Verifying Climate Treaties

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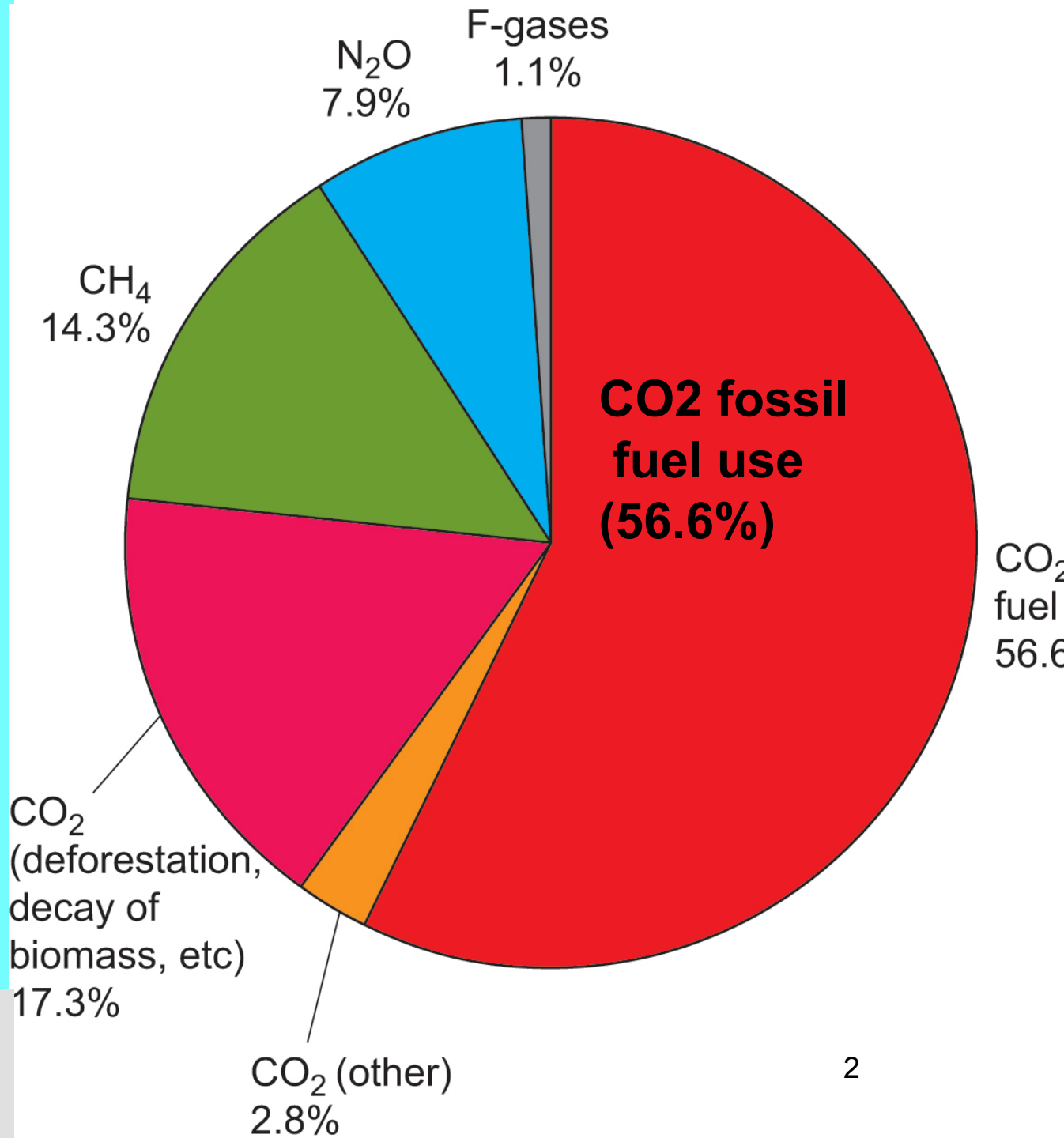
The Philomathia Foundation Symposium at Berkeley:
Pathways to a Sustainable Energy Future
October 1-2 2010

Greenhouse Gas covered by the UN Framework Convention for Climate Change



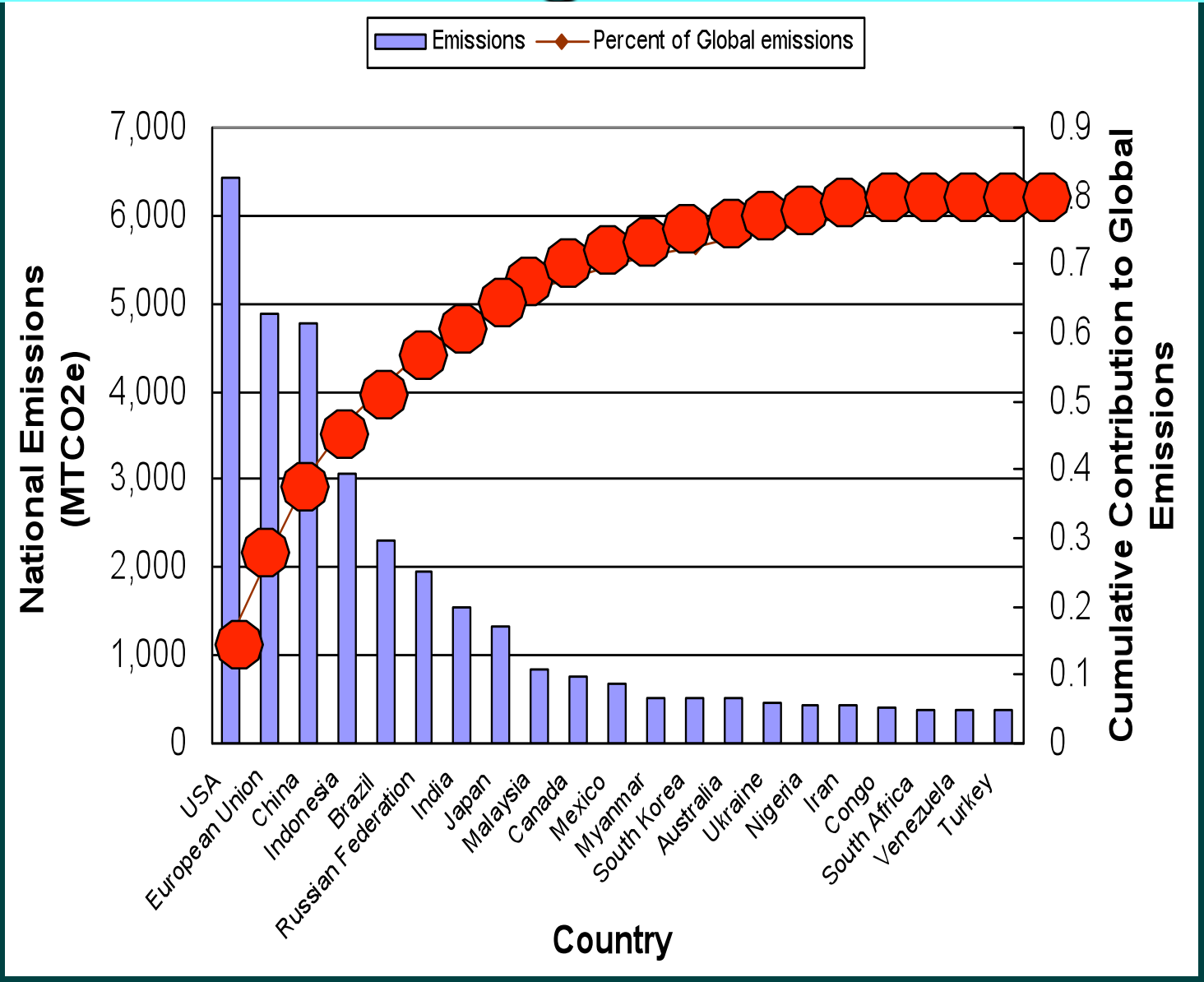
Emissions weighted by 100 -yr global warming potential (IPCC 2007)

Methods for Estimating National Emissions

United Nations Framework Convention for Climate Change (UNFCCC) National inventories:

- Estimates anthropogenic emissions and removals (sinks)
- Based on socio-economic statistics
- Self-reporting – varying degrees of confidence

One-quarter of countries are responsible for 80% of global emissions



US Emission Estimates – agree to 3%

Calculate from mass of fuel

Measure directly at stack

US Fossil Fuel CO2 Emission

DOE: Energy Information Agency:

- inventory of fuels
- Emission = Fuel weight x emission factor

EPA: eGRID

- inventory of consumption
- Emission = Activity x emission factor

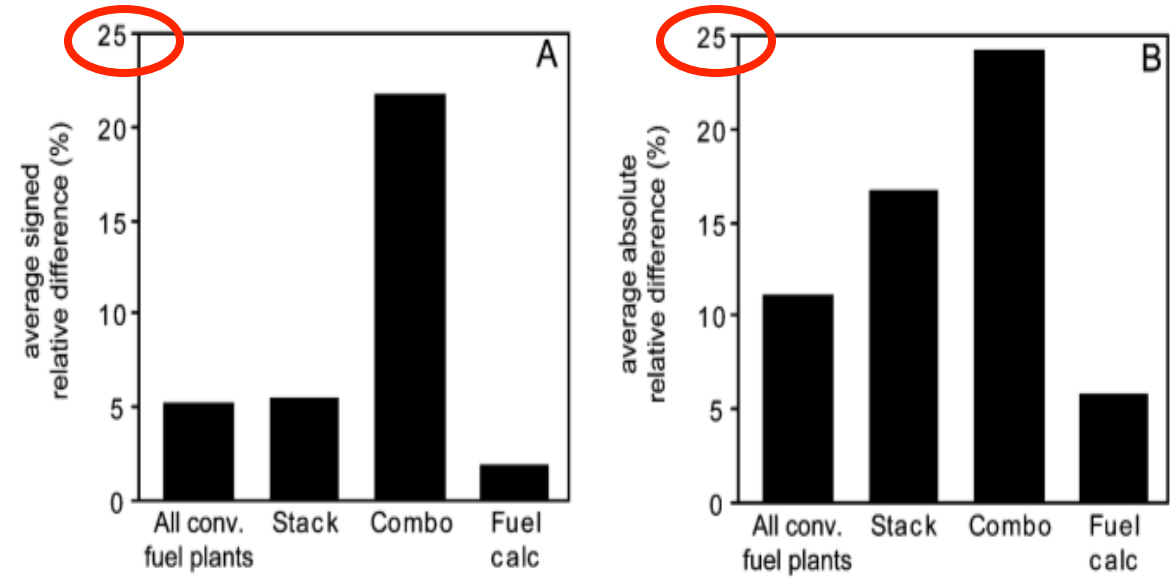
(Steel Production) (Emission per ton steel)

