Spaceborne Observations of Global & Regional Atmospheric Pollution

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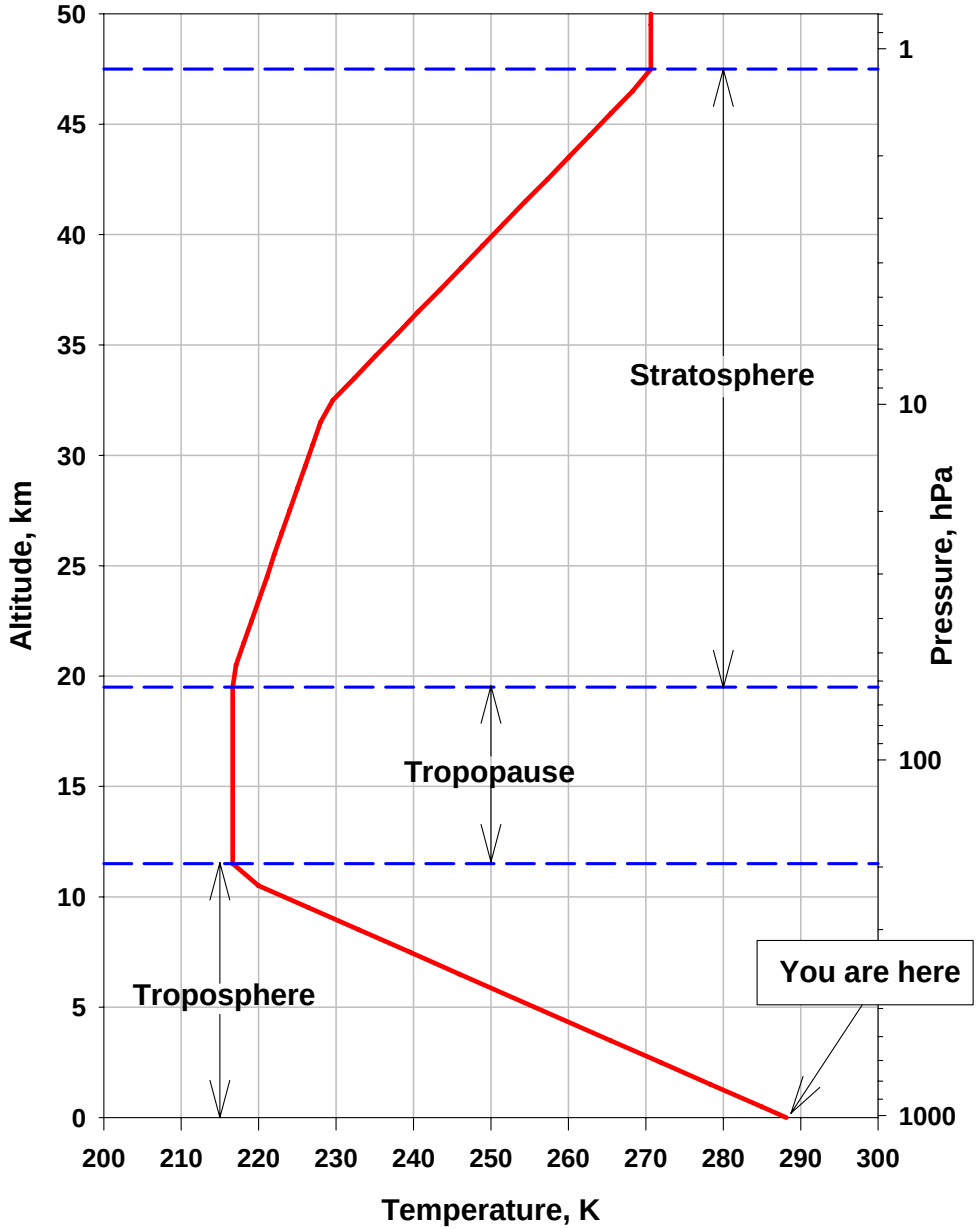
Introduction (1)

The principal atmospheric pollutants are particulates (e.g., soot from coal and wood fires), carbon monoxide (CO, also primarily from combustion processes including automotive exhausts) and ozone (O_3, which is controlled by some fairly complex atmospheric chemistry involving sunlight).

This talk will focus on CO and O_3, both of which are sufficiently long-lived to be transported over intercontinental distances.

It will be shown how spaceborne observations bring an entirely new perspective to the general problem of air quality.

A Global Average Atmospheric Temperature Profile



Introduction (2)

Ozone in the atmosphere is not necessarily bad. Some 90% of the total is in the stratosphere where it protects living organisms by absorbing harmful ultraviolet radiation.

However, at the surface, ozone is *very bad*. Being highly reactive, it destroys plants and seriously affects respiration in humans and animals.

In the mid-troposphere, ozone is good – it is the source of hydroxyl radical (OH) that, in turn, cleanses the atmosphere of pollutants (such as CO and CFC substitutes).

Just below the tropopause, ozone is again bad – it is a greenhouse gas.

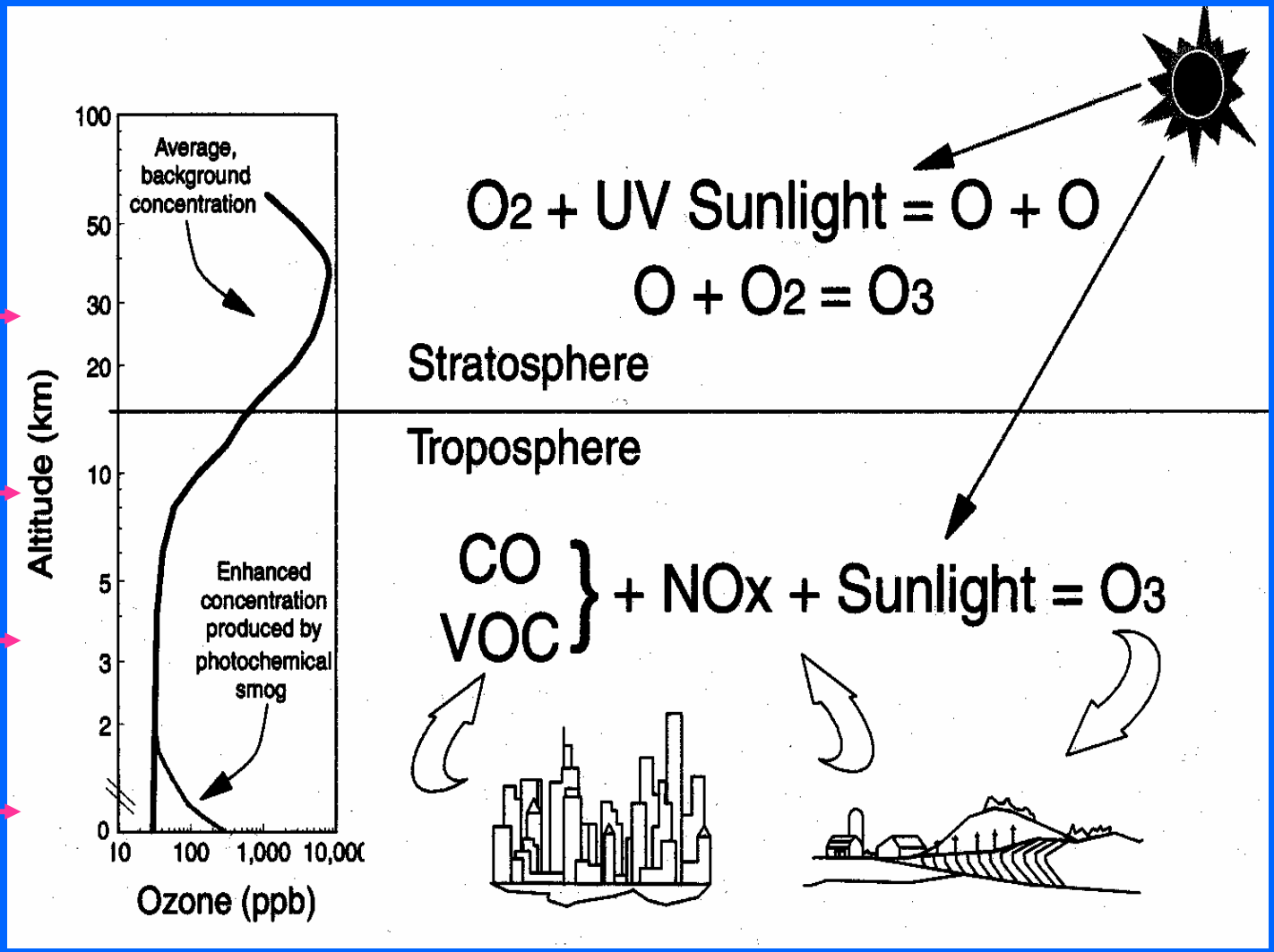
Differing Roles of Ozone in the Atmosphere: Where, When and How Much

Good
(UV shield)

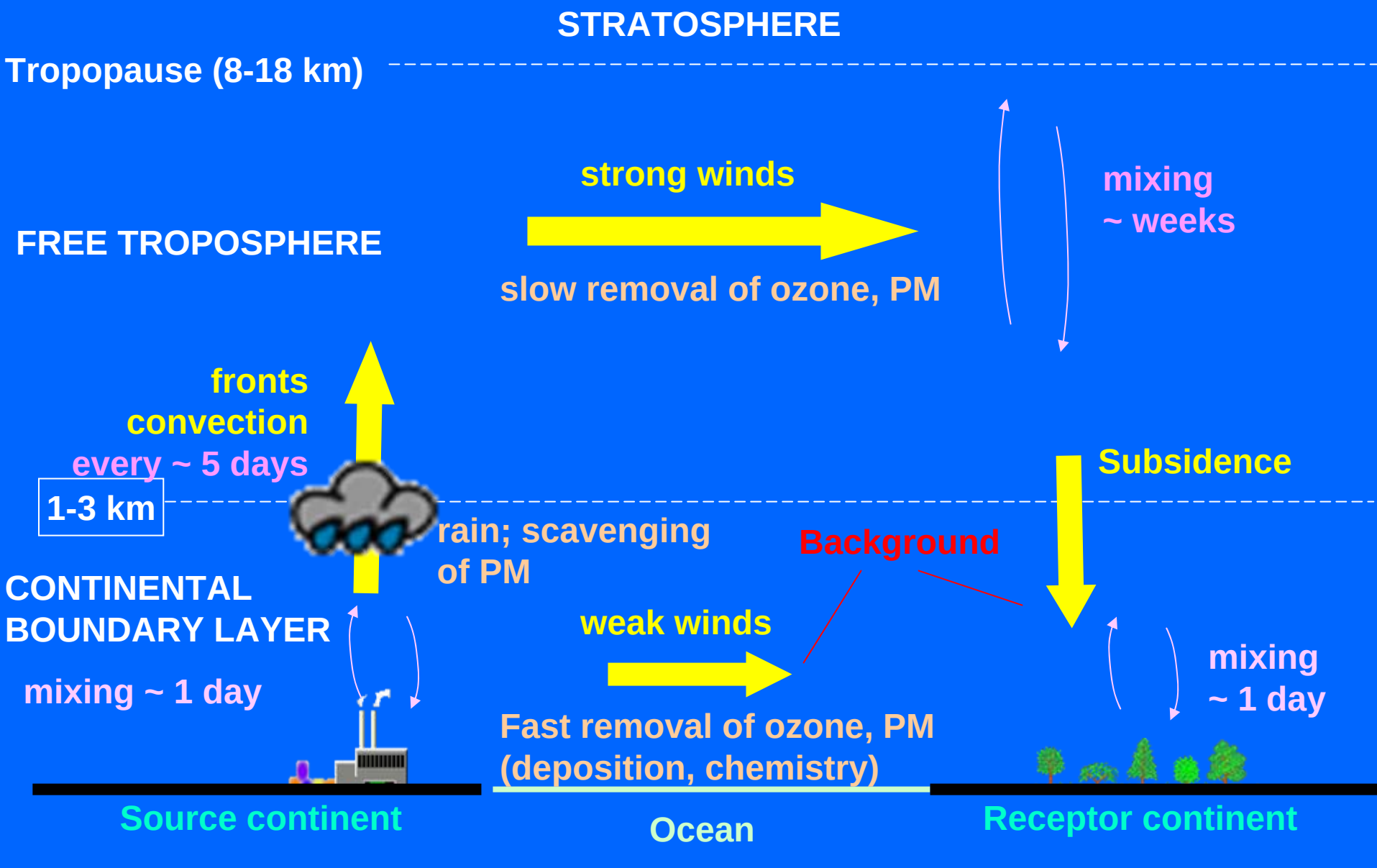
Bad
(Greenhouse gas)

