CLIMATE CHANGE: THE SUN'S ROLE

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FOR

HUGH'S 80TH!

BACKGROUND MATERIALS

IPCC: Climate Change 2001: Working Group I: The Scientific Basis:
http://www.grida.no/climate/ipcc_tar/wg1/index.htm

A Global Warming Primer [July 2002]:
http://gemarsh.com

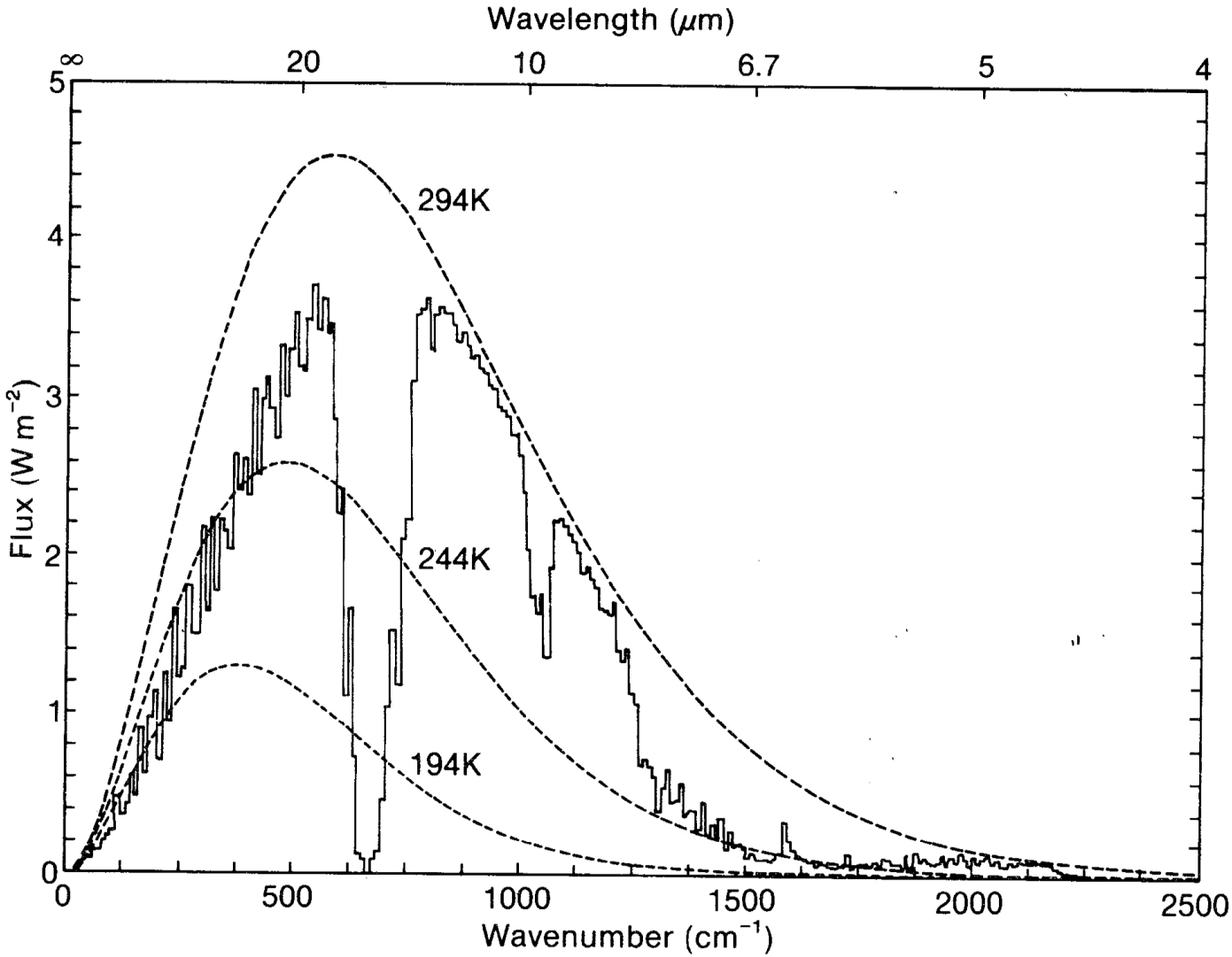
Climate Change: The Sun's Role [June 2007]:
http://gemarsh.com

Click on Category: Global Warming.

WHY THE SUN AND NOT JUST CO_2?

- **SUBSTANTIAL RESEARCH INDICATES THAT SOLAR VARIATION MAY ACCOUNT FOR 50%-100% OF THE NET WARMING OF 0.7°C-1.5°C OVER THE LAST 350 YEARS.**

- **CO_2 IS A *MINOR* BUT IMPORTANT GREENHOUSE GAS: WATER VAPOR IS RESPONSIBLE FOR UP TO 90% OF THE GREEN-HOUSE EFFECT.**



BLACK BODY EMISSION FOR 194 °K, 244 °K AND 294 °K (DASHED LINES). NET FLUX AT THE TROPOPAUSE—CLEAR-SKY, 294 °K (SOLID LINE). PRIMARY CO_2 ABSORPTION BANDS ARE AT 4.26 μ, 7.52 μ, AND 14.99 μ. FROM: IPCC 1990 REPORT.

RADIATIVE FORCING-I

DEFINED AS THE CHANGE IN NET DOWNWARD RADIATIVE FLUX AT THE TROPOPAUSE RESULTING FROM ANY PROCESS THAT ACTS AS AN EXTERNAL AGENT TO THE CLIMATE SYSTEM.

CHANGE IN FORCING DUE TO A CHANGE IN CO_2 CONCENTRATION:

$$\Delta F = \alpha \ln (C/C_0)\ W/M^2,$$

WHERE C_0 AND C ARE THE INITIAL AND FINAL CO_2 CONCENTRATIONS.

