Evaluation of Near-Real-Time Biomass Burning Emissions Estimates derived from MODIS and GOES Active Fire Detections during 2006

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Outline

- Present new technique for generating daily global near-real-time biomass burning emissions constrained by MODIS active fire detections
- Brief overview of 3 other global to regional techniques also constrained by active fire detects, including GOES geostationary
- Comparison of Area-Burned and CO emission estimates over the Continental US during 2006
- Evaluation of CO emissions over the US
- Global evaluation (brief)

New technique: RAQMS* global emissions

- Developed to provide daily emissions for RAQMS forecasts used to support flight planning and data analysis during the March-May 2006 NASA INTEX-B and August-October 2006 NOAA TexAQS field campaigns

- Basic approach: Emission = (Carbon fuel consumed) x (area burned)

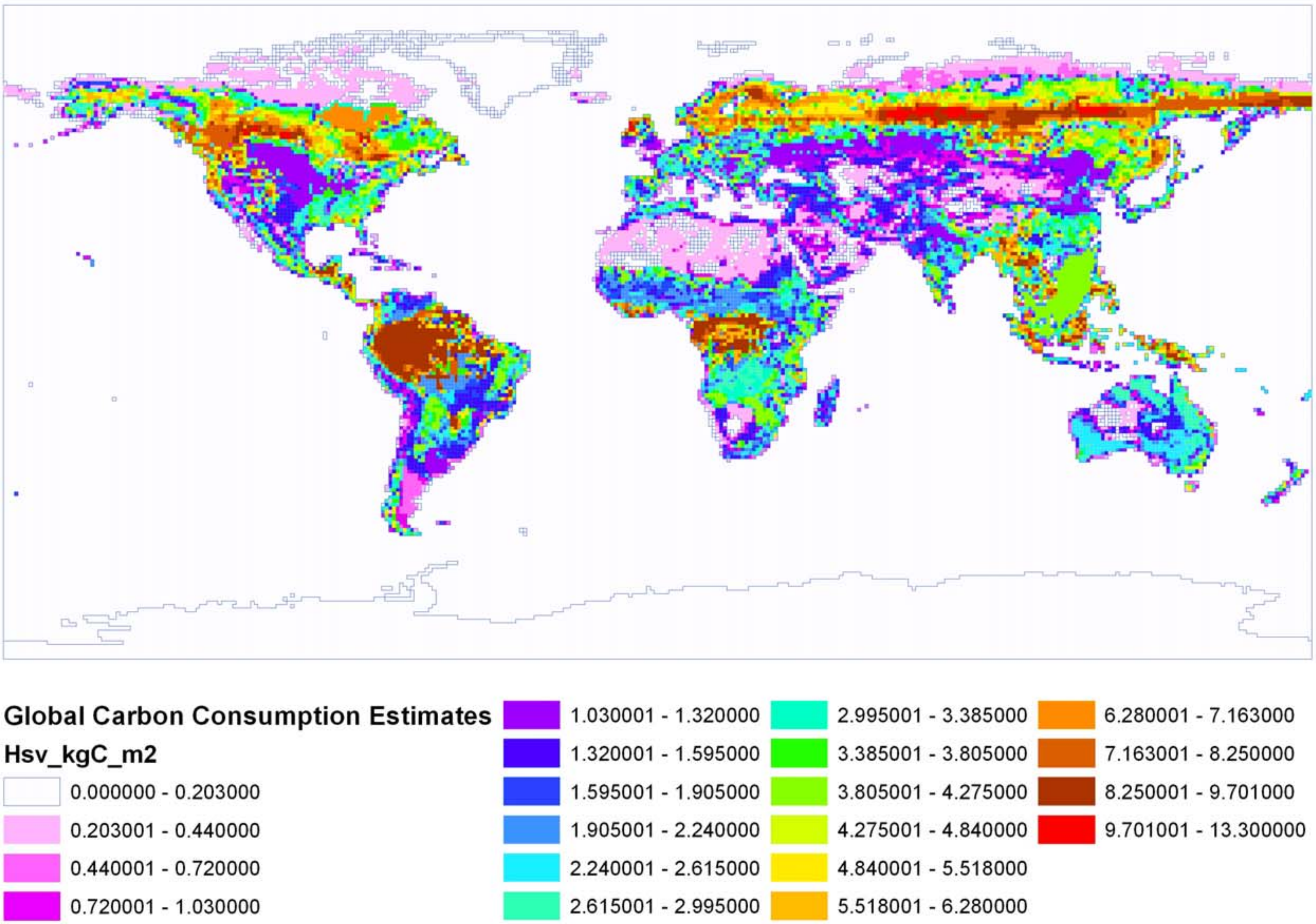
  1. Gridded carbon fuel consumption databases, representing ecosystem- and severity-dependent amounts of carbon released from burning of vegetation and sequestered fuel [Olson et al., 1983; Zinke et al., 1986; Soja et al., 2004], for 3 classes of fire severity.

  2. Meteorology-based estimates of fire weather severity, based on the US Forest Service Haines Index [Haines, 1988] which considers <u>atmospheric moisture</u> and <u>thermal stability</u> to indicate potential for the rate of spread of a fire on a given day.

  3. Satellite fire detections (MODIS) to estimate area burned.

**RAQMS is the NASA/University of Wisconsin Realtime Air Quality Modeling System*

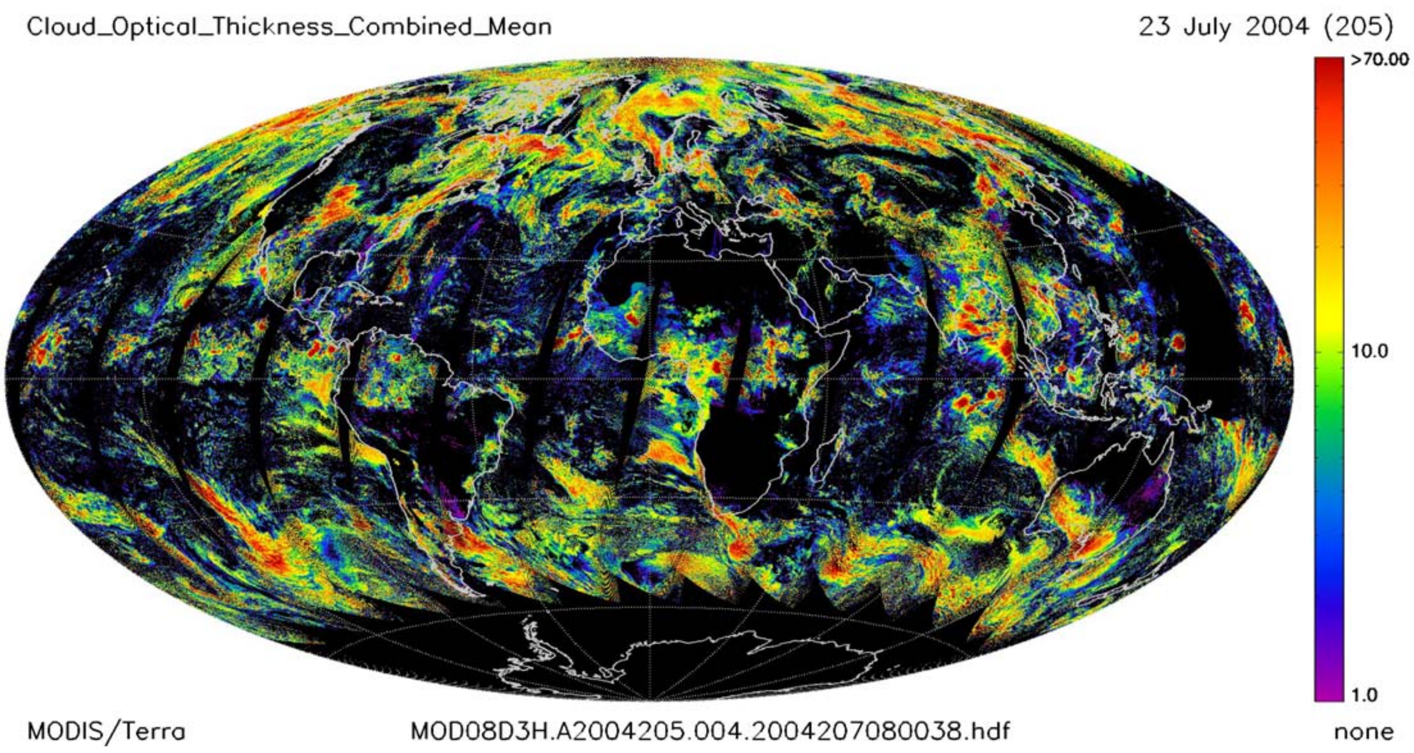
Example: carbon consumption estimates for *high-severity* fires



We use the high severity carbon consumption database where the Haines Index is 6, medium severity where the Index is 5, and low severity where the Index is 4 or less.

Inferring area burned from MODIS active fire detections

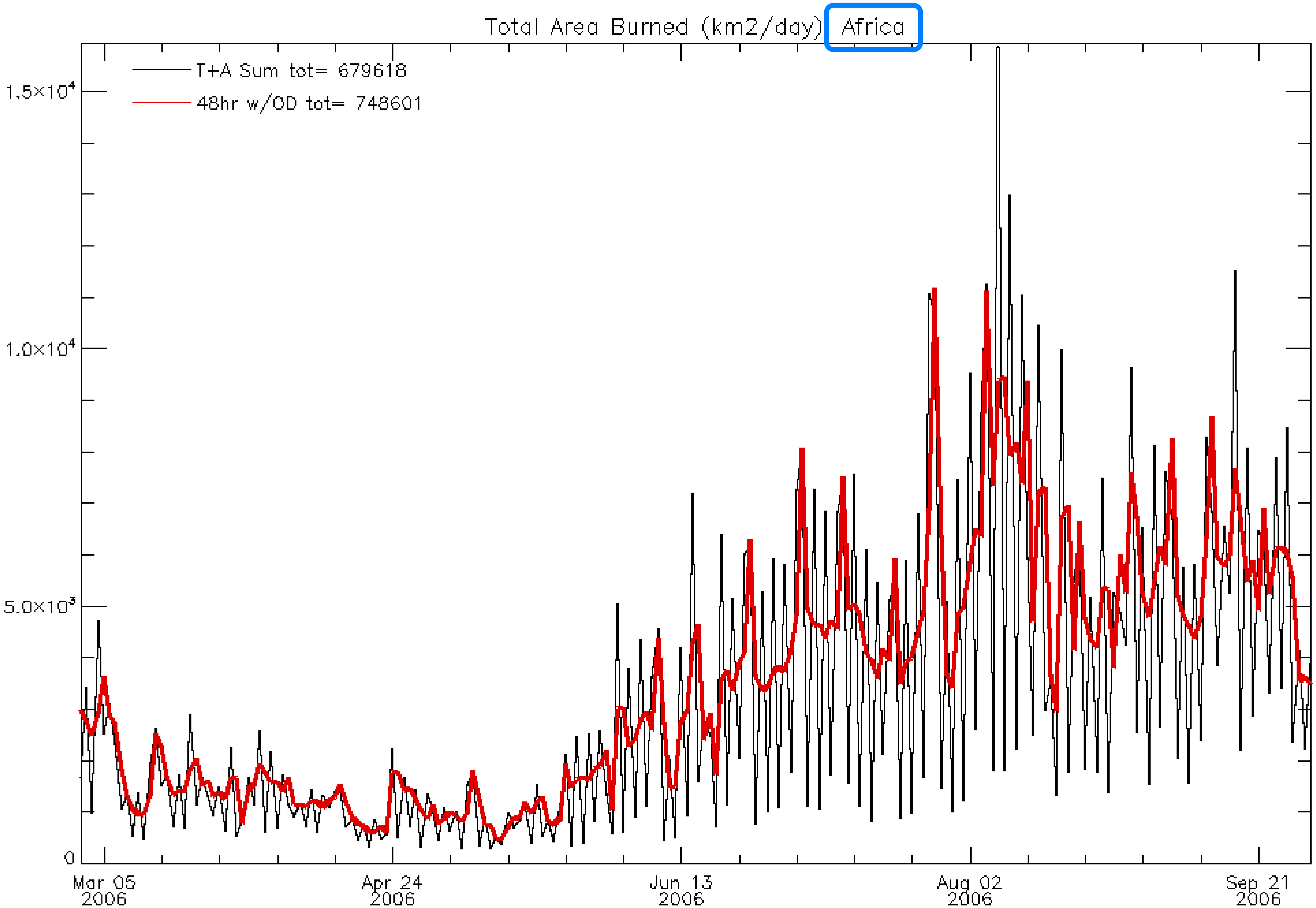
- Need for generating global emissions in near real time dictates the use of MODIS Rapid Response fire detections for estimating area burned
- Large uncertainty in inferring daily area burned from instantaneous active fire detections; additional sources of uncertainty include missing fire detections (e.g., due to cloud cover), false detections, and multiple detections of the same fire [Giglio, 2007]
- Terra/Aqua orbit parameters yield latitude-dependent sampling biases in daily estimates
  - Equatorial regions may be viewed only every other day
  - Convergence of orbit tracks at high latitude gives multiple viewing opportunities per day
  - Figure illustrates 1 day of MODIS Terra coverage (for cloud optical thickness)



RAQMS global emissions: Area burned

- Current approach for generating DAILY estimates with reduced biases in coverage/sampling :
  - Combine fire detections from MODIS Terra and Aqua (each provides one daytime and one nighttime observation of most of the globe at a nominal 1km x 1km horizontal resolution)
  - Consider 48 hours of MODIS data to ensure complete coverage over tropics
  - Eliminate multiple detections of the same fire (i.e., same nominal 1km x 1km pixel)
  - Each unique fire detection is assumed to correspond to a daily area burned of 1 km^2 (0.75 km^2 in grass/savannah ecosystems)
- Research in progress!

