Ice Core Evidence of Recent Volcanic Contribution to Stratospheric Aerosols

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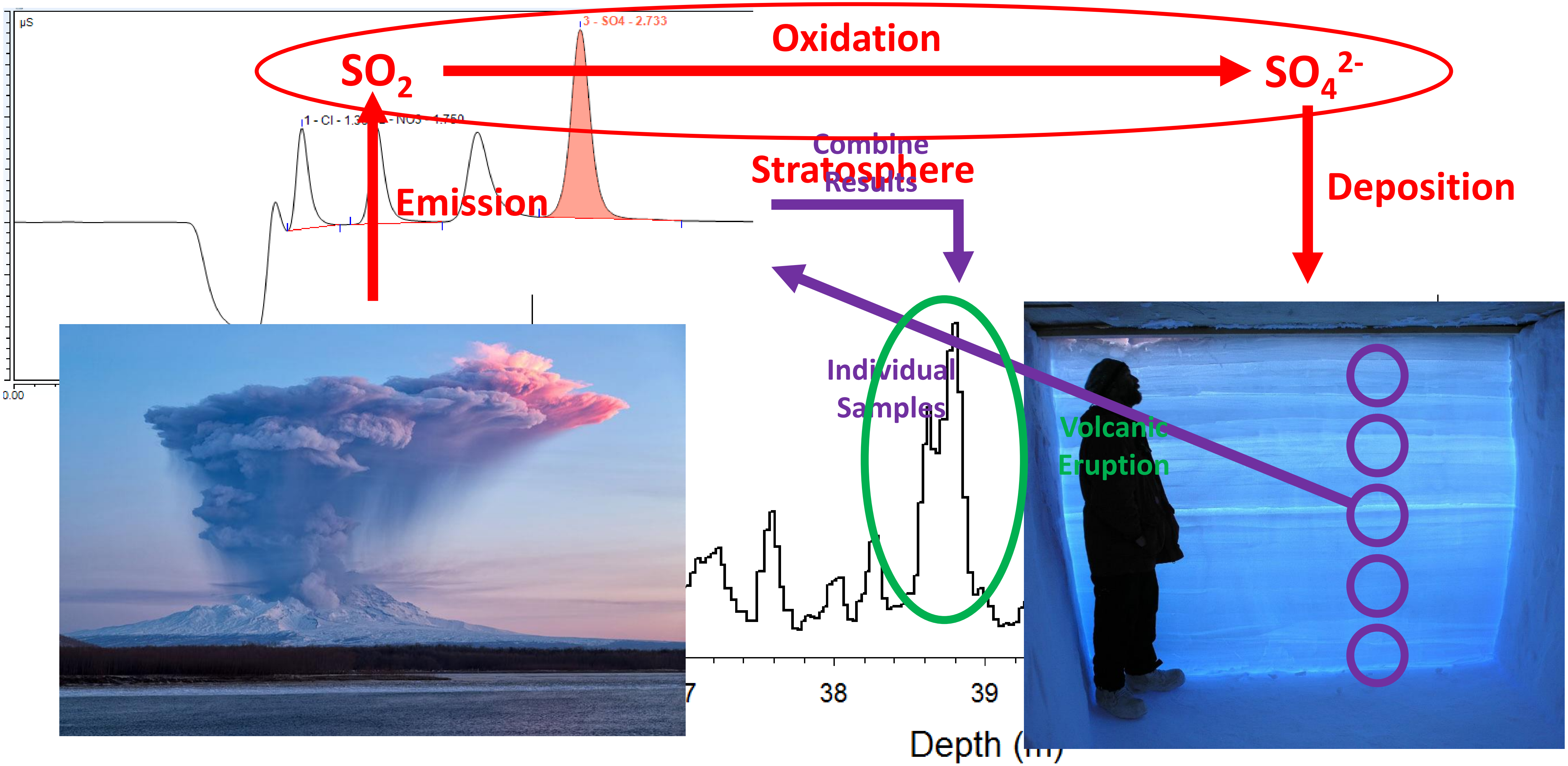
Objectives

- Compare SO_4^{2-} measurements in snow and ice with remotely sensed SO_2 and aerosol optical depth to investigate:
  - ➢if moderate S.H. eruptions have detectable impact on SO_4^{2-} deposition in Antarctica.
  - ➢differences in SO_4^{2-} deposition between West and East Antarctica.
  - ➢how SO_4^{2-} measured in snow reflects AOD.

Background



Photos: Shivulech, Gennady Teplitskiy / Shutterstock; Snow pit, Kendrick Taylor/Desert Research Institute

Sample Details

- South Pole Ice Core (SPC14)
  - Collected in 2014.
  - 0 - 7.06 meters depth (2014 to 1978).
  - Sample resolution = 9.3±2.2 mm (8 samples/yr).
- WAIS Divide Snow Pit (WAIS Snow Pit D)
  - Collected in 2013.
  - 2.63 meters depth (austral summer 2013 to austral winter of 2007).
  - 1 sample every 3 cm
- Both cores dated using annual layer counting.

