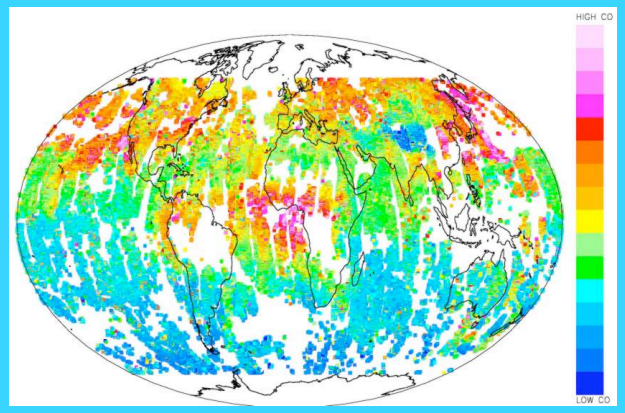
Carbon Monoxide Measurements from Space
Past, Present and Future



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Outline

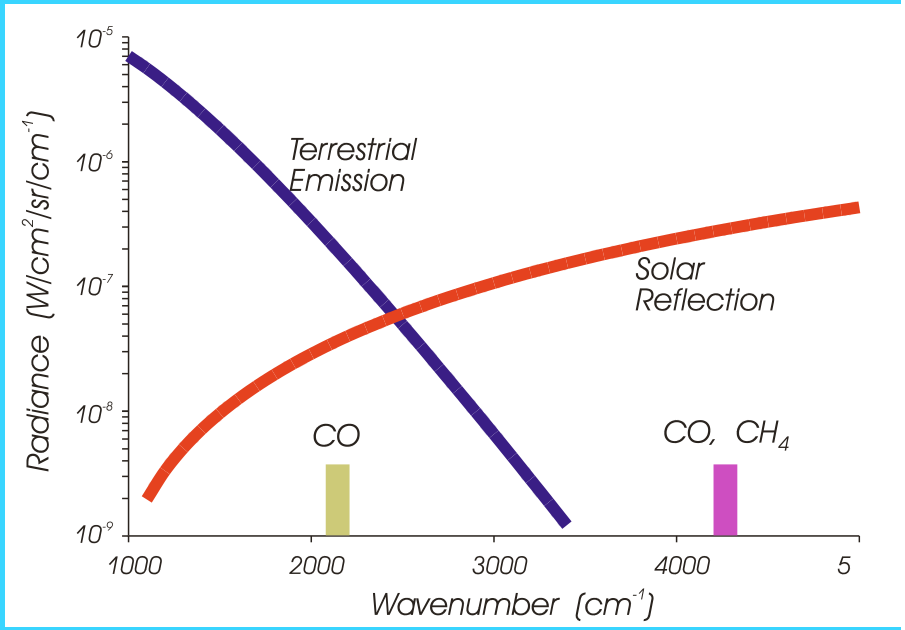
- Basic Sounding Issues
- Current Measurements
- Prospect for future measurements

Basic Sounding Issues

- Spectral range
  - Absorption bands
  - Spectral resolution
  - Vertical resolution
- Viewing Geometry
  - Limb
  - Nadir
- Orbital considerations
  - Coverage
- Miscellaneous
  - Clouds and bias

Spectral Bands

- CO only has two usable spectral bands in the infrared plus microwave rotation spectrum
- Band at 2140 cm-1 (4.7um) has a strong emission component in nadir signals
- Band at 4200 cm-1 (2.4.um) is much weaker (overtone band) and has significantly less emission signal
- All bands have other components as contaminating spectra
- Choice of spectral band significantly influences the type of information retrieved from the measurement



