

# **History of Earth Radiation Budget Measurements**

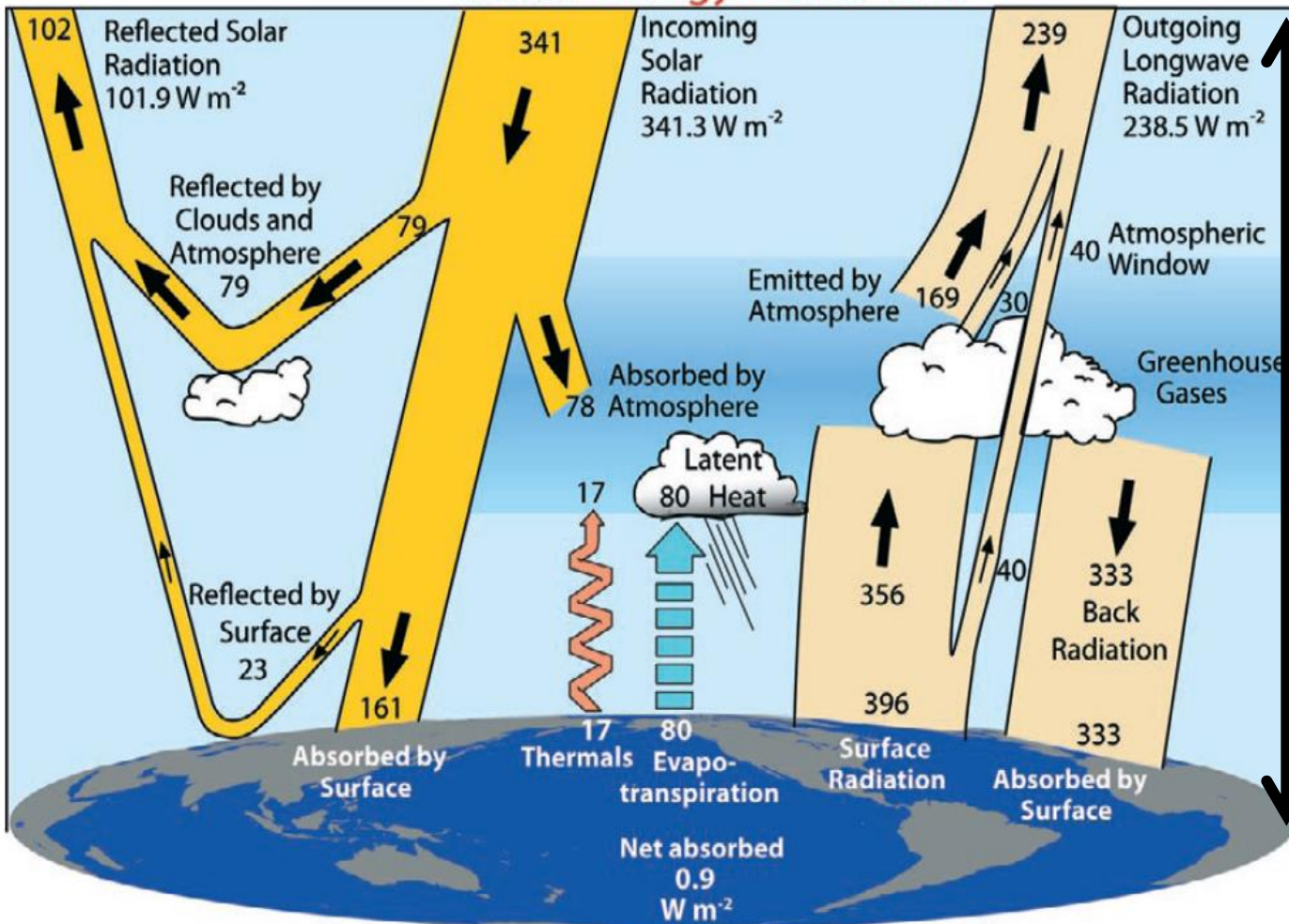
*With results from a recent assessment*

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MPI Meteorology, Hamburg, Germany**

**Centenary of the Royal Meteorological Institute of Belgium,  
September 26-27, 2013**

## Global Energy Flows $\text{W m}^{-2}$



**At TOA:**

**Measurements + ancillary data**

**Within atmosphere:**

**Radiation fields must be computed with ancillary data only.**

**At surface:**

**Ancillary data only + control measurements**

(Trenberth et al., BAMS, 2009)

## **Why do we need measurements of the total radiation budget?**

**How much energy drives the circulation in our climate system? Do models reproduce “observed” energy transports?**

**Can we identify changes due to increasing Greenhouse Effect? Can we explain observed heat storage in the ocean?**

**How important is the role of clouds, aerosols and GHGs?**

**Divergence in atmosphere vs.  $x$ ,  $y$ ,  $z$  and time ?**

**Poleward heat fluxes at equator and midlatitudes?**

# History in brief

## Before 1959:

Earthshine and solar emission from ground

Numerical studies with climate data, e.g.: Dines, 1907; Abbot & Fowle, 1908; Simpson 1929, London 1956, ...

~ 1800

Planetary albedo:  
35 to 45%

Planetary emission:  
220 to 280 Wm<sup>-2</sup>

Solar constant:  
1360 to 1380 Wm<sup>-2</sup>

## After launch of Explorer VII 1959:

TIROS and Nimbus “families”: up to 1970

ERBE (ERBS, ERB): 1972 to 1995

CERES: 2000 to now

European ScaRaB and **GERB**:

Numerical studies: ISCCP, SRB, **CERES**, ....

1959 ..... 2012

Planetary albedo: 29 to 31%

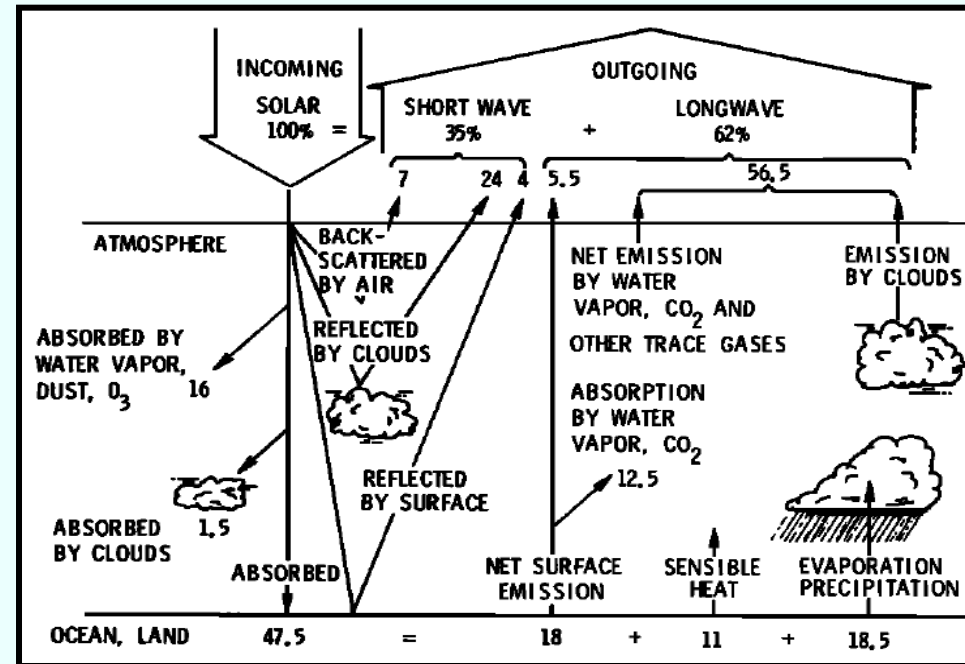
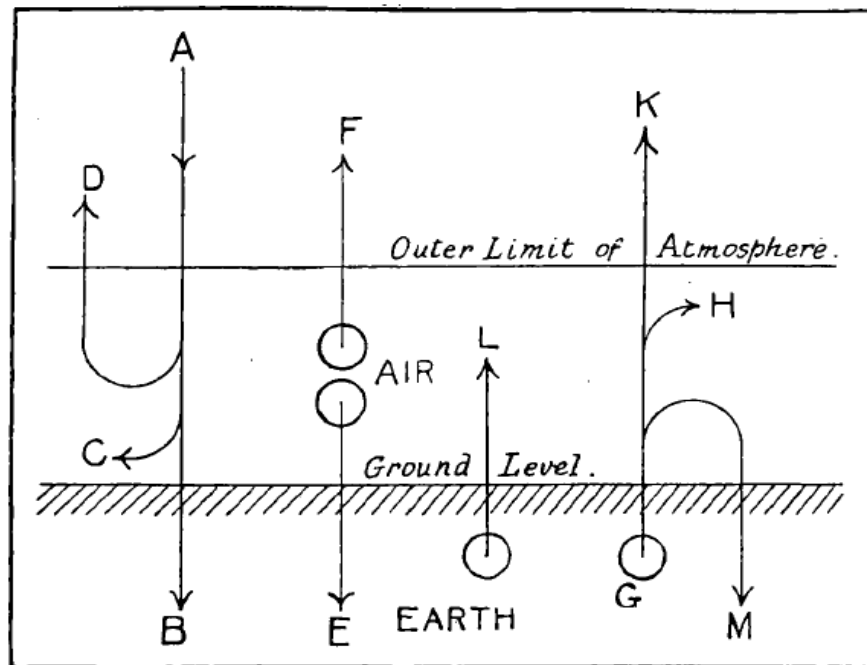
Planetary emission: 250 to 255 Wm<sup>-2</sup>

... with many regional details

Solar constant: from 1372 “down” to 1361 Wm<sup>-2</sup>

# The pre-satellite era (1800 to 1959)

Investigations before WW-I were dominated by **astronomers** and their instrumental capabilities to measure solar radiation. Measurements of the insolation at TOA began around 1800 (e.g. Foitzik and Hinzpeter 1958); values ranged between 1200 and 2000  $\text{Wm}^{-2}$ .

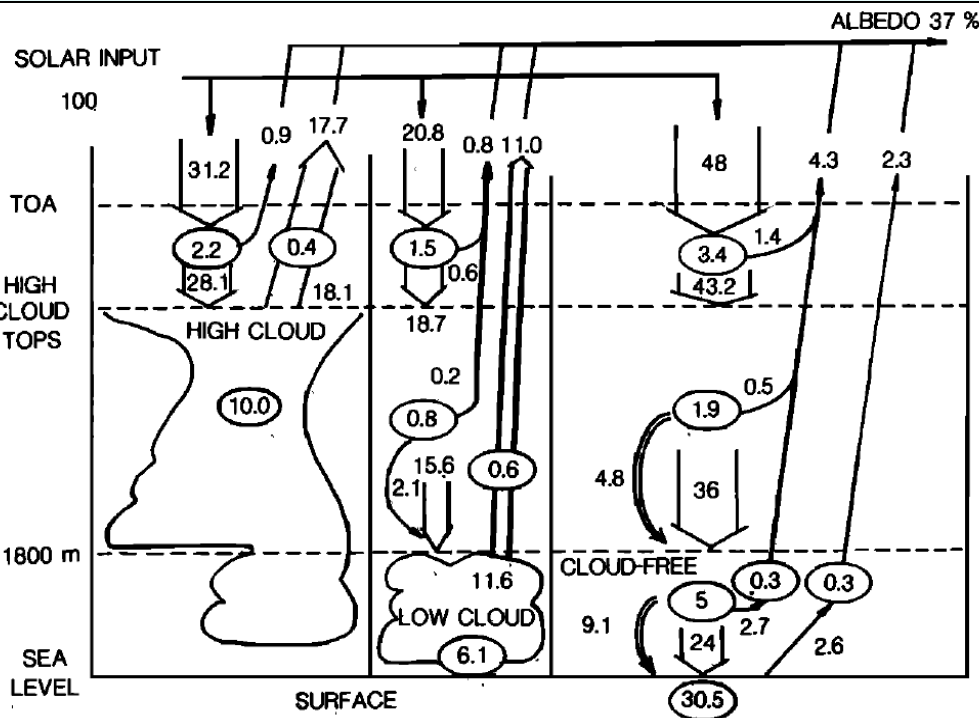


**W. H. Dines, 1917:** *J. R. Met. Soc.* 43, 151-158; with **A** =  $\text{TSI}/4$ , **D** = reflected solar, **C, B** = absorption, **E and F** = IR emission, **G** = IR emission from surface, where **K** transmitted to space, **H** absorbed in atmosphere and **M** "reflected" back to ground. **L** = upward fluxes of latent and sensible heat.

**Julius London, 1957,** provided first details at all levels, zonal profiles and Poleward energy fluxes.

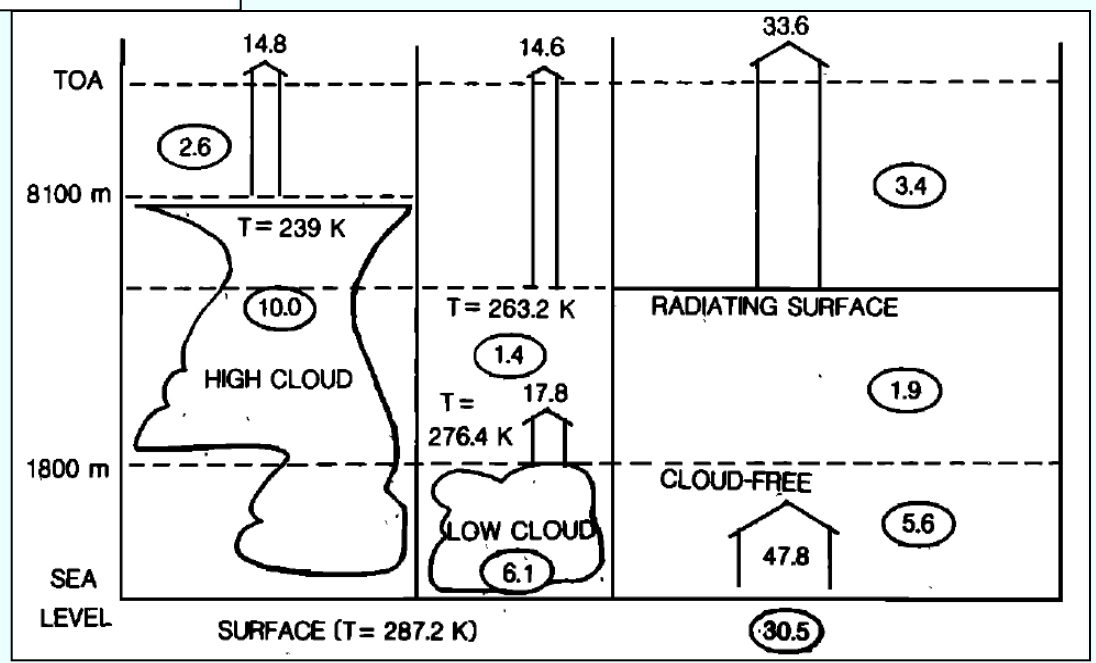
# Solar radiation

Hunt et al., 1986, *Rev. Geophysics*,  
compiled values from **Abbot and**  
**Fowle, 1908** (*Ann. Astro. Observ.*  
*Smiths. Inst., Vol. 2*)



Most numbers are fractions of the incident solar flux at TOA)