(Source: Google Earth. Image date: December 21, 2015. Accessed: January 31, 2018.)

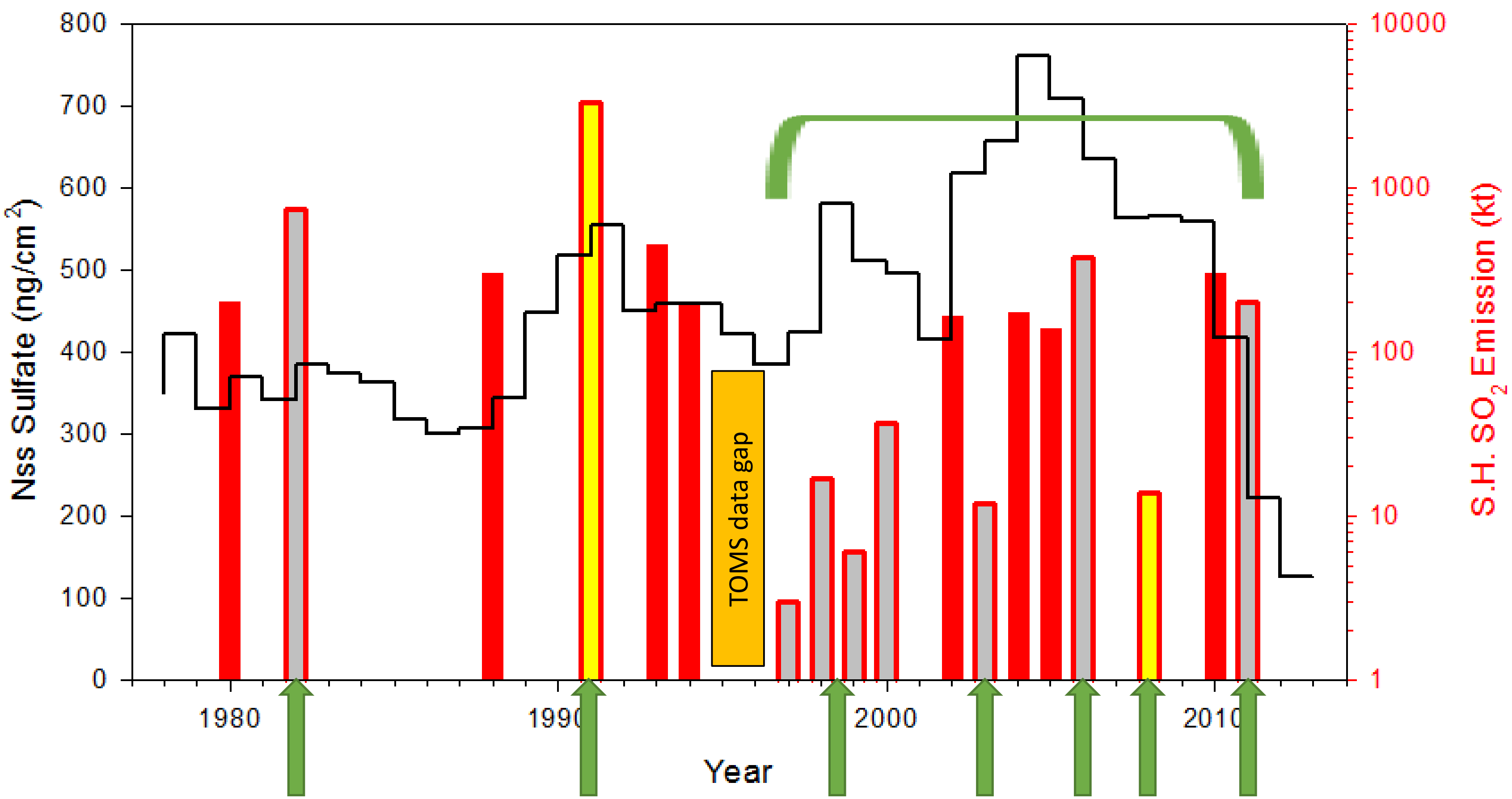
Filtering the Volcanic SO_2 Inventory

- Database must be reduced to eruptions that may produce Antarctic SO_4^{2-} signal.
- Establish estimated tropopause altitude bins.
- Eruptions removed which:
  1. were VEI 1 or 2 magnitude.
  2. were effusive.
  3. had latitude > 5°N.
- Limitations:
  1. may miss NH eruption signals (like Pinatubo?).
  2. may include “inappropriate” SH eruptions.
  3. plume height not this easy to measure!

