

MAP, 7-9 March 2007

The Past is Prologue: What have we learned ...

Jennifer Logan, Michael Prather

Mian Chin, Joyce Penner, Claire Granier,

Isabelle Bey, Martin Schultz, [Steve Pawson]

"those who do not understand history are condemned to repeat it..."

George Santayana,

Winston Churchill, . . .



Atmospheric Composition:

Reactive Gases, Aerosols, and CO₂

Atmospheric Composition



Deliverables / Expectations

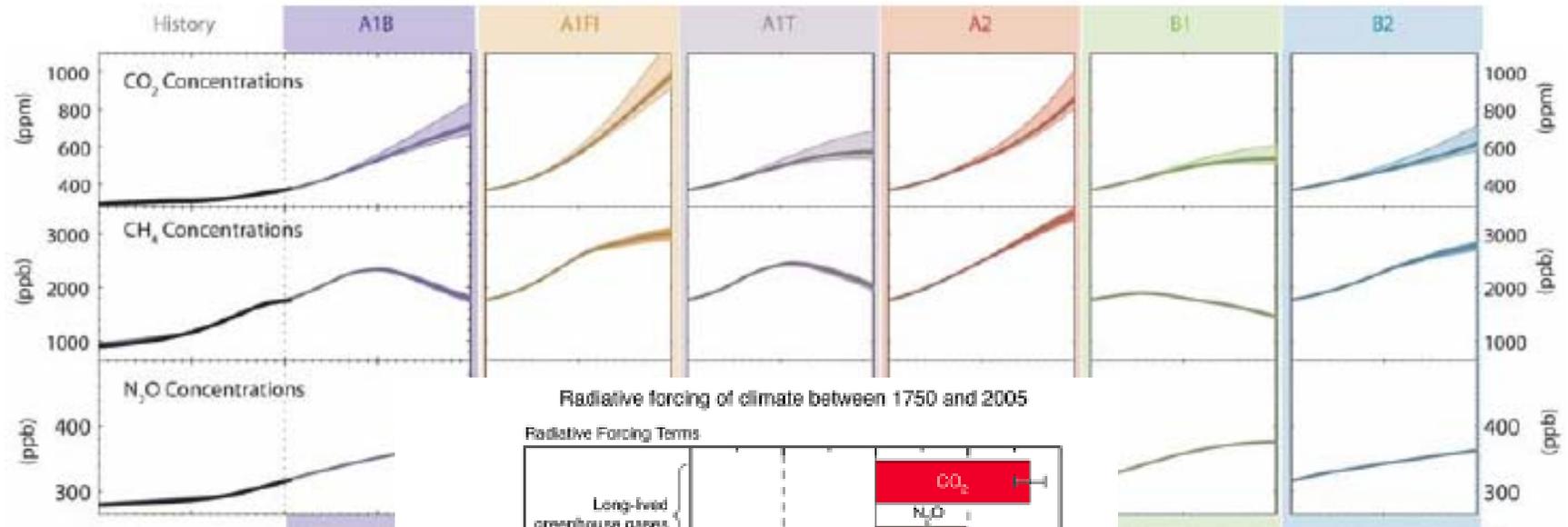
AR5 – radiative forcing projections to 2100 (SRES++)

Critical evaluation of SRES++ emission scenarios

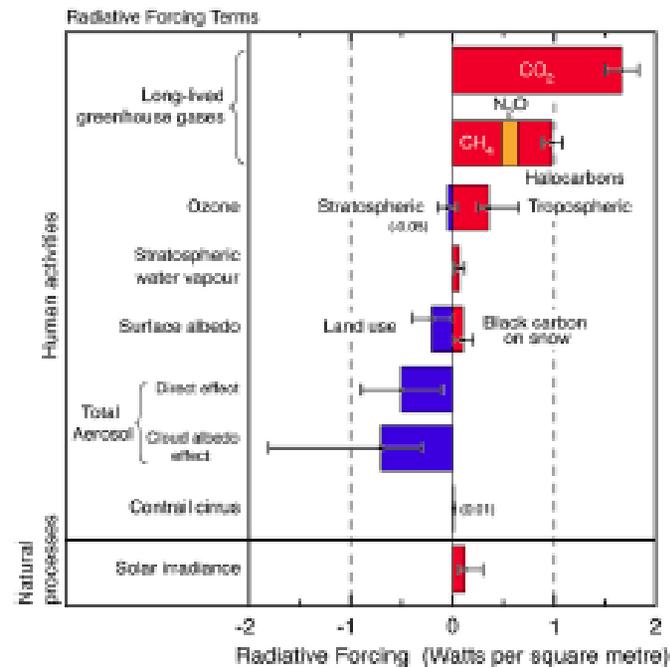
Air Quality studies – projected surface O₃ & aerosols (HTAP)

National Inventories – validation of reported anthropogenic emissions

AR4 failing: scenarios for atmospheric composition (except CO₂)

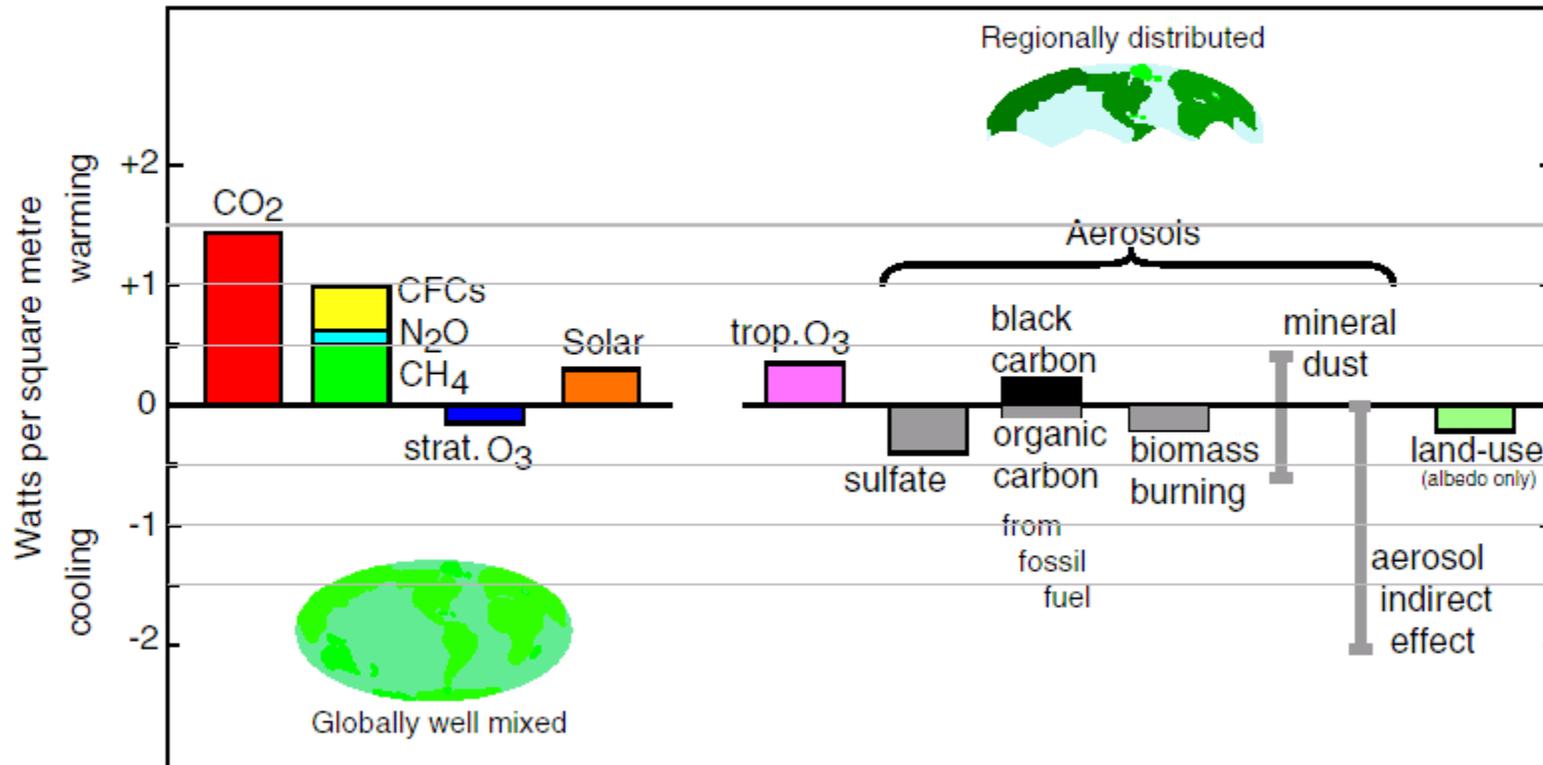


Radiative forcing of climate between 1750 and 2005

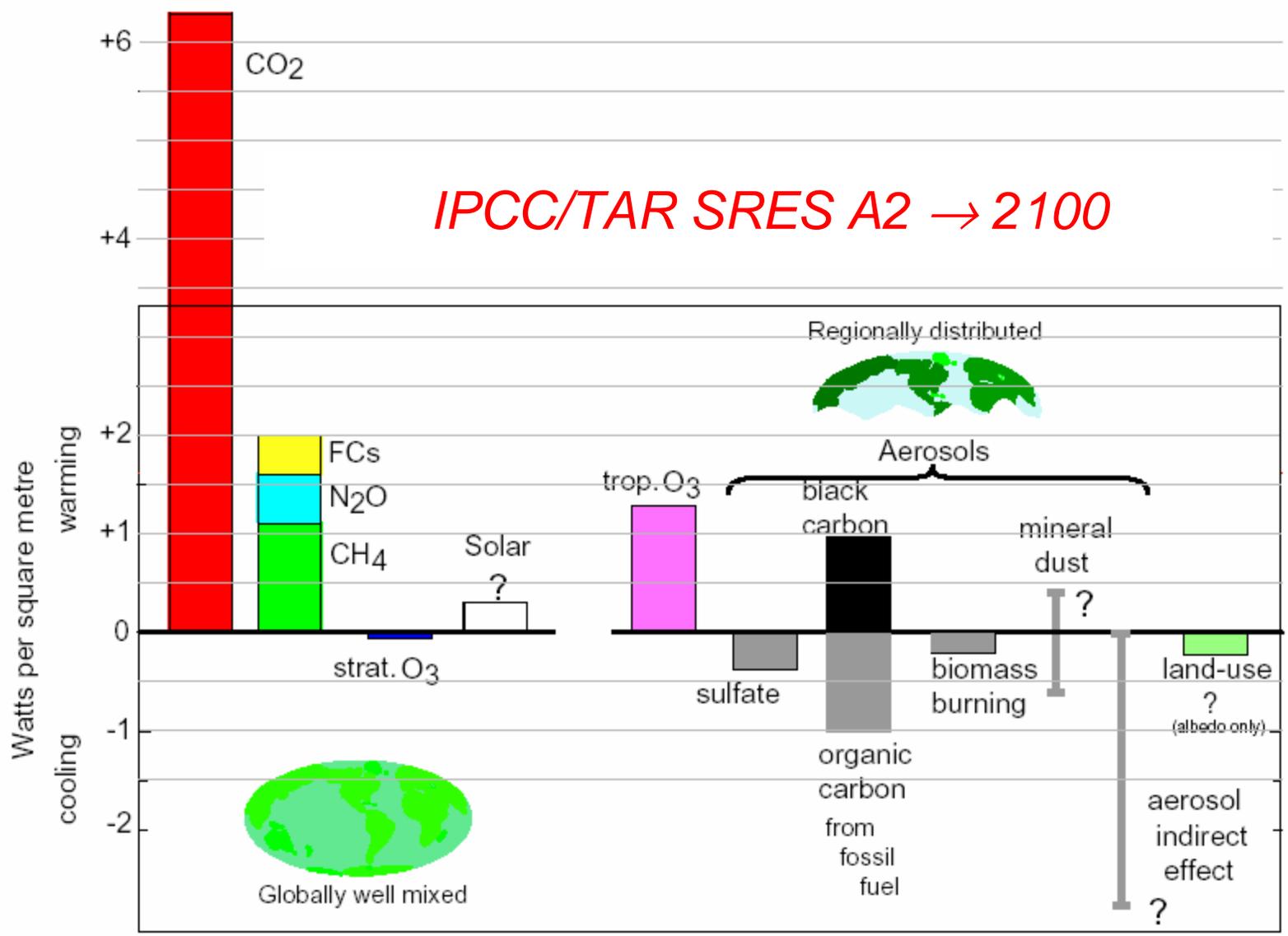


2001 TAR IPCC Radiative Forcing 1750 → 2000

Global Mean Radiative Forcing of Climate for year 2000 relative to 1750



IPCC/TAR SRES A2 → 2100



AR4 failing: scenarios for atmospheric composition (except CO₂)

Climate Forcing

In order to perform the experiments called for in support of the IPCC's Fourth Assessment Report, models require certain so-called "forcing" datasets. The forcing is mainly given in terms of atmospheric concentrations of greenhouse gases, ozone and aerosols. Although the atmospheric concentrations are based on emissions scenarios developed by IPCC, concentrations do not uniquely follow from emissions. ! Different concentrations can be derived from the same emissions scenarios, depending on the model used to derive them.

One set of concentrations that may be used to drive climate simulations can be obtained from Dr. Curt Covey (covey1@llnl.gov). Use of this dataset is not mandatory.

AR4 failing: scenarios for atmospheric composition (except CO₂)

Table 10.1. Radiative forcing agents in the multi-model global climate projections. The entries have the following meaning: Y = Forcing agent is included; C = Forcing agent varies with time during the 20th century (20c3m) simulations and is set to constant or annually cyclic distribution for scenario integrations; E = This GHG is represented using equivalent CO₂; and -- = Forcing agent is not specified in either the 20c3m or scenario integrations. Numeric codes indicate that the forcing agent is included using data described at: 1 = <http://www.cnrm.meteo.fr/ensembles/public/results/results.html>; 2 = Boucher and Pham (2002); 3 = Yukimoto et al., (2006) ; 4 = ftp://sprite.llnl.gov/pub/covey/4PCC_4AR_Forcing/; 5 = <http://aom.giss.nasa.gov/IN/GHGA1B.LP>; 6 = <http://www.cgd.ucar.edu/ccr/strandwg/ccsm/datasets/index.html>; and 7 = <http://sres.ciesin.org/data>.

