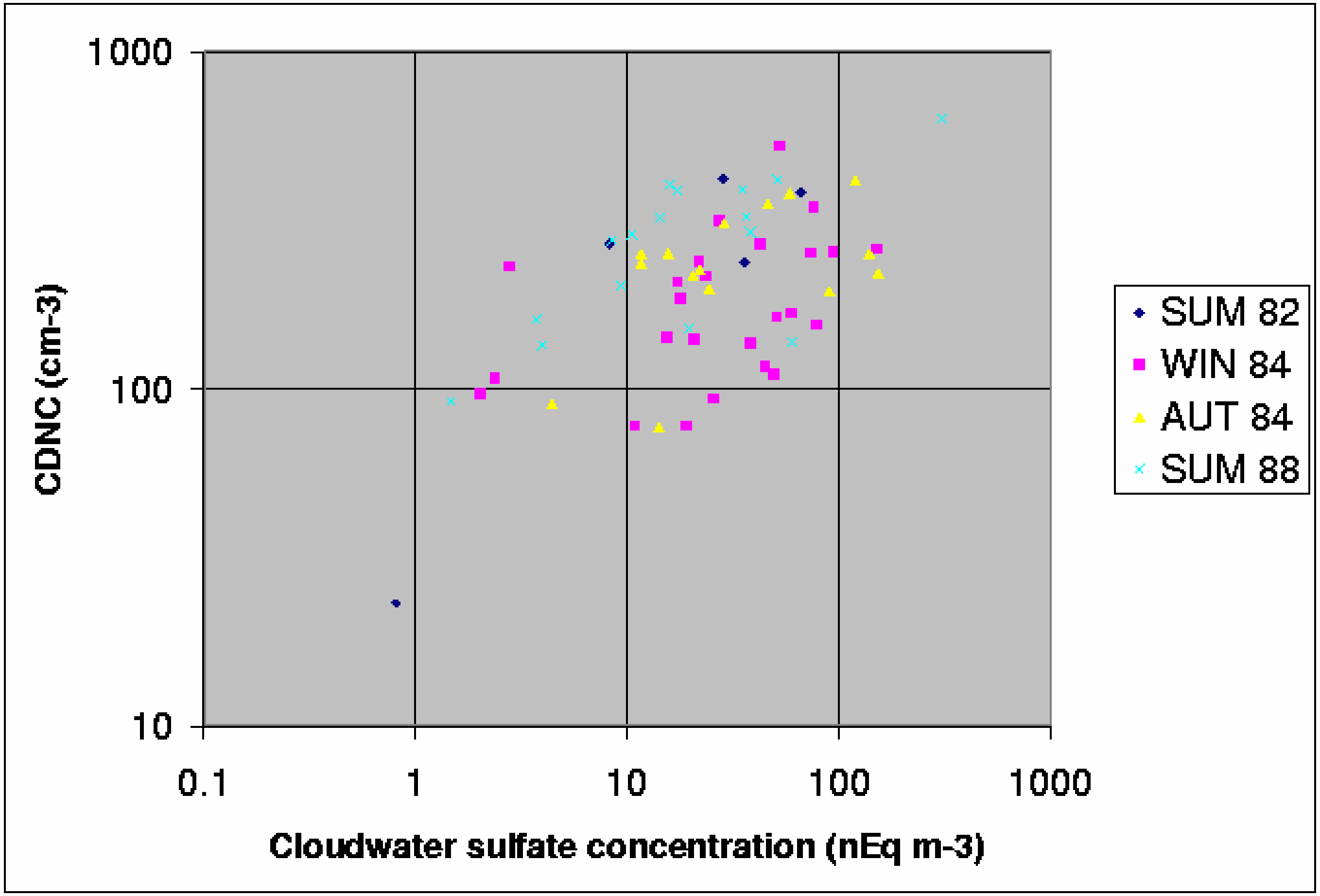
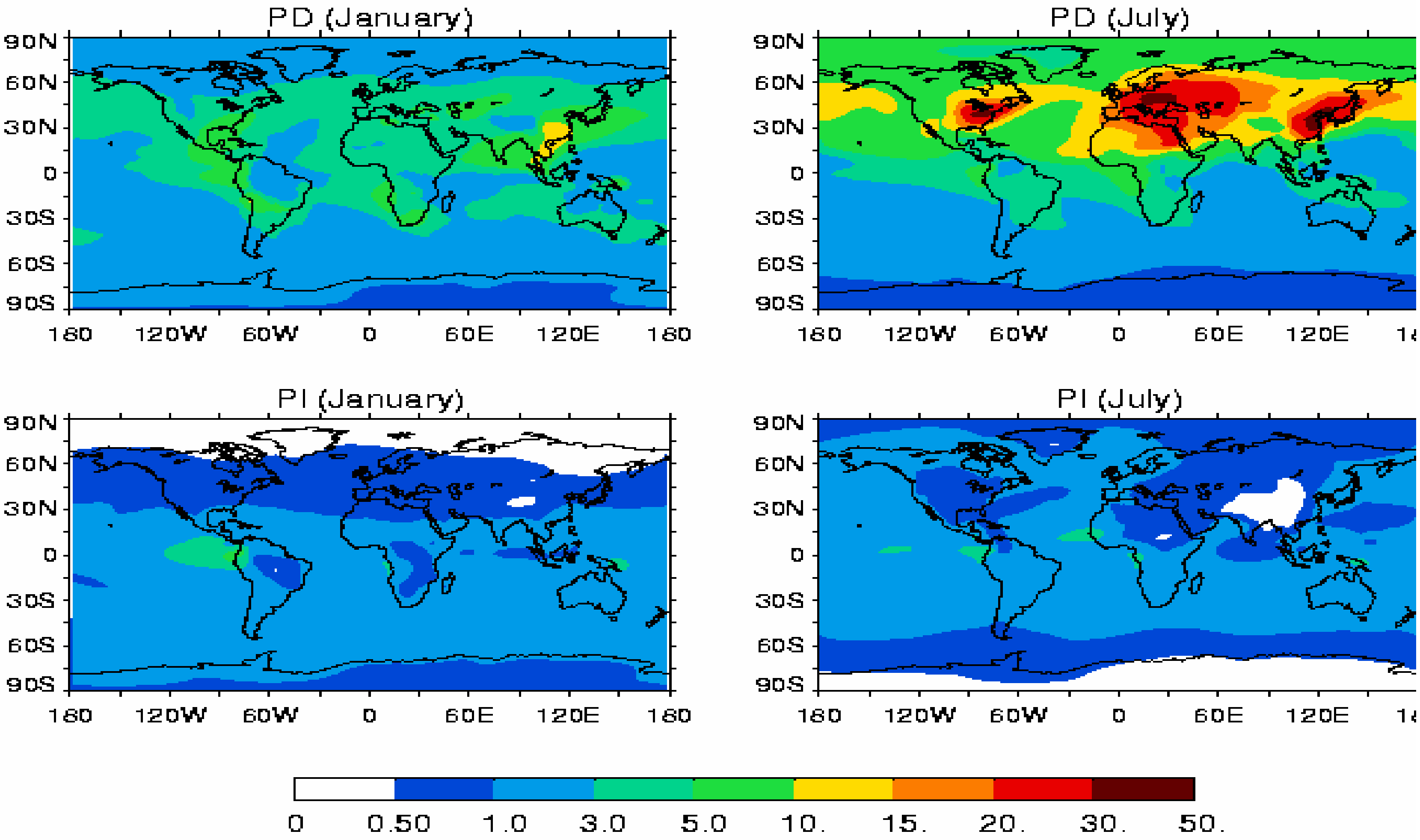
