The convective cloud population

Robert Houze
University of Washington

ASR Science Team Meeting, San Antonio, 31 March 2011

The convective cloud population

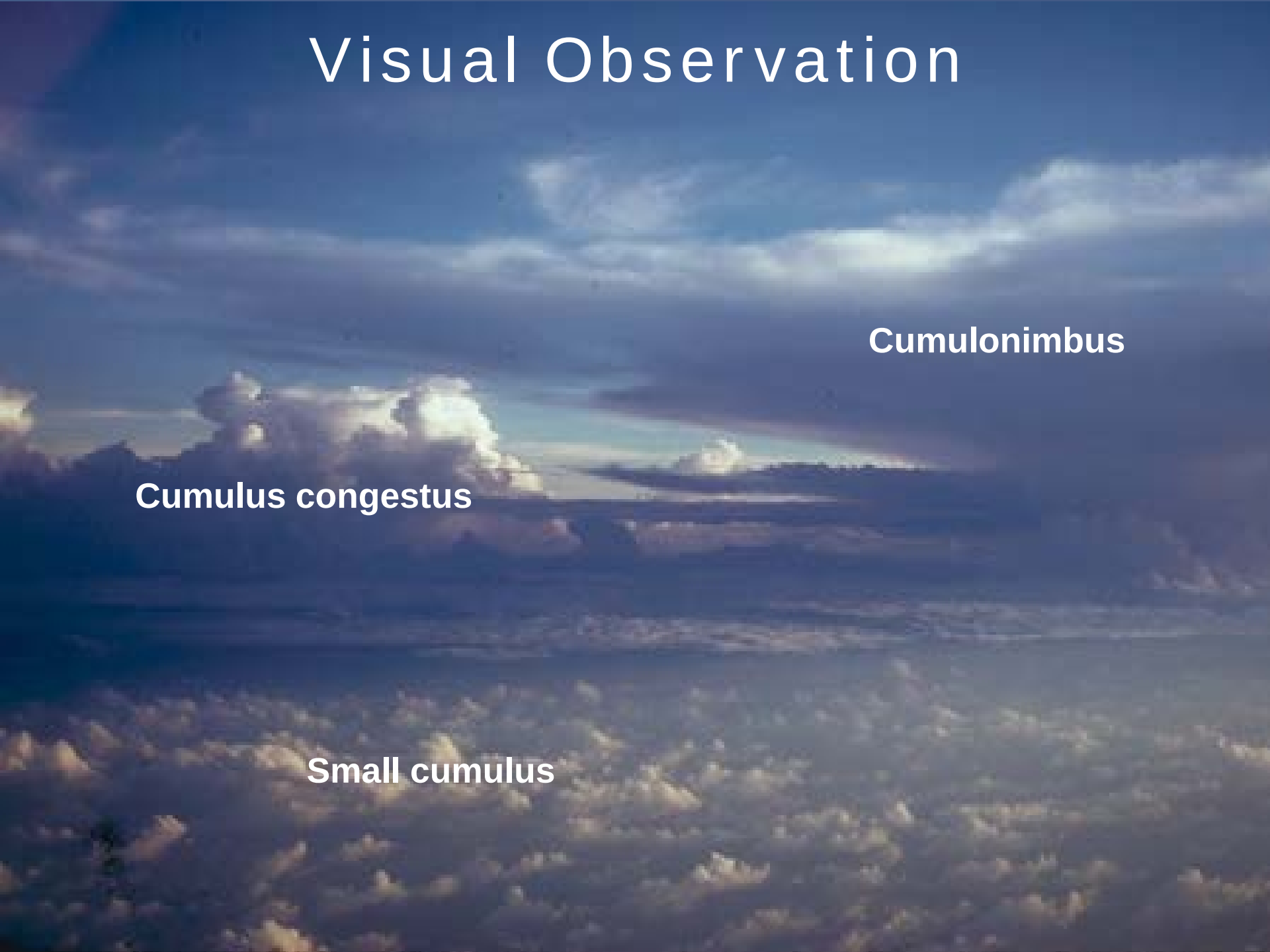
What do we know?

What role have radars played?

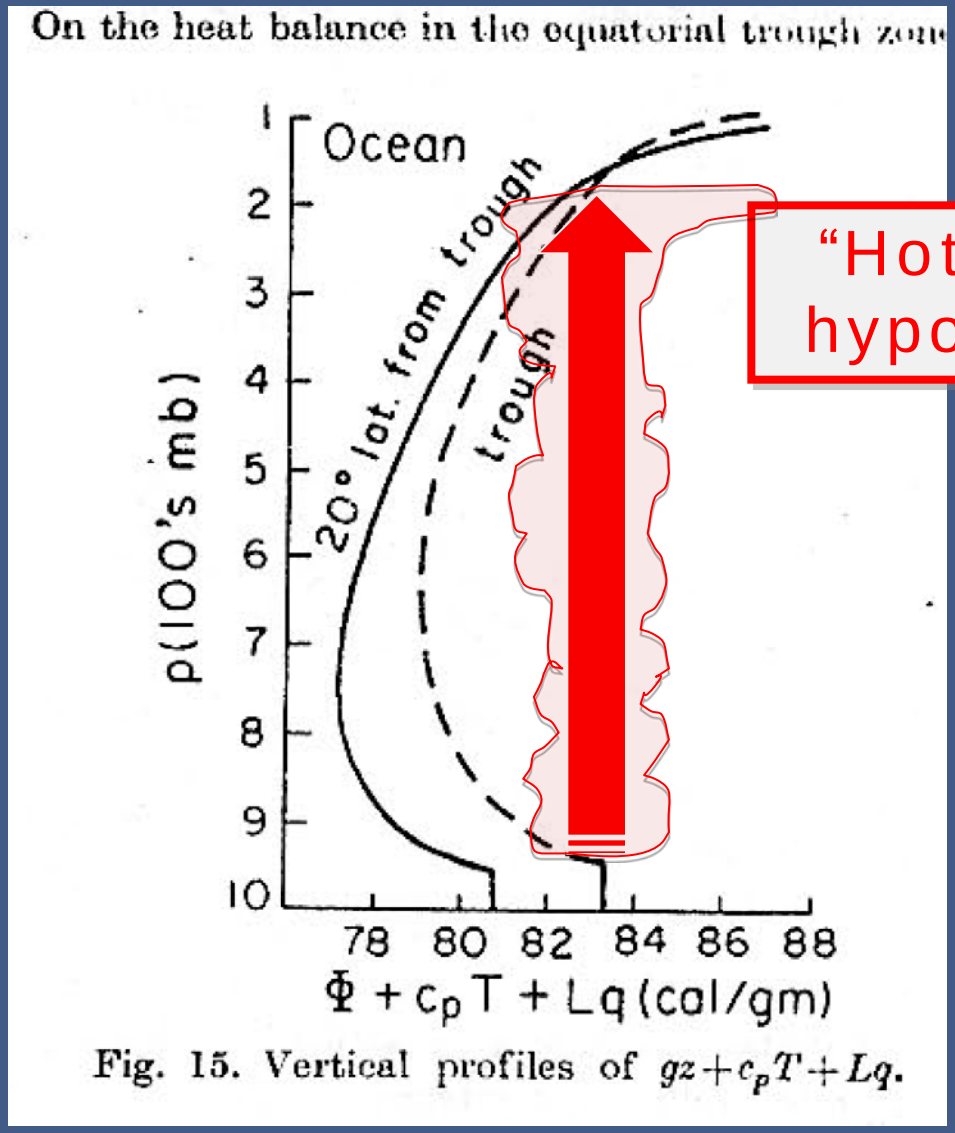
What comes next?

Before Satellites

Visual Observation



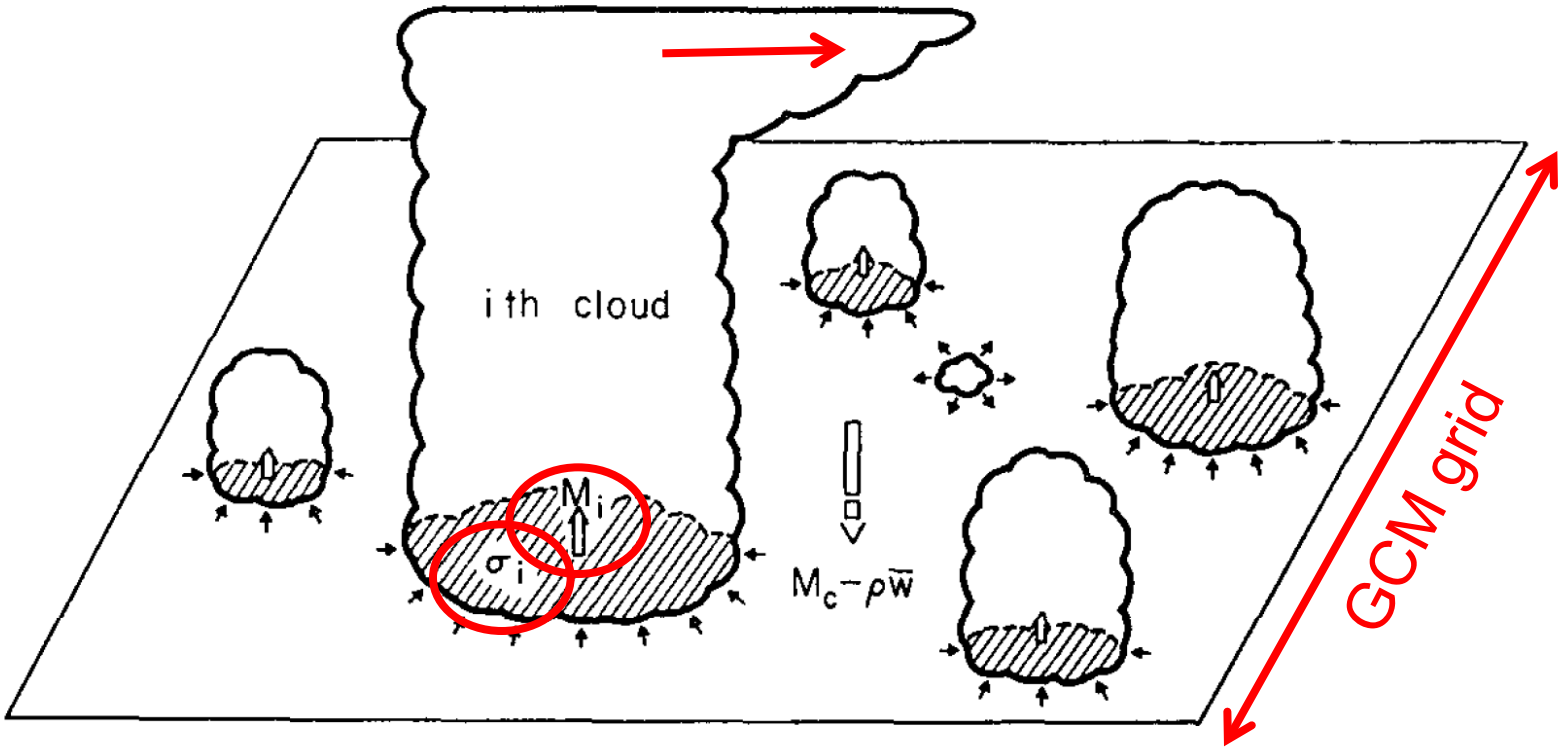
Radiosonde data in the tropics



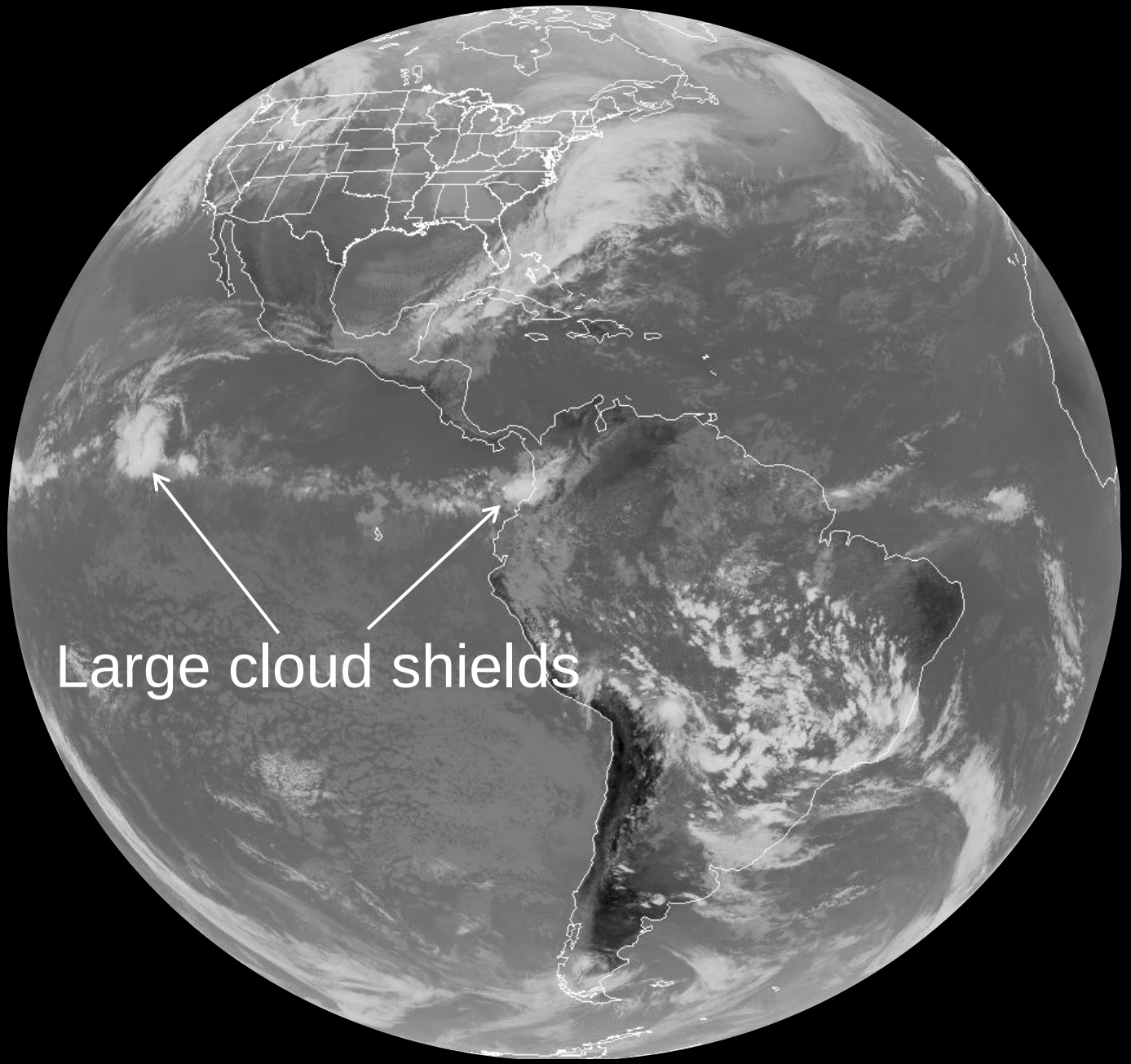
"Hot tower hypothesis"

Riehl & Malkus 1958

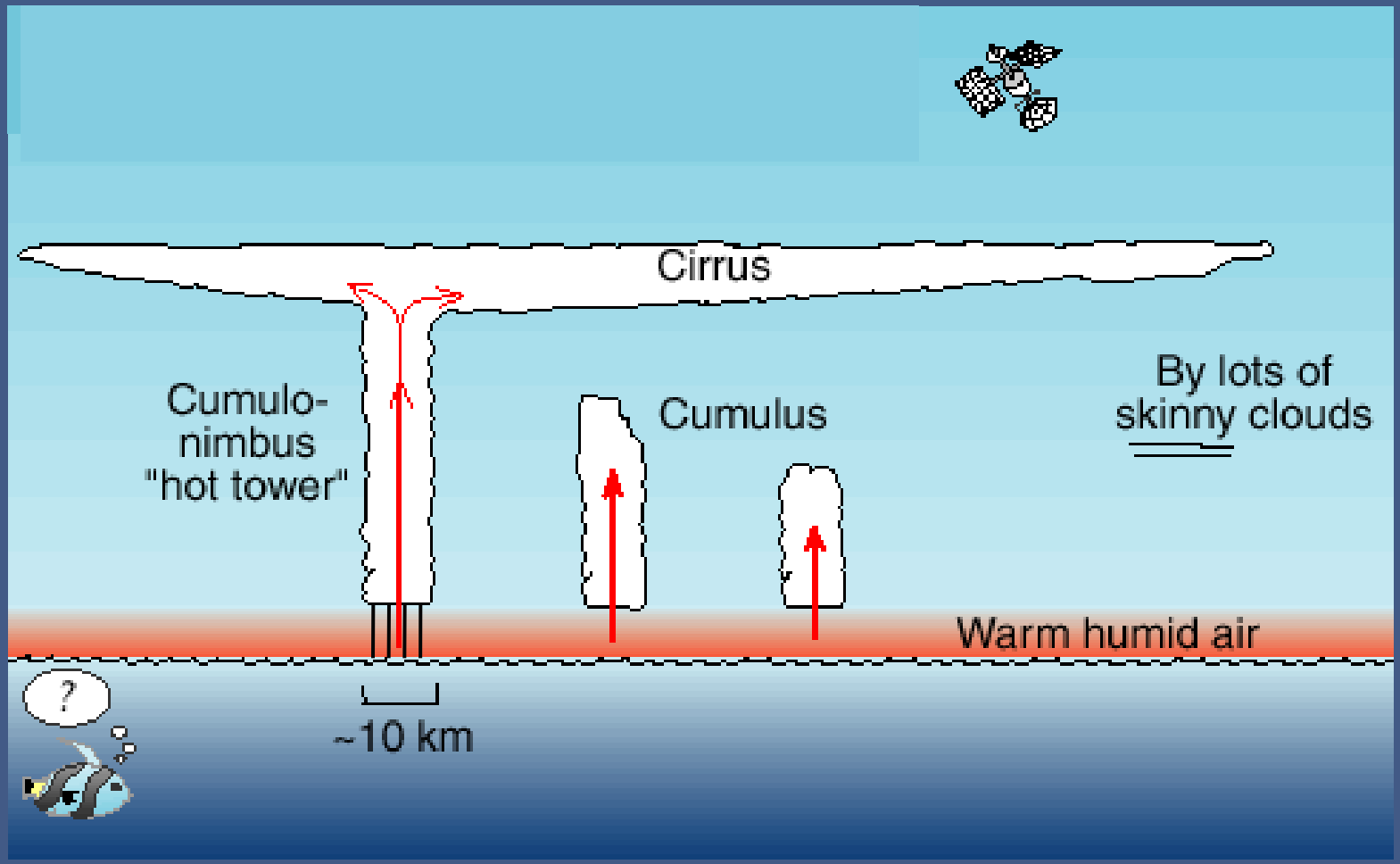
Convective parameterization



Satellite Observations: an “inconvenient truth”


Large cloud shields

Early 1970's

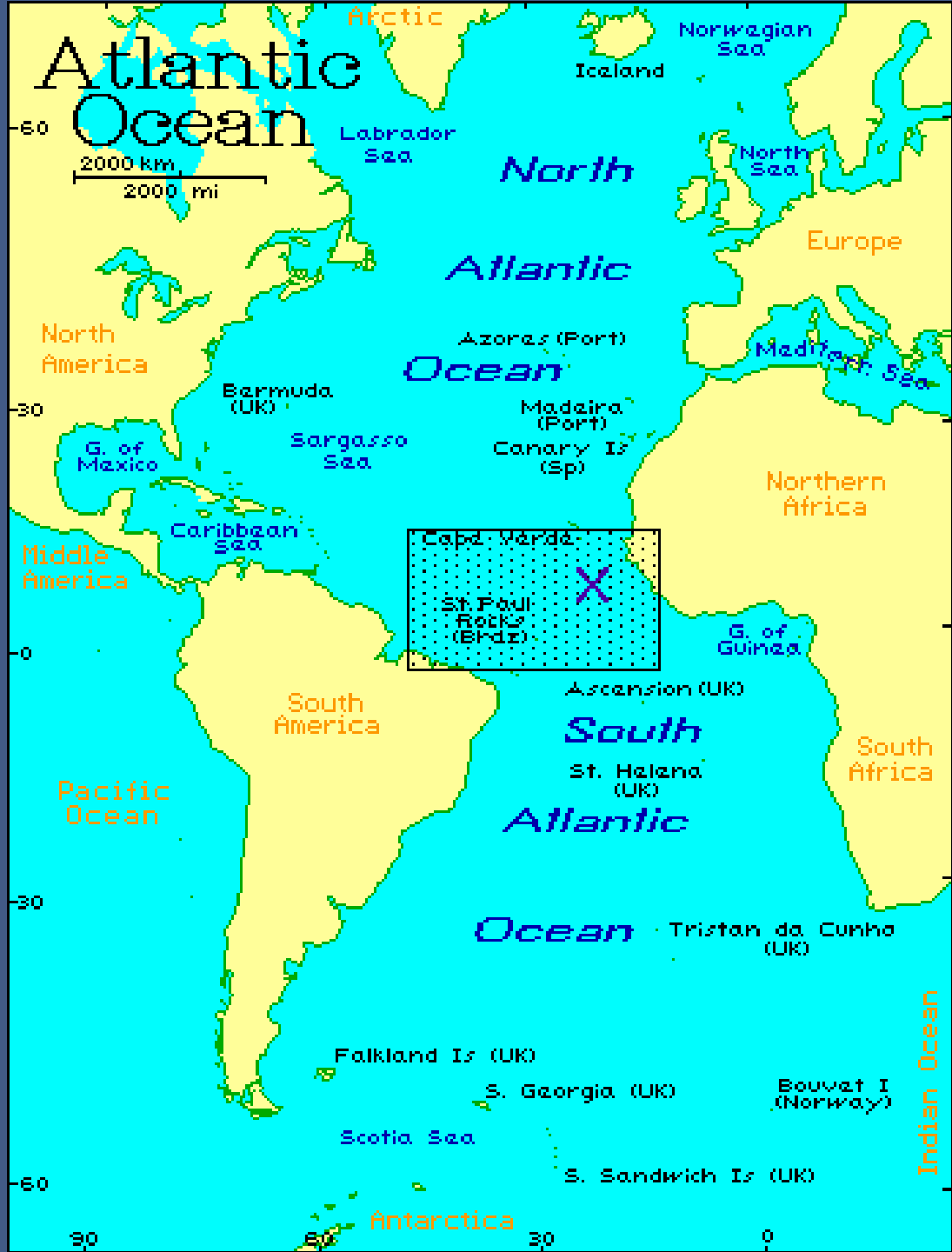


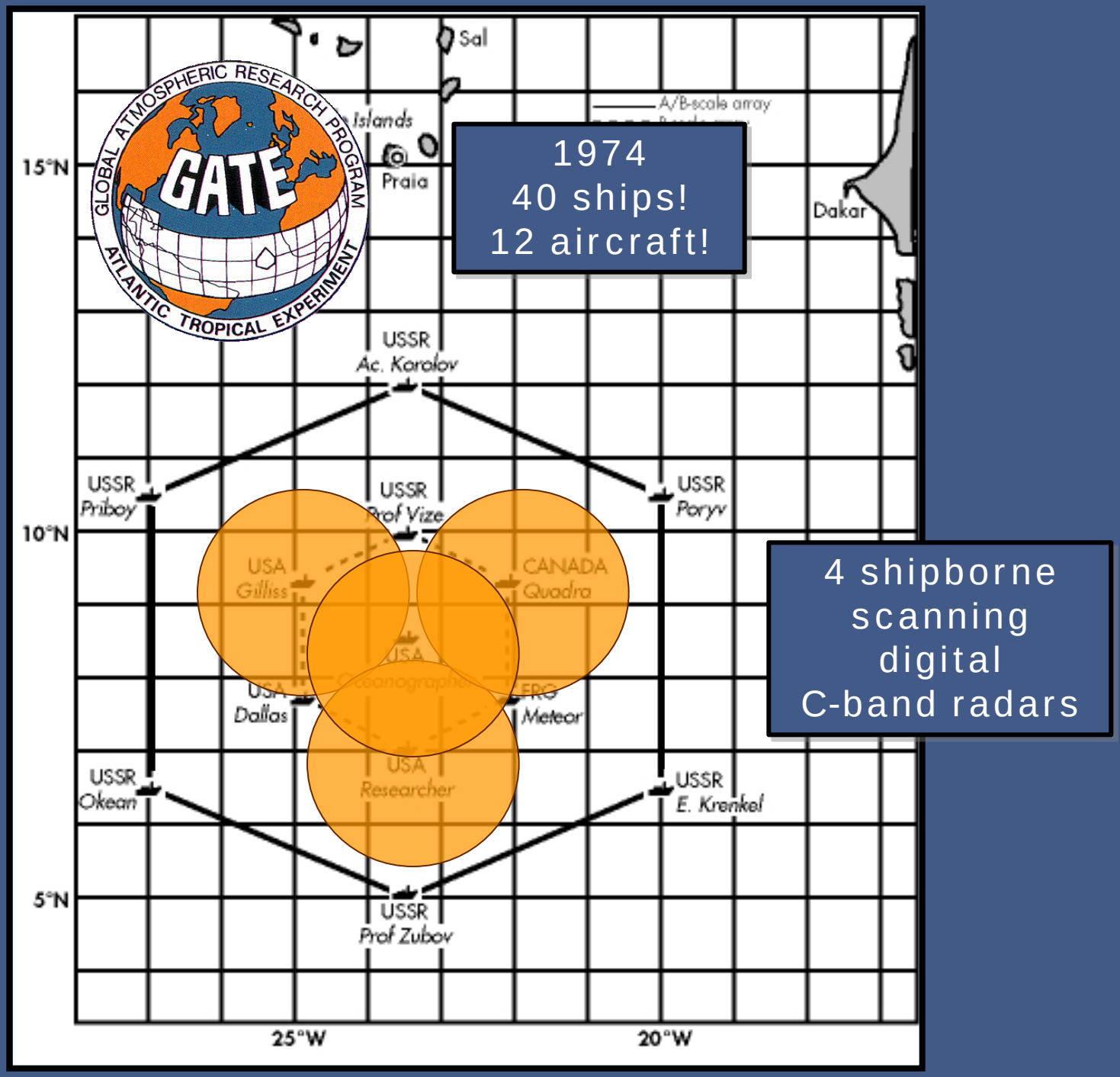
- Explained satellite pictures
- Retained the hot tower notion
- Included smaller clouds

