On Being Prepared for the Next Big Volcanic Eruption via Synergistic Satellite Remote Sensing

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U.S. NAVAL RESEARCH LABORATORY

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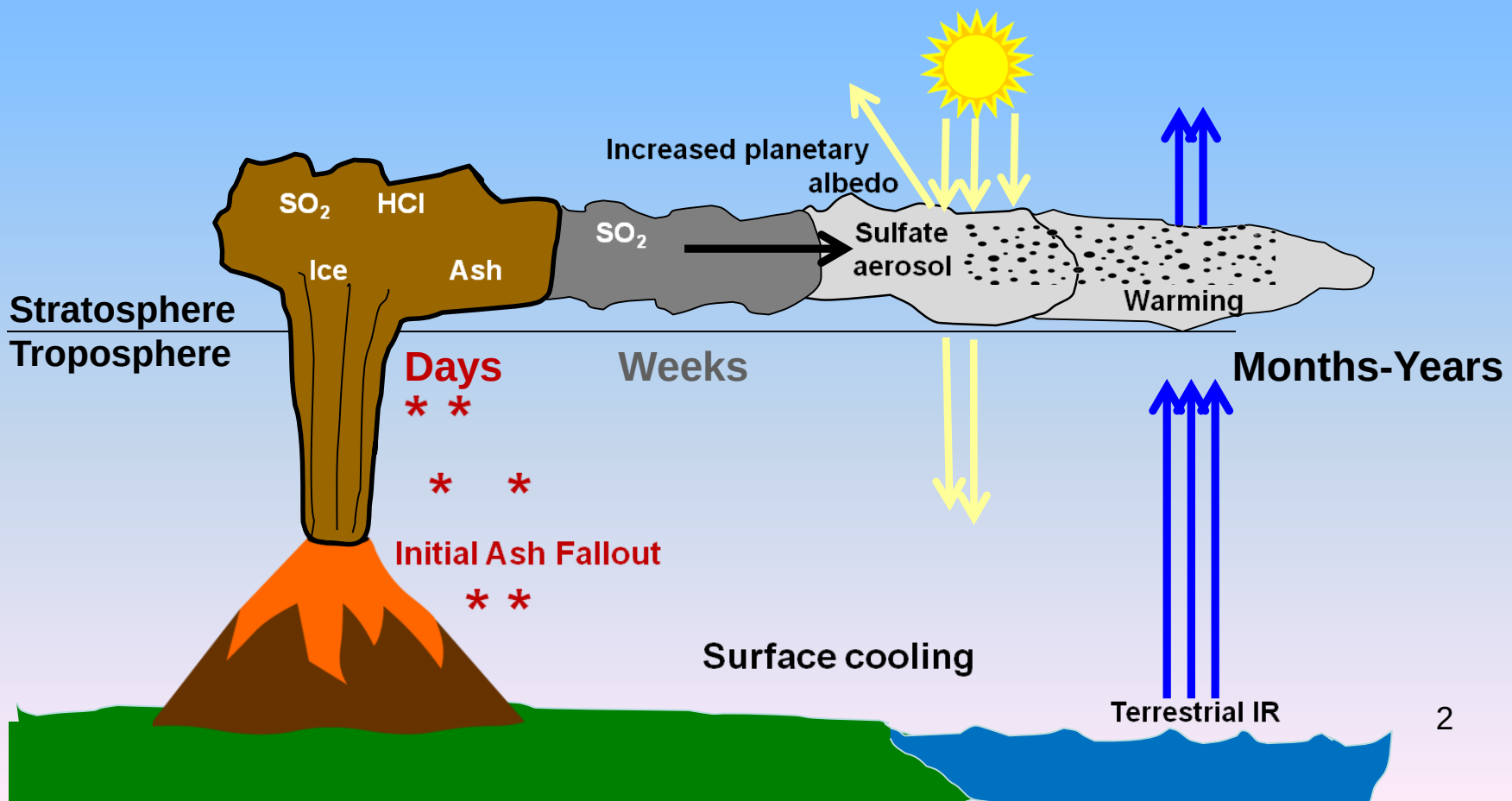
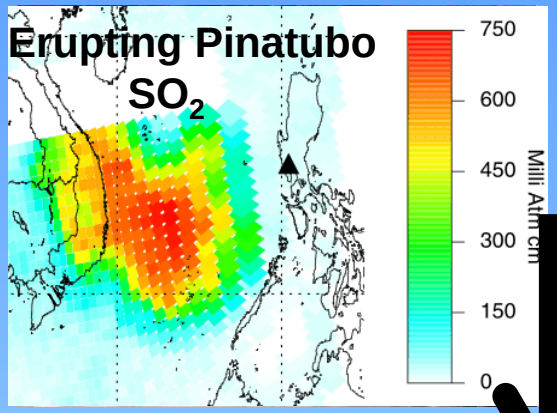
Background/Motivation

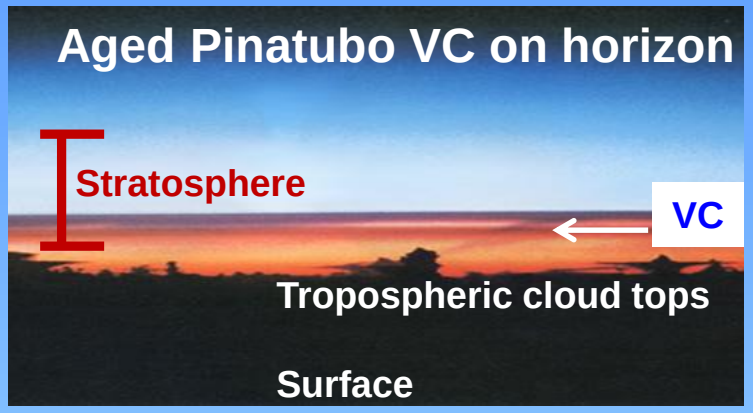
Stratospheric volcanic clouds impact weather, climate

Key factors: composition, mass, height



How different satellites “see” volcanic clouds (VC)





Synergistic Study of Satellite Remote Sensing (SRS) of Stratospheric Volcanic Clouds (VC)

Objective

To improve the full depiction of stratospheric VC by…
…characterizing the full 3-D VC throughout its lifetime
…blending complementary SRS data

Approach

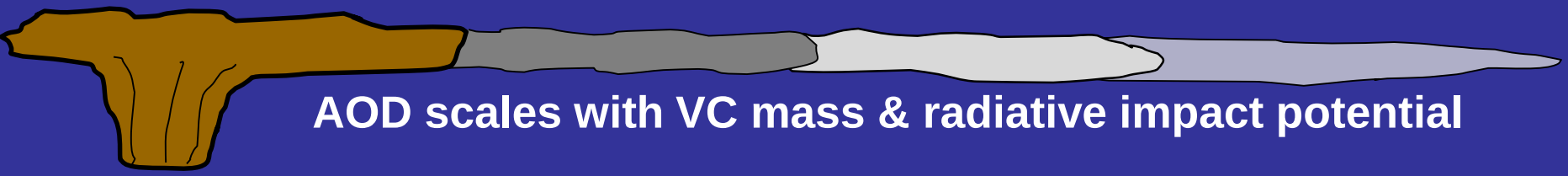
- **Perform case studies in the satellite era (i.e. since 1979)**
- **Use whatever SRS data are available for each eruption and VC**