Latitude	Tropopause (km)
5° N-10° S	15.3
10° S-30° S	14.4
30° S-35° S	11.7
35° S-40° S	10.8
40° S-45° S	10

Simon, Carn (2015), Multi-Satellite Volcanic Sulfur Dioxide L4 Long-Term Global Database V2, Greenbelt, MD, USA, Goddard Earth Science Data and Information Services Center (GES DISC), accessed 15 December 2017, 10.5067/measures/so2/data402.

SPC14 Ice Core

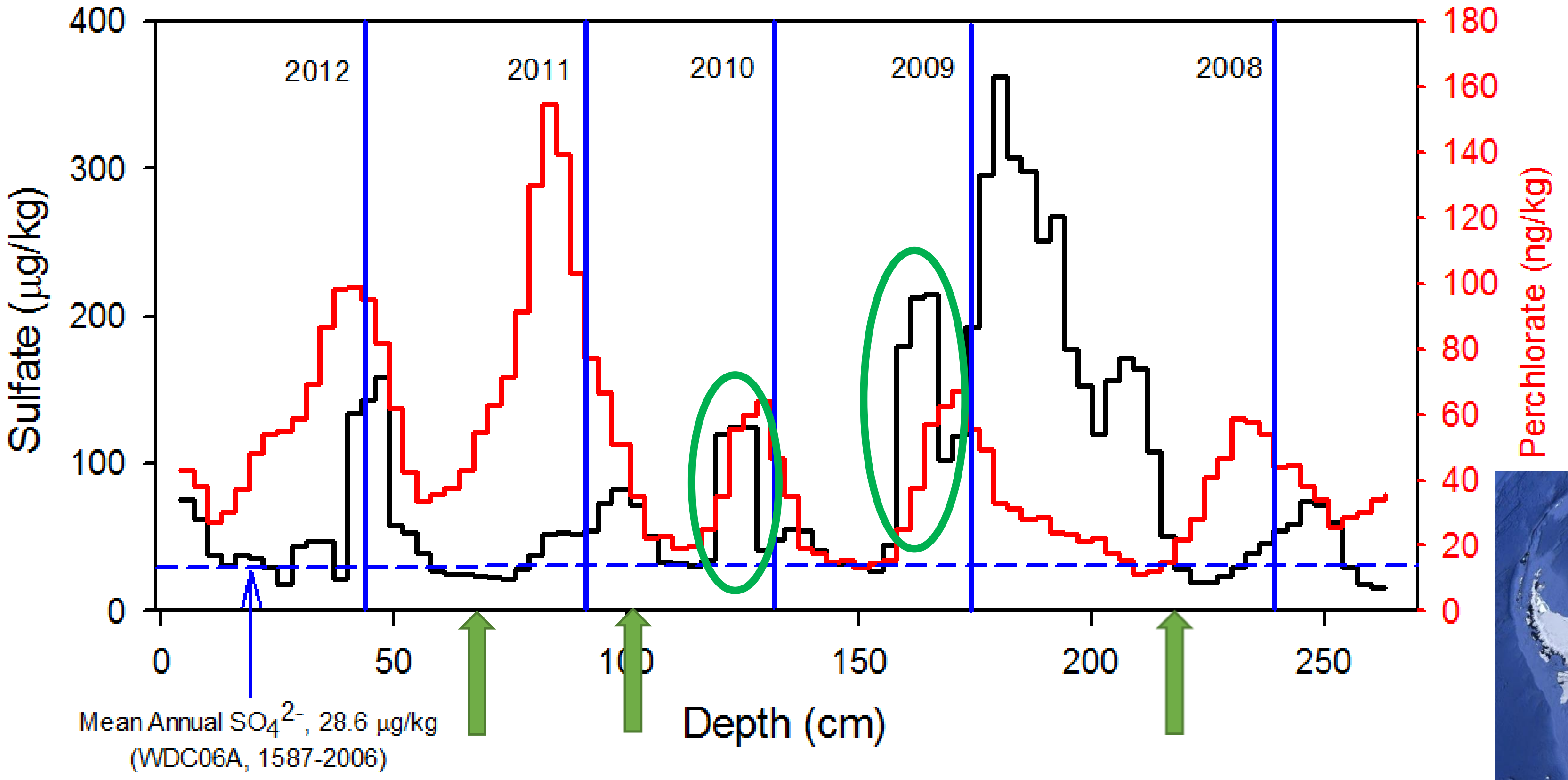


- Mean SO_4^{2-} flux 332.8 ng/cm^2.
- Total annual SO_2 emission from cleaned eruption list.
- Years include eruptions >> 40°S latitude.
- Annual totals include tropopause-altitude plume heights.
- Note eruption frequency from 1997-2011.

