Aerosols in the CCSM3.1 coupled-carbon climate model Dust flying leap.

Natalie Mahowald, Keith Lindsay, Daniel Rothenberg, and many others: Peter Thornton, Scott Doney, Keith Moore, Jeff Lee, Gordon Bonan, Jim Randeron, Inez Fung….

Aerosol interactions in coupled carbon climate model

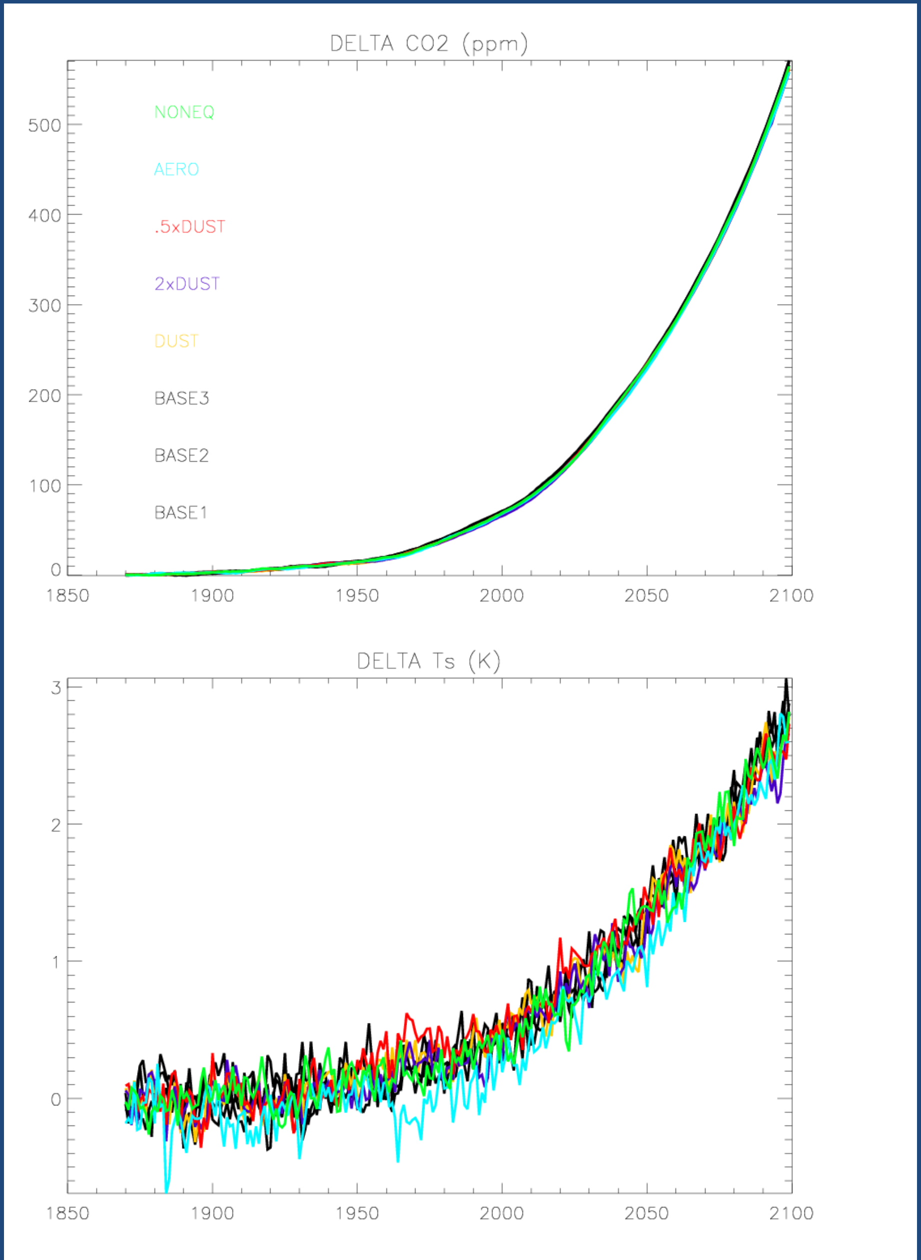
- Abstract:
  - Include dust, as well as separately simulations with aerosols (sulfate, volcanoes, BC/OC and ozone changes).
  - 0^{th} order: no impact of having aerosols in model on climate or carbon: this is in contrast to results of Hadley center
  - There are statistically significant small changes in global numbers, as well as regional differences
  - Ocean productivity changes significantly as a result of dust
  - Also show sensitivity studies of not being in equil and running with co2 trajectories (instead of interactive co2), and these do not show big differences.

New simulations (using model described in Thornton et al., in press)

- BASE
  - 2 additional ensemble members
- NON-EQ
  - start with slightly drifting conditions: does it matter? The answer is no, except for where the carbon starts out.
- TRAJ
  - Use trajectories of co2 instead of interactive co2 (here we chose the trajectory from the BASE1 run). In other words, is there any problem with the methodology in the IPCC long term runs? The answer is NO, there's no difference, except small regional differences, so this won't show up in too many plots.
- DUST
  - Interactive source, transport, deposition of dust: impacts LW and SW radiation, iron deposition to oceans.
  - Note that mean dust distribution here different than prescribed dust, also LW included here, not in prescribed case.
- 2xDUST: increase source of dust by 100% over 230 years
- 0.5x DUST: decrease source of dust by 50% over 230 years
- AEROSOLS: include interactive dust, sulfate, plus changes in volcanoes, BC and OC aerosols, from that specified for the CCSM3.1 IPCC simulations (Meehl et al., 2003), these simulations also include changes in stratosphere ozone.

Why 2x dust, 0.5 x dust?

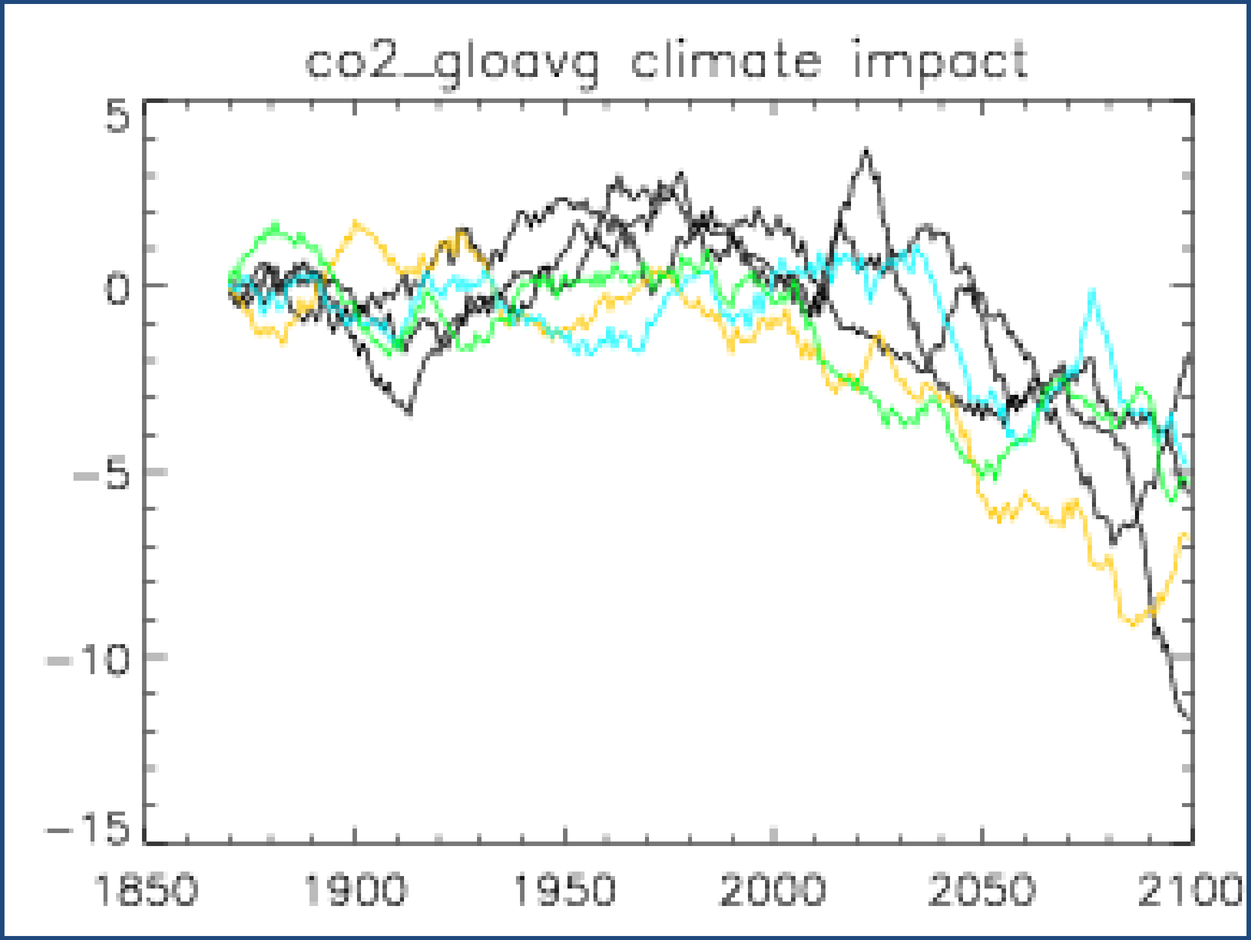
- We do not know whether dust is increasing or decreasing (Mahowald and Luo, 2003; Mahowald, 2007; Mahowald et al., 2009)
- Climate:
  - Drying: could be causing increase in dust (Mahowald, 2007)
- CO_2:
  - CO_2 fertilization of plants could be causing an increase in productivity of plants , especially in arid regions (Smith et al., 2007) or not (Caspersen et al., 2007)
- Human land use
  - Perturbing soils by agriculture or pasture locally changes ability to produce dust (Gillette et al., 1988; Neff et al., 2005)
  - Global importance not known (0-50%): e.g. Prospero et al., 2002; Tegen et al., 2004; Mahowald et al., 2004
- Human water use
  - E.g. Dry Owens Lake (Reheis et al.,)
  - No trend in dust seen in Aral Sea (Mahowald et al, 2007), although the size of lake has been shrinking…
- Uncertainties in human impacts on dust still large: +/- 50%



