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Stratospheric Aerosol Climatologies and Climate Forcing

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Reviews of Geophysics

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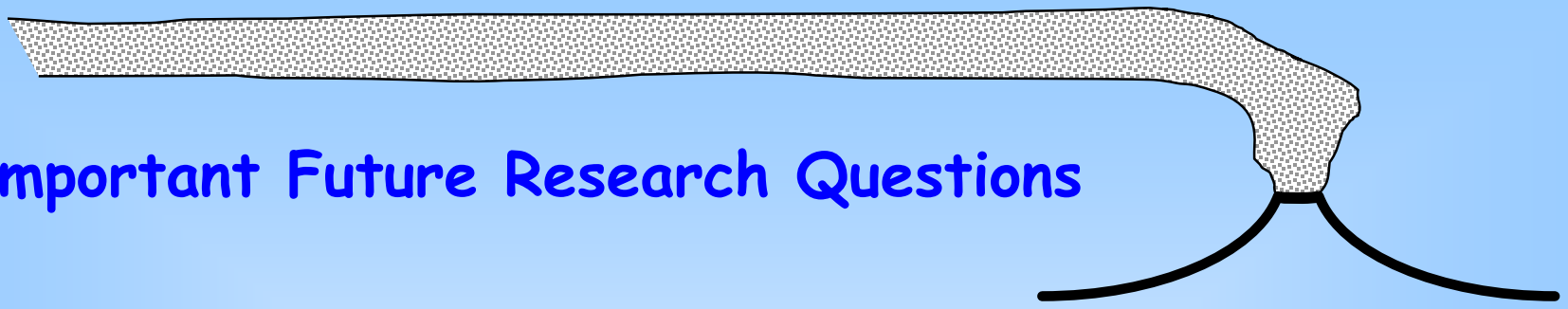

Important Future Research Questions

What exactly goes into the atmosphere during an explosive eruption? The impacts of volcanic eruptions on weather, climate, and atmospheric chemistry depend on what material eruptions put into the atmosphere. Climatically significant inputs include sulfur species (especially SO_2), halogens, H_2O, and fine silicate particles. What are the magmatic controls on how much sulfur is emitted from eruptions? When eruptions take place in wet environments, how much of the water in the plume is primary magmatic water, as compared to entrained water from the atmosphere, lakes, or the ocean? What are the detailed chemical and microphysical transformations that occur in the eruption column and downwind plume, and how do they affect the composition of the stratospheric injection?

Robock, Alan, 2002: Blowin' in the wind: Research priorities for climate effects of volcanic eruptions. *EOS*, **83**, 472.
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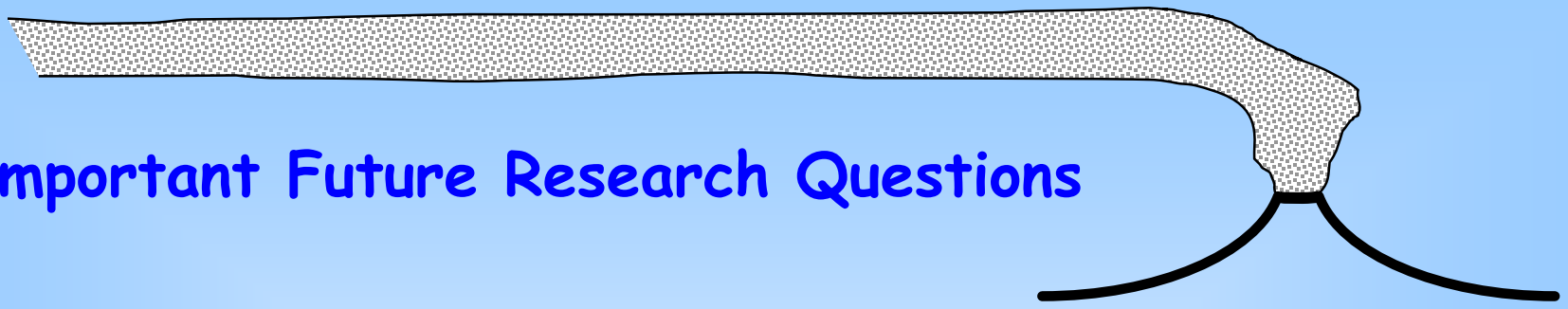
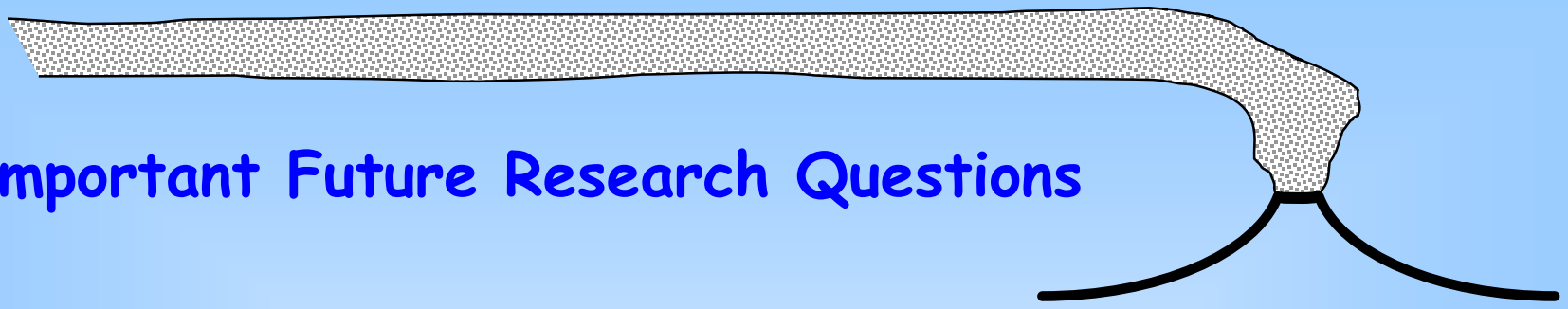