RADIATIVE FORCING-II

SINCE 1990, ESTIMATES BY THE IPCC OF THE COEFFICIENT α VARY AS FOLLOWS:

1990: 6.3 W/M^2
2001: 5.35 W/M^2
2007: 5.5 W/M^2

THESE ESTIMATES "IMPLICITLY INCLUDE THE RADIATIVE EFFECTS OF GLOBAL MEAN CLOUD COVER". BUT, ESTIMATES OF THE RADIATIVE EFFECTS OF CLOUDS ARE QUITE UNCERTAIN.

INCLUDING A SOLAR COMPONENT, THIS STUDY FINDS THAT $\alpha \sim 3.5$ W/M^2. THIS MEANS THAT THE EARTH IS FAR LESS SENSITIVE TO CHANGES IN CO_2 CONCENTRATION THAN ESTIMATED BY THE IPCC.

THE SOLAR "CONSTANT"

- **NOMINAL RADIATION DENSITY [IRRADIANCE] FROM THE SUN [1367 W/M^2] IS CALLED THE SOLAR CONSTANT.**

- **THE SOLAR CONSTANT IS NOT CONSTANT. DURING THE LITTLE ICE AGE, THE BRIGHTNESS OF THE SUN IS ESTIMATED TO HAVE DECREASED BY 0.5% OR 6.8 W/M^2.**

- **ACTUAL IRRADIANCE MONITORED BY SPACECRAFT SINCE 1978: OUTPUT VARIED BY 0.15% OR 2 W/M^2.**

FORCING AND TEMPERATURE RISE

FORCING DUE TO CHANGE IN THE SOLAR CONSTANT:

$$\Delta F = \frac{\pi r^2}{4\pi r^2}(1 - 0.31)\,\Delta I = 0.1725\,\Delta I$$

r = RADIUS OF THE EARTH; ΔF = CHANGE IN RADIATIVE FORCING;

ΔI = CHANGE IN SOLAR IRRADIANCE; 0.31 FROM EARTH'S ALBEDO

IPCC METHODOLOGY GIVES THE RISE IN TEMPERATURE AT THE SURFACE OF THE EARTH AS $\Delta T_S = 0.476 \times \Delta F$ FOR *ANY* CHANGE IN FORCING ΔF (THIS INCLUDES THE EFFECT OF WATER VAPOR).

EXAMPLES:

A DOUBLING OF CO_2 IMPLIES A FORCING OF $\Delta F = 4$ W/M^2 THIS CORRESPONDS TO A RISE IN SURFACE TEMPERATURE OF $\Delta T_S = 1.9\ ^{O}C$

