# Fire characterization in the Amazon using multi-scale, multi-spectral satellite measurements

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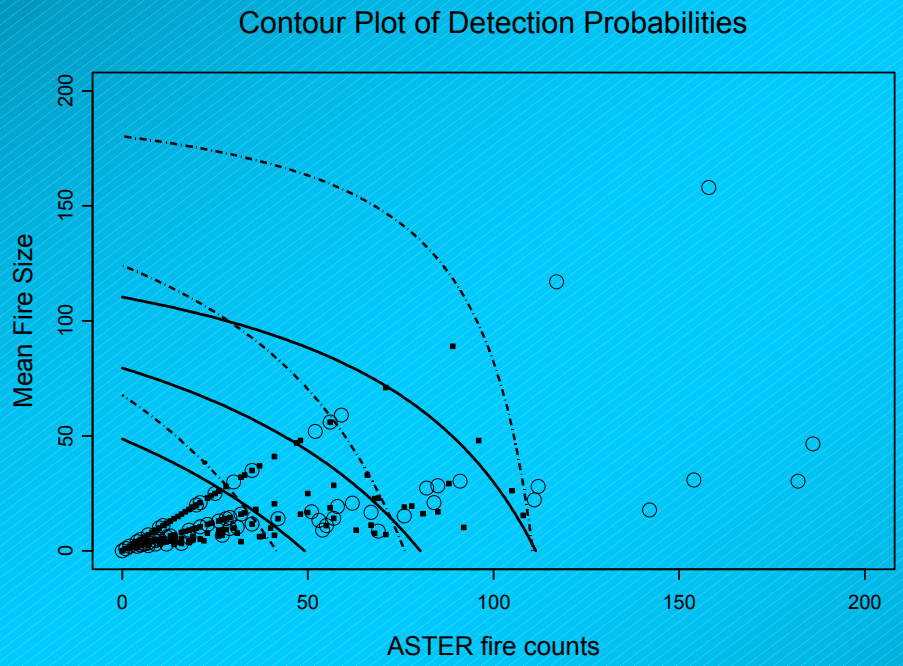
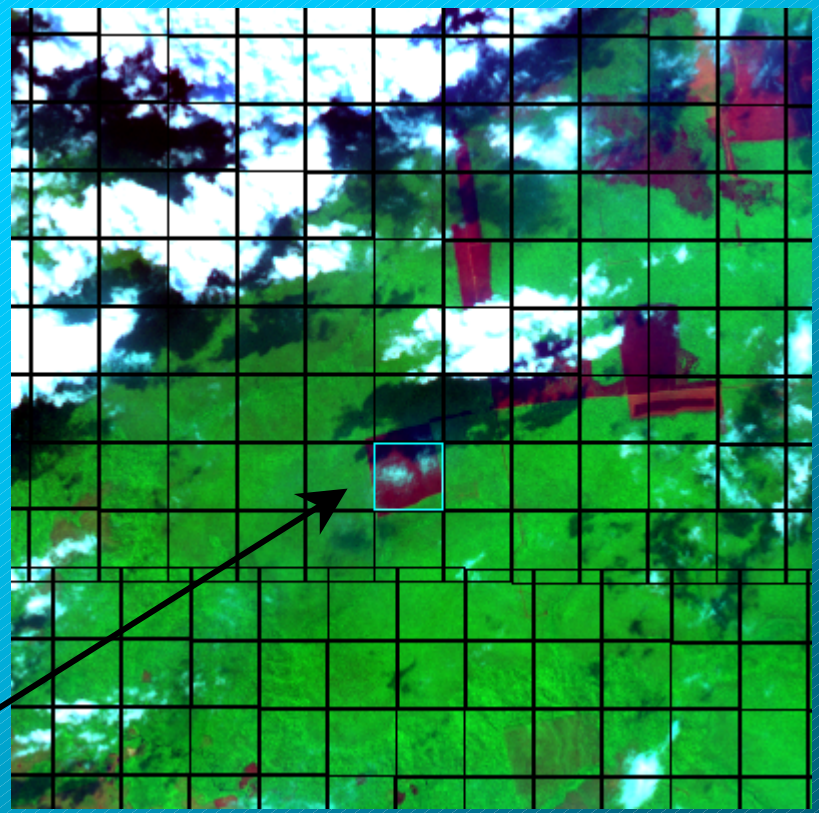
# Background

- “Quantifying the accuracy of the MODIS fire product and distinguishing between conversion and maintenance land cover dynamics” (LBA LC-23)
  - Validation of MODIS active fire product over Brazil
  - Classification to distinguish between conversion and maintenance fires
- “Land-Cover/Land-Use Change and Carbon Dynamics in an Expanding Frontier in Western Amazônia: Acre, Brazil” (LBA LC-02)
  - evaluation of GOES and MODIS fire data using ground truth

# MODIS active fire product (MOD14)

- Product accuracy has been evaluated as part of the LC-23 project using fire masks for coincident ASTER

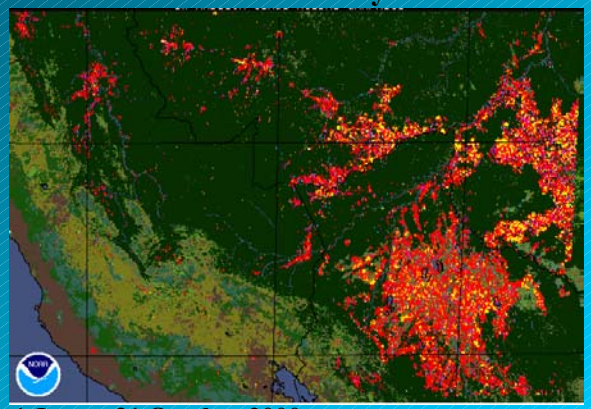


Typical commission error in the Amazon

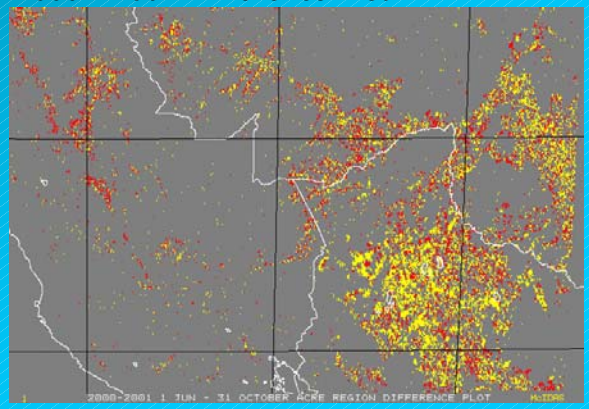
# GOES WF_ABBA Observations of Fire Activity in the Tri-Frontier from 2000 – 2004

**2000 Fire Season Summary**



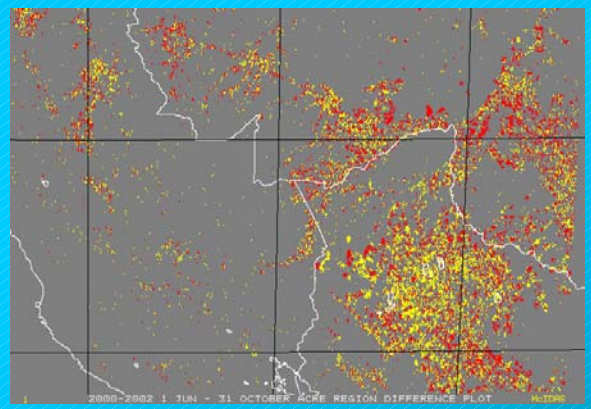
**1 June – 31 October 2000**

**2000 – 2001 Difference Plot**



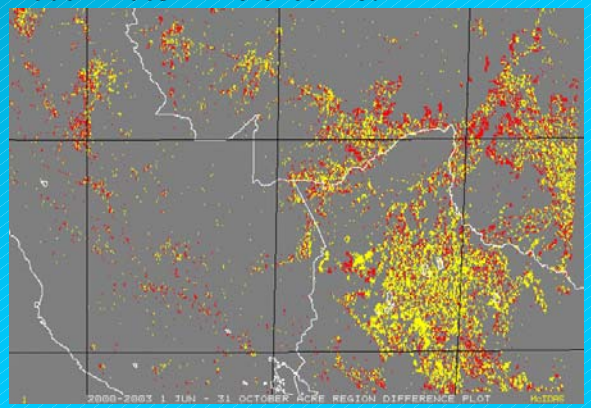
**Fires unique to 2000 (yellow)**
**Fires unique to 2001 (red)**

**2000 – 2002 Difference Plot**



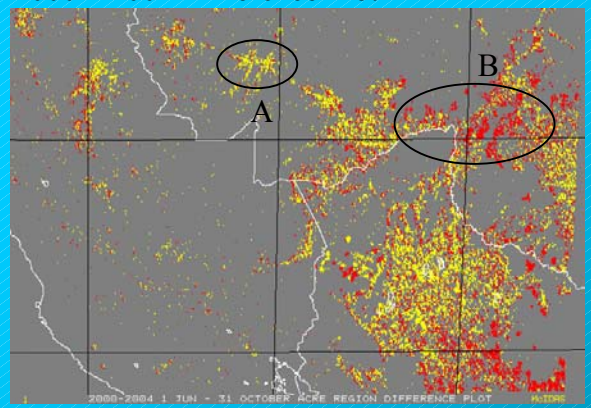
**Fires unique to 2000 (yellow)**
**Fires unique to 2002 (red)**

2000 – 2003 Difference Plot



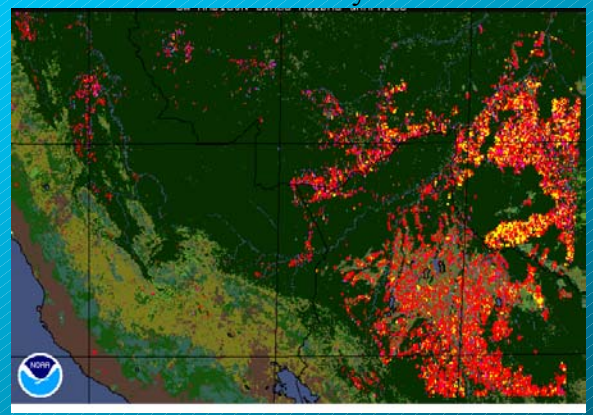
**Fires unique to 2000 (yellow)**
**Fires unique to 2003 (red)**

2000 – 2004 Difference Plot




**Fires unique to 2000 (yellow)**
**Fires unique to 2004 (red)**

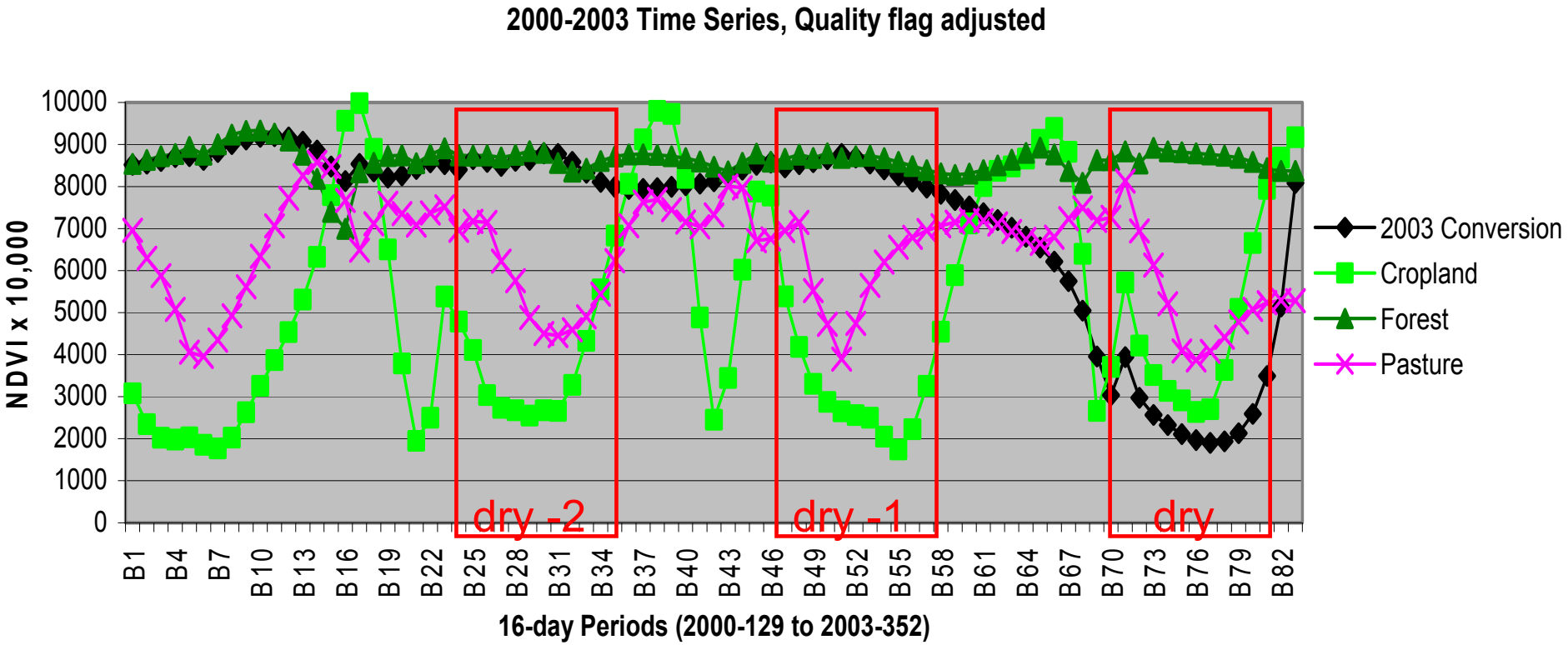
2004 Fire Season Summary



**1 June – 31 October 2004**

**The difference plots show fire pixels unique to each year and can show regions of expansion of fire activity in the tri-frontier.**