# Infrared radiation

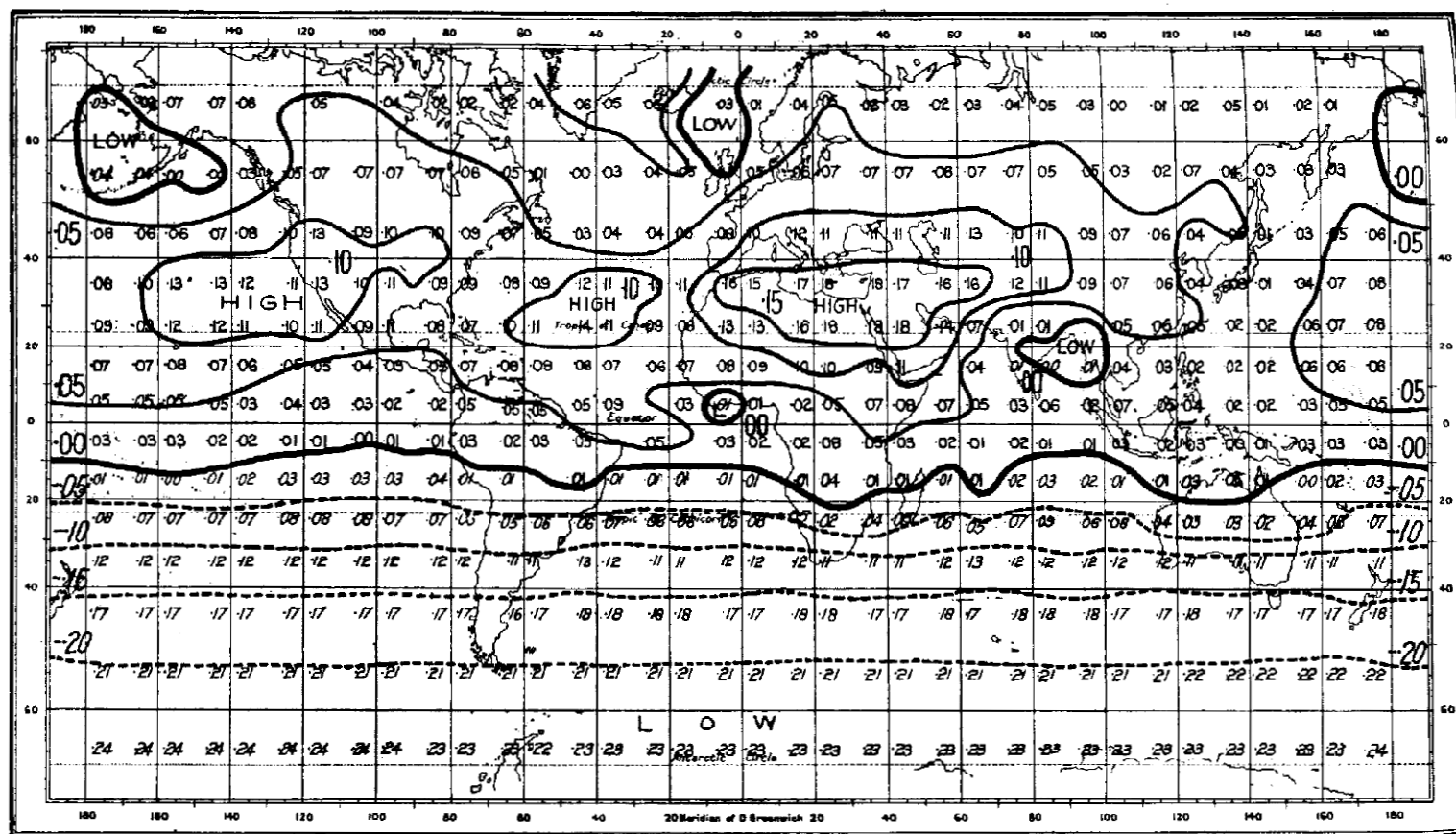




# First map of net radiation from **Simpson** (1929)

$S_0 = 1.952$ ,  
OLR = 0.280  
cal cm<sup>-2</sup> min<sup>-1</sup>,

Albedo: 0.455



$$2 \text{ cal cm}^{-2}\text{min}^{-1} = 1396 \text{ Wm}^{-2}$$





50<sup>th</sup> Anniversary of EXPLORER VII



**R.J. Parent**



**Launch on 13 October 1959**

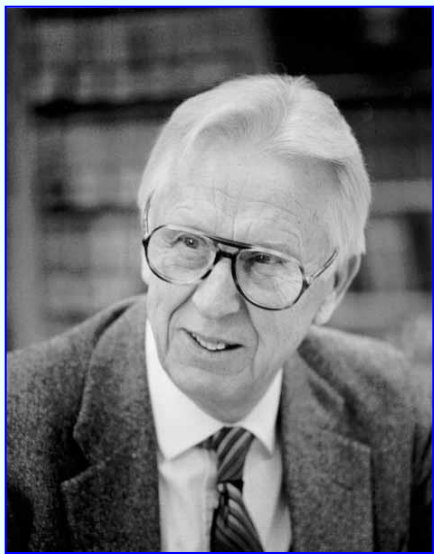


**V. E. Suomi**



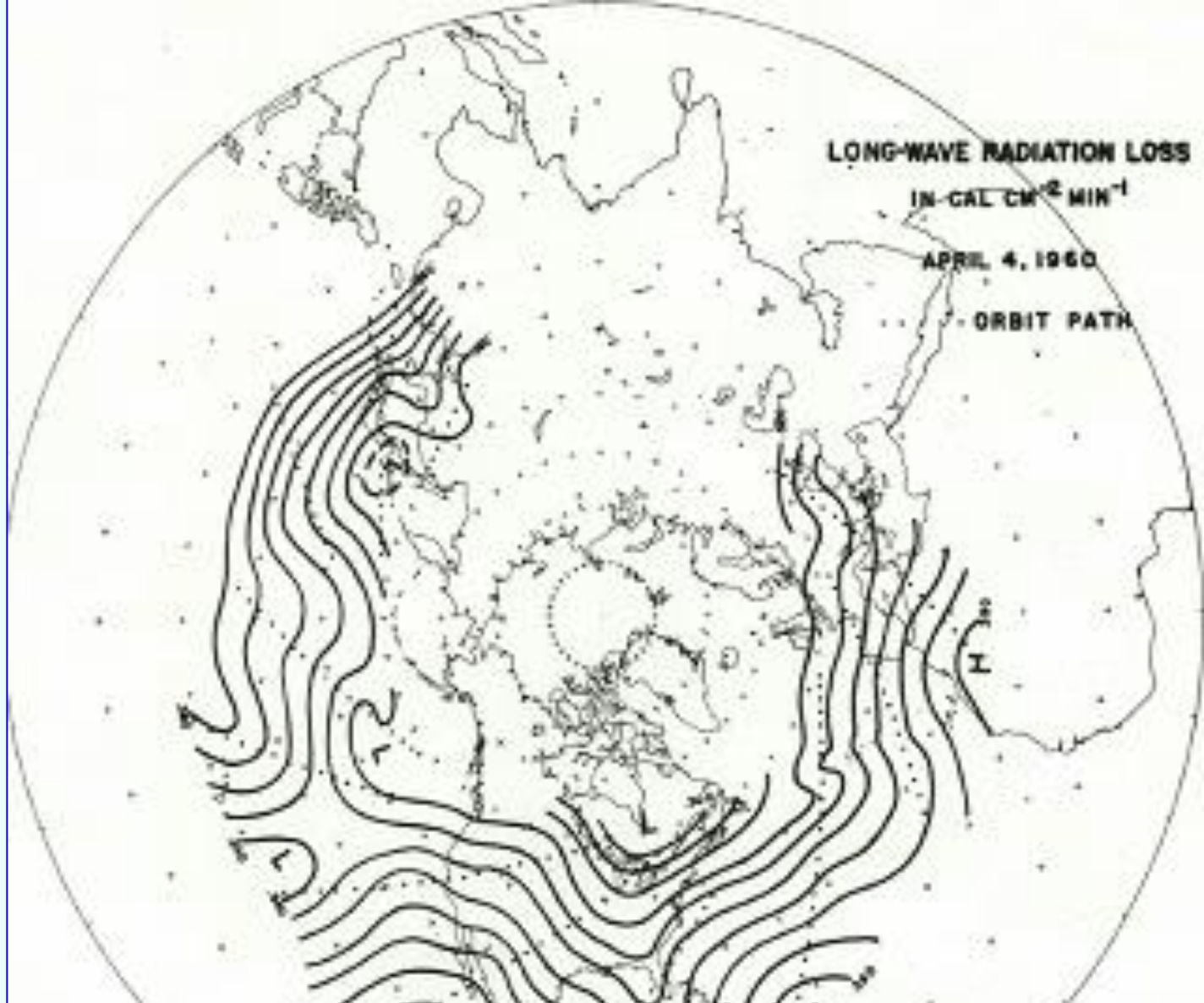
**Explorer 7**

**50  
YEARS**



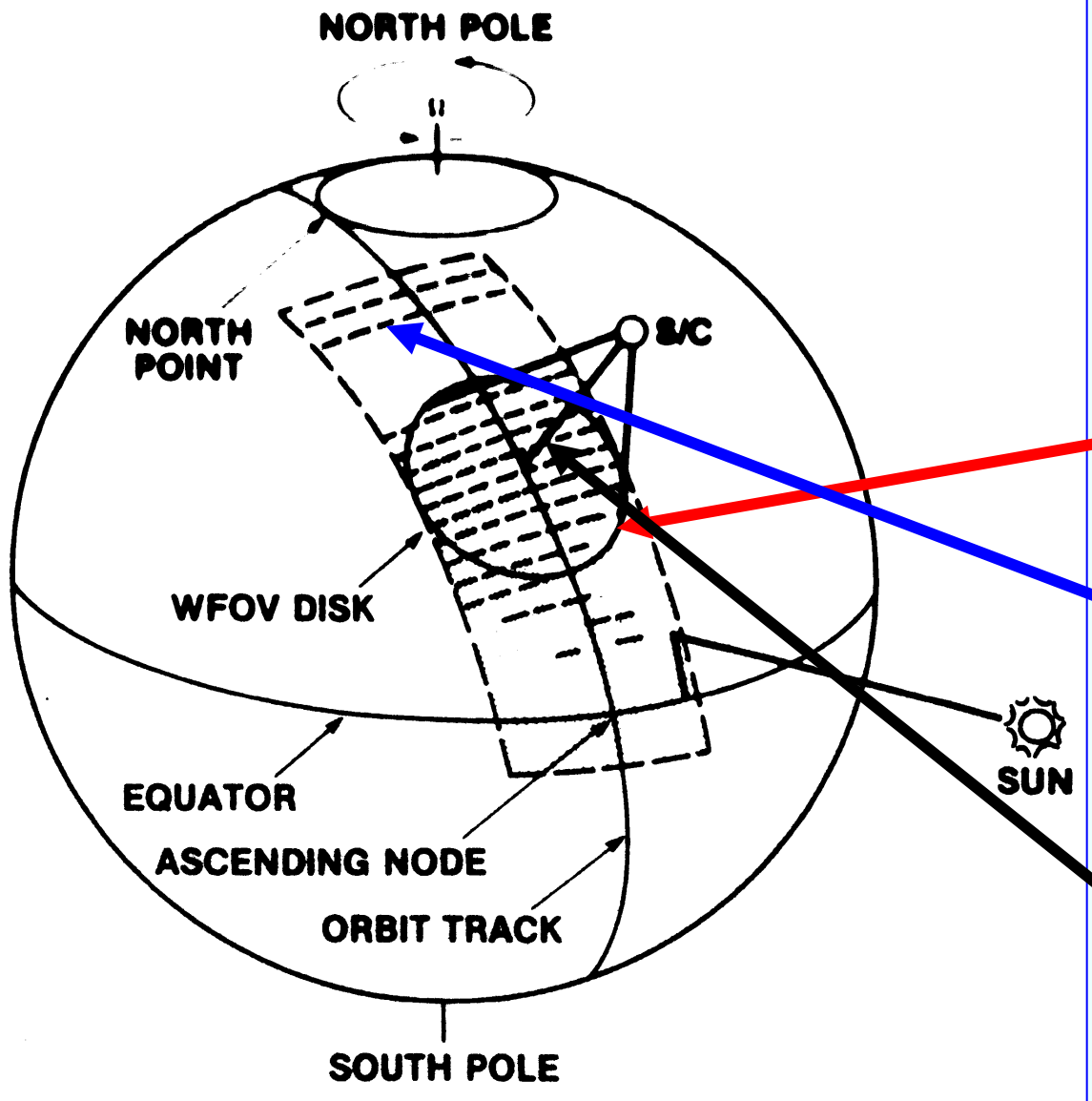
V. E. Suomi

*From Suomi 1960:*



Despite the necessary shortcomings in the analysis there does seem to be a clear indication that large scale outward radiation flux patterns exist and that these patterns are related to the large scale features of the weather. ~~Meteorologists expected a variation of outgoing~~

*From G.L. Smith 2008, personal commun.*



Two basic principles to measure ERB from earth orbiting satellites:

WFOV = wide field of view

NFOV = narrow field of view

Altitude: 600 to 1300 km

**A long way toward CERES (and GERB/ScaRaB)**

## Major steps in analyses of radiance measurements were developed:

Most steps are scene-dependent and require **ancillary data**:

- Compute Insolation at TOA from TSI and Sun-Earth geometry.
- Correction for **incomplete spectral response** of sensors within required broad-band regions (solar and infrared)
- Correction for **angular dependence** of reflected solar and emitted infrared radiation.
- Diurnal variation** and **seasonal cycle** of outgoing radiation fluxes (sampling in time) observed and “corrected”.

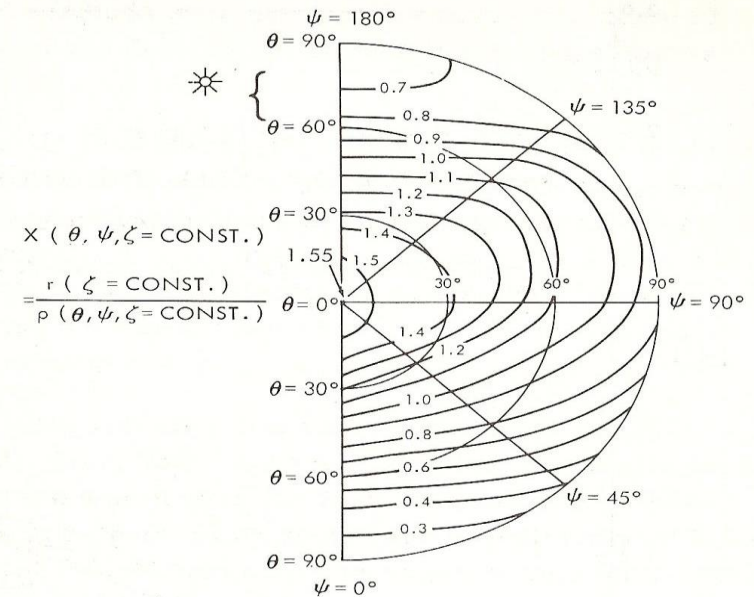


Figure 3—Dependence of the ratio  $X = r/\rho$  on the angles  $\theta$  and  $\psi$  of measurement, at very low sun ( $60^\circ < \zeta \leq 80^\circ$ ).

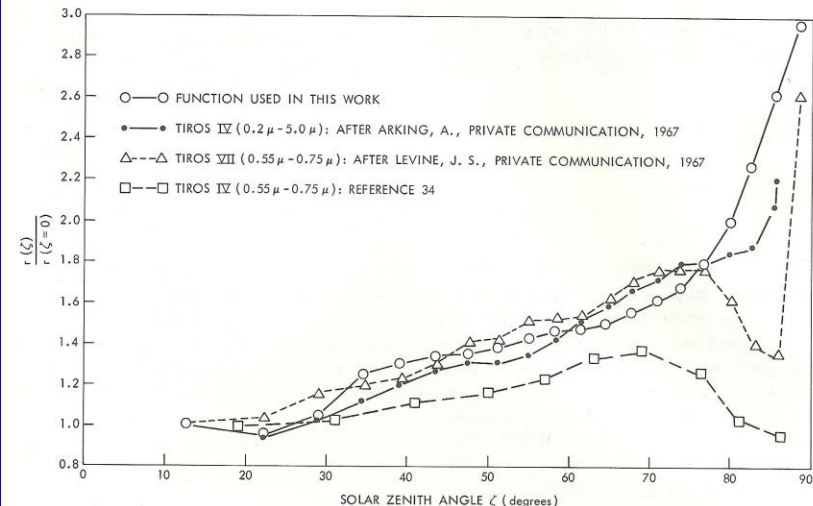


Figure 4—The relative change of the directional reflectance ( $r$ ) of the earth-atmosphere system with the sun's zenith angle ( $\zeta$ ).