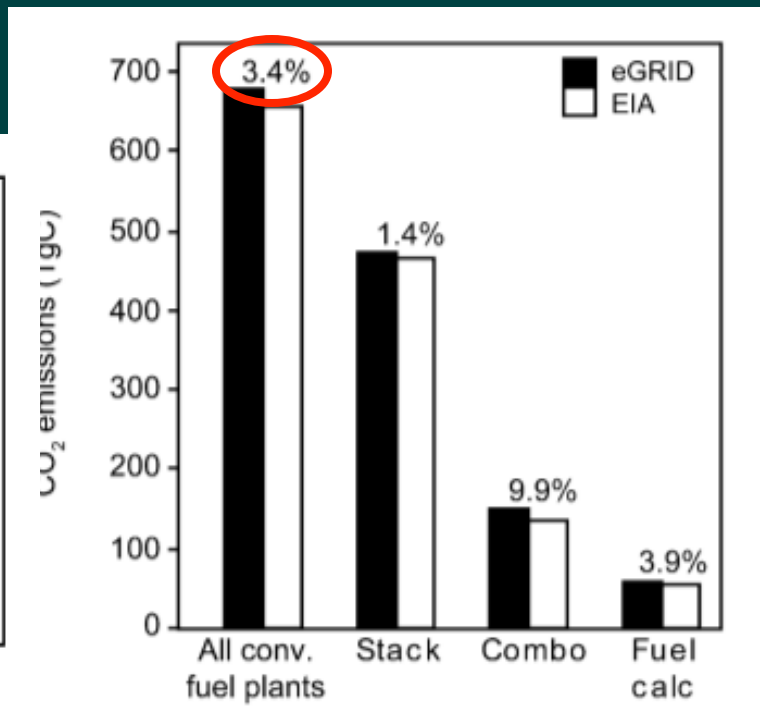
EPA does not include bunker fuels

Two estimates for USA, 2004

- EPA: eGRID
  - Fuel weight conversion for 61% plants
  - Stack measurements for 29% plants
  - Both (Combo) for remain 10%

- DoE: EIA
  - Fuel weight for all



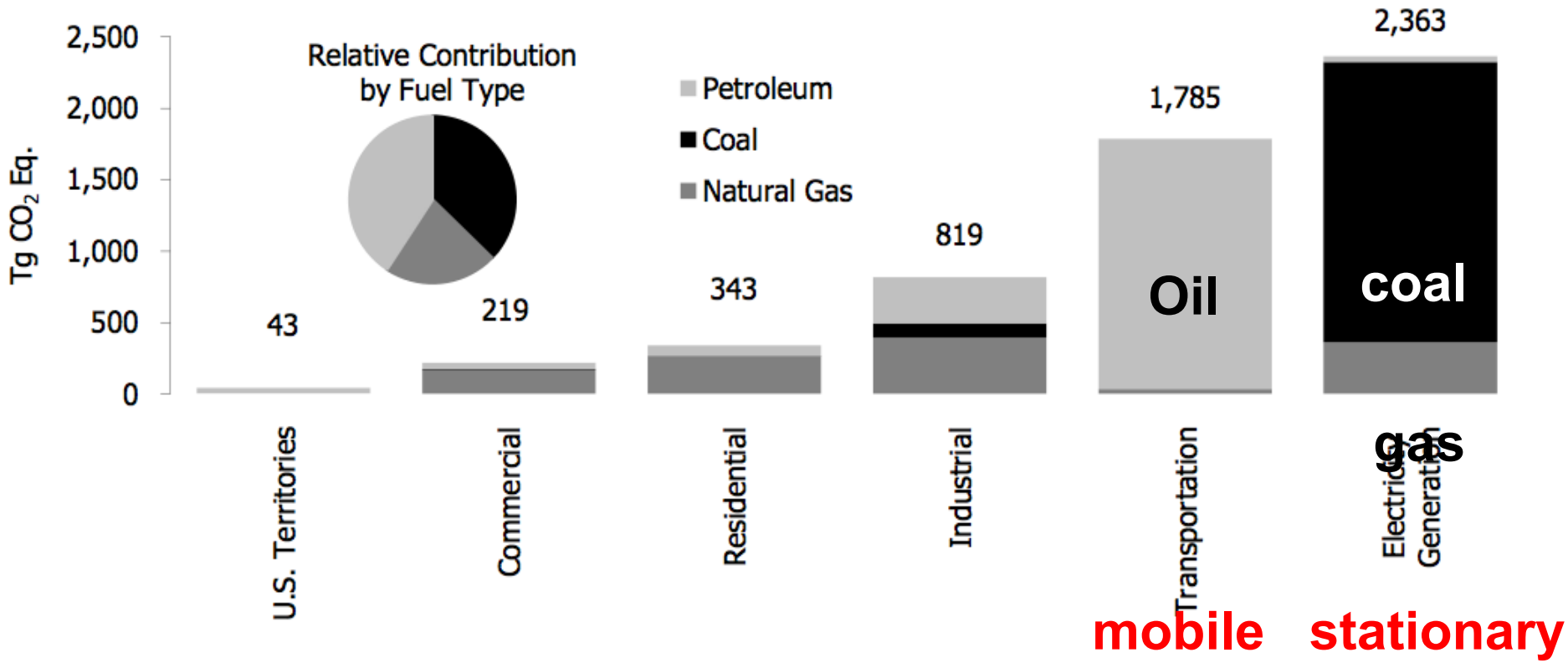


Individual Plant Level

Total Emission

Ackerman and Sundquist, Atm Env, 2008

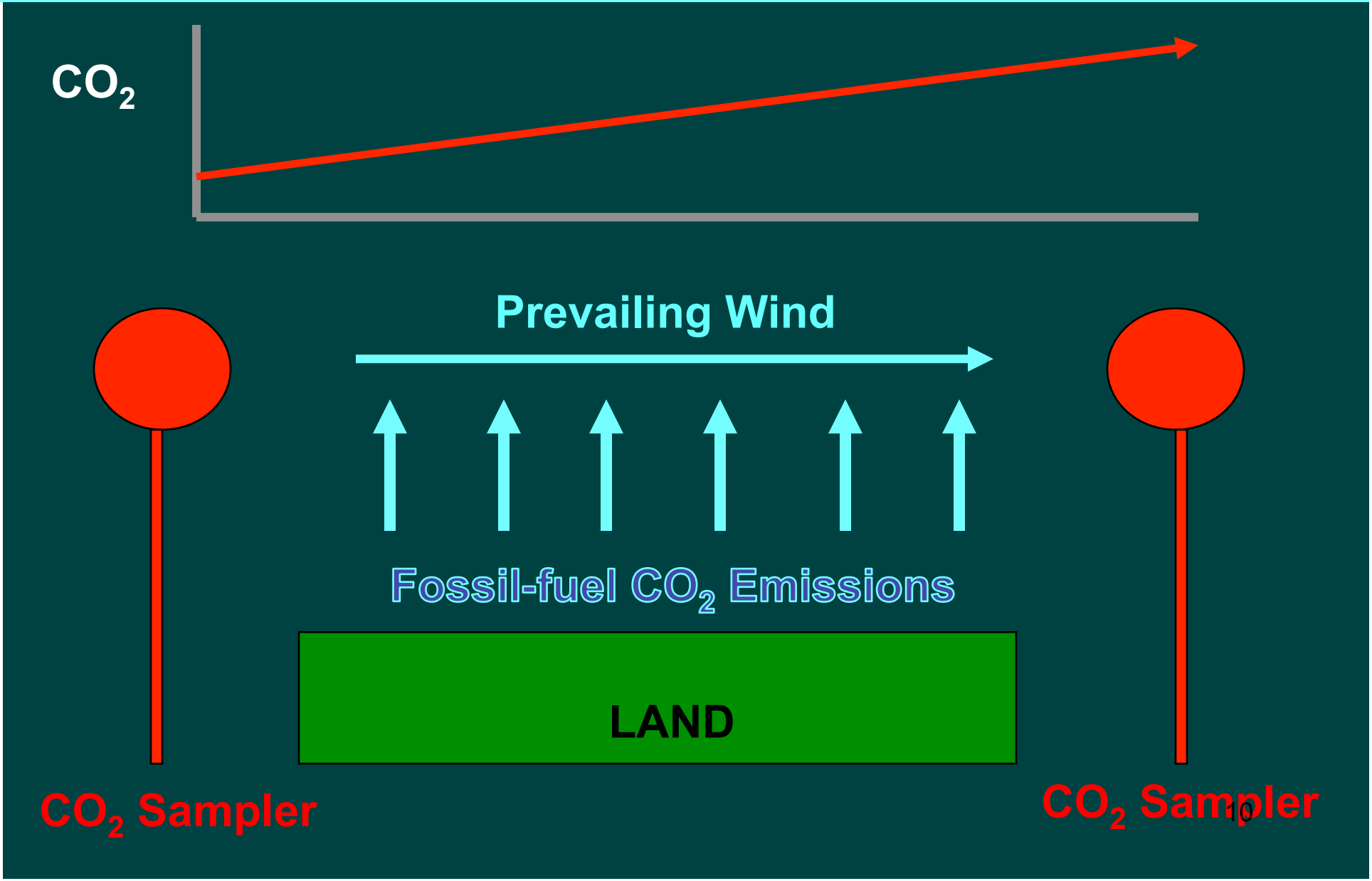
US Fossil Fuel Emission. 2006 (EPA)



