Developments in Radiative Forcing

Piers Forster, Tim Andrews (now at Met Office), Julia Crook

Thanks to:

Jonathan Gregory (Univ. Reading,UK Met Office),

Karl Taylor (PCMDI)

Olivier Boucher (when he was Met Office)

Tami Bond (Illinois)

Radiative forcing - duel role

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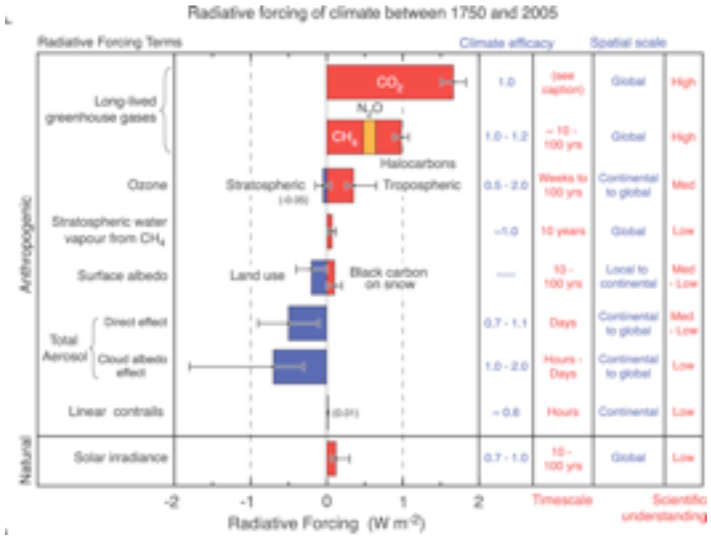
1.Climate Policy Role (Global Warming Potential)

2. Climate Model Diagnostic

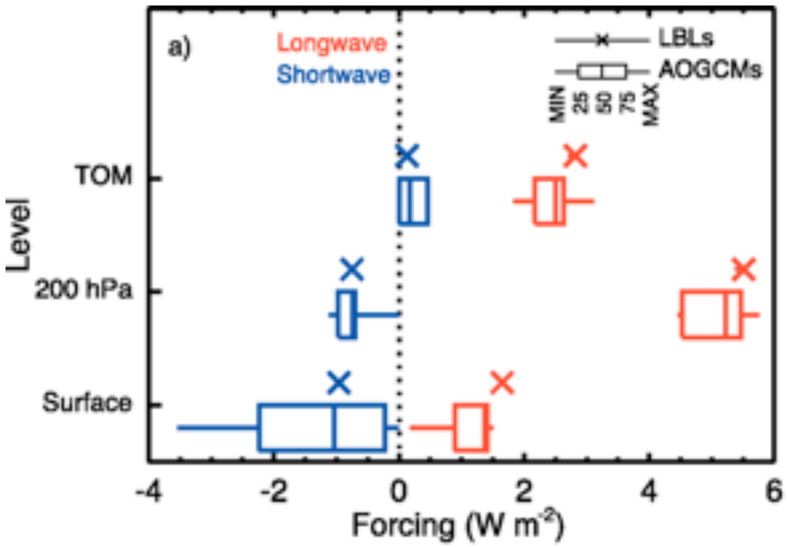


IPCC AR4

TAR and AR4 had difficulty with 2. as climate models did not have offline versions of their radiation codes, lacked ability to calculate stratospheric adjustment, and were developing interactive aerosol schemes

-> Good science in RF chapters isolated from rest of report

Radiation scheme intercomparisons CO2 forcing



up to

25% LW error, 100% SW error

Collins et al., JGR, 2006

Radiation scheme intercomparisons
CO2 forcing

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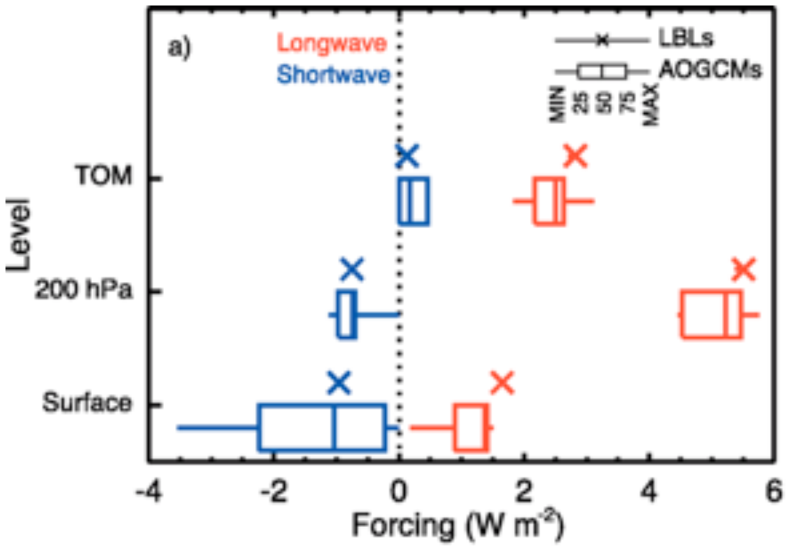

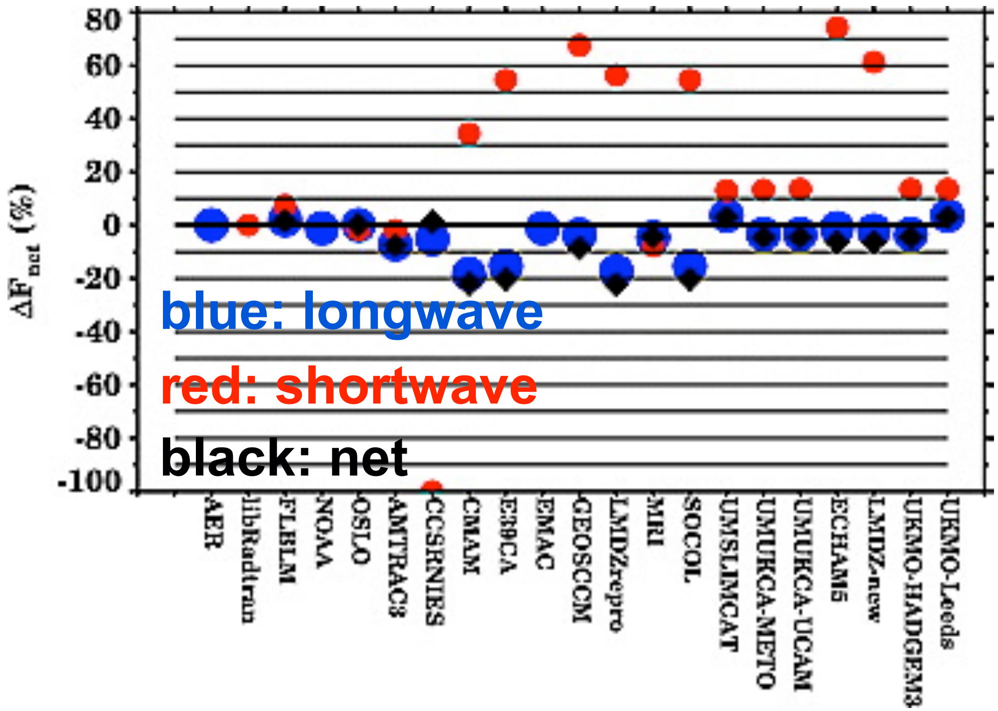

up to

25% LW error, 100% SW error

Errors generally less than 10%

Collins et al., JGR, 2006

Forster et al., JGR, 2011

Aim of talk

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Show how forcing diagnostics can be obtained with little fuss from climate models and why they are a very useful diagnostic

Outline of talk

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1. Terminology and definitions