Radars:
The second “inconvenient truth”

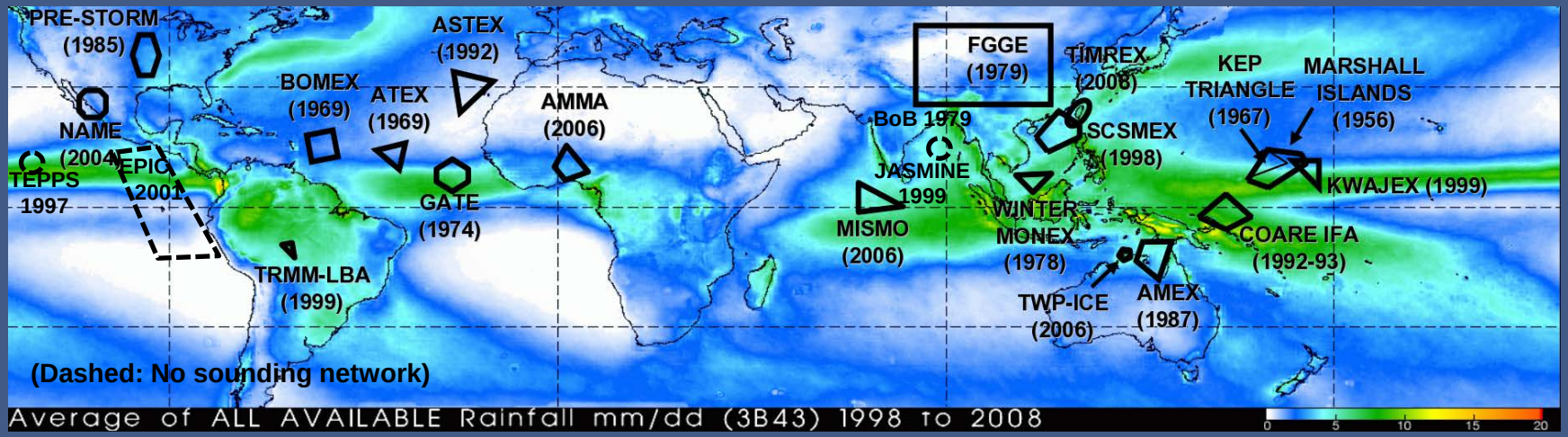
GATE 1974


GLOBAL ATMOSPHERIC RESEARCH PROGRAM
GATE
ATLANTIC TROPICAL EXPERIMENT


Atlantic Ocean
2000 km
2000 mi
Arctic
Norwegian Sea
Iceland
Labrador Sea
North Sea
North Atlantic Ocean
Europe
North America
Azores (Port)
Mediterr. Sea
Bermuda (UK)
Madeira (Port)
Canary Is (Sp)
Sargasso Sea
G. of Mexico
Northern Africa
Caribbean Sea
Middle America
Cape Verde
St. Paul Rocks (Brdz)
G. of Guinea
Ascension (UK)
South America
South Atlantic Ocean
South Africa
St. Helena (UK)
Pacific Ocean
Tristan da Cunha (UK)
Falkland Is (UK)
S. Georgia (UK)
Bouvet I (Norway)
Scotia Sea
S. Sandwich Is (UK)
Indian Ocean
Antarctica
60
30
0
90
60
30
0

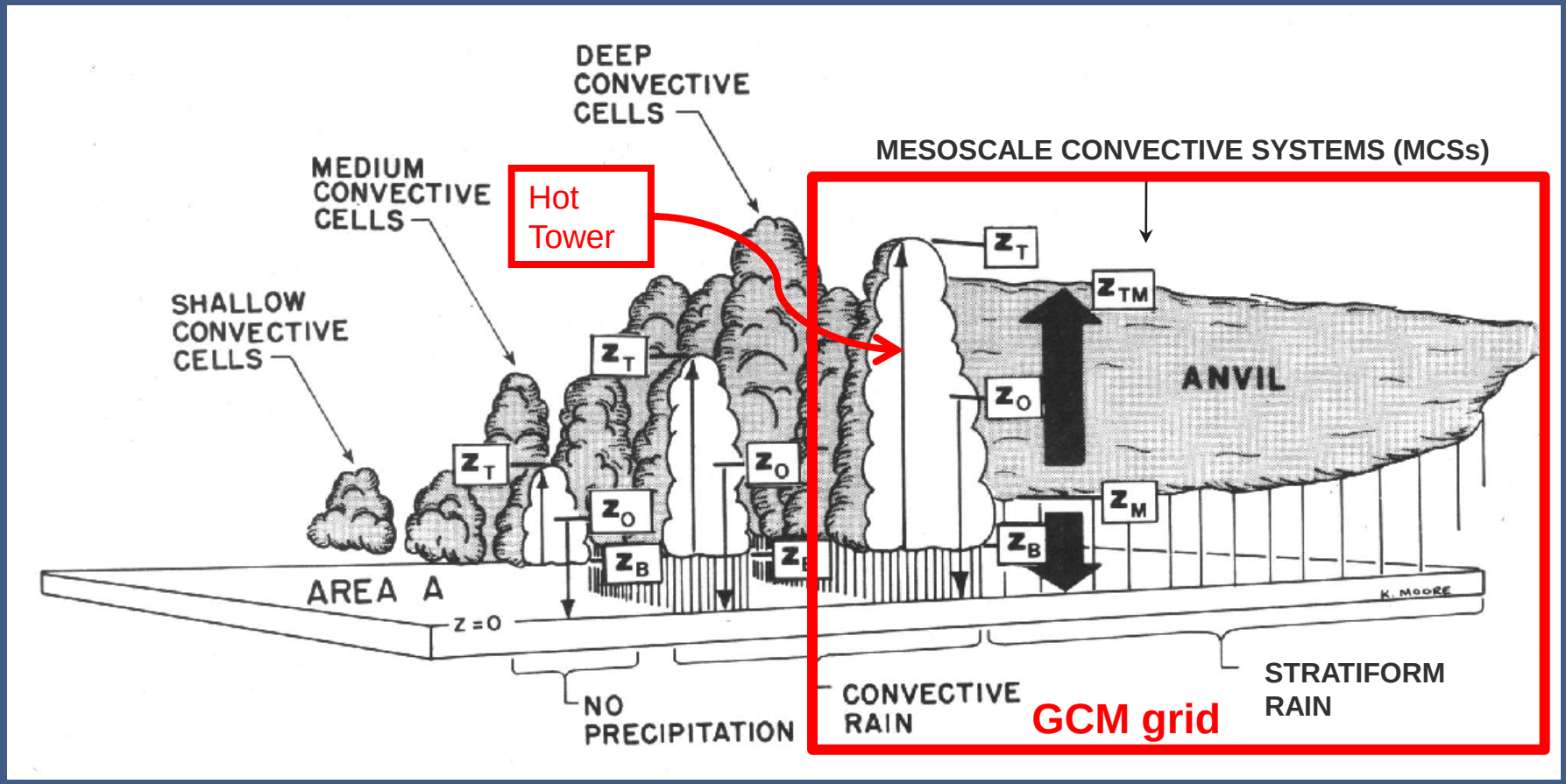

GLOBAL ATMOSPHERIC RESEARCH PROGRAM
GATE
ATLANTIC TROPICAL EXPERIMENT
1974
40 ships!
12 aircraft!
4 shipborne scanning digital C-band radars
A/B-scale array
Sal
Islands
Praia
Dakar
15°N
10°N
5°N
25°W
20°W
USSR
Ac. Koralov
USSR
Priboy
USSR
Prof Vize
USSR
Poryv
USA
Gilliss
CANADA
Quadra
USA
Oceanographer
USA
Dallas
FRG
Meteor
USA
Researcher
USSR
Okean
USSR
E. Krenkel
USSR
Prof Zubov

More Field Projects to Study Convection



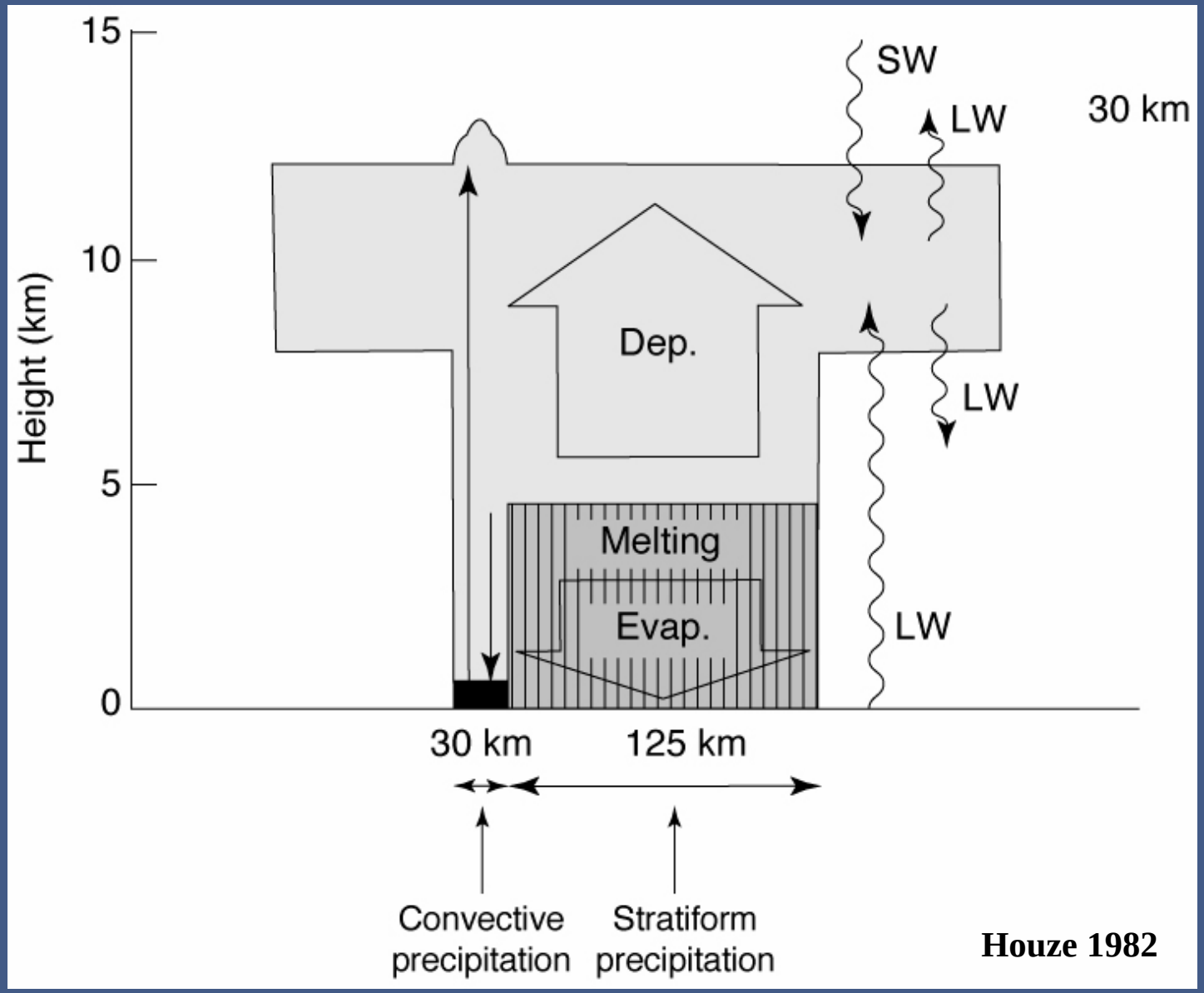
Ground, ship, & airborne cm radars

Post-GATE view of the tropical cloud population

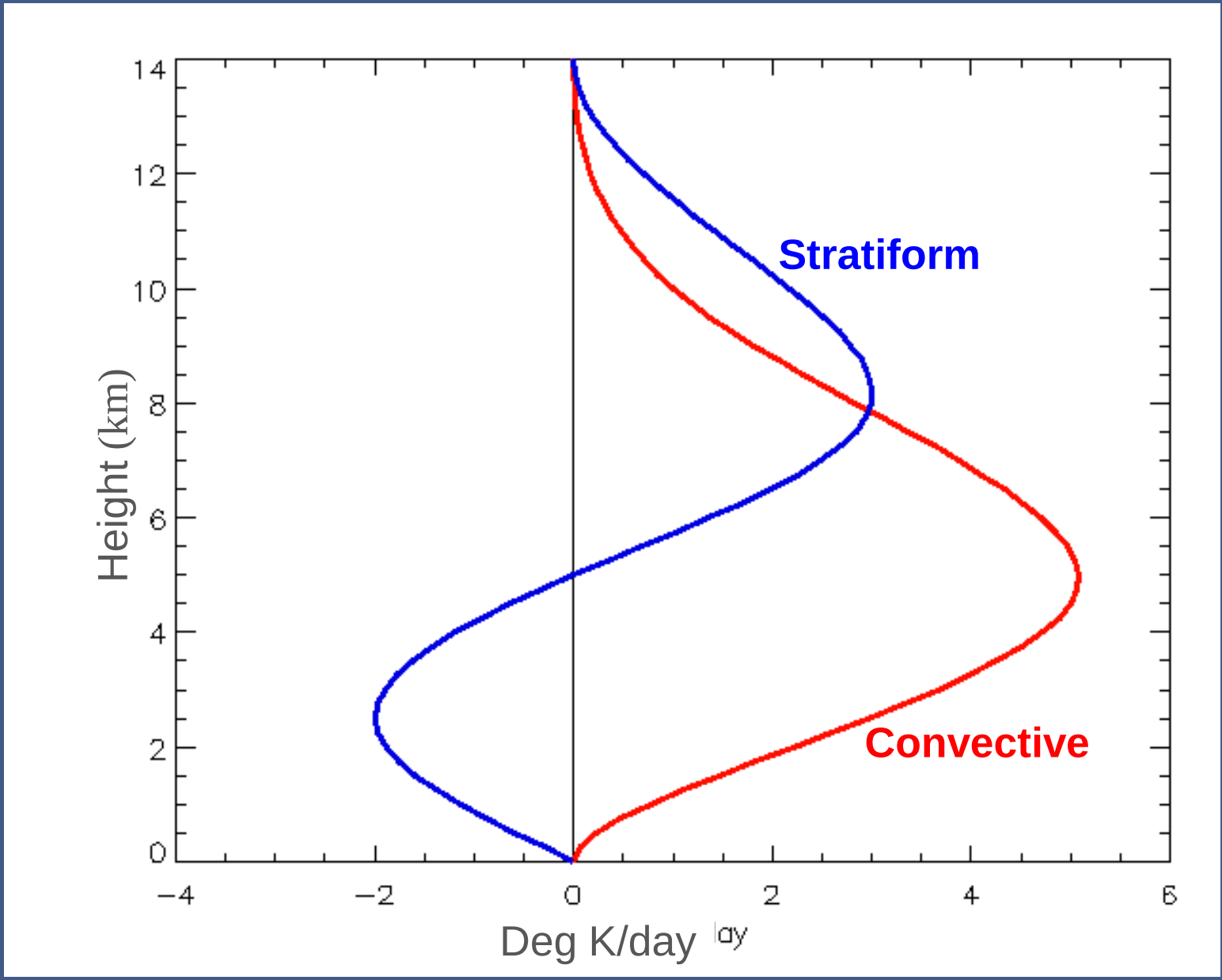


Houze et al. (1980)

