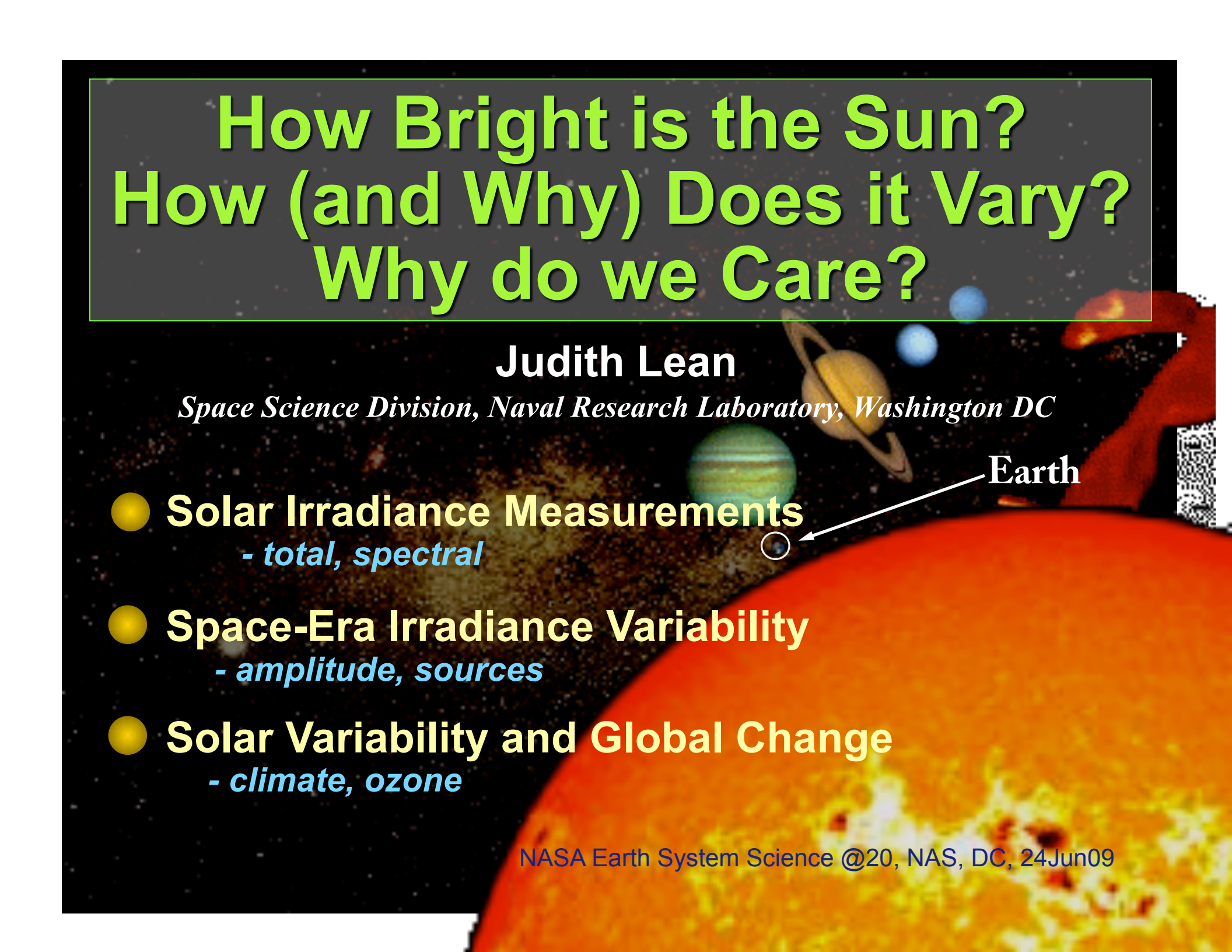
How Bright is the Sun?
How (and Why) Does it Vary?
Why do we Care?

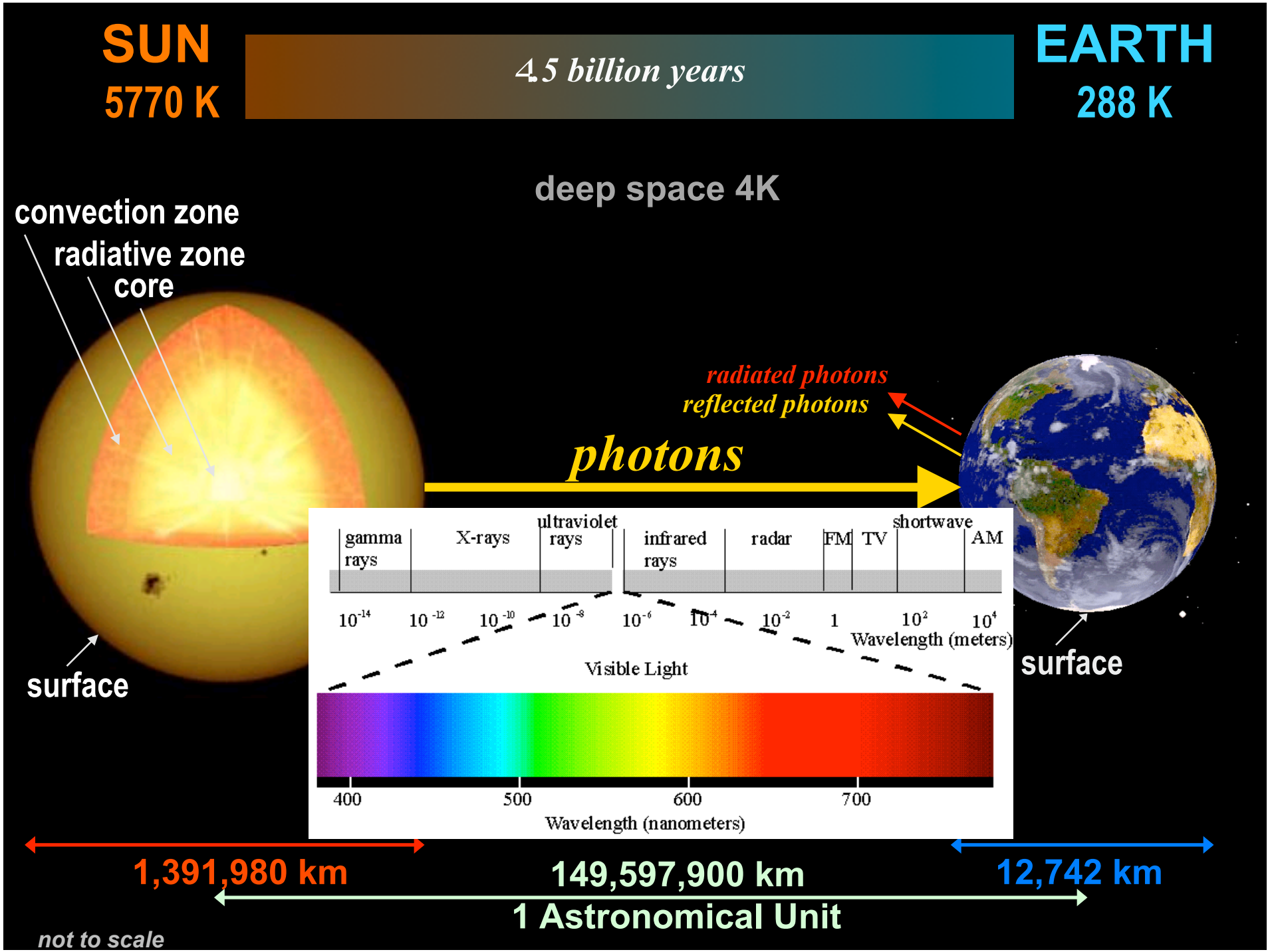
Judith Lean

Space Science Division, Naval Research Laboratory, Washington DC

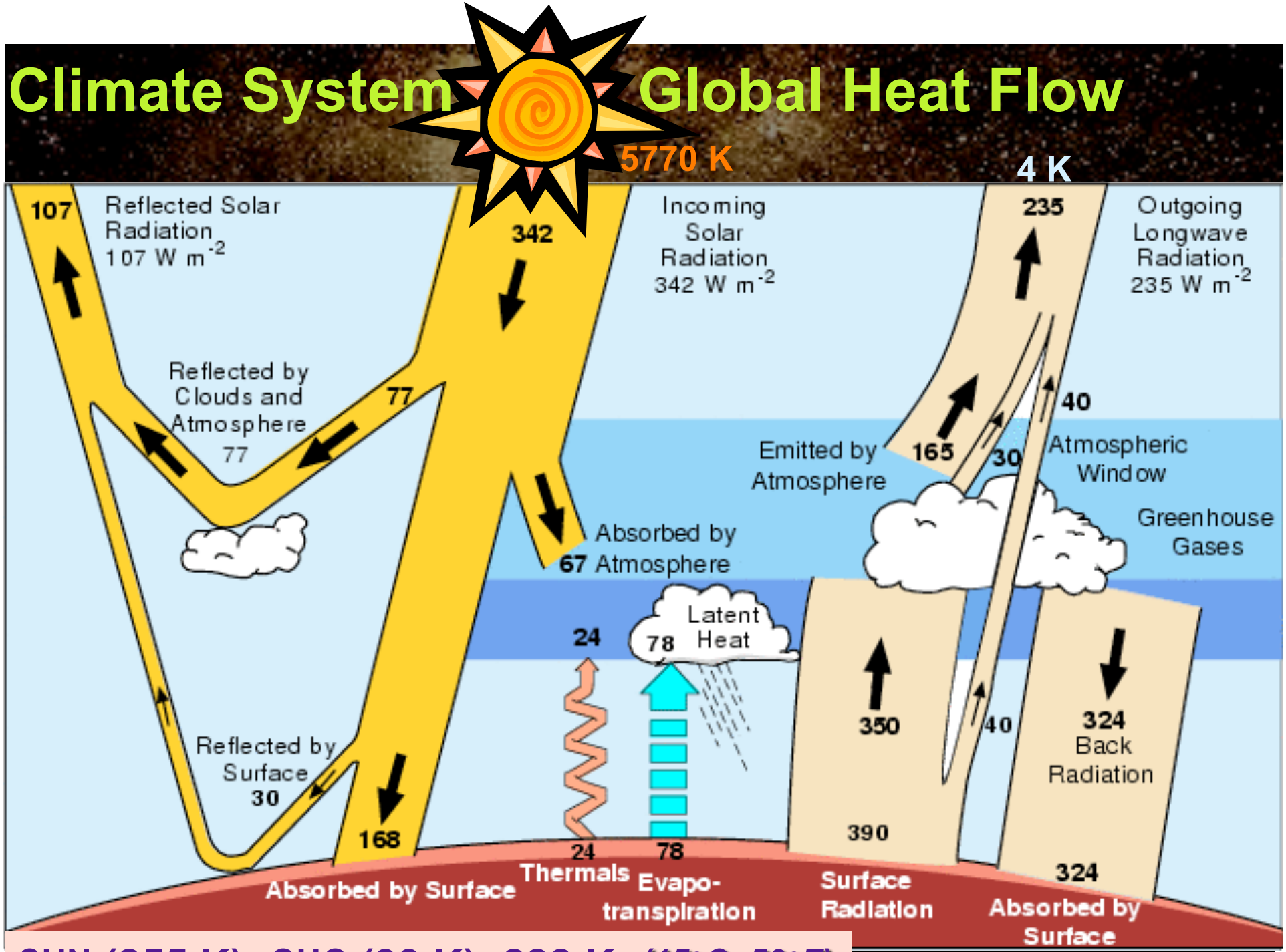


- **Solar Irradiance Measurements**
  - *total, spectral*
- **Space-Era Irradiance Variability**
  - *amplitude, sources*
- **Solar Variability and Global Change**
  - *climate, ozone*

NASA Earth System Science @20, NAS, DC, 24Jun09


SUN
5770 K
4.5 billion years
EARTH
288 K
deep space 4K
convection zone
radiative zone
core
radiated photons
reflected photons
photons
surface
surface
gamma rays
X-rays
ultraviolet rays
infrared rays
radar
FM
TV
shortwave
AM
10^{-14}
10^{-12}
10^{-10}
10^{-8}
10^{-6}
10^{-4}
10^{-2}
1
10^{2}
10^{4}
Wavelength (meters)
Visible Light
400
500
600
700
Wavelength (nanometers)
1,391,980 km
149,597,900 km
12,742 km
1 Astronomical Unit
not to scale

Climate System Global Heat Flow



SUN (255 K)+GHG (33 K)=288 K ***(15°C, 59°F)***

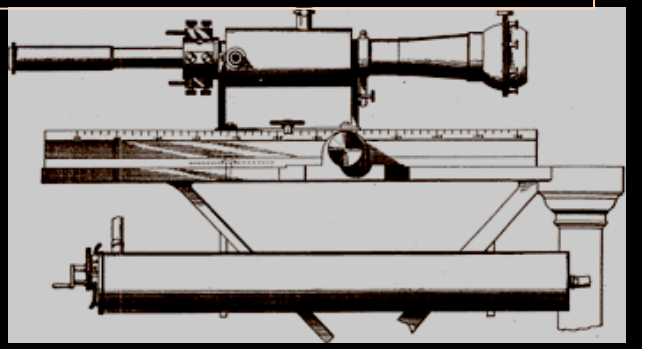
Kiehl and Trenberth, 1997

How Bright is the Sun?… *A Century of Enquiry*

Ground….
1837: Herschel
1880: Langley

"… the observation of the amount of heat the sun sends the earth is among the most important and difficult in astronomical physics, it may be termed the fundamental problem of meteorology"

From Langley's bolometer…
"An instrument that measures radiant energy by correlating the radiation-induced change in electrical resistance of a blackened metal foil with the amount of radiation absorbed"

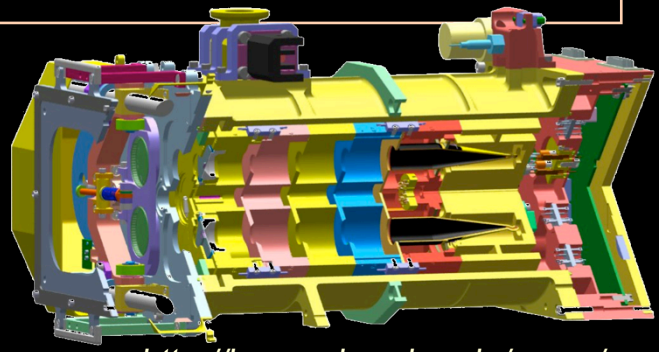


1902-1955: Abbot

Aircraft and Balloons
1967: 1359±13 W m^{-2}
1977: 1373±20 W m^{-2}

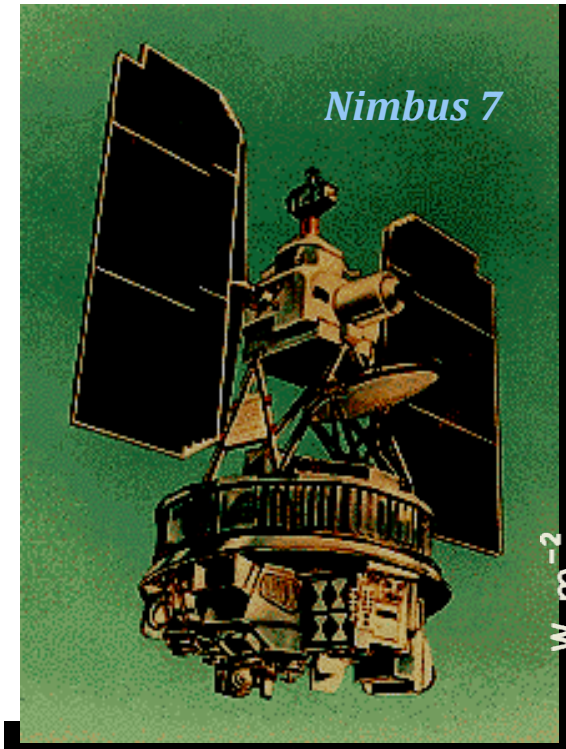
Space
1980: 1371±10 W m^{-2}
1990: 1365±10 W m^{-2}
2003: 1361±4 W m^{-2}

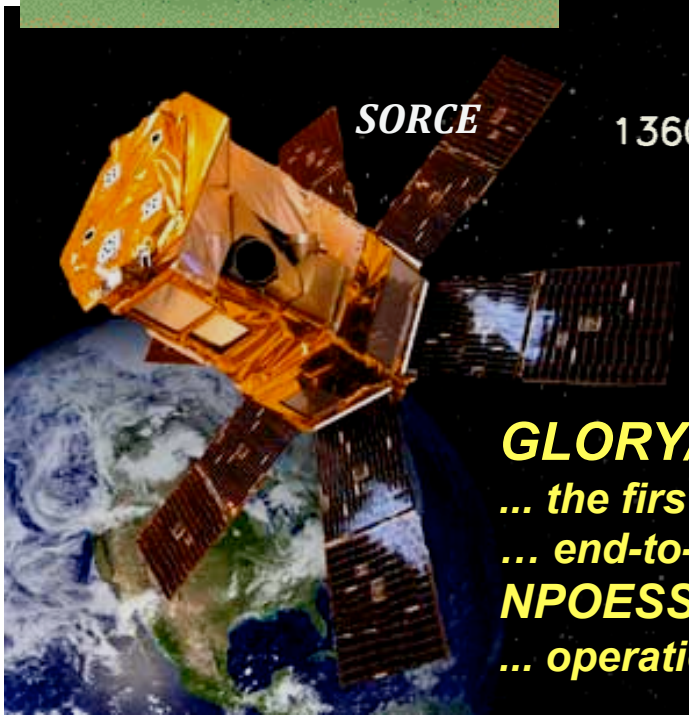
… to the Total Irradiance Monitor (TIM) on NASA's Solar Radiation and Climate Experiment (SORCE)
a state-of-the-art, active cavity electrical substitution radiometer with phase-sensitive detection, NiP black surfaces, redundant cavities, NIST calibration….

