The Persistently Variable "Background" Stratospheric Aerosol Layer and Global Climate Change

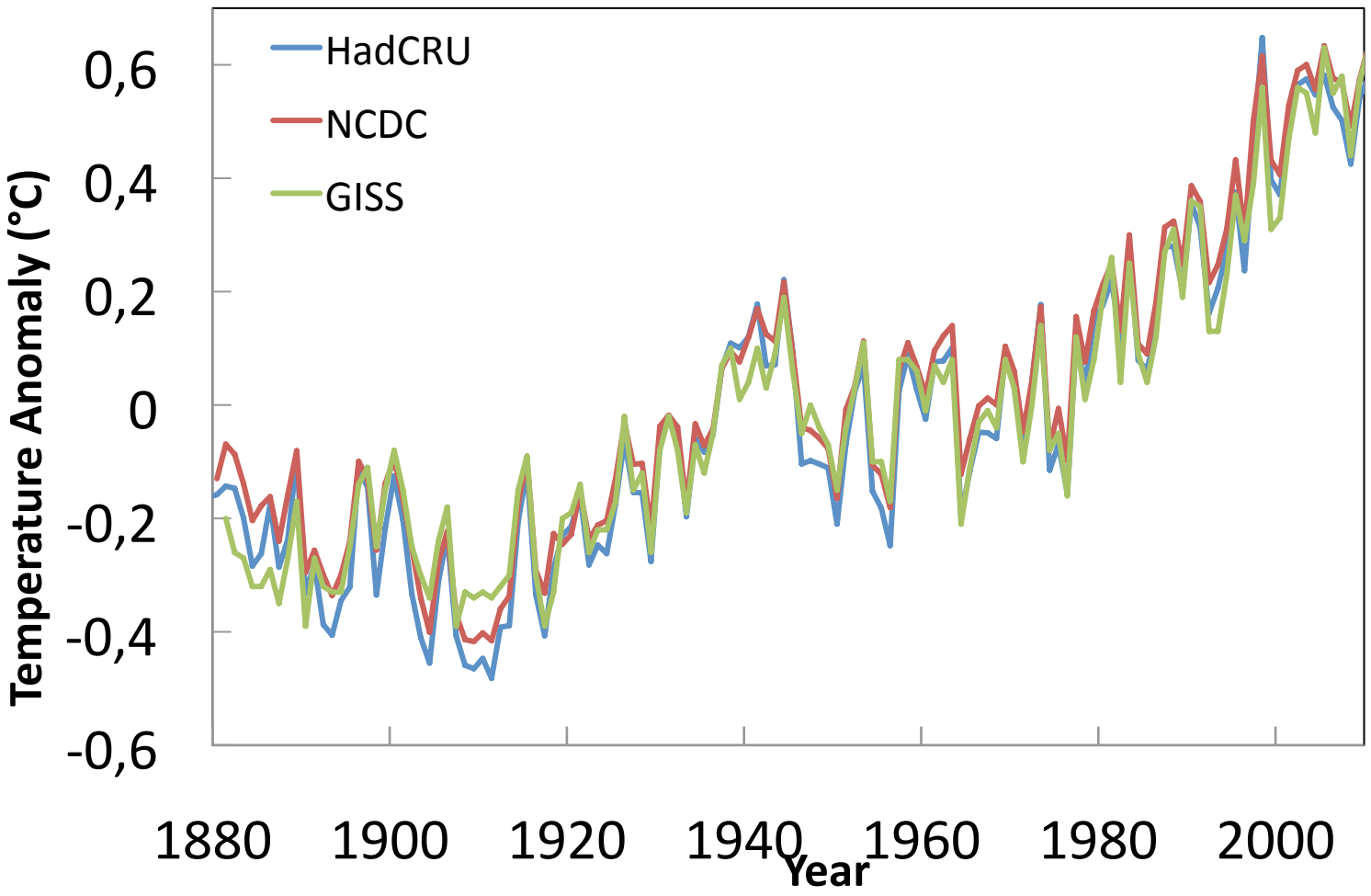
JS Daniel, S Solomon, RR Neely III, JP Vernier,
EG Dutton, LW Thomason

Solomon et al., Science, 333, 866-870, 2011

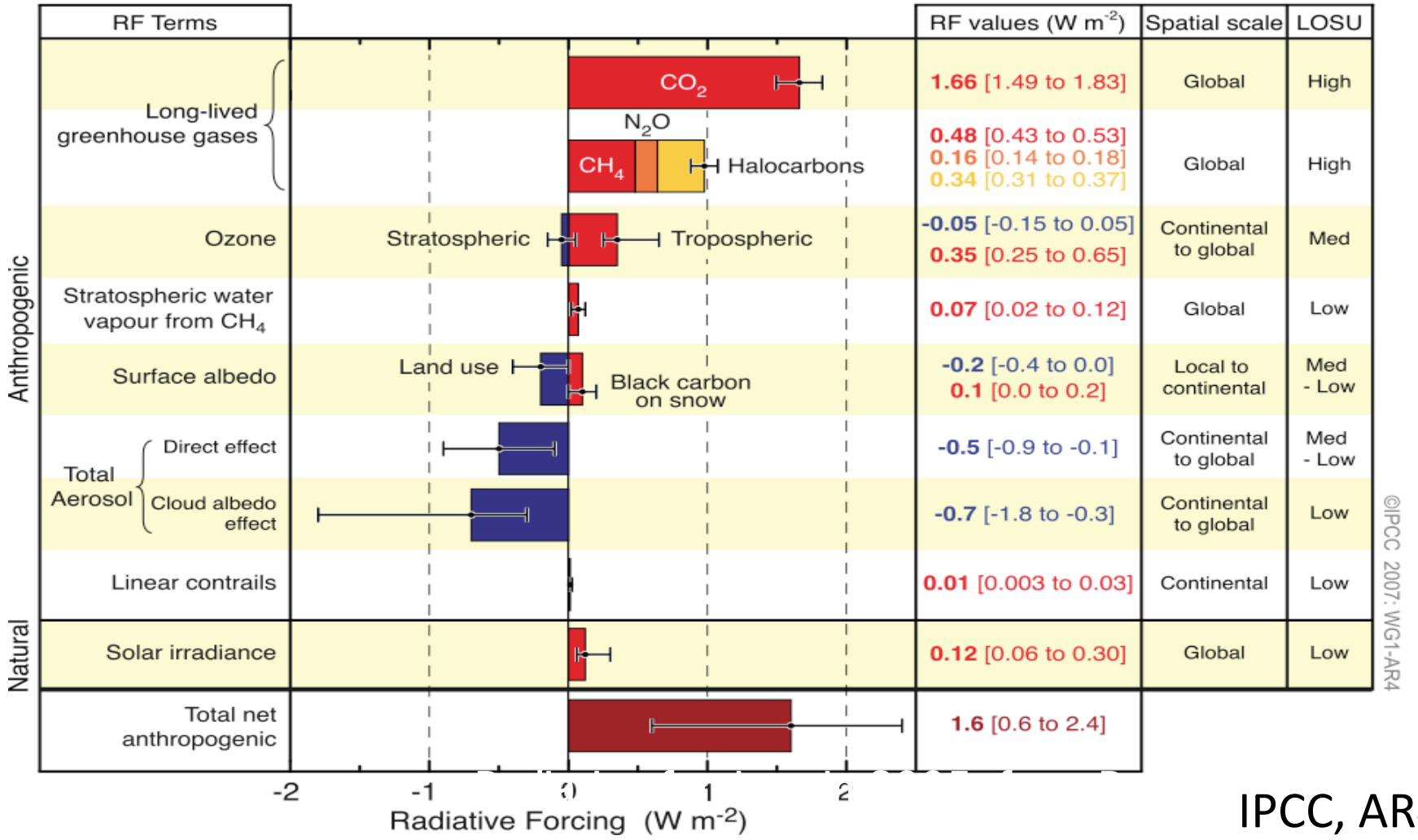
Motivation
Previous Decade: Forcing and T Response
Relevance to Future Climate

