Natural and Anthropogenic Influences on Earth's Surface Temperature

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- **Present, Space-Era**
  - *- surface, troposphere and stratosphere*
    - *.. ENSO, volcanic, solar and anthropogenic influences*
    - *.. global and regional patterns*
  - *- GISS climate model simulations (with David Rind)*
- **Past**
  - *- instrumental surface temperatures, since 1880*
  - *- Holocene, proxies in the past 10,000 years*
- **Future Decades**
  - *- forecasts of anthropogenic and solar influences*
  - *- scenarios for ENSO and volcanic influences*

EPA, 28Jan09

Disclaimer (added by EPA)

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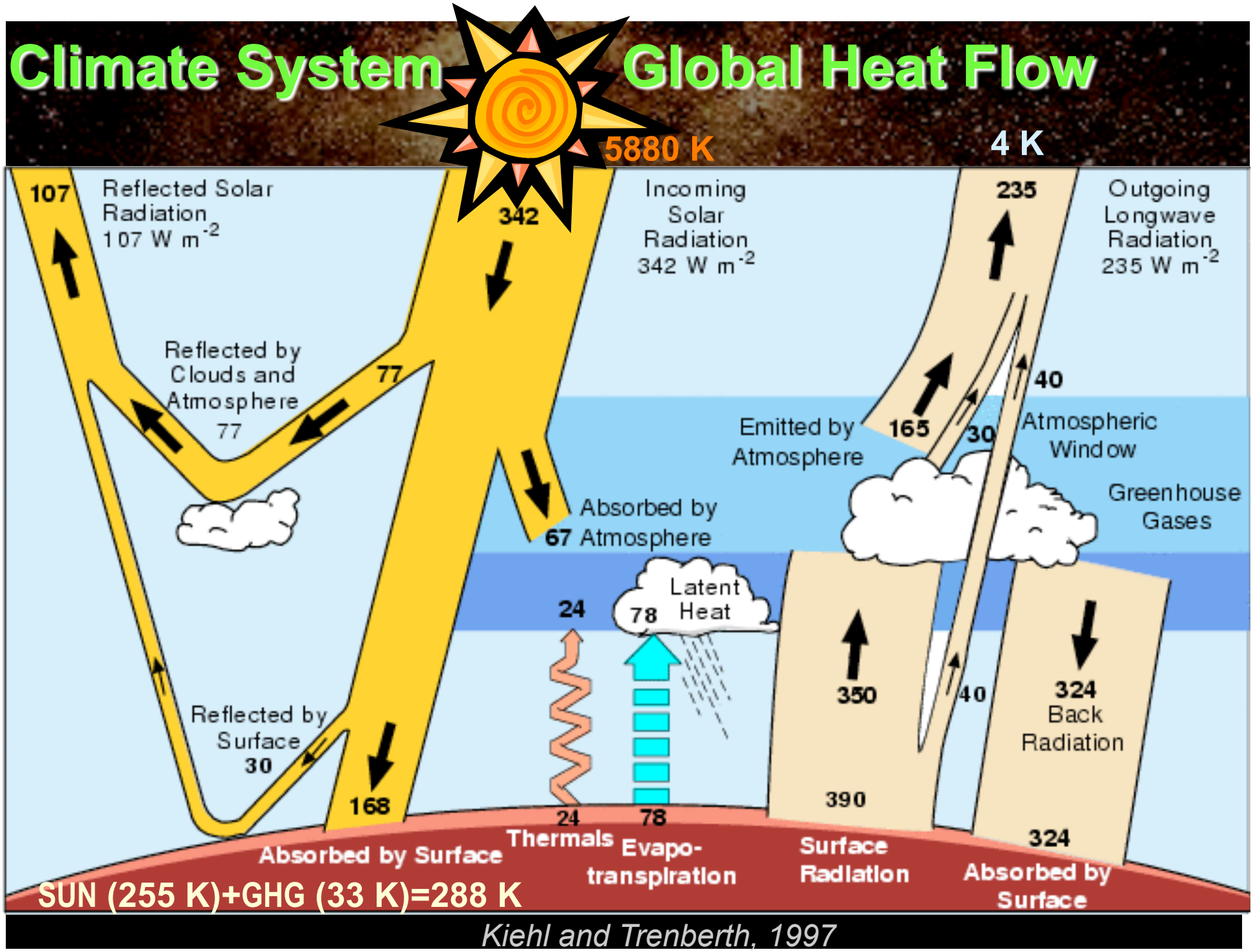


Kiehl and Trenberth, 1997

There are Many Causes of Climate Change

Natural Forcings

- solar variability - *direct and indirect effects*
- volcanic eruptions - *stratospheric aerosols*

Internal Oscillations

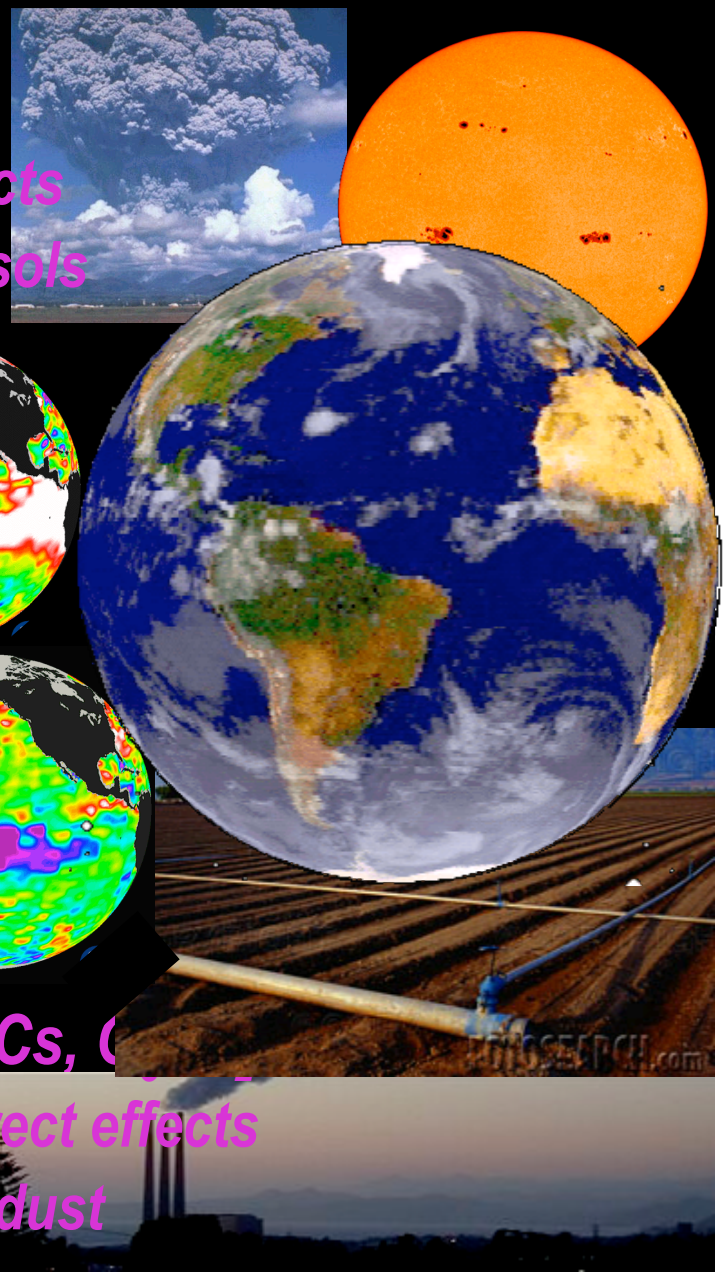
- atmosphere-ocean couplings
  - *El Niño Southern Oscillation (ENSO)*
  - *North Atlantic Oscillation (NAO)*

Land Cover Changes

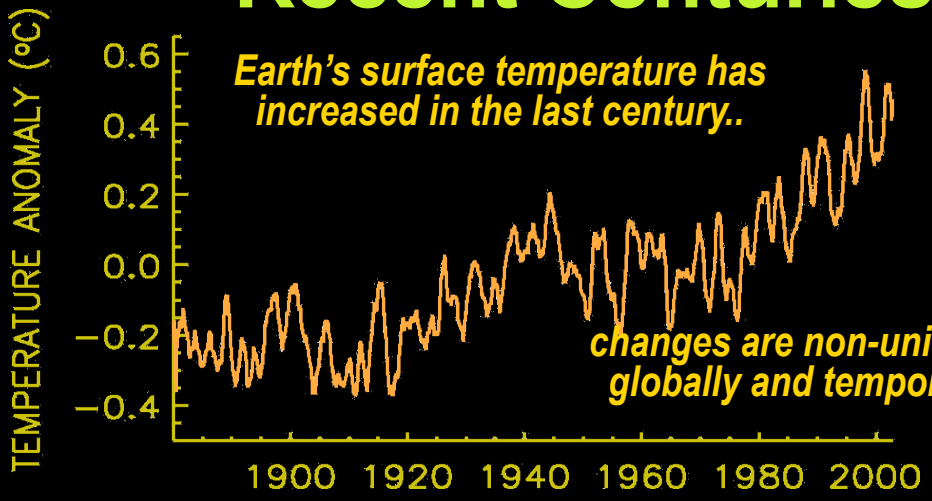
Anthropogenic Forcings

- atmospheric GH gases - *CO_2, CH_4, CFCs, O*
- tropospheric aerosols - *direct and indirect effects*

of soot, sulfate, carbon, biomass burning, soil dust

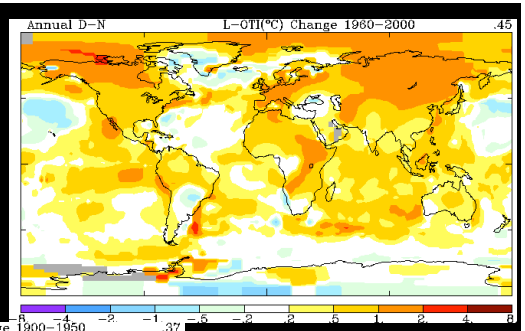


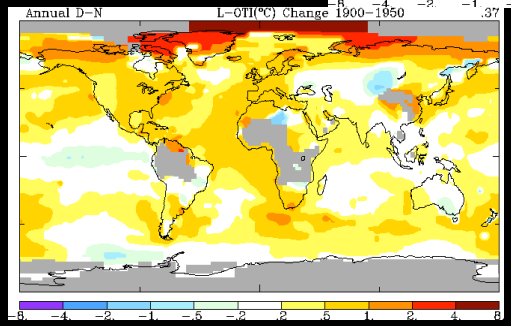
Surface Temperatures in Recent Centuries