Aerosol interactions do not make a difference to 0th order

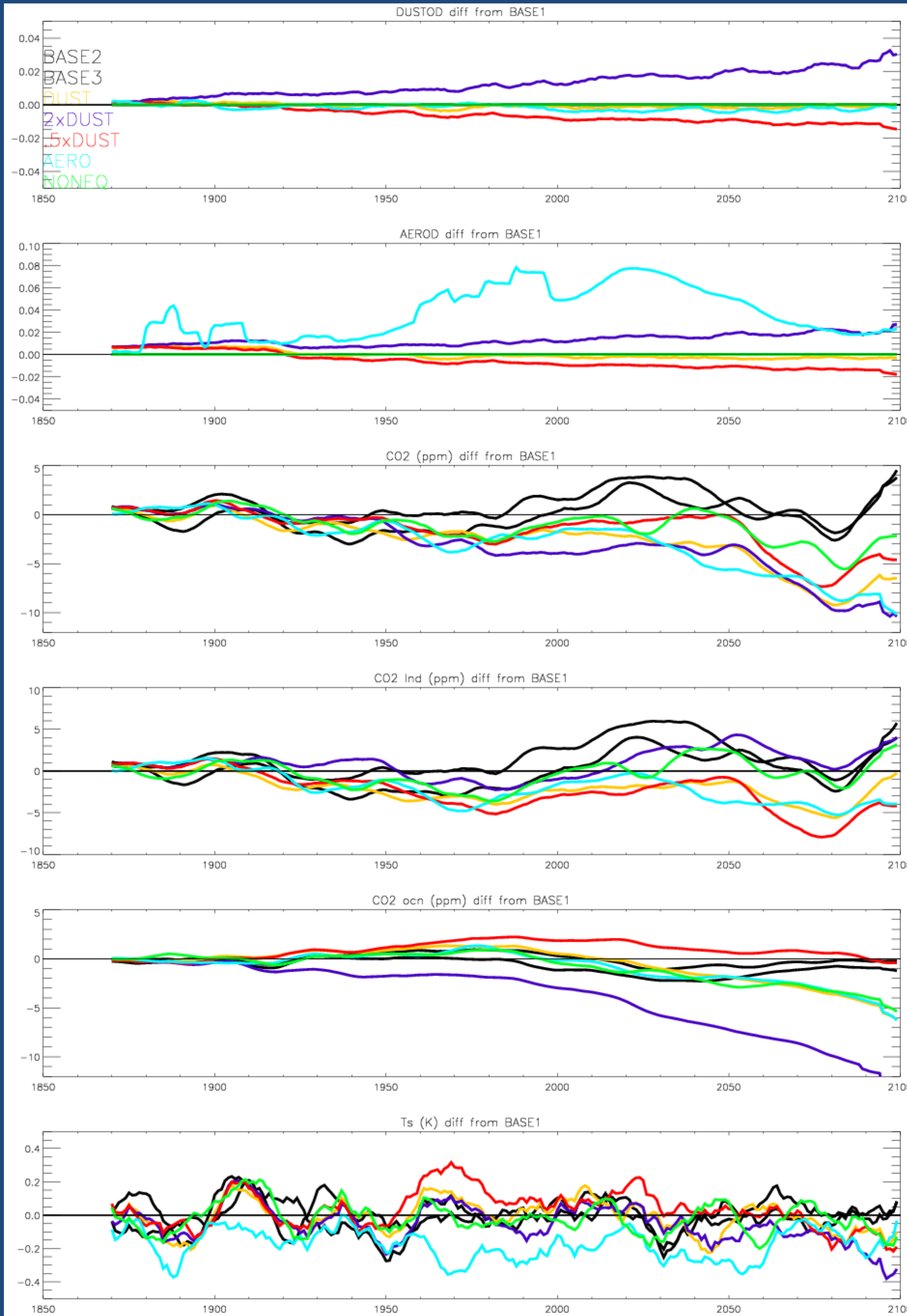
But statistical significant changes to global Ts, regional climate, and where the carbon goes do occur.

Climate effect:
Radiative coupled co2 - non coupled



Co2 ppm

How does the evolution of the system change with aerosols?



Dust AOD

AOD

Total CO2

Land CO2 tracer (atmos co2 from land)

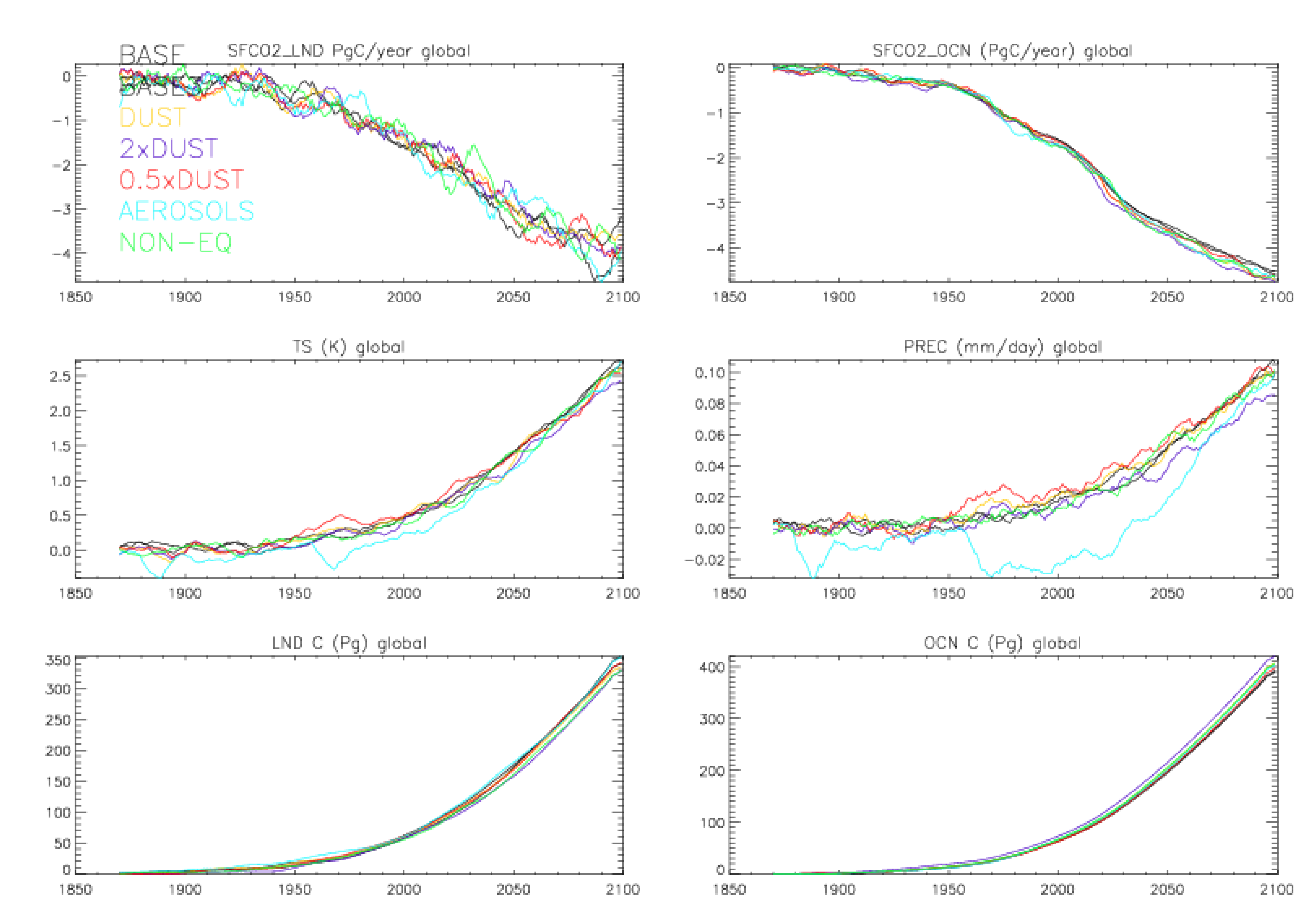
Ocean CO2 tracer (atmos co2 from land)

Ts(K)

Differences in the difference between transient and preindustrial for this case, versus BASE1.

1. Dust does not respond to climate much in these runs (need to hit source hard to get changes in dust)
2. CO2 differences at 2100 are <10ppm
3. Ocean and land CO2 respond oppositely
4. our model is less sensitive to the inclusion of aerosols than Jones et al., 2003

Another view of the global picture from the last page: BASE2 is missing from this plot.



