Clouds & Radiation: Climate data vs. model results

A tribute to ISCCP

25 years

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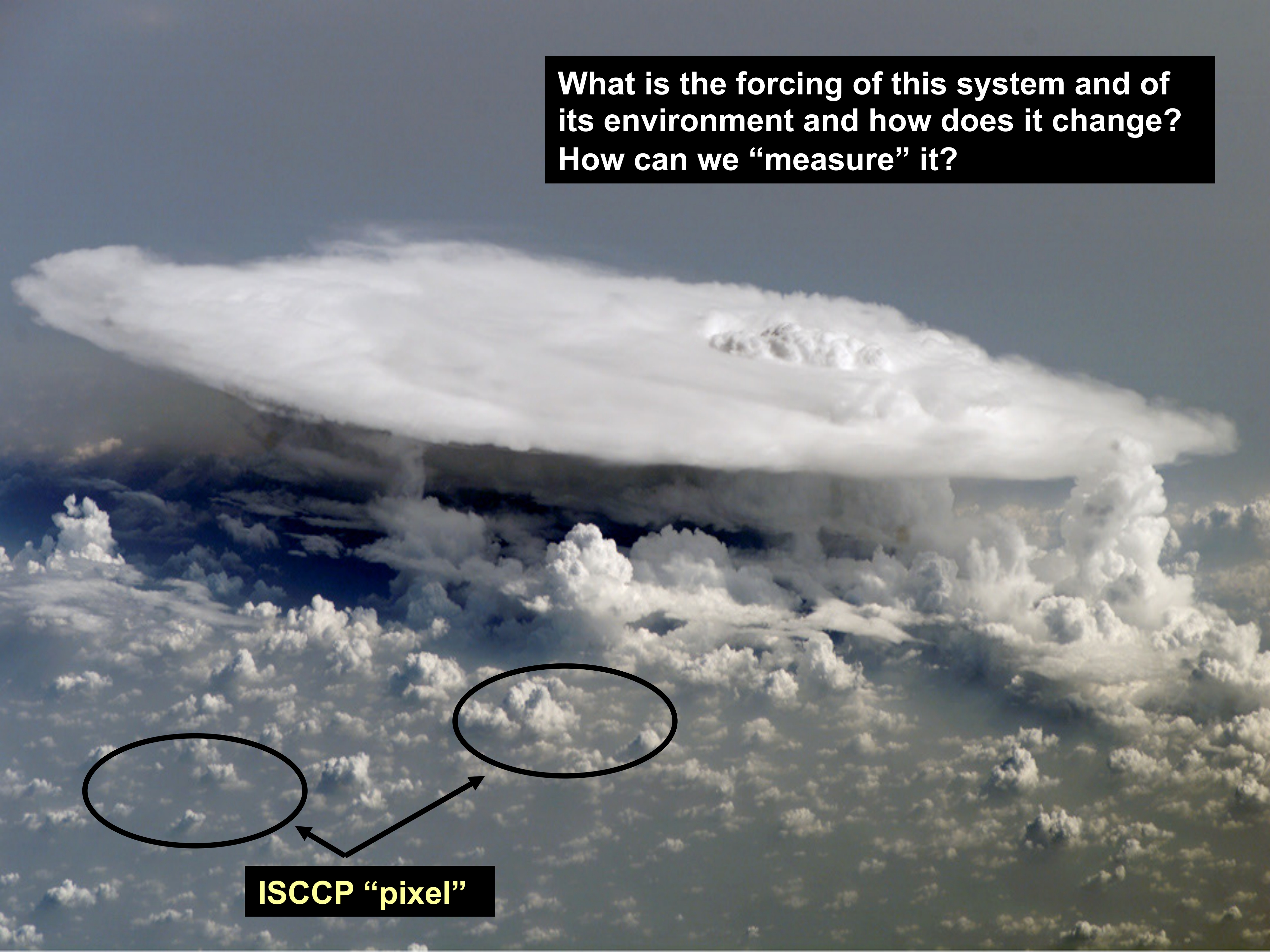

What is the forcing of this system and of its environment and how does it change? How can we "measure" it?
ISCCP "pixel"

During the early eighties we knew … :

Clouds (and aerosols) form in the atmosphere

"dynamic clusters"

of

solid and liquid particles

of different horizontal and vertical extent and "life time". These properties are forced by radiation and by internally and externally forced turbulence of different scales in time and space.

Computations of cloud interaction with radiation need information in

high spatial and time detail

on

thermodynamic phase, number densities, sizes, shapes, index of refraction

and on radiative properties of the ambient atmosphere and surface.

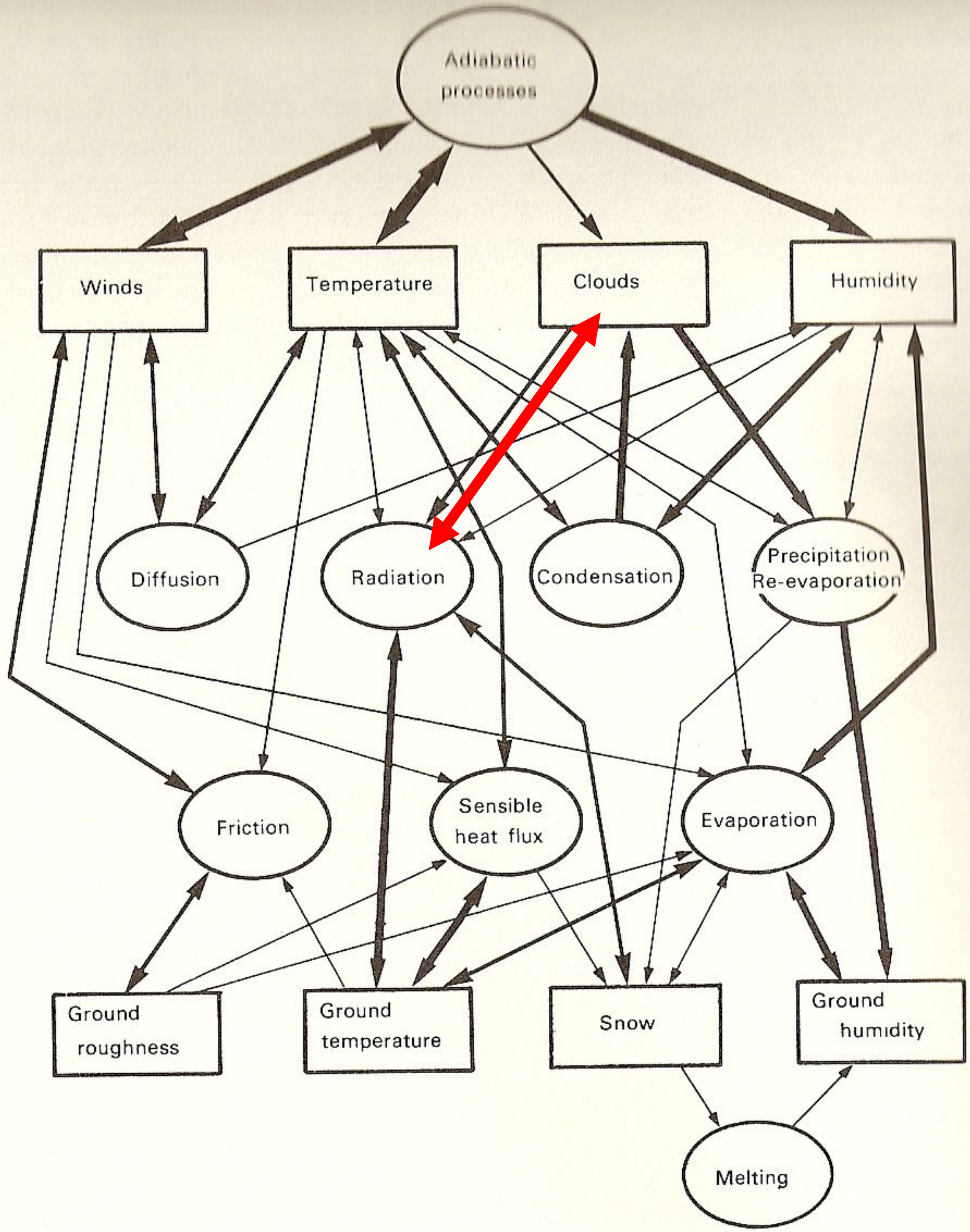
This information must be retrieved from

(all) available

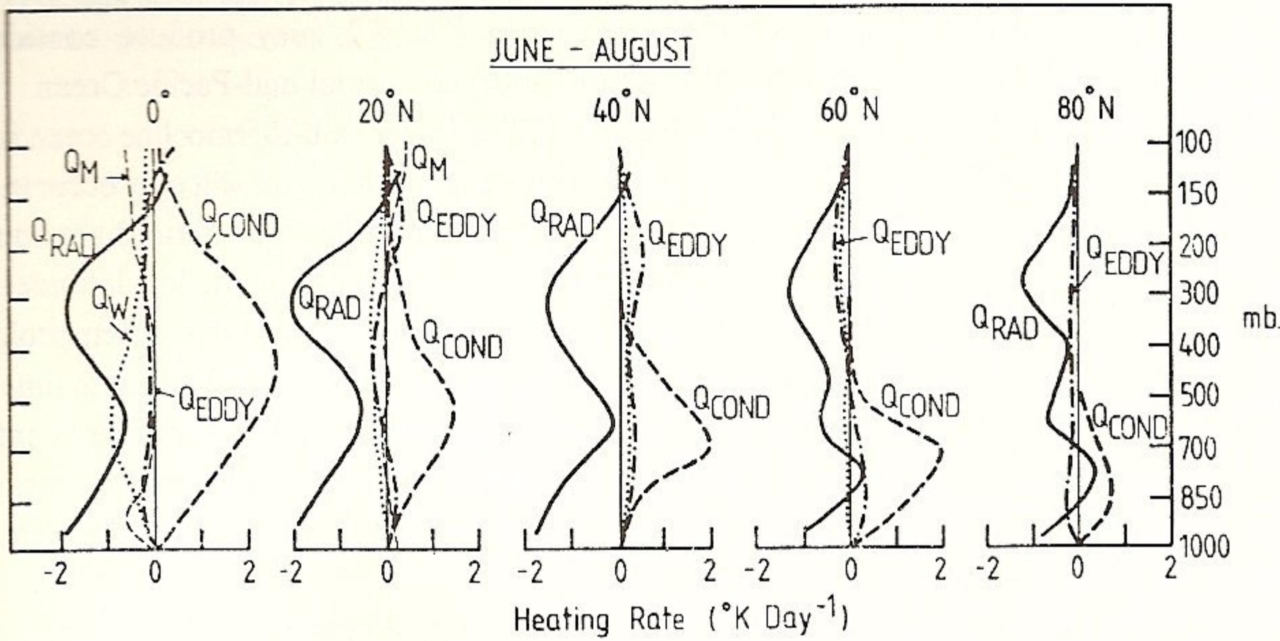
remote measurements.

But, how??

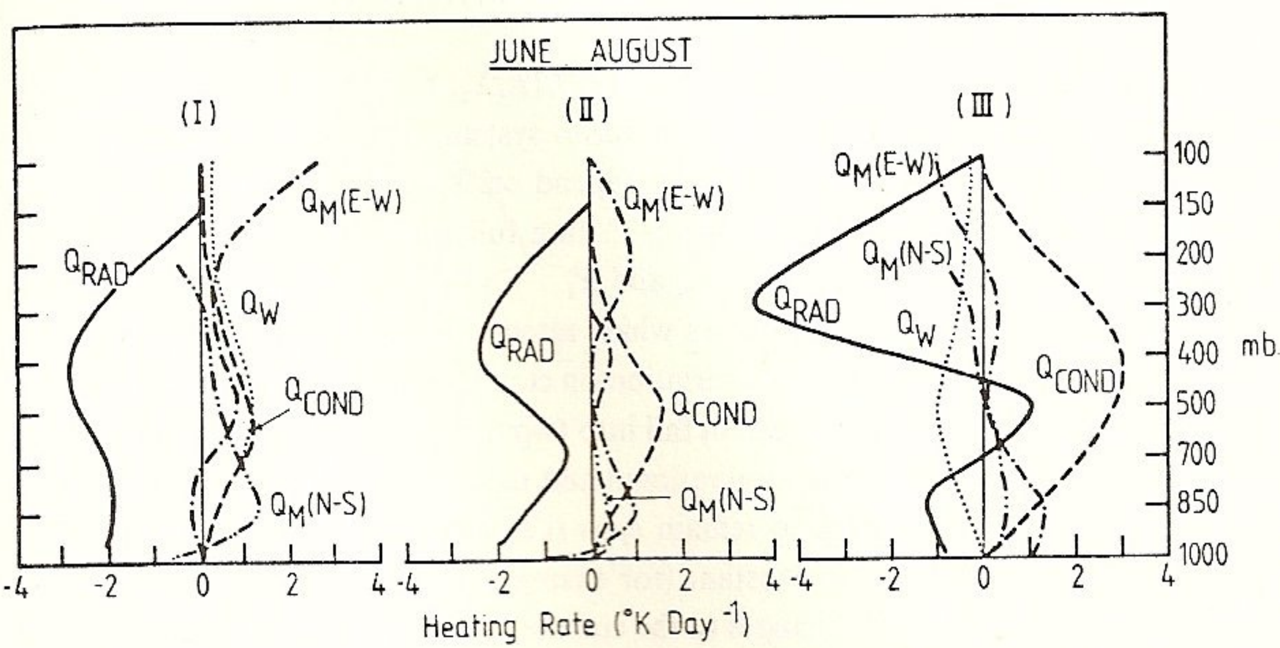
The major processes participating in cloud-radiation interactions are understood. But many details are still missing in circulation models.



From Simmons & Bengtsson, 1984, in Houghton, ed. "The Global Climate"



(a)



(b)

Webster & Stephens, 1984, in Houghton, ed., "The Global Climate"

Clouds effect not only the radiation budget a surface.

Vertical distributions of heating rates attributable to various transports during NH summer:

a.) zonal averages

b.) along 25°N over Saudi Arabia, Arabian Sea and the Bay of Bengal

Radiation fields can be measured at TOA but must be computed at all atmospheric layers using additional „ancillary“ data.

BUT:

Quality of all radiation products depends on the quality of such input data:

- **Cloud field properties**
- **Ancillary data on other properties of atmosphere and surface**

What are they?

Variables	Data set of variables
Cloud Cover, Optical Thickness, Top Temperature by Type	**ISCCP satellite radiances**
Cloud Particle Size	ISCCP-based Climatology
Cloud Vertical Structure	Combined ISCCP-Rawinsonde Climatology
Atmospheric Temperature and Tropospheric Humidity	TOVS, Oort Climatology for filling
Atmospheric Humidity (Upper Troposphere, Stratosphere)	SAGE Climatology
Atmospheric Composition	Actual record from Various Sources
Stratospheric Total Ozone	TOMS, TOVS for filling
Stratospheric Ozone Profiles	SAGE Climatology
Stratospheric Aerosols	SAGE
Tropospheric Aerosols	Baseline Current-day Climatology
Snow cover	NOAA product
Sea Ice cover	NSIDC product
Diurnal Cycle of Air Temperature over Land	Climatology based on surface weather reports and NCEP reanalysis
Surface Skin Temperature and Visible Reflectance	**From ISCCP retrievals**
Surface Spectral Albedo and Emissivity by Type	GISS GCM reconstruction by surface type and season

These variables are all subject of errors !

CLOUDS !

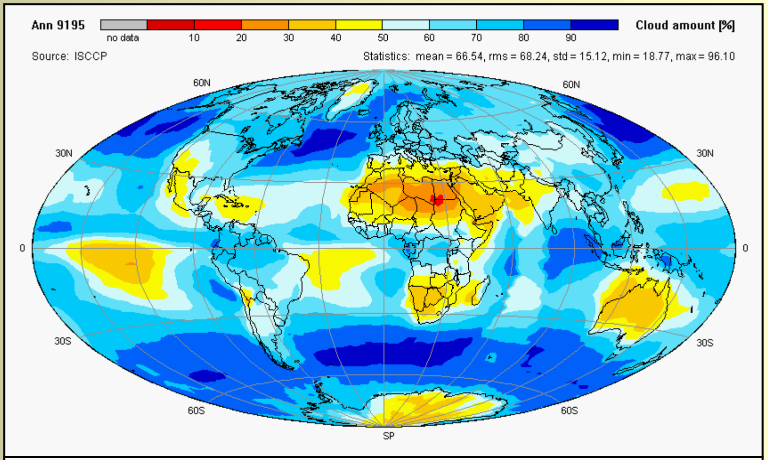
Clouds reduce emission and enhance reflection to space; they enhance emission and reduce solar flux to ground.

