Monitoring biomass burning activity at landscape to global scales using multi-resolution satellite data: algorithm developments and data application

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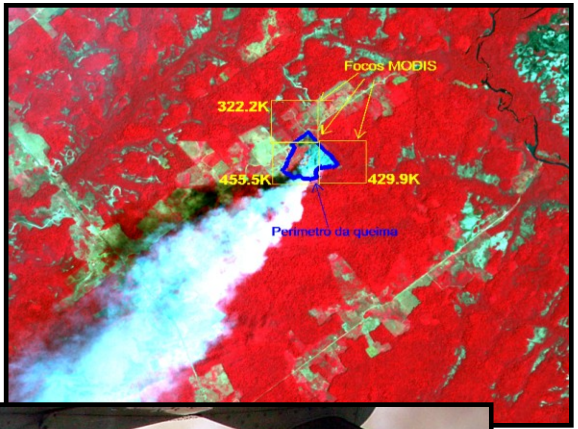
Biomass Burning – Observations, Modeling, Data Assimilation
Boulder, CO

Motivation

- Fire as a major environmental problem* globally
  - tropical areas specially affected
    - Largely associated with deforestation
  - Significant effects on biodiversity
  - Important source of aerossols&GHG
  - Major climate change element

  ** Fires can also have a positive impact*

- Social implications
  - Economy (property damage, disruption of power lines, transportation, etc)
  - Human life/health



NASA/LBA Field Campaigns in Amazonia

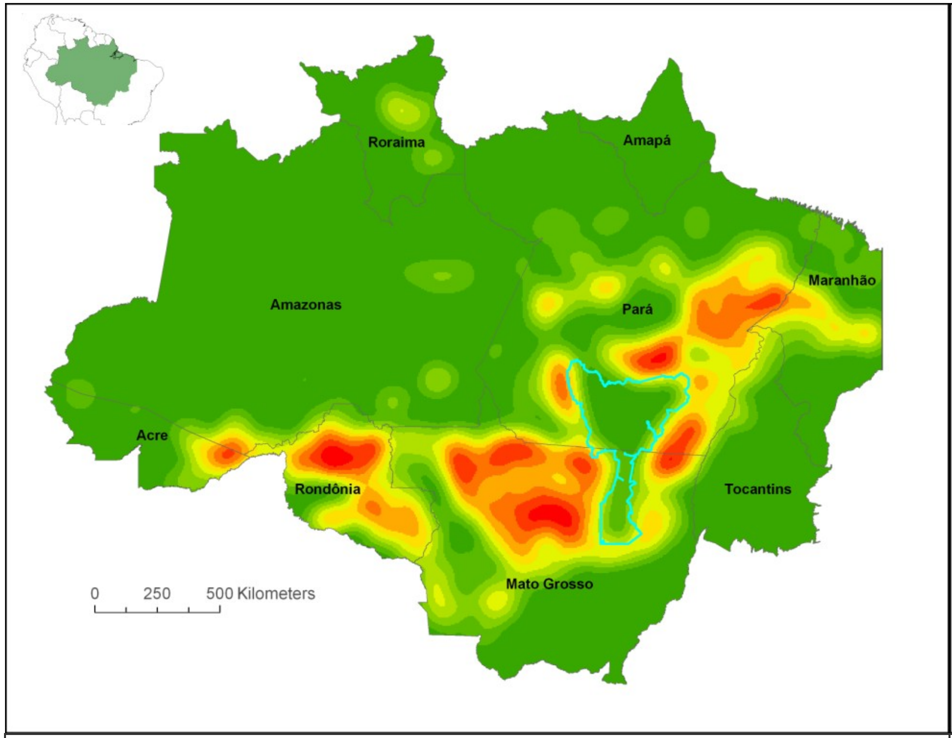
2003, 2004

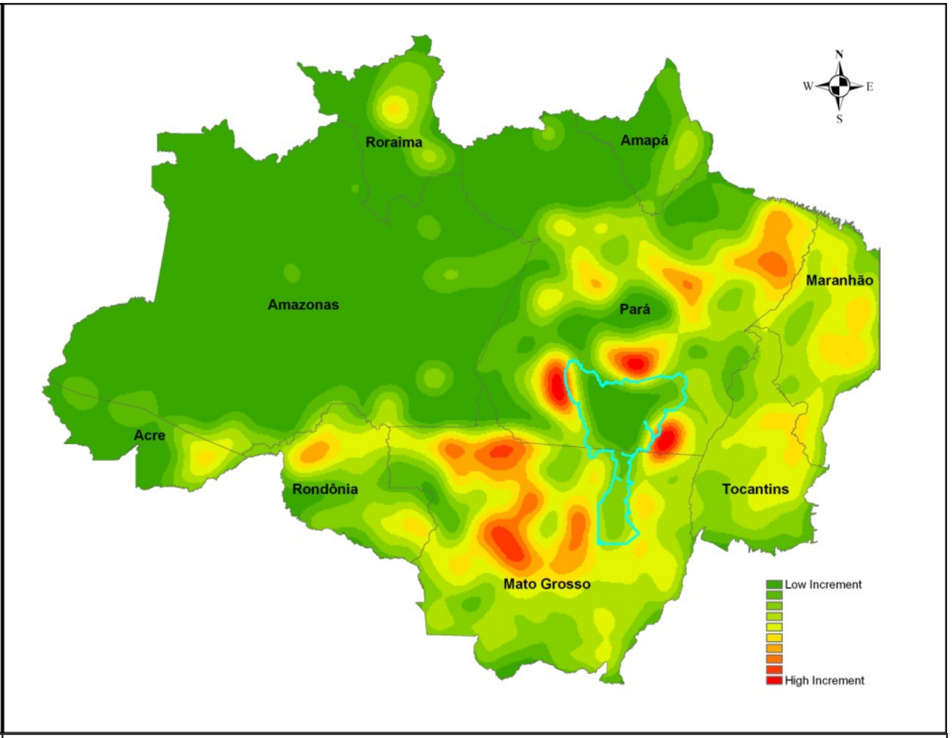
UNDP, 2000-2004

Location Matters
Fires ↔ Land Use

Vegetation fires in the tropics are strongly associated with deforestation activities

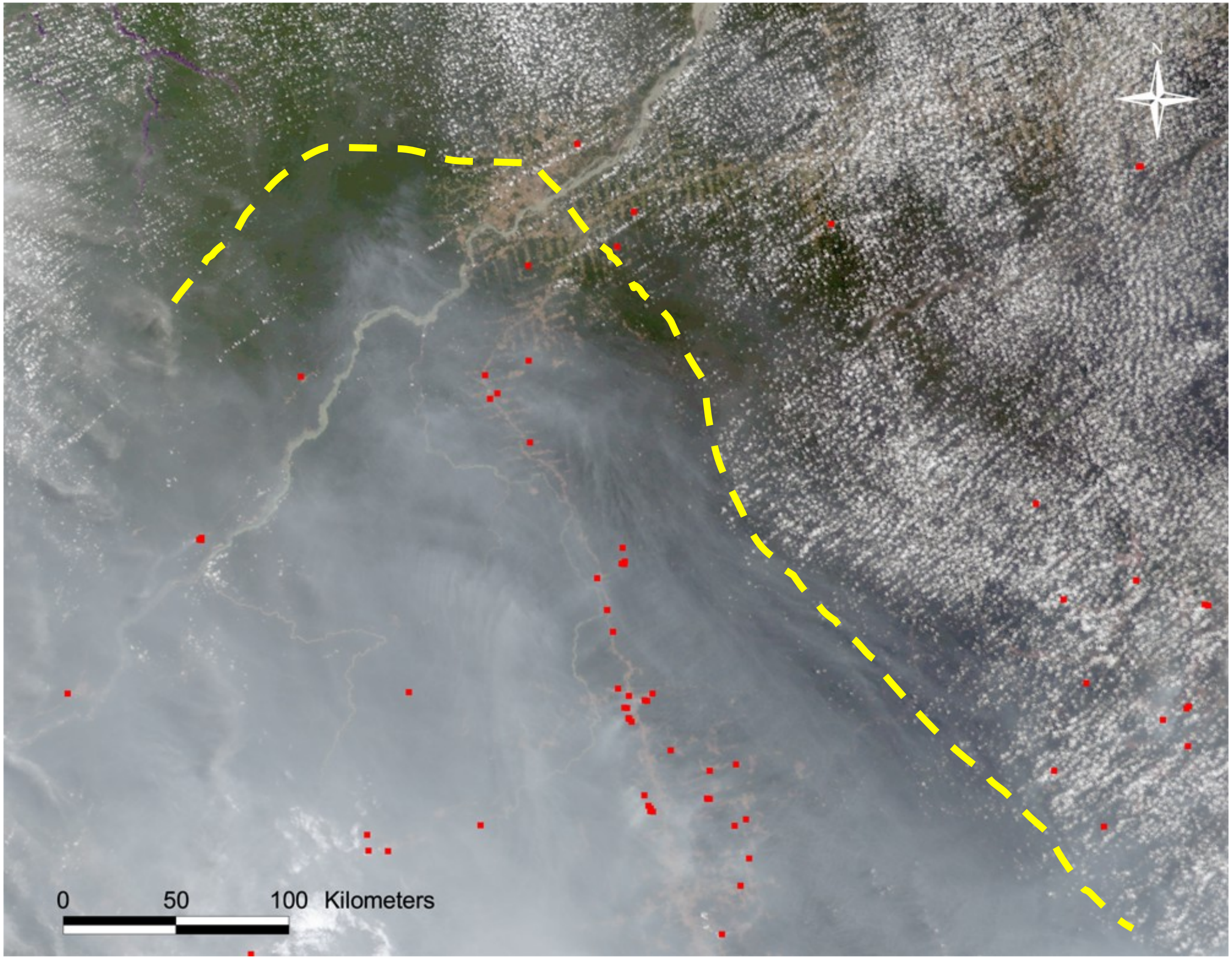
→ Massive amounts of biomass burning emissions





PRODES 120 m Resolution Deforestation Data	TRMM VIRS 2.5 km Active Fire Detection Data
Areas of Deforestation Increment in 2002-2004	Fire Expansion Areas (= [2002-2004] – [1998-2000])

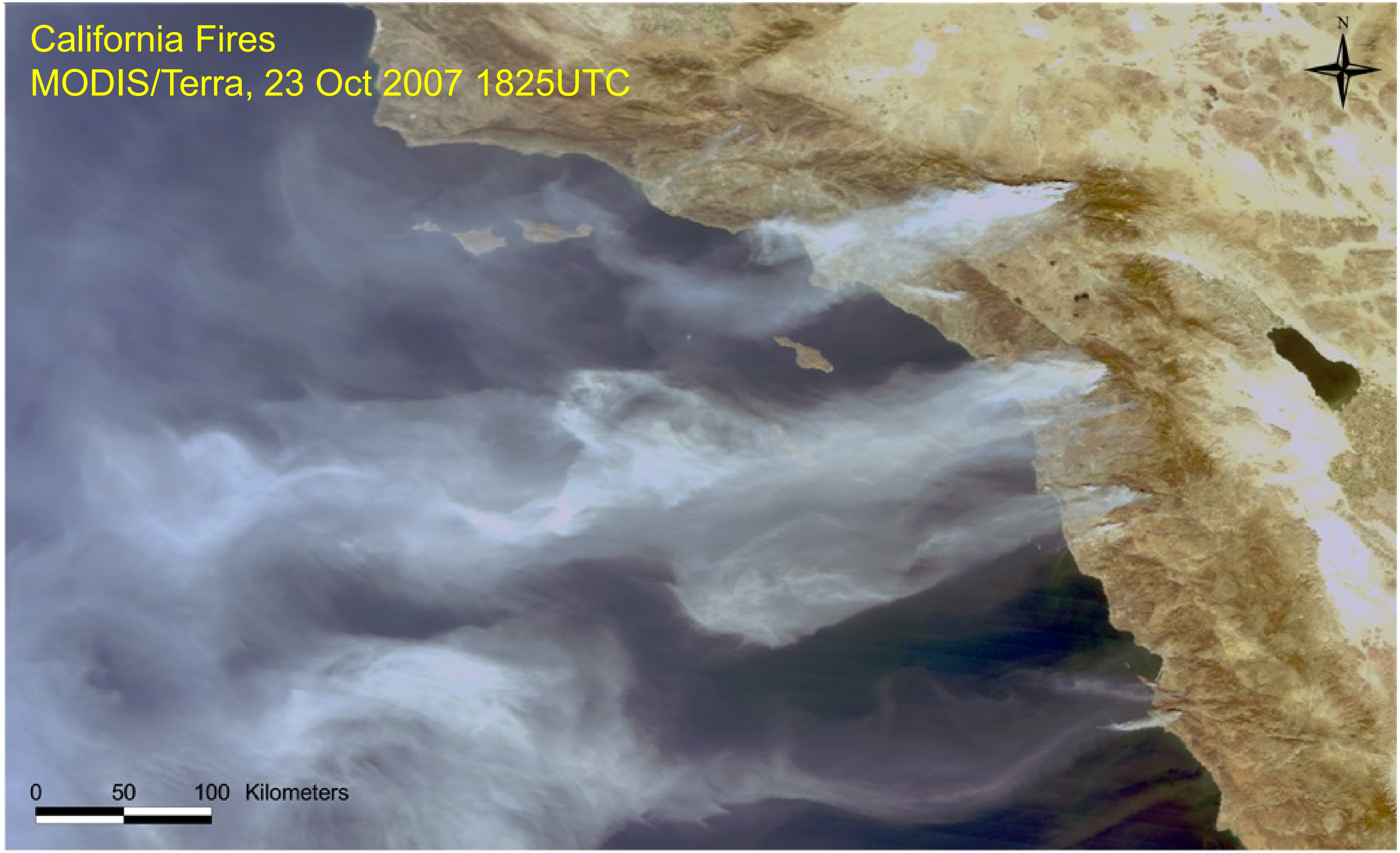
Frequency Also Important



Amazonia Fires
MODIS/Terra
24 Aug 2005 1415UTC

Cloud suppression due to smoke [Andreae *et al*., 2004; Koren *et al*., 2004]

Fires in the U.S.



Research Priorities

- Development/Refinement of Fire Detection Algorithms
  - Supporting MODIS & GOES imager validation/refinement
  - Supporting GOES-R/ABI and NPOESS/VIIRS algorithm development
  - Generate quality information for NRT applications (e.g., rapid response systems)
  - Create longer-term environmental data records
    - Performing product inter-comparison/integration
    - Correcting for errors of omission/commission
- Applications
  - Study causes and consequences of fires
    - Land use/land cover change in Amazonia
  - Generate biomass burning emissions data

Primary Remote Sensing Fire Products

- Active fire detection
  - Intended for near-real time application (<3h latency)
  - Main data sets:
    - Polar orbiters: snapshot of daily fire activity x moderate spatial resolution
    - Geostationary: higher temporal frequency x lower spatial resolution
  - Burn severity analyses possible via related parameters (persistence, fire radiative power (FRP), size/temperature)

- Burned area mapping
  - Reduced near-real time application (usually a few days worth of data required to generate product)
  - Provides complete mapping (to the extent possible) of fire-affected area
  - Burn severity analyses difficult using moderate/coarse spatial resolution data
    - Landsat type data ok (e.g., NBR)

Active Fire Detection Algorithms

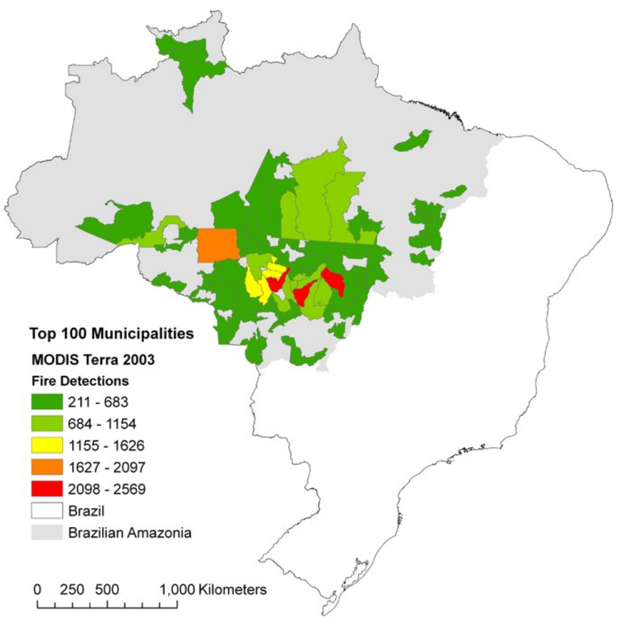
- Fixed Threshold Methods (INPE)
  - Set of single/multi-band tests applied to target pixel
  - Regionally adjusted/tuned
- Contextual Methods (MODIS, GOES, FIMA, ABI, VIIRS)
  - Use of dynamic multi-band tests applied to target pixel using adjacent pixel information
  - Can be used both regionally/globally

Regardless of method used, satellite fire detection algorithms must always balance commission and omission errors

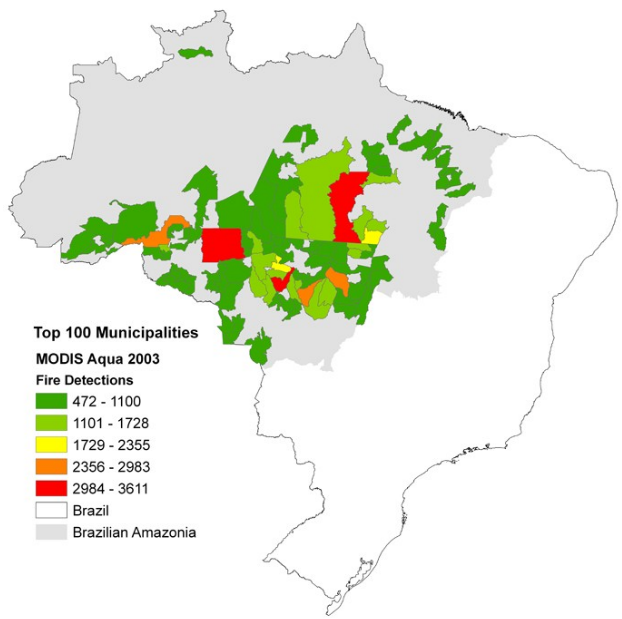
Major Products Generating Conflicting Information

Important differences between products

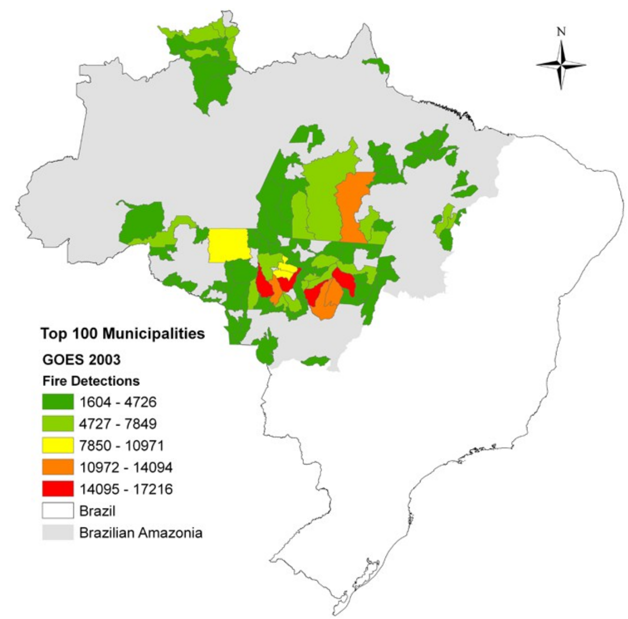
Implications for regional fire management / decision making



MODIS Terra



MODIS Aqua



GOES Imager

⇒ Different municipalities highlighted by each fire detection product

⇒ Different ranking of the areas selected

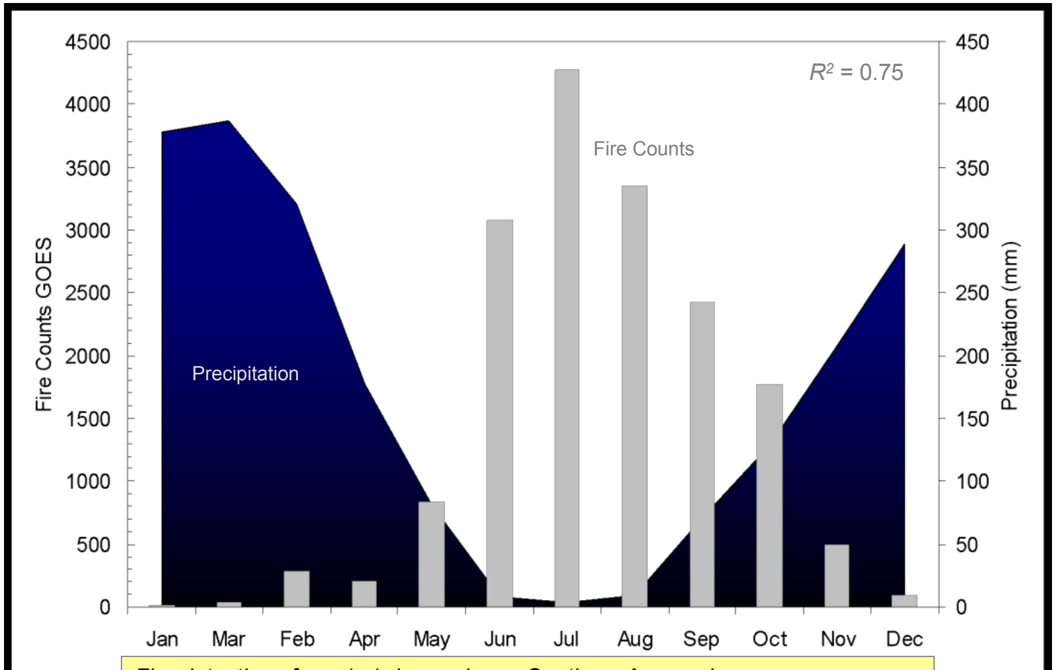
W. Schroeder, 2008

Cloud Obscuration

The presence of opaque clouds will prevent fire detection leading to omission errors

