The Effect of Environmental Conditions on Tropical Deep Convective Systems

Bing Lin, Bruce Wielicki, Patrick Minnis, Lin Chambers,
Yongxiang Hu, Kuan-Man Xu and Alice Fan

NASA Langley Research Center

CERES Science Team Meeting
Geophysical Fluid Dynamics Laboratory
Princeton, NJ, May 4, 2005

Outline

1. Background

    deep convective system vs SST:

        dehydration of convection

2. Method: TRMM satellite & ECMWF

    CERES + VIRS + TMI

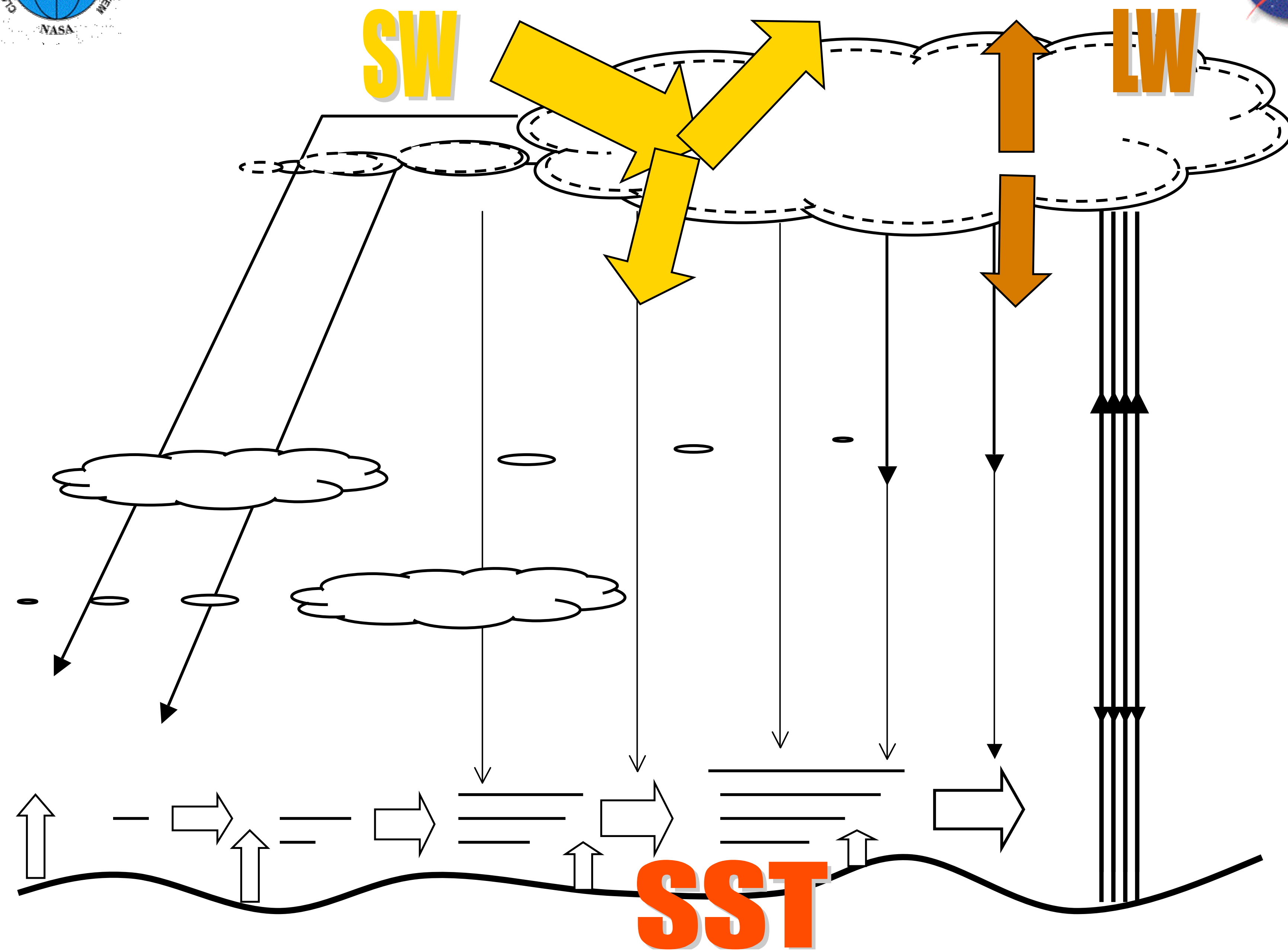
    ECWMF: boundary layer moisture, vector wind

