CLOUD—CLIMATE FEEDBACK(S?)

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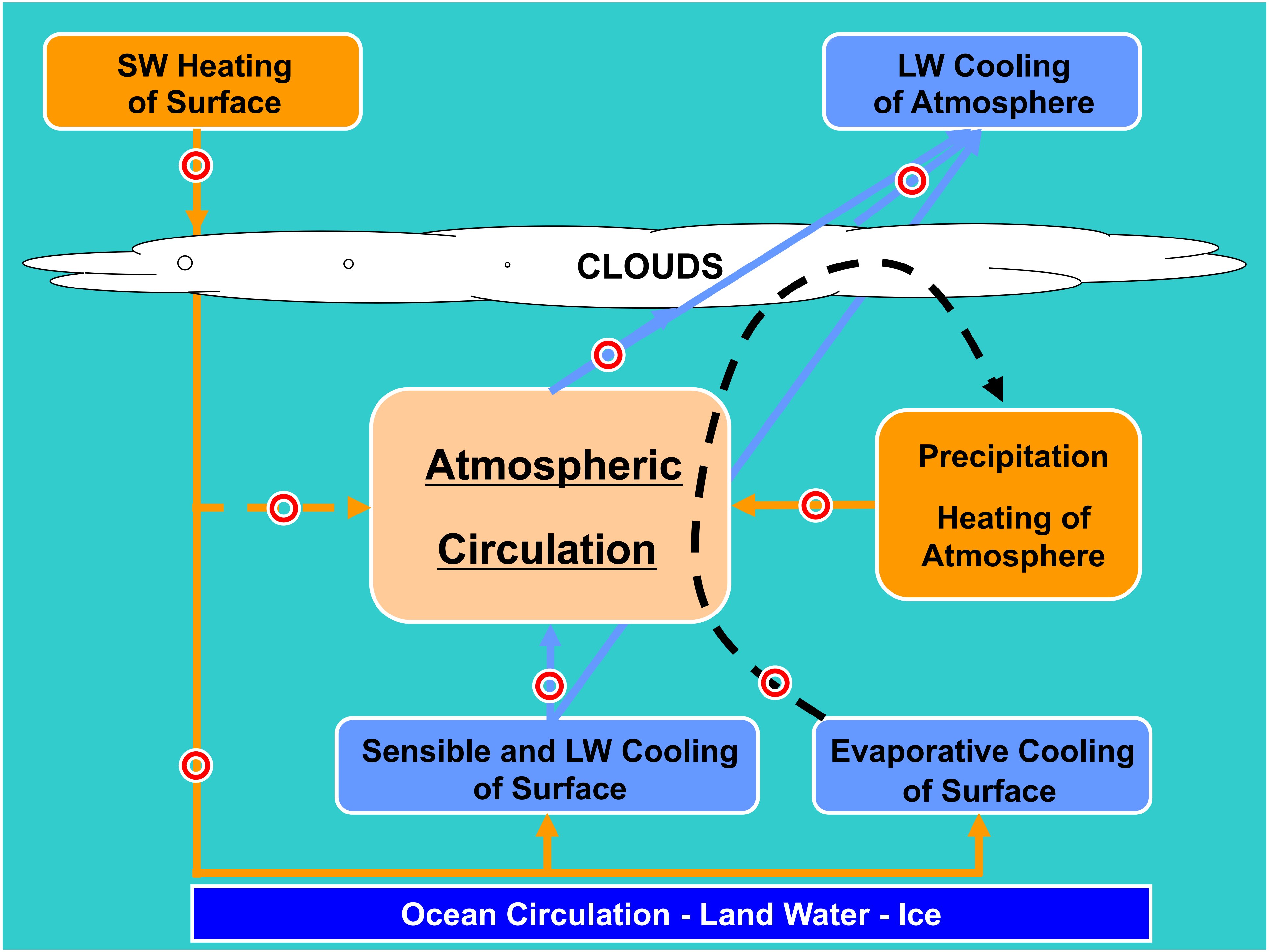
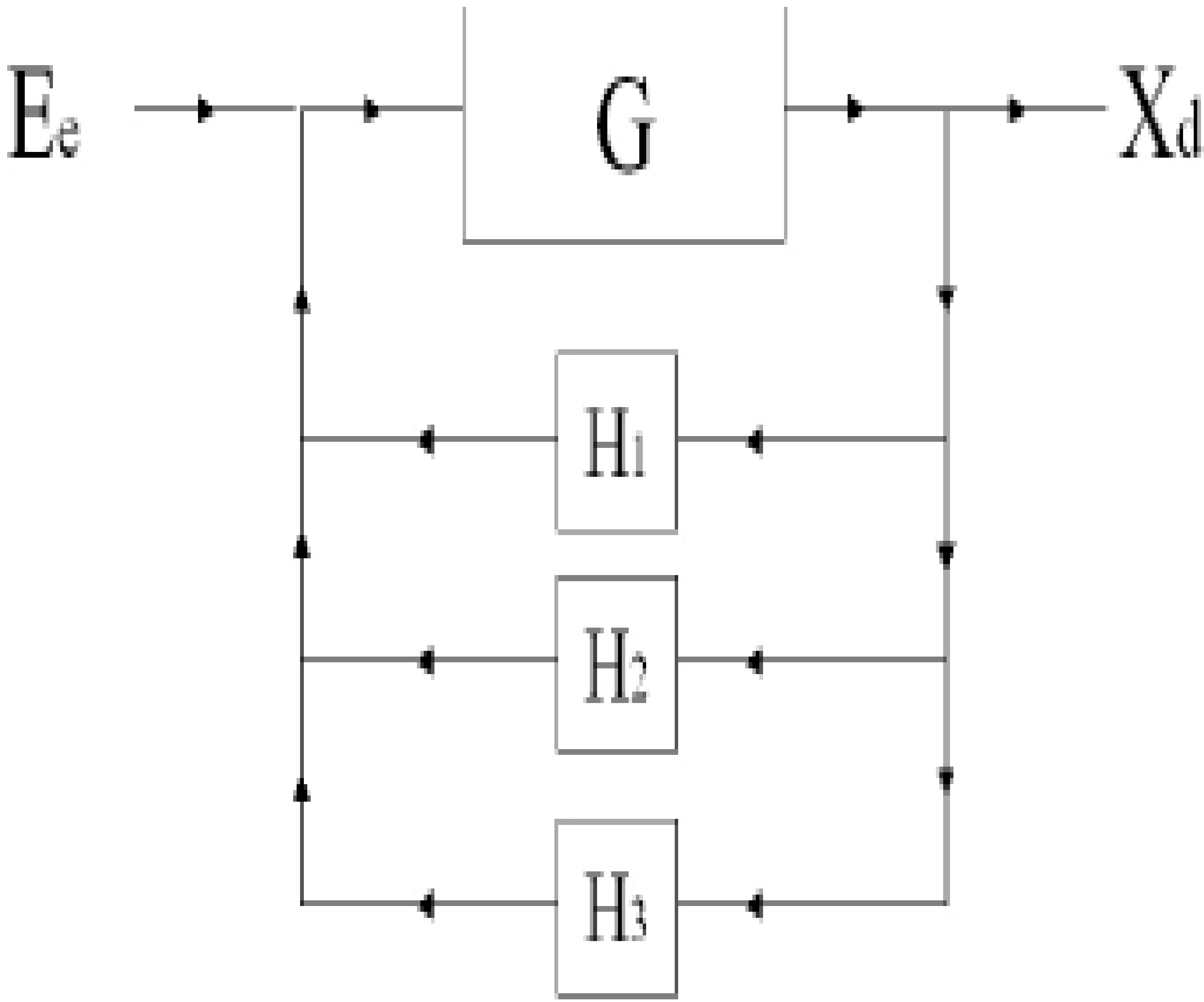
9 September 2009


SW Heating of Surface
LW Cooling of Atmosphere
CLOUDS
Atmospheric Circulation
Precipitation Heating of Atmosphere
Sensible and LW Cooling of Surface
Evaporative Cooling of Surface
Ocean Circulation - Land Water - Ice

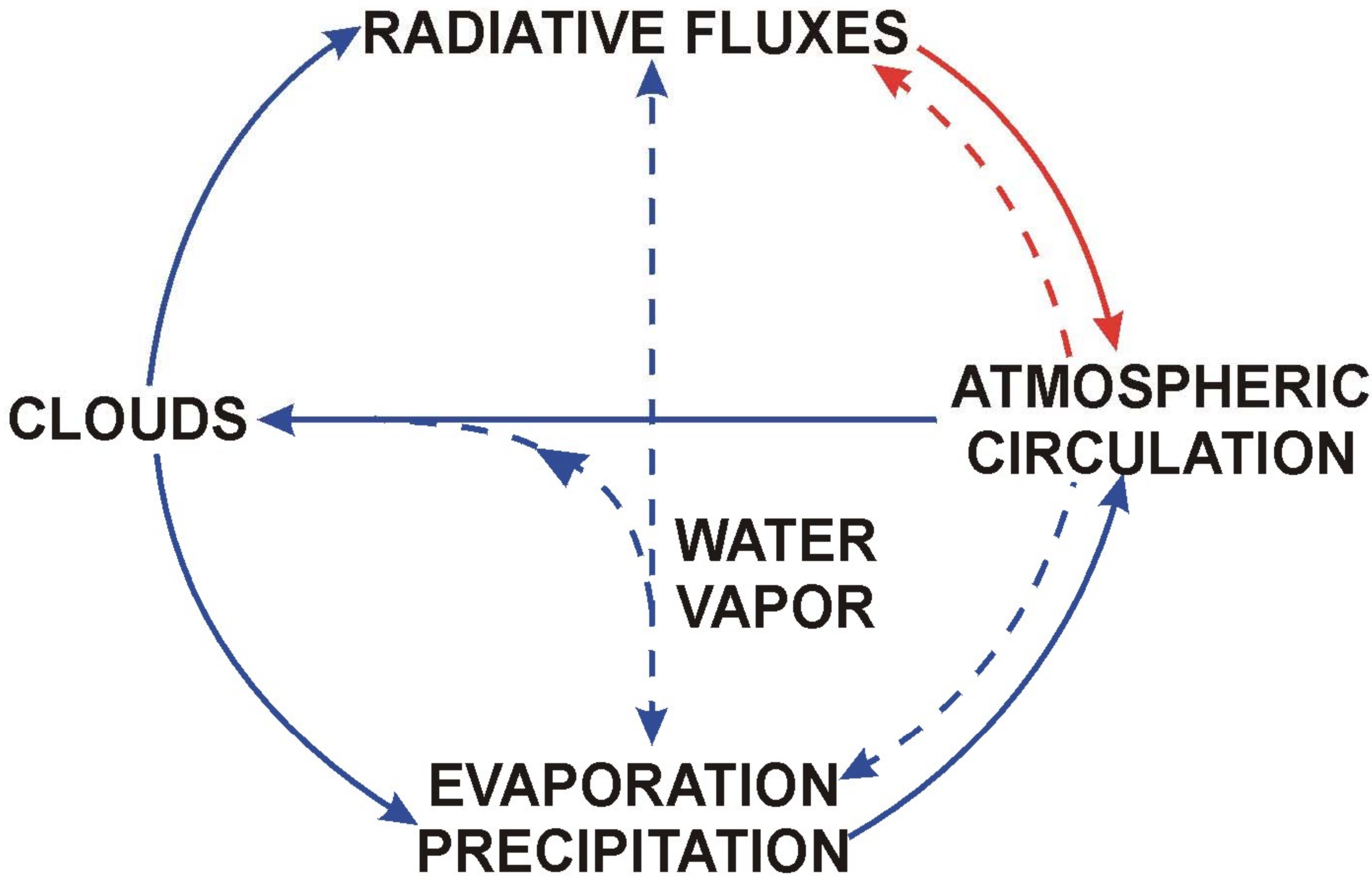
What About Model Analyses?
(some examples)

- “Cess” experiment results do not correctly predict model climate sensitivity
- Most model analyses still assume linearly independent effects (might be useful metrics)
- More appropriate model analyses of feedback cannot be verified by observations
- Model analyses cannot inform understanding of real climate feedbacks (but can assist forming hypotheses)



E_e
G
X_d
H_1
H_2
H_3

ENERGY AND WATER CYCLE OF CLIMATE



General Feedback Formulation

$$\Delta X_e(t_0 + 2\Delta t) = EX_e\,(t_0 + 2\Delta t) + \sum_i \frac{\partial X_e(t_0 + 2\Delta t)}{\partial X_i(t_0 + \Delta t)} \,.\, \Delta X_i(t_0 + \Delta t)$$

$$+ \sum_i \sum_j \frac{\partial X_e(t_0 + 2\Delta t)}{\partial X_i(t_0 + \Delta t)} \frac{\partial X_i(t_0 + \Delta t)}{\partial X_j(t_0)} \,.\, \Delta X_j(t_0)$$

Classical Formulation

$$\Delta X_e(t_0 + 2\Delta t) = EX_e + \sum_i \frac{\partial X_e(t_0 + 2\Delta t)}{\partial X_i(t_0 + \Delta t)} \frac{\partial X_i(t_0 + \Delta t)}{\partial X_d(t_0)} \,.\, \Delta X_d(t_0)$$

NECESSARY Assumptions

Forcing is Constant

Sensitivities are Constant

No System Memory

Single-Variable Cause-Effect Relationships

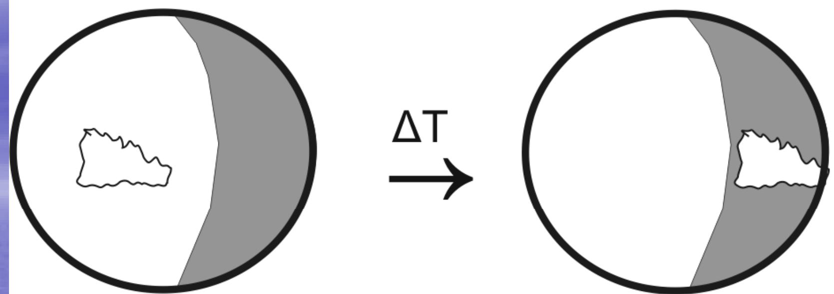
Some Other Common Assumptions

System in Static Equilibrium

Small Pertubations Allow for Linearized Analysis

Small Feedbacks Can be Ignored

Cloud cover feedback
with Δcloud cover = 0
(hypothetical examples)

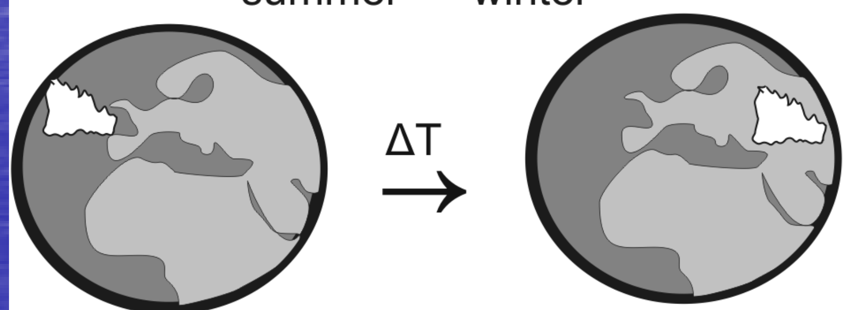


Solar zenith angle effect

day → night (need diurnal cycle!!)

tropics → midlatitudes

summer → winter



Surface albedo effect

ocean → land

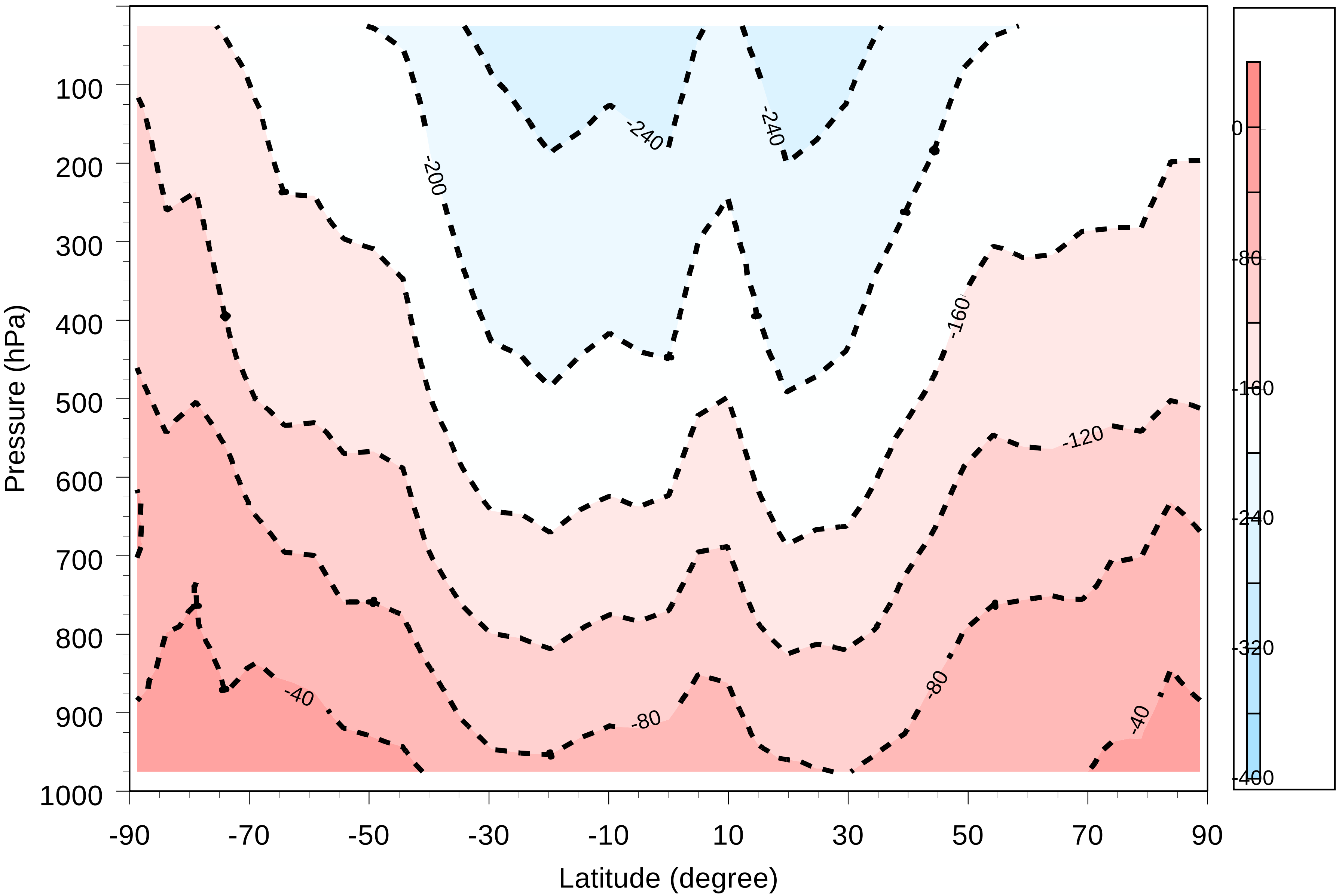
forest → snow

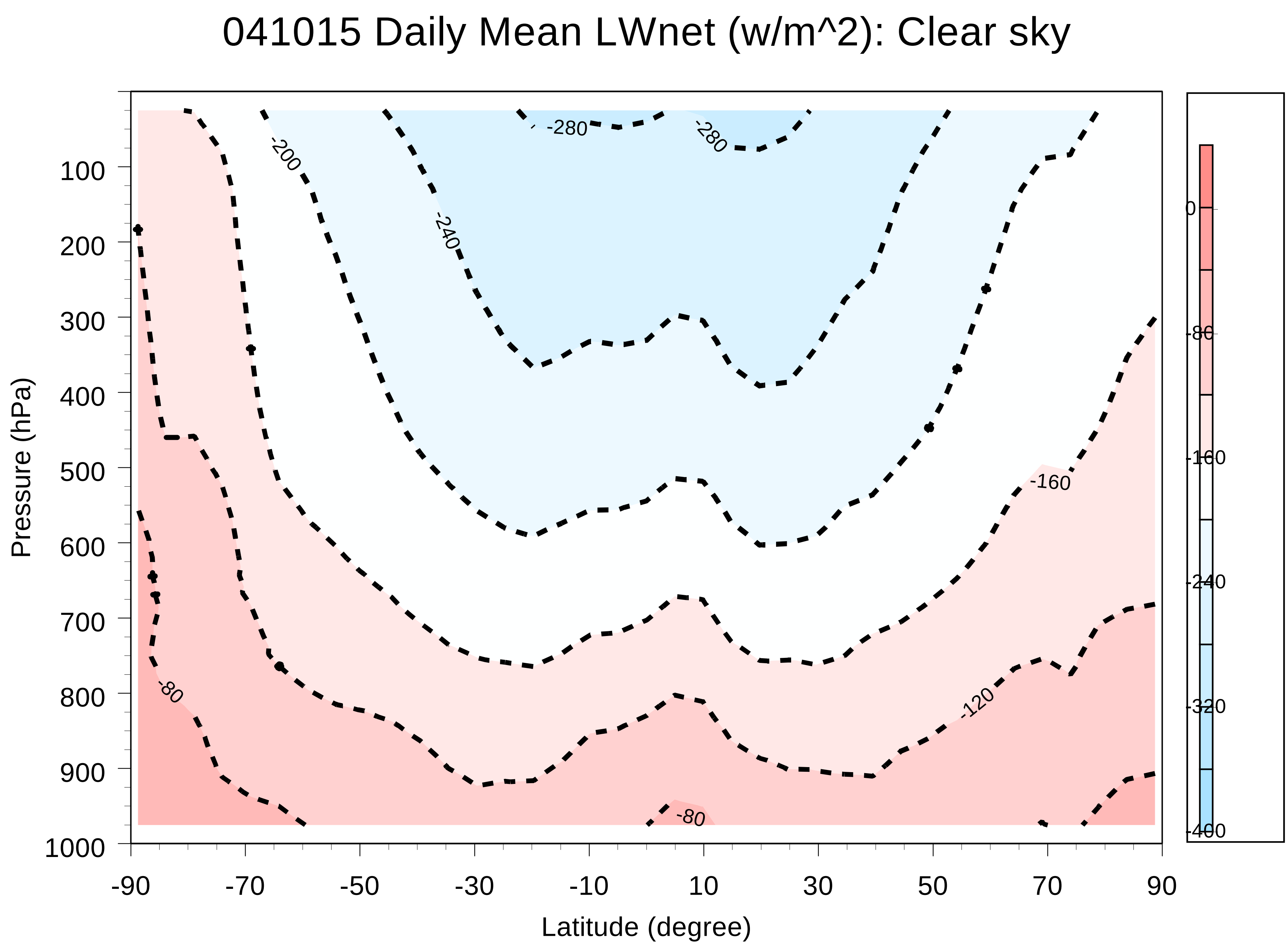
∂Rad/∂C is undefined

∂C/∂T is zero

DELGENIO

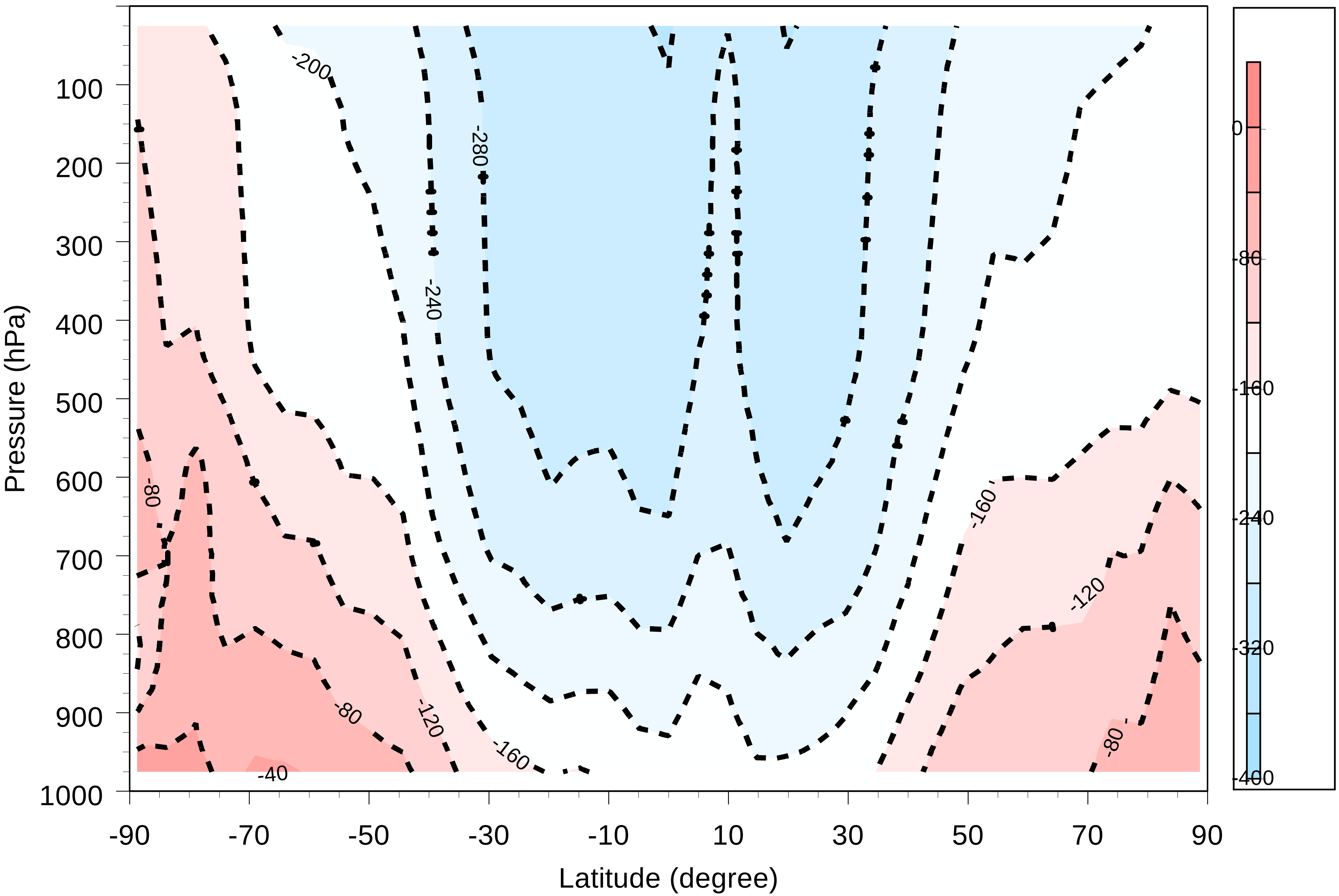
041015 Daily Mean LWnet (w/m^2): All sky



