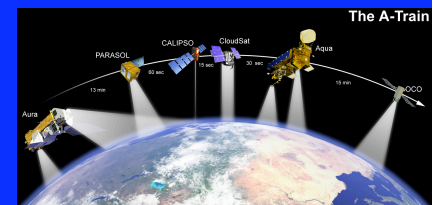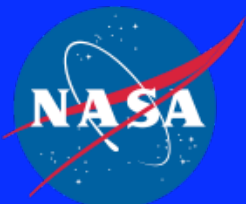# Low Cloud Feedback Diagnosed from LES Modeling and CERES Observations
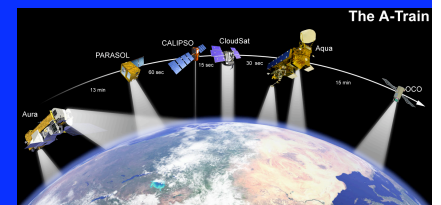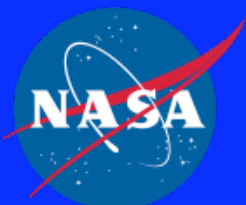
Kuan-Man Xu
NASA Langley Research Center

Anning Cheng and Zachary A. Eitzen
Science Systems and Applications, Inc.

The A-Train

Introduction

- Previous satellite data analyses suggested a strong positive low-cloud feedback (Tselioudis *et al.* 1992; Tselioudis & Rossow 1994; Clement *et al.* 2009 *[Science]*)

- All of them examined the covariance or correlation between cloud property (ln τ and A) and SST changes

- Dynamic and thermodynamic changes of low cloud environments (resulting in transitions between cloud regimes) are likely to be responsible for these results *(similar to changes in clouds in estimating aerosol indirect effects*)

- Thus, these analyses likely misinterpreted the covariance (correlation) as cloud feedback *(similar to overestimate of aerosol indirect effects)*

- The present study attempts to isolate cloud feedbacks for specific cloud regimes with LES study and observational analysis of satellite data utilizing a joint dynamic and thermodynamic stratification approach
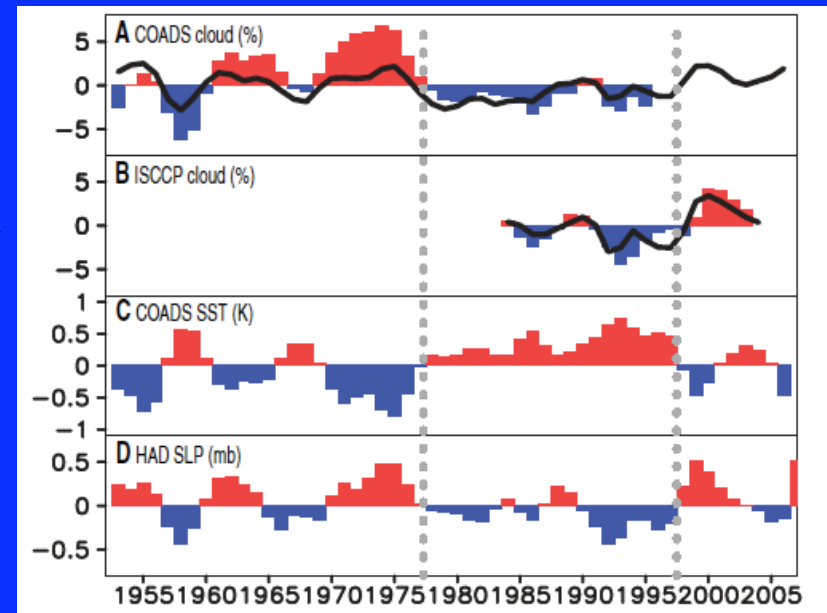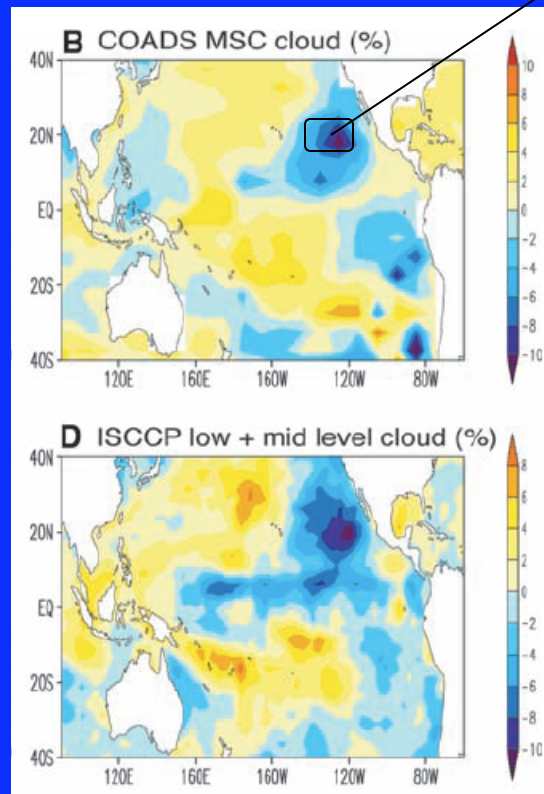
Introduction, 2

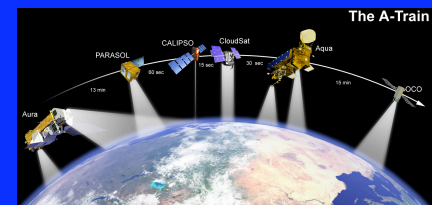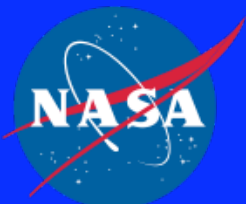**Observational and Model Evidence for Positive Low-Level Cloud Feedback**

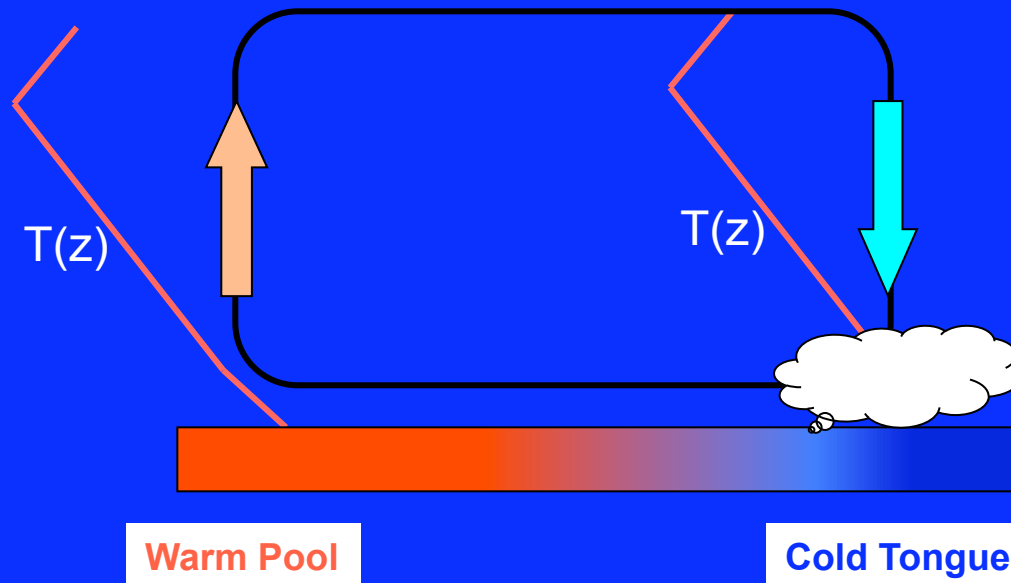Amy C. Clement,[1]* Robert Burgman,[1] Joel R. Norris[2]   *Science*

dA/d(SST)

B COADS MSC cloud (%)

D ISCCP low + mid level cloud (%)

A COADS cloud (%)

B ISCCP cloud (%)

C COADS SST (K)

D HAD SLP (mb)

Time series of annual mean anomalies over 115°-145°W, 15°-25°N region

The A-Train

Sketch of a two-box dynamic system

Moist Adiabat

RH Fixed

T(z)

T(z)

Zhang & Bretherton,
(2008; *J. Climate*)

Warm Pool

Cold Tongue

✦ Prescribed large-scale forcings are constrained by this system;
✦ A large-eddy simulation (LES) model simulates the cold tongue only;
✦ Sea surface temperature (SST) is 2 K higher everywhere in a perturbed (warmer) climate, compared to the control climate;
✦ Climate sensitivity (& cloud feedback) is obtained from the differences between the perturbed and control simulations.
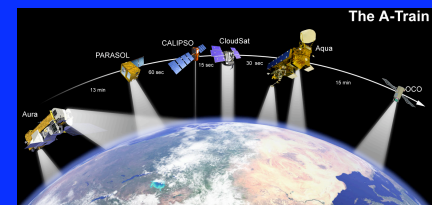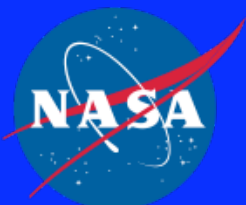
The A-Train
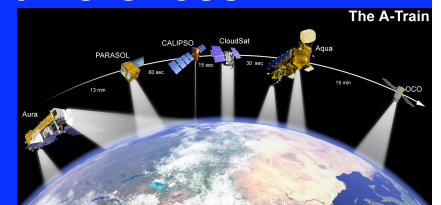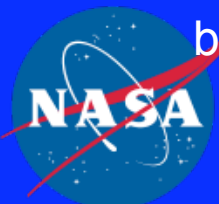
Low cloud regimes in eastern Pacific