3. Results

    DCS characteristics, wet processes, radiative feedbacks

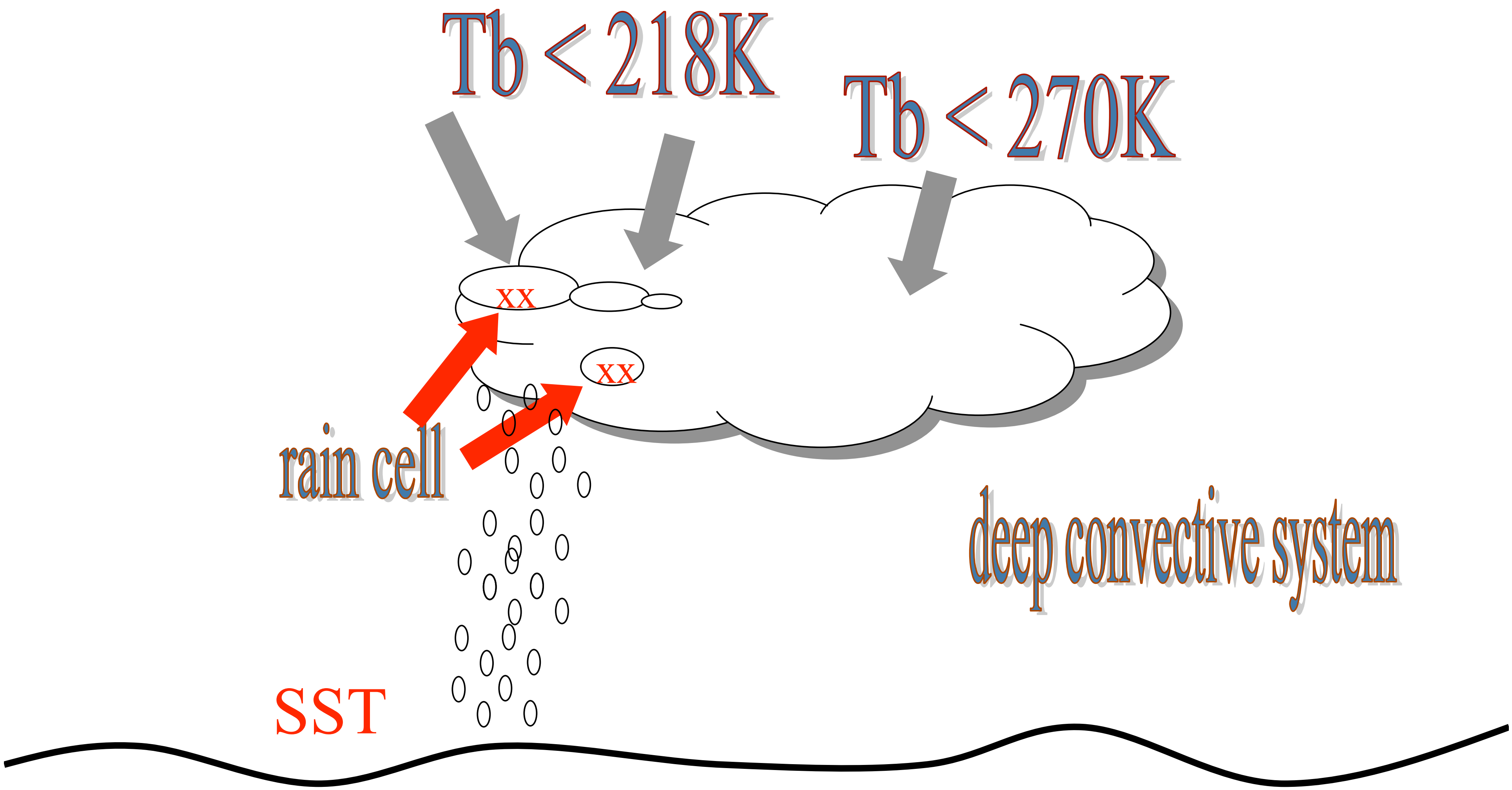
4. Summary

Tropical Deep Convective System



Analysis Method

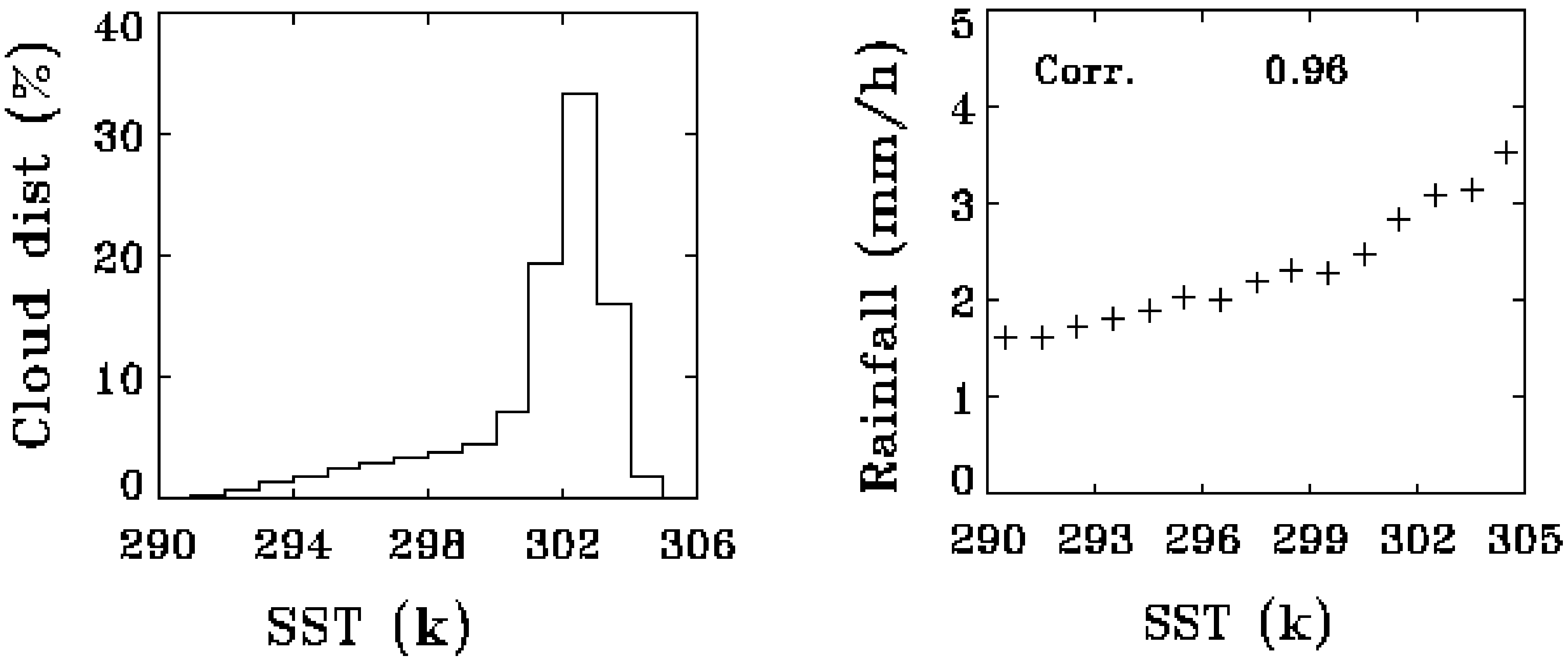
Matching TRMM CERES, VIRS, & TMI data
Cloud detection, WP, Radiation, and rain



Data sources and geophysical properties

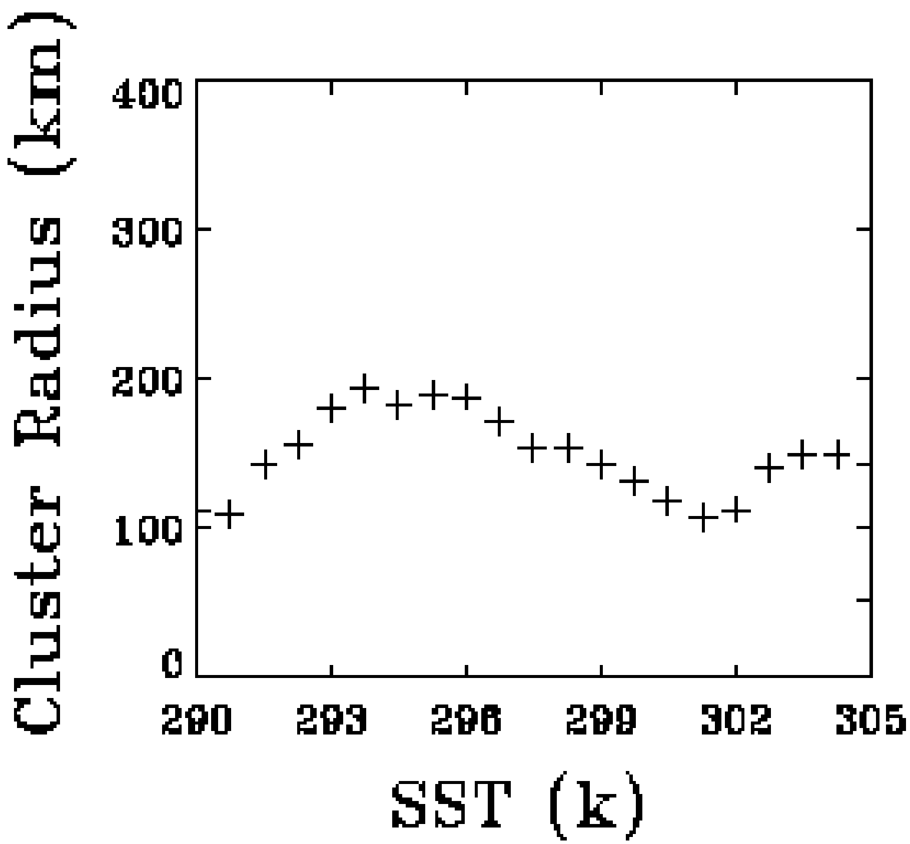
Sources	Properties
CERES SSF	Ac, albedo, SW and LW fluxes, SST under clear/cloudy, dry/moist conditions
CERES VIRS cloud product	Ac, Tc, P_{wi}, τ, De, IWP, LWP
TMI	rain clouds: Ac, RR, precip. LWP/IWP; non-rain regions: Ac, LWP, WS, WV_L, Es, SST
ECMWF	V, ω, T(z), WV_L, Es, SST

