Impacts of changes in biogenic emissions on tropospheric ozone between 1954 and 2004.

S.A. Monks[1] , S.R. Arnold[1], A. Guenther[2], L.K. Emmons[3] T.Stavrakou[4]

1. Institute for Climate and Atmospheric Science, University of Leeds, UK.
2. Atmospheric Chemistry & Meteorology, Pacific Northwest National Laboratory, Richland, USA
3. Atmospheric Chemistry Division, NCAR, USA.
4. Belgian Institute for Space Aeronomy, Avenue Circulaire 3, 1180, Brussels, Belgium

NATURAL ENVIRONMENT RESEARCH COUNCIL

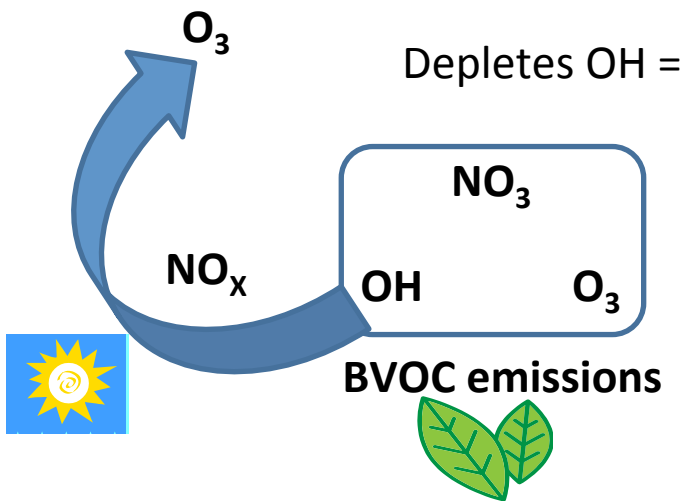
UNIVERSITY OF LEEDS

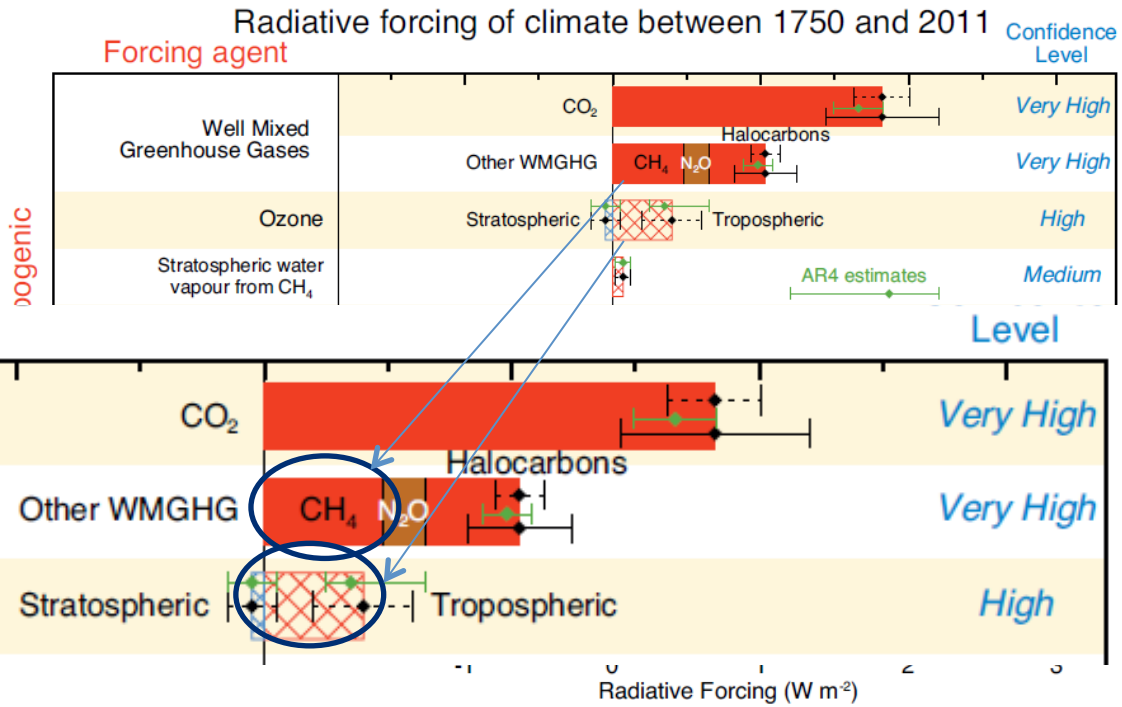
NCAR

Introduction:
Atmospheric Chemistry of Biogenic Emissions

Terrestrial vegetation emits a wide range of biogenic volatile organic compounds (BVOCs), which are:

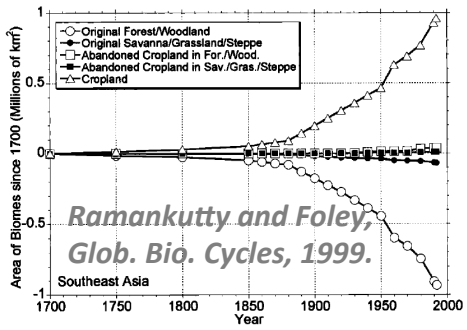
- A large source of atmospheric carbon (up to 90%)
- BVOCs are highly reactive
- Play important roles in both climate and air quality





Causes of Biogenic Emission Changes

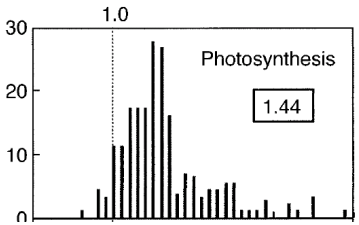
Land use and land cover changes



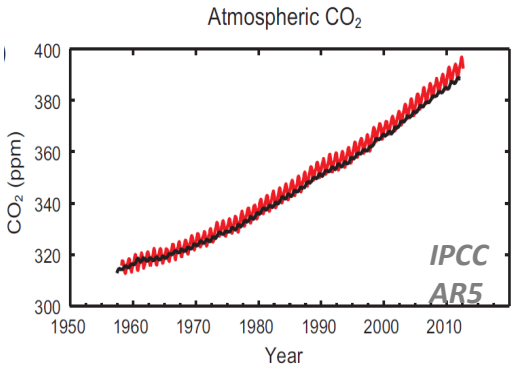
Light

Nutrient Availability

Korner et al., Ecological Applications, 2000.