I will compare our land and ocean fluxes to Gurney et al./Gruber etal, estimates

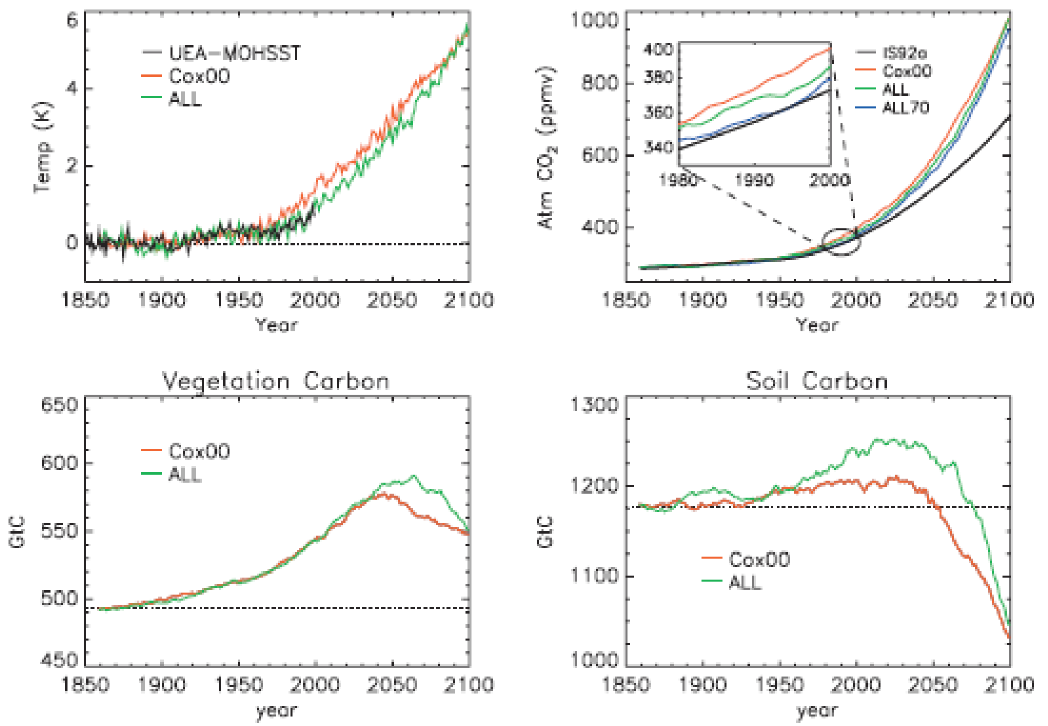
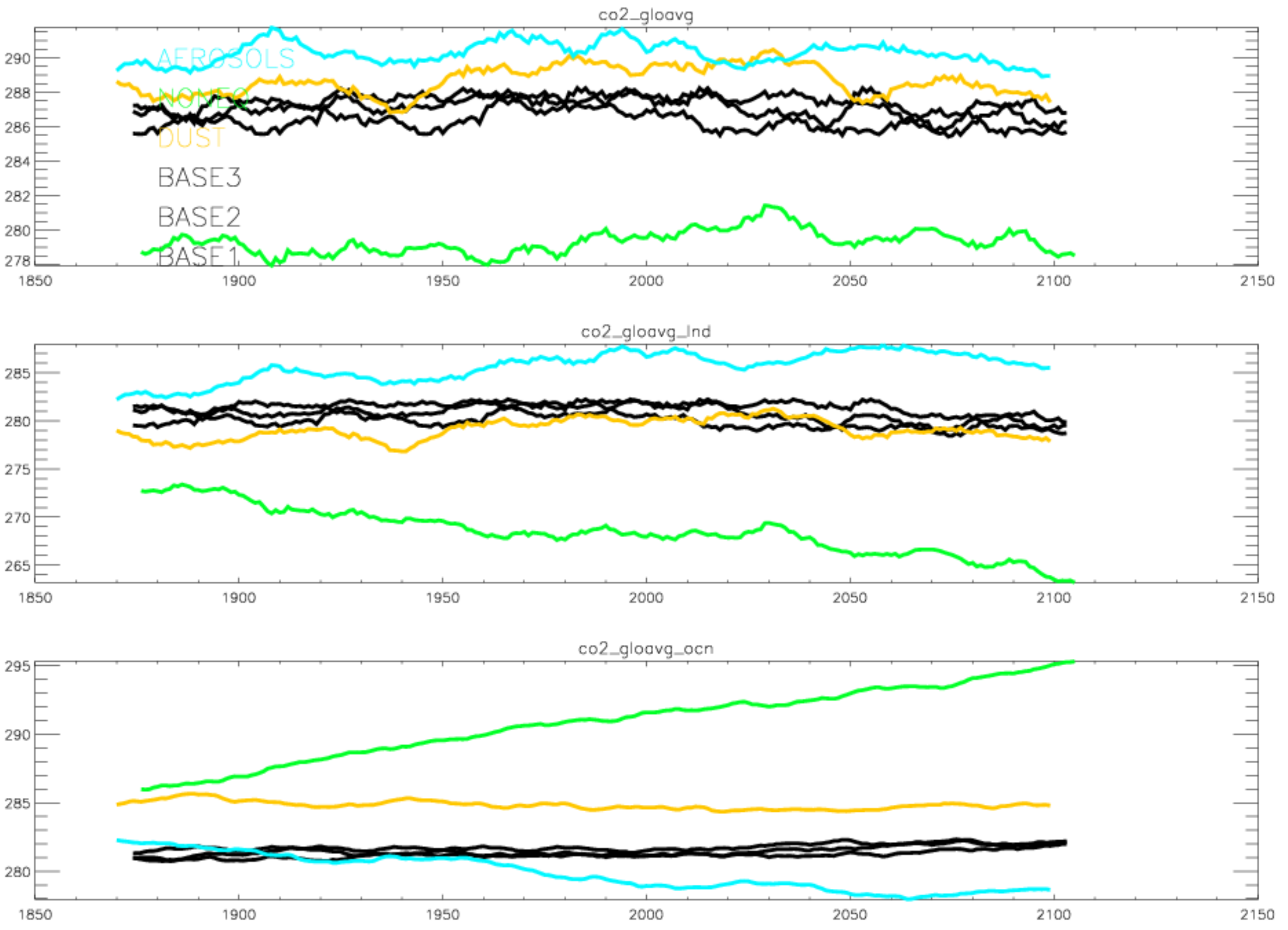


Figure 1. Modelled historical and future changes of climate and the carbon cycle from simulations including non-greenhouse gas forcing (green lines, from ALL) and excluding non-greenhouse gas forcing (red lines, from Cox00). (a) Global temperature increase compared to observations (black line), (b) Change in atmospheric CO_2 compared to standard IS92a concentrations (black line) and the ALL70 simulation (blue line), (c) vegetation carbon store, (d) soil carbon store.

Jones et al., 2006

Non-equilibrated system

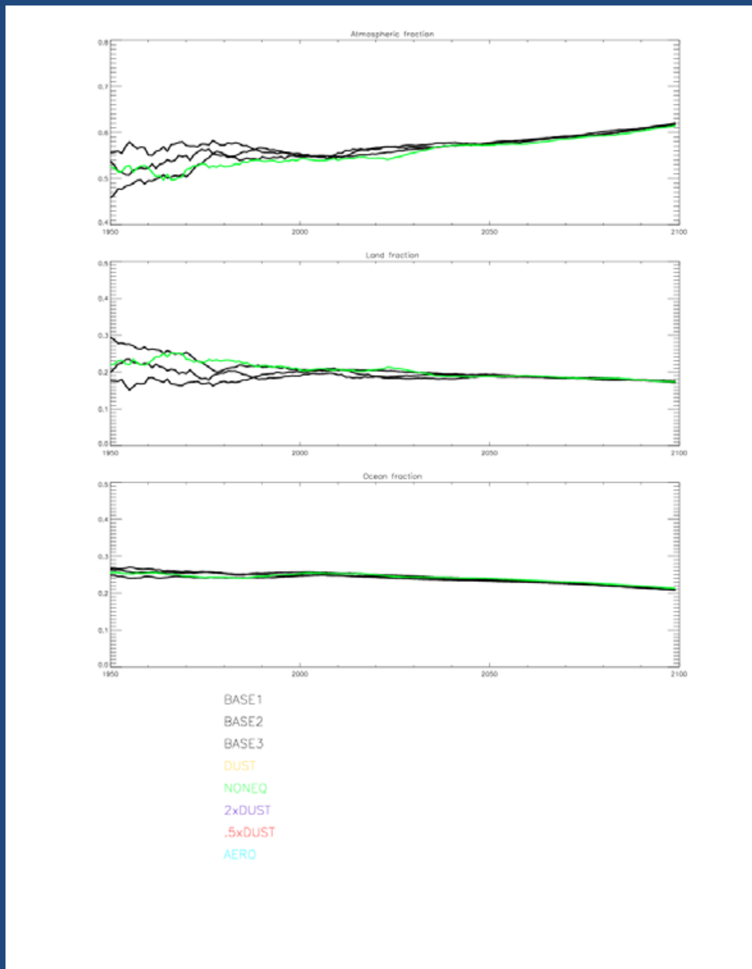


Non-eq: ocean and land respond oppositely.

Out of equil: 10ppm/230 years:

21 GtC/230 years= 0.09 GtC/year disequil in one variable.

(CCSM4 drift over 200 years: 0.033PgC/year)



As Thorton et al said: our model has too much carbon staying in the atmosphere.

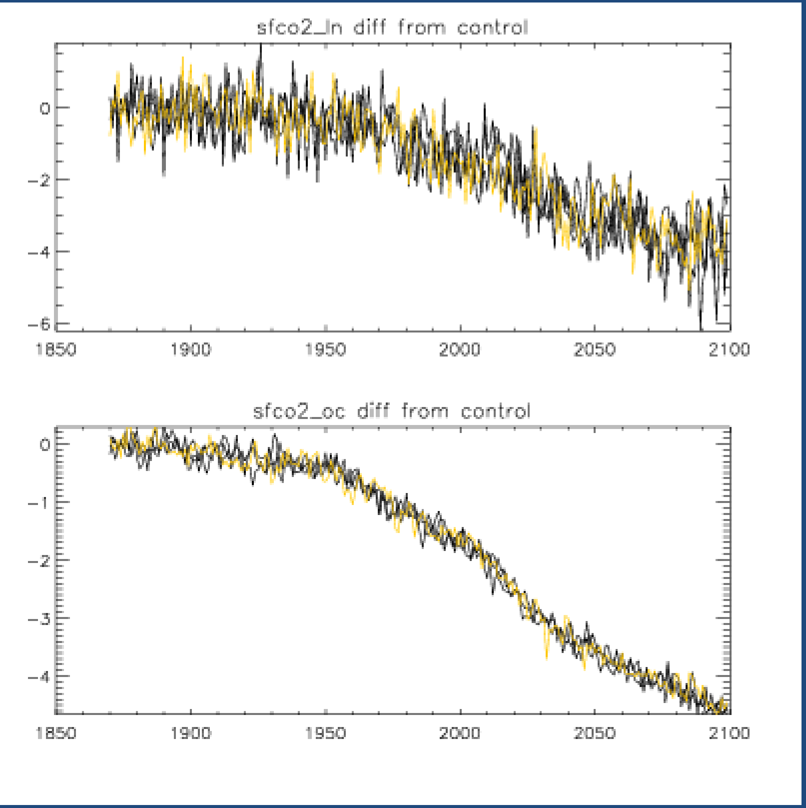
Non-equil doesn't make too much difference at 2100, but does slightly change transitions along the way: here too much in land, and ok in ocean for first 50-100 years.

Also will look at spatial differences.

Notice that here we have corrected for drifts in the control (much worse if we didn't)

I'm not sure we'll show this, but only discuss.

Co2 trajectories instead of interactive



Using trajectories instead of interactive show no statististical signif difference at global scale (not shown in real paper).

Black are 3 BASE: yellow is ‘trajectory fixed co2’ case.

No stat sig in atmospheric fraction (not shown).

