Cloud susceptibility from MODIS Level-3 daily cloud products

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Susceptibility and relative susceptibility

$$S_\lambda = \frac{dR_\lambda(\tau_\lambda, g_\lambda, \tilde{\omega}_\lambda)}{dN} = \frac{\partial R_\lambda}{\partial \tau_\lambda}\frac{d\tau_\lambda}{dr_e}\frac{dr_e}{dN} + \frac{\partial R_\lambda}{\partial g_\lambda}\frac{dg_\lambda}{dr_e}\frac{dr_e}{dN} + \frac{\partial R_\lambda}{\partial \tilde{\omega}_\lambda}\frac{d\tilde{\omega}_\lambda}{dr_e}\frac{dr_e}{dN}$$

$$+ \quad - \quad - \qquad - \quad + \quad - \qquad + \quad - \quad -$$

From a BB RT code:

$$\Delta R = \frac{\sum_i w_i F_i^{\uparrow}\left(\tau_i + \Delta\tau_i, g_i + \Delta g_i, \tilde{\omega}_i + \Delta\tilde{\omega}_i\right)}{\mu_0 F_e^{\downarrow}} - \frac{\sum_i w_i F_i^{\uparrow}\left(\tau_i, g_i, \tilde{\omega}_i\right)}{\mu_0 F_e^{\downarrow}}$$

Where $\Delta\tau$, Δg, $\Delta\tilde{\omega}$ are due to Δr_e (< 0) changes arising from ΔN (> 0) changes under constant LWC:

$$N = \frac{3LWC}{4\rho_w \pi k^3 r_e^3} \Rightarrow \Delta r_e = r_e\left[1 - \left(\frac{N}{N + \Delta N}\right)^{1/3}\right] = r_e\left[1 - \left(\frac{1}{1 + \frac{\Delta N}{N}}\right)\right]^{1/3} \Rightarrow \frac{\Delta r_e}{r_e} \approx -\frac{1}{3}\frac{\Delta N}{N}$$

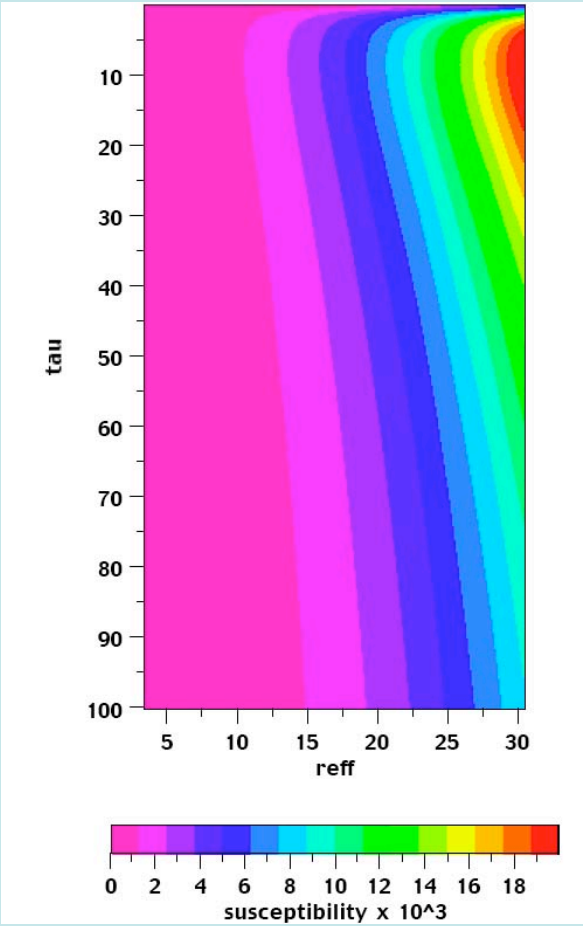
Δr_e determined by specifying either:

(1) absolute change in N, ΔN (e.g., 1 cm^{-3}) $\longrightarrow$ susceptibility

(2) relative change in N, $\Delta N/N$ (e.g., 10%) $\longrightarrow$ relative susceptibility

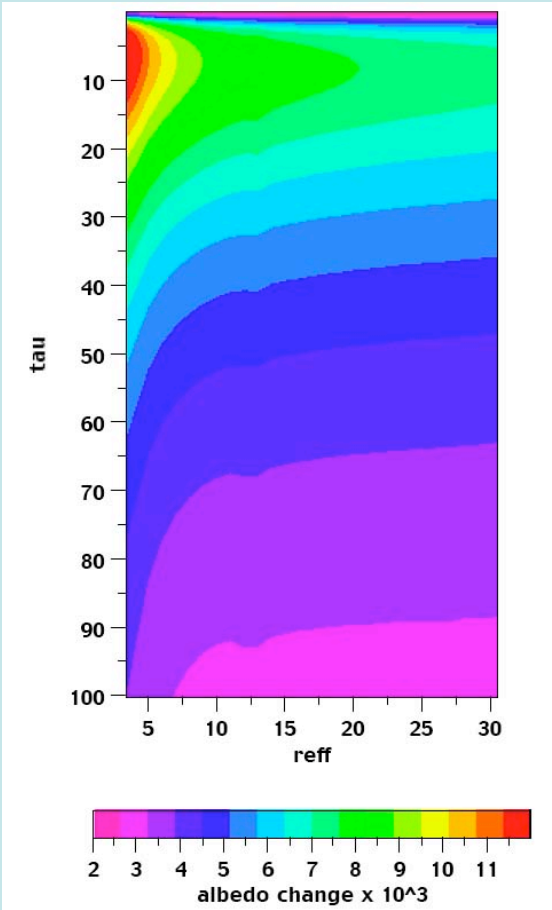
Theoretical calculations (no atmosphere or surface)

Susceptibility ΔN=1 cm^{-3}



$$\Delta R \approx \frac{4\pi}{9LWC}\tau\frac{\partial R}{\partial \tau}k^3 r_e^3 \Delta N$$

Relative susceptibility $\Delta N/N$=10%



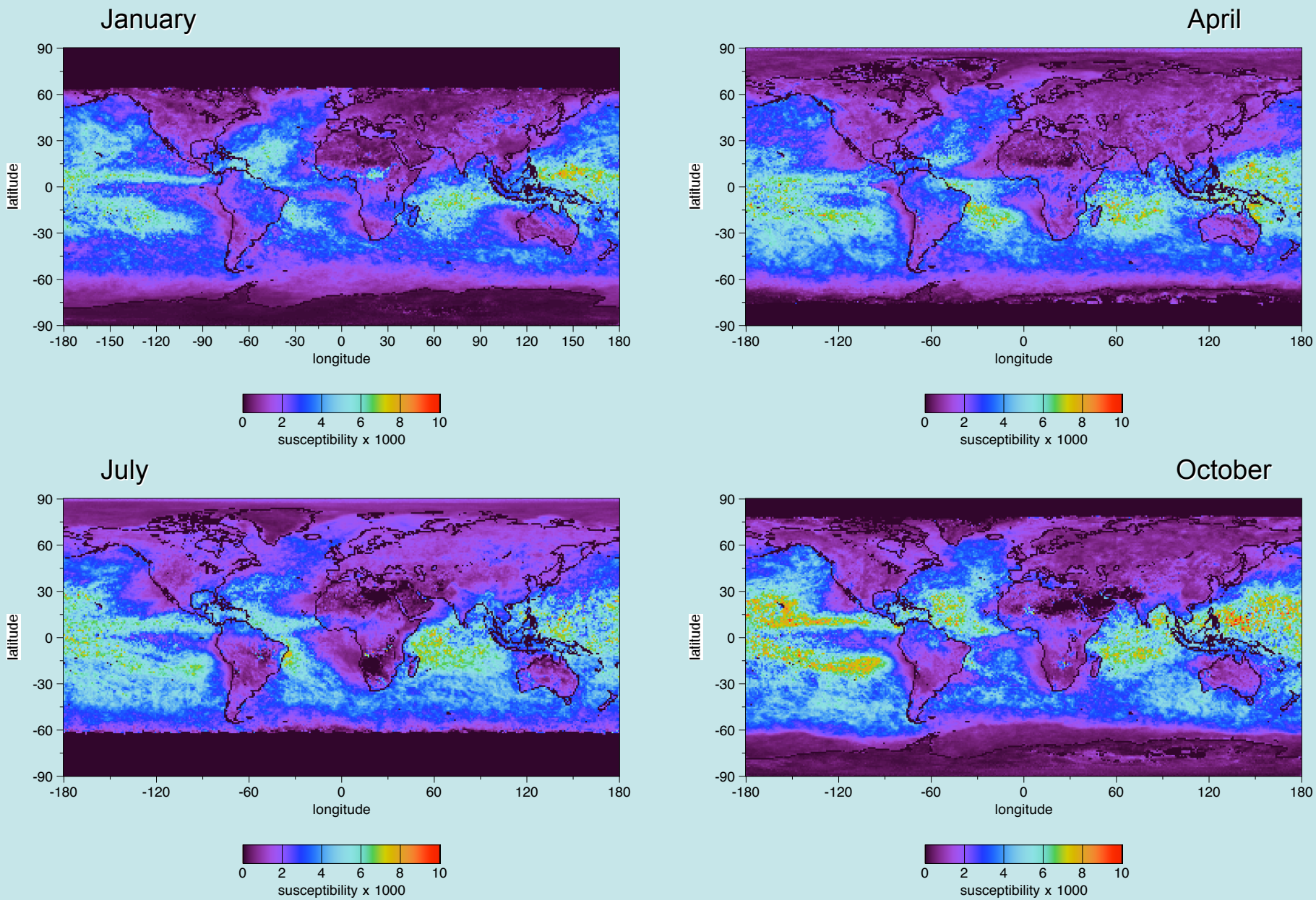
$$\Delta R \approx \frac{1}{3}\tau\frac{\partial R}{\partial \tau}\frac{\Delta N}{N}$$