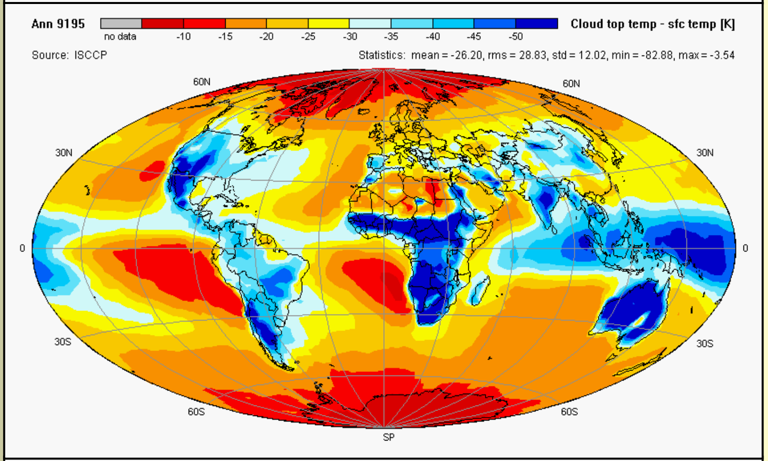
Comparison of annual, global averages of the cloud effect (in Wm^{-2}):

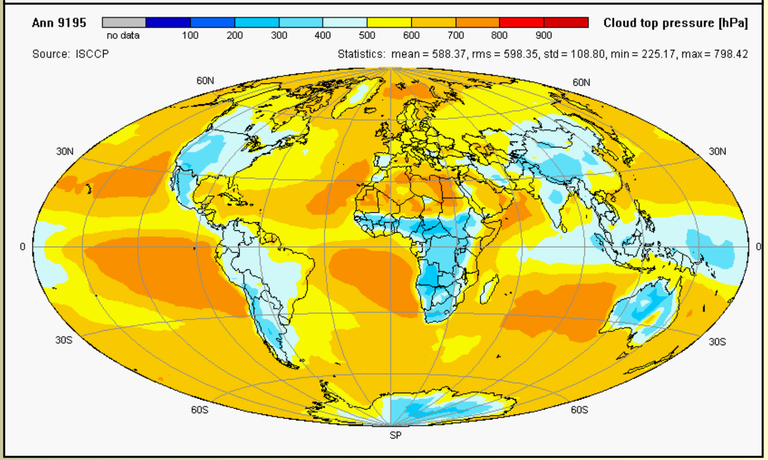
data-set	upward fluxes at TOA (-)			downward fluxes at surface (+)		
	solar	*IR*	*solar+IR*	*solar*	*IR*	*solar+ IR*
ISCCP (1/84-12/95)	-50.1	25.7	-24.4	-58.9	31.0	-27.9
SRB (1/84-12/95)	-47.4	28.3	-19.1	-56.8	35.6	-21.2
CERES (3/00-2/04)	-46.6	26.7	-19.9	-51.1	30.6	-20.5
IPCC median (84-95)	-49.1	26.8	-22.3	-63.0	30.5	-32.5

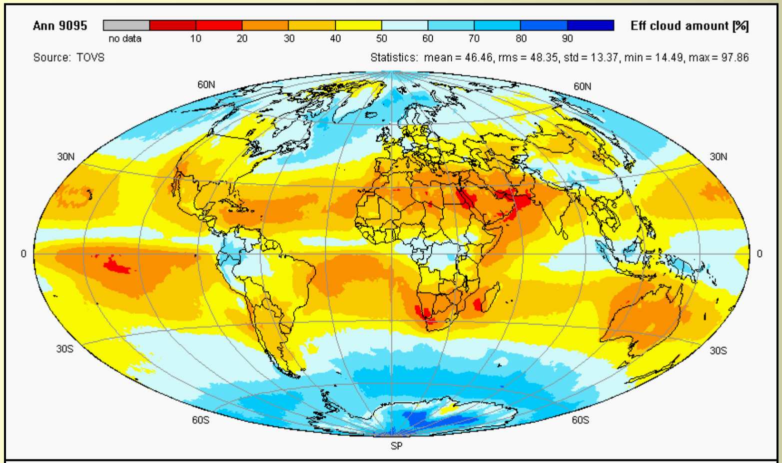
Cloud effect (CE) = cloudy - clear

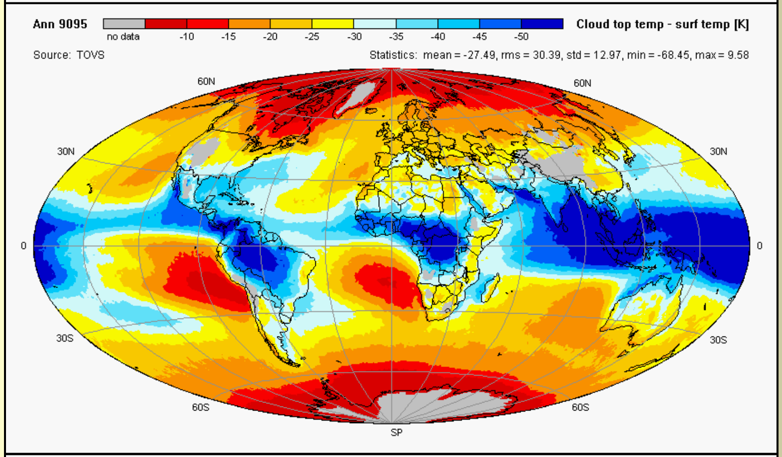
ISCCP

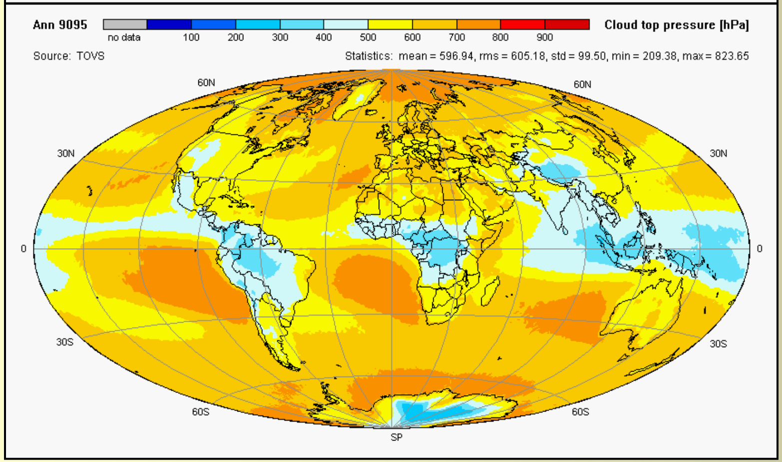

Ann 9195
no data 10 20 30 40 50 60 70 80 90
Cloud amount [%]
Source: ISCCP
Statistics: mean = 66.54, rms = 68.24, std = 15.12, min = 18.77, max = 96.10
60N 30N 0 30S 60S SP


Ann 9195
no data -10 -15 -20 -25 -30 -35 -40 -45 -50
Cloud top temp - sfc temp [K]
Source: ISCCP
Statistics: mean = -26.20, rms = 28.83, std = 12.02, min = -82.88, max = -3.54
60N 30N 0 30S 60S SP


Ann 9195
no data 100 200 300 400 500 600 700 800 900
Cloud top pressure [hPa]
Source: ISCCP
Statistics: mean = 588.37, rms = 598.35, std = 108.80, min = 225.17, max = 798.42
60N 30N 0 30S 60S SP


Ann 9095
no data 10 20 30 40 50 60 70 80 90
Eff cloud amount [%]
Source: TOVS
Statistics: mean = 46.46, rms = 48.35, std = 13.37, min = 14.49, max = 97.86
60N 30N 0 30S 60S SP


Ann 9095
no data -10 -15 -20 -25 -30 -35 -40 -45 -50
Cloud top temp - surf temp [K]
Source: TOVS
Statistics: mean = -27.49, rms = 30.39, std = 12.97, min = -68.45, max = 9.58
60N 30N 0 30S 60S SP

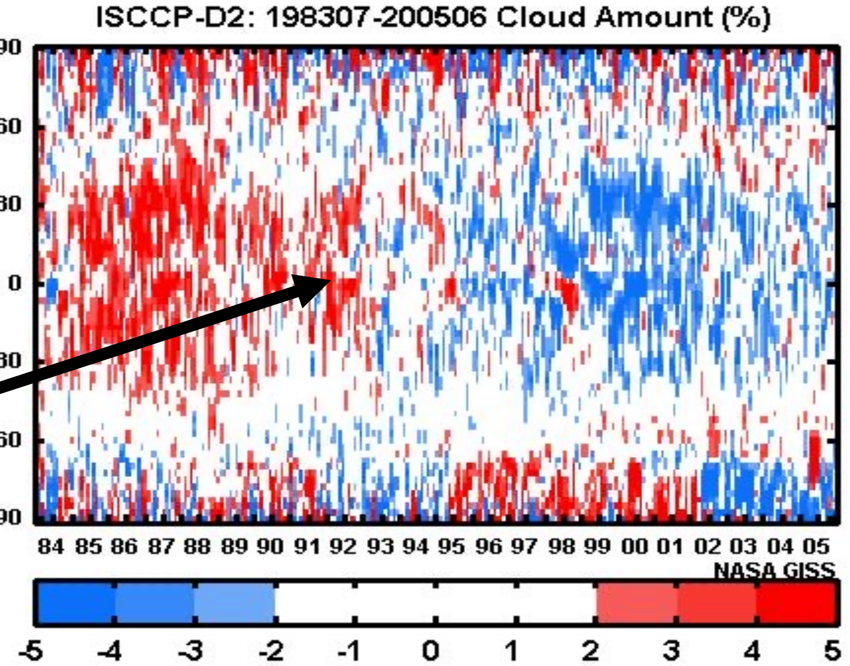

Ann 9095
no data 100 200 300 400 500 600 700 800 900
Cloud top pressure [hPa]
Source: TOVS
Statistics: mean = 596.94, rms = 605.18, std = 99.50, min = 209.38, max = 823.65
60N 30N 0 30S 60S SP

TOVS

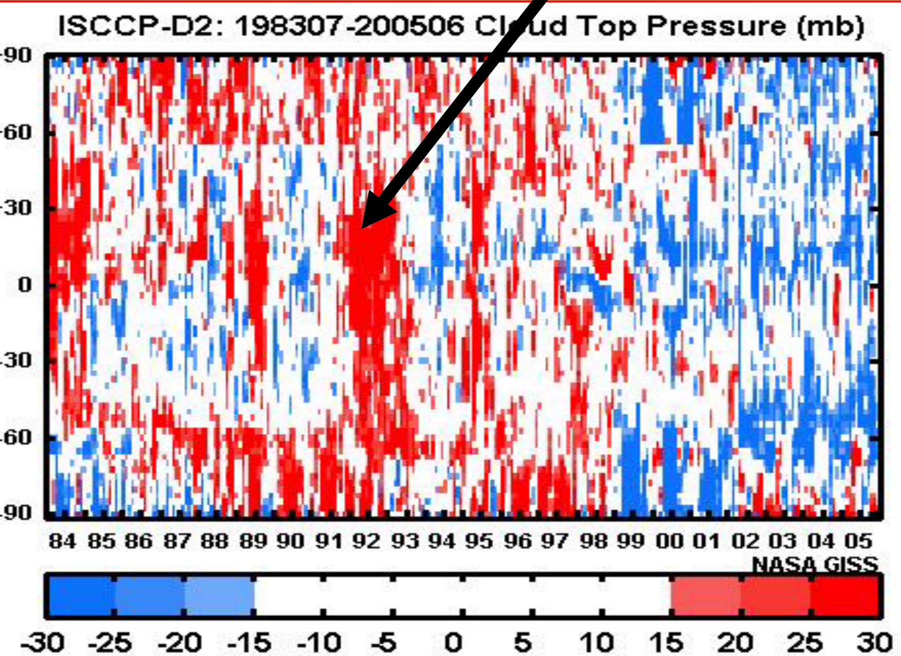
ISCCP:

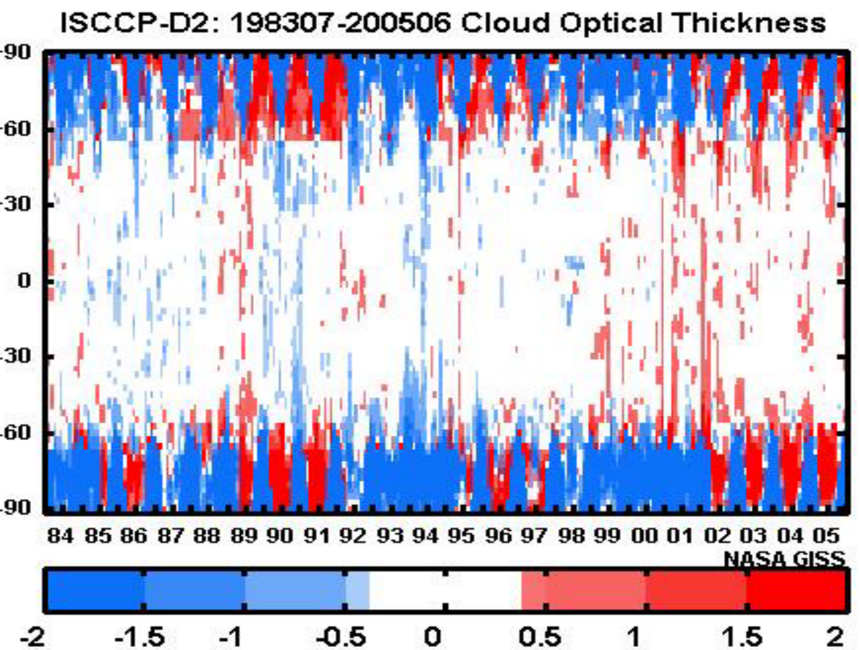
Monthly zonal anomalies of all clouds: top pressure, optical thickness & amount.

Method: Rossow & Garder, 1993



Pinatubo, June 1991



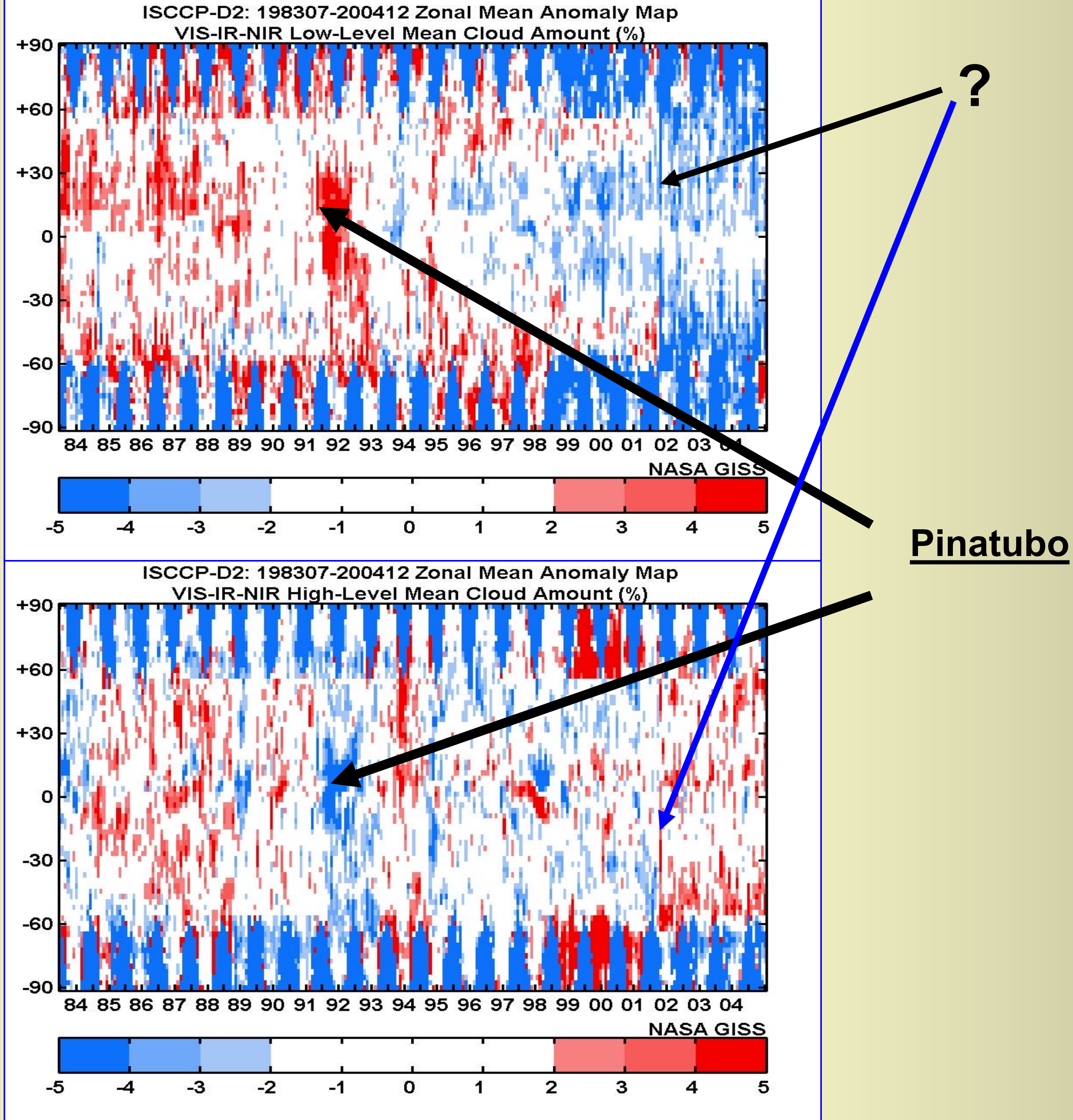


ISCCP:

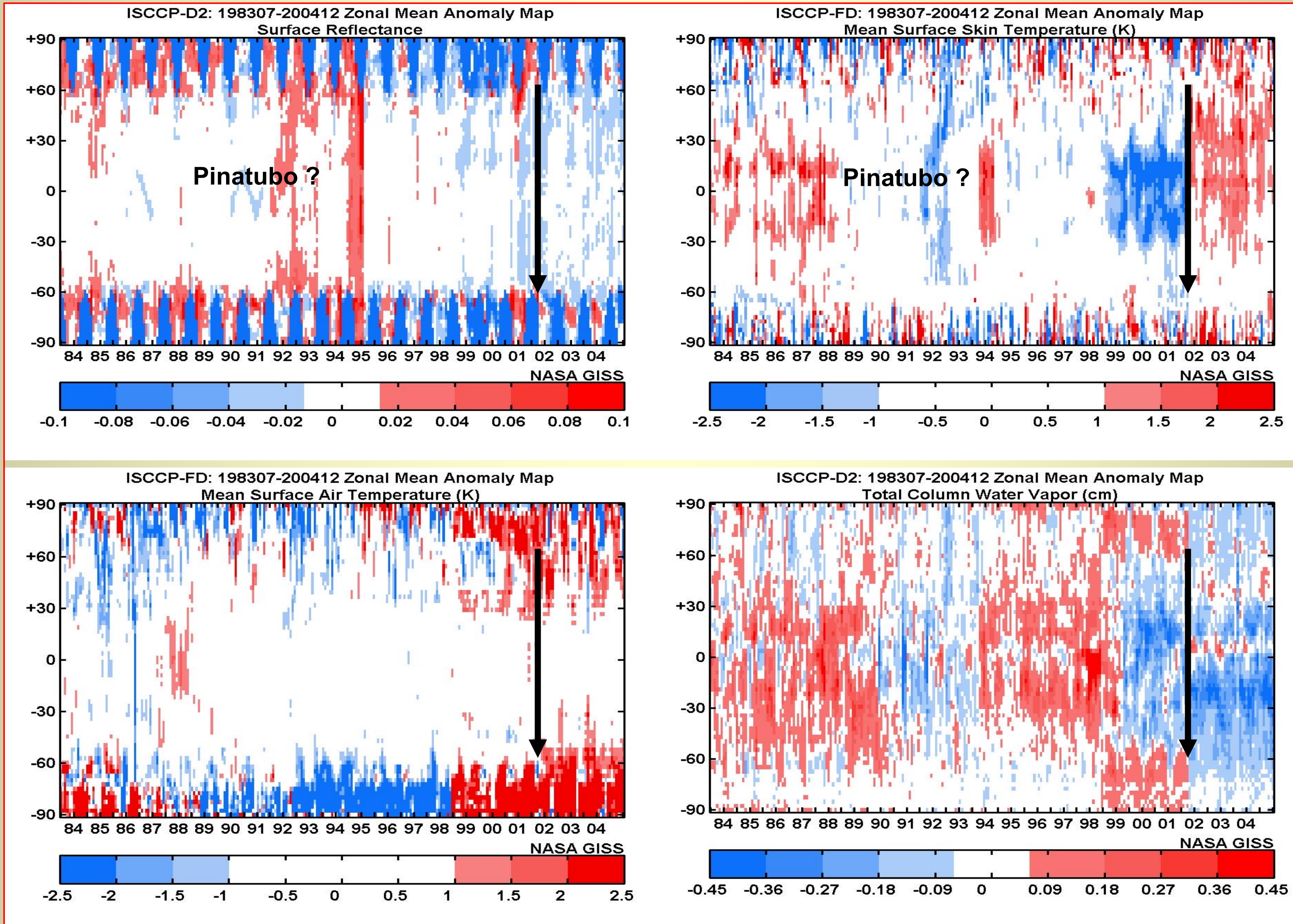
Cloud amounts:

low & high

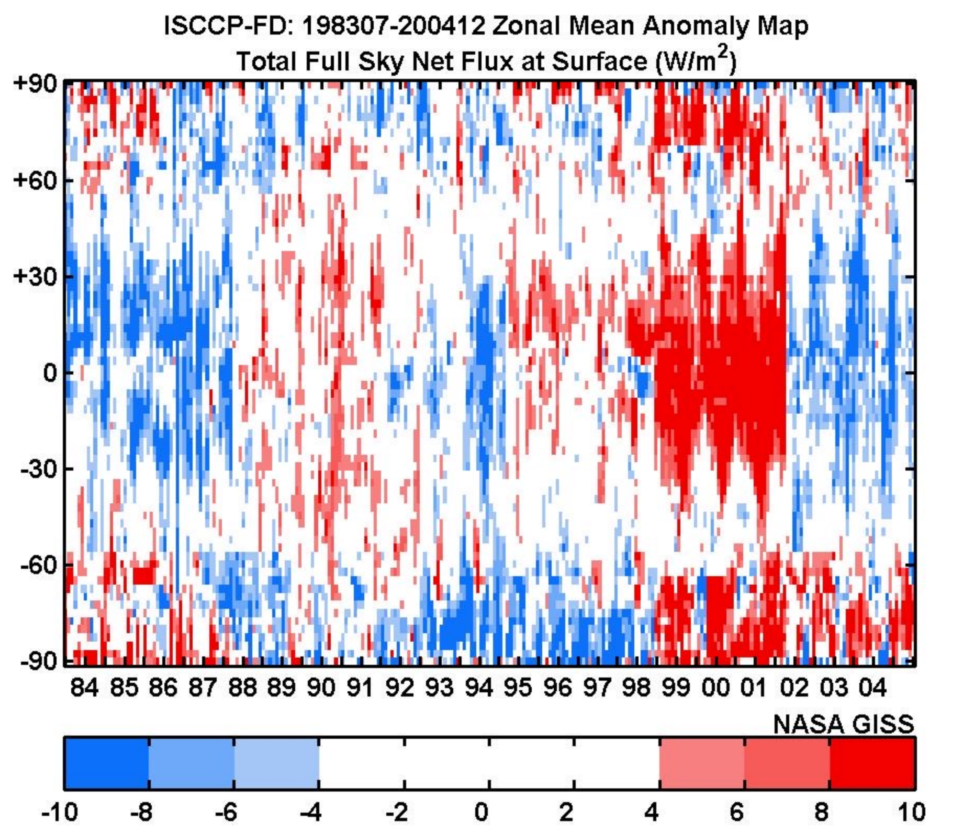
Information is needed on the atmospheric structure.

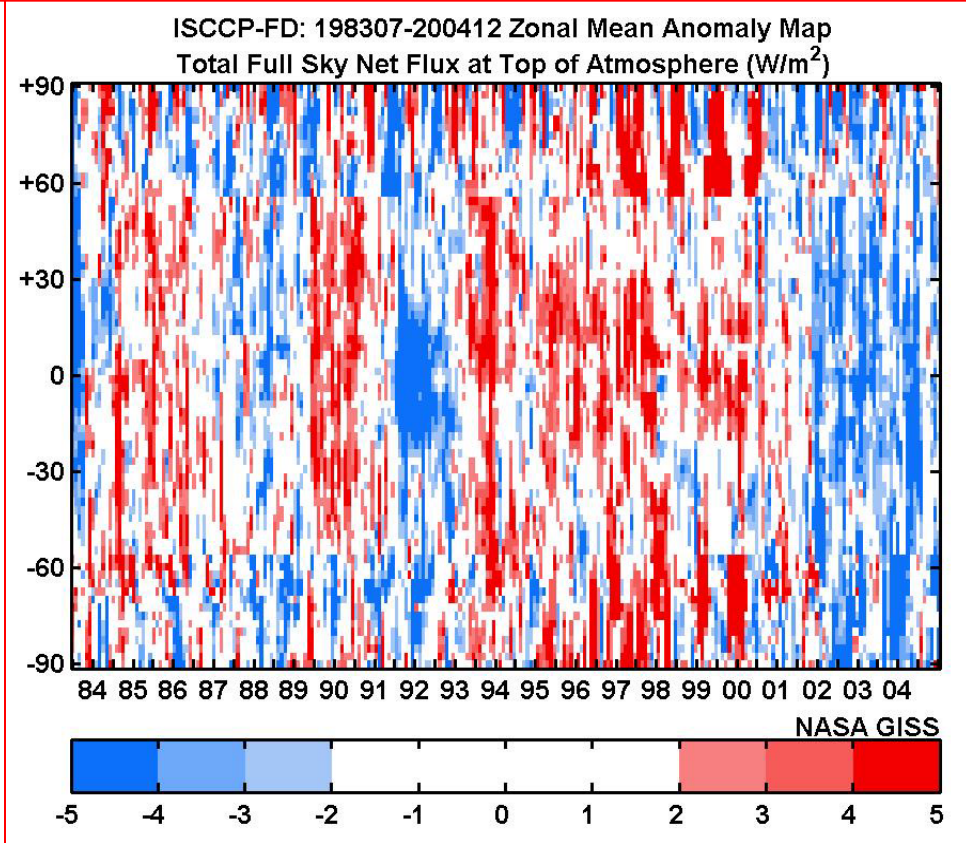


<u>ISCCP:</u> Surface reflectance & temperature, water vapor & air temperature are the most important ancillary data. http://ISCCP.giss.nasa.gov



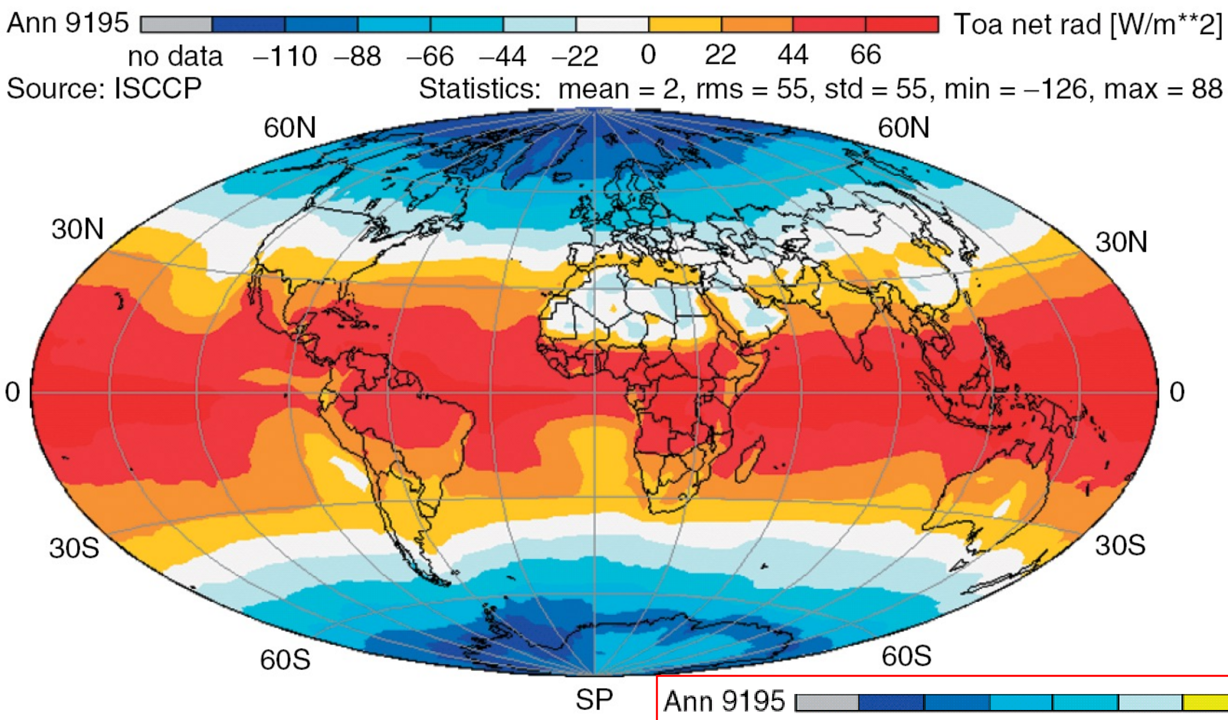
Uncertainties in ancillary and in cloud data can propagate into all computations of the radiation products. For example:



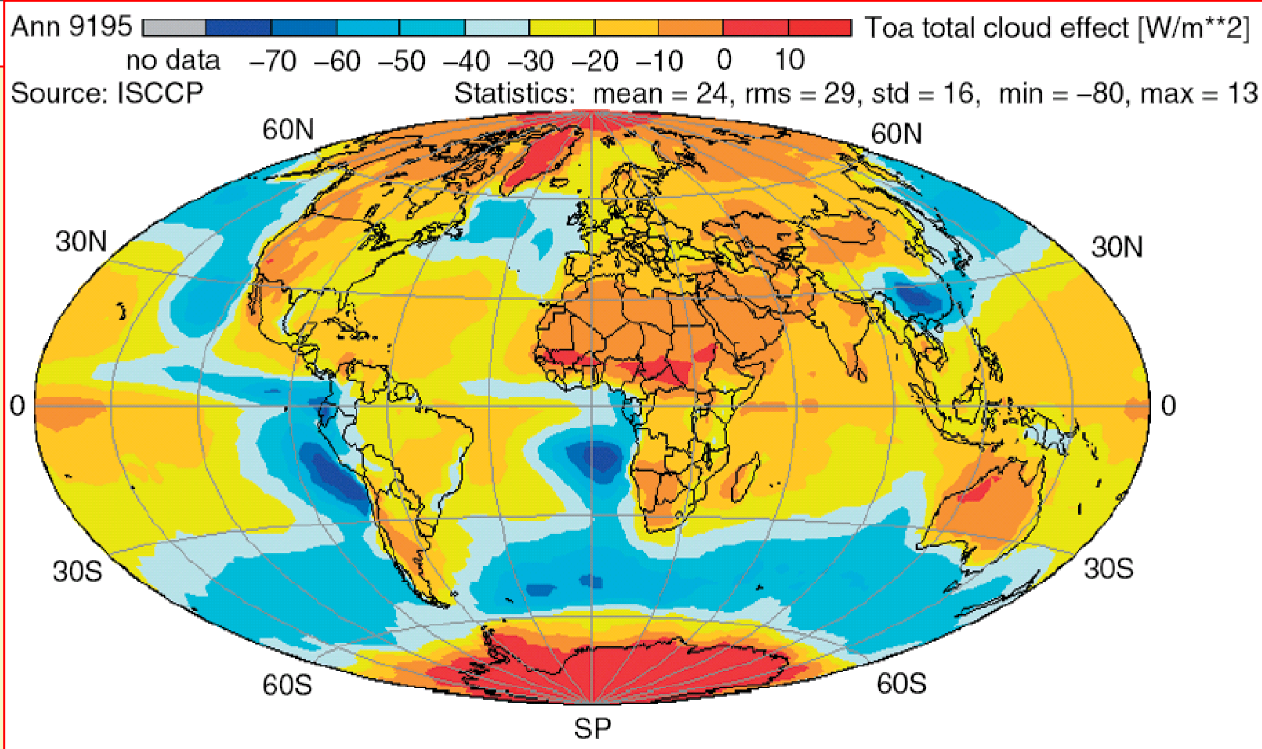


Total <u>net radiation</u> at surface **Total <u>net radiation</u> at TOA**

Total net radiation at TOA

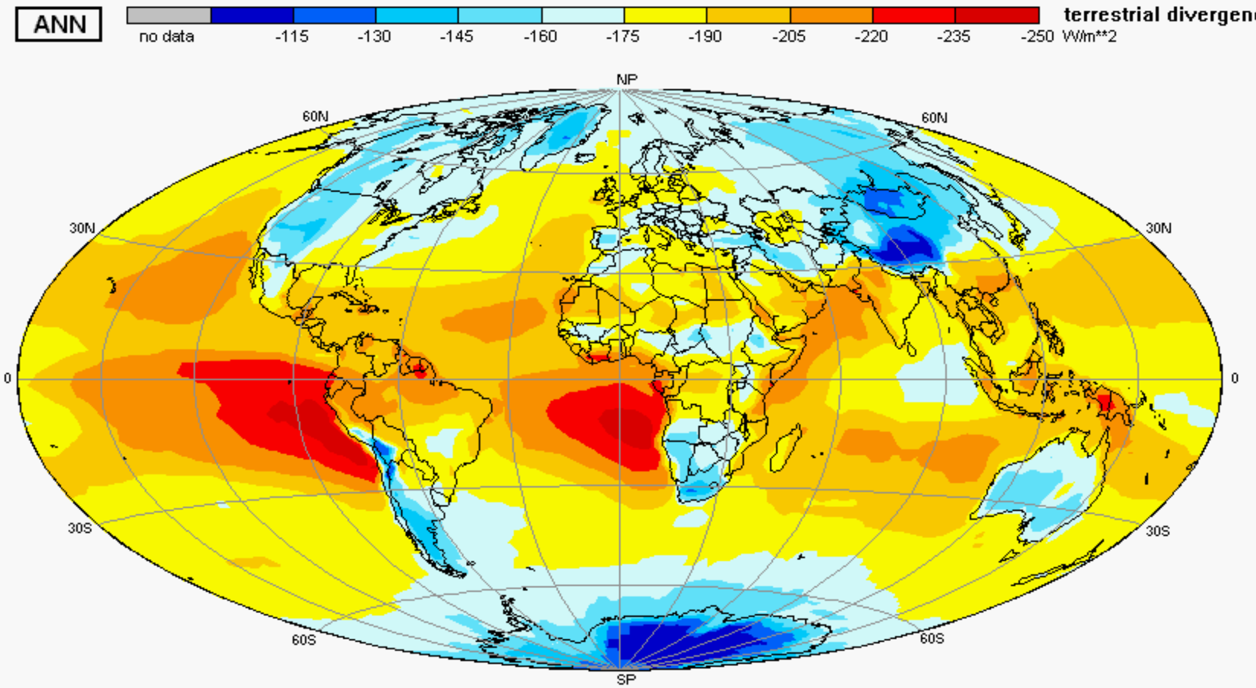


Raschke et al., 2005, IJClim.



CE on total net radiation at TOA:

Clouds reduce the net gain of the "clear earth".



