Met Office
Hadley Centre

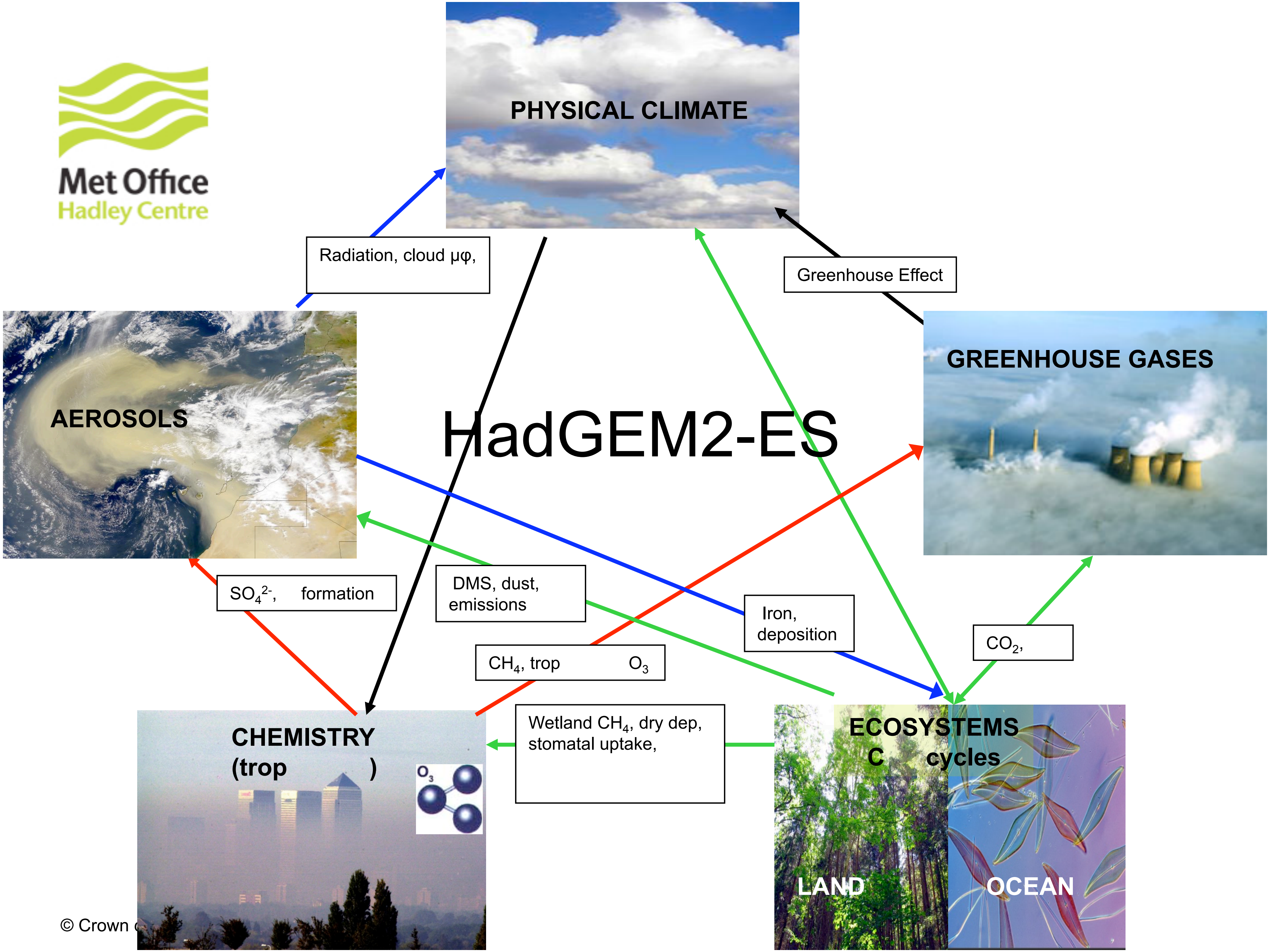
Quantifying biogeochemical feedbacks in an Earth system model

Bill Collins, Olivier Boucher, Jonathan Gregory, Chris Jones

SRG. Oct. 2011

Table of Contents

- Earth system feedbacks in HadGEM2-ES
- Feedback analysis framework
- Examples
  - CLAW
  - Wetland methane
- Combining feedbacks
- Summary



PHYSICAL CLIMATE
Radiation, cloud μφ,
Greenhouse Effect
AEROSOLS
HadGEM2-ES
GREENHOUSE GASES
SO_4^{2-}, formation
DMS, dust, emissions
Iron, deposition
CO_2,
CH_4, trop O_3
Wetland CH_4, dry dep, stomatal uptake,
CHEMISTRY (trop)
O_3
ECOSYSTEMS C cycles
LAND
OCEAN

Formulation of generalised framework

- How can we quantify the climate-composition feedbacks in the ESMs?