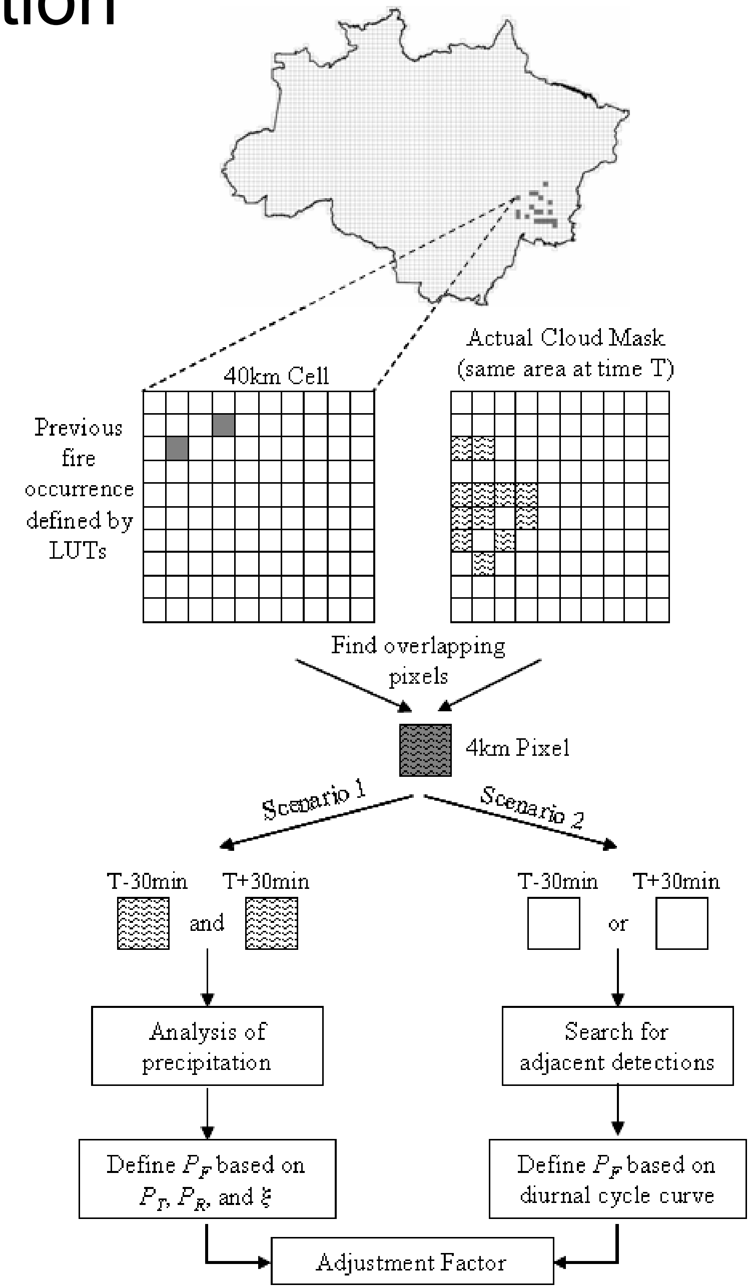
Problem is particularly important in tropical areas where clouds can be frequently observed even during the dry season

Correction for omission due to clouds in tropical areas can take advantage of fire regimes that are fundamentally driven by human activities and influenced by rainfall seasonality



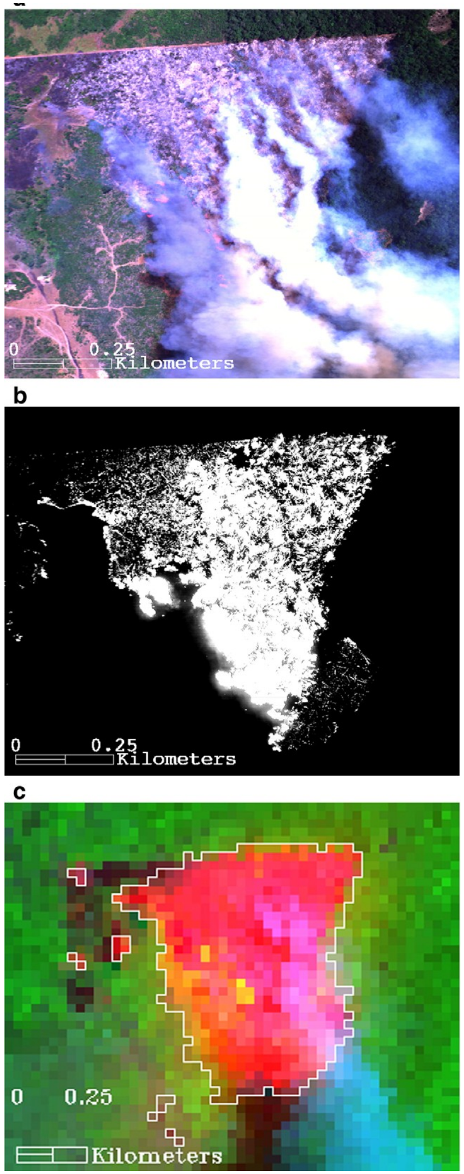
Fire detections for a 1×1 degree box – Southern Amazonia

Precipitation from nearest weather station and same year



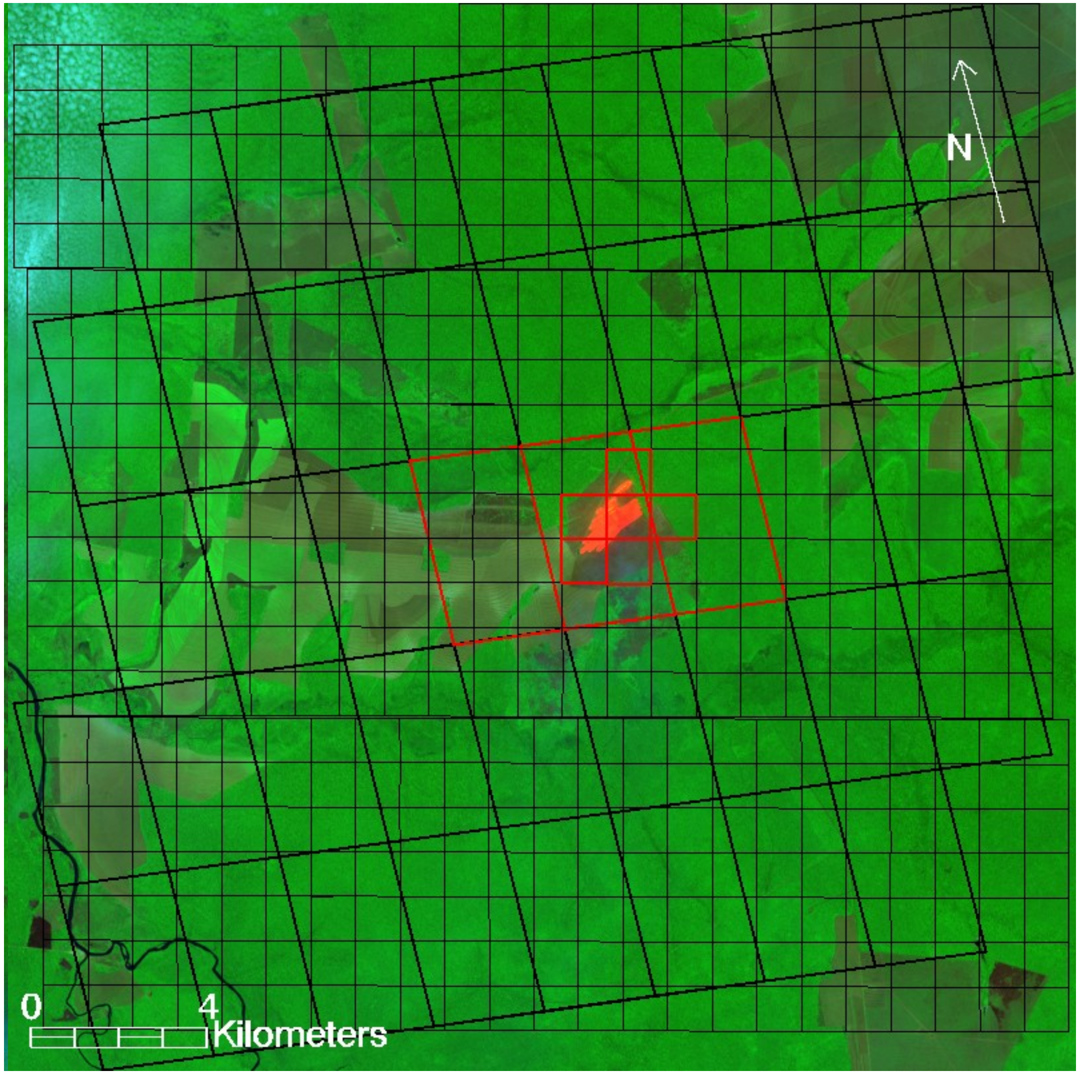
Schroeder *et al*., 2008

Validating Active Fires: Data Requirements



Prescribed burn coincidently imaged by airborne sensor,ASTER, MODIS and GOES - Amazonia Jan 2003

Fires will predominantly occupy a small fraction of a moderate-to-coarse resolution pixel:
Fine resolution data are required for validation

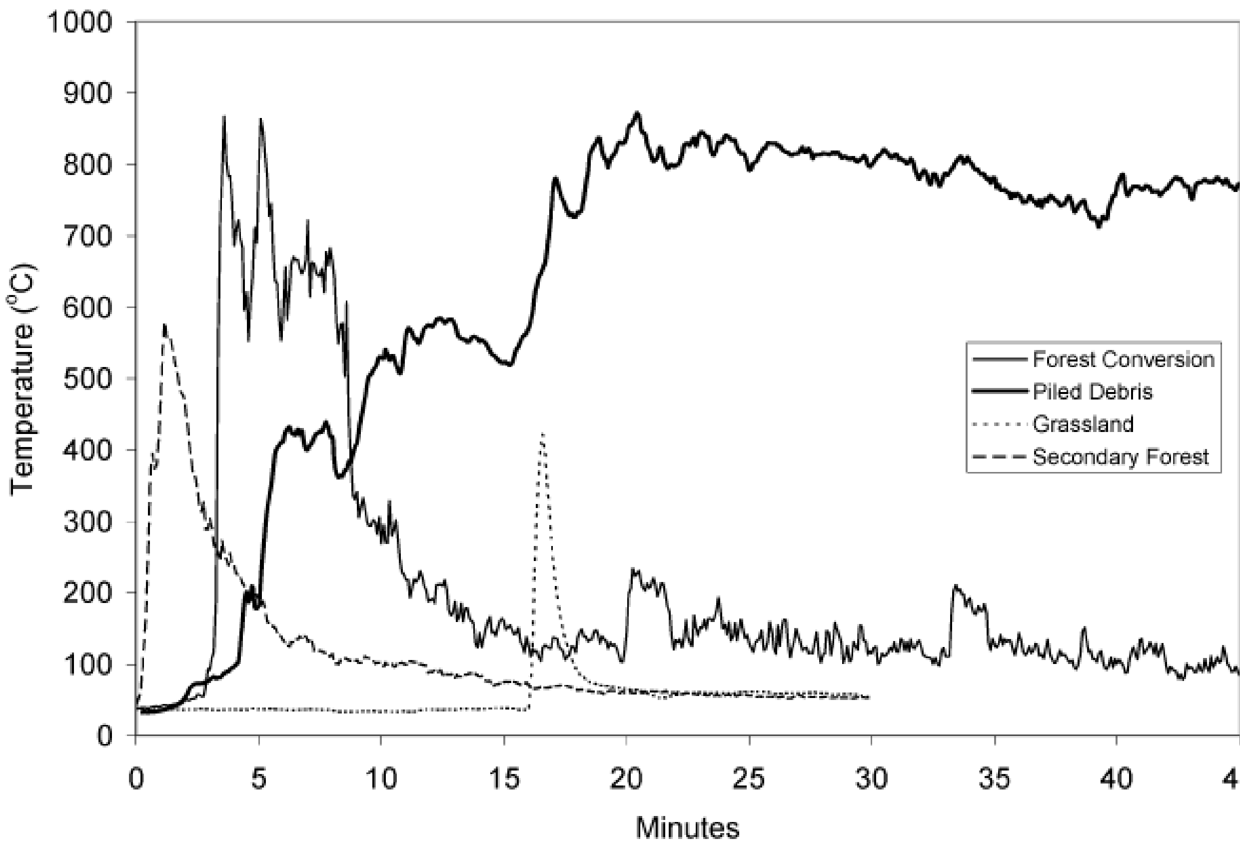


Validating Active Fires: Data Requirements

Maintenance

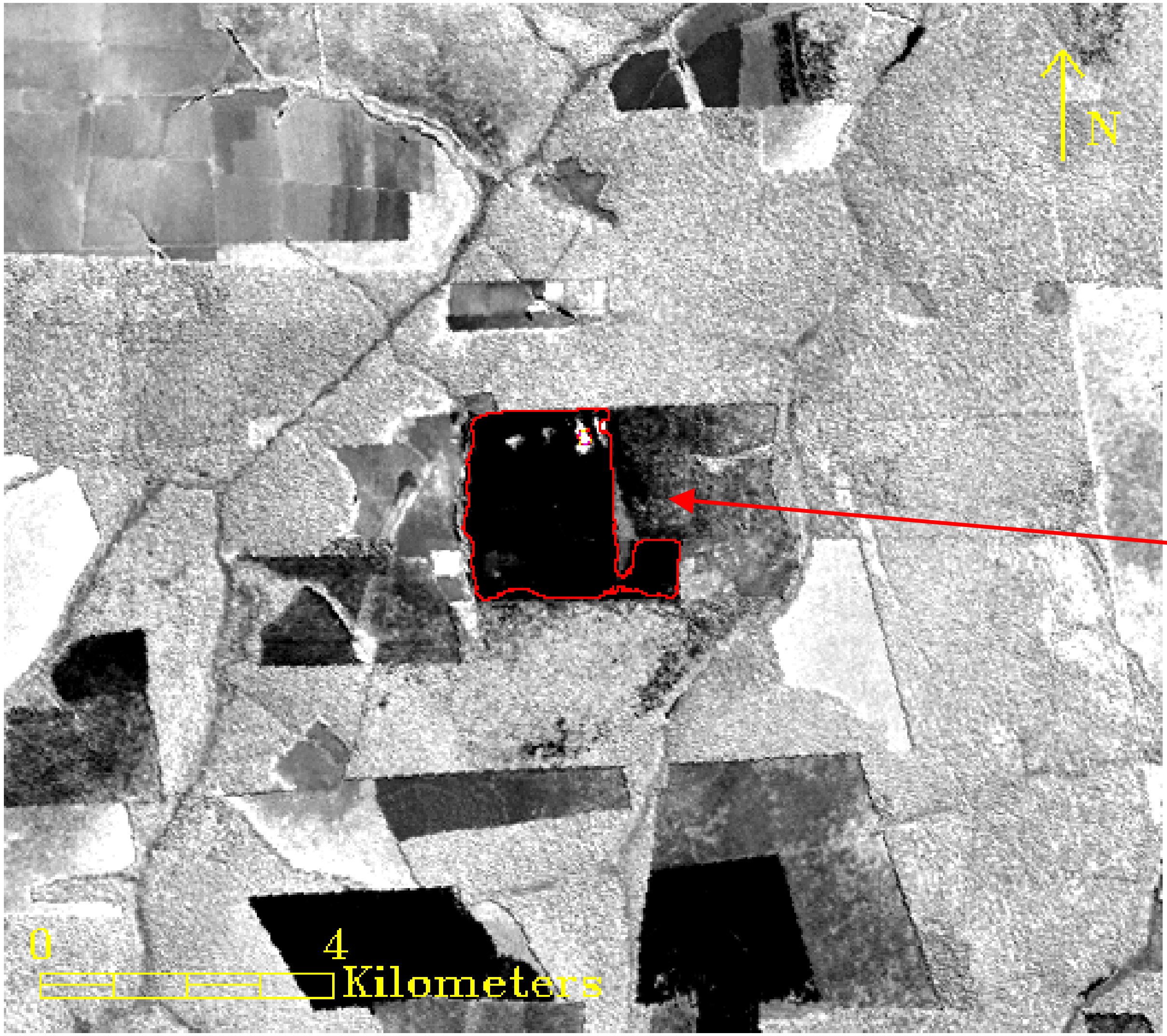
Conversion

Fires are highly dynamic – temperatures can vary significantly over small spatial and temporal scales: Coincident data are required for validation



Schroeder *et al.*, 2008

Validating Active Fires: Data Requirements



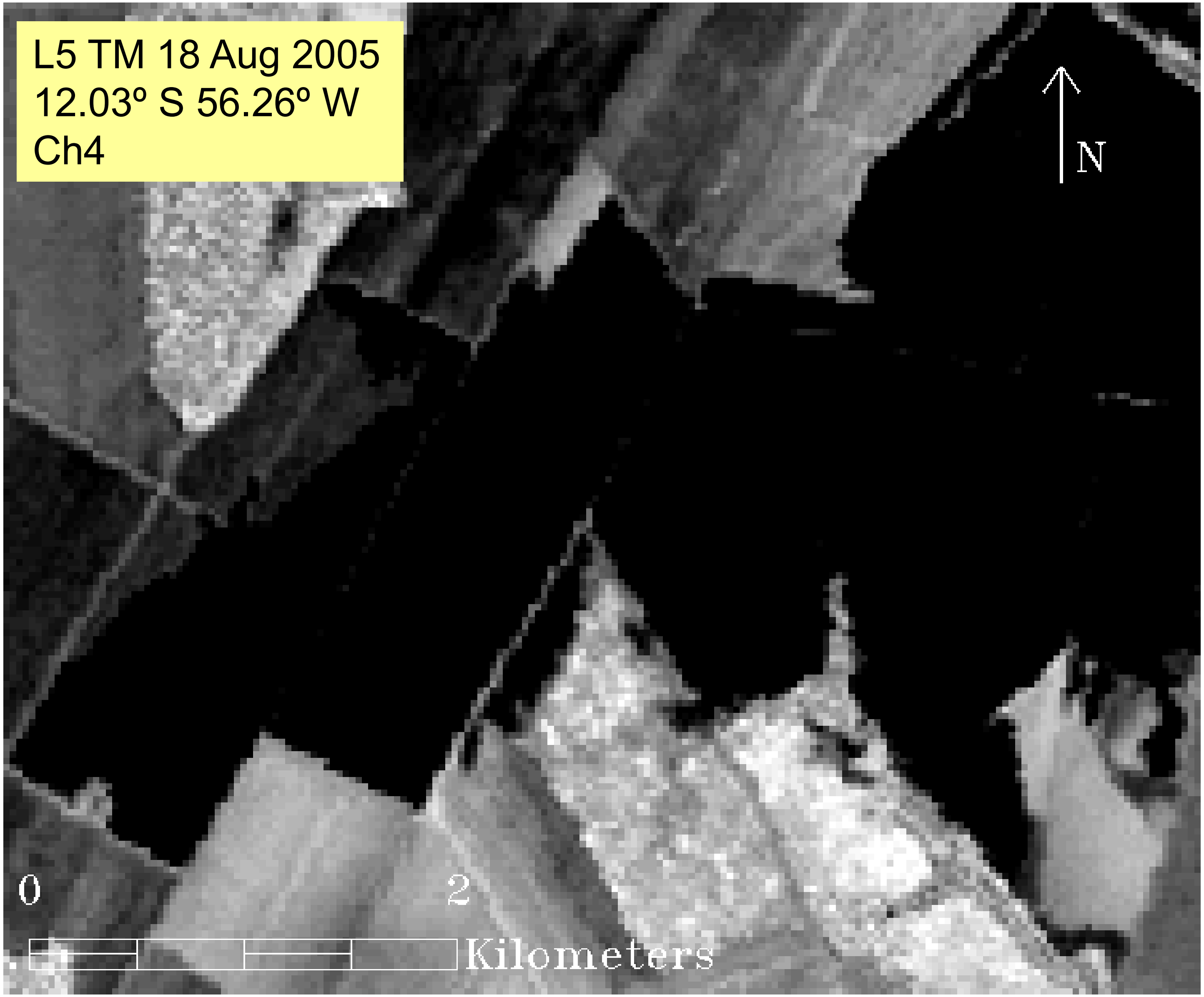
Landsat 5 TM Ch4 (0.76-0.90µm) 17 Jul 2005

Use of burnt area polygons as a reference for active fire validation can be misleading