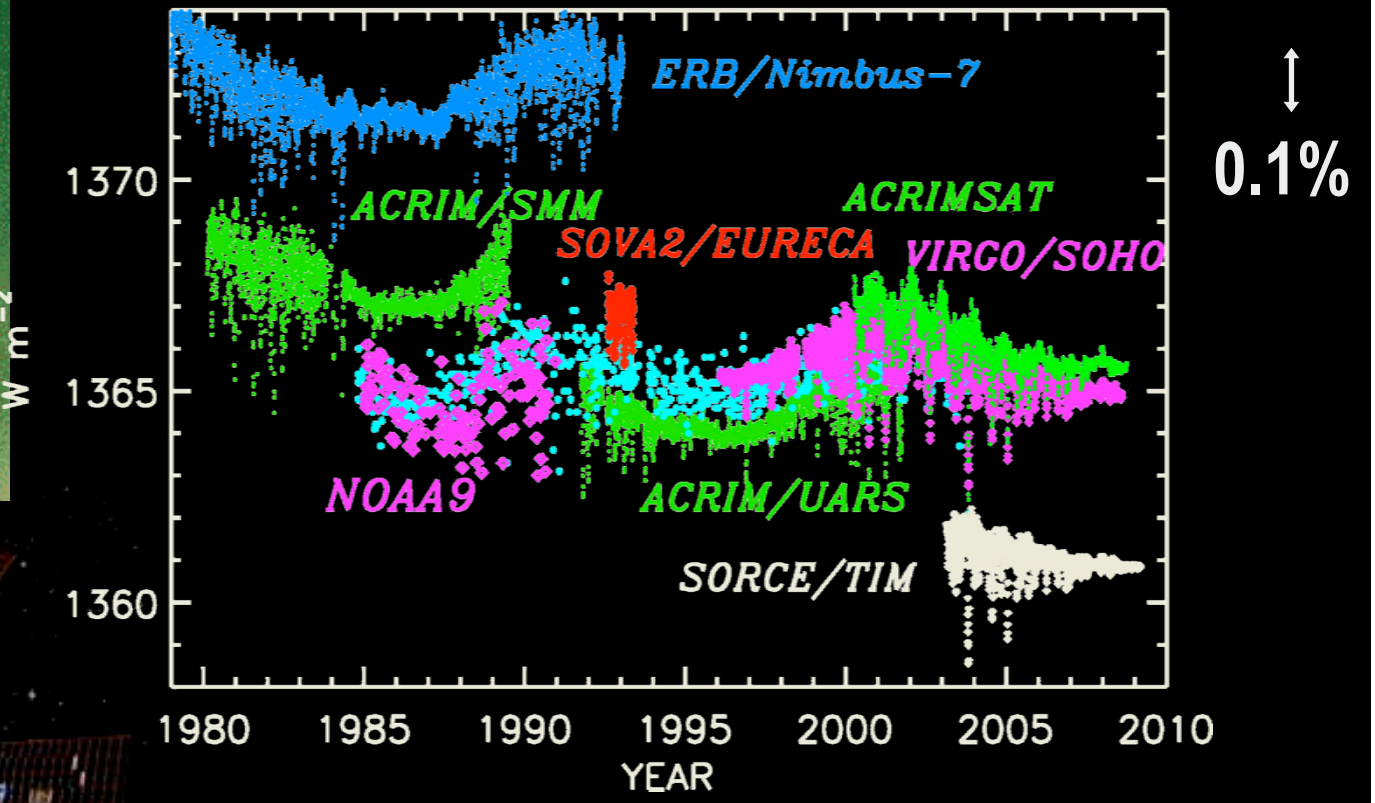


http://lasp.colorado.edu/sorce/

Total Solar Irradiance Measurements from Space







GLORY/TIM: 2010 ?→

... the first "benchmark" irradiance measurement

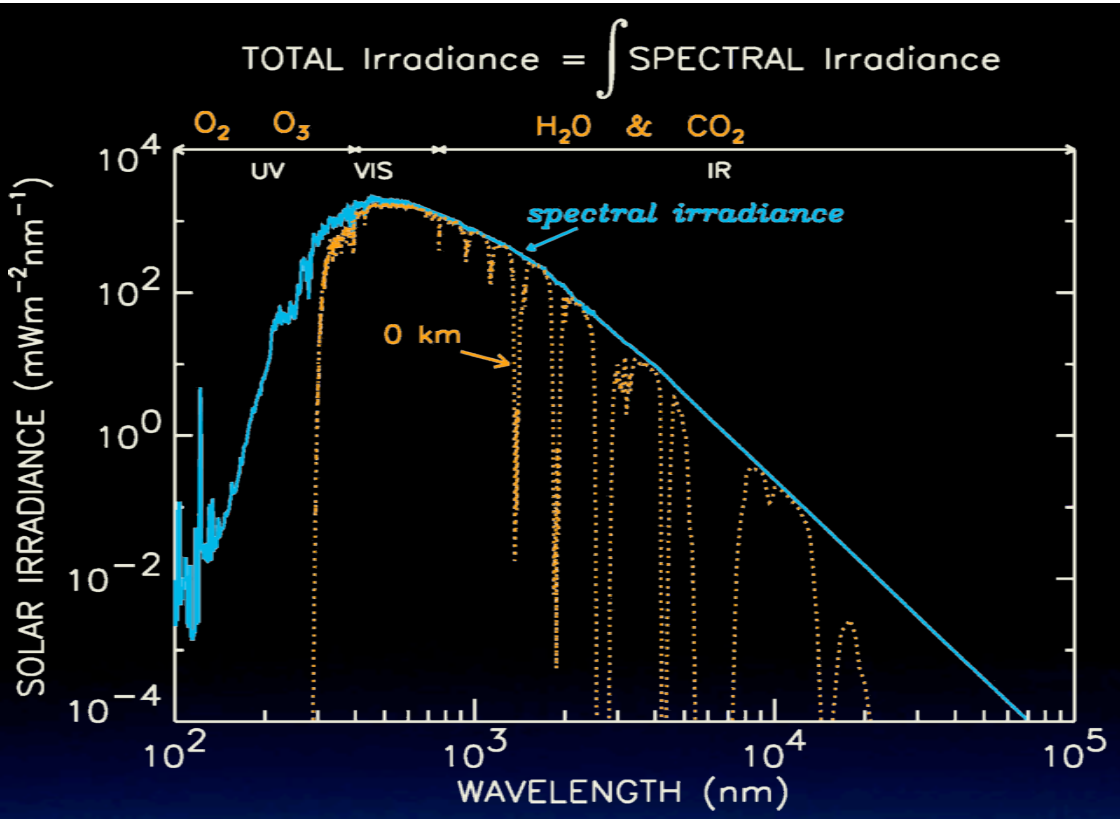
… end-to-end calibration with NIST cryogenic radiometer

NPOESS/TSIS: 2013 ?→

... operational solar monitoring

Solar Spectral Irradiance:

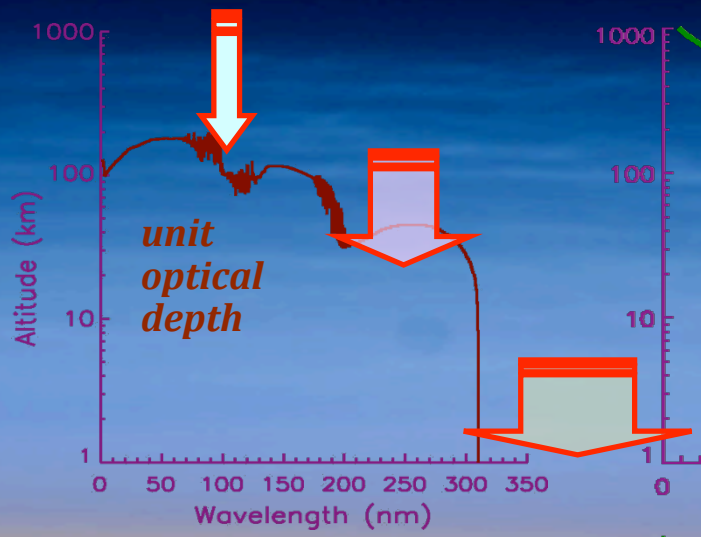
separating photon fluxes into wavelength bands

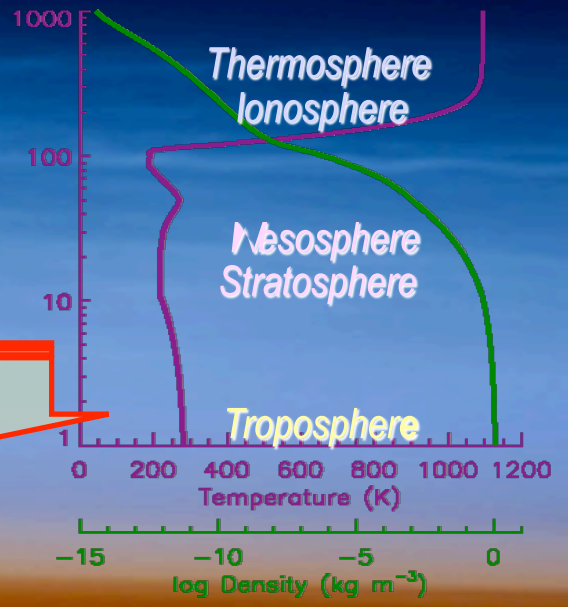


wavelengths < 120 nm
0.003±0.001 Wm^{-2}

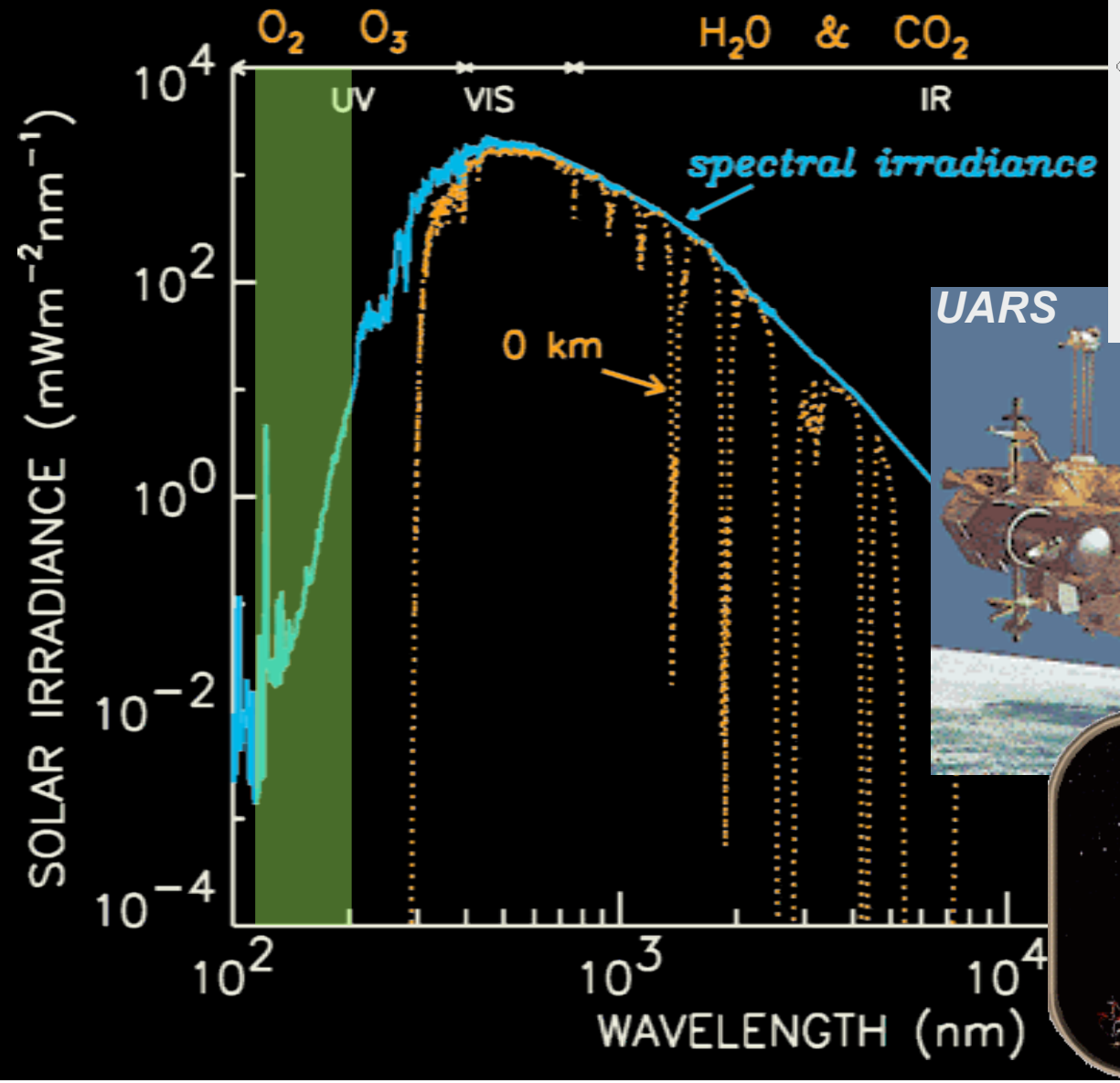
wavelengths 120-300 nm
14.9±0.1 Wm^{-2}

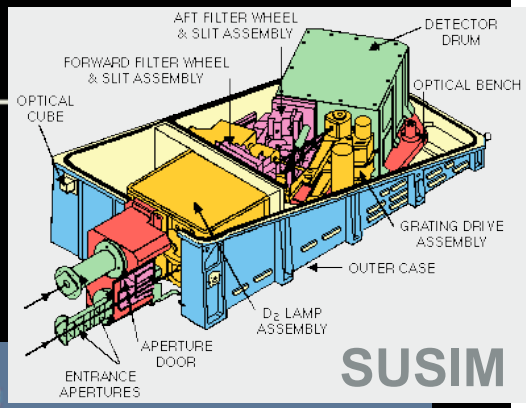
wavelengths > 300 nm
1350.5 ± 0.5 Wm^{-2}



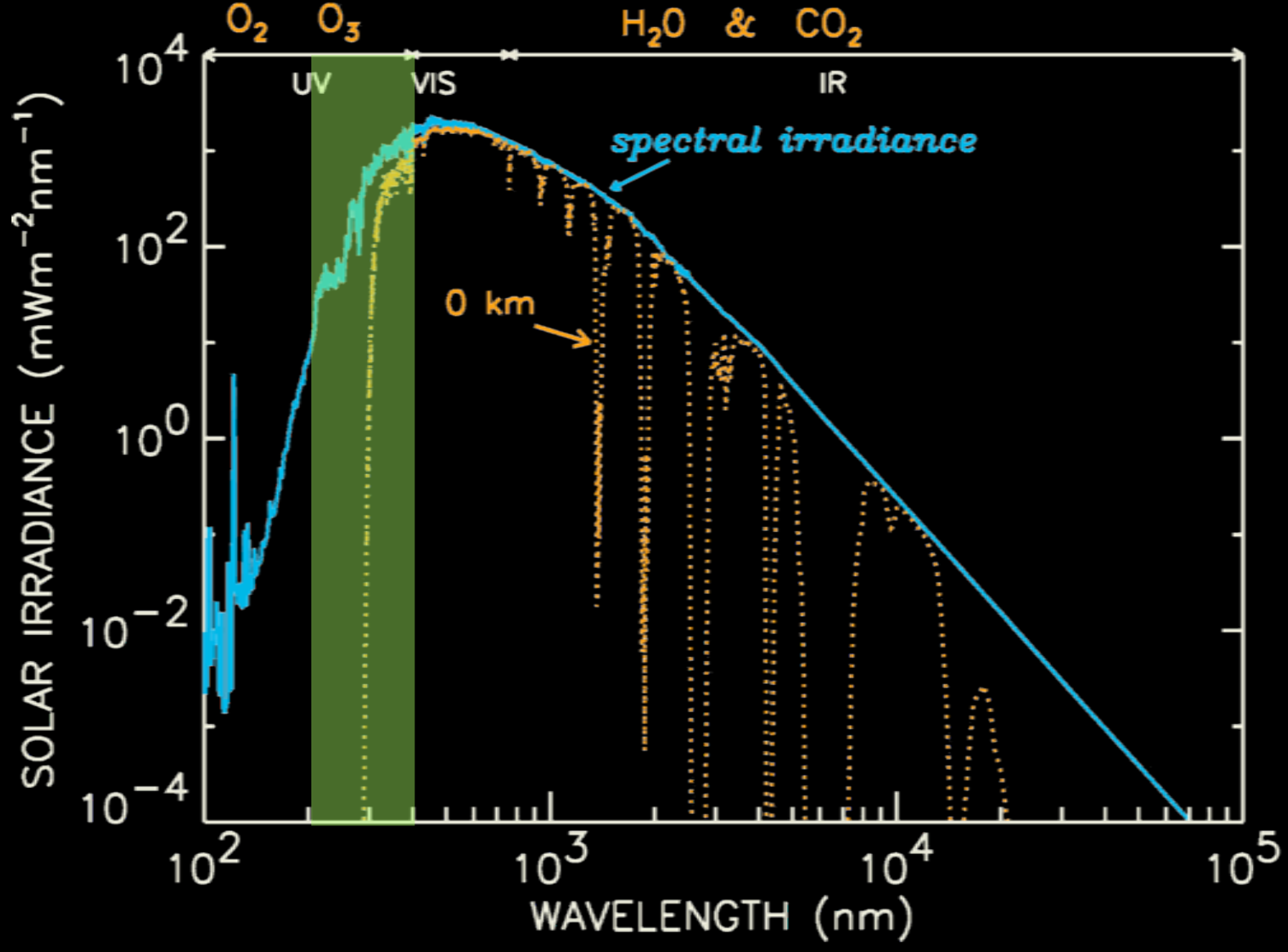


Solar Spectral Irradiance Observations: Far Ultraviolet (120-200 nm)