Good
(OH source)

Bad
(Smog)



CONTINENTAL VENTILATION AND INTERCONTINENTAL TRANSPORT

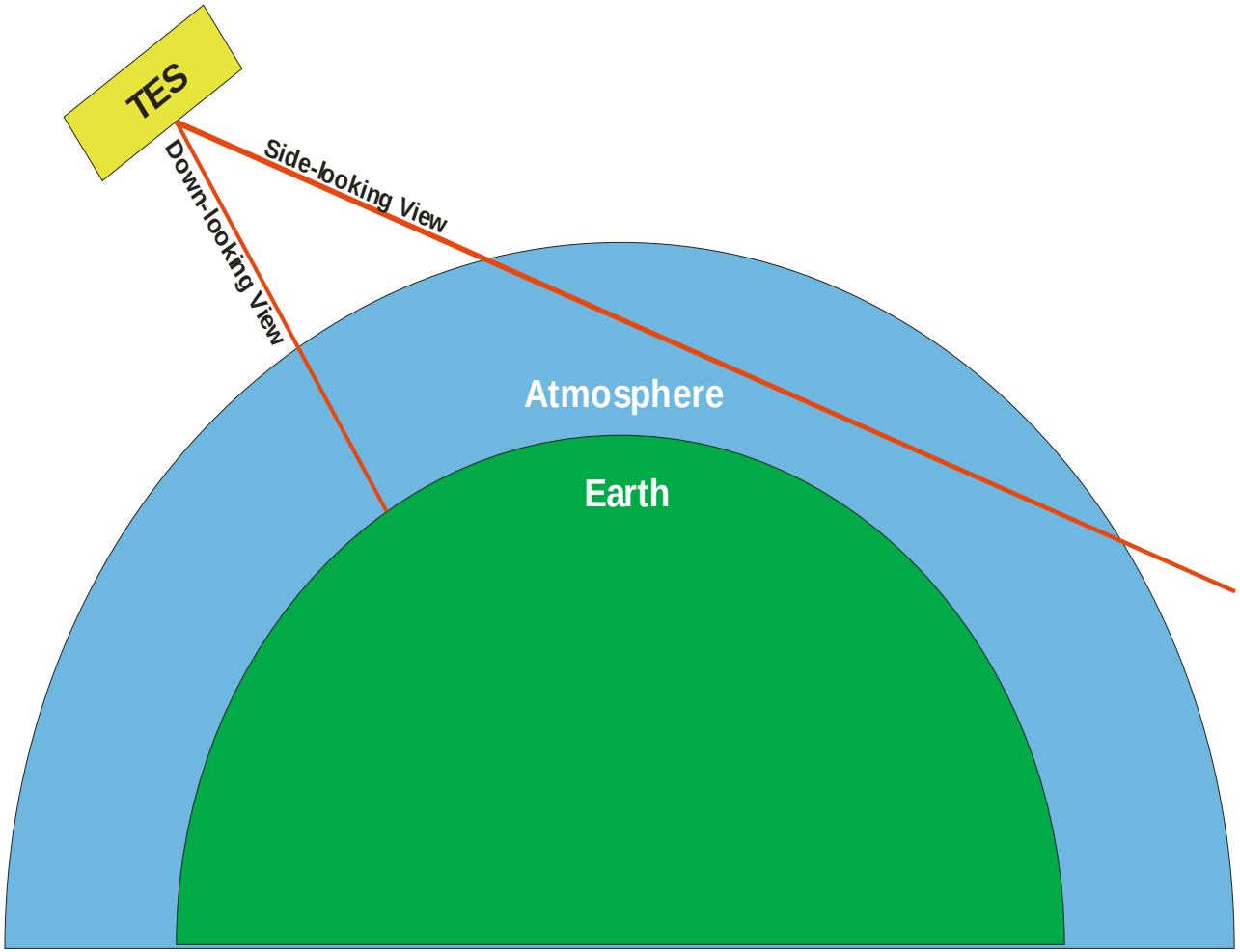


Introduction (3)

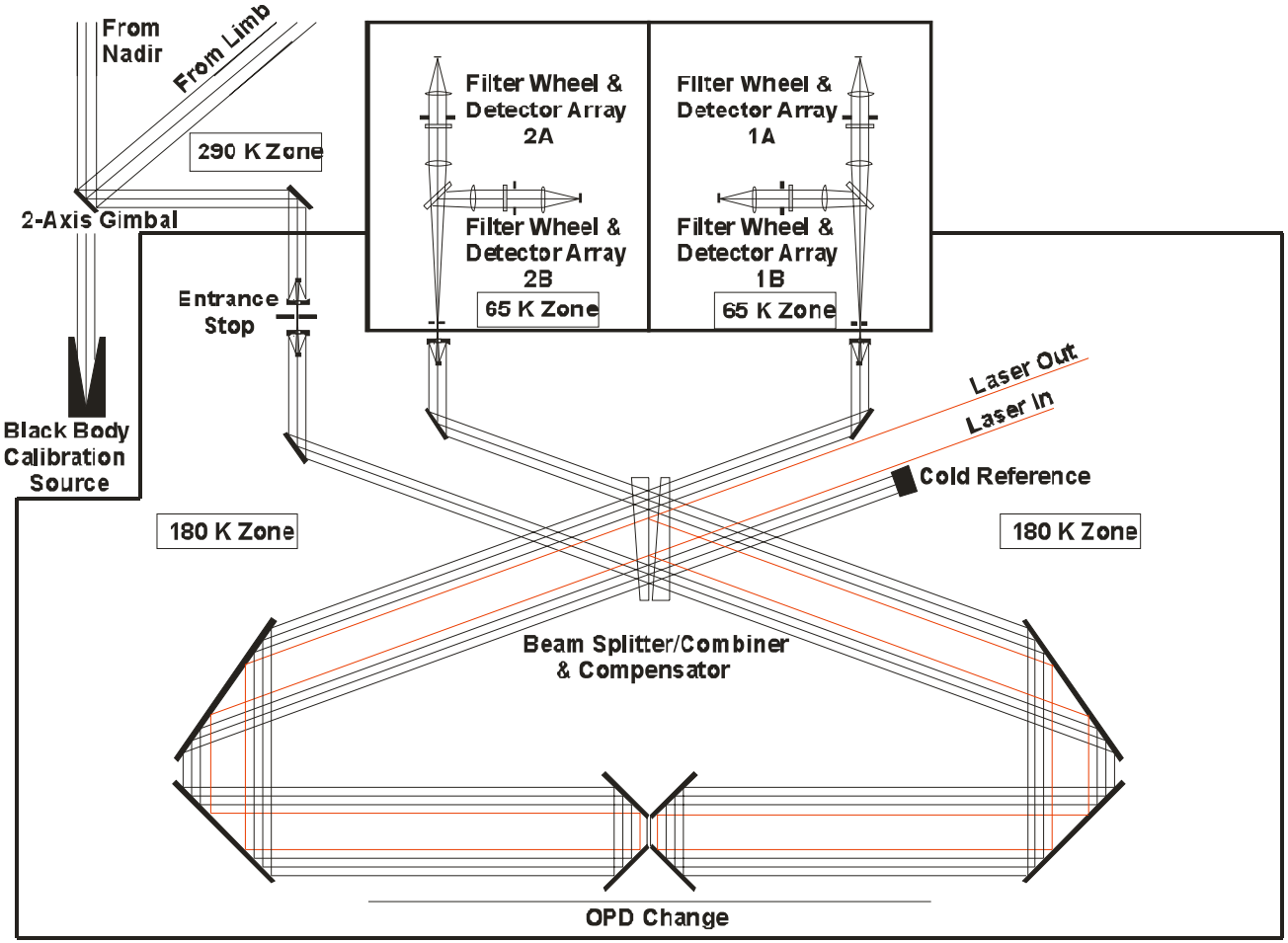
Most of this talk will be about an instrument specifically designed to make global and regional measurements of the key pollutant chemicals (especially ozone and carbon monoxide).

The instrument is called TES (Tropospheric Emission Spectrometer) that flies on the AURA spacecraft (with 3 other instruments) in a "polar" orbit that circles the Earth every 99 minutes. AURA was launched in July 2004 and is expected to last until at least 2009.

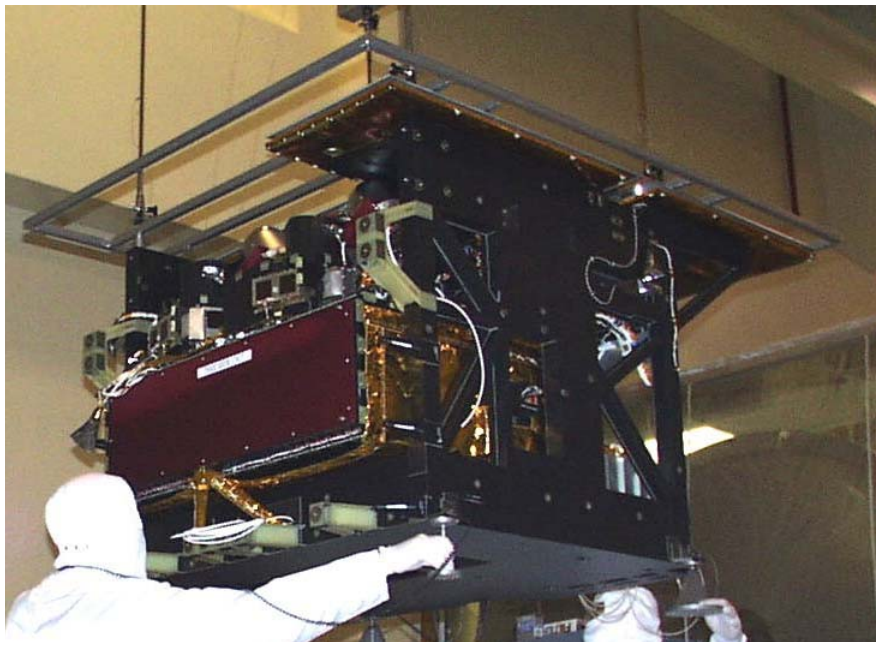
TWO WAYS OF LOOKING AT THE ATMOSPHERE



TES Optical Schematic



TES Interferometer and Detectors



TES (without thermal blankets or radiators)