Burnt Area

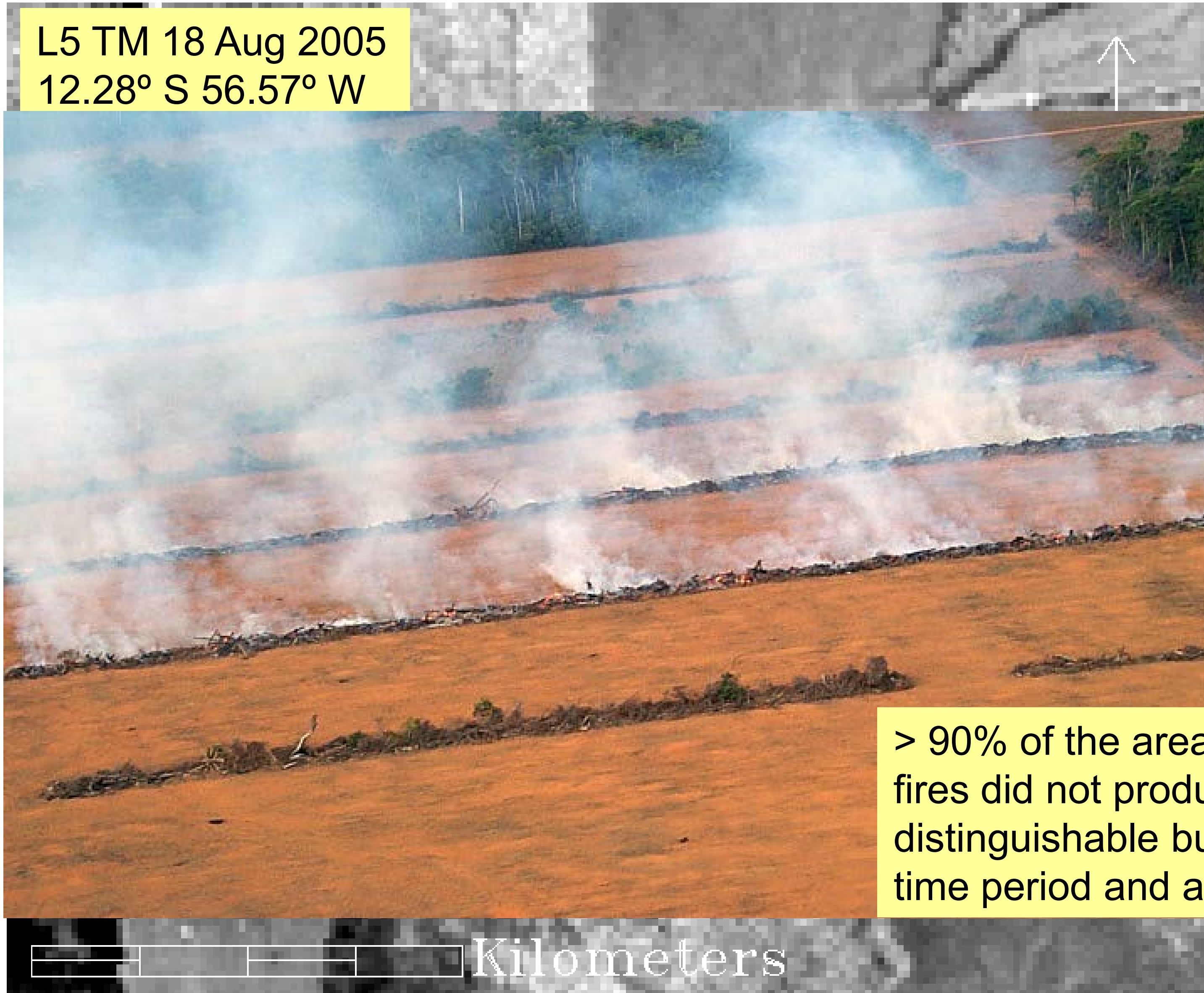
Active fire detection may occur without spatially coincident burn scar

The Case of Central Mato Grosso State in Brazilian Amazonia



Example of Free running head fire

The Case of Central Mato Grosso State in Brazilian Amazonia

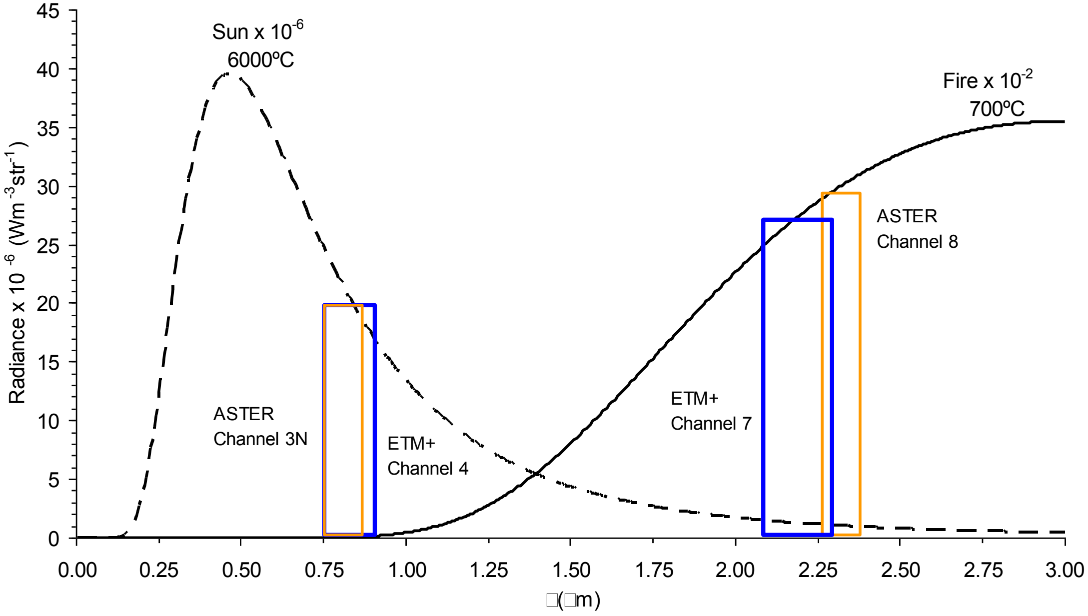


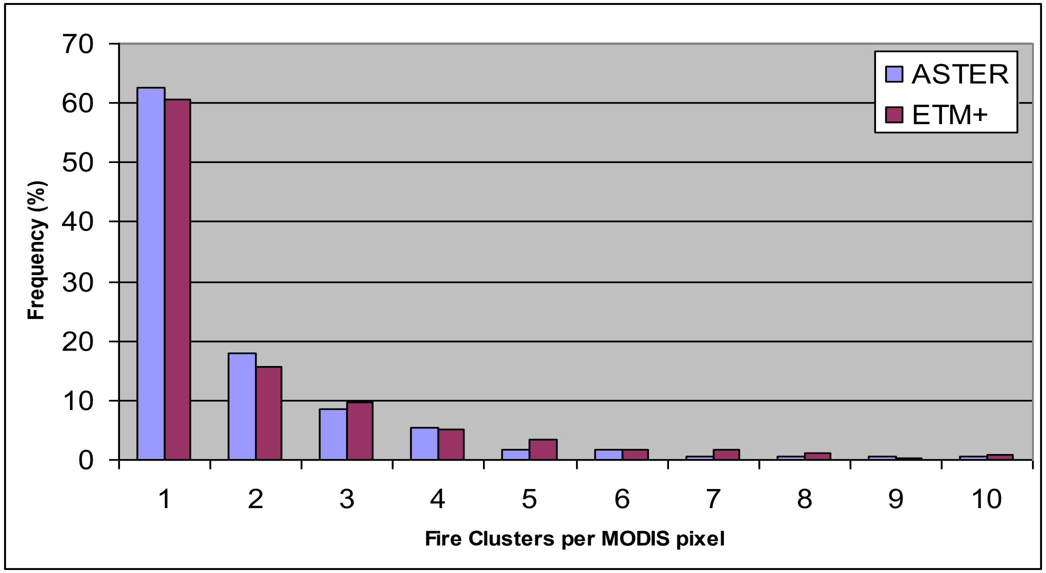
Example of piled debri burning

> 90% of the areas with active fires did not produce a distinguishable burn scar for the time period and area analyzed

Generating coincident fine resolution active fire reference data from ASTER and ETM+

ASTER bands 3 and 8 and ETM+ bands 4 and 7

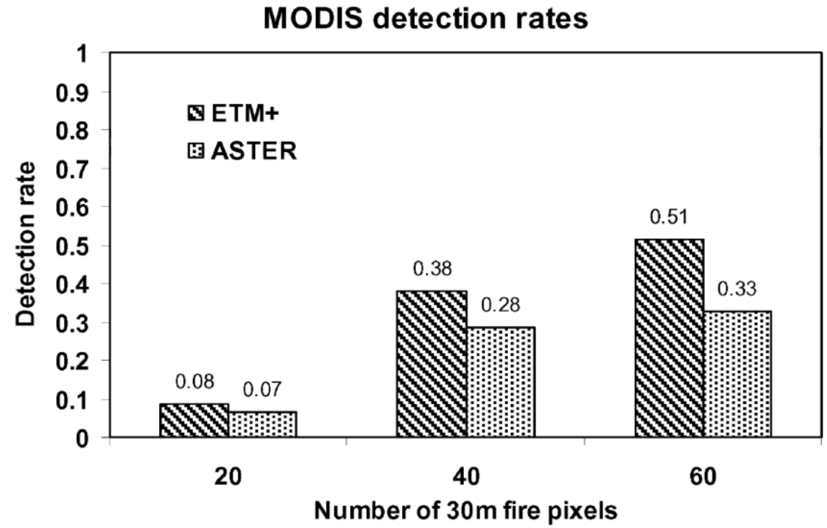


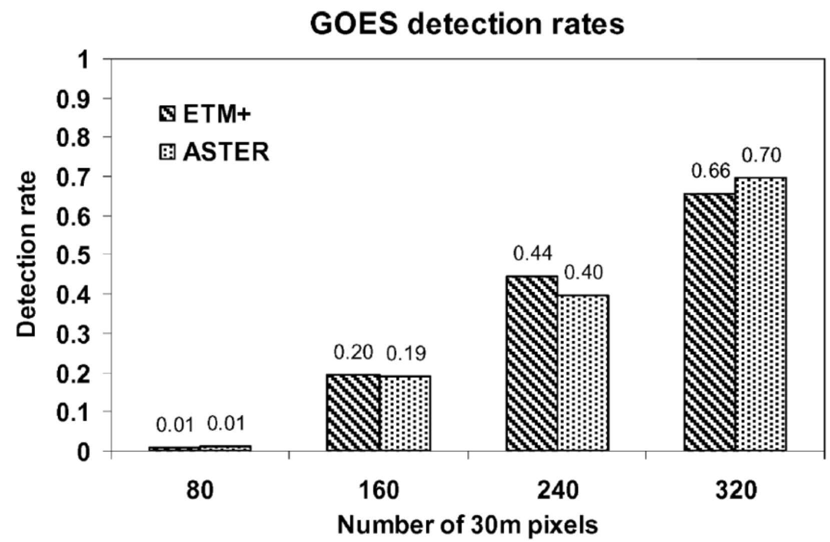


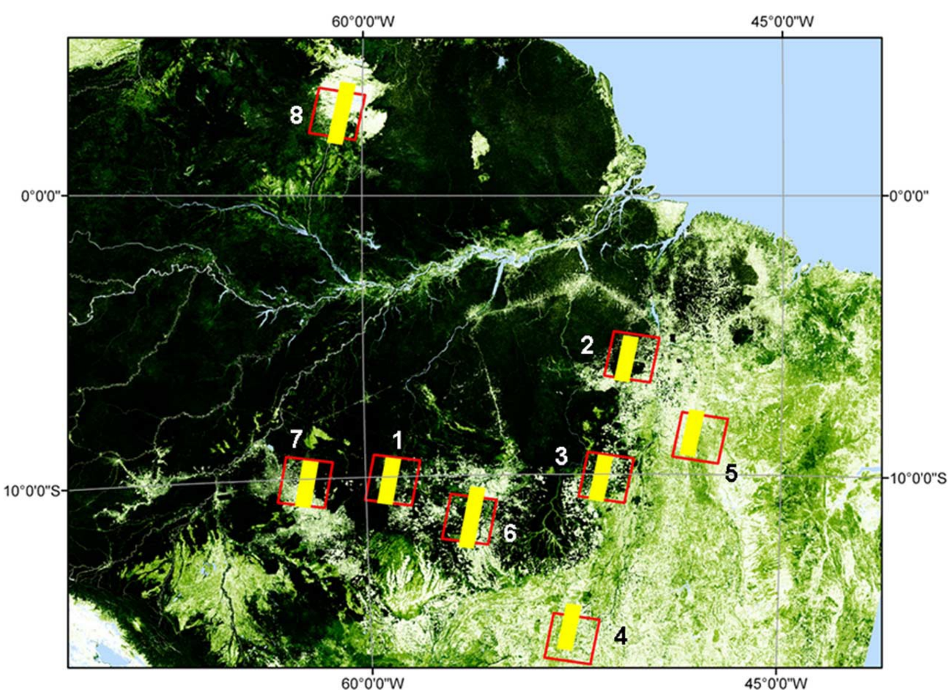
Developing Active Fire Validation Protocols

Use of same-day ETM+ and ASTER (30min apart) to evaluate near-coincident GOES and MODIS probability of detection

Max 15min separation allowed – larger temporal window will result in artificial increase/decrease in probability of detection calculated





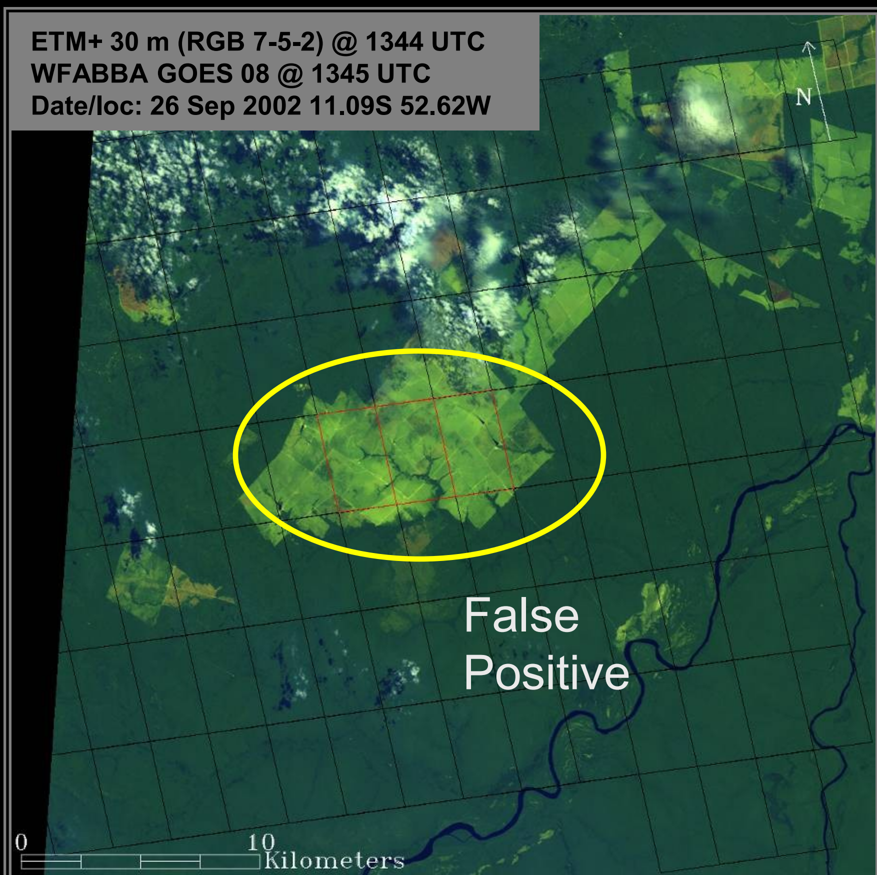


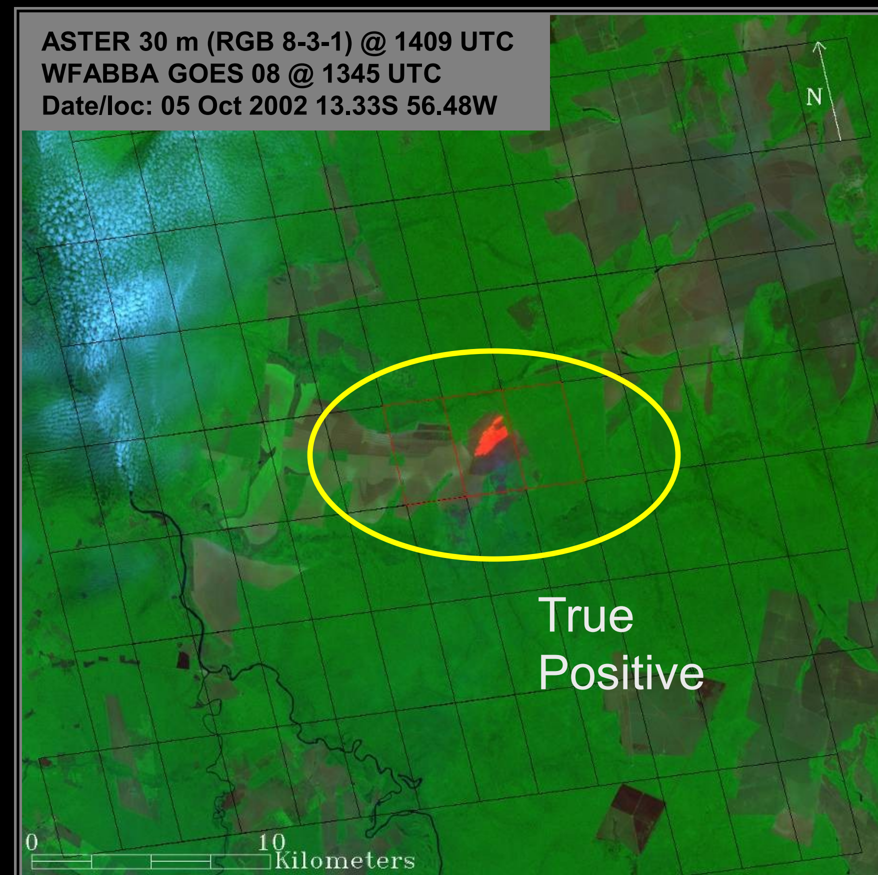
Csiszar and Schroeder, 2008

Validating GOES and MODIS Active Fire Detection Products Using ASTER and ETM+ Data

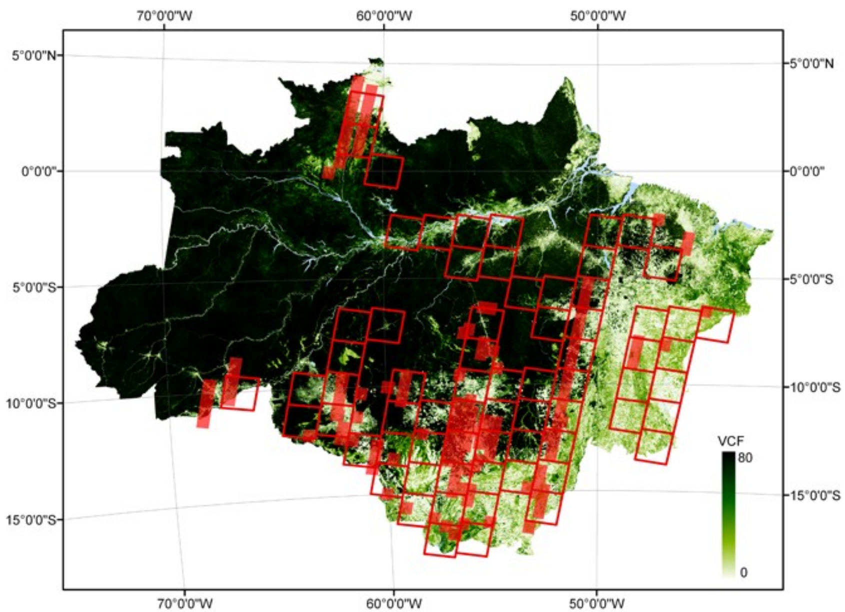
Constrain acquisition to within 15min difference between sensors to reduce short term variations in fire conditions

Commission and omission errors are derived using fire summary statistics from 30m masks





Regional Validation Studies



Used 280 ASTER and ETM+ scenes to validate MODIS and GOES over Amazonia

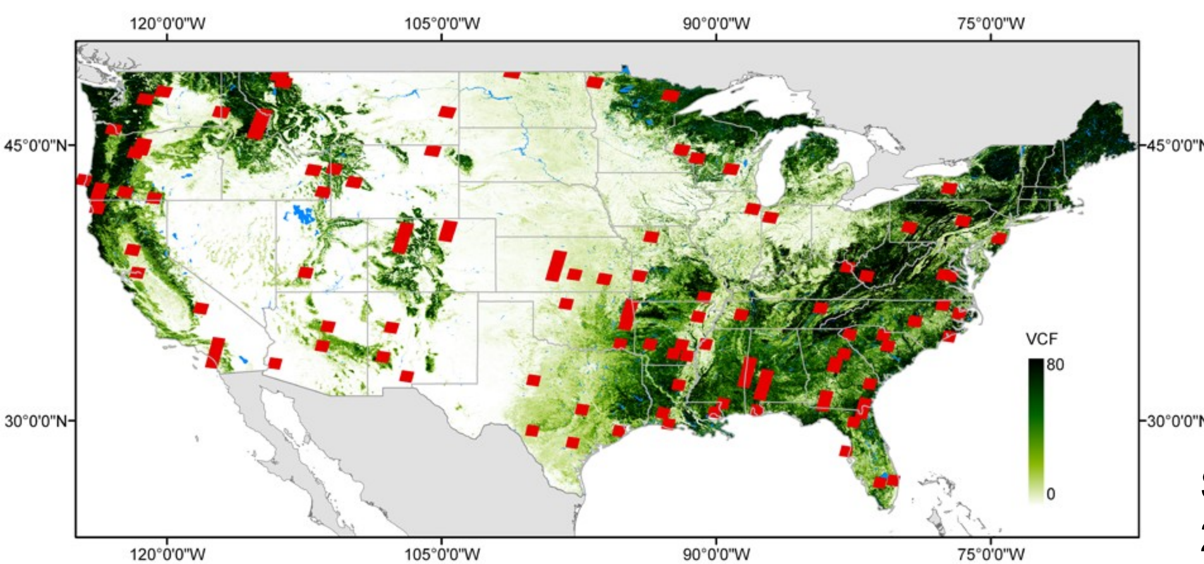
Schroeder *et al*., 2008a

Other studies include:

Morisette *et al*., 2005

Csiszar *et al*., 2006

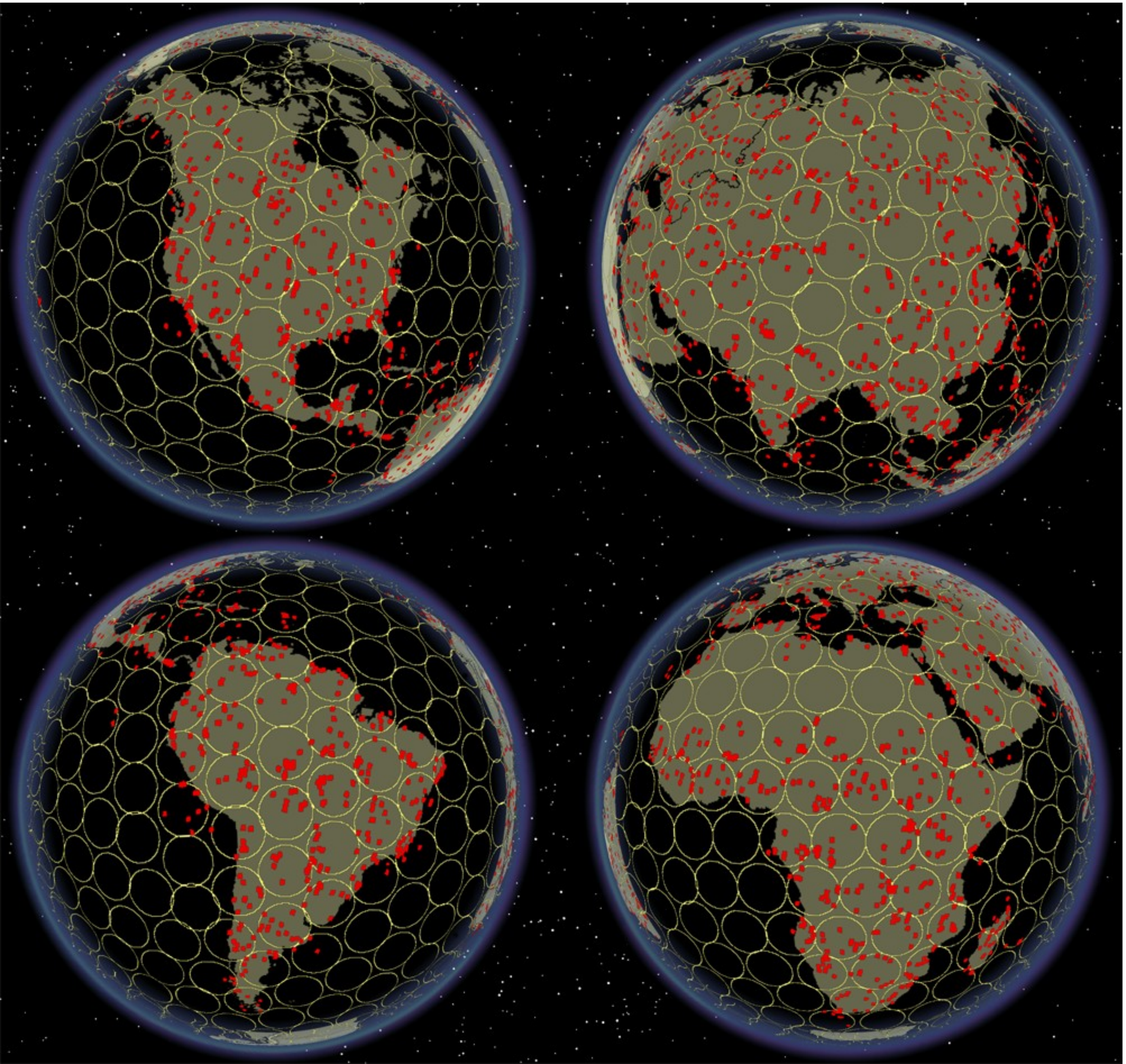
Giglio *et al*., 2008



Used 115 ASTER scenes to validate NOAA's Hazard Mapping System

Schroeder *et al*., 2008b

Global Validation of MOD14 (Stage 3)



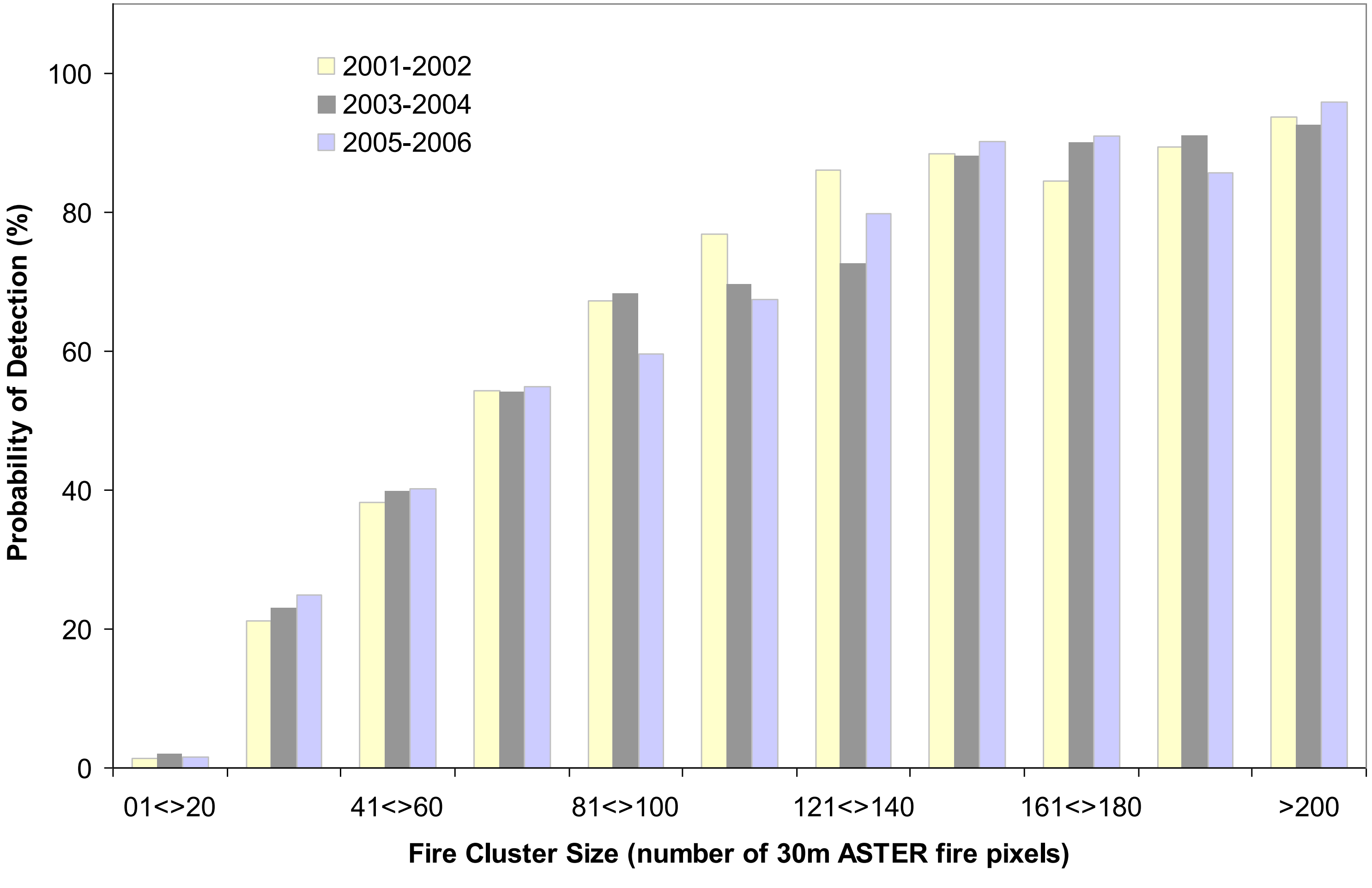
- 2,500 ASTER scenes
- 2001-2006
- Daytime & Nighttime data
- 16K MODIS fire pixels analyzed

Schroeder *et al*. (in preparation)

Validation Results – Binary Product (MOD14)

Temporal Consistency of Detection Performance

Subset of points covering the range of 20-40% tree cover
No statistically significant difference over time (i.e., $\Delta D_t = 0$; $p < 0.01$)

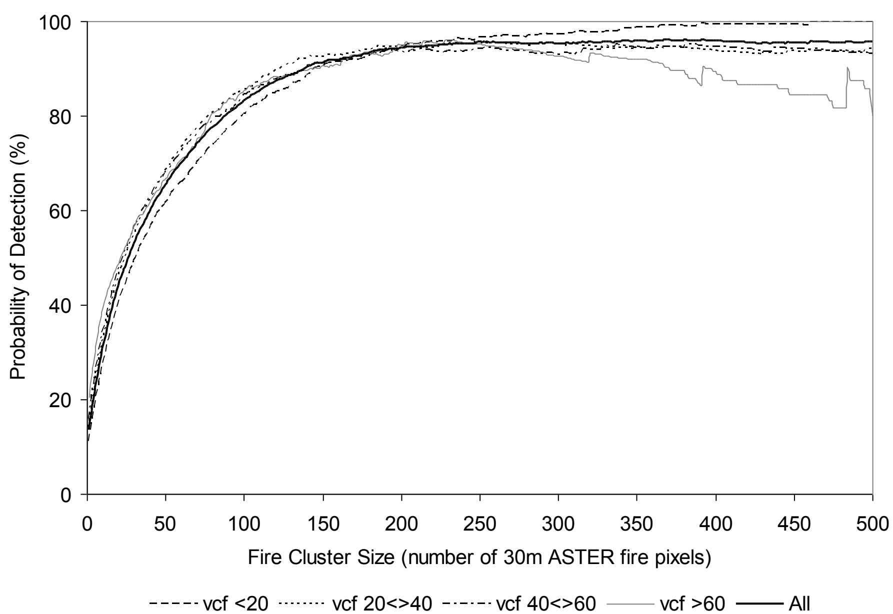


Validation Results – Binary Product (MOD14)

Probability of detection derived using summary statistics of ASTER active fire pixels found within the MODIS/Terra footprint.

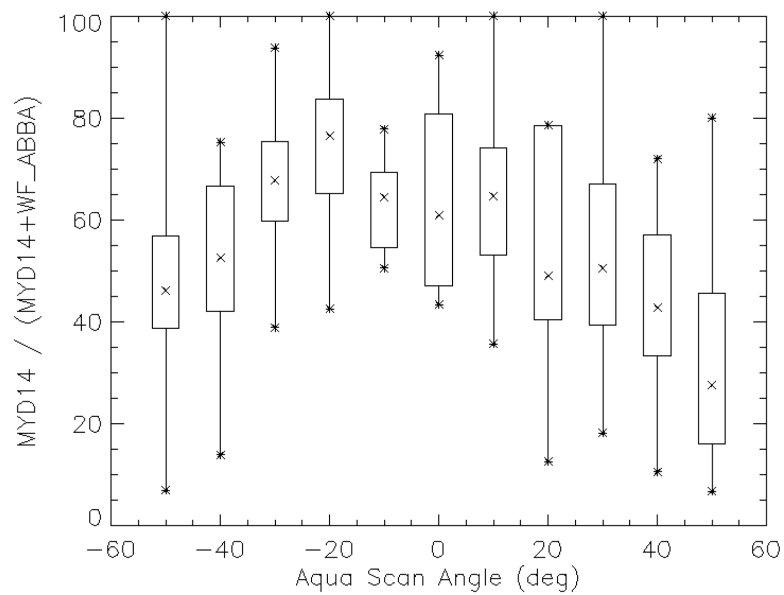
Probability of detection

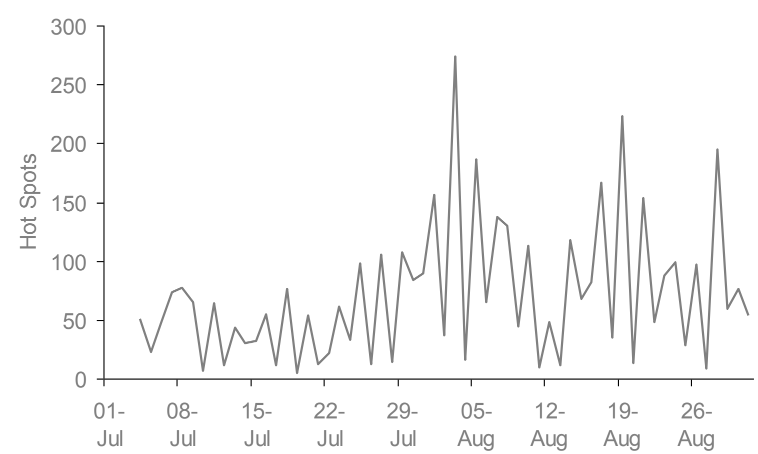
~10% difference in probability of detection for small-to-intermediate fires (1-100 ASTER fire pixels) detected in low and high percent tree cover (TC) regions



Schroeder *et al*. (in preparation)

Effects of Viewing Geometry

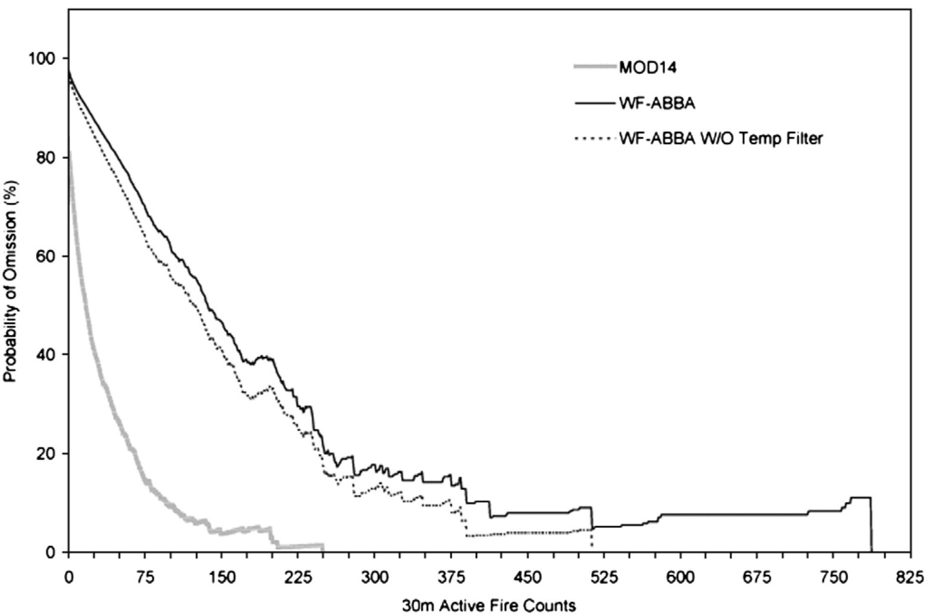




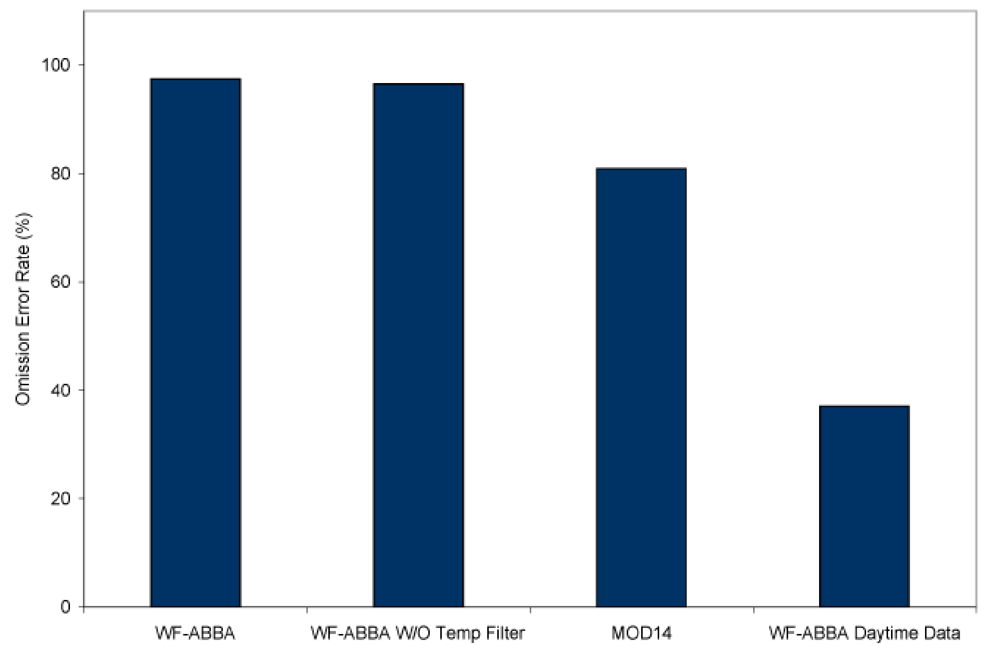
Validation Results – Binary Product (WF_ABBA)

Probability of omission derived using summary statistics of ASTER active fire pixels found within the GOES Imager footprint.

Comparison with MODIS Terra using instantaneous GOES imager data (~10:30am local)



WF_ABBA product benefits from fire diurnal cycle resulting in significantly fewer fires being omitted at the end of the day



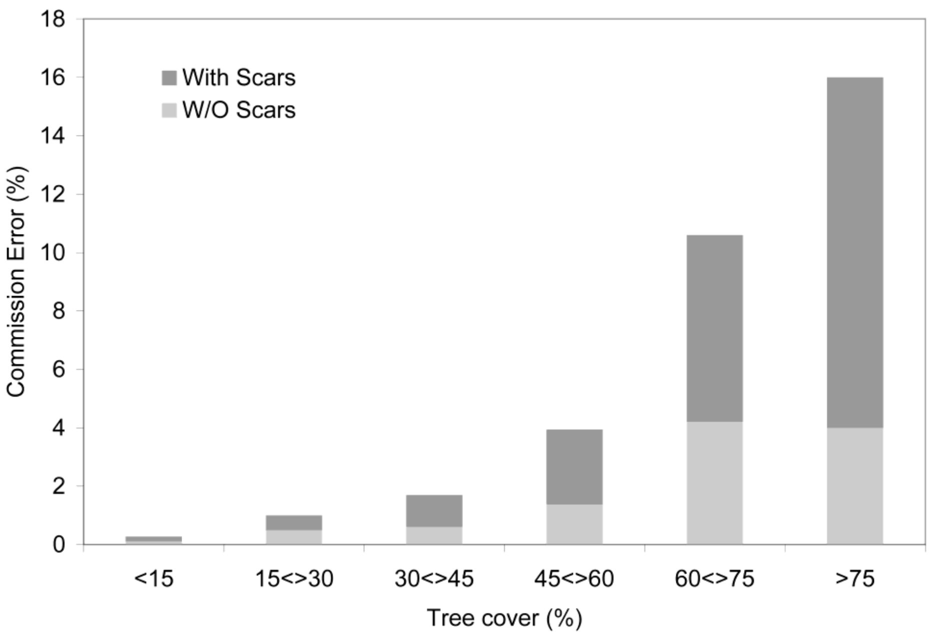
Results – Commission Errors (MOD14 & WF_ABBA)

MOD14 and WF_ABBA fire pixels without coincident ASTER (ETM+) fire activity

Recently burned pixels with discernable scars constitute a large fraction of the false detections. Overall fire-unrelated commission error ~2%

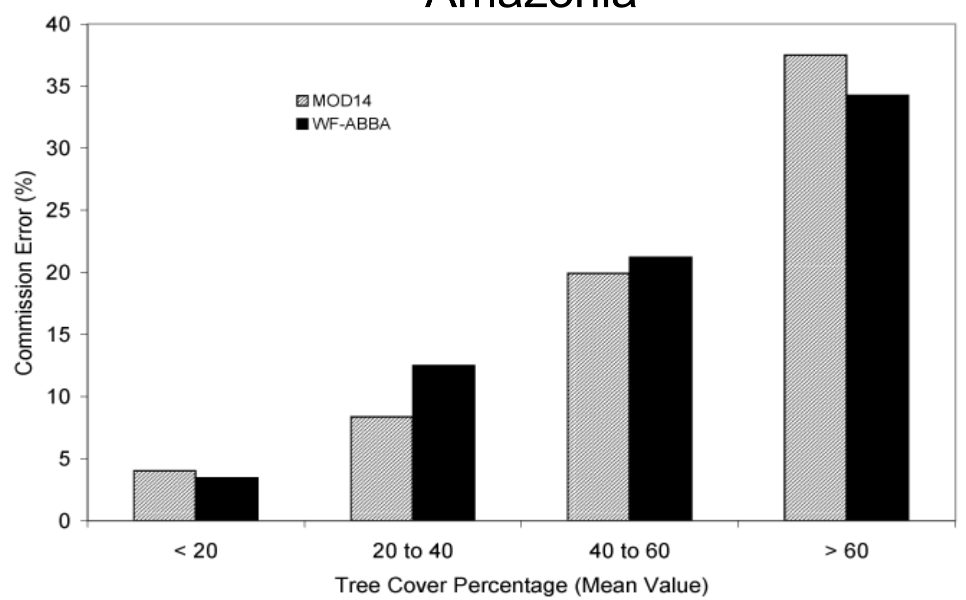
Nighttime commission error rate is zero.