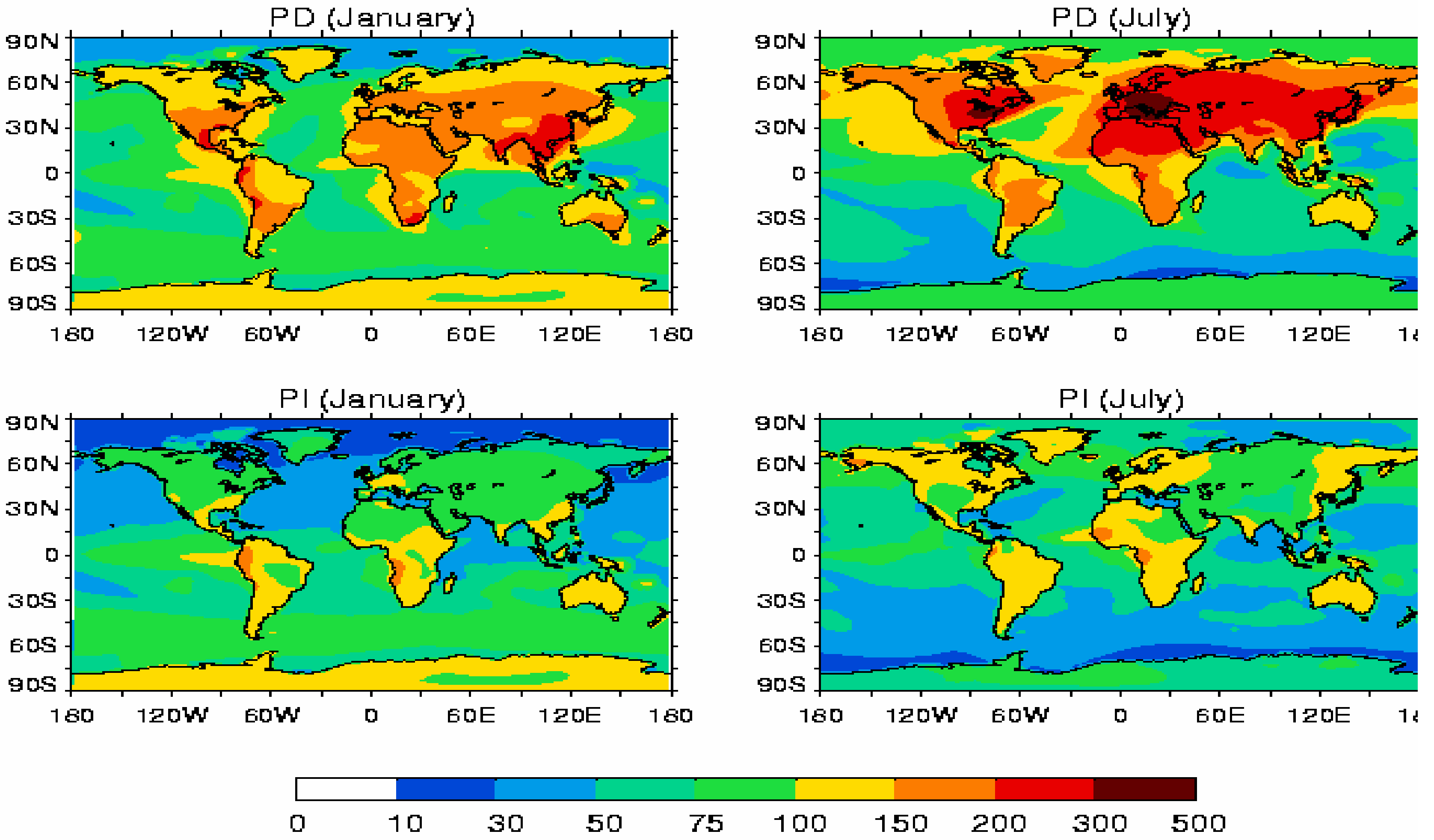
AEROSOL – CLOUD Interactions

