The GeoCARB Mission

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with

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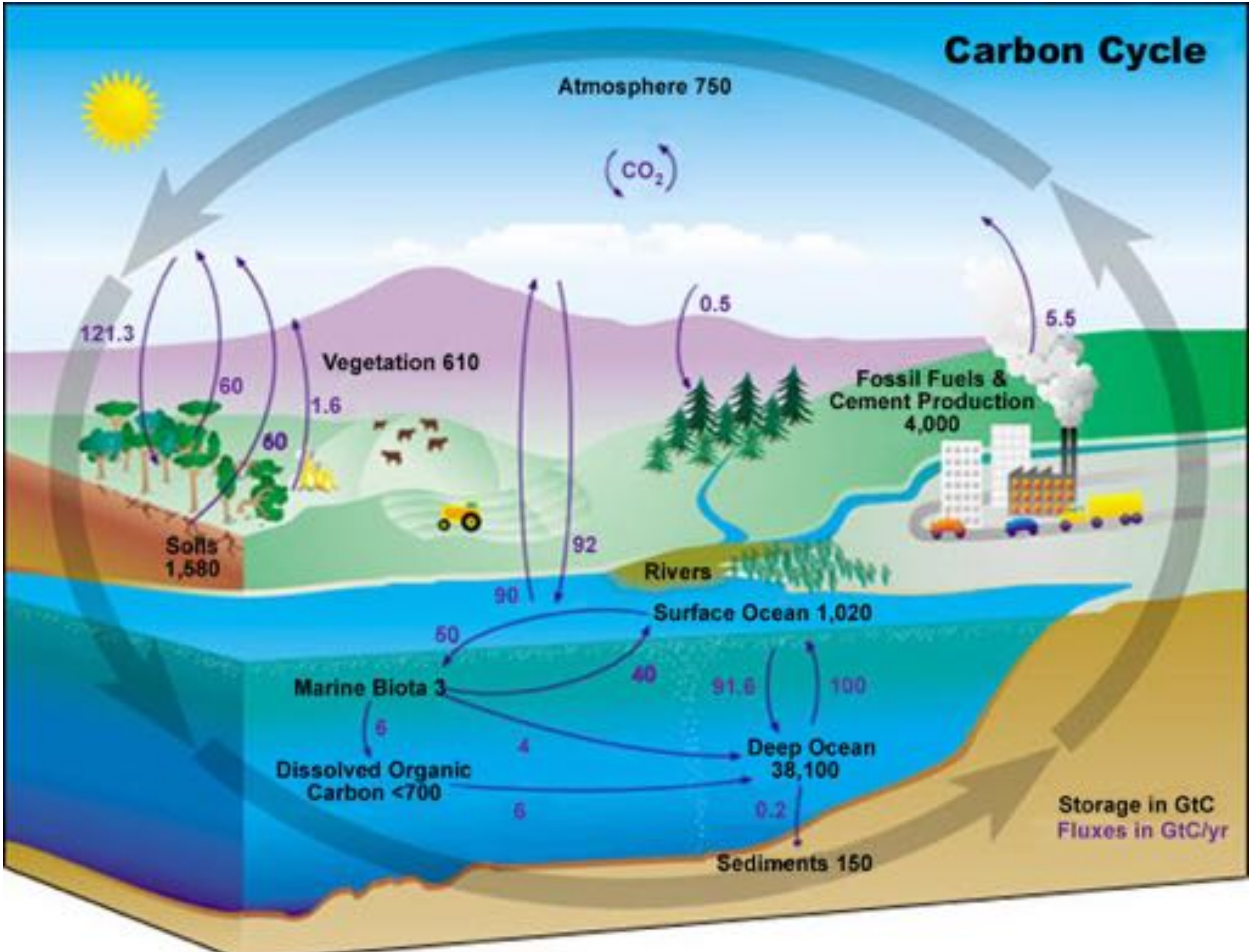
Circa 1980



Carbon Cycle
Atmosphere 750
CO_2
121.3
60
60
1.6
Vegetation 610
90
92
0.5
5.5
Fossil Fuels & Cement Production 4,000
Soils 1,580
Rivers
Surface Ocean 1,020
50
40
Marine Biota 3
91.6
100
6
4
Deep Ocean 38,100
Dissolved Organic Carbon <700
6
0.2
Sediments 150
Storage in GtC
Fluxes in GtC/yr

Fate of Anthropogenic CO_2 Emissions (2004-2013 average)

32.4±1.6 $GtCO_2$/yr *91%*

3.3±1.8 $GtCO_2$/yr *9%*

+

15.8±0.4 $GtCO_2$/yr
44%

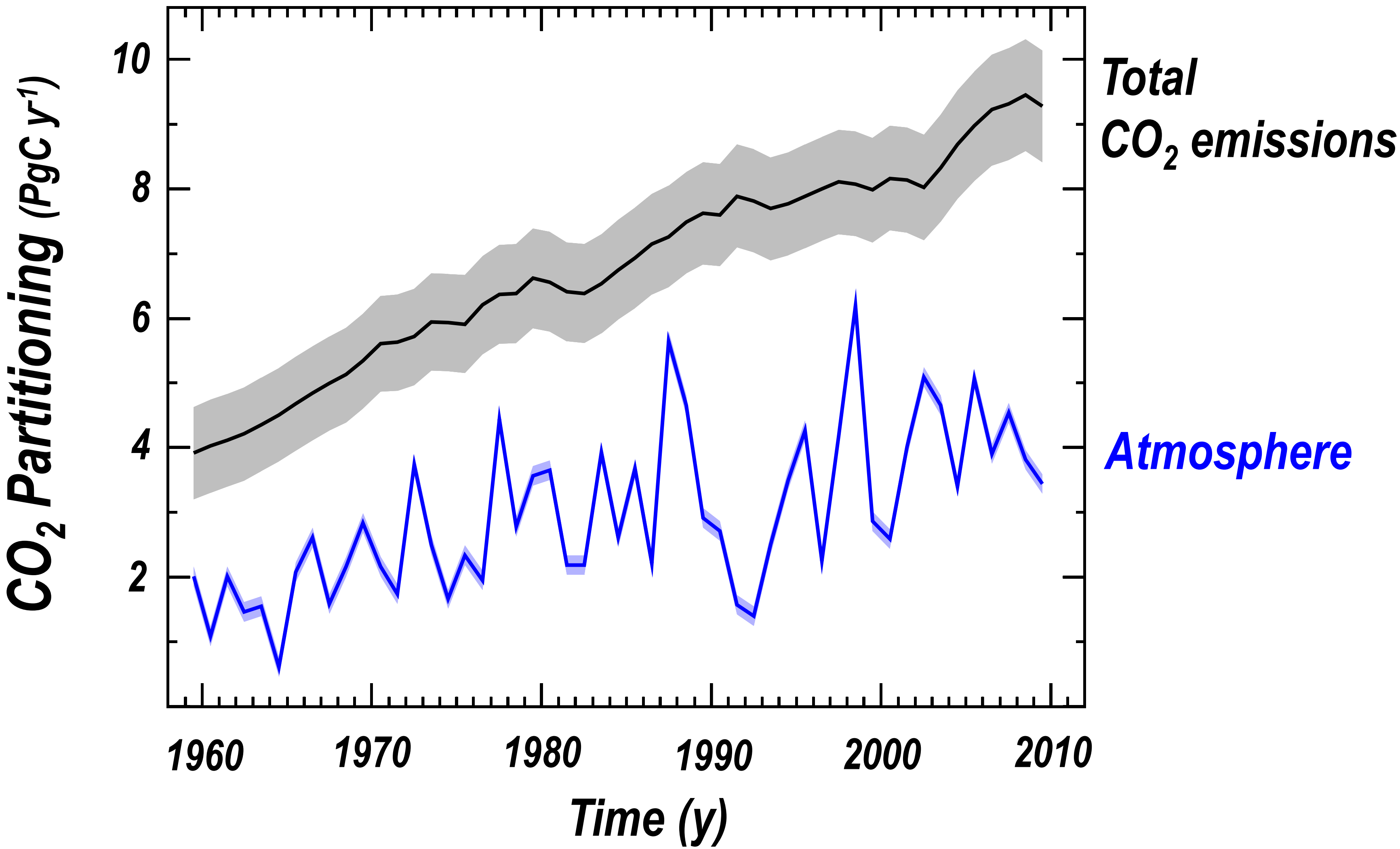
10.6±2.9 $GtCO_2$/yr
29%
Calculated as the residual of all other flux components

