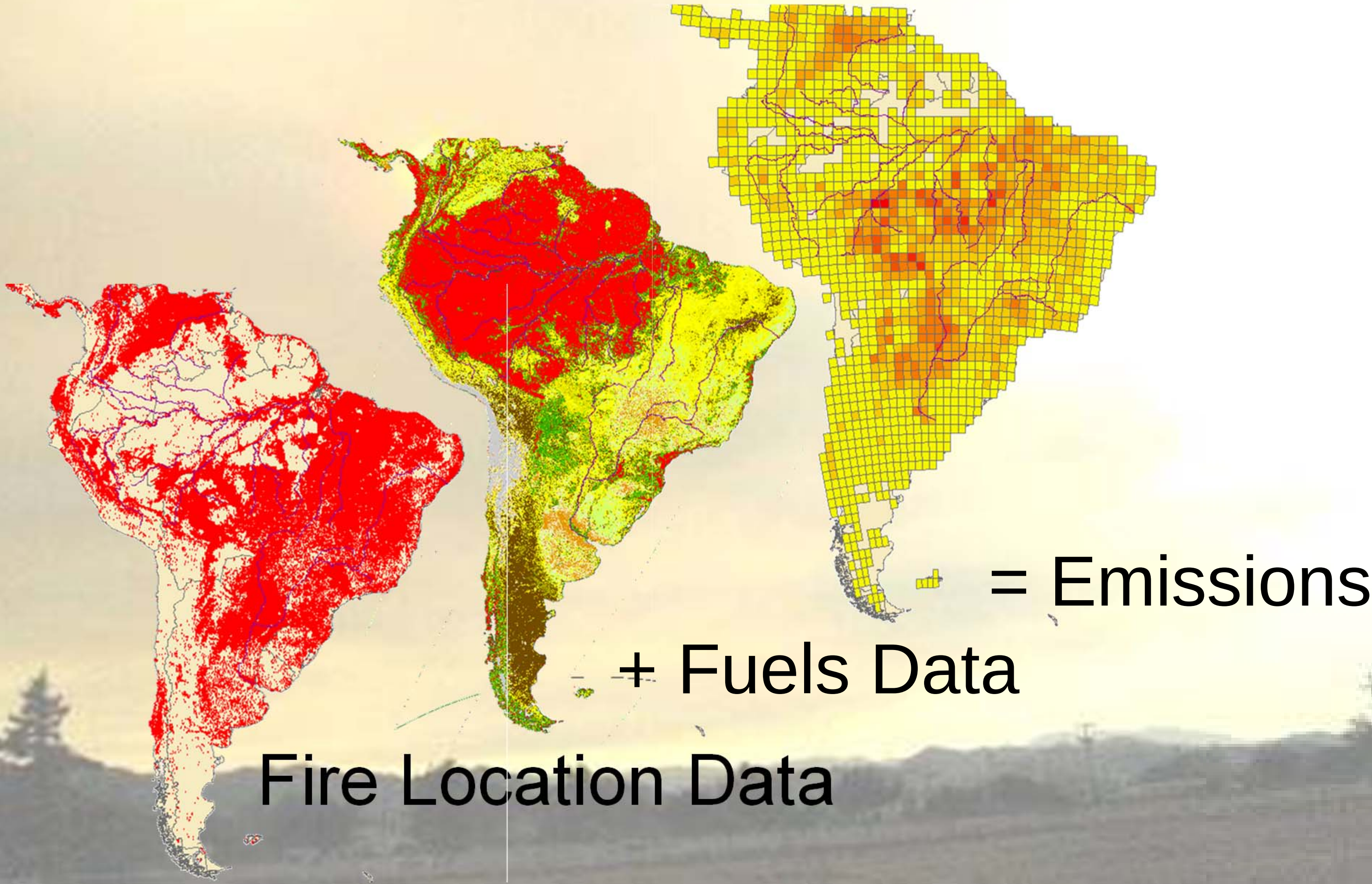
Considerations for Satellite Based Fire Emissions

Edward Hyer, NRL

Outline

1. Data Requirements for Fire Observations
2. Challenges to quantitative fire emissions estimation from space: what we’re up against
3. Fire detection vs. scale: do different sensors see the same thing?
4. Derivation of a combined cloud-cover-geometry correction for MODIS fires
5. A few more words about fire diurnal cycles

The Heart of the Process



Implications of these limitations for smoke emission estimation

- An operational emissions estimation system should:
  - Produce consistent emissions from a variable constellation
  - Correct for known sensor properties affecting fire detection
  - Capture variability in fire behavior at diurnal and sub-diurnal scales

