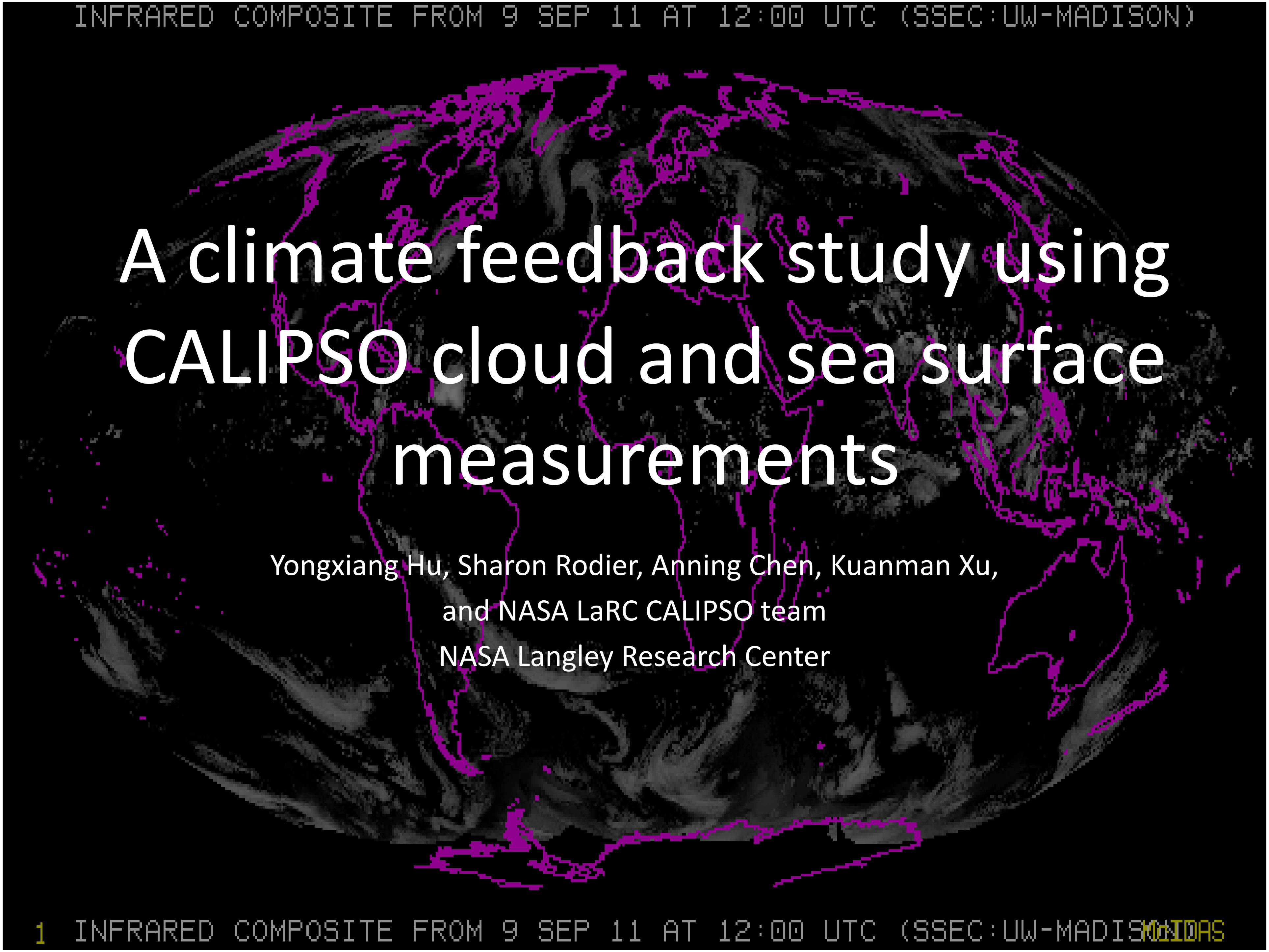

A climate feedback study using CALIPSO cloud and sea surface measurements

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Outline of the talk

1. CALIPSO cloud phase statistics: found more supercooled liquid water clouds in storm track and high latitude

2. Impact on cloud modeling: more reasonable middle level clouds

3. Impact on climate sensitivity: enhanced positive feedback (temperature increase due to CO_2 increase, reduced meridianal temperature gradient, reduced baroclinicity and surface wind at storm track, reduced high latitude air-sea turbulence exchange speed and biological bump, reduced cloud albedo and increased CO_2).

Methods to discriminate liquid and ice phase

- **MODIS**: absorption of solar infrared radiation (ice absorbs slightly more than liquid for each scattering event)

- **Parasol**: linear polarization of reflected sunlight at rainbow angles (liquid: highly polarized)

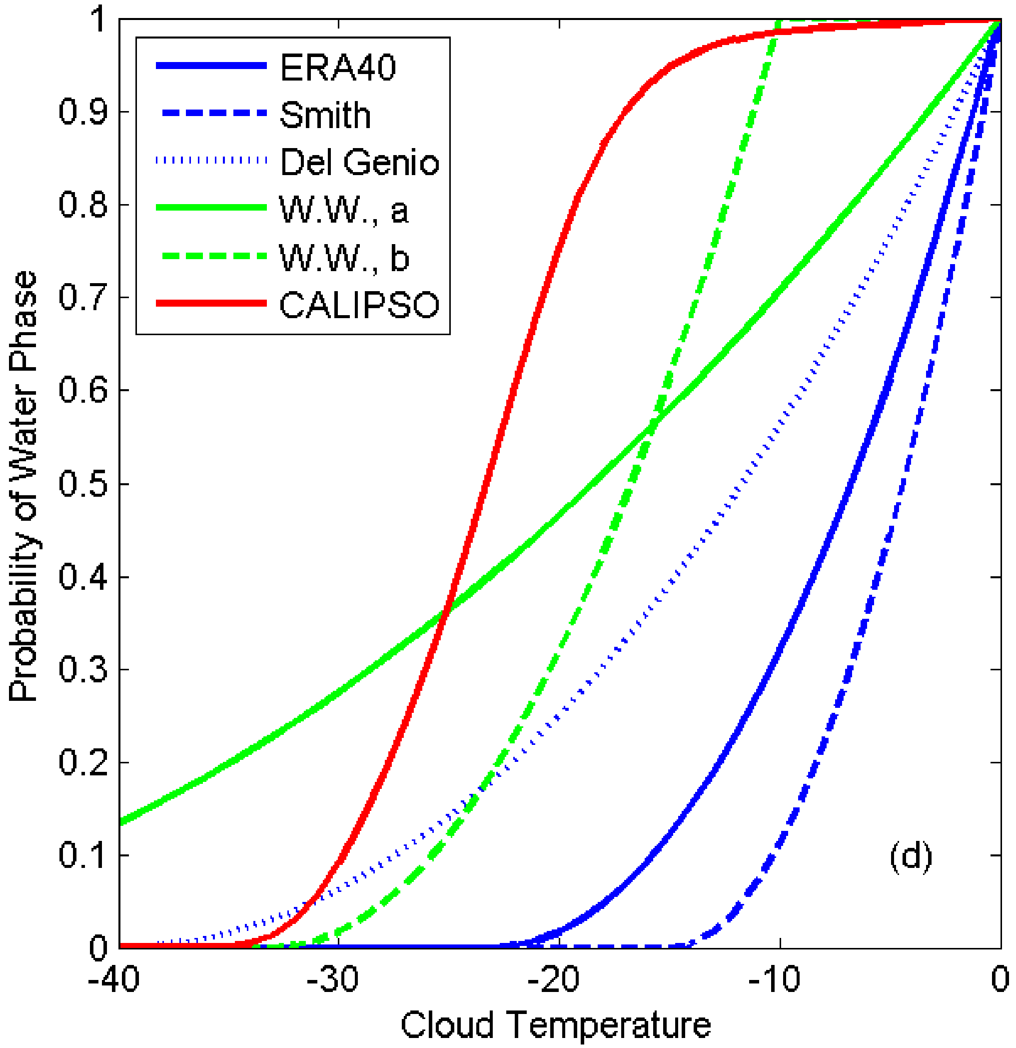
- **CALIPSO**: polarization change of backscattered laser light (ice: yes; water: no)