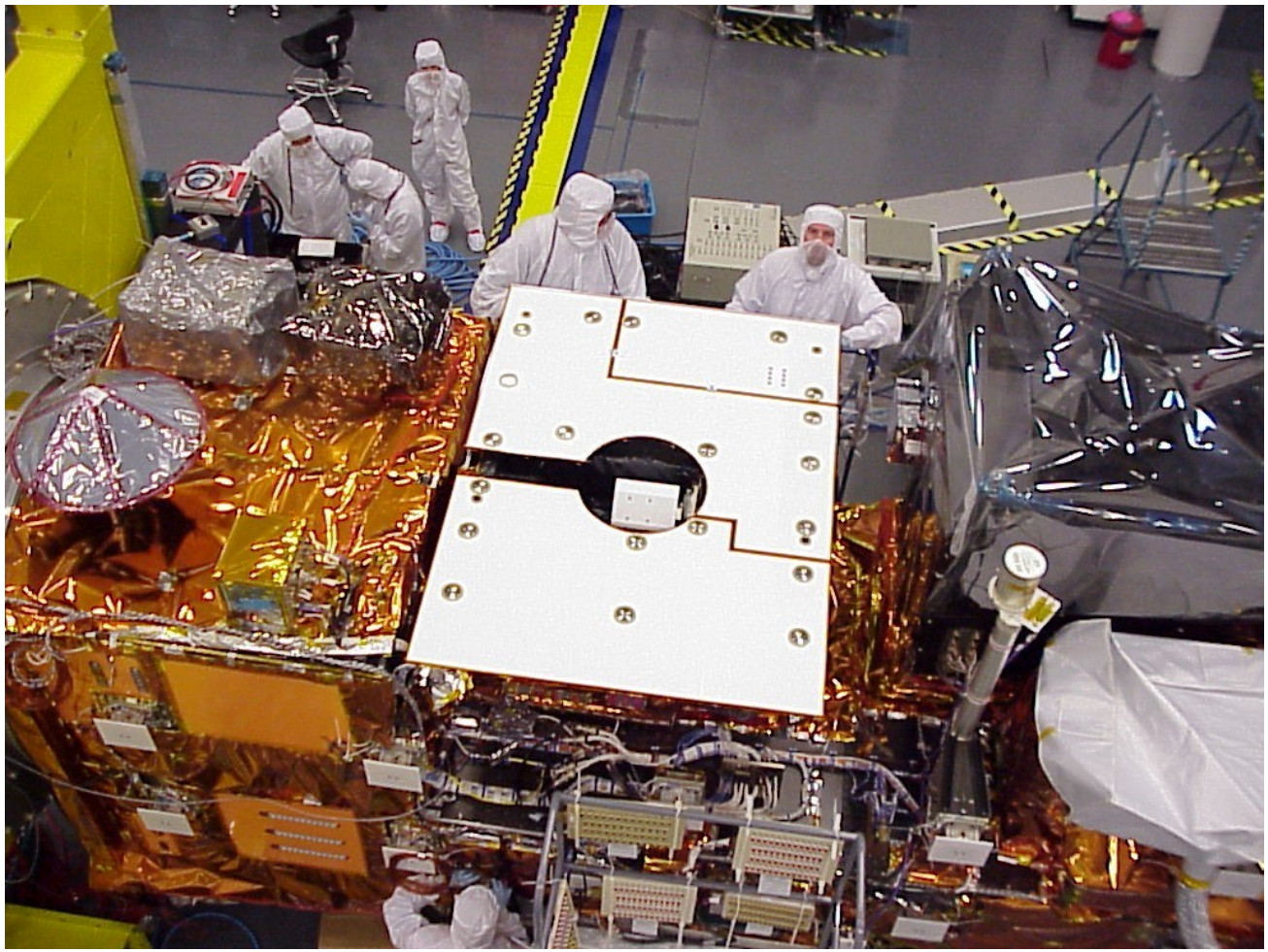
Spectrometer Type	**Connes'-type 4-port FTS**
Max. Optical Path Difference	**± 8.45 cm (nadir & calibration)** **± 33.8 cm (limb)**
Scan (integration) Time	**4 sec (nadir & calibration)** **16 sec (limb)**
Sampling Metrology	**Nd:YAG laser**
Spectral Resolution (unap)	**0.07 cm^{-1} (nadir)** **0.018 cm^{-1} (limb)**
Spectral Coverage	**650 to 3050 cm^{-1}** **(3.2 to 15.4 ? m)** **in 200 – 300 cm^{-1} bands**
Detector Arrays	**4 (1 x 16) arrays, optically-conjugated, all MCT PV @65K**
Signal-to-Noise Ratio (spectral)	**Up to 200:1** **Minimum requirement is 30:1**
Radiometric Calibration	**Internal, adjustable, cavity blackbody (340K) + cold space view**
Spatial Calibration	**Illuminated slit scanned across FOV**
Radiometric Accuracy	**< 1K 650 – 2500 cm^{-1}** **< 2K 2500 – 3050 cm^{-1}**

TES Pointing and Operating Modes

Field of Regard	**45° cone about nadir; trailing limb 0 – 34 km; cold space; internal calibration sources**
Pointing Accuracy	**75 μrad pitch 750 μrad yaw 1100 μrad roll**
Spatial Resolution	**0.5 x 5 km (nadir) 2.3 x 23 km (limb)**
Operating Modes	**1) Global (spot) coverage in 16 orbits every other day 2) Continuous transects up to 800 km long 3) Stare at specific targets for up to 208 seconds**

TES gimbal pointing mirror

TES on Aura

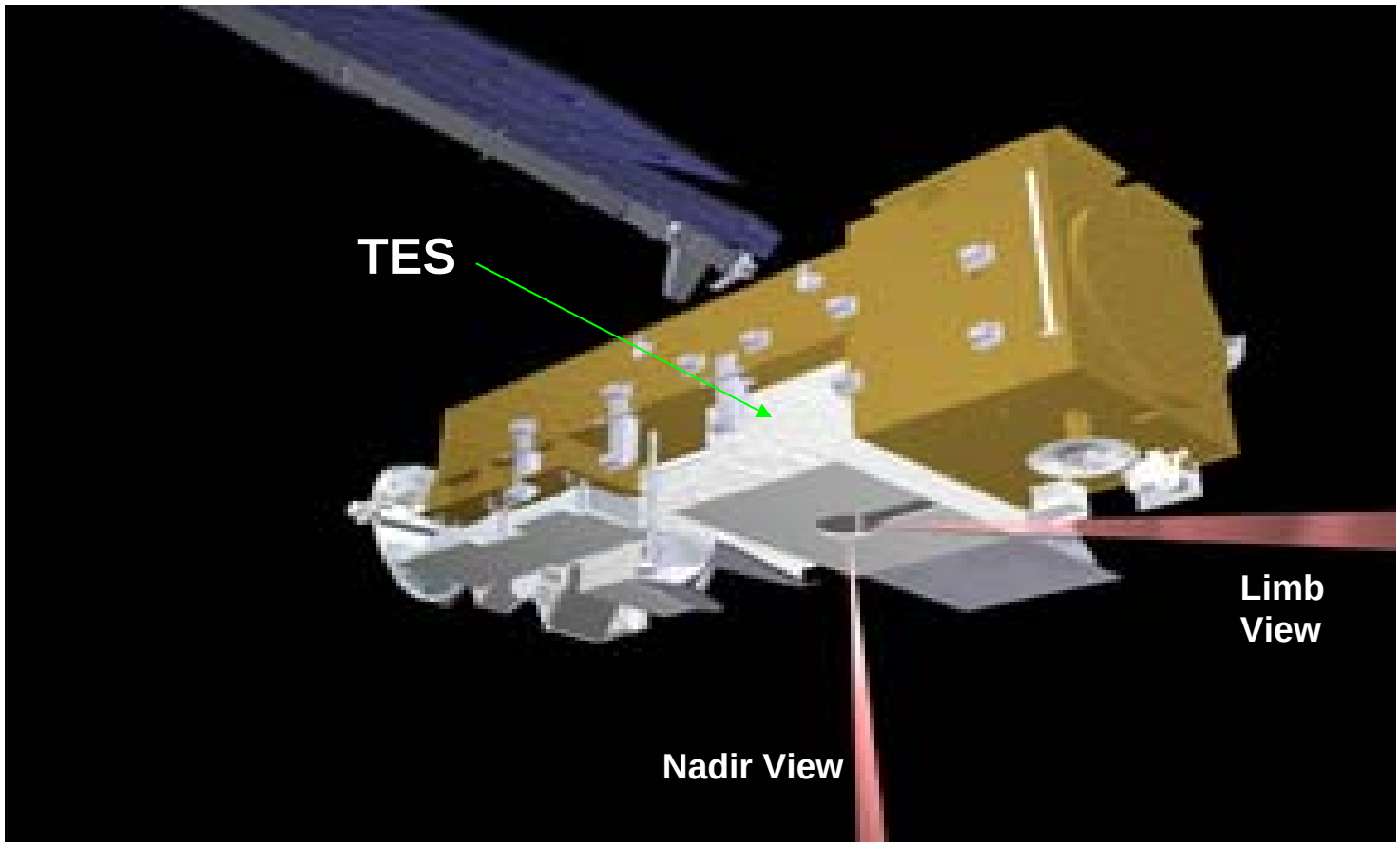


Space View Side

AURA Launch 3 am 14 July 2004

AURA Launch 3 am 14 July 2004

TES on the Aura Spacecraft



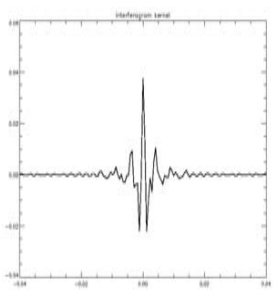
TES Algorithm Overview

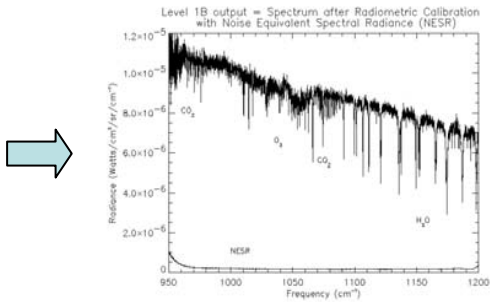
Level 1A: Produces geolocated interferograms.

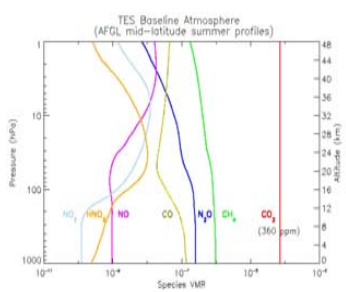
Level 1B: Produces radiometrically and frequency calibrated spectra

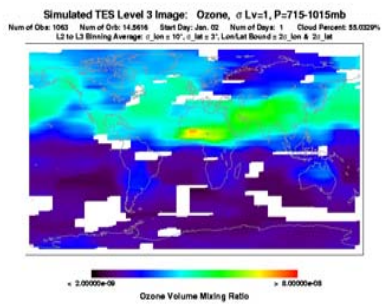
Level 2: Produces concentration and temperature profiles.

Level 3: Produces global maps.