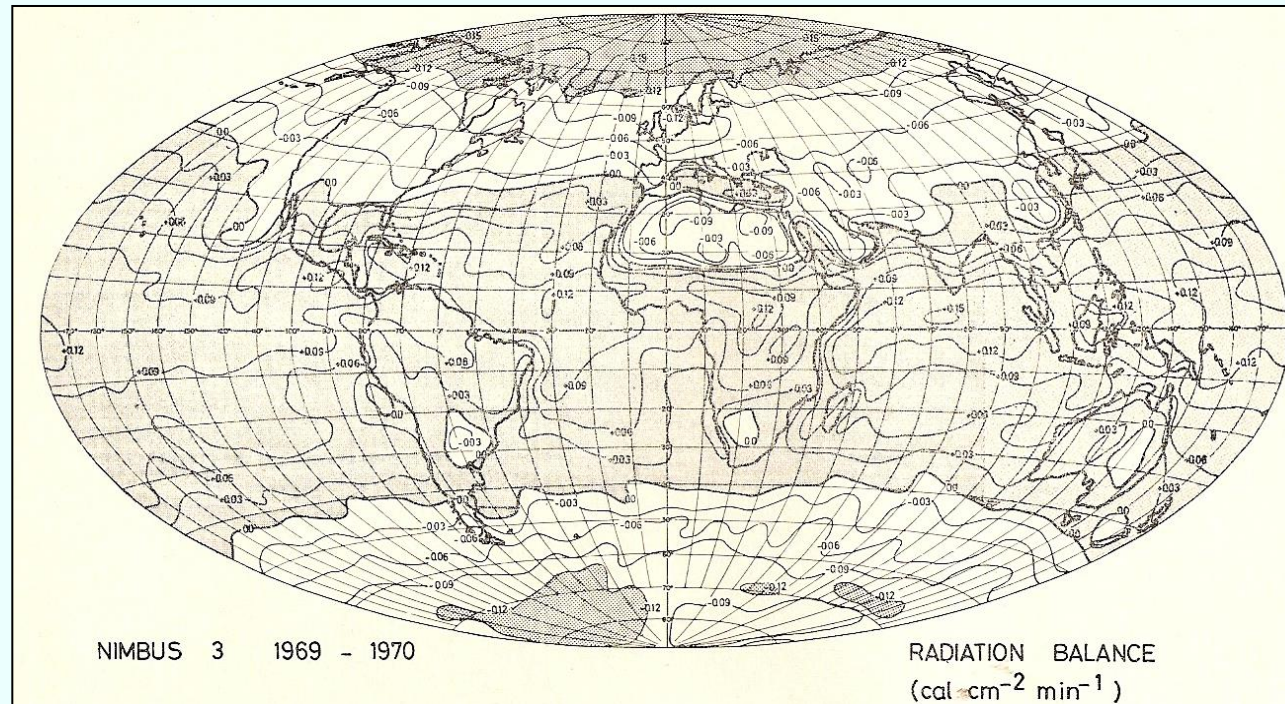


# Early experimental satellites (1959 to 1980)

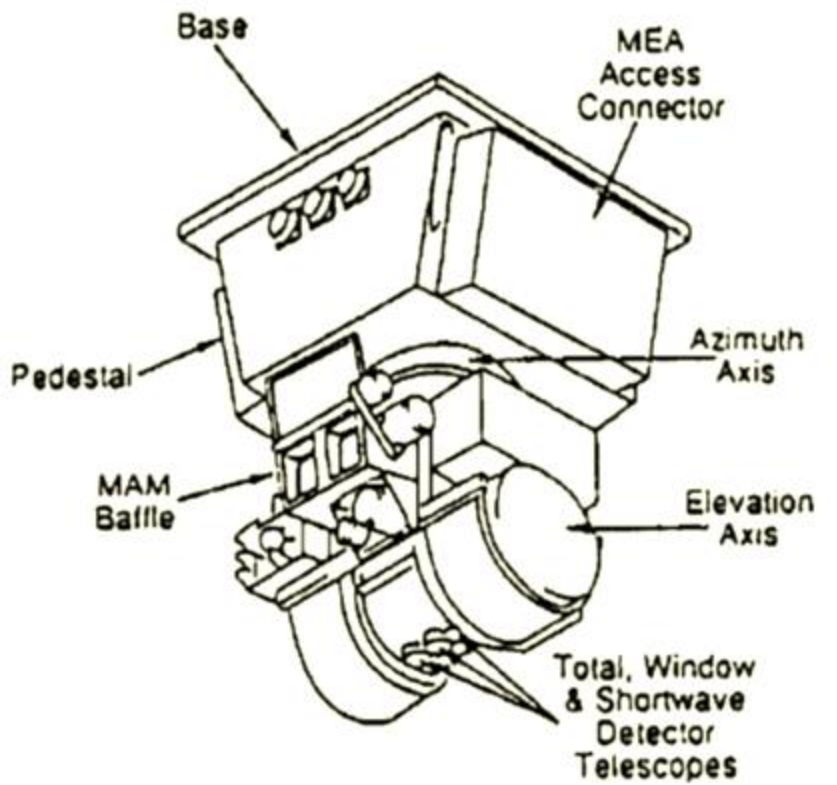
Explorer 6, 7; TIROS 2, 3, 4, 7, 9; Nimbus 2, 3;  
Cosmos-, NOAA-, and the ERBE- family until 1987

## Major early qualitative findings:

- (1) Earth is “darker” (30%) and “warmer” ( $>255\text{K}$ )
- (2) Northern deserts in Africa and Asia are regions of permanent radiation deficit
- (3) Clouds increase the planetary albedo and decrease the OLR
- (4) Annual poleward transports confirmed

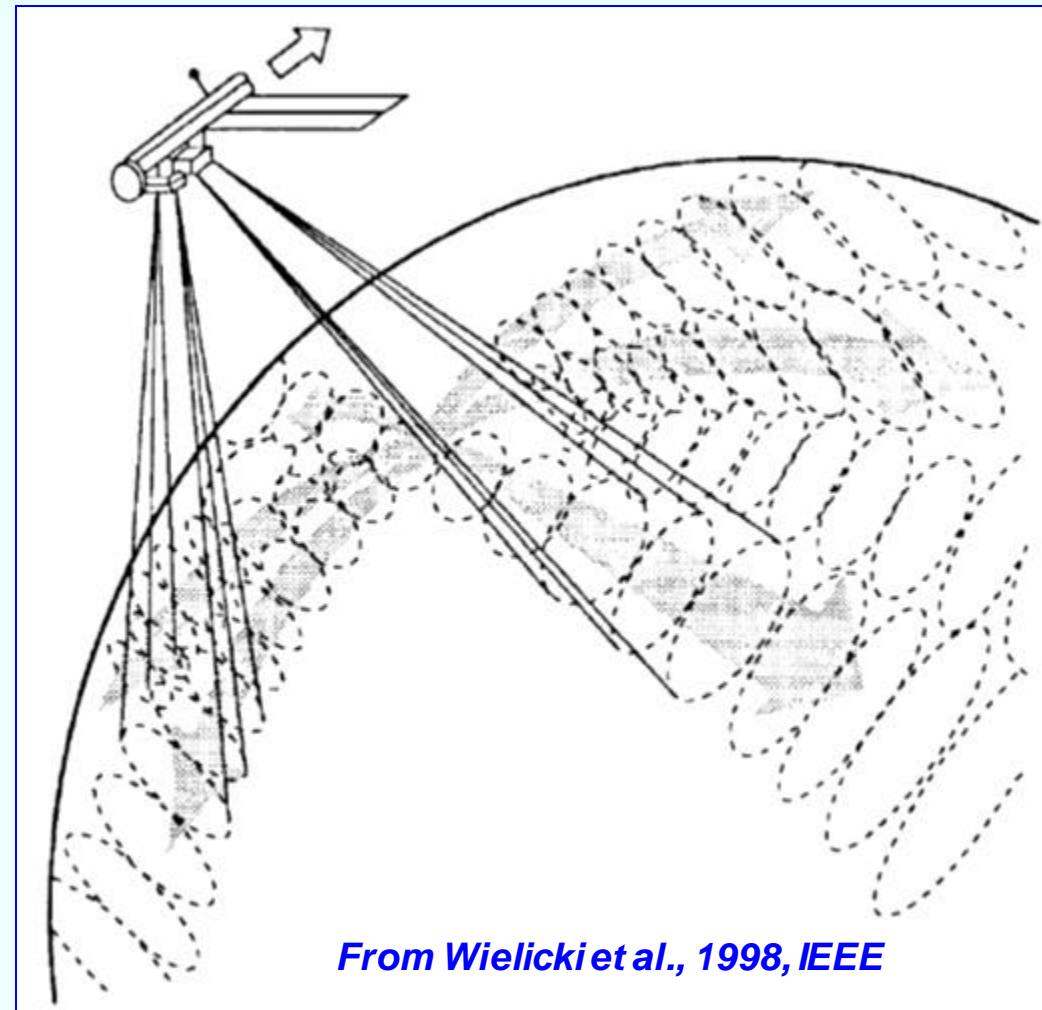


(Raschke, et al., 1973, *JAS*, 30)



# STATUS NOW:

**CERES radiometers** enable rotation of the planes of scanning.



*From G.L. Smith et al., 1994*

*From Wielicki et al., 1998, IEEE*

# **Major Problems at Present:**

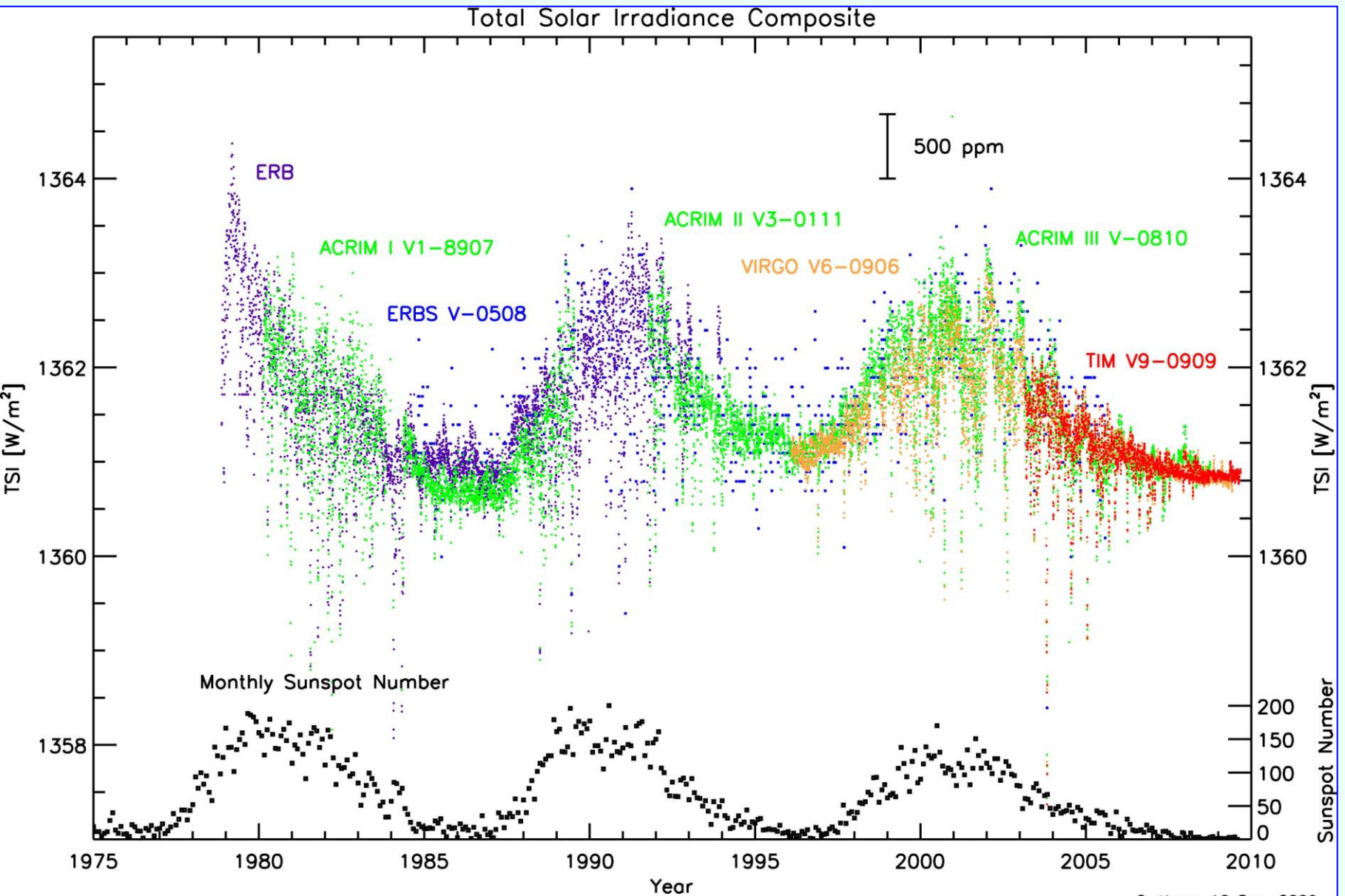
- a.) **Time sampling** of TOA measurements; stability and calibration of instruments
- b.) **Ancillary data** on the state of the system atmosphere-surface
  - for retrieval of TOA fluxes from broad-band measurements and
  - for computations of radiative energy fluxes within the atmosphere and at ground
- c.) **Radiative transfer modeling** of atmosphere (clouds!!) and surface
- d.) **Cloud determination** and **“masking”** from other satellite data to estimate clear-sky processes and surface temperature as well.

**Uncertainties in initial ancillary data  
propagate into all results!**



# Total Solar Irradiance 1975 to Sept. 2009 *Mission SORCE*)

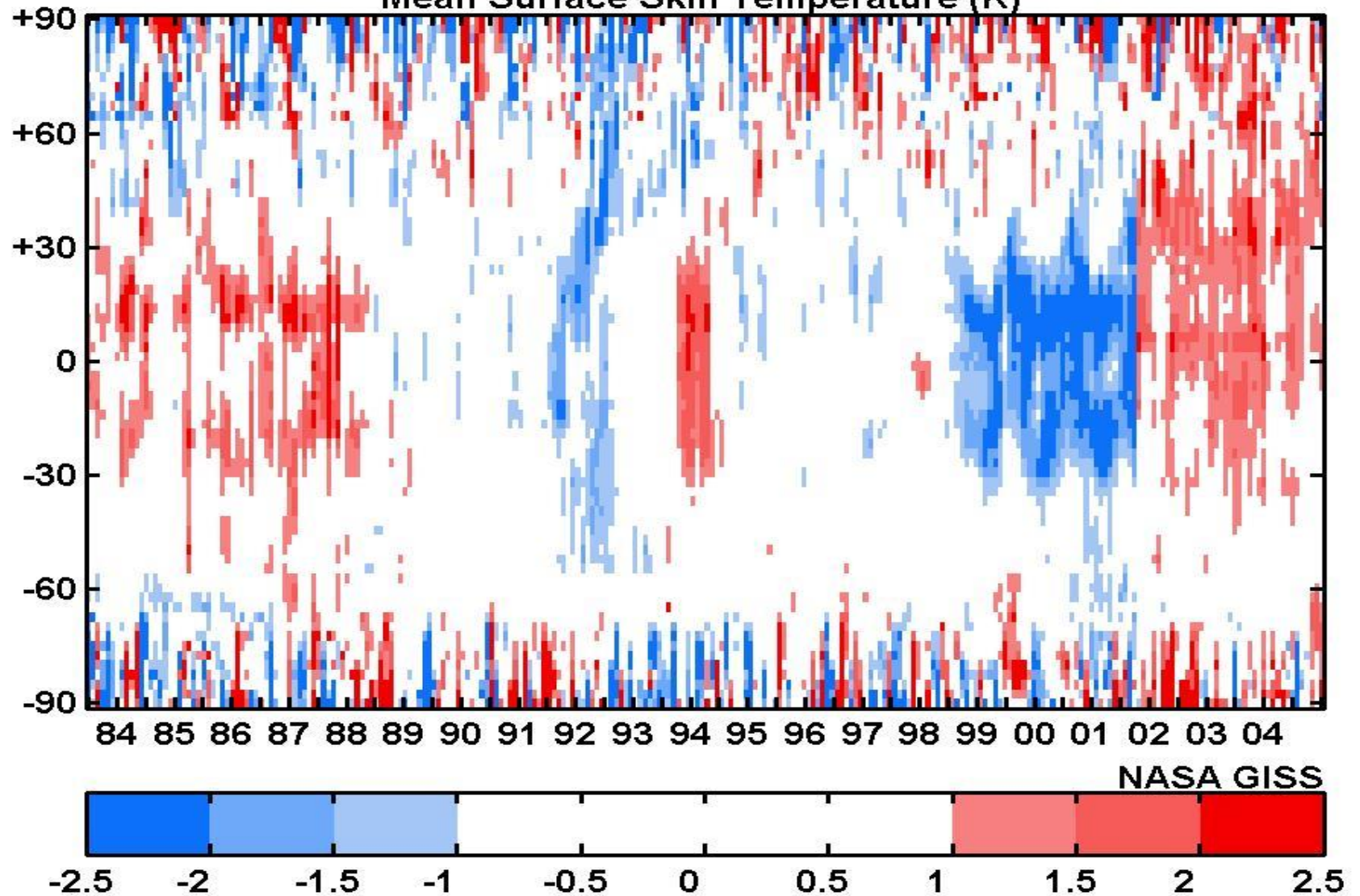
Greg Kopp 2009





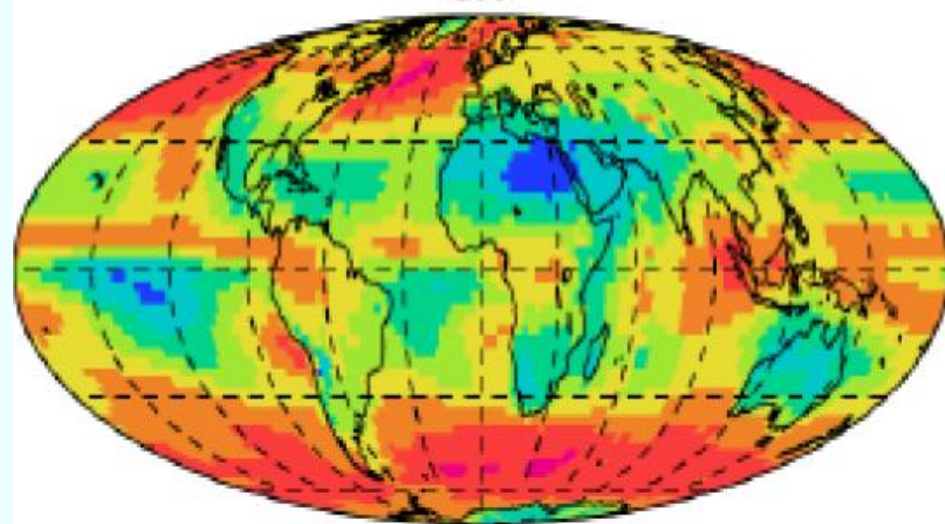
ISCCP-FD: 198307-200412 Zonal Mean Anomaly Map

