Observing climate 2: atmospheric gases

John Remedios

Earth Observation Science and NCEO
Dept. of Physics and Astronomy
U. Leicester

Outline

- The Big Picture for Atmospheric gases and climate
- Instruments
- Ozone layer
- Fires
- The future

Acknowledgements:

David Moore (Leicester)

The ESA MIPAS team

The Eumetsat IASI team

The National Centre for Earth Observation

The Big Picture

IPCC figures from Ch. 2, 8; WG I report 2013

Hartmann, D.L., A.M.G. Klein Tank, M. Rusticucci, L.V. Alexander, S. Brönnimann, Y. Charabi, F.J. Dentener, E.J. Dlugokencky, D.R. Easterling, A. Kaplan, B.J. Soden, P.W. Thorne, M. Wild and P.M. Zhai, 2013: Observations: Atmosphere and Surface. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 159–254, doi:10.1017/CBO9781107415324.008.

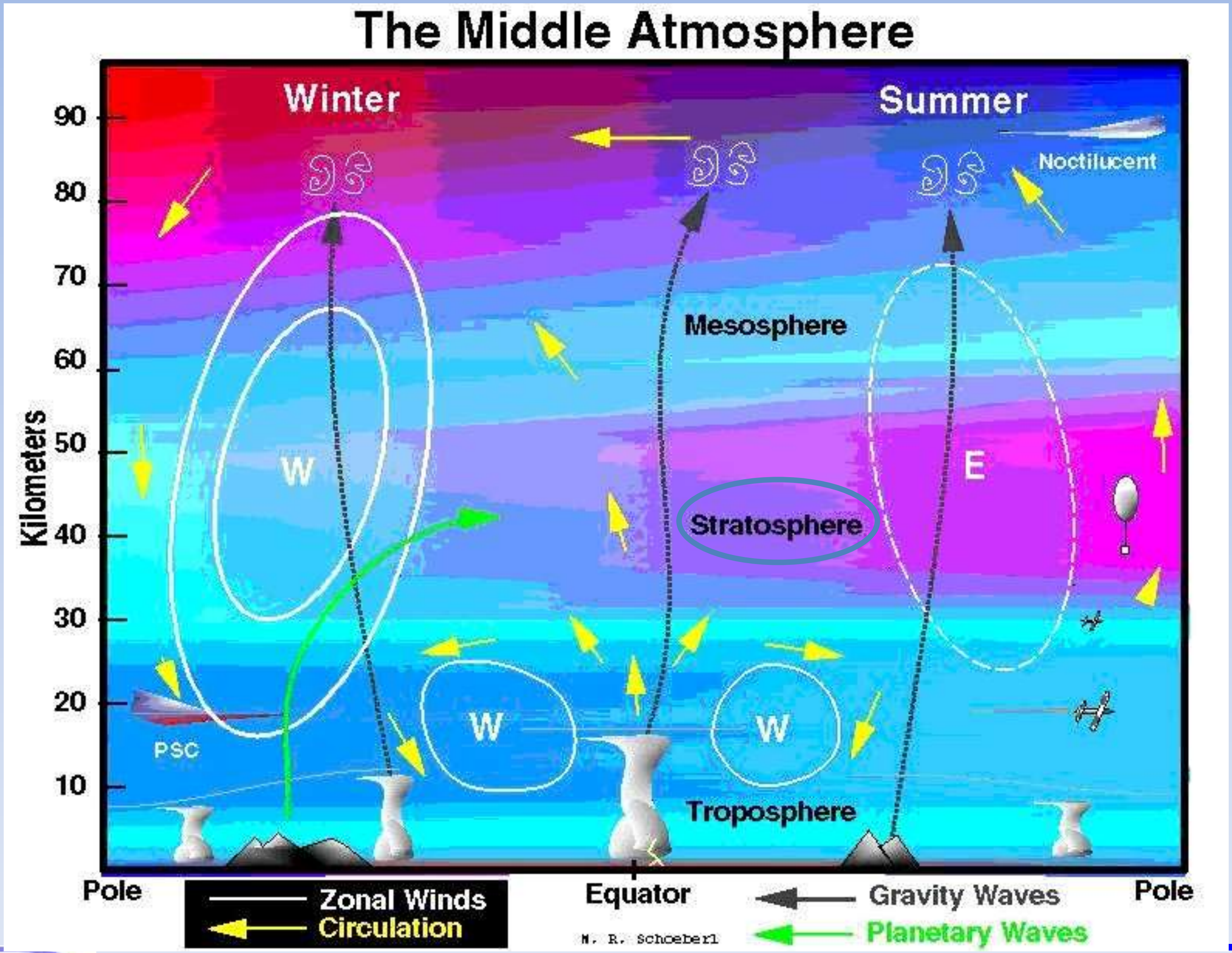
Myhre, G., D. Shindell, F.-M. Bréon, W. Collins, J. Fuglestvedt, J. Huang, D. Koch, J.-F. Lamarque, D. Lee, B. Mendoza, T. Nakajima, A. Robock, G. Stephens, T. Takemura and H. Zhang, 2013: Anthropogenic and Natural Radiative Forcing. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 659–740, doi:10.1017/ CBO9781107415324.018.

Climate-chemistry

Knowledge of atmospheric gases is important:

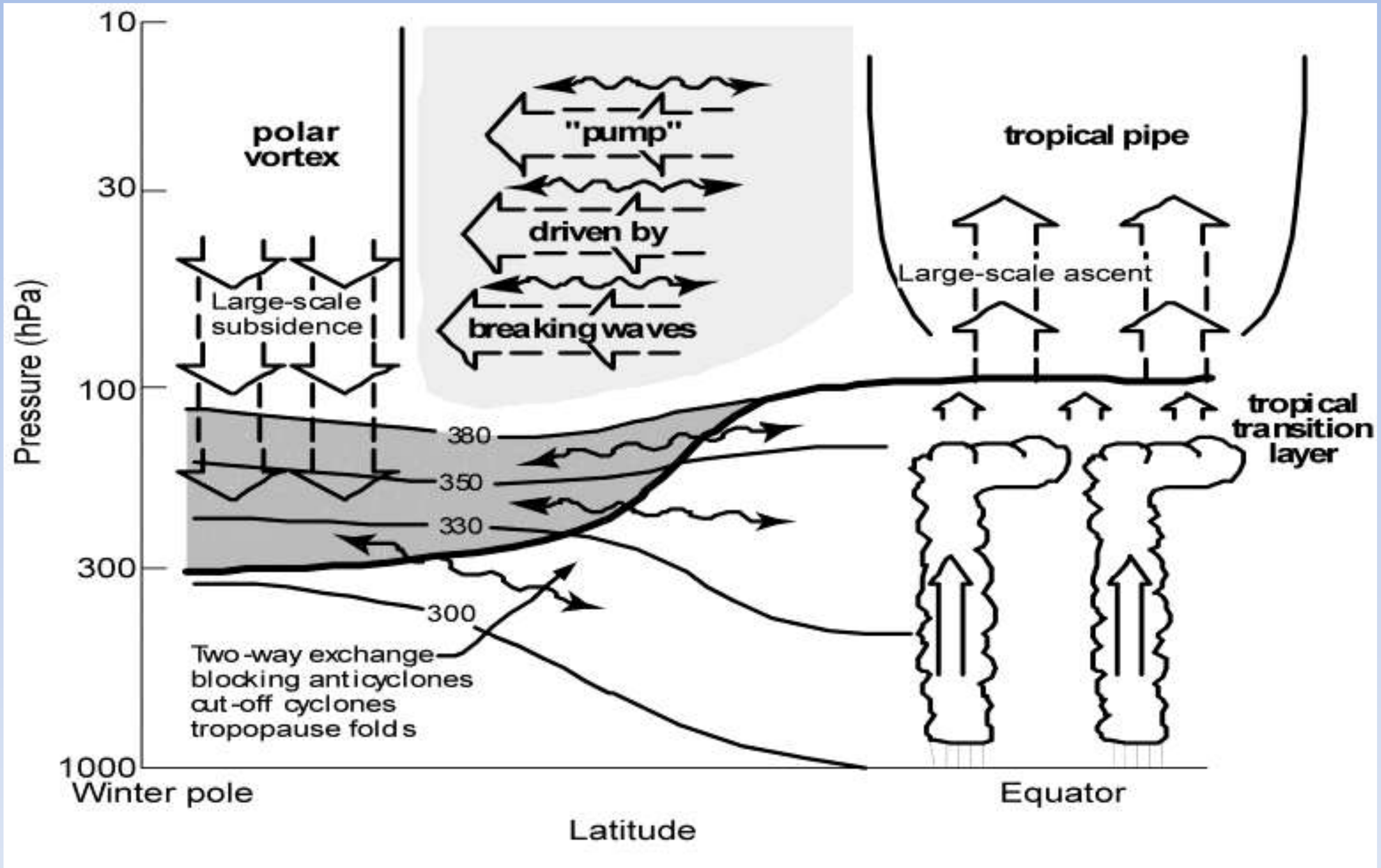
- Atmospheric gases drive radiative transfer between space and surface;
- Knowledge of atmospheric chemistry informs predictions for climate change: greenhouse gas changes, particularly methane; global ozone and ozone hole changes; forcing from minor trace gases; aerosol formation
- Changing atmospheric gases can impact on atmosphere circulation
- Biogenic effects are an important aspect of land-atmosphere interactions.
- Important interactions between climate controls and anthropogenic pollution controls
- Atmospheric gases control Earth habitability

THE STRATOSPHERE

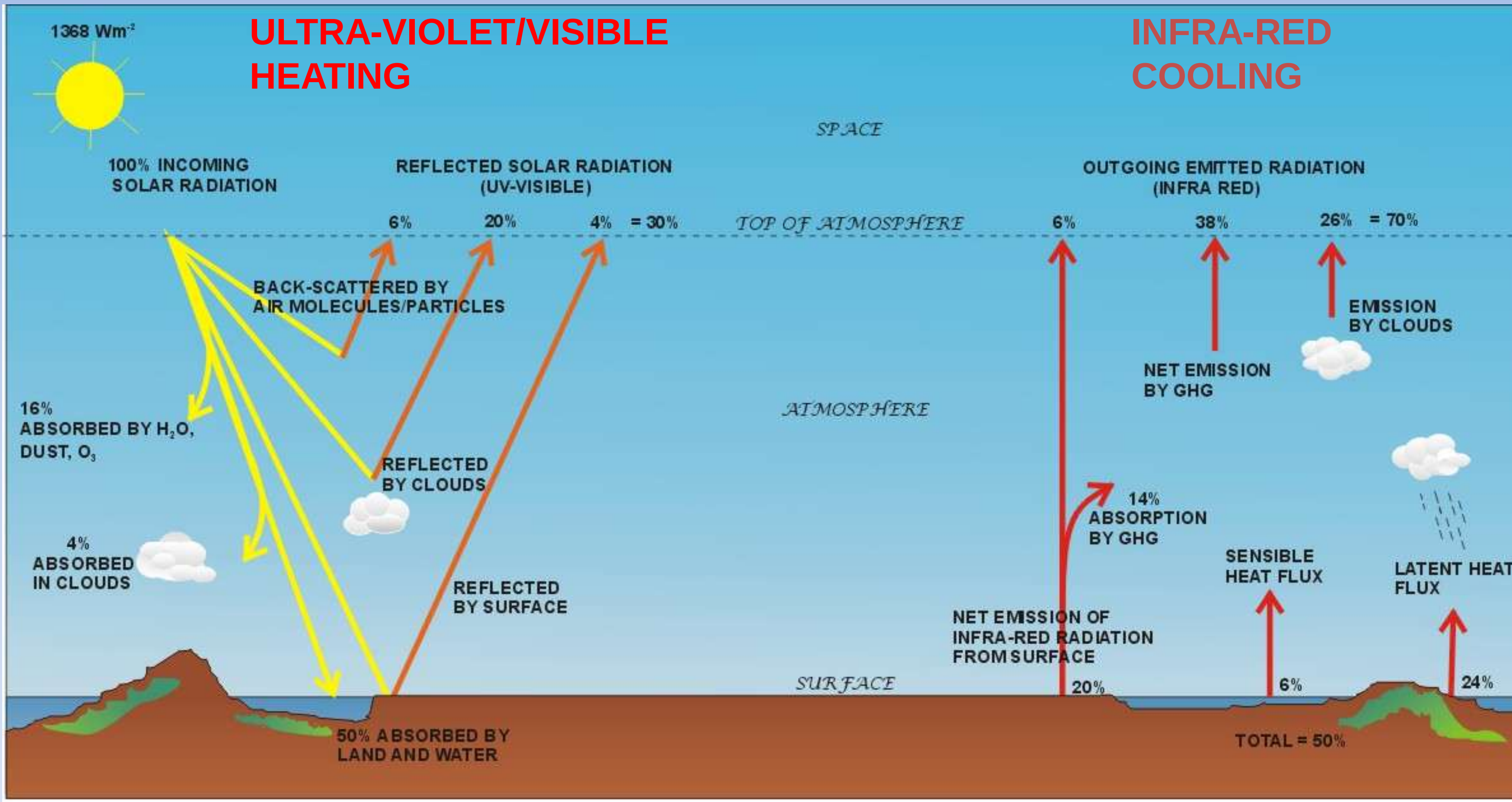


TROPICAL TROP-STRAT EXCHANGE

•



RADIATIVE TRANSFER AND RADIATION BUDGET



GHG - Greenhouse gases: CO_2, H_2O, CH_4, N_2O, O_3 and CFCs.

LATENT HEAT FLUX: Heat transfer mainly due to *evaporation* at the surface and later *condensation* in the atmosphere.
SENSIBLE HEAT FLUX: Heat transfer from the surface to the atmosphere through *condensation*, *convection* and *turbulent mixing*.

Radiative forcing

Need a **defined term** to quantitatively link atmospheric gases to radiative forcing.

Radiative forcing (RF) can be considered as "The effective change in the radiative energy balance of the Earth system between modern and pre-industrial times".

- Units are Wm^{-2} (power)
- IPCC 2007(4th assessment report) looked at 2005 relative to pre-industrial times (1750)
- IPCC 2013 (5th assessment report) looked at 2011 relative to 1750

Strictly: Change in net downward radiative flux at the tropopause after allowing for stratospheric temperatures to readjust to radiative equilibrium, while holding surface and tropospheric temperatures and state variables fixed at the unperturbed values.

Effective Radiative Forcing (ERF) allows parameters to respond to perturbations except for ocean and sea ice.

A simple linear model can estimate surface temperature, Ts, change:

$$\Delta Ts = \lambda \times RF$$

where λ is a climate sensitivity parameter and is calculated with a model (the amount of surface T change per unit change in radiative power).

<u>Example</u>

RF (CO_2) ≈ 1.5 Wm^{-2}; λ ≈ 0.8 $K/(Wm^{-2})$.