Model	Forcing Agents																		
	Greenhouse Gases						Aerosols										Other		
	CO ₂	CH ₄	N ₂ O	Strat O ₃	Trop O ₃	CFCs	SO ₄	Urban	Black carbon	Organic carbon	Nitrate	1st Indirect	2nd Indirect	Dust	Volcanic	Sea Salt	Land Use	Solar	
BCCR-BCM2.0	1	1	1	C	C	1	2	C	--	--	--	--	--	C	--	C	C	C	
BCC-CM1	Y	Y	Y	Y	C	4	4	--	--	--	--	--	--	--	C	--	C	C	
CCSM3	4	4	4	6	6	4	6	--	6	6	--	--	--	C	C	C	--	C	
CGCM3.1(T47)	Y	Y	Y	C	C	Y	2	--	--	--	--	--	--	C	C	C	C	C	
CGCM3.1(T63)	Y	Y	Y	C	C	Y	2	--	--	--	--	--	--	C	C	C	C	C	
CNRM-CM3	1	1	1	Y	Y	1	2	C	--	--	--	--	--	C	--	C	--	--	
CSIRO-Mk3.0	Y	E	E	Y	Y	E	Y	--	--	--	--	--	--	--	--	--	--	--	
ECHAM5/MPI-OM	1	1	1	Y	C	1	2	--	--	--	--	Y	--	--	--	--	--	--	

Success Story

CCMval & UNEP/WMO 2006: use of **hindcasts** with **projections**

A Strategy for Process-Oriented Validation of Coupled Chemistry– Climate Models

BY V. EYRING, N. R. P. HARRIS, M. REX, T. G. SHEPHERD, D. W. FAHEY, G. T. AMANATIDIS, J. AUSTIN,
M. P. CHIPPERFIELD, M. DAMERIS, P. M. DE F. FORSTER, A. GETTELMAN, H. F. GRAF, T. NAGASHIMA, P. A. NEWMAN,
S. PAWSON, M. J. PRATHER, J. A. PYLE, R. J. SALAWITCH, B. D. SANTER, AND D. W. WAUGH

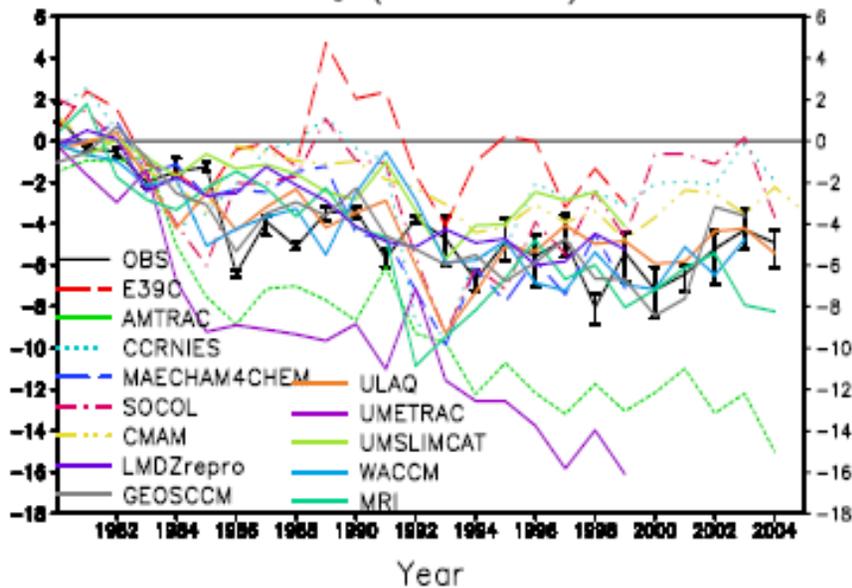
Evaluating CCMs with the presented framework will increase our confidence
in predictions of stratospheric ozone change.

CCMval & UNEP/WMO 2006: use of hindcasts with projections

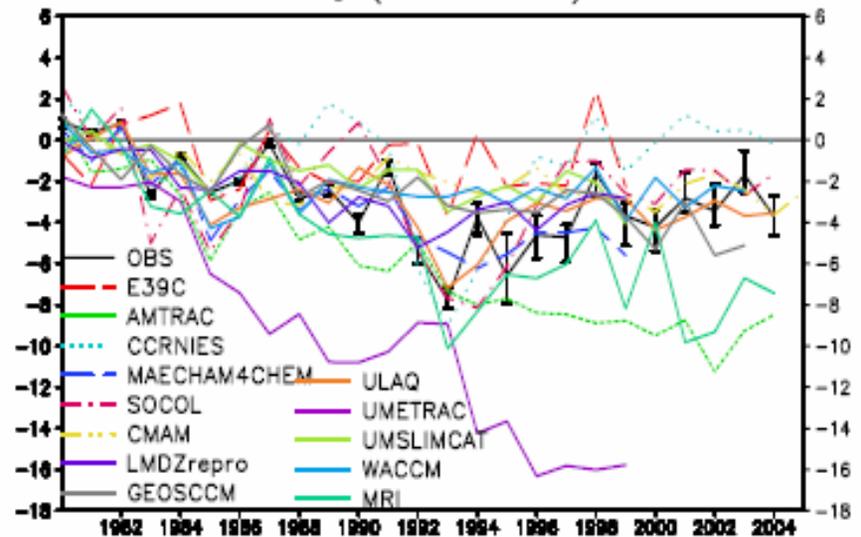
Table 2: Summary of proposed WMO/CCMVal simulations.

Scenario	Period	Trace Gas	Halogens	SSTs	Background & Volcanic Aerosol	Solar Variability	QBO	Enhanced BrO _y
REF1	1980-2004 If possible 1960 to 2004	OBS GHG used for WMO/UNEP 2002 runs. Extended until 2004	OBS used for WMO/UNEP 2002 runs.	OBS HadISST1	OBS Surface Area Density data (SAD) provided by David Considine	OBS MAVER data set, observed flux	OBS or internally generated	-
REF2	1980-2025 If possible until 2050.	OBS + A1B(medium)	OBS + Ab scenario from WMO/UNEP 2002	Modeled SSTs	-	-	-	-

Anomalies O₃ (60S–35S):3D CCMs



Anomalies O₃ (35N–60N):3D CCMs



CCMval & UNEP/WMO 2006

Can place model projections
in context of hindcasts!

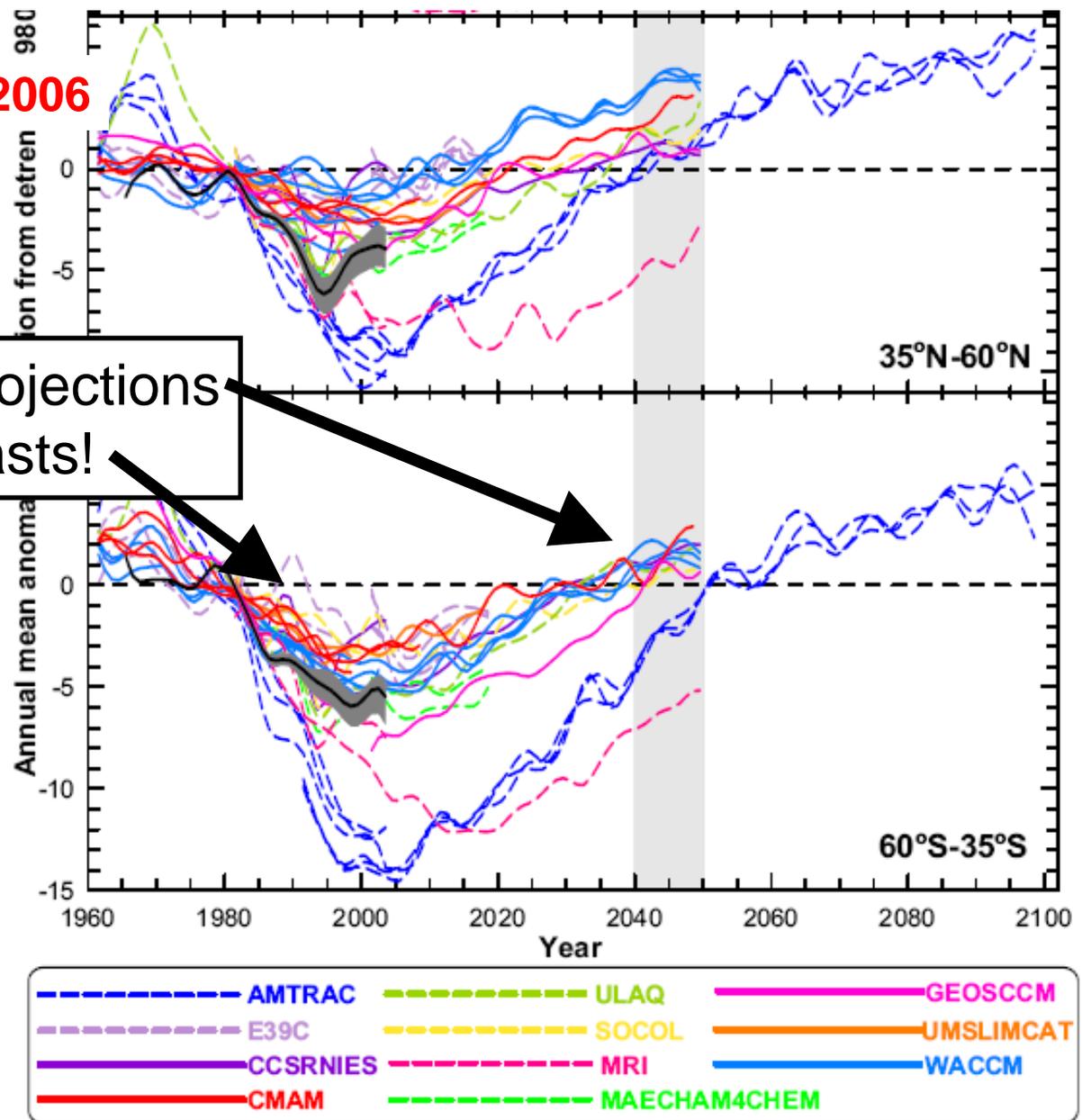


Figure 6-10. Annual mean zonal mean total column ozone anomalies from CCMs (colored lines) and from four observational datasets (thick black line and gray shaded area show the mean and range of observed anomalies; see Chapter 3). The time series are formed using the REF1 and REF2 or SCN2 simulations of each model (see Table 6-4). The time series have been smoothed as in Figure 6-9. The light gray shading between



WCRP-SPARC/IGBP-IGAC Atmospheric Chemistry & Climate Initiative



Research Implementation Bodies

CCM-Val
(stratos. gas-phase chemistry)

AEROCOM
(tropospheric aerosols)

"Tropos Chem"
(tropos. gas-phase chemistry)

AC&C Research Activities

- 1) 20 yr hindcast for tropospheric gases/aerosols
- 2) What controls the distribution of tropospheric aerosols/gases? (Step 1: Focus on 5km to tropopause distribution)
- 3) Cloud/aerosol/chemical interactions
- 4) Future scenarios; sensitivities & uncertainties

Overarching Activities

- 1) Emissions Assessment w/GEIA
- 2) Data Center /AEROCOM/CCM-Val
- 3) AC&C Web page & "E-newsletter"

Unifying thematic areas

- a) Composition impacts on climate
- b) Climate impacts on chemistry
- c) Climate impacts on surface-level ozone & aerosols ("air quality")



2001 TAR: Global Air Quality

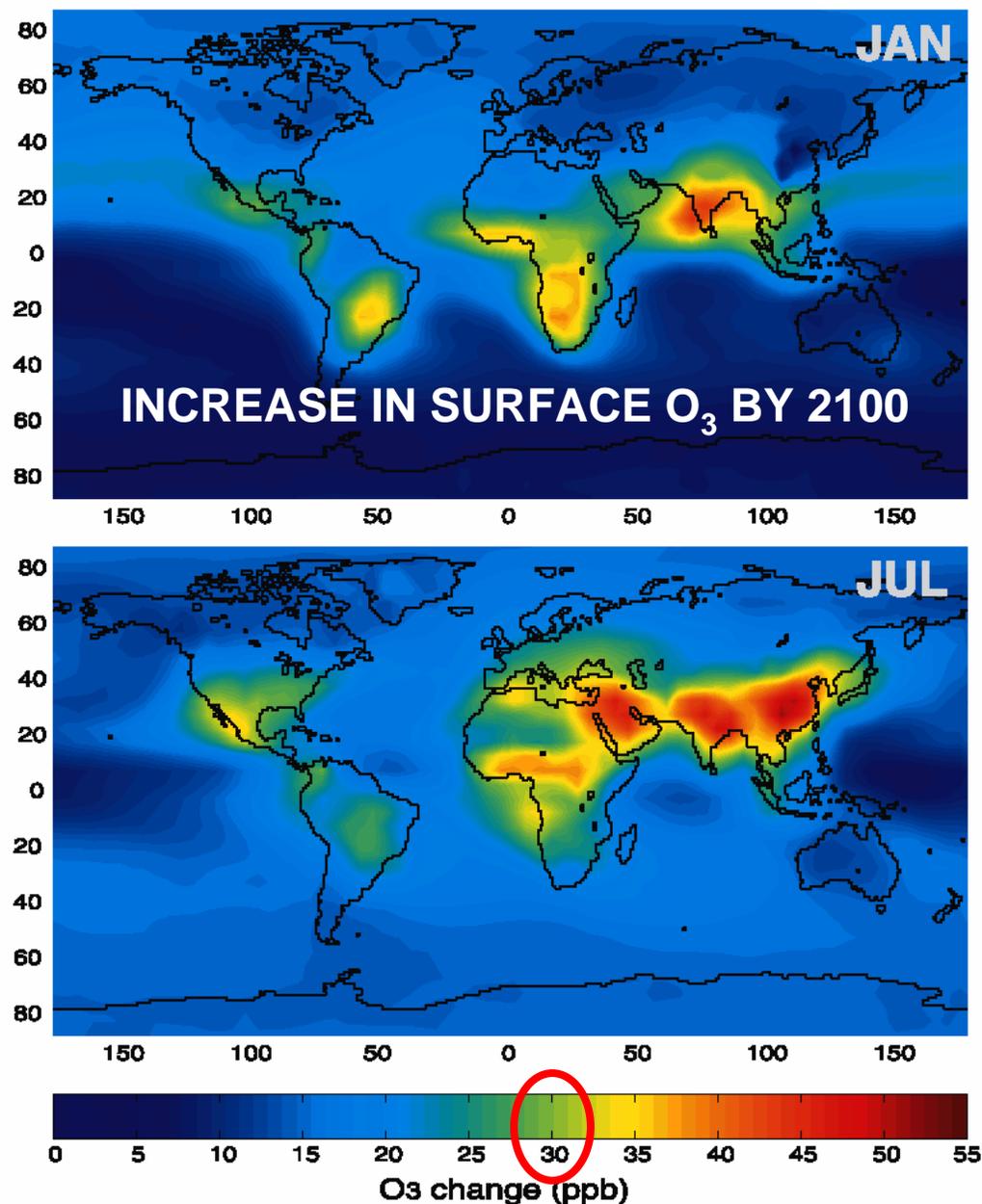
GEOPHYSICAL RESEARCH LETTERS, VOL. 30, NO. 2, 1100, doi:10.1029/2002GL016285, 2003

Fresh air in the 21st century?

fresh air in the 21st century?

Michael Prather,¹ Michael Gauss,² Terje Berntsen,² Ivar Isaksen,² Jostein Sundet,² Isabelle Bey,³ Guy Brasseur,⁴ Frank Dentener,⁵ Richard Derwent,⁶ David Stevenson,⁶ Lee Grenfell,⁷ Didier Hauglustaine,⁸ Larry Horowitz,⁹ Daniel Jacob,¹⁰ Loretta Mickley,¹⁰ Mark Lawrence,¹¹ Rolf von Kuhlmann,¹¹ Jean-Francois Muller,¹² Giovanni Pitari,¹³ Helen Rogers,¹⁴ Matthew Johnson,¹⁴ John Pyle,¹⁴ Kathy Law,¹⁴ Michiel van Weele,¹⁵ and Oliver Wild¹⁶

IPCC (2001). “Changes projected in the SRES A2 and A1FI scenarios would degrade air quality over much of the globe by increasing background levels of O₃. In northern mid-latitudes during summer, the zonal average increases near the surface are about 30 ppb or more, raising background levels to nearly 80 ppb, threatening attainment of air quality standards over most metropolitan and even rural regions, and compromising crop and forest productivity. This problem reaches across continental boundaries since emissions of NO_x influence photochemistry on a hemispheric scale.”



