How can we improve estimates of indirect aerosol forcing?

Joyce Penner and Cheng Zhou
University of Michigan
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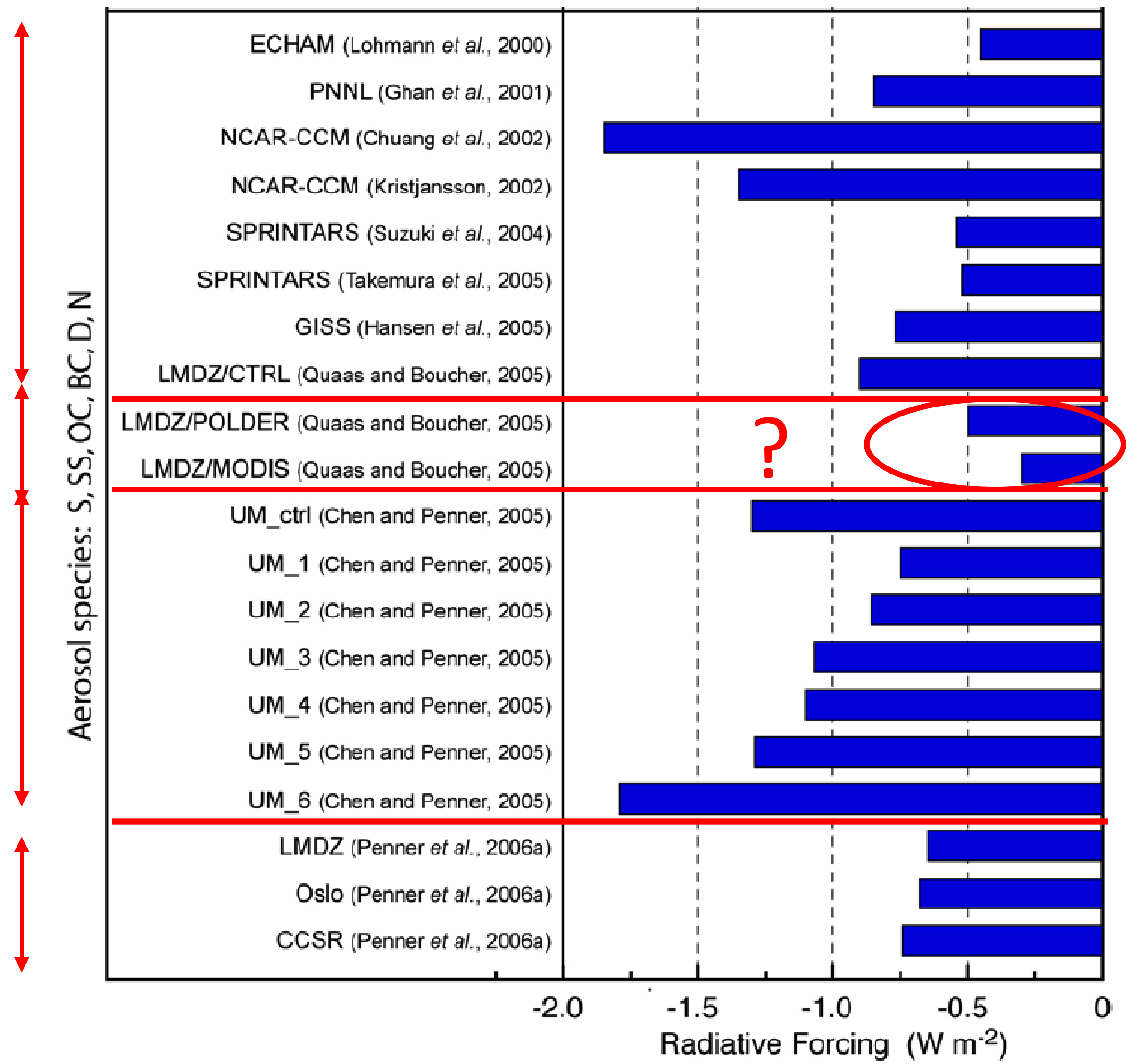
Estimates of albedo effect vary widely:

Published since 2001 IPCC report:

Based on fitting model to satellite:

Based on a single model varying method to treat aerosol effects

Based on 3 models with fixed aerosol concentrations



Are there issues with satellite-based observation methods?

- Averaging data (and model) over larger areas gives less sensitivity (Quaas et al., 2004)
- Using τ_a as a proxy for aerosol number in regression estimates tends to underestimate the first indirect effect (Feingold, 2003).
- Using regression techniques tends to underestimate the first indirect effect (Feingold, 2003)

Use parcel model to examine sensitivity of regression method use in satellite analyses:

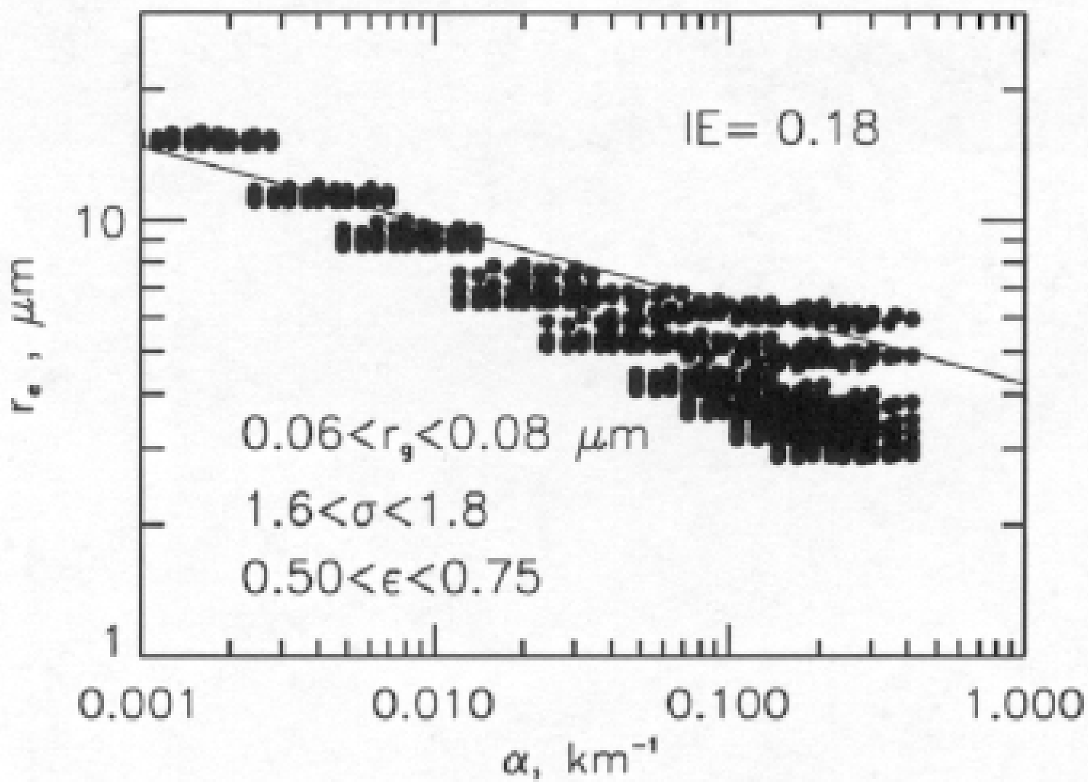


Figure 3. r_e vs. α for a range of r_g, σ, ε, and w. The fit is weighted by a Gaussian distribution of w, centred at $w = 0$.