Supercooled water clouds from CALIPSO observation >> from existing models / observations

Red: CALIPSO cloud phase – temperature relation

Green: cloud phase – temperature relation from Polder

Blue: cloud phase – temperature relation in varies models

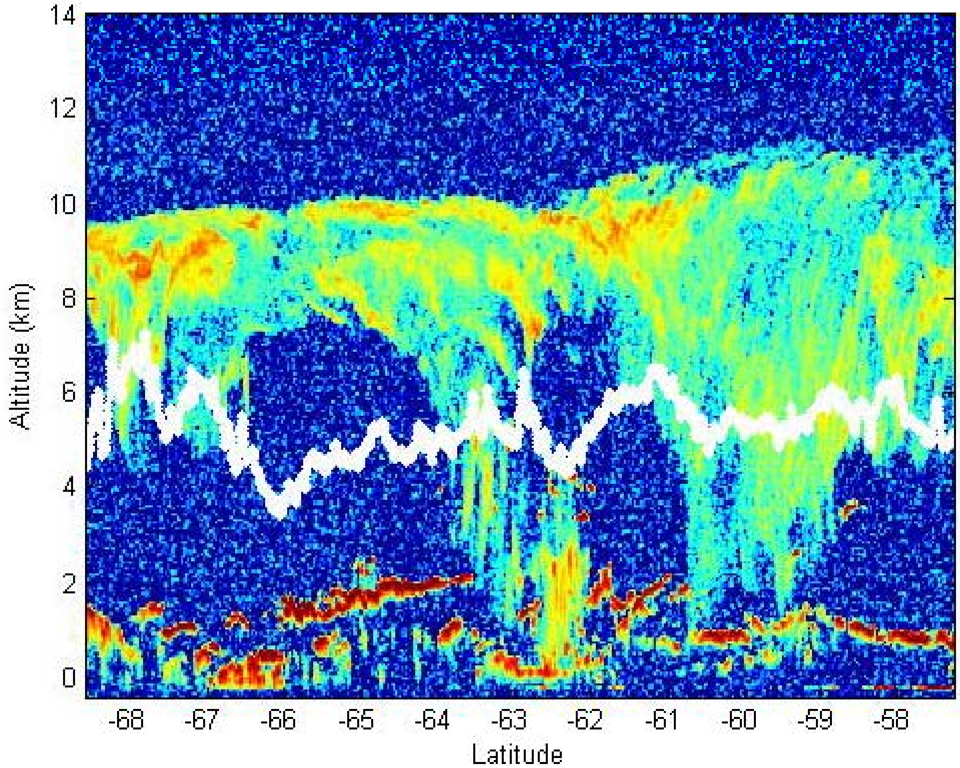


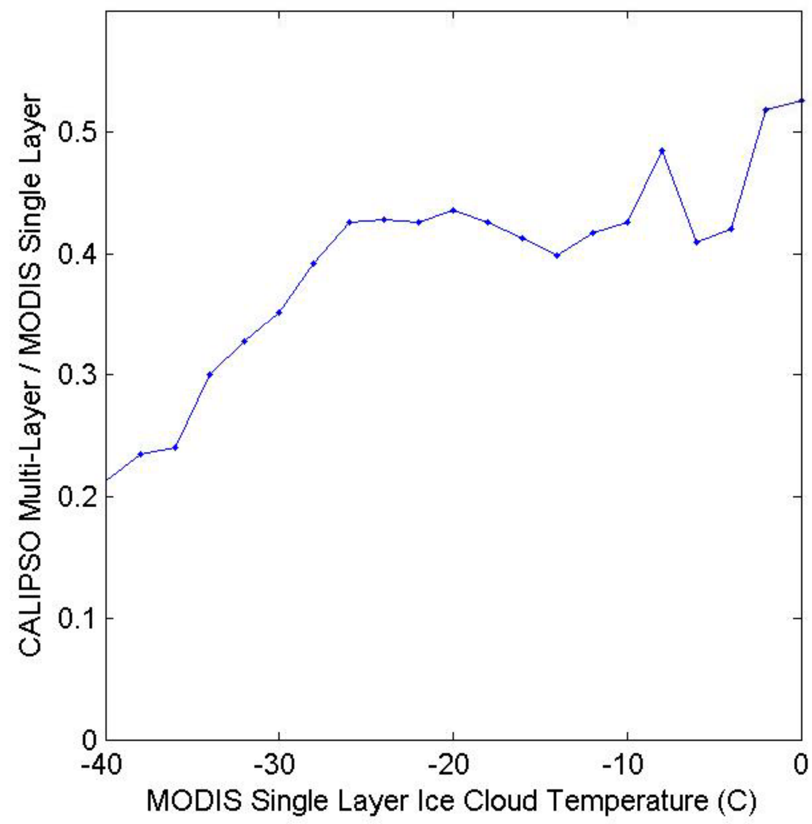
Hu et al. (2010, JGR): Occurrence, liquid water content, and fraction of supercooled water clouds from combined CALIPSO/IIR/MODIS measurements

Multi-layered clouds cause problems in cloud phase discrimination for passive sensing

CALIPSO thin/cold ice over thick/warm water = MODIS thick middle level ice cloud and thus over-estimate of warm ice cloud by passive sensors