ISS023E057948

The World Is Warming

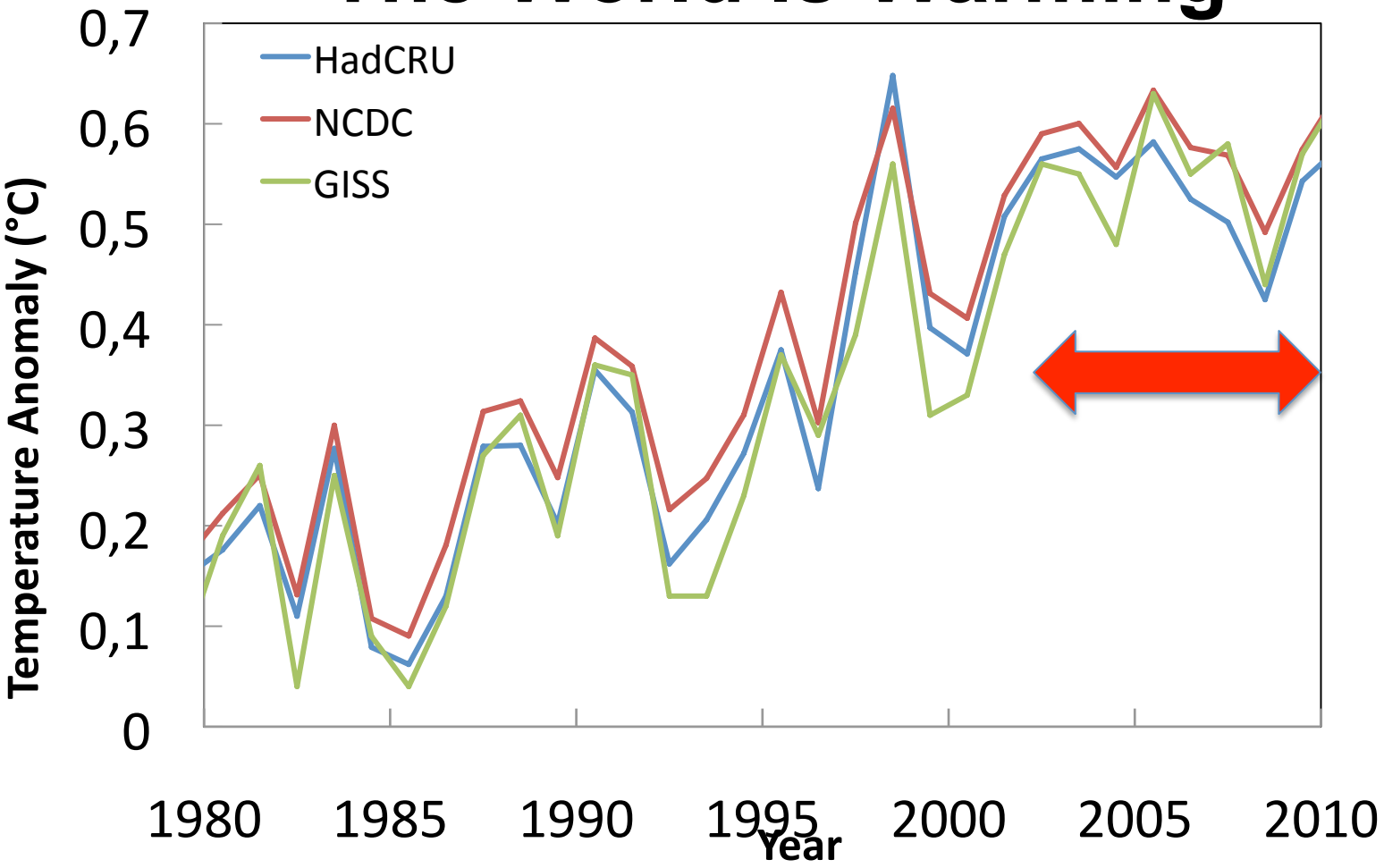


Radiative Forcing



IPCC, AR4

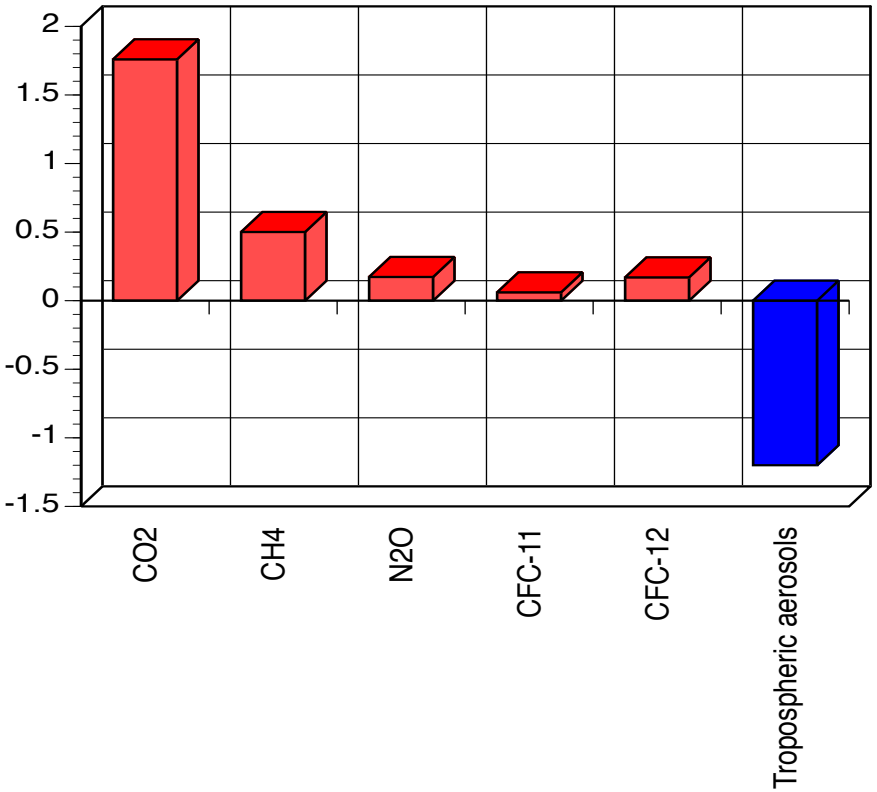
The World Is Warming



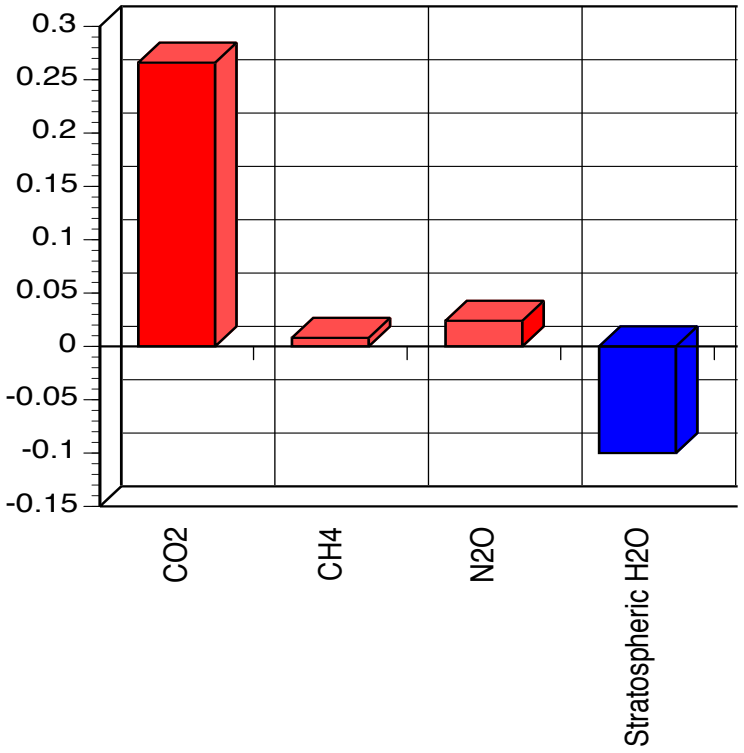
But since the early 2000s, not as fast

Over Decadal Scales, Others Compounds Important

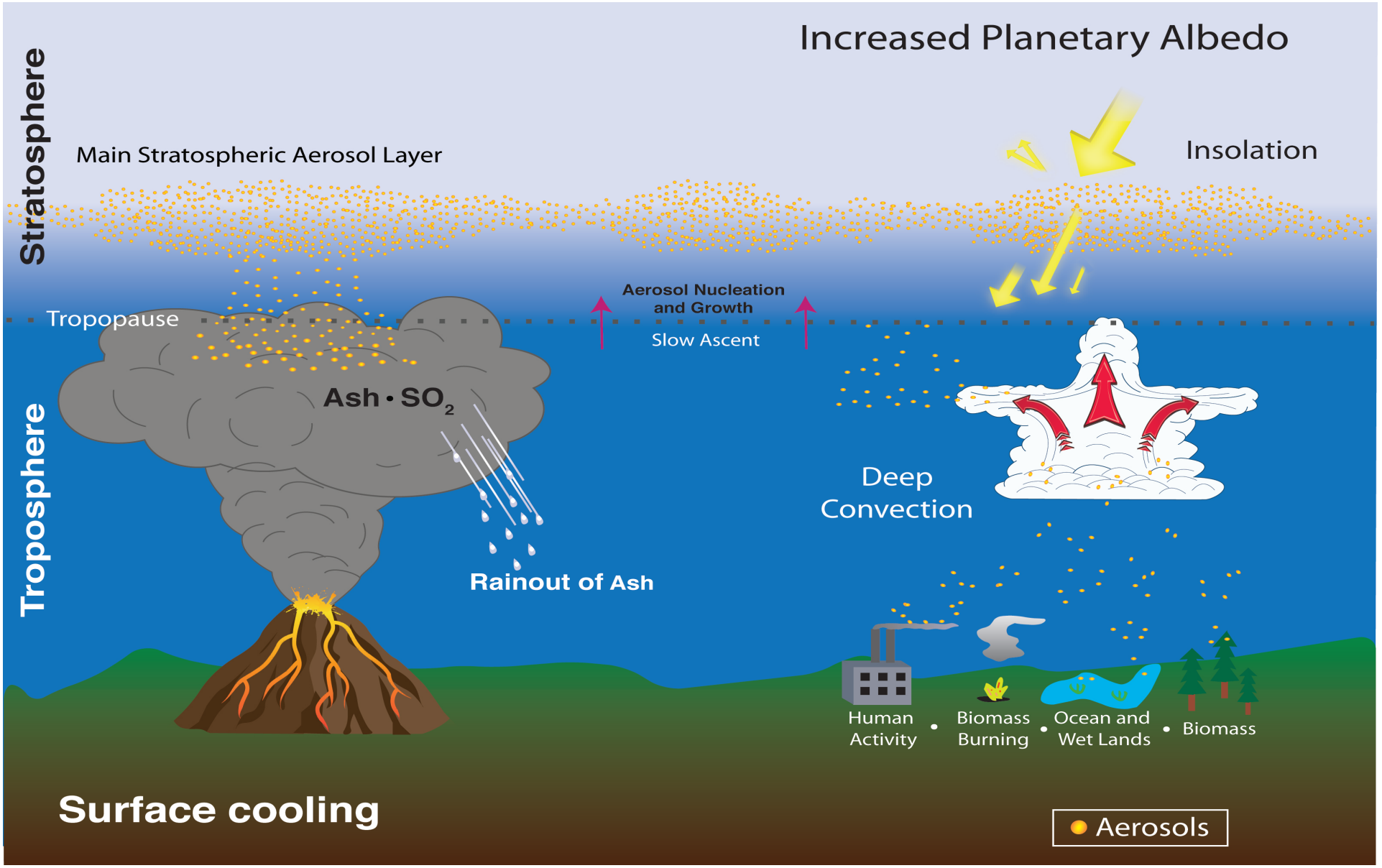
1750 to present



1999 to 2009



Solomon et al., 2010

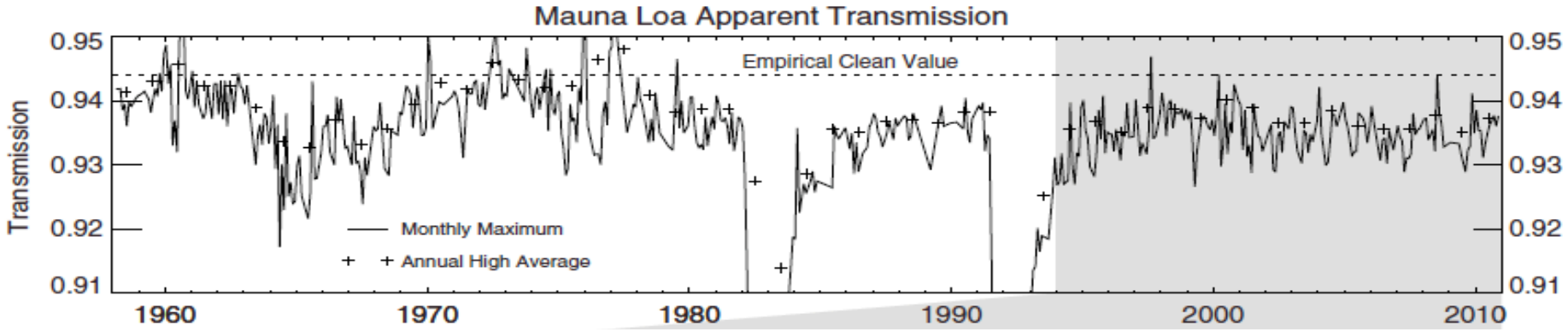

Increased Planetary Albedo
Stratosphere
Main Stratospheric Aerosol Layer
Insolation
Tropopause
Aerosol Nucleation
and Growth
Slow Ascent
Troposphere
Ash · SO2
Deep
Convection
Rainout of Ash
Human
Activity
Biomass
Burning
Ocean and
Wet Lands
Biomass
Surface cooling
Aerosols