SZA=60°

Susceptibility from MODIS

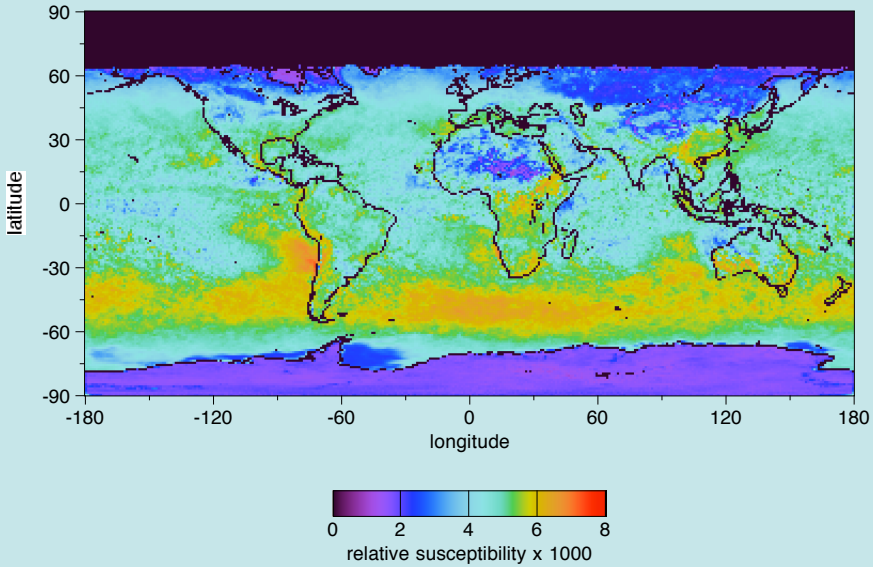
- D3 data provide means of τ and r_e and joint τ - r_e histograms at 1°
- Either can be used to calculate broadband unperturbed and perturbed (due to Δr_e changes) albedos; their difference is susceptibility
- The albedo is obtained with the aid of a modified version of the BB SW RT code by Chou et al.
- Atmospheric and surface effects, consistent with retrievals, are included
- Daily susceptibility values are averaged to monthly scales
- Susceptibility has been calculated for four months (January, April, July, October 2005) of Collection 5 Terra and Aqua liquid cloud data
- Here we show results only from joint τ - r_e histograms