Hence expect ΔTs ≈ 1.2 K which is a bit high compared to observations but quite reasonable

IPCC: Land Surface Air Temp

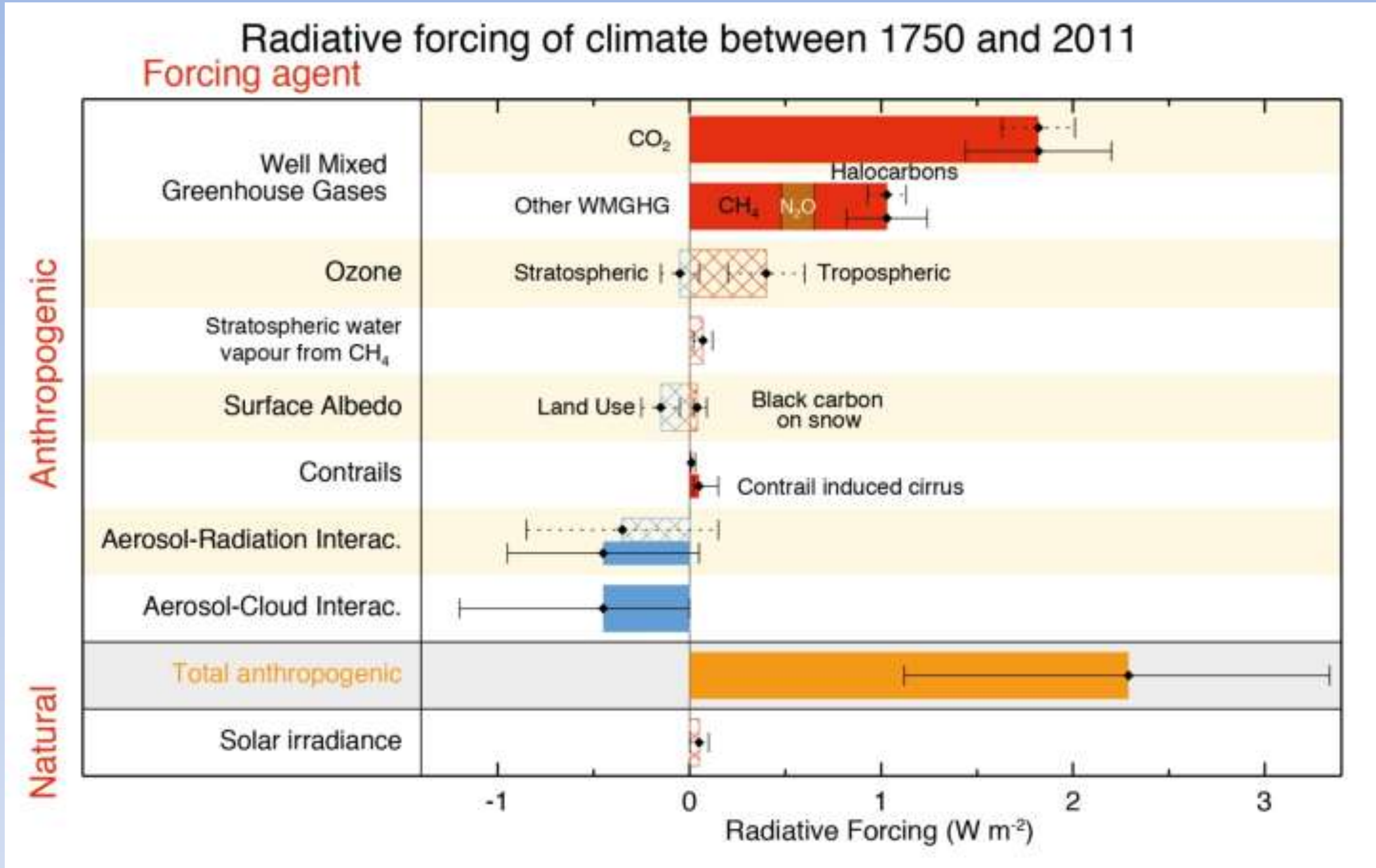
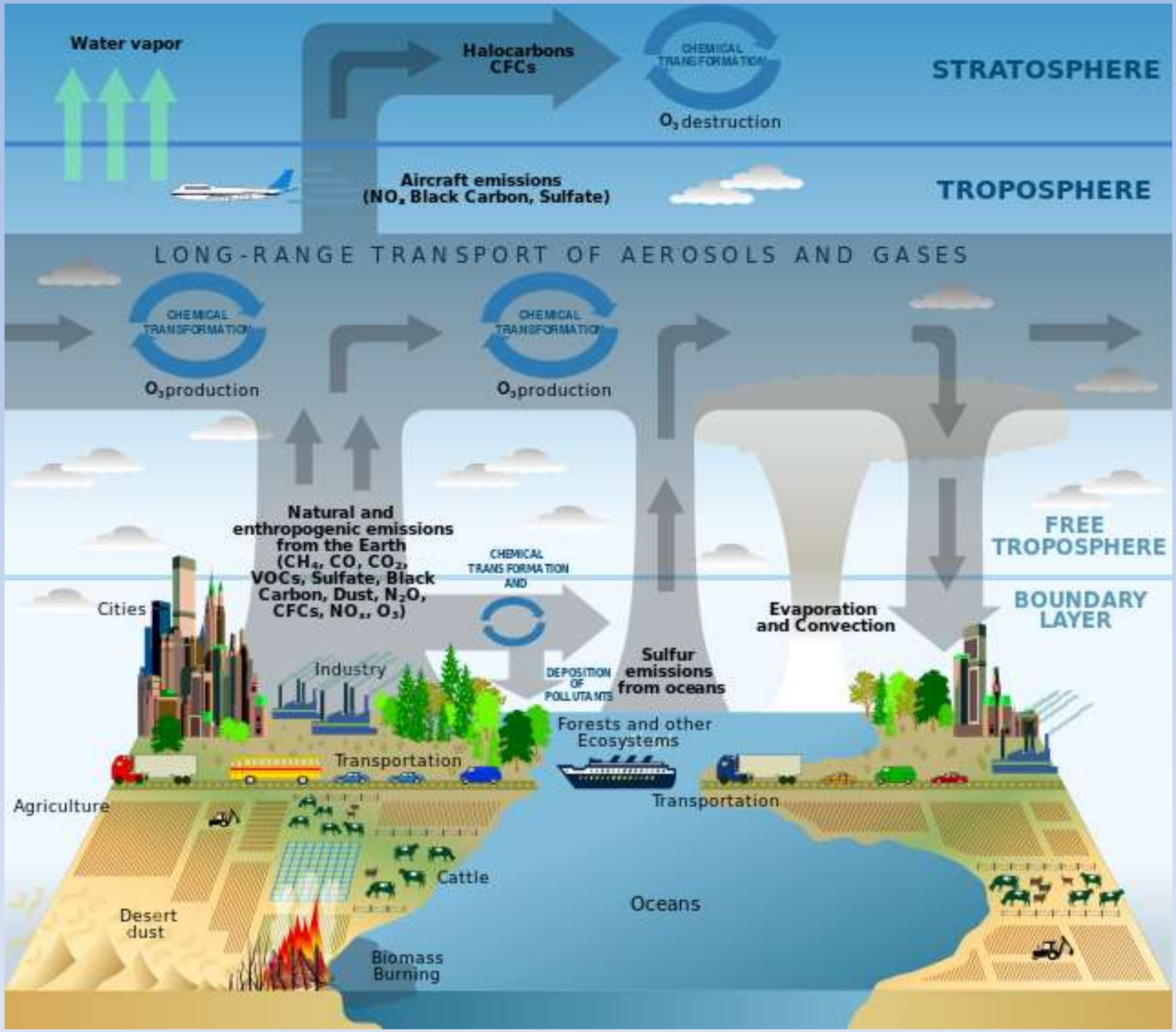


Figure 8.15: Bar chart for RF (hatched) and ERF (solid) for the period 1750–2011, where the total ERF is derived from Figure 8.16. Uncertainties (5–95% confidence range) are given for RF (dotted lines) and ERF (solid lines).

Schematic: climate-chemistry



Phillipe Rekacewicz - Strategic Plan for the U.S. Climate Change

IPCC: Radiative forcing components

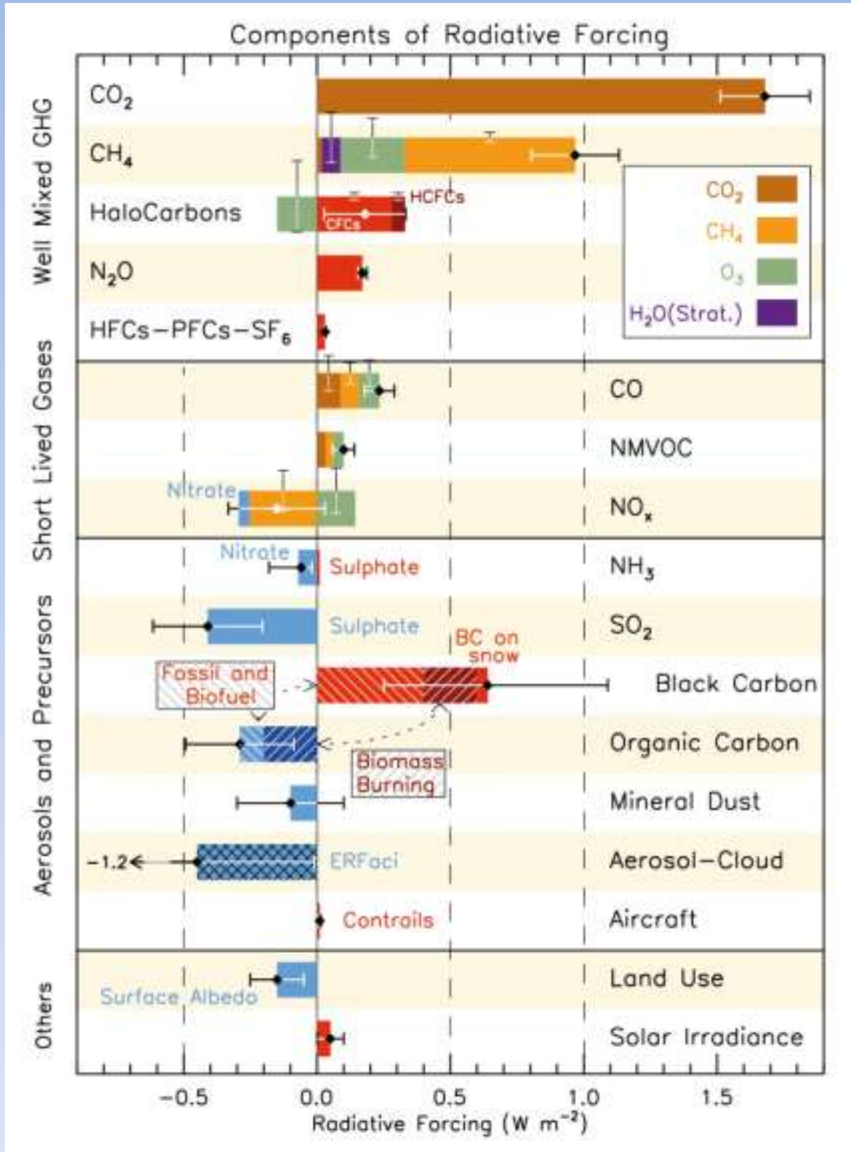


Figure 8.17: RF bar chart for the period 1750–2011 based on emitted compounds (gases, aerosols or aerosol precursors) or other changes. Numerical values and their uncertainties are shown in Supplementary Material Tables 8.SM.6 and 8.SM.7. Note, that a certain part of CH4 attribution is not straightforward and discussed further in Section 8.3.3. Red (positive RF) and blue (negative forcing) are used for emitted components which affect few forcing agents, whereas for emitted components affecting many compounds several colours are used as indicated in the inset at the upper part the figure. The vertical bars indicate the relative uncertainty of the radiative forcing induced by each component. Their length is proportional to the thickness of the bar, i.e., the full length is equal to the bar thickness for a ±50% uncertainty. The net impact of the individual contributions is shown by a diamond symbol and its uncertainty (5– 95% confidence range) is given by the horizontal error bar. ERFaci is ERF due to aerosol-cloud interaction. BC and OC are co-emitted, especially for biomass burning emissions (given as Biomass Burning in the figure) and to a large extent also for fossil and biofuel emissions (given as Fossil and Biofuel in the figure). SOA has not been included since the formation depends on a variety of factors not currently sufficiently quantified.

Summary

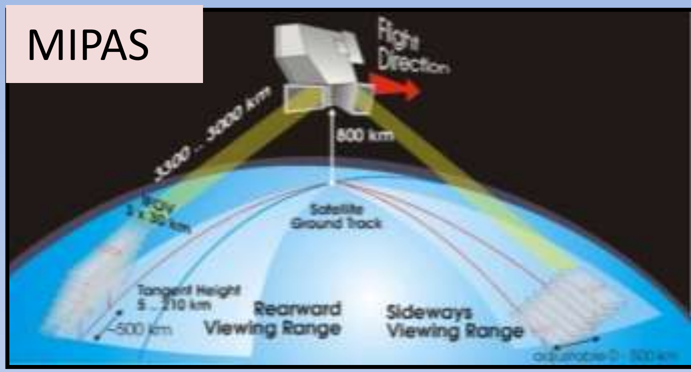
Major atmosphere gases for climate

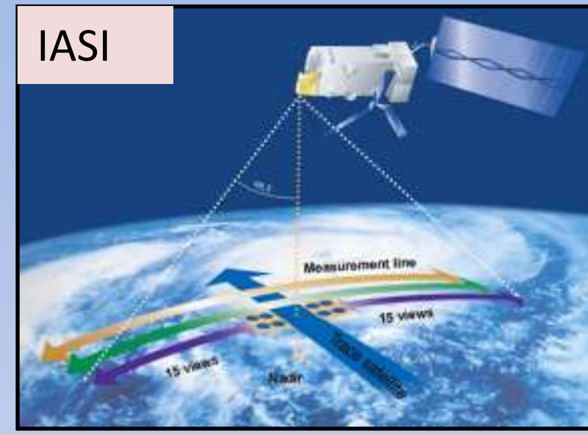
- Well-mixed “anthropogenic” greenhouse gases: CO_2, CH_4, N_2O, Halocarbons (CFCs, HCFCs); HFCs-PFCs-SF6
- Naturally highly variable greenhouse gases: ozone (O_3), water vapour (H_2O)
- Short lifetime gases: CO, Nox (NO, NO_2); NMVOCs
- Aerosol precursors: NH_3, SO_2

Instruments:

Spectrometers, one of the advances of the decade!

MIPAS and IASI instruments





MIPAS specifics	
Platform	ENVISAT
Instrument type	**Fourier Transform Spectrometer**
Mass	320 kg
Spectral range	**4.15 to 14.2 microns in 5 spectral bands (685-2410 cm^{-1})**
Spectral resolution	0.025cm^{-1} (March 2002-March 2004) 0.0625 cm^{-1} (August 2004-April 2012)
Vertical range	**6 to 68 km**
Vertical resolution	3 km from 6 to 42 km, 5 km from 42 to 52 km, 8 km from 52 to 68 km
Species measured	**L1b emission spectra - Potential to observe many gases** **L2 vertical profiles- operational products: H_2O, O_3,CH_4, N_2O, NO_2, HNO_3**

IASI specifics	
Platform	METOP
Instrument type	**Michelson Interferometer**
Mass	210 kg
Spectral range	**3.62 to 15.5 microns (645-2760 cm^{-1})**
Spectral resolution	0.5cm^{-1}
Species measured	**L1C emission spectra** **L2 vertical profiles- operational products: CO_2, N_2O, CFC-11, CFC-12, OCS, H_2O, O_3,CH_4, NH_3, CO, HNO_3, HCOOH, CH_3OH, SO_2**

The Earth emitted radiation

The Earth radiates energy because it has a temperature (300 K), just like the sun (6000 K) emits in the visible. We can observe this in spectra recorded by satellites at Top of atmosphere (TOA).