α= aerosol extinction (or optical depth)

Feingold, 2003

Expand equation for α to determine true indirect effect

$$\alpha \approx N_a^{c_1} r_g^{c_2} \sigma^{c_3} \varepsilon^{c_4}$$

$$-IE' = \frac{d\ln r_e}{d\ln \alpha} = S(N_a)\frac{\partial \ln N_a}{\partial \ln \alpha} + S(r_g)\frac{\partial \ln r_g}{\partial \ln \alpha} + S(\sigma)\frac{\partial \ln \sigma}{\partial \ln \alpha} + S(\varepsilon)\frac{\partial \ln \varepsilon}{\partial \ln \alpha}$$

Table 2. Contributions $C(X_i) = S(X_i)/c_i$ to IE′ (Equation 4)

				RH = 95%	λ = 532 nm
	All	Clean	Polluted	All	All
$C(N_a)$	−0.299	−0.315	−0.225	−0.299	−0.299
$C(r_g)$	−0.026	−0.024	−0.032	−0.028	−0.021
$C(\sigma)$	0.043	0.026	0.071	0.051	0.030
C(\epsilon)	−0.115	−0.102	−0.133	−0.049	−0.104
IE′	0.40	0.41	0.32	0.33	0.39
IE	0.16	0.14	0.03	0.17	0.13

$c_i = \frac{\partial \ln \alpha}{\ldots}$ = 1.00, 3.36, 4.35, and 0.26 for N_a, r_g, σ and ε, respectively, at

Conclusion: Satellite-based estimates based on regression are probably flawed

- Use of optical depth as proxy for all aerosol properties underestimates regression between aerosol and drops

- However, model-based estimates do not agree with satellite data, so are also flawed

PNAS paper: Penner et al. 2011: Examined satellite estimates using model:

Quaas method: $\left[\dfrac{\partial \alpha}{\partial \ln N_d}\right]_{f,L} \dfrac{d \ln N_d}{d \ln \boldsymbol{\tau}_a} \Delta \ln \boldsymbol{\tau}_{anth}$

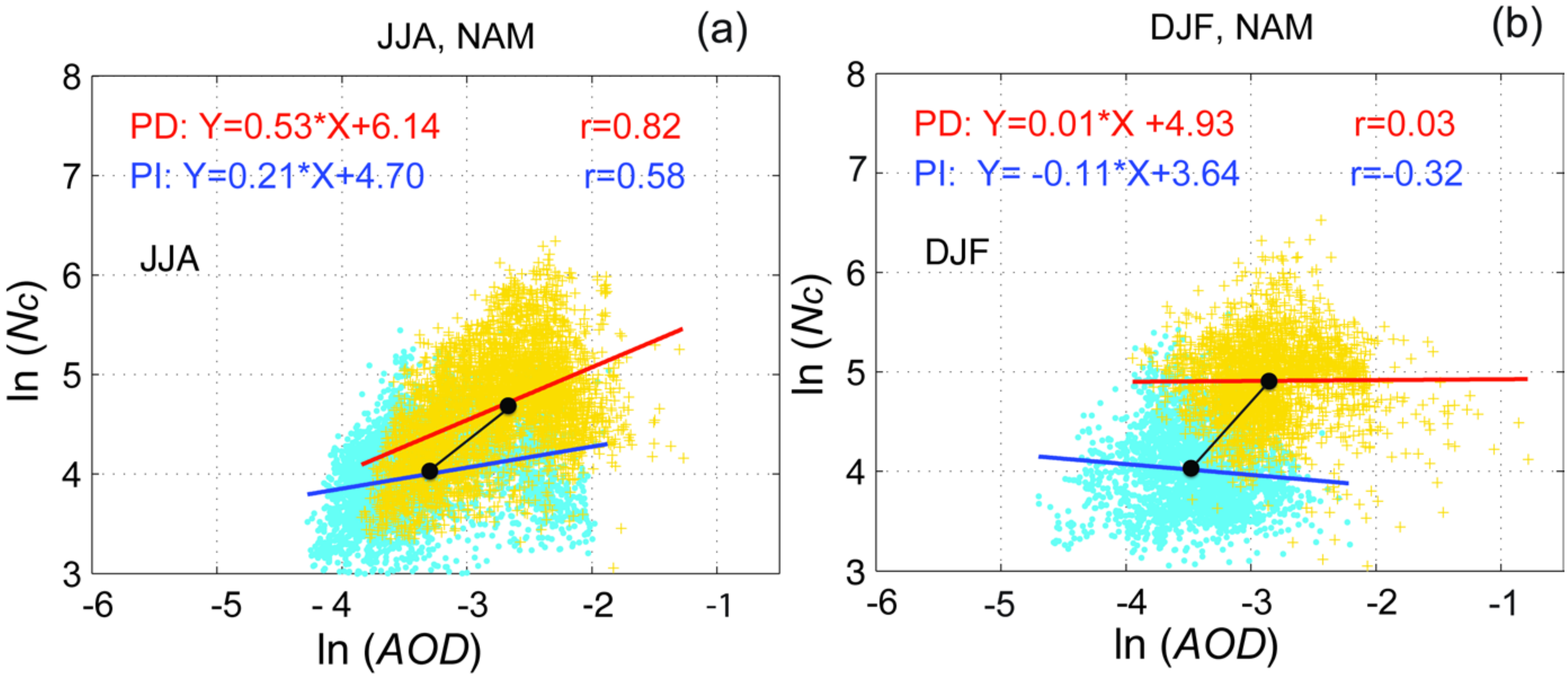
Examine slope using model:

$$\alpha_{N_d} = \frac{d \ln N_d}{d \ln AI}$$

With AI = τ_a or $\tau_a \lambda$

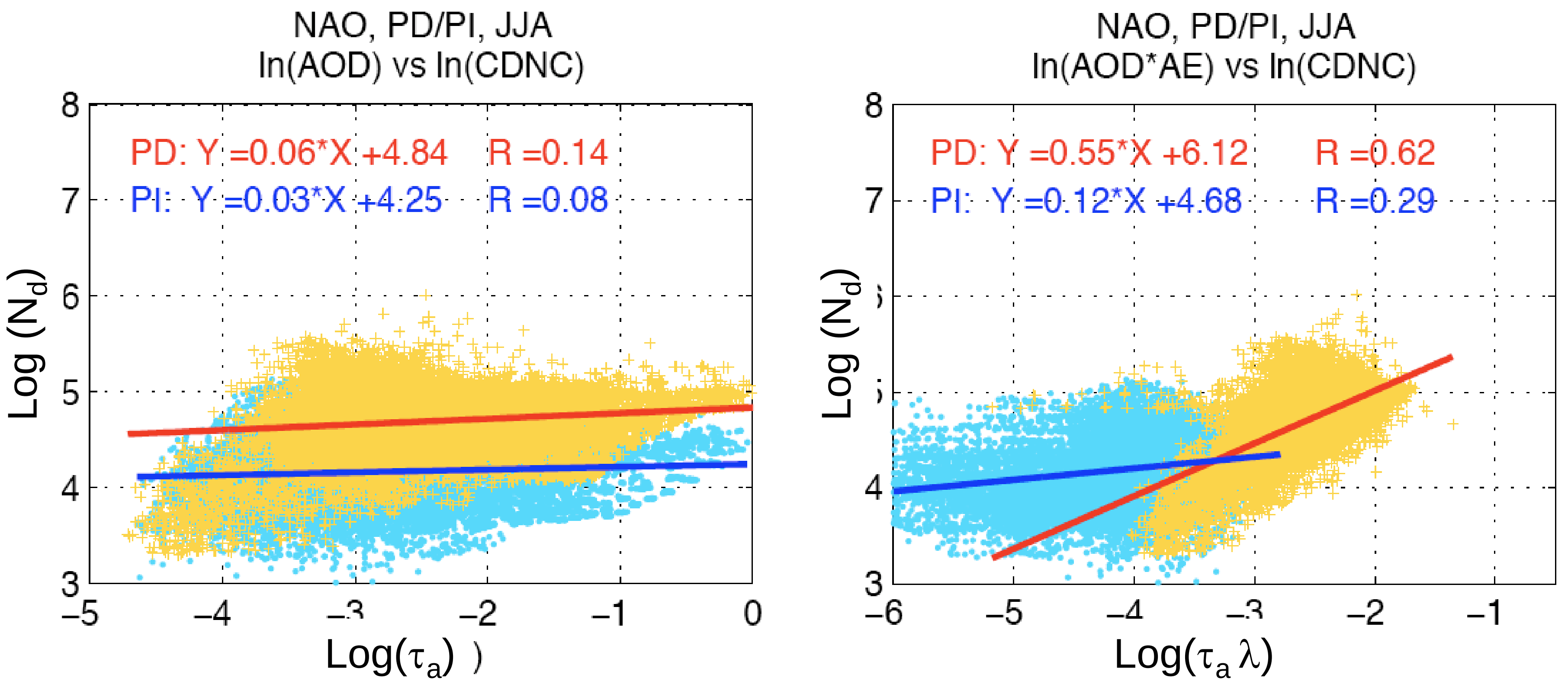
where $\lambda =$ Ångström exp.