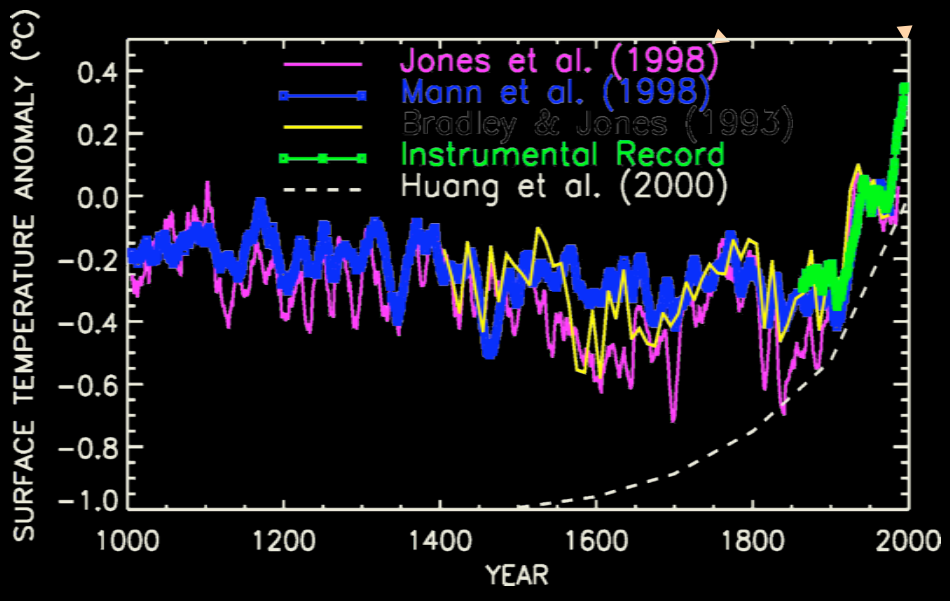
http://giss/nasa/gov

1960-2000



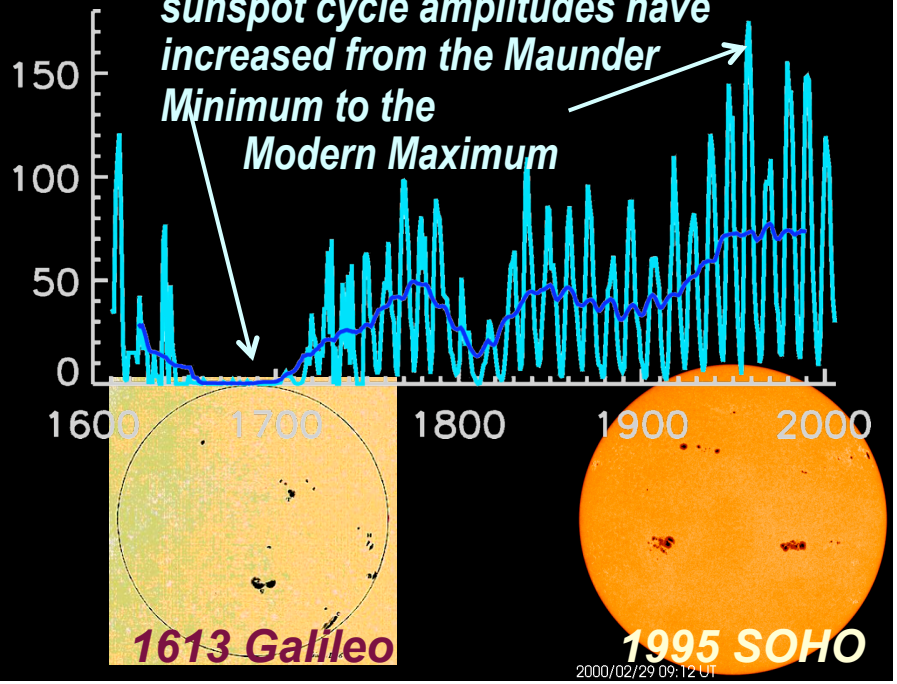


1900-1950

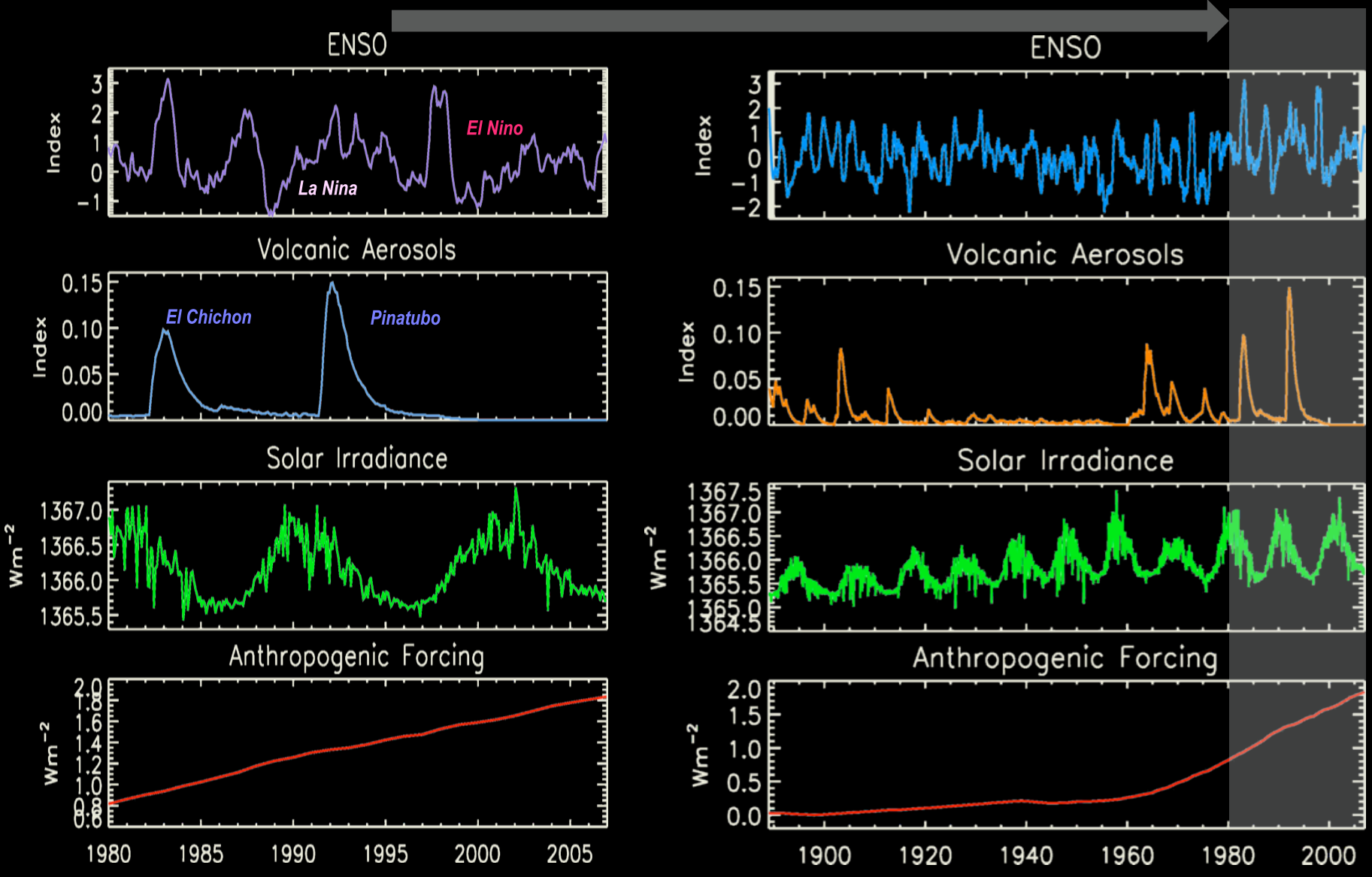


Is the Sun to Blame?

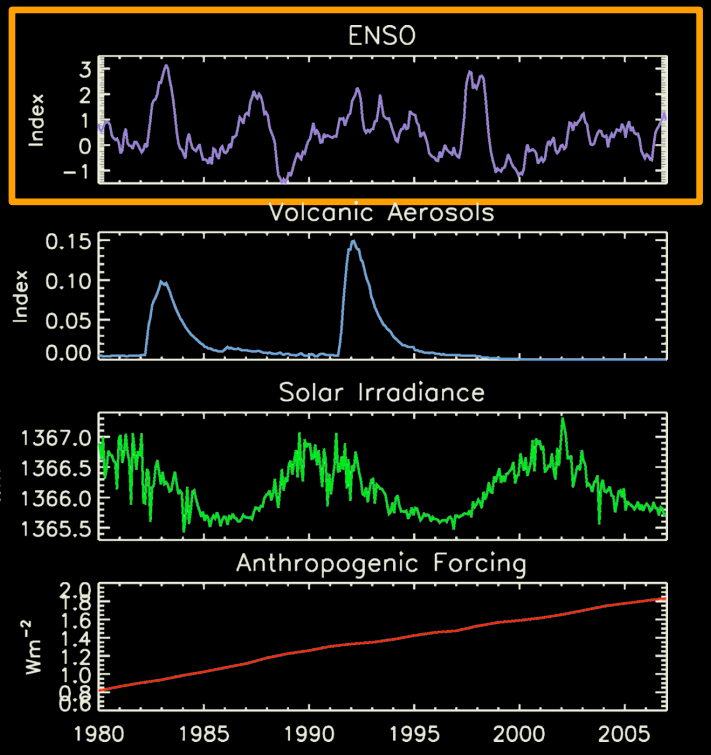
sunspot cycle amplitudes have increased from the Maunder Minimum to the Modern Maximum



