The Sun-Climate Connection

What have we learned during this solar minimum?

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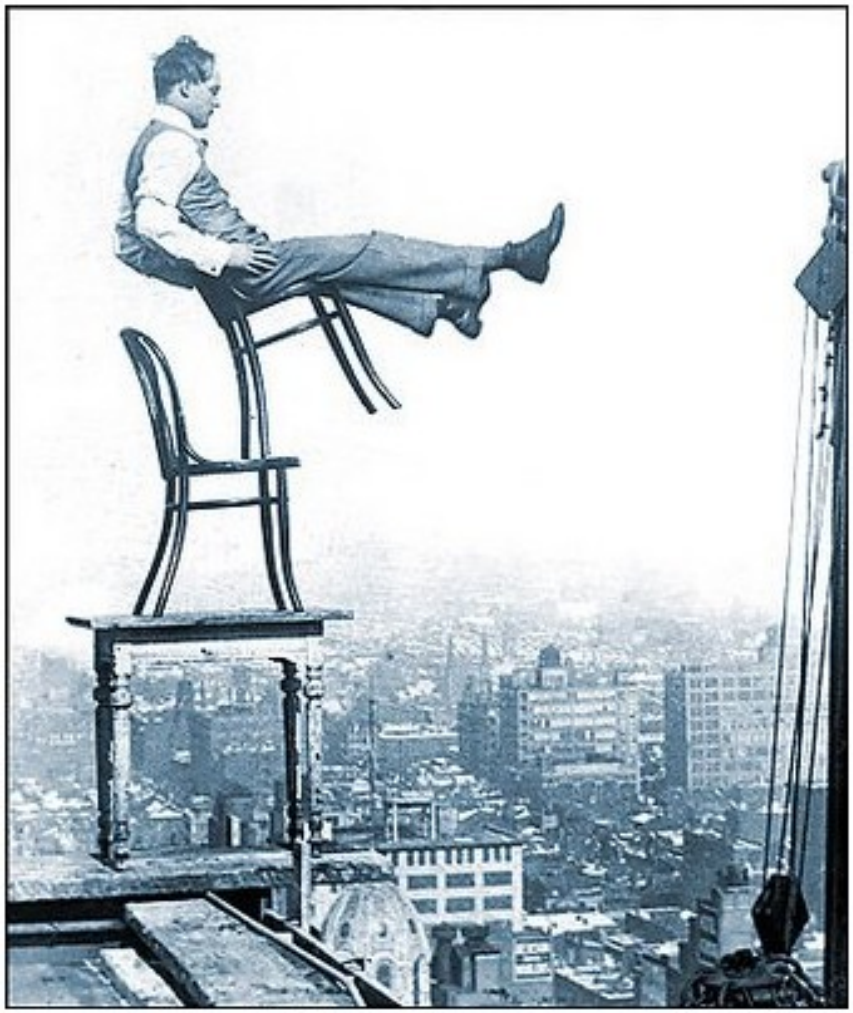

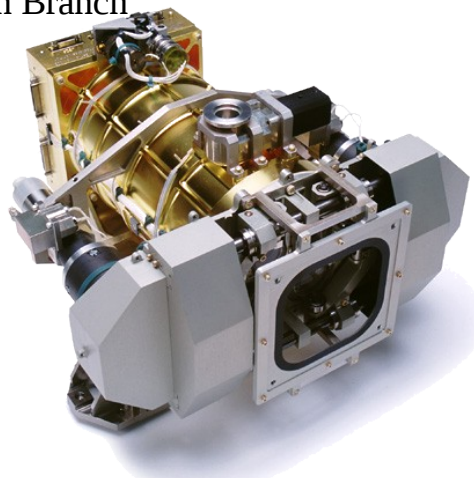

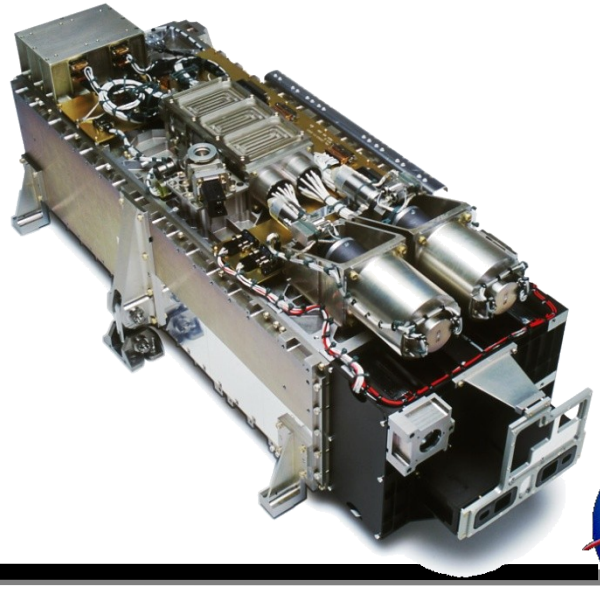

The Sun-Climate Connection

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About the Center

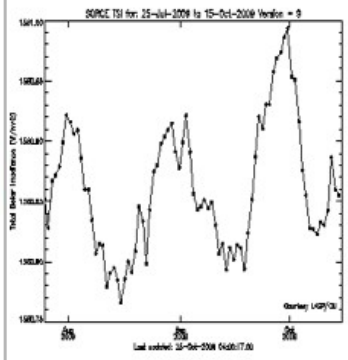
Placed within the Earth-Sun Exploration Division at NASA's Goddard Space Flight Center, Sun-Climate Center is an integrated program of observational systems and research to improve the understanding and prediction of the response of Earth's climate to solar forcing from monthly to multi-centennial time scales, to protect life on Earth, and to ensure the safety of human explorers.

The Sun-Climate Center is one of the nine cross-cutting themes of the Earth-Sun Exploration Division. It is an interdisciplinary union of researchers in the Solar Physics and Climate and Radiation branch at Goddard Space Flight Center.

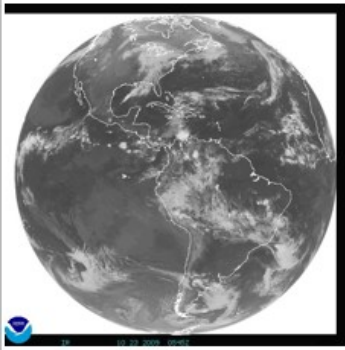
New high-accuracy measurements allow us to study the link between solar activity and climate changes. Below we included near real-time images of processes that might be crucial for the understanding of the solar influence on climate.

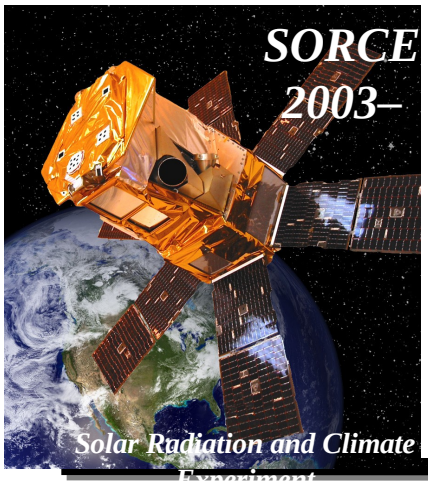
Modern satellite-based measurements provide information about the variable sun with unprecedent accuracy.
The figure shows how the sun presents itself to us at this moment.

Sunspots and active regions influence the solar irradiance which determines the energy input into the Earth's climate system.
The figure shows the total solar irradiance during the last 3 months.