Mauna Loa Observations – Lidar and Radiation

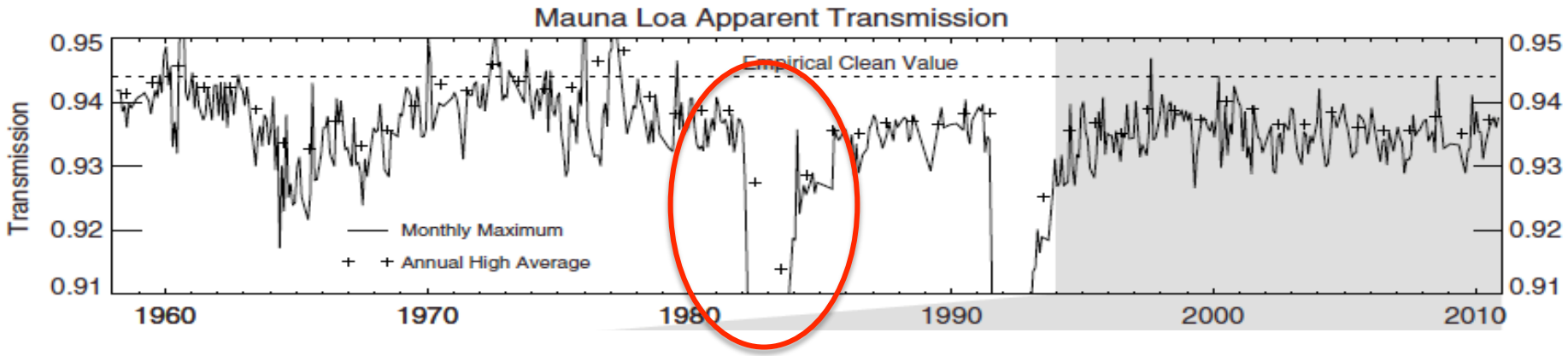
location, height, meteorology

stratospheric observation

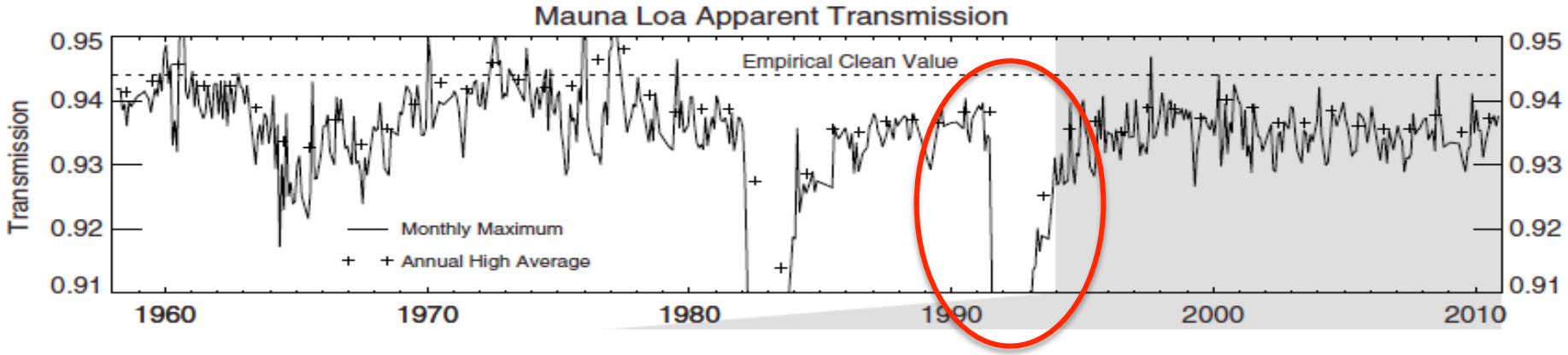
Mauna Loa Observations Show Consistent Picture



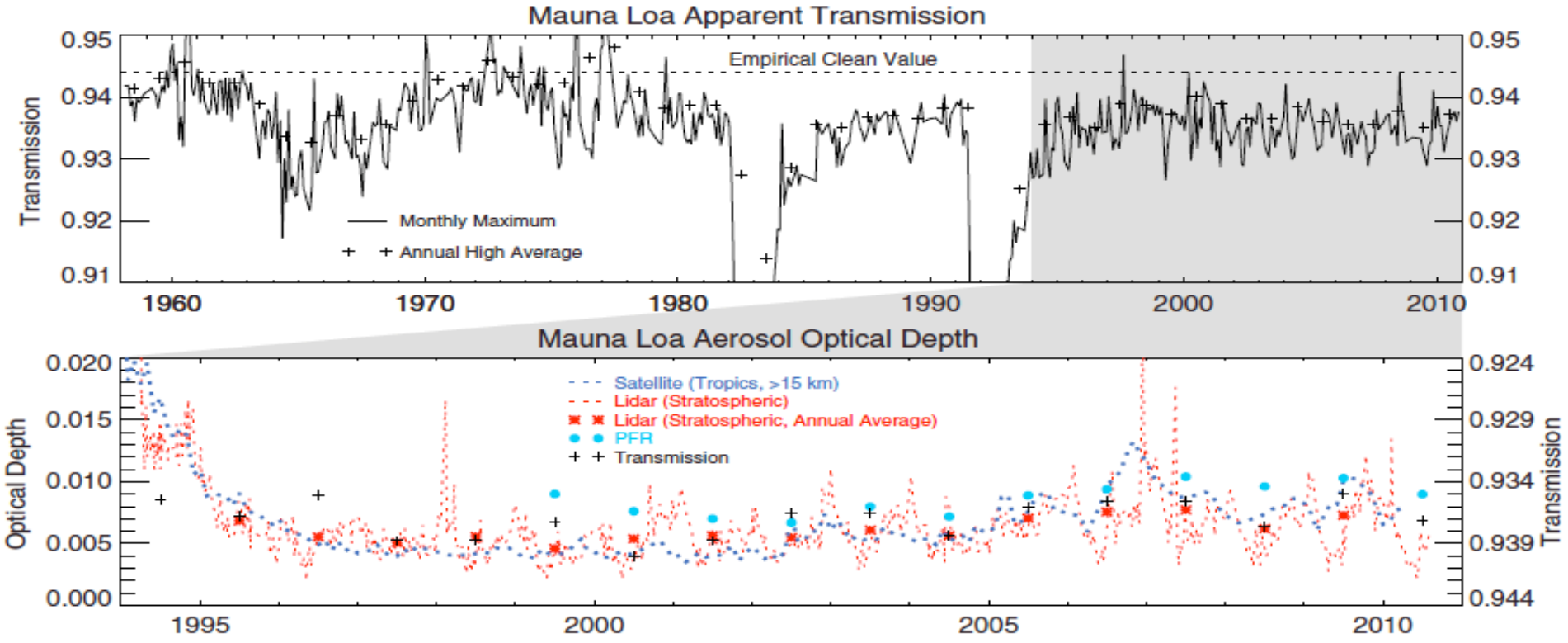
Mauna Loa Observations Show Consistent Picture



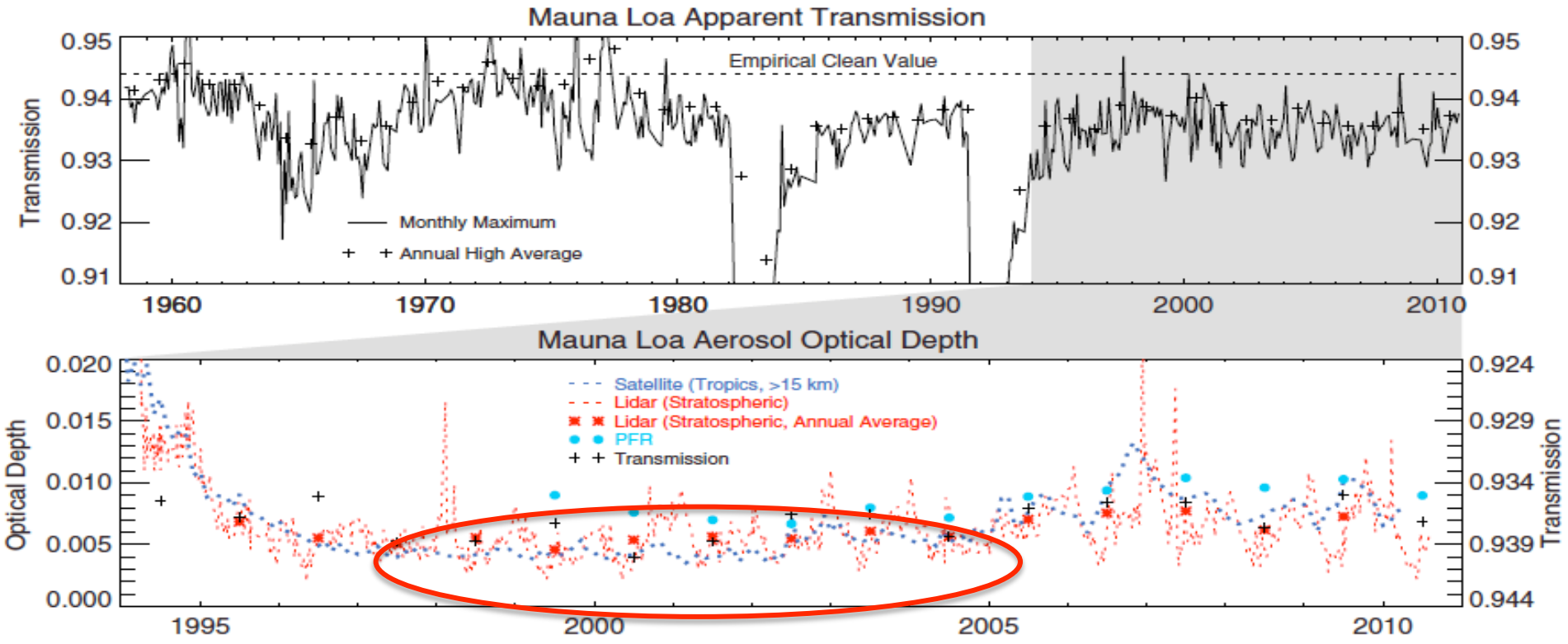
Mauna Loa Observations Show Consistent Picture



