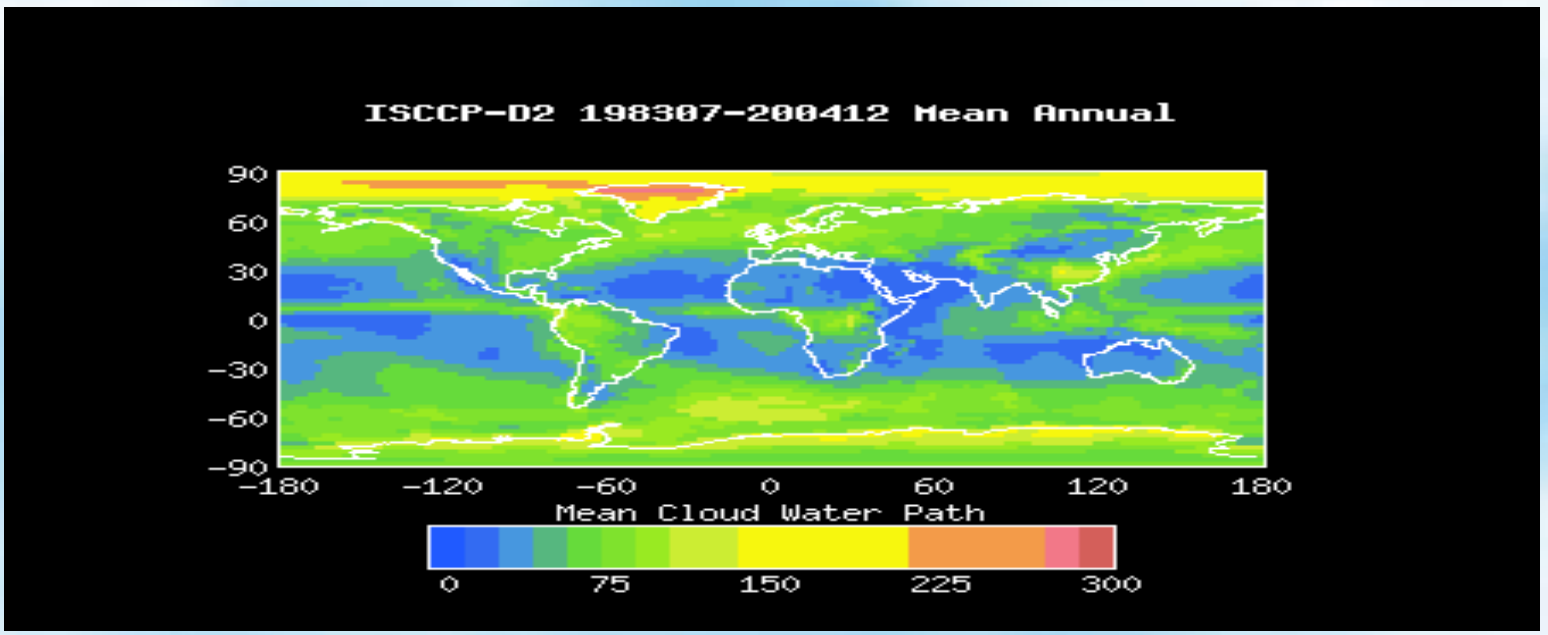
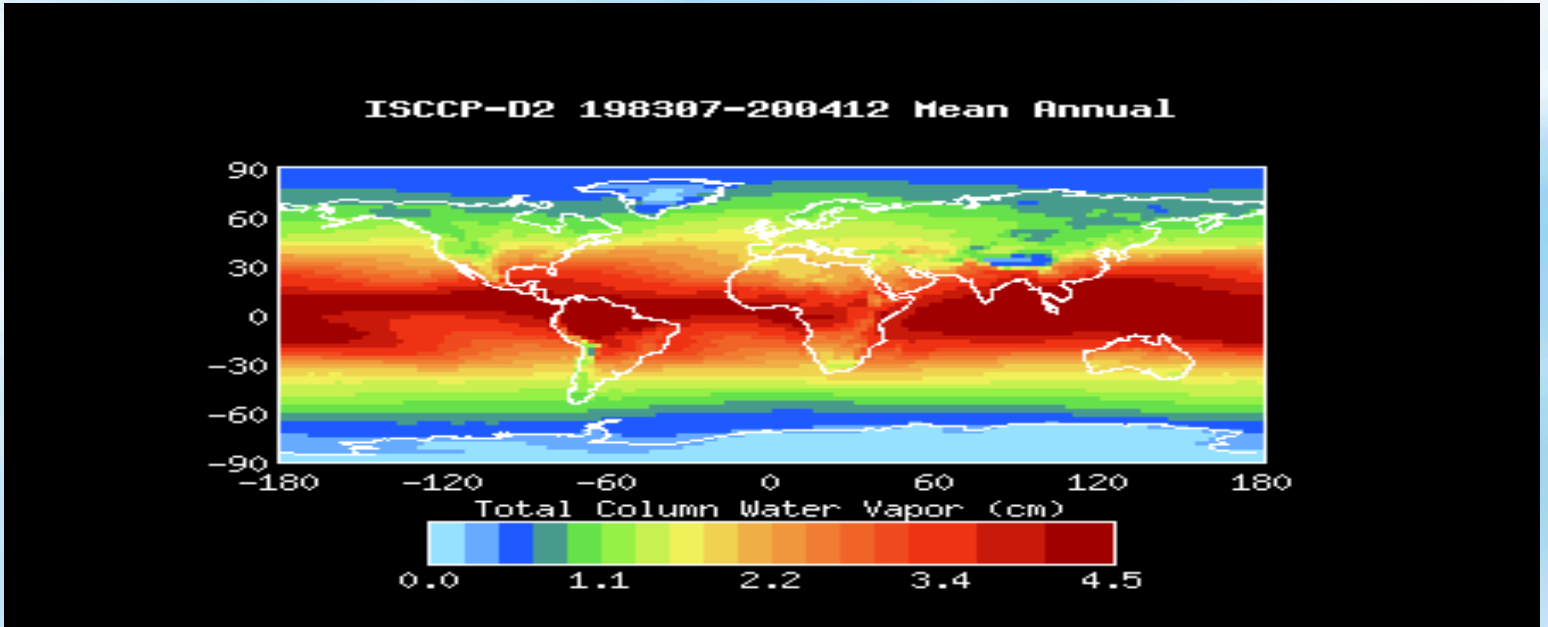
CLOUD DYNAMICS

William B. Rossow

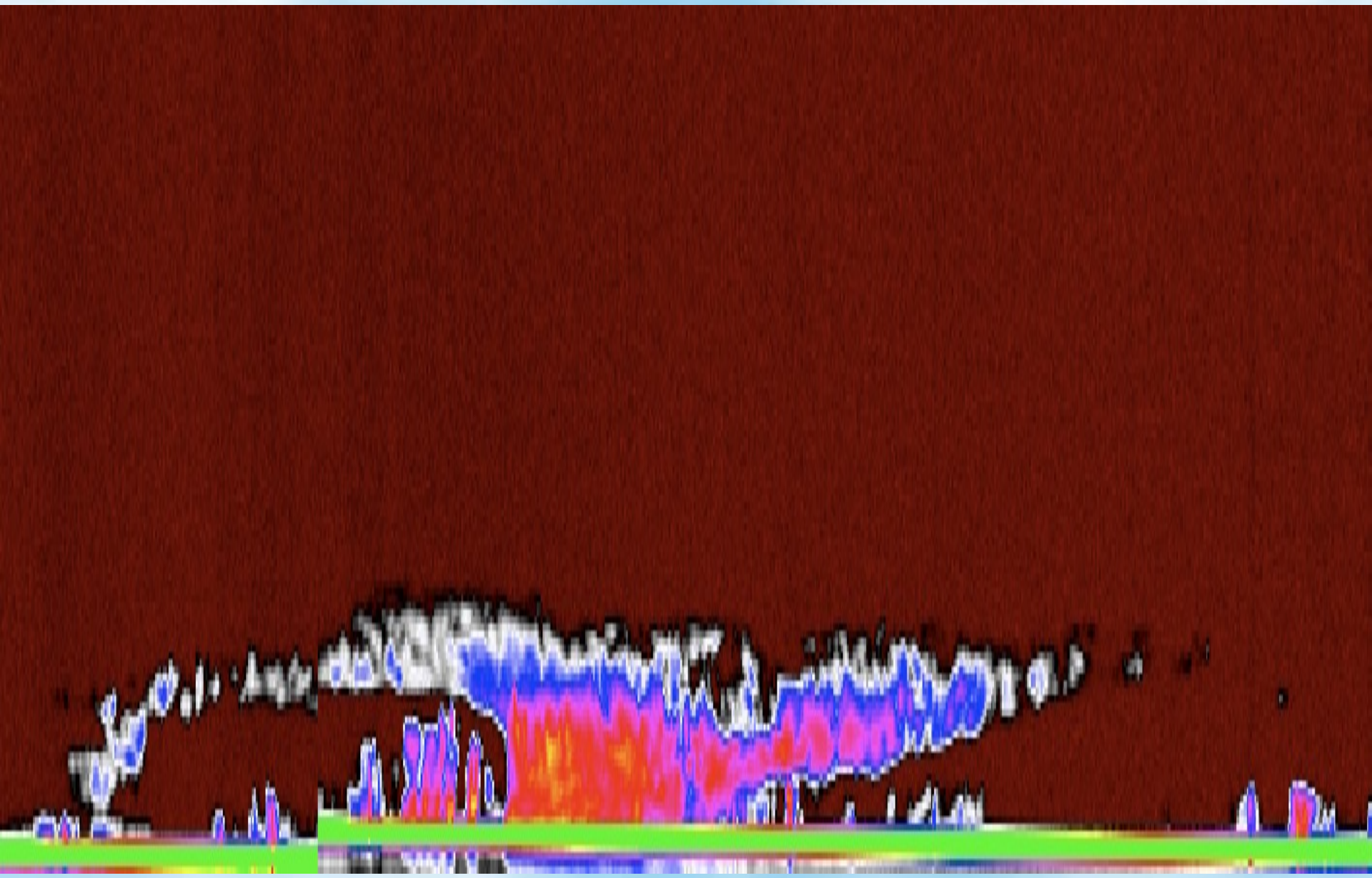
July 2008

Global Distribution of Cloud Water and Water Vapor





CloudSat First Light



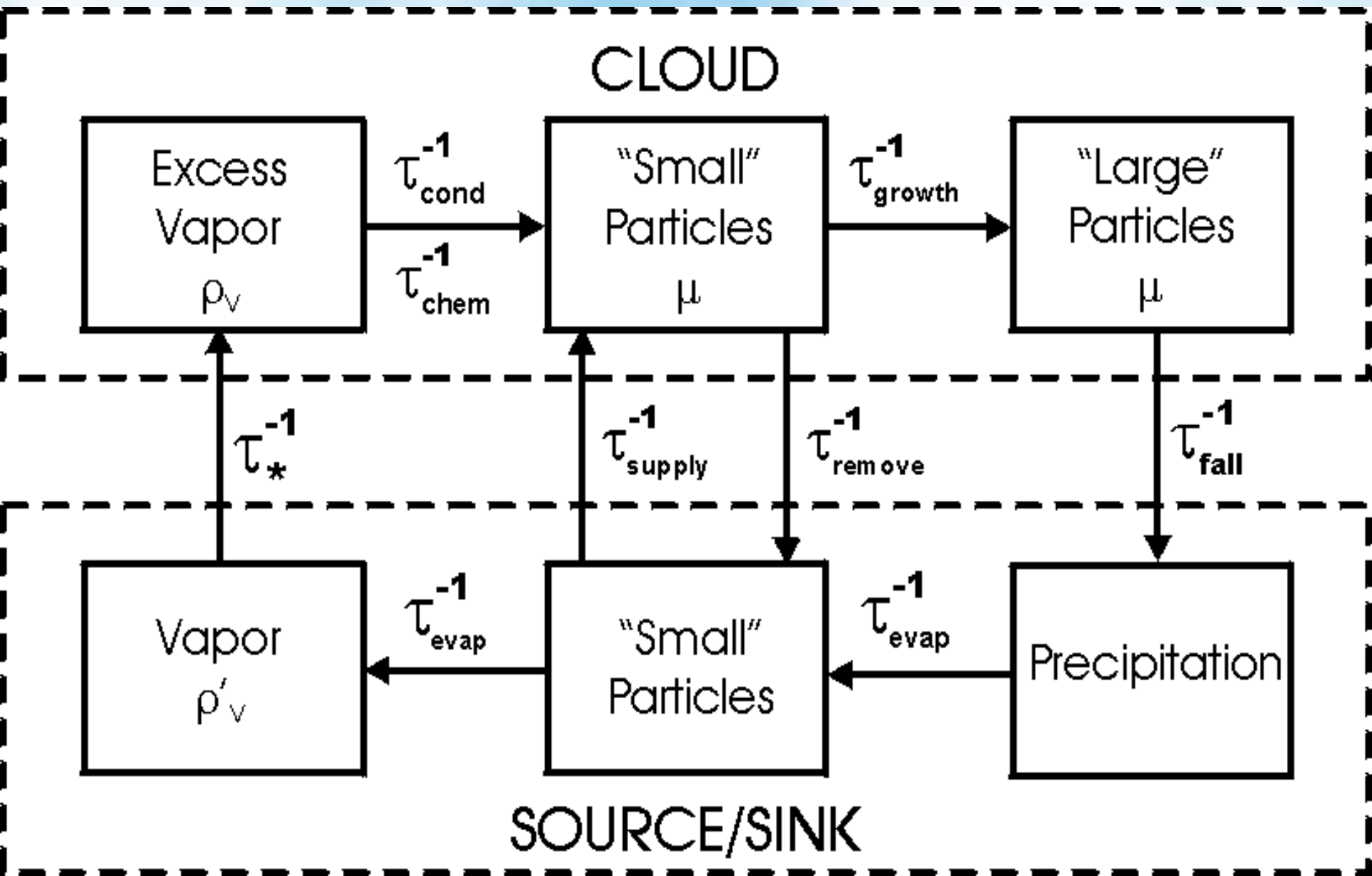
CLOUDS ARE NOT

AN EQUILIBRIUM STATE

USUALLY NOT

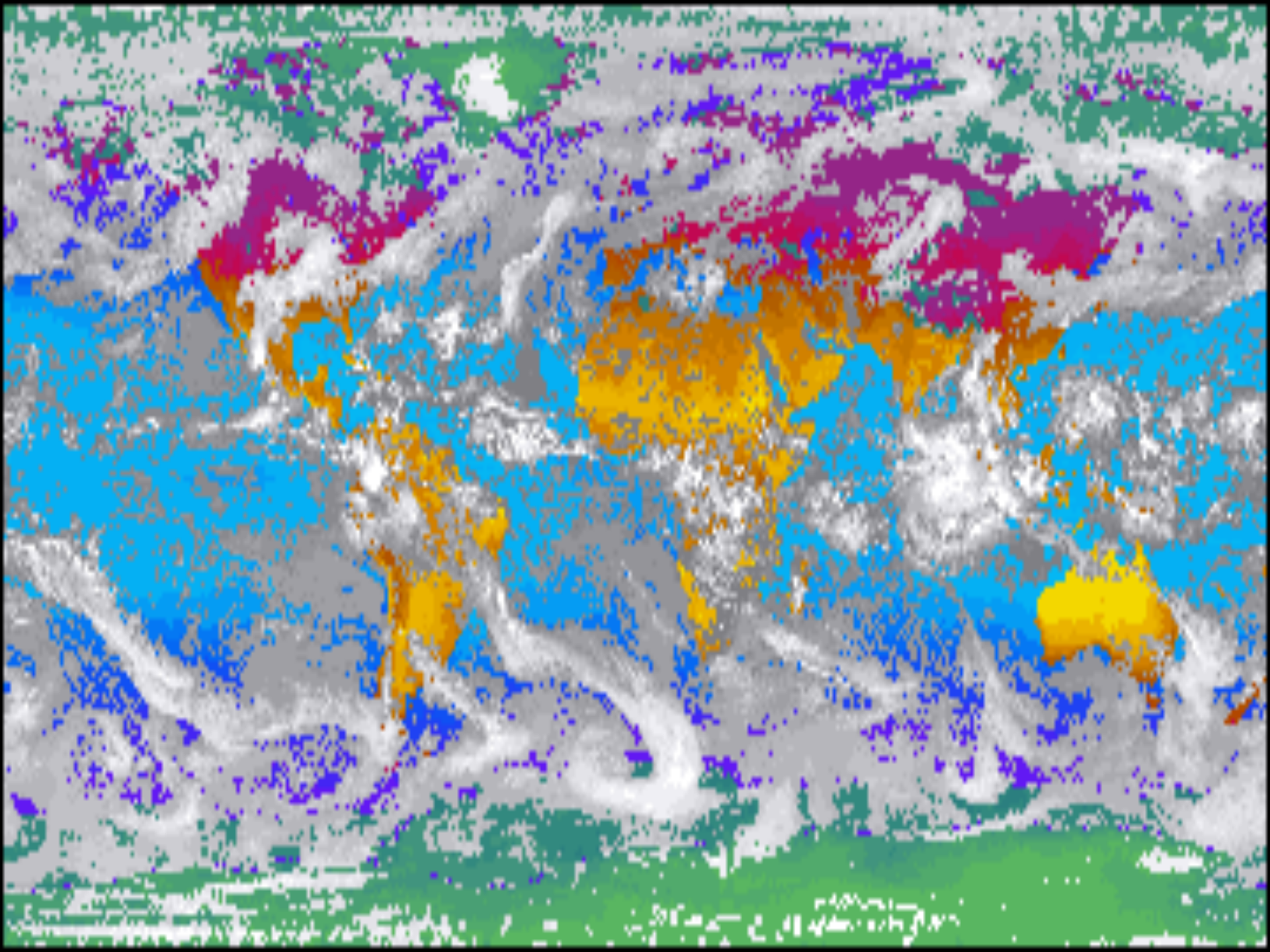
EVEN BALANCE OF RATES

Schematic Cloud Microphysics



CLOUDS ARE EMBEDDED IN THE GENERAL CIRCULATION

NON-LOCAL DYNAMICAL META-STATE



TWO CRITICAL PHASE CHANGES

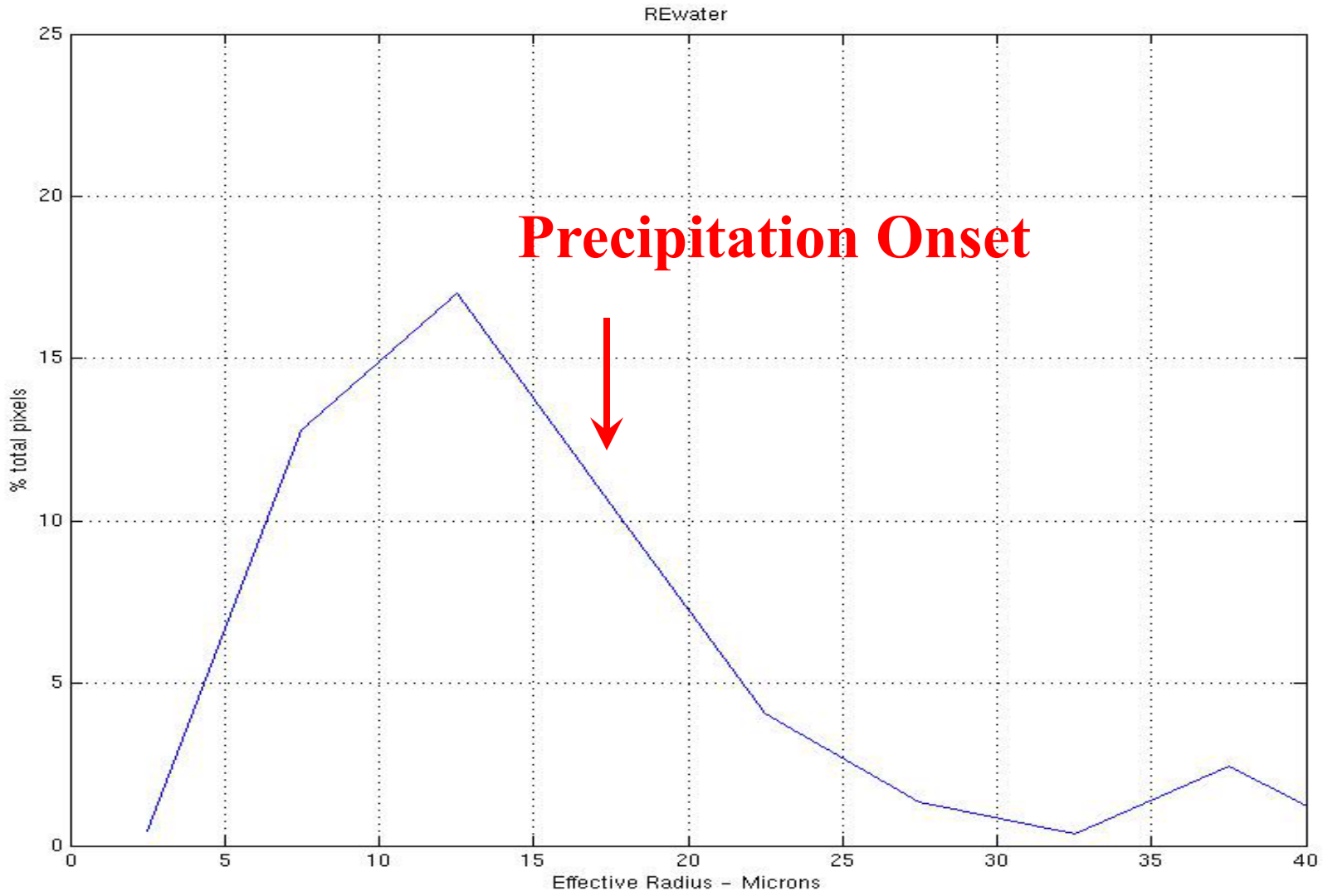
PHASE OF CLOUD PARTICLES

SIZE OF CLOUD PARTICLES, PRECIPITATION ONSET

NUMBER OF CLOUD PARTICLES
IS NOT TOO CRITICAL

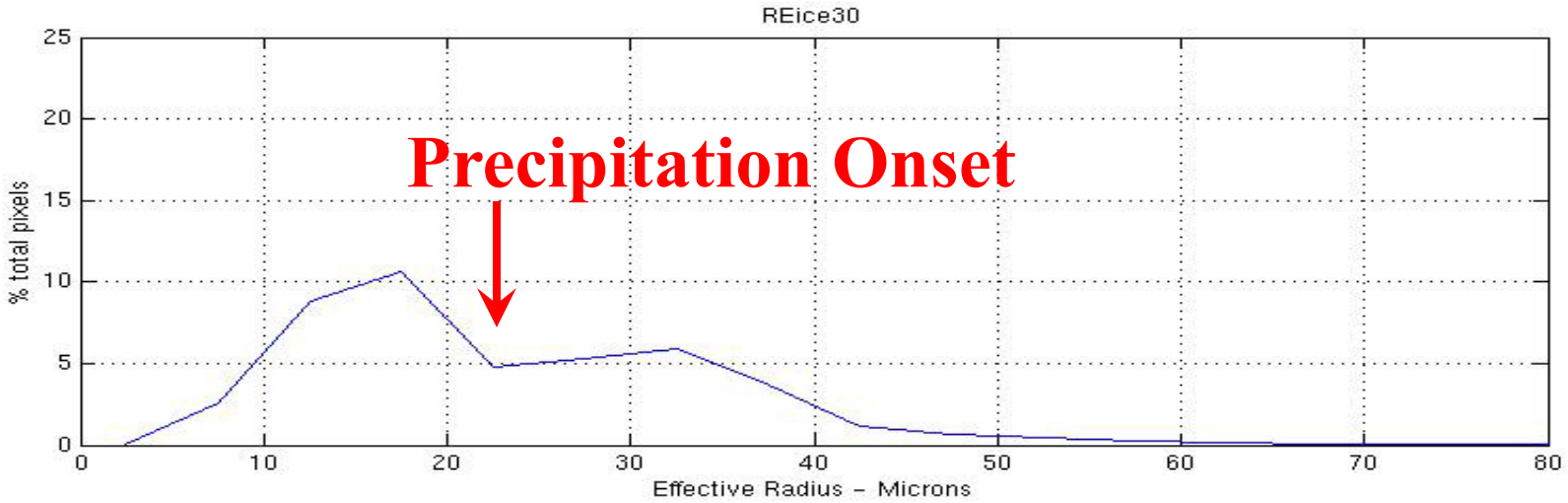
Effective Radius (μm) for Liquid Clouds (Temperature > 273 K)