Reduction in local consumption may not reduce local CO2

Trust but Verify

Atmospheric CO_2 Pattern Reflects Emission Pattern

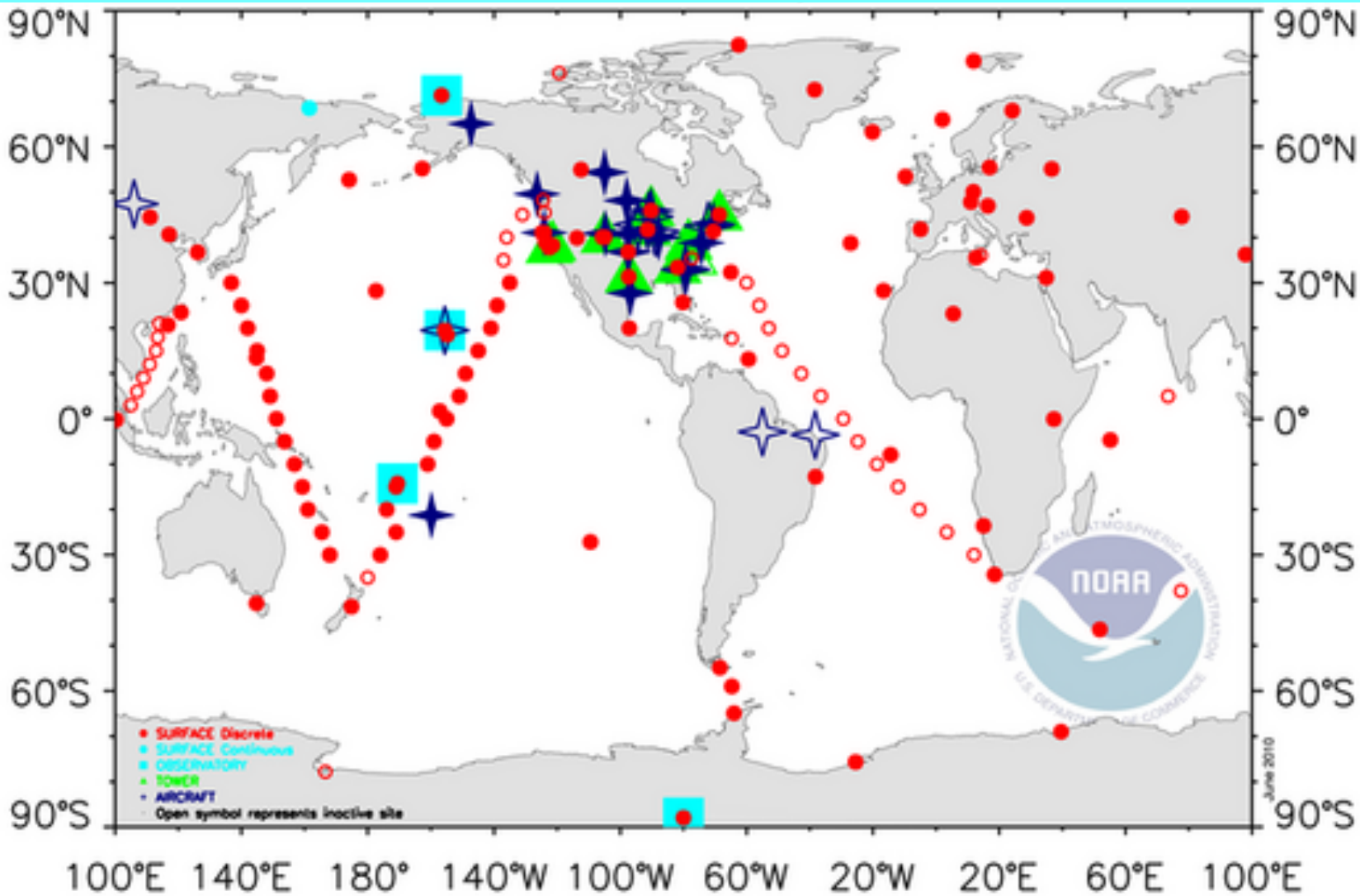


Methods for Estimating Emissions

- UNFCCC National inventories
  - Estimates anthropogenic emissions and removals (sinks)
  - Based on socio-economic statistics

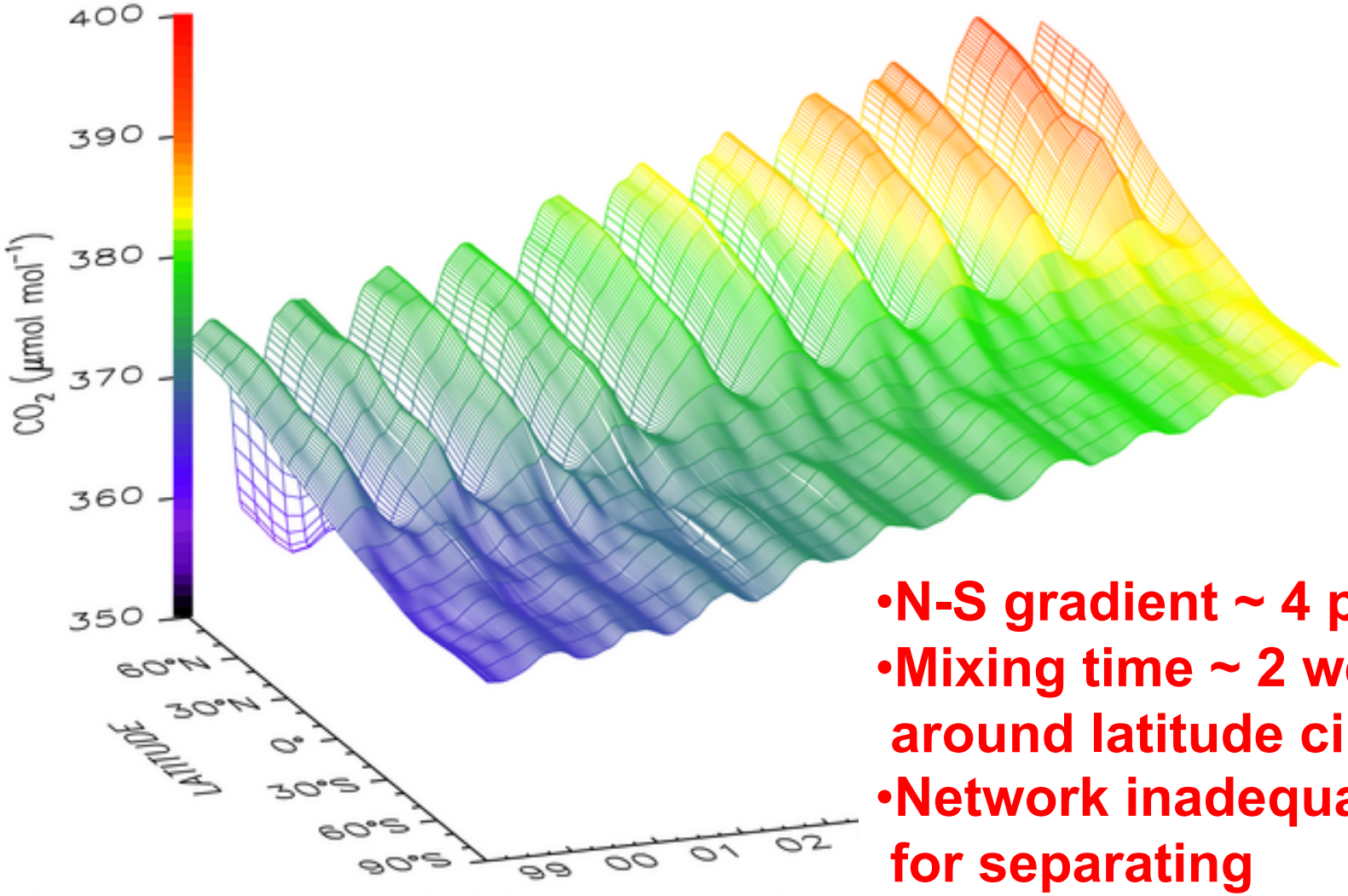
- Tracer-transport inversion
  - Estimates net anthropogenic and natural sources and sinks
  - Based on atmospheric and/or oceanic measurements of the gases and models of air and water flow

Current sampling in remote marine locations



NOAA ESRL Carbon Cycle operates 4 measurement programs. Semi-continuous measurements are made at 4 baseline observatories, a few surface sites and from tall towers. Discrete surface and aircraft samples are measured in Boulder, CO. Presently, atmospheric carbon dioxide, methane, carbon monoxide, hydrogen, nitrous oxide, sulfur hexafluoride, the stable isotopes of carbon dioxide and methane, and halocarbon and volatile organic compounds are measured. Contact: Dr. Pieter Tans, NOAA ESRL Carbon Cycle, Boulder, Colorado, (303) 497-6678, pieter.tans@noaa.gov, http://www.esrl.noaa.gov/gmd/ccgg/.