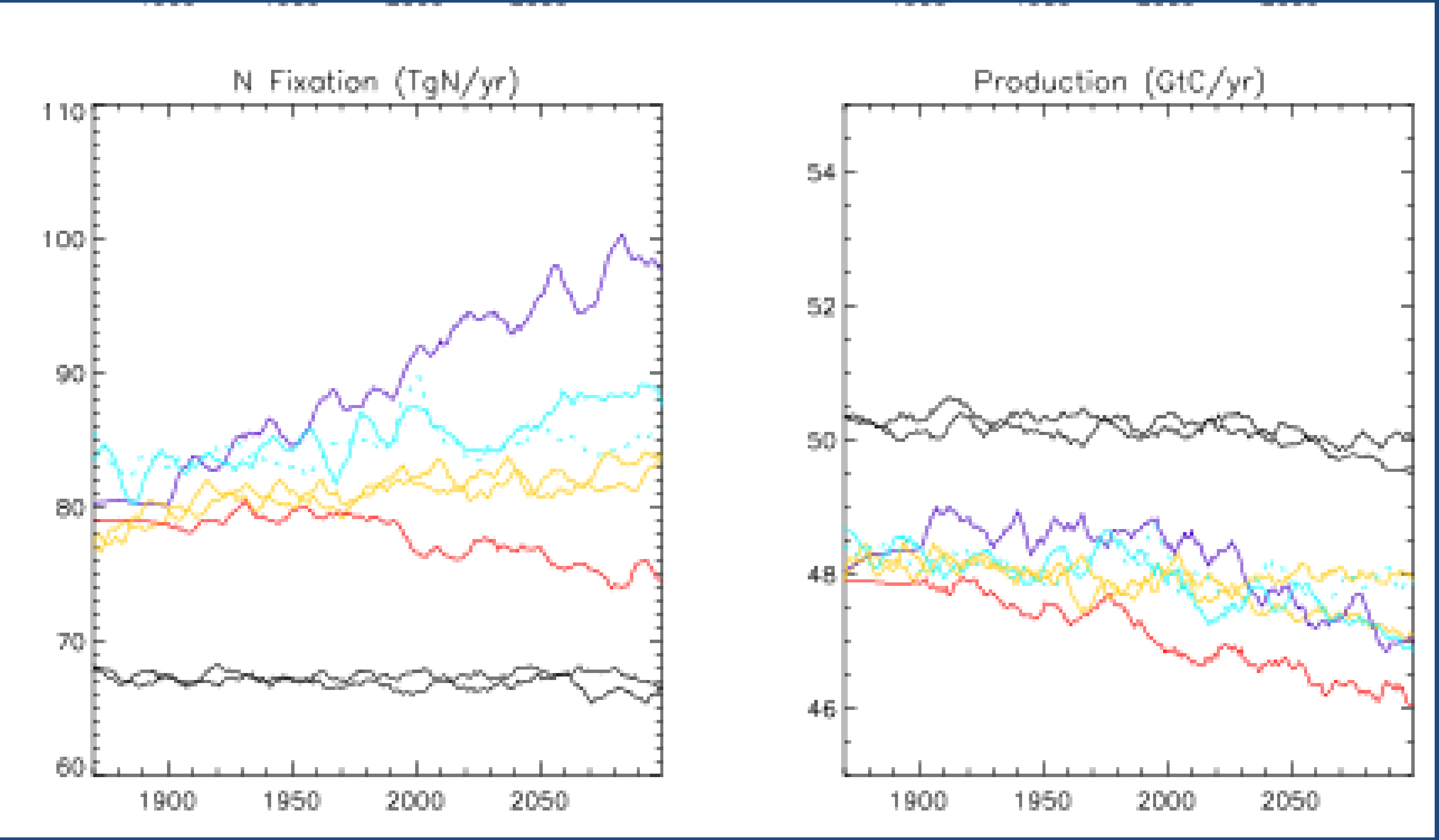
Feedbacks on climate

Friedlingstein et al., 2006 approach

Feedback Analysis

case	alpha	beta_o	beta_l	gamma_o	gamma_l	gain
BASE1	0.0056	0.88	0.68	-5.62	2.54	0.0046
BASE2	0.0059	0.88	0.66	-4.64	4.06	0.0022
BASE3	0.006	0.88	0.64	-2.78	6.5	-0.008
aerosol	0.0054*	0.94*	0.65	-3.18	10.29*	-0.0162
dust	0.006	0.92*	0.60*	-5.32	17.2*	-0.0284
non_eq.	0.0056	0.85*	0.73*	-5.31	5.4	-0.0002

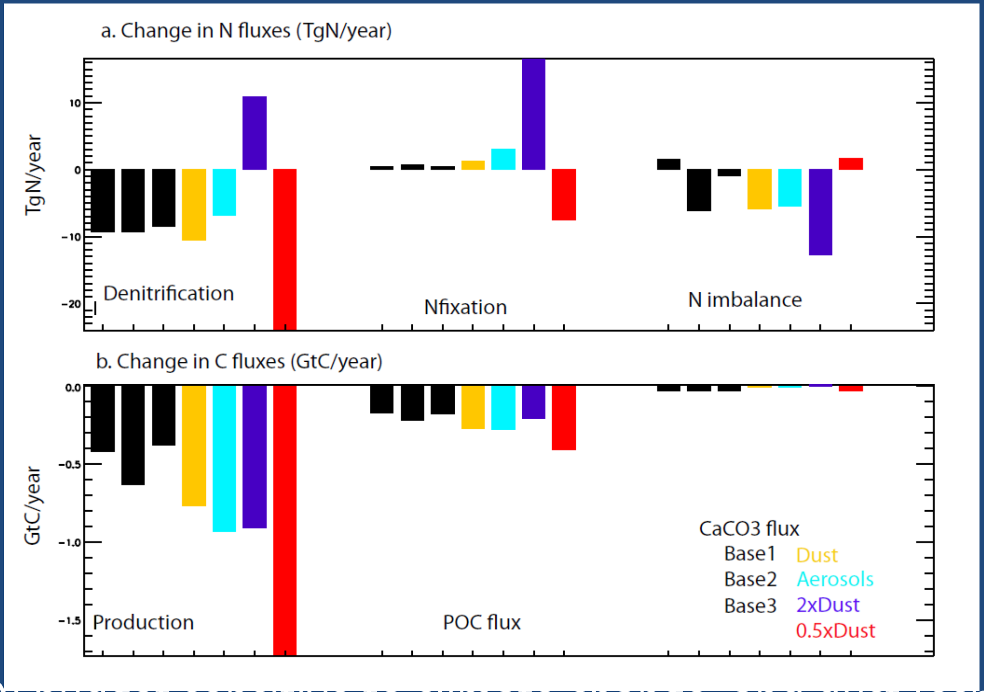
Feedbacks between carbon and climate system change with dust and aerosols



N Fixation (TgN/yr)
110
100
90
80
70
60
1900
1950
2000
2050
Production (GtC/yr)
54
52
50
48
46
1900
1950
2000
2050

Changes in ocean cycle

changes between 2080-2099 and PI control for each case



N budget sensitive to climate change, and dust (especially latter). More dust increases nfixation and denitrification. Climate change increases N fixation slightly and reduces denitrification.

C budget: co2 uptake reduced in all cases: perhaps a little more when aerosols and dust are prognostic.

Same data as previous

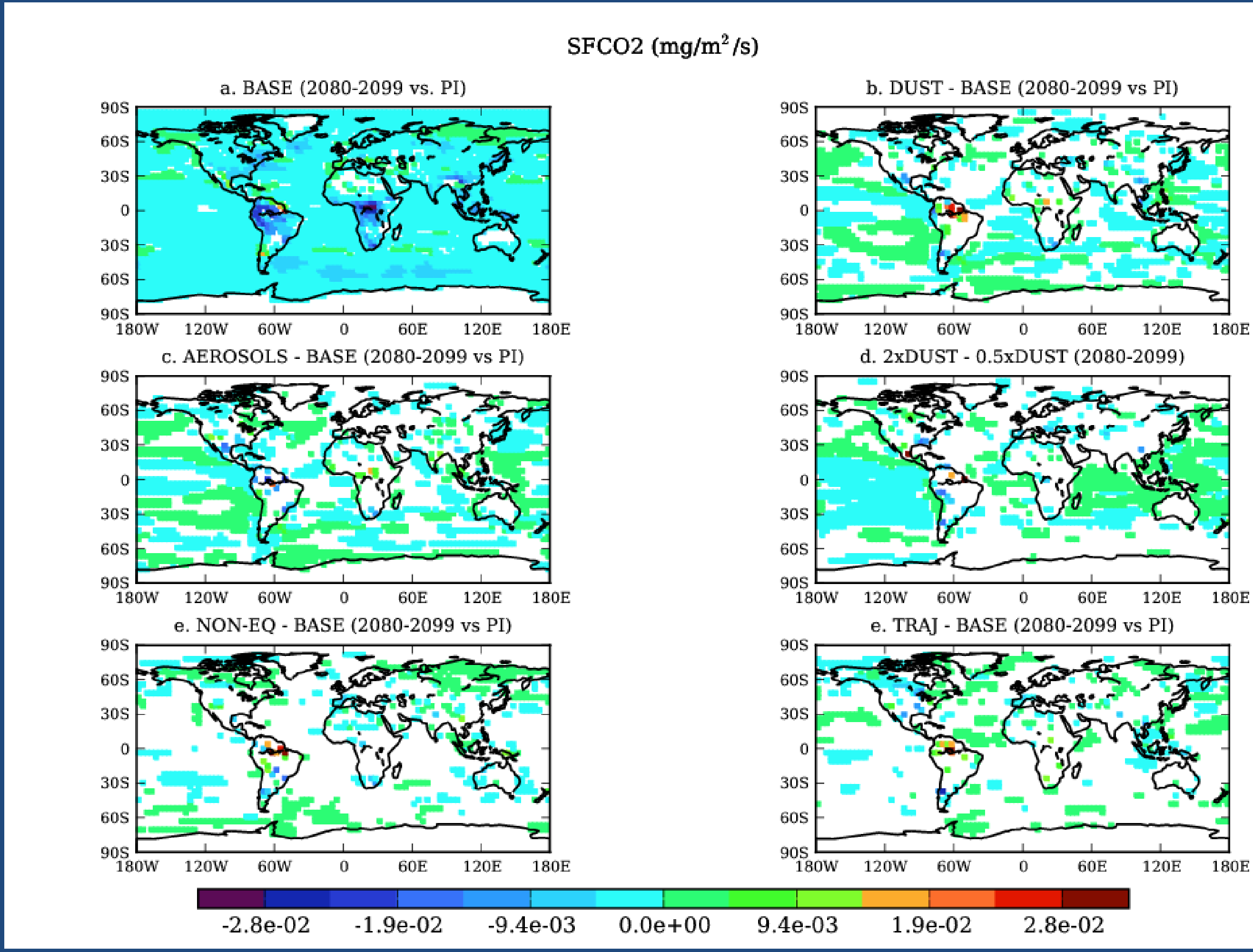
	Denitr(TgN/y)	NFixat(TgN/y)	NImbal(TgN/y)	Produc(GtC/y)	POCExp(PgC/y)	CaCO3Exp(PgC/y)	S-A CO2(GtC/y)		
control cases:	---------------	---------------	---------------	---------------	---------------	-----------------	---------------		
BASE	71.37	66.65	288.24	50.03	6.43	0.45	-0.07	286.26	29.16
DUST	102.73	82.29	289.32	47.93	6.1	0.39	0.05	284.89	38.77
AEROSOLS	106.84	85.61	284.43	48	6.12	0.4	0.01	287.64	49.78
change (2080-2099 minus PI)									
	Denitr (TgN/y)	Nfixation (TgN/y)	NImbal(TgN/y)	Produc(GtC/y)	POC Export (PgC/y)	CaCO3Exp(GgC/y)	S-A CO2(GtC/y)		
BASE1	-9.28	0.43	1.61	-0.42	-0.17	-0.03	-4.32	476.03	77.28
BASE2	-9.28	0.79	-6.18	-0.63	-0.22	-0.03	-4.33	476.99	73.23
BASE3	-8.46	0.51	-0.93	-0.38	-0.18	-0.03	-4.37	477.75	78.16
DUST	-10.51	1.22	-5.84	-0.77	-0.27	-0.01	-4.64	471.71	77.44
Aerosols	-6.87	3.01	-5.45	-0.93	-0.28	-0.01	-4.52	469.51	70.58
2x dust	10.86	16.57	-12.8	-0.91	-0.21	0.01	-4.67	470.69	92.74