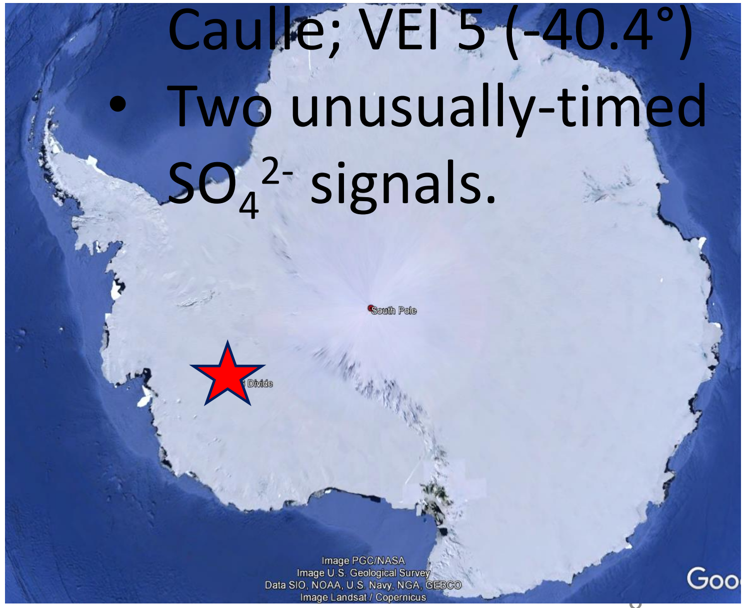
Key Observations

- High frequency of recent moderately-sized explosive eruptions may have produced significant decadal-scale increase in Nss SO_4^{2-} deposition at SP.
- 1978-1995 had a mean annual SO_4^{2-} flux of 404 ng/cm^2, and 0.7 moderate eruptions/yr.
- 1996-2011 had a mean annual SO_4^{2-} flux of 553 ng/cm^2,and 1.2 moderate eruptions/yr.
- Nss SO_4^{2-} flux indicate satellite data gap from 1995 to mid-1996 does not likely contain "missing" moderate SH explosive eruptions from the cleaned eruption list.

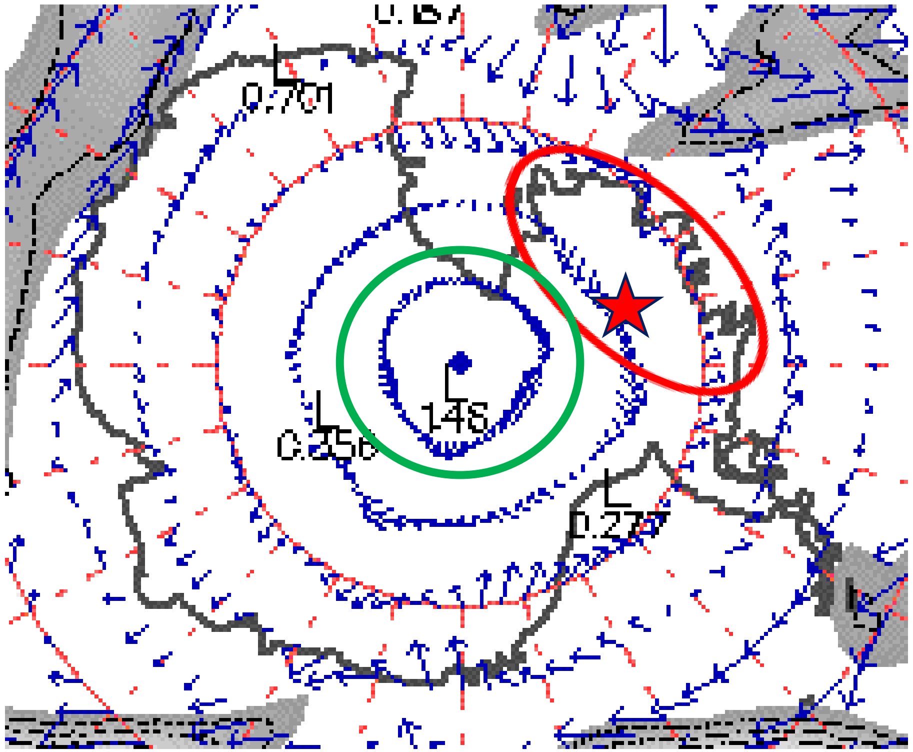
WAIS Divide Snow Pit D



- Three eruptions from filtered list occur in this timeframe.
- Chaitén; VEI 4 (-42.8°)
- Merapi; VEI 4 (-7.5°)
- Puyehue-Cordón Caulle; VEI 5 (-40.4°)
- Two unusually-timed SO_4^{2-} signals.