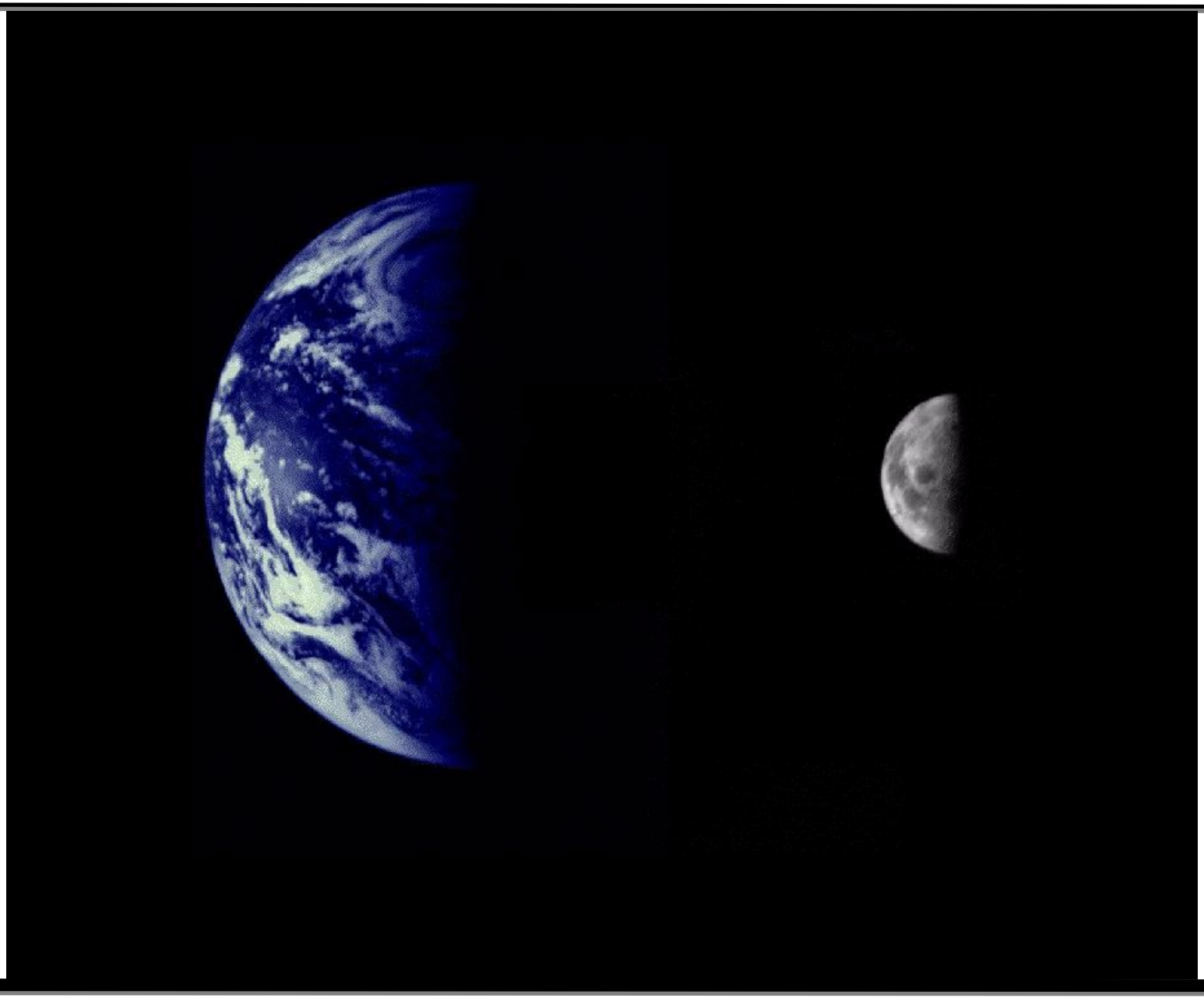
There are indications that the variable solar input does significantly influence our climate.
The figure shows our weather at this moment. It is yet unclear how the sun contributes to the variability in our climate system.