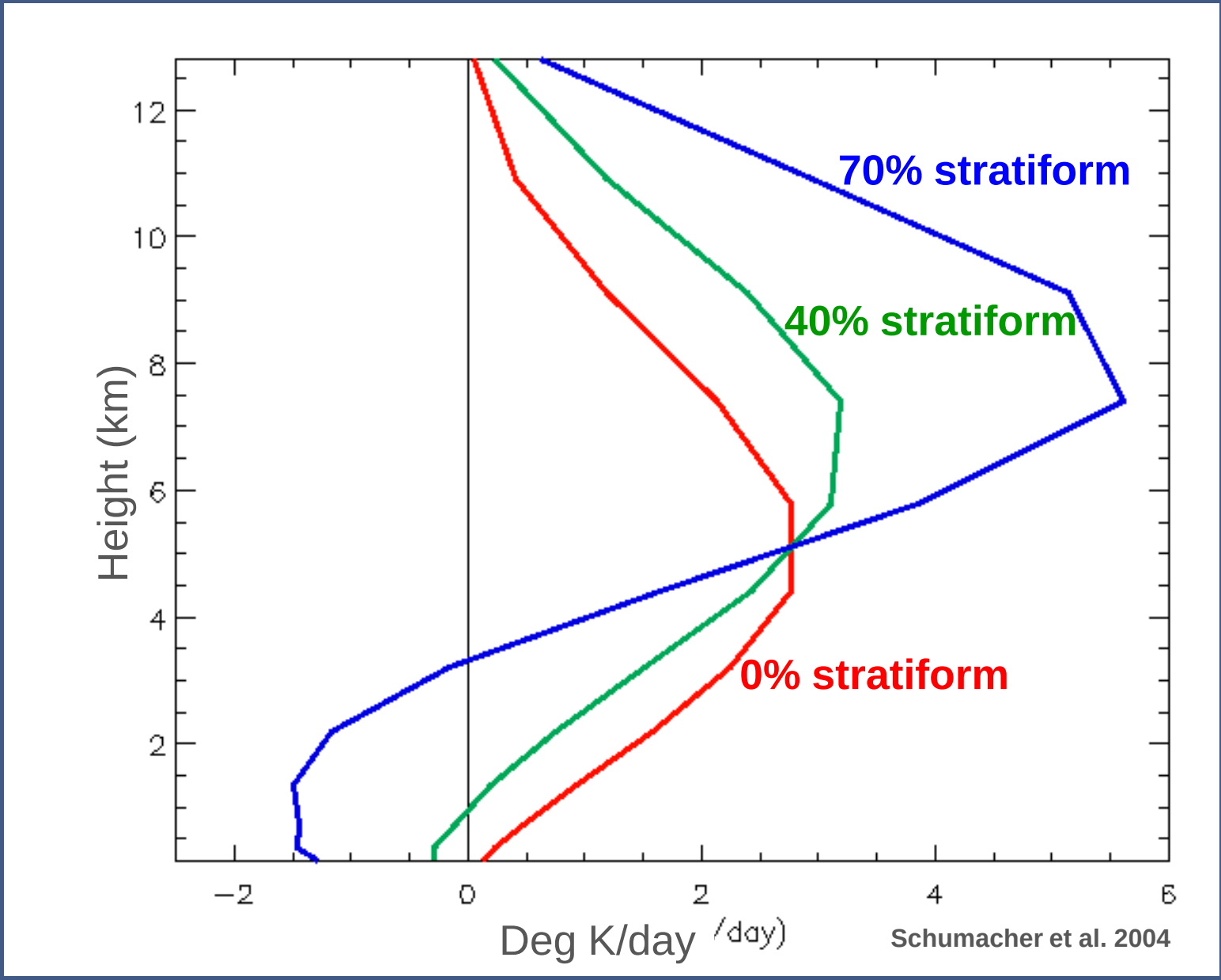
Heating and cooling processes in an MCS



Simplified MCS Heating Profiles



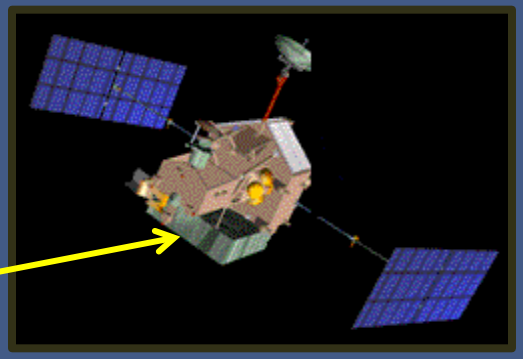
MCS Net Heating Profiles

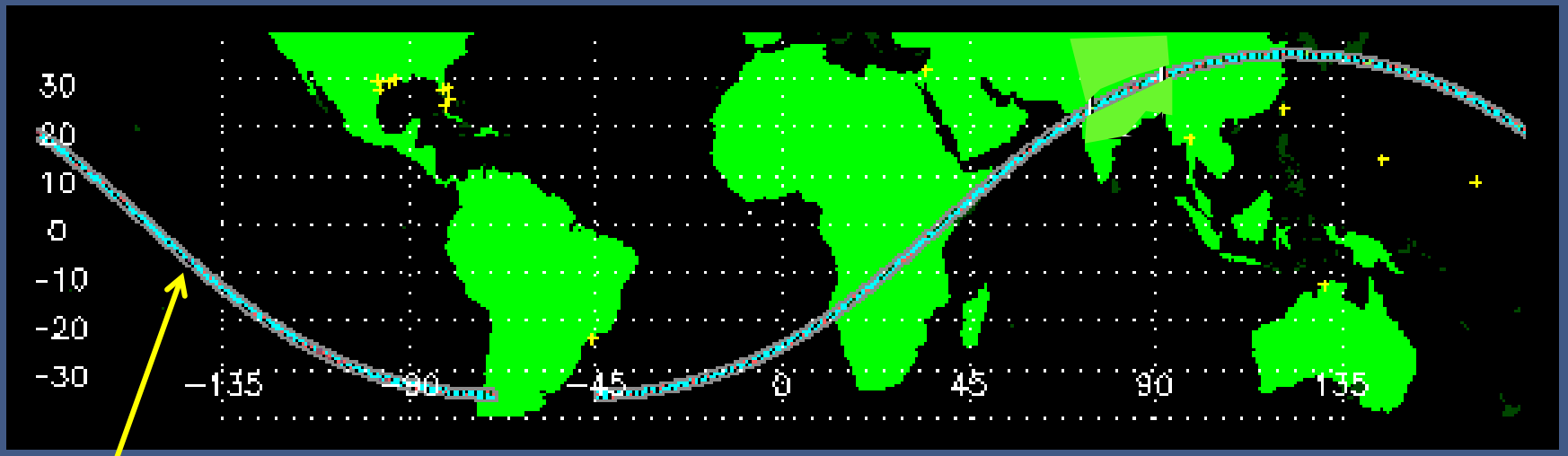


Precipitation Radar in Space

The TRMM Satellite

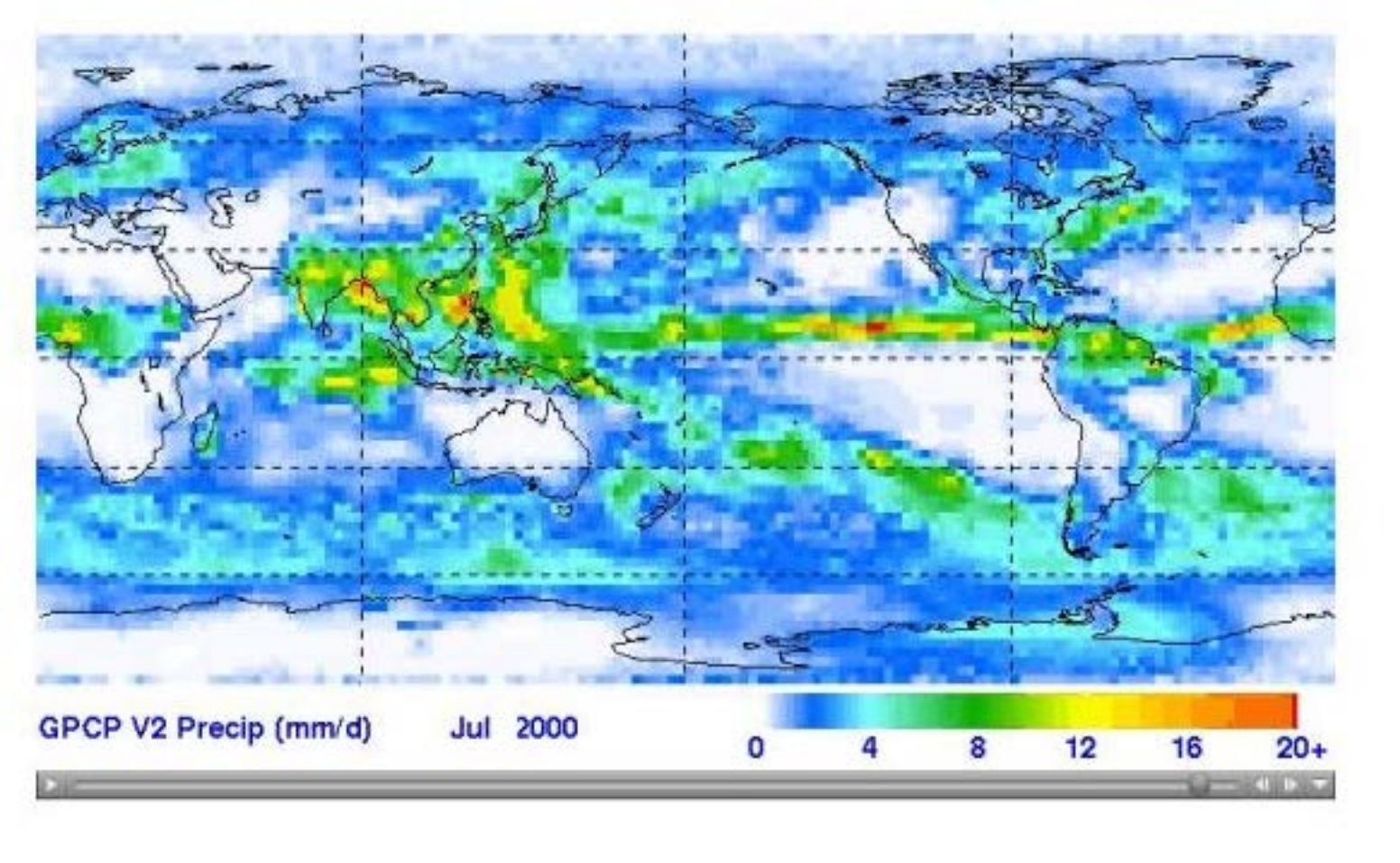
Ka-band Radar





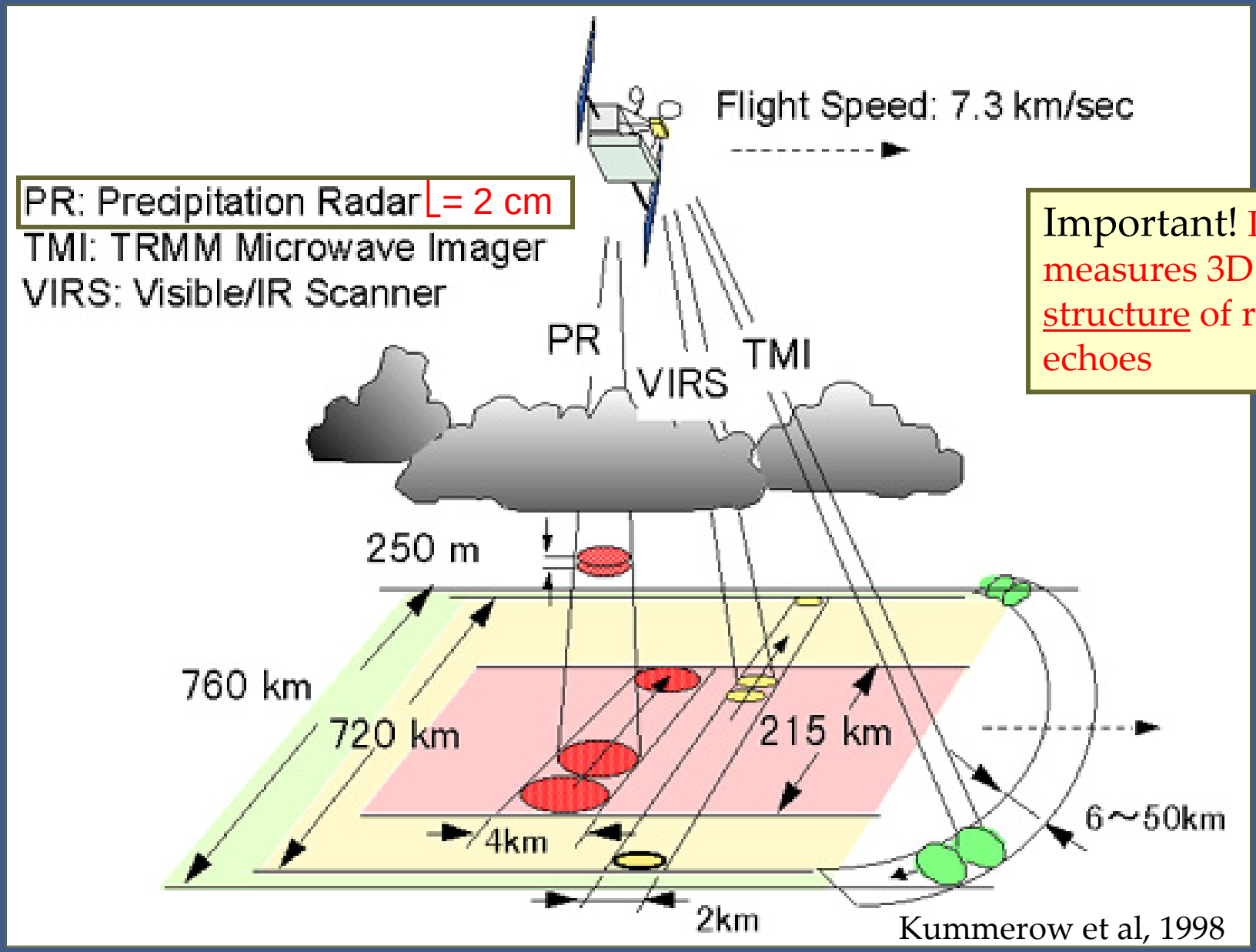
Low altitude, low inclination orbit

Rainfall mapping revolutionized!



Combined satellite rainfall July 2000
TRMM plus passive microwave sensors + other

TRMM Satellite Instrumentation



Important! PR measures 3D structure of radar echoes

Kummerow et al, 1998

How tropical rain is distributed by cloud size and type

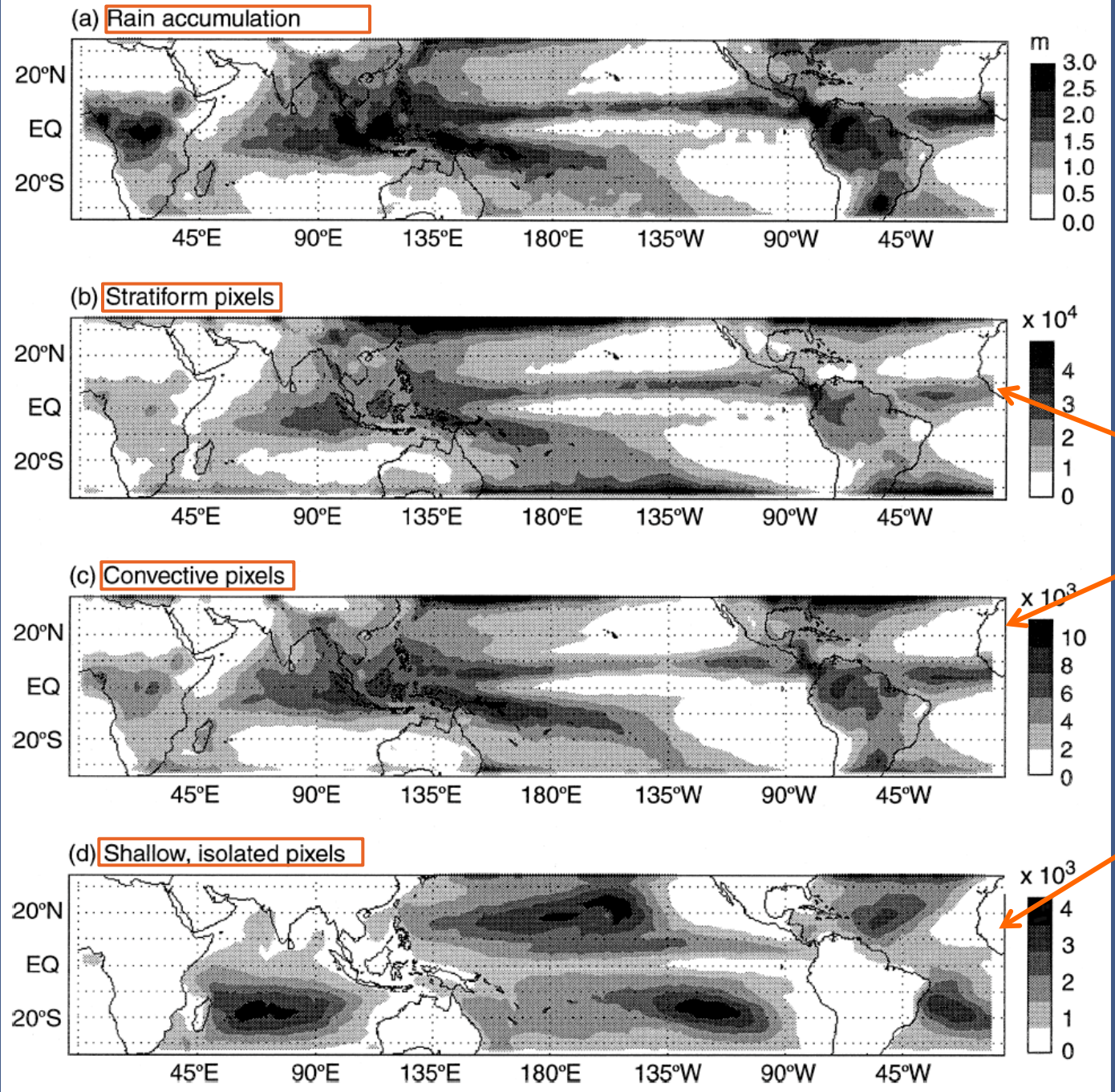


FIG. 1 TRMM version-5 PR 2.5° observations from 1998 to 2000 for annually averaged (a) rain, (b) stratiform pixel count (rain-types 10–14), (c) convective pixel count (rain-types 20–25), and (d) shallow, isolated pixel count (rain-types 15, 26–29).

2 Years of TRMM PR data

Large Cbs MCSs

Small isolated Cbs

Schumacher & Houze 2003

Traditional conceptual view of mean meridional distribution of tropical convection

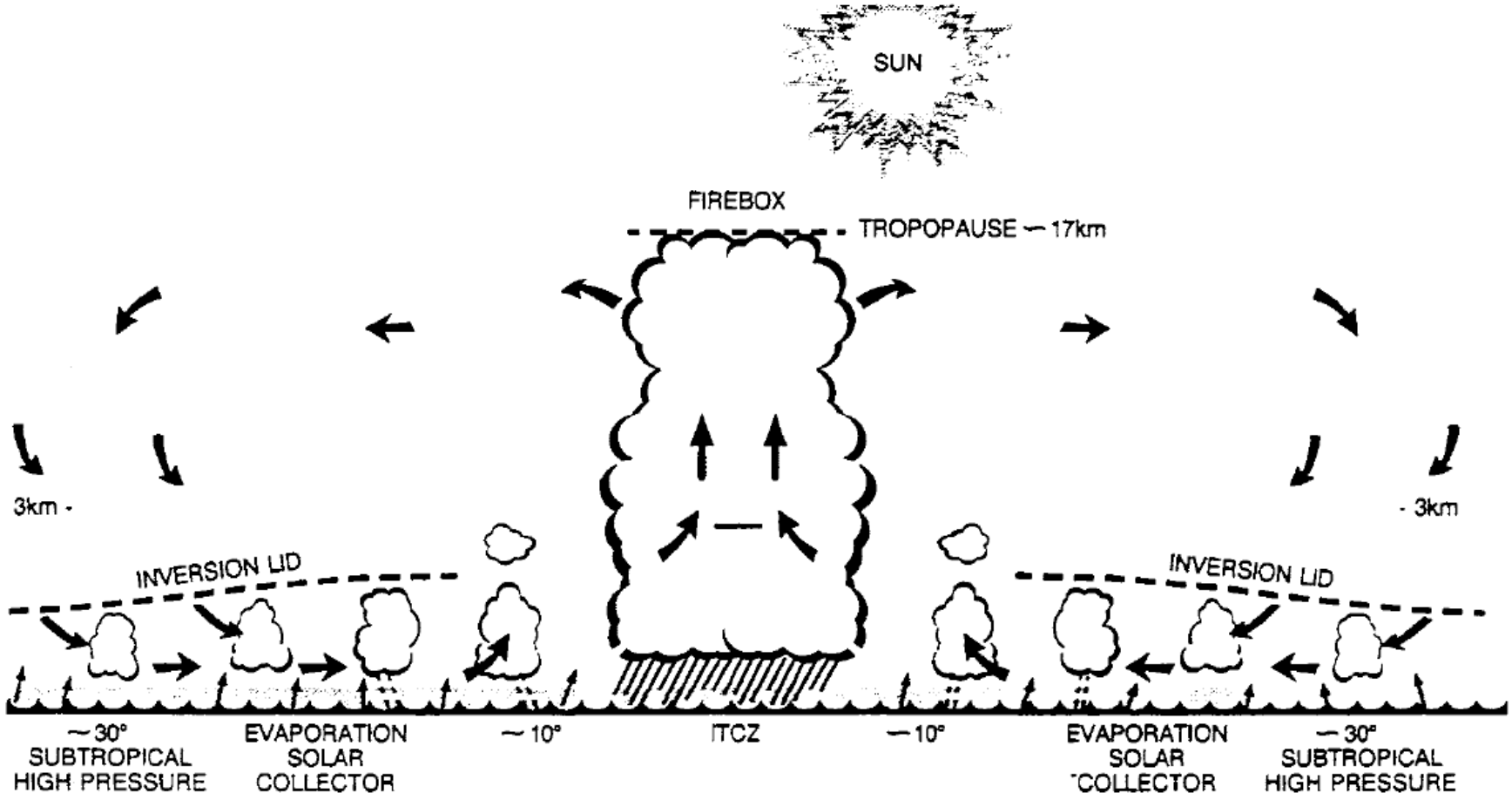
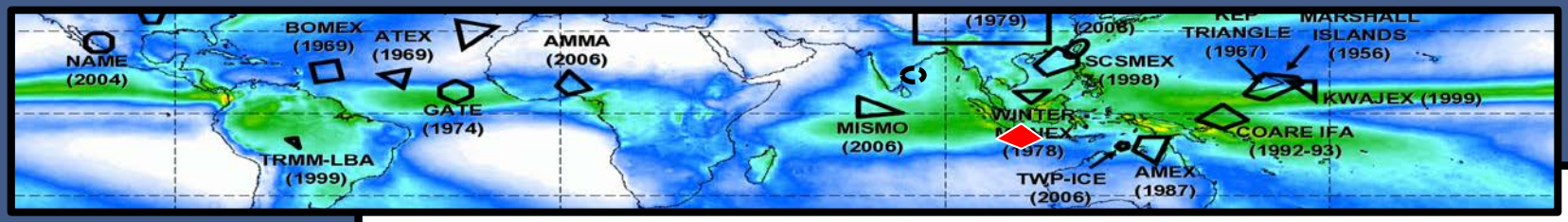


FIG. 1. Schematic north–south slice through the tropical atmosphere showing the towering rainclouds in the ITCZ "firebox" (not to scale). Arrows show the meridional Hadley circulation, whose upper branch transports some of the released heat energy poleward in both hemispheres