Payoff

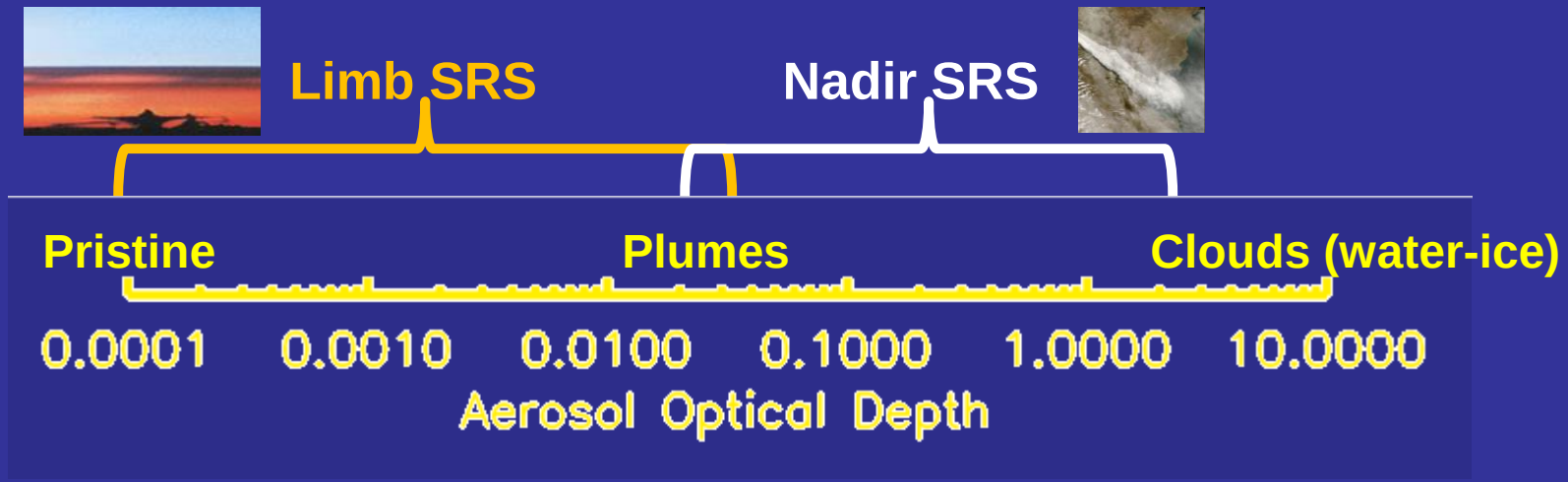
- **Improved understanding of critical SRS assets.**
- **An optimized observing strategy for the SRS of future VCs.**

Our focus:

Aerosol Optical Depth (AOD)



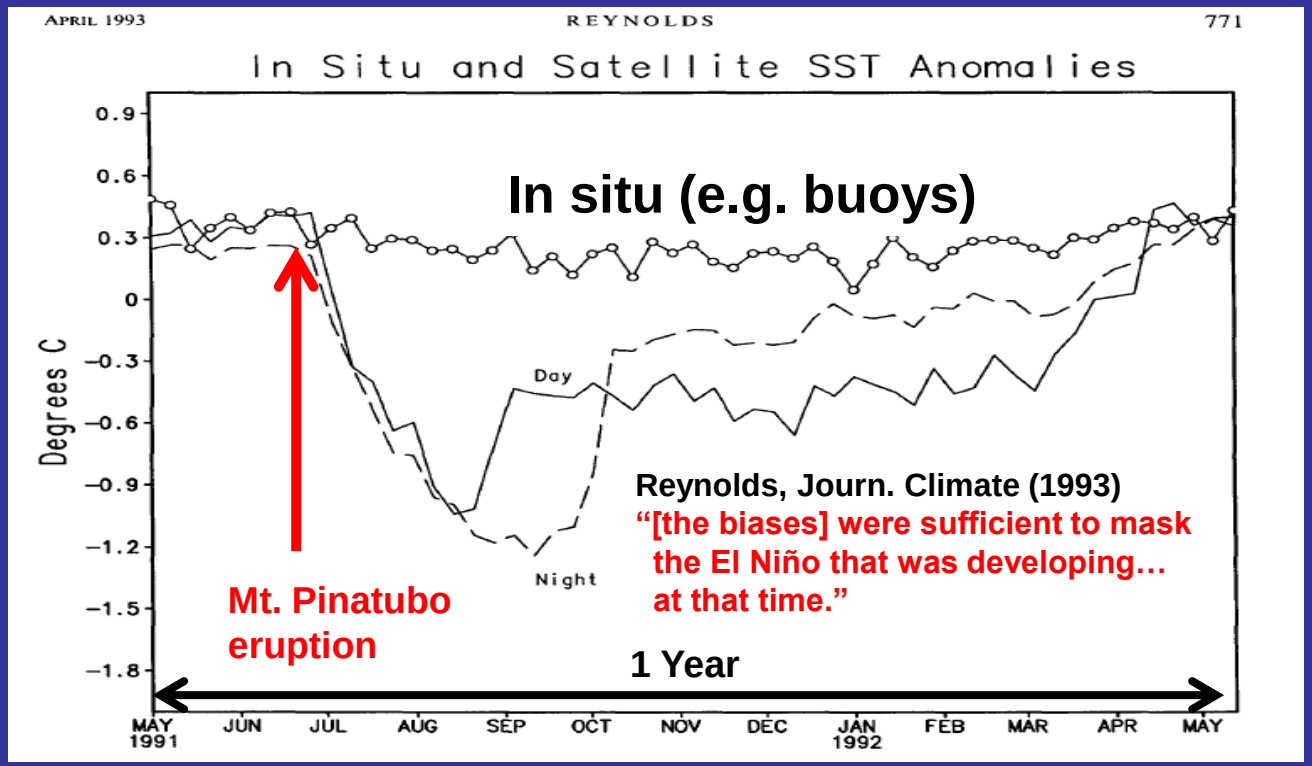
AOD scales with VC mass & radiative impact potential

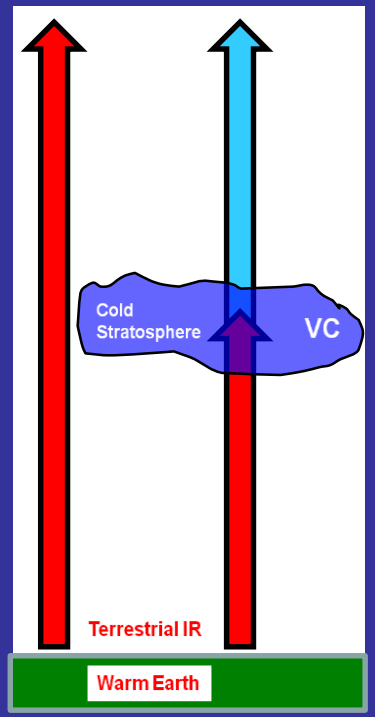


Problem: Misinterpretation of nadir vis & thermal IR data

* The eruption: Mt. Pinatubo, June 1991

* At issue: NOAA's AVHRR (nadir imager) sea-surface temperature (SST) retrieval
  * SST based on supposed cloud-cleared pixels
  * Unexpected cloudlike IR absorption…by cold stratospheric sulfates