Key Observations

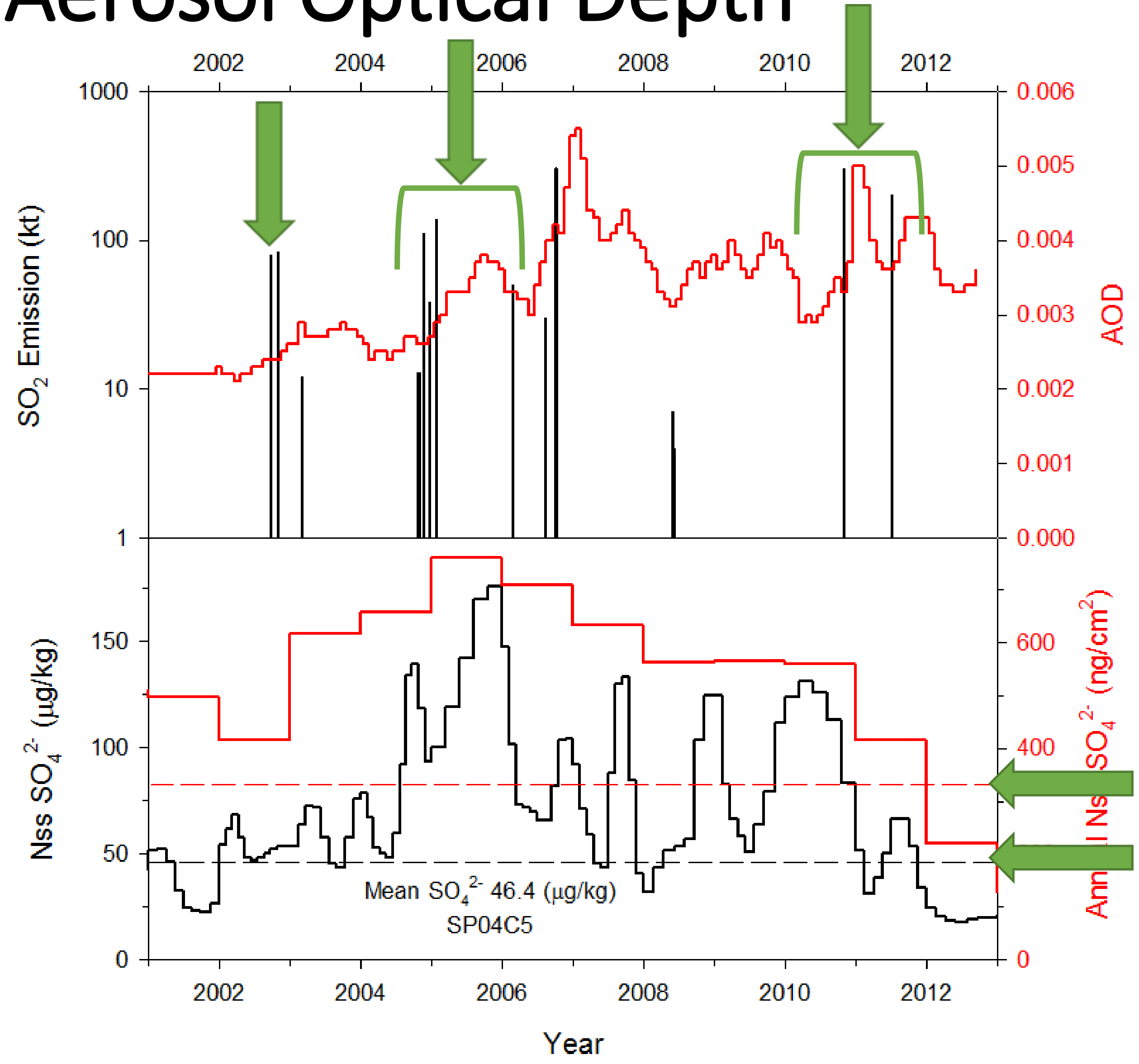


Source:
http://nicmosis.as.arizona.edu:8000/ECLIPSE_WEB/ECLIPSE_03/wind_pattern.gif, accessed January 1, 2018

- PCC, did not produce well defined signal in WAIS or SP.
- Merapi did not significantly increase volcanic sulfate in WAIS or SP cores.
- Chaitén produced much-enhanced SO_4^{2-} deposition at WAIS compared to SP.
- WAIS volcanic SO_4^{2-} deposition may be highly influenced by atmospheric conditions.

S.H. Aerosol Optical Depth

- Dashed lines indicate background SO_4^{2-} concentration and flux.
- Merapi and PCC do not appear to influence SO_4^{2-} at SP, though S.H. AOD increased.
- High-frequency Manam eruptions with very high-altitude plumes ($\bar{x} = 18.8\ km$, *n*=6) may have enhanced SO_4^{2-} deposition from levels possibly elevated by Ruang and Reventador.



AOD data: https://data.giss.nasa.gov/modelforce/strataer/tau.line_2012.12.txt, accessed 15 December 2017 (Sato et.al).

Summary of Observations

- High frequency of eruptions may produce significant decadal-scale increase in Nss SO_4^{2-} deposition at SP.
- Much stronger signal preserved from moderate high latitude eruptions as compared to tropics.
- Sampling location is a critical consideration when interpreting volcanic signals in ice cores.
- Increased SO_4^{2-} deposition not strongly correlated to hemispheric-scale AOD measurements.

