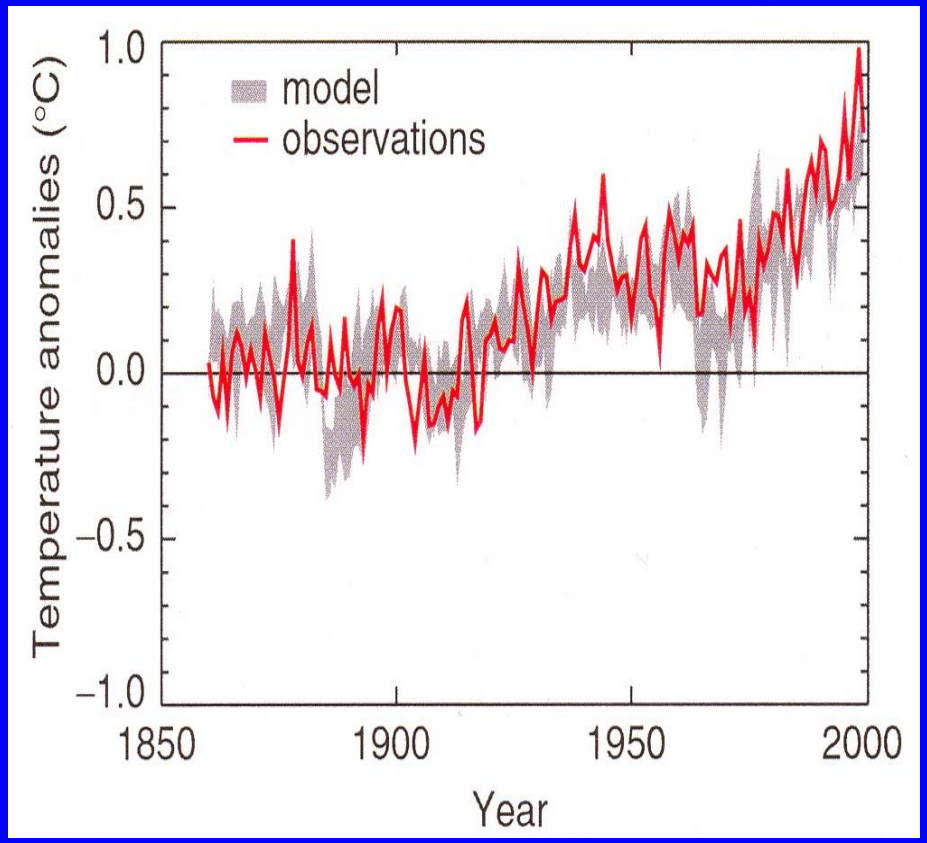
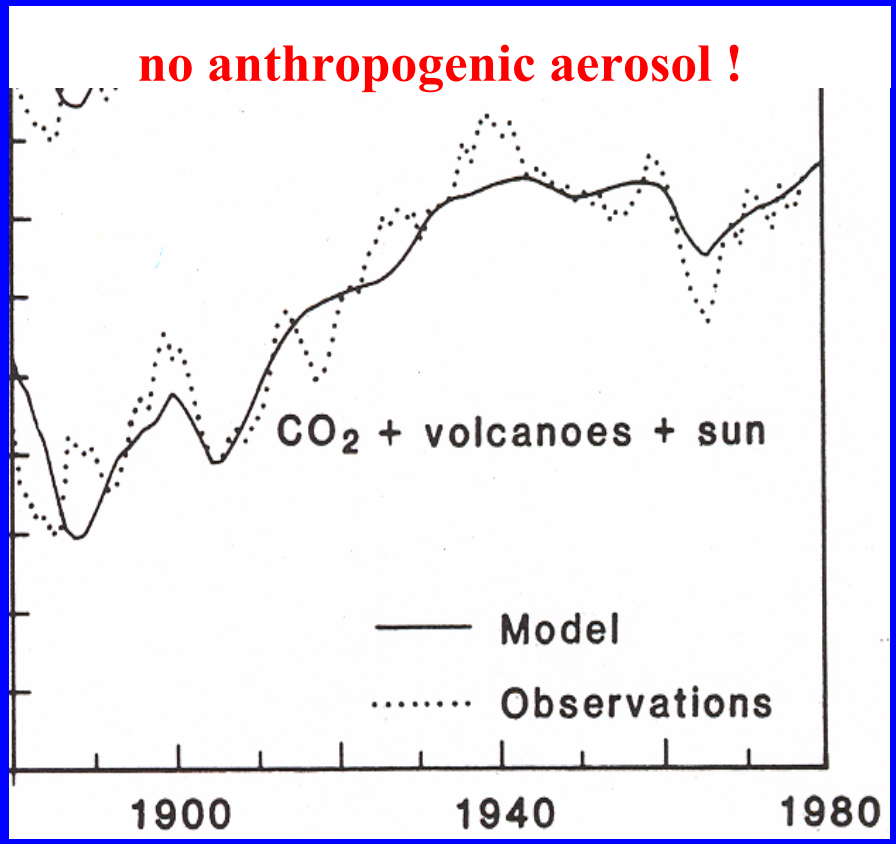
IPCC (2001)