Mauna Loa Observations Show Consistent Picture

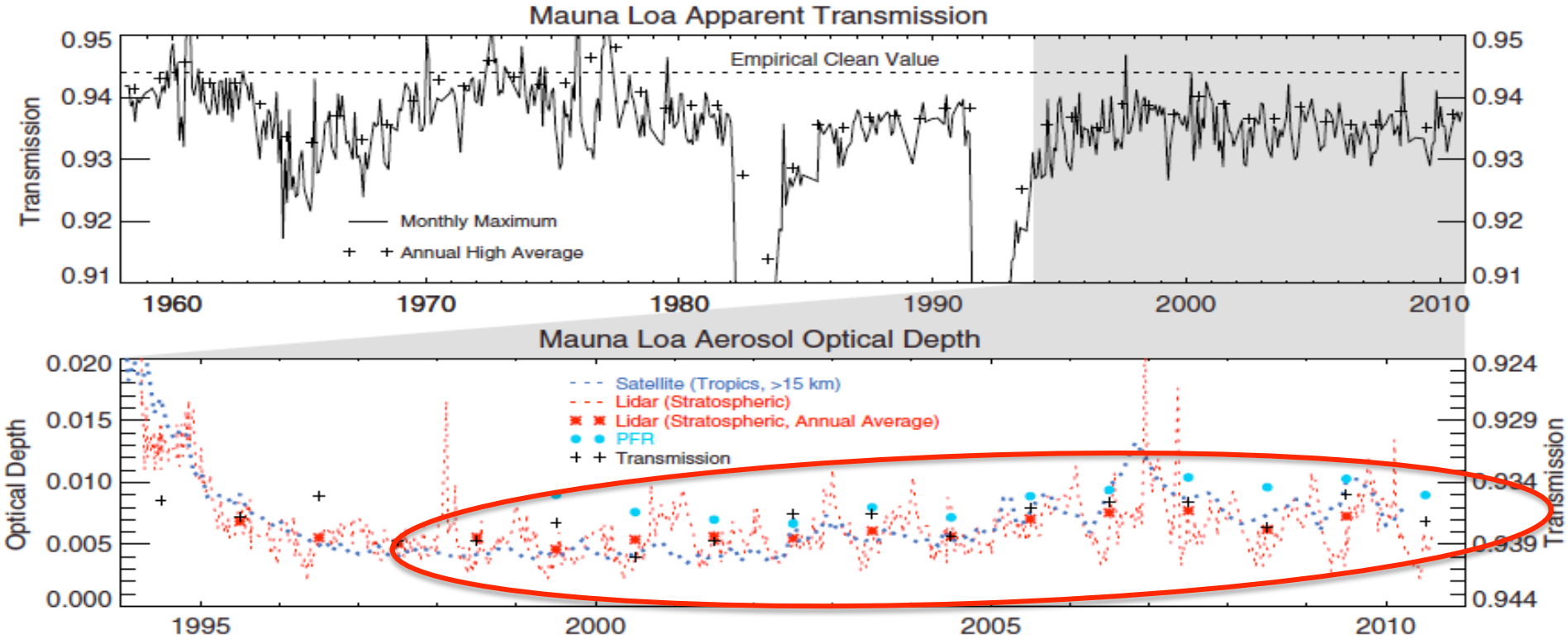


Mauna Loa Observations Show Consistent Picture

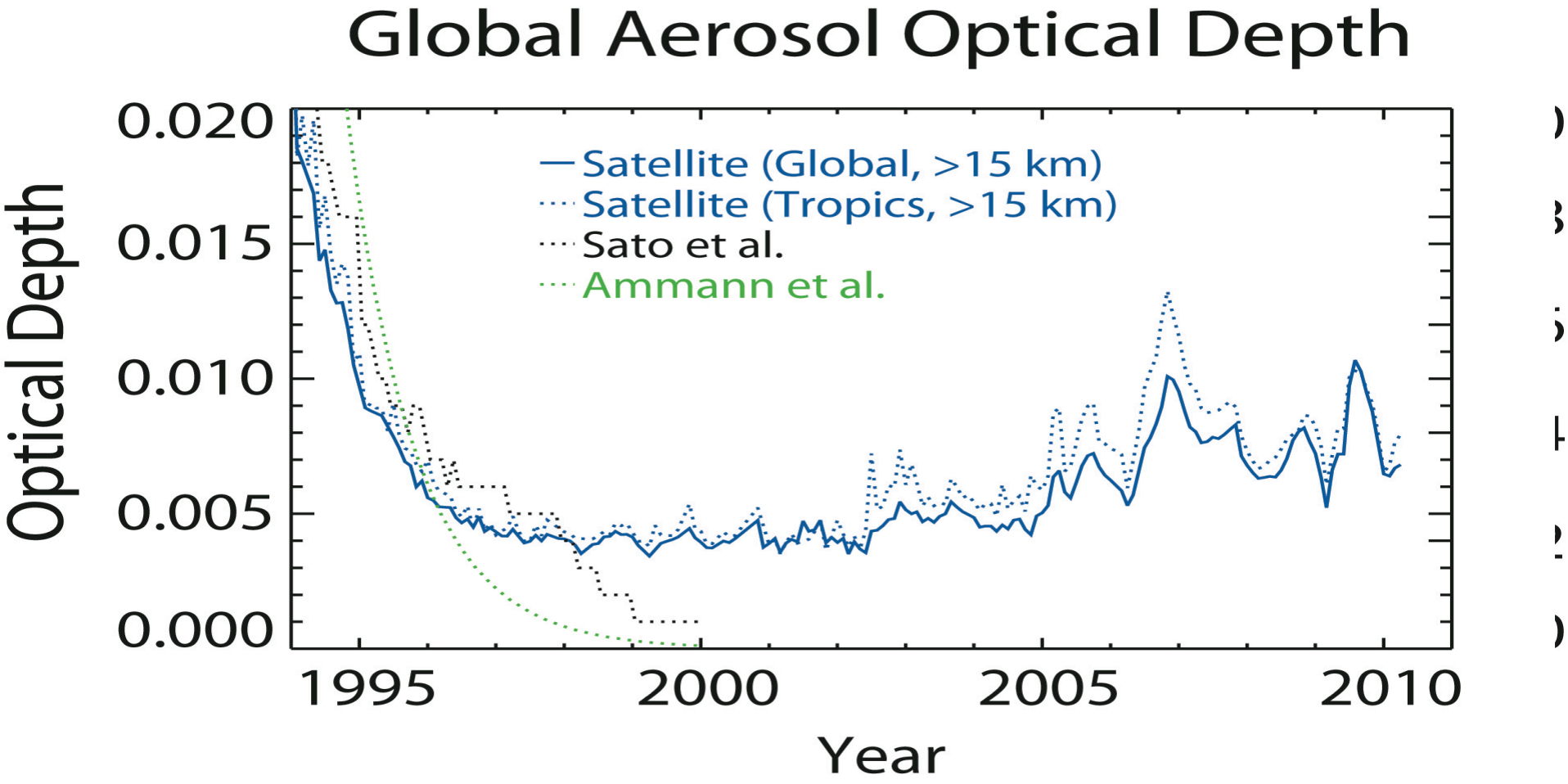


Optical depths do not return to 0 after Pinatubo

Mauna Loa Observations Show Consistent Picture

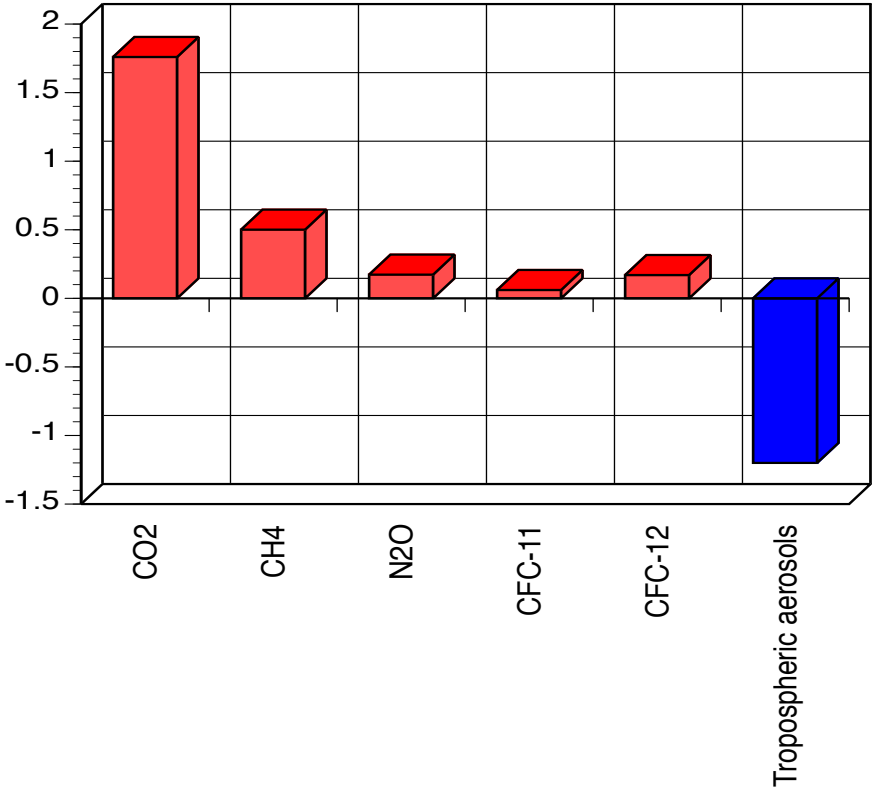


Although variable, there is an increasing trend

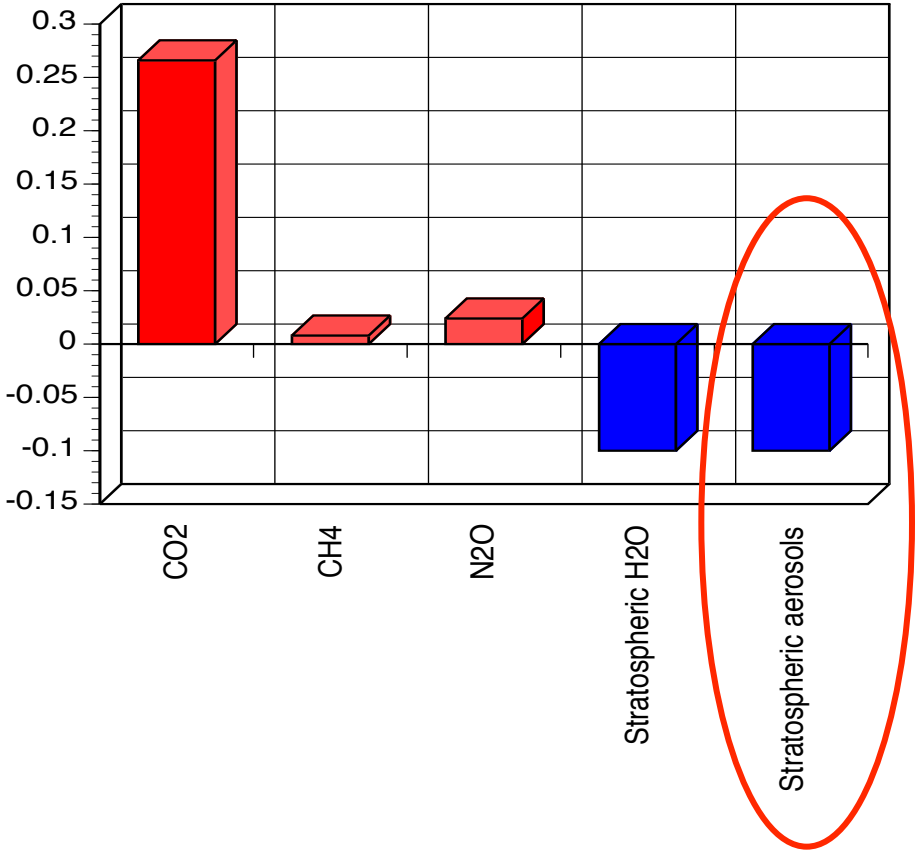

Global Aerosol Optical Depth
Optical Depth
0.020
0.015
0.010
0.005
0.000
1995
2000
2005
2010
Year
Satellite (Global, >15 km)
Satellite (Tropics, >15 km)
Sato et al.
Ammann et al.