Daily area-burned estimates: All Terra+Aqua vs. Current Method



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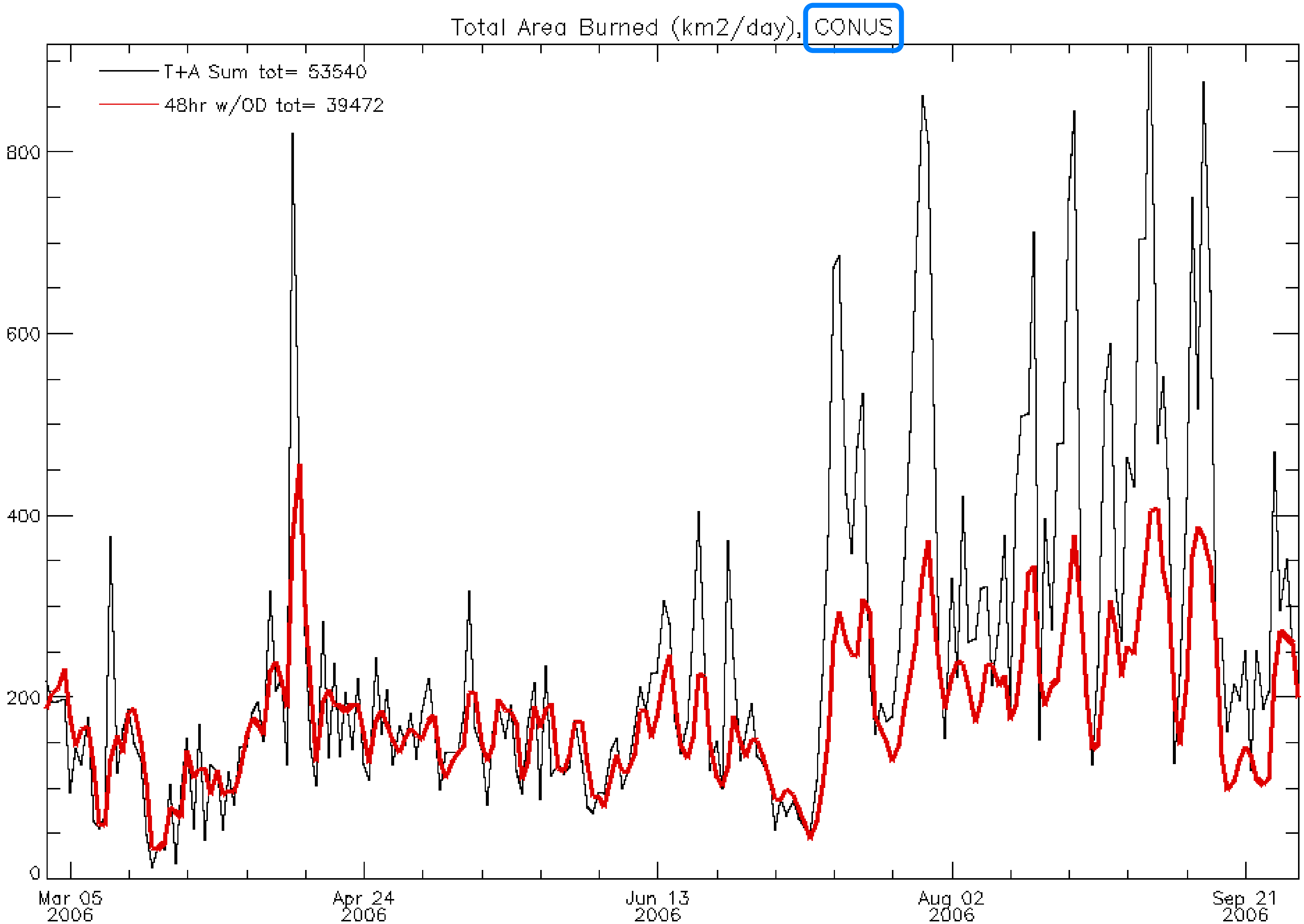
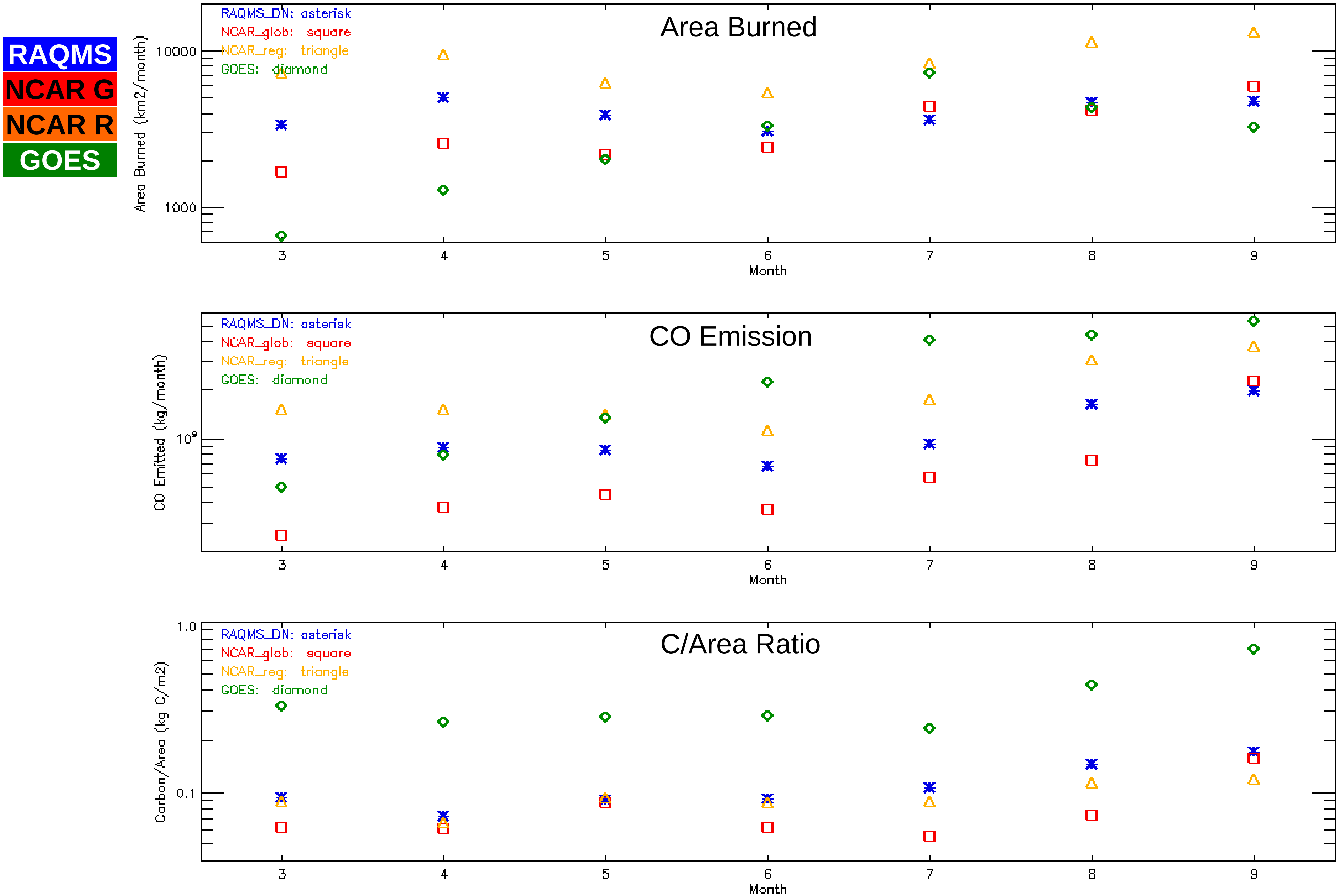


Parameters of 2006 biomass burning emission techniques considered

	NASA Global (RAQMS)	**NCAR Global (MOZART)**	**NCAR Regional**	**NOAA GOES**
Domain	Global	Global	North+Central America	CONUS
Satellite Fire Detection	MODIS Rapid Response	MODIS Climate Modeling Grid	MODIS Rapid Response	GOES processed half-hourly
Area Burned Estimate	1km^2 for each unique Terra+Aqua detect in running 48-hr window	GFEDv2 scaled by Terra 8-day Climate Modeling Grid detects	Vegetated fraction of 1km^2 from combined Terra+Aqua detects	Simulated from WF_ABBA subpixel algorithm
Emissions Estimate	Calculated from fire severity-based carbon consumption databases (severity estimated with Haines Index) and published emission ratios	GFEDv2 scaled by Terra 8-day Climate Modeling Grid detects	Calculated from biomass fuel loading databases, MODIS vegetation products, and published emission ratios	Calculated from fuel loading databases, combustion efficiency parameters, and emission factors from FOFEM model
2006 Dates of Coverage	Feb 1 Š Oct 15	Jan 1 Š Dec 31	Jan 1 Š Dec 31	Mar 1 Š Sep30
Horizontal Resolution	1 deg x 1 deg	1 deg x 1 deg	1 km (MODIS nadir pixel size)	4 km (GOES nadir pixel size)
Temporal Resolution	Daily	8-days	Daily	Daily
Species available in this intercomparison	CO, NO, C, area-burned	CO, NO, CO2, CH4, PM2.5, area-burned	CO, CO2, CH4, PM2.5, VOC, NOx, area-burned	CO, area-burned
Other species typically produced	Other species calculated from C	Other species calculated from CO2	PM10, HCN, CH3CN, NH3, SO2, Hg	PM2.5, CH4

2006 Monthly total biomass burning estimates over Continental US (CONUS)



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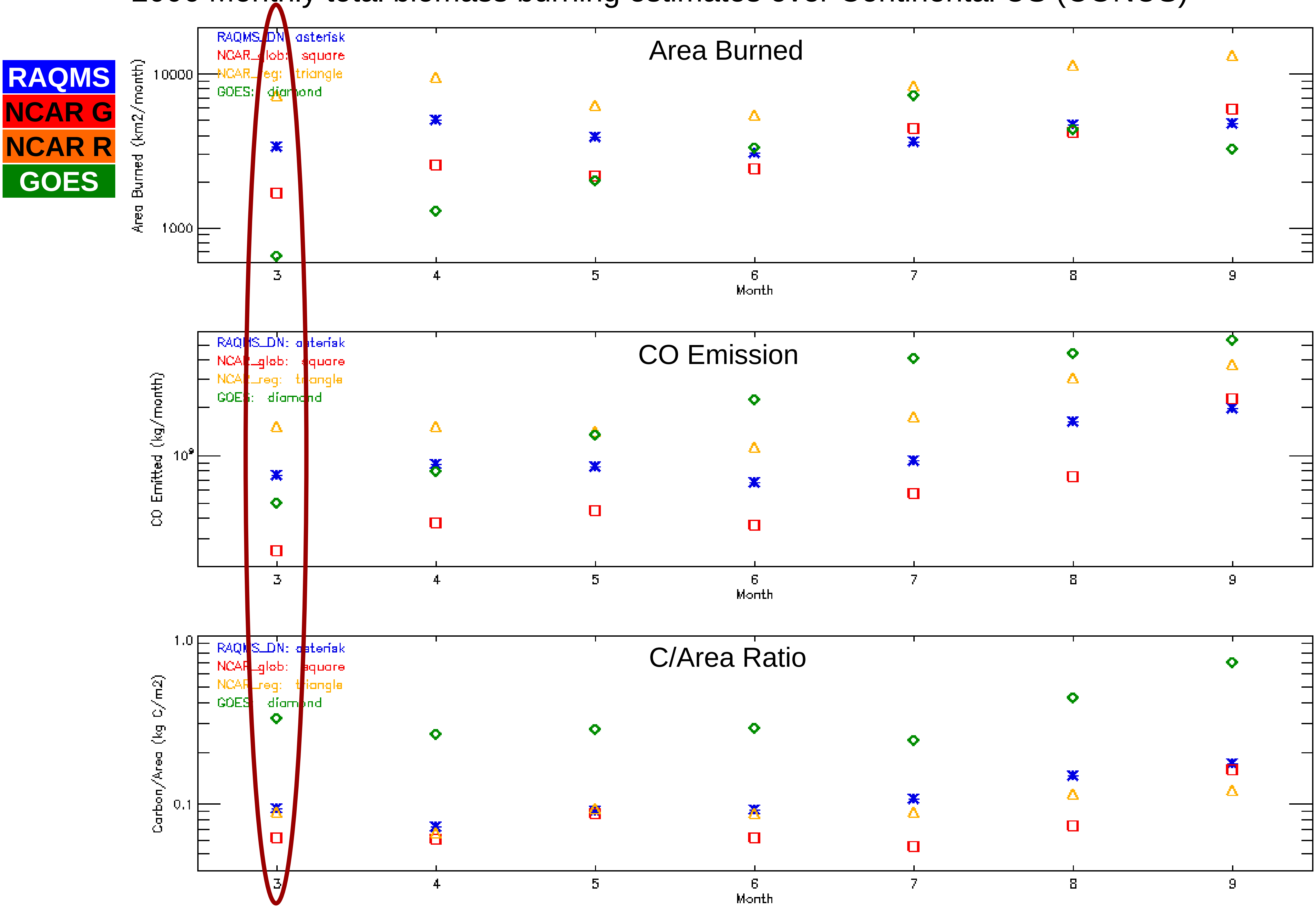
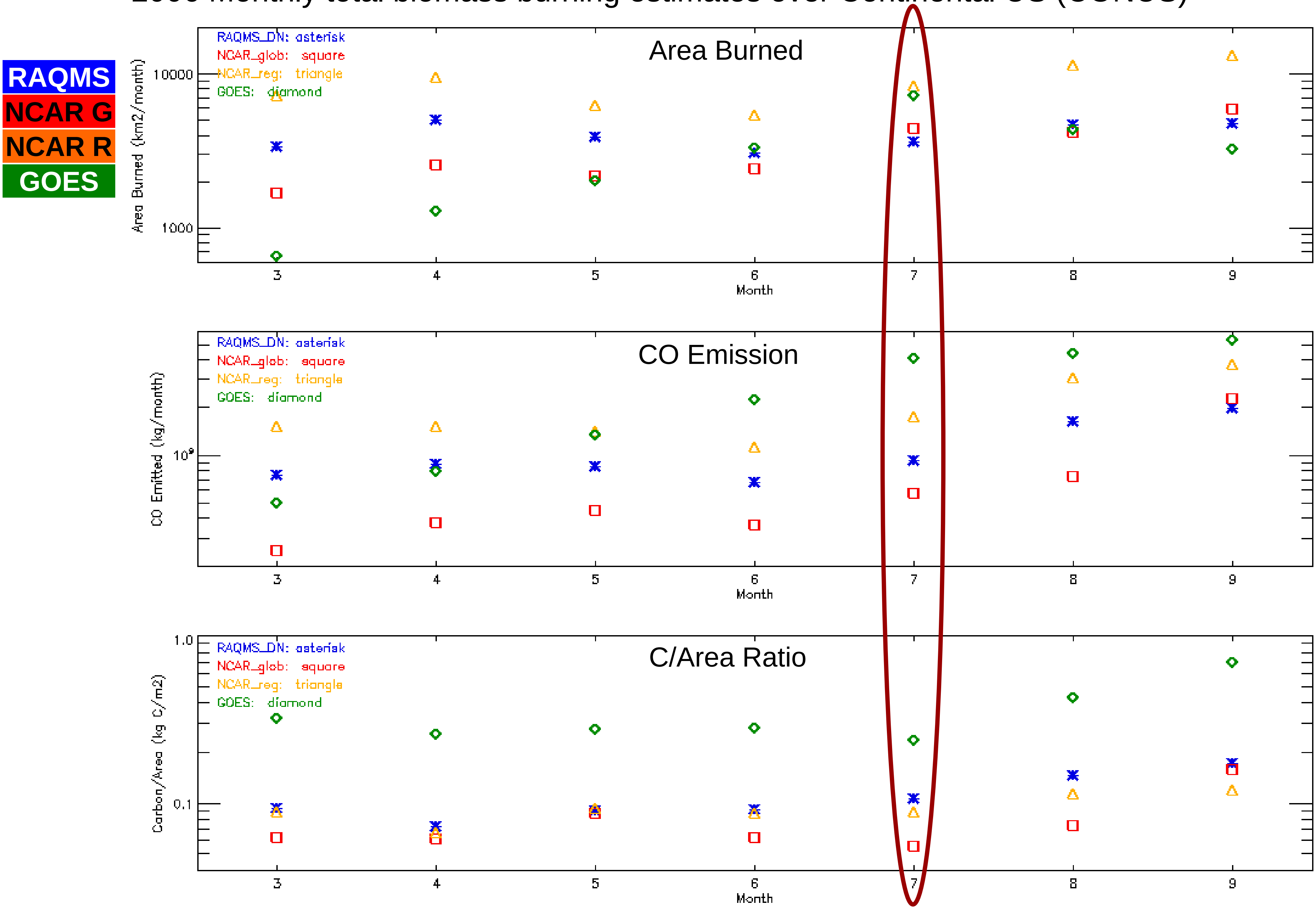