Hansen et al. (1981)



What impact has Aerosol Science had on Climate Science?

Questions in play for Climate Science

1. Prove or disprove negative forcing larger than -2 W/m2

Do we know, independently of the temperature record, that there has been a positive and substantial forcing of climate over the industrial era?

2. Prove or disprove negative forcing larger than -1 W/m2

Do climate models simulate the 20th century temperature record for the right reasons?

3. Determine aerosol forcing to within +/-0.5 W/m2

Based on the 20th century temperature record, what is the sensitivity of Earth's climate to external forcing?

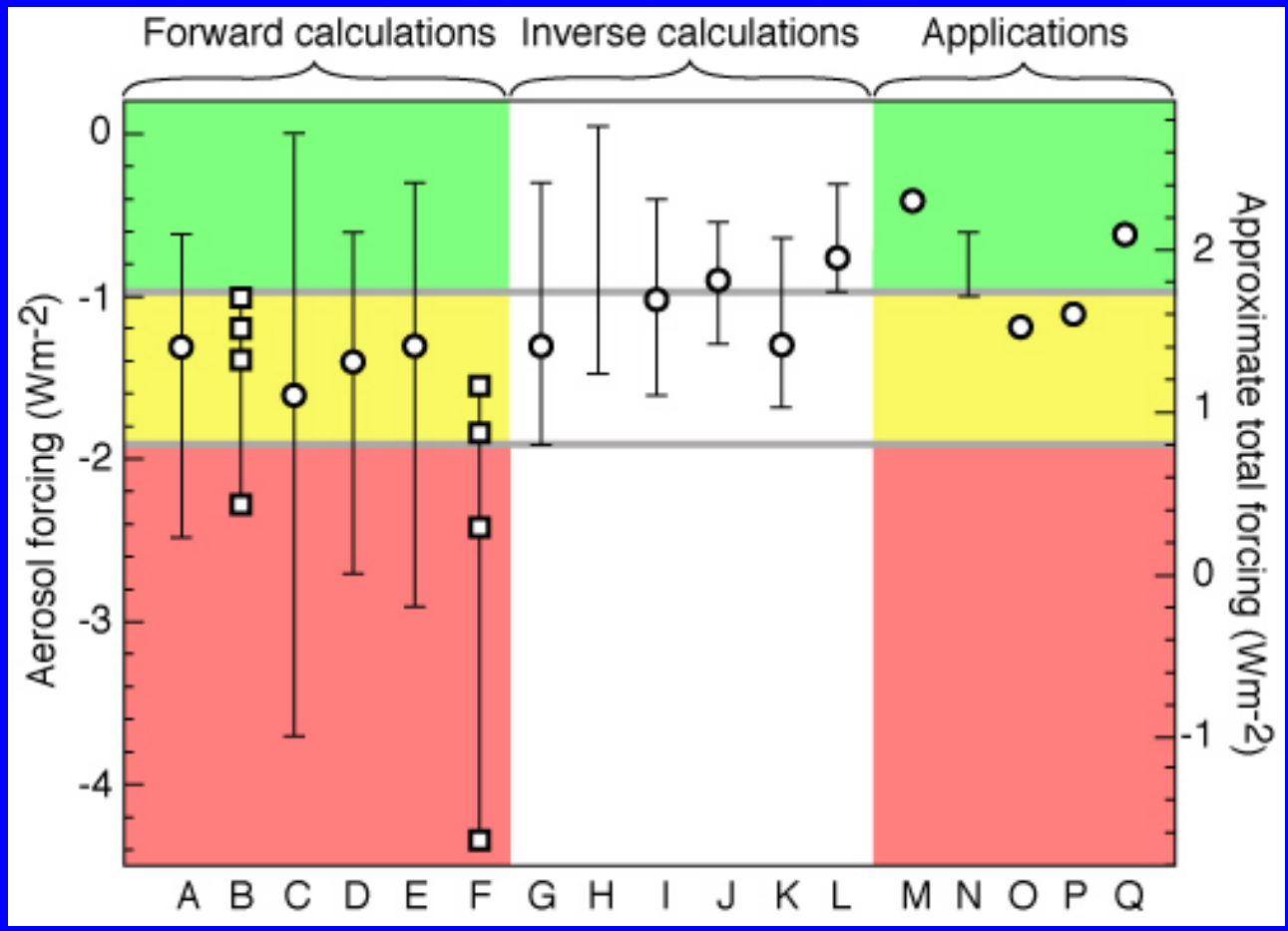
Climate Science Requirements

(if Aerosol Science is to have an impact)

1. Prove or disprove negative forcing larger than -2 W/m2 **>>> paradigm test**

2. Prove or disprove negative forcing larger than -1 W/m2 **>>> sensitivity test**

3. Determine aerosol forcing to w/i +/- 0.5 W/m2 **>>> sensitivity quantification**
[Schwartz, 2004]



Global forcing due to clear-sky aerosol

direct aerosol forcing of climate (DAFC)

$$DAFC = (1-A_c) < \delta(x,y,t)\, f_f(x,y,t)\, f_{af}(x,y,t)\, E_a(x,y,t) >$$

$< >$	global, annual average
A_c	global fractional cloud cover
δ	aerosol optical depth
E	forcing efficiency per unit optical depth
f_f	fine-mode fraction of δ
f_{af}	anthro. fraction of fine-mode
E_a	forcing efficiency of anthropogenic aerosol

} satellites

Uncertainty Requirements for Each Parameter

Reference Zero-D Model

climate forcing

$$DAFC = (1-A_c)\ \langle\delta\rangle\ \langle f_f\rangle\ \langle f_{af}\rangle\ \langle E_a\rangle + \text{correlations}$$

$$0.4 \quad 0.13 \quad 0.5 \quad 0.6 \quad 40 \quad 0?$$