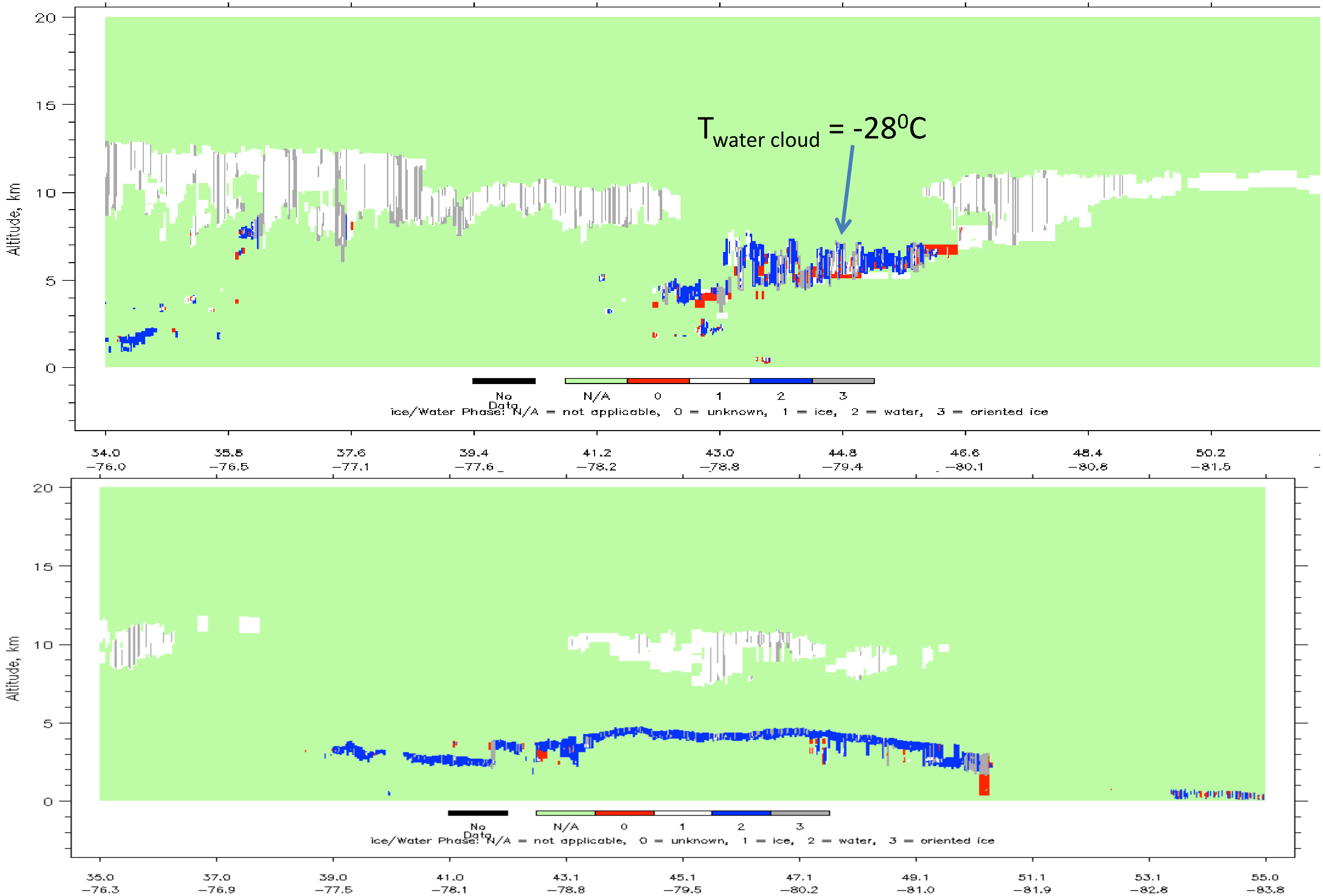
White line: MODIS cloud height



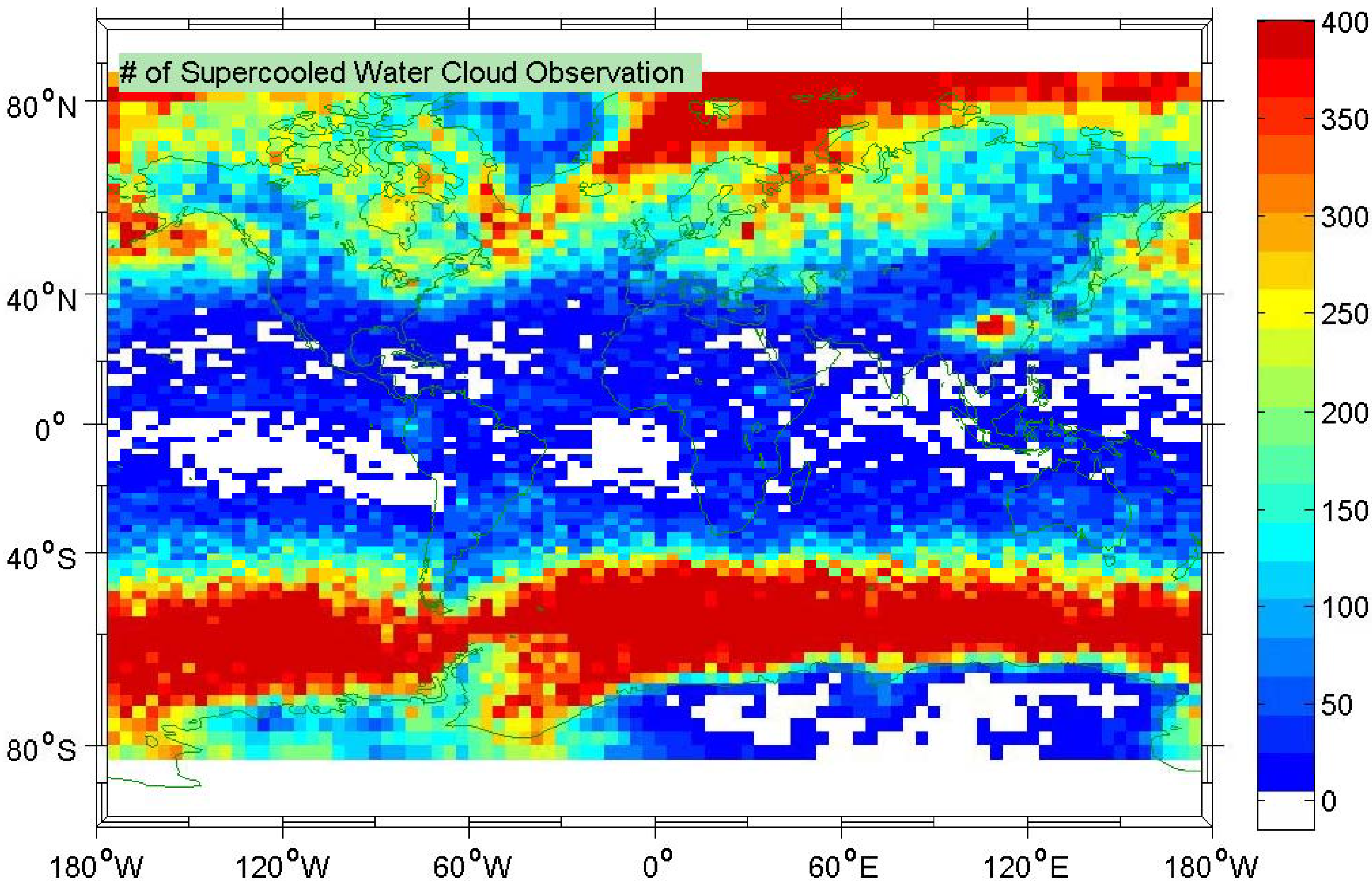


Aircraft measurements confirms CALIPSO phase

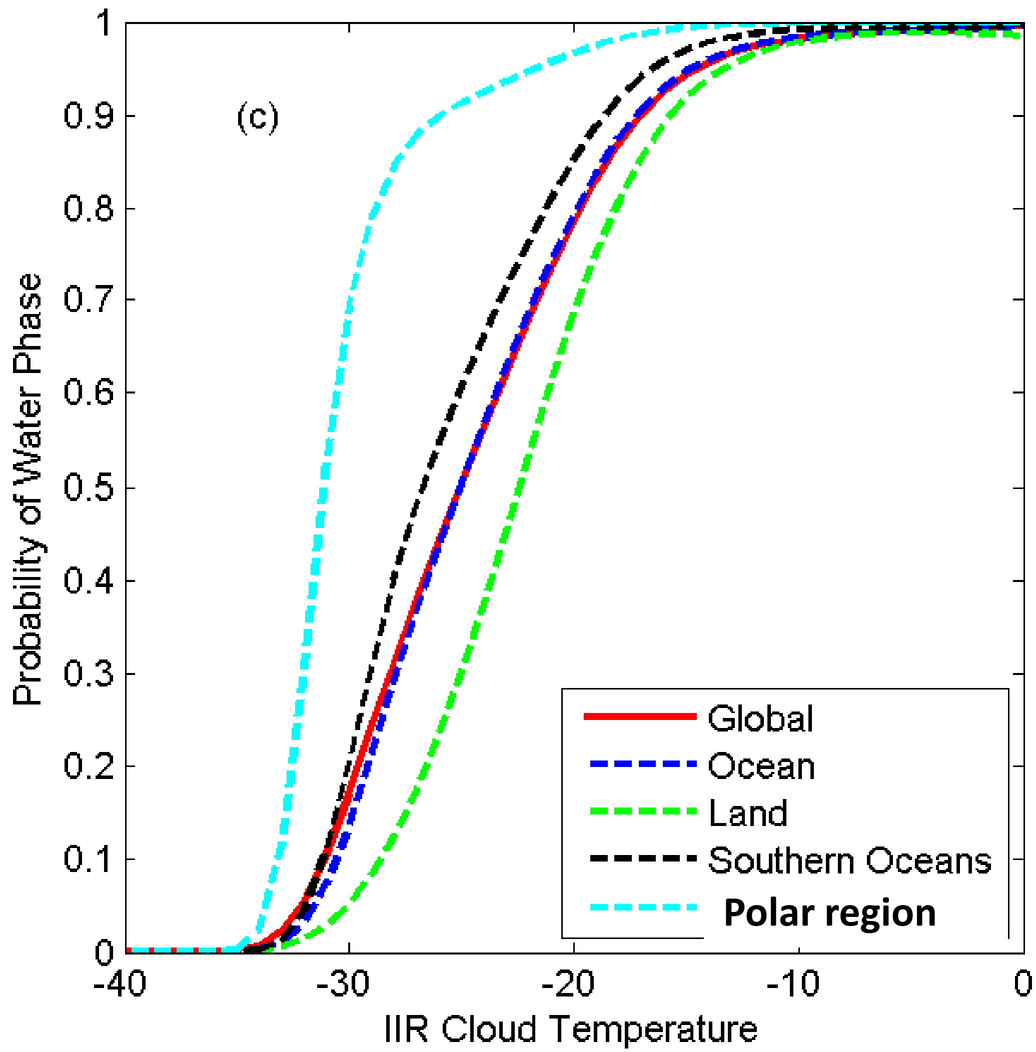
[Noh, Y.-J., C. Seaman, T. H. Vonder Haar, D. R. Hudak, and P. Rodriguez (2011), Comparisons And Analyses Of Aircraft And Satellite Observations For Wintertime Mixed-Phase Clouds, *J. Geophys. Res.*, doi:10.1029/2010JD015420]