# QA Filtered NDVI time series for Dry seasons

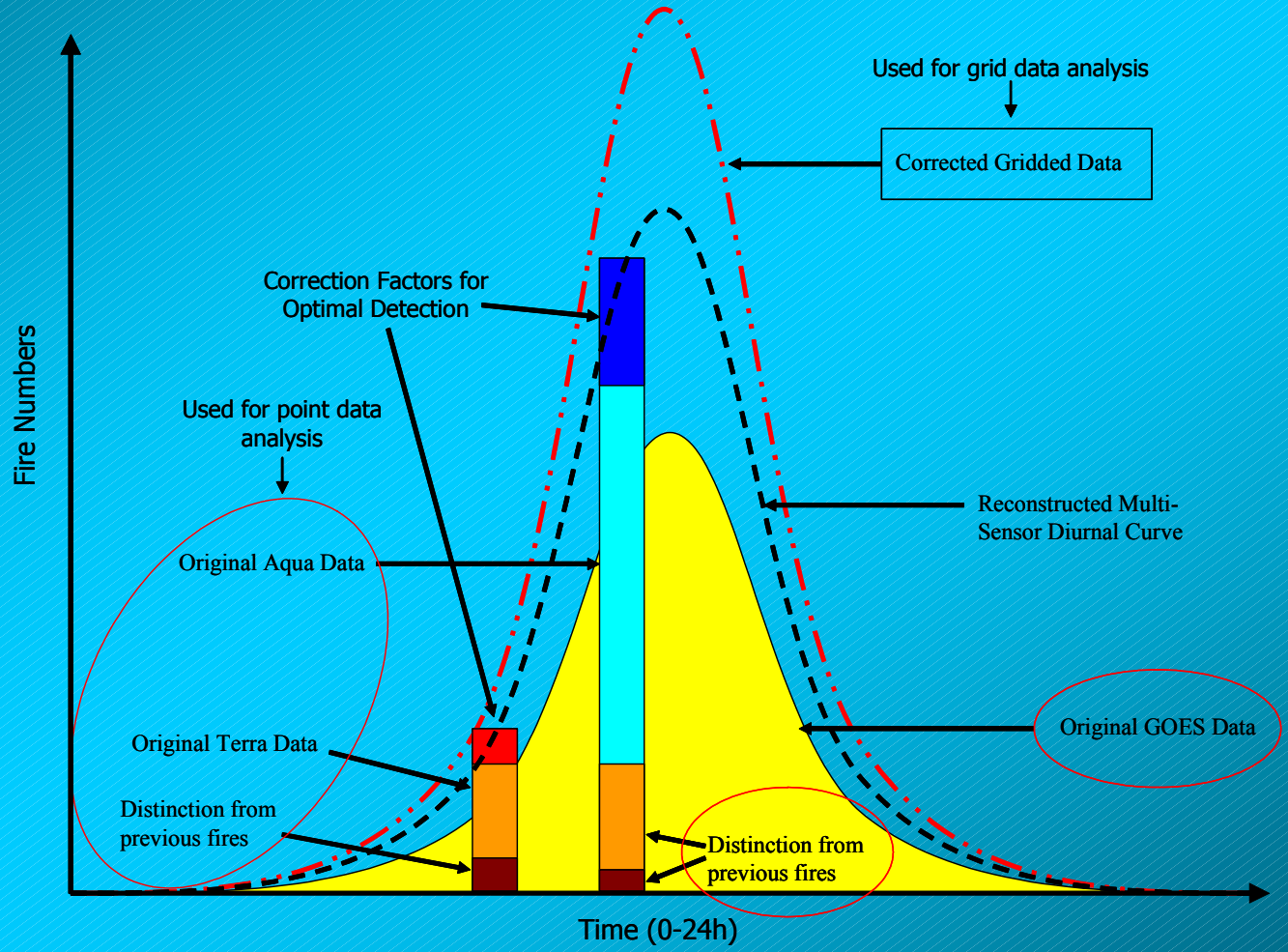



- classification of fires into “conversion” and “maintenance” classes
- used classes from the long-term time series signal to see if short-term signals are consistent

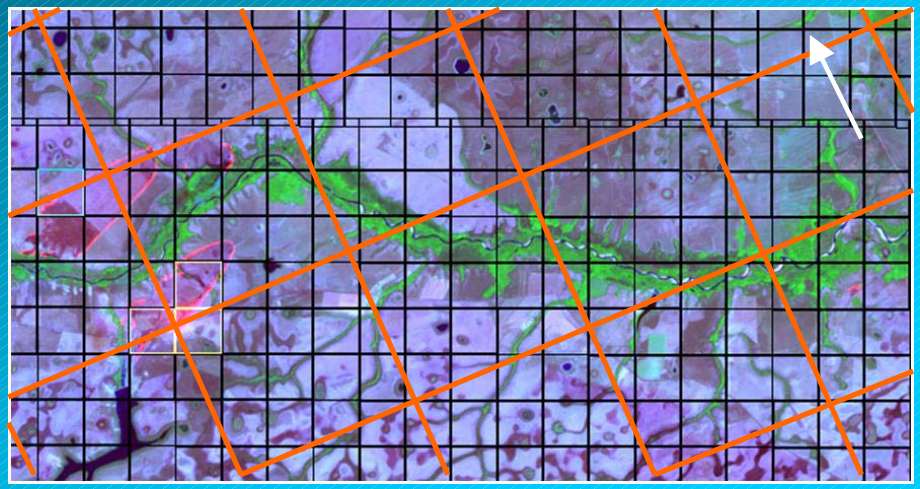
# New project

- “Analysis of Long-Term Fire Dynamics and Impacts in the Amazon Using Integrated Multi-Source Fire Observations” (LBA LC-35)
  - multi-platform fire product validation (MODIS, GOES)
  - development of multi-sensor fire product
  - creation of 11-year fire record
  - creation of emission data record

# Multi-sensor approach



# Multi-sensor, multi-scale analysis



1km MODIS grid

4km GOES grid

**High resolution, common baseline (e.g. ASTER) to link products from moderate and coarse resolution sensors.**

# Value added products

- “Traditional” approach
  - yes/no binary active fire product
    - location of pixel flagged as containing fire
  - yes/no binary burned area product
    - identification of pixel/gridcell where fire occurred and the approximate date of burning
- More detailed exploitation of the radiative signal for fire characterization is still in the research domain

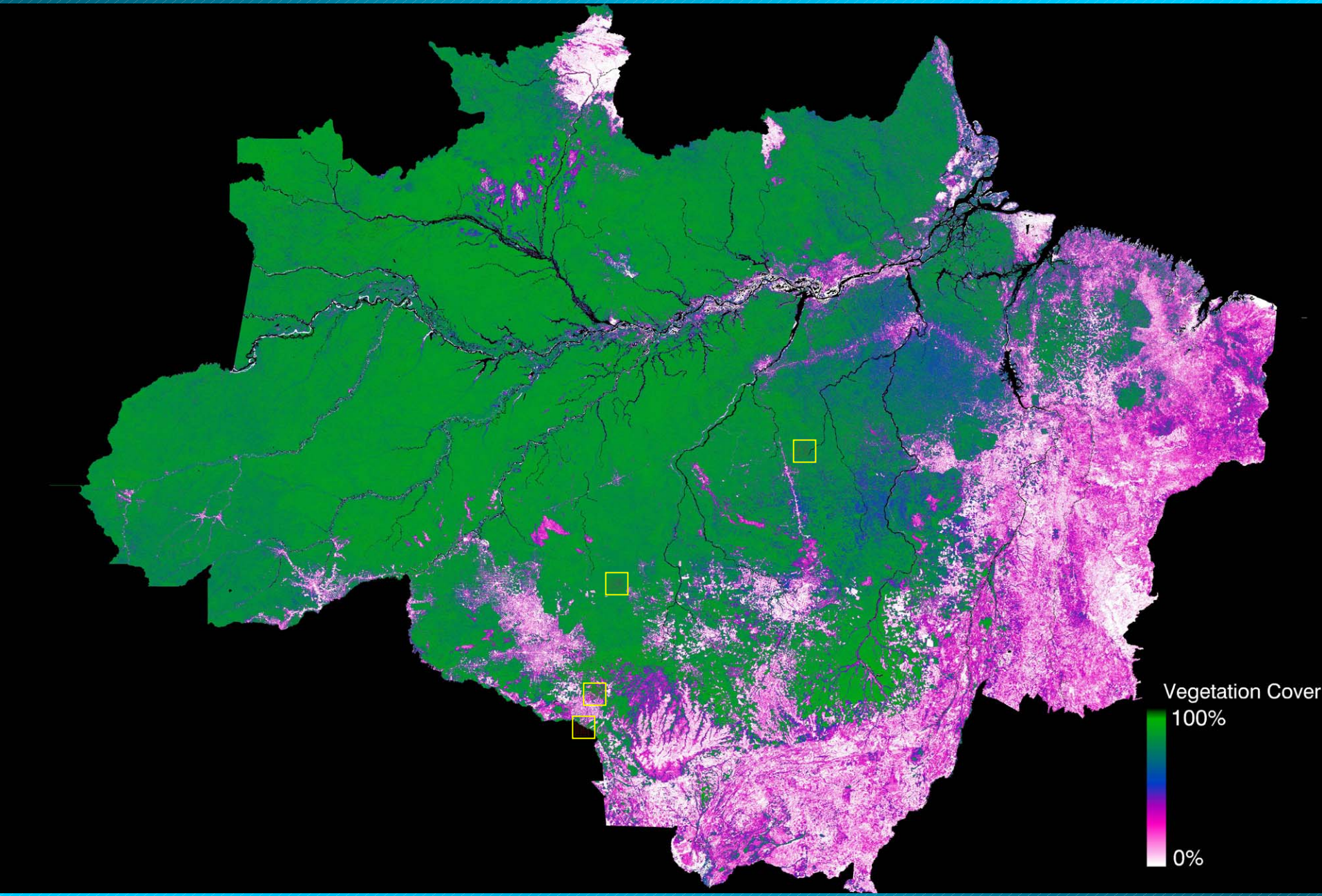
# Objectives of this study

- Evaluate the potential and limitations of a set remote sensing data for the characterization of fires in the Amazon
  - a. intensity of burning
  - b. severity of burning
- Compare to type of fire – conversion vs. maintenance
- Are the above three indicators complementary of inter-related?

# Data

- MODIS 1km active fire and thermal anomaly product (MOD14)
  - fire locations and Fire Radiative Power
- MODIS 500m daily reflectance product (MOD09)
  - burn severity
- ASTER 15-30-90m Level 1B registered radiance at the sensor
  - fire locations
- ASTER 15-30m Surface Reflectance (AST07)
  - burn severity

# Brazilian Amazon



# Data: ASTER triplets

burned areas
active fires

| L1B filename | Date | Time | Lat | Lon |
|---|---|---|---|---|
| | | | | |
| AST_L1B#00308032003141908_10062005131749.hdf | 3-Aug-03 | 14:19:08 | -10.04 | -59.91 |
| AST_L1B#00308192003141917_09162005123510.hdf | 19-Aug-03 | 14:19:17 | -10.04 | -59.92 |
| AST_L1B#00309042003141918_09232005111625.hdf | 4-Sep-03 | 14:19:18 | -10.05 | -59.89 |
| | | | | |
| AST_L1B_00308032003142010_09162005124108.hdf | 3-Aug-03 | 14:20:10 | -13.79 | -60.74 |
| AST_L1B_00308192003142019_09162005123608.hdf | 19-Aug-03 | 14:20:19 | -13.78 | -60.76 |
| AST_L1B_00309042003142020_09162005124413.hdf | 4-Sep-03 | 14:20:20 | -13.79 | -60.7 |
| | | | | |
| AST_L1B#00308032003141952_10062005132010.hdf | 3-Aug-03 | 14:19:52 | -12.72 | -60.5 |
| AST_L1B_00308192003142001_06142005114950.hdf | 19-Aug-03 | 14:20:01 | -12.71 | -60.51 |
| AST_L1B#00309042003142003_10062005132040.hdf | 4-Sep-03 | 14:20:03 | -12.72 | -60.49 |
| | | | | |
| AST_L1B#00308192003141917_09162005123510.hdf | 19-Aug-03 | 14:19:17 | -10.04 | -59.92 |
| AST_L1B#00309042003141918_09232005111625.hdf | 4-Sep-03 | 14:19:18 | -10.05 | -59.89 |
| AST_L1B#00309202003141934_09172005110842.hdf | 20-Sep-03 | 14:19:34 | -10.04 | -59.92 |
| | | | | |
| AST_L1B#00308212003140554_10062005131846.hdf | 21-Aug-03 | 14:05:54 | -6.44 | -55.05 |
| AST_L1B#00309062003140554_10062005132202.hdf | 6-Sep-03 | 14:05:54 | -6.44 | -55.02 |
| AST_L1B#00309222003140613_10062005132233.hdf | 22-Sep-03 | 14:06:13 | -6.39 | -55.38 |