Natural and Anthropogenic Climate Influences

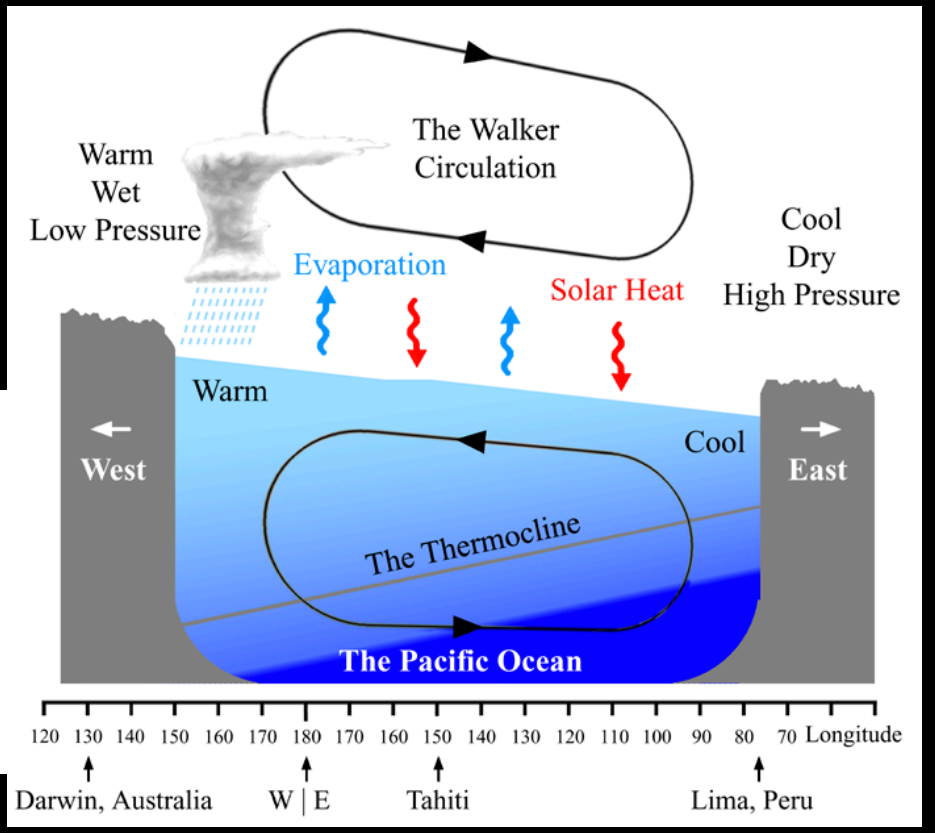


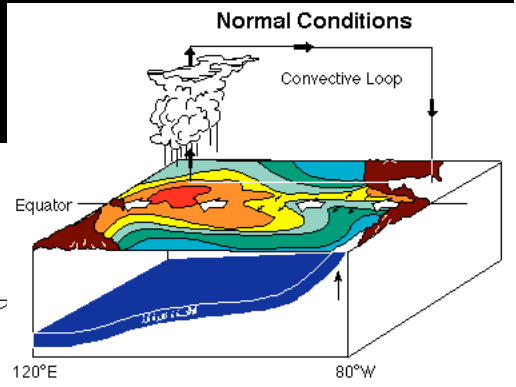
ENSO – El Niño Southern Oscillation

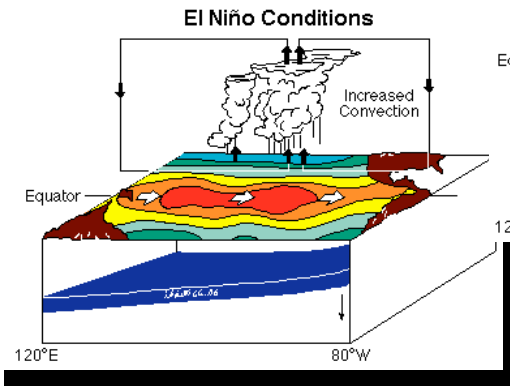


multivariate ENSO index

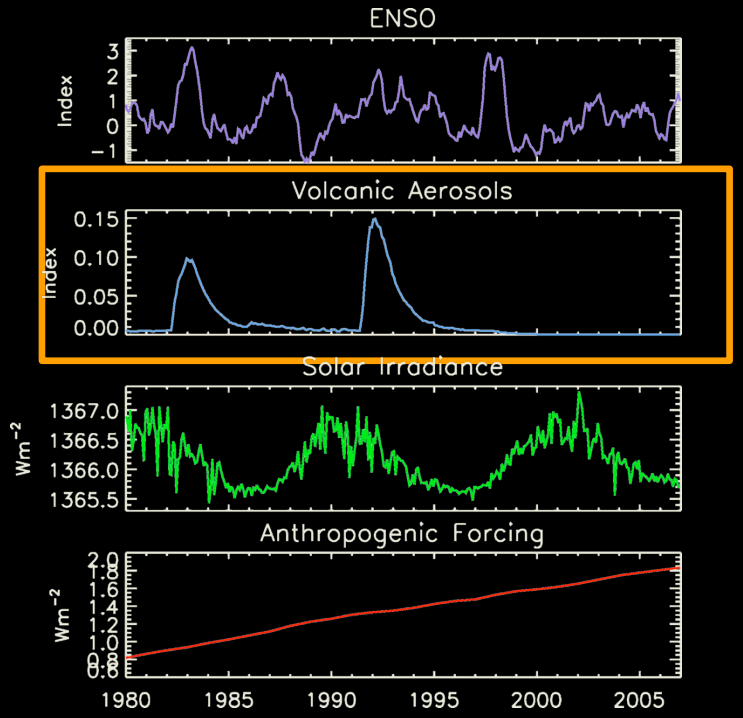
- weighted average of the main ENSO features contained in sea-level pressure, surface wind, surface sea and air temperature, and cloudiness in the tropical Pacific (*Walter and Timlin, 1998)*

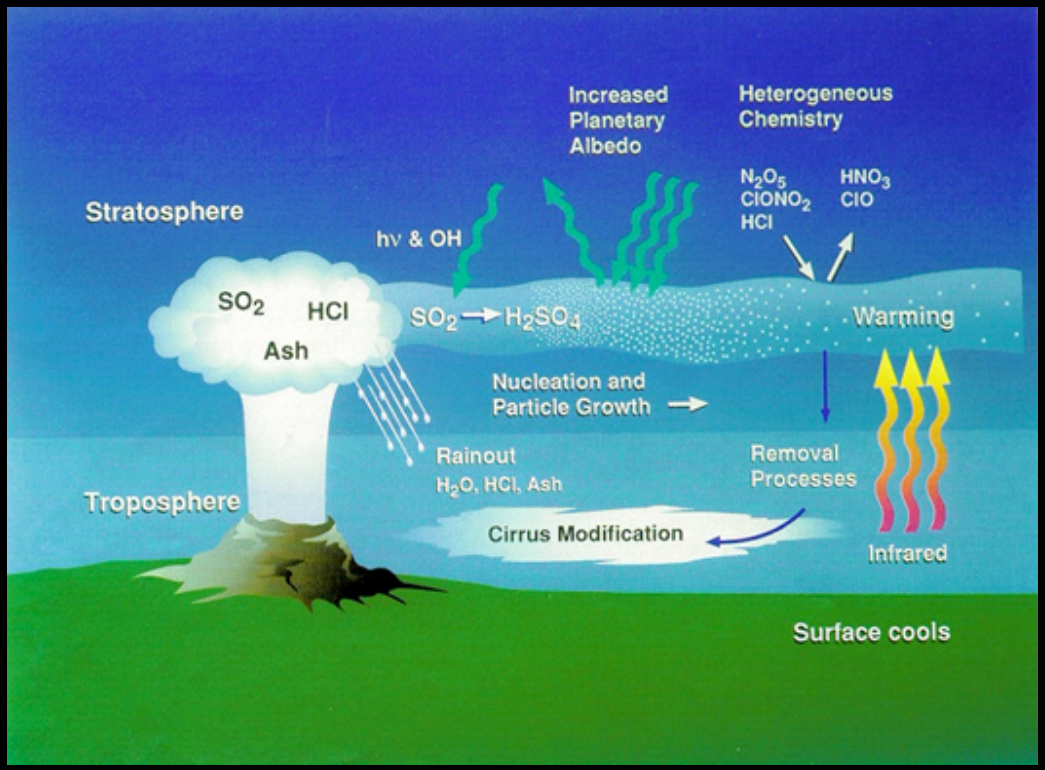




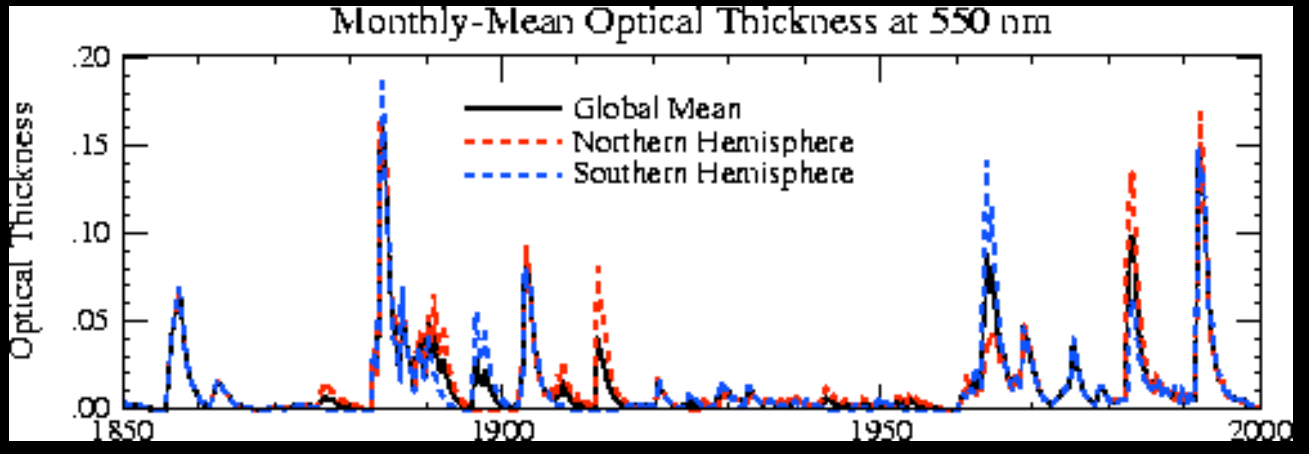


Volcanic Stratospheric Aerosols

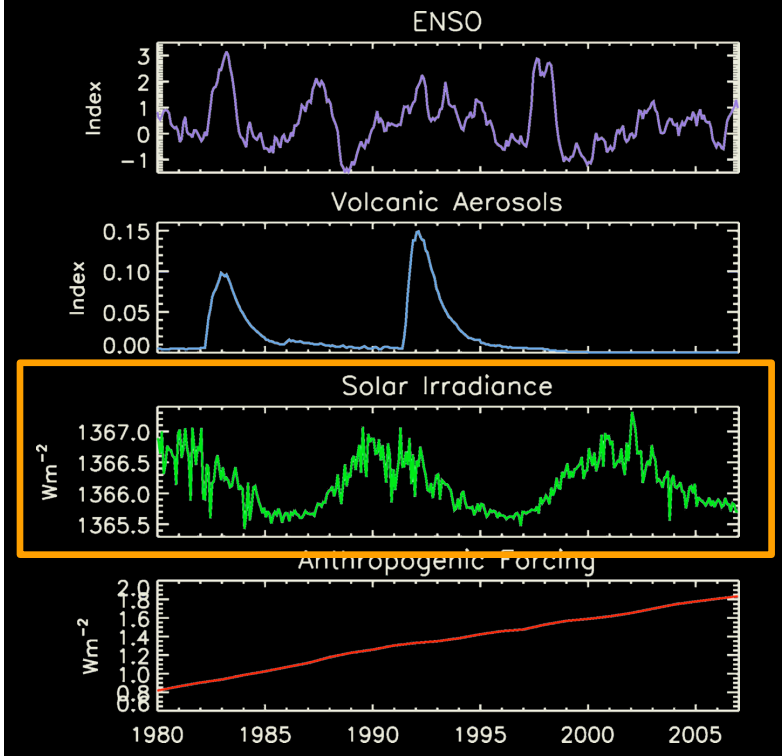




optical thickness at 550 nm - compiled by *Sato et al.* (1993) since 1850, updated from to 1999 from *giss.nasa.gov* and extended to the present with zero values