A CHANGE OF 1 W/ M^2 IN SOLAR FORCING WOULD RAISE THE SURFACE TEMPERATURE OF THE EARTH BY 0.476 ^{O}C

TOTAL SOLAR IRRADIANCE & SUNSPOT NUMBER

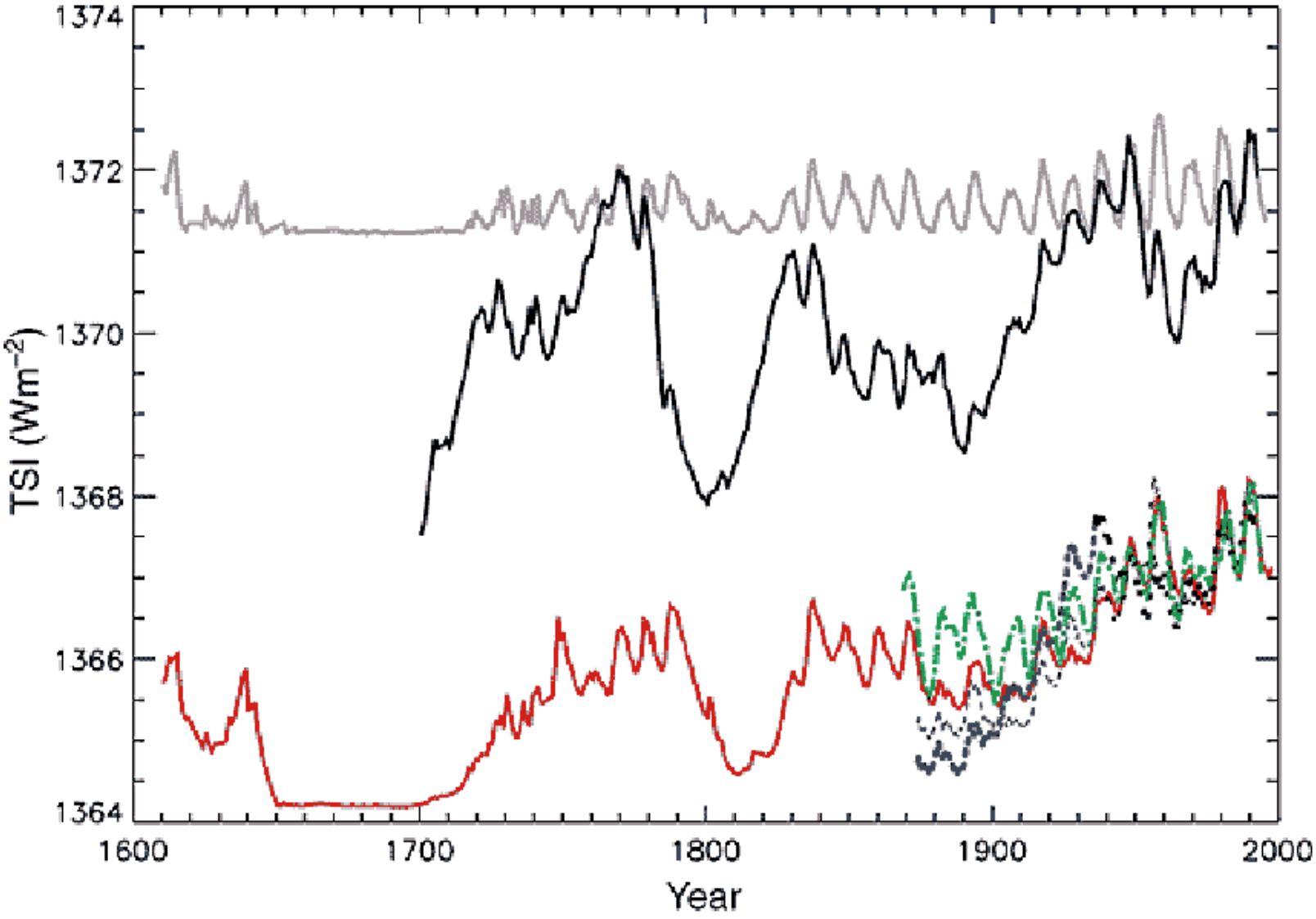


FIG. 6.5 OF *CLIMATE CHANGE 2001: THE SCIENTIFIC BASIS*

SIMPLE PHENOMENOLOGICAL ESTIMATE OF CLIMATE CHANGE DUE TO SOLAR VARIATION

- **GLOBAL TEMPERATURE CHANGE DURING LITTLE ICE AGE (LIA) ESTIMATED TO BE 0.3-0.5 ^{o}C ~ 0.4 ^{o}C.**
- **CHANGE IN TSI BETWEEN LIA AND ~1850 IS ~1.75 W/M^2 OR, IN TERMS OF FORCING δF = 0.3 W/M^2.**
- **THEREFORE, SENSITIVITY OF EARTH TO CHANGES IN SOLAR FORCING (INCLUDING ALL FEEDBACKS) IS**

$$\delta T / \delta F = 0.4\ ^{o}\text{C}/0.3\ \text{W/M}^2 = 1.33\ ^{o}\text{C W}^{-1}\ \text{M}^2.$$

SIMPLE PHENOMENOLOGICAL ESTIMATE (CONT)

- **CHANGE IN SOLAR IRRADIANCE SINCE 1900 IS ~1.5 W/M^2 CORRESPONDING TO $\Delta F = 0.26$ W/M^2.**

- **THEREFORE, THE CHANGE IN TEMPERATURE SINCE 1900 DUE TO SOLAR VARIATION IS**

$$\Delta T = \Delta F \, (\delta T / \delta F) = 1.33 \, ^{o}\text{C W}^{-1} \text{M}^2 \text{ X } 0.26 \text{ W/M}^2 = 0.35 \, ^{o}\text{C}$$

- **SINCE THE RISE IN TEMPERATURE SINCE 1900 HAS BEEN ~0.7 ^{o}C, THE INCREASE IN SOLAR ACTIVITY IS RESPONSIBLE FOR ~50%.**

SIMPLE PHENOMENOLOGICAL ESTIMATE (CONT)

THERE HAS BEEN A 2007 *MODEL-DEPENDENT* RESCALING BY A FACTOR OF 0.27 OF THE LOWER CURVE OF THE FIGURE SHOWN EARLIER BY THE IPCC. THE APPROACH USED HERE IS INDEPENDENT OF SUCH A RESCALING SINCE BOTH ΔF AND δF CHANGE BY THE SAME FACTOR.

[YANG, LEAN, AHD SHEELEY, JR., *AP.J.* 625, 522 (2005) AND 2007 IPCC REPORT]

A SECOND INDEPENDENT ESTIMATE OF SURFACE TEMPERATURE CHANGE DUE TO THE SUN

SOLAR VARIATIONS AND FEEDBACK

- **TO AFFECT CLIMATE, SMALL OBSERVED VARIATIONS IN SOLAR IRRADIANCE REQUIRE A POSITIVE FEEDBACK OF SIGNIFICANT MAGNITUDE.**

- **THE FOCUS HERE WILL BE ON THE CORRELATION BETWEEN SOLAR ACTIVITY AND VARIATIONS IN THE EARTH'S ALBEDO.**

CHANGES IN CLOUD COVER AND RADIATIVE FORCING-I

- **SIMPLE APPROXIMATION:**

SOLAR IRRADIANCE = I = 1365 W/M^2; ALBEDO = A = 0.3.

EARTH REFLECTS: IA = 409.5 W/M^2

CORRESPONDS TO A RADIATIVE FORCING OF 102.4 W/M^2

- **IPCC MAINTAINS THAT CLOUDS ARE RESPONSIBLE FOR ~60% OF THE 102.4 W/M^2 OR 61.4 W/M^2.**

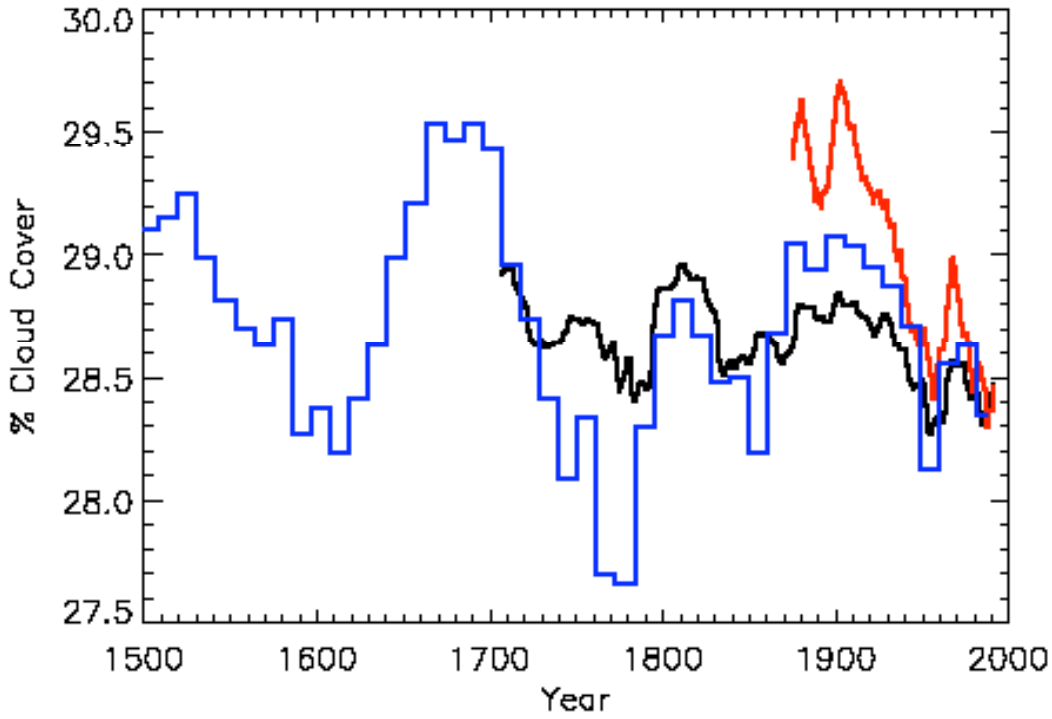
- **THEREFORE: A 1% CHANGE IN CLOUD COVER CORRESPONDS TO A NET FORCING OF ~1 W/M^2.**

