Royal Netherlands
Meteorological Institute
Ministry of Infrastructure and the Environment

Climate Change Impacts on Atmospheric Chemistry in EC-Earth Driven Simulations

Twan van Noije, Achim Strunk, Philippe Le Sager

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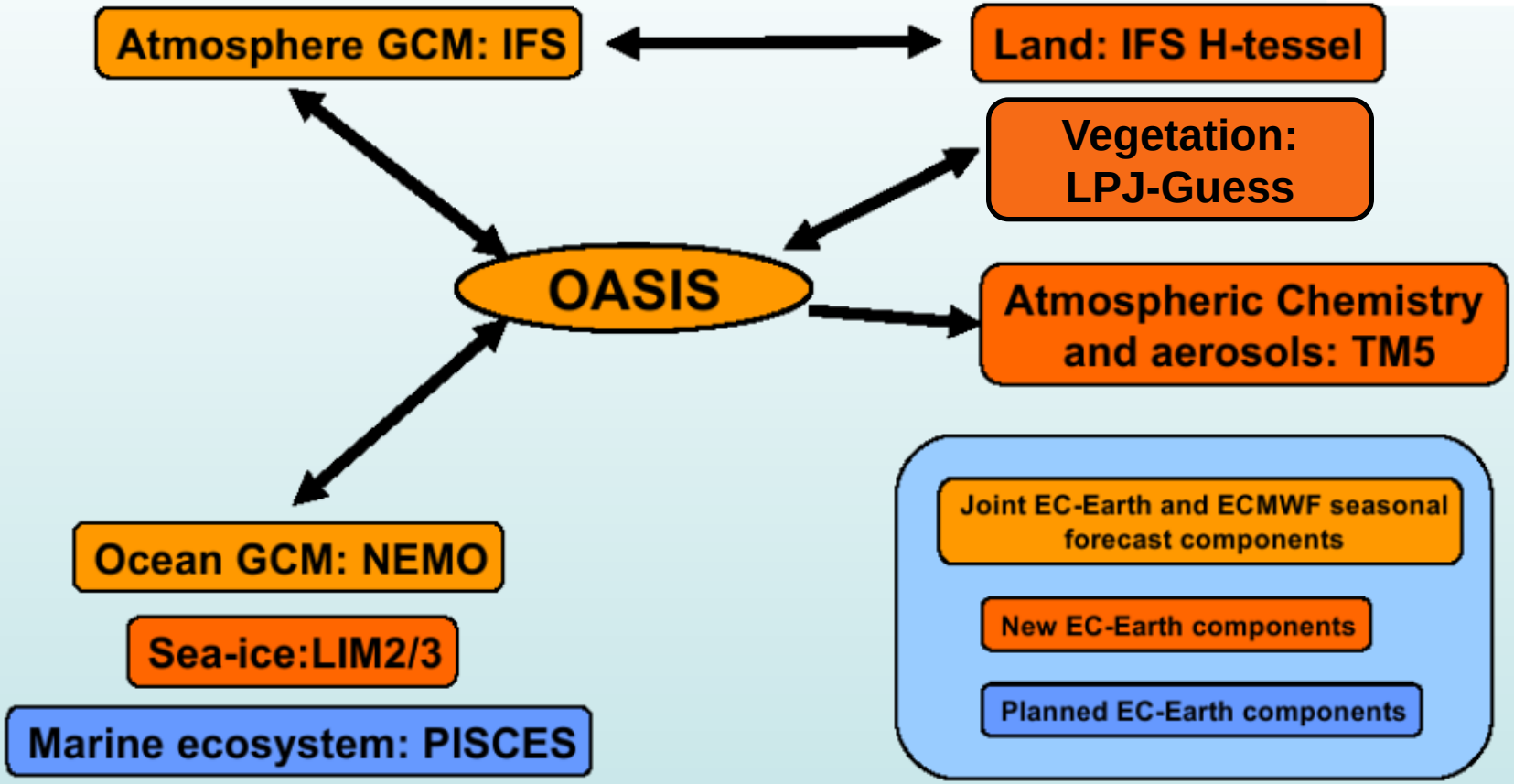
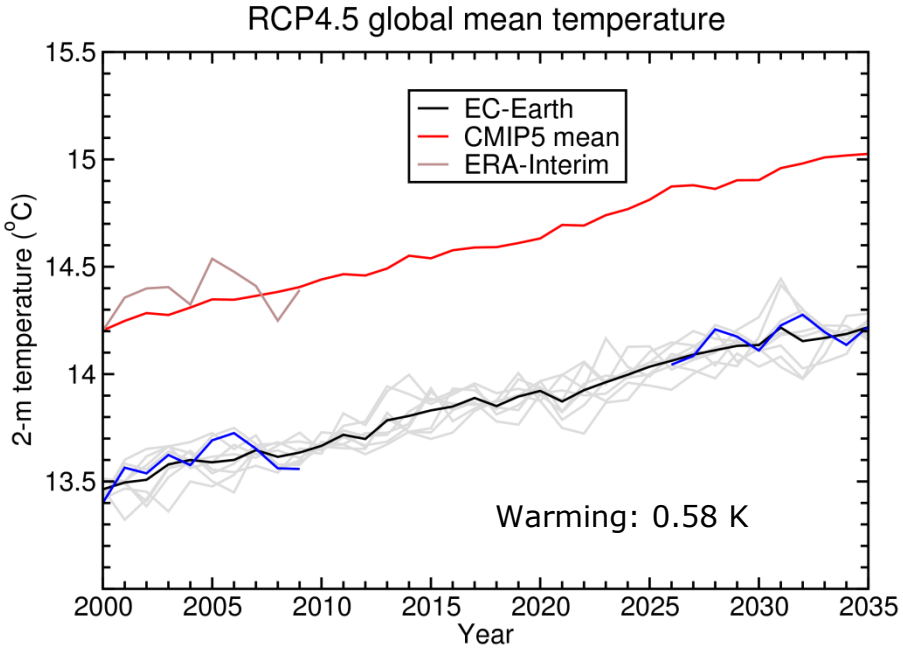
EC-EARTH components