Important Future Research Questions

How do quiescent emissions change over time? What is their current source strength? Explosive eruptions are not the only volcanic source to the atmosphere. While quiescent emissions have regional rather than global impacts, they are important in the context of anthropogenic tropospheric aerosols [*Graf et al.*, 1997]. If the source strength changes significantly over time, this can produce large regional climate changes. More monitoring of the chemistry and magnitude of continuing quiescent emissions will be essential if we are to understand issues such as the impact of anthropogenic aerosols.



Important Future Research Questions

How can we better quantify the record of climatically significant volcanism? To measure the natural climatic forcing from volcanic eruptions for the past, so that we may place anthropogenic climate change in context, we need a better record of the frequency and magnitude of past eruptions. Unlike many other attempts to reconstruct past climate and its forcing, the evidence from past volcanic eruptions is preserved in ice cores, waiting for us to analyze it. A major advance to allow better interpretation of the location of eruptions that produce ice core signatures would be better atmospheric models of transport and deposition that could trace sulfate aerosols from the vent to the ice.

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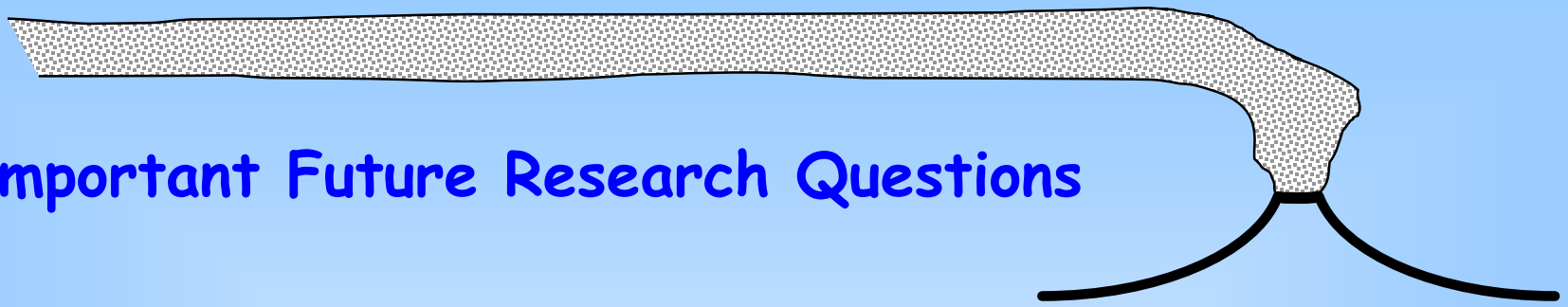

Important Future Research Questions

How can we better quantify the record of climatically significant volcanism? (continued) More study is also needed of possible volcanic components of distal sediments on land and in lakes and deep oceans. Volcanic geology and stratigraphy remain important areas of study, and continued refinement of petrologic methods will enhance interpretation of in situ deposits. Archeology and biostratigraphy of deposits associated with eruptions are relatively untapped approaches that can help to date and interpret the local environmental impact of past eruptions.