26%
9.4±1.8 $GtCO_2$/yr

Source: CDIAC; NOAA-ESRL; Houghton et al 2012; Giglio et al 2013; Le Quéré et al 2014; Global Carbon Budget 2014

Key Diagnostic of the Carbon Cycle

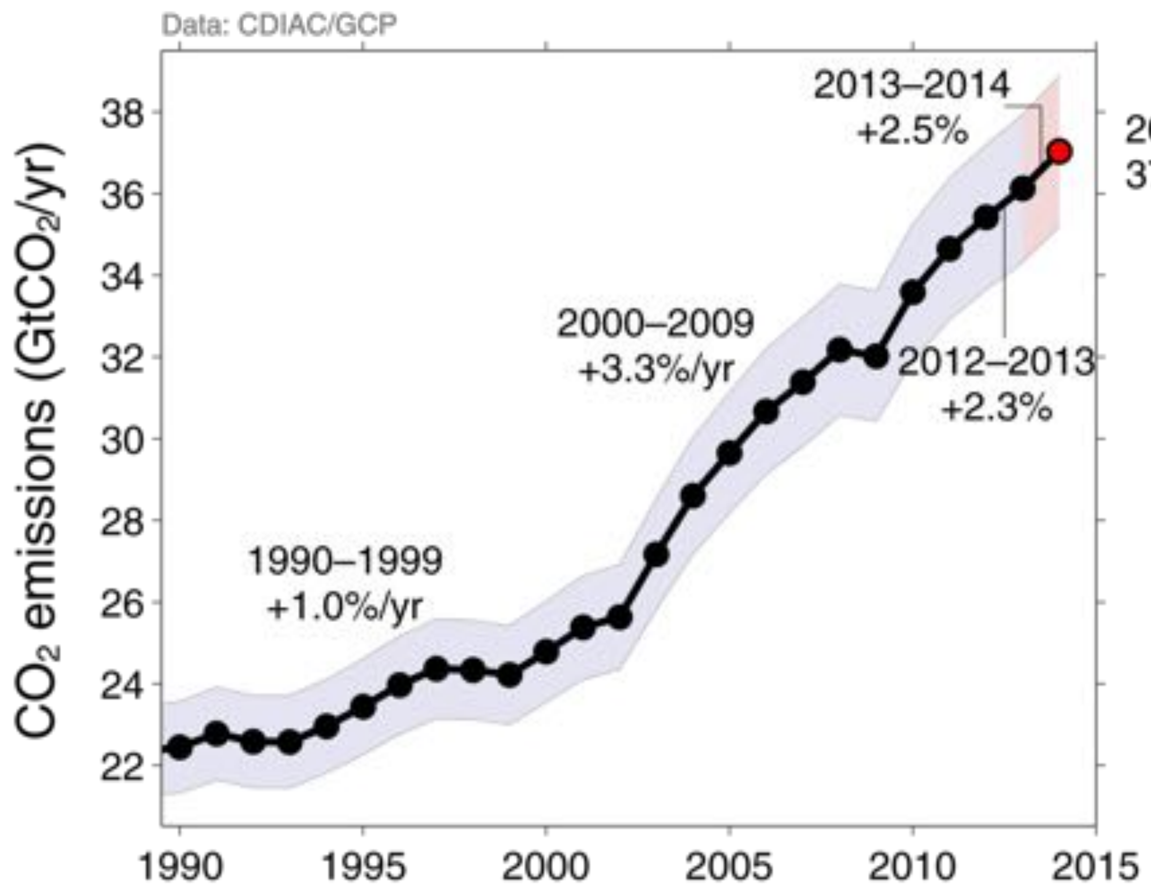
Evolution of the fraction of total emissions that remain in the atmosphere



Fossil Fuel and Cement Emissions

Global fossil fuel and cement emissions: 36.1 ± 1.8 $GtCO_2$ in 2013, 61% over 1990

● Projection for 2014 : 37.0 ± 1.9 $GtCO_2$, 65% over 1990



10.1 GtC!

Uncertainty is ±5% for one standard deviation (IPCC "likely" range)

Estimates for 2011, 2012, and 2013 are preliminary

Source: CDIAC; Le Quéré et al 2014; Global Carbon Budget 2014

The Central Questions on the CO_2 Forcing

Currently, 45% of all CO_2 emissions accumulate in the atmosphere: How might this change (because of climate or …)?

Ocean removes 26%

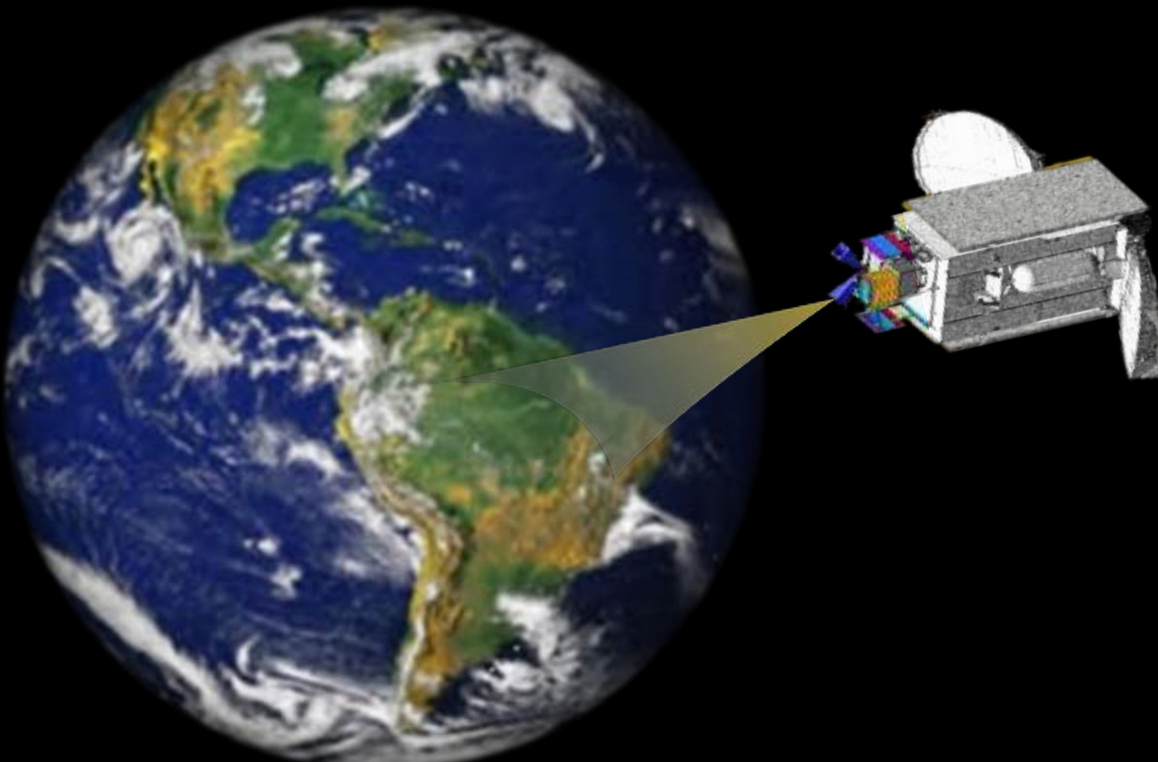
Land removes 29%

Carbon must be managed, but if we are to manage carbon then we must measure carbon—you can not manage that which you do not measure.