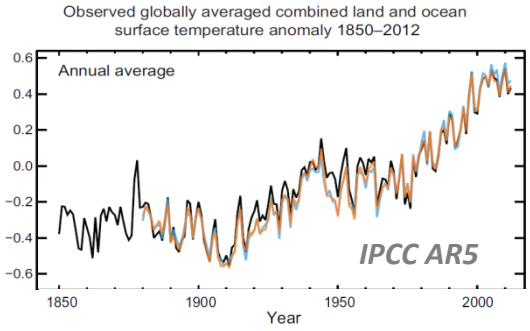
CO_2 fertilisation



BVOC emissions

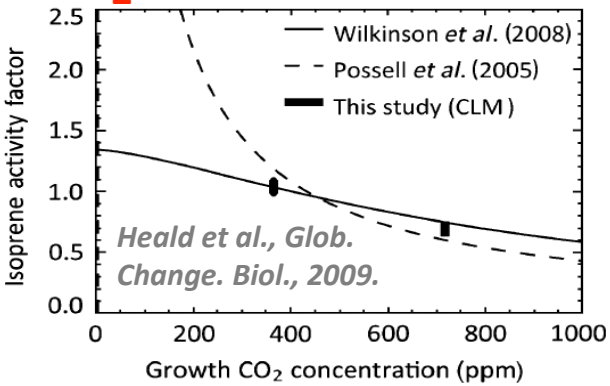
Soil Moisture/ Precipitation

Temperature

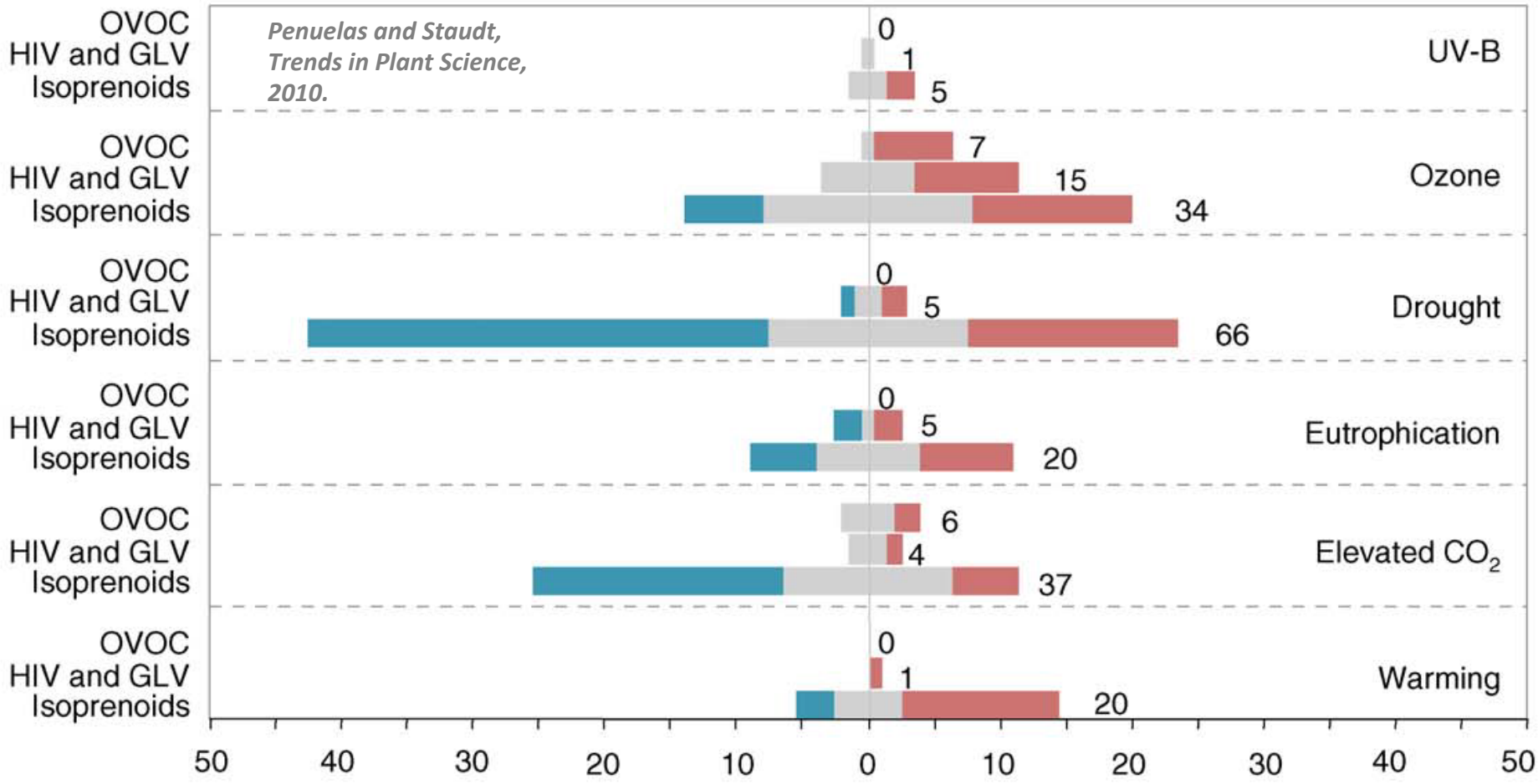


Ozone

CO_2 Inhibition



Causes of Biogenic Emission Changes



Isoprenoids (isoprene, 2-methyl-3-butenol, monoterpenes and sesquiterpenes)

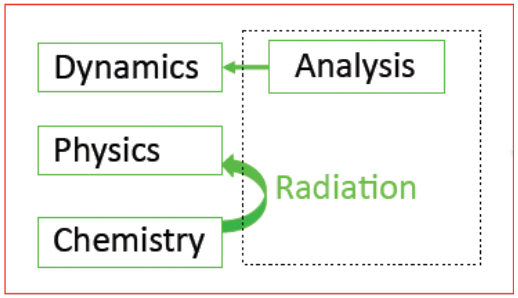
Key:
Horizontal axis shows number of published results reporting
- No significant emission change
- Emission decreases
- Emission increases