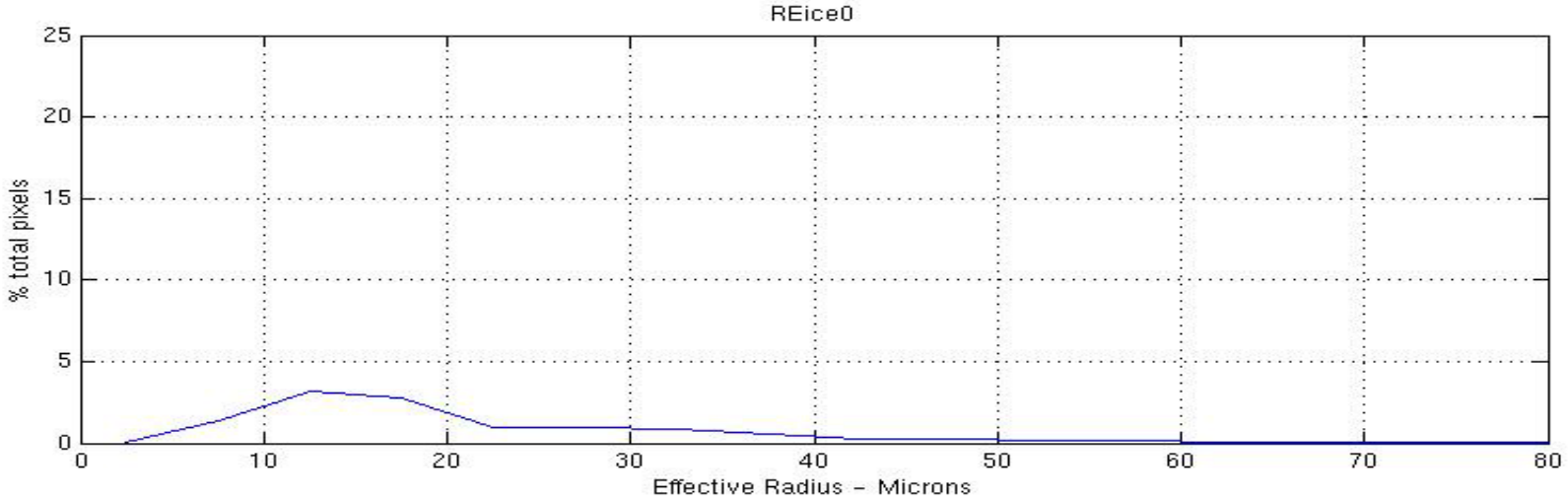
NOAA-14 for 1995



Effective Radius (μm) for Ice Clouds (Temperature < 260 K)

NOAA-14 for 1995



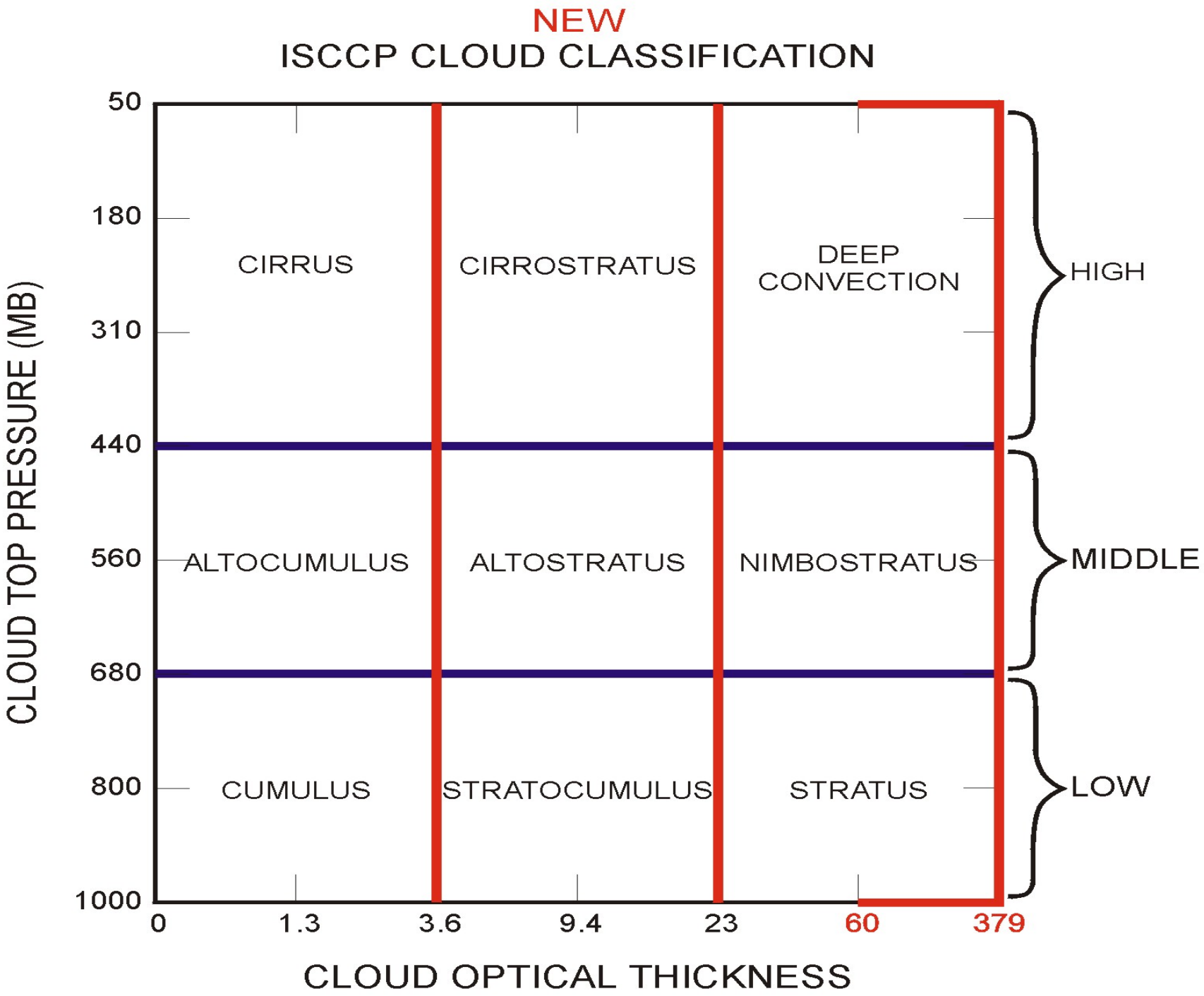


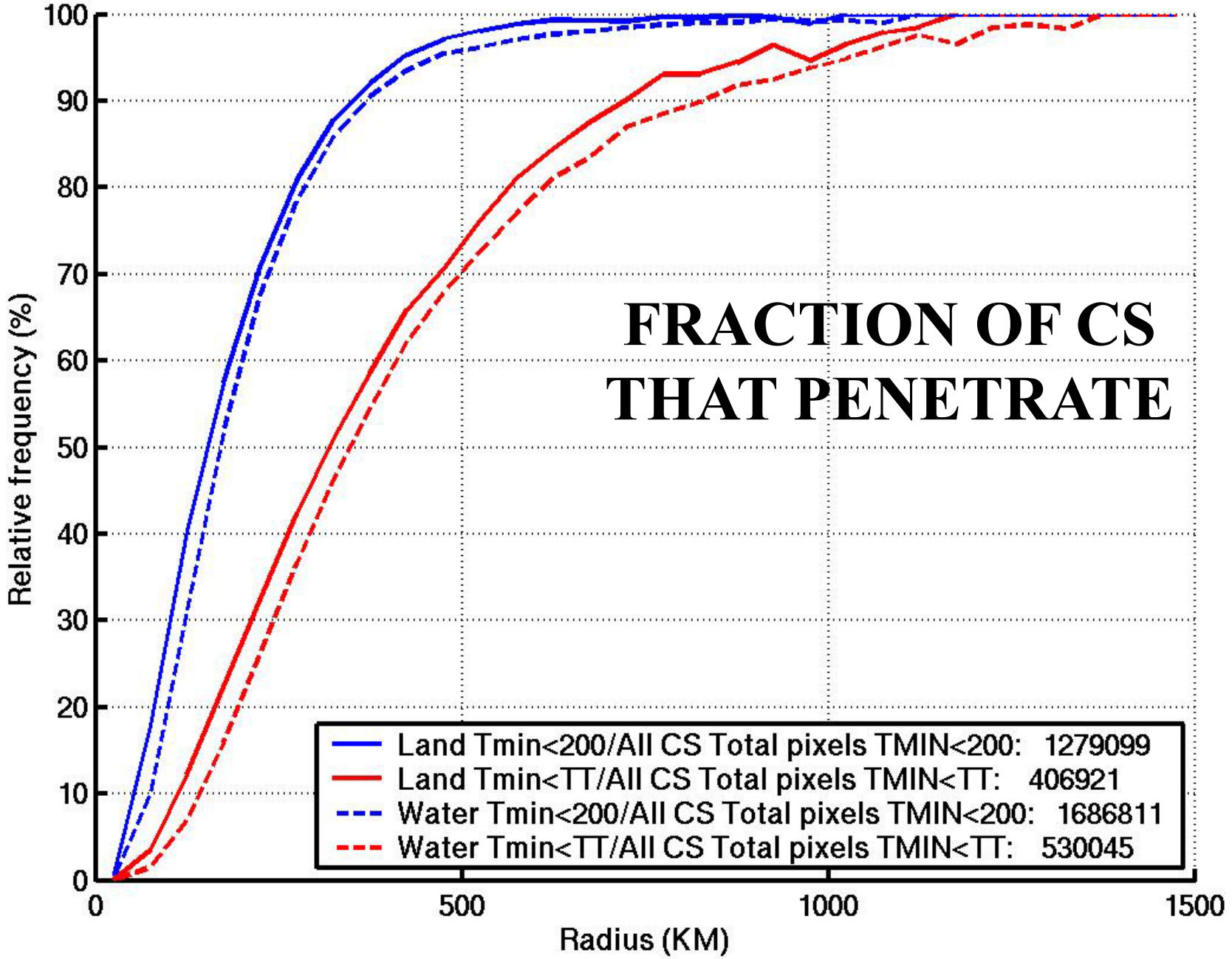
DYNAMICAL ANALYSIS APPROACHES

ATTRIBUTE COMPOSITES

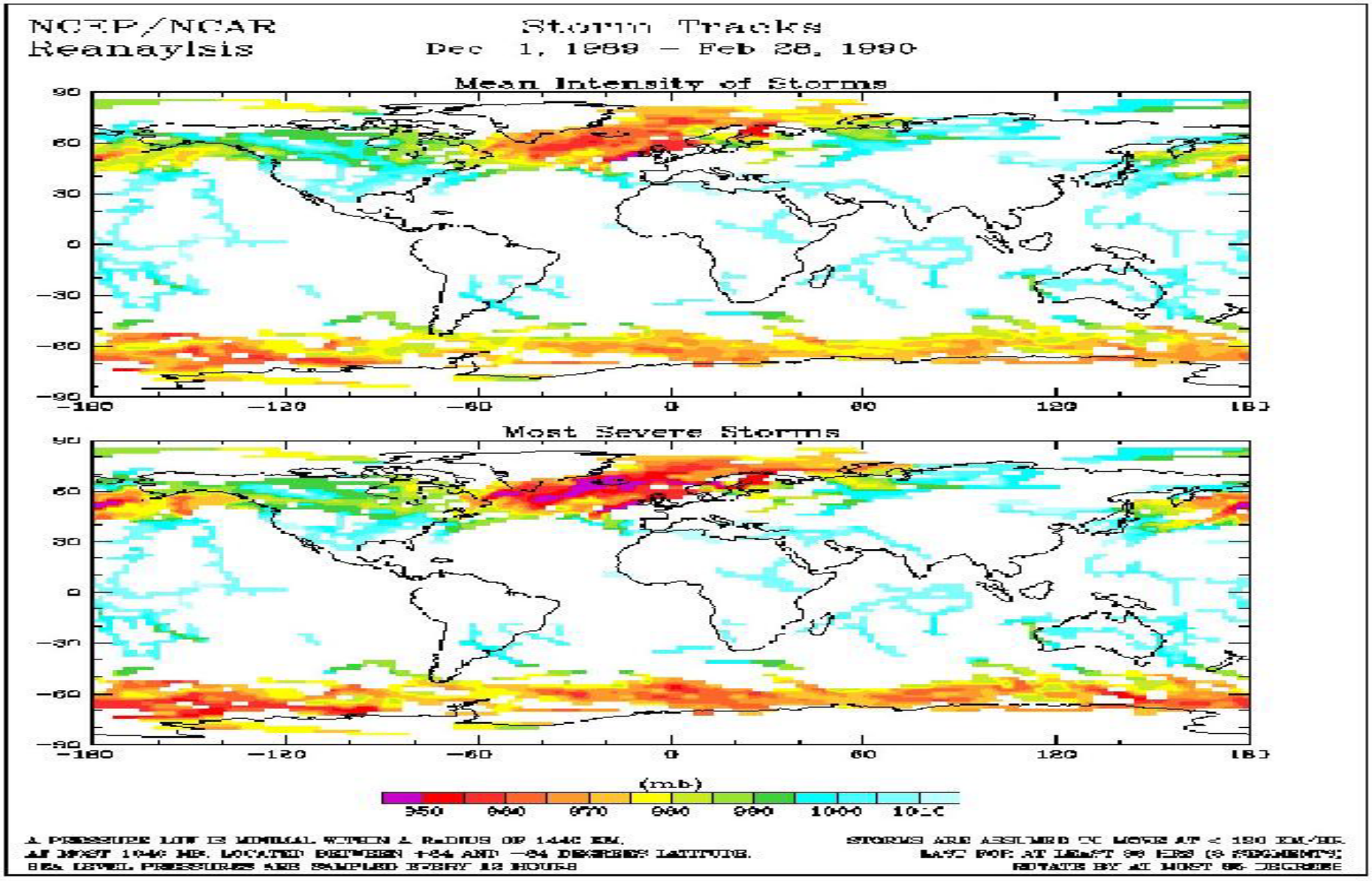
LAGRANGIAN EVOLUTION

STATE TRANSITIONS

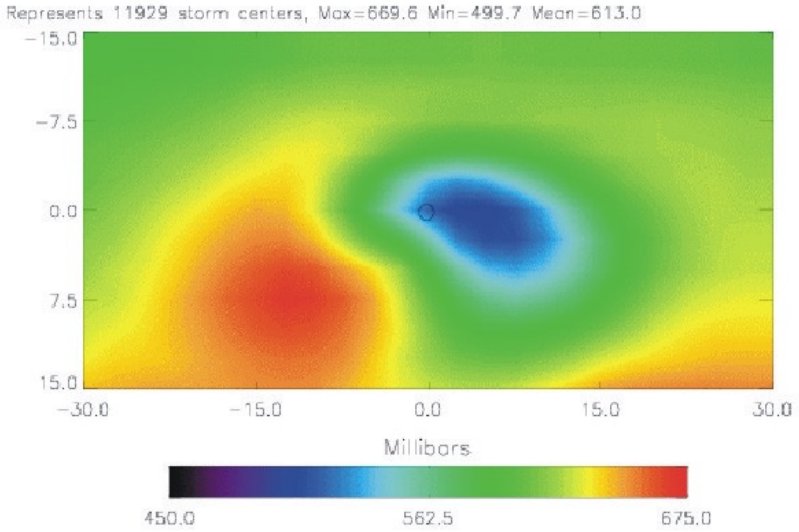

NEW
ISCCP CLOUD CLASSIFICATION
CLOUD TOP PRESSURE (MB)
50
180
310
440
560
680
800
1000
CIRRUS
CIRROSTRATUS
DEEP CONVECTION
ALTOCUMULUS
ALTOSTRATUS
NIMBOSTRATUS
CUMULUS
STRATOCUMULUS
STRATUS
HIGH
MIDDLE
LOW
0
1.3
3.6
9.4
23
60
379
CLOUD OPTICAL THICKNESS


FRACTION OF CS
THAT PENETRATE
Relative frequency (%)
Radius (KM)
0
10
20
30
40
50
60
70
80
90
100
0
500
1000
1500
Land Tmin<200/All CS Total pixels TMIN<200: 1279099
Land Tmin<TT/All CS Total pixels TMIN<TT: 406921
Water Tmin<200/All CS Total pixels TMIN<200: 1686811
Water Tmin<TT/All CS Total pixels TMIN<TT: 530045

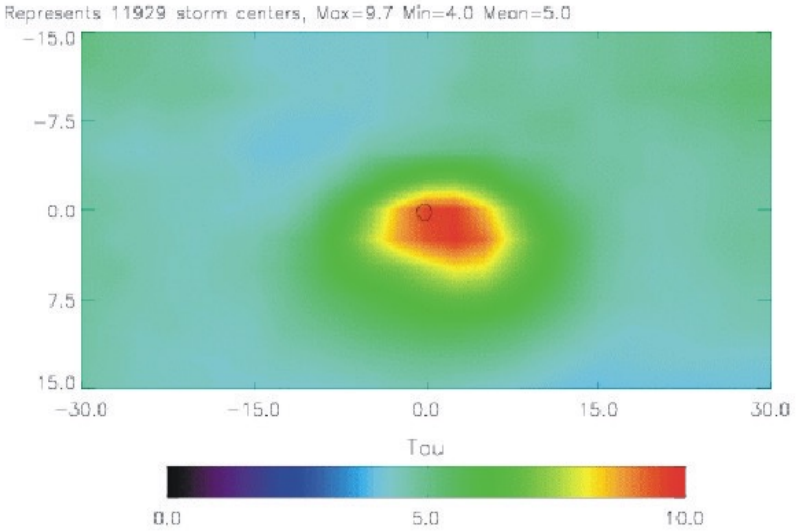
Storm Tracks



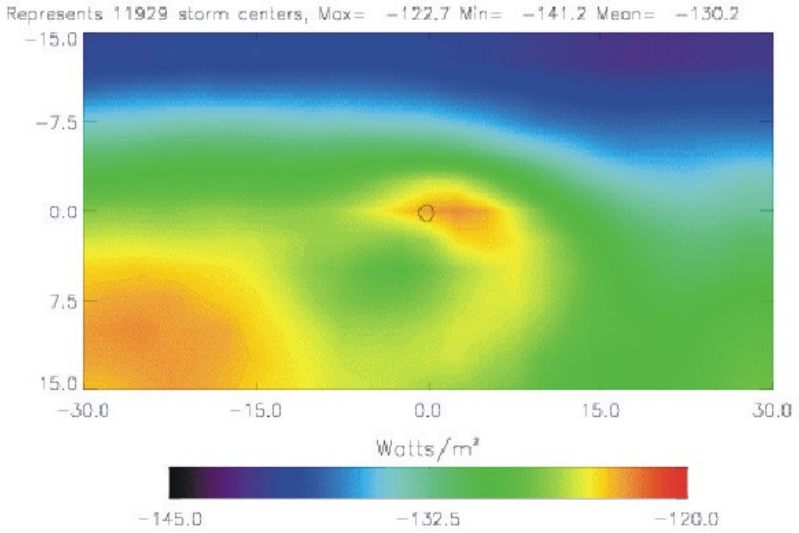
ALL – D1 CLDTPRES_VIS
ALL 30N-65N NCEP DJF SLP ANOM



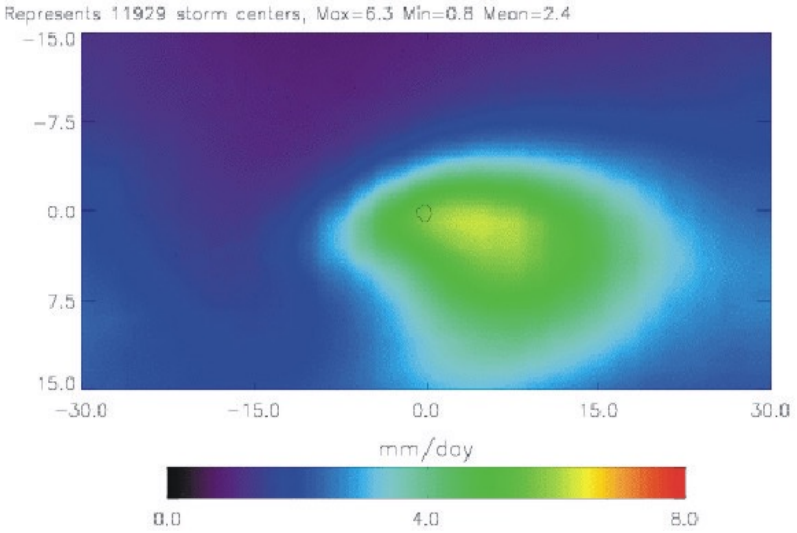
ALL – D1 Optical Depth
ALL 30N-65N NCEP DJF SLP ANOM

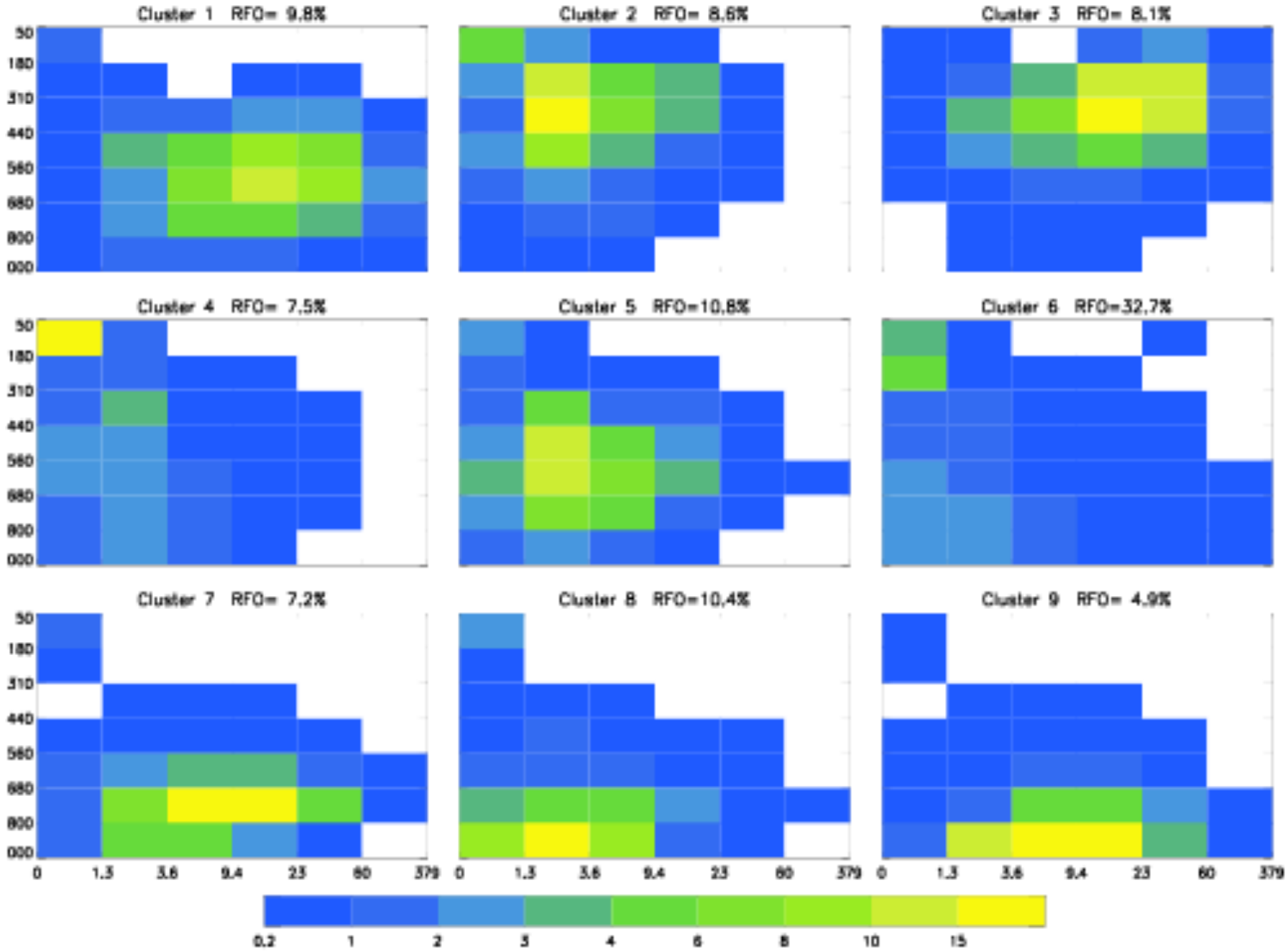


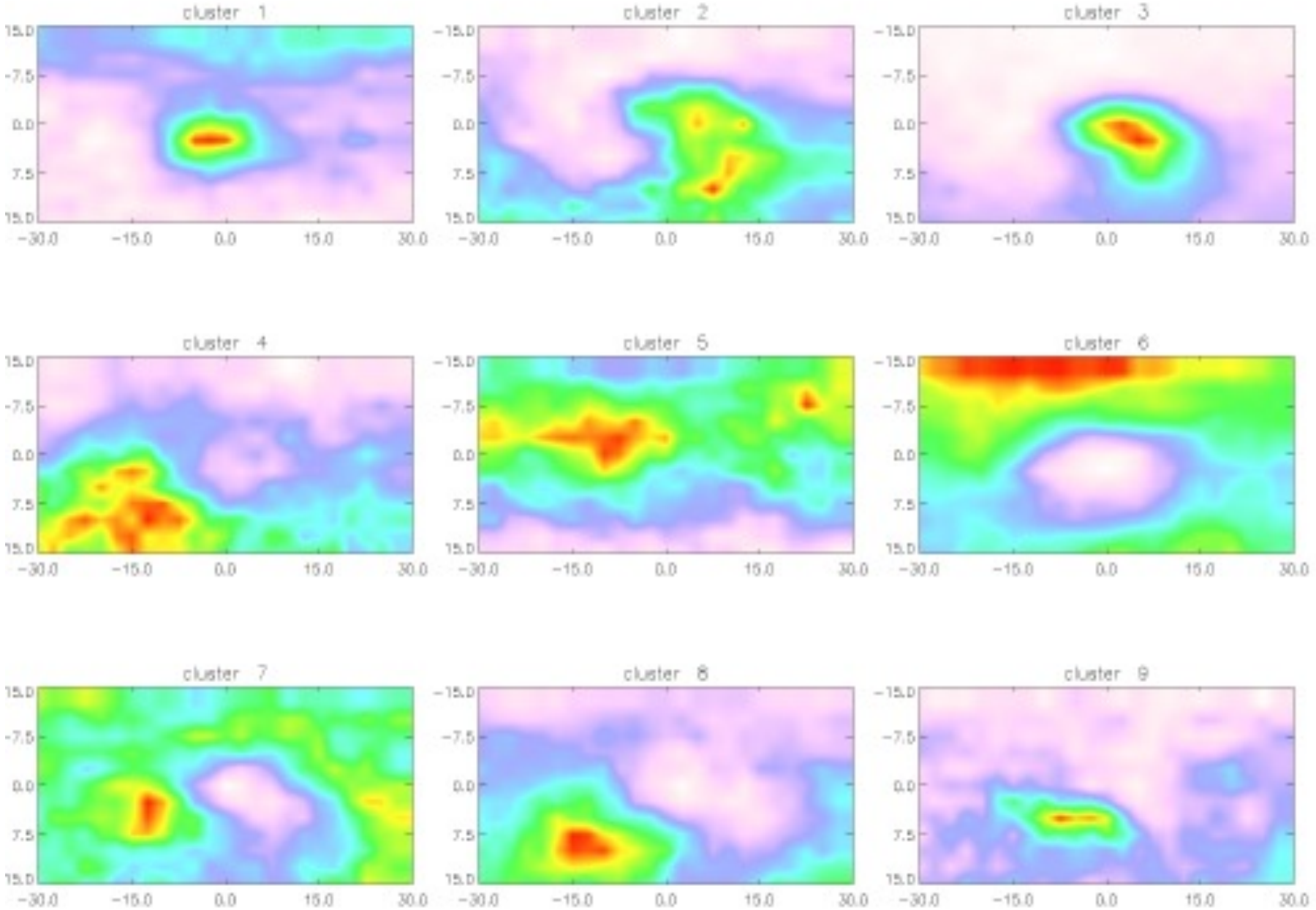
ALL – Net flux in ATM
ALL 30N-65N NCEP DJF SLP ANOM



