Quantifying Carbon Cycle-Climate Feedbacks

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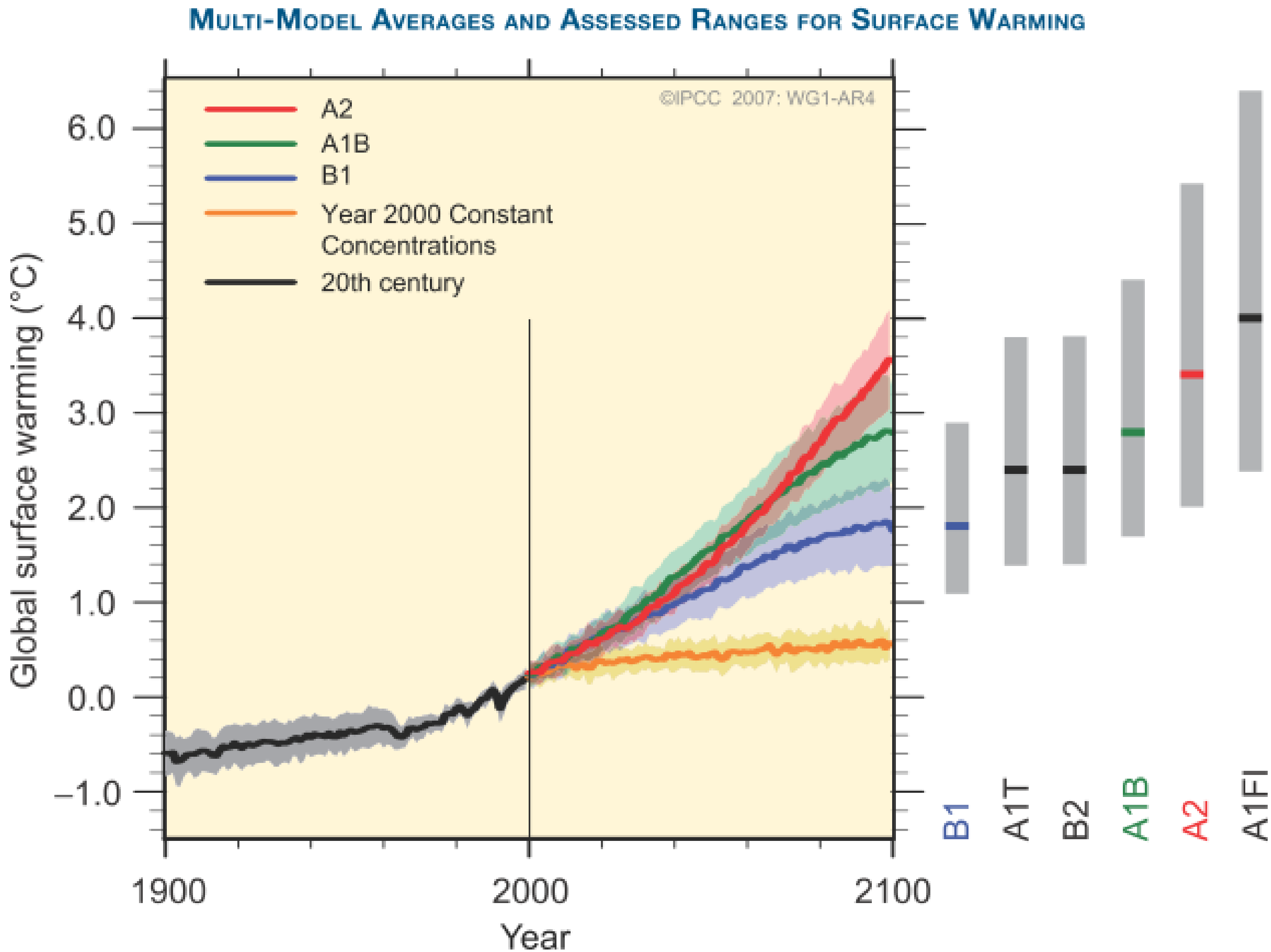
Feedbacks Overview

- $T_e = [S_o(1\text{-}A)/4\sigma]^{1/4} = (s/\sigma)^{1/4}$
- $\Delta T_{eq} = f\ \Delta t_o$
- Positive or negative
  - E.g.: Permafrost melt, CO_2 fertilization
- $\Delta T_{eq} = \Delta T_o + \Delta T_{feedbacks}$
- Objective: Deconstruct Carbon Cycle Portion of $\Delta T_{feedbacks}$
  - Useful for comparing models and getting at mechanisms

Hansen et al, 1984



MULTI-MODEL AVERAGES AND ASSESSED RANGES FOR SURFACE WARMING
©IPCC 2007: WG1-AR4
A2
A1B
B1
Year 2000 Constant Concentrations
20th century
Global surface warming (°C)
6.0
5.0
4.0
3.0
2.0
1.0
0.0
–1.0
1900
2000
2100
Year
B1
A1T
B2
A1B
A2
A1FI