2007 AR4: Global Air Quality

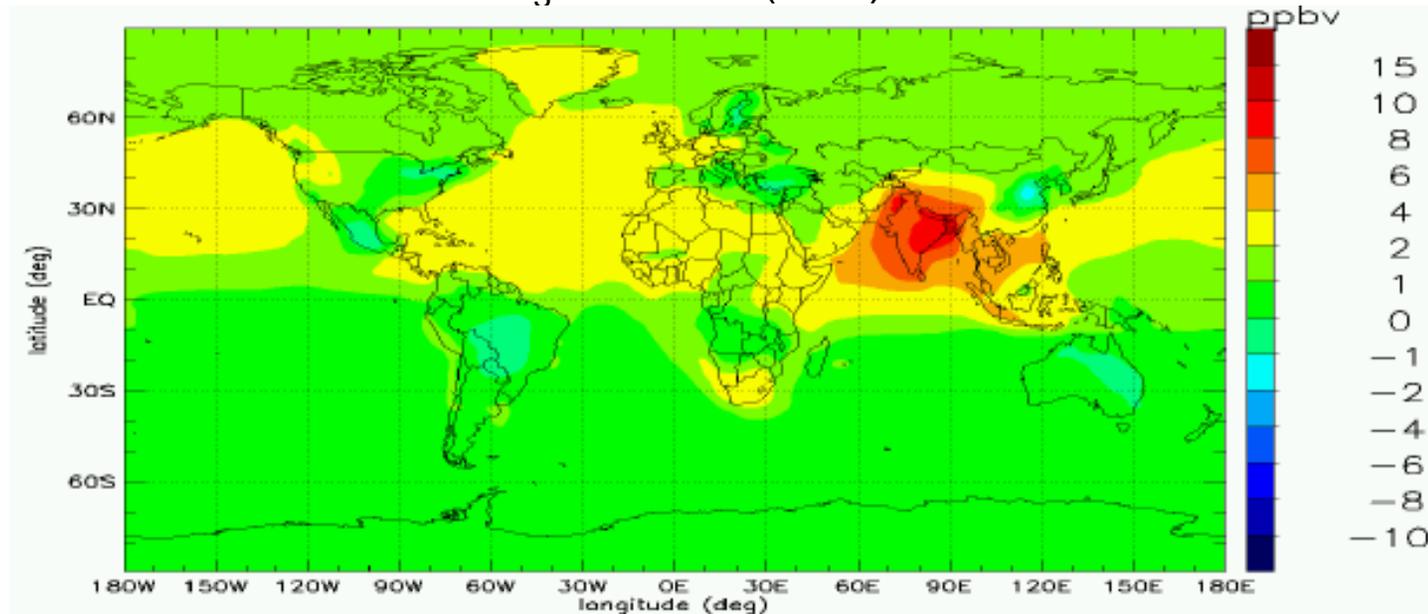
The global atmospheric environment for the next generation

F.Dentener¹, D.Stevenson², K.Ellingsen³, T.van Noije⁴, M.Schultz¹⁸, M.Amann⁵,
 C.Atherton¹², N.Bell⁹, D.Bergmann¹², I.Bey⁸, L.Bouwman⁶, T.Butler¹⁴, J.C.
 B.Collins²⁰, J.Drevet⁸, R.Doherty², B.Eickhout⁶, H.Eskes⁴, A.Fiore¹⁶, M.G.
 D.Haughlustaine¹³, L.Horowitz¹⁶, I.S.A. Isaksen³, B.Josse¹⁵, M.Lawrence¹⁴,
 J.F.Lamarque¹⁷, V.Montanaro²¹, J.F.Müller¹¹, V.H.Peuch¹³, G.Pitari²¹, J.P.
 J.Rodriguez²², M.Sanderson²⁰, N.H.Savage¹⁹, D.Shindell⁹, S.Strahan¹⁰, S.S.
 K.Sudo⁷, R.Van Dingenen¹, O.Wild⁷, G.Zeng¹⁹.

Table 1. Overview of simulations, prescribed methane volume mixing ratios and global anthropogenic emissions of CO, NMVOC, SO₂ and NH₃. Emissions in Tg Full Molecular Weight/year.

Simulation	Meteorology	Description	CH ₄ [ppbv]	CO	NMVOC	NO _x (NO ₂)	SO ₂	NH ₃
S1-B2000	CTM 2000 GCM SSTs 1990s	Baseline.	1760	977	147.1	124.8	111.1	64.8
S2-CLE/CLEc	CTM 2000 GCM SSTs 1990s	IIASA CLE 2030. Current Legislation scenario.	2088	904.1	145.5	141.1	117.6	84.8
S3-MFR	CTM 2000 GCM SSTs 1990s	IIASA MFR 2030 Maximum Feasible Reduction scenario	1760	728.7	104.4	76.0	35.8	84.8
S4-A2	CTM 2000 GCM SSTs 1990s	SRES A22030, the most 'pessimistic' IPCC SRES scenario	2163	1268.2	206.7	206.7	202.3	89.2
S5c-CLE2030c	only GCM SSTs 2030s	IIASA CLE 2030 + Climate Change	2012	904.1	145.5	141.1	117.6	84.8

INCREASE IN SURFACE O₃ BY 2030 (CLE)



How well do we understand trends and interannual variability in trace gases/aerosols that affect climate?

- Focus on recent past, with a reasonable set of observations (~25 years at most).
- Multiyear hindcasts or inversions
- Selected examples
 - CH_4
 - CO
 - OH (sink for CO , CH_4 , lots of pollutants)
 - trop. ozone
 - aerosols
 - CO_2

What do we need?

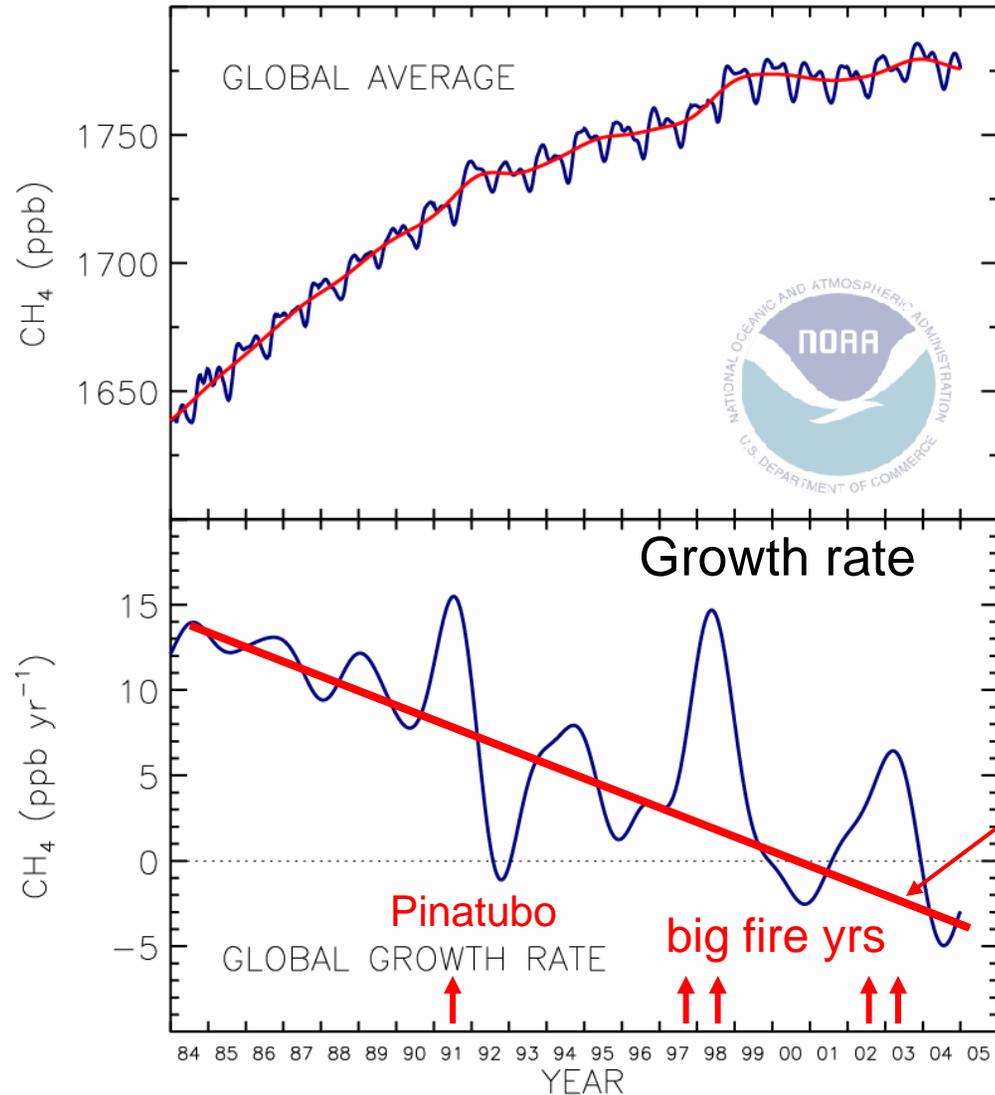
- **Meteorological data to drive the model**
 - NCEP reanalysis
 - GEOS-4 reanalysis (earlier, GEOS-1, Strat)
 - ERA-40 (earlier, ERA-15)

- **Anthro. emissions (fossil fuel, industry, cows, ...)**
 - EDGAR (every 5 years), HYDE (every 10 y)
 - RETRO (every year, 1960-2000)
 - Customized, scaling a base inventory with activity data

- **“Natural”, e.g., biomass burning, wetlands, ...**
 - Scaling a base inventory (e.g., TOMS AI, fire counts)
 - Bottom-up, process based, using satellite data, or a model

- **Observations for evaluation (or as input)**
 - CH₄, CO, O₃ (in situ, trop. column), NO₂ column, ...

Figure from NOAA ESRL, GMD
Methane Measurements
 NOAA ESRL GMD Carbon Cycle



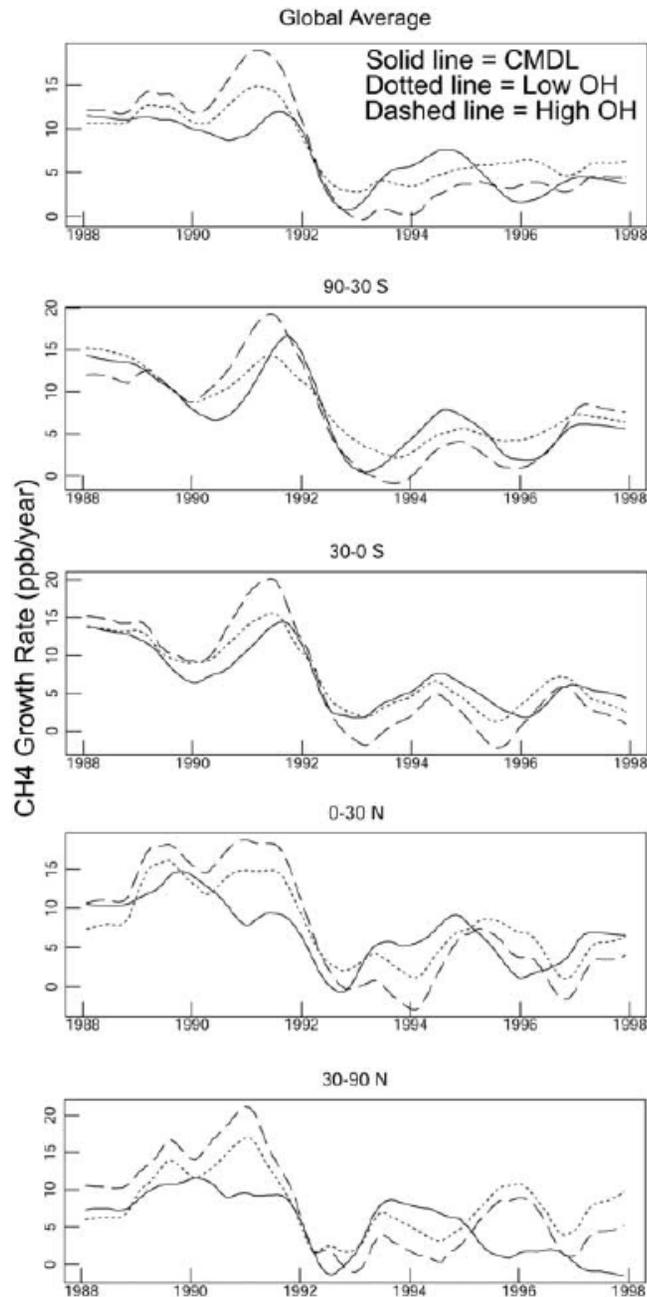
Methane, 1984-2005

Do we understand the downward trend in the growth rate?

Several papers on wiggles, Pinatubo effects, fires, El Nino, etc

Steady decrease in growth rate, with wiggles, or growth rate of zero?
What happens next?

Top: Global average atmospheric methane mixing ratios (blue line) determined using measurements from the GMD cooperative air sampling network. The red line represents the long-term trend. Bottom: Global average growth rate for methane. Contact: Dr. Ed Dlugokencky, NOAA ESRL GMD Carbon Cycle, Boulder, Colorado, (303) 497-6228 (ed.dlugokencky@noaa.gov, <http://www.cmdl.noaa.gov/ccgg>).



A 3-d model analysis of the slowdown and interannual variability in the CH₄ growth rate, 1988-1997. (Wang, et al., GBC, 2004).
GEOS-Chem model, GEOS-1 and Strat met. data,

Slowdown in growth rate caused by:

1. slower growth in sources due to the economic downturn in the former Eastern bloc
2. increases in OH due to column ozone decrease (solar cycle + mid-lat. trends)

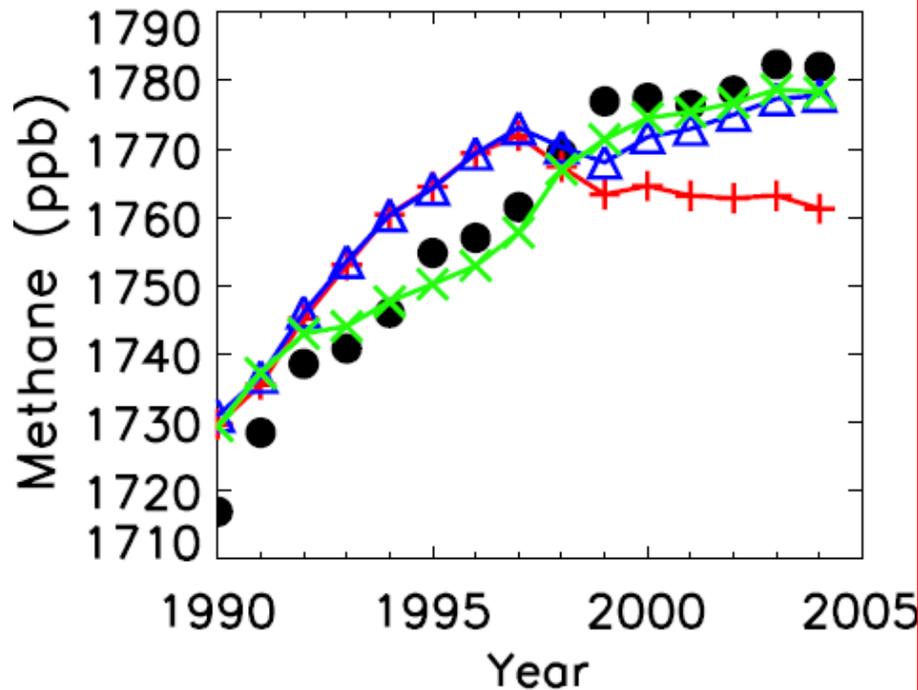
Variability – wetland emissions + OH (especially post-Pinatubo)

Increases in trend likely in the future, due to increases in emissions, ozone recovery

Impact of meteorology and emission on methane trends, 1990-2004

Fiore et al., GRL, 2006.

MOZART-2 model, NCEP met. data. Emissions: EDGAR for anthro.



Black = data

Red = const. anthro. Emissions

Blue = Time. dep. Anthro. emissions

Green = as blue + wetlands

Conclusions:

CH₄ trend mostly controlled by small changes in the sink (OH), < 2%.

An increase in lower trop. temp. causes 35% is this change.

OH increases by 1.2% from 1991-1995 to 2000-2004.

Why? Increase in NO_x from lightning in the model. This source is tied to convection in the model

Contribution of anthropogenic and natural sources to atmospheric methane variability.

Bousquet et al., Nature, 2006.

LMDZ-INCA model, ERA-40 met. data., 1984-2003. Emissions: EDGAR anthro.

Inverse study. OH interannual variability taken from inverse analysis of methyl chloroform.