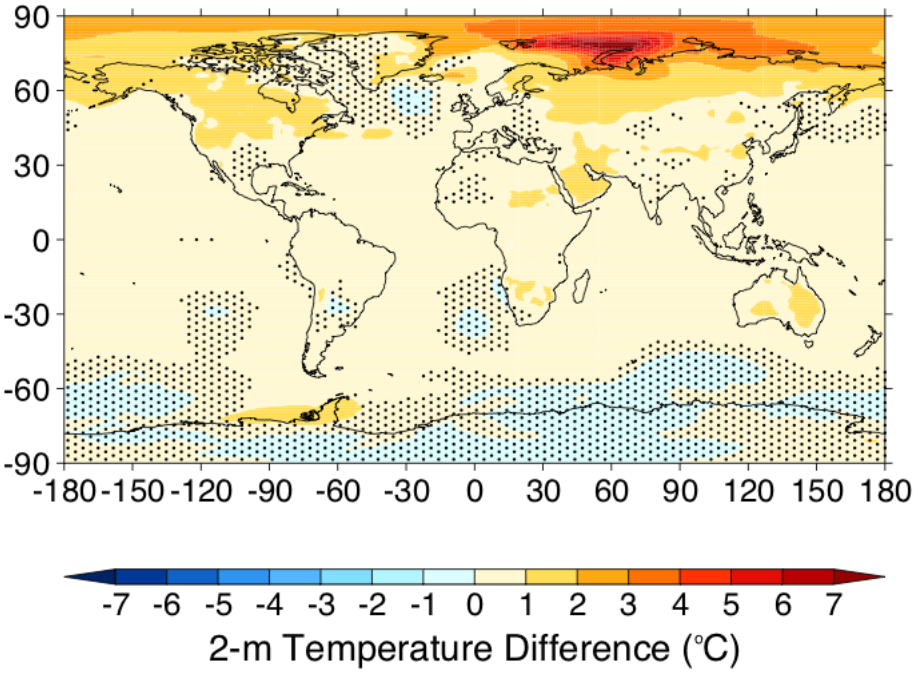


IFS to TM5	TM5 to IFS
Wind divergence/vorticity	Ozone concentration
Temperature	Methane concentration
Specific humidity	Aerosol number concentrations (per mode)
Cloud liquid/ice water content	Aerosol component mass concentrations (per mode)
(Overhead/Underfeet) Cloud fraction	Aerosol extinction (per wavelength)
Up-/downdraft convective air mass flux	Aerosol single-scattering albedo (per wavelength)
Up-/downdraft detrainment rate	Aerosol asymmetry parameter (per wavelength)
Surface pressure	
10-m u/v wind	
2-m (dewpoint) temperature	
Surface E-W/N-S momentum stress	
Surface sensible/latent heat flux	
Surface solar radiation	
Stratiform precipitation as rain	
Convective precipitation as rain	
Skin reservoir water content	
Snow depth	
Soil wetness in top soil layer	
Low/high vegetation cover fractions	
Vegetation type fractions	
Surface roughness	
Sea-ice fraction	

Simulation of near-term climate change effects (~25 years)

- Decadal simulations (CBM4+M7)
- Offline meteorology:
  - EC-Earth output for 2000-2009 resp. 2026-2035 (RCP4.5)
- Online emissions: SS, oceanic DMS, LNOx
- Other emissions prescribed for 2000-2009:
  - Anthropogenic and biomass burning: CMIP5/ACCMIP (RCP4.5)
  - Biogenic and other oceanic: MACC (MEGAN/POET)
  - Dust: AeroCom
- 3x2 degrees, 31/62 levels