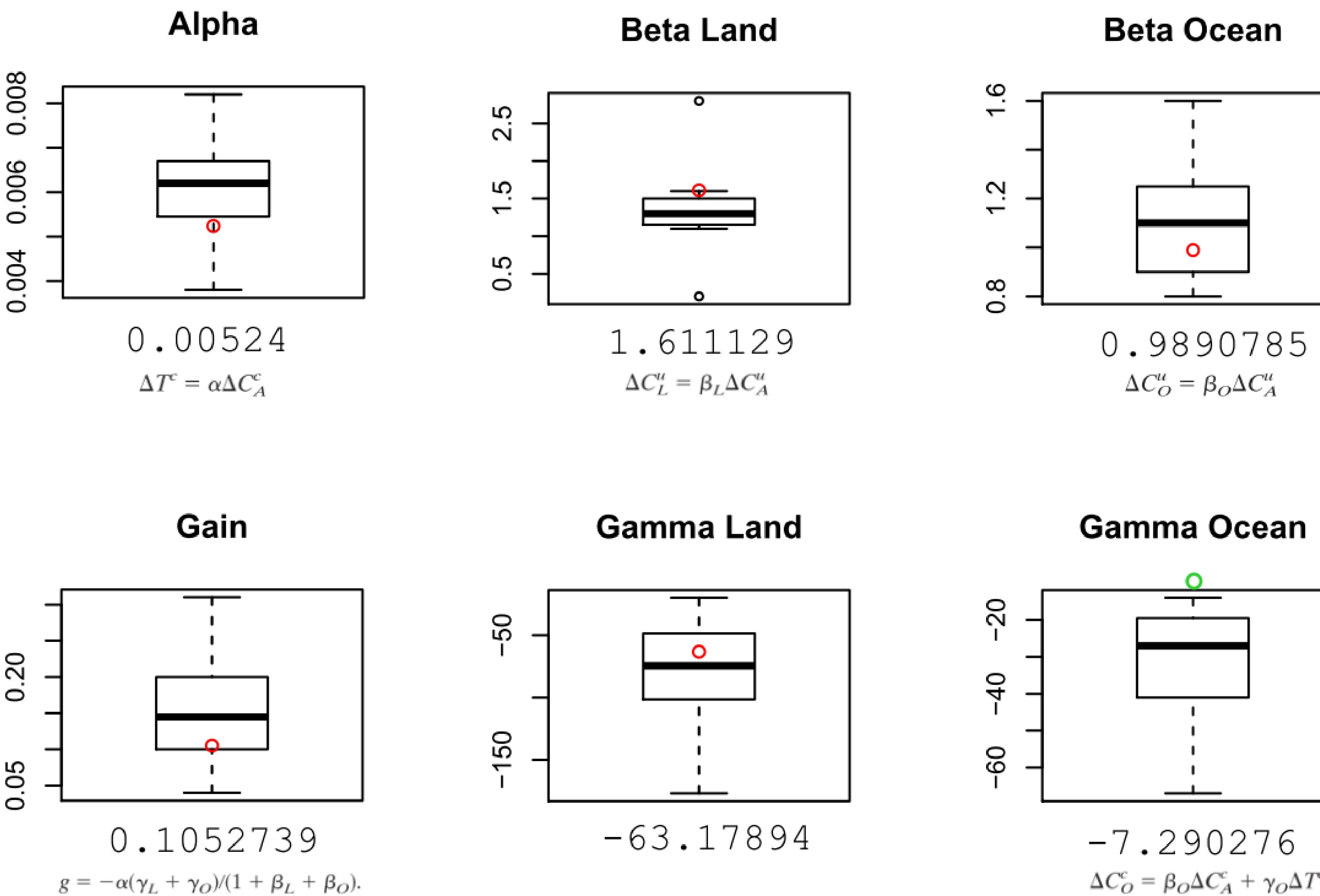
Terminology

- α = K / ppm CO_2
  - Linear transient climate sensitivity
- β = GtC / ppm CO_2
  - Sensitivity of carbon uptake to atmospheric CO_2
- γ = GtC / K
  - Sensitivity of carbon uptake to temperature change
- $g = (\Delta T_{feedbacks})/(\Delta T_{eq})$
  - Ratio of feedback response to total response

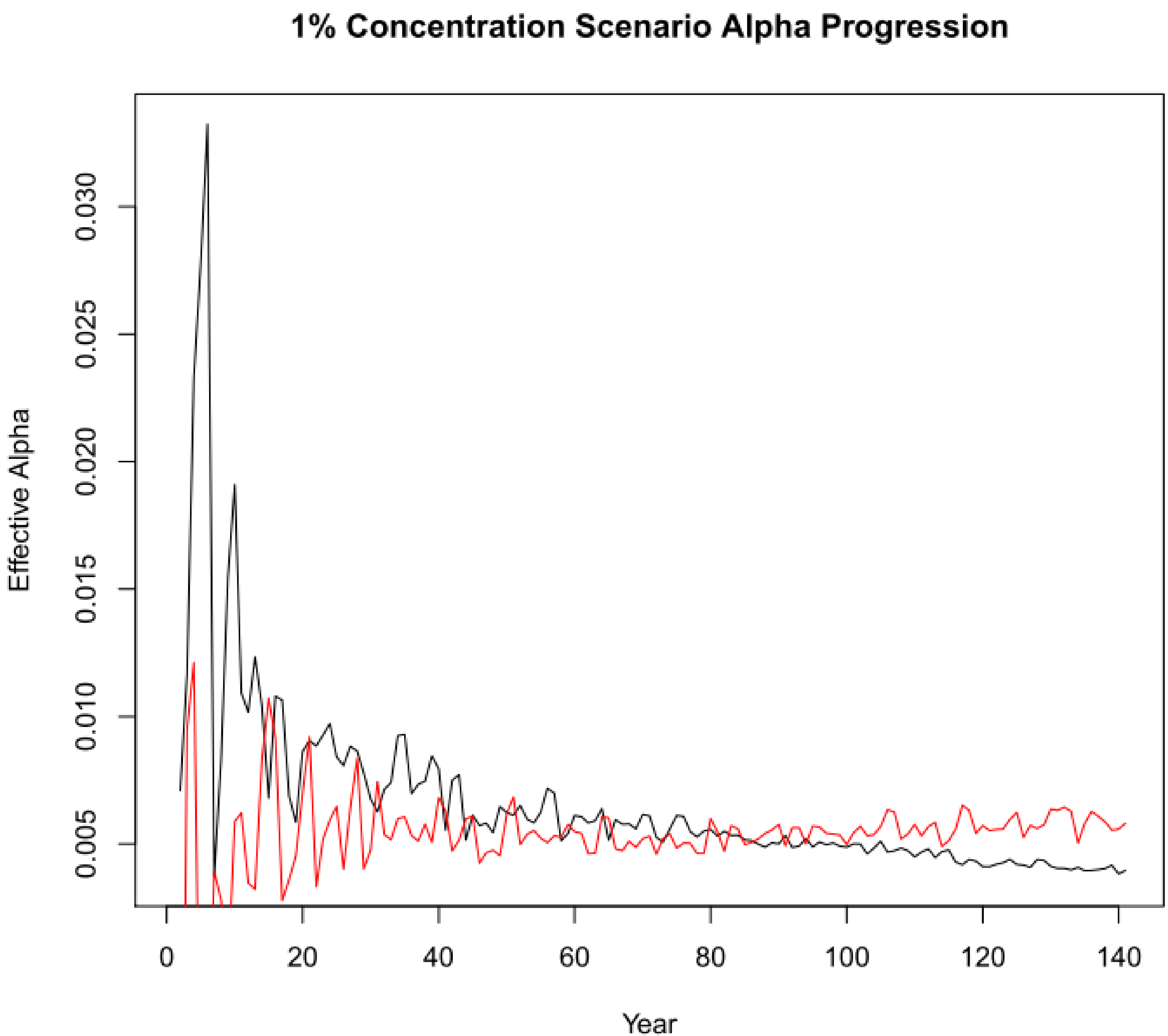
Friedlingstein et al, 2006; Gregory et al, 2009; Roy et al, 2010

ESM2M Analysis

- Three runs with 1% increase CO_2 per year over preindustrial levels until point of doubling
  - Fully coupled, radiatively uncoupled, biogeochemical uncoupled
  - Preformed linear regressions on different runs to calculate feedback factors
  - Grid cell by grid cell regressions to preform regional analysis