Loss of heat radiation by the atmosphere only

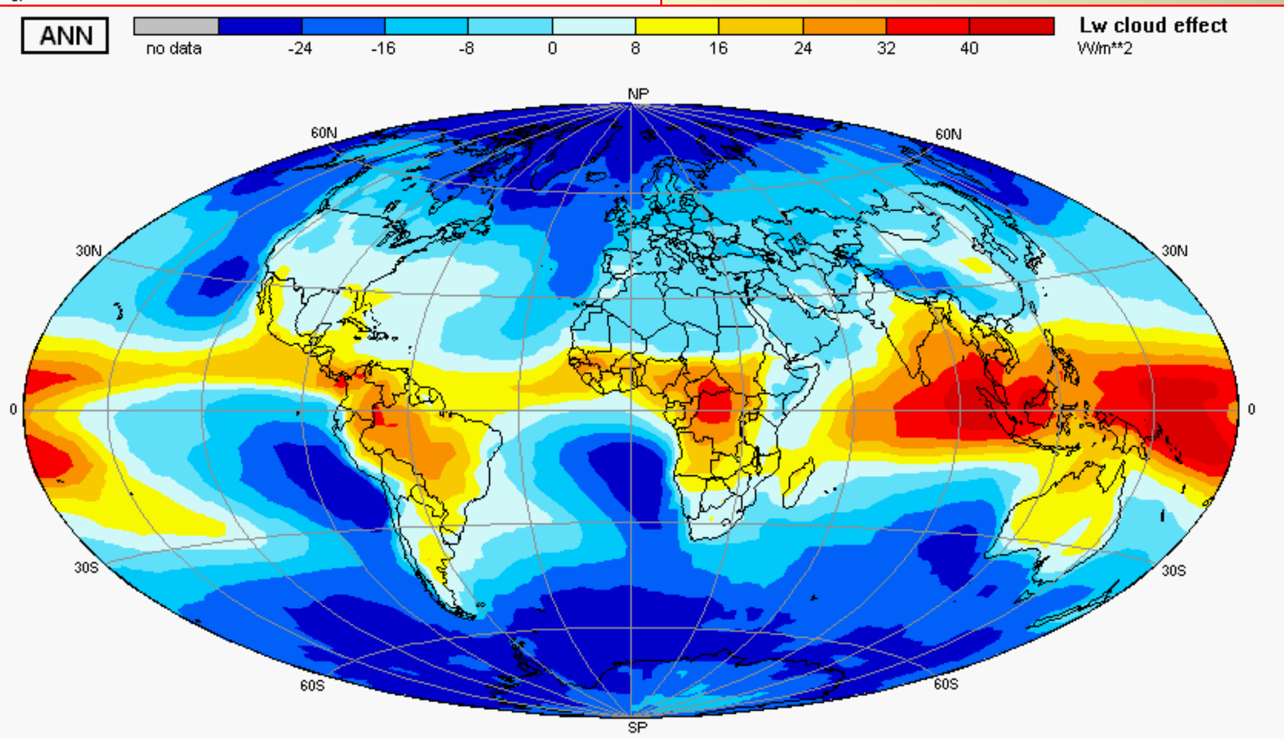
1991 - 1995

ISCCP

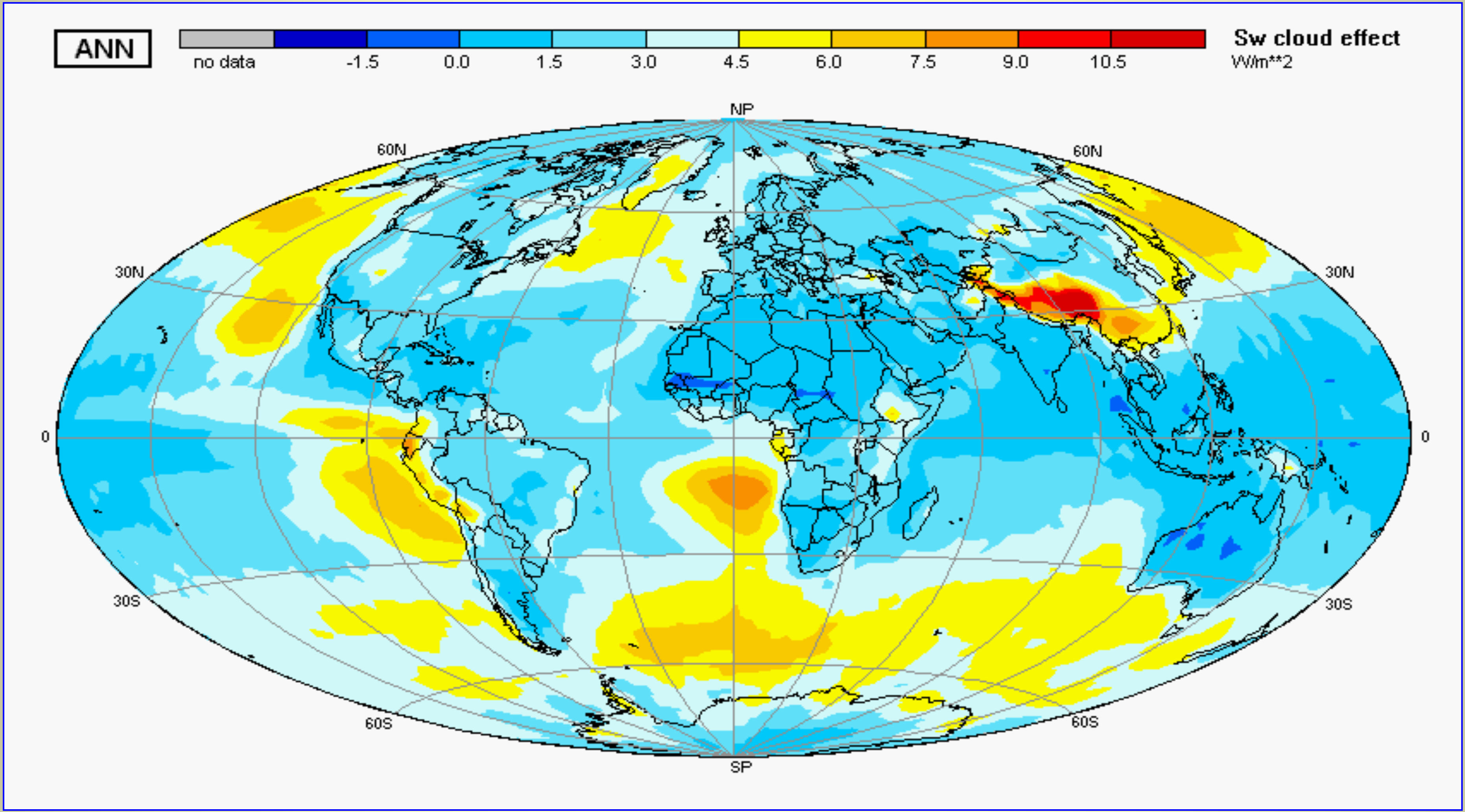
Raschke et al., 2005, IJClim.

CE on loss of heat radiation by the atmosphere

Low clouds tend to reduce, high clouds tend to enhance.



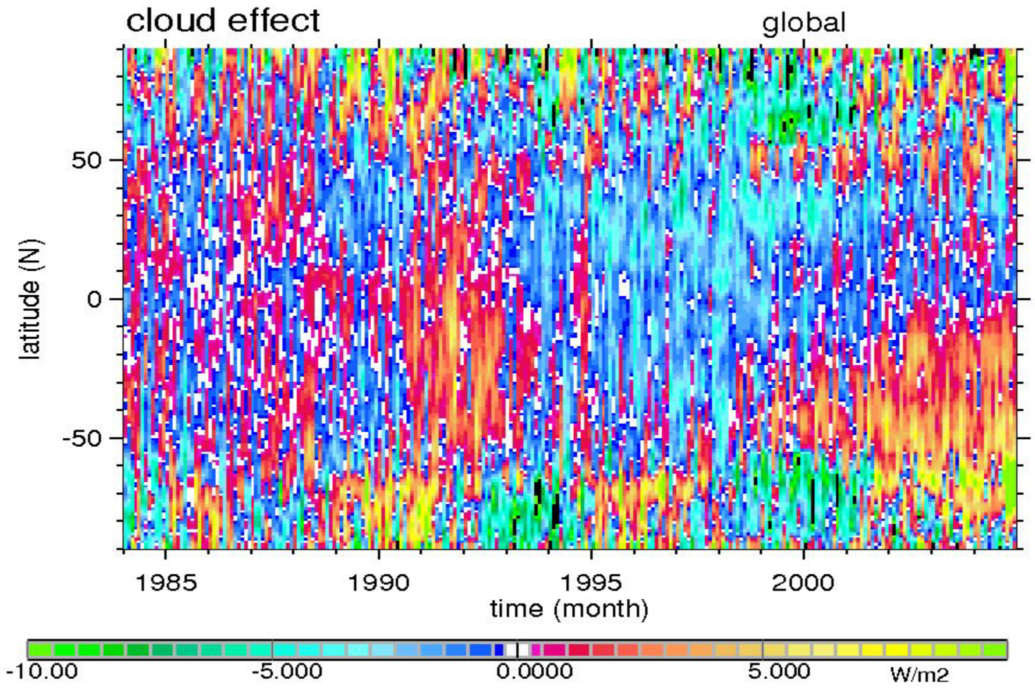
CE on solar vertical radiative flux divergence, computed in ISCCP, 1991 to 1995



1991 - 1995

Raschke et al., 2005, IJClim.

Comparison: ISCCP, SRB, CERES, IPCC-models



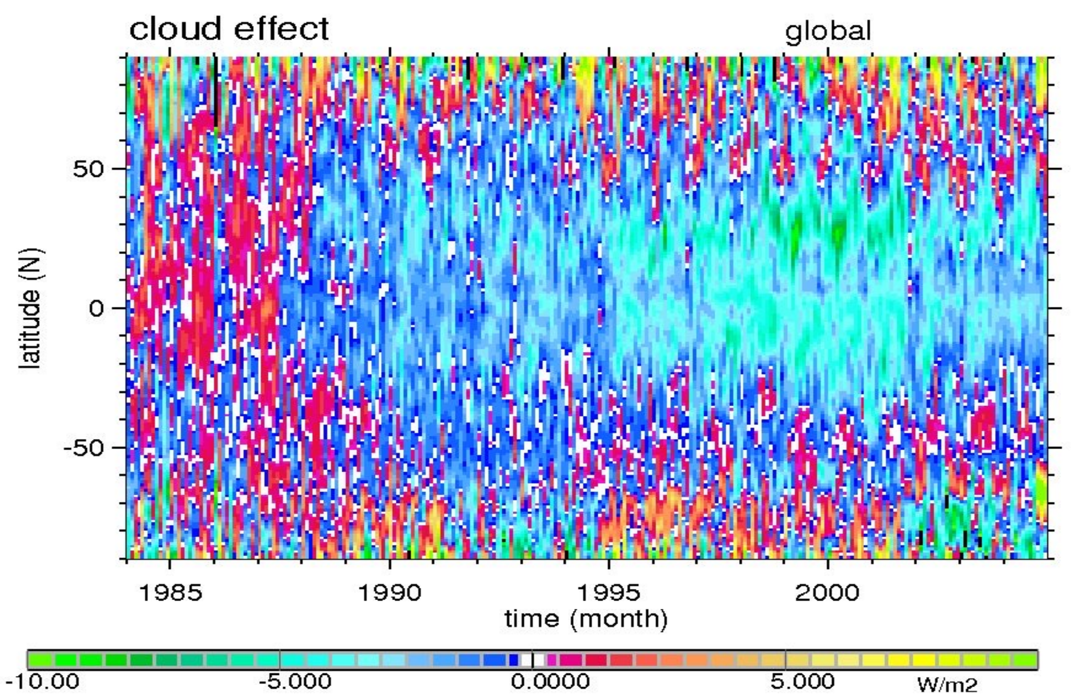
These anomalies in ancillary data „reoccur“ in ISCCP radiation products.

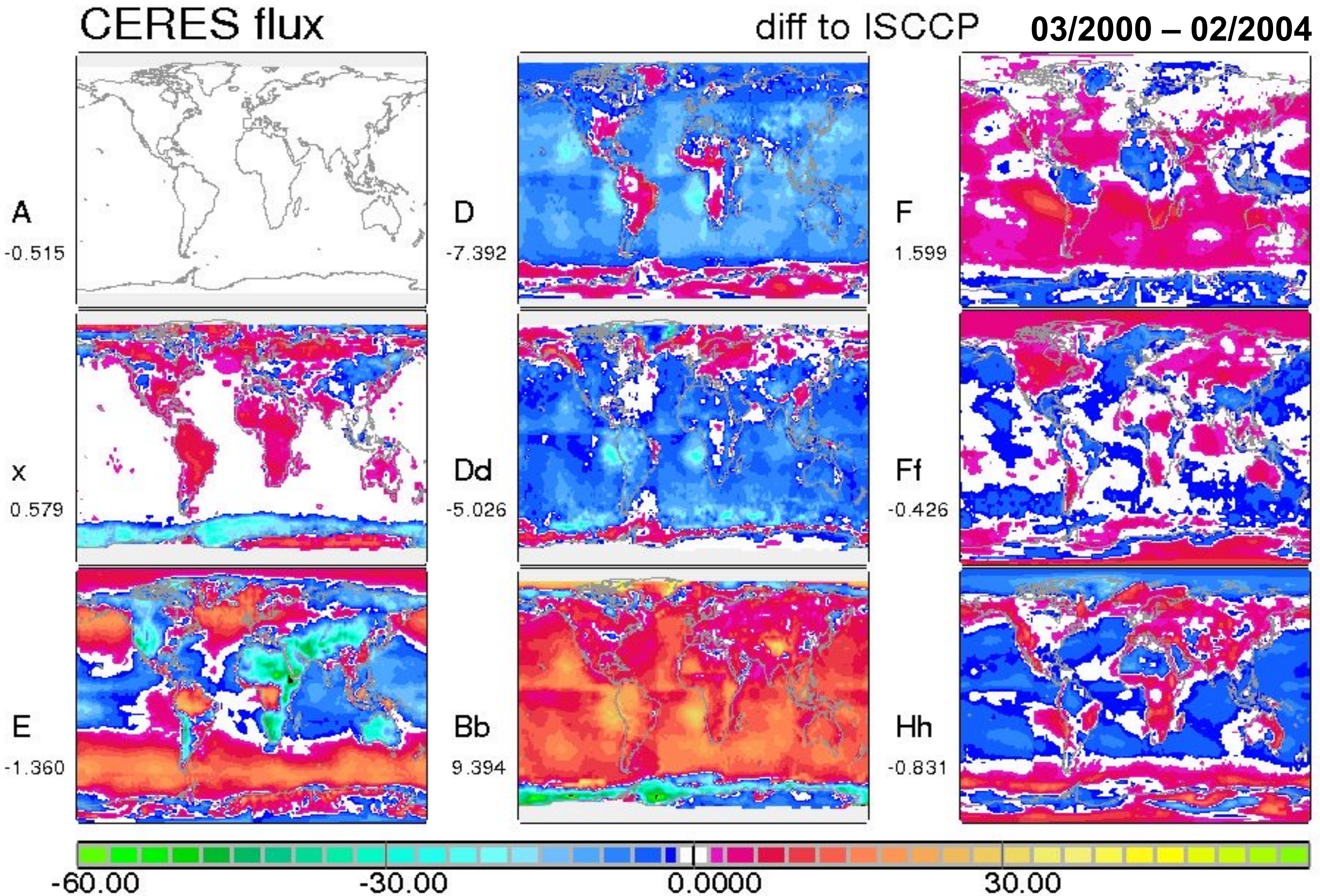
CE on downward atmospheric radiation at surface; ref.: 85-88