2. How new definitions of forcing helps us understand climate response

   a. feedback processes

   b. global hydrological cycle changes

3. How forcing helps us test climate models

   a. tropical warming

   b. CMIP5 model response

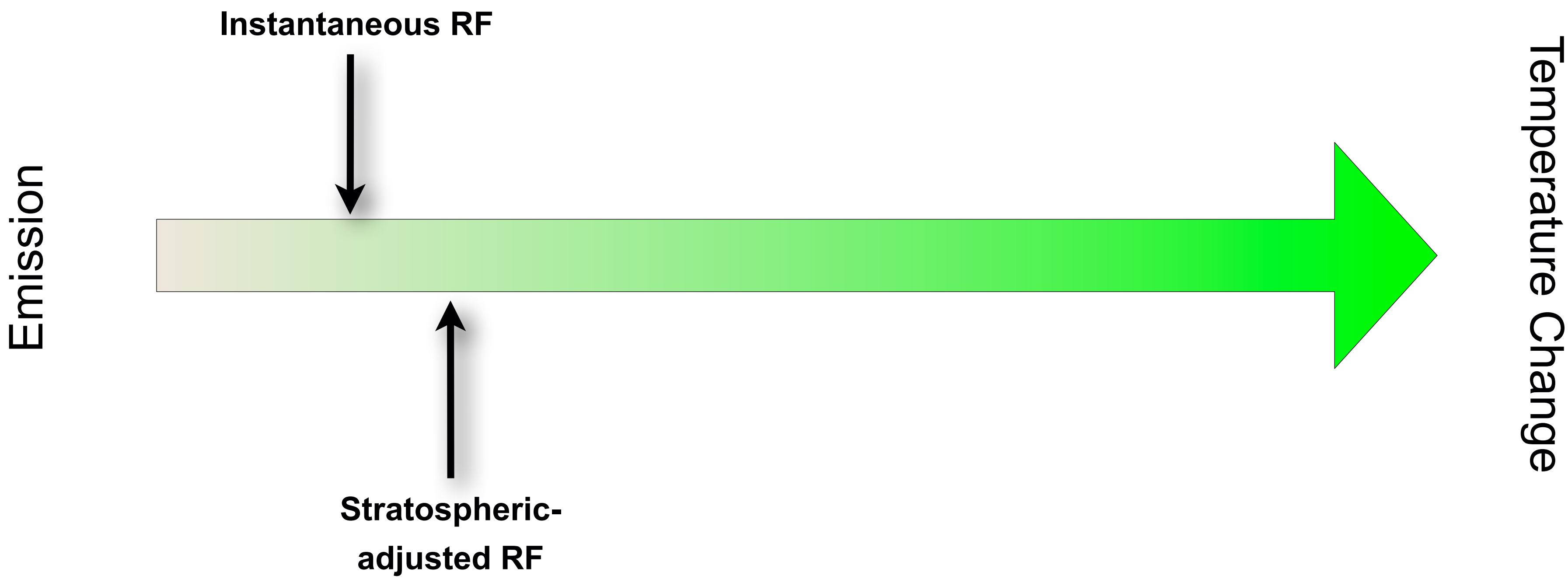
   c. aerosol effects

4. Conclusions

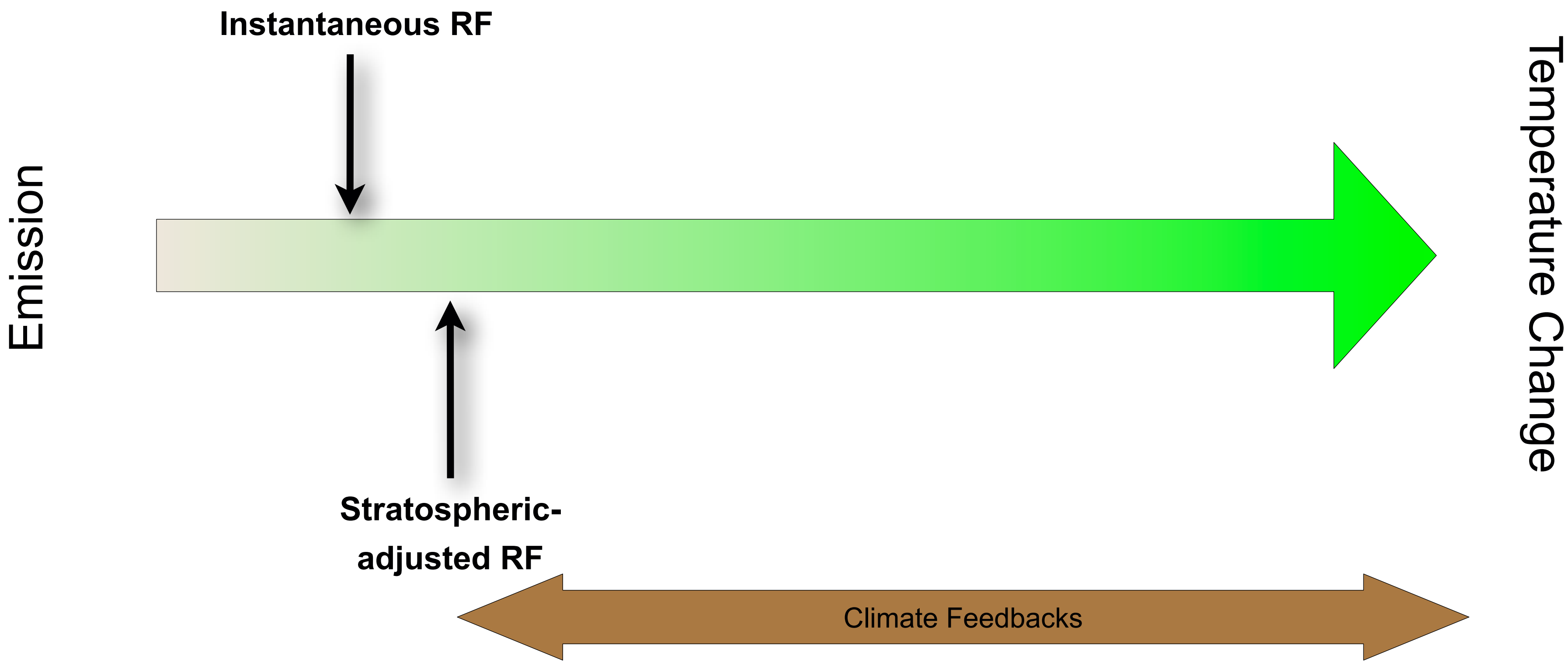
Looking at how the atmosphere rapidly adjusts when a forcing is applied tells you a lot about its ultimate response.

Caution: Climate models seem to be getting similar responses for different reasons

Terminology



Terminology



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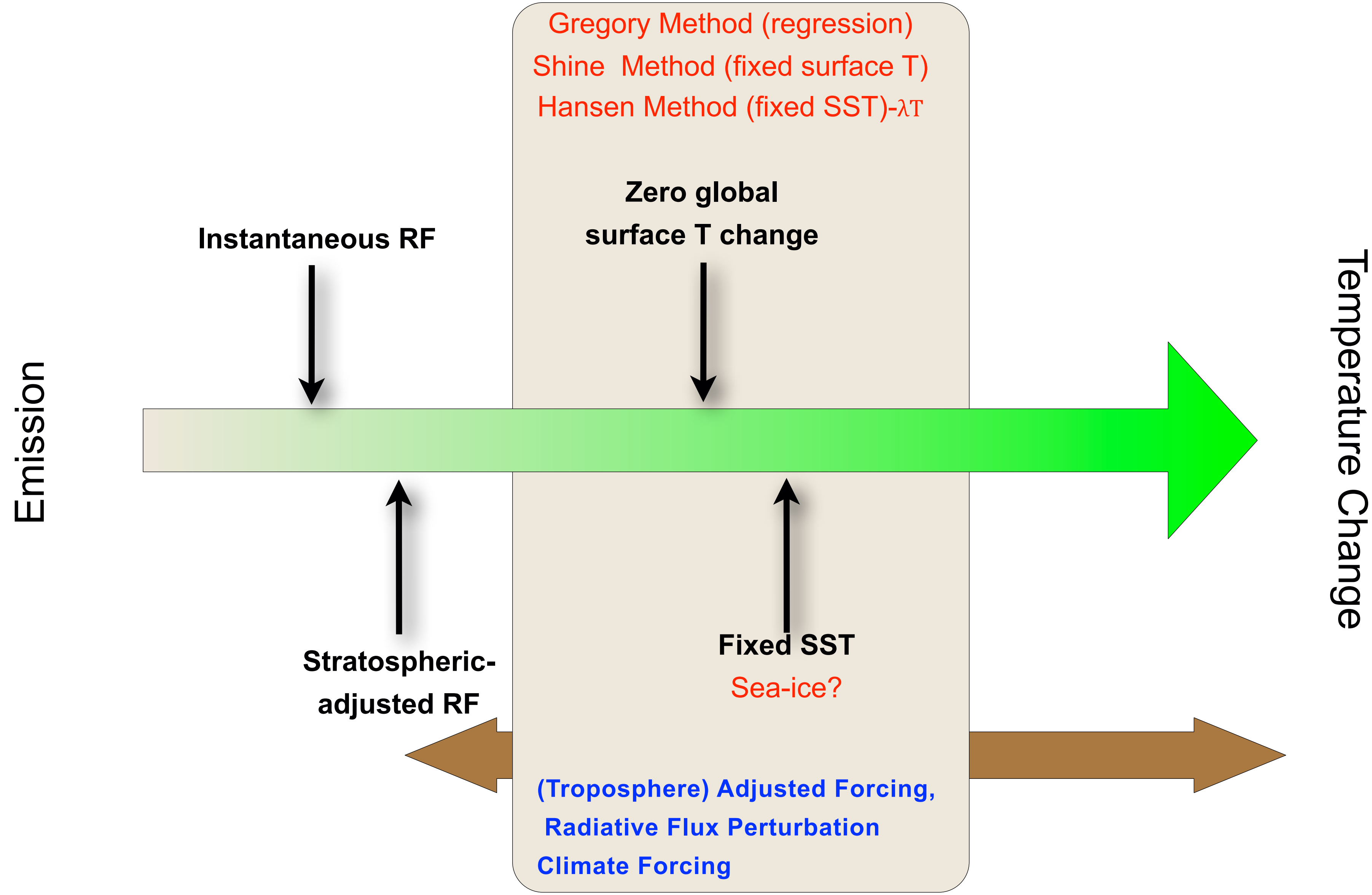