MOD14 Global Validation



Schroeder *et al*. (in preparation)

MOD14 & WF_ABBA
Amazonia



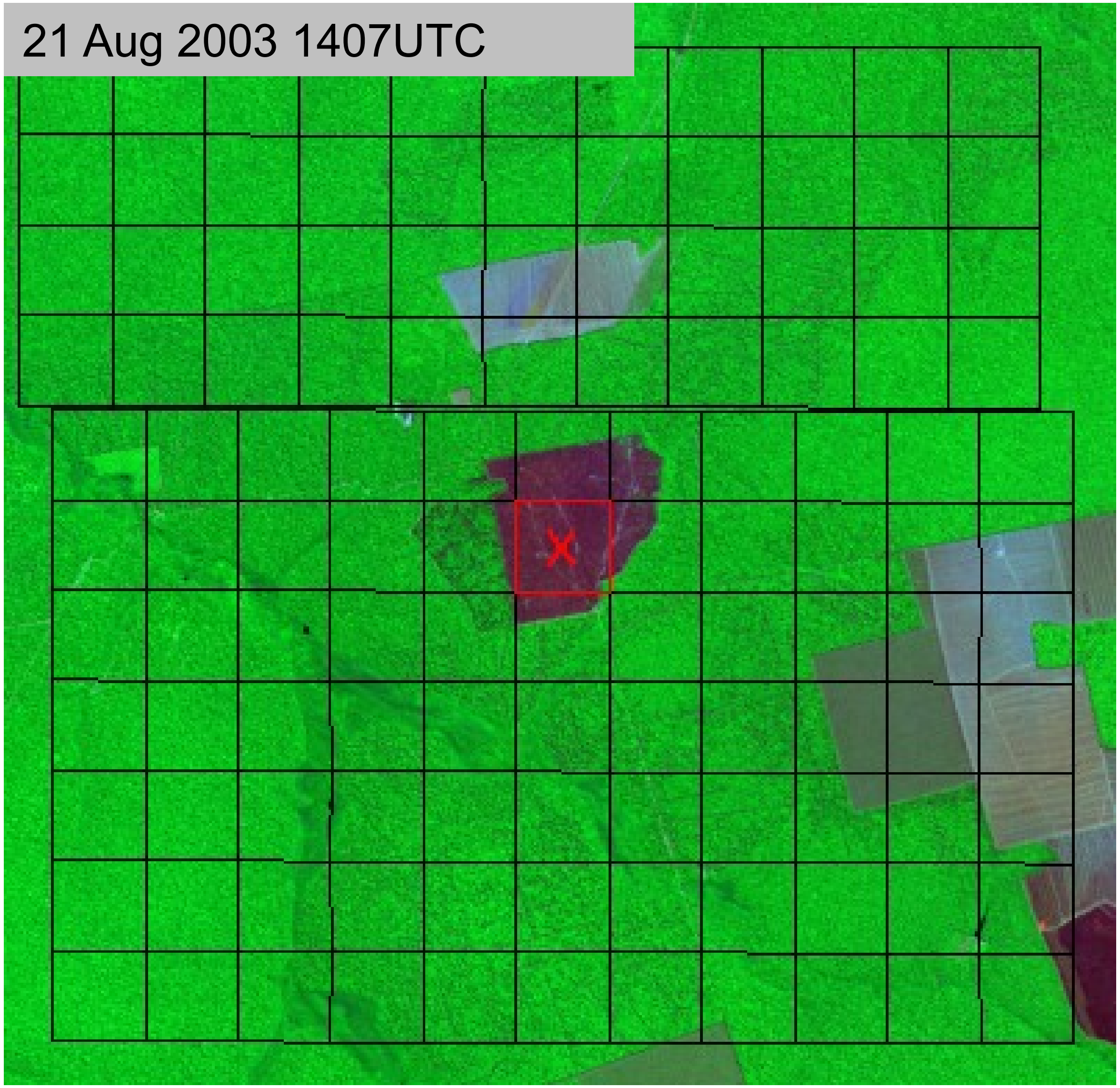
(Schroeder et al., 2008b)

Results – Commission Errors

Typical false alarm in MOD14 data

Commission errors can occur multiple times at the same location

MODIS/Terra was found to detect twice as many false positives as MODIS/Aqua



Results – Commission Errors

Tracking commission errors over time using multi-temporal GOES data

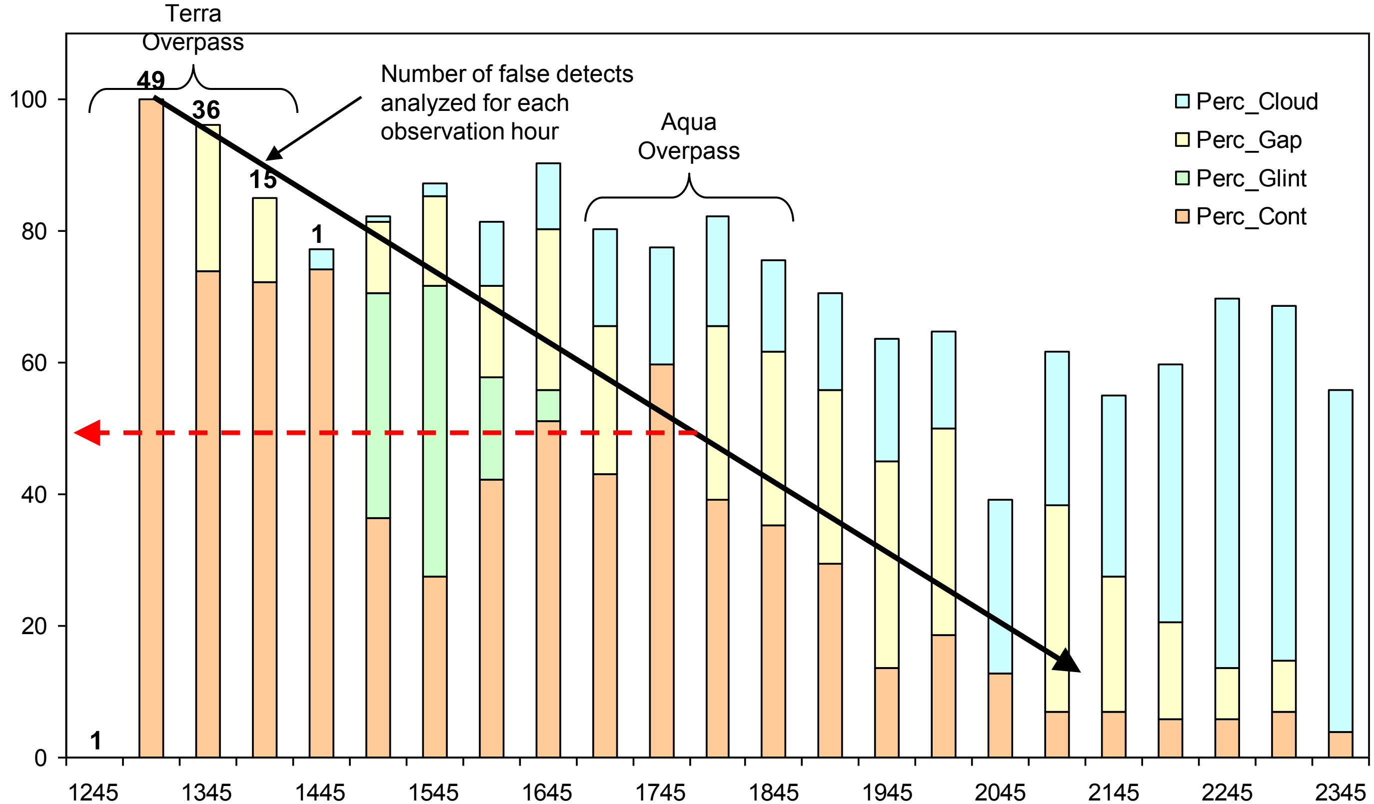
Mid afternoon surface heating doesn't appear to sustain nor increase commission errors observed during morning hours

• perc_cloud = cloud coverage impeding surface observation

• perc_gap = image gaps due to rapid scan operation

• perc_glint = potential omission due to sun glint mask

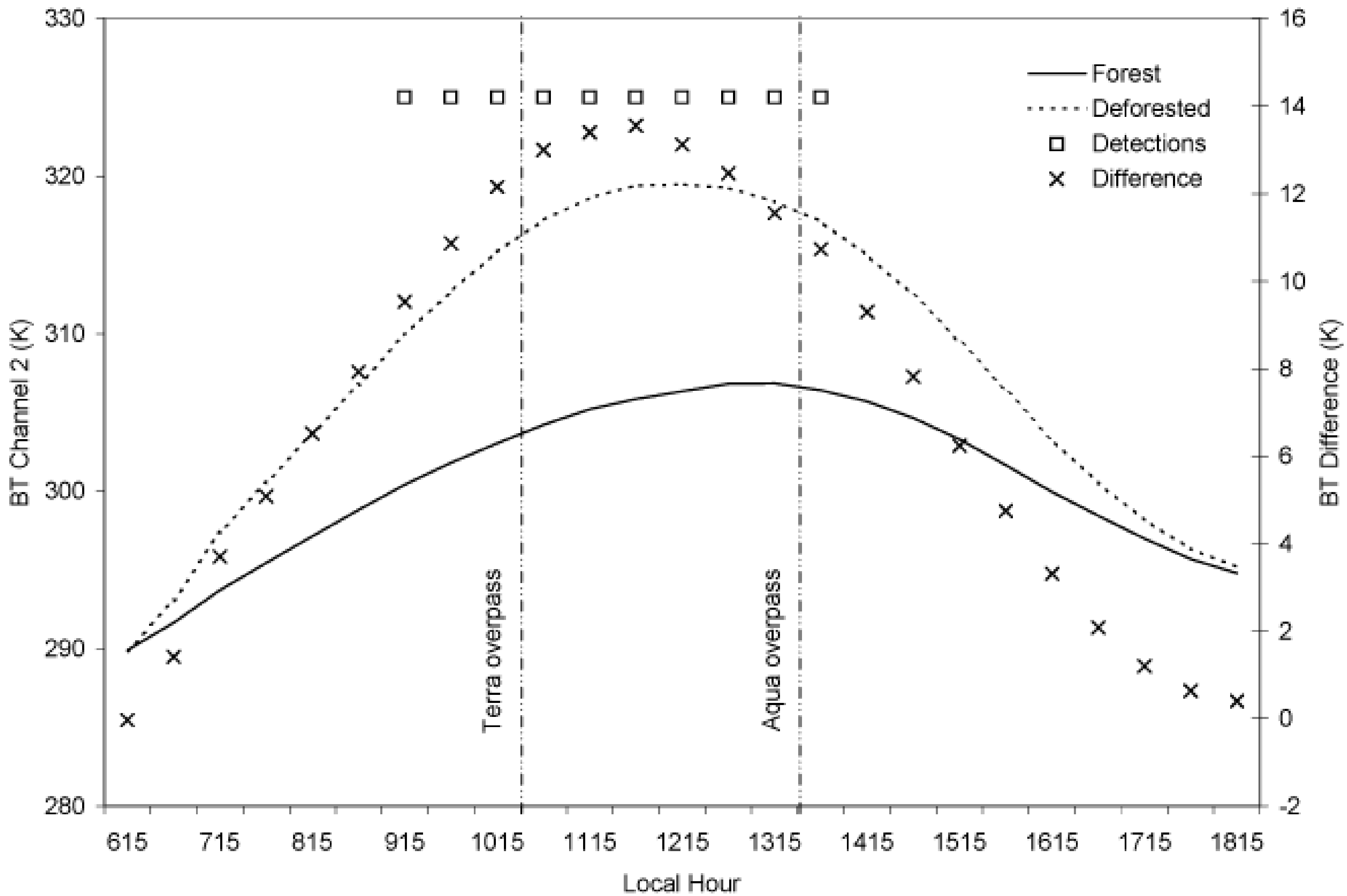
• perc_cont = the percentage of false detects from the previous hours that remained in the data



Schroeder *et al.*, 2008

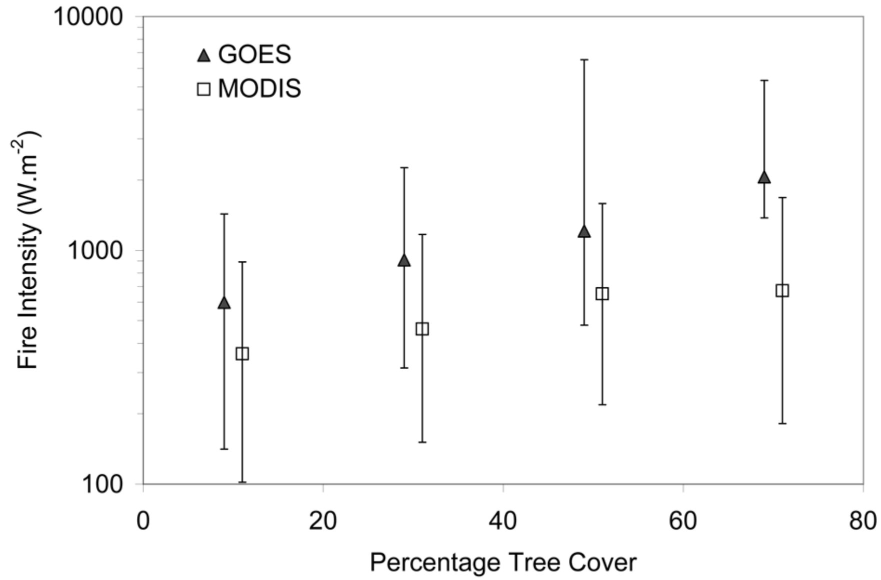
Results – Commission Errors

→ Delayed daily temperature cycle of forested areas causing peak of maximum temperature contrast with deforested areas to move closer to local noon



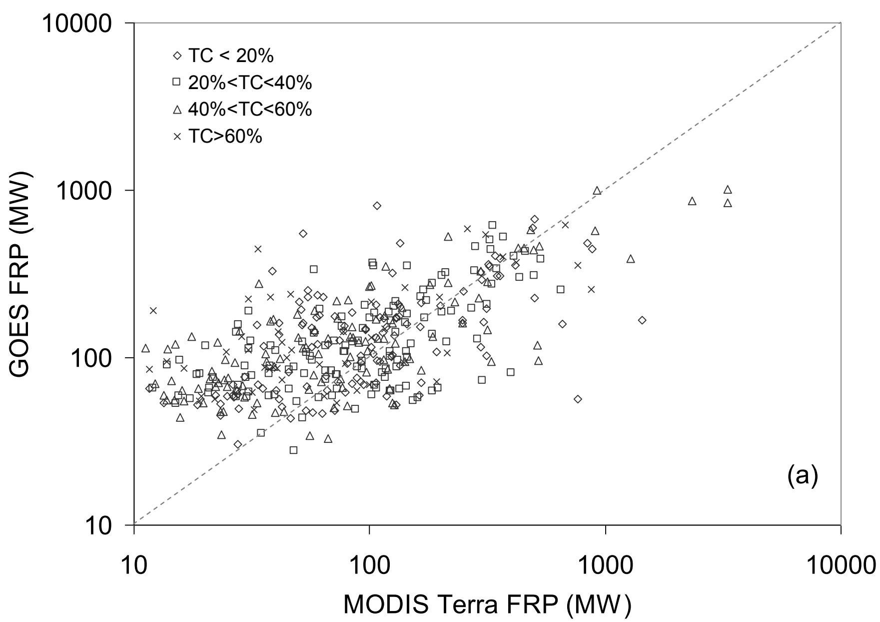
Schroeder *et al.*, 2008

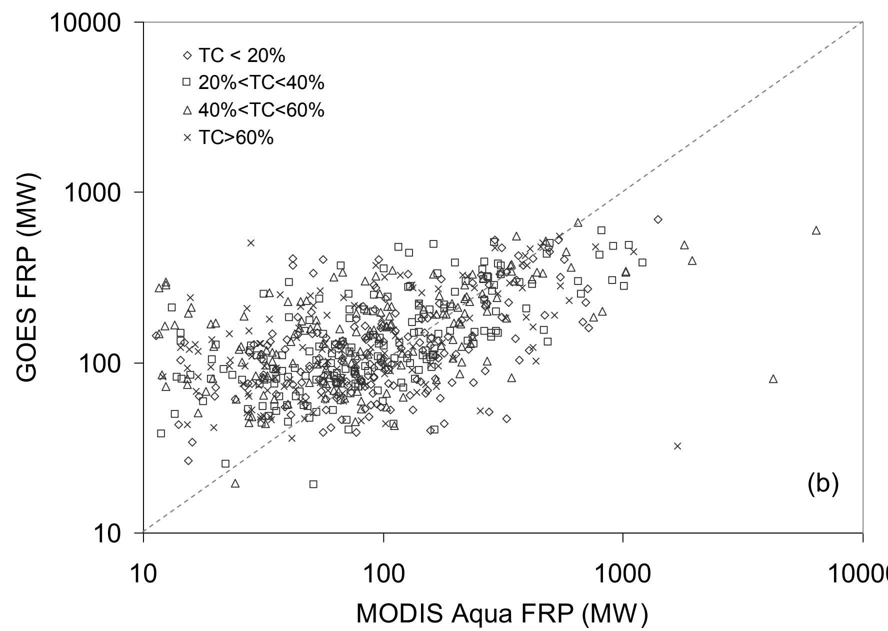
Assessment of Fire Characterization Data from GOES and MODIS (FRP)



Fire Radiative Power (FRP) correlates well with total biomass consumed during combustion – satellite derived estimates remain involved in large uncertainty

(PSF, omission, atmosphere, background)



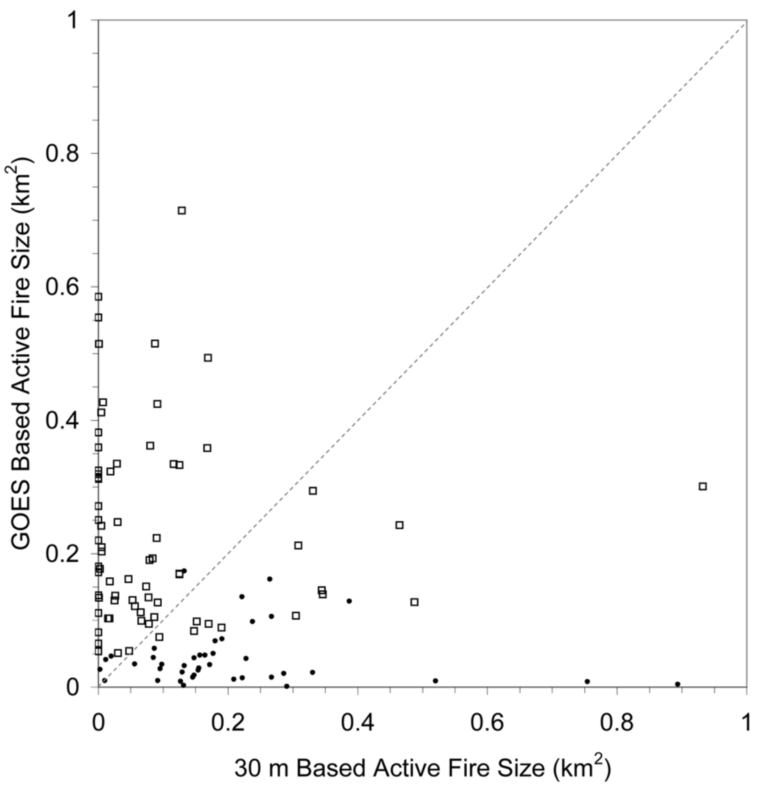


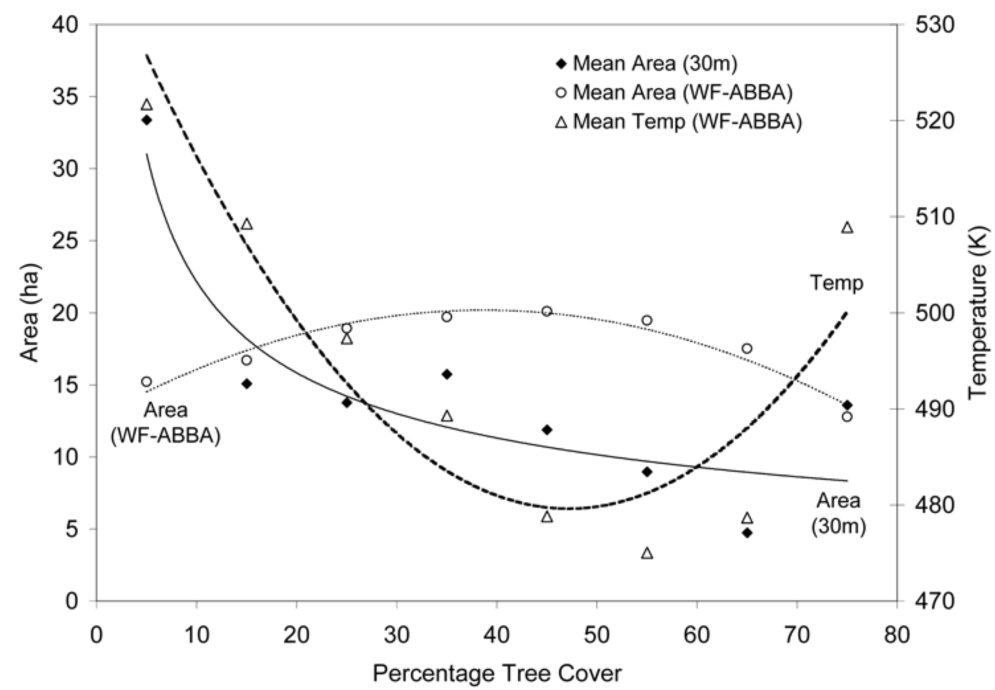
Schroeder *et al.*, in press

Assessment of Fire Characterization Data from GOES (fire size & temperature)

Comparison of GOES fire size to ASTER and ETM+ 30m active fire masks suggesting large and variable errors

GOES fire temperature estimates do not agree with ground reference data and validation results (densely vegetated areas should show higher fire temperatures)

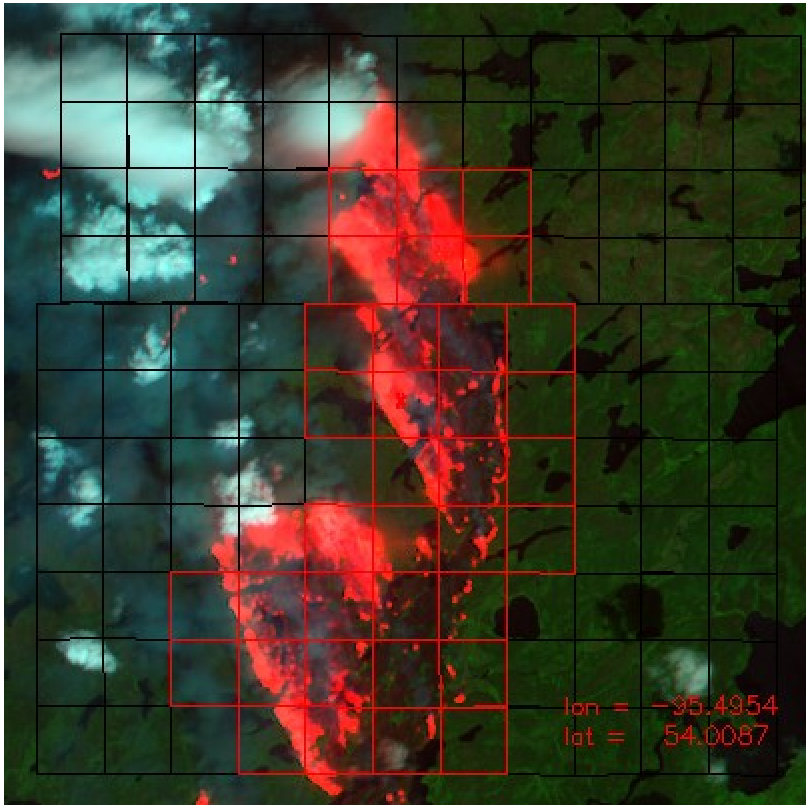


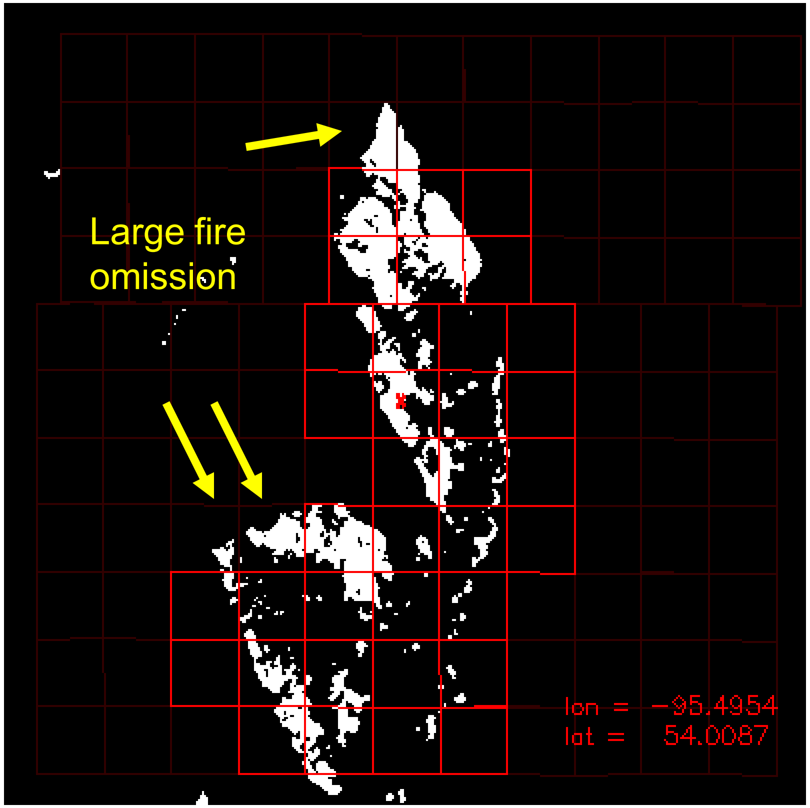


Schroeder *et al.*, in press

MODIS Algorithm Development

Further algorithm improvement is being performed using cases representing omission and commission errors that were not resolved by the current MOD14 Collection 5 product.