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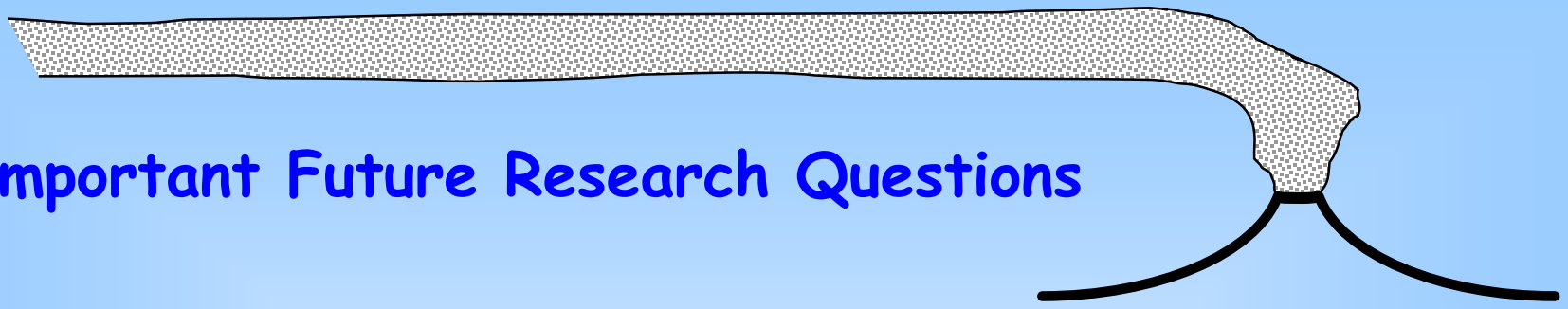

Important Future Research Questions

Can we design an improved system for measuring and monitoring the atmospheric gases and aerosols resulting from future eruptions? In spite of current technology, without better planning and an investment in equipment, there may be significant gaps in observations of the next major volcanic eruption. Near vent observations, unless the eruption is forecast in advance as were Mount St. Helens in 1980 and Mount Pinatubo in 1991, will depend on work with local observers. As many volcanoes are in developing countries, a program to train, work with, and support local observers will significantly enhance our ability to monitor small and medium eruptions.

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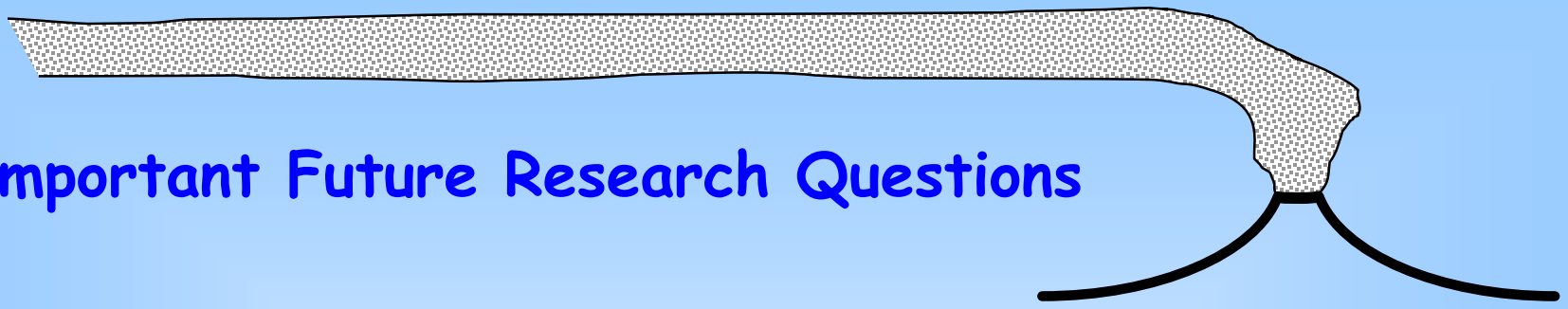
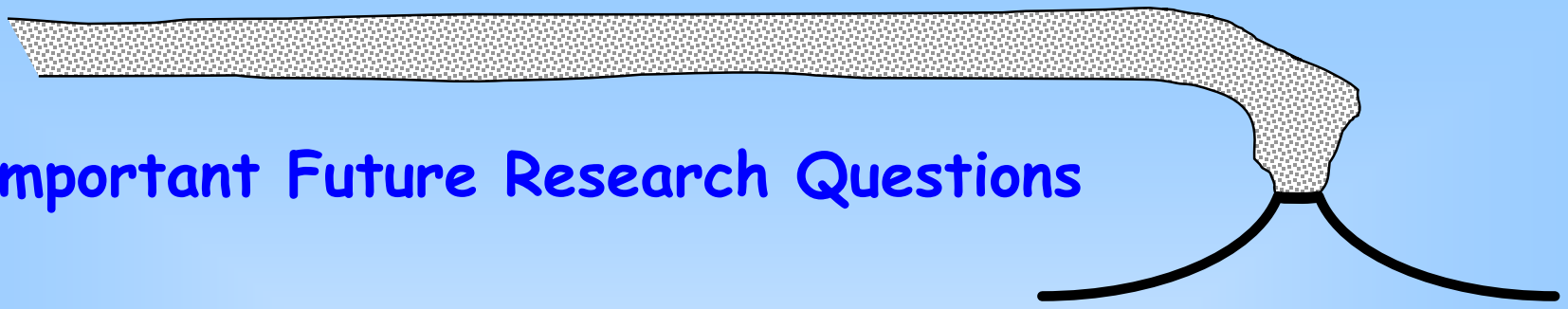