Why changes in productivity?

- Dust changes
- Mixed layer depth changes
- (show later)

2080-2099 –PI: more uptake of CO2 in most places: outgassing terrestrial high latitudes

(only stat sig results shown at 95%)



Including interactive aerosols shifts co2 regionally

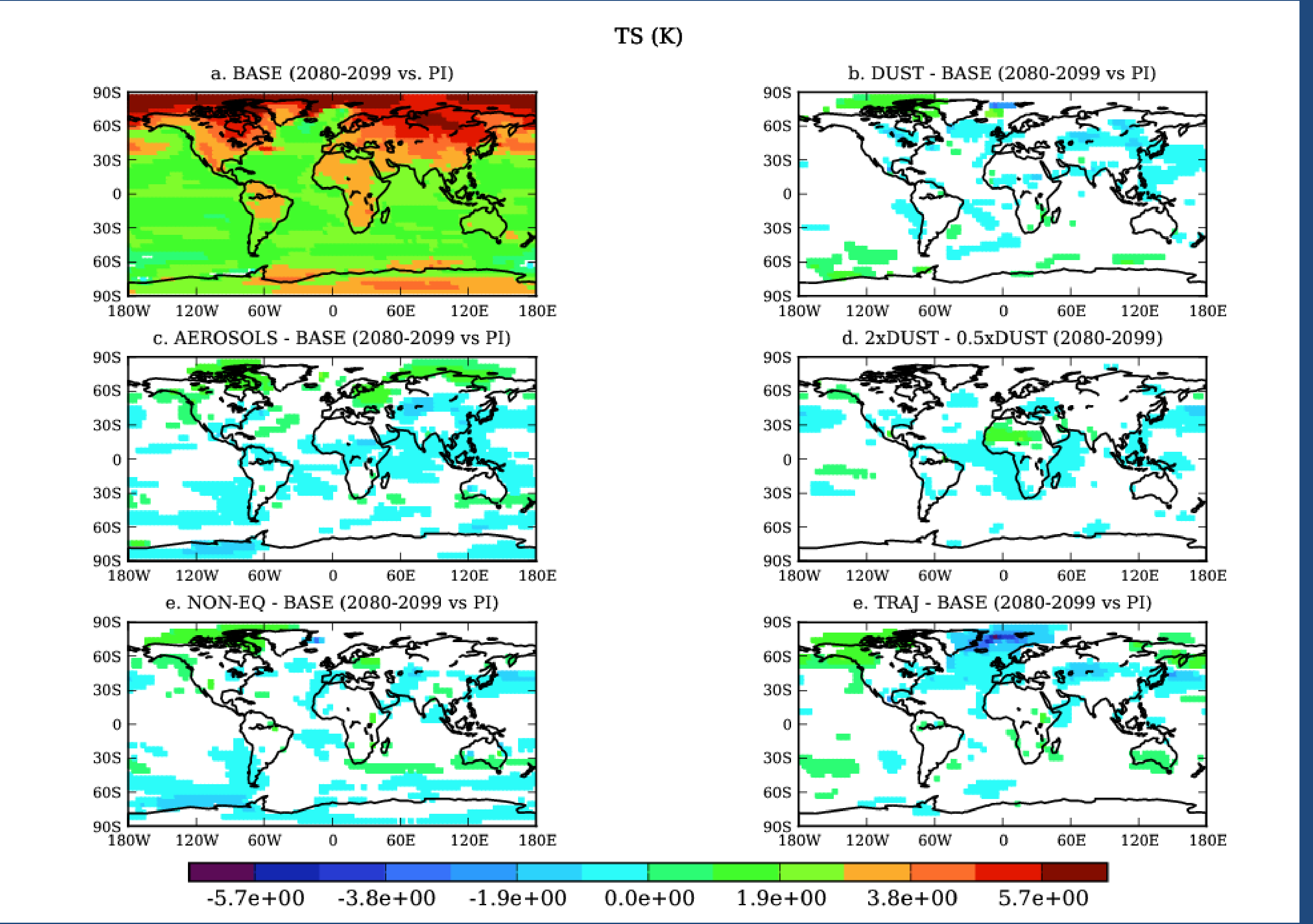
Why:

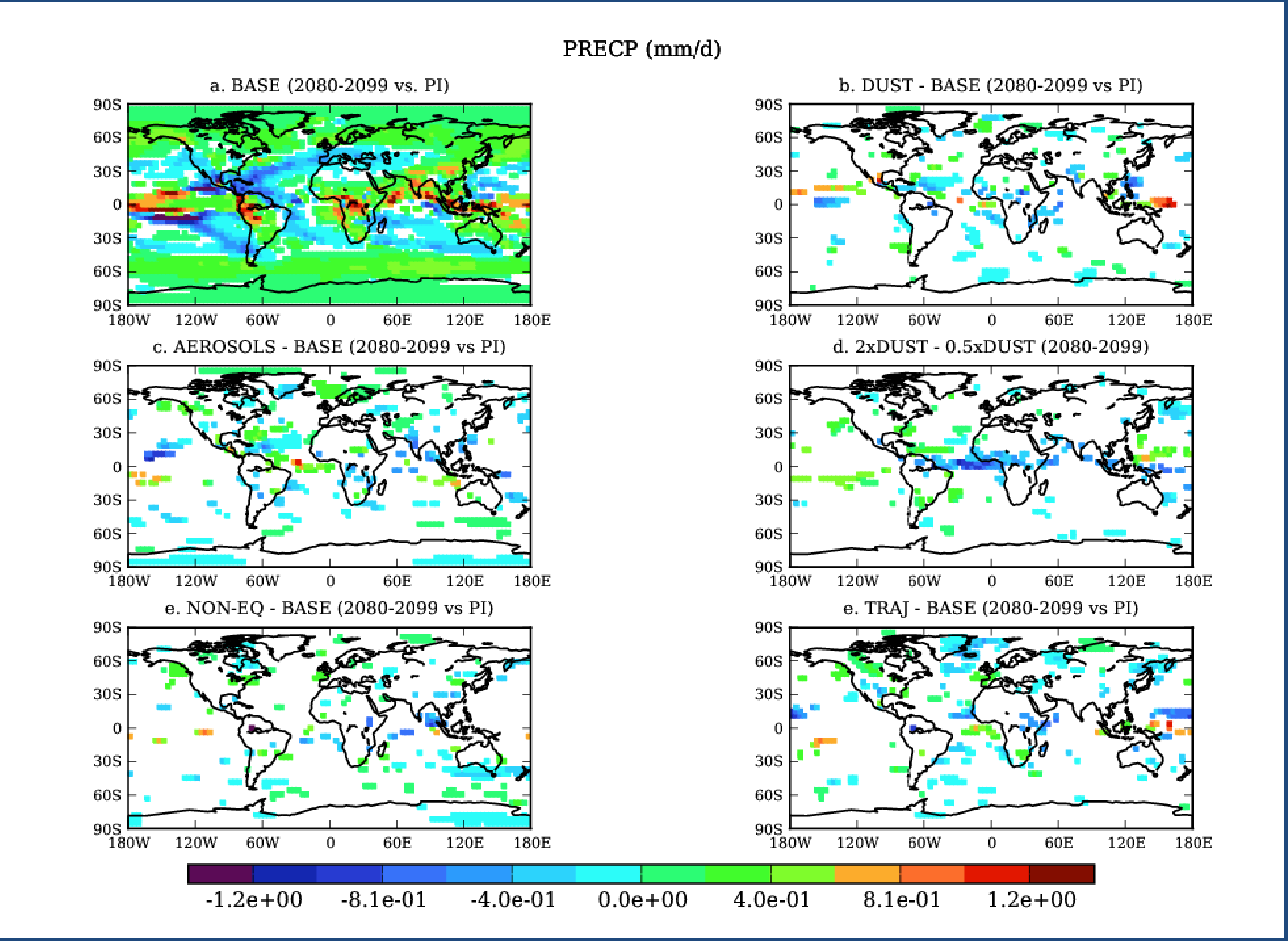
Aerosols:

1. Fertilize oceans
2. Reduce insolation, increase diffuse radiation
3. Change climate (Precip, Ts, wind stress)

2080-2099 –PI: warming in high latitudes

Aerosols and/or dust: change regional patterns

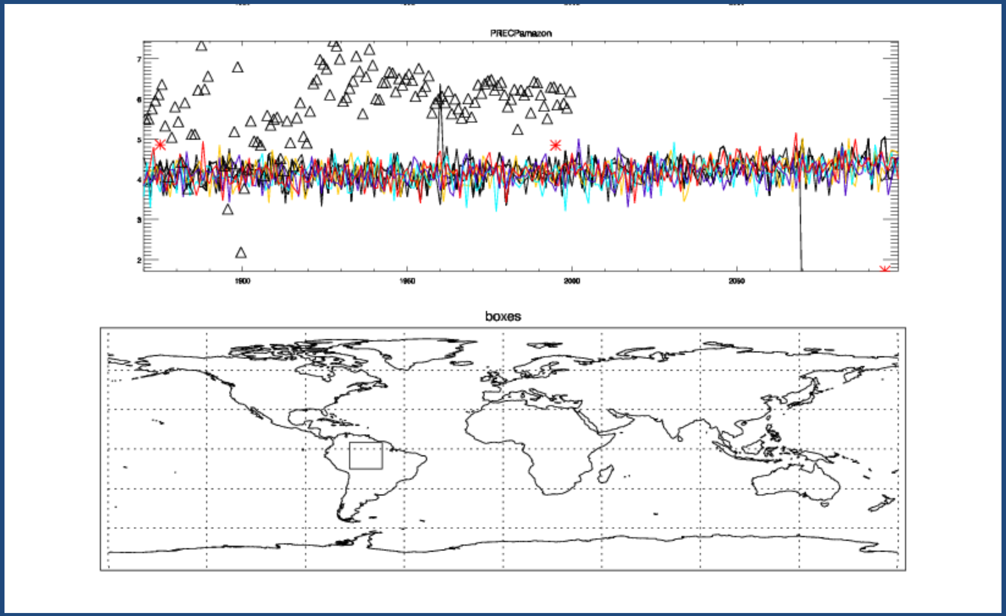




Higher CO2 shifts precipitation patterns: more precip over some regions, less over others

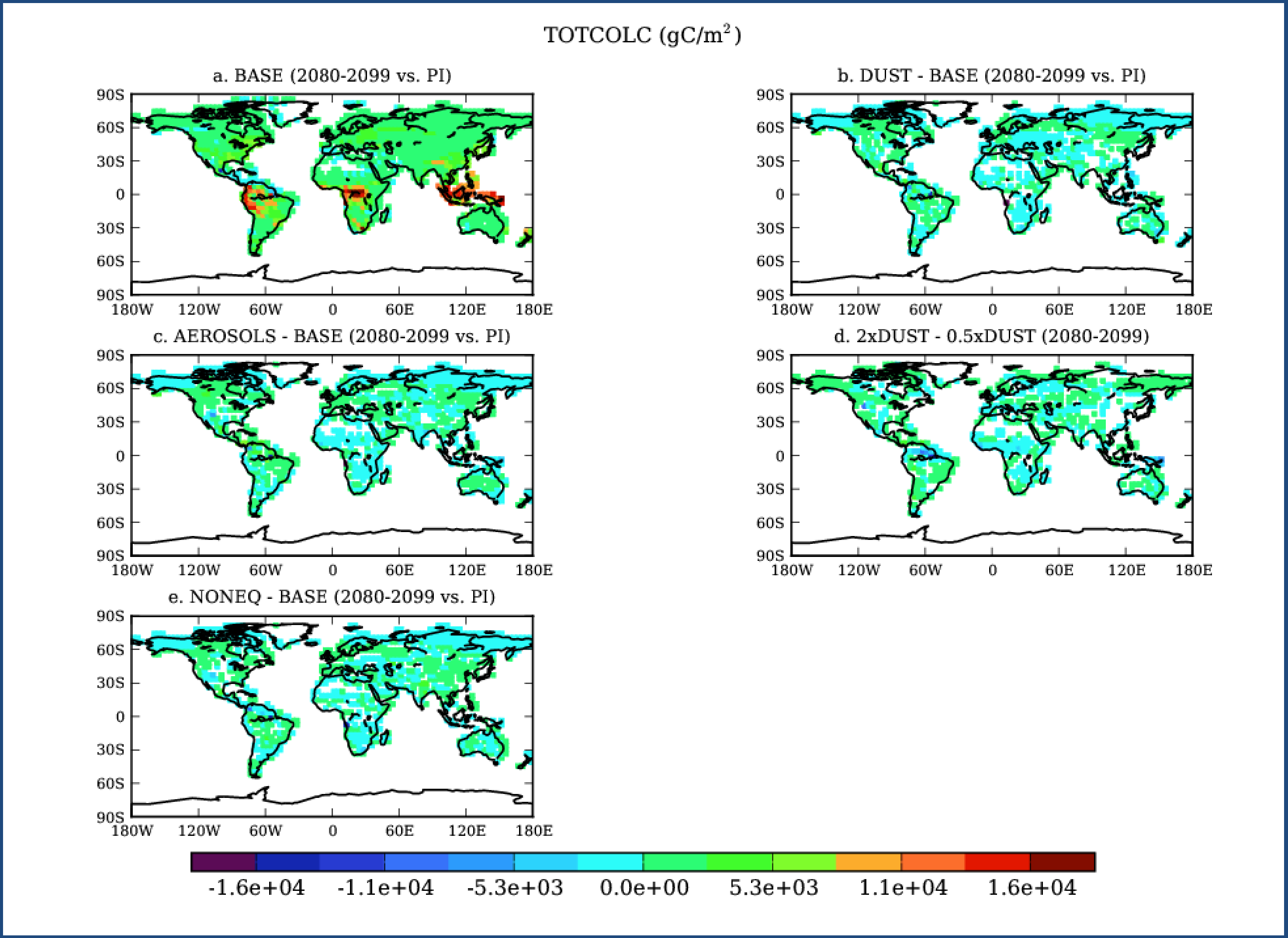
Inclusion of aerosols changes patterns

Amazon precip response to co2 and aerosols: not much in our model, contrasts with hadley center (triangle: obs, red star: Hadley center Cox et al., 2003).



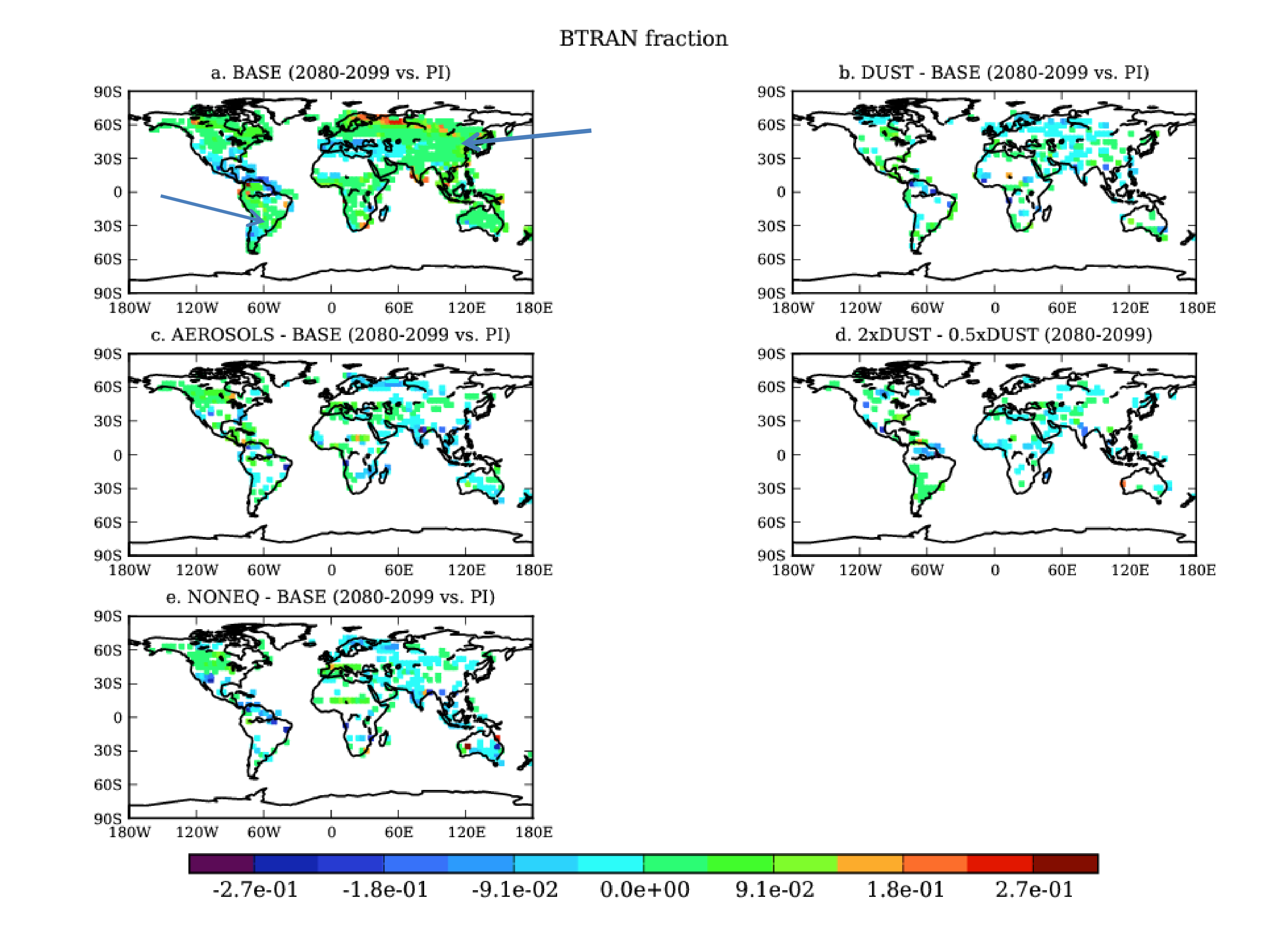
Land response

2080-2099 –PI: Mostly more biomass (exceptions exist)