Acknowledgements

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Selected S.H. Eruptions

Volcano	Latitude	Longitude	Year	Month	Day	VEI	Alt. (km)	SO2 (kt)
Cordon Caulle	-40.59	-72.117	2011	Jun	4	5	14	200
Merapi	-7.542	110.442	2010	Nov	4	4	17	300
Chaiten	-42.833	-72.646	2008	May	2-6	4	14-17	14
Rabaul	-4.271	152.203	2006	Oct	7	4	18	300
Tungurahua	-1.467	-78.442	2006	Aug	16	3	16	30
Manam	-4.1	145.061	2006	Feb	27	3	19	50
Manam	-4.1	145.061	2005	Jan	28	4	24	140
Manam	-4.1	145.061	2004	Dec	20	3	17	38
Manam	-4.1	145.061	2004	Nov	24	4	18	111
Manam	-4.1	145.061	2004	Oct	31	3	17	13
Manam	-4.1	145.061	2004	Oct	24	3	18	13
Tungurahua[1]	-1.467	-78.442	2003	Mar	8	3	15.023	12
Reventador	-0.078	-77.656	2002	Nov	3	4	17	84
Ruang	2.3	125.37	2002	Sep	26	4	22	80
Ulawun	-5.05	151.33	2000	Sep	28	4	16	37

Volcano	Latitude	Longitude	Year	Month	Day	VEI	Alt. (km)	SO2 (kt)
Tungurahua[1]	-1.467	-78.442	1999	Nov	16	3	15.02	6
Manam	-4.1	145.061	1998	Oct	5	3	16	17
Manam	-4.1	145.061	1997	Feb	8	3	16	3
Rabaul	-4.271	152.203	1994	Sep	19	4	20	200
Lascar	-23.37	-67.73	1993	Apr	19	4	16	450
Hudson	-45.9	-72.97	1991	Aug	15	5	18	2700
Hudson	-45.9	-72.97	1991	Aug	12	5	16	600
Makian	0.32	127.4	1988	Jul	29	3	16	50
Banda_Api	-4.525	129.871	1988	May	9	3	16	250
Galunggung	-7.25	108.058	1982	Jul	13	3	16	355
Galunggung	-7.25	108.058	1982	May	17-18	3	16	190
Galunggung	-7.25	108.058	1982	May	5	3	16	100
Galunggung	-7.25	108.058	1982	Apr	24	3	18	100
Ulawun	-5.05	151.33	1980	Oct	7	3	20	200

[1] Plume height was estimated.

