Atmospheric Composition, Biogeochemical Cycles and Climate Change: Feedbacks and Interactions

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Aspen Global Change Institute --- Session II --- August 2000

AGCI Agenda

- **Sessions of the meeting**
  - Aimed at extensive discussion
  - Talks roughly 30 minutes each with 15 minutes for discussion
  - Try as much as possible to group talks around themes
  - Most sessions with talks in the morning, some in late afternoons and early evening
  - Leave additional time for Working Group discussions
- **Working Groups**
  - Some meeting time aimed at Working Groups that allow us to focus on specific topics

AGCI Working Groups

- **Three working groups formed**
  - Biogeochemical Cycles and Climate Change
    - Chair: Scott Elliott
  - Air Quality and Climate Change
    - Chair: Denise Mauzerall
  - Climate Model Requirements
    - Chair: Richard Somerville
- **Synthesis**
  - Synthesize the findings of the meeting and the working groups
    - Chair: Bob Hudson
- **Goals and objectives**
  - Status of understanding
  - Key uncertainties
  - A research agenda
- **Draft reports from each group by end of meeting**

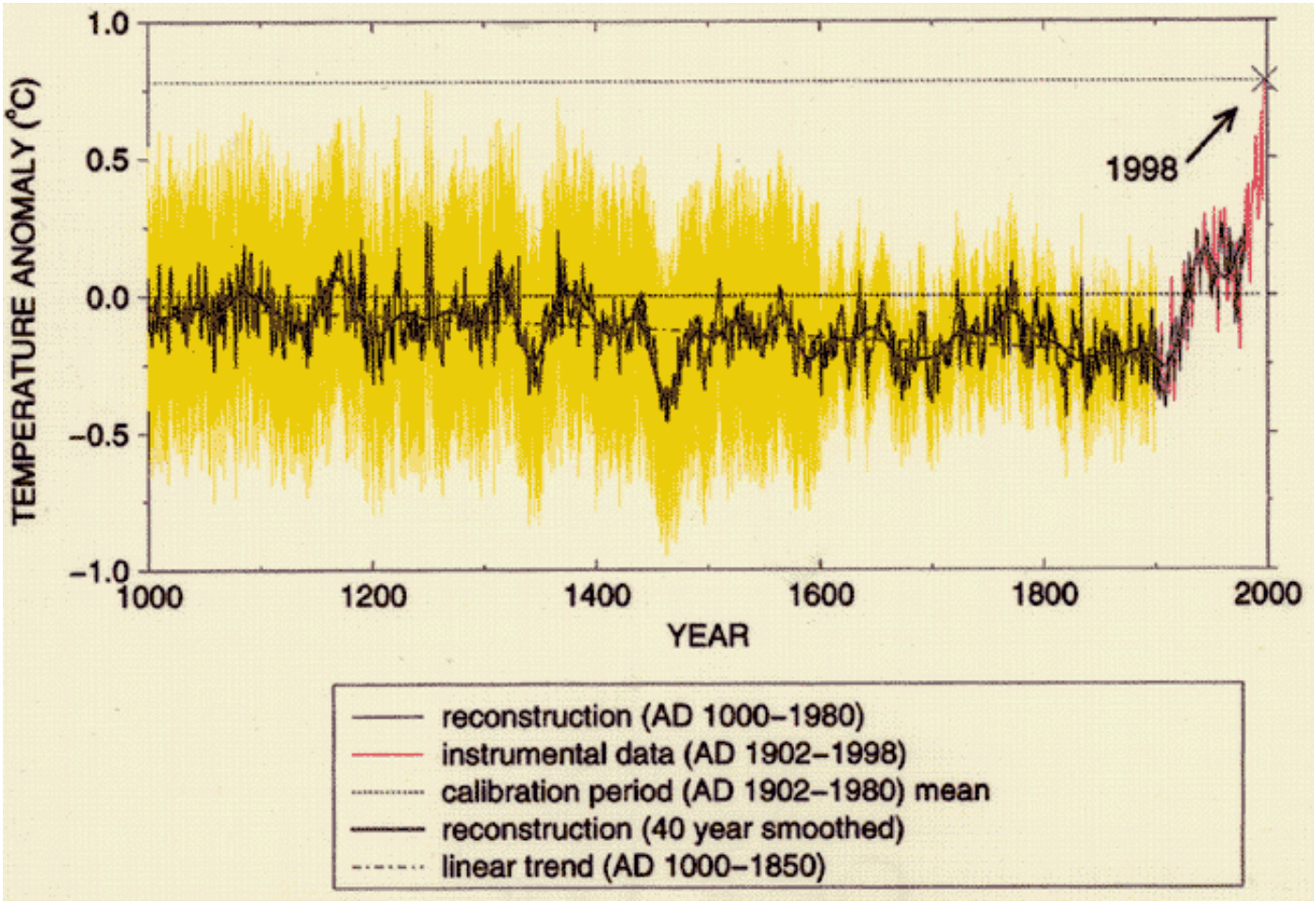
Key Research Questions: Biogeochemical Cycles

- **Traditional**
  - How are greenhouse gas emissions changing?
  - What are the biogeochemical cycle budgets? Are natural sources changing as well as human-related sources?
  - How well do we know the individual sources?
- **Interactions and Feedbacks with climate change**
  - How will the individual biogeochemical sources respond to a changing climate?
  - How would a changing climate affect biogeochemical emissions of CO_2, CH_4, N_2O, CO, NMHCs, SOx, NOx?
  - What are the implications of the responses in biogeochemical cycles on projected atmospheric composition? Would this impact on projections of future climate?
- **What are the key uncertainties and what modeling and measurement tools are needed to resolve key uncertainties?**

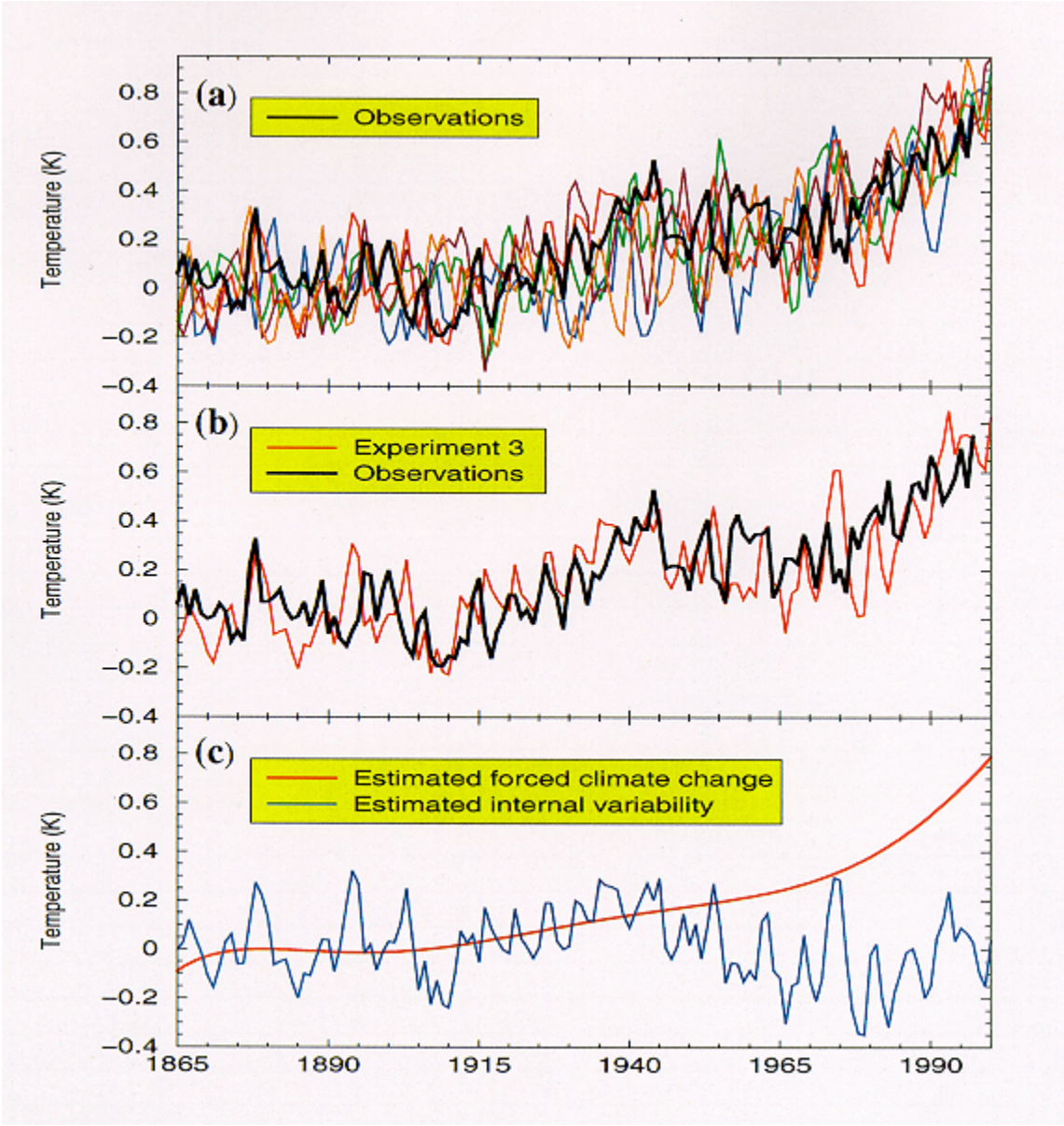
Key Research Questions: Air Quality

- **Traditional**
  - How are urban/regional to global emissions of NOx, CO, NMHCs, etc. affecting O_3, CH_4, aerosol concentrations in troposphere?
  - How is tropospheric OH being affected by changes in CH_4, CO and emissions of other gases?
- **Interactions and Feedbacks with climate change**
  - How is local/regional air quality affecting climate change? Role of biomass burning? Role of long range transport?
  - How is and will climate change affect local/regional air quality? How might climate change affect emissions of pollutants as well as the resulting pollutant distributions?
  - Could air quality interactions with climate result in a significant change in our understanding of future projections of climate change?
- **What are the key uncertainties and what modeling and measurement tools are needed to resolve key uncertainties?**

1990s: Warmest in this Millennium



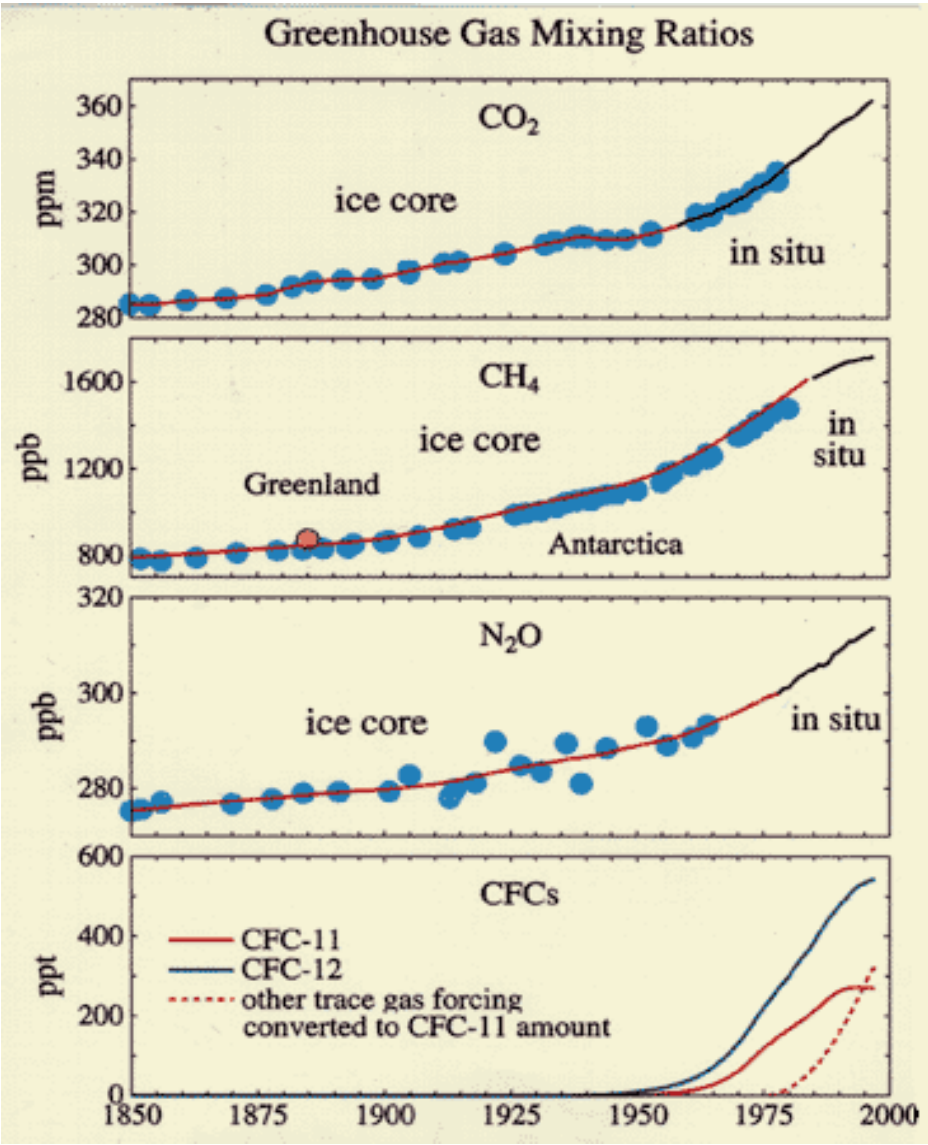
Mann et al., 1999



GFDL

Ocean-Atmosphere Climate Model

From Delworth and Knutson (1999)



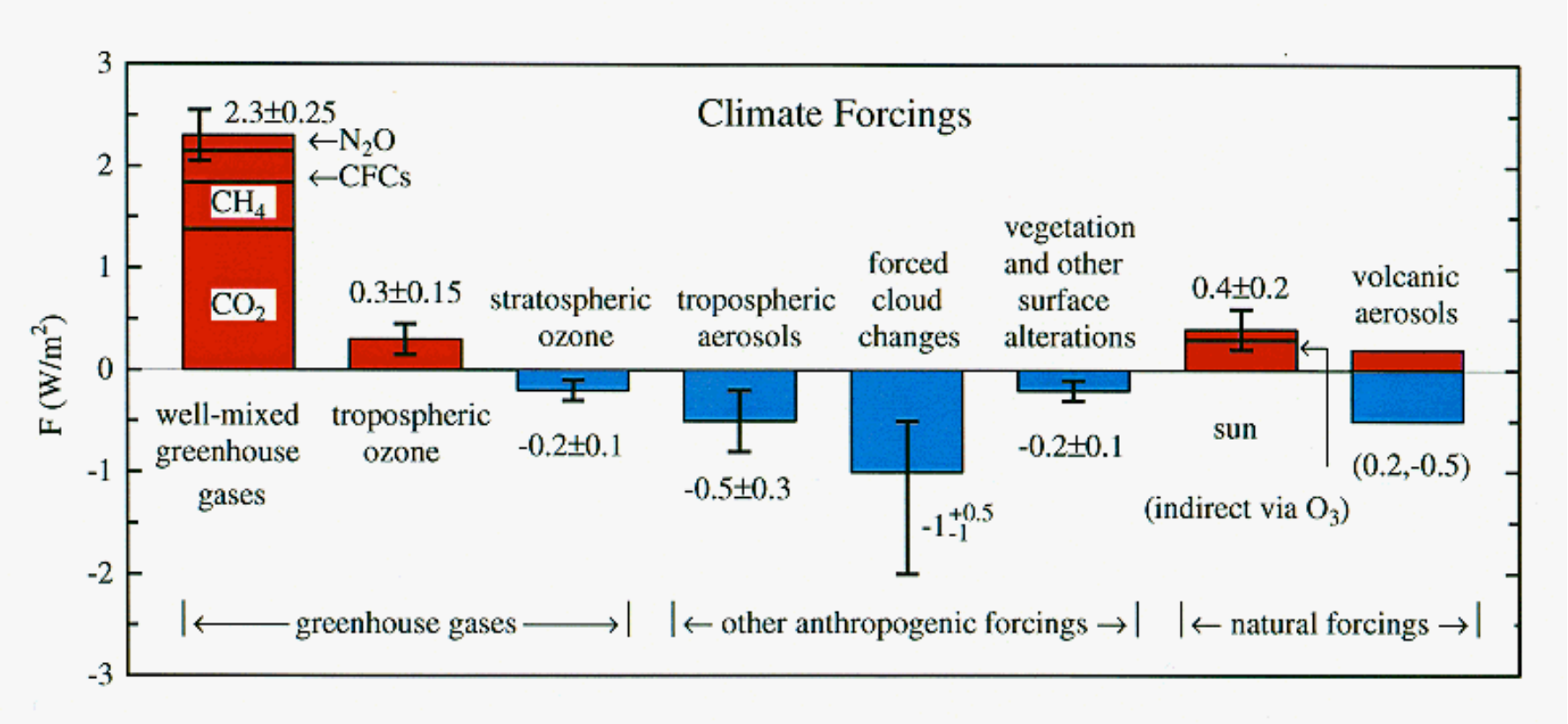
Large increases in atmospheric concentrations of greenhouse gases over the last century

The Effect of a Gas on Climate?