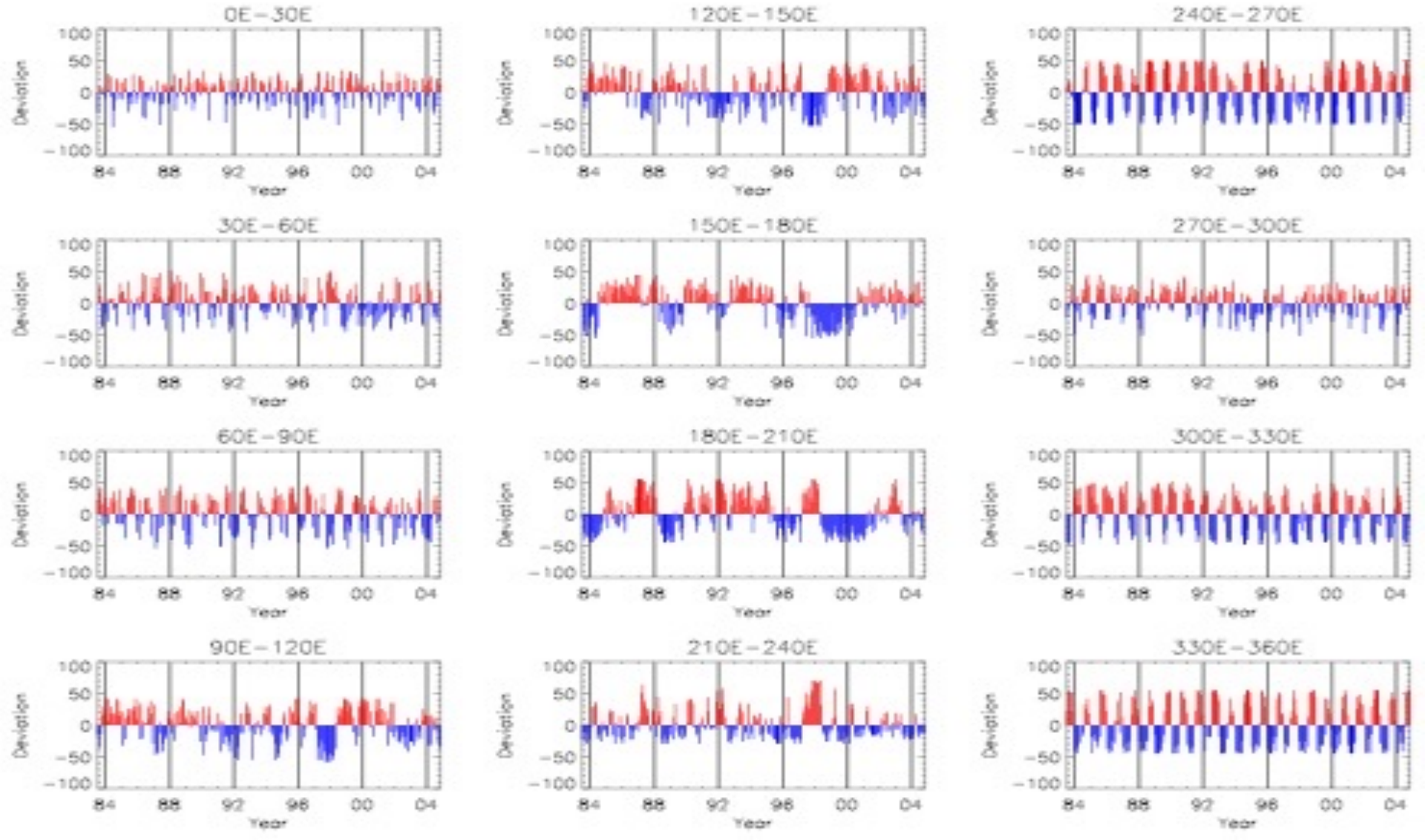
ALL – GPCP PRECIP
ALL 30N-65N NCEP DJF SLP ANOM




Cluster 1 RFO= 9.8%
Cluster 2 RFO= 8.6%
Cluster 3 RFO= 8.1%
Cluster 4 RFO= 7.5%
Cluster 5 RFO=10.8%
Cluster 6 RFO=32.7%
Cluster 7 RFO= 7.2%
Cluster 8 RFO=10.4%
Cluster 9 RFO= 4.9%
50
180
310
440
560
680
800
000
0
1.3
3.6
9.4
23
60
379
0.2
1
2
3
4
6
8
10
15


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

Monthly Variation of "More Convective" State in Tropical Longitude Sectors



STATE DEPENDENT RELATIONSHIPS

$$\frac{\partial CLOUD}{\partial TIME} \Leftrightarrow PHYSICAL\ PROCESSES$$

$$\frac{\partial CLIMATE}{\partial TIME} \Leftrightarrow \frac{\partial TIME}{\partial CLOUD} \Leftrightarrow FEEDBACKS$$

BACKUP SLIDES

Thanks to a Cast of Hundreds

Radiation Codes: **Lacis, Mishchenko**, Pardo, Cairns, Travis

Cloud Detection Methods: Arking, Briand, Coakley, Desbois, Hahn, Harrison, Minnis, Mosher, Ruprecht, **Seze**, Simmer, E. Smith, **Stubenrauch**, Vonder Haar, Warren, Wylie

ISCCP Participants: US, Canada, France, Germany, UK, Japan, China

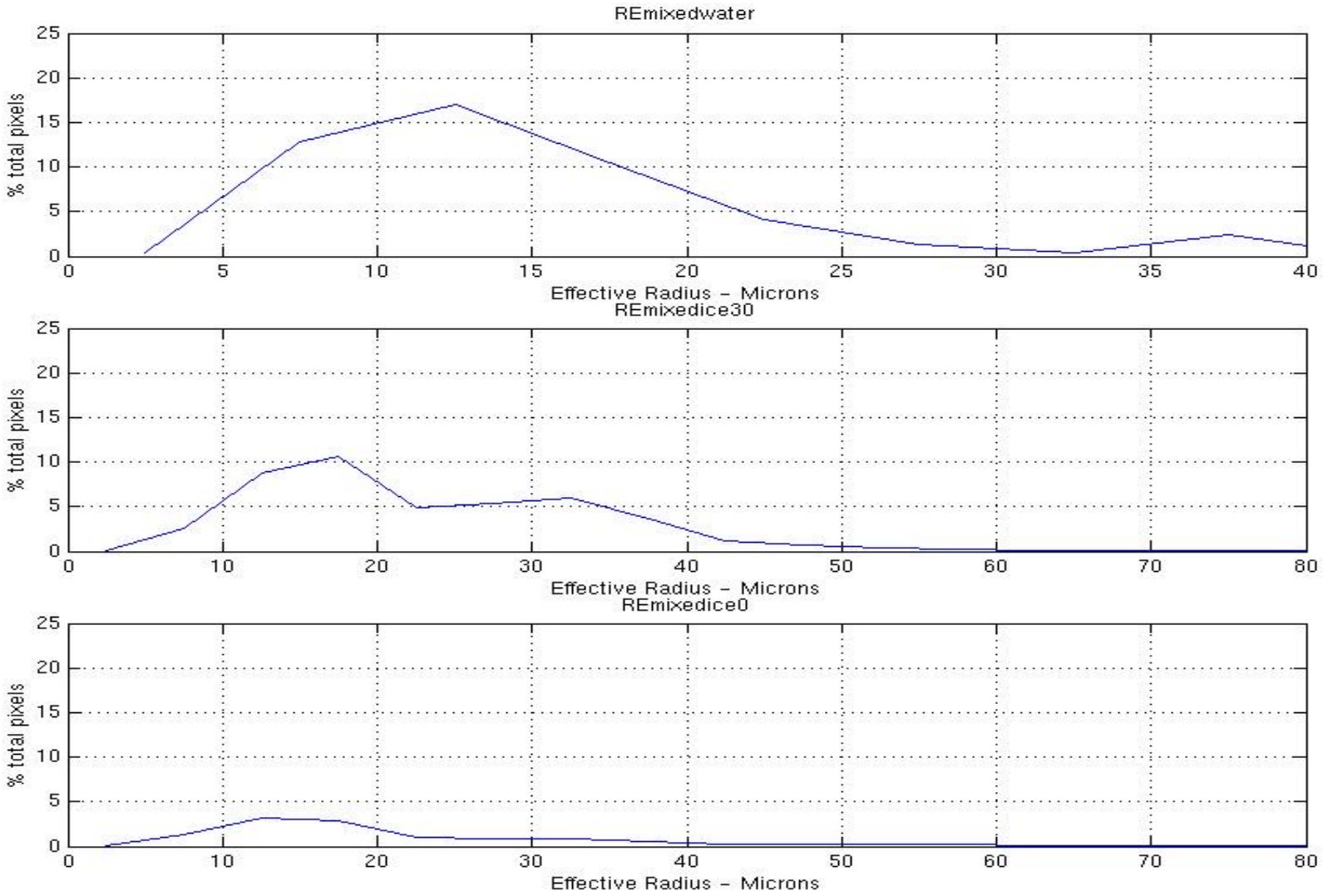
GISS-ISCCP Team Leaders: Bishop, Kinsella, Garder, Golea, Walker

Valued Advice: Bates, Curry, London, Raschke, **Schiffer**, Stephens, Wielicki

Analysis: Aires, Carlson, T. Chen, Garder, Del Genio, Fu, Han, Jakob, Jin, Liao, Lin, Luo, Machado, Pearl, Polak, Prigent, Roebeling, Romanski, Rozendaal, Siqueira, Stubenrauch, Tselioudis, Walker, Wang, Xu, Ye, Y-C. Zhang

Effective Radius (μm) for Mixed Clouds (260 < Temperature < 273 K)