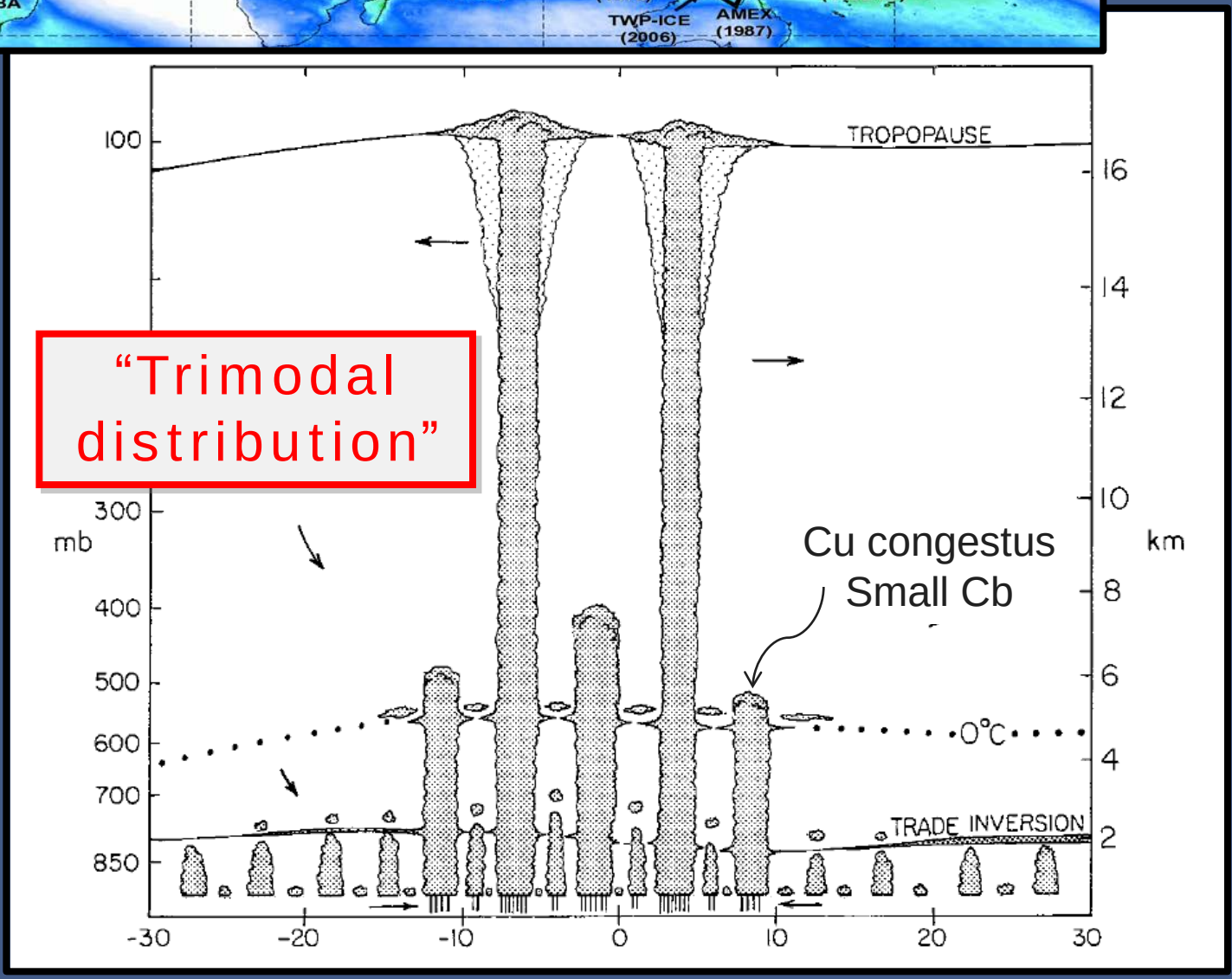
Simpson 1992



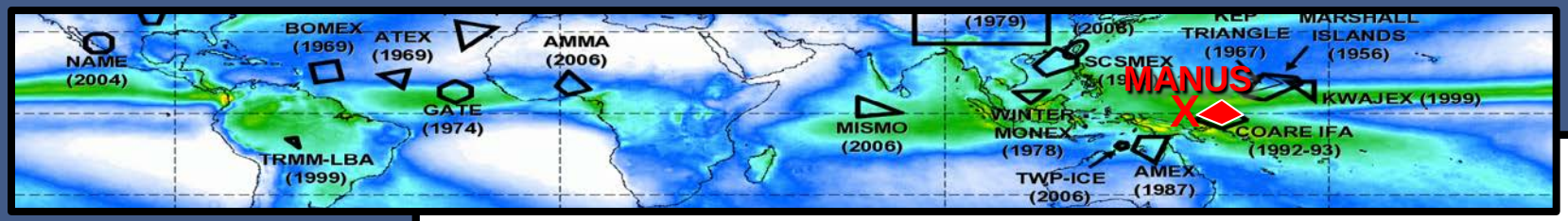
Suggested by

TOGA COARE radiosonde data

Johnson et al. 1999



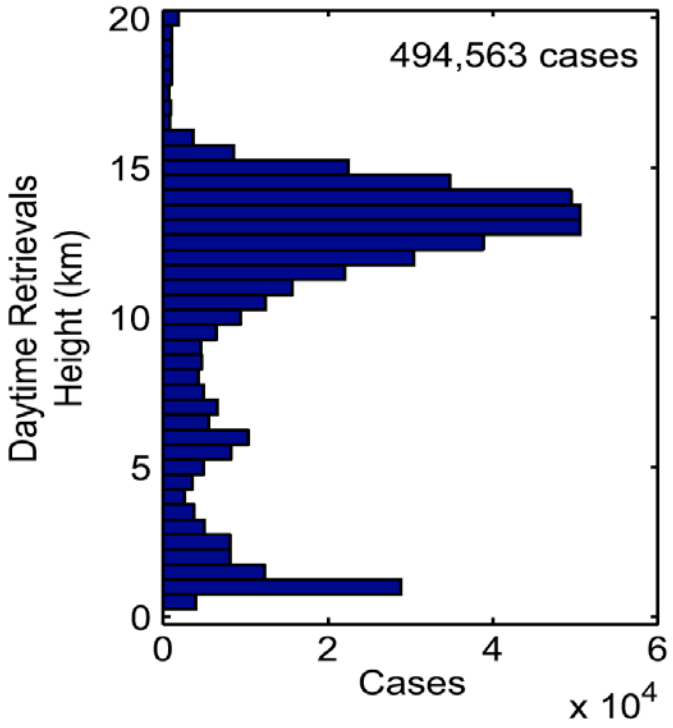
Cloud Radars

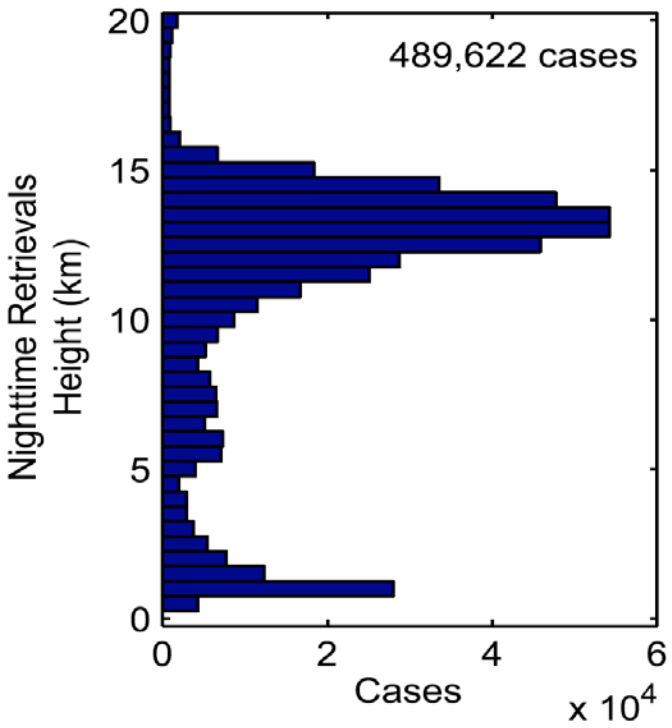


"Trimodal" distribution

Hollars et al. 1999

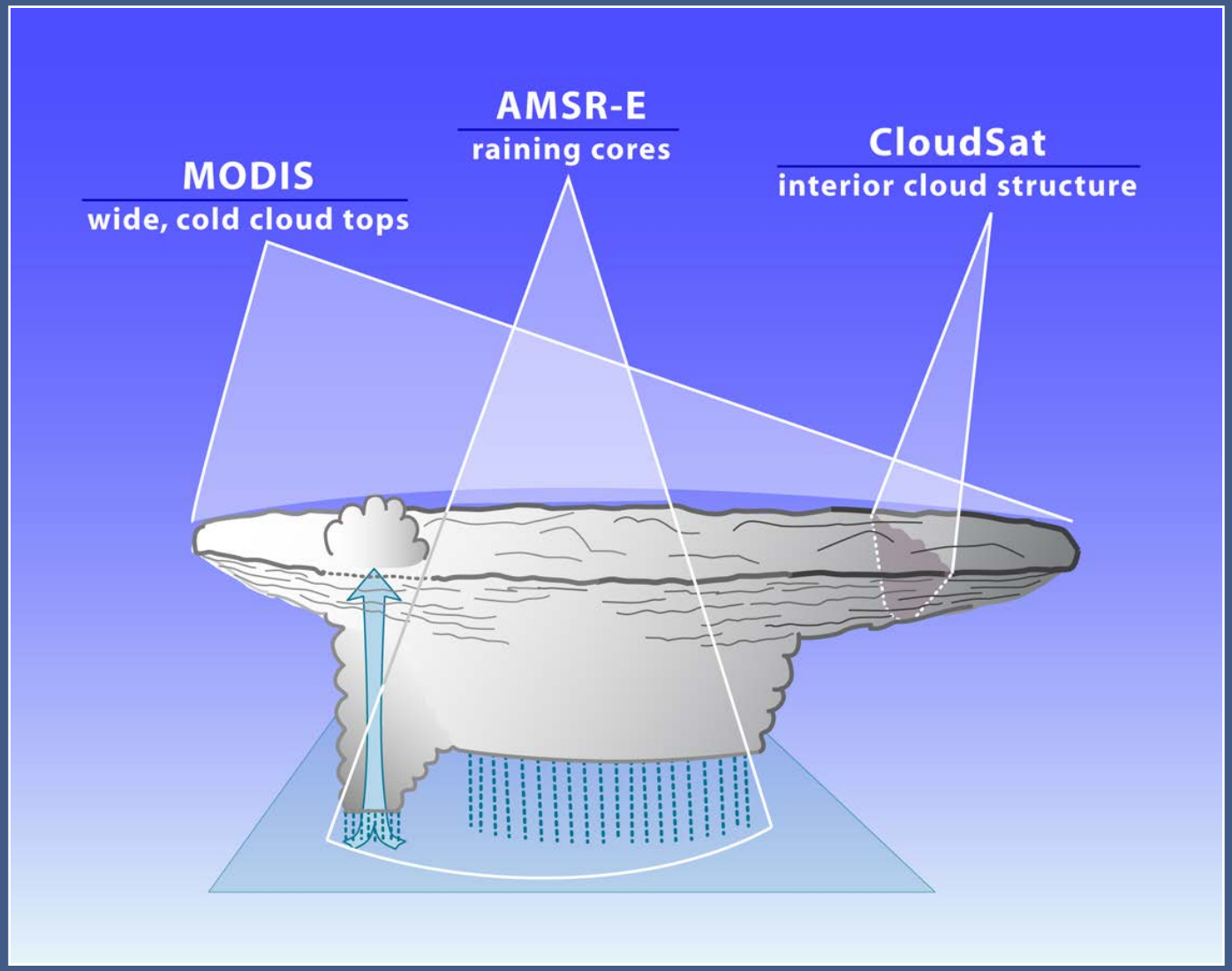
Evidence from Manus ARM cloud radar observations





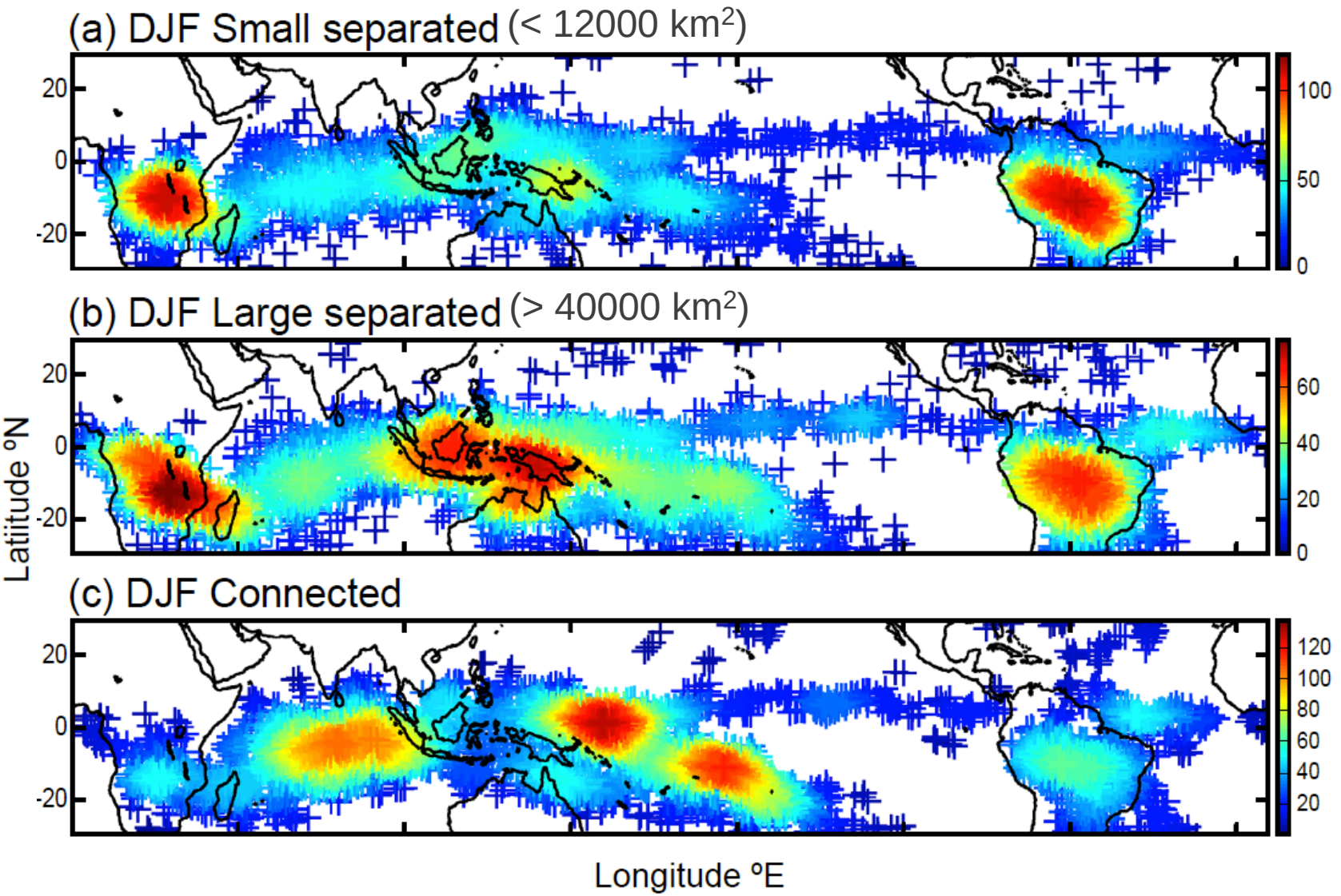
Cloud Radar in Space

Anvils of Mesoscale Convective Systems (MCSs)



Yuan and Houze 2010

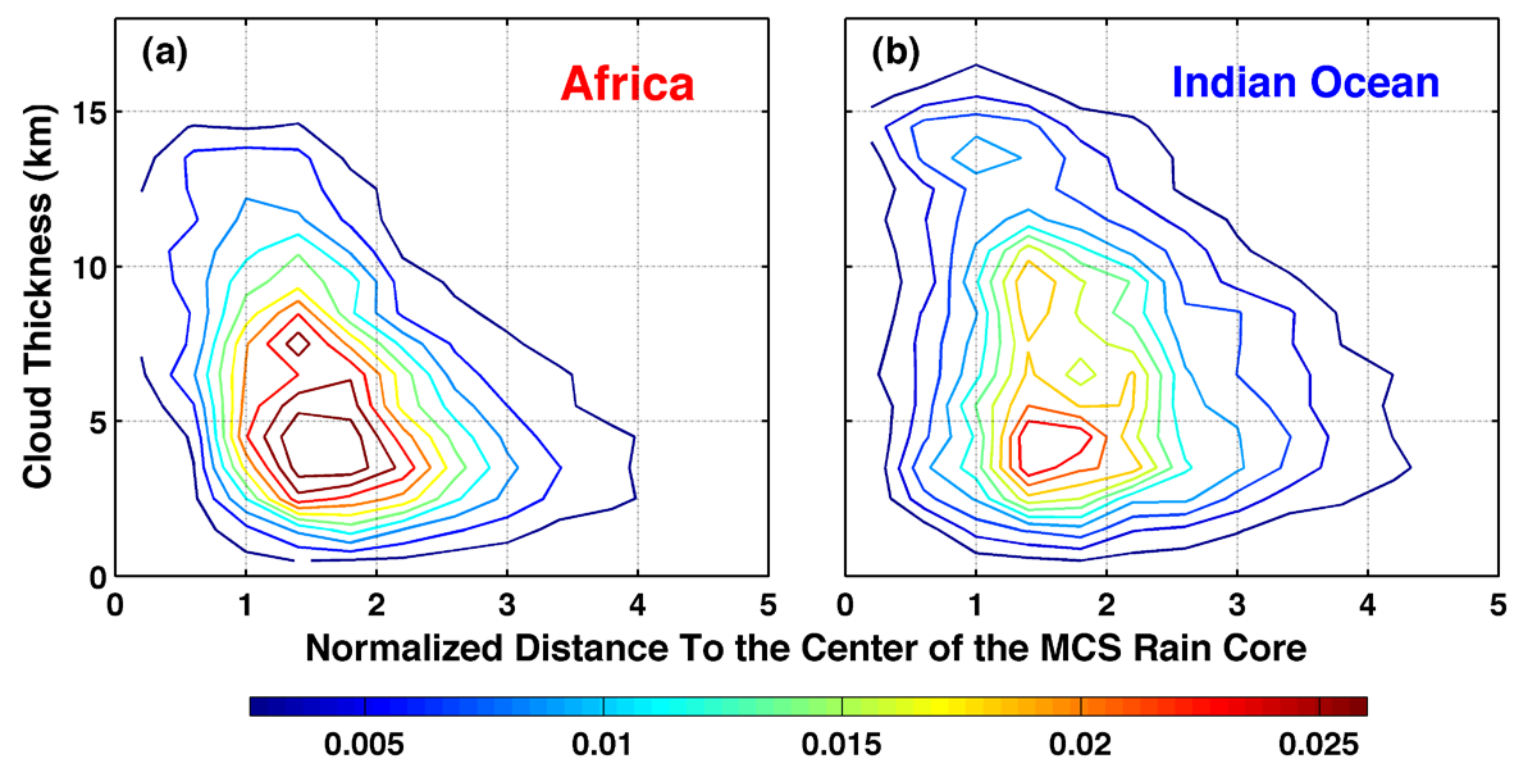
MCSs Over the Whole Tropics



Yuan and Houze 2010

Morphology of MCS anvils in different parts of the tropics

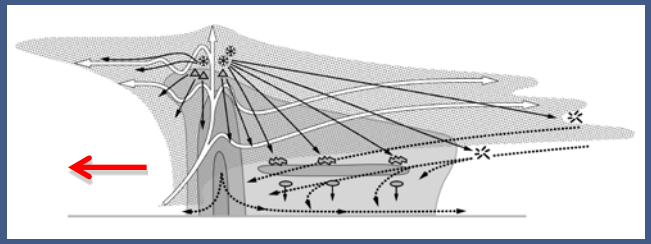
CloudSat data



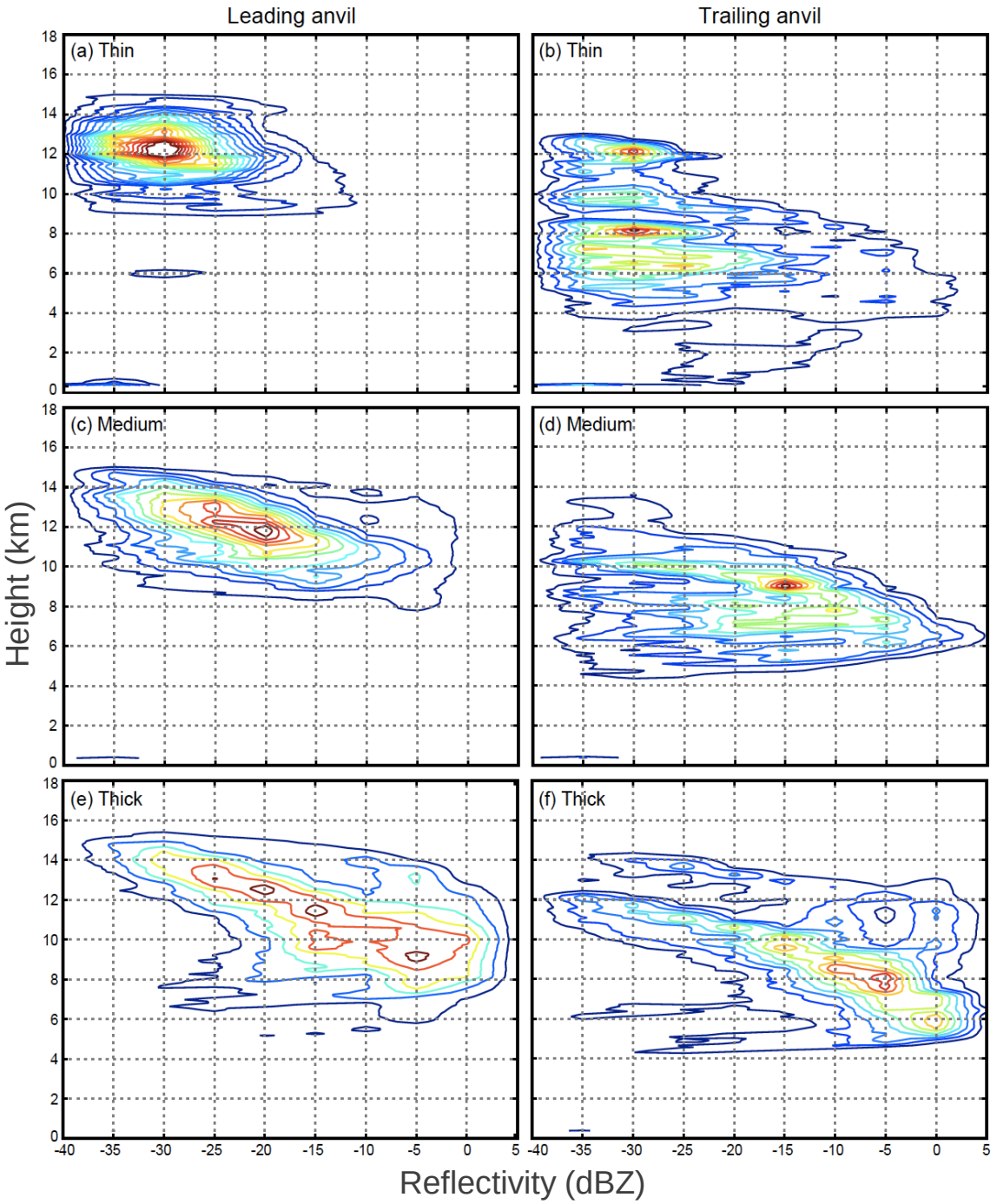
Yuan and Houze 2010

Internal structures of MCS anvils

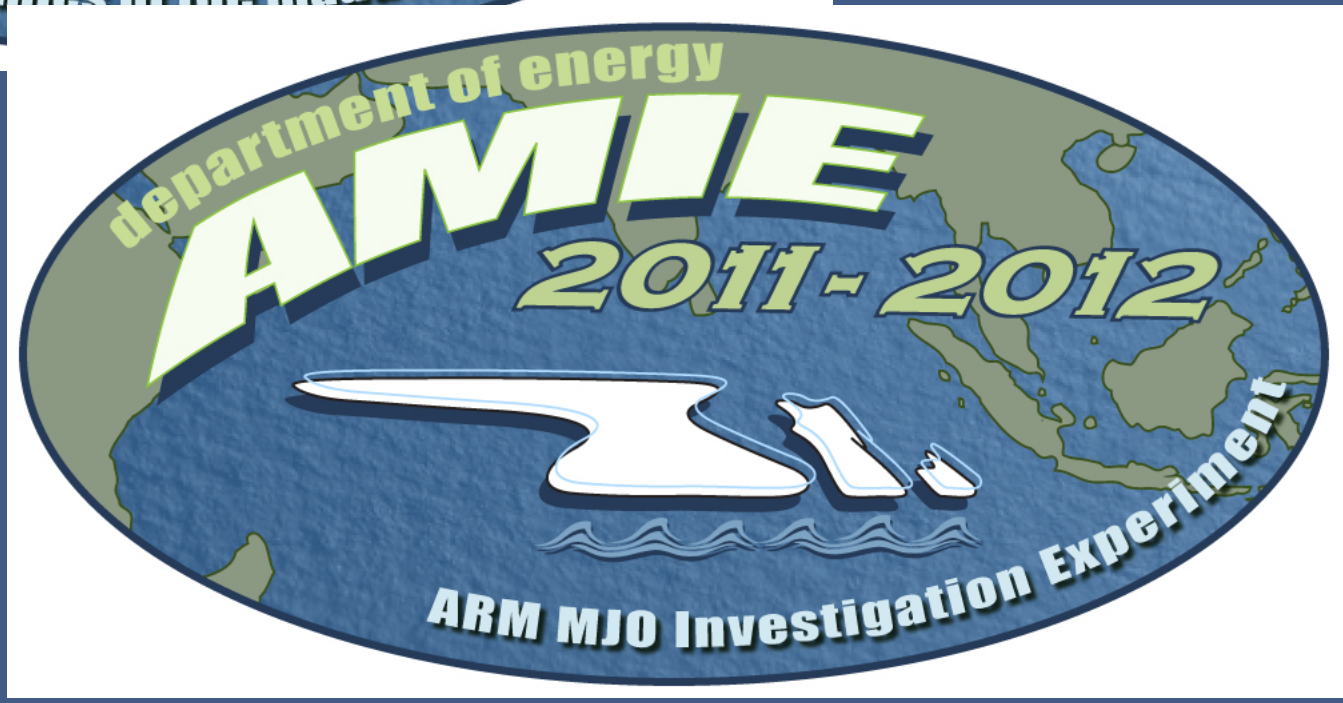
Data from MCSs seen by ARM W-band radar in Niamey, Niger