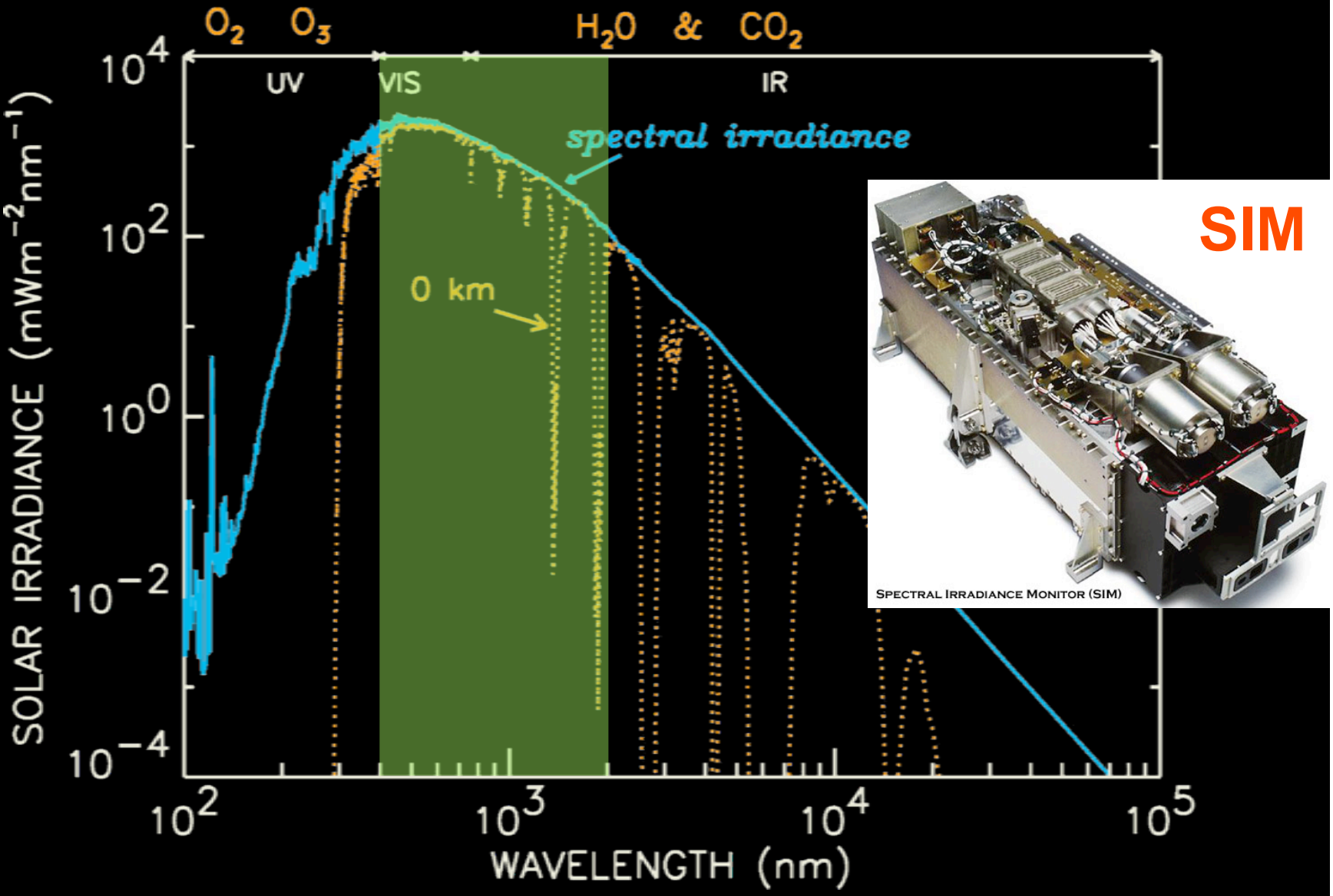




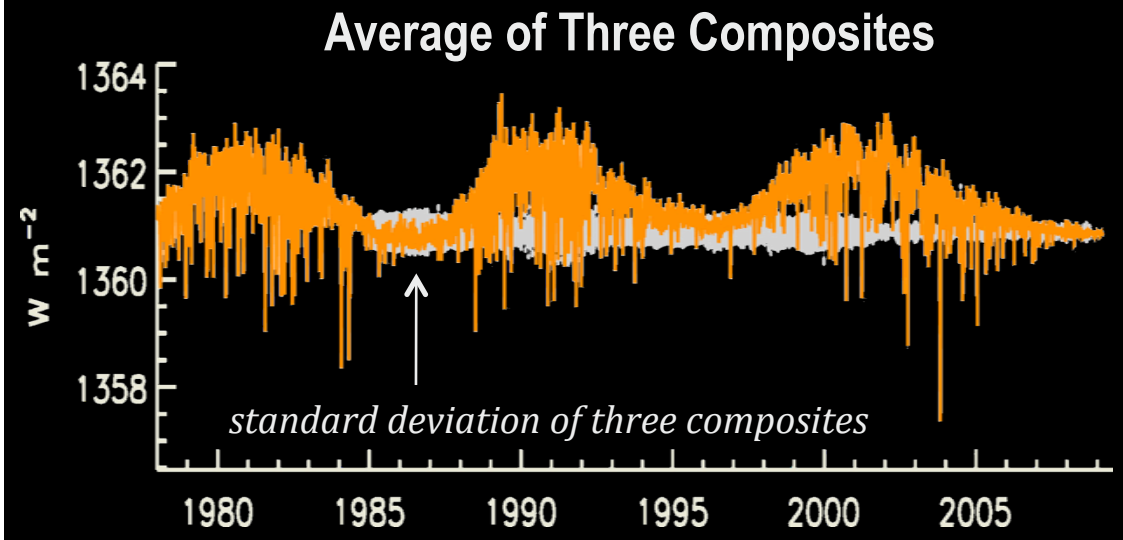
Solar Spectral Irradiance Observations: Middle and Near UV (200-400 nm)



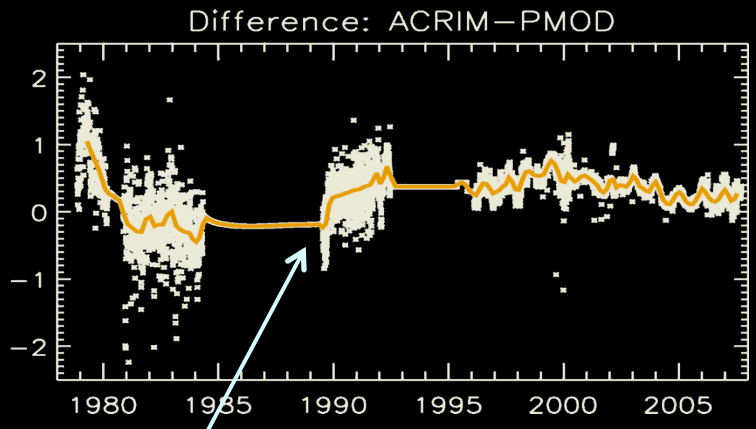
Solar Spectral Irradiance Observations: Visible and Near IR (400-2000 nm)



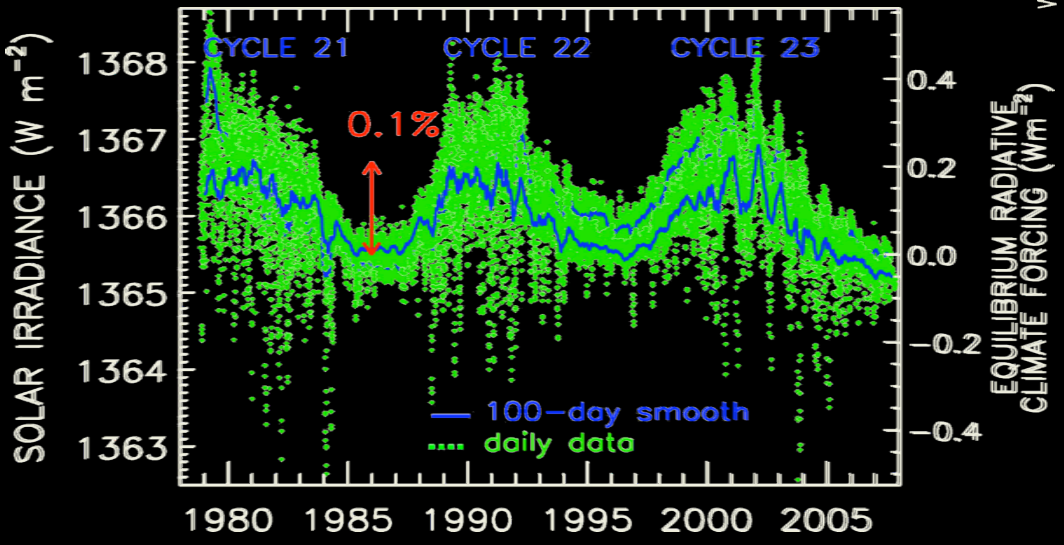
How Does Solar Irradiance Vary?



- 5-min oscillation ~ 0.003%
- 27-day solar rotation ~ 0.2%
- 11-year solar cycle ~ 0.1%
- longer-term variations not yet detectable –
  .....do they occur?



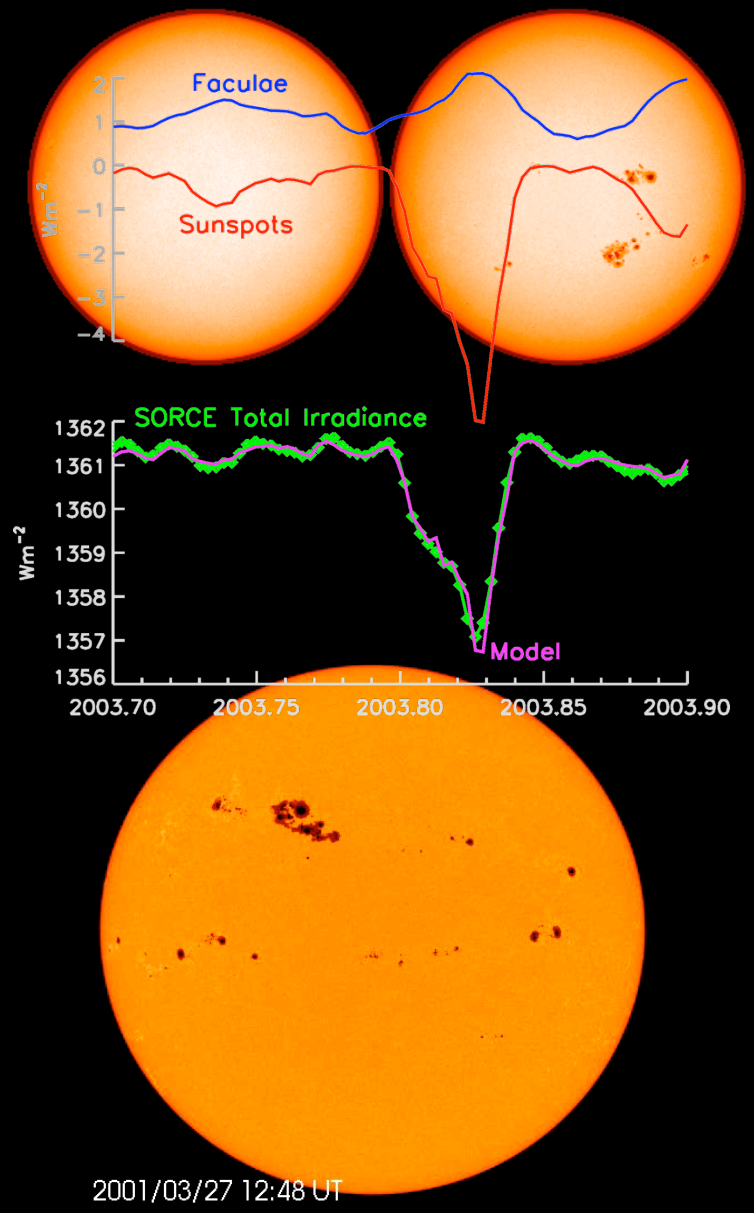
PMOD

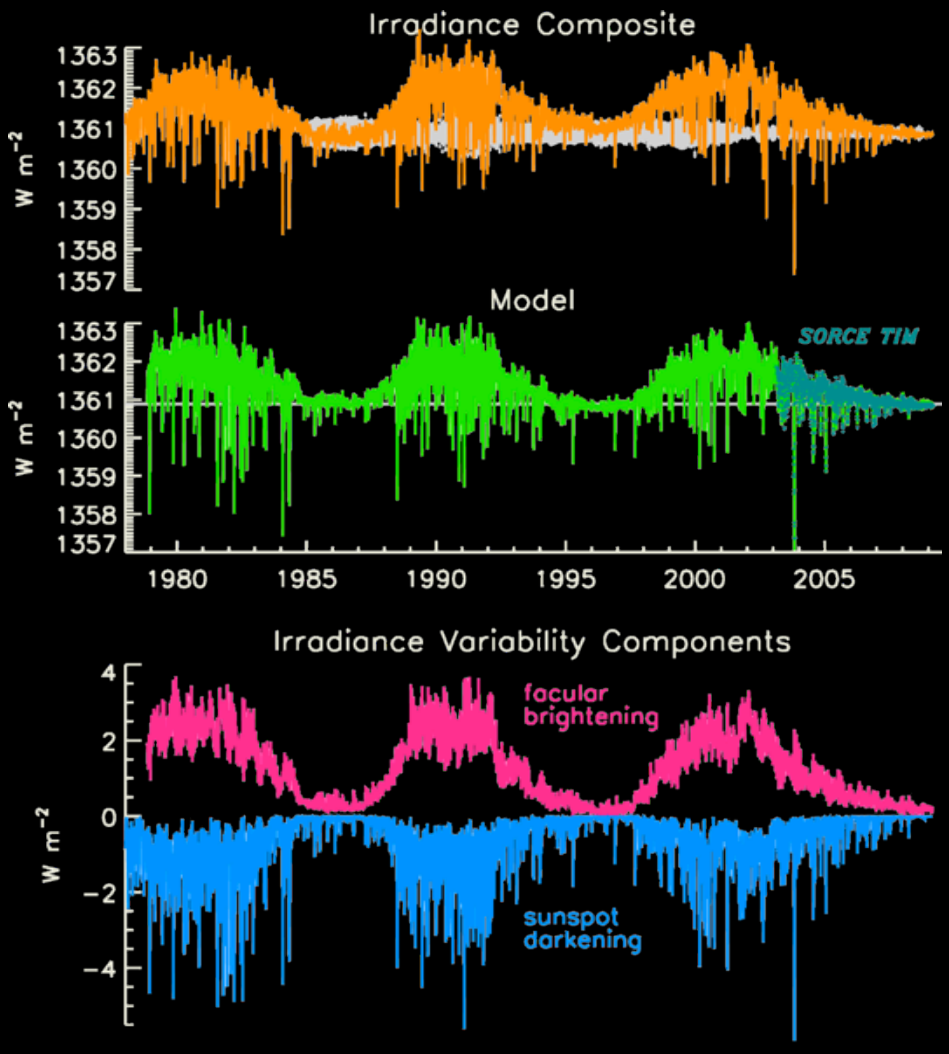


- upward trend in ACRIM composite occurs primarily from an increase in 1989-1992

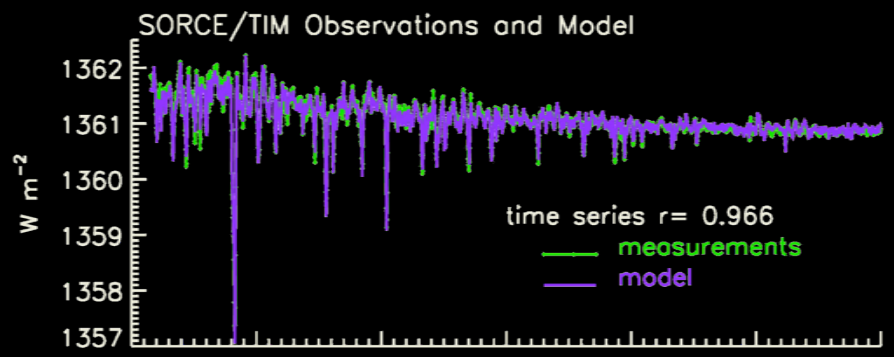
- attributable to ERB instrument sensitivity drifts near end of Nimbus 7 mission

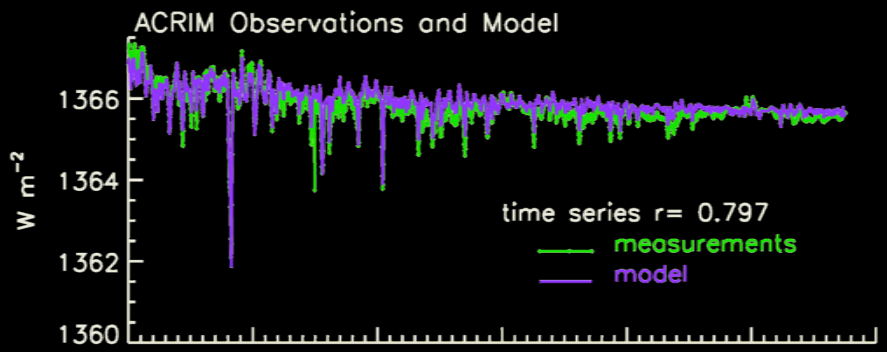
Why Does Solar Irradiance Vary?