# Fire Radiative Power

- total integrated *instantaneous* rate of radiative energy emitted by all fires within the satellite pixel (Kaufman et al., 1998; Wooster et al. 2003):

$$FRP = A_{sa}\,\varepsilon\sigma\sum_{i=1}^{n} f_i T_i^4 \qquad \text{[MW]}$$

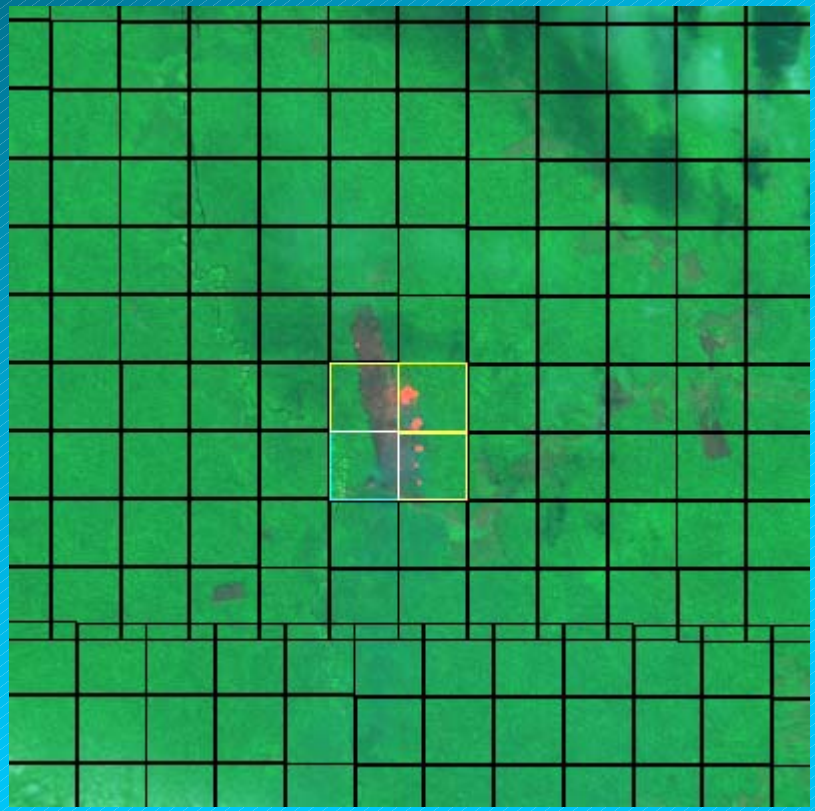
- $A_{sa}$ = the total area of the satellite pixel [$m^2$]
- $\varepsilon$ = fire emissivity
- $\sigma$ = Stephan-Boltzmann constant [$5.67 \times 10^{-8}$ $J^{-1}m^{-2}K^{-4}$]
- $f_i$ = fractional area of the *i*th thermal component
- $T_i$= temperature of the *i*th thermal component [K]
- $n$ = number of thermal components

# Fire Radiative Power (FRP)

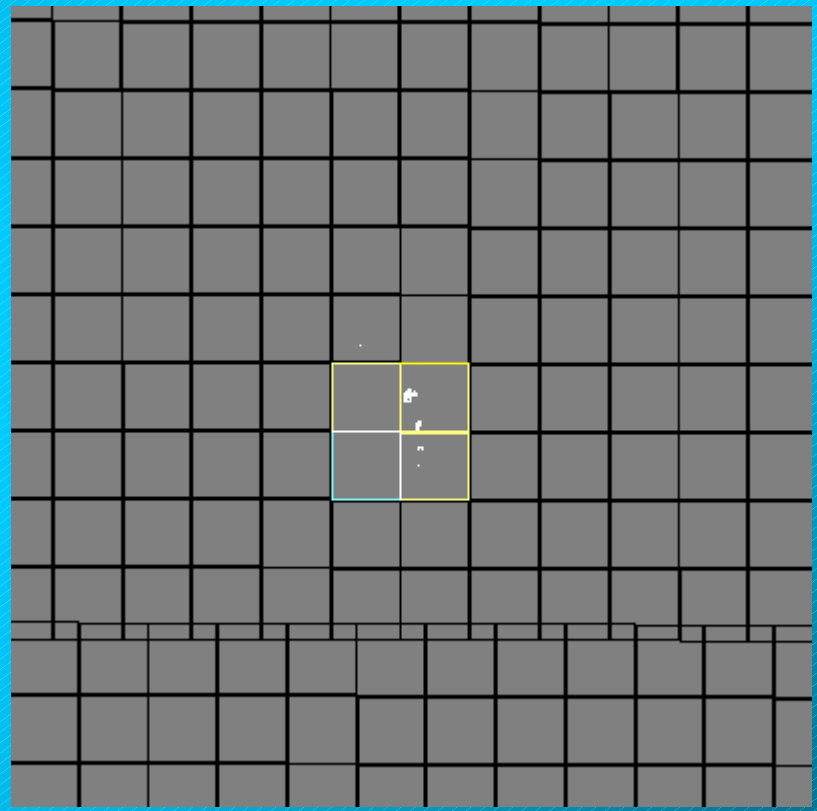
- Fire Radiative Power has been shown to correlate with instantaneous biomass consumption rate (Wooster et al., 2002, 2003).
- MODIS on the experimental polar orbiting Terra and Aqua satellites is the first sensor to enable systematic retrievals of FRP at a global scale (Justice et al., 2002).
- FRP is part of the standard MOD14 product suite
- ASTER saturation levels are too low for FRP retrieval in most cases
- Take advantage of coincident observations from MODIS and ASTER at different scales