CE = cloudy minus clear

ISCCP

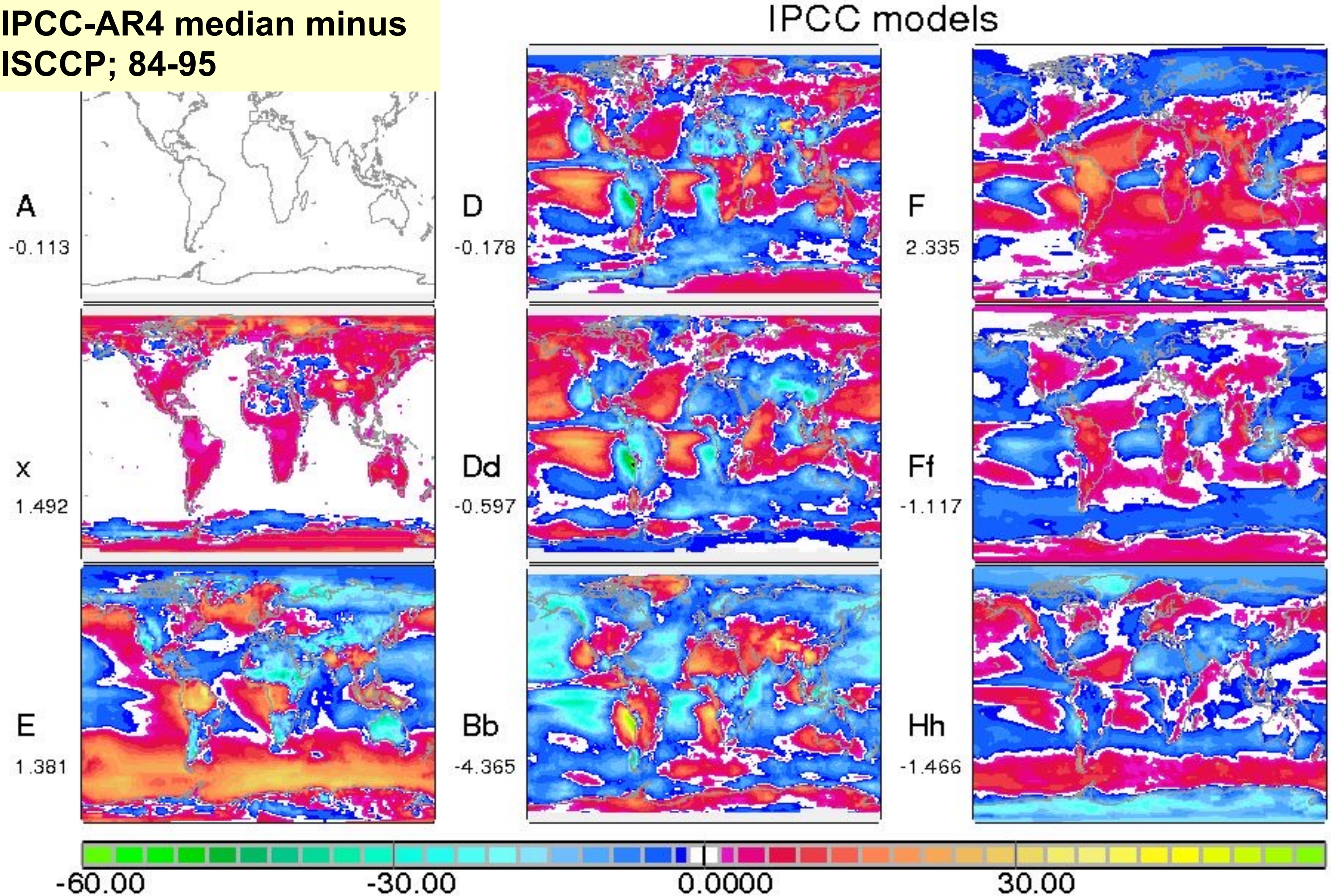
SRB





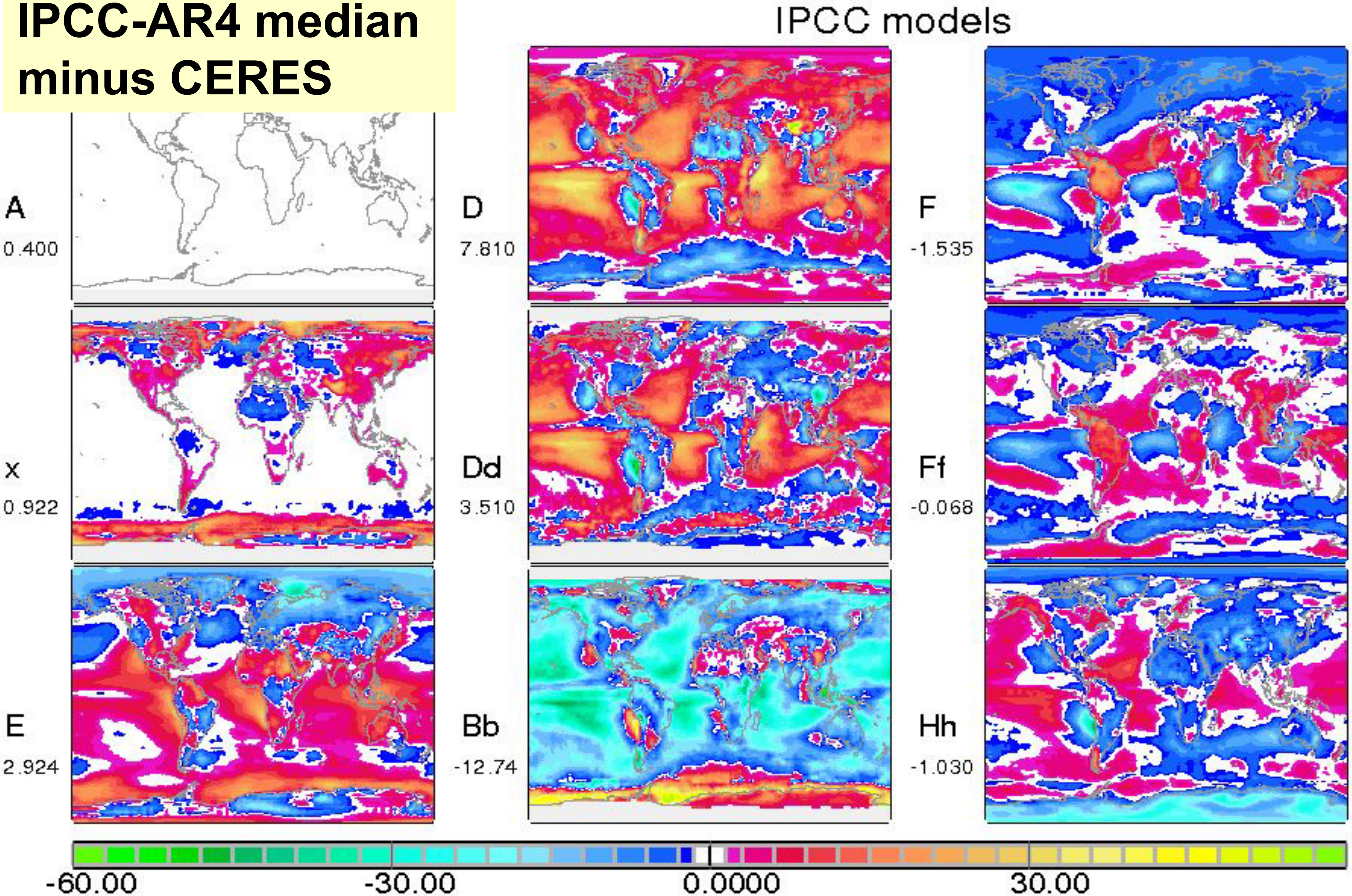
A = Incident solar at TOA, X = Effective surface albedo, E = Emission from surface, D = Outgoing solar at TOA, F = Outgoing infrared at TOA, Dd = CE on outgoing solar at TOA, Bb = CE on downward solar at surface, Ff = CE on outgoing infrared at TOA, Hh = CE on downward infrared at surface

IPCC-AR4 median minus ISCCP; 84-95



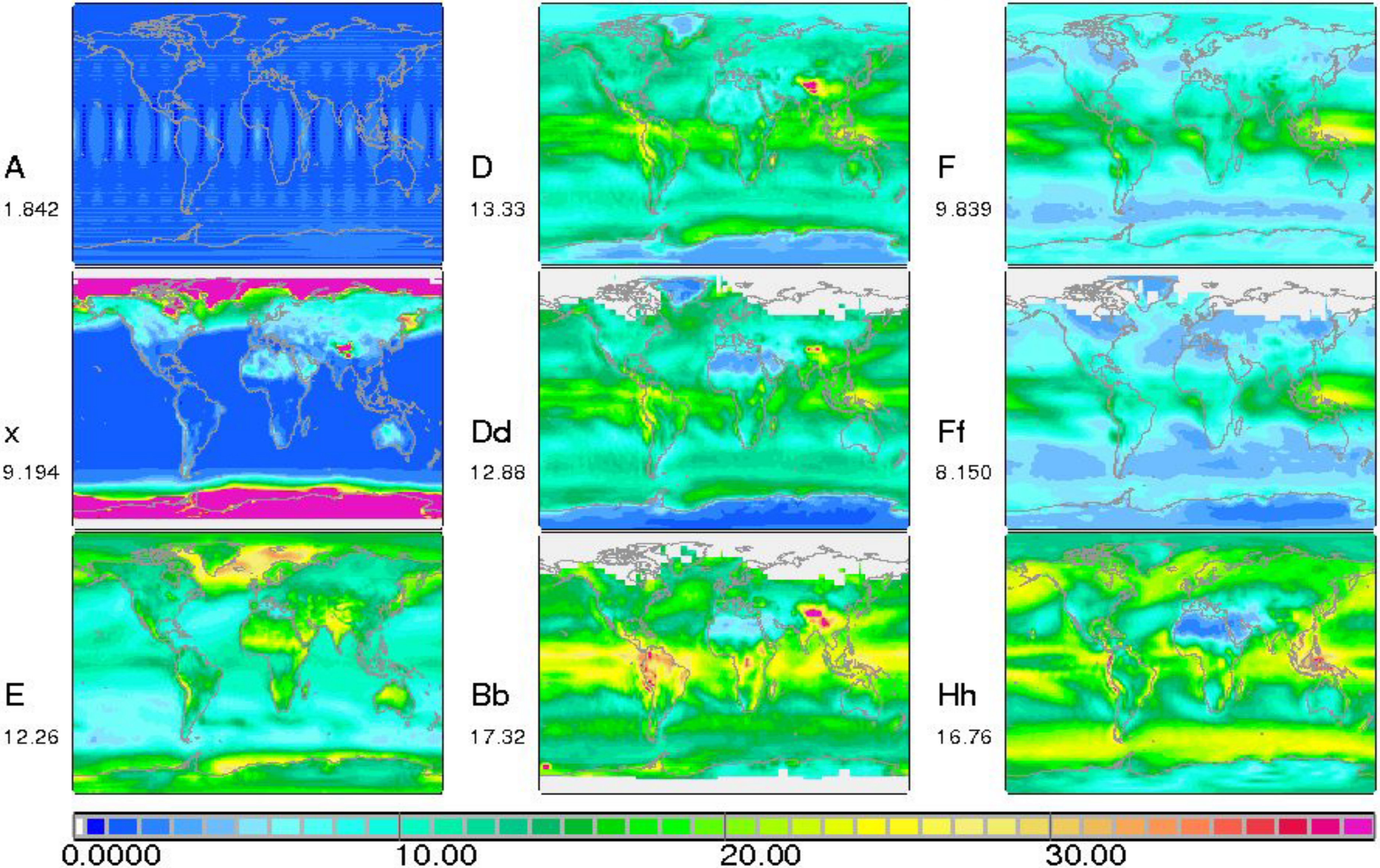
A = Incident solar at TOA, X = Effective surface albedo, E = Emission from surface, D = Outgoing solar at TOA, F = Outgoing infrared at TOA, Dd = CE on outgoing solar at TOA, Bb = CE on downward solar at surface, Ff = CE on outgoing infrared at TOA, Hh = CE on downward infrared at surface

IPCC-AR4 median minus CERES



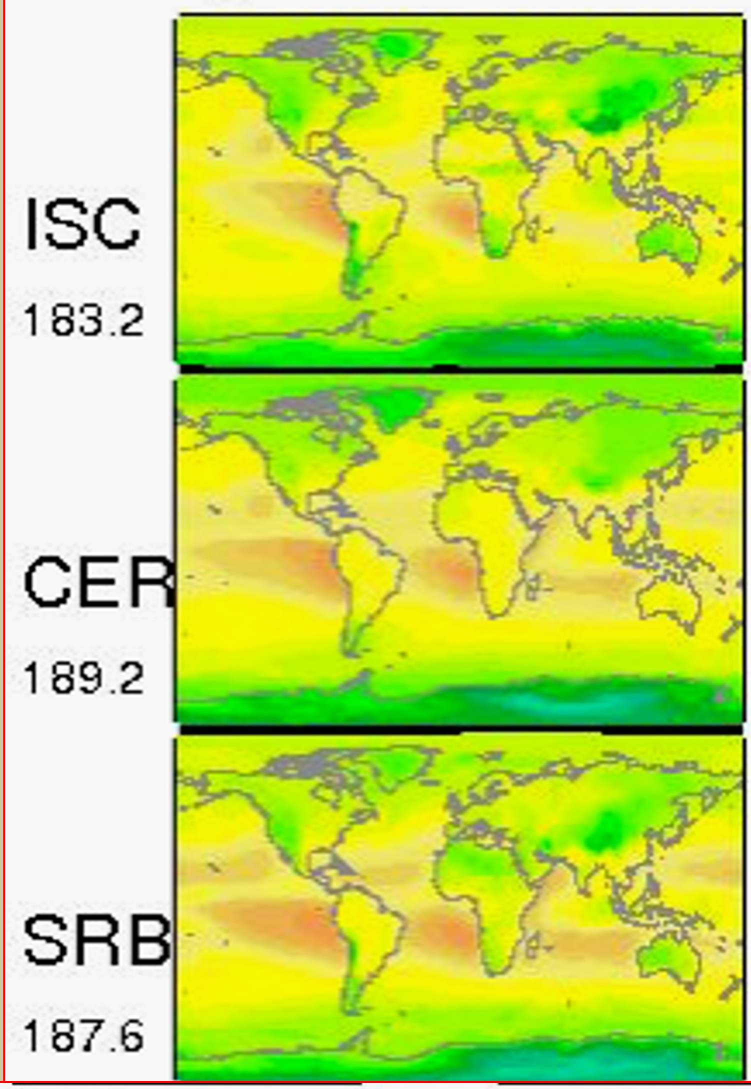
A = Incident solar at TOA, X = Effective surface albedo, E = Emission from surface, D = Outgoing solar at TOA, F = Outgoing infrared at TOA, Dd = CE on outgoing solar at TOA, Bb = CE on downward solar at surface, Ff = CE on outgoing infrared at TOA, Hh = CE on downward infrared at surface

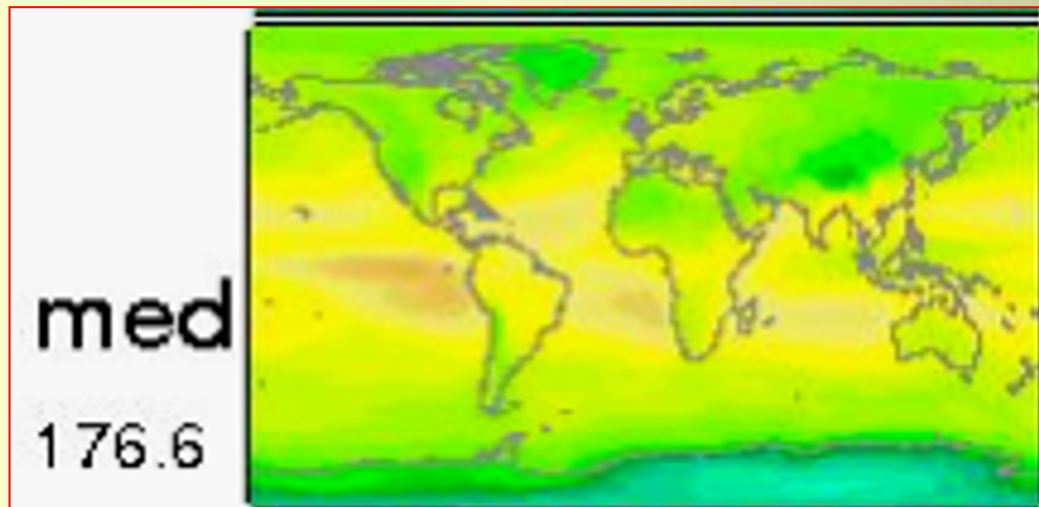
standard deviation fields **20** IPCC models **84-95**

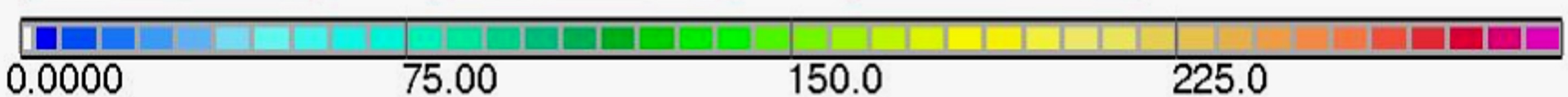


A = Incident solar at TOA, X = Effective surface albedo, E = Emission from surface, D = Outgoing solar at TOA, F = Outgoing infrared at TOA, Dd = CE on outgoing solar at TOA, Bb = CE on downward solar at surface, Ff = CE on outgoing infrared at TOA, Hh = CE on downward infrared at surface

How is the vertical distribution ?