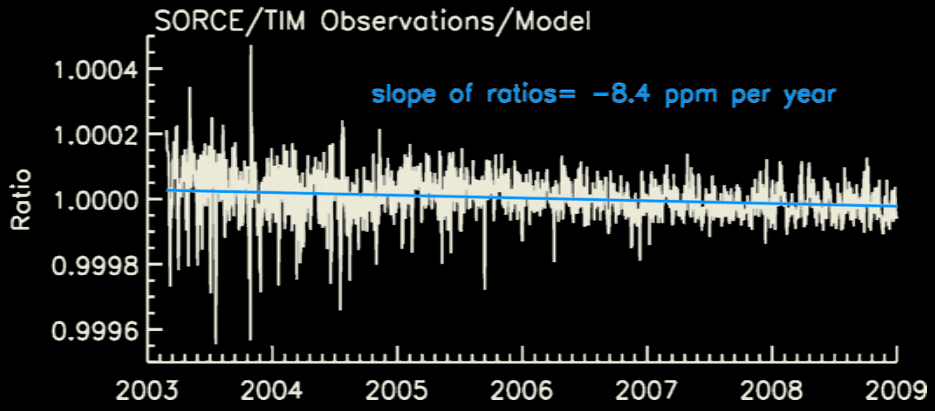


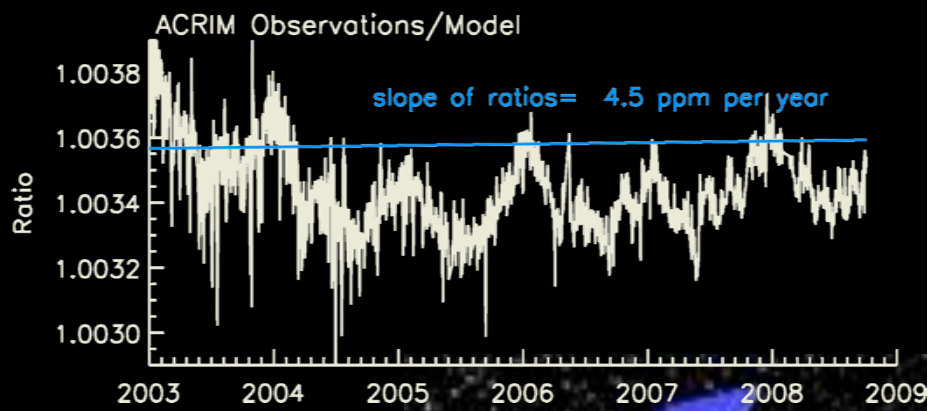


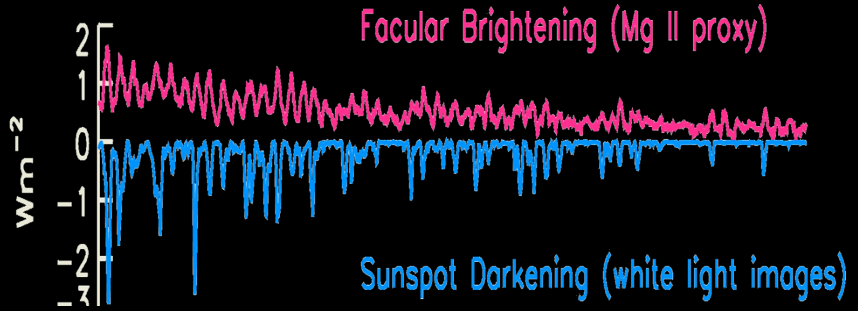
Observations vs. Model

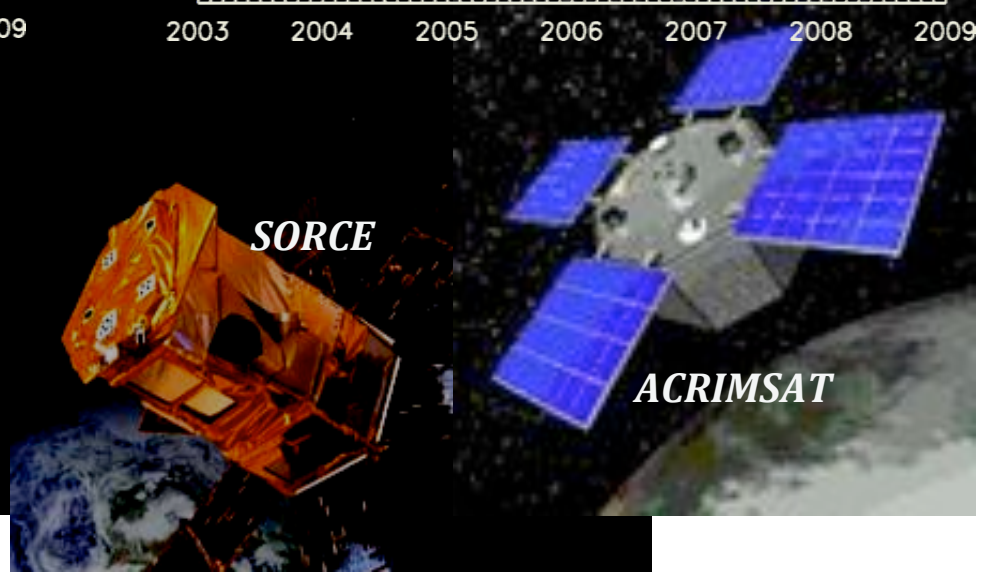








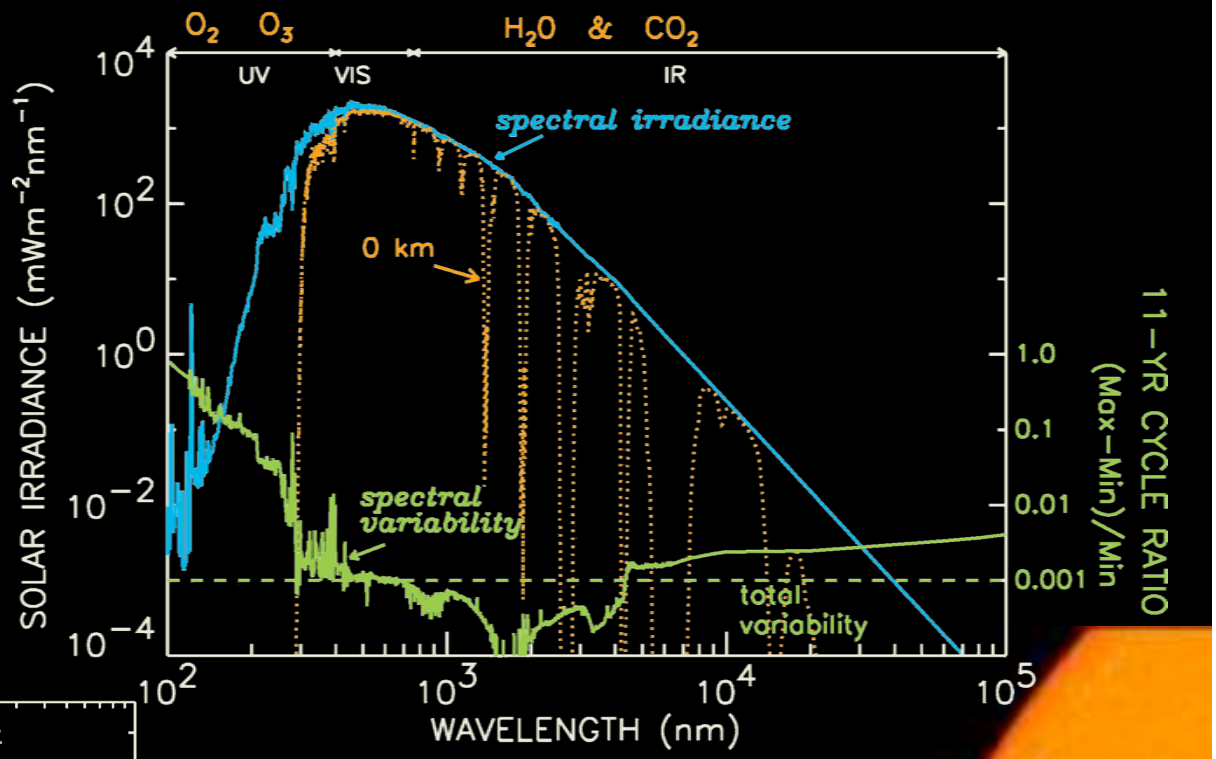


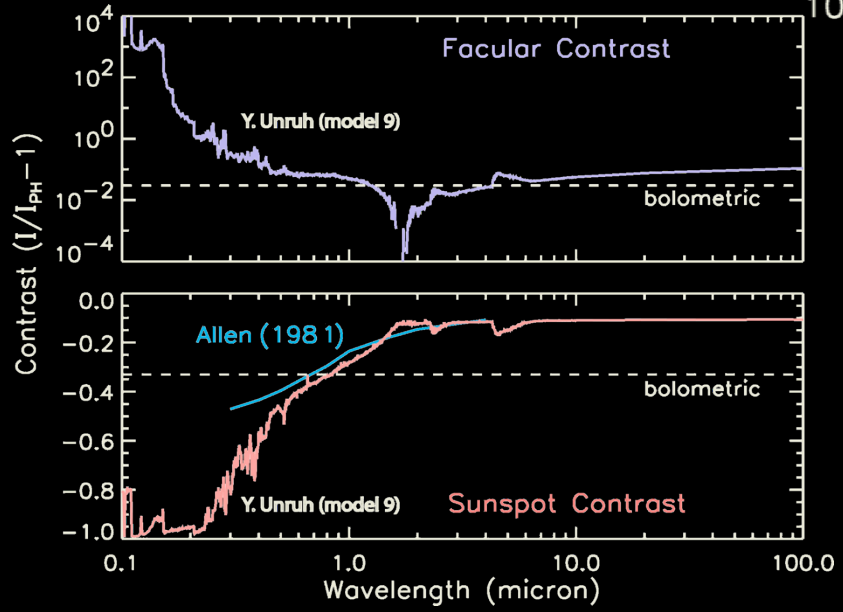


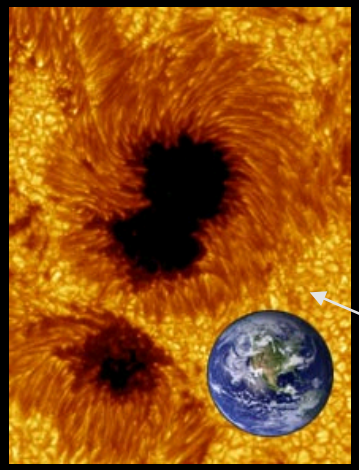
How Does Spectral Irradiance Vary? (and Why)

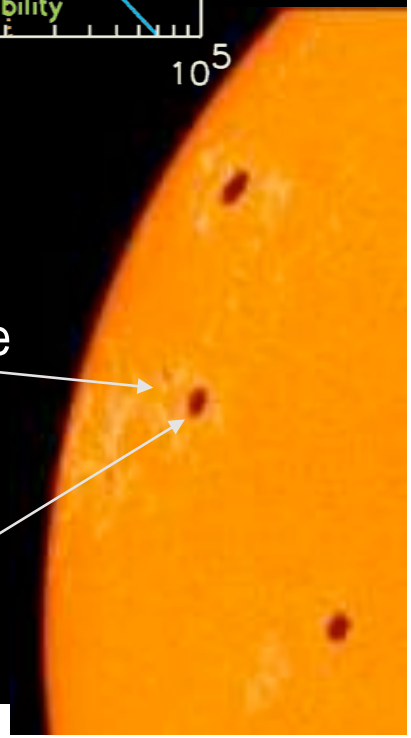
sources of solar irradiance variability are wavelength-dependent...

THUS, spectral irradiance variations depend on wavelength

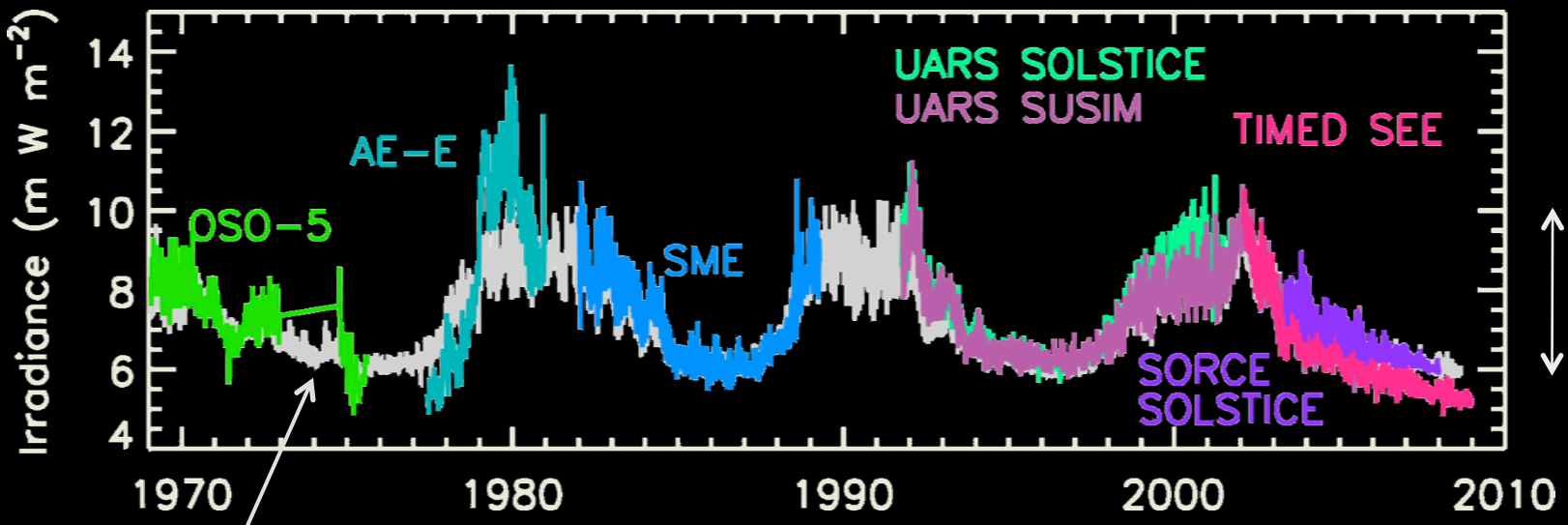




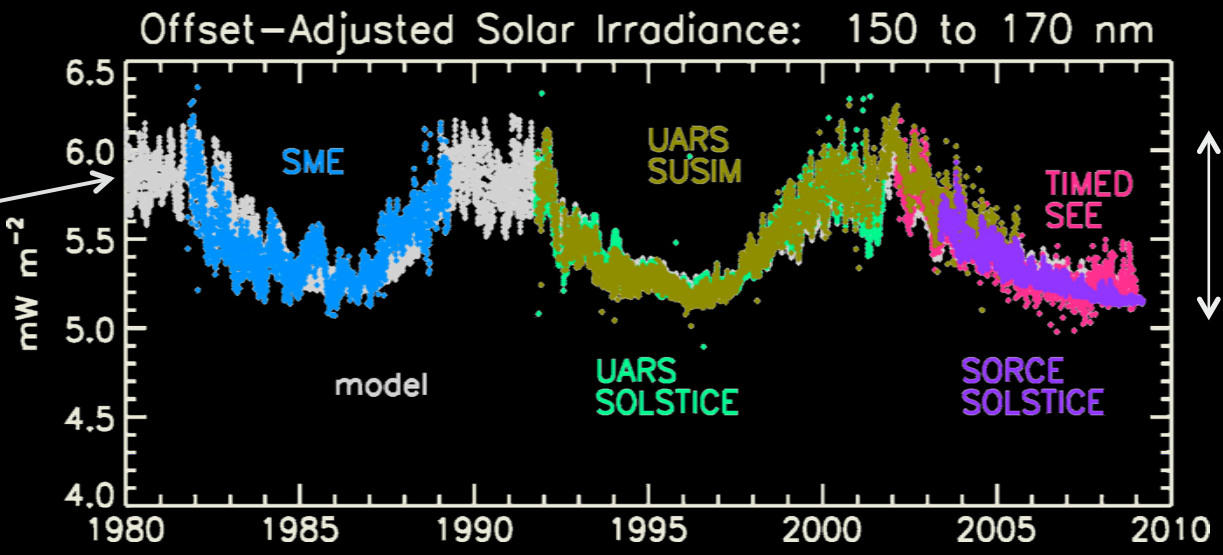




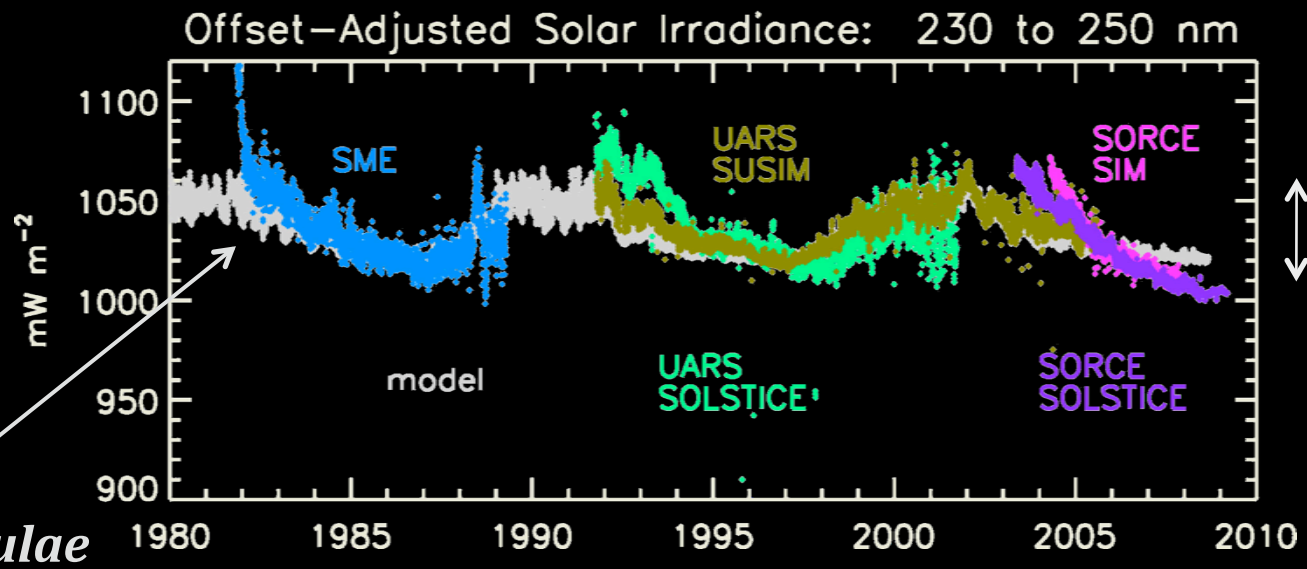
Solar Spectral Irradiance Variations: Far Ultraviolet (120-200 nm)



model of faculae and sunspot influences

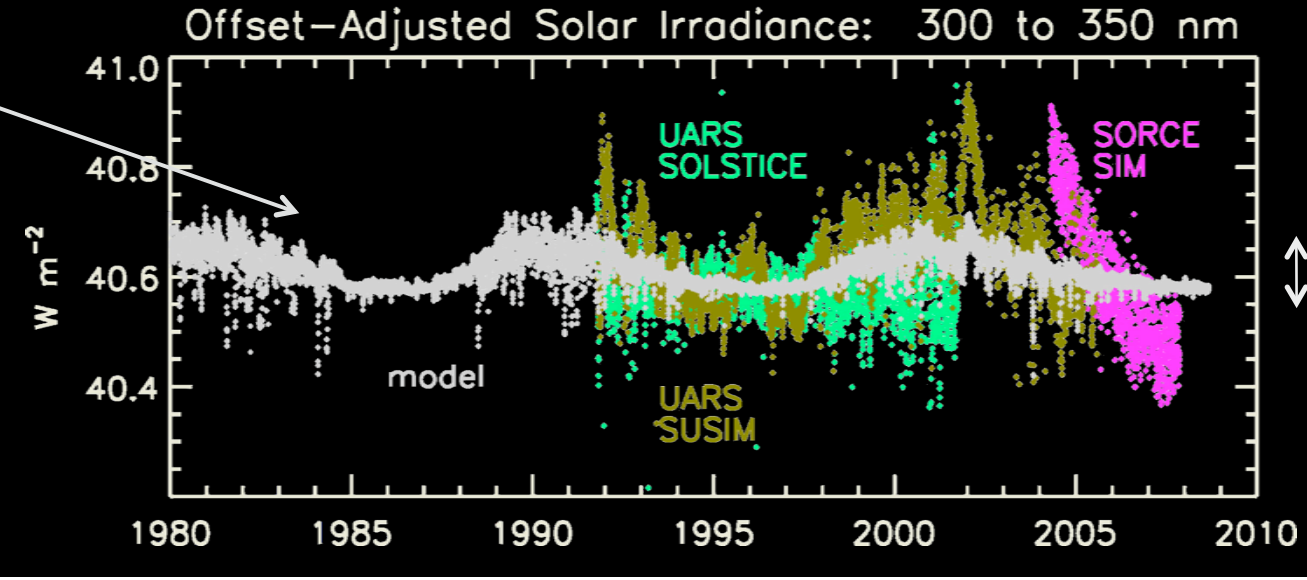


Solar Spectral Irradiance Variations: Middle and Near Ultraviolet (200-400 nm)