Mean Surface Skin Temperature (K)



ISCCP: Deseasonalised anomalies of monthly emission from surface ( $\text{W/m}^2$ )

ISCCP



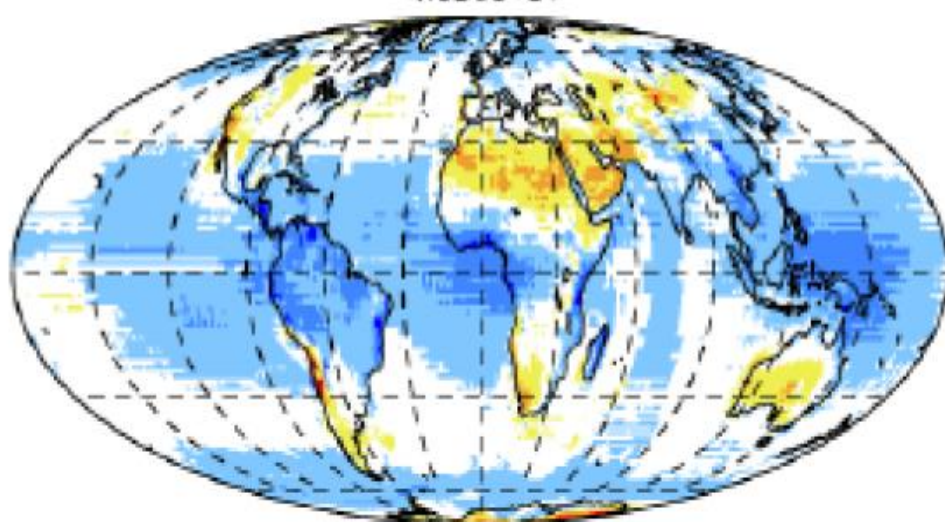
0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9

Cloud data is most important for RB studies.

Annual mean **cloud amount (CA)** of the ISCCP and differences to results of MODIS-ST and MODIS-CE

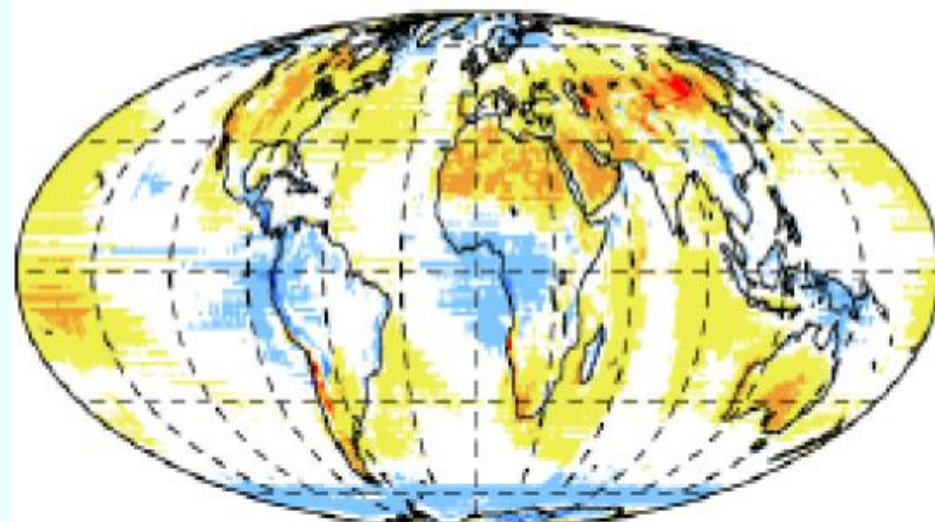
(From GEWEX Cloud Assessment Report, 2012)

-MODIS-ST

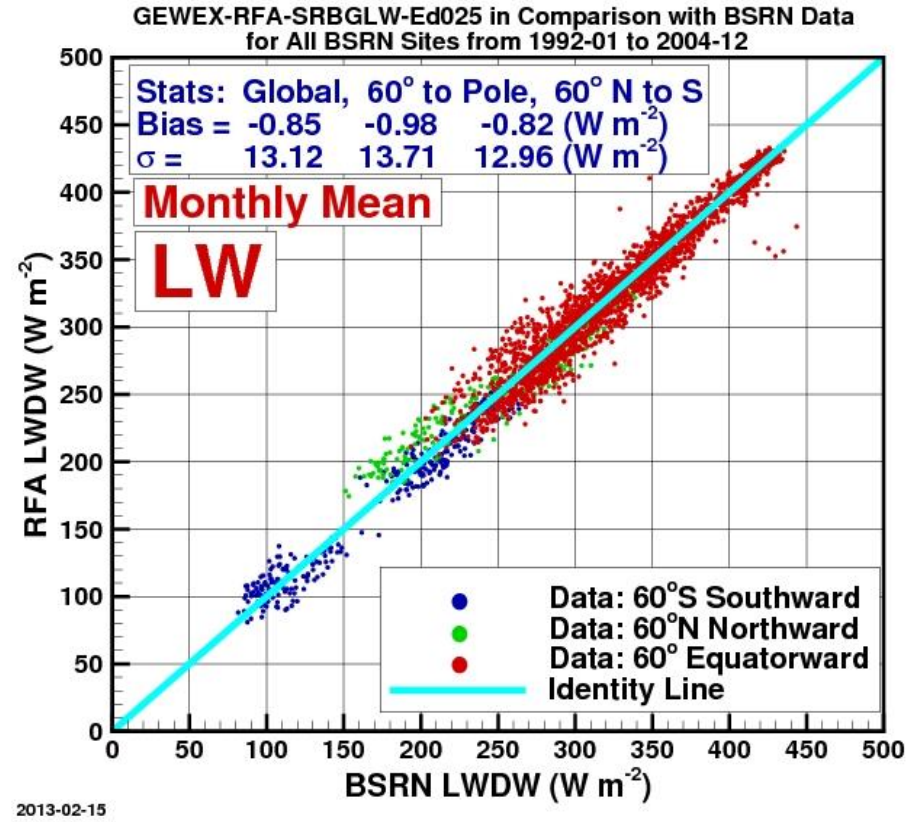
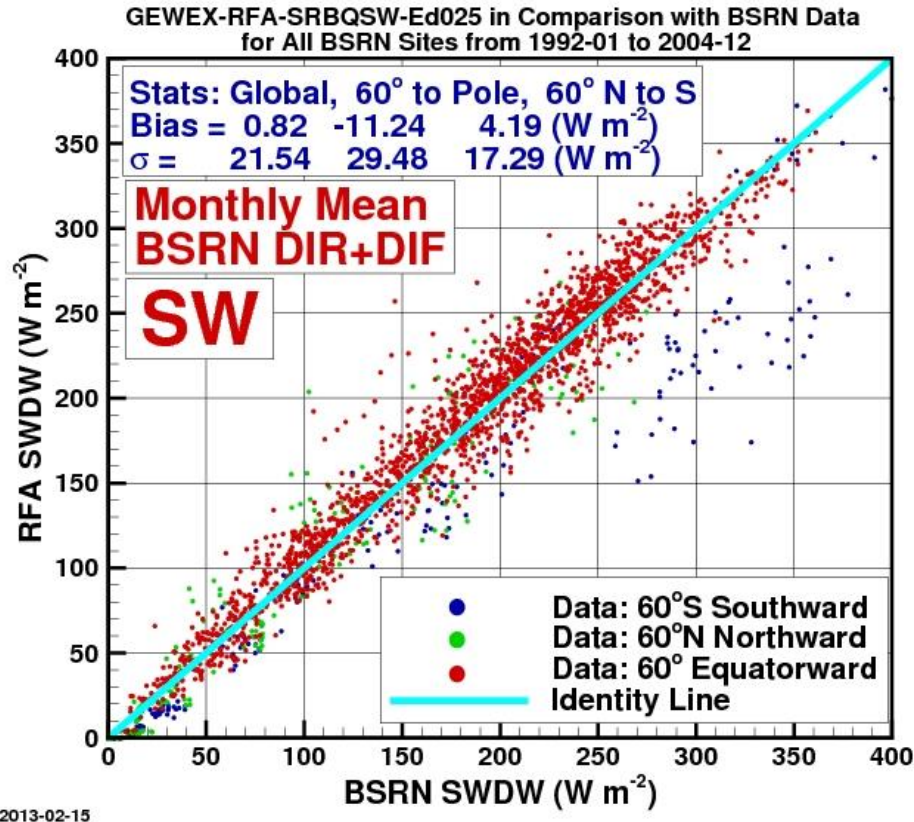


-0.35 -0.25 -0.15 -0.05 0.05 0.15 0.25 0.35

-MODIS-CE





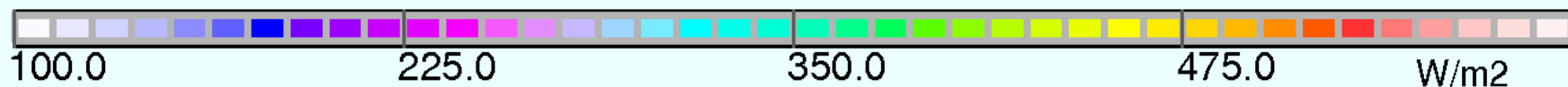
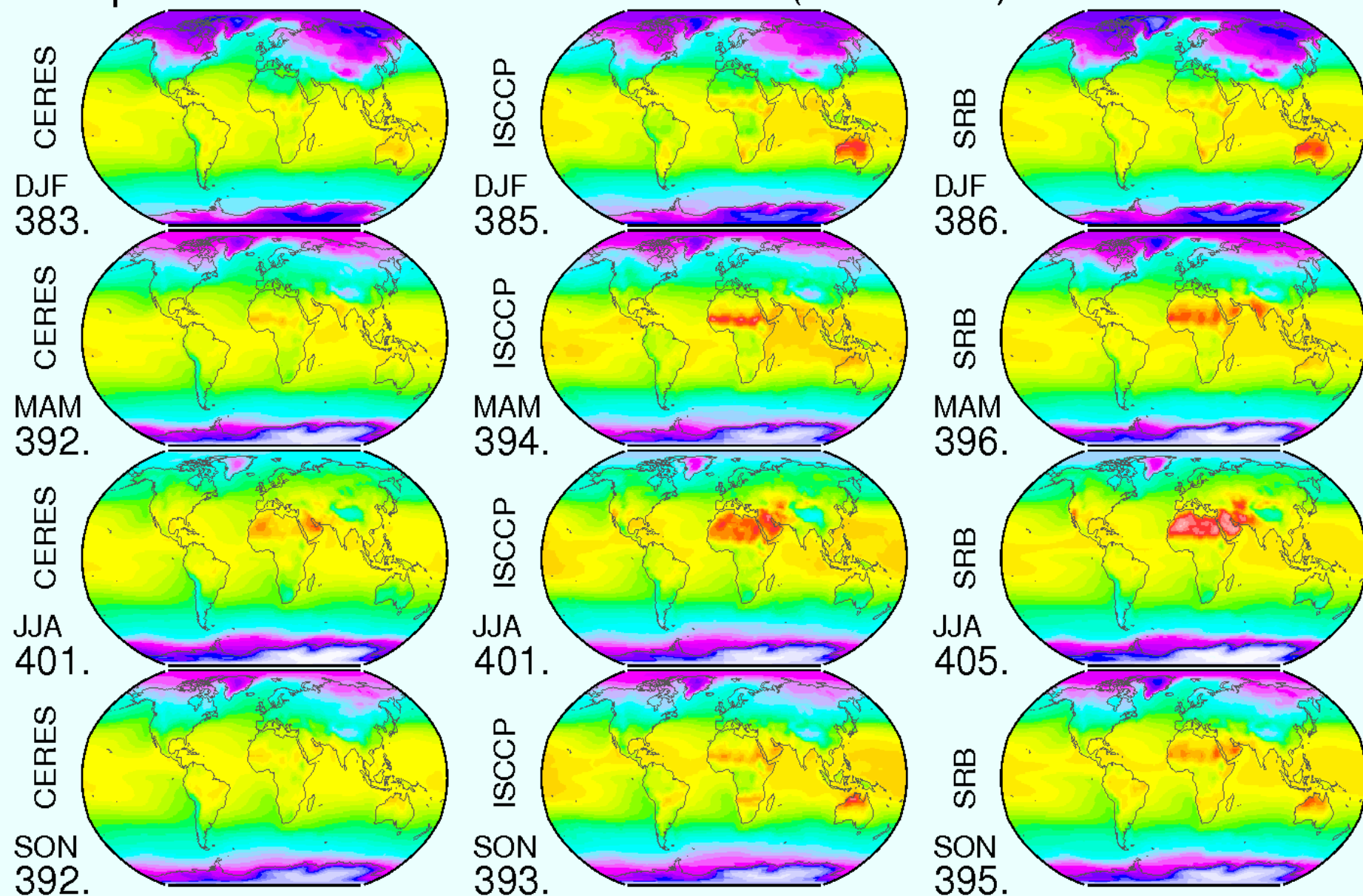