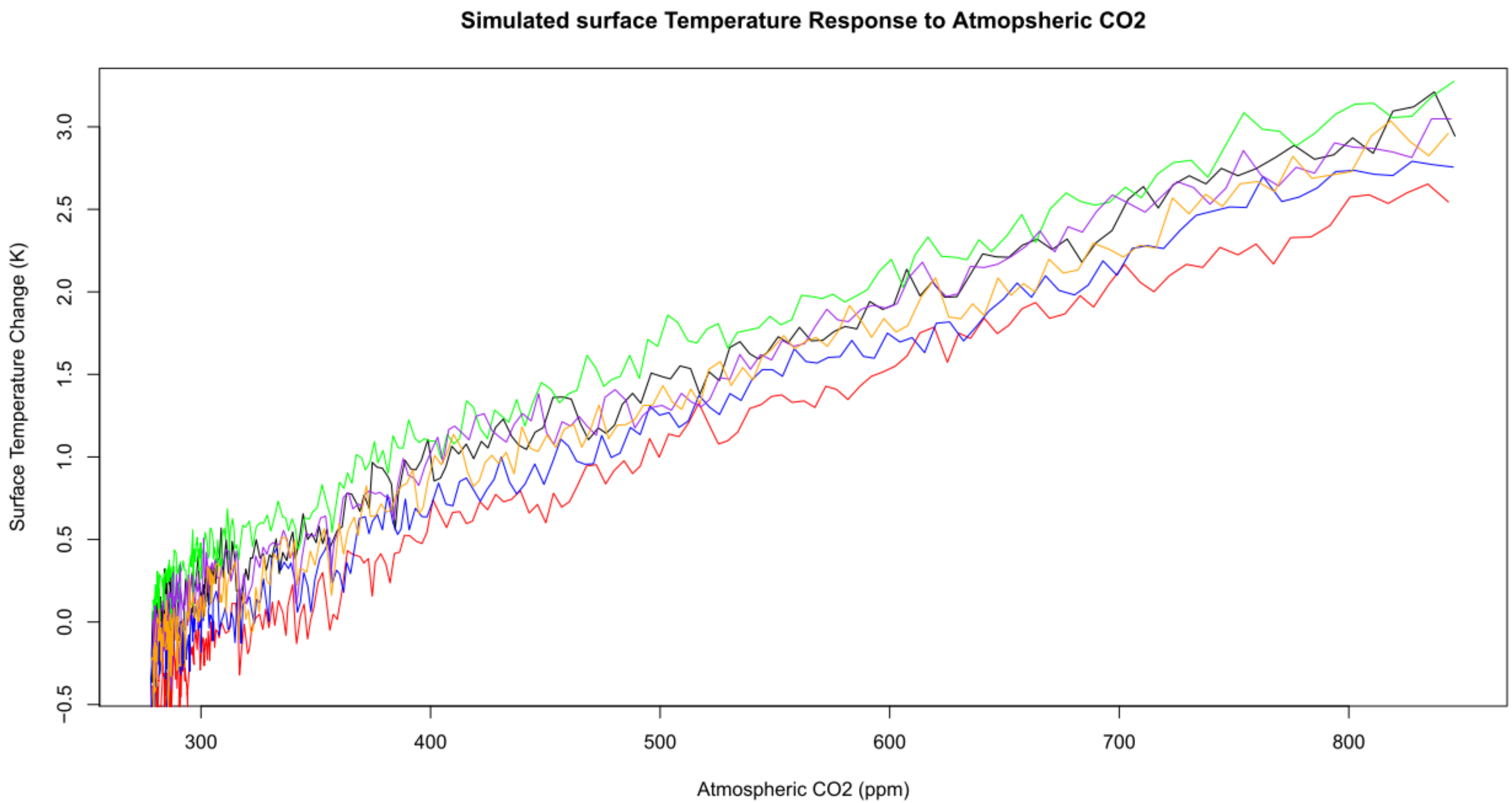
Alpha
0.008
0.006
0.004
0.00524
$\Delta T^c = \alpha \Delta C_A^c$
Beta Land
2.5
1.5
0.5
1.611129
$\Delta C_L^u = \beta_L \Delta C_A^u$
Beta Ocean
1.6
1.2
0.8
0.9890785
$\Delta C_O^u = \beta_O \Delta C_A^u$
Gain
0.20
0.05
0.1052739
$g = -\alpha(\gamma_L + \gamma_O)/(1 + \beta_L + \beta_O).$
Gamma Land
−50
−150
-63.17894
Gamma Ocean
−20
−40
−60
-7.290276
$\Delta C_O^c = \beta_O \Delta C_A^c + \gamma_O \Delta T^c$



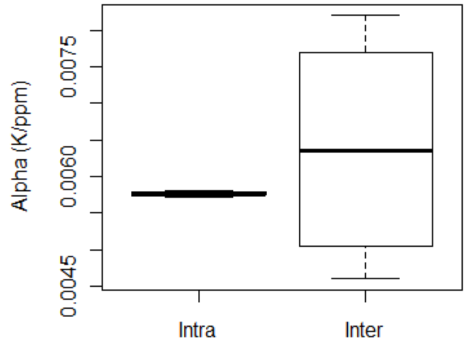
1% Concentration Scenario Alpha Progression
Effective Alpha
0.005
0.010
0.015
0.020
0.025
0.030
Year
0
20
40
60
80
100
120
140

Ensemble Analysis

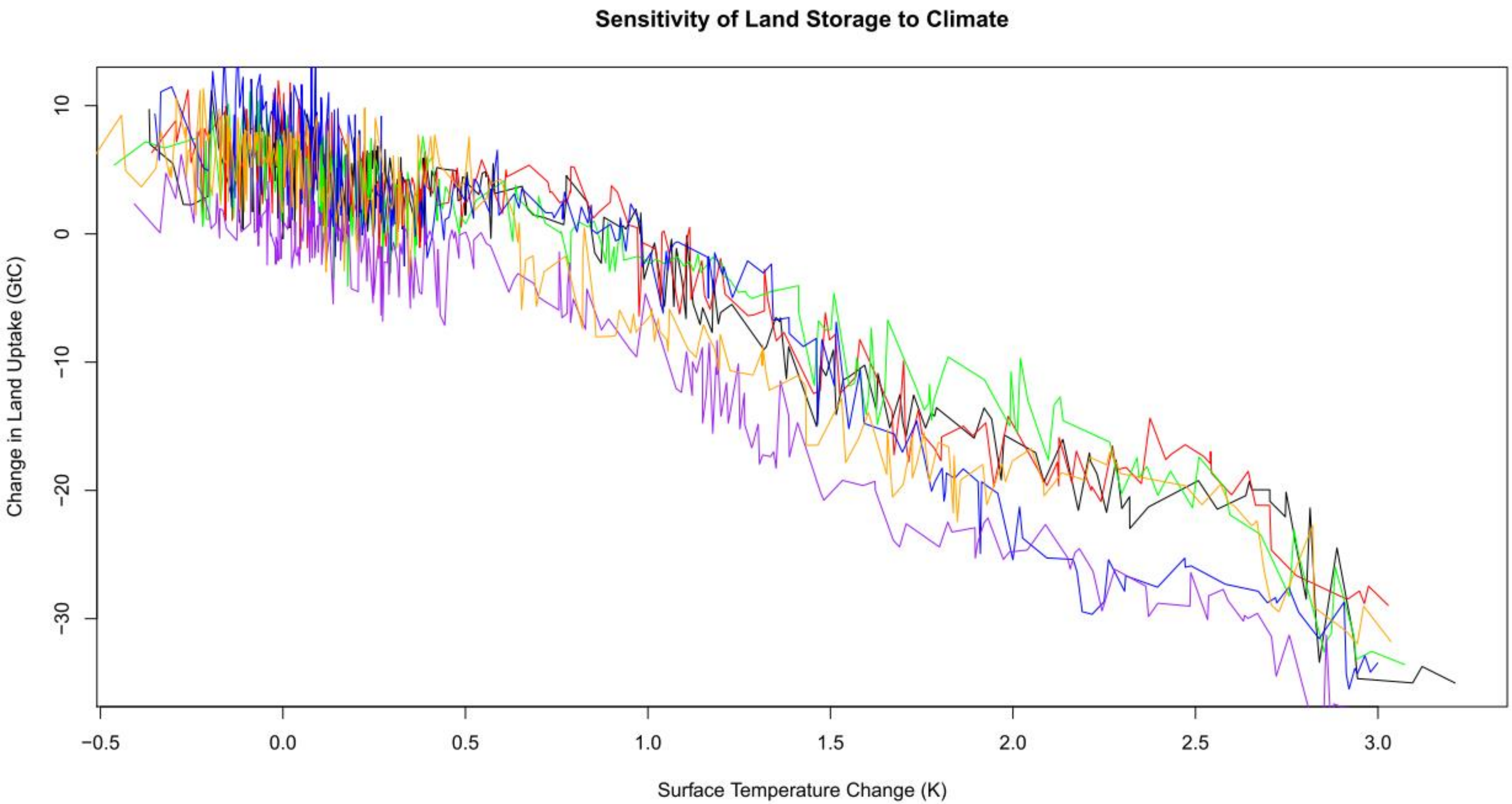
- NCAR CSM1.4
- 6 different ensemble fully coupled runs
- Used Friedlingstein et al 2006 method
- β calculated from one radiatively uncoupled run
- All runs from 1820 to 2000 using historical forcings, from 2000 to 2100 using A2 scenario