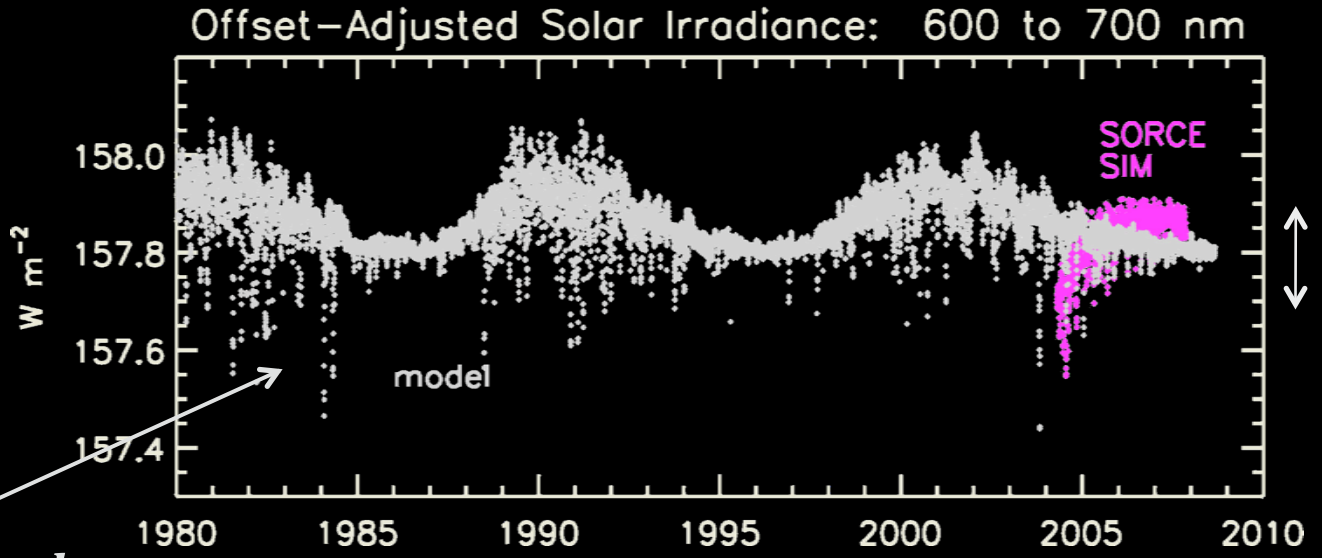
4%

model of faculae and sunspot influences

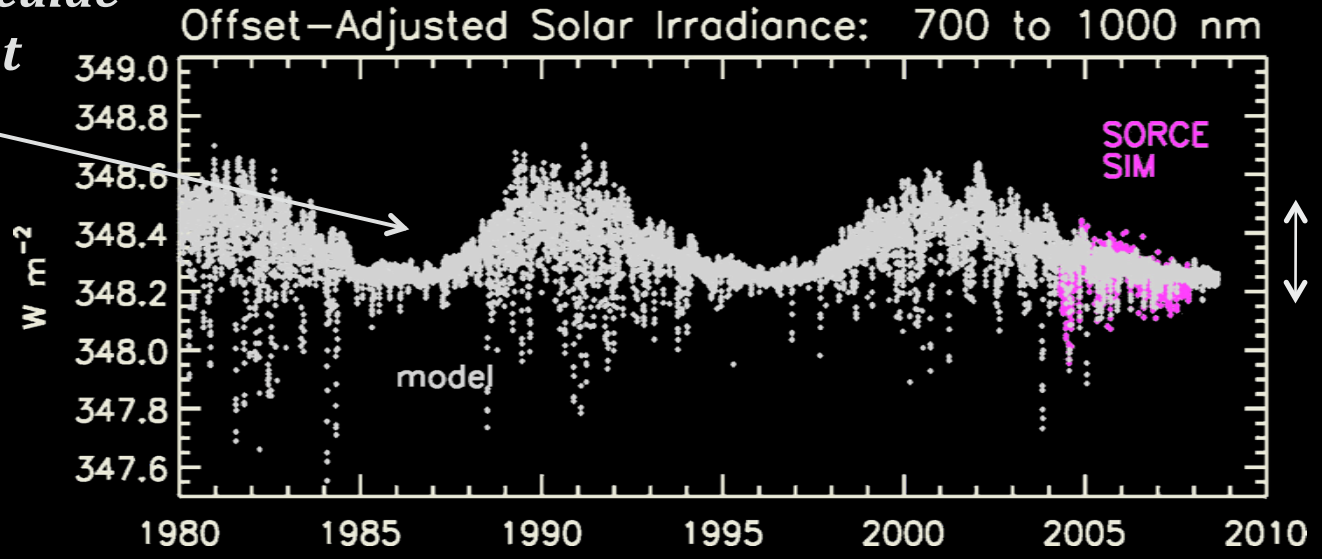


0.2%

Solar Spectral Irradiance Variations: Visible and Near IR (400 – 2000 nm)



model of faculae and sunspot influences



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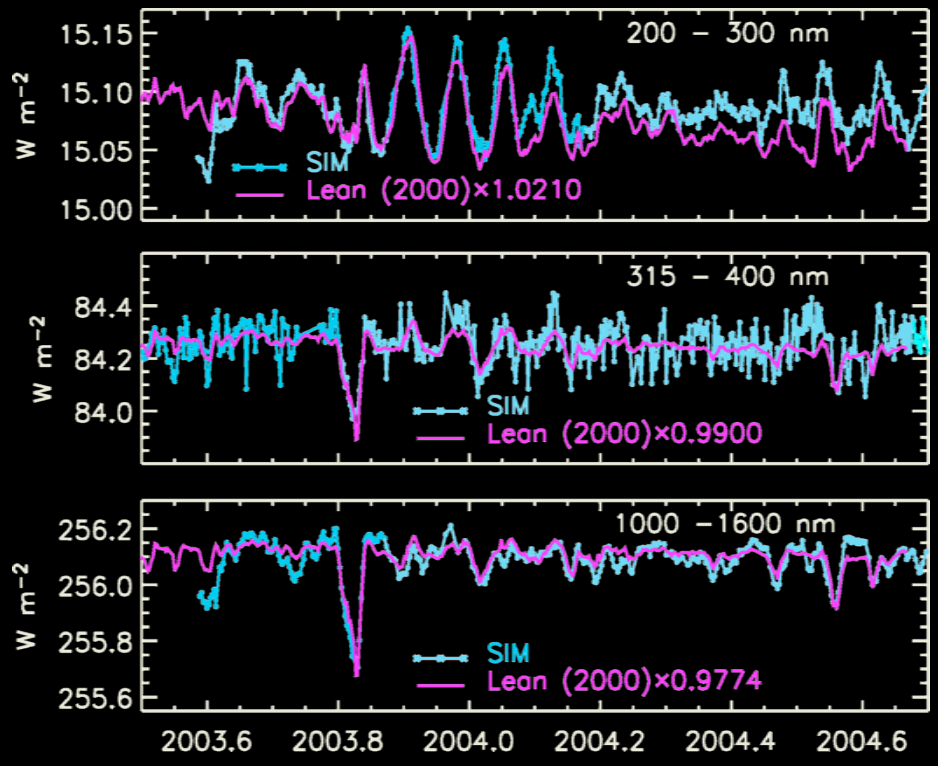
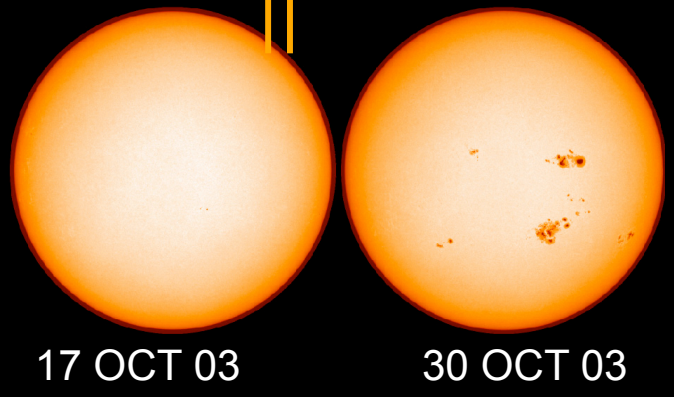
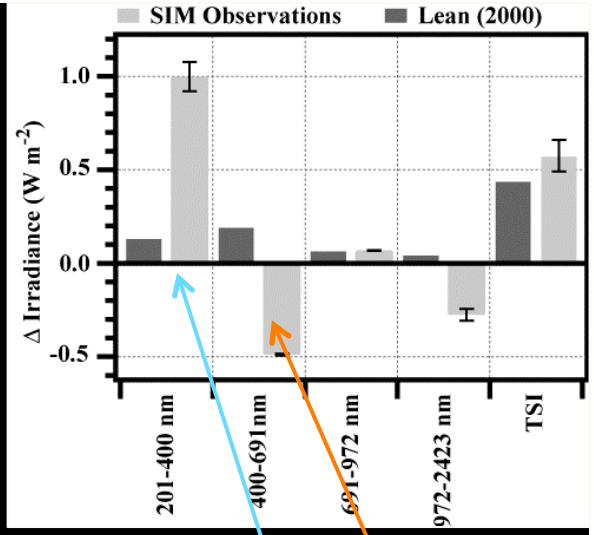
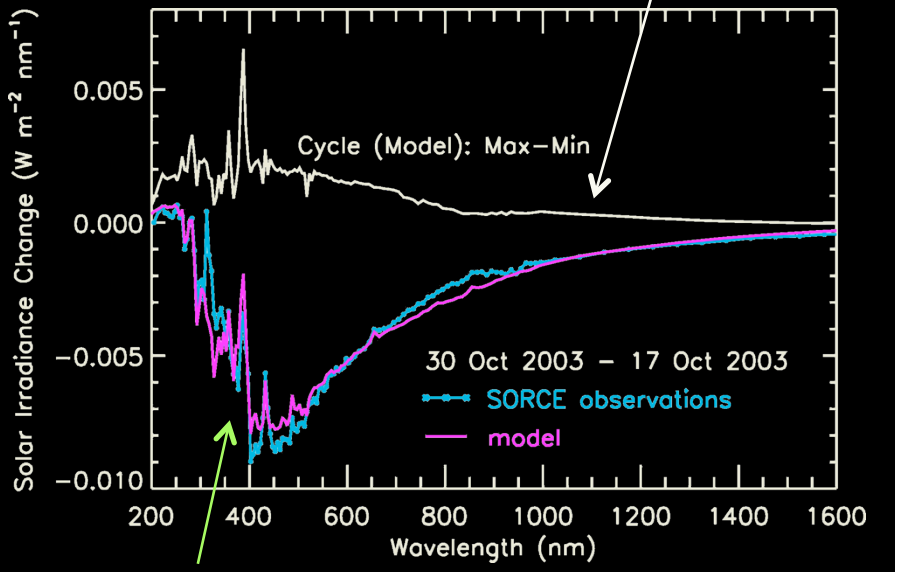




Harder et al., GRL, 2009

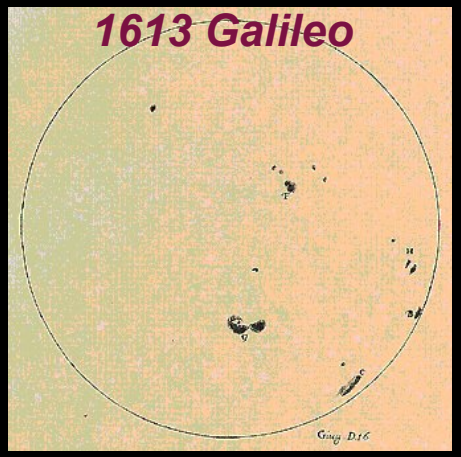


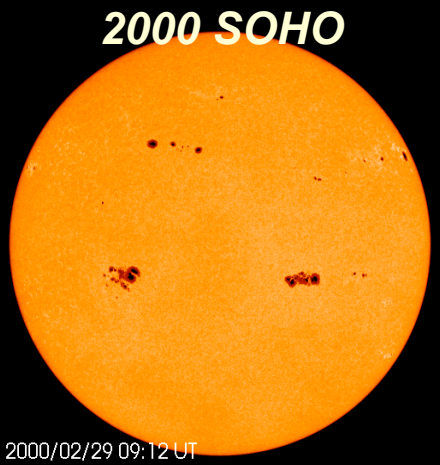
SIM solar cycle variations are out-of-phase at visible wavelengths and larger at UV wavelengths. compared with model



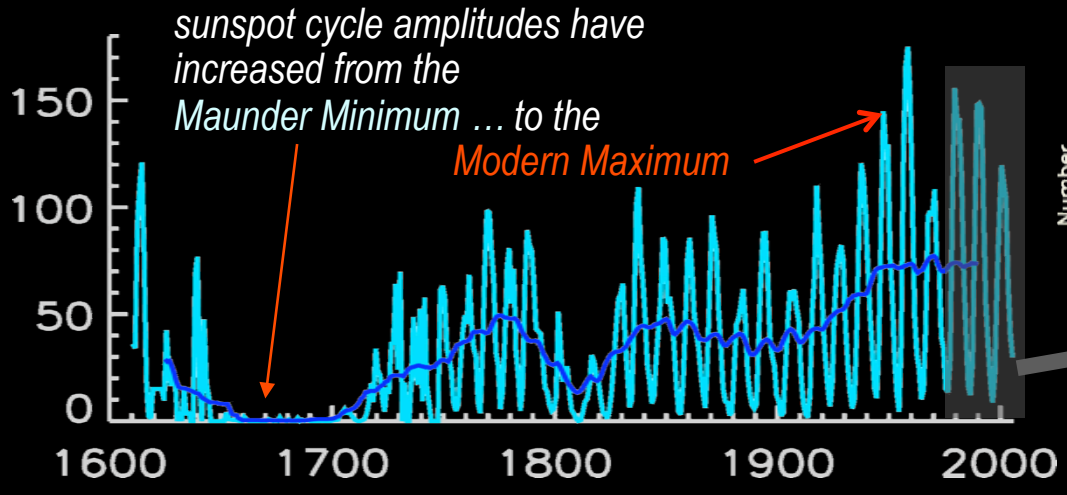
good agreement at all wavelengths for 27-day rotational modulation

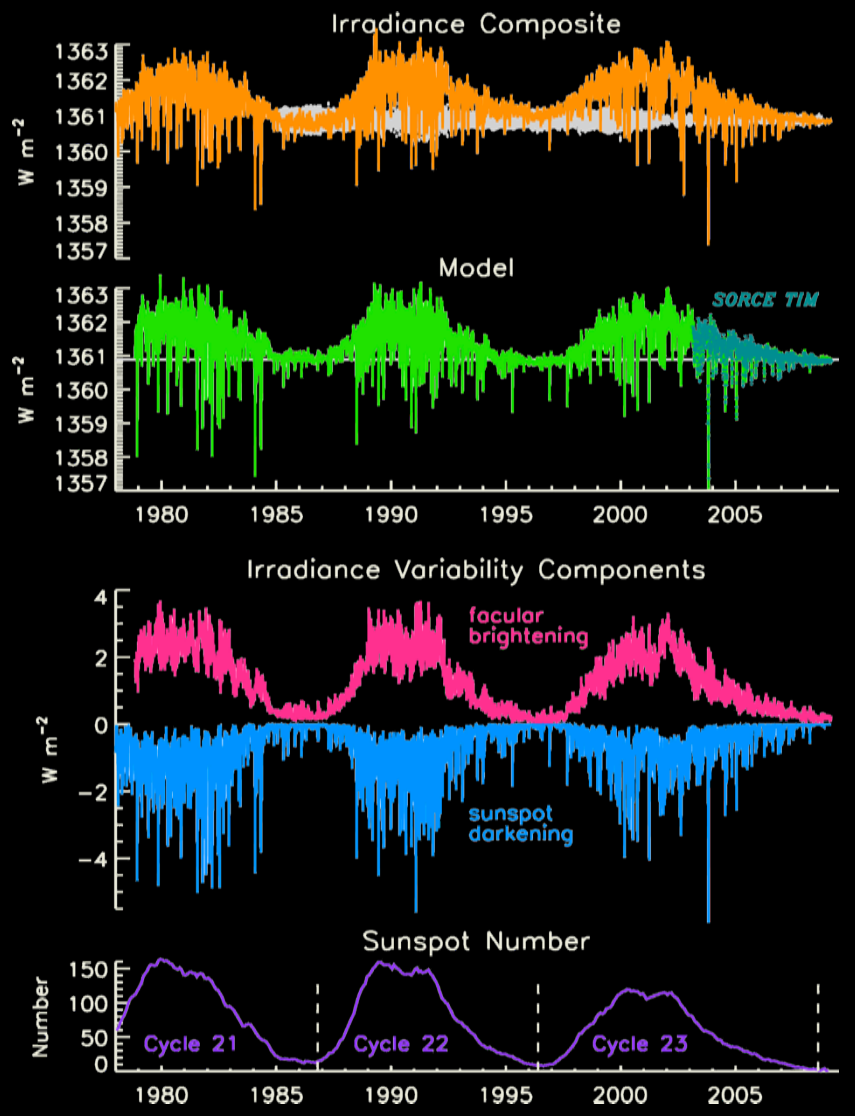
Reconstructing Past Solar Irradiance Variations