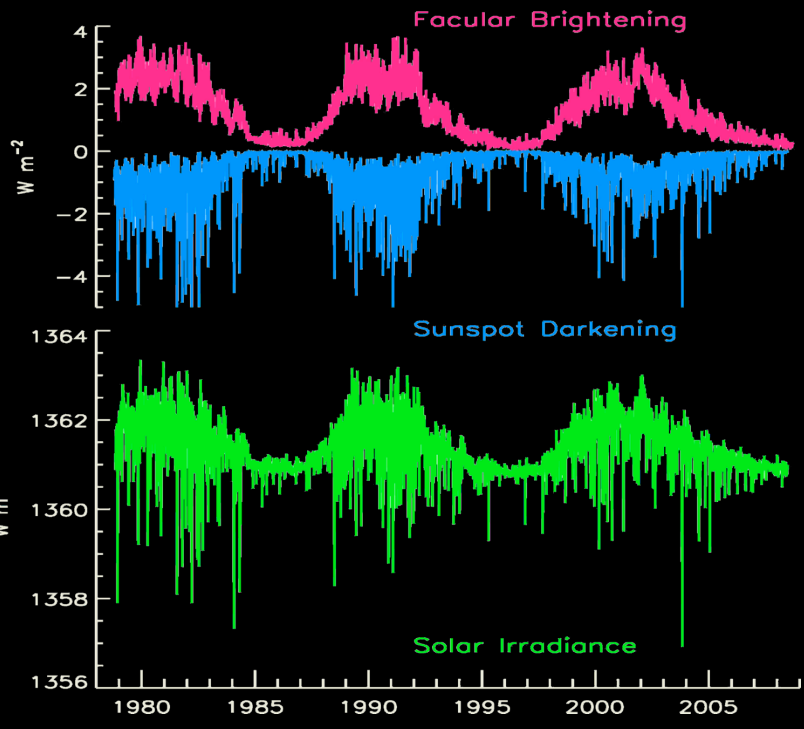


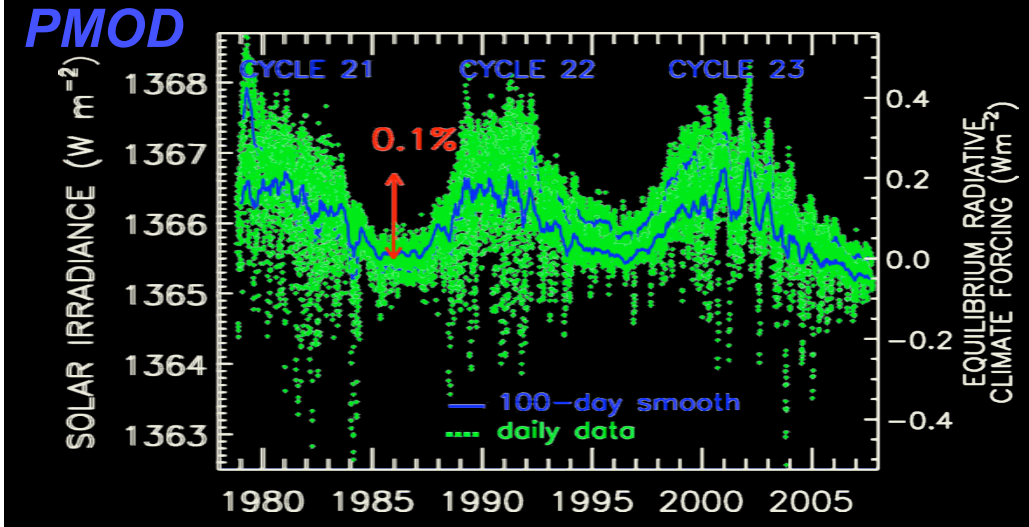
Solar Irradiance



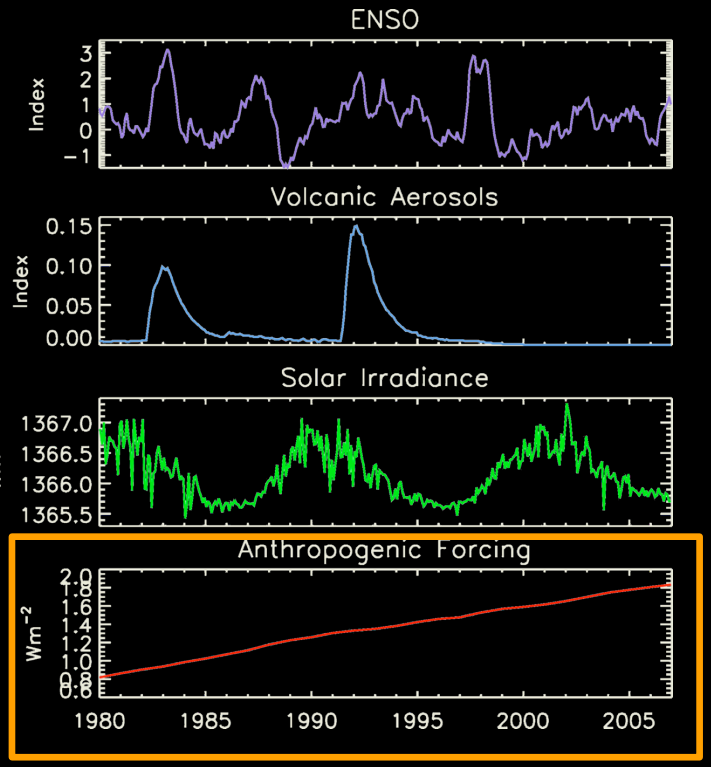
Net effect of sunspot darkening and facular brightening

- model developed from observations of total solar irradiance (*Lean et al. 2005*)