ISCCP 1984-2004 July Climatology, LOW Cloud Amount
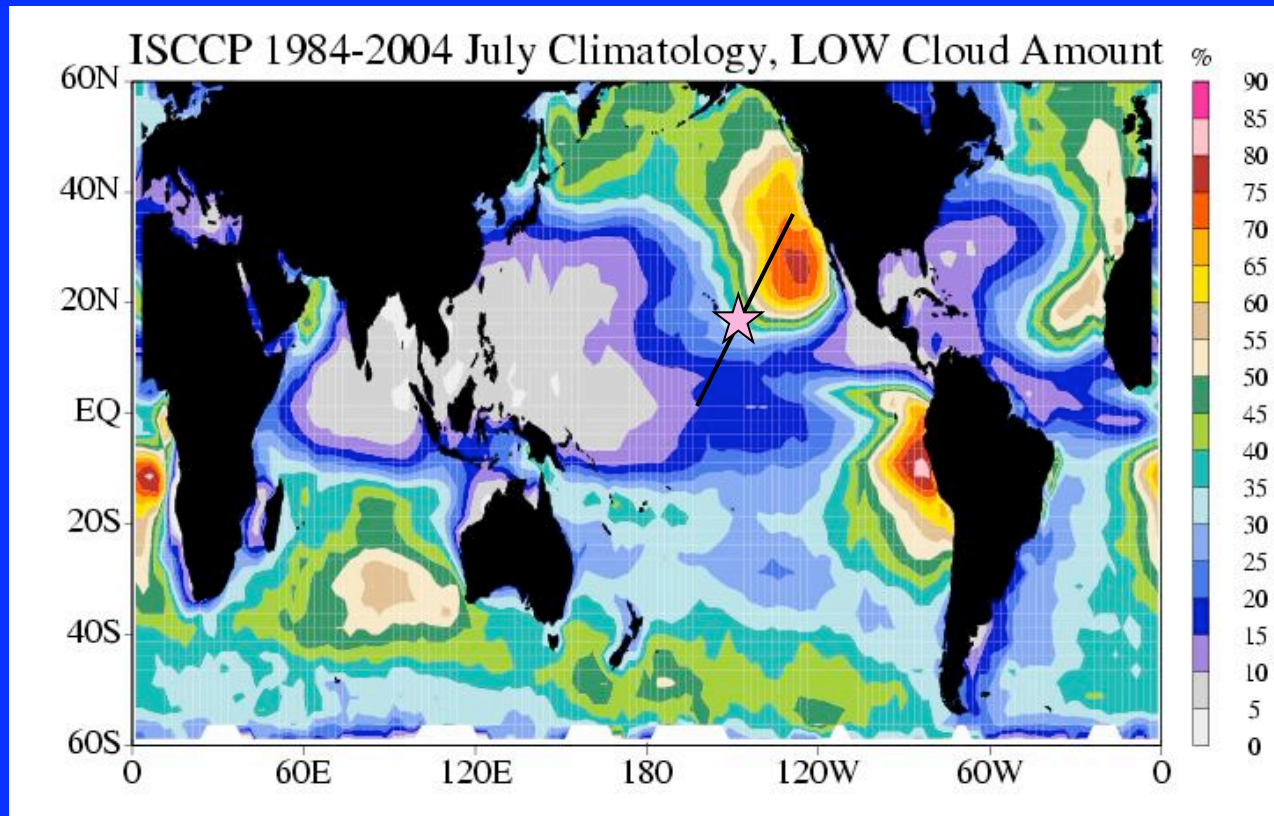
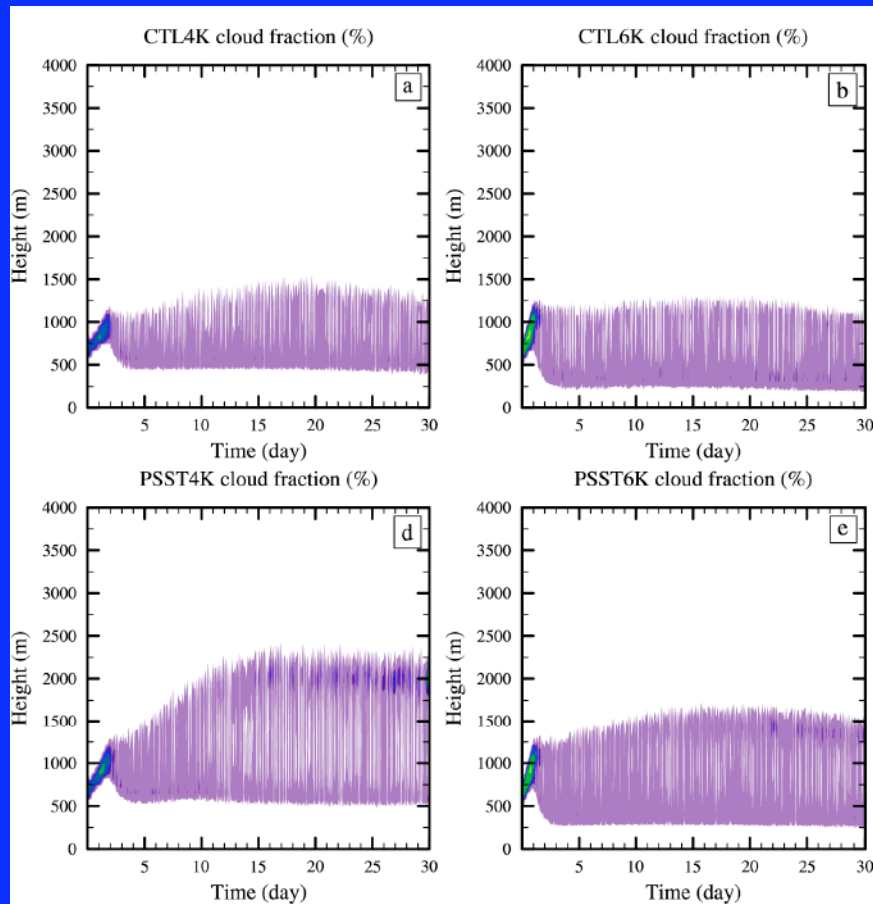ΔSST = 4K, 6K: Cumulus regimes