Global Distribution of Atmospheric CO_2



Three-dimensional representation of the latitudinal distribution of atmospheric carbon dioxide in t
cooperative air sampling network were used. The surface represents data smoothed in time and
NOAA ESRL Carbon Cycle, Boulder, Colorado, (303) 497-6678, pieter.tans@noaa.gov, http://ww

- **N-S gradient ~ 4 ppm**
- **Mixing time ~ 2 weeks around latitude circle**
- **Network inadequate for separating continental emissions**

Improving Independent Estimates of Fossil -Fuel CO2 Emissions

- Deploy a CO_2-sensing satellite
- Establish new atmospheric sampling stations (ground, ocean surface, aircraft) in strategic locations
- Measure ^{14}C in the CO_2 samples already being collected

Carbon data assimilation

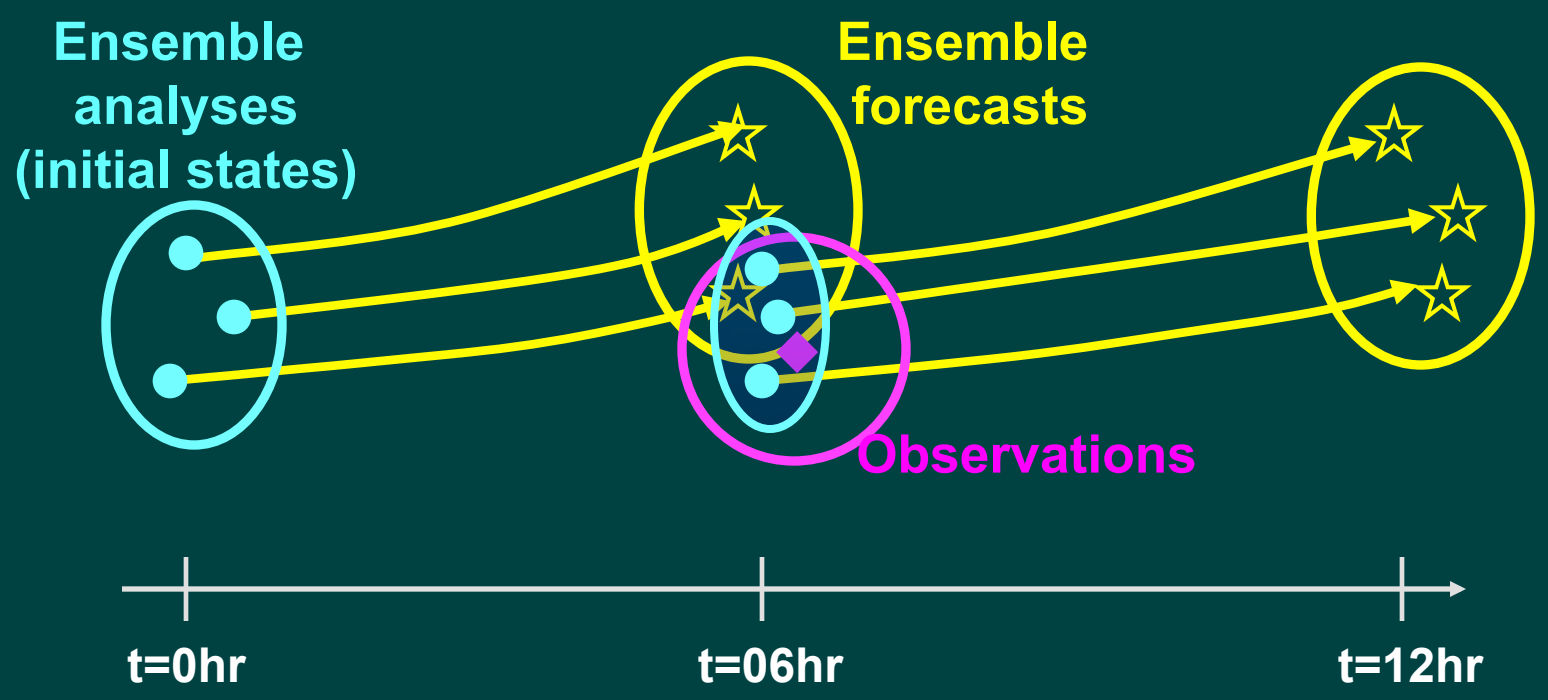
Combine information from

- Imperfect model
- Incomplete observations

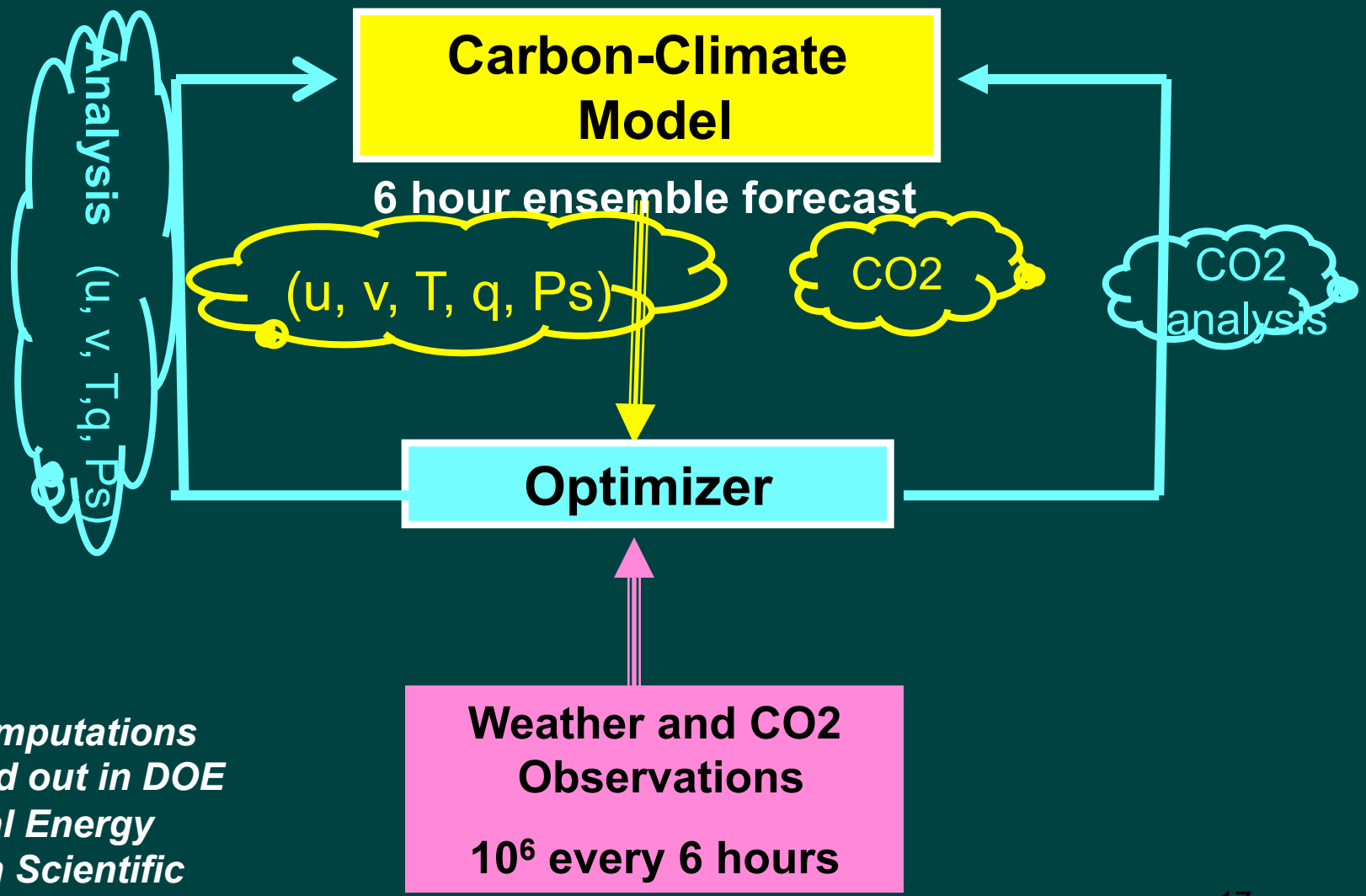
→best estimate of the meteorological state and CO_2

→CO_2 sources and sinks

Carbon Data Assimilation



Carbon Data Assimilation

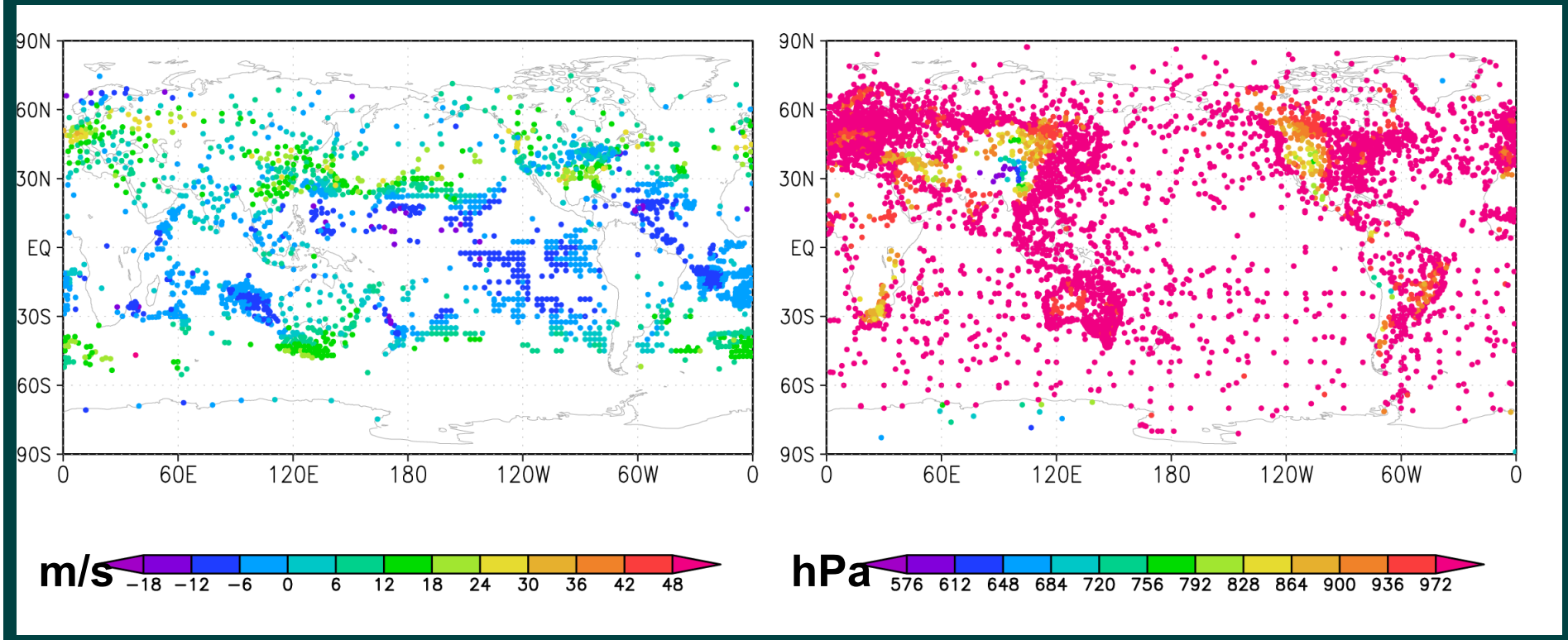


All the computations were carried out in DOE National Energy Research Scientific Computing Center (NERSC)

