Resolution of Outstanding Issues in Climate Research with Earth Radiation Budget Data: Past and Future

V. Ramanathan

Clouds and the Earth's Radiant Energy System (CERES) Science Team Meeting
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ARTICLES

Observational determination of the greenhouse effect

A. Raval & V. Ramanathan

Department of Geophysical Sciences, University of Chicago, Chicago, Illinois 60637, USA

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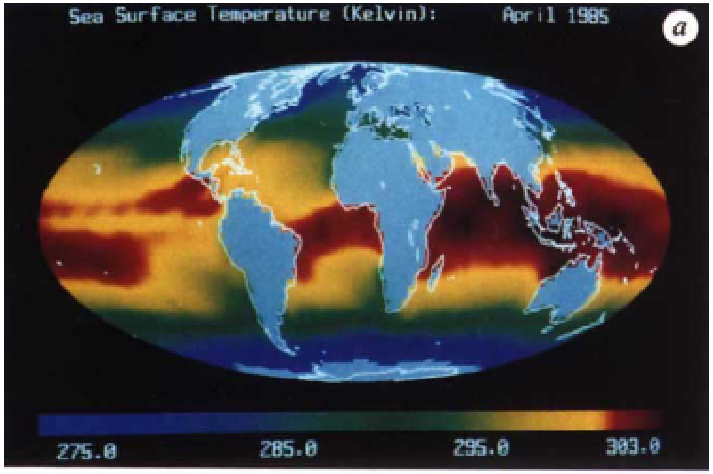


Raval, A. and V. Ramanathan, 1989: Observational Determination of the Greenhouse Effect. Nature, 342: 758-761

Earth Radiation Budget Experiment: { Joined Team in 1975}

History:

Proposed by: NASA Langley Research Center

Original Team Proposing the Mission: 1974-1976
George Sweet; George Young; E. Harrison; L. Smith and Post Doc (V. Ramanathan)

Science Team Chairman (>1978): B. Barkstrom

The work described here involved Collaboration with:
Barkstrom; Harrison; Cess; Coakley; Wielicki
and numerous post docs and students from 1985 to 2011.

Reprinted from
3 October 1975, Volume 190, pp. 50-52

SCIENCE

1975

Greenhouse Effect Due to Chlorofluorocarbons: Climatic Implications

V. Ramanathan
NASA Langley Research Center, Hampton ,VA

Abstract. ***The infrared bands of chlorofluorocarbons and chlorocarbons enhance the atmospheric greenhouse effect. This enhancement may lead to an appreciable increase in the global surface temperature if the atmospheric concentrations of these compounds reach values of the order of 2 parts per billion.***

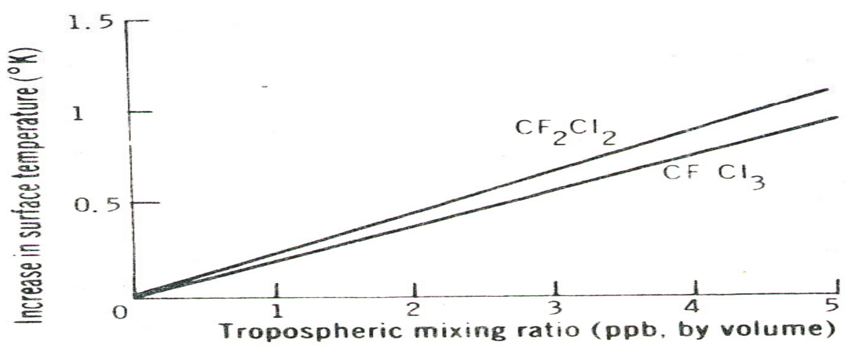


Fig. 1. Increase in global surface temperature is a function of the tropospheric concentrations of CF_2Cl_2 and $CFCl_3$. Results are for globally averaged conditions with 50 percent cloud cover.

PART-A: Determination of Forcing

I. Cloud-Radiative Forcing

II. Atmospheric Greenhouse Effect

III. Atmospheric Solar Absorption

The Albedo Field and Cloud Radiative Forcing Produced by a General Circulation Model with Internally Generated Cloud Optics

THOMAS P. CHARLOCK AND V. RAMANATHAN*

Atmospheric Sciences Division, NASA Langley Research Center, Hampton, VA

(Manuscript received 24 September 1984, in final form 19 February 1985)

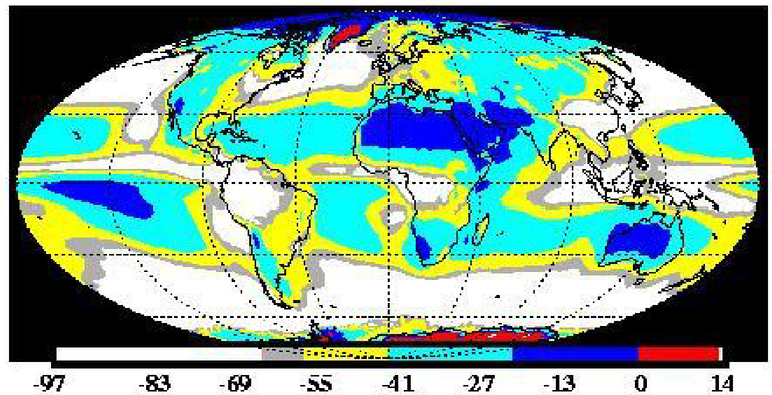
ABSTRACT

A spectral general circulation model (GCM) is run for perpetual January with fixed sea surface temperature conditions. It has internally generated, variable cloud optical properties as well as variable cloud areas and heights. The cloud optics are calculated as functions of the cloud liquid water contents. The cloud liquid water contents are in turn generated by the model hydrological cycle. Model generated and satellite albedos are in rough agreement. An analysis of the cloud radiative forcing indicates that cloud albedo (cooling) effects overcome cloud infrared opacity (heating) effects in most regions, which is in accord with the inferences from satellite radiation budget measurements. Furthermore, both the computed and observed albedo of clouds decrease from low to high altitudes. When compared to a version of the model with fixed cloud optics, the model with variable cloud optics produces significantly different regional albedos, especially over the tropics. The cloud droplet size distribution is also found to have a significant impact on the model albedos. The temperature of the tropical upper troposphere is somewhat sensitive to the microphysical characteristics of the model cirrus clouds.

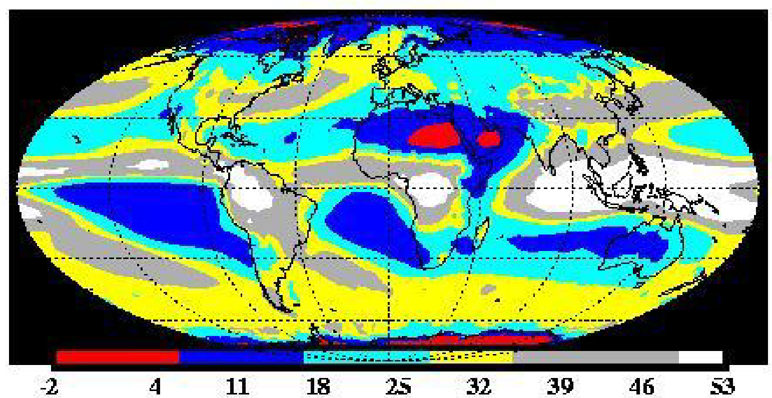
The present study is an attempt to calculate the regional albedo of the planet more rigorously than has been done previously. Simplifying assumptions relating to cloud droplet size and lifetime must still be made. The model's results for the radiation budget are encouraging, and it seems that the hydrological cycles of GCMs are sufficiently realistic to warrant a more physically based (than the one employed here) treatment of cloud microphysical and radiative processes.

Charlock, T. P. and V. Ramanathan, 1985: The Albedo Field and Cloud Radiative Forcing Produced by a General Circulation Model with Internally Generated Cloud Optics. J. Atmos. Sci., 42: 1408-1429

OBSERVED (ERBE) SW CLOUD FORCING [W m^{-2}], 1985-1989



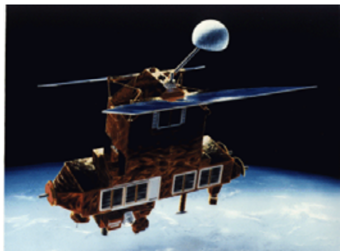
OBSERVED (ERBE) LW CLOUD FORCING [W m^{-2}], 1985-1989

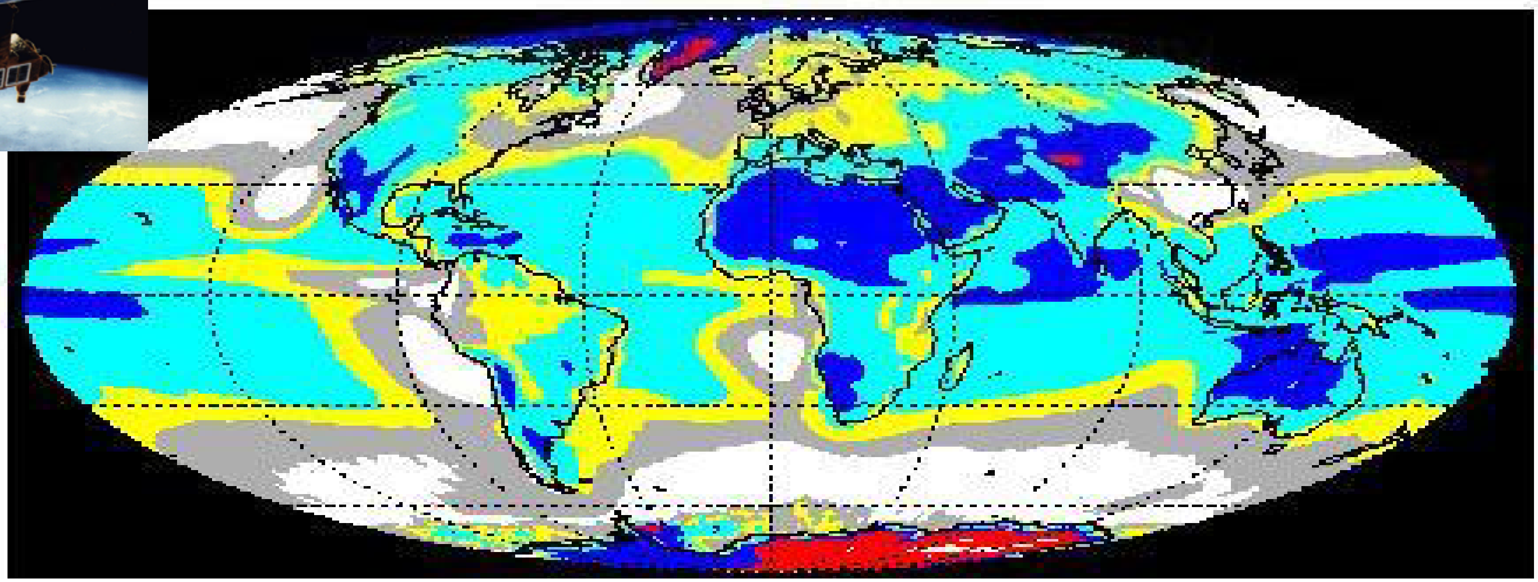


Source: Ramanathan et al (1989 & 1991); Harrison et al (1990)

OBSERVED (ERBE) NET CLOUD FORCING [$W\ m^{-2}$], 1985-1989

Ramanathan et al, Science 1989
Harrison et al, 1990





Cloud-Radiative Forcing and Climate: Results from the Earth Radiation Budget Experiment

V. Ramanathan, R. D. Cess, E. F. Harrison, P. Minnis, B. R. Barkstrom,
E. Ahmad, D. Hartmann

The study of climate and climate change is hindered by a lack of information on the effect of clouds on the radiation balance of the earth, referred to as the cloud-radiative forcing. Quantitative estimates of the global distributions of cloud-radiative forcing have been obtained from the spaceborne Earth Radiation Budget Experiment (ERBE) launched in 1984. For the April 1985 period, the global shortwave cloud forcing [−44.5 watts per square meter (W/m^2)] due to the enhancement of planetary albedo, exceeded in magnitude the longwave cloud forcing (31.3 W/m^2) resulting from the greenhouse effect of clouds. Thus, clouds had a net cooling effect on the earth. This cooling effect is large over the mid- and high-latitude oceans, with values reaching −100 W/m^2. The monthly averaged longwave cloud forcing reached maximum values of 50 to 100 W/m^2 over the convectively disturbed regions of the tropics. However, this heating effect is nearly canceled by a correspondingly large negative shortwave cloud forcing, which indicates the delicately balanced state of the tropics. The size of the observed net cloud forcing is about four times as large as the expected value of radiative forcing from a doubling of CO_2. The shortwave and longwave components of cloud forcing are about ten times as large as those for a CO_2 doubling. Hence, small changes in the cloud-radiative forcing fields can play a significant role as a climate feedback mechanism. For example, during past glaciations a migration toward the equator of the field of strong, negative cloud-radiative forcing, in response to a similar migration of cooler waters, could have significantly amplified oceanic cooling and continental glaciation.