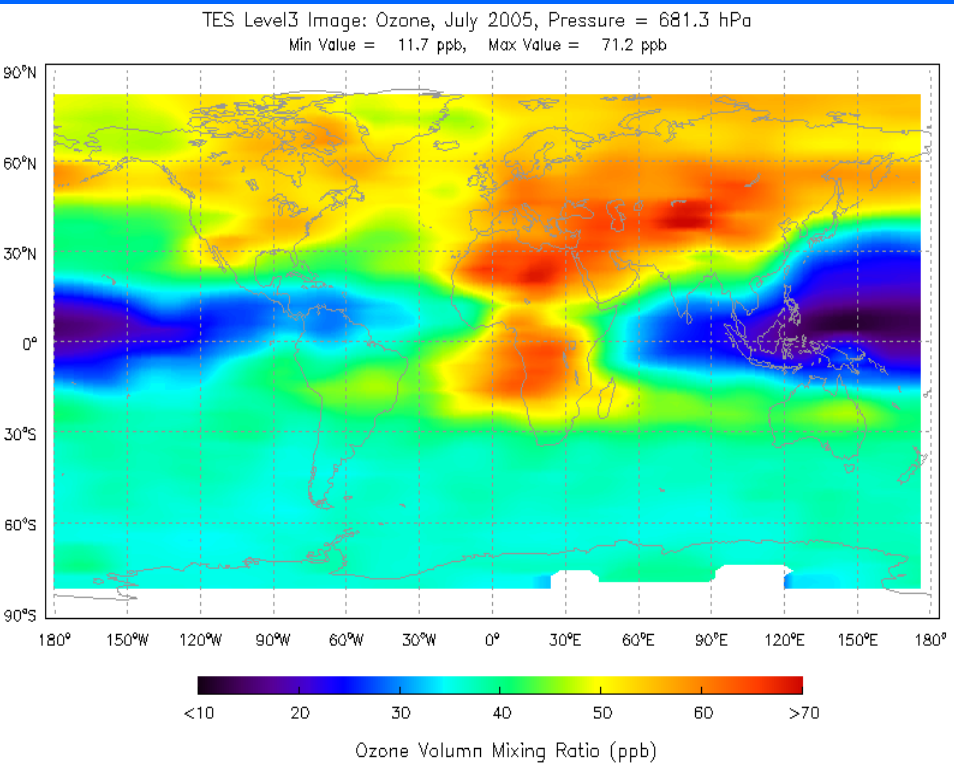


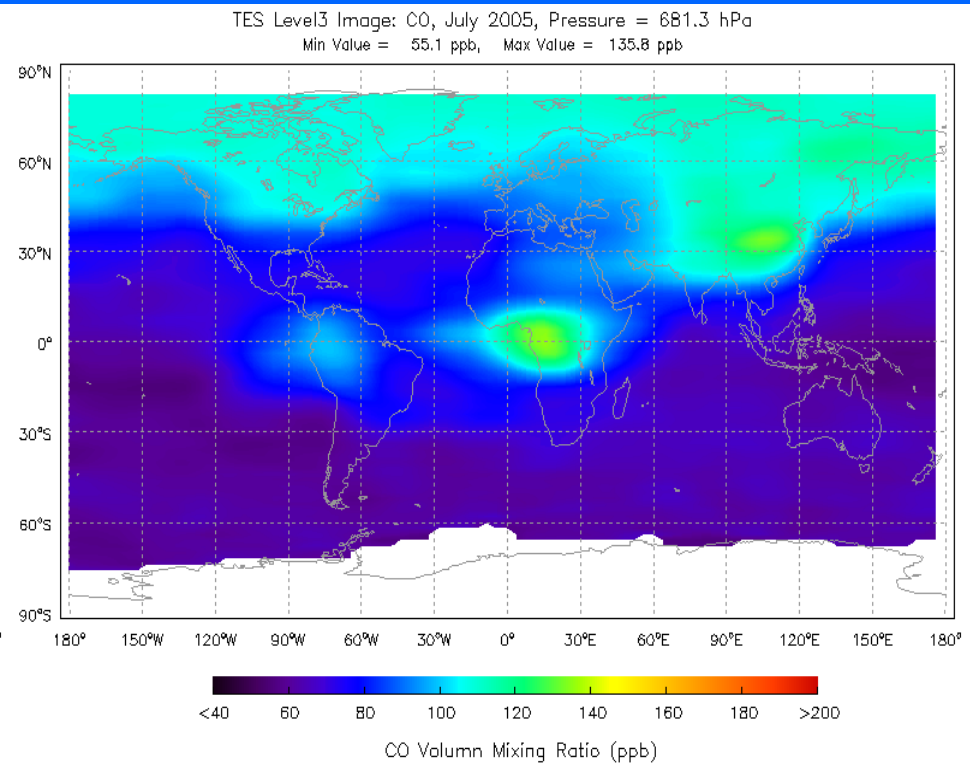






TES Monthly Mean Concentrations at 4 km, July 2005

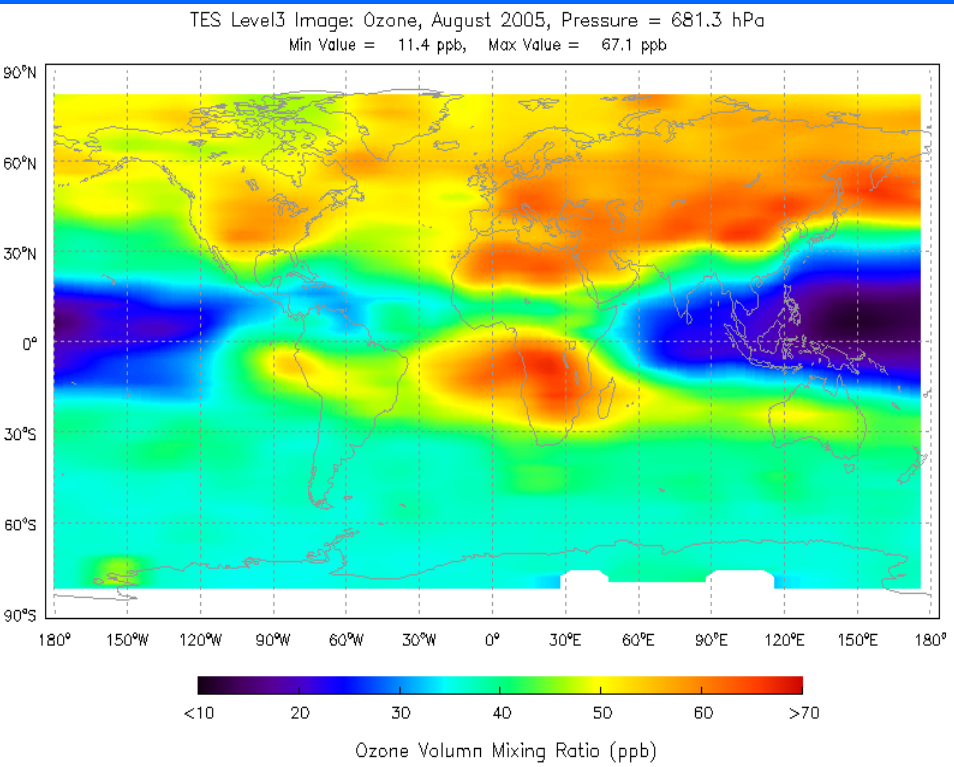


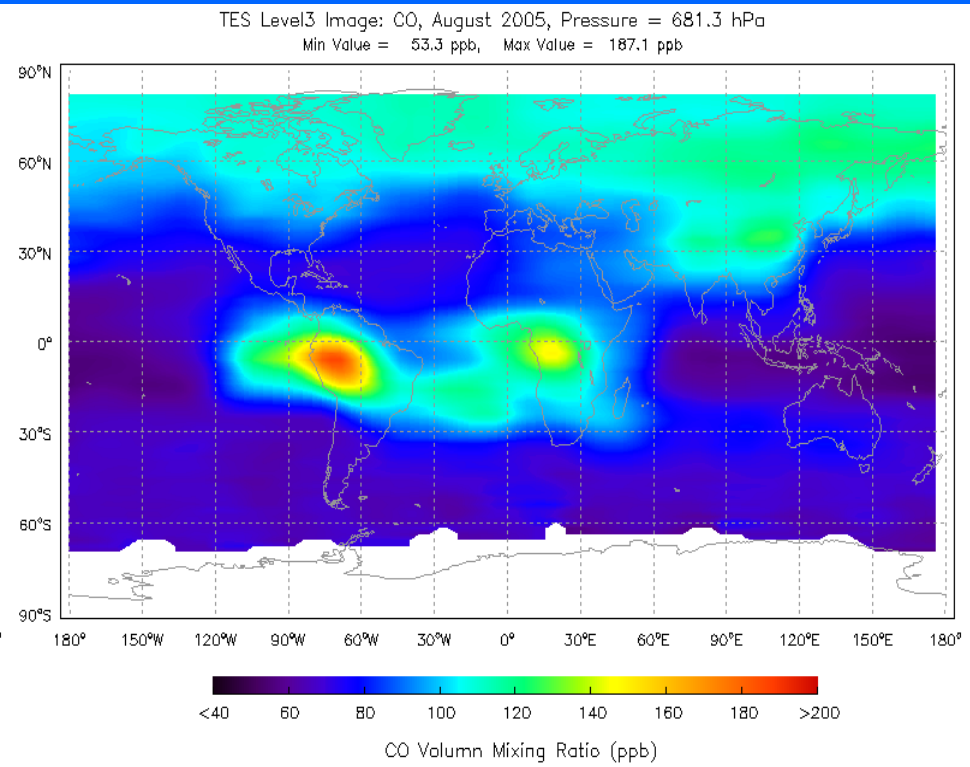


Ozone

Carbon Monoxide

TES Monthly Mean Concentrations at 4 km, August 2005

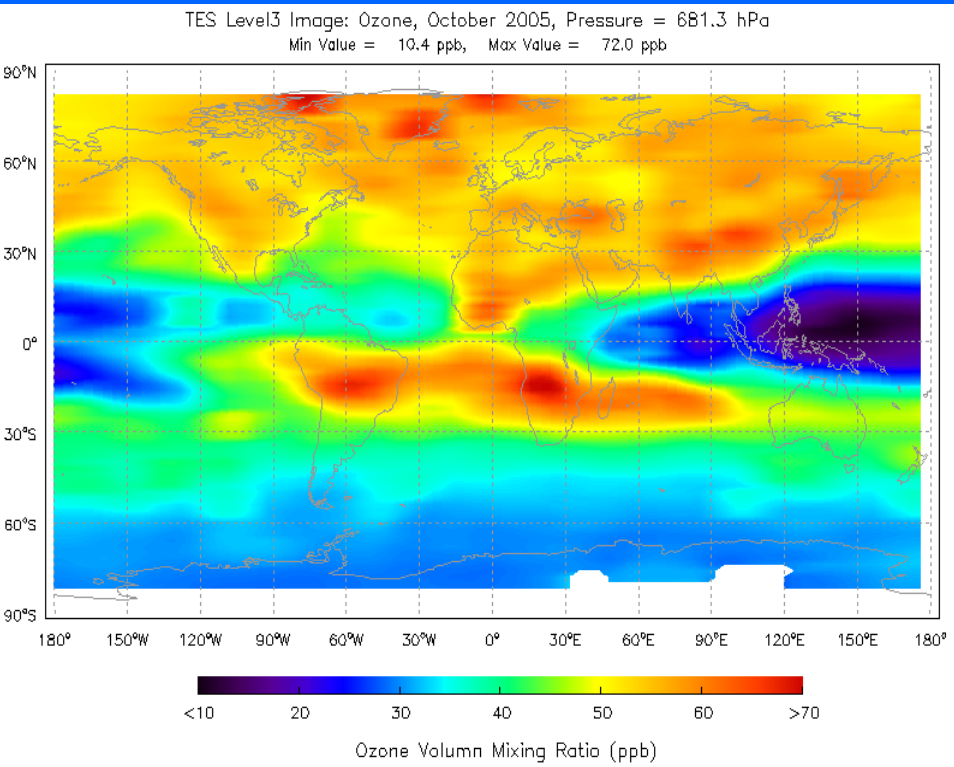


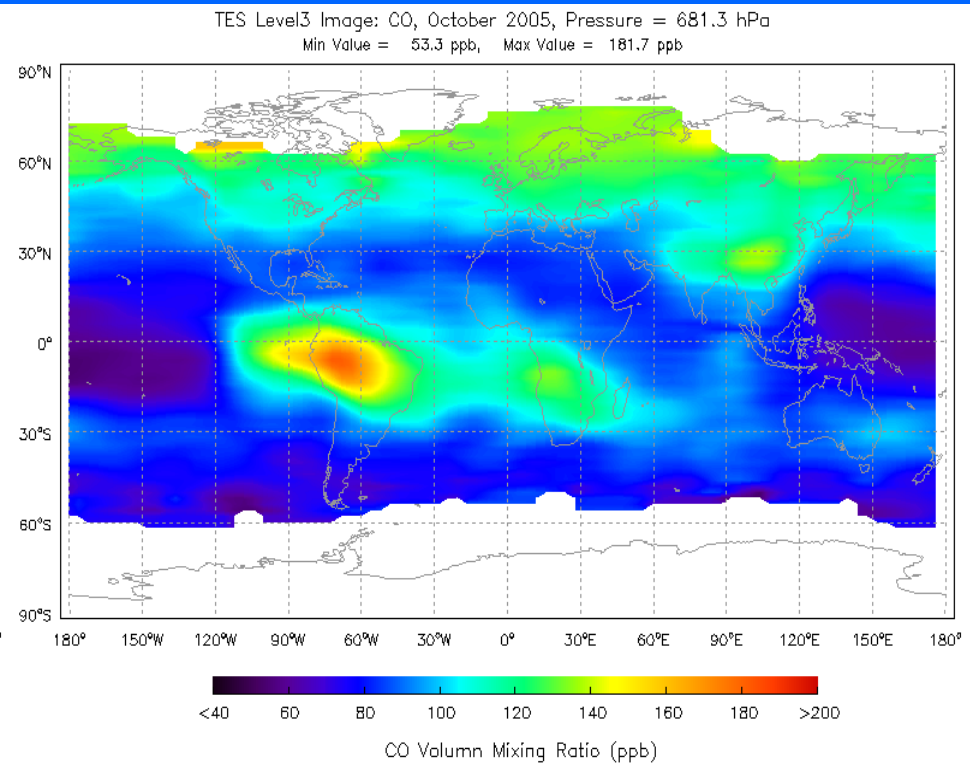


Ozone

Carbon Monoxide

TES Monthly Mean Concentrations at 4 km, October 2005

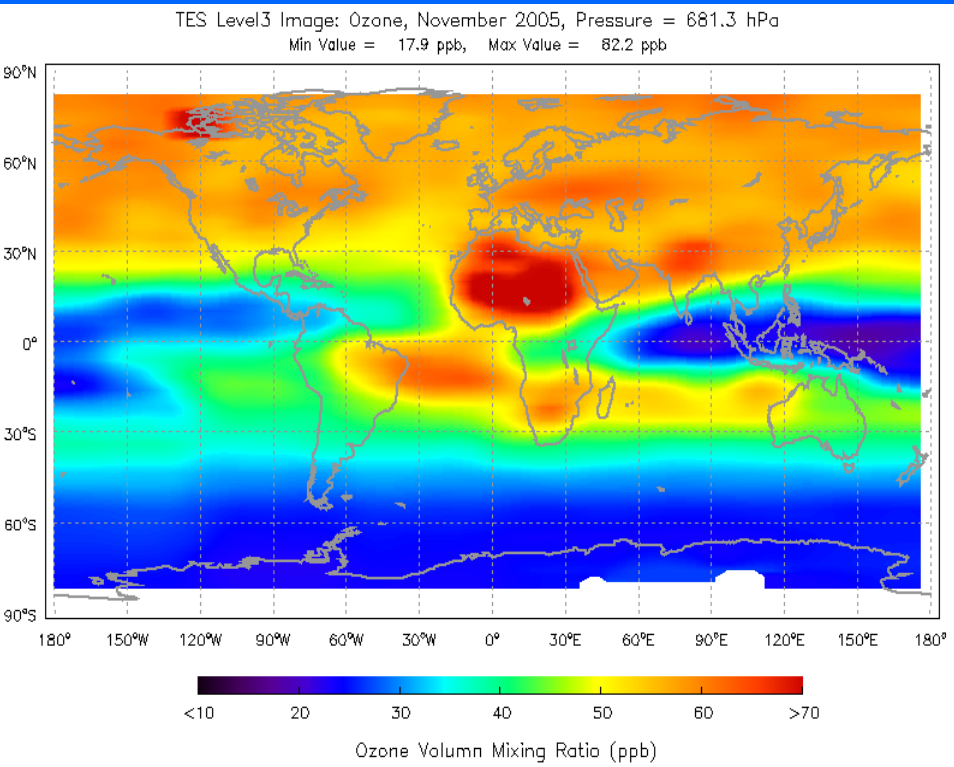


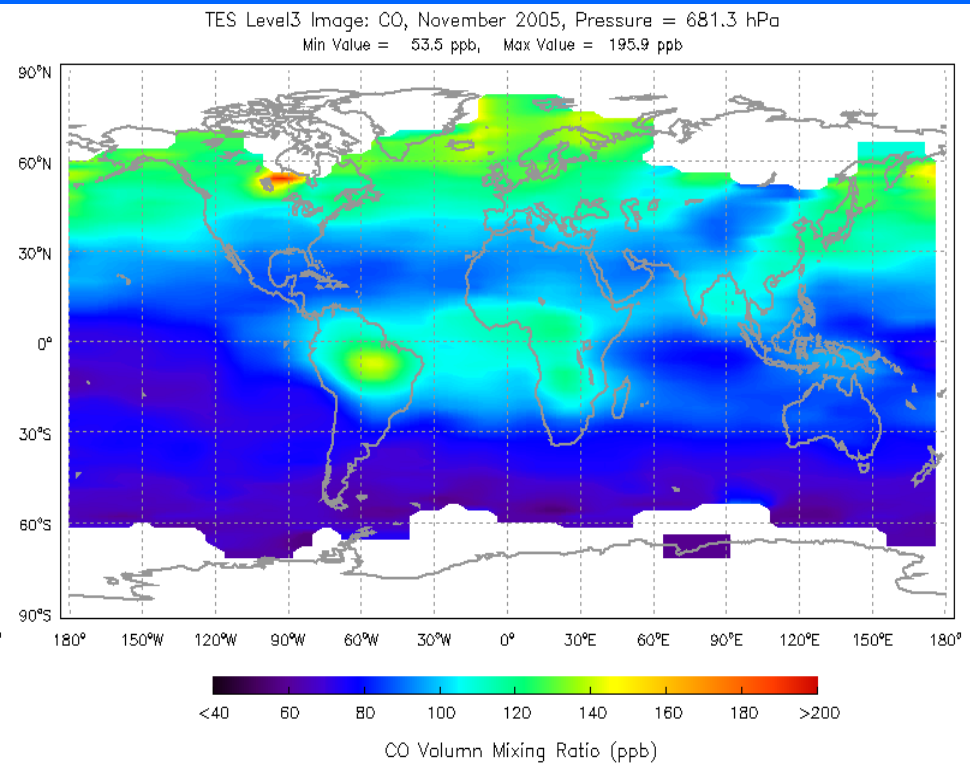


Ozone

Carbon Monoxide

TES Monthly Mean Concentrations at 4 km, November 2005

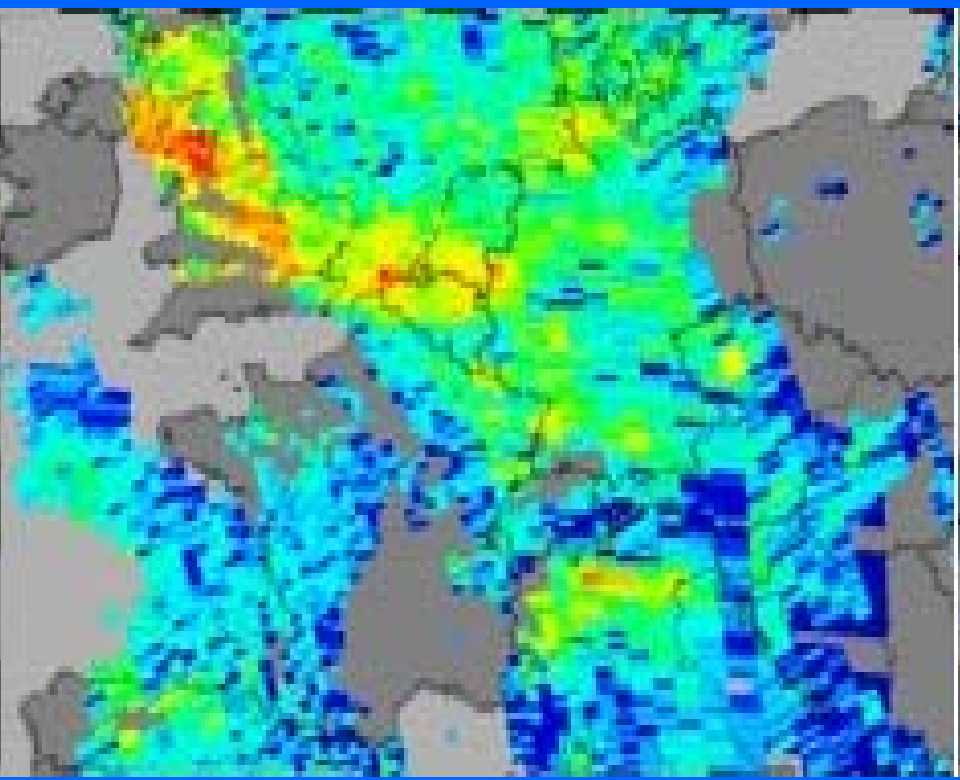




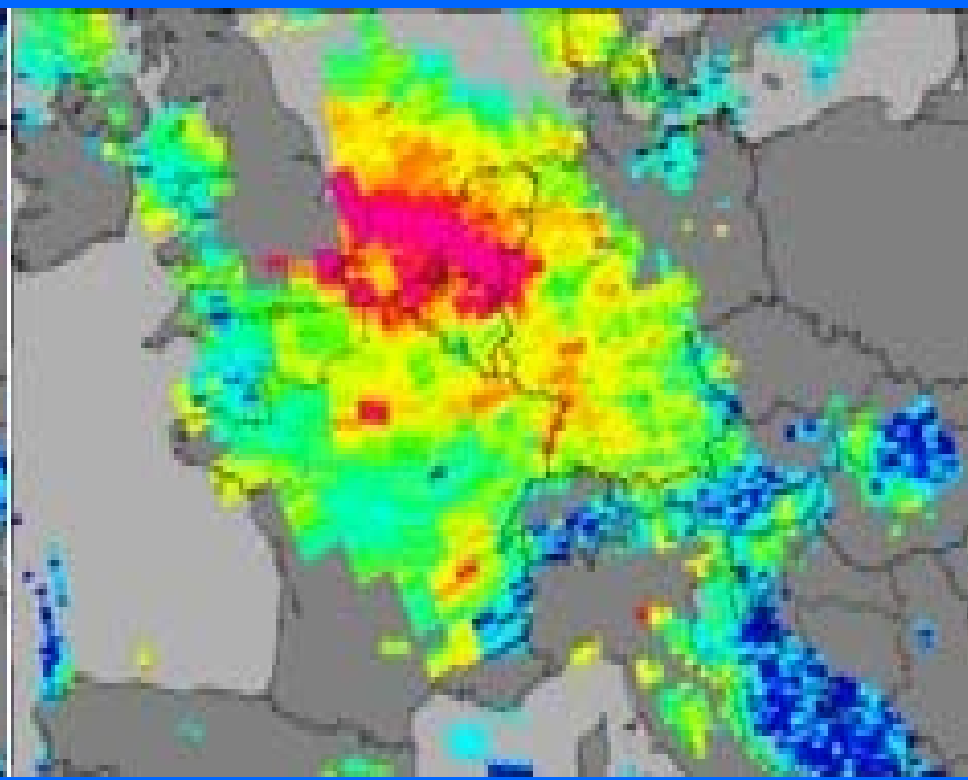
Ozone

Carbon Monoxide

Ozone Monitoring Instrument (OMI, also on AURA)