Shifts in biomass occur with aerosols or dust

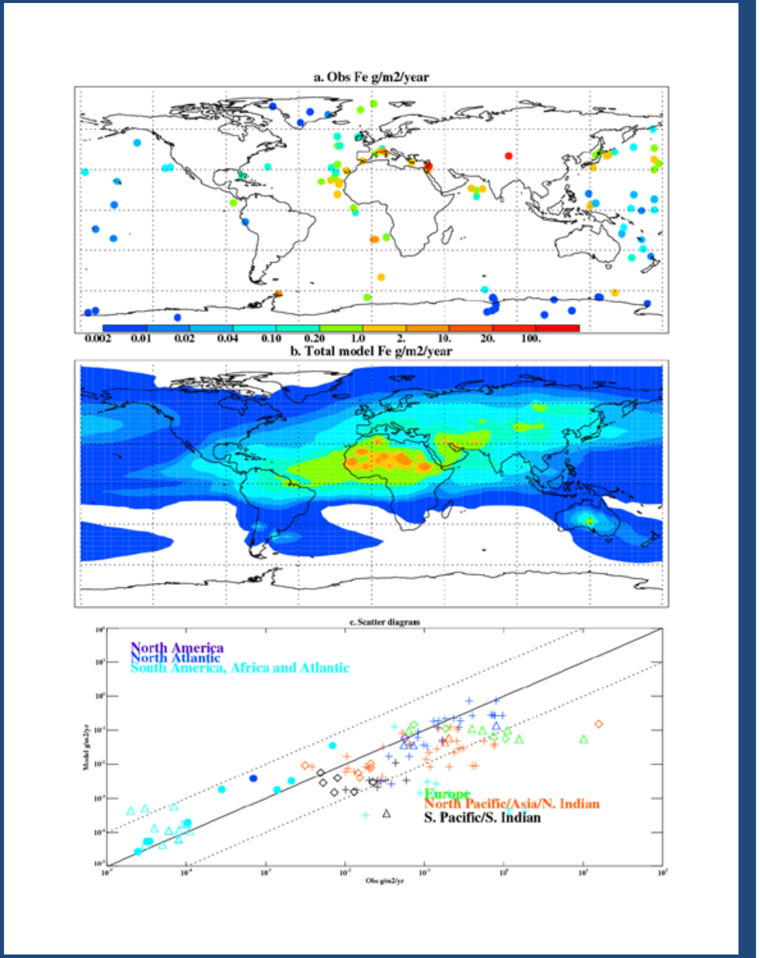
Btran: soil moisture effect on photosynthesis: 1.0 (wet), 0.0 (dry)