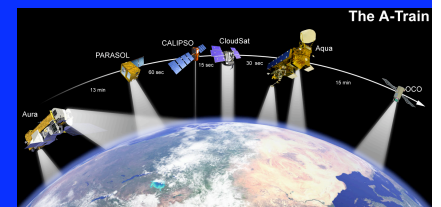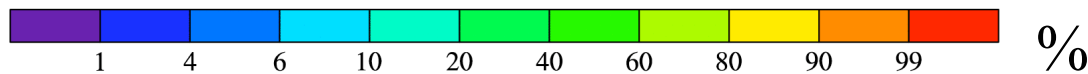ΔSST =12K, 14K: Stratocumulus regimes
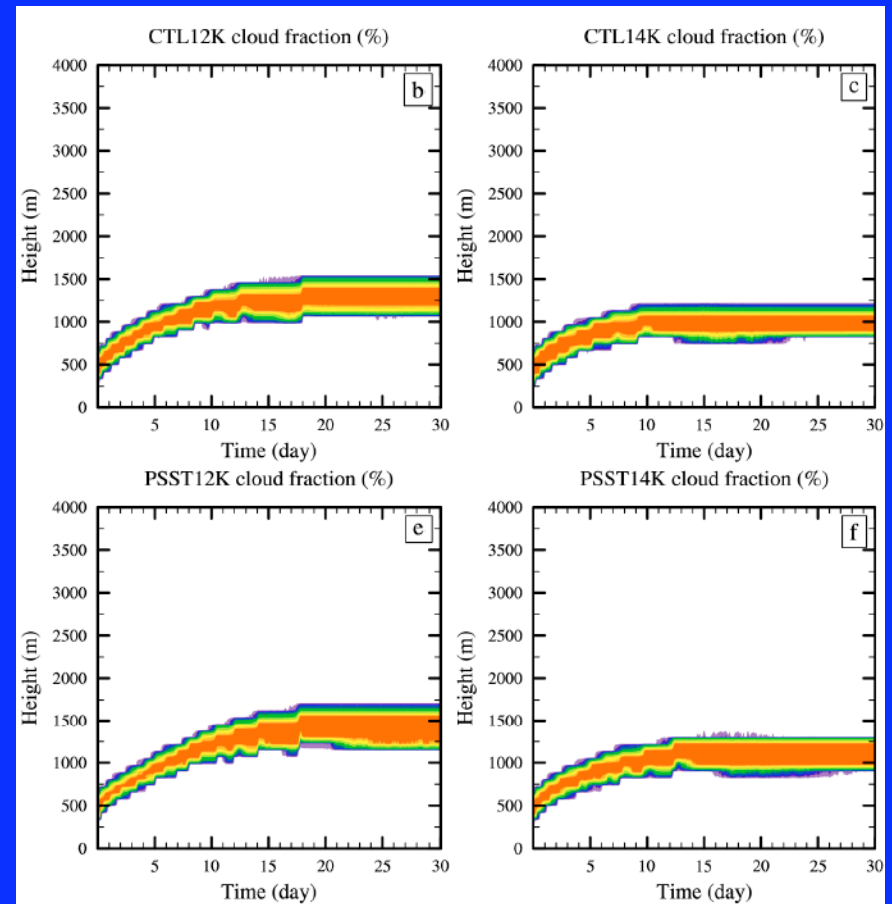
Δ = warm pool – cold tongue
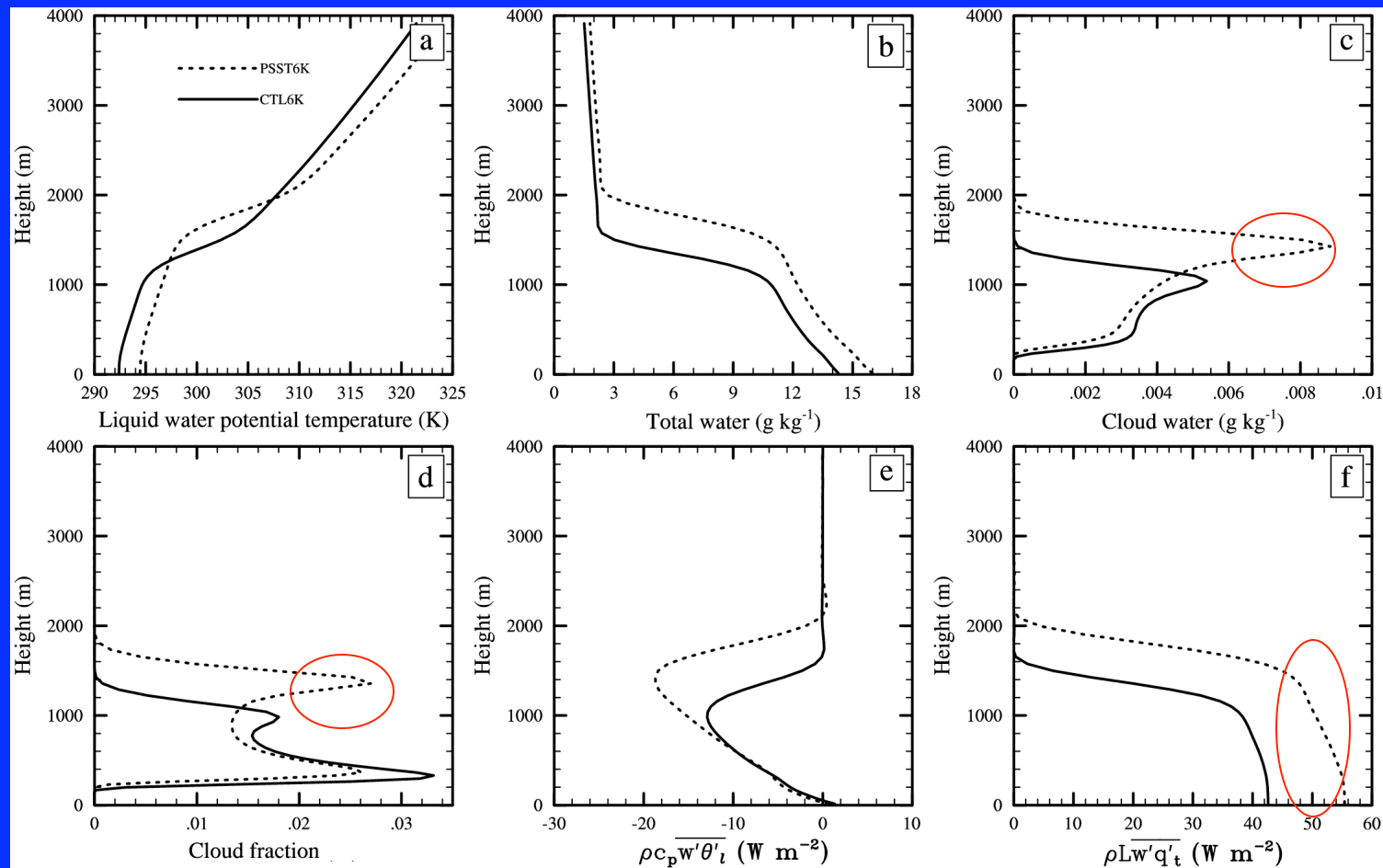
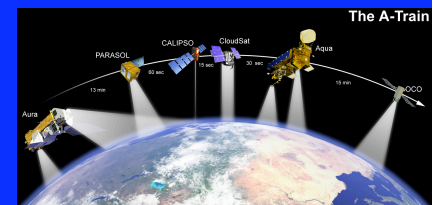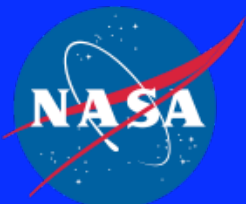# Temporal evolution of cloud fraction
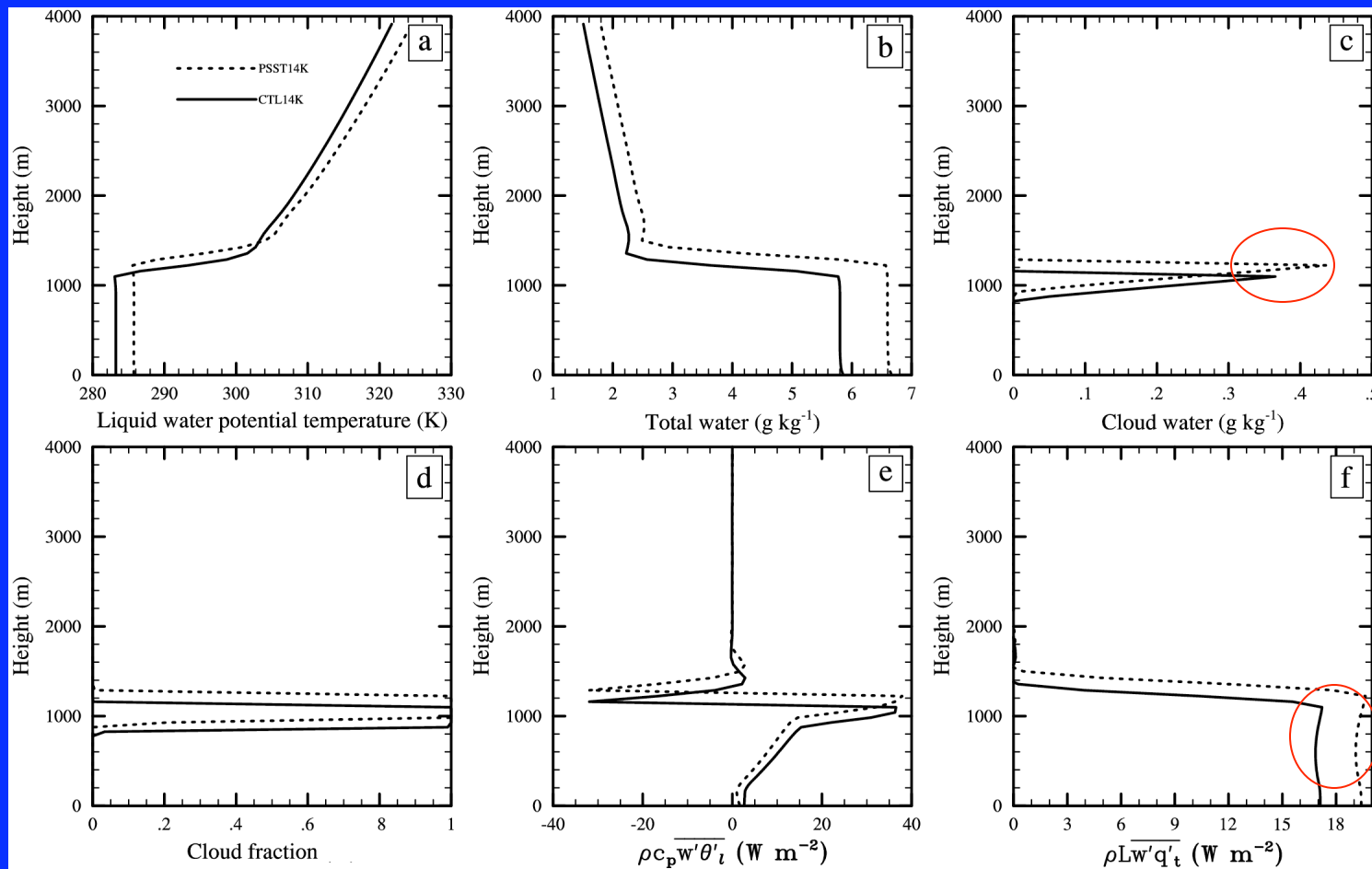
Cumulus regime