Meteorological observations include radiosonde, satellite, ships etc: examples

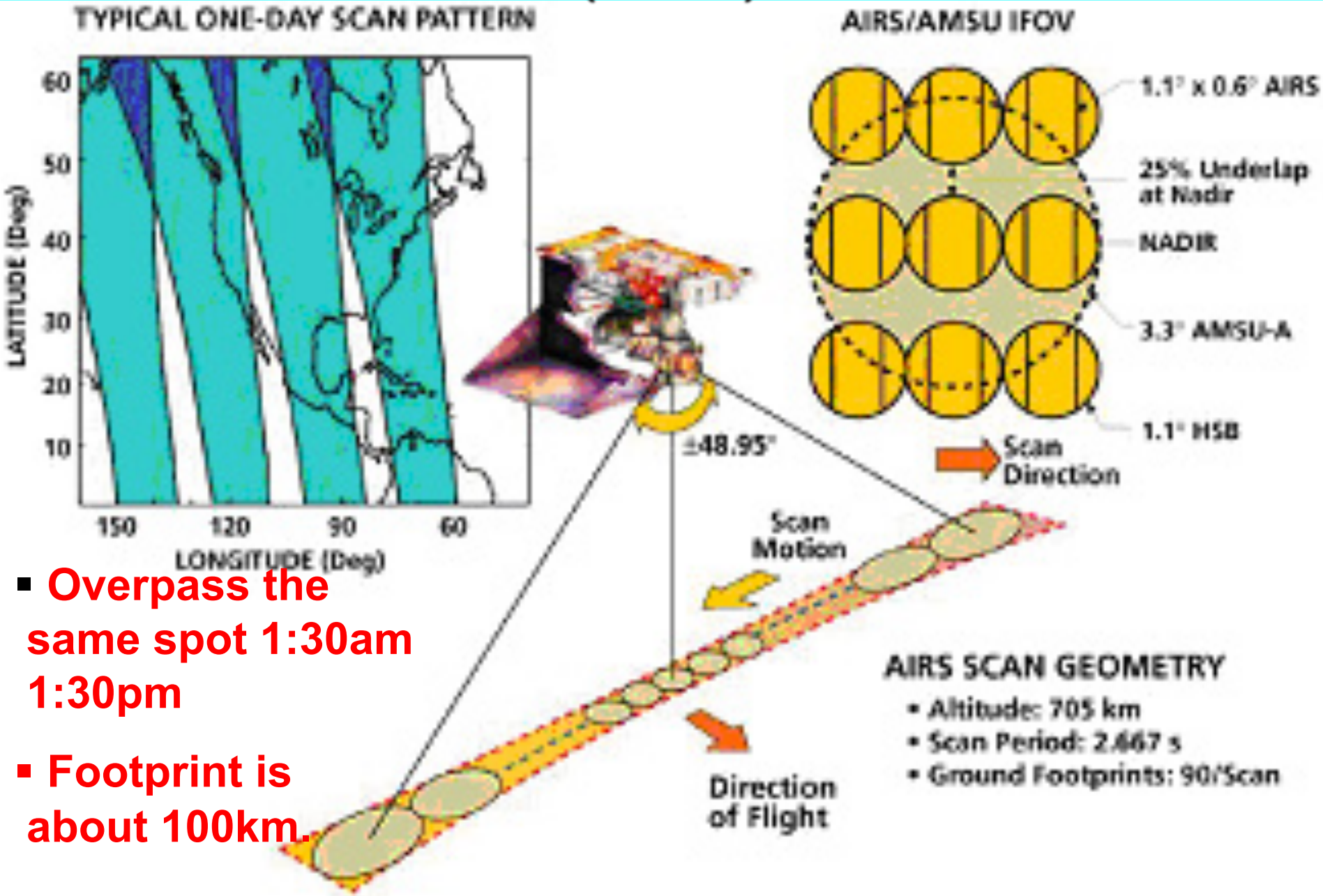
Zonal wind within 500hPa and 600hPa

Surface pressure



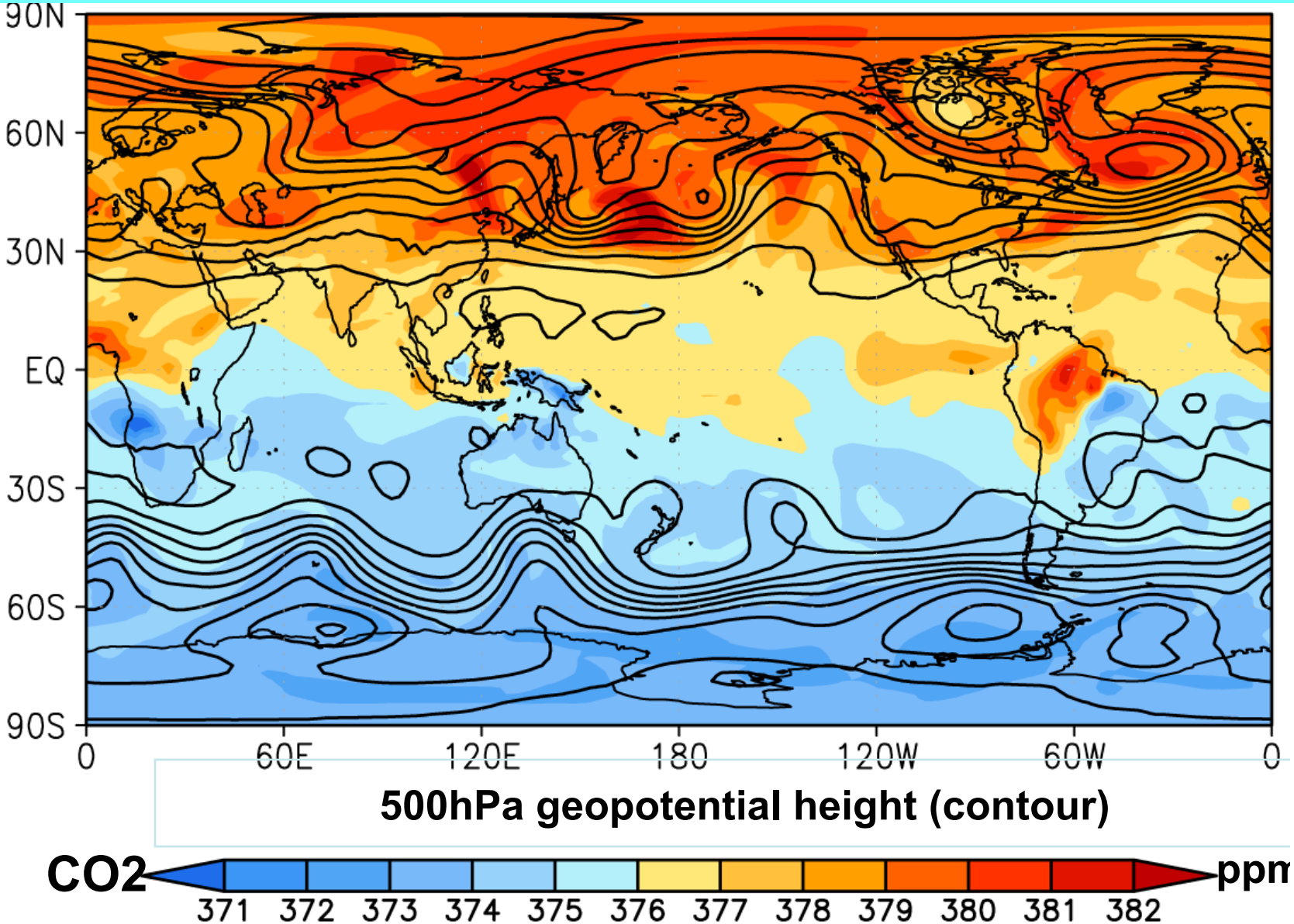
- Assimilate all the quality-controlled meteorological observations assimilated in the DOE/NCEP Reanalysis 2 products (Kanamitsu et al. (2002). 10^6 observations within 6-hour.

CO_2 from Atmospheric InfraRed Sounder (AIRS)



- Overpass the same spot 1:30am 1:30pm
- Footprint is about 100km.