AIRS on Aqua
Future Systems
OCO
International

Challenging: Cost, Coordination, Calibration, Coverage (C^5), Plus

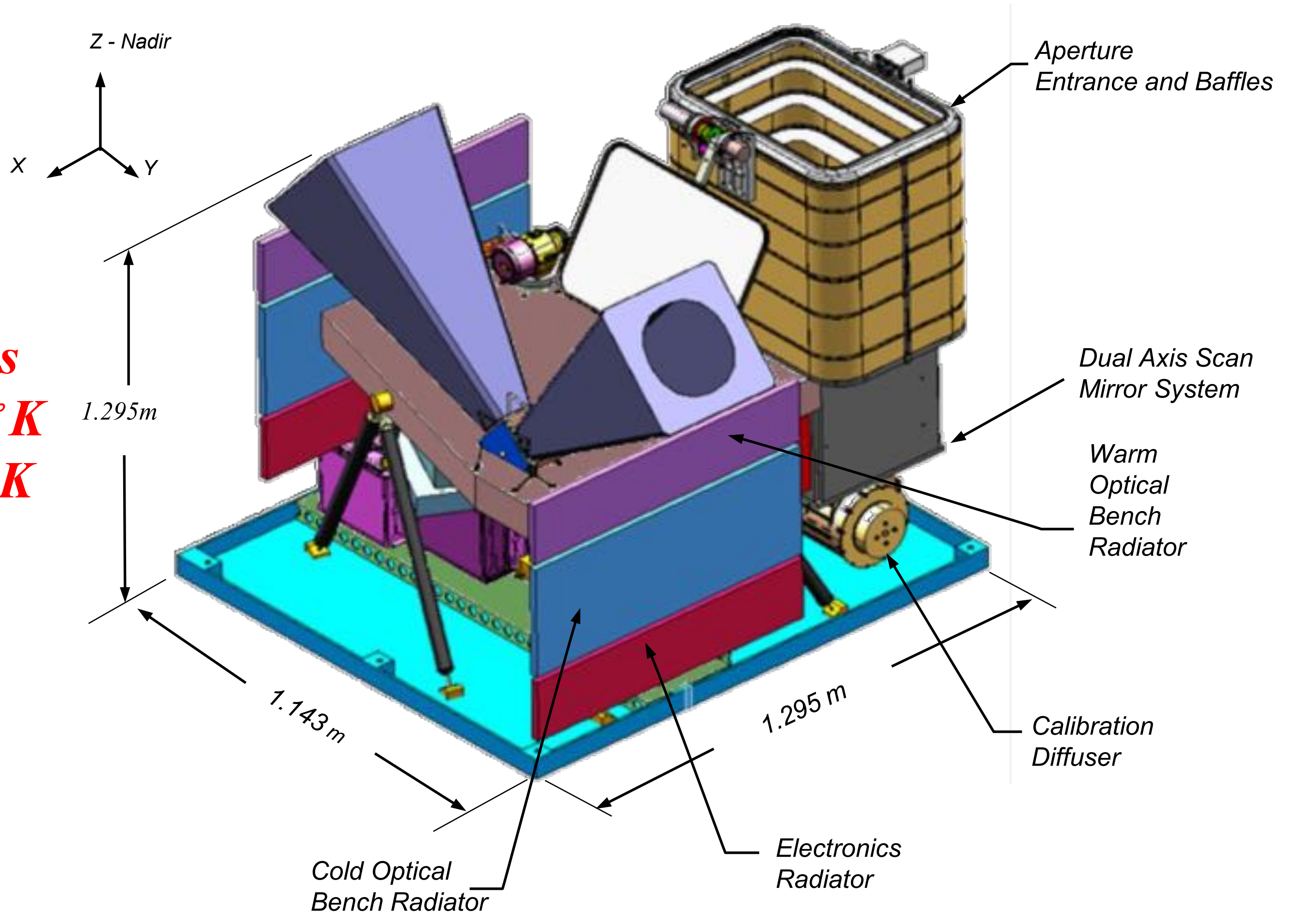
- Transport Model and its Adjoint: Errors, Biases, Low level transport, Vertical transport, Variability …
- Observed Concentrations of CO_2: Errors, Biases, Column Variability, Aerosols and Clouds, …
- Numerical Issues: Independence of Observations, Convergence and Model Scale, Prior Strength, …

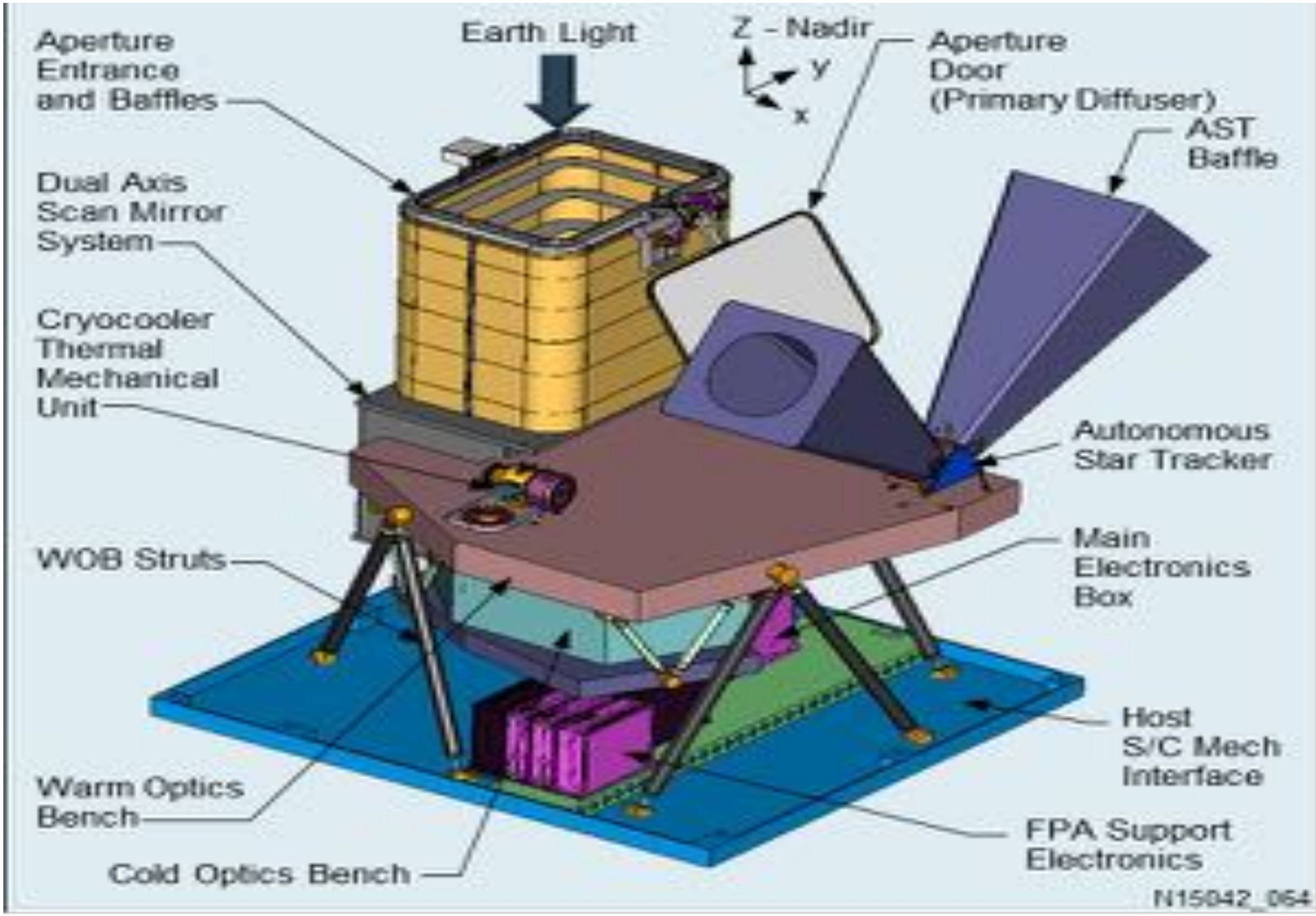


The GeoCARB Instrument

- ***Measures CO, CO2, O2, CH4, and SiF***
- ***Scanning IR slit spectrometer (0.76, 1.61, 2.06, 2.32μm)***
- ***3-5 km resolution***