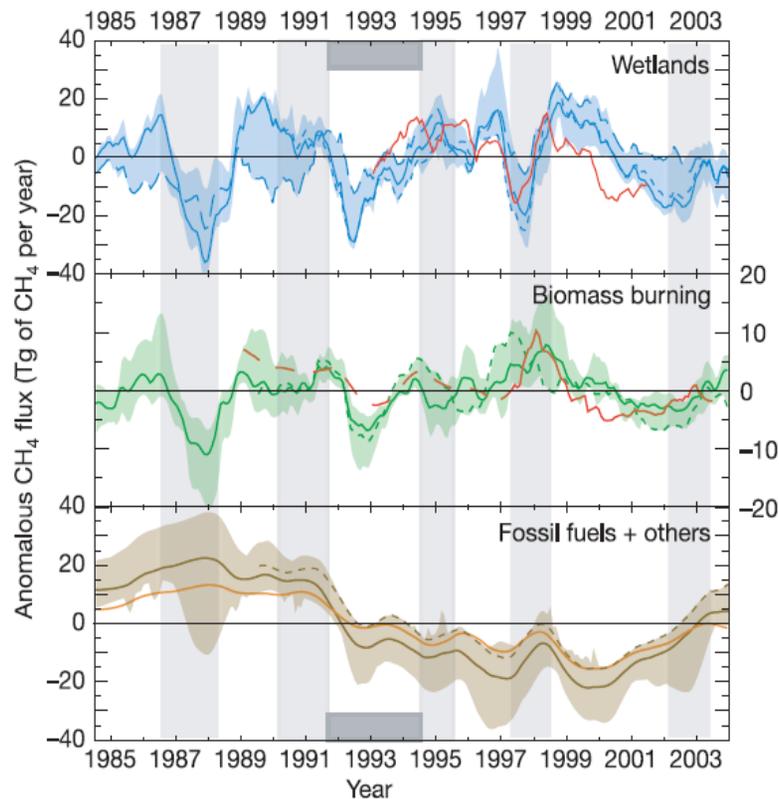


Figure 2 | Variations in CH₄ emissions attributed to different processes. Shown are the interannual global CH₄ flux anomalies (in Tg of CH₄ yr⁻¹)

Conclusions:

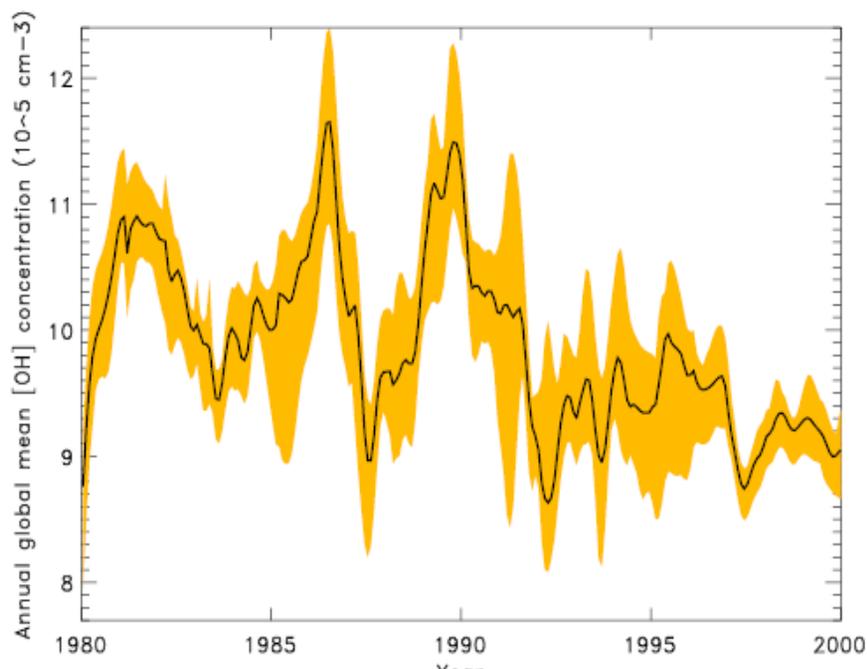
Variability dominated by wetland sources (depends on assumed OH, 50% less with constant OH)

Decrease in growth rate caused by decline in anthro. emissions, but they started to rise again in 1999.

Not clear if these are consistent with bottom-up estimates

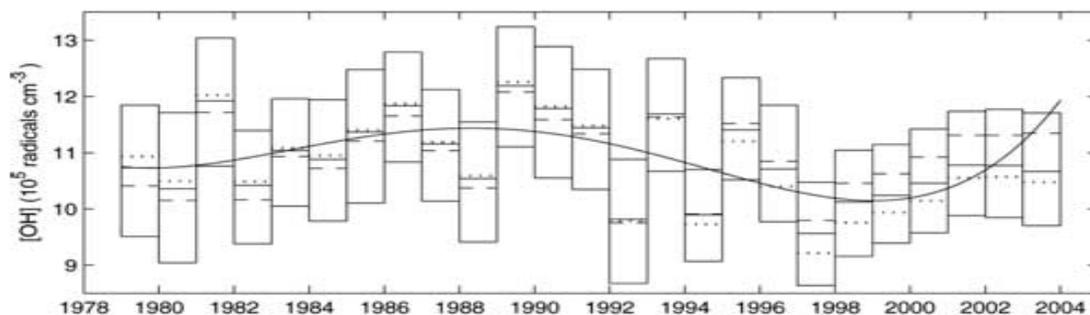
Interannual variability in OH derived from methylchloroform (MCF) inversion

Bousquet et al. 2005



This approach assumes MCF emissions each year are well known. Same emissions and MCF observations used by each group.

Are bottom-up calculations consistent with these results?



Prinn et al., 2005

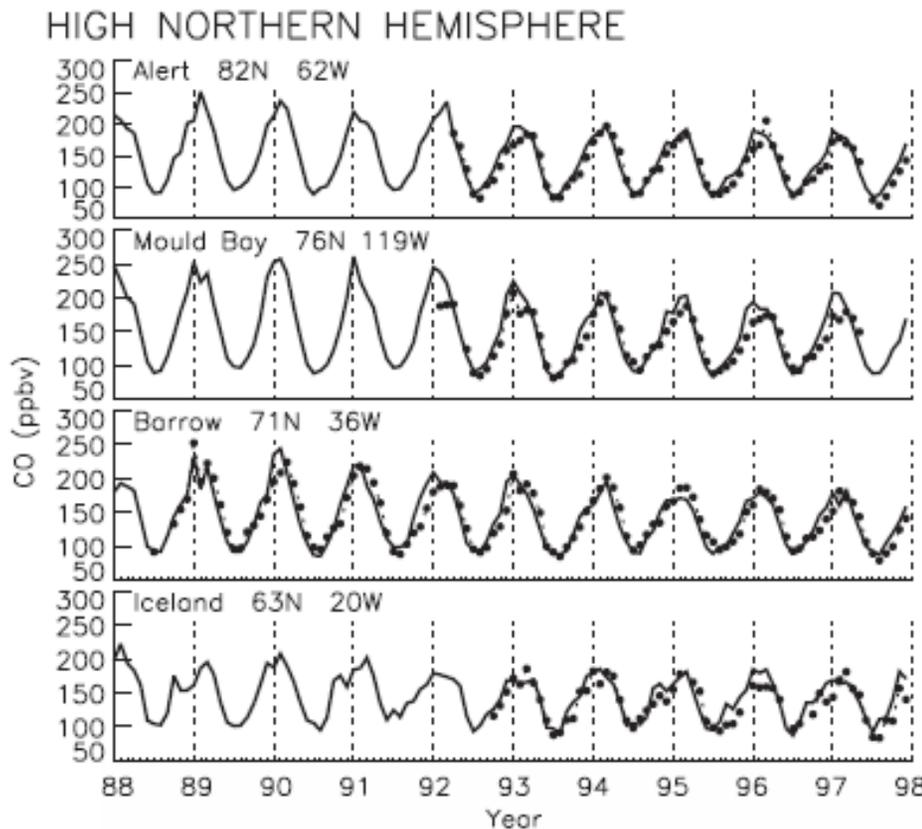
The global budget of CO, 1988-1997: source estimates and validation with a global model. (Duncan et al., 2007)
GEOS-Chem, GEOS-1/STRAT.

Conclusions:

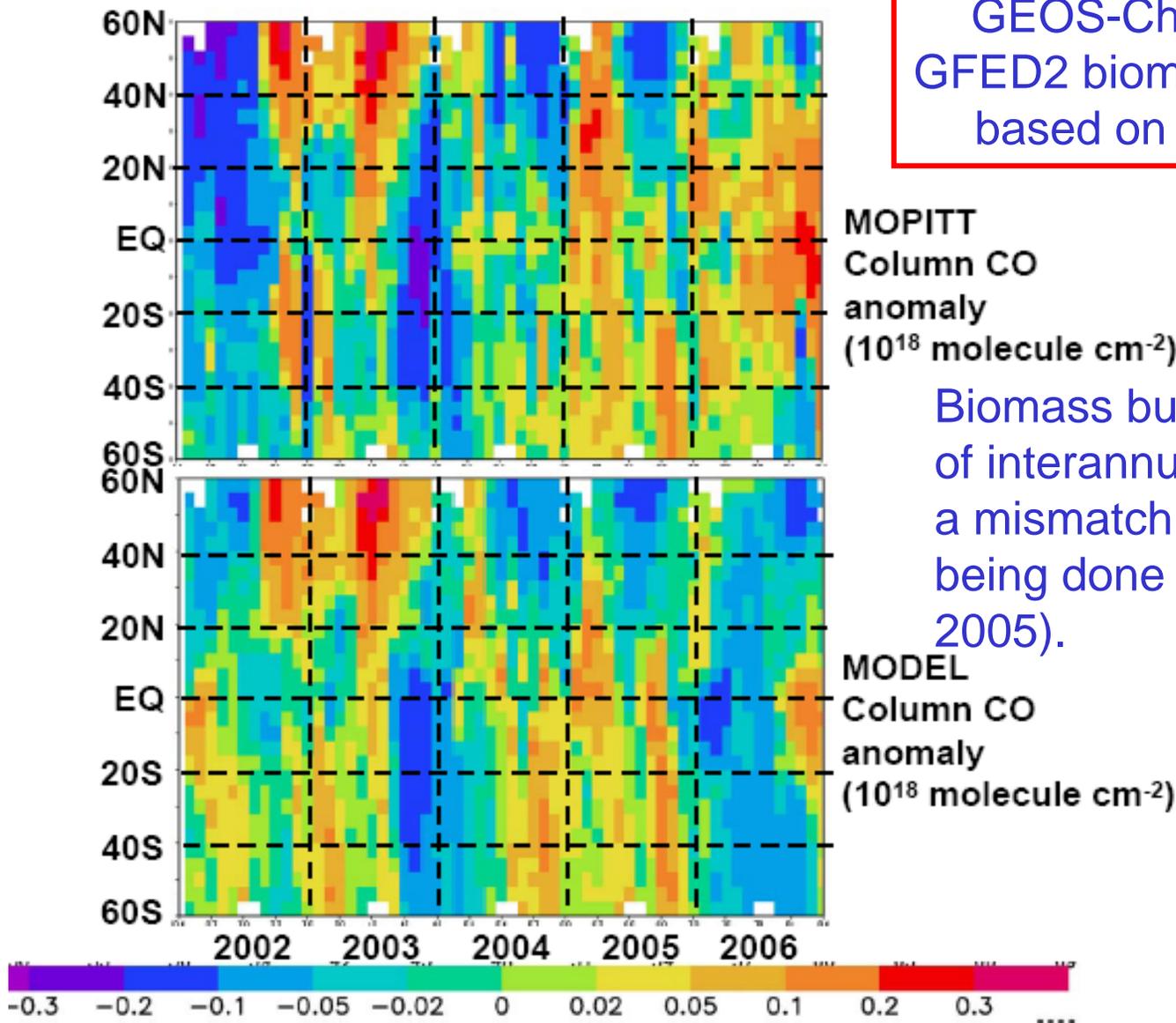
Emissions hardly changed from 1988 to 1997: increases in Asia are offset by decreases in Europe/U.S.

The decrease in CO at high northern latitudes (20%) and in the North Pacific (10%) are caused by the decrease in European (and US) emissions.

The EDGAR CO inventory is too low by ~25%, for known reasons. (Problem with Asian emissions, shown in lots of TRACE-P studies, Streets et al., 2006).



P. Kasibhatla, Duke Univ.
GEOS-Chem model, GEOS-4,
GFED2 biomass burning emissions,
based on MODIS area burned



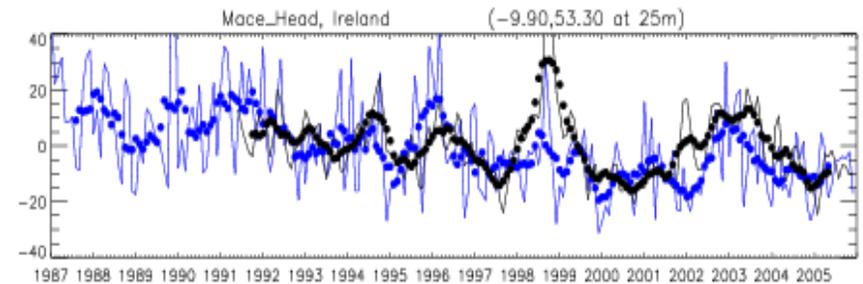
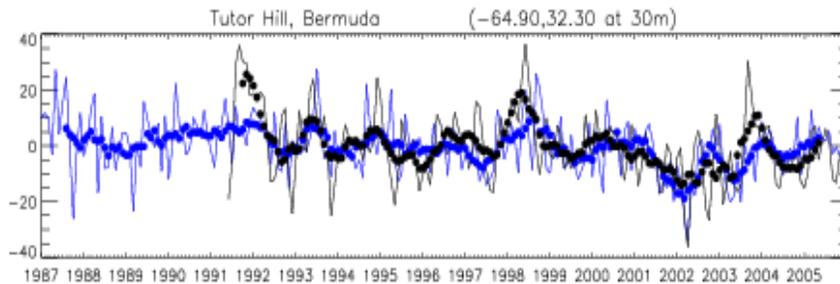
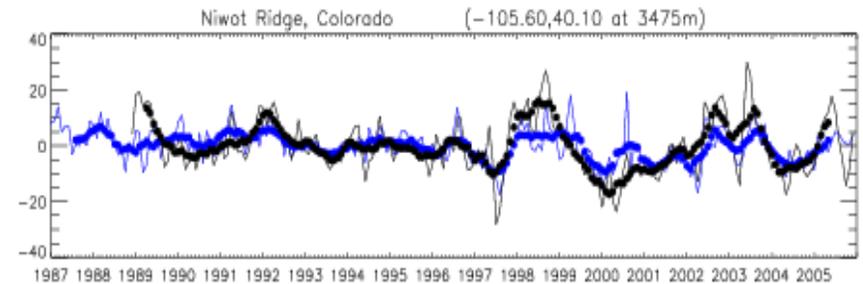
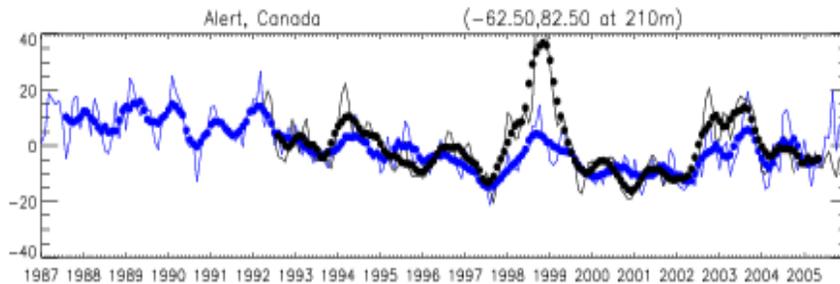
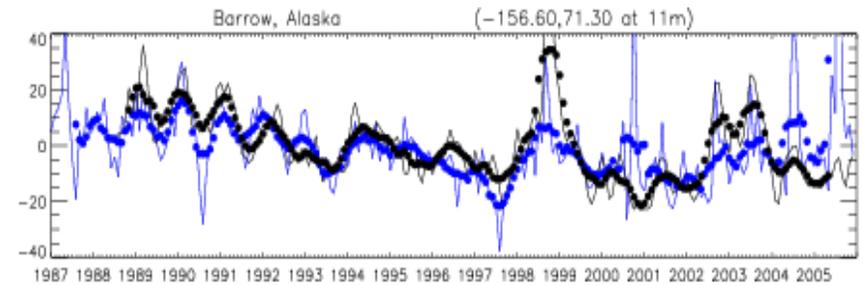
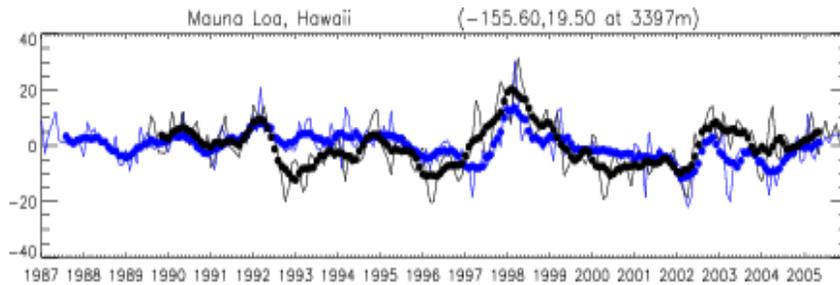
Biomass burning is the main cause of interannual variability in CO, but a mismatch – inversions analyses being done (as in Van der Werf, 2005).