NOAA-14 for 1995



OUTLINE --- Some Recent Results

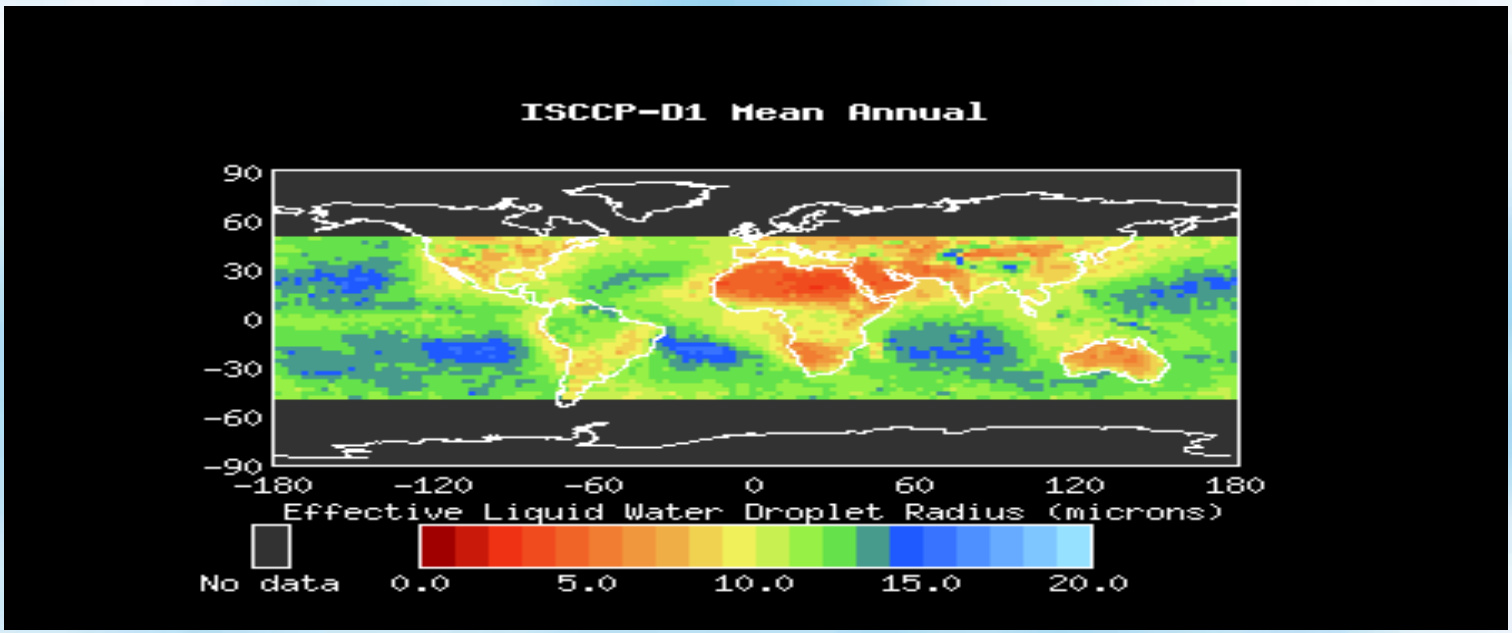
CLOUD MICROPHYSICS

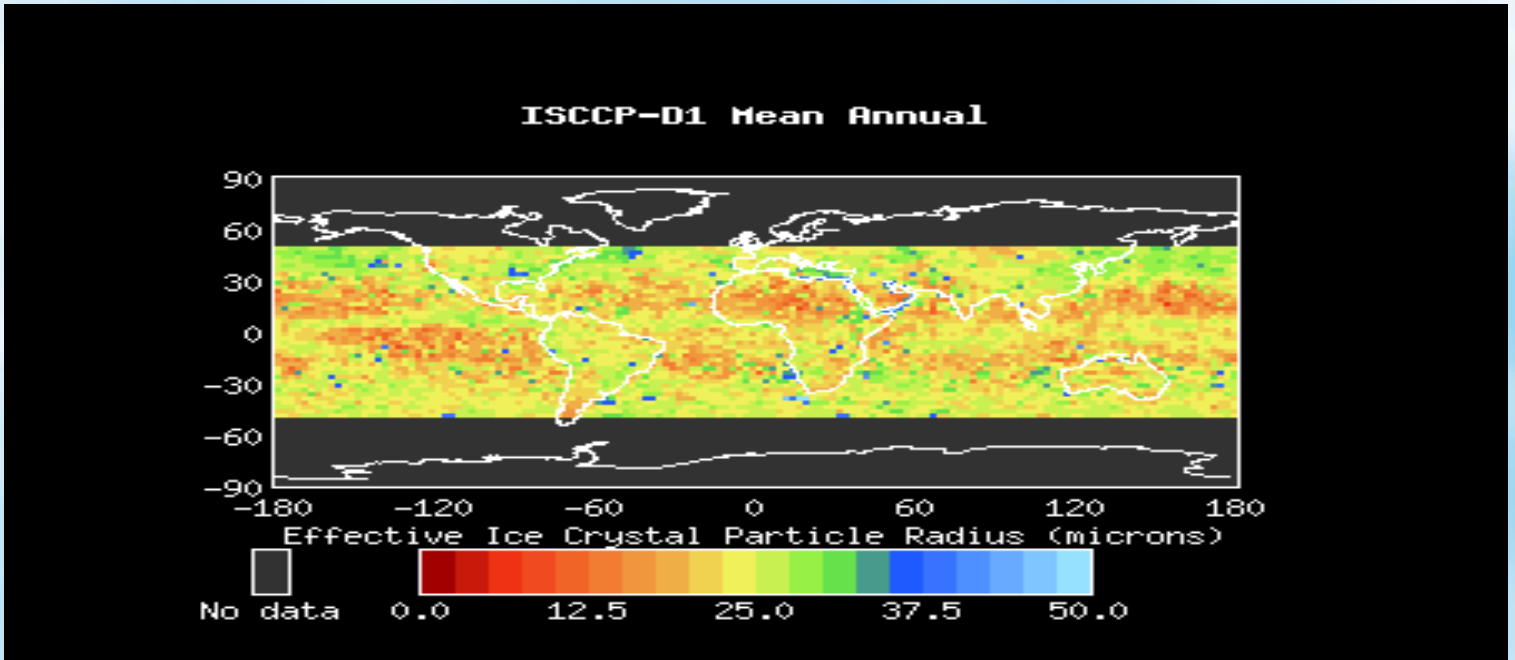
“STORM” CLOUDS

skipped -- CLOUD-TRACKED WINDS

CLOUDS & GENERAL CIRCULATION

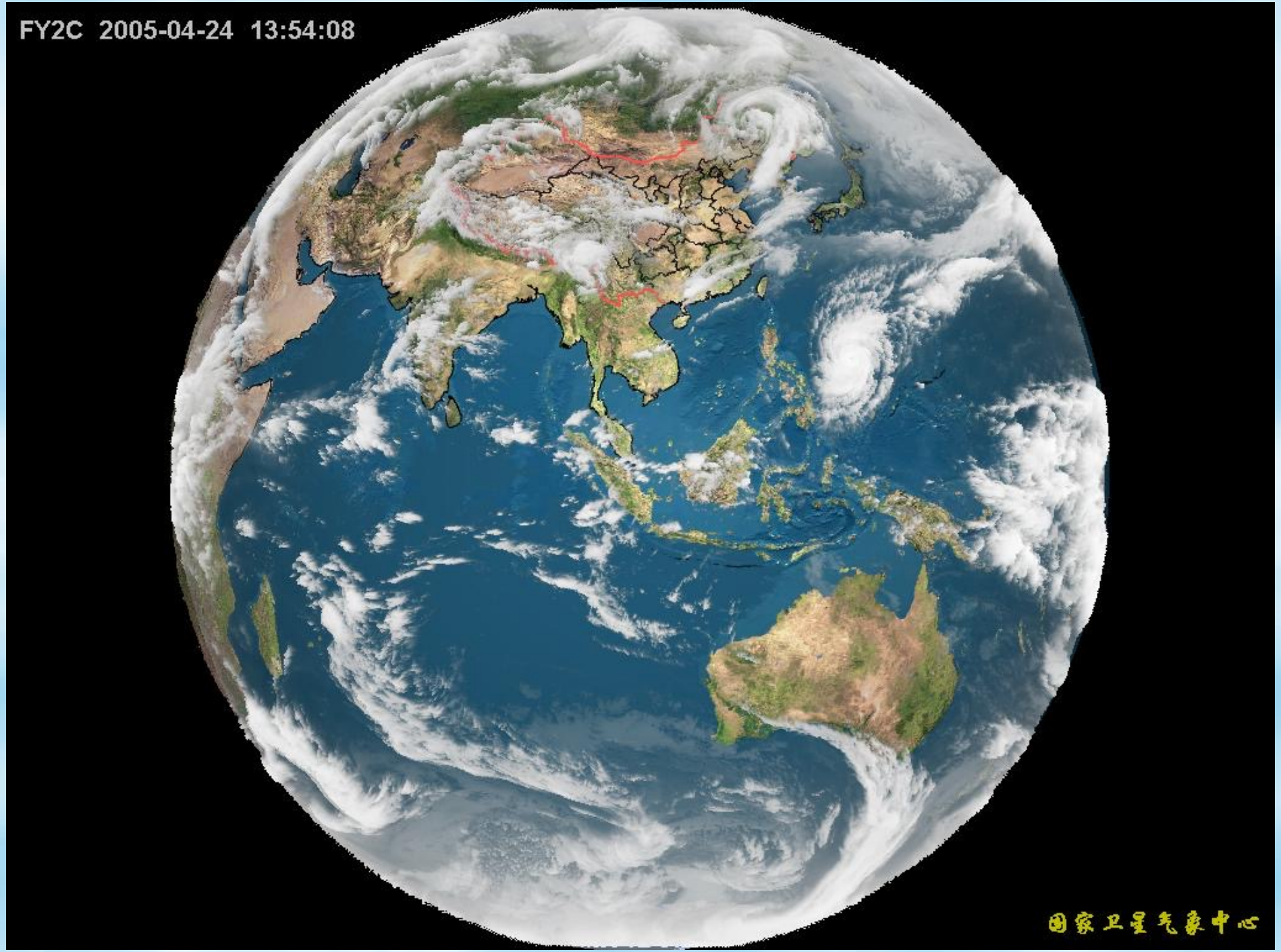
Average Cloud Particle Sizes



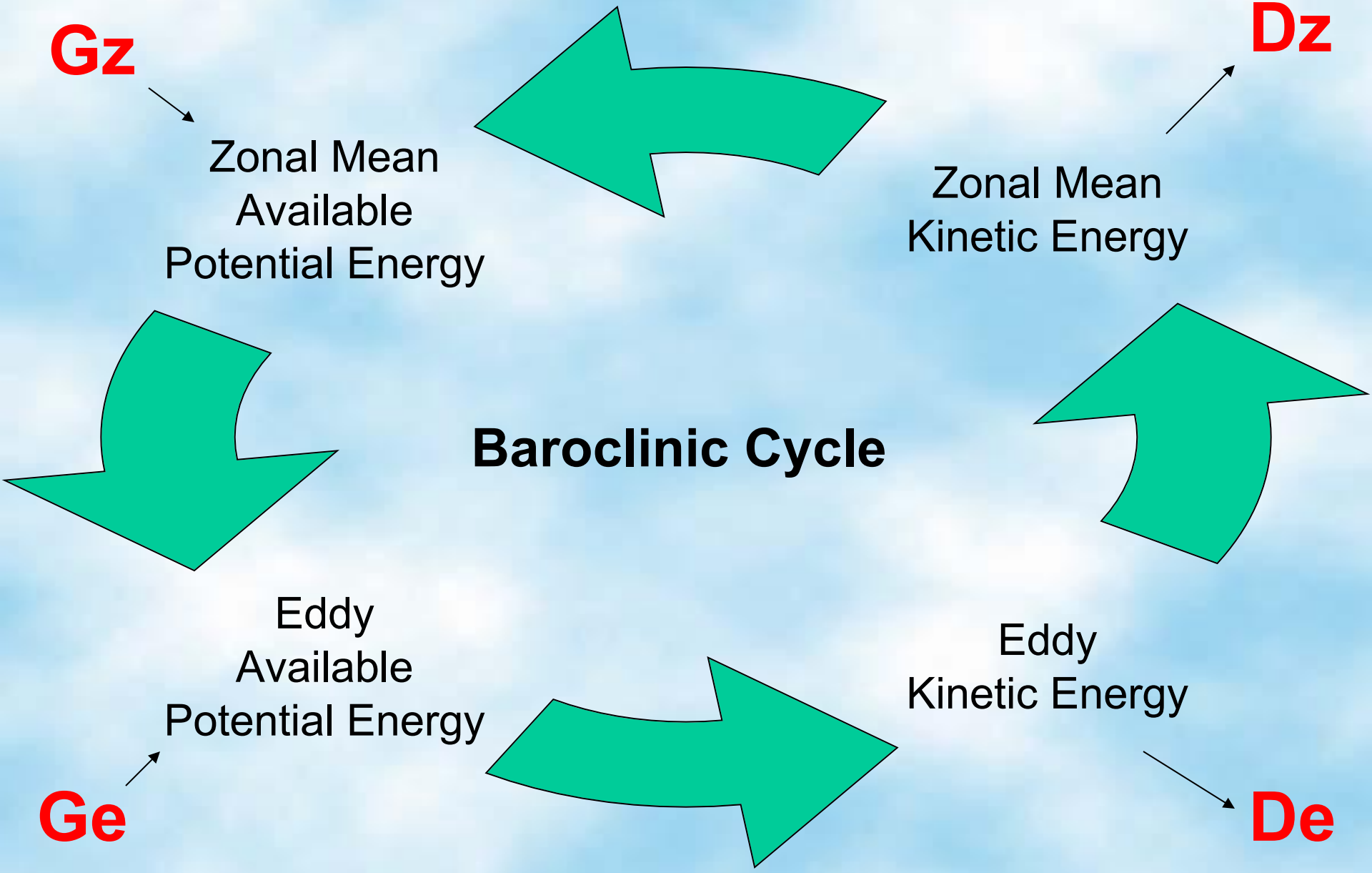


STORM CLOUDS

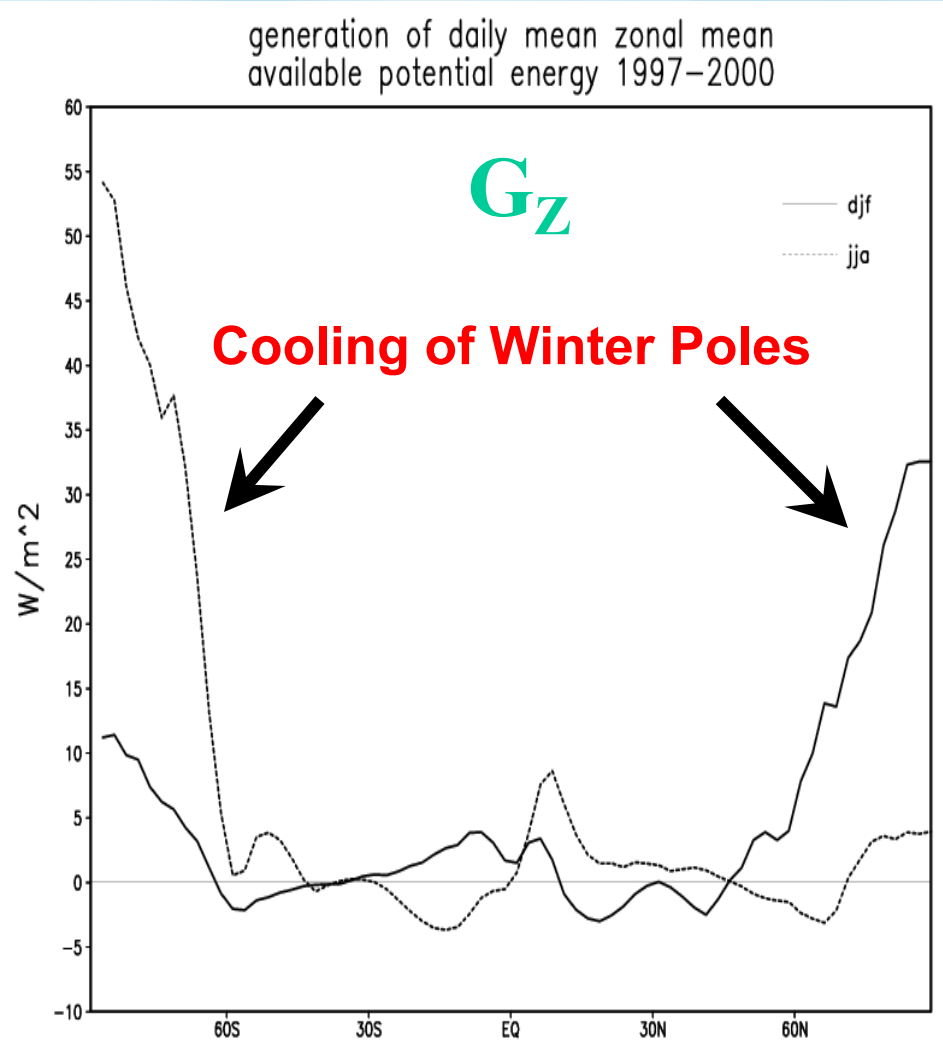
Storm as Perturbation of Mean State

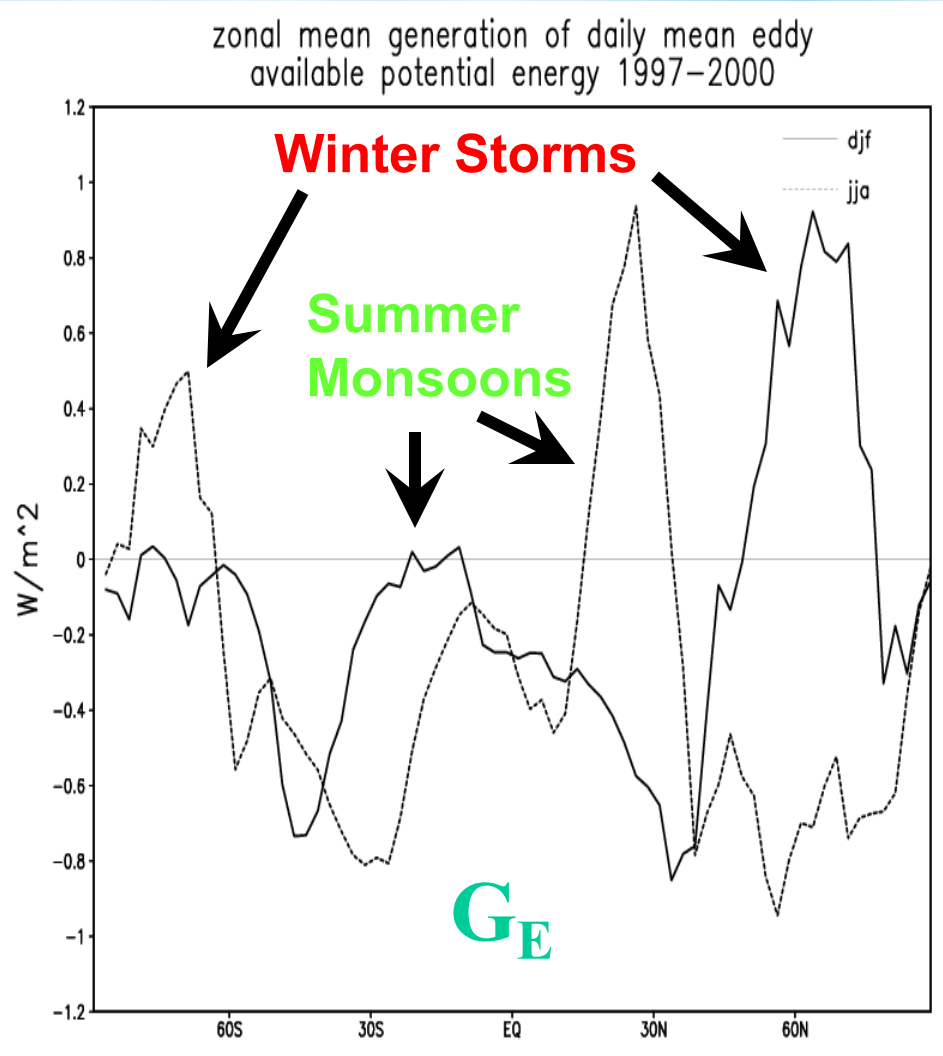

FY2C 2005-04-24 13:54:08
国家卫星气象中心

Energy Cycle of Atmosphere

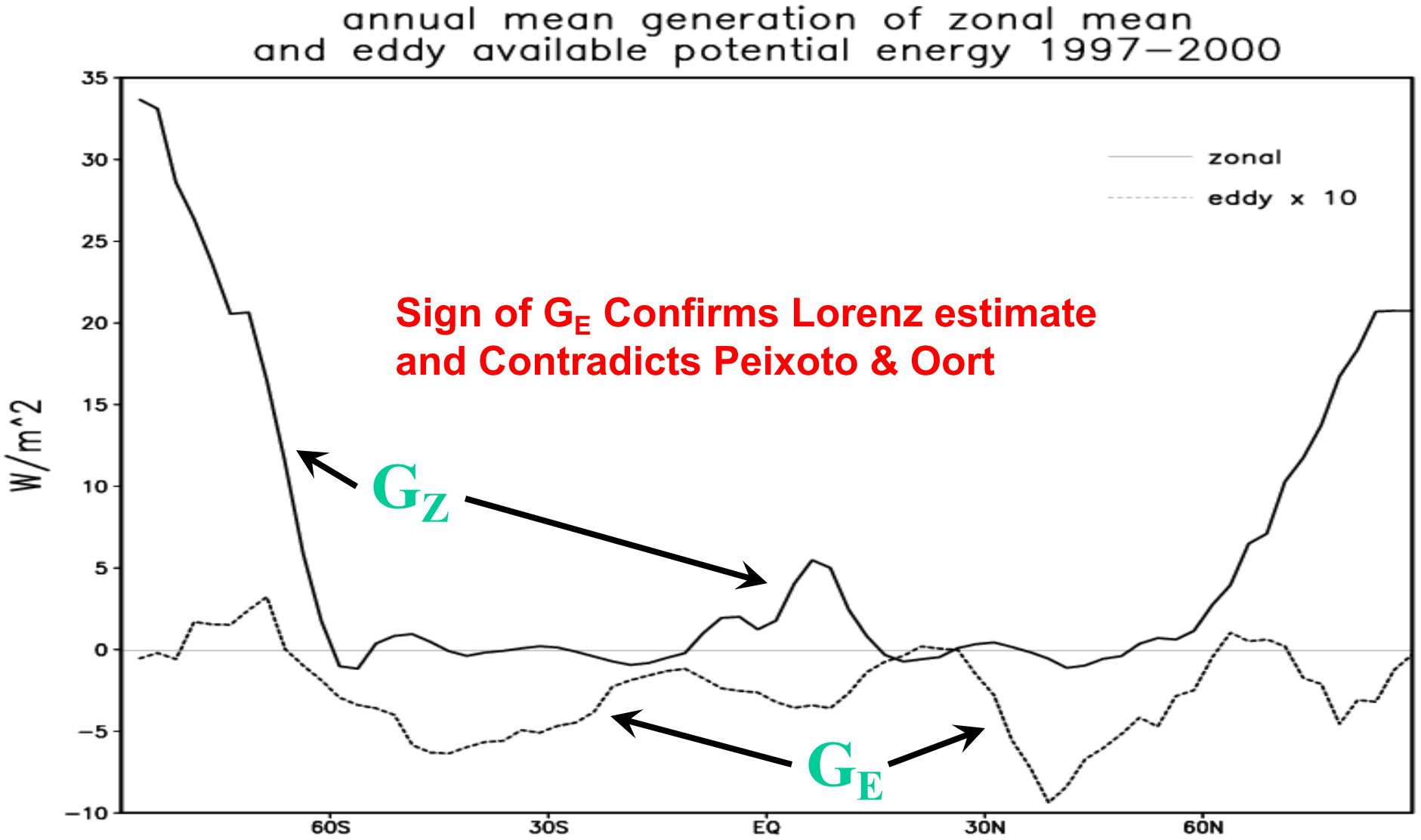


First Determination of Gz and Ge from Observations





Annual Mean Generation of APE



Current Cloud Property Data Sets

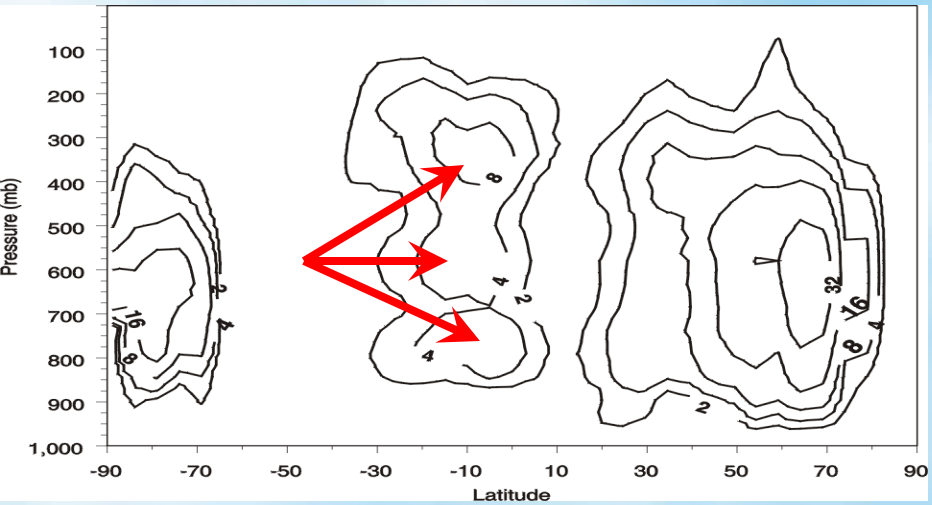
- (Quantity±instantaneous error, mean uncertainty, source)

- Cloud Cover ± 15%, 5%, satellite, surface weather obs.
- Cloud Top Temperature ± 3-6K, 2K, satellite
- Cloud Top Height ± 0.5-1.9 km, 0.3 km, satellite
- Cloud Optical Thickness ± 25%, 10%, satellite
- Cloud Particle Size ± 2 ?m (liquid), ± 10 ?m (ice),
  1 ?m (liquid), 10 ?m (ice), satellite
- Cloud Water Path ± 15% (liquid), ± 200% (ice),
  10% (liquid), 100% (ice), satellite
- Cloud Base Temperature ± 3-6K, 2K, surface obs.
- Cloud Base Height ± 0.5-1 km, 0.3 km, surface obs.
- Precipitation ± 30%, 15%, satellite, surface obs.
- Lightning ± 30%, 10%, satellite

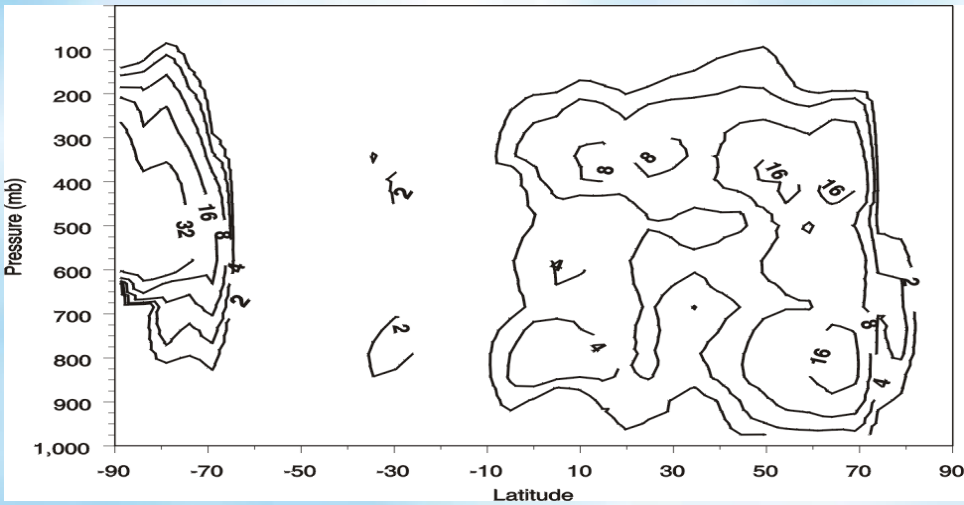
What's Left to Do? → Cloud Vertical Structure!!