Important Future Research Questions

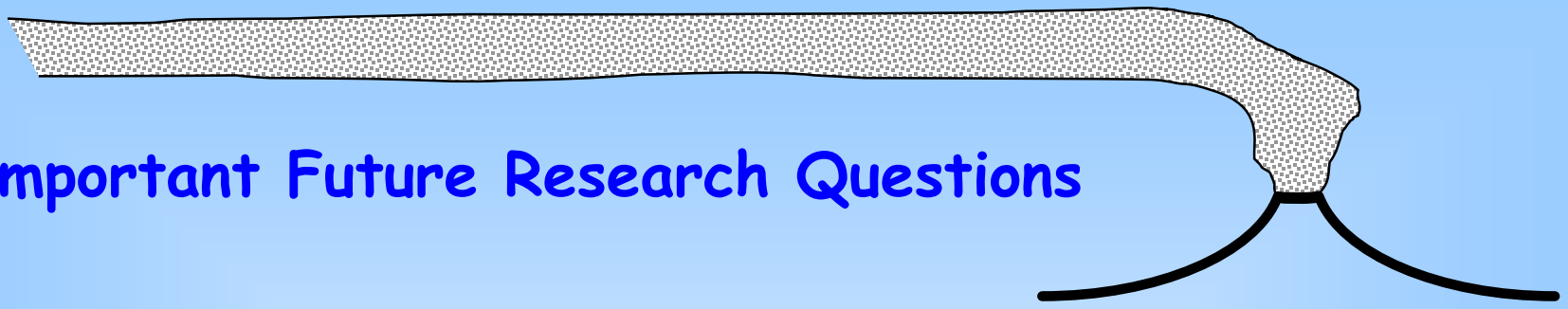
Can we design an improved system for measuring and monitoring the atmospheric gases and aerosols resulting from future eruptions? (continued) Given the lack of a global satellite monitoring system, to be ready for the next major eruption we should have a fleet of stratospheric balloons, lidar-equipped airplanes, and stratospheric airplanes equipped for in situ observations ready to be deployed within weeks of the eruption.



Important Future Research Questions

Can we design an improved system for measuring and monitoring the atmospheric gases and aerosols resulting from future eruptions? (continued) While there are many lidar observatories in the Northern Hemisphere mid-latitudes, and several in the Southern Hemisphere mid-latitudes, there are no lidars in the tropics designed for measuring stratospheric aerosols. It would be relatively cheap and quick to fill in this gap. New satellite missions are beginning to help.

Because of the diversity of observations available for eruptions, a data assimilation system using atmospheric models must be developed; it is the only way to produce a stratospheric aerosol data set that can be used for atmospheric chemistry and climate calculations.



Important Future Research Questions

How can we better model the climatic impact of eruptions, including microphysics, chemistry, transport, radiation, and dynamical responses? A few general circulation models have simulated the general climatic response to the 1991 Pinatubo eruption using a specified distribution of aerosols [*Stenchikov et al.*, 1998]. Remaining problems include adequately accounting for the effects of the Quasi-Biennial Oscillation, microphysical evolution and transport of the aerosols, effects on ozone, the amount and impacts of water vapor injection into the stratosphere, and the regional response.

Important Future Research Questions

How can we better model the climatic impact of eruptions, including microphysics, chemistry, transport, radiation, and dynamical responses? (continued) Data assimilation experiments and model intercomparison programs, like the Pinatubo Model Intercomparison Project (PINMIP) now being carried out under the General Circulation Model-Reality Intercomparison Project for SPARC (GRIPS), will help to improve the models. The ultimate goal would be to couple conduit models of magma, plume models discussed above, and microphysical and transport models in the stratosphere to climate models to predict the impact of the next large eruption as soon as it occurs. An important ancillary activity is to better characterize the climatic response to past volcanism. Tree ring analysis would be an important source of information.