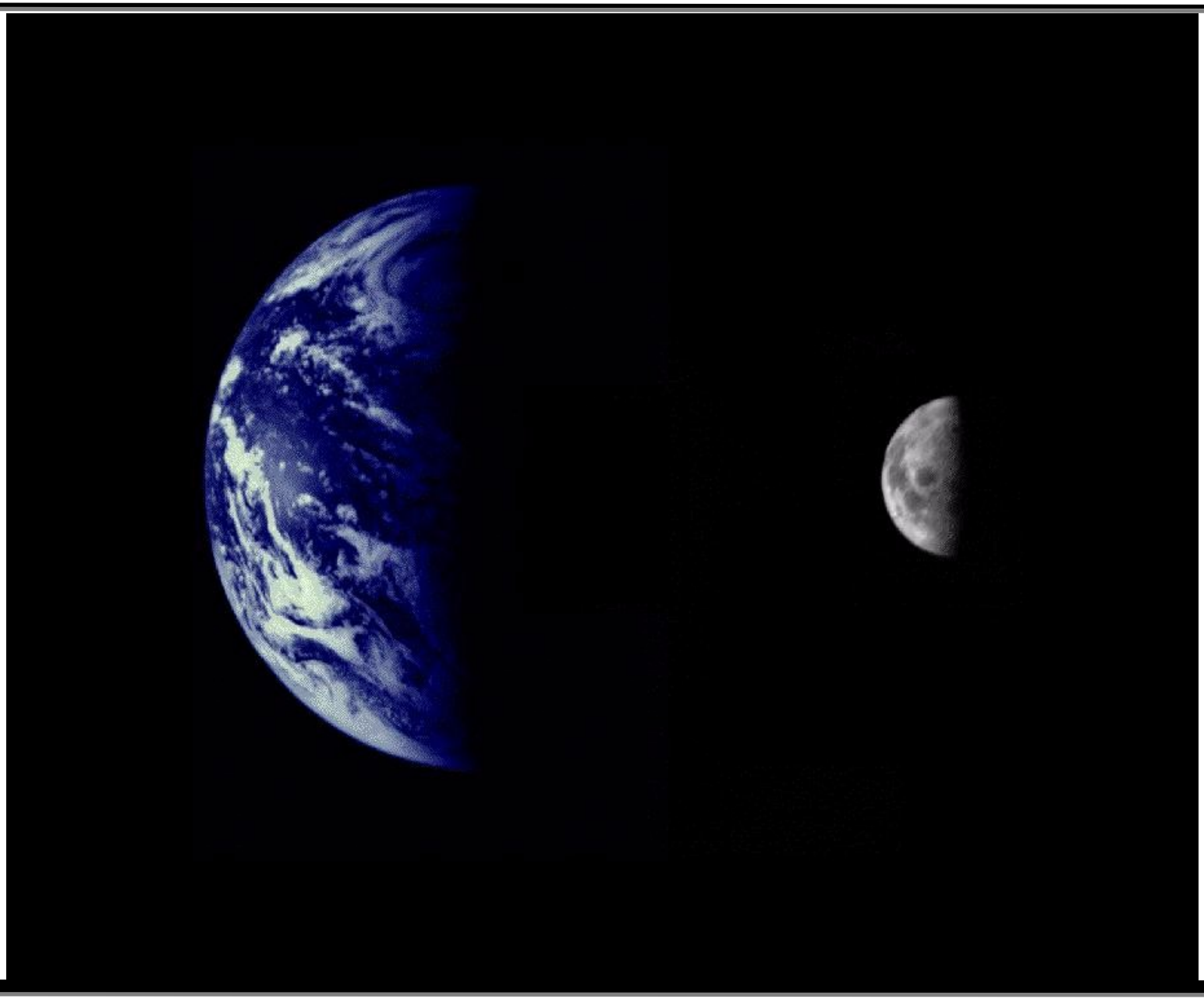


CLOUDS AND THE EARTH'S RADIANT ENERGY SYSTEM
CERES
NASA

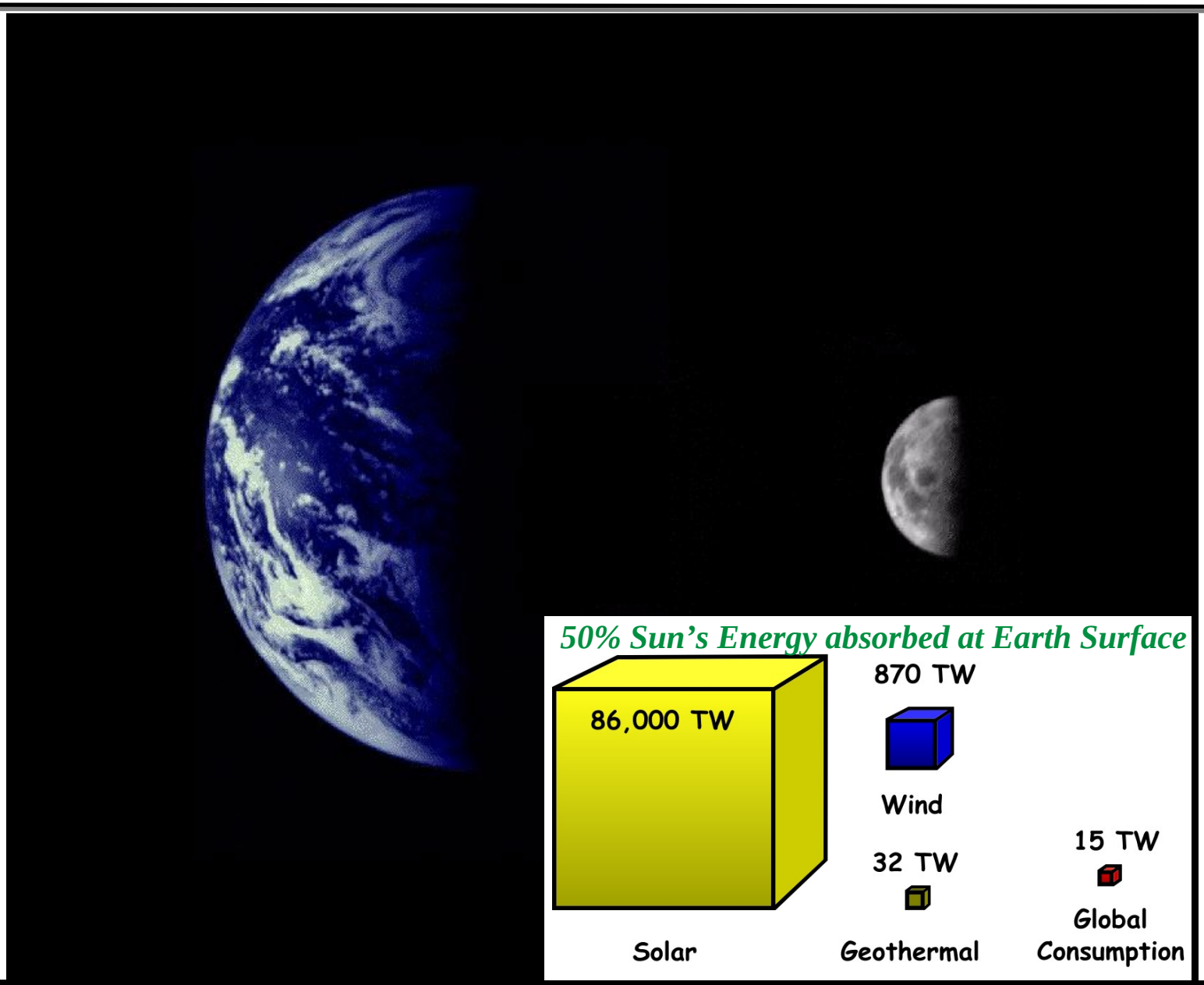
Total Solar Irradiance x $4\pi(1AU)^2$ = Solar Luminosity



Total Solar Irradiance x $4\pi(1AU)^2$ = Solar Luminosity



Total Solar Irradiance x 4 π (1AU)² = Solar Luminosity



Global Means from NCAR CCM

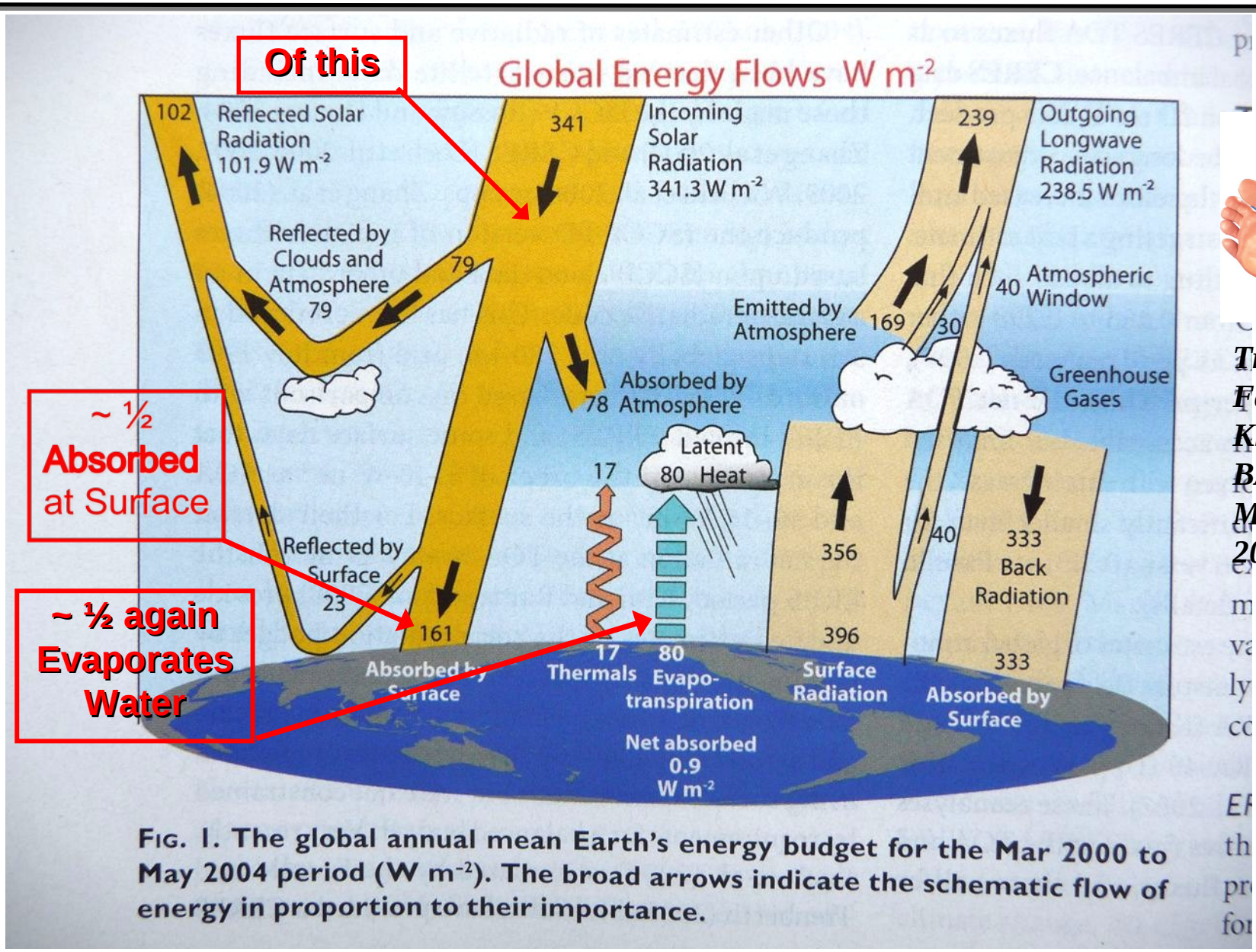
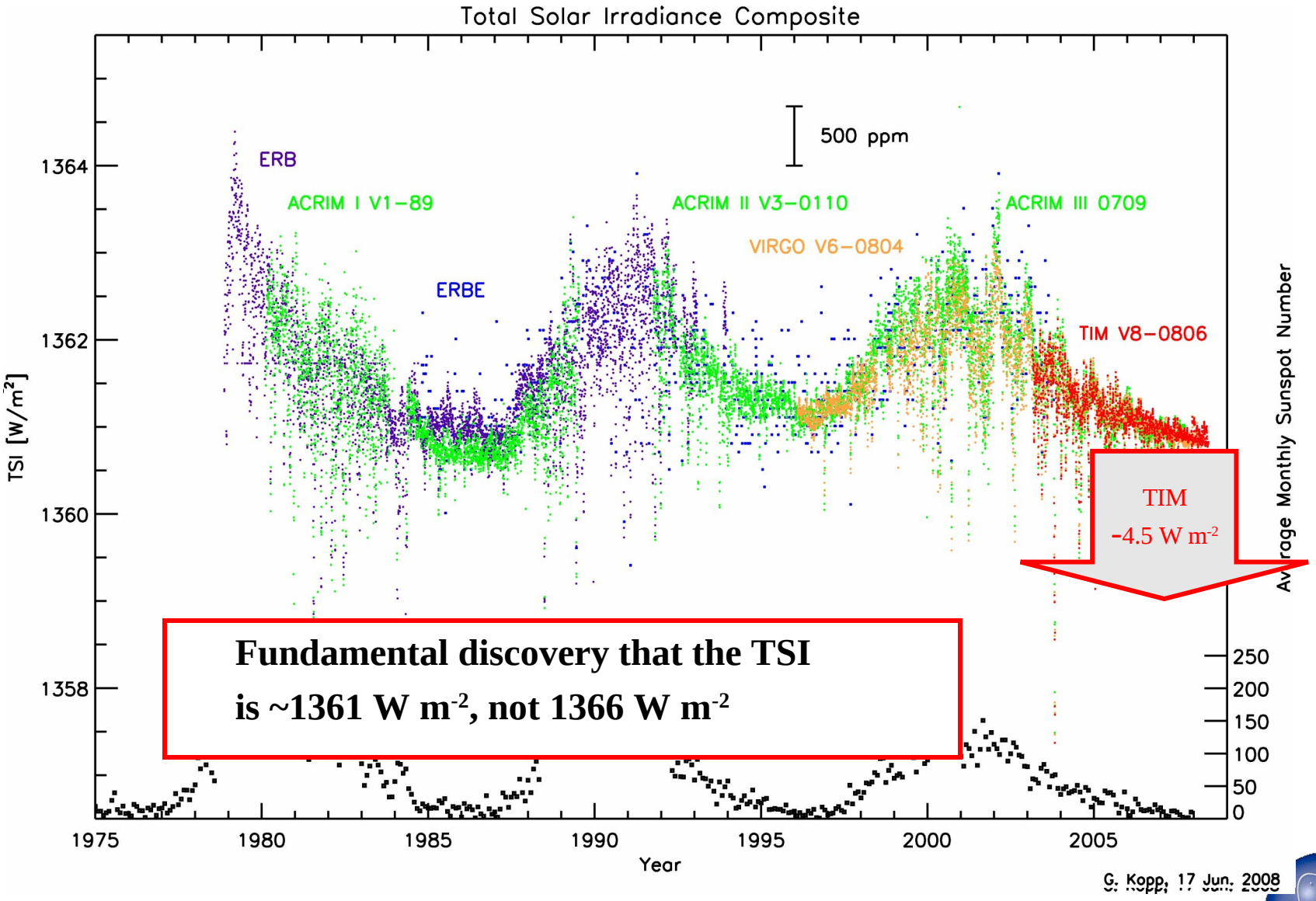