CO_2 Weather (12Z 27Feb2003)



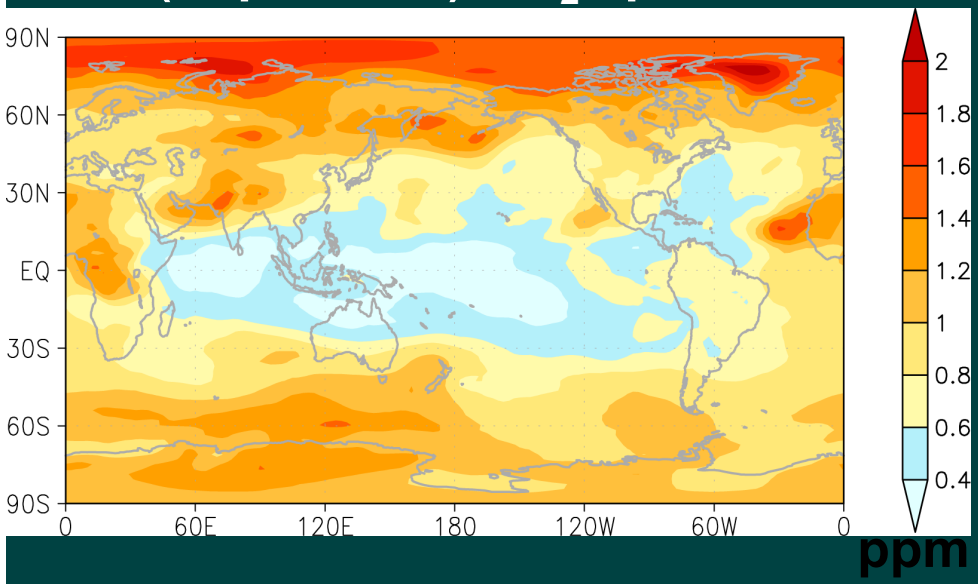
N_Hem
Winter

FF
Decom
position

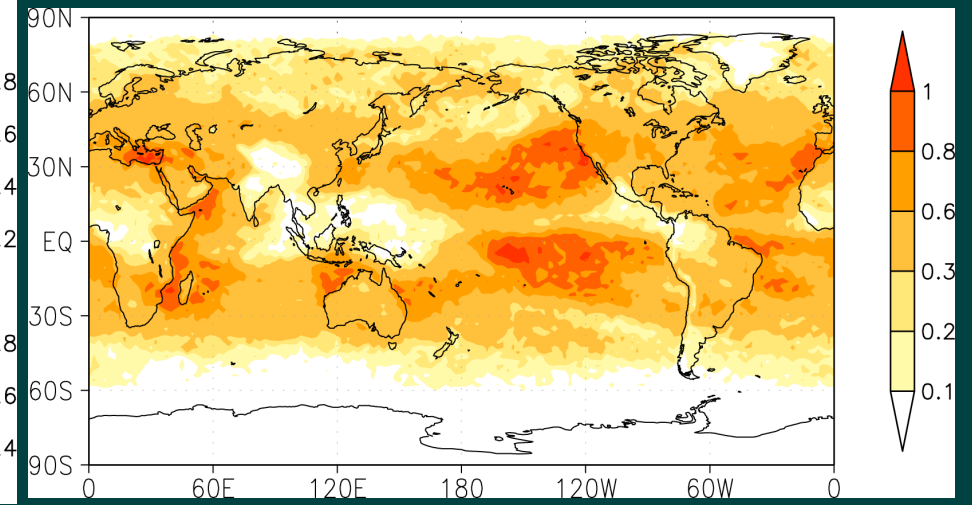
Liu Fung Kalnay Sun 2010

CO_2 analysis spread ranges from 0.4ppm to 2ppm at 400hPa

400hPa monthly mean (September) CO_2 spread



Average num of CO_2 observations at each grid box within 6 hours

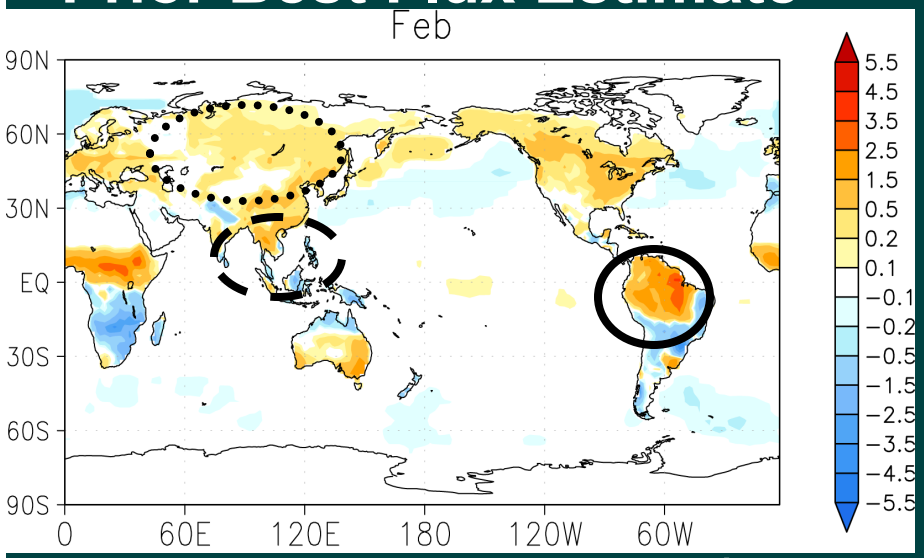


- Analysis ensemble spread is related to observation coverage, forecast error and observation error;
- Larger spread over high latitudes, and over land;
- Smaller spread over tropical ocean is due to observation coverage and information propagation through forecast.

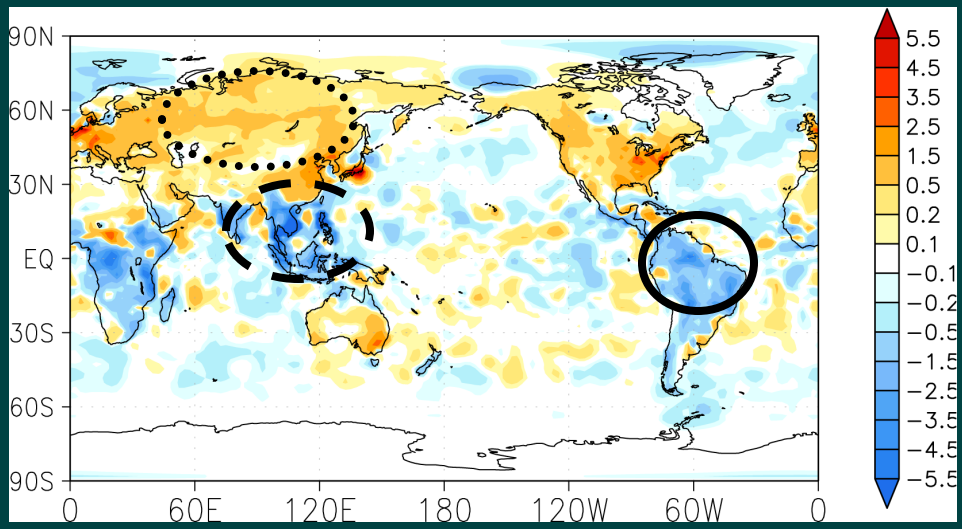
Assimilation greatly alters fluxes in Tropics!

February 2003

Prior Best Flux Estimate



Carbon flux analysis



(unit: 10^{-8} kg/m^2/s):

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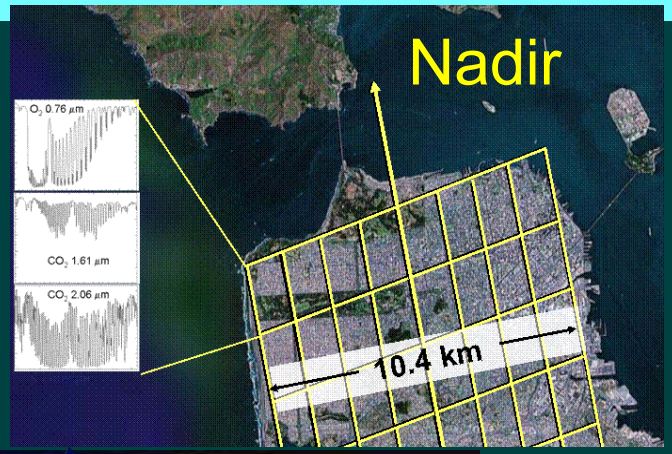
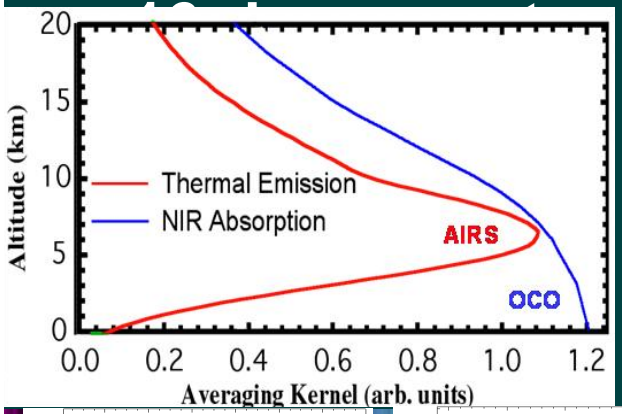
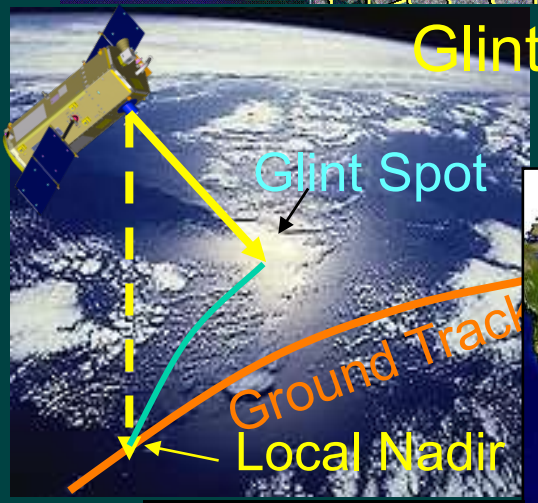
- **Stronger source in the NH winter;**
- **Stronger sink in the tropics and SH subtropics; They were poorly constrained by surface observations.**
- **More variable fluxes over ocean compared to compilation of ship obs of air-sea CO2 flux.**