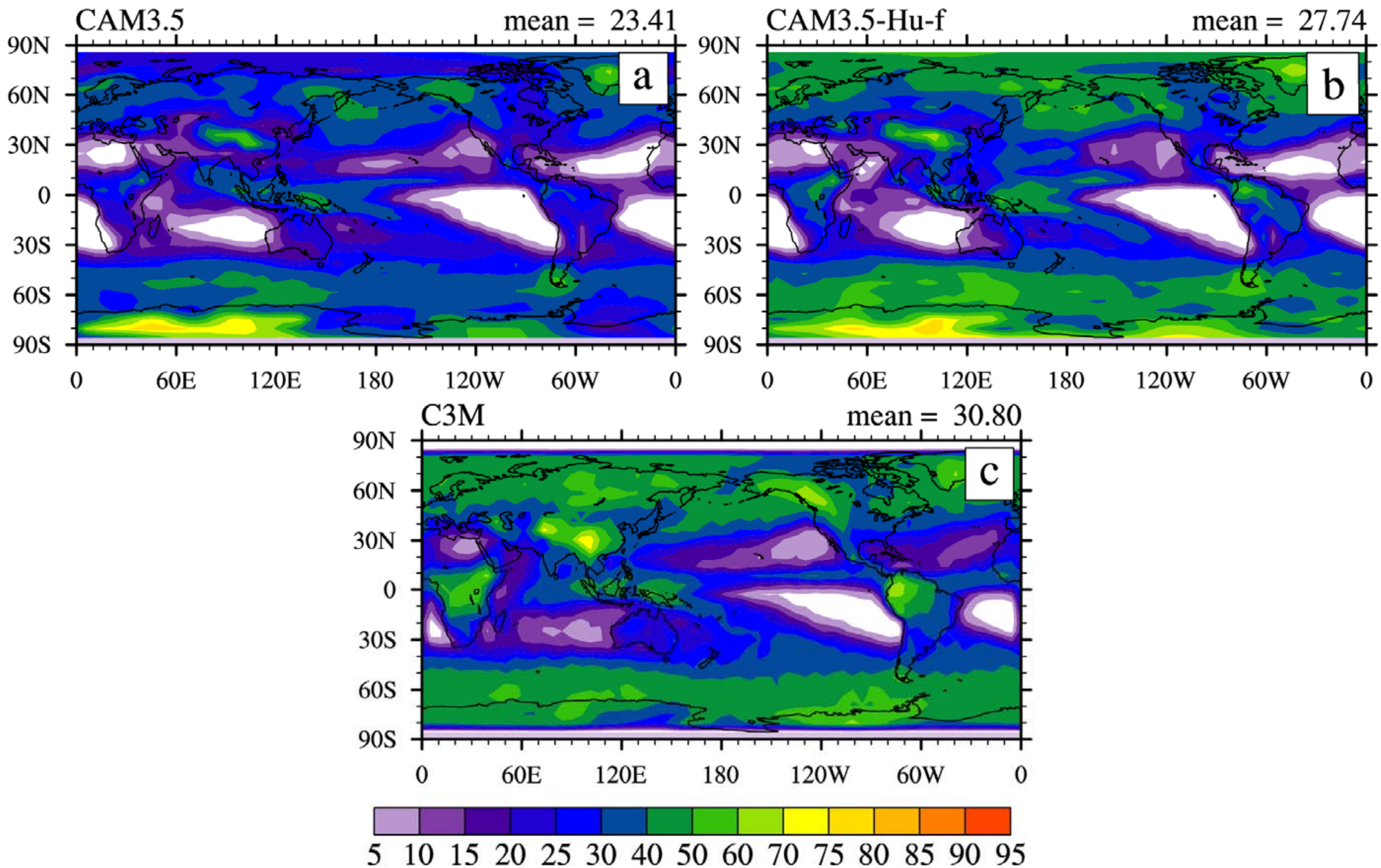
Spatial distribution of supercooled water clouds



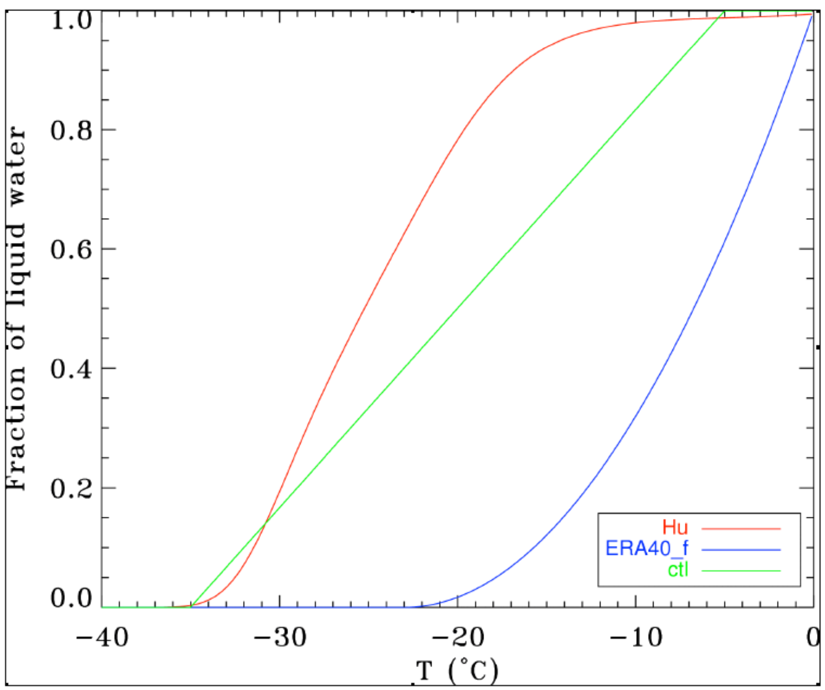
Spatial distribution of supercooled water clouds: lack of ice nuclei (dust and biological particles) at Southern oceans and polar region

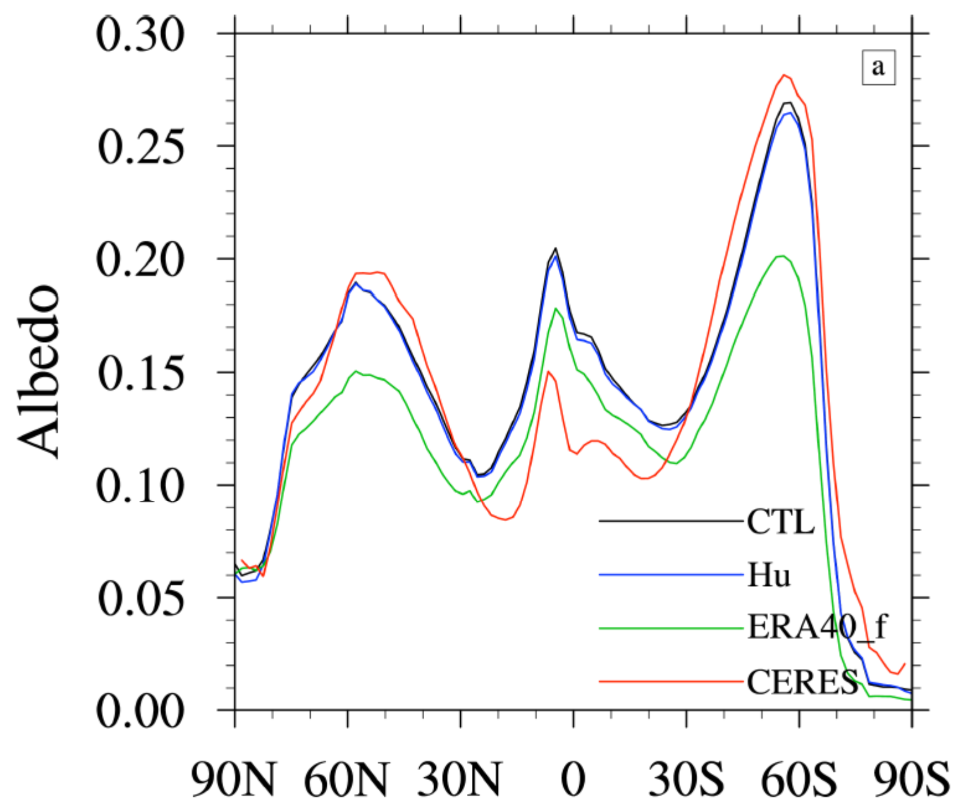


Impact on GCMs: (a) mid-level cloud fraction NCAR CAM3.5; (b) CAM3.5 with cloud phase – temperature relation from Hu et al. 2010; (c) cloud fraction from CALIPSO/CloudSat