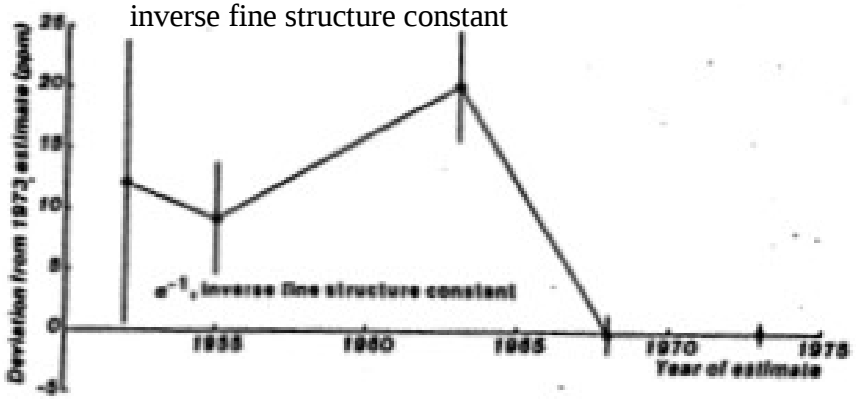
FIG. 1. The global annual mean Earth's energy budget for the Mar 2000 to May 2004 period (W m^{-2}). The broad arrows indicate the schematic flow of energy in proportion to their importance.

Trenberth, Fasullo and Kiehl, BAMS, March, 2009.