Intra-model	
NCAR Run	Alpha
a-1830	0.005786
b-1849	0.005746
c-1869	0.005746
d-1879	0.005721
e-1907	0.005770
f-pap	0.005811
Avg	0.005763
SD	0.000032321

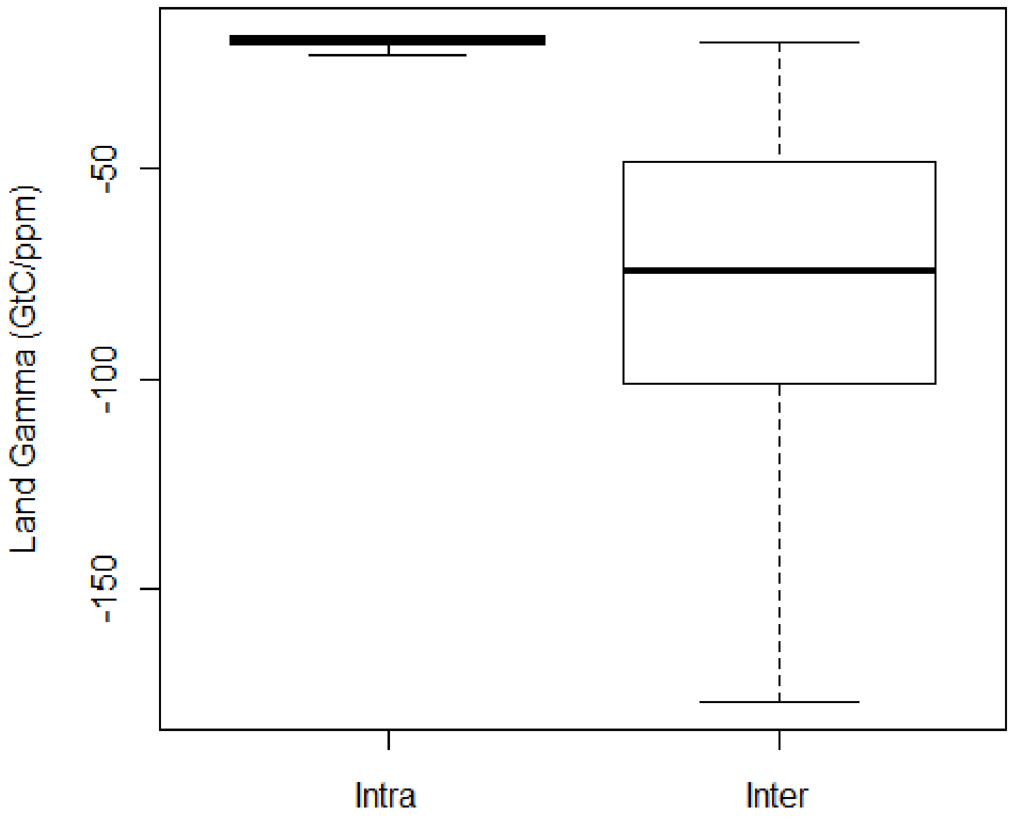


Inter-model	
Model	Alpha
IPSL	0.0072
NCAR	0.0046
BCM-C	0.0055
MPIM	0.0082
Avg	0.006375
SD	0.001626