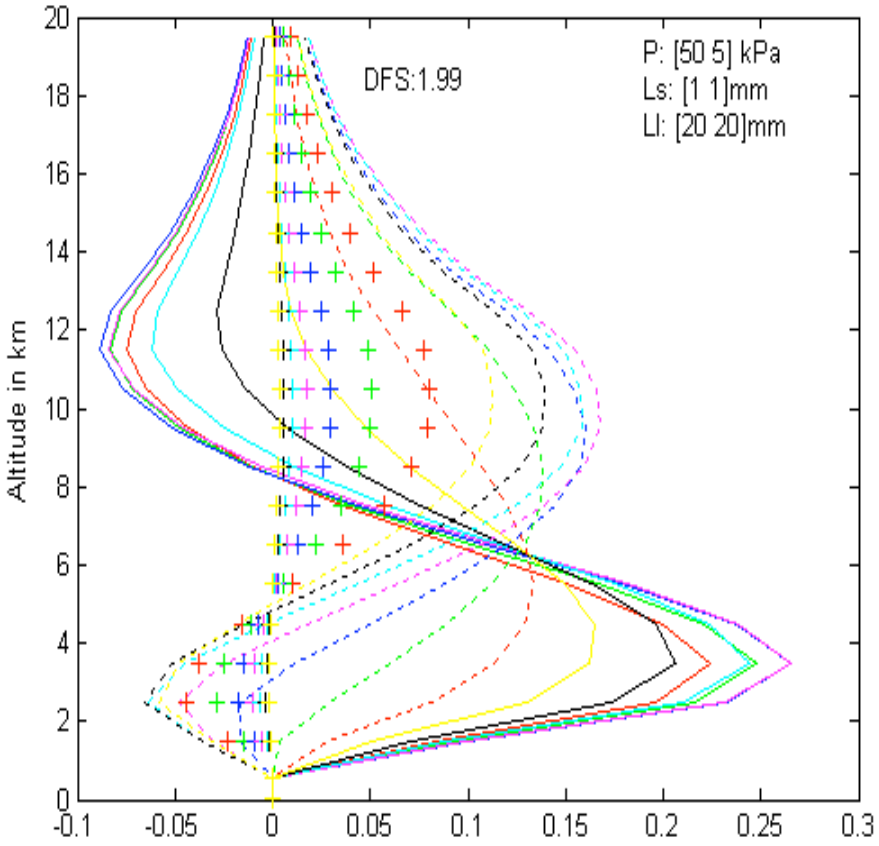
Spectral Resolution

- Spectral resolution affects how much information can be retrieved from a given measurement
- More spectral resolution
  - More detail (information)
  - Less signal-to-noise
- All space instruments have some compromise in spectral resolution
- Spectral resolution determines the amount of information that can be retrieved from a measurement
  - Often manifests itself in terms of vertical resolution

The Limits of Physics

	Signal-to-Noise			
Res'n	10	50	100	500
1	**0.061**	**0.63**	**0.92**	**1.6**
.5	**0.11**	**0.77**	**0.97**	**1.5**
.1	**0.5**	**1.9**	**2.4**	**3.4**
.05	**1.5**	**2.5**	**3**	**4.5**
.025	**1.9**	**2.8**	**3.3**	**4.7**
.0125	**2**	**3.1**	**3.6**	**5.3**
.006	**2.19**	**3.41**	**4.12**	**5.75**