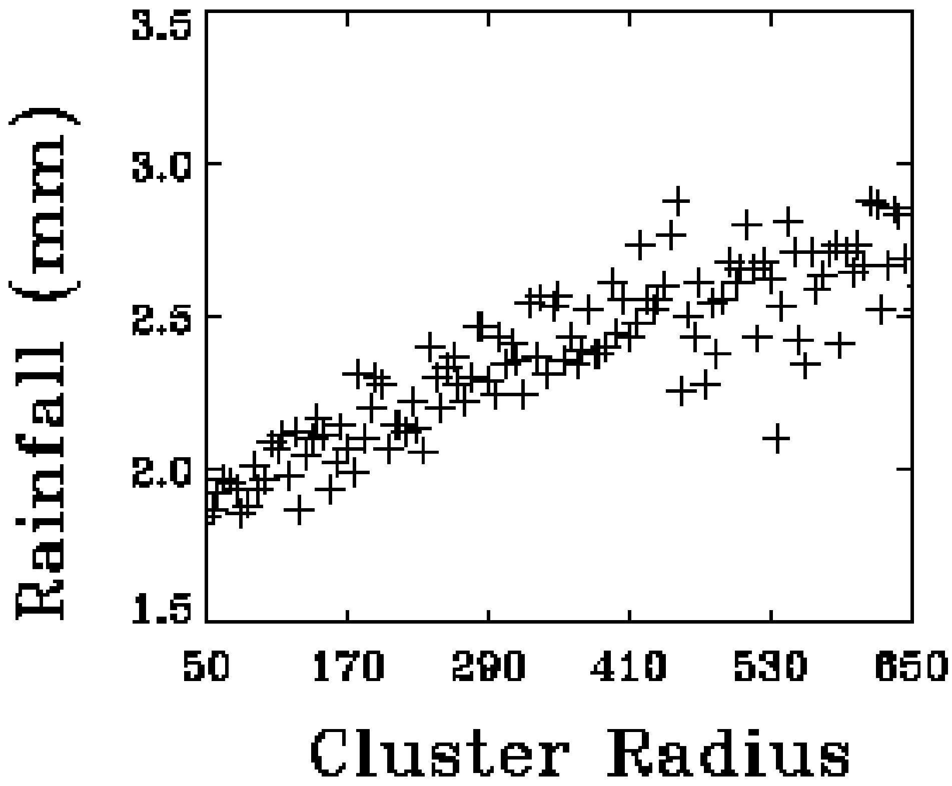
DCS Statistical Characteristics



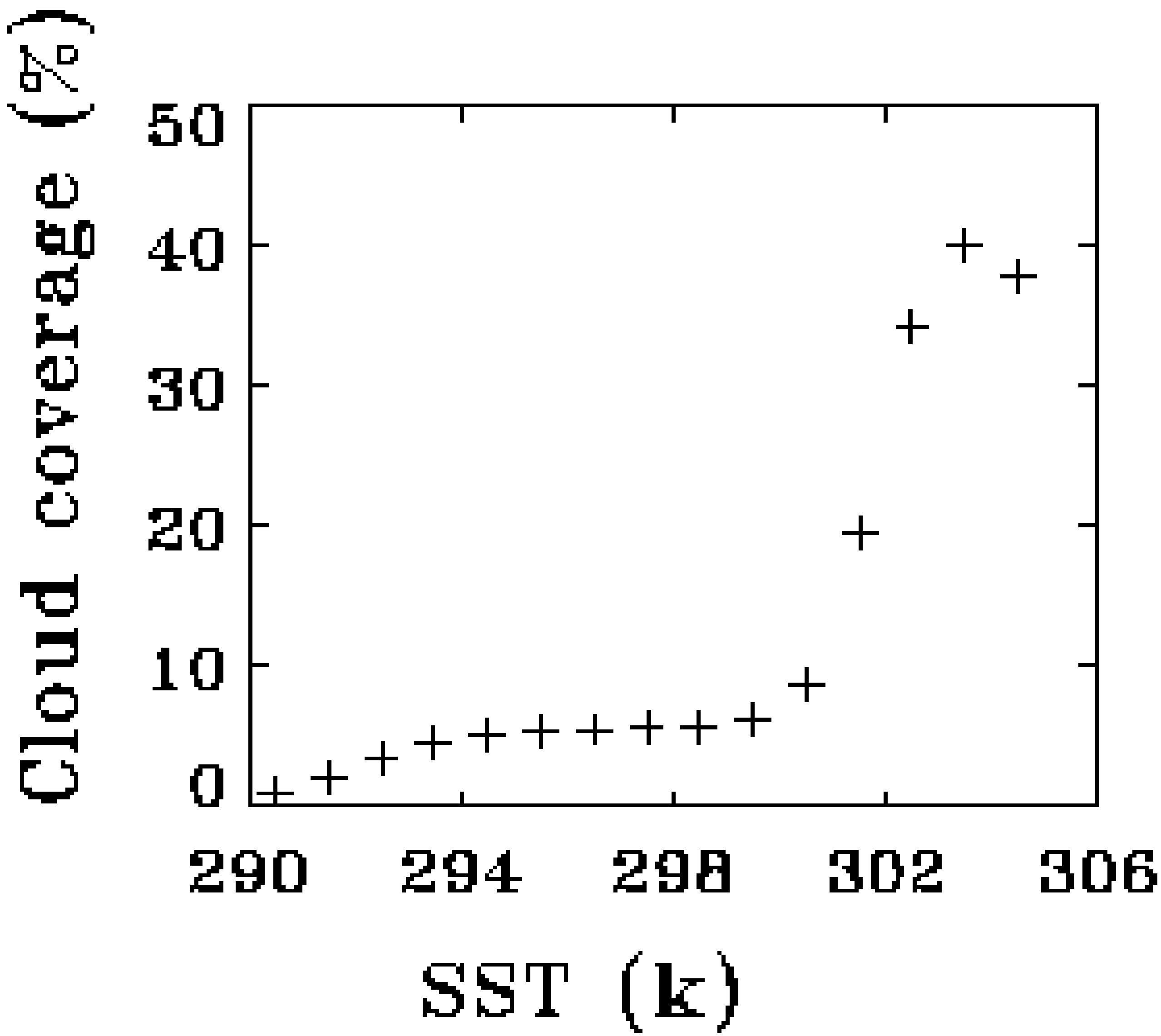
DCS PDF & RR

DCS effective size

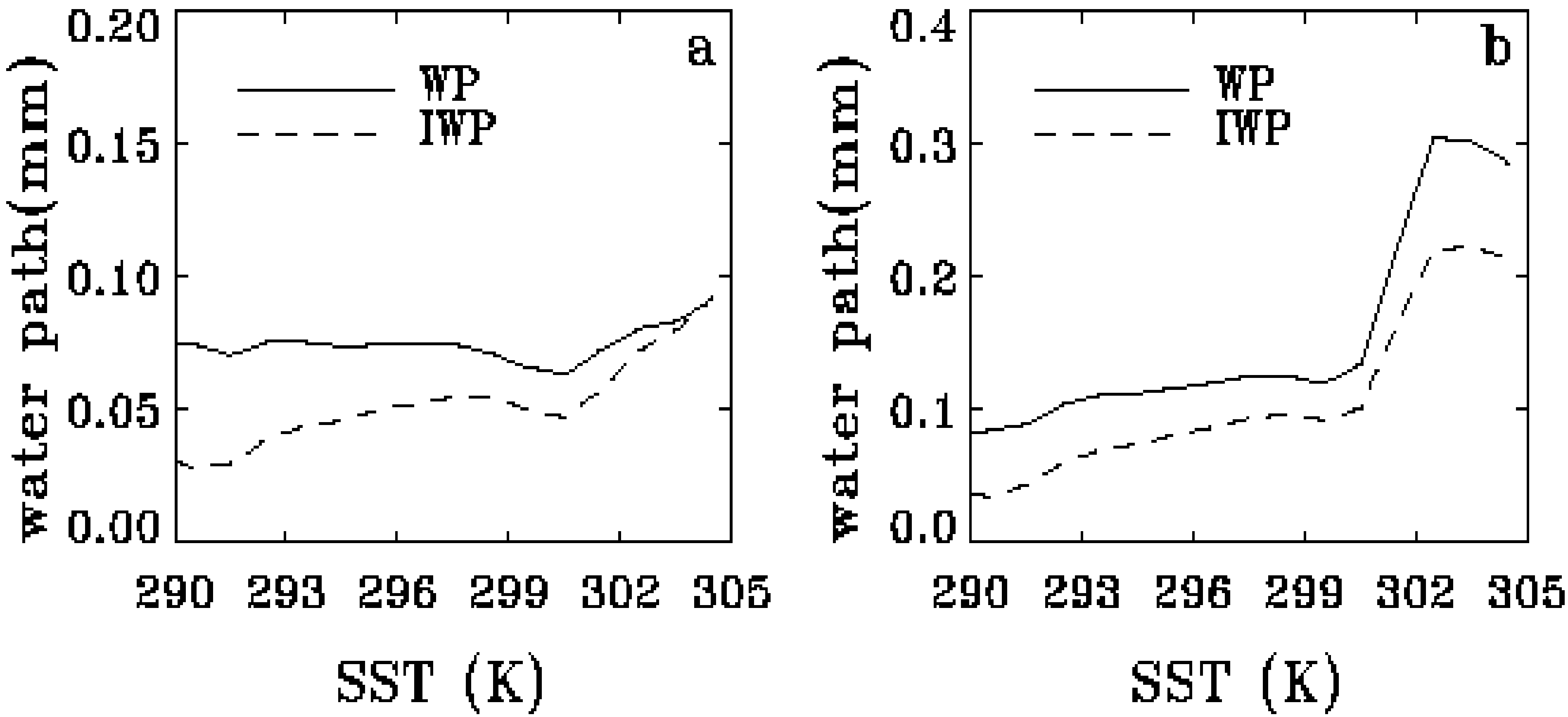




DCS area coverage vs SST



DCS WP & IWP



Deeper convection under warmer SST conditions could cause higher rainfall efficiency, which would result in DCS reductions in warmer environments. Why is there no evidence of DCS dehydrations?

Rainfall efficiency

- $\eta = RR/Ms$

  $= RR/(-\partial WV_L/\partial t + E_s - \nabla \bullet WV_L V_L)$ (1)

  for lowest 500m PBL

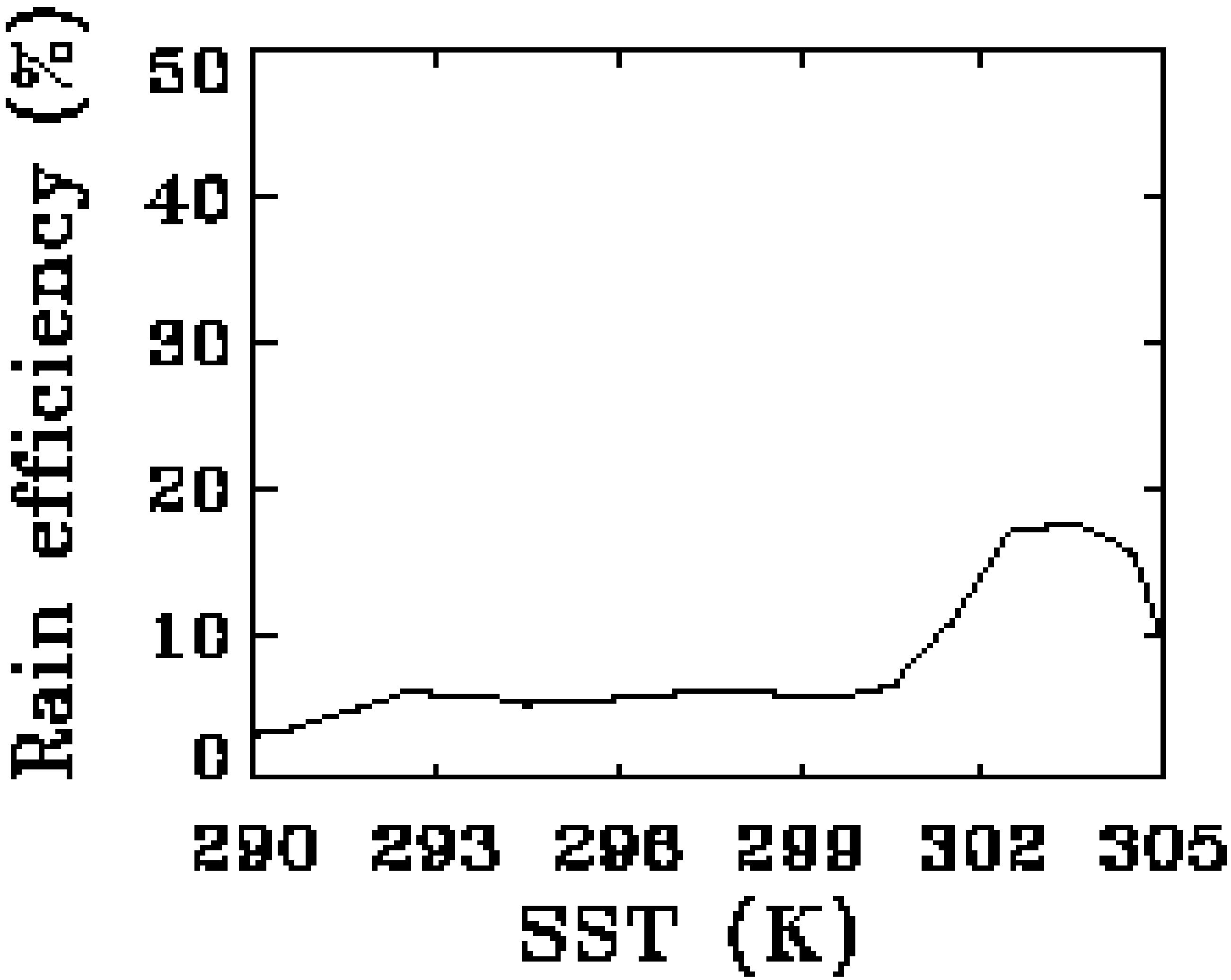
  ecmwf: WV_L, Es and $\nabla \bullet WV_L V_L$