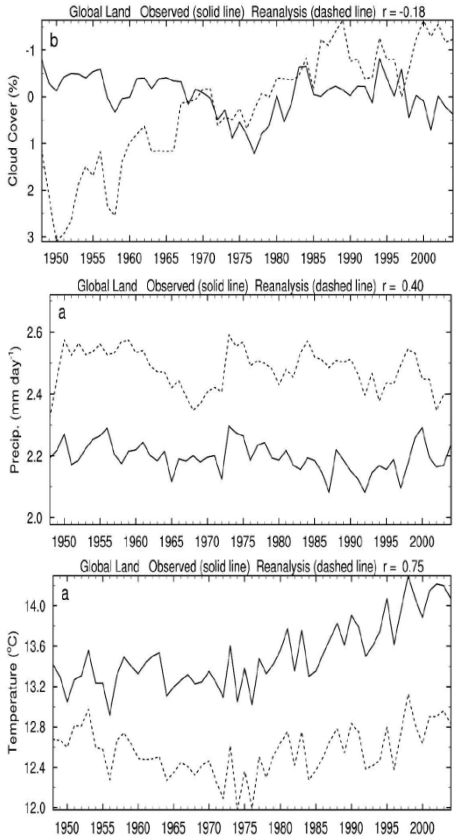
Community Earth System Model (CESM) Set-up

NCEP Reanalyses Offline Data → **CLM4 (Community Land Model)** → **CAM4 (Community Atmosphere Model)**

Lamarque et al., Atmos. Chem. Phys., 2012 .

Atmosphere Model version 4





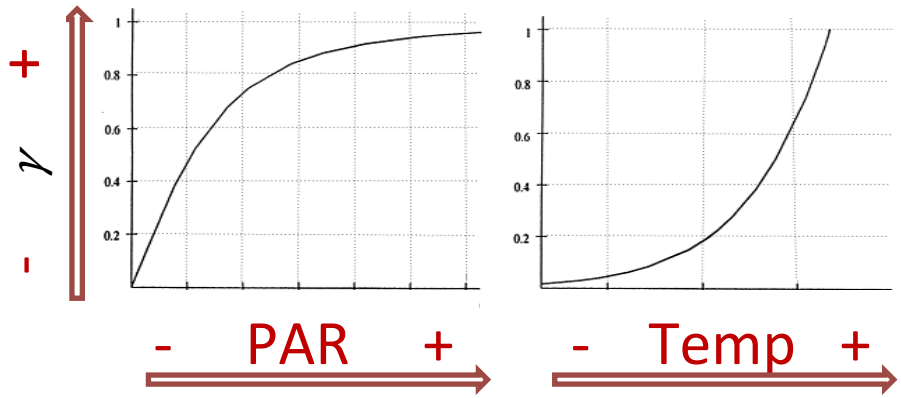
Qian et al., AMS., 2006 .

Guenther et al., GMD., 2012 .

MEGANv2.1

$$F_i = \gamma_i \sum \varepsilon_{i,j} \chi_j$$

- F_i: Emission of species i
- γ_i: Activity Factor of species i
- $\varepsilon_{i,j}$: EF of species i for land cover type j
- χ_j: Fraction of land cover type j

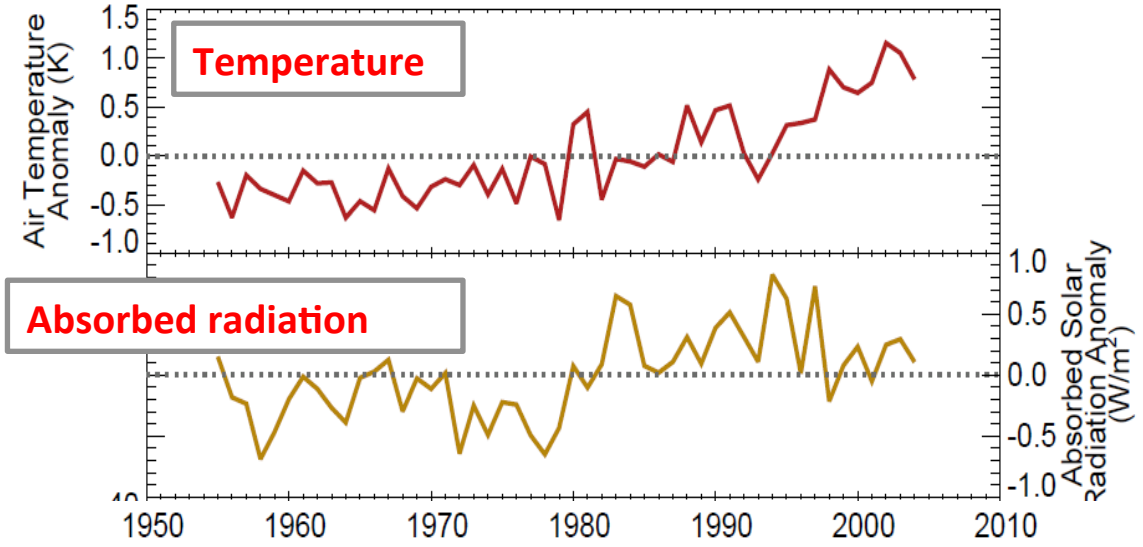


CLM Land Model Simulations

AIM: Study drivers of historical changes in BVOC emissions.

1) CLM4+MEGANv2.1 : 3 x 50-year simulations for 1955-2004.

CLM Runs	CO2	Land Cover	Aim
CLIM	367 ppm (Yr 2000)	MODIS (Yr2000)	Changes in climate
CLIM_CO2	Transient	MODIS (Yr2000)	Isoprene CO2 inhibition
CLIM_CO2_LC	Transient	Transient	Land cover change

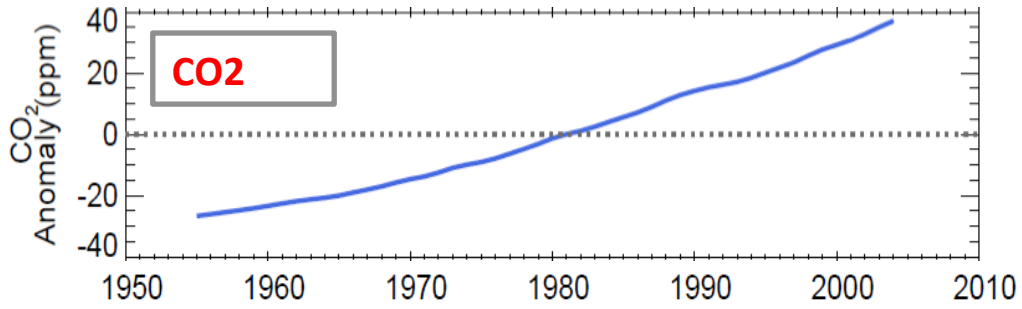


CLM Land Model Simulations

AIM: Study drivers of historical changes in BVOC emissions.