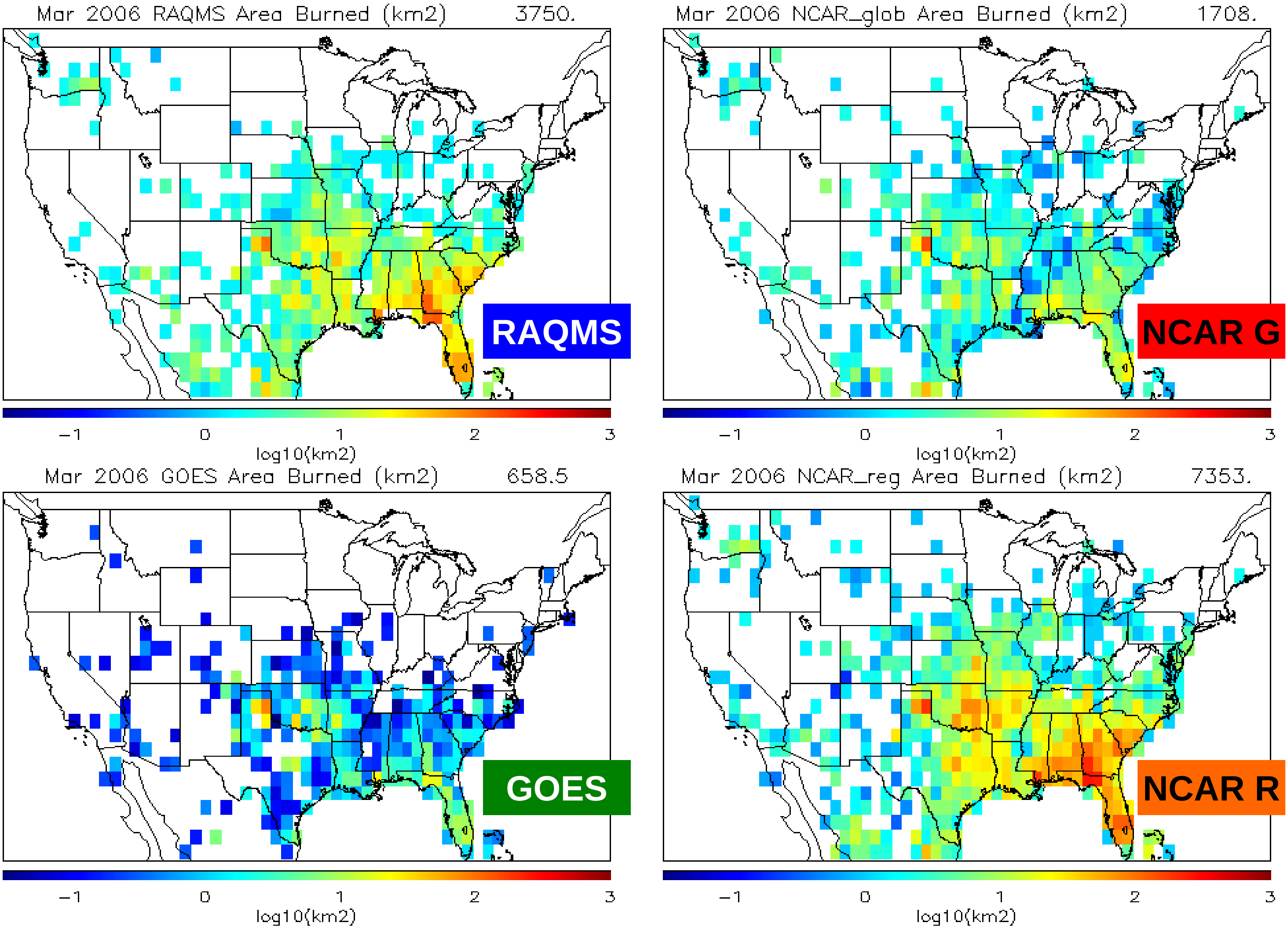
March: Large spread in Area Burned and CO Emission estimates

2006 Monthly total biomass burning estimates over Continental US (CONUS)

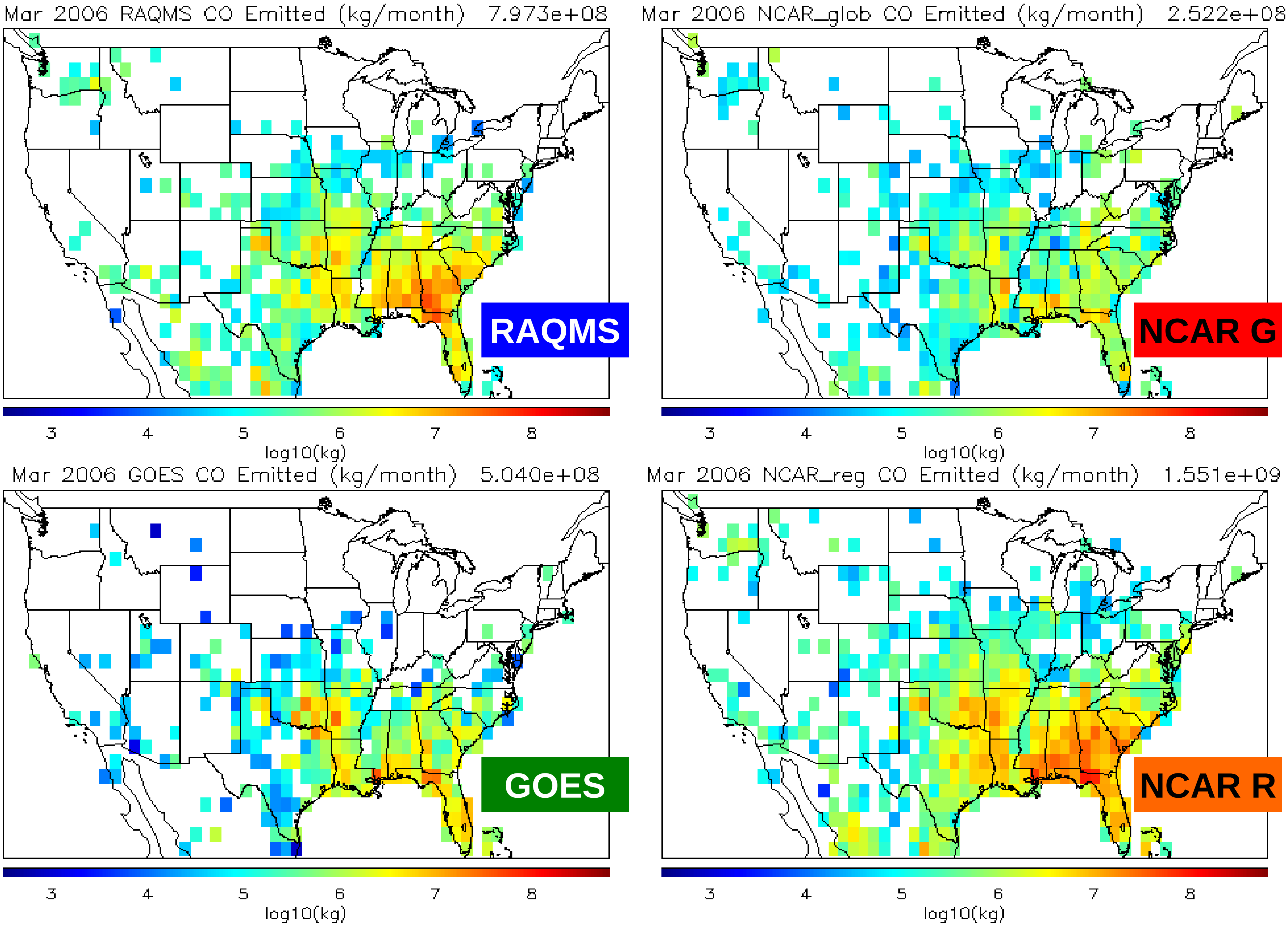


July: Best agreement in Area Burned but large spread in CO Emission estimates

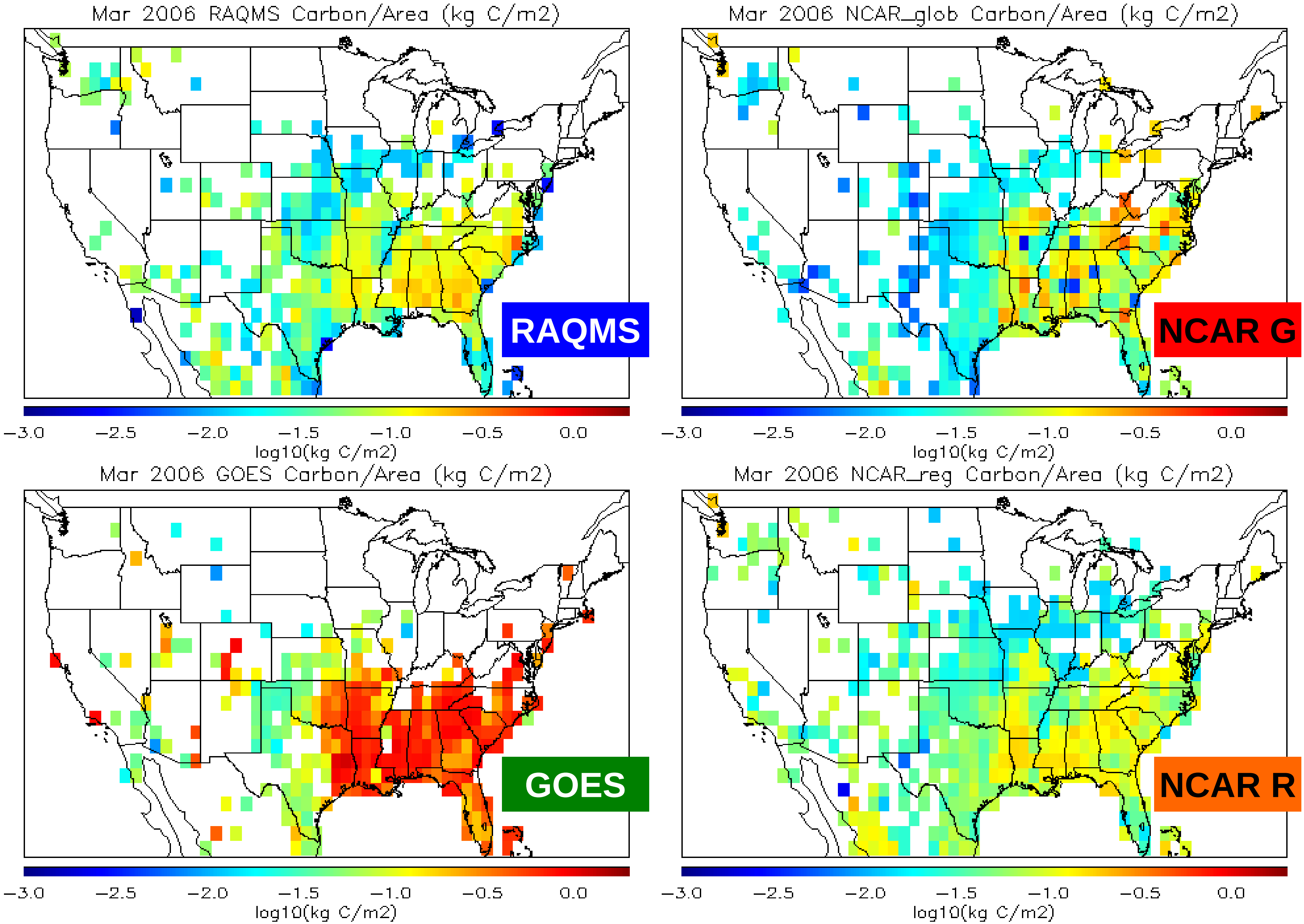
March 2006 Area Burned Estimates (1-degree)