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

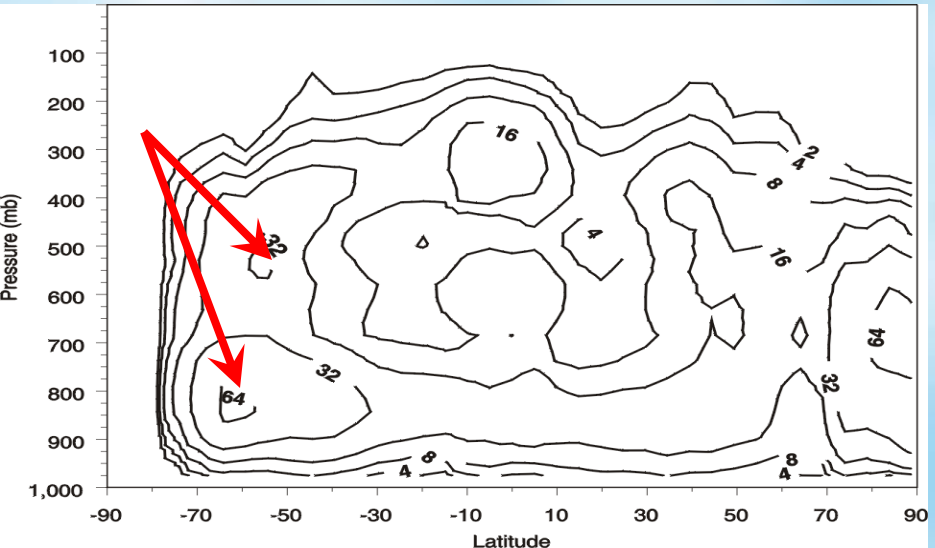
Land DJF



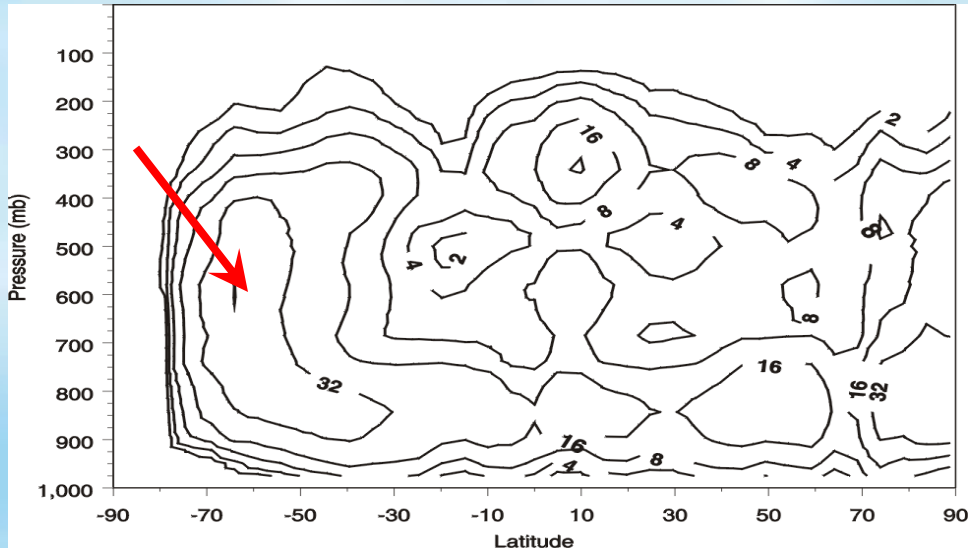
Land JJA



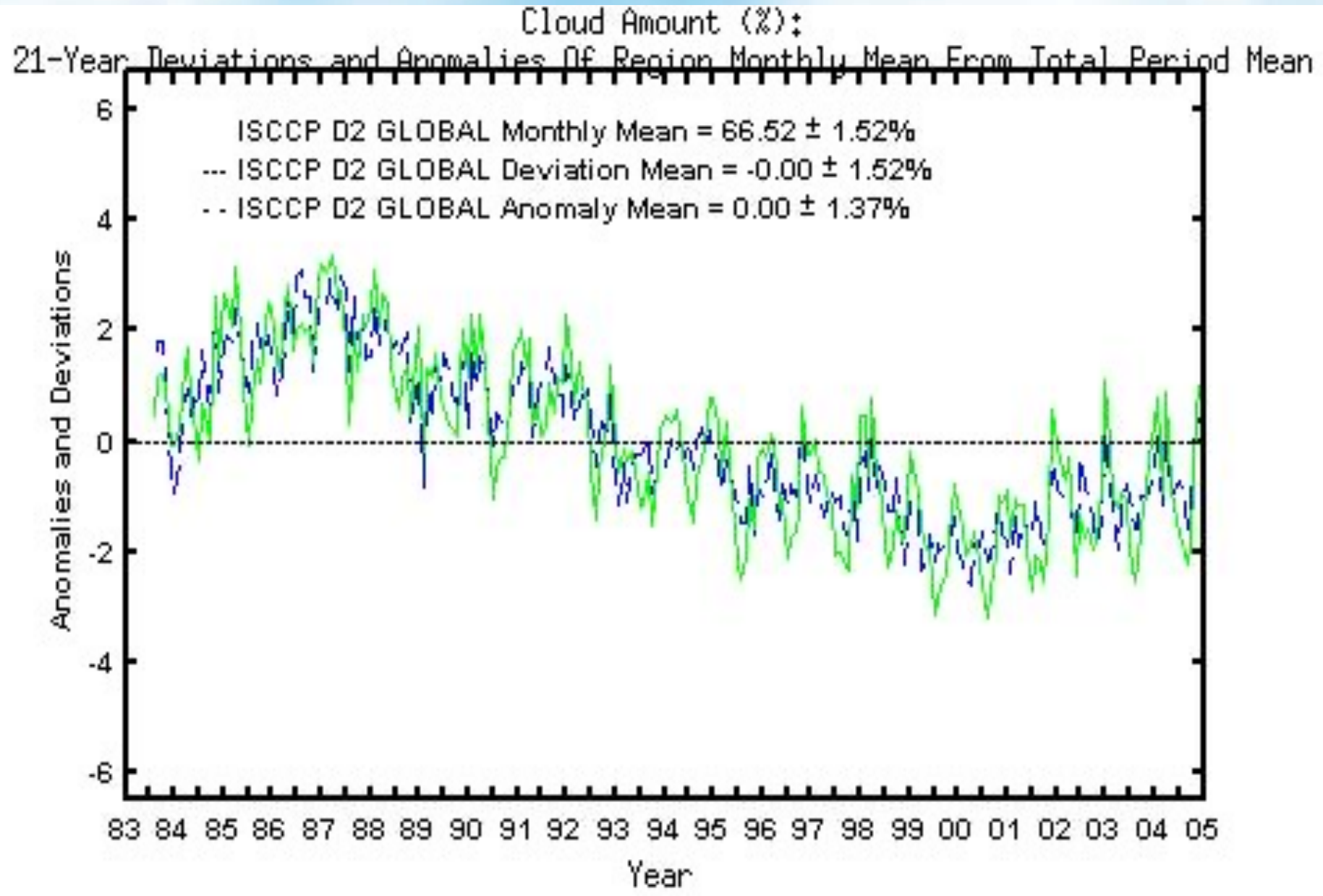
Ocean DJF



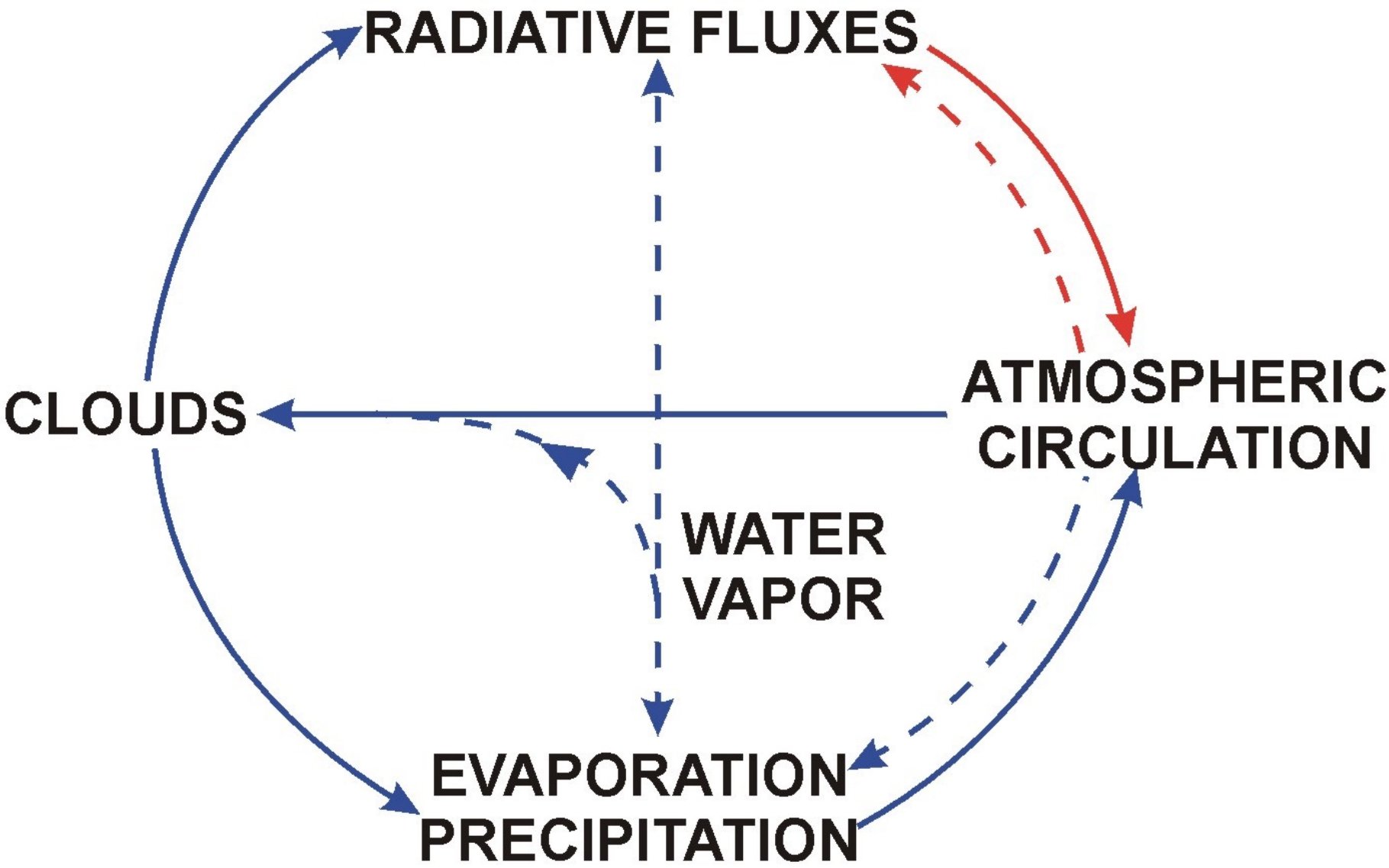
Ocean JJA



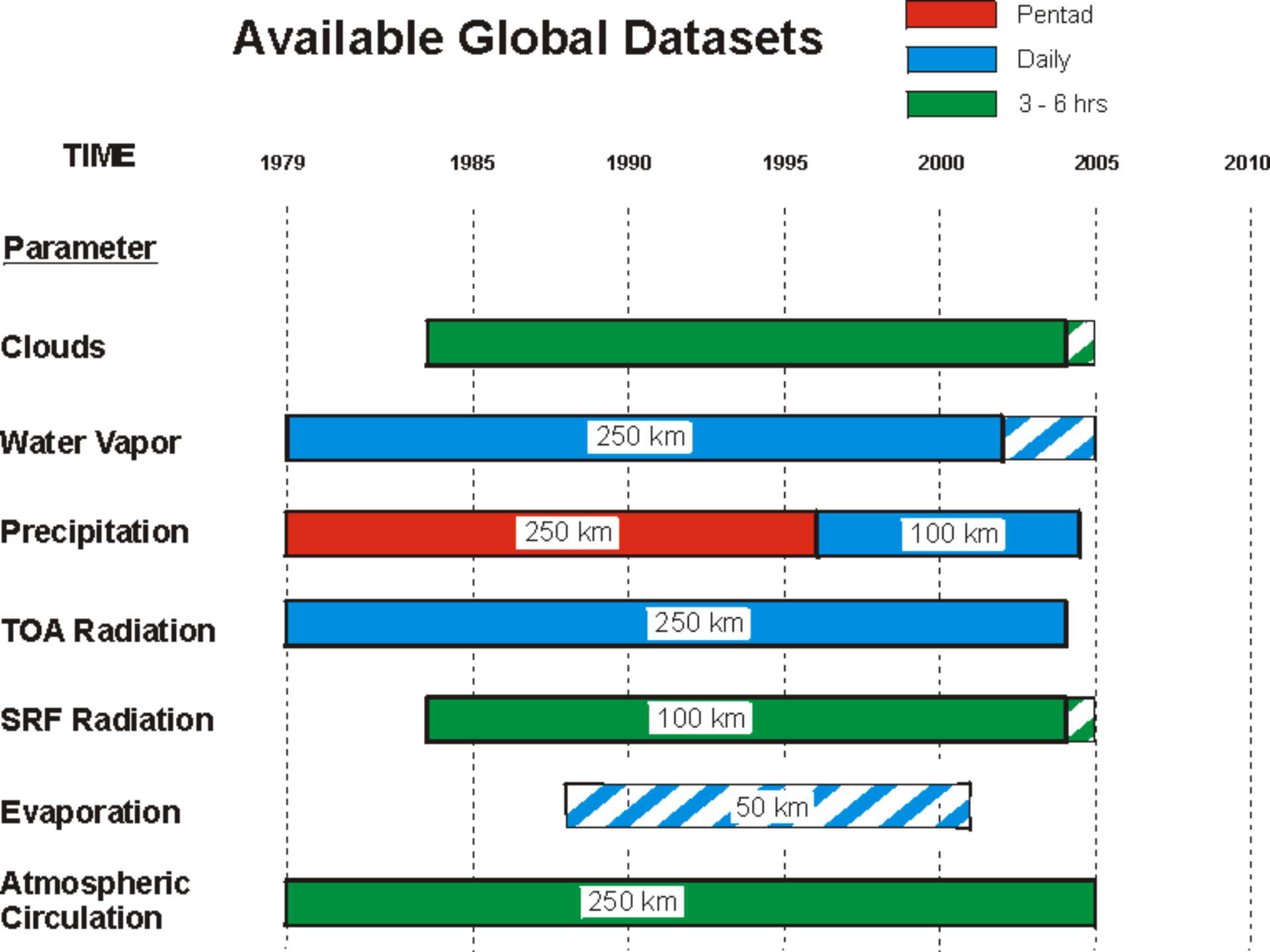
EXTENDING THE RECORD



ENERGY AND WATER CYCLE OF CLIMATE

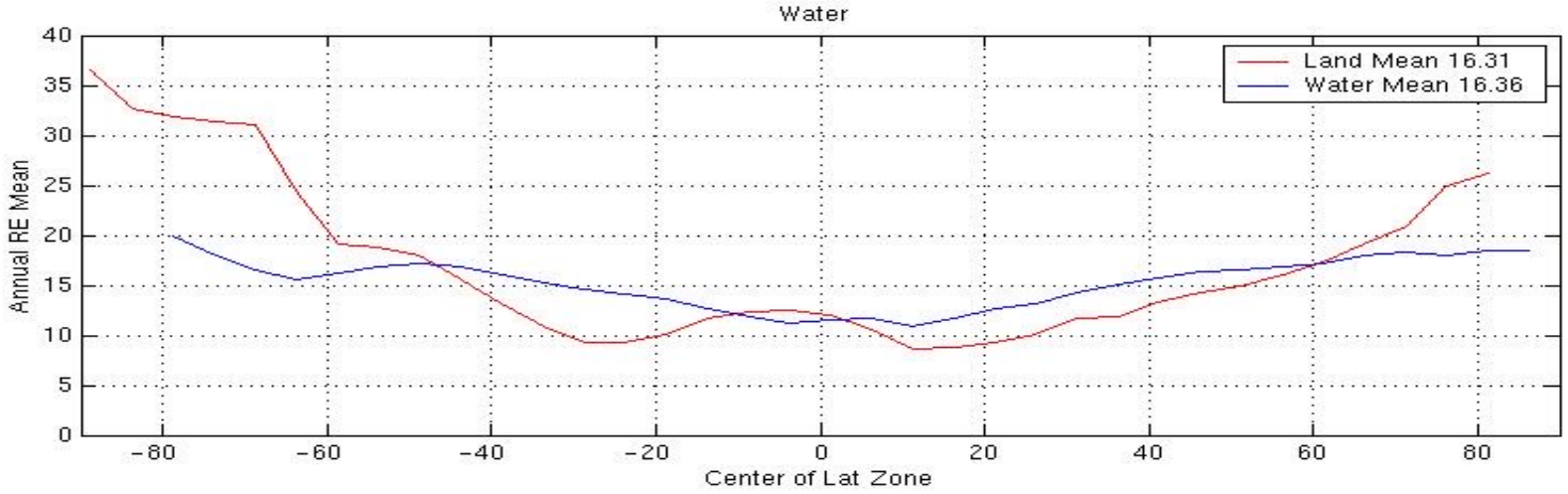


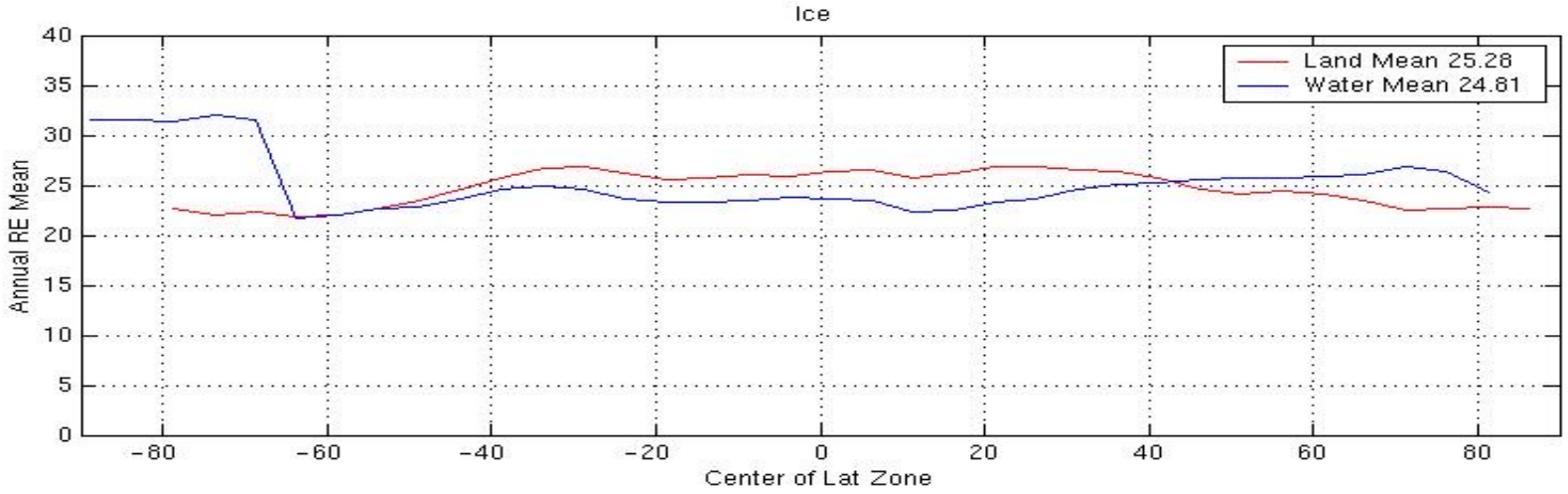
Available Global Datasets



Annual Mean Effective Radius (μm)
Liquid and Ice for Land and Water

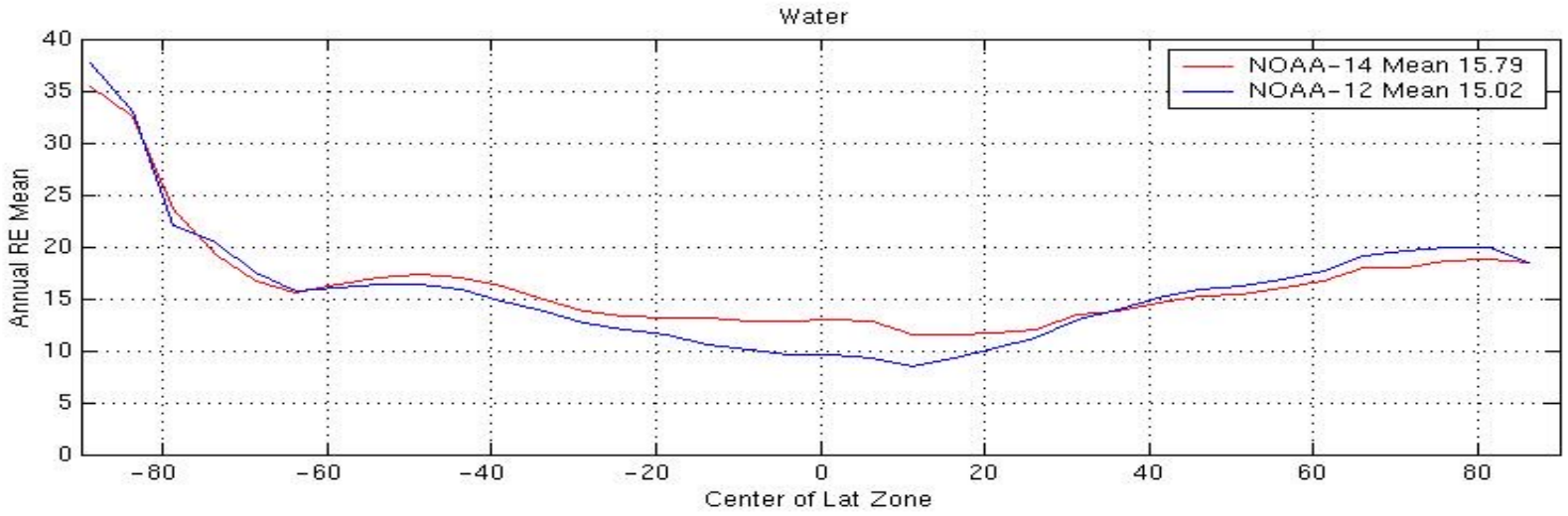
NOA/NOM for 1995

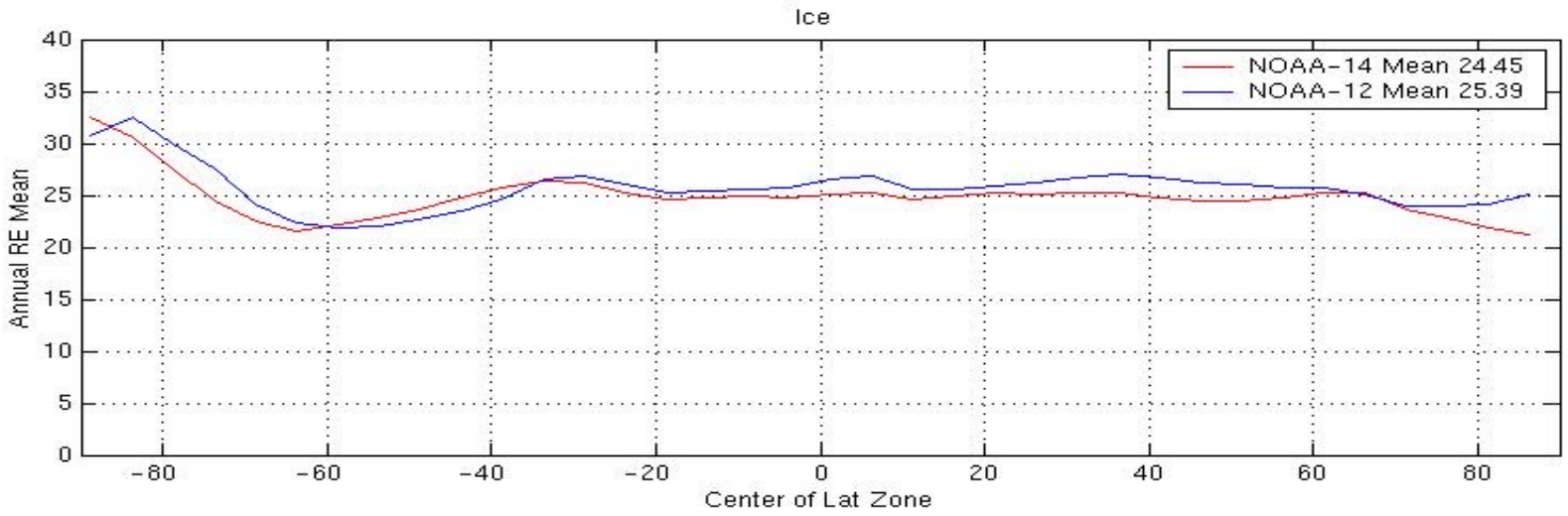




Annual Mean Effective Radius (μm)
Liquid and Ice for Morning and Afternoon

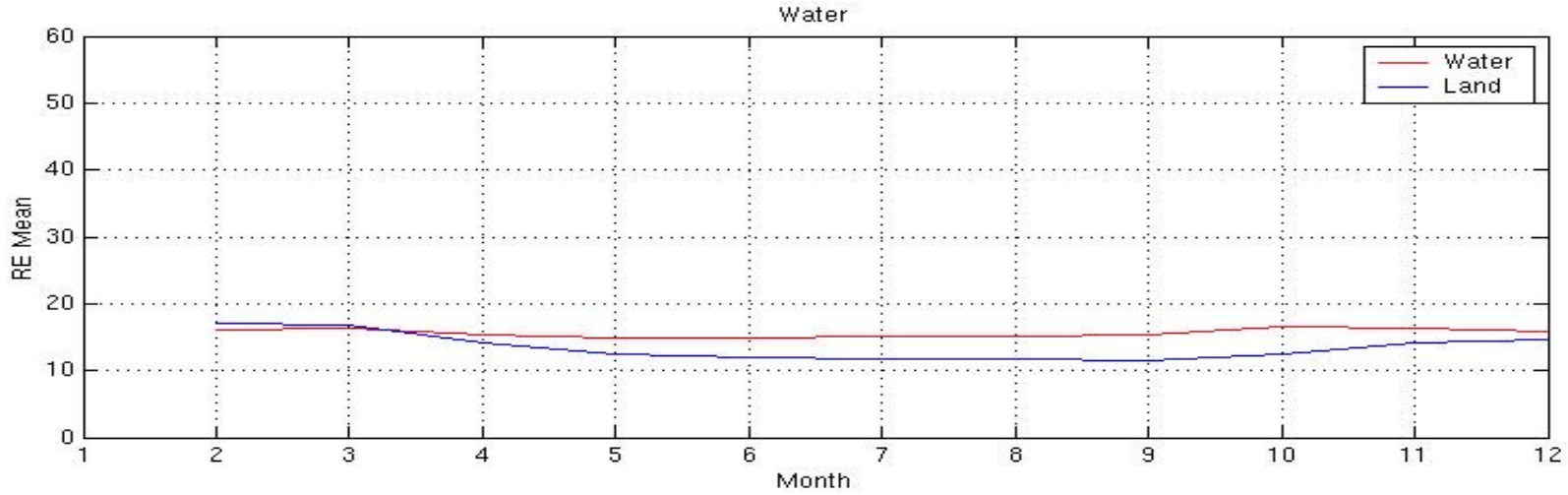
For 1995

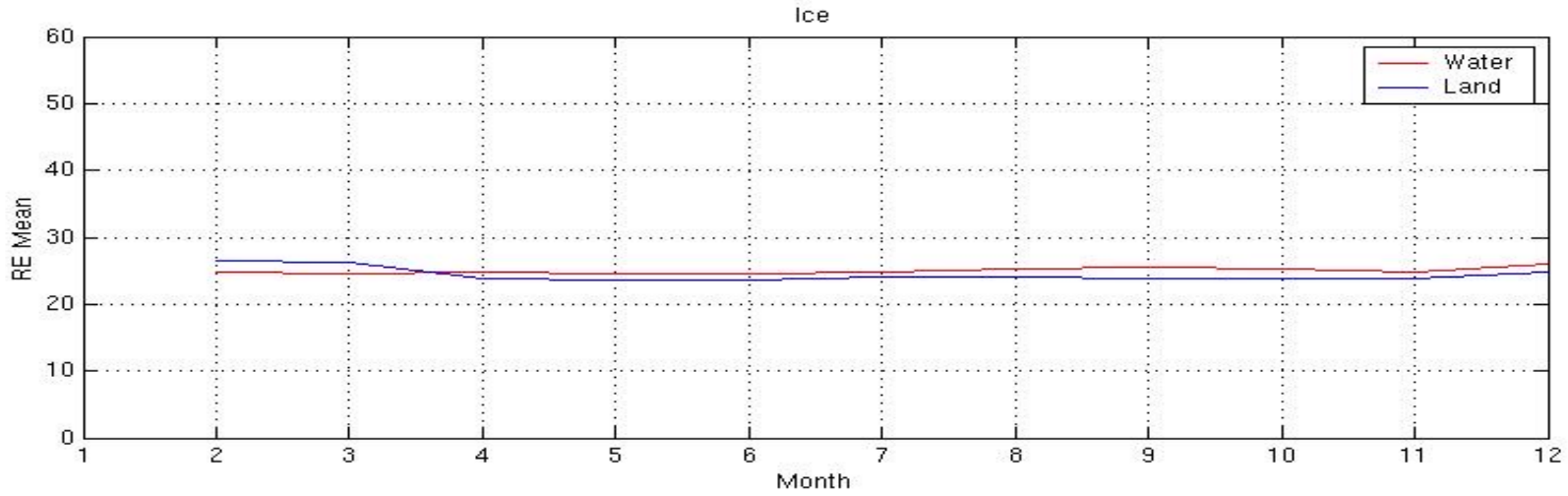




Regional (30º-60ºN) Monthly Mean Effective Radius (µm) Liquid and Ice for Water and Land

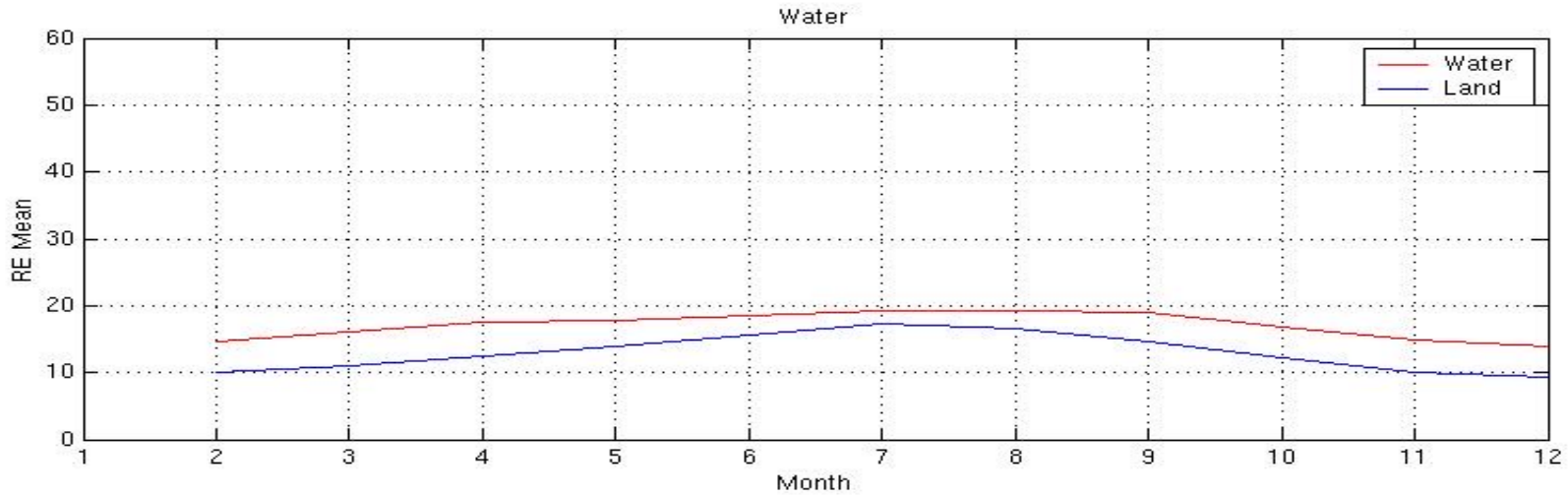
For 1995

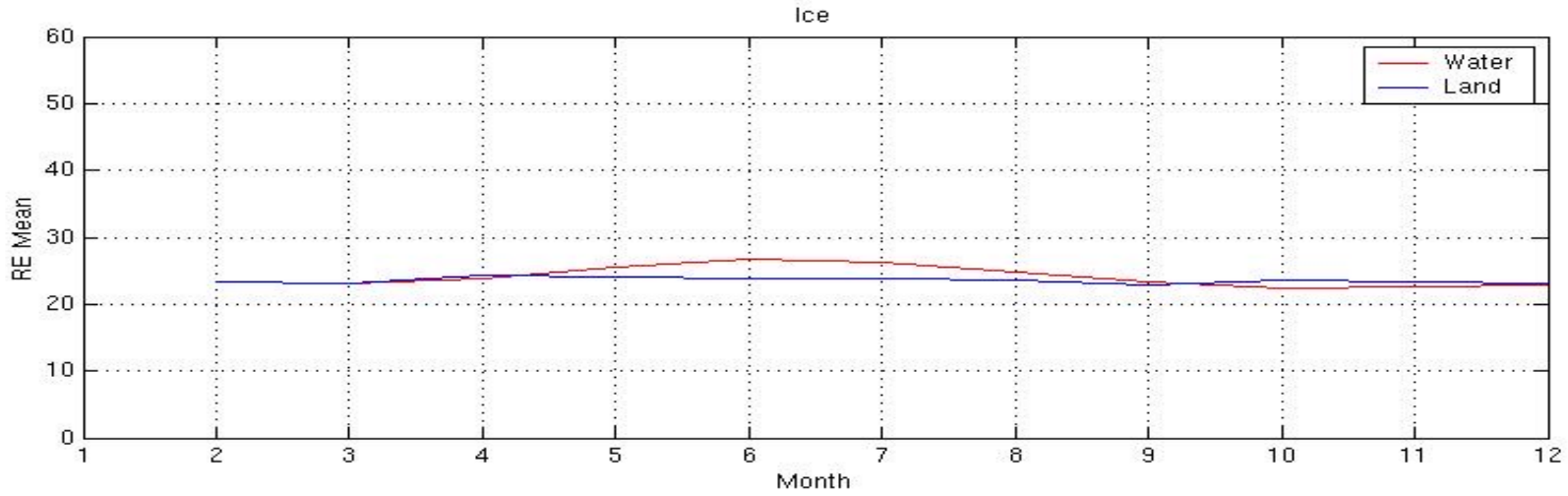




Regional (30º-60ºS) Monthly Mean Effective Radius (μm) Liquid and Ice for Water and Land

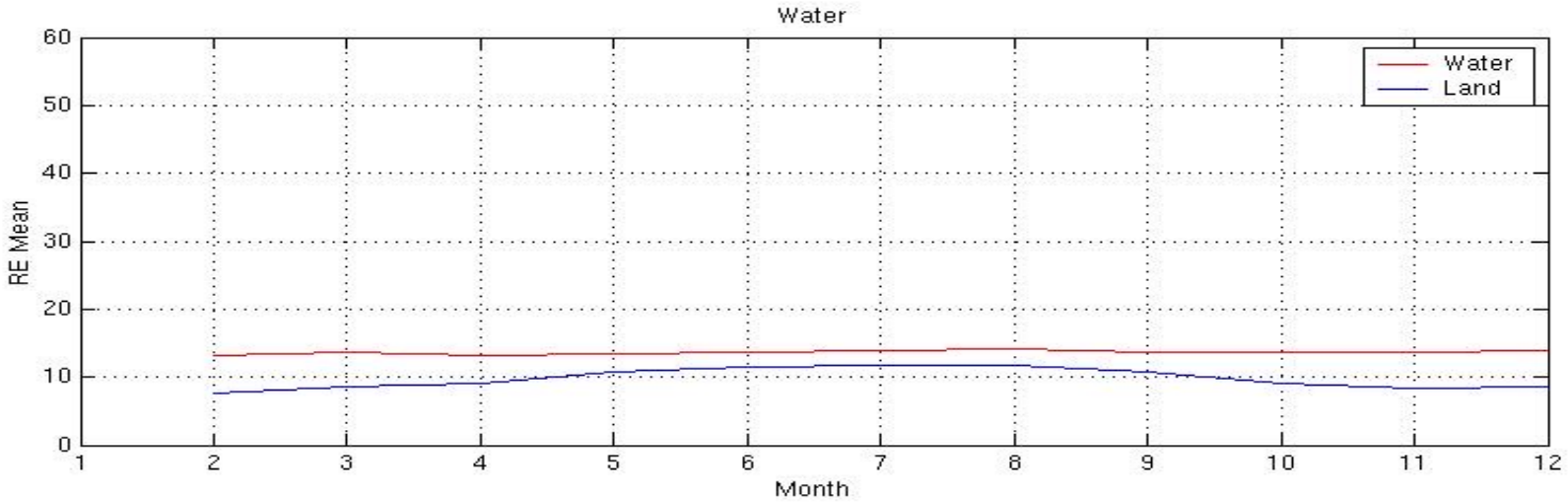
For 1995

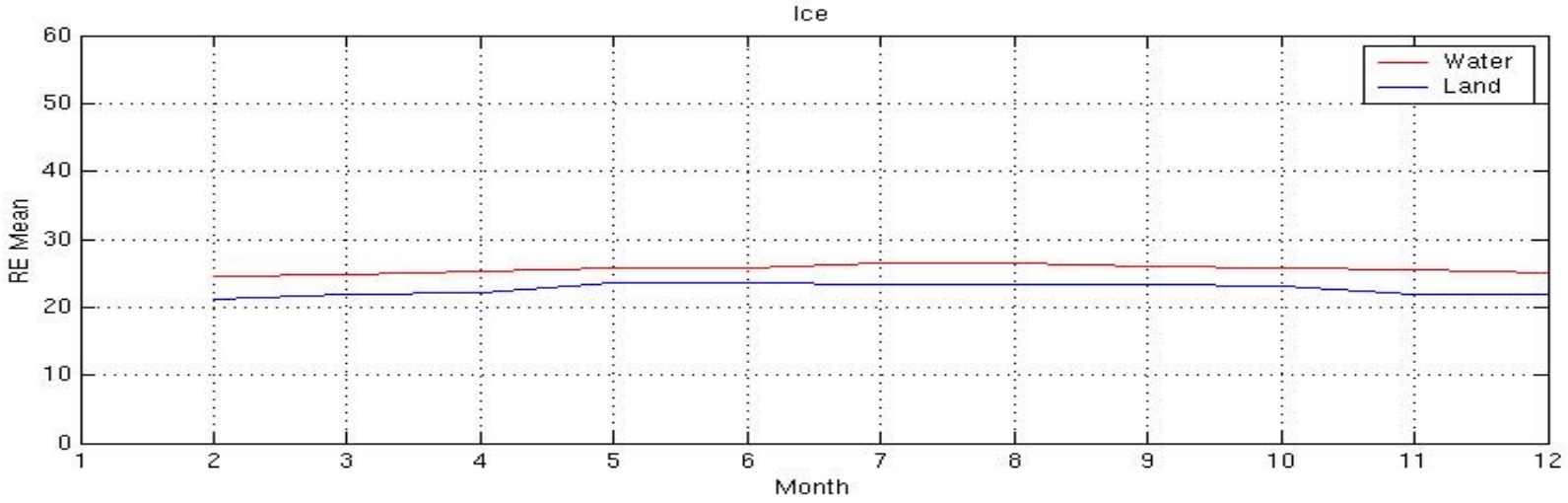




Regional (0º-30ºN) Monthly Mean Effective Radius (µm) Liquid and Ice for Water and Land