Corresponding Uncertainty Requirements

DAFC target	$\langle\delta\rangle$	$\langle f_f\rangle$	$\langle f_{af}\rangle$	$\langle E_a\rangle$ (W/m^2/δ)
2 W/m^2	**+/- 0.09**	**+/- 0.3**	**+/- 0.5**	**+/- 30**
1 W/m^2	**+/- 0.04**	**+/- 0.17**	**+/- 0.24**	**+/- 15**
0.5 W/m^2	**+/- 0.02**	**+/- 0.09**	**+/- 0.12**	**+/- 7**

Forcing Efficiency per Unit Optical Depth, E

DAFC target	$<E_a>$ error
2 W/m^2	**+/- 30**
1 W/m^2	**+/- 15**
0.5 W/m^2	**+/- 7**

potentially robust retrieval product

e.g., ratio of

- broadband TOA forcing retrieval from CERES
- δ(550) retrieval from MODIS

widely reported

- many studies in literature

critical for translating δ observations to forcing estimates

- δ observations provide a strong observational anchor
- hope is that E is relatively constant over large regions and/or can be predicted with models

Factors controlling forcing efficiency

Diurnally-averaged E for an optically thin aerosol layer:
(illustrating dependencies on aerosol properties,
ambient RH, and geophysical parameters)

$$E = -DS_0 T_{at}^2 \, \omega \, \beta_{up} \left((1 - R_s)^2 - \left(\frac{2R_s}{\beta_{up}} \right) \left(\frac{1}{\omega} - 1 \right) \right)$$

<u>geophysical variables</u>
(functions of location, time, height)

- D daylight fraction
- T_{at} atmospheric transmission
- R_s surface reflectivity

<u>aerosol variables</u>
(functions of size, comp., RH)

- ω single scattering albedo
- β_{up} upscatter fraction

(S_0 is the solar constant)

Forcing efficiency: definitional clarity

$$E = \frac{\Delta F \ (W/m^2)}{\text{aerosol optical depth}}$$

Comparison of previous studies requires common definition. Here . . .