Validation of downward fluxes with ground-based measurements

Here: BSRN

# upward LW flux at surface

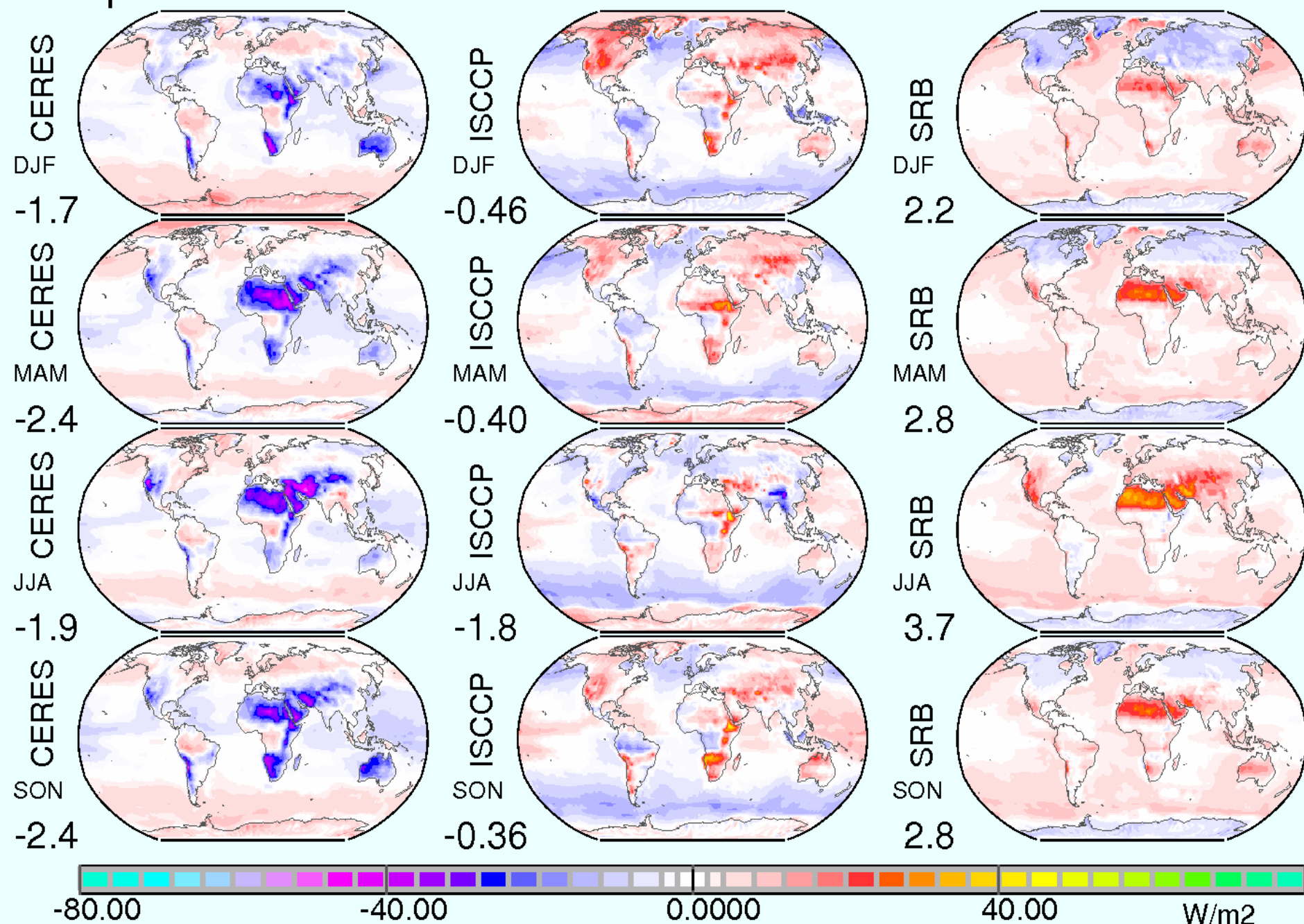
(2000-2003)

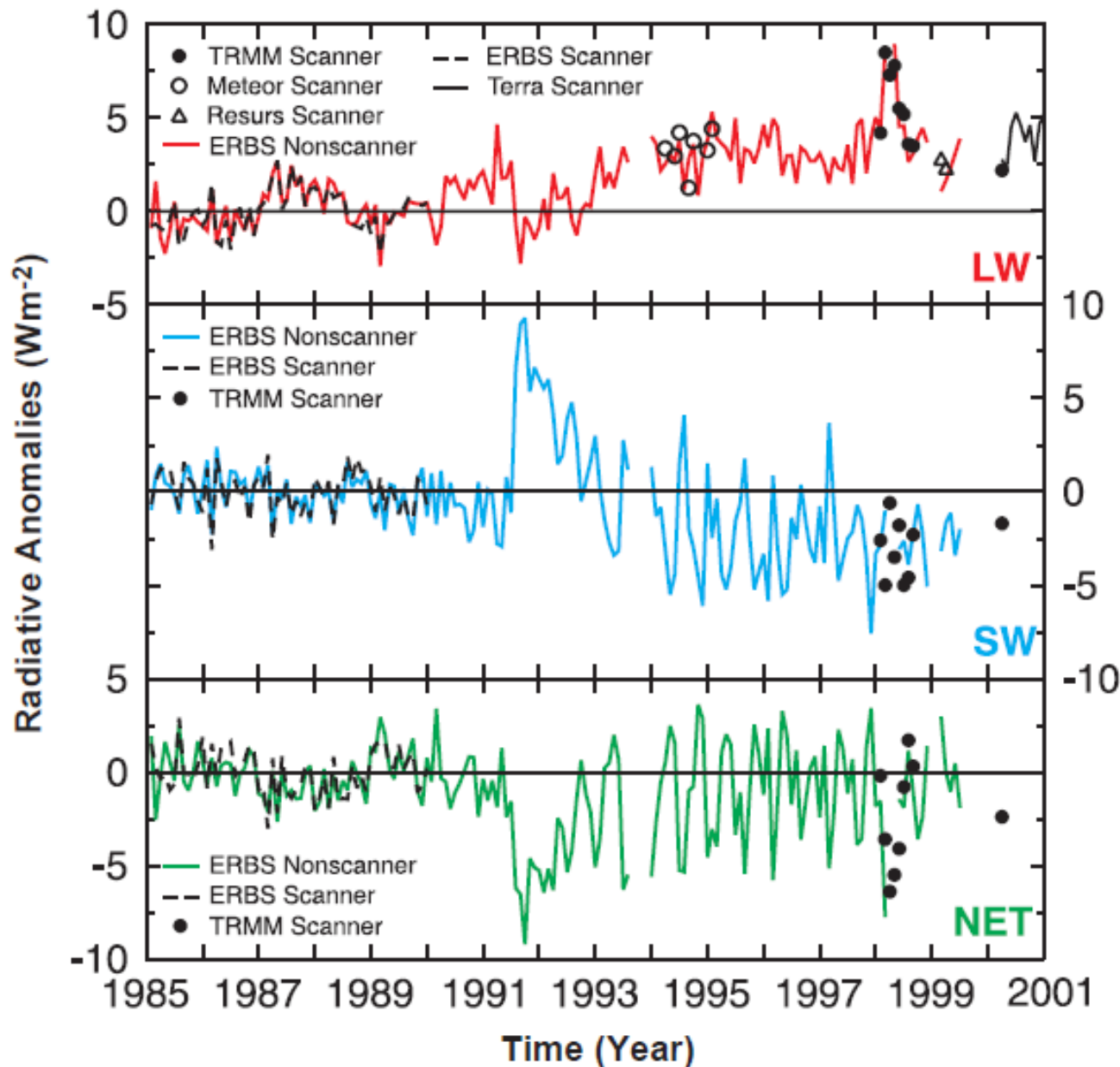




# upward LW flux at surface

# difference to CIS



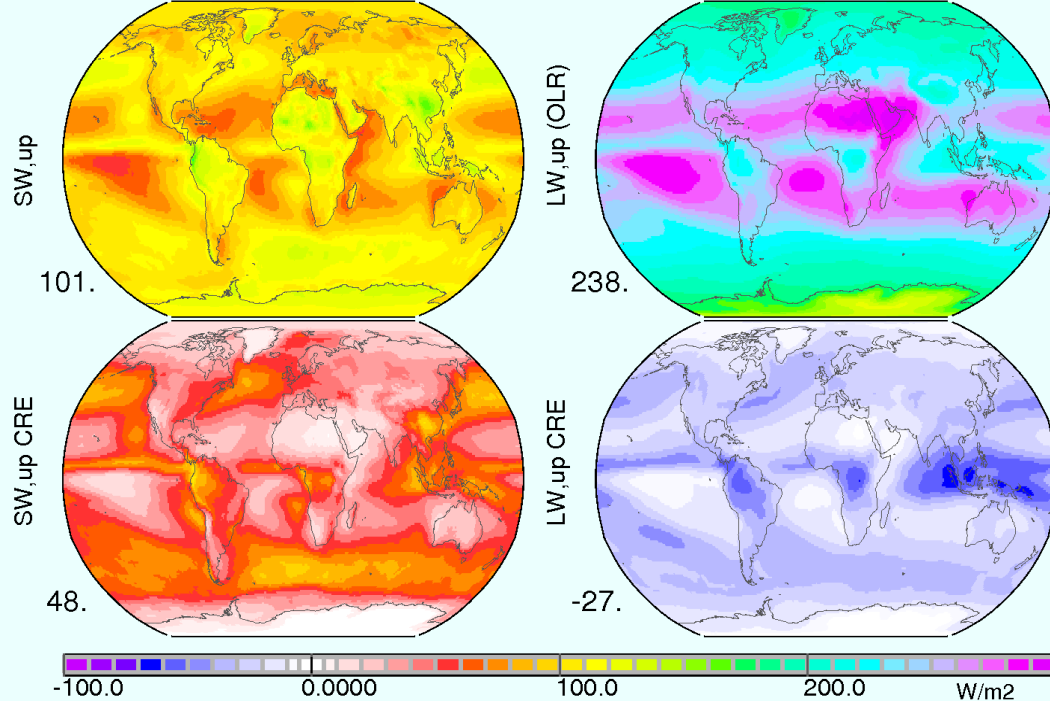


**An attempt to combine more recent individual measurements into a time series:**

**Satellite record of tropical mean ( $20^{\circ}\text{S}$  to  $20^{\circ}\text{N}$  latitude) anomalies in broadband thermal emitted LW flux, solar reflected SW flux, and net radiative flux.**

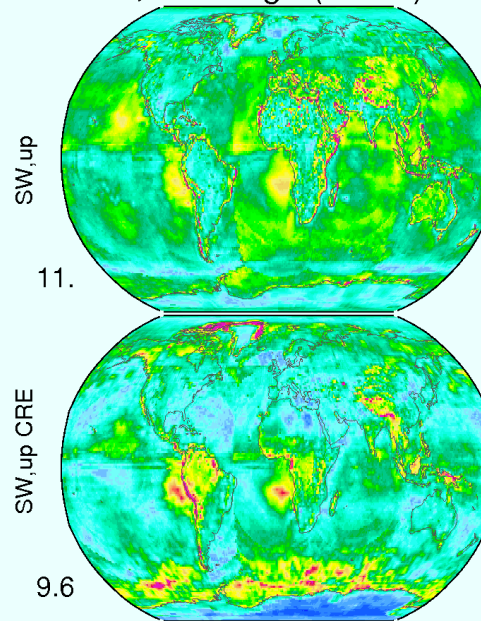
# **Ranges of uncertainty between ISCCP, CERES and SRB results**



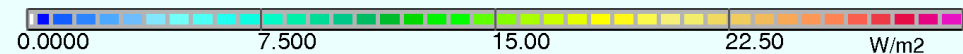
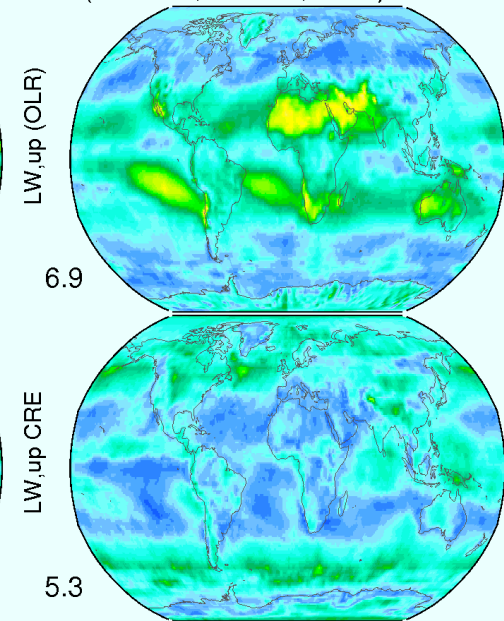


$$\text{CIS} = (\text{CERES} + \text{ISCCP} + \text{SRB}) / 3$$

TOA, sat range (00-03)



(CERES, ISCCP, SRB)



Local ranges of deviations  
between the three data sets

atm averages (00-03)

(CERES, ISCCP, SRB)

# CIS annual averages (2000 to 2003)

DIV

-115.

DIV CRE

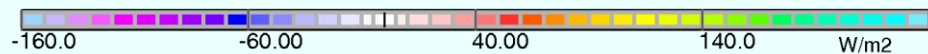
-4.4

GH

154.

GH CRE

27.



atm, range (00-03)

(CERES, ISCCP, SRB)

DIV

18.

DIV CRE

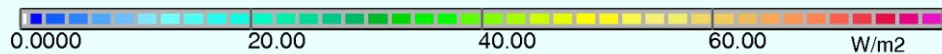
15.

GH

18.

GH CRE

6.8

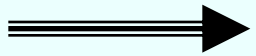


Ranges of mutual local deviations

# GEWEX (~ 1984):

... to improve our knowledge on energy and water transports within the atmosphere-surface system:

- **radiation**, precipitation, evapo(transpi)ration
- water and heat within the atmosphere
- river systems