- Moisture supply to DCS clusters:

  $M_s = -\partial Q_b/\partial t + E_s - \nabla \bullet Q_b V$ (2)

  tendency, evaporation and convergence

Rainfall efficiency

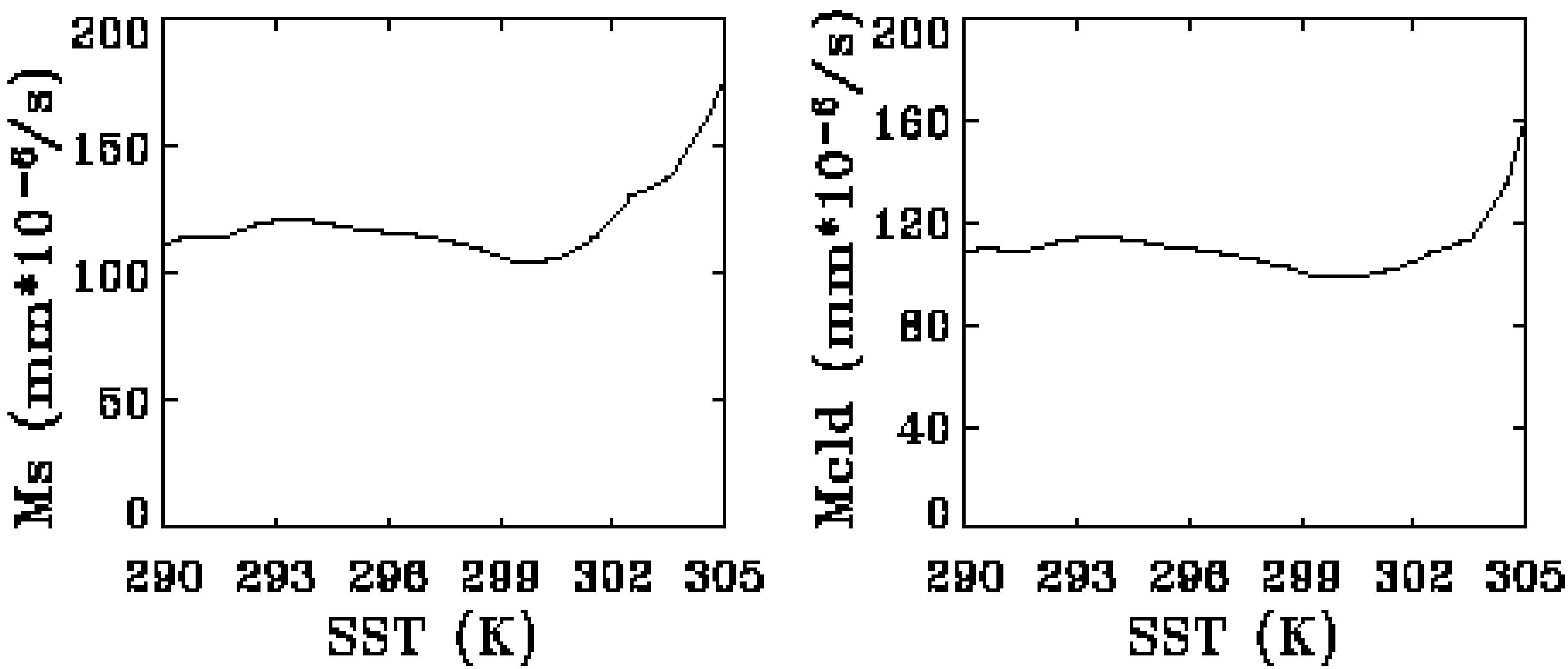


Moisture transport for anvils

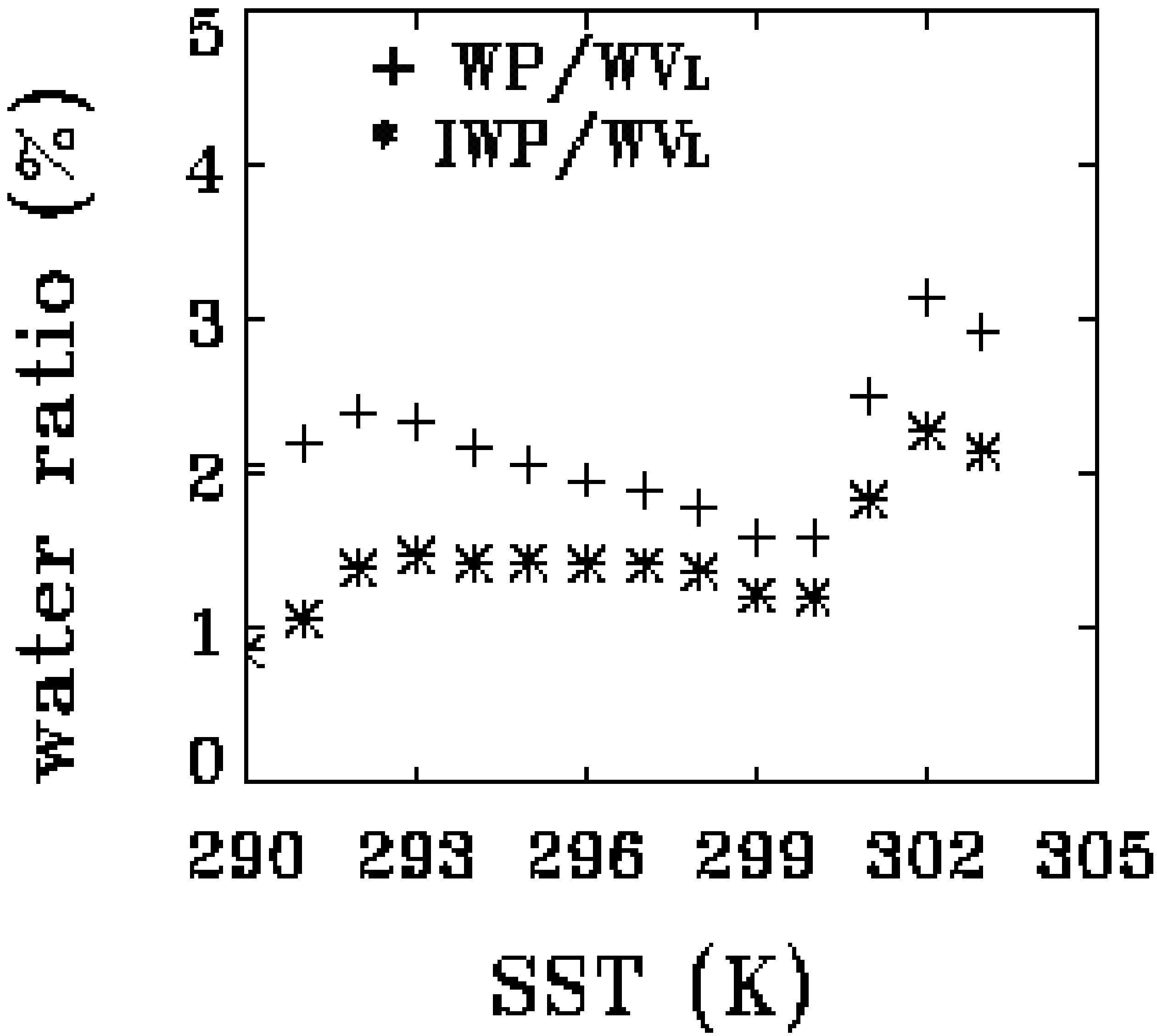
- Moisture for anvil-cirrus clouds:
- $M_{cld} = Ms - RR = Ms\,(1 - \eta)$ (3)
- $\Delta M_{cld} = \Delta(Ms\,(1 - \eta))$ (4)

- change of anvil moisture transport with T
- $\Delta M_{cld}/M_{cld} = \Delta M_{cld}\,/(Ms\,(1 - \eta))$
- $= \Delta Ms/Ms - \Delta\eta/(1 - \eta)$
- $\approx 6.3\% - 3\%/(1 - 0.15) \approx 2.8\%$ (5)