Cloud phase – temperature relation affect global distribution of cloud albedo in GCMs





Increased supercooled water → higher albedo at storm track→ high climate sensitivity

(Tsushima et al., Climate Dynamics, DOI 10.1007/s00382-006-0127-7, 2006)

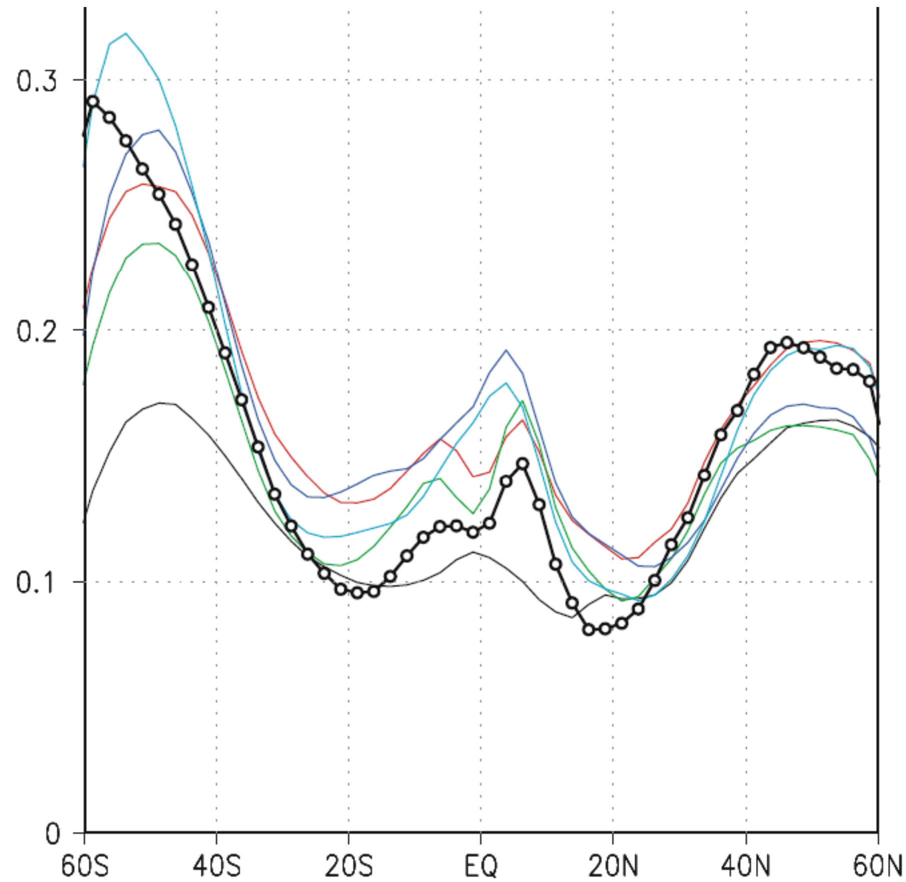


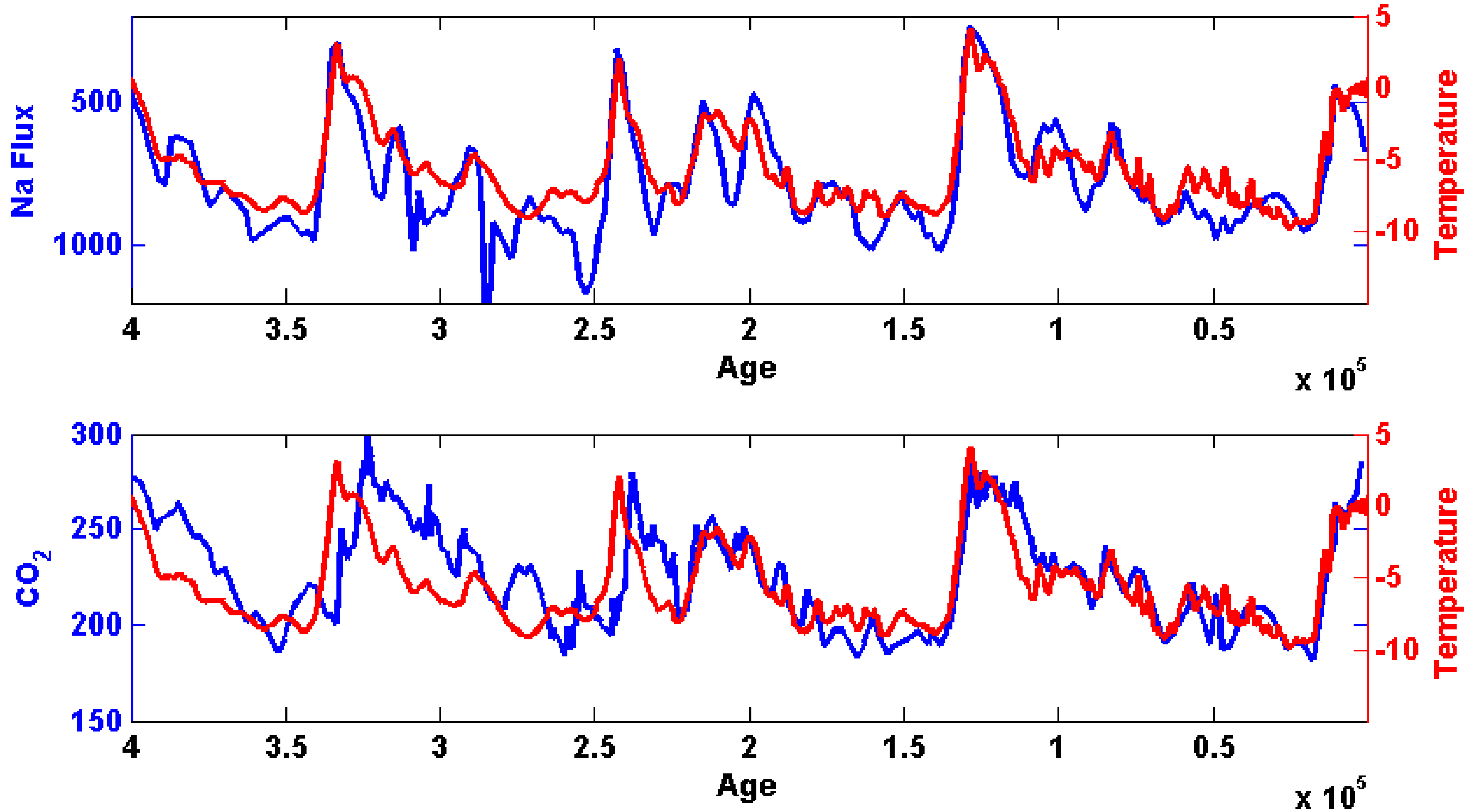
Fig. 4 Zonally averaged annual mean cloud albedo forcing. *Thin lines* are for models (*black*: UIUC, *red*: GFDL, *green*: HadSM4, *blue*: "MIROC low", *light blue*: "MIROC high"). *Line with circle mark* is observation