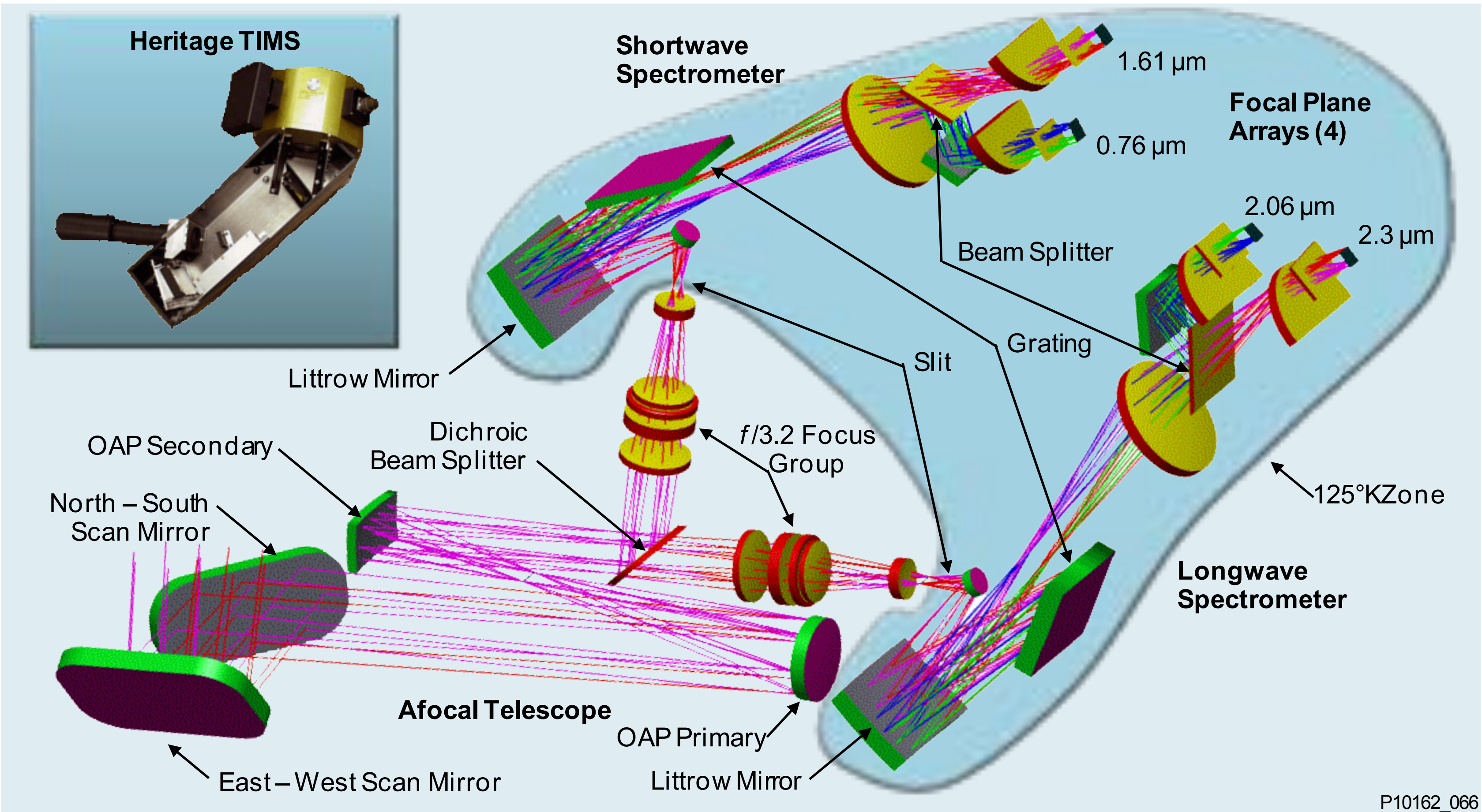
152 W
150 kg
10,500 kbps
WOB: 295° K
COB: 125° K





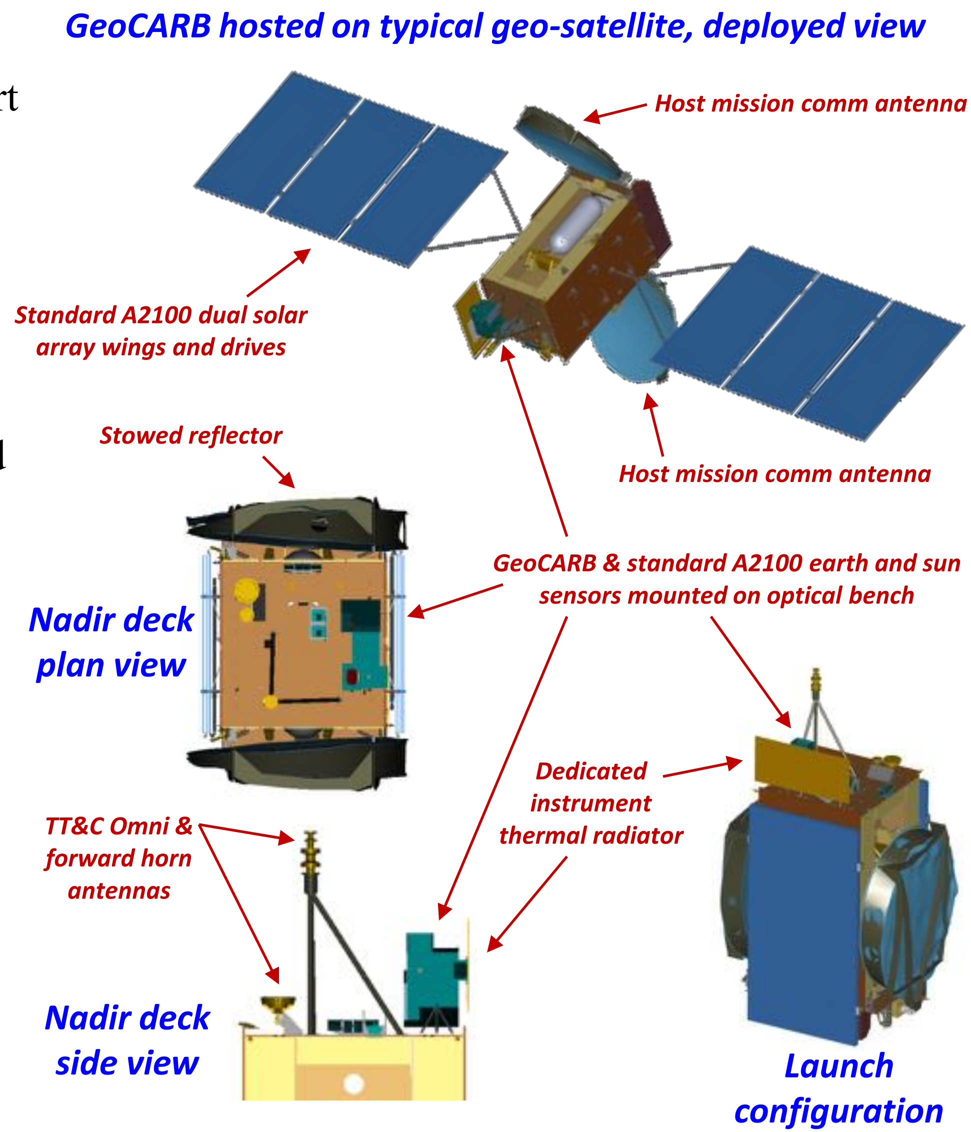
Aperture
Entrance
and Baffles
Earth Light
Z - Nadir
y
x
Aperture
Door
(Primary Diffuser)
AST
Baffle
Dual Axis
Scan Mirror
System
Cryocooler
Thermal
Mechanical
Unit
Autonomous
Star Tracker
WOB Struts
Main
Electronics
Box
Host
S/C Mech
Interface
Warm Optics
Bench
FPA Support
Electronics
Cold Optics Bench
N15042_064