1) CLM4+MEGANv2.1 : 3 x 50-year simulations for 1955-2004.

CLM Runs	CO2	Land Cover	Aim
CLIM	367 ppm (Yr 2000)	MODIS (Yr2000)	Changes in climate
CLIM_CO2	Transient	MODIS (Yr2000)	Isoprene CO2 inhibition
CLIM_CO2_LC	Transient	Transient	Land cover change



CLM Land Model Simulations

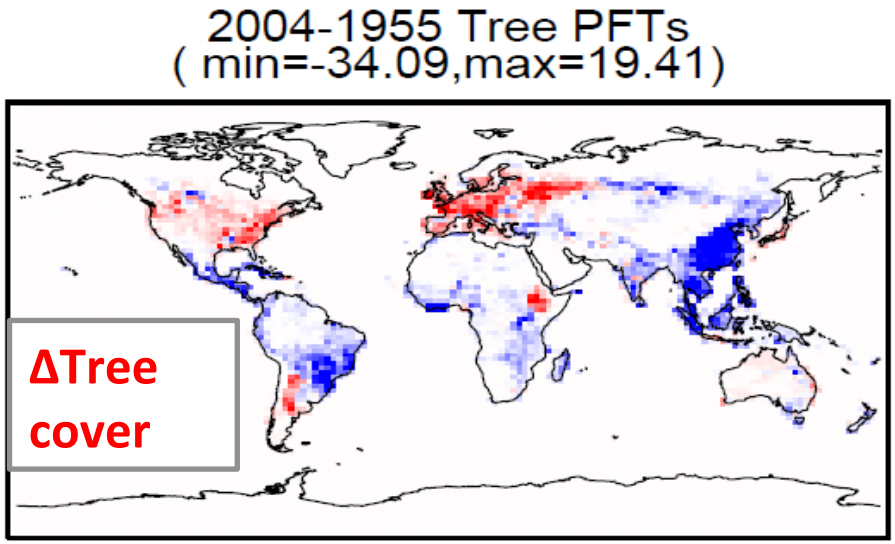
AIM: Study drivers of historical changes in BVOC emissions.

1) CLM4+MEGANv2.1 : 3 x 50-year simulations for 1955-2004.

CLM Runs	CO2	Land Cover	Aim
CLIM	367 ppm (Yr 2000)	MODIS (Yr2000)	Changes in climate
CLIM_CO2	Transient	MODIS (Yr2000)	Isoprene CO2 inhibition
CLIM_CO2_LC	Transient	Transient	Land cover change

The LCLUC dataset used in CLM4 uses a global historical transient land use and land cover change dataset (Hurtt et al. 2006).

Made to match MODIS in the year 2000 to ensure consistency.



Other datasets

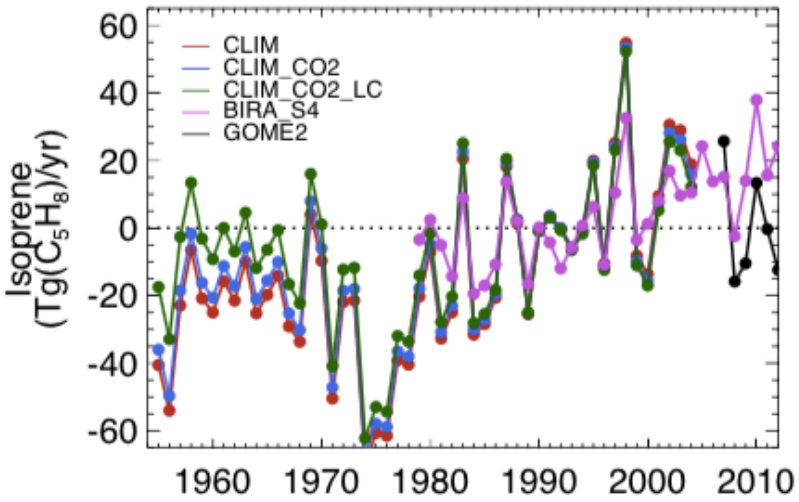
1) BIRA_S4: MEGAN-MOHYCAN model (Stavrakou et al., 2014, ACP)

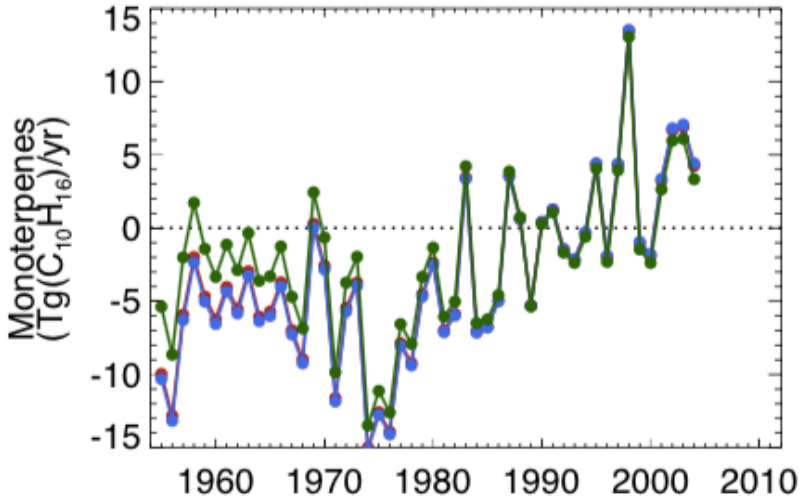
- MEGAN - Guenther et al., (2006) version
- ECMWF ERA-Interim
- Over Asia:
  - reduced forest EF over Asia
  - palm oil land cover (higher EF than crops)