CHANGES IN CLOUD COVER AND RADIATIVE FORCING-II

- **GENERALLY ACCEPTED OVERALL CLIMATE SENSITIVITY TO RADIATIVE FORCING IS 0.53 ^{o}C W^{-1}M^{2}.**

- **THIS MEANS A FORCING OF ~1 W/M^{2} FROM A 1% CHANGE IN CLOUD COVER CORRESPONDS TO A TEMPERATURE CHANGE OF 0.53 ^{o}C.**

CLOUD COVER 1500-2000

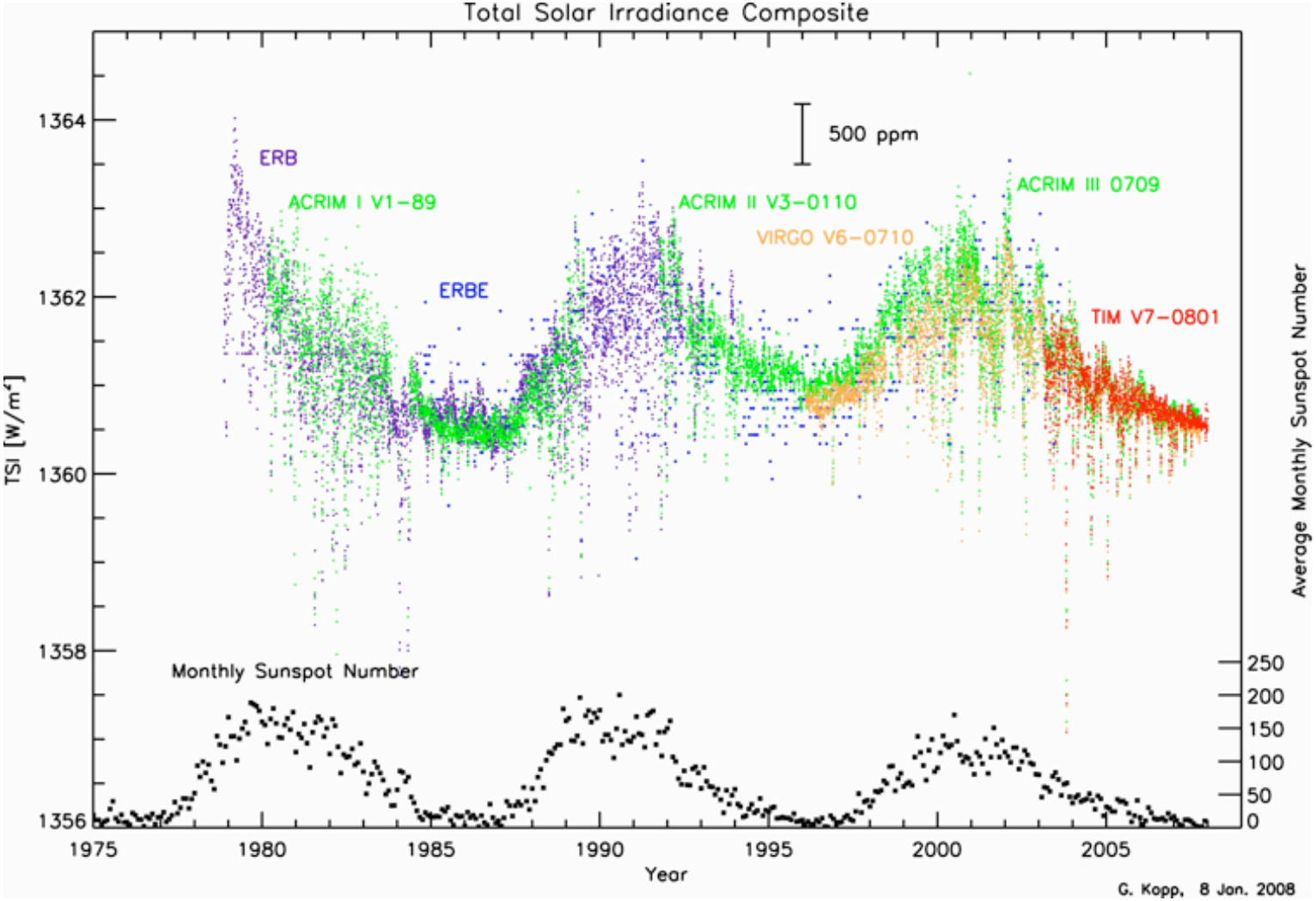


THE 11-YEAR SMOOTHED RECONSTRUCTED CLOUD COVER FOR THE WHOLE EARTH DERIVED FROM THE ZURICH SUNSPOT NUMBER (MIDDLE CURVE), THE AA INDEX (TOP CURVE), AND THE HELIOCENTRIC POTENTIAL (THE CURVE EXTENDING FROM THE YEAR 1500). FROM E.P. BAGO AND C.J. BUTLER, *ASTRONOMY AND GEOPHYSICS* 41, 18 (2000).