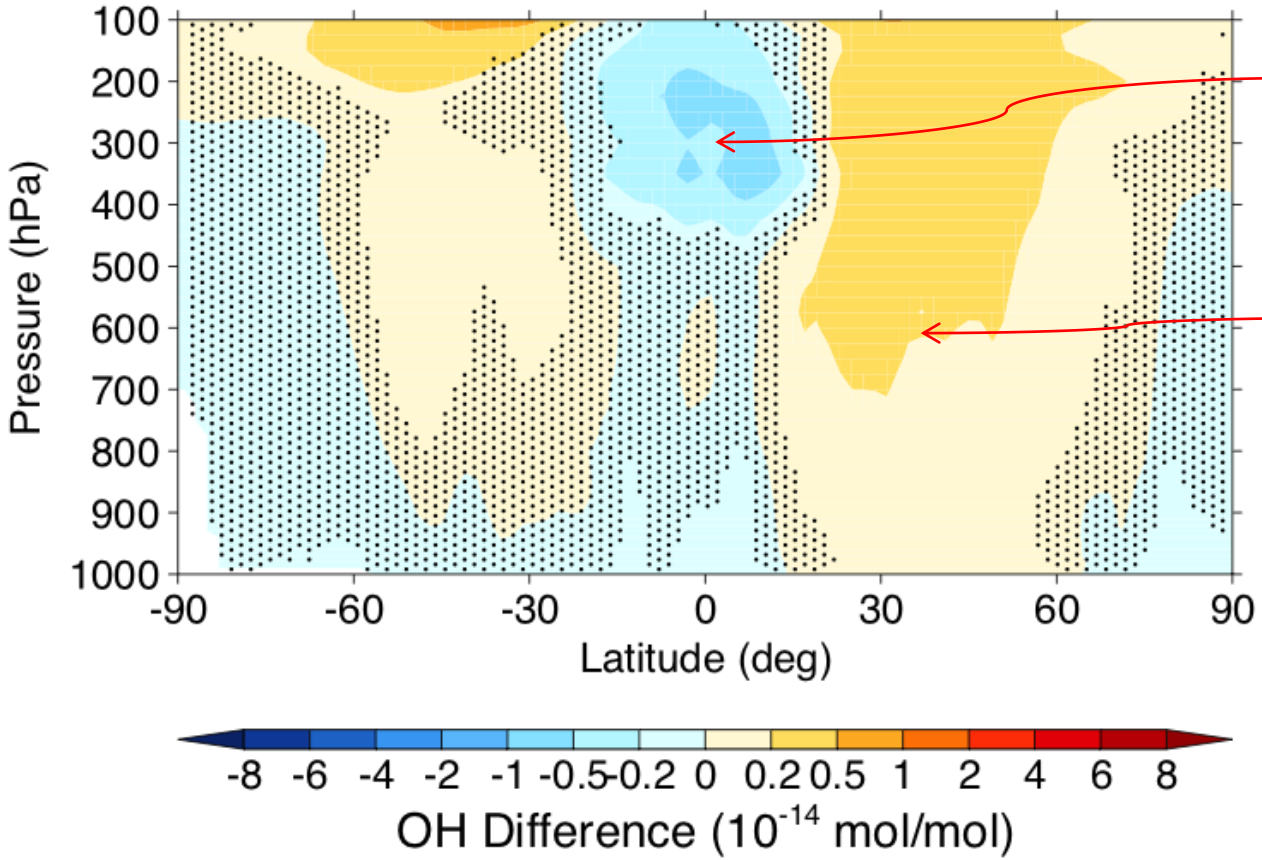


In our TM5 simulations LNOx decreases by 7.0%

(from 6.7 ± 0.15 Tg N/yr to 6.2 ± 0.23 Tg N/yr)

in contrast with the expectation that the flash rate will increase due to global warming (e.g. Price and Rind, 1994)

Oxidizing capacity



Reduced LNOx

Enhanced O_3 photolysis

$$O_3 + h\nu \rightarrow O(^1D) + O_2$$
$$O(^1D) + H_2O \rightarrow 2OH$$

CH_4 tropospheric lifetime reduced by 1.8% or 3.2%/K