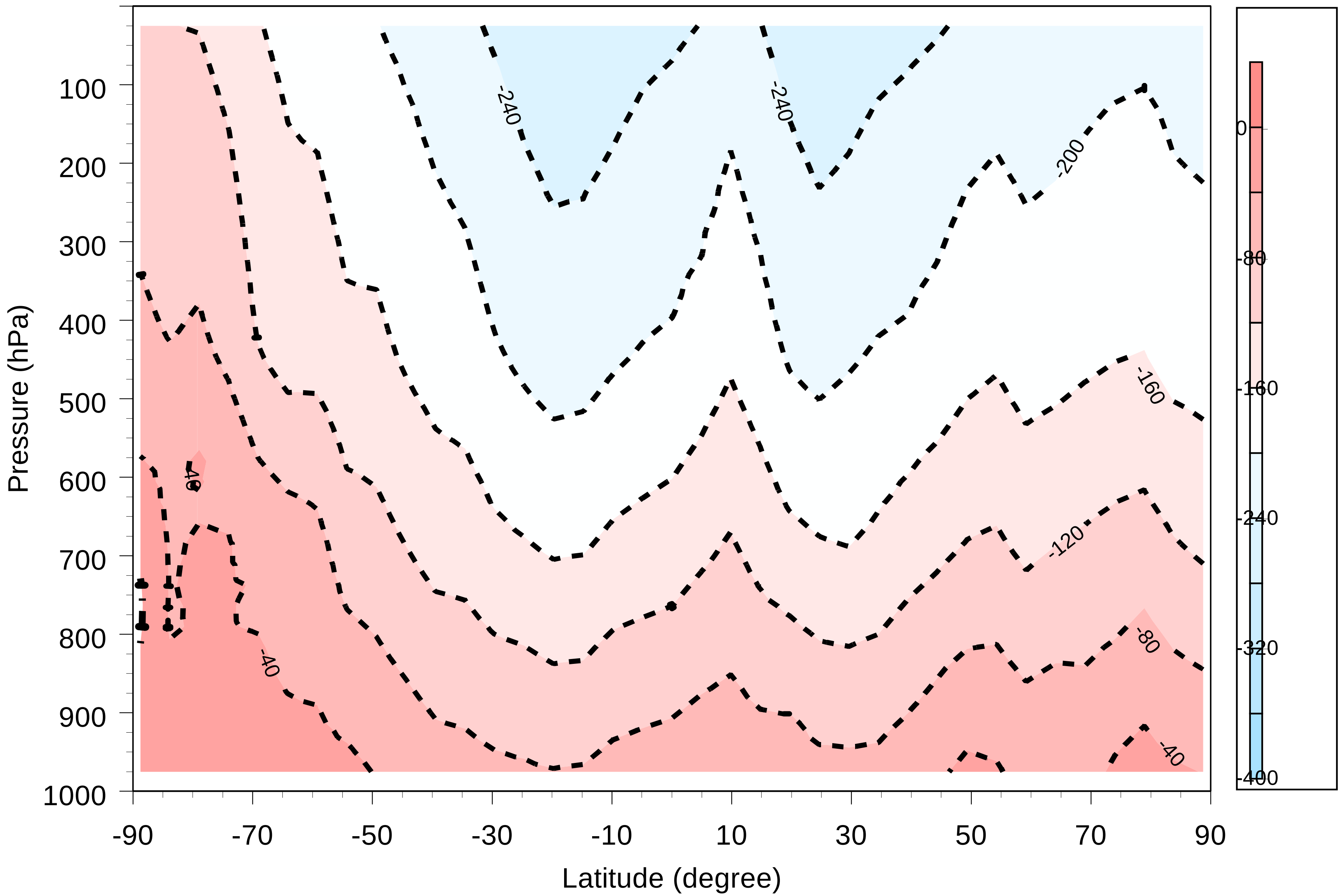


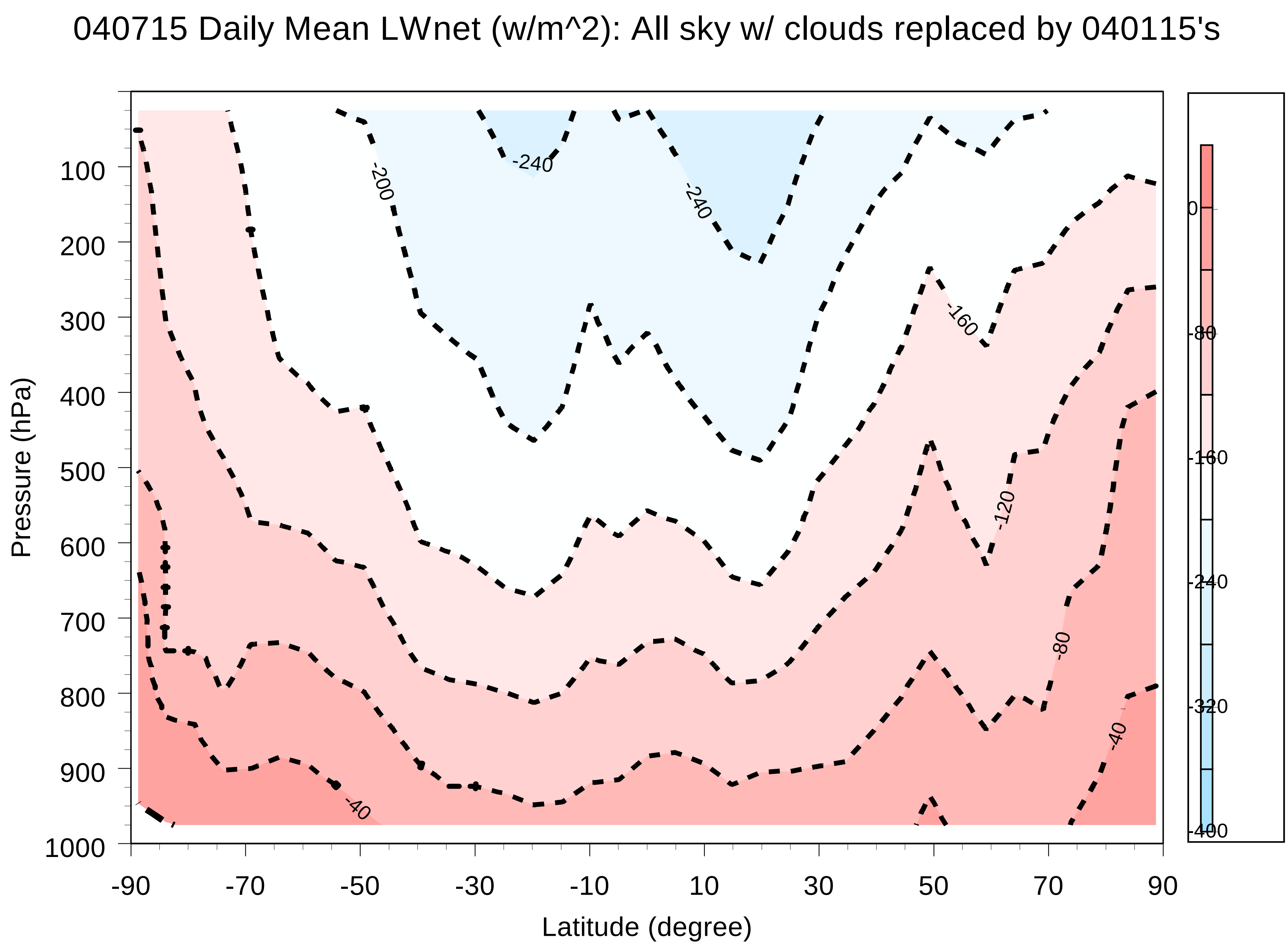
041015 Daily Mean LWnet (w/m^2): Clear sky
Pressure (hPa)
100
200
300
400
500
600
700
800
900
1000
-90
-70
-50
-30
-10
10
30
50
70
90
Latitude (degree)
-280
-280
-200
-240
-160
-120
-80
-80
0
-80
-160
-240
-320
-400

041015 Daily Mean LWnet (w/m^2): All sky W/O PW

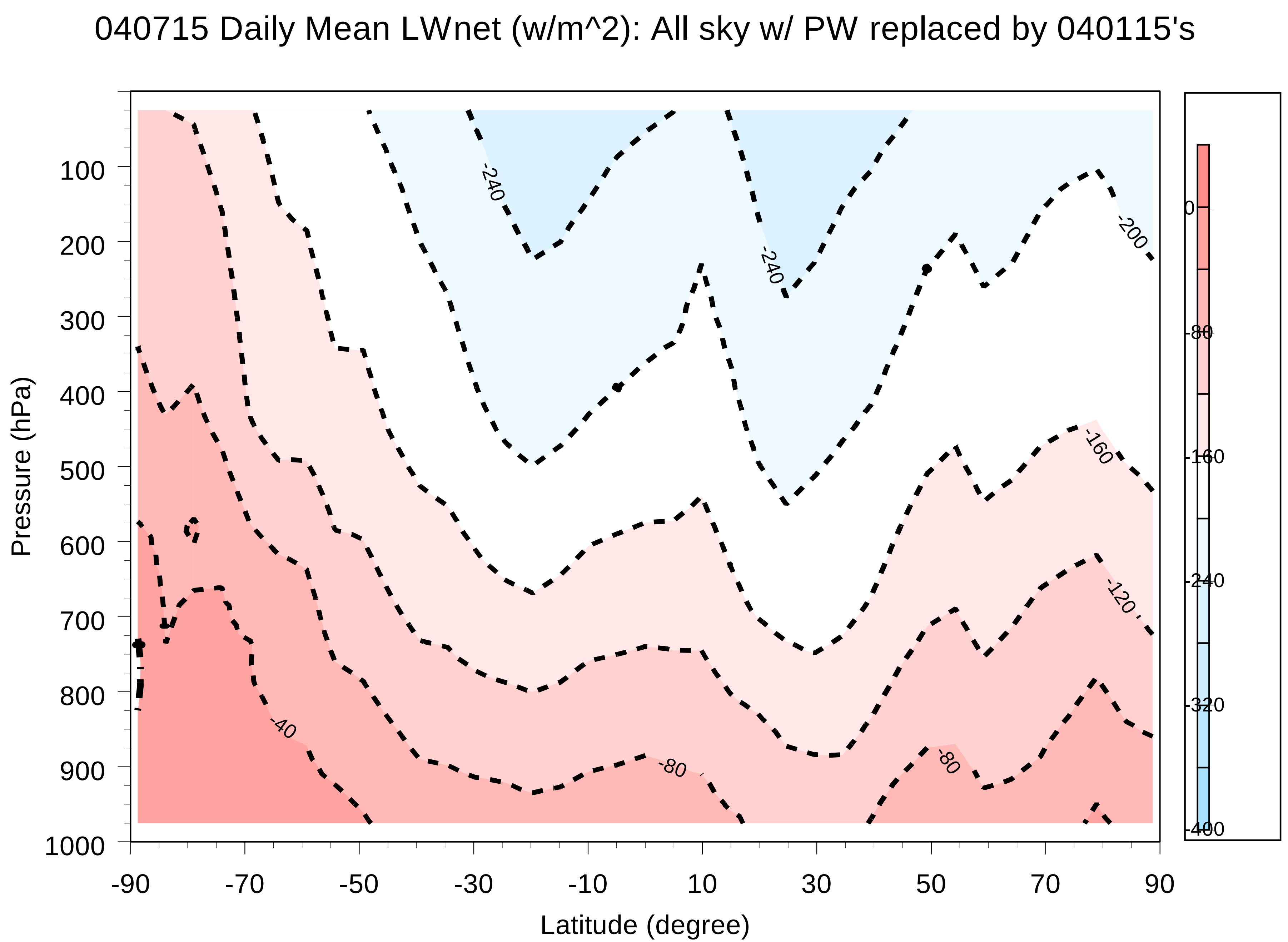


040715 Daily Mean LWnet (w/m^2): All sky



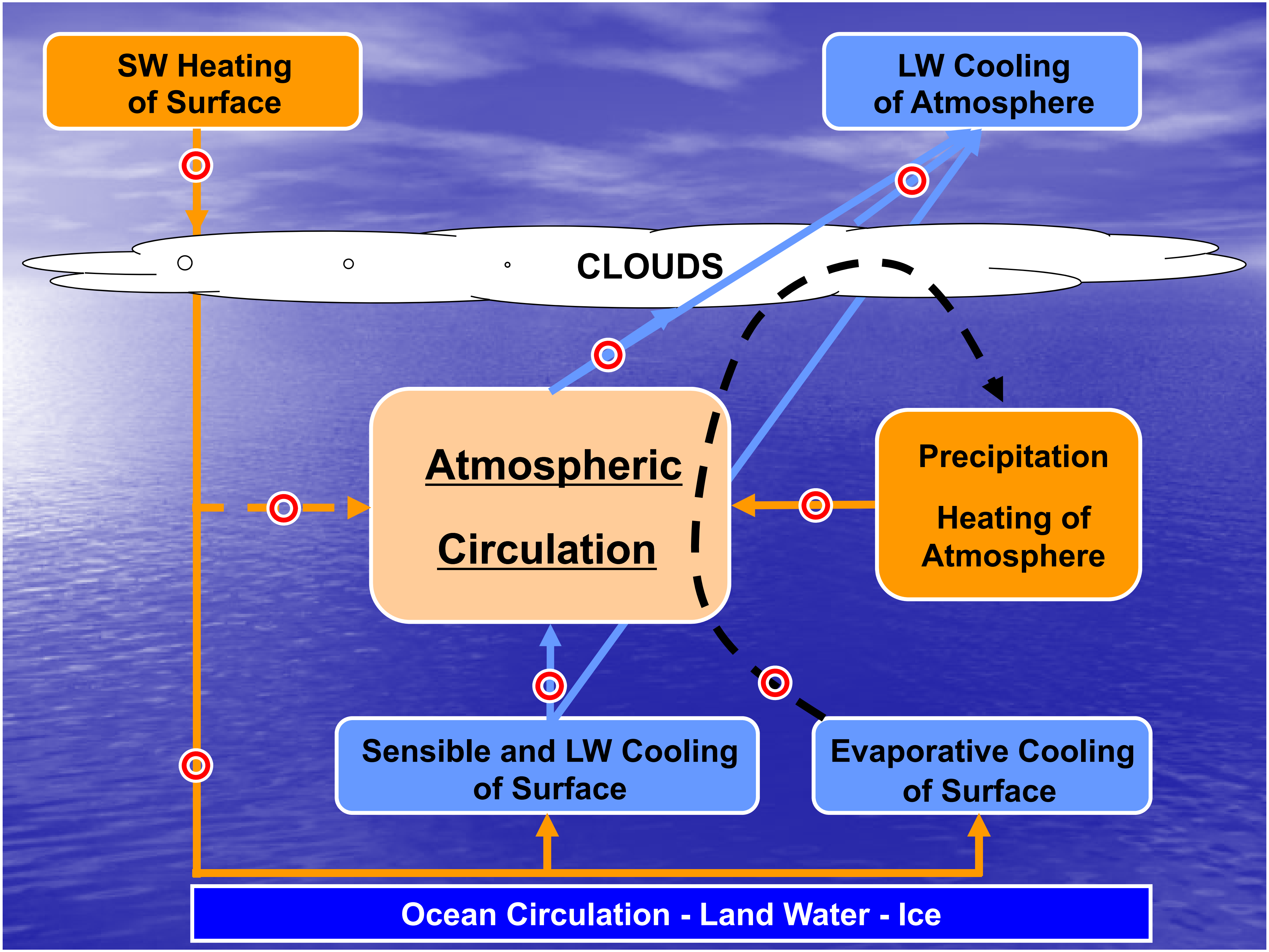


040715 Daily Mean LWnet (w/m^2): All sky w/ clouds replaced by 040115's
Pressure (hPa)
100
200
300
400
500
600
700
800
900
1000
-90
-70
-50
-30
-10
10
30
50
70
90
Latitude (degree)
-240
-200
-240
-160
-120
-80
-40
-40
0
-80
-160
-240
-320
-400



040715 Daily Mean LWnet (w/m^2): All sky w/ PW replaced by 040115's
Pressure (hPa)
Latitude (degree)
100
200
300
400
500
600
700
800
900
1000
-90
-70
-50
-30
-10
10
30
50
70
90
-240
-240
-200
-160
-120
-80
-80
-40
0
-80
-160
-240
-320
-400

NEED HOLISTIC OBSERVATIONAL EVALATION


SW Heating of Surface
LW Cooling of Atmosphere
CLOUDS
Atmospheric Circulation
Precipitation Heating of Atmosphere
Sensible and LW Cooling of Surface
Evaporative Cooling of Surface
Ocean Circulation - Land Water - Ice

SOME QUESTIONS

BASIC IDEA is reduce "dimension of problem" by Associating Diabatic Heating with Each Meteorological State

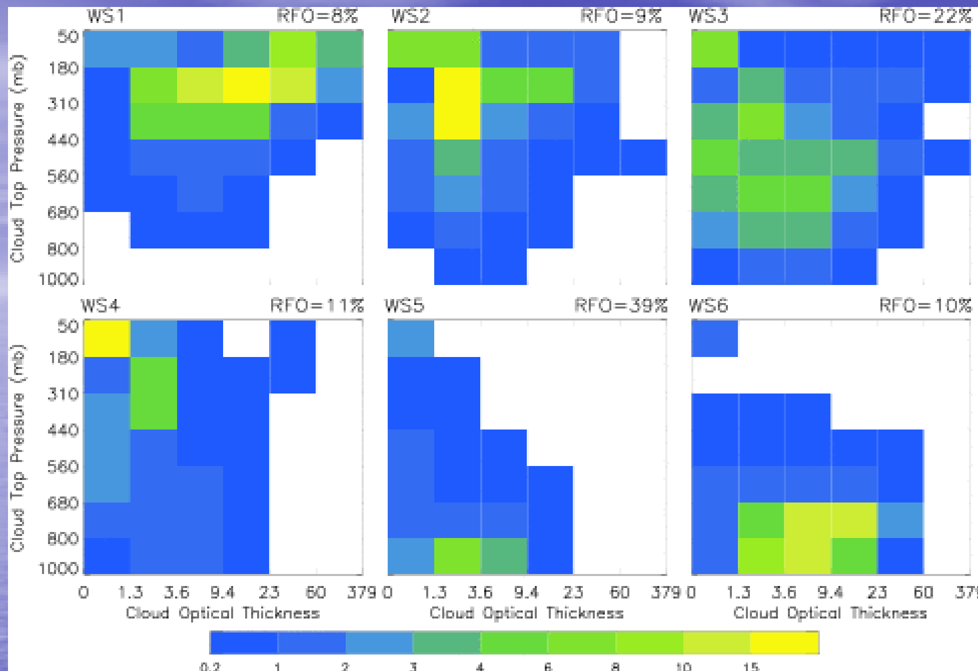
Should States be classified locally or globally?

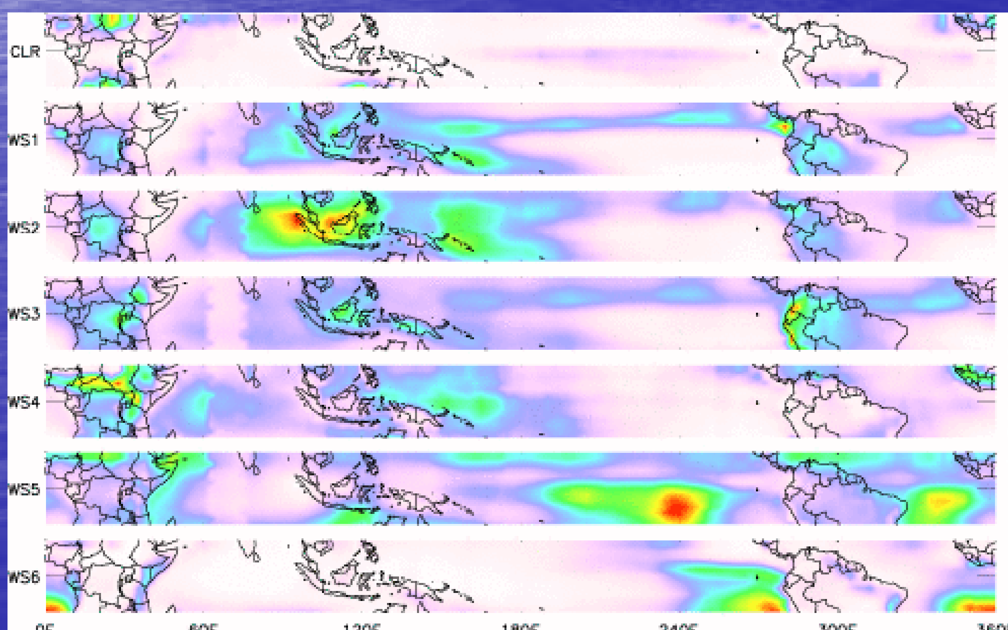
Should atmosphere AND ocean be considered?

Will this approach really simplify the problem?