- **Determined by its *radiative forcing* relative to other forcings on climate**

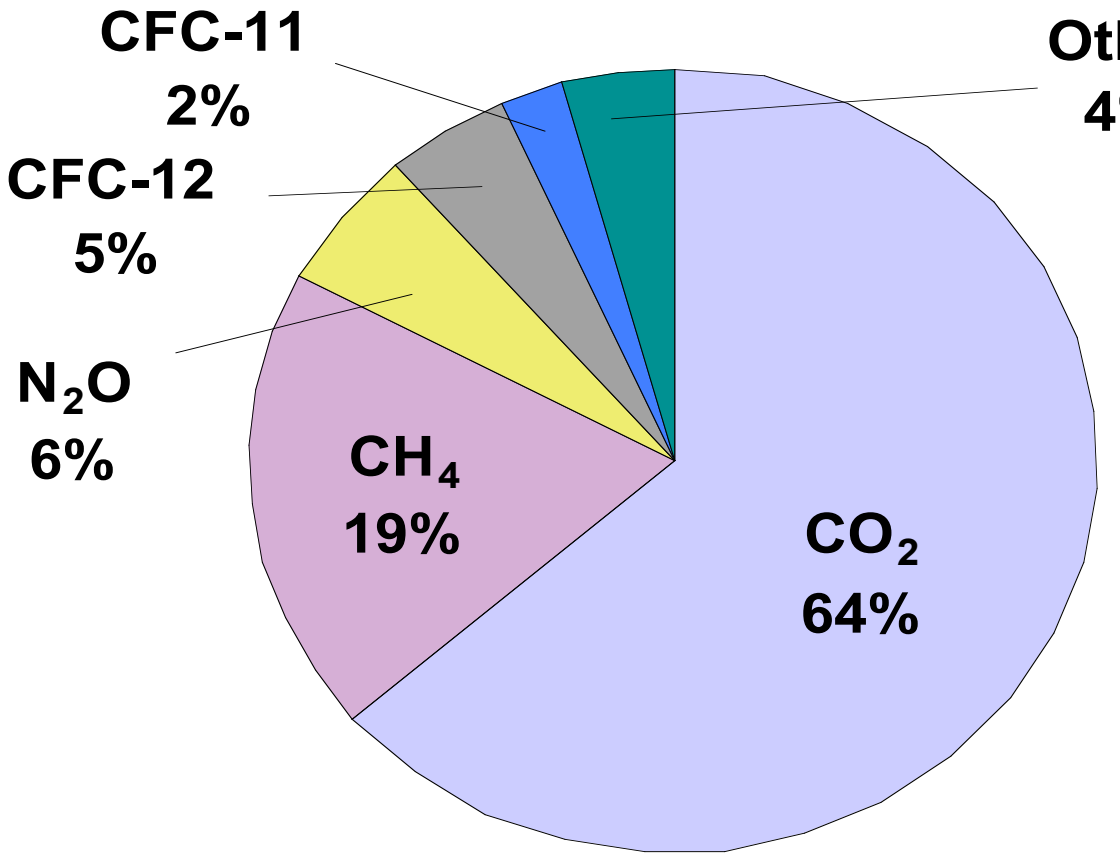
- **What is radiative forcing?**
  - **Increase in concentration of a greenhouse gas allows more of the outgoing infrared radiation of the Earth to be absorbed by the atmosphere**
  - **This reduces the efficiency by which the Earth cools to space**
  - **Tends to warm the lower atmosphere and surface**

Radiative Forcing since 1850



NASA GISS analysis (Hansen et al., 1999)

Radiative Forcing: 1750 to 1992

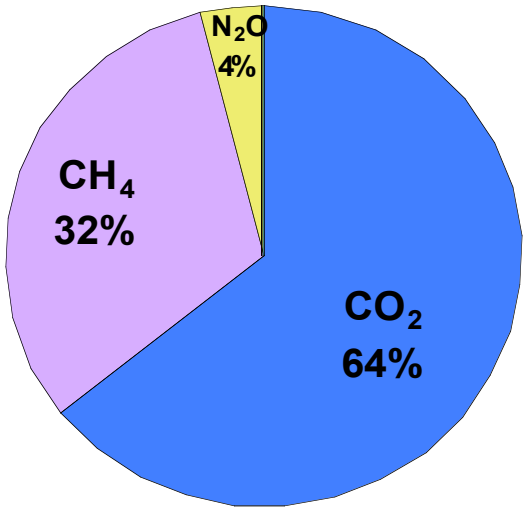


Based on

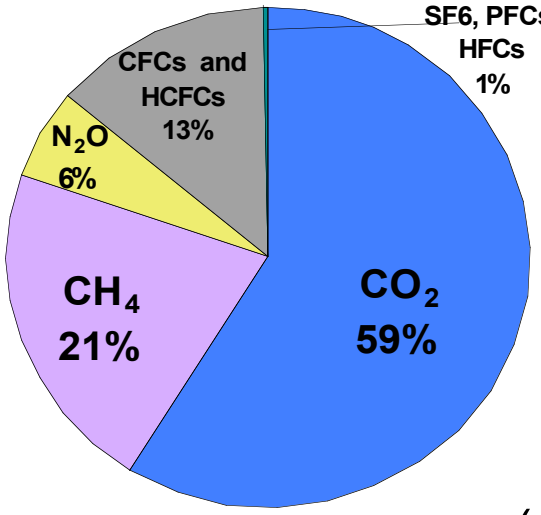
IPCC, 1996

Total change in radiative forcing=2.45 Wm^{-2}

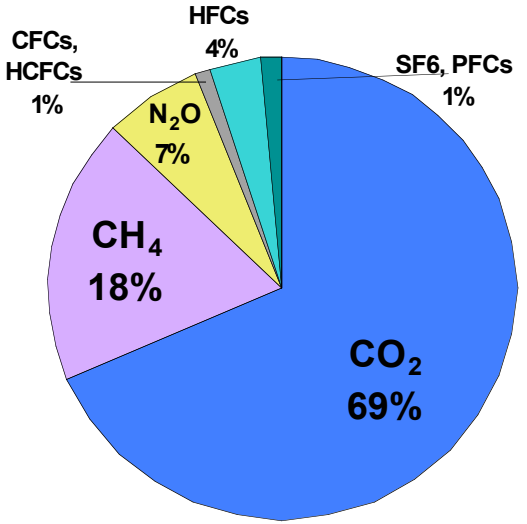
Increase in Radiative Forcing from pre-industrial times



(1765-1900) = 0.53 Wm^{-2}



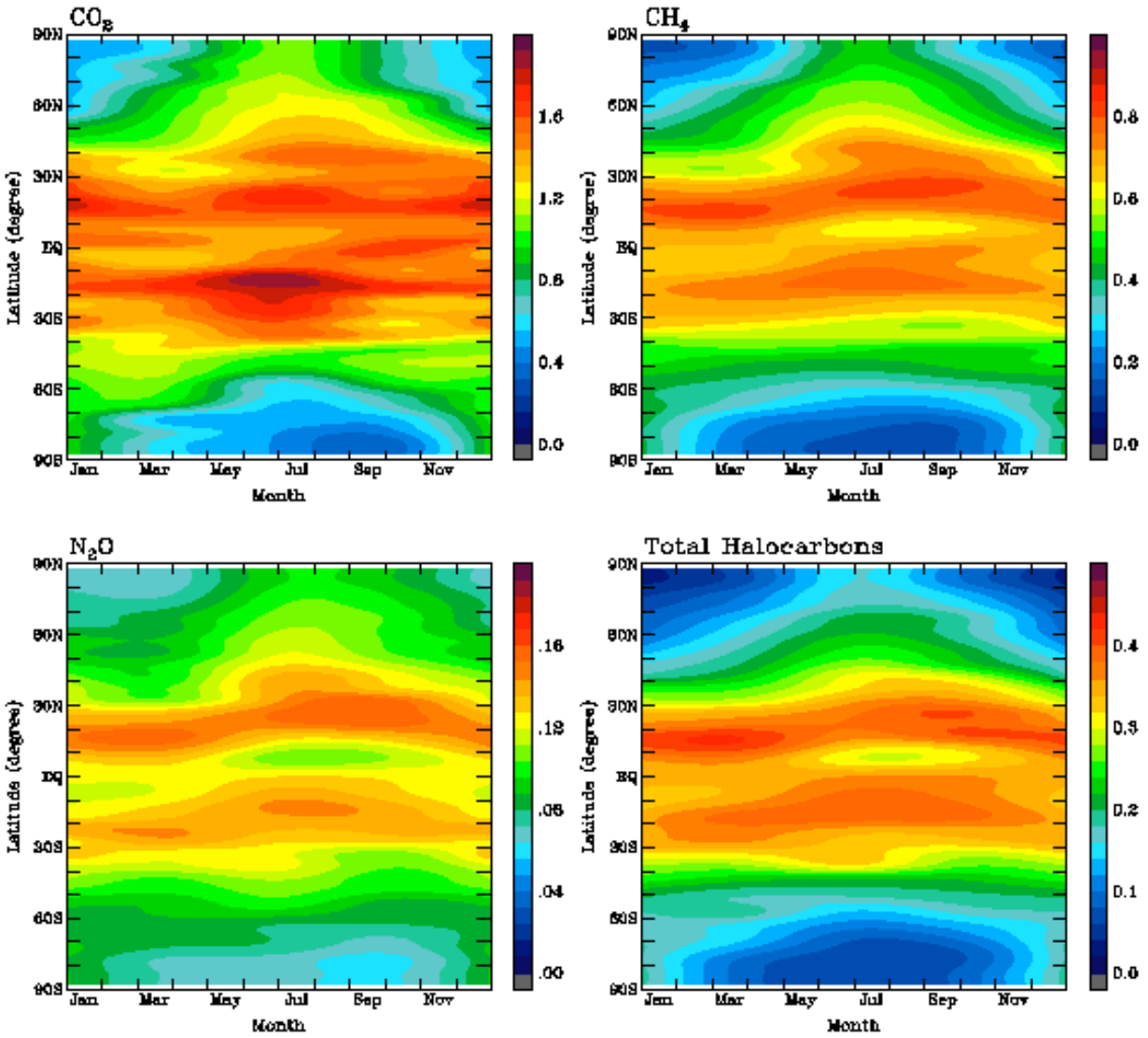
(1765-2000) = 2.45 Wm^{-2}



(1765-2100) = 5.05-8.31 Wm^{-2}

Based on Jain et al.2000

Estimated Seasonal and Latitudinal Dependent Changes in Radiative Forcing (Wm^{-2}) for the Period 1750-1992 for CO_2, CH_4, N_2O, and Halocarbons

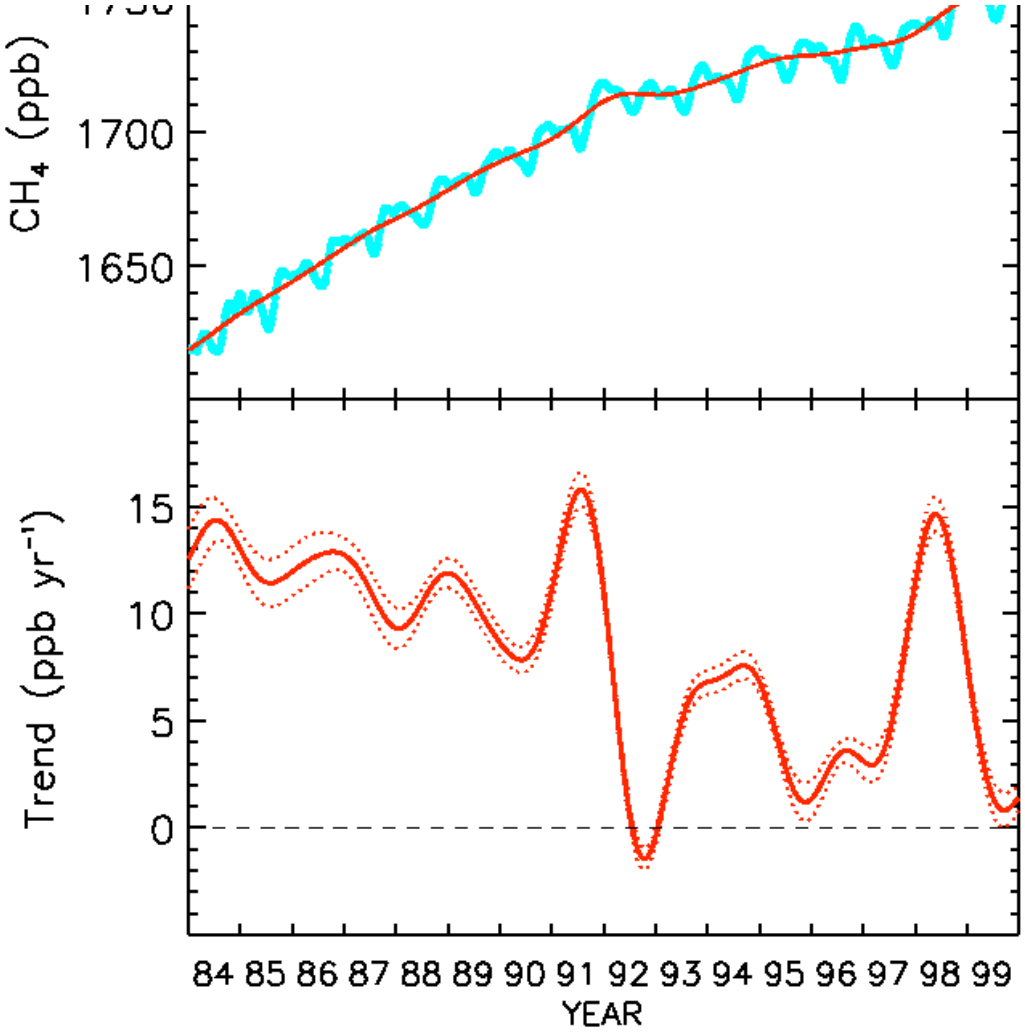


Jain et al. (2000)

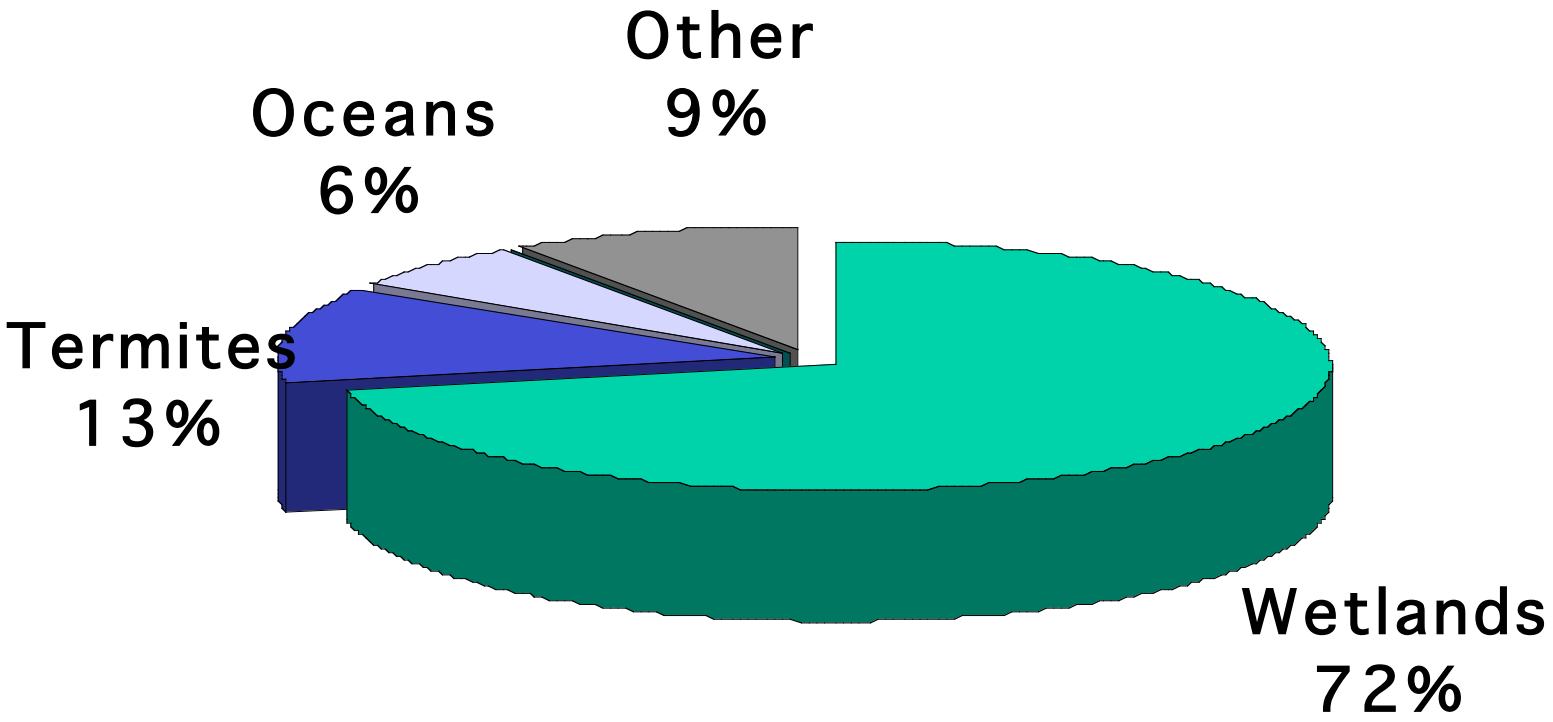
Methane in the Global Environment

- CH_4 is the most abundant organic trace gas in the atmosphere
- CH_4 is the 2nd most important changing greenhouse gas
  - Need accurate determination of future concentrations
- CH_4 is important to tropospheric and stratospheric chemistry
  - CH_4 affects tropospheric OH, CO and CH_2O
  - CH_4 affects O_3 in the troposphere and stratosphere
  - CH_4 important to Cl deactivation in stratosphere