Stratocumulus regime

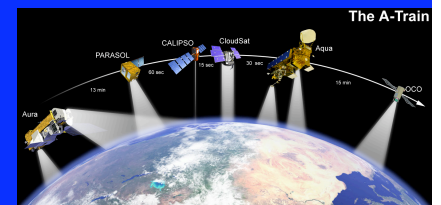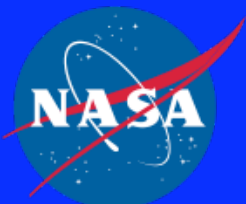# Thermodynamic and cloud profiles of equilibrium states for cumulus regime

ΔSST = 6K

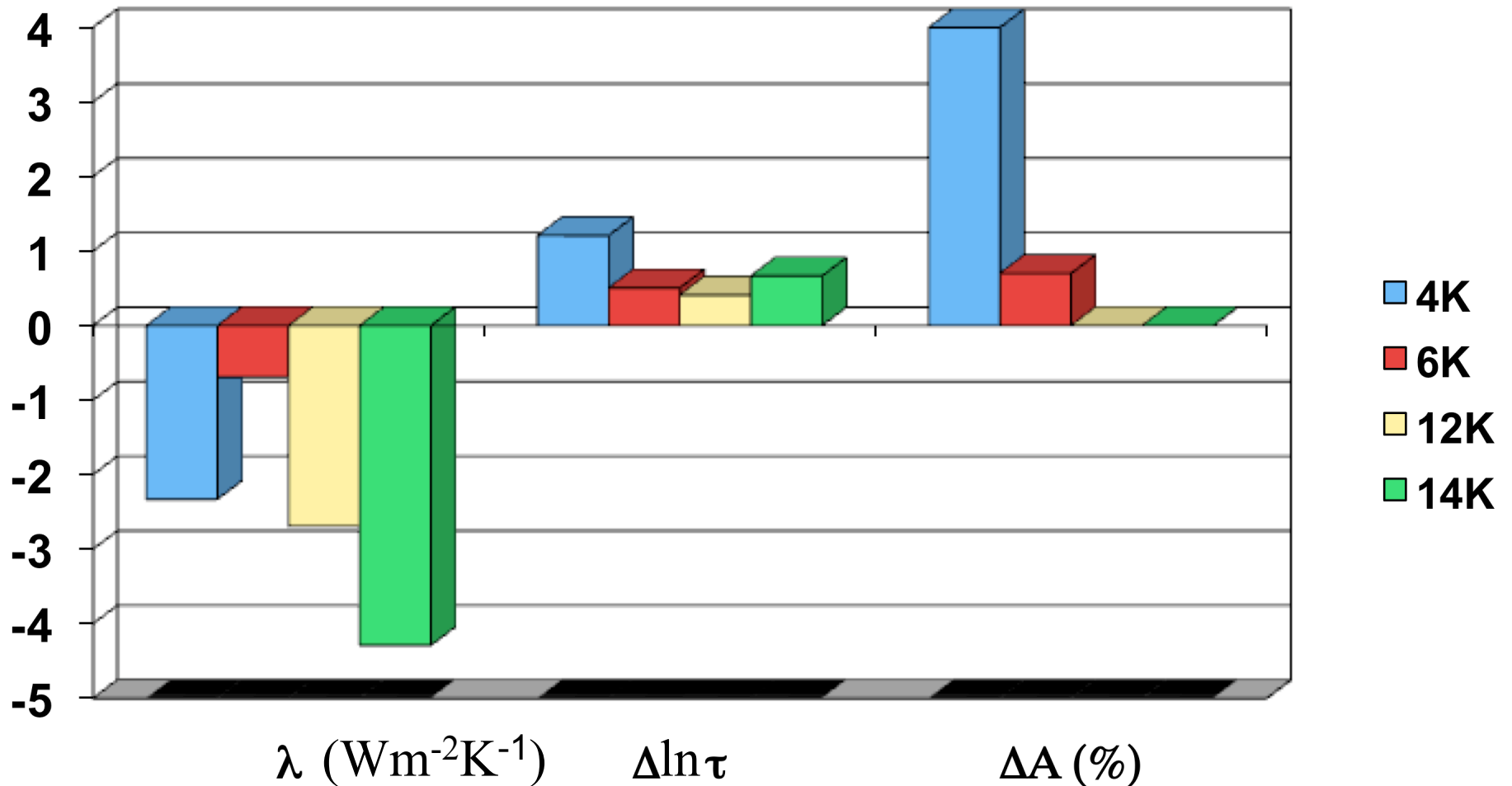# Thermodynamic and cloud profiles of equilibrium states for stratocumulus regime
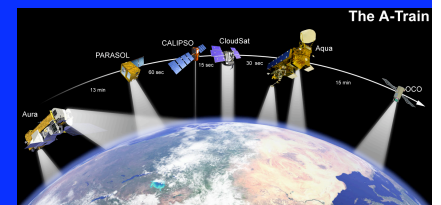

ΔSST= 14K

Cloud feedback parameter and changes in cloud optical depth (τ) and cloud fraction (A)

Summary of LES results

- For low clouds, the changes in both cloud optical depth (τ) and cloud fraction (*A*) with SST can produce either positive or negative cloud feedback

- LES modeling results indicate a negative low-cloud feedback for two specific cloud regimes [dynamic and thermodynamic conditions are similar between warmer and control climate]

- The simulated negative cloud feedback is related to the increased moisture transport at +2K SST, leading to large increase in PW and LWP (thus larger τ), as well as a small increase in cloud fraction in the cumulus regime

- Detailed results are presented in Xu *et al.* (2009; *J. Atmos. Sci., in press*): "Cloud-resolving simulation of low-cloud feedback to an increase in sea surface temperature"
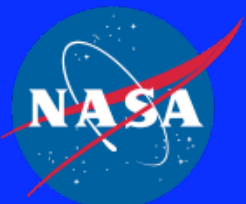
Objective and approach for satellite data analysis of cloud feedback

- To what extent do the changes in dynamics & thermodynamics reduce the total covariance between cloud property (e.g., ln τ, A and radiative flux) and SST?

- ➢ Use satellite cloud property and radiative flux measurements, combined with ECMWF ERA Interim data

- ➢ Use the interannual variations as a proxy for studying cloud feedbacks [cloud feedback operates at many temporal scales]

- ➢ Use a joint dynamic and thermodynamic stratification approach

The A-Train
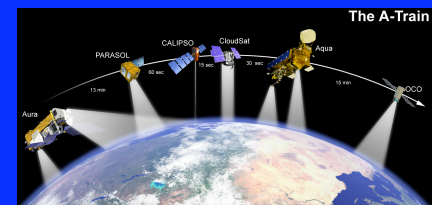
Data Sources (CERES Level 3)

- The period of data analysis covers the first five years of CERES-Terra data (March 2000-February 2005)

- Radiative fluxes are from the monthly mean 1°x1° CERES-EBAF data (Loeb *et al.* 2009; *J. Climate*)

- Cloud optical depth and cloud fraction are from the monthly mean 1°x1° CERES SRBAVG GEO data

- SST is from NOAA monthly mean Reynolds SST data

- Meteorological state variables are from ECMWF ERA-Interim reanalysis (1.5°x1.5°)

- Anomalies are calculated by subtracting each month's value from the five-year mean for that month