# Example FRP retrievals

August 19 2003 14:19:17



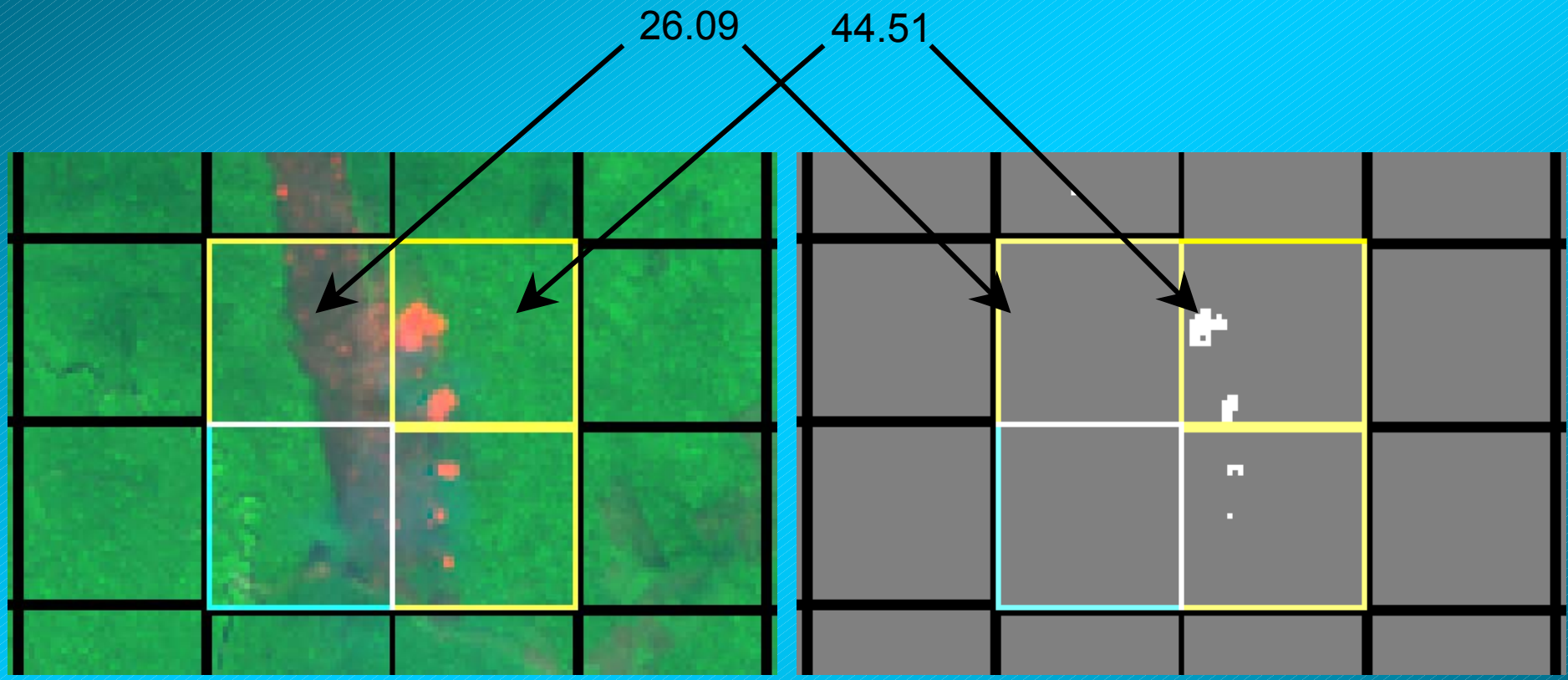
ASTER 8-3-1 RGB



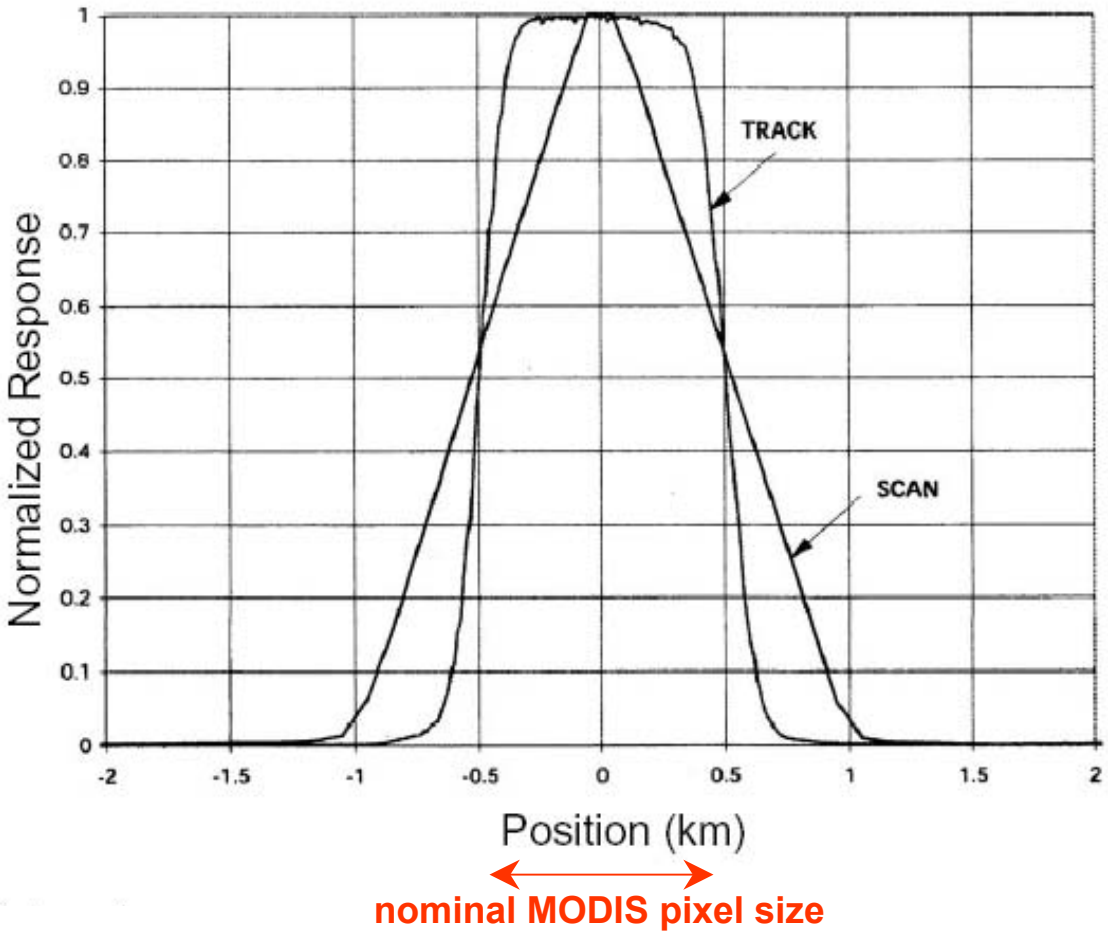
ASTER fire mask

MODIS active fire product; yellow: high confidence, blue: nominal confidence

# Example FRP retrievals [MW]

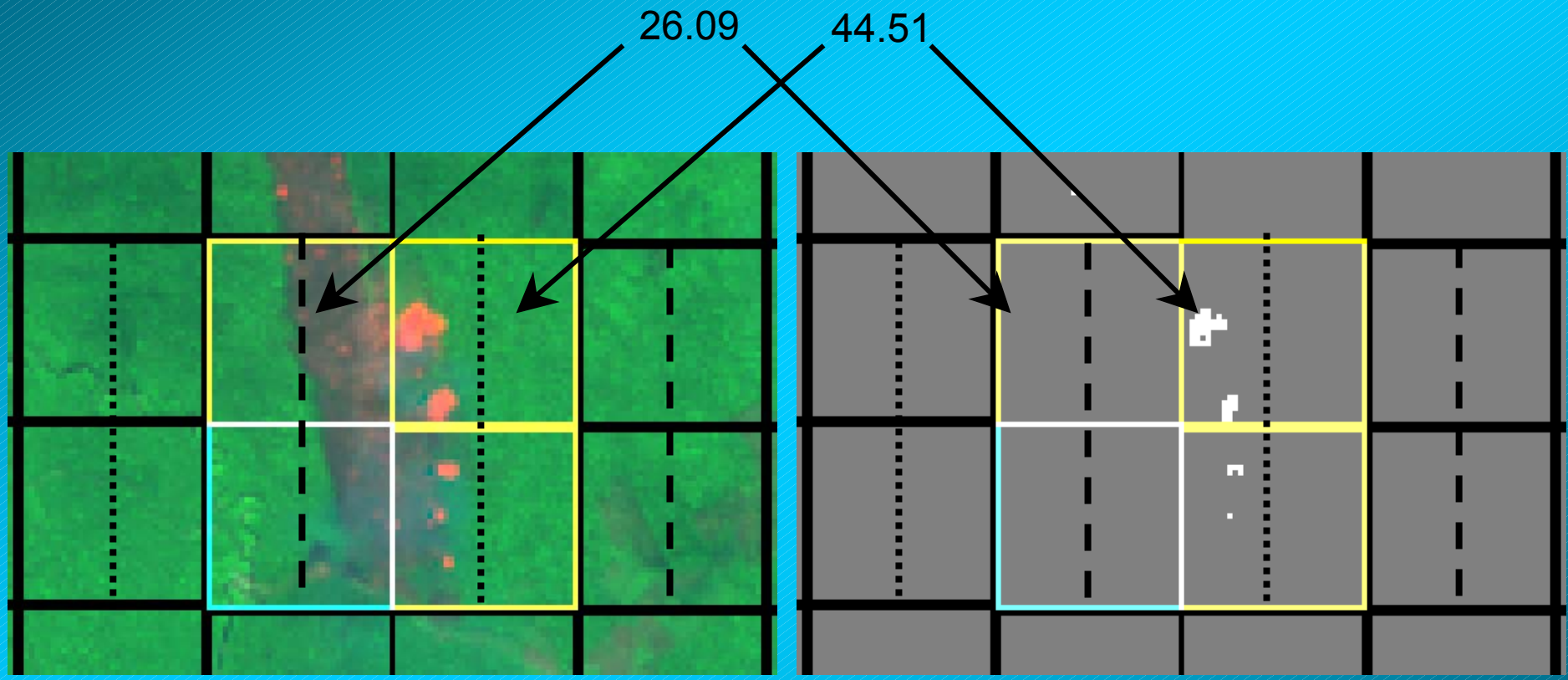


# MODIS Measured PSF (1km nadir observation)

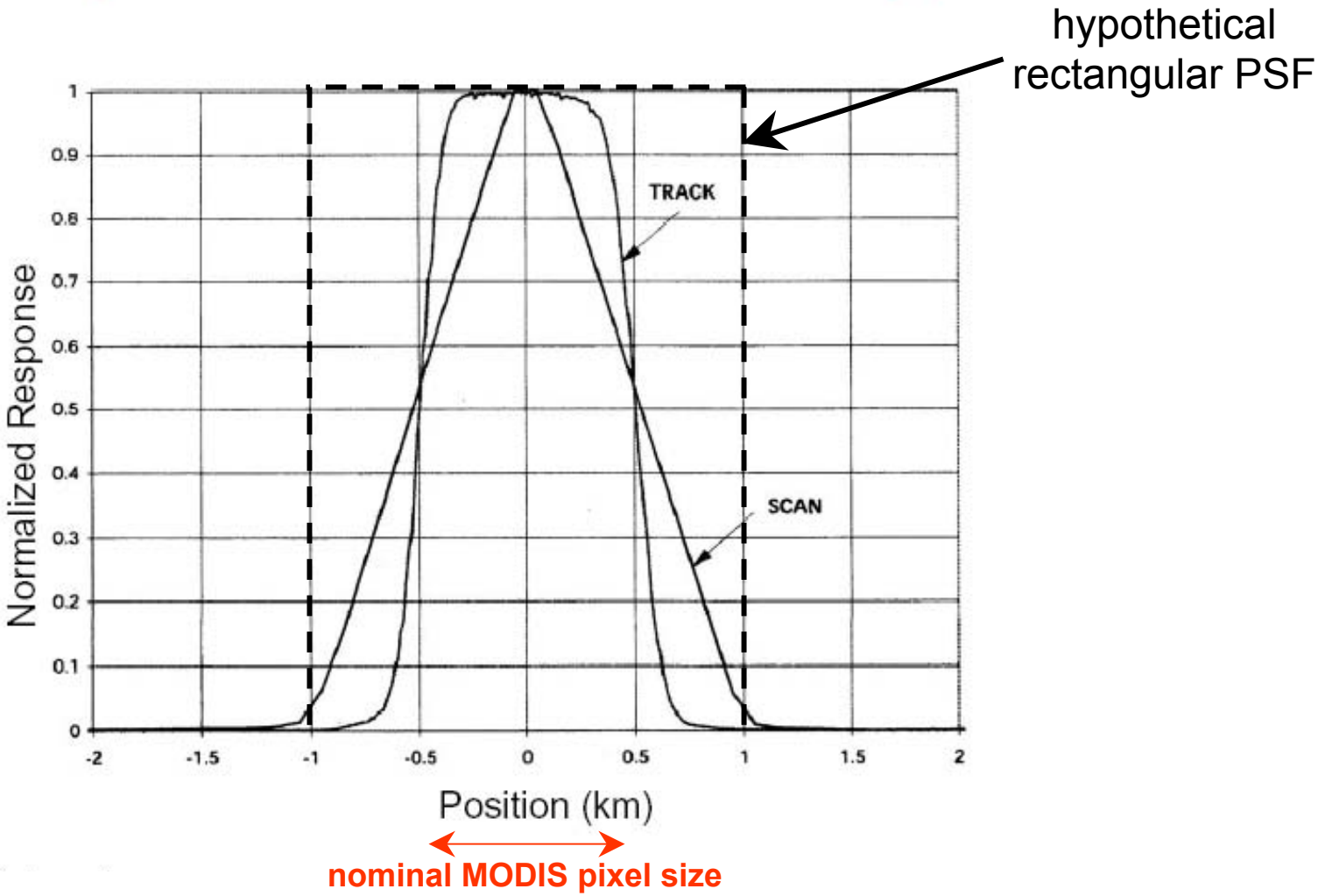



PSF: Point Spread Function

# Example FRP retrievals [MW]



# MODIS Measured PSF (1km nadir observation)



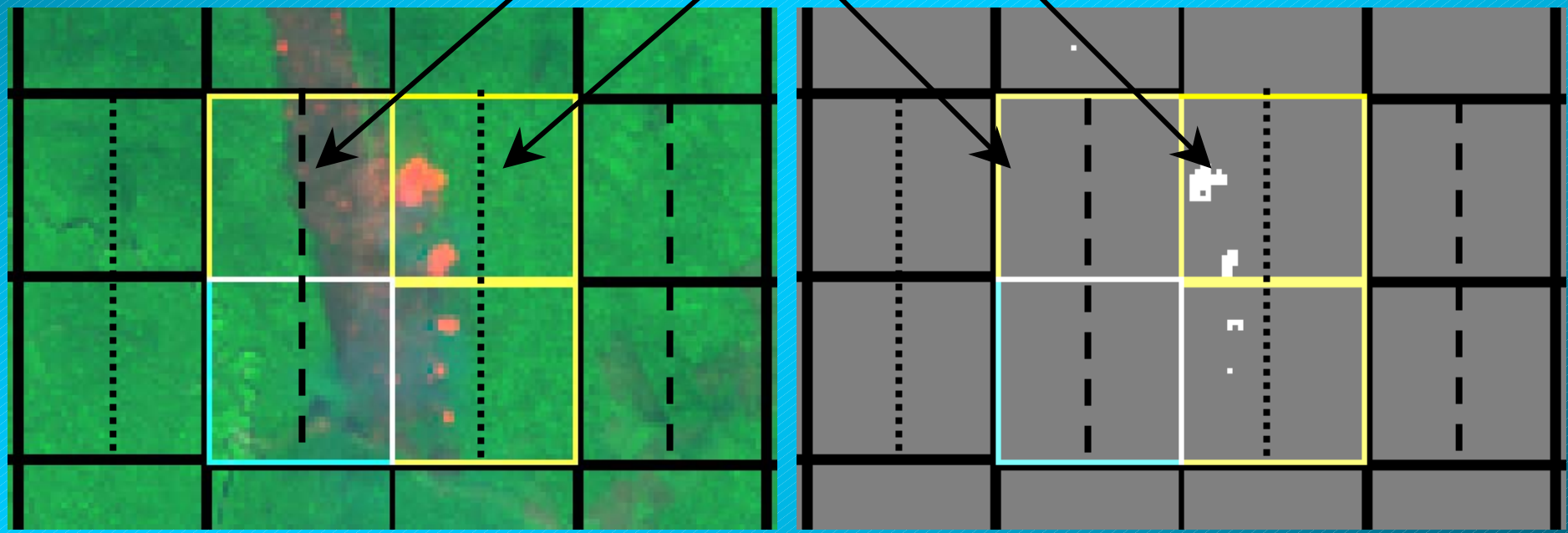

PSF: Point Spread Function

# Example FRP retrievals [MW]

$$FRP = A_{sa}\,\varepsilon\sigma\sum_{i=1}^{n} f_i\,k_i\,T_i^4 \xrightarrow{\text{(assuming constant } f \text{ and uniform } T)} FRP_a = FRP \times n \,/\, \sum_{i=1}^{n} k_i$$