- Friedlingstein 2006 split the carbon cycle sensitivity into:
  - Impacts of CO_2 on itself (β)
  - Impacts of temperature on the carbon cycle (γ)
  - E.g. land carbon storage: $C_L = C_L^0 + \beta_L \Delta C + \gamma_L \Delta T$

- This can be generalised for many species
  - β_{ij} now refer to the impact of species *j* on species *i*.
  - $C_i = C_i^o + \Sigma_j \beta_{ij} \Delta C_j + \gamma_i \Delta T$

- The total forcing = sum of the $\Delta C_i \times$ forcing efficiency Φ_i
  - $F = \Sigma_i \Phi_i \Delta C_i = \Delta T / \lambda$ (λ is transient climate sensitivity)

- From this we can calculate gain factors for the feedbacks
  - $G_i = 1 / (1 - \lambda \gamma_i \Phi_i)$
  - $G_i = 1 / (1 - (\Phi_i / \Phi_j) \beta_{ij} f_j)$

Calculating γs and βs

- Consider 5 species:
  - CH_4 (1), O_3 (2), sulphate (3), other aerosols (4) and dust (5)

γ

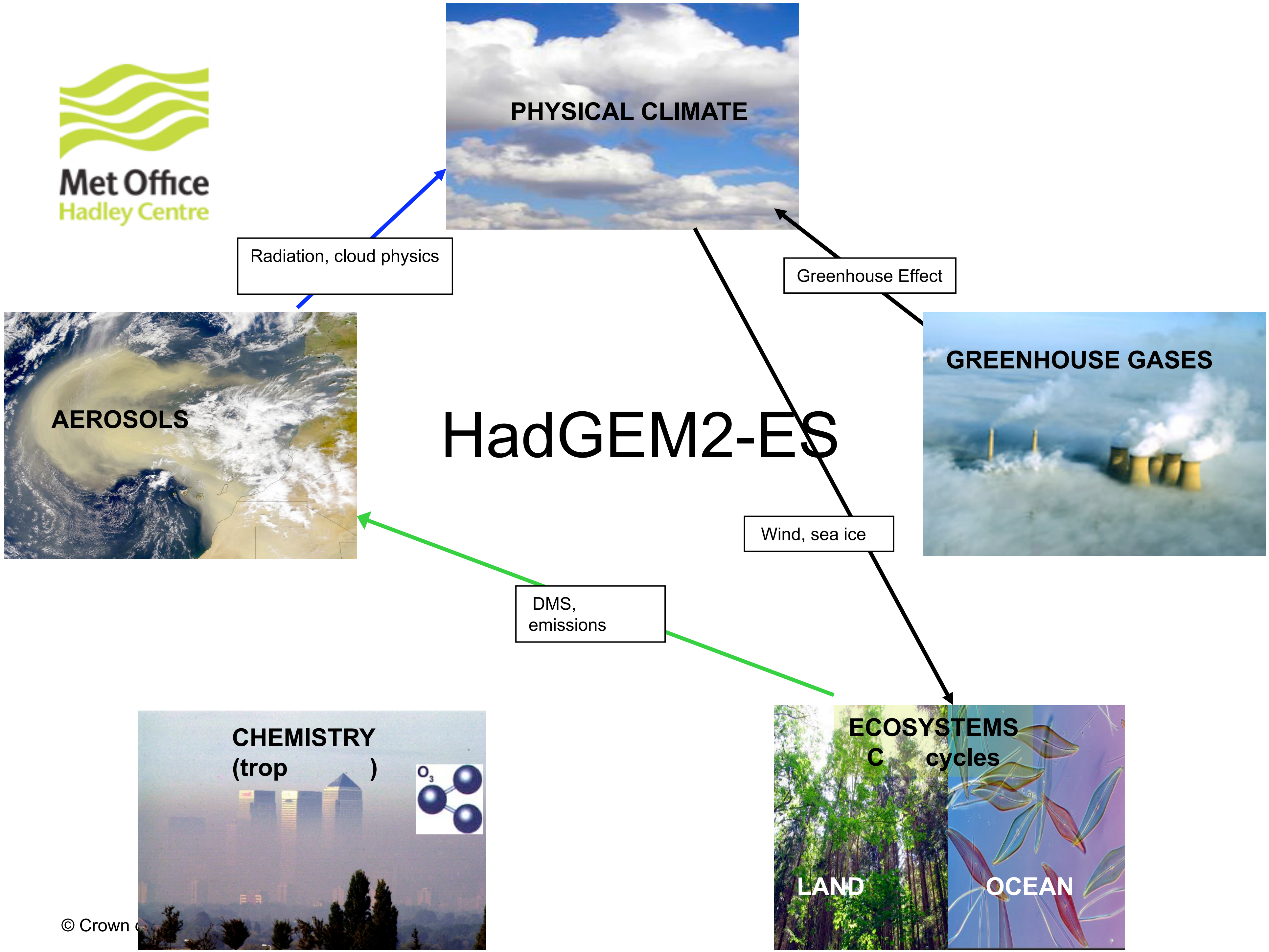
  - γ_1 – methane feedback from wetland emissions and lifetime changes
  - γ_2 – feedback from ozone lifetime change
  - γ_3 – sulphate feedback from DMS emissions and sulphate lifetime changes
  - γ_4 – other aerosol emissions and removal
  - γ_5 – dust emissions and lifetime