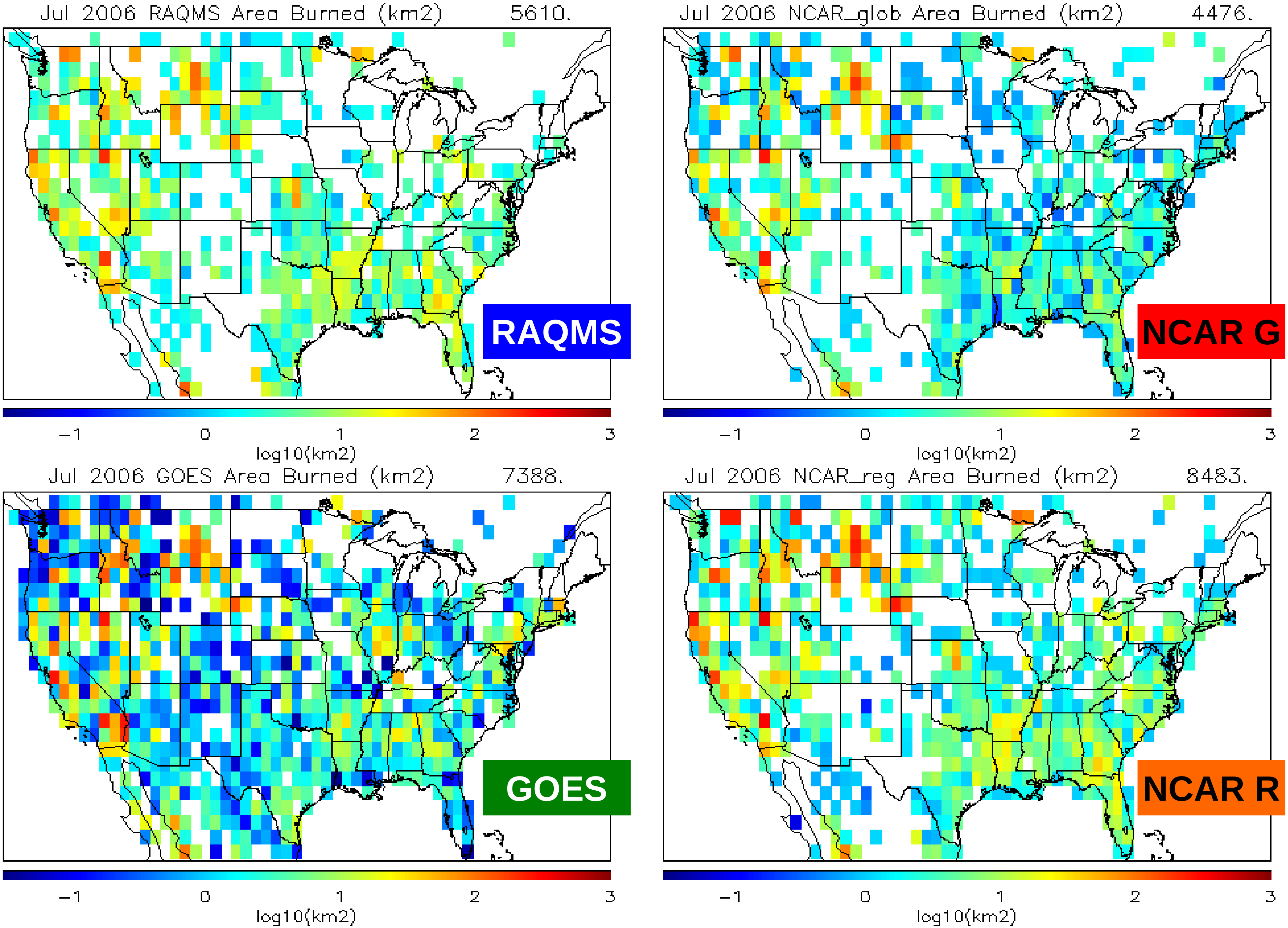
March 2006 CO Emission Estimates (1-degree)



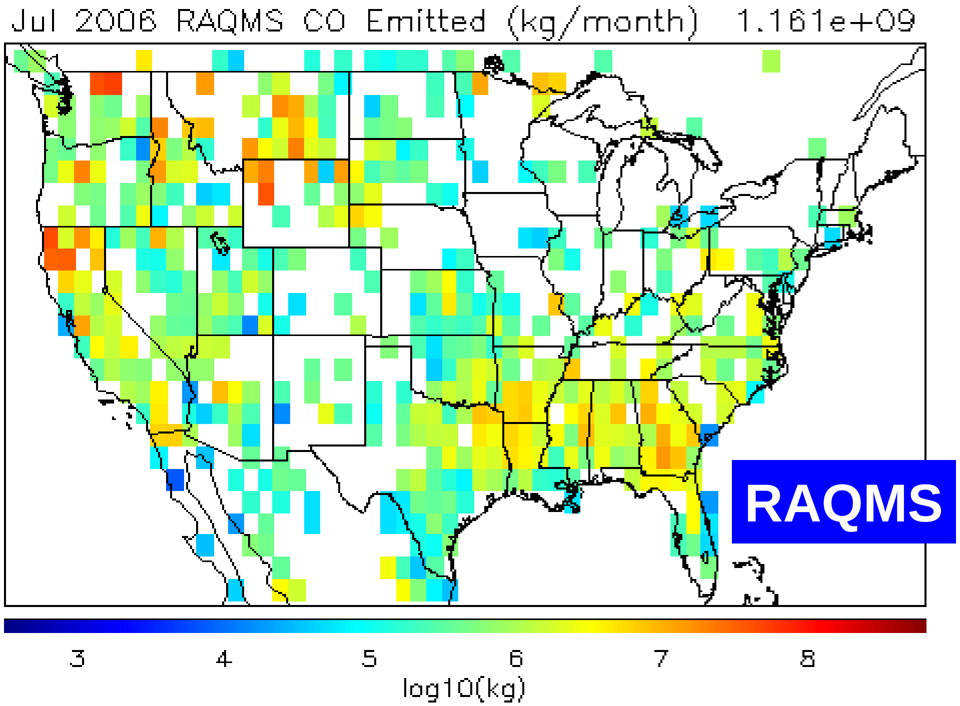
March 2006 Carbon/Area Burned Ratio (1-degree)

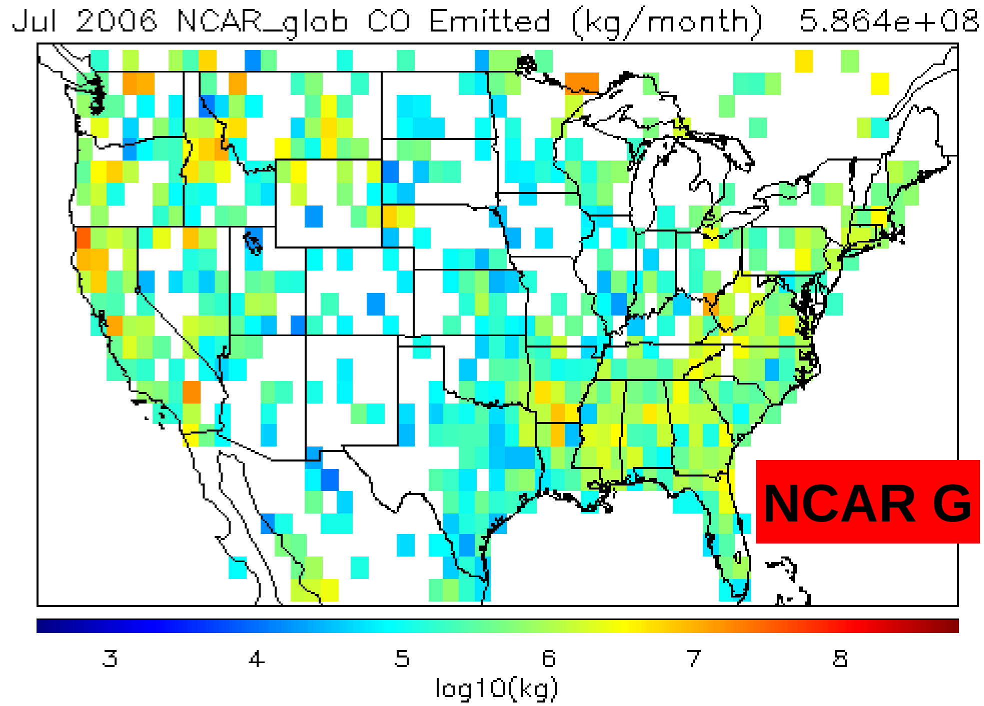


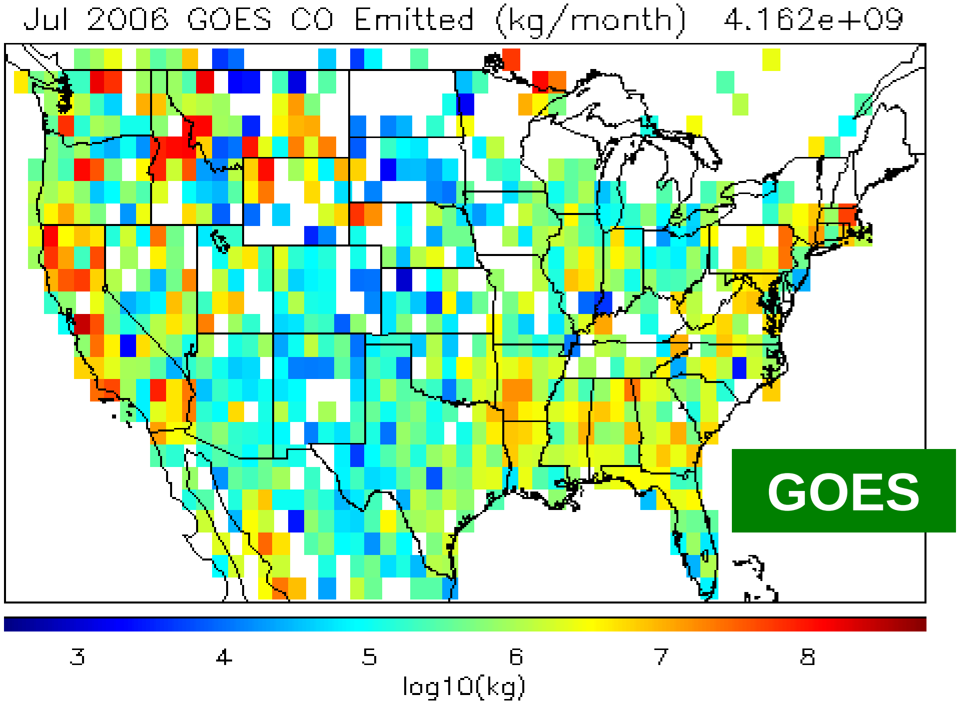
July 2006 Area Burned Estimates (1-degree)

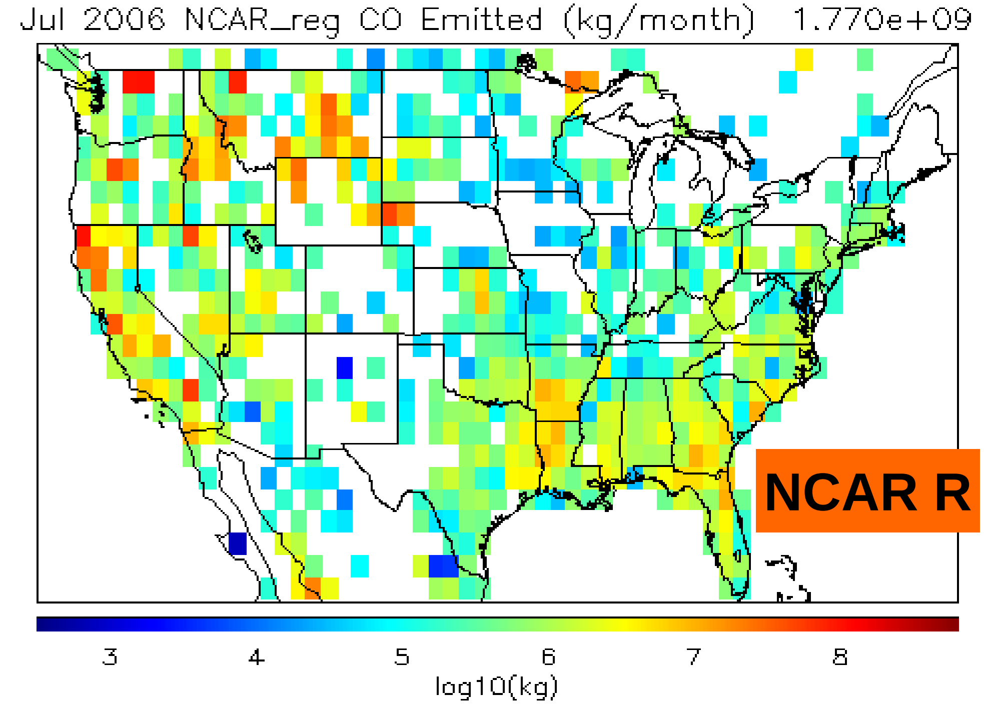


July 2006 CO Emission Estimates (1-degree)