Moisture supply for DCS and anvil formation



Water ratio



Feedbacks: radiation fields

DCS Radiative Forcing

related to clear skies

$$F_{LW} = (-LW_{DCS}) - (-LW_{clr}) = LW_{clr} - LW_{DCS} \quad (1a)$$

$$F_{SW} = (S - SW_{DCS}) - (S - SW_{clr}) = SW_{clr} - SW_{DCS} \quad (1b)$$

$$F_{Net} = F_{SW} + F_{LW} \quad (1c)$$

Generalized Radiative Forcing

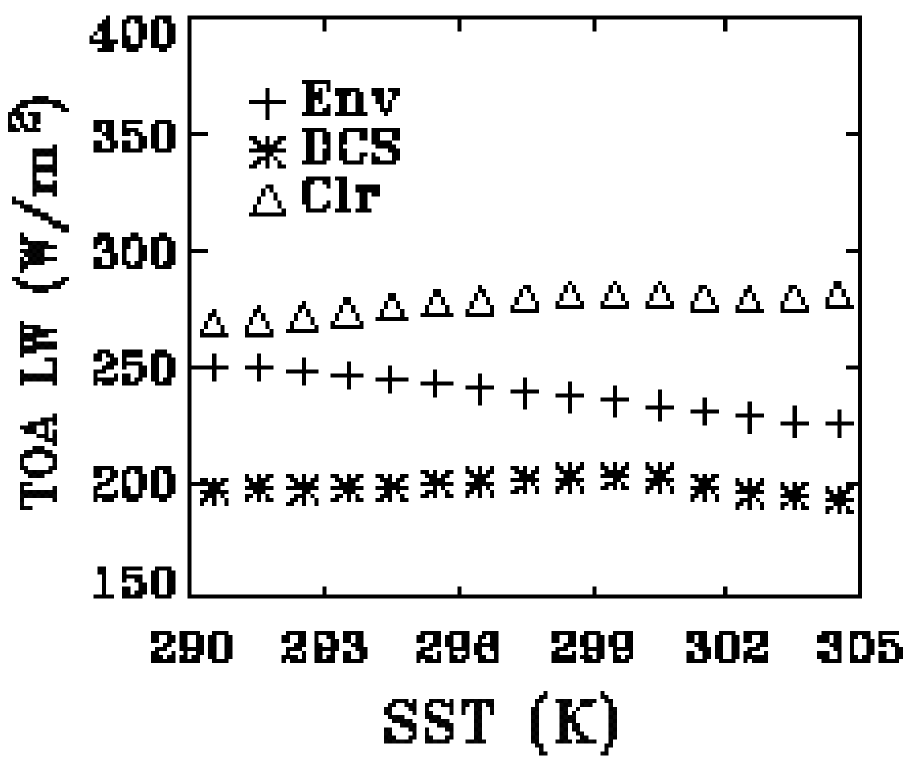
due to DCS development from an existing environmental condition

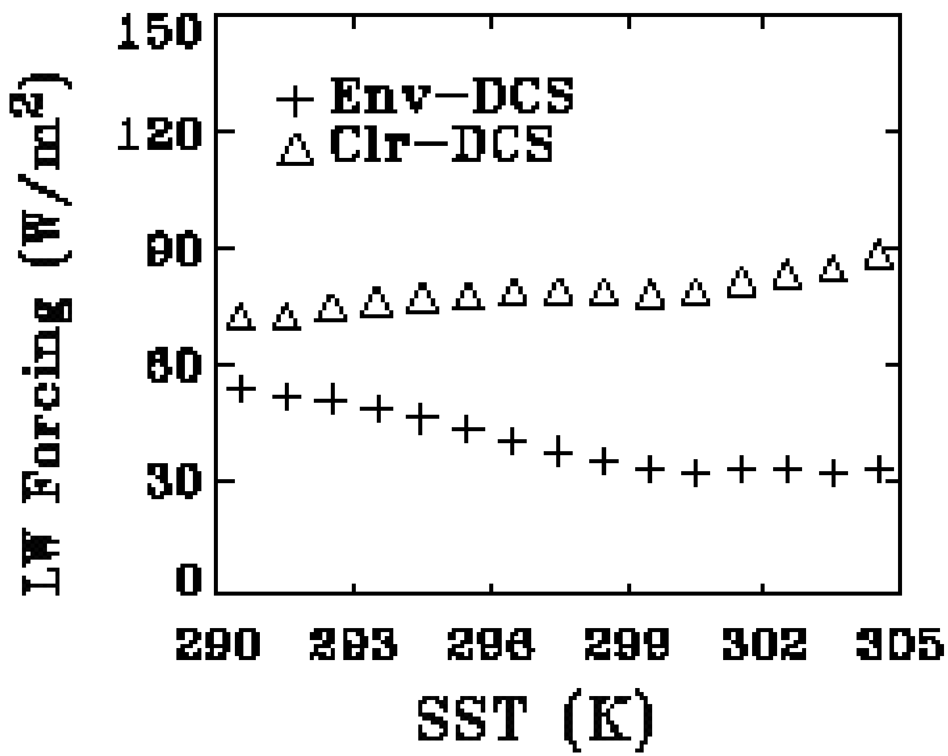
$$G_{LW} = (-LW_{DCS}) - (-LW_{env}) = LW_{env} - LW_{DCS} \quad (2a)$$