$k_i$ = MODIS PSF

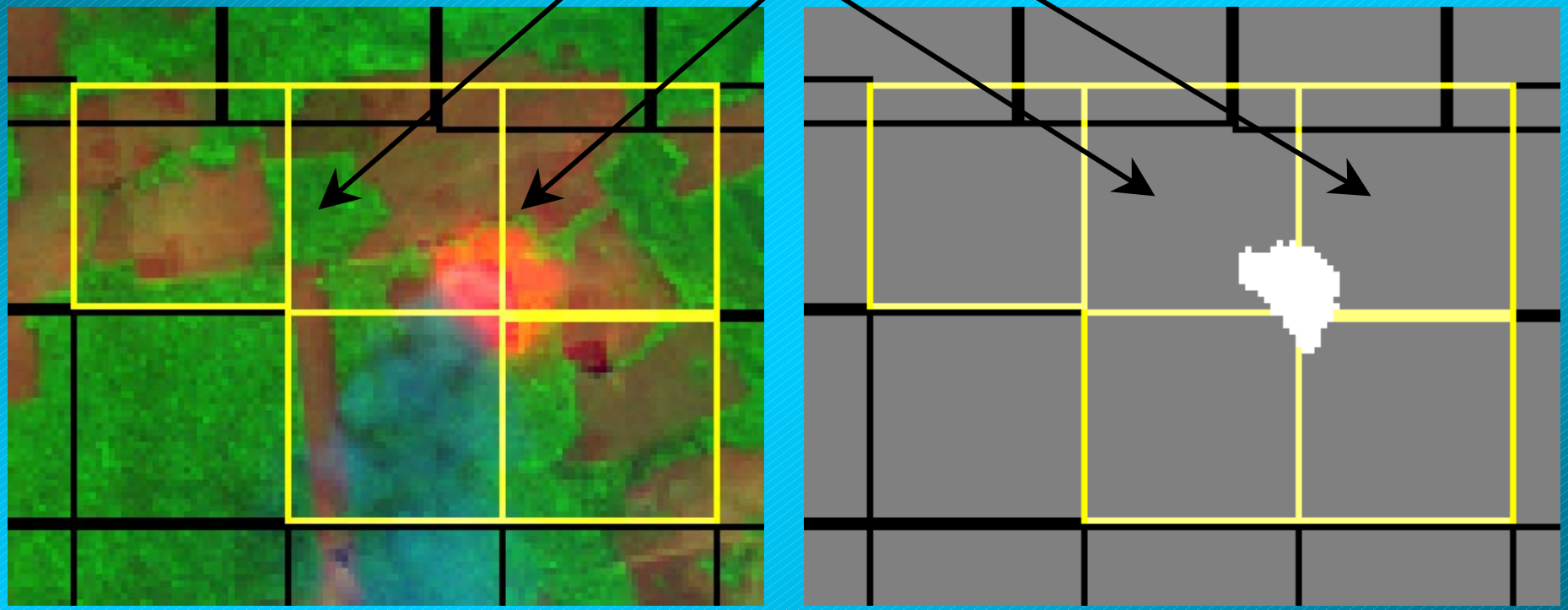
$n$ = number of ASTER fire pixels




ORIGINAL

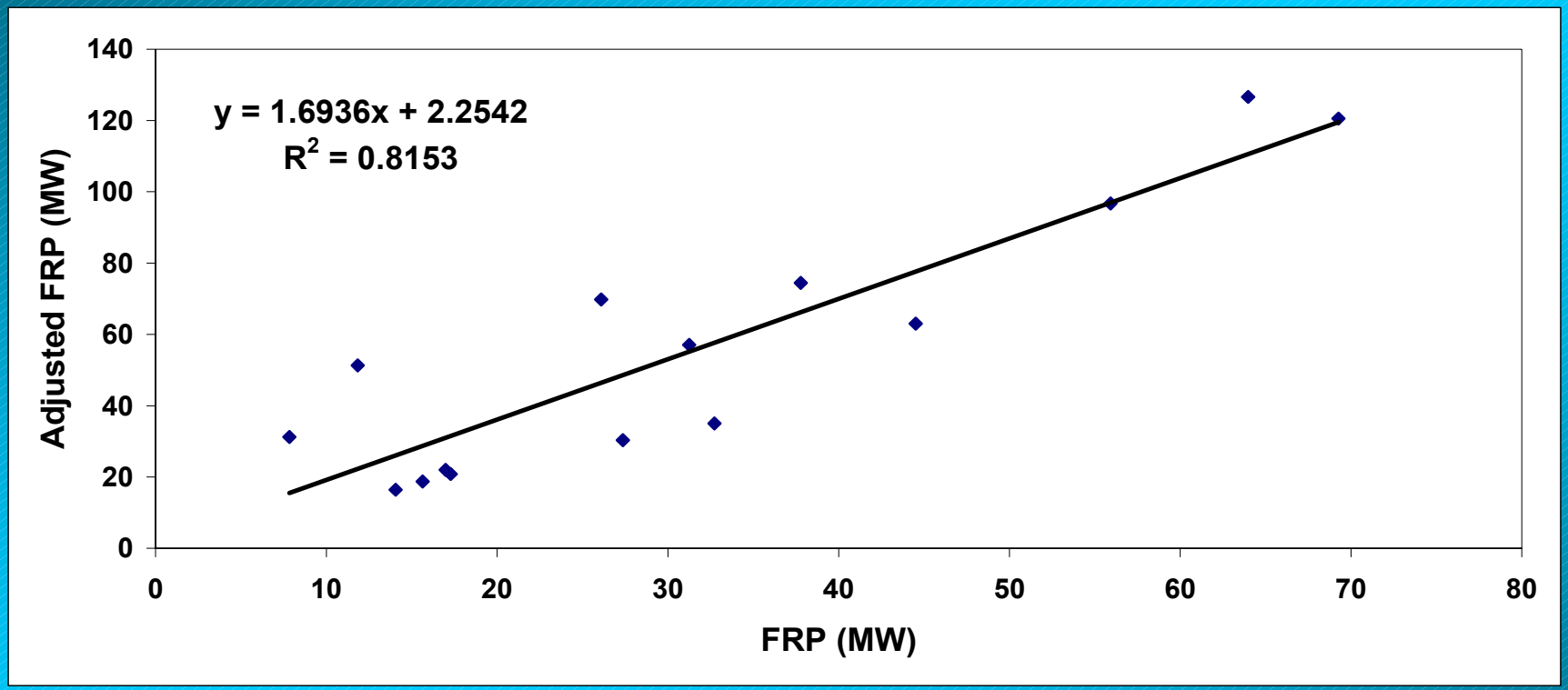
ADJUSTED

# Another FRP example [MW]

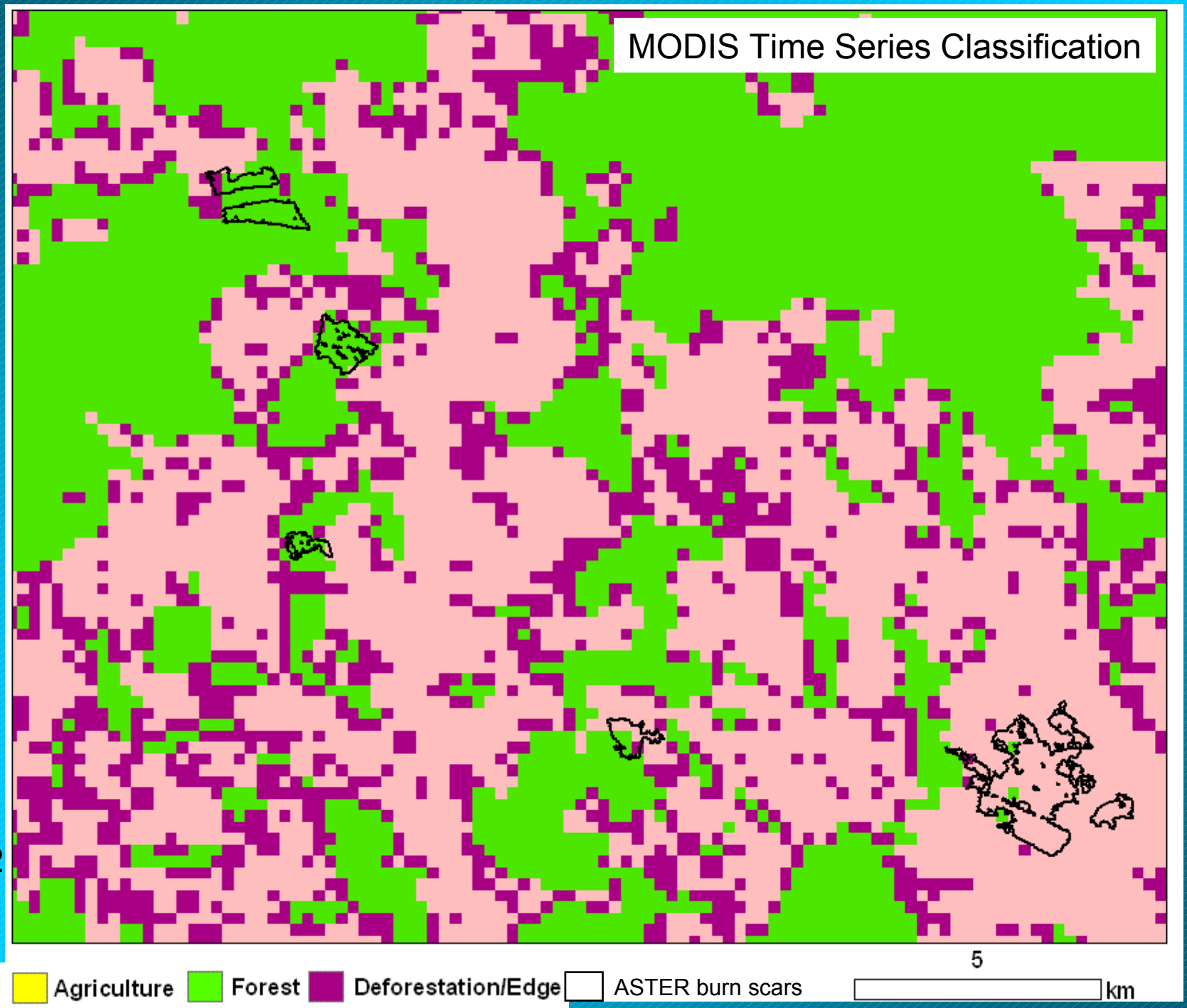


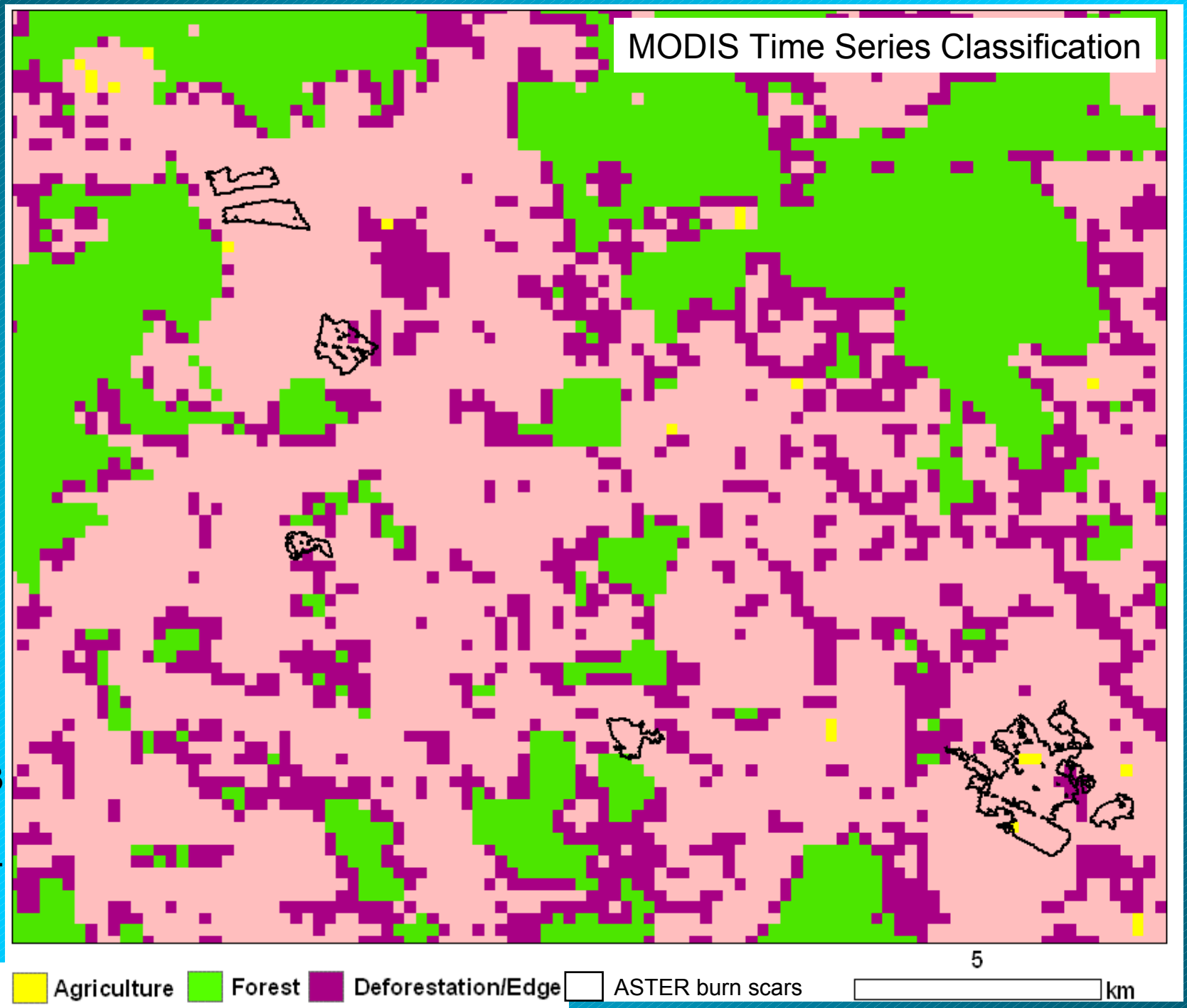

ORIGINAL
CORRECTED

# Is FRP adjustment necessary?




- FRP correlates well with adjusted FRP
  - a consequence of the random distribution of fires within MODIS pixels
- over large samples statistical analysis of FRP is useful and sufficient
- for quantitative studies (e.g. direct emission estimates) PSF effect needs to be accounted for


MODIS Time Series Classification
Oct 2001
–
Oct 2002
5
Pasture
Agriculture
Forest
Deforestation/Edge
ASTER burn scars
km


MODIS Time Series Classification
Oct 2003
–
Oct 2004
Pasture
Agriculture
Forest
Deforestation/Edge
ASTER burn scars
5
km