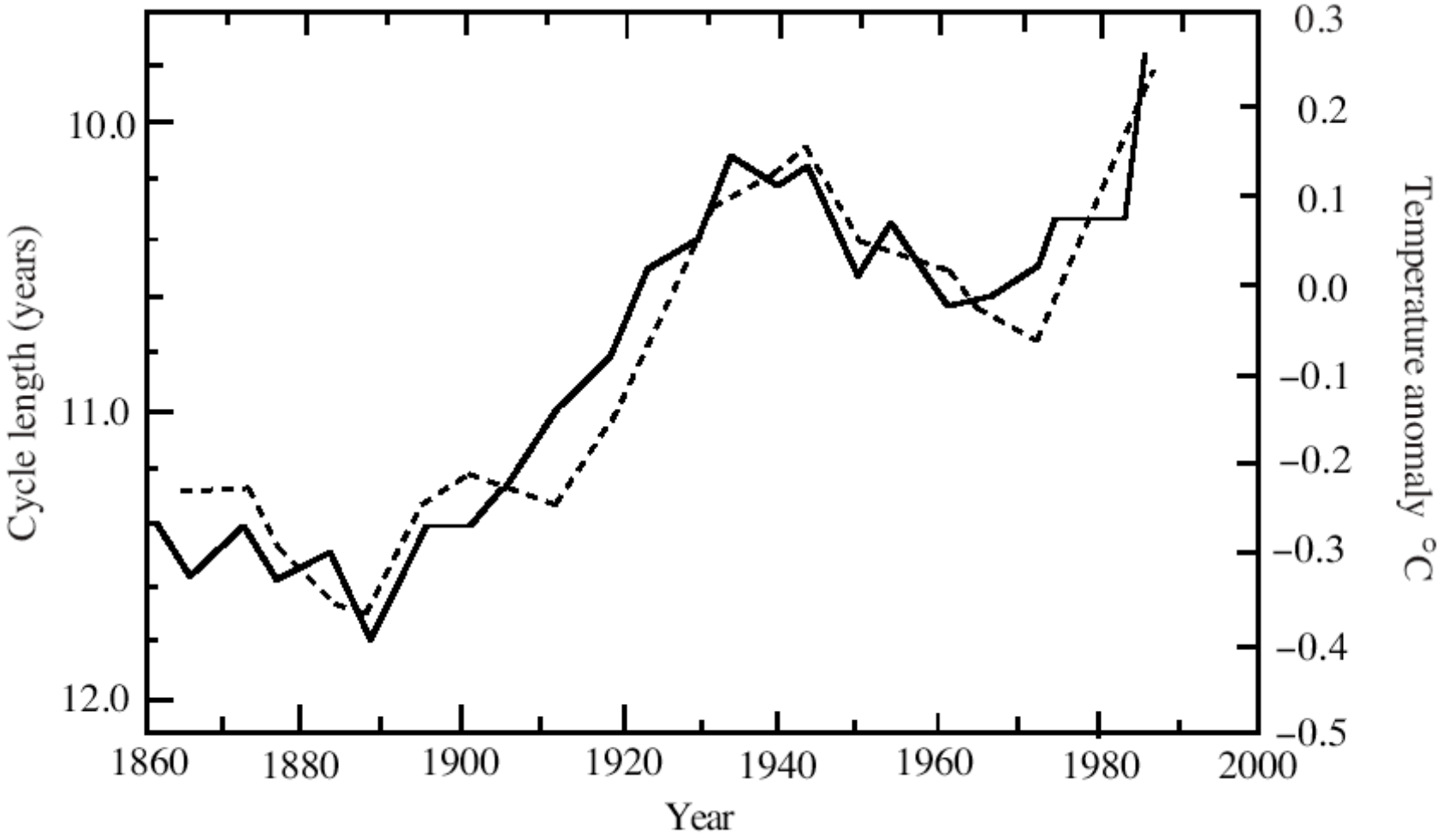
- **THIS SHOWS A DECREASE IN CLOUD COVER OF ~0.7% SINCE 1900 (USING THE MIDDLE CURVE). CORRESPONDS TO $\Delta F \sim 0.7\ W/M^2$.**
- **THE GENERALLY ACCEPTED VALUE OF CLIMATE SENSITIVITY TO RADIATIVE FORCING IS 0.53 $^{O}C\ W^{-1}M^2$. THIS GIVES A TEMPERATURE RISE OF 0.37 ^{O}C—VERY CLOSE TO THE VALUE OF 0.35 ^{O}C ESTIMATED EARLIER FROM THE LITTLE ICE AGE. THESE ARE INDEPENDENT ESTIMATES!**

SOLAR ACTIVITY

COMPOSITE TOTAL SOLAR IRRADIANCE



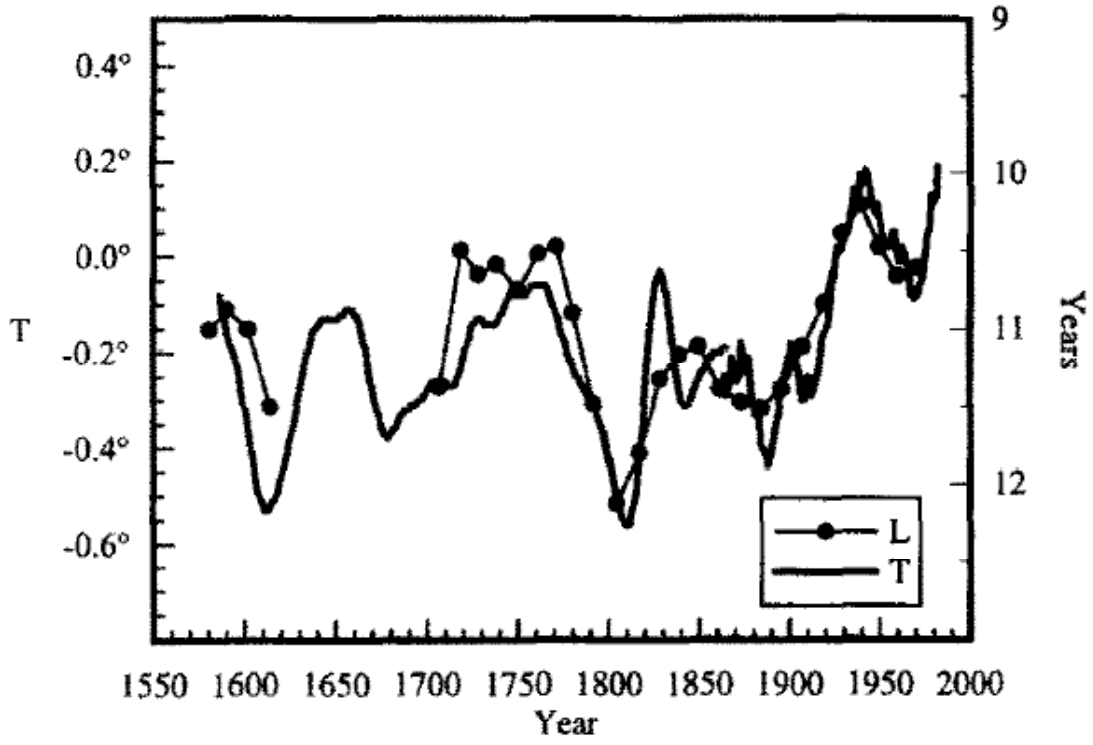
SOLAR CYCLE LENGTH & TEMPERATURE ANOMALIES-I