How these two competing effects of clouds vary with time, geography, or cloud type and structure is not well understood; nor do we know how clouds modulate meridional and regional radiative heating. Such heating drives the general circulation of the atmosphere and oceans. Significantly different estimates of cloud radiative effects have been used in models of past and future climates. In short, the fundamental question, whether clouds cool or warm the climate, has remained unanswered.

Cloud-radiative interactions represent a large source of uncertainty in several areas including: (i) the prediction of climate changes associated with an anthropogenic increase in trace gases, and (ii) the understanding of past and future climate changes caused by variations in the solar constant or the orbital parameters of the earth (*3*, *4*). General circulation model (GCM) studies (*4*) have contributed to our understanding of cloud-climate feedback, and limited observational studies (*5*) have aided the identification of complex mechanisms of cloud-climate interaction. However, a global perspective on cloud-radiative interactions based on observations has been lacking.

Observations of the modulation of the solar and LW radiation fluxes by clouds can provide needed insights into the cloud-climate interaction. Such modulations are called the shortwave (SW) and longwave cloud-radiative forcing (*6*). We have obtained quantitative estimates of the global distributions of SW and LW forcing from the Earth Radiation Budget Experiment (ERBE), a system of satellites that provides data on incoming and emitted radiation (*7*). In this article, we develop the cloud-radiative forcing concept, describe global variations in the forcing on the basis of the ERBE data, and, finally, discuss the implications of these data for understanding past and future climatic changes.

Description of ERBE. The ERBE includes three satellites in different orbits, a system that improves temporal sampling and can provide data on diurnal variations. The Space Shuttle Challenger

Ramanathan, V., R. D. Cess, E. F. Harrison, P. Minnis, B. R. Barkstrom, E. Ahmad, and D. Hartmann, 1989: Cloud-Radiative Forcing and Climate: Results from the Earth Radiation Budget Experiment. Science, 243: 57-63

Observational determination of the greenhouse effect

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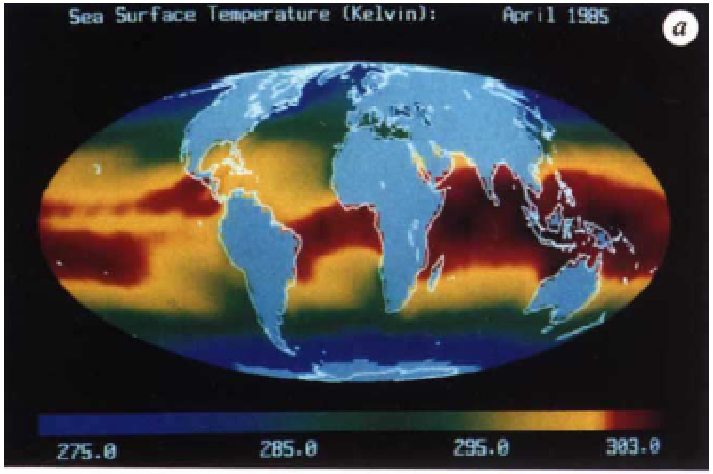

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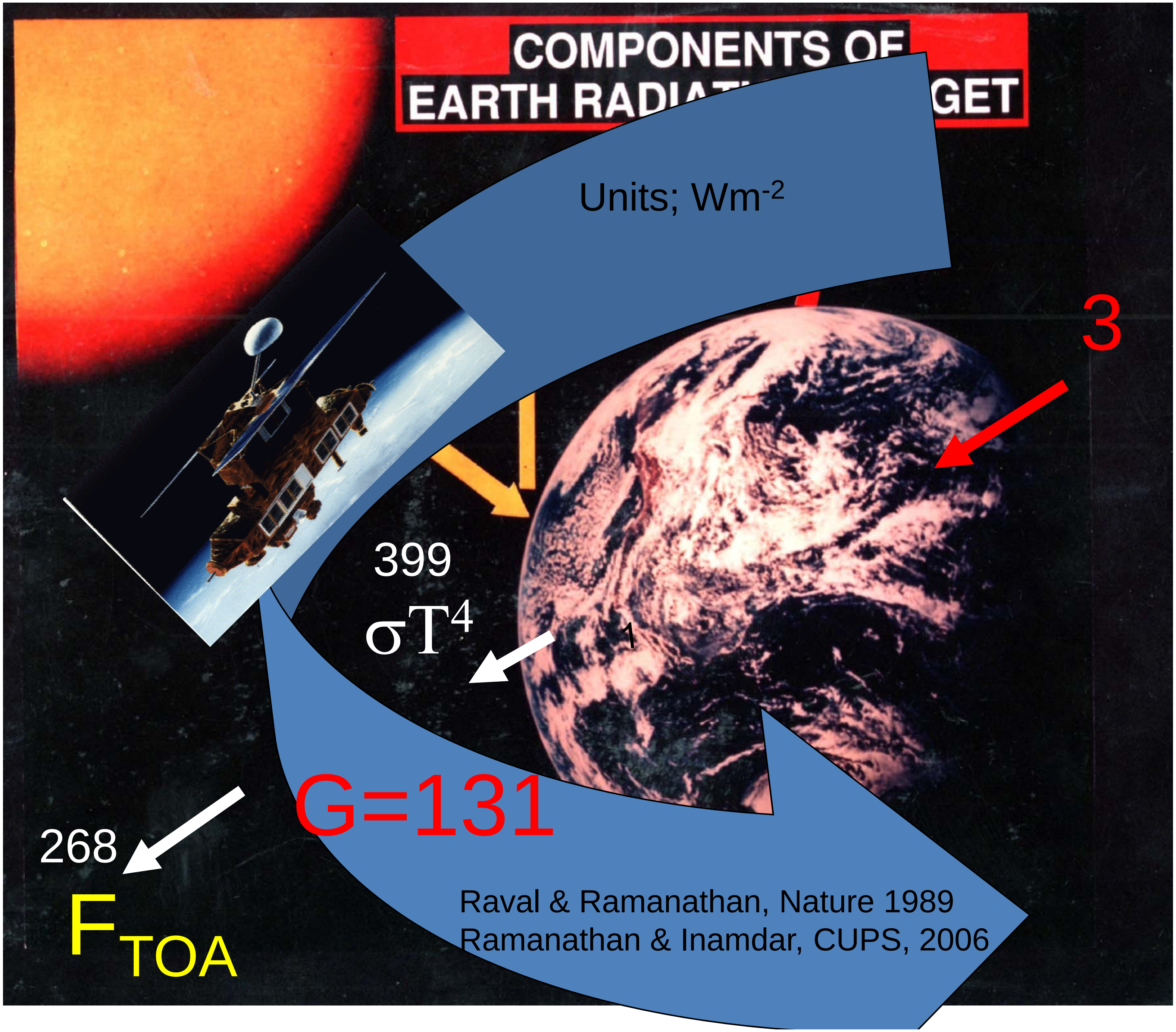
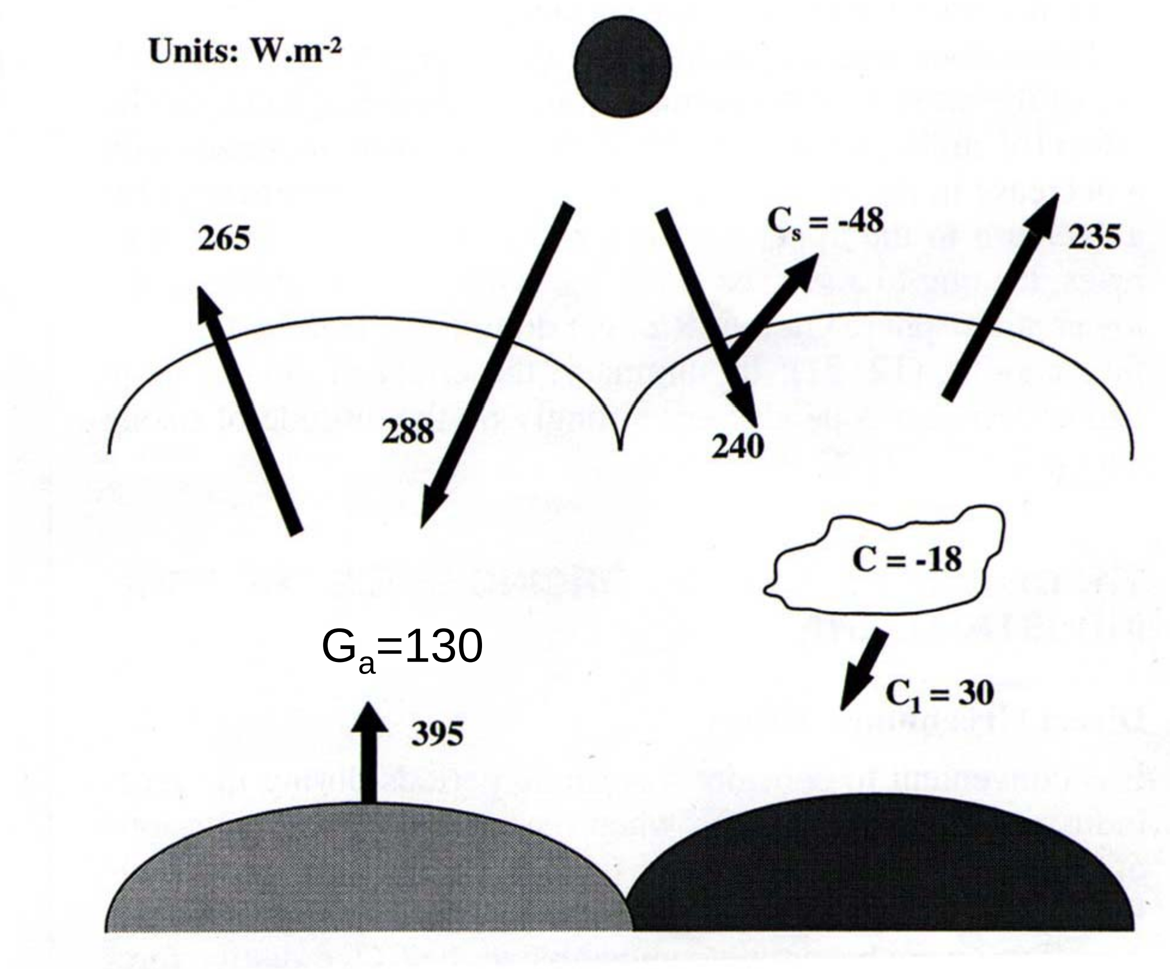
Atmospheric Greenhouse Effect (No Clouds)