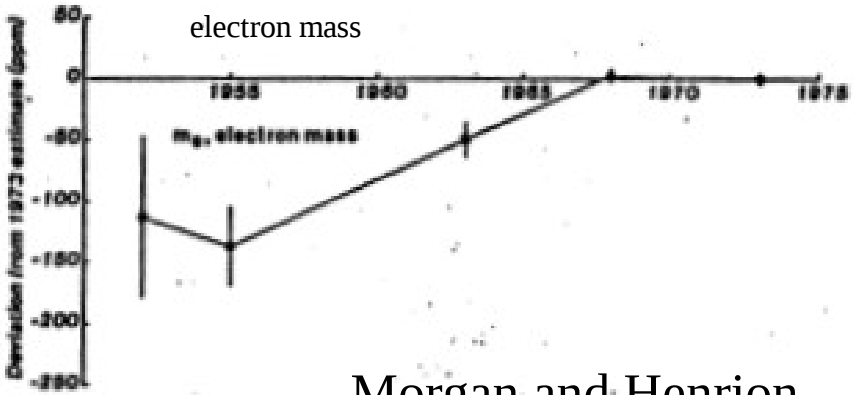
TSI Record with SORCE TIM



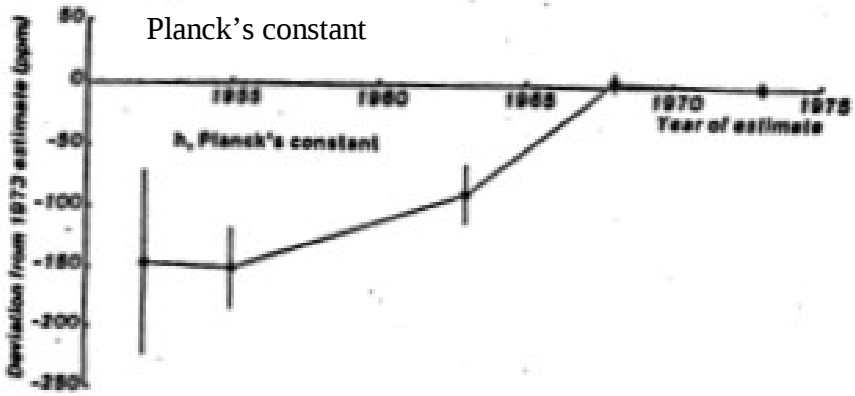
inverse fine structure constant



electron mass



Planck's constant



electron charge

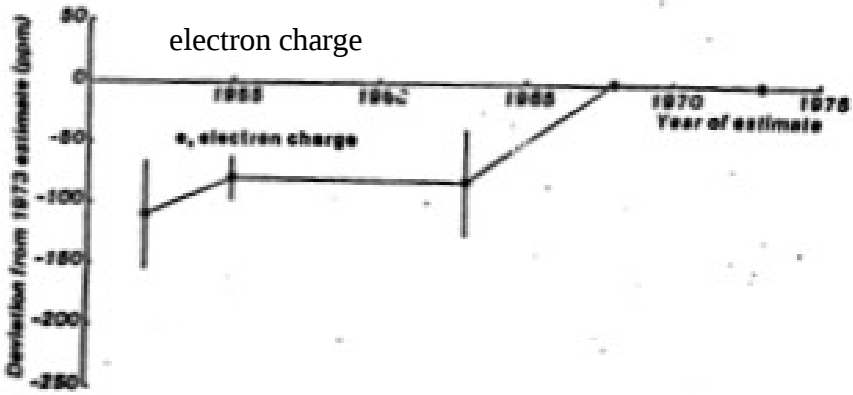
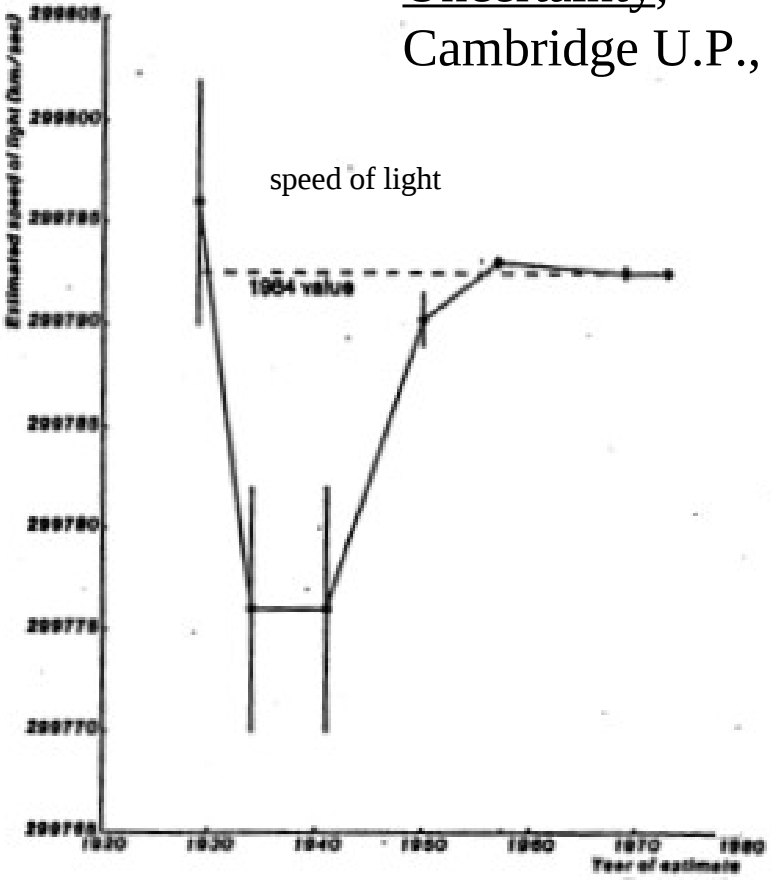


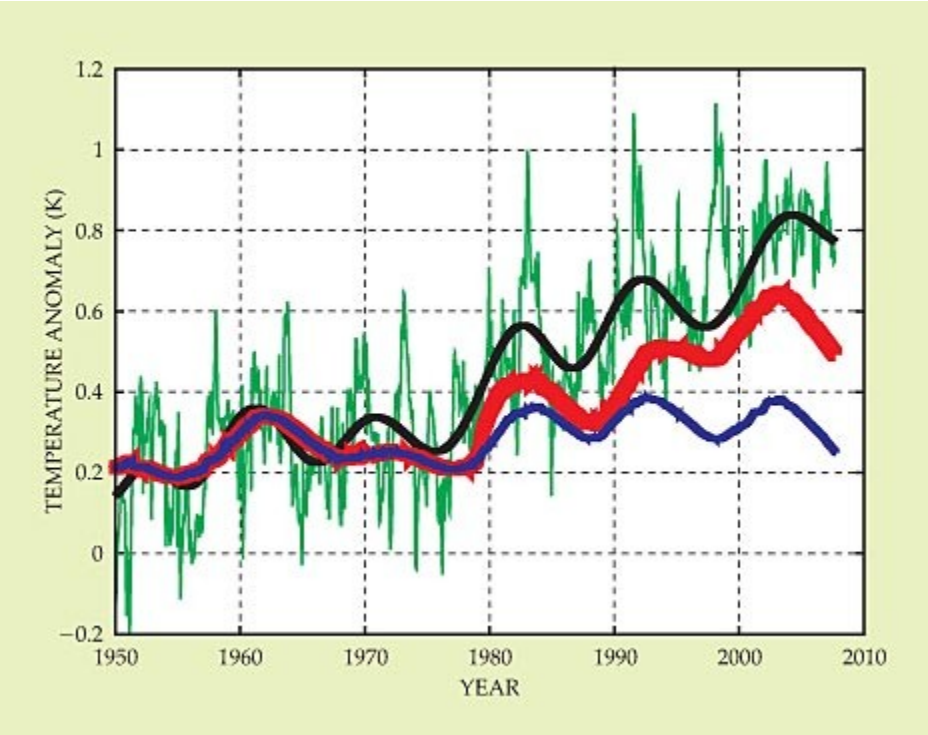
Figure 6.12. Recommended values for five standard physical constants, along with reported uncertainties for the period 1952–1973 (Cohen and Flambaum, 1976).

Morgan and Henrion, Uncertainty, Cambridge U.P., c1990.

speed of light



Solar Contribution to 50 year Temperature trend?



Global Surface T anomalies
Filtered Global Sfc Temp
Solar Reconstruction[1]
Solar Reconstruction[2]

1 Willson & Mordvinov, GRL, 2003
2 Fröhlich and Lean PMOD composite

- **No feedbacks: requires 0.75% increase in TSI.**
- **With feedbacks: doubling in sensitivity, still requires a 0.4% increase in TSI over this period, or 700 ppm per decade.**
- **A trend of this magnitude is *not observed* by the TIM onboard SORCE.**
- **SIM solar spectral observations indicate much smaller surface radiative forcing than previously assumed.**

Scafetta and West, Physics Today, 2008.

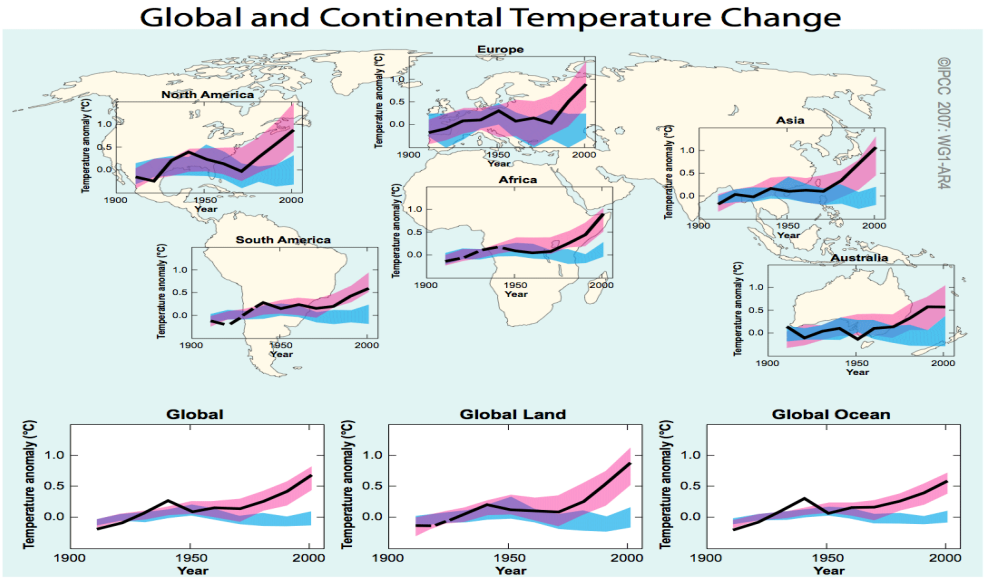
*"We estimate that the **Sun could account for as much as 69% of the increase in Earth's average temperature**, depending on the TSI reconstruction used."*

Is global warming likely to have been induced by our Sun?