Simulation of tropospheric chemistry from 1987-2005 using GEOS-Chem driven by GEOS-4.

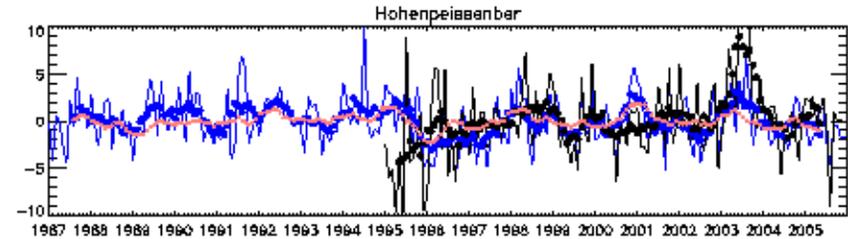
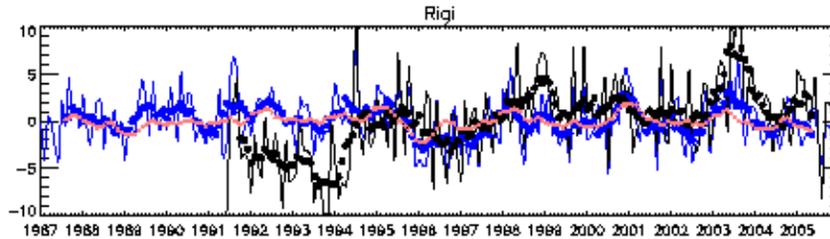
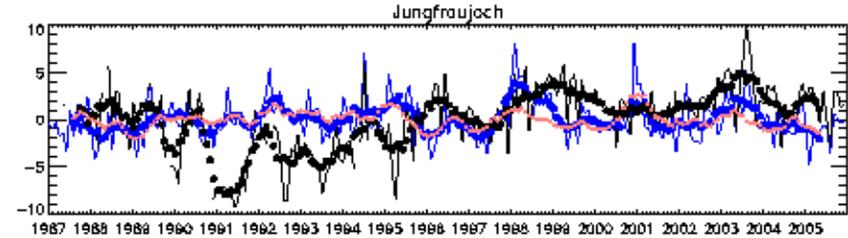
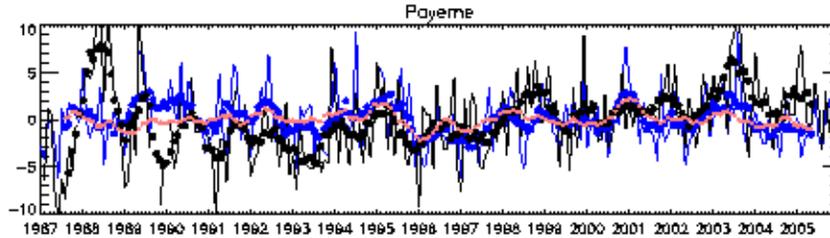
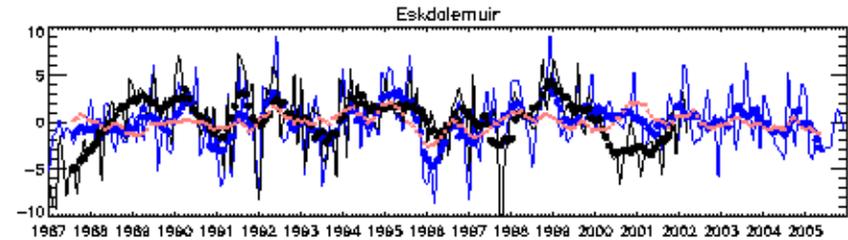
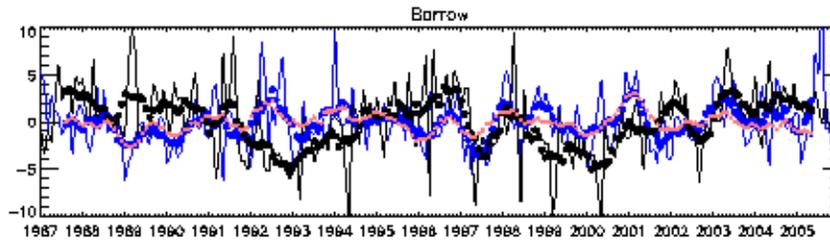
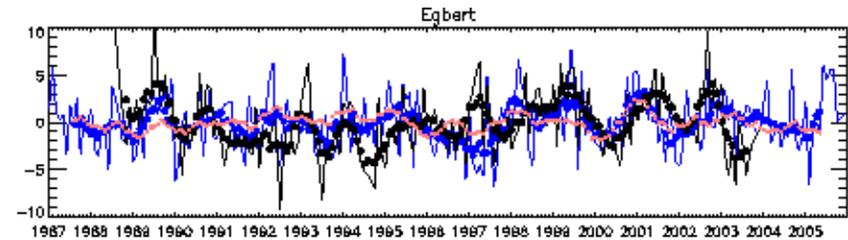
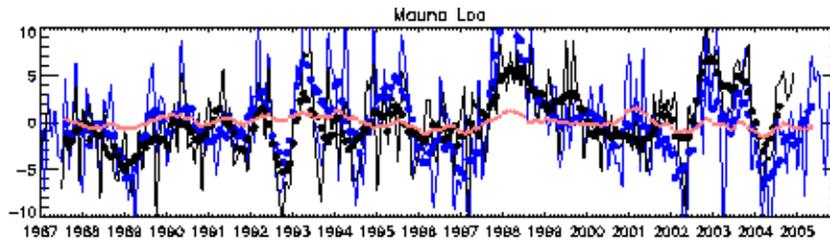
Isabelle Bey's group, EPFL, Switzerland.

- Anthropogenic emissions: base inventory scaled to national inventories (N. America, Europe), or fossil fuel statistics (by country)
- Biomass burning scaled to TOMS AI (up to 97), fire counts for 1997-2005
- CH₄ specified using NOAA/GMD data
- Column ozone from TOMS/SBUV
- No realistic treatment of temporal changes in stratospheric input.

CO anomalies

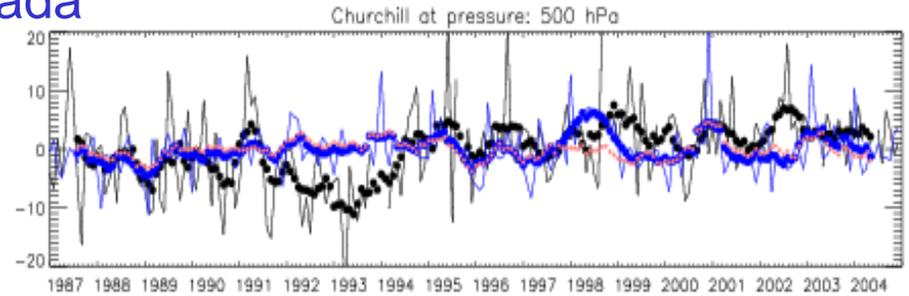
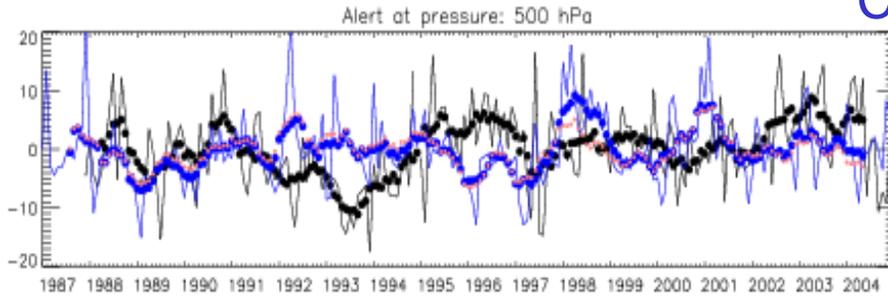


Surface ozone anomalies (mid-latitudes)

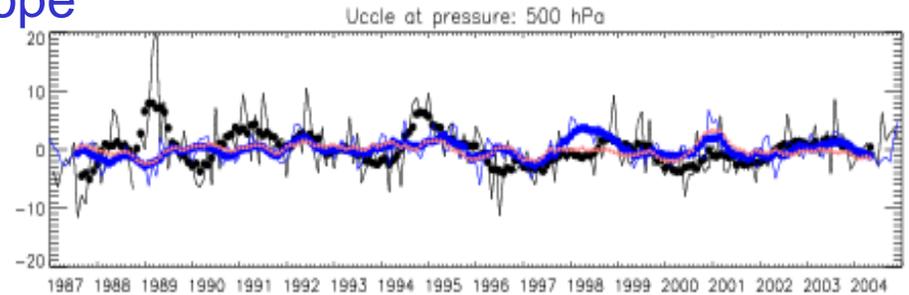
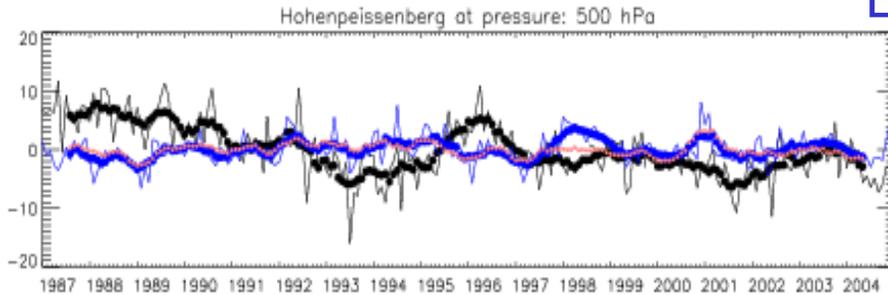


Ozone anomalies (500 hPa)

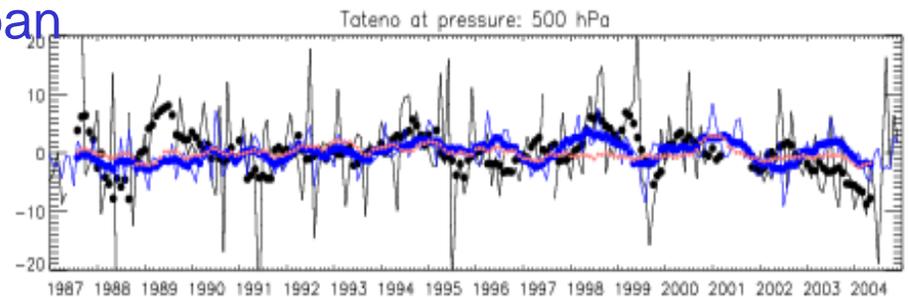
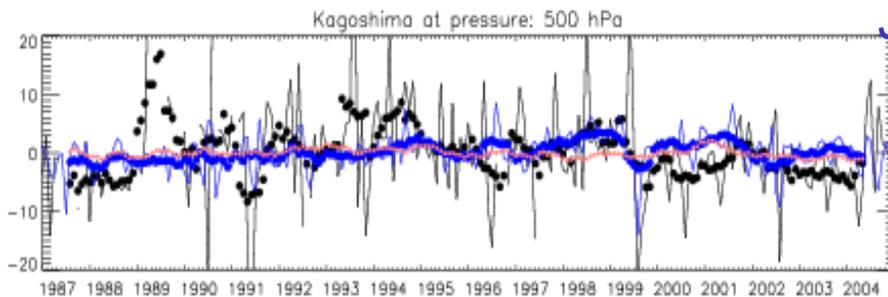
Canada



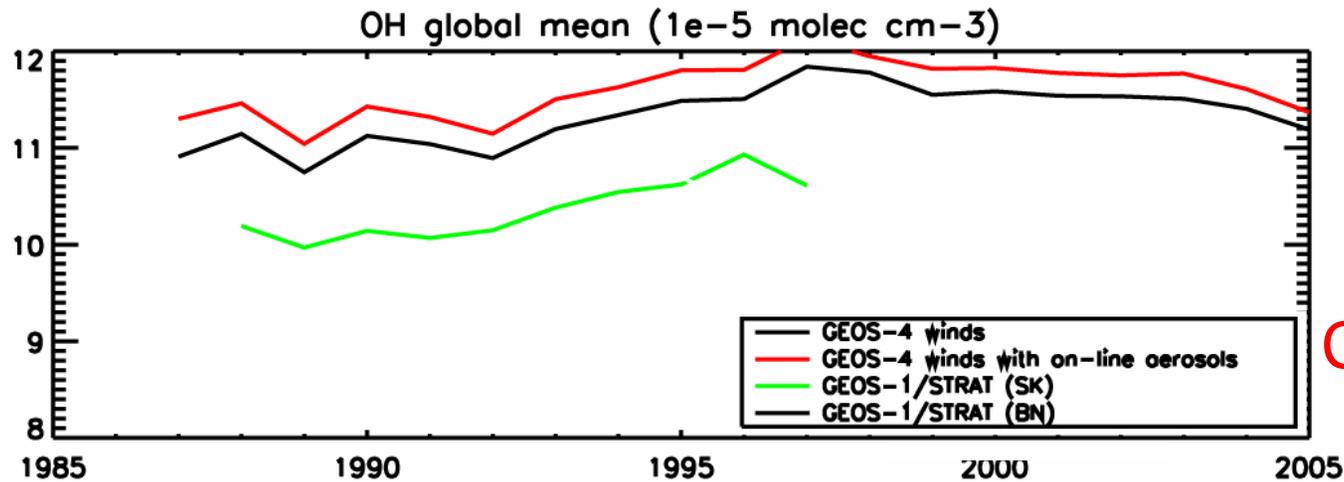
Europe



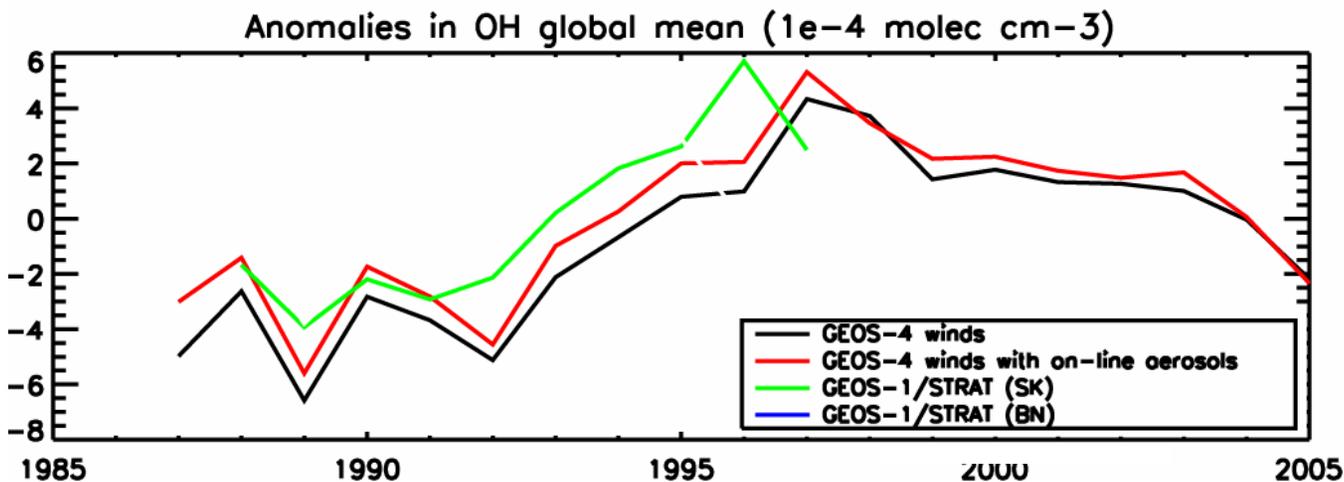
Japan



OH from 1987-2005 from GEOS-Chem (Bey)