Susceptibility ΔN=1 cm^{-3}, LWC=0.3 gm^{-3}, Terra

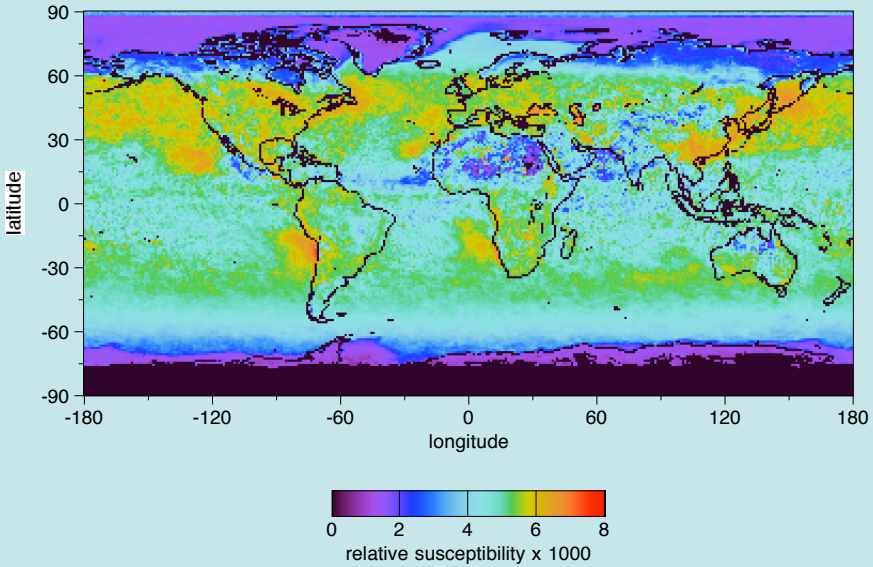


Relative susceptibility ΔN=10%, Terra

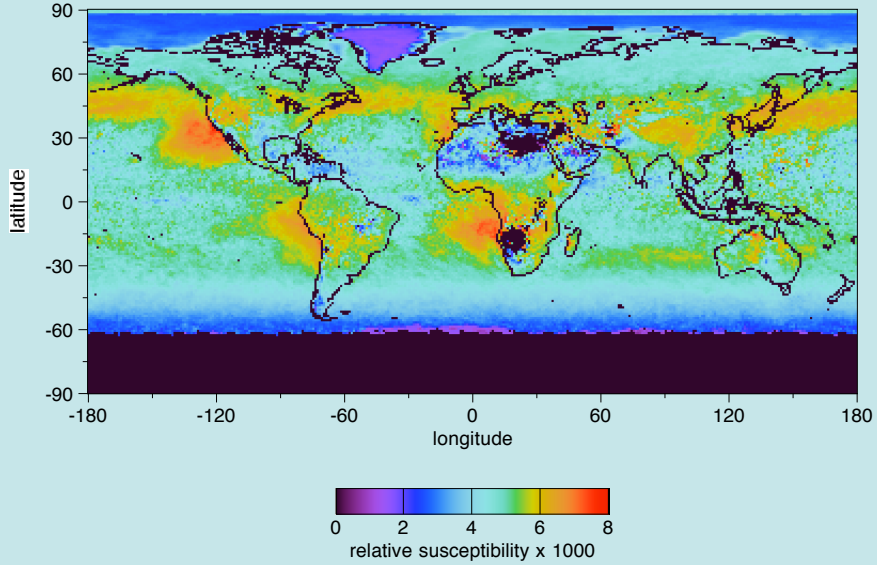
January



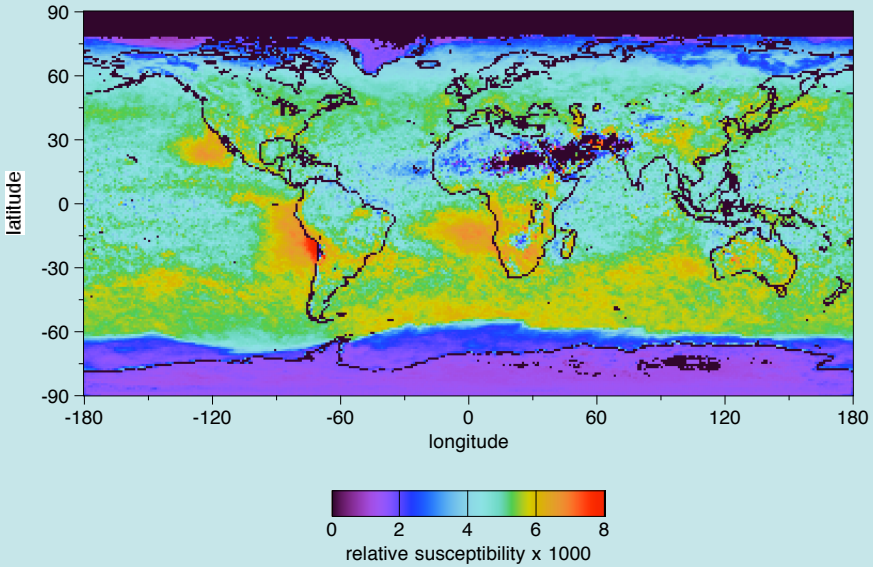
April



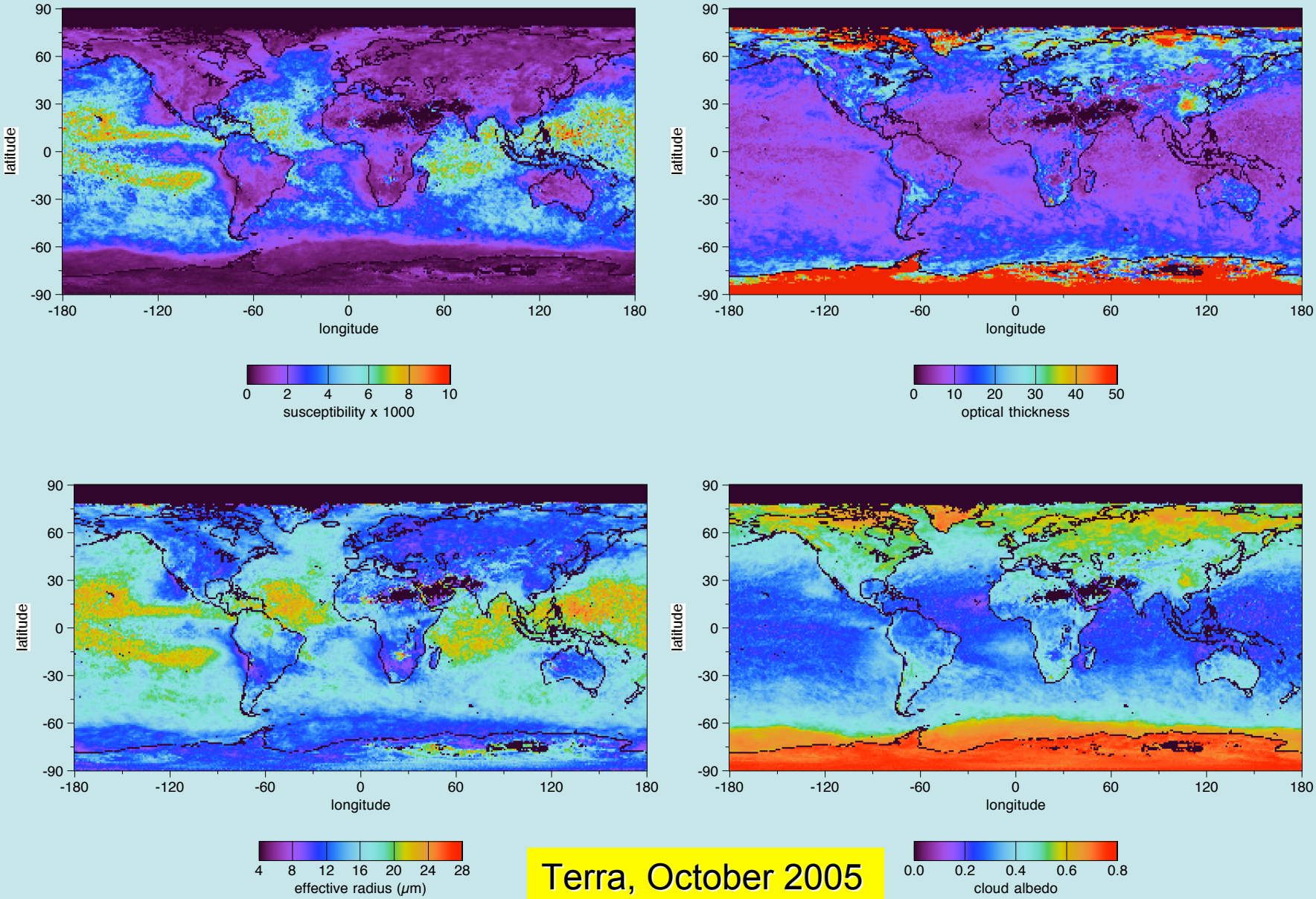
July