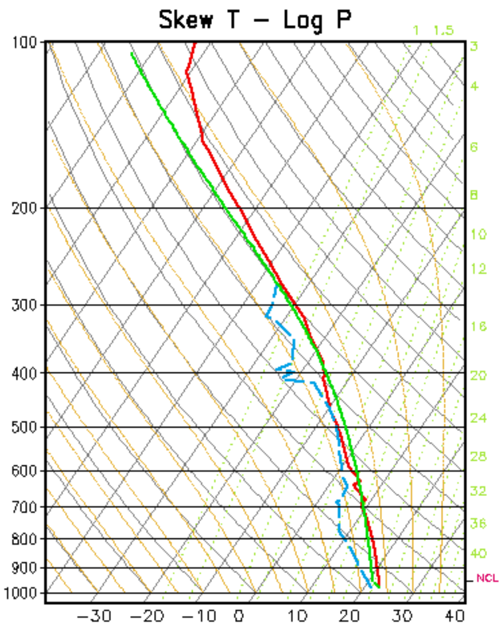


21 June 2003 1738UTC

Background: (left) ASTER RGB (8-3-1) (right) ASTER fire mask

Grid: MODIS nominal (1km) pixel grid – MOD14 fire pixels highlighted in red

Early Assessment of NPOESS/VIIRS and GOES-R/ABI Active Fire Detection Products



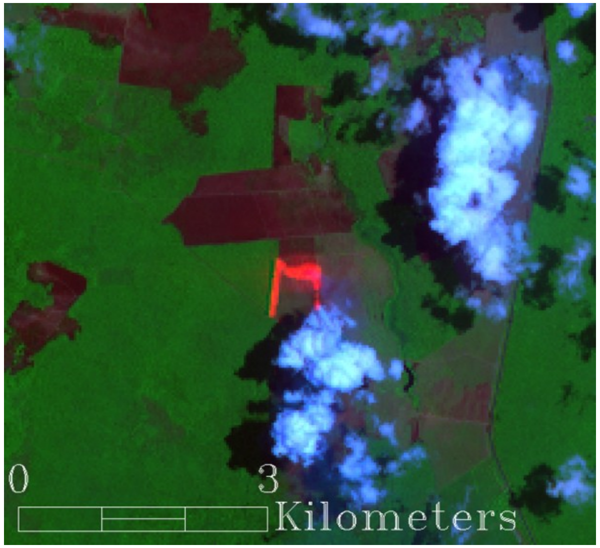
Fire Pixel Radiance =

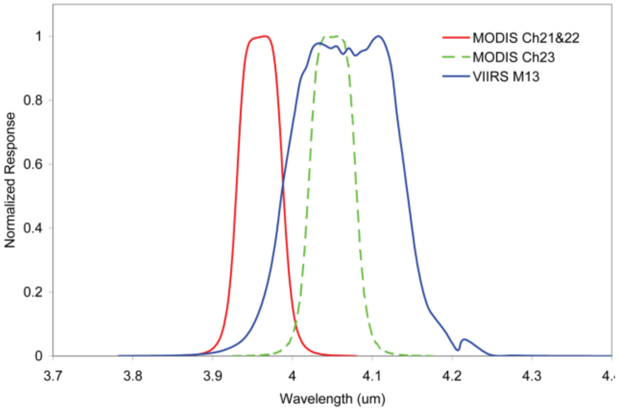
[ASTER Sfc Temp,

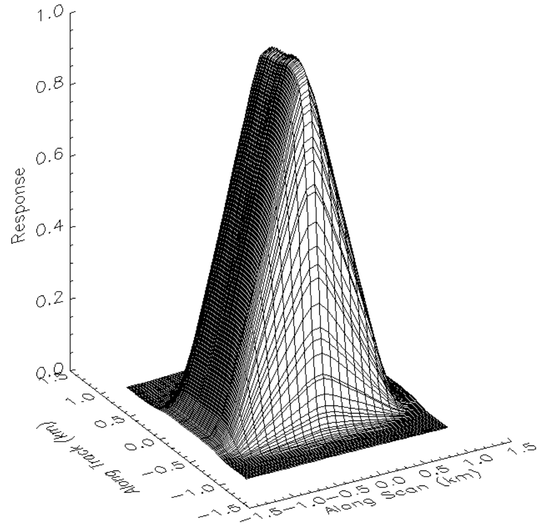
ASTER Fire Mask,

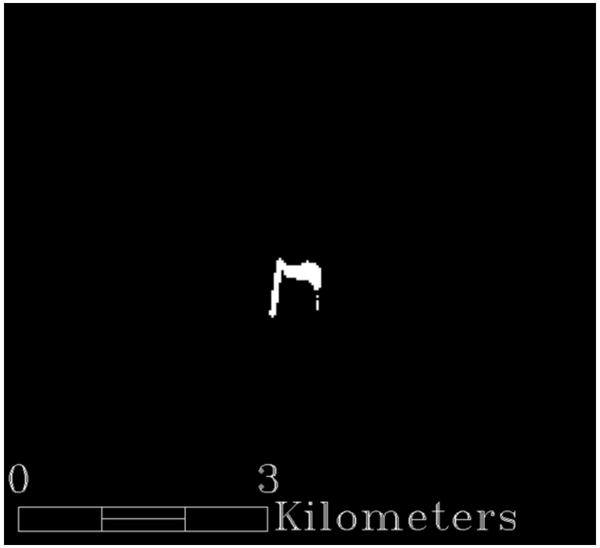
Sensor's PSF + SRF,

(Atm + Solar)]



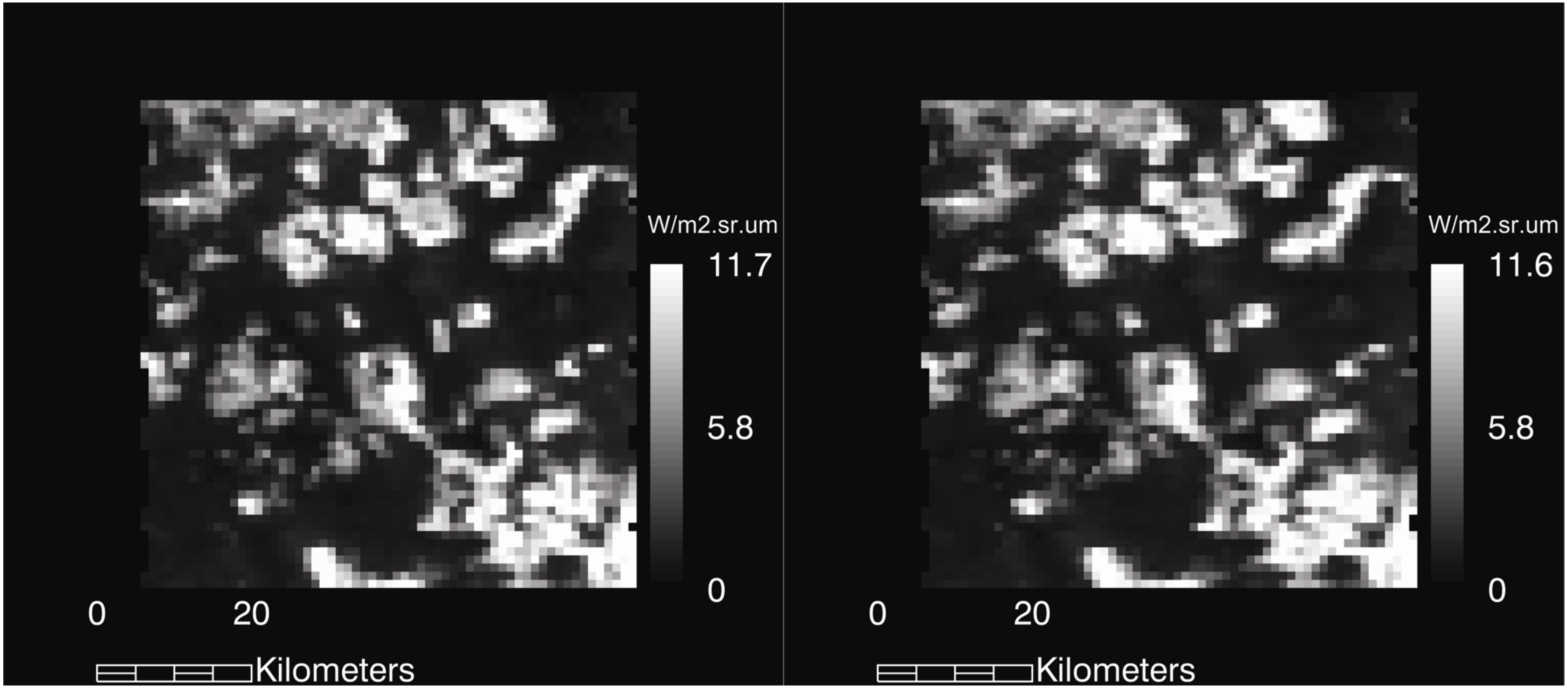






Early Assessment of NPOESS/VIIRS and GOES-R/ABI Active Fire Detection Products

TIR – Initial Tests: Deriving MODIS L1B TOA Radiances using ASTER Channels 13&14

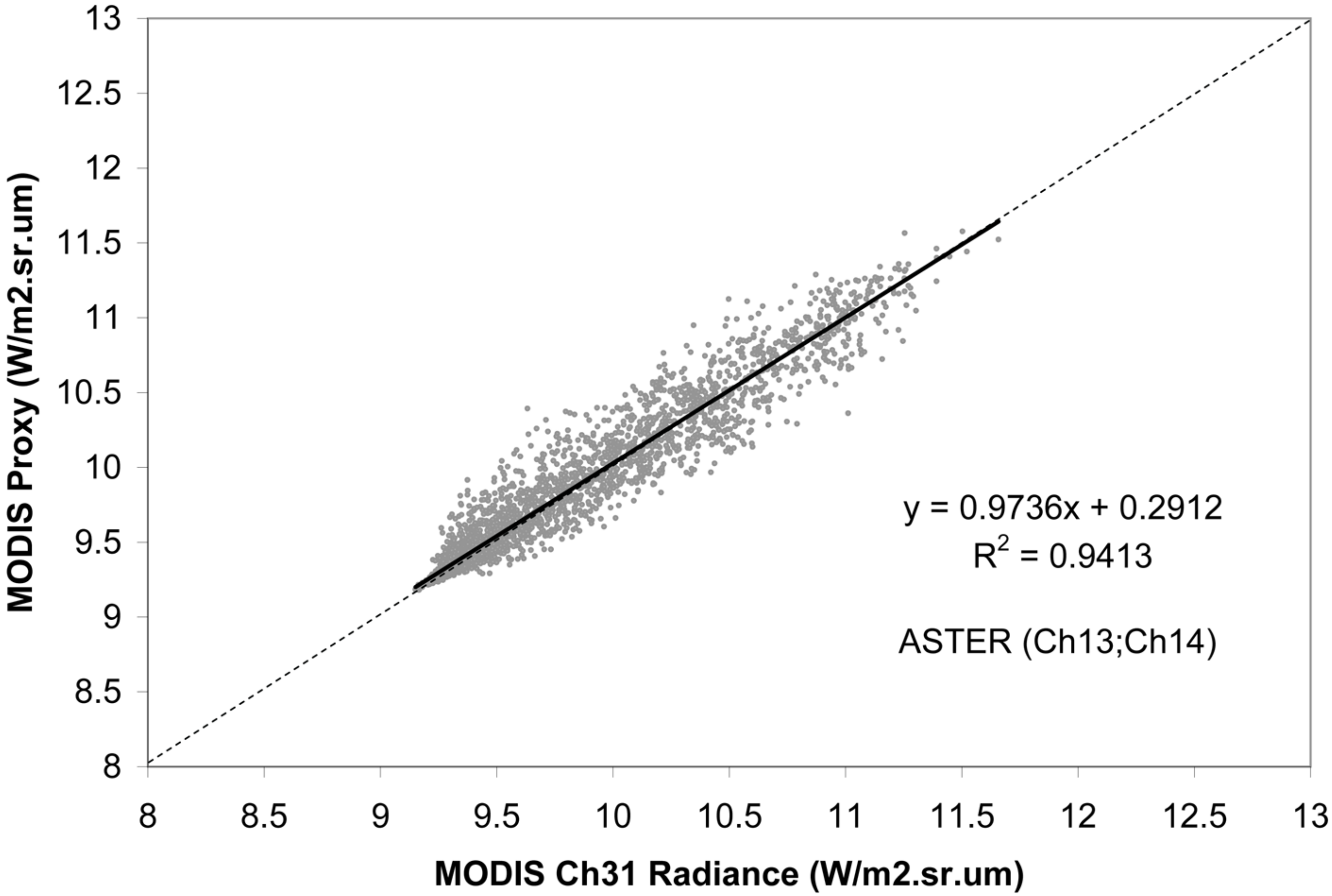


MODIS L1B Ch31
07 Aug 2004 1405 UTC
11.7º S 56.6º W

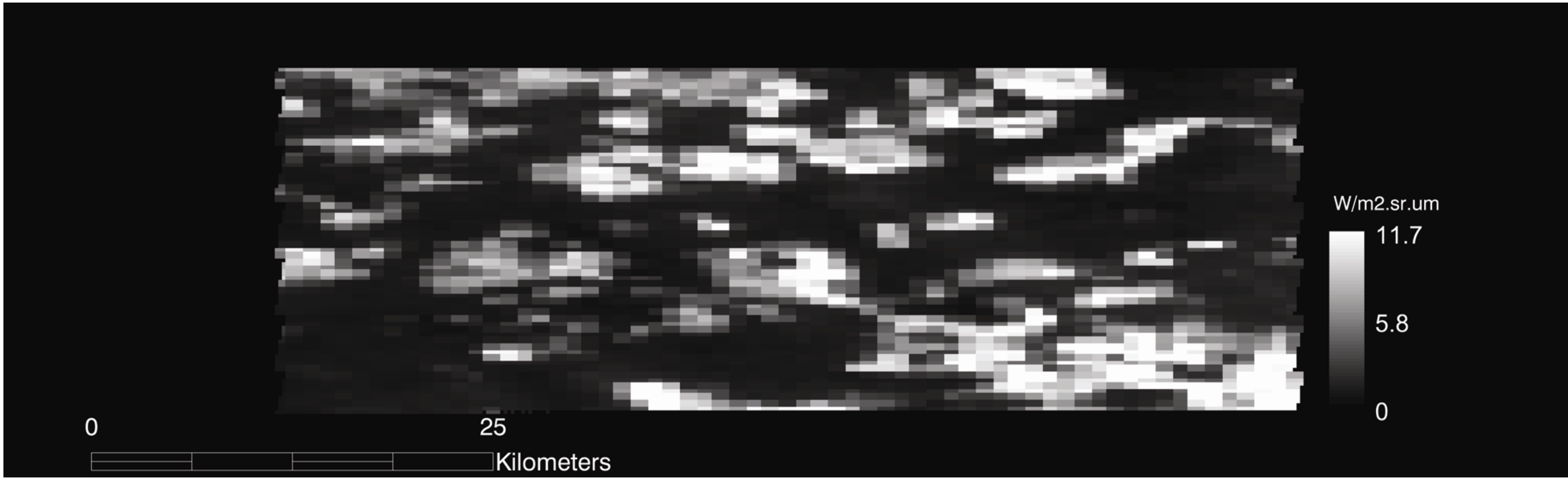
UMD MODIS Ch31 Proxy Data
07 Aug 2004 1405 UTC
11.7º S 56.6º W

Early Assessment of NPOESS/VIIRS and GOES-R/ABI Active Fire Detection Products

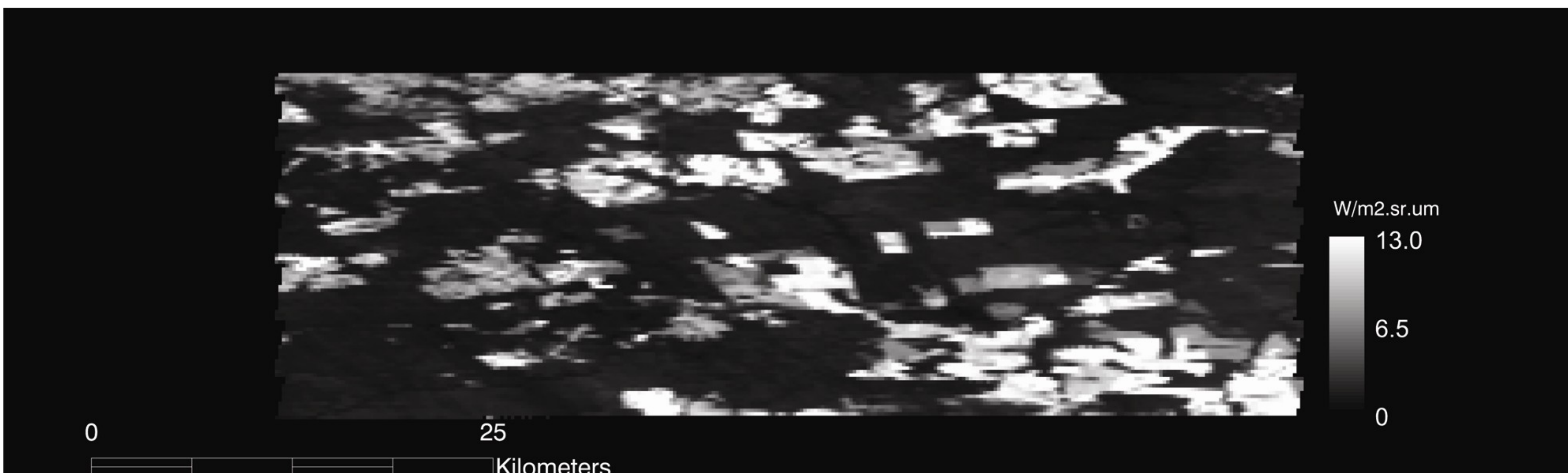
TIR – Initial Tests: Deriving MODIS L1B TOA Radiances using ASTER Channels 13&14