NOAA CMDL Methane

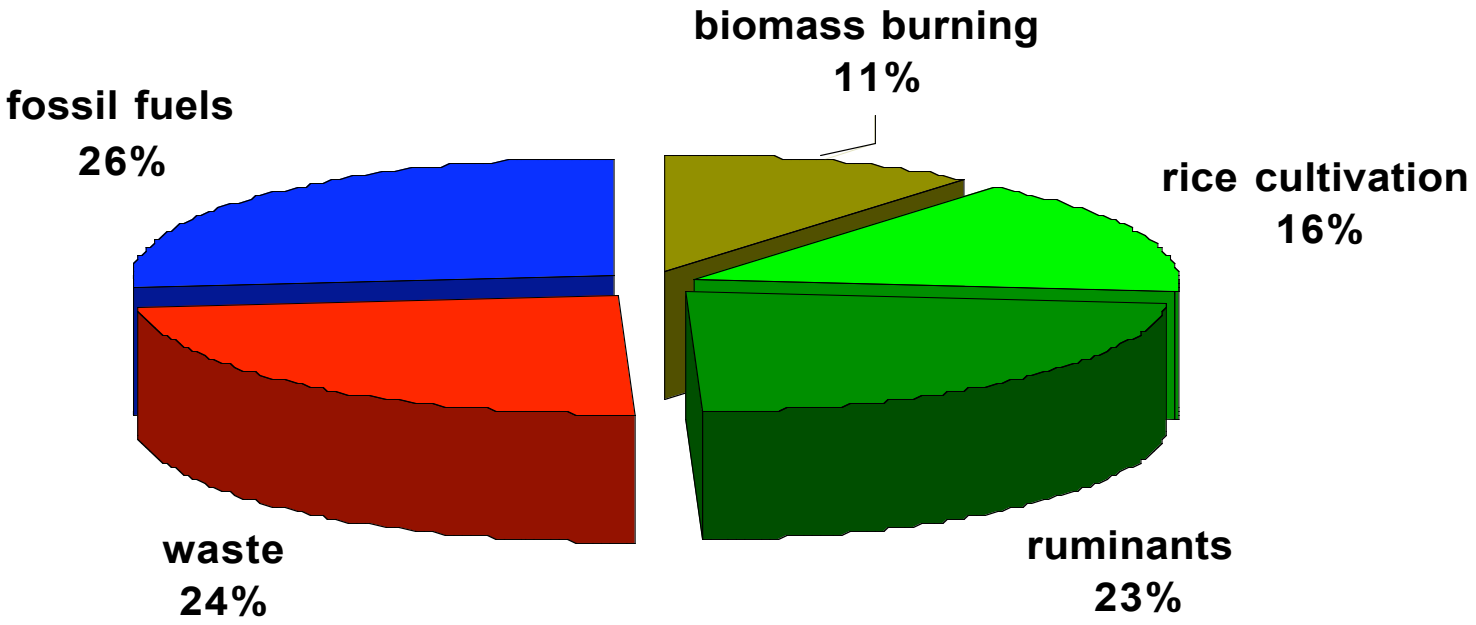


Natural Methane Emissions



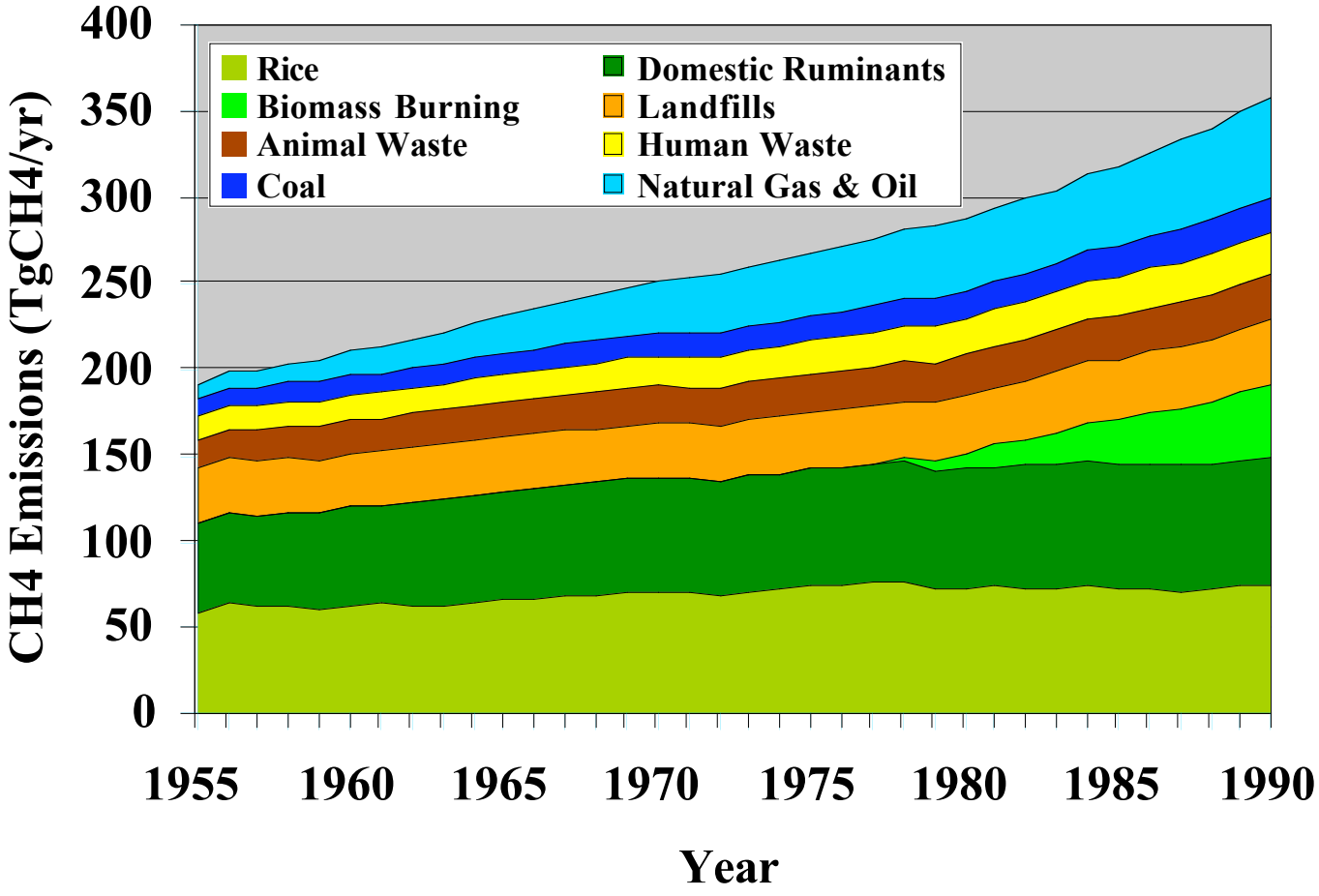
Total natural sources ~ 160 Tg
Based on IPCC, 1995

Human-Related Methane Emissions

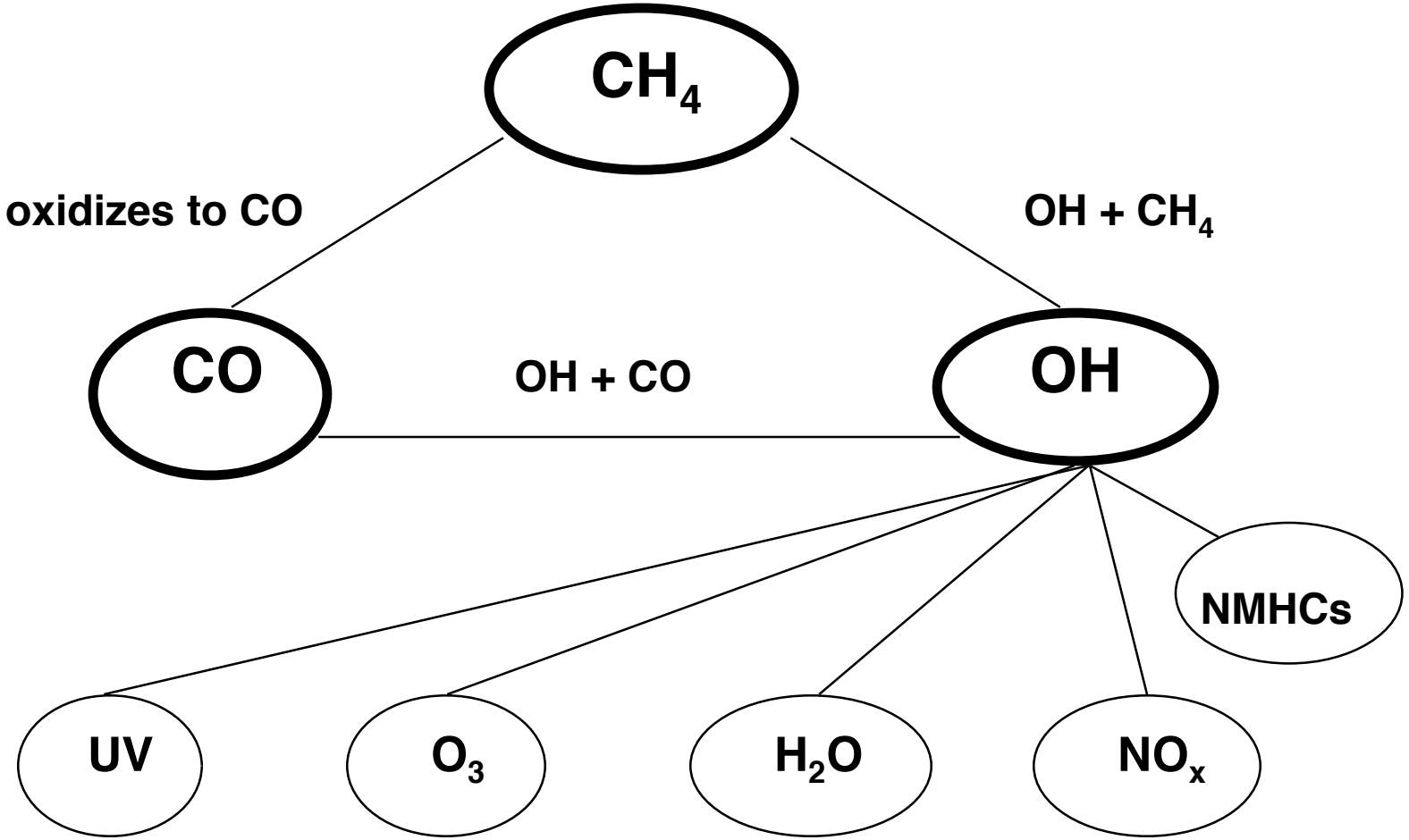


Based on IPCC, 1995

Trends in Anthropogenic CH_4 Emissions



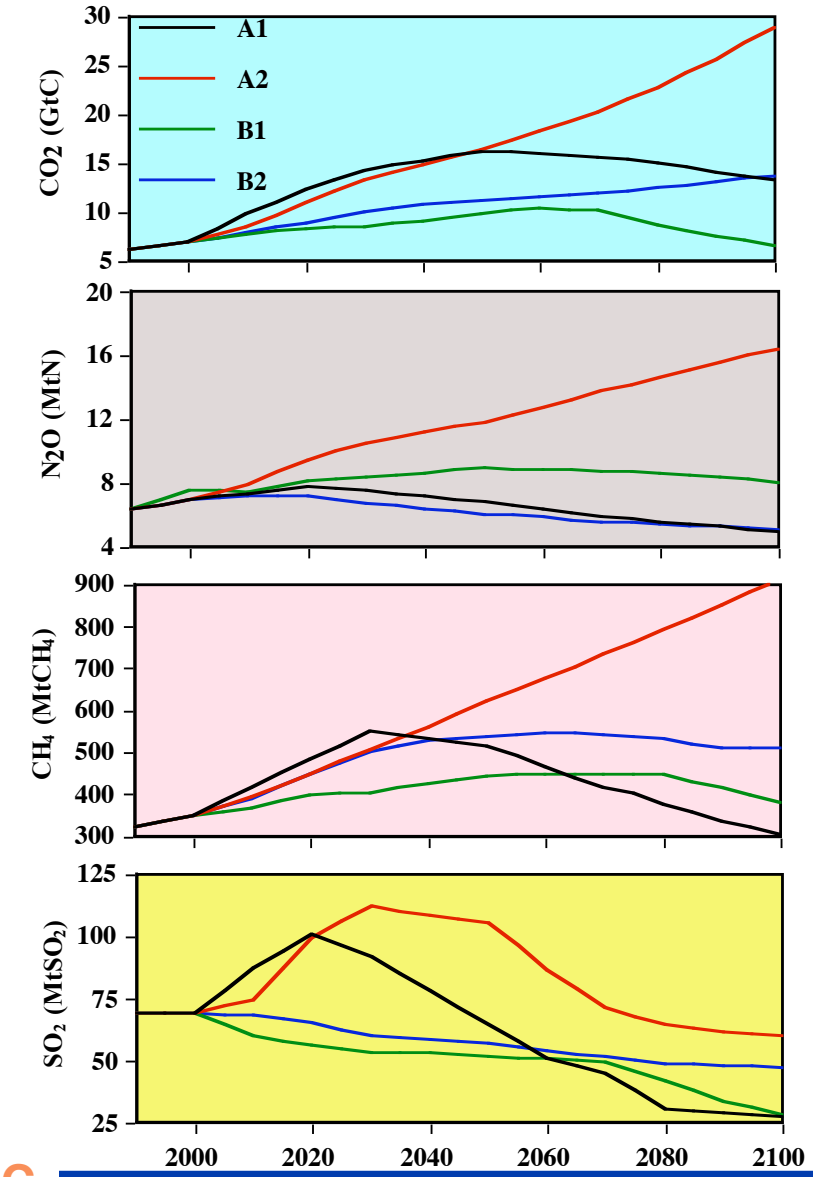
Simplified CH_4/OH/CO Chemistry



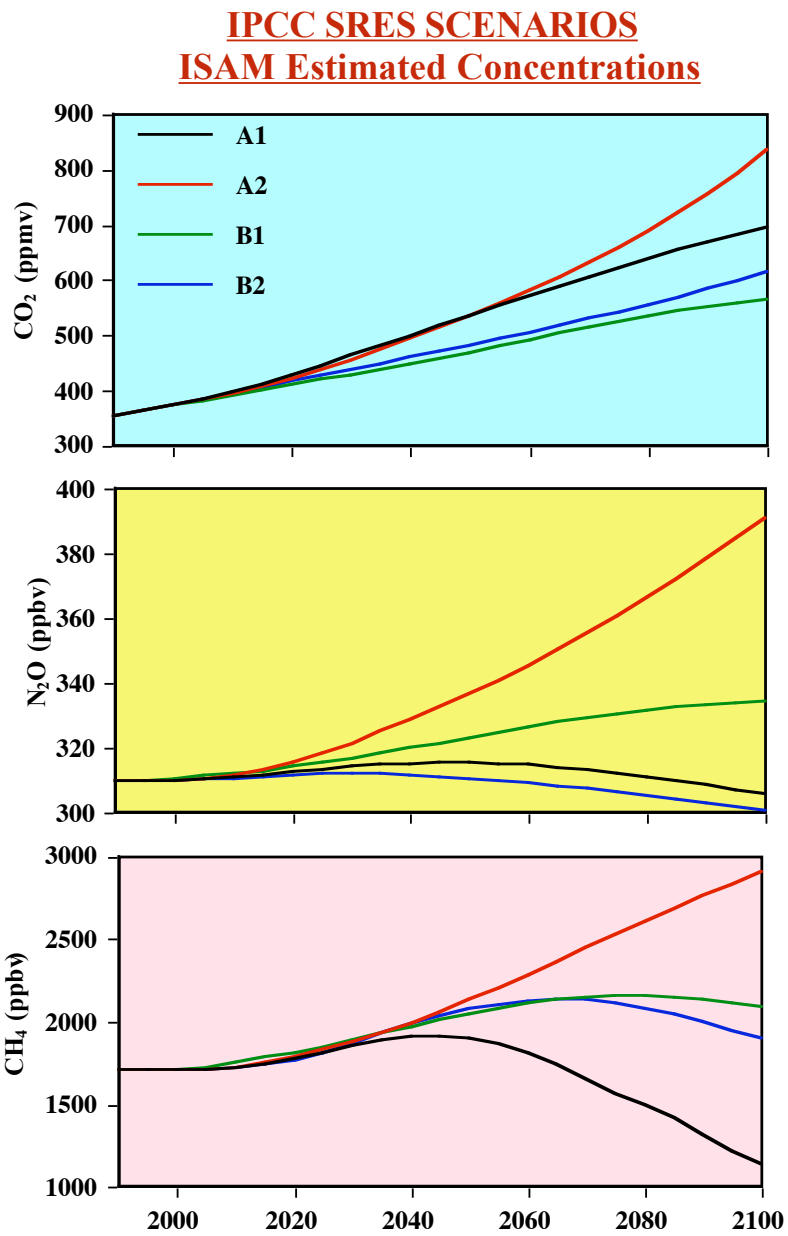
IPCC (2000) SRES Scenarios --- "Business as Usual"