# Fire classification

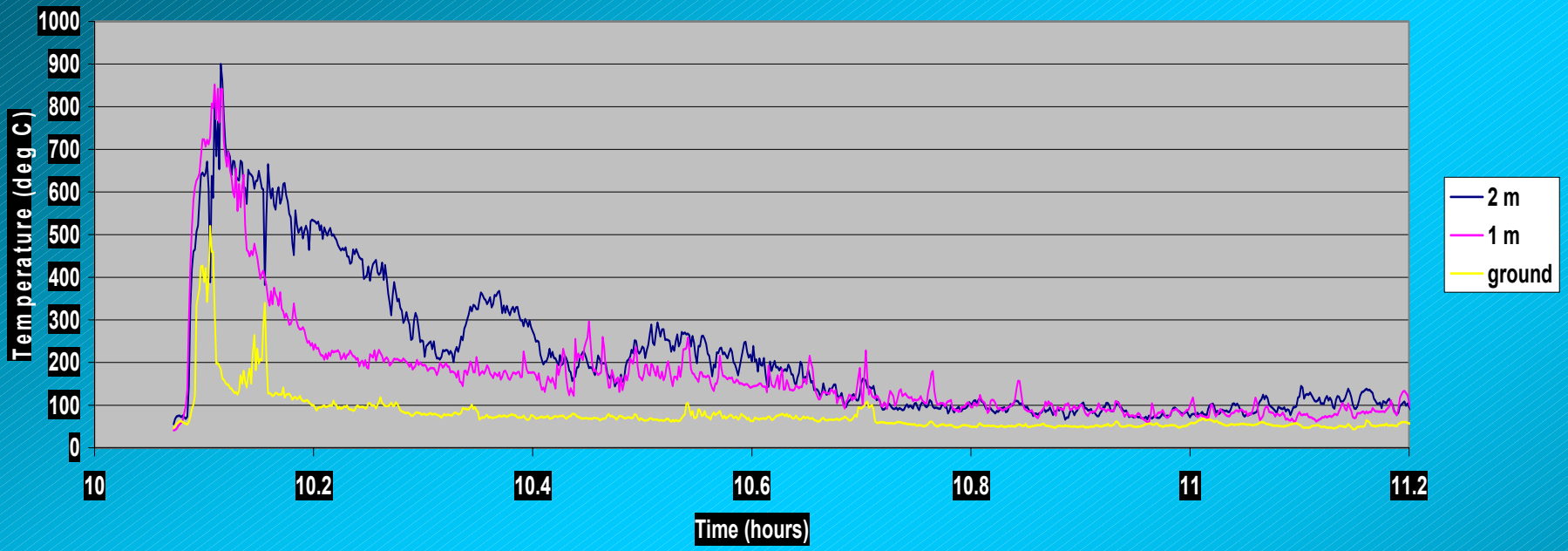
**conversion fires**

**maintenance fires**

# In-situ observations

**thermocouple measurements of fire temperature for conversion and maintenance fires**

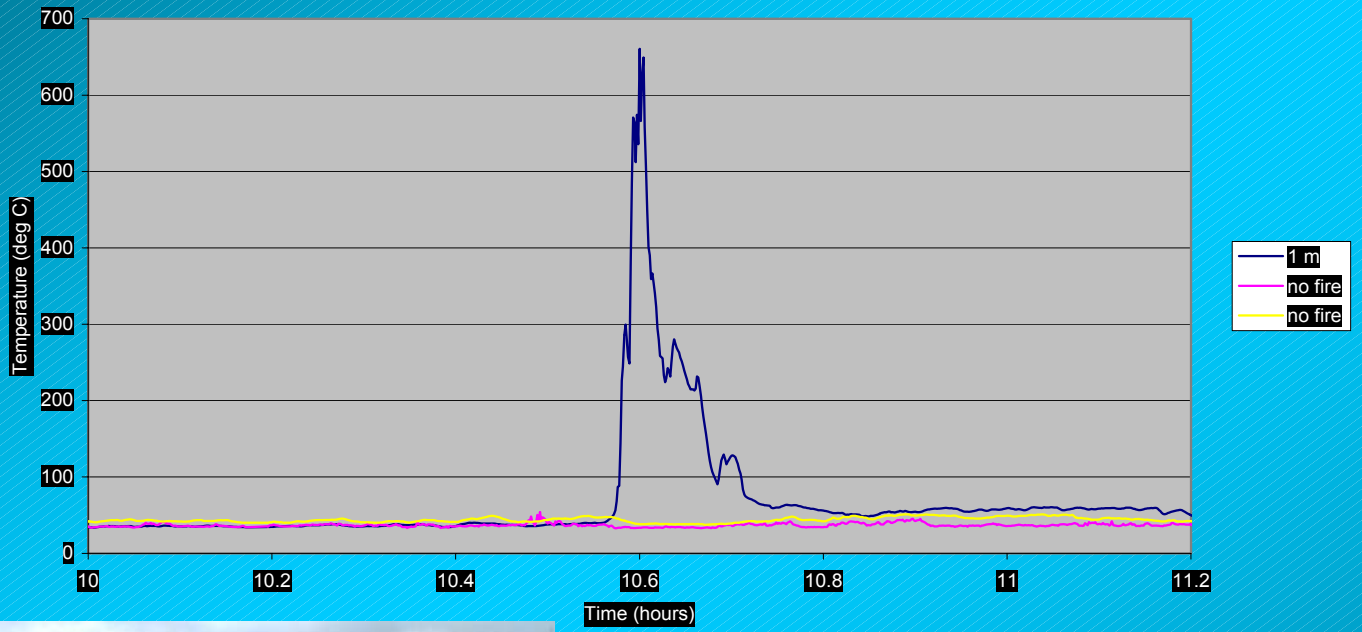
# In-situ observations




**conversion fire**

**Tapajos, October 2003**

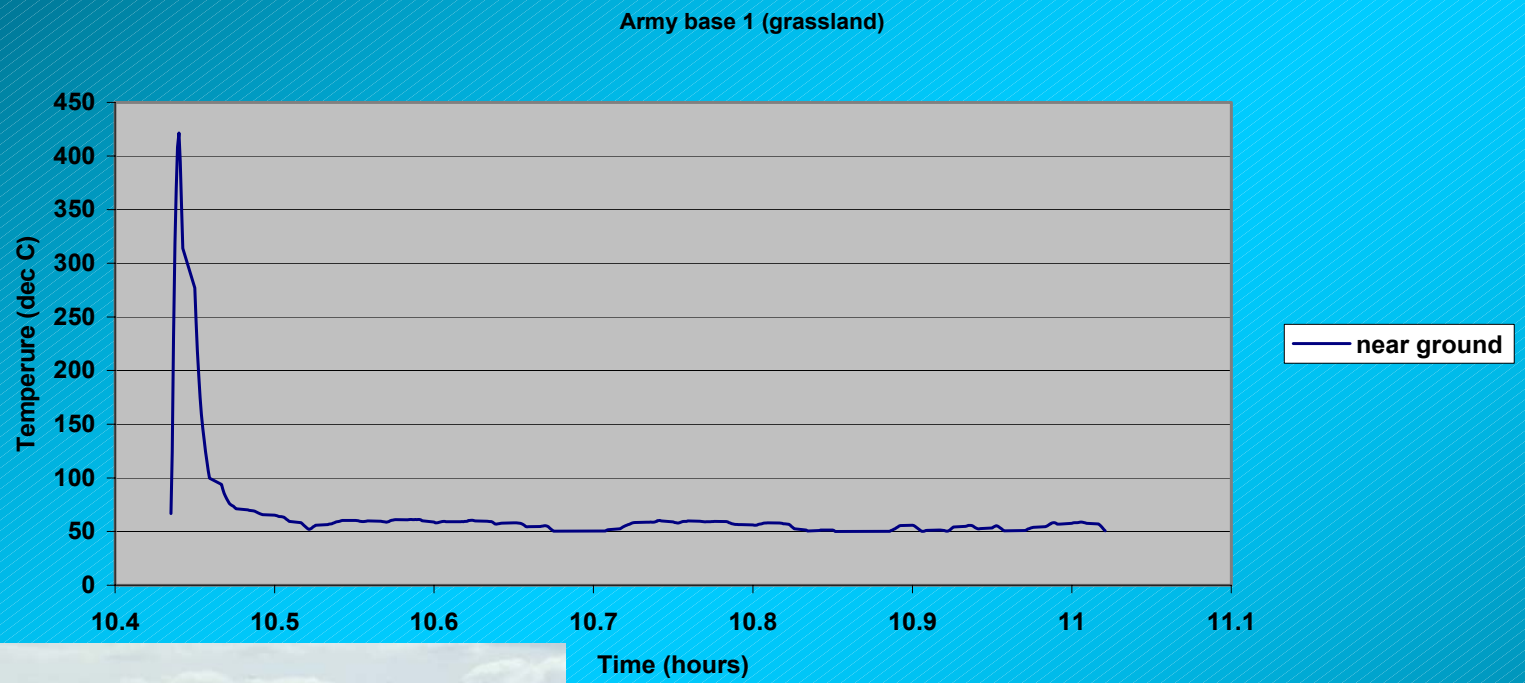
# In-situ observations




**maintenance fire**

**Tapajos, October 2003**

# In-situ observations




**grassland fire**

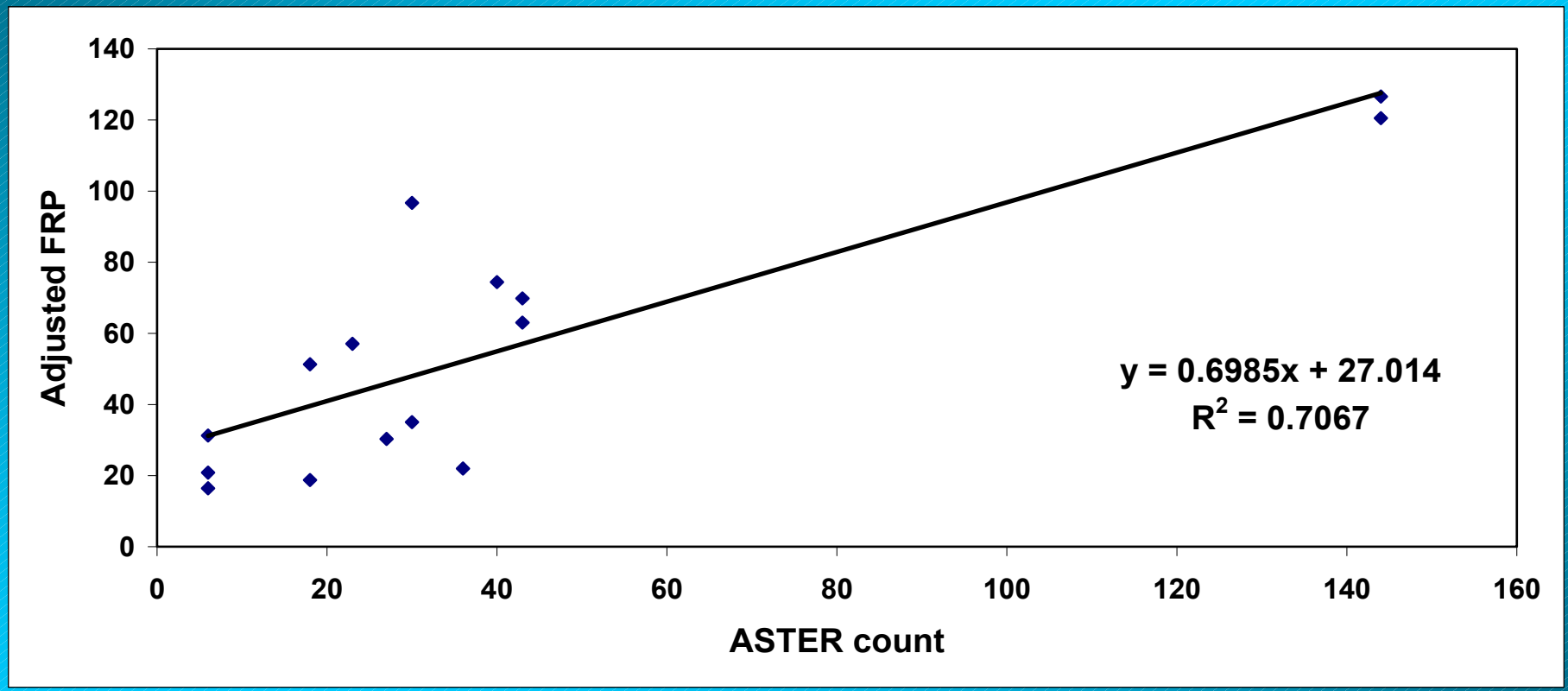
**Roraima, February 2004**

# Comparison with classification results

| Fire type | Mean FRP | Mean $FRP_a$ | | |
|---|---|---|---|---|
| Conversion | 26.51 | 50.51 | | |
| Maintenance | 41.47 | 65.78 | | |

**FRP values in [MW]**

# What drives the FRP value?




- size of fire
- intensity of fire

$$FRP_n = FRP_a / n = FRP / \sum_{i=1}^{n} k_i$$

normalization for per ASTER pixel mean radiant intensities

# Comparison with classification results

| Fire type | Mean FRP | Mean $FRP_a$ | Mean $FRP_n$ | |
|---|---|---|---|---|
| Conversion | 26.51 | 50.51 | 2.38 | |
| Maintenance | 41.47 | 65.78 | 1.35 | |

FRP values in [MW]

# Comparison with classification results

| Fire type | Mean FRP | Mean $FRP_a$ | Mean $FRP_n$ | Mean # ASTER |
|---|---|---|---|---|
| Conversion | 26.51 | 50.51 | 2.38 | 26 |
| Maintenance | 41.47 | 65.78 | 1.35 | 70 |

FRP values in [MW]

**Over our limited sample, fire radiant intensity tends to be higher for deforestation (conversion) fires than for maintenance fires. Original FRP measurements indicate the opposite.**