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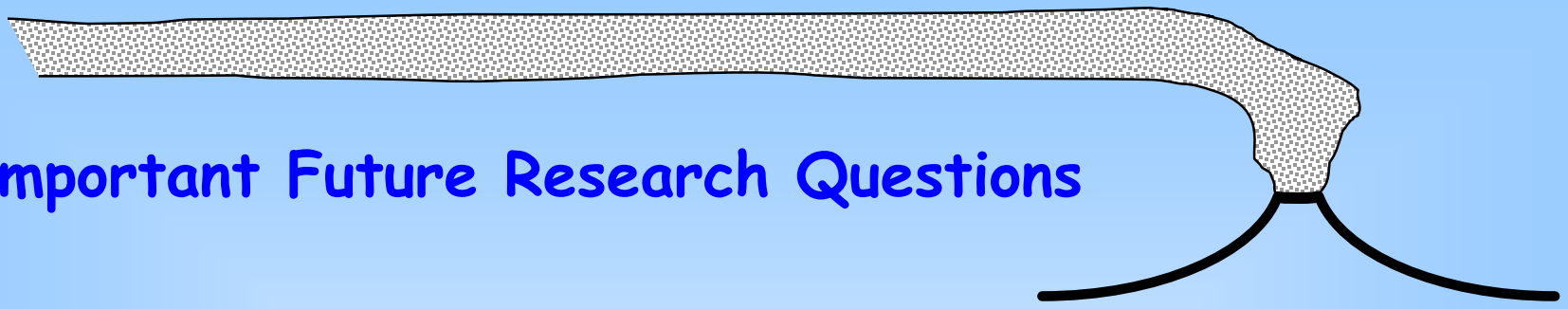
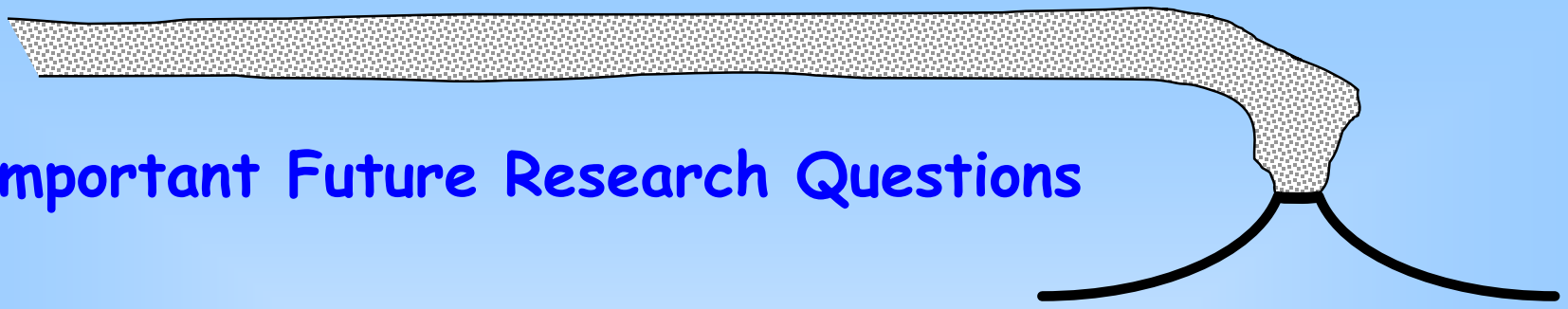


Important Future Research Questions

How do high-latitude eruptions affect climate? Most research on the impacts of volcanic eruptions on climate has focused on tropical explosive eruptions, such as the recent 1963 Agung, 1982 El Chichón and 1991 Pinatubo eruptions. But there have been larger high-latitude eruptions in the historic past that have also had profound influences, the most notable recent one being the 1783 Laki fissure eruption in Iceland. The eruption affected air quality and climate for most of the Northern Hemisphere. If it occurred today, it could halt air traffic there for 6 months [*Thordarson and Self*, 2002]. Questions that still need answers include whether high-latitude eruptions can affect the climate in the other hemisphere, and what the effects would be of eruptions from high latitude Southern Hemisphere volcanoes.