Climate sensitivity and clouds in storm track

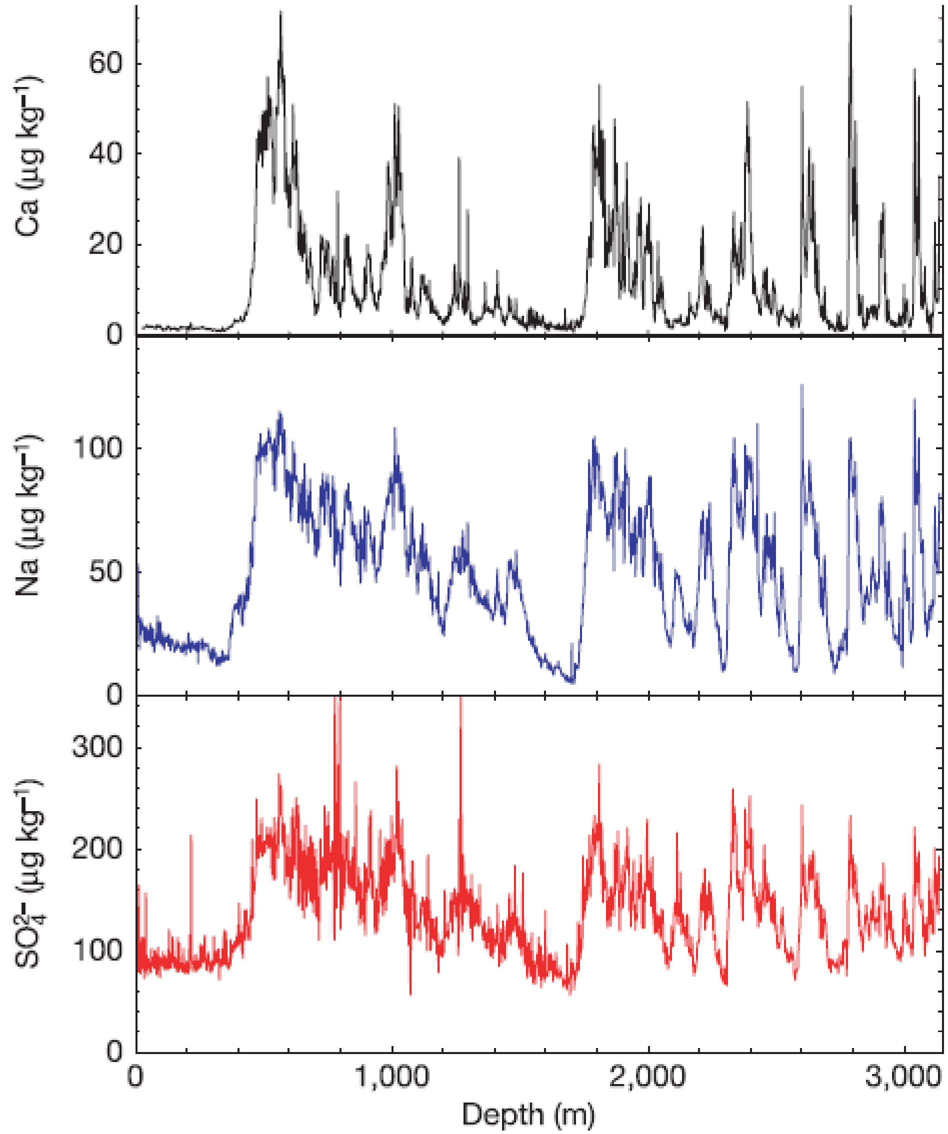
- Positive feedbacks: CO_2 increase and temperature increase → reducing meridianal temperature gradient → reduction in baroclinic instability → reducing clouds in storm track and sea surface wind → reduction of global albedo, air-sea turbulence exchange and biological pump → more CO_2 increase and temperature increase

- Current reanalysis and climate models under-estimate middle level and low level clouds at storm track, and underestimate the positive feedback and climate sensitivity

Warmer planet, lower high latitude wind



Warmer planet, lower high latitude wind,
and, reduced high latitude ocean productivity and DMS