ADAPTED FROM E. FRIIS-CHRISTENSEN AND K. LASSEN *SCIENCE* 254, 698 (1991)

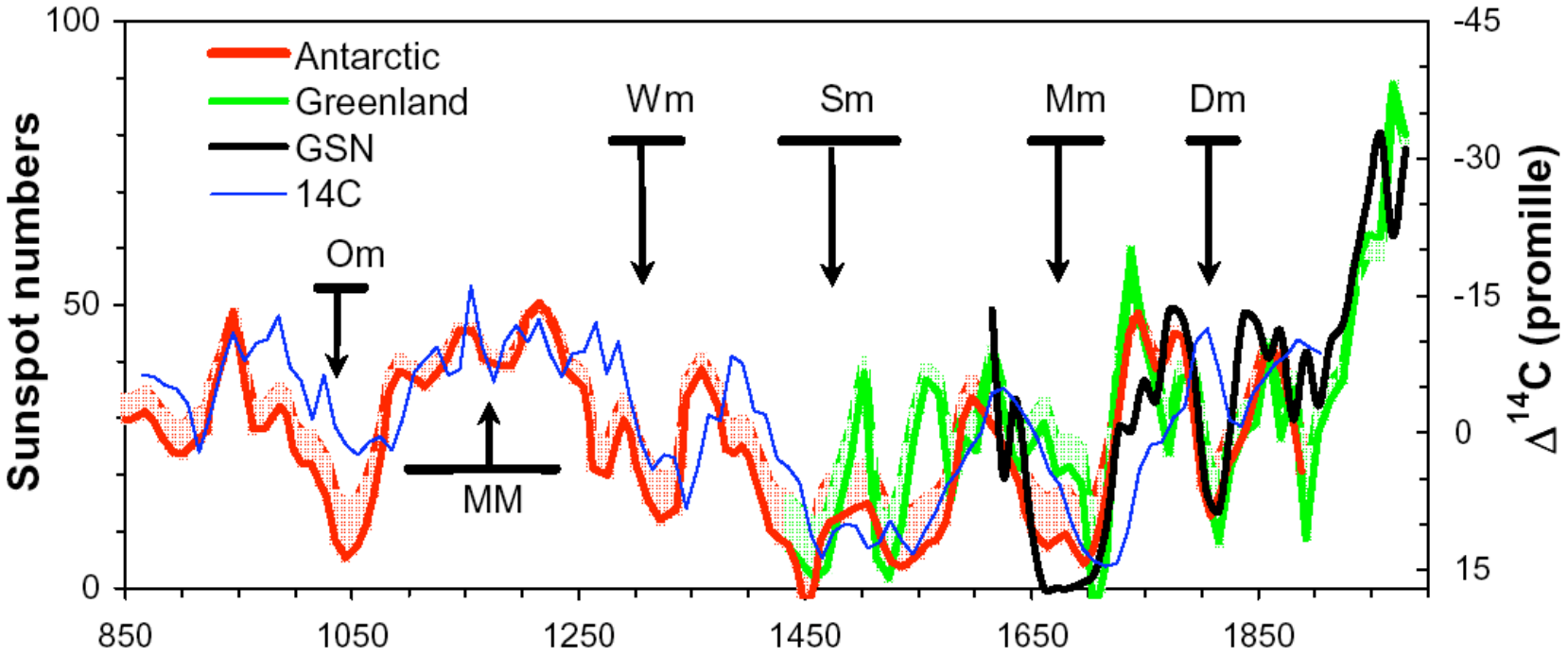
SOLID CURVE: SOLAR CYCLE LENGTH. DASHED CURVE: NORTHERN HEISPHERE TEMPERATURE ANOMALIES RELATIVE TO THE PERIOD 1951-1980.

SOLAR CYCLE LENGTH &TEMPERATURE ANOMALIES-II



11-YEAR AVERAGE VALUES OF THE NORTHERN HEMISPHERE LAND TEMPERATURE (T), BEFORE 1860 ESTIMATED BY MEANS OF TREE RING ANALYSES, AND LONG TERM VARIATION OF SOLAR ACTIVITY EXPRESSED BY THE LENGTH (L, YEARS) OF THE SUN SPOT CYCLE (BEFORE 1850 ESTIMATED BY MEANS OF AURORAL OBSERVATIONS). FROM EIGIL FRIIS-CHRISTENSEN AND HENRIK SVENSMARK, *ADV. SPACE RES.* VOL. 20, NO. 415, PP. 913-921 (1997).