Comparison with other models

Model	CH_4 tropospheric lifetime decrease per degree global warming (%/K)
CESM-CAM-superfast	3.5
GFDL-AM3	3.4
GISS-E2-R	1.1
MIROC-CHEM	4.1
MOCAGE	3.0
NCAR-CAM3.5	4.3
STOC-HadAM3	2.4
UM-CAM	4.1
ACCMIP Mean	***3.2 ± 1.1***
MAGICC6	3.16 (assumed)
TM5	**3.17**

Negative climate feedback

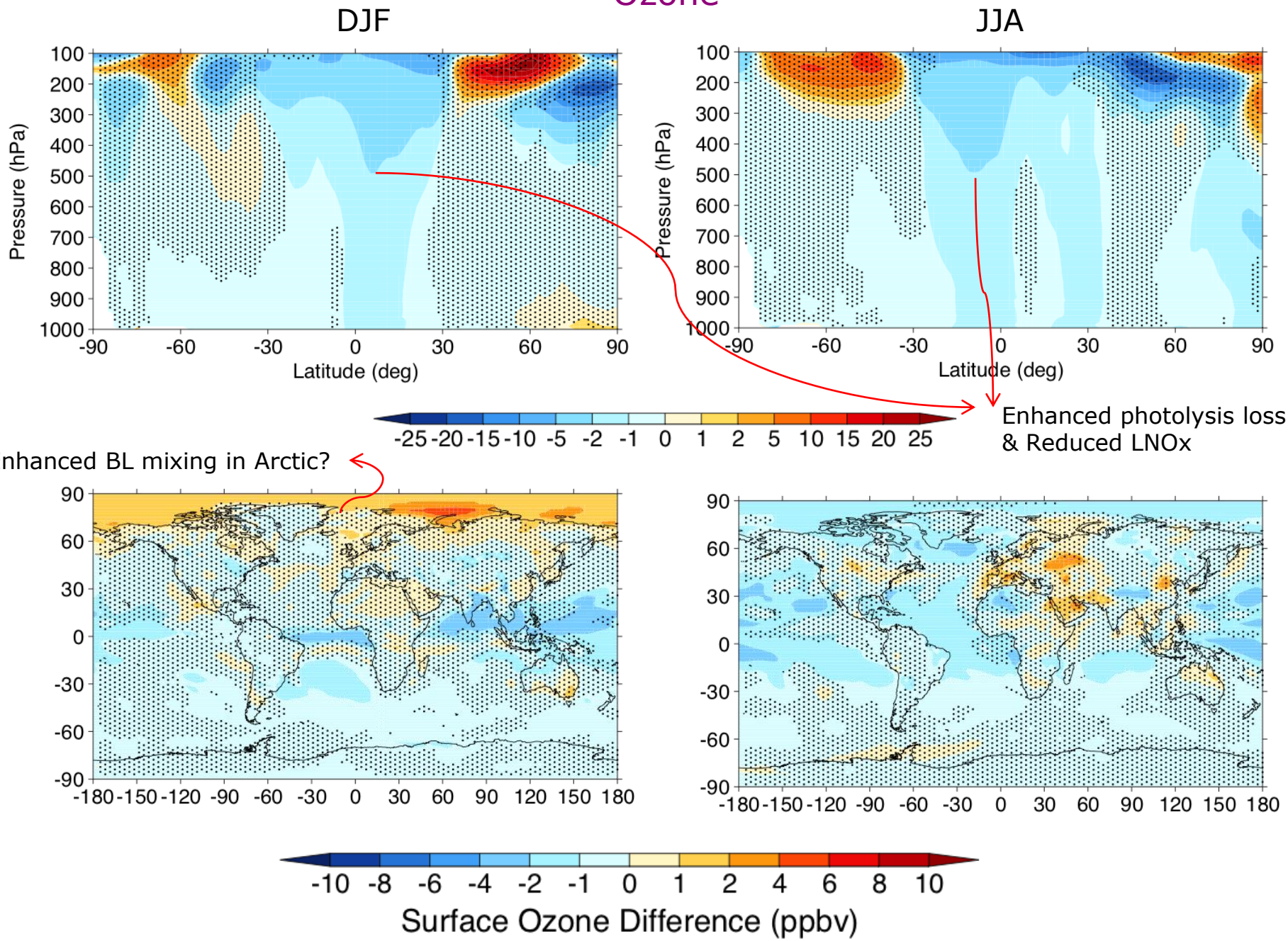
Atmospheric CH_4 lifetime reduced by 1.8% or 3.1%/K