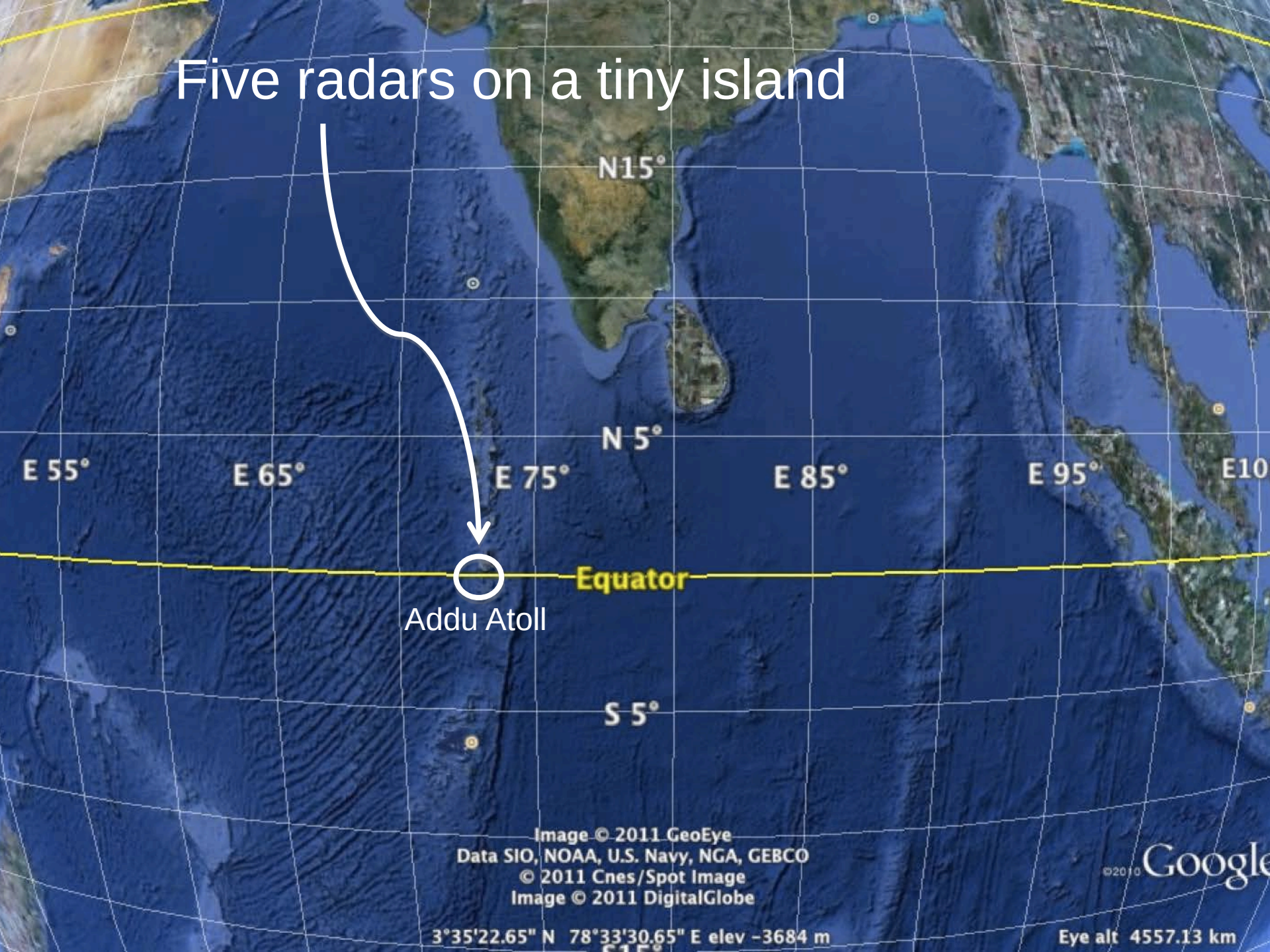


Cetrone & Houze 2011
and also
Yuan et al. 2011-CloudSat



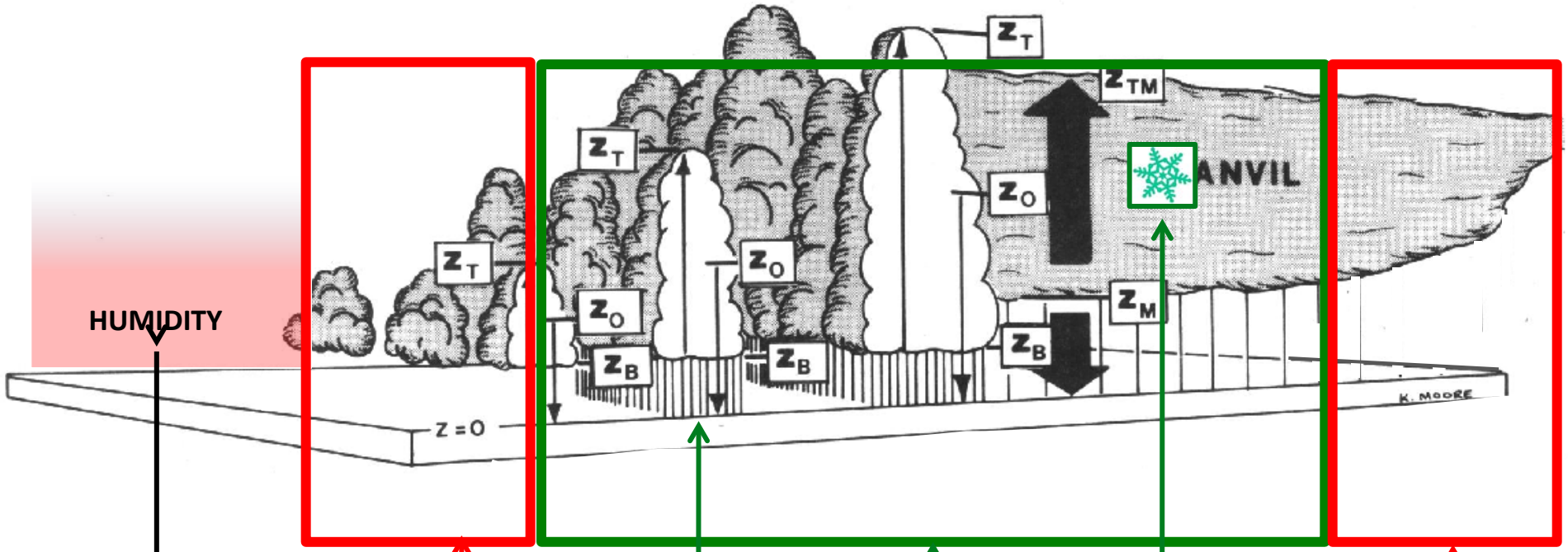

DYNAMO
2011 - 2012
dynamics of the madden-julian oscillation


department of energy
AMIE
2011 - 2012
ARM MJO Investigation Experiment


Five radars on a tiny island
N15°
N 5°
E 55°
E 65°
E 75°
E 85°
E 95°
E10
Equator
Addu Atoll
S 5°
Image © 2011 GeoEye
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
© 2011 Cnes/Spot Image
Image © 2011 DigitalGlobe
3°35'22.65" N 78°33'30.65" E elev -3684 m
Eye alt 4557.13 km
©2010 Google

Radar Supersite Approach

Will document many aspects of the convective population



DUAL WAVELENGTH
Water vapor

MM-WAVELENGTH
Non-precipitating Cumulus

DOPPLER
Air motions

CM-WAVELENGTH
Precipitation

POLARIMETRY
Microphysics

MM-WAVELENGTH
Anvil cloud


Summary & Conclusions

Timeline of progress

Pre-satellite era

→Hot towers and smaller clouds

Radars in field projects

→MCSs, squall lines, stratiform precipitation

Precipitation radar in space

→Global patterns—convective, stratiform, shallow, MCSs

Cloud radars

→ARM—layers, trimodality, anvils of MCSs

→CloudSat—global distributions of MCSs, anvils, ...

Dual wavelength

→Water vapor

What we've learned

Spectrum of convective cloud types and sizes covers a wide range of types and sizes of convective entities

- **Mesoscale systems with stratiform rain**
- **Top-heavy heating profiles**
- **Multimodal size distributions**
- **Shallow isolated cells**
- **Structures of large anvil clouds**
- **Global variability of the population**

Where we are going

How does convective population project onto larger-scale dynamics?

- **Latent heating profiles**
- **Radiative heating profiles in anvils of MCSs**
- **Nonprecipitating convective clouds**
- **Relation between humidity field and cloud population evolution**
- **Role of clouds in MJO, ENSO, monsoon, & coupled equatorial waves**

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NASA grants NNX07AD59G, NNX07AQ89G, NNX09AM73G, NNX10AH70G, NNX10AM28G,
NSF grants, ATM-0743180, ATM-0820586,
DOE grant DE-SC0001164 / ER-6

Extra slides

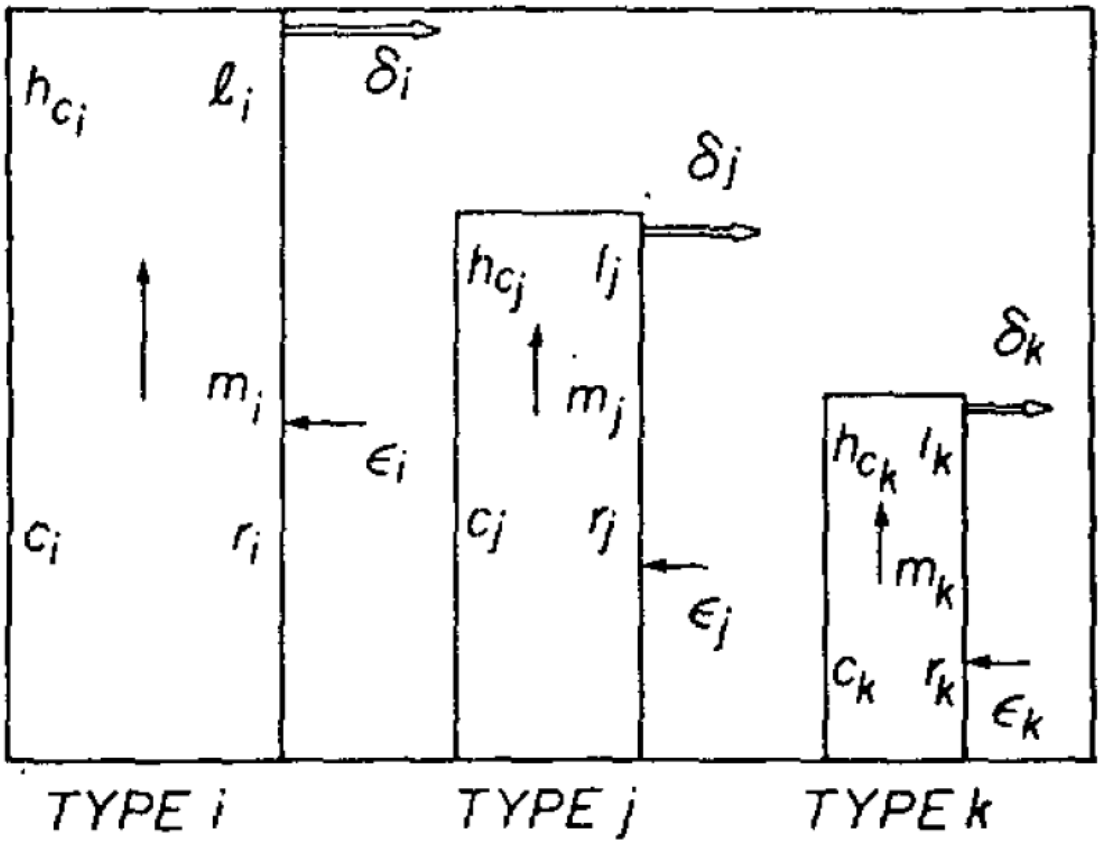
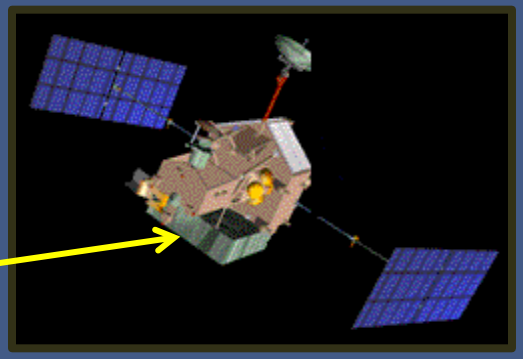
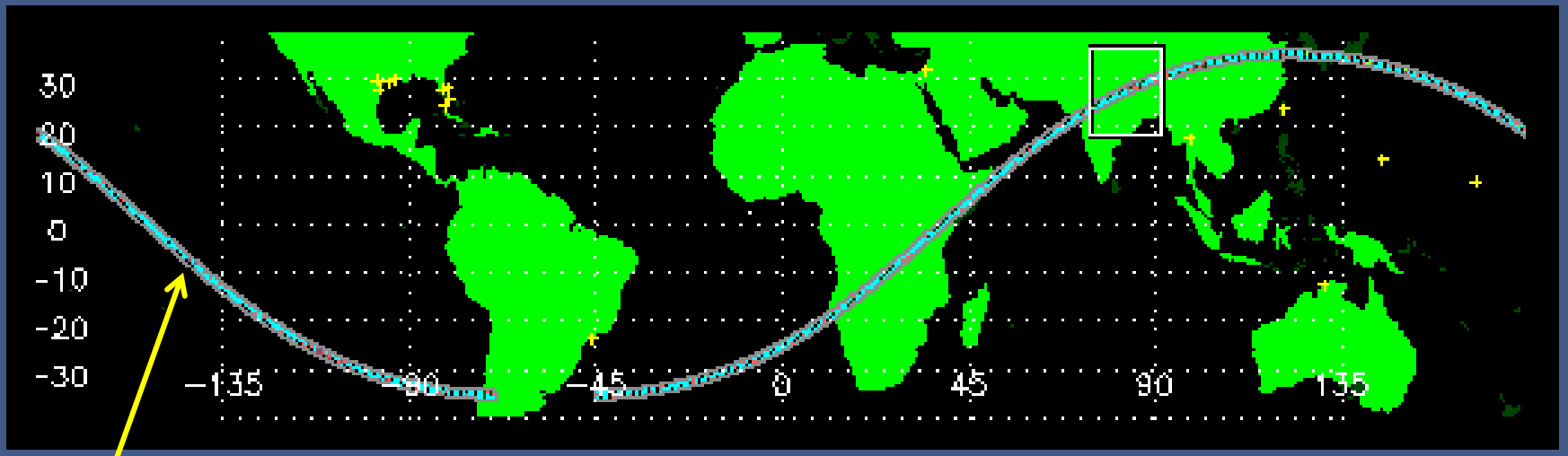


FIG. 2. Idealized view of cumulus cloud types, classified according to their top heights (see text for notation).

The TRMM Satellite



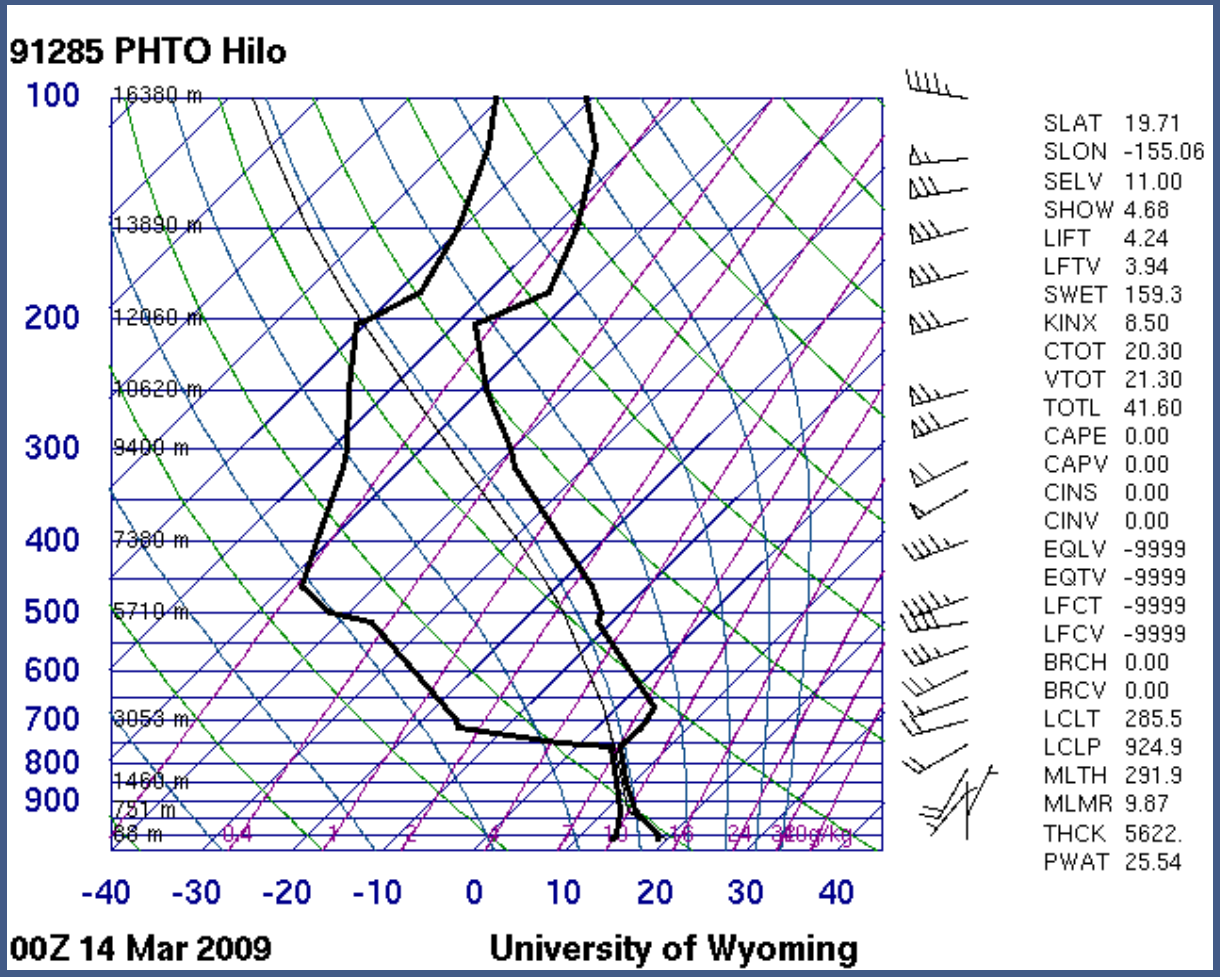
Radar



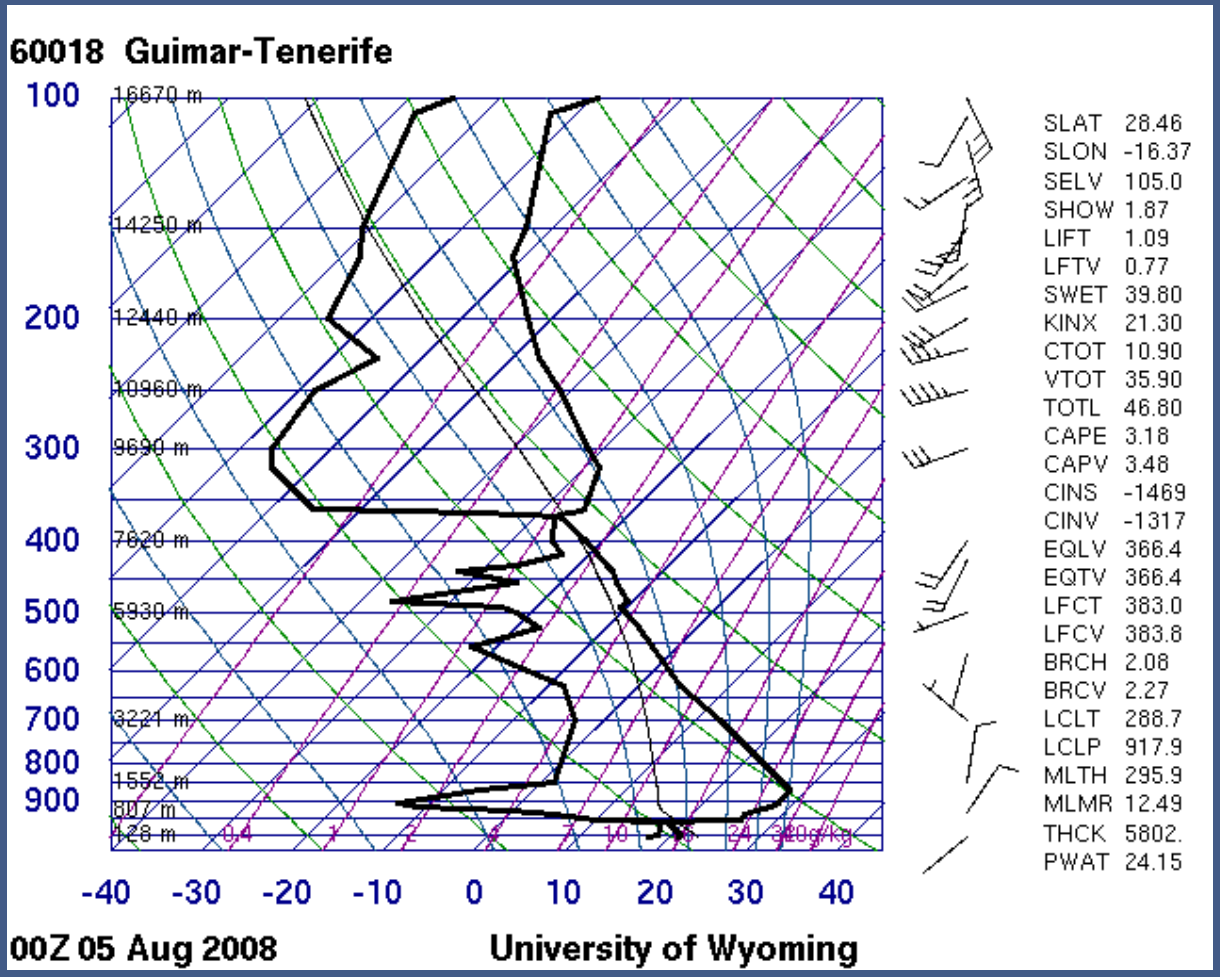
Low altitude, low inclination orbit

How do the environments of these regimes differ?