$$G_{SW} = (S - SW_{DCS}) - (S - SW_{env}) = SW_{env} - SW_{DCS} \quad (2b)$$

$$G_{Net} = G_{SW} + G_{LW} \quad (2c)$$

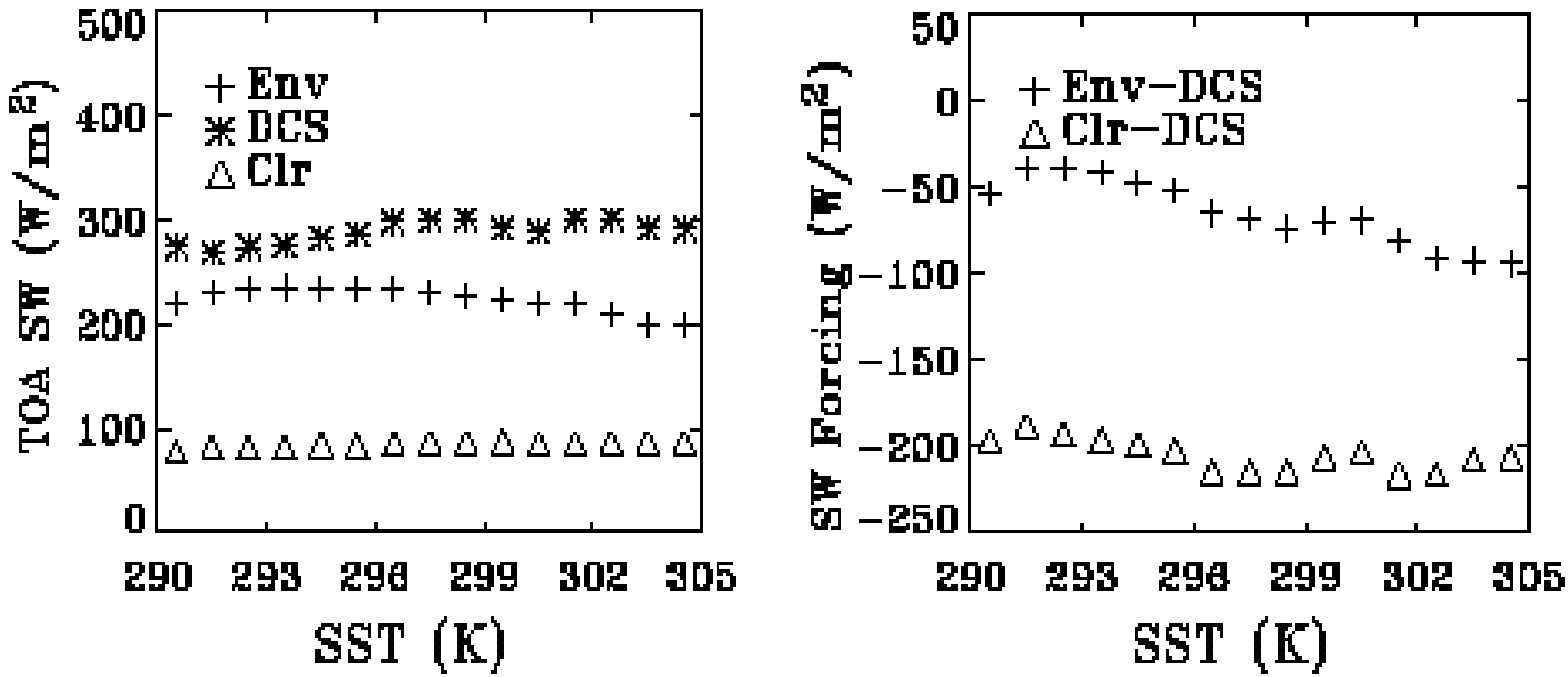
LW radiation





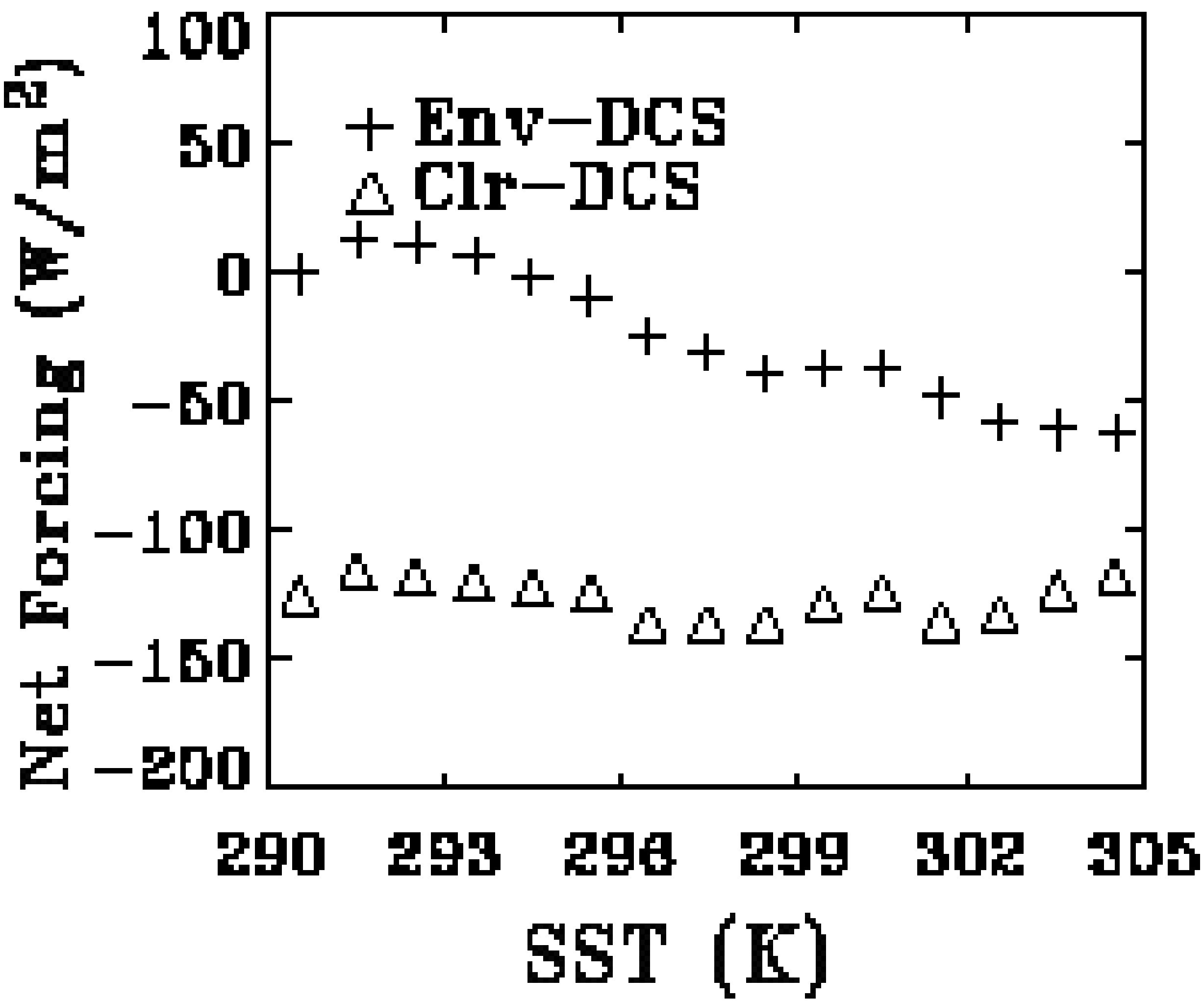
Note: Clr, Env and DCS represent values for clear, environmental and DCS skies. Thus, F = Clr – DCS; G = Env – DCS

SW radiation



Note: Clr, Env and DCS represent values for clear, environmental and DCS skies. Thus, F = Clr – DCS; G = Env – DCS

Net radiation



Note: Clr, Env and DCS represent values for clear, environmental and DCS skies. Thus, F = Clr – DCS; G = Env – DCS

Summary

- **DCS precipitation and its efficiency increase with SST, especially over warm environments. In spite of this, DCS area coverage increases with SST.**
- **Both the boundary layer moisture supply for deep convection and the moisture transported to the upper troposphere for cirrus-anvil cloud formation increase. These results significantly differ from hypothesized dehydration scenarios for a warm climate.**
- **The average net DCS radiative forcing from environmental conditions is relatively weak (about –20 W/m^2) while the radiative forcing from clear conditions is strong (about –125 W/m^2).**

→ a negative DCS radiative feedback

Acknowledgement

Many people, especially Sunny Sun-Mack, Jianping Huang, and Gary Gibson have significant contributions to this study.

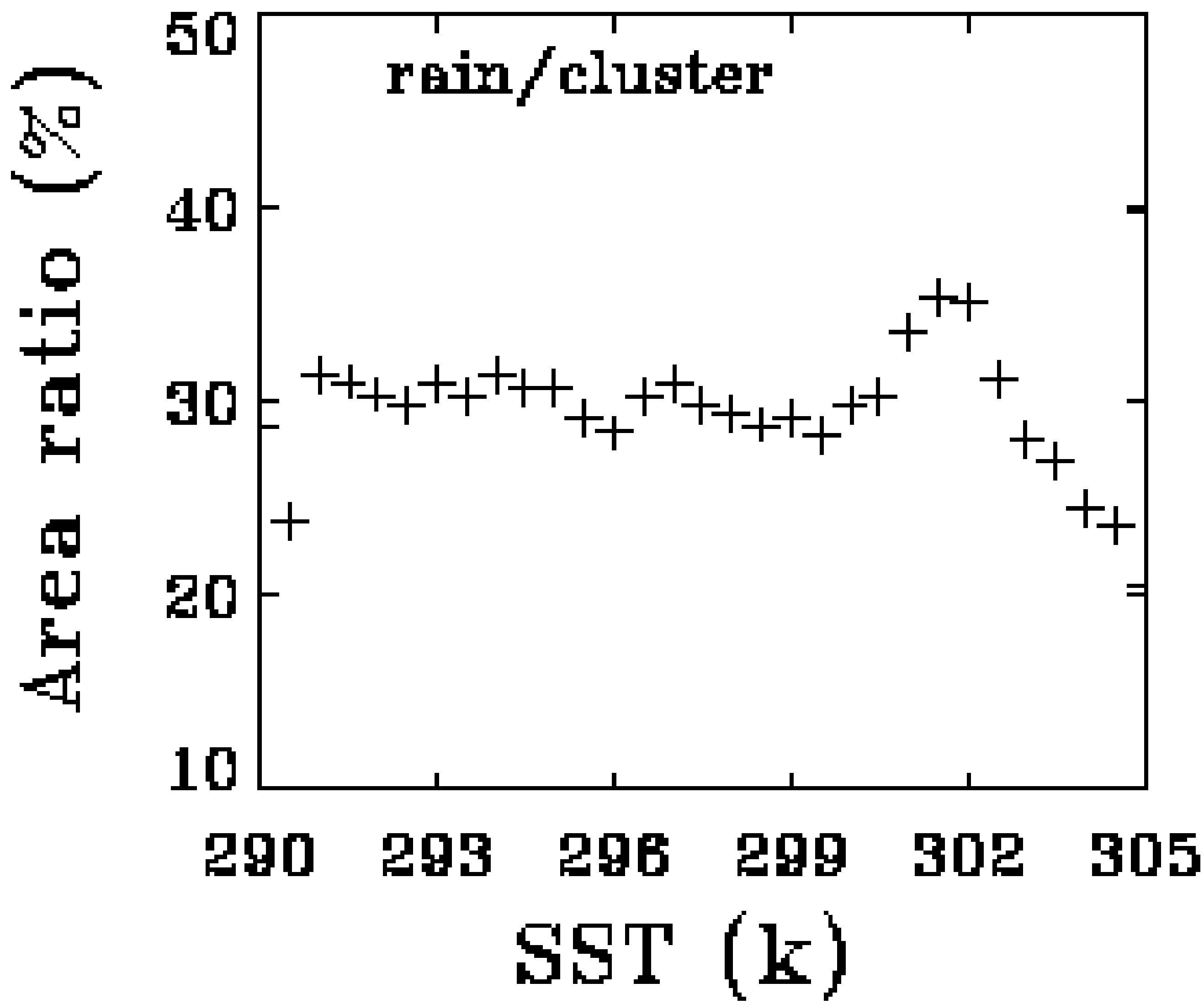
This research is supported by the NASA EOS science data analysis and radiation programs and CERES mission.