- •GFDL AM2; N45 - 2x2 degrees (Anderson et al., 2004).
- •Aerosol distributions (PI and PD) from MOZART model.
- • Prognostic cloud water and fraction scheme (based on Tiedtke, 1993; adapted by Klein, 2003).
- • Cloud microphysical processes follow Rotstayn (1997) and Rotstayn et al. (2000).
- • Autoconversion parameterization (Khairoutdinov and Kogan, 2000).
- • Apply Boucher – Lohmann semi-empirical aerosol mass → cloud drop number relationship.
- • Apply to liquid phase only.
- • Volume-mean drop radius related to effective radius (Martin et al., 1994).
- •SW radiative properties of clouds (Slingo, 1989).

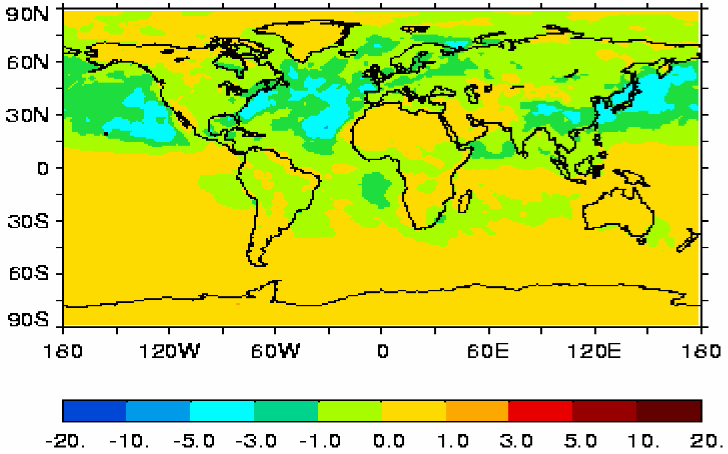
Boucher-Lohmann semi-empirical framework




PD (January)
PD (July)
PI (January)
PI (July)
90N
60N
30N
0
30S
60S
90S
180
120W
60W
0
60E
120E
180
0
0.50
1.0
3.0
5.0
10.
15.
20.
30.
50.