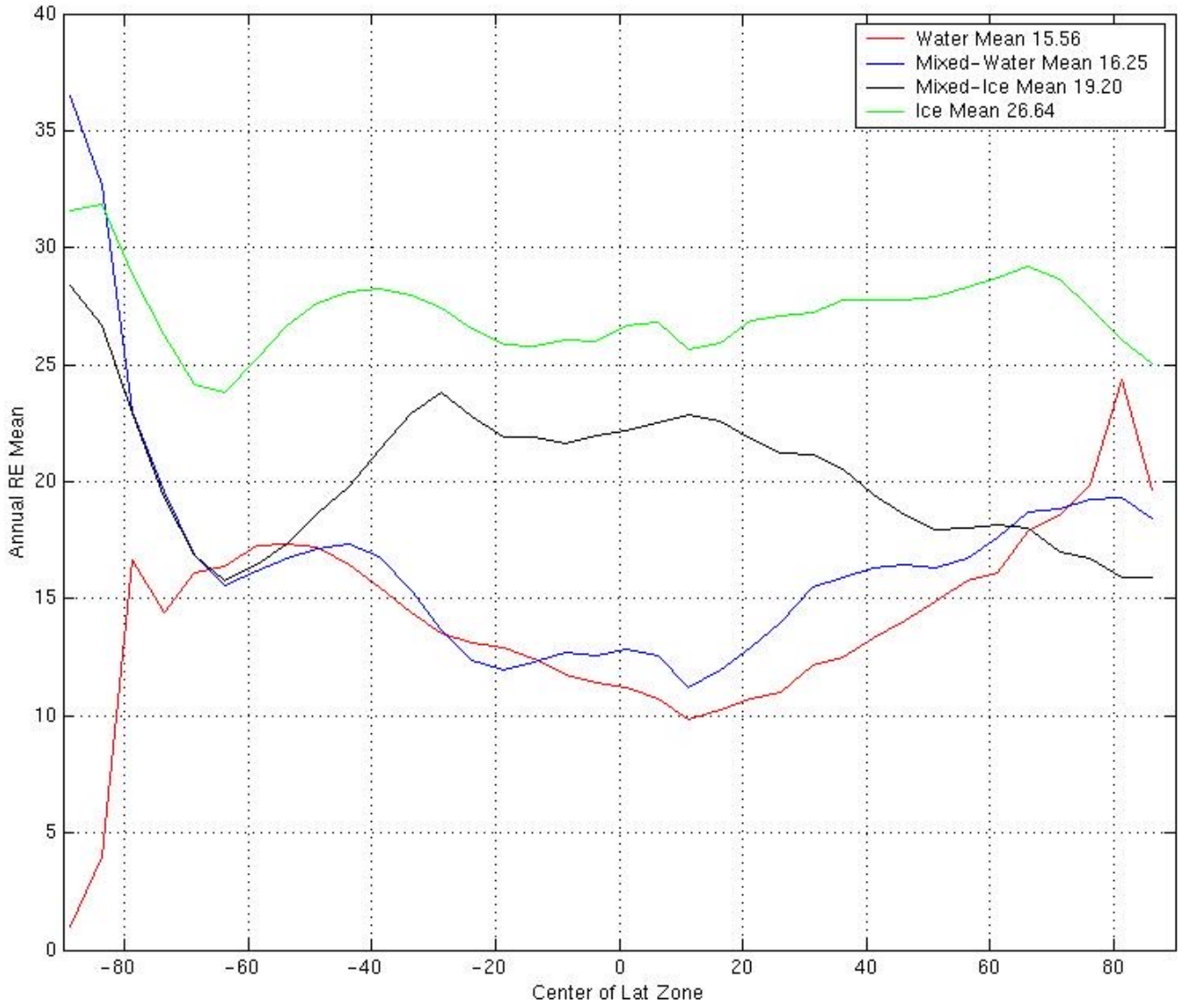
For 1995



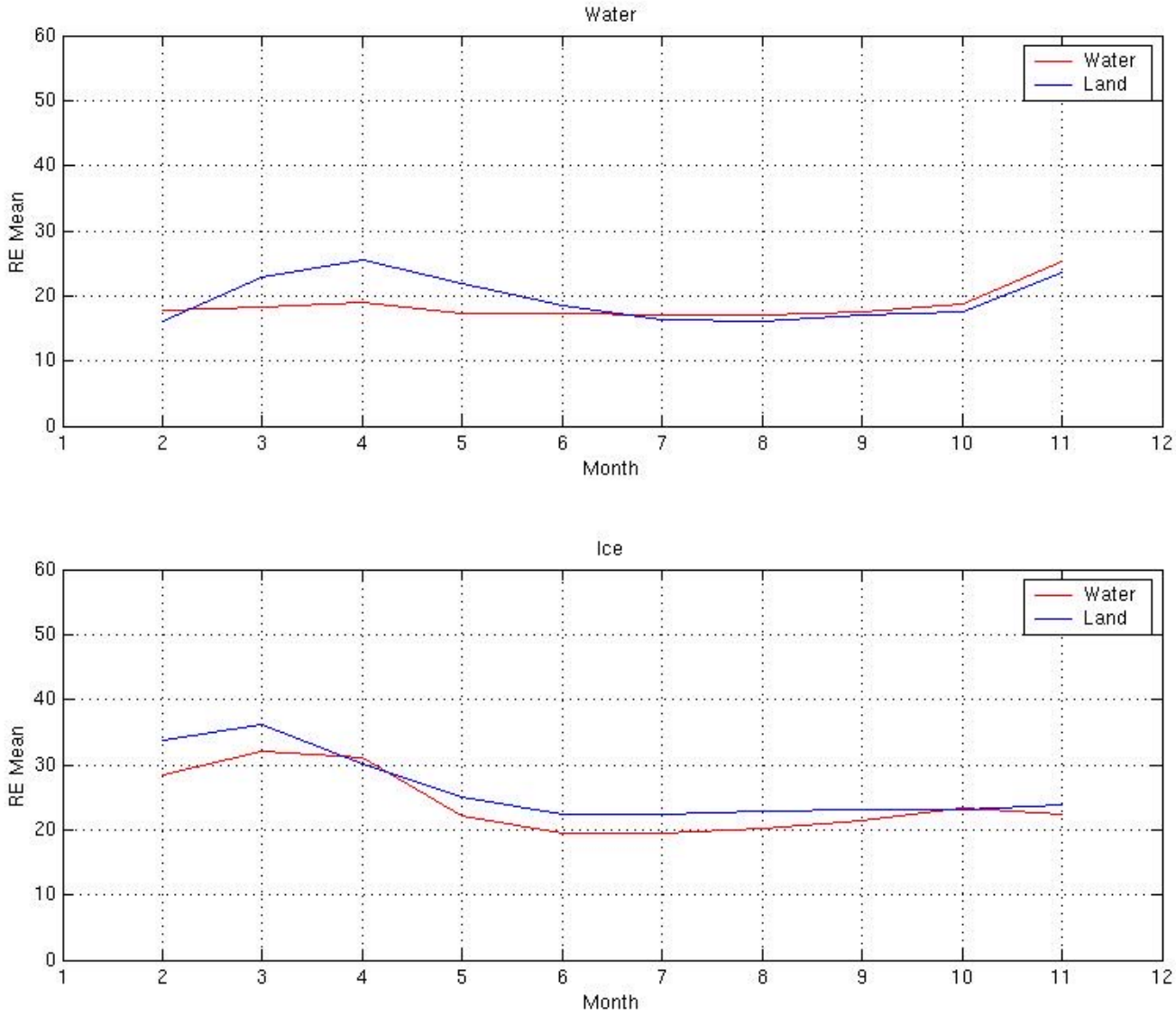


NOA 1995 Annual means by Cloud type

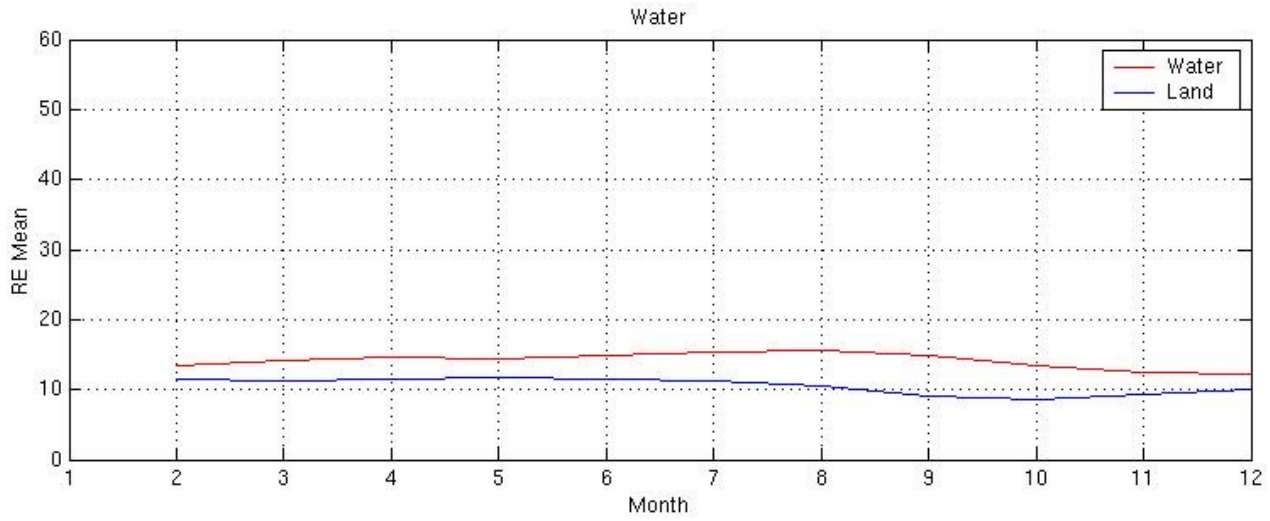
Effective Radius (Microns)

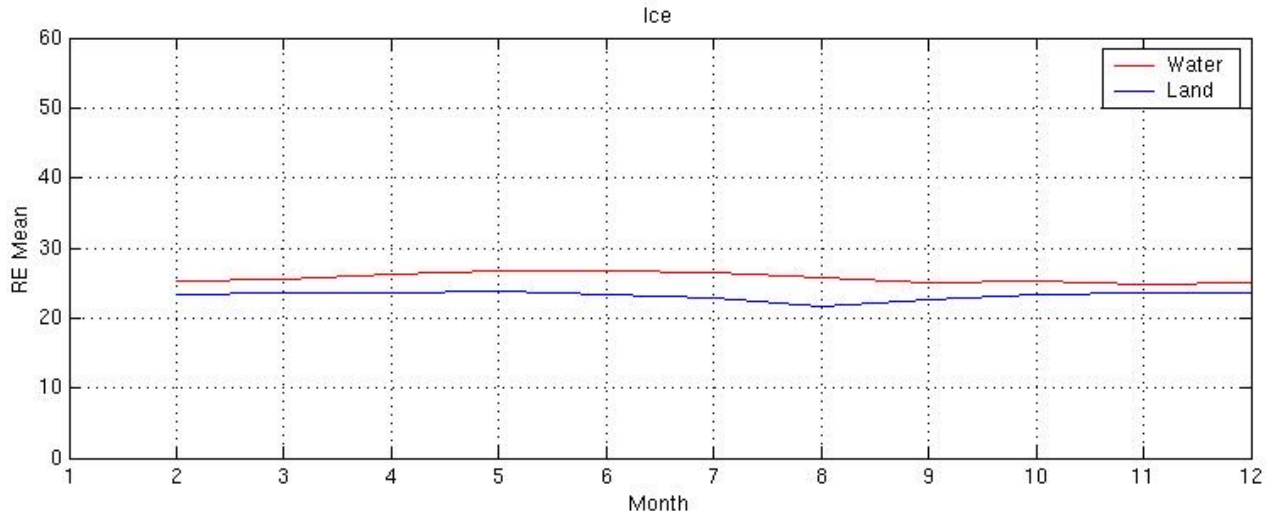


NOA&NOM (combined)1995 monthly means Effective Radius (Microns)
LAT REGION >60

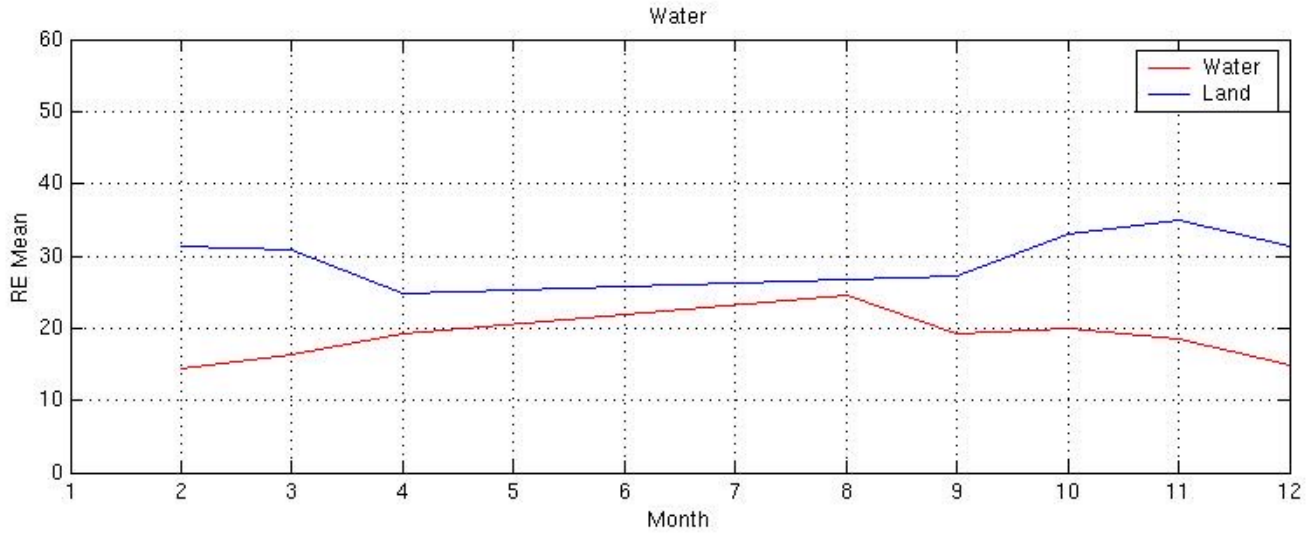


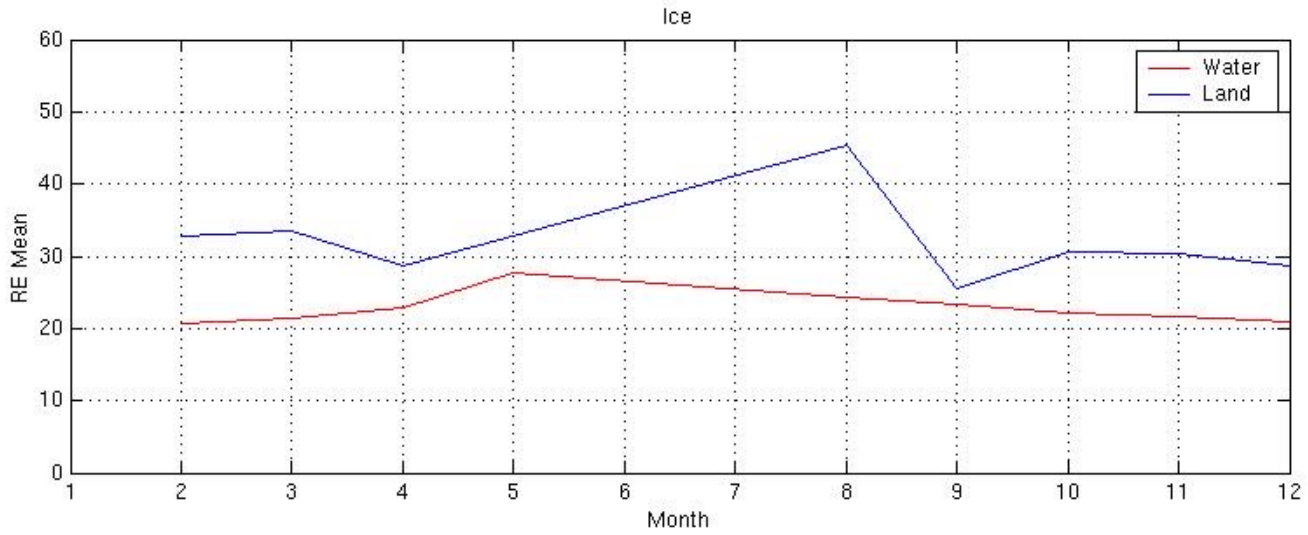
NOA&NOM (combined)1995 monthly means Effective Radius (Microns)
-30<LAT REGION <0

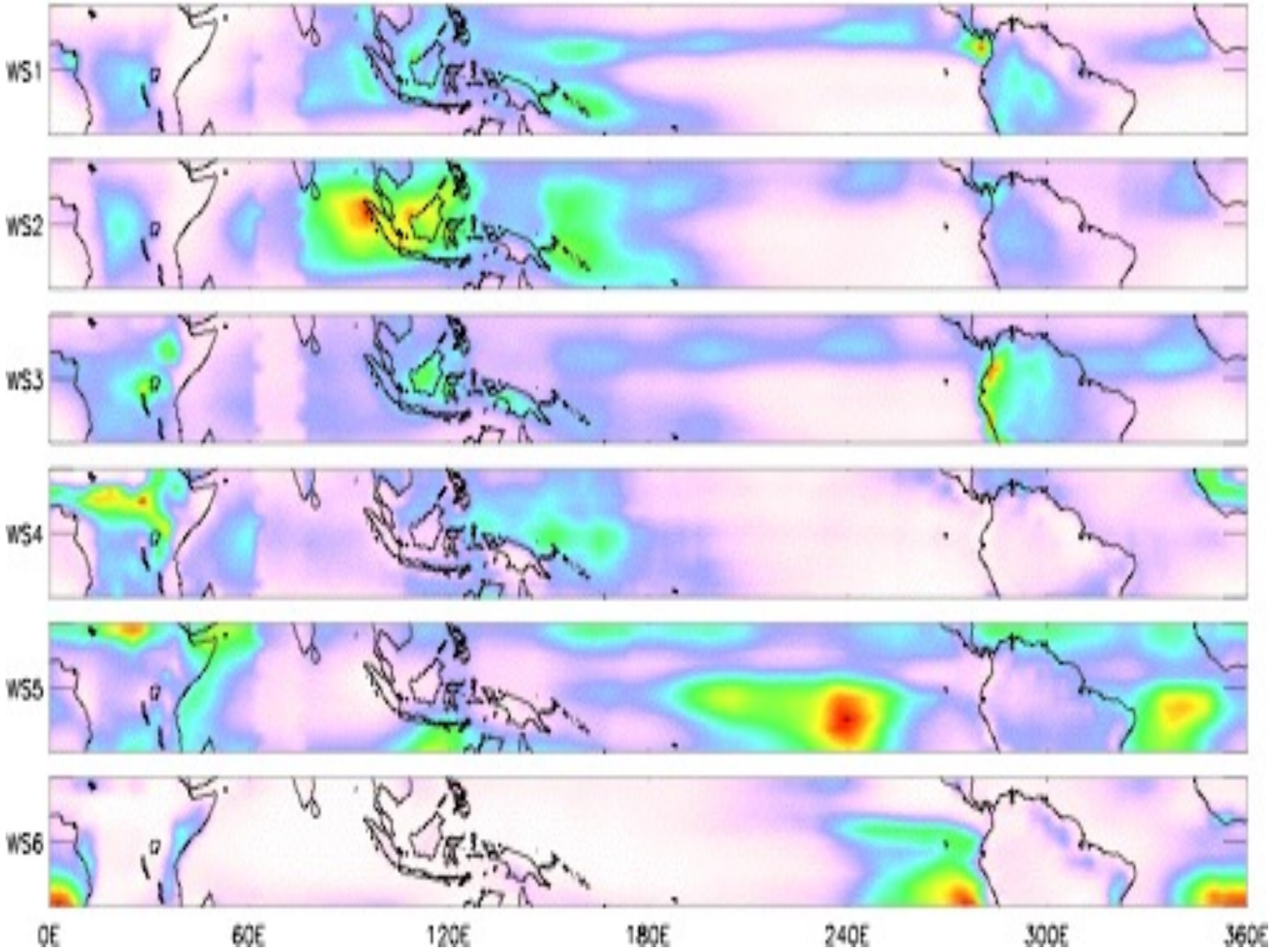




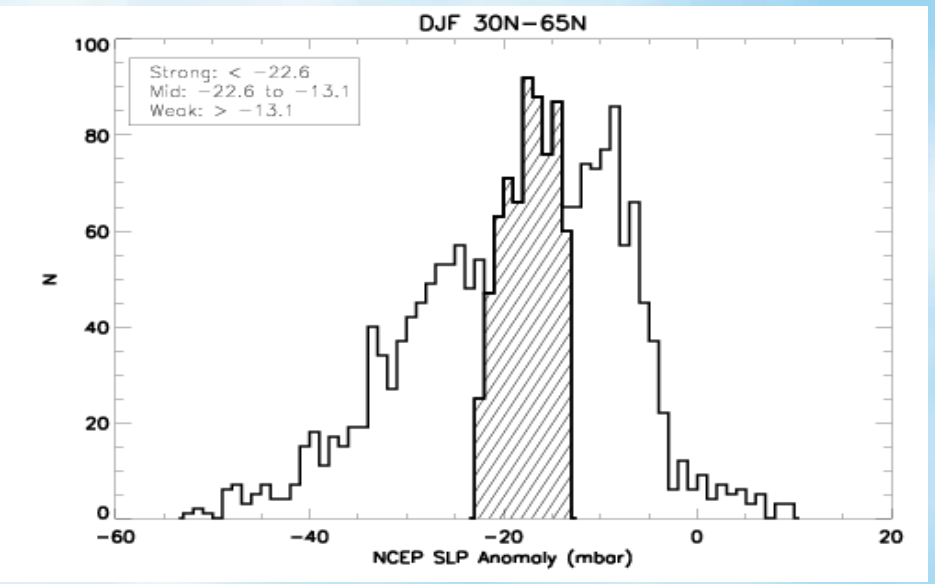
NOA&NOM (combined)1995 monthly means Effective Radius (Microns)
LAT REGION>-90