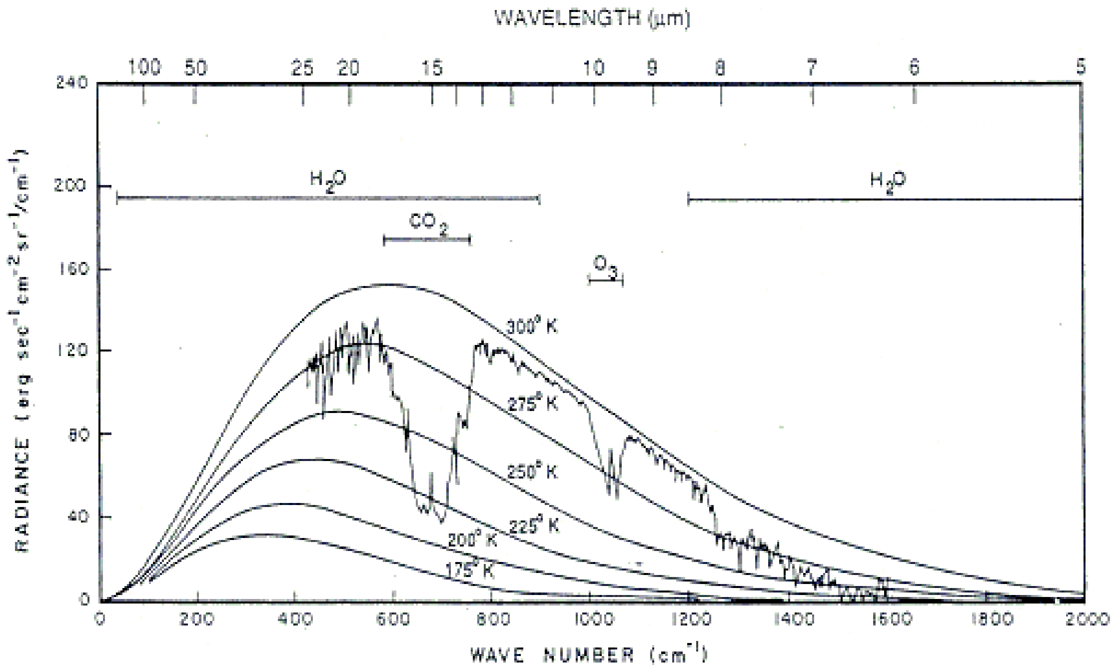
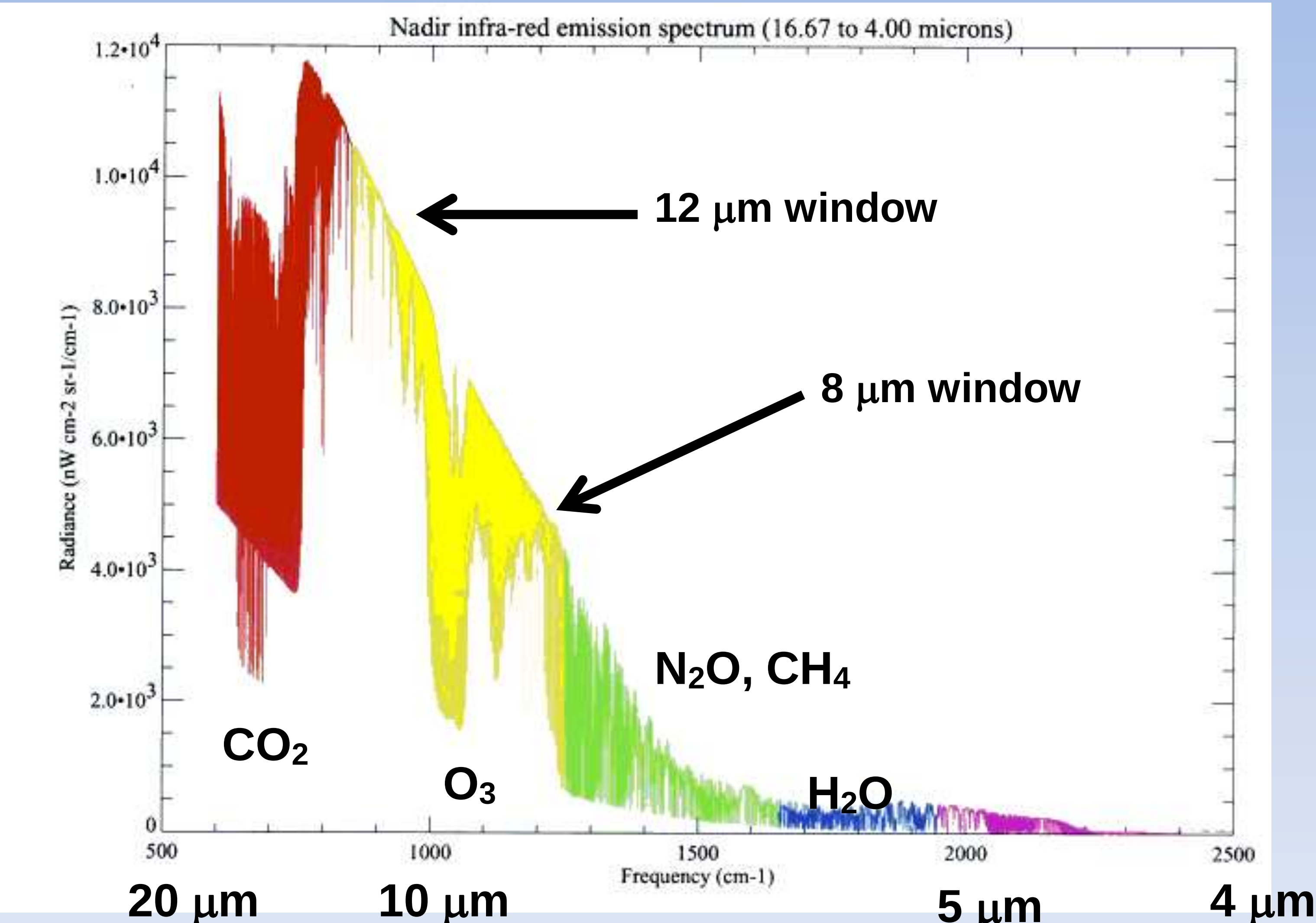


Figure 8.5 Spectrum of outgoing LW radiation over (215° W, 15° N) observed by Nimbus-4 IRIS, as a function of wavenumber λ^{-1}. Blackbody spectra for different temperatures and individual absorbing species indicated. Adapted from Liou (1980).

Planck function shows that the emitted energy peaks between 15 and 20 µm: the thermal infra-red! TOA spectra are clearly modified Planck curves.

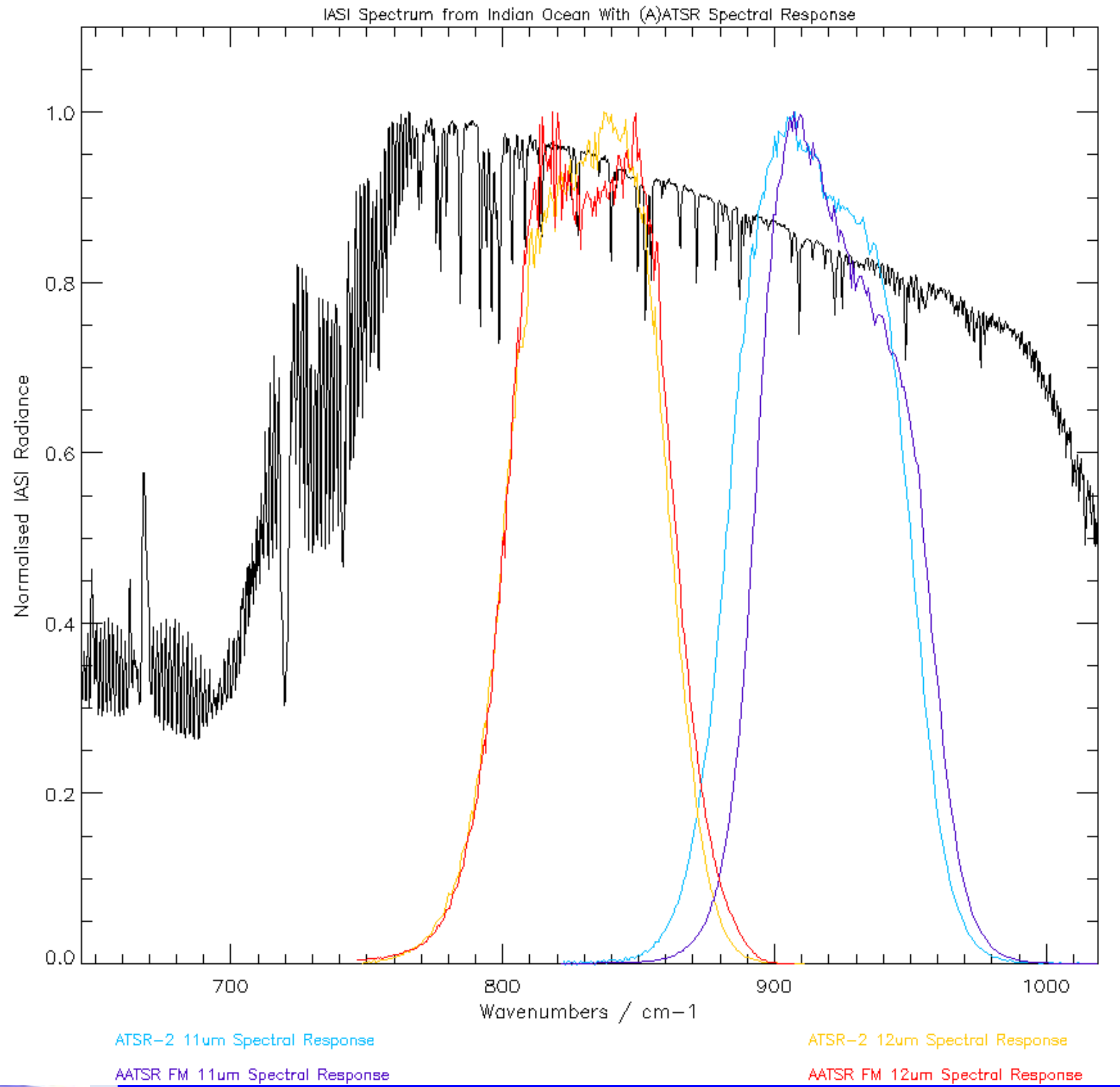
The infra-red (emission) spectrum

Wavenumber = 1/ λ but in cm^{-1}. Ref. pt. 10 μm = 1000 cm^{-1}



[Nadir simulated signal for an infra-red instrument]

IASI spectrum at 11, 12 micron



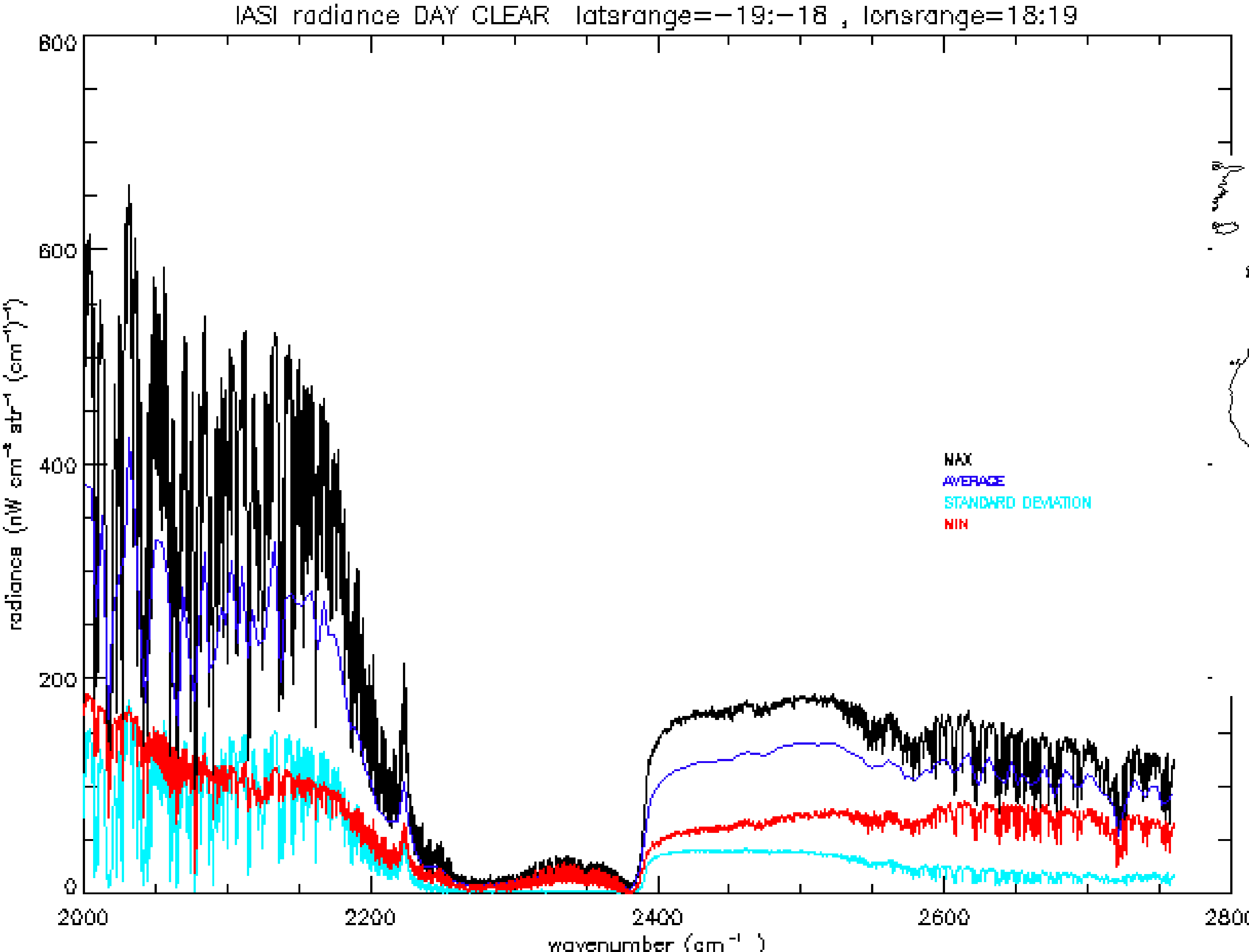
Thermal emission part of the outgoing spectrum is driven by temperature and modified by gases

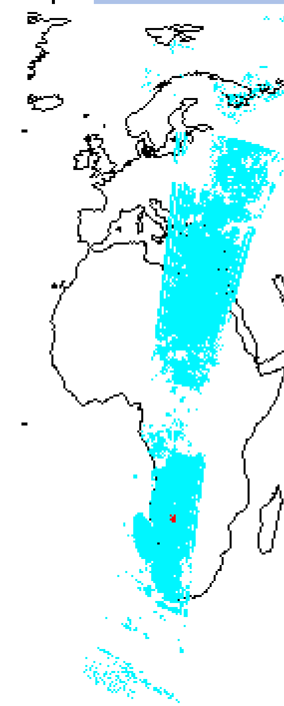
ATSR spectral functions overlaid on typical IASI spectrum.