October

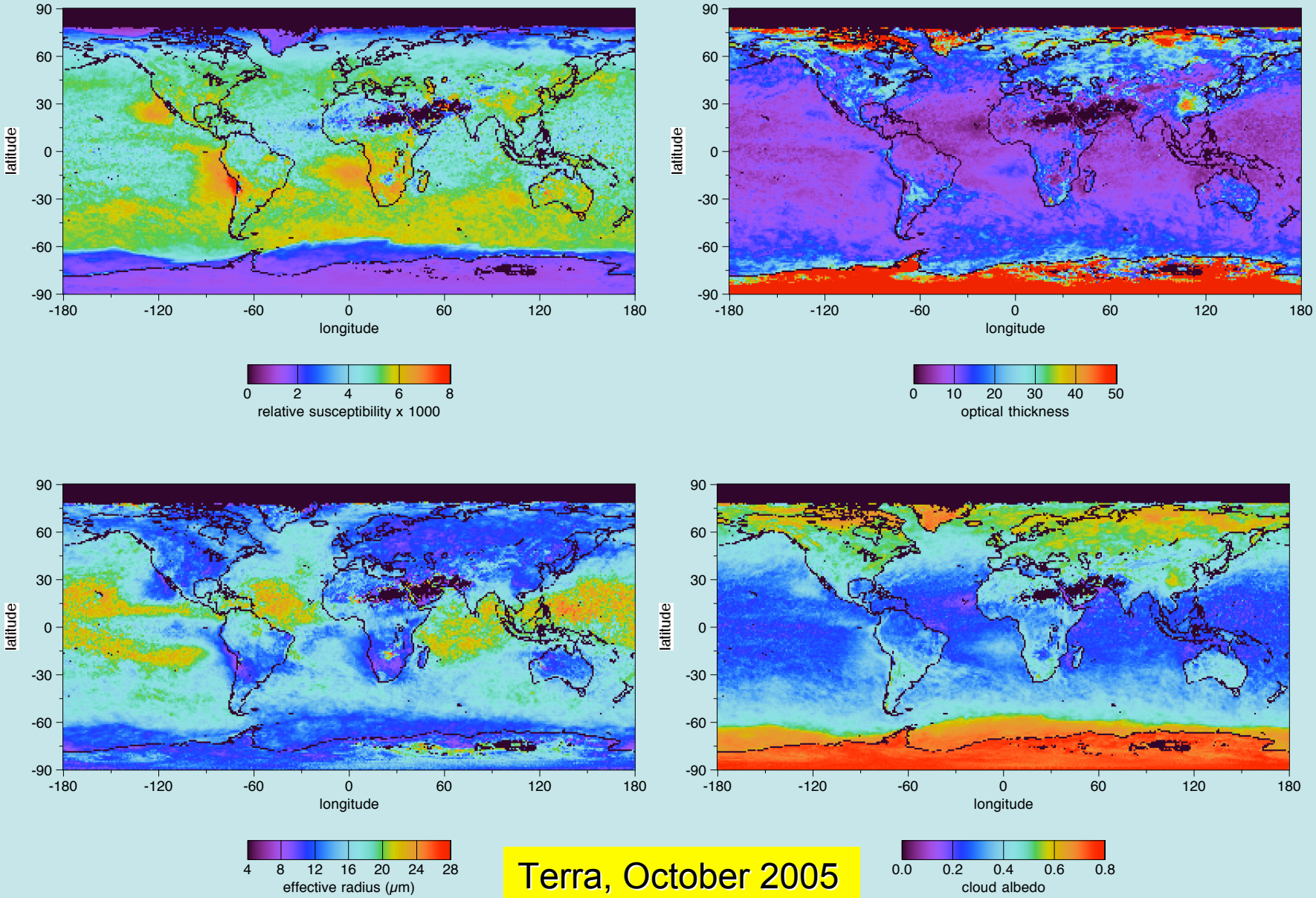


Susceptibility correlates with effective radius



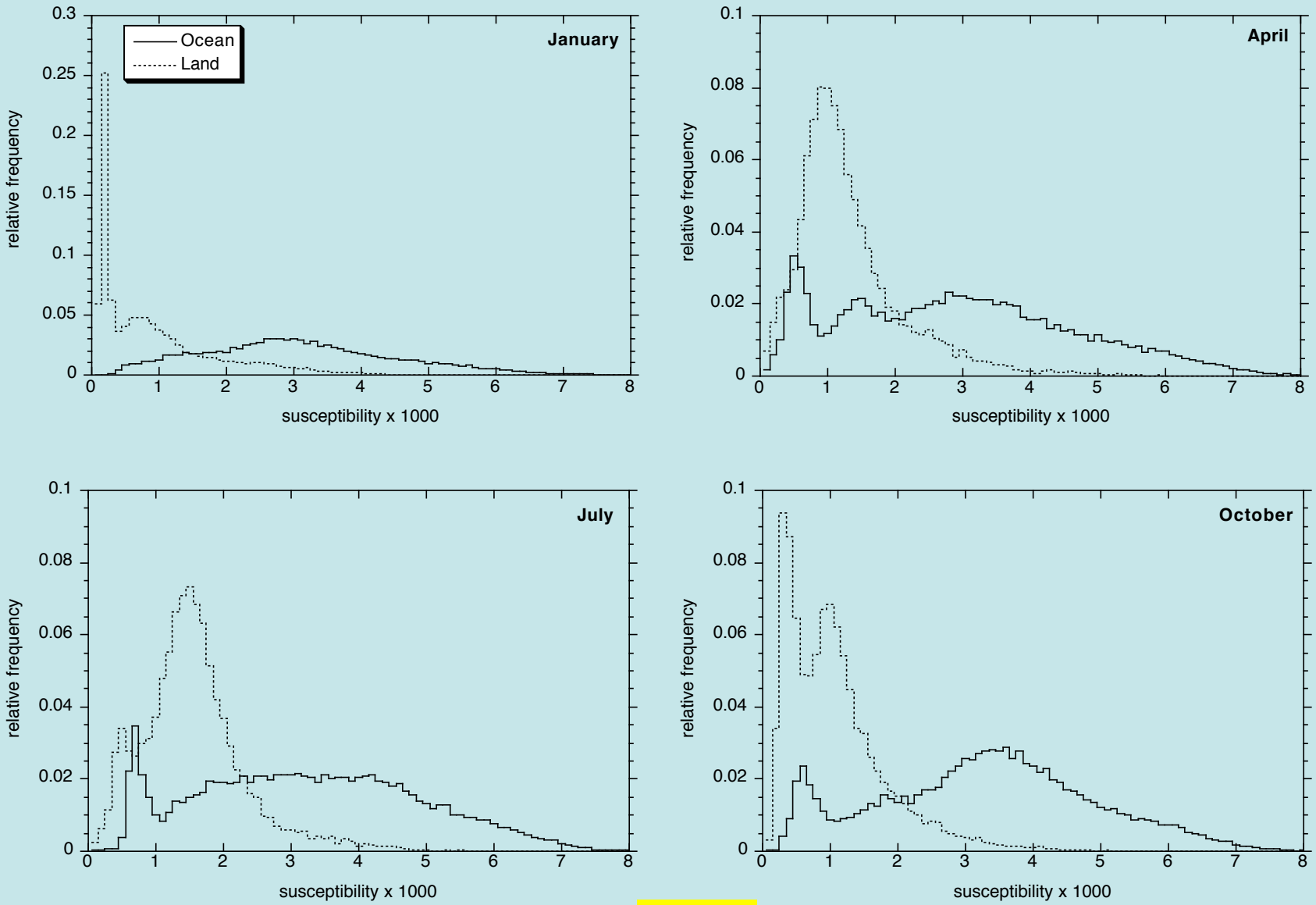
Terra, October 2005

Relative suscept. correlates with intermediate albedos



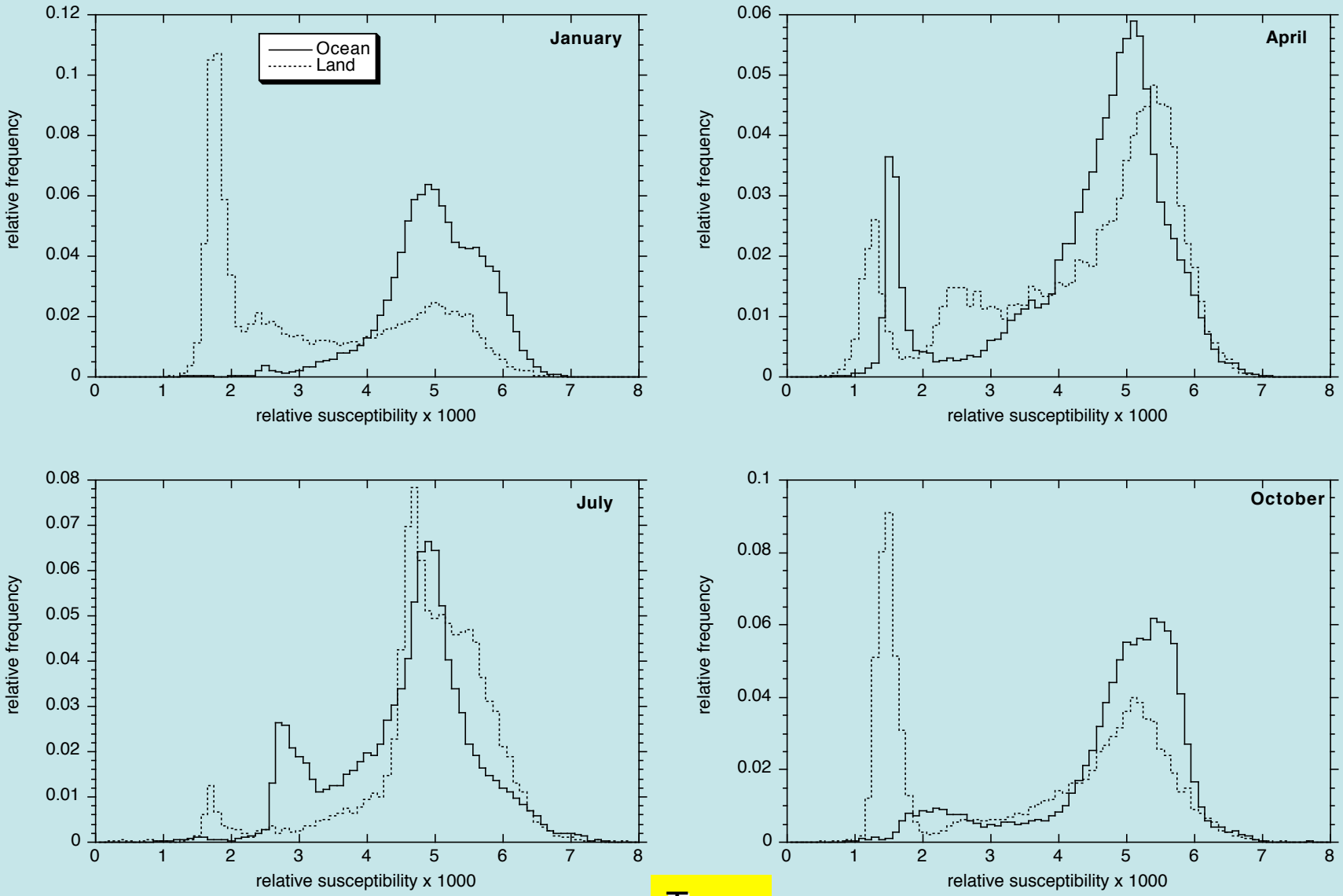
Terra, October 2005