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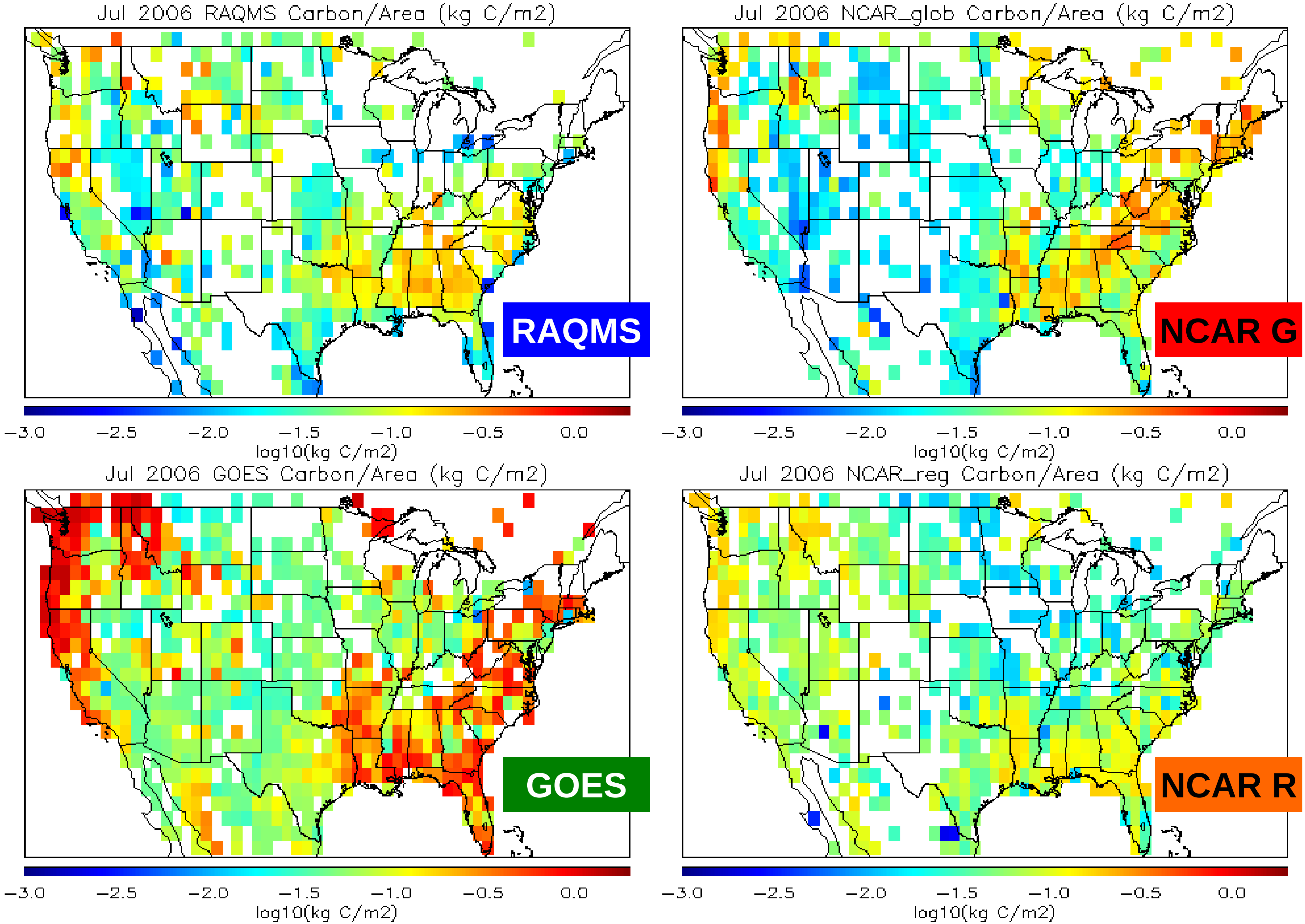
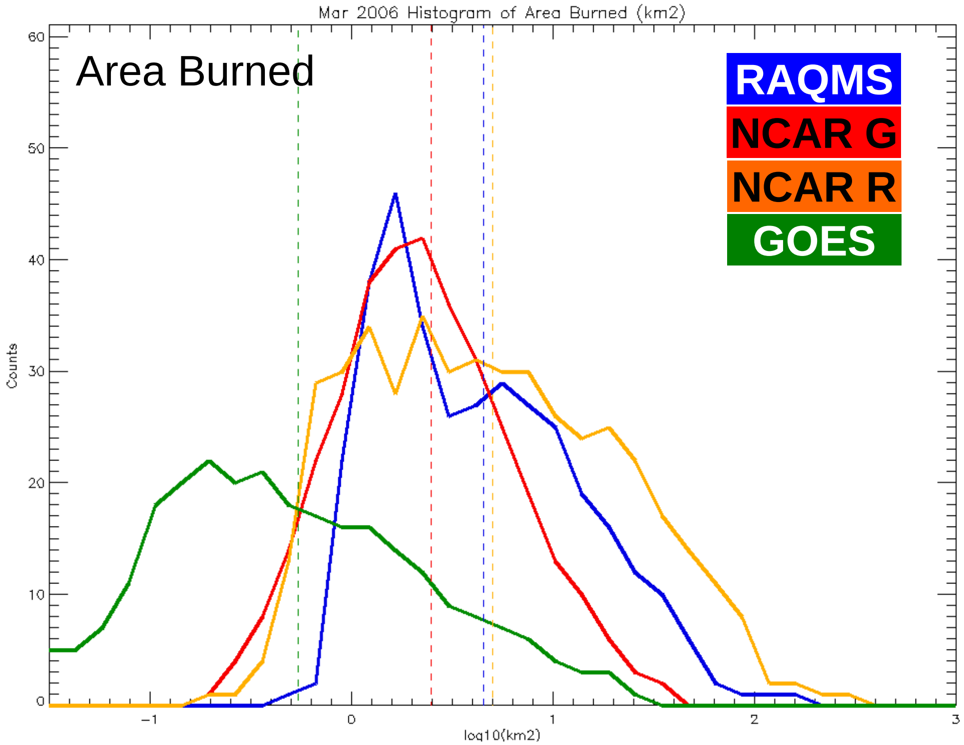
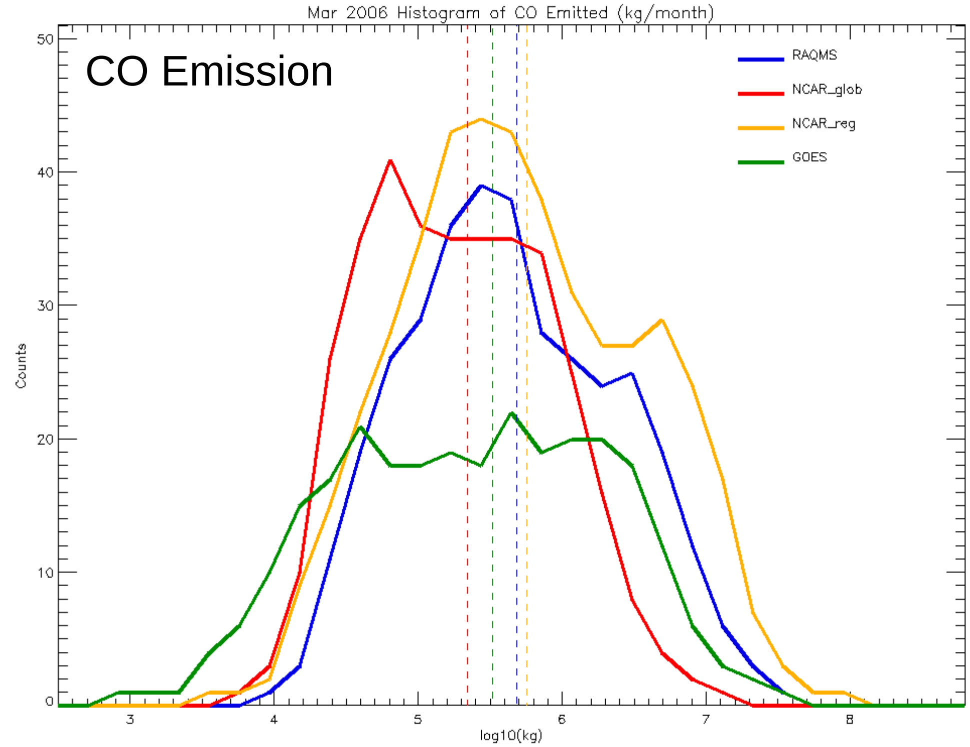
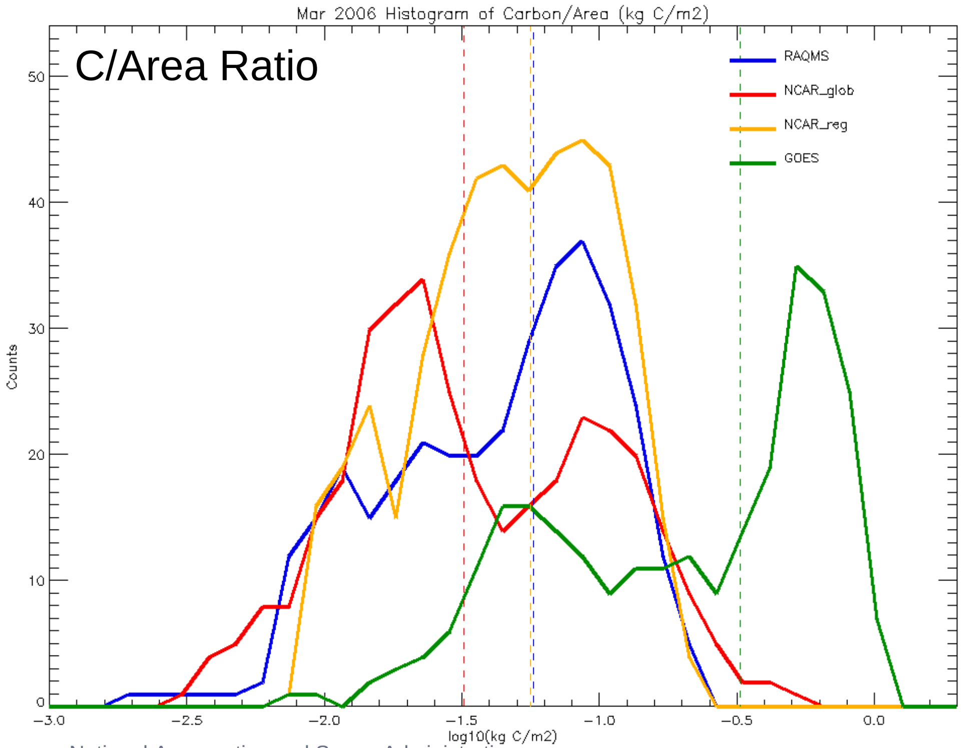


Histograms of March 2006 1-degree biomass burning estimates (CONUS)