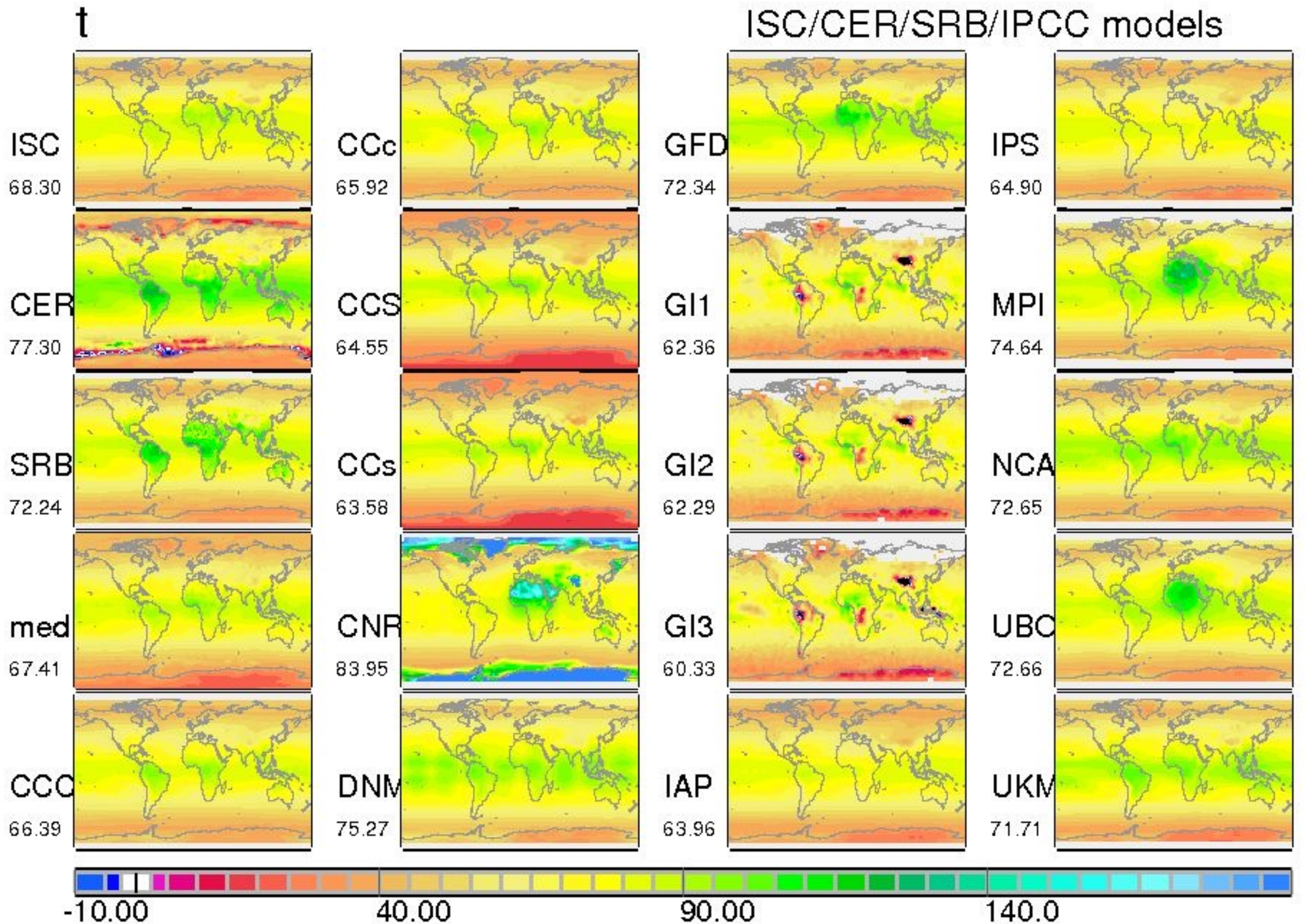




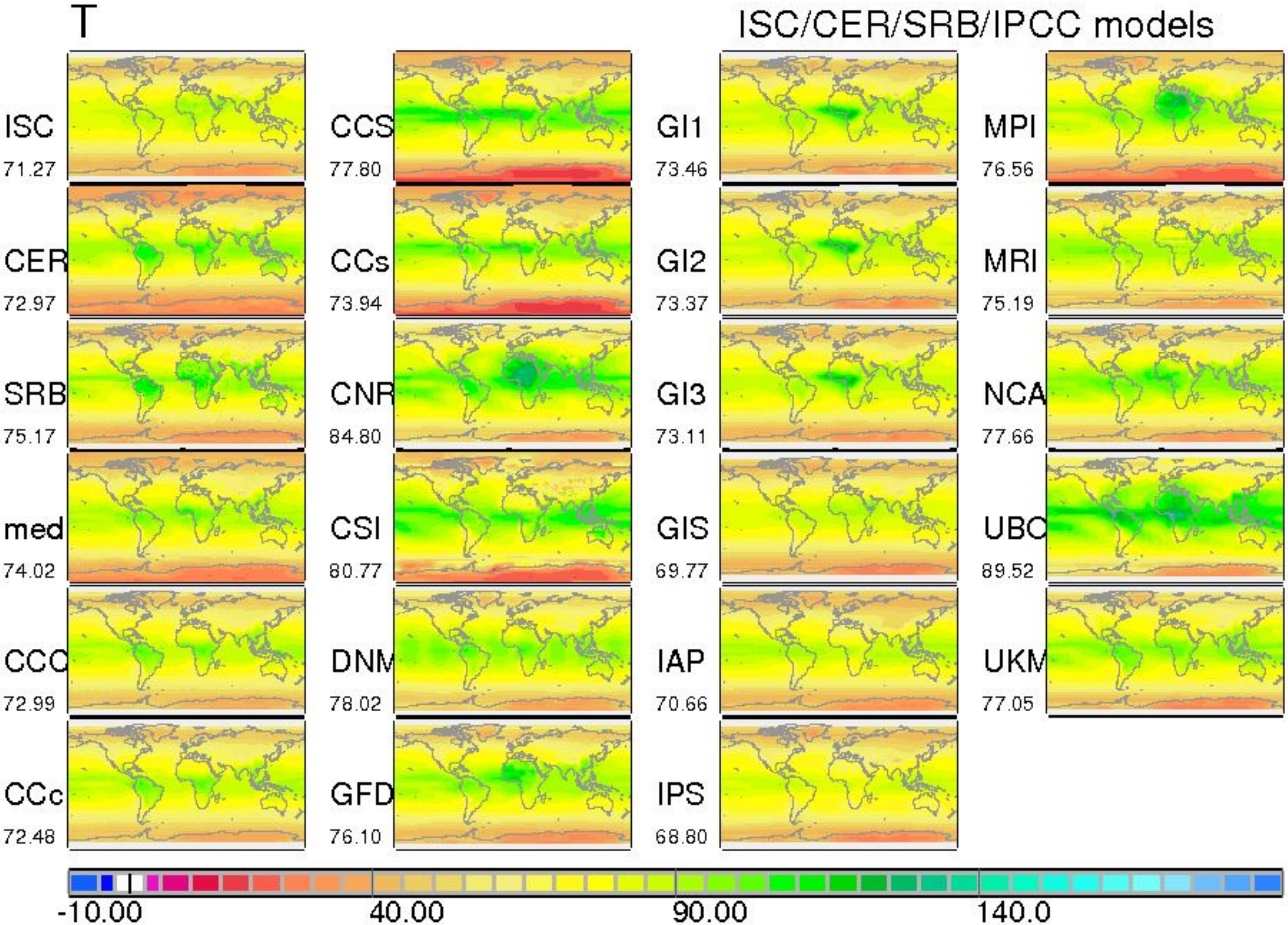


Cloudy sky multi-annual (1984-1995) infrared radiative flux divergence for climatologies (ISCCP, CERES, SRB) and IPCC-4AR model median of 20 models.

All values should be considered to be negative, since the atmosphere is radiatively cooled.



Annual clear sky absorption of solar radiation within the atmosphere

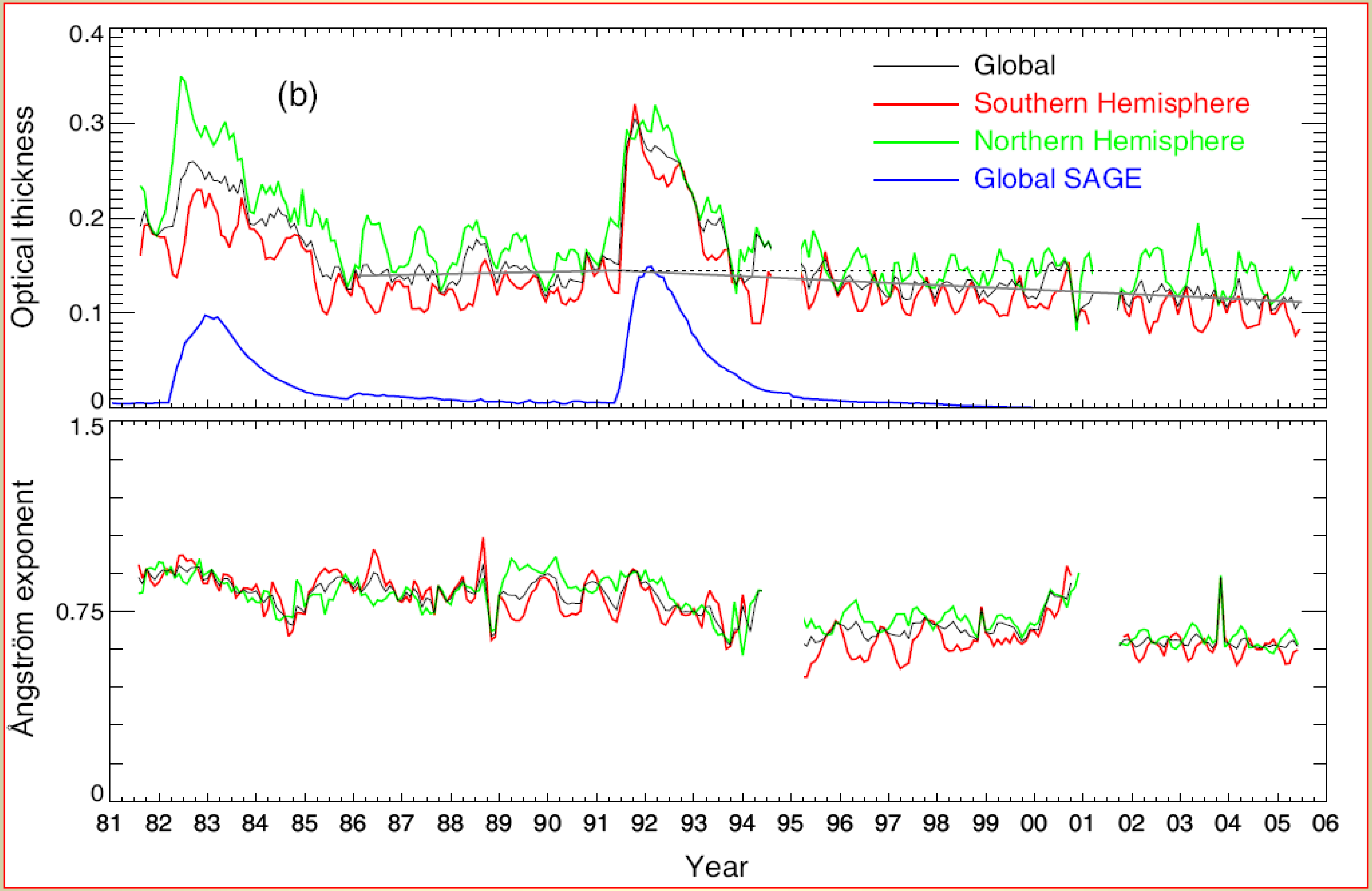


Annual cloudy sky absorption of solar radiation within the atmosphere

The role of aerosols

ISCCP

Aerosol optical depth (global average over oceans) from ISCCP radiance data seems to decrease after 1995.



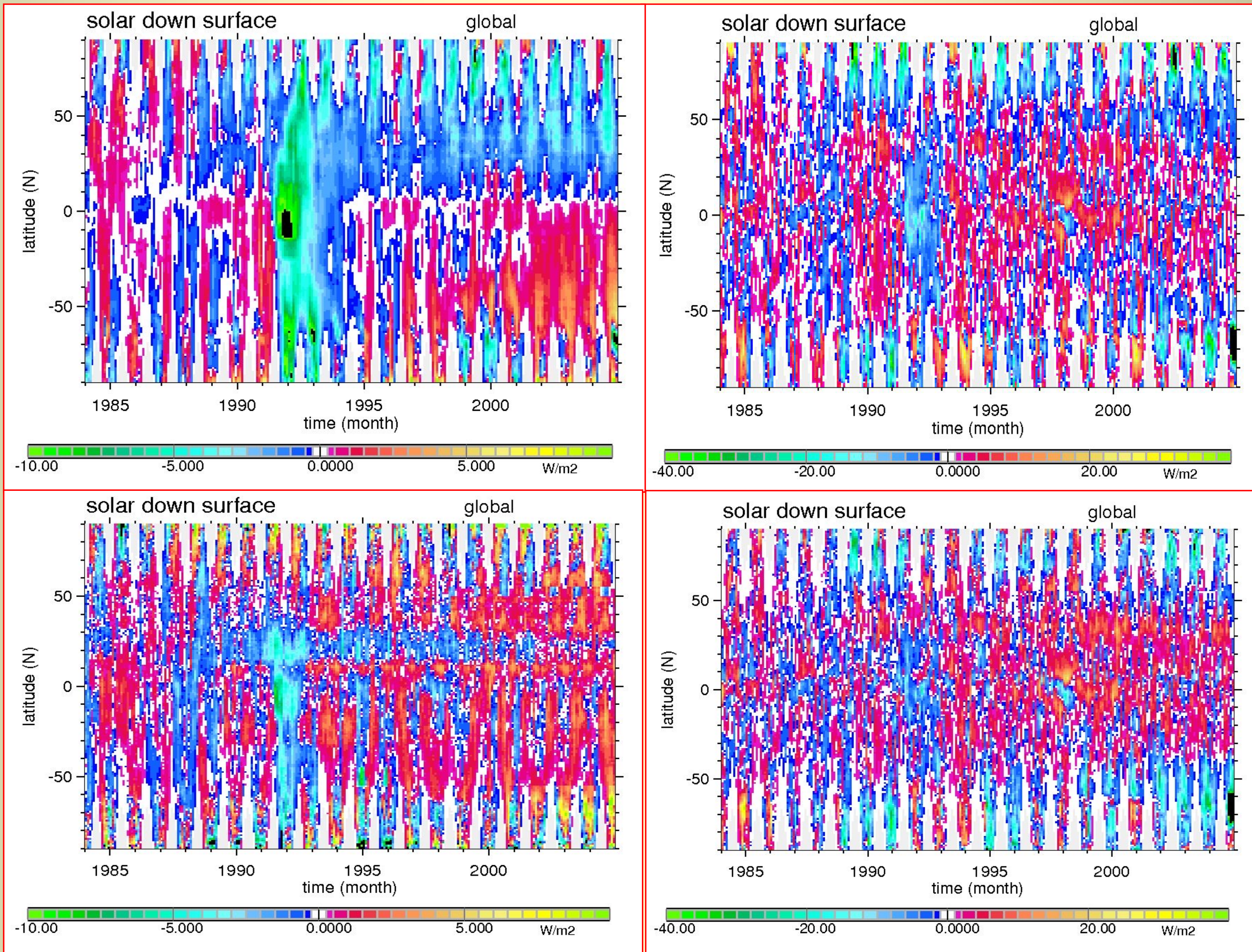
(Mishchenko et al. 2007)