Daily Maps of Tropospheric NO_2

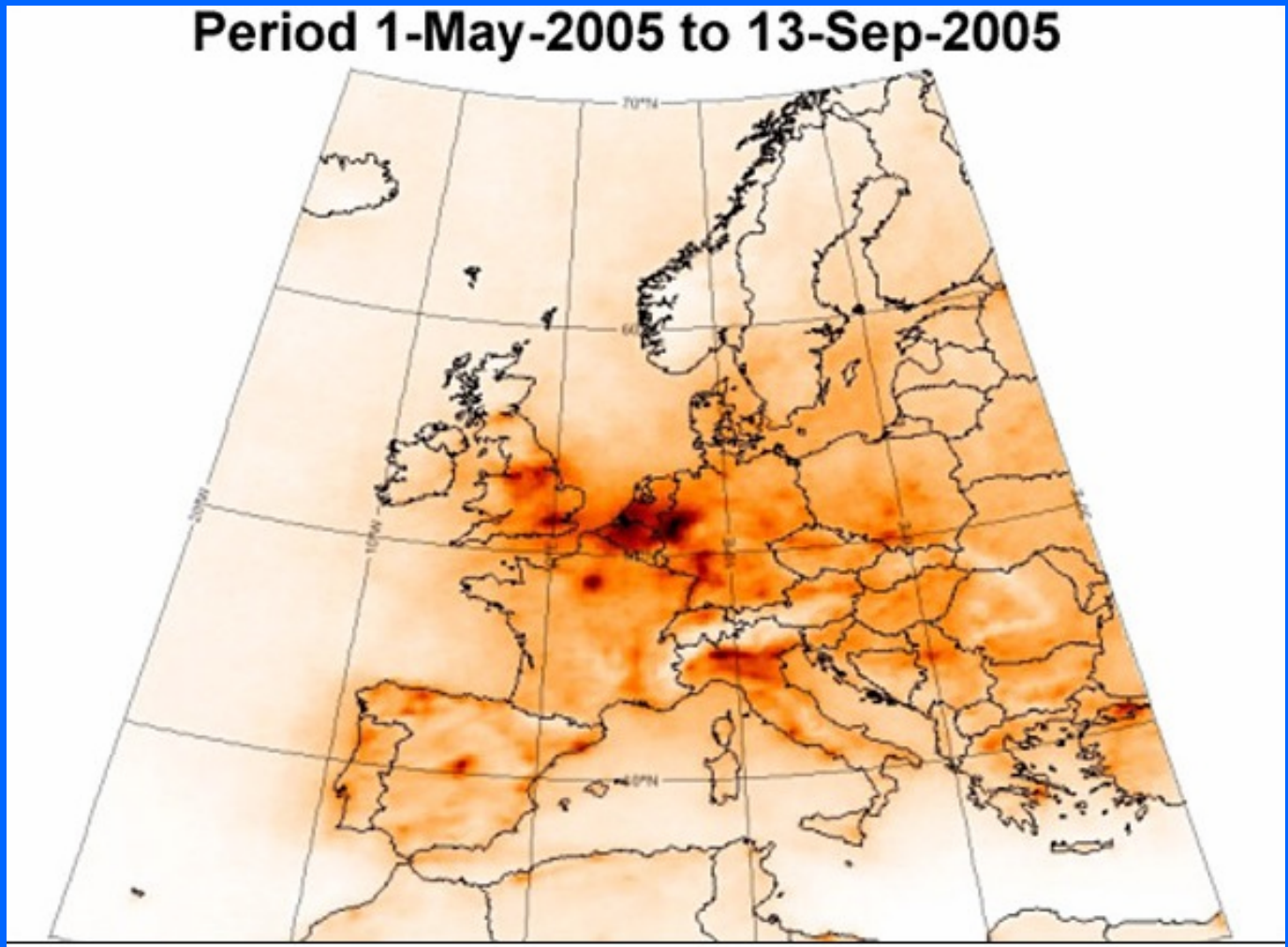


Sunday 16 October 2005



Monday 17 October 2005

OMI Summer Average NO_2



The map details strong presence of nitrogen dioxide, an important precursor in the production of ground-level ozone. (*Image: KNMI/FMI/NIVR/Nasa*)

Chemistry & Transport Models

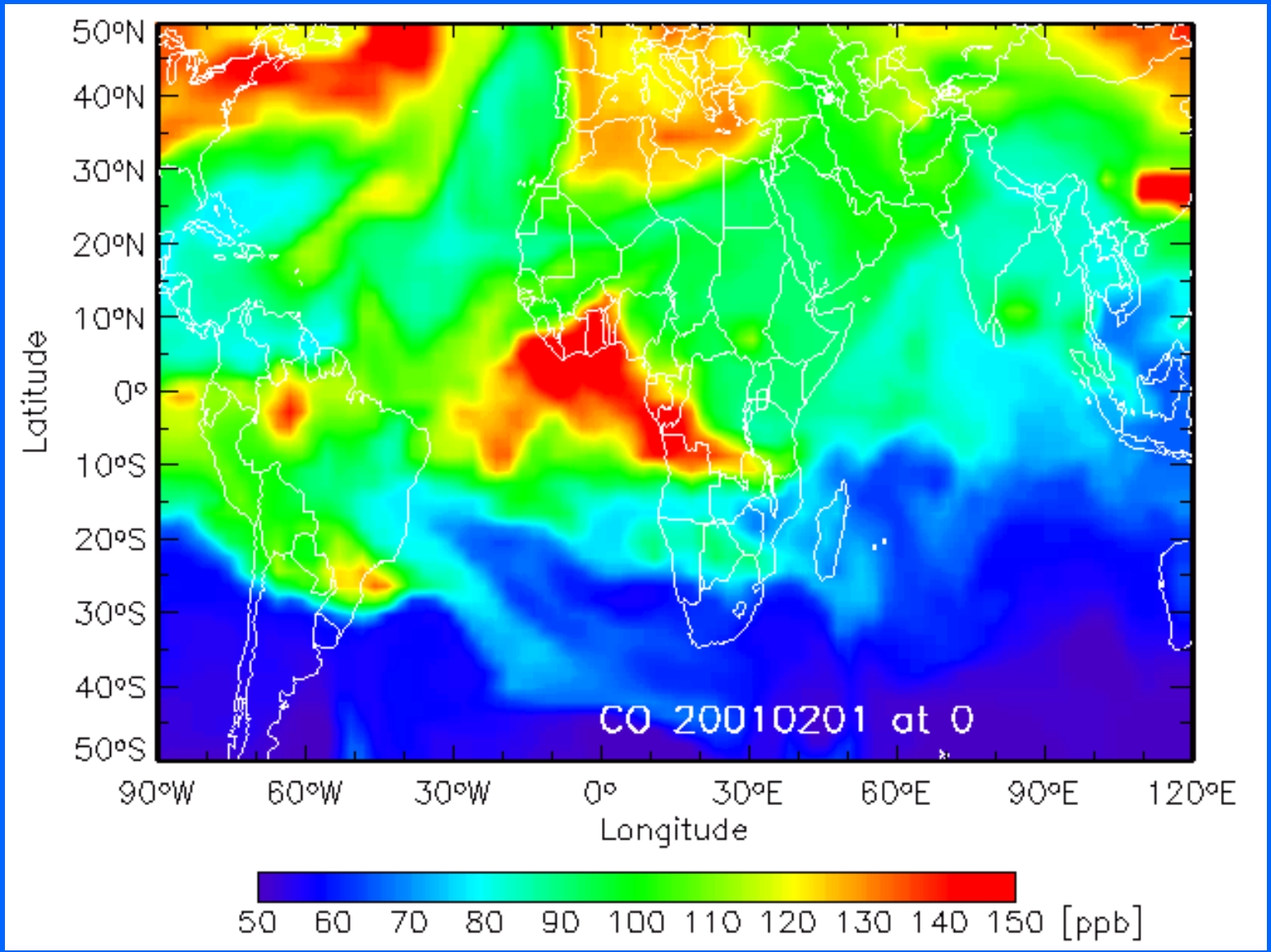
The next slide shows an example of a Chemistry & Transport Model (CTM).

CTM's inject as much atmospheric chemistry as possible into a rendition of atmospheric circulation. In this case, the circulation was based on the actual meteorology for the month of February 2001.

The sources of the chemicals are emission inventories that are good in the developed world, less so elsewhere.