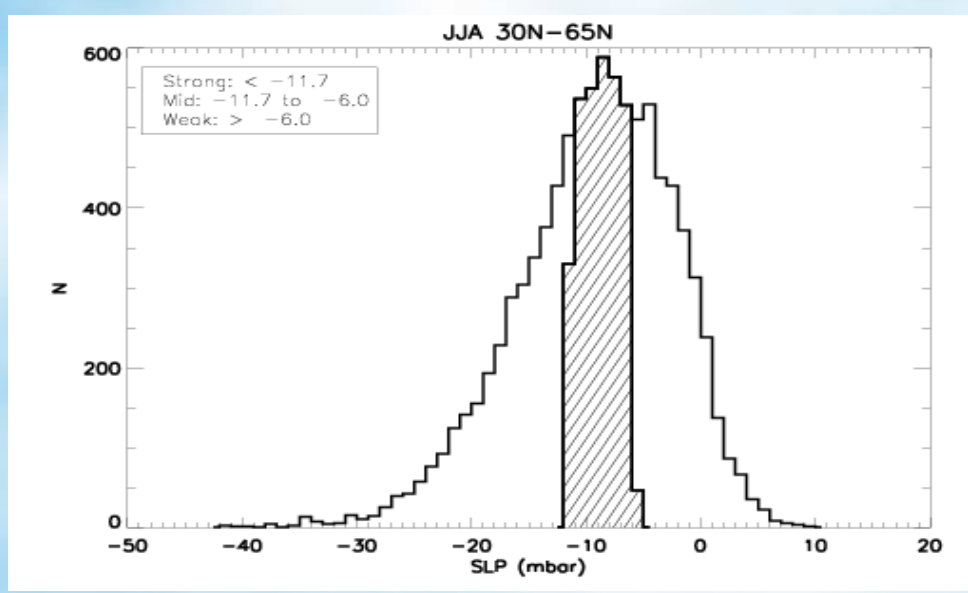


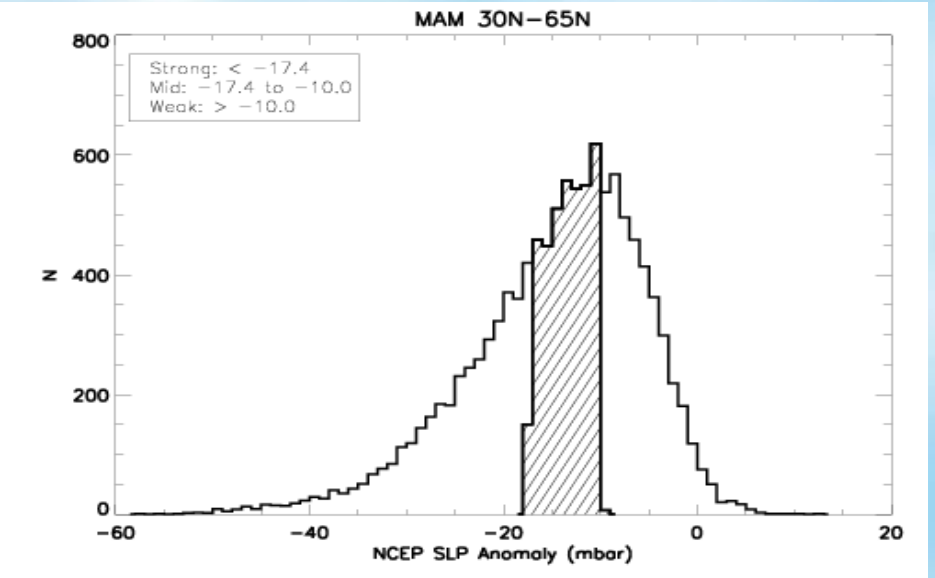


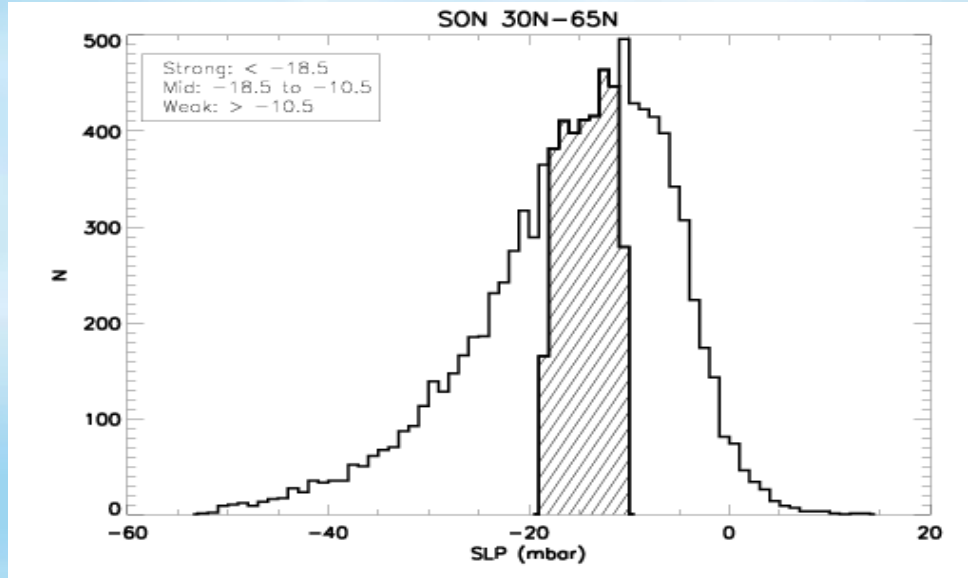

WS1
WS2
WS3
WS4
WS5
WS6
0E
60E
120E
180E
240E
300E
360E

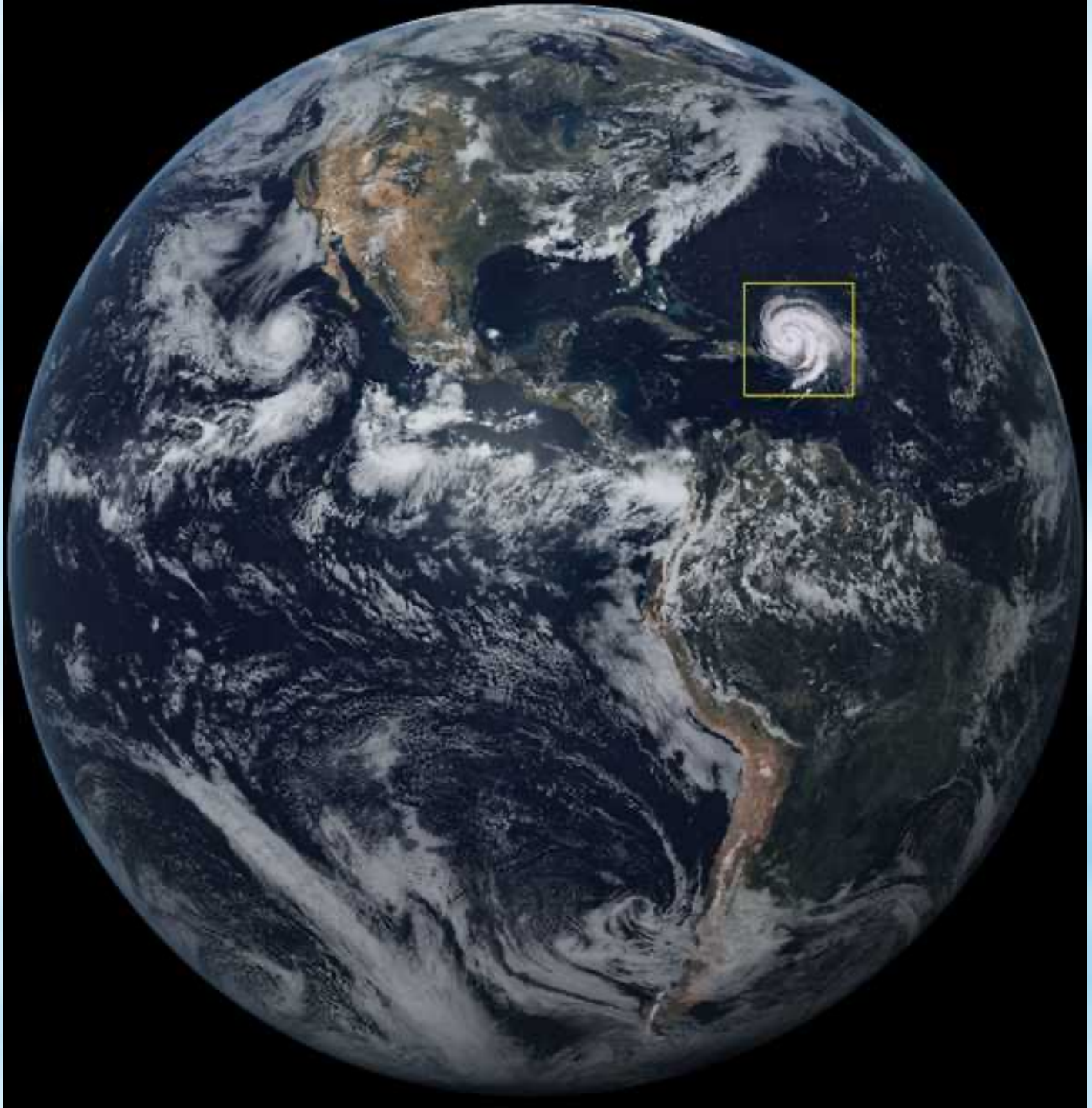
Surface Pressure Anomalies



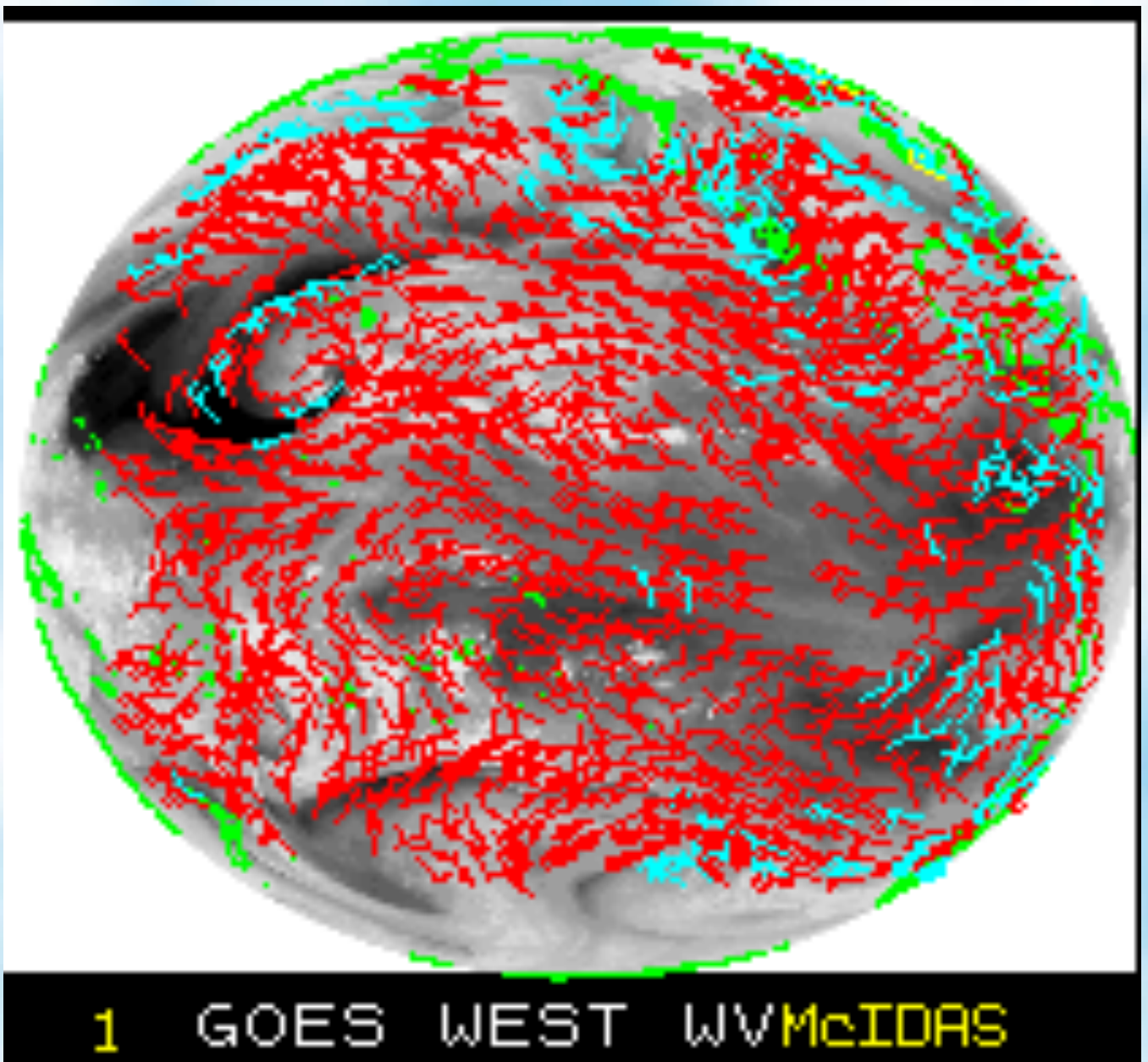




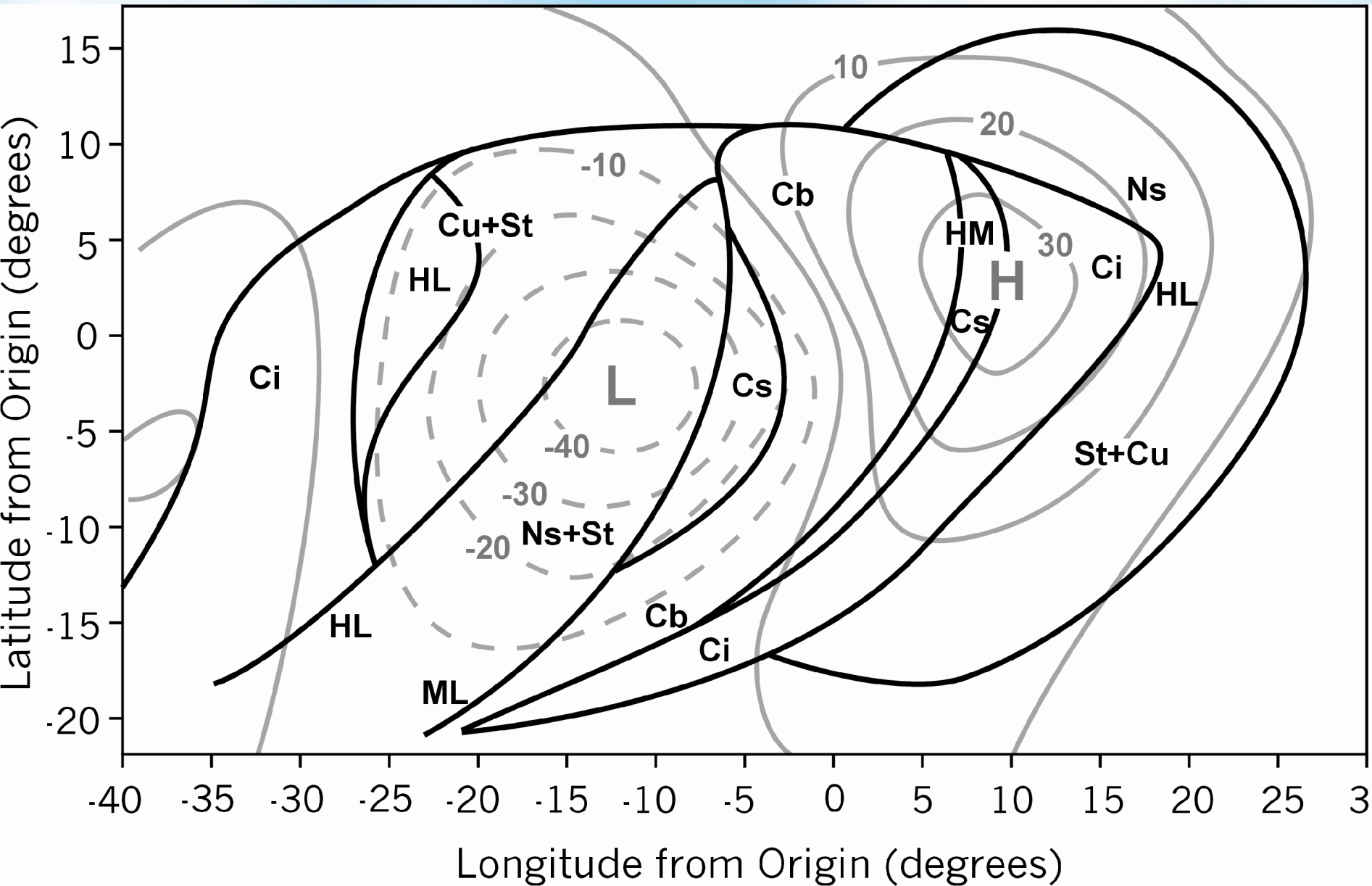




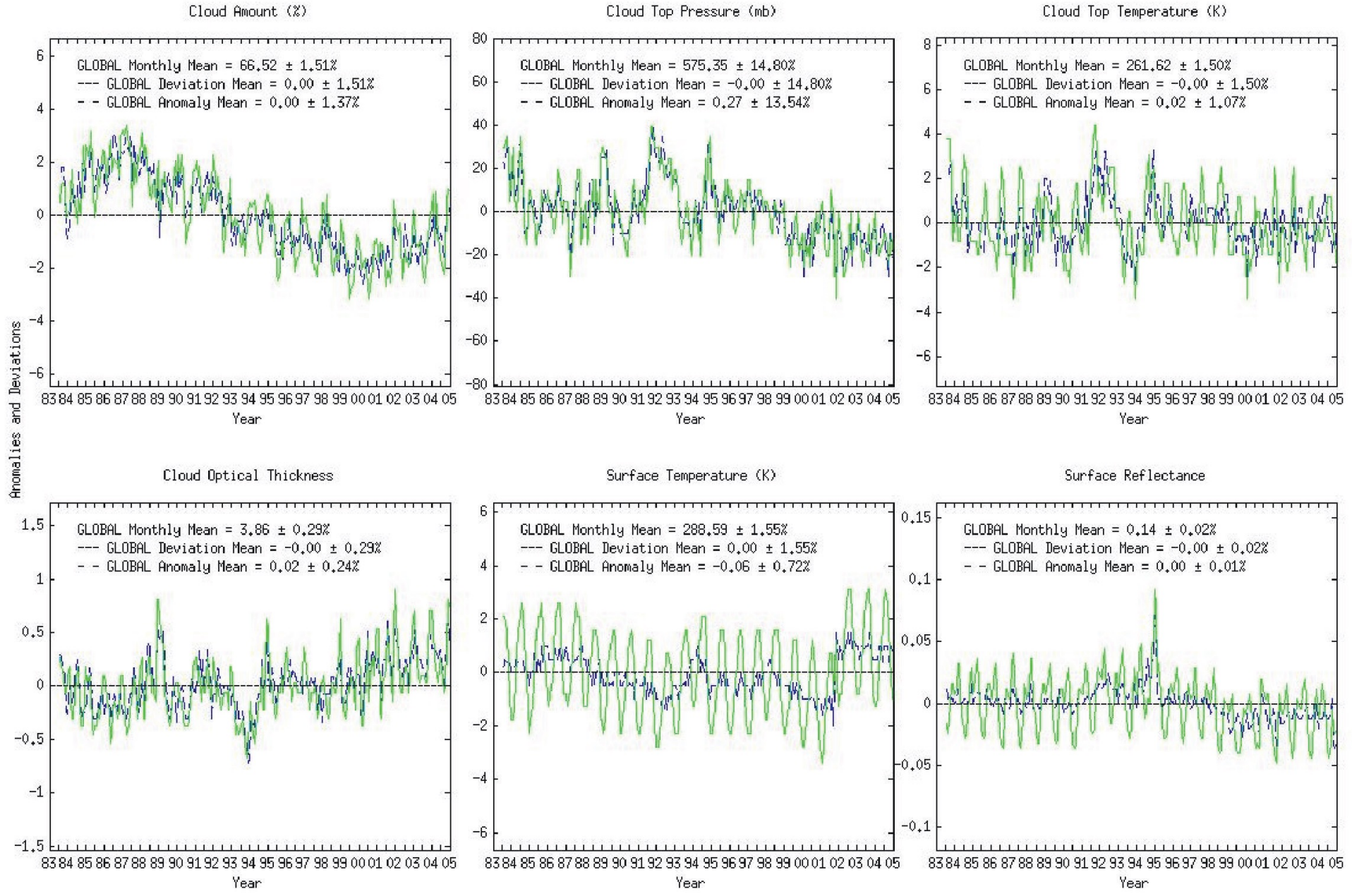
“SMALL” CLOUDS USED TO DETERMINE HORIZONTAL WINDS



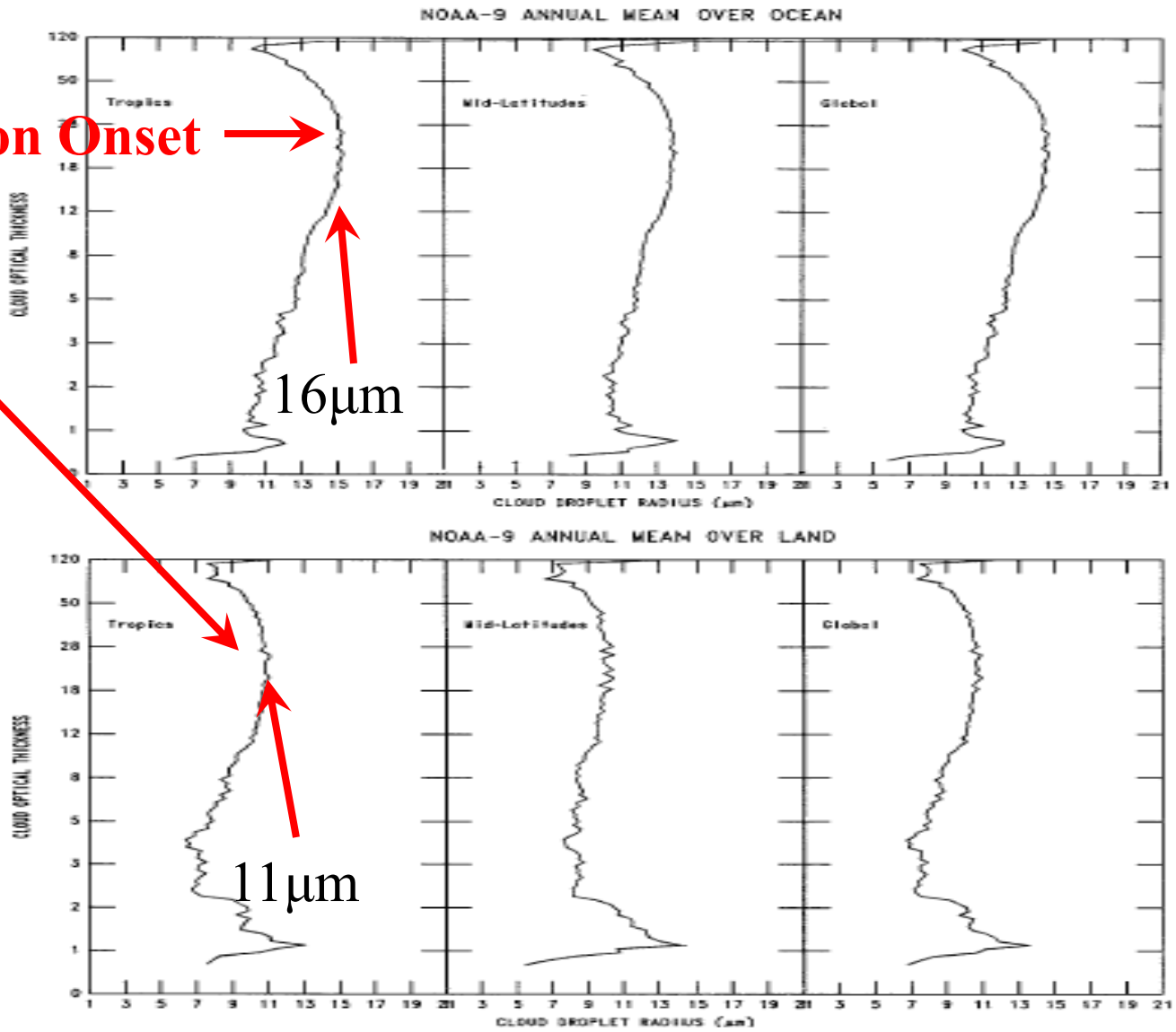
Composite Cyclone Cloud Vertical Structure



ISCCP D2: 21-Year Deviations Of Global Monthly Mean From Total Period Mean



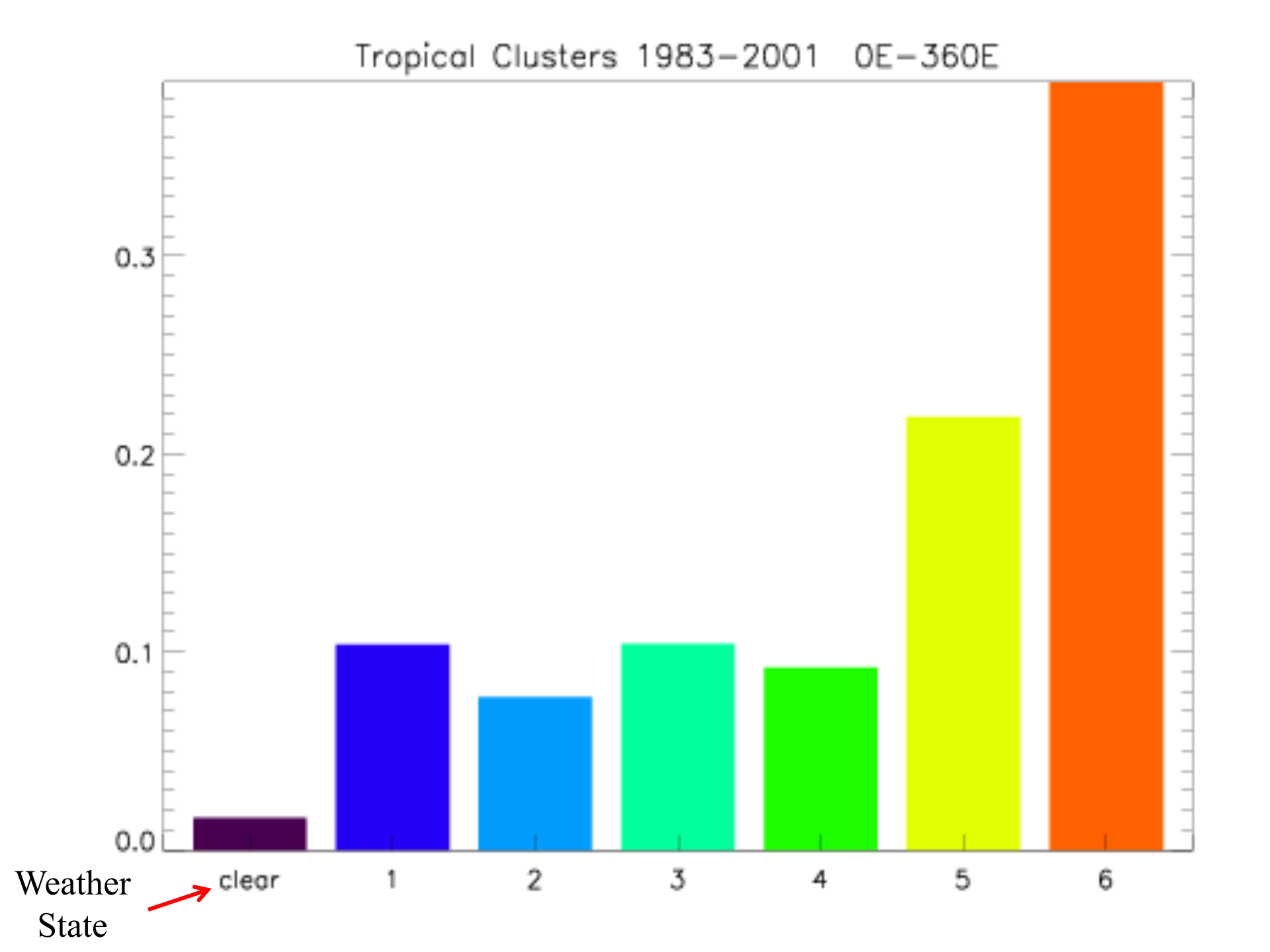
Average Cloud Droplet Size as Function of Cloud Optical Thickness