→ RF reduction of 27 mW/m^2/K

→ Climate feedback parameter: g ≈ -3.1%

(climate sensitivity: 0.8 K/(W/m^2), efficacy: 145% [Hansen et al., 2005])

Ozone


DJF
JJA
Pressure (hPa)
Latitude (deg)
-25 -20 -15 -10 -5 -2 -1 0 1 2 5 10 15 20 25
Enhanced photolysis loss
& Reduced LNOx
Enhanced BL mixing in Arctic?
-10 -8 -6 -4 -2 -1 0 1 2 4 6 8 10
Surface Ozone Difference (ppbv)

7.9%/K

Tropospheric O_3	EC-Earth 2000-2009	EC-Earth 2026-2035 Climate
STE (Tg/yr)	333	349 (+4.6%)
Chemical prod. (Tg/yr)	4192	4197
Chemical loss (Tg/yr)	3623	3656
Net prod. (Tg/yr)	569	540
Deposition (Tg/yr)	902	888
Burden (Tg)	321	315 (-1.8%)
Lifetime (days)	25.9	25.3

Burden reduction of 3.1%/K → RF reduction of *roughly* 0.020 W/m²/K

→ Negative climate feedback parameter: g ≈ -1.3%

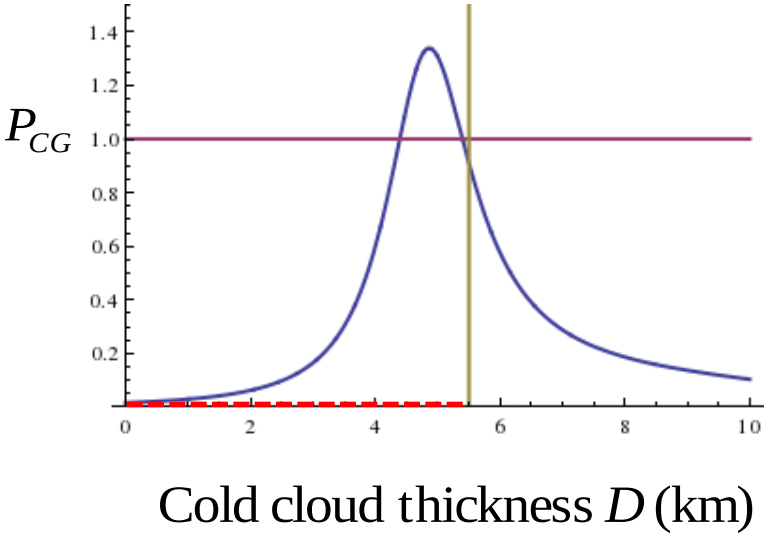
(efficacy: 82% [Hansen et al., 2005])