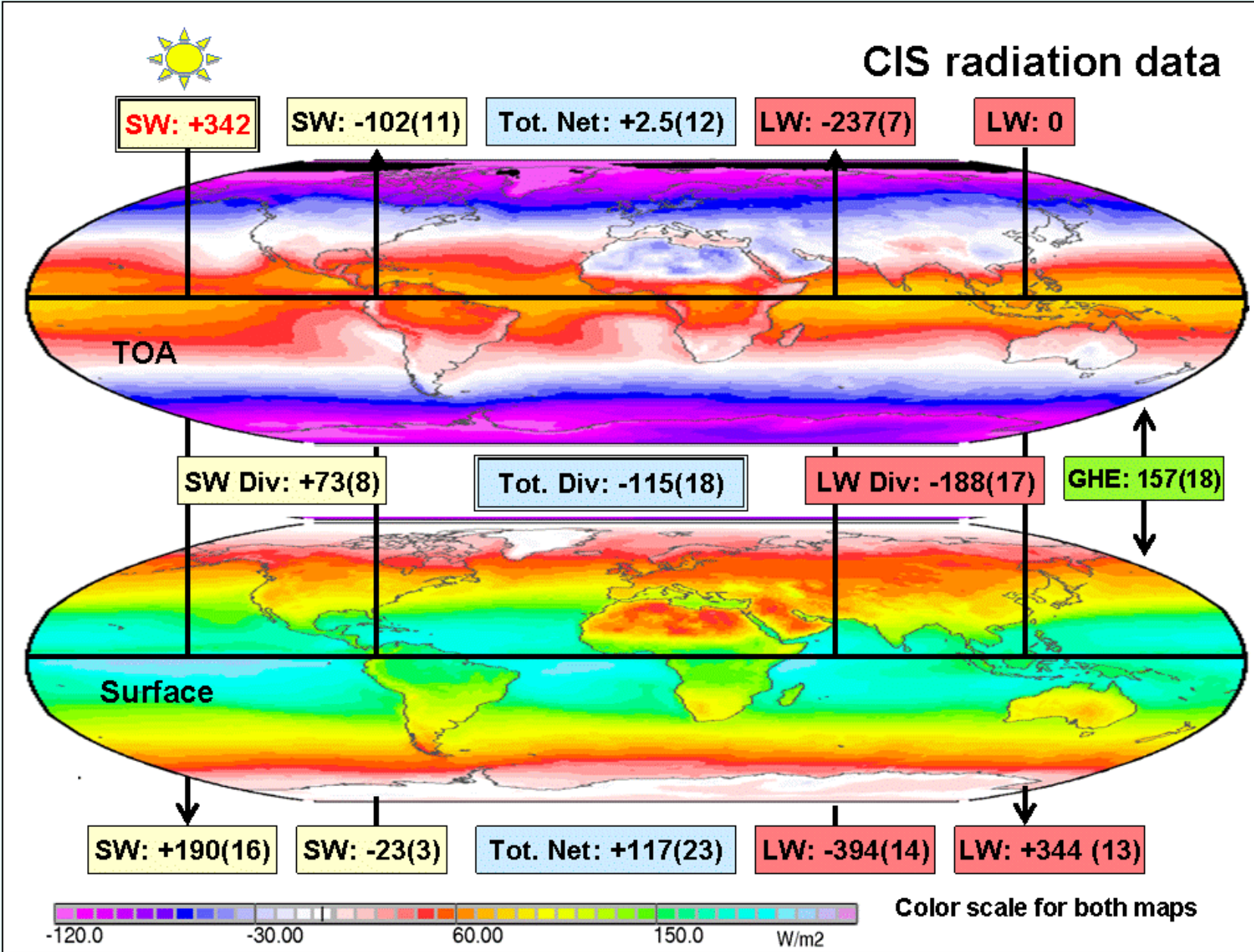


Numerous modeling, experimental, monitoring and data collection activities

~ Year 2000: Major call for **assessment of existing data series**

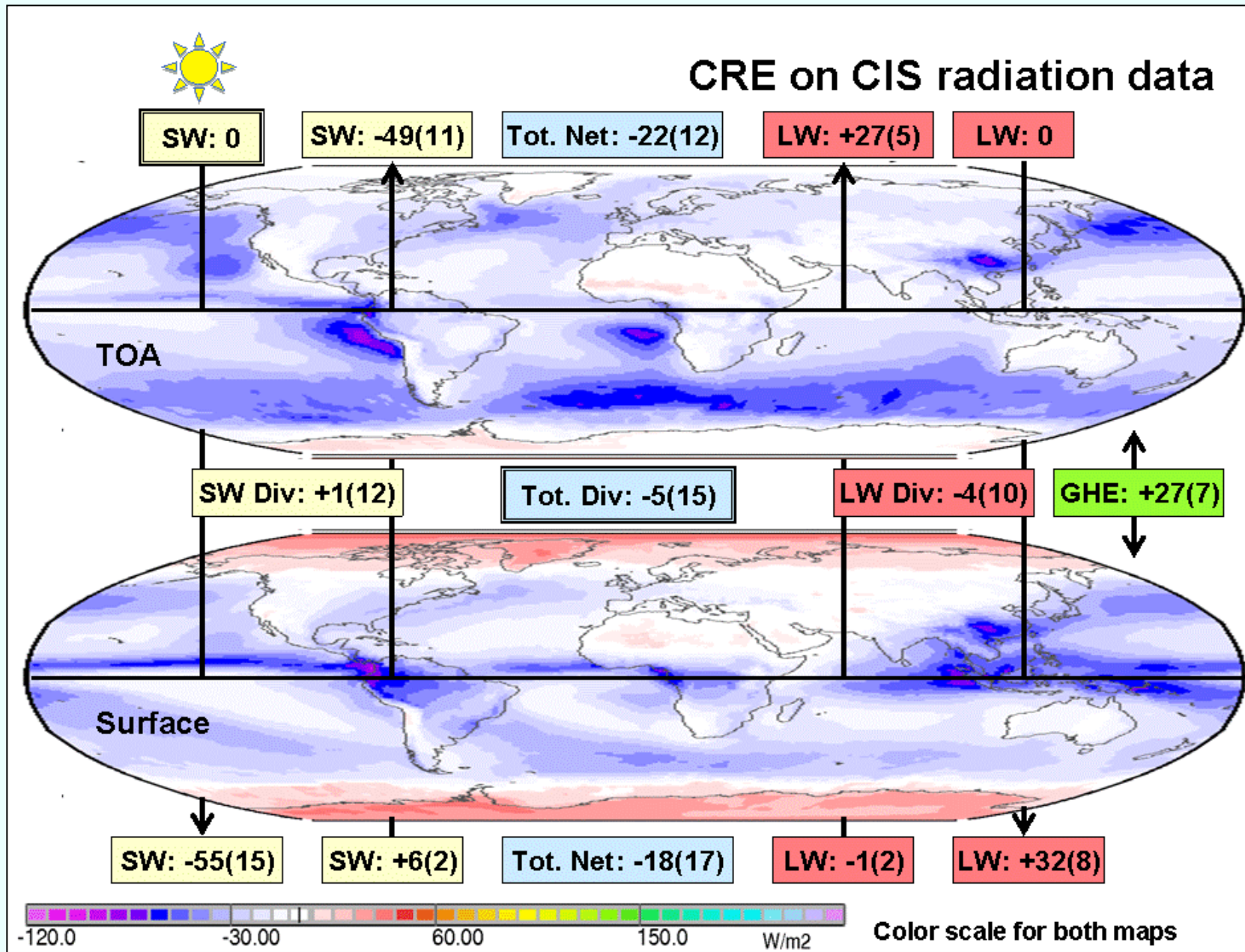


$CIS = (CERES + ISCCP + SRB) / 3$



2000  
to  
2003

# CRE = Cloud Radiative Effects

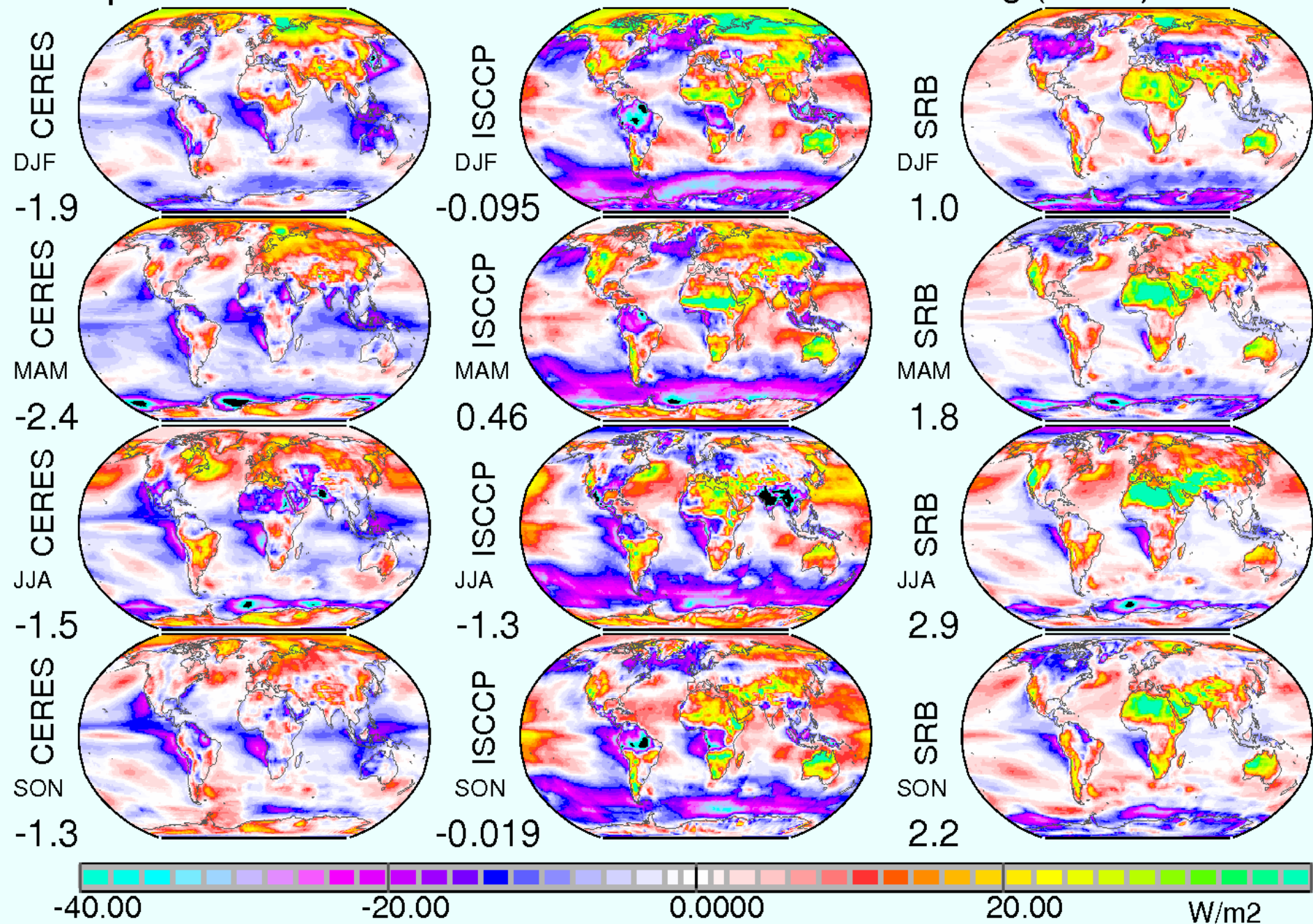


# **Differences to model results**



upward LW flux at surface

diff to modeling (IPCC)



# IPCC minus CIS radiation data



SW: 0

SW: -3(8)

Tot. Net: 0(4)

LW: 2(7)

LW: 0

TOA

SW Div: 2(-1)

Tot. Div: 11 (0)

LW Div: 9(-1)

GHE: 1(0)

Surface

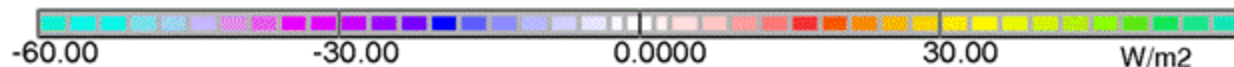
SW: -3(12)

SW: -2(1)

Tot. Net: -12(-2)

LW: 1(-1)

LW: -10(6)

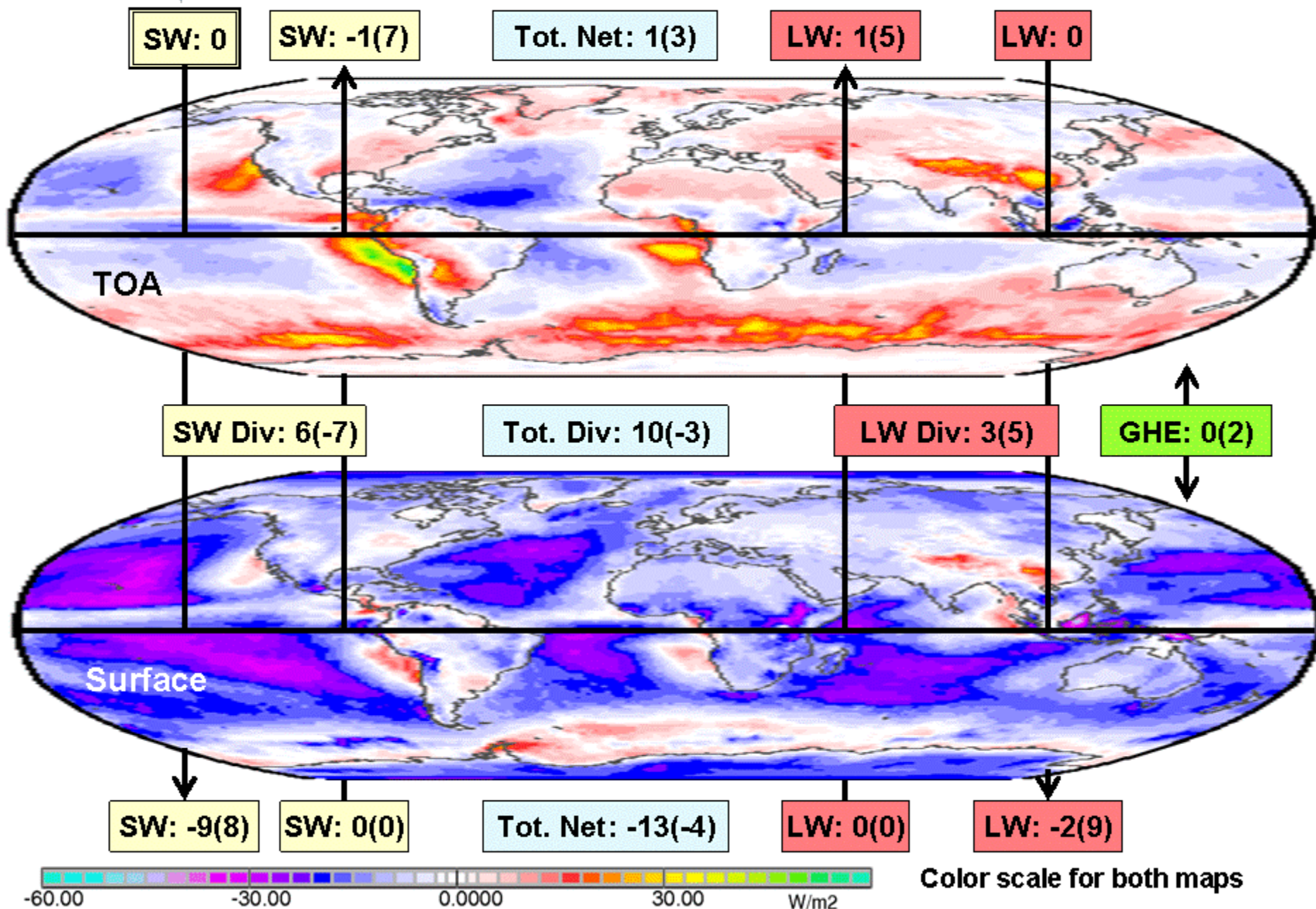


Color scale for both maps



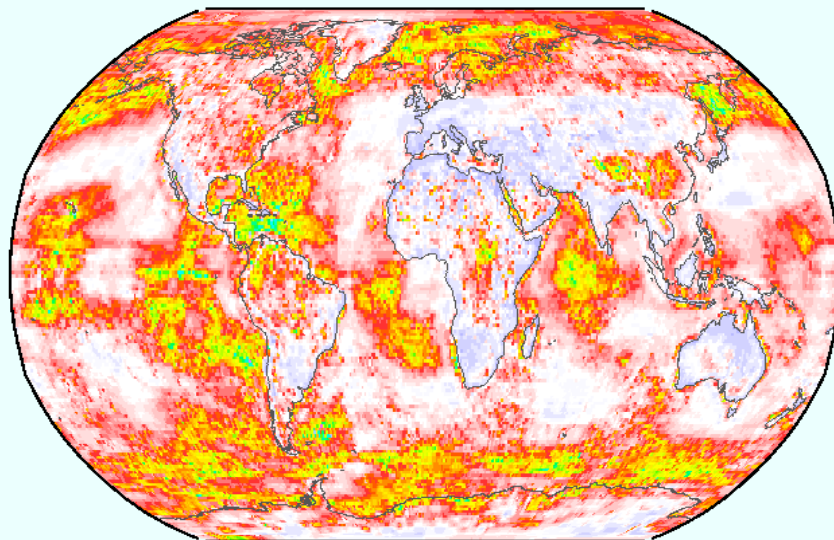


# IPCC minus CIS of CRE radiation data

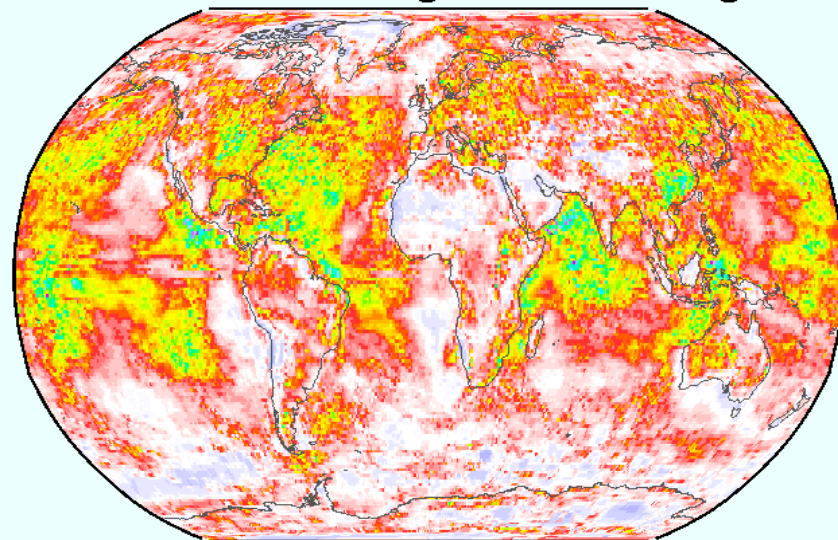




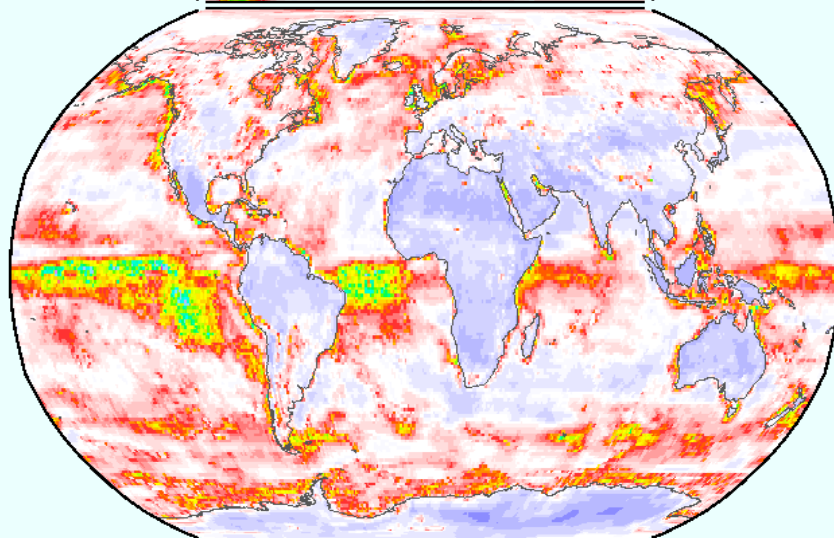
69. net ToA



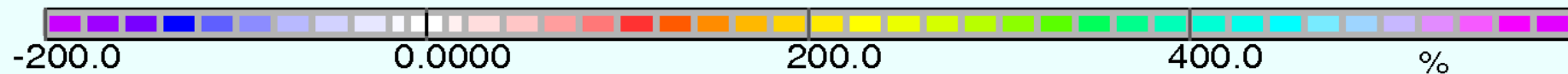
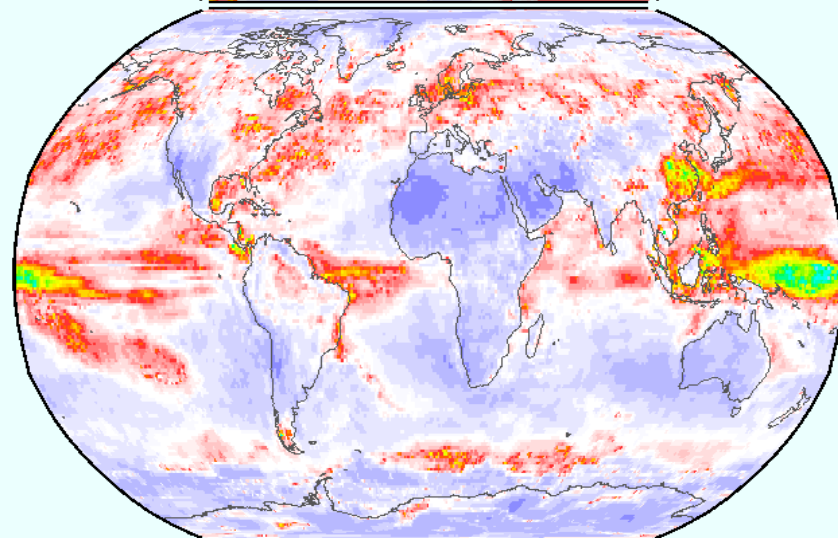
101. TOA CRE