The A-Train
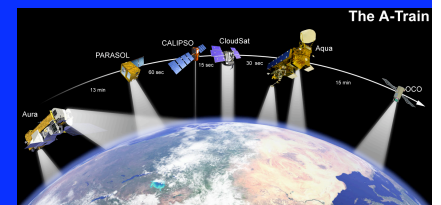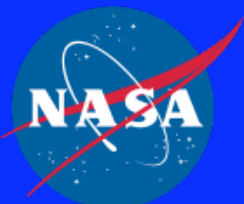
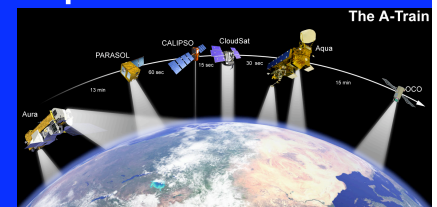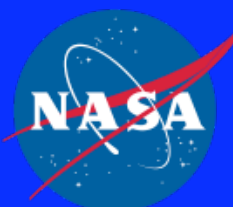# Change in A (% K⁻¹), ln (τ) (K⁻¹) & net cloud radiative effect (W m⁻² K⁻¹) with SST
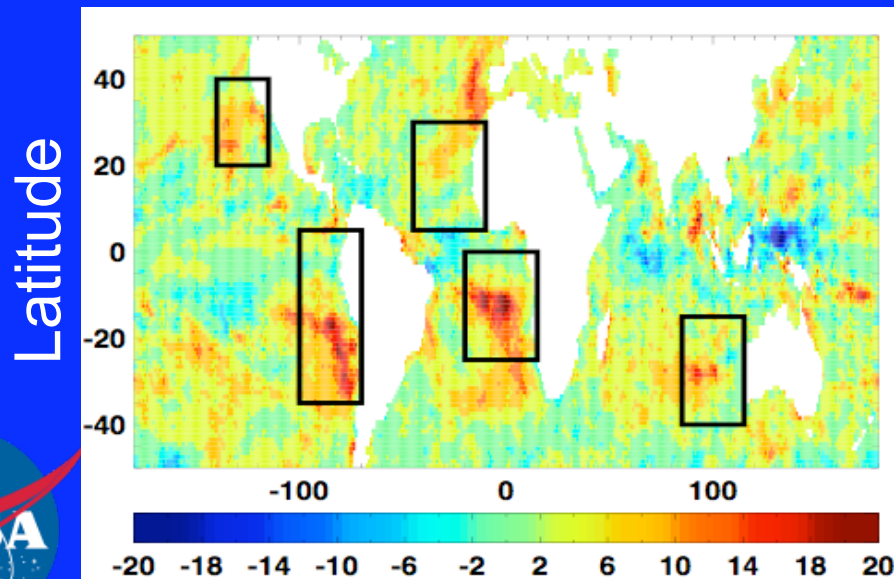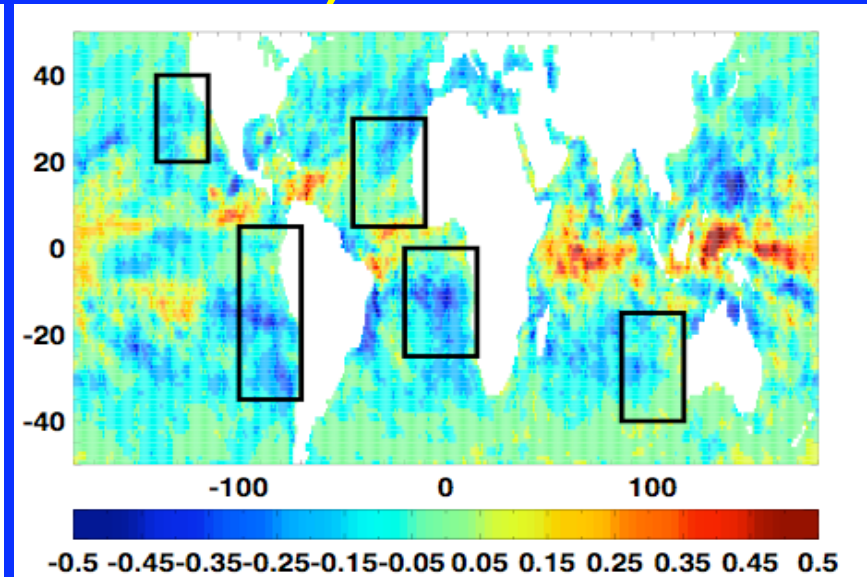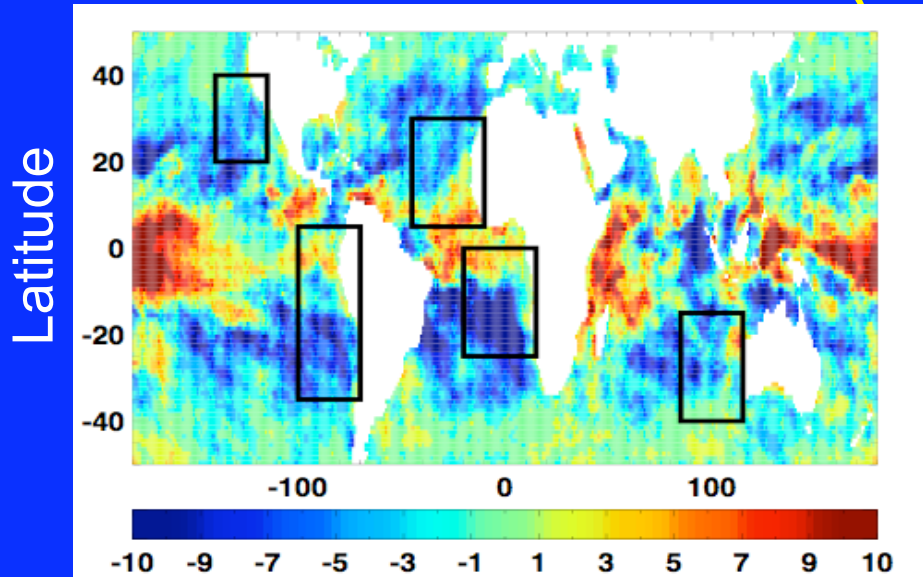
Linear regression of property anomaly with SST anomaly from 60 numbers at each 1x1 grid;
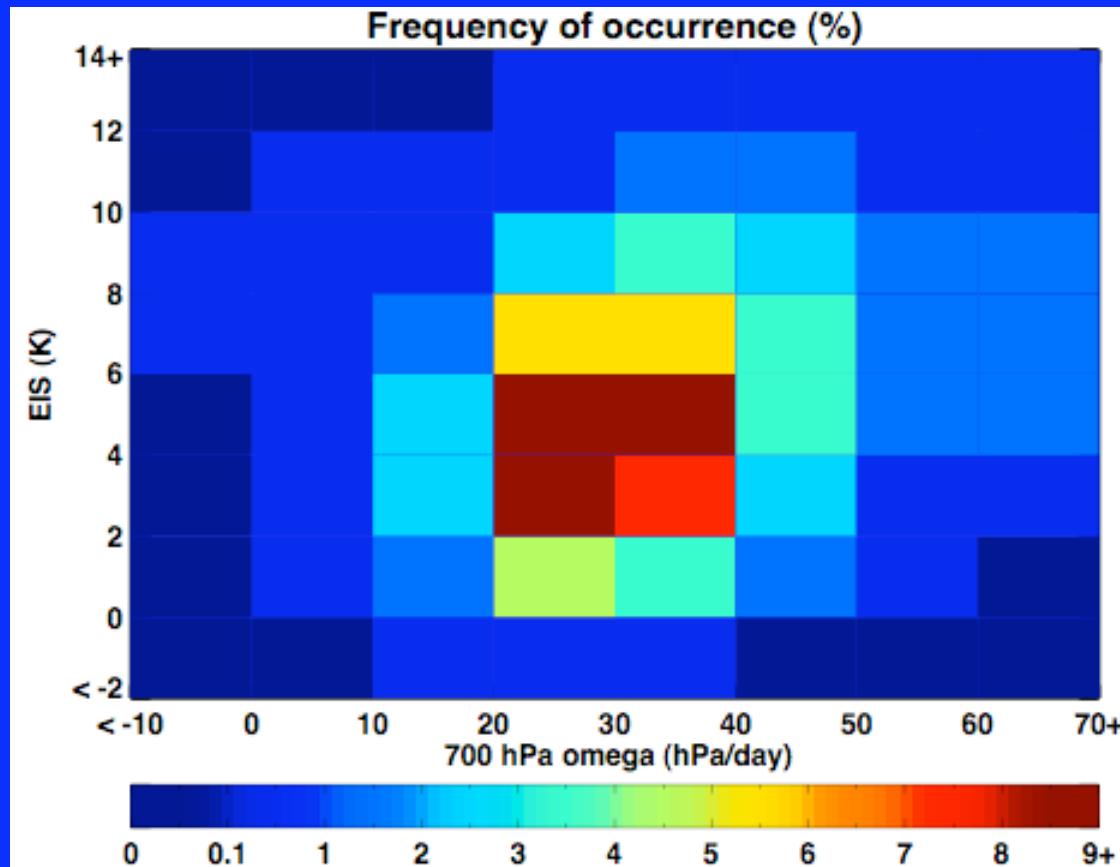
In the low cloud regions, results are consistent with positive cloud feedback as in Clement *et al.*
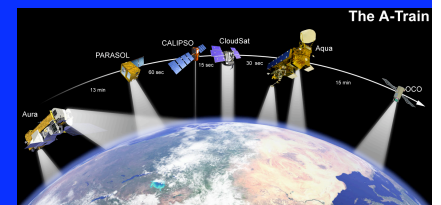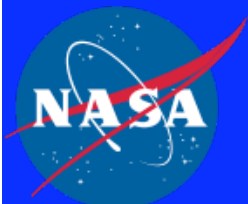
Dynamic/thermodynamic regimes of low clouds

EIS: Estimated Inversion strength (Wood & Bretherton 2006)
Both EIS and $\omega_{700\ hPa}$ are calculated from ECMWF ERA Interim data

Five low cloud regions only

Exclude grids with > 10% upper clouds

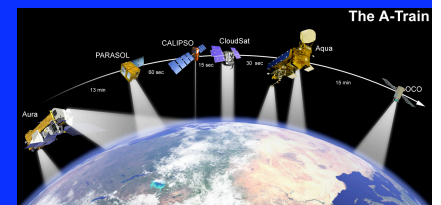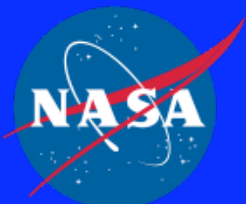# How to estimate dynamic and thermodynamic effects in the covariance?