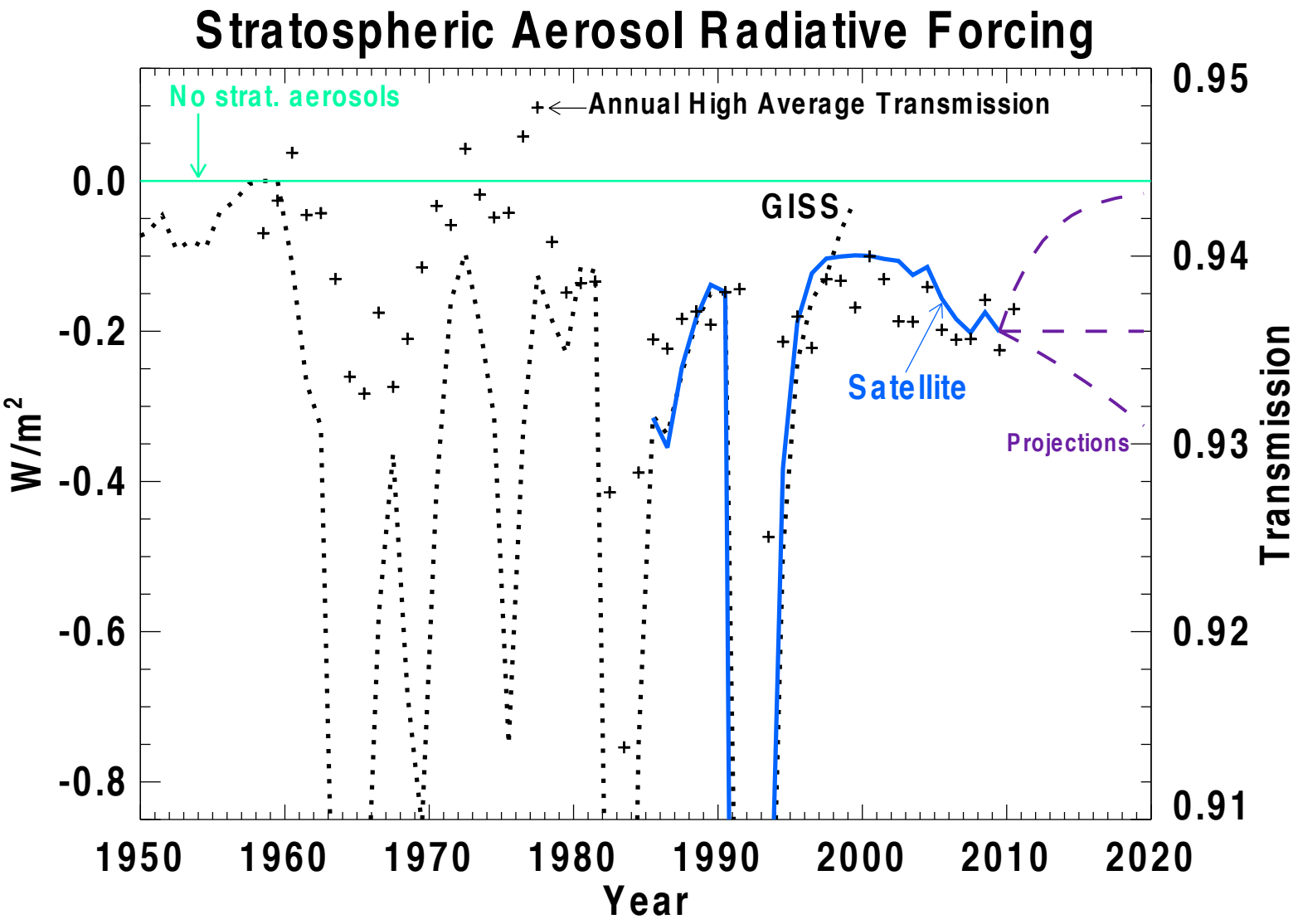
Over Decadal Scales, Others Compounds Important

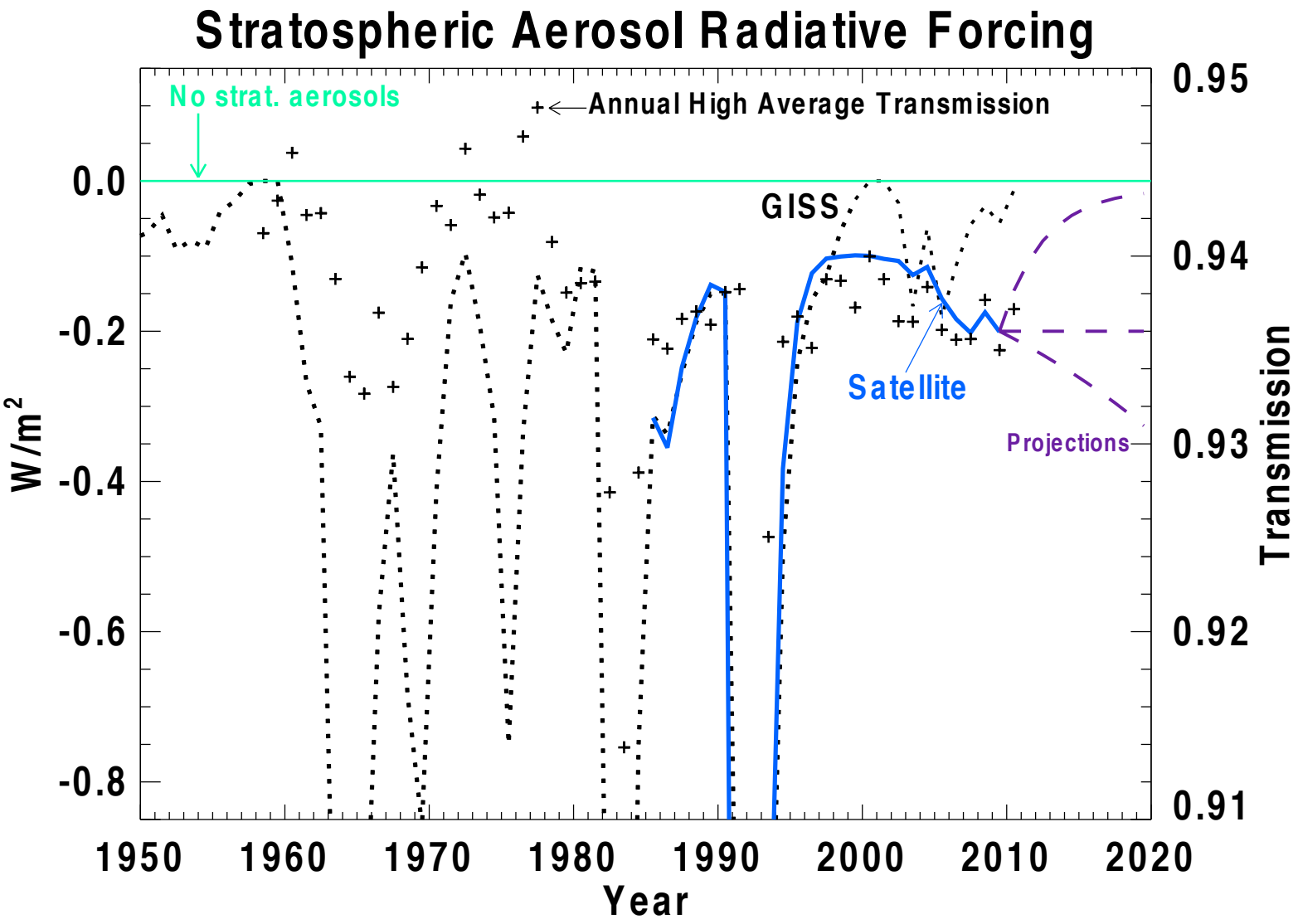
1750 to present



1999 to 2009




Stratospheric Aerosol Radiative Forcing
No strat. aerosols
Annual High Average Transmission
GISS
Satellite
Projections
0.0
-0.2
-0.4
-0.6
-0.8
W/m2
0.95
0.94
0.93