“Two” Spectrometers. The non-OCO channel for CH4 and CO has been Proven by an IIP-NASA

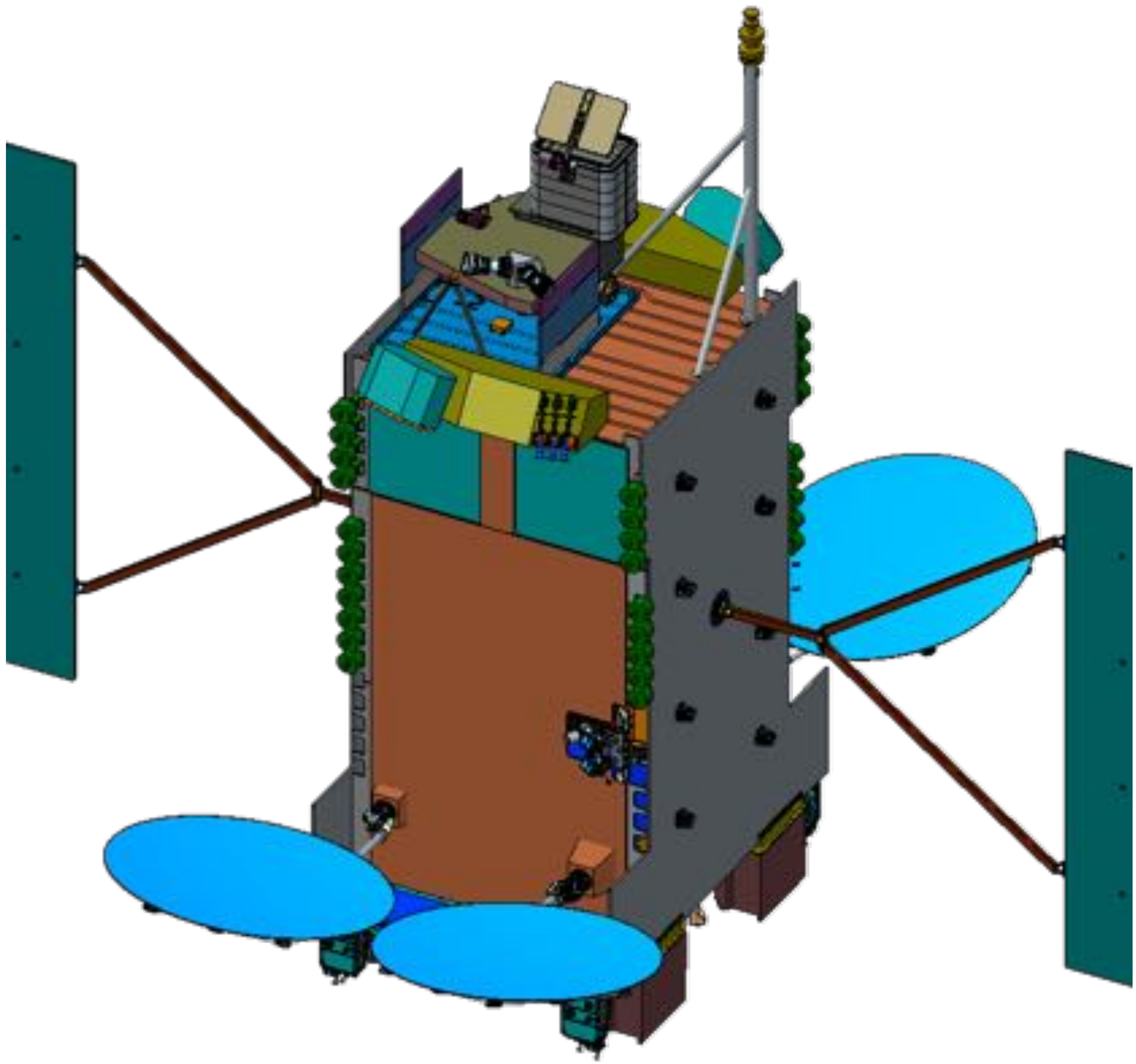


Accommodation of GeoCARB on Host Mission

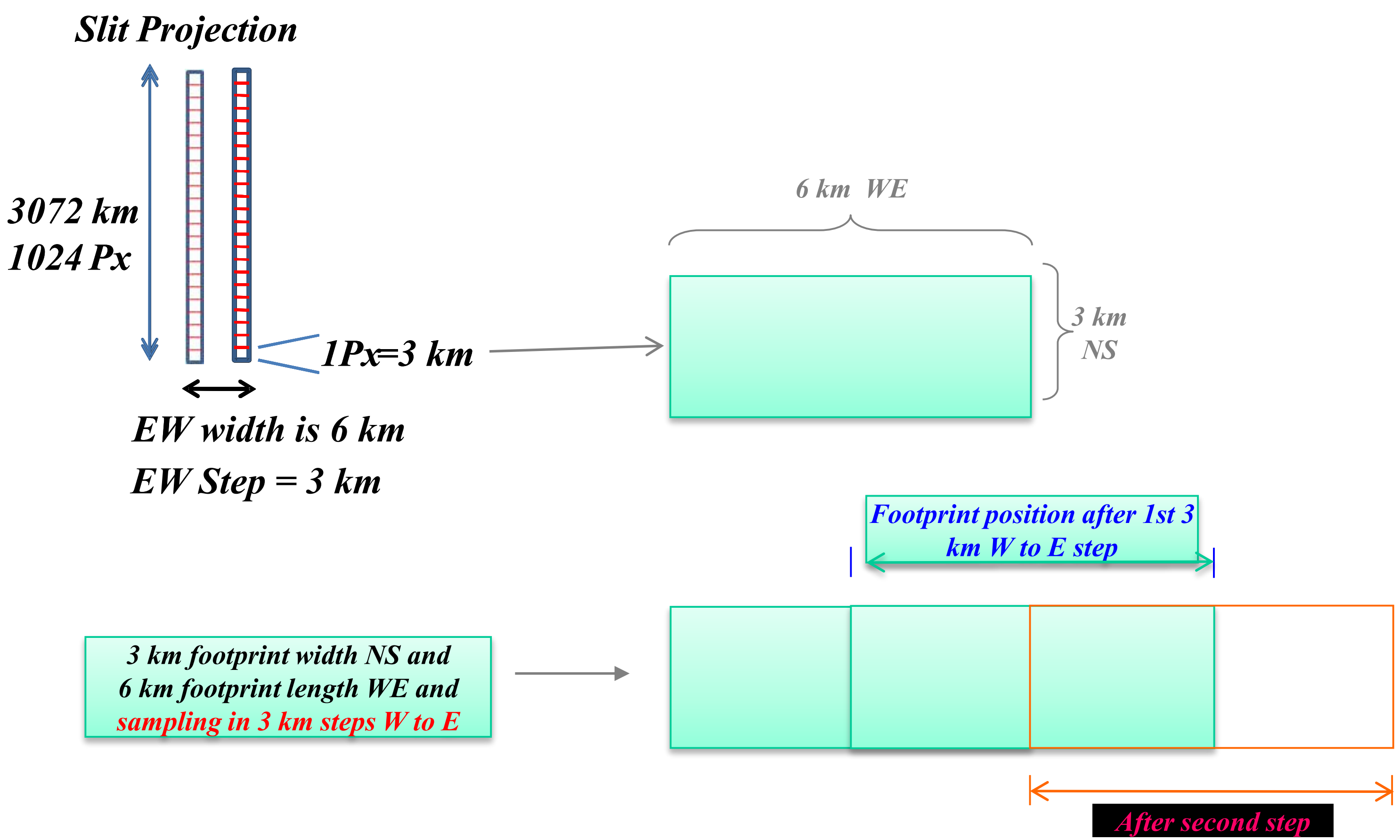
- Hosted on a typical Geo-Communication spacecraft with added interface items to support instrument
  - Mounted directly to nadir deck
  - Data downlink via host channel
  - Standard attitude & orbit control
- Consumes relatively small amount of mass and power (S/C impacts chart)
- Physical accommodation
  - Requires large part of nadir deck
  - No impact on S/C equipment panels
  - Dedicated thermal radiator
- Electrical accommodation
  - Energy via standard 70 V DC power bus
  - On/off, basic health & safety command /telemetry via standard interfaces