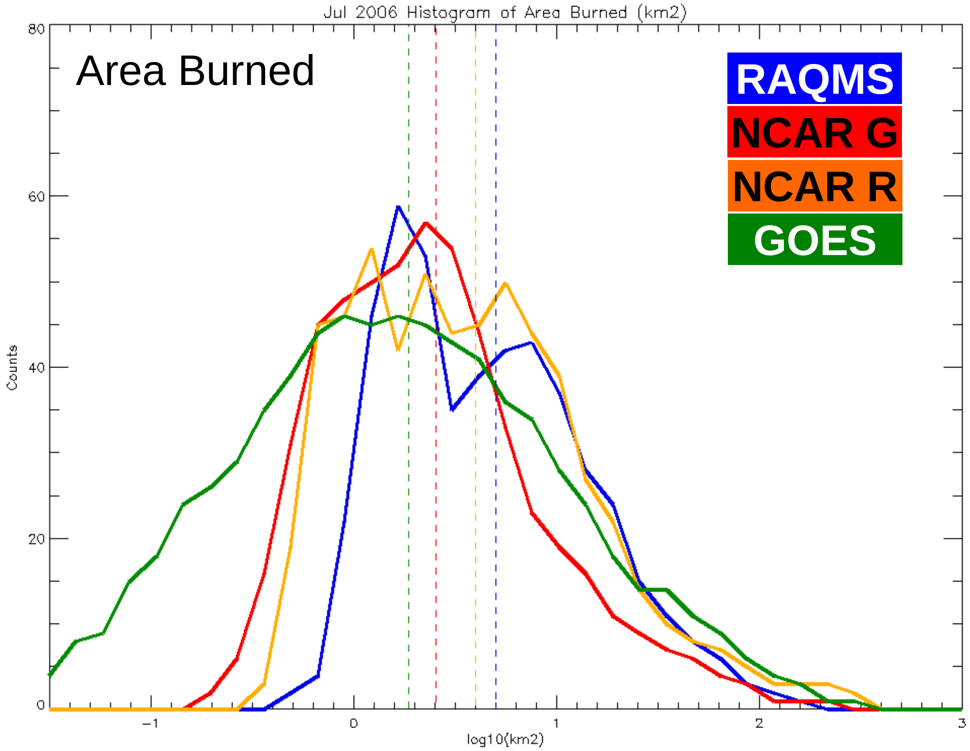


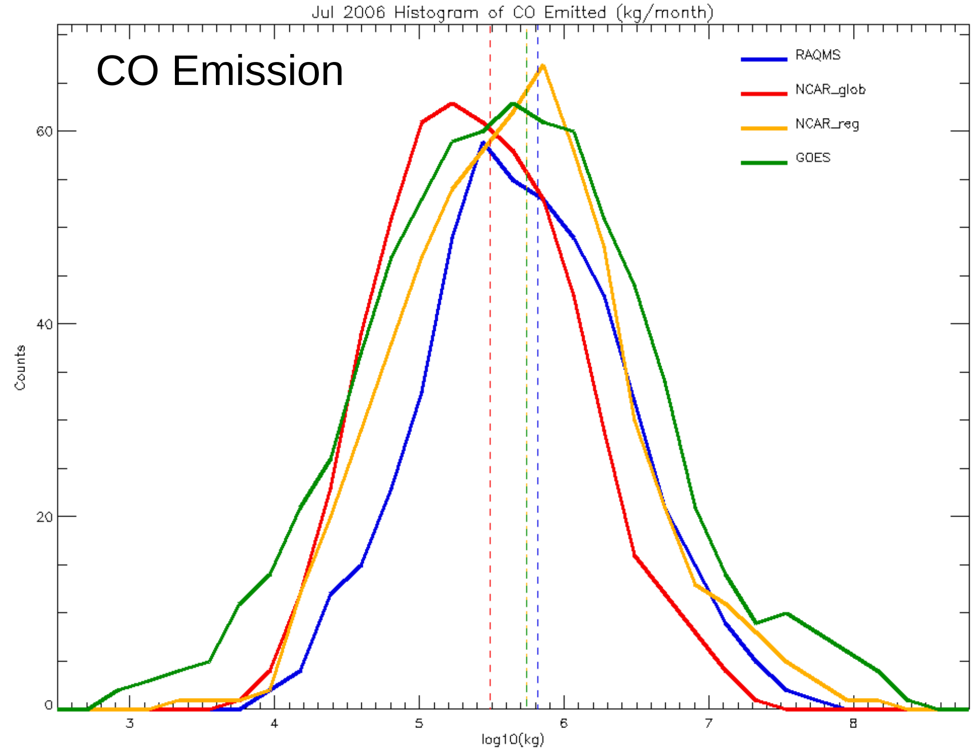


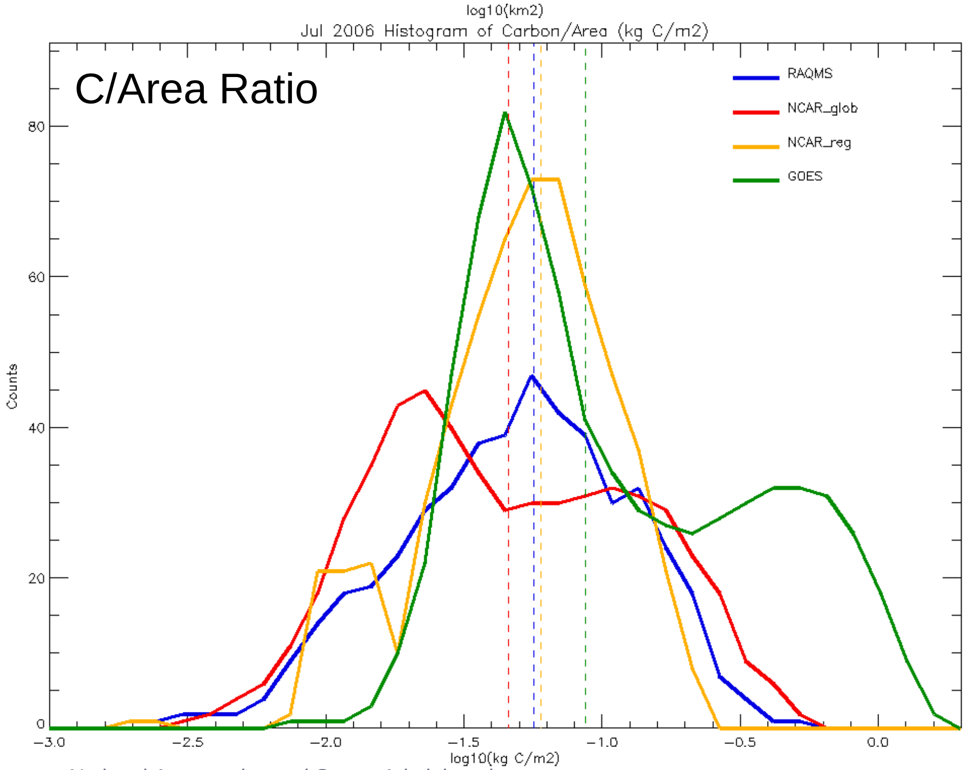


- GOES area burned skewed toward small values
- GOES has a relatively broad flat peak in CO emission histogram, MODIS techniques tend toward bimodality
- Carbon/Area ratio shows an appearance of bimodality in all four techniques
- GOES has distinct population of points with large ratios, consistent with the large ratios found in the southeastern US
- Logarithmic x-axes: the rightmost (largest) values dominate monthly totals

Histograms of July 2006 1-degree biomass burning estimates (CONUS)

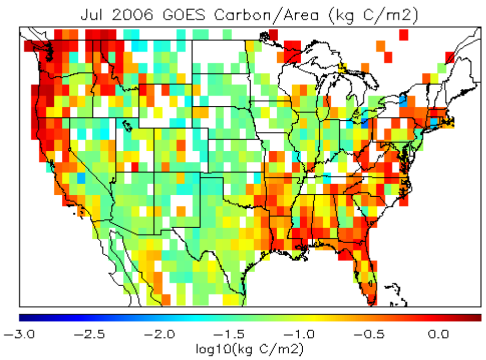


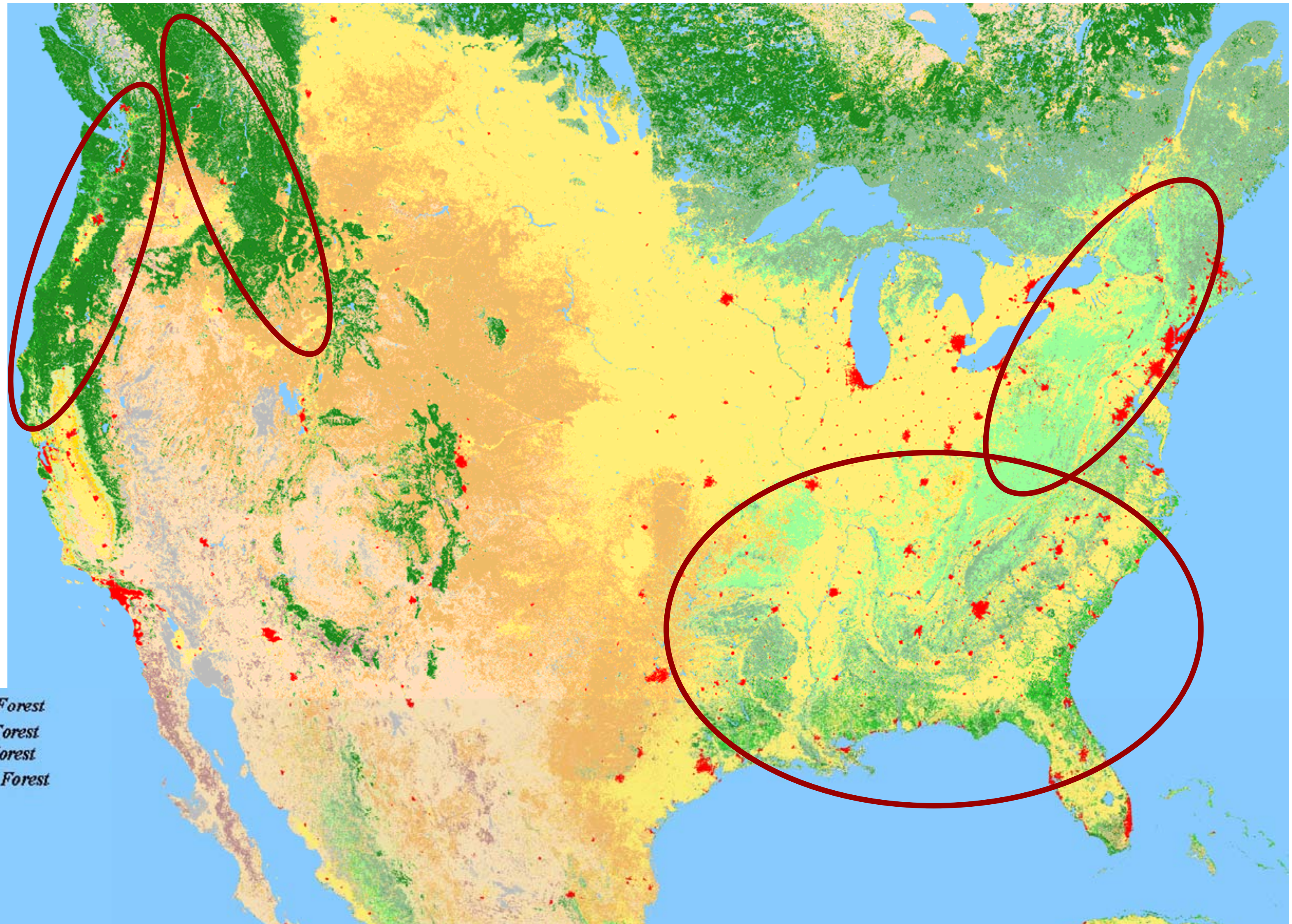




- Area histograms more similar in July than March:
  (1) GOES peak shifted to larger values
  (2) All methods have tail of high values associated with large fire activity in Northwest
- CO emission distributions have similar shapes, GOES distribution is broadest and RAQMS distribution is narrowest
- The Carbon/Area ratios are quite different from March - GOES distribution still bimodal but the dominant peak occurs at values similar to other techniques

MODIS Land Cover Map





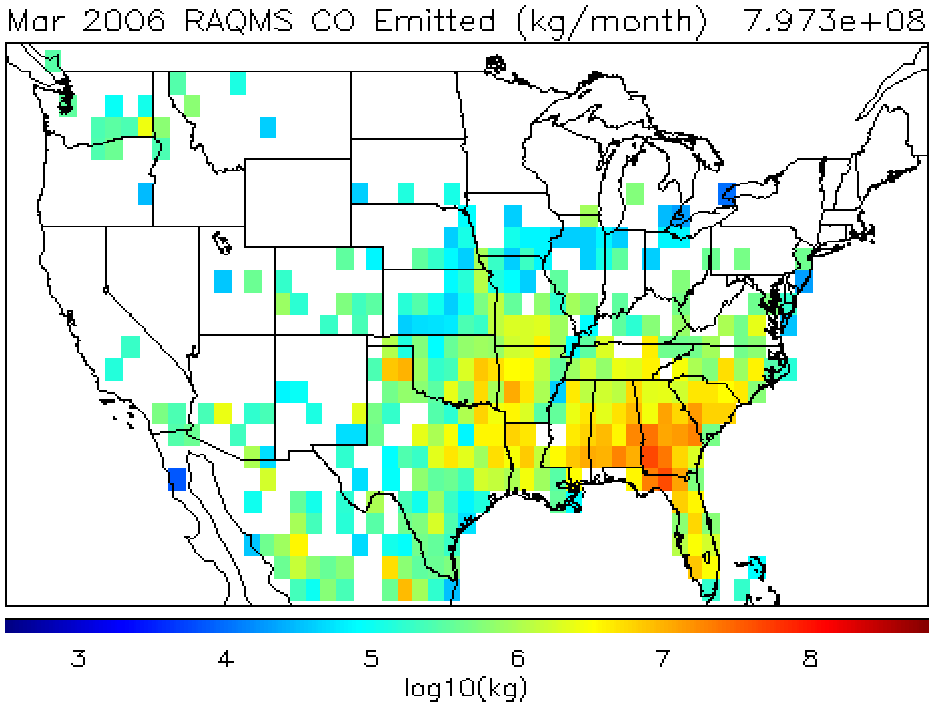
Large differences in Carbon emission per unit area burned appear associated with Forested ecosystems