Problem: Misinterpretation of limb-view aerosol profiles

* The eruption: Sarychev Peak, June 2009

* Discrepancy between SRS aerosol data & climate model

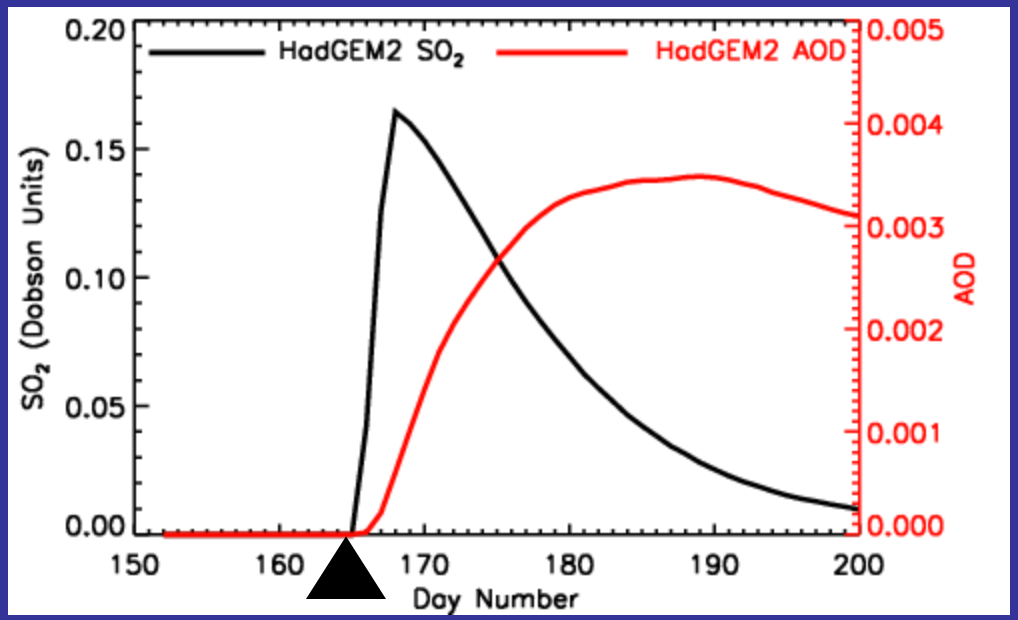
Haywood et al. (*Journ. Geophysics. Res*., 2010)
"Observations of the eruption of the Sarychev volcano and simulations using the HadGEM2 climate model"

From their conclusions:

"[HadGEM2]…aspects… require refining…

…the transformation of SO_2 to…sulfate appears too quick when compared to…observations."

Their Figure 8 (adapted):



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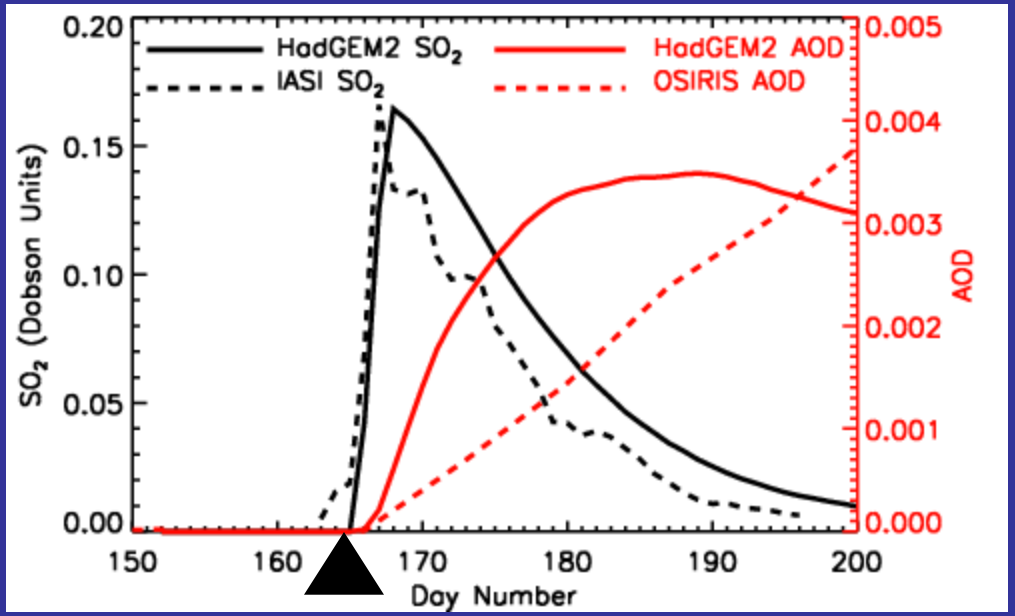
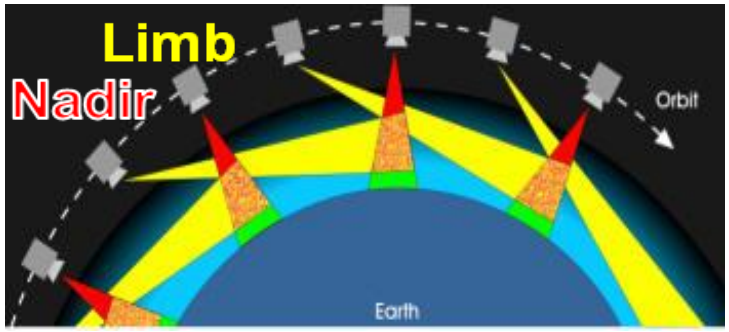


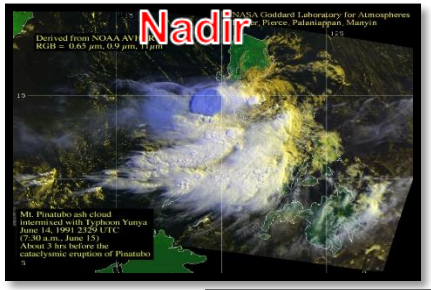
Haywood et al.'s "ground truth" for AOD was a single SRS data set.

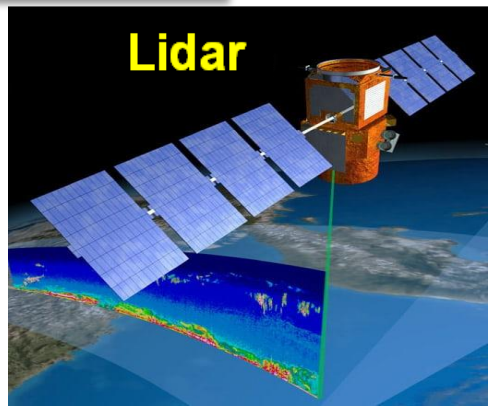
Approach

Case studies: El Chichon (‘82), Pinatubo (‘91), and other stratospheric eruptions.