GeoCARB on a 13kw Communications Spacecraft

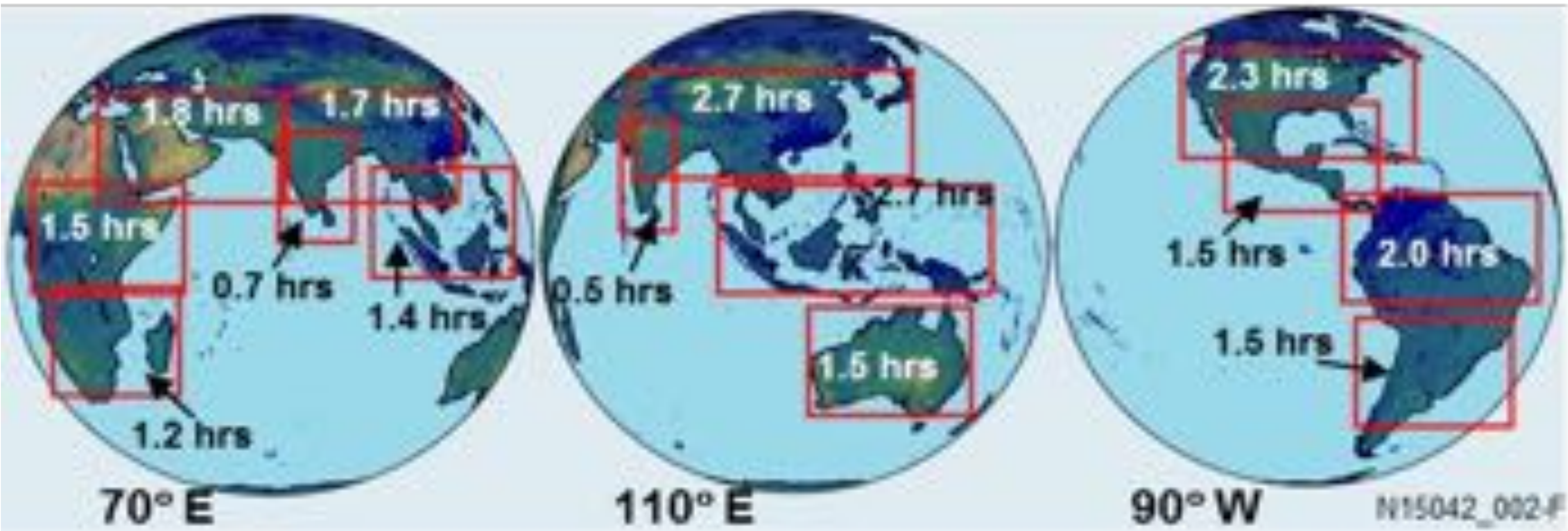


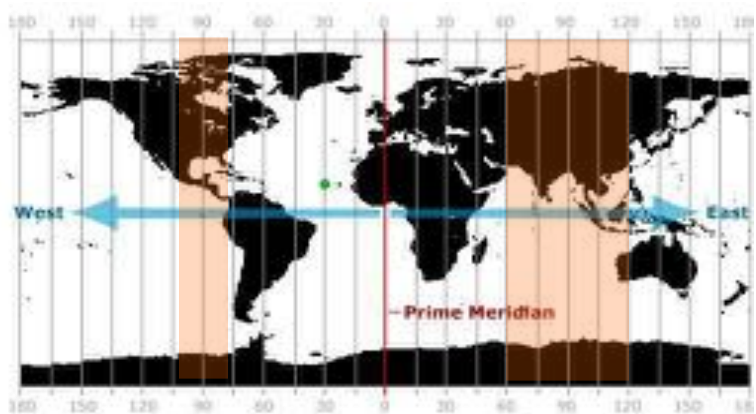
– 3 km x 6 km pixel within 3, 072 km x 6km “slit print”
– 3 km E-W sampling
– 4.42sec integration + step time



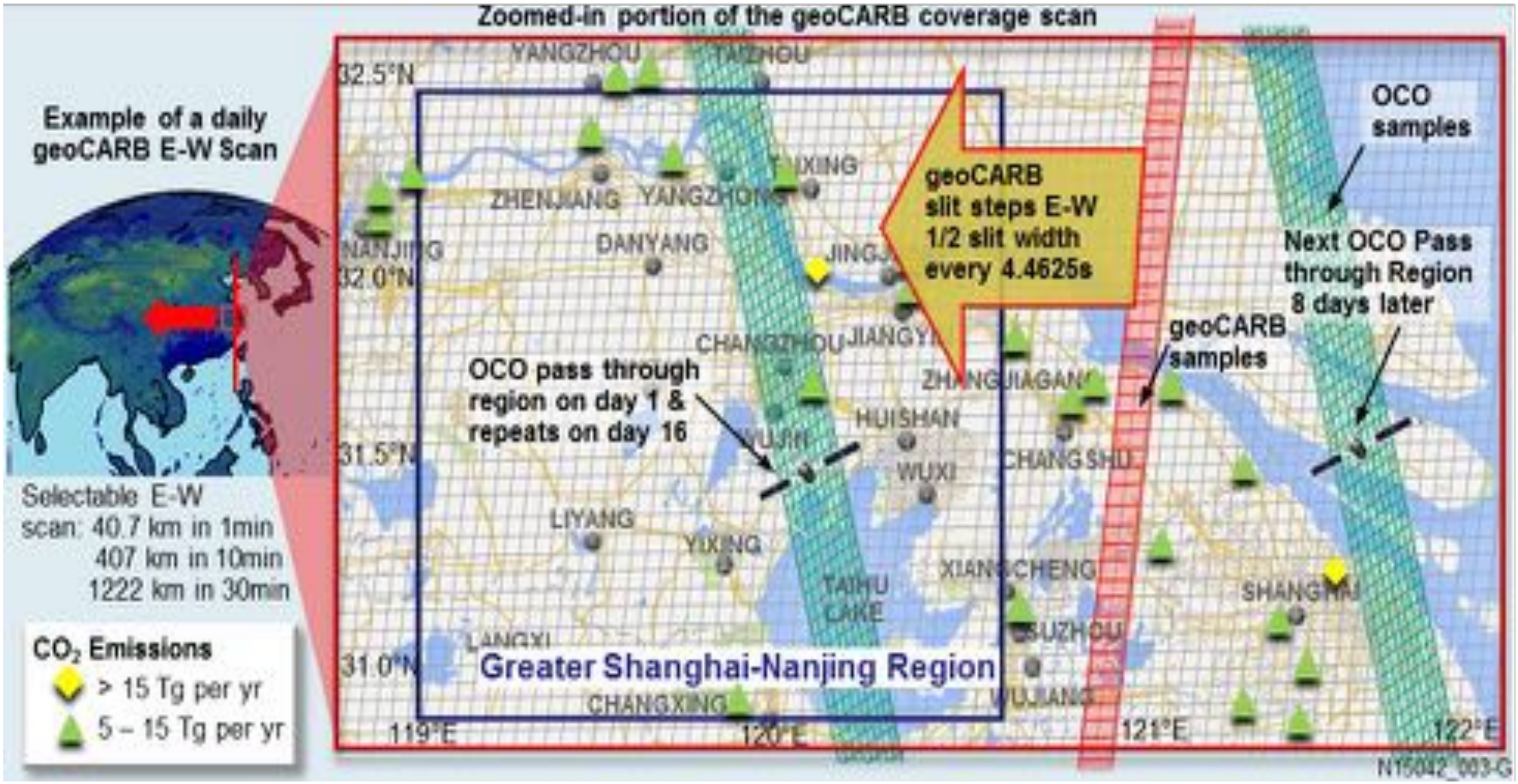
the spectrum of the 3 km x 6 km footprint is one row of pixels in the spectral direction corresponding to each of the 1024 pixels along the slit