- **SRES "MARKER" Scenarios A1, A2, B1, and B2 are based on narrative storylines, describe alternative future developments in economics, technical, environmental and social dimensions.**
  - ***A1*** **rapid economic growth, low population growth, rapid introduction of new and more efficient technology. In this world, people pursue personal wealth rather than environmental quality.**
  - **A2 emphasis on family values and local traditions, high population growth, and less concern for rapid economic development.**
  - **B1 rapid change in economic structures, "dematerialization" and introduction of clean technologies. The emphasis is on global solutions to environmental and social sustainability.**
  - **B2 emphasizes local solutions to economic, social, and environmental sustainability, with less rapid and more diverse technological change but a strong emphasis on community initiative and social innovation to find local, rather than global solutions.**

IPCC SRES EMISSION SCENARIOS



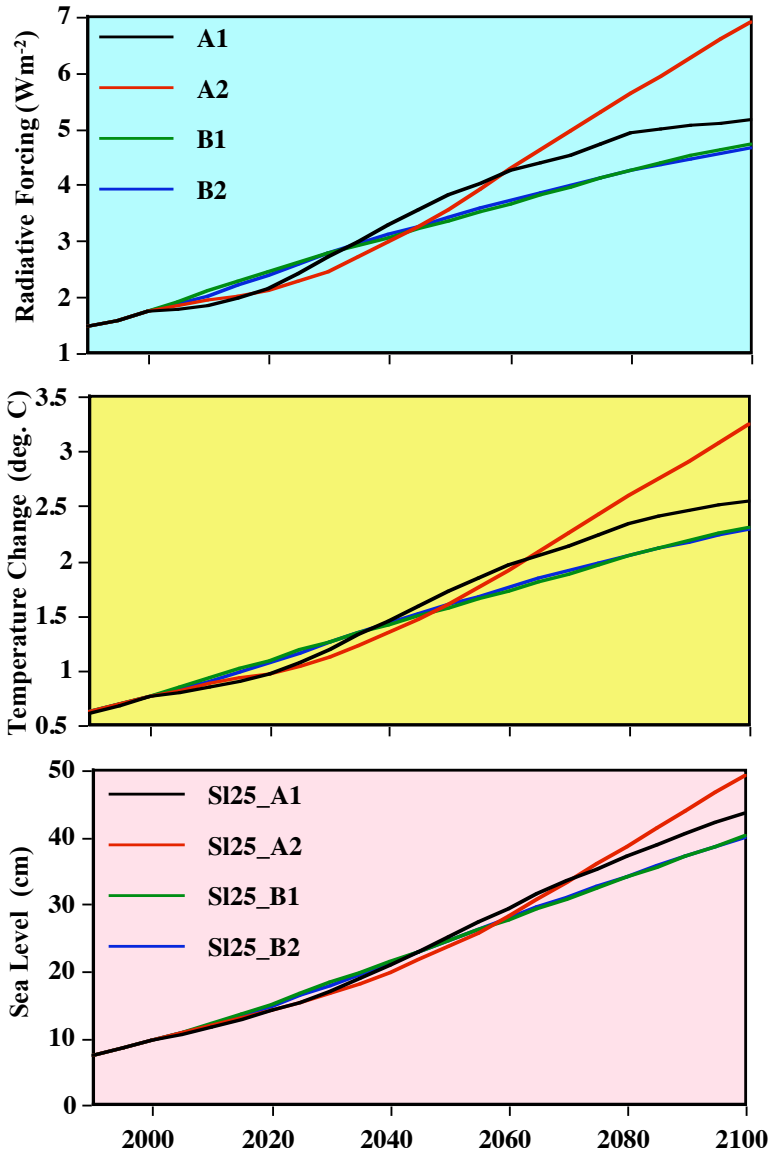
Emissions for the SRES Scenarios



Gas Concentrations derived for the SRES Scenarios

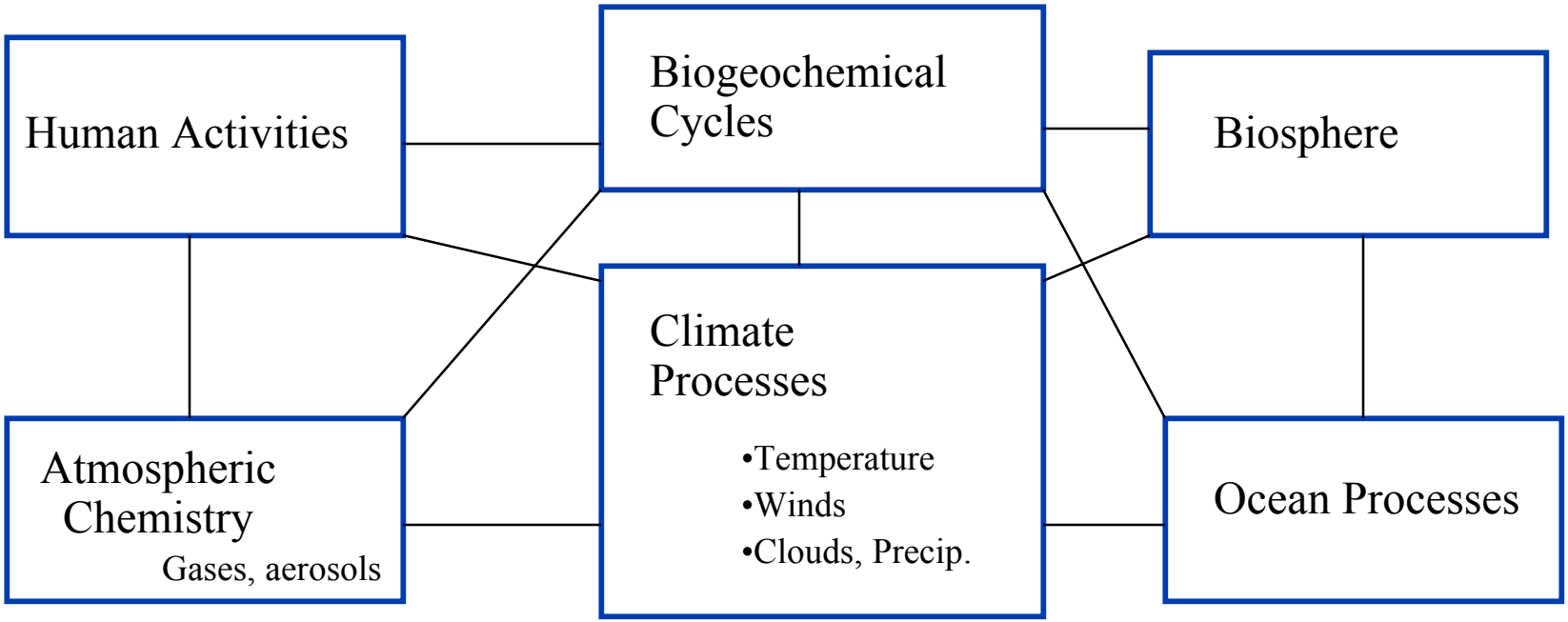
IPCC SRES Scenarios

ISAM Estimated Radiative Forcing, Temperature and Sea Level



Derived radiative forcing, temperature change and sea level rise for the SRES scenarios

The Earth-Climate system



- Computational resources still insufficient to model the entire system as a whole
- Many processes still not sufficiently understood

Impacts of Climate Change

- Global climate change much better understood than the impacts it will produce
- Large uncertainties remain in interpreting climate change to the local and regional scale
- Nonetheless, climate change could have significant impacts on social, environmental and economic systems

Concerns about Impacts of Climate Change are at the Local to Regional Level

- **Concerns**
  - Temperature, precipitation, winds
  - Changes in sea level
  - Severe weather
- **Impacts**
  - Water quality / quantity
  - Air quality
  - Agriculture
  - Forests
  - Ecosystems
  - Communities, cities
  - Human health
  - Infrastructure (transportation, energy systems)

Type of Extreme	Potential Impacts	Major Past Episodes
	•	Droughts Low streamflow-poor waterquality;
	•	
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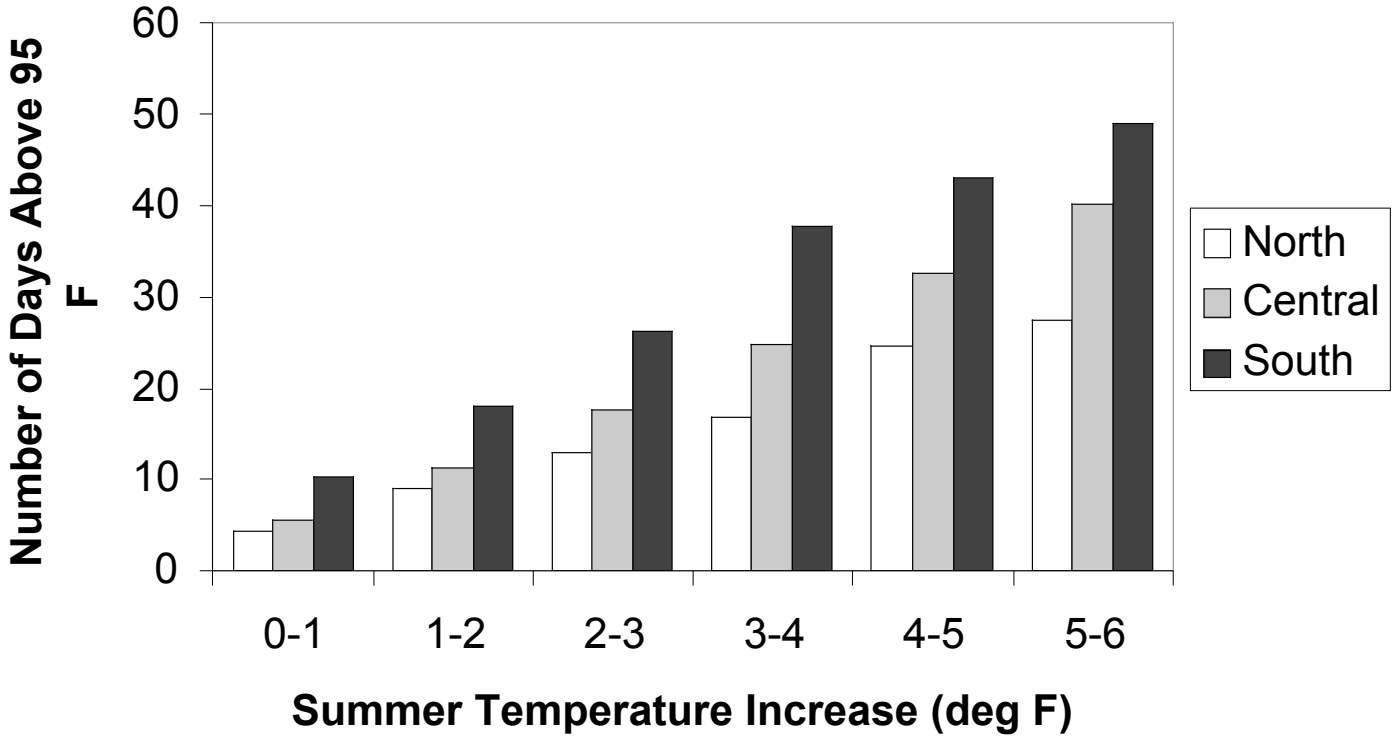
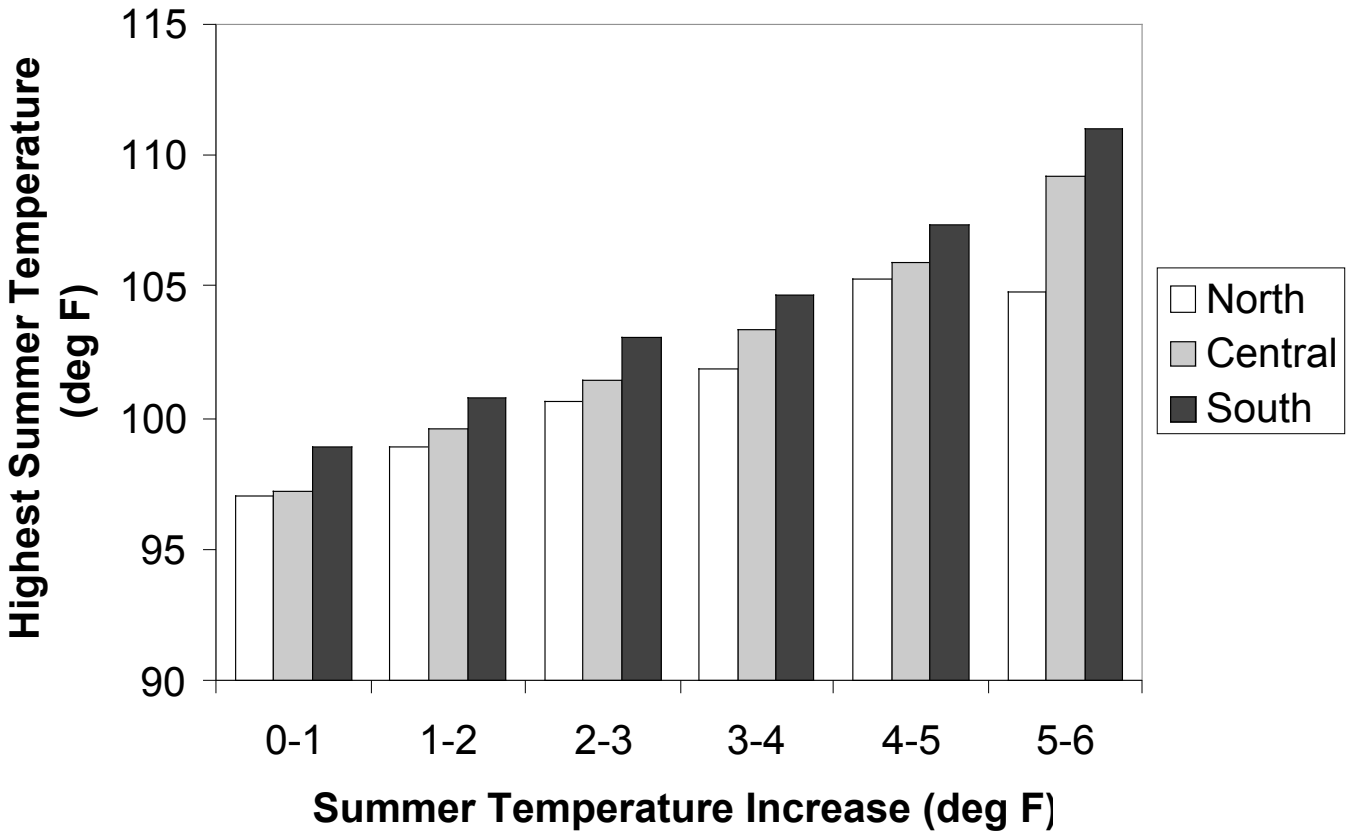
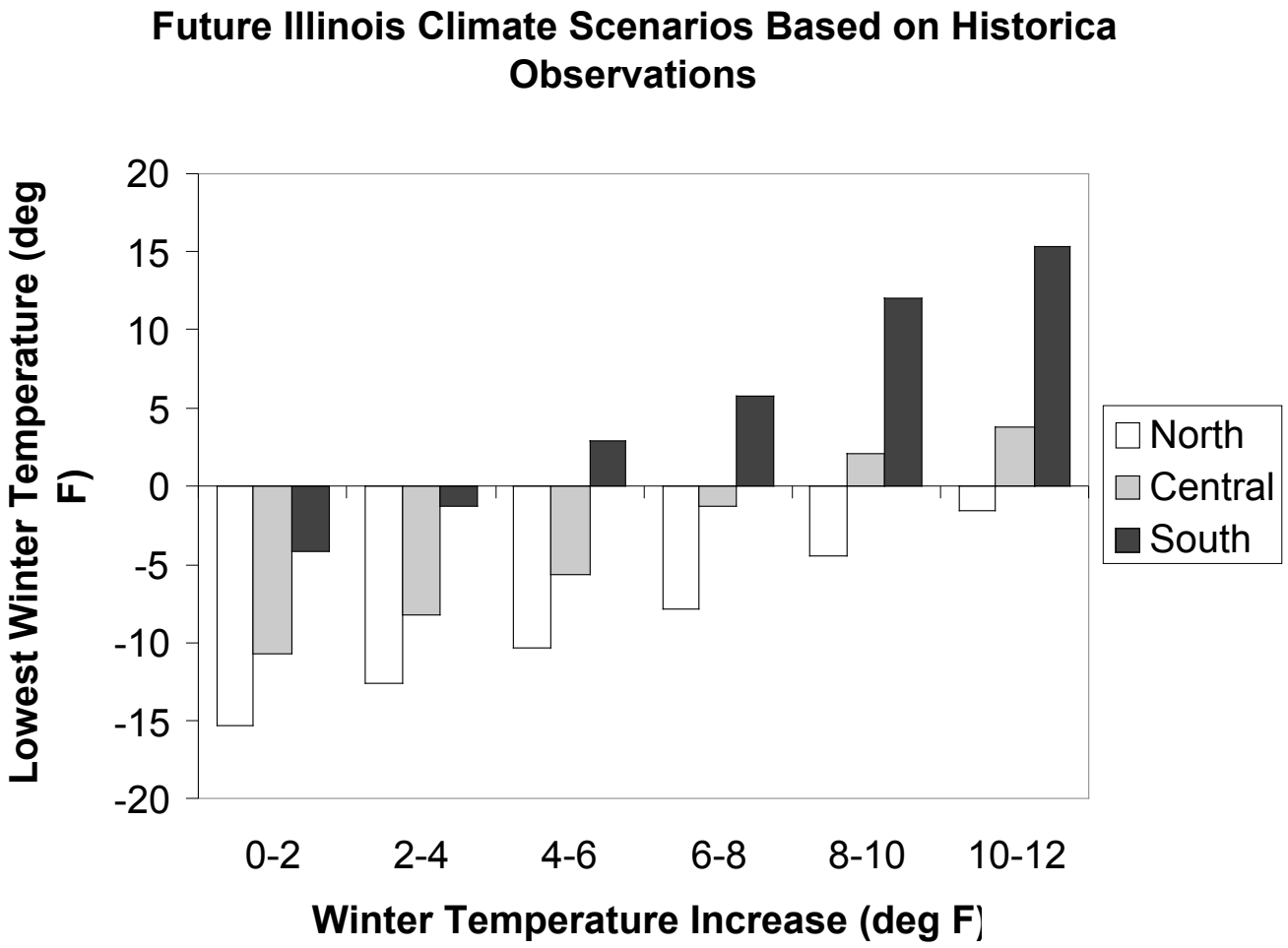
Future Illinois Climate Scenarios Based on Historical Observations