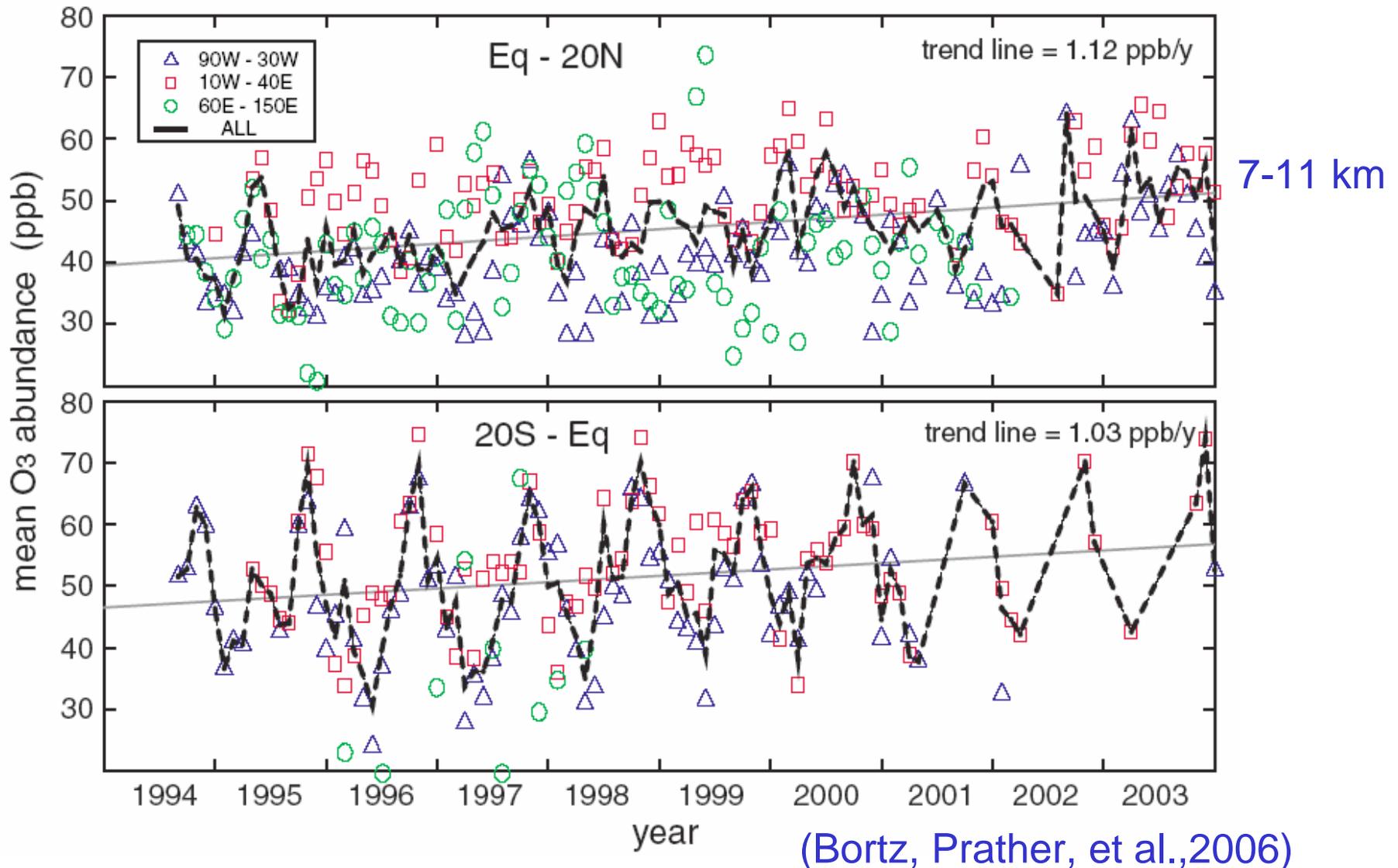


Changes caused by H_2O in GEOS-4?

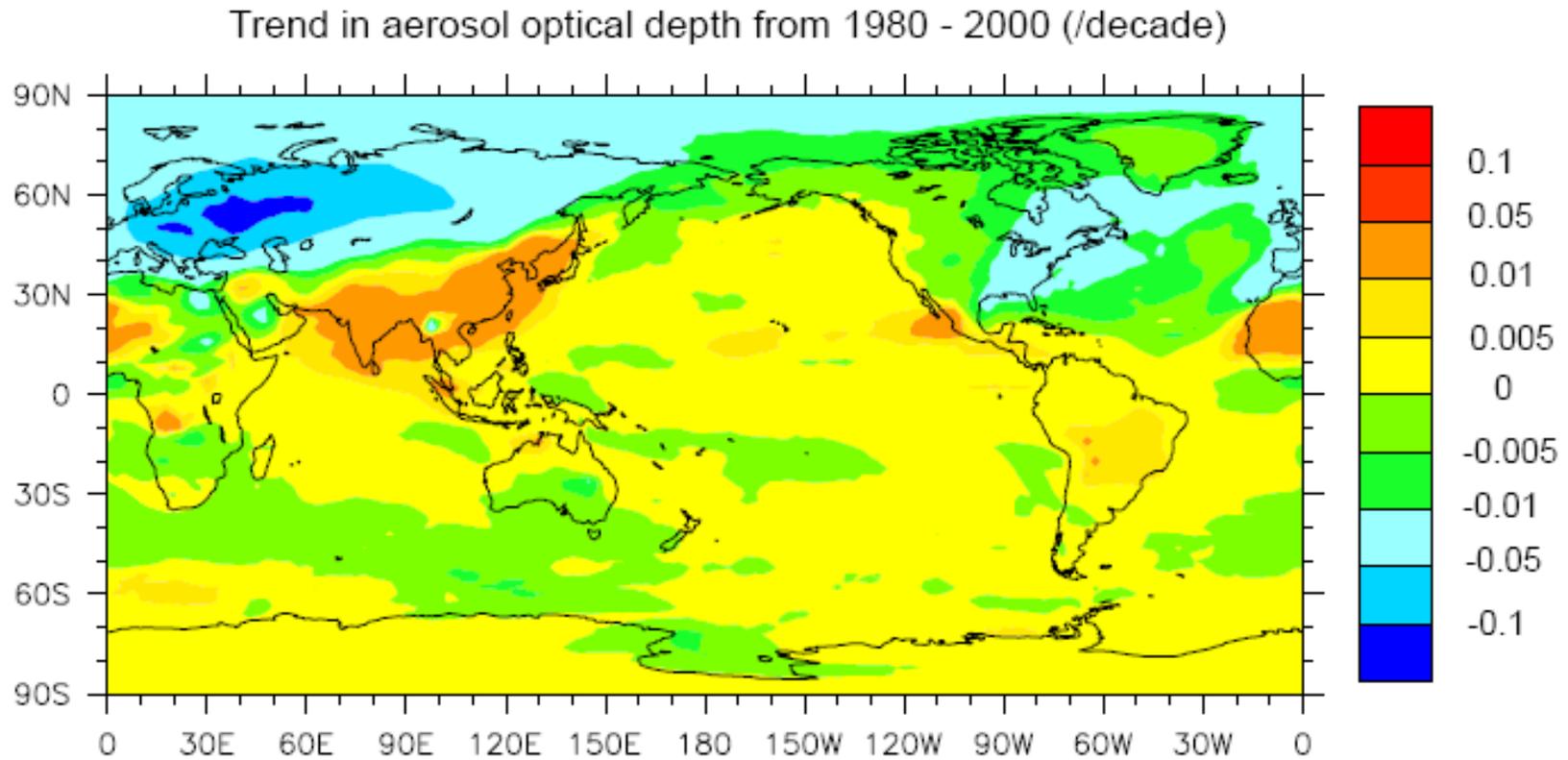


Steven Pawson is looking at this

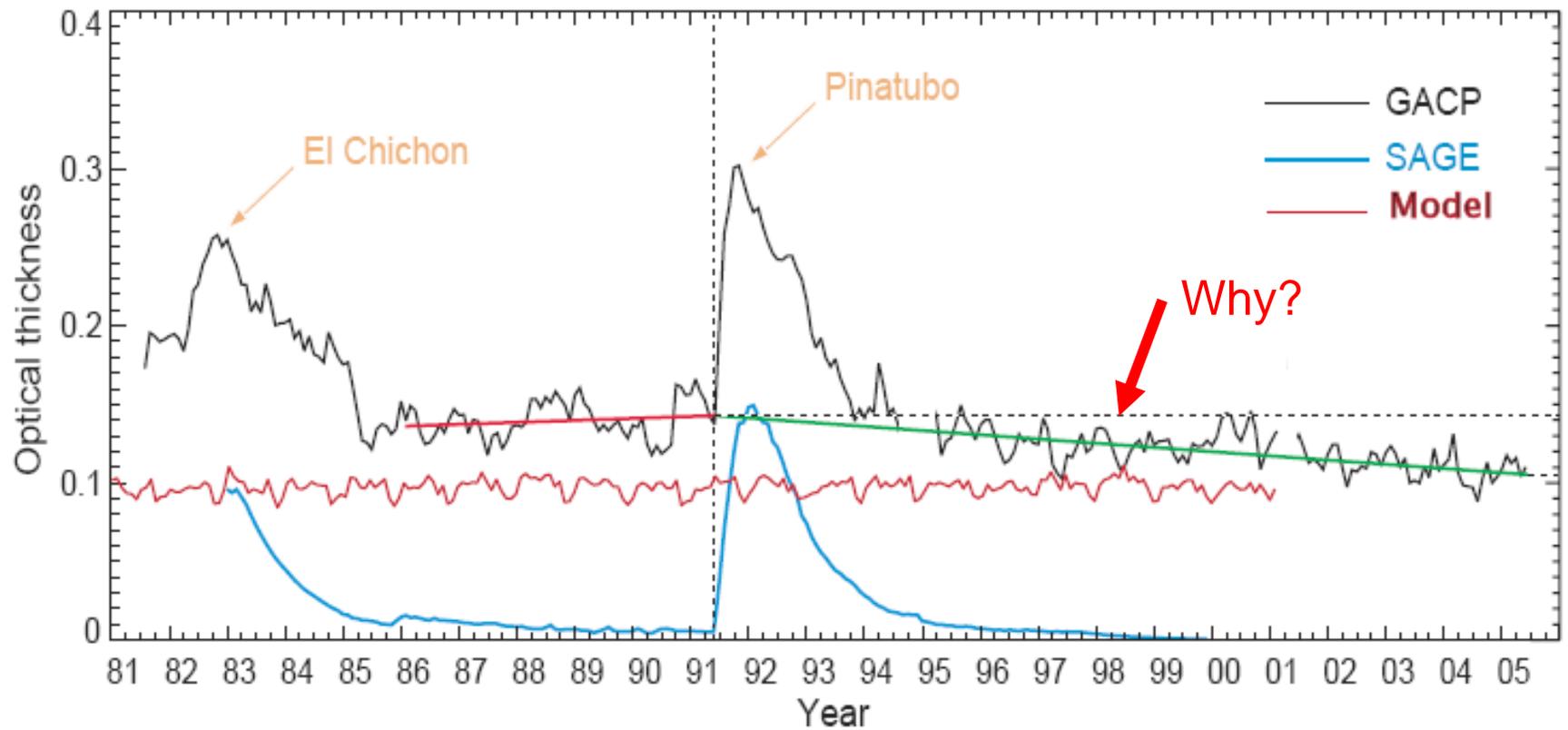
Trend/variability in tropical tropospheric O₃ – MOZAIC data
We need to understand this.



Modeled aerosol trends 1980-2000 (Joyce Penner)

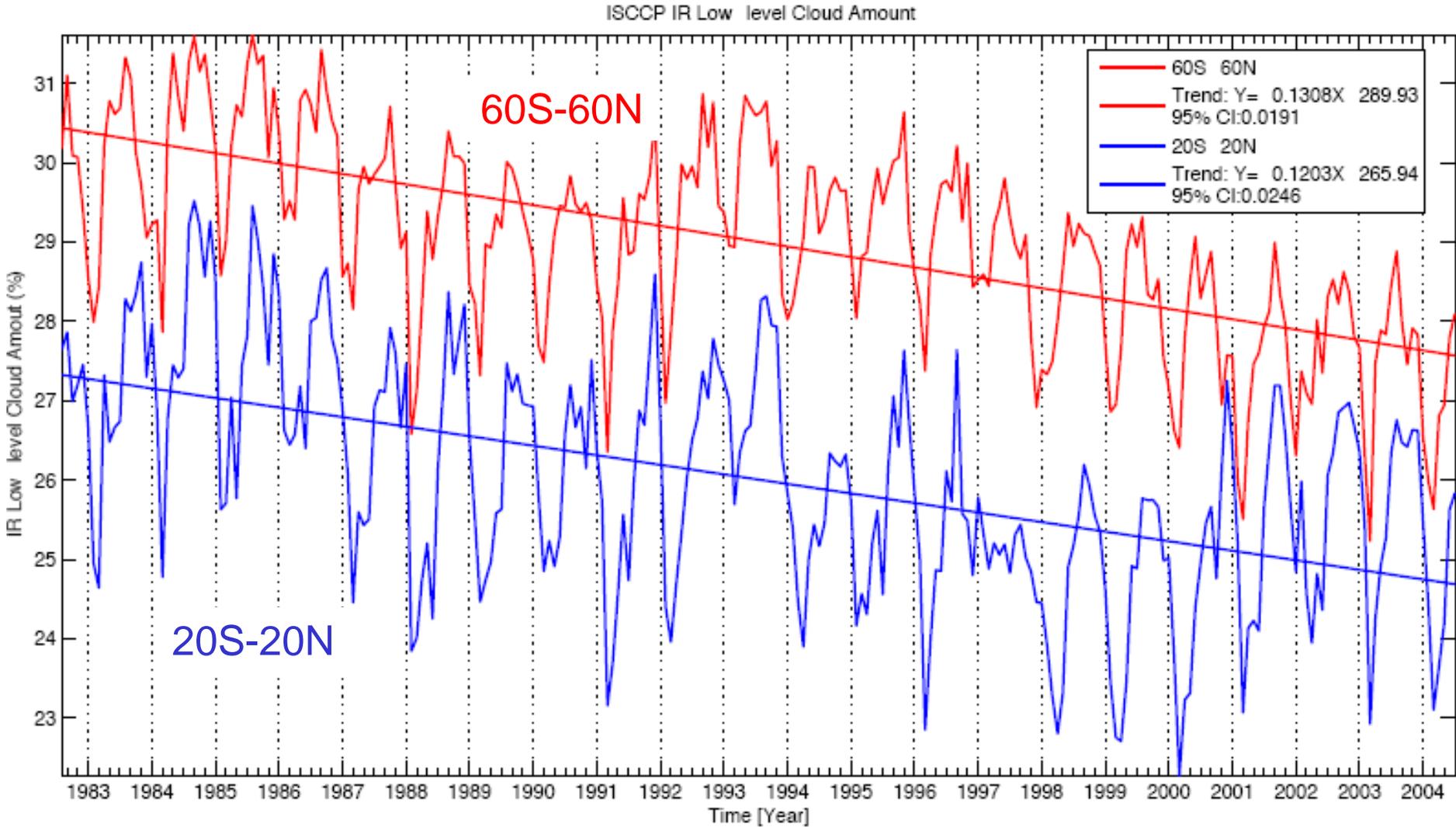


Observed Total Aerosol trends 1980-2005 (Joyce Penner)