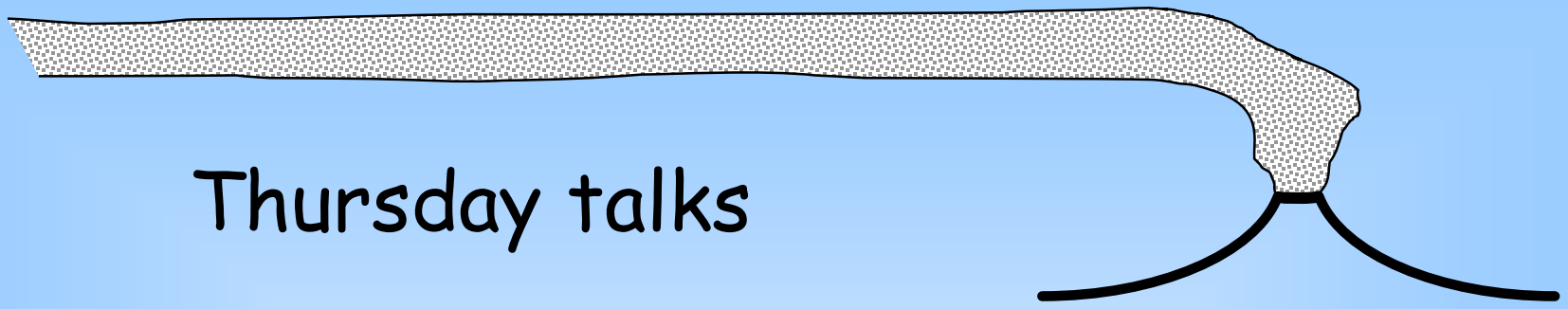
Important Future Research Questions

How important are indirect effects of volcanic emissions on clouds? The indirect effect of tropospheric sulfate emissions on clouds is an area of intensive research. Can volcanic examples be used to improve current models? Do the aerosols from the stratosphere seed cirrus clouds and affect their optical properties and lifetimes?



Important Future Research Questions

Where are the important potential sites for future eruptions? For monitoring, emergency response, warning aircraft, and real-time prediction of climatic response, it would be helpful to know which volcanoes would be most likely to erupt. This will involve production of improved risk maps and catalogs of hazards. It will again require working with and supporting local observers.



Thursday talks

Thomason: How hard it is to derive data from SAGE III

Bhartia: How hard it is to derive data from OMPS

Peter: Observed CMIP6 stratospheric aerosol climatology

Griessbach: Proposed IRLS instrument compared to MIPAS

Osipov: Climate forcing from SO_2

Mills: Simulated stratospheric aerosols since 1980 with WACCM

Aquila: Simulated stratospheric aerosols since 1980 with GEOS-5

Schallock: Simulated response with EMAC using MIPAS

Revell: Response to CCMI and CMIP6 with SOCOLv3

Marshall: Statistical emulation of climate model response

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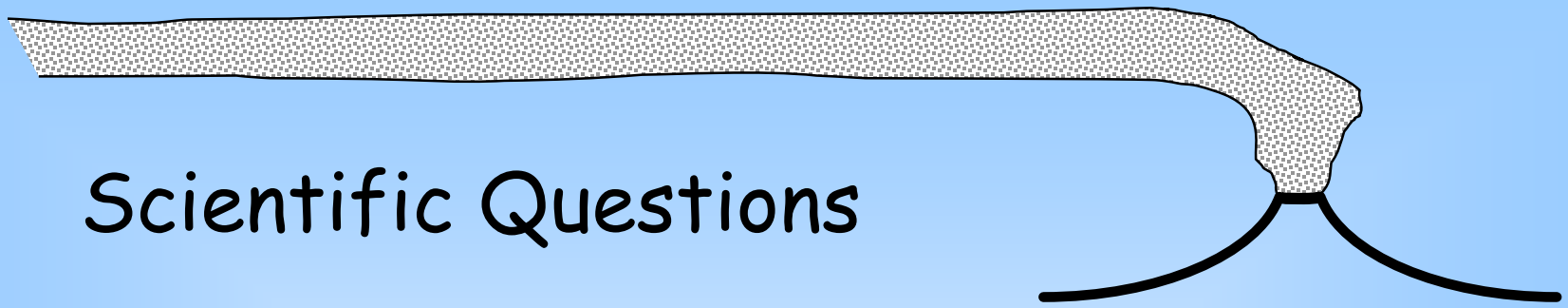

Scientific Questions

1. **How much SO_2 did the 1991 Pinatubo eruption put into the stratosphere?**

Bluth (1992): 17-20 Mt observed from TOMS

Mills (2018): 10 Mt needed to get correct response from WACCM Is this the correct amount or is it model-dependent?

Did the SO_2 get removed quickly on ash? Was ice involved? How well was SO_2 observed?

Points to the need for better observations immediately after the next large eruption (VolRes, NASA).