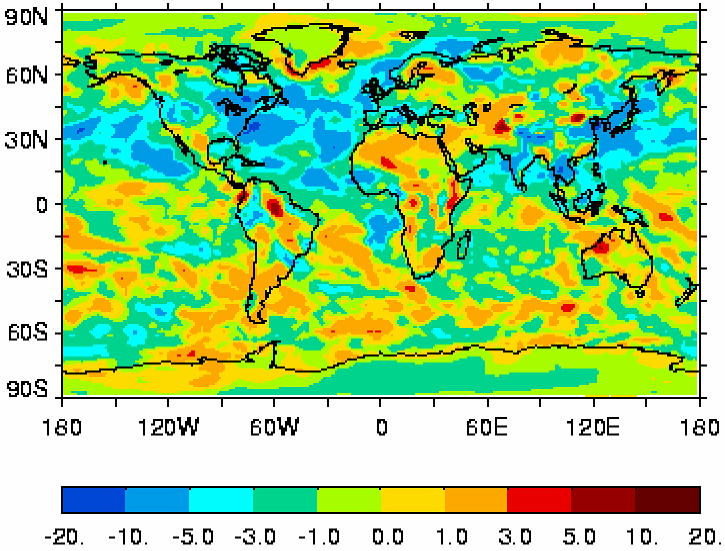

PD (January)
PD (July)
PI (January)
PI (July)
90N
60N
30N
0
30S
60S
90S
180
120W
60W
0
60E
120E
180
0
10
30
50
75
100
150
200
300
500

1st effect: Forcing



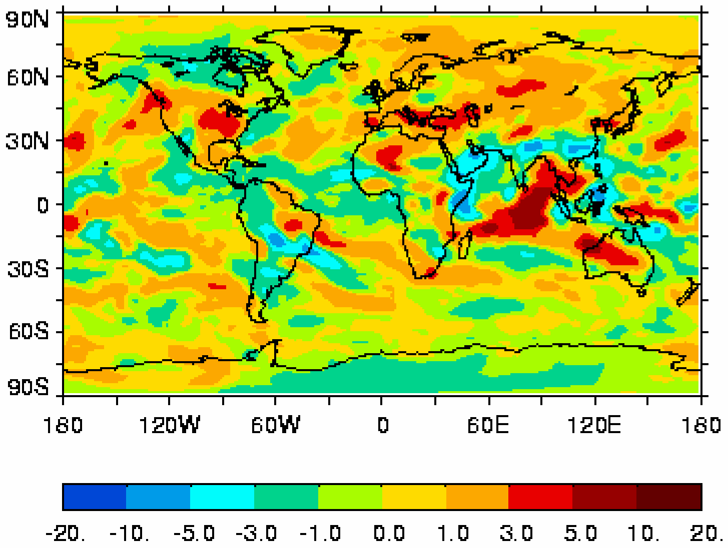
Global-mean = -1.5
NH/ SH = 4
Land/ Ocean = 0.75