0.92
0.91
Transmission
1950
1960
1970
1980
1990
2000
2010
2020
Year


Stratospheric Aerosol Radiative Forcing
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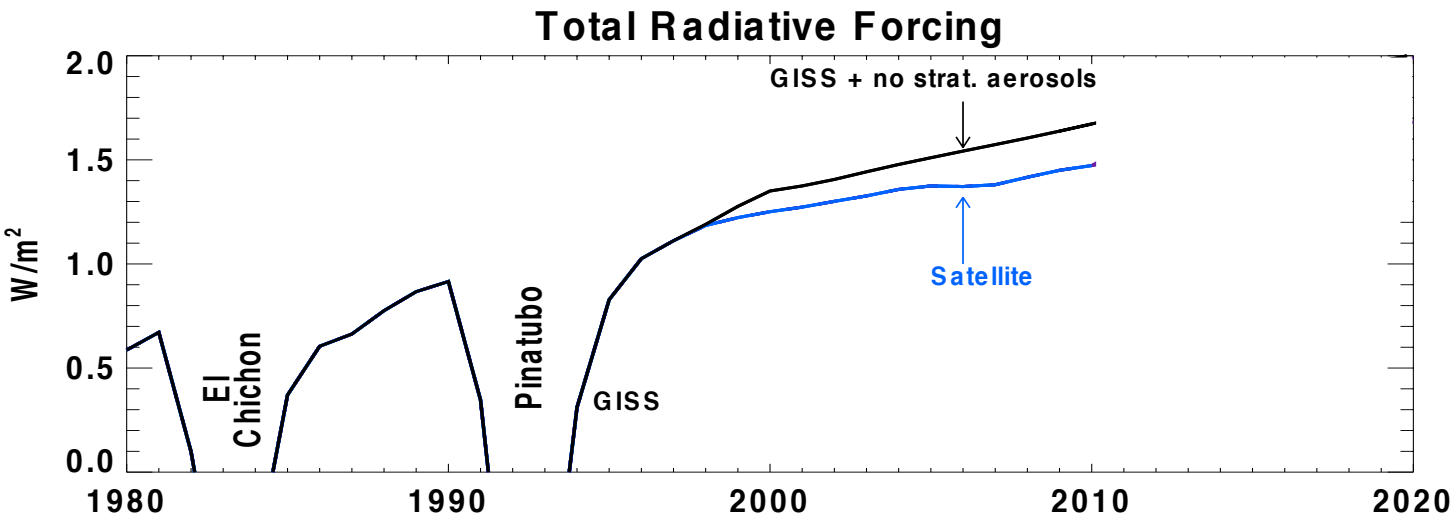
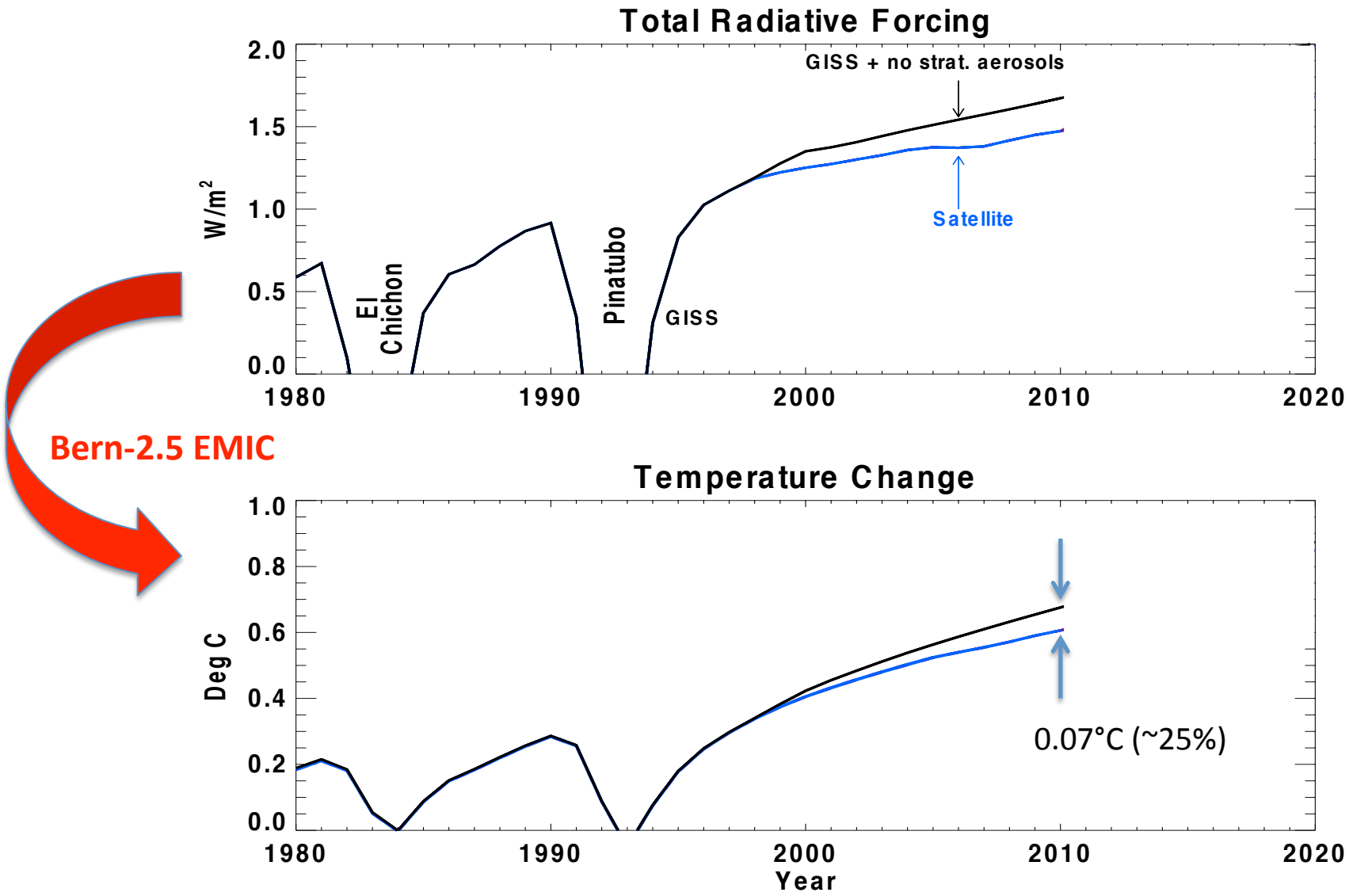
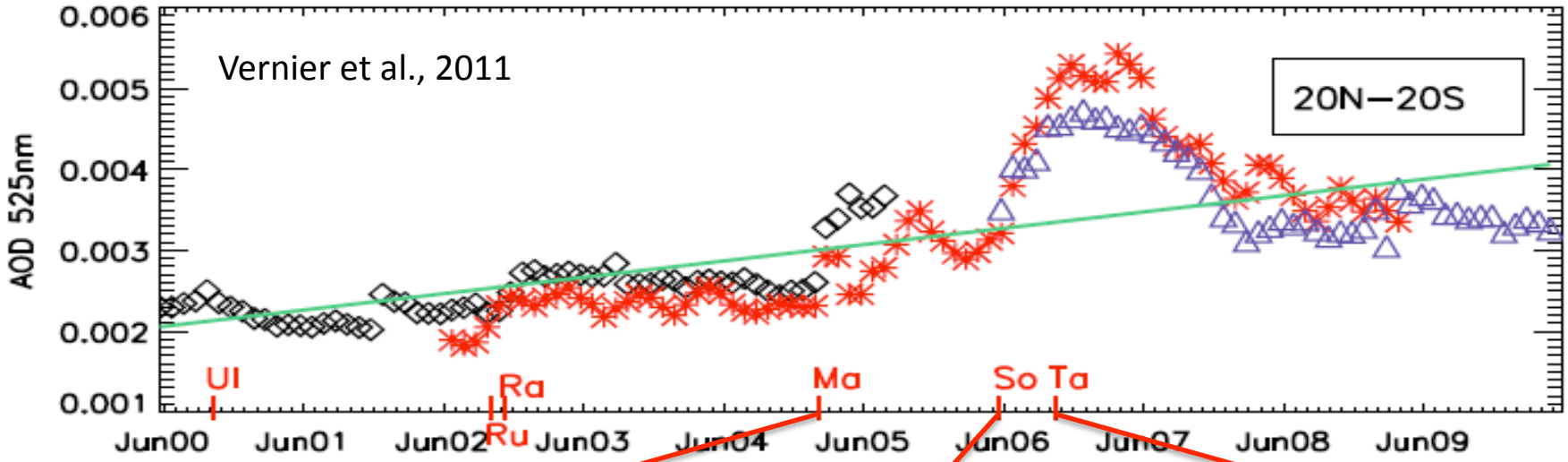
1950
1960
1970
1980
1990
2000
2010
2020
Year


