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David Hofmann's Pioneering Observations of Stratospheric Volcanic Aerosols

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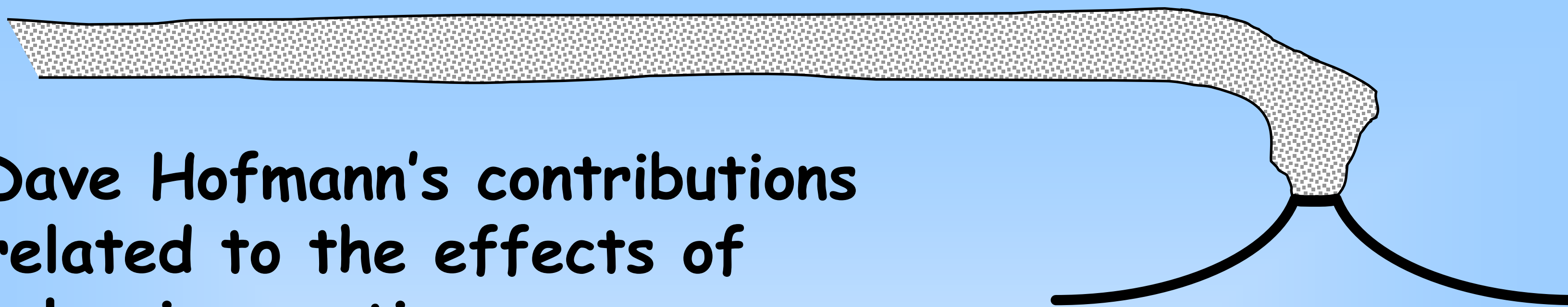

Dave Hofmann's contributions related to the effects of volcanic eruptions

- balloon observations of stratospheric aerosols
- lidar observations of stratospheric aerosols
- observations of polar stratospheric clouds
- observations of ozone
- effects of volcanic eruptions on carbon cycle

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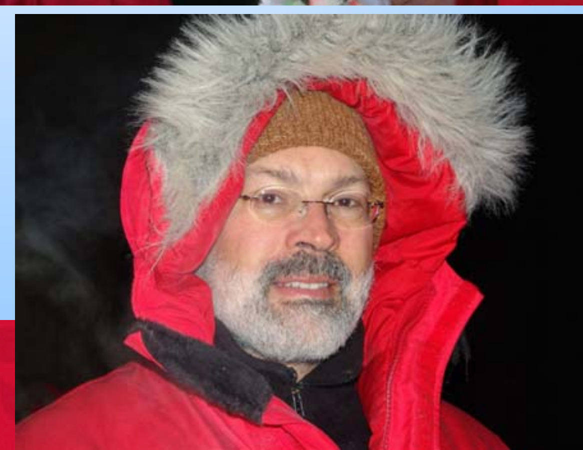
Department of Environmental Sciences

Dave Hofmann

I am not an observationalist.

But once I got to participate in an observation program, helping observe ozone and aerosols at McMurdo, Antarctica in spring 2004.



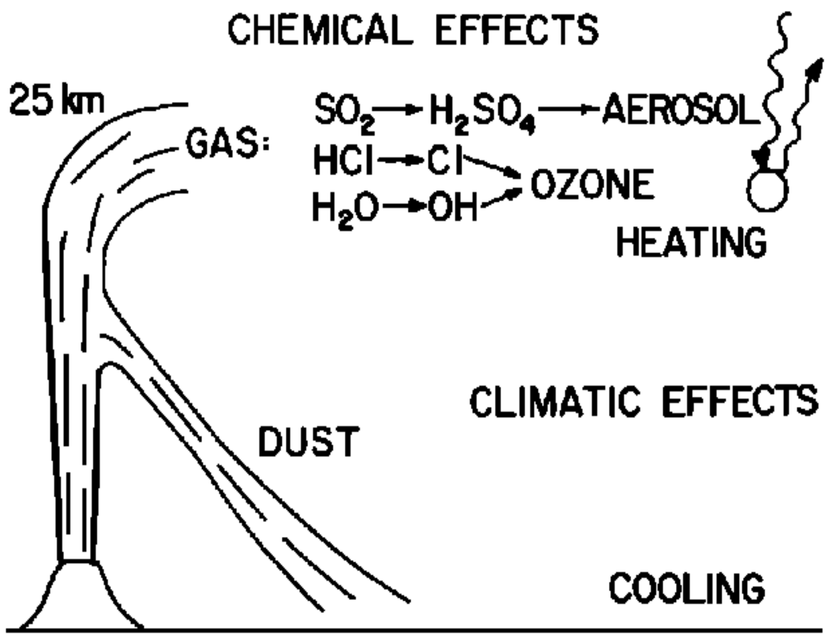


Fig. 1. Schematic drawing of the effects of volcanic eruptions on the atmosphere. Silicate particles fall out relatively rapidly while gaseous products remain to form aerosol droplets and possibly alter the ozone distribution. These perturbations can affect climate through alterations of the atmosphere's thermal structure.

Hofmann (1987), *Rev. Geophys.*

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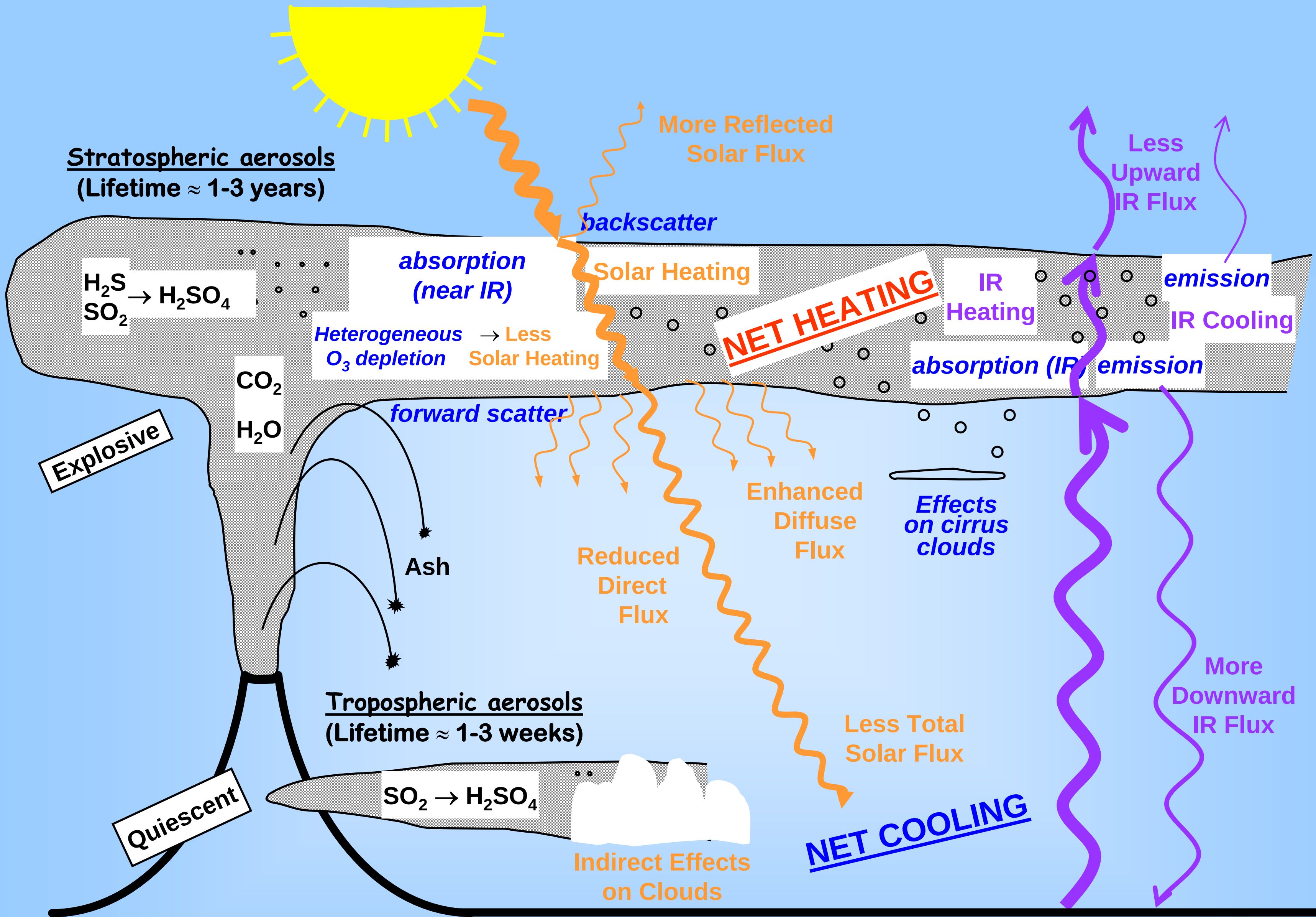
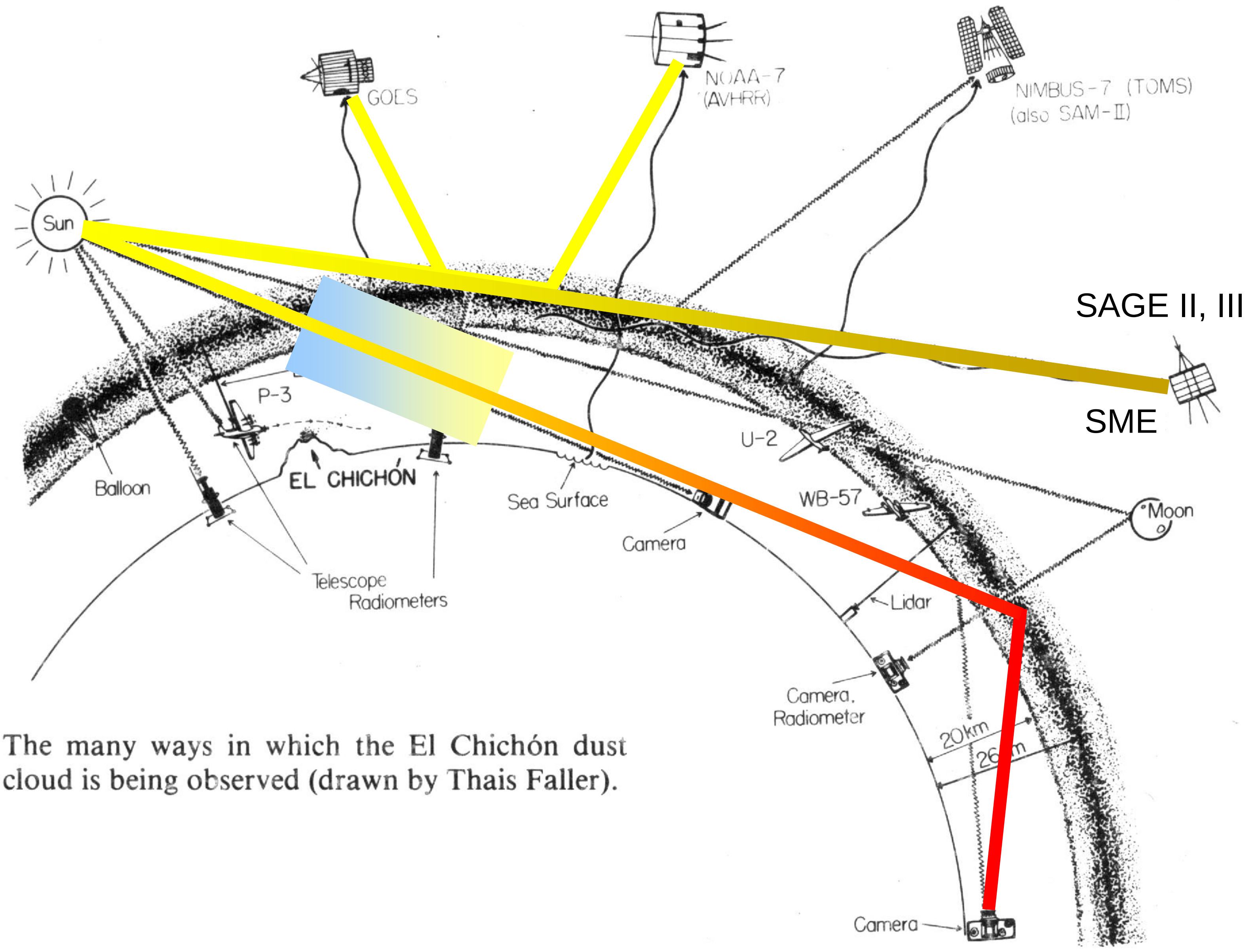