Terminology

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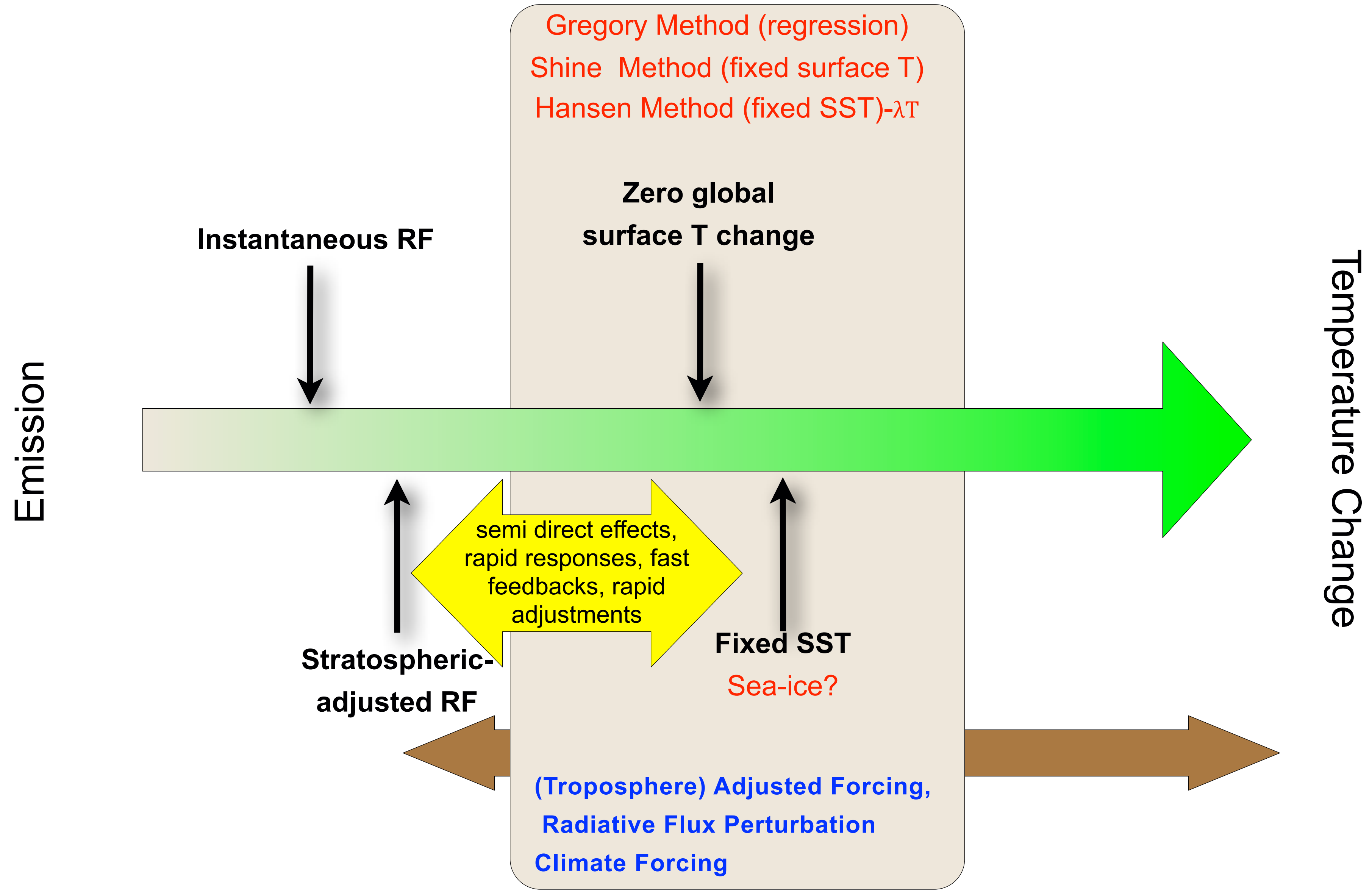

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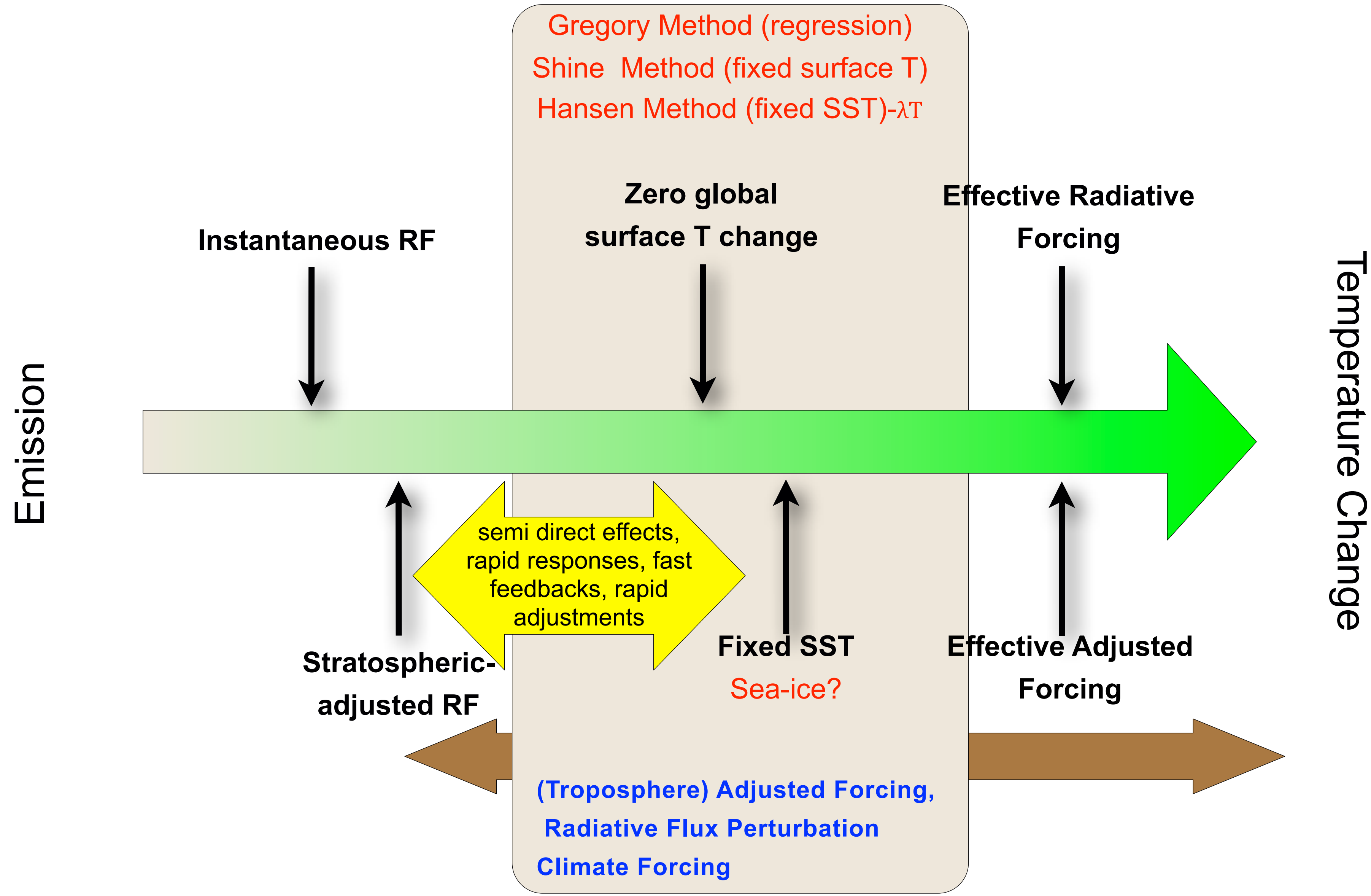

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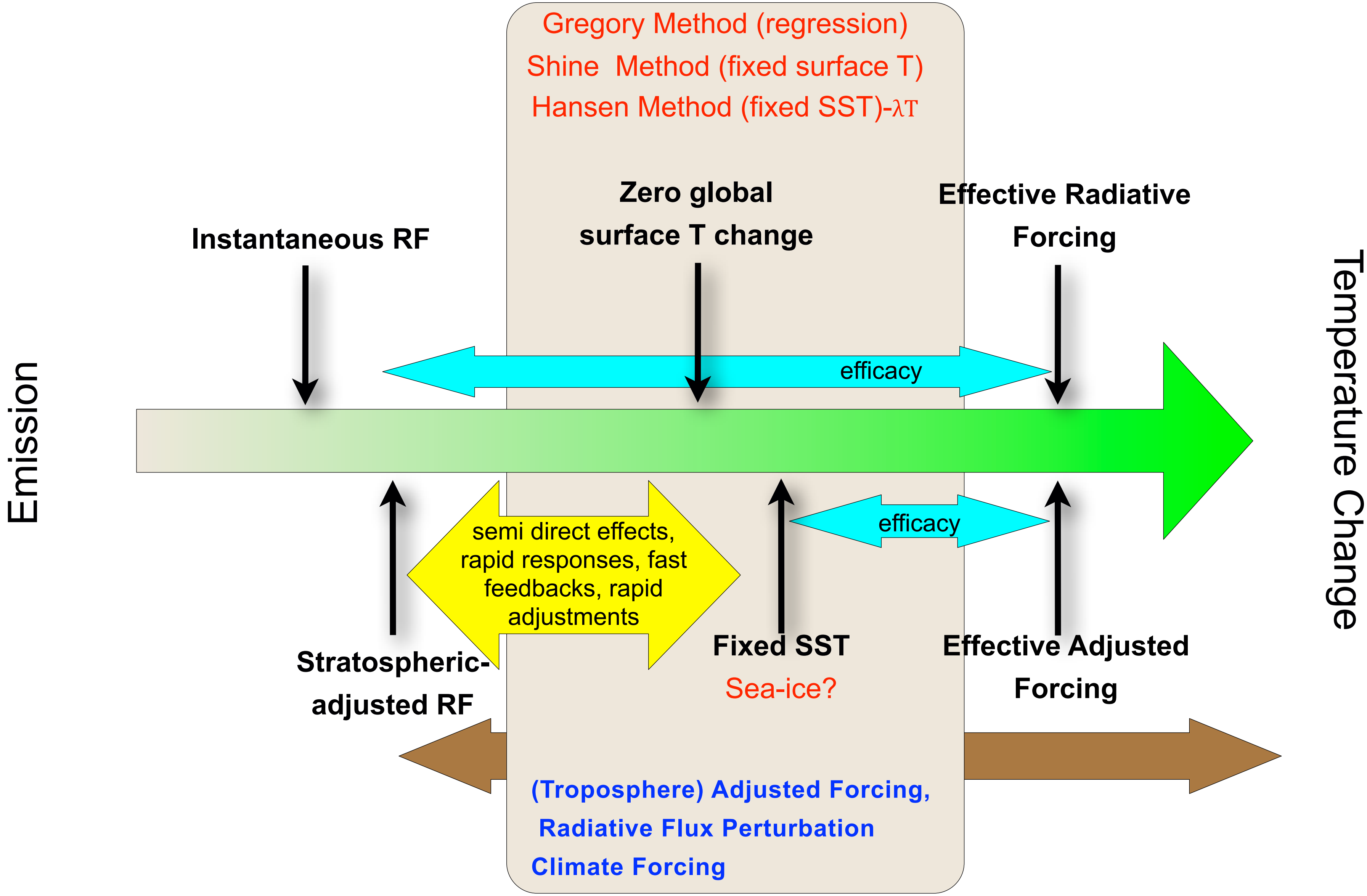