Total Radiative Forcing
2.0
1.5
1.0
0.5
0.0
W/m2
1980
1990
2000
2010
2020
GISS + no strat. aerosols
Satellite
El Chichon
Pinatubo
GISS


Total Radiative Forcing
GISS + no strat. aerosols
Satellite
El Chichon
Pinatubo
GISS
W/m2
2.0
1.5
1.0
0.5
0.0
1980
1990
2000
2010
2020
Bern-2.5 EMIC
Temperature Change
Deg C
1.0
0.8
0.6
0.4
0.2
0.0
0.07°C (~25%)
Year

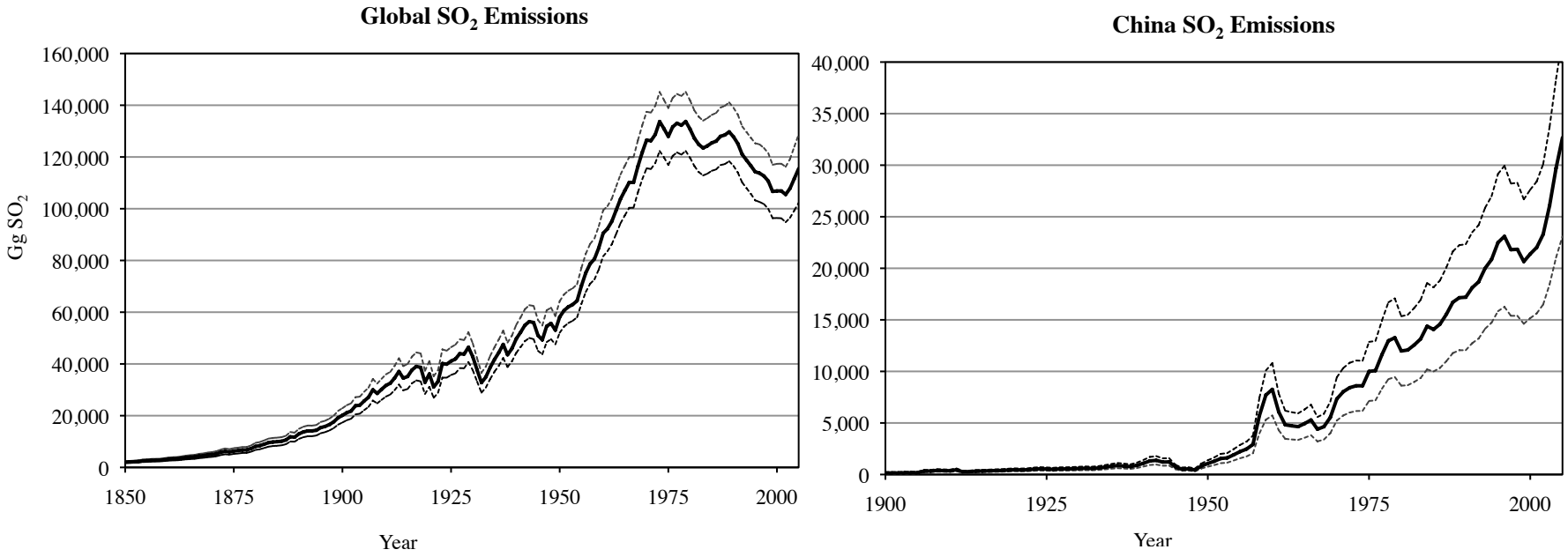


Manam

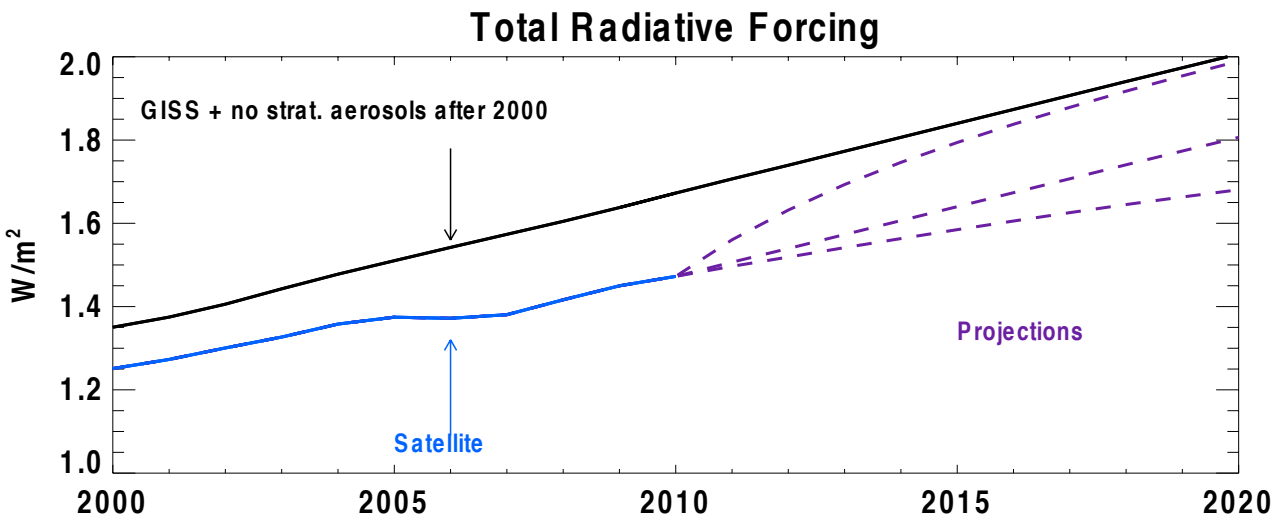
Soufriere Hills

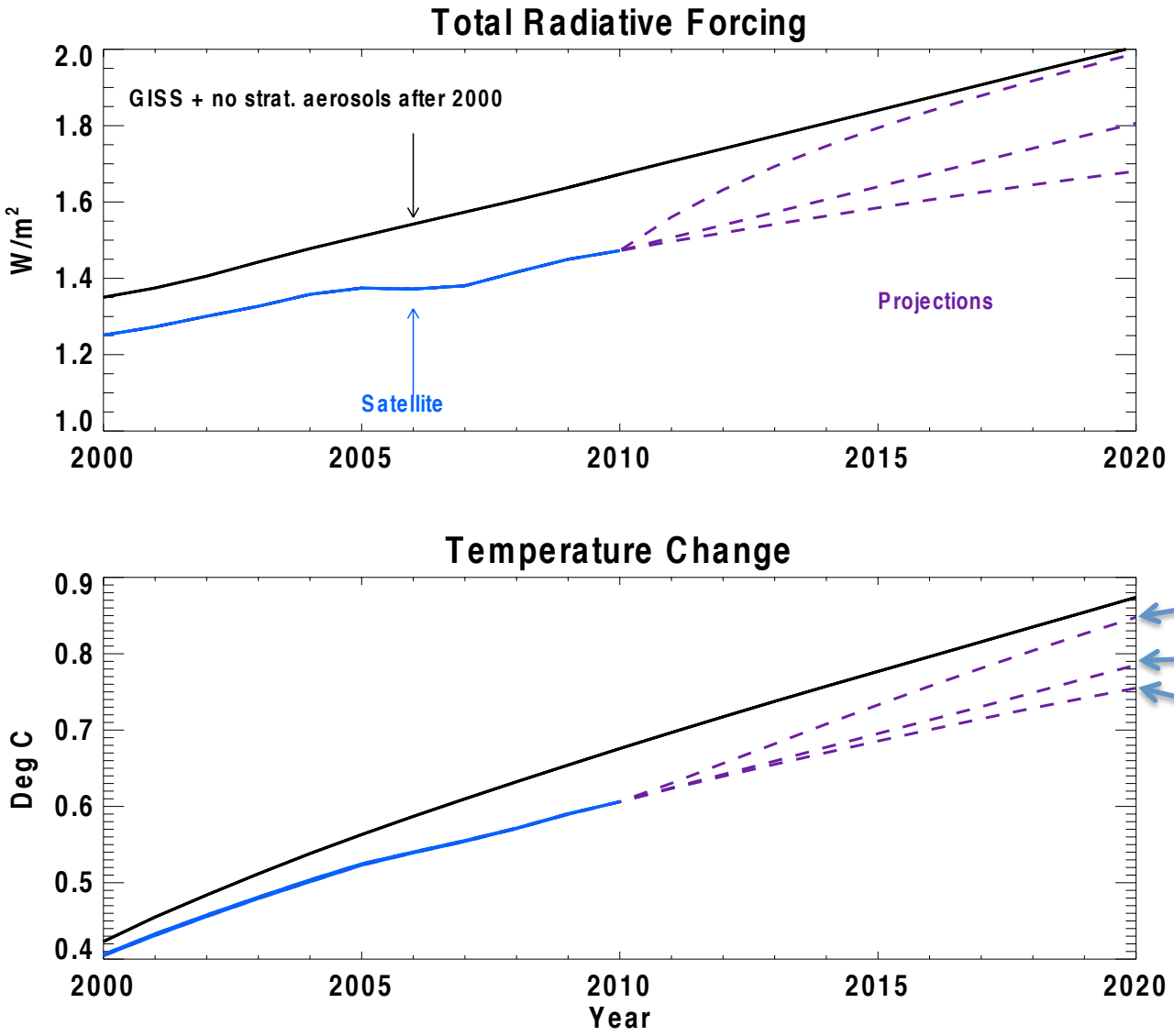
Tavurvur

Anthropogenic Sulfur Emissions



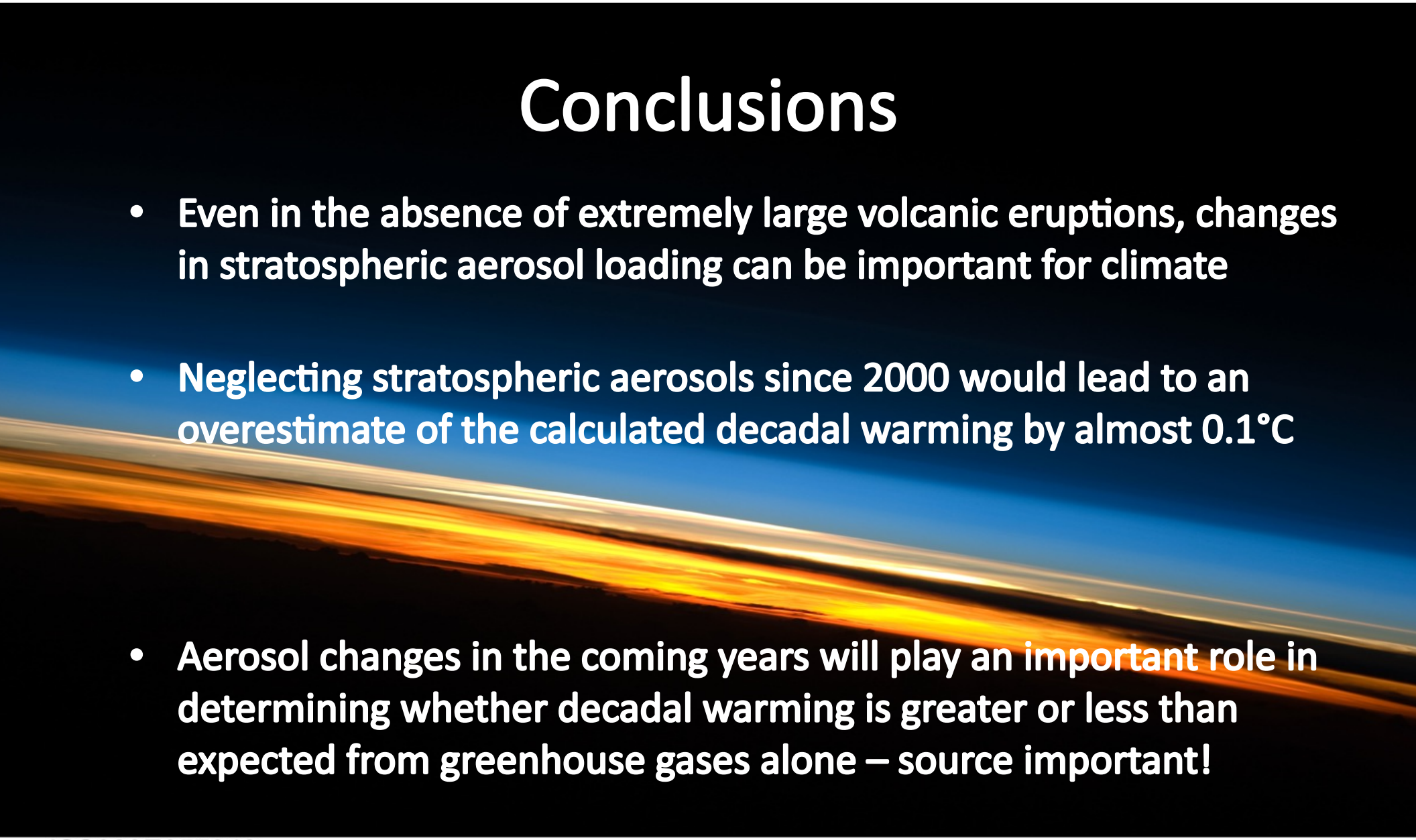
(Smith, 2011)


Total Radiative Forcing
GISS + no strat. aerosols after 2000
Satellite
Projections
W/m²
2.0
1.8
1.6
1.4
1.2
1.0
2000
2005
2010
2015
2020


Total Radiative Forcing
GISS + no strat. aerosols after 2000
Projections
Satellite
W/m²
2.0
1.8
1.6
1.4
1.2
1.0
2000
2005
2010
2015
2020
Temperature Change
Deg C
0.9
0.8
0.7
0.6
0.5
0.4
Year
2010-2020
T Change
0.24K
0.18K
0.15K

Conclusions

- Even in the absence of extremely large volcanic eruptions, changes in stratospheric aerosol loading can be important for climate
- Neglecting stratospheric aerosols since 2000 would lead to an overestimate of the calculated decadal warming by almost 0.1°C
- Aerosol changes in the coming years will play an important role in determining whether decadal warming is greater or less than expected from greenhouse gases alone – source important!