Deseasonalised vs. 1985-1988

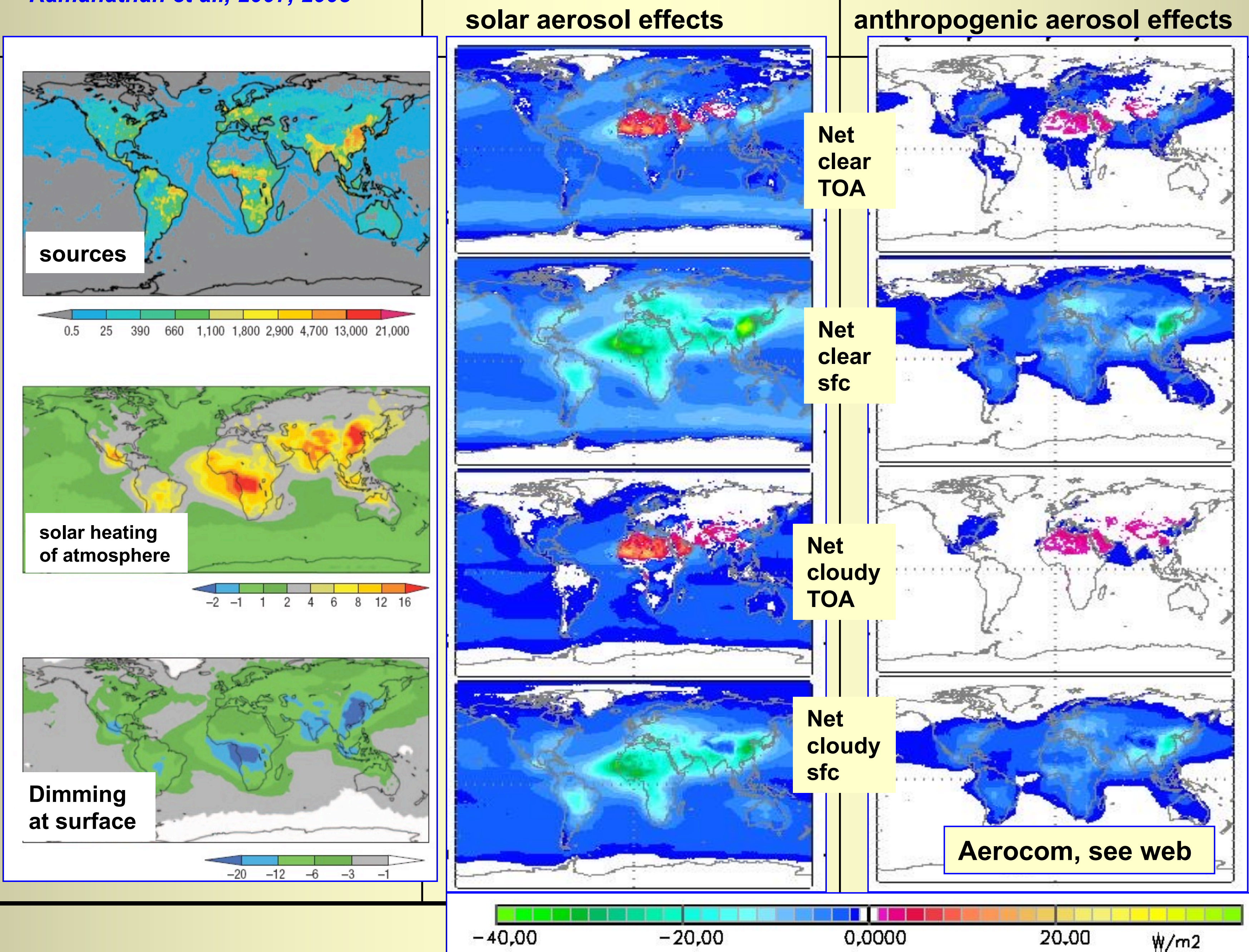
Clear | **Cloudy**

ISCCP

SRB

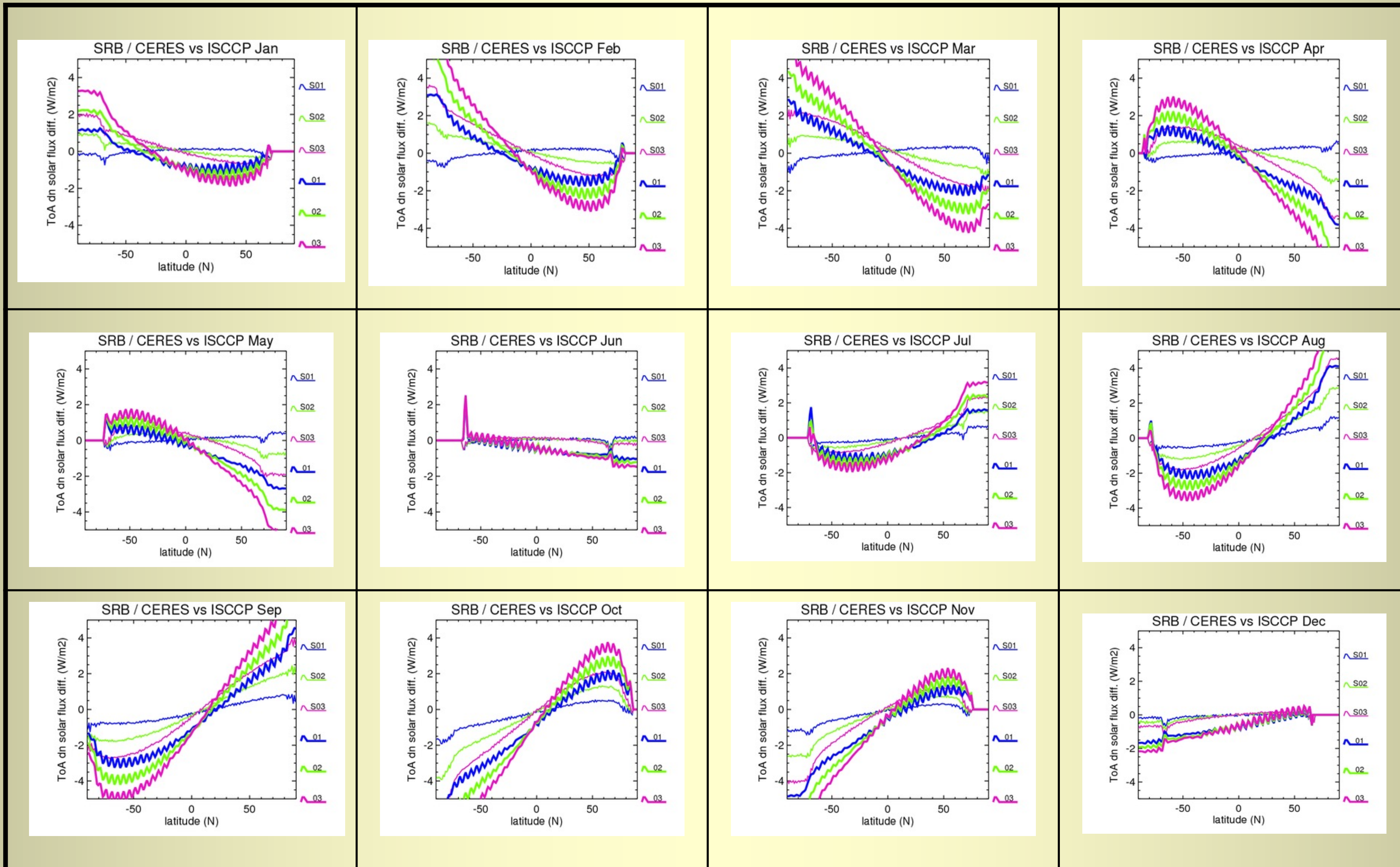


Ramanathan et al., 2007, 2008

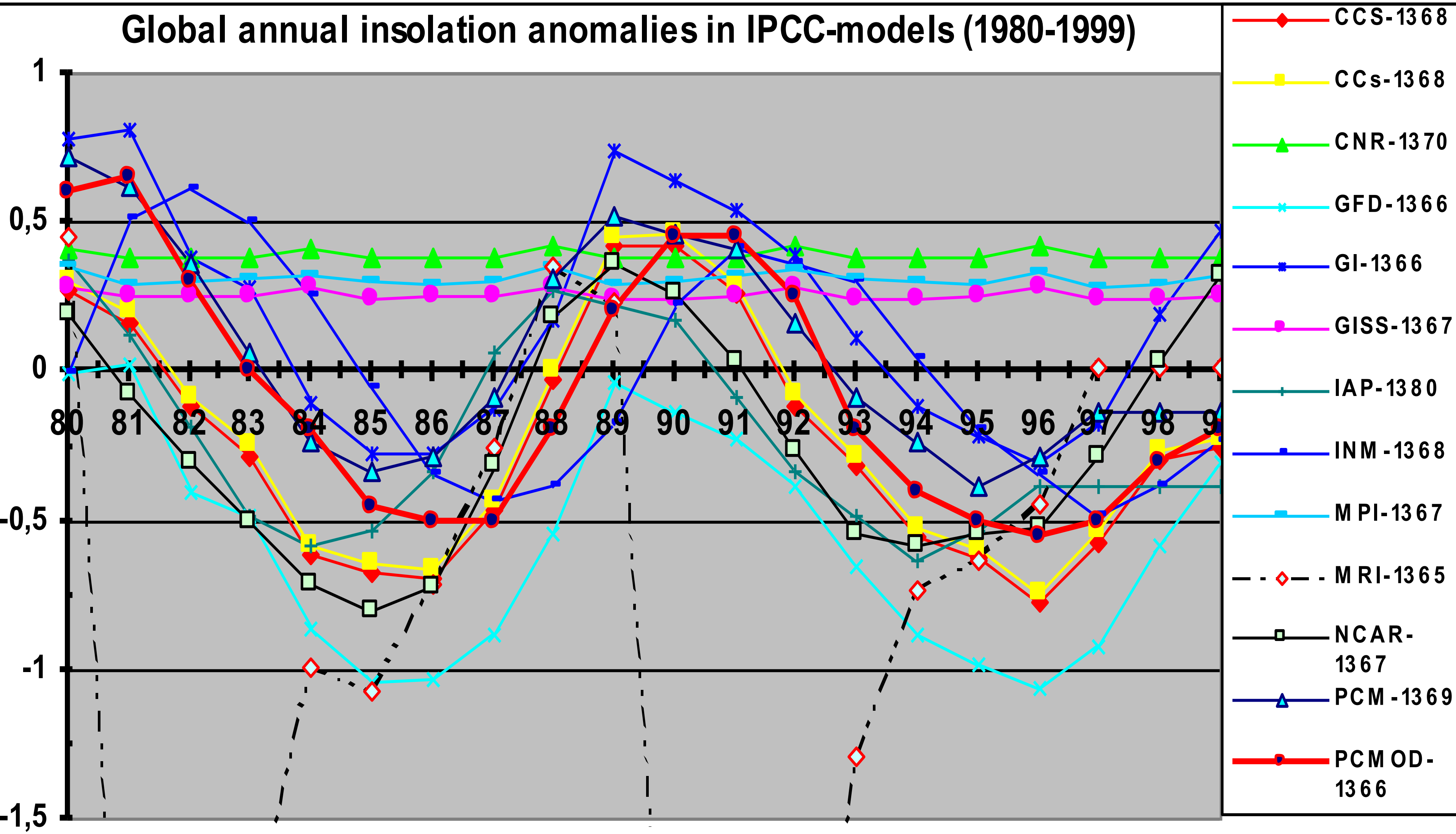


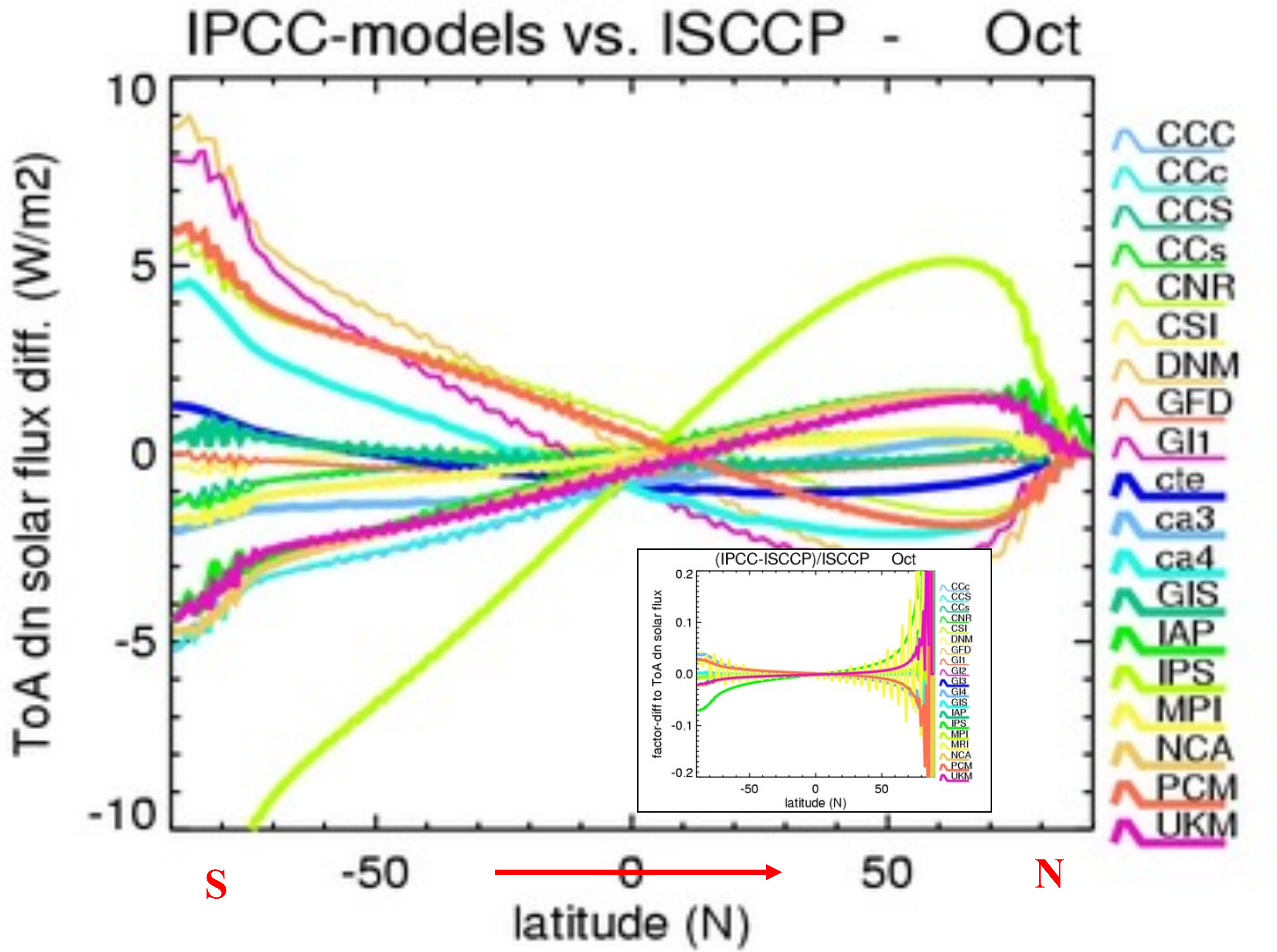
A final small problem:
Insolation at TOA

Can we correctly compute the incoming solar radiation at a spherical shell at about 50 km distance from the Earth's surface, the "top of the atmosphere" ?



Monthly averages of the differences to ISCCP values of zonal averages of the daily insolation as computed for the SRB climatology (thinner lines) and the CERES climatology (thicker lines), respectively. Note these differences are proportional to the radial velocity of the Earth's orbit. Curves for the years 2001, 2002 and 2003 are in red, green and blue, respectively.


Global annual insolation anomalies in IPCC-models (1980-1999)
1
0,5
0
-0,5
-1
-1,5
80
81
82
83
84
85
86
87
88
89
90
91
92
93
94
95
96
97
98
CCS-1368
CCs-1368
CNR-1370
GFD-1366
GI-1366
GISS-1367
IAP-1380
INM-1368
MPI-1367
MRI-1365
NCAR-1367
PCM-1369
PCMOD-1366


IPCC-models vs. ISCCP - Oct
ToA dn solar flux diff. (W/m2)
10
5
0
-5
-10
-50
0
50
latitude (N)
S
N
CCC
CCc
CCS
CCs
CNR
CSI
DNM
GFD
GI1
cte
ca3
ca4
GIS
IAP
IPS
MPI
NCA
PCM
UKM
(IPCC-ISCCP)/ISCCP Oct
factor-diff to ToA dn solar flux
0.2
0.1
0.0
-0.1
-0.2
-50
0
50
latitude (N)
CCc
CCS
CCs
CNR
CSI
DNM
GFD
GI1
GI2
GI3
GI4
GIS
IAP
IPS
MPI
MRI
NCA
PCM
UKM

Conclusions:

Huge progress has been made during the past 25 years, but we are still far away to find an „acceptable” agreement between measured and modeled cloud and radiation fields due to „errors“ on both sides. We therefore call for

a.) “re-analyses” and verification of “measured” cloud and radiation fields and provision of the results on at least a monthly basis (ISCCP, SRB, CERES, others?);

b.) updating of all (!) ancillary data, in particular of surface properties before used again;

c.) use of same Total Solar Irradiance models and same models for spatial distribution over the Earth;

d.) repetition of the IPCC modeling over a prescribed period (e.g. 20 years) with well and uniquely defined surface conditions (e.g. surface albedo);

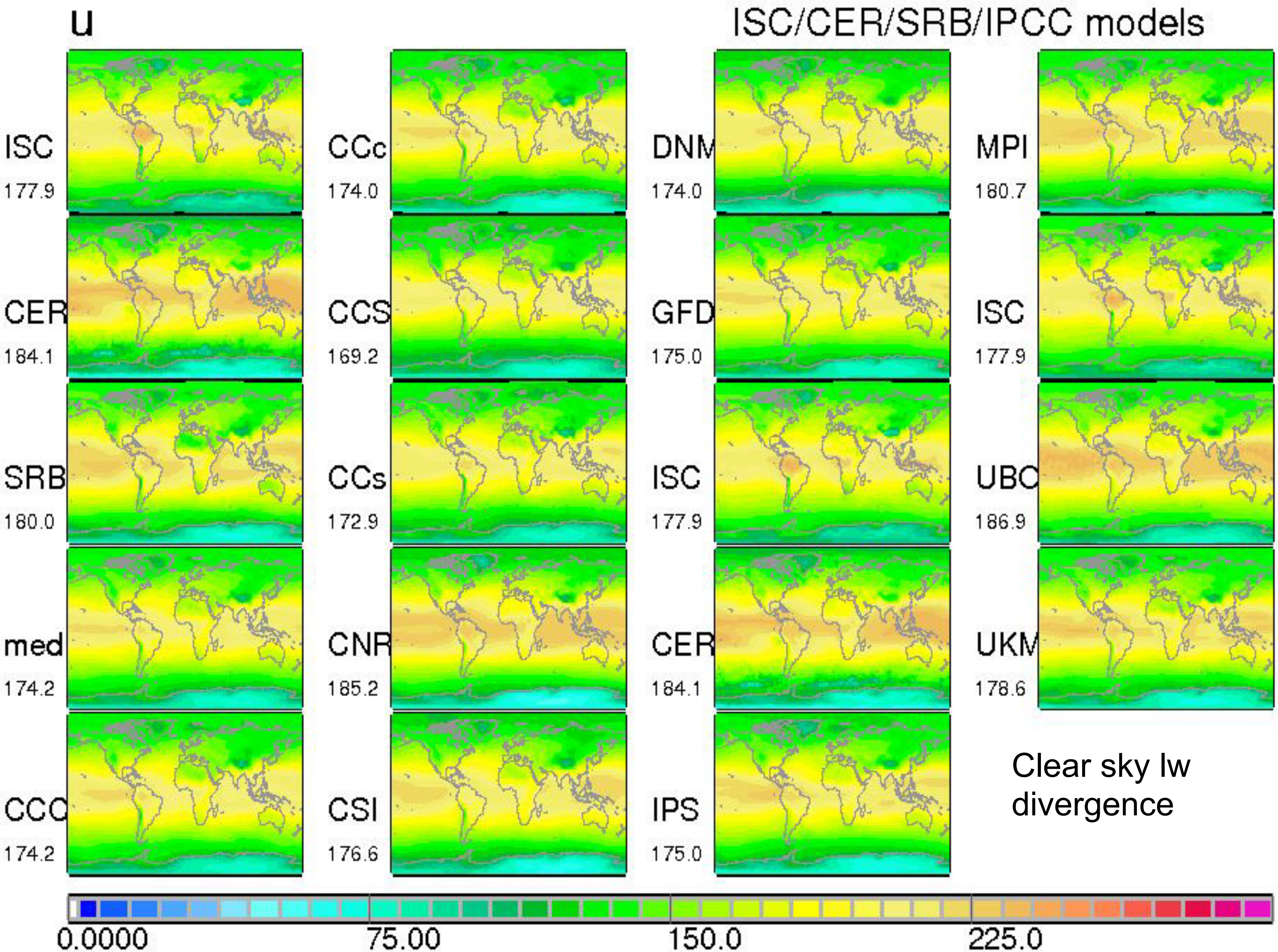
Research should be encouraged to “transit” to higher spatial and spectral resolutions and include information on vertical structures from direct sounders.

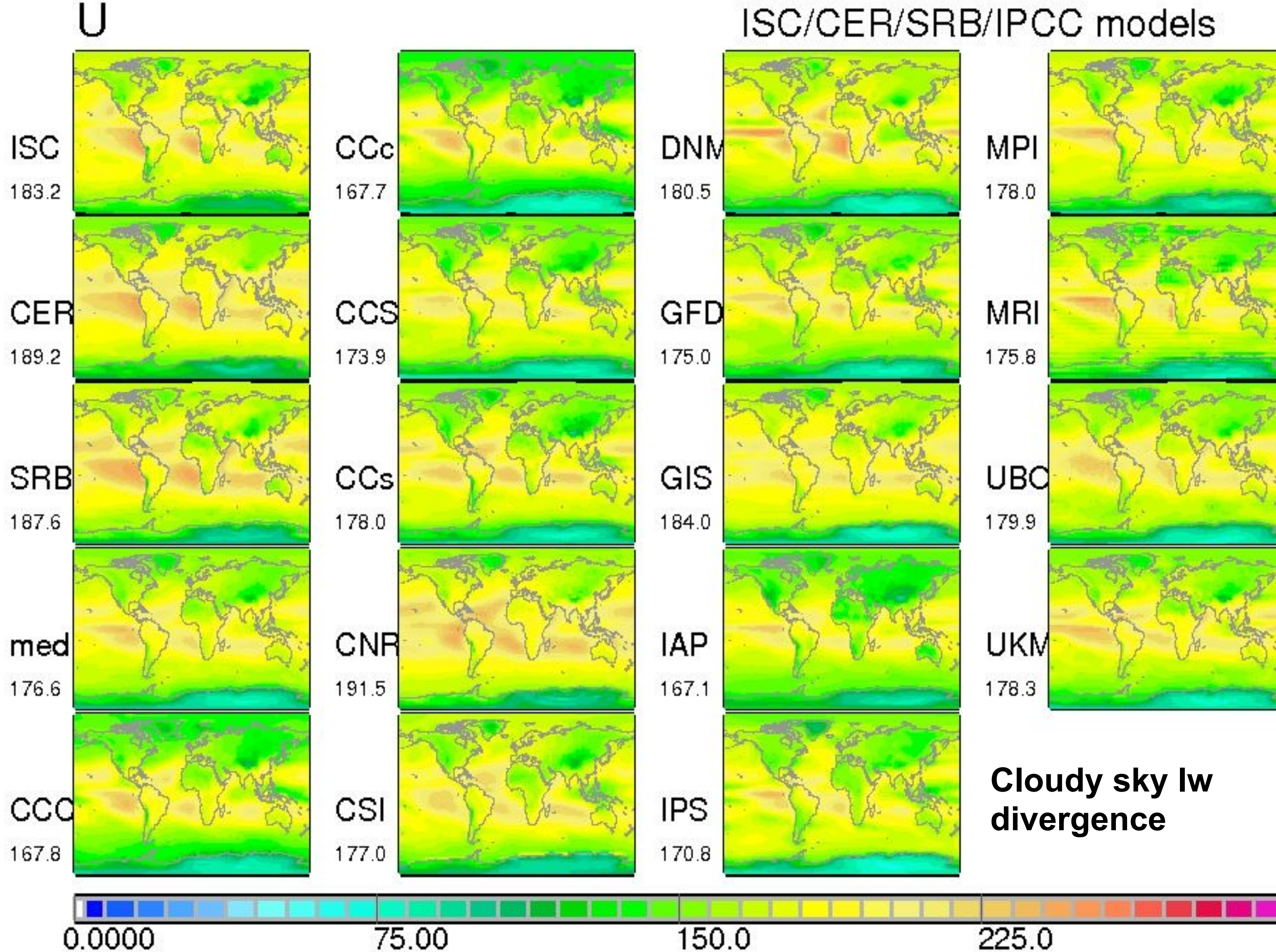
We still need to learn more about data uncertainties and how to avoid them !