Blend available SRS viewpoints







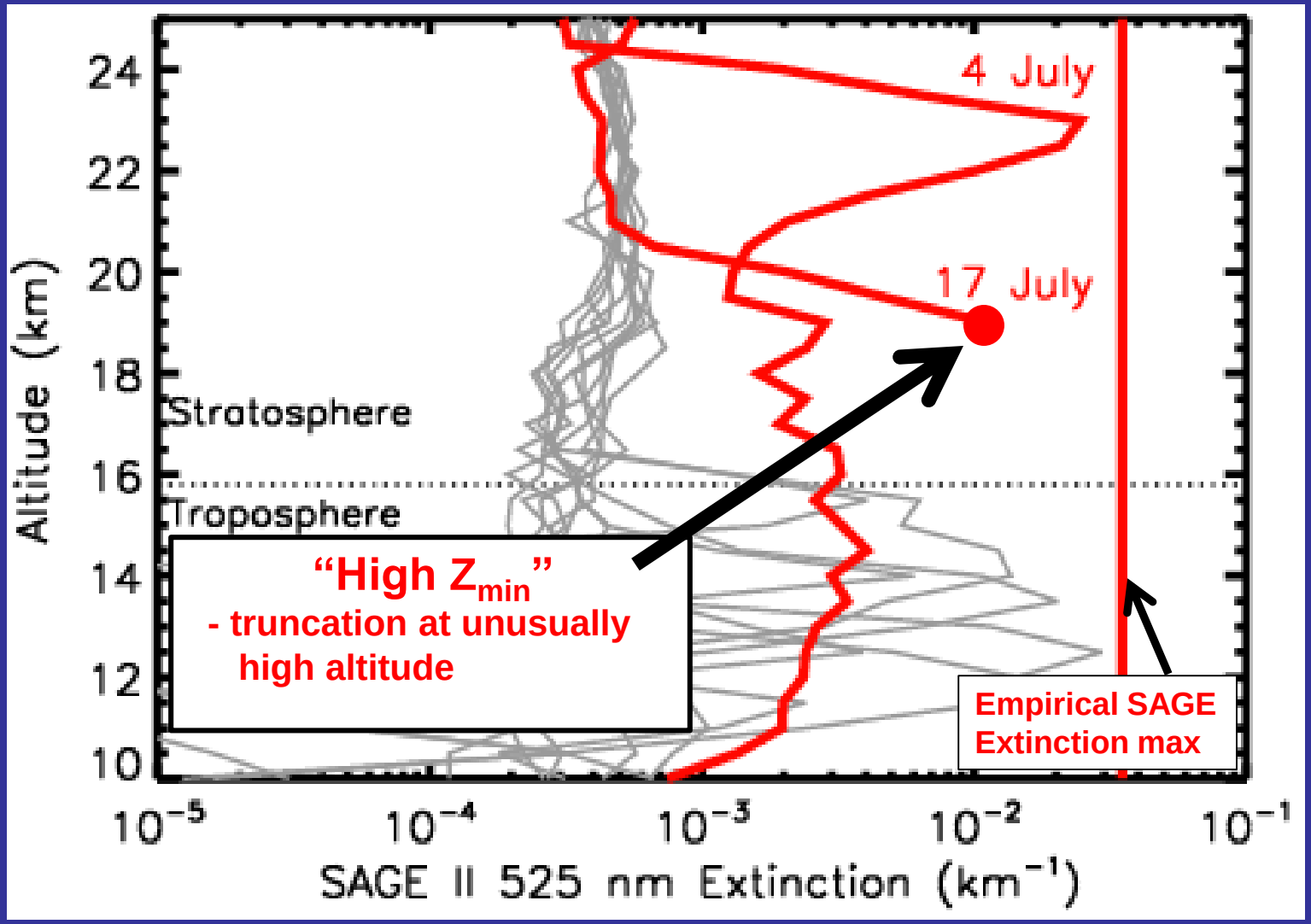
Satellite-Era Stratospheric Eruptions

(Selected Available SRS)

Volcano	Year	Nadir Imager	Limb Profiler	Lidar
El Chichon	1982	AVHRR	SAGE I	
Kelut	1990	AVHRR	SAGE II	
Pinatubo	1991	AVHRR	SAGE II	
Cerro Hudson	1991	AVHRR	SAGE II	
Spurr	1992	AVHRR	ISAMS	
Lascar	1993	AVHRR	SAGE II	
Kliuchevskoi	1994	AVHRR	SAGE II	
Rabaul	1994	AVHRR	SAGE II	
Hekla	2000	MODIS	POAM III	
Ruang	2002	MODIS	SAGE II	
Reventador	2002	MODIS	SAGE II	
Manam	2005	MODIS	SAGE II	
Sierra Negra	2005	MODIS	SAGE II	
Soufrière Hills	2006	MODIS	OSIRIS	CALIPSO
Rabaul	2006	MODIS	OSIRIS	CALIPSO
Chaitén	2008	MODIS	OSIRIS	CALIPSO
Okmok	2008	MODIS	OSIRIS	CALIPSO
Kasatochi	2008	MODIS	OSIRIS	CALIPSO
Redoubt	2009	MODIS	OSIRIS	CALIPSO
Sarychev Peak	2009	MODIS	OSIRIS	CALIPSO
Grímsvötn	2011	MODIS	OSIRIS	CALIPSO
Nabro	2011	MODIS	OSIRIS	CALIPSO
Kelut	2014	VIIRS	OMPS/LP	CALIPSO
Calbuco	2015	VIIRS	OMPS/LP	CATS