TIR – Deriving VIIRS M15 TOA Radiances using ASTER Channel 13

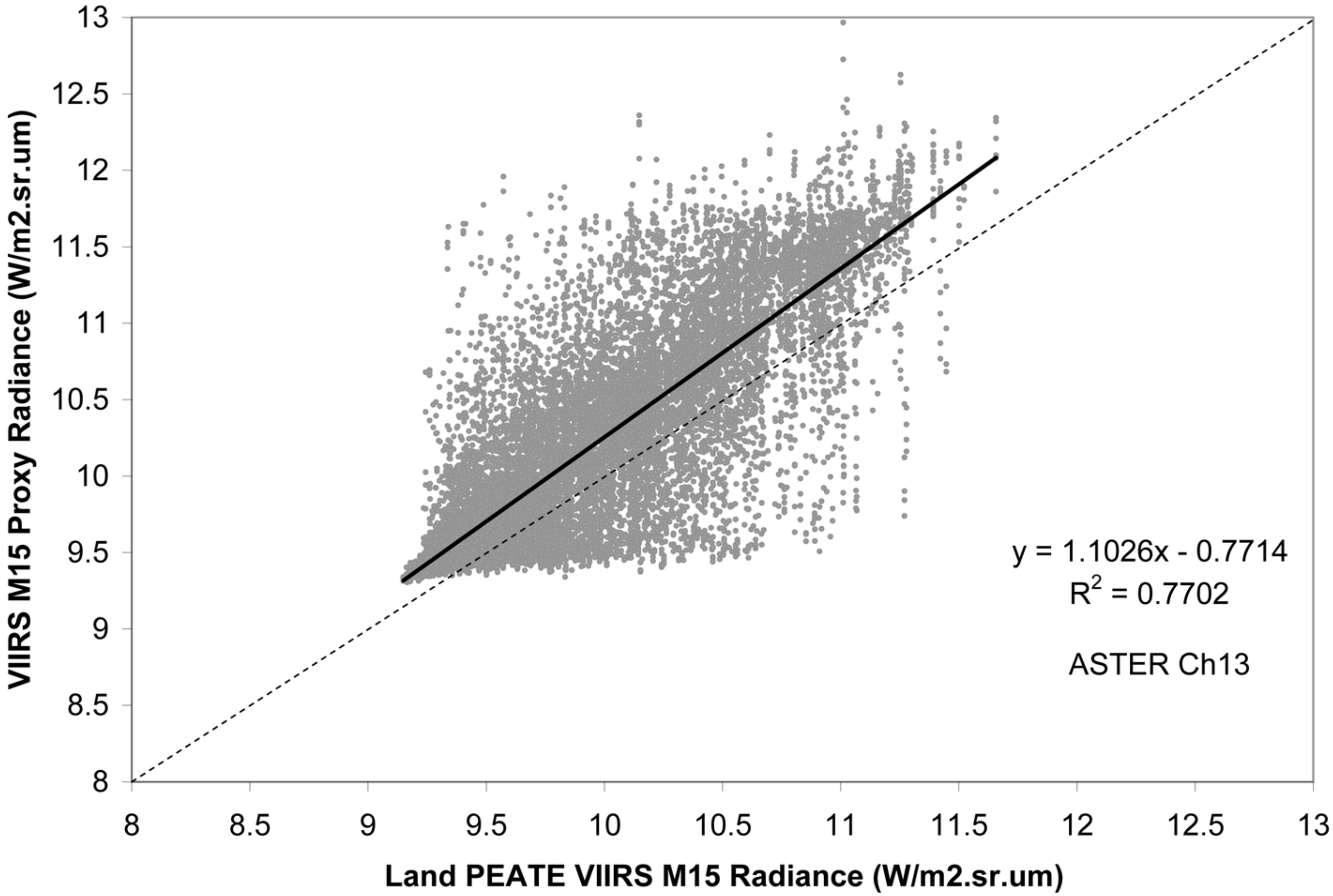


Land PEATE VIIRS M15 Proxy



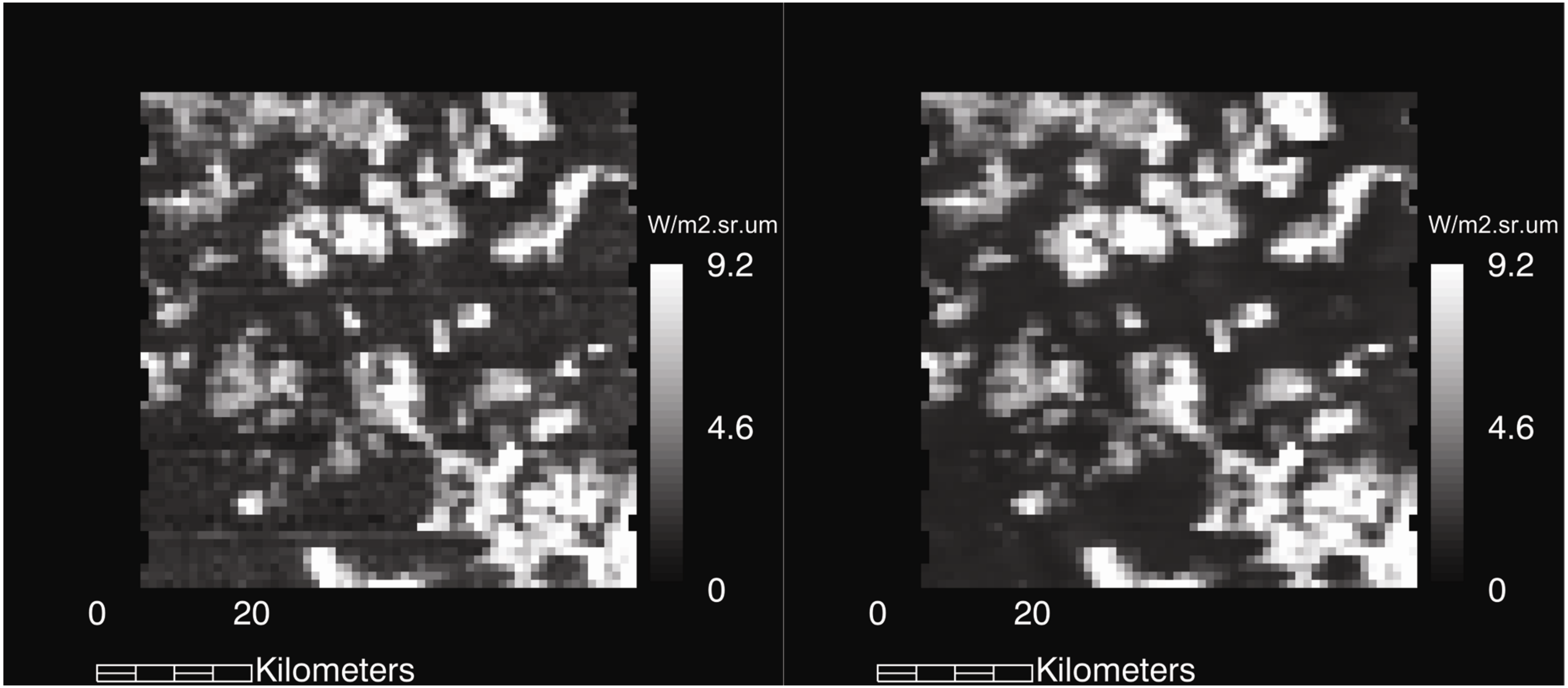
UMD VIIRS M15 Proxy

TIR – Deriving VIIRS M15 TOA Radiances using ASTER Channel 13



MIR – Initial Tests:

Deriving MODIS L1B TOA Radiances using ASTER Surface Kinetic Temperature data

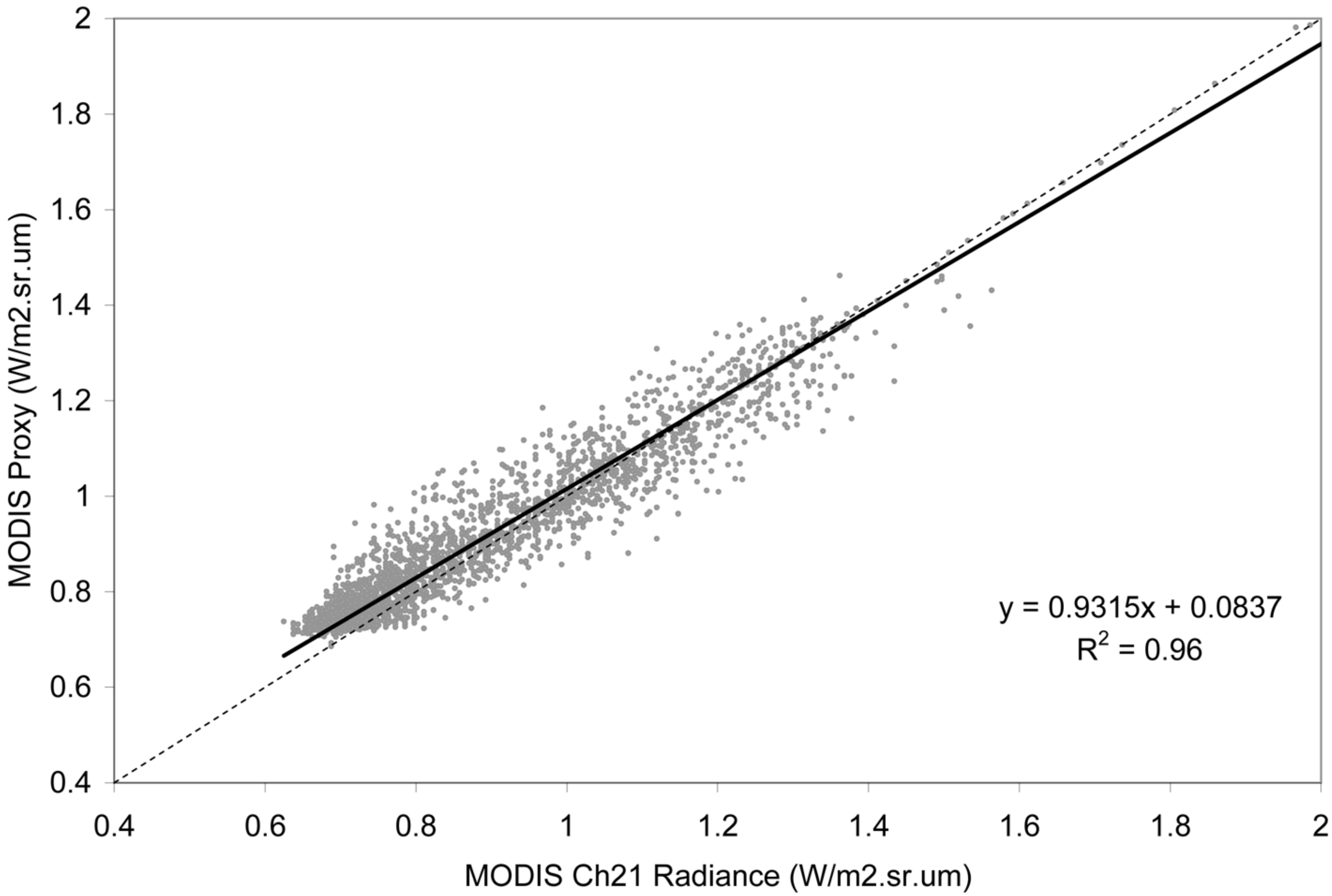


MODIS L1B Ch21
07 Aug 2004 1405 UTC
11.7° S 56.6° W

UMD MODIS Ch21 Proxy Data
07 Aug 2004 1405 UTC
11.7° S 56.6° W

MIR – Initial Tests:

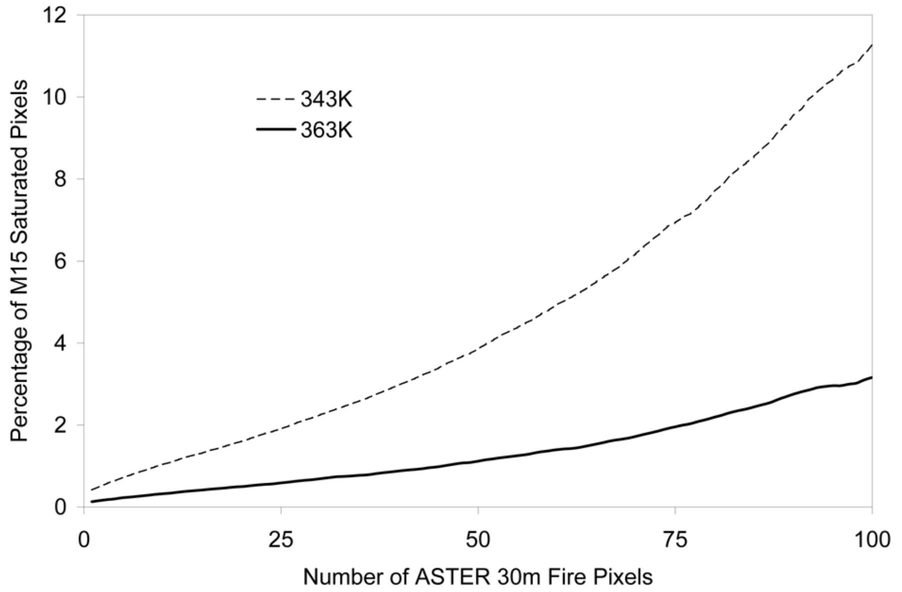
Deriving MODIS L1B TOA Radiances using ASTER Surface Kinetic Temperature data

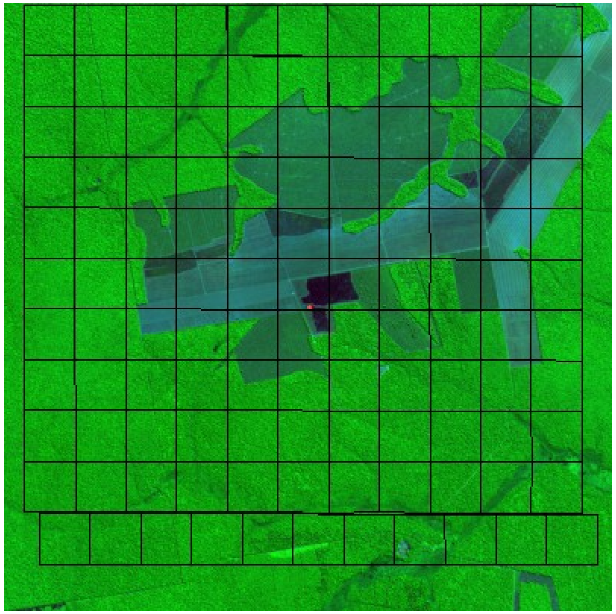


Results

Assessing impact of pixel resampling scheme and TIR (M15) saturation temperature

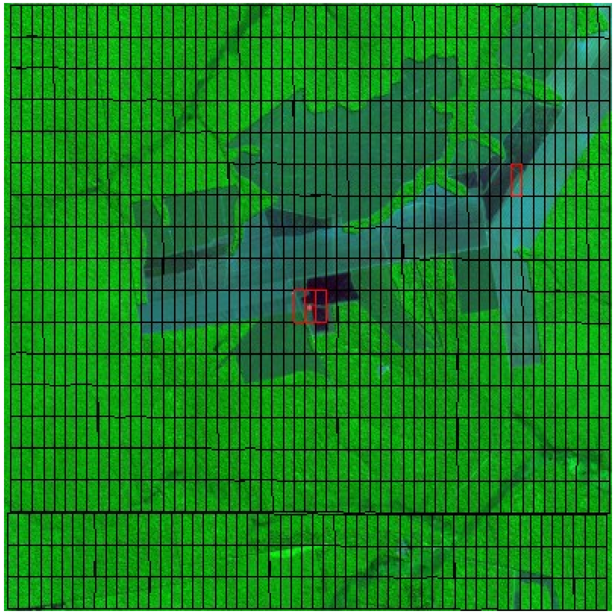
Reporting to NPOESS Integrated Program Office (IPO) – including software and hardware recommendations for optimal fire product performance





MODIS 1km

VIIRS Aggregated (750x750m)

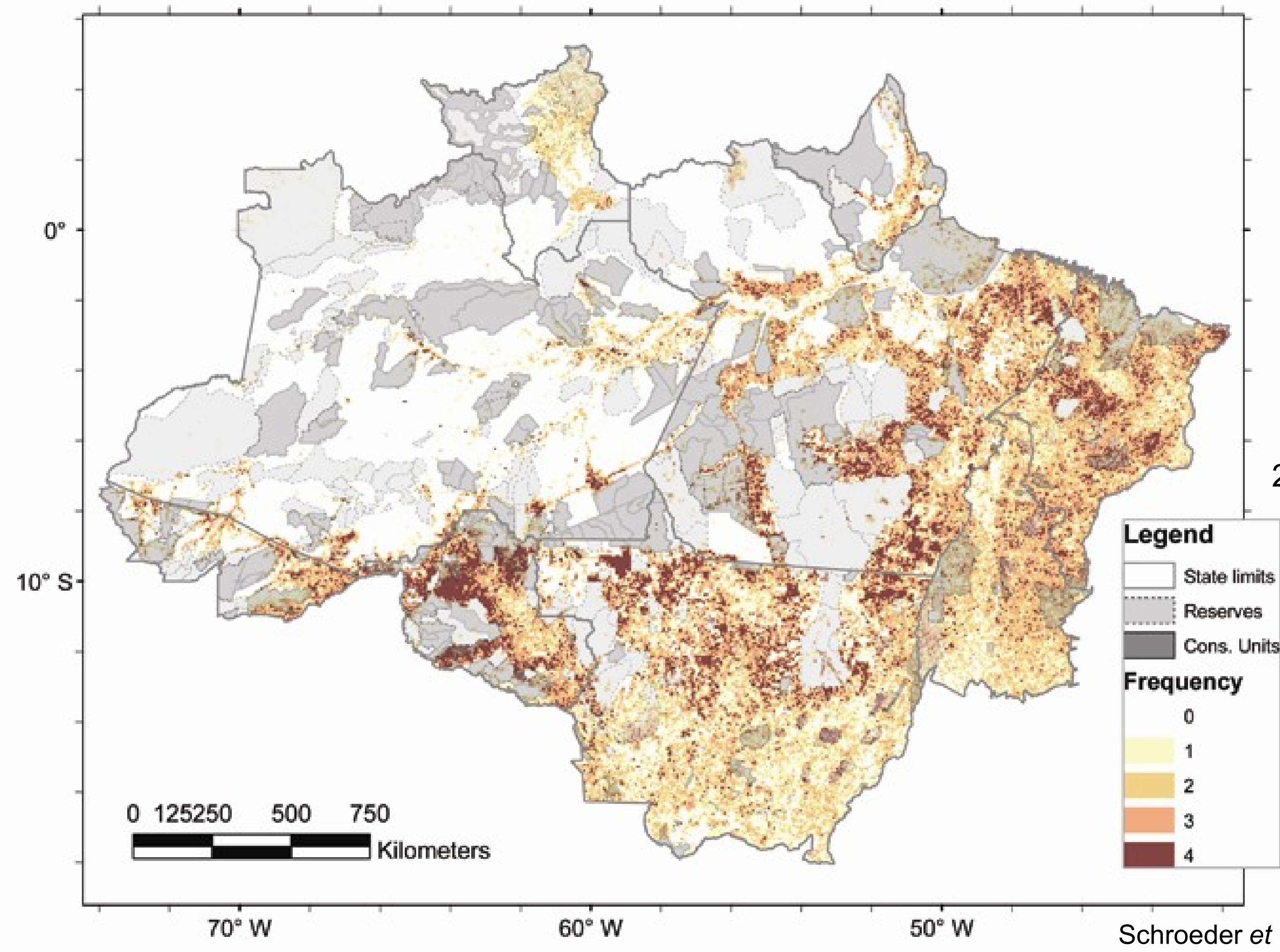


VIIRS Un-Aggregated (215x750m)

Data Applications

Main Drivers of Fire Activity in Amazonia – Humans

Land Use as a major element defining fire spatial and temporal distribution across the region