Susceptibility for continental and marine clouds



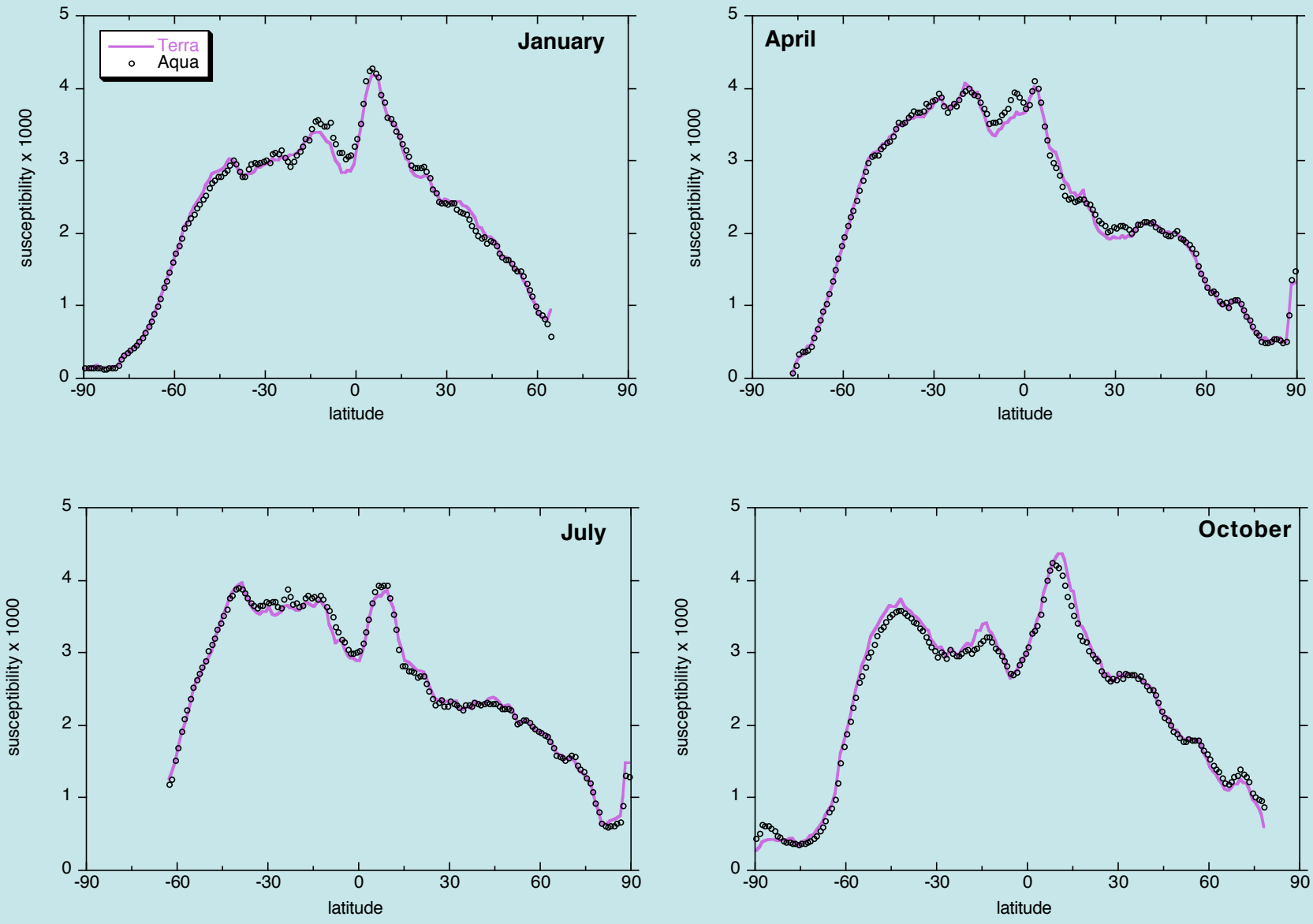
Terra

Relative suscept. for continental and marine clouds

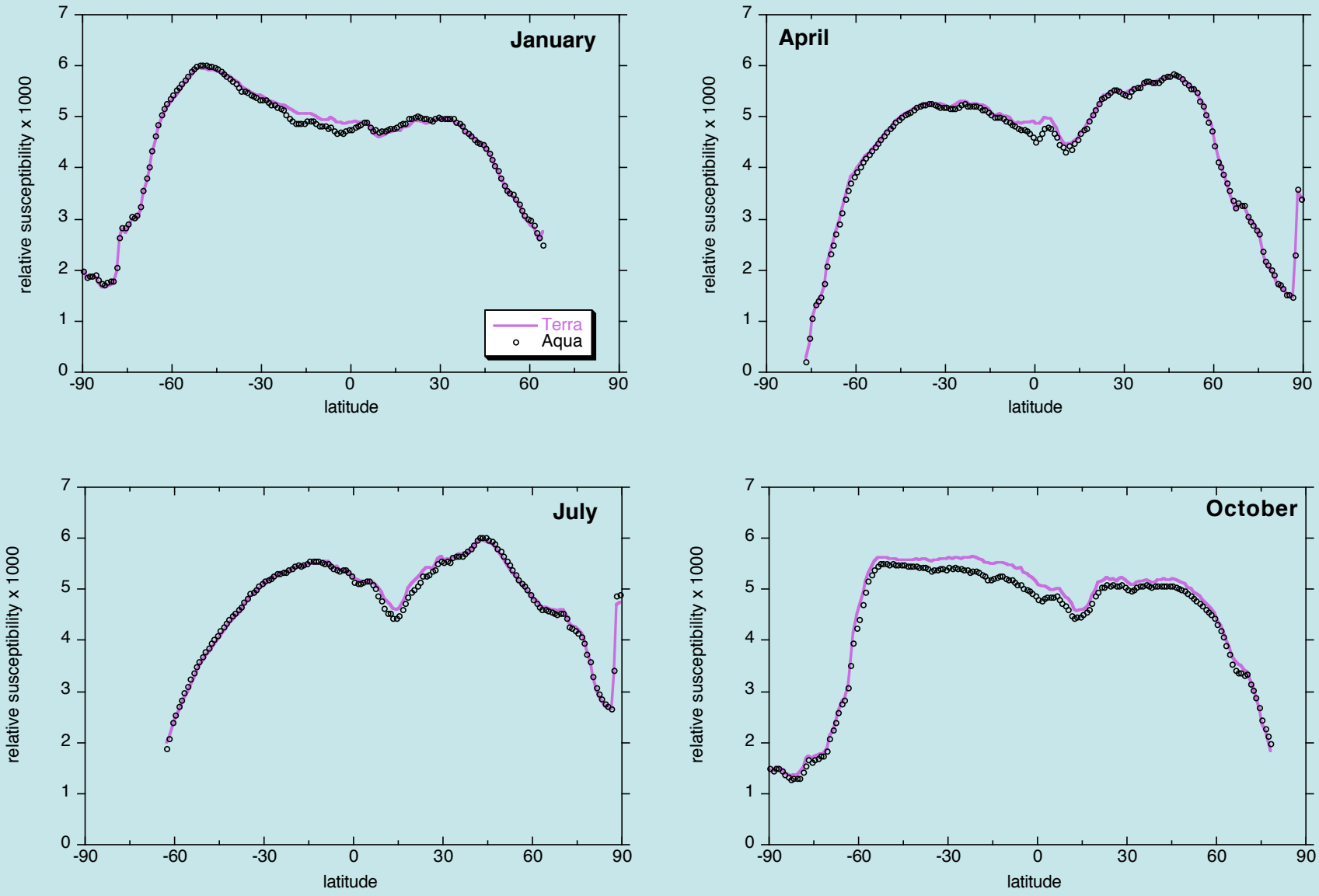


Terra

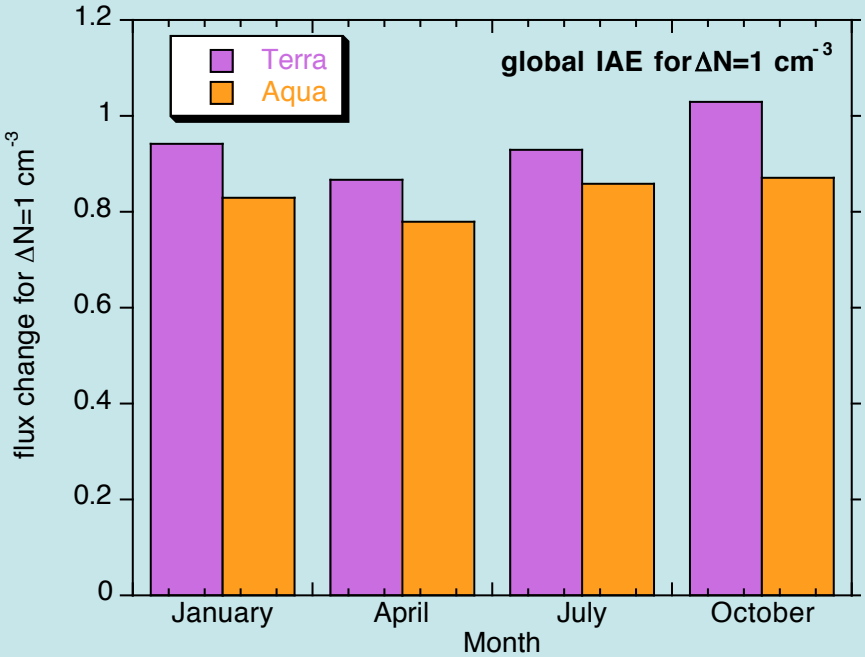
Susceptibility, Terra-Aqua zonal contrast