1st effect: Rad. flux change

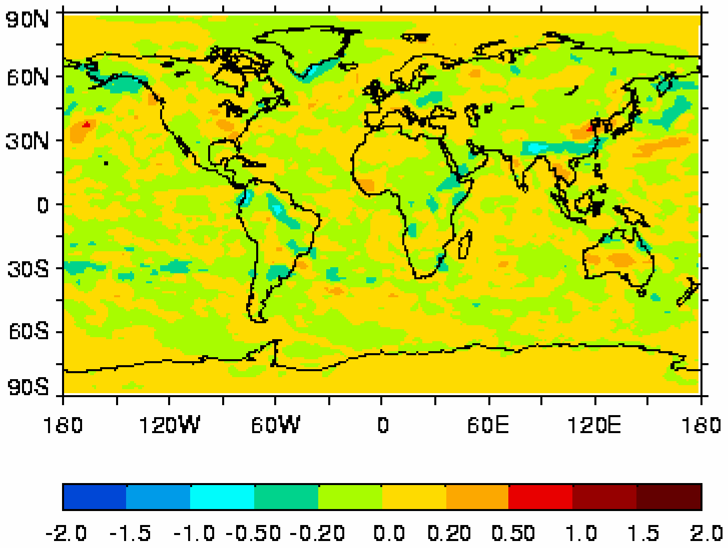


Global-mean = -1.3
Solar = -1.4
NH/ SH = 4
Land/ Ocean = 0.7

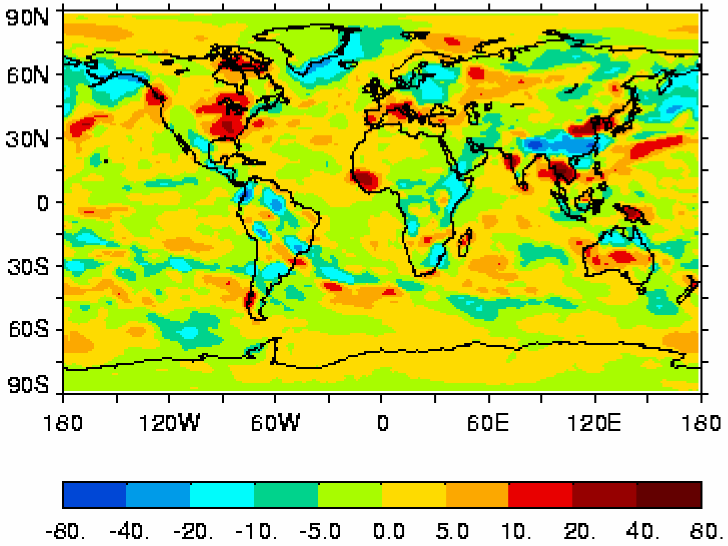
1st effect: LW flux change



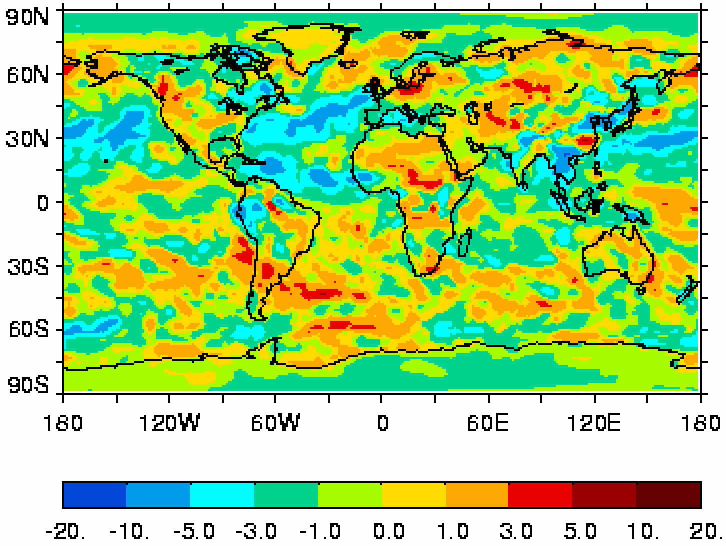
1st effect: d (cloud amount)



1st effect: d (LWP)