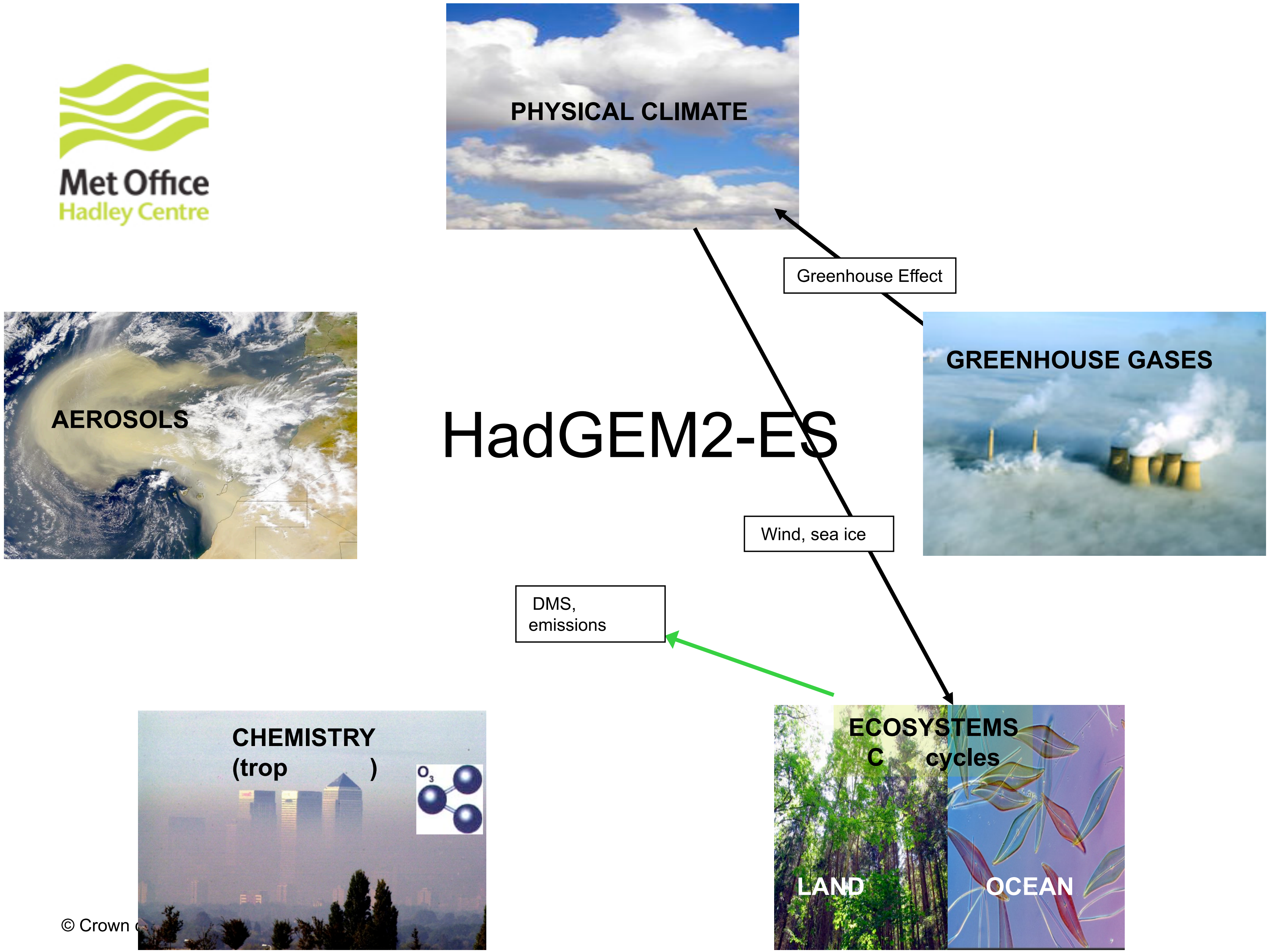
β

Impact of species j

Impact on species i

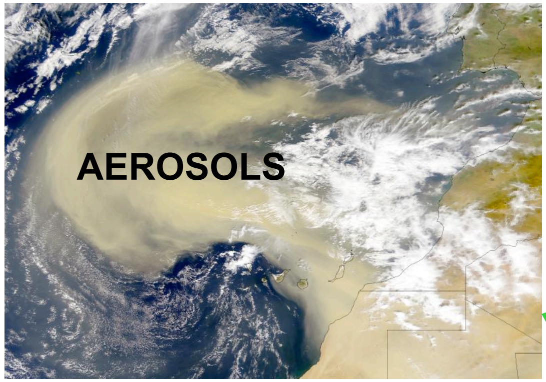
Species	0 (CO_2)	1 (CH_4)	2 (O_3)	3 (sulphate)	4 (other aerosols)	5 (dust)
0 (CO_2)	**β_{00} (fertilisation effect)**					**β_{05} (dust fertilisation of the ocean)**
1 (CH_4)		β_{11} (methane lifetime effect)	β_{12} (chemical effect)			
2 (O_3)		β_{21} (chemical effect)				
3 (sulphate)		**β_{31} (oxidation)**	β_{32} (oxidation)			β_{35} (dust fertilisation)
4 (other aerosols)						
5 (dust)	β_{50} (CO_2 impact on vegetation)					β_{55} (dust self feedback)


Met Office
Hadley Centre
PHYSICAL CLIMATE
Radiation, cloud physics
Greenhouse Effect
AEROSOLS
HadGEM2-ES
GREENHOUSE GASES
Wind, sea ice
DMS,
emissions
CHEMISTRY
(trop)
O3
ECOSYSTEMS
C cycles
LAND
OCEAN


PHYSICAL CLIMATE
Greenhouse Effect
GREENHOUSE GASES
AEROSOLS
HadGEM2-ES
Wind, sea ice
DMS,
emissions
CHEMISTRY
(trop)
ECOSYSTEMS
C cycles
LAND
OCEAN