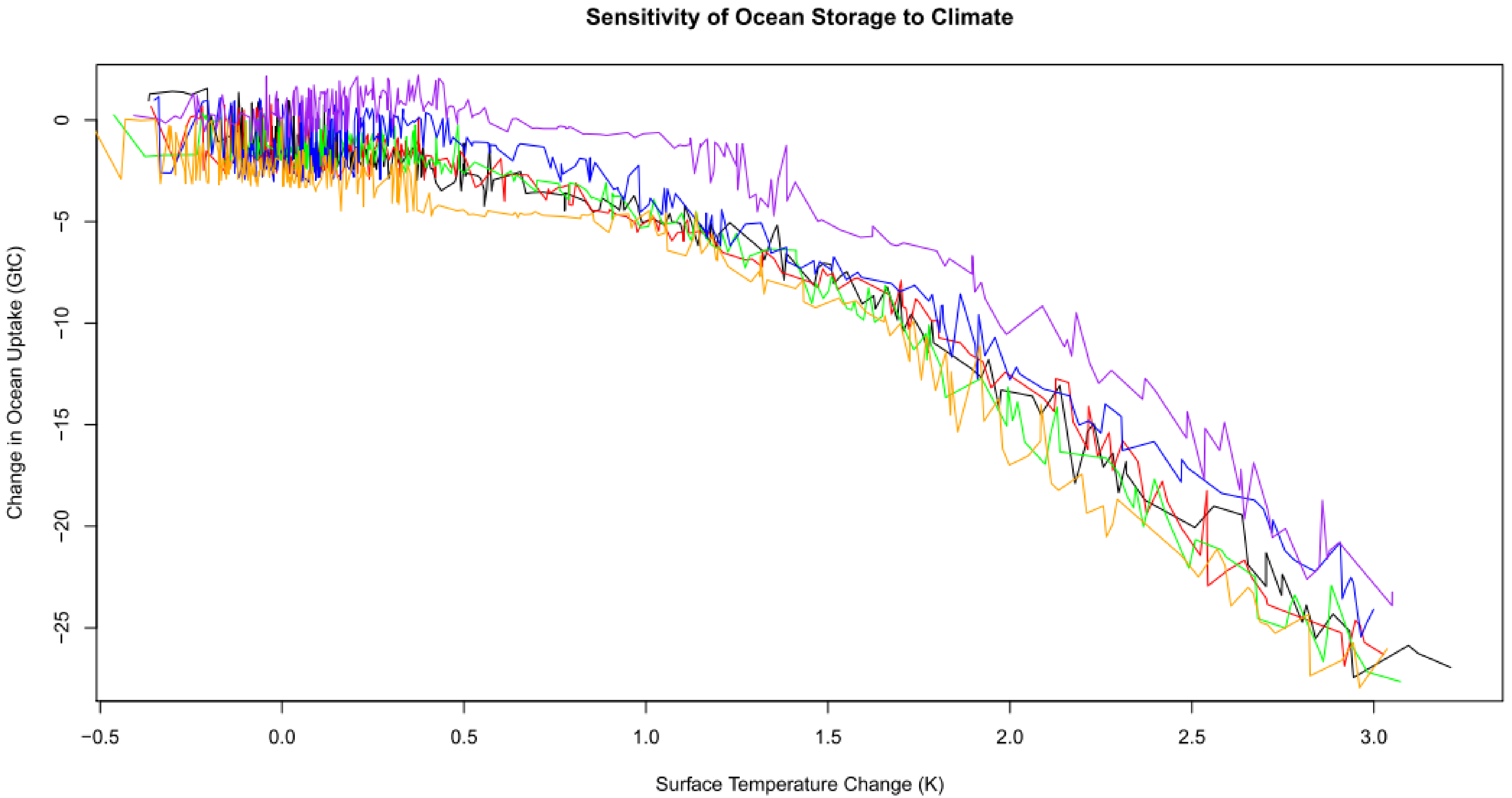


Sensitivity of Land Storage to Climate
Change in Land Uptake (GtC)
Surface Temperature Change (K)
10
0
−10
−20
−30
−0.5
0.0
0.5
1.0
1.5
2.0
2.5
3.0

Intra & Inter Model Land Gamma

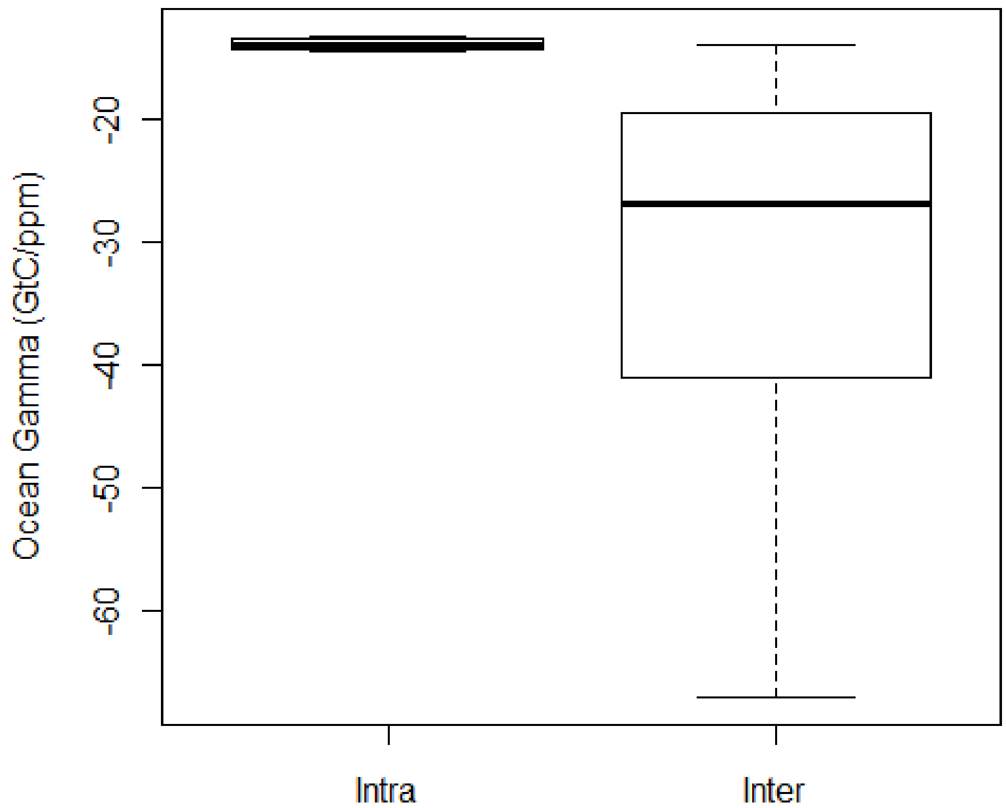


8.30% SD 57.9% SD



Sensitivity of Ocean Storage to Climate
Change in Ocean Uptake (GtC)
Surface Temperature Change (K)
0
−5
−10
−15
−20
−25
−0.5
0.0
0.5
1.0
1.5
2.0
2.5
3.0