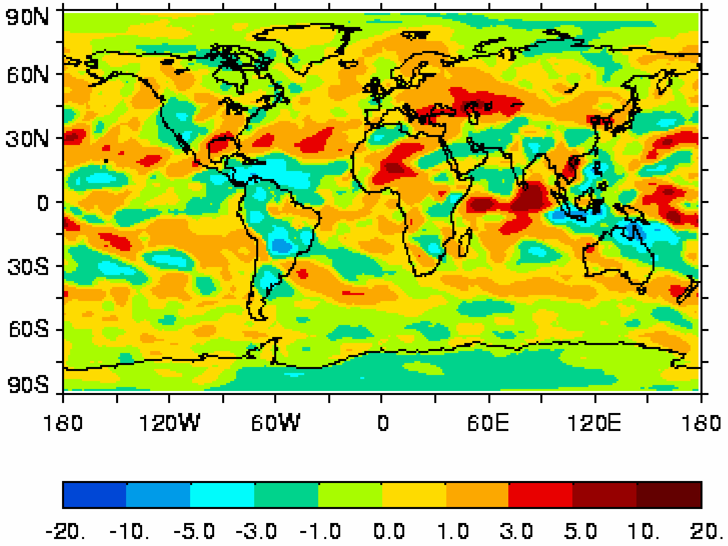


2nd effect: Rad. Flux change

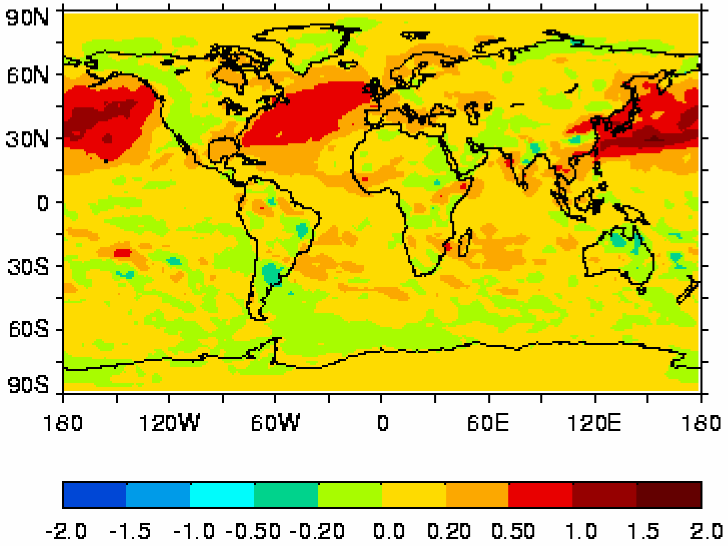


Global-mean = - 0.8
Solar = -1.0
NH/ SH = 2.8
Land/ Ocean = 0.4

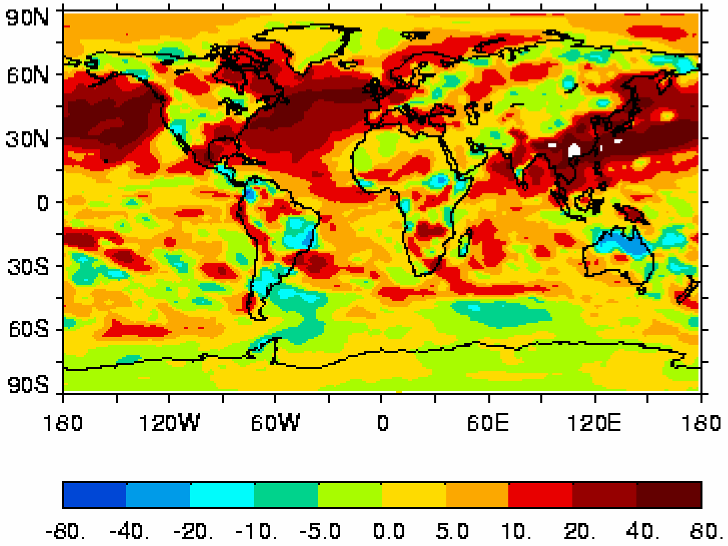
2nd effect: LW flux change



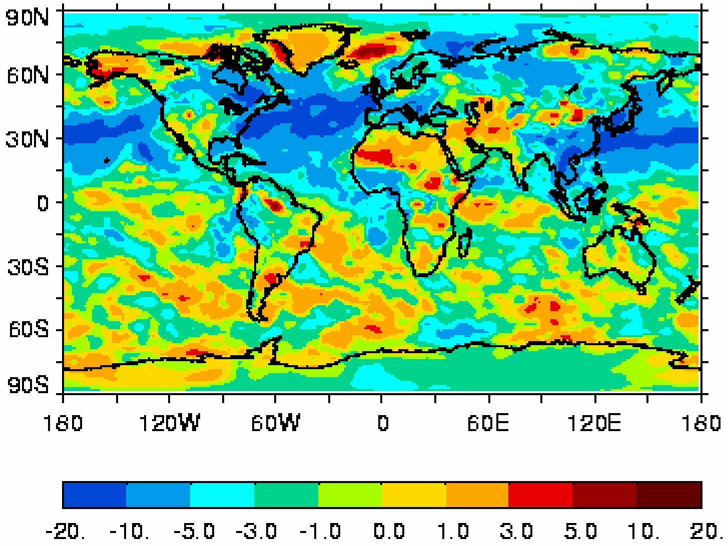
2nd effect: d (cloud amount)



2nd effect: d (LWP)