Robock (2000), *Rev. Geophys.*


Mt. Erebus, Sept. 22, 2004

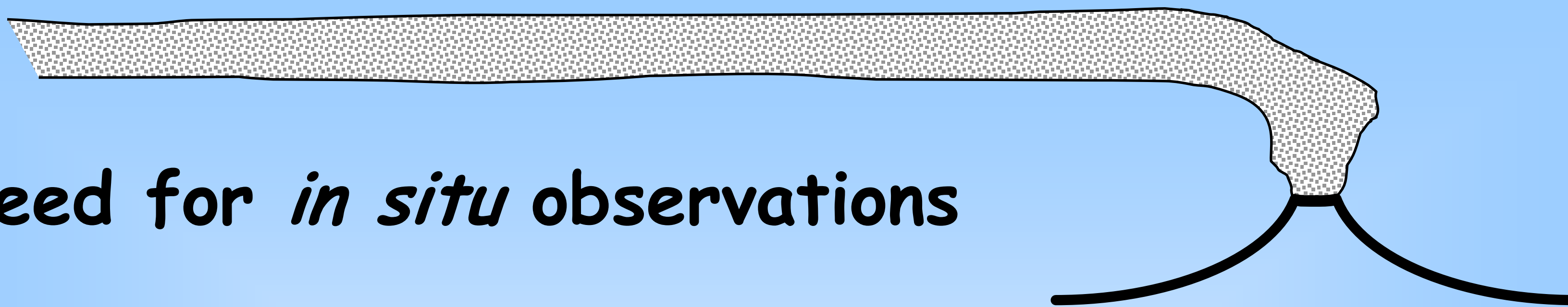

Mt. Erebus, Oct. 3, 2004



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

Robock (1983)

Need for *in situ* observations



In discussing lidar data ... However, as in all remote sensing techniques, data interpretation in terms of particle properties is subject to great uncertainty; i.e., aerosol number, size, and composition (index of refraction) cannot be determined from such data alone. However, in conjunction with occasional in situ measurements of particle properties, the technique is very powerful.

Hofmann (1987), *Rev. Geophys.*

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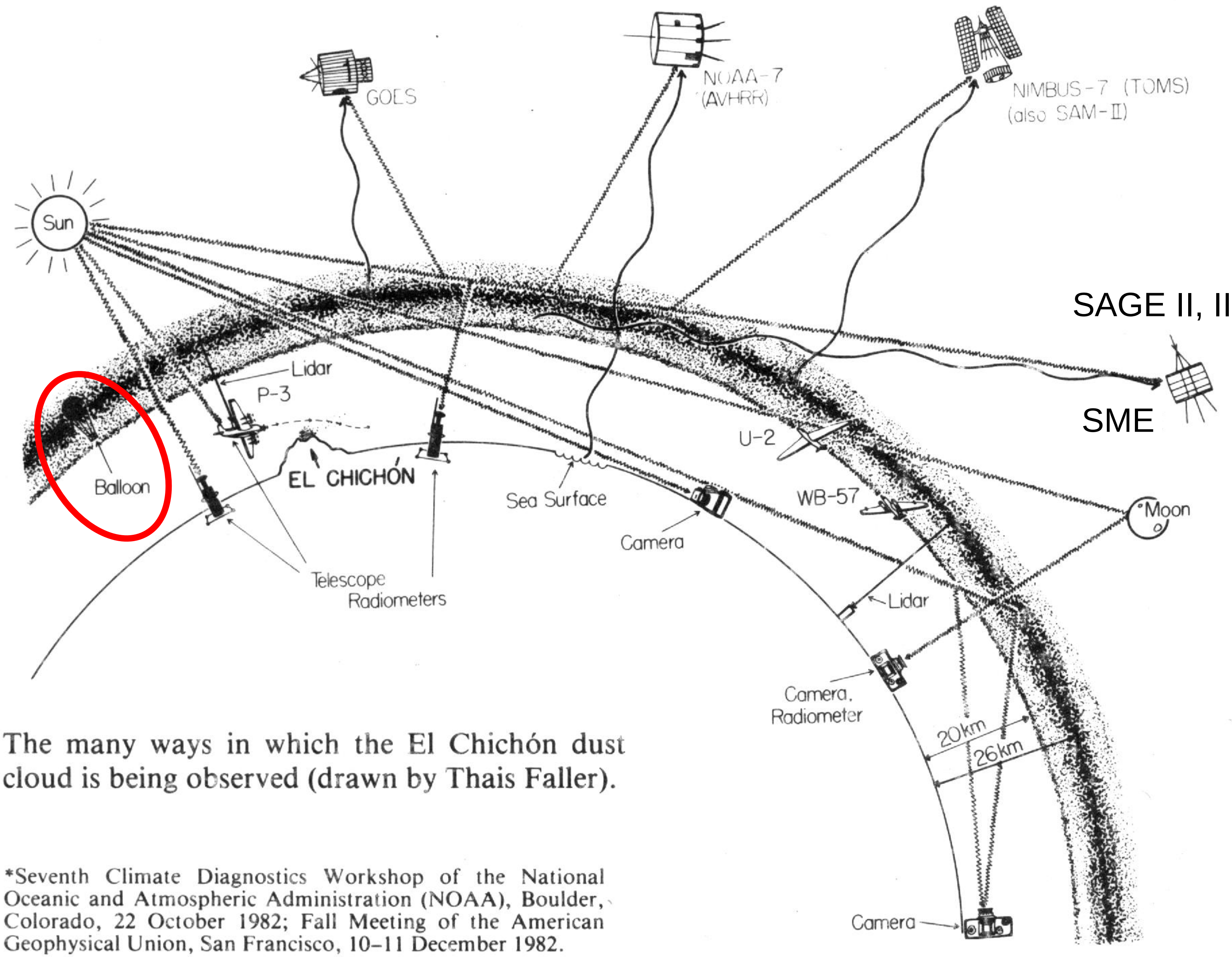
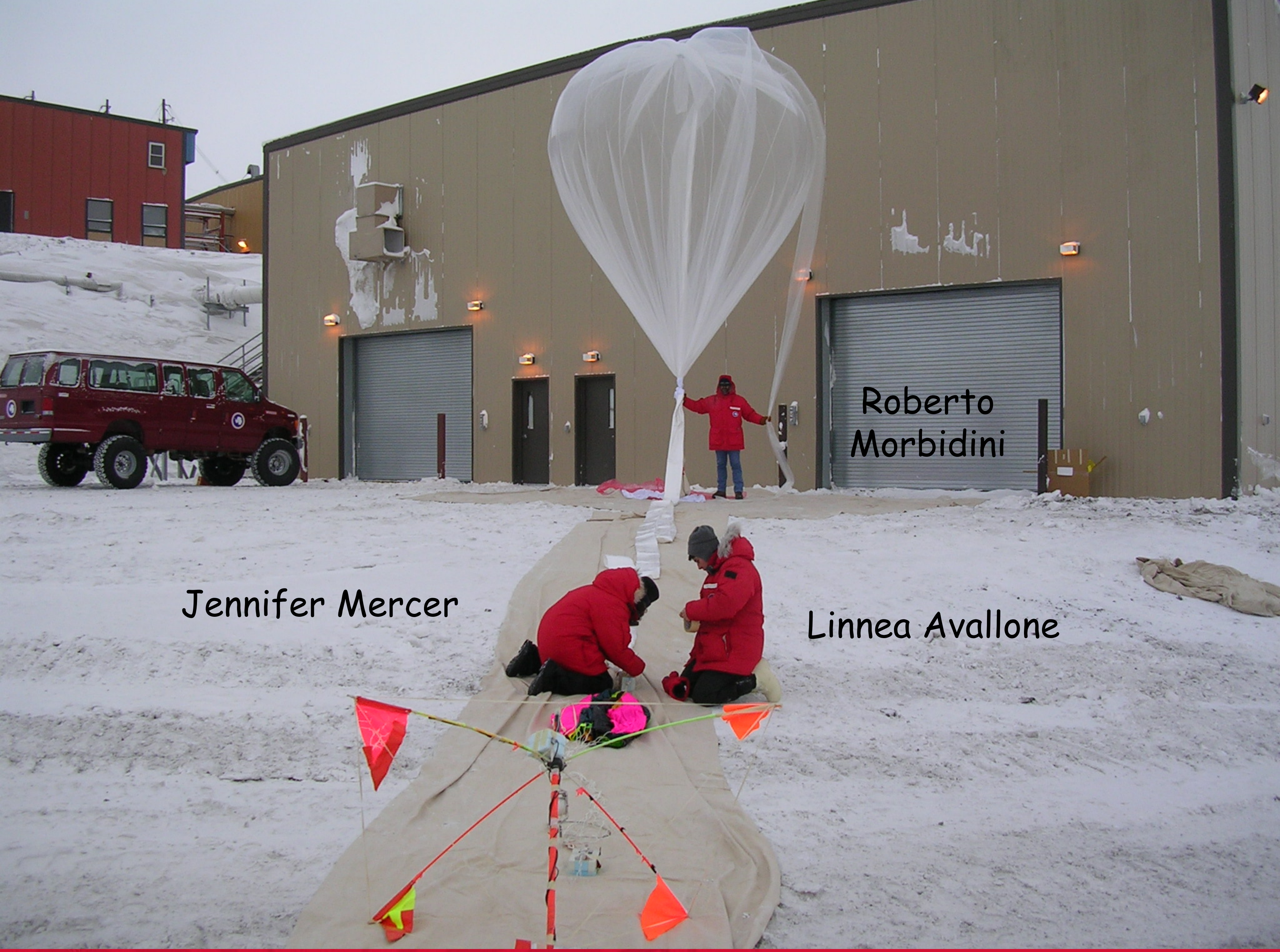
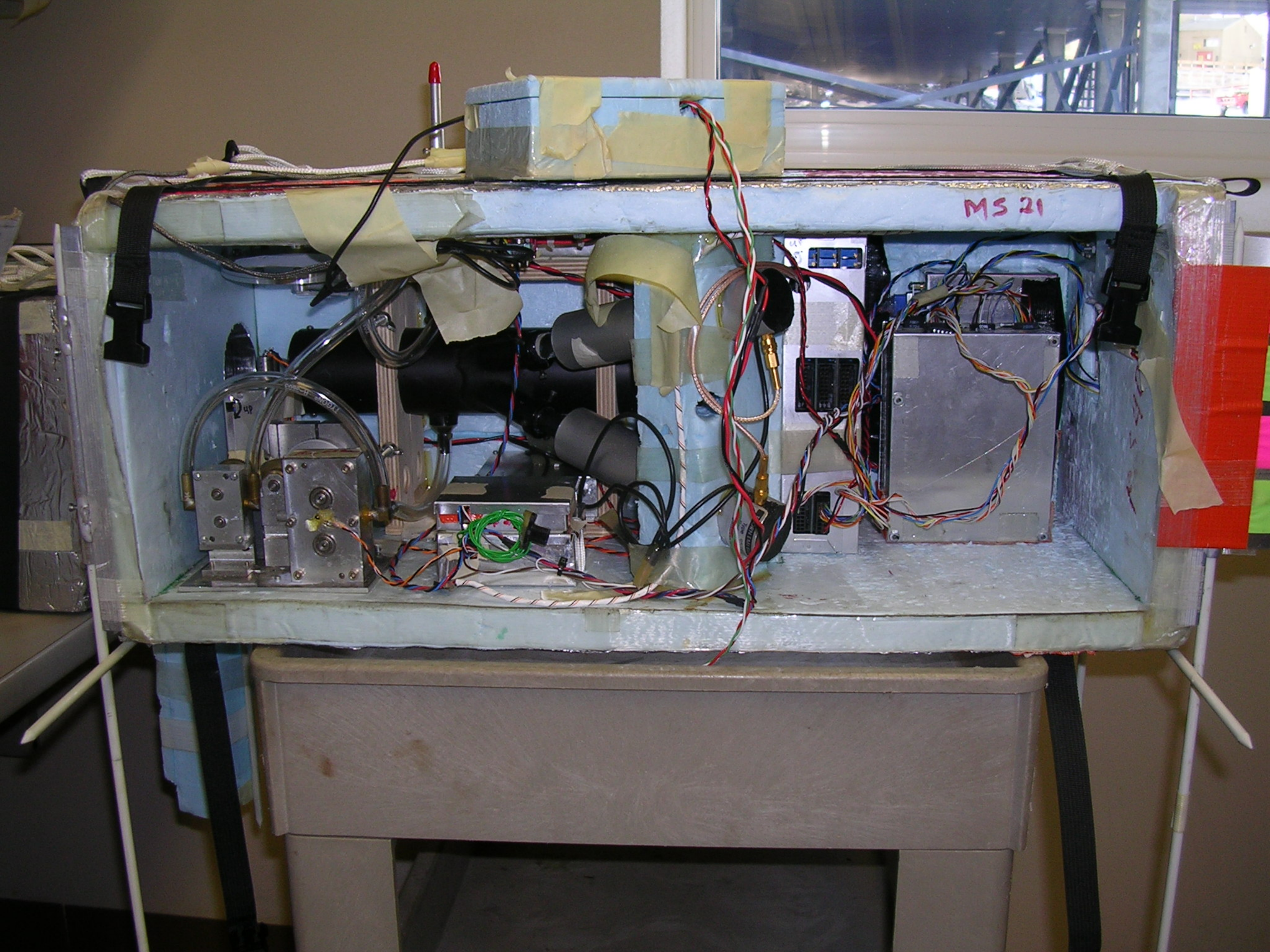