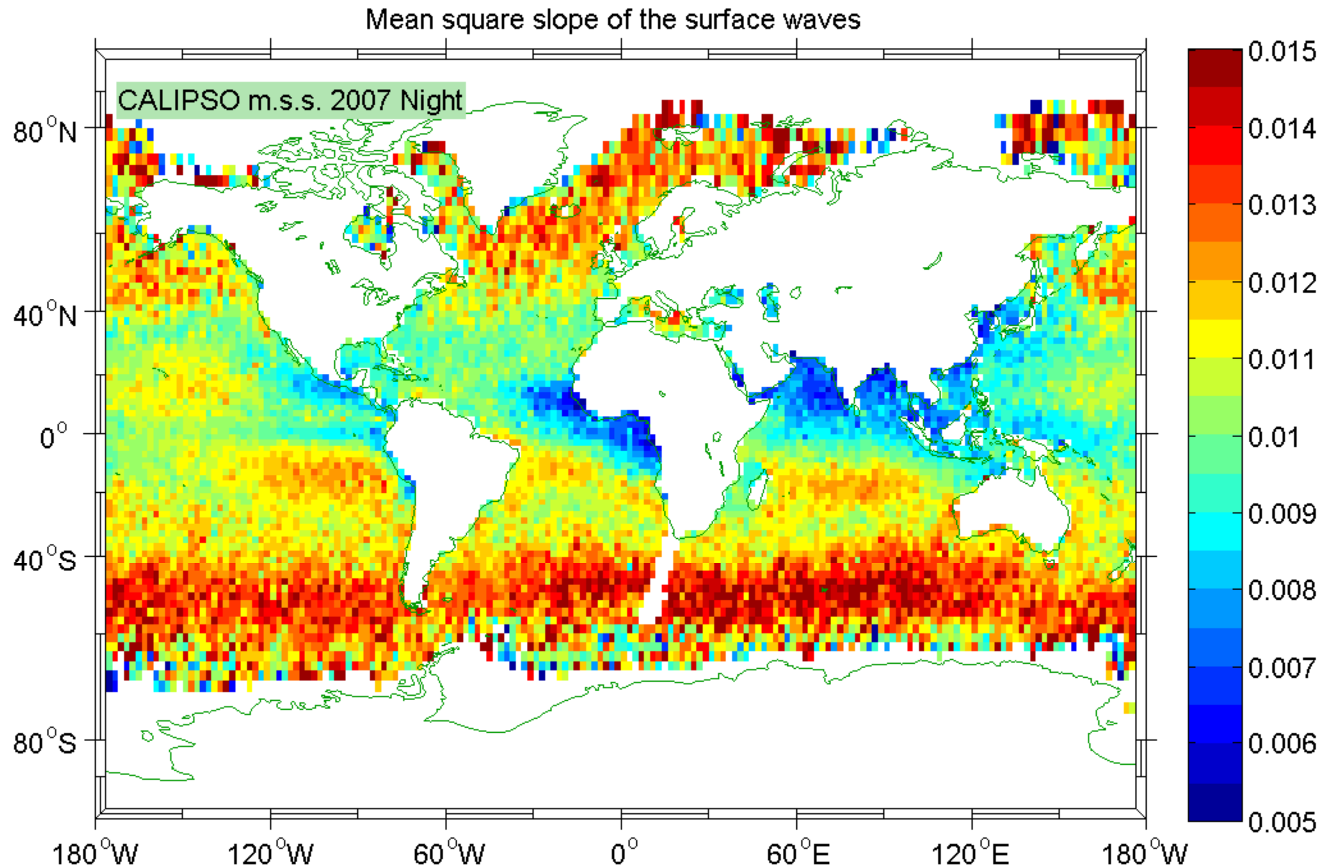


(Wolff et al., 2006, Nature, Vol 440|23 March 2006|doi:10.1038/nature04614)

Do we see the the feedbacks at shorter time scales from A-train measurements?

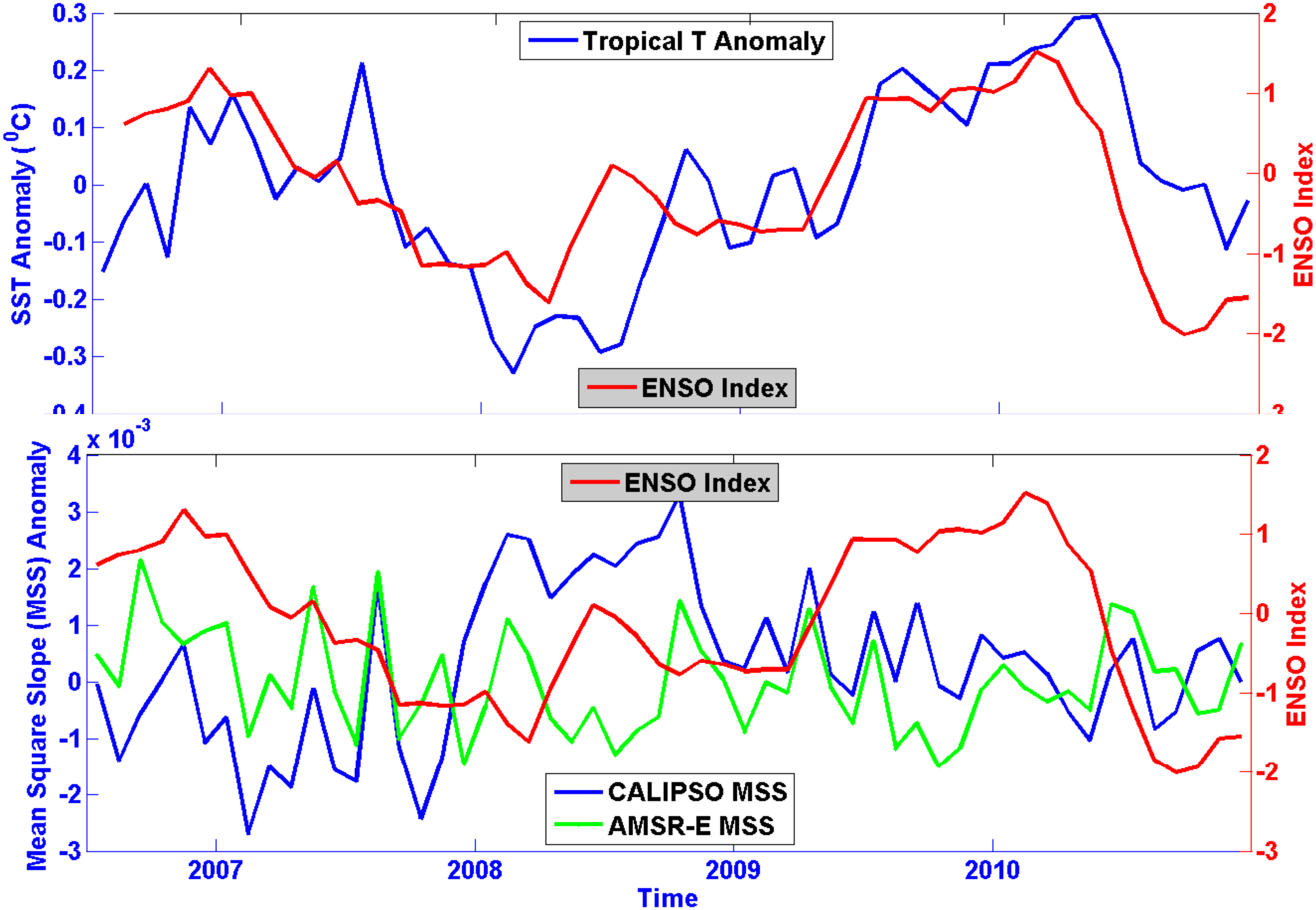
CALIPSO accurately measures surface mean square wave slope <S²> (wind):

Ocean Surface Backscatter $\gamma = C^* [\sec^4\theta / \langle S^2 \rangle \exp(-0.5 \tan^2\theta / \langle S^2 \rangle] = C / \langle S^2 \rangle$



Shorter temporal scale of storm track cloud dynamics feedback?

Anti-correlation of SST and high latitude wind from AMSR-E CALIPSO



Summary

1. CALIPSO cloud phase statistics suggest that there are a lot of supercooled liquid water in storm track clouds, possibly due to lack of ice nuclei (dust, pollen, …)

2. The potential lack of heteorogeneous ice nucleation at storm track is likely why CALIPSO/CloudSat saw a lot more middle level clouds than cloud, weather and climate models

3. Impact on climate sensitivity: observations such as ACE and extended A-train data record are needed to reduce uncertainty in modeling of climate sensitivity and feedback mechanism (temperature increase due to CO_2 increase, reduced meridianal temperature gradient, reduced baroclinicity and surface wind at storm track, reduced high latitude air-sea turbulence exchange speed and biological bump, reduced cloud albedo and increased CO_2)