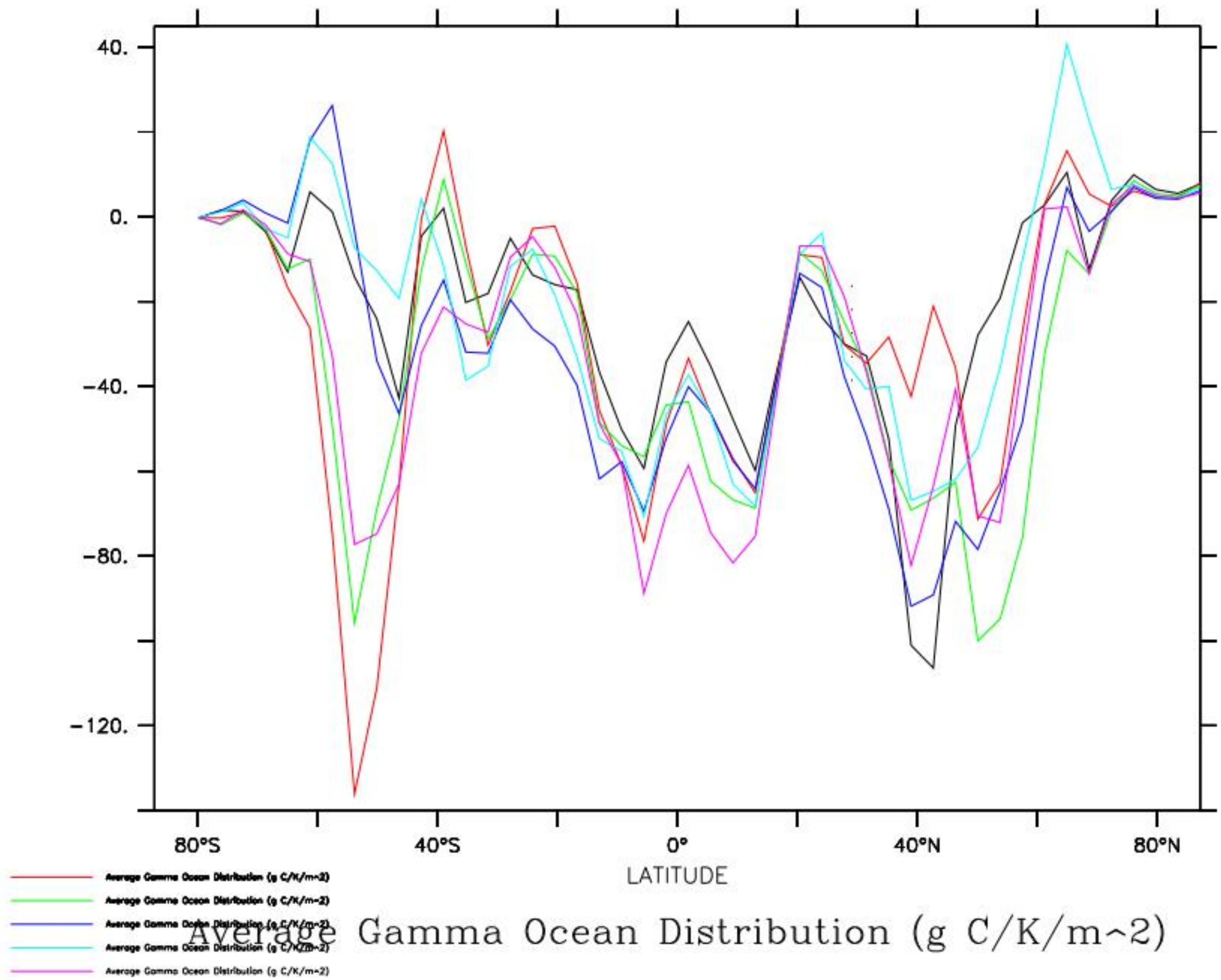
Intra & Inter Model Ocean Gamma



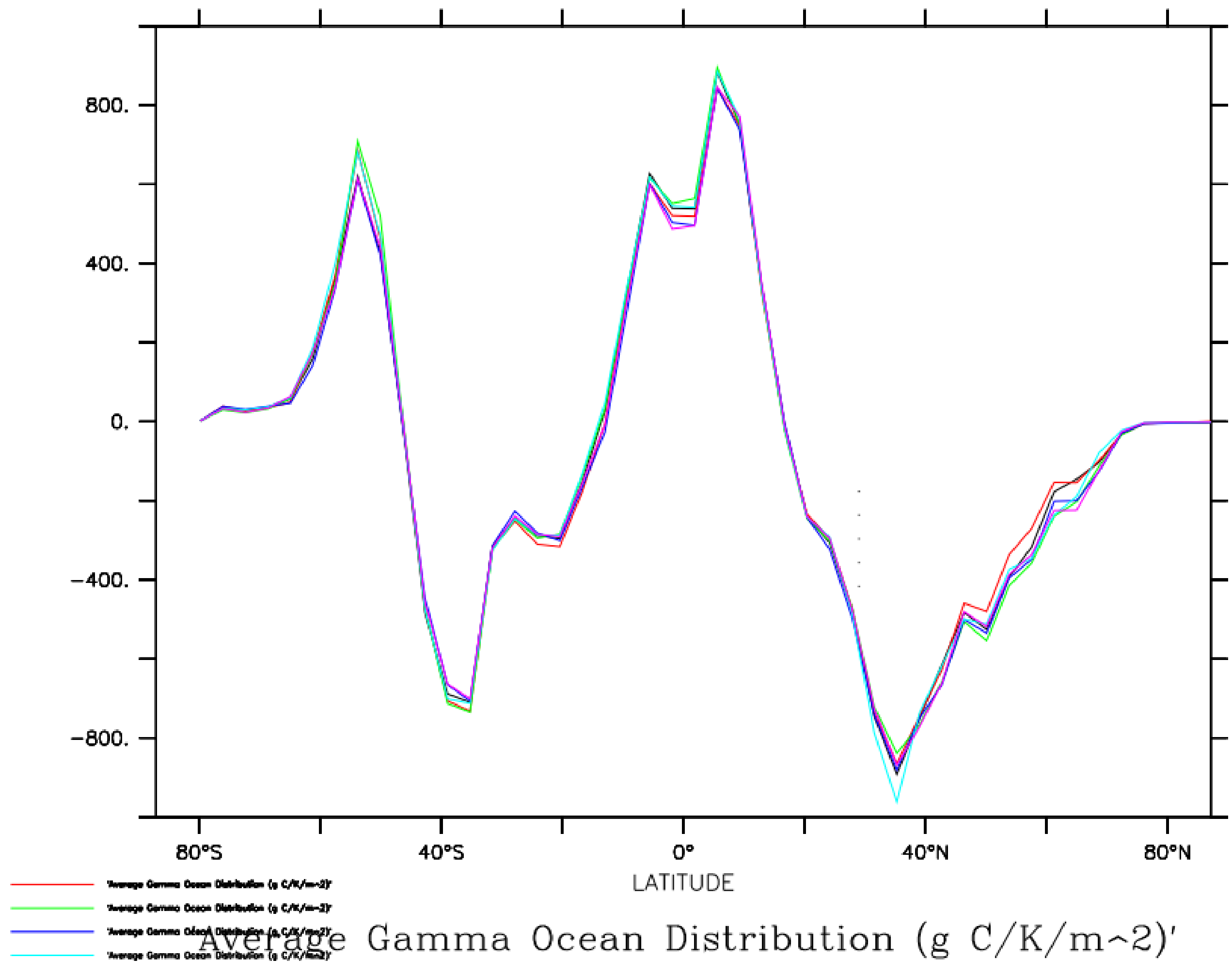
3.69% SD

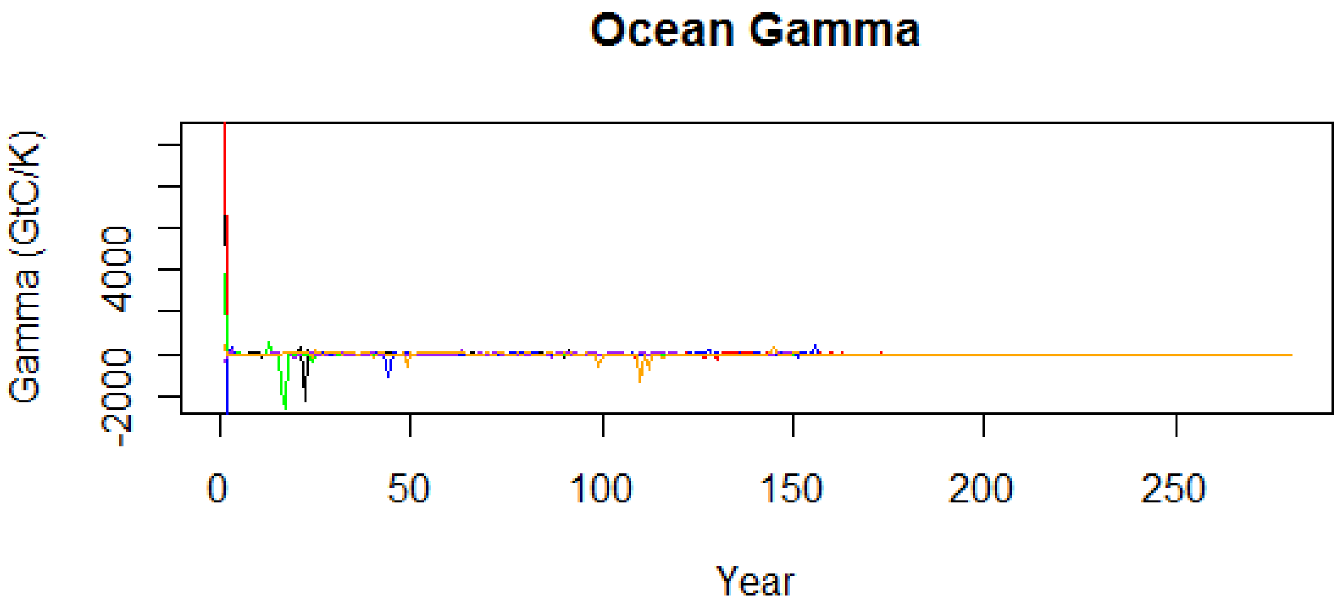
54.27% SD

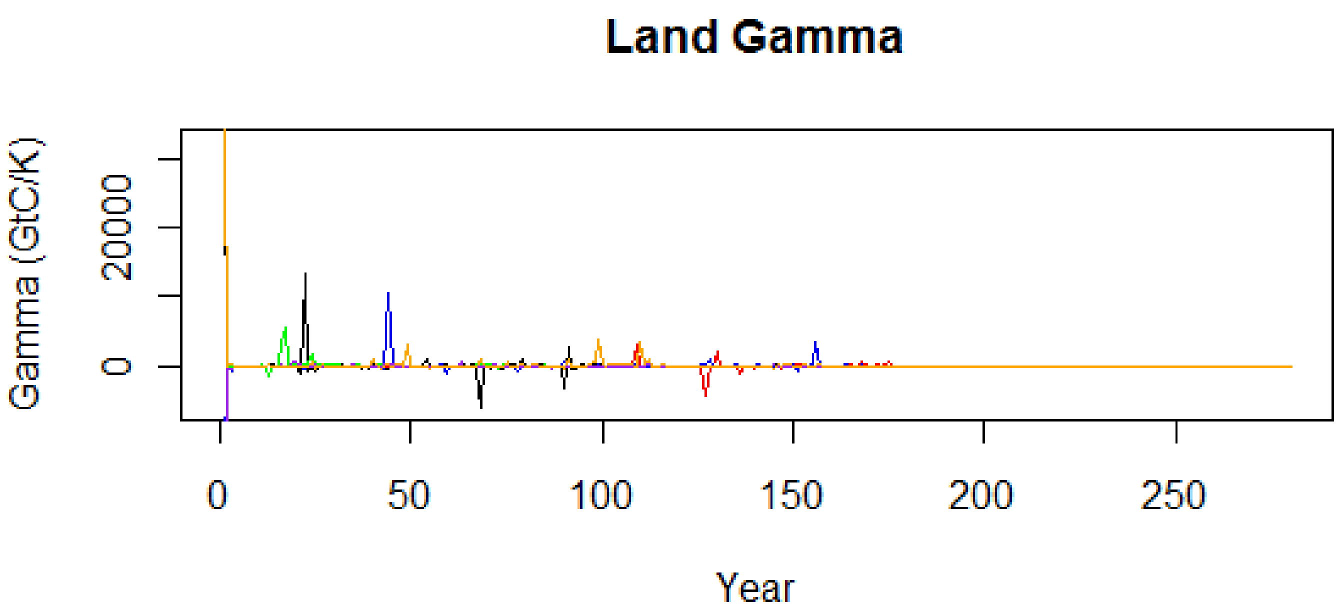
Ocean Gamma: 1820-2100

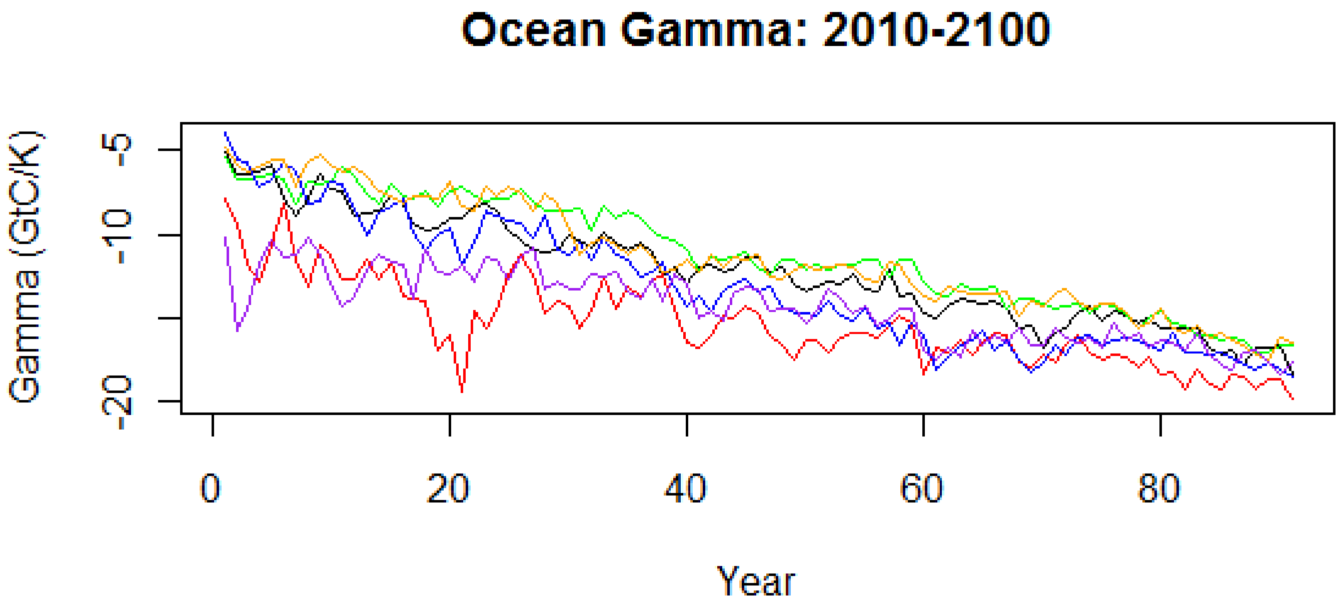


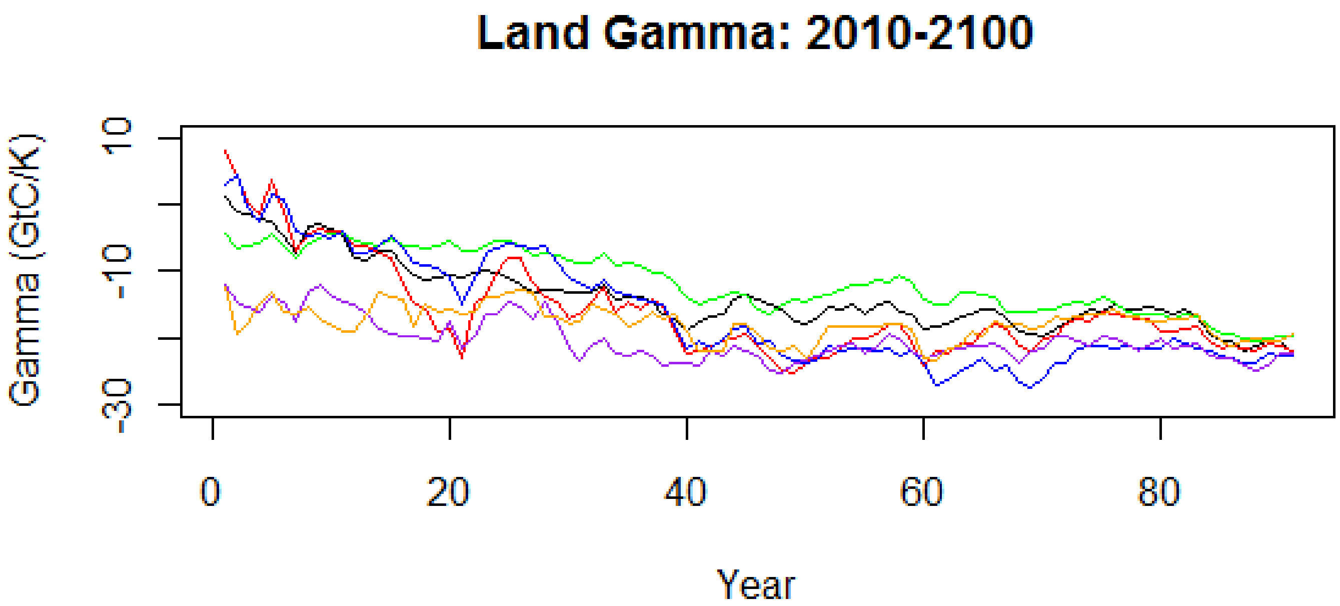
Ocean Gamma: 2010-2100

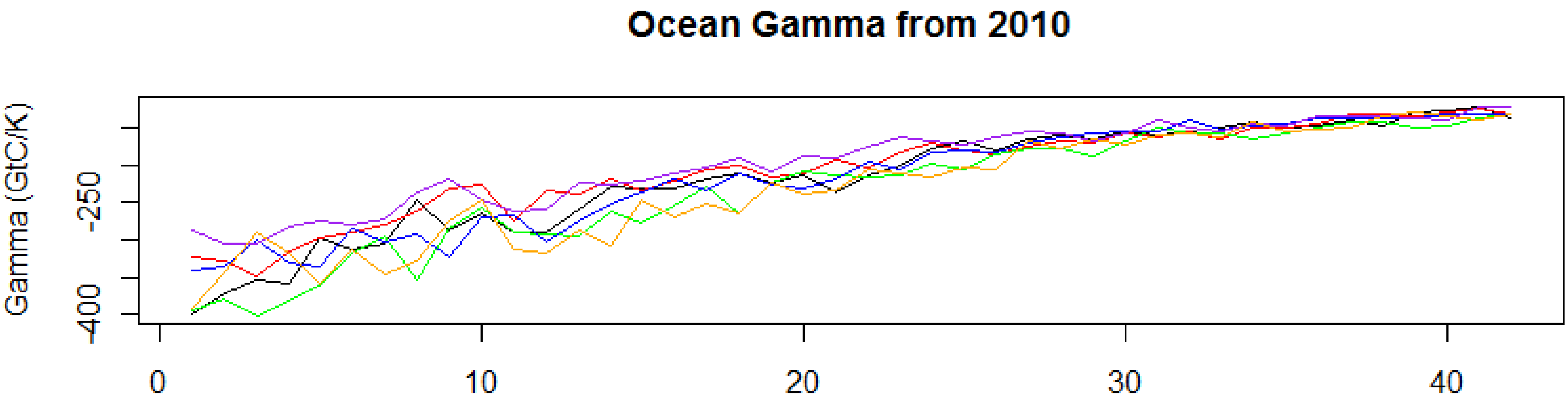



Ocean Gamma