CLOUDS AND THE EARTH'S RADIANT ENERGY SYSTEM
CERES
NASA

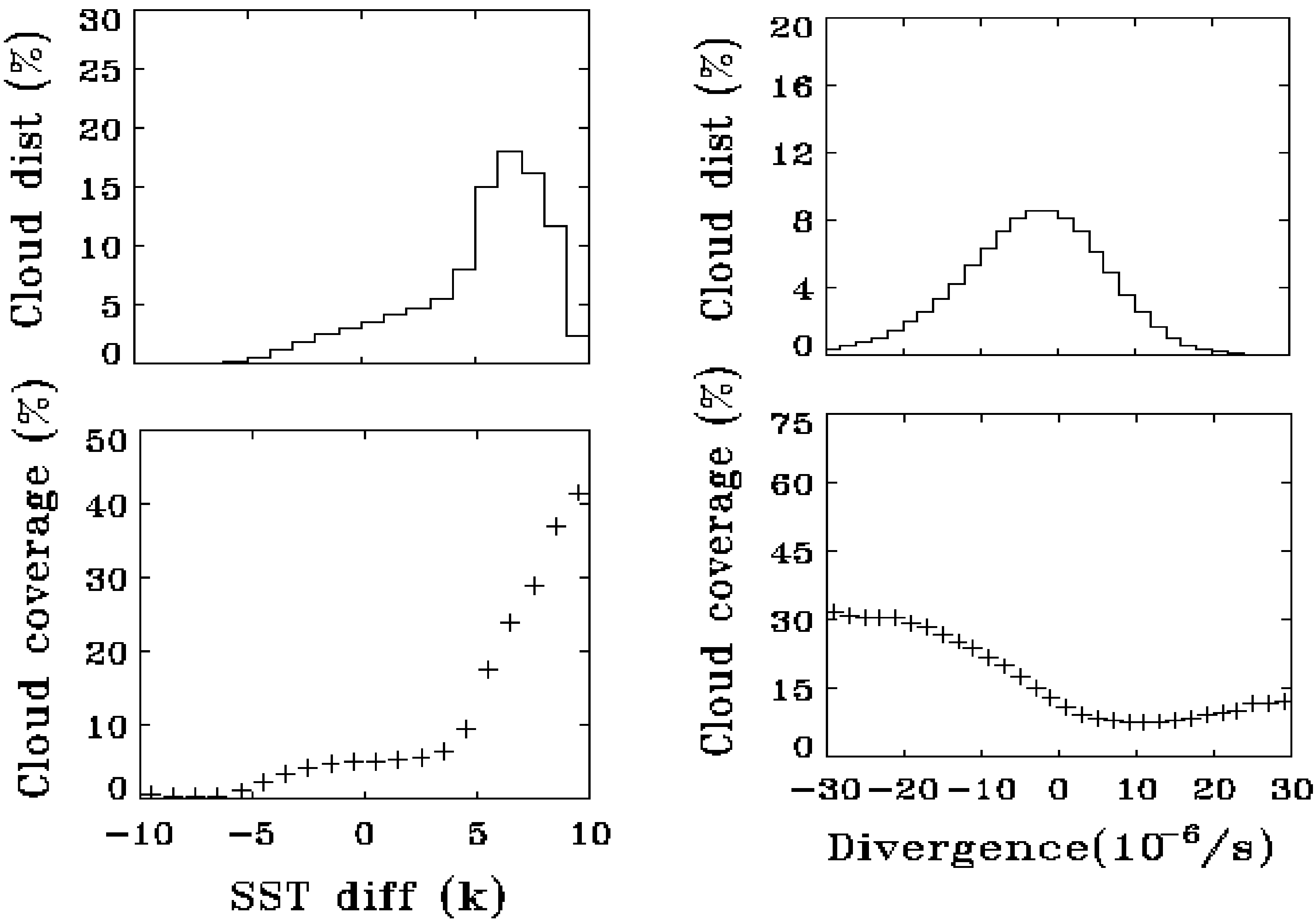
NASA

Backup Slices

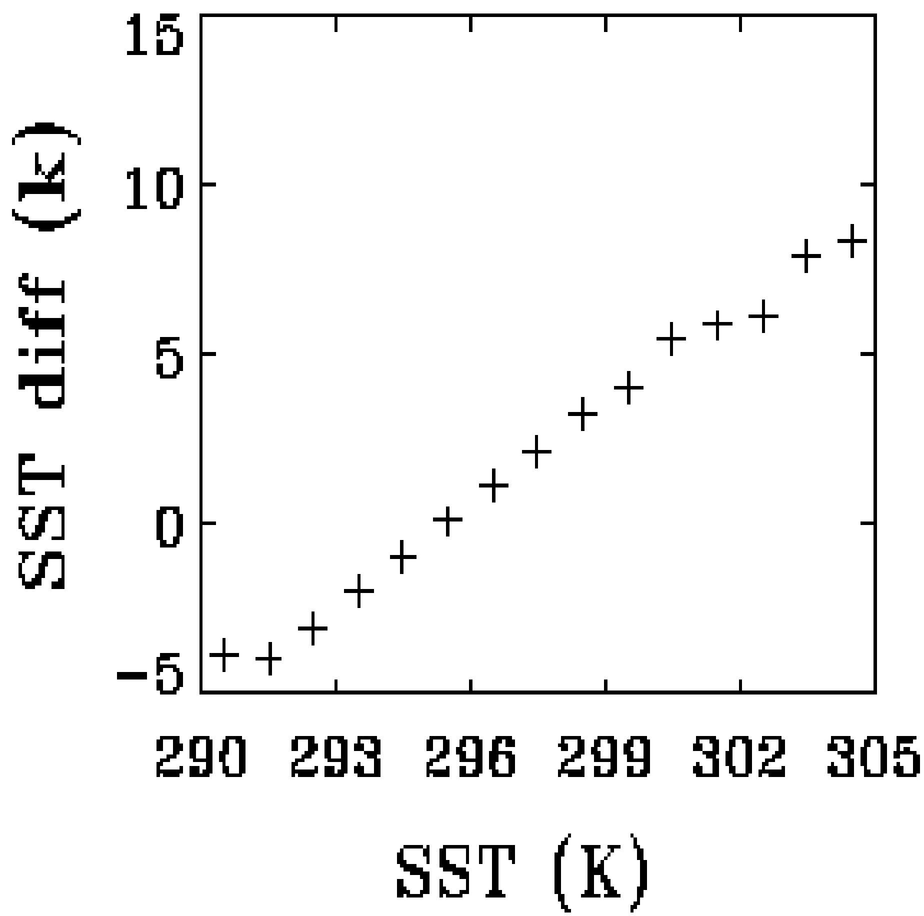
Area ratio of rain and cluster

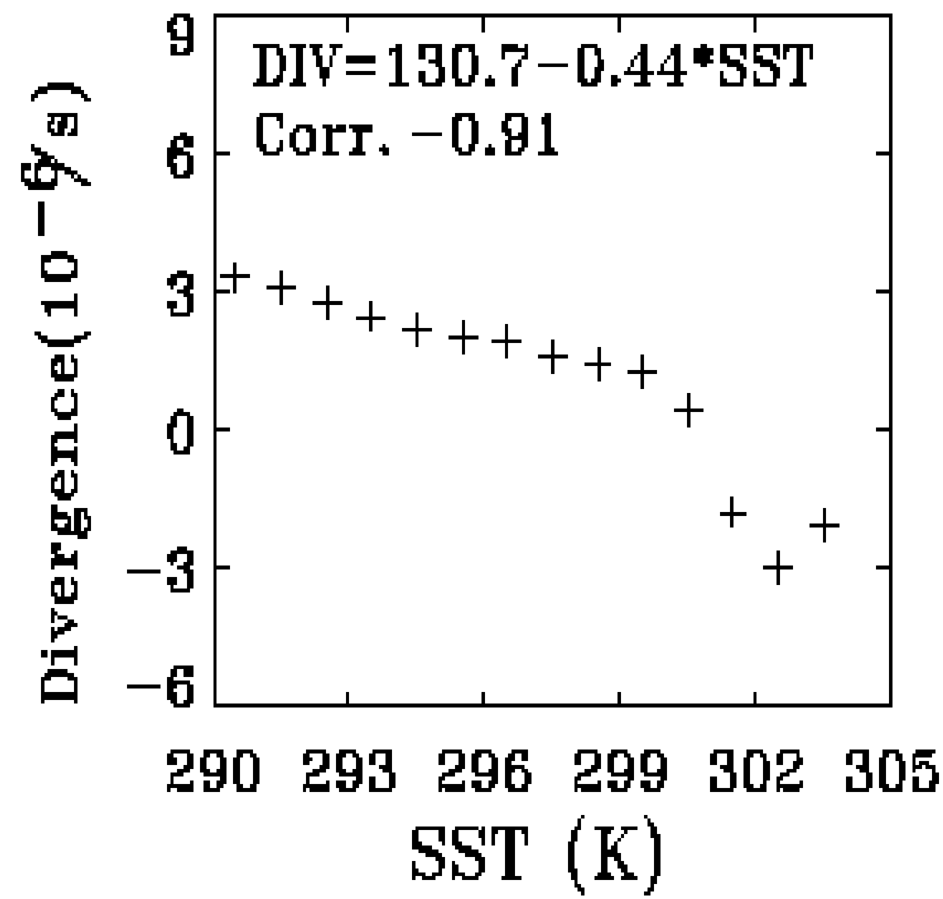


DCS vs DSST & convergence

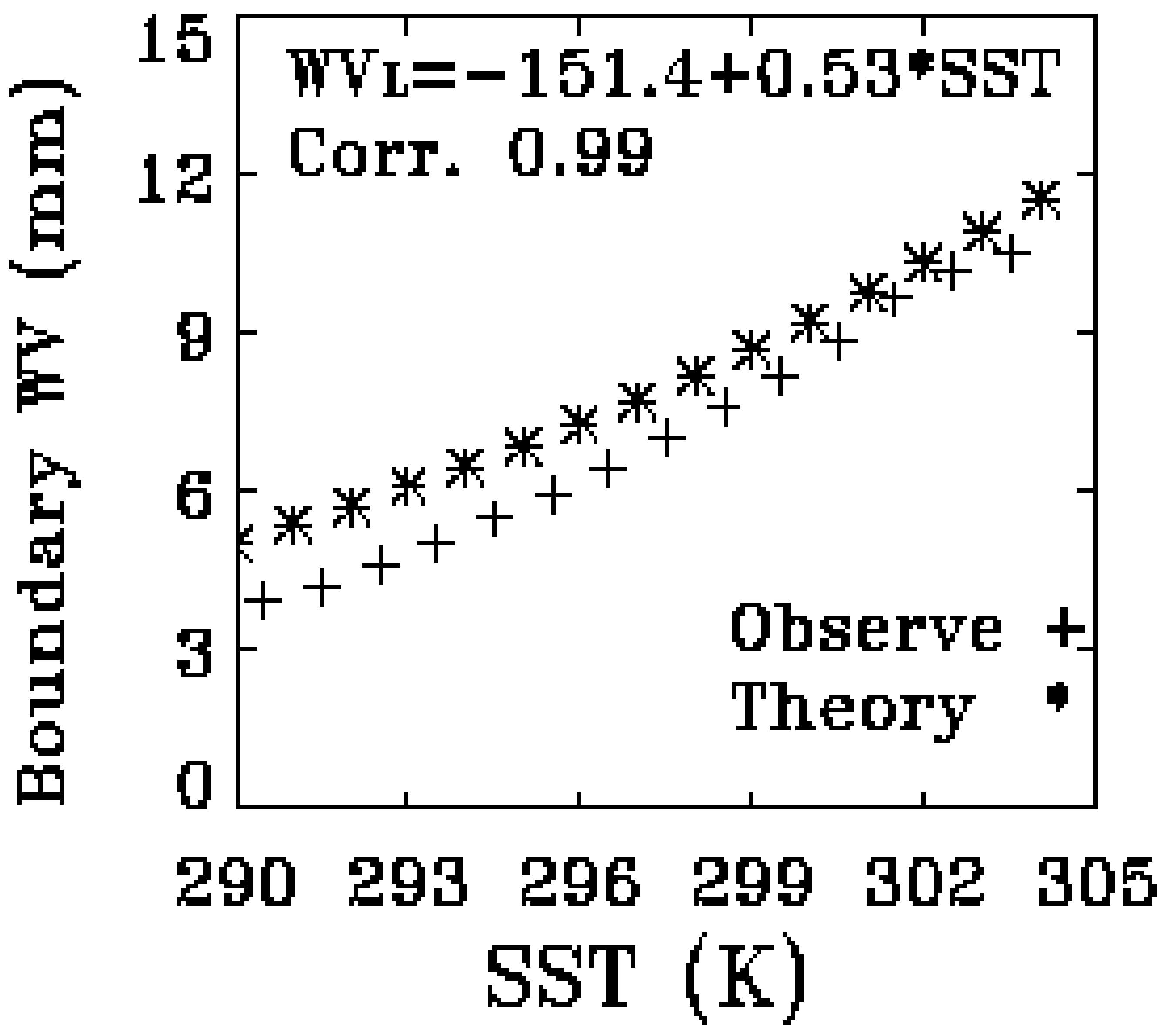


ΔSST & ∇•V vs SST


SST diff (k)
15
10
5
0
−5
290
293
296
299
302
305
SST (K)


DIV=130.7−0.44*SST
Corr. −0.91
Divergence(10−6/s)