DFS = Degrees of Freedom for Signal

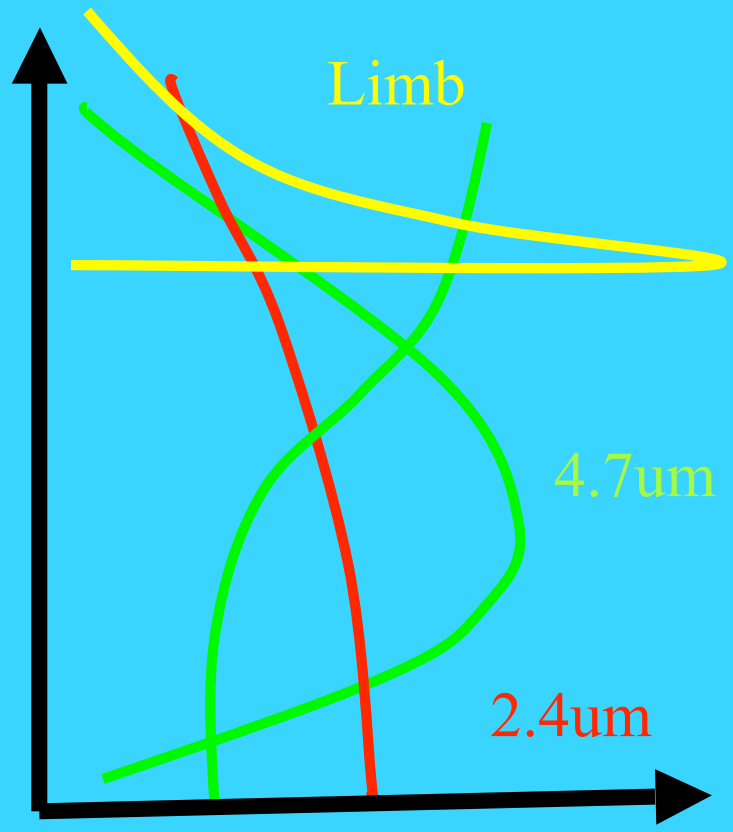


Mapping the Troposphere

Exchange

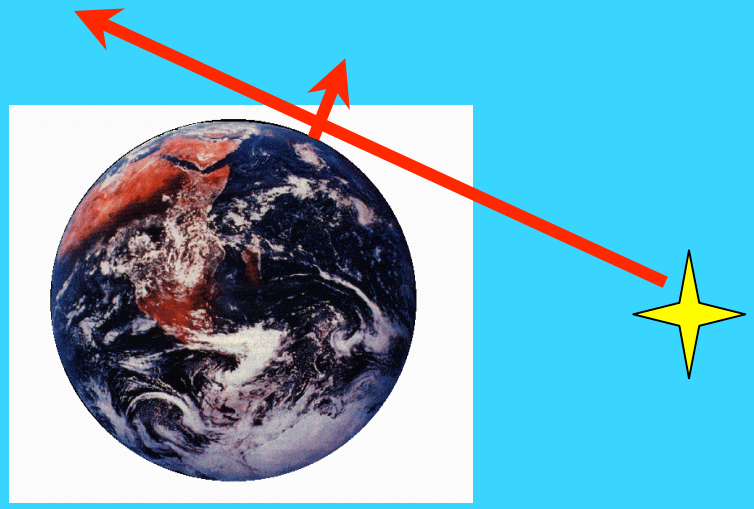
Transport

Emissions



Viewing Geometry

- **Nadir Viewing**
  - Good horizontal resolution
  - Poor Vertical resolution
  - Less sensitive
  - Need to find gaps in clouds and aerosols
  - Can probe lower atmosphere to “surface”



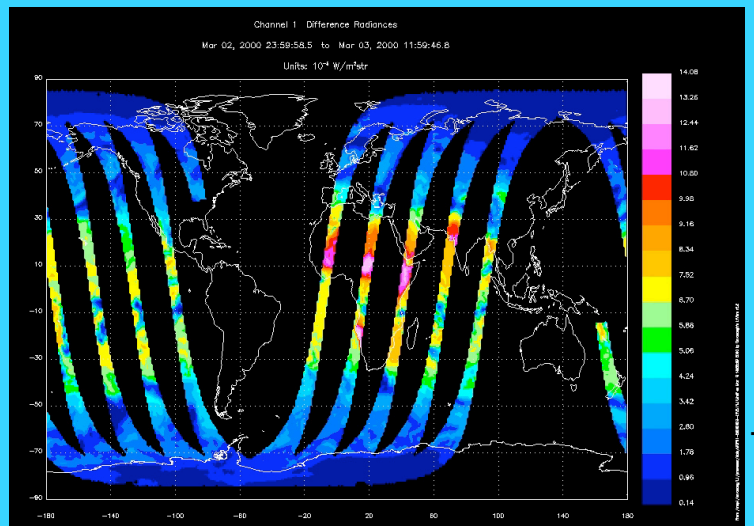
- **Limb/Occultation Viewing**
  - Poor horizontal resolution
  - Good vertical resolution
  - Very sensitive
  - Highly sensitive to clouds and aerosols
  - Probability of measurement rapidly declines below tropopause – very low below 5km