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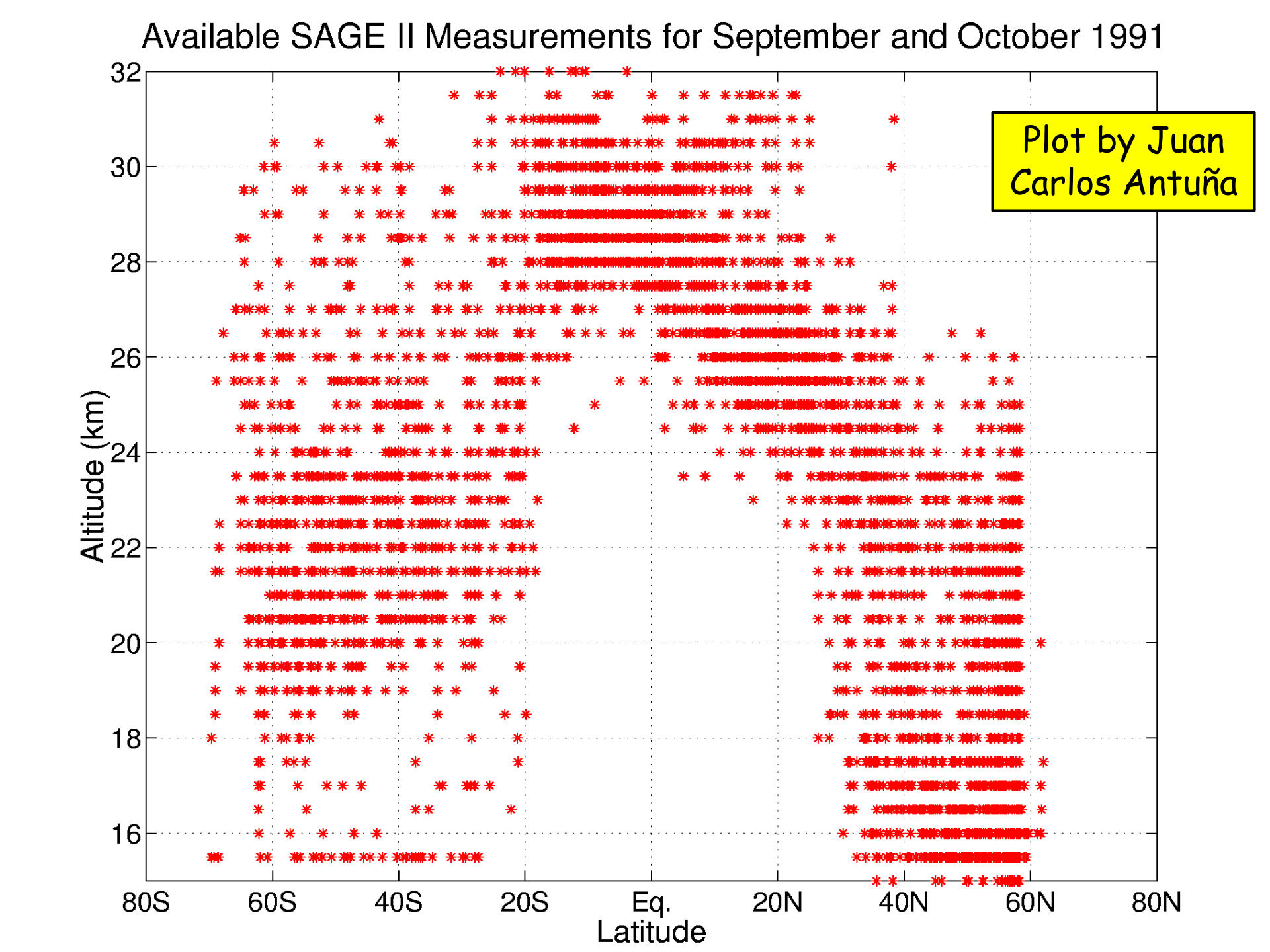
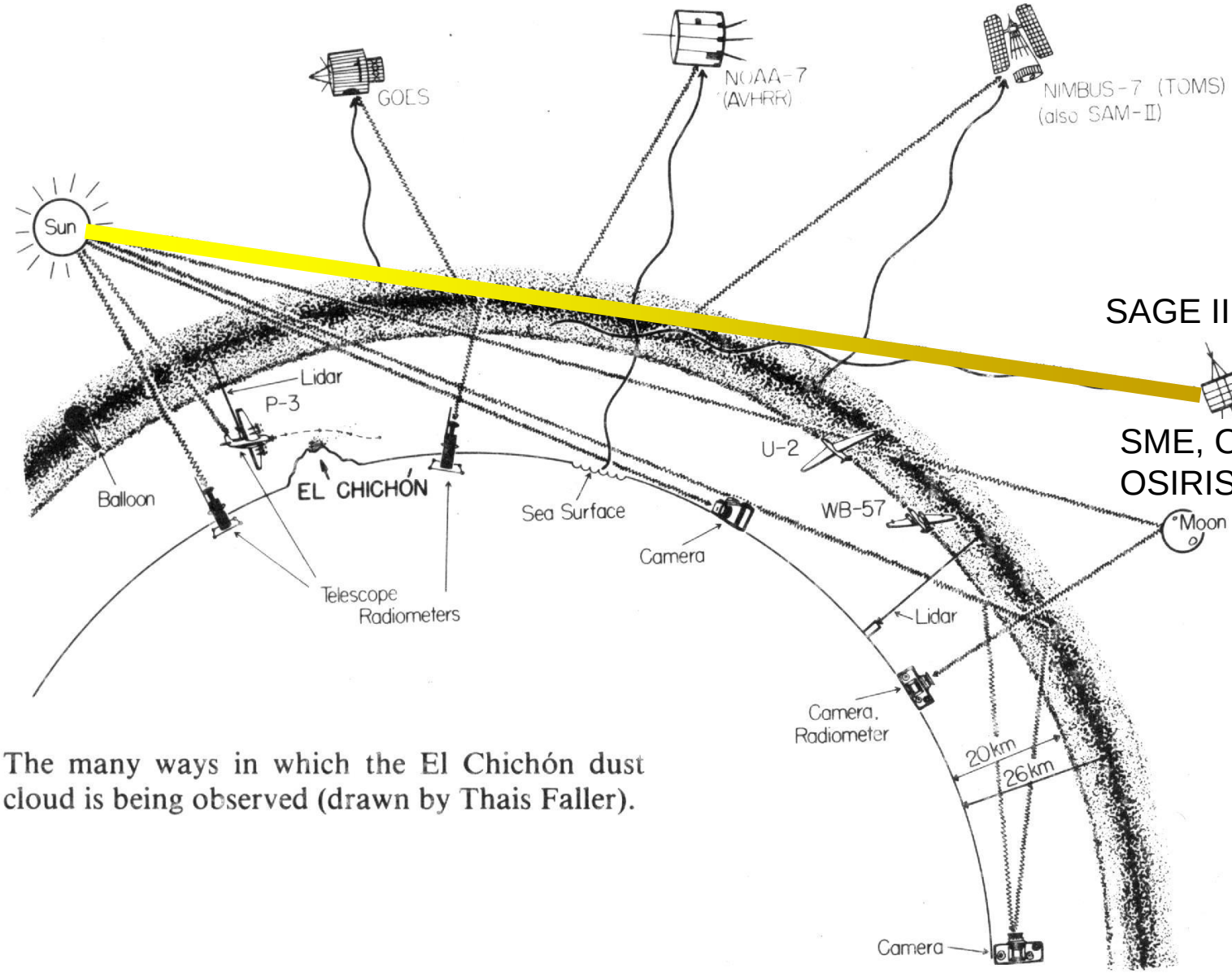