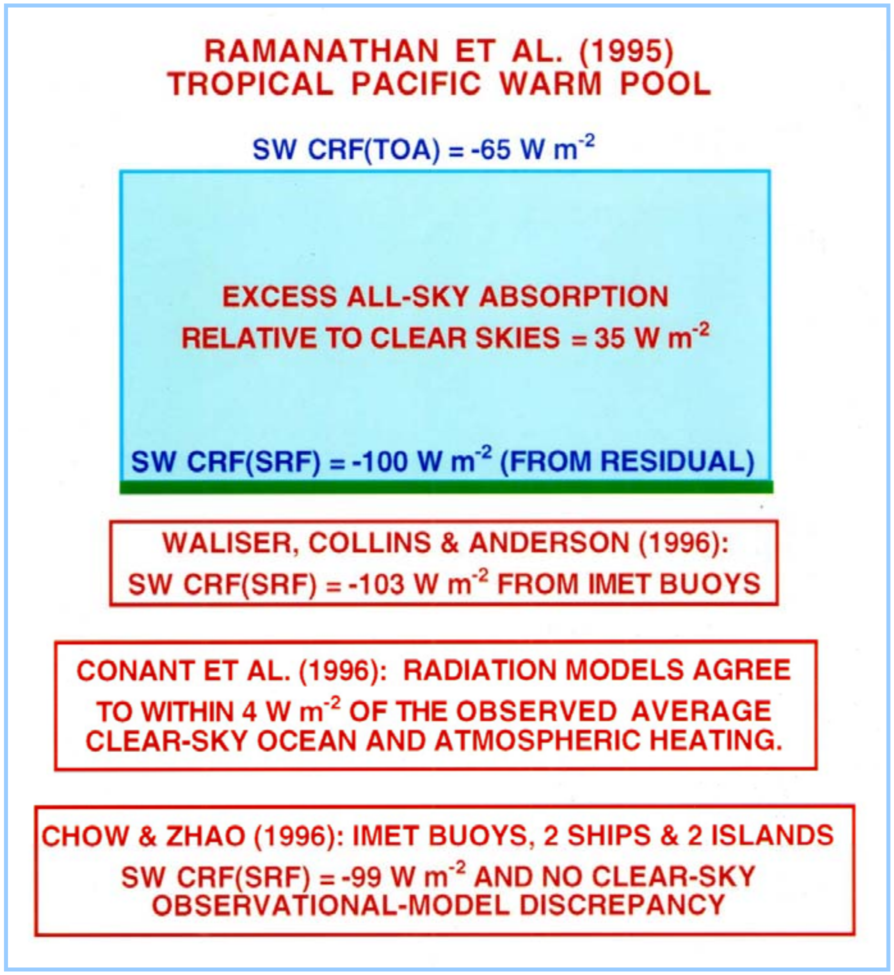


<u>Resolution of the Basic TOA Forcing Terms</u>



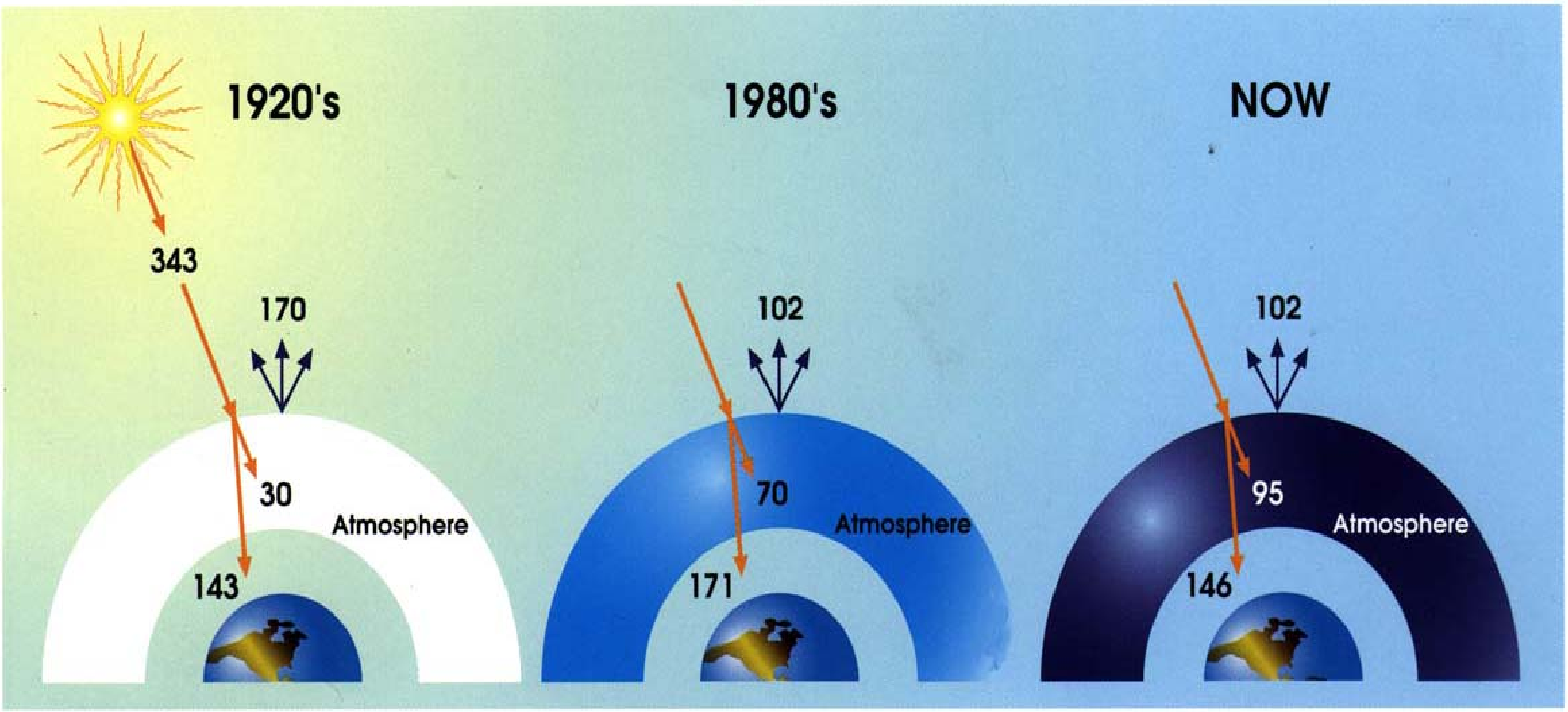
Source: *Ramanathan*, 1998

Solar Absorption: Anomalies in the Warm Pool

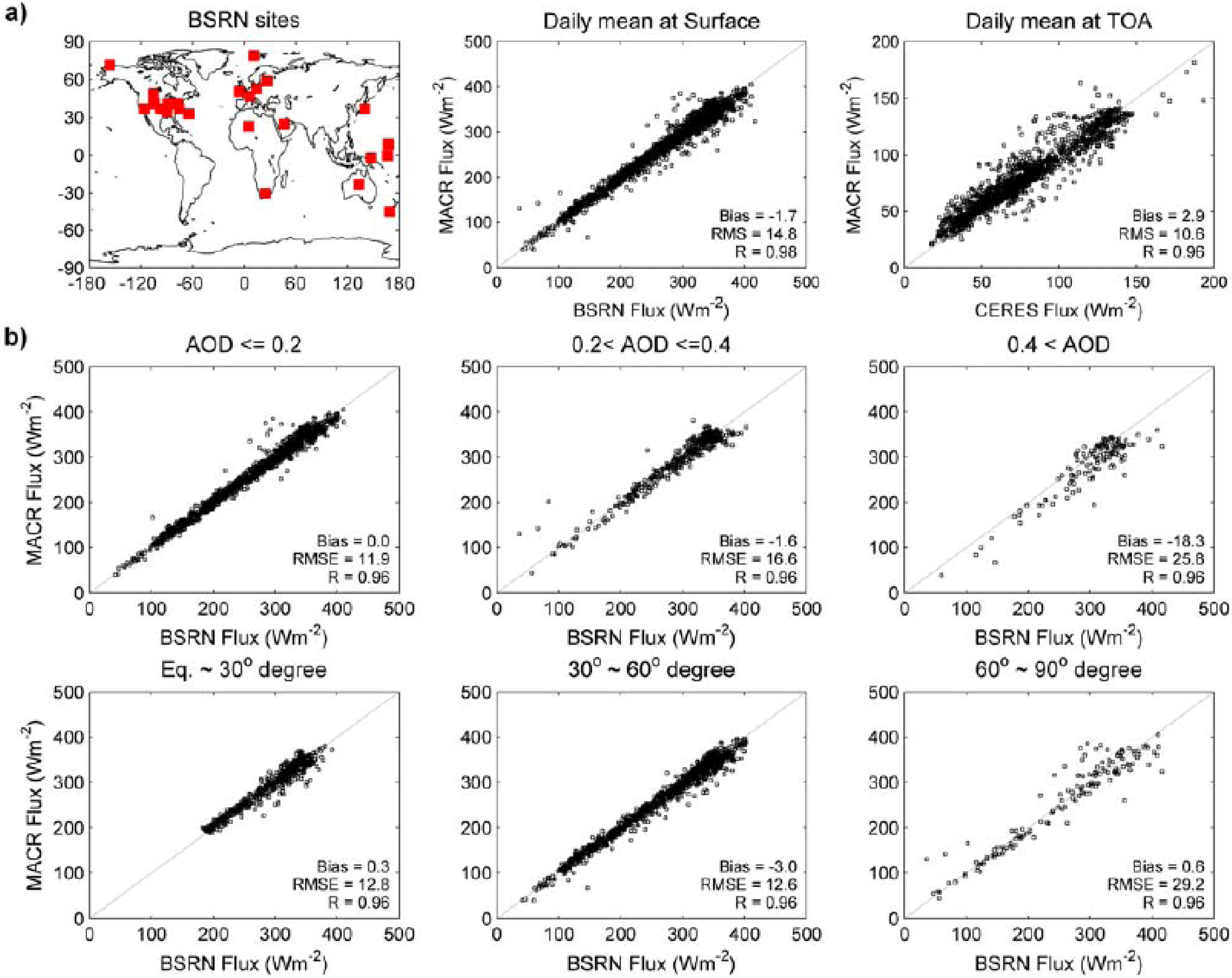


CESS (1995) Found Similar anomalies Globally

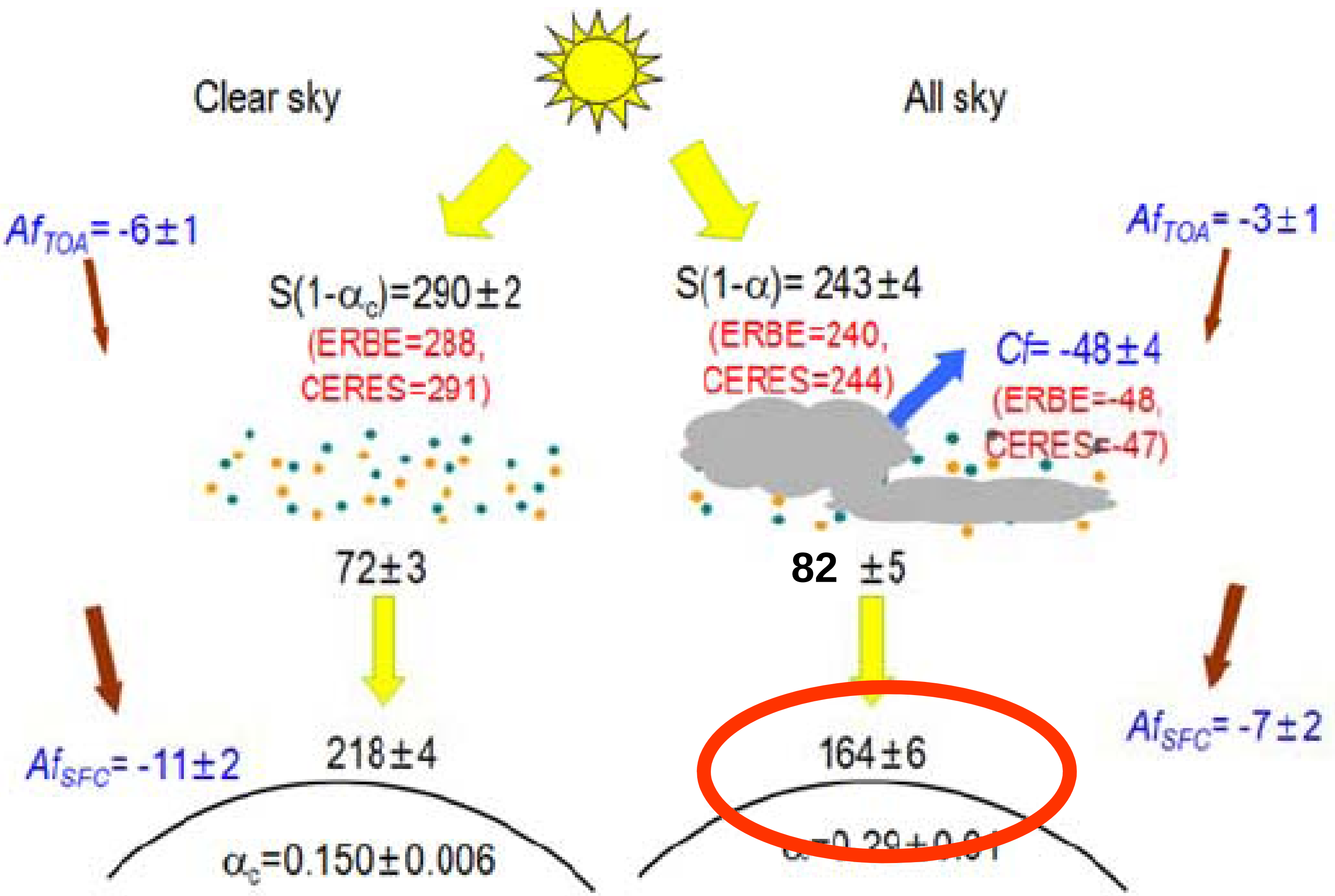
volution of the understanding of the atmospheric absorption in the global energy budget (in Wm^{-2})



Source: Ohmura and Gilgen, 1993; Cess et al. 1995; Pilewskie and Valero, 1995; Ramanathan et al., 1995