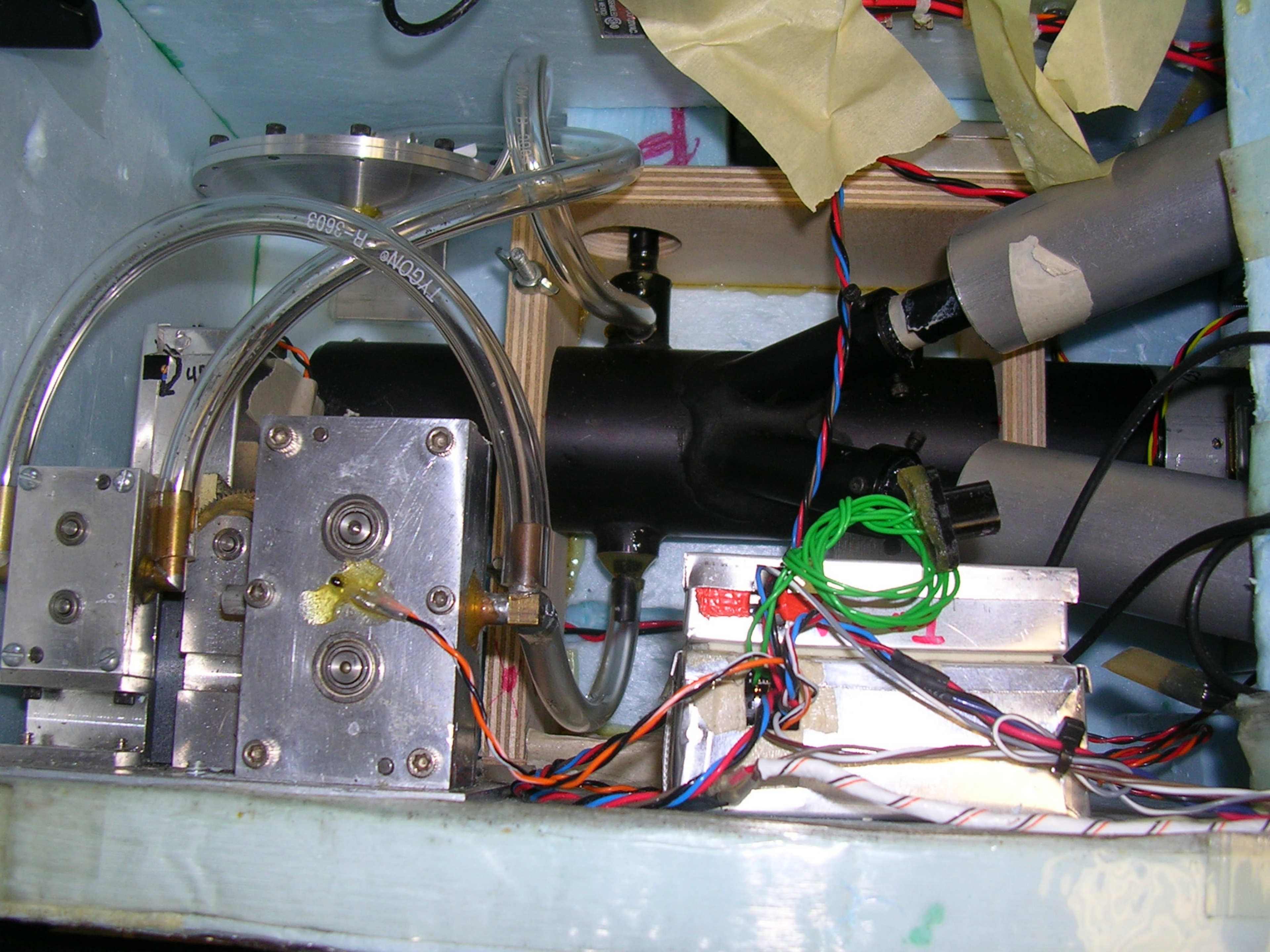
The many ways in which the El Chichón dust cloud is being observed (drawn by Thais Faller).

