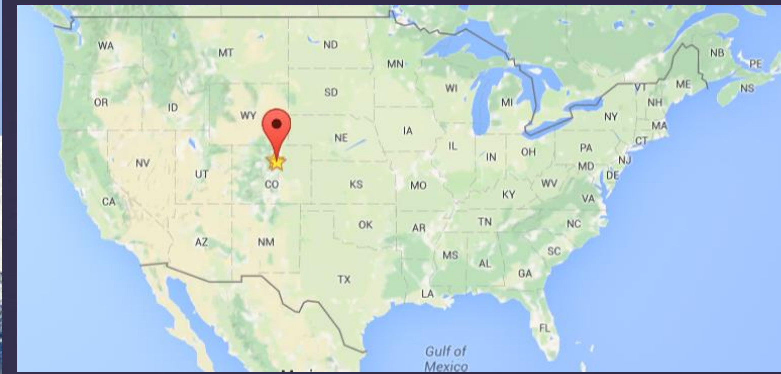
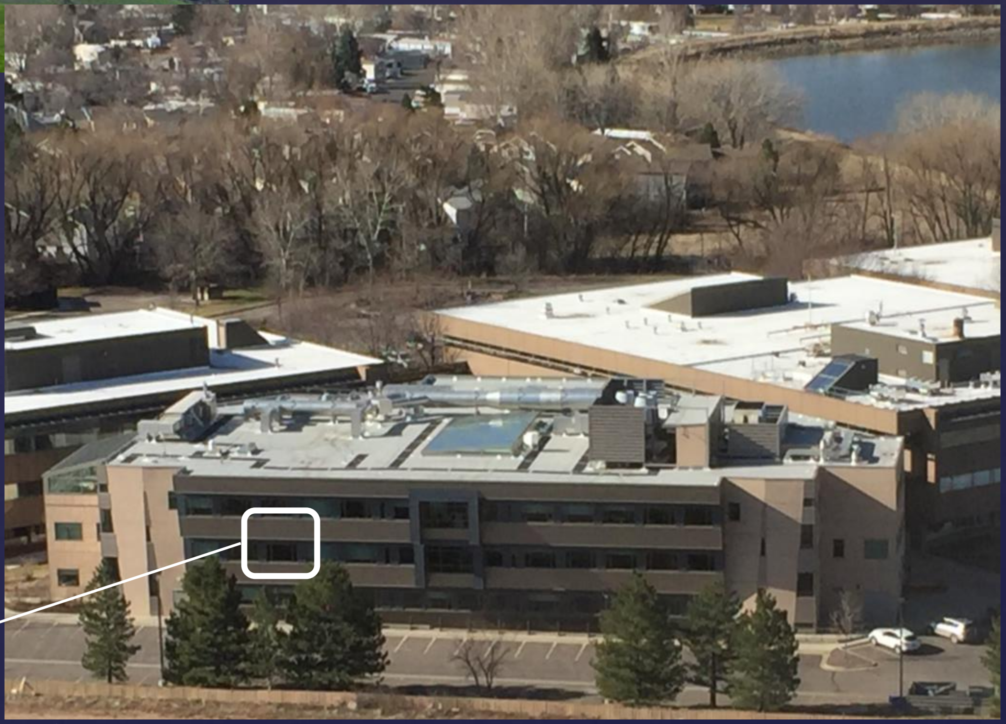


NCAR Mesa Lab.

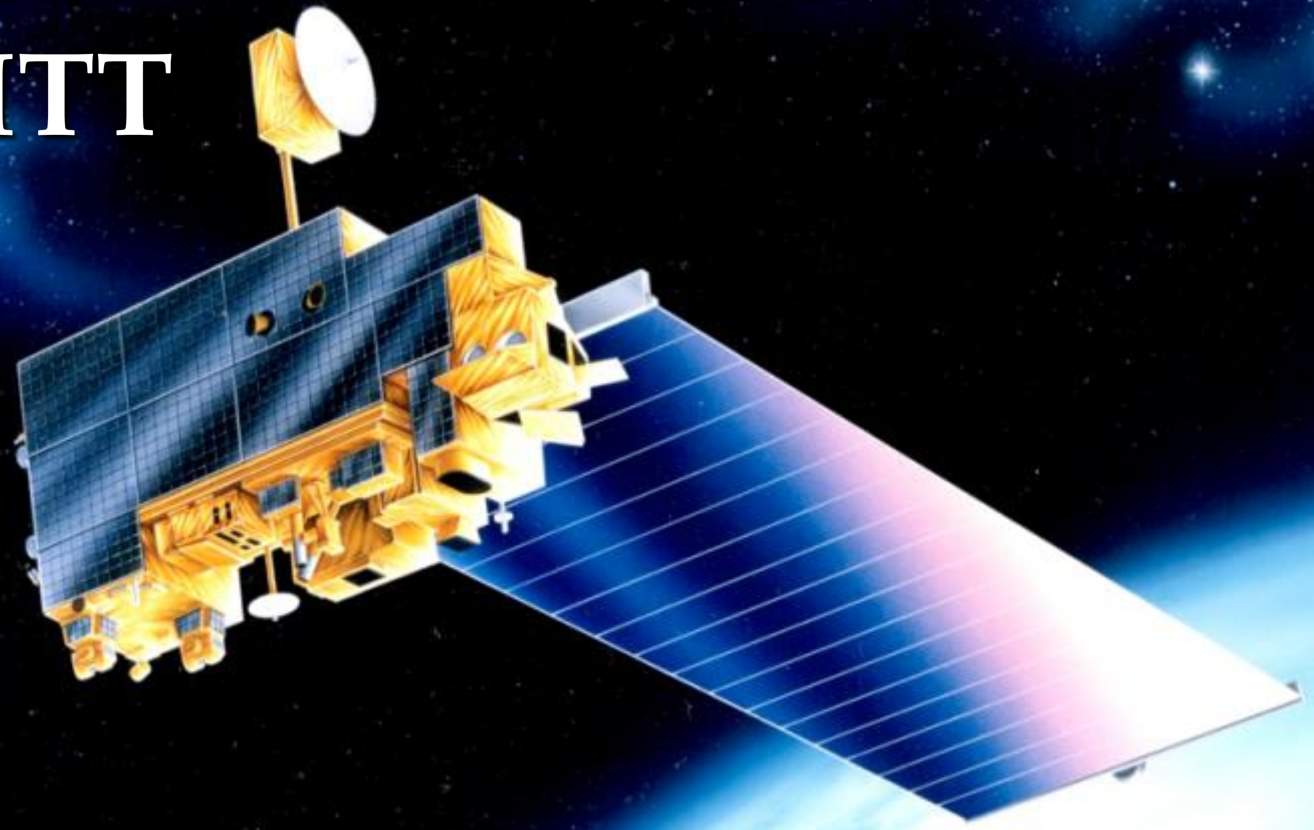
Helen Worden
Atmospheric Chemistry Observations and Modeling (ACOM) Laboratory,

National Center for Atmospheric Research (NCAR)



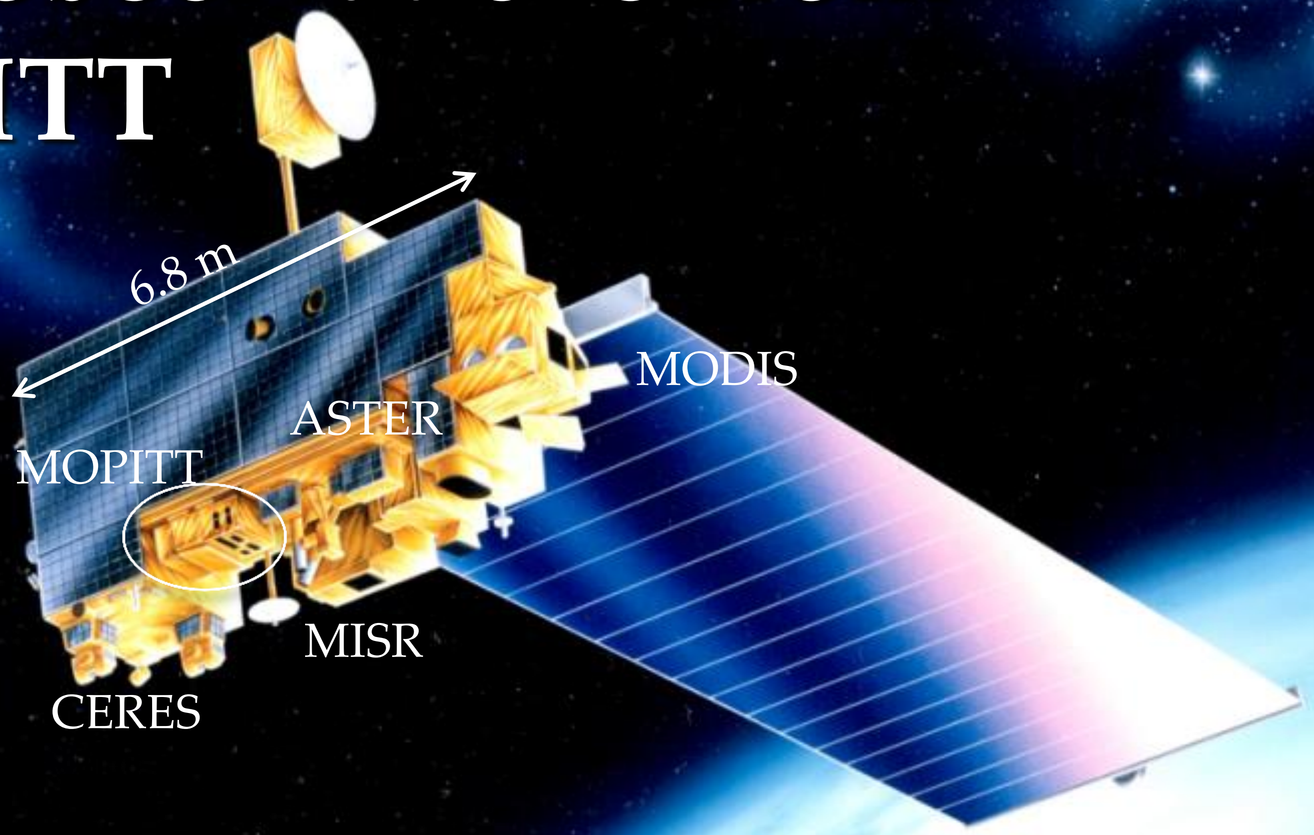
my office
NCAR Footlhills Lab.

16 years of Carbon monoxide (CO) observations from MOPITT



Over 16 years of observing pollution in the troposphere from space

16 years of Carbon monoxide (CO) observations from MOPITT



Over 16 years of observing pollution in the troposphere from space

16 years of Carbon monoxide (CO) observations from MOPITT

TERRA Fun Facts

Launched December 1999
Design Life = 6 years
Cost = $1.3 Billion
705 km above Earth
10:30 equator x-ing
16 orbits/day

NCAR MOPITT Team

Merritt Deeter (P.I.), Jérôme Barré, Rebecca Buchholz, Vince Dean, David Edwards, Louisa Emmons, Gene Francis, Benjamin Gaubert, John Gille, Debbie Mao, Sara Martinez-Alonso, Gabriele Pfister, Helen Worden, Daniel Ziskin

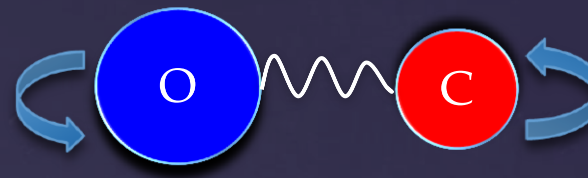
NCAR

- Why Carbon Monoxide (CO)?
- First satellite CO observations
- Global CO distributions
- CO from Fires
- Estimating CO emissions
- Trends in CO
- MOPITT Multi-spectral CO observations
- Conclusions

Outline

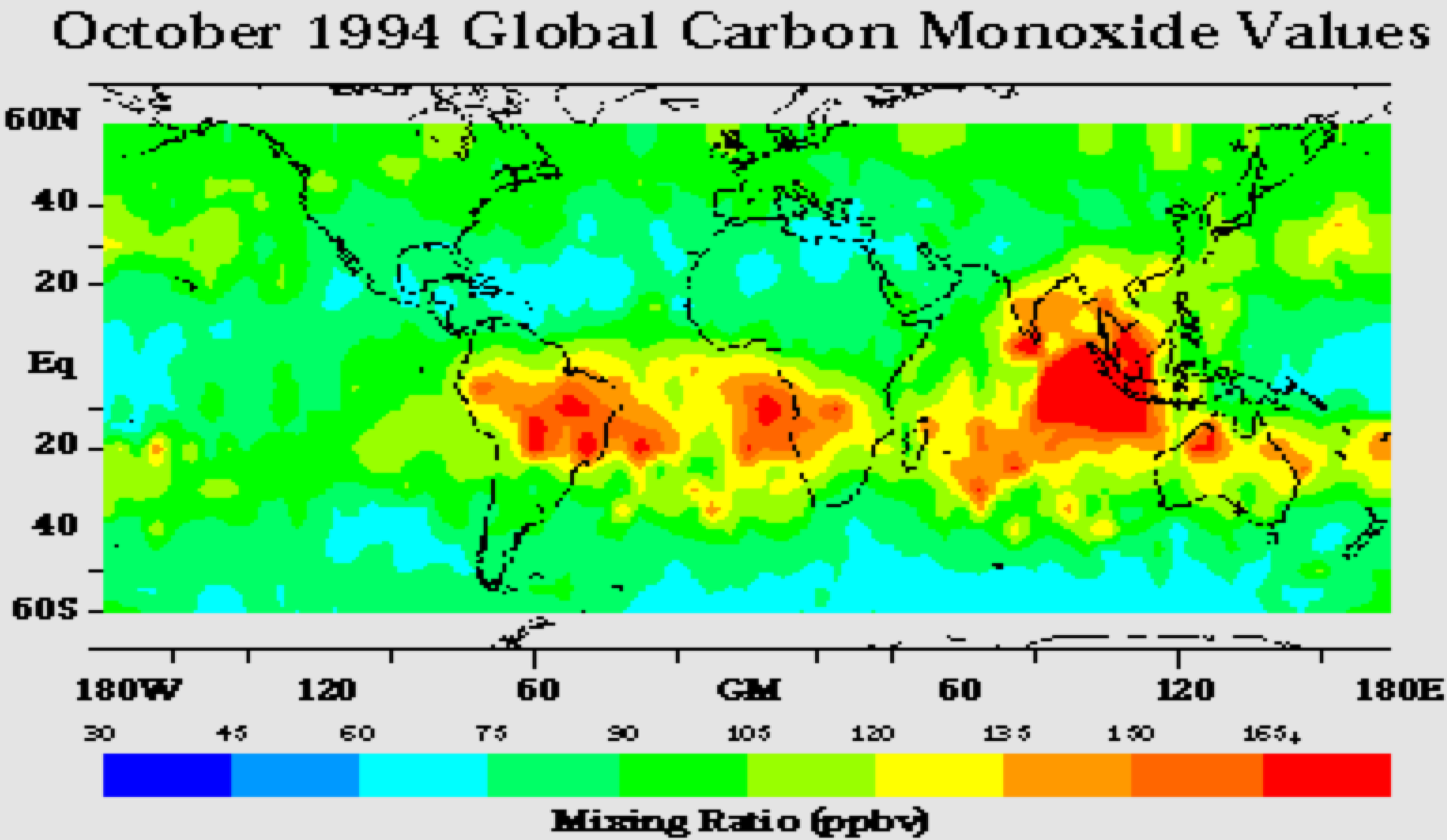
NCAR

Why CO?