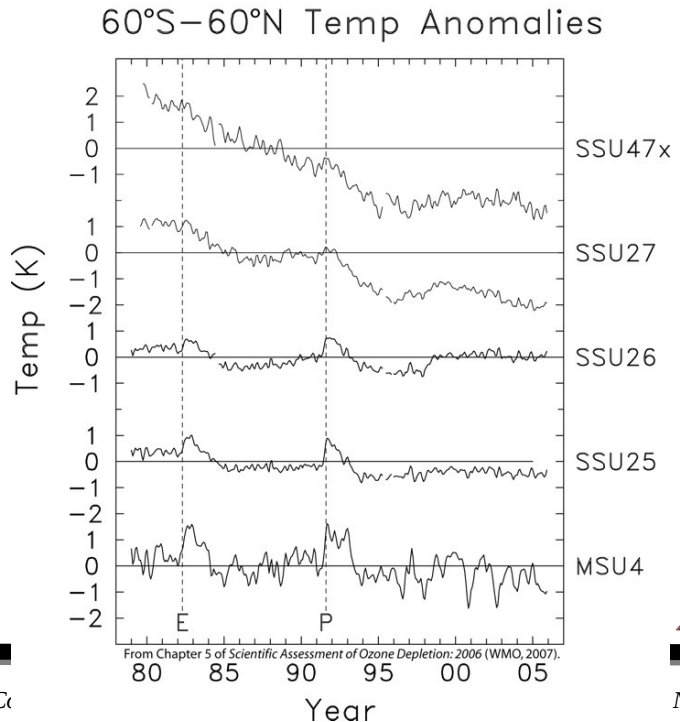
All regions

All regions warmed at
and near Earth's surface :

the surface.

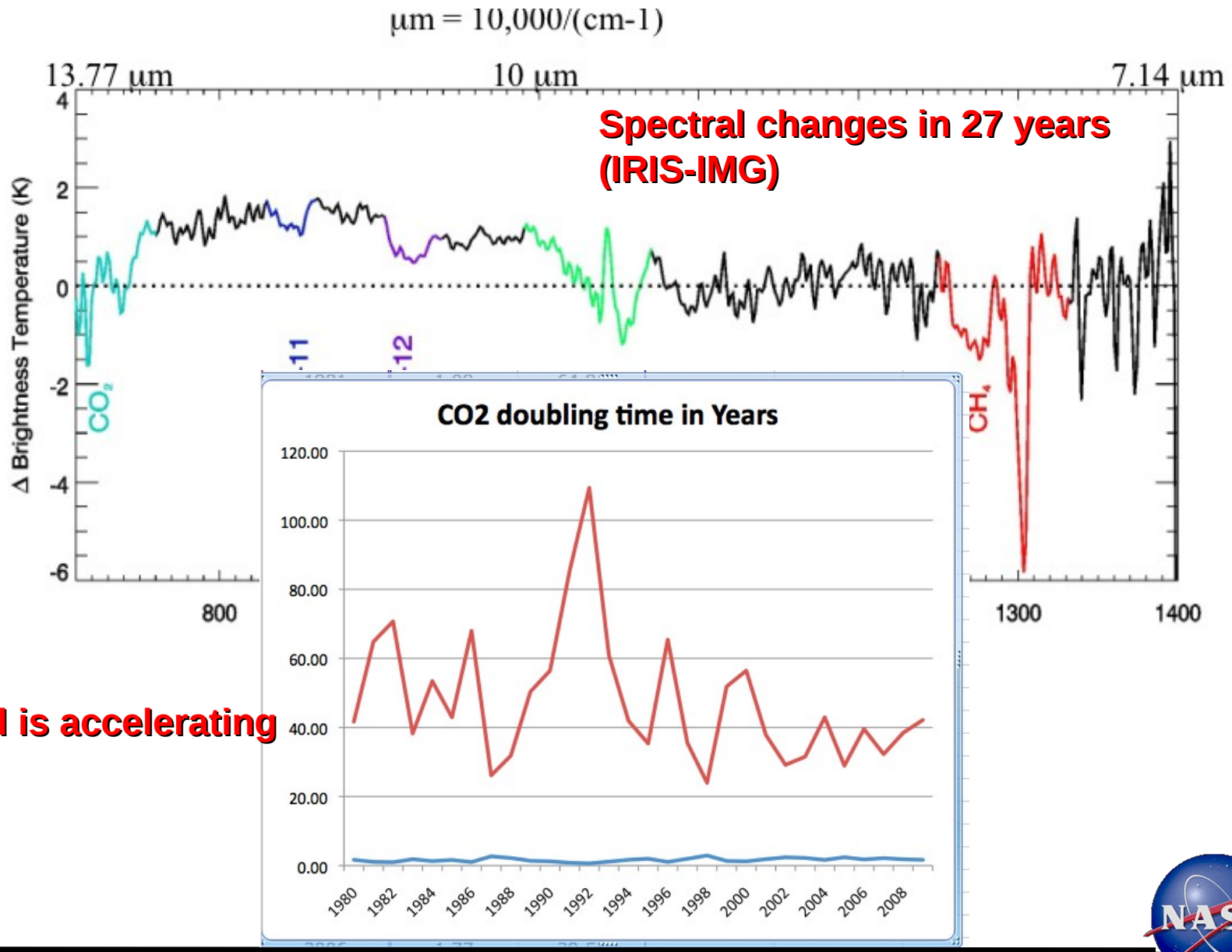


Yet the *stratosphere* cooled
the *most* at *highest altitude* :



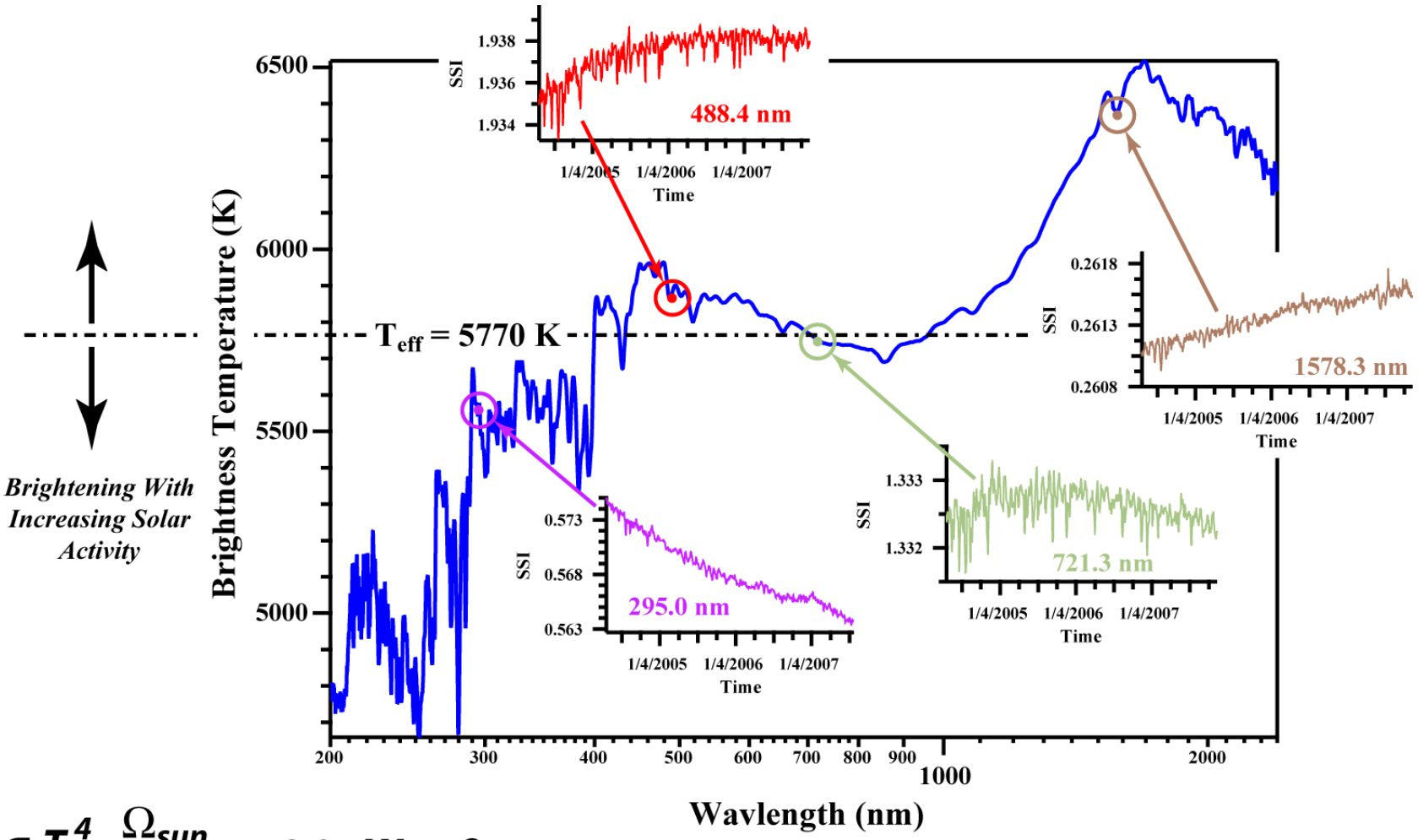
This combination is not easily made consistent with solar warming, but clearly results from greenhouse warming.