AATSR spectral filters are “pre-flight”

Both ATSR-2 and AATSR filter functions are shown

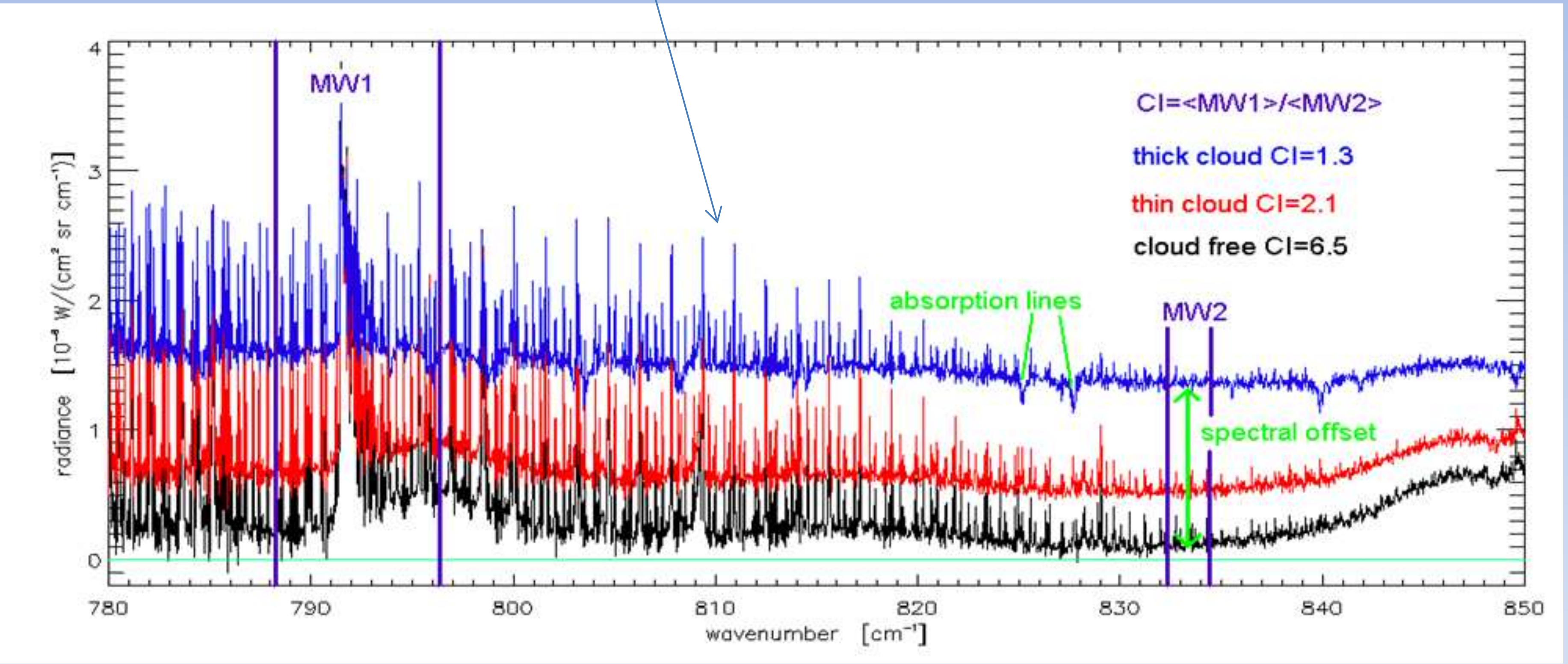
IASI spectra; 5 to 3.6 microns





Example MIPAS spectra (12 microns)

Emission lines

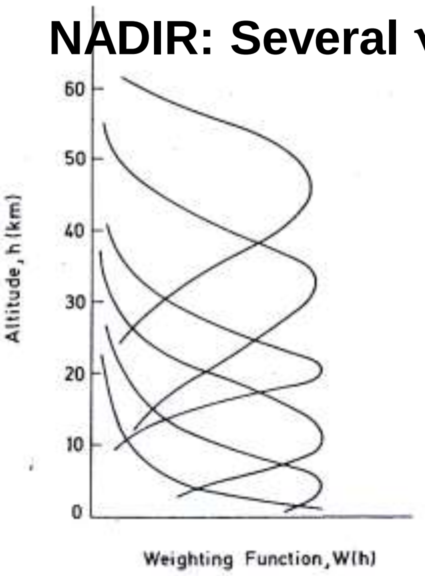


Some Satellite spectrometers

Instrument	Spectrometer-type	Wavelength region	Satellite/Launch
GOME	Grating	UV-Visible	ERS-2 1995
AIRS	Grating	I/R	Aqua 2002
MIPAS	Fourier Transform	I/R	Envisat 2002
SCIAMACHY	Grating	UV-VIS-SWIR	Envisat 2002
GOMOS	Grating	UV-VIS (stellar)	Envisat 2002
ACE	Fourier transform	I/R out to 3 microns	Scisat 2003
TES	Fourier transform	I/R	Aura 2004
IASI	Fourier transform	I/R	Metop 2006
GOME-2	Grating	UV-VIS	Metop 2006

Nadir and Limb Views; Weighting fns (adapted from SCIAMACHY)

NADIR: Several ν/λ



LIMB: One ν/λ

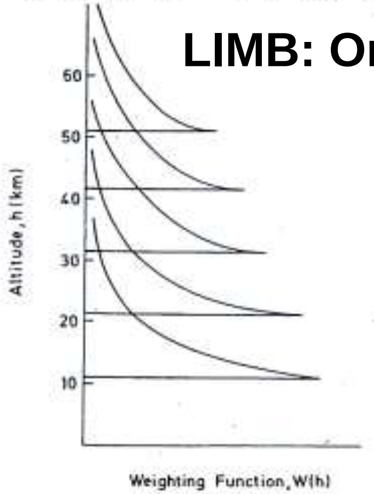
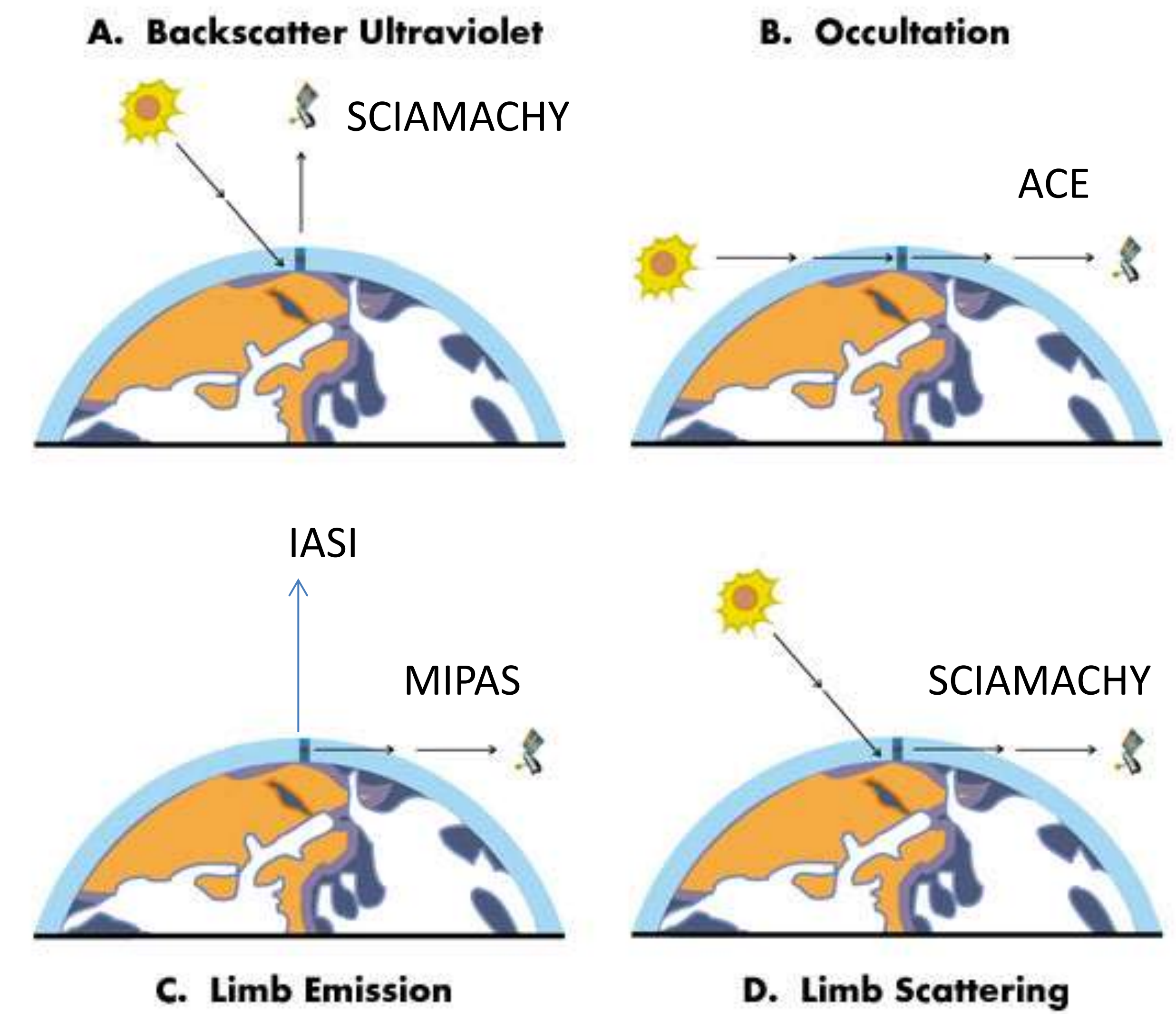


Fig. 4.4 — Weighting functions in the case of limb sounding.



ULIRS – University of Leicester IASI Retrieval Scheme

Pre-process and Cloud Clear IASI Data

Get ECMWF T, Altitude and H_2O Profiles

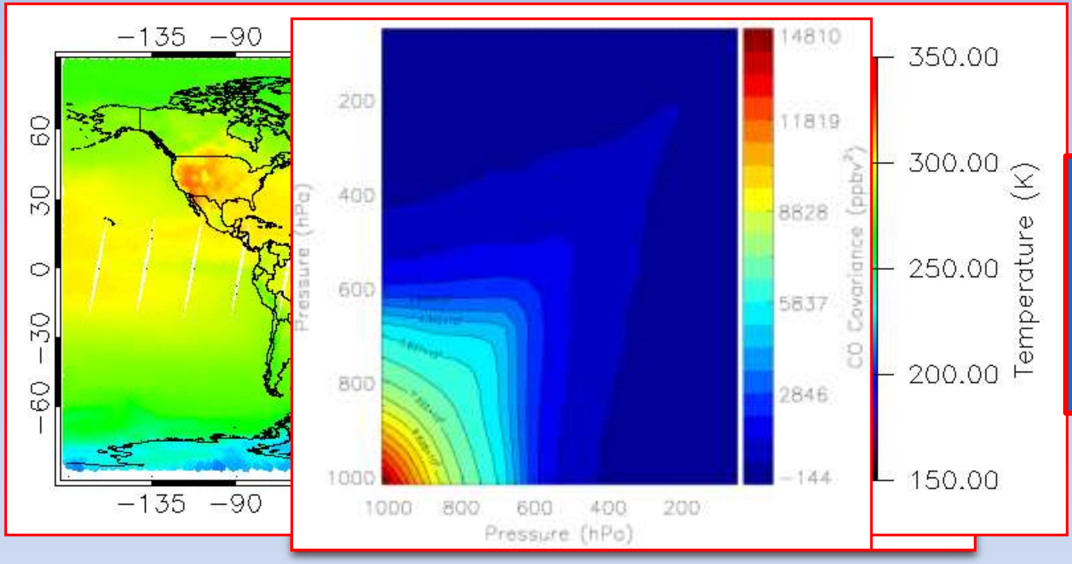
Get Surface Emissivity from CIMSS

Calculate a priori statistics from TOMCAT (for CO) or mix INTEX-B/ACE/MIPAS for organics.

Select Climatology

Perform OEM Retrieval Using Oxford RFM

Convert to Total Column Using DEM Data



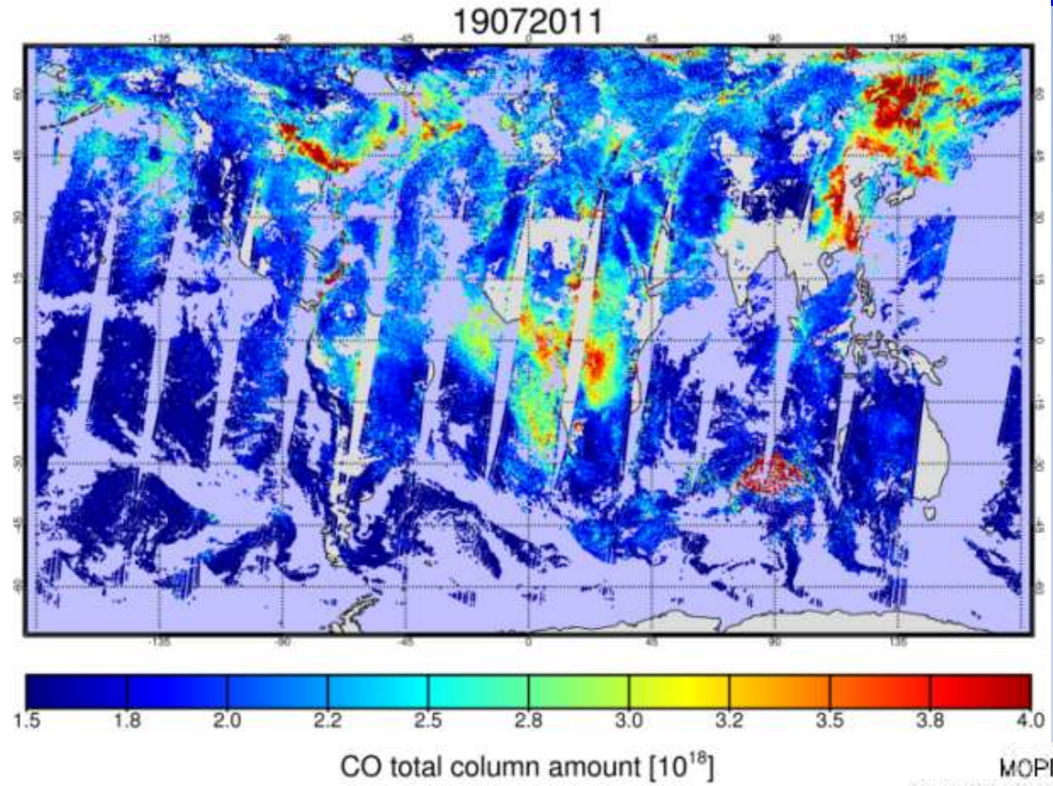
Full details of ULIRS in Illingworth et al., AMT, 2011