Available SAGE II Measurements for September and October 1991
Plot by Juan Carlos Antuña
Altitude (km)
32
30
28
26
24
22
20
18
16
80S
60S
40S
20S
Eq.
20N
40N
60N
80N
Latitude



The many ways in which the El Chichón dust cloud is being observed (drawn by Thais Faller).

Robock, Alan (1983), The dust cloud of the century, *Nature*, 301, 373-374.

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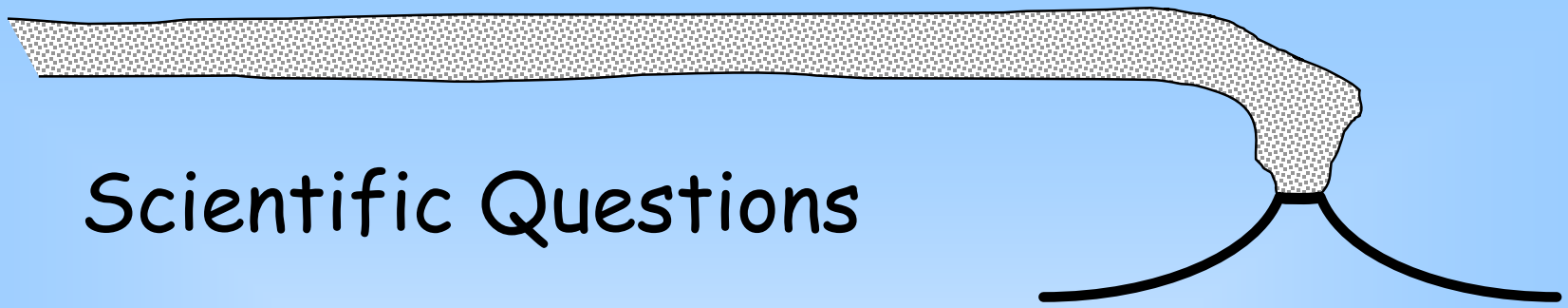

Scientific Questions

2. What is the correct climate response to volcanic eruptions?

Does it depend on ash, water, or sulfate injections?

Does it depend on model microphysical simulations?

What about interactions with ozone response?

How important is having the correct QBO?

How important is having the correct ENSO phase?

How important is the time of year to producing the correct dynamical responses, including winter warming?

Points to the importance of VolMIP project.

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London Sunset After Krakatau

4:40 p.m., Nov. 26, 1883

Watercolor by William Ascroft

Figure from Symons (1888)