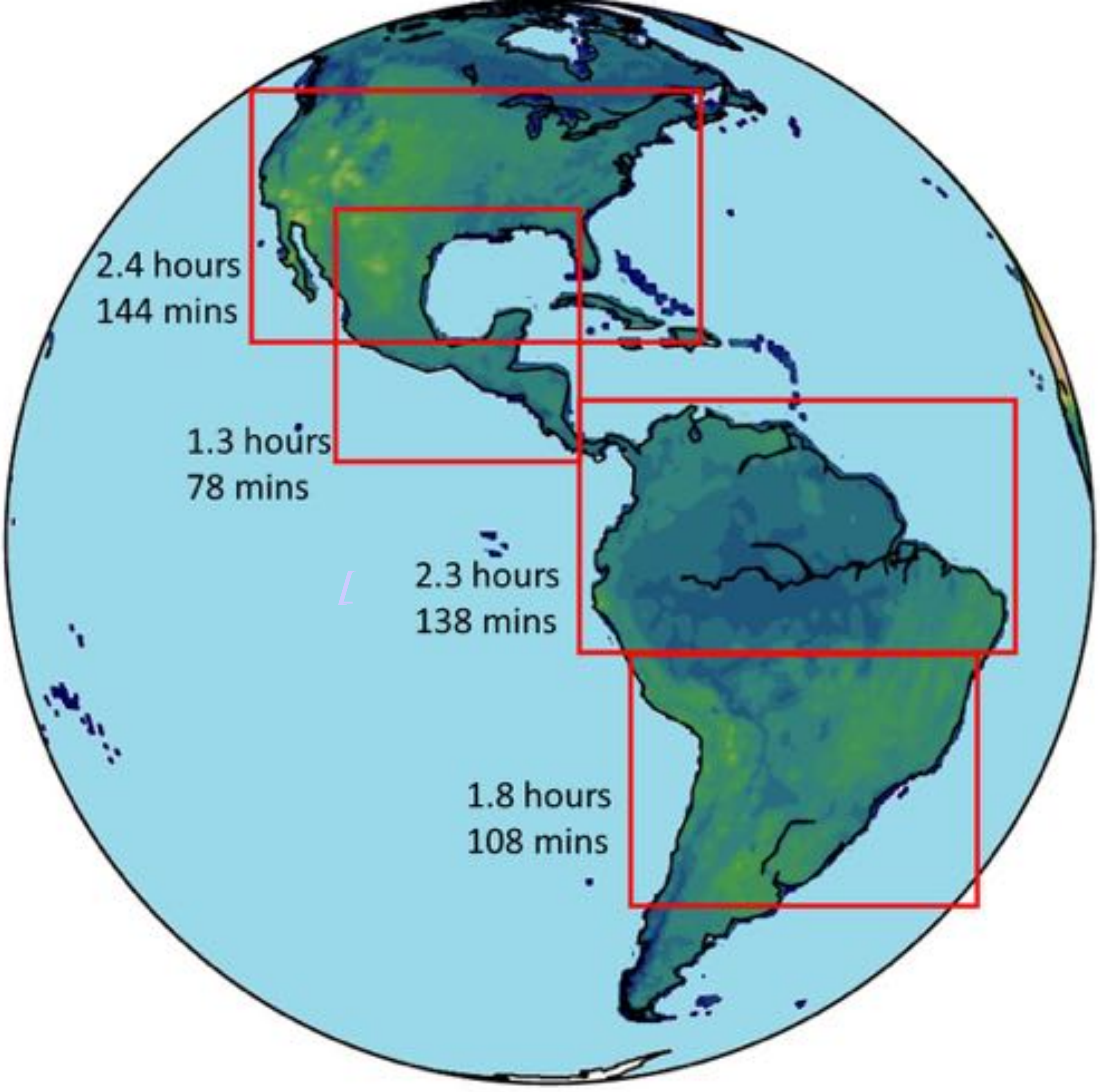
Example GEO slots: 70° E, 110° E, and 90° W





Moving the slit from East to West, geoCARB provides continental-scale "mapping-like" coverage




2.4 hours
144 mins
1.3 hours
78 mins
2.3 hours
138 mins
1.8 hours
108 mins


Slit extends North/South 4°
Example of a daily geoCARB E-W Scan
Next OCO Pass through Region 8 days later
OCO samples
geoCARB slit steps E-W ½ pixel every 4.4625s
geoCARB samples
OCO pass through region on day 1 & repeats on day 16
Selectable E-W scan: 40.7 km in 1m
407 km in 10m
1222 km in 30m
CO2 Emissions
> 15 Tg per yr
5 – 15 Tg per yr
20.5°N
20.0°N
19.5°N
19.0°N
101°W
100°W
99°W
98°W
Mexico City
STATE OF MEXICO
Toluca
Metepec
Pachuca
Tlaxcala
Puebla
Atlixco
Cuernavaca
Cuautla
Maravatio
Ciudad Hidalgo
Zitácuaro
Valle de Bravo