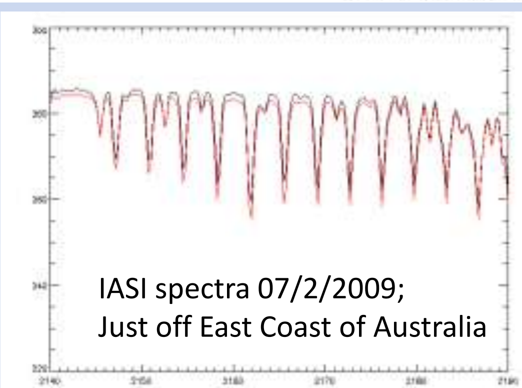
IASI CO Retrievals

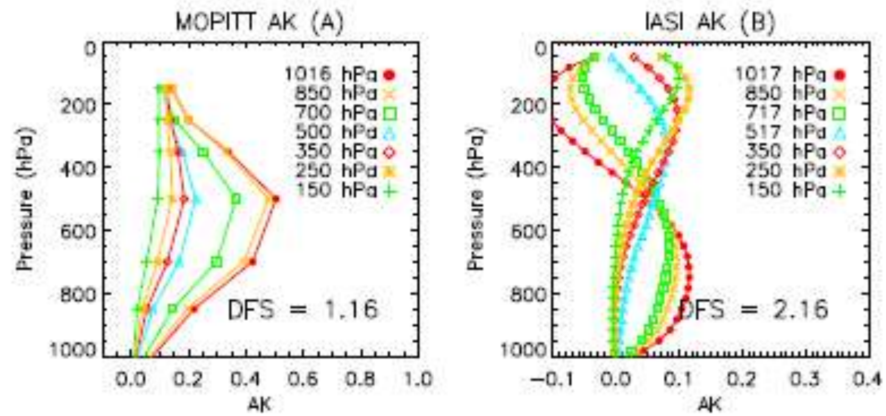
D. Moore; Illingworth et al, ACP, 2011

Averaging kernels

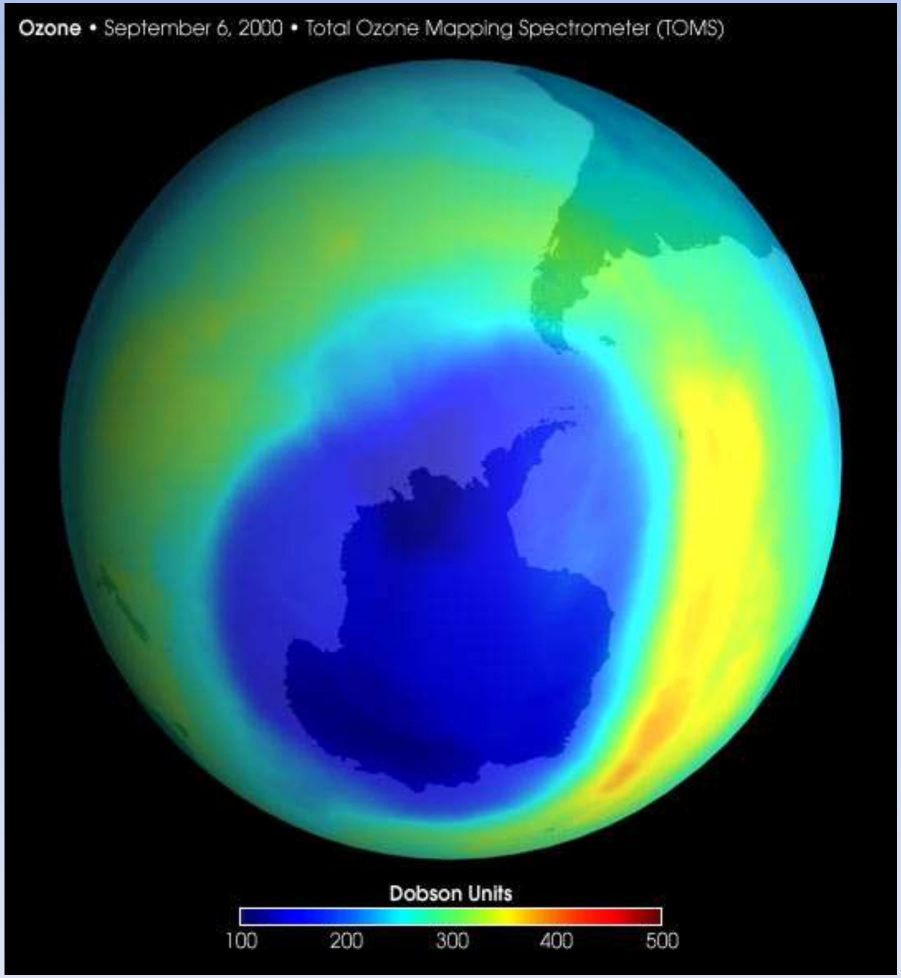
- AK show you the sensitivity of the data to altitude
- AK functions can be used to transform high resolution data to satellite perspective







The ozone layer: A well known story



O3 trends across globe

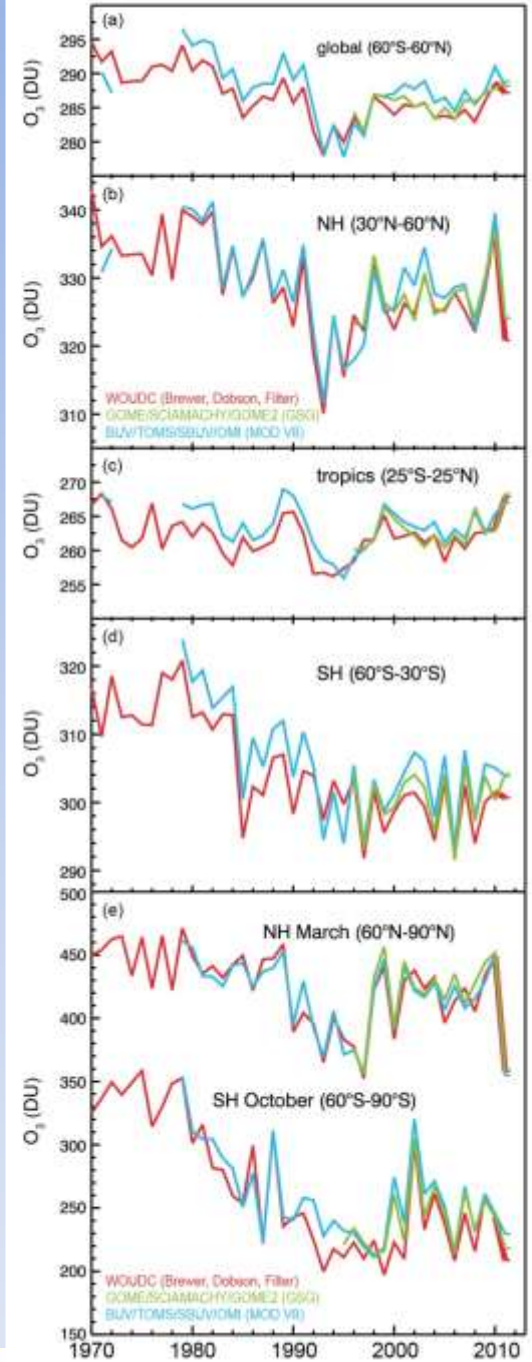


Figure 2.6: Zonally averaged, annual mean total column ozone in Dobson Units (DU; 1 DU= 2.69 × 1016 O3/cm2) fromground-based measurements combining Brewer, Dobson, and filter spectrometer data WOUDC (red), GOME/SCIAMACHY/GOME-2 GSG (green) and merged satellite BUV/TOMS/SBUV/OMI MOD V8 (blue) for a)Non-Polar Global (60°S–60°N), b) NH (30°N–60°N), c) Tropics (25°S–25°N), d) SH (30°S–60°S) and e) March NHPolar (60°N–90°N) and October SH Polar. Adapted from Weber et al. (2012; see also for abbreviations).

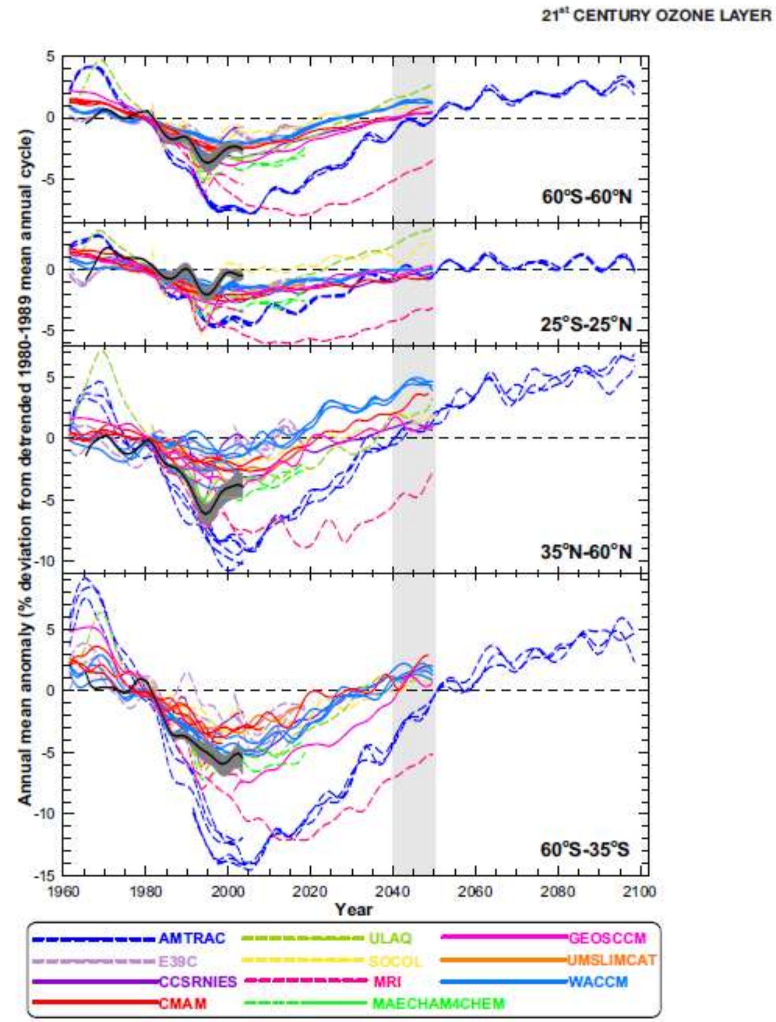
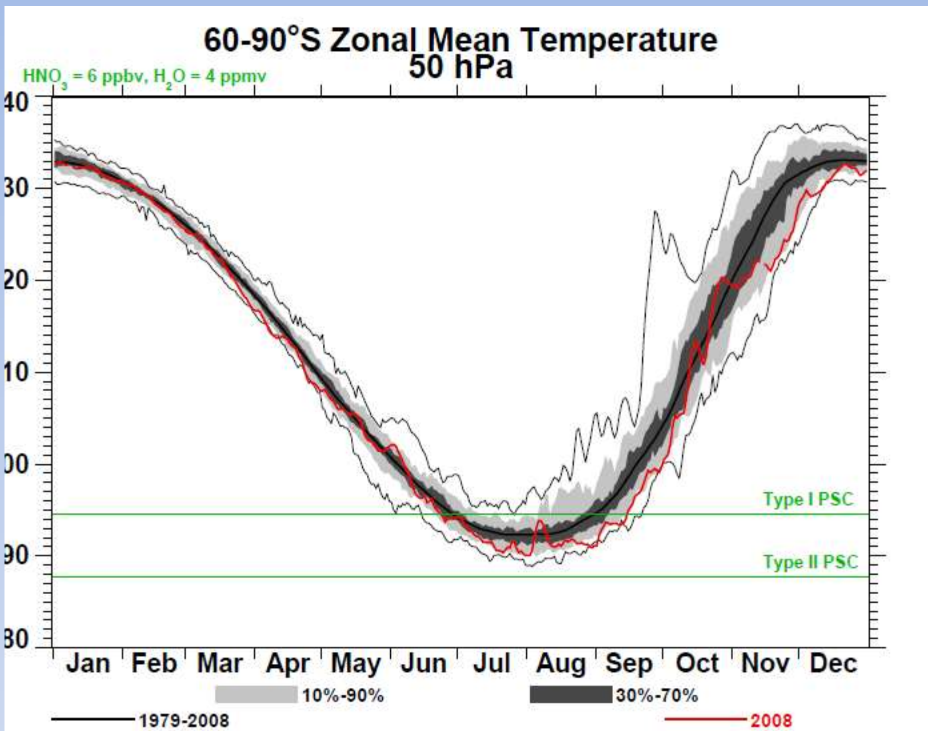
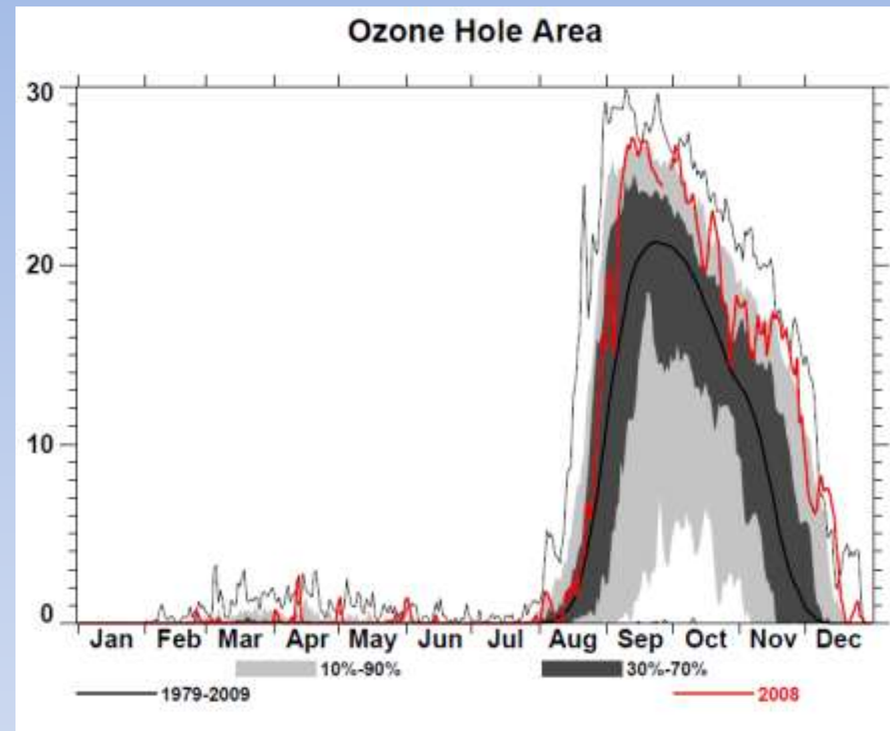


Figure 6-10. Annual mean zonal mean total column ozone anomalies from CCMs (colored lines) and from four observational datasets (thick black line and gray shaded area show the mean and range of observed anomalies; see Chapter 3). The time series are formed using the REF1 and REF2 or SCN2 simulations of each model (see Table 6-4). The time series have been smoothed as in Figure 6-9. The light gray shading between 2040 and 2050 shows the period when EESC is expected to return to 1980 values. As for the 2-D model results, the anomalies were calculated by subtracting the detrended 1980-1989 mean annual cycle. The mean annual cycles subtracted from the raw monthly means to calculate these anomalies are shown in Figure 3-26. For further details on the method for calculating the anomalies, see Eyring et al. (2006).