SUNSPOT NUMBERS 850 CE-PRESENT



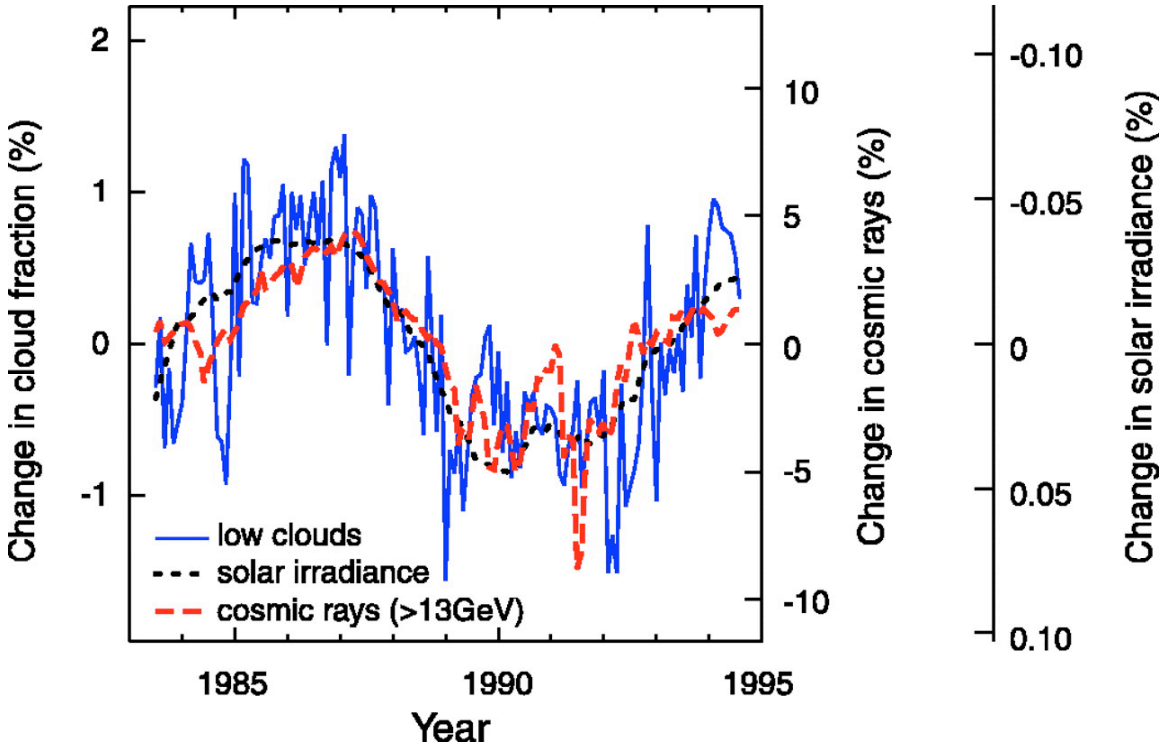
FROM: I. G. USOSKIN, ET AL., *PHYS. REV. LETT.* 91, 211101 (2003).
Mm = MAUNDER MINIMUN, MM = MEDIEVAL MAXIMUM. "THE MOST STRIKING FEATURE OF THE CONPLETE SN PROFILE IS THE UNIQUENESS OF THE STEEP RISE OF SUNSPOT ACTIVITY DURING THE FIRST HALF OF THE TWENTIETH CENTURY. NEVER DURING THE 11 CENTURIES PRIOR TO THAT WAS THE SUN NEARLY AS ACTIVE."

GALACTIC COSMIC RAYS & SOLAR ACTIVITY

- **AN INCREASE IN SOLAR ACTIVITY MEANS THE "SOLAR WIND"—MADE UP OF ELECROMAGNETIC RADIATION AND ENERGETIC PARTICLES—DRIVES MATTER AND MAGNETIC FLUX TRAPPED IN THE PLASMA OF THE INTER-PLANETARY MEDIUM OUTWARD CREATING THE "HELIOSPHERE". THIS SHIELDS THE EARTH FROM GALACTIC COSMIC RAYS.**

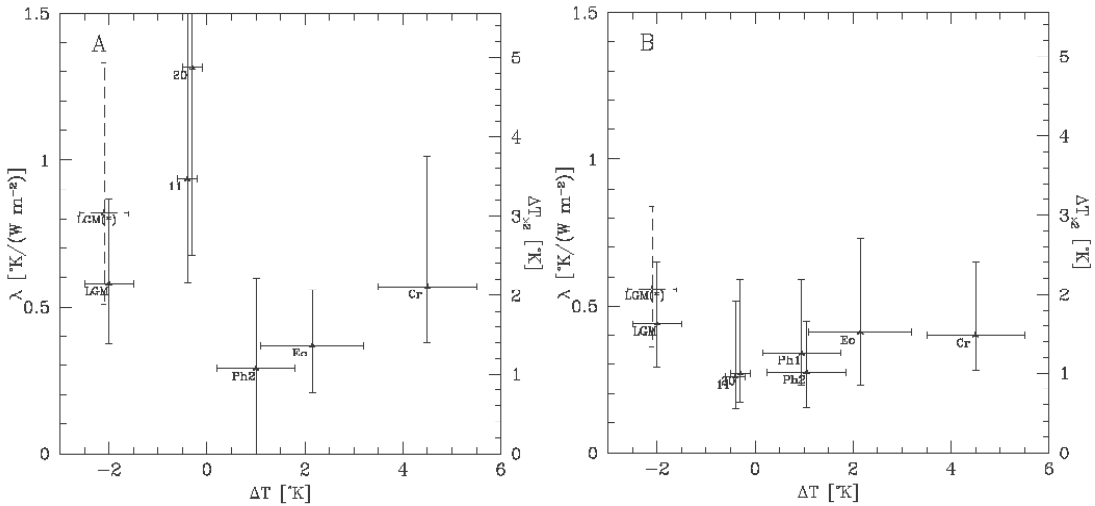
- **SOLAR VARIABILITY AFFECTS THE SUN'S IRRADIANCE AND MODULATES GALACTIC COSMIC RADIATION STRIKING THE EARTH'S ATMOSPHERE.**

COSMIC RAYS & CLOUD COVER



VARIATIONS OF LOW-ALTITUDE CLOUD COVER (LESS THAN ABOUT 3 KM), COSMIC RAYS, AND TOTAL SOLAR IRRADIANCE BETWEEN 1984 AND 1994. FROM K.S. CARSLAW, R.G. HARRISON, AND J. KIRKBY, *SCIENCE* 298, 1732 (2002). NOTE THE INVERTED SCALE FOR SOLAR IRRADIANCE.