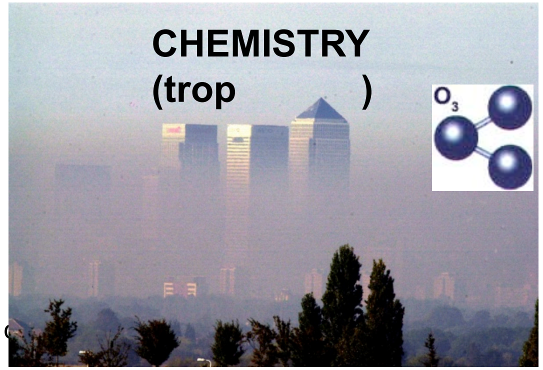
Met Office
Hadley Centre

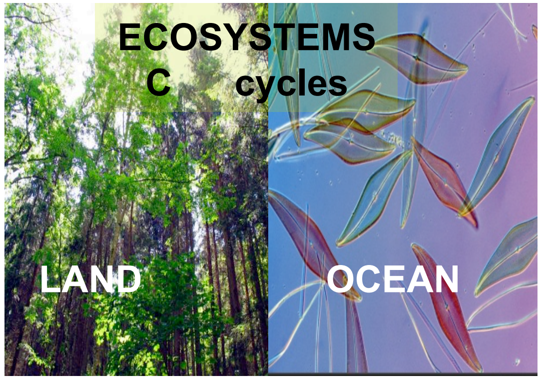
Radiation, cloud physics



HadGEM2-ES

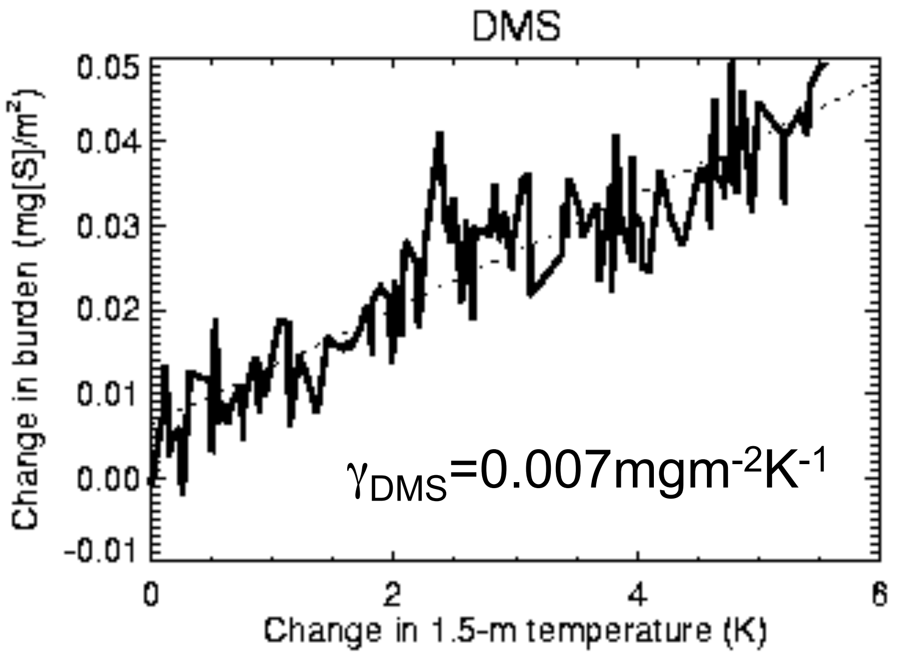
DMS,
emissions

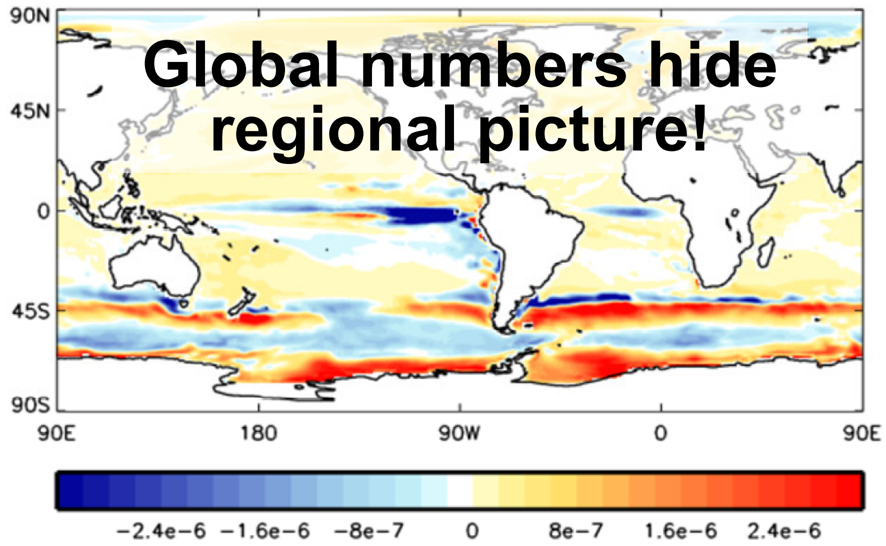




CLAW

- Increase CO_2 by 1%/yr
  - ΔT=5.5K after 140 years
- Little change in global-average ocean DMS. (not true regionally)
- However sea-air flux increases (windspeed and sea ice)
  - $\gamma_{DMS}=0.007 mgm^{-2}K^{-1}$
- Decoupled experiment to calculate forcing efficiency
  - $\Phi_{DMS}=-5\ Wm^{-2}/mgm^{-2}$
  - Direct + 1st indirect
- Feedback: $\gamma\ \Phi = -0.035\ Wm^{-2}K^{-1}$