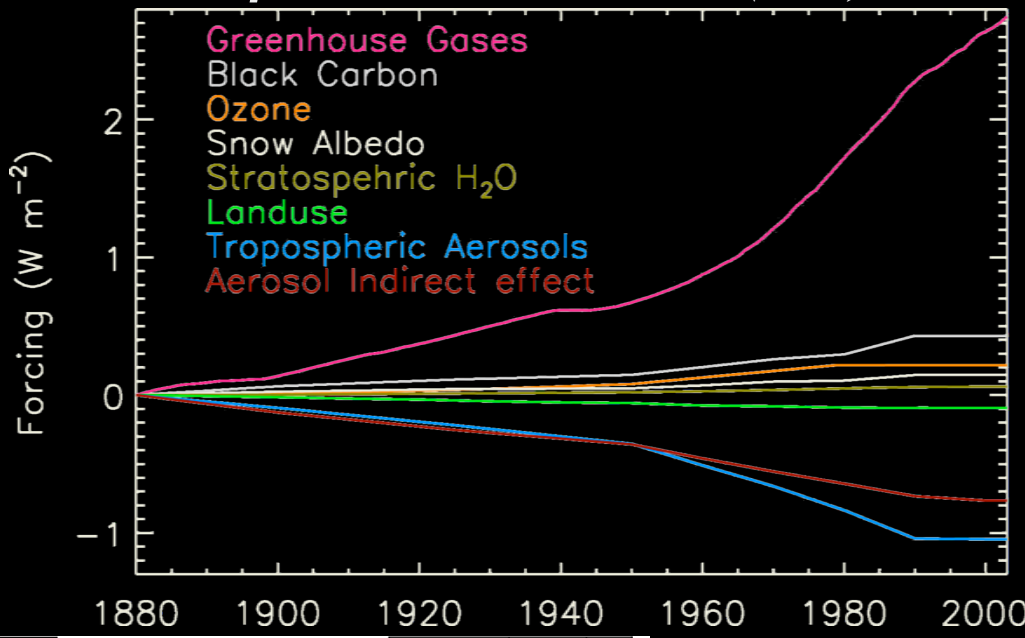


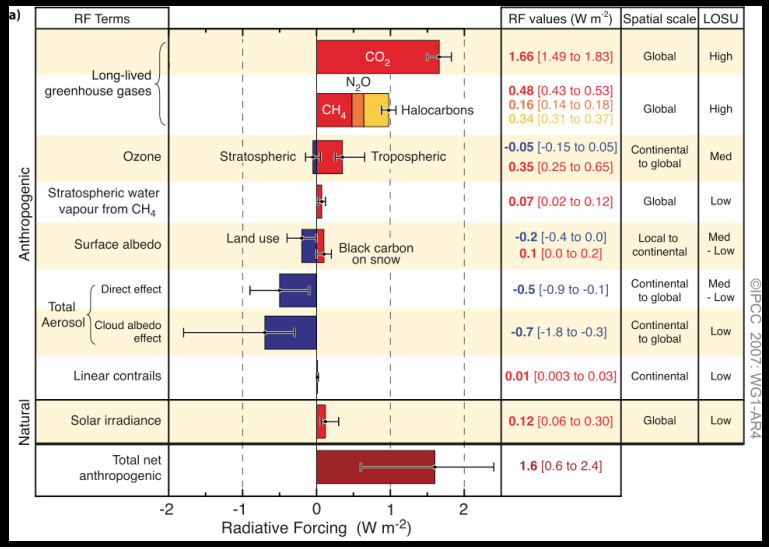


Anthropogenic Influence

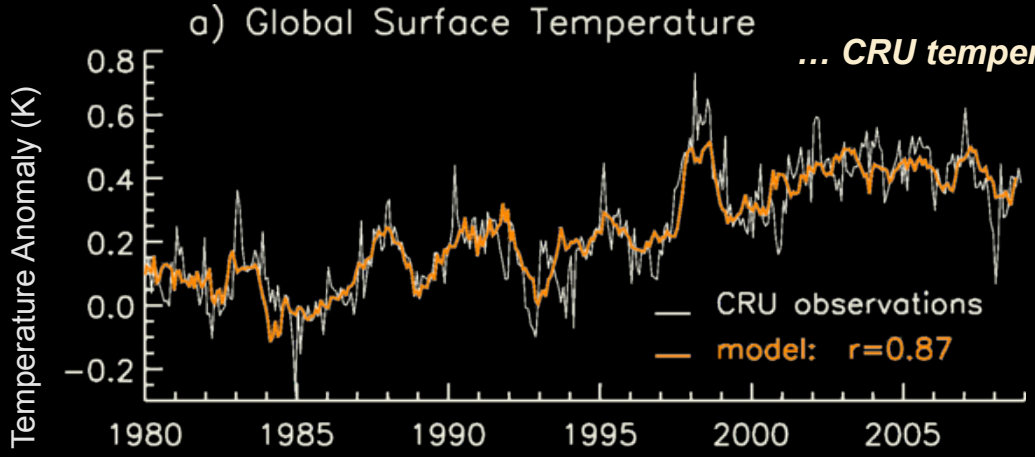


net effect of eight different components *Hansen et al. (2007)*





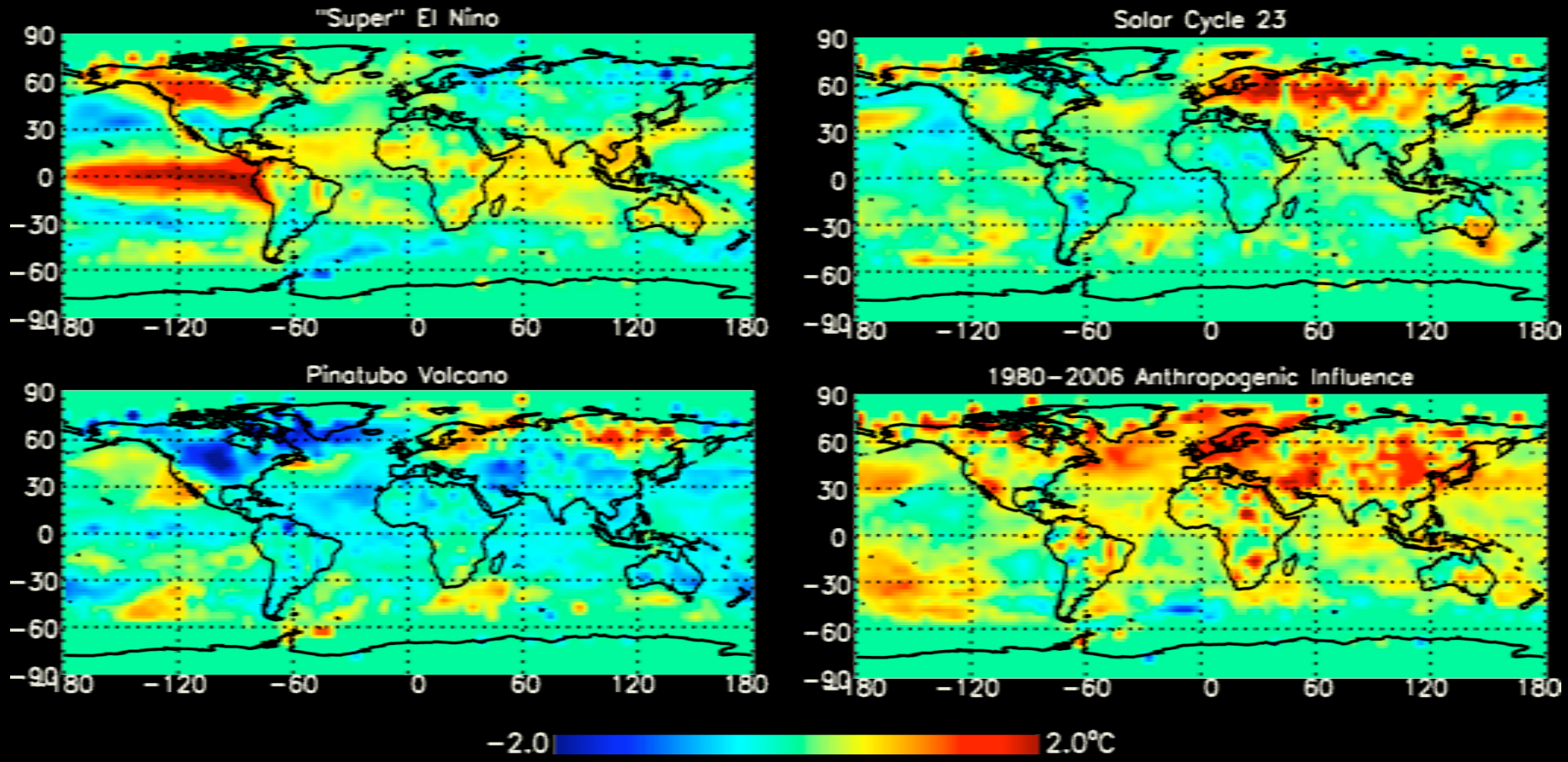
Global Surface Temperature Response to Natural and Anthropogenic Influences: 1980-2008

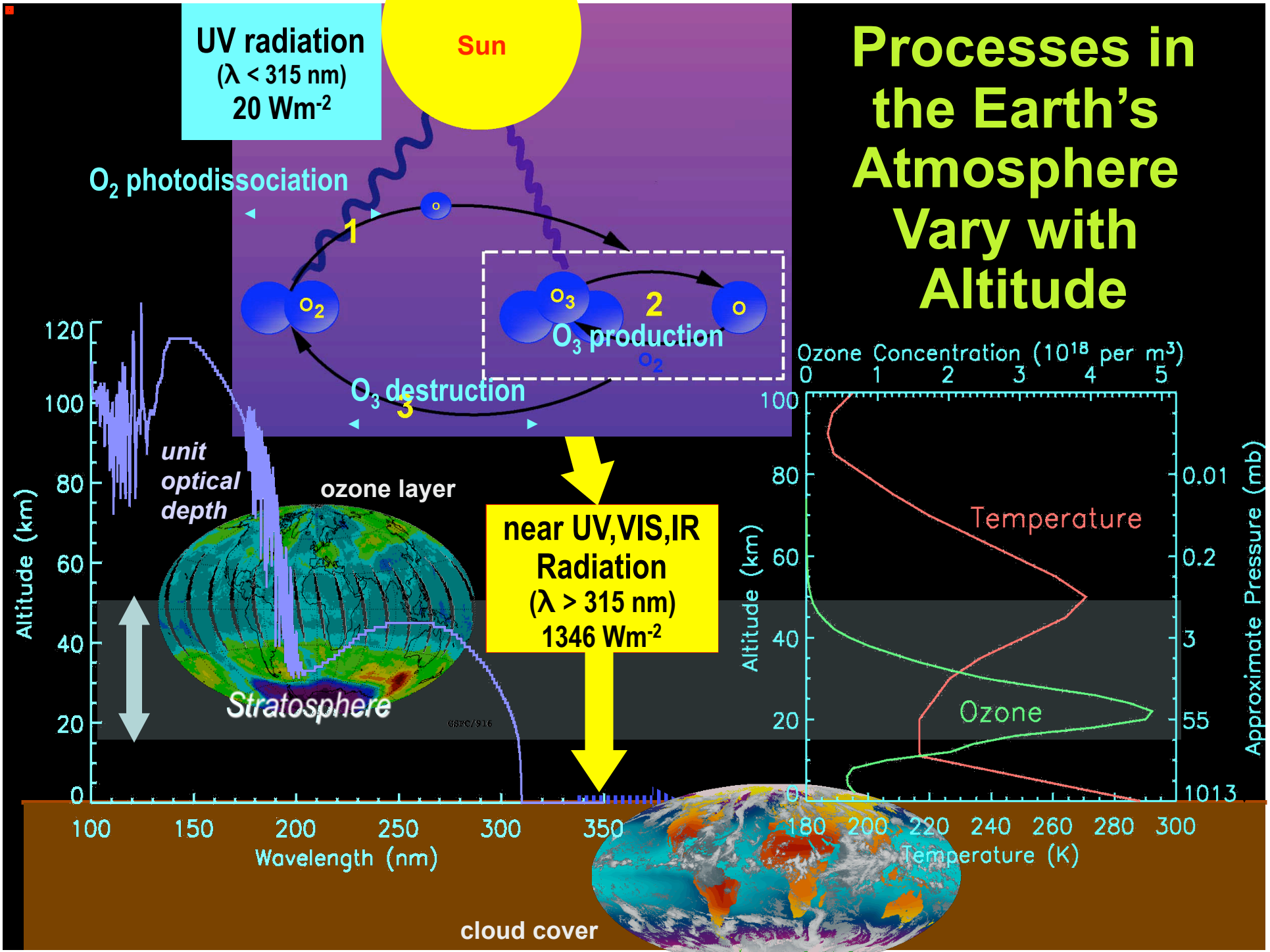


… CRU temperature data, Univ. East Anglia, UK

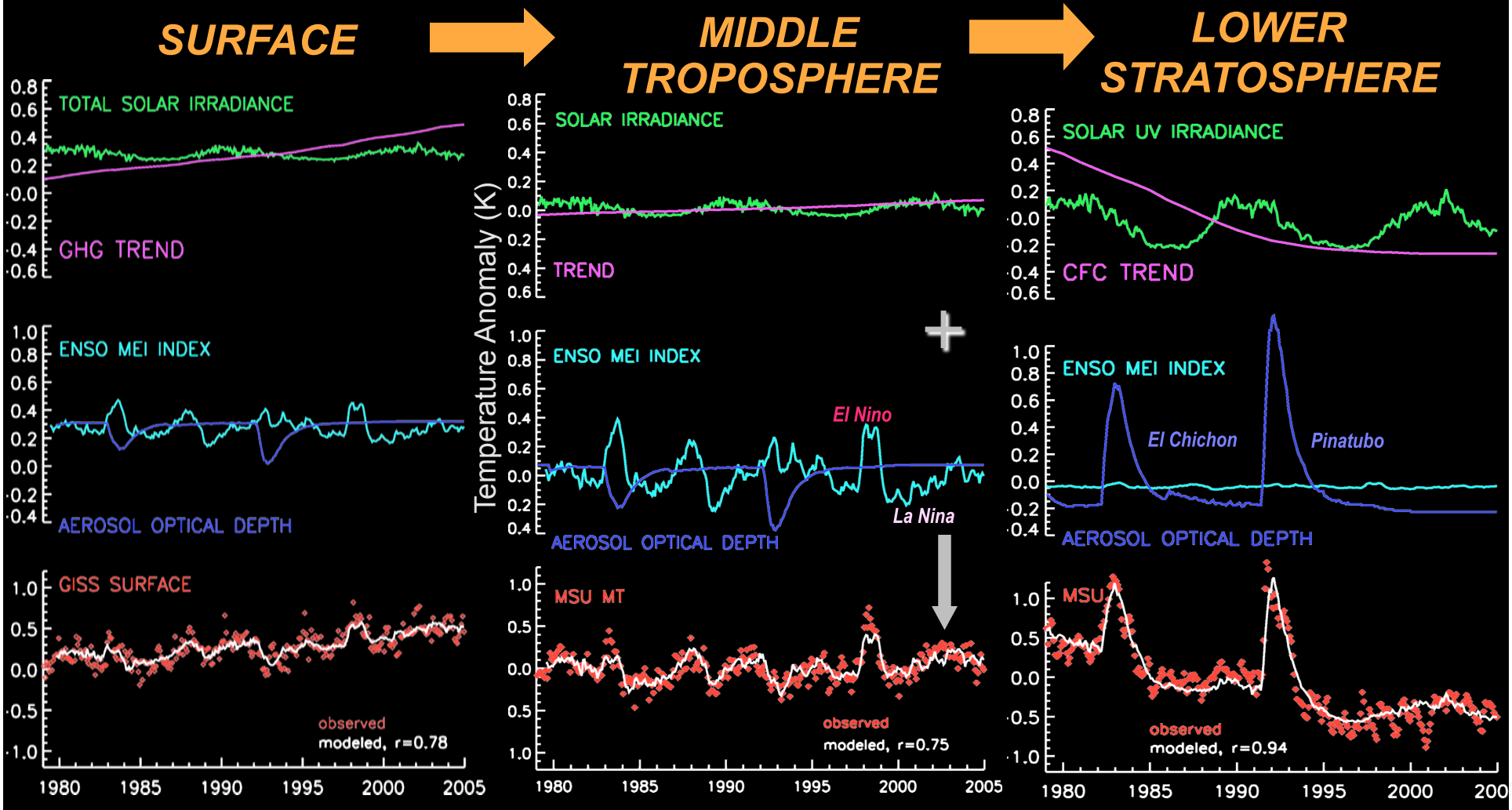
Combined ENSO + volcanic aerosols + solar activity + anthropogenic effects explain 76% of observed temperature variance