ISCCP PC - TAU histogram pattern and Map in Tropics over 21.5 years

1983 - 2004 time period



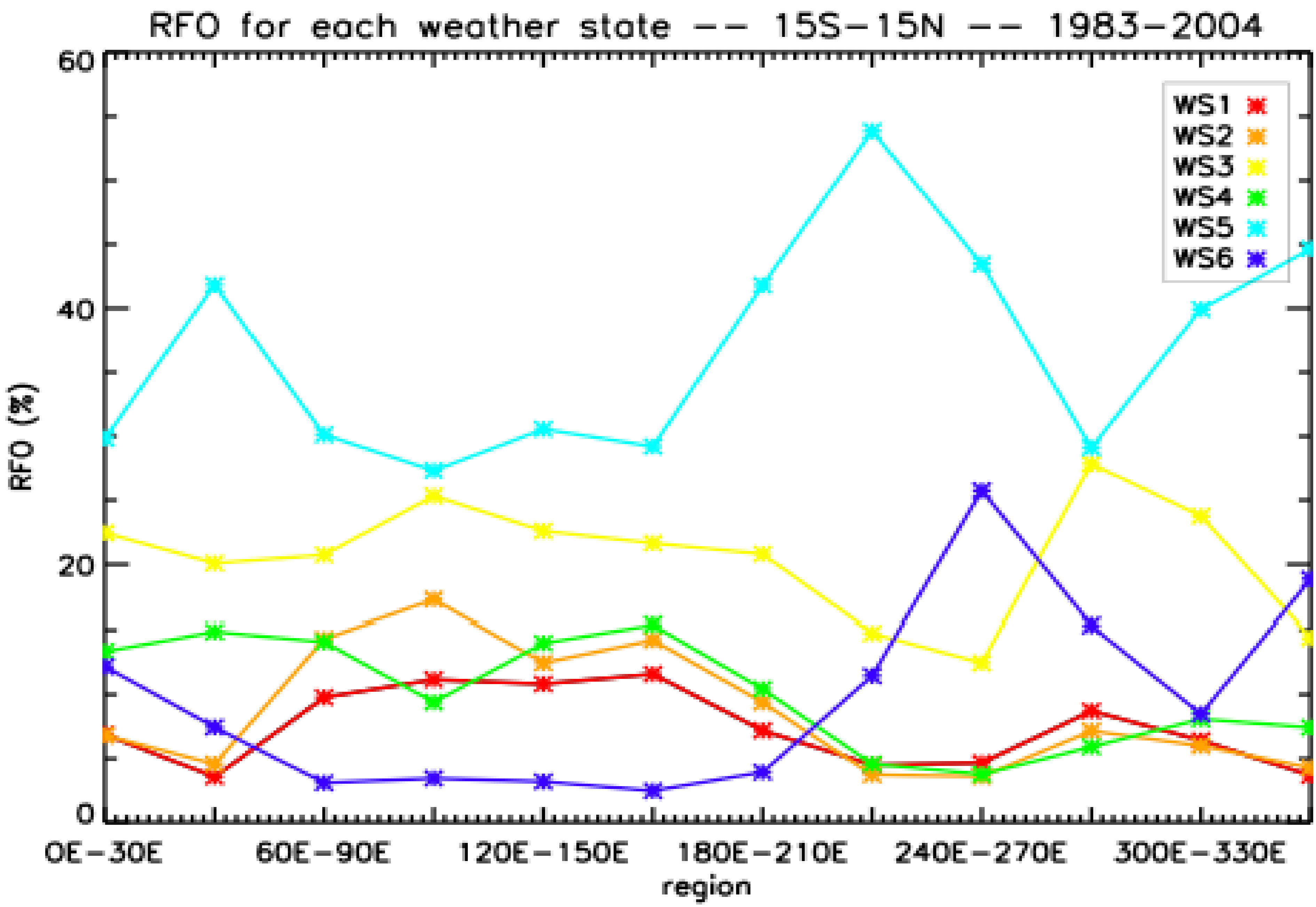


Rossow et al, GRL, 2005

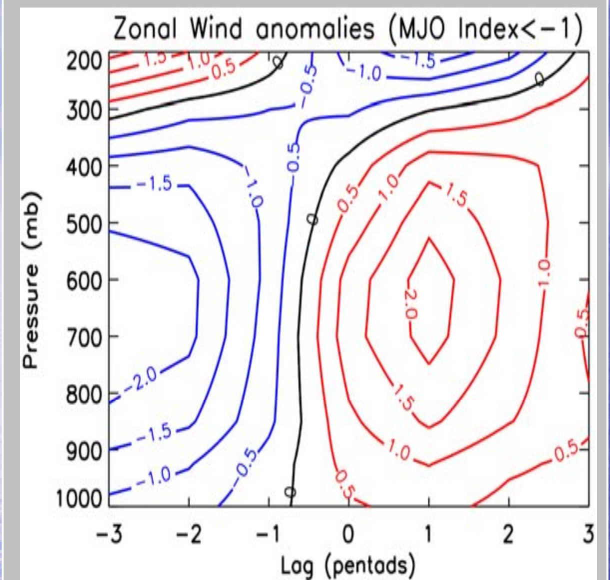
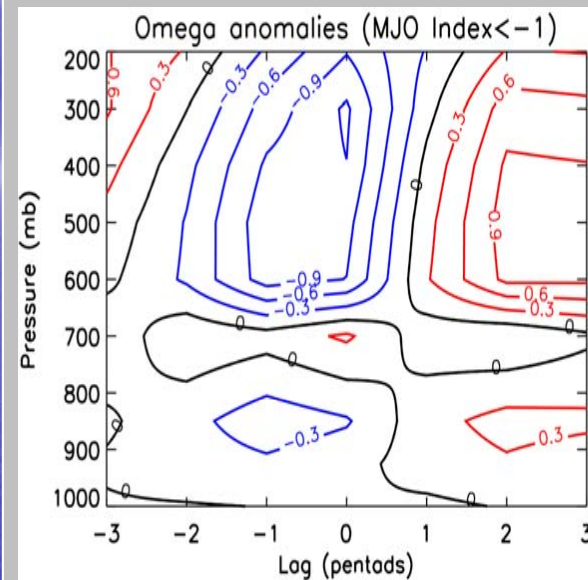
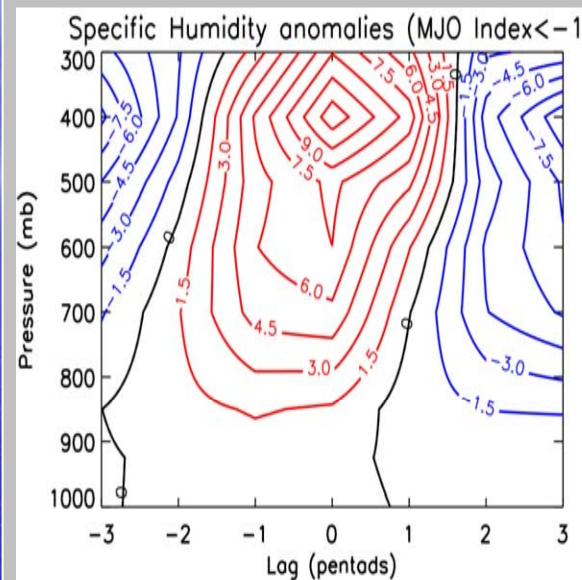
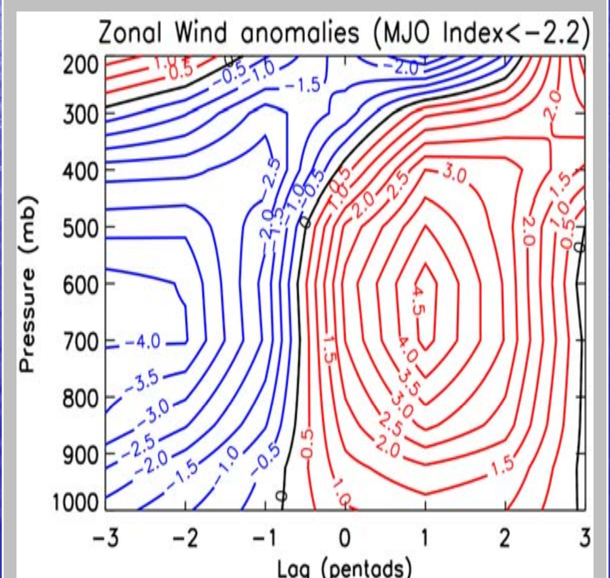
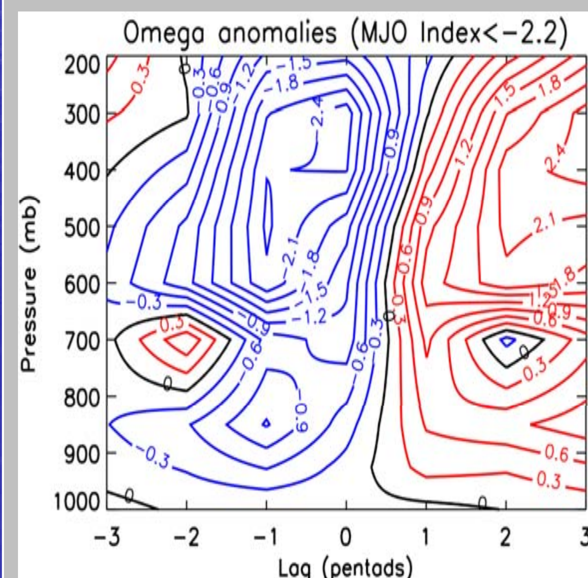
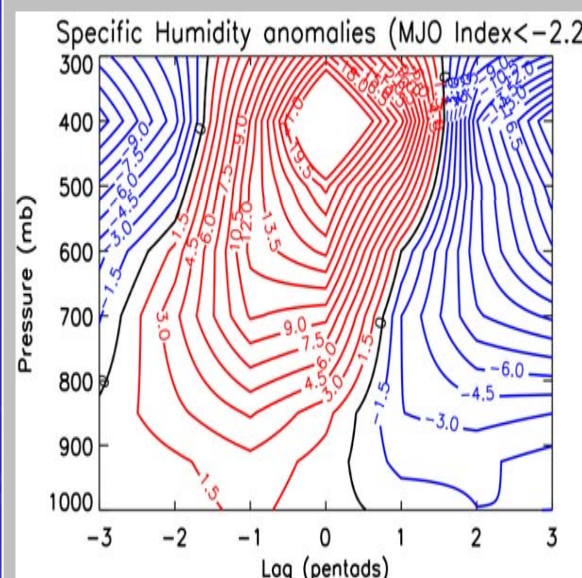
Cluster Analysis + ISCCP D1 data

- WS1 : Deep cumulus clouds
- WS2 : Anvils clouds
- WS3 : Congestus clouds
- WS4 : Cirrus clouds
- WS5 : Shallow cumulus clouds
- WS6 : Stratocumulus clouds

Relative Frequency of Occurrence (RFO) in the Tropics



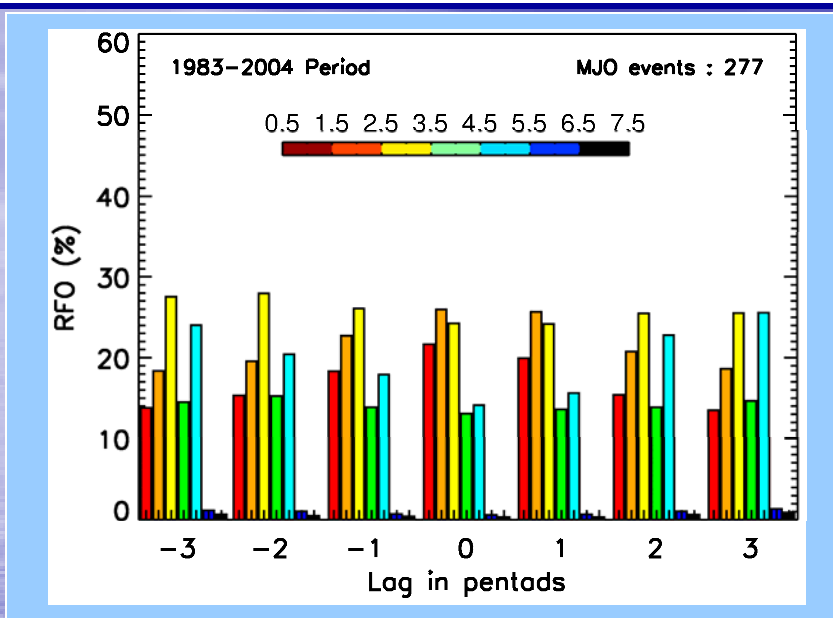
Anomaly cross sections **in 60E-180E region / 5S-5N latitude band**

	Zonal Wind anomalies	Omega anomalies	Specific Humidity anomalies
Weak MJO (index < -1)			
Strong MJO (index < -2.2)			

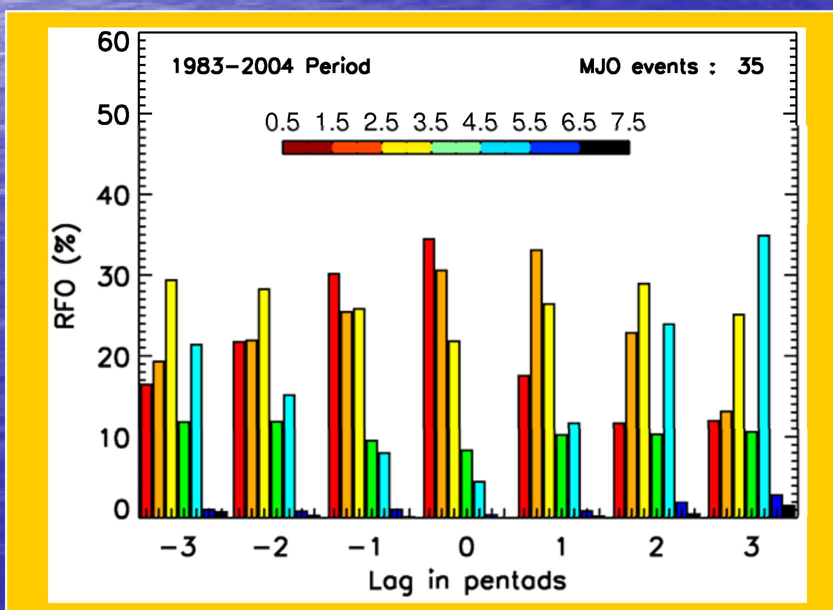
RFO of each cloud regime in 60E-180E region / 5S-5N latitude band

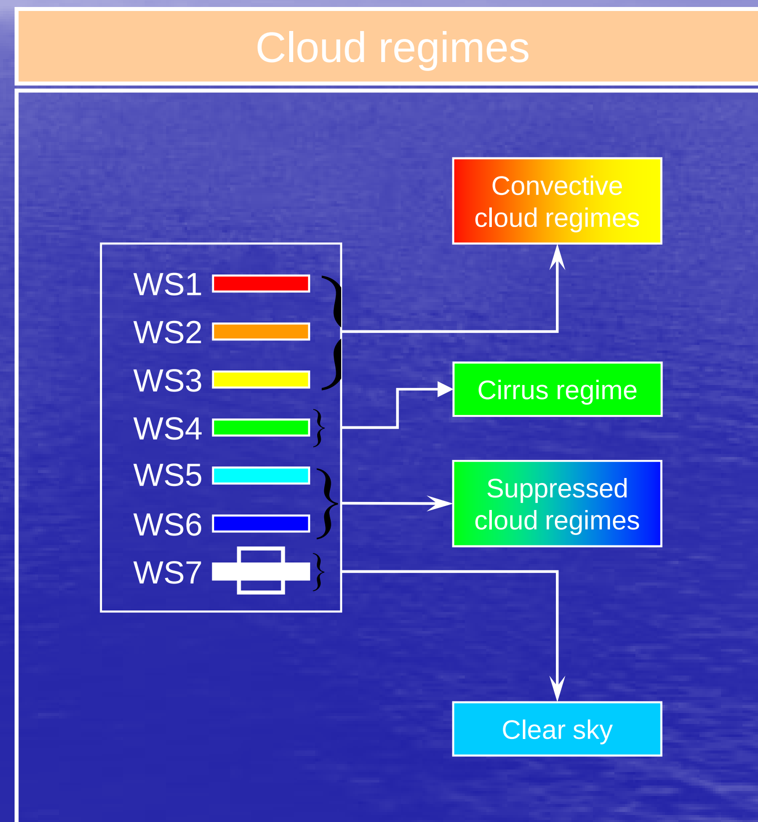
(MJO events in November-April periods from 1983 - 2004)

Weak MJO (index < -1)

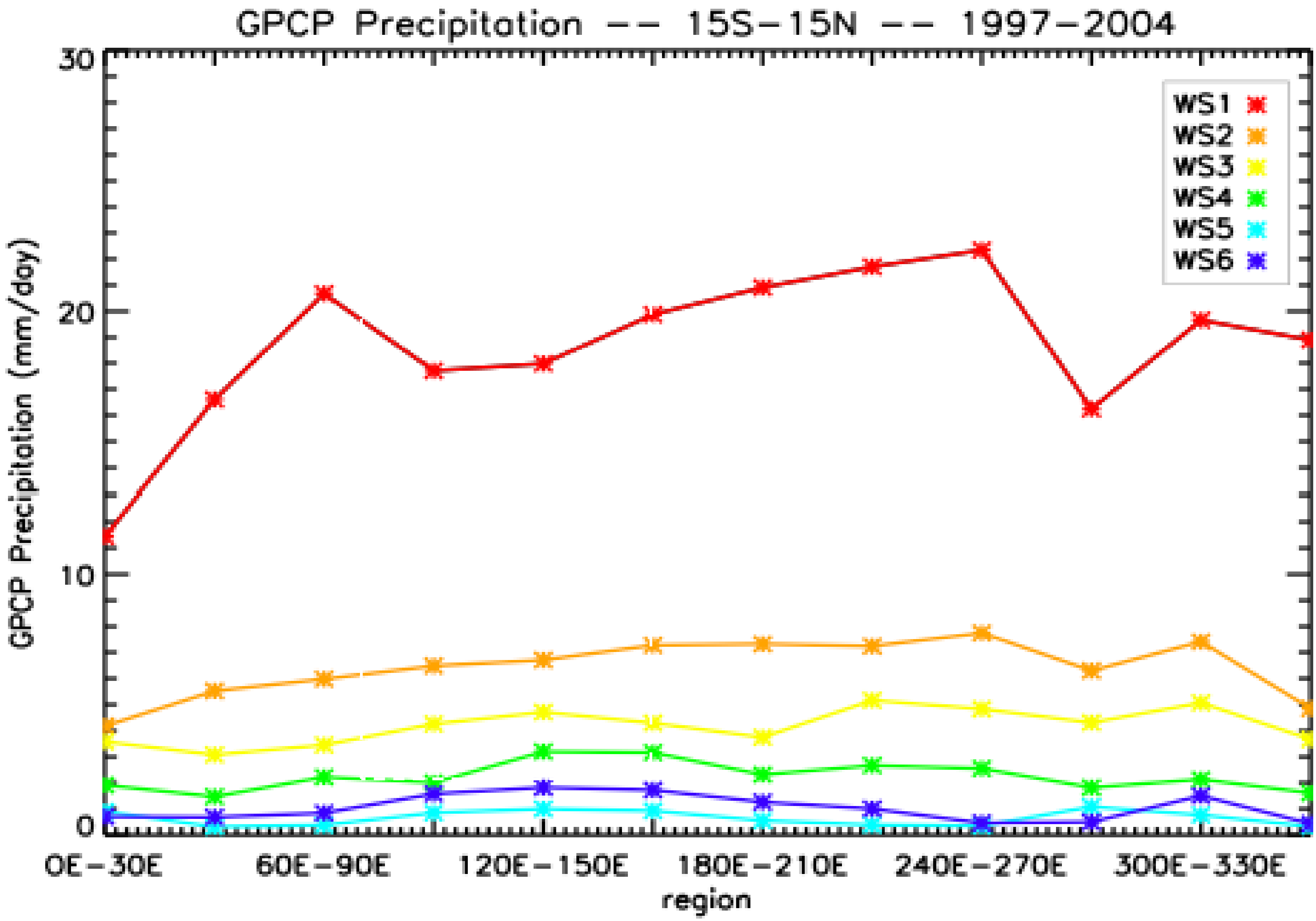


Strong MJO (index < -2.2)



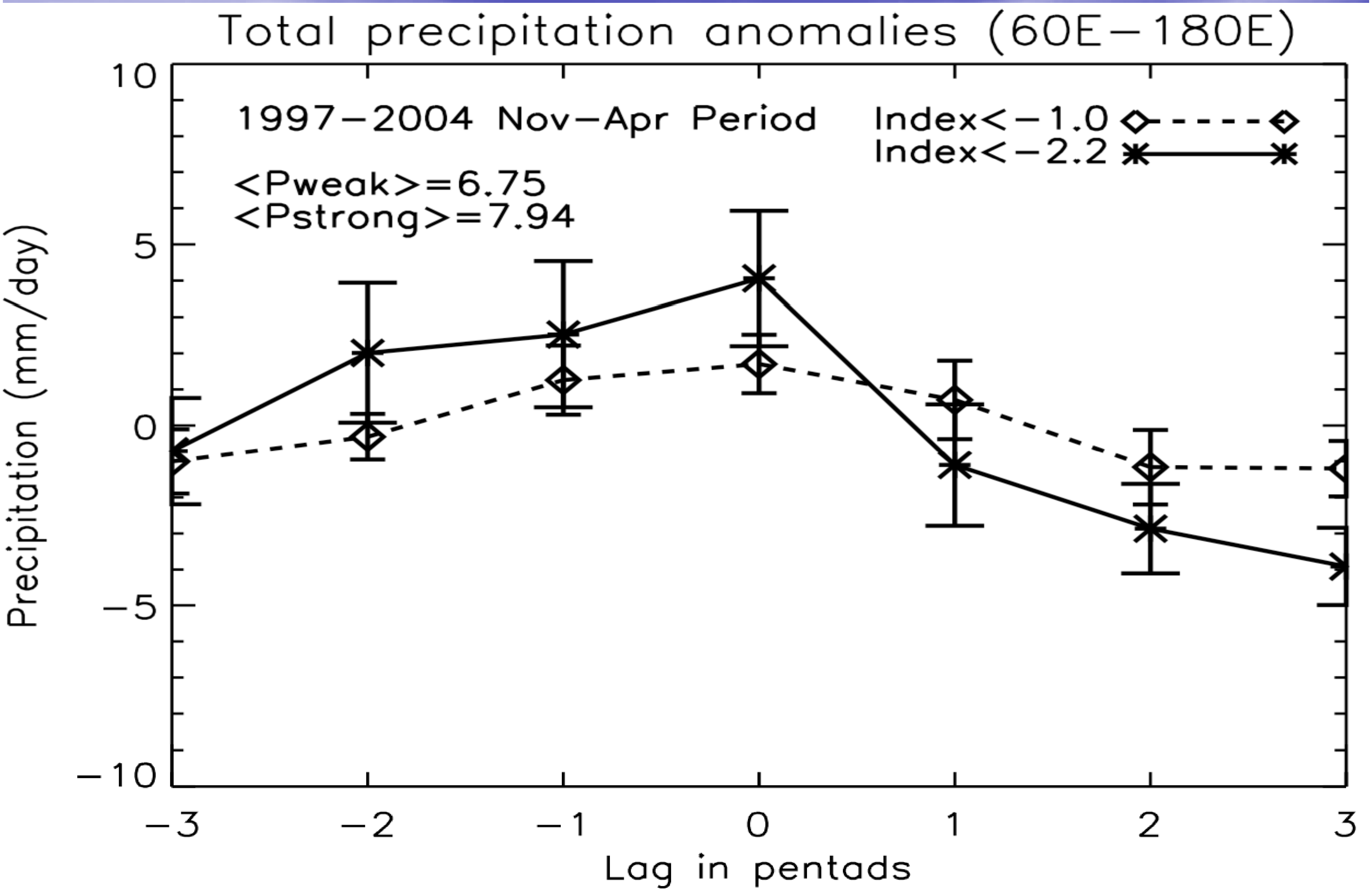


Composite of precipitation in Tropics (1997 - 2004)



Composite Total Precipitation Anomalies, 60E-180E -- 5S-5N latitude

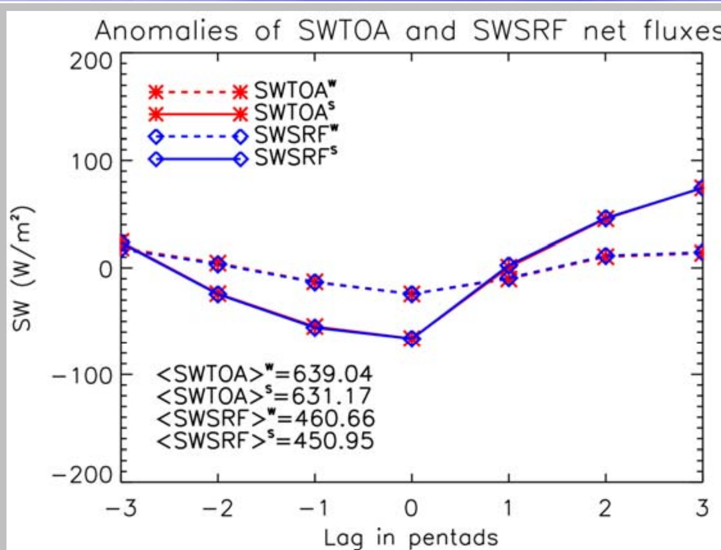
(MJO events in November-April periods from 1997 - 2004)

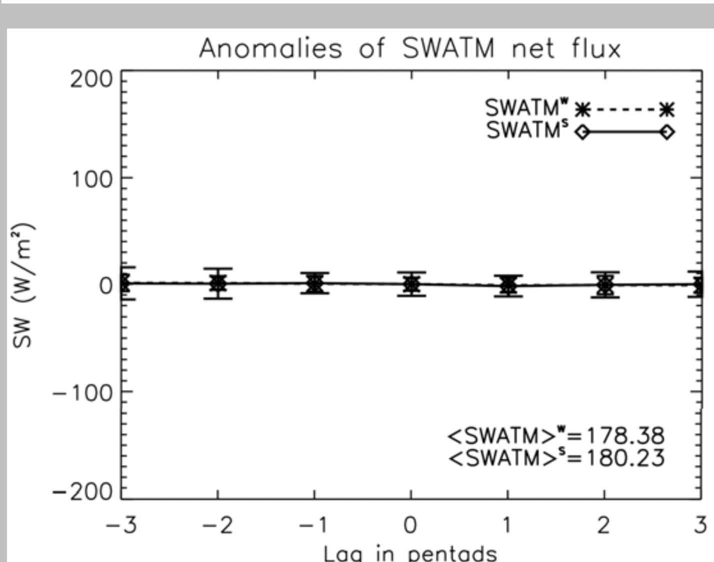


Composite total radiative net flux anomalies, 60E-180E -- 5S-5N latitude

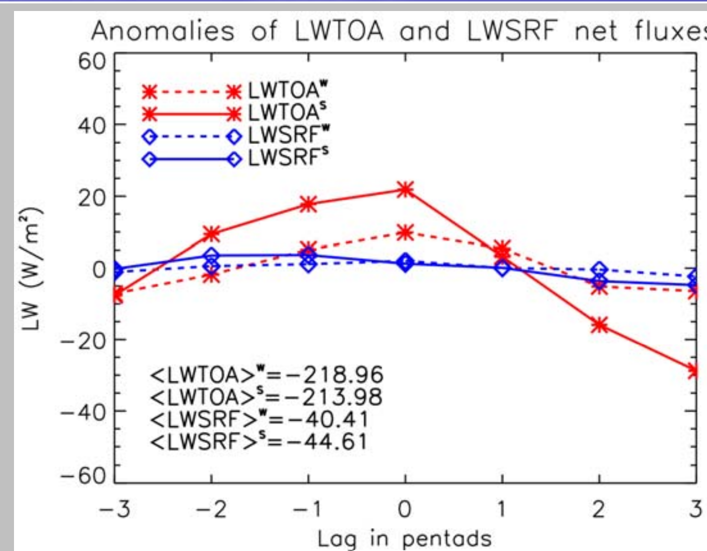
(MJO events in November-April periods from 1997 - 2004)

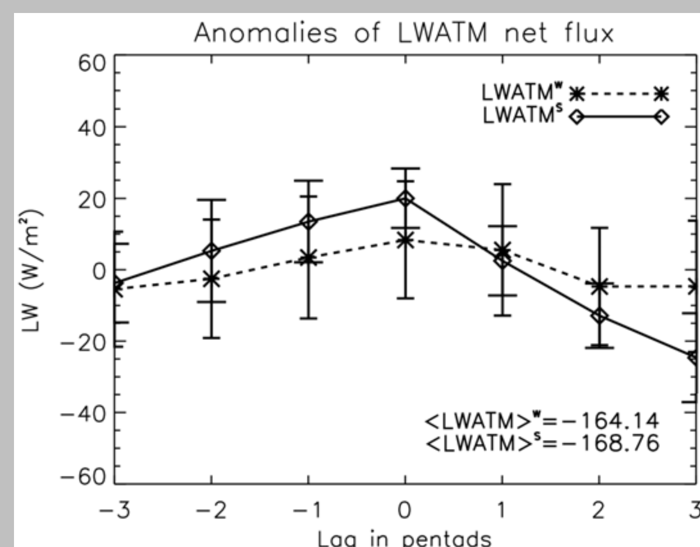
Shortwave net flux anomalies





Longwave net flux anomalies

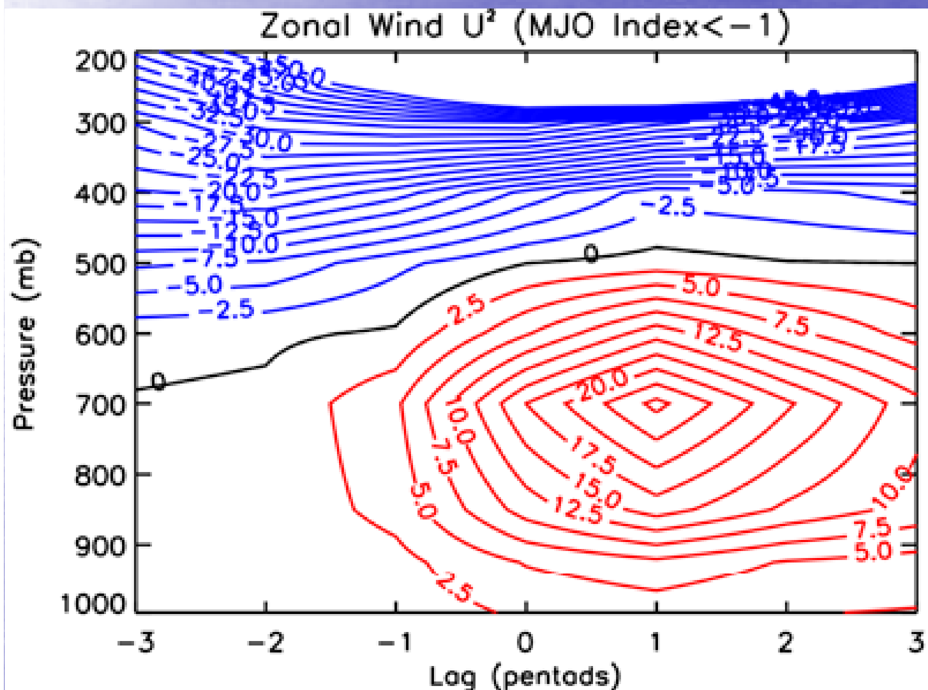




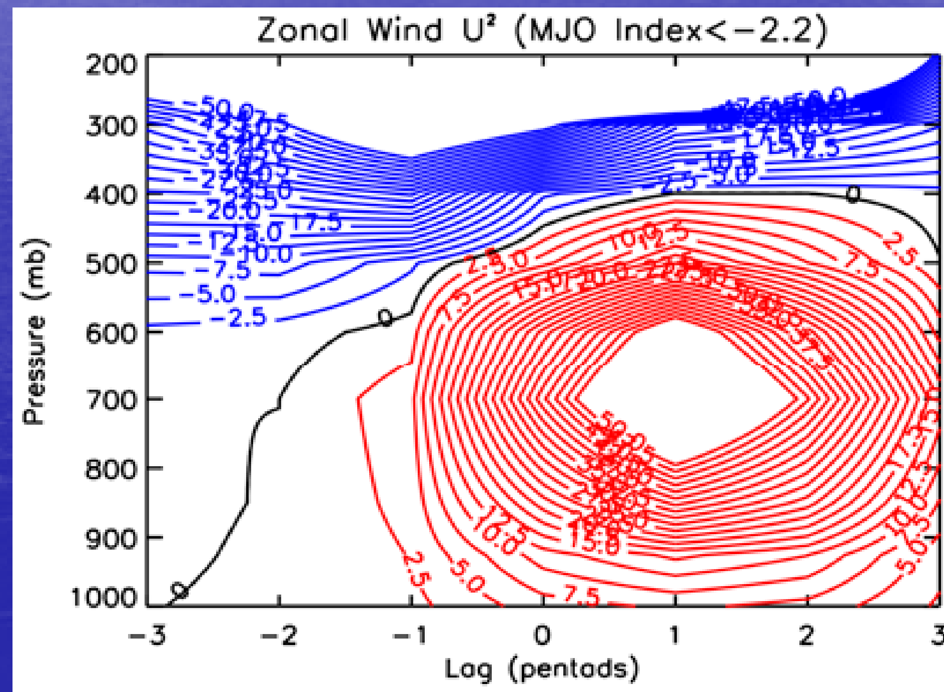
Composite Total Zonal Wind U^2 (m^2/s^2) Cross Sections in Tropics

(MJO events in November-April periods from 1983 - 2004)

Weak MJO



Strong MJO



WHAT DO WE NEED?