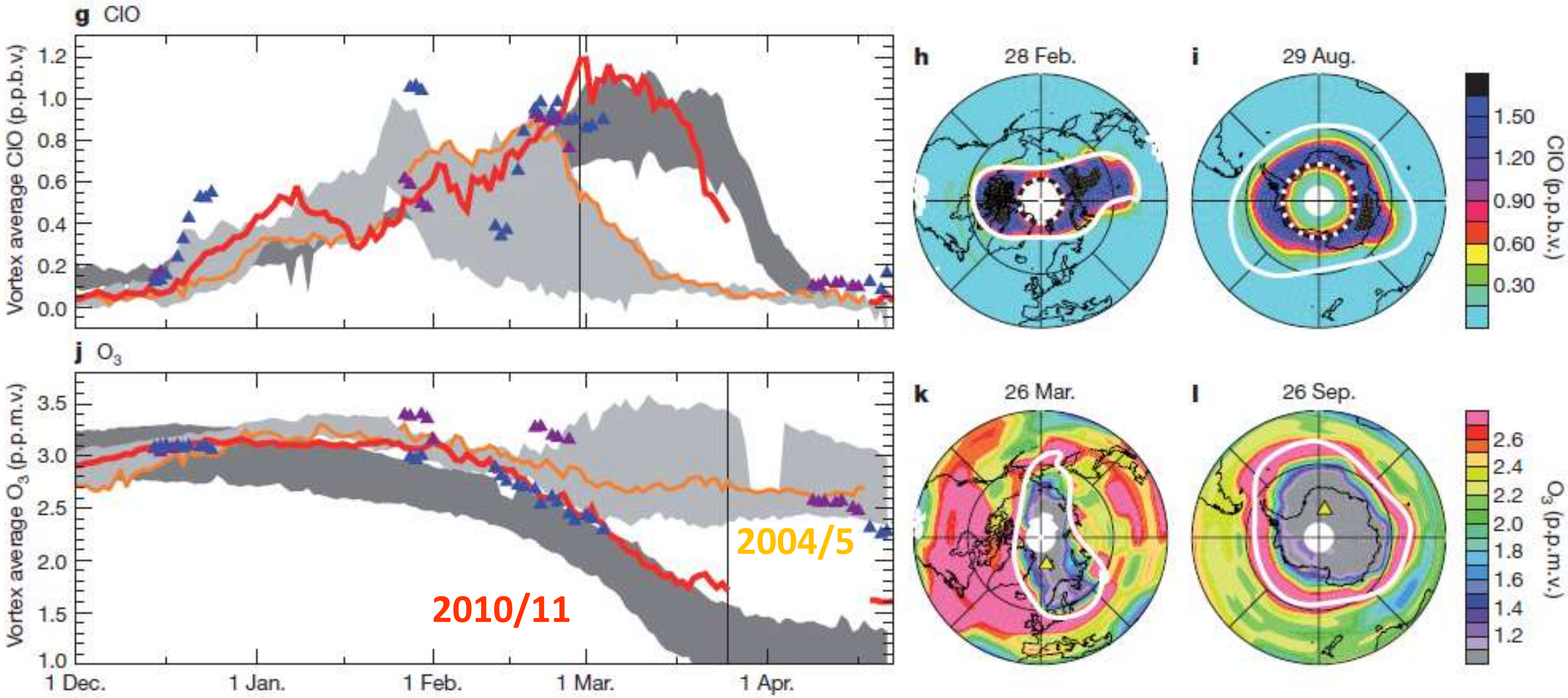
Ozone Holes and Temperature





- Greenhouse gas increases may lead to lower stratospheric temperature decreases and more prolonged cold winters.
- Since stratospheric ozone is also a radiative forcing gas, there is a feedback between stratospheric ozone and surface

Arctic ozone loss 2011- Santee et al, Nature

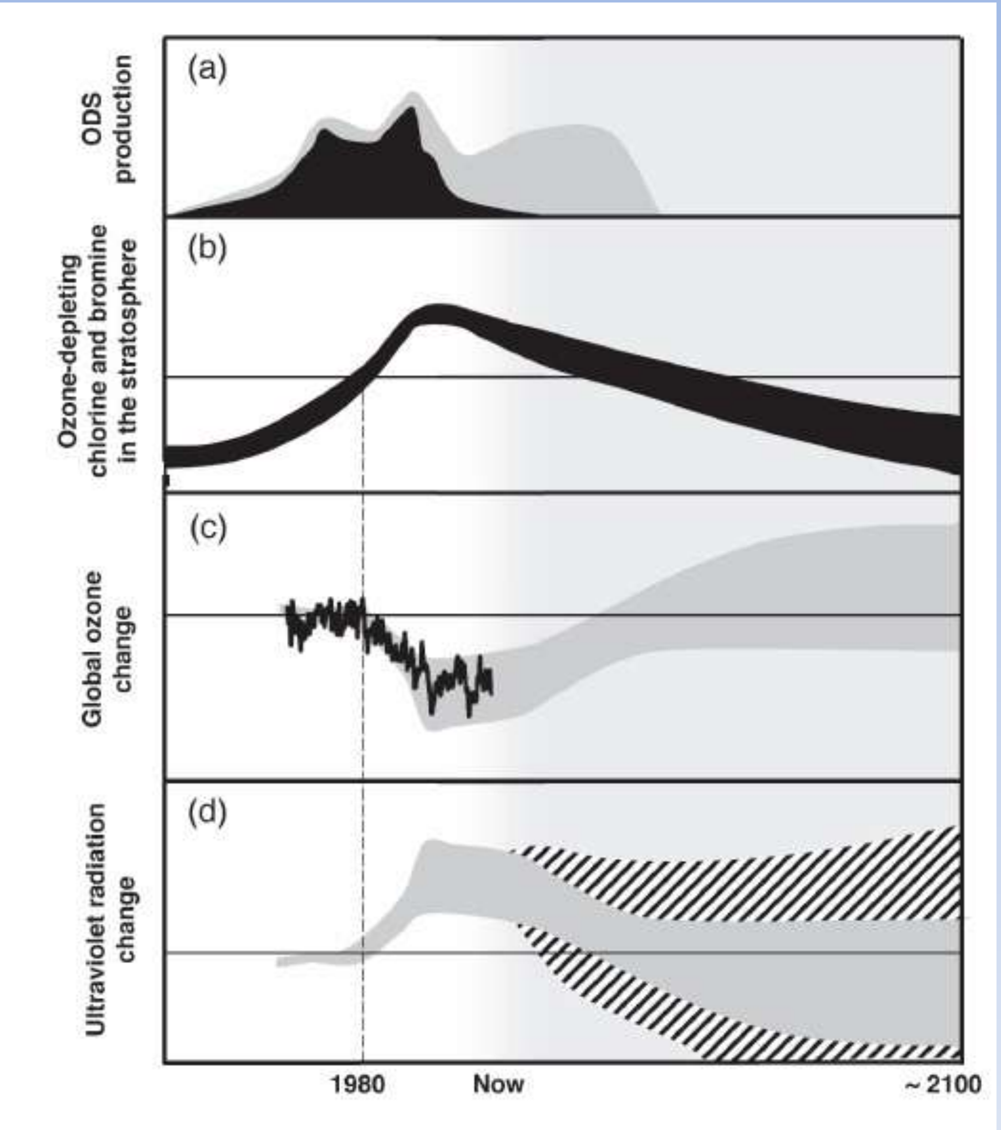


Light gray shade = Average Arctic 2005-2010

Dark gray shade = Average Antarctic 2005-2010

Red=Arctic 2010/11

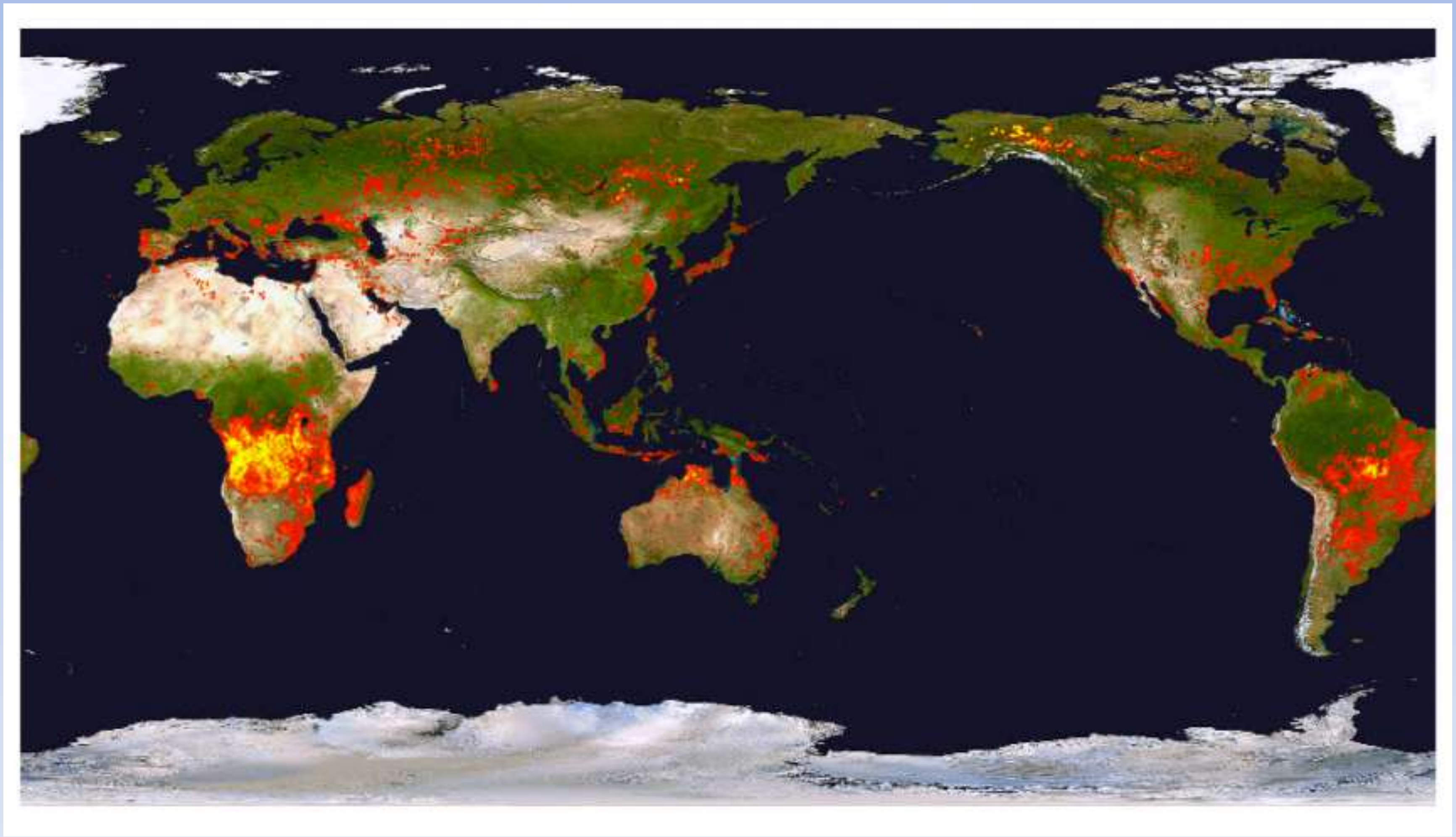
Projected ozone impacts



Fires and fire emissions

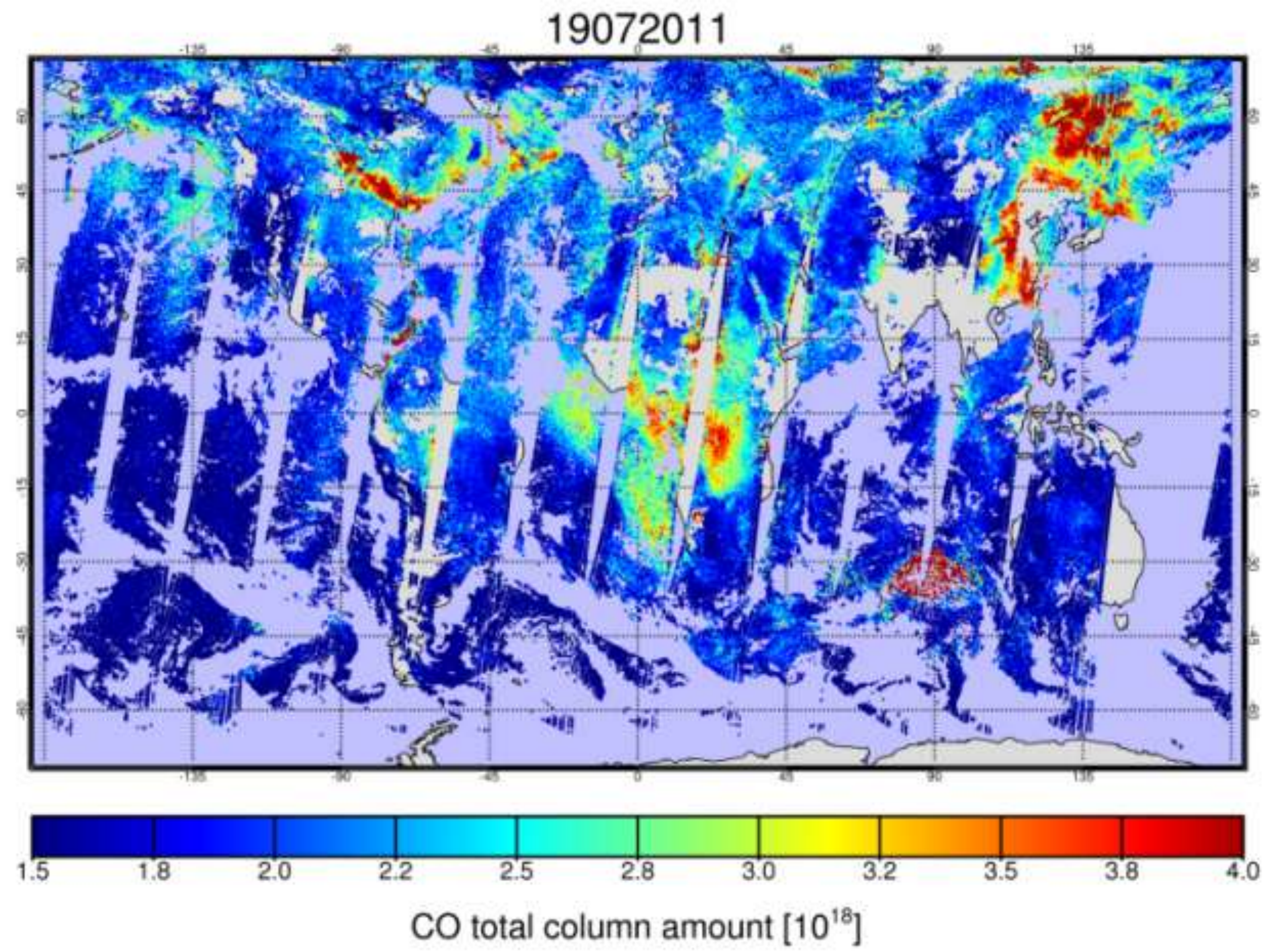
Nadir sounders and the MIPAS instrument

Fires



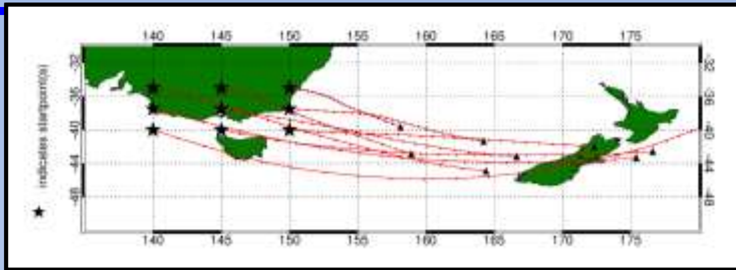
MODIS Fire Map: 9th - 19th July, 2004

ULIRS IASI CO

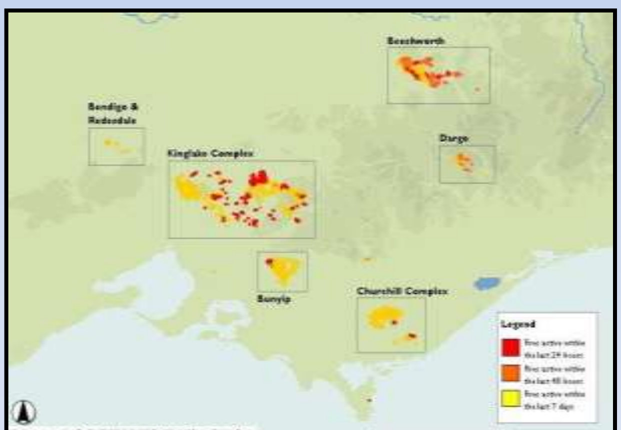


D. Moore

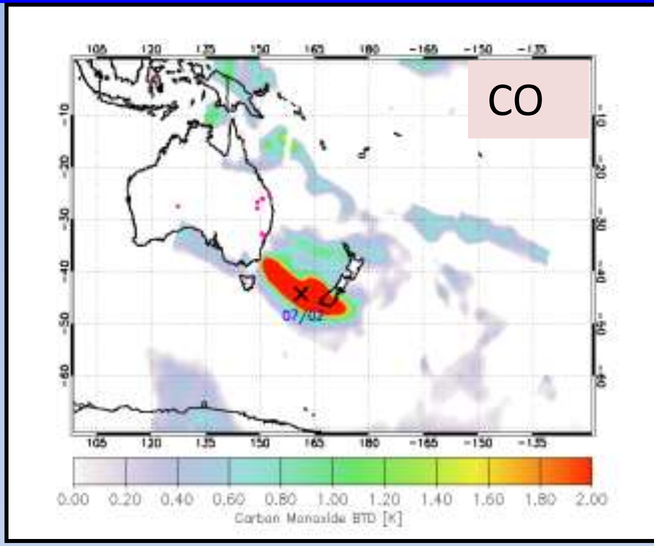
"Black Saturday" bush fires

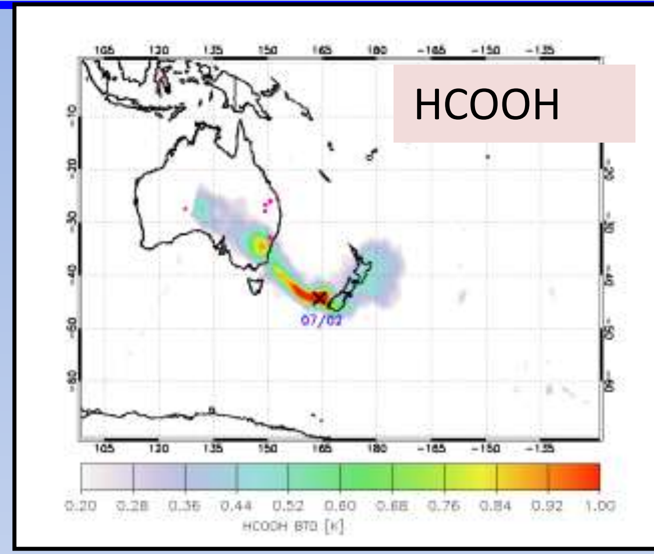


- A series of bushfires which started in South-Eastern Australia on February 7th 2009
- Over 450000 hectares burnt
- Fires burned over the period 7/2 – 14/3
- Other work determines stratospheric aerosol/gas injection