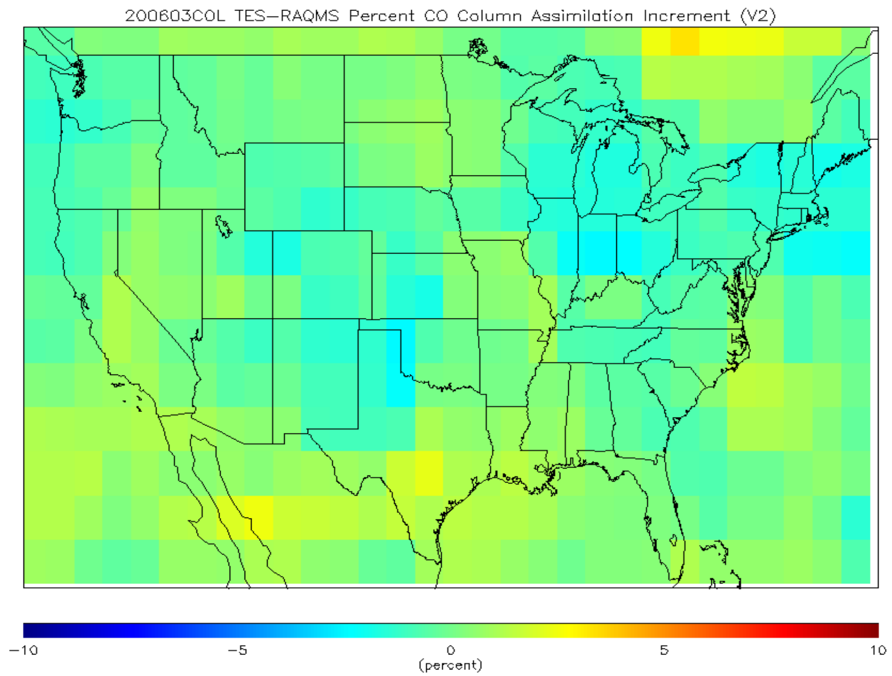
Evaluation of CO emissions using TES observations

- RAQMS global reanalysis, using RAQMS emissions presented here, with assimilation of CO observations from the TES instrument on the Aura satellite
- CO assimilation increment (assimilation result minus model first guess) provides a qualitative evaluation of biomass burning CO emissions where CO variability is primarily a result of burning
- Figures on next pages shows mean daily assimilation increment expressed as a percentage of total column CO
- Positive values indicate TES observations are larger than model first guess (i.e., CO emissions too small)

Evaluation of CO emissions using TES observations - March

- Mean daily assimilation increment expressed as a percentage of total column CO
- Positive values: TES observations larger than model first guess (CO emissions too small)

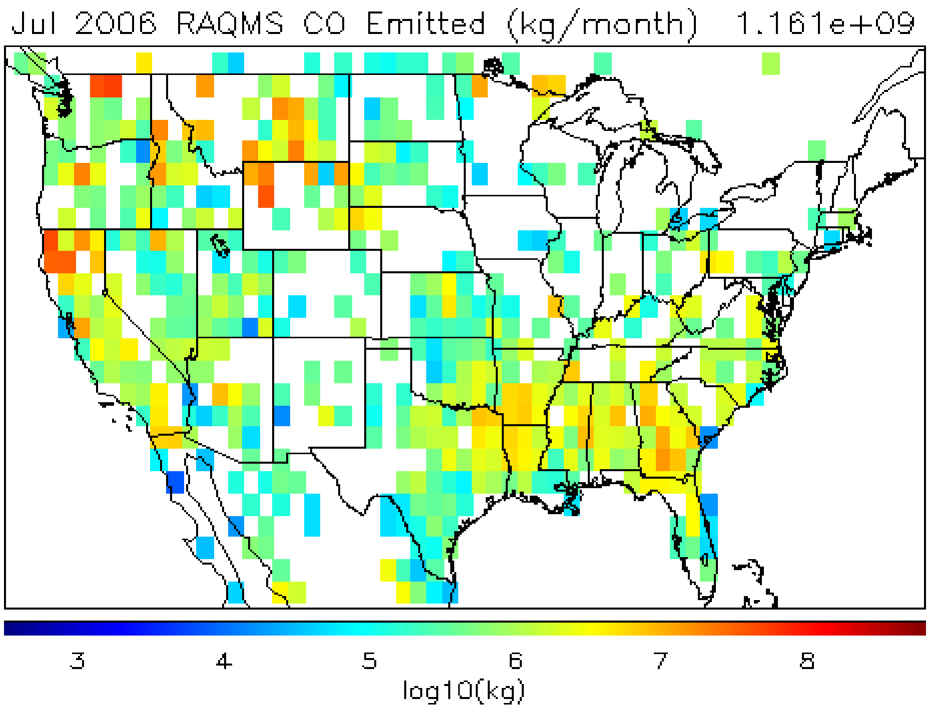


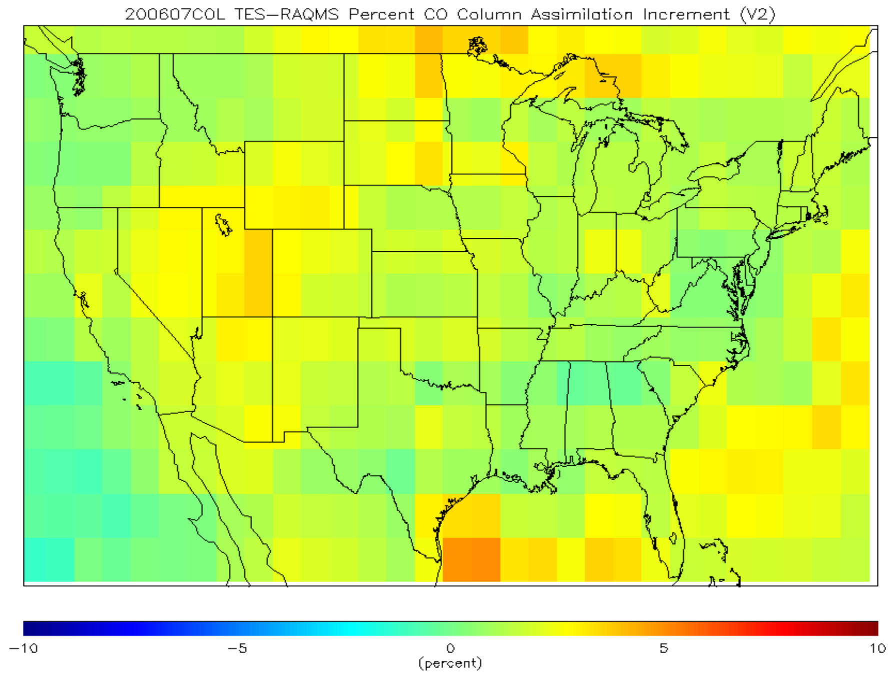


- Model first guess CO is 1-2% lower than TES (positive assimilation increment) through much of southeast, suggesting the daily variation and magnitude of RAQMS fire emissions are realistic but could have a low bias
- Indication of high bias in emissions over north Texas

Evaluation of CO emissions using TES observations - July

- Mean daily assimilation increment expressed as a percentage of total column CO
- Positive values: TES observations larger than model first guess (CO emissions too small)

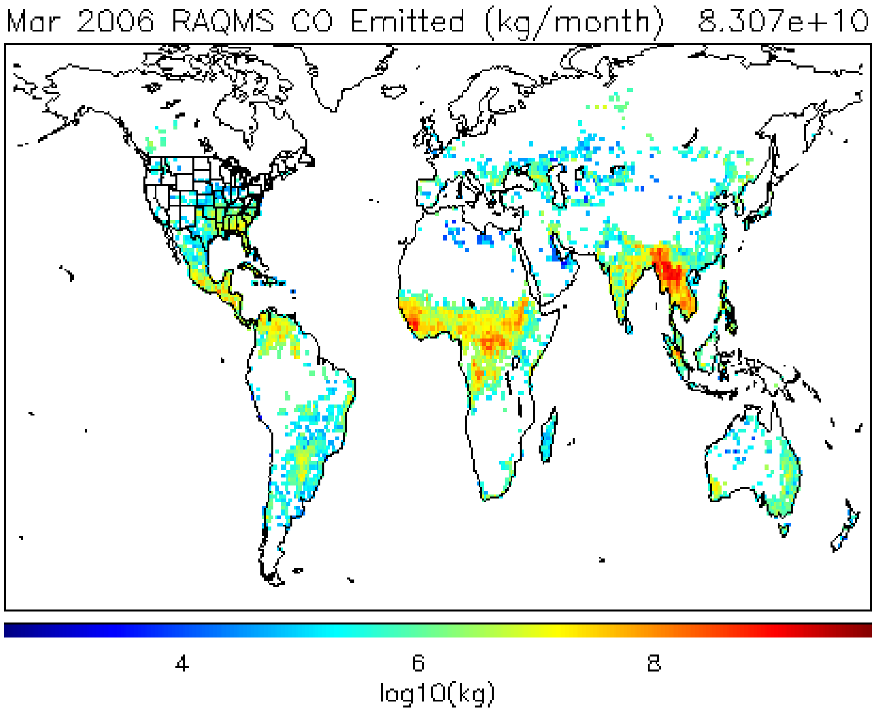




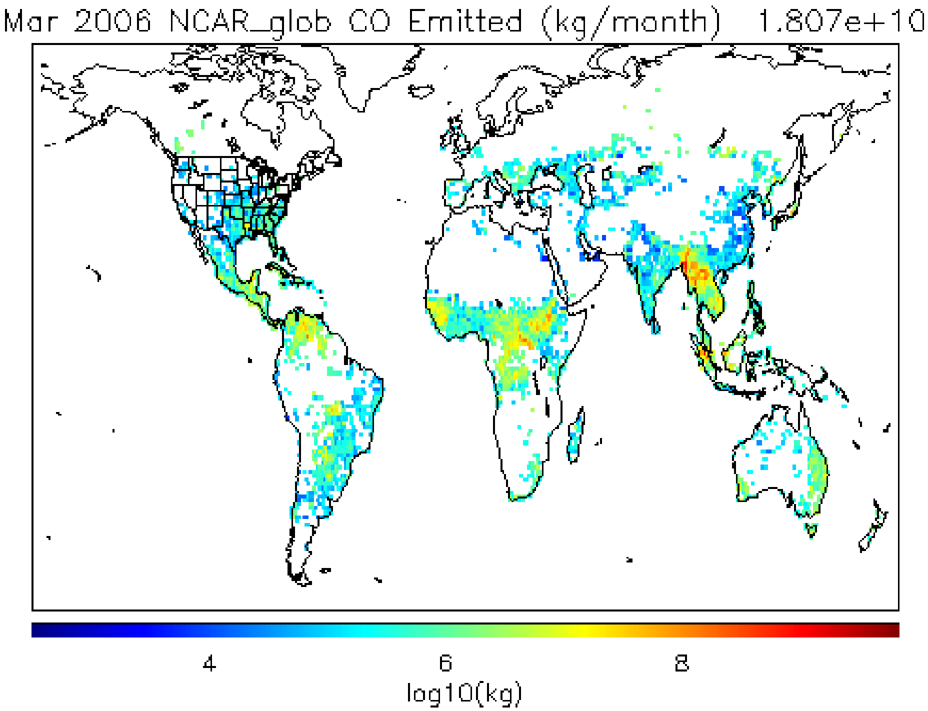
- Assimilation increments over burning locations in Northwest and California range from zero to 3%, suggesting that RAQMS emissions have a low bias
- Still indication of low bias in emissions over the Southeast