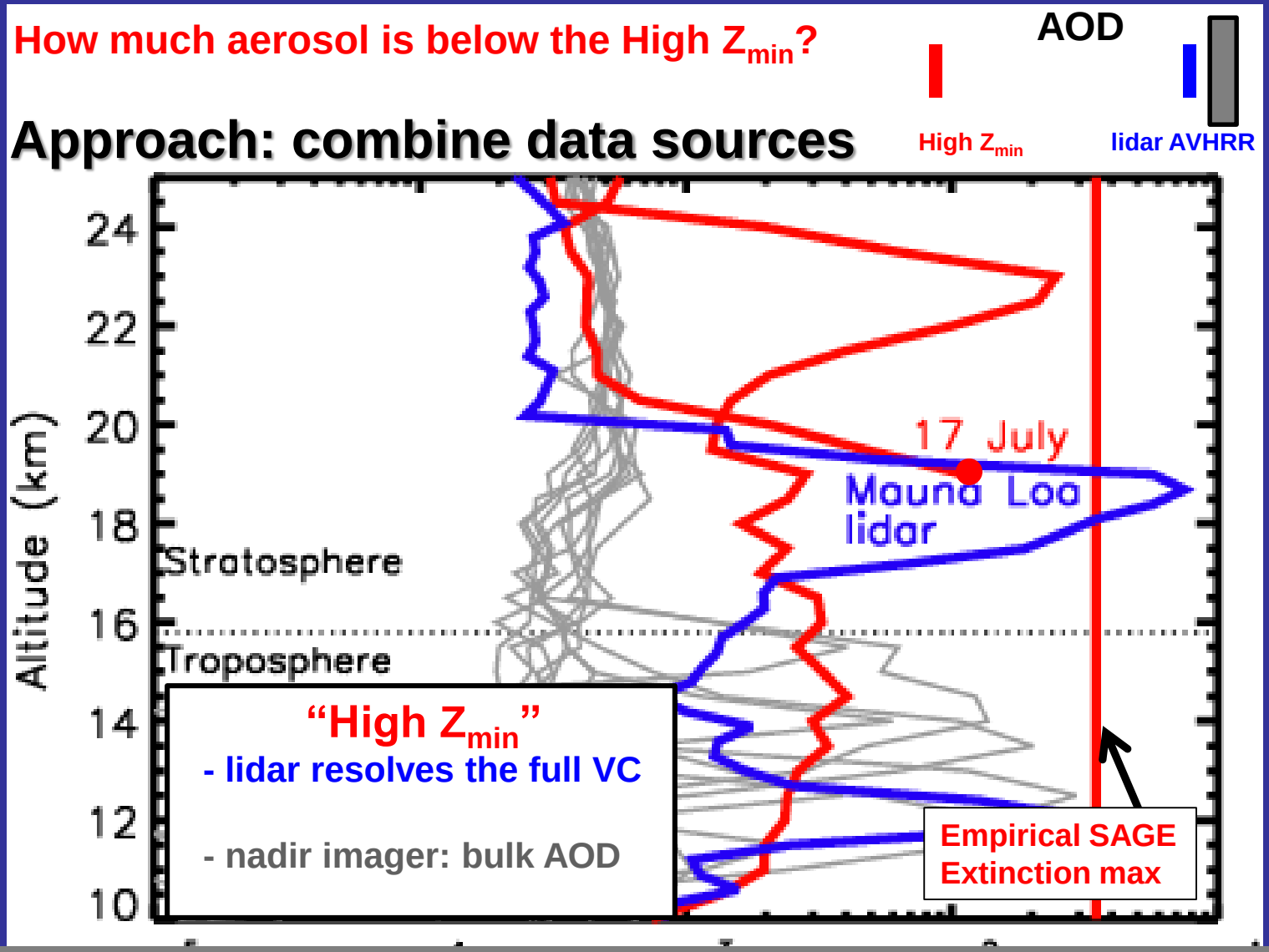
Case study periods: **> 1 year (El Chichon & Pinatubo)**
< 1 year (others)

Example:
Post Pinatubo



How much aerosol is below the High Z_{min}?

Approach: combine data sources

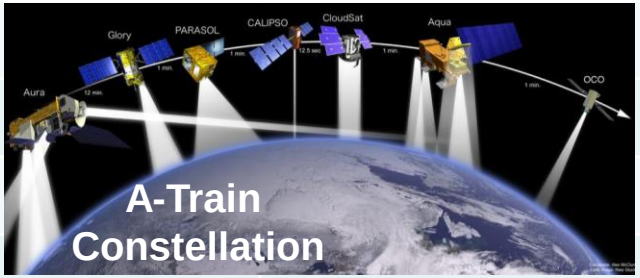


*Collocated AVHRR nadir-image aerosol optical depth > 0.11

* Russell et al. (1996)

Exploit complementary SRS data having distinct traits.

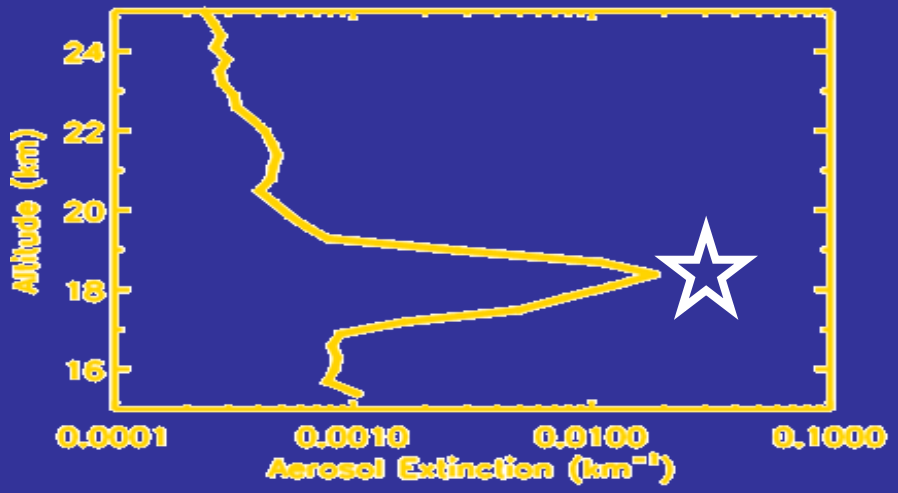
Imager		Profiler			
Nadir Passive		Limb Passive		Nadir Active	Nadir Hyperspectral
AVHRR	(0, 2, 1, 2)*	SAGE II	(0, 5, 2, 0)	CALIPSO (0,1,1,0)	AIRS (0,0,>1000,>1000)
GOES	(0, 1, 1, 2)	POAM	(1, 4, 4, 0)	CATS (0,1,1,0)	IASI (0,0,>1000,>1000)
MODIS	(0,11,15,10)	HALOE	(0, 0, 2, 2)		
VIIRS	(0, 7, 8, 4)	HIRDLS	(0, 0, 0, 2)		
TOMS	(6, 0, 0, 0)	OMPS/LP	(0, 3, 0, 0)		
OMI	(>5,>5, 0, 0)	MLS	(microwave)		

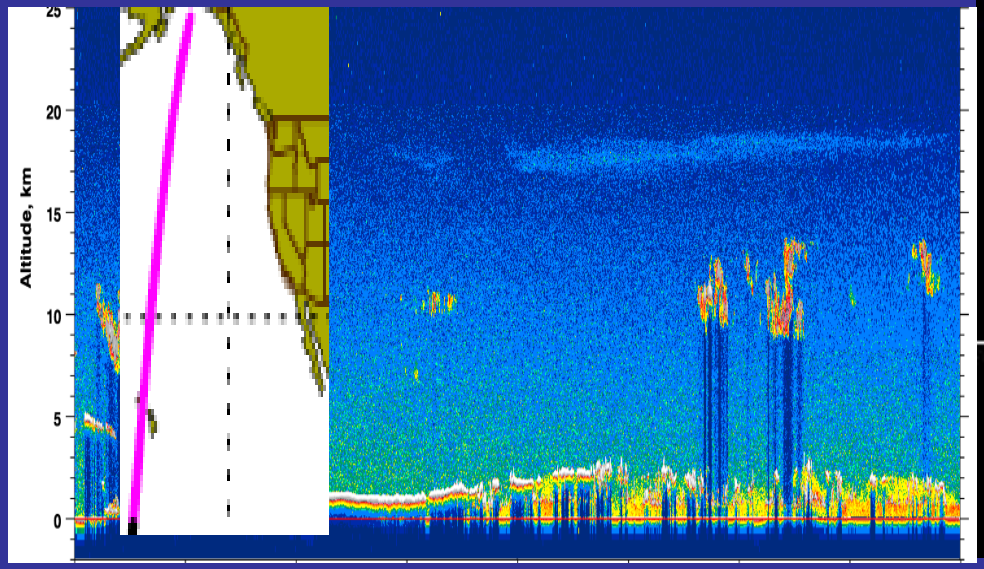


* Number of sensor channels in each wavelength band
(UV, Vis, SWIR, LWIR)