More Advanced Observational Analysis Methods

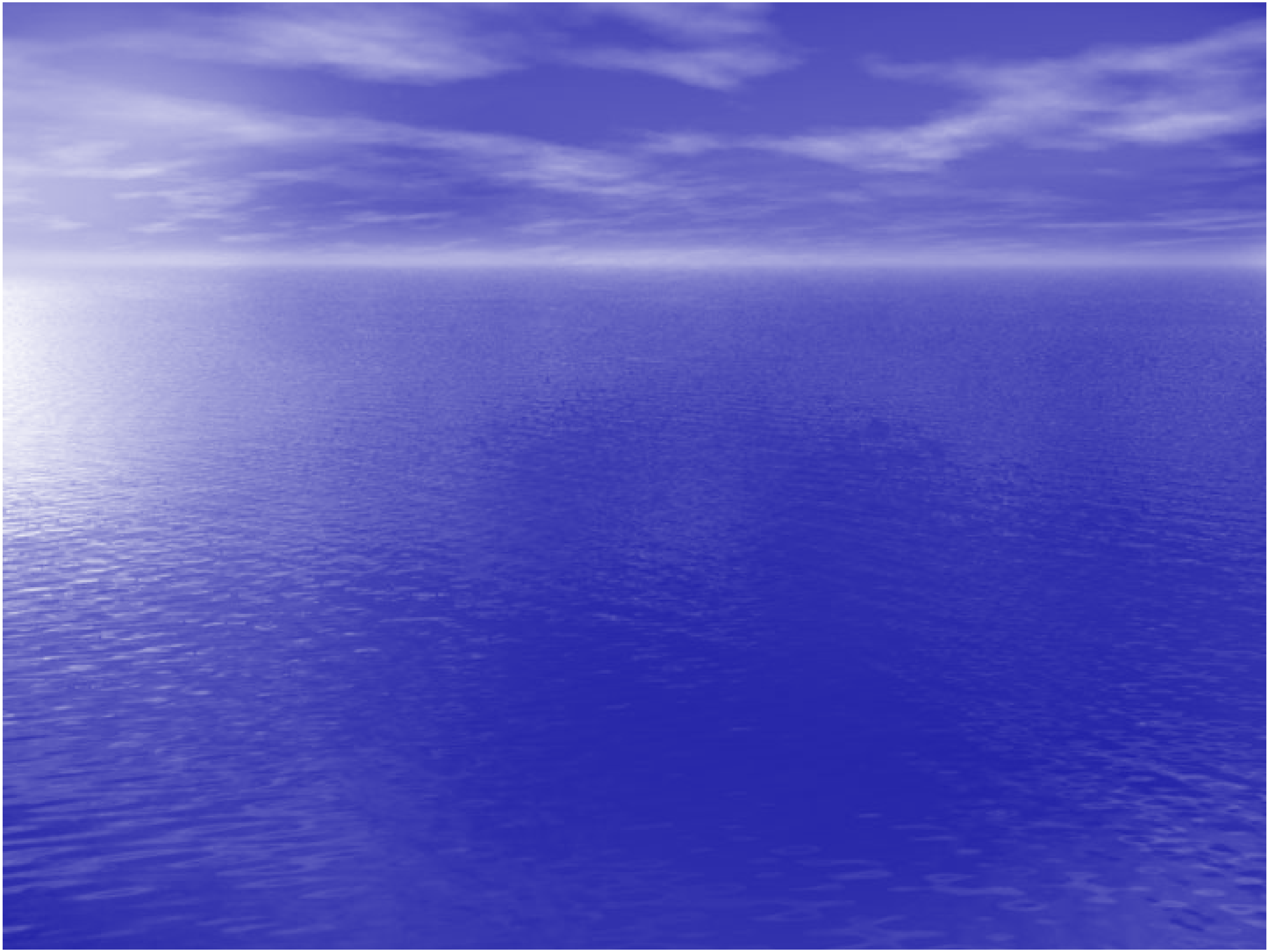
Data available:

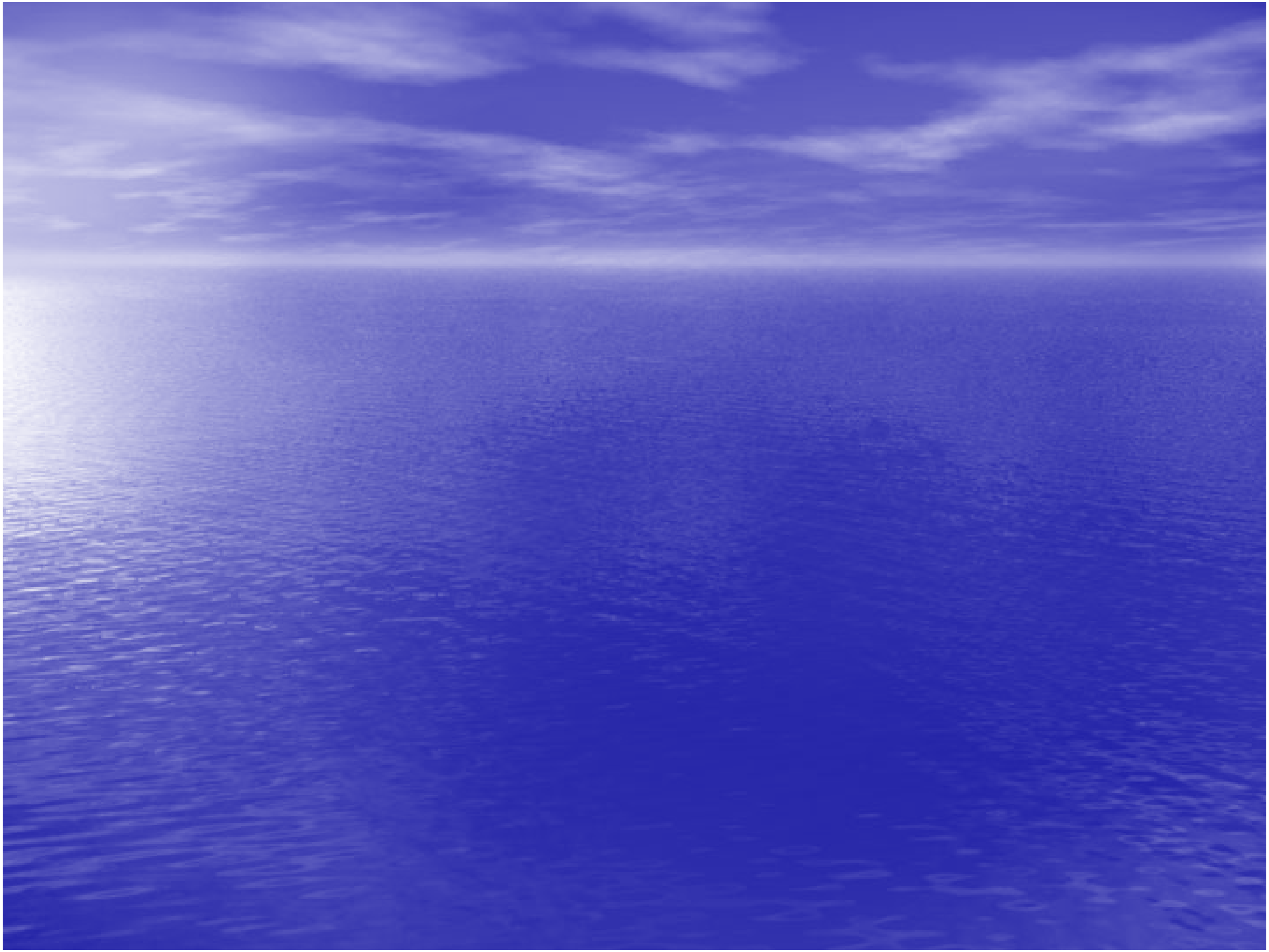
- about 10 years of weather-scale variations of atmospheric diabatic heating over oceans
- 30 years of atmospheric state and dynamics
- basic ocean state and circulation

Data coming:

- about 20 years of global weather-scale variations of atmospheric diabatic heating with vertical structure
- more detailed ocean circulation variations

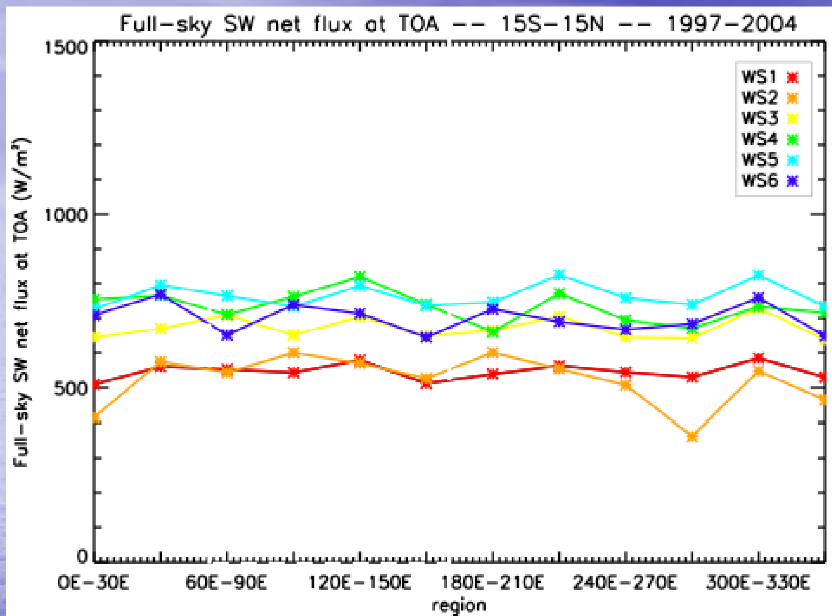
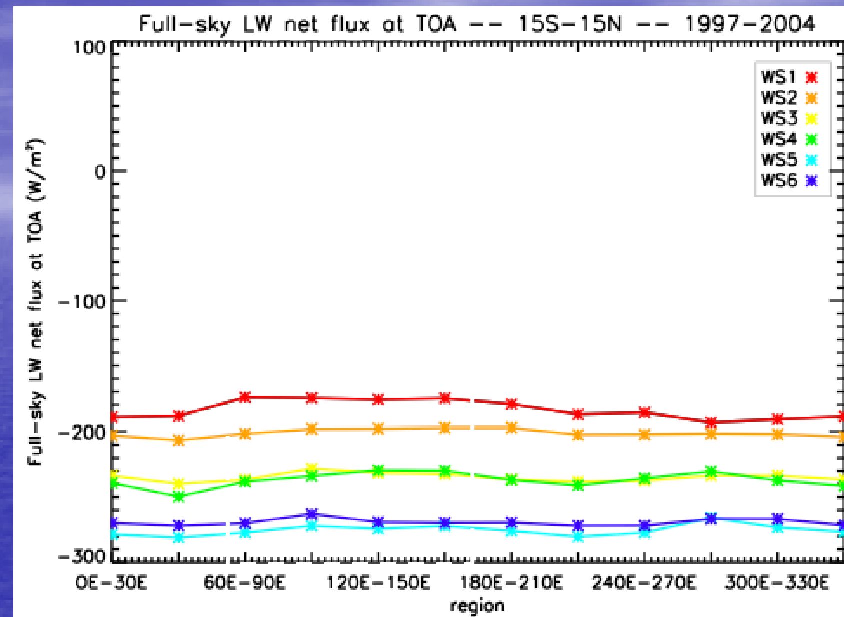
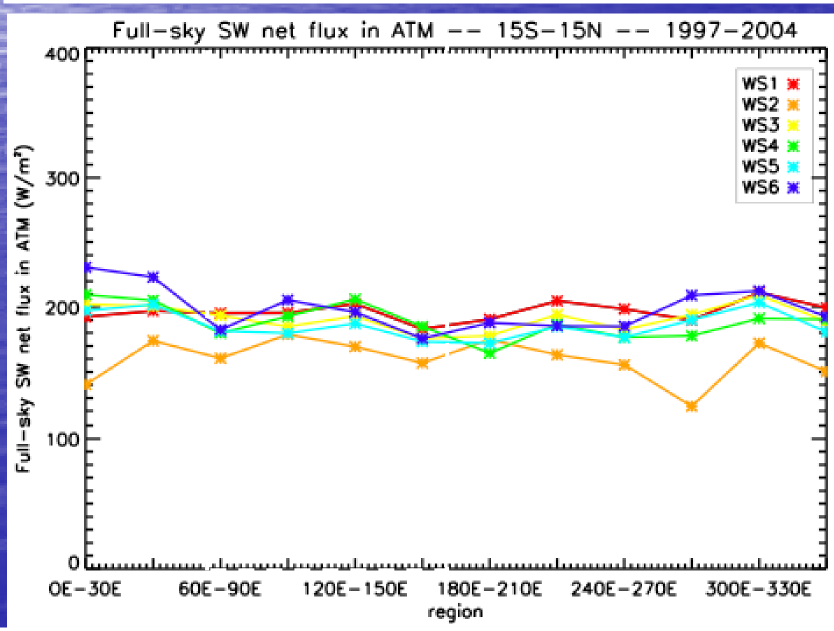
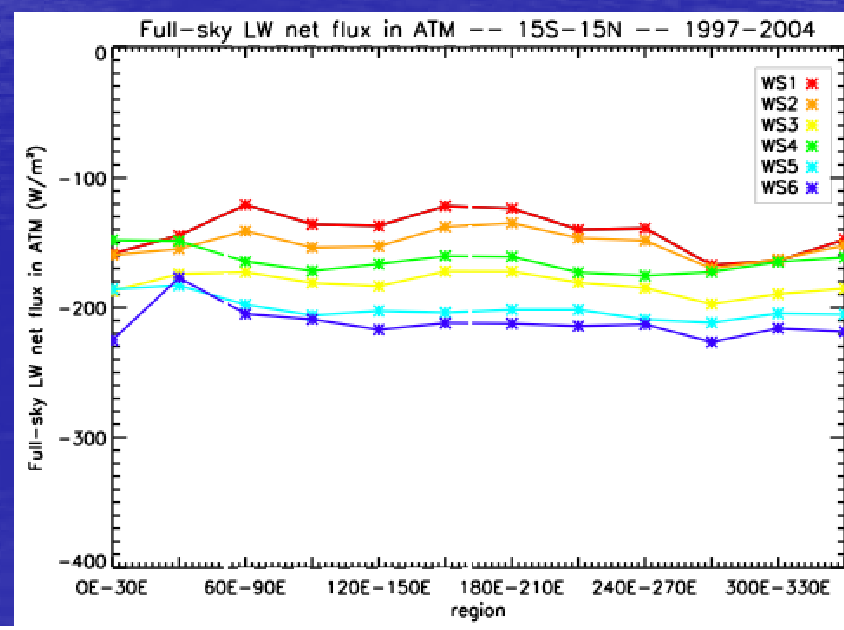
Data needed: more information about water partitioning on land and more detail about ocean variations

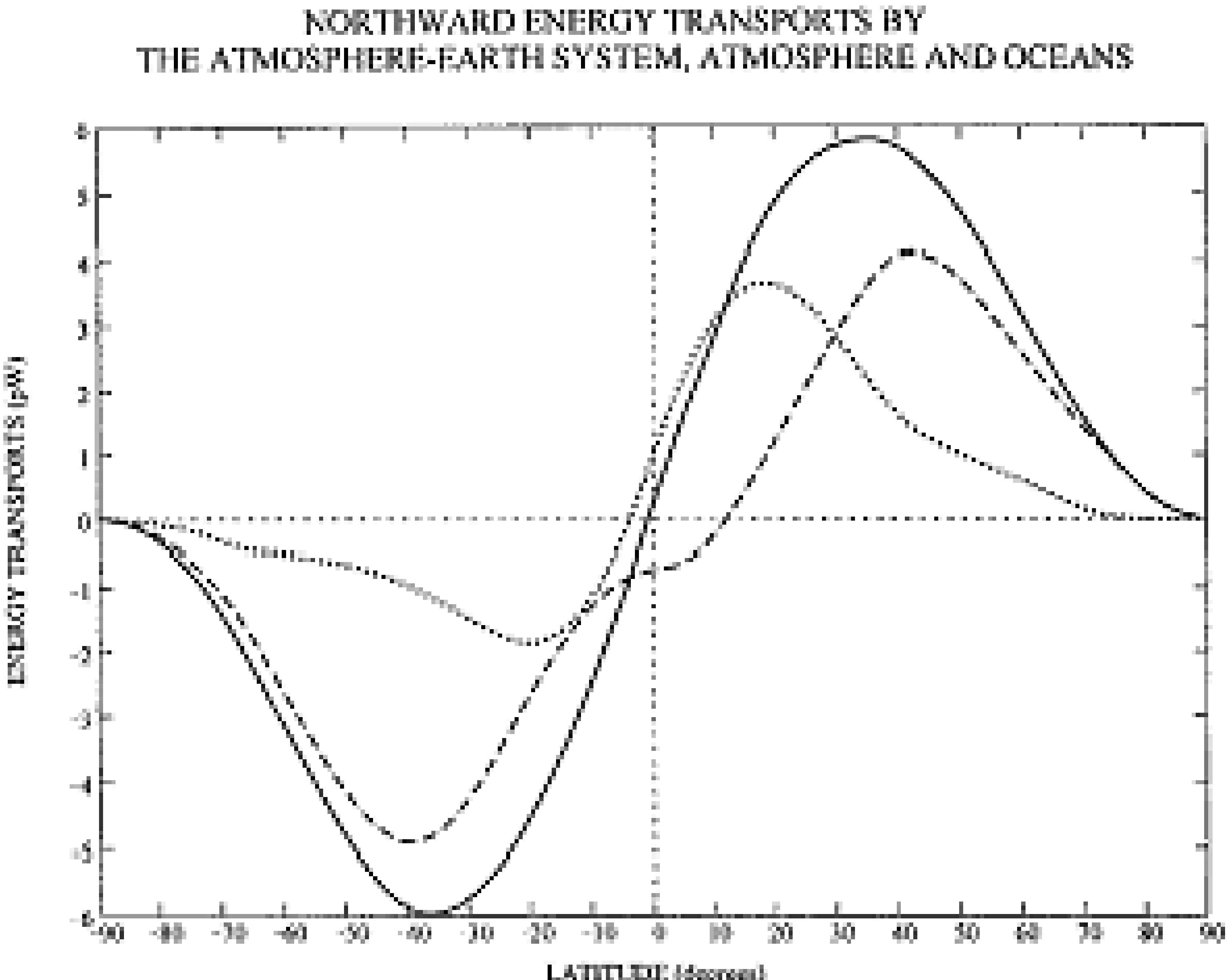




BACKUP SLIDES

Composite of Radiative net fluxes in Tropics (1997 - 2004)

	Shortwave net flux	Longwave net flux
Net flux at TOA		
Net flux in ATM		



NORTHWARD ENERGY TRANSPORTS BY
THE ATMOSPHERE-EARTH SYSTEM, ATMOSPHERE AND OCEANS
ENERGY TRANSPORTS (pW)
LATITUDE (degrees)

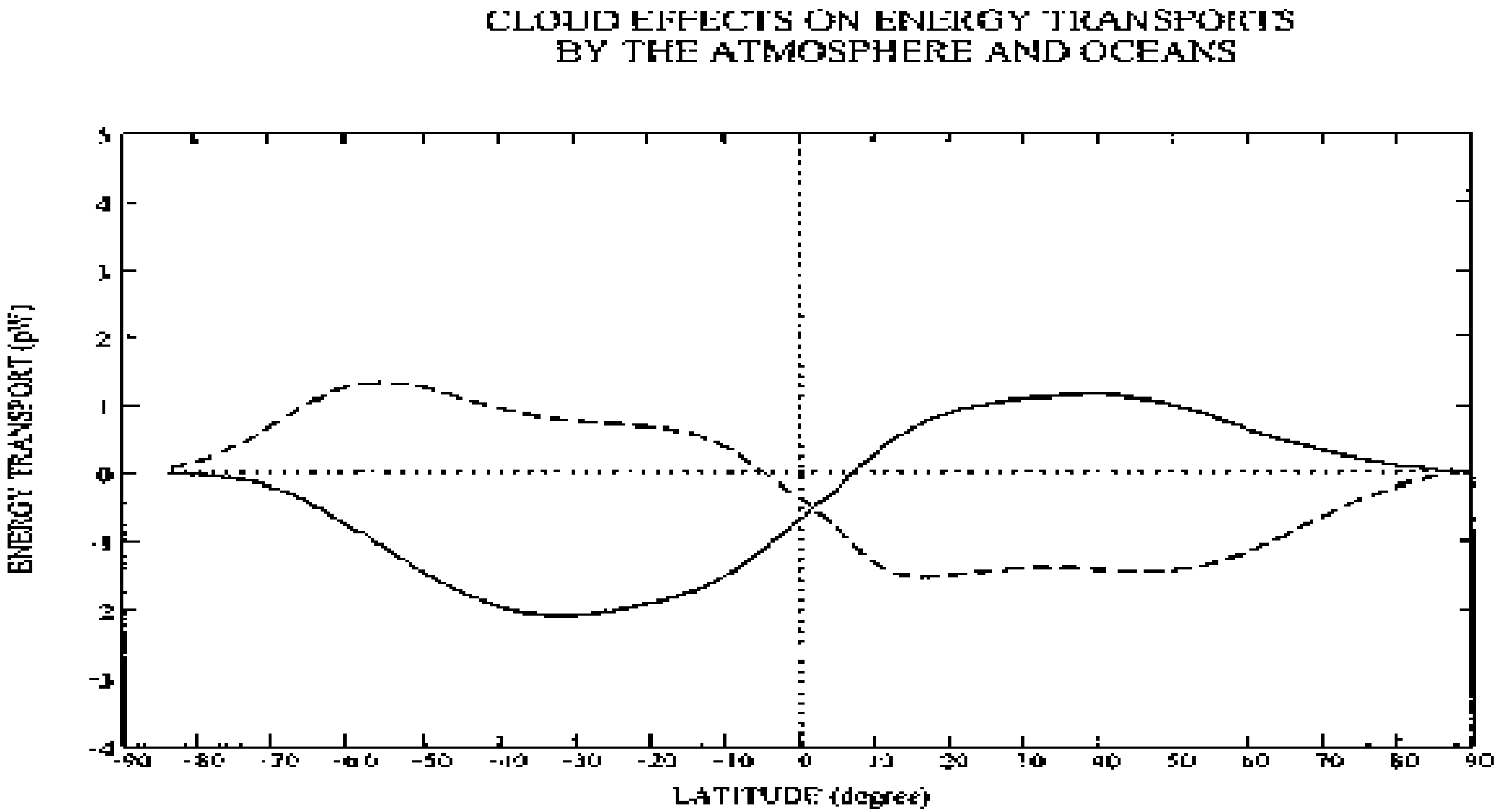
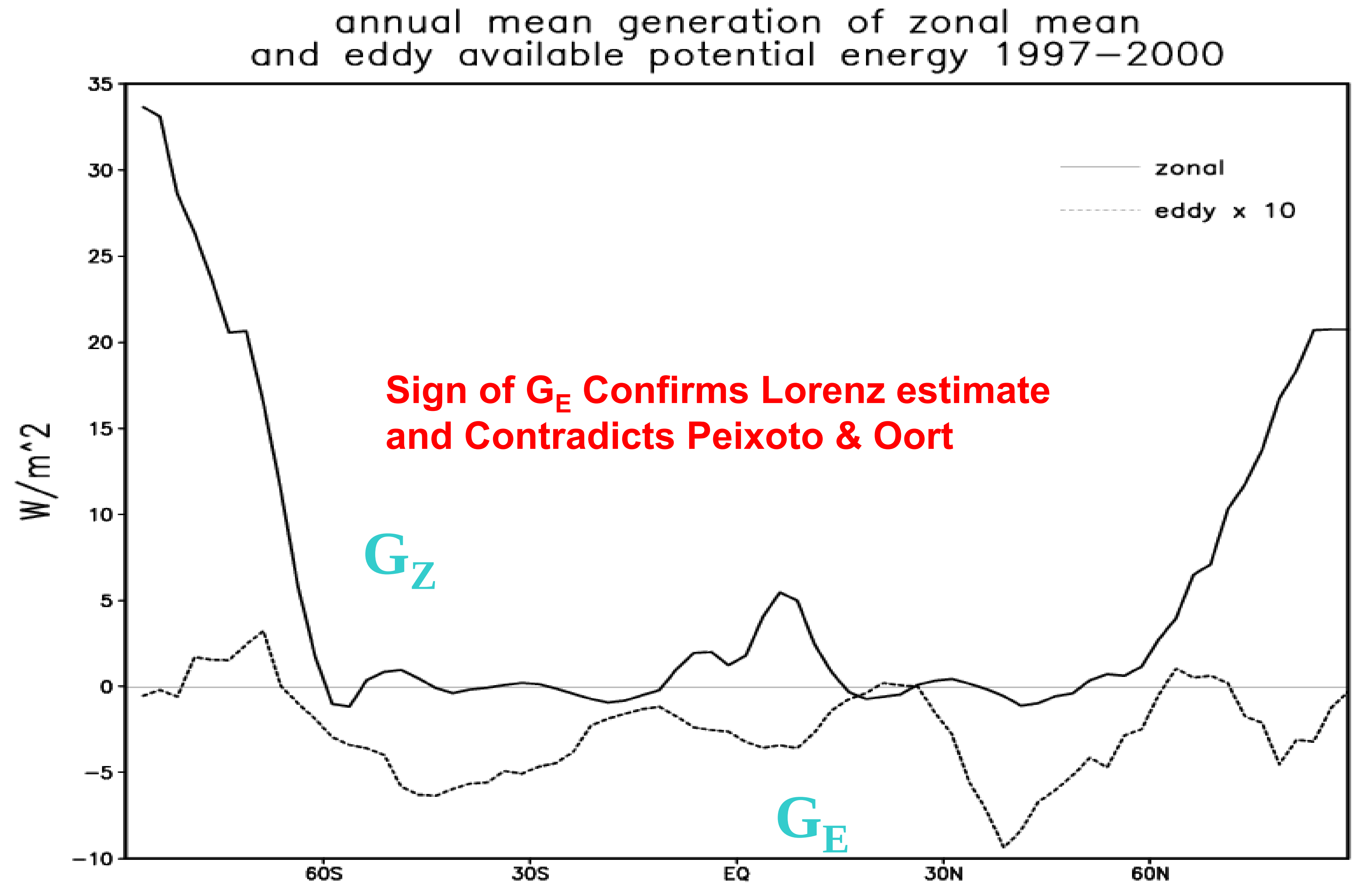


FIG. 16. Qualitative indication of cloud-radiative effects on the zonal annual mean northward total energy transports (PW) by the atmosphere (solid line) and the ocean (dashed line) given by the differences in the inferred transports using total radiative fluxes (cloudy plus clear) and clear-sky radiative fluxes. The changes in the transports shown result from adding clouds, all other factors being held constant.