Past Solar Activity



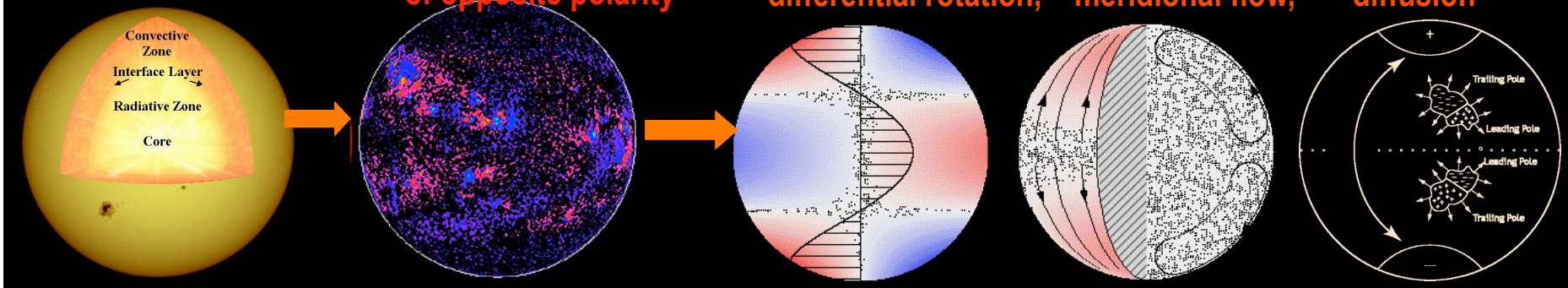


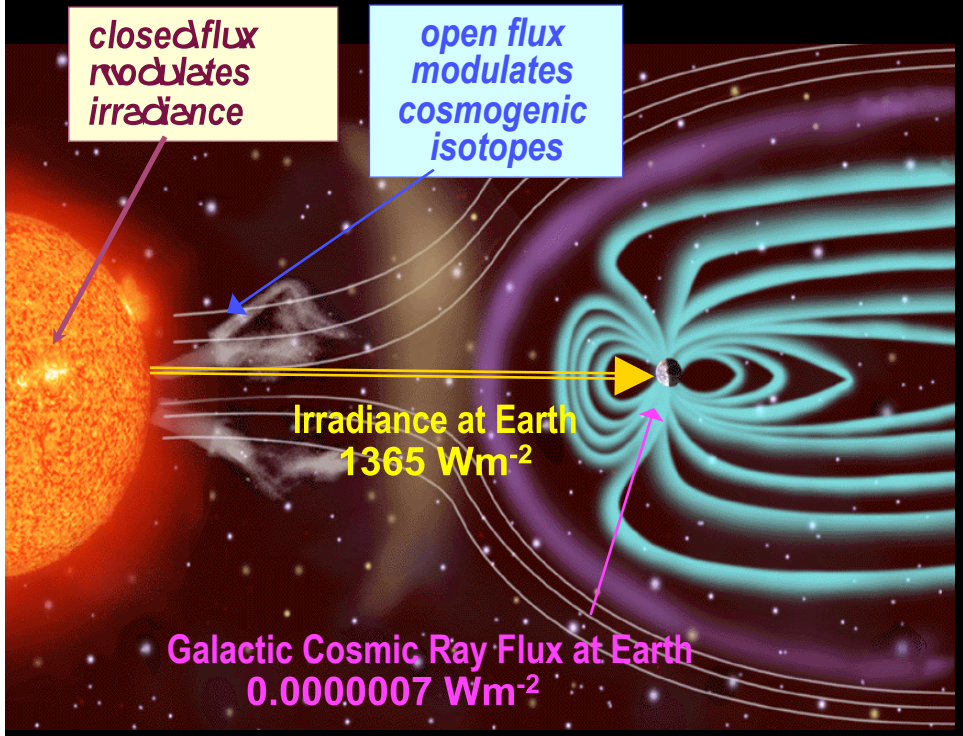
Estimating Long-Term Solar Variability

sub-surface dynamo

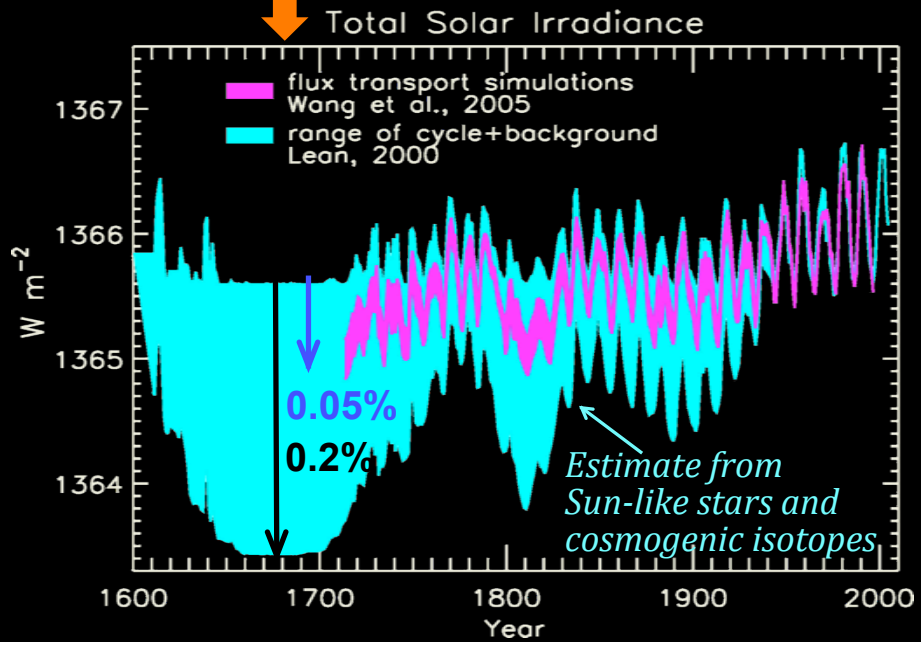
surface magnetic fields of opposite polarity

transported by… differential rotation, meridional flow, diffusion





NRL Flux Transport Model



Why Do We Care?
The Sun's Role in Global Change

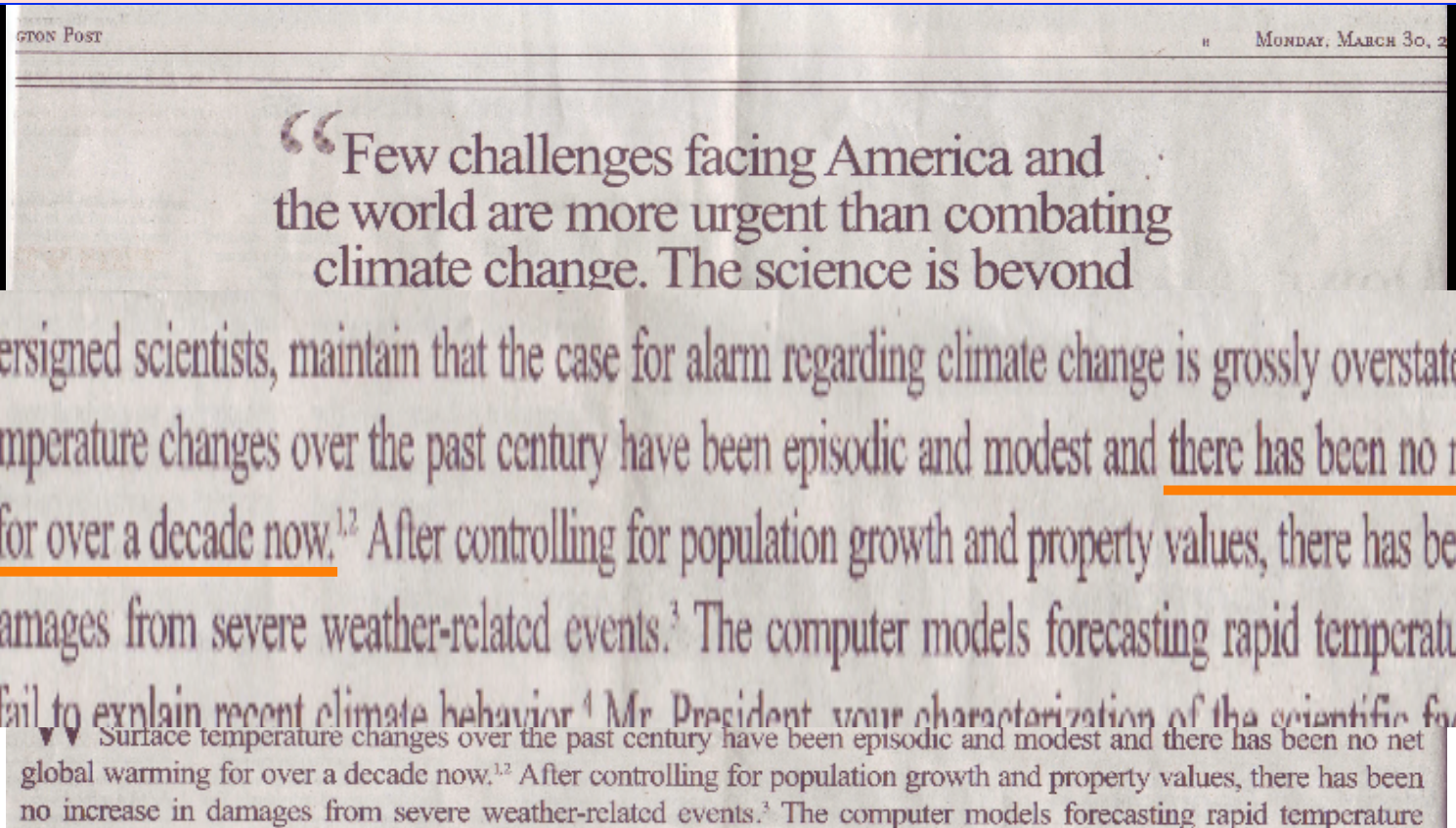
1898

Samuel Pierpont Langley .. The New Astronomy

" Since we are the children of the Sun, and our bodies a product of its rays. I am convinced that it is a worthy problem to learn how things earthly depend on this material ruler of our days."

2009

Washington Post, 30 March 2009
(Funded by the CATO Institute)



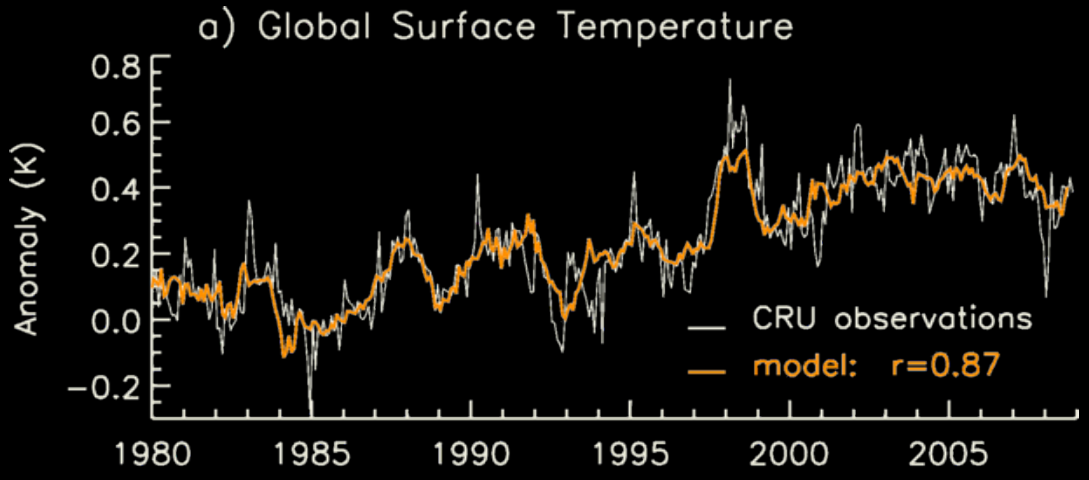
GTON POST MONDAY, MARCH 30, 2

"Few challenges facing America and the world are more urgent than combating climate change. The science is beyond

We, the undersigned scientists, maintain that the case for alarm regarding climate change is grossly overstated. Surface temperature changes over the past century have been episodic and modest and there has been no net global warming for over a decade now.[1,2] After controlling for population growth and property values, there has been no increase in damages from severe weather-related events.[3] The computer models forecasting rapid temperature change abjectly fail to explain recent climate behavior.[4] Mr. President, your characterization of the scientific facts

We Surface temperature changes over the past century have been episodic and modest and there has been no net global warming for over a decade now.[1,2] After controlling for population growth and property values, there has been no increase in damages from severe weather-related events.[3] The computer models forecasting rapid temperature

Global Surface Temperature Responds to Natural and Anthropogenic Influences

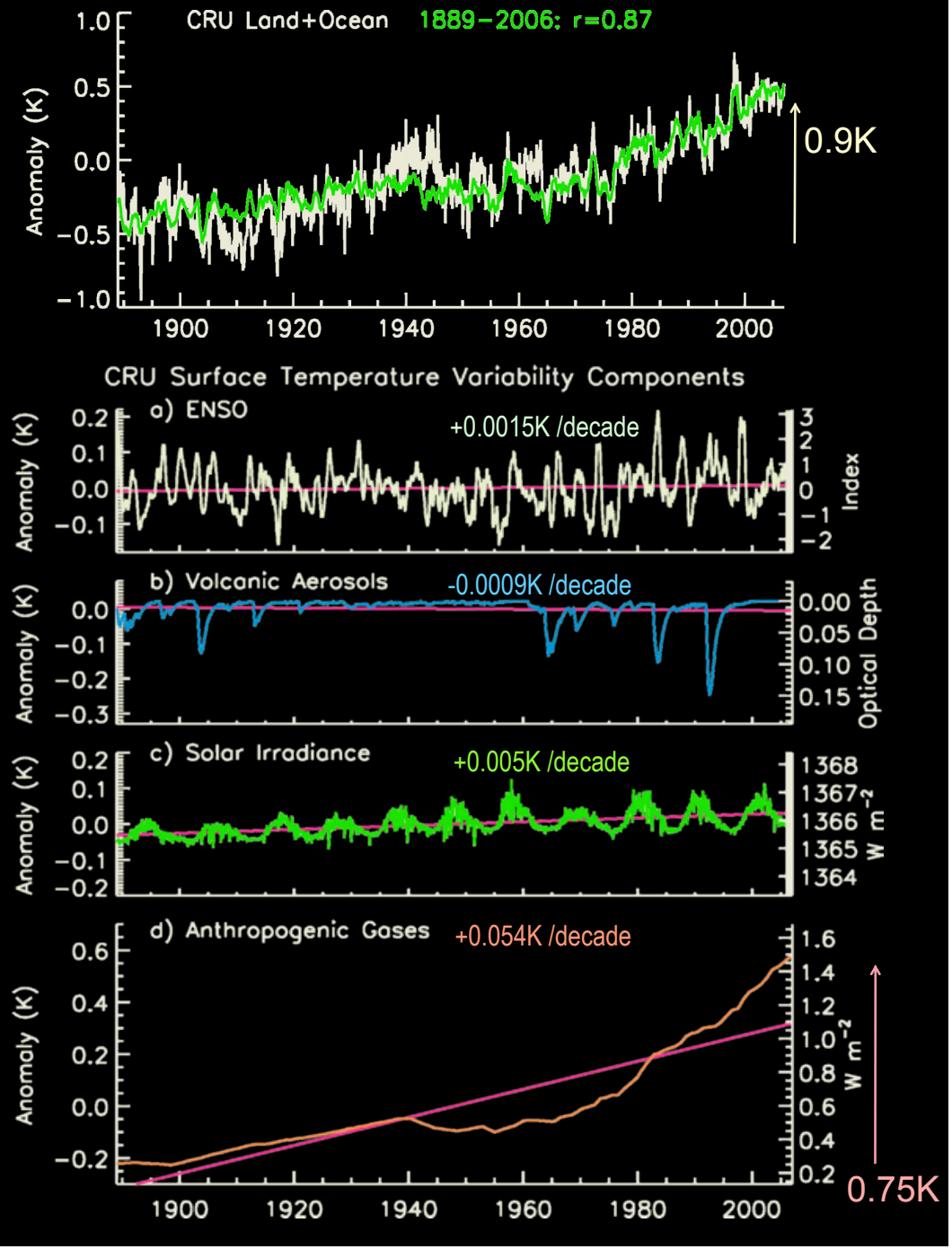


76% of observed temperature variance explained by:
ENSO +
volcanic aerosols +
solar activity +
anthropogenic influences

Earth's Surface Temperature Change Since 1890

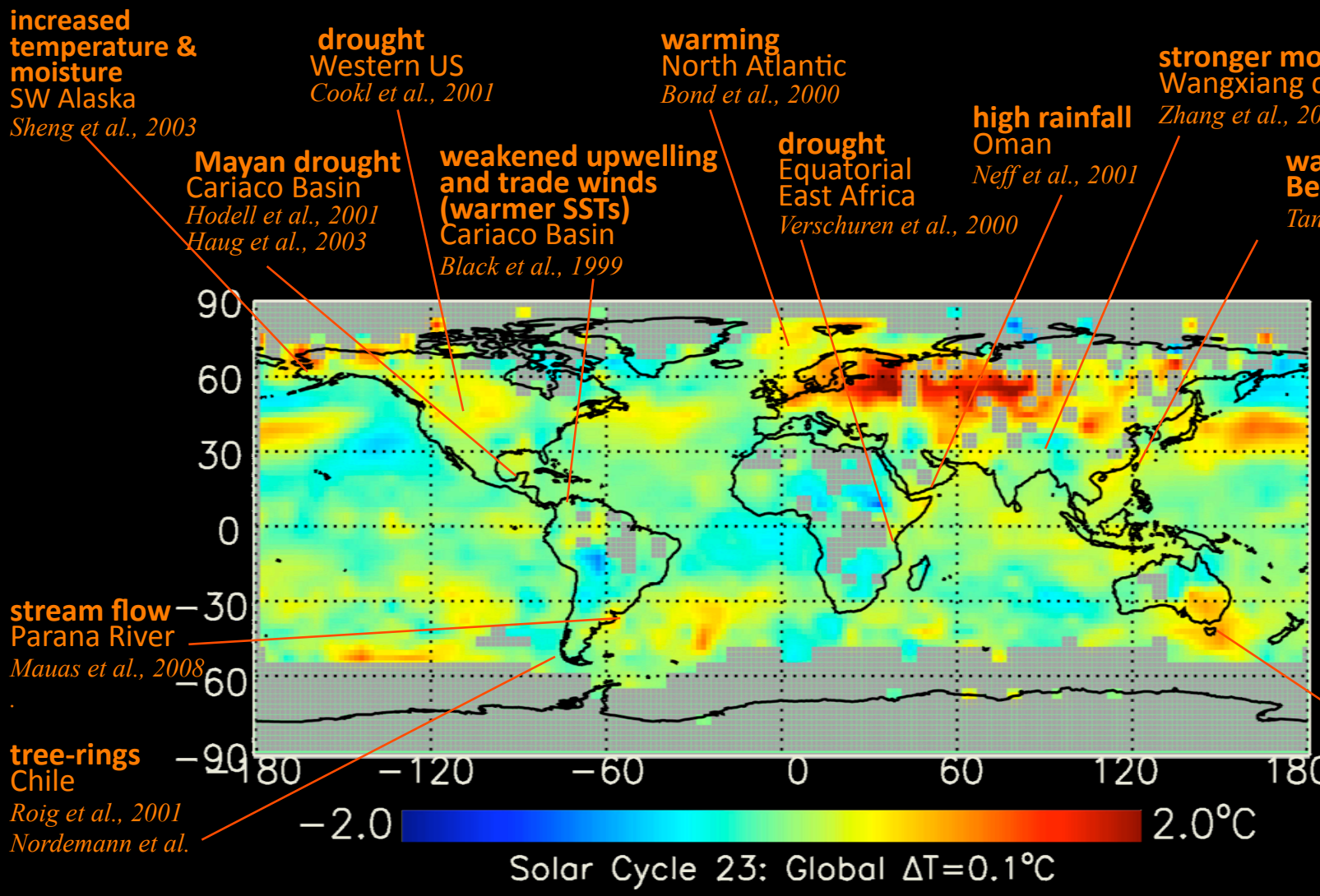
Natural components account for <15% of warming since 1890

Decompositions of *historical* and *recent* global surface temperatures give consistent individual natural and anthropogenic components:



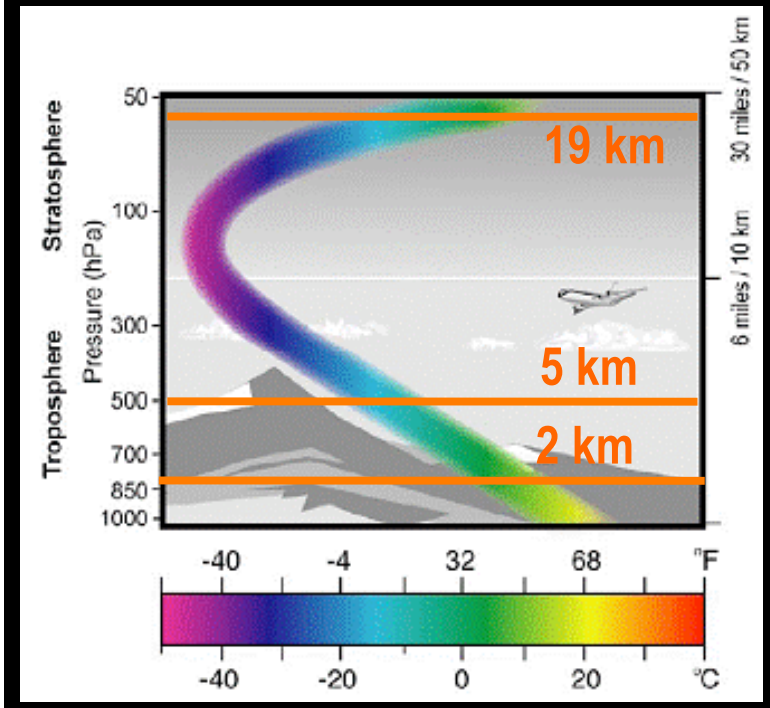
Paleo Sun–Climate Synopsis

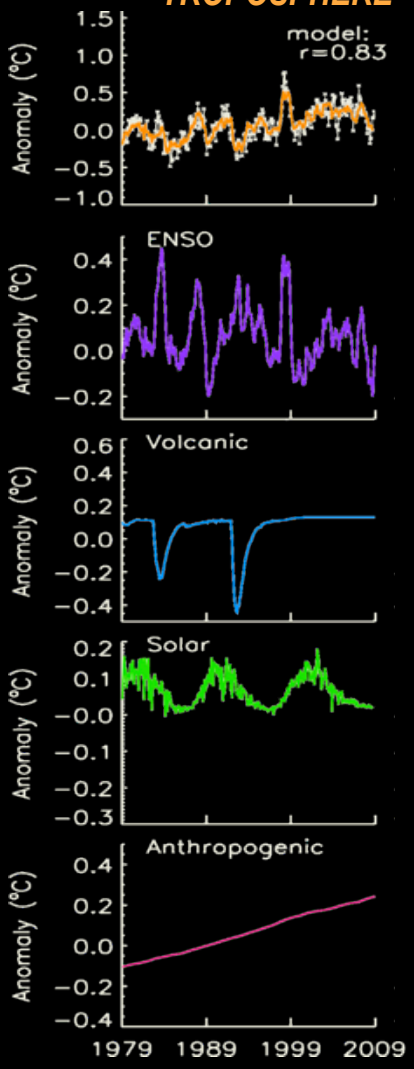
…when solar activity is high….



significant local changes do not imply global changes of equal magnitude

Natural and Anthropogenic Change in Earth's Atmosphere

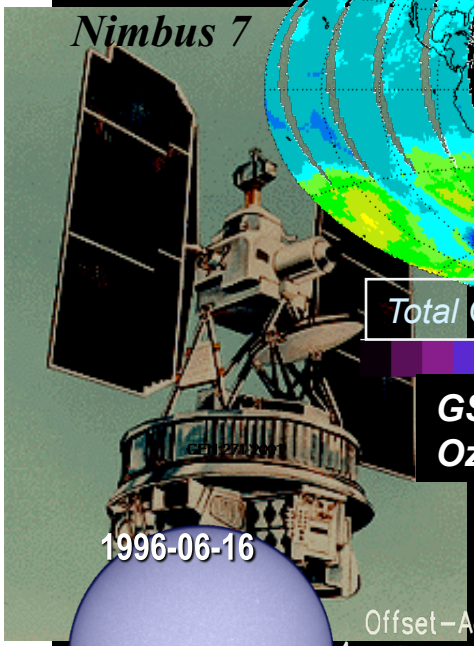


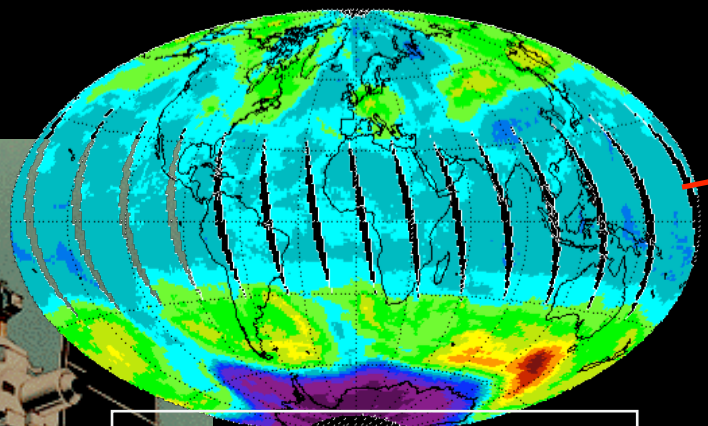


solar increase → warming
CO_2 increase → warming
volcanoes → cooling

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

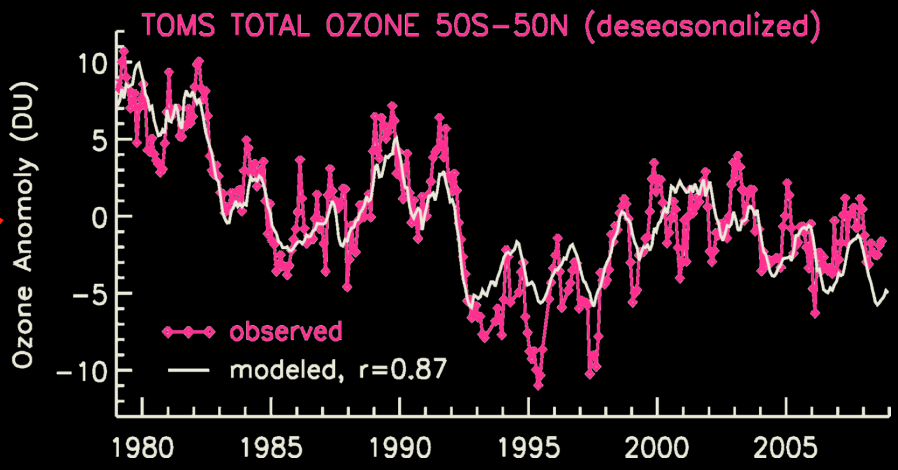
Ozone Depletion



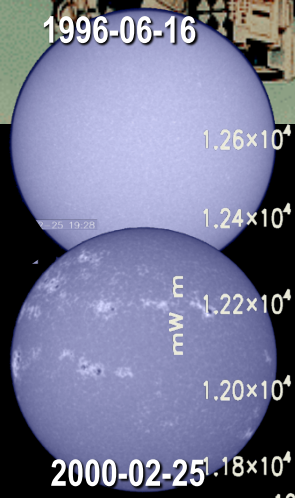


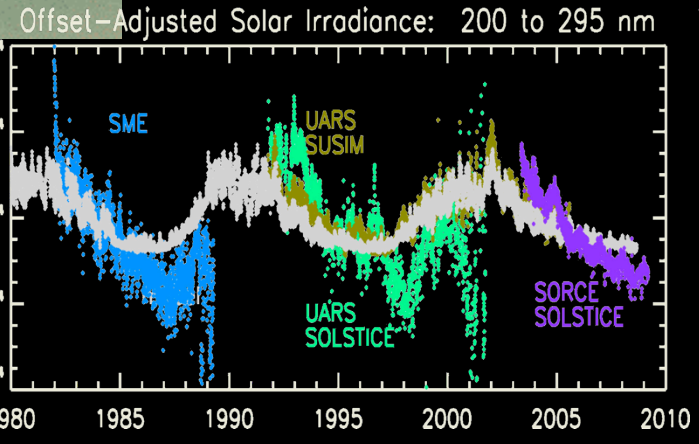
Total Ozone 50S-50N ~ 280 DU

GSFC TOMS Total Ozone Sep 16, 2001

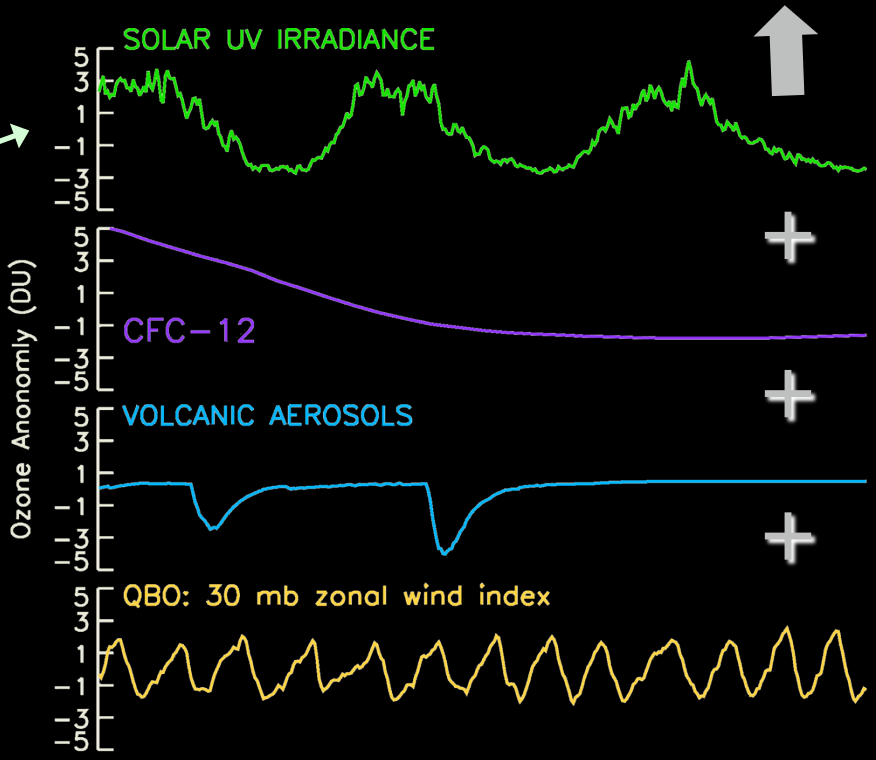


UV radiation: 200-295 nm





solar upper photosphere



How – and Why - will Climate Change in the next Decades?

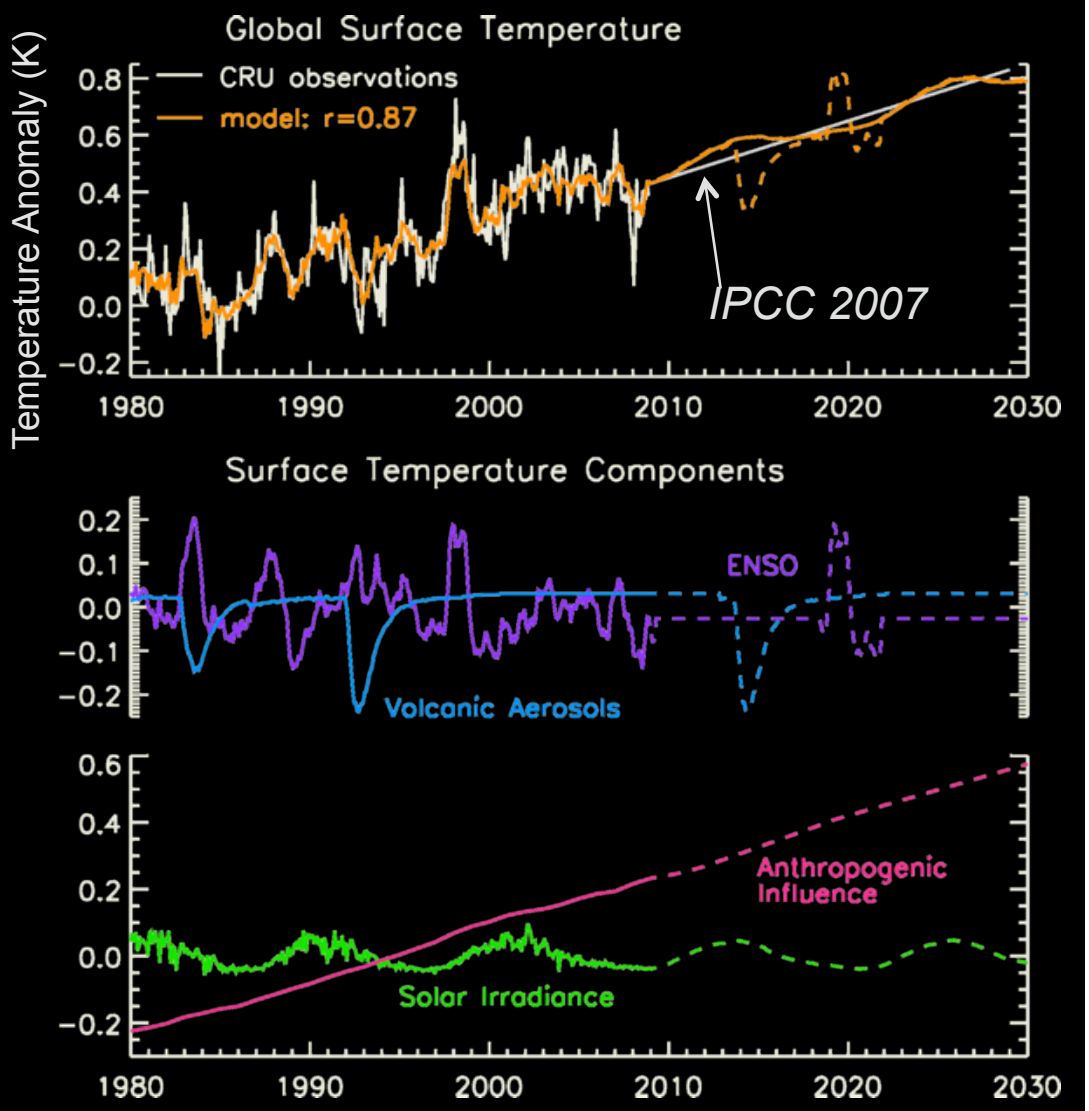
Nature, 25 May 2006

Currently, the Sun is at a solar minimum, and most predictions suggest that the next solar maximum in five or six years' time will be weak. …

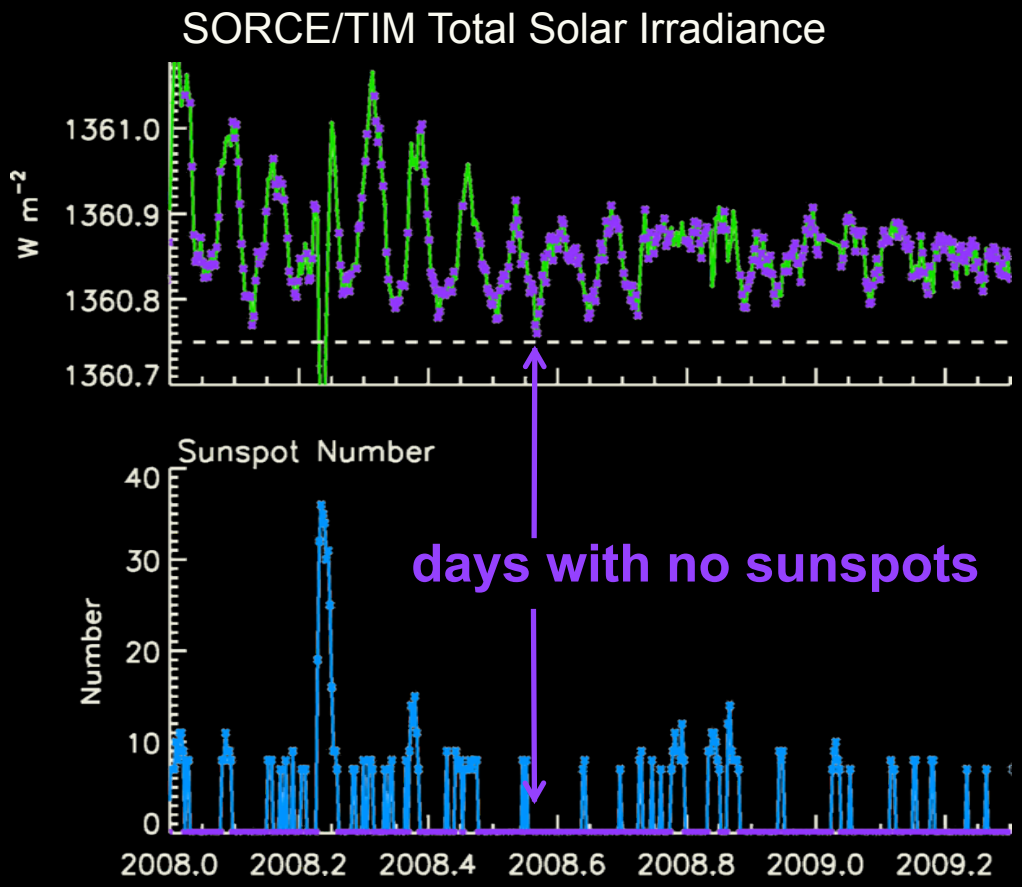
Climate skeptics who argue that human activities are not responsible for global warming have seized on these results….
So convinced are they that last year two Russian skeptics placed a $10,000 bet that global temperatures will show an average fall for 2012–17 — on the assumption that the next solar cycle will be weak.