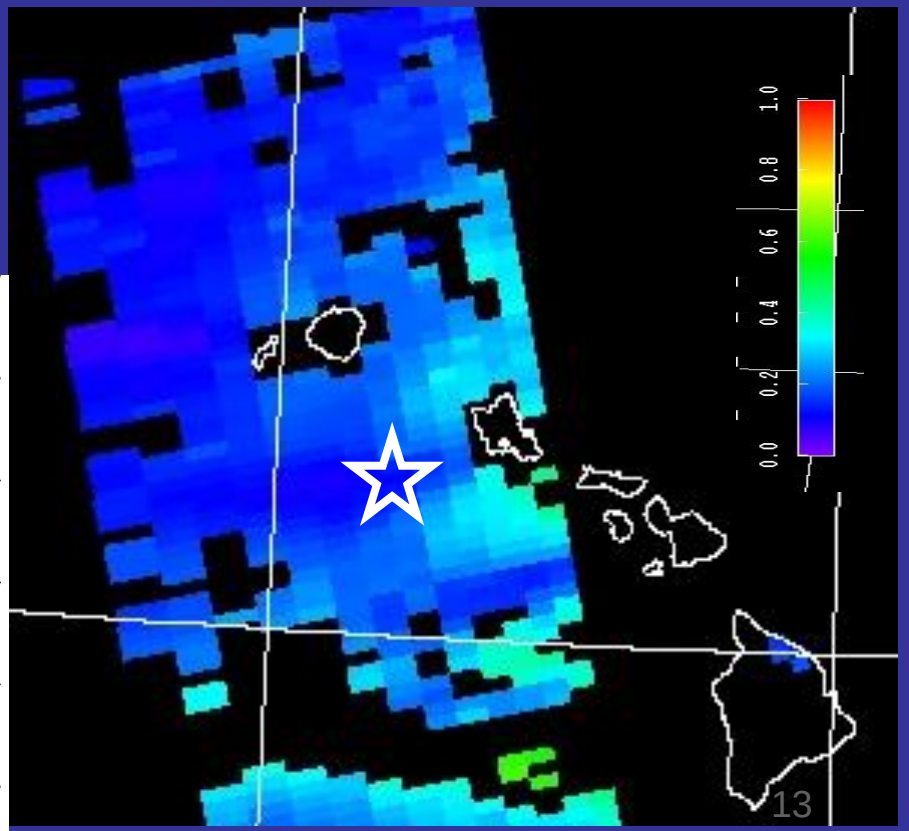
Example: Nabro VC, 5 weeks old, near Hawaii

CALIPSO (lidar, visible) & MODIS (imager, vis, IR)

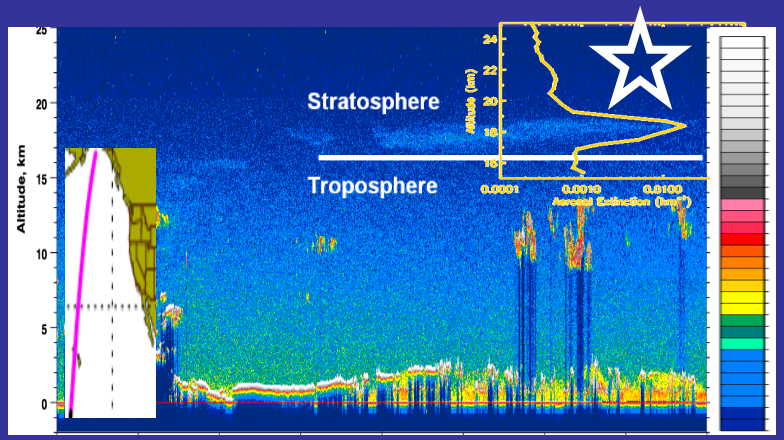


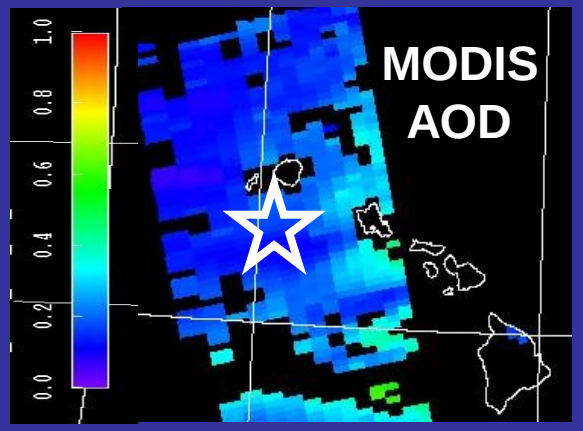


MODIS AOD



CALIPSO & MODIS





Collocation

CALIPSO Strat. AOD (independent variable)

MODIS Reflectance, AOD, BT

Scene Organization

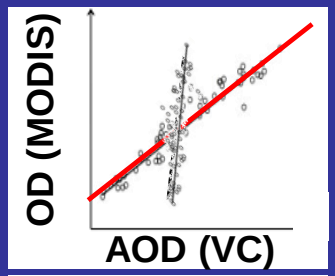
CALIPSO Profiler

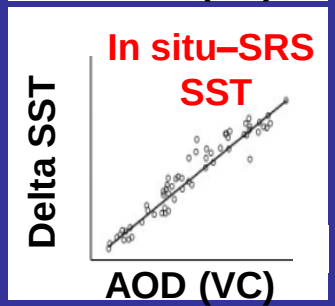
VC? Yes/No

MODIS Imager

- Clear
- Turbid
- Cloud

Analyze Scene Data Sets

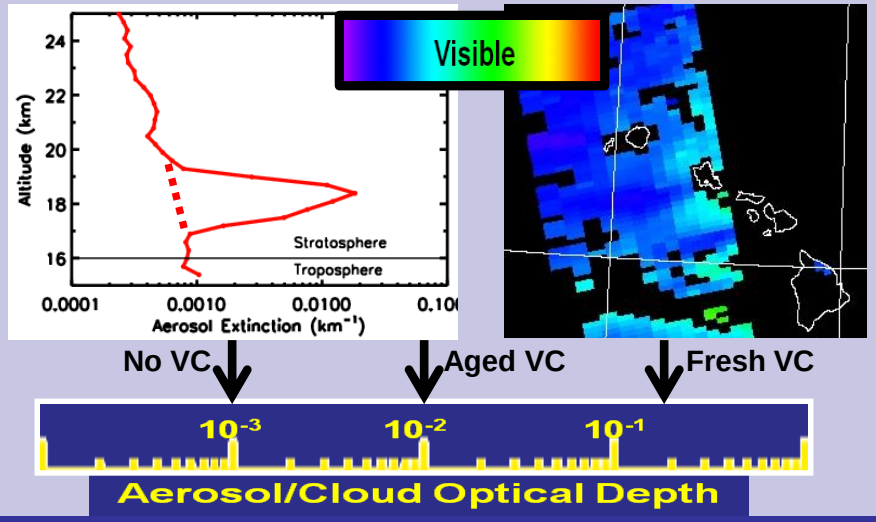




Can dependent variables be transformed to "independent?"