# Burn severity

- Normalized Burn Ratio

$$NBR = \frac{R_{NIR} - R_{SWIR}}{R_{NIR} + R_{SWIR}}$$

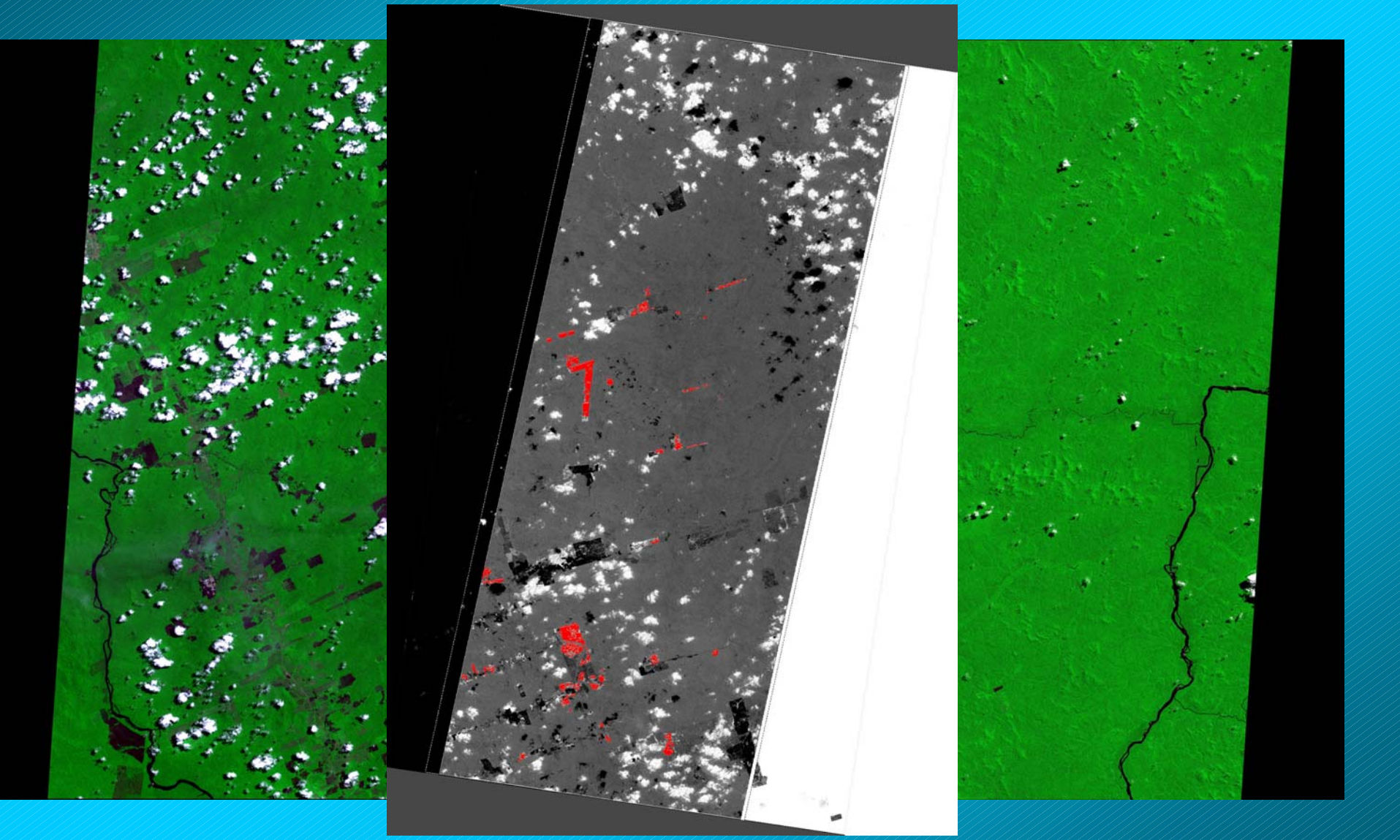
$R_{NIR}$ = near-infrared reflectance
$R_{SWIR}$ = shortwave-infrared reflectance

| | $R_{NIR}$ | $R_{SWIR}$ |
|---|---|---|
| ASTER | Band 3: 0.76 - 0.86 µm | Band 6: 2.185 - 2.225 µm |
| MODIS | Band 2: 0.84 - 0.88 µm | Band 7: 2.11 - 2.16 µm |

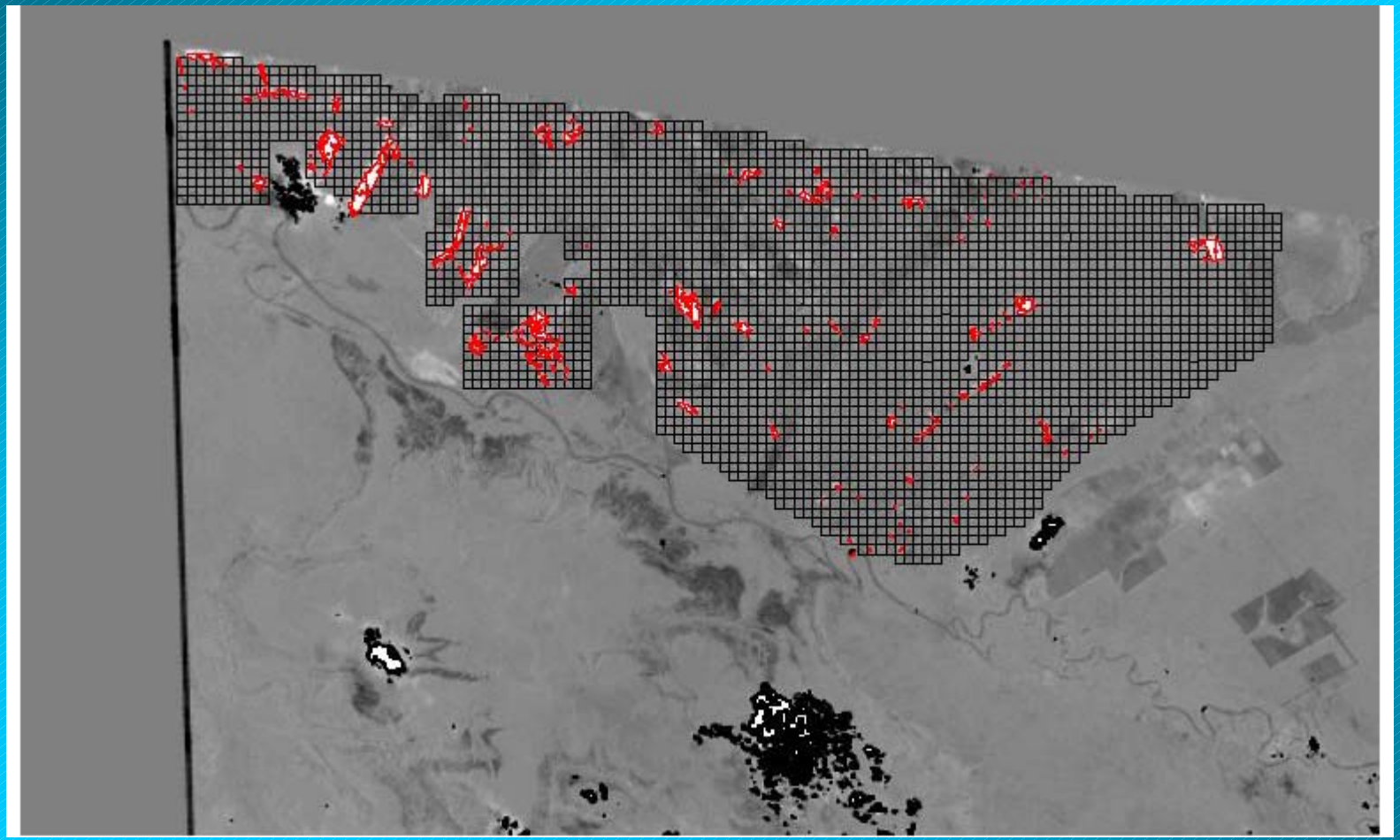
- Normalized Difference Burn Ratio

$$dNBR = NBR_{preburn} - NBR_{postburn}$$

# Brazilian Amazon

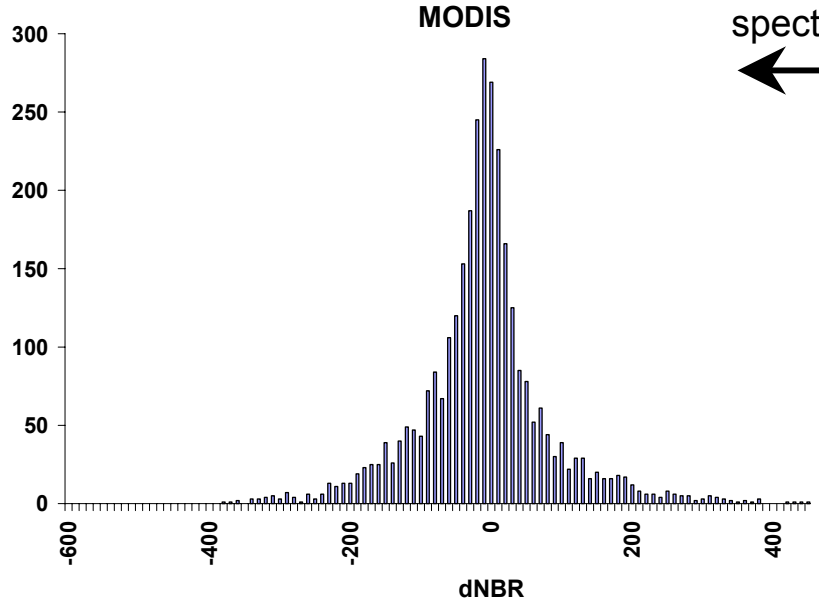


# MODIS dNBR vs. ASTER dNBR

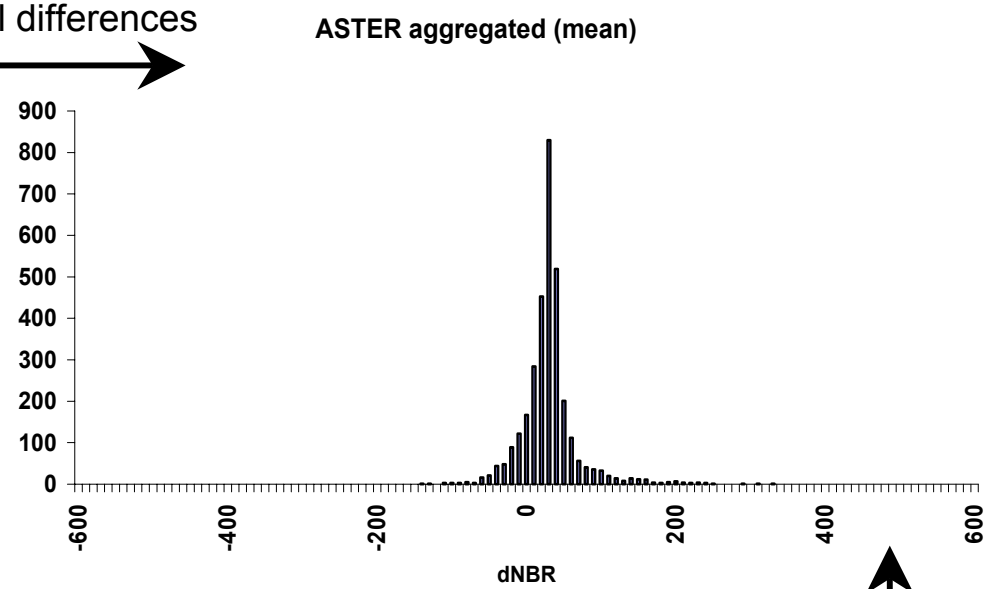


- MODIS grid mapped onto ASTER
- area with burn scars, but no clouds and cloud shadows selected
- compared MODIS dNBR with original resolution and aggregated ASTER dNBR