Information Requirements

- Latency of Data
  - Faster is better
  - for GEO, should be within one hour
  - for LEO, less strict
    - requires diurnal interpolation
- Data delivered
  - Fire detections
    - location + timing
    - view conditions
  - Satellite Scan pattern
    - scanned
    - not scanned
    - no detection possible
  - Ancillary
- Resolution Requirements
  - Location of Fires (Spatial Resolution)
    - For atmospheric purposes: ~10km
    - For fuels mapping: ~100m
  - Timing of Fires
    - Hourly or better
  - Intensity of Fires
    - This is a subpixel property
    - Current products provide information, but application poses challenges

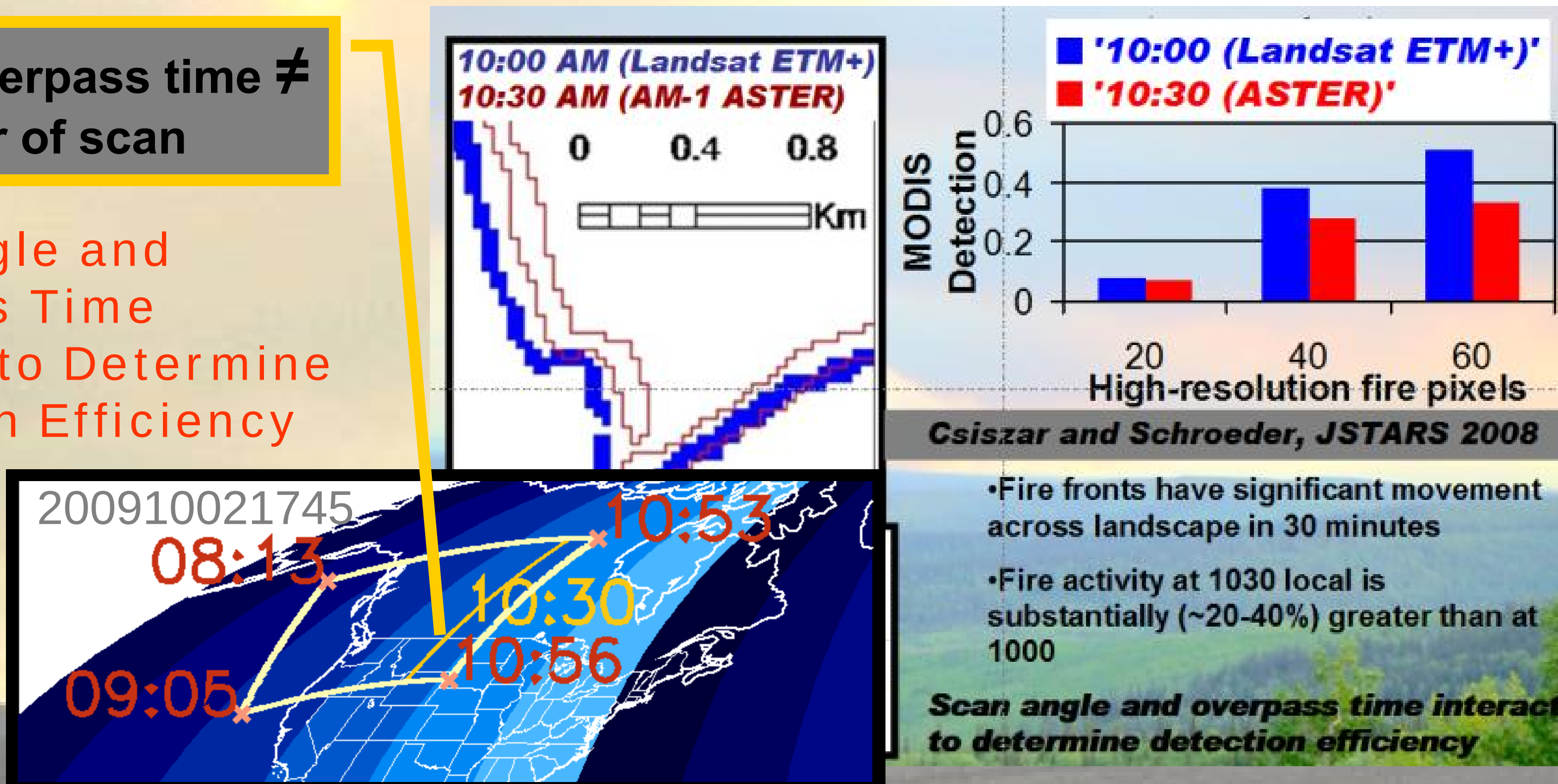
How well do current satellites meet these requirements?