COSMIC RAYS AND CLIMATE SENSITIVITY



ESTIMATED SENSITIVITY λ AS A FUNCTION OF THE DIFFERENCE BETWEEN THE TEMPERATURE TODAY AND THE TIME IN THE PAST FOR WHICH THE SENSITIVITY WAS CALCULATED. VALUES ARE FOR THE LAST GLACIAL MAXIMUM (LGM), THE 11 YEAR SOLAR CYCLE OVER THE PAST 200 YEARS (11), 20TH CENTURY GLOBAL WARMING (20), PHANEROZOIC BY COMPARISON OF THE TROPICAL TEMPERATURE TO COSMIC RAY FLUX VARIATIONS (Ph1) OR CARBON DIOXIDE VARIATIONS (Ph2), EOCENE (Eo) AND MID-CRETACEOUS (Cr). FROM N. J. SHAVIV, *JOURNAL OF GEOPHYSICAL RESEARCH* 110, A08105 (2005).

COSMIC RAYS AND CLIMATE SENSITIVITY (CONTINUED)

- ***OVERALL*** **CLIMATE SENSITIVITY (INCLUDING LINK TO COSMIC RAY FLUX) À LA SHAVIV IS $\lambda = 0.34\ ^{o}C\ W^{-1}\ M^{2}$.**

- **0.7% DECREASE IN CLOUD COVER—OBSERVED SINCE 1900—CORRESPONDS TO A NET RADIATIVE FORCING OF 0.7 W/M^{2}.**

- **THEREFORE, INCREASE IN EARTH'S TEMPERATURE SINCE 1900 DUE TO THE DECREASE IN ALBEDO IS**

$$\Delta T_{CL} = 0.34\ ^{o}C\ W^{-1}\ M^{2}\ X\ 0.7\ W/M^{2} = 0.24\ ^{o}C$$

COSMIC RAYS AND CLIMATE SENSITIVITY (CONTINUED)

- **IPCC GIVES THE RISE IN RADIATIVE FORCING DUE TO THE INCREASE IN SOLAR IRRADIATION SINCE 1750 (EQUALS THAT IN 1900) AS 0.12 W/M^2. THE TEMPERATURE CHANGE DUE TO THIS MUST BE ADDED TO THAT DUE TO ALBEDO DECREASE.**

$$\Delta T_{IR} = 0.34\ ^{o}C\ W^{-1}\ M^2\ X\ 0.12\ W/M^2 = 0.04\ ^{o}C$$

- **TOTAL TEMPERATURE CHANGE SINCE 1900 DUE TO DECREASE IN ALBEDO AND INCREASE IN SOLAR IRRADIANCE IS THEN $\Delta T = \Delta T_{CL} + \Delta T_{IR} = 0.28\ ^{o}C$, OR ~40% OF THE TEMPERATURE RISE SINCE 1900.**

IMPLICATIONS

- **THE SUN IS RESPONSIBLE FOR 40-50% OF THE WARMING SINCE 1900. THE IPCC ESSENTIALLY DISMISSES SOLAR INFLUENCE OVER THIS PERIOD.**

- **THE COEFFICIENT α RELATING RADIATIVE FORCING TO CHANGES IN CO_2 CONCENTRATIONS USED BY THE IPCC IS TOO LARGE, MAKING CLIMATE MORE SENSITIVE TO CO_2 INCREASES THAN IT IS.**

IMPLICATIONS (CONT)

- **GLOBAL TEMPERATURE CHANGE SINCE 1900 IS ~0.7 ^{o}C. SUBTRACT 0.3 ^{o}C, THE AVERAGE OF THE THREE PREVIOUS CALCULATIONS. THIS LEAVES 0.4 ^{o}C. USING THE IPCC METHODOLOGY, 0.4 ^{o}C CORRESPONDS TO A RADIATIVE FORCING OF 0.84 W/M^2. THEREFORE, THE VALUE OF α SHOULD BE**

$$\alpha = \Delta F/\ln(C/C_0) = 0.84 \text{ W/M}^2/\ln(381/300) = 3.5 \text{ W/M}^2$$

- **THIS IS 36% LESS THAN THE VALUE USED IN THE 2007 IPCC REPORT.**

HOW DOES THIS COMPARE TO OTHER FINDINGS?

- **J. LEAN, ET AL., *GEOPHYS. RES. LETT.* 22, 3195 (1995):**

74% OF NORTHERN HEMISPHERE TEMPERATURE RISE 1610-1800

56% OF NORTHERN HEMISPHERE TEMPERATURE RISE 1800-PRESENT

- **E. W. CLIVER, ET AL., *GEOPHYS. RES. LETT.* 25, 1035 (1998):**

50-100% OF NET WARMING OF 0.7-1.5 ^{o}C OVER LAST 350 YRS

- **OTHER AUTHORS FIND SIMILAR RESULTS [SEE THE *GLOBAL WARMING PRIMER*]**

WHAT ABOUT THE REST OF THE WARMING?

JAMES HURRELL AND THE NORTH ATLANTIC OSCILLATION [GEOPHYS. RES. LETT. 23, 665 (1996)]:

"NEARLY ALL OF THE COOLING IN THE NORTHWEST ATLANTIC AND THE WARMING ACROSS EUROPE AND DOWNSTREAM OVER EURASIA SINCE THE MID-1970S RESULTS FROM CHANGES IN THE NAO"

SUMMING IT UP

SINCE GLOBAL AVERAGE TEMPERATURE IS DOMINATED BY TEMPERATURE VARIABILITY OVER NORTHERN LAND MASSES, CHANGES IN THE NAO WHEN COMBINED WITH THE TEMPERATURE RISE DUE TO THE SUN IMPLIES THAT CO_2 MAY BE RESPONSIBLE FOR ONLY A SMALL PORTION OF THE GLOBAL TEMPERATURE RISE SINCE THE MID-1970s