Future Illinois Climate Scenarios Based on Historica Observations




Future Illinois Climate Scenarios Based on Historica Observations
Lowest Winter Temperature (deg F)
20
15
10
5
0
-5
-10
-15
-20
0-2
2-4
4-6
6-8
8-10
10-12
Winter Temperature Increase (deg F)
North
Central
South

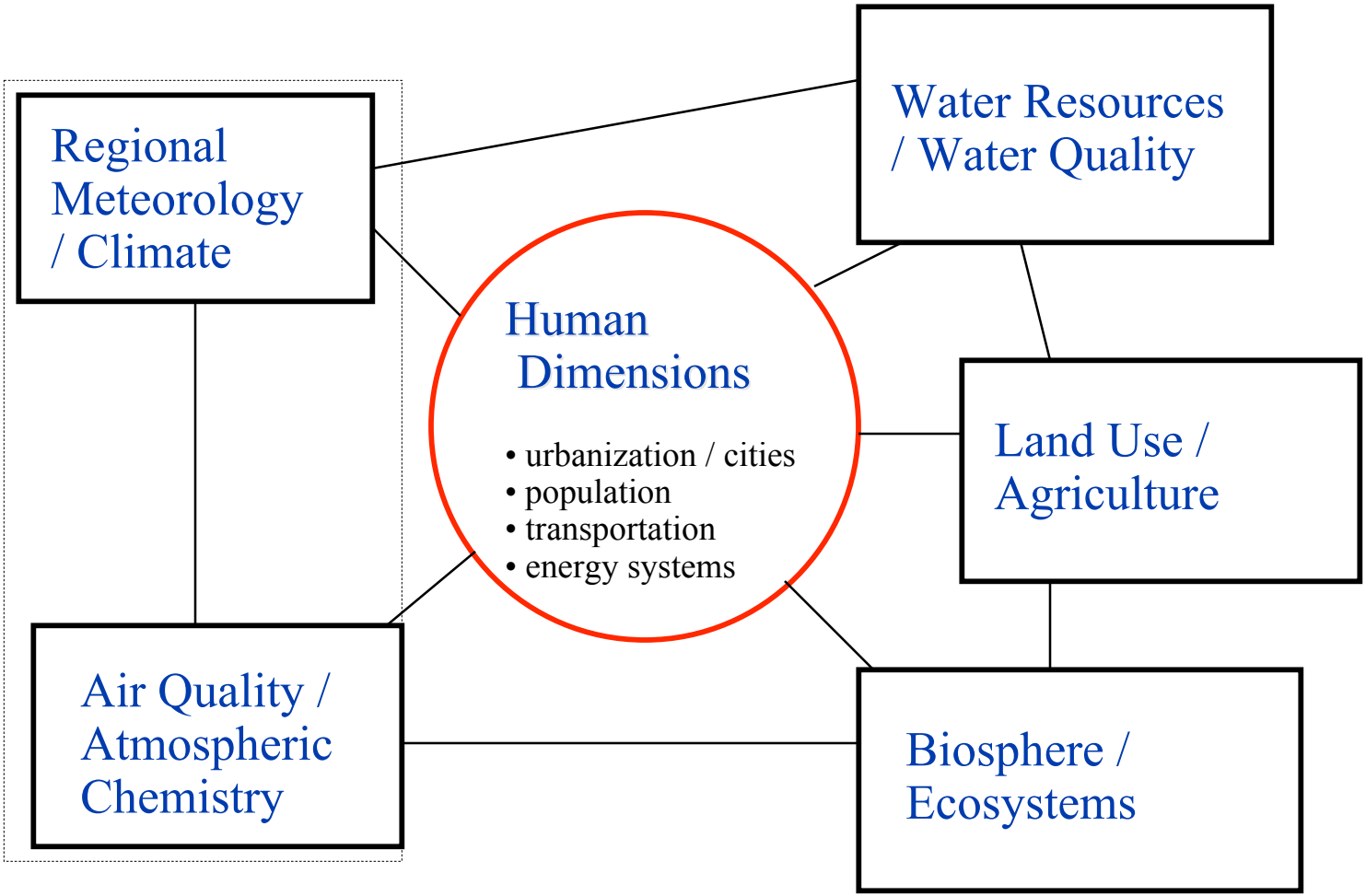
Potential impacts of climate change on communities

- More intense heat waves
  - e.g., effects on elderly
- Increased air quality issues
- More intense storms (tornadoes, tropical storms, hail, lightning)
- Drainage issues when there is extreme rainfall
- Reduced river water could lead to water shortage and quality issues

A New Concept: The Virtual Region

- A vision for a comprehensive environmental observation and simulation system
- Exploit and integrate current trends in several key enabling technology areas
  - Environmental sensors are becoming smarter, cheaper, smaller, less invasive, and more mobile;
  - Computing capability continues to double every 18 months, and processors are getting smaller, more embedded, and less demanding of power;
  - Wireless communication systems are becoming cheaper, smaller, adaptive, and more seamlessly connected to the Internet and other ubiquitous communication channels; GPS is widely available;
  - Geographic Information Systems (GIS) are becoming distributed over multiple sites, and accessible over the Internet;
  - Advanced algorithms are emerging which can fuse “live” sensor datastreams with simulation models in real time, and which can extract features or events from the enormous data volumes which will result from the merging of high-resolution models and dense sensor networks.

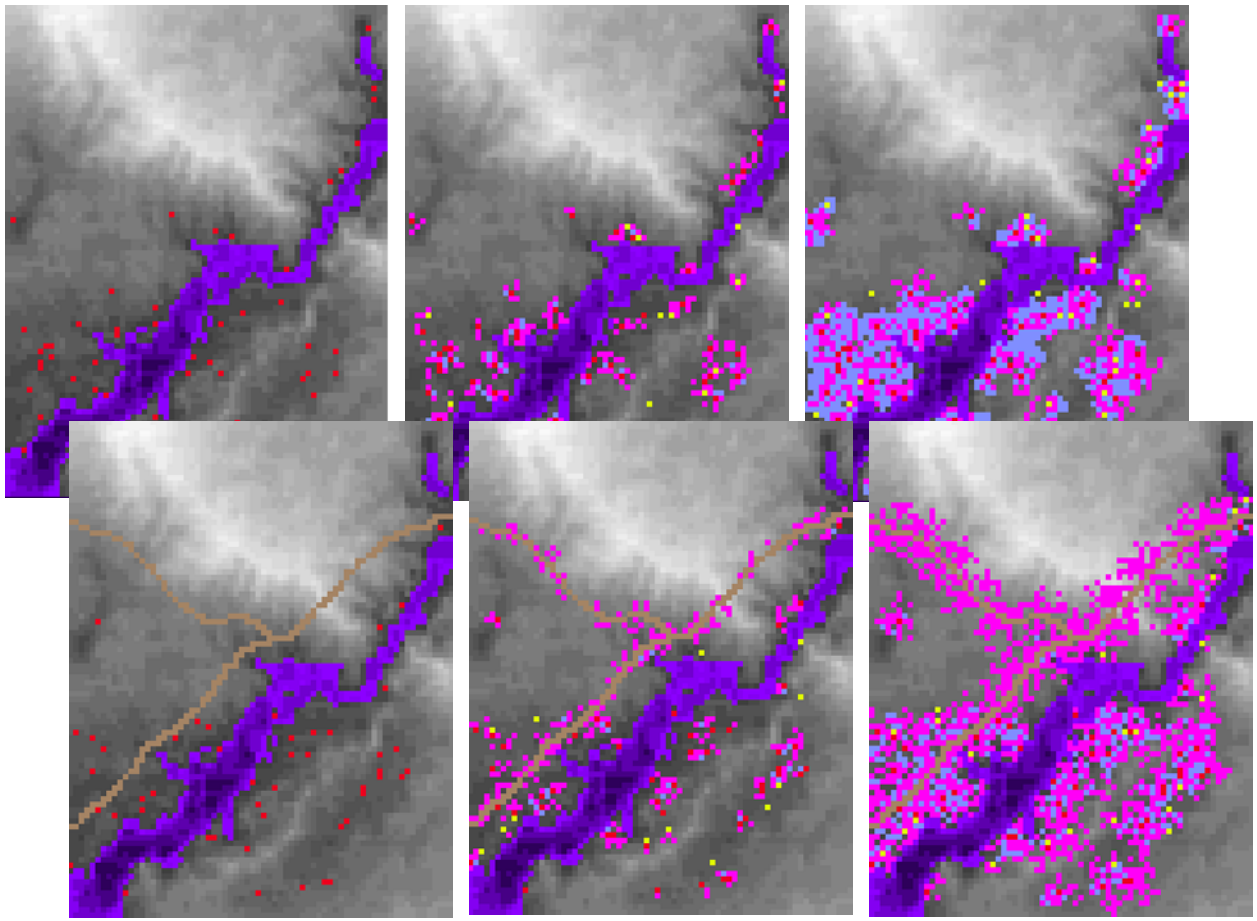
The need for Regional Integrated Studies



Extending regional analyses to the stakeholders

- development of Decision Support Systems needs to be a core activity in regional system analyses
- integration of science and technology in regional management and local decision making (involvement of communities)

Example of Decision Support System



Dynamic modeling enables rapid experimentation with "what-if" scenarios. Here urban sprawl is affected by land value and relief, and by the location of new roads (below)

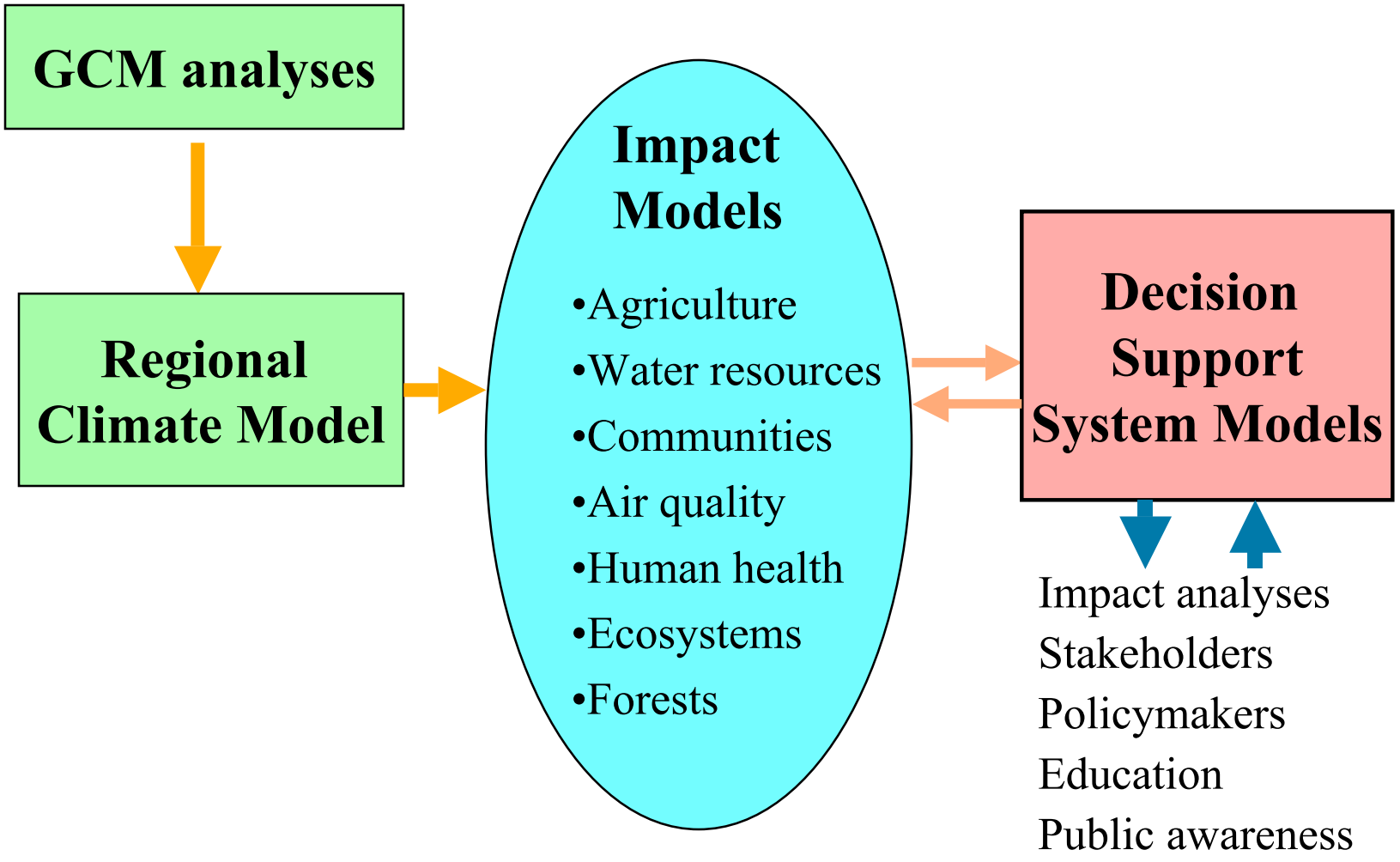
Kane County Urban Expansion Model

Future research needs: Biogeochemical cycles

- Much enhanced understanding of the carbon and nitrogen cycles is needed
  - Determine terrestrial and ocean fluxes of the key greenhouse gases: CO_2, CH_4, and N_2O (also NOx, CO)
  - Potential for significant feedbacks on climate?
  - Carbon sequestration as potential climate policy?
- Couple global observations and modeling with local flux measurements
  - Combine satellite data with flux data in integrated studies