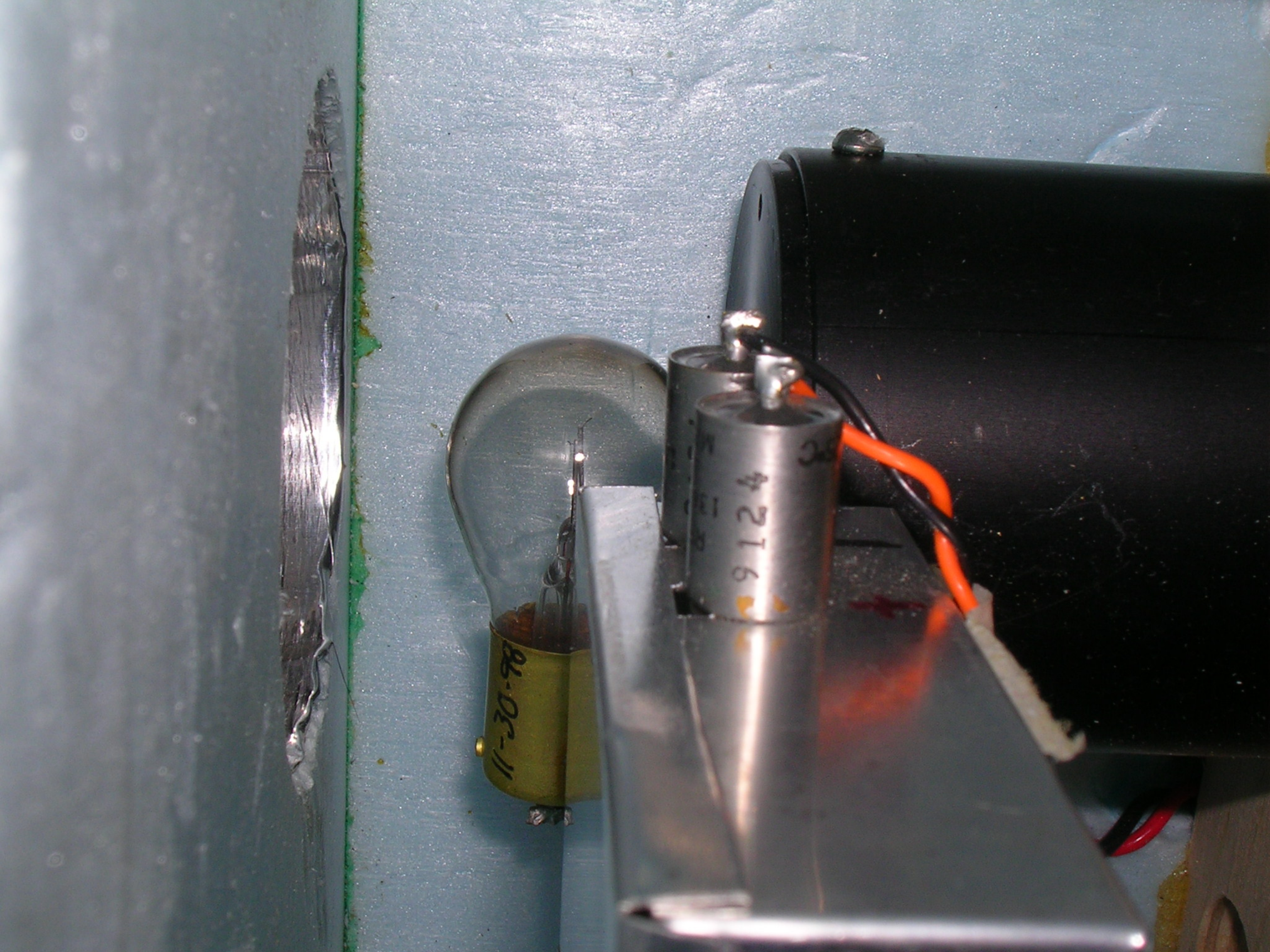
*Seventh Climate Diagnostics Workshop of the National Oceanic and Atmospheric Administration (NOAA), Boulder, Colorado, 22 October 1982; Fall Meeting of the American Geophysical Union, San Francisco, 10–11 December 1982.

Robock (1983)


Roberto
Morbidini
Jennifer Mercer
Linnea Avallone


MS 21


TYGON® R-3603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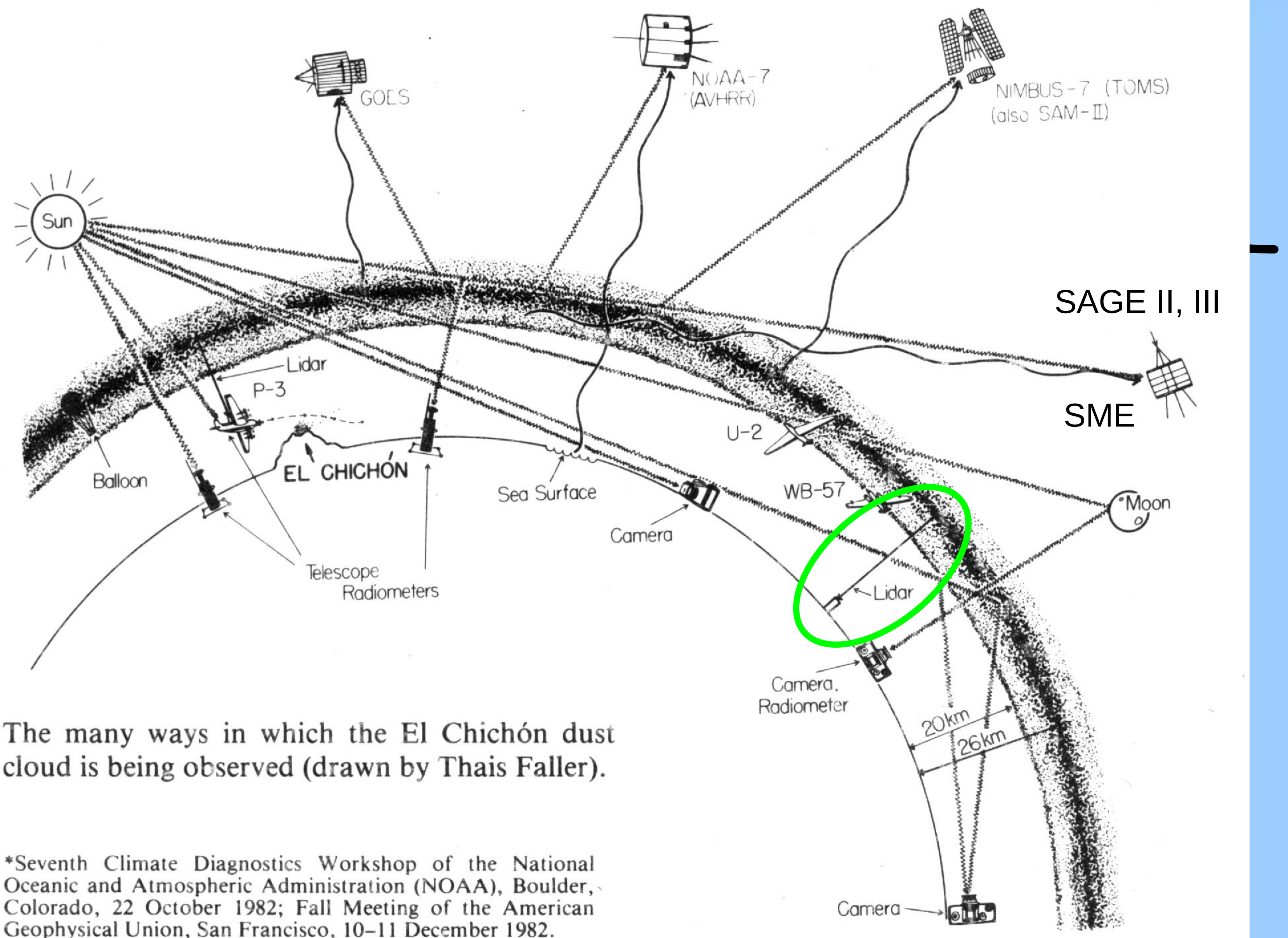

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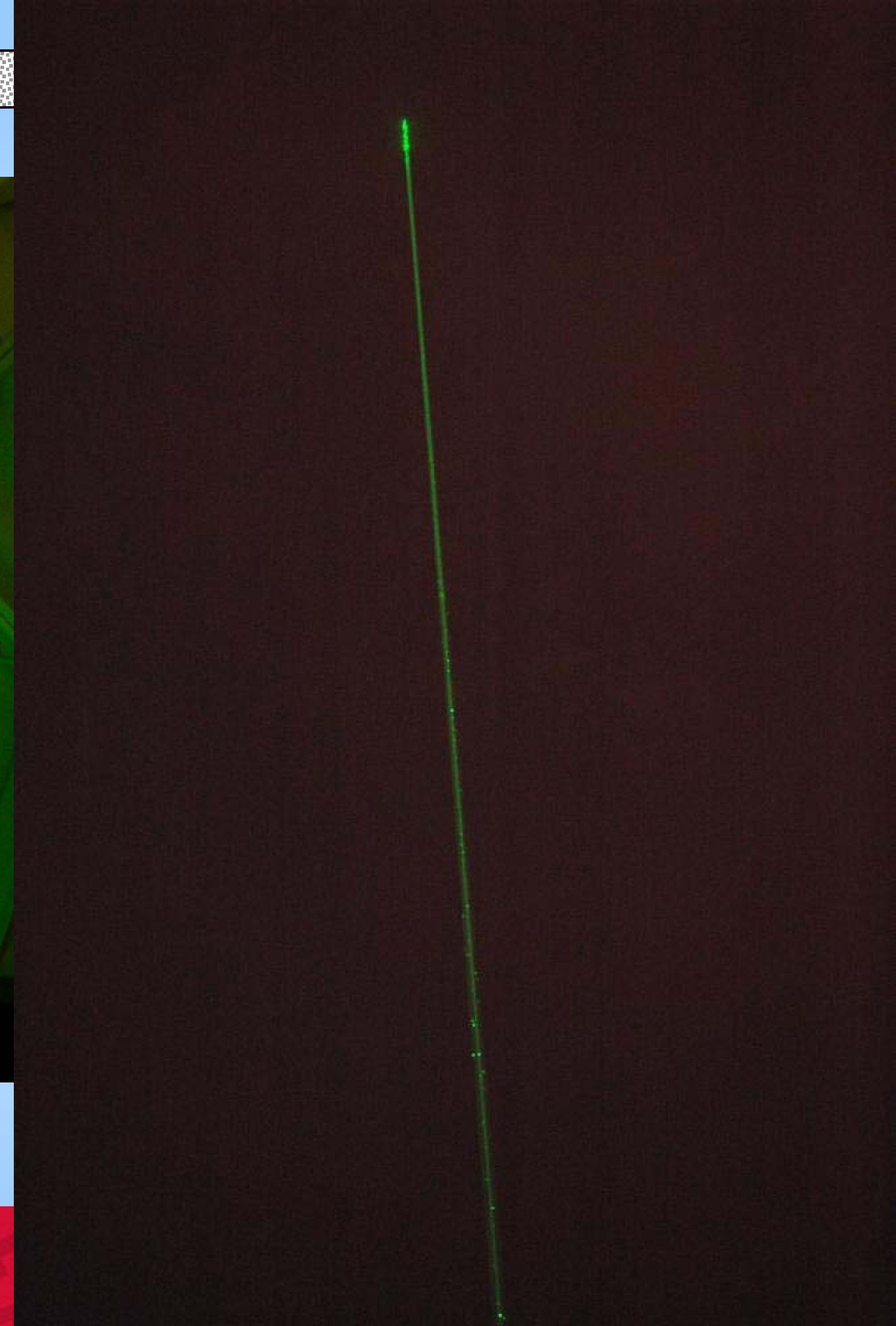
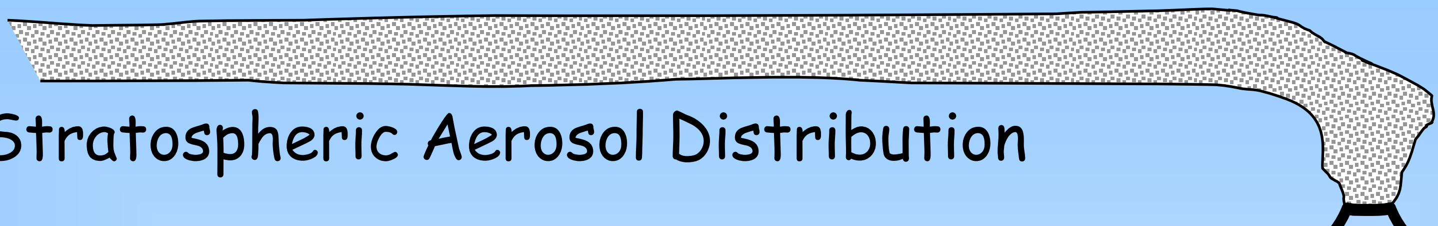
Robock (1983)