GOES

AVHRR

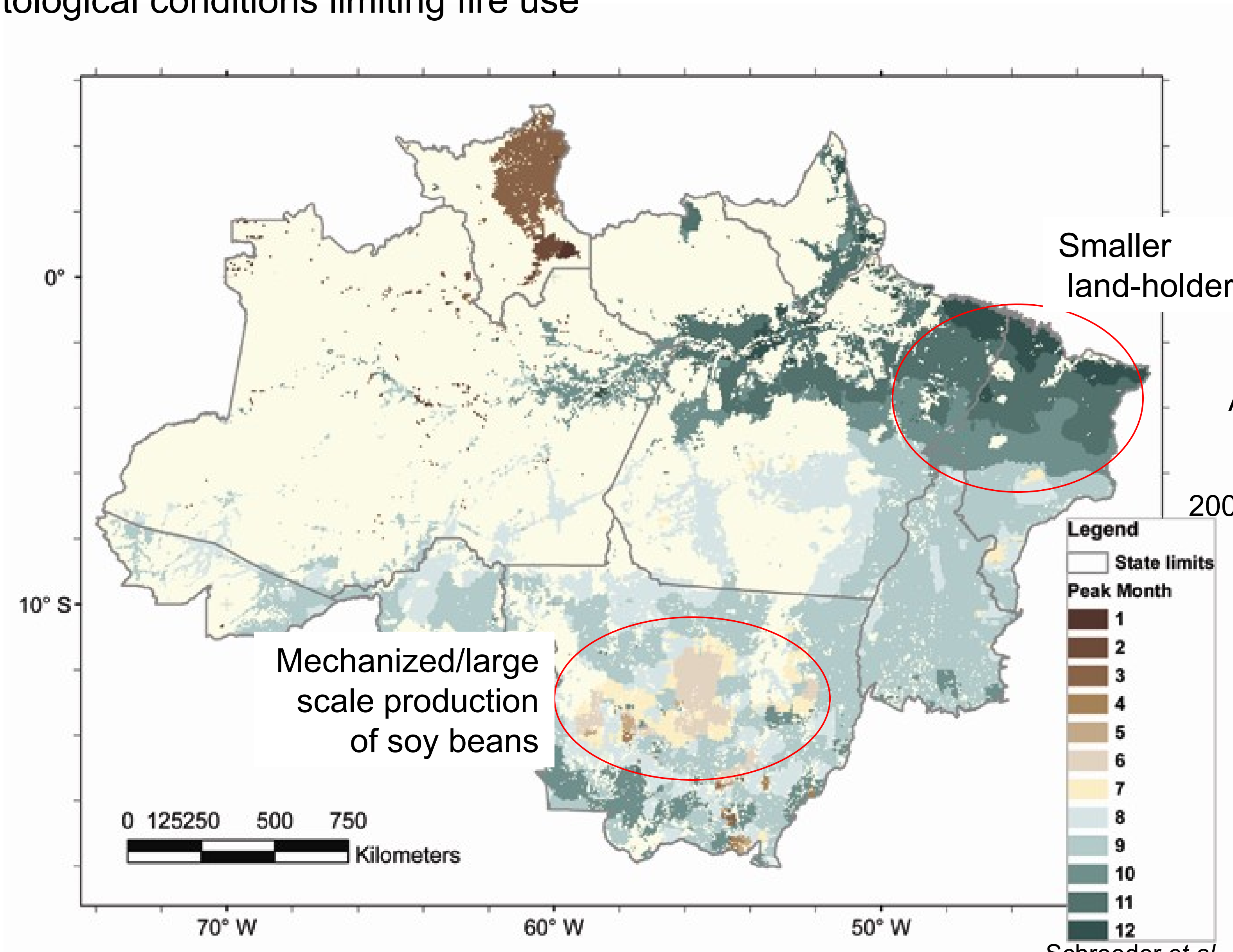
MODIS

2003-2006

Schroeder *et al.*, 2009

Main Drivers of Fire Activity in Amazonia – Physical Conditions

Climatological conditions limiting fire use



GOES

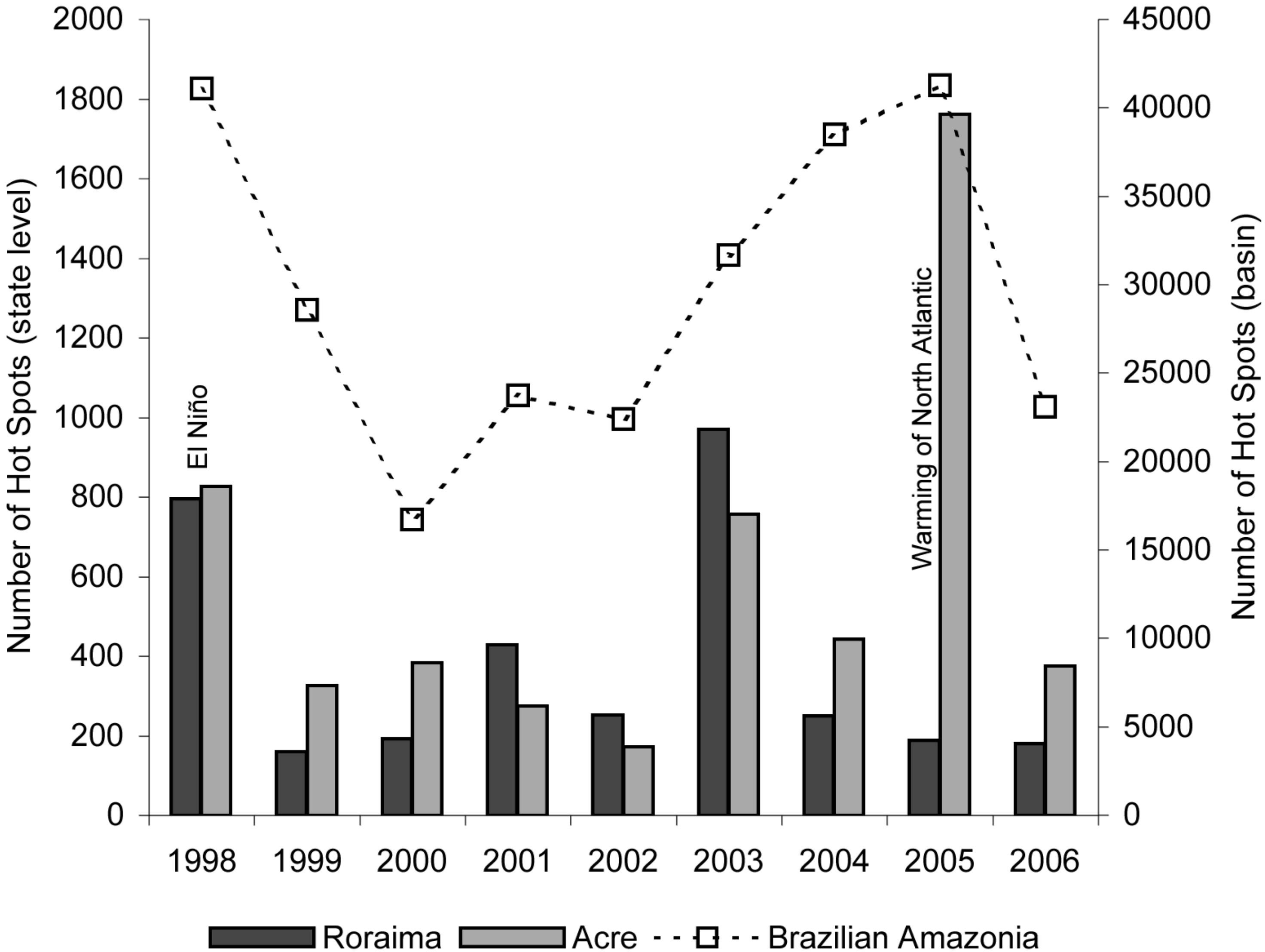
AVHRR

MODIS

2003-2006

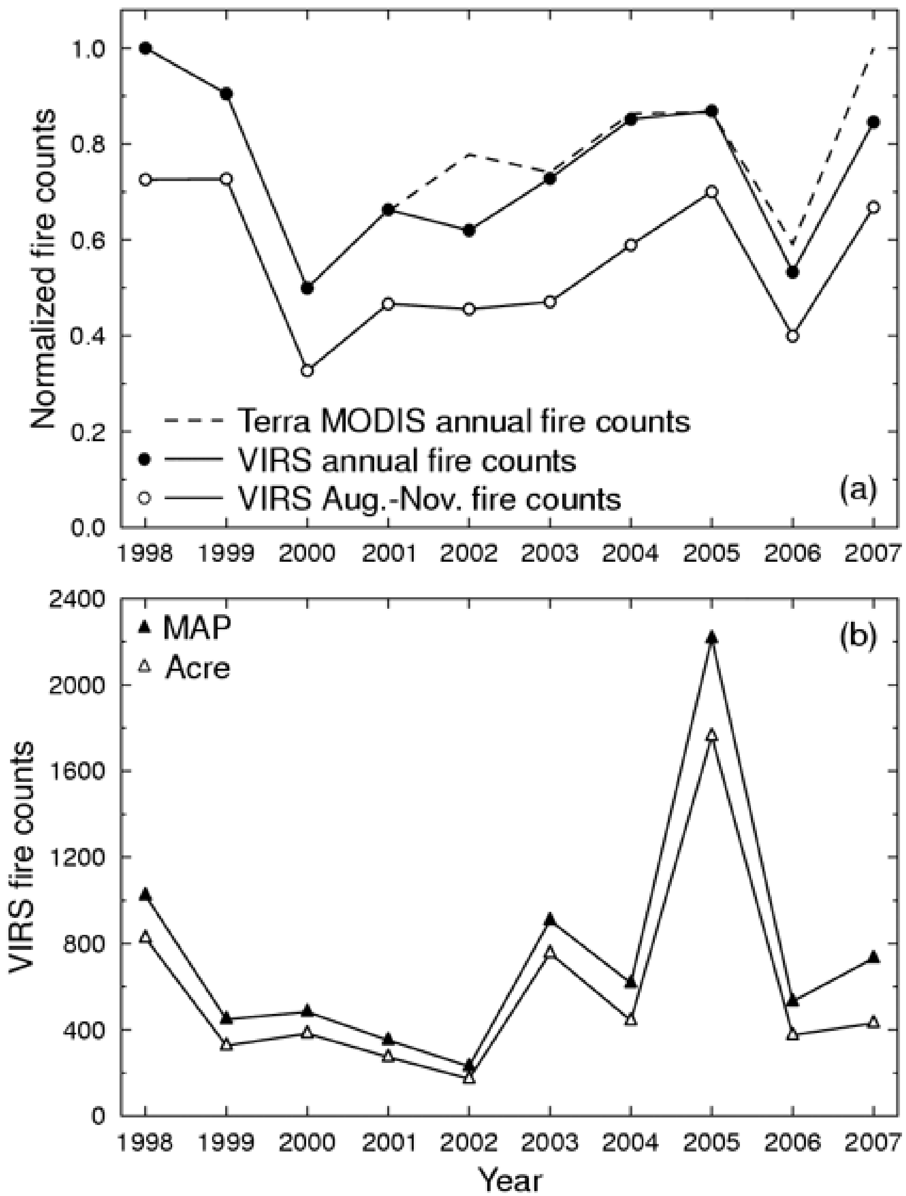
Schroeder *et al.*, 2009

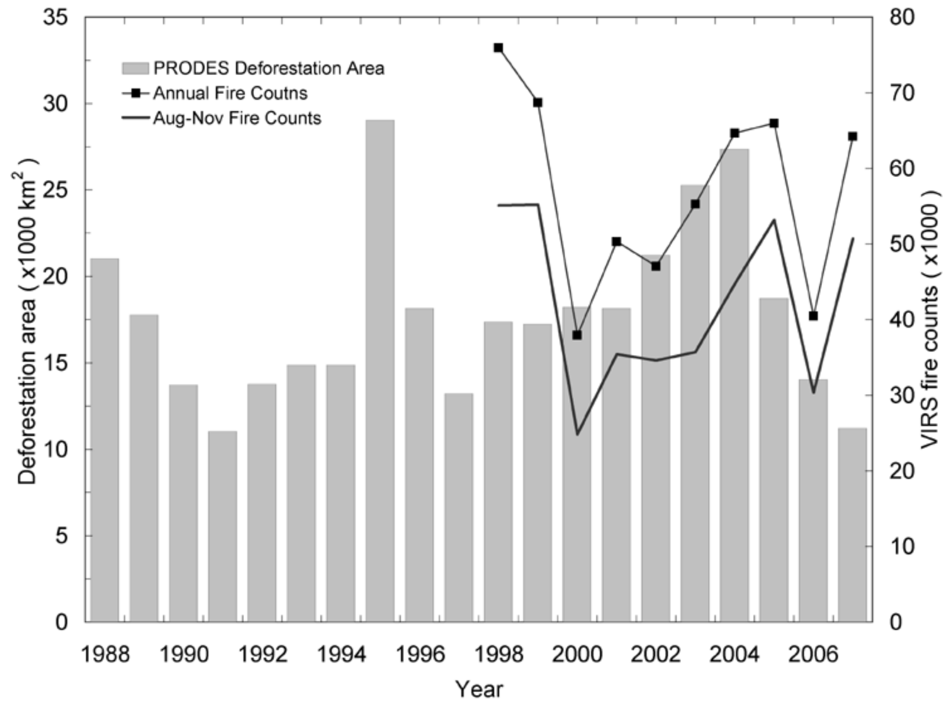
Response to Major Climate Anomalies



Schroeder *et al.*, 2009

Inter-annual Variation of Fire Activity in Amazonia

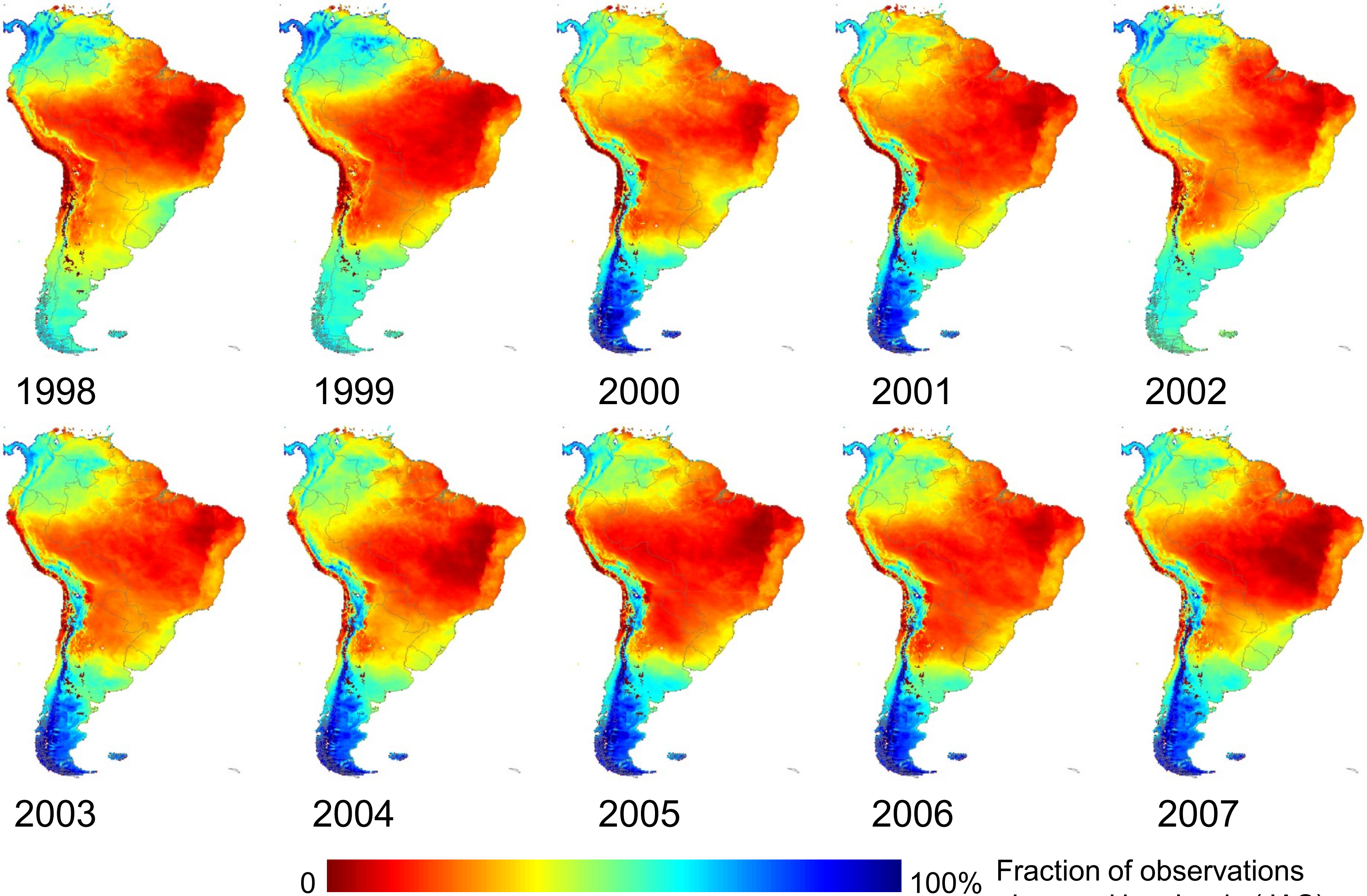




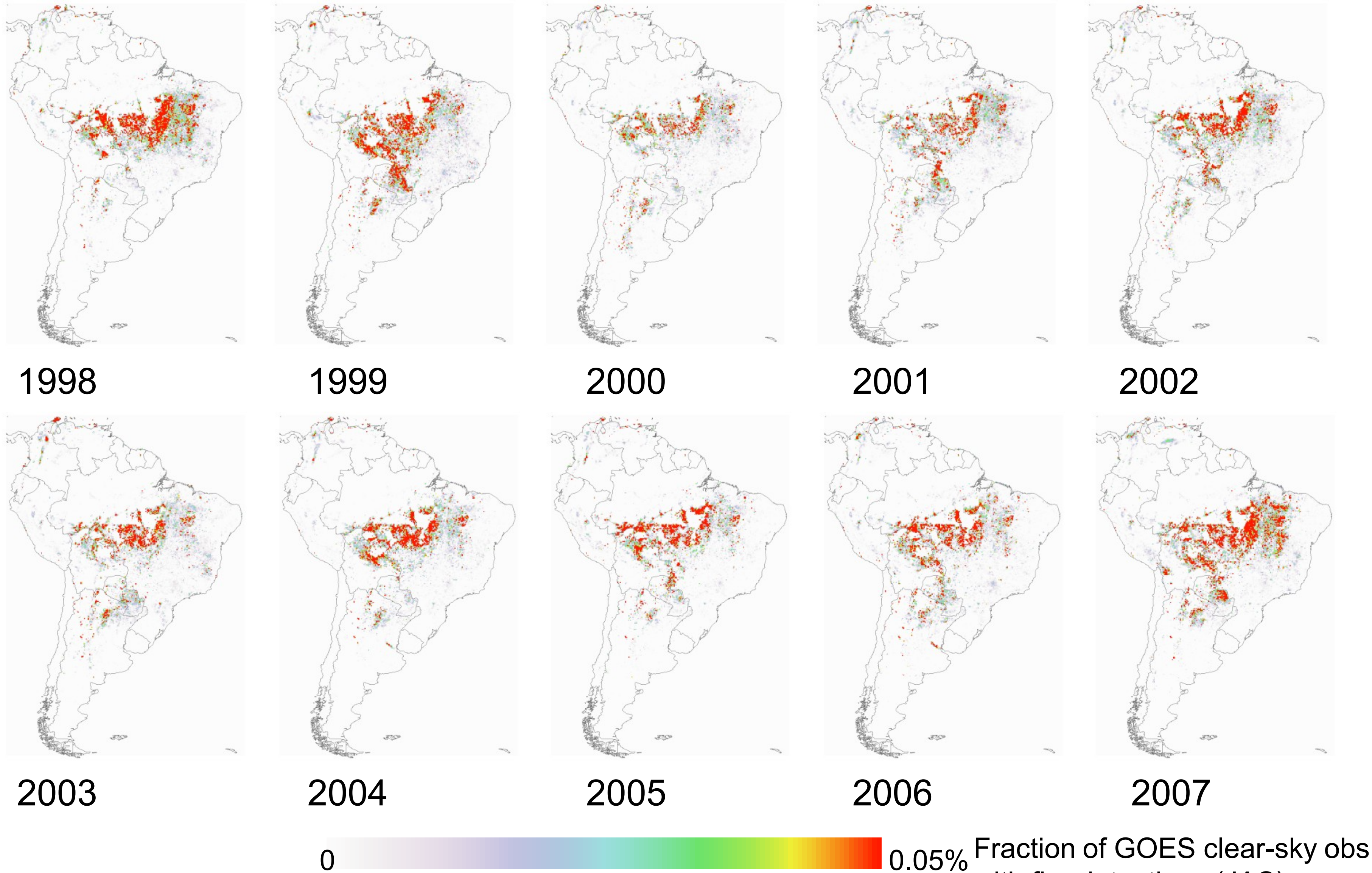
Schroeder *et al*., 2009

Comment on Koren et al., 2007 (*GRL*)

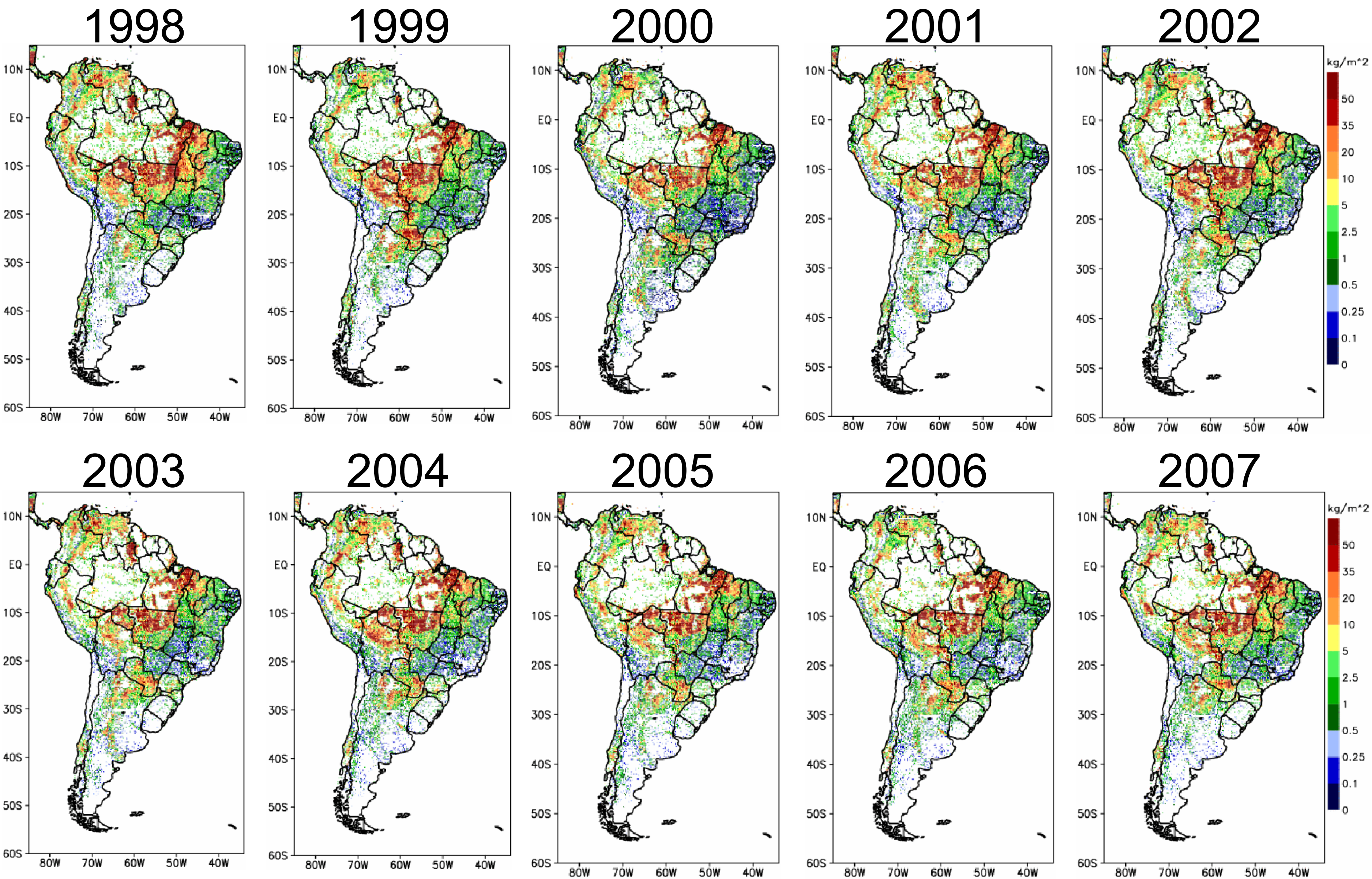
Longer-term Biomass Burning Emissions Inventory for South America Using Integrated Satellite Data



Longer-term Biomass Burning Emissions Inventory for South America Using Integrated Satellite Data



Longer-term Biomass Burning Emissions Inventory for South America Using Integrated Satellite Data



Conclusions

- Multi-scale approach is essential to generate quality fire information from moderate and coarse spatial resolution satellite sensors
    - land use is a major driver of fires in the tropics (maintenance x conversion)
    - landscape features may influence fire product performance (deforestation sites → false alarms)
    - biomass load dictates fire characteristics (low x high intensity fires) (positive feedbacks)
    - atmospheric conditions (clouds) influence omission errors and fires influence cloud formation
    - climate anomalies have major effect on large scale fire activity

- With the use of coincident higher resolution data from spaceborne and airborne remote sensing instruments current active fire detection algorithms can be validated and refined
- Improved data simulation based on observed higher resolution data enables development of fire detection algorithms for future satellite missions
- Integrated fire product using polar & geostationary sensor data is being developed with the support of quality reference data
    - Omission and commission errors and fire data complementarities are accounted for
- Enhanced multi-sensor fire data enabling longer-term analyses
    - Creation of stable environmental data records
    - Data being used as input for biomass burning models
    - Inter-annual analyses of spatial and temporal patterns of fire activity made possible