Changes in Earth's Spectrum Show Greenhouse Gases



CO2 trend is accelerating

Changes in Sun's Spectrum Are Out-of-Phase



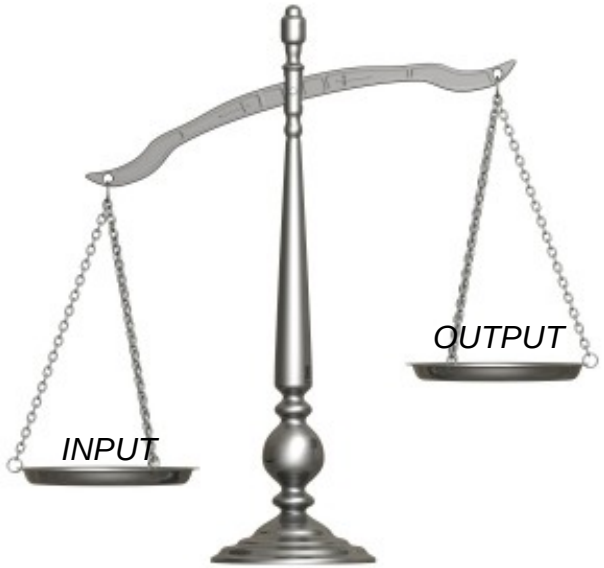
$$\sigma T_{eff}^4 \frac{\Omega_{sun}}{\pi} \approx 1361 \text{ W m}^{-2}$$

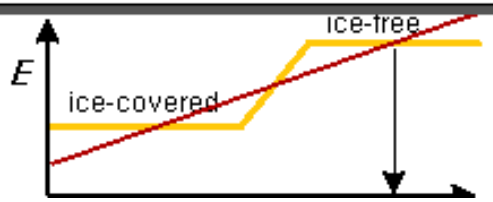
Surface Energy Balance

NCAR Model	SORCE/CERES Observed
+341.3	+340.0
-101.9	-99.5
-238.5	-239.6
+0.9	+0.8
Planetary Albedo:	
29.9%	29.3%
Atmospheric Shortwave Absorbed:	
22.9%	22.6%

Solar Constant	σ_o = 1361 W/m^2
Earth Absorptance	a = 0.707
Stefan-Boltzmann	σ = 0.554 X 10^{-7} W/m^2/°K^4

Model	INPUT per unit area	OUTPUT	Equil.Temp.	Sensitivity dT(100*dσ_o/σ_o)
B.body	aσ_o/4 = 240 W/m^2	σT^4	T = 255 K = -18 C	T/400 = 0.64 K (minimum)
H_2O shield				
T_1	σT_o^4	$2\sigma T_1^4$	T_1 = 255 K	
T_o	aσ_o/4 + σT_1^4	σT_o^4	$T_o = 2^{1/4} T_1$ = 303 K = 30 C	T_o/400 = 0.76K
Empirical	240W/m^2	210 +2 T_o	T_o = 15 C	1.2 K
Ice-Albedo	a(To)σ_o/4	210 + 2 T_o	T_o = 15 C	> 1.2 K





Summary

What have we learned during this solar minimum?

Approximate Radiative Balance of Solar Input and Earth Output

- TSI = 1361 ± 0.8 W/m^2, ~ 4.5 W/m^2 (1/3 %) lower than previously accepted
- Reflected = 99 W/m^2, and Emitted = 240 W/m^2

Imbalance implies continued warming – Greenhouse dominates, Sun a player.

- Current Minimum TSI slightly lower than previous Minimum TSI, offsets some warming
- ***Albedo*** **smaller**, ~**29%** (vs ~31%) – more solar energy absorbed than previously accepted
- ***Atmosphere's Absorption*** **larger** ~**23%** (vs ~20%) due to Aerosol & H_20 Continuum
- Net Imbalance of ~ 0.85 Watts-per-(meter)^2 – *ocean heat storage estimate.*

Sun's *Spectrum* is changing, as is Earth's

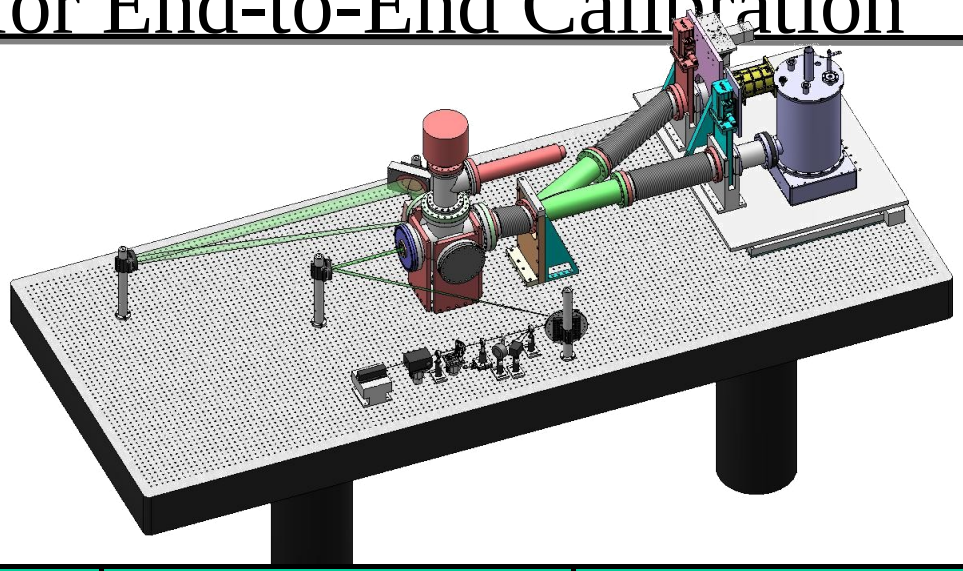
- Near-Ultraviolet changes more than TSI, explaining 1.0 K variations at ~40 km, top of O_3 layer
- Visible and Near-Infrared changes *out-of-phase* with TSI.
- TSI, integral of the spectrum, is comprised of spectral regions that have compensating effects.
- Surface solar forcing is very small, with direct surface response < 0.1 K in 11-year cycle