Comparison of Global CO Emissions: March 2006

RAQMS

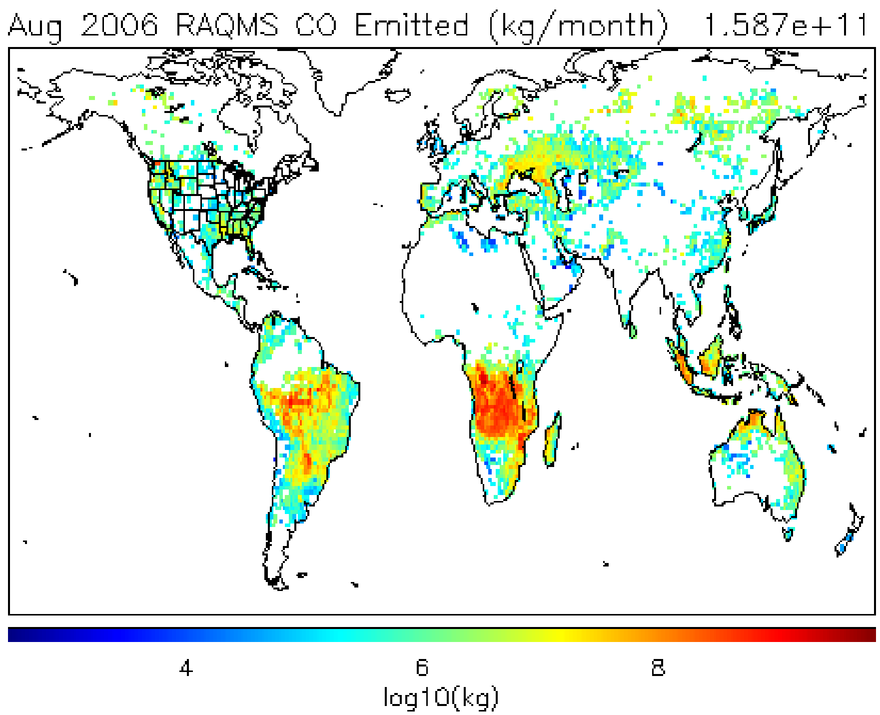


NCAR Global



Comparison of Global CO Emissions: August 2006

RAQMS



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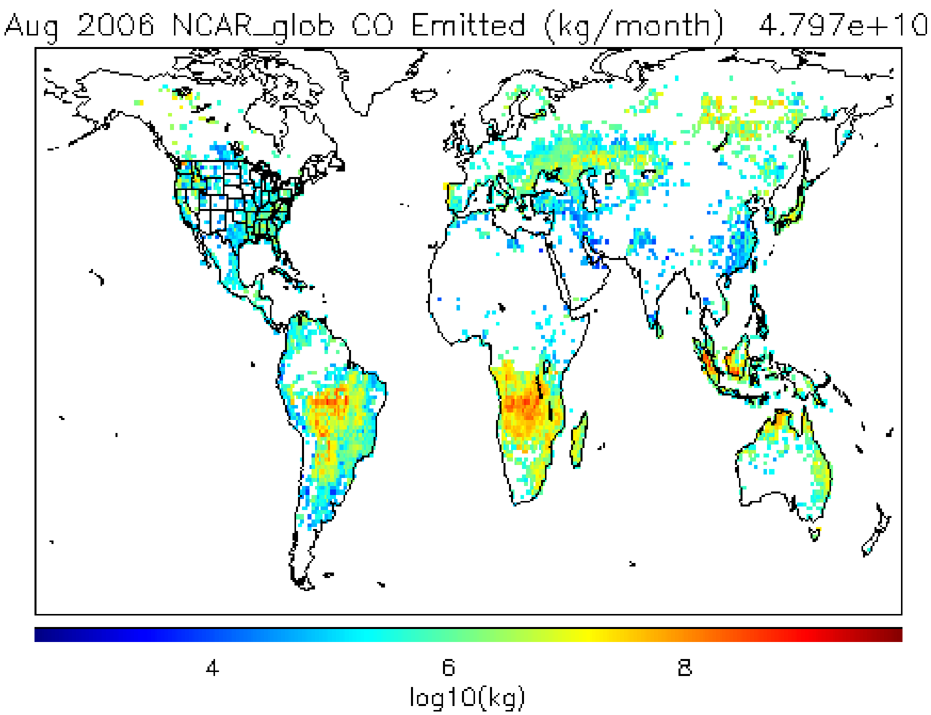
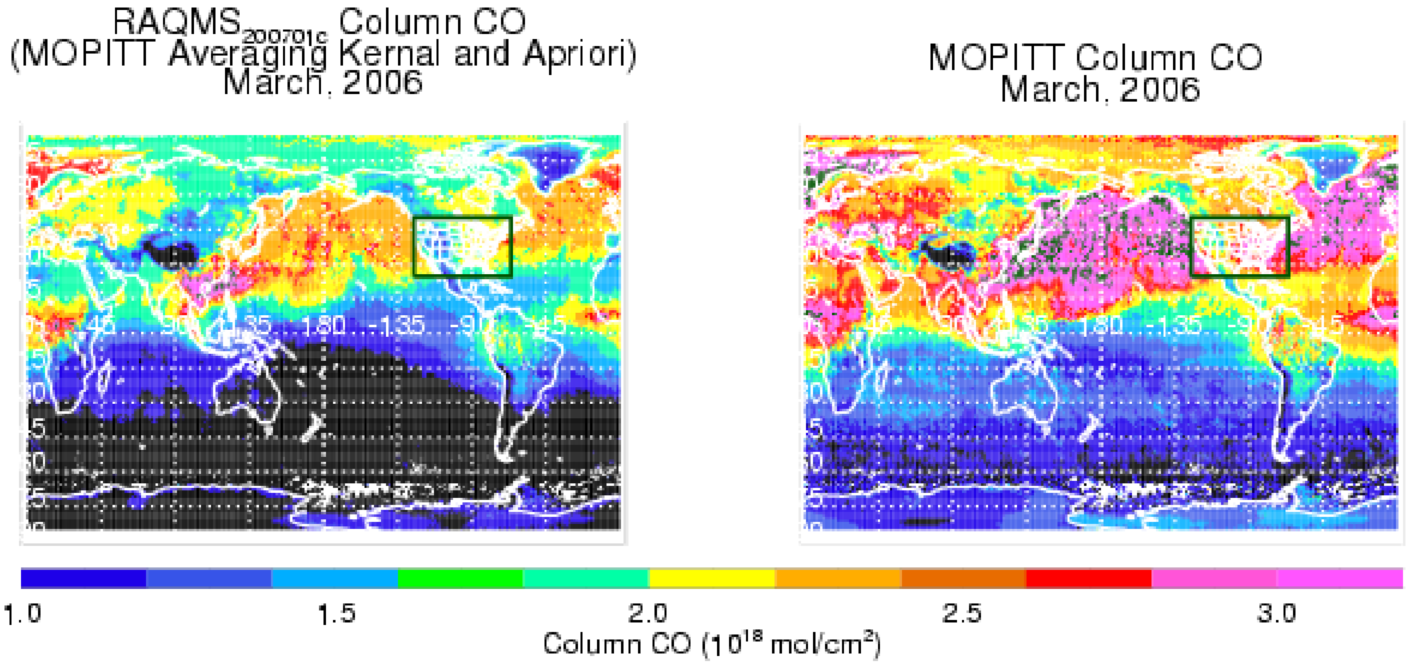
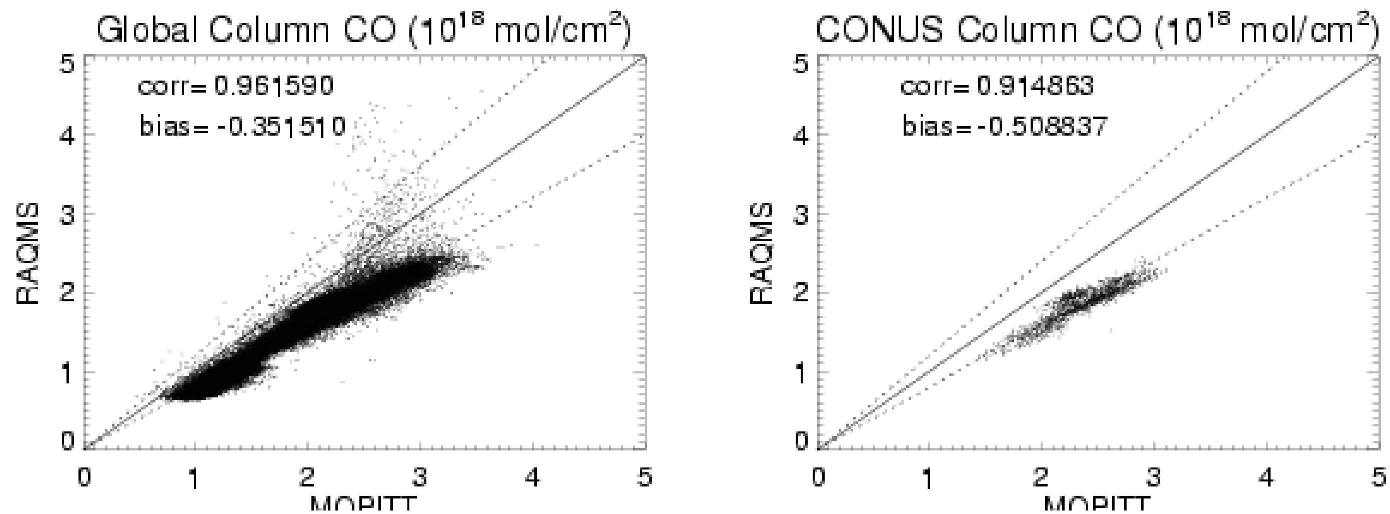


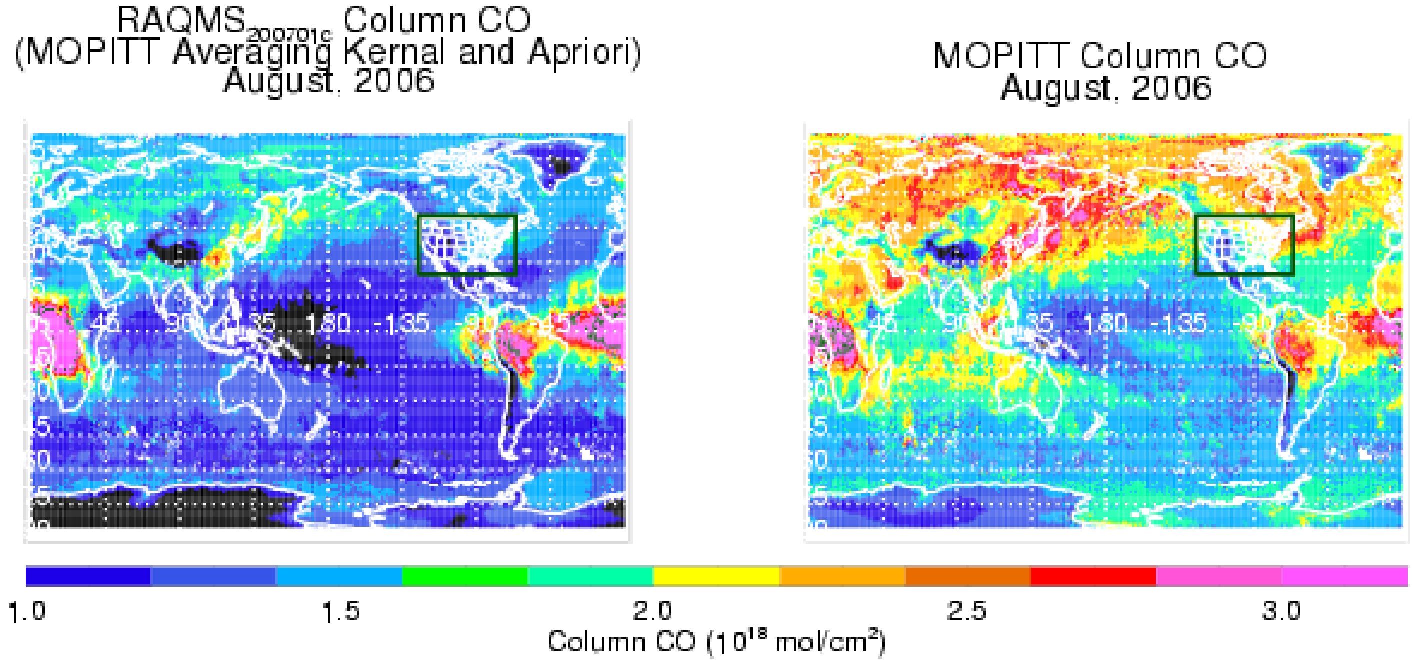
Evaluation of RAQMS Global CO with MOPITT observations: March 2006

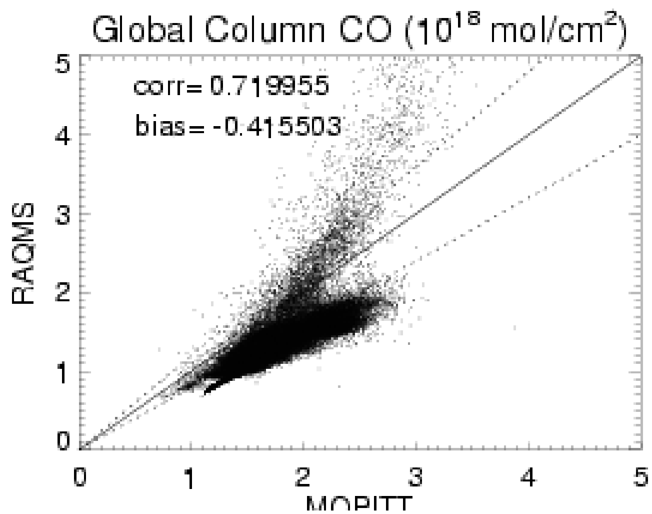


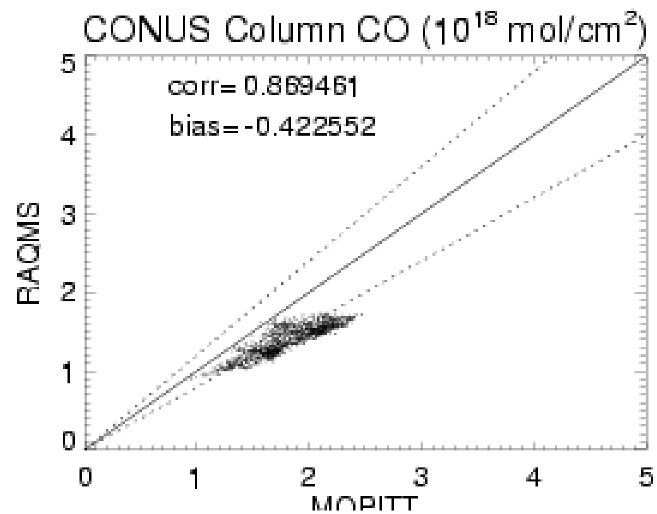


- Over CONUS, RAQMS consistent with MOPITT (known 18% high bias in these observations)
- Globally, high correlation but RAQMS has high bias over Southeast Asia
- Good comparison over equatorial Africa

Evaluation of RAQMS Global CO with MOPITT observations: August 2006







- Over CONUS, RAQMS again consistent with MOPITT (column values smaller than March)
- Globally, lower correlation than March
- RAQMS high bias over tropical burning regions in Africa and South America

Summary

1. Over CONUS there is a wide spread in area burned estimates with a significant fraction of GOES area-burned estimates smaller than $1km^2$. The GOES technique employs a sub-pixel algorithm to infer instantaneous fire sizes while the MODIS-based techniques assume a burn area on the order of $1km^2$ is associated with fire detections. Estimates of total area burned are dominated by large fires and the techniques show more consistency during months when large fires occur.

2. CO emissions are more consistent than area estimates over CONUS. This is a result of significant differences among the techniques in net CO emission rates per unit area within particular ecosystems and vegetation classes. Visual inspection of ecozone maps suggests largest differences are associated with forested land.

3. Over CONUS, the RAQMS CO emissions appear reasonable but low biased in regions of large burning during both spring and summer. NCAR Regional (spring and summer) and GOES (summer) emissions are larger than RAQMS during these episodes, but we have not conducted simulations with these emissions.

4. Globally, significant high bias in RAQMS CO emissions during 3 of 4 times and locations of large tropical biomass burning, demonstrating an ecosystem dependence within tropical regions. Not yet determined whether these biases are associated with area burned, fuel/combustion estimates, or a combination.

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