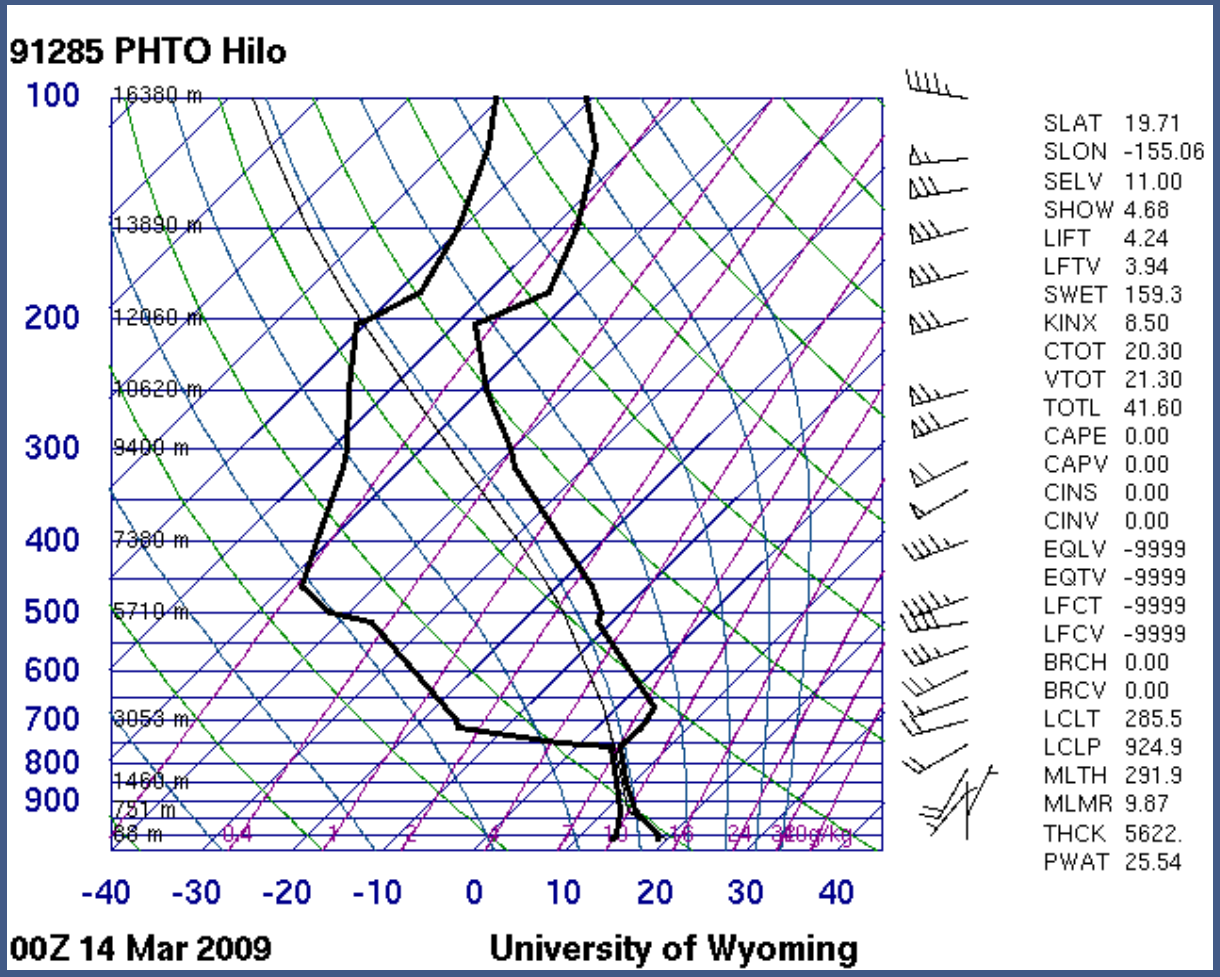
Trade Wind Regime



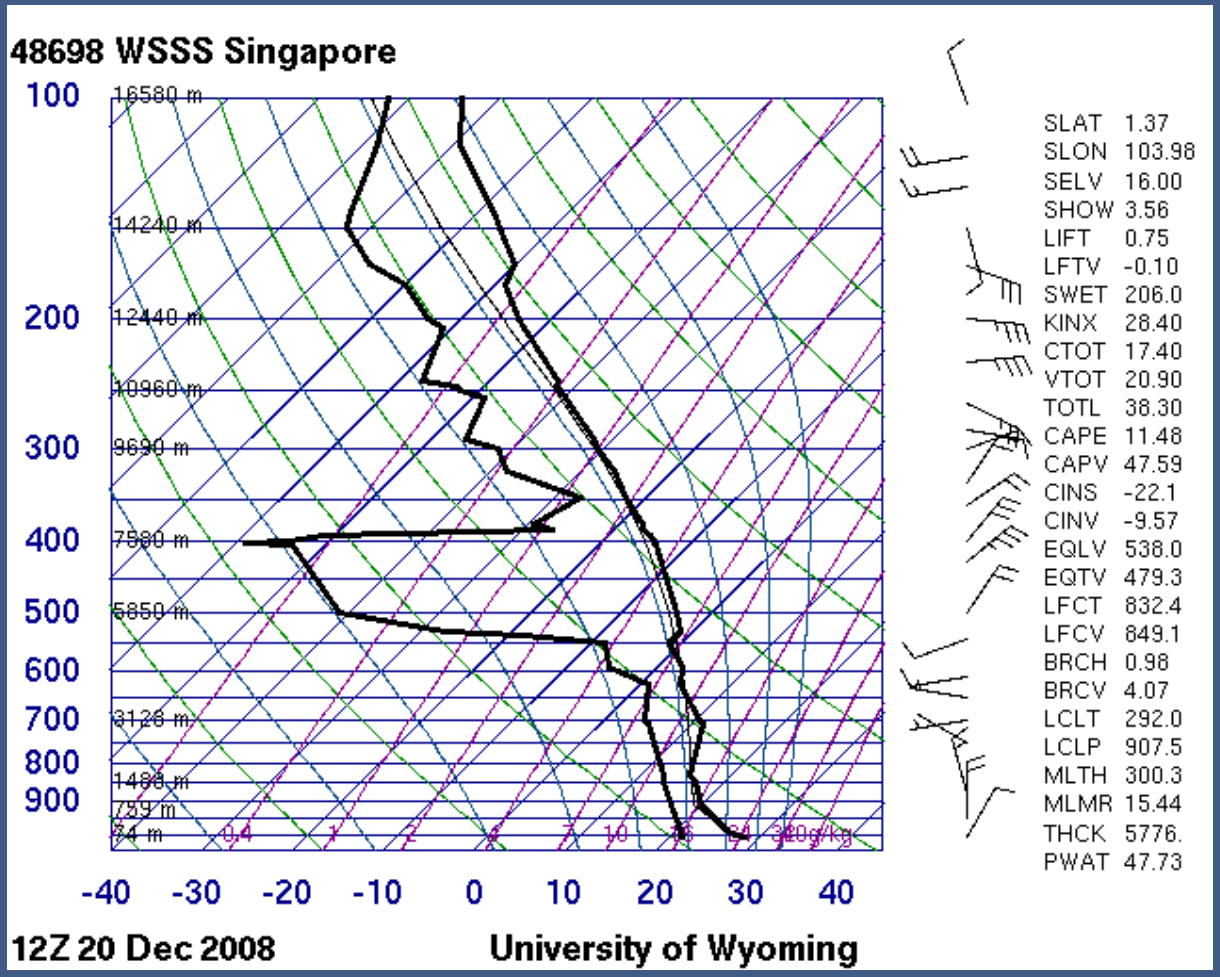
Stratocumulus Regime

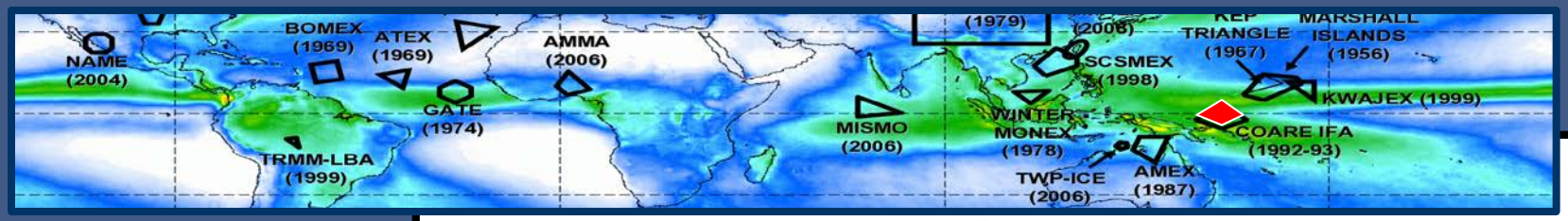


Trade Wind Regime



Indo/Pacific Warm Pool

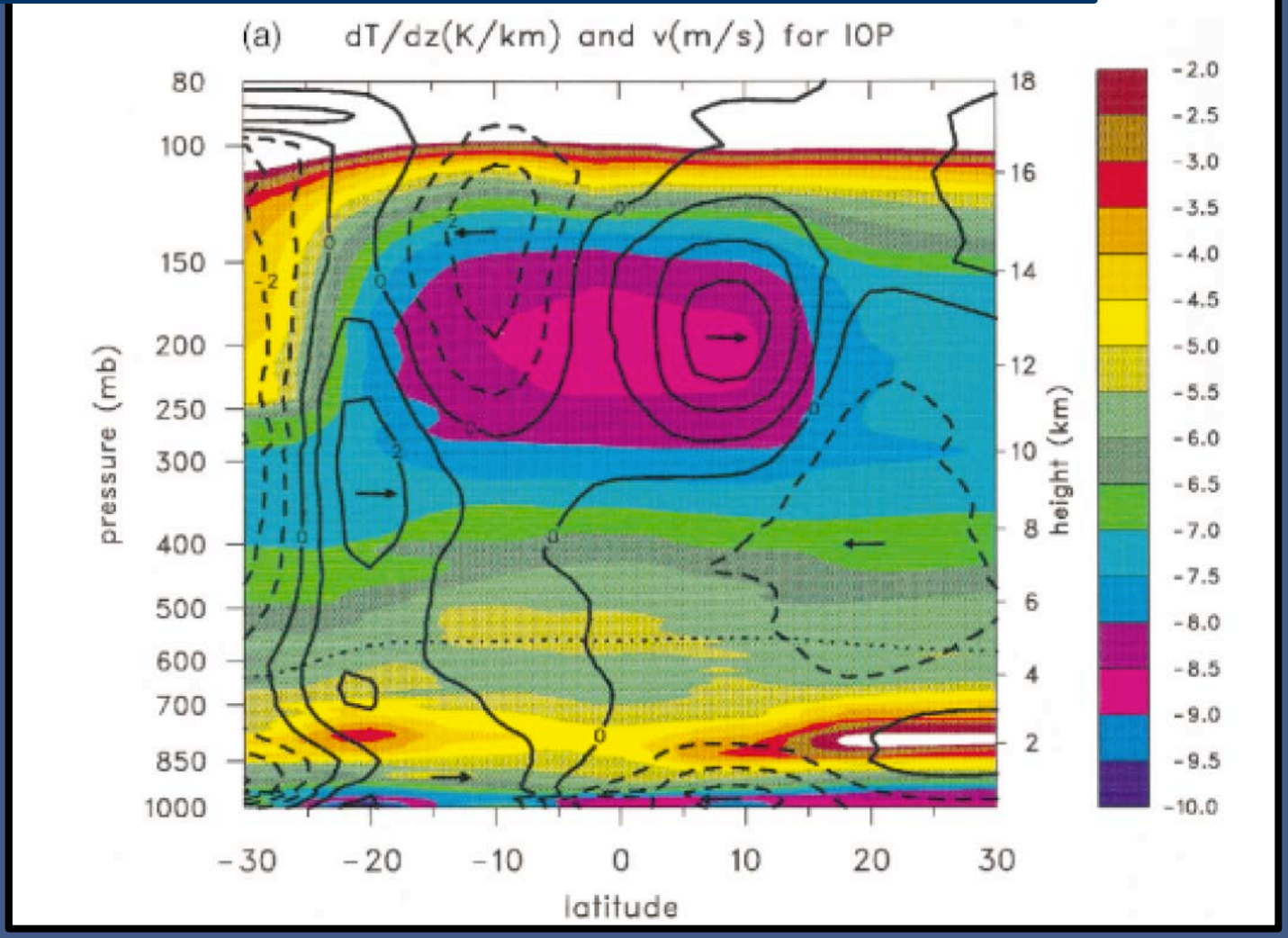




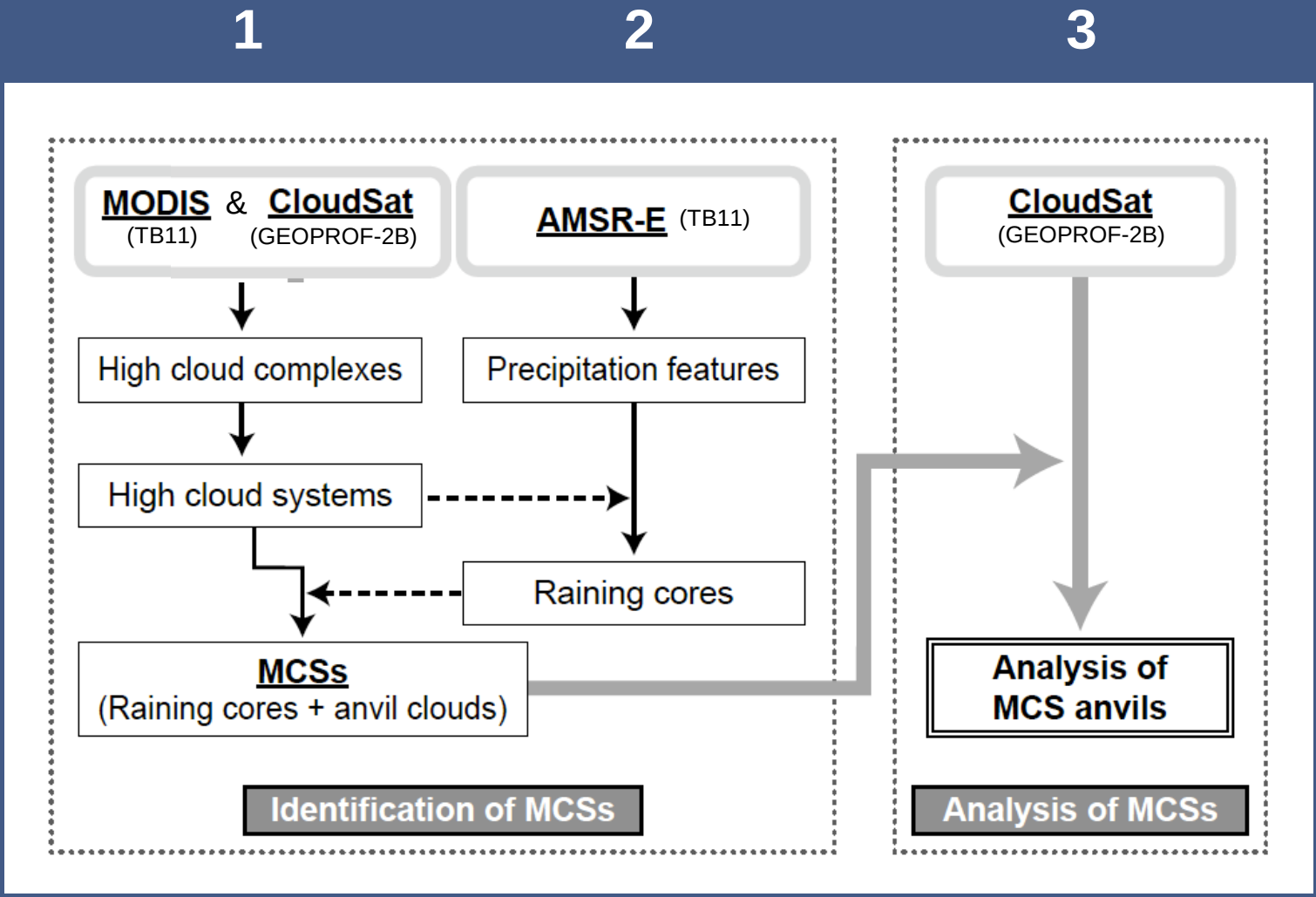
"Trimodal" distribution

Johnson et al. 1999

Evidence from TOGA COARE sounding data

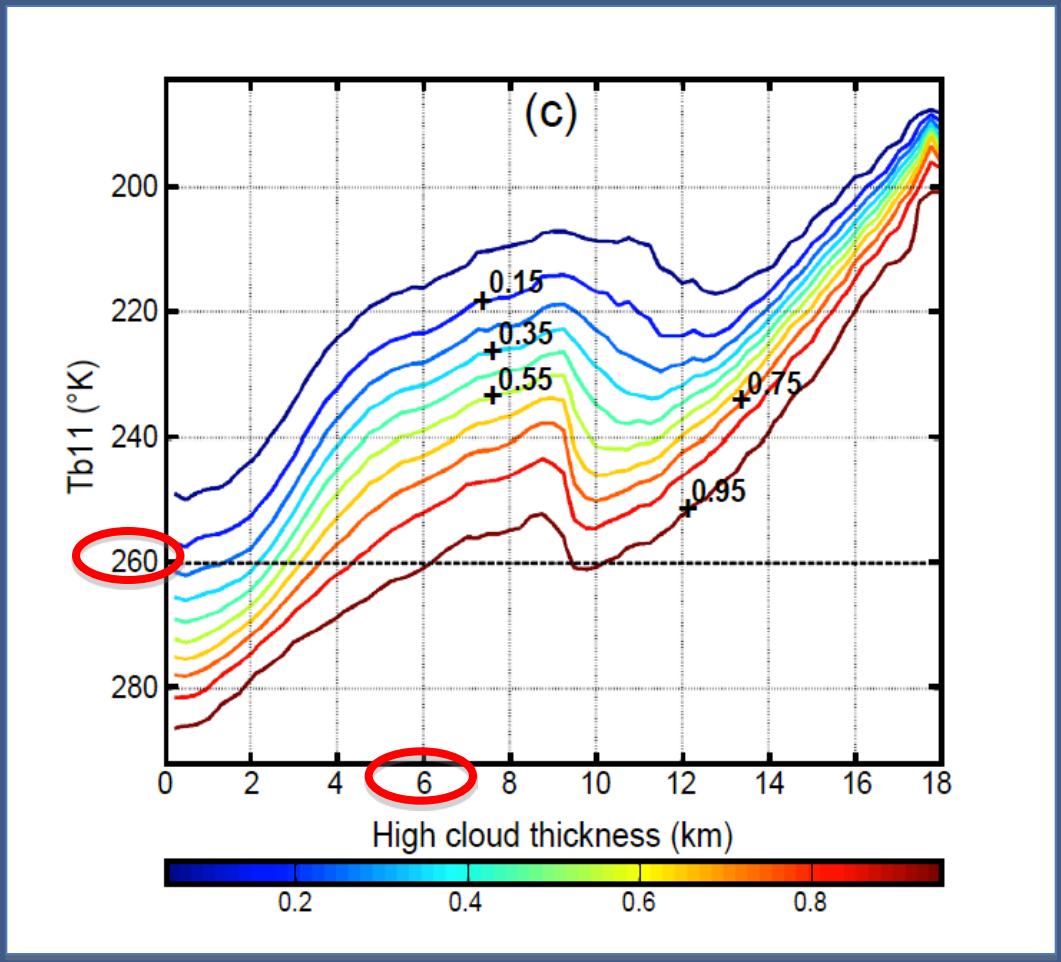


Three steps of analysis of multi-sensor data



Yuan and Houze 2010

Use MODIS and CloudSat to find threshold of thick high cloud

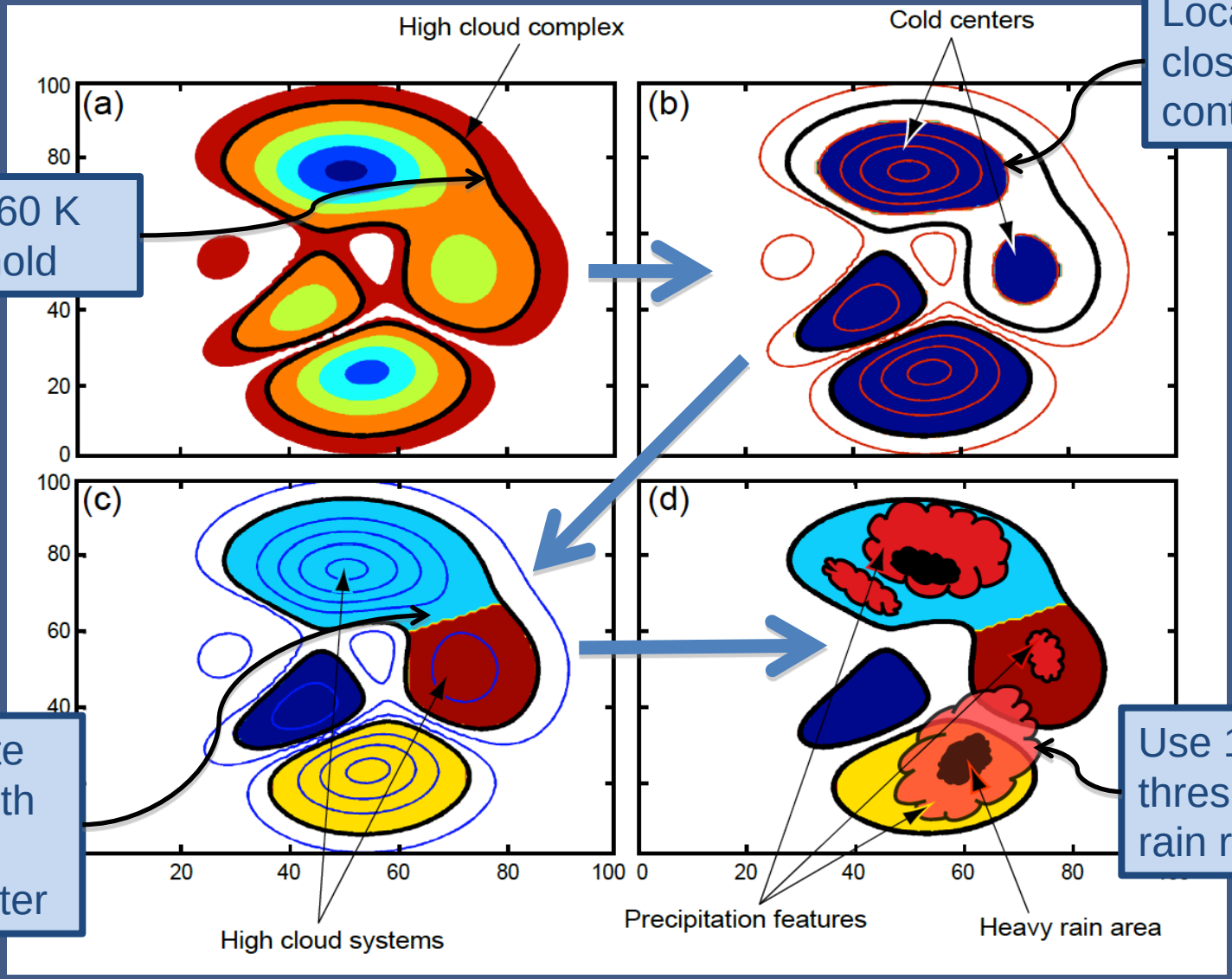


MODIS

CloudSat

Yuan and Houze 2010

1-Find“cold centers”
2-Use AMSR-E to find rain areas



Locate 1st closed contour

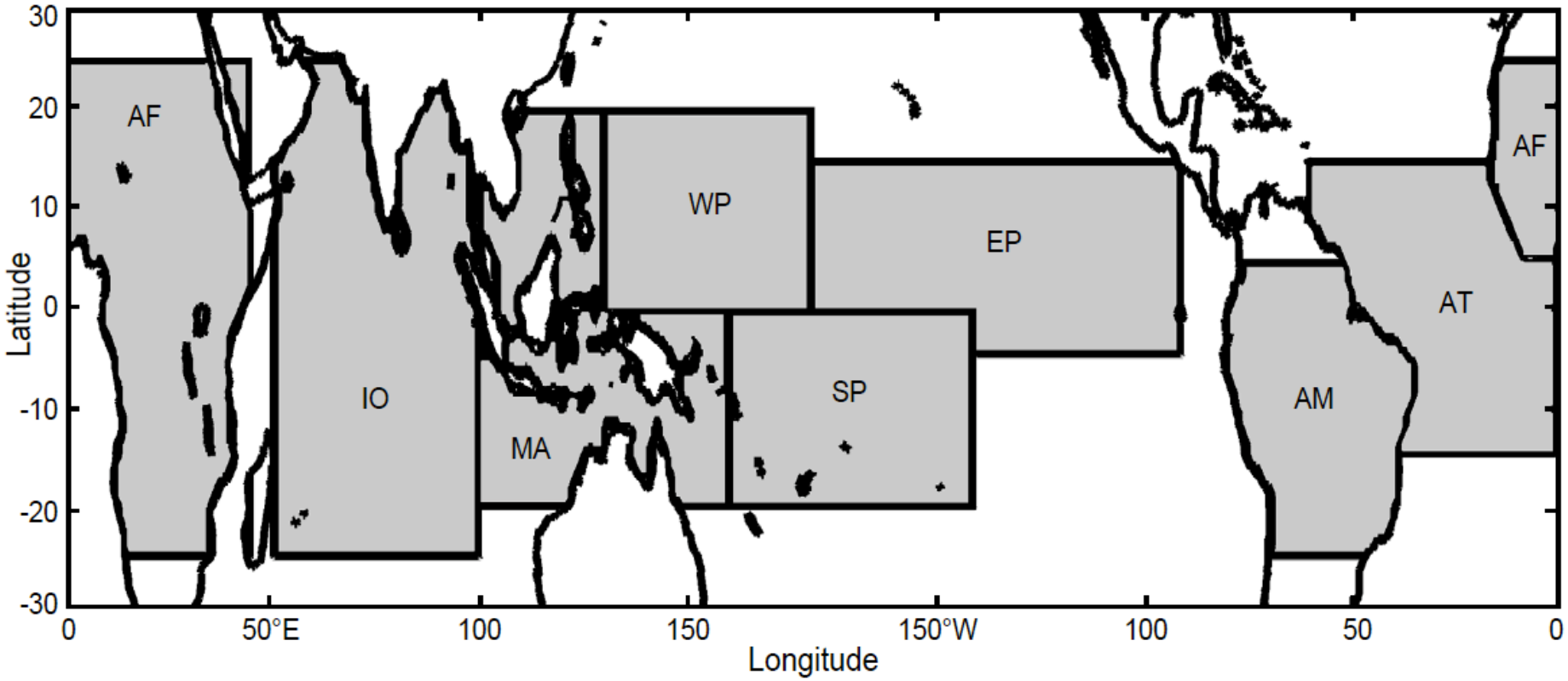
Use 260 K threshold

Associate pixels with nearest cold center

Use 1 mm/h threshold for rain rate

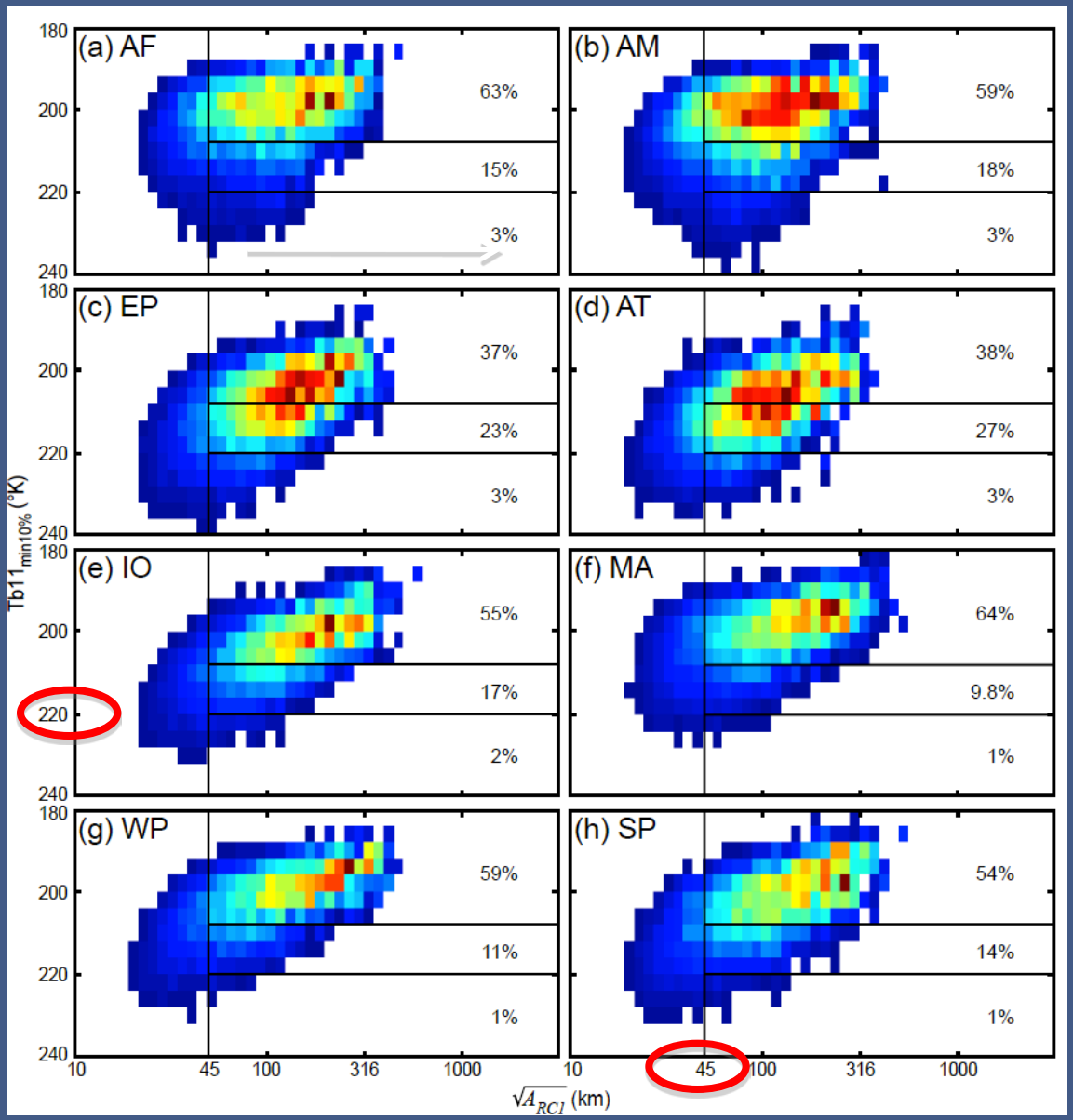
Yuan and Houze 2010

Define criterion for MCS that is reasonable for all these regions



Yuan and Houze 2010

Colors show rain amount



Temperature defining cold center