Francesco Cairo and Roberto Morbidini

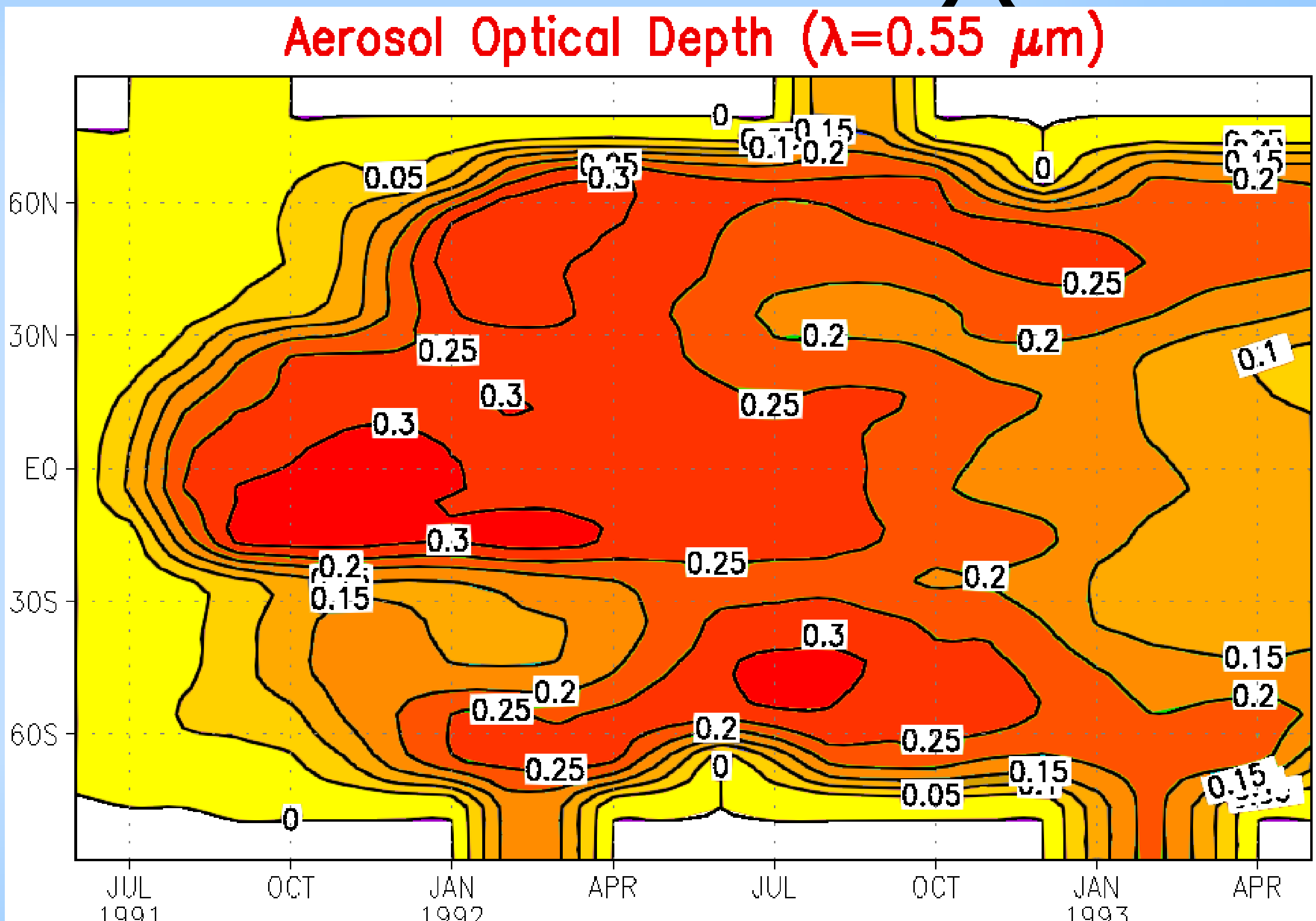




Stratospheric Aerosol Distribution

SKYHI
4-ensemble
mean

Calculated from Stenchikov et al. (1998) data set



Press Release

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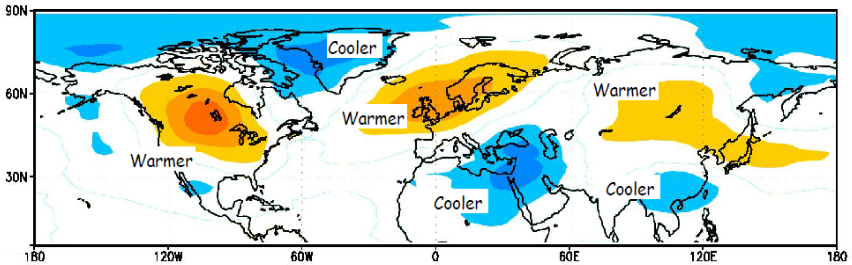
__ Volcano Erupts: Winter Warming and Summer Cooling Predicted

On ___, 20__ the ___ volcano in ___ erupted, putting ___ million tons of SO_2 into the stratosphere. This sulfur gas will produce a cloud of sulfuric acid particles that is the largest since the 1991 Mount Pinatubo eruption, and which will last for several years. Based on the Pinatubo experience, the observed climatic response to all large tropical volcanic eruptions in the past, and extensive computer modeling studies conducted since the Pinatubo eruption, it is possible to make a prediction of the climatic response over the next year.

Prediction: The coming winter of 20__-20__ will be warmer than normal by several degrees Fahrenheit over the central United States and Canada, western Europe and Siberia, and it will be cooler by several degrees Fahrenheit over northeastern Canada and Greenland, the eastern Mediterranean, and China. The volcanic particles will heat the lower stratosphere, producing a change in the atmospheric wind pattern. The winds will blow warm air into some regions and colder air into other regions more often than normal, producing particular patterns. The following map, based on what happened in the winter of 1991-92, shows areas where the climate will be significantly abnormal. The summer will be several degrees Fahrenheit cooler over most of North America, Eurasia, and Africa.

Predicted Winter Temperature Anomalies



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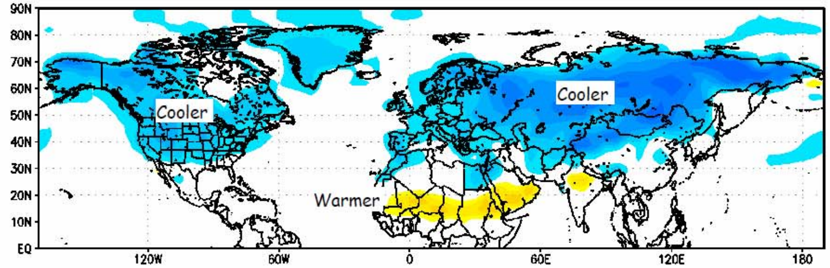
__ Volcano Erupts:
Strong Summer Cooling and Monsoon Failure over Africa and India Predicted

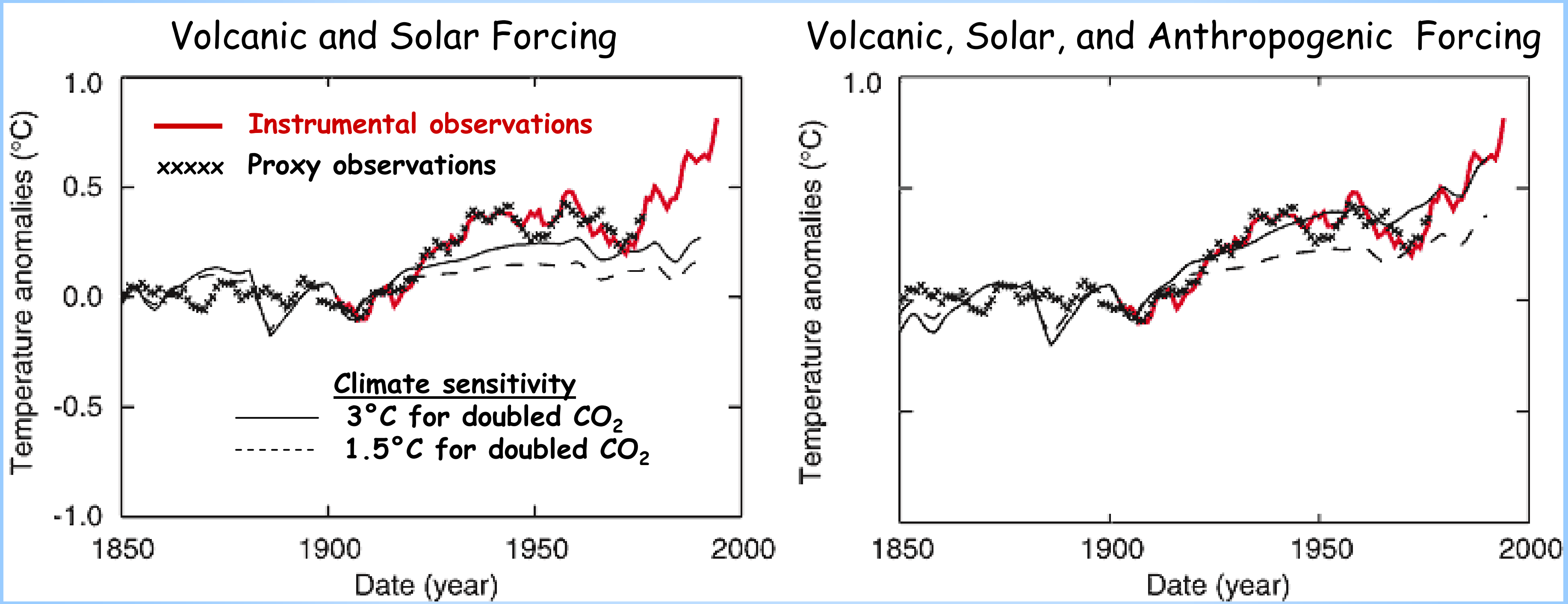
On ___, 20__ the ___ volcano in ___ erupted, putting ___ million tons of SO_2 into the stratosphere. This sulfur gas will produce a cloud of sulfuric acid particles that is the largest since the 1991 Mount Pinatubo eruption, and which will last for several years. This eruption, unlike Pinatubo, was at a high latitude, and the climate response will rather resemble that after the 1783 Laki eruption in Iceland and the 1912 Katmai eruption in Alaska. Based on the observed climatic response to these large high-latitude volcanic eruptions in the past, and extensive computer modeling studies conducted in the past several years, it is possible to make a prediction of the climatic response over the next year.