9
6
3
0
−3
−6
290
293
296
299
302
305
SST (K)

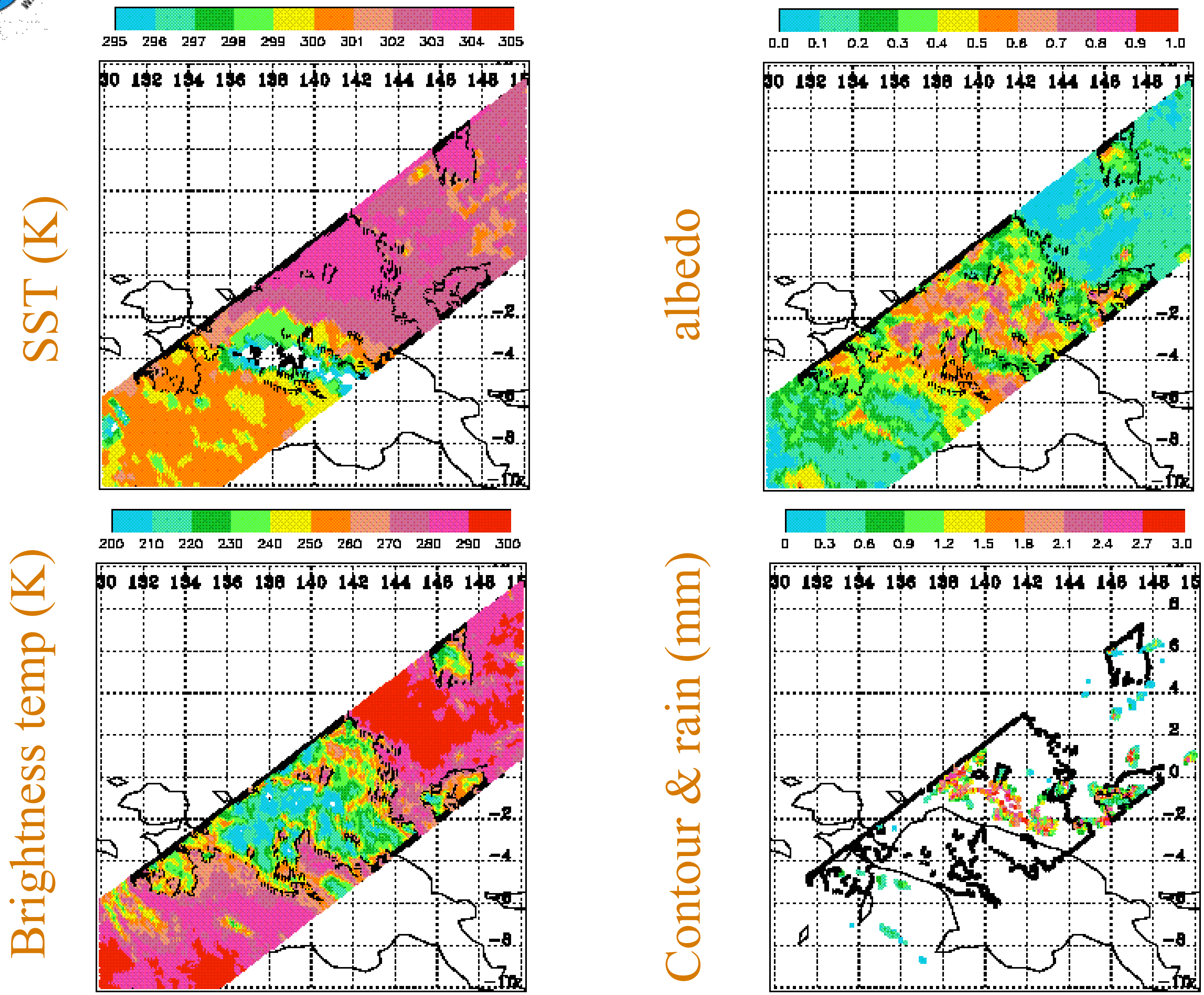
Boundary layer moisture



CLOUDS AND THE EARTH'S RADIANT ENERGY SYSTEM
CERES
NASA

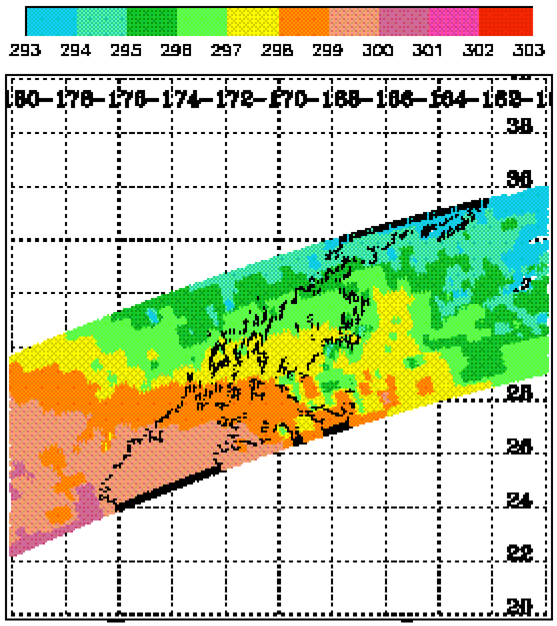
NASA

warm SST case (980801)

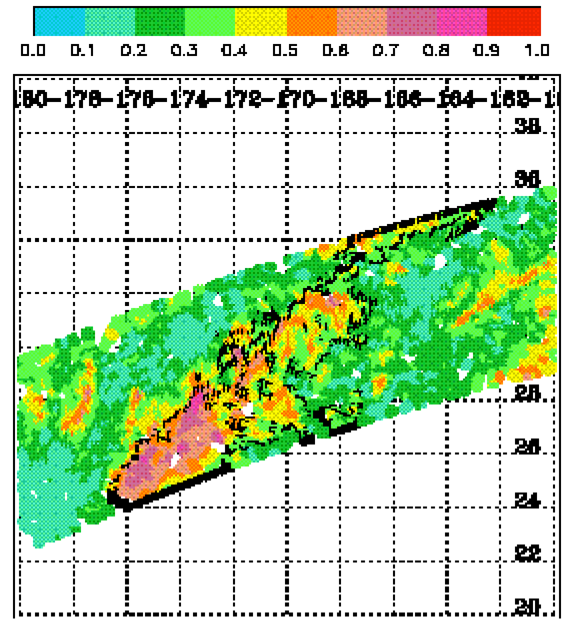


subtropical case (980619)

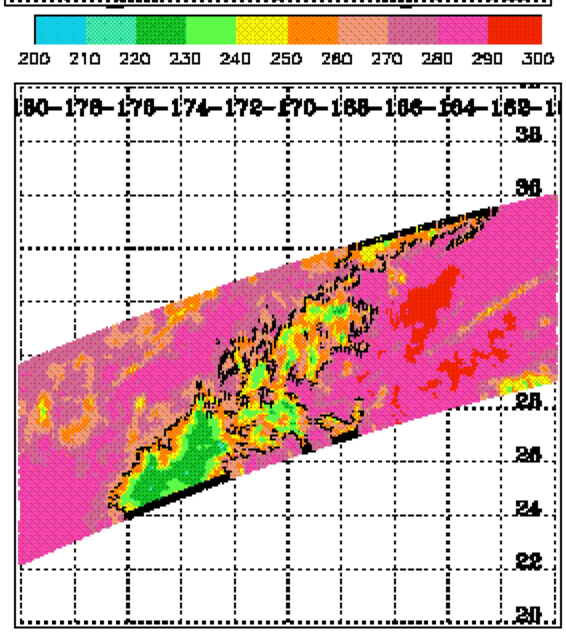
SST (K)



albedo



Brightness temp (K)



Contour & rain (mm)