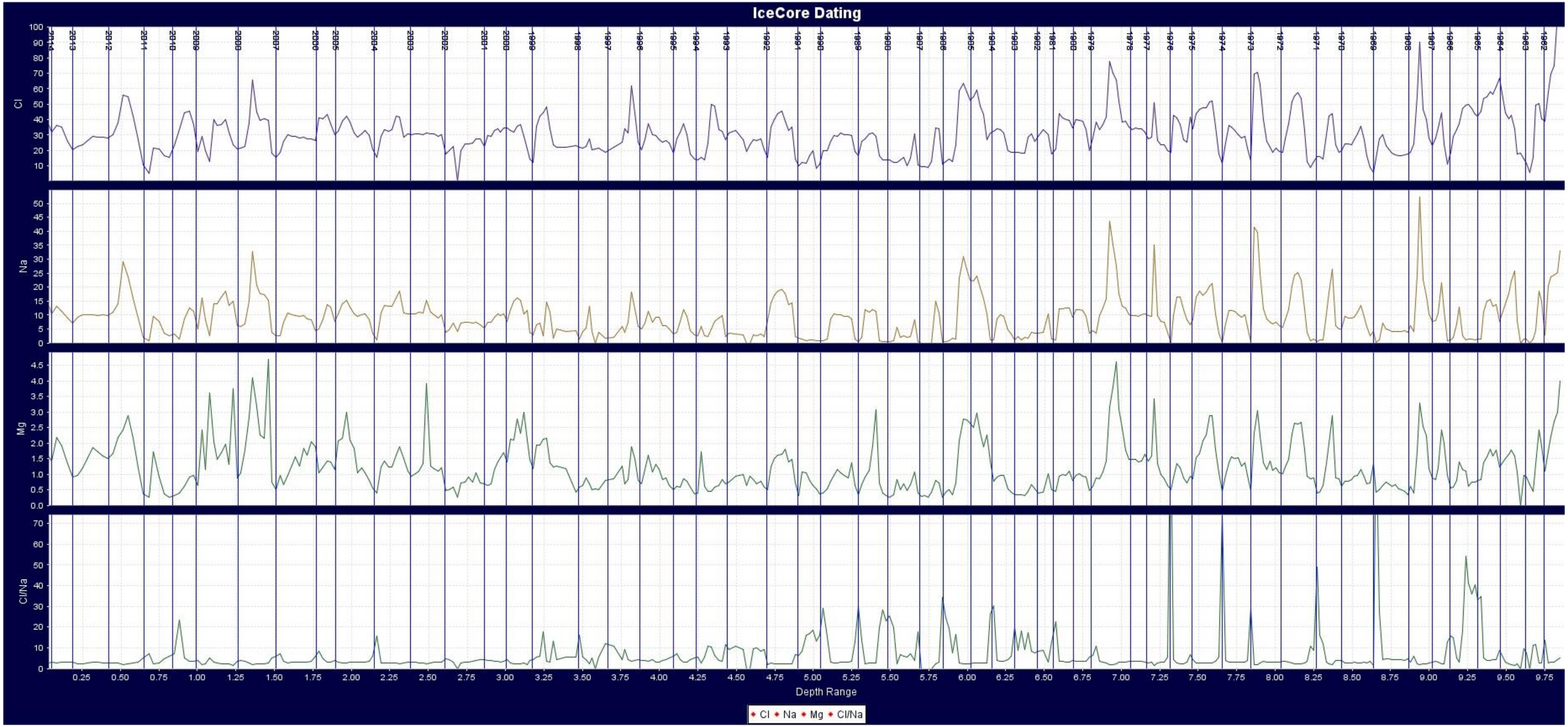
Annual Signals

- Chloride – Sea salt, maxima in winter at SP.
- Sodium – Sea salt, maxima in winter at SP.
- Magnesium – Dust and sea salt, maxima in winter at SP.
- Sulfate – Maxima in spring at WAIS.
- Perchlorate – Maxima in summer at WAIS, used only for contemporary periods.
- In all cases, consideration of typical accumulation rate is considered.

Satellites

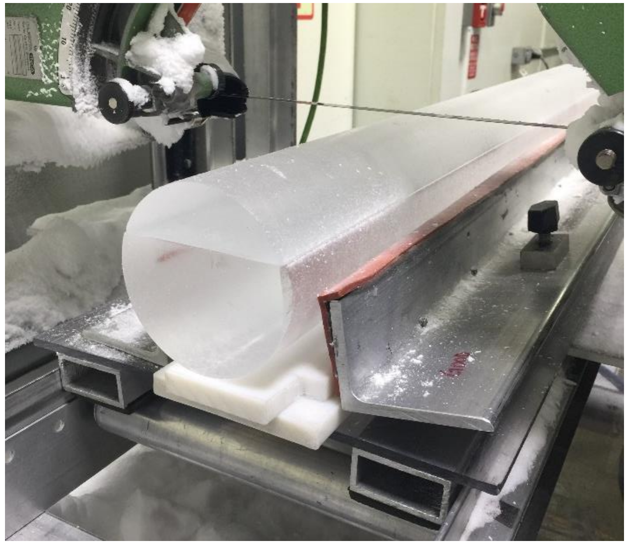
- Nimbus-7: Total Ozone Mapping Spectrometer (1978-1995)
- Meteor-3: TOMS (1991-1994)
- Advanced Earth Orbiting Satellite: TOMS (1996-1997)
- Earth Probe: TOMS (1996-2004)
- Aura: Ozone Monitoring Instrument (2004-2018)
- Suomi National Polar-orbiting Partnership: Ozone Mapping and Profiler Suite (2011-Current)