- Important role in atmospheric chemistry & climate
  - Main sources are incomplete combustion (both fires & fossil fuel), biogenic emissions & hydrocarbon oxidation
  - Primary sink is oxidation by OH – more CO => longer CH_4 lifetime
  - Precursor to CO_2 and tropospheric O_3
  - Indirect radiative forcing (RF) of 0.22 W/m^2 for CO emissions (IPCC AR5)
- Ideal tracer for pollution transport
  - Lifetime is weeks to months, so CO is transported globally, but not evenly mixed (like longer lived species)
  - Easy to measure elevated CO above background levels with infrared spectra
- Global direct emissions of CO (~half of atmospheric CO)
  - ~500-600 Tg/yr anthropogenic (relatively stable)
  - ~300-600 Tg/yr biomass burning (large interannual variability)

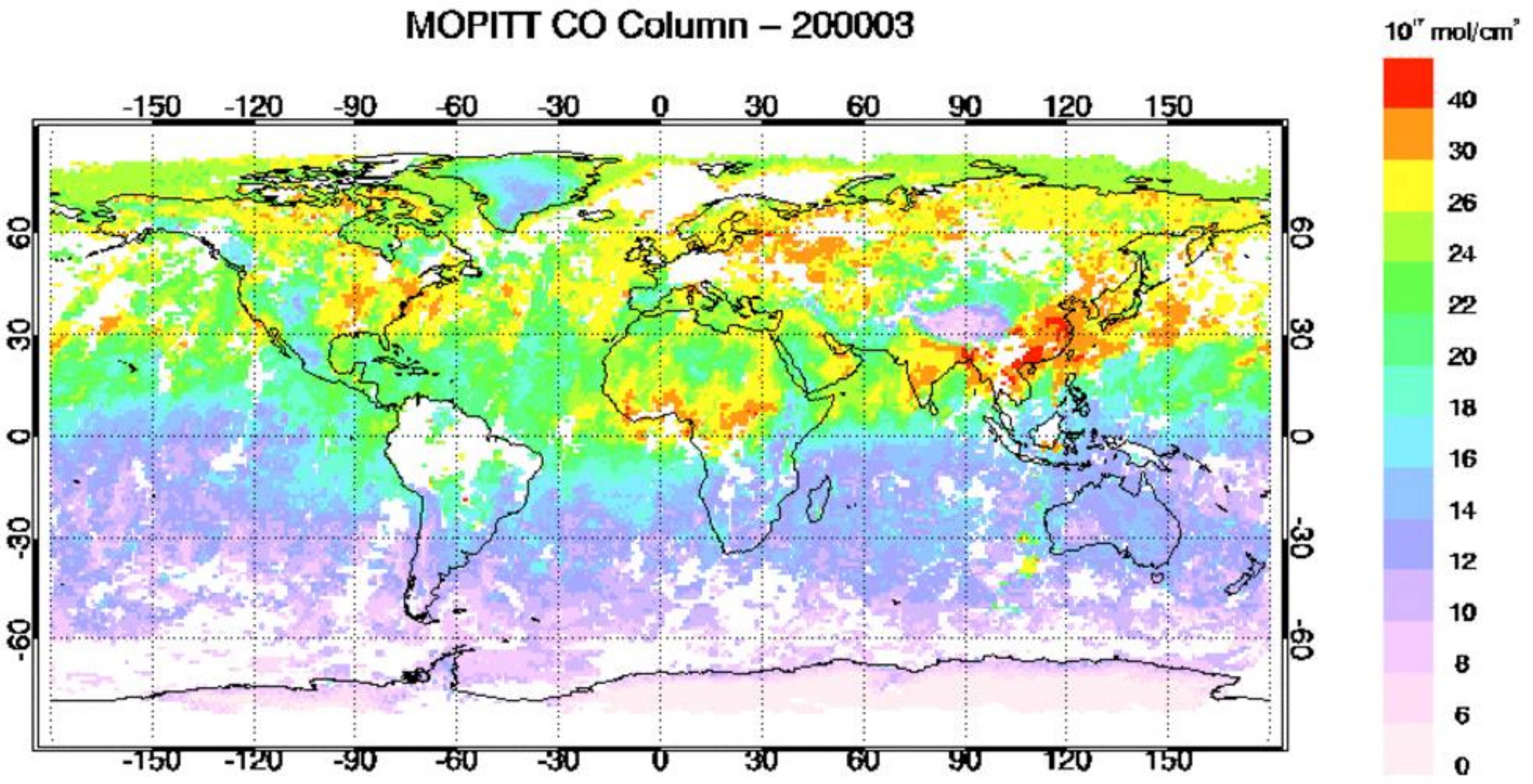
NASA NCAR



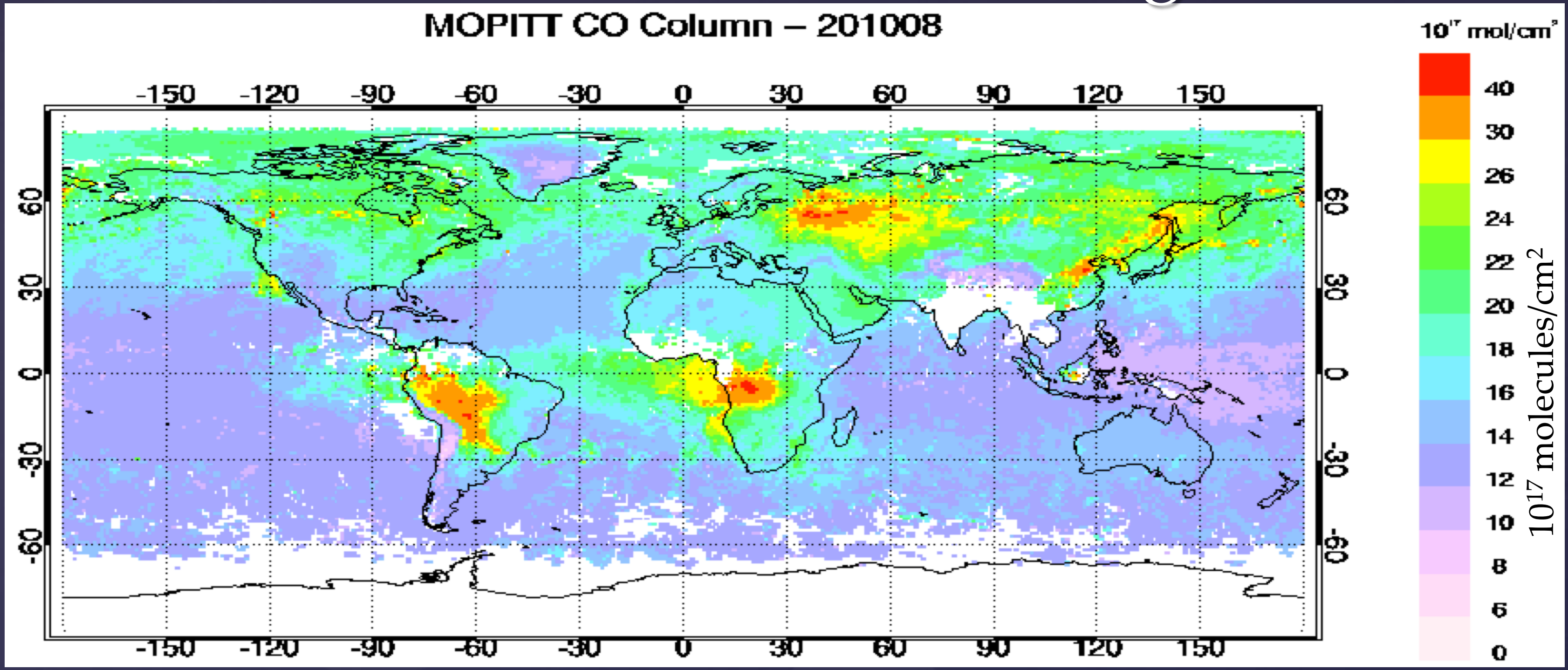
MAPS (Meas. Of Air Pollution from Satellites)

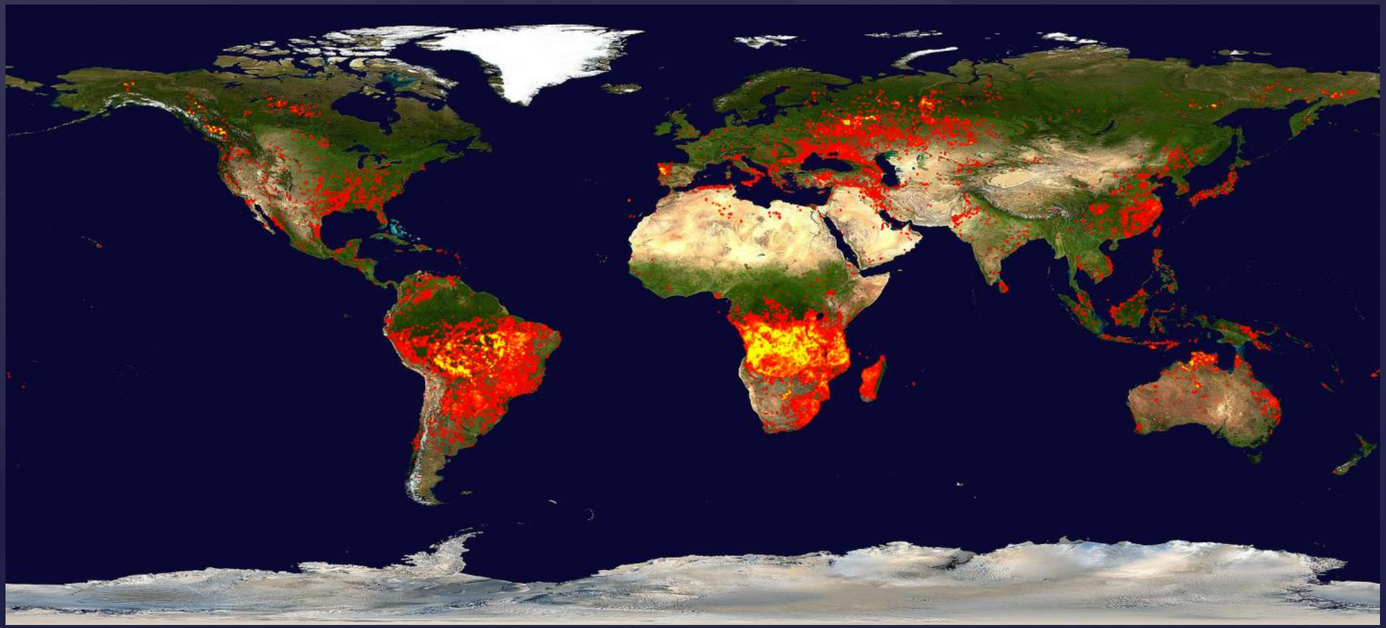
- Gas filter correlation radiometer (GFCR) on the Space Shuttle
- 4 missions: Nov. 1981, Oct. 1984, April 1994, Oct. 1994