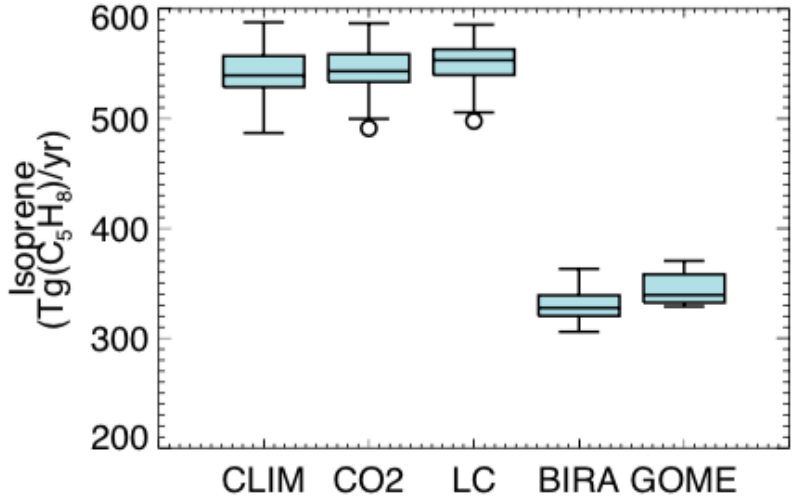
2) GOME: Formaldehyde inversions (De Smedt et al., 2012, AMT)

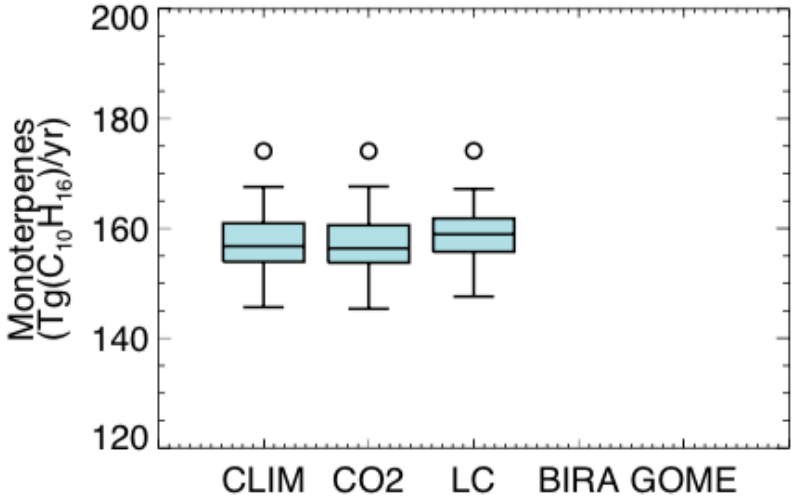
- HCHO is produced from C5H8 oxidation (~30% globally, up to 90% in highly vegetated regions).
- Retrievals of HCHO from GOME-2/MetOp-A satellite are used to estimate fluxes of biogenic C5H8 between 2007 and 2012.
- IMAGES v2 global CTM used to estimate emissions.
- Uncertainties - HCHO also produced from other sources and isoprene chemistry.

Global Trend in Isoprene and Monoterpene Emissions







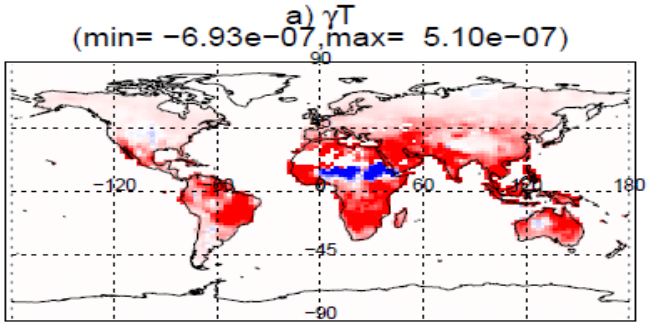


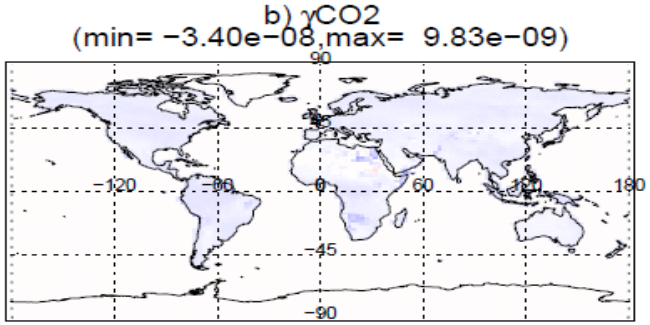
Total ΔIsoprene: **46Tg** (CLIM), **40Tg** (CLIM_CO2), **33Tg** (CLIM_CO2_LC), **20Tg** (BIRA)

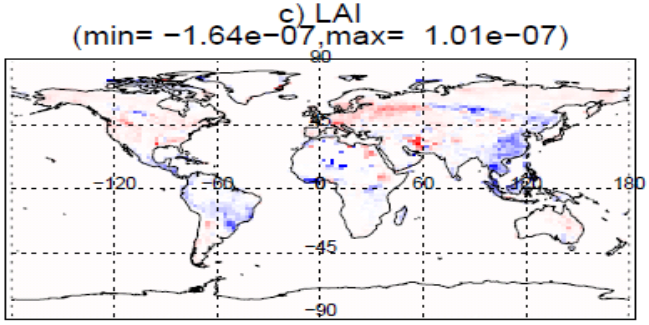
8.4% (CLIM), **7.3%** (CLIM_CO2, **6.0%** (CLIM_CO2_LC), **6.1%** (BIRA)

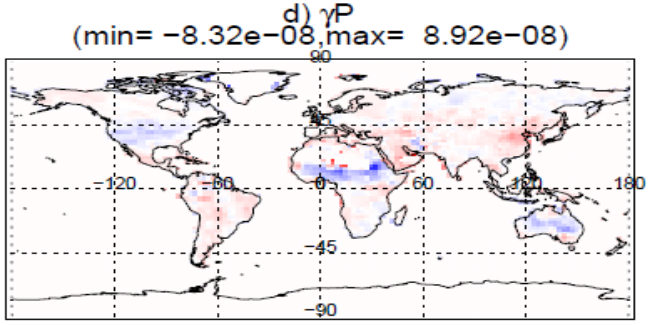
Changes in Activity Factors

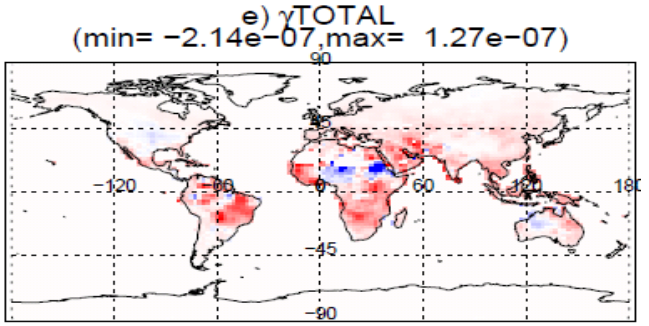
Differences between the 1955-1964 (B1960) and 1995-2004 (B2000) mean activity factors from the CLIM_CO2_LC simulation.