Annual Mean Generation of APE



Even this result is still only qualitative

and

does NOT indicate feedback

on Climate Change

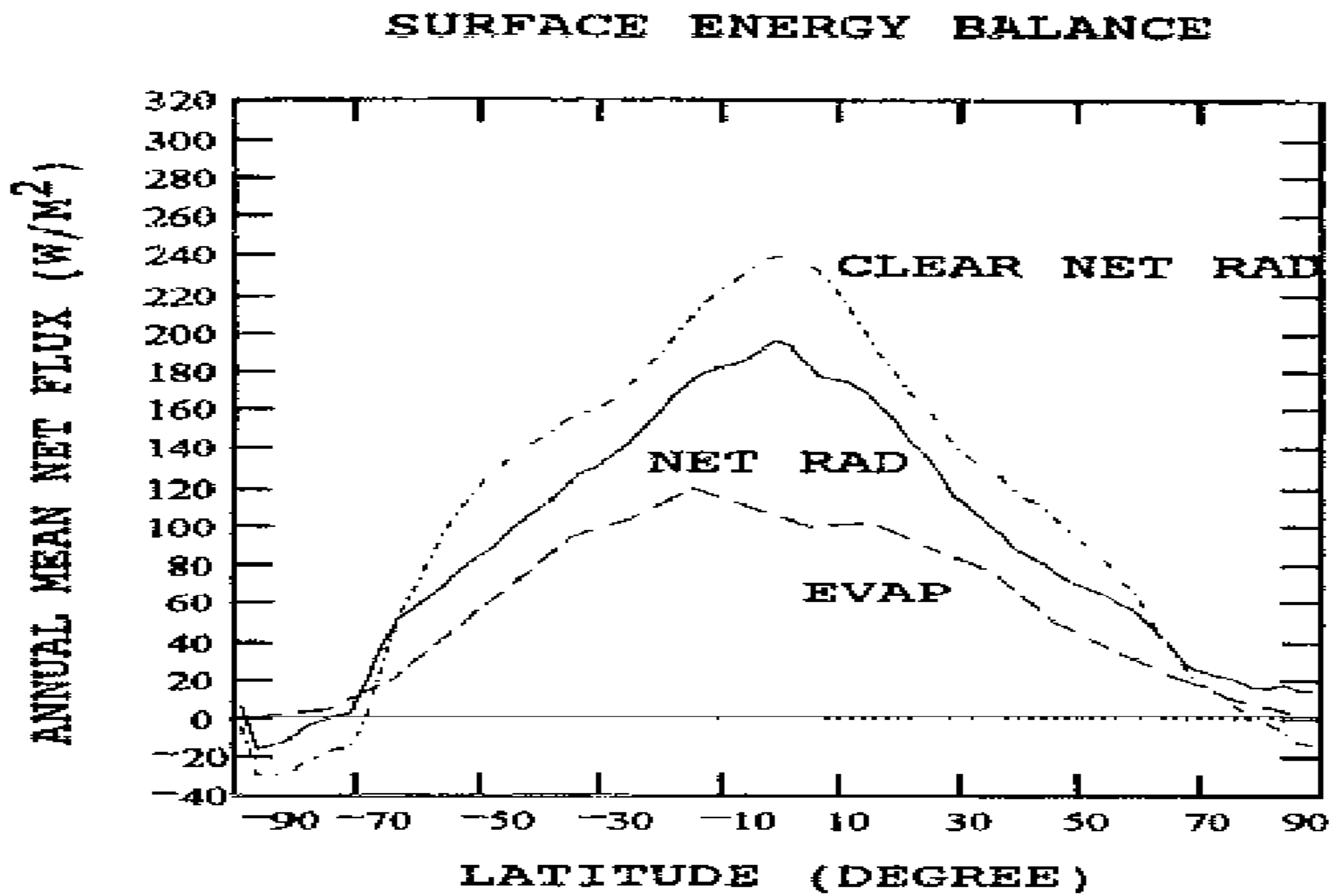


Figure 21. Annual, zonal mean surface net radiative heating for full sky and clear sky from FC and surface evaporative cooling (shown with positive sign) from *Peixoto and Oort* [1989] in W/m^2.

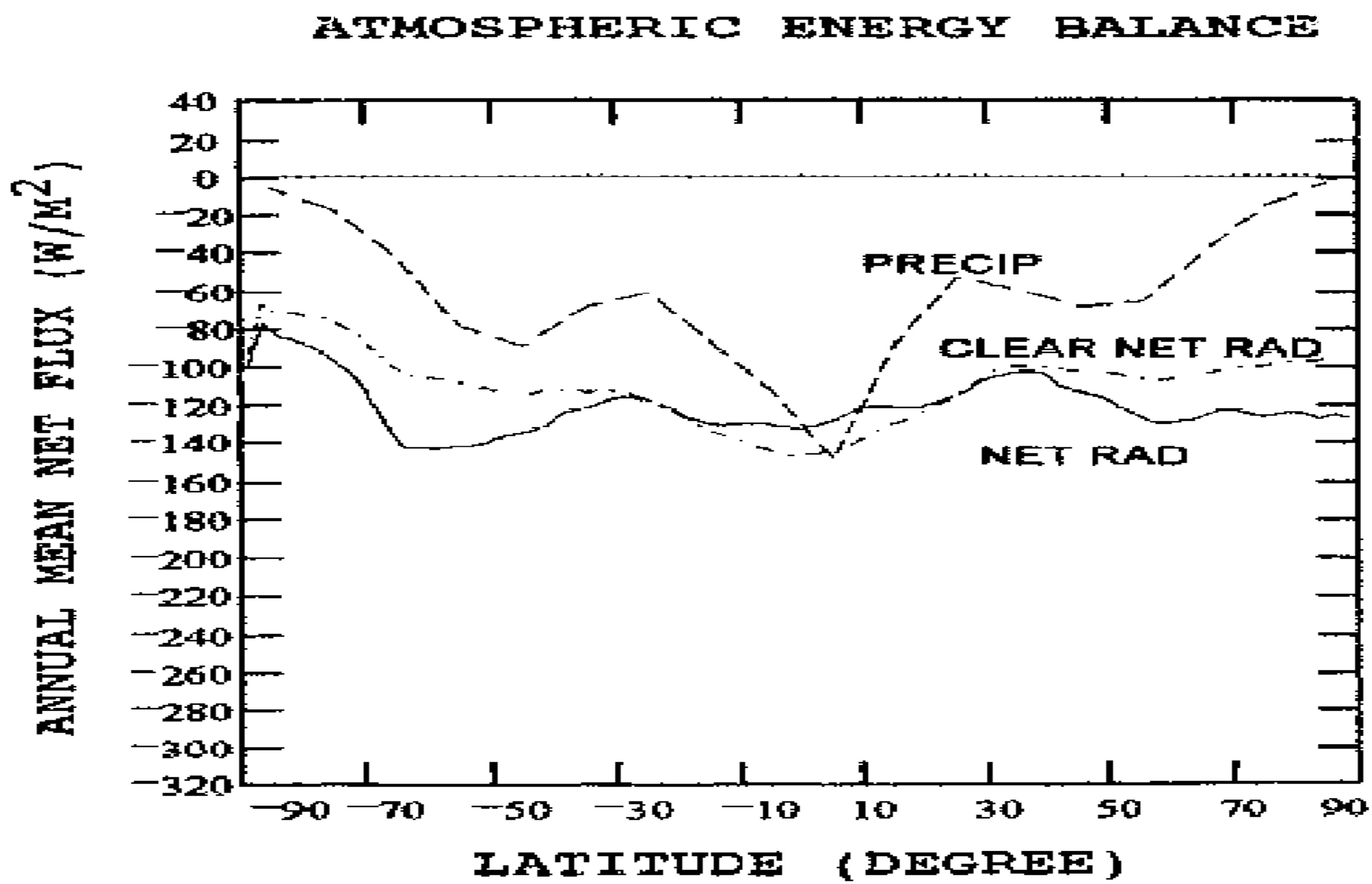
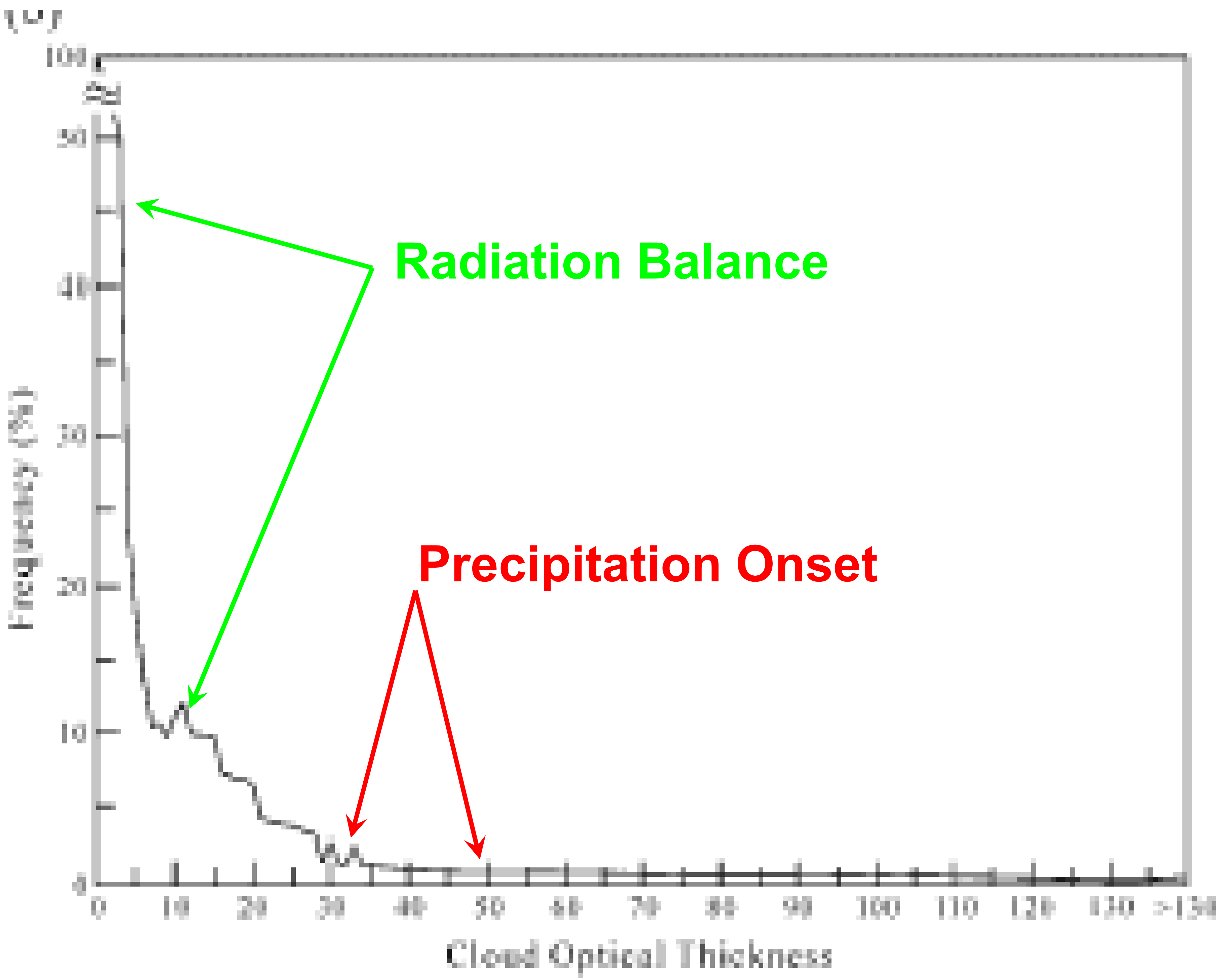
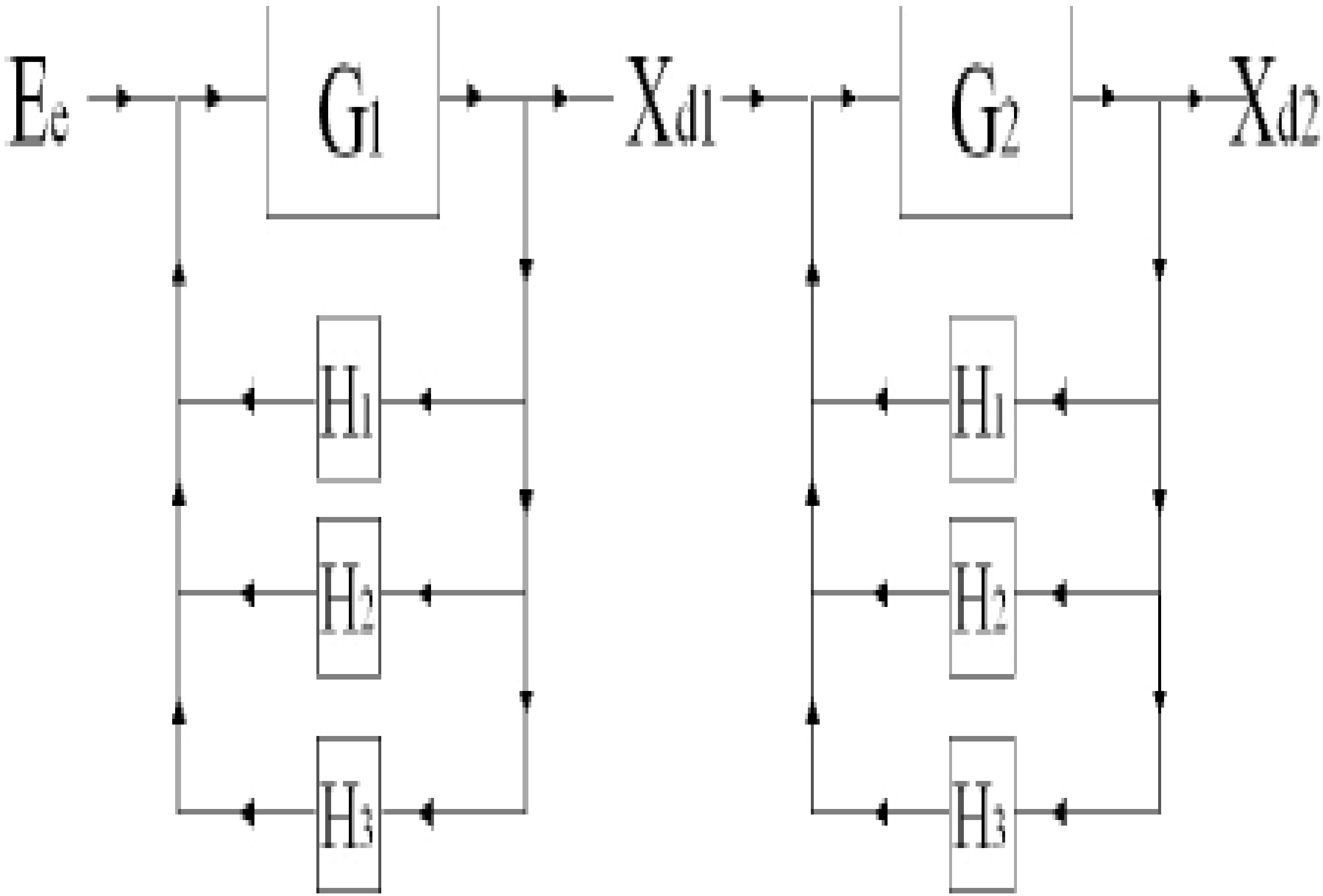


Figure 25. Annual, zonal mean atmospheric net radiative cooling for full sky and clear sky from FC and atmospheric heating by precipitation (shown with negative sign) from *Peixoto and Oort* [1989] in W/m².

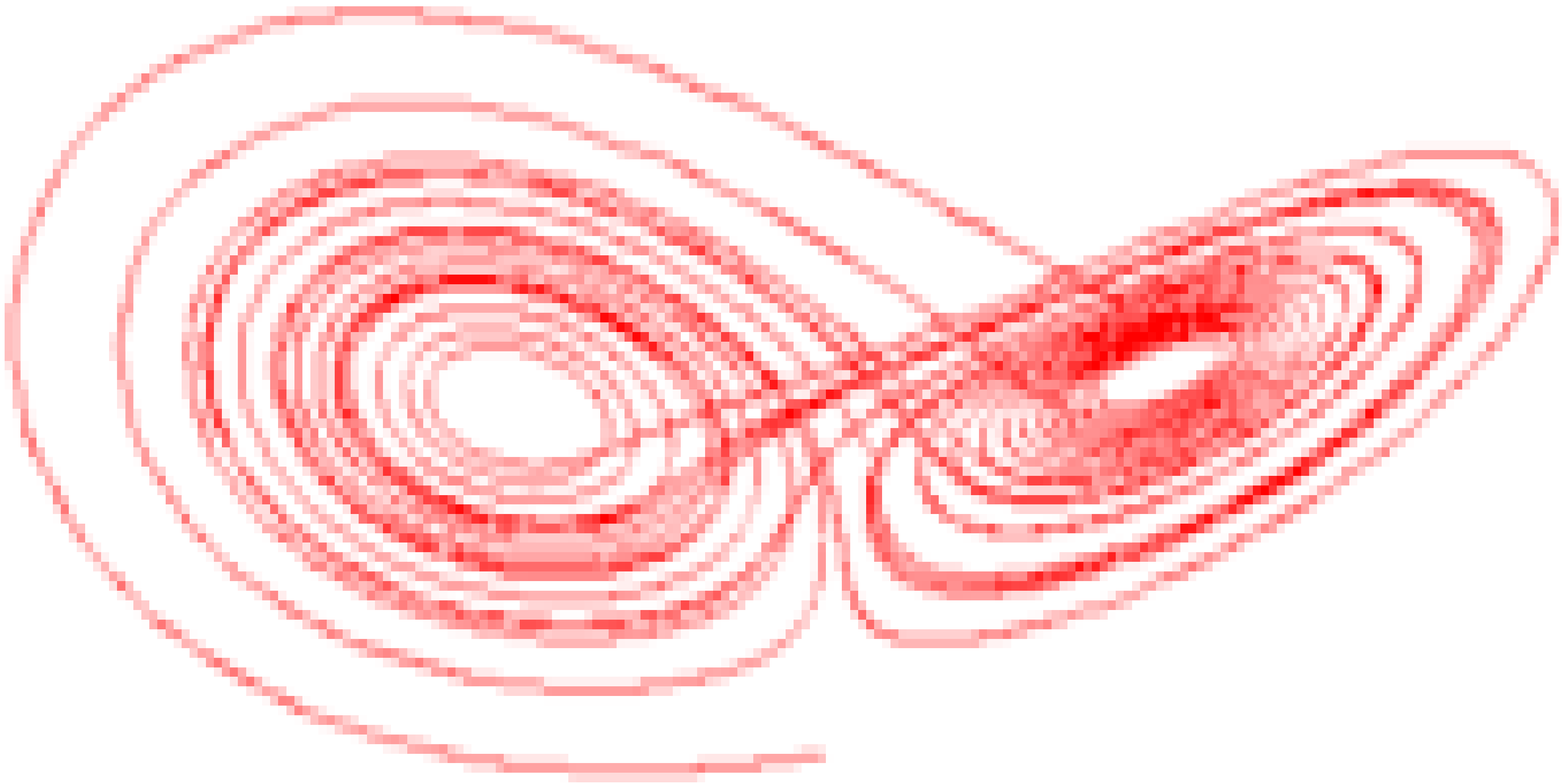


Radiation Balance
Precipitation Onset
Frequency (%)
Cloud Optical Thickness
0
10
20
30
40
50
60
70
80
90
100
110
120
130
>130

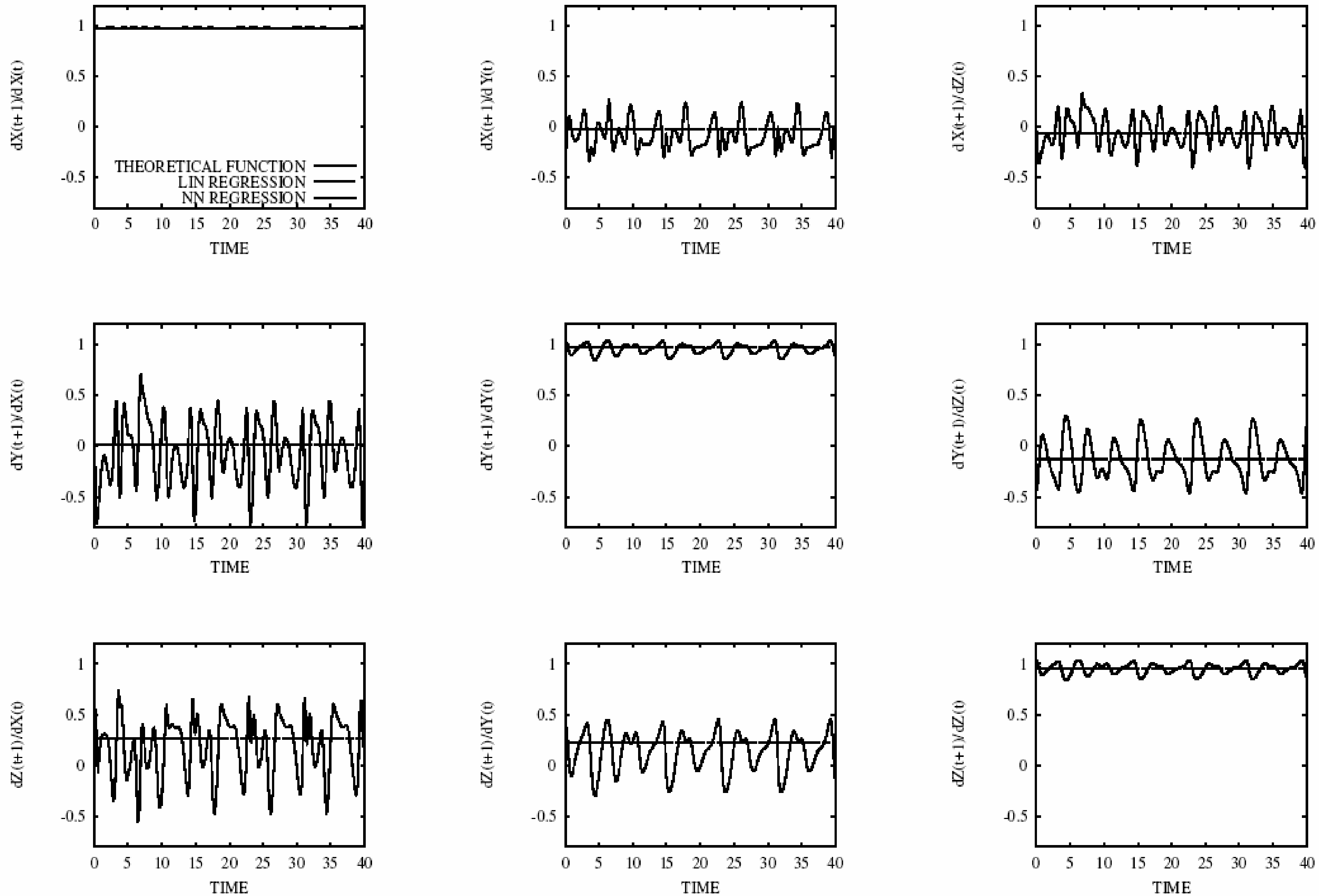


Ee
G1
Xd1
G2
Xd2
H1
H2
H3
H1
H2
H3

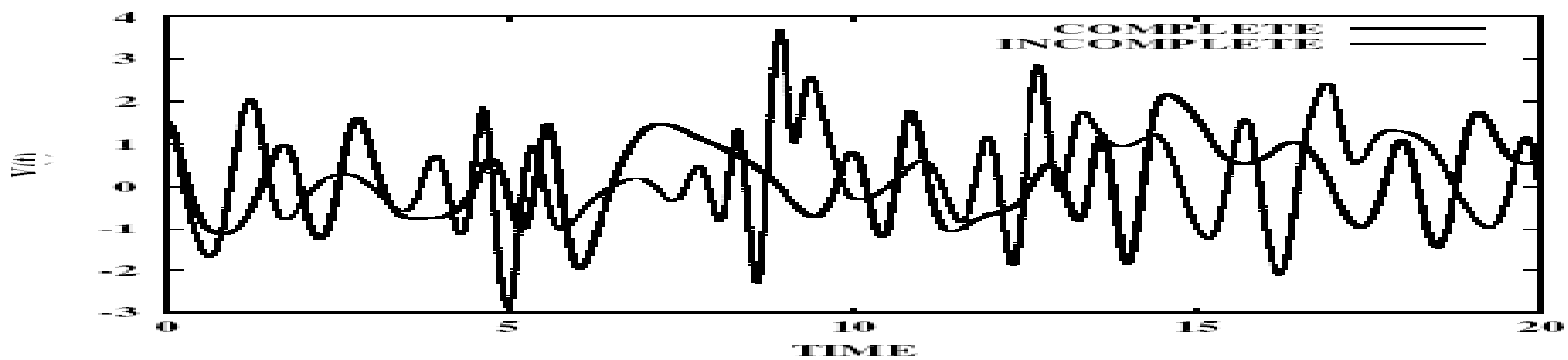
How Do You Know Where You Are?