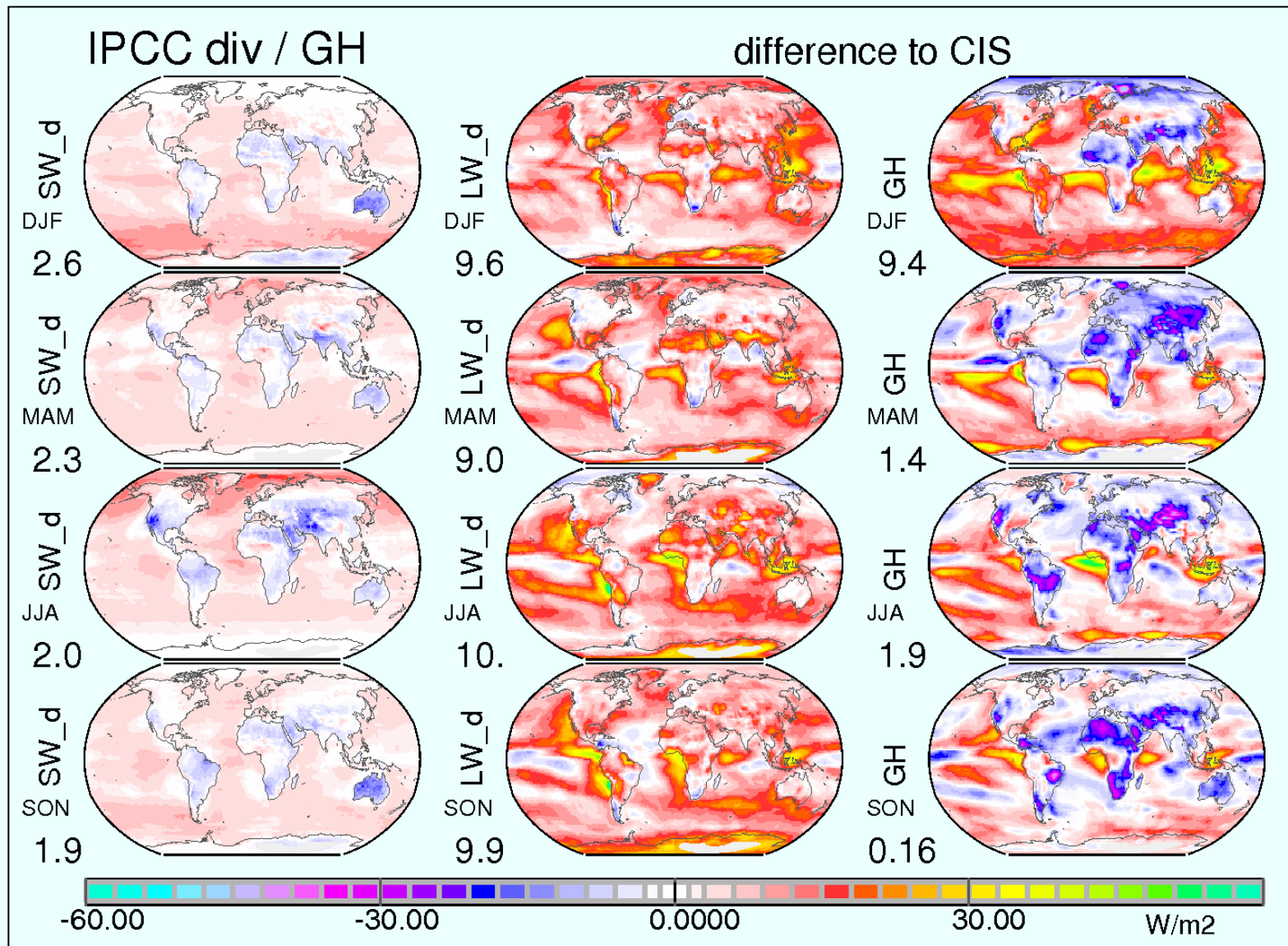
31. net surf



7.0 surf CRE



**Ratios between differences of ranges of deviation:  
( $\Delta$ IPCC- $\Delta$ CIS)/ $\Delta$ CIS (in percent)**



***SW and LW Divergence and Greenhouse effect of the atmosphere: Differences between IQ-averages of the IPCC model and of CIS averages. Values below labels indicate global averages.***

all-sky	CIS S=342	IPCC CMIP 3 S=342	Trenberth 2007 S=342	Stephens 2012 S=340	Wild 2013 S=340	Annual global averages of CIS, IPCC and other datasets for <a href="#">all-sky</a> conditions  (in Wm <sup>-2</sup> )
TOA total net	+ 2.5	+ 2	0	0	0	
SW up at TOA	- 101	- 102	- 102	- 100	- 100	
LW up at TOA	- 238	- 235	- 239	- 240	- 239	
IR-GHE	154	157	157	158	158	
SW dn at sfc	190	187	184	188	185	
SW up at sfc	- 25	- 24	- 23	- 23	- 24	
LW dn at sfc	344	334	333	345	342	
LW up at sfc	- 394	- 393	- 396	- 398	- 397	
SW net at sfc	165	163	161	165	161	
LW net at sfc	- 50	- 59	- 63	- 53	- 55	Rounding errors: > ± 0.5 Wm <sup>-2</sup>
Tot net at sfc	115	104	98	112	106	
SW div in atm	76	75	79	75	79	
LW div in atm	- 188	- 176	- 176	- 187	- 185	
Total div in atm	- 112	- 101	- 97	- 112	- 106	



# Summary and recommendations

1. Clouds reduce (enhance) downward SW and upward LW (upward SW and downward LW) radiation. CRE on net fluxes and on divergences are mixed depending on cloud top height and wavelength.
2. Uncertainties and diversities are often higher in IPCC than in CIS data. They are caused by uncertainties in **ancillary data** and in **cloud treatment**.
3. Specific problems occur over **mountainous** continental and over both sub-arctic regions (What is the radiation budget of a grid element over the Andes?).

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**We recommend to re-analyze all datasets and to agree on same properties for the surface albedo and emission!**

**We encourage for international competition!**

**Apply unique and stringent quality control procedures!**

**Plan careful for next radiation assessment with more recent data.**

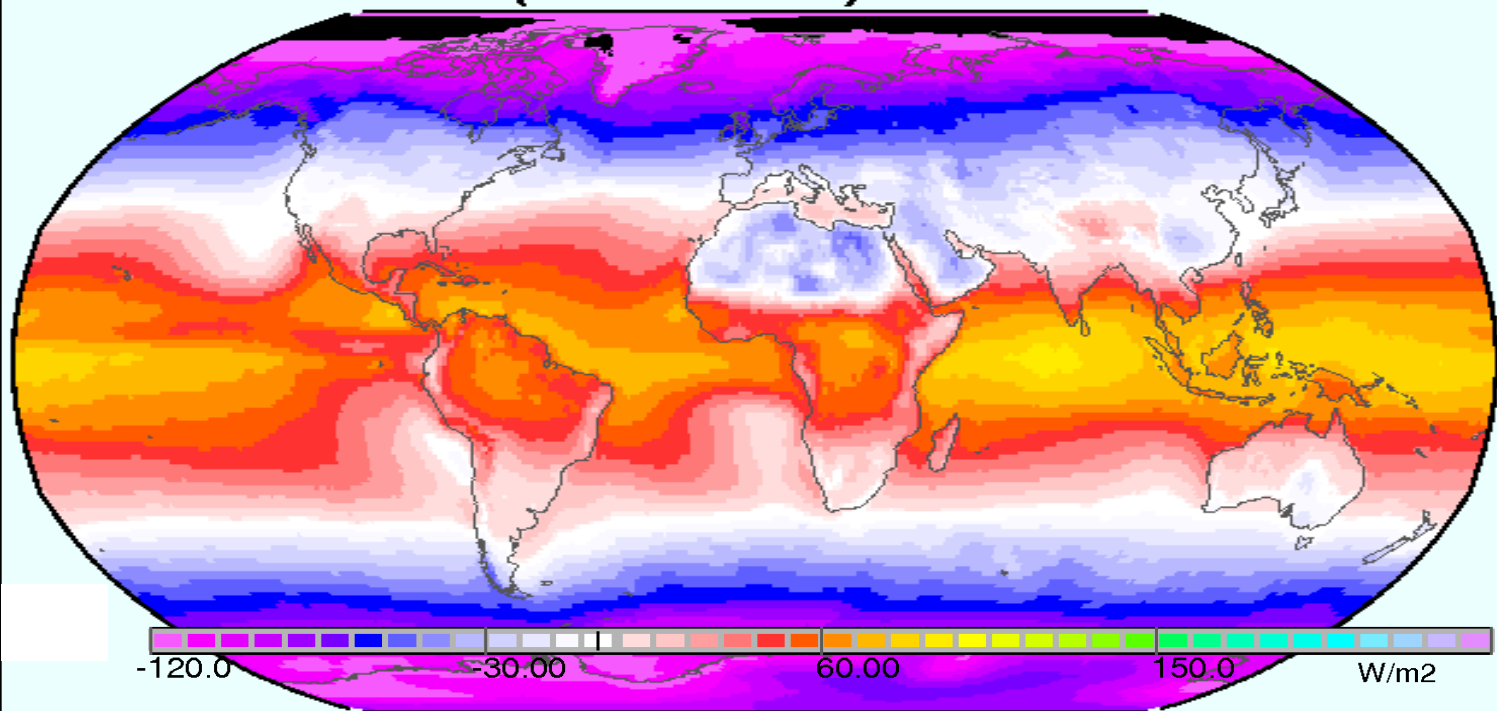
**The future:  
EarthCare  
Launch in 2017?**