Scanning, Orbits and Coverage

- Scanning of the instrument increases coverage
  - The pixel distorts at large viewing angles
  - The radiative transfer problem becomes more complex at high viewing angles
- Raising the orbit increases coverage
  - Increases pixel size unless optics are also corrected
  - Can also increase temporal coverage through swath overlap
- Inclination of orbit dictates latitude limits
  - Scanning can increase things a bit but not to completely compensate

The Poles of Orbits

- **Low-Earth Orbit (6-900km)**
  - Repeat coverage times 1/day or less
  - Planetary coverage 1/day (present) n/day (future)
  - Polar coverage better than equatorial coverage
  - Distance makes instrument/satellite design easier/cheaper
- **Geostationary Orbit**
  - Repeat times 1/hour easily achievable
  - 1/3 planet coverage
    - No coverage of 2/3 planet
  - Equatorial coverage better than polar coverage
  - Distance makes instrument/satellite design more difficult/expensive

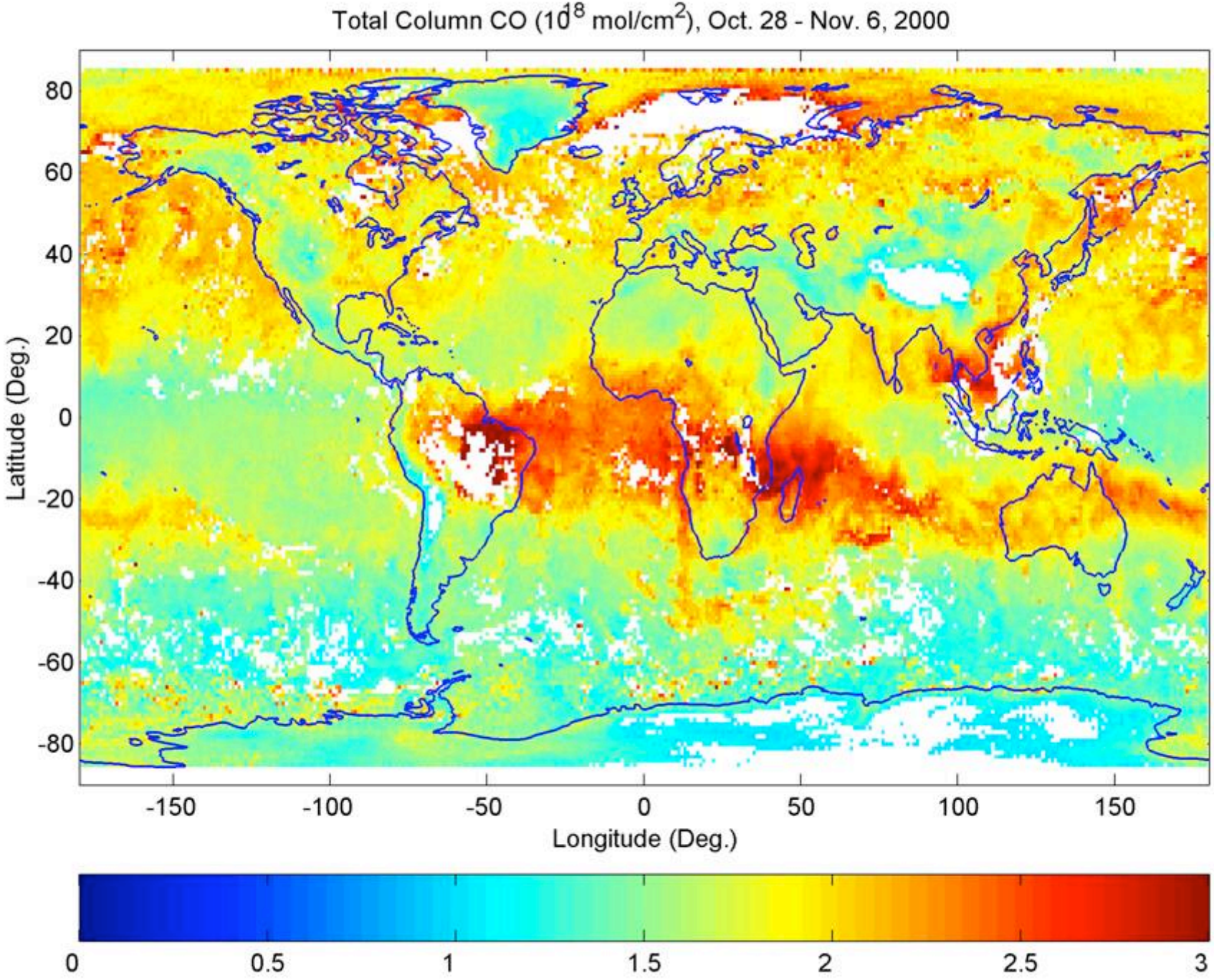


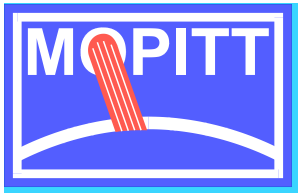
Bias

- All satellite instruments have bias
  - Horizontal spatial bias
    - Horizontal spatial bias often appears as “no coverage”
      - Low Earth Orbit satellites have more polar coverage
      - Geostationary satellites don’t cover the poles
  - Vertical spatial bias
    - 4.7um and limb/occultation instruments do not measure near the ground
  - Temporal bias
    - Low earth orbiters are often “sun synchronous”
      - Measurements at each latitude are only made at one/ two local times
    - 2.4um are made in reflected sunlight
      - No night coverage and limited solar zenith angle in practice

Bias

- Other biases
  - Cloud bias
    - No measurements through clouds so measurements are biased to cloud-free regions
  - Aerosol bias
    - Same arguments apply to aerosol/smoke
  - Land bias
    - 2.4um reflected sunlight over the ocean is very weak – instruments tend to only operate over land