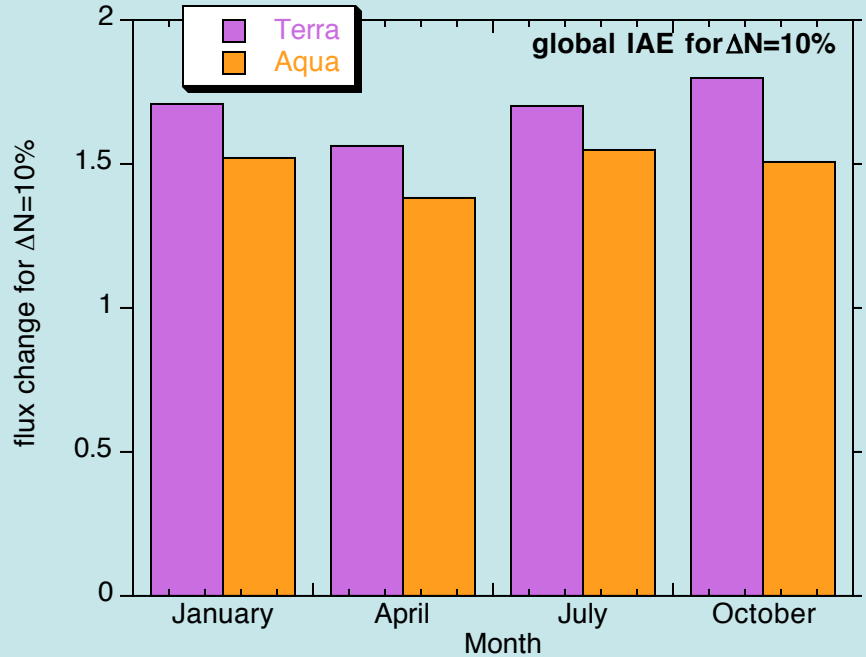
Relative susceptibility, Terra-Aqua zonal contrast



Examples of potential global IAE forcings



ΔN=1 cm^{-3}, LWC = 0.3 gm^{-3}



$\Delta N/N$ = 10%

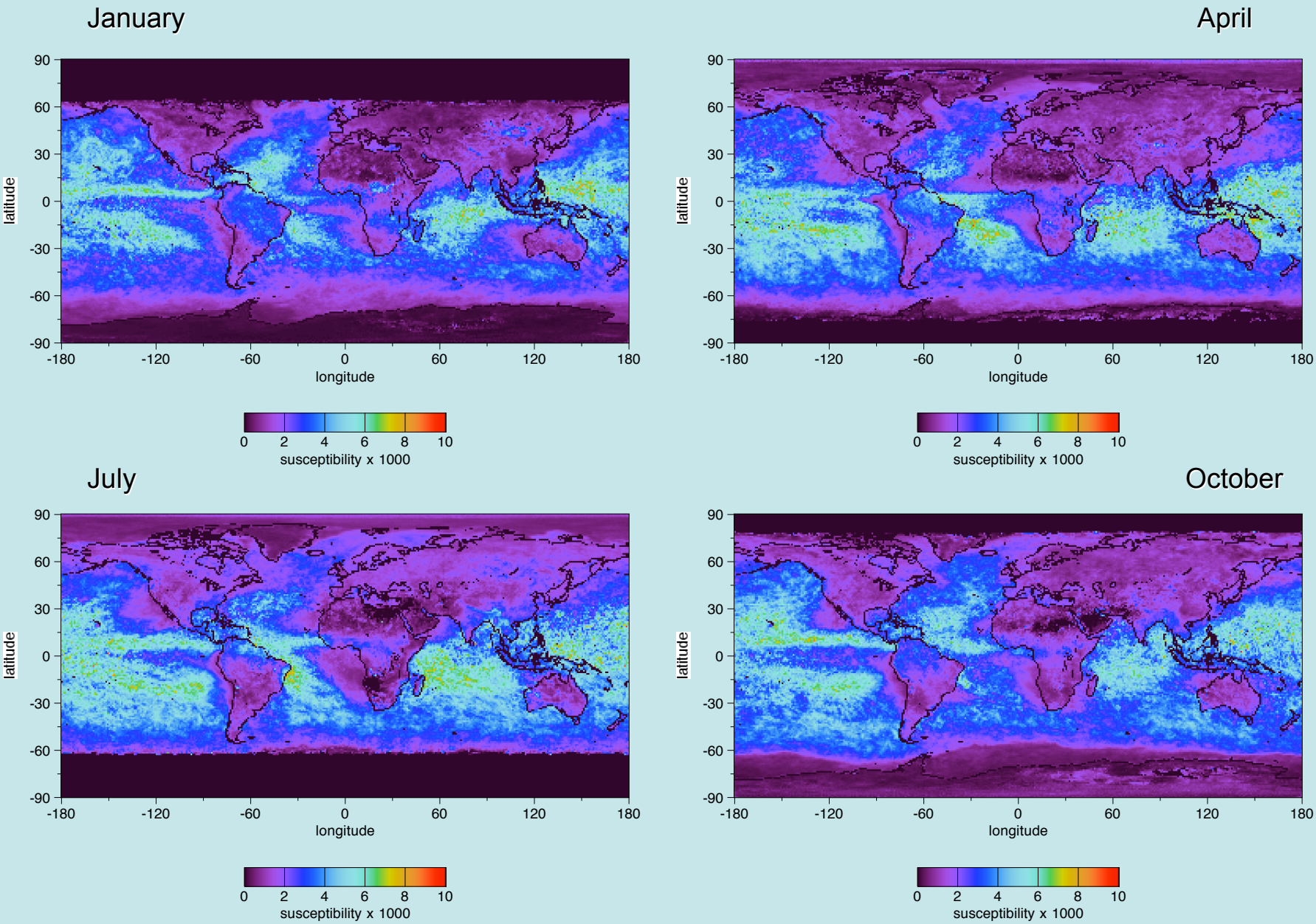
Susceptibility-cloud fraction relations are important!