Prediction: The coming summer of 20__ will be colder than normal by several degrees Fahrenheit over most of North America and Eurasia, but warmer over the Sahel region of Africa. The Africa and Asian summer monsoon precipitation will be less than normal, and subsequent river flow in the Nile and Niger Rivers will be reduced for a couple years. This cooling will reduce the temperature difference between the continents and the oceans, and this is what normally drives the monsoon. The reduced precipitation and cloudiness over Africa and India will actually increase the temperature there. The winter over the continents will also be cooler, but the summer effect will be larger. The following map, based on simulations of the summer response to the Laki eruption, shows areas where the climate will be significantly abnormal.

Predicted Summer Temperature Anomalies



Volcanic forcing needed to explain climate change of past 150 years: Energy-balance climate model simulations



Third Assessment Report of the IPCC (2001)

Fig. 12-6 (from Free and Robock, 1999)

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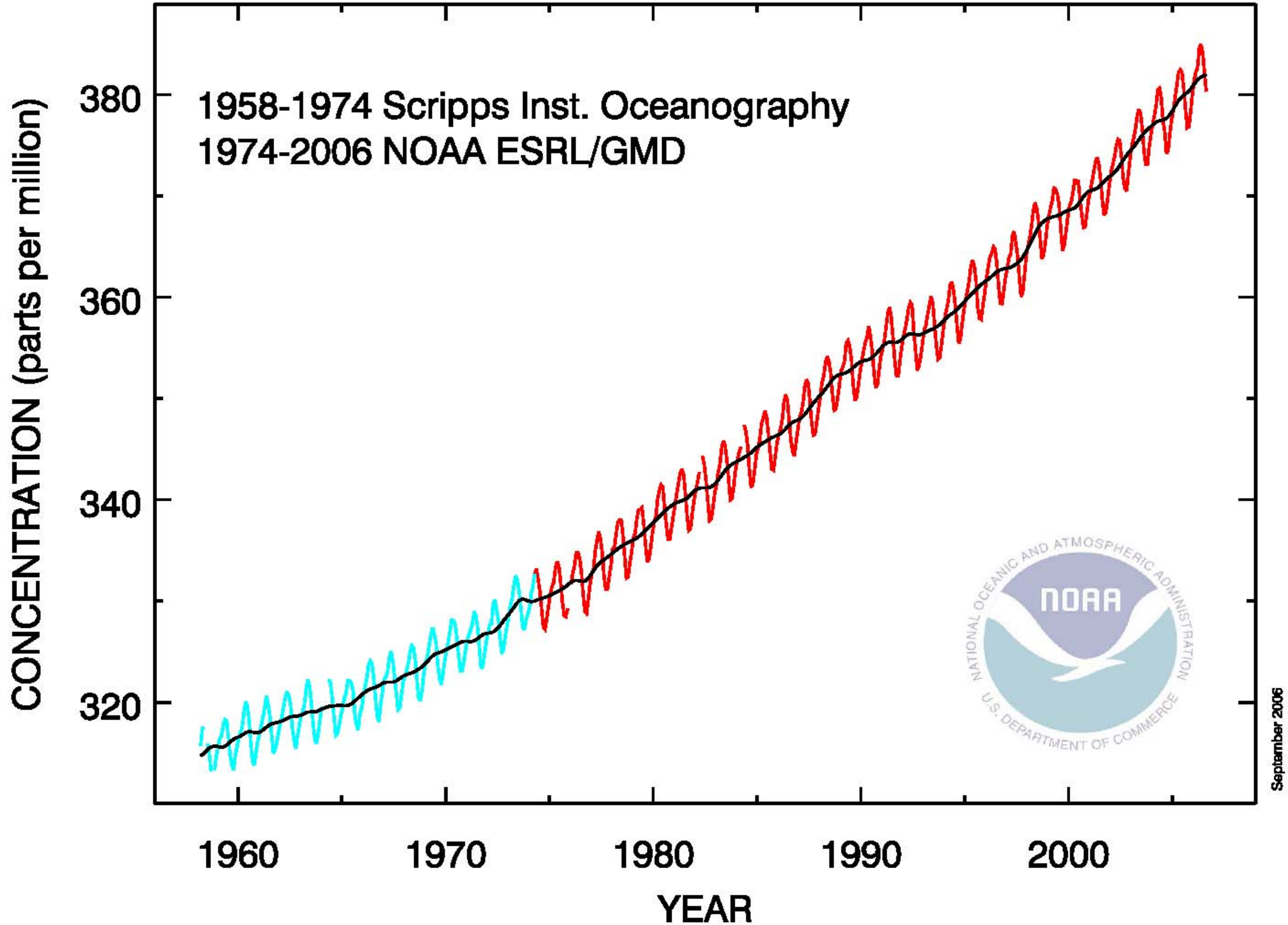
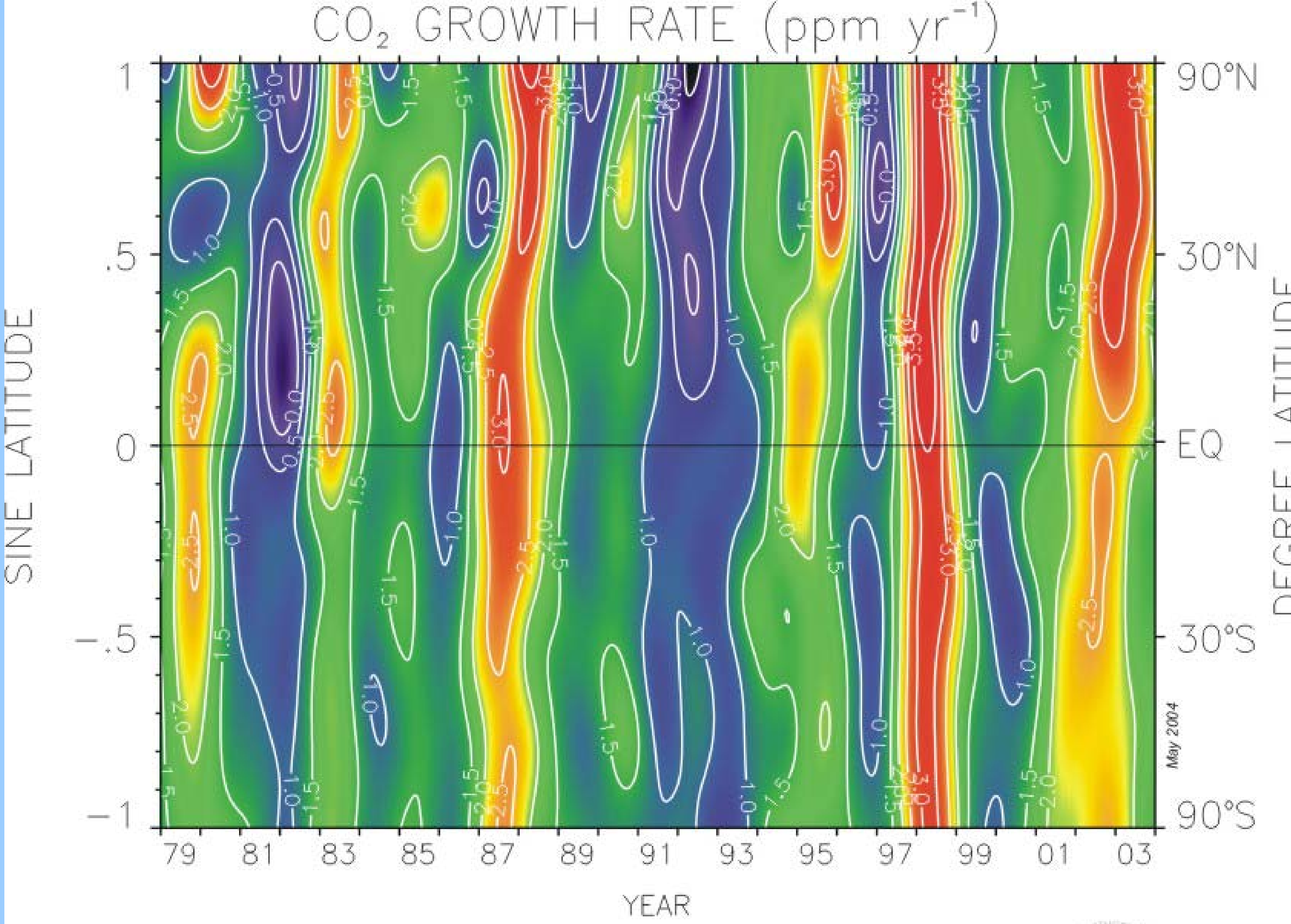
Atmospheric CO_2 at Mauna Loa Observatory