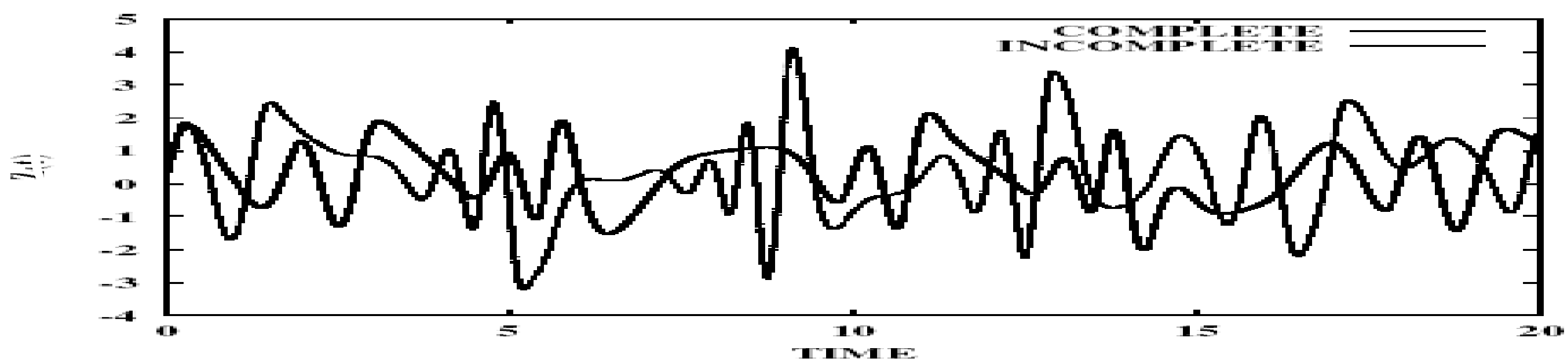


Time-Dependence of Sensitivities

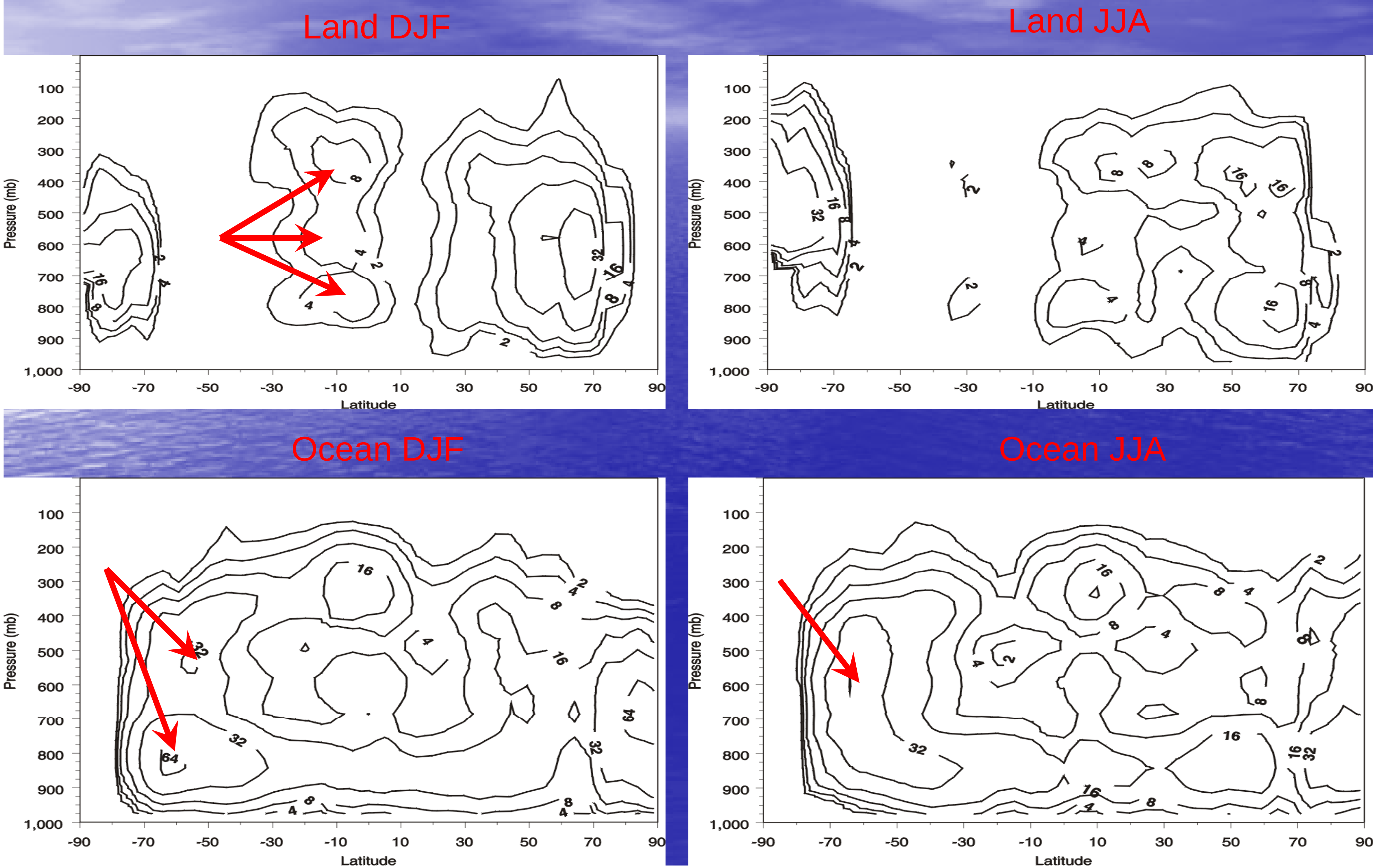


Approximate Model

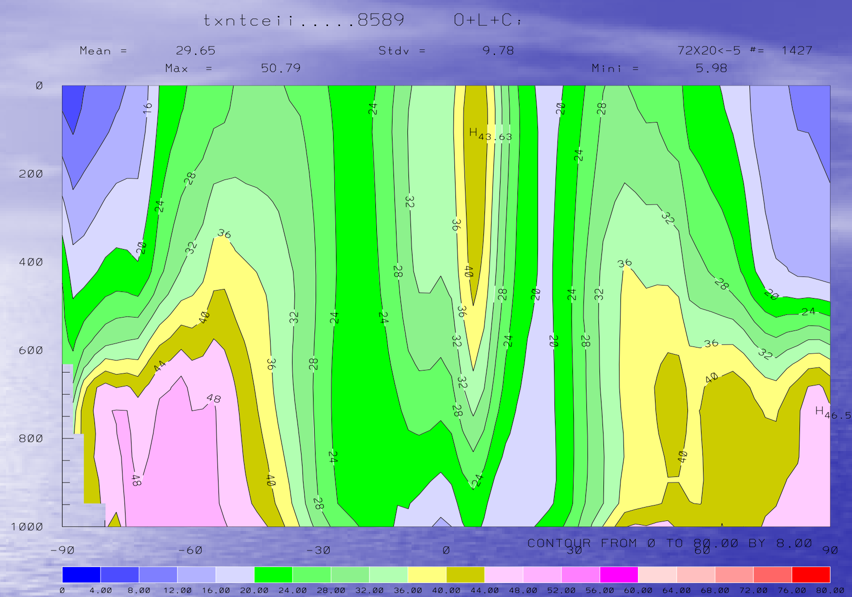




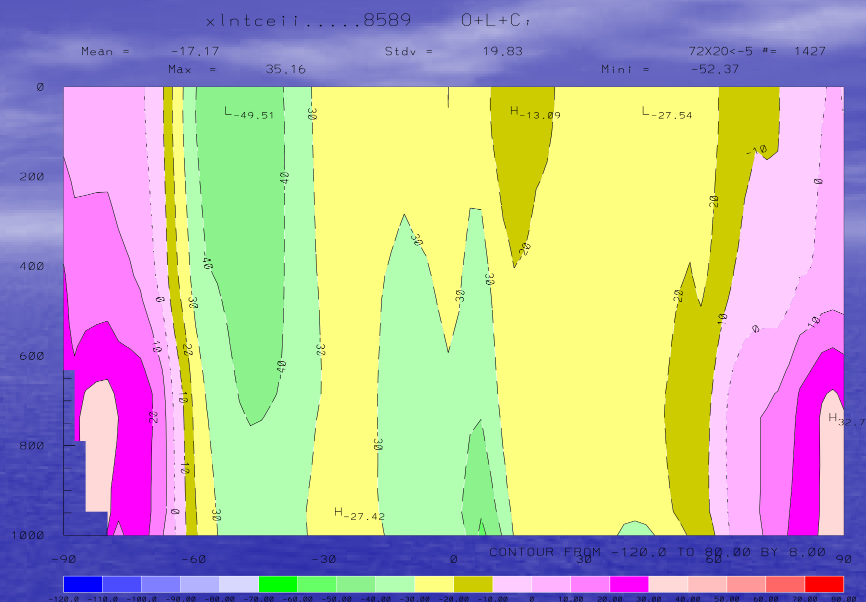
Zonal Seasonal Mean Pressure-Latitude Cross-Sections of Cloud Frequency of Occurrence



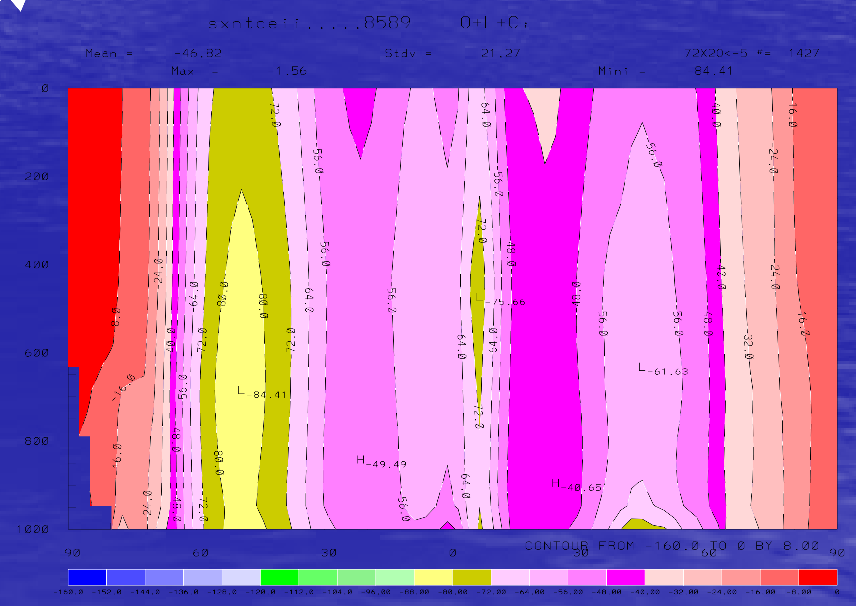
Cloud Effects on Radiation Profiles



LW

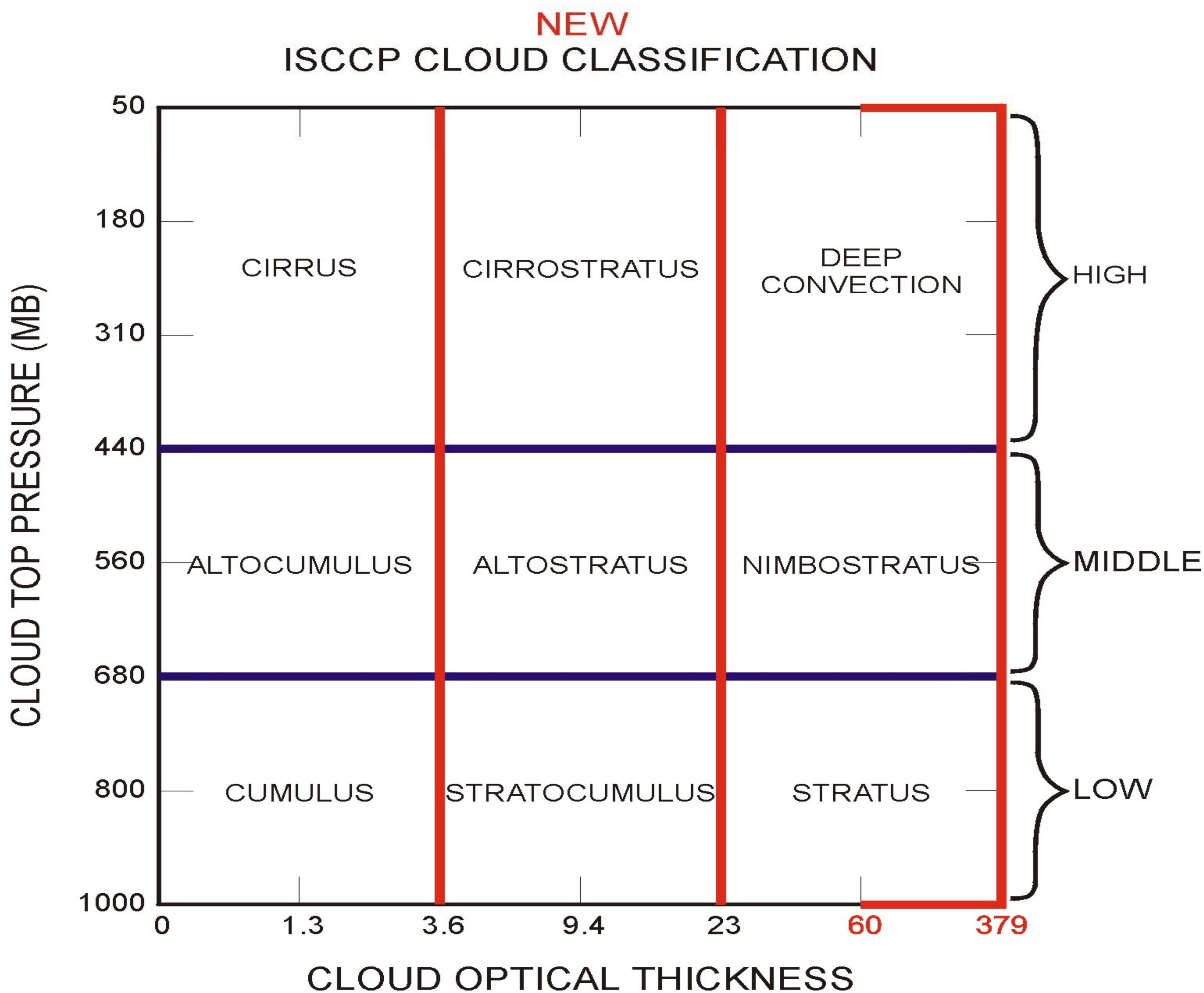


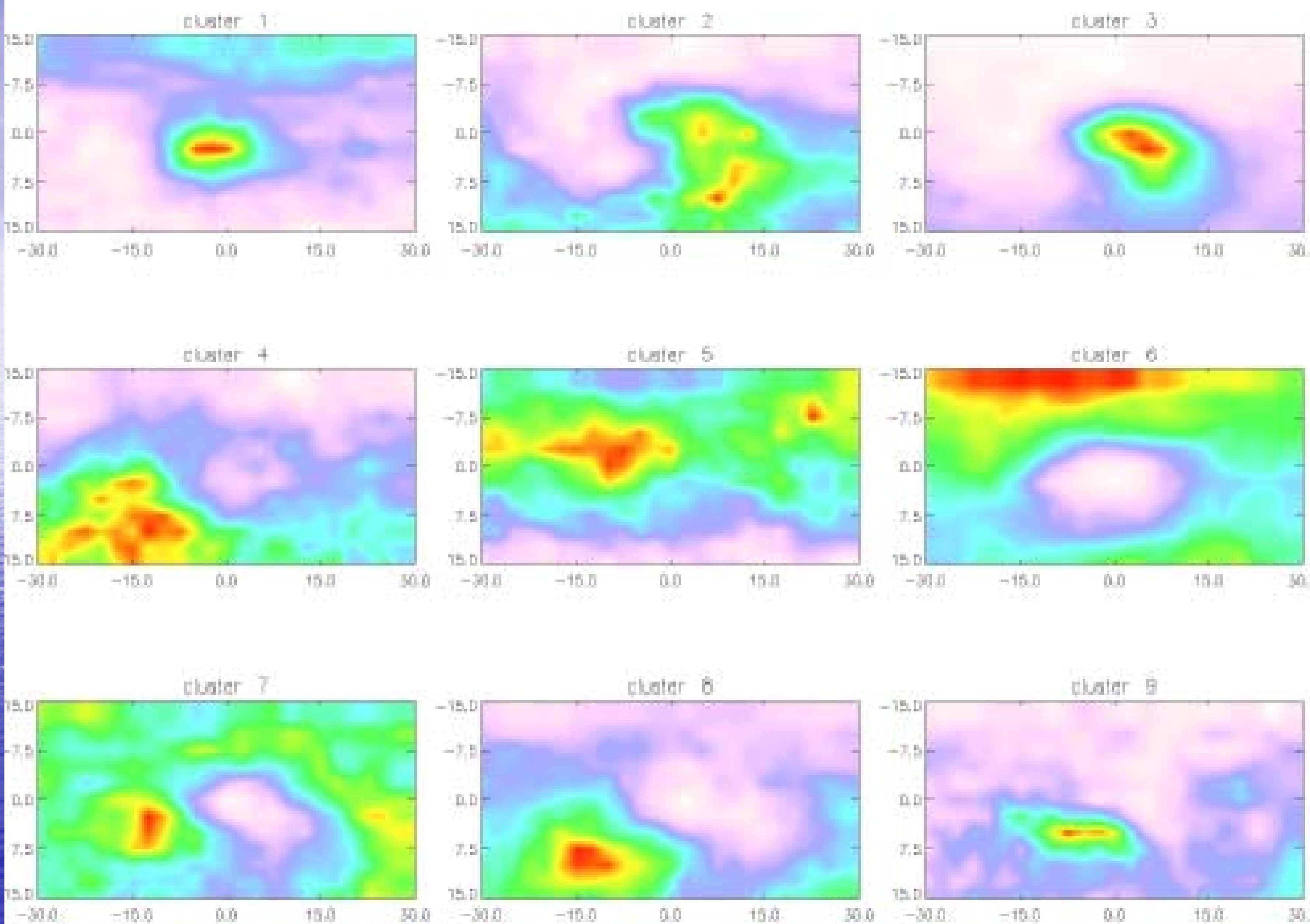
TOTAL



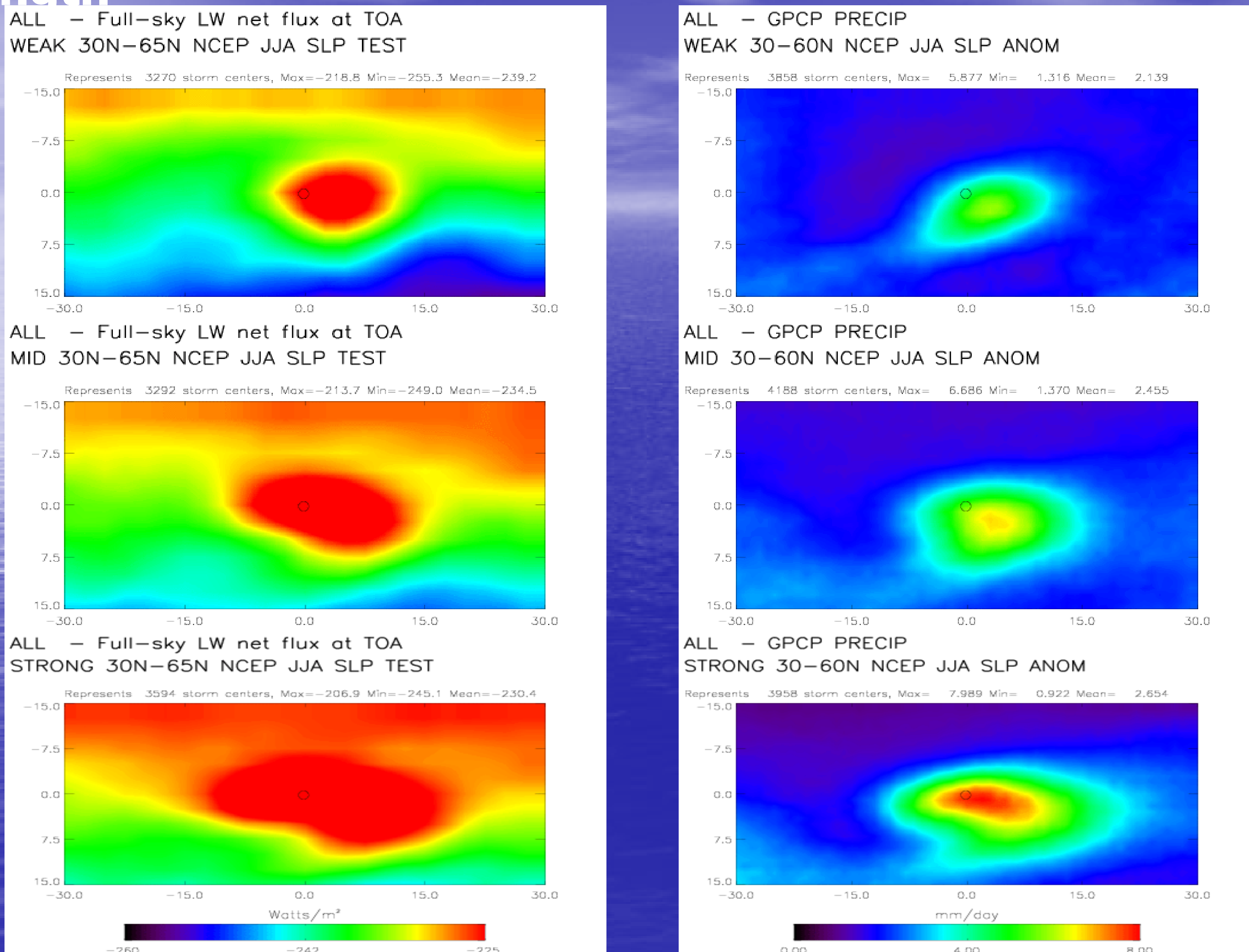
SW

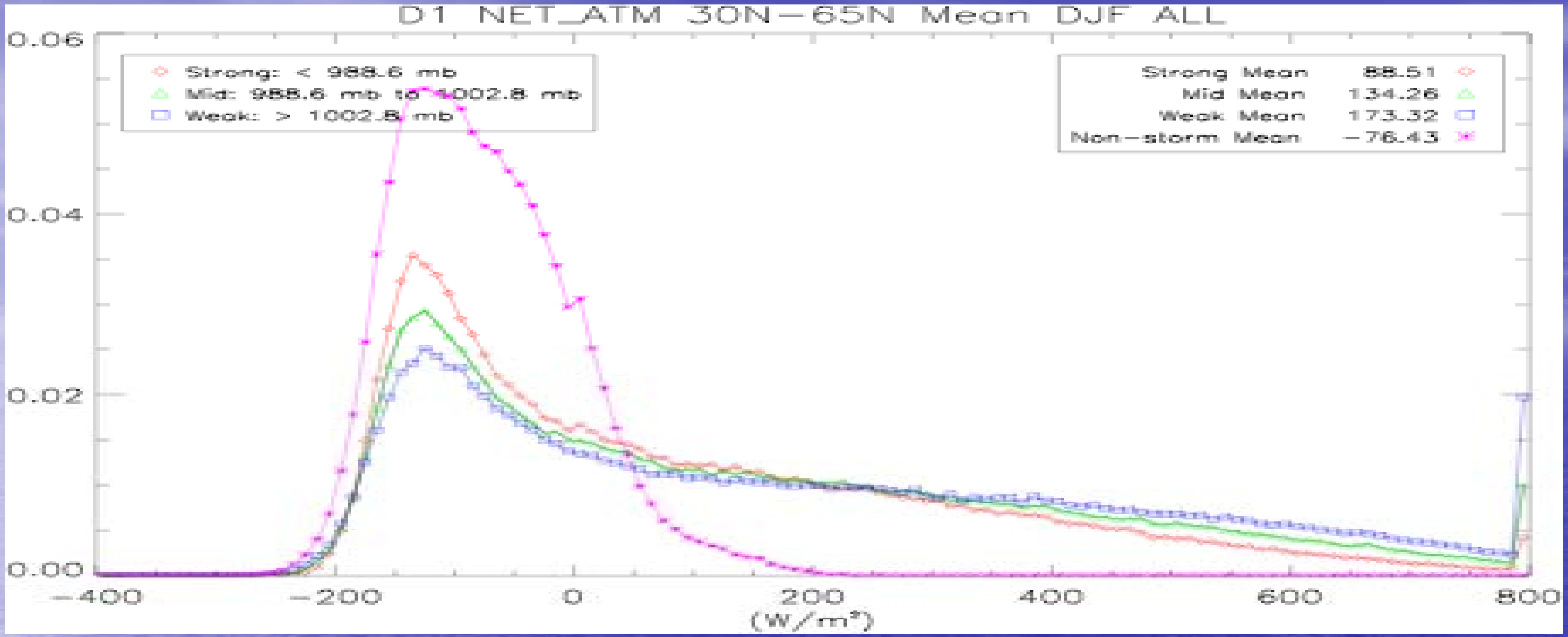
85-89 Annual Net Cloud Effect/Forcing profile (W/m^2): LW (top left), Total (top right), and SW (bottom).