Extras After This

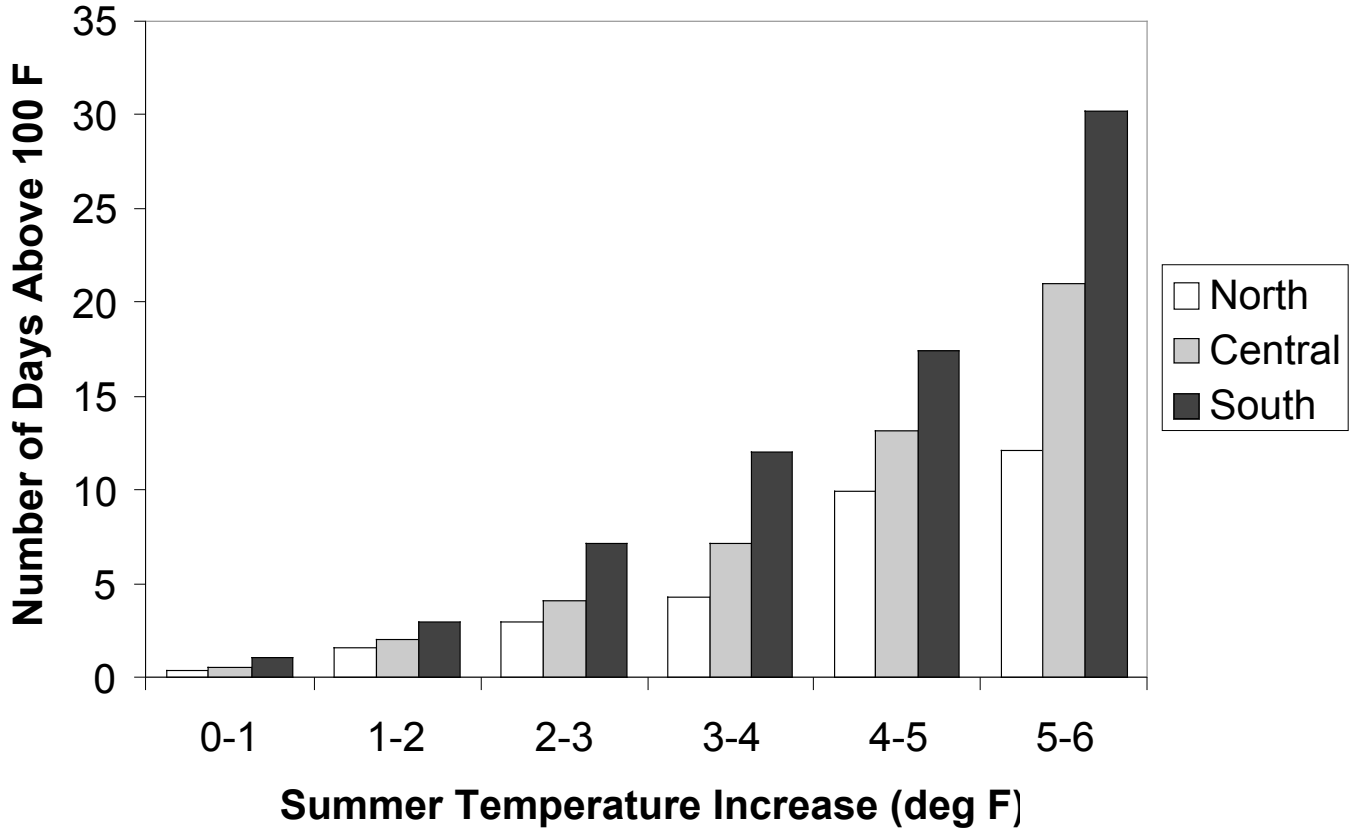
Regional Climate Studies



Issues in Developing Climate Policy: Connecting Science and Social Science

- The need for new technology
  - accelerate improvements in energy systems and materials
- Potential impact of carbon sequestration on climate policy
- Coupling of the science with policy analyses
  - Integrated assessment analyses
  - Weighing the risks
    - There are positives as well as negatives
  - Science knowns relative to unknowns
    - Possibility of surprises
  - Mitigation versus adaptation
  - Potential environmental and societal impacts relative to more immediate economic impacts

Future Illinois Climate Scenarios Based on Historica Observations



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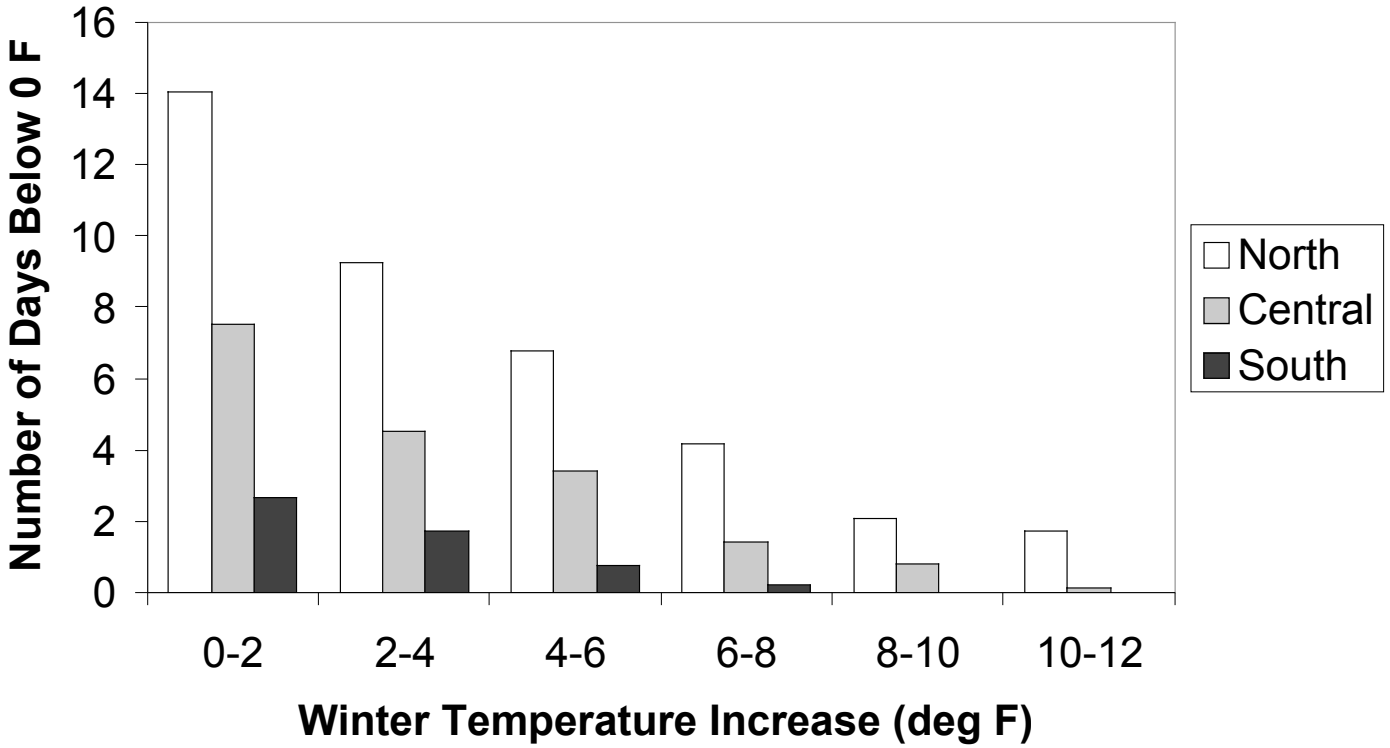

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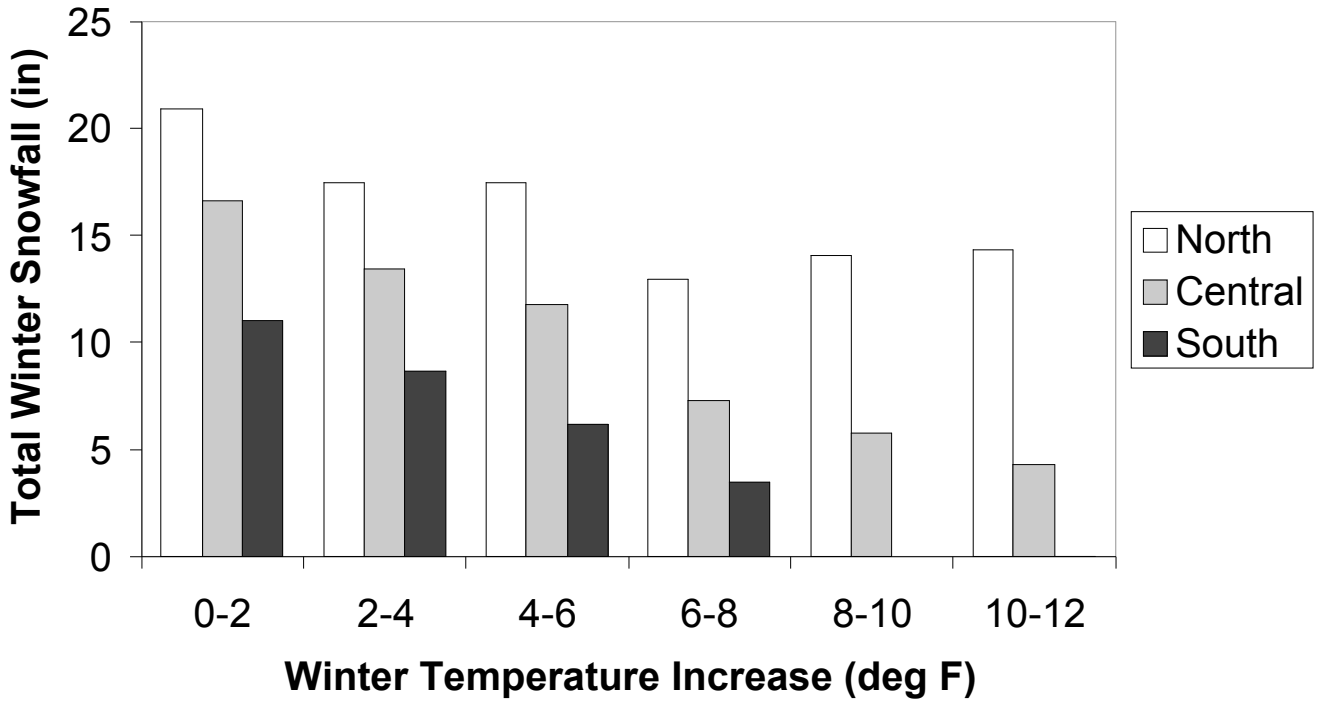
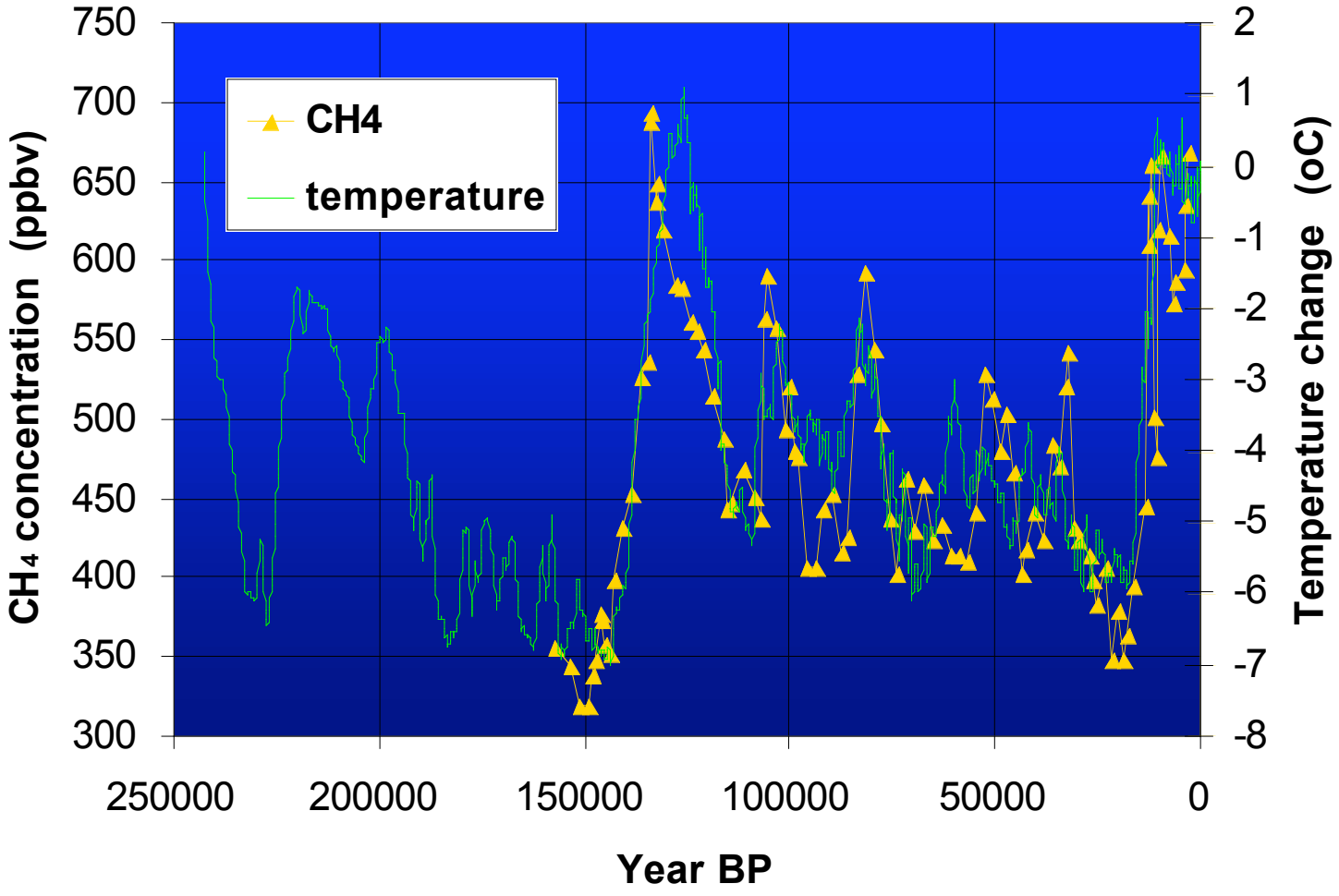
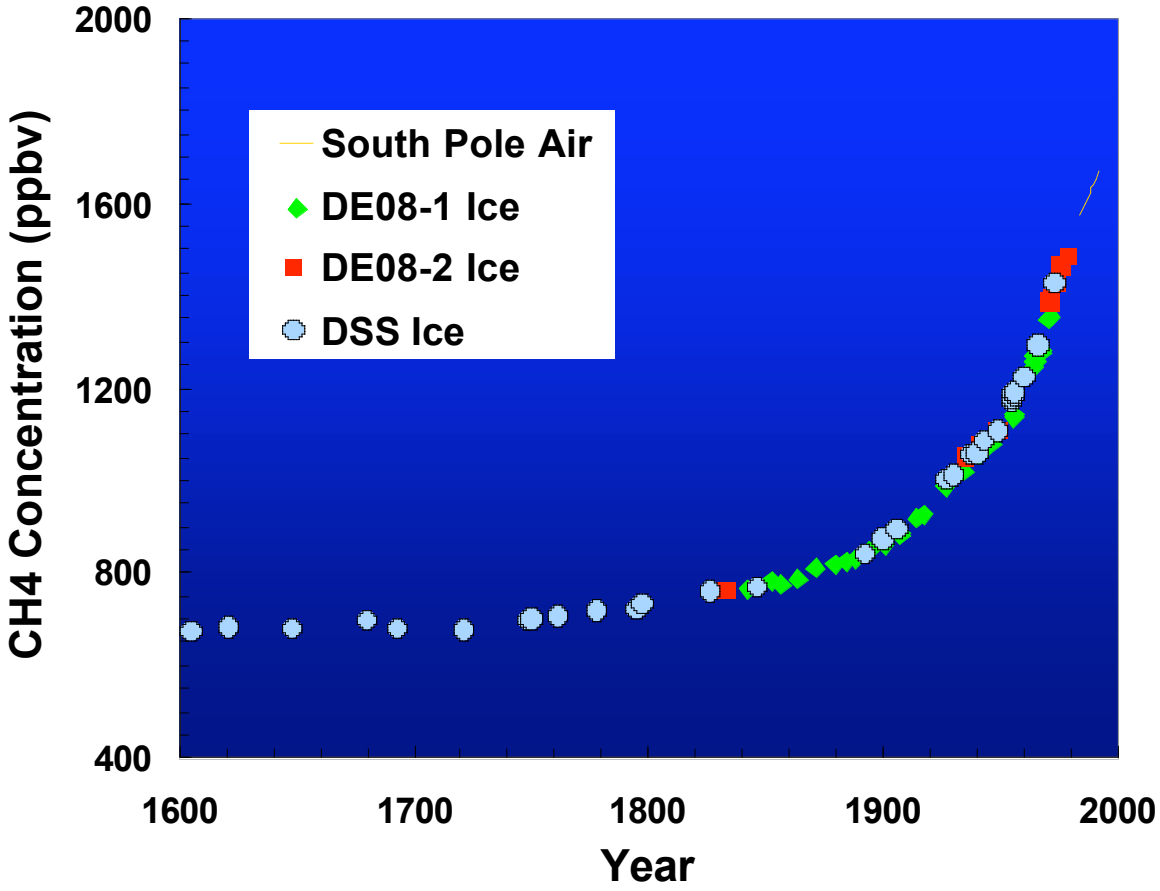