# MODIS dNBR vs. ASTER dNBR

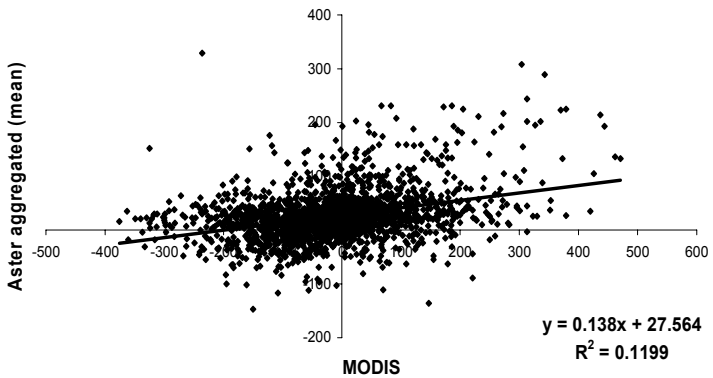


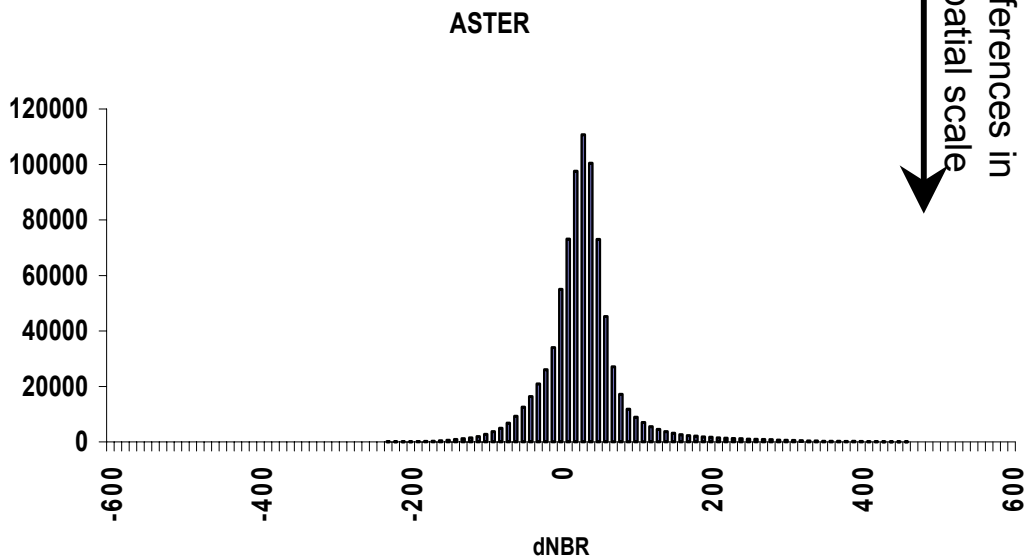

spectral differences



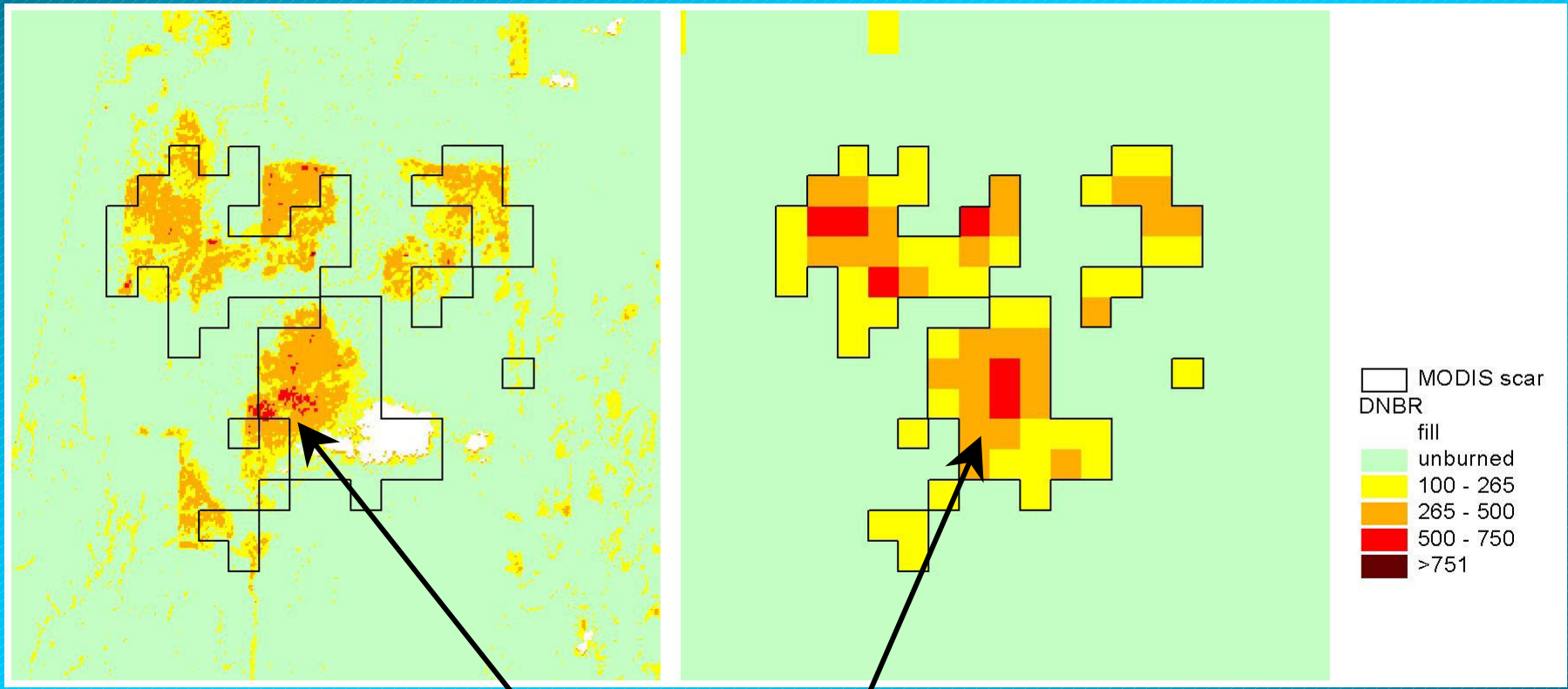

differences in spatial scale

spatial misregistration



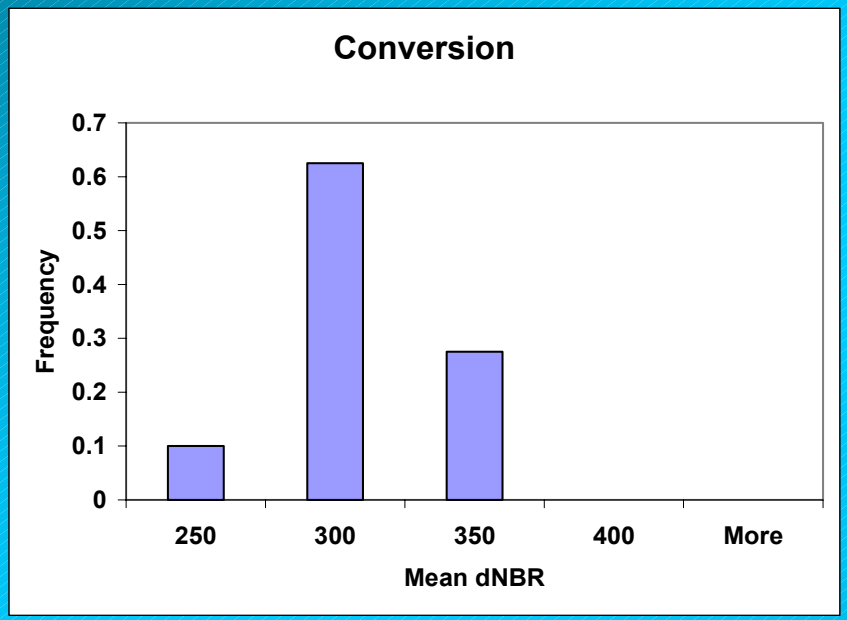



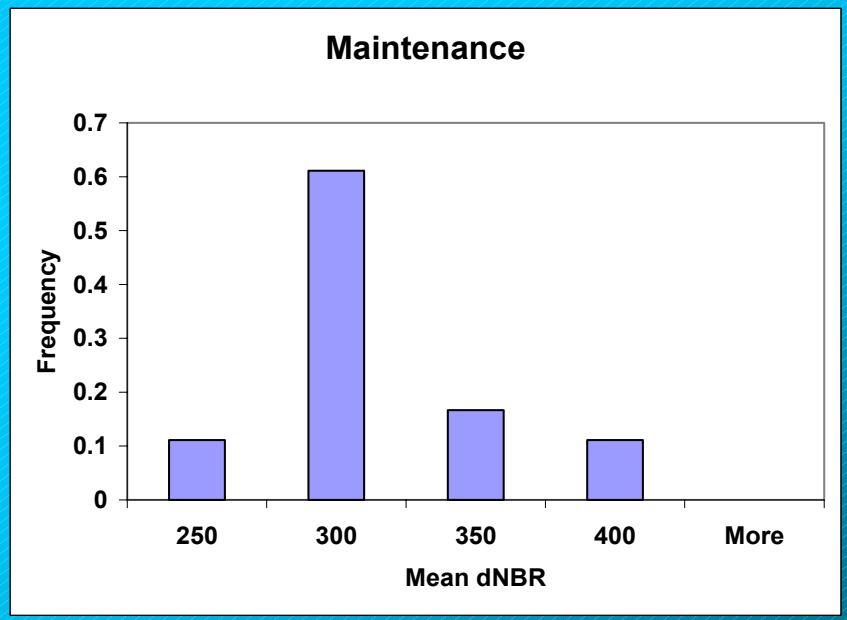
# MODIS dNBR vs. ASTER dNBR




artifacts from the MODIS gridding / sampling procedure

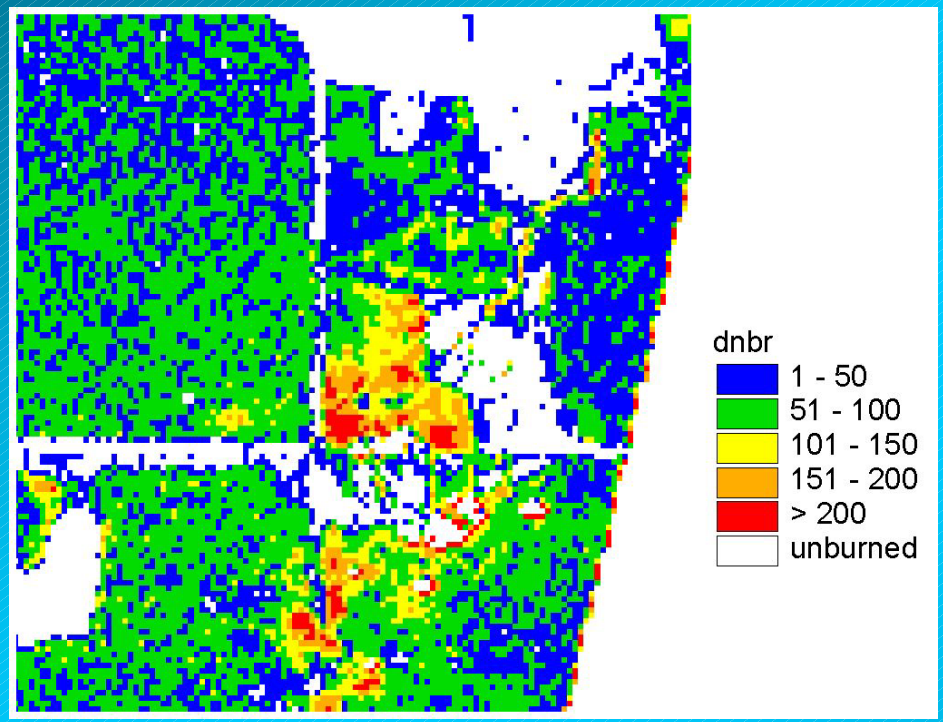
# ASTER dNBR vs. fire classification

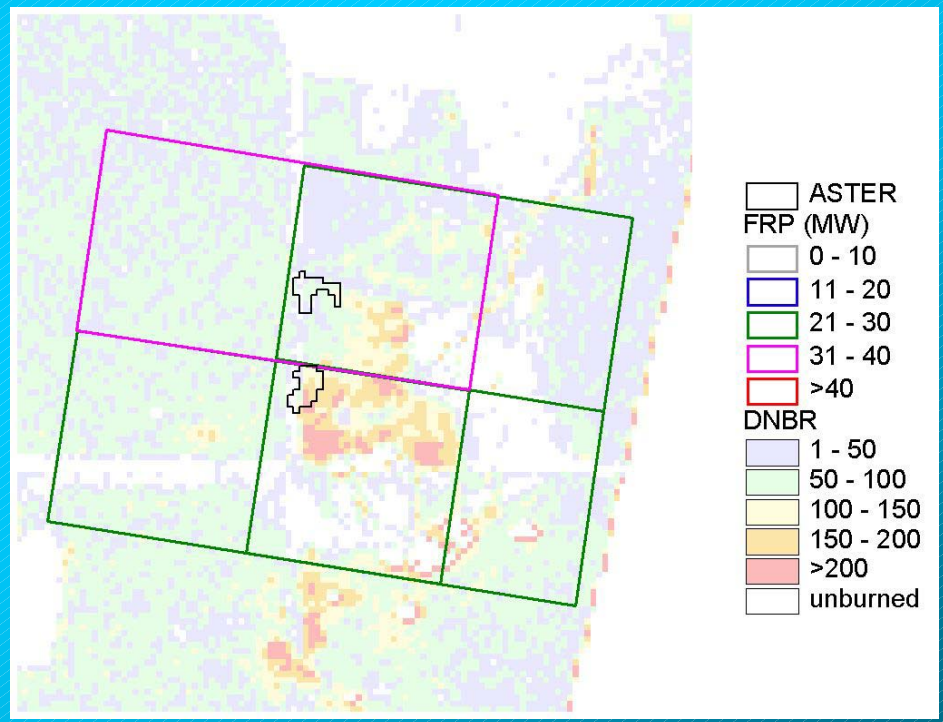



No clear distinction in the dNBR signal between conversion and maintenance fires

# Mapping active fires and dNBR




ASTER active fire masks mapped onto dNBR

# $FRP_n$ vs. dNBR

| $FRP_n$ [MW] | mean dNBR |
|---|---|
| 1.123 | 105 |
| 1.168 | 48 |
| 1.545 | 232 |
| 2.481 | 438 |
| 4.342 | 201 |

- very limited sample
- no tendency to correlate observed
- instantaneous vs. cumulative
- time-integrated FRP: Fire Radiative Energy (FRE)

# Conclusions

- Fire Radiative Power
  - provides direct observation of the burning process
  - adjustments are necessary for individual quantitative studies – fusion of MODIS and ASTER provides a way
  - normalized radiant intensity higher for conversion than for maintenance fires (?)
- Differential Normalized Burn Ratio
  - scale of the heterogeneity of burning does not allow the meaningful use of MODIS-derived dNBR
  - higher resolution dNBR (e.g. ASTER) useful for mapping burned areas
  - more ambiguous signal
    - provides cumulative observations: implicitly includes post-fire processes also!
  - just a “snapshot” of multi-year processes: cannot clearly distinguish between fire types
  - additional information on burning?

# Future

- FRP
  - evaluate statistics of instantaneous fire sizes
    - decouple size/intensity signal in FRP
  - evaluate view angle effects
  - include FRP in regional and local scale analyses
- dNBR
  - analyze ground and aircraft observations
  - look at alternative ways to explore information from reflective bands
- develop multi – parameter, multi-sensor fire products -> LC-35 project