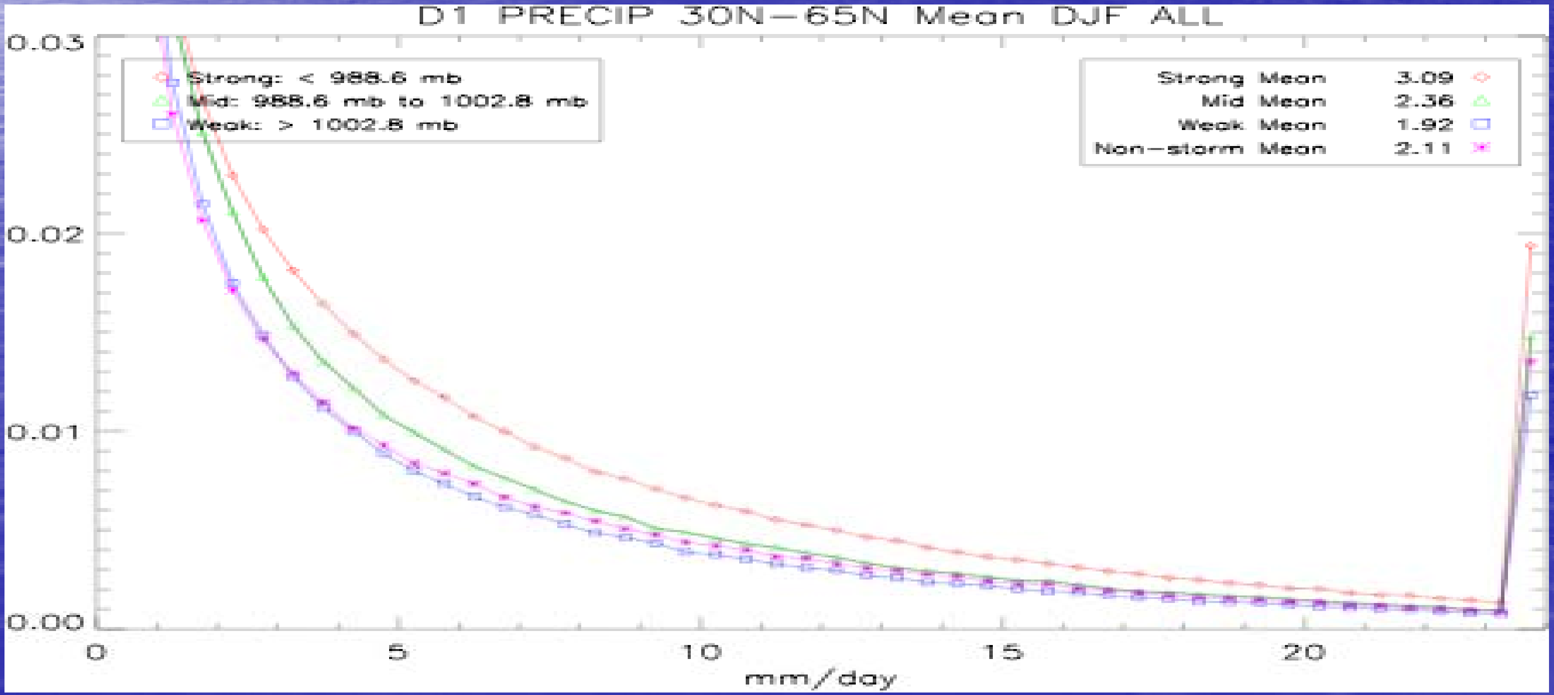

NEW
ISCCP CLOUD CLASSIFICATION
50
180
310
440
560
680
800
1000
CLOUD TOP PRESSURE (MB)
CIRRUS
CIRROSTRATUS
DEEP CONVECTION
ALTOCUMULUS
ALTOSTRATUS
NIMBOSTRATUS
CUMULUS
STRATOCUMULUS
STRATUS
HIGH
MIDDLE
LOW
0
1.3
3.6
9.4
23
60
379
CLOUD OPTICAL THICKNESS


cluster 1
cluster 2
cluster 3
cluster 4
cluster 5
cluster 6
cluster 7
cluster 8
cluster 9
-15.0
-7.5
0.0
7.5
15.0
-30.0
-15.0
0.0
15.0
30.0

Composite of Diabatic Heating of Atmosphere with Cyclone Strength

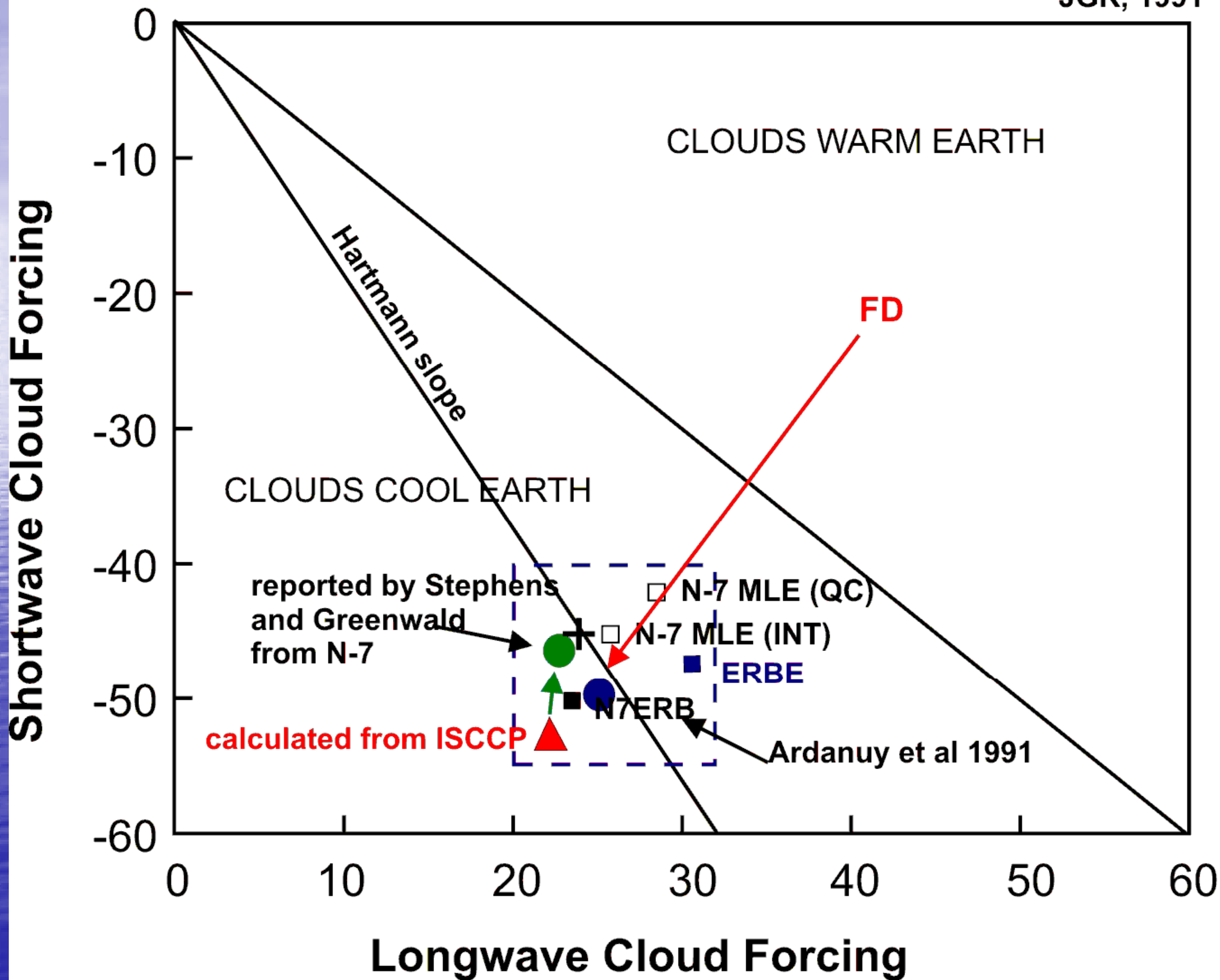



D1 NET_ATM 30N−65N Mean DJF ALL
0.06
0.04
0.02
0.00
Strong: < 988.6 mb
Mid: 988.6 mb to 1002.8 mb
Weak: > 1002.8 mb
Strong Mean 88.51
Mid Mean 134.26
Weak Mean 173.32
Non−storm Mean −76.43
−400
−200
0
200
400
600
800
(W/m²)

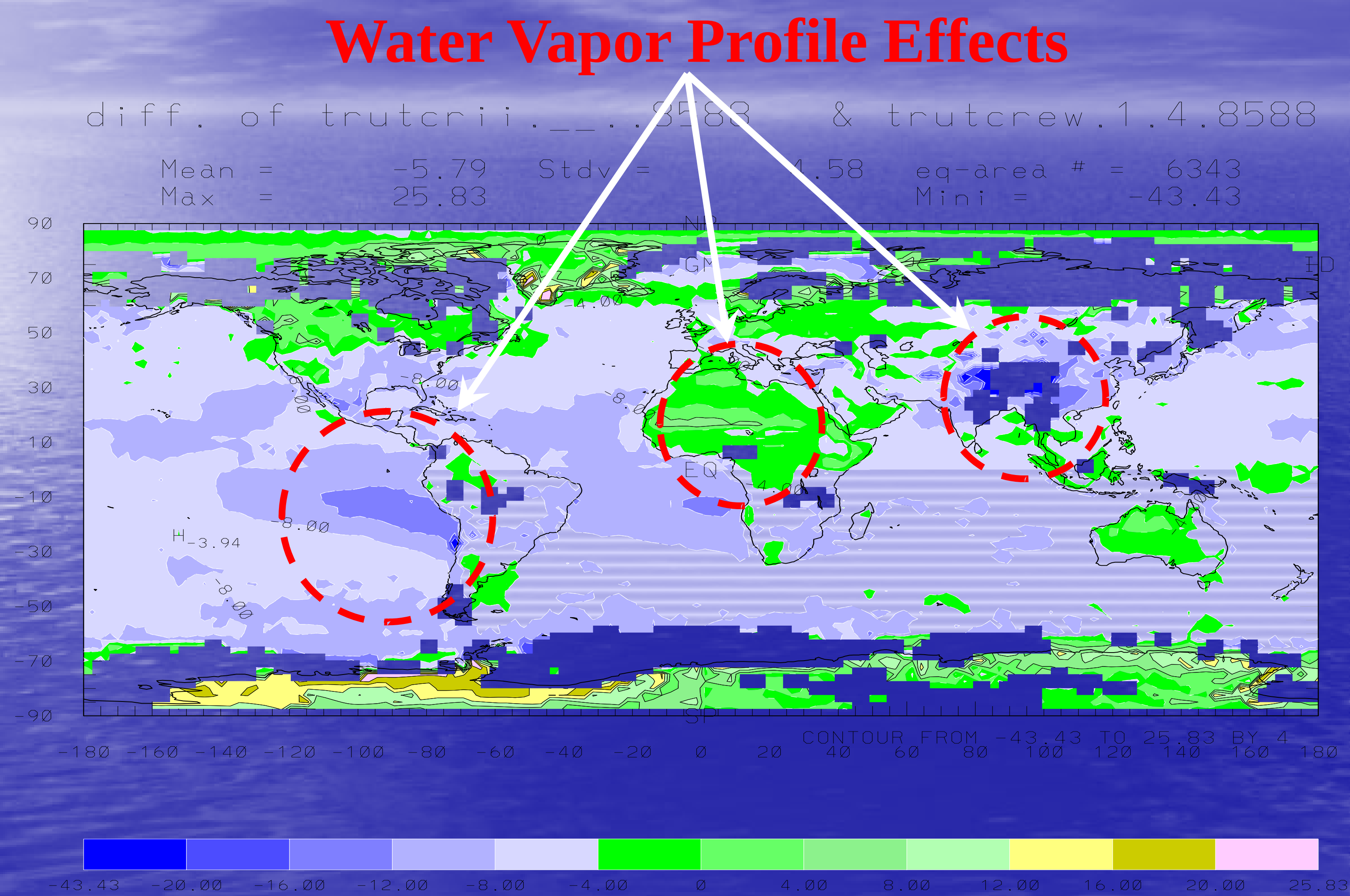

D1 PRECIP 30N−65N Mean DJF ALL
0.03
0.02
0.01
0.00
Strong: < 988.6 mb
Mid: 988.6 mb to 1002.8 mb
Weak: > 1002.8 mb
Strong Mean 3.09
Mid Mean 2.36
Weak Mean 1.92
Non−storm Mean 2.11
0
5
10
15
20
mm/day

Comparison of Studies

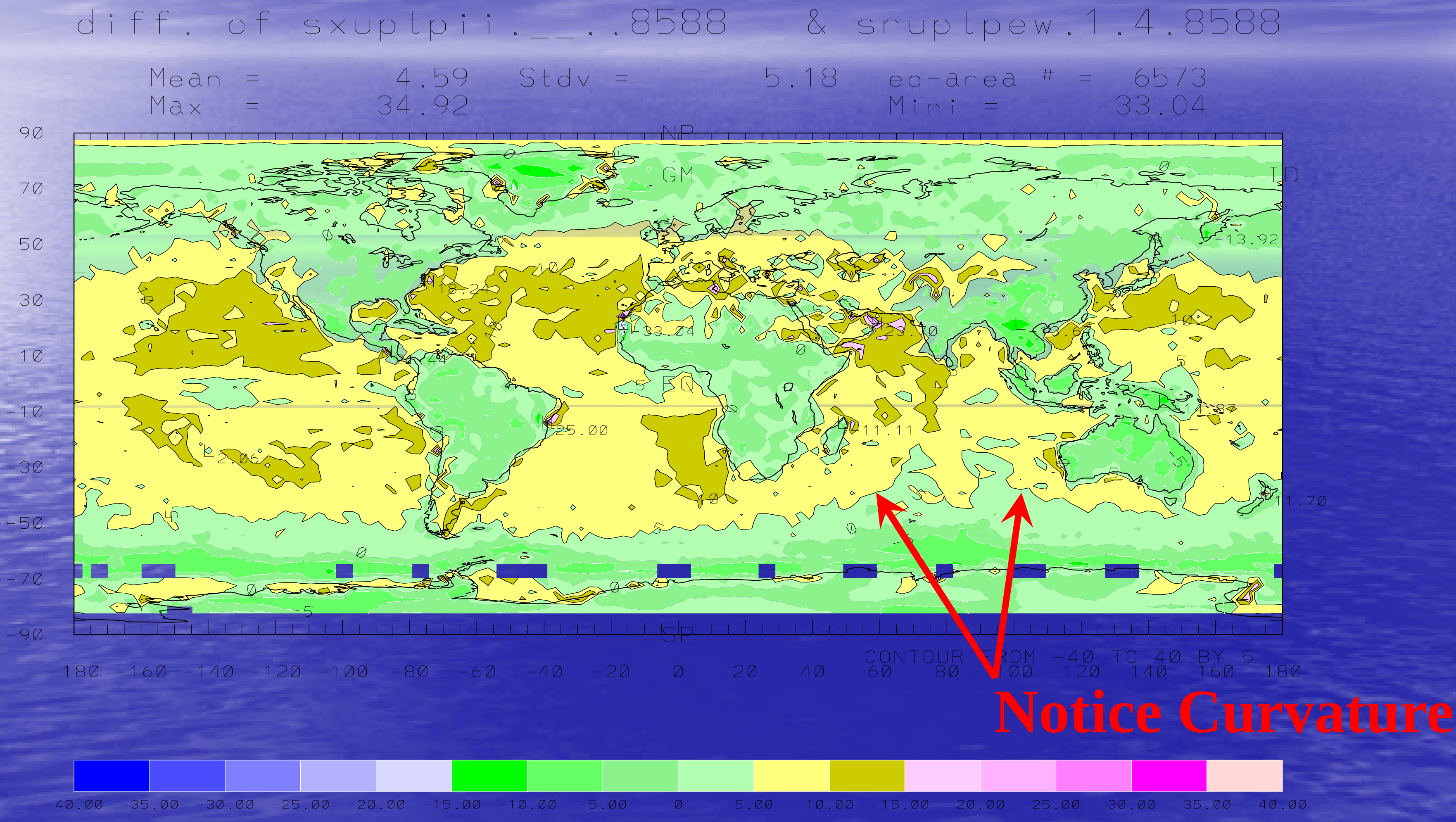
Ardanuy, Stowe, Gruber and Weiss, JGR, 1991



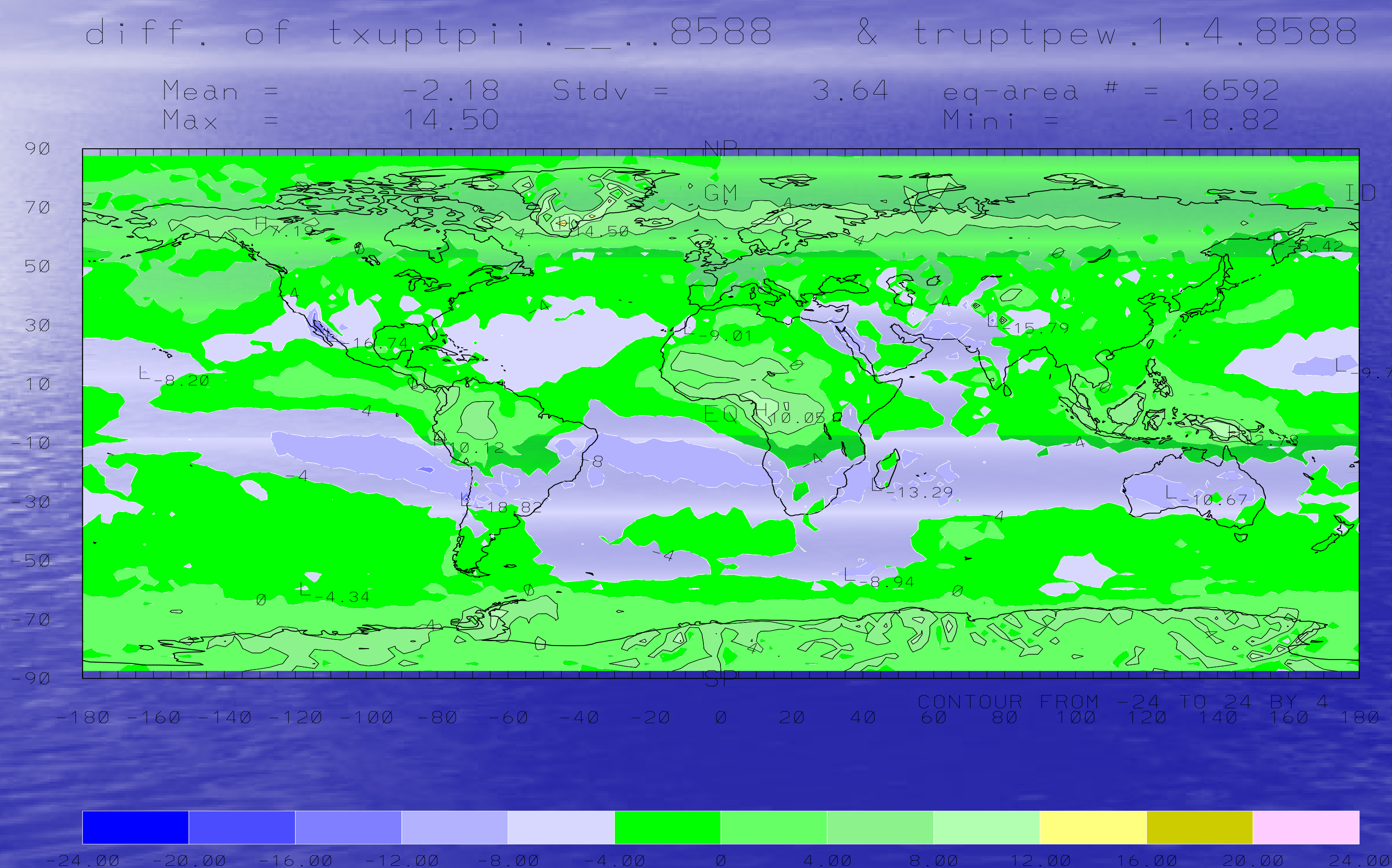
ISCCP-FD Minus ERBE Annual Mean Clear-Sky TOA LW↑ (W/m^2) for 85-88