NB: fixed BVOC emissions, CH4 concentration

LNOx bug

"As the mixed phase region within the cold cloud sector expands as a cloud develops, the probability of dielectric breakdown increases due to increases in the electric field strength. This results in an increase in intracloud lightning discharges, or a decrease in the **fraction of cloud-to-ground discharges** in the thunderstorm." (Price and Rind, 1994)

$$P_{CG} = \frac{1}{aD^4 + bD^3 + cD^2 + dD + e} \quad (D \geq 5.5\,\text{km})$$



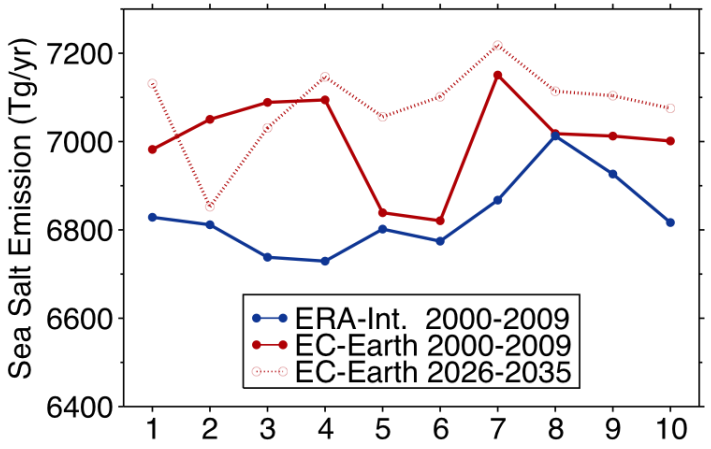
GC/IC ratio for NOx production per flash was 10:1

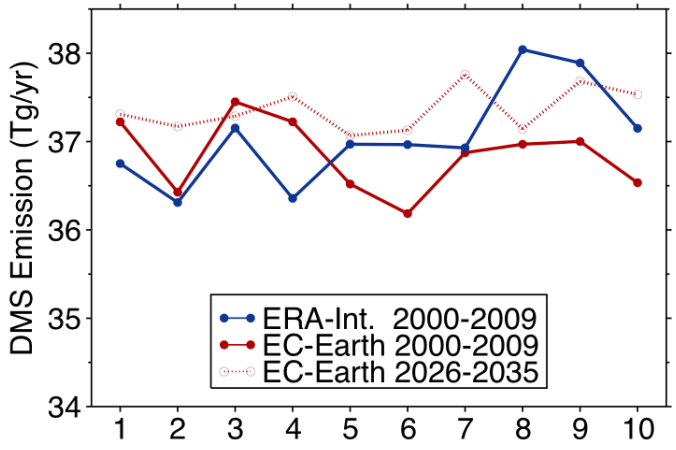
Set to 1:1 in new version

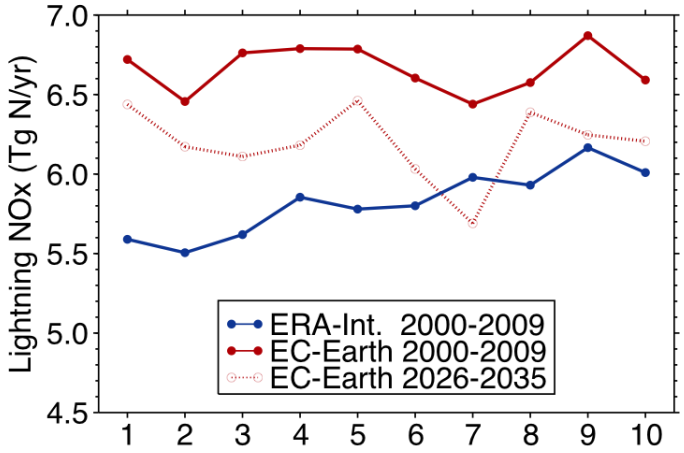
(Ridley et al., 2005; Ott et al., 2010)

Conclusions

- TM5 is part of EC-Earth release v2.4
- Now also possible to drive TM5 by offline EC-Earth output
- Decadal simulations of near-term climate change effects show negative climate feedbacks via CH_4 and O_3
- However, O_3 response incomplete (fixed BVOCs)
- Lightning NOx response probably in wrong direction (due to bug)