Anomaly of a cloud/radiative property, A:

$A = A (SST, EIS, \omega_{700}, \ldots)$

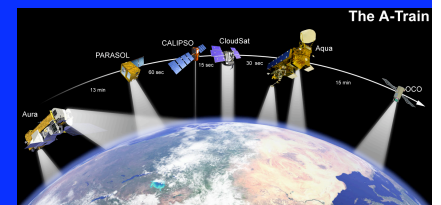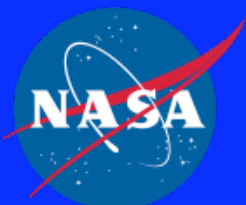f_{EIS}, $f_{\omega_{700}}$ are frequencies within an EIS, ω_{700} bin

$$\frac{\partial A}{\partial SST}_{total} = \frac{\partial A}{\partial SST}_{partial} + \sum_{EIS} \frac{\partial A}{\partial \omega_{700}} \frac{\partial \omega_{700}}{\partial SST} f_{EIS} + \sum_{\omega_{700}} \frac{\partial A}{\partial EIS} \frac{\partial EIS}{\partial SST} f_{\omega_{700}} + \ldots$$

Performing regressions for the LHS term and the individual terms within the brackets on the RHS

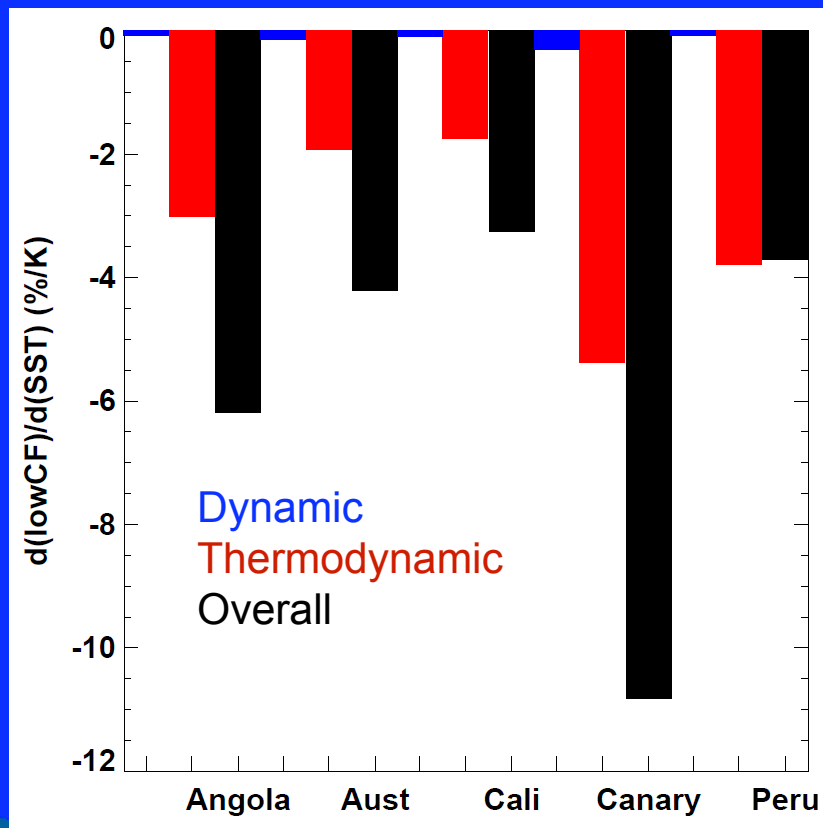The A-Train

Changes in cloud properties with SST for low cloud regions

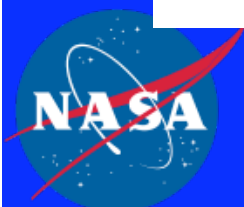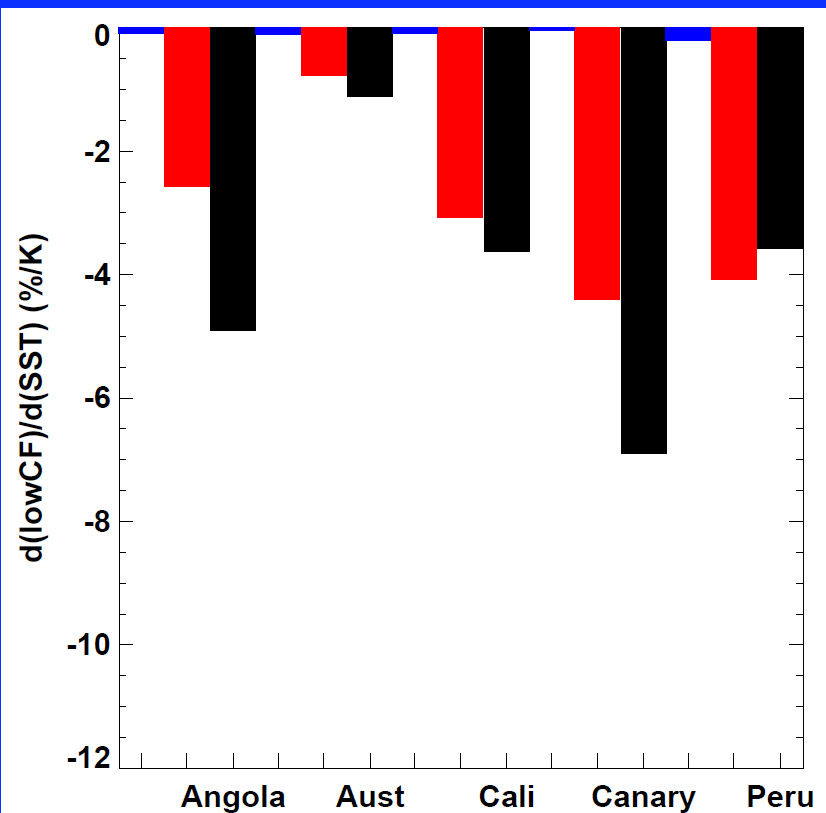| Cloud property	All effects	Dynamic effects	Thermod effects	Residual
Cloud fraction (% K^{-1})	-5.15	-0.18	-2.77	-2.2
Ln (τ) (K^{-1})	-0.131	-0.006	-0.064	-0.061
Net CRE (W m^{-2} K^{-1})	6.86	0.23	3.36	3.27
SW CRE (W m^{-2} K^{-1})	7.33	0.21	3.52	3.60