15 years of MOPITT observations



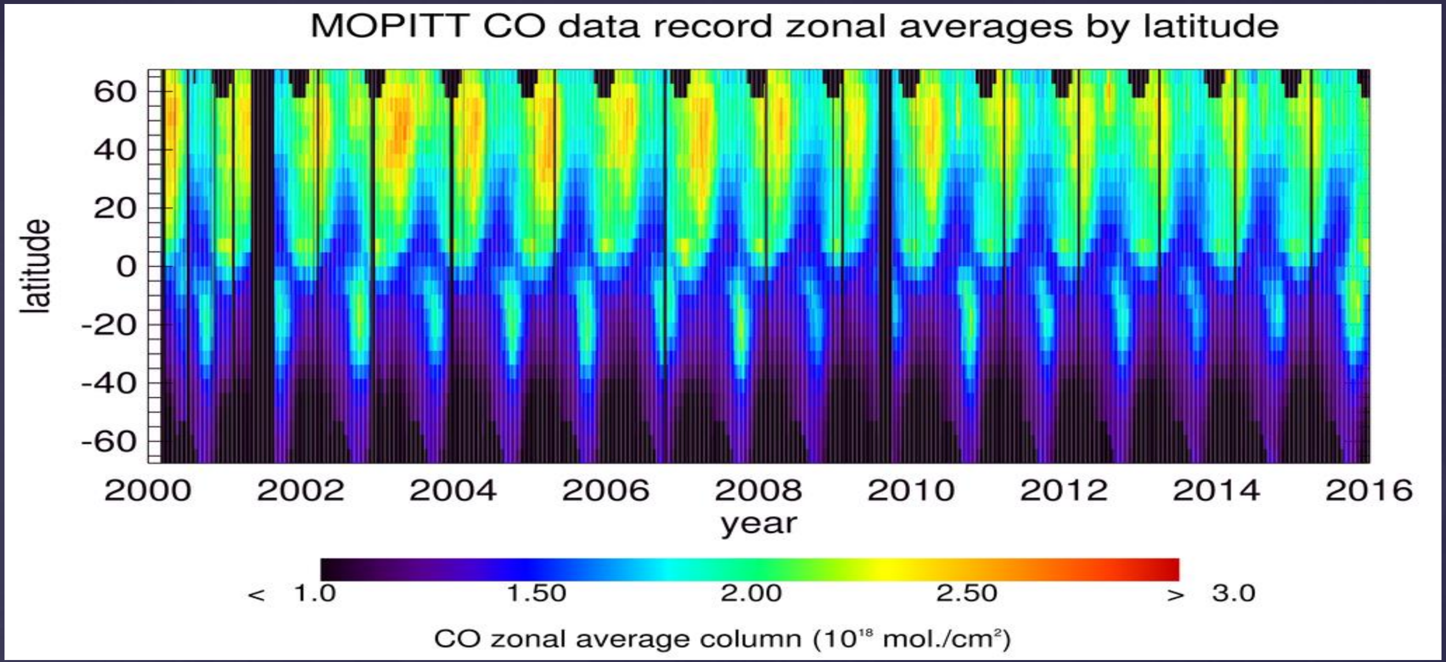
MOPITT CO total column, Aug. 2010



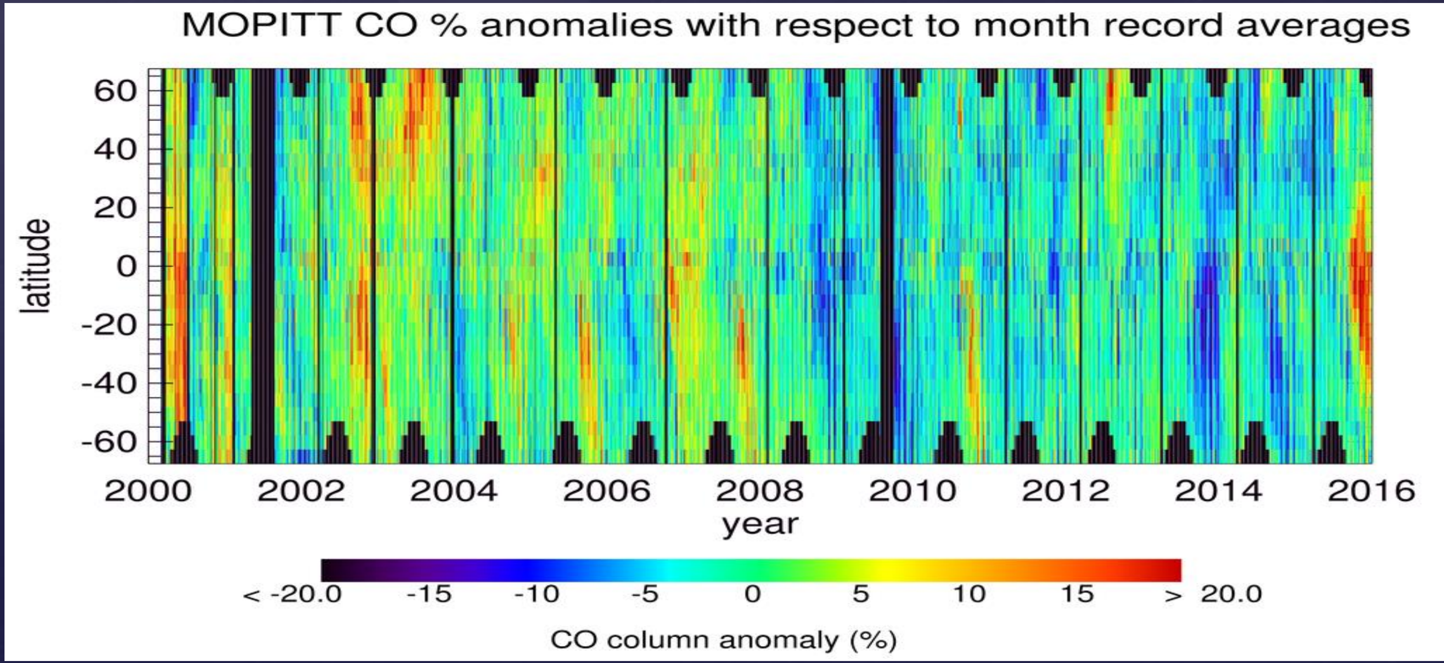


MODIS
Fire counts
9-18 Aug.
2010

NASA
NCAR



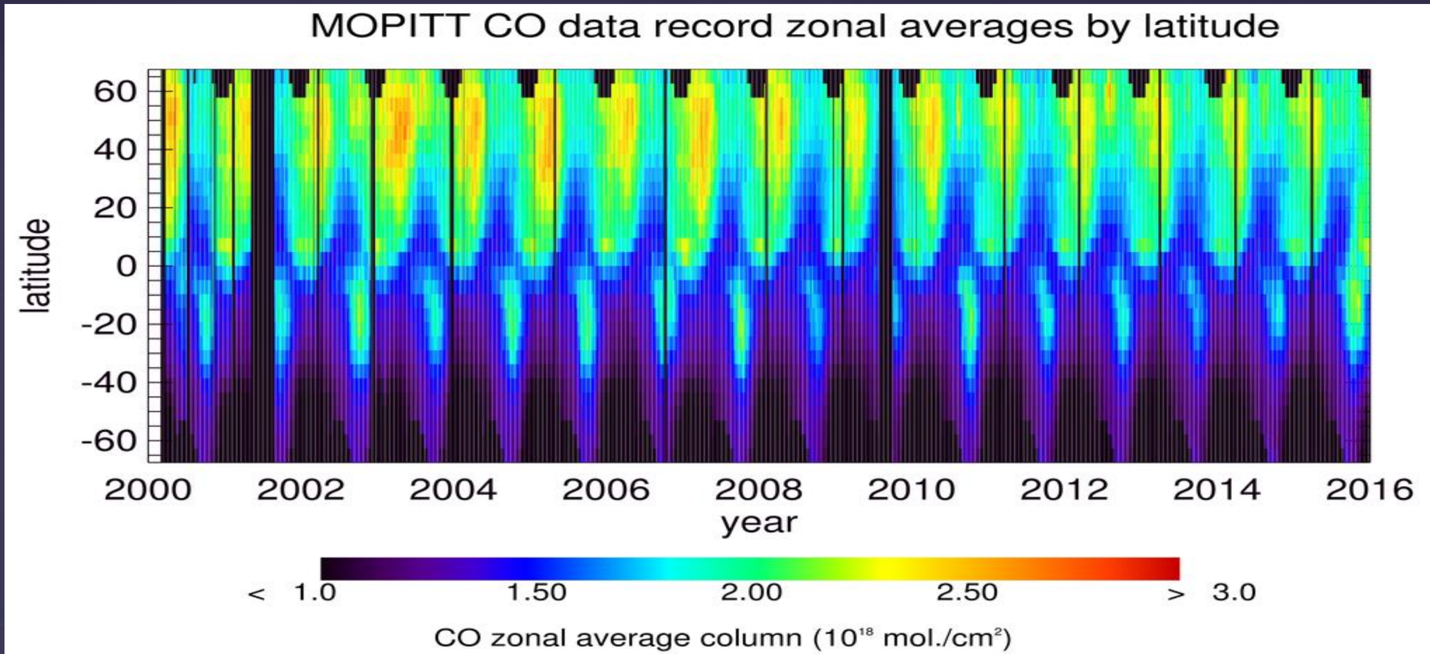
16 Year MOPITT Data Record

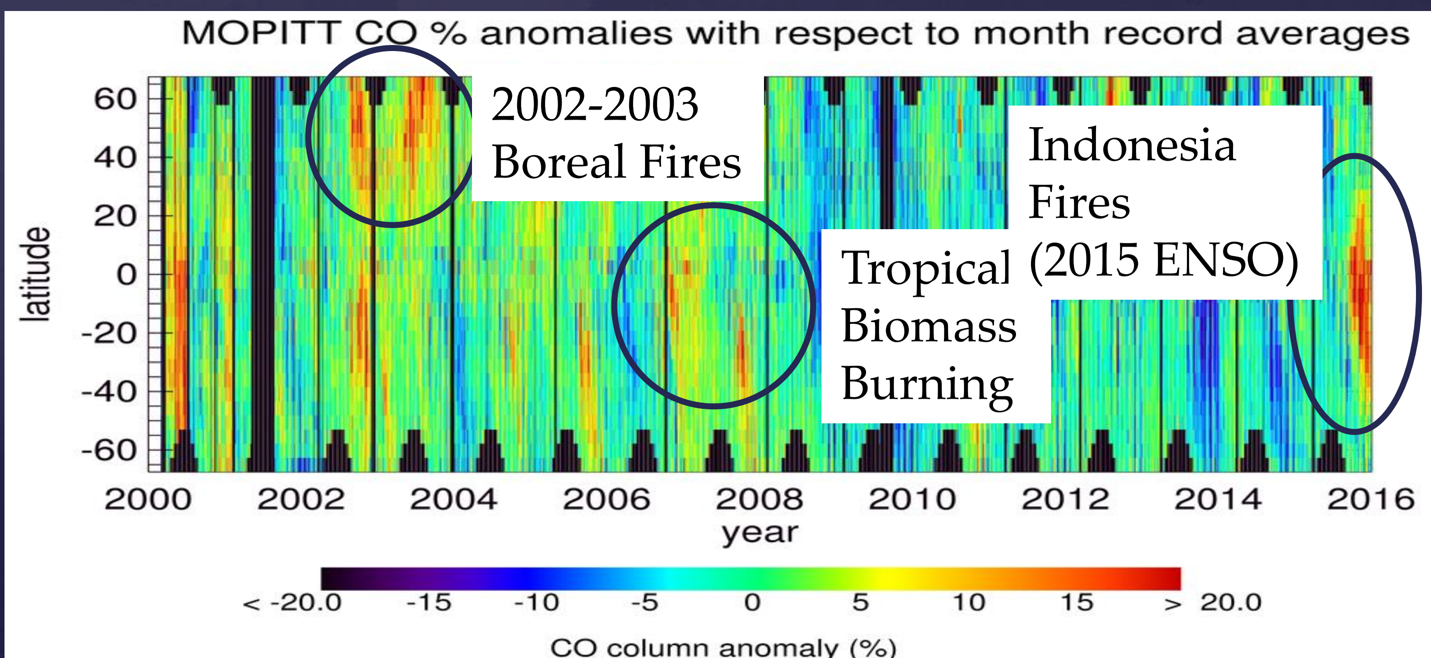


NASA

NCAR

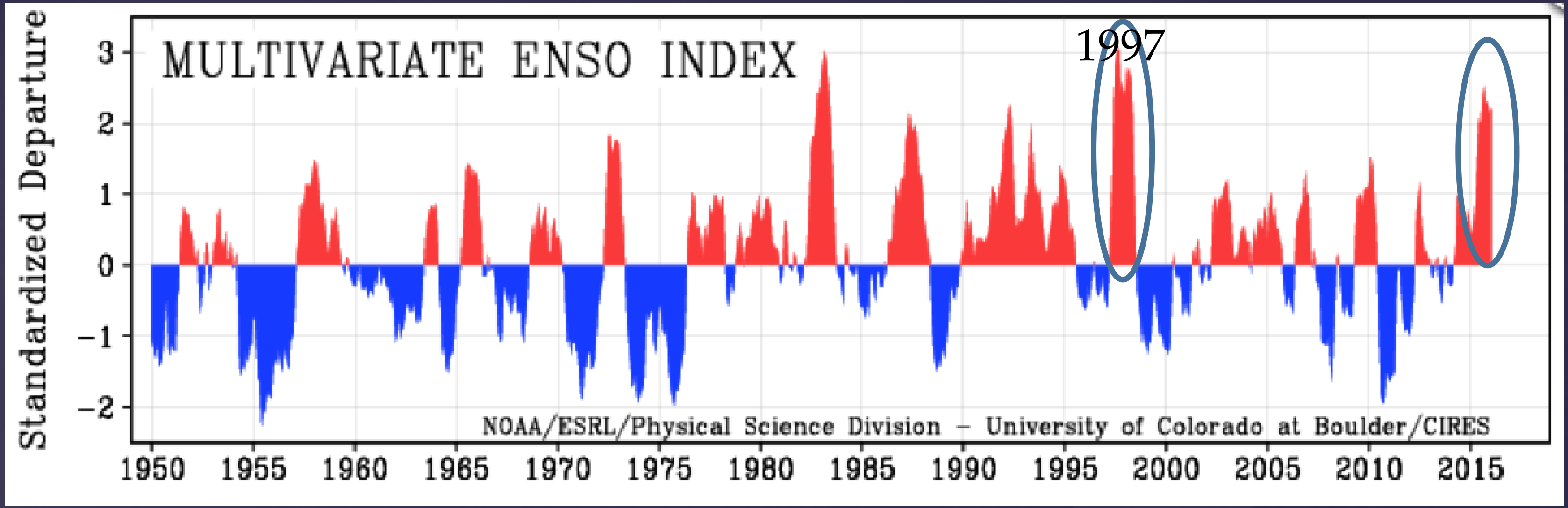
16 Year MOPITT Data Record

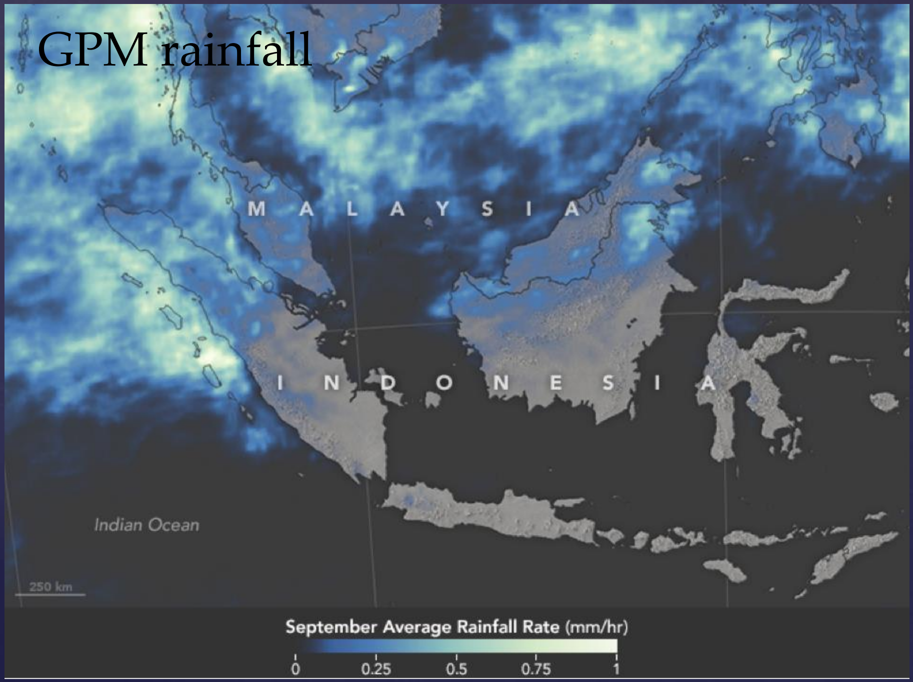


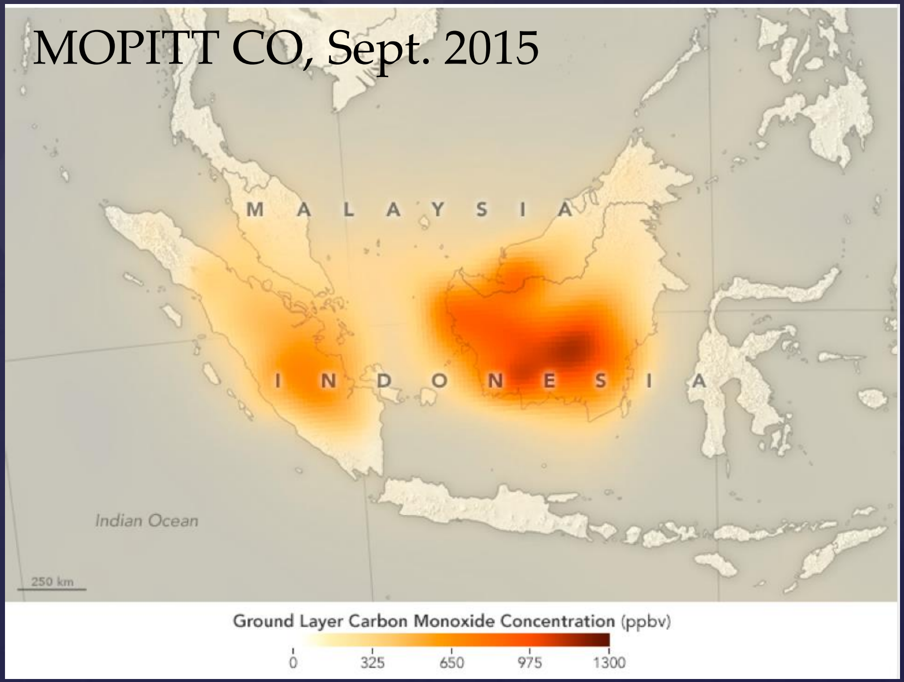


Seeing Through the Smoky Pall:
Observations from a Grim Indonesian Fire Season

http://www.earthobservatory.nasa.gov

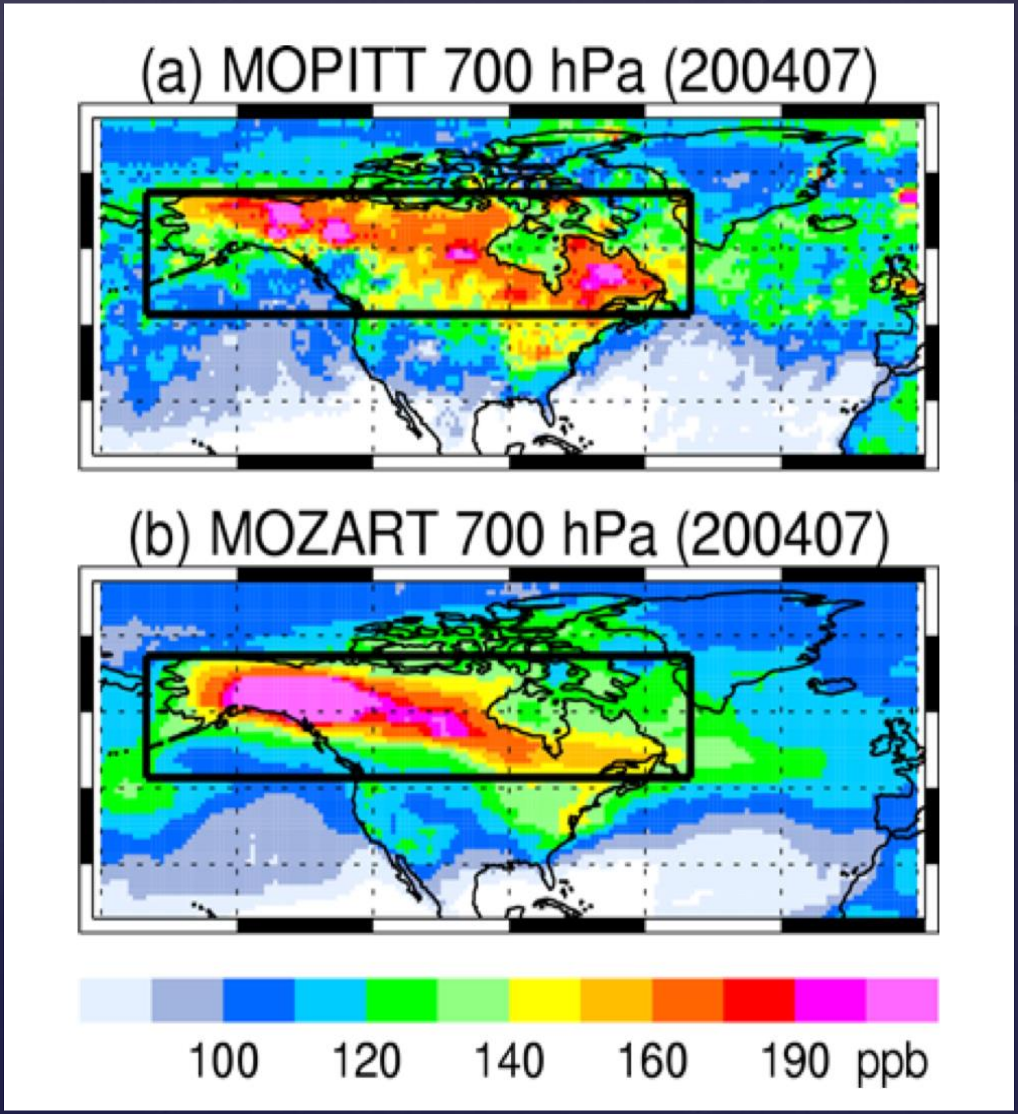


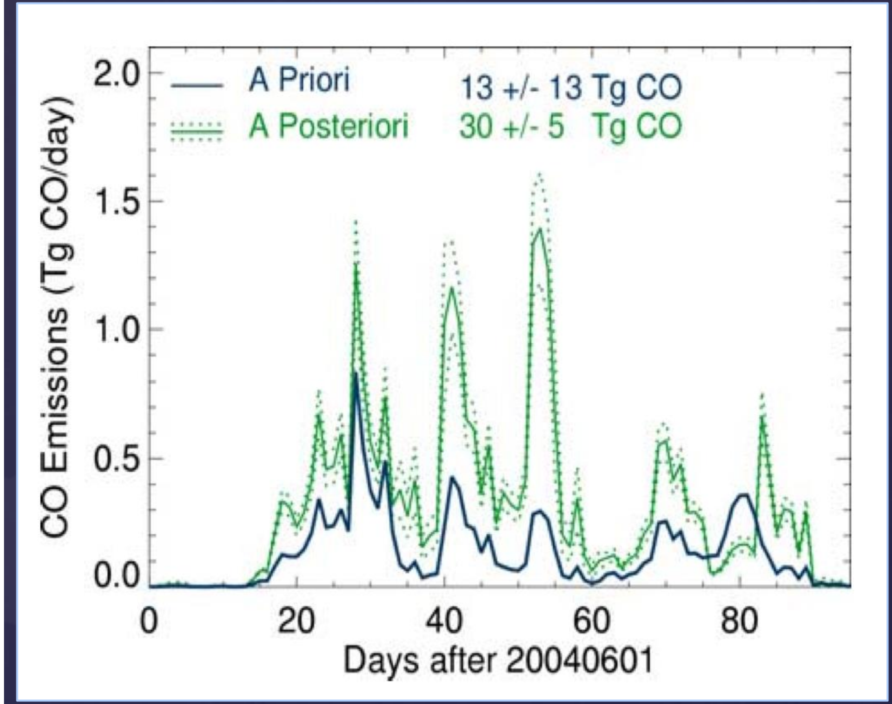




Rainfall and CO images from NASA Earth Observatory

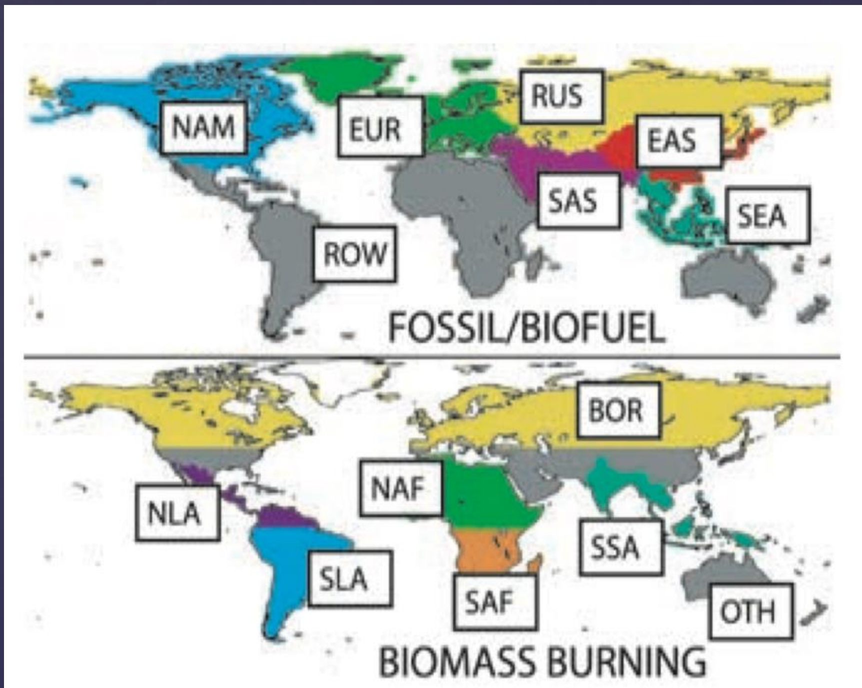
Fire emission estimates from inverse modeling
Pfister et al., GRL, 2005

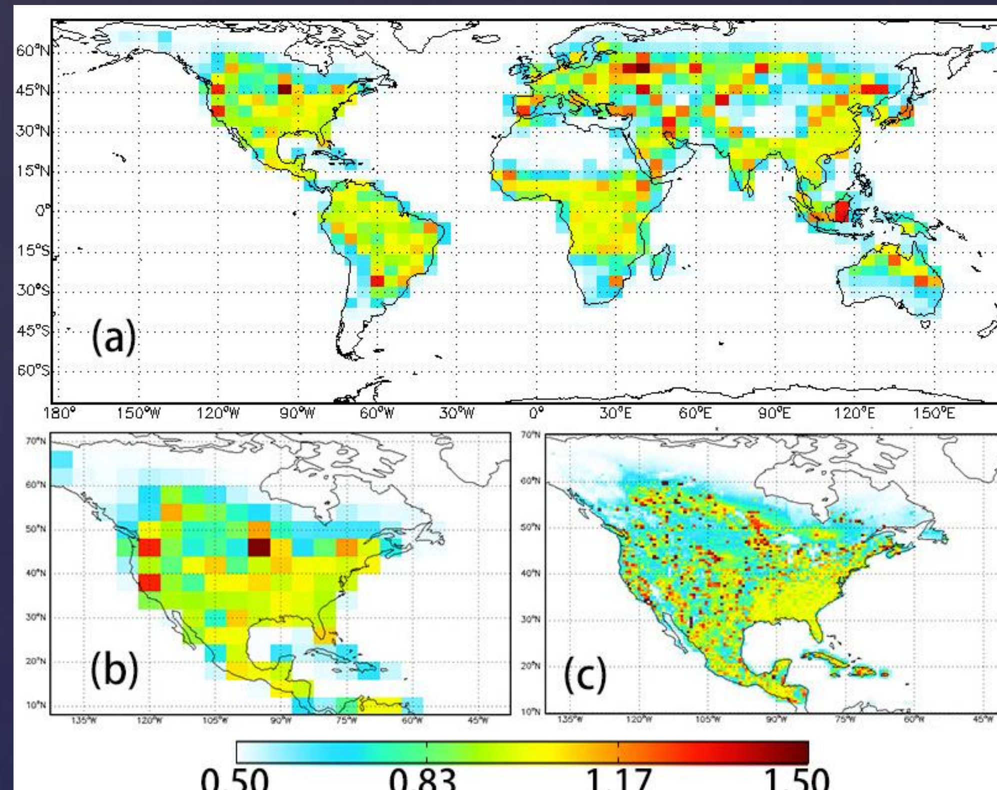




This paper showed 30 ± 5 Tg CO emitted during June-Aug 2004 Alaska/Canada fires - comparable to 3-months of US anthropogenic CO emissions