New LASP Facility for End-to-End Calibration

- compare each TSI instrument against NIST-calibrated cryogenic radiometer in the TSI Radiometer Facility (TRF)

Glory TSI agrees to 200 ppm

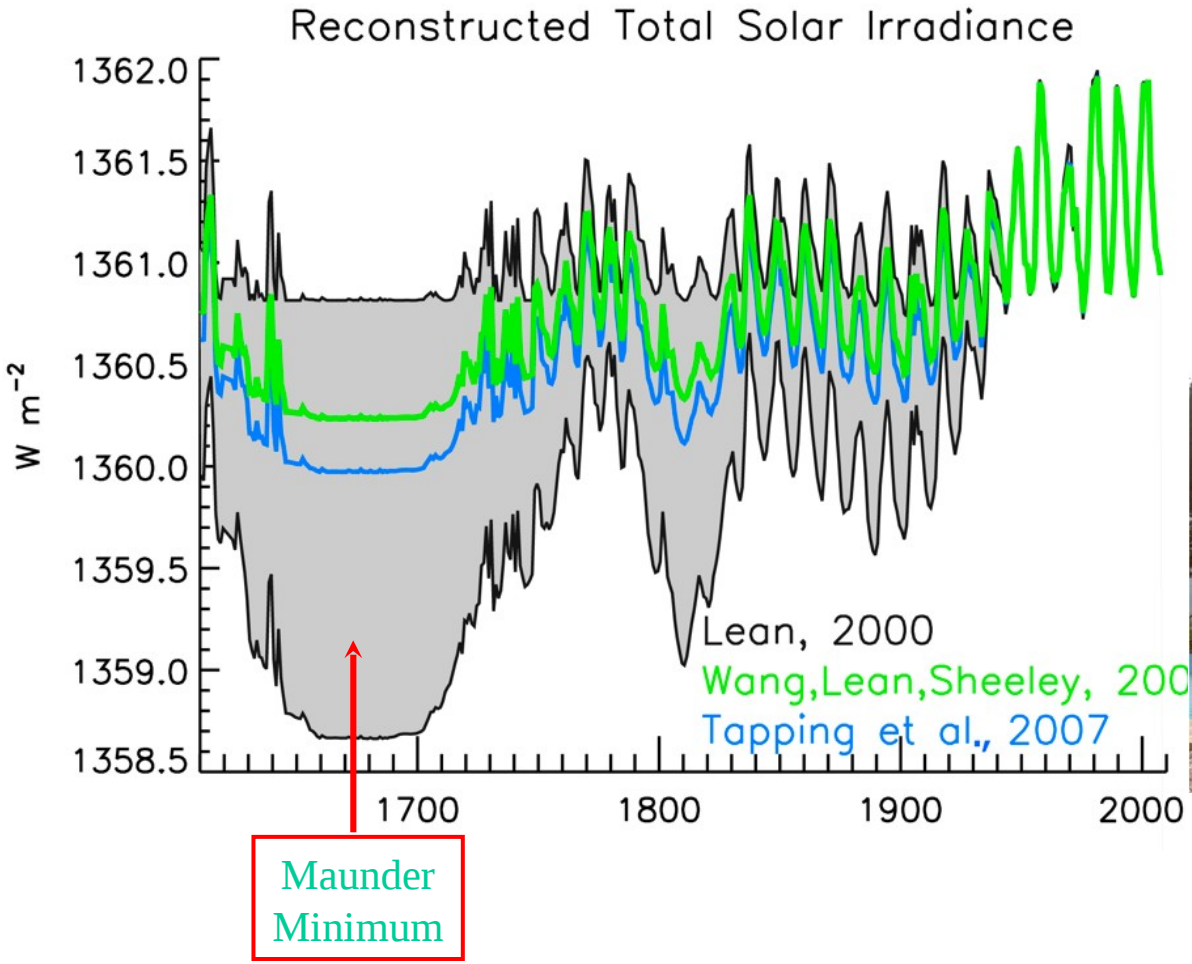
PICARD PMO instrument at TRF late summer



Facility	SI Reference	Operating Conditions	Comments
Table Mountain	none	•vacuum •solar viewing •window transmission •circumsolar scatter	no link to SI and scatter effects limit usefulness of comparison
World Radiation Reference (WRR)	linked to NPL (with high uncertainties)	•solar viewing •air operations •circumsolar scatter	air operations and scatter limit absolute accuracy
NRL Cryo Radiometer	NIST calibrated cryo radiometer	•vacuum •solar power level	not built
TSI Radiometer Facility (TRF)	NIST calibrated cryo radiometer	•vacuum •solar power level	proven on Glory/TIM

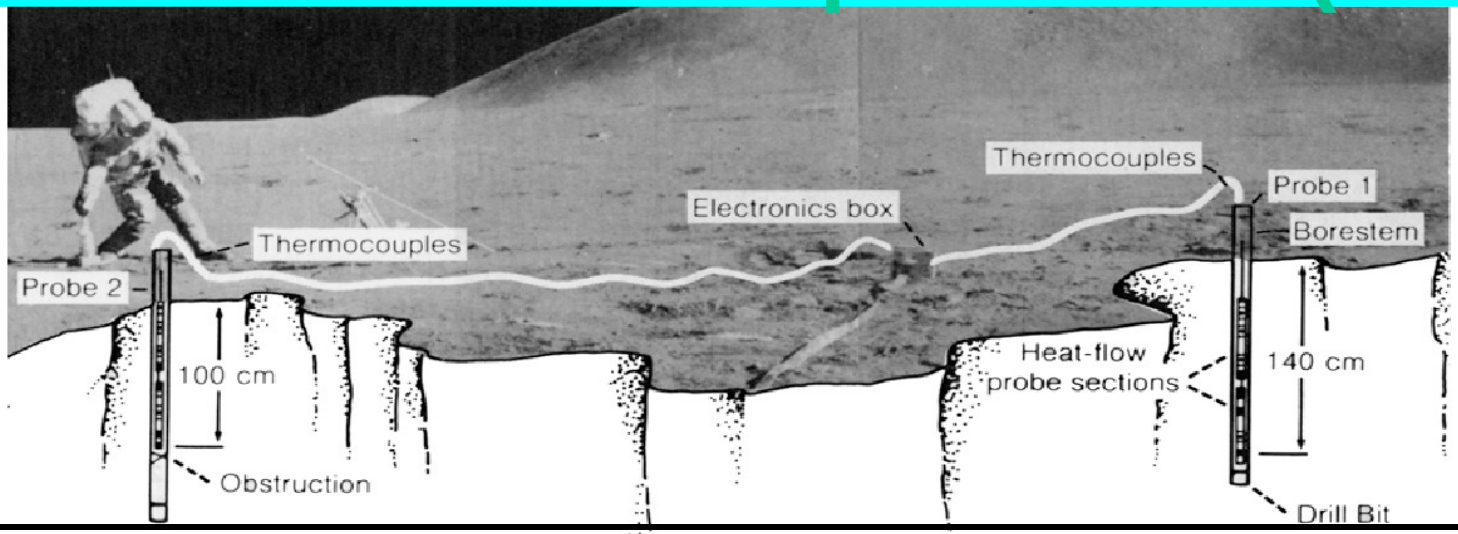
Long-Term Reconstructions

- **Improved solar models will enable improved reconstruction of the irradiance back to the Maunder Minimum**



Current Estimate for Maunder Minimum 400-year Variability 0.07% = 1 W/m²

Apollo Heat Flow Experiments (HFEs)



Heat Flow Experiments (HFEs) from Apollo 15 & 17 show very small thermal diffusivity of lunar regolith ≈ $10^{-8} m^2/s$, 100 X smaller than that of Earth's crust.

Temperature anomalies as response to two scenarios of reconstructed TSI at the equator, mid-latitude and near south pole.