Regional differences in changes in low-cloud fraction with SST

Terra observations

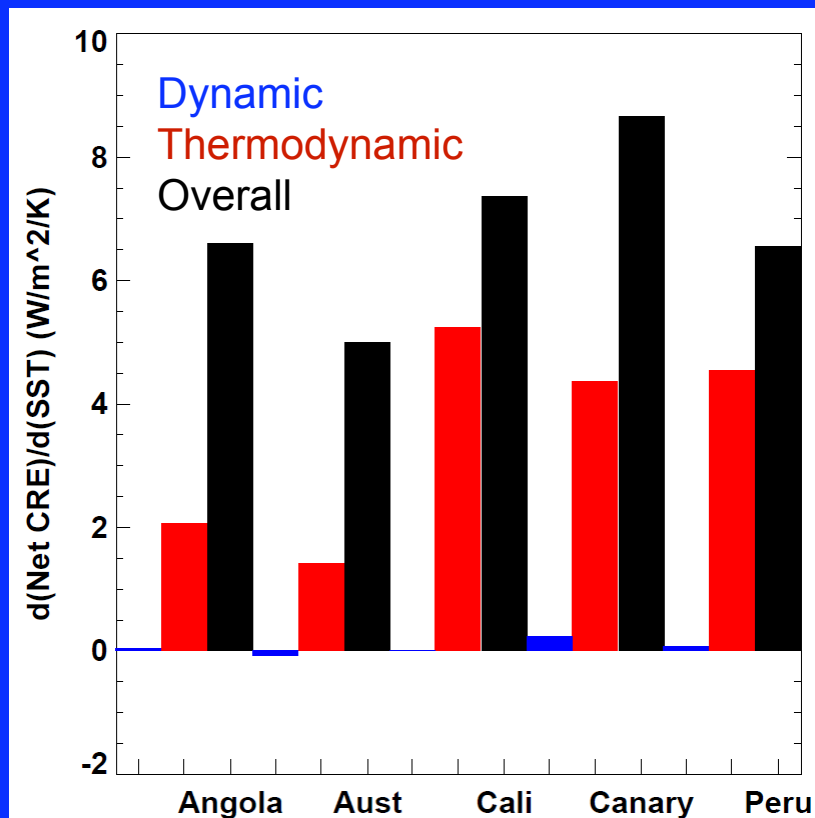ERA-Interim data

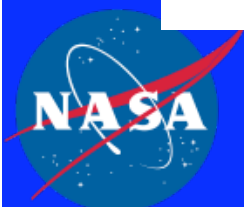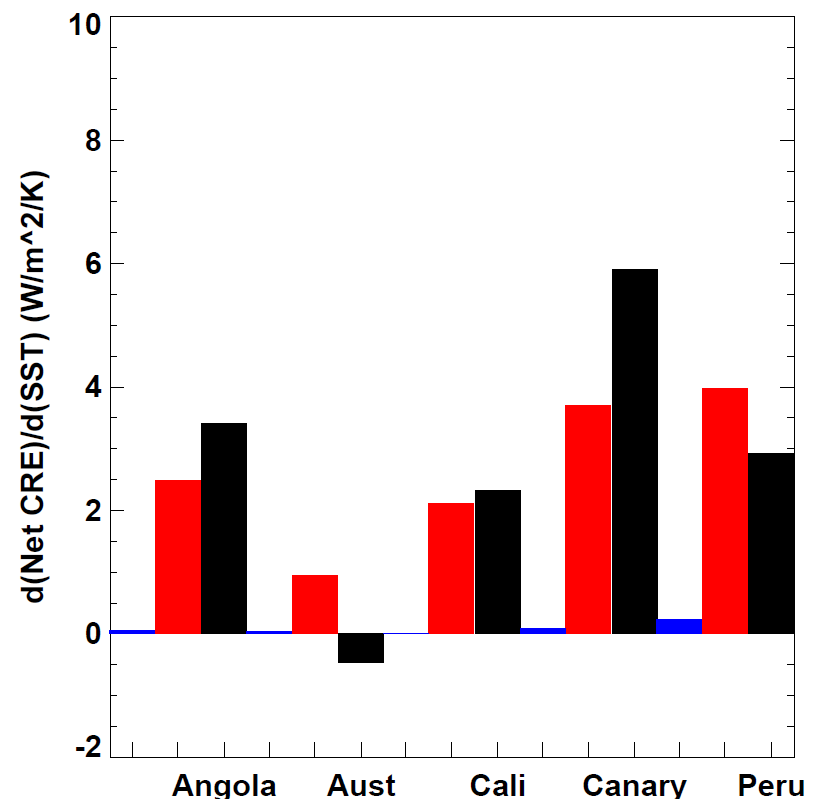# Regional differences in changes in cloud radiative effect with SST



Terra observations

ERA-Interim data

Summary – satellite data analysis

- Previous satellite data analyses might suggest a strong positive cloud feedback since the covariances between SST and cloud property related to dynamic & thermodynamic changes were not removed

- Once the covariances due to dynamic/thermodynamic changes are removed, the implied positive cloud feedback is much smaller or even negative in some regions

- ECMWF ERA Interim reproduces the observed dynamic and thermodynamic effects well, except for the region off Australia; the total and residual covariances differ somewhat between ERA and CERES data

- Future plans: i) to better exclude mid/upper level clouds in the analysis with the help of CALIPSO and CloudSat data and ii) to estimate low cloud feedbacks for shorter temporal scales
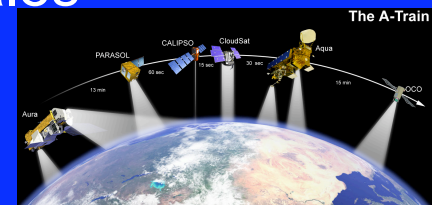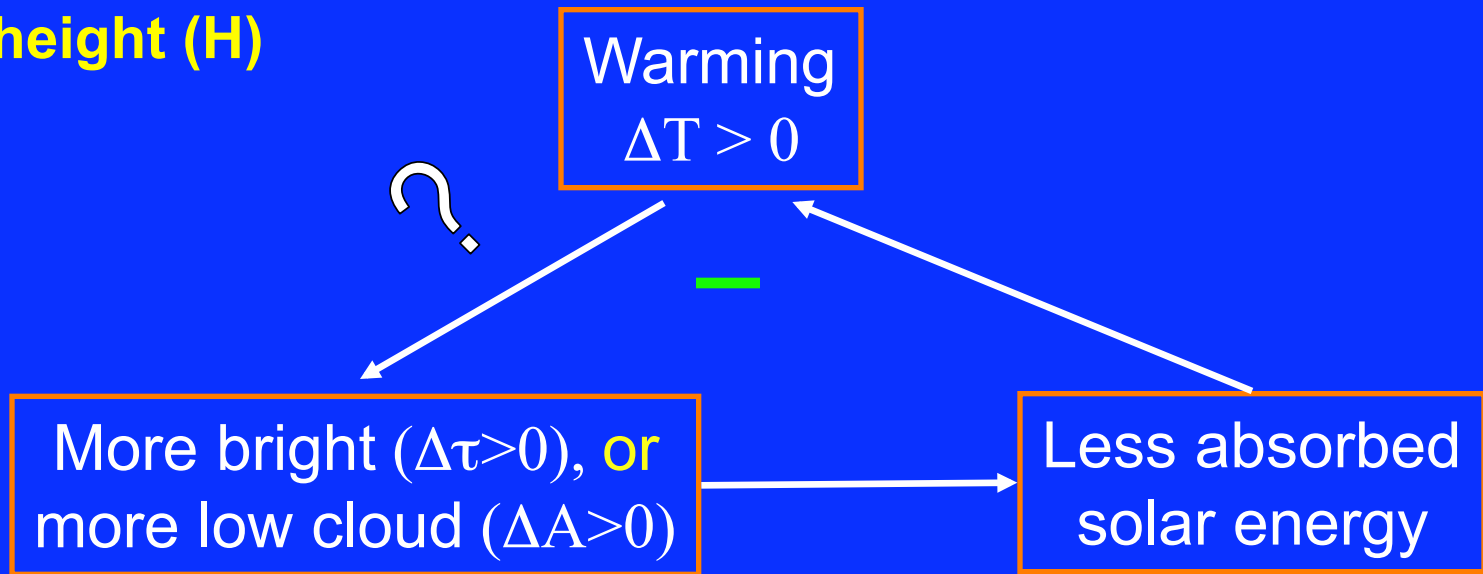
Thank you for your attention!
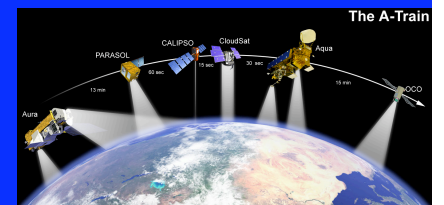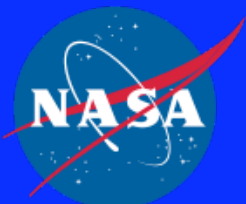
What determine low cloud feedback?

1. Cloud optical thickness (τ) (Somerville & Remer 1984)

2. Cloud amount (A)

3. **Cloud height (H)**

Warming
$\Delta T > 0$

?