Model inversion for CO emissions



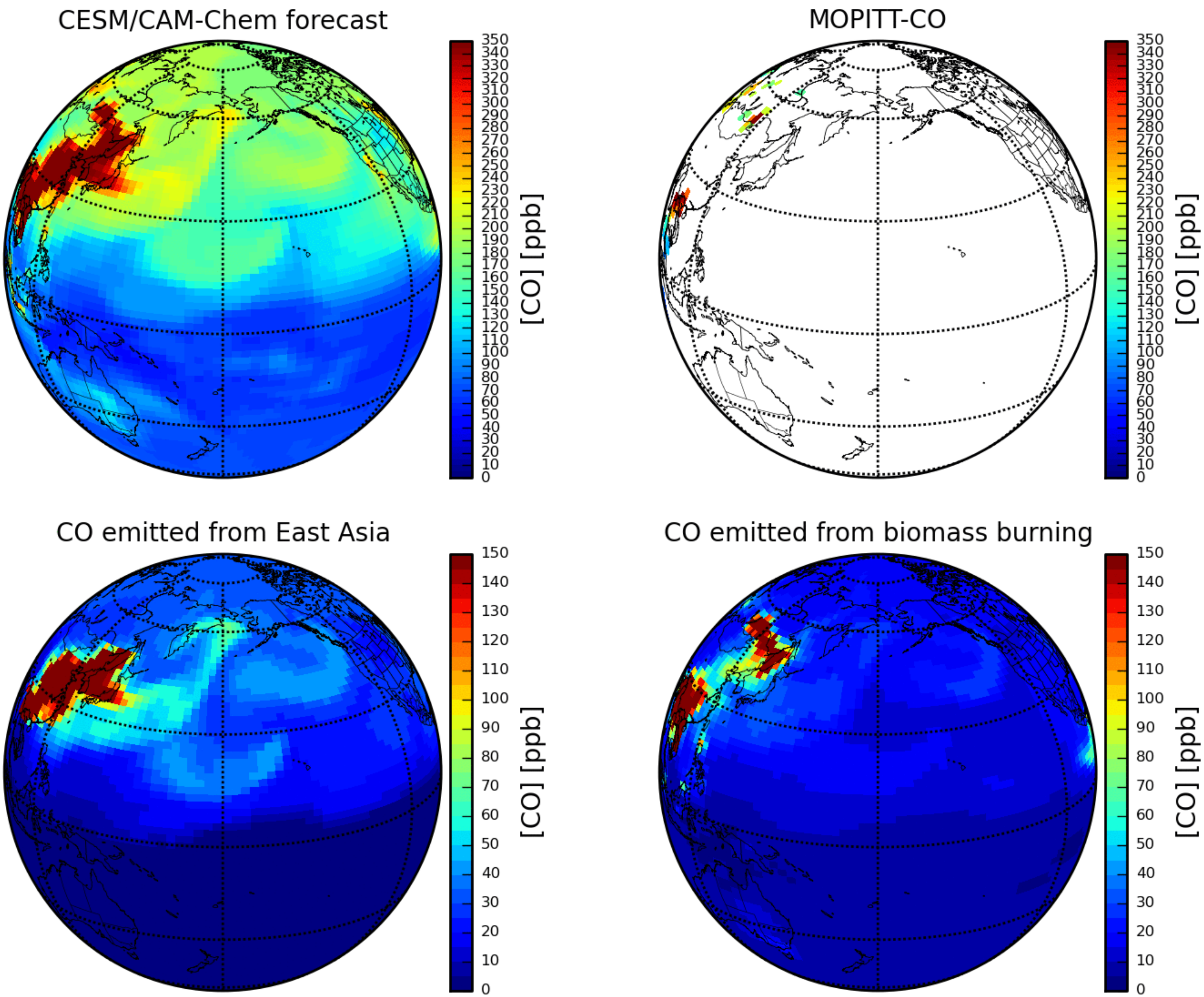


Arellano, GRL, 2004

Jiang, ACPD, 2015

2003/04/01 00 UTC

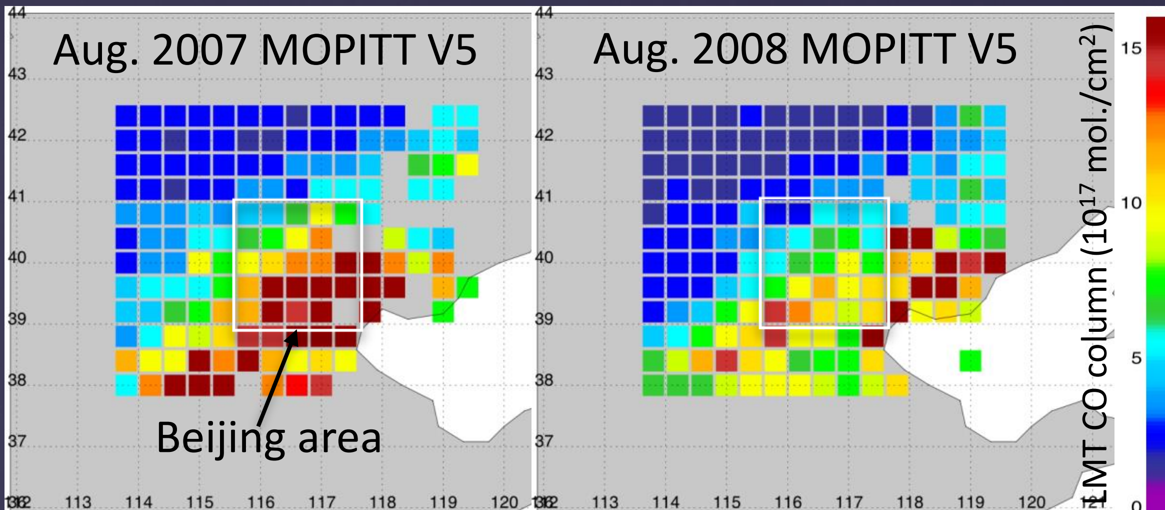
Gaubert et al., in prep



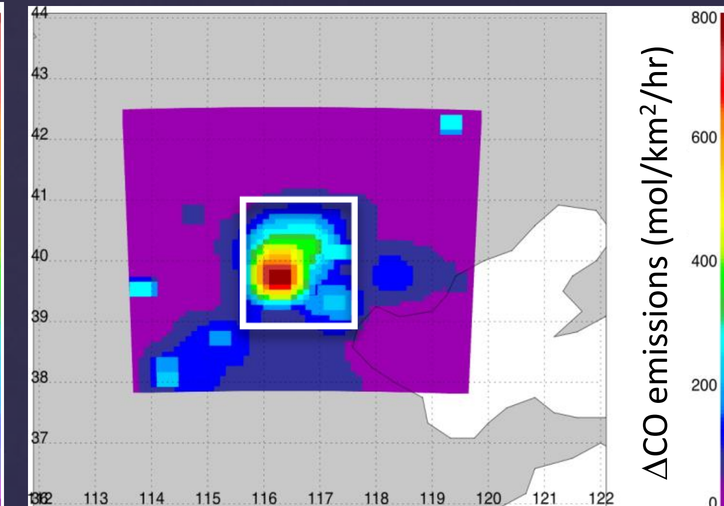
TRAFFIC RESTRICTIONS DURING THE 2008 BEIJING OLYMPICS

Worden et al., May 2010 EGU

Satellite-based estimates of reduced CO and CO_2 emissions due to traffic restrictions during the Beijing 2008 Olympics



Near-surface CO from MOPITT observations

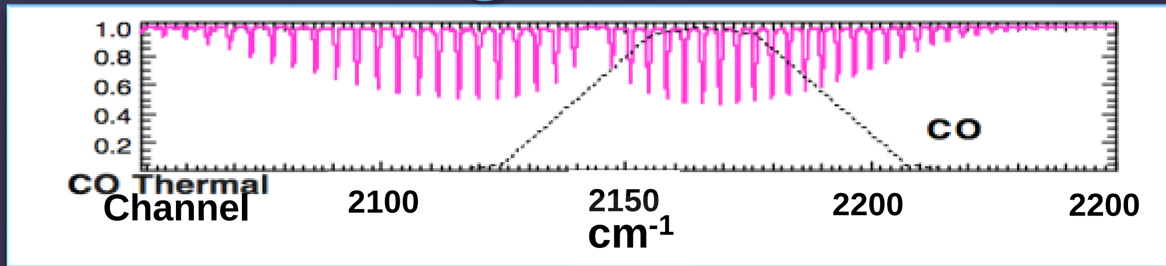


2007-2008 CO Emissions difference in WRF-Chem

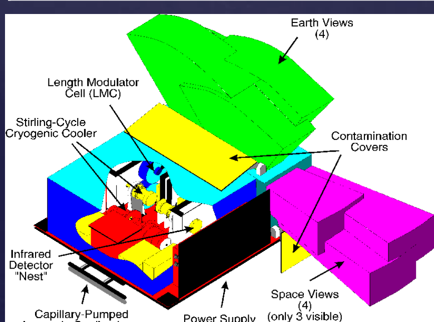
- Total CO reduction from Olympics = 2.95 ±1.8 Gg[CO]/day
- 60% of this reduction was in the transportation sector
- Since we know the CO/CO_2 emissions factor for fossil fuels this converts to 60 ±36 Gg[CO_2]/day for reduction in CO_2 emissions
- This is ~1/360 of the reduction in CO_2 emissions needed to keep warming under 2°C by 2100 (IPCC-RCP2.6), which suggests urban traffic controls could have a significant impact on CO_2 emissions.

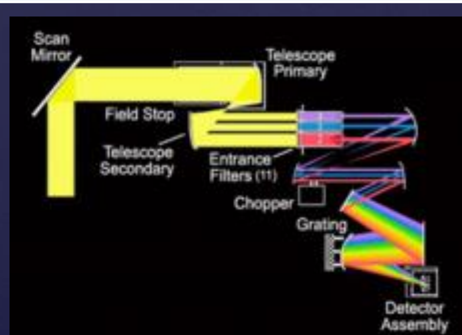
[Worden et al., *GRL*, 2012]

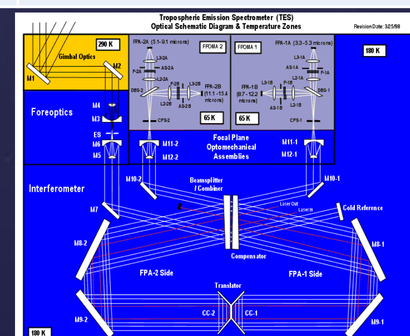
Nadir-viewing IR CO observations

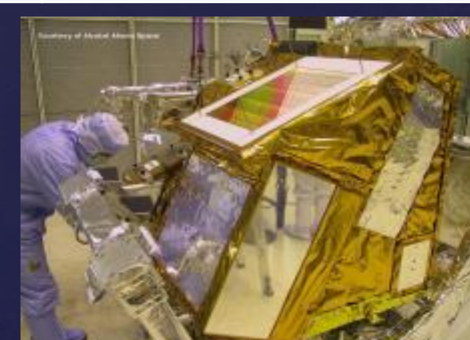


MOPITT V5T	AIRS V5	TES V4	IASI FORLI_2010
Gas Filter Corr. Radiometer (GCFR)	Grating Spectrometer	Fourier Transform Spectrometer (FTS)	FTS
EOS-Terra (1999)	EOS-Aqua (2002)	EOS-Aura (2004)	MetOp (2006)
10:20 am Eq.-x	1:20 pm	1:40 pm	9:30 am
Global coverage in 3 days	Nearly twice/day	Global sampling in 16 days	twice/day
22km x 22km footprint	13.5km x 13.5km	5km x 8km footprint	12km diameter footprint
0.04 cm^{-1} (effective)	~1.8 cm^{-1} (2150 cm^{-1})	0.1 cm^{-1} (apodized)	0.5 cm^{-1} (apodized)









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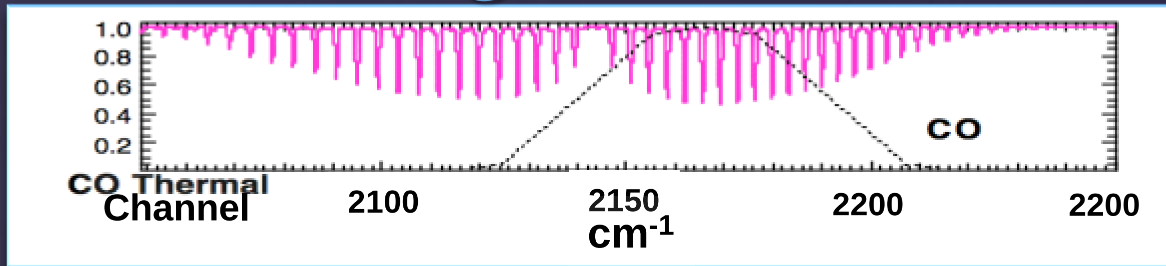