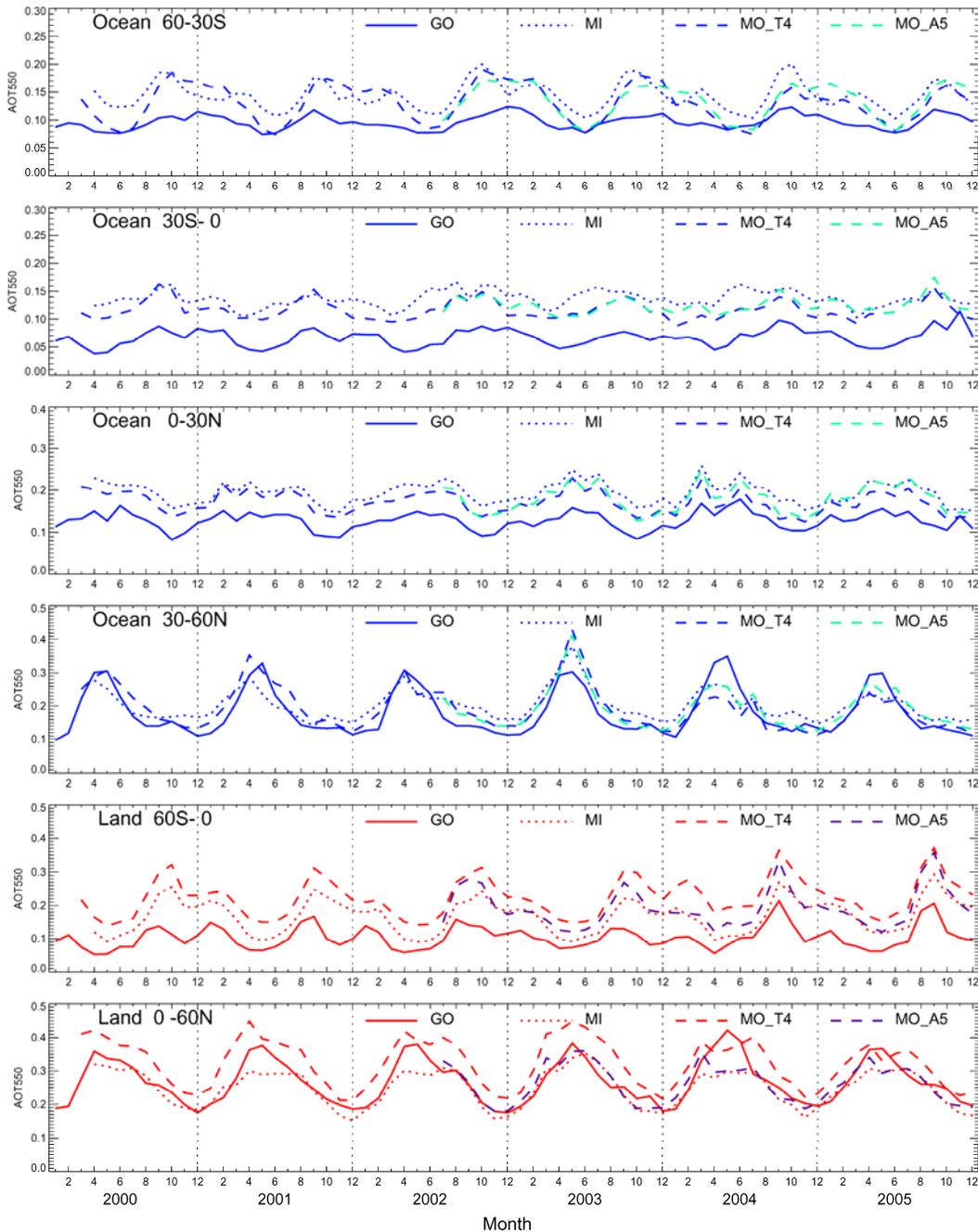


ISCCP IR Low Cloud Amount (1983-2004) (Penner)

Why the decrease? Are aerosol and cloud trends related?



GOCART, MODIS, MISR time series, 2000 – 2005

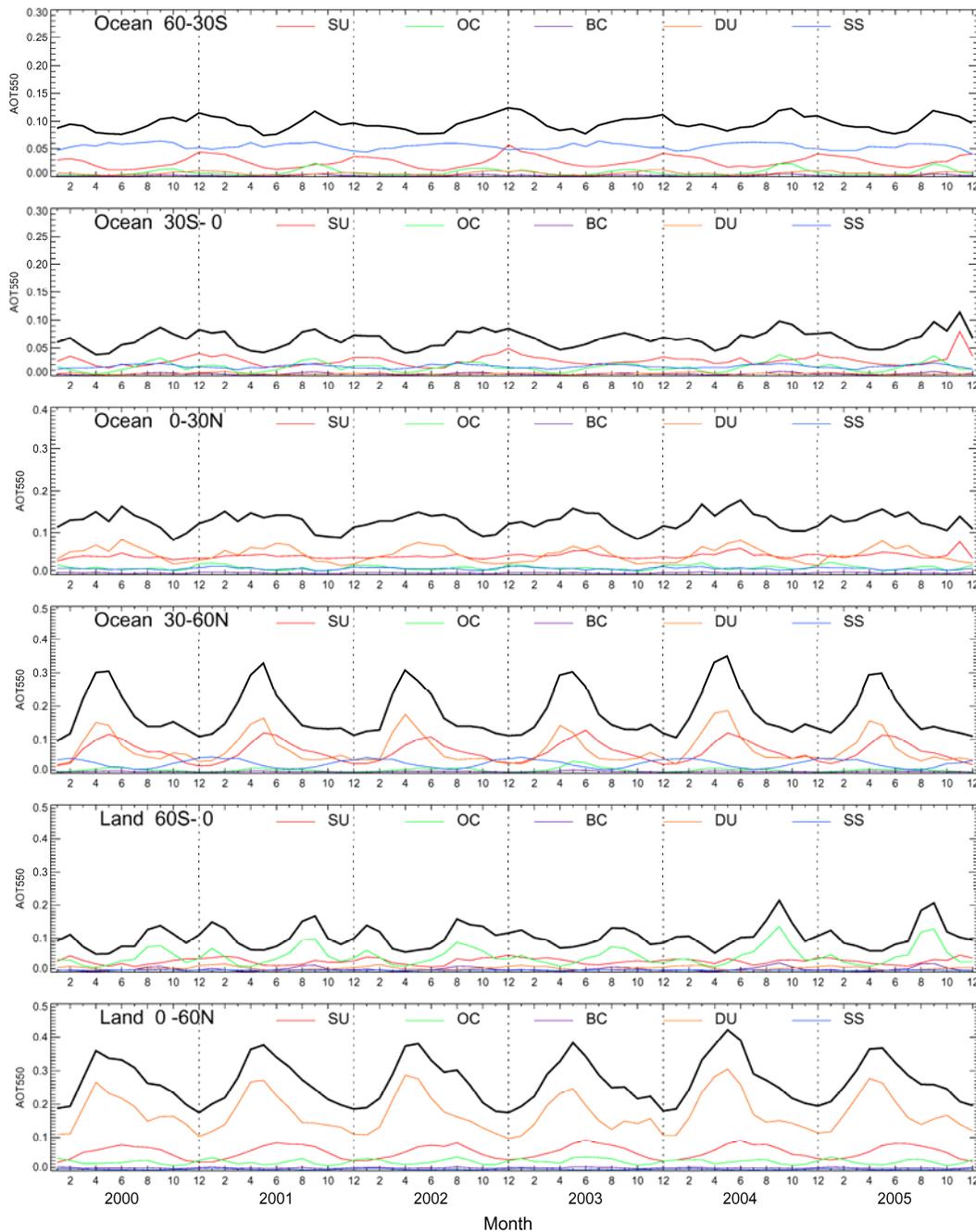


Mian Chin

- GOCART lower than MODIS and MISR over oceans, 60S to 30N
 - biomass burning emissions too low
 - Satellite retrieval may have high bias
- GOCART and satellite obs. very similar, 30N to 60N

- GOCART lower than satellite obs in SH
 - biomass burning emissions too low
- Very similar in the NH
- MODIS C5 is lower than C4 over land
- MISR lowest max

Composition of GOCART AOT, 2000 – 2005 (M. Chin)



- SU and SS out-of-phase on seasonal variations
- AOT cycle determined by SU (DMS) and CC (fire)

- SU regulates seasonal variation
- SU is higher than SS

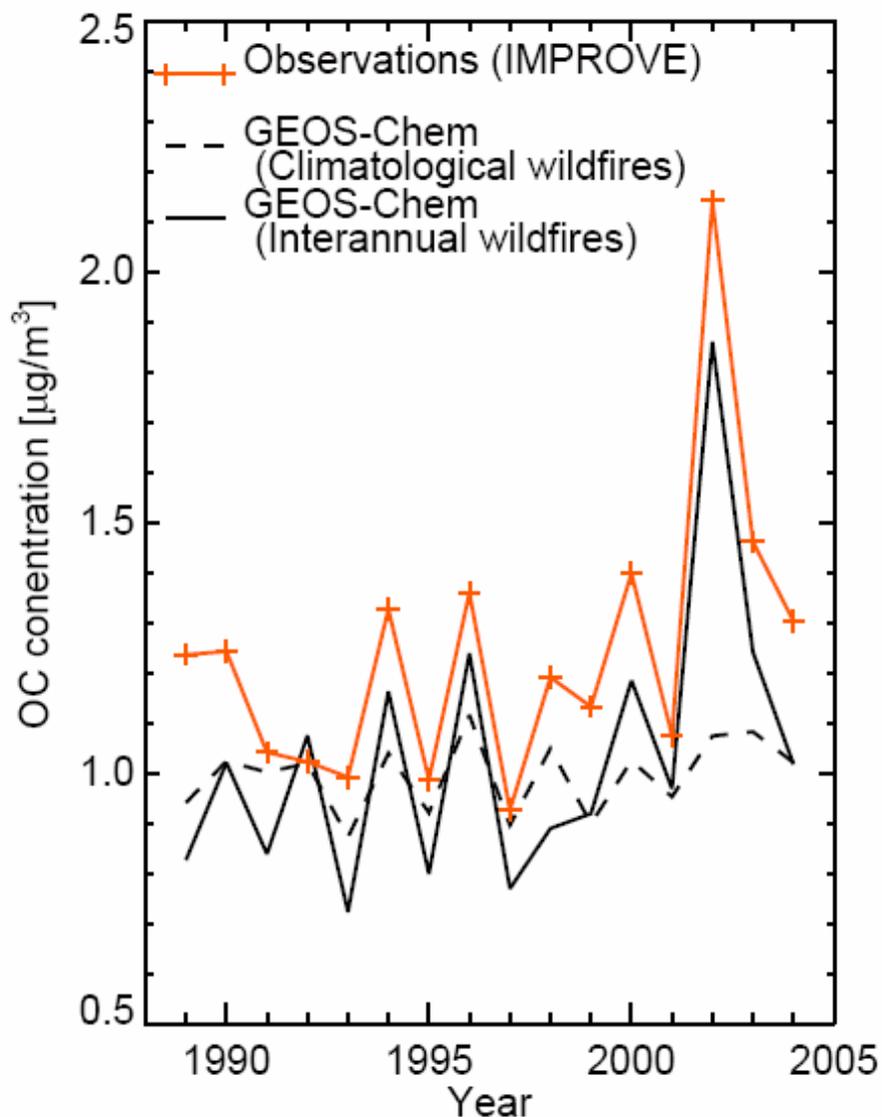
- DU determines seasonal variation
- DU and SU AOT about the same

- DU and SU in-phase
- DU and SU AOT about the same

- Biomass burning CC dominates (tropical Africa in Jan-Mar, S. Africa in Jul-Nov)

- DU dominates

Organic carbon aerosols over the
Western U.S. in summer.



15 year run, GEOS-4.

Variability and trends driven
by wildfire emissions in the
western U.S.

Spracklen et al. (2007)

Fires in the U.S. are
increasing, climate related.
(Westerling et al., Science,
2006)

RETRO

REanalysis of the TROpospheric chemical composition
over the past 40 years)

Martin Schultz, Julich, Germany

12 partners from 8 countries
5 work packages (plus coordination)
duration: January 2003 – June 2006

total budget: 2 M€

“The primary objective of RETRO is to understand, detect and assess long-term changes and interannual variability of the tropospheric chemical composition over the last 40 years, thereby providing the essential framework within which to understand possible future changes.”

RETRO models

- **5 global models participated:**
 - 2 chemistry-GCMs
 - 3 CTMs
- **all models used ERA-40 data**
 - different variables
 - analysed versus forecasted fields
- **all models used RETRO emissions**
 - differences for biogenic emissions and injection height
- **stratospheric boundary conditions differ**
- **3 models (2 chemistry-GCMs and 1 CTM) ran the complete 40-year period**

Anthropogenic Emissions

Comparison with expert EMEP emissions
(year 2000)

NOx

CO

Hintergrund

Meteorologische
Trends

Spurengas-
konzentrationen

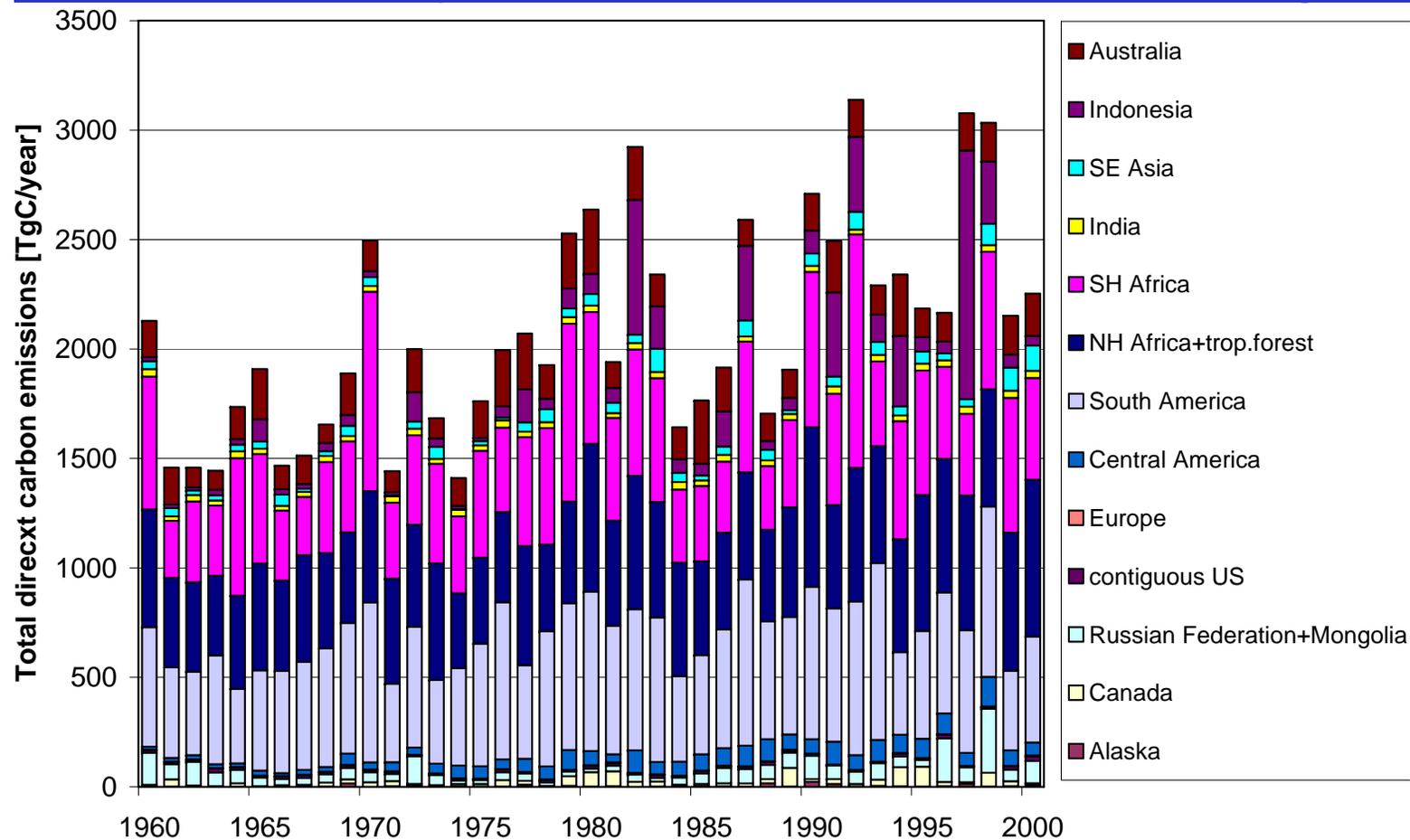
Modellvergleiche

Szenarien

Country/ Region	RETRO TEAM	EMEP	RETRO TEAM	EMEP
Germany	2.5	1.7	4.7	4.9
United Kingdom	1.6	1.7	3.5	3.9
France	1.5	1.4	3.0	6.6
Italy	1.4	1.4	2.9	5.2
Spain	1.1	1.3	1.5	2.8
Poland	1.0	0.8	2.4	3.5
EU25*	12.2	11.5	25.5	36.6