Terminology

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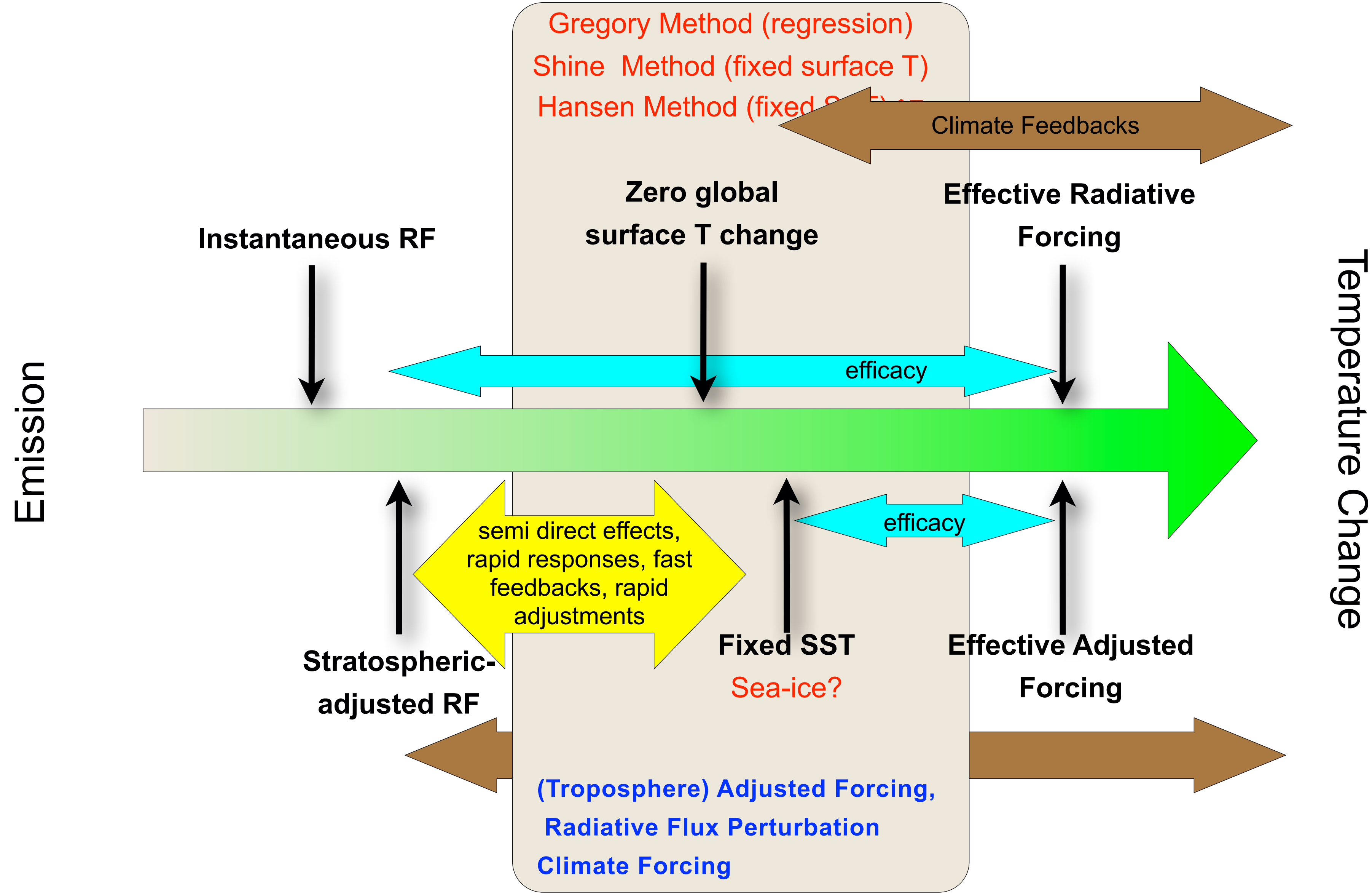

Black Carbon Forcing terms

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Direct Effect	Radiative forcing
Liquid cloud effect	Radiative forcing
Mixed phase cloud effect	Adjusted forcing
Ice cloud effect	Adjusted forcing
Semi direct effect	Rapid adjustment
Snowpack effect	Effective adjusted forcing
Sea-ice effect	Effective radiative forcing
total climate forcing	**Effective BC climate forcing**

Bond et al., 201X!

Be careful to include everything and not to double count

Efficacy of adjusted forcing

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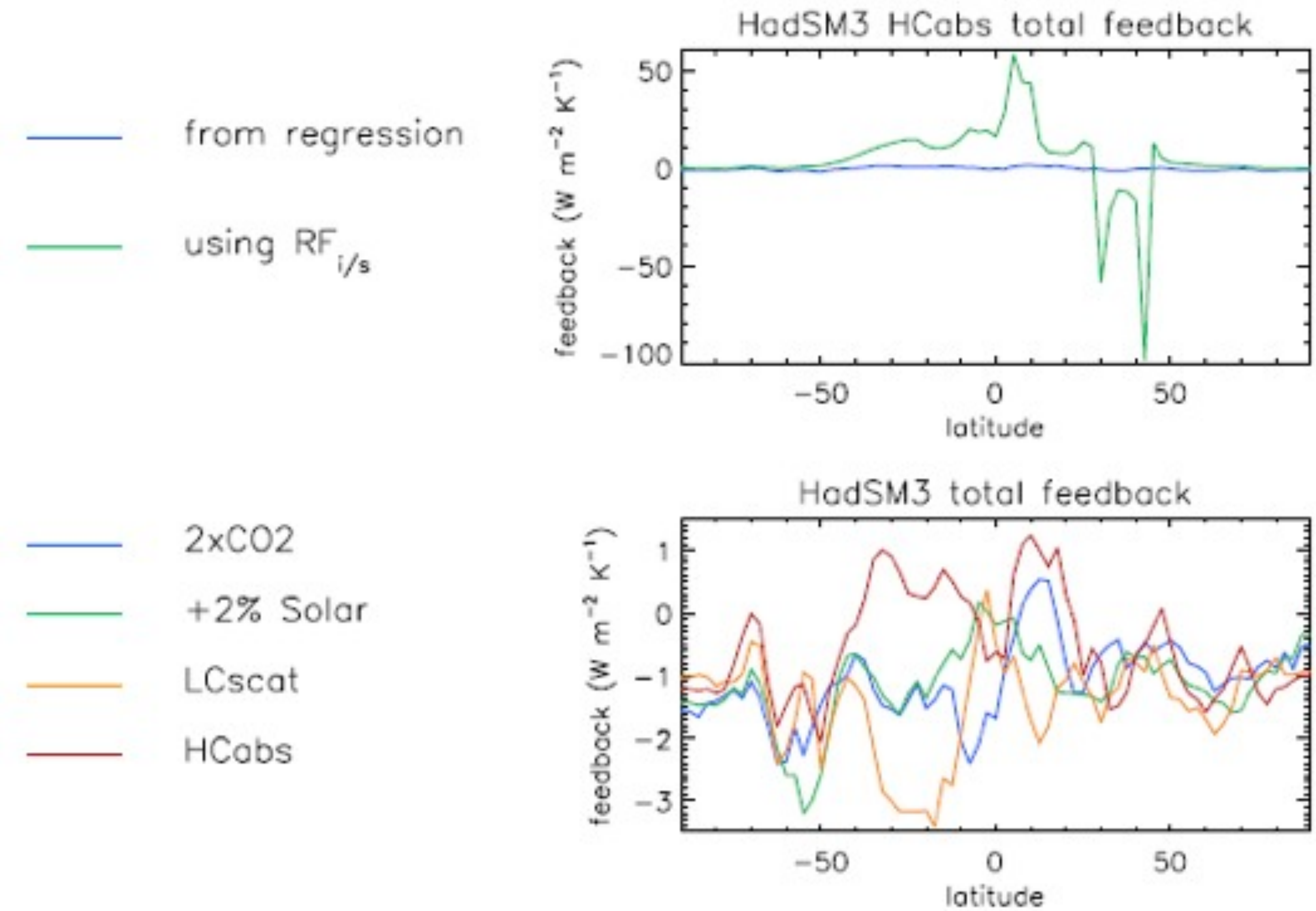