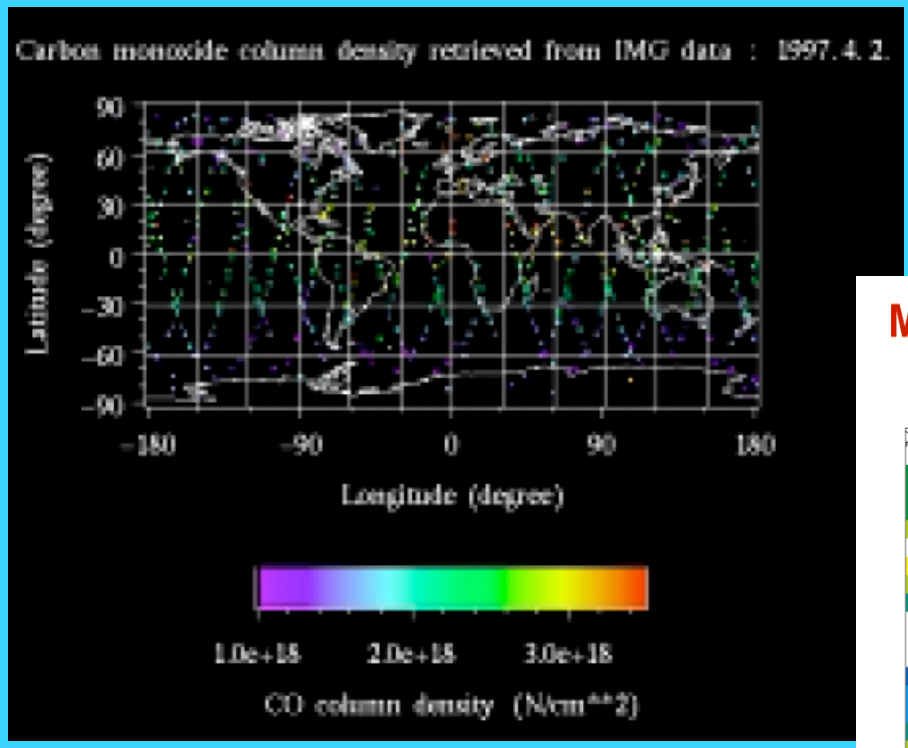

Total Column CO (10^{18} mol/cm^2), Oct. 28 - Nov. 6, 2000
Latitude (Deg.)
80
60
40
20
0
-20
-40
-60
-80
-150
-100
-50
0
50
100
150
Longitude (Deg.)
0
0.5
1
1.5
2
2.5
3



The Ideal CO-Measuring Instrument

- There isn't one!
- All CO-measuring instruments are developed within these trade spaces
- All CO-measuring instruments have strengths and weaknesses

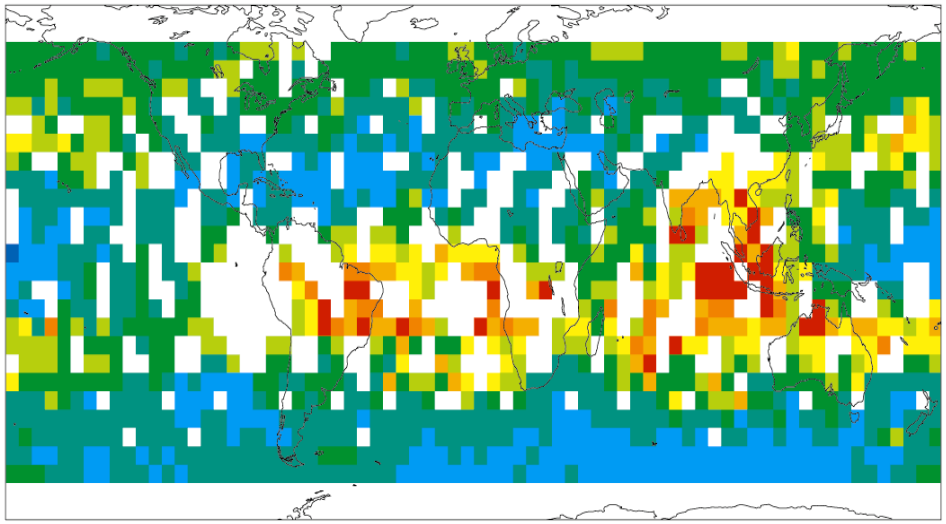
Past Instruments



Measurement of Air Pollution from Satellites (MAPS)