Methane in Ice Cores

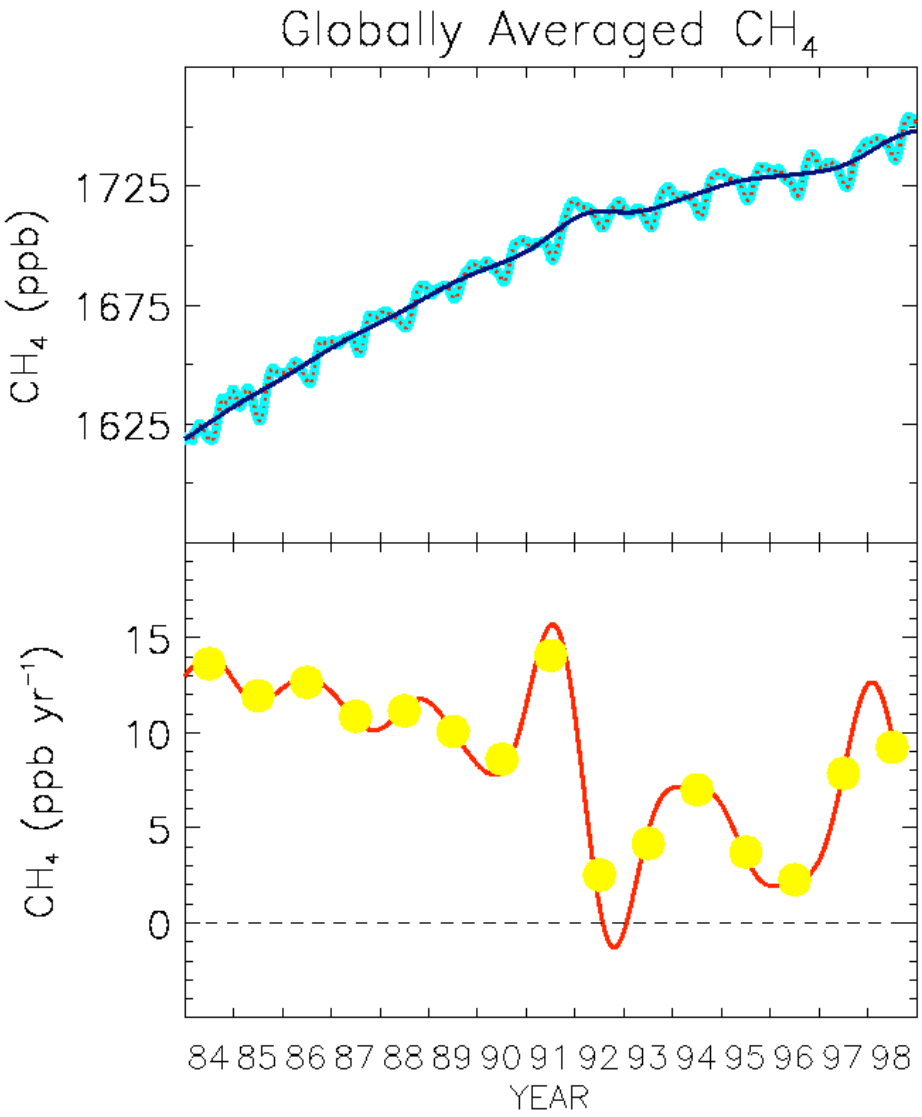


Source: Jouzel, 1987, 1993, 1996; Chappellaz, 1990

400 Year Trend in Methane



Source: Etheridge et al., 1998

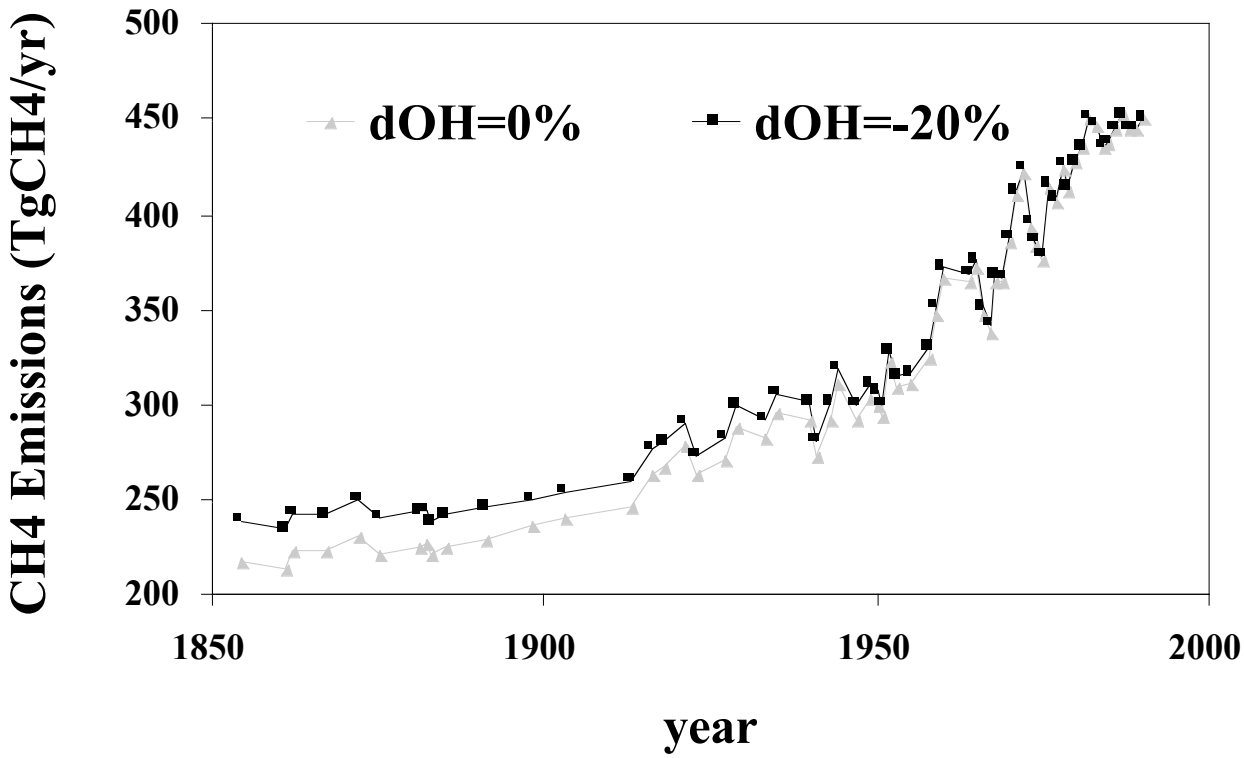


Mixing ratio

Growth rate

Source: NOAA CMDL data from Dlugokencky , *pers. Comm., 1999*

Large Increase in Methane Emissions over Last 150 years

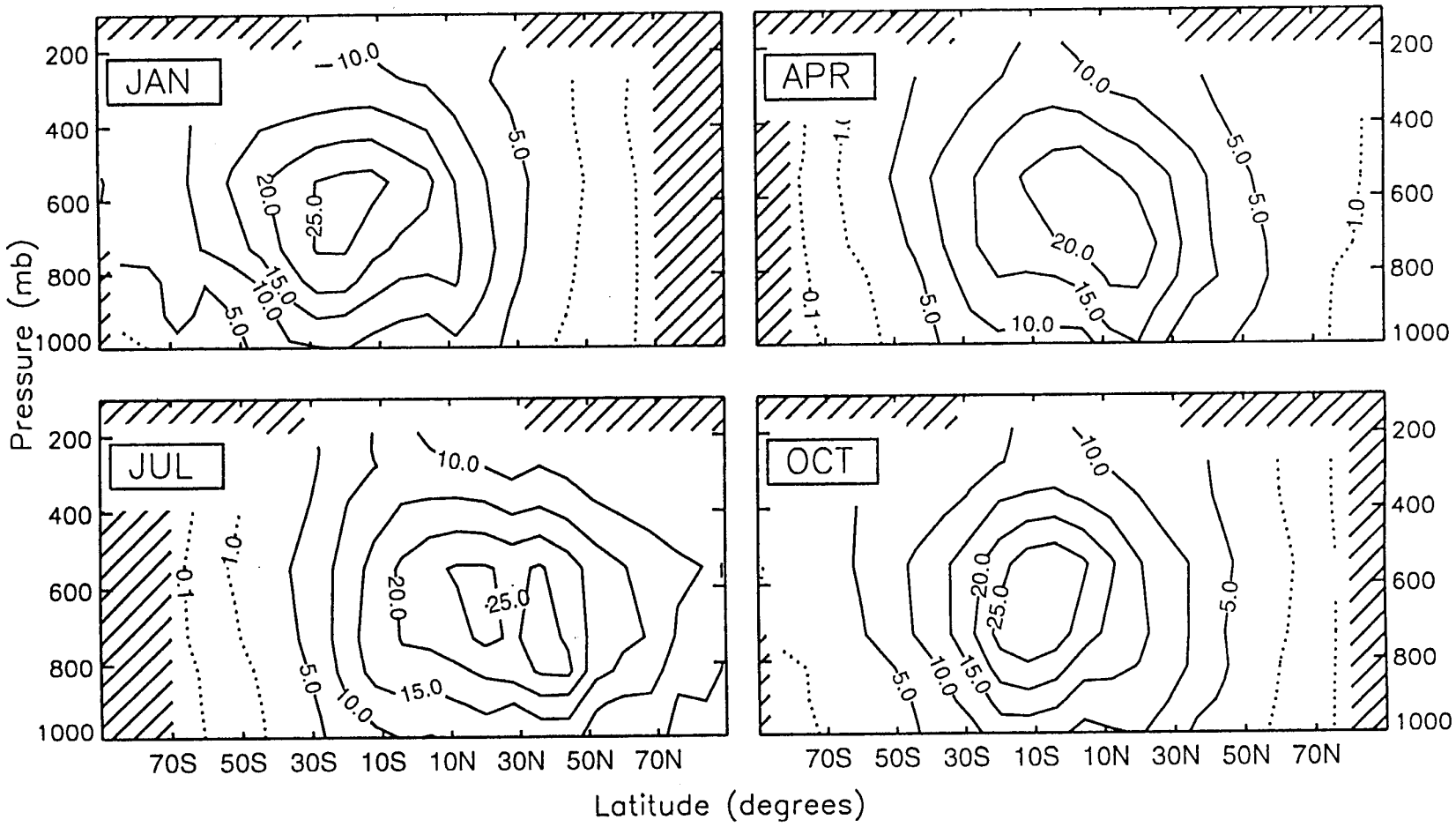


Based on top-down analysis by Khalil & Rasmussen (1994a)

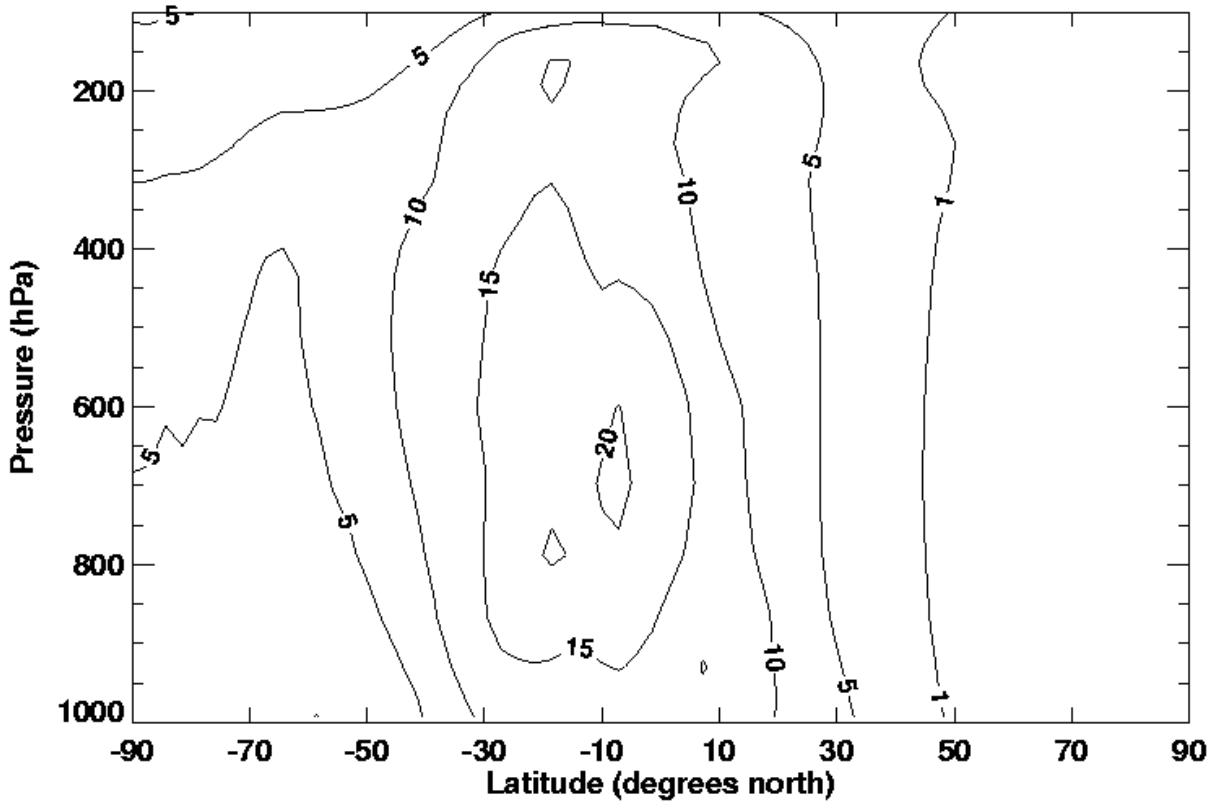
Methane Sinks

- almost 90% of CH_4 is removed in troposphere through reactions with OH
- remainder removed by transport to the stratosphere (~6%) & by soil reactions (~4%)
- OH is a spatially variable radical with a lifetime of a few seconds
- detailed modeling of OH is crucial

Spivakovsky et al., monthly and latitudinally averaged OH concentrations ($1x10^5$ molecules/cm^3)

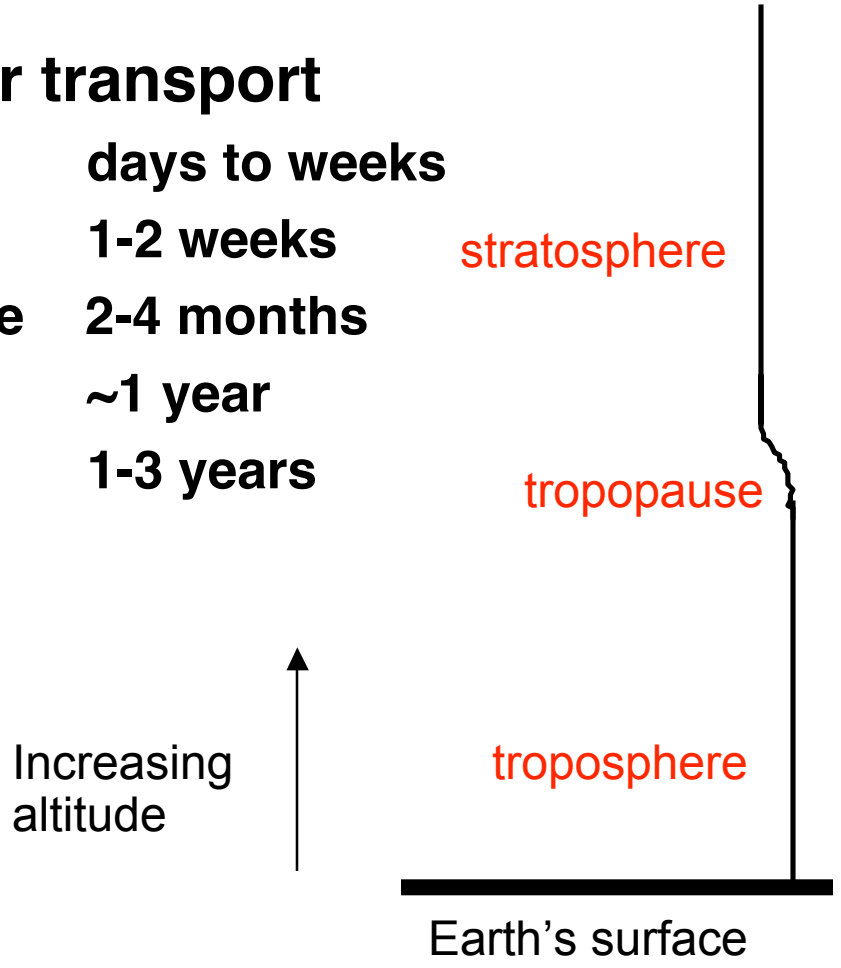


MOZART2 January monthly and latitudinally averaged OH concentrations (1x10^5 molecules/cm^3)