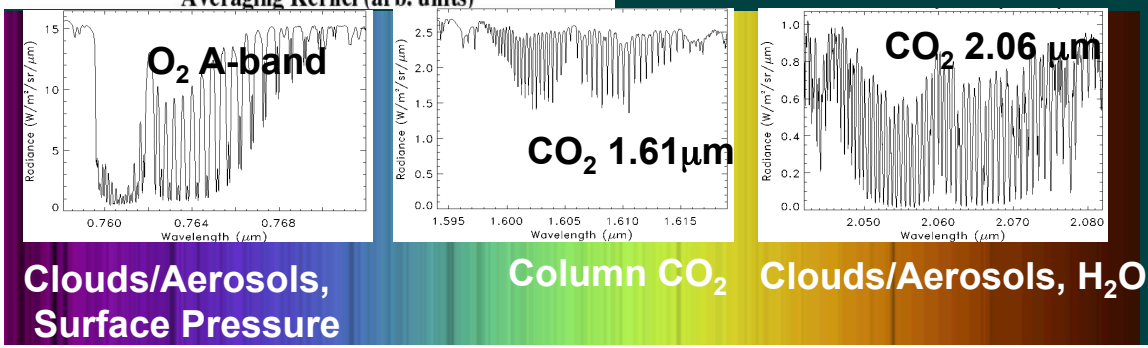
Orbiting Carbon Observatory (OCO)

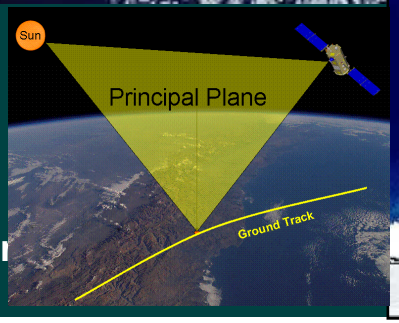
- High resolution spectra of reflected sunlight in near IR CO_2 and O_2 bands
- 3 km^2 footprint at nadir
- 3 Hz
- Sun-Synchronous Orbit (7km/s):

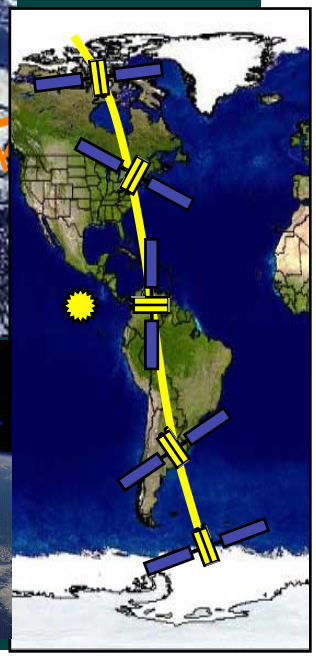


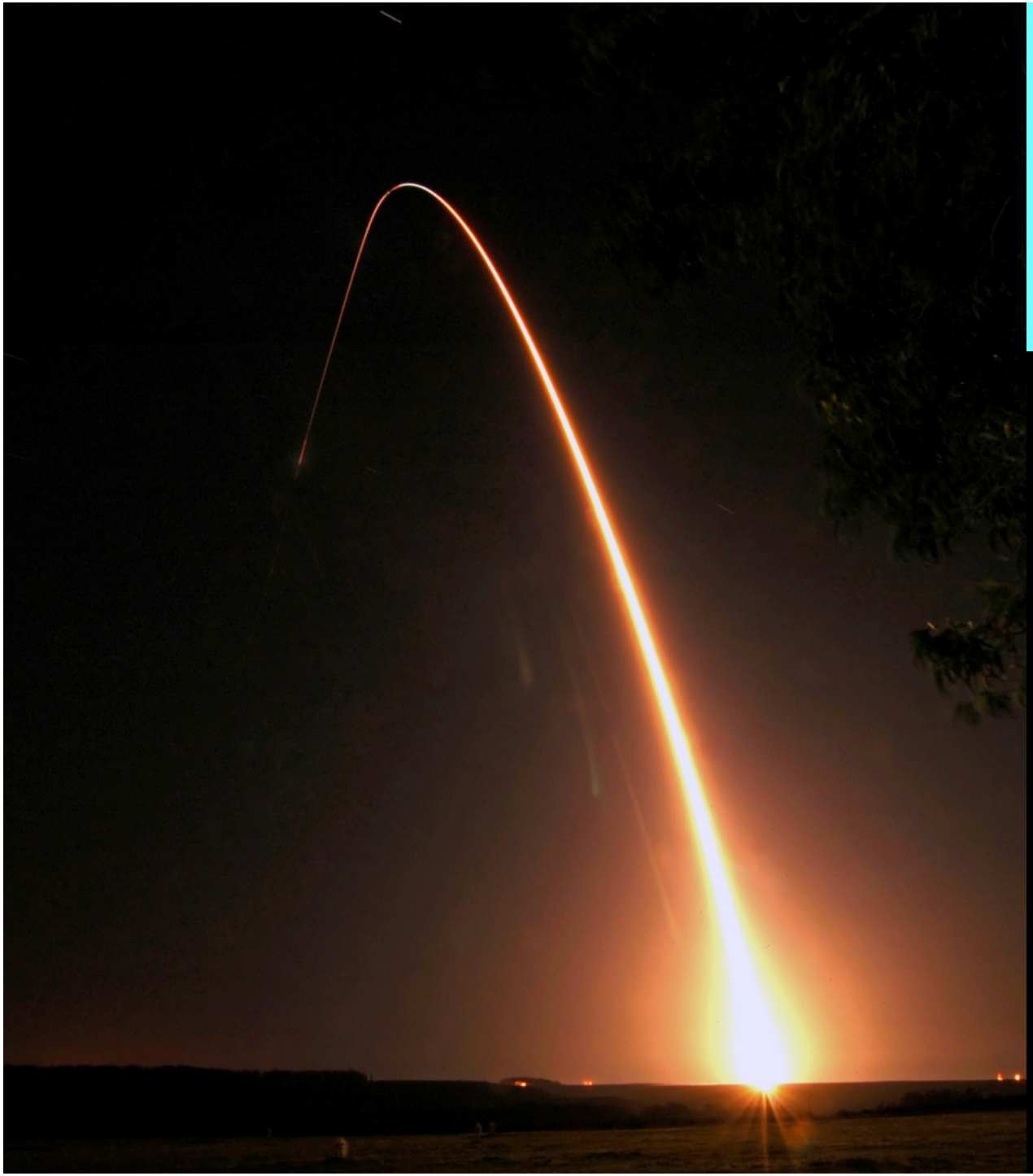












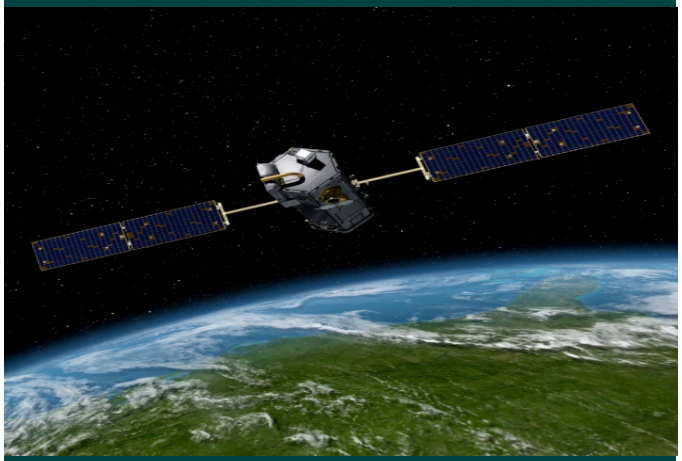
OCO Launch: 01:55:30 PST 24 February 2009

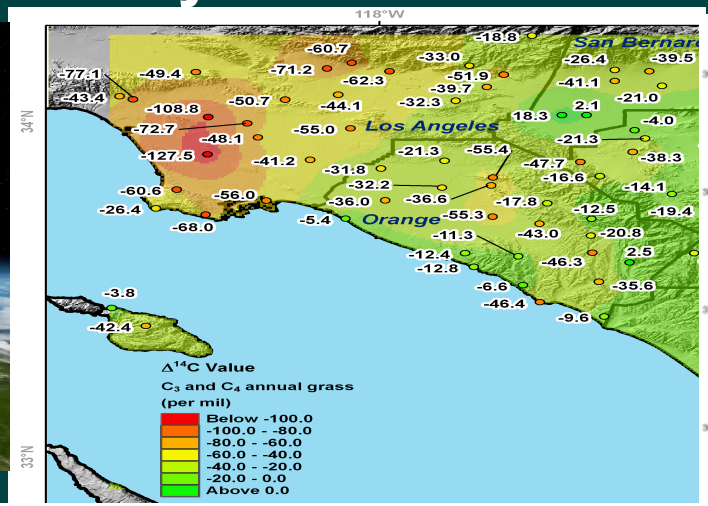
Approved for reflight, 2010: climate treaty verification.