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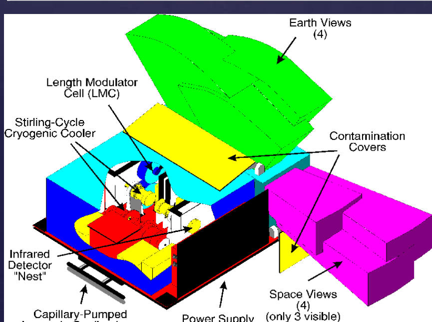
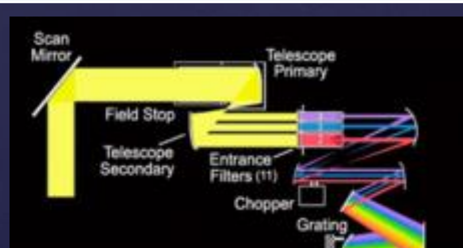
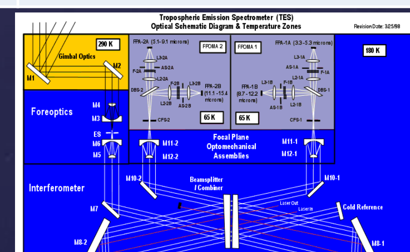
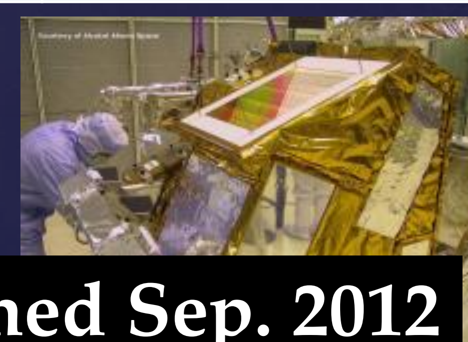
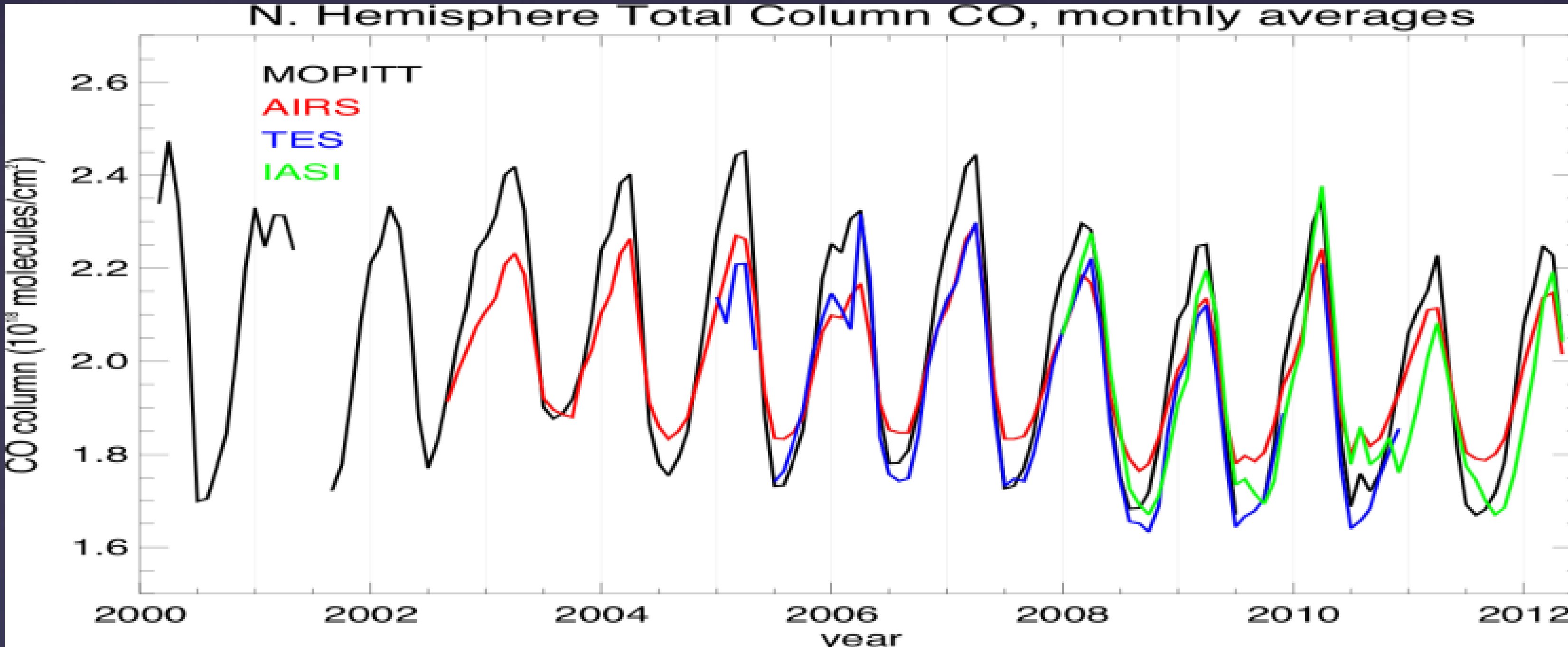


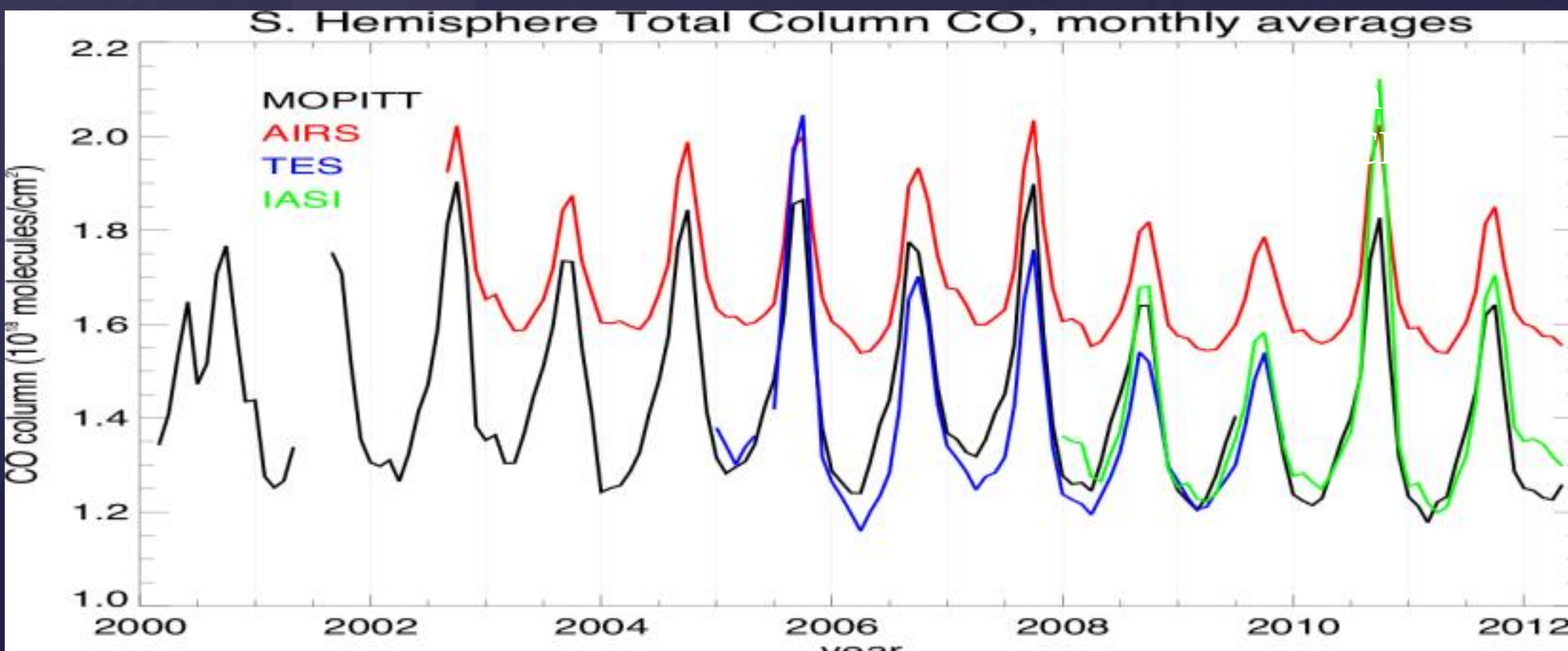


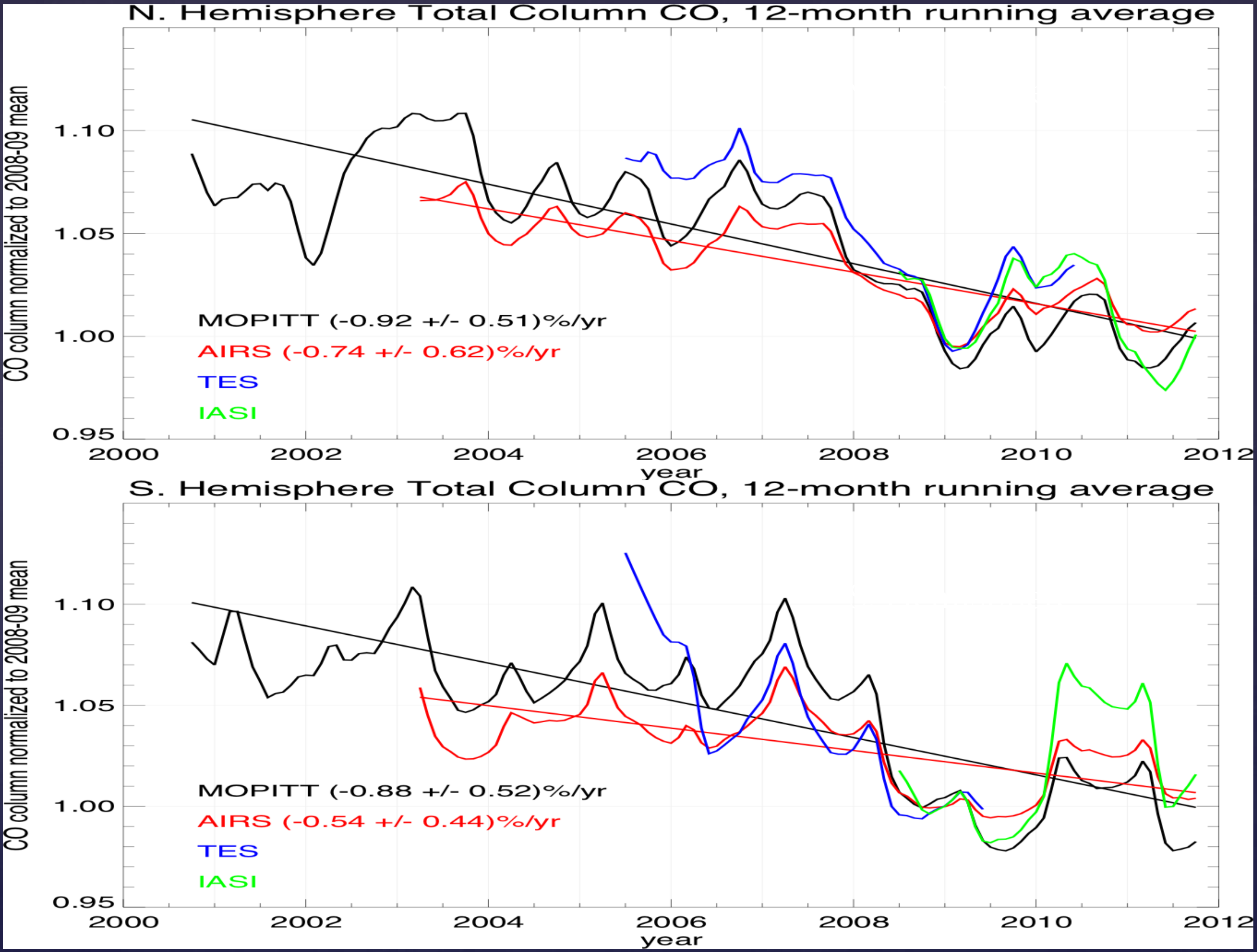




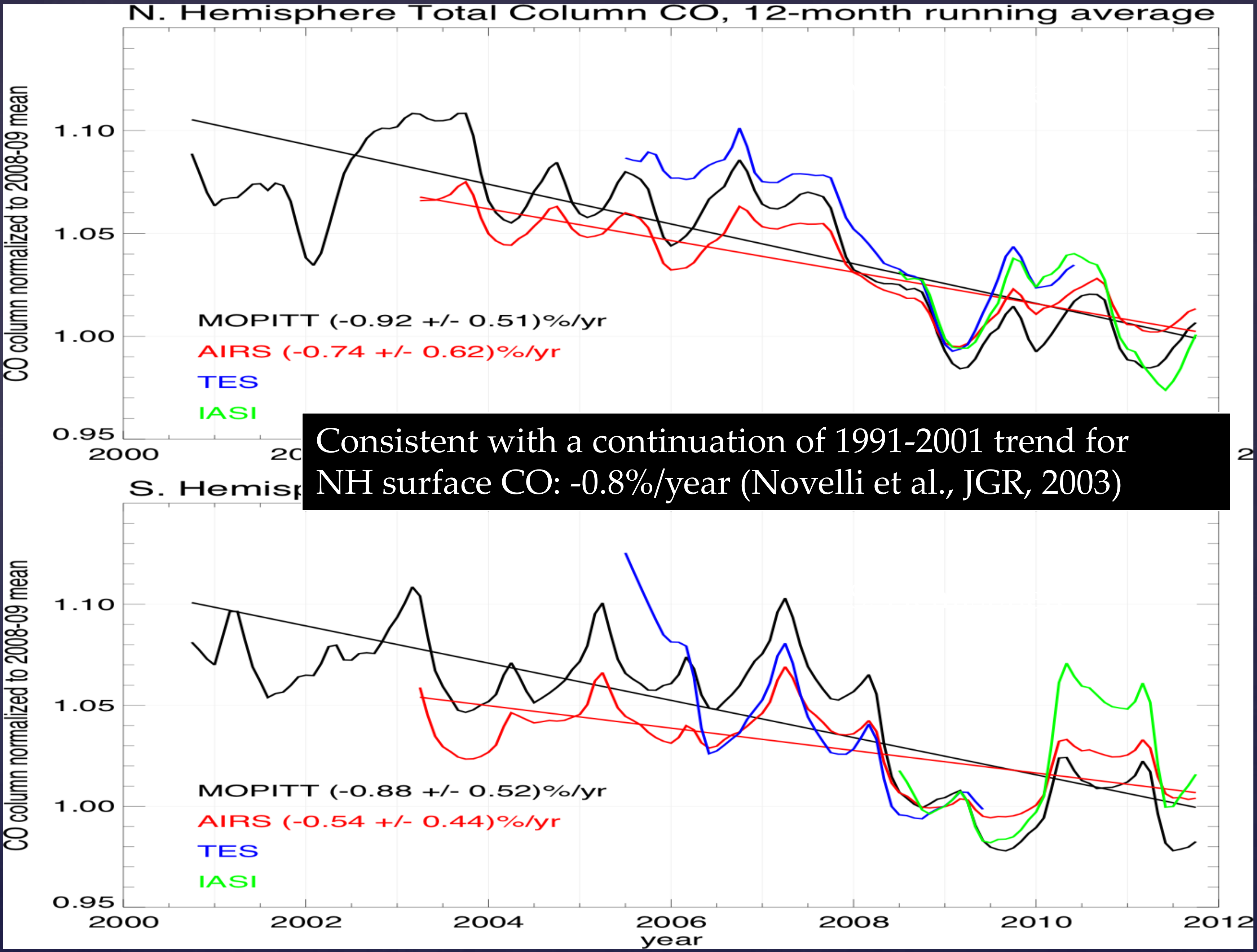
IASI-B on MetOp-B launched Sep. 2012


N. Hemisphere Total Column CO, monthly averages
MOPITT
AIRS
TES
IASI
CO column (10^18 molecules/cm^2)
2.6
2.4
2.2
2.0
1.8
1.6
2000
2002
2004
2006
2008
2010
2012
year