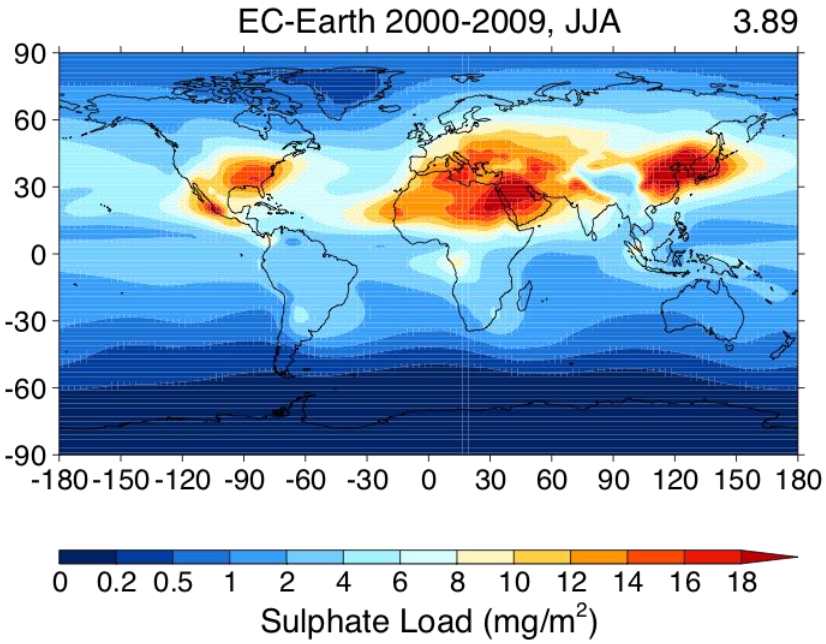


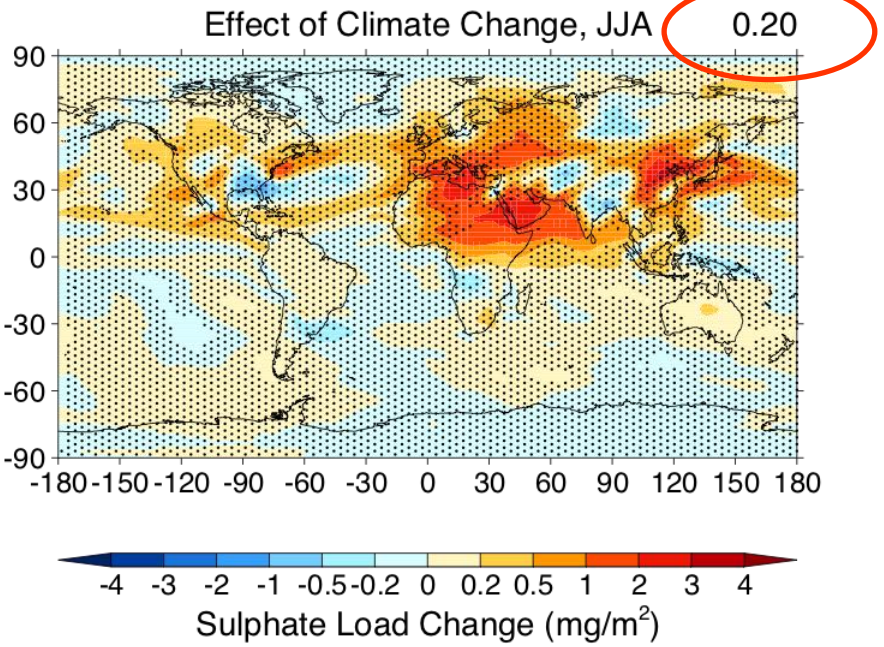




Emission	ERA-I 2000-2009	EC-Earth 2000-2009	EC-Earth 2026-2035	Significance Level
SS (Tg/yr)	6828 ± 86	7005 ± 106	7083 ± 96 (+1.1%)	90% (not significant)
DMS (Tg/yr)	37.1 ± 0.6	36.8 ± 0.4	37.4 ± 0.2 (+1.5%)	99.6%
LNOx (Tg N/yr)	5.82 ± 0.21	6.66 ± 0.15	6.19 ± 0.23 (-7.0%)	>99.99%

5.1%/0.58K → 8.9%/K





Other aerosol components show relatively smaller changes

(with prescribed SOA formation and dust emissions)