3) Temporal Sampling is too slow

- Fire is a highly variable signal
  - 30 minutes is a long time

Nominal overpass time ≠ center of scan

Scan Angle and Overpass Time Interact to Determine Detection Efficiency



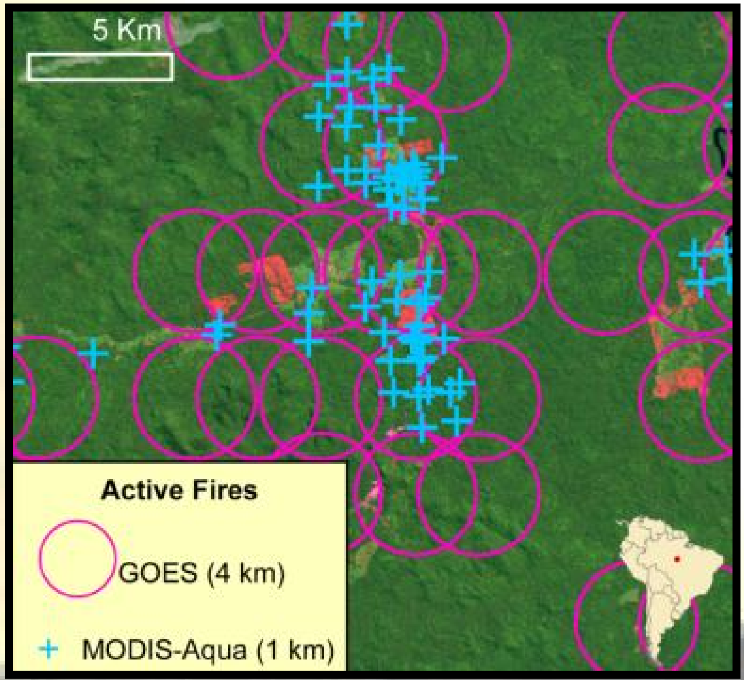
2) Spatial Information is Too Coarse

- Fire is a highly variable signal
  - 30 minutes is a long time
  - 1500m is a big jump

•Spatial resolution of sensors does not allow 100% attribution of fuels in mixed landscapes

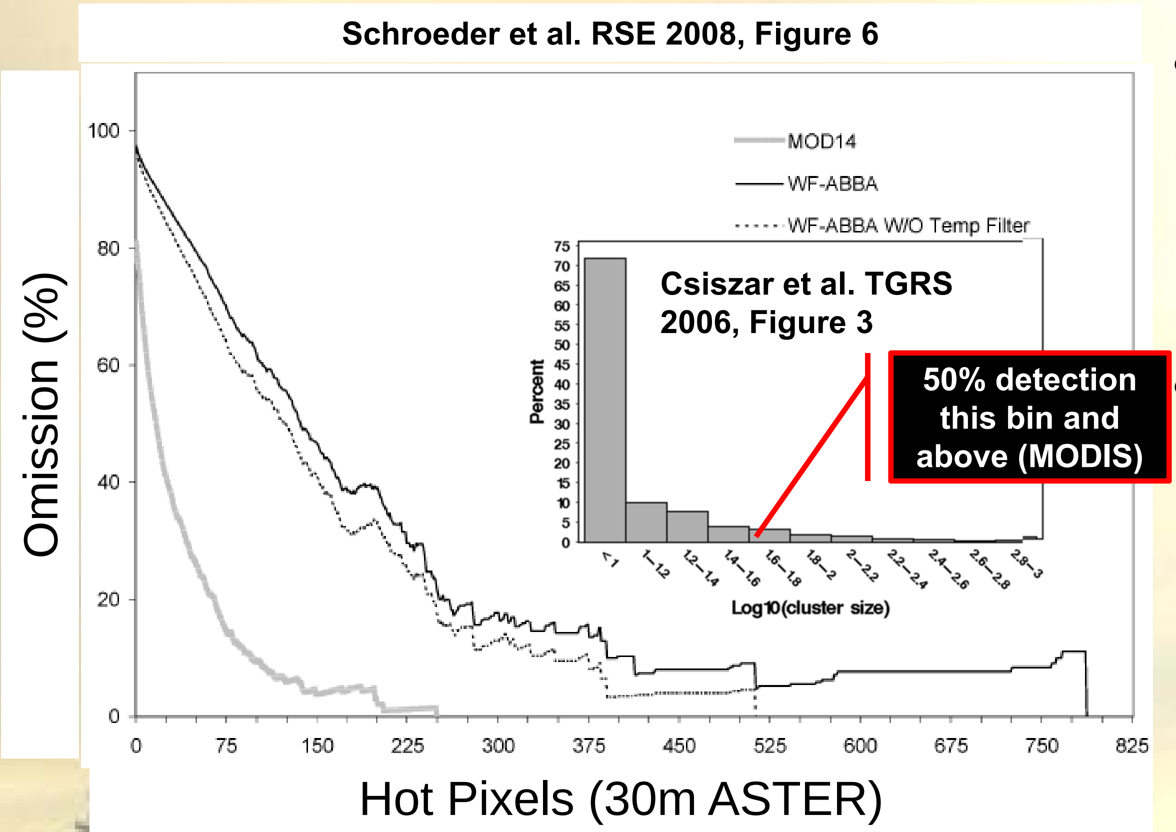
•Systematic bias because fires are not evenly distributed spatially (Hyer and Reid, GRL 2009)