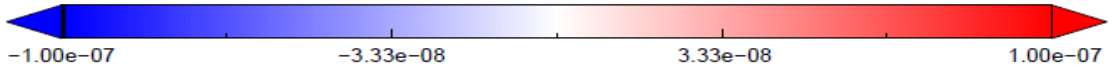




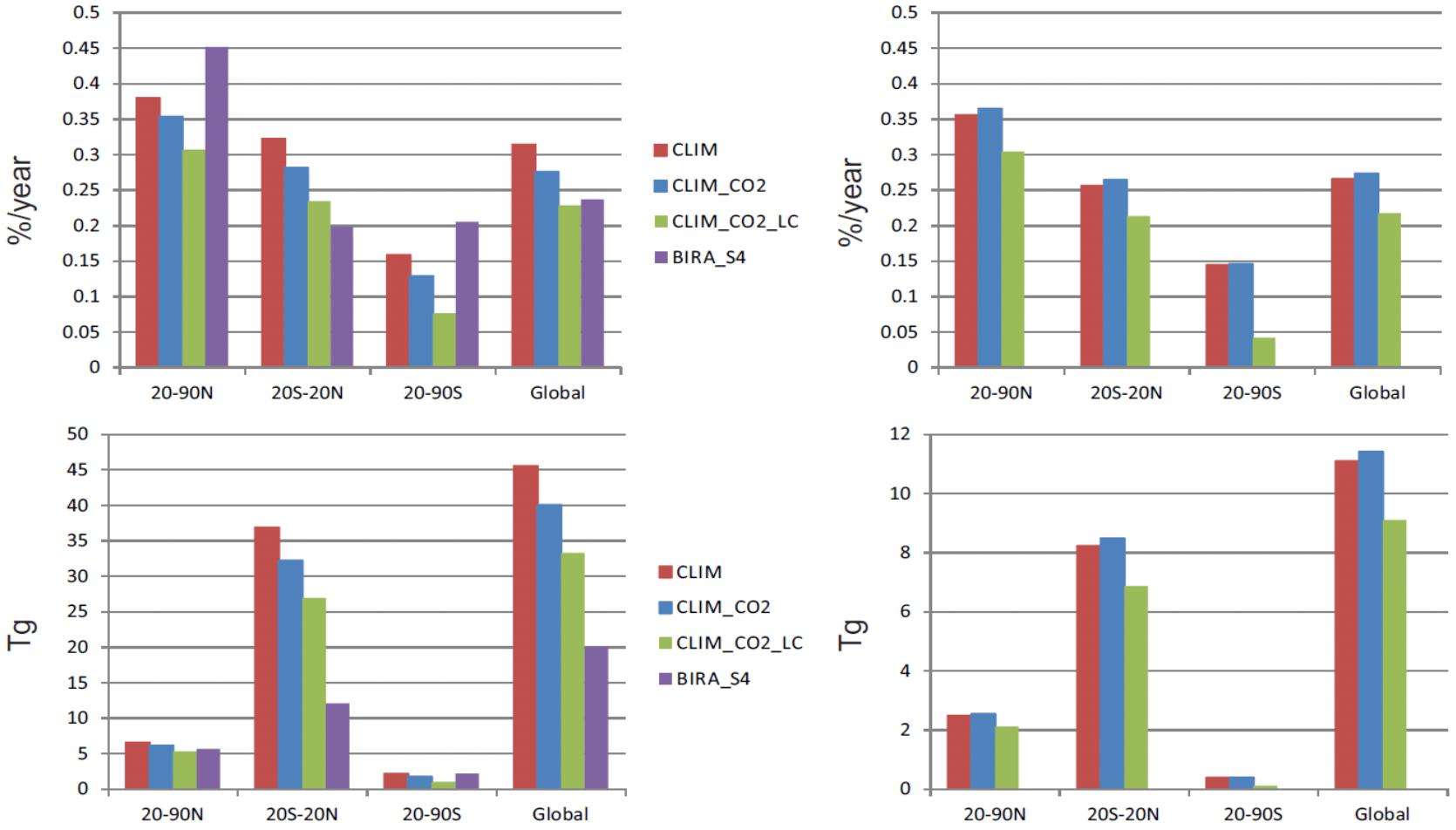




$$\gamma_i = C_{CE} LAI \gamma_{P,i} \gamma_{T,i} \gamma_{A,i} \gamma_{SM,i} \gamma_{C,i}$$



Changes in Isoprene and Monoterpene Emissions



Total change over 1979-2004:

Biggest rate of change occurs in the 20-90N region

Biggest absolute change occurs in the 20S-20N region

Atmospheric Chemistry Simulations

AIM: Study impacts of historical changes in BVOC emissions on atmospheric composition.