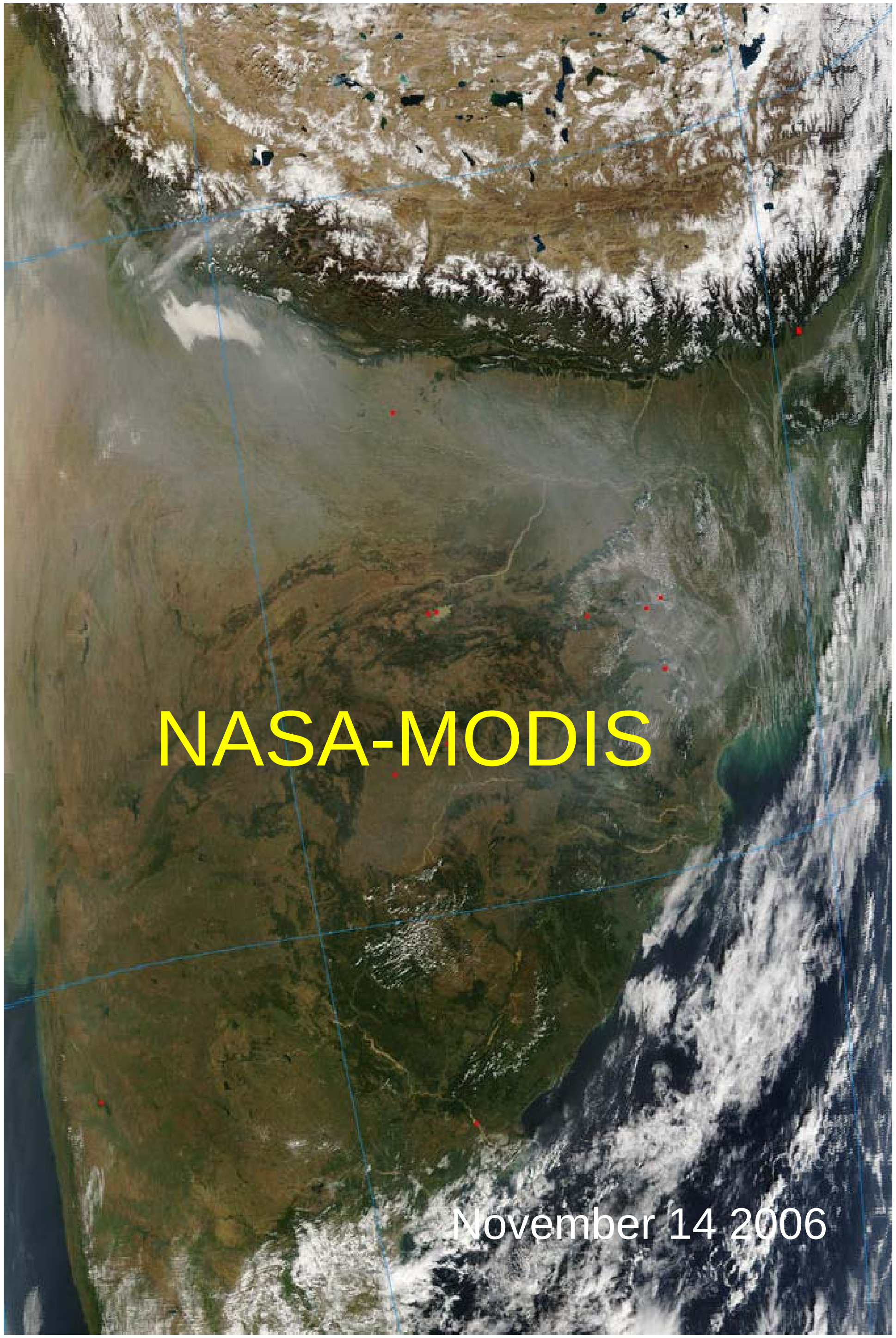

a)
BSRN sites
Daily mean at Surface
Daily mean at TOA
MACR Flux (Wm-2)
BSRN Flux (Wm-2)
CERES Flux (Wm-2)
Bias = -1.7
RMS = 14.8
R = 0.98
Bias = 2.9
RMS = 10.6
R = 0.96
b)
AOD <= 0.2
0.2< AOD <=0.4
0.4 < AOD
Bias = 0.0
RMSE = 11.9
R = 0.96
Bias = -1.6
RMSE = 16.6
R = 0.96
Bias = -18.3
RMSE = 25.8
R = 0.96
Eq. ~ 30° degree
30° ~ 60° degree
60° ~ 90° degree
Bias = 0.3
RMSE = 12.8
R = 0.96
Bias = -3.0
RMSE = 12.6
R = 0.96
Bias = 0.6
RMSE = 29.2
R = 0.96

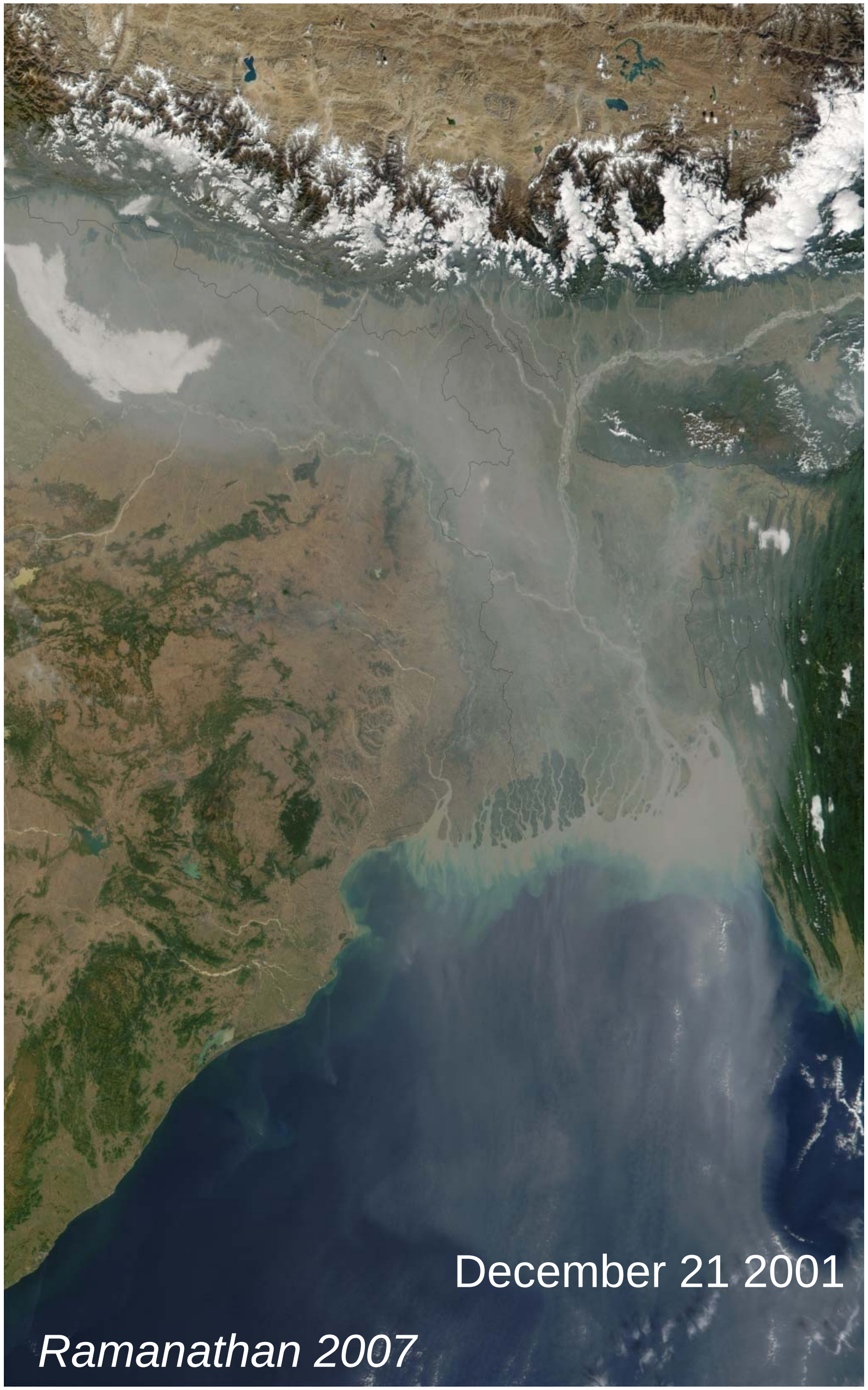
KIM AND RAMANATHAN: SOLAR RADIATION BUDGET AND FORCING



Solar radiation budget and radiative forcing due to aerosols and clouds

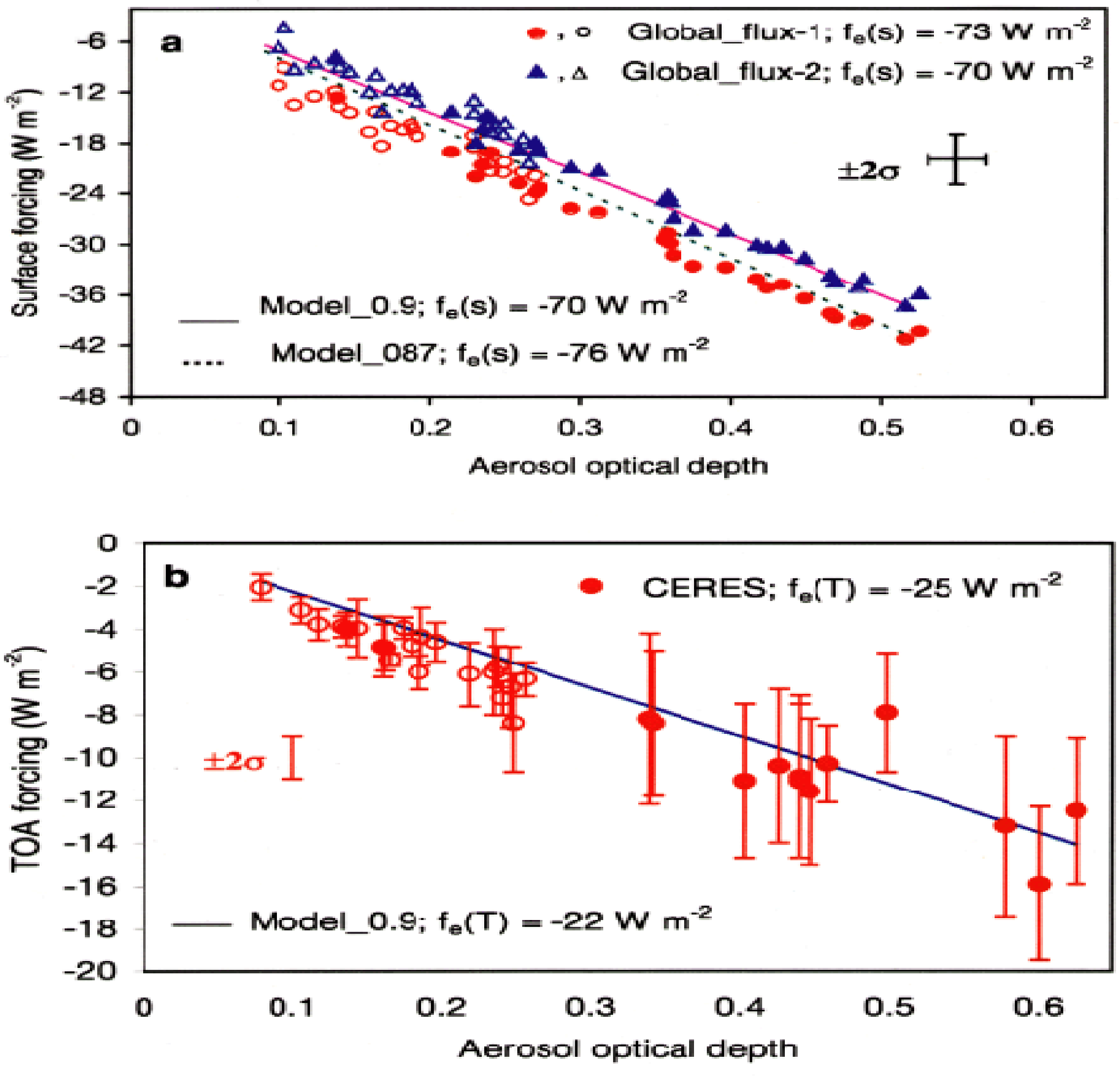
JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 113, D02203, doi:10.1029/2007JD008434, 2008


NASA-MODIS
November 14 2006


December 21 2001
Ramanathan 2007

Direct observations of Aerosol Direct Forcing: CERES on TRMM Over Maldives
INDOEX Results