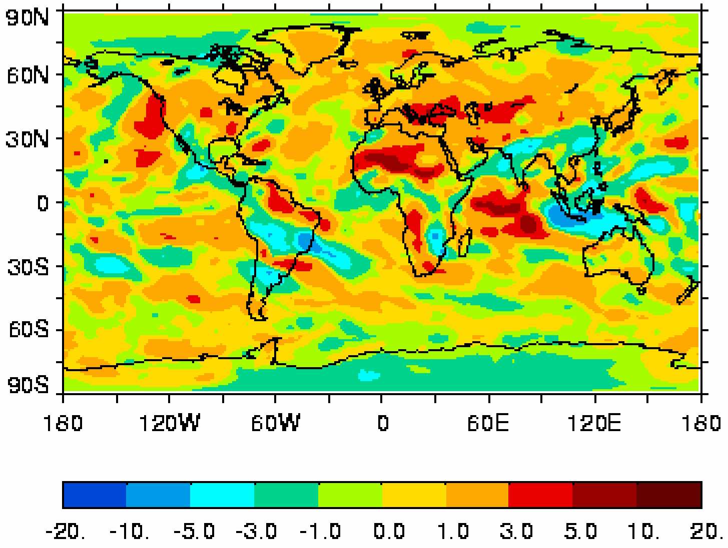


Combined effect: Rad. Flux change

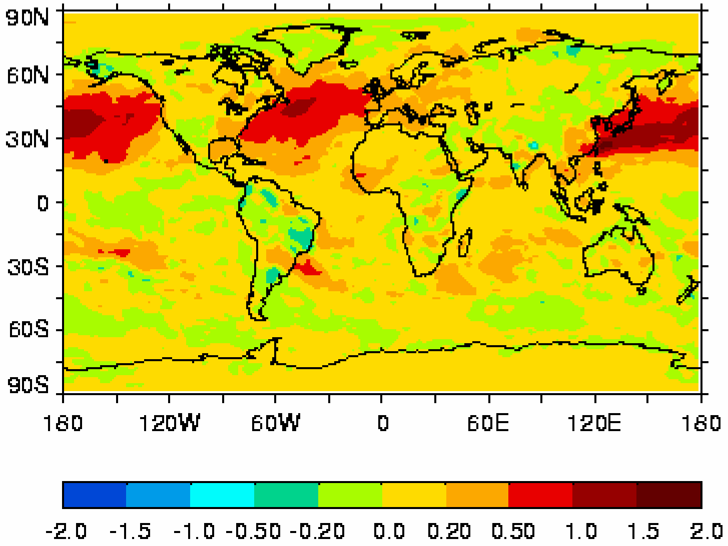


Global-mean = - 2.2
Solar = -2.5
NH/ SH = 3.6
Land/ Ocean = 0.6

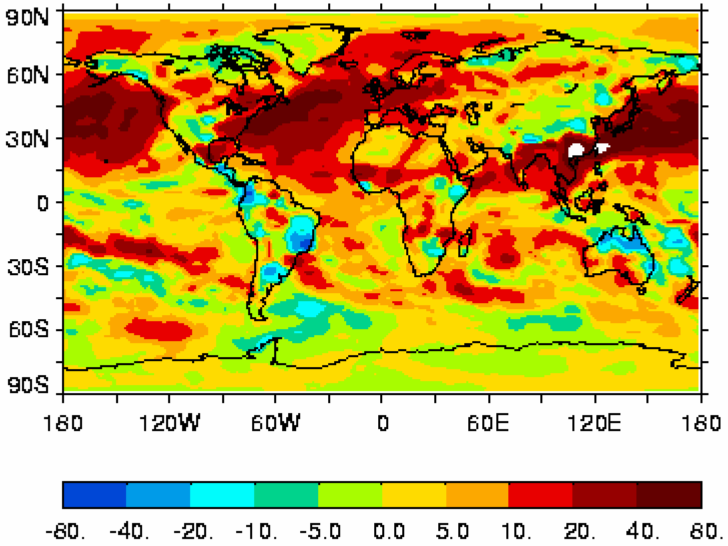
Combined effect: LW flux change



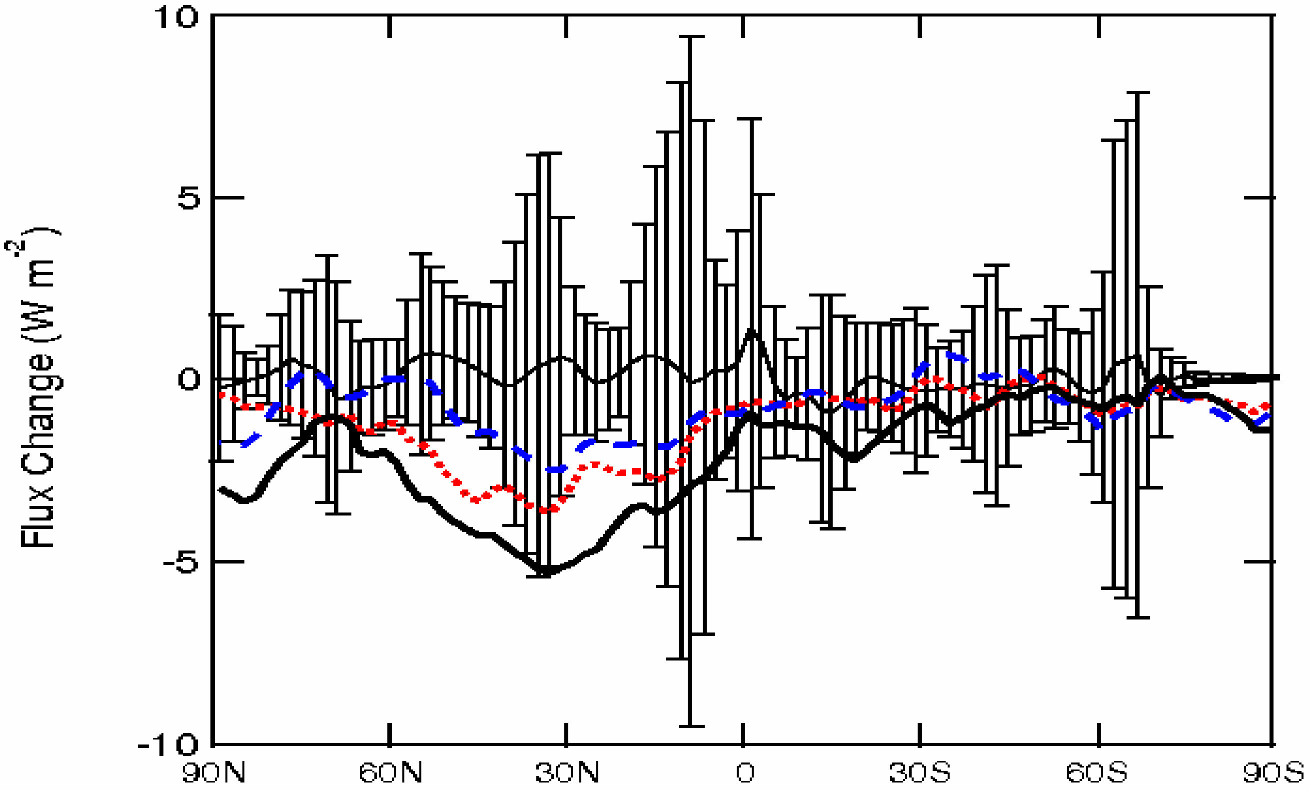
Combined effect: d (cloud amount)