- top-of-atmosphere
- clear-sky regions only
- 24-hour average
- flux is shortwave (solar) only
- optical depth is at 550 nm wavelength

Forcing efficiency: current estimates

Method	Domain	Number of studies	Number of regions		δ (550nm)	DARF W/m2	E W/m2/δ
modeling	global oceans	2	---		0.098 (12%)	-2.4 (28%)	-25 (16%)
satellite	global oceans	5	---	mean →	0.125	-5	-40
				std/mean →	(13%)	(8%)	(17%)
satellite	regional, annual	1	6		0.112 (45%)	-5.1 (45%)	-44 (30%)
satellite & sunphot.	regional intensives	3	3		0.94 (82%)	-23 (76%)	-27 (11%)
				σ_{sp} m-1	b	ω	
in-situ	regional, annual	1	4	39 (52%)	0.121 (8%)	0.938 (3%)	-81 (2%)
in-situ	regional, intensives	4	6	77 (93%)	0.111 (9%)	0.877 (8%)	-68 (14%)

RED: extensive parameters BLUE: intensive parameters

from Table 1 of Anderson et al. (2004)

Relation to component mass forcing efficiency

$$\Delta F = m E_m = m \alpha_m E_\delta = \delta \; E_\delta$$

observational constraints

α_m(m^2/g): extinction efficiency

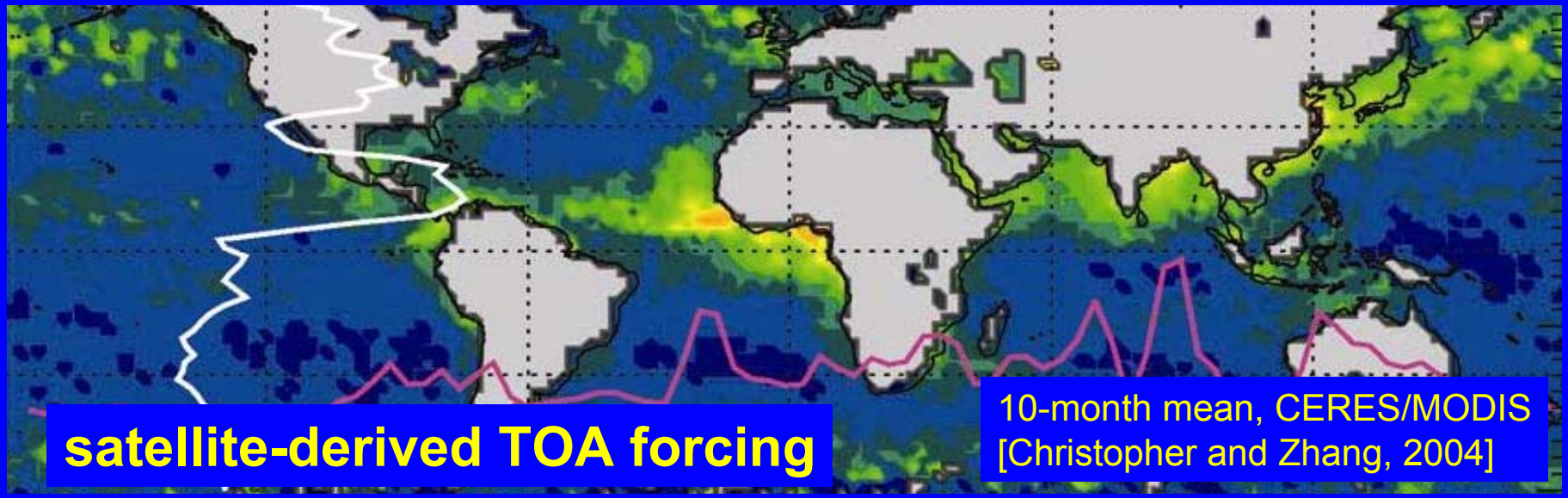
$$E_m = \alpha_m \; E_\delta$$

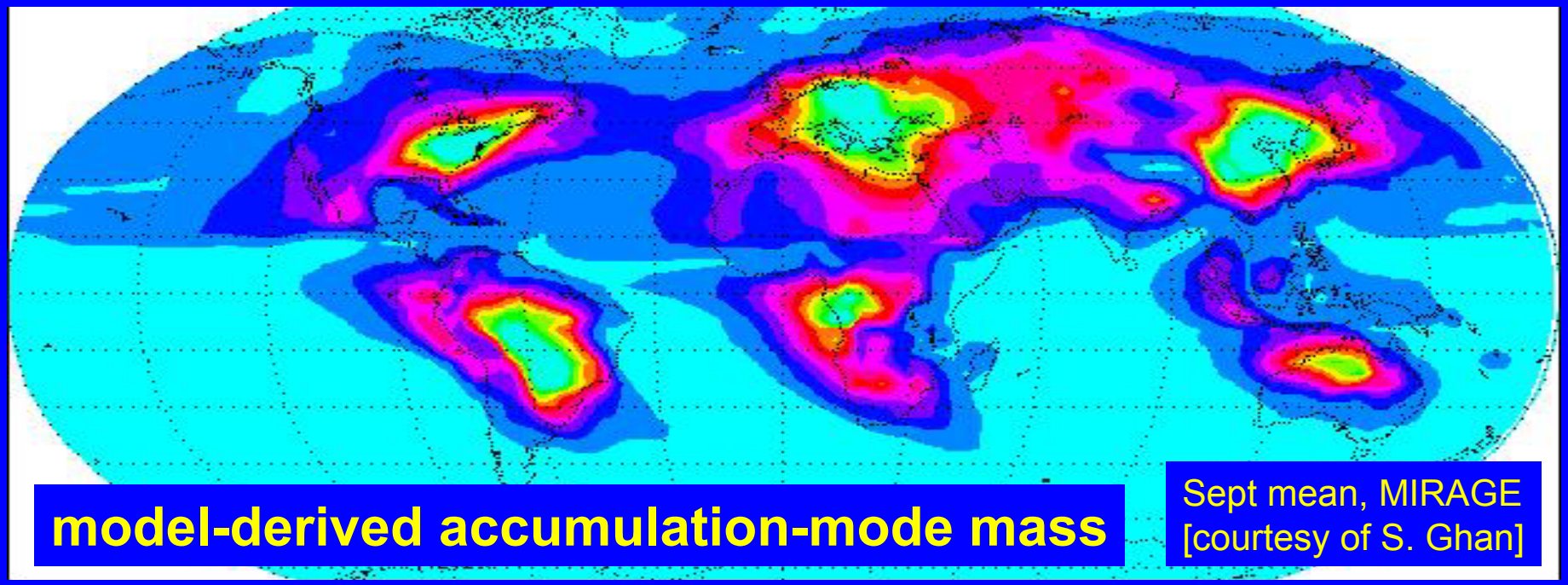
60-600

3-10
hydration (dry size)

20-60	range
R_s, ω (g, δ)	sources of uncertainty

What fraction of climate (anthro) forcing is over the ocean???





Forcing Efficiency per Unit Optical Depth, E

DAFC target	$\langle E_a \rangle$ error
2 W/m^2	**+/- 30**
1 W/m^2	**+/- 15**
0.5 W/m^2	**+/- 7**

(more) Issues

No explicit validation program
(though much validation work has been done for flux and δ retrievals)

Retrieval (so far) has only been applied to the ocean

Sample fraction over the global ocean is generally small
raising the potential for bias.

Results depend strongly on cloud-clearing scheme
[Loeb et al., 2004]

Need models or methods to go from observables to desired parameters:
- instantaneous to diurnal average
- E to E_a