Direct observations: Clear-Sky Forcing Efficiency



Ramanathan, Roberts, Ramana, Corrigan , Nature, 2007

PART-B: Estimation of Feedback from ERBE Data

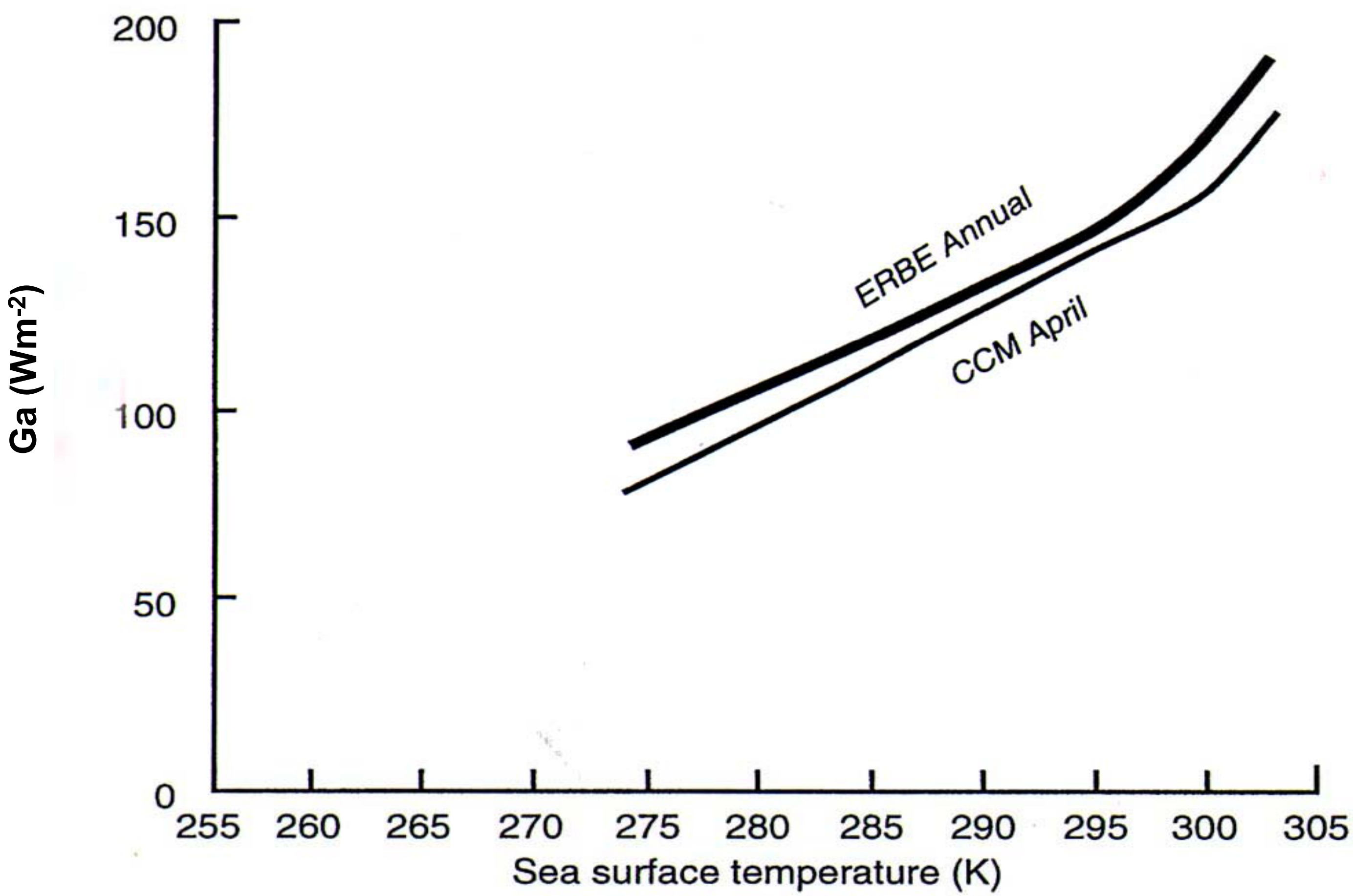
The Water Vapor Feedback

Temp dependence of Saturation vapor pressure:

$$e_s : e^{-5400/T}$$

$$\frac{d \ln e_s}{dT} = \frac{5400}{T^2} \approx 0.07$$

Comparison of G_a and sea surface temperature

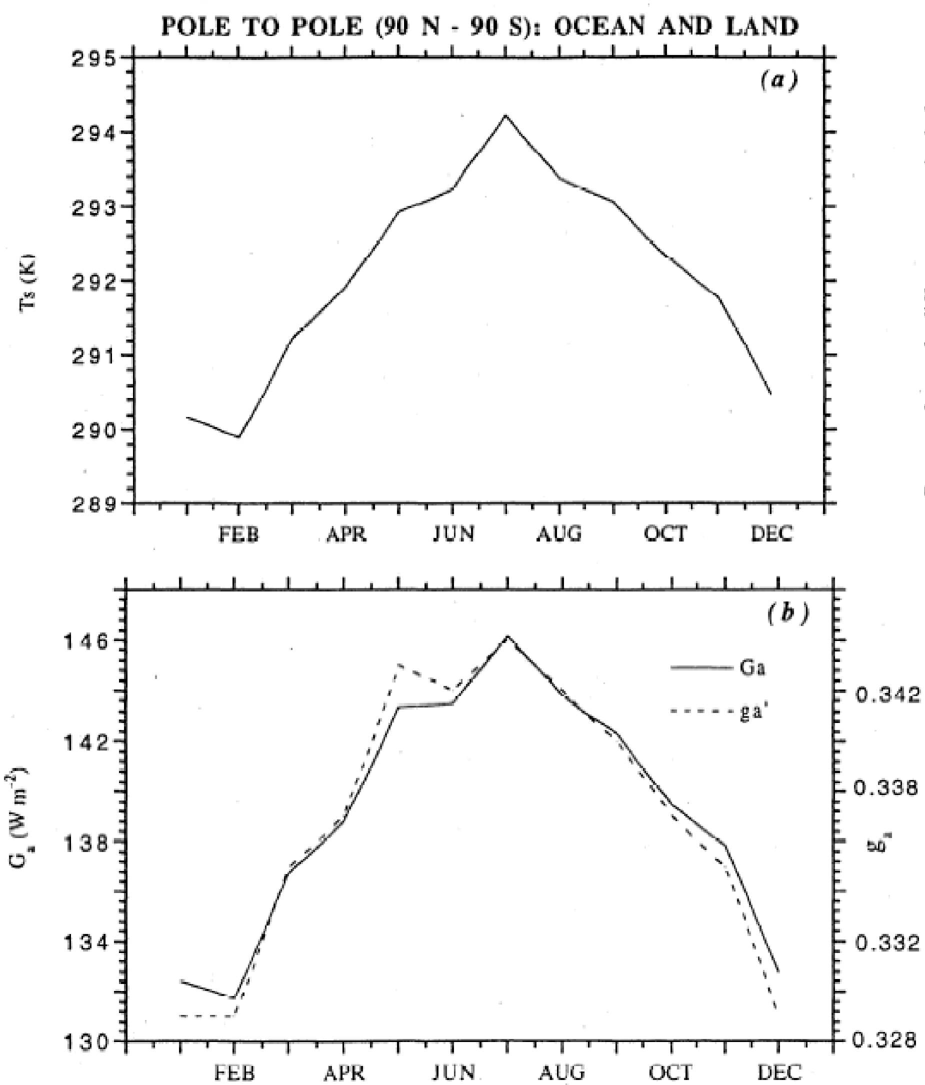


Source: ***Ramanathan*, 1998**

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 103, NO. D24, PAGES 32,177–32,194, DECEMBER 27, 1998

Tropical and global scale interactions among water vapor, atmospheric greenhouse effect, and surface temperature

Anand K. Inamdar and V. Ramanathan



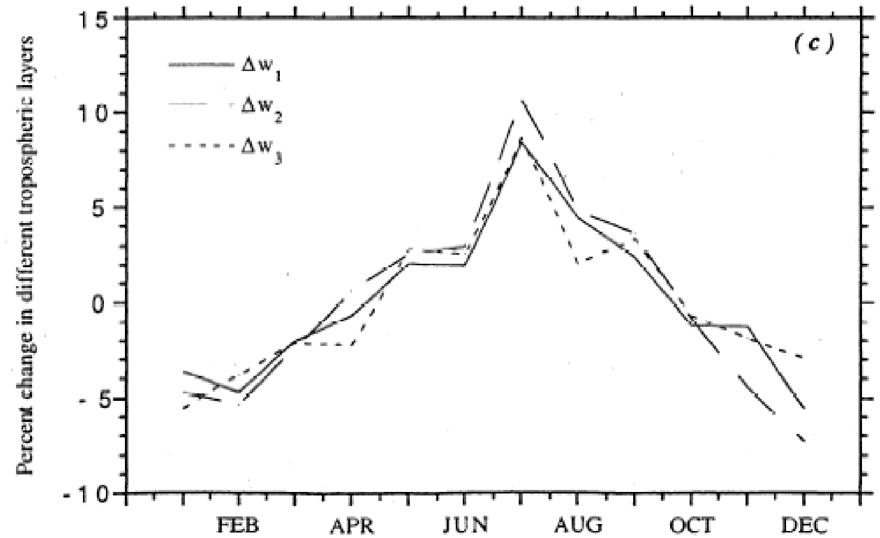
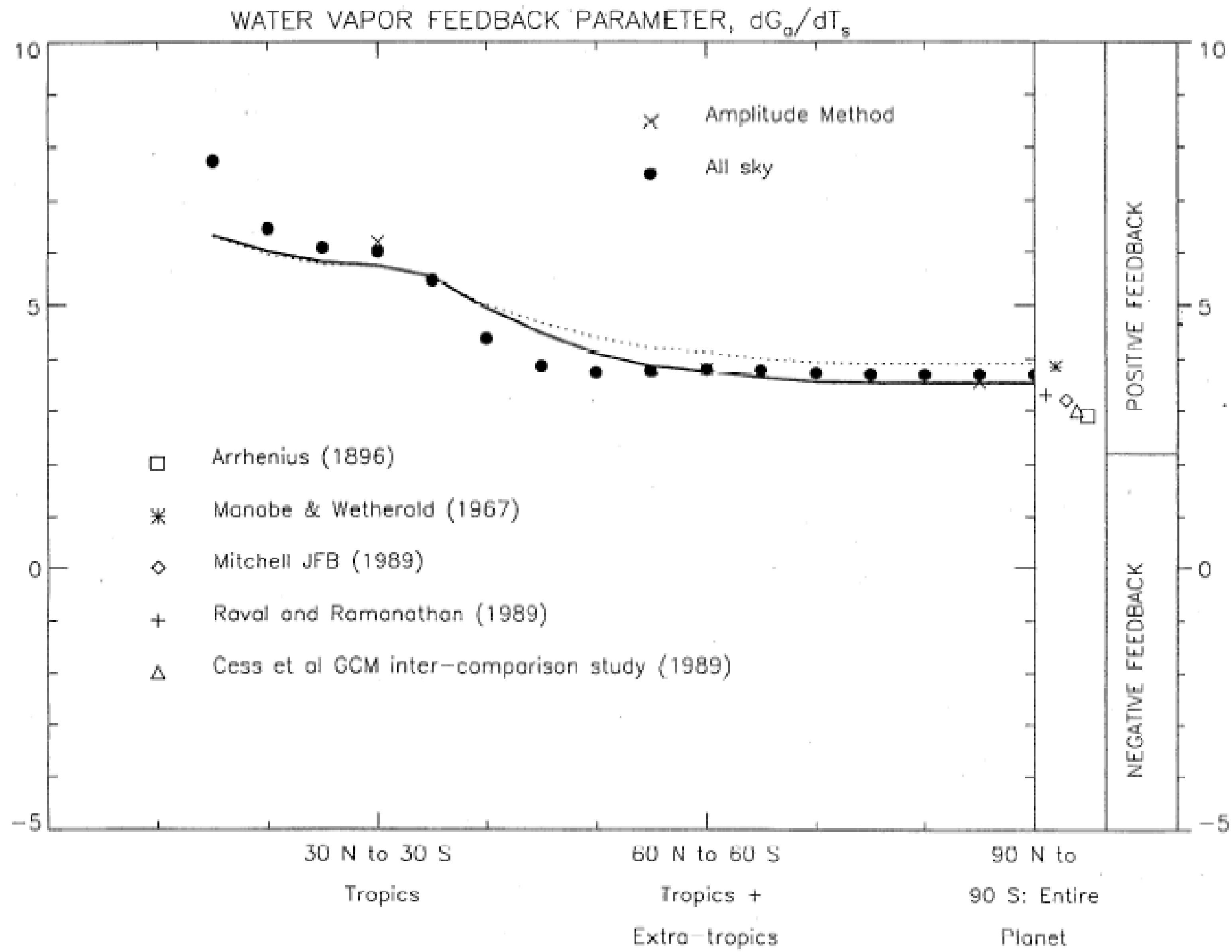
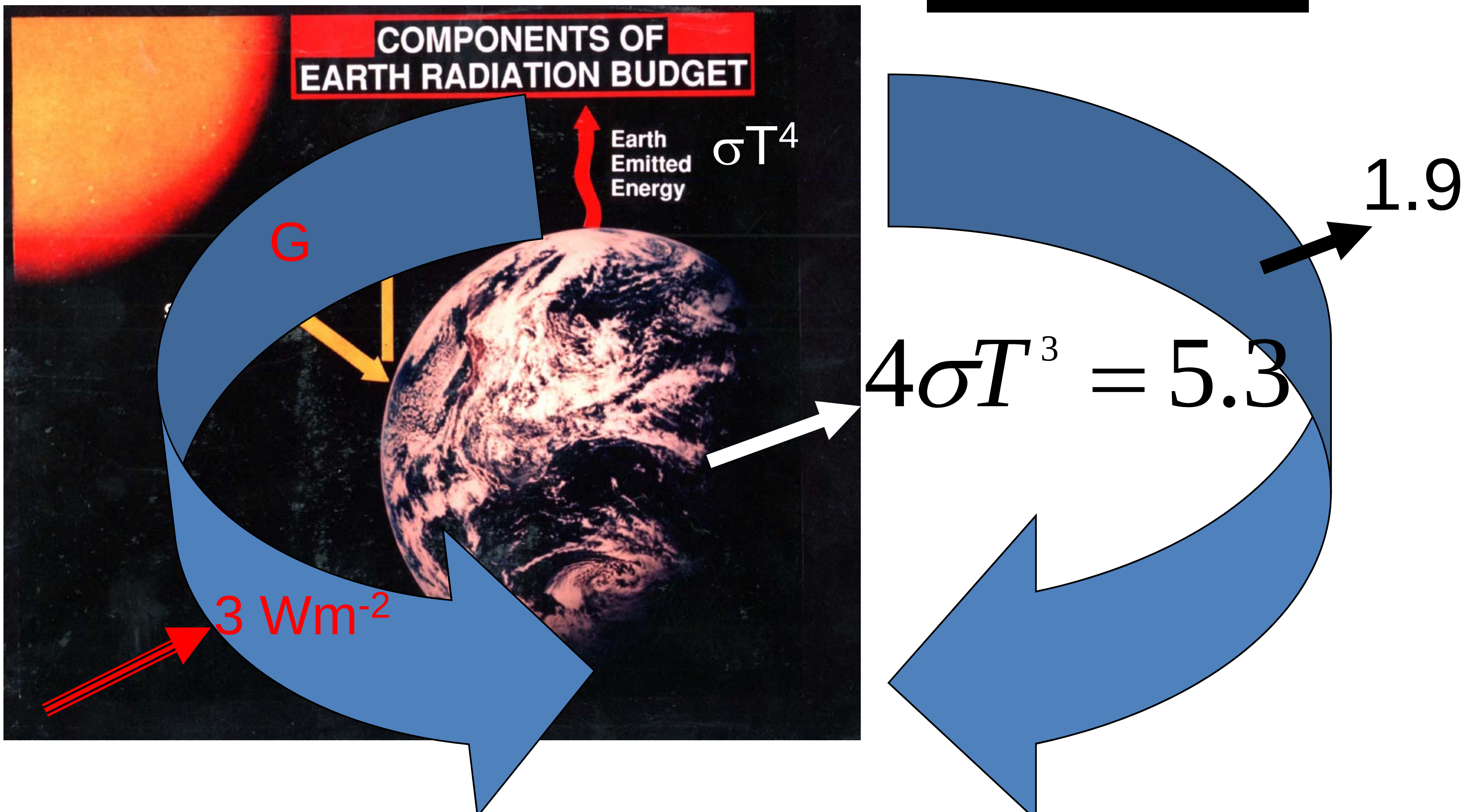