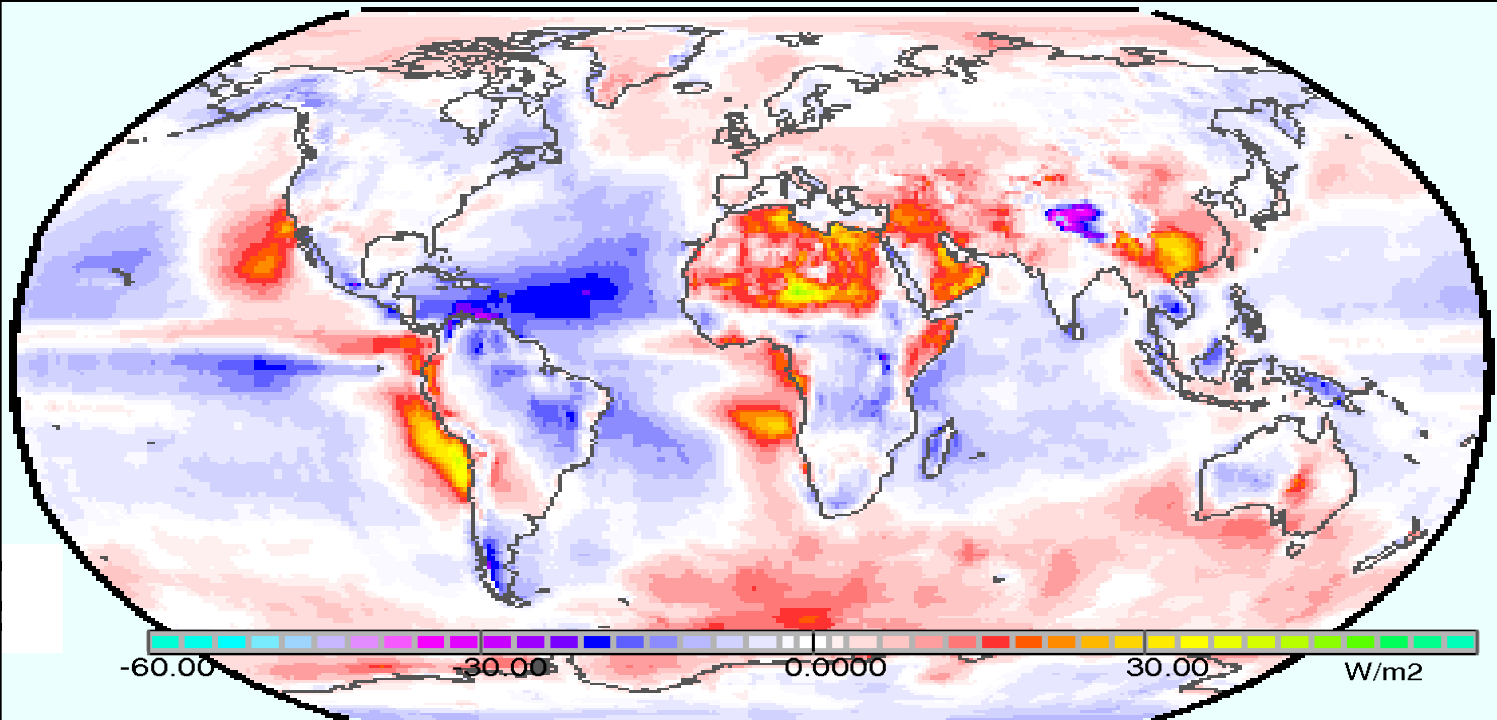


# Annual Radiation Budget at TOA:

CIS and

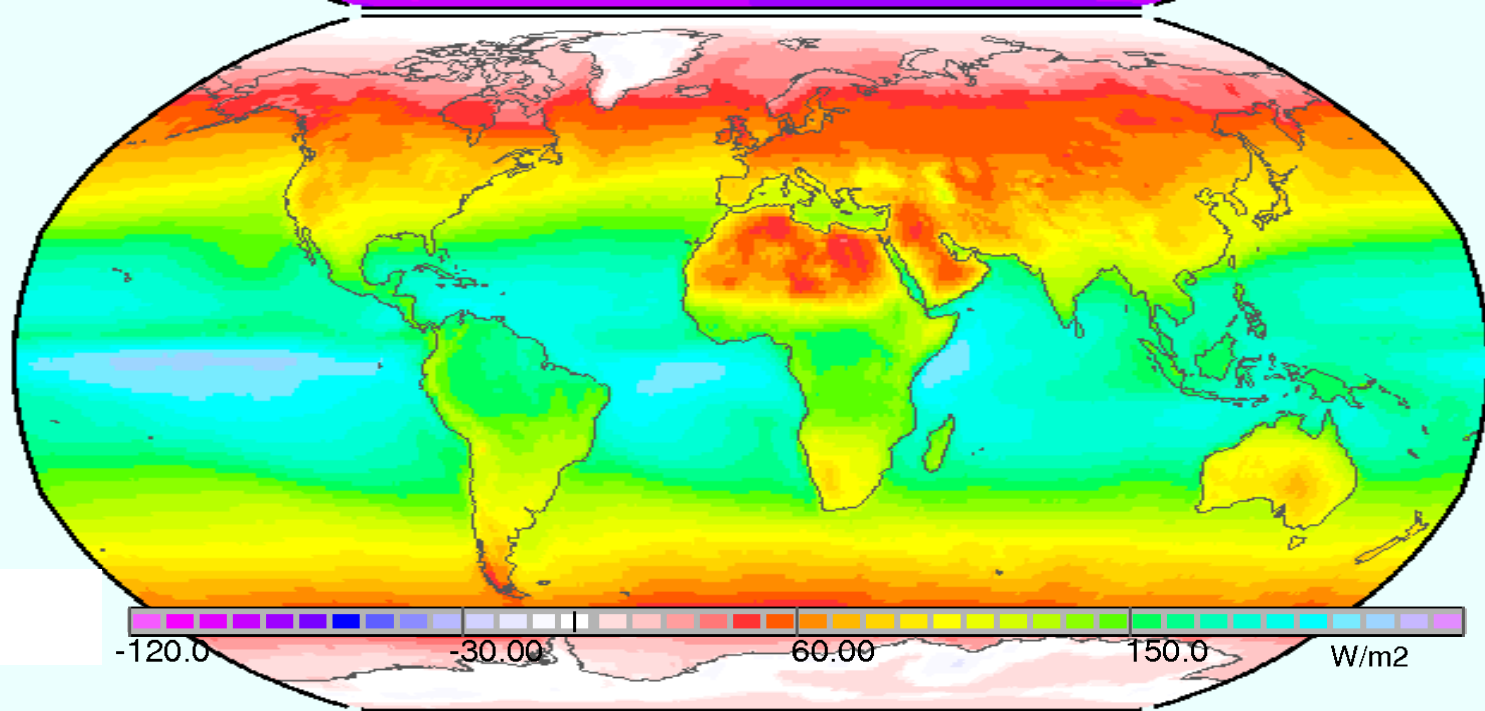


IPCC  
minus  
CIS

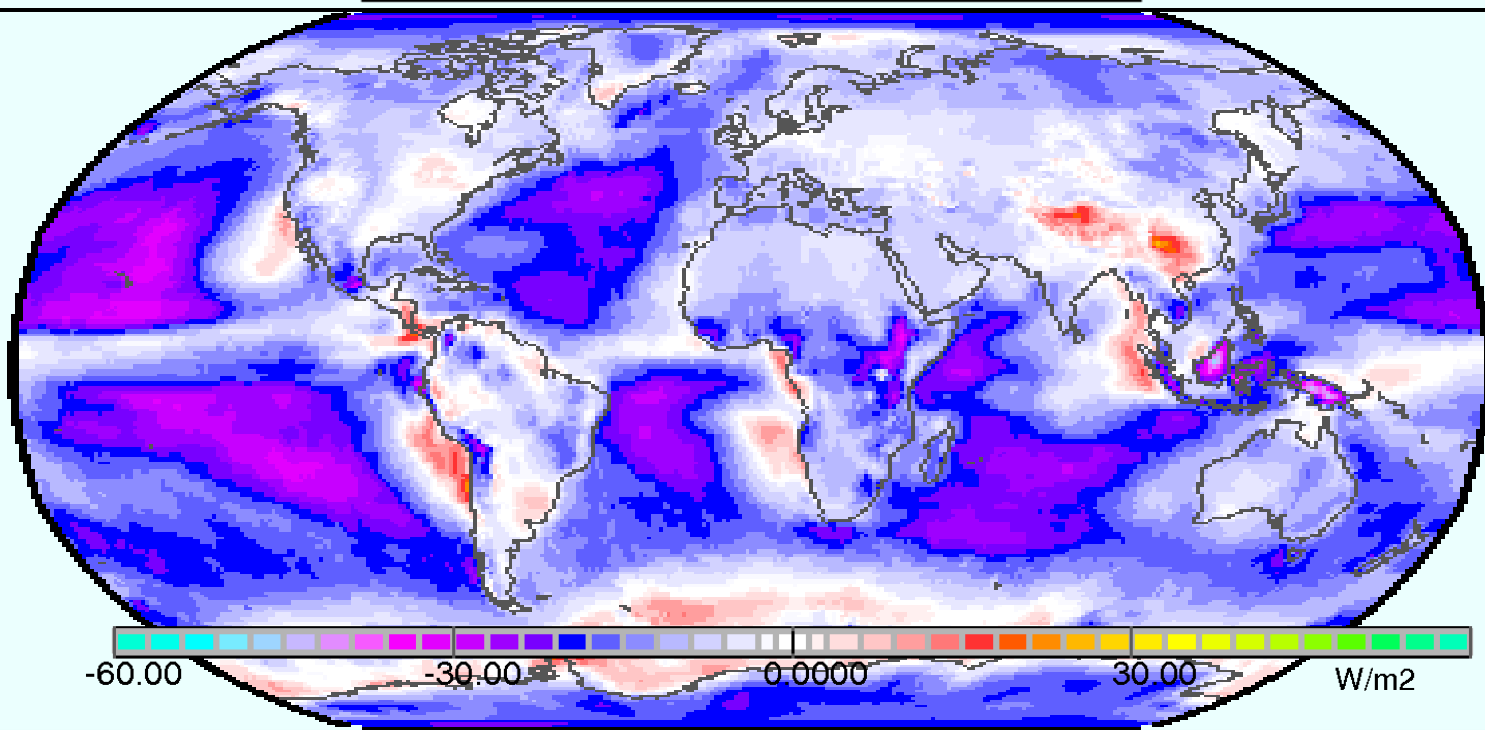


# Annual Radiation Budget at Surface:

CIS and

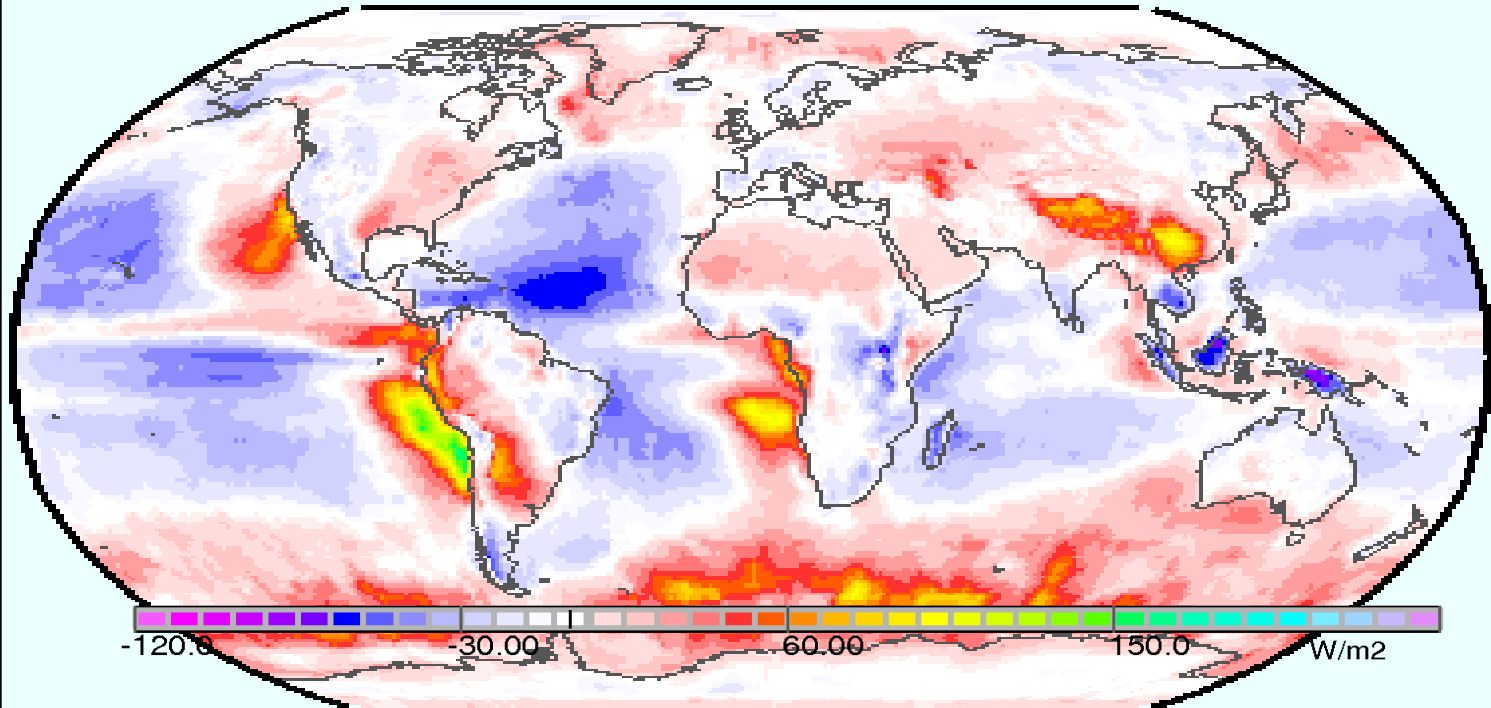


IPCC minus  
CIS

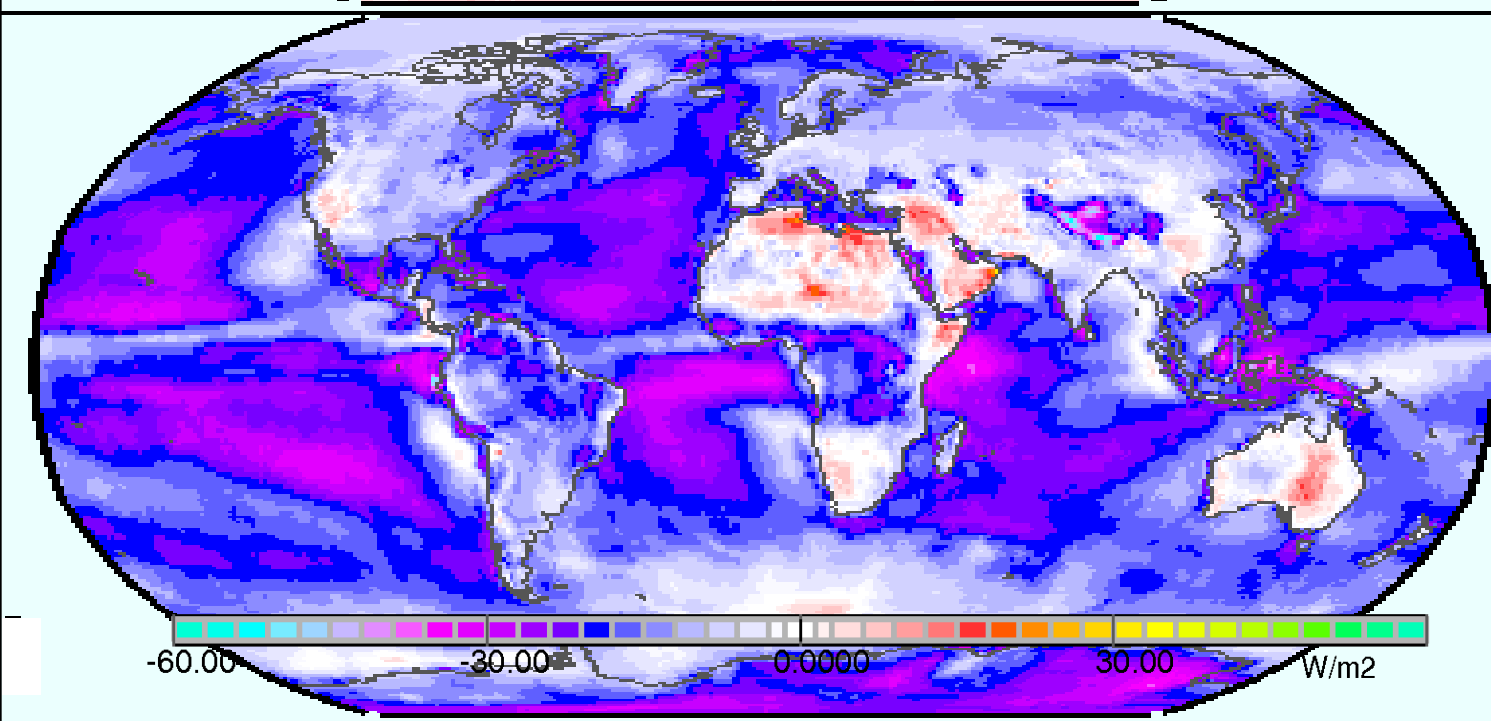


**CRE on  
Annual  
Radiation  
Budget at  
Surface:**

**CIS and**



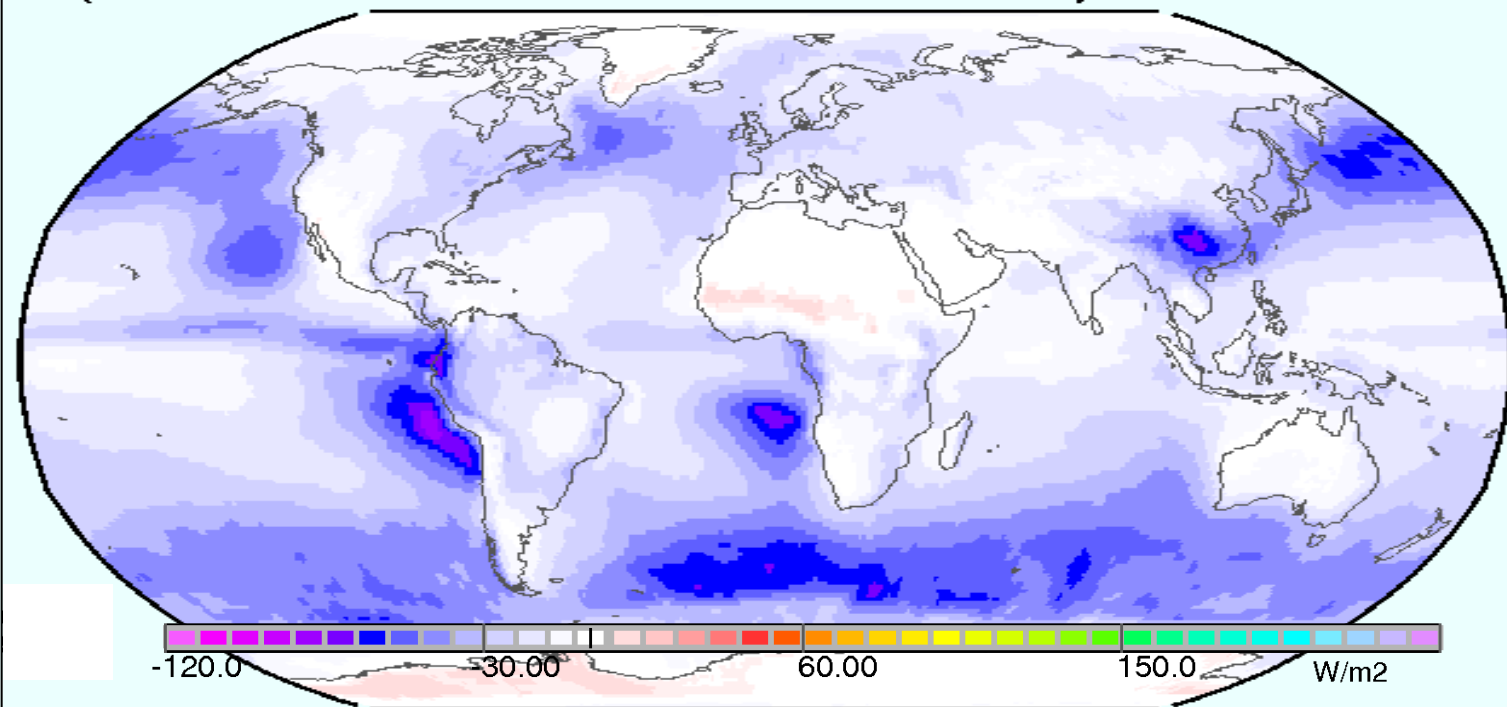
**IPCC minus  
CIS**





**CRE on  
Annual  
Radiation  
Budget at  
TOA:**

**CIS and**



**IPCC minus  
CIS**