More bright ($\Delta\tau > 0$), or more low cloud ($\Delta A > 0$)
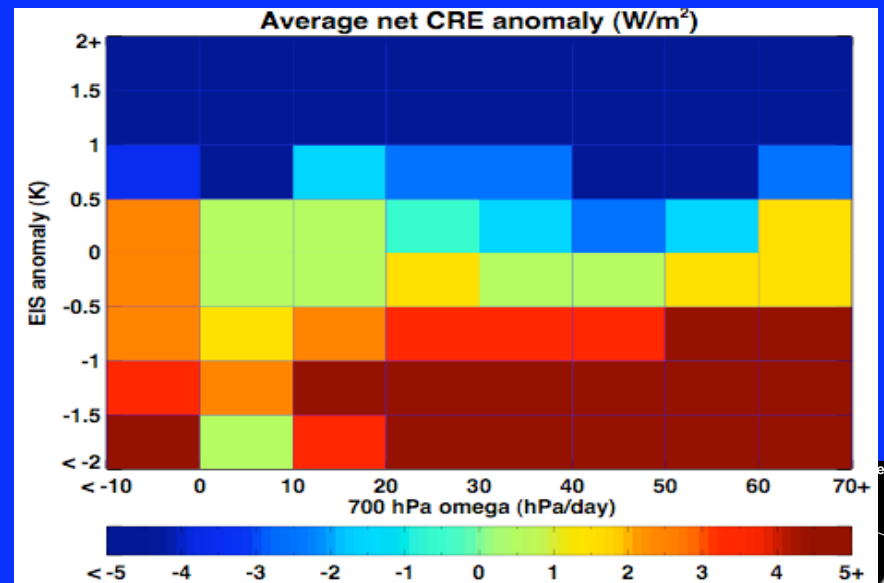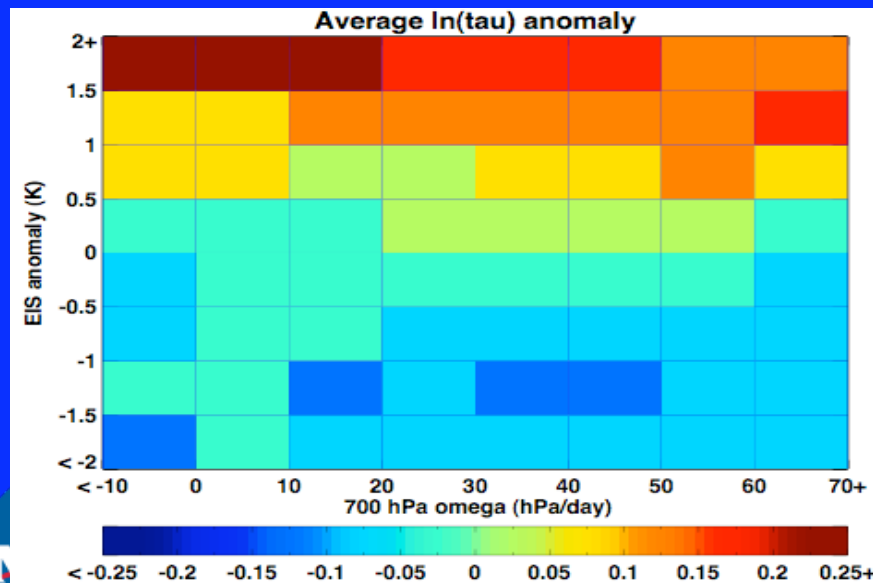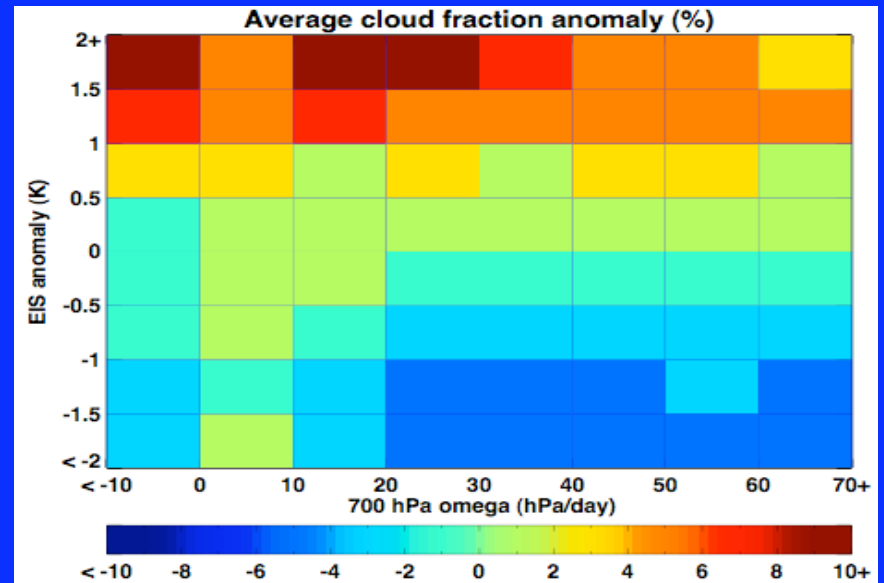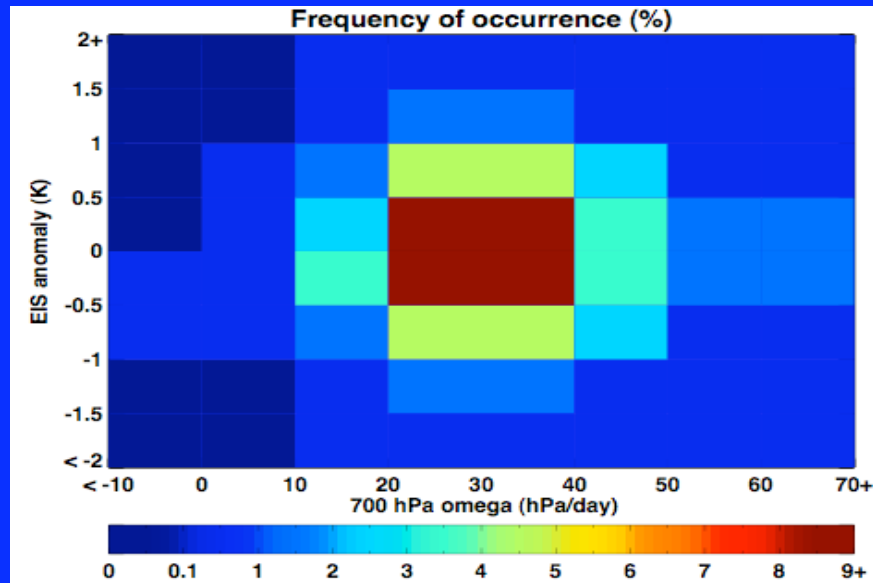
Less absorbed solar energy

The obstacle to understand the low cloud feedback problem is how low clouds respond to a warming. Either positive or negative feedback is possible, as evident from results from different GCMs!
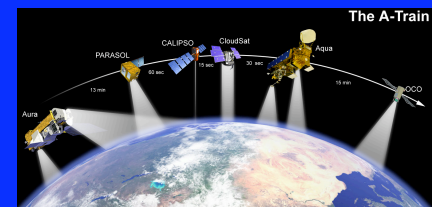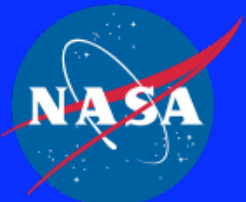
Percent of changes in selected properties
compared to that of water vapor pressure (e*)
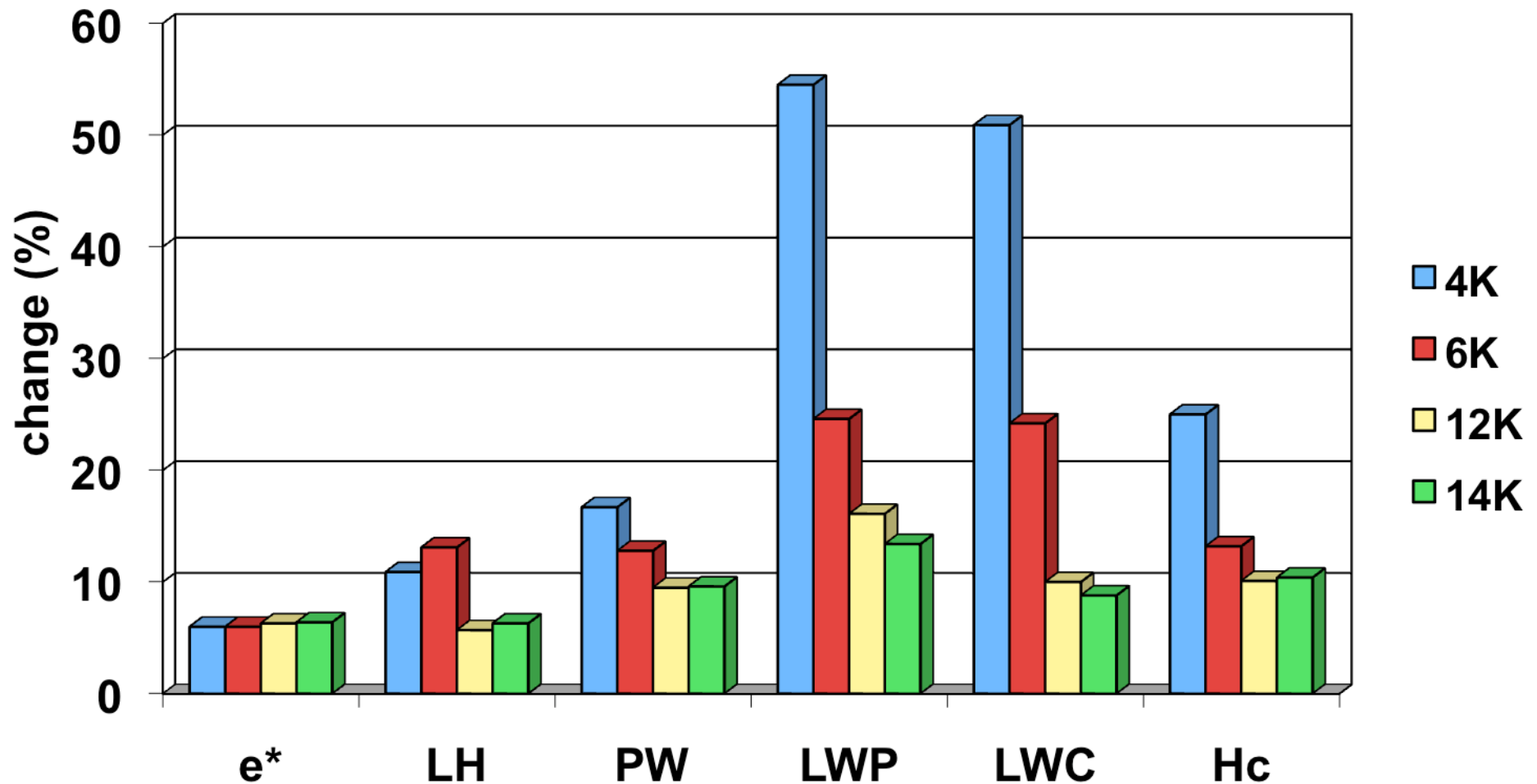
EIS partial derivatives

Terra + Aqua July 2003

Low cld frac all data

0.0   0.2   0.4   0.6   0.8   1.0