Figure 4. Same as Figure 3 but for 90°N–90°S.


WATER VAPOR FEEDBACK PARAMETER, dGa/dTs
10
5
0
−5
Amplitude Method
All sky
Arrhenius (1896)
Manabe & Wetherald (1967)
Mitchell JFB (1989)
Raval and Ramanathan (1989)
Cess et al GCM inter-comparison study (1989)
POSITIVE FEEDBACK
NEGATIVE FEEDBACK
30 N to 30 S
Tropics
60 N to 60 S
Tropics +
Extra-tropics
90 N to
90 S: Entire
Planet

Unit: $Wm^{-2}K^{-1}$



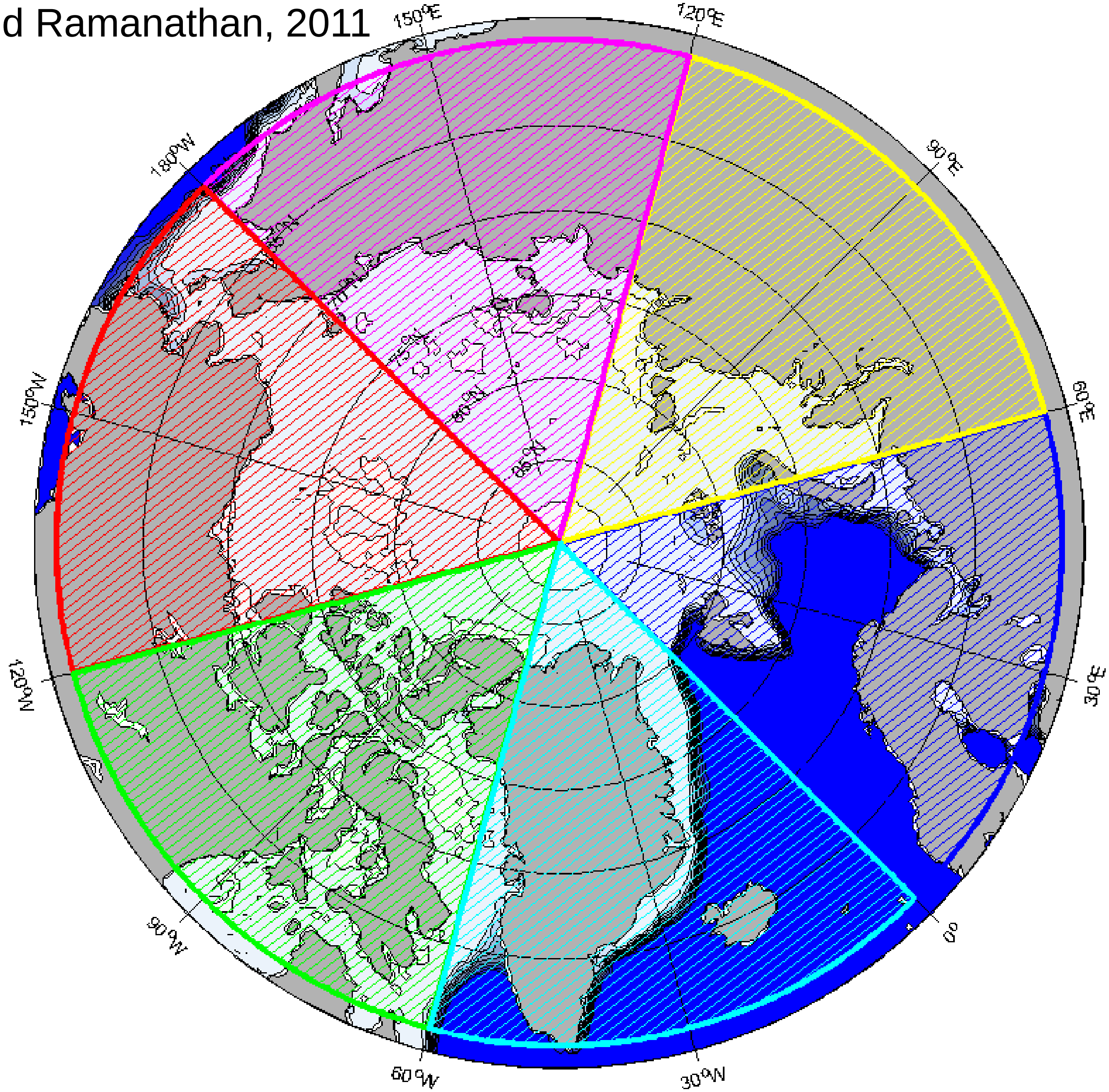
$$\frac{dG}{dT} = 3.4Wm^{-2}K^{-1}$$

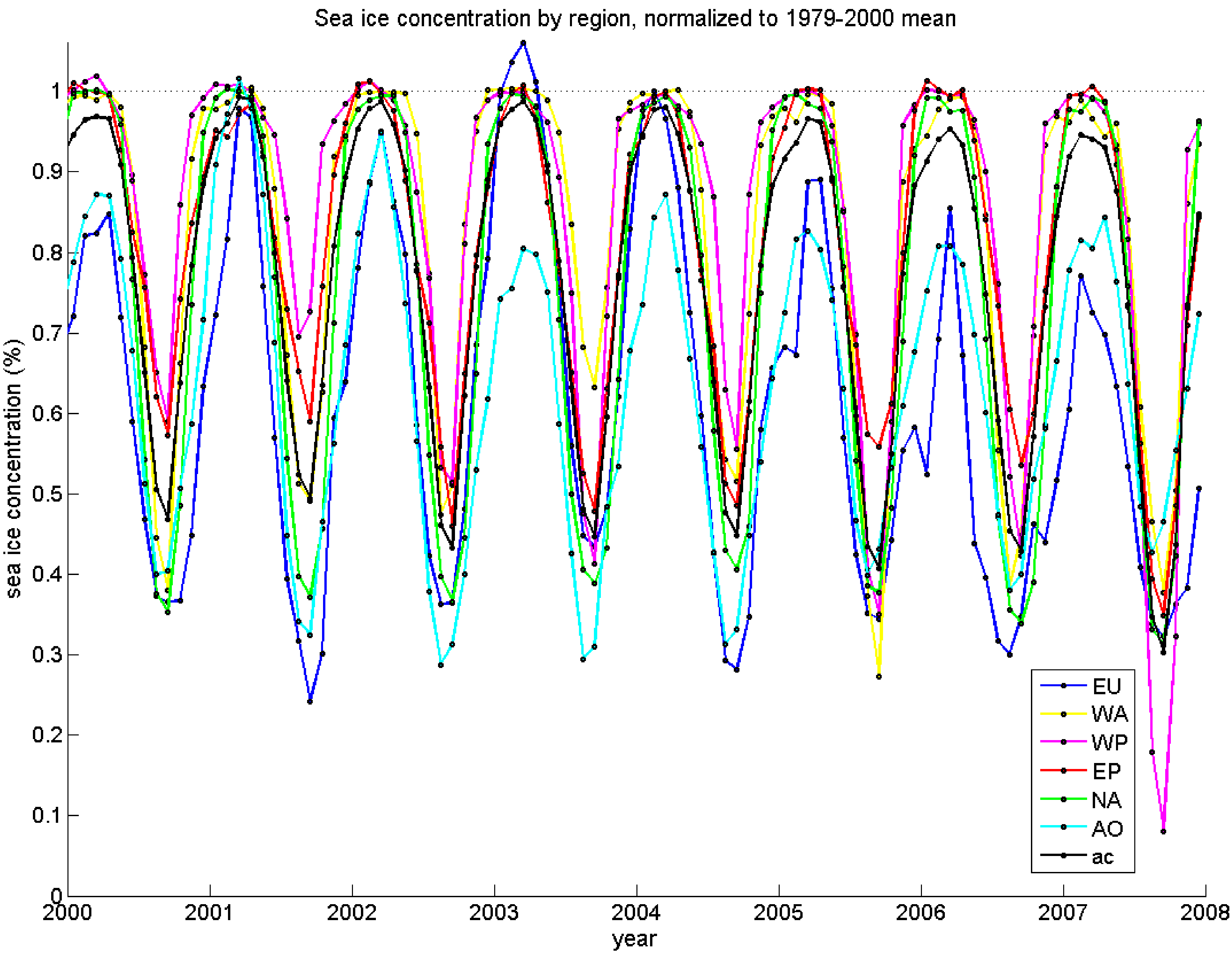
$$\Delta T = \frac{3}{1.9} \approx 1.5K$$