S. Hemisphere Total Column CO, monthly averages
MOPITT
AIRS
TES
IASI
CO column (10^18 molecules/cm^2)
2.2
2.0
1.8
1.6
1.4
1.2
1.0
2000
2002
2004
2006
2008
2010
2012
year



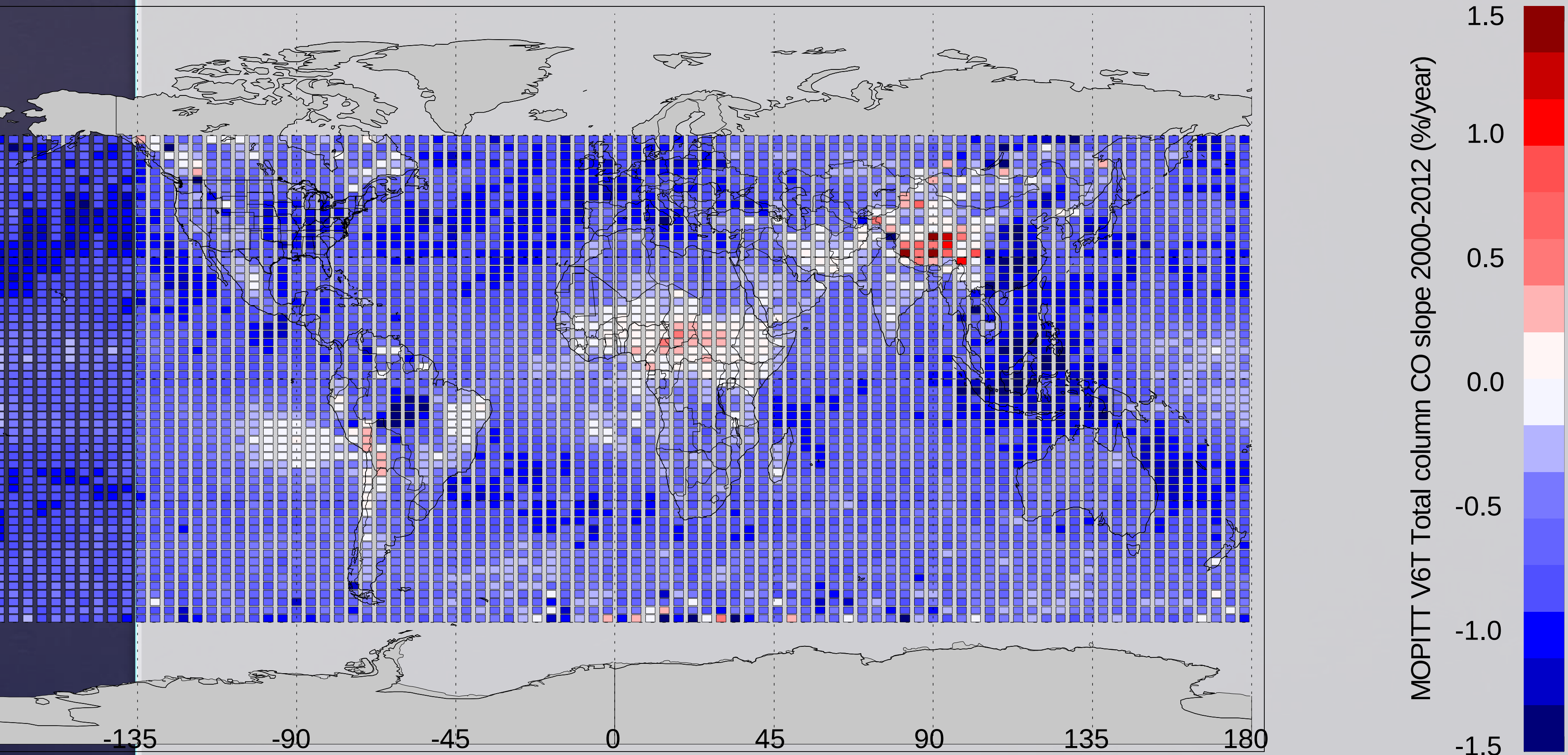
Worden et al., ACP, 2013



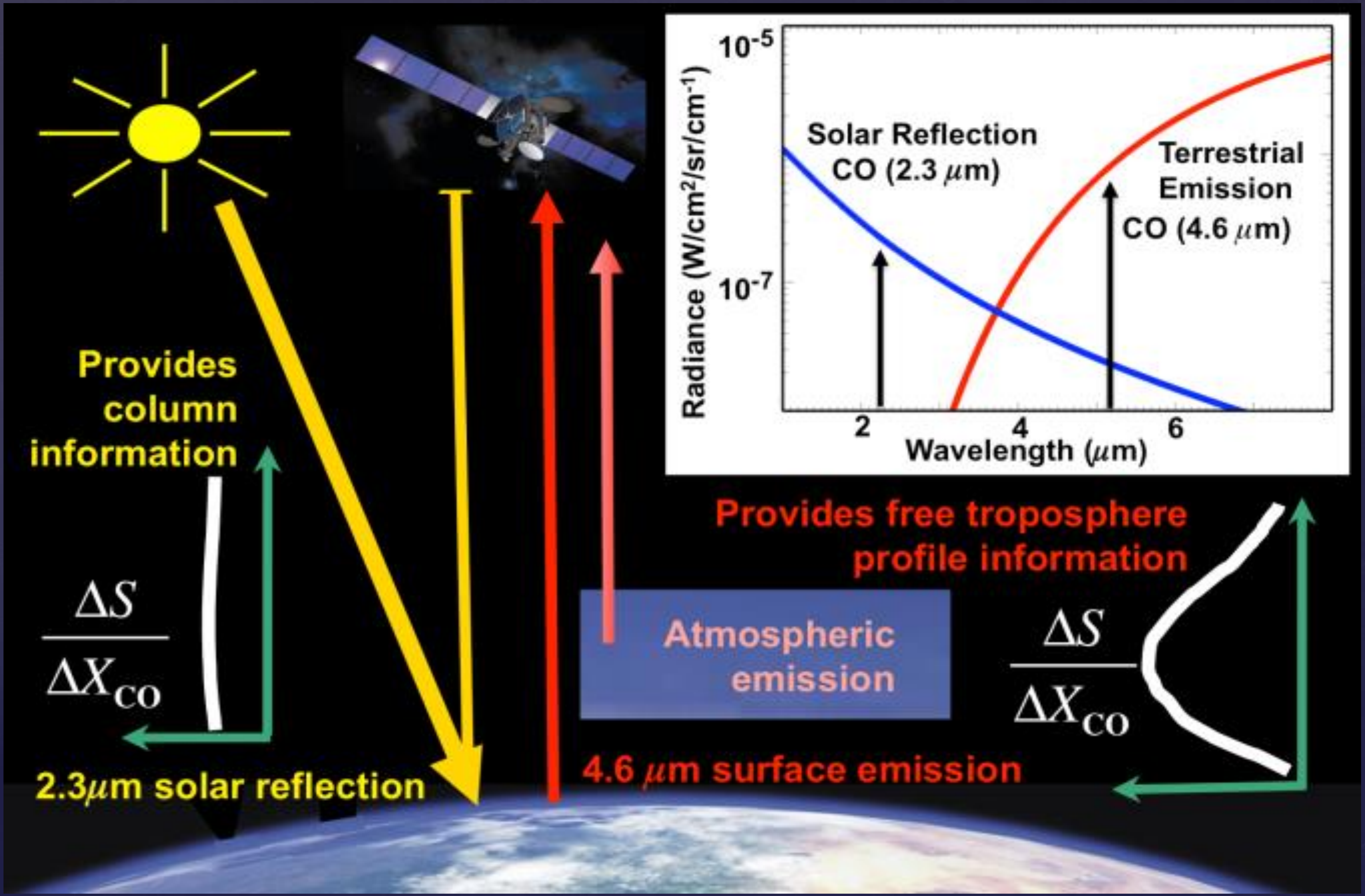
Consistent with a continuation of 1991-2001 trend for NH surface CO: -0.8%/year (Novelli et al., JGR, 2003)

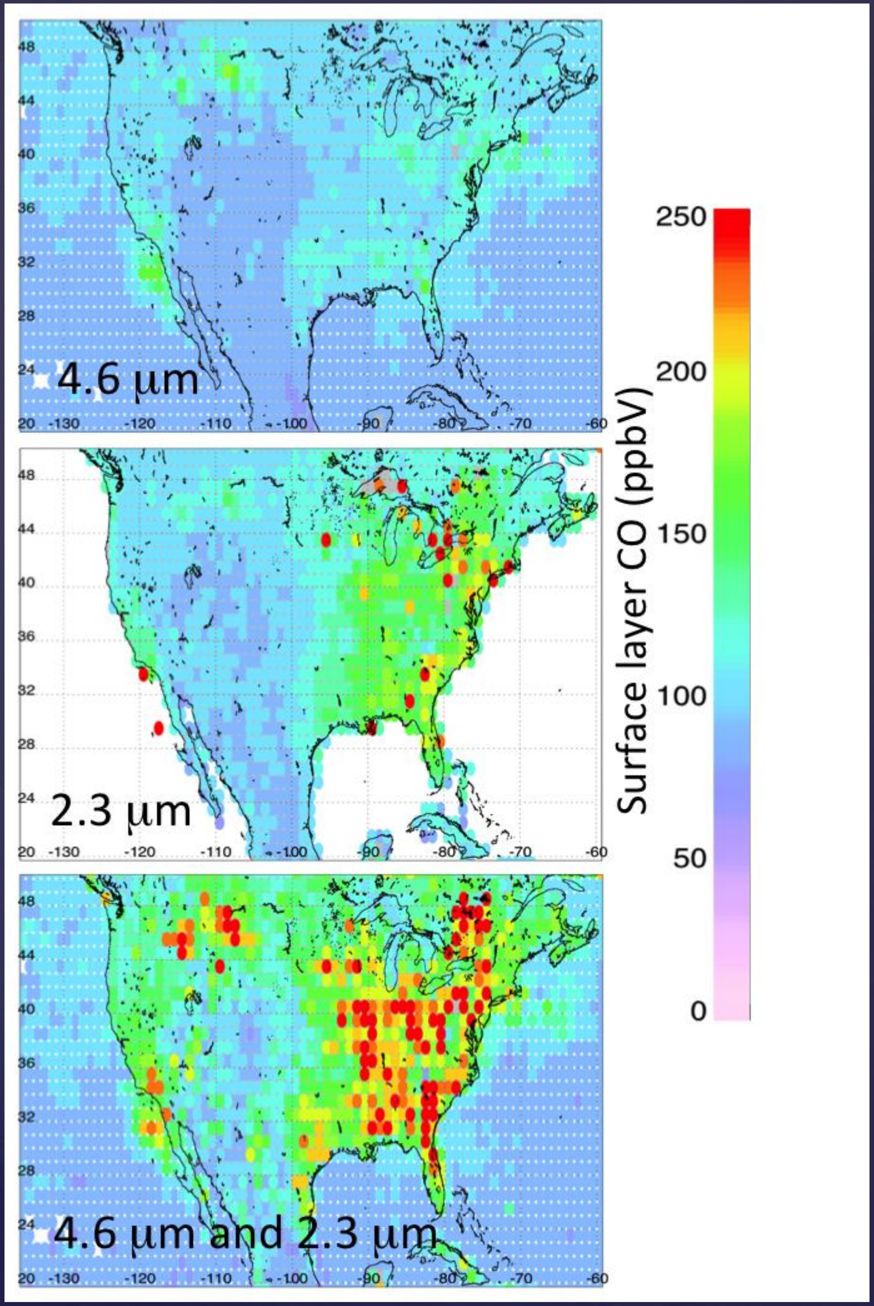
Worden et al., ACP, 2013

MOPITT V6T CO TOTAL COLUMN SLOPES (%/YEAR)



MOPITT Instrument Concepts: Thermal and Shortwave Infrared Measurements



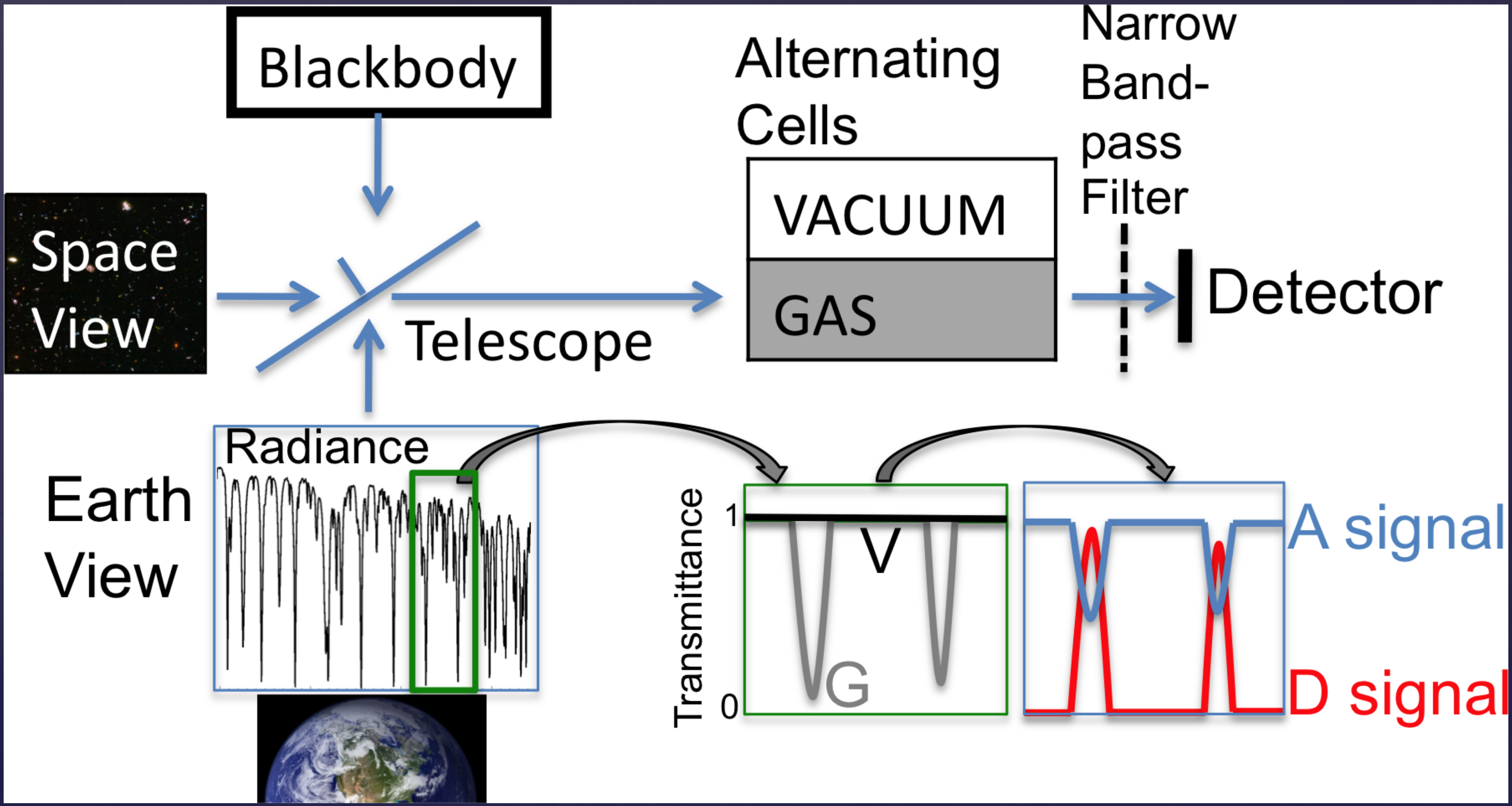


MOPITT multispectral retrievals have increased sensitivity to surface layer CO over land