Carbon Monoxide Mixing Ratios in Middle Troposphere

SRL-2 September 30 - October 11, 1994

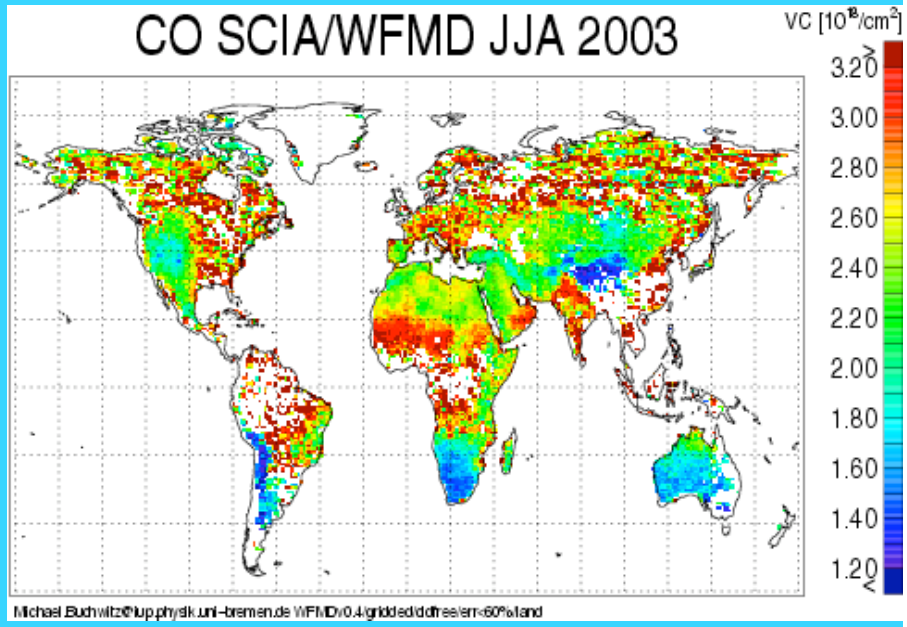


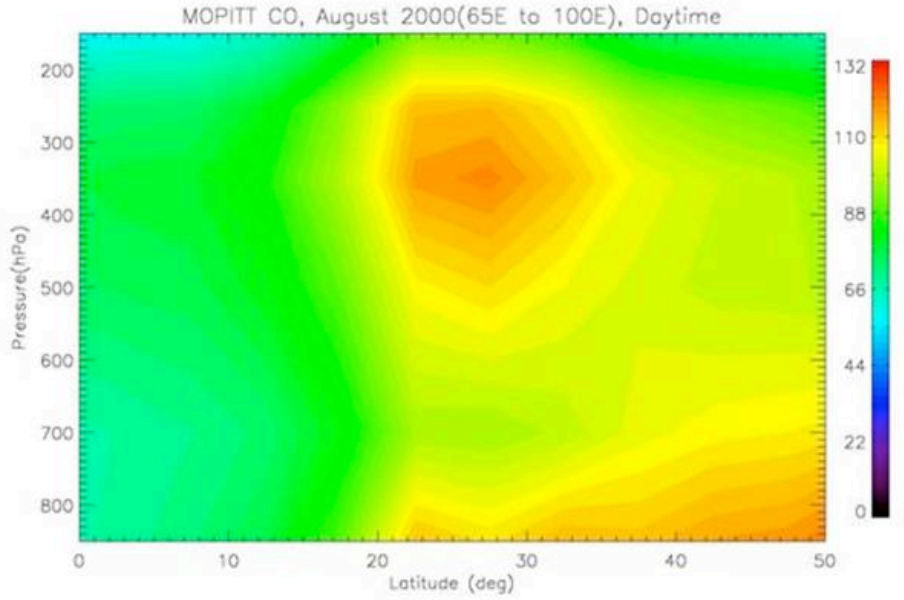
Mixing Ratio (ppbv)