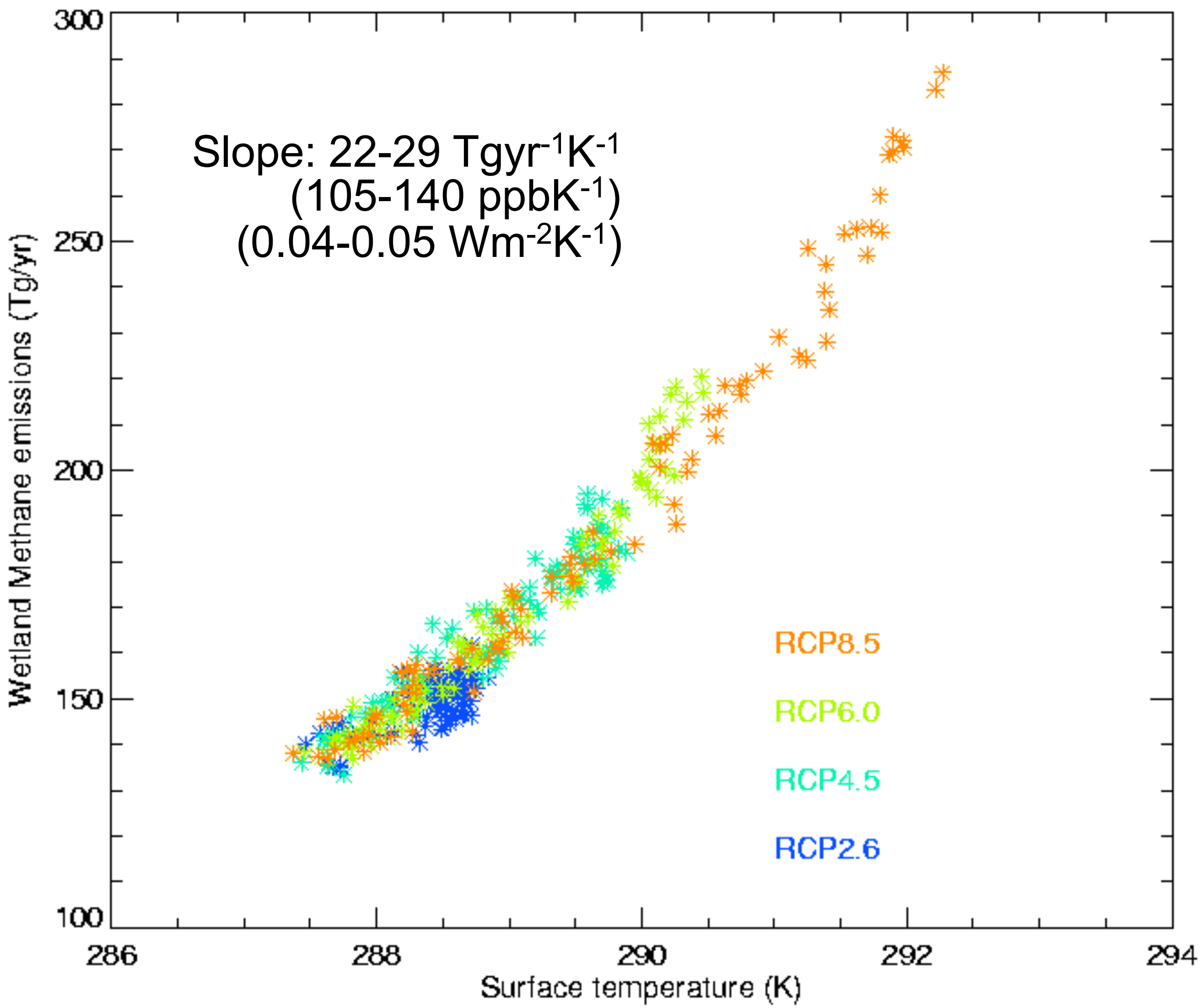


Wetland methane feedback

Methane emissions from wetland areas

Depend on temperature and precipitation

- γ_i=105-140 ppbK^{-1}
- Climate feedback 0.04-0.05 Wm^{-2}K^{-1}
- → amplification by ~3-4%