Nevertheless, they provide an excellent picture of how pollution spreads across the planet (and they are improving all the time).

Harvard University GEOS-CHEM Model: CO at 5 km, 2001 February



The Next Step

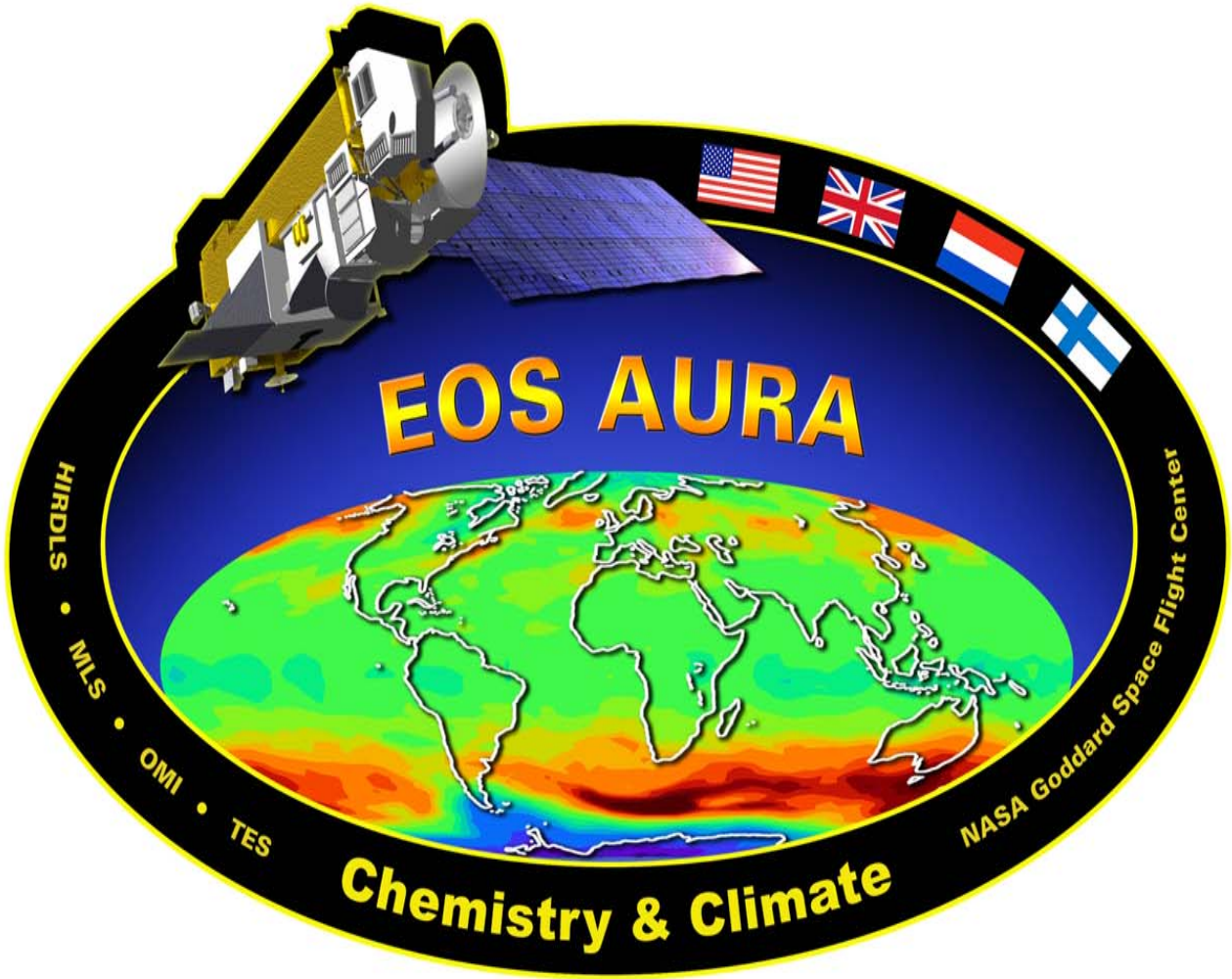
The next step in this field is called “Data Assimilation”.

In this process, a model such as the one on the previous slide is continuously updated by observations.

This task is computationally *very expensive* but will eventually permit the issuance of a “chemistry forecast” on the evening news. Several groups around the world are working on this problem.

Indeed, data assimilation was originally developed for numerical weather forecasting using (mainly) weather balloon reports from around the world (every 6 hours).