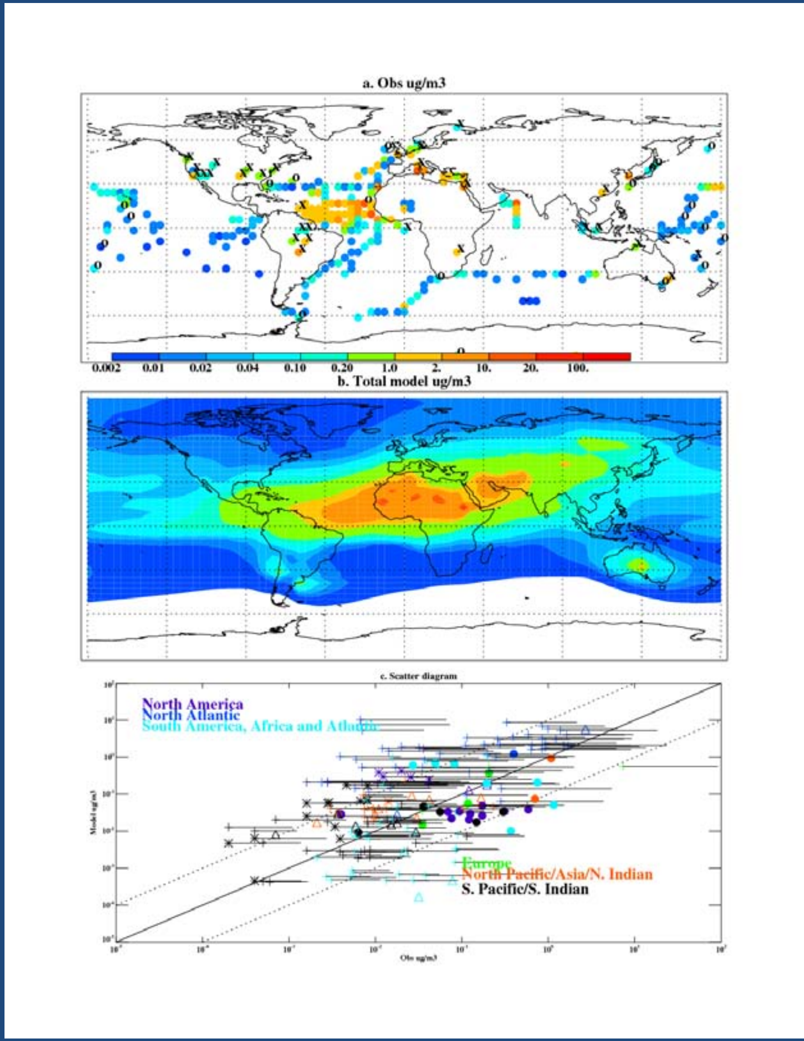


Aerosols make wetter, dust ma some areas wet some drier

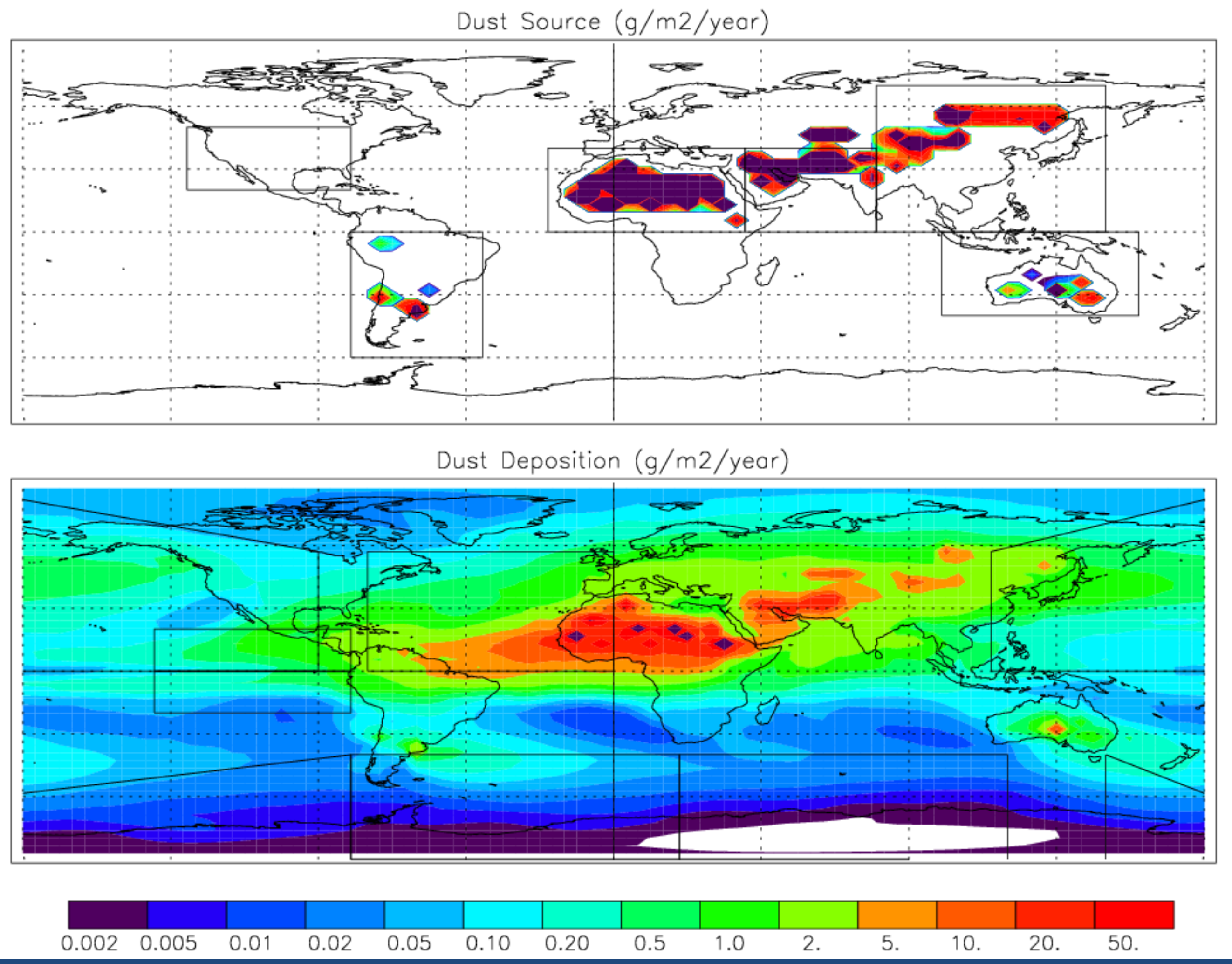
Dust response

Dust in model is 'tuned' to be reasonable against observations



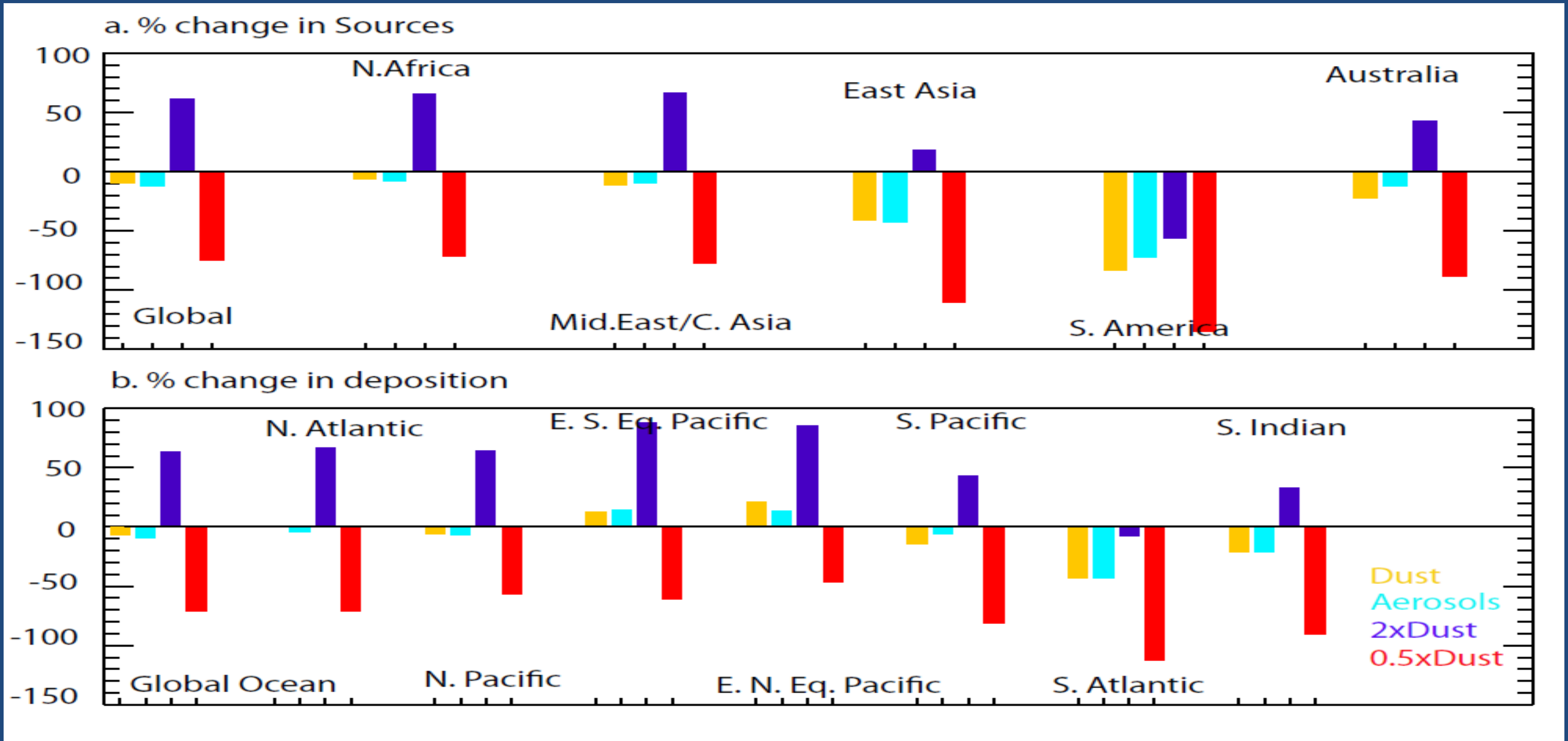


Response of dust in model



These boxes show location of regions on next two pages

Dust source and deposition (% change over 230 years)

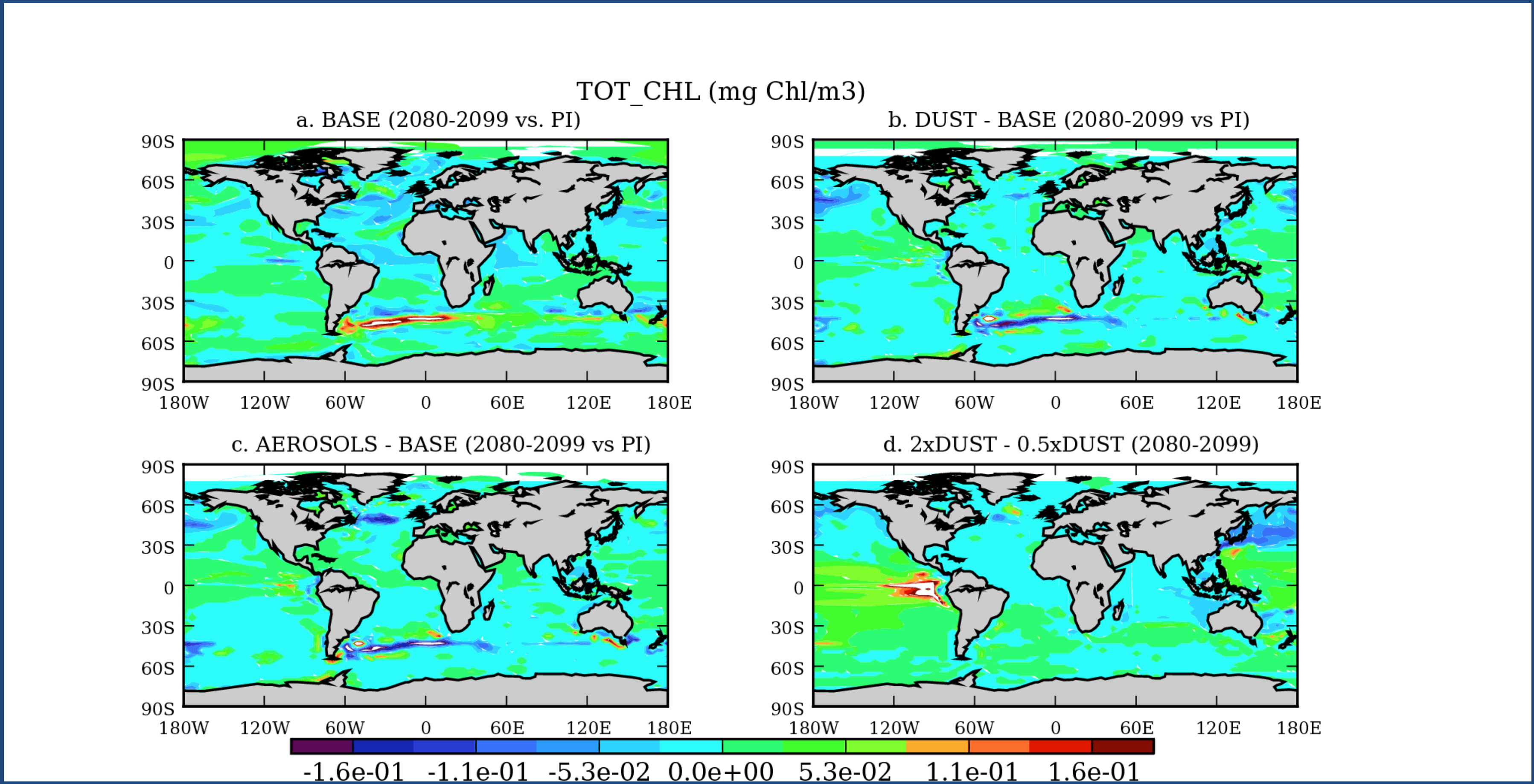


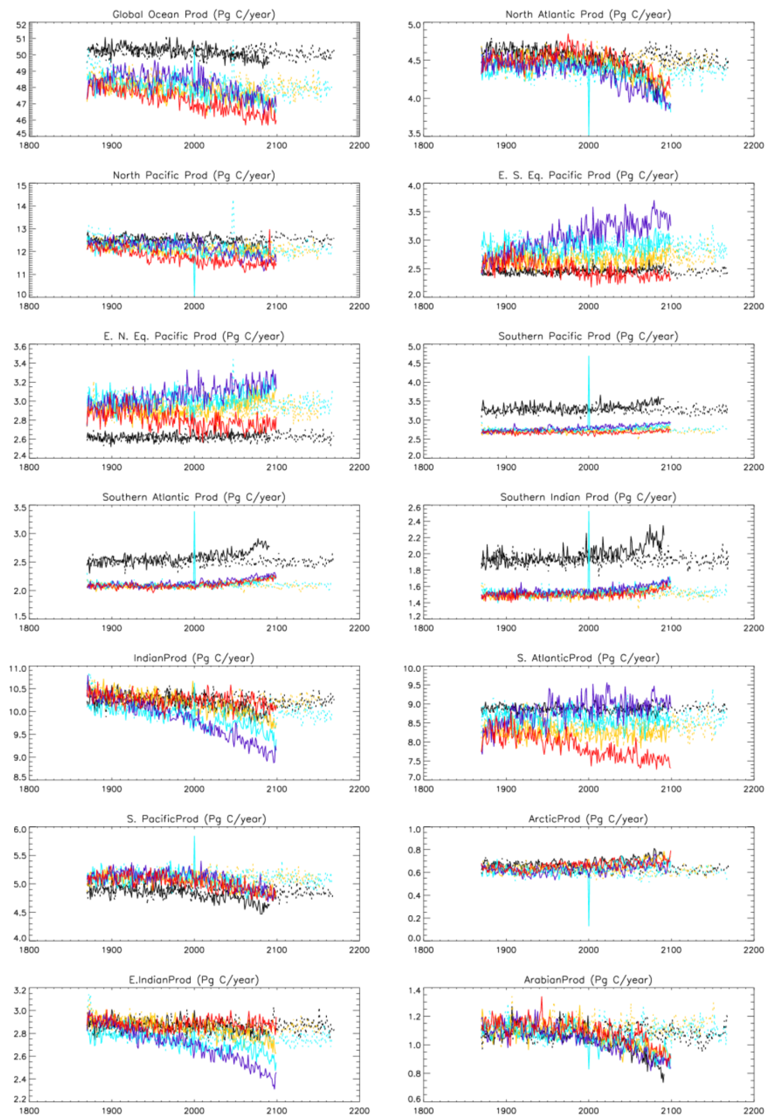
Notice that global sources change as prescribed, but little response otherwise. Regional changes can be strong: especially South America (goes down under climate change even in 2x dust case,) and East Asia, doesn't go up as much as it should)

Ocean response

Tot chlor

Significant changes in chlor predicted with aerosols and/or dust





Regional trends in productivity

Why is ocean productivity going down?
North Pacific, Indian, North Atlantic

Goes down in
North Atlantic: mixed layer depth goes down ,limited by P and N. responds to dustiness opposite what we would expect (physical climate response when lots of dust?).
North Pacific: similar (but also light limited diatoms). North Pacific responds to dust (2x vs. 0.5 dust: with more dust shifts to more N limited from fe limited
E. S. Eq. Pacific, E. N. Eq. pacific: responds to dust in predictable manner: increase in dust=>more productivity, decrease in dust .> less productivity
S. Pacific, S. Atlantic, S. Indian: up a little, with dust
Indian Prod: down