Summary

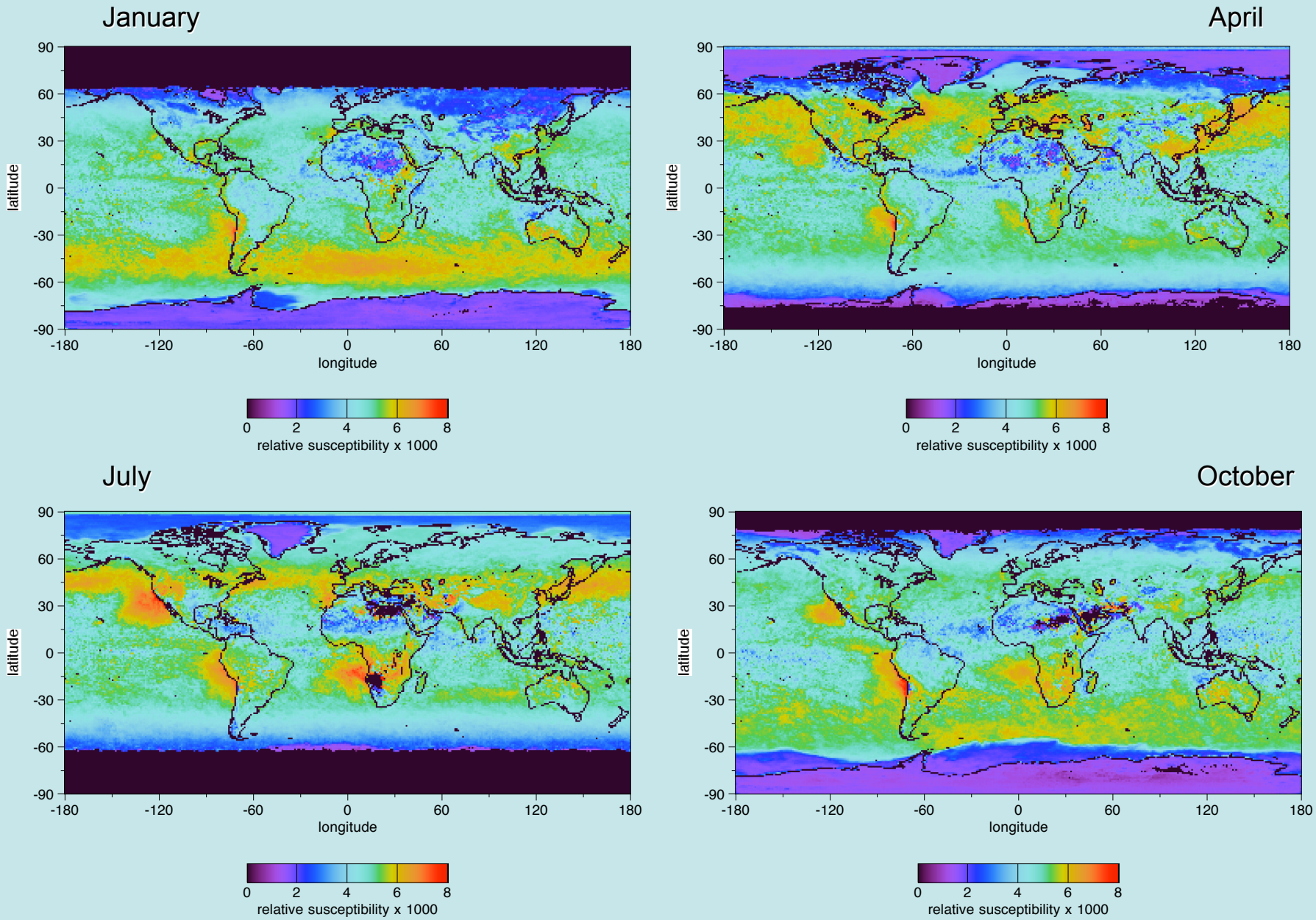
- Susceptibility is a useful concept for identifying regions prone to significant IAE radiative perturbations not only due to their proximity to pollution sources, but also due to the nature of the prevailing clouds under current climate conditions; it therefore provides an additional constraint in cloud modeling studies
- A global picture of liquid cloud susceptibility can be obtained from MODIS in a straightforward manner with the aid of some RT modeling
- Significant seasonal variations of susceptibility are observed, consistent with seasonal shifts in cloud patterns and properties
- As expected, marine clouds are more susceptible than continental clouds
- Morning-afternoon susceptibility differences are relatively small
- The current distribution of liquid cloud optical thickness and effective radius, as observed from MODIS, yields ~1.5 Wm^{-2} IAE for a uniform 10% increase in CDNC under constant LWC conditions

Additional Slides

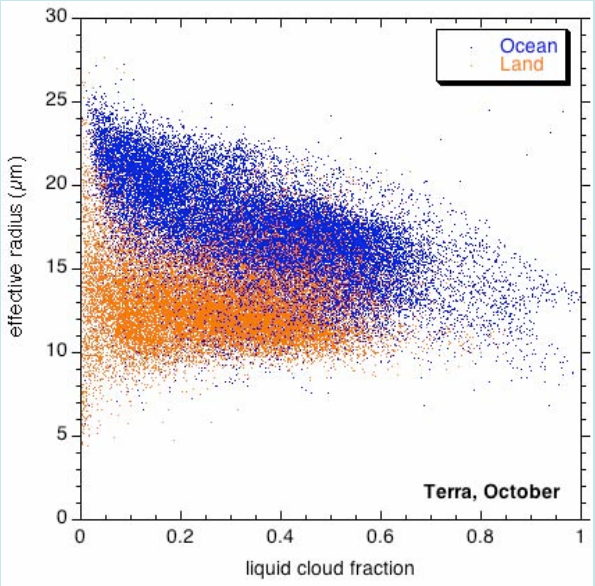
Susceptibility ΔN=1 cm^{-3}, LWC=0.3 gm^{-3}, Aqua