Claudia's and other assessment reports

ISCCP

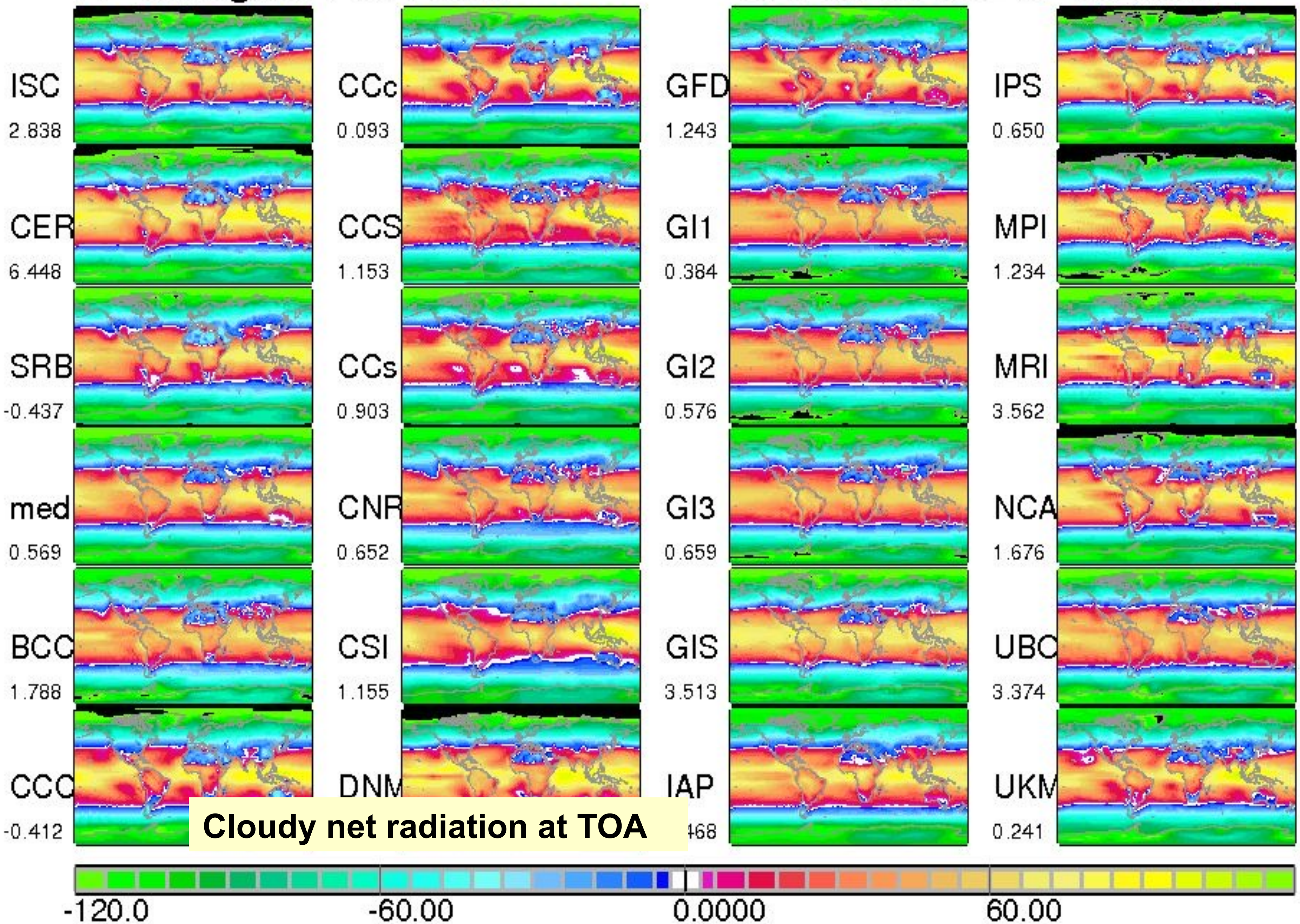
Many Thanks


u
ISC/CER/SRB/IPCC models
ISC
177.9
CCc
174.0
DNM
174.0
MPI
180.7
CER
184.1
CCS
169.2
GFD
175.0
ISC
177.9
SRB
180.0
CCs
172.9
ISC
177.9
UBC
186.9
med
174.2
CNR
185.2
CER
184.1
UKM
178.6
CCC
174.2
CSI
176.6
IPS
175.0
Clear sky lw divergence
0.0000
75.00
150.0
225.0

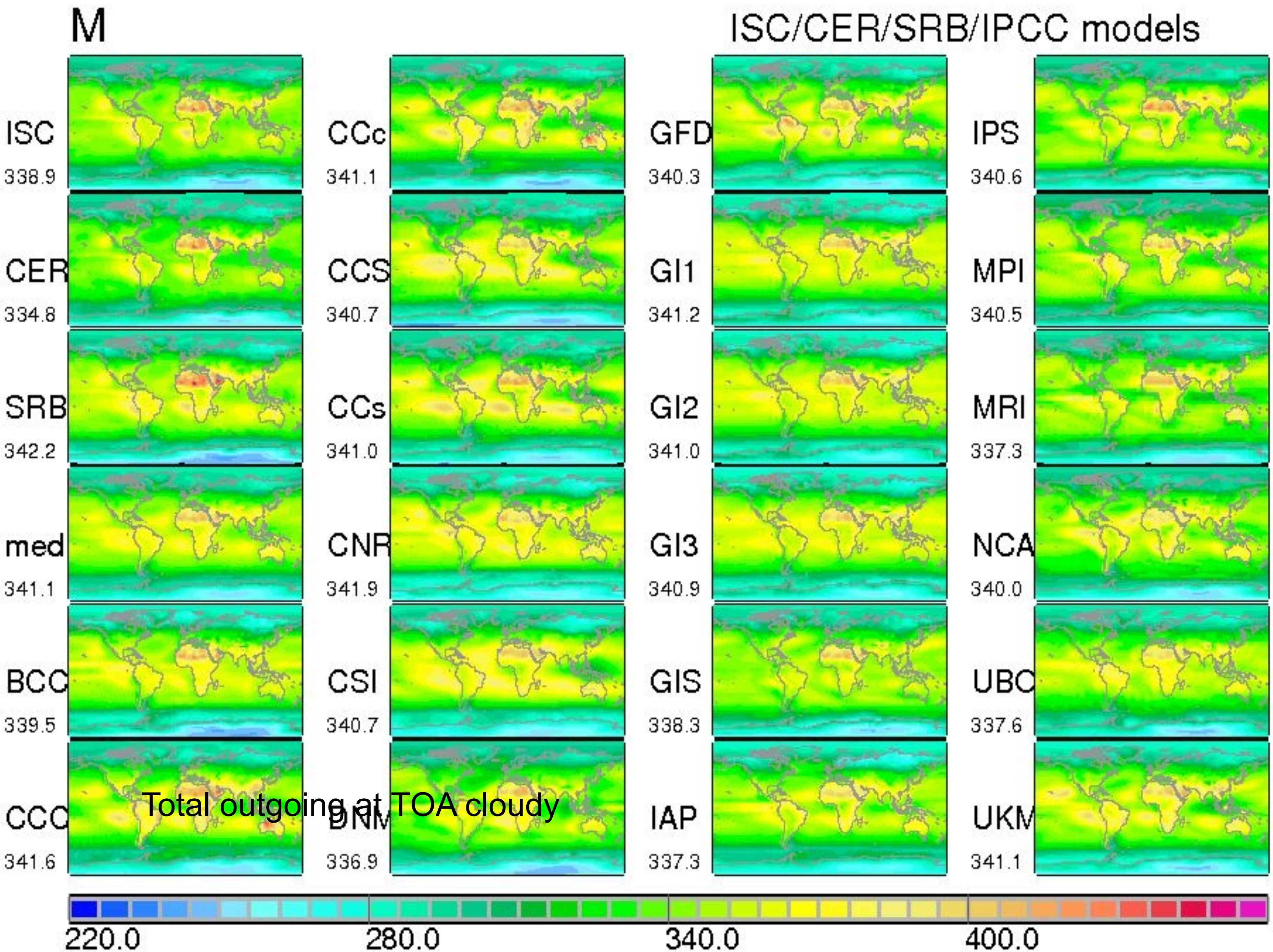


U
ISC/CER/SRB/IPCC models
ISC 183.2
CCc 167.7
DNM 180.5
MPI 178.0
CER 189.2
CCS 173.9
GFD 175.0
MRI 175.8
SRB 187.6
CCs 178.0
GIS 184.0
UBC 179.9
med 176.6
CNR 191.5
IAP 167.1
UKM 178.3
CCC 167.8
CSI 177.0
IPS 170.8
Cloudy sky lw divergence
0.0000
75.00
150.0
225.0

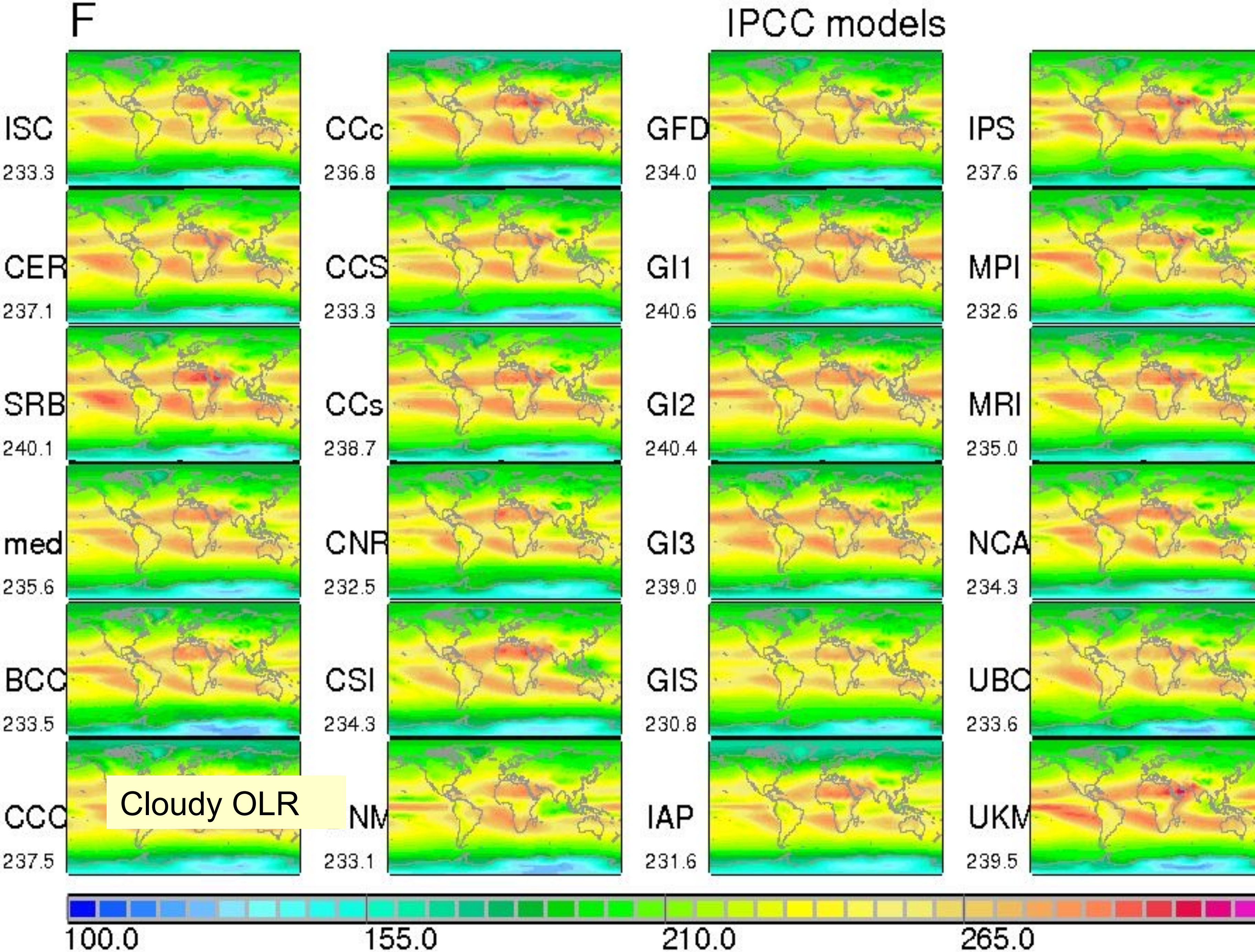
R - net gain / net loss   ISC /CER /SRB /IPCC-mod

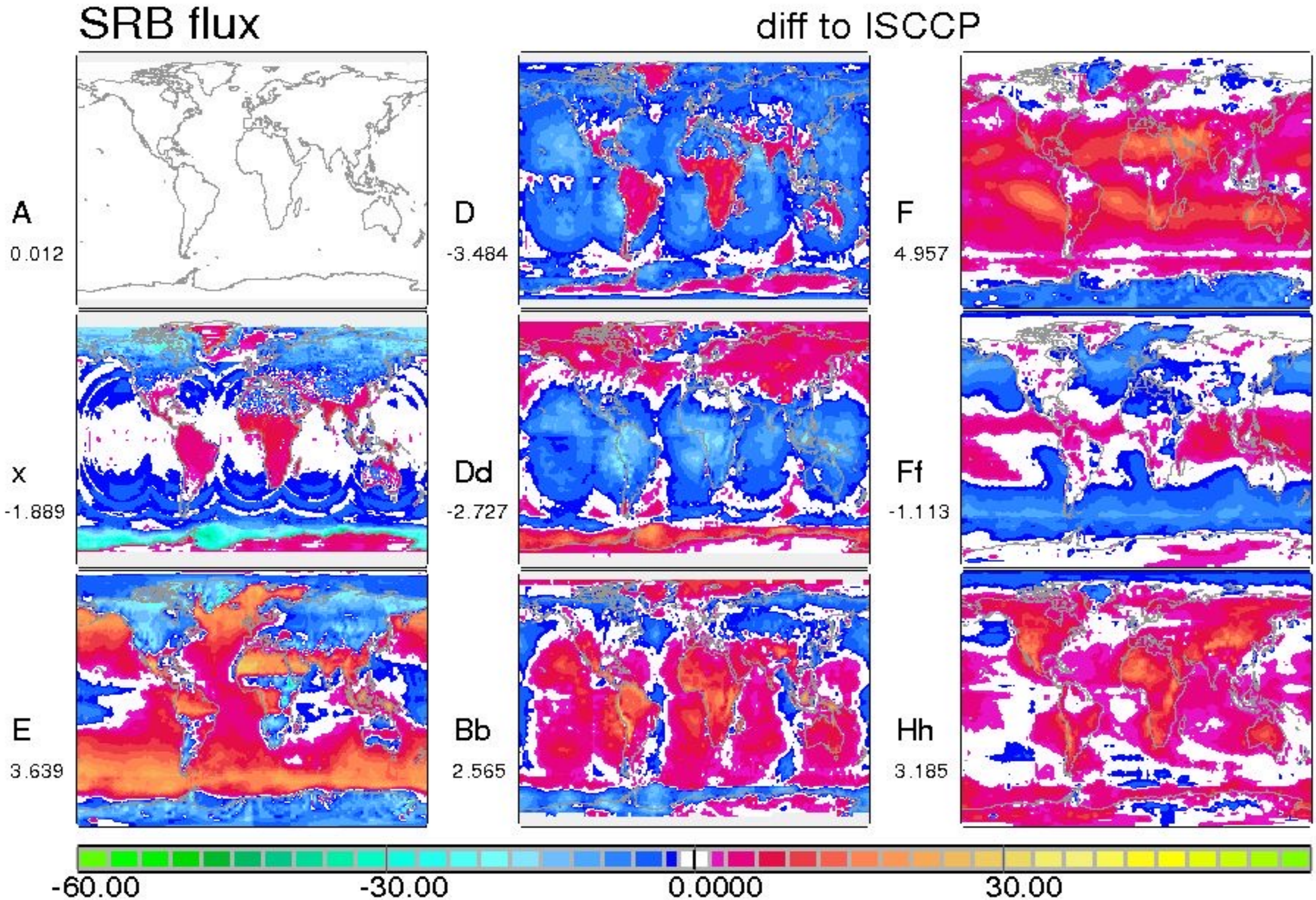


Cloudy net radiation at TOA



M
ISC/CER/SRB/IPCC models
ISC
338.9
CCc
341.1
GFD
340.3
IPS
340.6
CER
334.8
CCS
340.7
GI1
341.2
MPI
340.5
SRB
342.2
CCs
341.0
GI2
341.0
MRI
337.3
med
341.1
CNR
341.9
GI3
340.9
NCA
340.0
BCC
339.5
CSI
340.7
GIS
338.3
UBC
337.6
CCC
341.6
Total outgoing at TOA cloudy
336.9
IAP
337.3
UKM
341.1
220.0
280.0
340.0
400.0


F
IPCC models
ISC
233.3
CCc
236.8
GFD
234.0
IPS
237.6
CER
237.1
CCS
233.3
GI1
240.6
MPI
232.6
SRB
240.1
CCs
238.7
GI2
240.4
MRI
235.0
med
235.6
CNR
232.5
GI3
239.0
NCA
234.3
BCC
233.5
CSI
234.3
GIS
230.8
UBC
233.6
CCC
237.5
Cloudy OLR
NM
233.1
IAP
231.6
UKM
239.5
100.0
155.0
210.0
265.0



A = Incident solar at TOA, X = Effective surface albedo, E = Emission from surface, D = Outgoing solar at TOA, F = Outgoing infrared at TOA, Dd = CE on outgoing solar at TOA, Bb = CE on downward solar at surface, Ff = CE on outgoing infrared at TOA, Hh = CE on downward infrared at surface