1) Created 2 **decadal mean** emission dataset from the CLM **CLIM+CO2+LC** run for **1955-1964 (B1960) and 1995-2004 (B2000).**

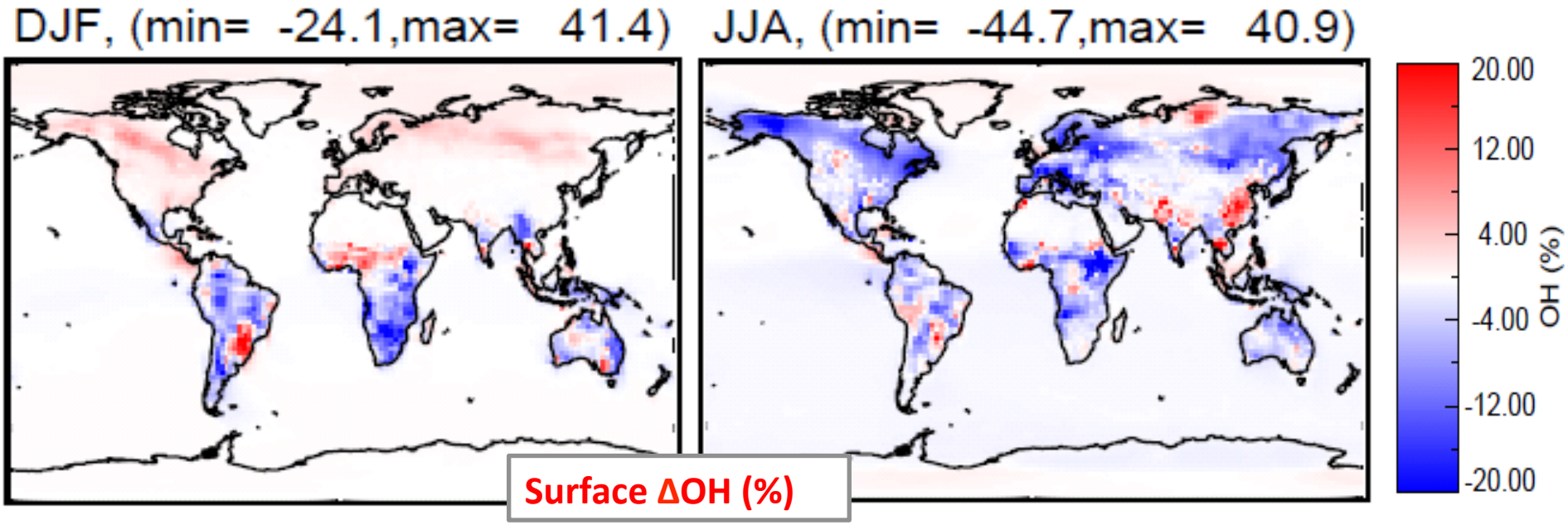
2) CAM4: 3 x 1-year simulations using GEOS-5 2009 met.

CAM4 Runs	Biogenic emissions (CLM+MEGAN)	Anthropogenic emissions (MACCity)	Biomass Burning emissions (MACCity)
CTRL	1955-1964 climatology	1960	1997-2008 climatology
ANTH	1955-1964 climatology	2000	1997-2008 climatology
ANTH_BIO	1995-2004 climatology	2000	1997-2008 climatology

Impact on tropospheric OH and methane lifetime

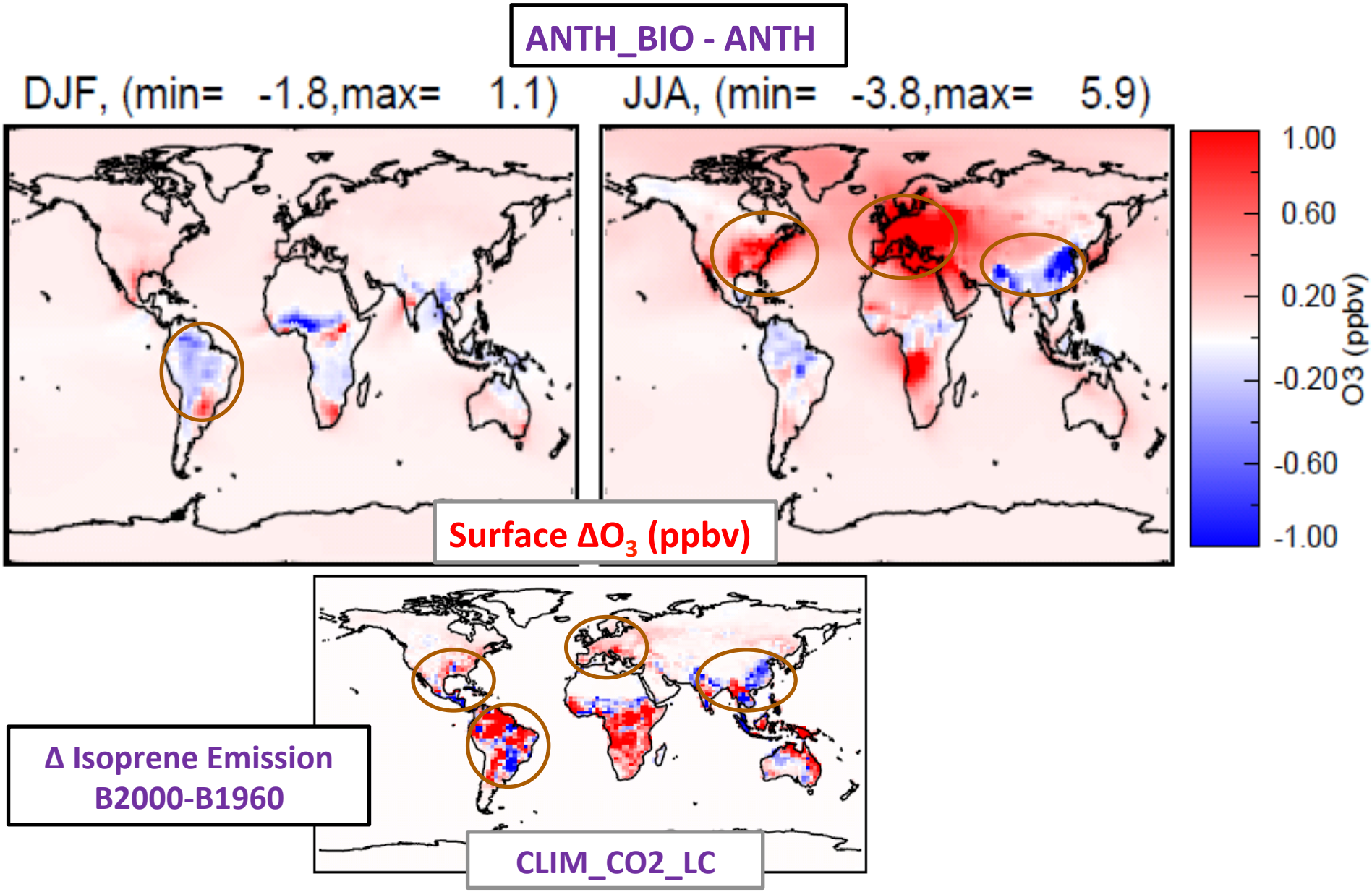
Run	[OH] ($x10^5$ molec/cm^3)	CH_4 Lifetime (yrs)
CTRL	9.8	9.23
ANTH	11.2 (+14%)	8.01 (-13%)
ANTH_BIO	11.1 (-1%)	8.07 (+1%)