The planet gives off 1.9 Wm^{-2} per degree C increase in Temperature

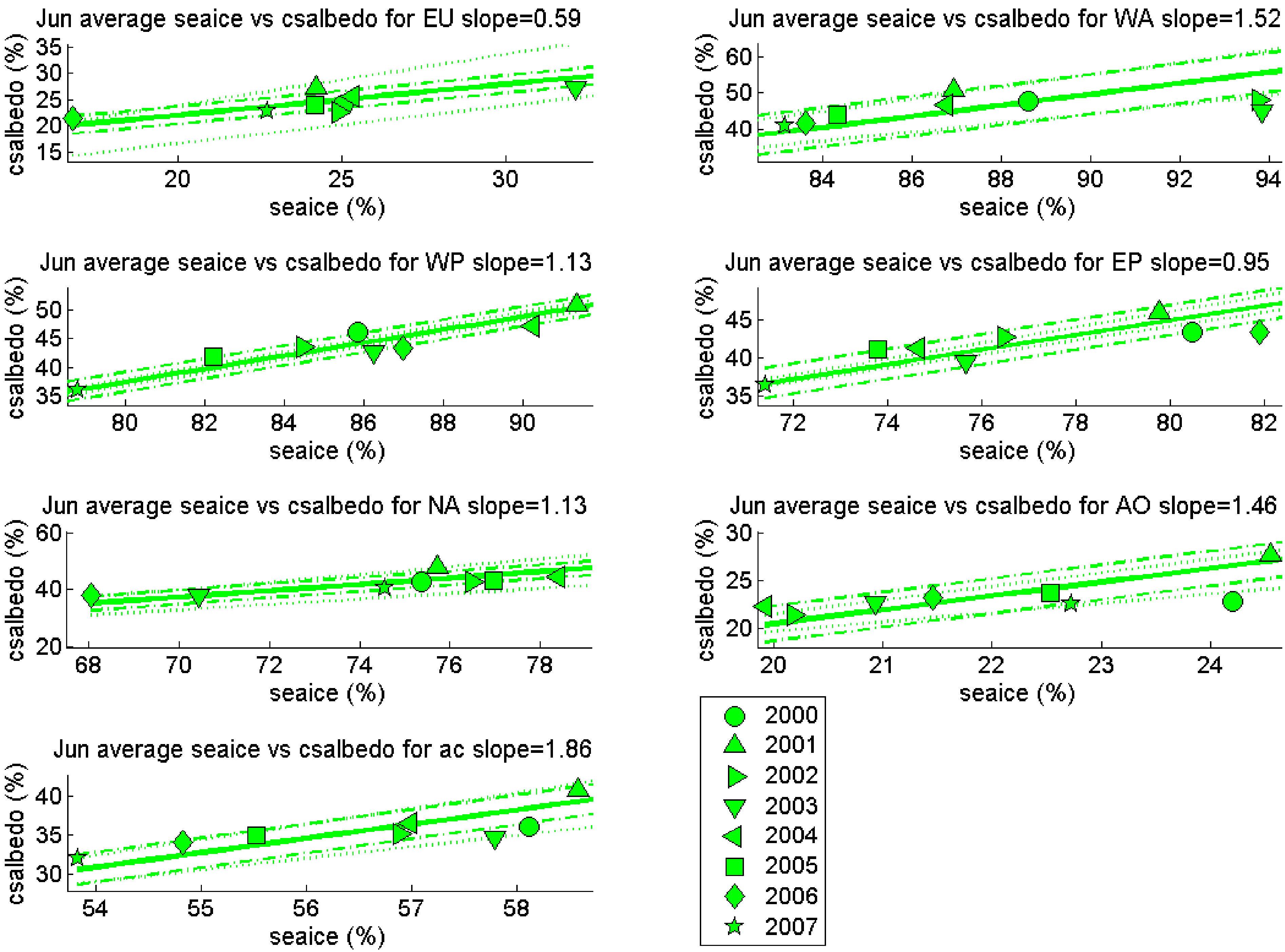
Inamdar and Ramanathan 1998

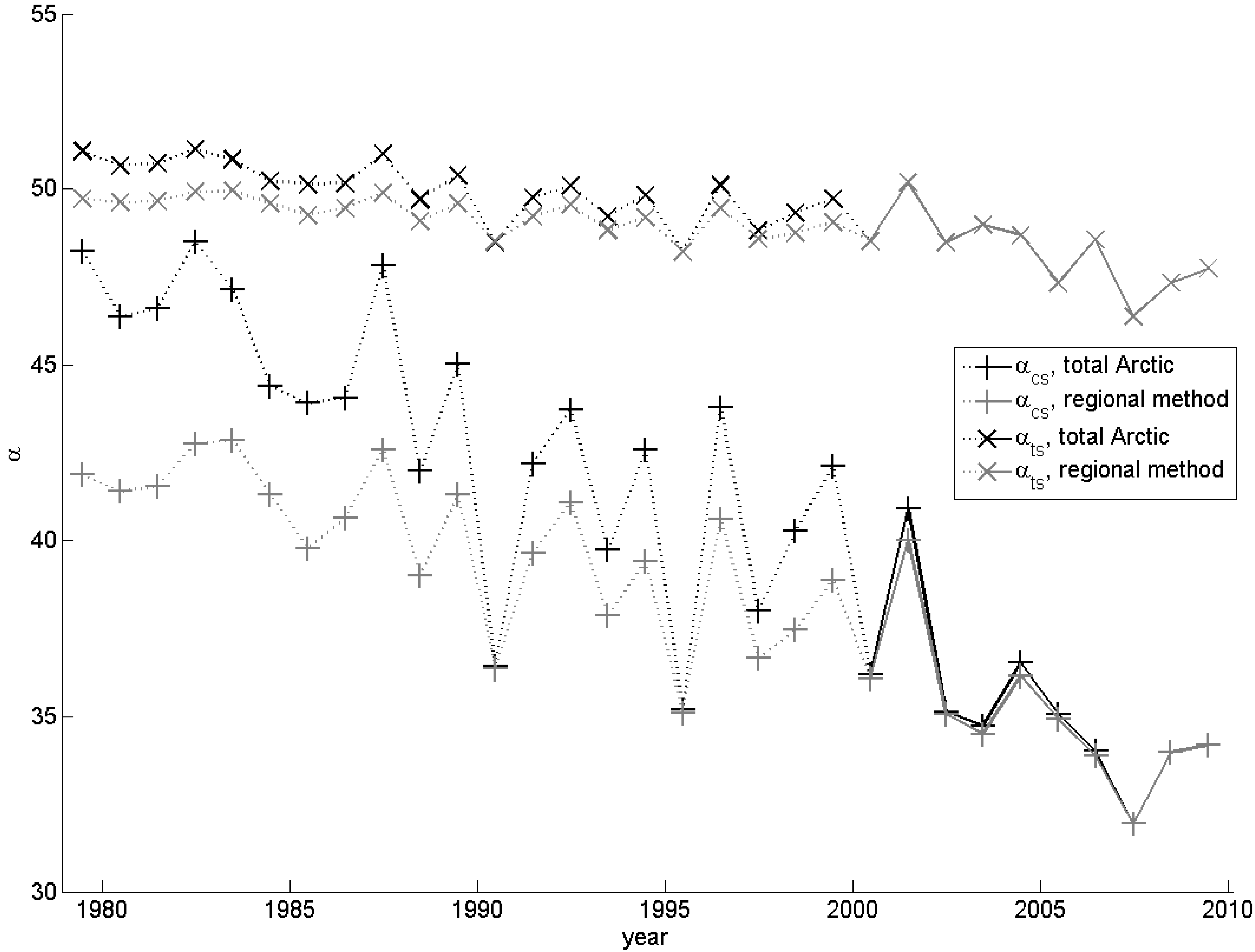
Sea Ice-Albedo Feedback
Pistone and Ramanathan, 2011





Sea ice concentration by region, normalized to 1979-2000 mean
sea ice concentration (%)
year
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
2000
2001
2002
2003
2004
2005
2006
2007
2008
EU
WA
WP
EP
NA
AO
ac


Jun average seaice vs csalbedo for EU slope=0.59
Jun average seaice vs csalbedo for WA slope=1.52
Jun average seaice vs csalbedo for WP slope=1.13
Jun average seaice vs csalbedo for EP slope=0.95
Jun average seaice vs csalbedo for NA slope=1.13
Jun average seaice vs csalbedo for AO slope=1.46
Jun average seaice vs csalbedo for ac slope=1.86
csalbedo (%)
seaice (%)
2000
2001
2002
2003
2004
2005
2006
2007



55
50
45
40
35
30
1980
1985
1990
1995
2000
2005
2010
year
α
α_{cs}, total Arctic
α_{cs}, regional method
α_{ts}, total Arctic
α_{ts}, regional method

Table 2 Feedbacks due to Arctic sea ice retreat by the regional kernel method. Two measures of range are given. The second column gives the range between methods (regional versus total Arctic, kernel versus direct calculation), and the third gives 90% confidence intervals from a bootstrap calculation; these ranges are consistent with each other.

Δ=1979-2007	$\left(\frac{\partial S}{\partial si}\right)\left(\frac{\partial si}{\partial T_s}\right)$	Range (methodological)	Calculation uncertainty
Northern Hemisphere: $\Delta T_{s,NH}(1979-2007) = 0.58$ K			
$\left(\frac{dS_{abs}}{dT_{s,NH}}\right)$	0.21 $Wm^{-2}K^{-1}$	0.15 to 0.27	0.16 to 0.26
Global: $\Delta T_{s,glb}(1979-2007) = 0.39$ K			
$\left(\frac{dS_{abs}}{dT_{s,glb}}\right)$	0.10 $Wm^{-2}K^{-1}$	0.08 to 0.14	0.08 to 0.13

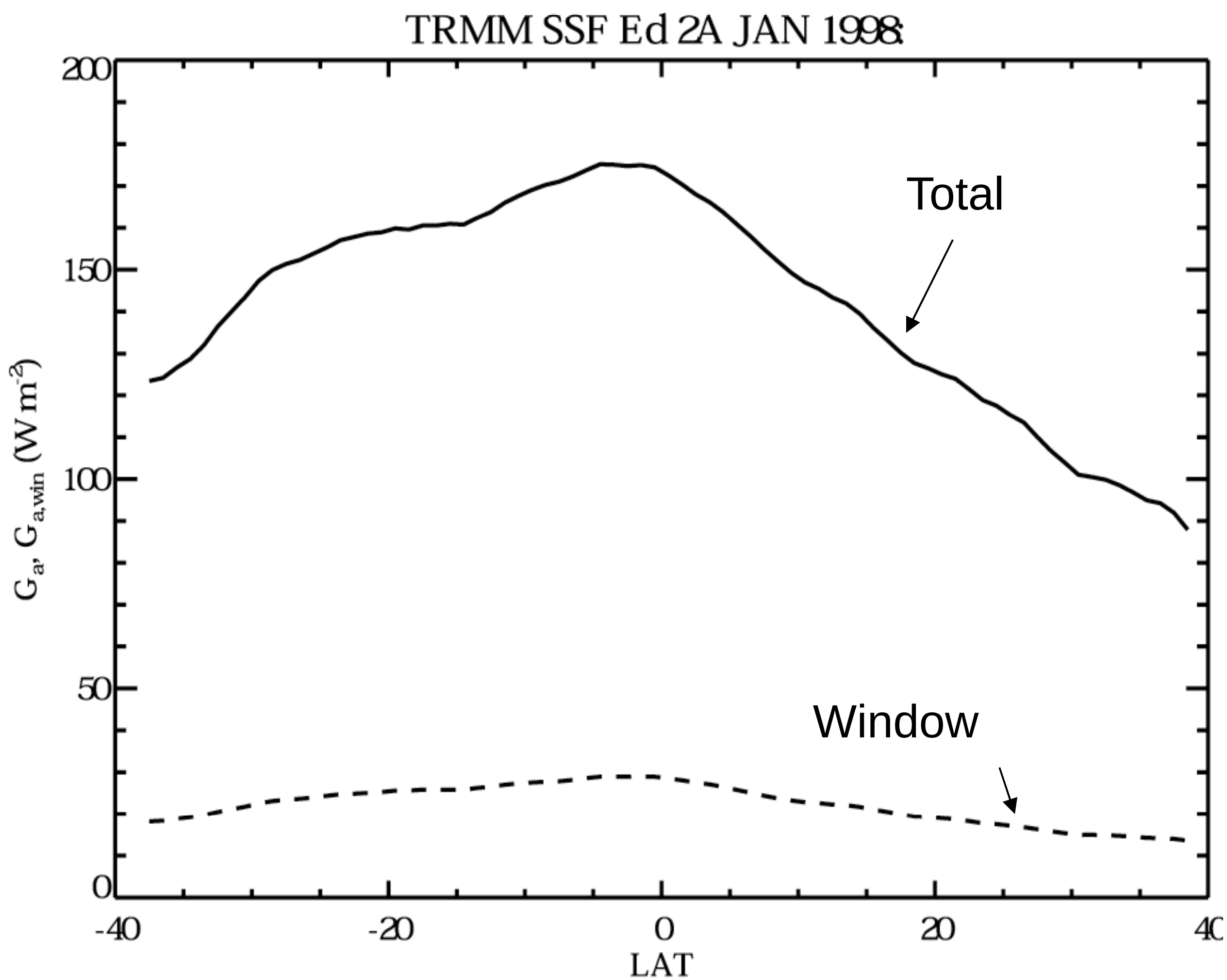
Some Outstanding Issues That Can be Looked at with CERES Data