Surface Temperature Regional Response Patterns (5°×5° lat-long)




Processes in the Earth's Atmosphere Vary with Altitude
UV radiation
(λ < 315 nm)
20 Wm-2
Sun
O2 photodissociation
1
O
O2
O3
2
O
O3 production
O2
O3 destruction
3
near UV,VIS,IR
Radiation
(λ > 315 nm)
1346 Wm-2
unit
optical
depth
ozone layer
Stratosphere
GSFC/916
Altitude (km)
Wavelength (nm)
Ozone Concentration (10^18 per m^3)
Temperature
Ozone
Temperature (K)
Approximate Pressure (mb)
cloud cover
UW-SSEC
T(C) 5 15 25 -55 -25 5 35
ICE SEA SURFACE SYNOPTIC OBS CLOUD TOP

Earth's Atmosphere Responds to Natural and Anthropogenic Influences

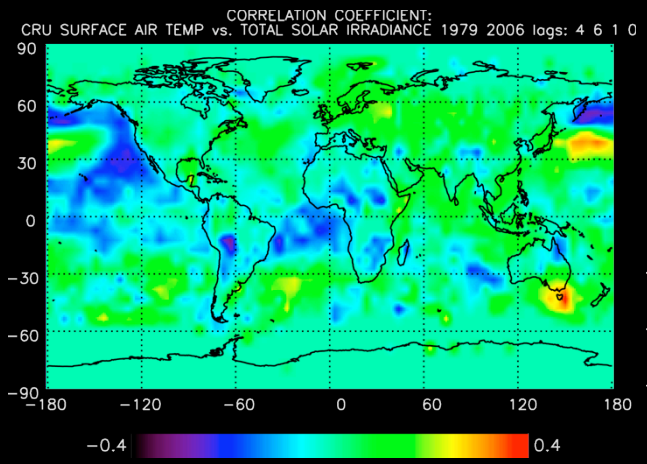


solar increase → *warming*
CO_2 increase → *warming*
volcanoes → *cooling*

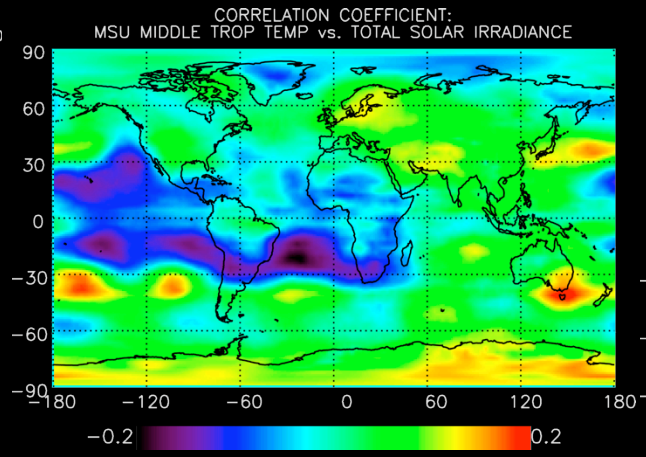
solar increase → *warming*
CO_2 & CFC increase → *cooling*
volcanoes → *warming*

Temperature Correlation Spatial Patterns

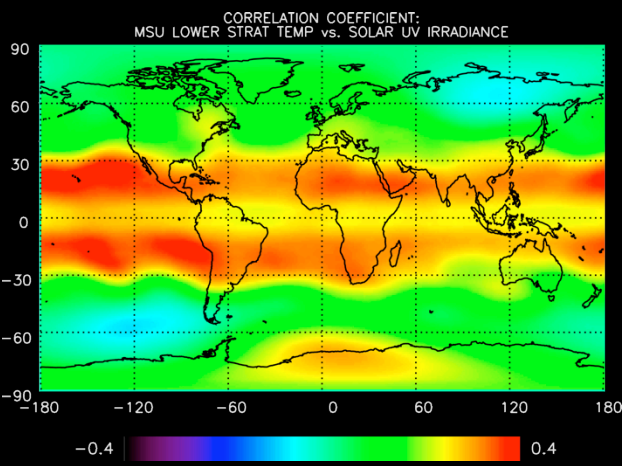
SURFACE



MIDDLE TROPOSPHERE



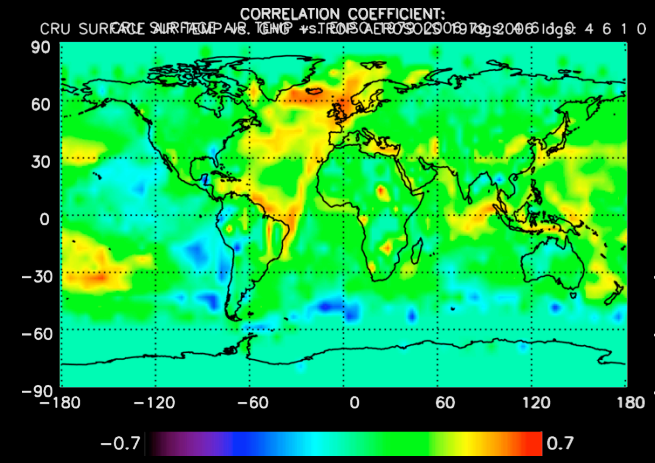
LOWER STRATOSPHERE

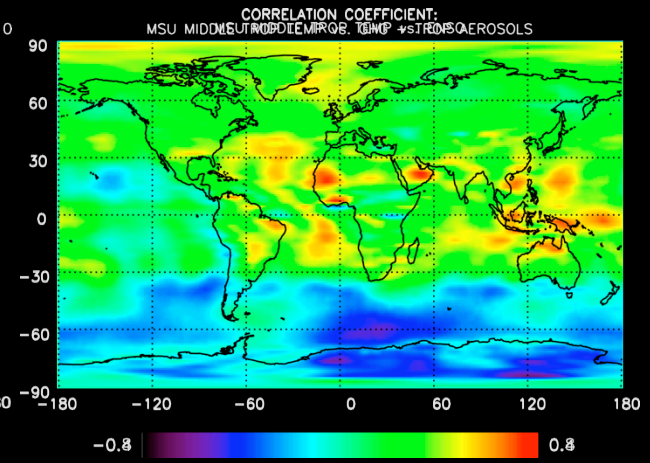


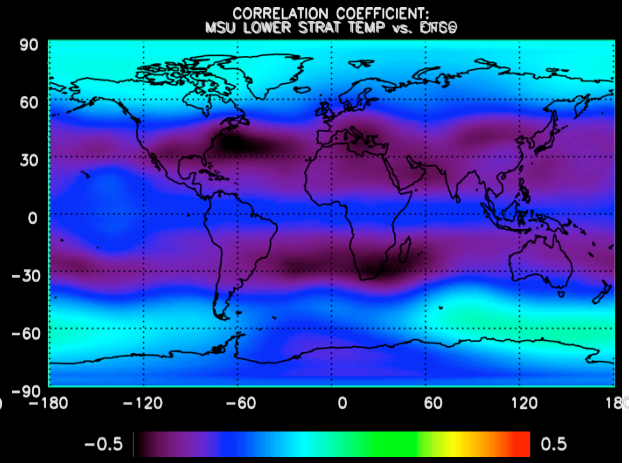
CRU 5º (lat) × 5º(long)

Solar Irradiance

MSU 2.5º (lat) ×2.5º(long)

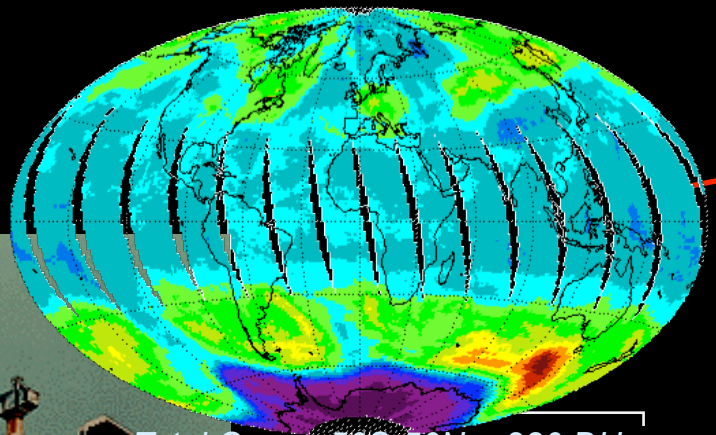






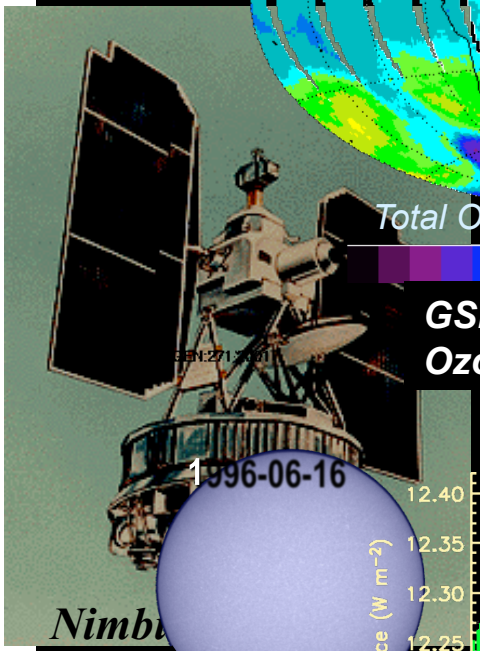
Anthropogenic Gases

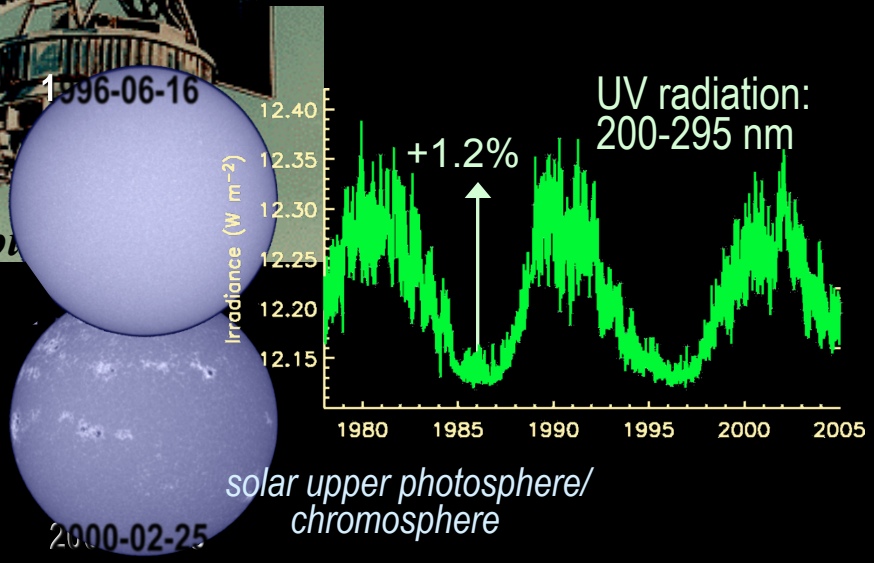
The Ozone Layer Responds to Natural and Anthropogenic Influences

