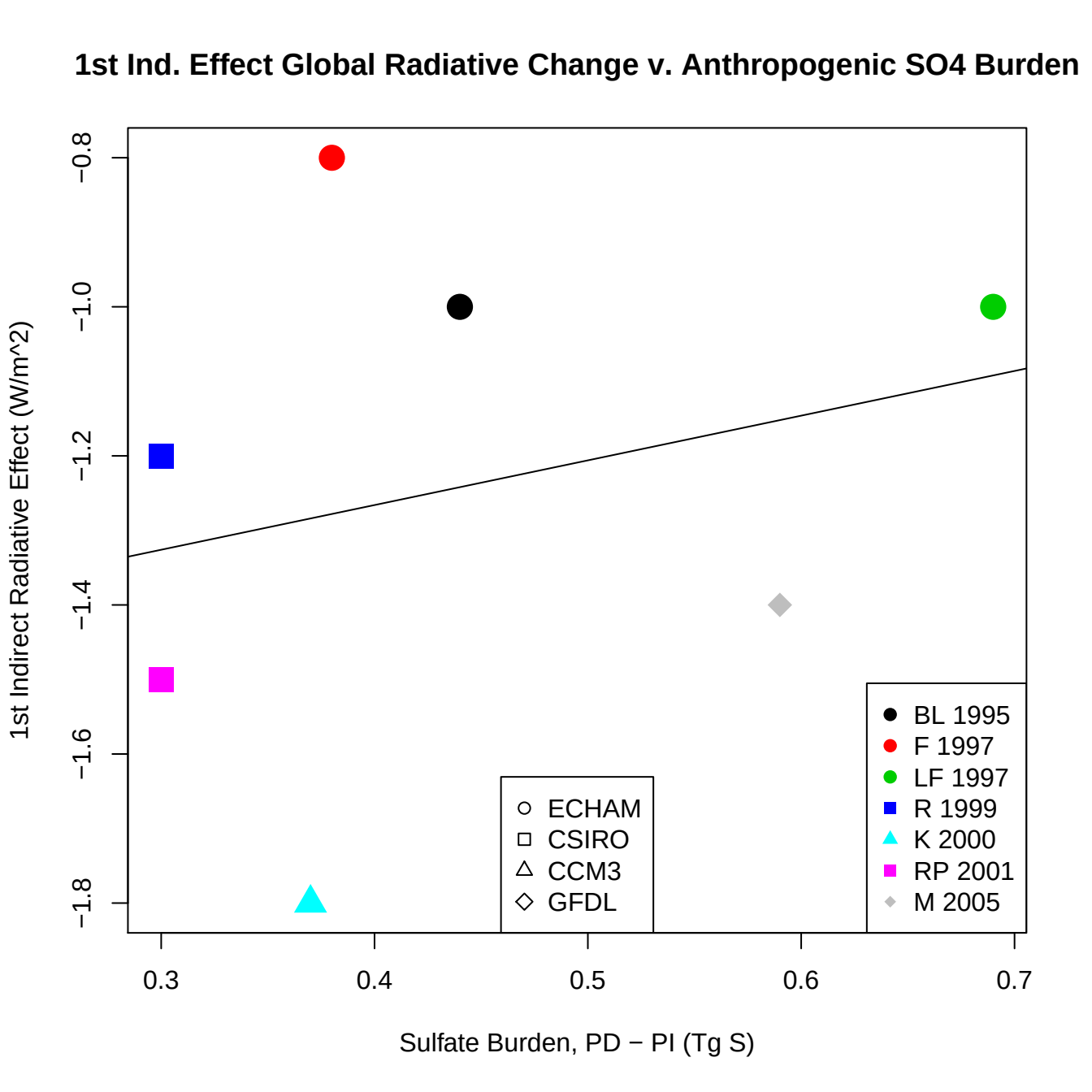
1st Ind. Effect Global Radiative Change v. Anthropogenic SO4 Burden
1st Indirect Radiative Effect (W/m^2)
−0.8
−1.0
−1.2
−1.4
−1.6
−1.8
0.3
0.4
0.5
0.6
0.7
Sulfate Burden, PD − PI (Tg S)
ECHAM
CSIRO
CCM3
GFDL
BL 1995
F 1997
LF 1997
R 1999
K 2000
RP 2001
M 2005

| PAPER | MODELS USED/SPECIFICS | KEY FINDINGS |
|---|---|---|
| Boucher and Lohmann 1995 | $SO_4$ acts as CCN → effect on shortwave radiation through cloud optical properties. Use output from **MOGUNTIA** chemical transport model as input for **two GCMs (LMD, ECHAM)**; subsequent estimates use **B&L 1995 empirical relationship between cloud aerosol # and CD #** | **Anthropogenic cloud-albedo effect (-1.0 $W/m^2$)** on same order as direct effect, but larger uncertainty (+/- 0.5$W/m^2$); highest forcings occur off polluted NH coasts |
| Feichter et al. 1997 | Calculated **$SO_4$ mass dist'n and radiative forcing** due to $SO_4$. Coupled **ECHAM-4** (GCM) to a **sulfur cycle model** which treats sulfur species (DMS, $SO_2$, $SO_4$) as prognostic variables | **Anthropogenic cloud-albedo effect of ~ -0.8$W/m^2$**, stronger than direct effect (-0.35$W/m^2$); direct forcing strongest over polluted continental regions (e.g. India), indirect forcing stronger over sea than land |
| Lohmann and Feichter 1997 | Estimated 1st and 2nd indirect effects due to $SO_4$ aerosols; used **ECHAM model with COUPL cloud microphysics** and several variations of COUPL (**COUPL-CC** – adds **cloud cover parameterization, COUPL-CC-Aut** – changes **autoconversion rate** of cloud droplets) | COUPL scheme: anthropogenic **cloud-albedo effect of -1.0 $W/m^2$**; total IE: -1.4 $W/m^2$ COUPL-CC scheme total IE: -4.8 $W/m^2$ due to larger increase in LWP and cloud cover; COUPL-CC-Aut scheme total IE: -2.2$W/m^2$ |
| Rotstayn 1999 | Used **CSIRO** (Australian GCM) with physically based cloud parameterization scheme to calculate 1st and 2nd indirect effects due to $SO_4$ aerosols; **estimate CDNC empirically** from monthly mean $SO_4$ fields | **Anthropogenic cloud-albedo effect of -1.2$W/m^2$**; total indirect effect of -2.1 $W/m^2$ due to increases in cloudiness and LWP; 2nd indirect effect **at least 25% of total indirect forcing** in each experiment |