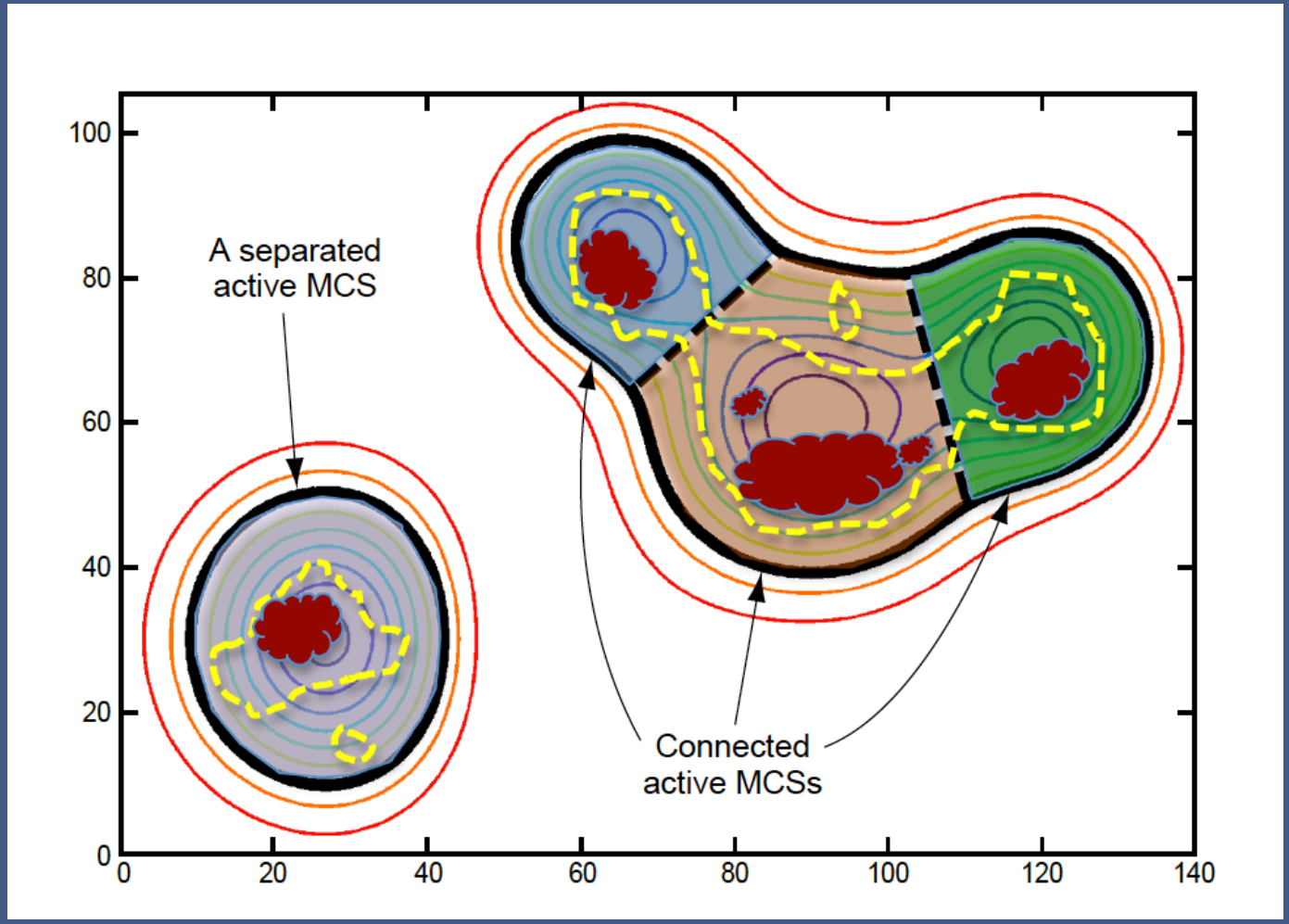
Size of cold cloud top

TB11 = 220
Area > 2000 km^2

account for most of the rainfall

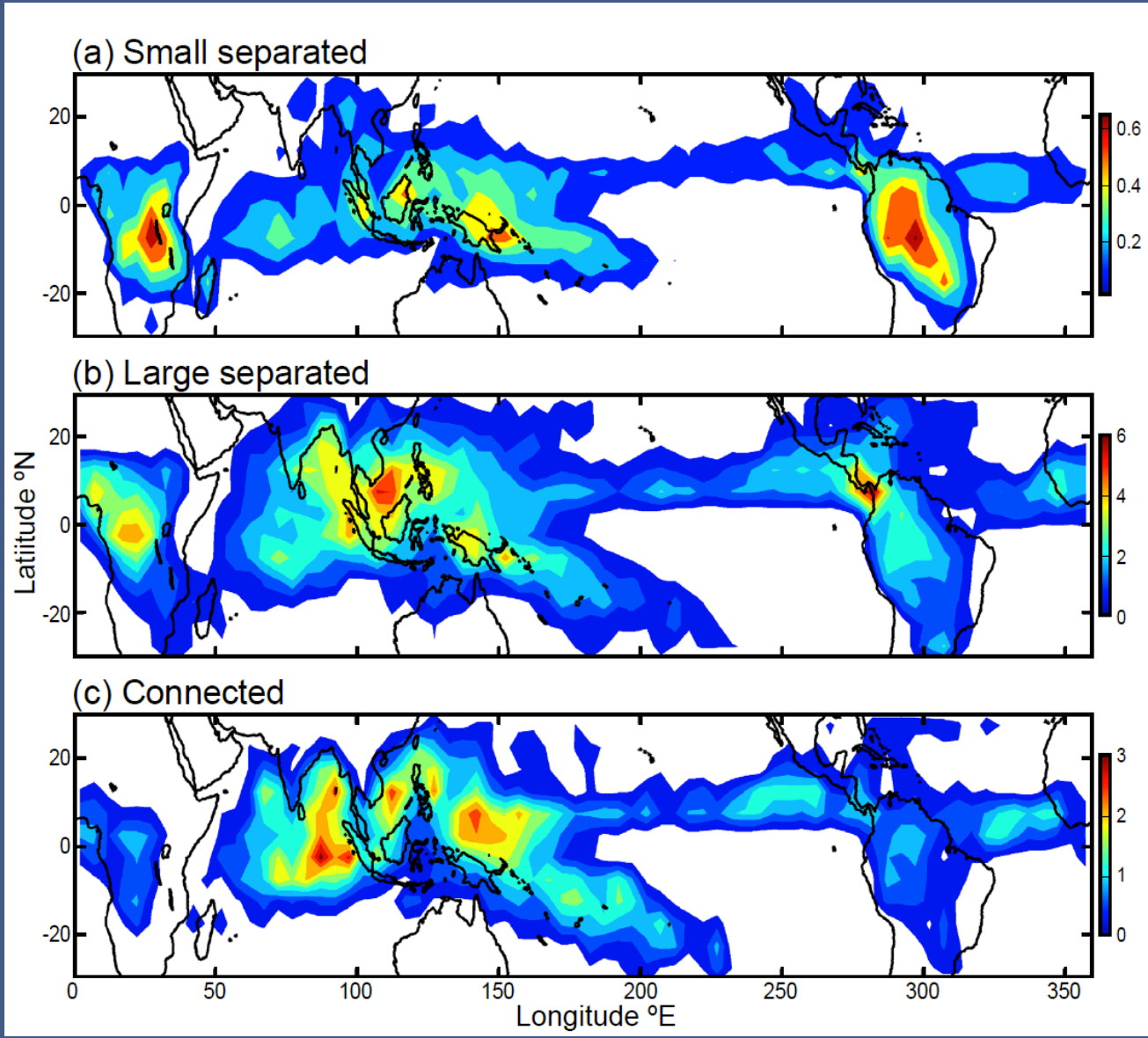
Yuan and Houze 2010

“Connected” and “Separated” MCSs



Yuan and Houze 2010

Frequency of MCS anvils over tropics

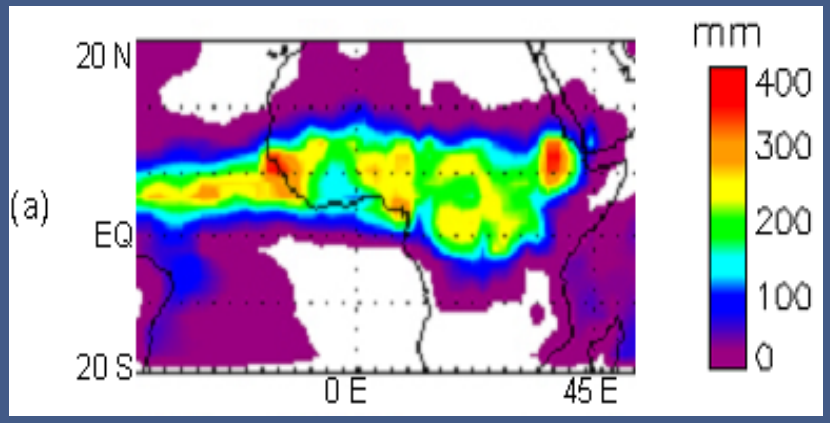


Yuan and Houze 2010

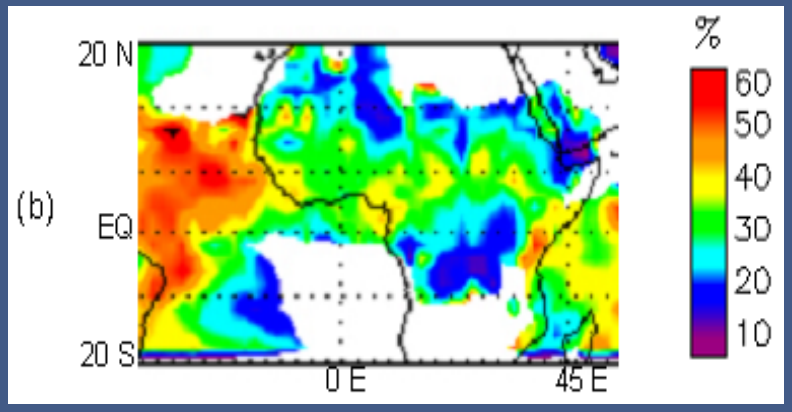
Land vs Ocean

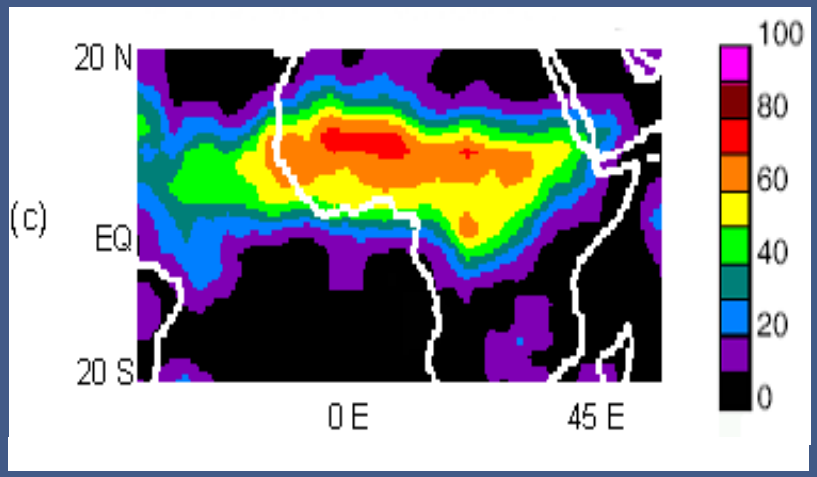
TRMM view of Africa vis a vis the Atlantic

Rain

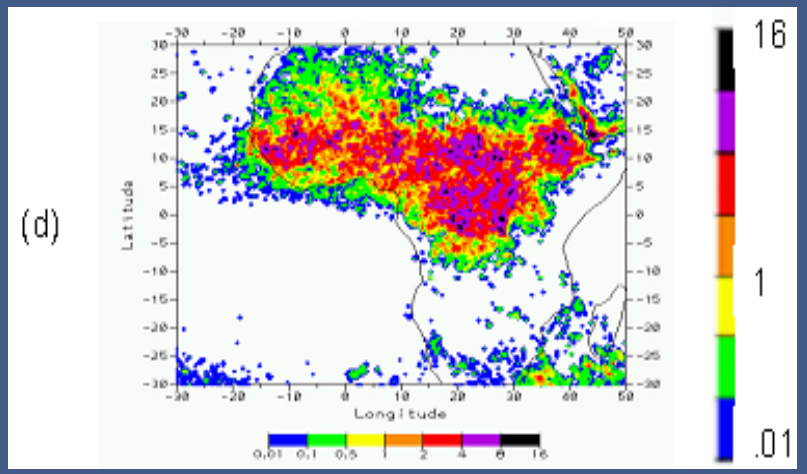


Stratiform Rain Fraction





MCSs with large 85 GHz ice scattering



Lightning

Yanai, Esbensen, and Chu 1973

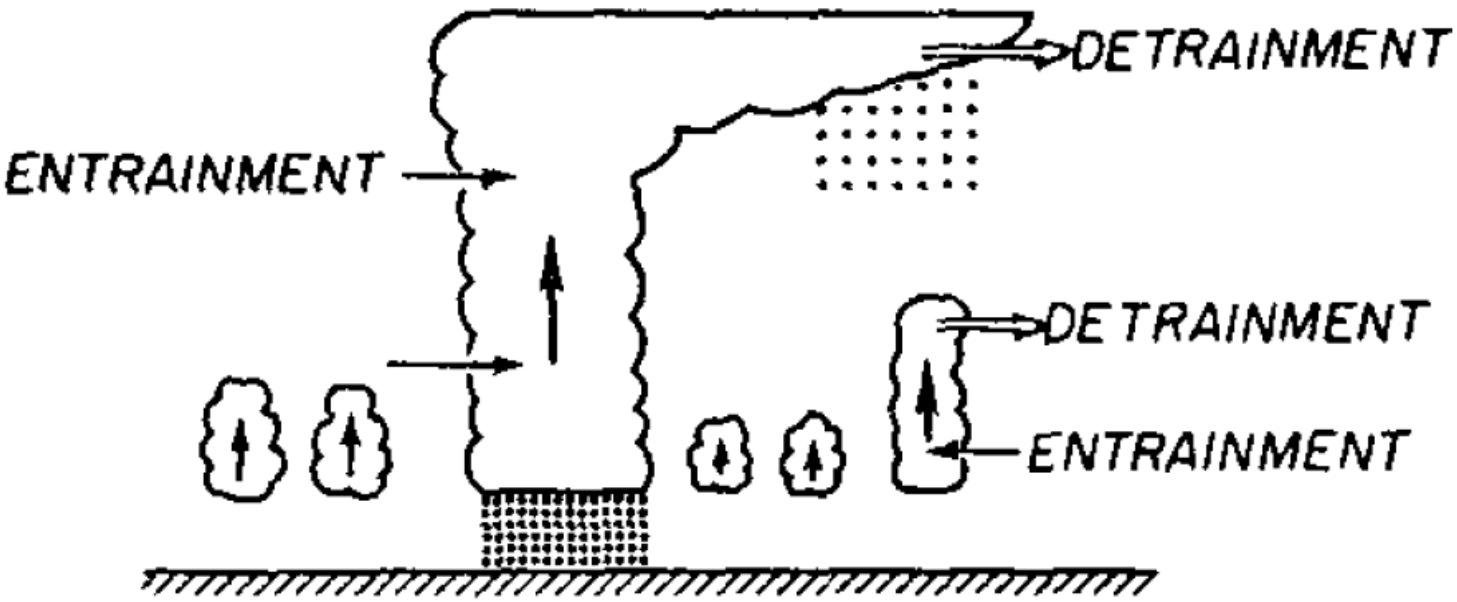


FIG. 1. Schematic view of an ensemble of cumulus clouds.

Yanai, Esbensen, and Chu 1973

(ii) There is some evidence which suggests the existence of short-lived mesoscale organization of cumulus convection (e.g., Zipser, 1969). If this is true in general, further modification of the formulation will be needed.

FIG. 1. Schematic view of an ensemble of cumulus clouds.