NAM: Scatter plot of ln(N_d) vs ln(AOD)



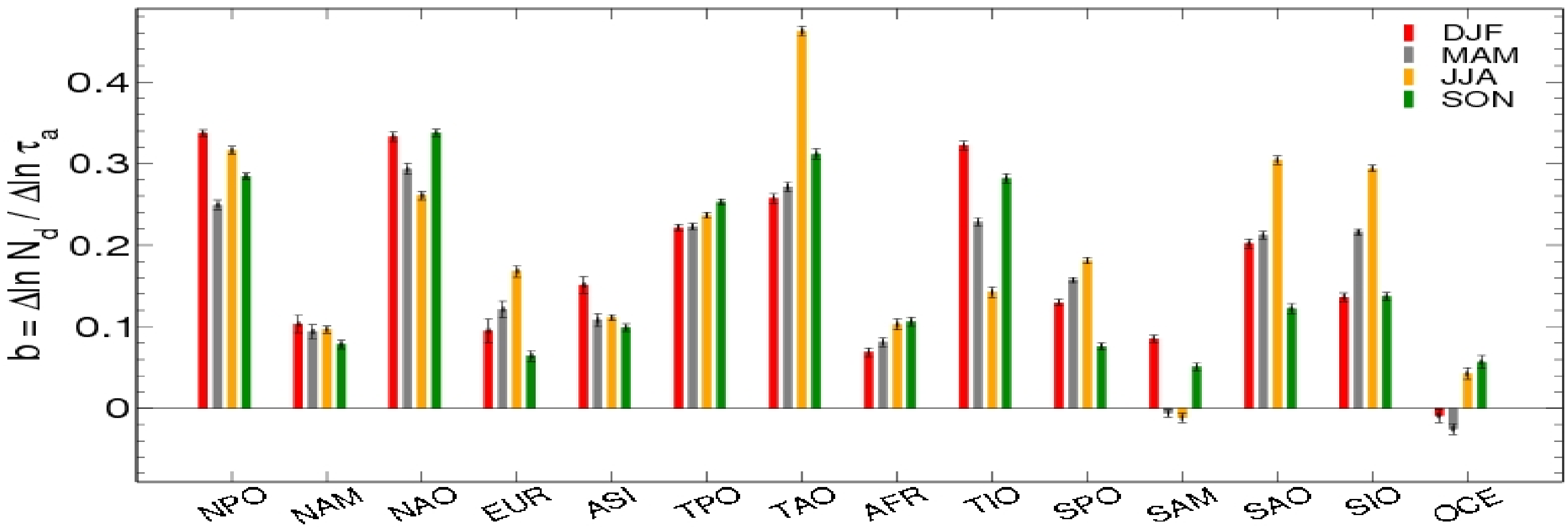
N_d may not always increase with optical depth

NAO: Scatter plot of $\ln(N_d)$ vs $\ln(AI)$

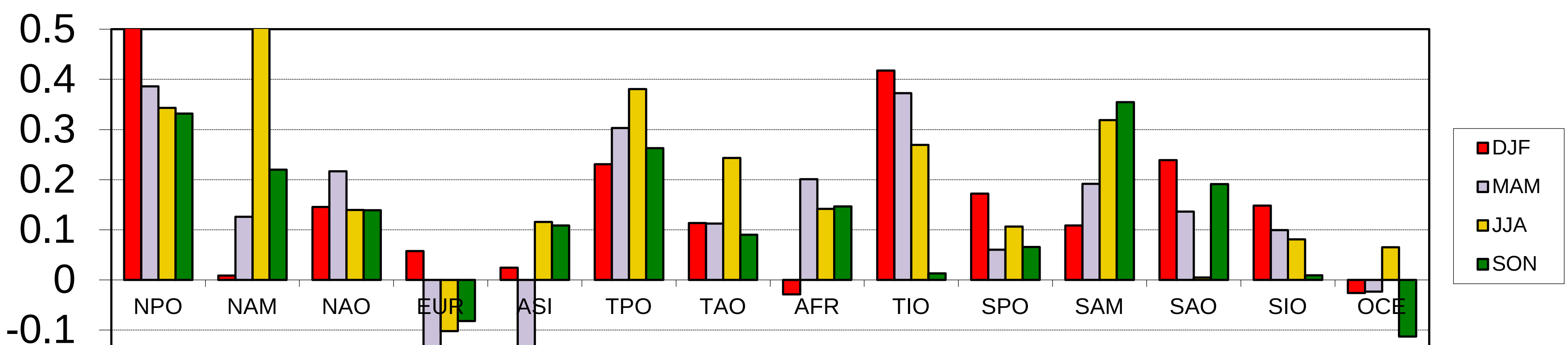


There is a much stronger relationship between $\log(N_d)$ and $\log(\tau_a \lambda)$ than between $\log(N_d)$ and $\log(\tau_a)$

Modeled $\dfrac{d\ln N_d}{d\ln \tau_a}$ compared to satellite data:

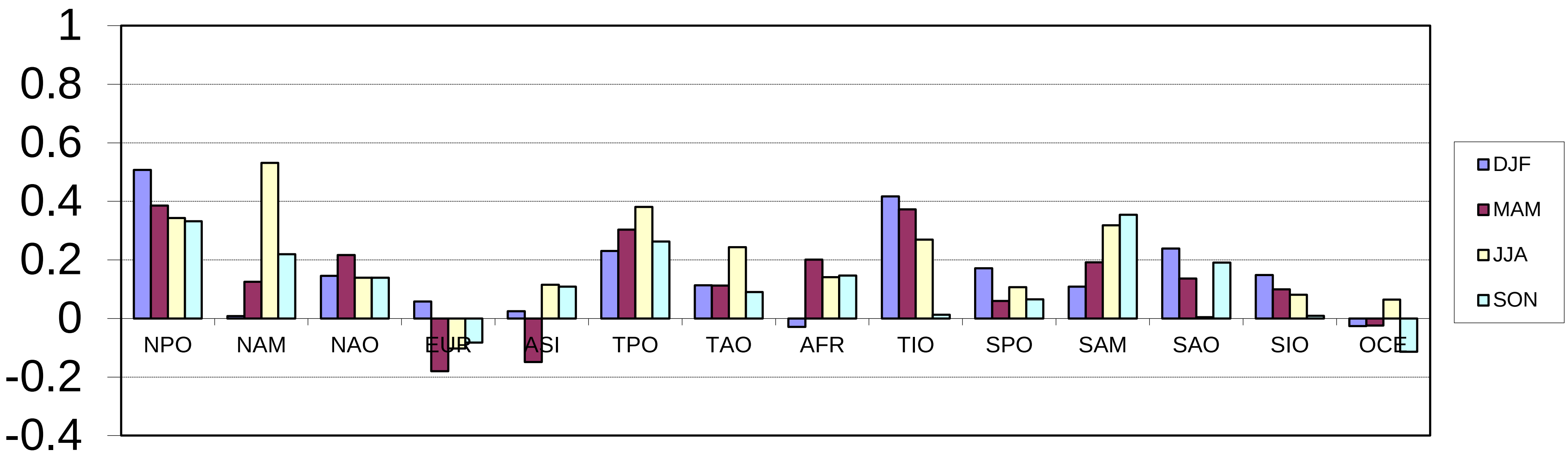


Modeled values are significantly different on a regional scale:

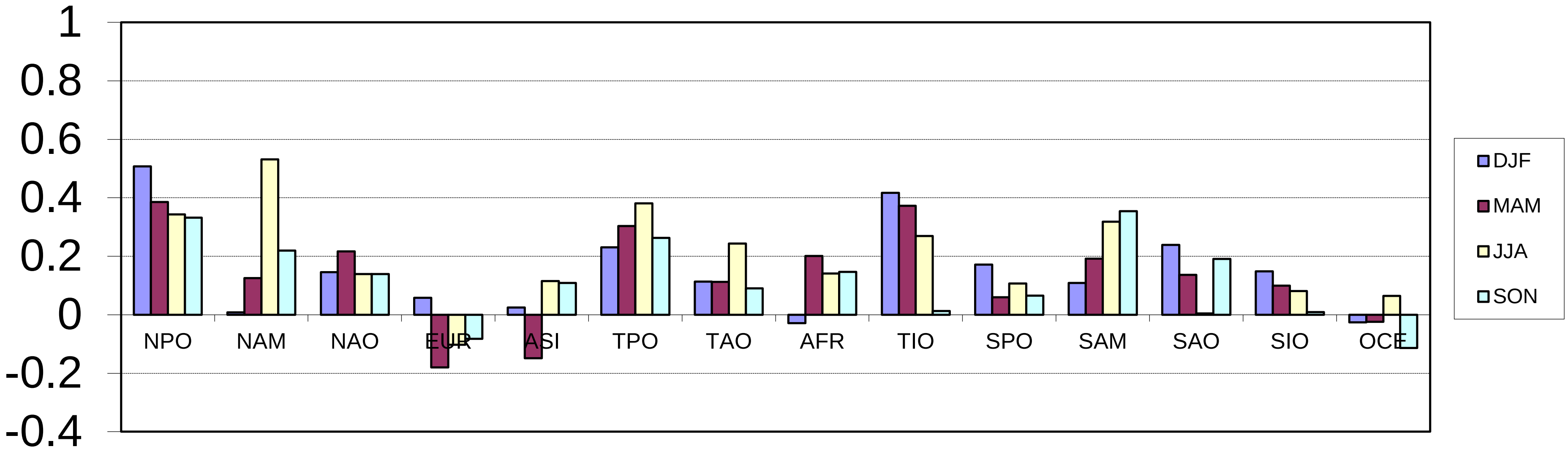


Evaluate satellite method using model as true estimate for the change in N_d

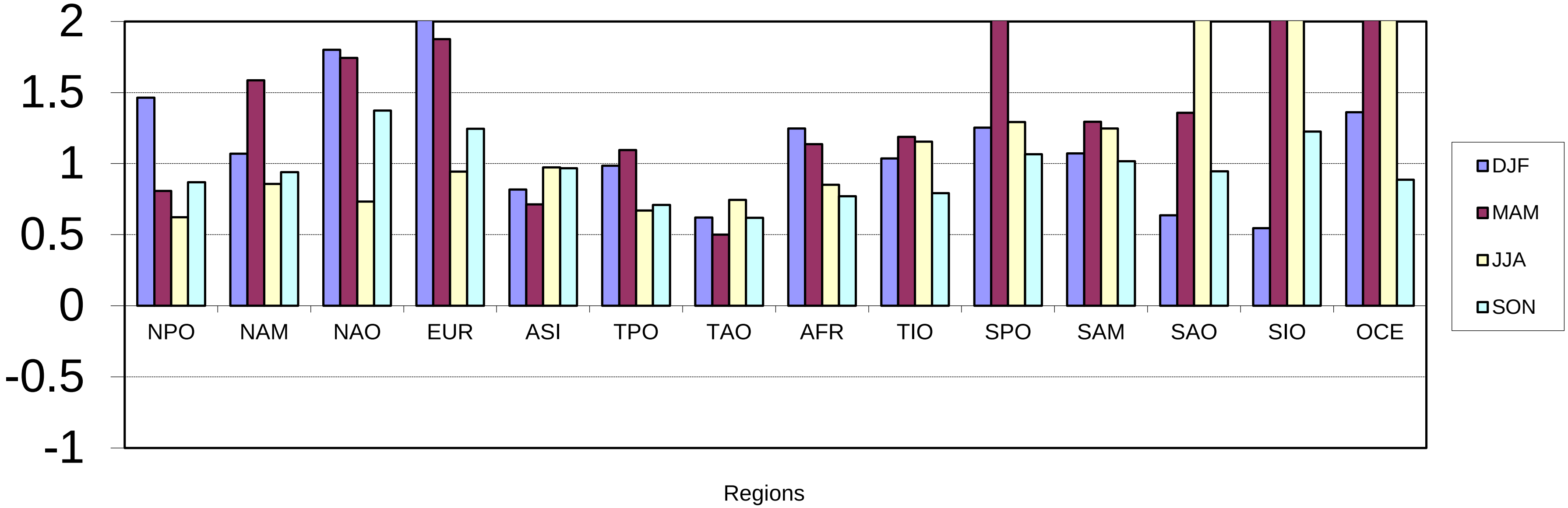
$\ln(N_d)$ vs $\ln(AOD)$ using PD:



Model slope of ln(Nd)/ln(AOD) using PD only:

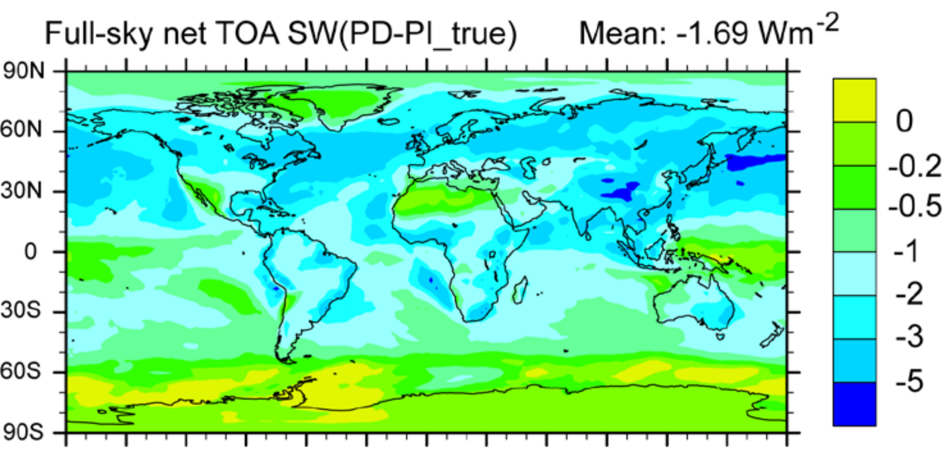


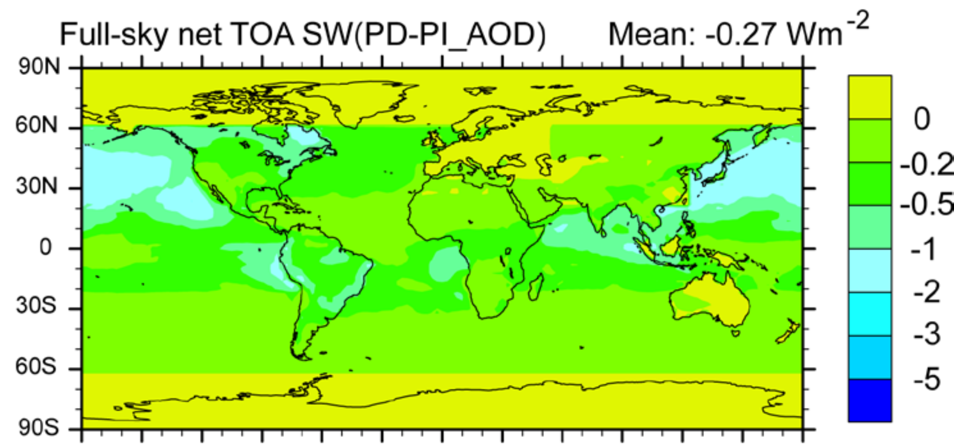
Model slope of ln(Nd)/ln(AOD) using PD and PI:



Use present day $\ln(N_d)/\ln(AOD)$ to estimate PI N_d and forcing:

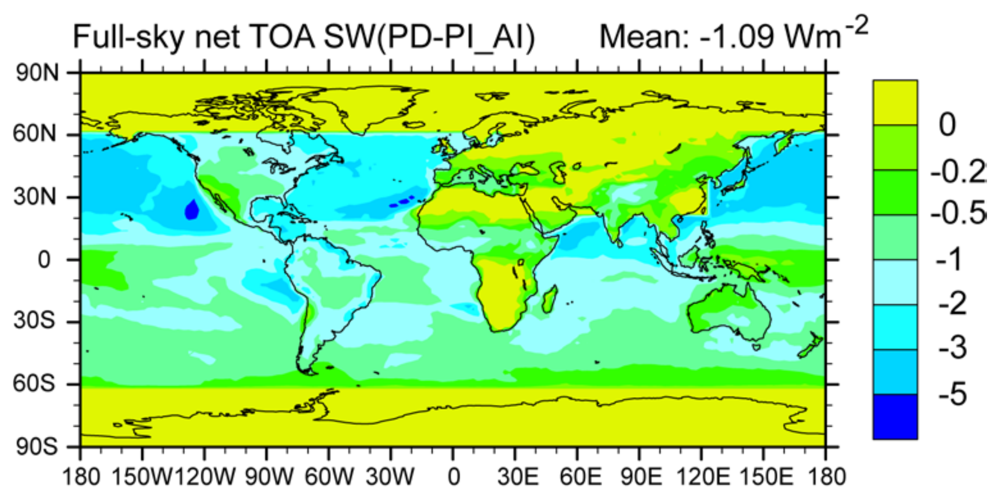
$$N_d(PI) = \exp(\ln(N_d(PD)) - \frac{\Delta \ln(N_d(PD))}{\Delta \ln(\tau_a(PD))}(\ln(\tau_a(PD)) - \ln(\tau_a(PI))))$$



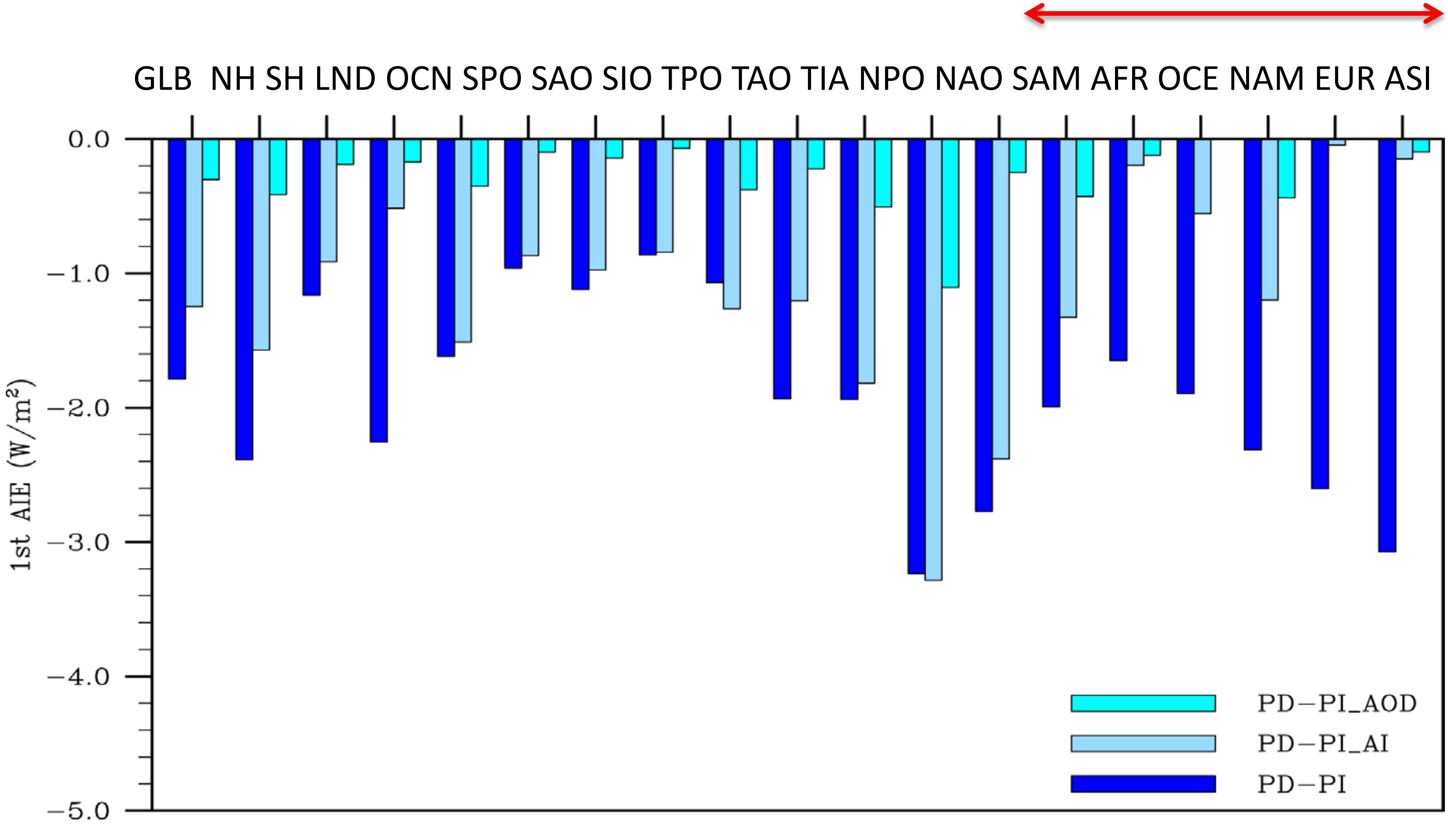


Use of AI to estimate PI N_d

Provides a closer global average:

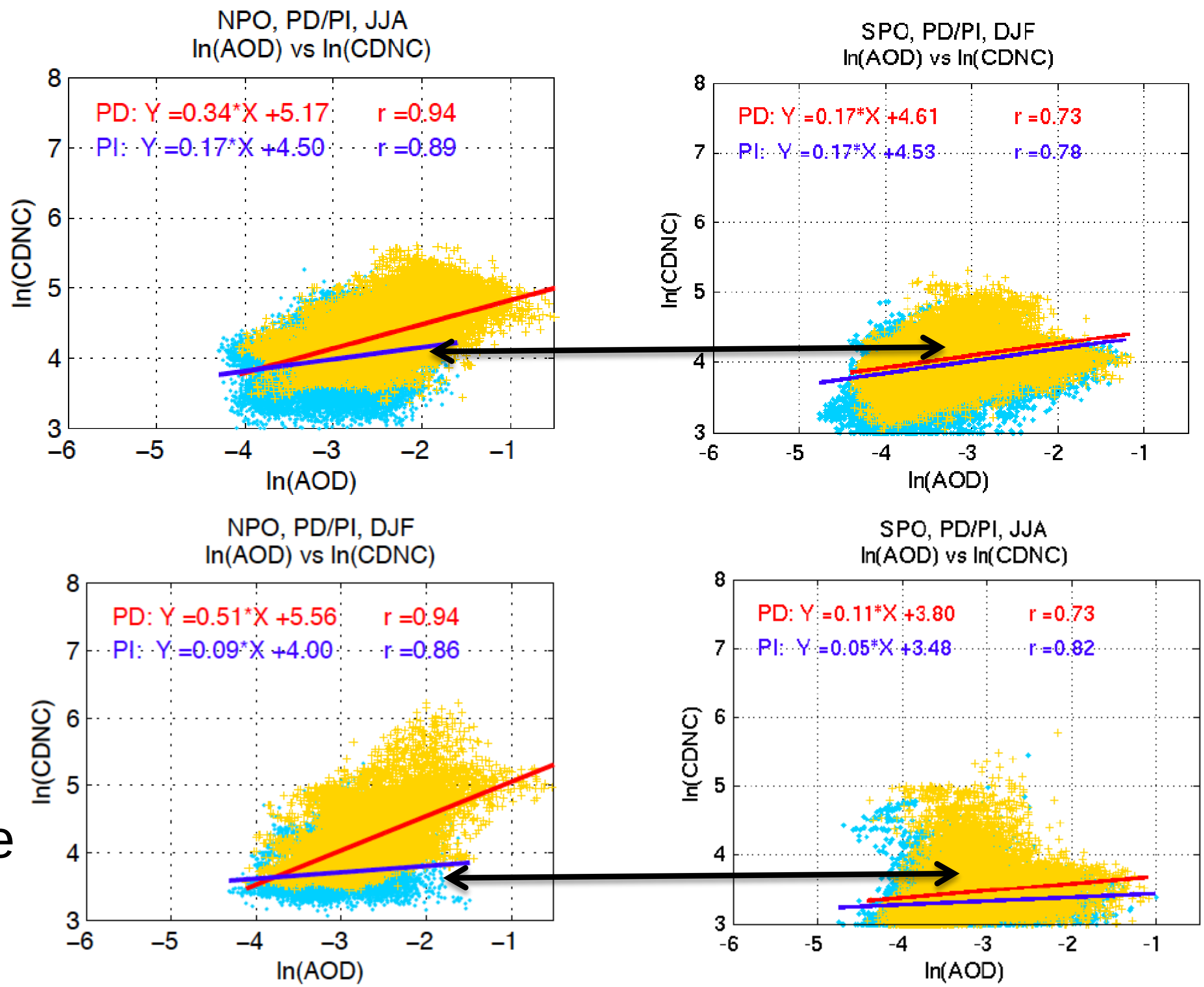


But the regional forcing is off especially over land areas:



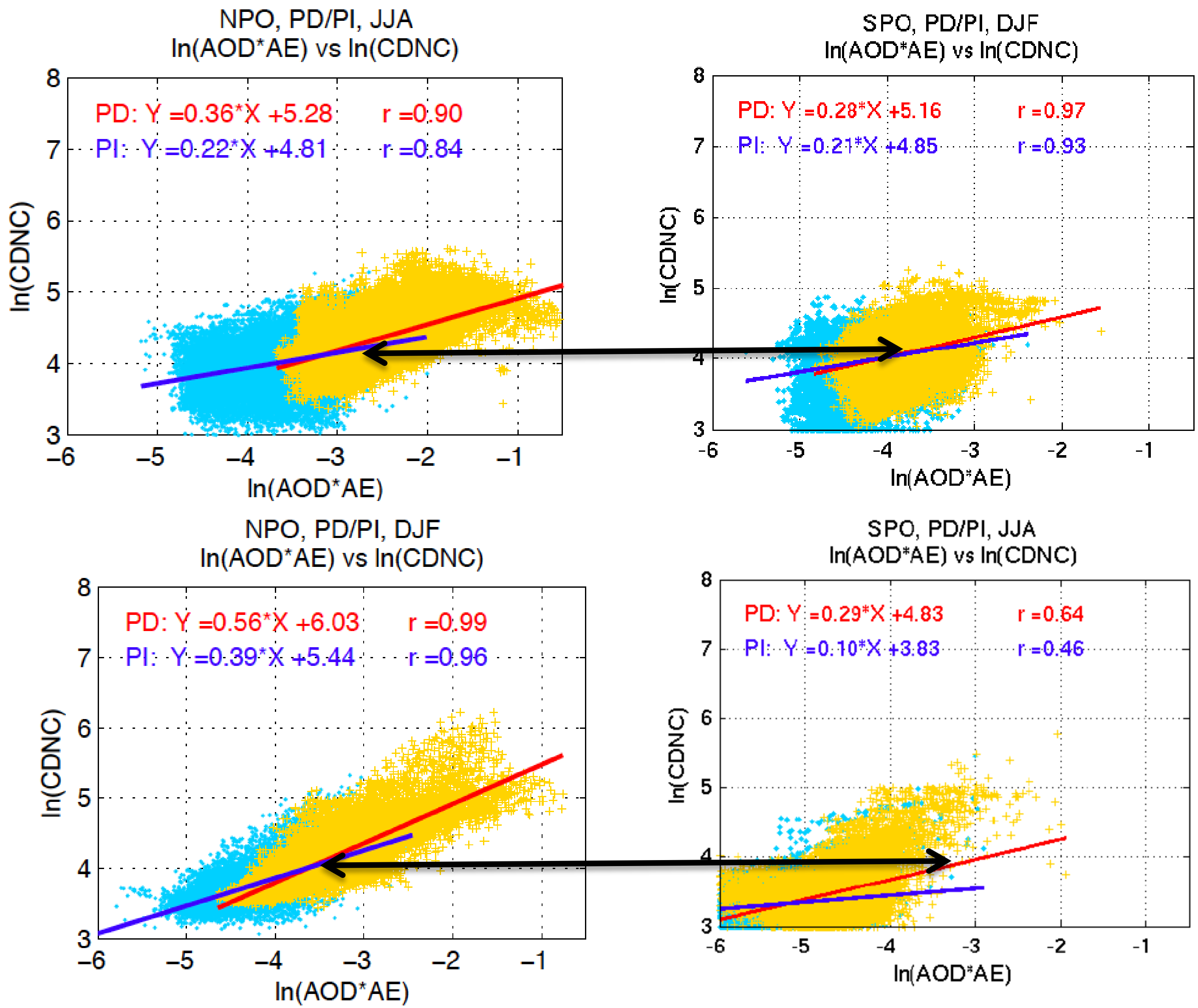
How to use satellite data together with model data to get the best result? Here, we used the model to pick regions:

IF PI slope (and values) for NPO are similar to SPO slope (and values) then can use spatial variation in CF and LWP from PD satellite data

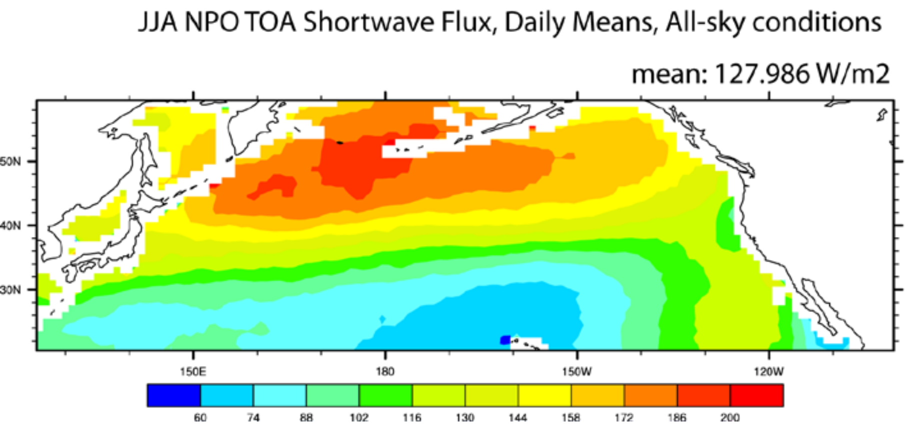


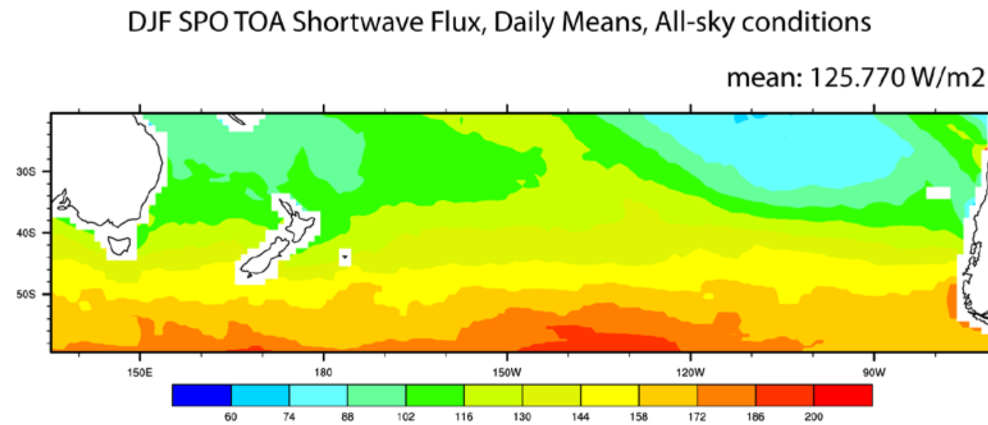
How to use satellite data together with model data to get the best result? Here, we used the model to pick regions:

AI slope for PD SPO is not as good a match for PI NPO, but perhaps acceptable.



CERES: Difference in flux is > 2Wm^{-2}



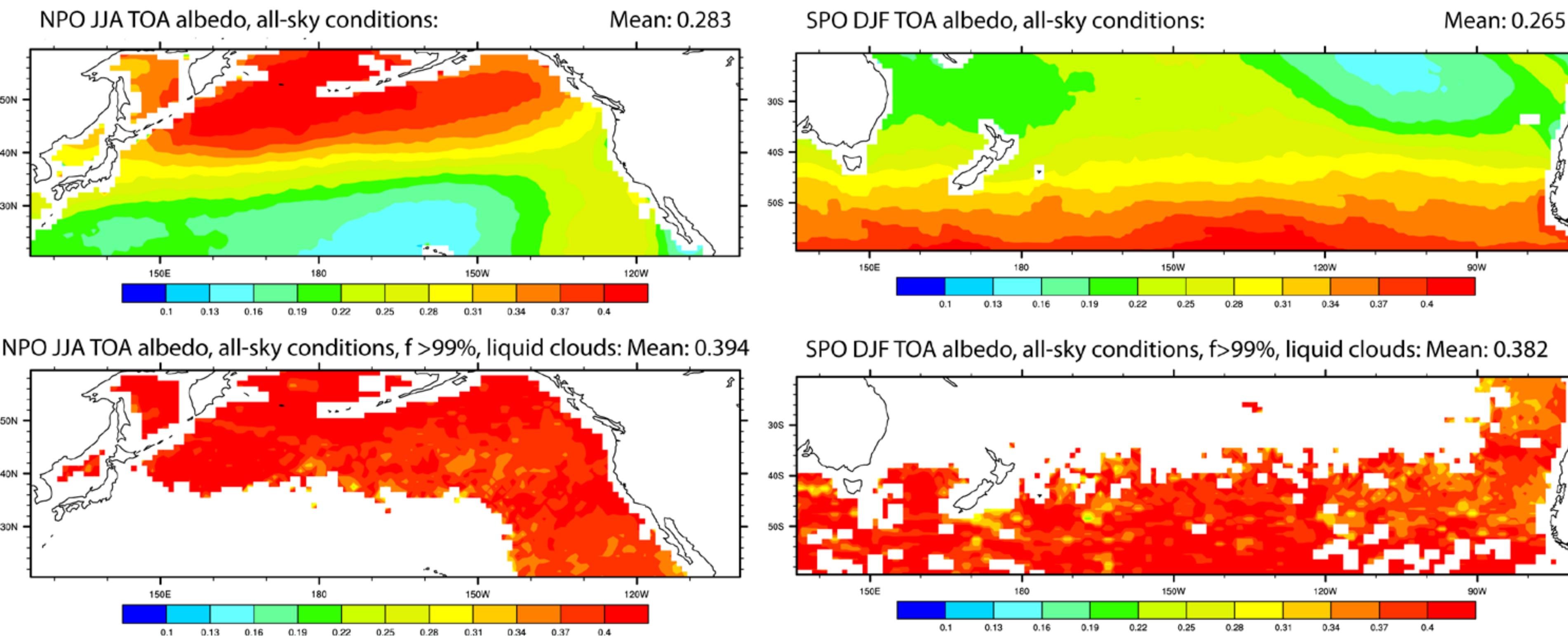


NPO JJA Solar insolation: 450.7 Wm^{-2}

SPO DJF Solar insolation: 476.8 Wm^{-2}

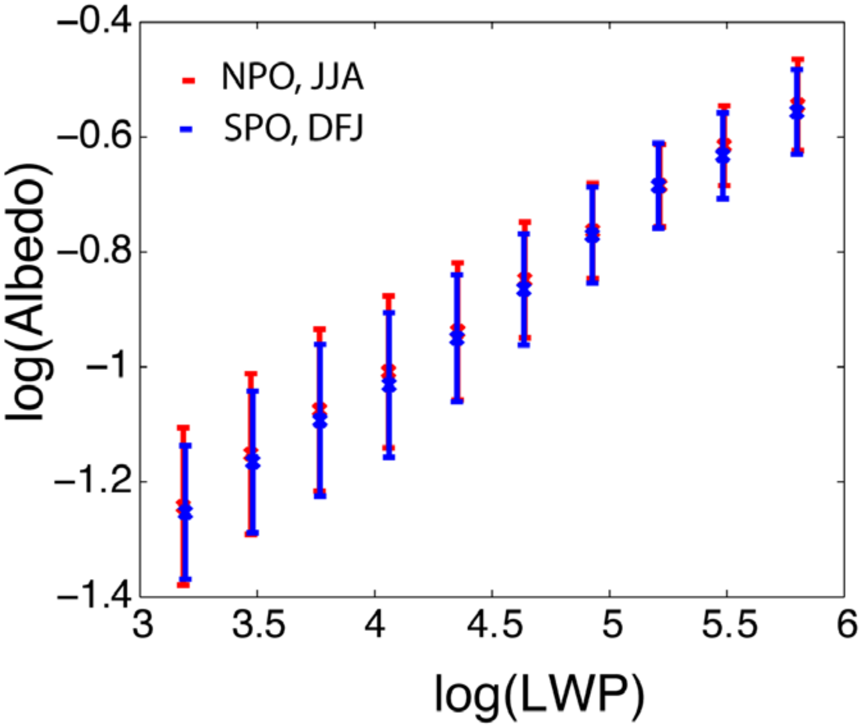
But, we need to account for difference in incoming solar insolation, exclude ice clouds, and account for differences due to changes in LWP, CF

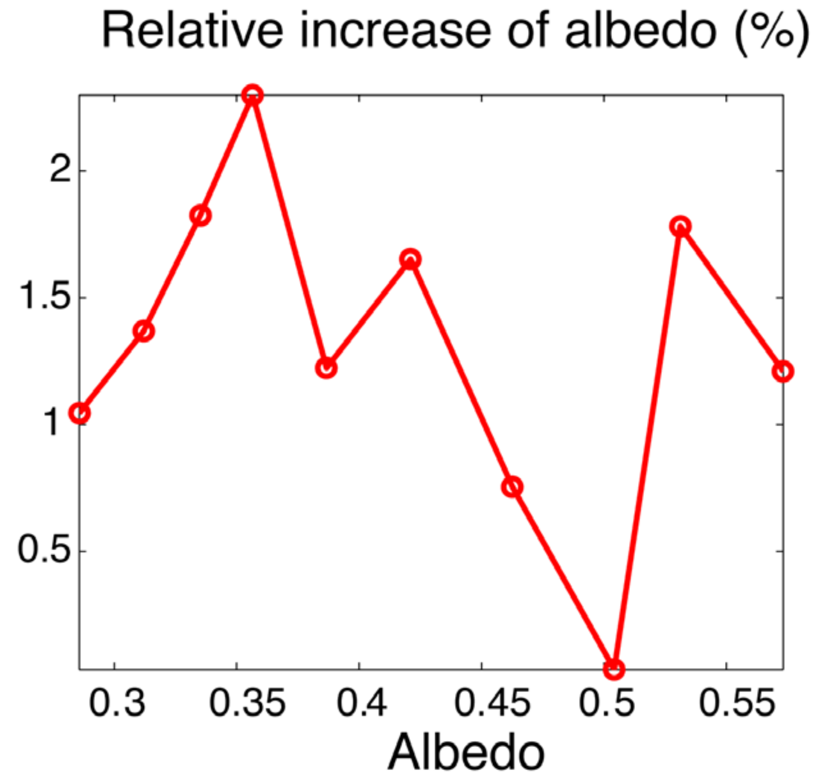
Use CERES estimates of albedo:



Restrict analysis of albedo change to clouds with f>99% or f>50%

Estimate "albedo effect" by normalizing to fixed LWP:





Albedo effect: (first indirect effect)

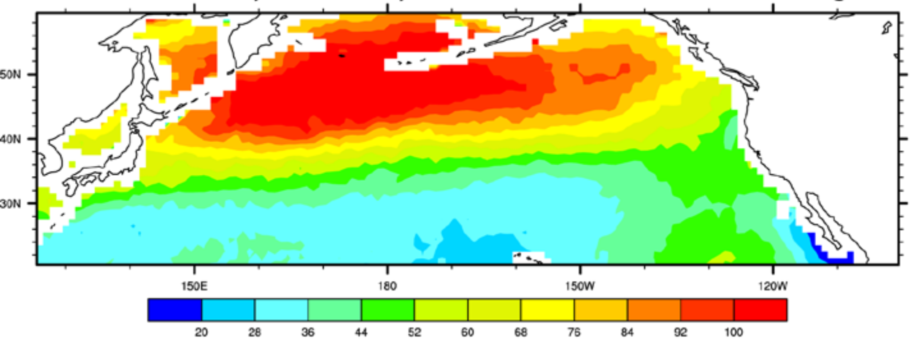
change in cloudy sky albedo × cloud fraction × solar insolation

= -1.8 to -2.2 Wm^{-2} (range for f>0.5% to f>0.99%);

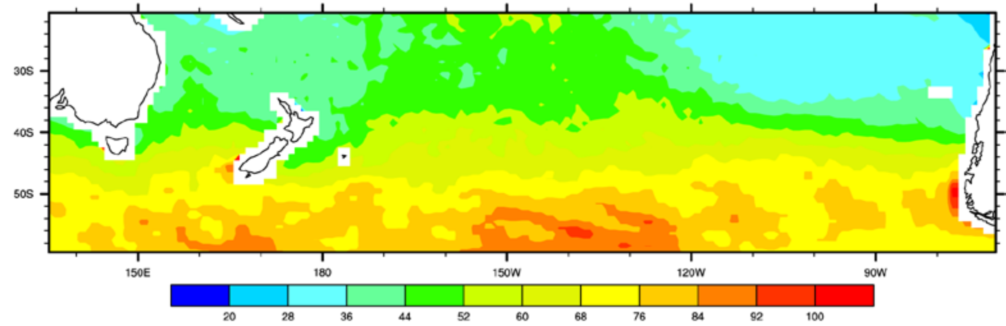
Compare to Model:-2.65 Wm^{-2} or -3.6Wm^{-2} (w/same methodology)

1^{st} + 2^{nd} indirect effect: Increase in LWP and N_d:

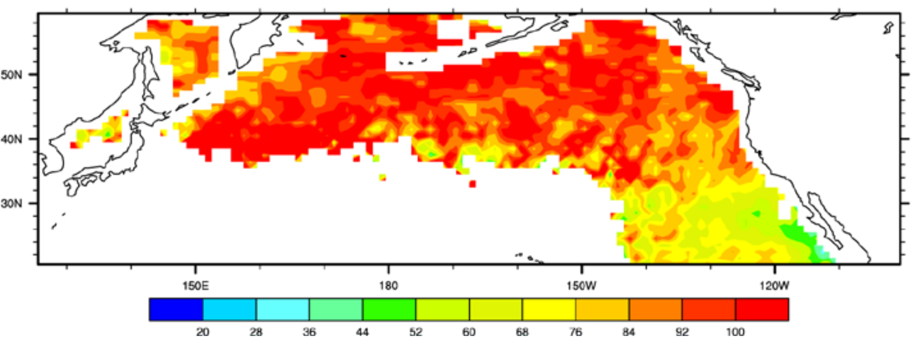
NPO JJA LWP, daily means, daytime conditions Mean: 61.690 gm-2



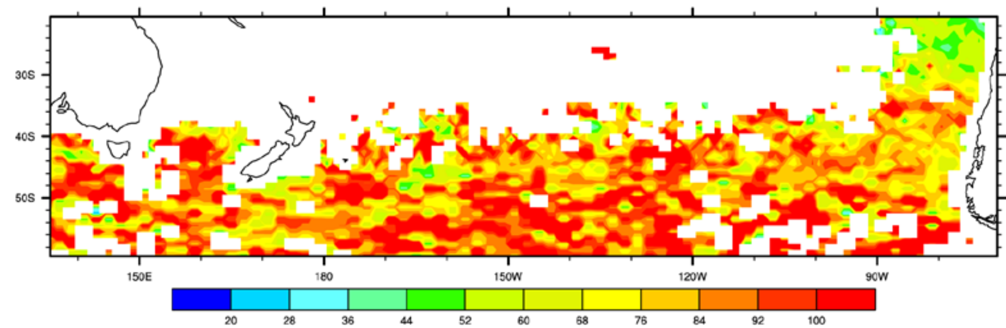
SPO DJF LWP, daily means, daytime conditions Mean: 54.020 gm-2



NPO JJA LWP, daily means, daytime conditions, f>99% Mean: 84.846 gm-2



SPO DJF LWP, daily means, daytime conditions, f>99% Mean: 82.439 gm-2



SW TOA change due to LWP+N_d in all clouds : -3.8 Wm^{-2}

Summary

- Use of spatial variations of satellite data without consideration of temporal variations is subject to large errors (Penner, et al. 2011)
- Results for South Pacific Ocean can be averaged to estimate pre-industrial conditions
- Albedo forcing in NPO is -1.8 to -2.2 Wm^{-2}
- Reasons for disagreements with model results clearly identified:
  - Due to identified differences in LWP, cloud fraction, AOD
- Including changes in LWP (not sorting) increases this to -3.8 Wm^{-2} (note: accounting for changes in CF would make our estimated forcing even larger)

Assumptions

- Modeled Nd-AOD in SPO can be used to gauge PI conditions in NPO
- The increase in albedo for liquid clouds is the same for all cloud fractions
- Our flux estimates assume no masking of outgoing SW by ice clouds
- Regions with f<50% are not included

Can we improve on (2) and (4) above?

Assumptions: The increase in albedo for liquid clouds is the same for all cloud fractions; Regions with f<50% not included:

- Instead of sorting by LWP, match regions in NPO and SPO by meteorological forcing:
  - Stability
  - Surface latent heat flux
  - Surface sensible heat flux
  - Large scale wind, RH, and T forcing
- Add use of Calypso data to check whether aerosols/clouds are "mixed" (at same altitude) (e.g. Costantino & Bréon paper) (separate by CTP or just use constant LWP?)
- Harder to be assured that AOD over a small region would be representative of PD-PI changes: need to check using model/data comparisons
- Will need to use level 2 satellite data which is more intensive
- Can perhaps expand to running cloud resolving models as a check on GCM's

Next steps for AEROCOM

- Perhaps need one or two model/data groups to engage in this activity
- Could perhaps expand to other regions by comparison of PD values only (similar to Quaas et al. 2009)
- Finding data that can be used for PI values for other regions may be difficult