Assuming Past is Prologue….

future near-term climate change will vary because of both natural and anthropogenic influences



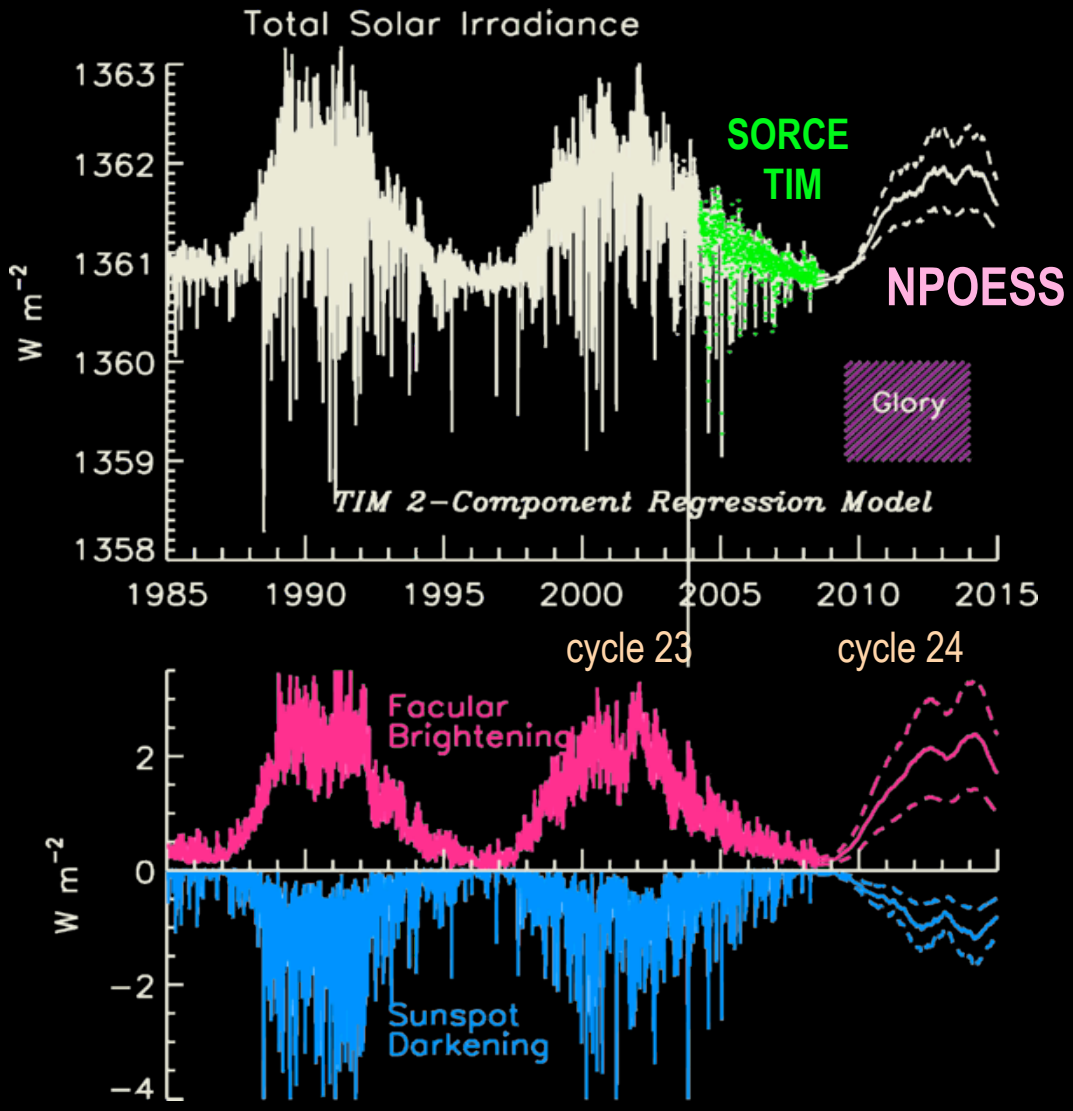
Are we entering a protracted solar minimum?



- *TIM total solar irradiance has varied continuously throughout the current quiet period, even when sunspots were absent*
- *Bright faculae have been present on the disk throughout the minimum period, producing rotational modulation*
- *Lowest levels reached in mid 2008..... solar cycle minimum?*
- *Hinode EUV (coronal) signal also minimum in mid 2008*

An accurate, precise, long solar irradiance record is crucial to constrain solar-driven climate change.

How – and Why - will Solar Irradiance Change in the Next Decade?



Solar Cycle 24:

- 40% higher than cycle *23*
  (Dikpati et al, 2005)
- less active than cycle 23
  (Wang and Sheeley, 2009)

GLORY/TIM: 2010 →

... the first "benchmark" irradiance measurement

... end-to-end calibration with NIST cryogenic radiometer

NPOESS/TSIS: 2013 →

... operational solar monitoring

... total and spectral irradiance

... SORCE, TIM and SIM heritage

SUMMARY

How Bright is the Sun?

- Total Irradiance – 1361 Wm^{-2} (SORCE/TIM) or 1365 Wm^{-2} (ACRIM)?
- Spectral Irradiance – percentage uncertainties

  ... absolute offsets among independent instruments exceed variability

How Does it Vary?

- Total Irradiance – 0.1% during recent activity cycles, 0.3% in strong rotational modulation, <0.1% since Maunder Minimum?
- Spectral Irradiance – 1% to 40% in UV, 0.1% in visible

  ... SORCE observations have larger UV changes than model or prior observations

  ...are variations in visible and near-IR spectrum out-of-phase with solar activity?
- Past and future solar Irradiance changes are uncertain

  ... continuous, high precision monitoring will advance understanding

Why do we Care?

- Natural climate change occurs simultaneously with anthropogenic influences

  ... solar & volcanic influences, internal modes (ENSO, QBO), greenhouse gases, aerosols

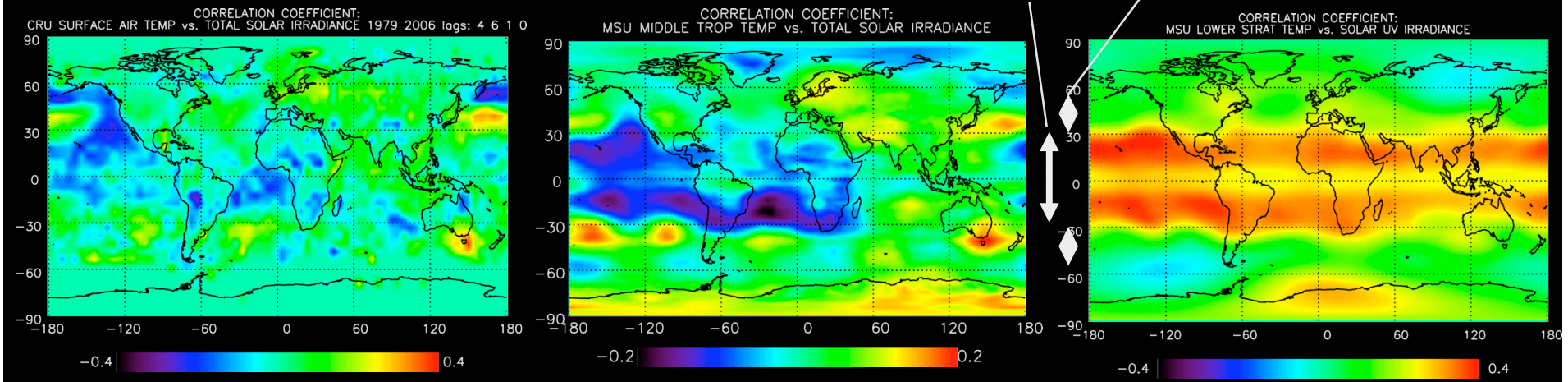
  ... solar influence may both accelerate and mitigate global warming in the next two decades

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

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

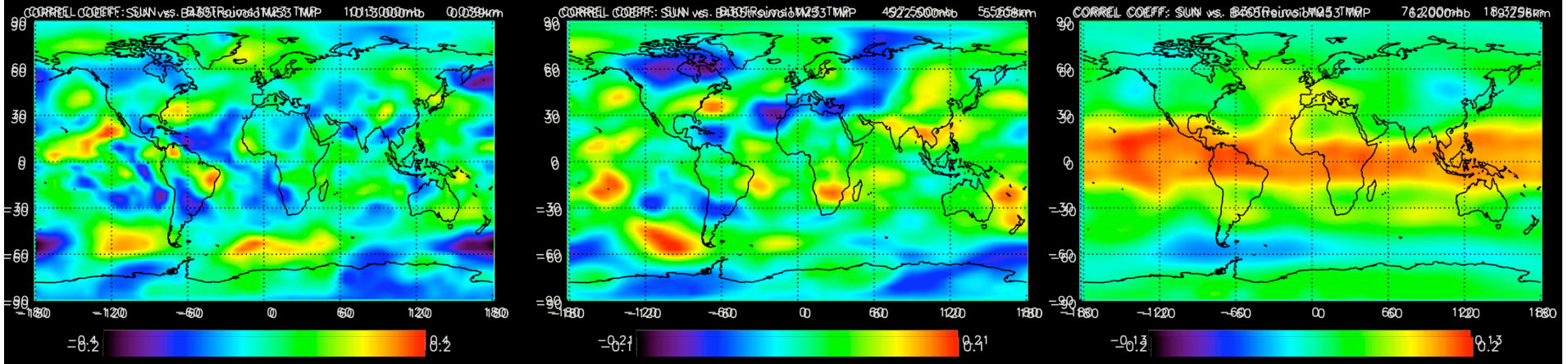
Multiple regression

Hadley cell Ferrel cell

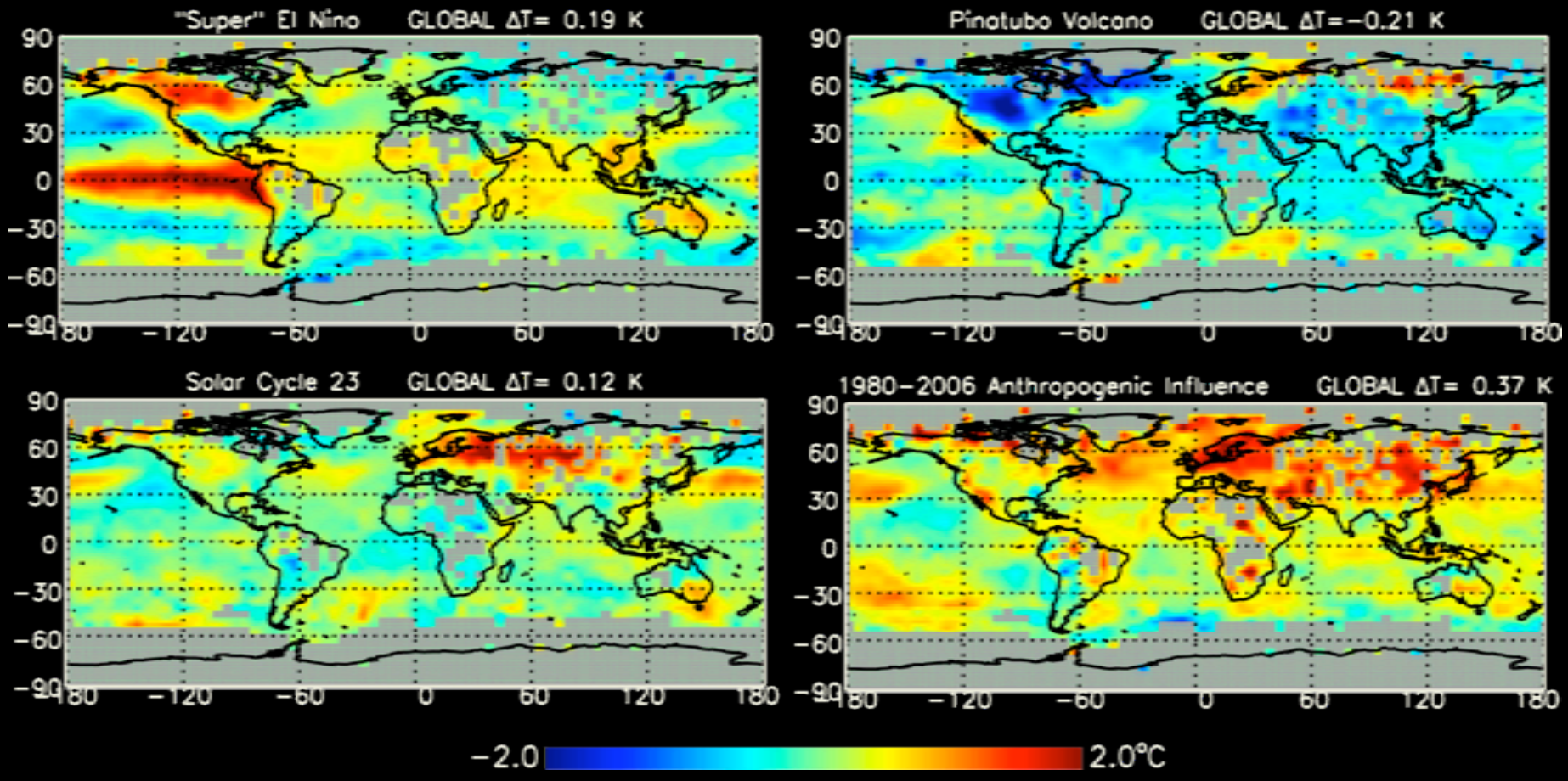


B465trsuvoioTM53… *solar, interactive ozone*

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



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



LISIRD: Lasp Interactive Solar IRradiance Datacenter

http://lasp.colorado.edu/lisird/

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LISI

LASP INTERACT

IRRADIANCE DA

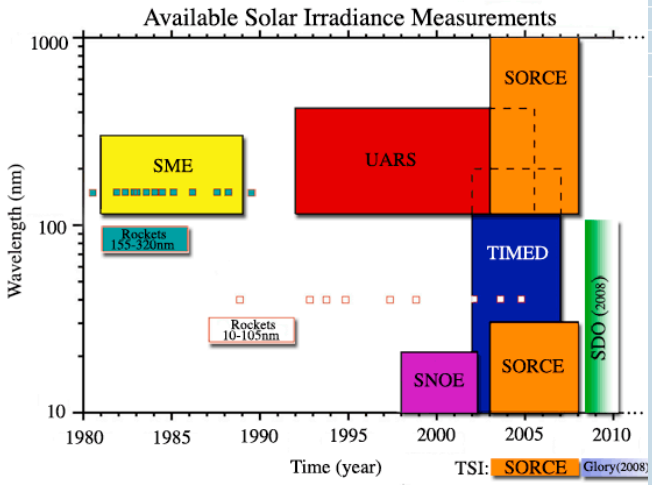
WHAT IS LISIRD?

Welcome to the Lasp Interactive Solar IRradiance Datacenter or LISIR website. This data center is currently in its early stages of development. LAS plans to have LISIRD provide convenient interactive access to a comprehensiv set of solar irradiance measurements, models, and composite solar irradianc spectra and time series. Click here to begin querying data.

Currently, we have a Data Access Interface that queries data from several LAS missions: SORCE, TIMED SEE, SME, UARS SOLSTICE, and soon SNOE (se graphic below).

We encourage community input to help us make this the most useful site possibl You can help LASP by taking our on-line survey. We also welcome ar comments you might have concerning the features, capabilities, and data sets yo would like to see provided at this data center. We will endeavor to take in account the comments and requests we receive in order to make this data cent as useful as possible.

Below is a quick-look graphic of current available measurements (by clicking o different regions of the graphic, you will be taken to that dataset):



In order to maximize the accessibility and usability of solar irradiance data an information from multiple missions, LASP has initiated the process of developin

Institute of Meteorology: Input Data

http://www.geo.fu-berlin.de/en/met/ag/strat/forschung/SOLARIS/Input_data/index.html

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Input Data:

Recommendations for CMIP5

I) Solar Irradiance Data

Variations in the total solar irradiance (TSI), the so-called "solar constant", over a solar cycle are small (0.08%) (e.g., Fröhlich, 2000). However, variations in the ultraviolet (UV) part of the solar spectrum, which is important for ozone production and middle atmosphere heating, range from 8% at 200nm to about 5% from 220nm to 260nm, 0.5% around 300nm, and 0.1% above 400nm (e.g., Lean et al., 1997; Woods and Rottman, 2002). Much larger variations are observed at shorter wavelengths (over 50% at 120nm, 10-15% from 140-200nm), which are mainly absorbed in the higher atmosphere (mesosphere and thermosphere).

To account for the highly variable and wavelength-dependent changes in solar irradiance, daily spectrally resolved solar irradiance data from 1 Jan 1950 to 31 Dec 2006 (in mW/m^2/nm) are provided by Judith Lean for different time periods, different time resolution (daily or monthly) and different wavelength regions. The data were derived with the method described in Lean et al. (1997), Lean (2001), and Lean et al. (2005). A short description of how the data were (re)constructed can be found here.

Each modelling group is required to integrate these data over the individual wavelength intervals in their

- radiation scheme (to adjust the shortwave heating rates) and
  he photolysis rates).

rovided solar flux data directly (integrated over the respective emistry schemes), rather than a parameterization with the sed.

t and zipped. To unzip use "gunzip file.gz".

ed as follows:

header ...

wavelength grid centers ...

wavelength bands width (1 nm bins from 0 to 750 nm, 5 nm bins from 750 to 5000 nm, 10 nm bins from 5000 to 10000 nm, 50 nm bins from 10000 to 100000 nm) ...

Spectral irradiance (mW/m2/nm) daily for years indicated in the file name

YEAR MONTH DAY TSI in W/m2

solar flux data ...

YEAR MONTH DAY+1 TSI in W/m2

...

model: 1 nm bins
0-100,000 nm
daily since 1947
monthly since 1882
yearly since 1610

Climate Model Response to Radiative Forcing

surface temperature change — *forcing*

$$\Delta T = \kappa F$$

climate sensitivity

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

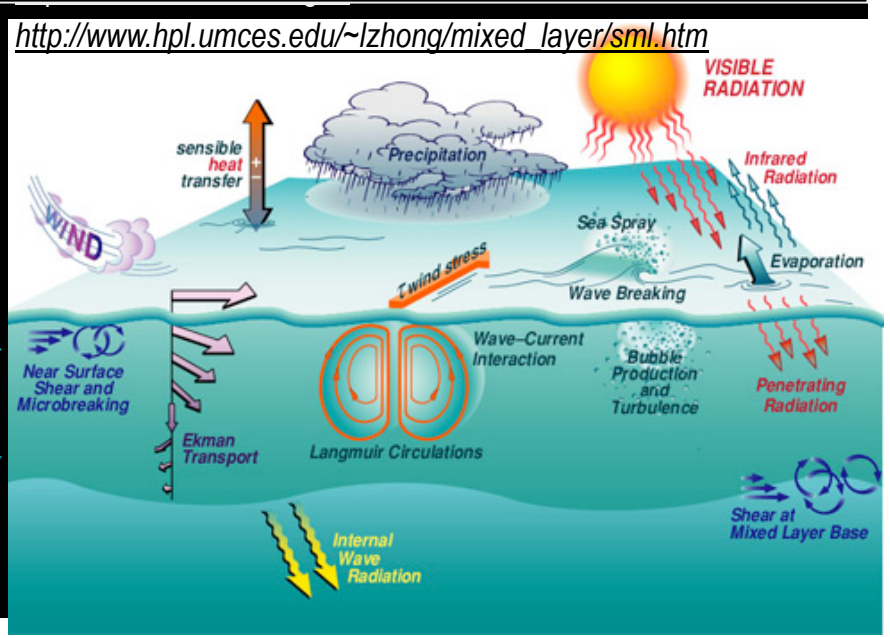
$\Delta T = 0.4°C$ (1980-2006)

$F = 1$ 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



Solar Radiative Processes Depend on Geography, Altitude, Wavelength

Sun

UV radiation
(λ < 315 nm)
20 Wm^{-2}

near UV,VIS,IR
Radiation
(λ > 315 nm)
1346 Wm^{-2}