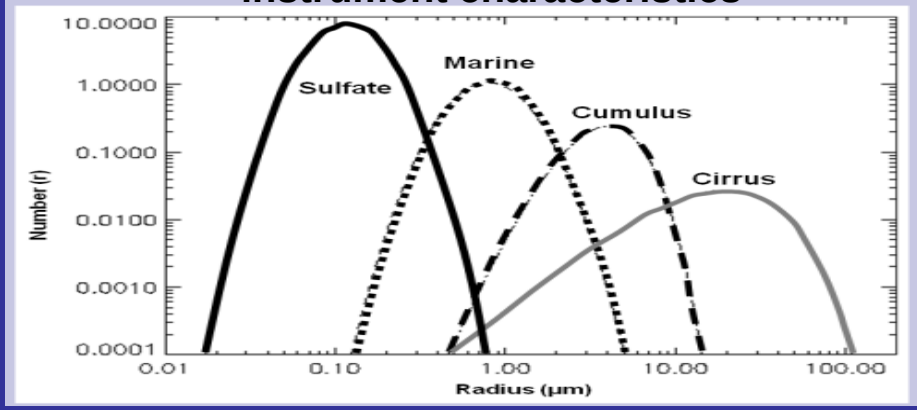
Radiative-Transfer Modeling of SRS measurements

Constrain model with observed AOD

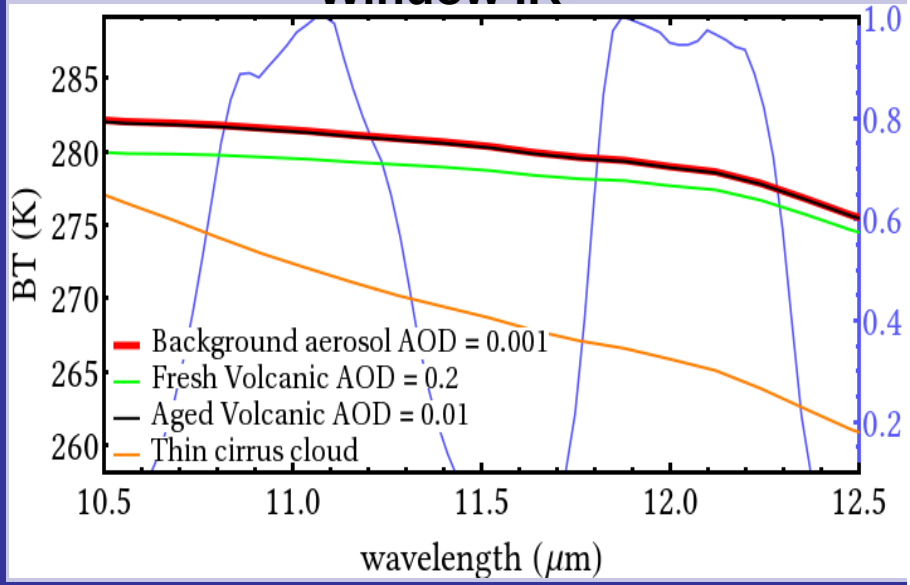


Full-spectrum Radiative Transfer Model

* plume/cloud microphysics
* temperature profiles
* instrument characteristics



Window IR



MODIS Channel Response

SRS data…
…provide clues to spectral VC pro

Theoretical simulations …
…constrain SRS
…comprehensive spectral VC sig

Synergistic Study of Satellite Remote Sensing (SRS) of Stratospheric Volcanic Clouds (VC)

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To improve the full depiction of stratospheric VC by…
…characterizing the full 3-D VC throughout its lifetime
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Approach

- Perform case studies in the satellite era (i.e. since 1979)
- Use whatever SRS data are available for each eruption and VC