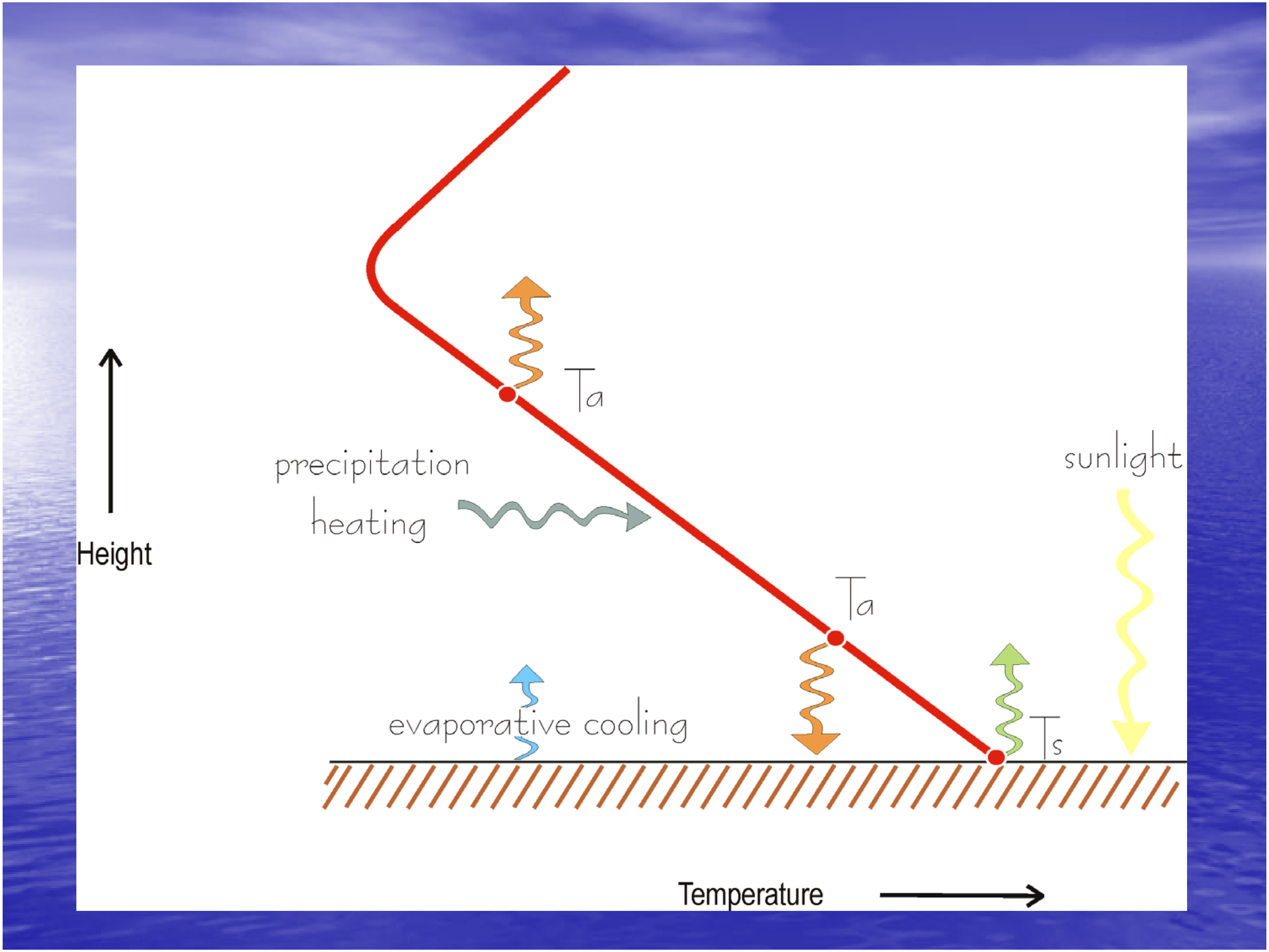


ISCCP-FD Minus ERBE Annual Mean Full-Sky TOA SW↑ (W/m^2) for 85-88

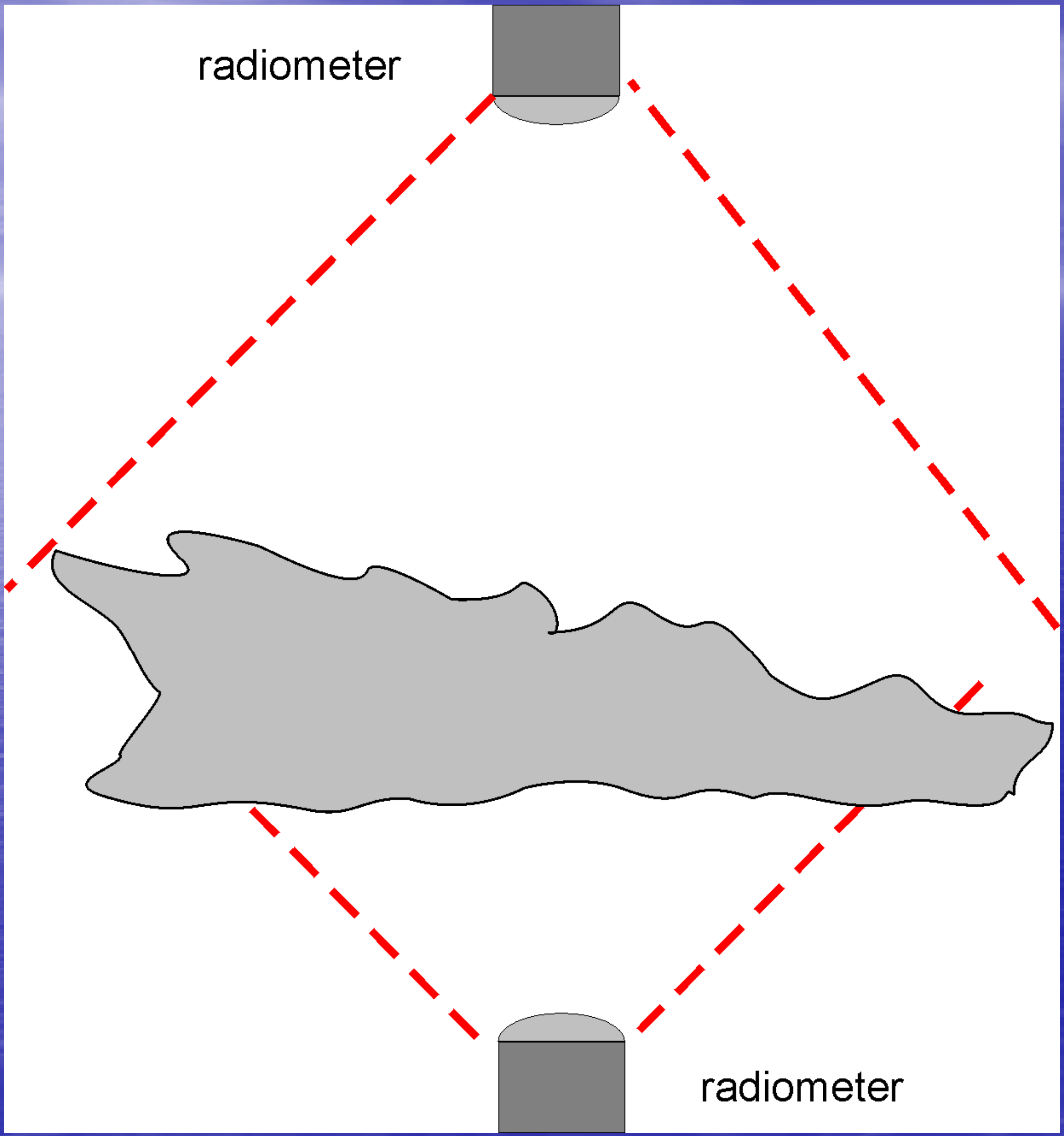


ISCCP-FD Minus ERBE Annual Mean Full-Sky TOA LW↑ (W/m^2) for 85-88





Ta
precipitation
heating
sunlight
Ta
Height
evaporative cooling
Ts
Temperature


radiometer
radiometer

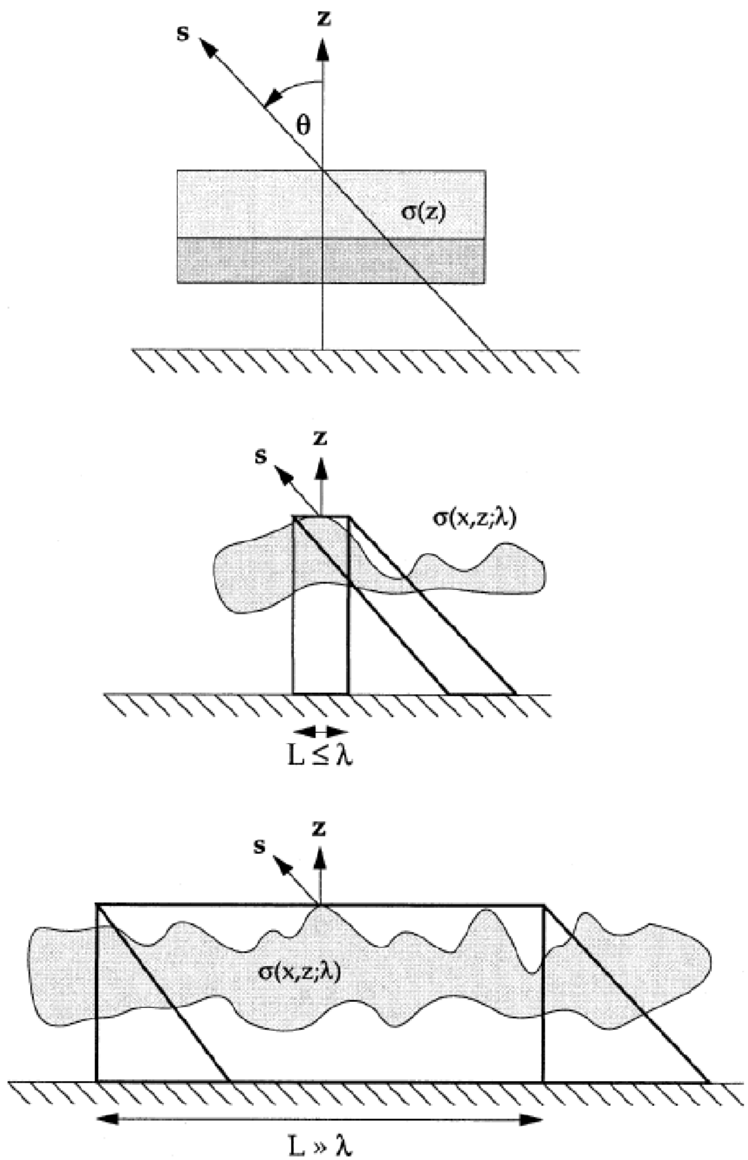
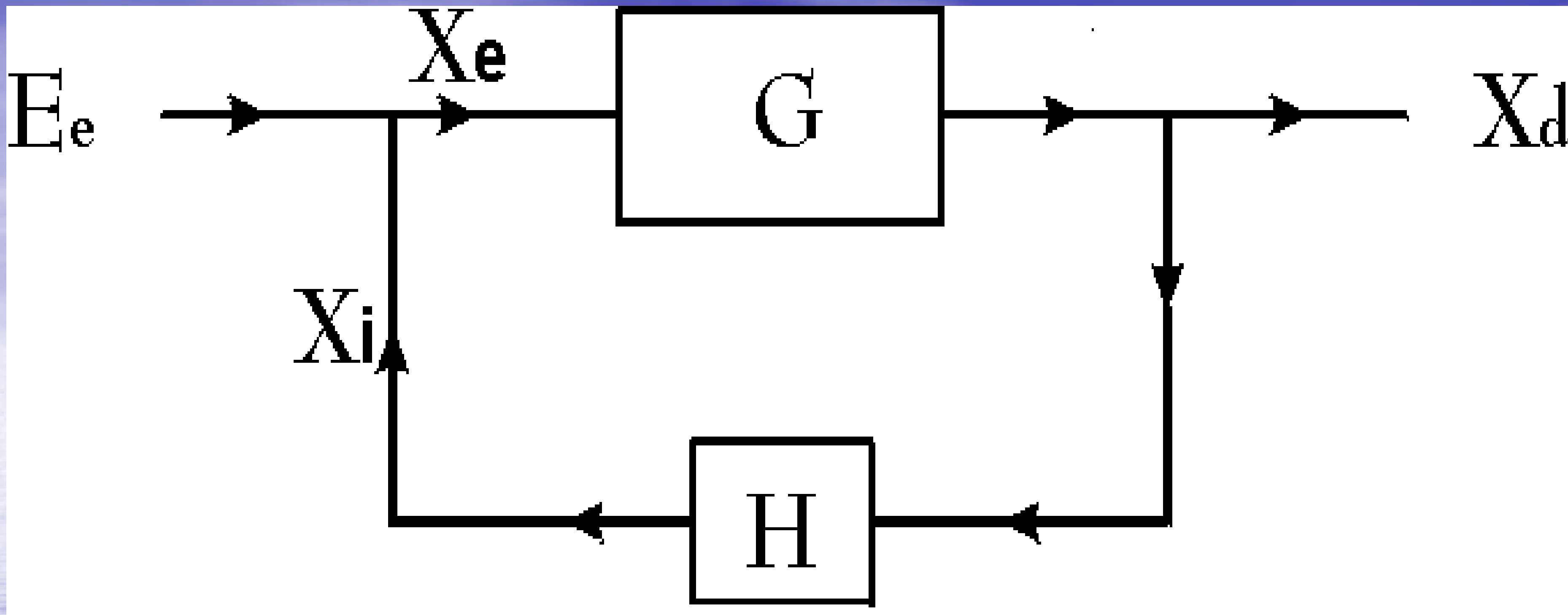


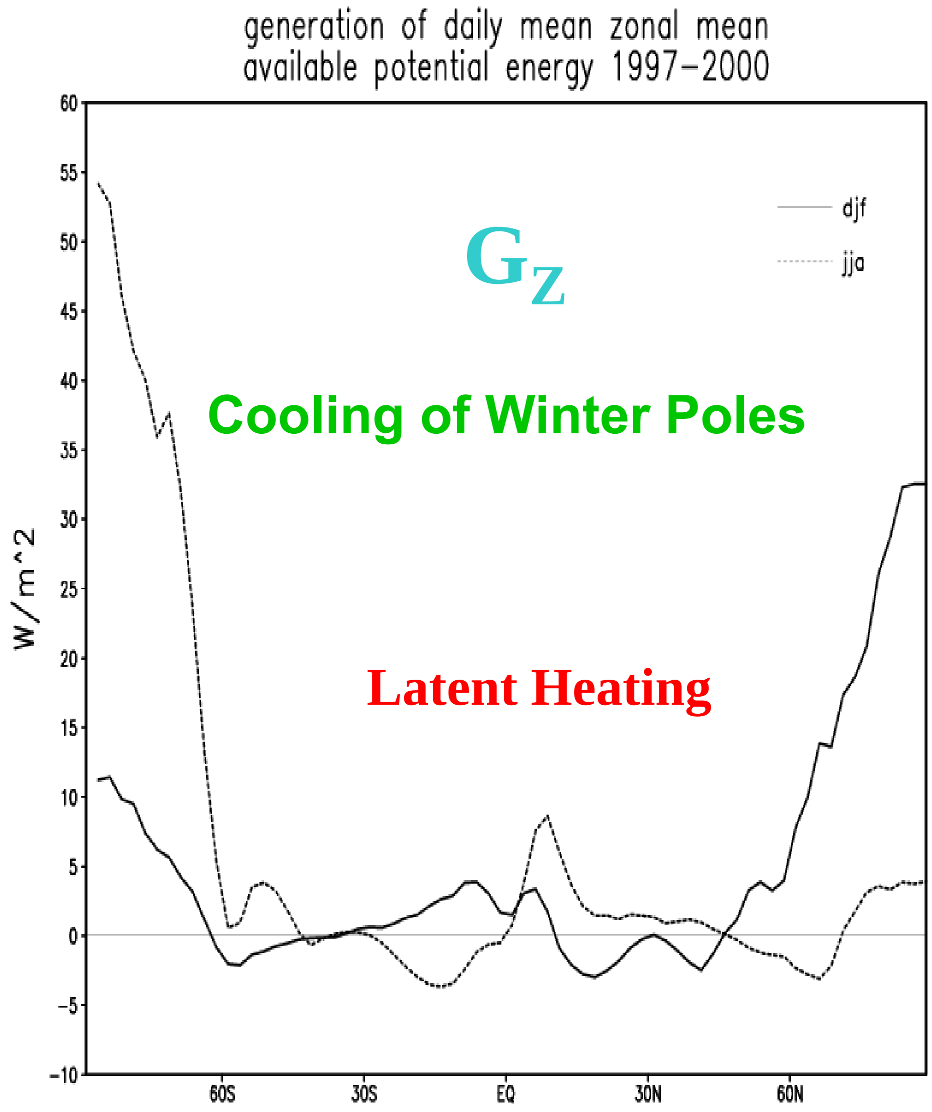
FIG. 1. Schematic illustrating different assumptions about variations of optical media used to model radiative transfer through cloudy atmospheres: (a) horizontally homogeneous layers with properties that vary only in the vertical, (b) horizontally and vertically inhomogeneous layer, (c) horizontally and vertically inhomogeneous layer that is statistically homogeneous in the horizontal direction.

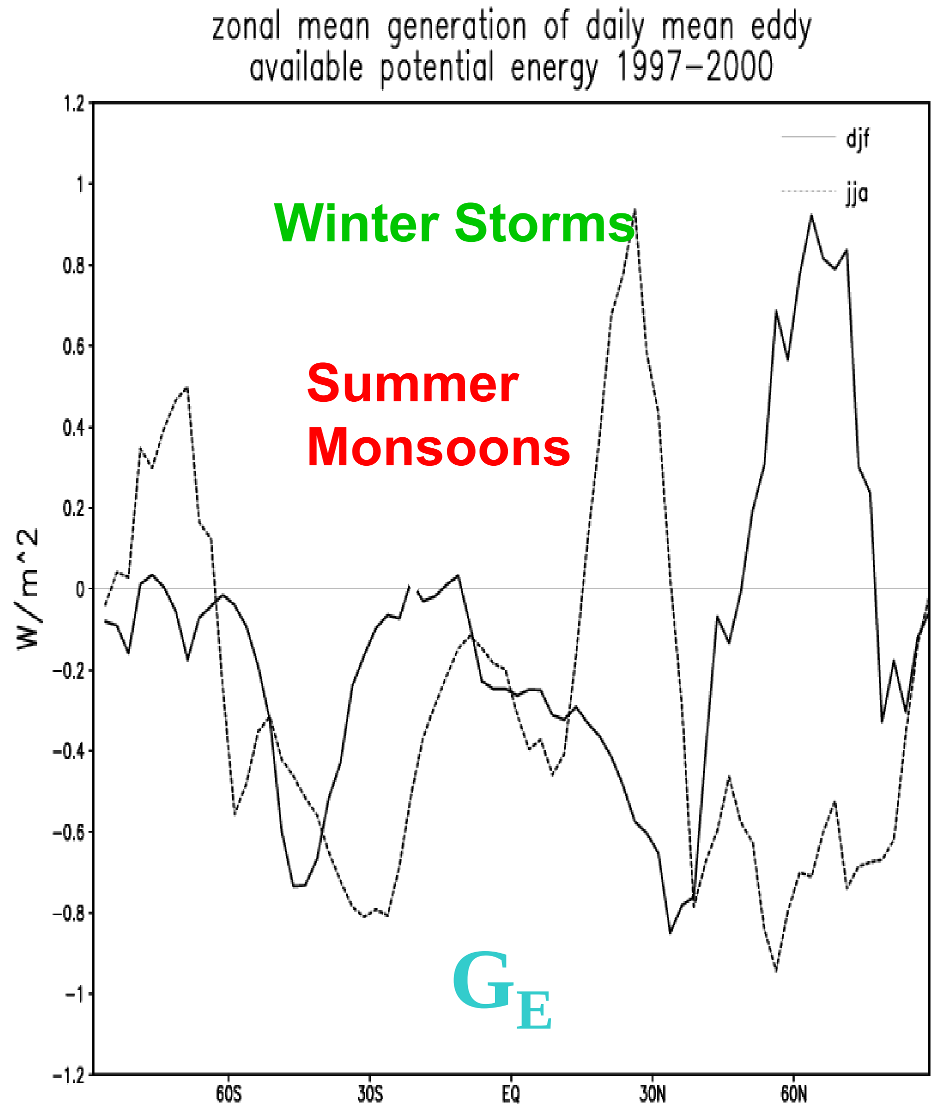


$$X_e \rightarrow X_d \rightarrow X_i \rightarrow X_e$$

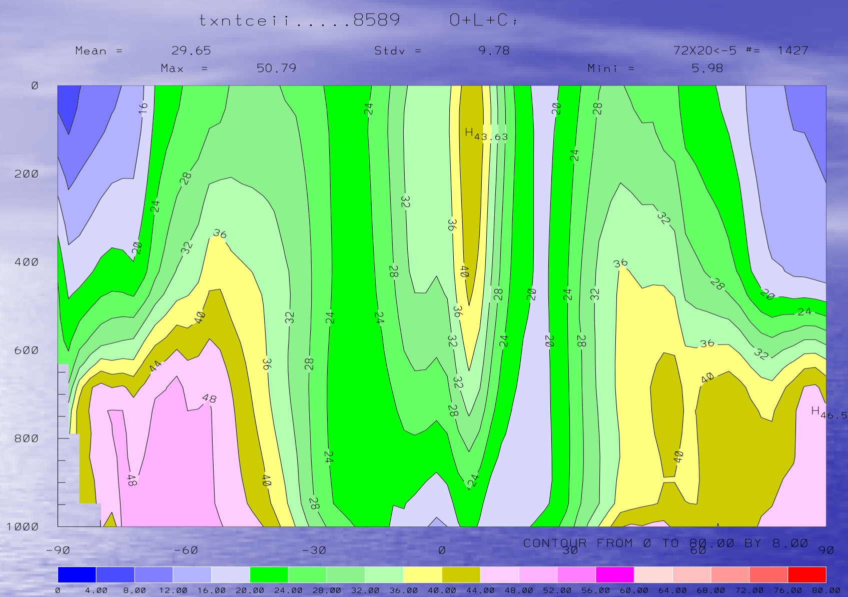
$$G = \frac{\partial X_e}{\partial X_d} \qquad H = \frac{\partial X_i}{\partial X_d}$$

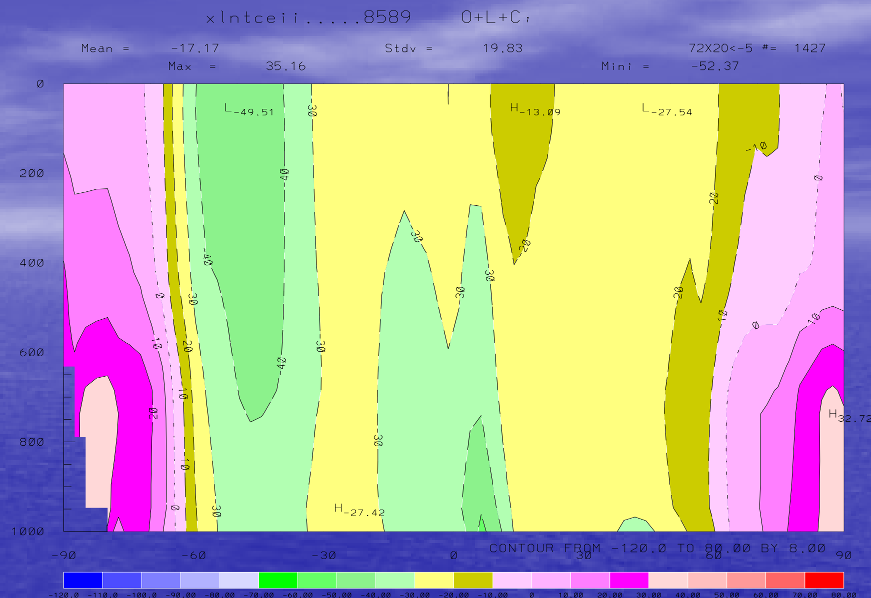
First Determination of Gz and Ge from Observations

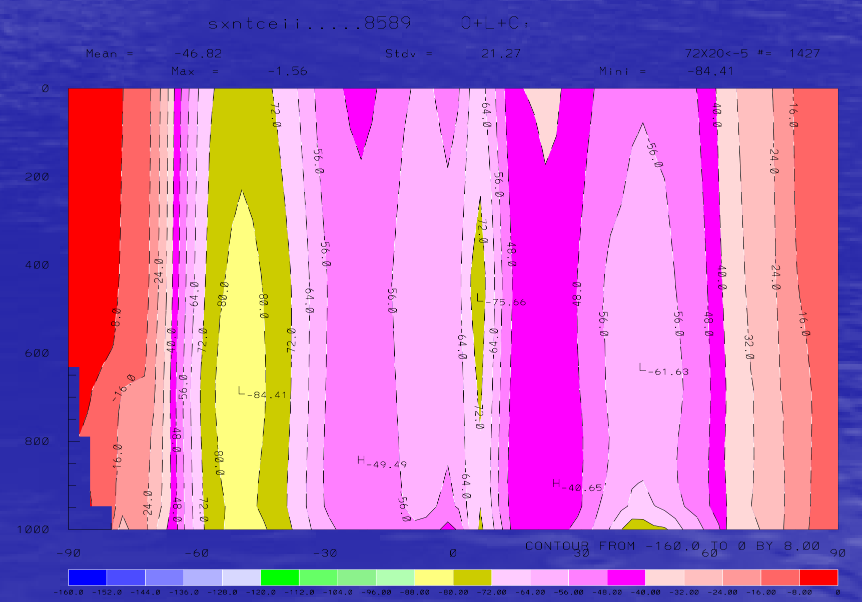




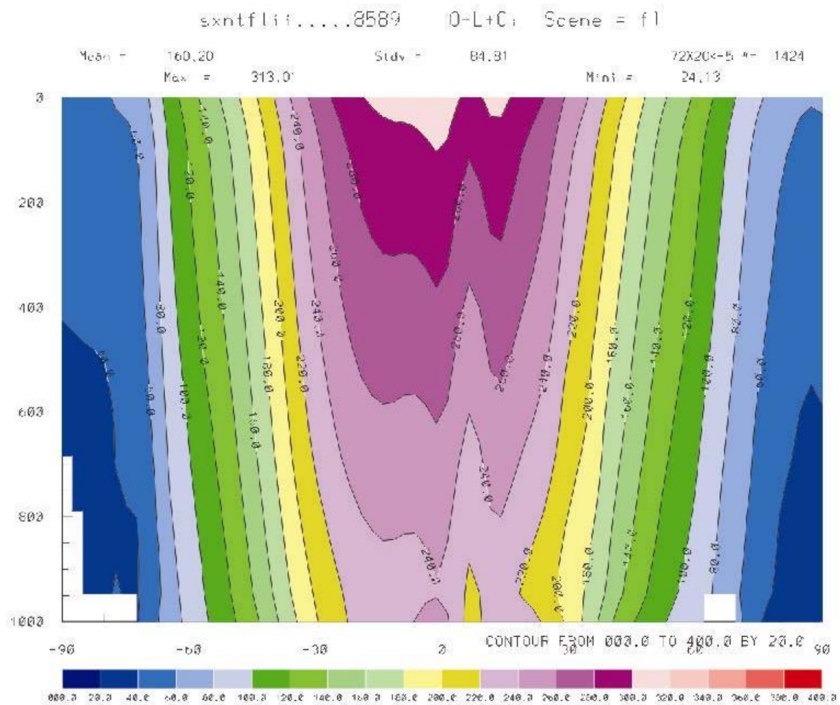
Zonal Cross-sections of Cloud Effect



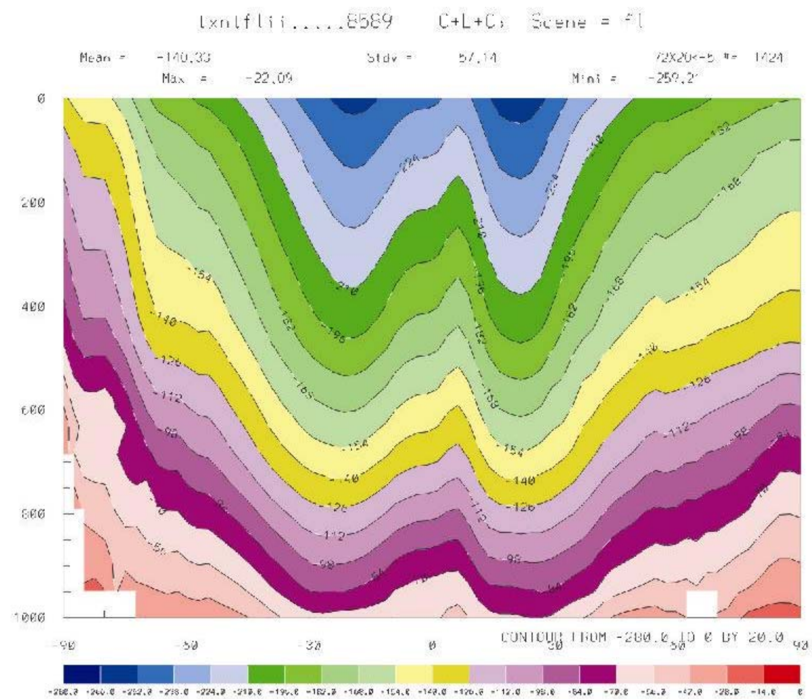




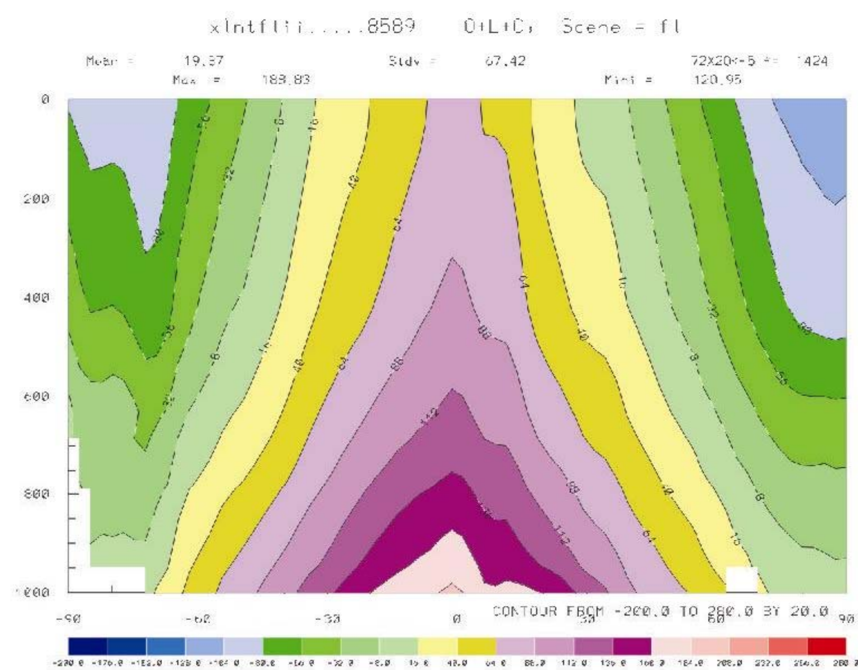
85-89 Annual Net Cloud Effect/Forcing profile (W/m^2): LW (top left), Total (top right), and SW (bottom).



Mean = 160.20
Max = 313.01
Stdv = 84.81
Min = 24.13
CONTOUR FROM 000.0 TO 400.0 BY 20.0



Mean = -140.33
Max = -22.09
Stdv = 57.14



Mean = 19.37
Max = 183.83
Stdv = 67.42
CONTOUR FROM -200.0 TO 200.0 BY 20.0