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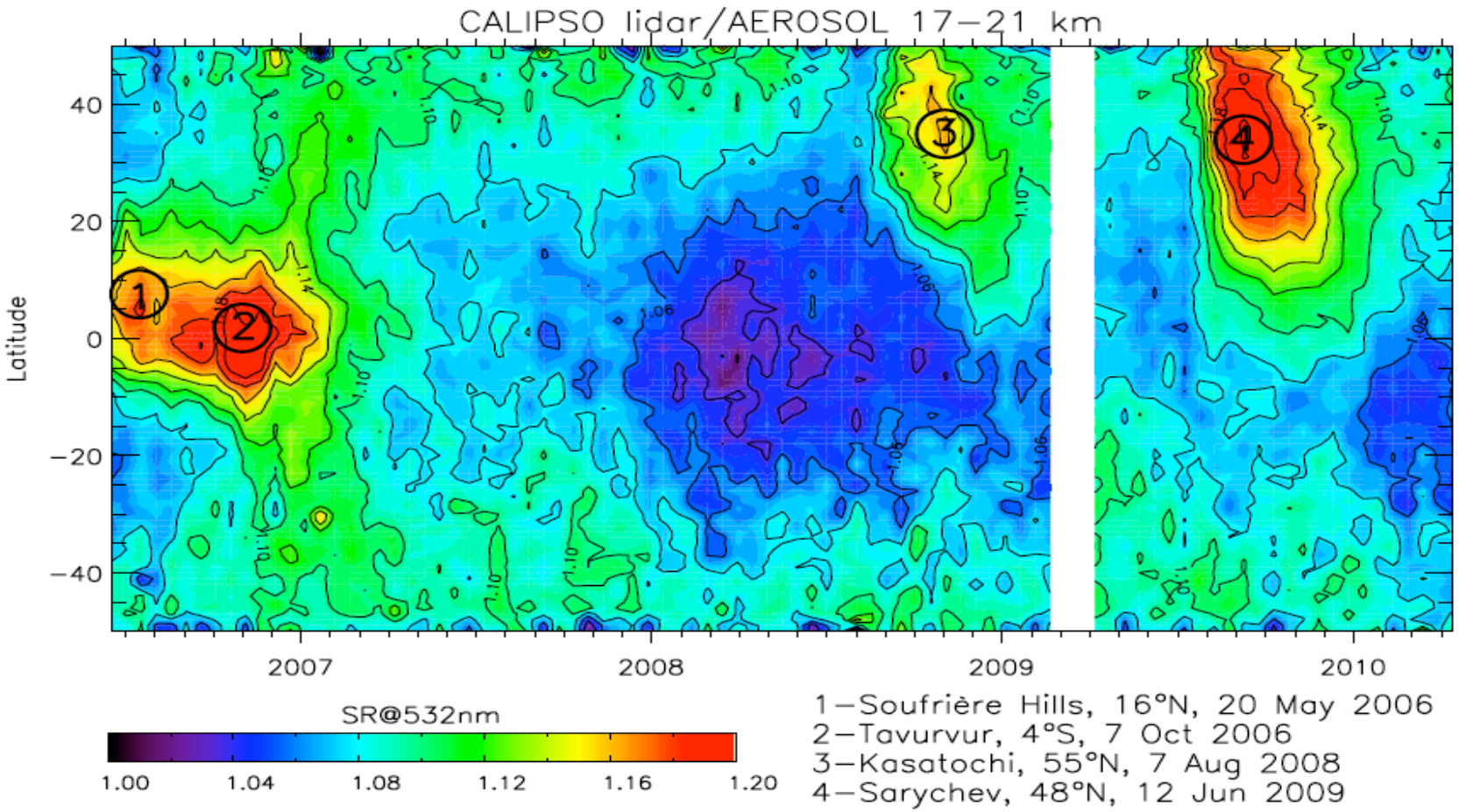
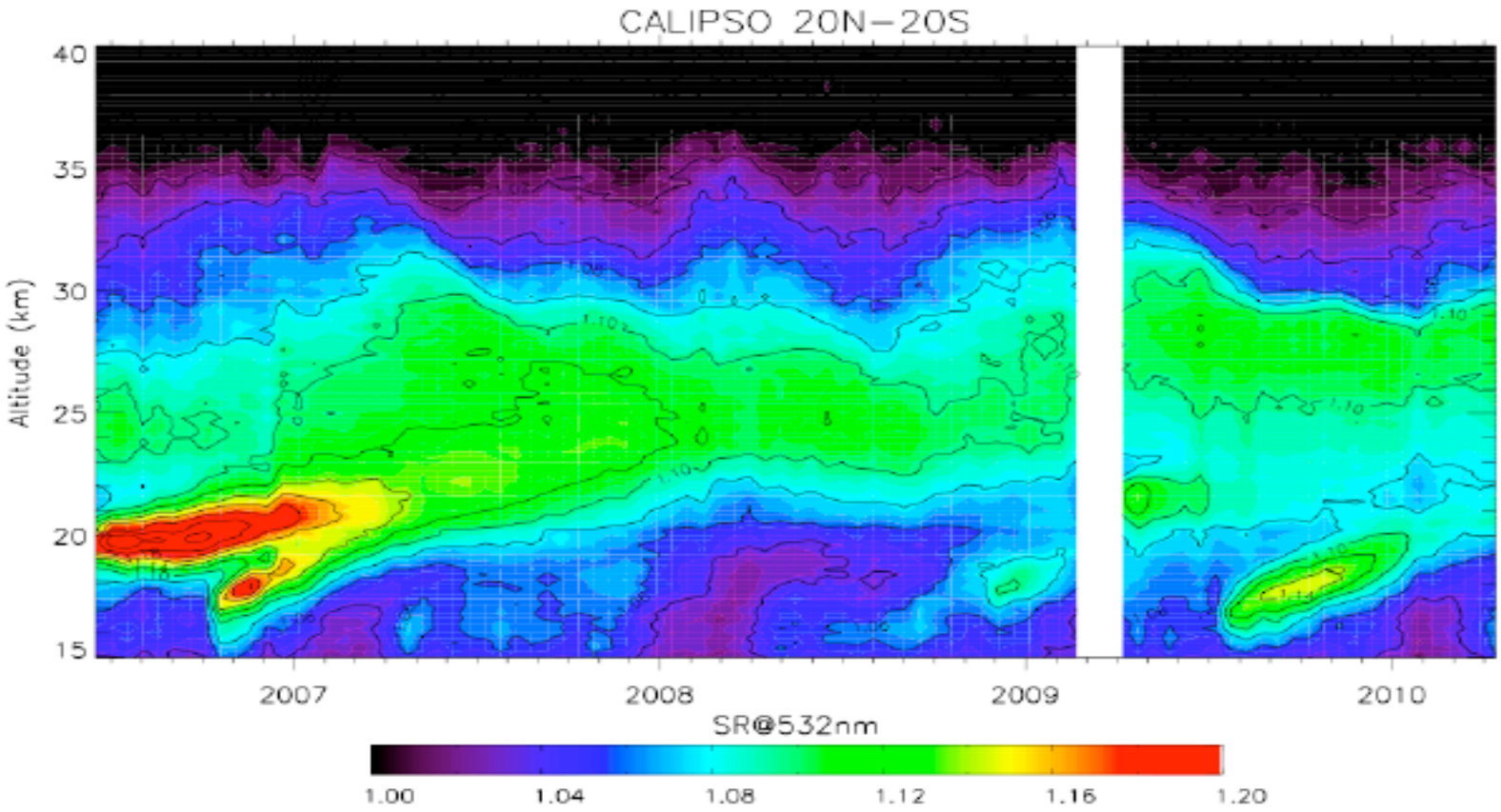
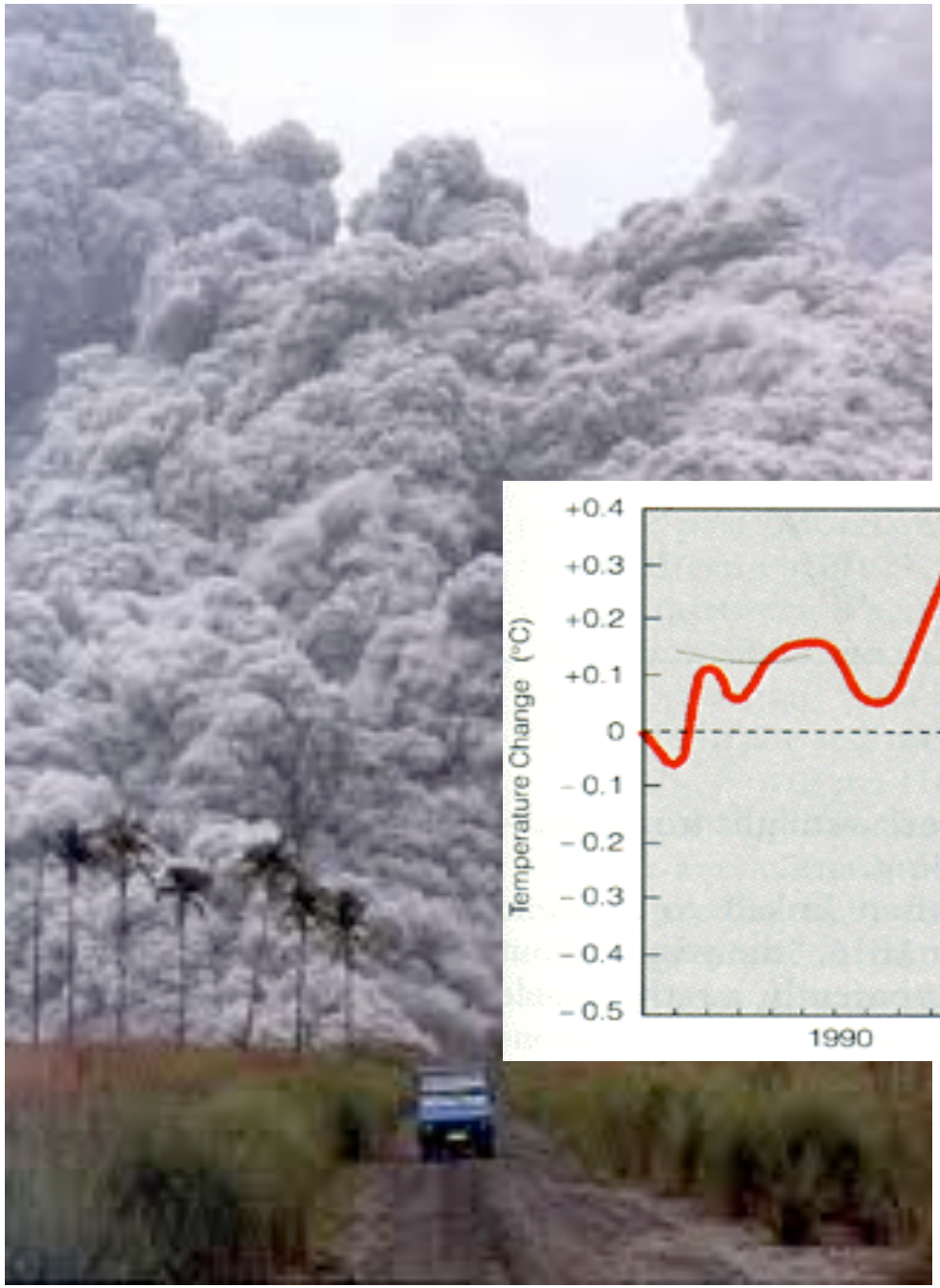
Additional Slides

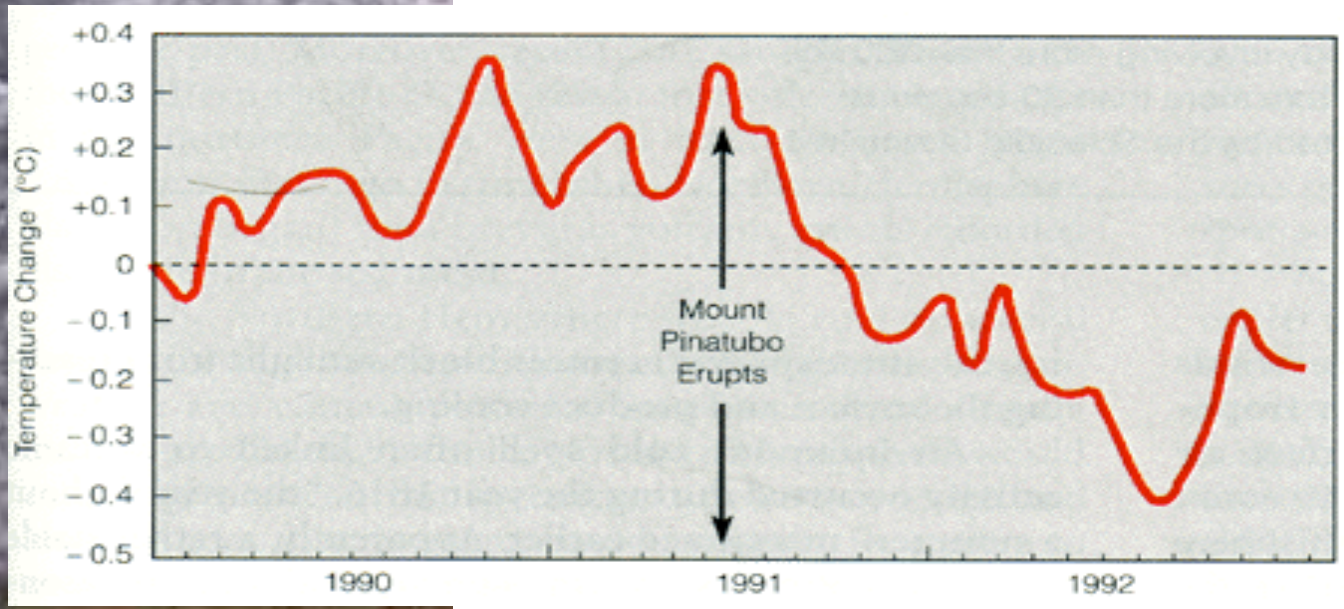
Volcano	Date	Latitude	VEI
Nevado del Ruiz (Ne)	14-Nov-85	5°S	4-5 ?
Augustine (Au)	27-Mar-86	59°N	4 ?
Chikurachki (Ch)	20-Nov-86	50°N	4
Kliuchevskoi (Kl)	30-Jan-90	56°N	4
Kelut (Ke)	10-Feb-90	8°S	4
Pinatubo (Pi)	15-Jun-91	15°N	5-6
Cerro Hudson (Ce)	12-Aug-91	46°S	5+
Spur (Sp)	27-Jun-92	61°N	4
Lascar (La)	19-Apr-93	23°S	4
Rabaul (Ra)	19-Sep-94	4°S	4 ?
Ulawun (Ul)	29-Sep-00	5°S	4
Shiveluch (Sh)	22-May-01	56°N	4 ?
Ruang (Ru)	25-Sept-02	2°N	4 ?
Reventador (Ra)	3-Nov-02	0°N	4
Manam (Ma)	27-Jan-05	4°S	4
Soufrière Hills (So)	20-May-06	16°N	4 ?
Tavurvur (Ta)	07-Oct-06	4°S	4 ?
Chaiten (Ch)	2-May-08	42°S	4 ?
Okmok (Ok)	12-juil-08	55°N	4
Kasatochi (Ka)	07-Aug-08	55°N	4
Fire/Victoria (Vi*)	07-Feb-09	37°S	
Sarychev (Sa)	12-Jun-09	48°N	4 ?


CALIPSO lidar/AEROSOL 17–21 km
Latitude
40
20
0
−20
−40
2007
2008
2009
2010
1
2
3
4
SR@532nm
1.00
1.04
1.08
1.12
1.16
1.20
1–Soufrière Hills, 16°N, 20 May 2006
2–Tavurvur, 4°S, 7 Oct 2006
3–Kasatochi, 55°N, 7 Aug 2008
4–Sarychev, 48°N, 12 Jun 2009


CALIPSO 20N−20S
Altitude (km)
40
35
30
25
20
15
2007
2008
2009
2010
SR@532nm
1.00
1.04
1.08
1.12
1.16
1.20



Major volcanic eruptions. Particles reflect light, change the energy budget, and force a change in climate.



SO_2 Emissions, China, Lu et al., 2010