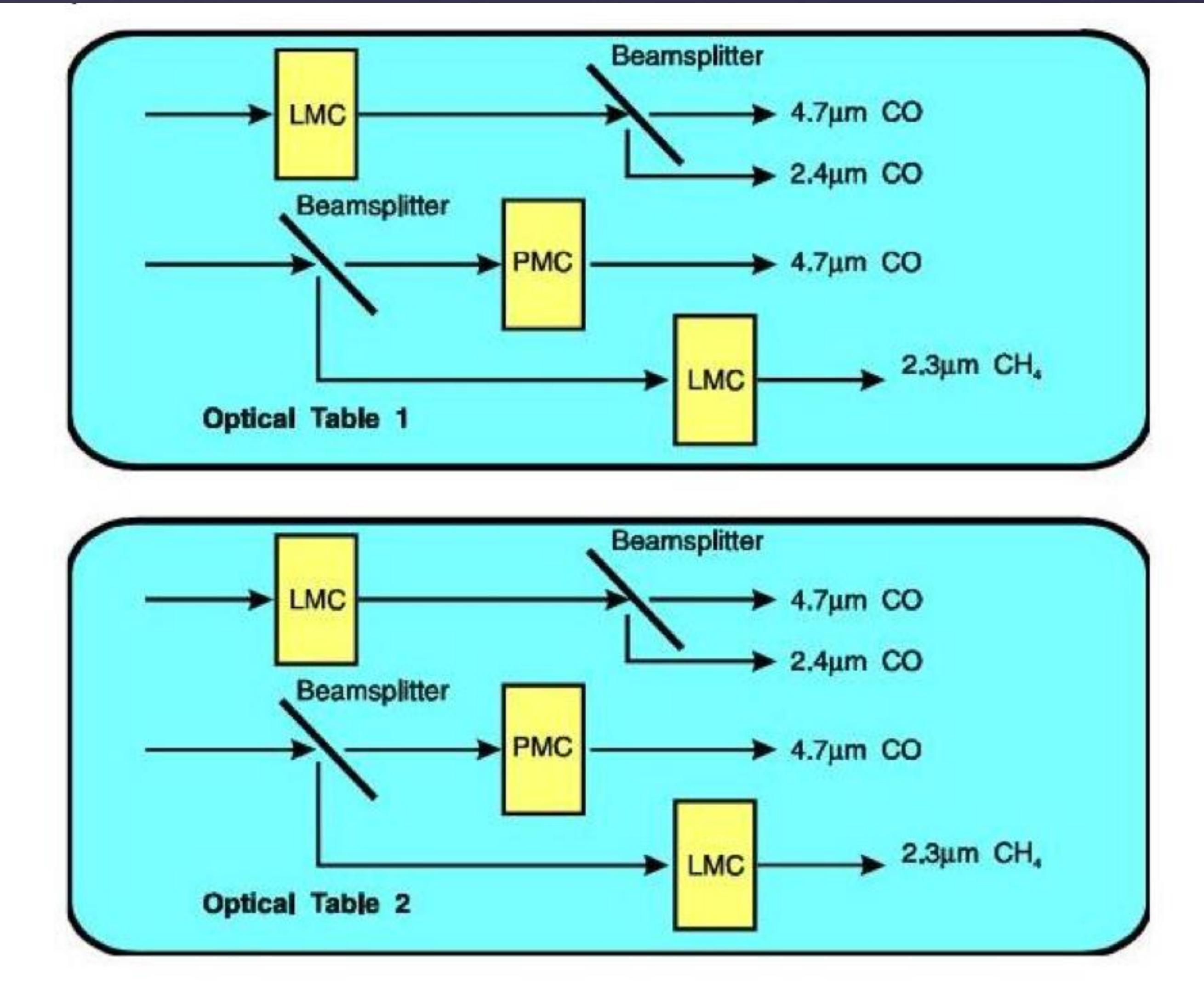
Conclusions

- CO observations from space have largest variability from biomass burning
- MOPITT CO measurements have been used to understand atmospheric chemistry and emissions at increasingly finer scales.
- All the satellite CO observations are consistent with a modest decreasing trend ~ -1%/year in total column CO over the Northern Hemisphere and less significant, but still decreasing trend in the Southern Hemisphere.
- Interesting questions remain about changes in emissions in some regions that show increasing CO trends.
- Need consistent, long term (~10 years or more) satellite records to observe global trends.

MOPITT Instrument Concepts: Simple Gas Filter Correlation Radiometer (GFCR)



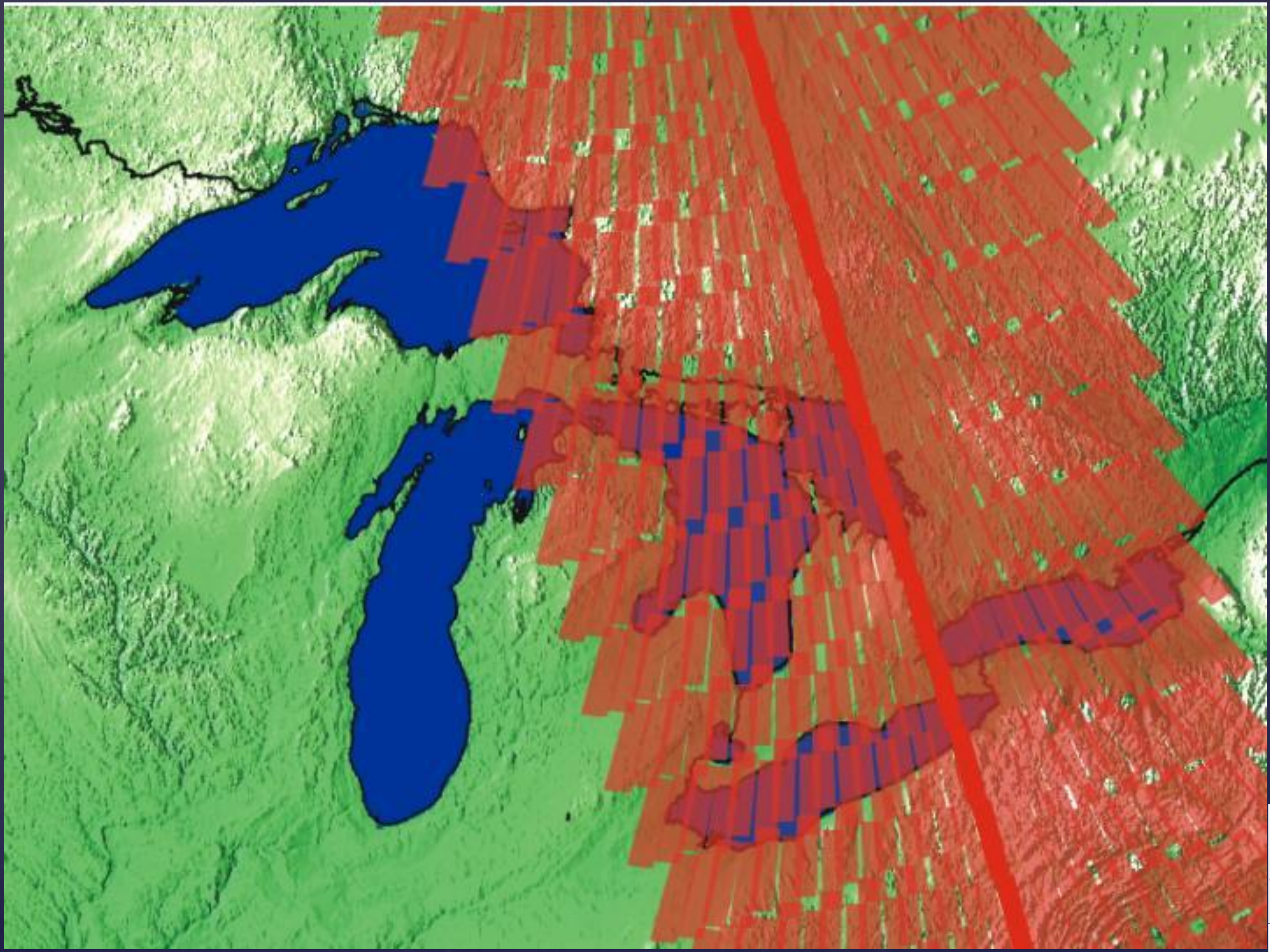
MOPITT Instrument Concepts: Optical Layout



Cooler for Optical Table 1 failed in May, 2001.

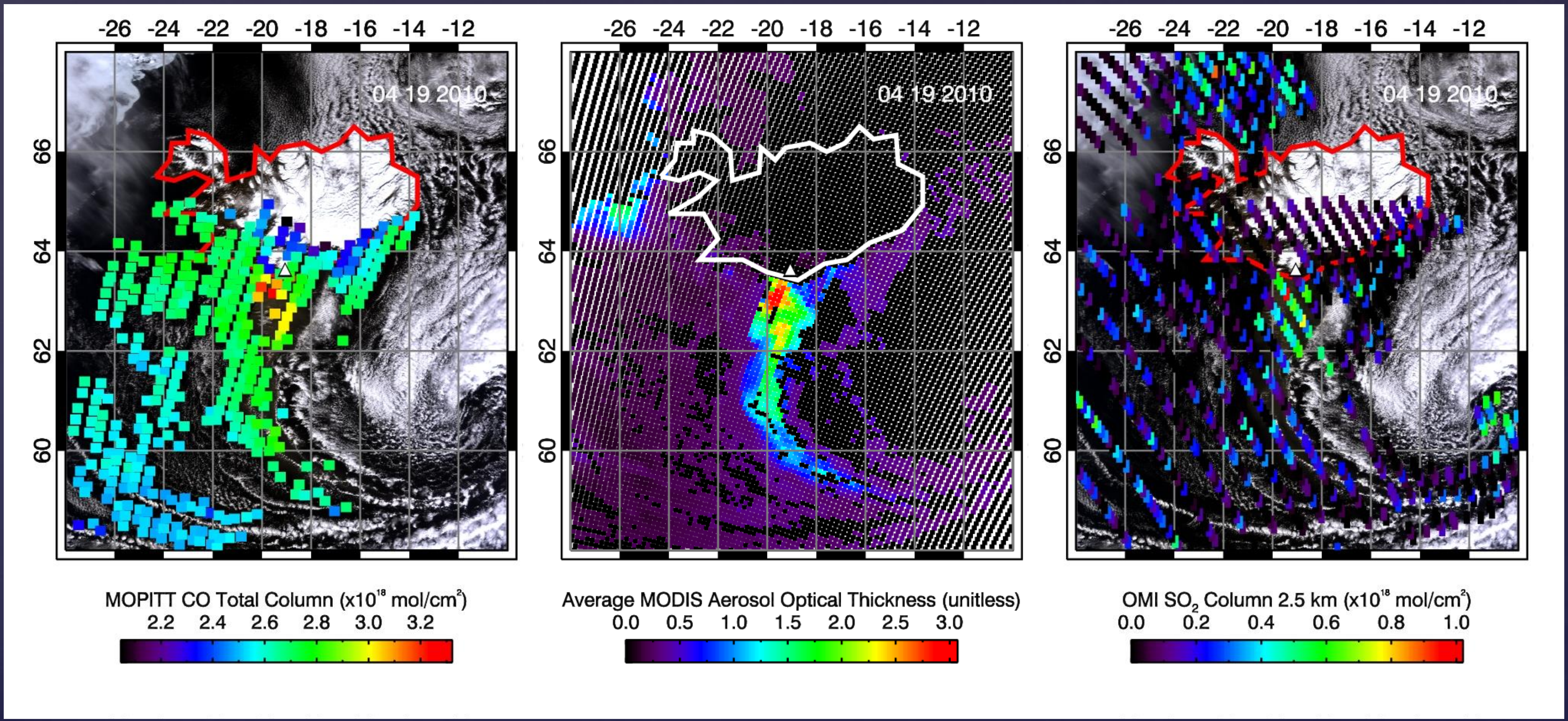
MOPITT has operated since August 2001 with Optical Table 2

MOPITT Instrument Concepts: Scanning Pattern



First detection of volcanic CO from space

MOPITT CO | MODIS AOD | OMI SO_2



Iceland Eyjafjallajökull eruption, April 19, 2010

Martínez-Alonso, GRL, 2012