Efficacy closer to 1.0 - at least in one model

Feedbacks diagnosed for and absorbing aerosol perturbation in HadSM3

Crook, et al., J Climate 2011

Fast response of global precipitation scales with atmospheric forcing

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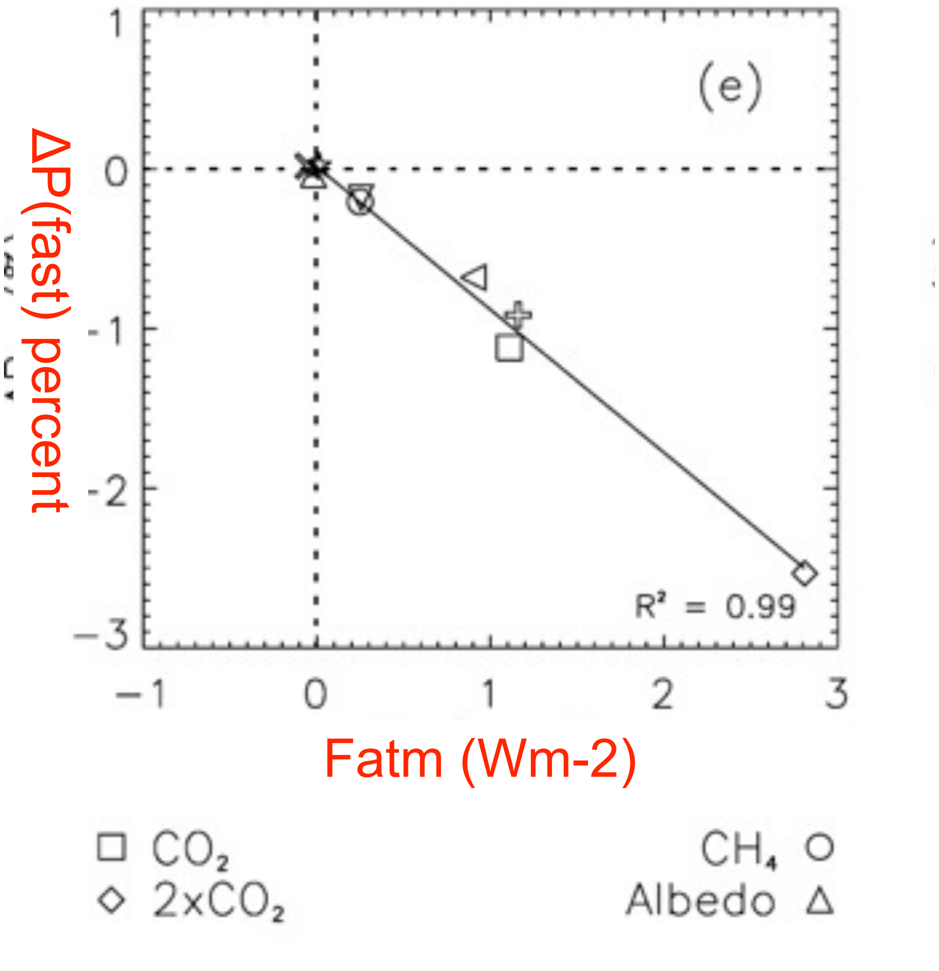

Fatm =
Ftoa - Fsurface

Andrews et al., 2010, Geophys. Res. Lett

Circulation changes

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Wyant et al. (2011) use a superparameterized climate model, SP-CAM (2D cloud resolving model in each grid column), with 4 x CO_2 and fixed-SSTs over the tropics to investigate tropical cloud adjustment

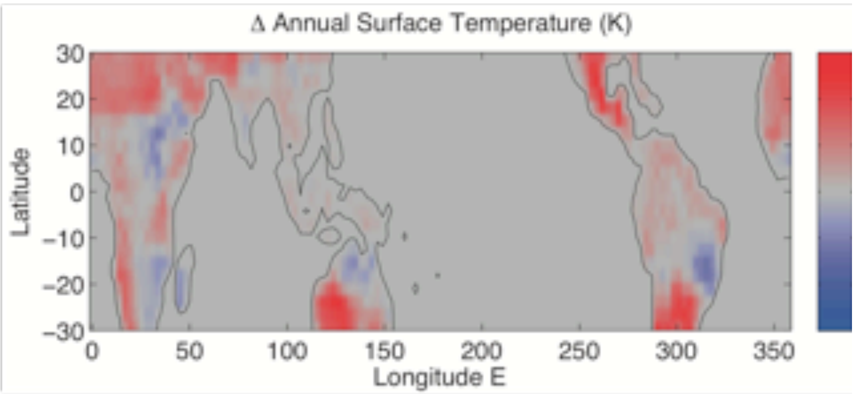
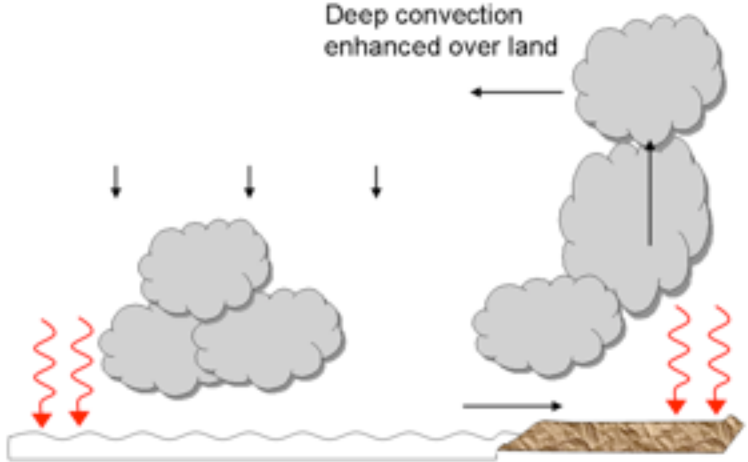


Figure 1: Annual mean change in surface temperature for SP-CAM due to 4xCO_2.



Courtesy of C. Bretherton

Find that land surface warming leads to more convection, cloud and precipitation, with the opposite happening over the oceans (which dominates global-mean change)

Rapid land warming: How fast is fast?

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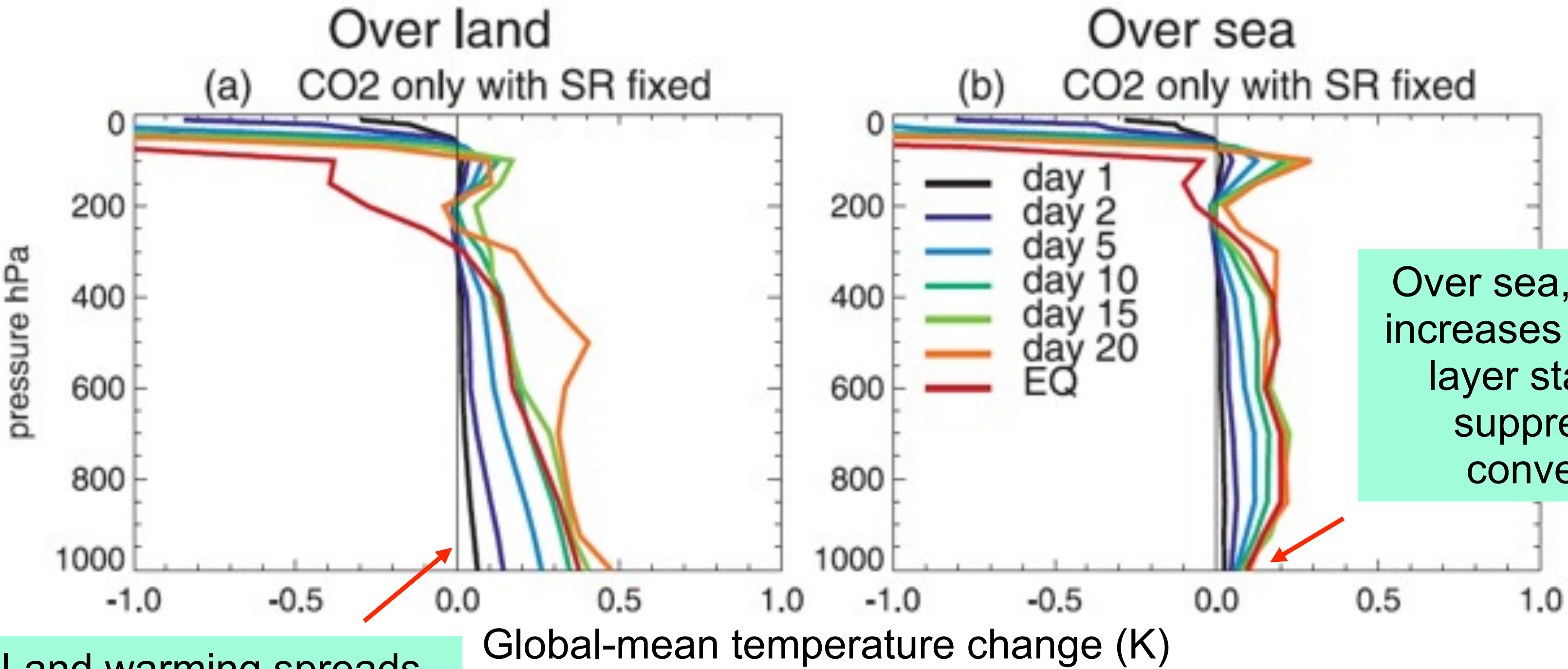
Dong et al. (2008) used 6 member $4xCO_2$ fixed-SST HadSM3 ensemble with daily diagnostics to look at timescale of adjustments:



Over sea, warming increases boundary layer stability – suppressing convection

Land warming spreads upwards from surface

Day 1: Land warms due to increased LW

Days 2-5: Processes adjust (e.g. clouds, precip)

Days 6-20: Troposphere approaches eqm

Ties is nicely with process-based understanding

Quantifying cloud adjustment terms

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Rapid adjustment terms for 2xCO2 (CO2 semi direct effect)

Table 1. Semi-Direct Forcing Components Induced by 2 × CO_2 for Various Slab Ocean GCMs[a] in units of $W m^{-2}$

	Clear-Sky LW (F_{LN})	Clear-Sky SW (F_{SN})	Cloud LW (F_{LC})	Cloud SW (F_{SC})	Net (F)
CCSM3.0	−0.28 ± 0.15	0.02 ± 0.28	−0.39 ± 0.12	−0.13 ± 0.14	−0.78 ± 0.34
CGCM3.1(T47)	0.45 ± 0.23	−0.17 ± 0.33	−0.16 ± 0.14	0.86 ± 0.19	0.98 ± 0.54
CGCM3.1(T63)	0.46 ± 0.23	0.02 ± 0.25	−0.22 ± 0.16	1.04 ± 0.43	1.30 ± 0.66
GISS-ER	–	–	–	–	0.01 ± 0.42
MIROC3.2(medres)	−0.57 ± 0.27	0.13 ± 0.24	−0.11 ± 0.09	1.02 ± 0.41	0.47 ± 0.69
MRI-CGCM2.3.2	−0.15 ± 0.36	−0.42 ± 0.25	−0.26 ± 0.17	0.54 ± 0.32	−0.29 ± 0.55
UKMO-HadGEM1	−0.62 ± 0.34	−0.39 ± 0.32	−0.24 ± 0.19	0.57 ± 0.30	−0.67 ± 0.69
Ensemble	−0.12 ± 0.48	−0.14 ± 0.23	−0.23 ± 0.10	0.65 ± 0.44	0.15 ± 0.80

Andrews and Forster (2008)

Strong positive SW CRE suggestive of a reduction in low-level cloudiness

Net cloud adjustment is generally positive, enhancing radiative forcing and hence climate sensitivity

Cloud adjustment vs cloud feedback

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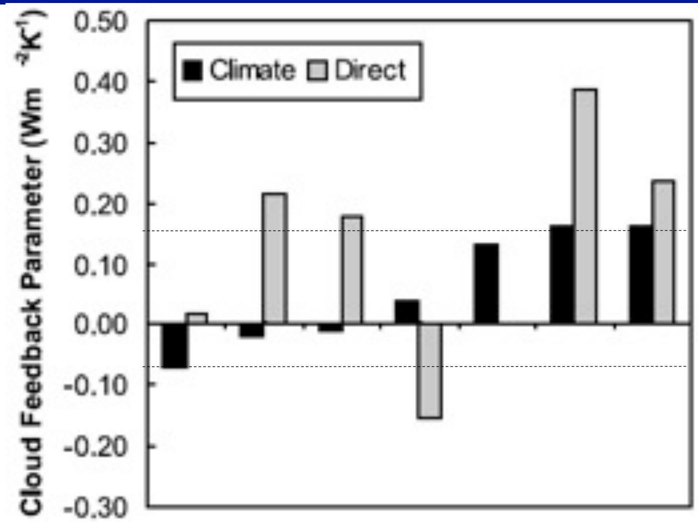
Climate = regression

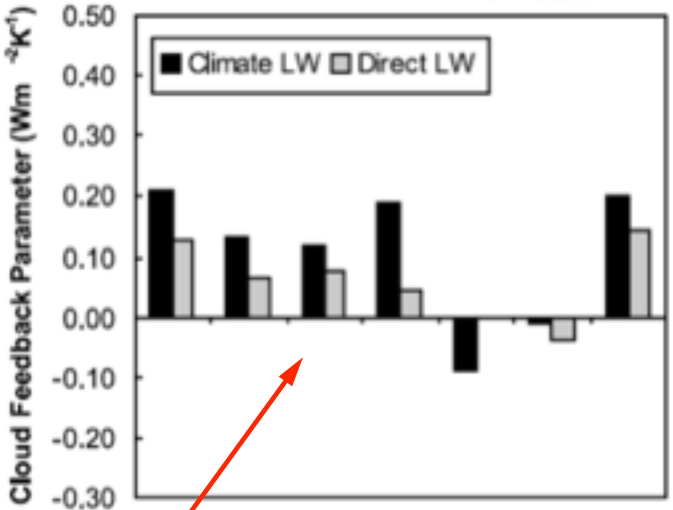
(only includes Δ*CRE* that scales with Δ*T* as feedback)

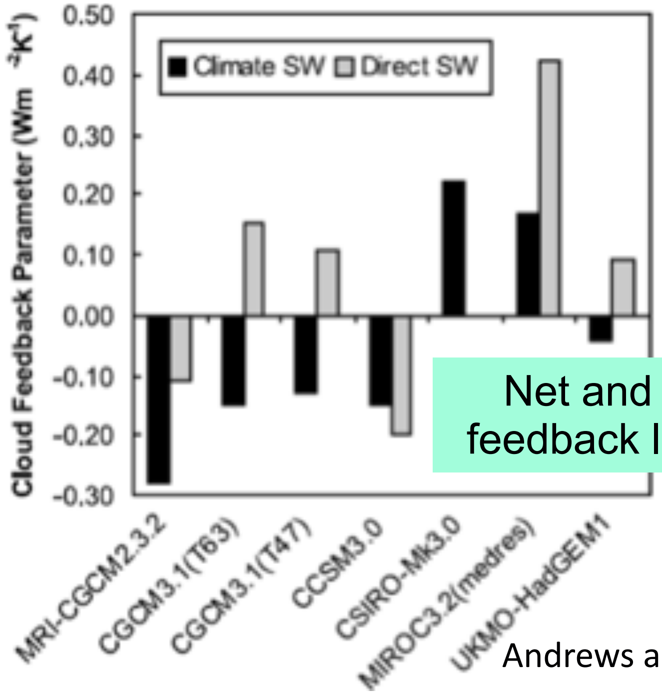
Direct = $\Delta CRE_{eqm}/\Delta T_{eqm}$

(counts all Δ*CRE* as feedback)



Reduced range of model predicted cloud feedback





Net and SW cloud feedback less positive

LW cloud feedback slightly more positive

Andrews and Forster (2008)

Which method to use?

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	Pros	Cons
Gregory Method (regression) $F=N+Y\Delta T$	Can be used with slabGCMs or AOGCMs	uncertain intercept for small forcing terms, are first time-steps linear?
Shine Method (fixed surface T everywhere)	Efficacies closer to one than fixed SSTs?	disrupts land DTR hard to engineer
Hansen Method fixed SST)-λT	Preserves zero temperature change	need to know climate sensitivity for land T changes
Hansen Method (fixed SST)	Straightforward method	Some global T response has already happened

Time to vote

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1	Radiative Flux Perturbation	Semi direct effects
2	Adjusted Forcing	Rapid adjustments
3	It’s a climate feedback, fool!	Fast feedbacks?

3. Forcing role in testing climate models

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- Tropical warming
- CMIP5 model response
- Aerosol effects

Tropical warming in models

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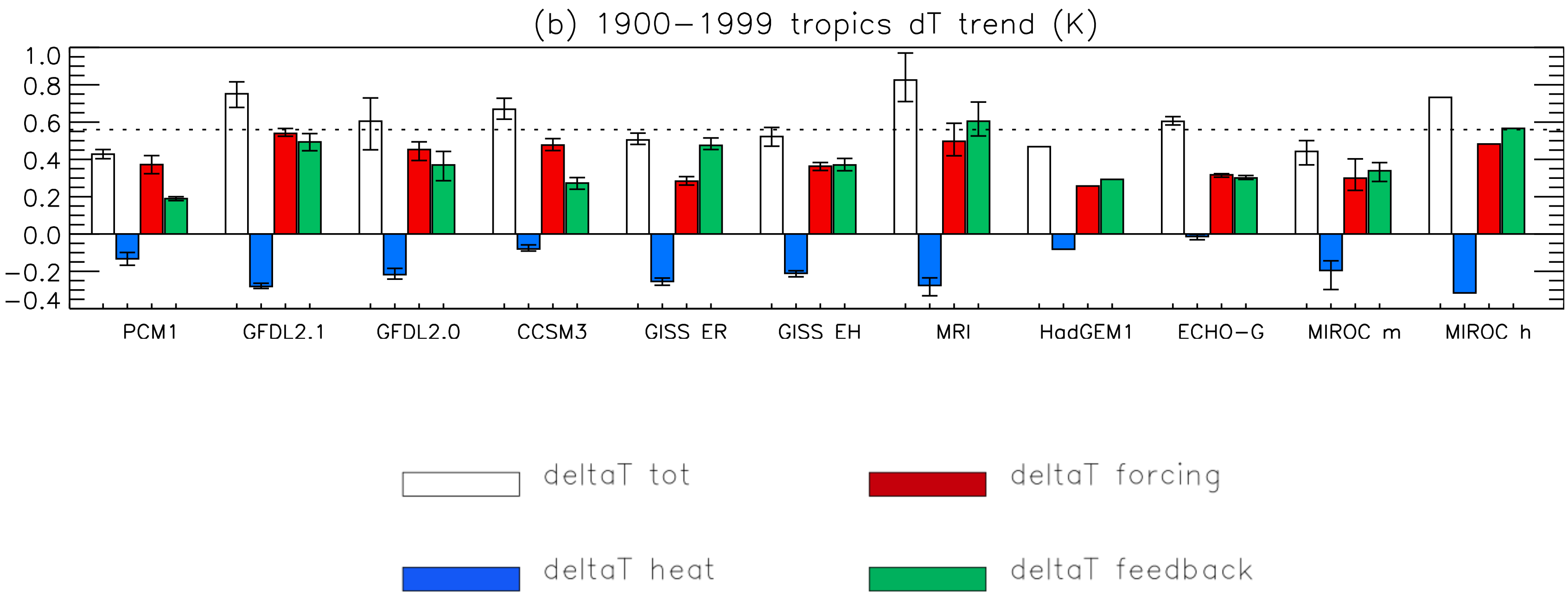
Regression splits response to forcing, feedback and heat transport



Crook et al., 2011, J. Geophys. Res.