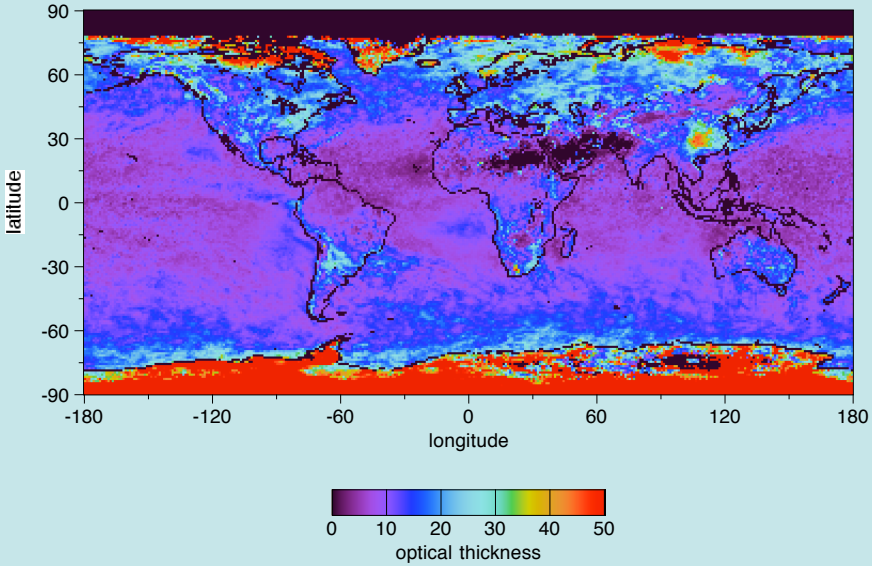


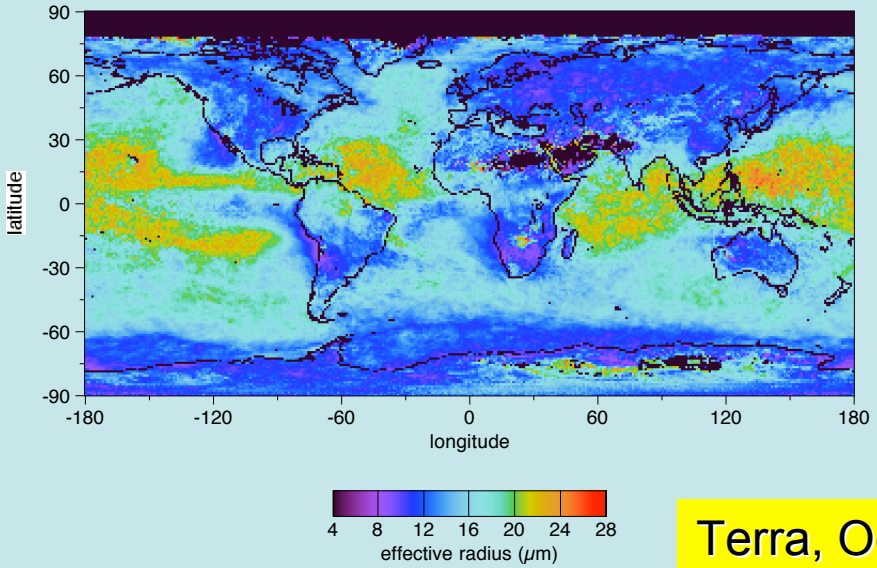
Relative susceptibility ΔN=10%, Aqua

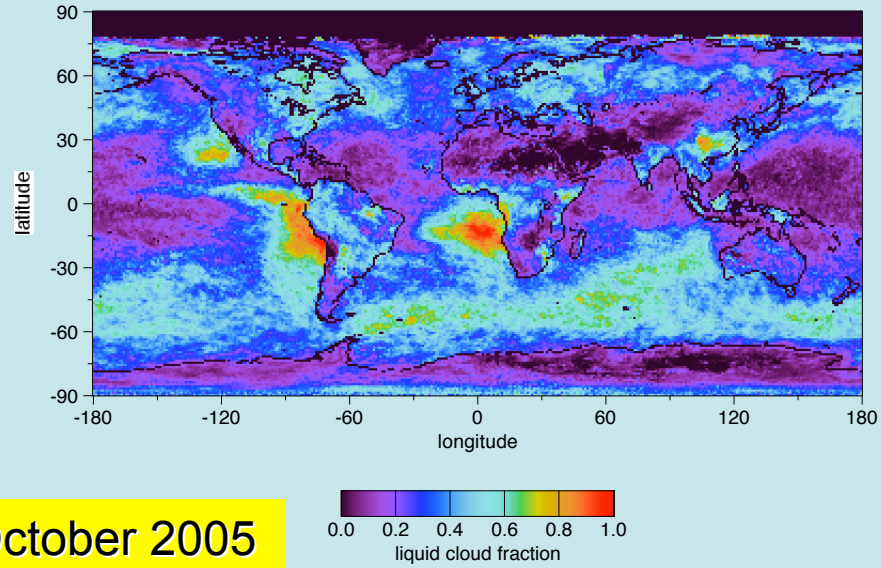


The impact of cloud fraction



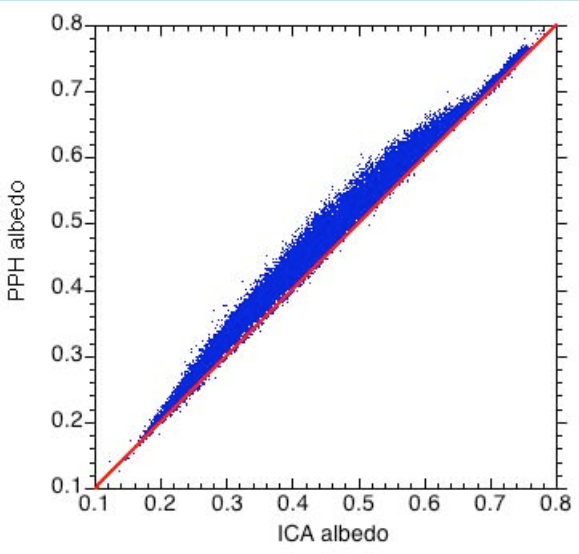


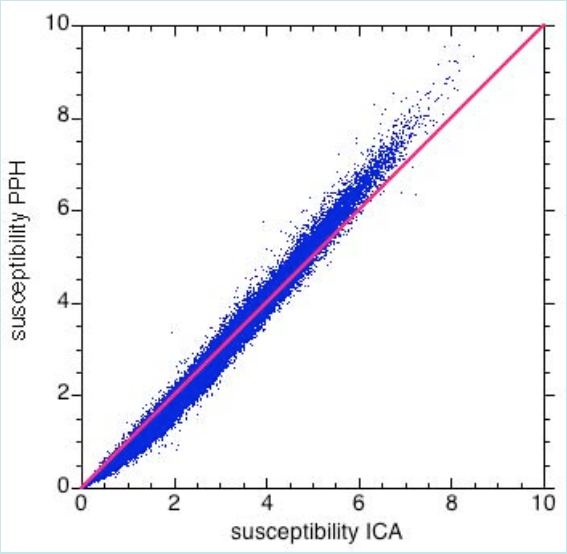


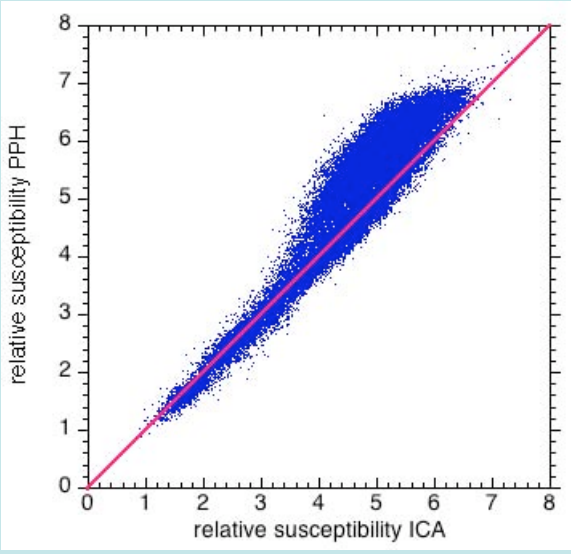


Terra, October 2005

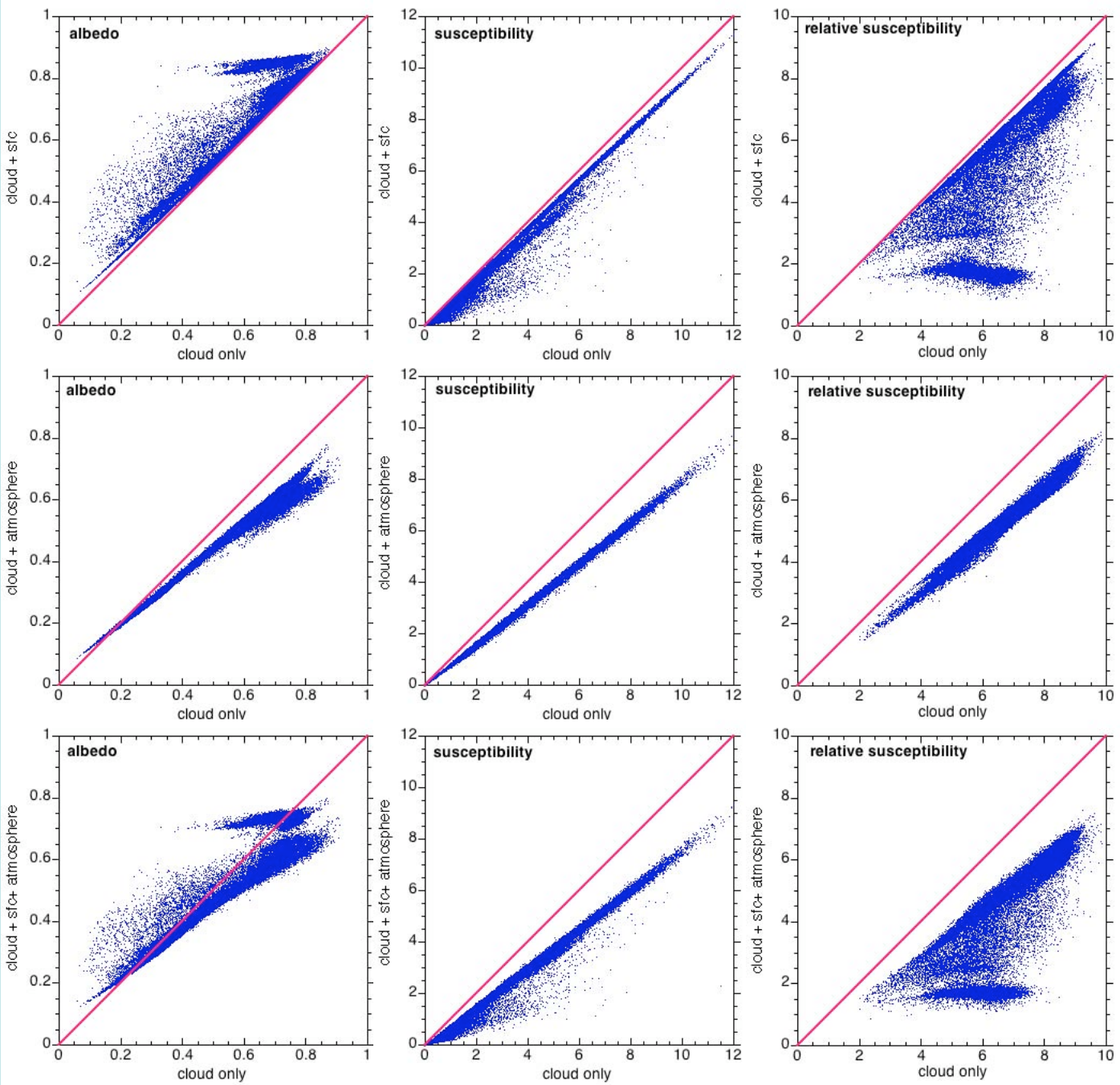
Impact of using 2D joints instead of means







Aqua, January 2005



Aqua, January 2005

Impact of atmosphere and surface albedo

PPH calculations