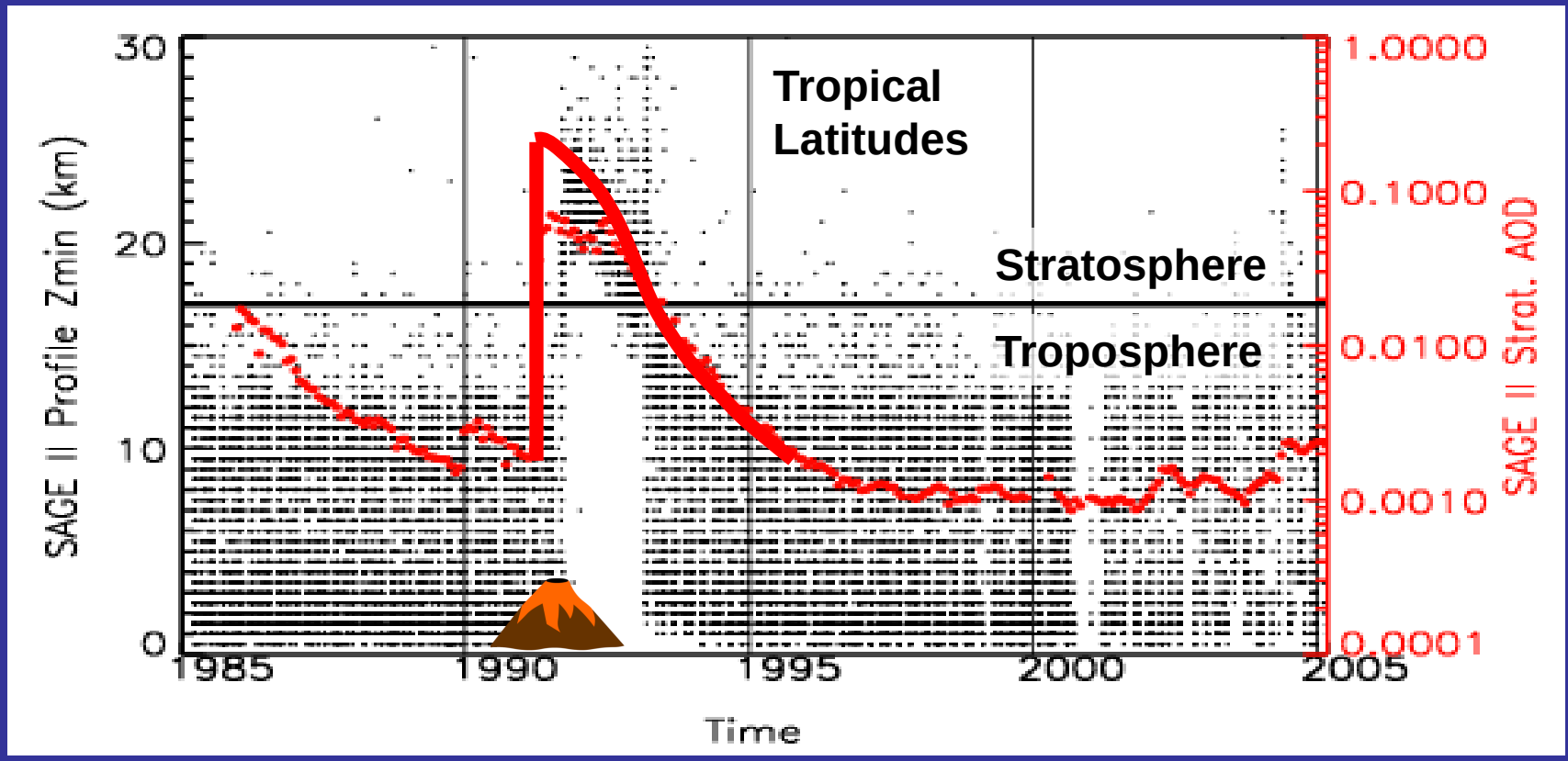
Payoff

- Improved understanding of critical SRS assets.
- An optimized observing strategy for the SRS of future VCs.

Collaborators welcome! **mike.fromm@nrl.navy.mil**

Importance of the data-synergy approach
- stratospheric SAGE High Z_{min} for > 1 year!

SAGE II Profile Z_{min} & AOD vs. Time



High Z_{min} occurrence suggests potential low-AOD bias.
Approach: Fuse SAGE with complementary data-source sensitive to greater AOD

Approach to Science Questions

1. Can a synergistic fusion of SRS data improve our understanding of total injected SO_2 mass?

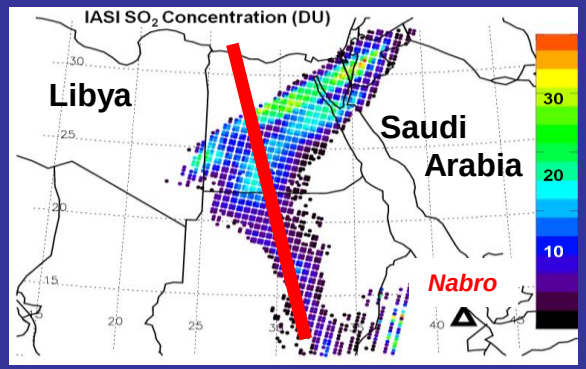
Phase 1 Activity:

*** Collocate nadir (image) and limb (profile) level-2 SO_2 data.**

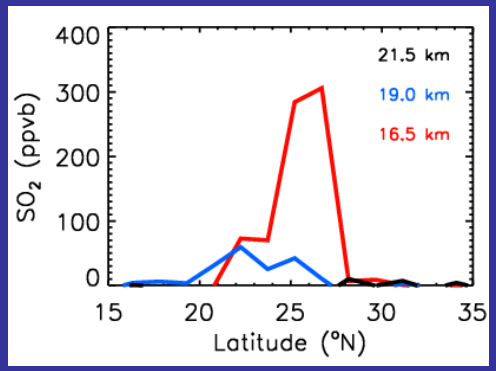
*** Construct 3D volume of injected SO_2 plume.**

Example: Nabro (Eritrea), 14 June 2011

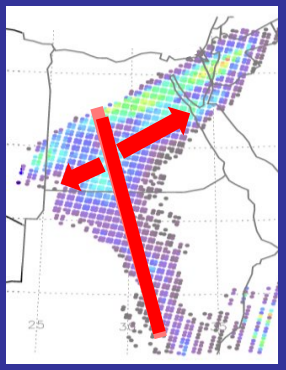
IASI (IR) nadir SO_2 column



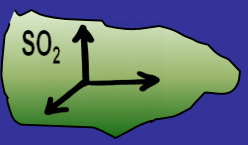
MLS (μwave) limb SO_2 profiles



How?
By adapting Miller et al. (JAMC, 2010) "Estimating Three-Dimensional Cloud Structure via Statistically Blended Satellite Observations"

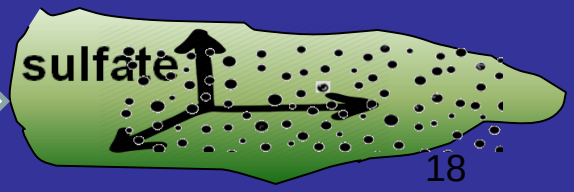


*** Calculate sulfate mass loading and 3D volume from SO_2 loading.**



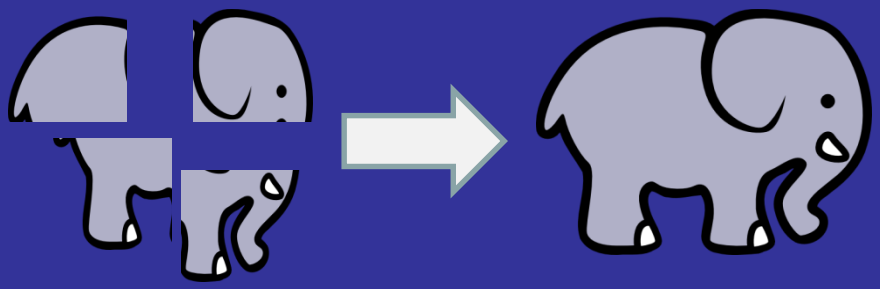
$$SO_2 + OH + O_2 + H_2O \rightarrow HO_2 + H_2SO_4$$

(liquid)



Approach to Science Questions

Outcome:



*** Theory- & SRS-based constraints on VC modalities**

*** Improved volcanic-event plume parameters for radiative-impact studies**

*** Guidance for future eruptions and SRS**

Science Questions

Can a synergistic fusion of SRS data improve our understanding of…

1. **…total injected SO_2 mass?**
2. **…VC mass, altitude, lifetime?**
3. **…how to distinguish VC from other clouds and aerosol plumes?**

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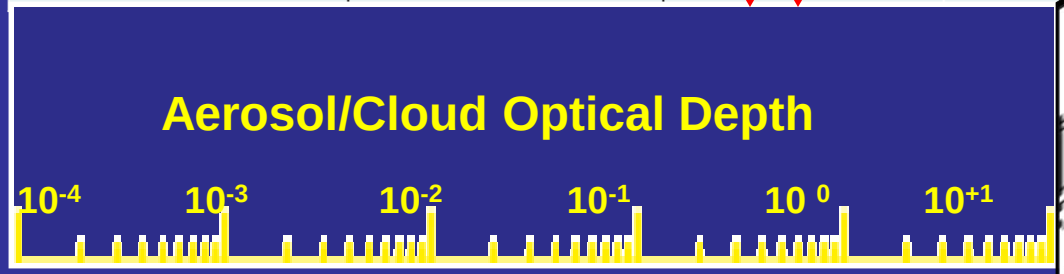

Plume Abundance (mass)