research capabilities, tools and a broader scientific spectrum for both research groups
- Common publications and definition of larger scale cooperative projects involving other research groups.
- Capacity building as expressed in theses and student exchanges
- Workshops and symposia

9) LINKS WITH ONGOING RESEARCH

A the CMM we are developing studies on:

- *Stratosphere-Troposphere Exchange (STE) processes and their impact on the ozone balance in the subtropics of the Southern Hemisphere: A multi-scale integrated study based at Cerro Tololo (30ºS, 70ºW, 2200 m.a.s.l)* (FONDECYT 1030809, 2003-2006).

  In this project, meteorological models will be used to produce dynamically interpolated three-dimensional (3-D) regional and meso-scale meteorological fields, which will drive a 3-D Eulerian transport model that will simulate the intrusion and subsequent dispersion of an ozone-like tracer subject to photolysis and dry deposition. The simulations will be evaluated against in situ and available satellite measurements of ozone, water vapor and other relevant STE tracers. These fields will also be available for studying aerosol-cloud-climate interactions as those proposed here.

- *Application and Development of Inverse Modeling techniques to air quality monitoring network design* (INRIA-CONICYT, 2002-2003).

  The overall objective of this project is to bring together the pieces for defining a long-term research axis and a common research project on inverse modeling applied to air pollution problems at the local and regional scale, with particular emphasis on monitoring network design to assess the impacts of the large-scale copper industry over in the densely populated and expanding urban areas of Central Chile. The increasing number of observations of chemical tracers and aerosols, both in-situ and

remote (e.g., satellites) brings now the possibility of applying assimilation data and inverse modeling in order to improve the performance of available three-dimensional chemistry transport models (3-D CTMs), to bracket the strength and location of emissions of relevant compounds, to optimize the design monitoring networks, to assess model errors and sensitivities, etc.. So, this collaboration would benefit from and provide support to the work proposed here by.

At the Geophysics Department:

- Studies are being conducted to generate an improved understanding of the dynamical processes involved in the existence and persistence of Southeastern Pacific stratus decks, their interaction with weather systems (including deep convection), the seasonal cycle and interannual climate variations over South America, and their feedback with the underlying ocean (FONDECYT, 1020833). This study includes the compilation of in situ observations that can be of use for validating model results. Other studies have focused on the mesoscale circulation regimes that explain the extreme aridity of the Atacama desert and their influence on the upwelling of cold nutrient-rich waters (e.g., Rutllant et al, 2003). These circulation patterns are crucial for determining the potential fluxes of biogenic sulfur species and the offshore dispersion of anthropogenic sulfur. An exploratory work by Huneeus et al (2003), suggests that the transport of anthropogenic sulfur would occur episodically in connection with the occurrence of coastal lows.

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