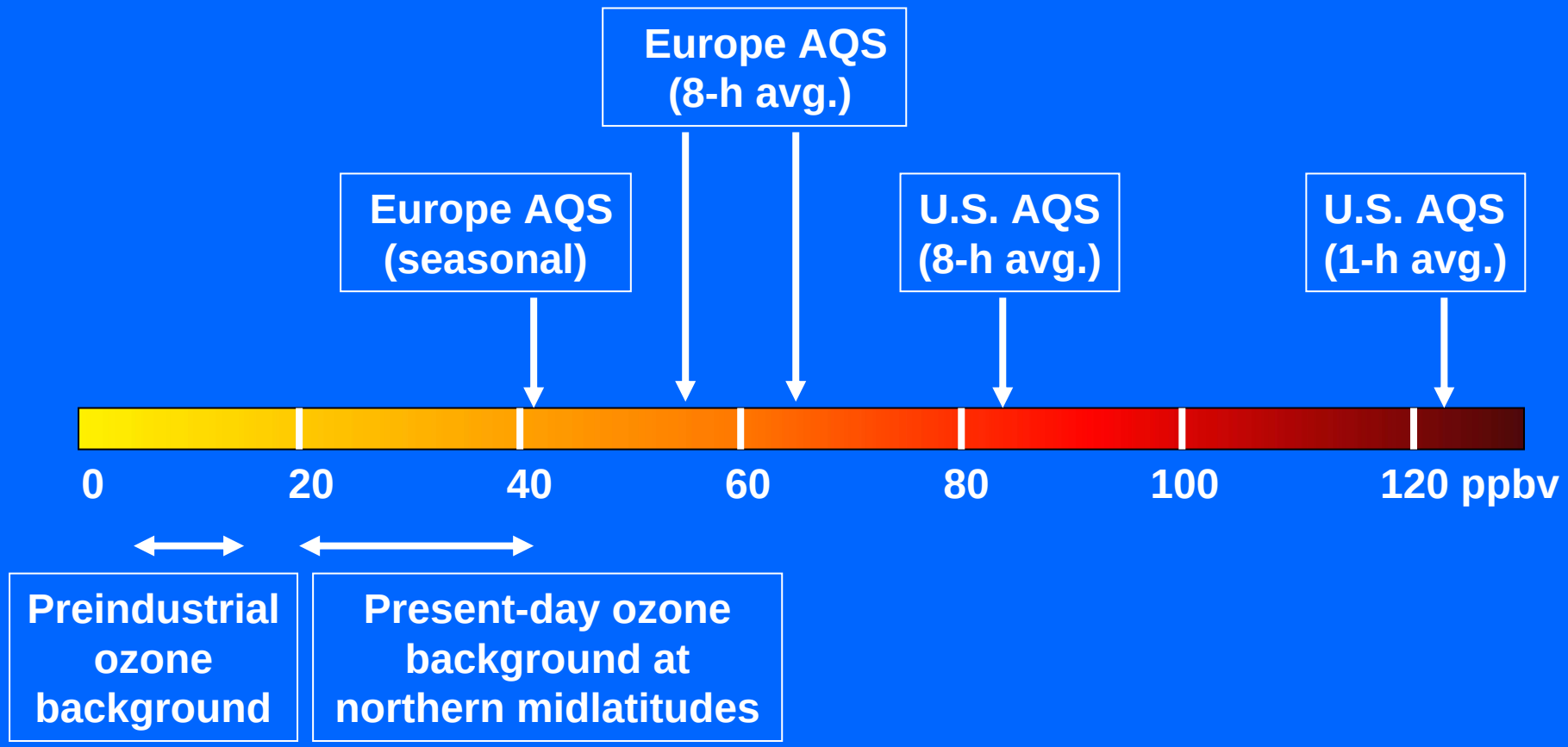
The TES Team



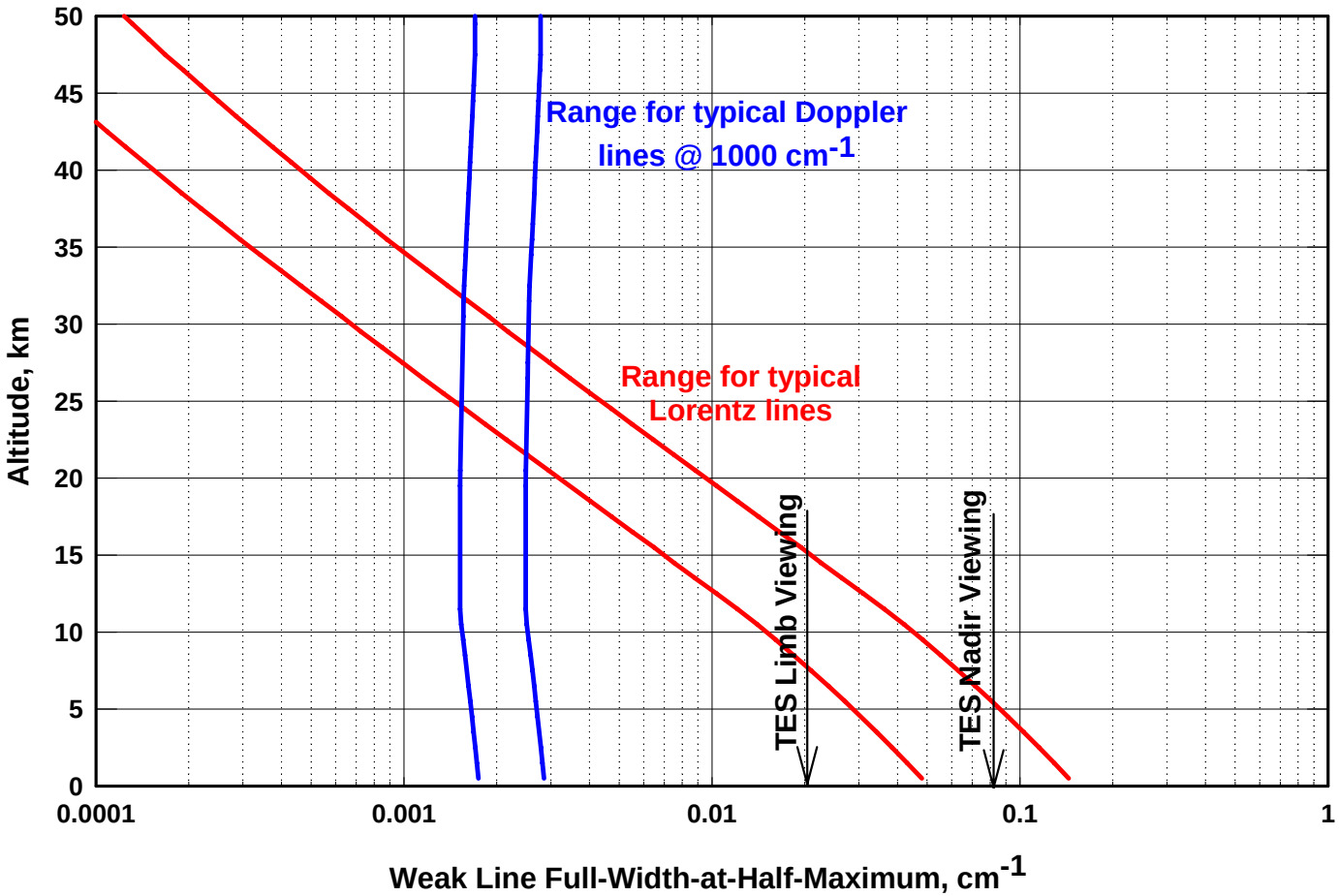
For more information, go to http://tes.jpl.nasa.gov

BACKUP

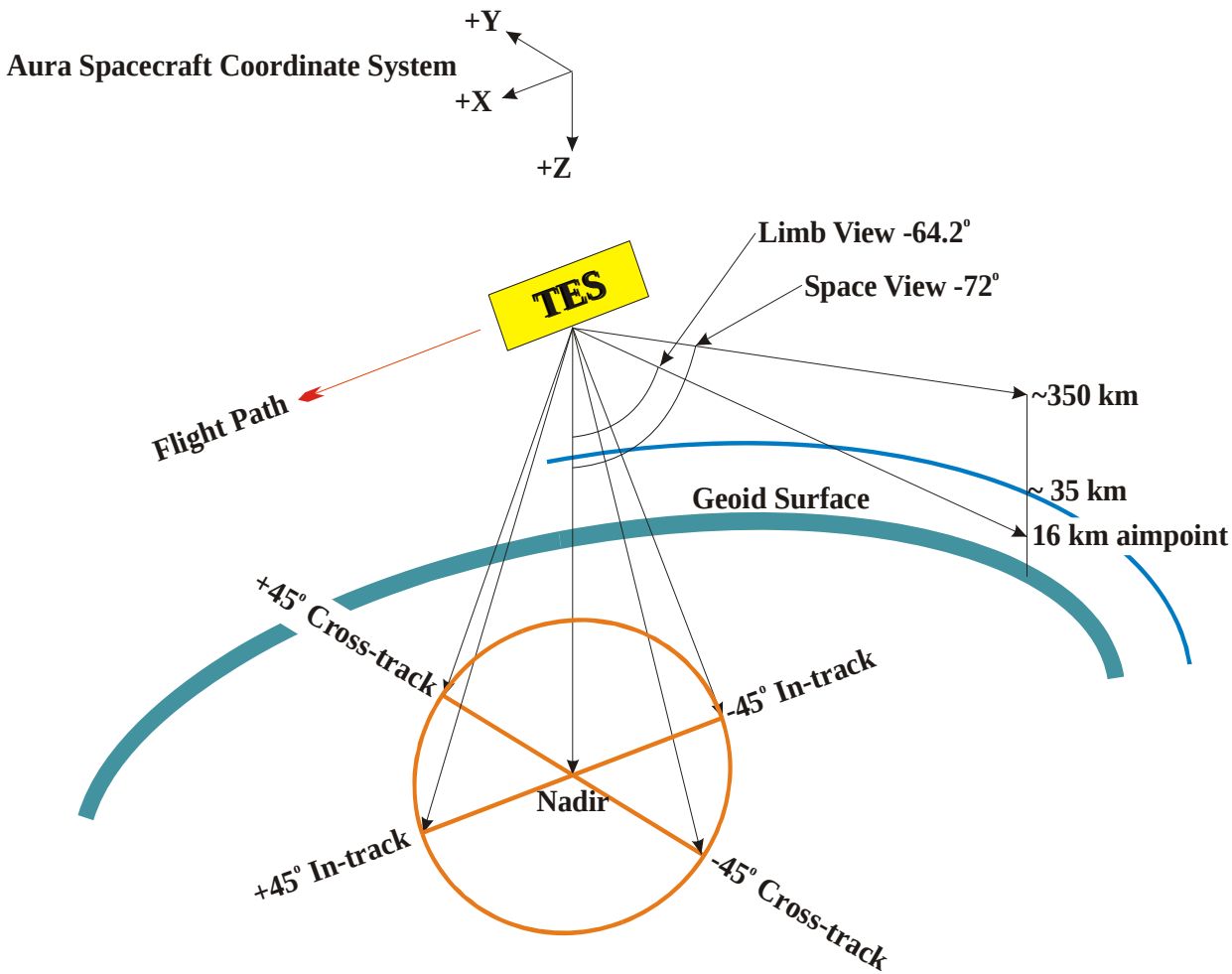
HEMISPHERIC OZONE POLLUTION: IMPLICATIONS OF ENHANCED BACKGROUND FOR MEETING AIR QUALITY STANDARDS (AQS)