Differ by 50%

Interannual variability of fire emissions – from a fire model, Reg-FIRM

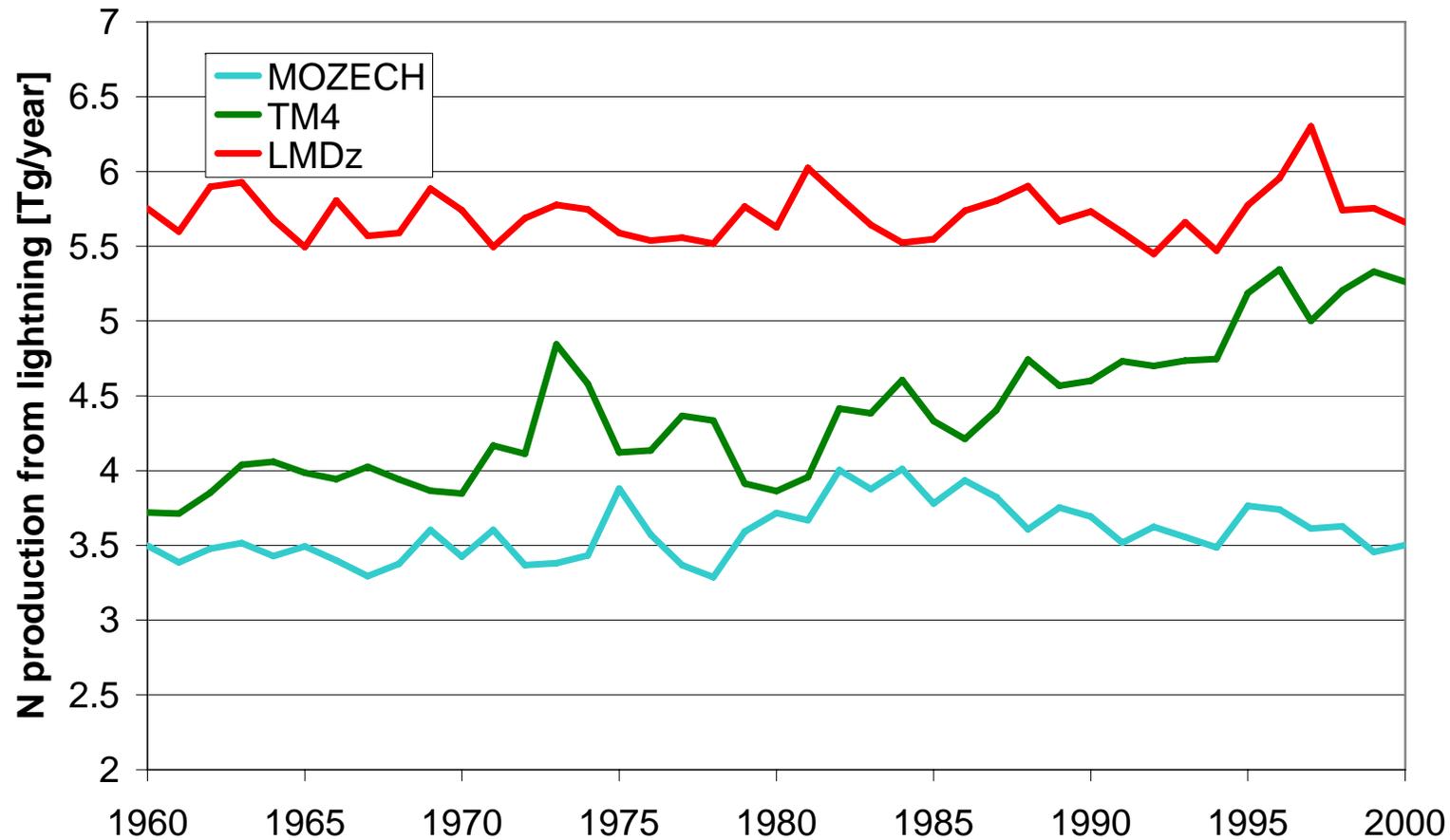


Fire disturbance model from Lund-Potsdam-Jena dynamic vegetation model

Evaluation for Iberian peninsula, Germany, Australia are published.

Applied globally.

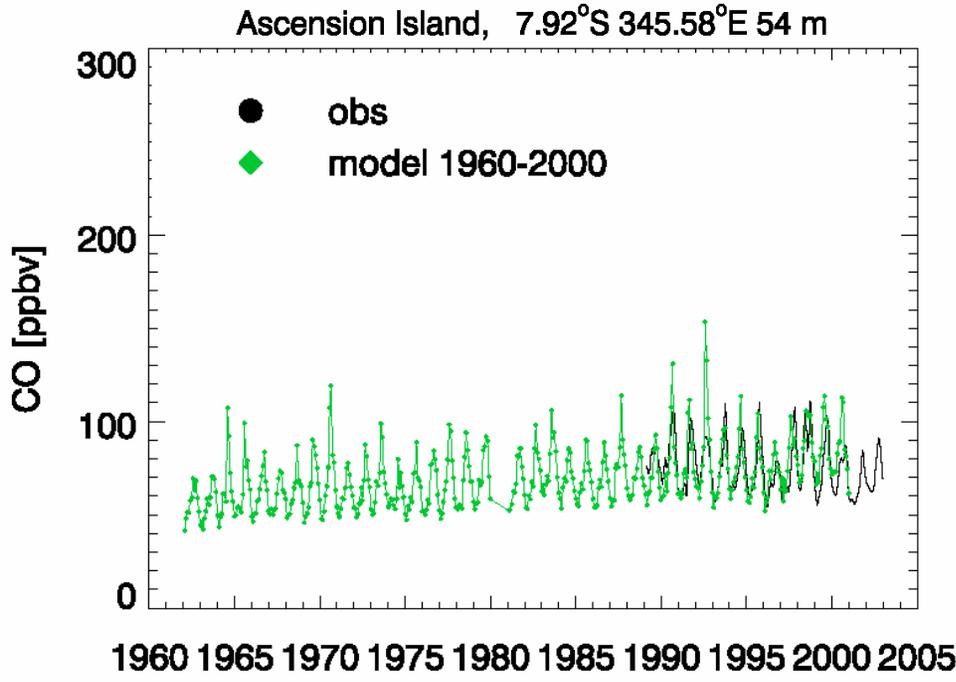
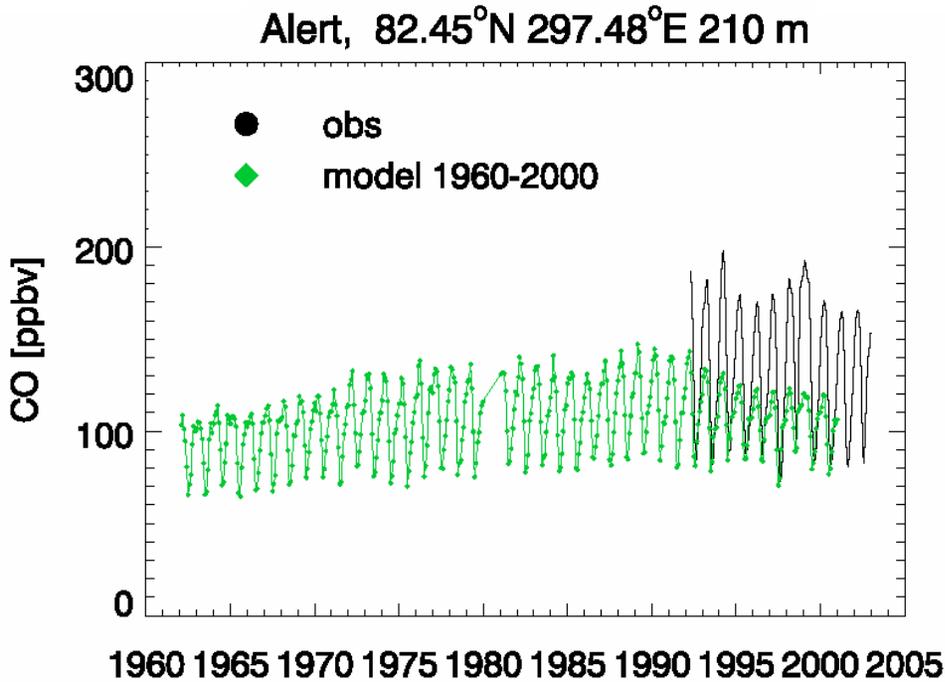
Trends in lightning NO_x



Spurious increase in (tropical) precipitation in ERA-40 is reflected in CTM results (e.g. increase in lightning NO_x in TM4 model).

Inconsistencies/problems in met. data translate into problems with chemistry simulations

Surface CO concentrations
(GMD)





Service d'aéronomie



Historical emissions

a new 1860-2000 inventory
of emissions of gases and particles

Claire GRANIER

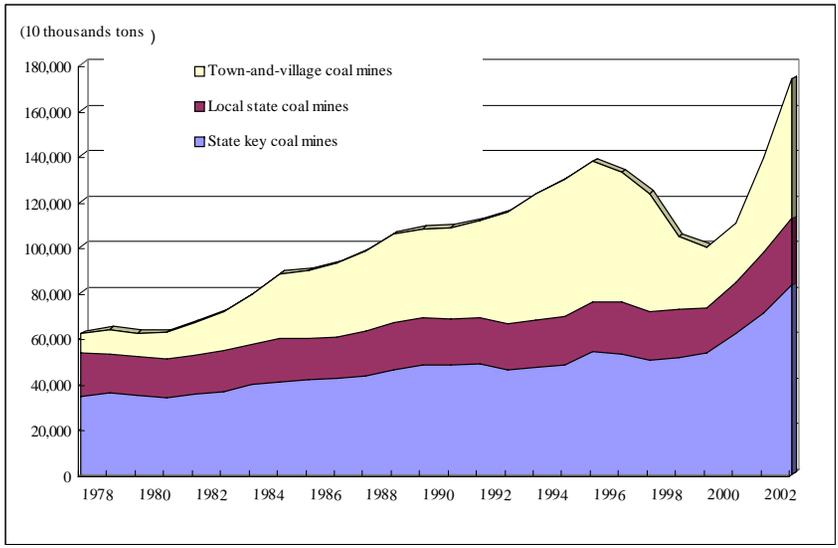
Service d'Aéronomie/IPSL, Paris
CIRES/NOAA Earth System Research Laboratory

Aude MIEVILLE, Service d'Aéronomie/IPSL, Paris

Cathy LIOUSSE and Bruno GUILLAUME,
Laboratoire d'Aerologie, Toulouse, France

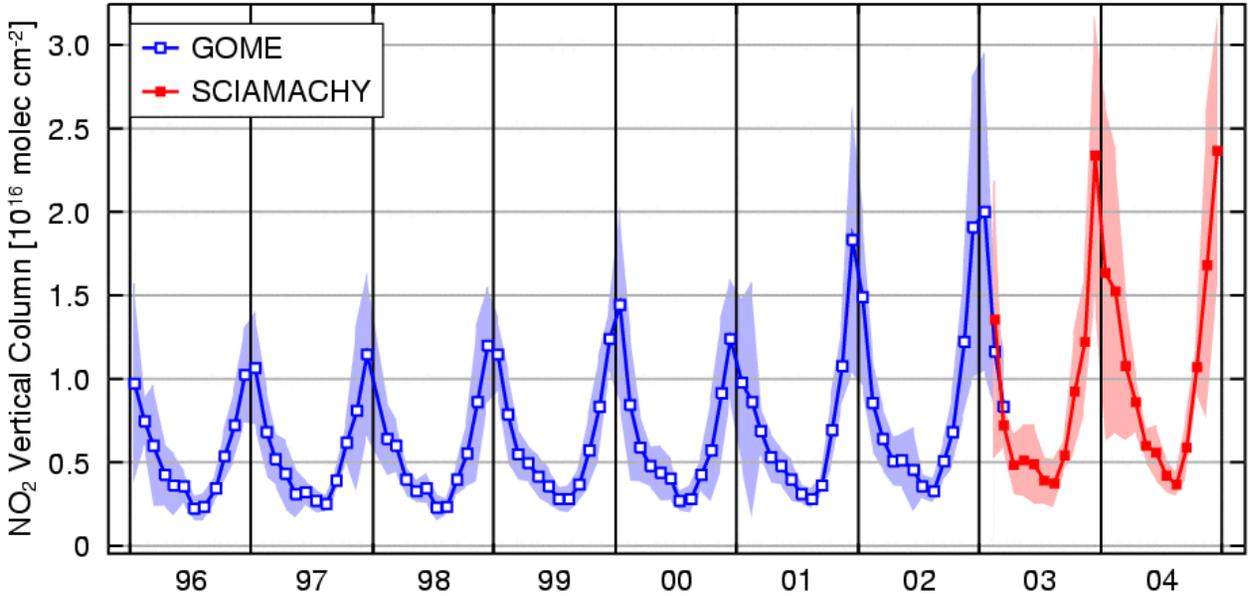


Mismatch between inventory and observations for NO₂



Coal production by types of coal
(China Coal Industry Yearbook)
Main source of NO_x emissions

NO₂ trop. column over China (Richter et al., Nature, 2005)



CHALLENGES:

anthropogenic emissions scenarios appear to be clones

Are there independent data sets here ?

feedbacks / forced changes (e.g., land use) in natural emissions

Can we account for these (e.g., fires, wetlands and CH₄) ?

collective learning & a coherent error analysis

How can we consolidate the knowledge of individual efforts ?

chemistry-aerosol-CO₂ studies \leftrightarrow climate model

???

A MAP Program: Focus on interannual-to-decadal variations in atmospheric composition (reactive gases, aerosols and CO₂) as driven by Earth system forcings.

for Internal Use:

Merge satellite (& field) observations with composition modeling

Couple 'lessons learned' across the MAP Earth system program (e.g., clouds and H₂O in reanalysis, strat-trop exchange)

for External Use:

AR5 – radiative forcing projections to 2100 (SRES++)

Critical evaluation of SRES++ emissions

Air Quality studies – projected surface O₃ & aerosols (HTAP)

National Inventories – validation of reported anthropogenic emissions through observations and 'inverse' modeling