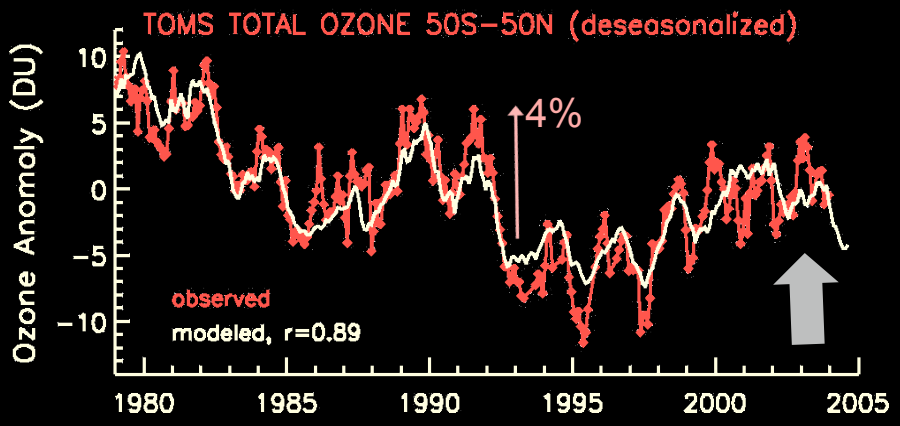


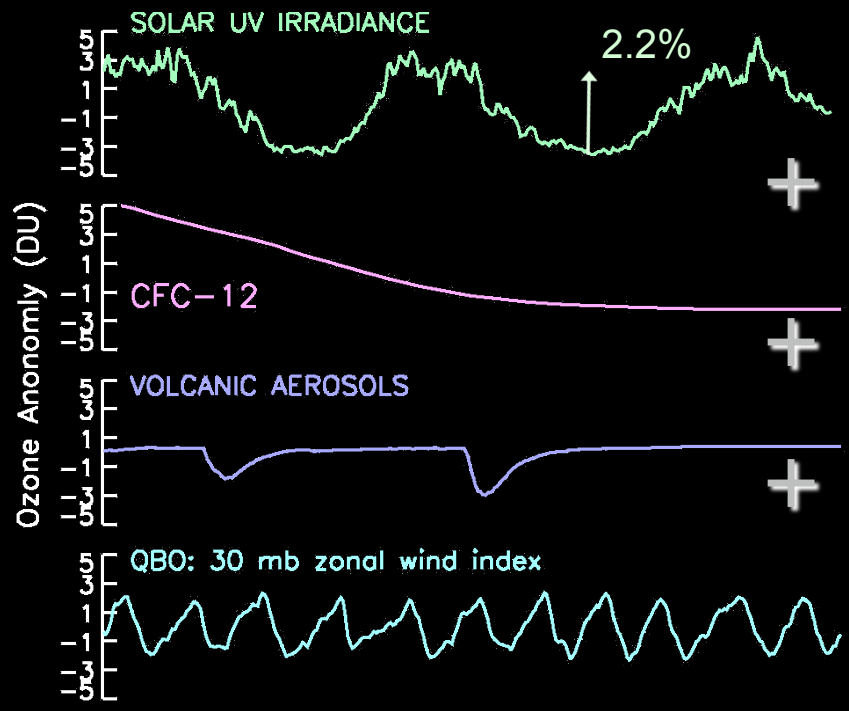
Total Ozone 50S-50N ~ 280 DU

GSFC TOMS Total Ozone Sep 16, 2001



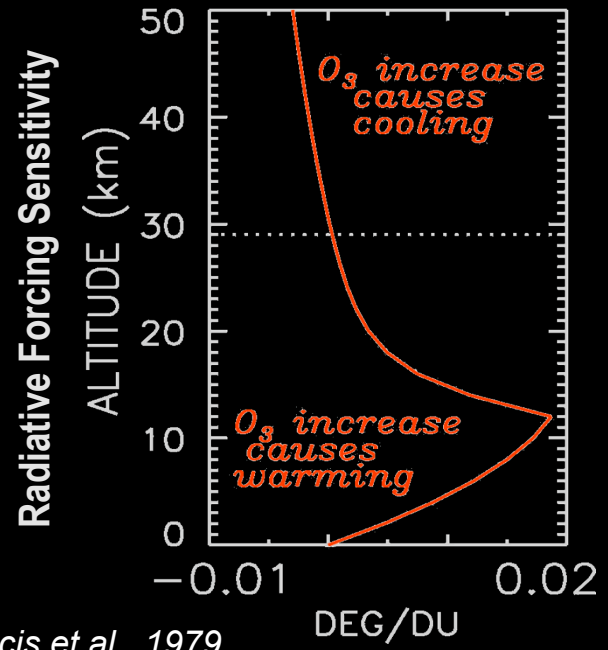






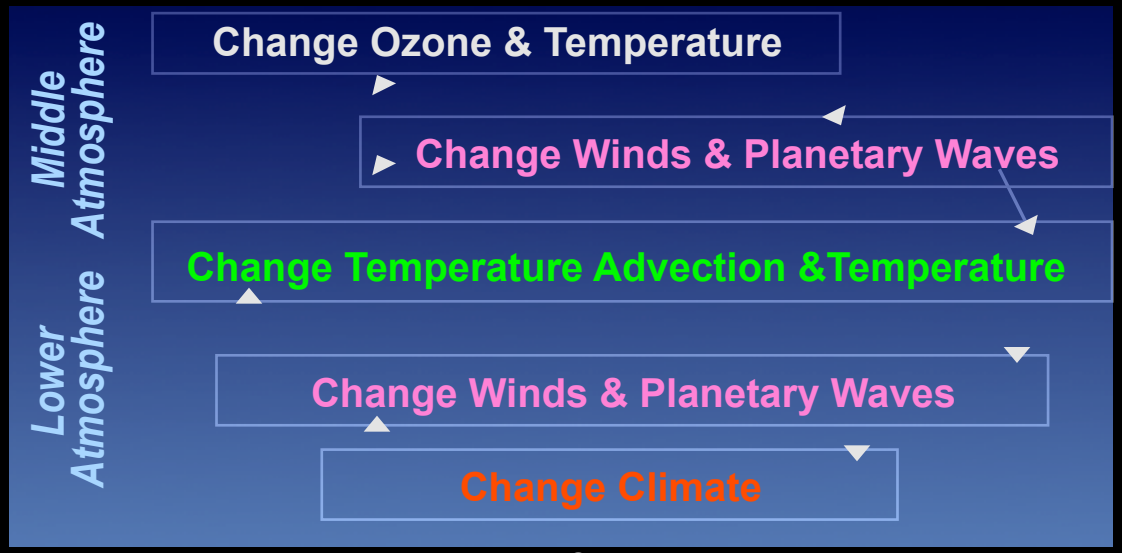
Stratosphere – Climate Coupling

Radiative Coupling via Absorption and Emission



Lacis et al., 1979

Dynamical Coupling via Wind-Wave Interactions

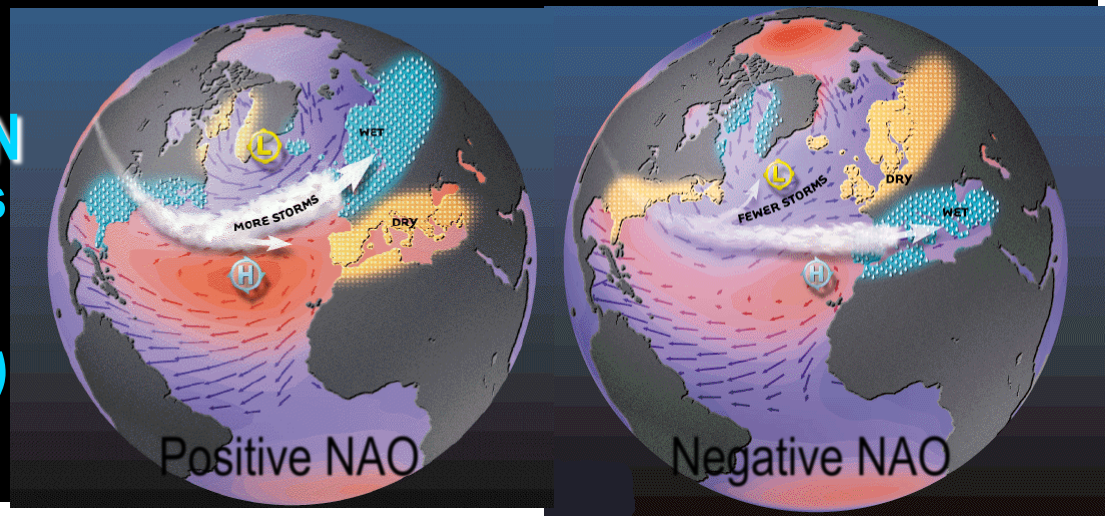


Shindell et al., 2003; Rind et al., 2004

NORTH ATLANTIC OSCILLATION

- solar irradiance cycle modulates stratospheric polar vortex
- tropospheric circulation
- *NAO (solar min) AO (solar max)*

Kodera, 2003



Climate Model Response to Radiative Forcing

surface temperature change ΔT = κ *forcing* F

climate sensitivity κ

IPCC range: 0.2-1°C per Wm^{-2}
paleoclimate: 0.75°C per Wm^{-2}
Hansen, 2004

current understanding assumes that climate response to solar radiative forcing is thermodynamic --

BUT empirical evidence suggests it is

…. dynamic, rather than (or as well as) thermodynamic
… engages existing circulation patterns (Hadley, Ferrel, and Walker cells) and atmosphere- ocean interactions (ENSO)
… involves both direct (surface heating) and indirect (stratospheric influence) components.

solar irradiance provides a well specified external climate forcing for testing models and understanding