The Water Vapor Continuum : Feedback

Spatial Structure of Clouds and Their Albedos

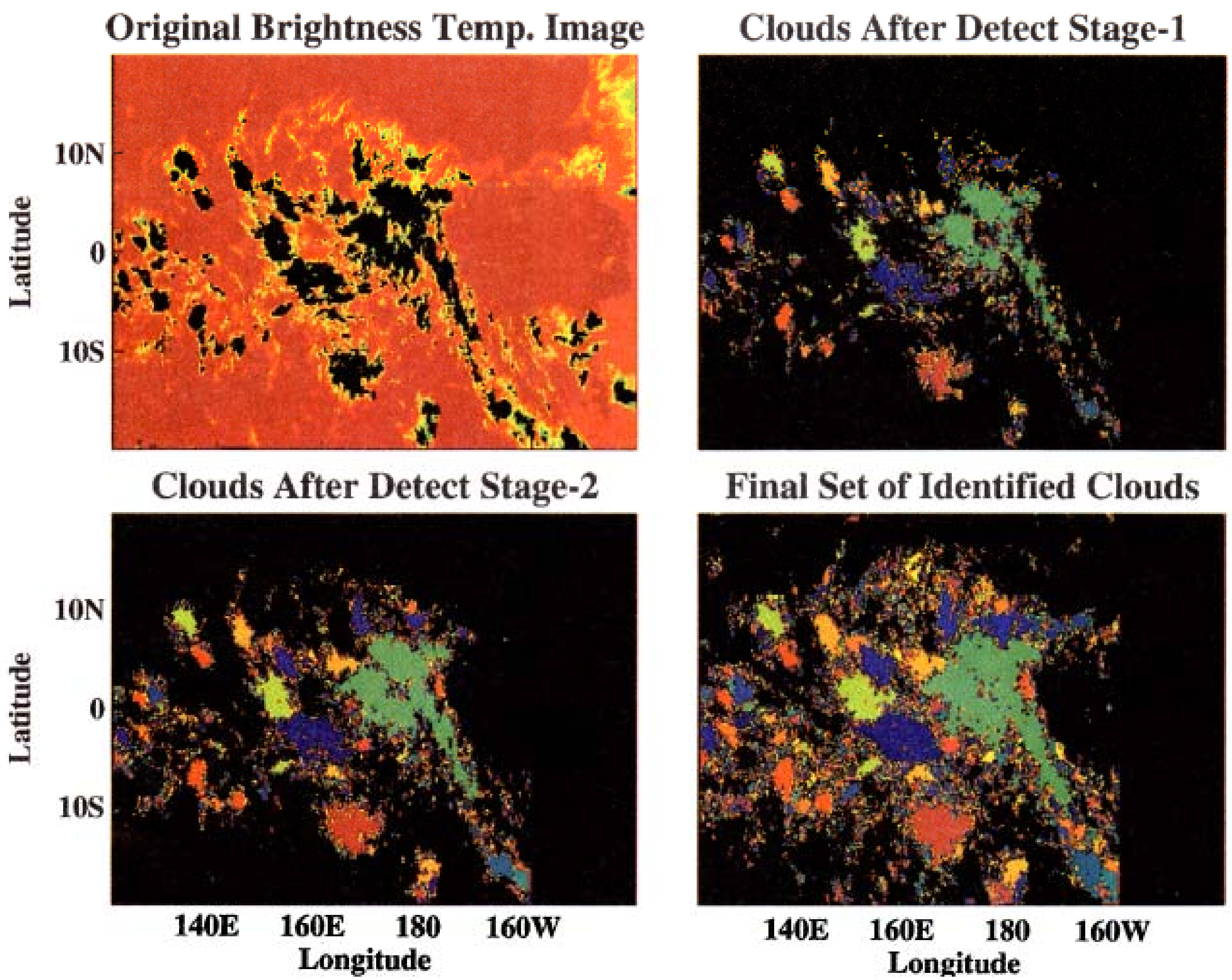
Planetary Albedo: Development of a Theory

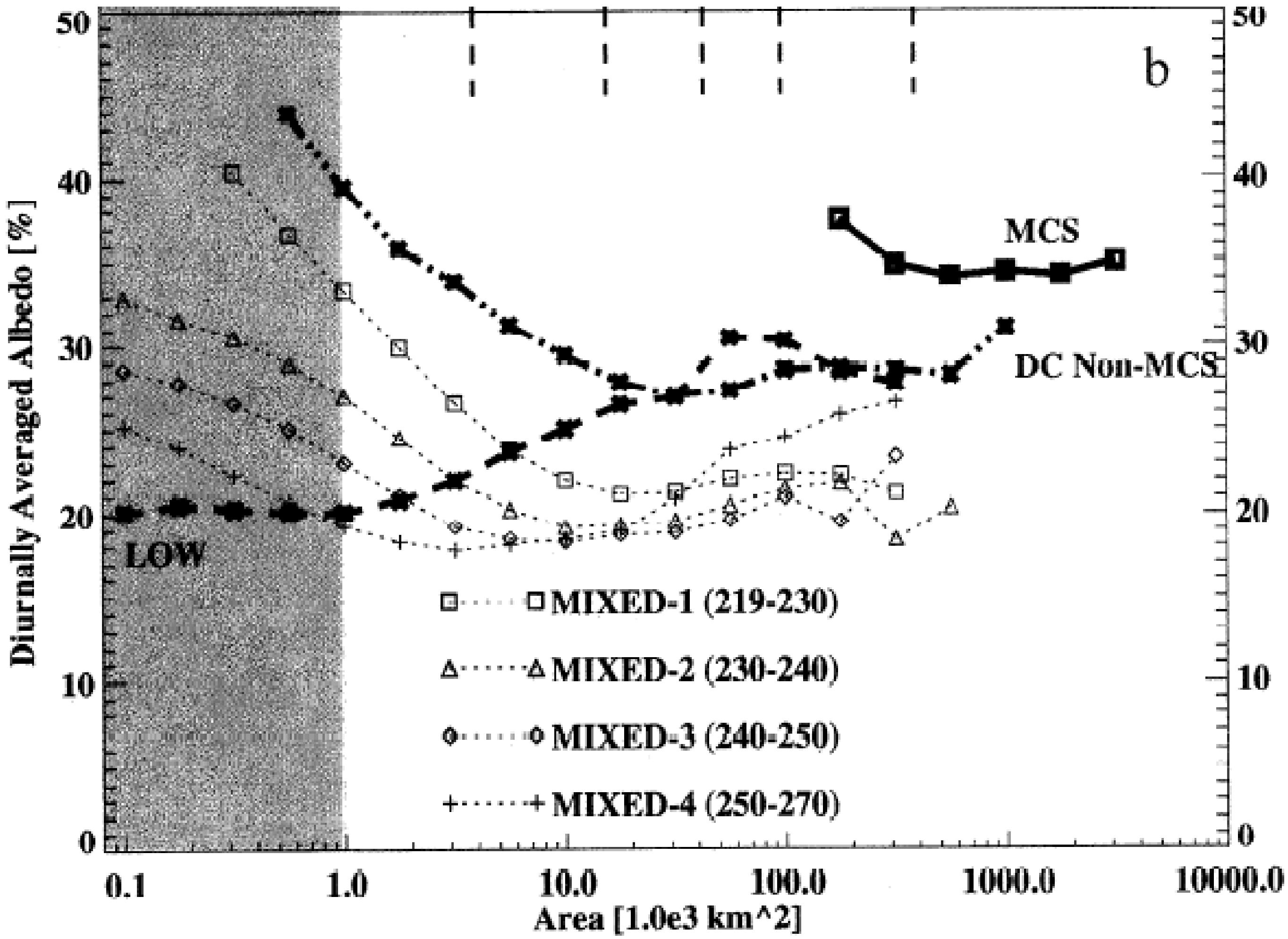
Zonal Distribution of Atm. Greenhouse Effect (Total & Window from CERES)



E.R. Boer and V. Ramanathan, Lagrangian Approach for Deriving Cloud Characteristics from Satellite Observations J. Geophys. Res. Atmospheres 1997

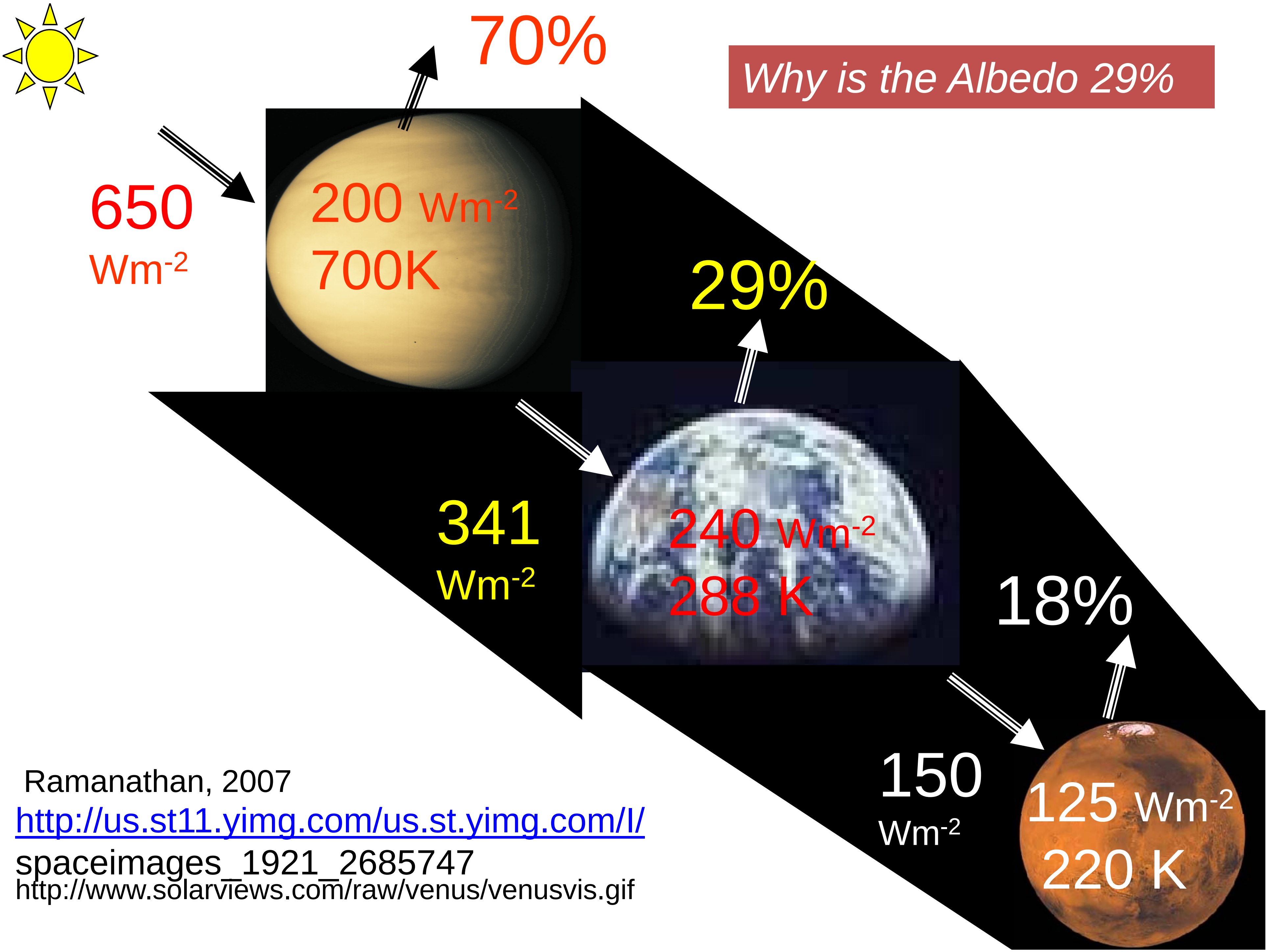
Bring In Spatial Structure of Clouds





E.R. Boer and V. Ramanathan, **Lagrangian Approach for Deriving Cloud Characteristics from Satellite Observations and Its Implications to Cloud Parameterization**. *J. Geophys. Res. Atmospheres 1997*

Why is the Albedo 29%



Ramanathan, 2007

http://us.st11.yimg.com/us.st.yimg.com/I/
spaceimages_1921_2685747

http://www.solarviews.com/raw/venus/venusvis.gif