Forcing from CMIP5 models

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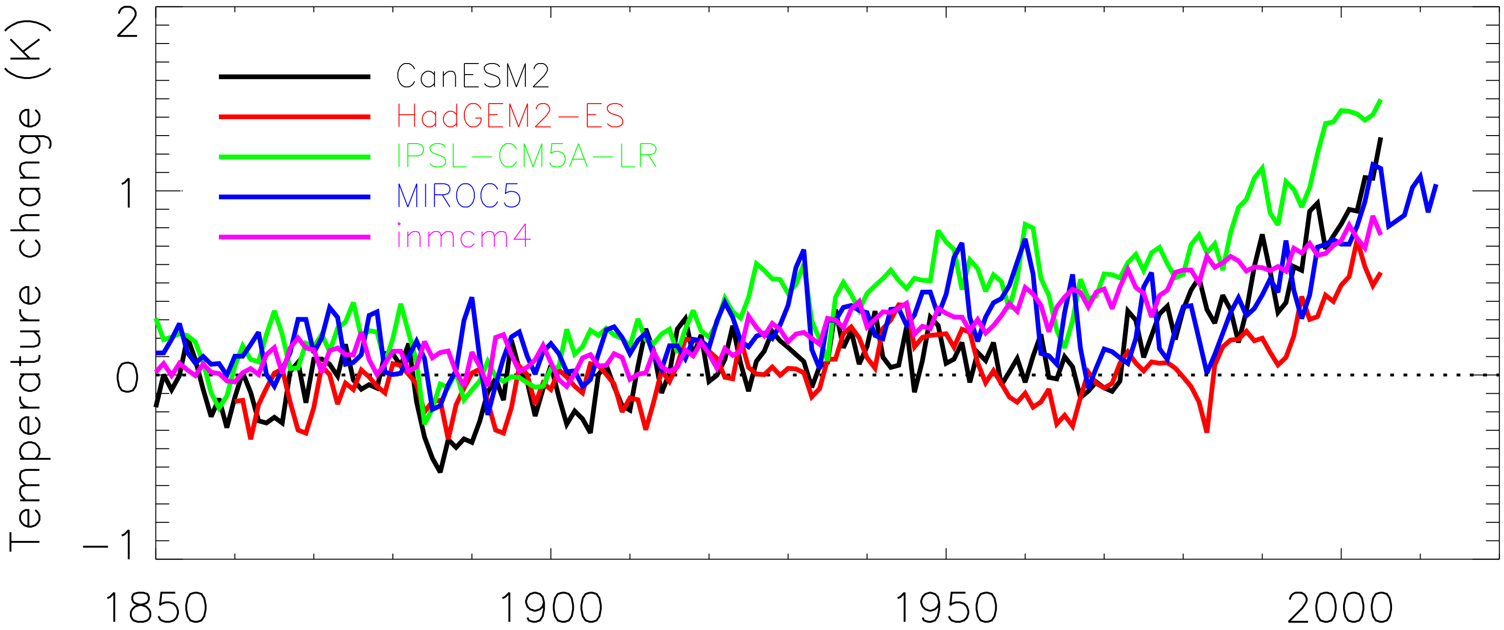
The assumed-efficacy-forcing or the slackers forcing



During transient change, radiative response is proportional to ΔT:

$$N = F - Y\Delta T$$

Method follows Forster and Taylor, 2006 J Climate

Y from 4xCO2 Experiments (Tim Andrews)

slackers forcing seems to work

Forcing from CMIP5 models

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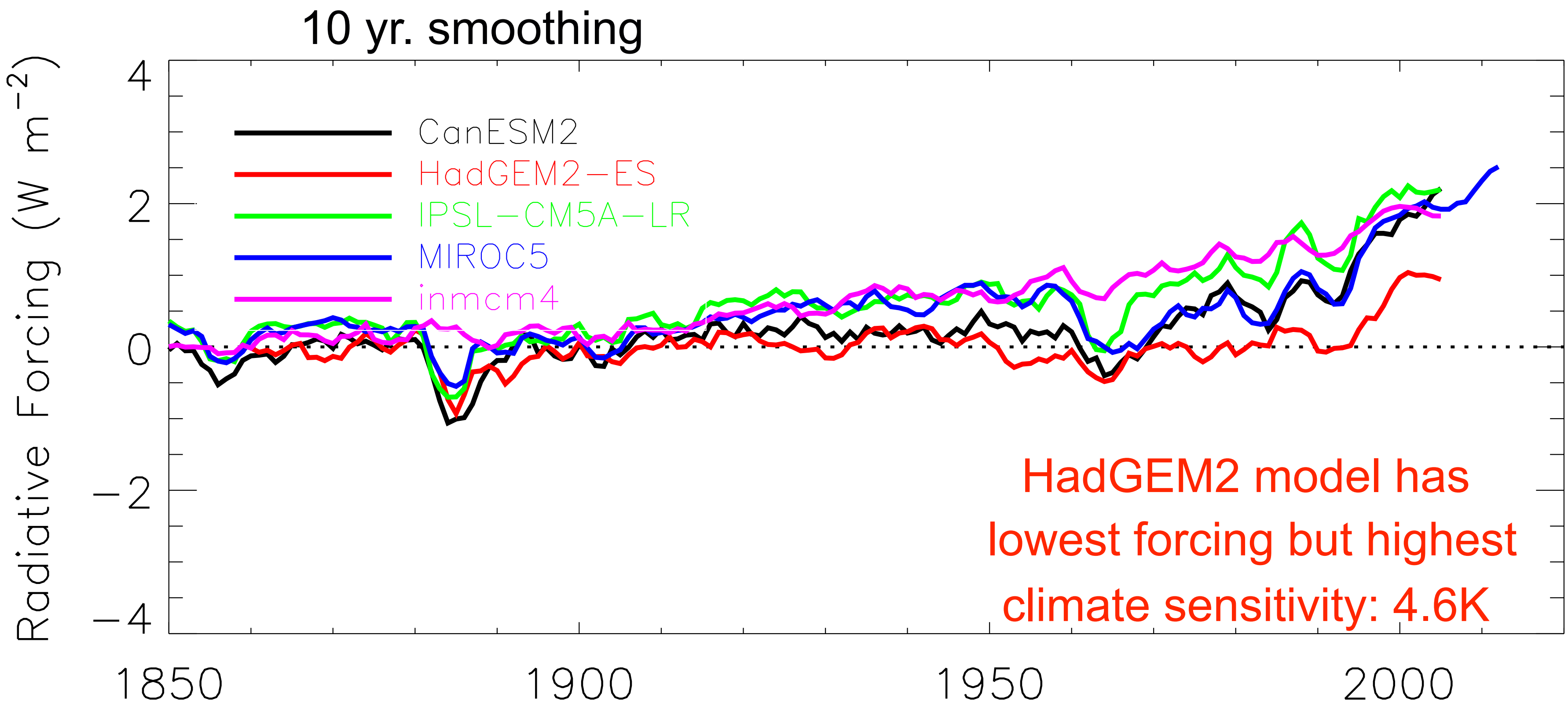

CMIP5 forcing components

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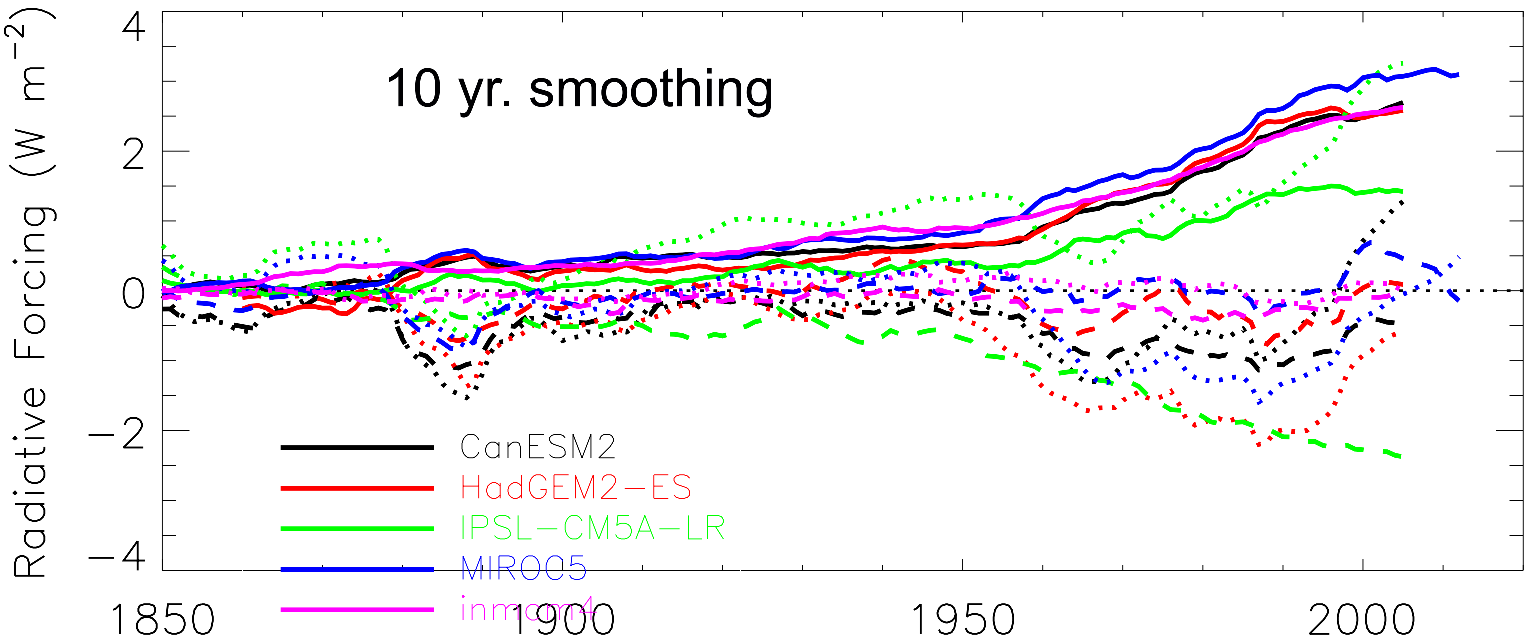