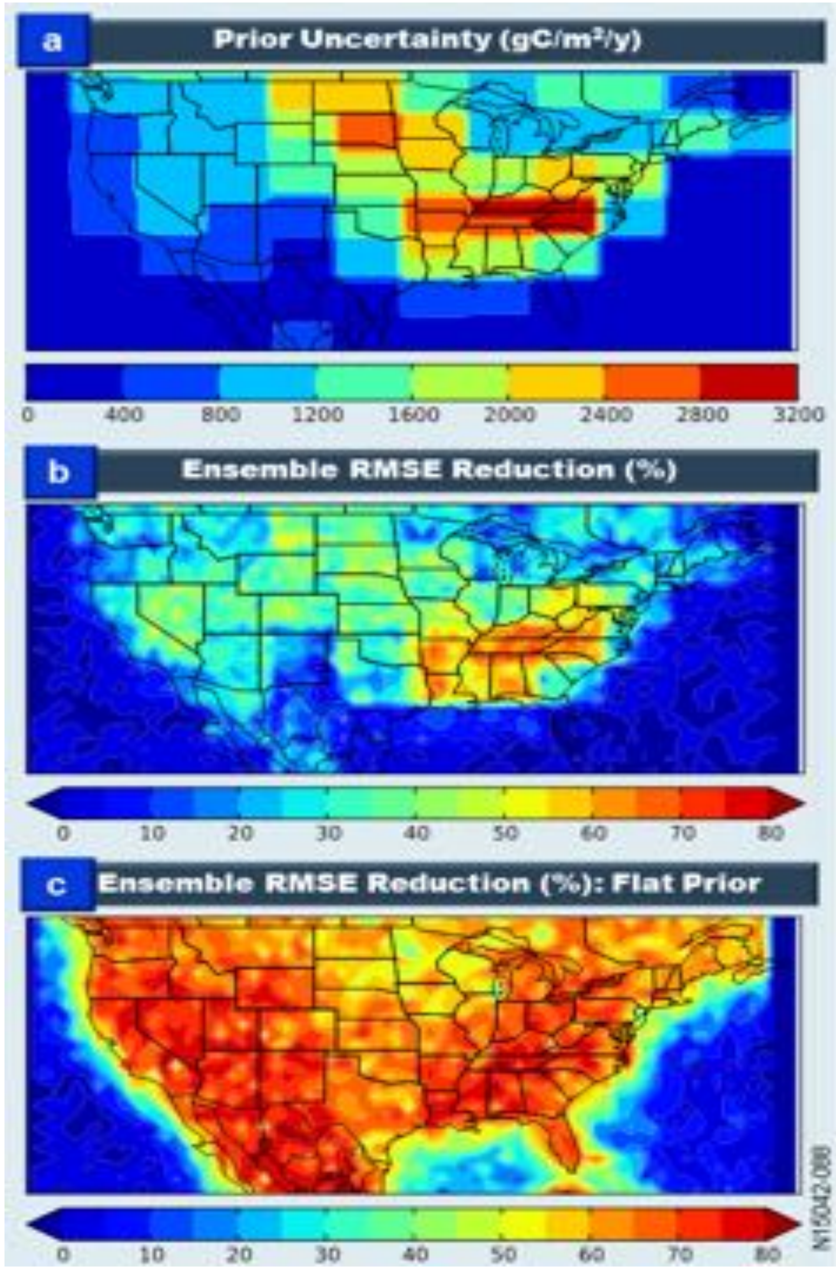
MODEL SET-UP: CONUS and Brazil

- ***Prior Fluxes: Statistical Perturbations of "Truth" Fluxes***
- ***Truth Fluxes***
  - ***CDIAC fossil fuel emissions***
  - ***CASA-GFED terrestrial fluxes and fire emissions***
  - ***Takahashi ocean fluxes***
- ***Uncertainty Covariance***
  - ***LPJ – CASA***
  - ***NCAR Ocean Biogeochemistry Model – Takahashi***
- ***Concentrations are created by running the transport model TM5 at 1° x 1° forward with the truth fluxes and ECMWF ERA-Interim meteorology***
- ***Concentrations are sampled with a pressure-weighted averaging kernel to produce simulated X_{CO2}***

CONUS and Generally: Error Assumptions

- ***Individual observations: Random and Systematic errors components***
- ***Random errors uncorrelated among observations in the same model 1°x1° grid box, Systematic errors are assumed to be perfectly correlated within the same grid box. Random error: σ_P ~ 0.35 – 1.3 ppm depending on air mass (m) and aerosol optical depth (τ)***
- ***System error: $\sigma_{sys}(m) = 0.3ppm + 0.2ppm \times (m-2)$,***
- ***The mean value of X_{CO2} at 1°x1° then has an error $\sigma_{xco2} = \sqrt{[\sigma^2_{sys} + (1.3\sigma_p)^2/n]}$, where the ad hoc error inflation 1.3 is chosen from caparisons of GOSAT/OCO-2 with TCCON.***
- ***σ_{XCO2} varies from ~ 0.5ppm at low view and zenith angles and multiple high SNR soundings to ~ 3ppm for a large airmass factor and a minimal number of low SNR soundings.***
- ***Exclude soundings when two-way slant $m\tau(in) + m\tau(out)$ is >0.6.***
- ***To account for correlations between systematic errors of neighboring 1°x1° mean values for X_{CO2}, we further inflate the 1°x1° errors by 2.5, which was derived assuming a spatial de-correlation length of 2° for the X_{CO2} systematic error.***

CONUS CO_2 Flux Uncertainty Reduction



Prior uncertainty for June

Corresponding error reduction

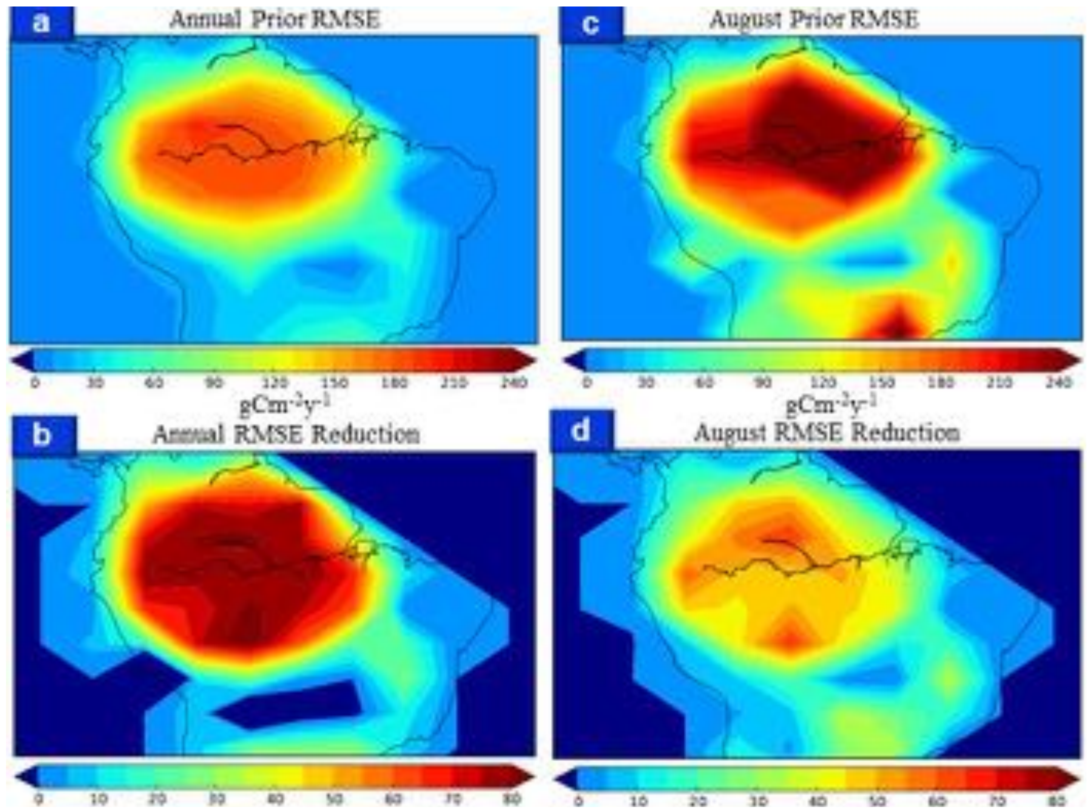
Error reduction for flat prior uncertainty 2.5 kgC per m^2/yr

Brazilian CO2 Sink Experiment

- *CO_2 Fertilization*
  - ***5% GPP Inflation for Tropical PFTs***
  - ***Spatially heterogeneous effect***

- ***Includes persistent cloudiness of Amazon as seen by CALIPSO***

- ***Fertilization signal is clearly recoverable.***



The GeoCARB Mission: Summary

- *Measure CO_2, CH_4, and CO concentrations with high accuracy by reflected sunlight via a 4 Channel Grating Spectrometer (essentially the OCO instrument plus a CH4 & CO channel in a GEO orbit)*
- *View from GEO enables continual precise concentration measurements at least daily at very fine spatial scales*
- *Determination of concentrations enables CO_2, CH_4, and CO flux calculations with:*
  - *Temporal resolution days*
  - *Spatial resolution of 10 kilometers or better*
- *Provide demonstrations of flux calculations relevant to policy and mitigation at power plant to country scales*

The GeoCARB Mission: Other Advantages

- ***Urban areas can be sampled multiple times daily;***
- ***Fluxes estimated with geoCARB observations will be less vulnerable to transport errors;***
- ***Observations are dense in time and space supporting connectivity to processes;***
- ***Coordination with GEO weather satellites (e.g., GOES) allows for scan strategies that maximize visibility, and***
- ***Finally, daily SIF measurements yield crop- and ecosystem-stress information at high time resolution (early-warning systems).***

ONE OTHER MATTER

- ***Carbon Workshop in March 2015 at the University of Oklahoma recommended conducting OSSE that would considered different configurations of ground and space-based observing systems***
- ***In the US, an informal working group involving GSFC, JPL, CSU, and OU (and possibly others) is beginning to "scope out" what we might contribute***
- ***Given the highly international characteristic of these issues in would be ideal if there might be other teams conducting OSSEs as well as helping to provide essential datasets (e.g., high resolution diurnal cloud masks)***
- ***The more the merrier; more importantly, different insights and approaches will lead to new discoveries!!***