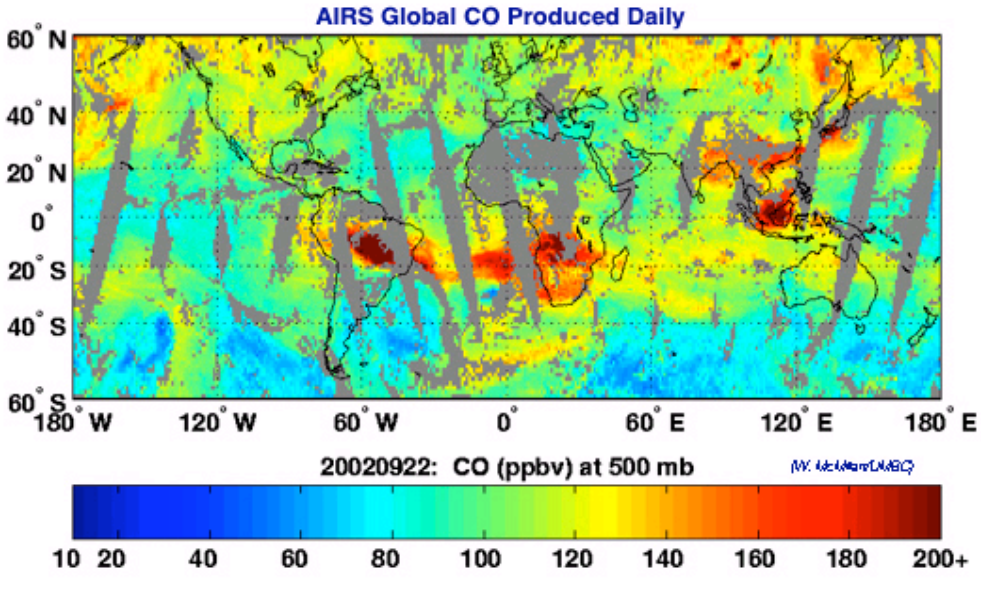
30 45 60 75 90 105 120 135 150 165+

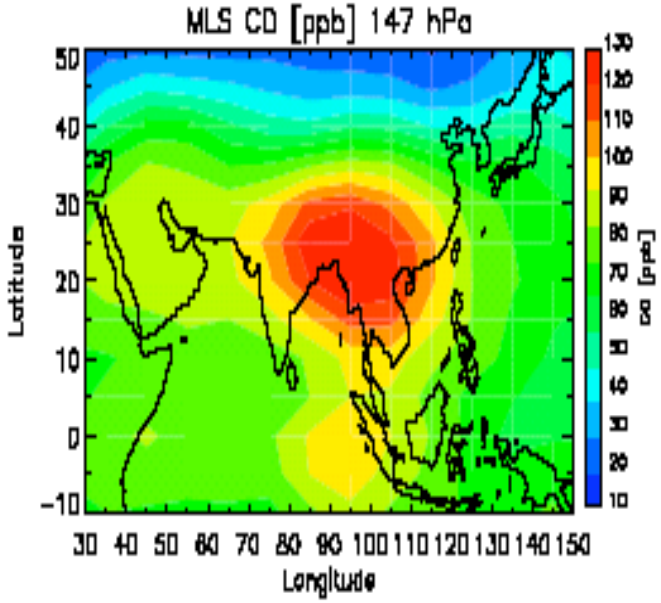
NASA LANGLEY RESEARCH CENTER / ATMOSPHERIC SCIENCES DIVISION

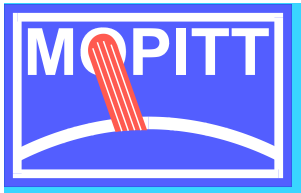
Current Instruments











Future Instruments

What Is Needed?

- Continuous Monitoring in some form
  - CO is variable on all space and time scales
  - Pick your problem and optimise the instrument for that problem
- Geostationary
  - High time resolution
  - Limited spatial resolution
  - Good for local/regional studies
  - Hopeless for global studies (unless we get at least 3 of them)
- Low Earth Orbit
  - Lower time resolution
  - Global coverage
- 4.7um channels
  - Vertical resolution
- 2.4um
  - With 4.7μm (not alone) can provide Boundary Layer measurements
- Solar occultation/emission sounders help with the upper levels and STE

Conclusions

- It's been a very interesting couple of decade!
- CO measurements from space are now in progress and becoming accepted in the community
- There are new possible measurements to be made
- Hence this workshop…….