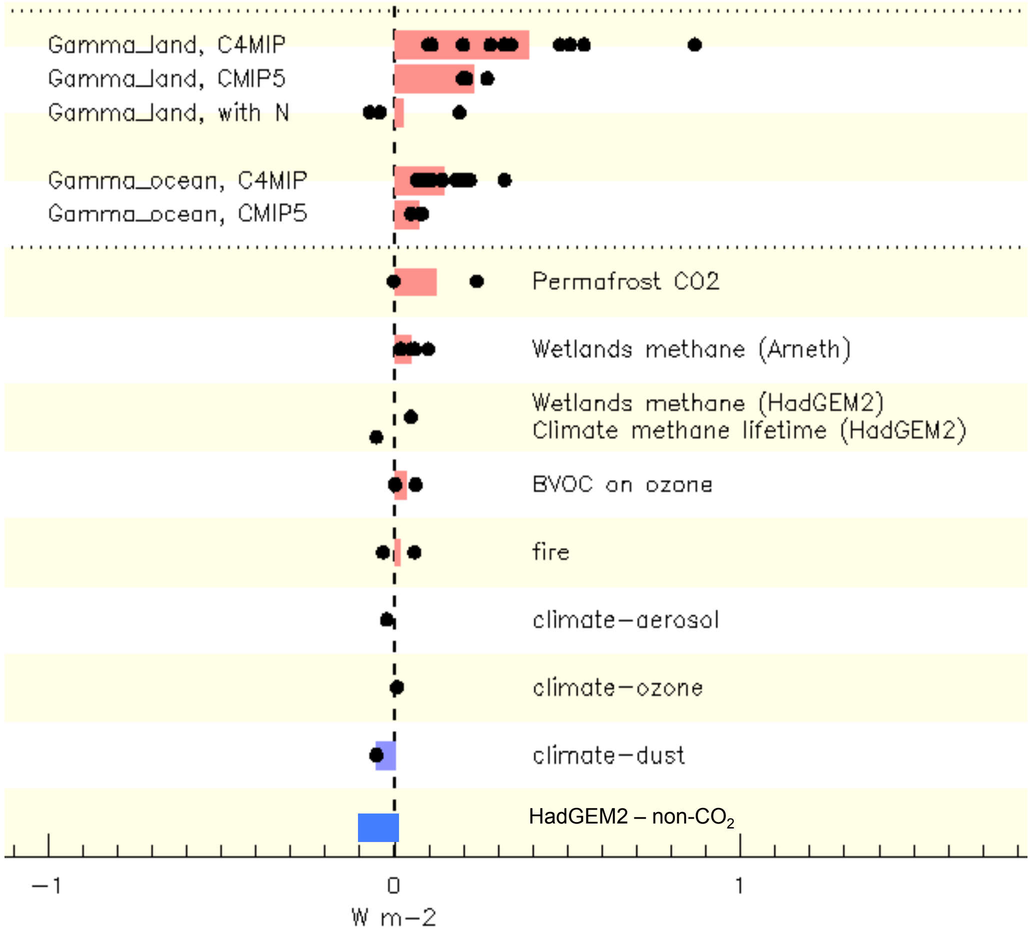
Climate feedbacks

- Large feedbacks from methane, but cancel
- Negative feedbacks from aerosols
- Overall negative

Species	γ (TgK^{-1})	Feedback ($Wm^{-2}K^{-1}$)
Methane **(wetland)** (lifetime)	-70 -> 78 **282->371** -352->-293	-0.01->0.01 **0.04->0.05** -0.05->-0.04
Ozone	1.8-2.0	0.007
DMS	**0.01**	**-0.035**
Sulphate	0.009	-0.01
Sea Salt	0.1	-0.01
BC	0	0
OC	0.004	-0.001
Biomass	0.03	-0.01
Dust	3.3	-0.05
Total		**-0.1**

Putting them all together…

- Based on Arneth et al. figure
- Allows comparison of feedback magnitudes
- Little estimate of uncertainty
- Need to compare with observations at the process level



Summary

- ESMs now simulate complex web of interactions
- Can now quantify these feedbacks
  - And express in common units ($Wm^{-2}K^{-1}$)
- Both positive and negative feedbacks
- Overall negative in HadGEM2-ES
  - DMS, dust
- Highly model dependent!
  - Observations needed to evaluate modelled processes
- Global means hide complex regional pictures