| Kiehl et al. 2000 | Used **CCM3 (NCAR GCM)** to calculate both direct and indirect radiative forcing due to $SO_4$ aerosols; sulfur chemistry model included in CCM3, predictive $SO_4$ chemistry | **Anthropogenic cloud-albedo effect of -1.78$W/m^2$**; maximum of indirect effect during NH spring, maximum of direct effect during NH summer; large uncertainty of indirect effect depending on method used |
| Rotstayn and Penner 2001 | Used **CSIRO GCM**; updated from Rotstayn 1999 with **new mass-flux convection scheme and changes to treatment of Sc and precipitation**;$SO_4$ obtained from monthly mean dist'ns from chemical transport model | **Anthropogenic cloud-albedo effect of -1.5 $W/m^2$**; Second indirect effect of -1.3 $W/m^2$; estimated climate sensitivity parameters for first (0.78 $Km^2/W$) and second (0.79$Km^2/W$) indirect effects; regional differences for 1st and 2nd IE |
| Ming et al. 2005 | Used **GFDL model** to calculate 1st and 2nd indirect effects of anthropogenic $SO_4$; aerosol climatologies obtained from MOZART chemical transport model | **Anthropogenic cloud-albedo effect of -1.4 $W/m^2$**; second indirect effect of -0.9$W/m^2$, but statistical significance low due to natural variability; for combined indirect effect, NH responsible for 77% of total change |
| Ming et al. 2007 | Used **GFDL GCM with added airmass-based droplet number concentration** as a third prognostic variable (in addition to cloud liquid water and cloud liquid amount) in cloud scheme | **Combined 1st and 2nd indirect effect of $SO_4$ and organic aerosols of -1.8 $W/m^2$**; LWP increase by 19%, total cloud amount by 0.6%; NH midlatitude regions strongly cool |
| Lohmann et al. 2010 | **Summary of aerosol indirect effect by publication year**; use Radiative Flux Perturbation (RFP) method to account for "fast feedbacks" in the climate system that effect radiative forcing estimates | To date, 1st indirect effect effect ranges from ~**-0.2$W/m^2$ to -1.78$W/m^2$**; combined indirect effect ranges from ~**-0.3$W/m^2$ to ~-3.8$W/m^2$** |
| Chen et al. 2010 | Used **GISS III GCM** to investigate response of climate system to present day and future indirect effects | **Net indirect forcing of -1.8$W/m^2$;** global mean **surface cooling of 1.12K**; **precipitation reduction of 3.36%** |