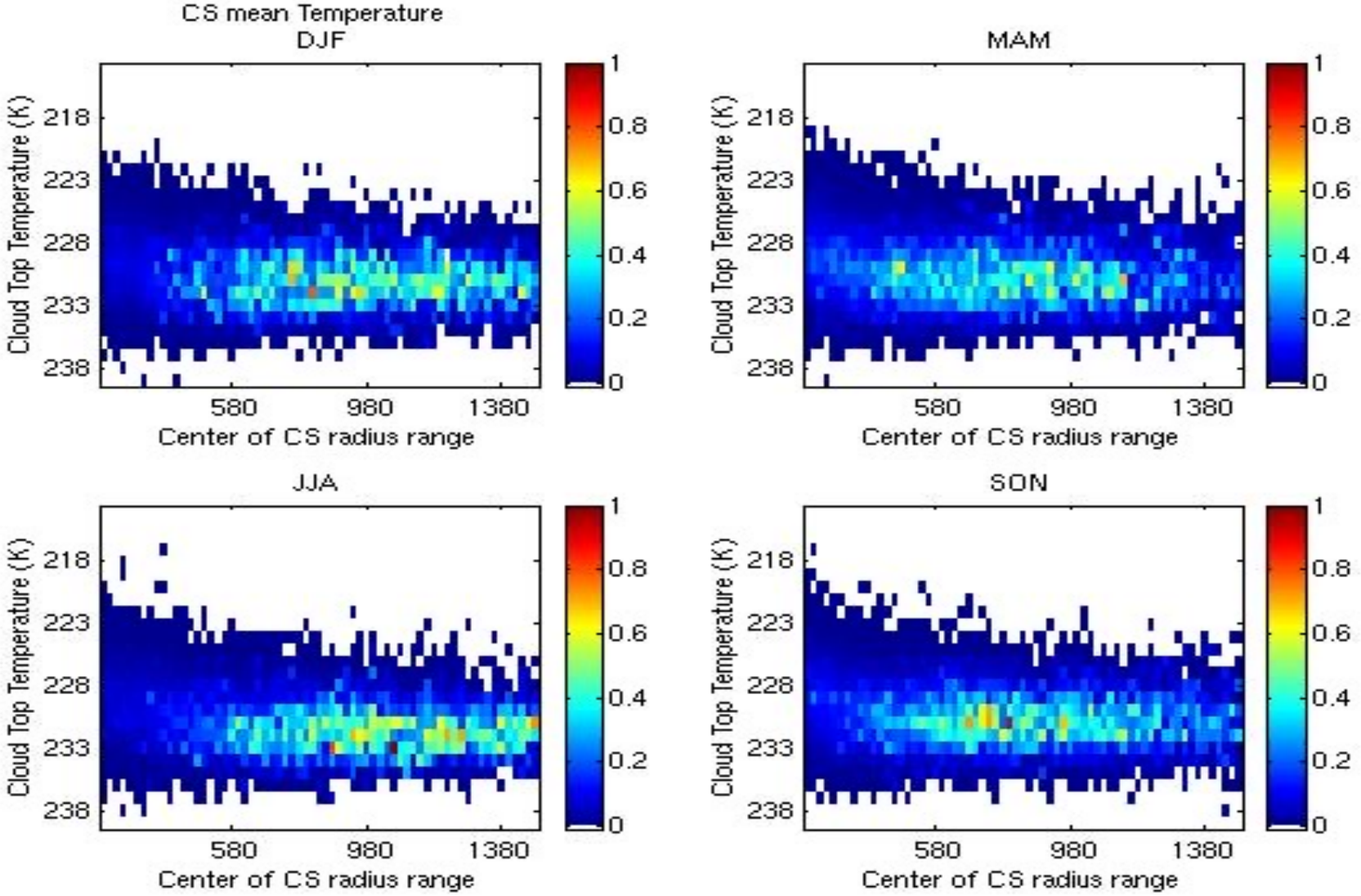
Precipitation Onset

16μm

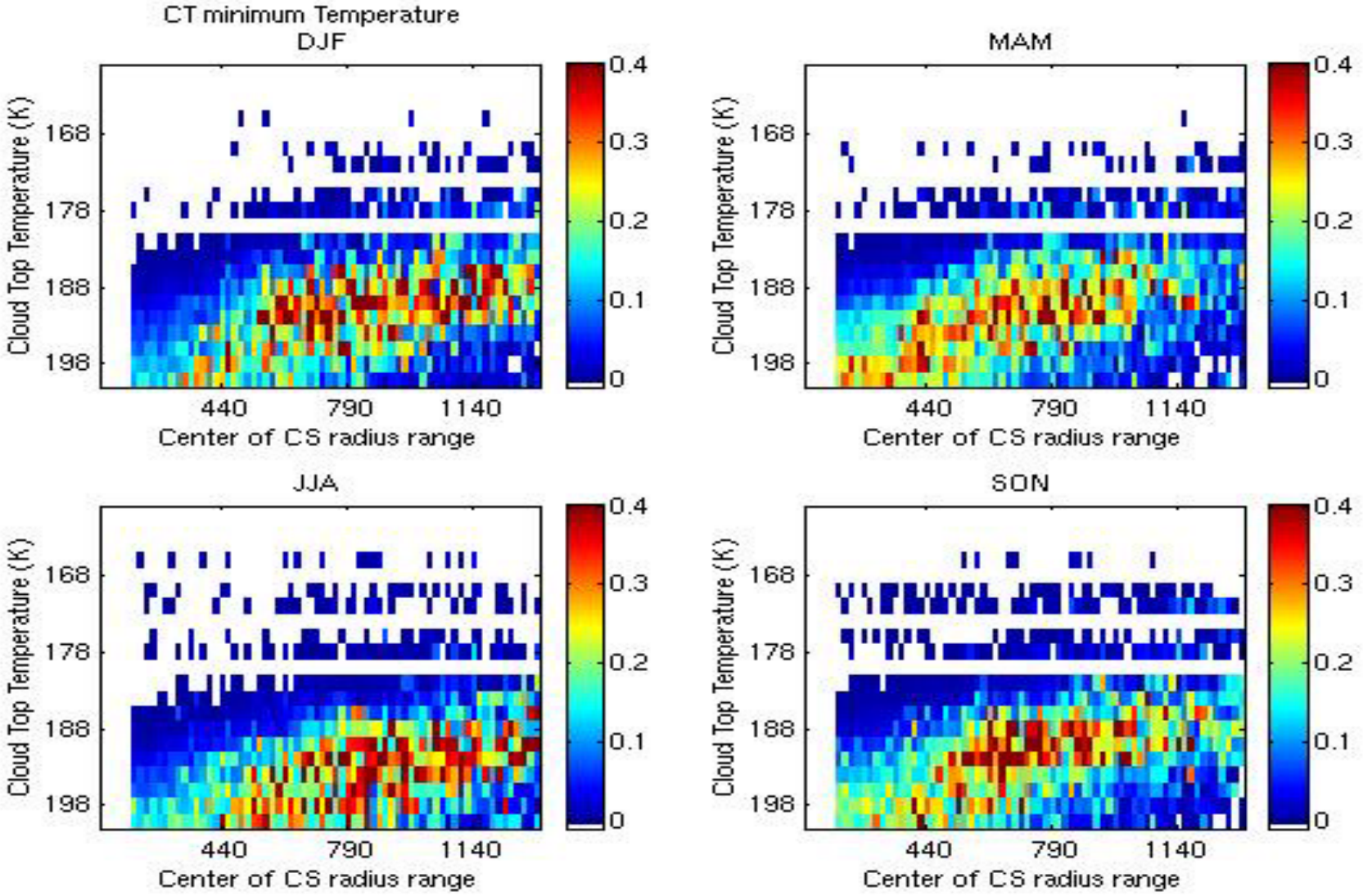
11μm


Tropical Clusters 1983–2001 0E–360E
0.3
0.2
0.1
0.0
clear
1
2
3
4
5
6
Weather State

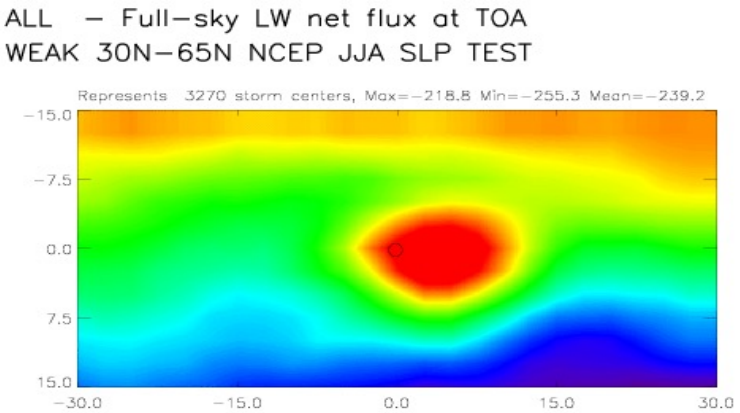
MEAN CLOUD TOP TEMPERATURE VERSUS SIZE

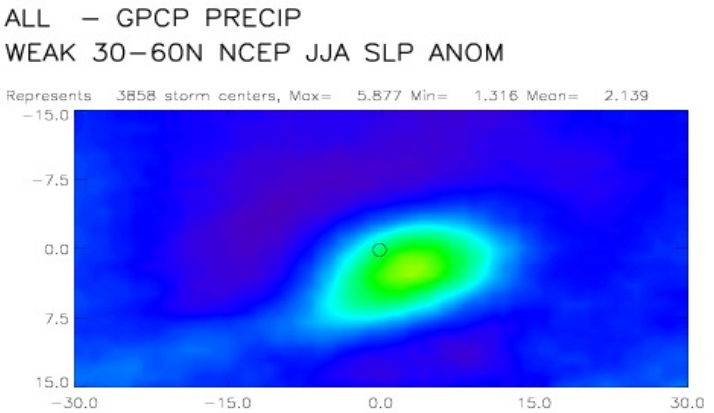


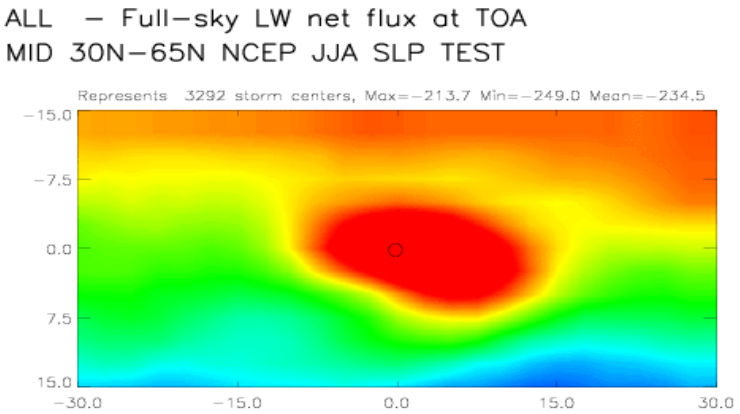
MINIMUM CLOUD TOP TEMPERATURE VERSUS SIZE

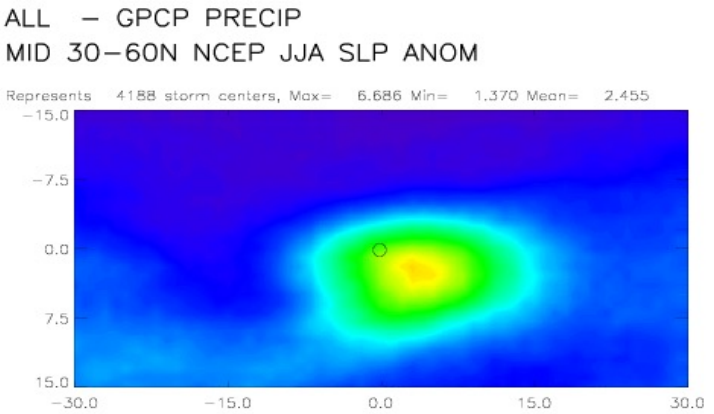


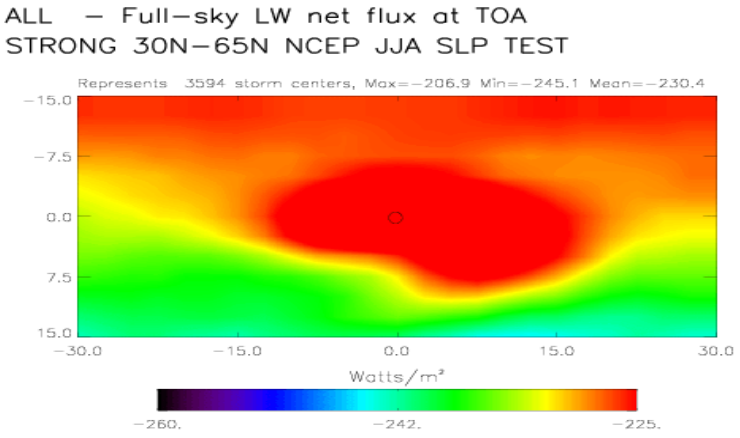
Composite of Diabatic Heating of Atmosphere with Cyclone Strength

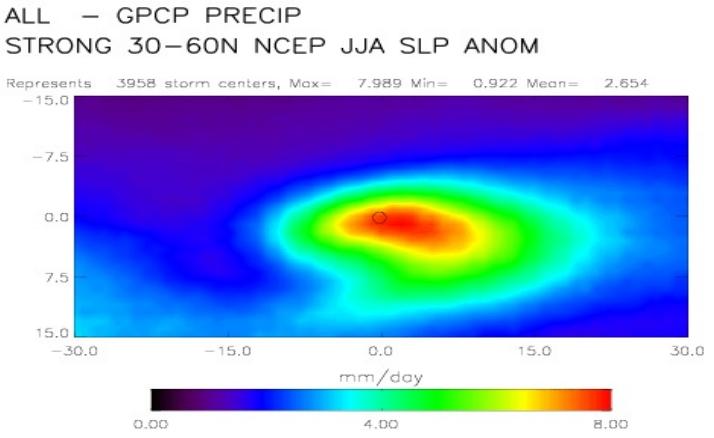


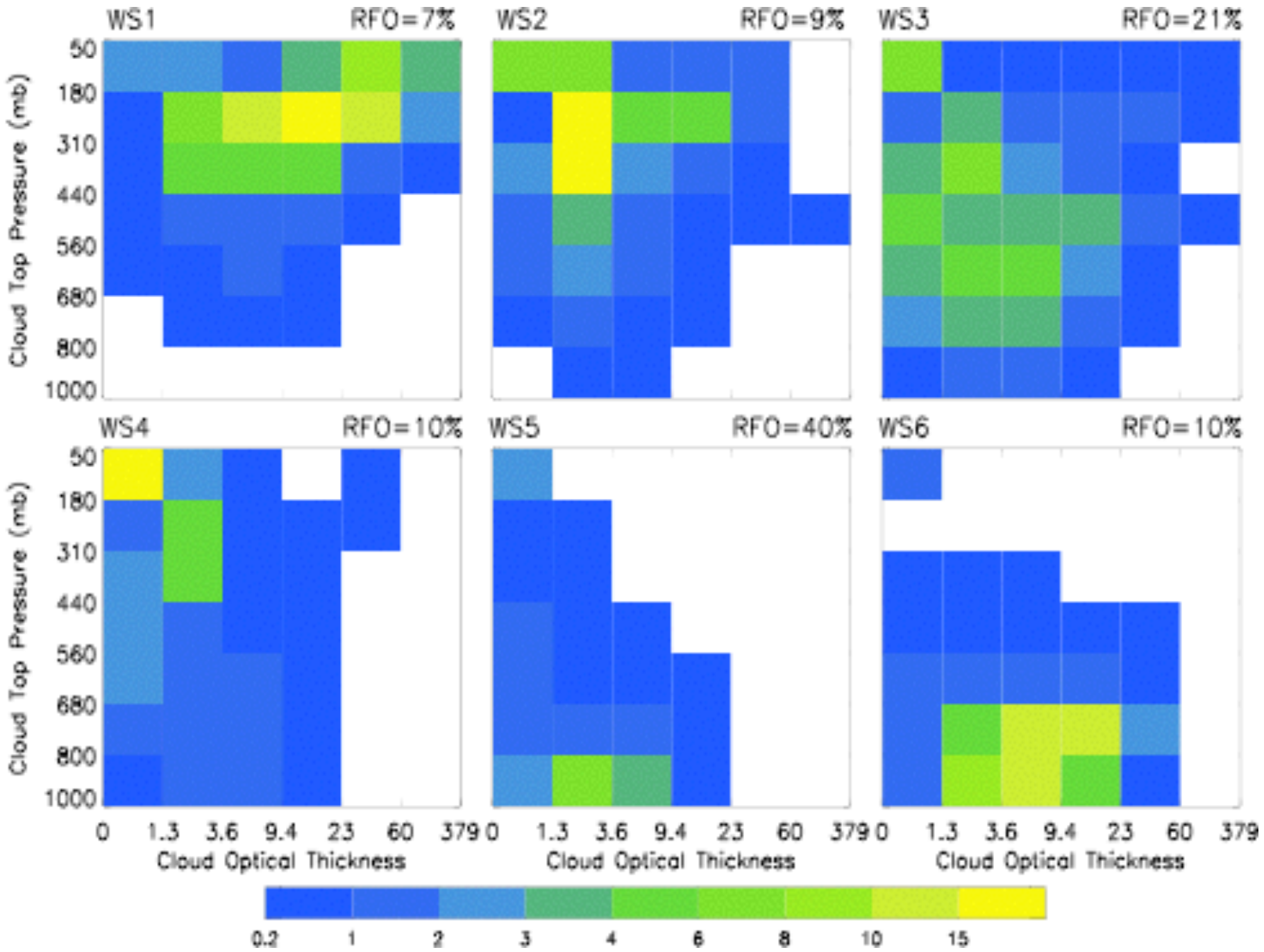






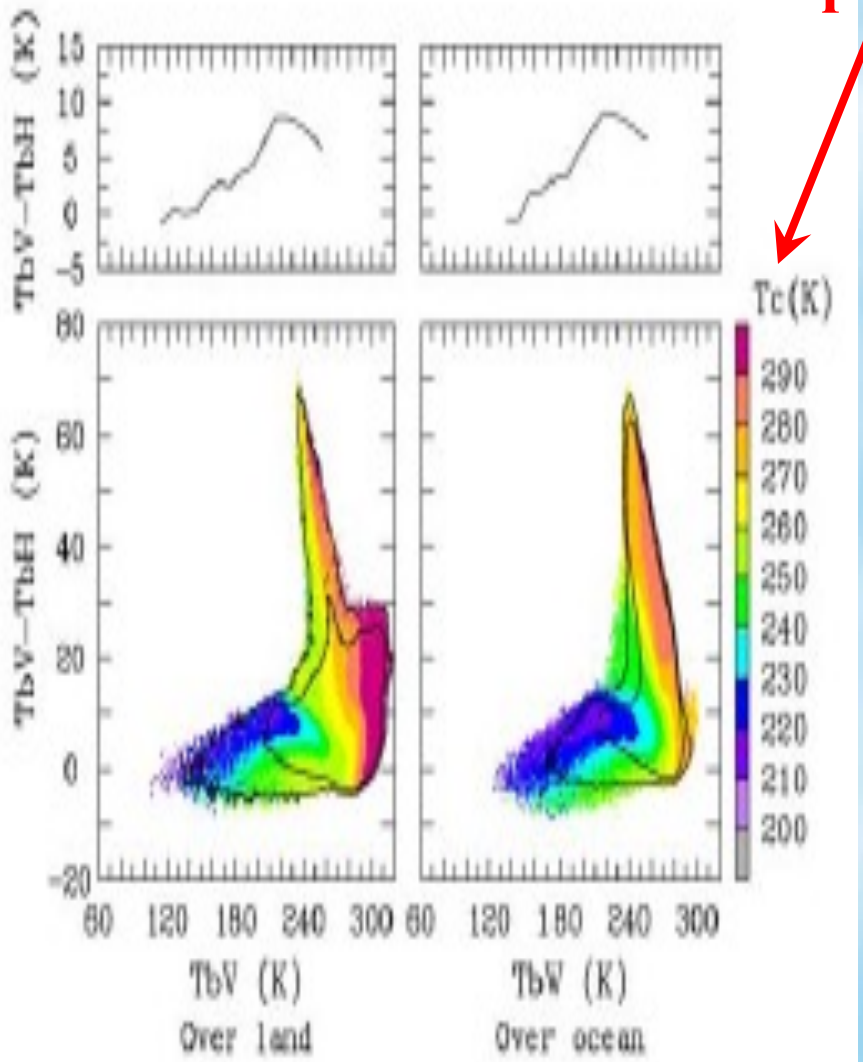




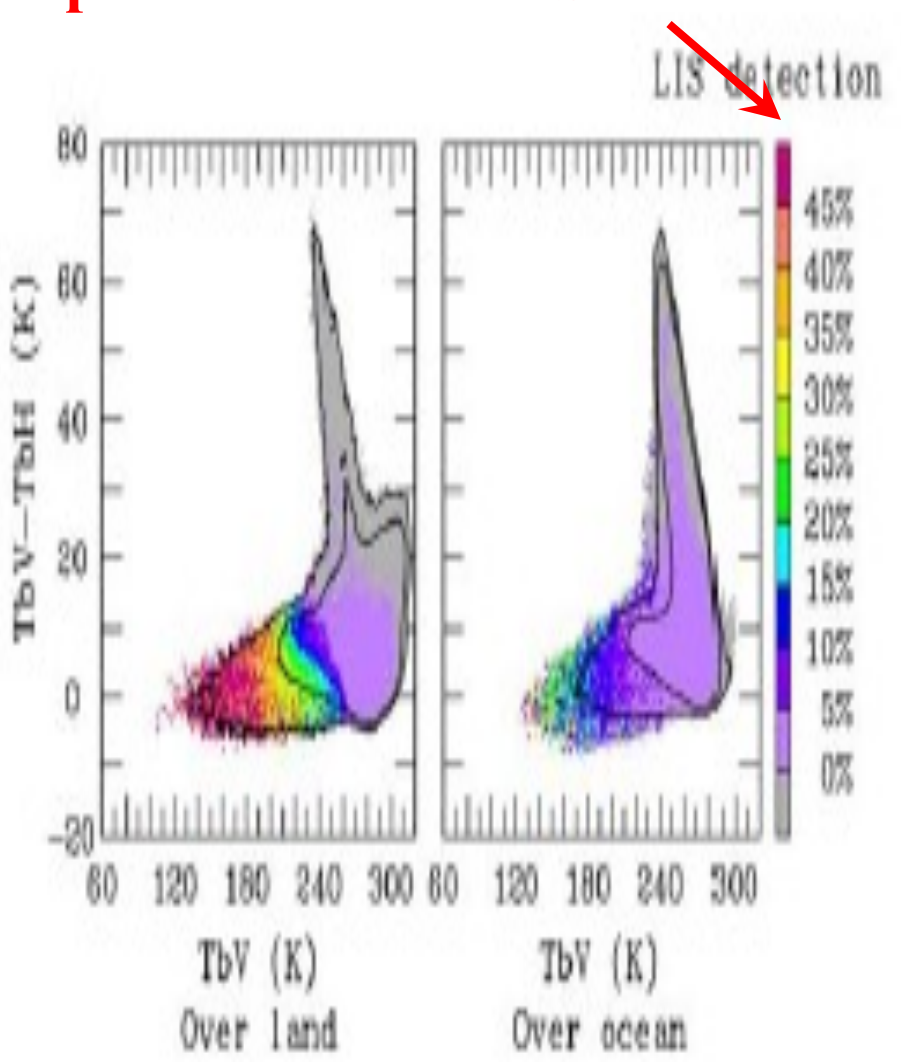

WS1
RFO=7%
WS2
RFO=9%
WS3
RFO=21%
WS4
RFO=10%
WS5
RFO=40%
WS6
RFO=10%
Cloud Top Pressure (mb)
50
180
310
440
560
680
800
1000
0
1.3
3.6
9.4
23
60
379
Cloud Optical Thickness
0.2
1
2
3
4
6
8
10
15

Correlation of Microwave Polarization Features and Lightning

Cloud Top Temperature



LIS Detection



Evolution of Tropical Convective Systems