ANTH – ANTH_BIO

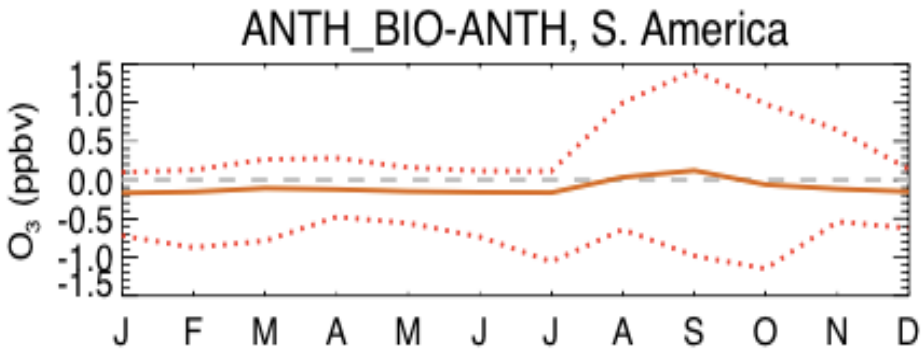


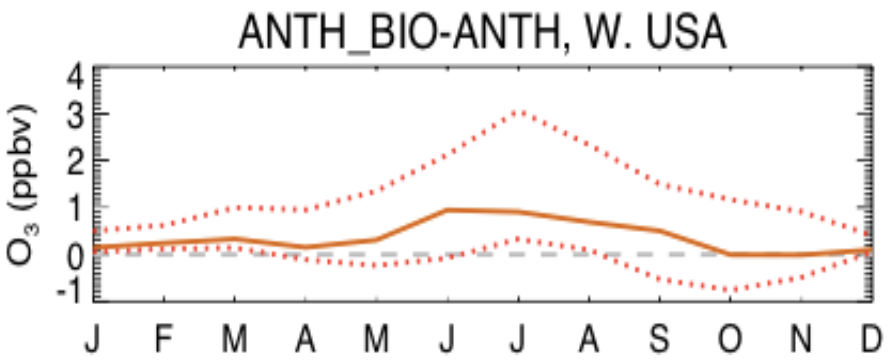
Surface ΔOH (%)

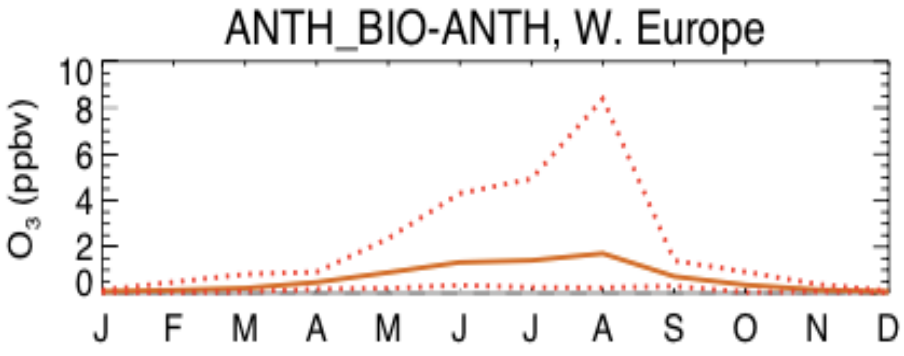
Impact of biogenic emission changes on ozone

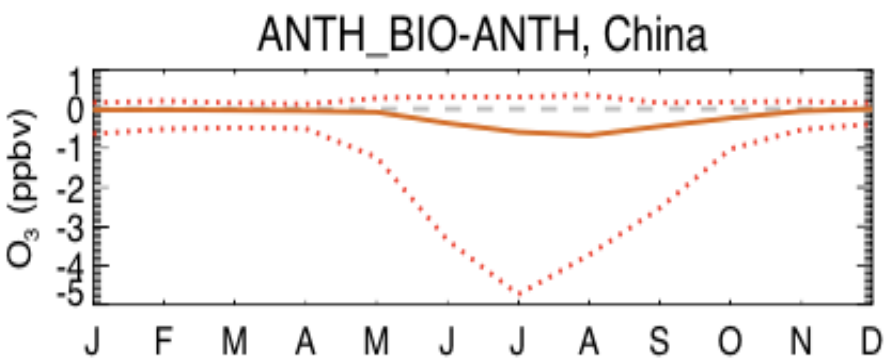


Impact of biogenic emission changes on ozone









- Up to 8 ppbv and 3 ppbv increase in O3 during summer over Western Europe and Western USA.
- Up to 5 ppbv decrease in O3 during summer over China.
- Between -1ppbv and +1.5 ppbv over South America.

Summary

- **Positive trend** in biogenic isoprene emissions in the CLM4+MEGAN over 1979-2004.
- **Increased temperature** is the dominant driver of this trend but land cover changes important regionally.
- **Total change over 1979-2004 - 8.4%** (CLIM), **7.3%** (CLIM_CO2, **6.0%** (CLIM_CO2_LC), however there are regional differences in response (both +ve and –ve changes).
- Global increase in BVOC emissions - **1% decrease OH** and a **1% increase methane lifetime**.
- **O_3** response dependent on local NO_X concentrations and local BVOC emission changes.
  - **Europe and North America** – Increase in emissions due to climate and reforestation in presence of anthropogenic NO_X - **O_3 formation**.
  - **China**- Decreases in emissions due to conversion of forests to cropland - **decrease in O_3**.
  - **South America** – Increase in emissions due to climate in low NO_X conditions - **decrease in O_3**, whilst in areas of **deforestation O_3 increases**.
- There are still large uncertainties in both the modelling of biogenic emissions and the atmospheric chemistry of isoprene.

Thank you

Acknowledgements:
UK Natural Environment Research Council funding
NCAR Advanced Study Program and NCAR Atmospheric Chemistry Division
MACCity emissions group.