Atmospheric Transport of Gases

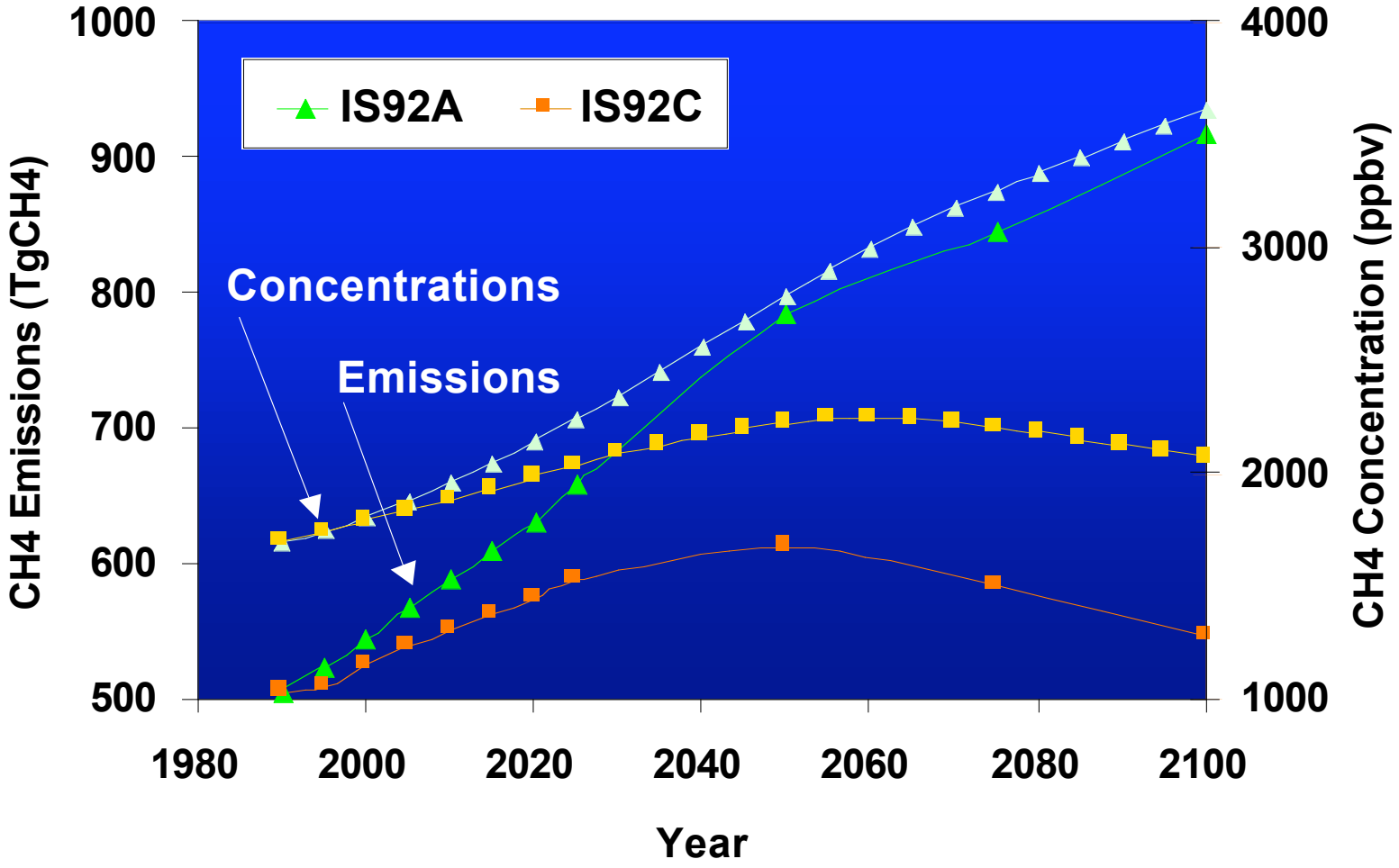
- **Average time scales for transport**
  - **To tropopause** — **days to weeks**
  - **Around longitude** — **1-2 weeks**
  - **Throughout hemisphere** — **2-4 months**
  - **Across equator** — **~1 year**
  - **Into stratosphere** — **1-3 years**



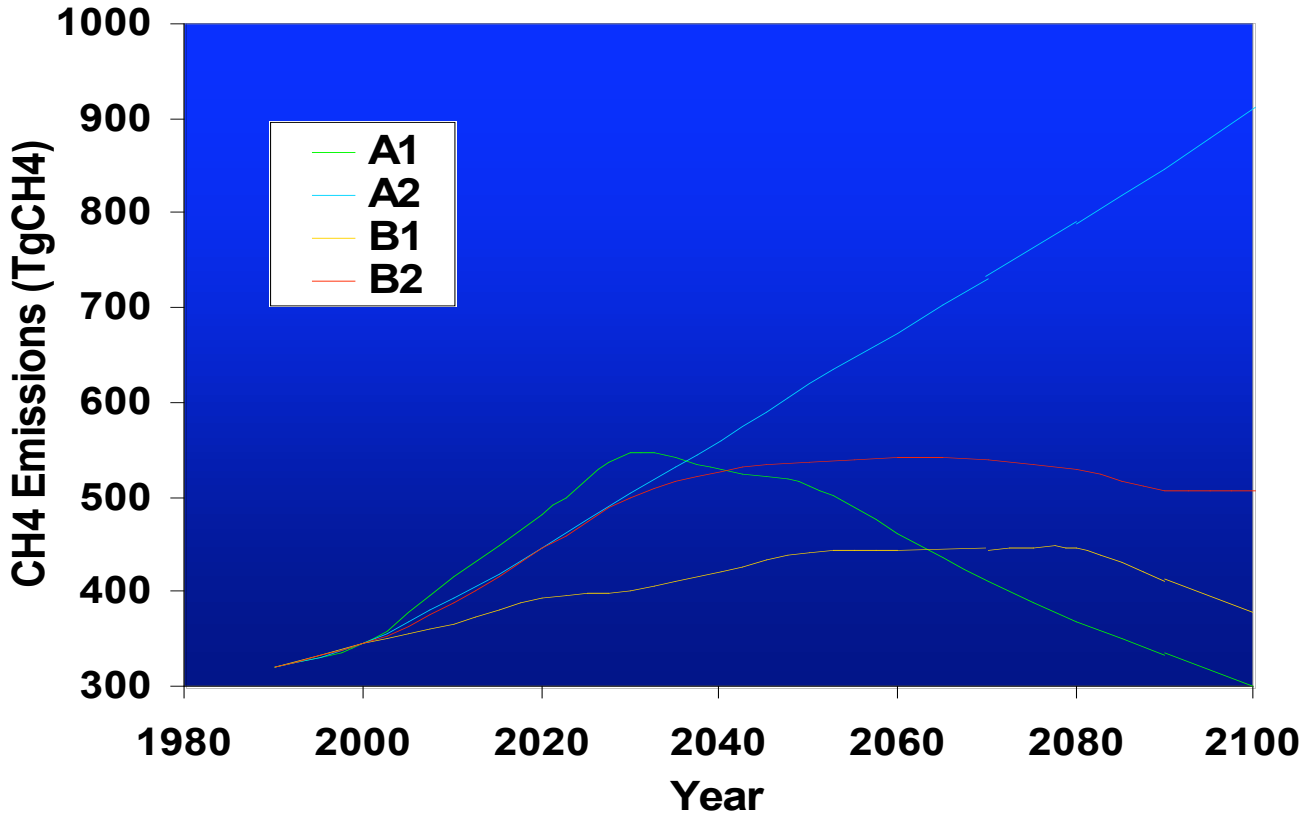
OH concentrations

- OH depends non-linearly on atmospheric concentrations of many tropospheric gases
- most important gases: CH_4, CO, NO_x, tropospheric O_3, NMHCs
- other factors: tropospheric water vapor, uv radiation flux which depends on stratospheric ozone

Projection of CH_4: IPCC IS92a and c



1999 IPCC SRES Projected CH_4 Emissions



N_2O Budget

- **Budget is not well understood**
- **Sources: total 14.7 (10-17) TgN/yr**

  natural — *9 (6-12) TgN/yr*

  oceans: 3 (1-5); tropical soils: 4 (2.7-5.7)

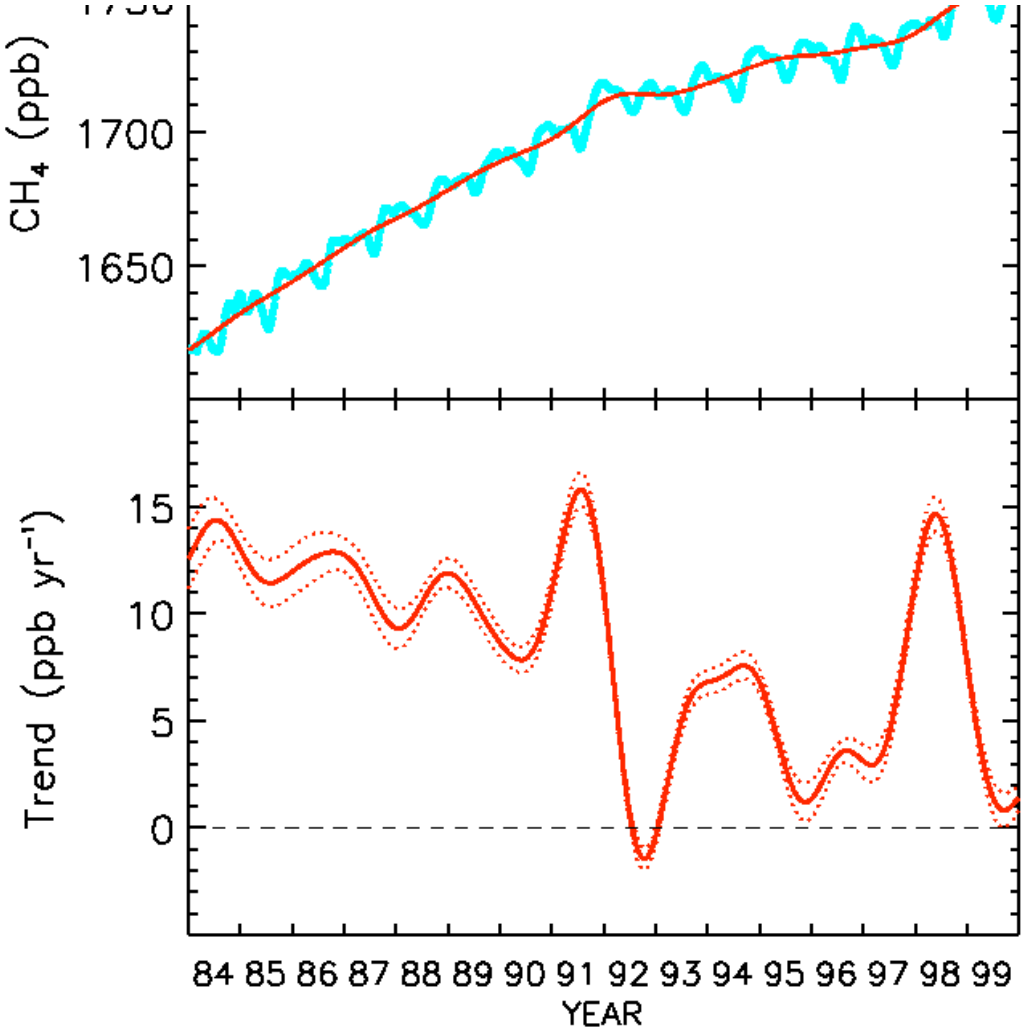
  temperate soils: 2 (0.6-4)

  human-related — 5.7 (3.7-7.7)

  cultivated soils: 3.5 (1.8-5.3); biomass burning 0.5;

  industry 1.3; cattle & feed lots 0.4
- **Need sources to exceed sinks by 3.9 TgN/yr to explain observed increase**
- **Known sinks 12.3 (9-16)**

NOAA CMDL Methane

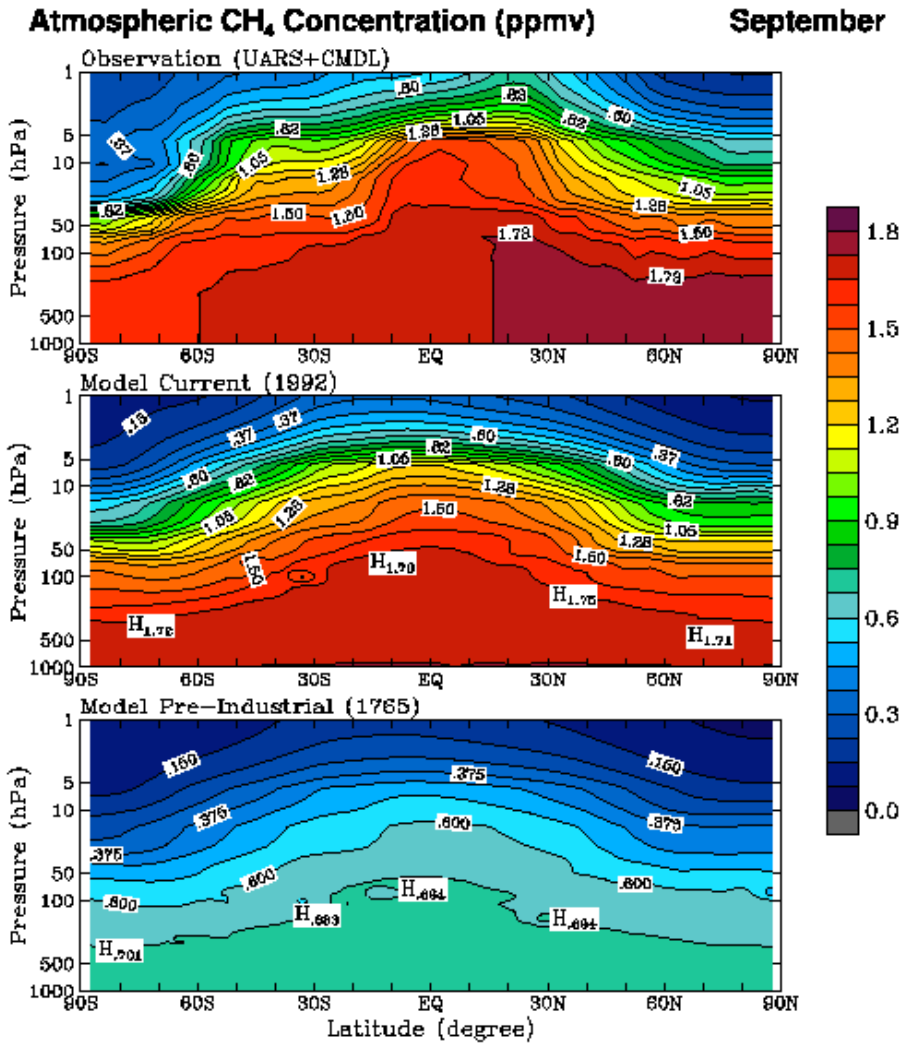


An Important Goal: Environmental Preservation and Human Well-Being

- Numerous stresses and interactions between human development and the environment
  - E.g., increasing population, urbanization creates stress
  - Air and water quality are high priority issues
  - Ozone depletion and climate change are global issues
  - Droughts / floods, disease epidemics, and availability of local living resources continue as concerns
- Interactions of various components of the Earth system affect the ability to address these issues
- Interactions across spatial scales from local to global are also important

Adaptive Management and Learning

- Need to develop a research framework that integrates from local to regional to global scales
- Need to link more effectively across research disciplines (multi- and inter-disciplinary)
- Need to coordinate academia, government, and private sector in more effective research partnerships (relating science to the needs of stakeholders)
- Need to develop new measurement capabilities (small sensors, satellites) and modeling (interactive feedbacks with the human elements) capabilities



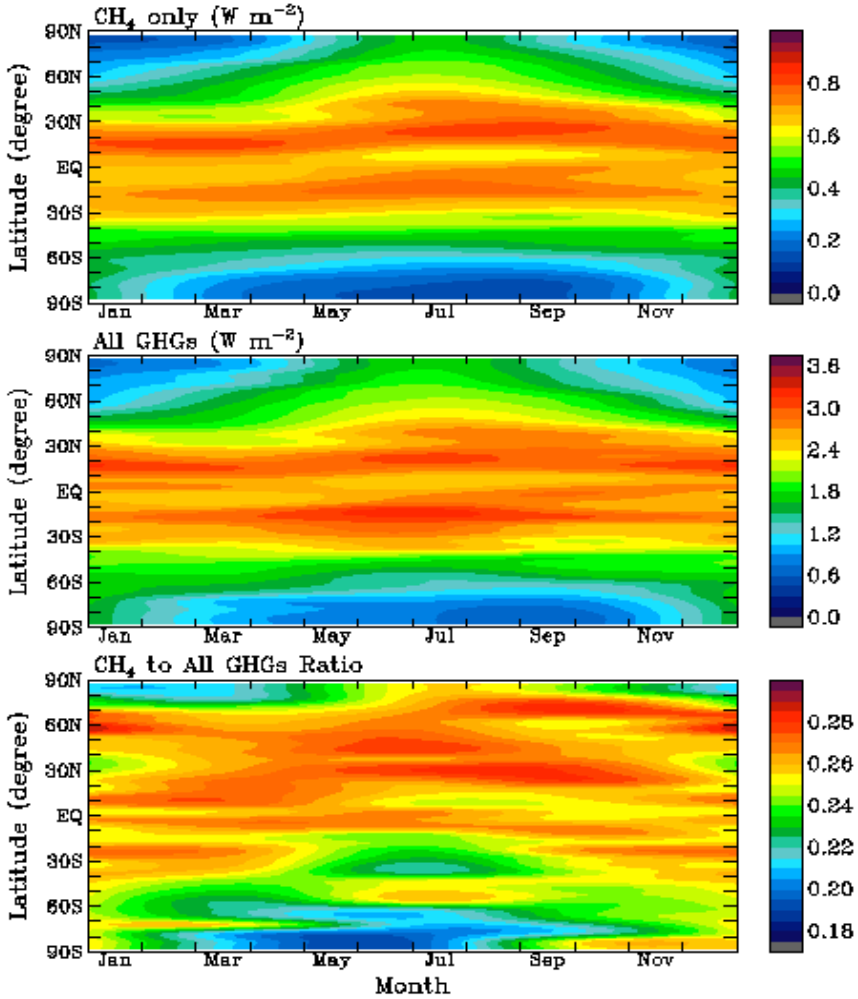
Observed

2-D Model

1992

Pre-ind.

Estimated Change in Radiative Forcing from 1765 to 1992



CH_4 only

All GHGs

Ratio