Combined effect: d (LWP)



Aerosol-Cloud interaction effect



Appendix: Averaging Scheme for Cloud Effective Radius

The optical depth of a cloud, $\tau(\lambda)$, can be expressed as

$$\tau(\lambda) = \frac{3\bar{Q}_{ext}}{4\rho_w} \int_0^h \frac{LWC}{r_e} dh, \tag{1}$$

where h is the altitude and $\bar{Q}_{ext}$ is the average efficiency for extinction. r_e and LWC represent the cloud effective radius and liquid water content, respectively, both of which vary with h. If an average effective radius, $\bar{r}_e$, is defined for the whole cloud layer, Eq. 1 becomes

$$\tau(\lambda) = \frac{3\bar{Q}_{ext}}{4\rho_w} \frac{1}{\bar{r}_e} \int_0^h LWC dh. \tag{2}$$

Since the liquid water path $LWP = \int_0^h LWC dh$,

$$\tau(\lambda) = \frac{3\bar{Q}_{ext}}{4\rho_w} \frac{LWP}{\bar{r}_e}. \tag{3}$$

By equating the right-hand sides of Eqs. 1 and 3, we can derive the following expression for $\bar{r}_e$:

$$\bar{r}_e = \frac{LWP}{\int_0^h \frac{LWC}{r_e} dh}. \tag{4}$$

In the case of overlapping cloud layers, Eq. 4 is rewritten as

$$\bar{r}_e = \frac{\sum_{i=0}^{N} LWP_i}{\sum_{i=0}^{N} \frac{LWP_i}{r_{e,i}}}, \tag{5}$$

where N is the total number of cloud layers and the subscript i denotes a particular layer.

The satellite observations of the effective radius are most sensitive to cloud tops (the first unit of optical depth) [*Breon and Colzy*, 2000]. In order to make the average effective radius diagnosed from GCM suitable for comparing with satellite data, assuming that the summations in Eq. 5 begin from cloud tops (i.e., layer 0 is the top layer),

$$\bar{r}_e = r_{e,0}, \tag{6}$$

if the optical depth of the top layer is greater than 1 (i.e., $\tau_0 > 1$). Otherwise,

$$\bar{r}_e = \frac{\sum\limits_{i=0}^{n} LWP_i}{\sum\limits_{i=0}^{n} \frac{LWP_i}{r_{e,i}}},\ if\ \sum_{i=0}^{n} \tau_i < 1\ and\ \sum_{i=0}^{n+1} \tau_i > 1. \tag{7}$$

Aerosol – Cloud interactions

- What physical effects are really incorporated in an observational-based framework? How do we know since they are likely implicit? Are these frameworks useful for directly enabling GCM parameterizations?
- Are chemical composition effects necessarily incorporated by semi-empirical relationships?
- Do these observed frameworks represent steady-state, or what do they represent?

➔

Even if only the “Twomey” mechanism were occurring, do these frameworks supply adequate realism in terms of the eventual “forcing”?

➔ <u>Questions concerning how far we can take the IPCC TAR estimates.</u>

If more than “Twomey” effects are involved, need to enhance strategies.

- Modeling of aerosol-cloud interactions

➔

Sources and sinks of CLOUDS and AEROSOLS need to be consistent

e.g., the same humidity criterion or vertical velocity criterion MUST drive both aerosol nucleation and growth process AND cloud condensation and precipitation evolution

- How do we verify the different aspects involved in the aerosol-cloud interactions – e.g., cloud amount changes; LWP changes; cloud overlap changes; effective radius – all simultaneously, as a function of time?
- Perhaps, useful to focus on a specific area, known to yield such interactions, and conducting the tests of models in a temporally evolving sense?