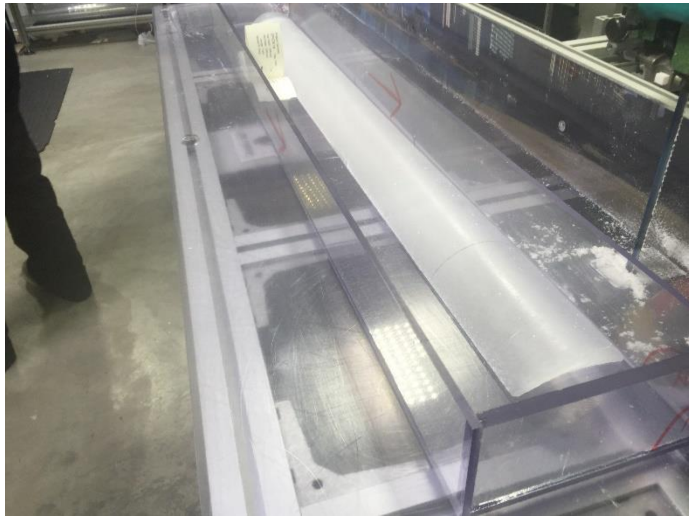
SPC14HA Dating

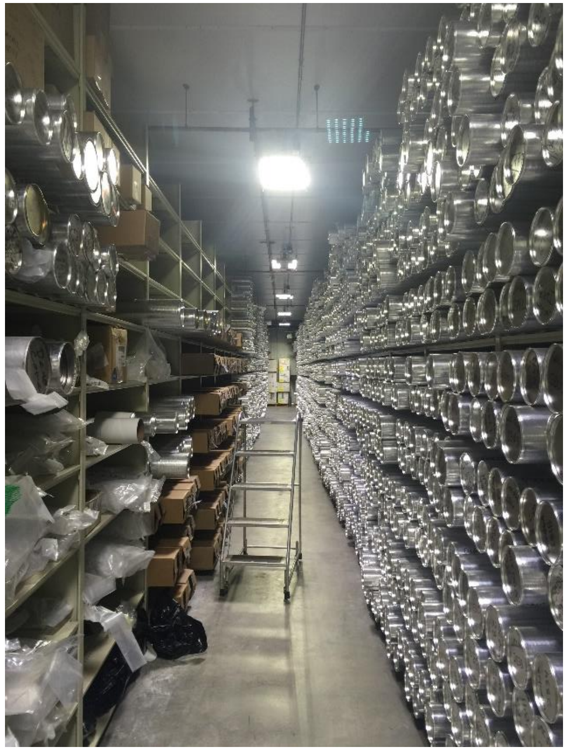


Ice Core Processing, National Ice Core Laboratory

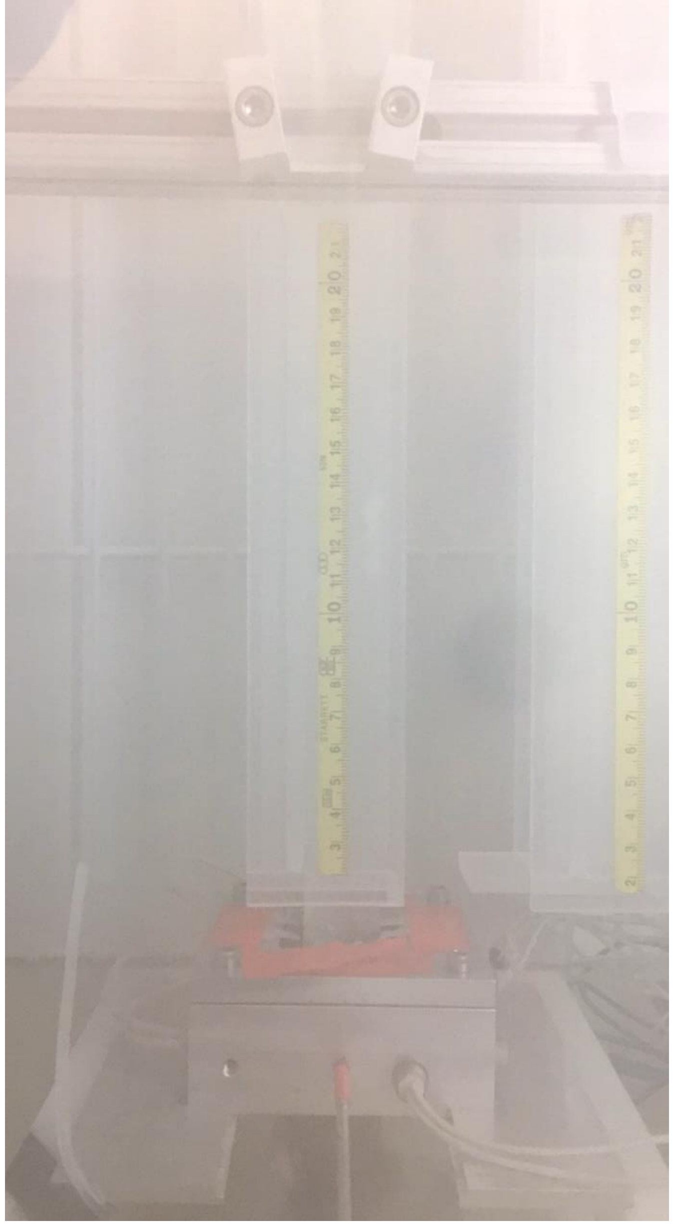
- Cores shipped to Denver, CO from Antarctica.
- Participating PI’s meet and cut the core into respective sample pieces (right, bottom left).







- Work room (top left) maintained at -20 °C
- NICL maintains the national ice core archive (center).
- Slice of core is maintained in a deep freeze (-40°C) archive for future research.
- Processing includes visual inspection, high resolution photography, Thin section sampling, and continuous electrical conductivity measurements.



Continuous Flow Analysis

- No need to decontaminate samples.
- Melts ice core, and pumps continuously to particle counter, fractions collectors.
- Typical melt rate is 3.5 ml/min
- Can melt up to 12 meters per day, compared to 1 meter per day discrete collection.
- 1 sec = 30 sec.