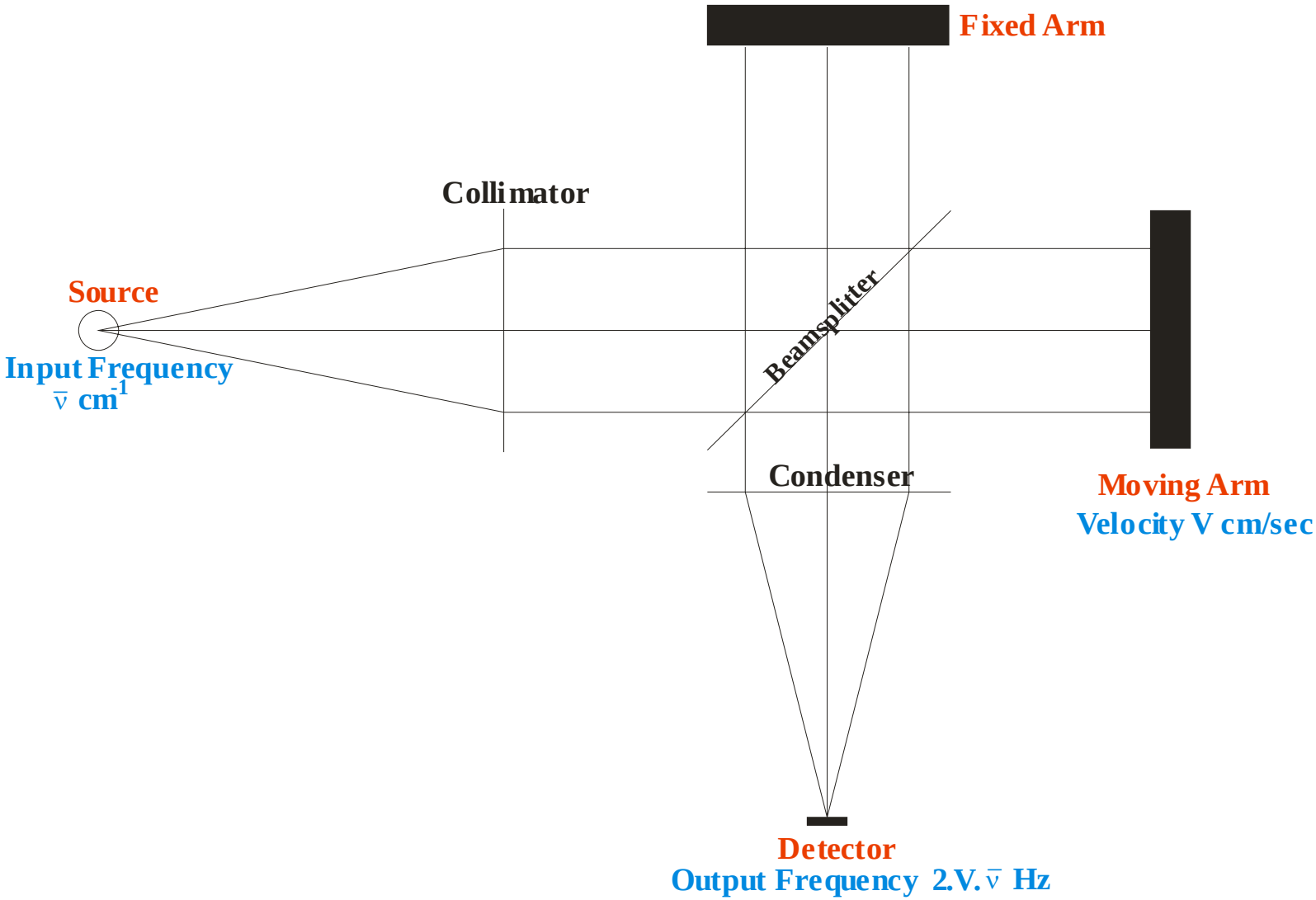
Spectral Linewidths in the Atmosphere



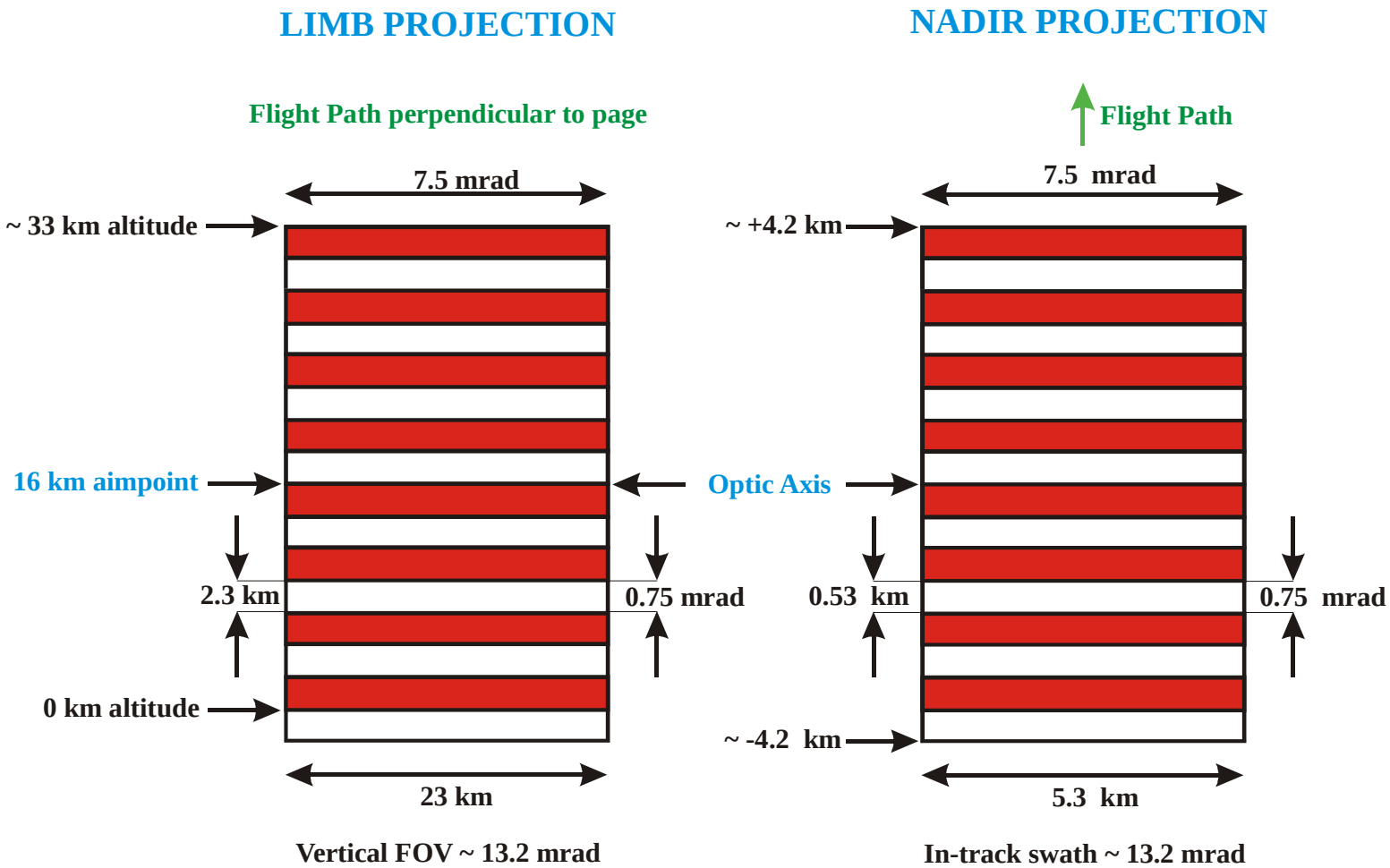
TES Viewing Modes



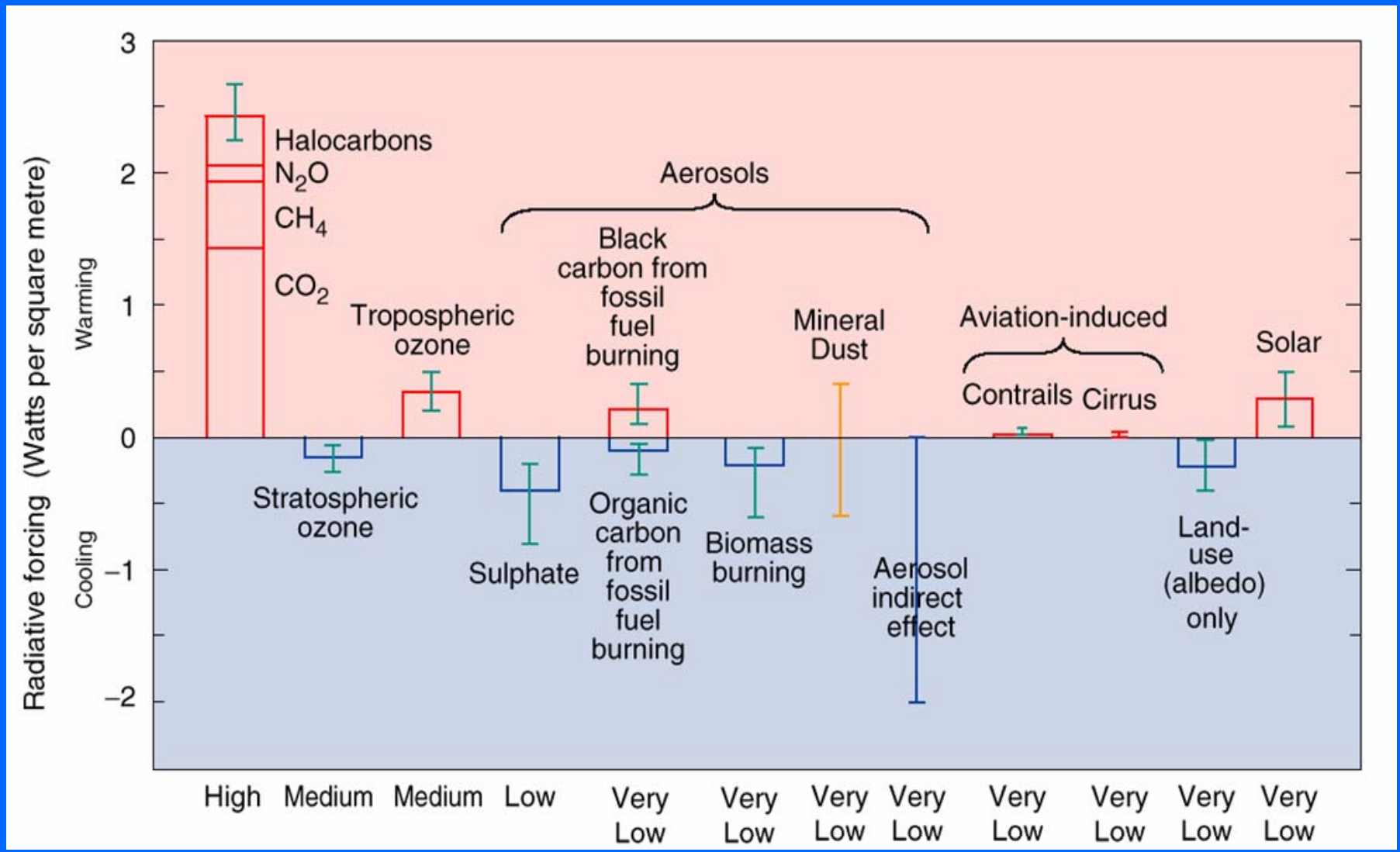
PRINCIPLE OF THE MICHELSON INTERFEROMETER



TES Footprint at Nadir & Limb



Ozone and Climate Forcing



The Connection Between Tropospheric Carbon Monoxide (CO) and Ozone (O_3)

When the concentration of Nitric Oxide (NO) is less than about 30 ppt (i.e., in unpolluted areas), CO *destroys* O3 *via*

$$HO_2 + O_3 \longrightarrow OH + 2O_2$$
$$CO + OH \longrightarrow H + CO_2$$
$$H + O_2 + M \longrightarrow HO_2 + M$$

("M" is any other molecule, e.g. N_2)

Net Result: $CO + O_3 \longrightarrow CO_2 + O_2$ (CO & O_3 anticorrelated)

However, in polluted areas (NO >> 30 ppt), CO *creates* O3!

$$NO_2 + h\nu \longrightarrow O + NO$$
$$O + O_2 + M \longrightarrow O_3 + M$$
$$CO + OH \longrightarrow H + CO_2$$
$$H + O_2 + M \longrightarrow HO_2 + M$$
$$HO_2 + NO \longrightarrow OH + NO_2$$

Net Result: $CO + 2O_2 + h\nu \longrightarrow CO_2 + O_3$ (CO & O_3 correlated)