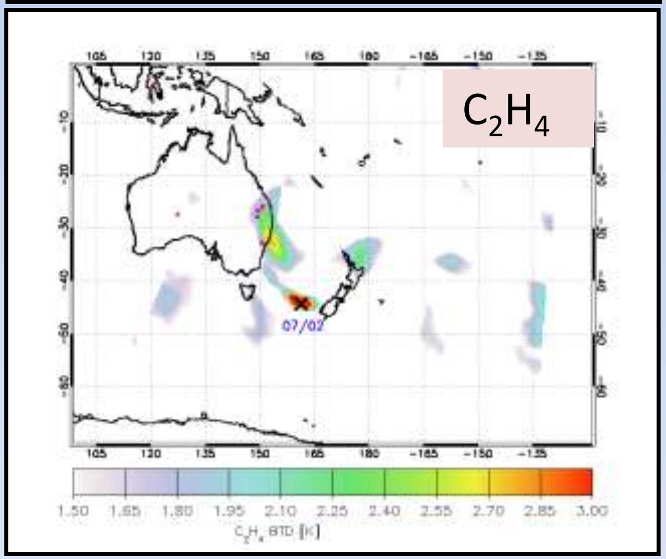


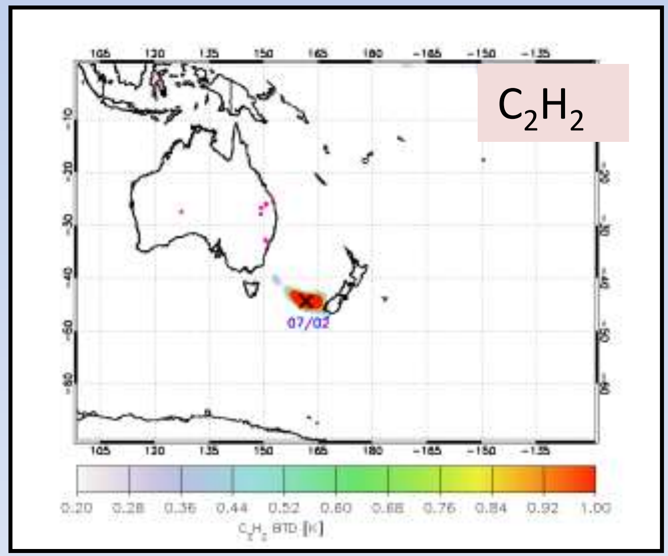
IASI observations of plumes





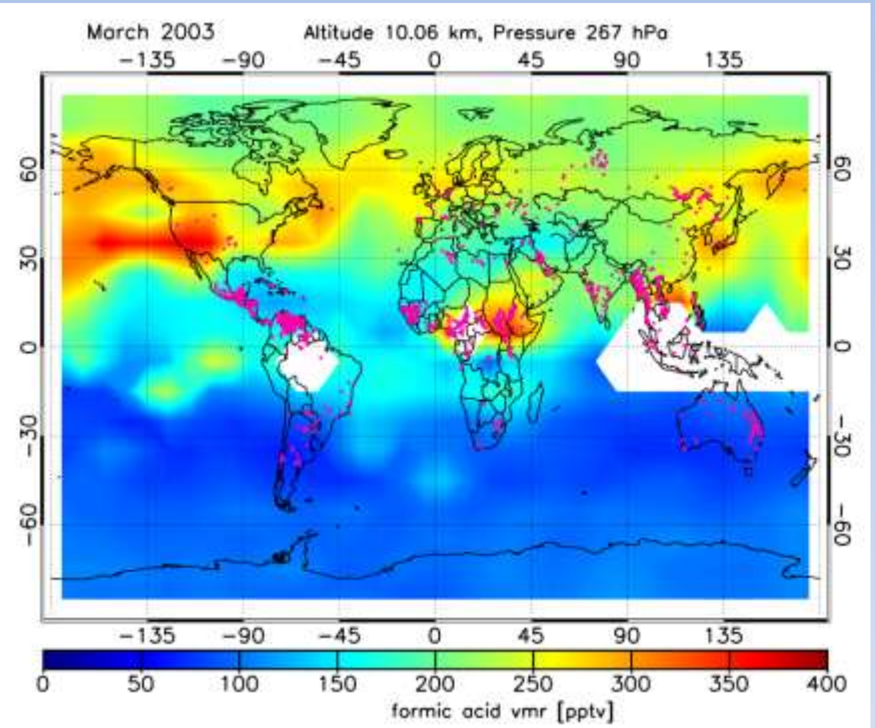
D. Moore

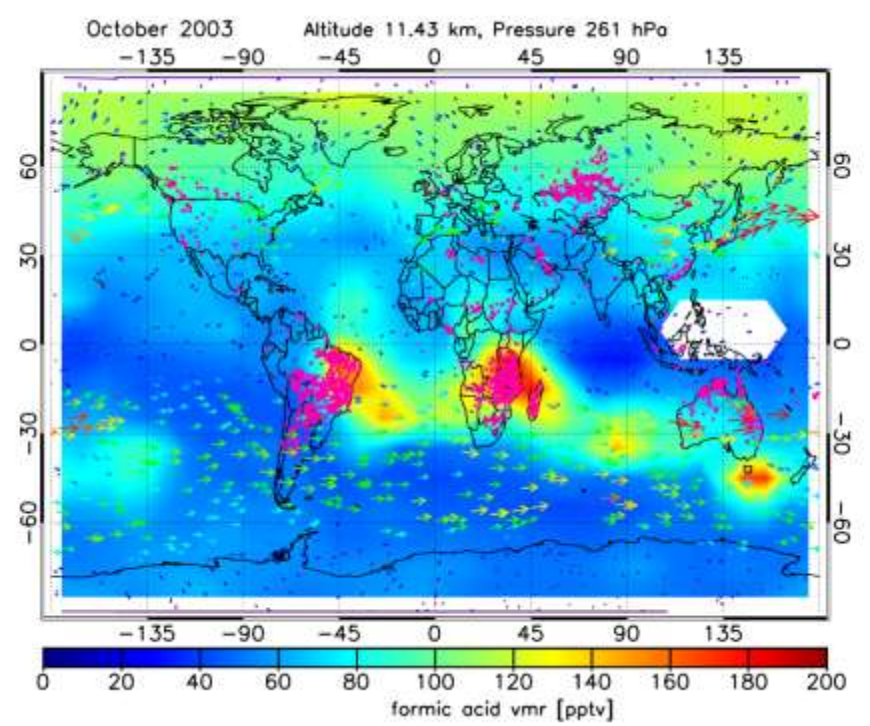




Formic acid in the UT

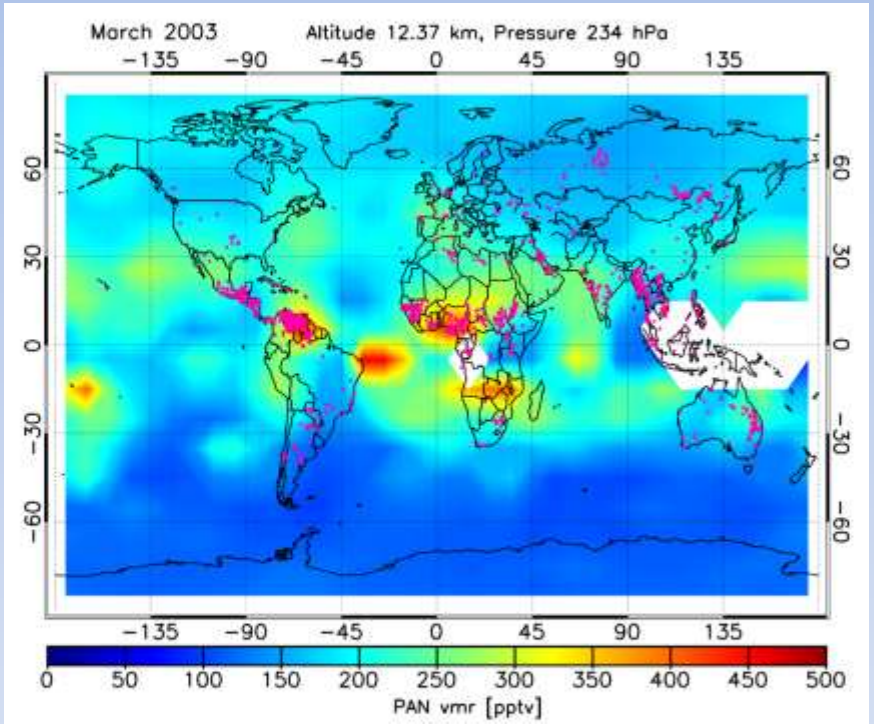
D. Moore

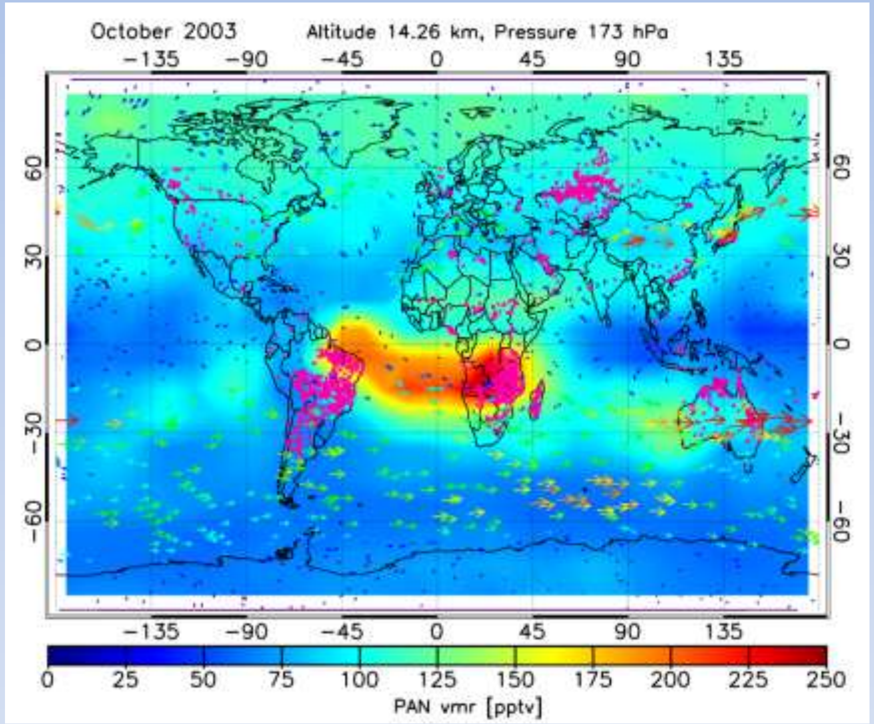




Peroxyacetyl nitrate (PAN), UT

D. Moore





The future

IPCC: Atmosphere accounting

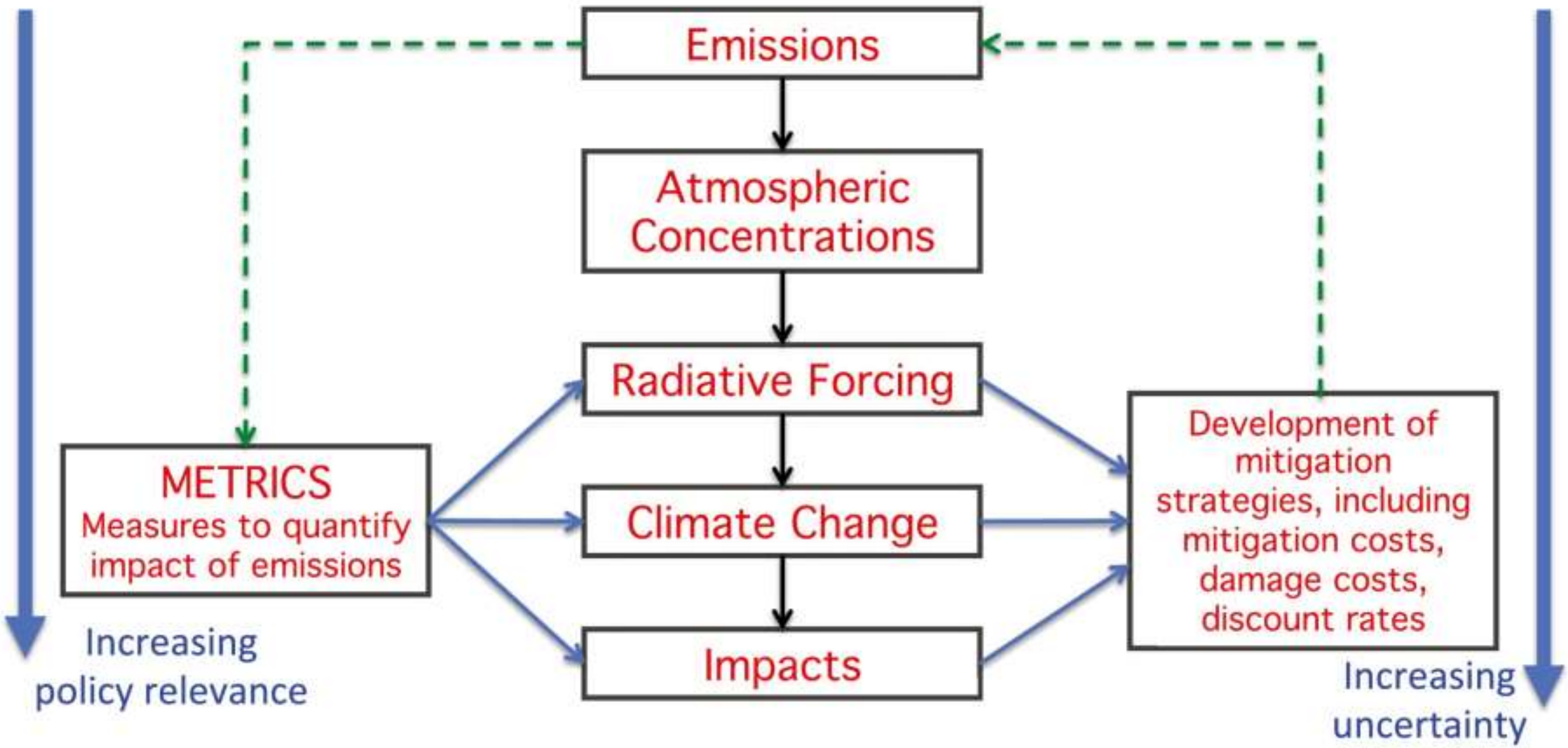
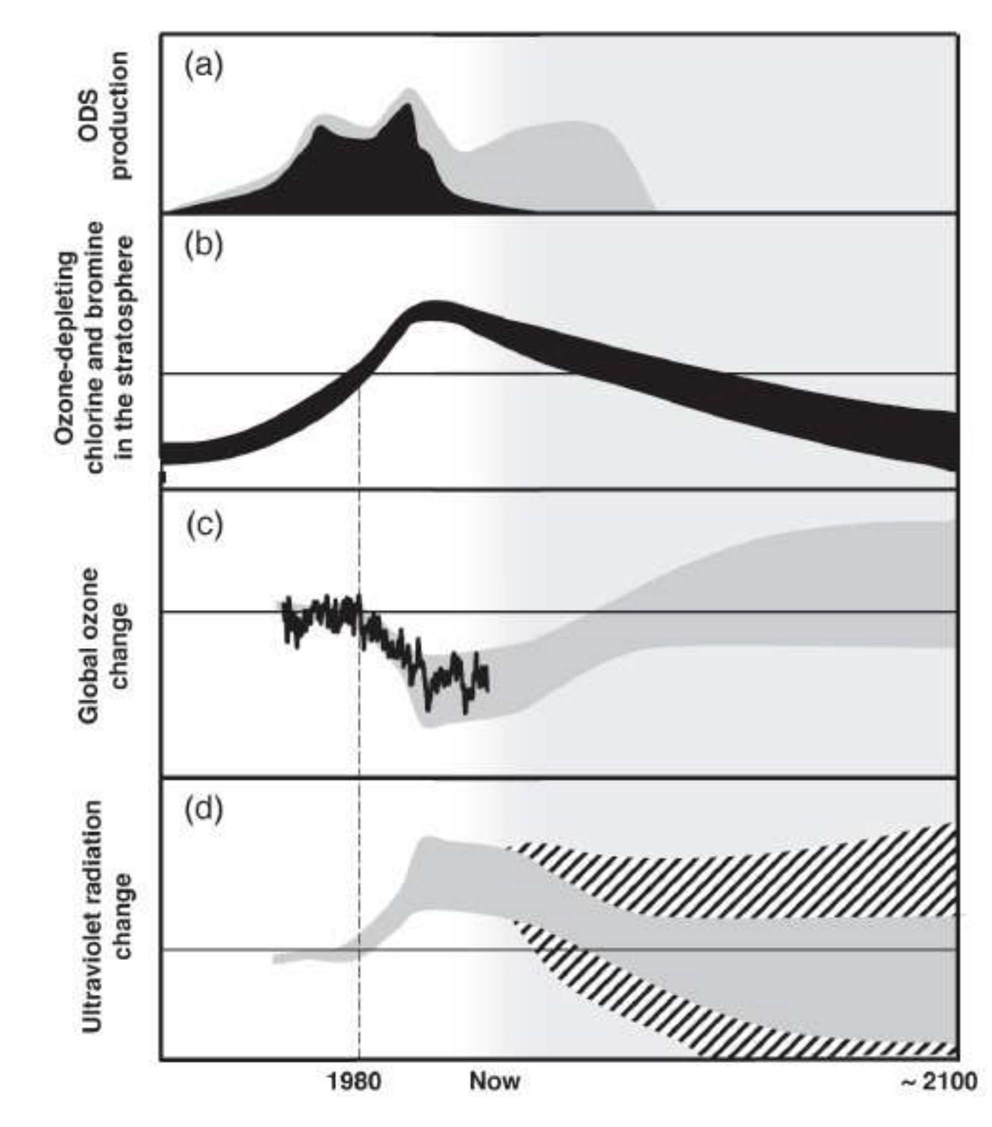


Figure 8.27: The cause-effect chain from emissions to climate change and impacts showing how metrics can be defined to estimate responses to emissions (left side) and for development of multi-component mitigation (right side). The relevance of the various effects increases downwards but at the same time the uncertainty also increases. The dotted line on the left indicates that effects and impacts can be estimated directly from emissions, while the arrows on the right side indicate how these estimates can be used in development of strategies for reducing emissions. Adapted from Fuglestvedt et al. (2003) and Plattner et al. (2009).