Gamma (GtC/K)
-2000
4000
0
50
100
150
200
250
Year

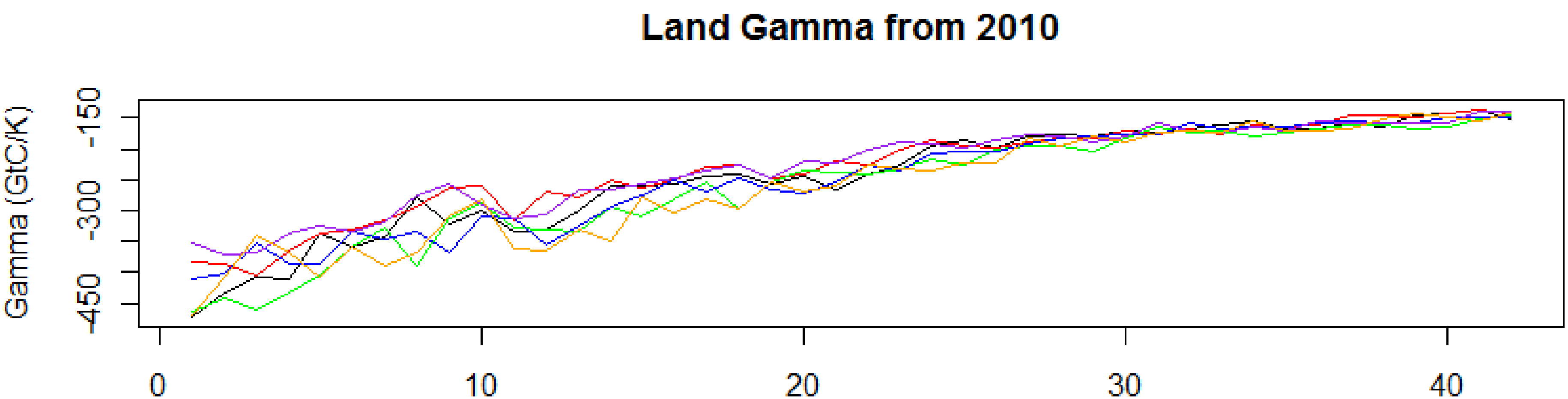

Land Gamma
Gamma (GtC/K)
0
20000
0
50
100
150
200
250
Year


Ocean Gamma: 2010-2100
Gamma (GtC/K)
-5
-10
-20
0
20
40
60
80
Year


Land Gamma: 2010-2100
Gamma (GtC/K)
10
-10
-30
0
20
40
60
80
Year



	All	2010-2100
% SD	**3.69**	**2.81**



	All	2010-2100
% SD	**8.30**	**12.63**

Conclusions

- ESM2M relatively unresponsive
- Feedback factors are not actually linear
- Regressions yield different results from instantaneous slope when started from different points
- Regional differences appear to converge after spin-up
  - Less clear on a global scale
- Larger β and γ if ignore spin-up, smaller α
- Intra-model uncertainty much smaller than inter-model uncertainty
  - Might make a difference on the margins

Thank You!