Anthropogenic Influence

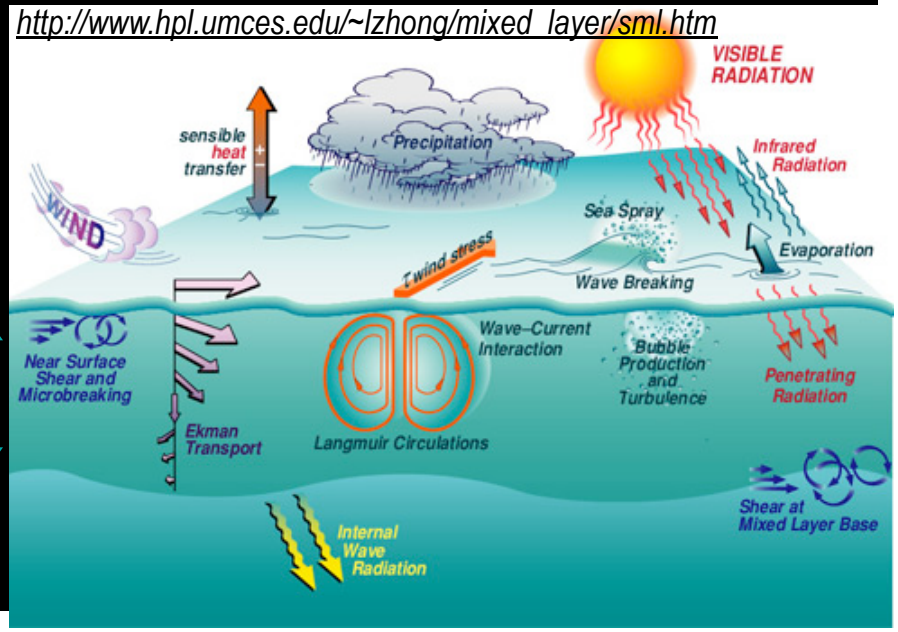
ΔT = 0.4°C (1980-2006)

F = 1 Wm^{-2} (total, not all radiative)

$\therefore \kappa \approx$ 0.4°C per Wm^{-2}

BUT…. response to cyclic decadal forcing is assumed to be attenuated by ~5× compared with "equilibrium" response

http://www.hpl.umces.edu/~lzhong/mixed_layer/sml.htm



GISS GCMAM Simulations: 1950-2005

GISS General Circulation Middle Atmosphere Model: Rind et al., JGR, 2007, 2008

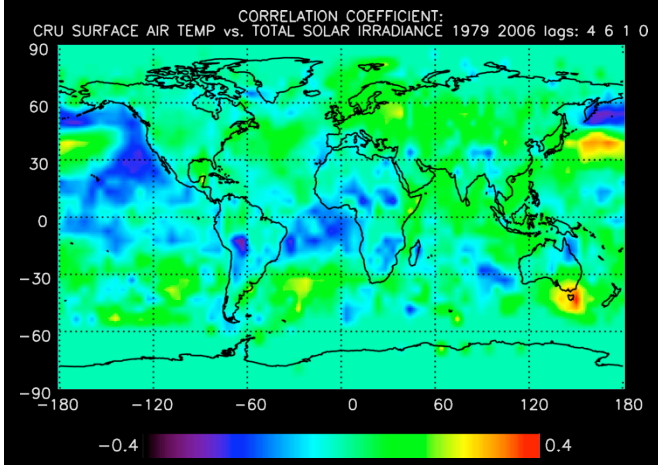
Run	Resolution	Forcing	Ozone	Ocean
1 B30TRoims1M23	4X5 (lat, lon) 23 layer (pressure)	solar (monthly mean spectra)	non-interactive	Q-flux, no diffusion (thru bottom of mixed layer)
2 B30TVoims1M23	4x5 23 layer	solar, trace gases, volcanic aerosols	non-interactive	Q-flux, no diffusion
3 B30TAoims1M23	4x5 23 layer	solar, trace gases, trop. + volcanic aerosols, trop + strat. ozone	non-interactive	Q-flux, no diffusion
4 B465trsoioTM23	4x5 23 layer	solar	Linoz chemically-unresponsive	Q-flux, no diffusion
5 B465trsuvoioTM23	4X5 23 layer	solar	Linoz	Q-flux, no diffusion
6 B465trsuvoioTM53	4x5 53 layer	solar	Linoz	Q-flux, no diffusion

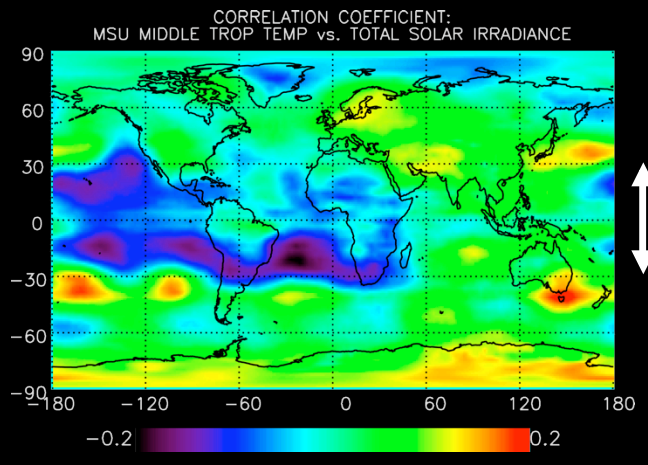
Observed and Modeled Temperature Spatial Patterns: SOLAR

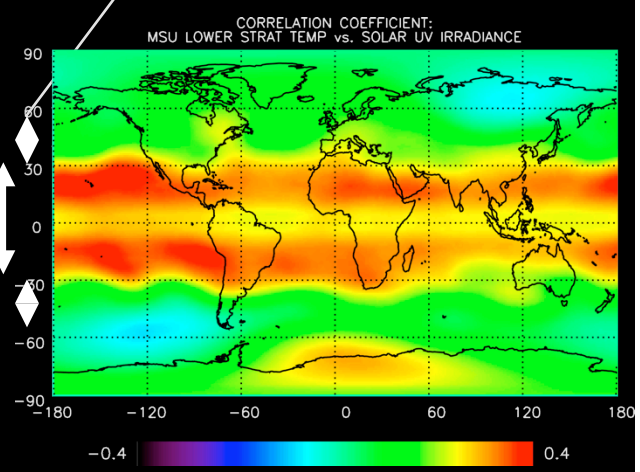
SURFACE ***MIDDLE TROPOSPHERE*** ***LOWER STRATOSPHERE***

Multiple regression

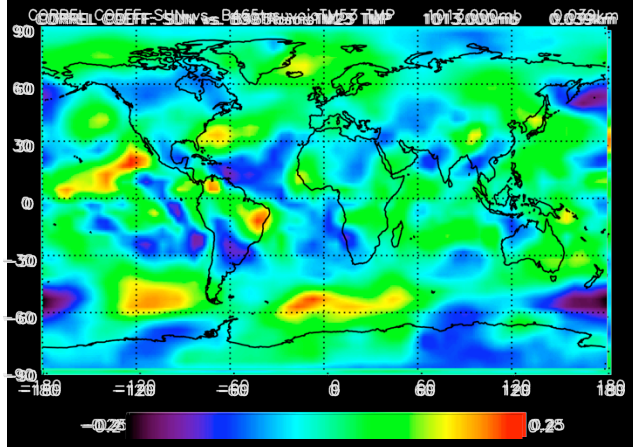
Hadley cell Ferrel cell

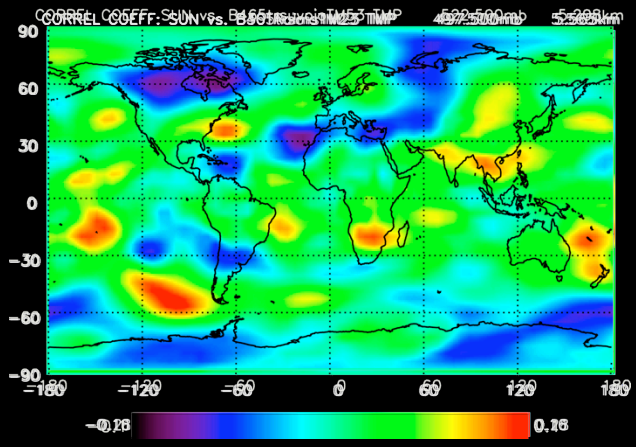


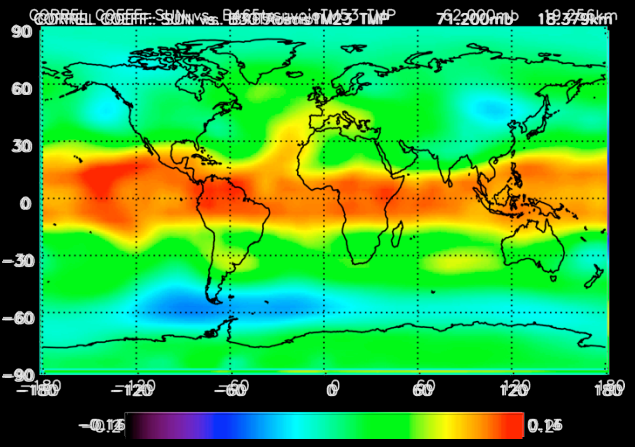




B465trsuvoioTM53… *solar, interactive ozone*







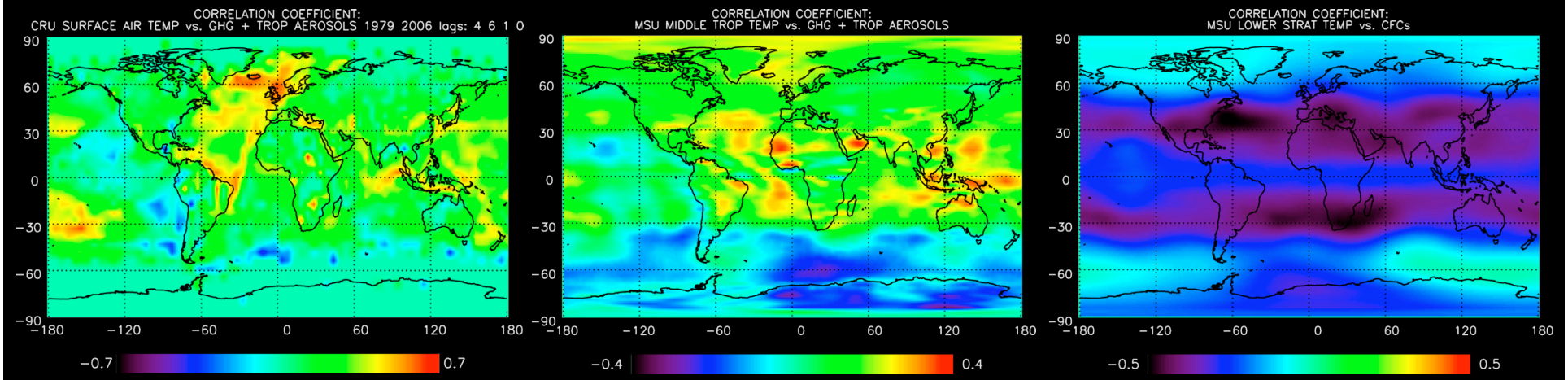
GISS GCMAM Simulations: 1950-2005

Run	Resolution	Forcing	Ozone	Ocean
2 B30TVoims1M23	4x5 23 layer	solar, trace gases, volcanic aerosols	non-interactive	Q-flux, no diffusion
3 B30TAoims1M23	4x5 23 layer	solar, trace gases, trop. + volcanic aerosols, trop + strat. ozone	non-interactive	Q-flux, no diffusion

Observed and Modeled Temperature Spatial Patterns (all months): ANTHROPOGENIC

SURFACE ***MIDDLE TROPOSPHERE*** ***LOWER STRATOSPHERE***

Multiple regression



B30TAoims1M23 … *solar, GHG, volcanic & trop. aerosols, trop. & strat. ozone*