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Principal investigator: Thomas Conway, NOAA CMDL

http://www.cmdl.noaa.gov/ccgg

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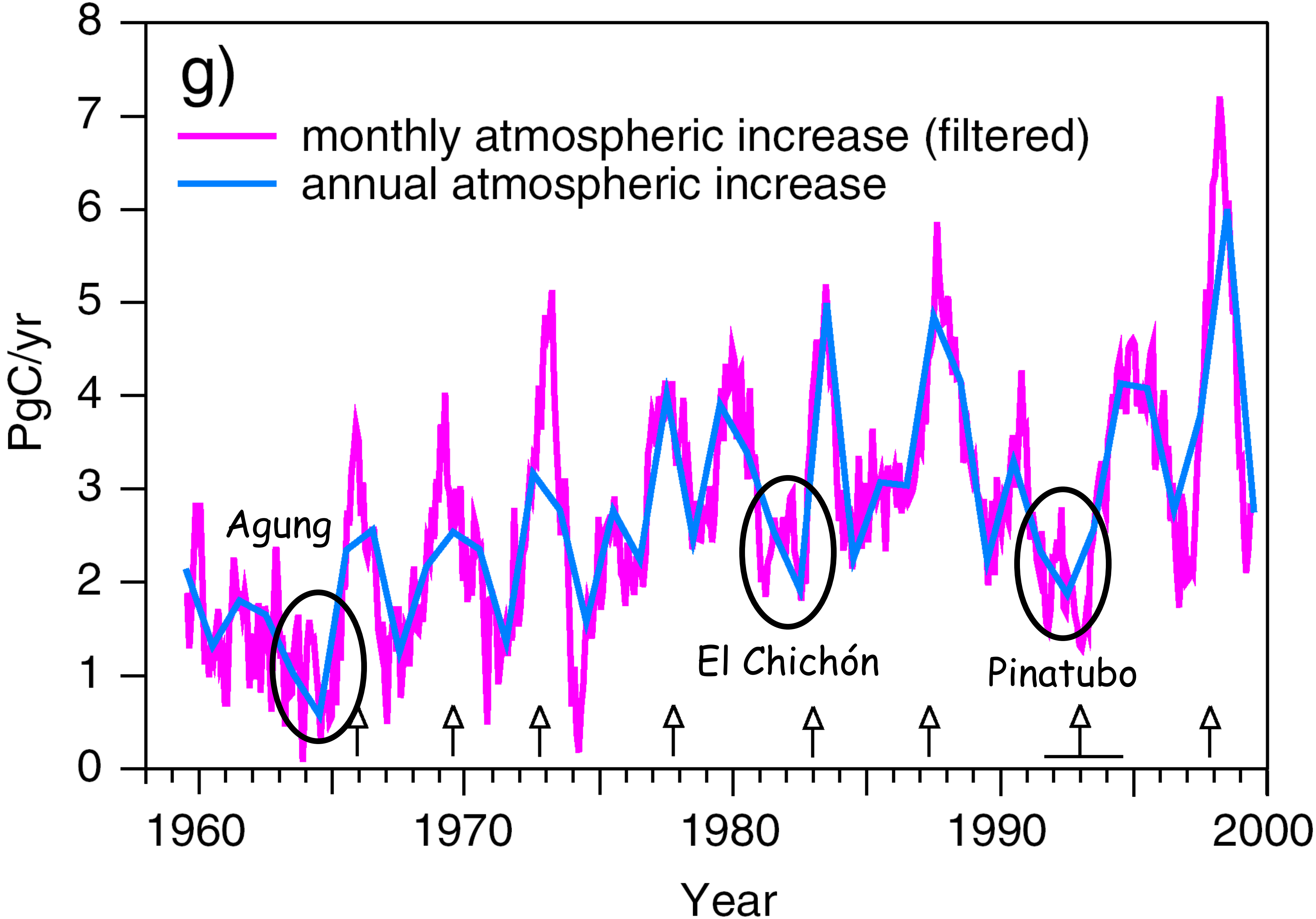
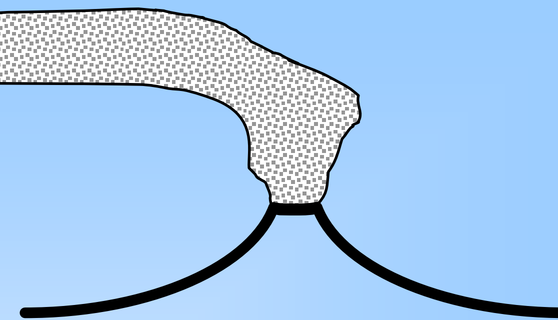
Possible causes of interannual CO_2 variations

- Changes in emissions
- Land use changes
- Unusual atmospheric temperatures or precipitation (e.g., drought)
- El Niño and La Niña episodes (affecting ocean sources and sinks as well as remote effects on land)
- Volcanic eruptions through effects on diffuse radiation

Hofmann (2004)

Rate of increase of CO_2 in the atmosphere





Diffuse Radiation from Pinatubo Makes a White Sky

Photographs by Alan Robock

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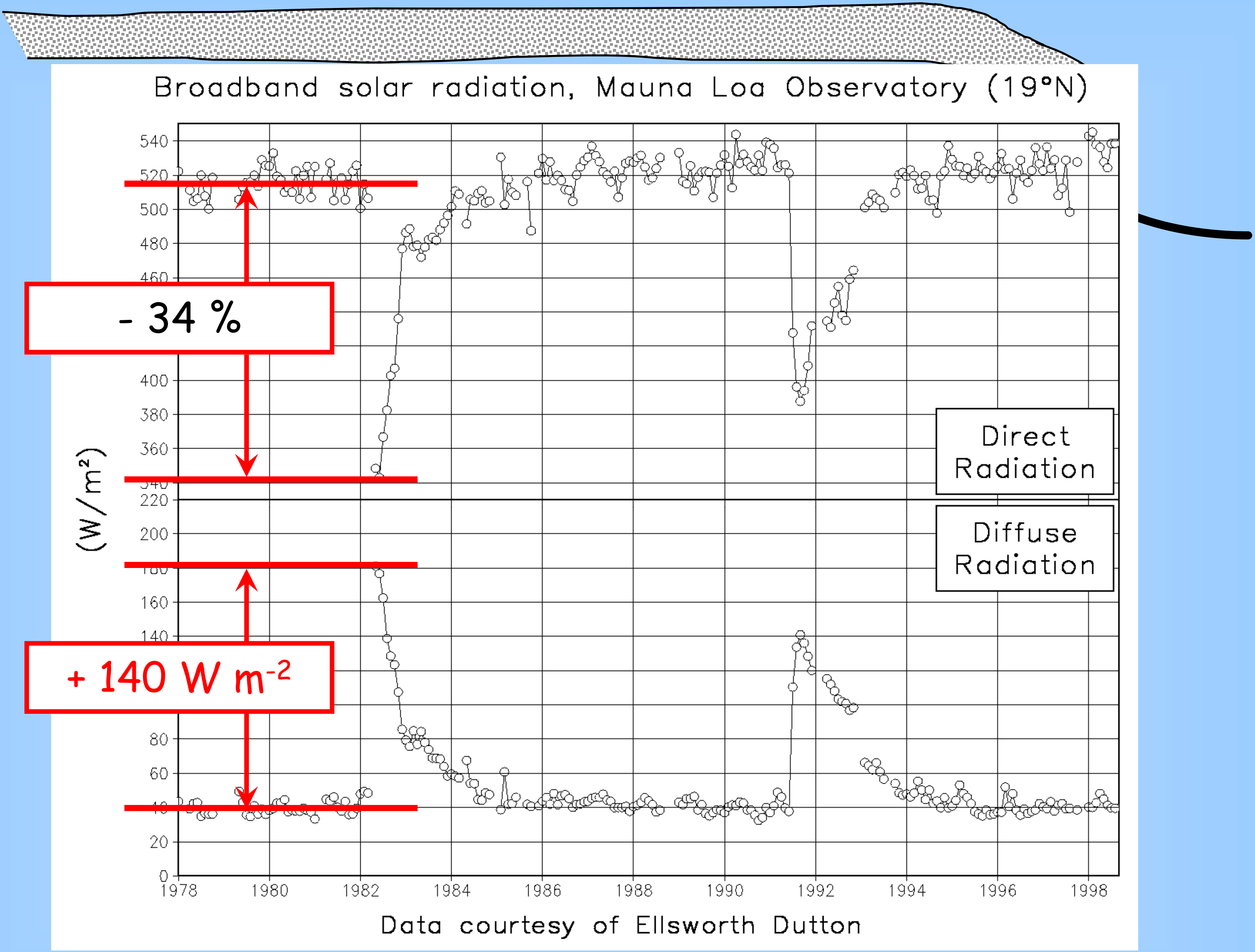
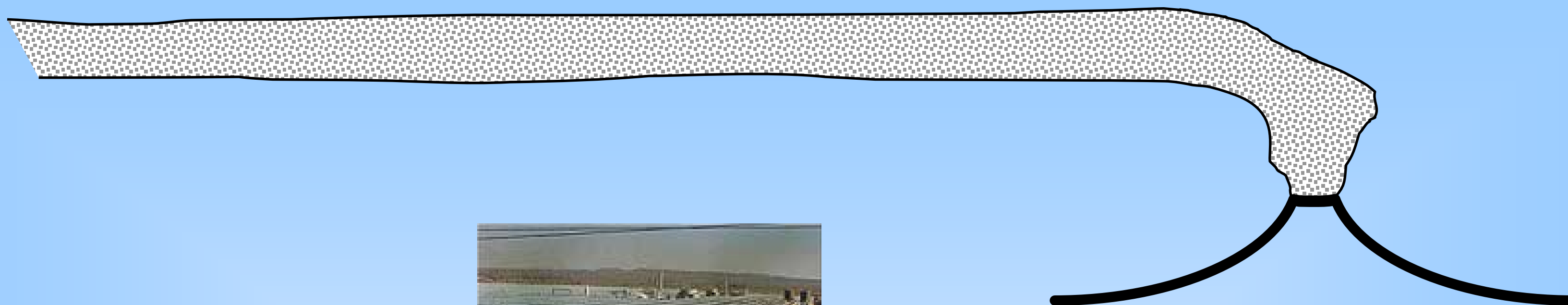

Broadband solar radiation, Mauna Loa Observatory (19°N)
(W/m²)
Direct Radiation
Diffuse Radiation
- 34 %
+ 140 W m-2
540
520
500
480
460
400
380
360
220
200
160
140
80
60
20
0
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
Data courtesy of Ellsworth Dutton



Nevada Solar One
64 MW

Solar steam generators requiring direct solar

Seville, Spain
Solar Tower
11 MW

http://www.electronichealing.co.uk/articles/solar_power_tower_spain.htm

http://judykitsune.wordpress.com/2007/09/12/solar-seville/

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Science and Engineering Visualization Challenge

Sept. 12, 2003 *Science*

FIRST PLACE

Mongolian Frost Rings

Dee Breger

Magnification: 35×

Sample courtesy of G. Jacoby

Krakatau?