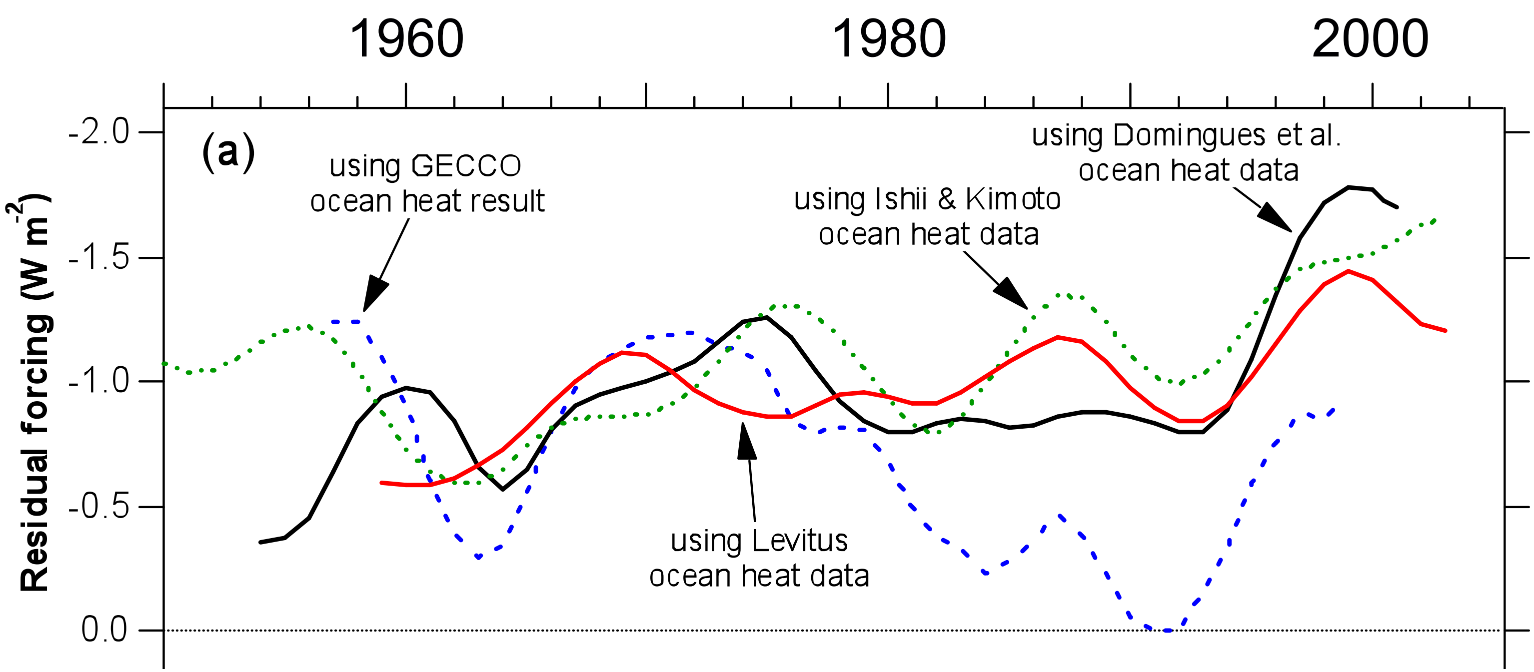
solid lines- LW clear-sky

dotted lines - SW clear sky (aerosol/surface albedo)

dashed lines - NET cloud radiative forcing

Warning very preliminary analysis!

Inverse forcing estimates



Top Down/Inverse approach to aerosol forcing

$$N = F_{known} + F_{unknown} - Y\Delta T$$

Ocean heat content

Forster et al., 2007

Forster and Gregory analysis of CERES

HadCRU

Murphy et al., PNAS 2010

Aerosol indirect developments

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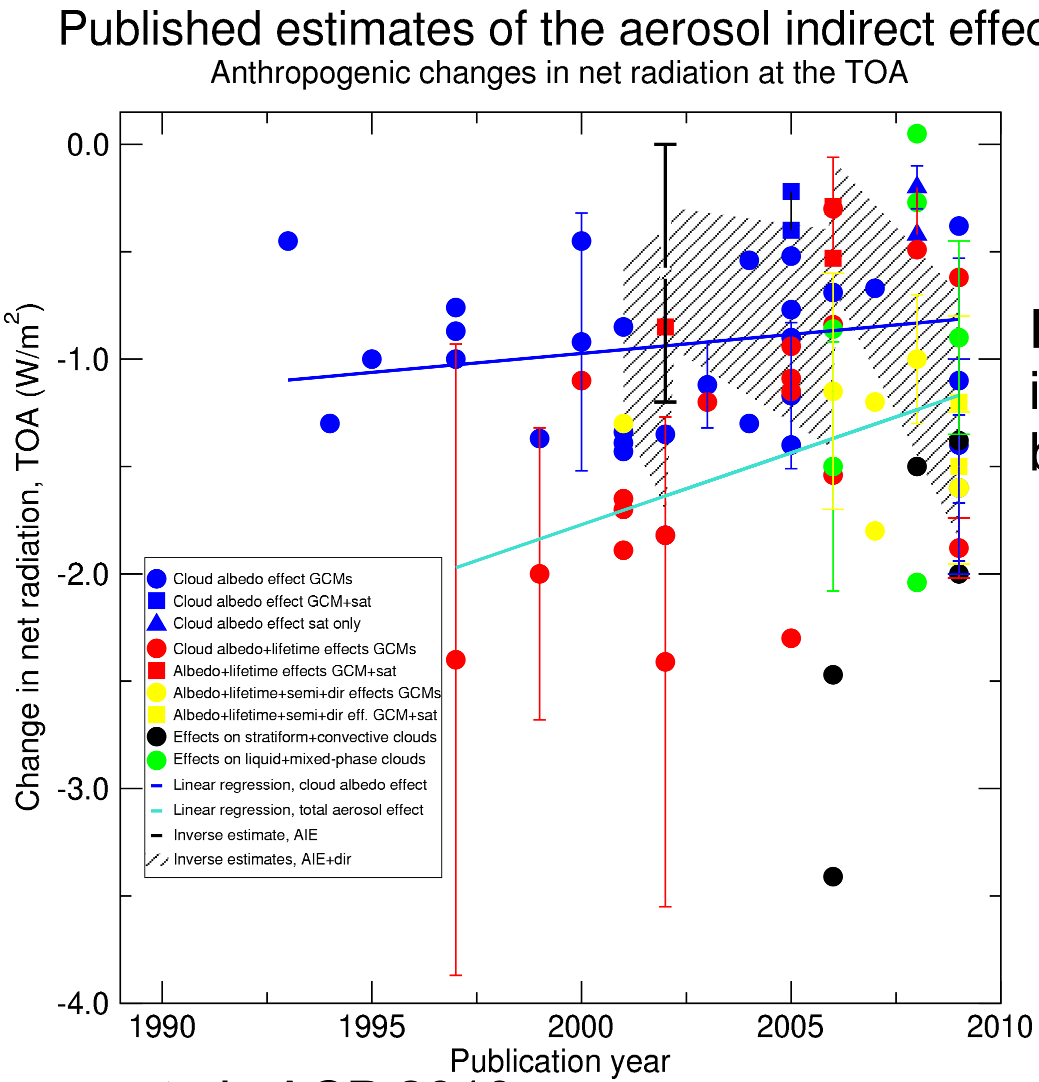

Is this trend all down to improvements in the forward/ bottom up estimate?

Lohmann et al., ACP 2010

Conclusions

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Looking at how the atmosphere rapidly adjusts when a forcing is applied tells you a lot about its ultimate response

Rapid adjustments

- significantly influence radiative forcing
- contribute to spread in response between models
- affect diagnosis of model feedbacks and hydrological responses

- **Forcing diagnostics provide a much needed test of climate model behaviour**
- **Caution: in some instances, climate models seem to be getting similar responses for different reasons, creates large divergence in future.**

- **RE climate policy, doesn't matter what forcing framework you use provided all forcing types accounted for without double counting**