Knowledge of global rainfall before satellites measured rain from space

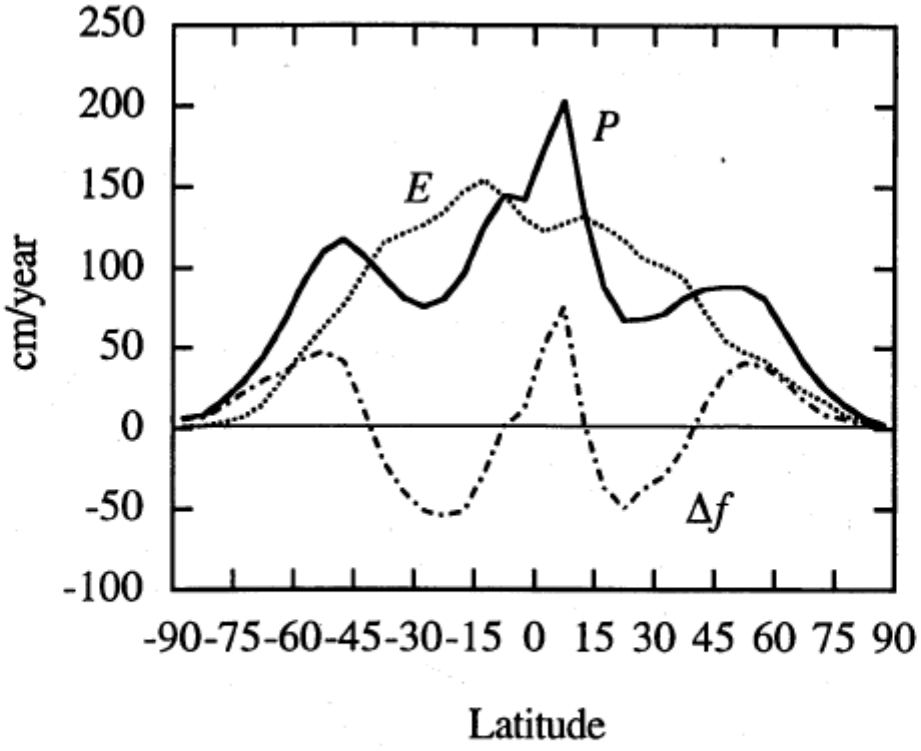
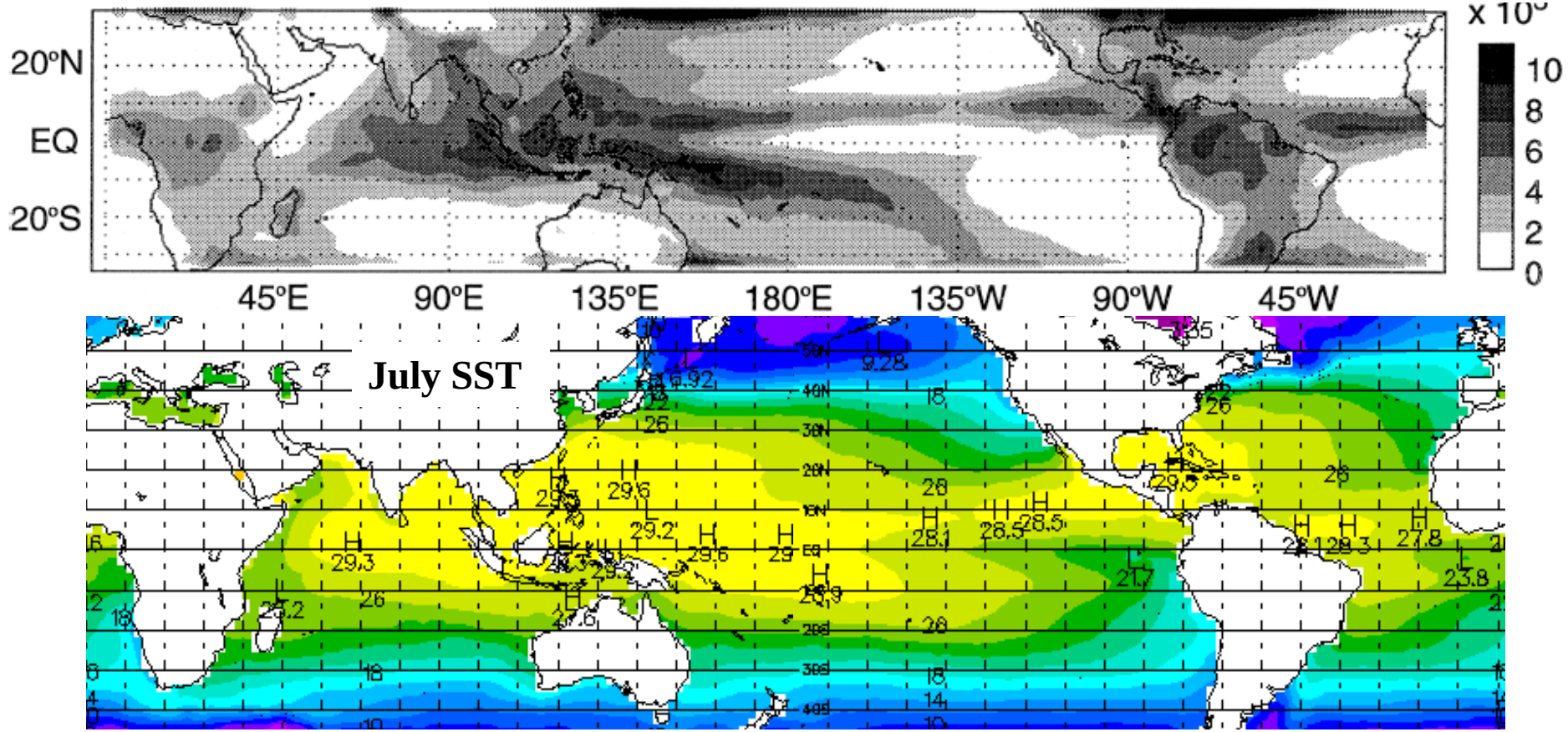


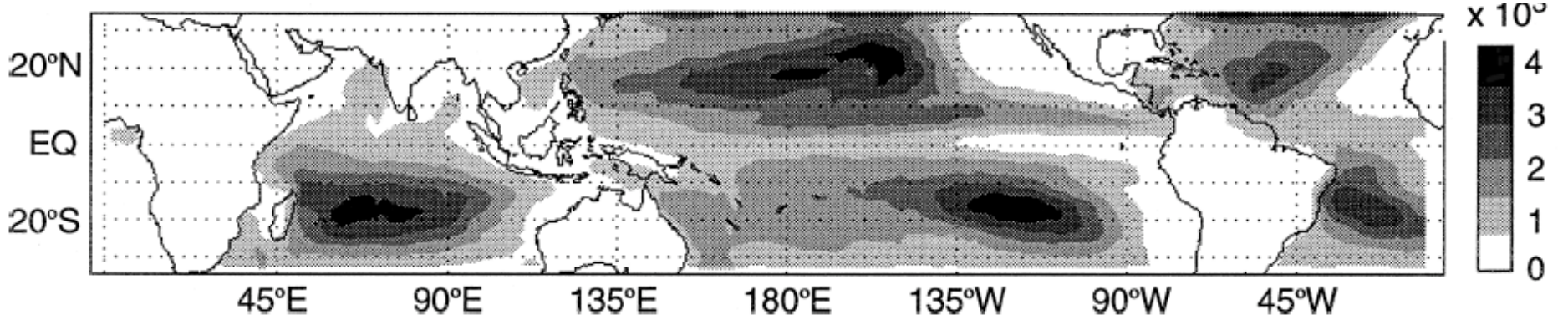
Fig. 5.2 Latitudinal distribution of the surface hydrologic balance, showing evaporation *E*, precipitation *P*, and runoff Δf. [Data from Baumgartner and Reichel (1975).]

Tropical cloud population related to SST

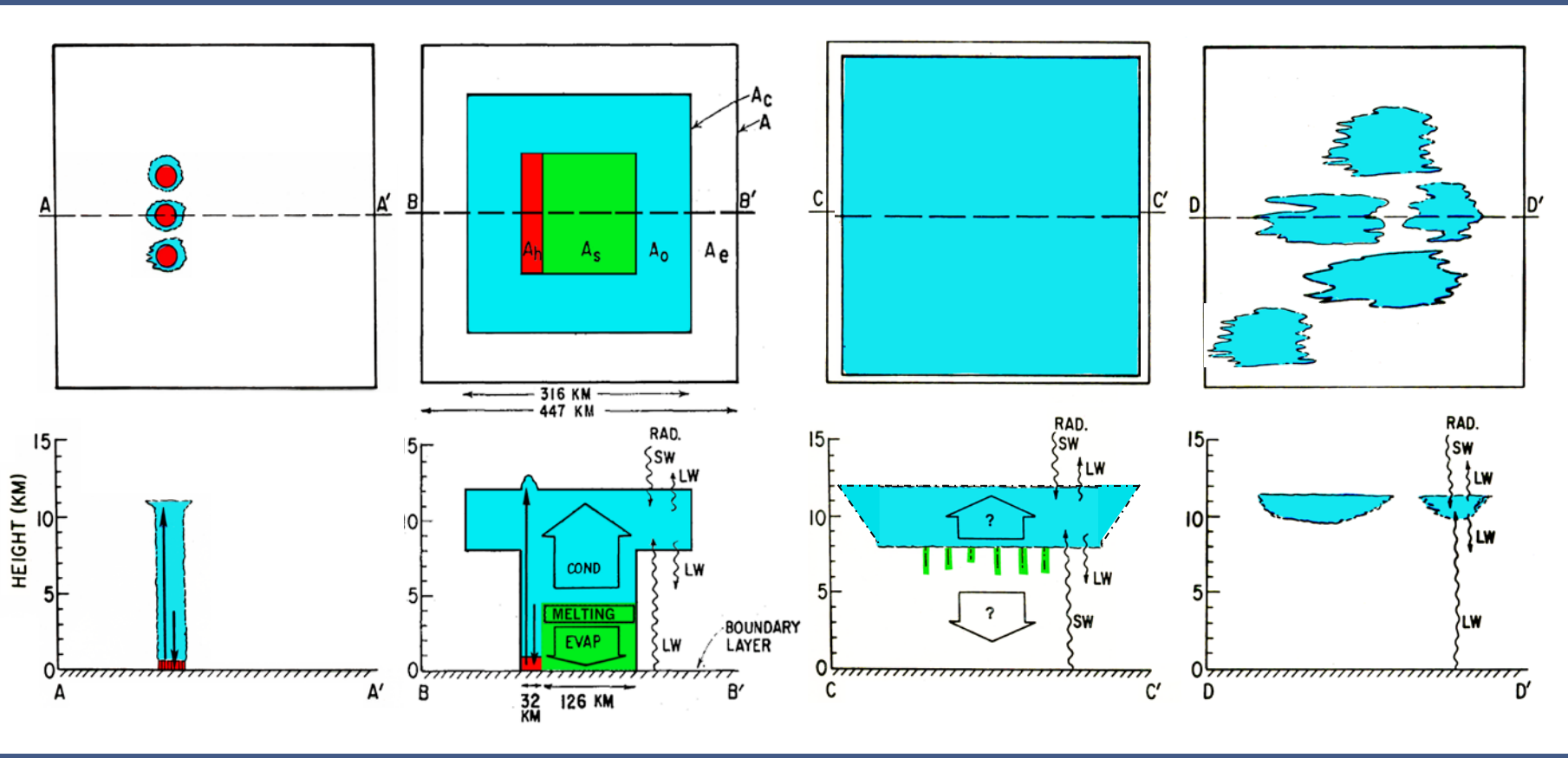
TRMM PR Deep Convective



TRMM PR Shallow, Isolated Convective

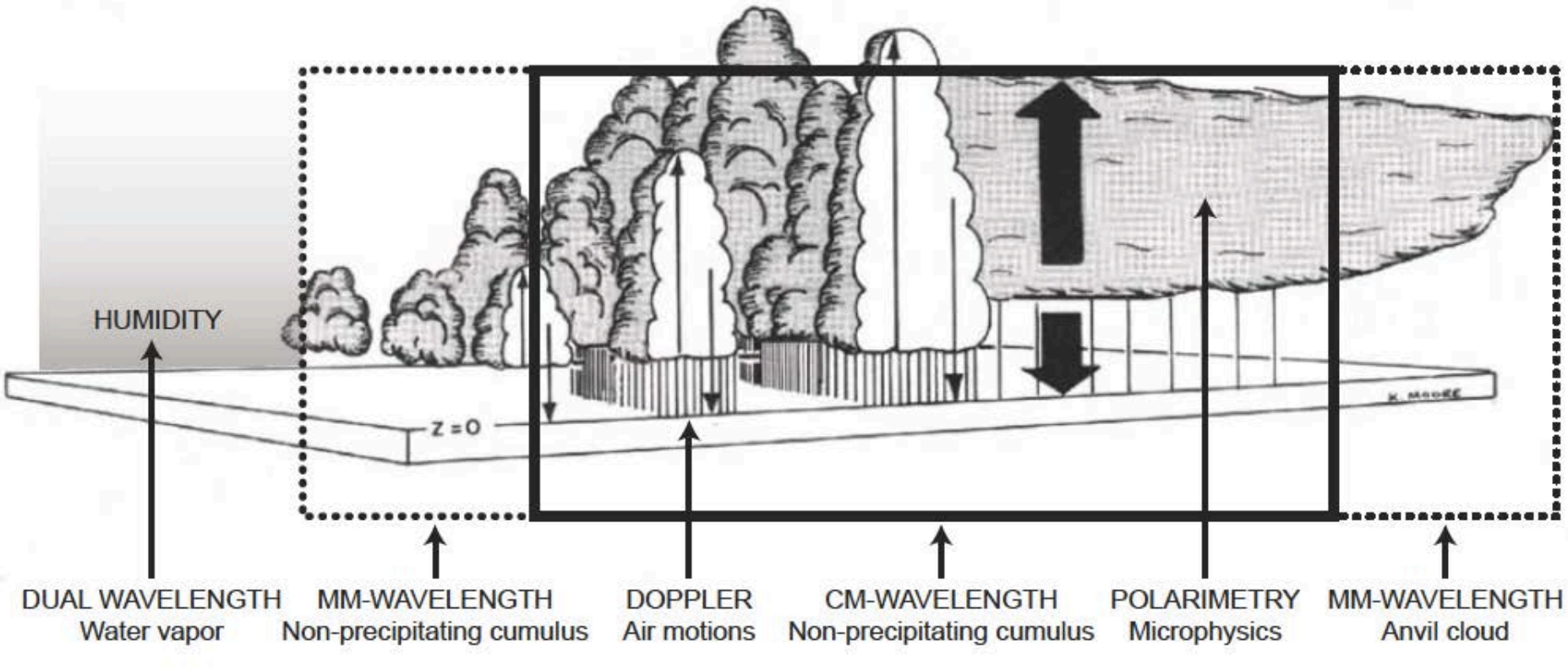


Idealized life cycle of tropical MCS



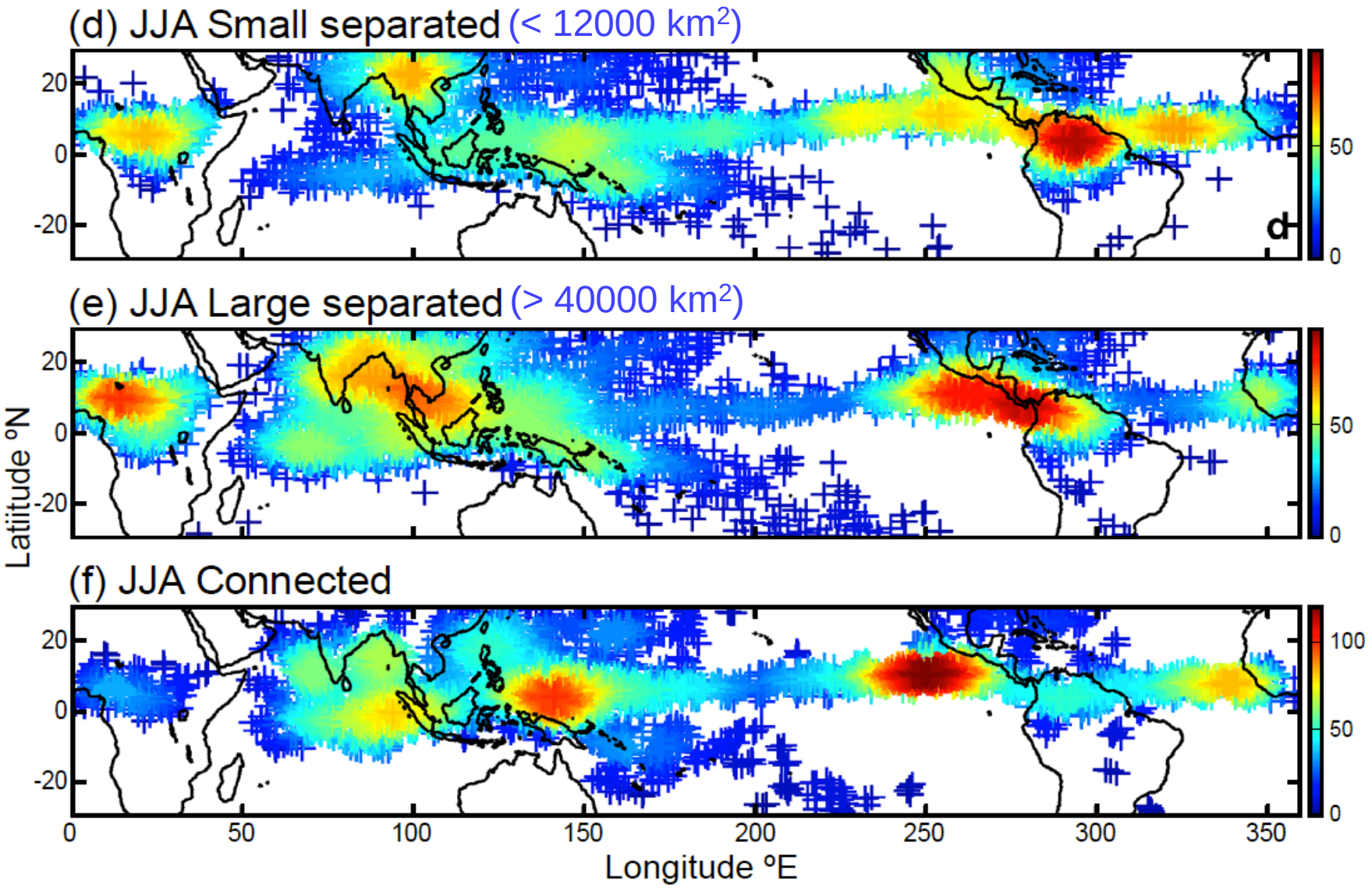
Houze 1982

Radar Supersite Approach



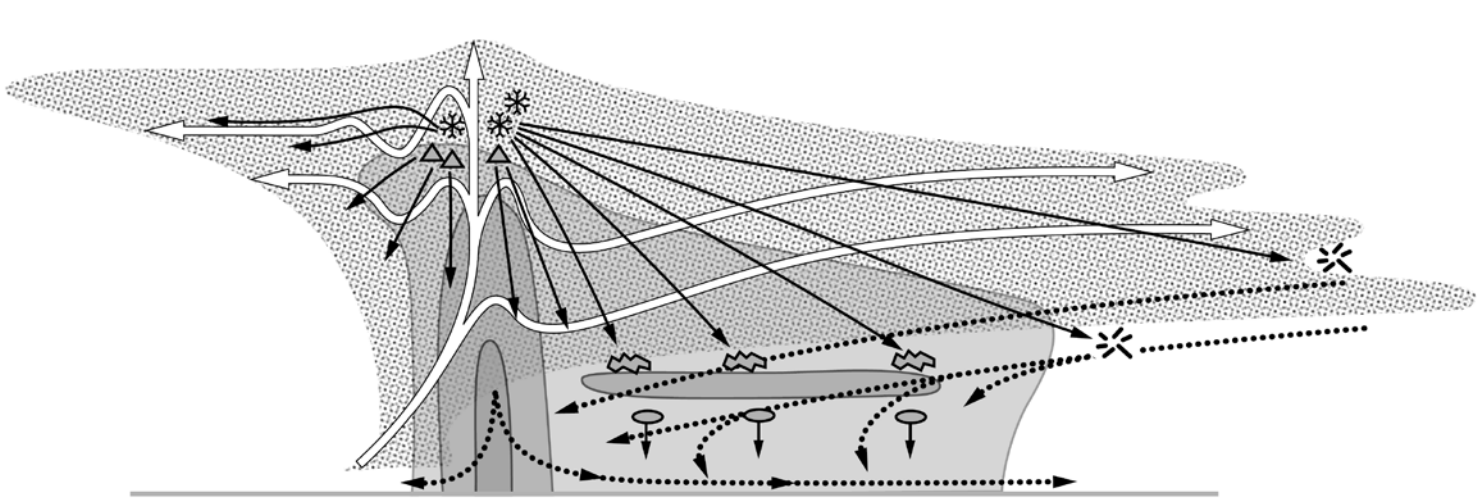
Will document many aspects of the convective population

MCSs Over the Whole Tropics



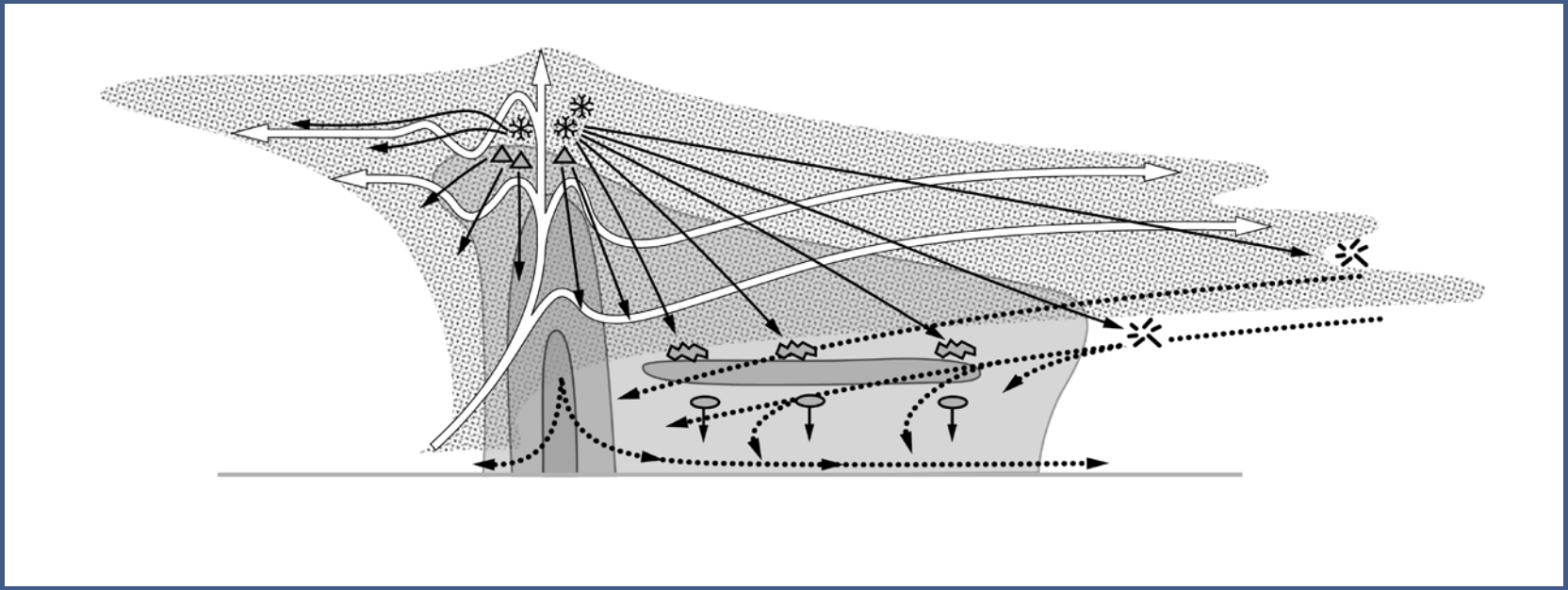
Yuan and Houze 2010

Internal structures of MCS anvils



Cetrone & Houze 2011

Microphysics of MCS anvils



Inferred from ground-based cloud radar data

Cetrone & Houze 2011