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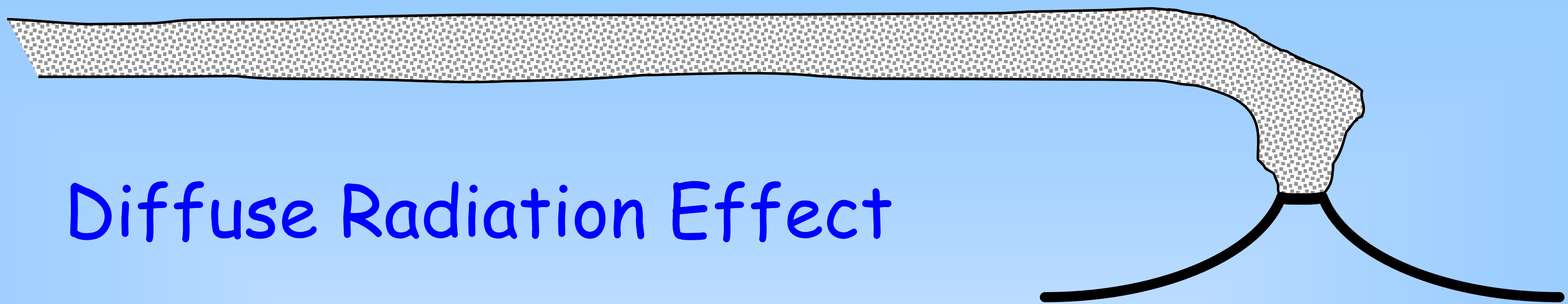
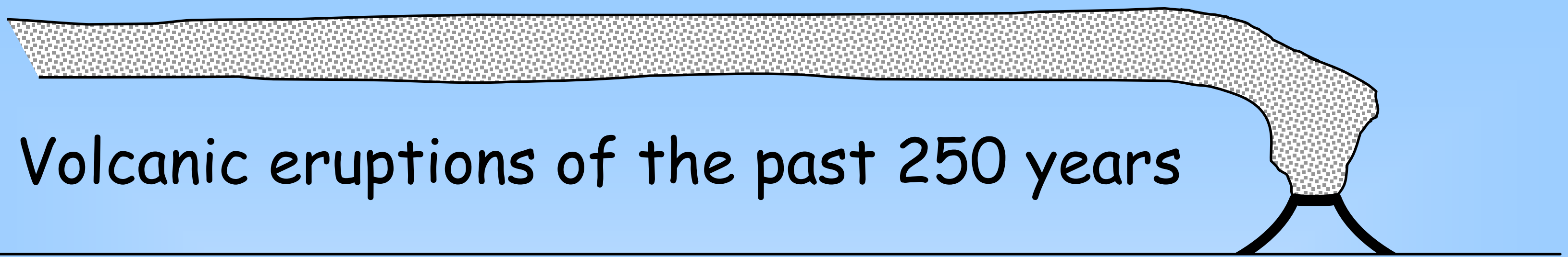


Diffuse Radiation Effect

The increased diffuse radiation allows plants to photosynthesize more of the time, increasing the CO_2 sink (Cohan et al., 2002; Gu et al., 2002, 2003; Farquhar and Roderick, 2003).

In fact, Gu et al. (2003) actually measured this effect in trees following the 1991 Pinatubo eruption.



Volcanic eruptions of the past 250 years

Volcano	Year of Eruption	VEI	d.v.i/E_{max}	IVI	Latitude
Laki craters [Lakagigar], Iceland	1783	4	2300	0.19	H
Unknown	1809	6	2000	0.25	L
Tambora, Sumbawa, Indonesia	1815	7	3000	0.5	L
Cosiguina, Nicaragua	1835	5	4000	0.11	L
Askja, Iceland	1875	5	1000	0.01*	H
Krakatau, Indonesia	1883	6	1000	0.12	L
Okataina [Tarawera], North Island, New Zealand	1886	5	800	0.04	L
Santa Maria, Guatemala	1902	6	600	0.05	L
Ksudach, Kamchatka, Russia	1907	5	500	0.02	H
Novarupta [Katmai], Alaska, United States	1912	6	500	0.15	H
Agung, Bali, Indonesia	1963	4	800	0.06	L
Mt. St. Helens, Washington, United States	1980	5	500	0	H
El Chichón, Chiapas, Mexico	1982	5	800	0.06	L
Mt. Pinatubo, Luzon, Philippines	1991	6	1000	—	L

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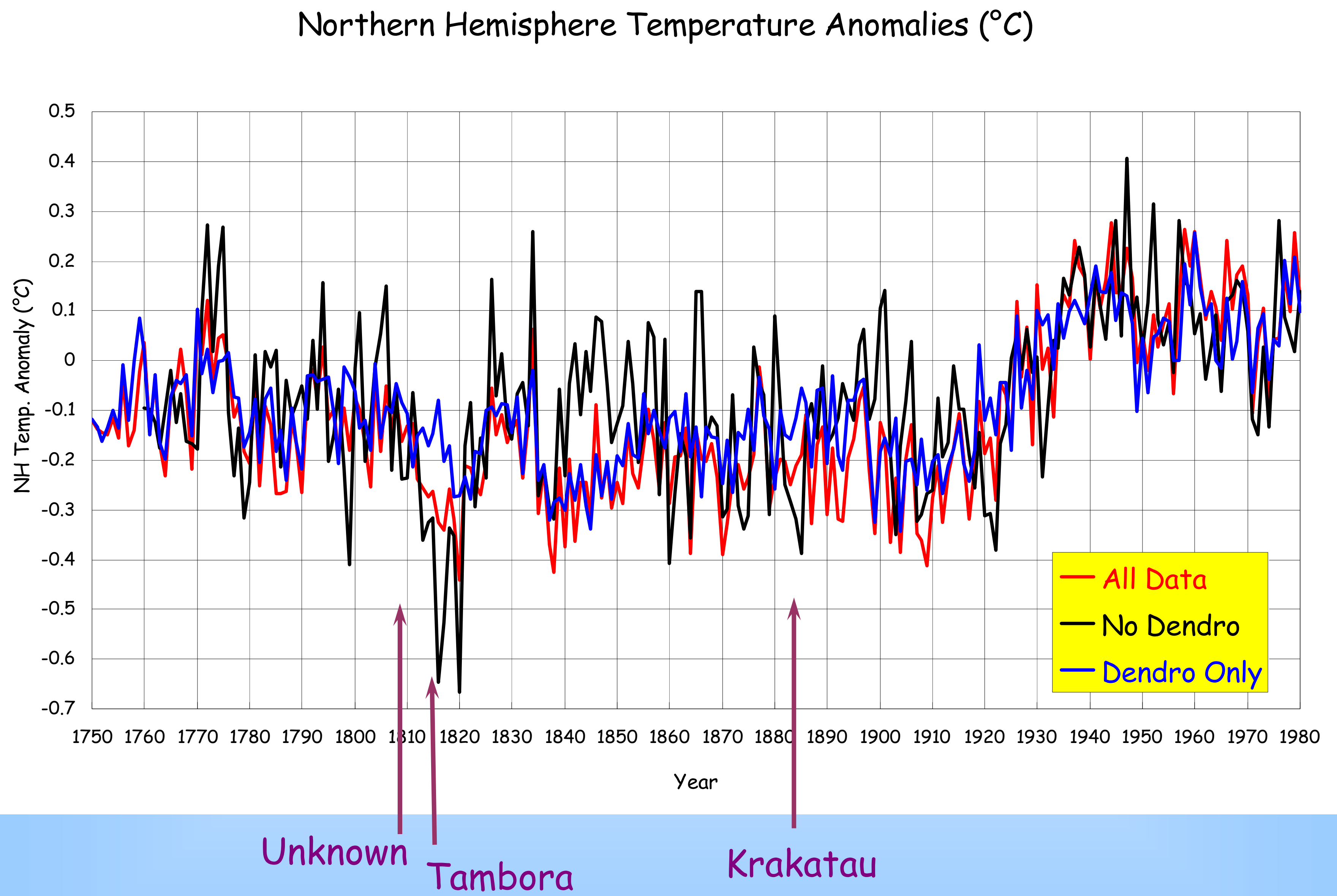
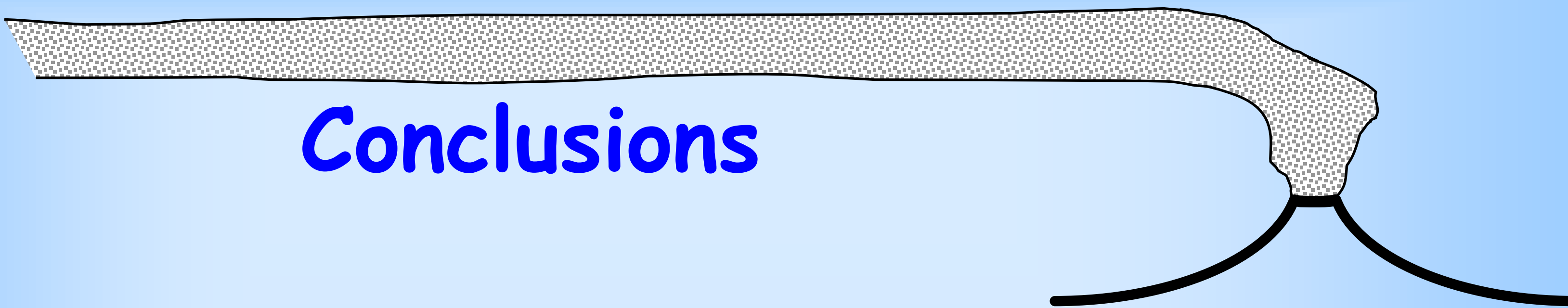


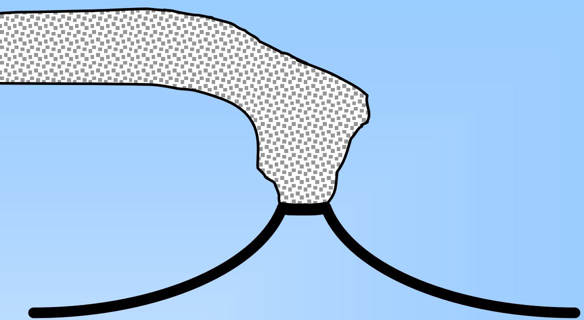
Reconstruction from Mann et al. (1998)

Conclusions



The effect of enhanced diffuse radiation and less direct radiation after volcanic eruptions on tree growth may bias interpretation of tree rings response following eruptions as being solely records of temperature.

When proxy records of Northern Hemisphere climate change are corrected for the diffuse effect, there is no impact on climate change for time scales longer than 20 years. However, it appears that there was a hemispheric cooling of about 0.6°C for a decade following the unknown volcanic eruption of 1809 and Tambora in 1815, and a cooling of 0.3°C for several years following the Krakatau eruption of 1883.



Are volcanic eruptions an innocuous example that can be used to demonstrate the safety of geoengineering?

No:

- ozone depletion
- reduction of precipitation, particularly the Asian and African summer monsoon, threatening the food supply of billions
- reduction of direct radiation for solar power
- no blue skies (but nice sunsets)

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London Sunset After Krakatau

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

Watercolor by William Ascroft

Figure from Symons (1888)