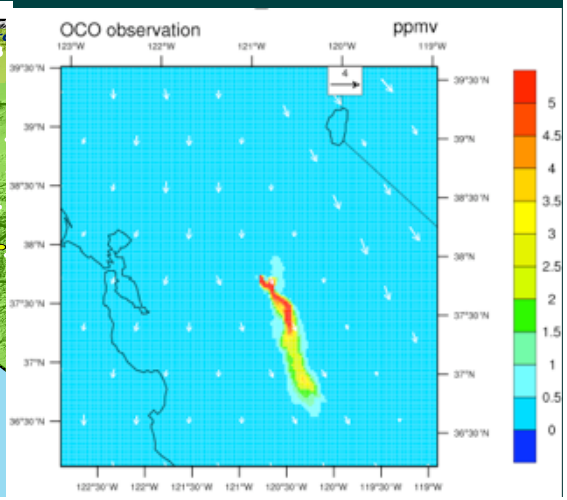
Outlook

NASA will launch a replacement for the Orbiting Carbon Observatory (OCO) ~2013

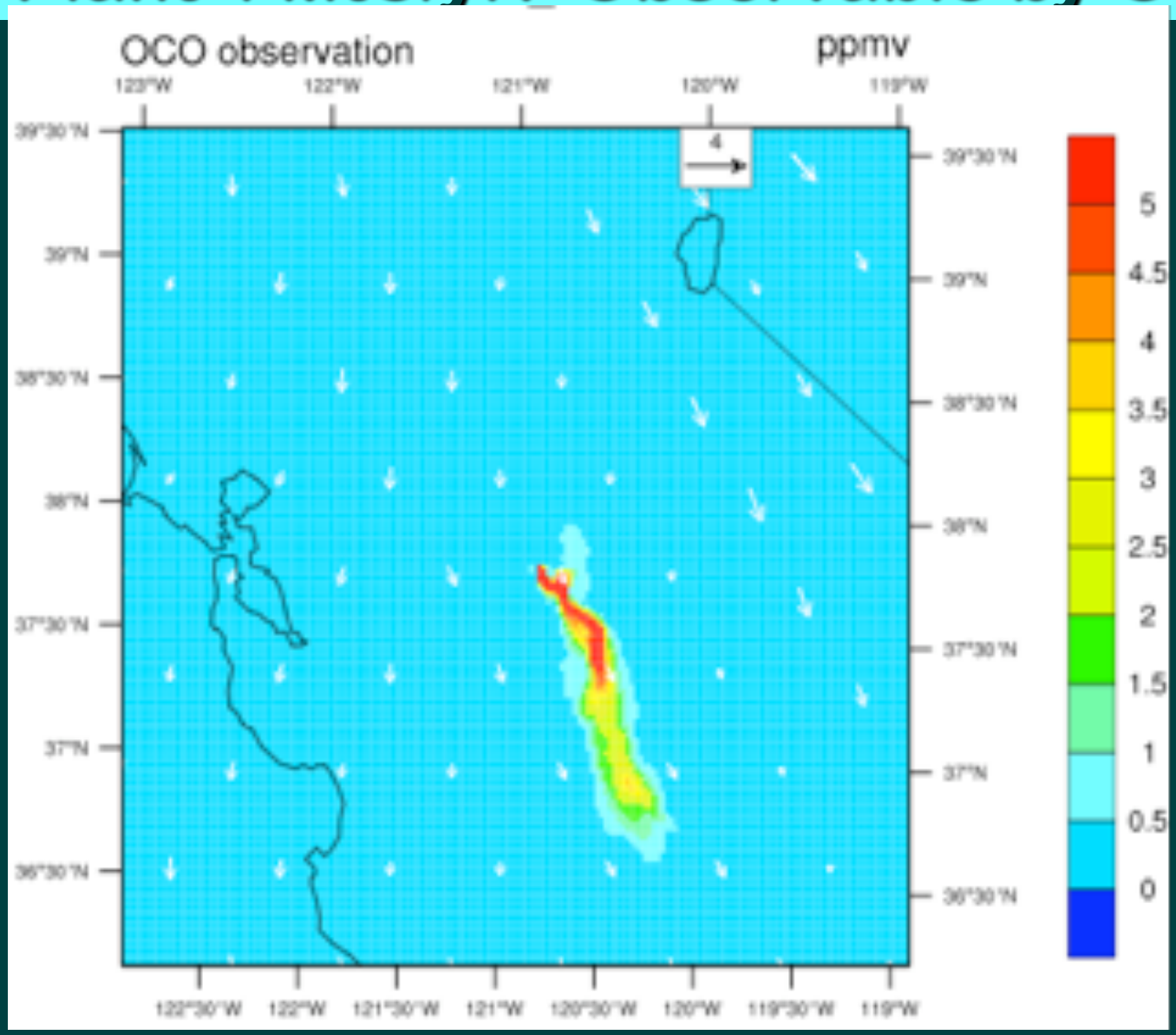
- **Most fossil-fuel CO_2 emissions emanate from large local sources**
- **OCO's high precision and small sampling area could detect these signals and attribute them to the emitting country**
- **Demonstrate the capability for monitoring CO_2 from space for a climate treaty**





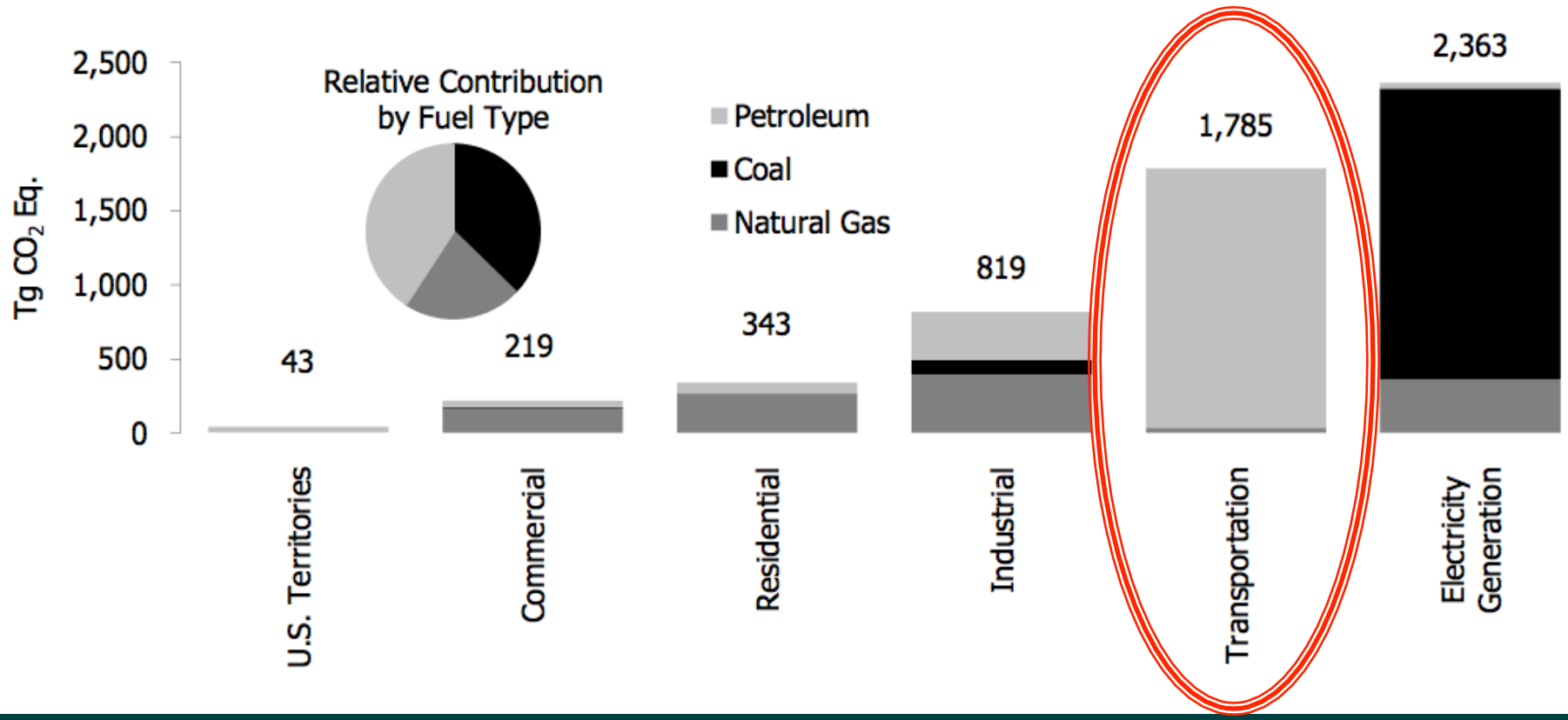


Simulation of CO2 from Hypothetical Power Plant 4 MtC/yr: Observable by OCO



Yang and Fung

Local Monitoring

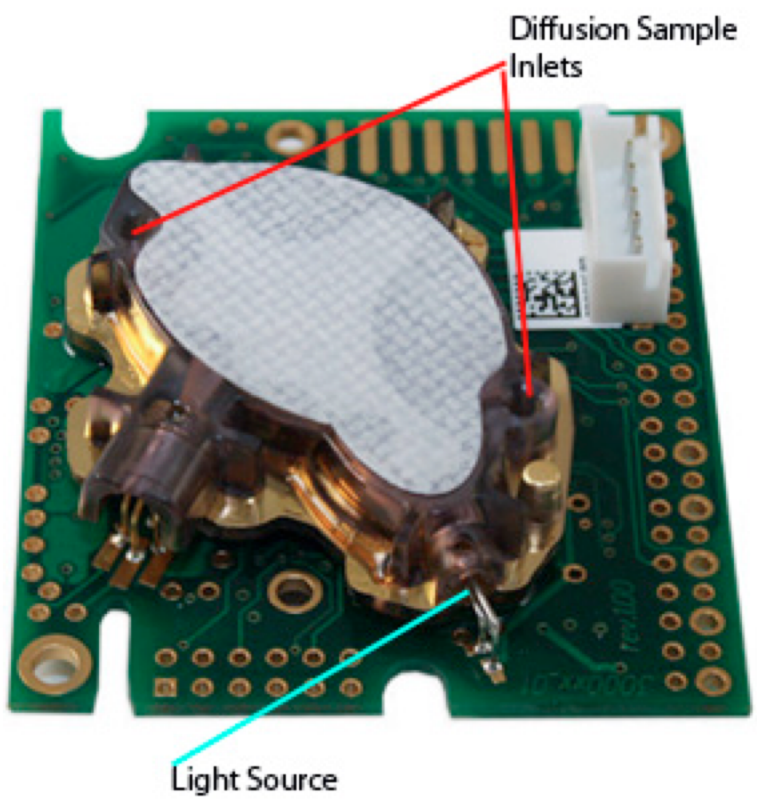


New CO2 sensors

Ron Cohen, Virginia Teige (UC Berkeley - Chemistry)

- Chabot Science Center and Oakland Unified School District
- CO2 sensors (Vaisala CarbooCAP +/- 3 ppm) will be deployed with other sensors for air quality (O3, NO2, CO) and environmental data (temperature, pressure, relative humidity)
- Real time sensing, wireless communication of data
- 0.5-1km grid over Oakland
- Deployment to start 2011.

K-30 Non-dispersive Infrared Instrument



Summary: Climate Treaty Verification

- Need to verify self-reported emission estimates
- Need to establish baseline emissions

- Satellite CO_2 + carbon data assimilation system → CO_2 fluxes at <national levels
- Will demonstrate CO_2 sensing at local scales