Projected ozone impacts



IPCC: Nitrogen Dioxide

Tropospheric ozone is also changing because of changes in chemistry drivers, e.g. NO_2

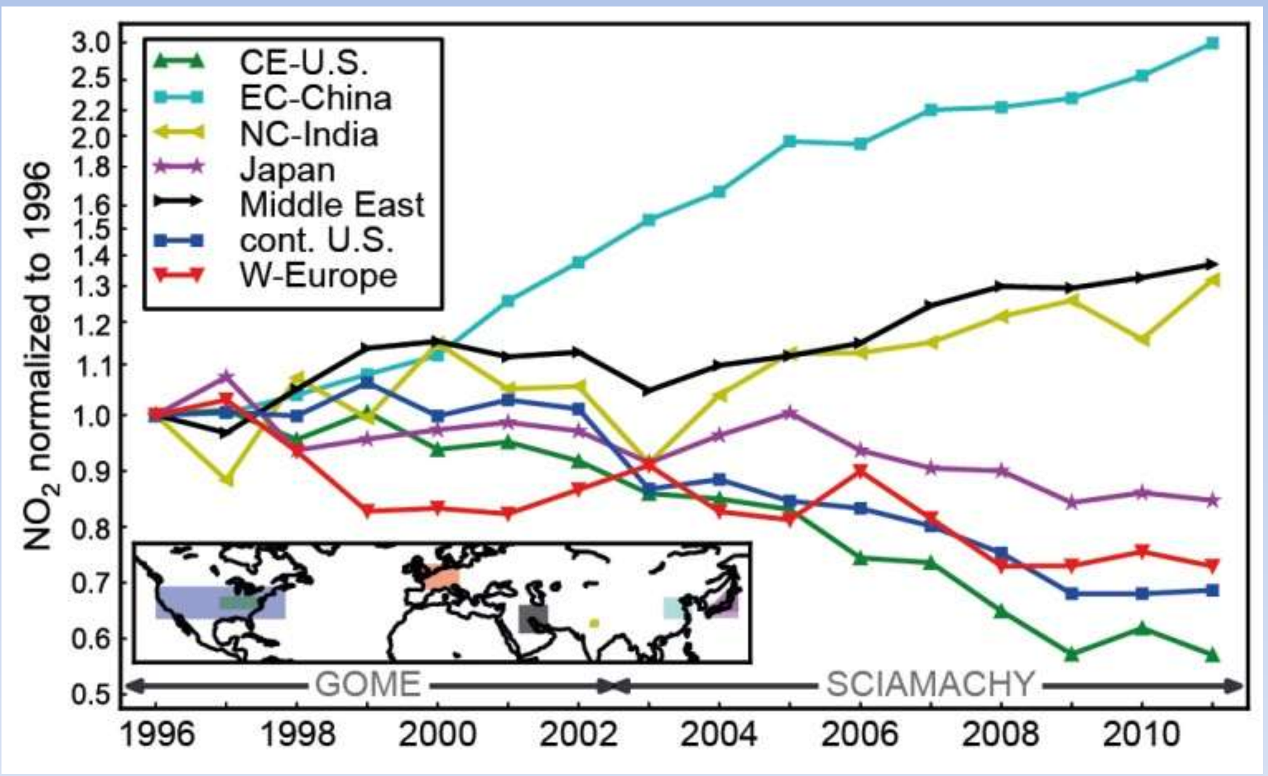
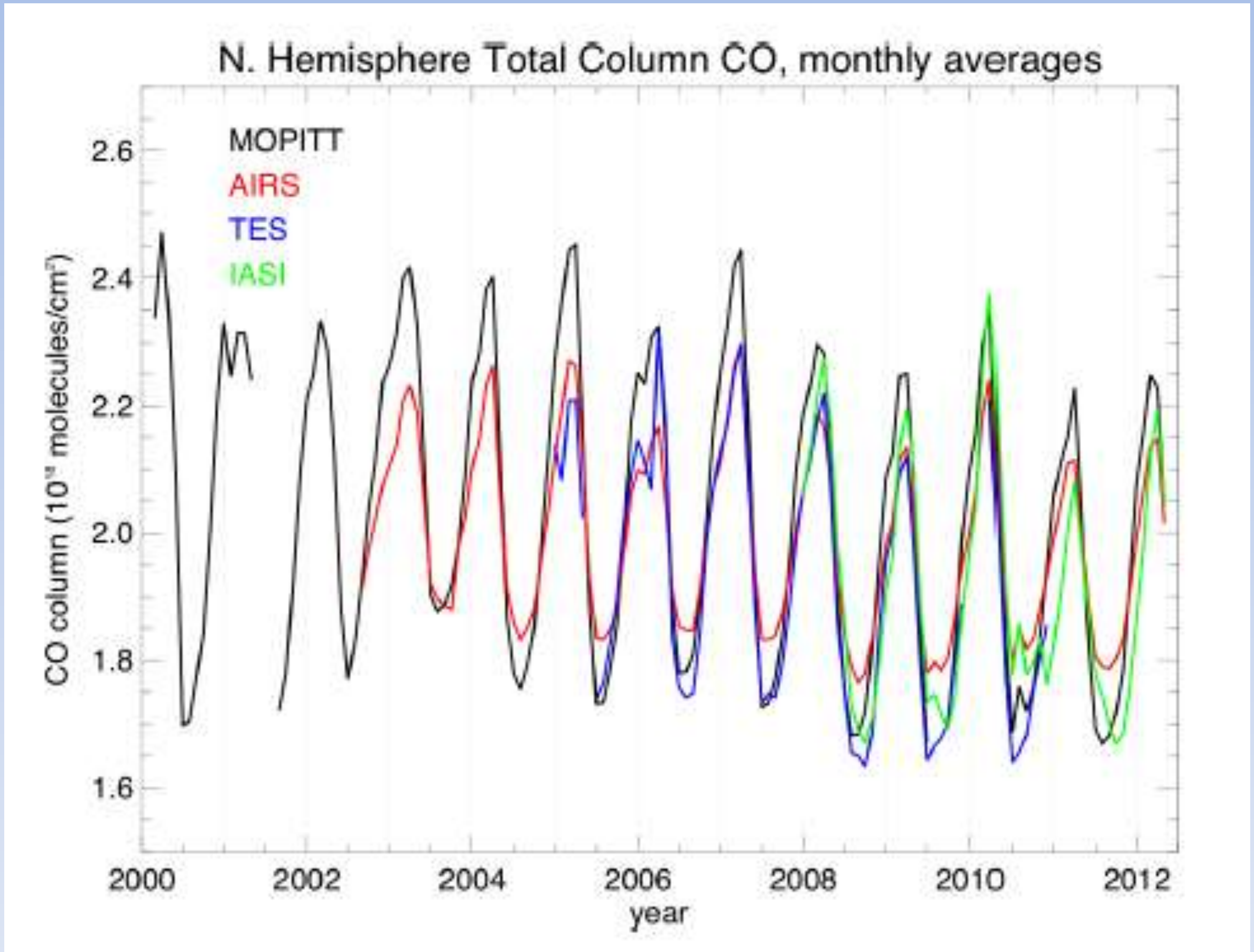


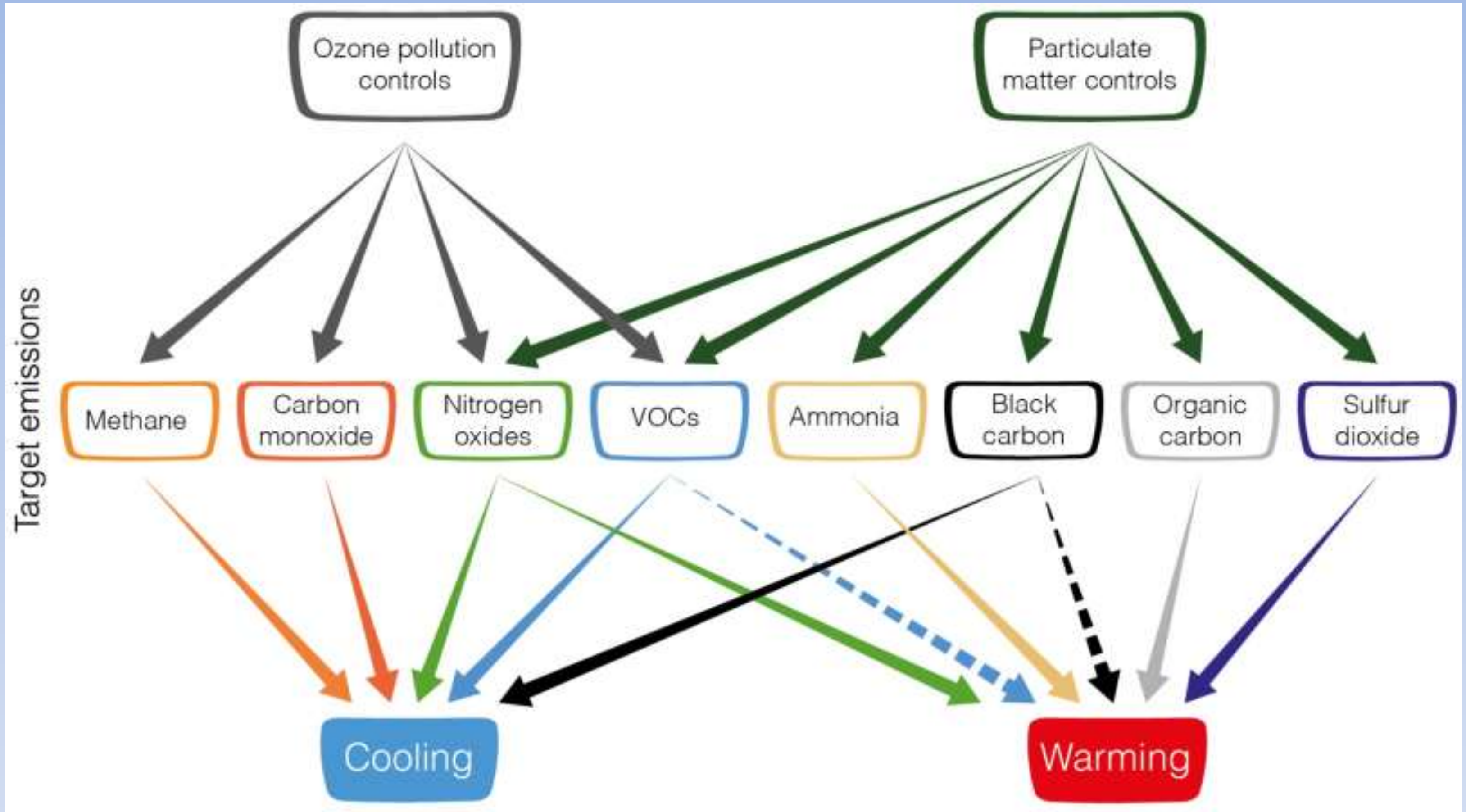
Figure 2.8: Relative changes in tropospheric NO2 column amounts (logarithmic scale) in 7 selected world regions dominated by high NOx emissions. Values are normalized for 1996 and derived from the GOME (Global Ozone Monitoring Experiment) instrument from 1996 to 2002 and SCIAMACHY (Scanning Imaging Spectrometer for Atmospheric Cartography) from 2003 to 2010 (Hilboll et al., 2013). The regions are indicated in the map inset.

Carbon Monoxide:

Worden et al, ACP, 2013



IPCC: Climate and other controls



FAQ 8.2, Figure 1: Schematic diagram of the impact of pollution controls on specific emissions and climate impact. Solid black line indicates known impact, dashed line indicates uncertain impact.