•Random error that disrupts spatial/temporal pattern of emissions



Hyer and Reid, GRL 2009

1) Most fires are missed



- “Most fires” does not necessarily mean “most fire activity”
- In many ecosystems, total emissions are dominated by the largest fires

Implications of these limitations for smoke emission estimation

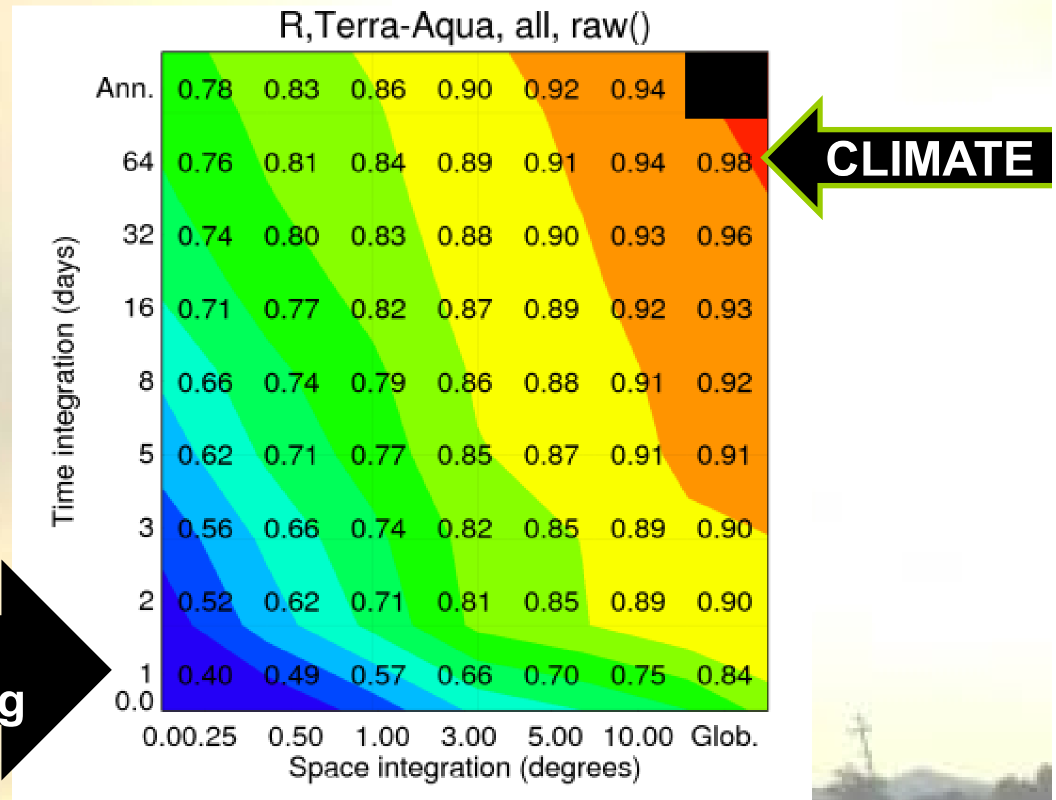
1. Omission errors dominate, so don’t discard data
   - Use all available sensors all the time
   - Find a way to use both MODIS and GEO data: MODIS is more sensitive, but GEO provides diurnal information very valuable for modeling plume transport
2. Scaling will be necessary: observations cannot ‘close the loop’ of fire energy
   - FRP gives a physically meaningful number, but scaling is required at multiple steps to get to emissions
3. Satellite overpasses are best treated as independent snapshots
   - Spatial scale of obs and speed of changes in fire behavior preclude modeling evolution
4. Terra=1030LST is an unacceptable assumption

Variability in Fire vs. Variability in Observations

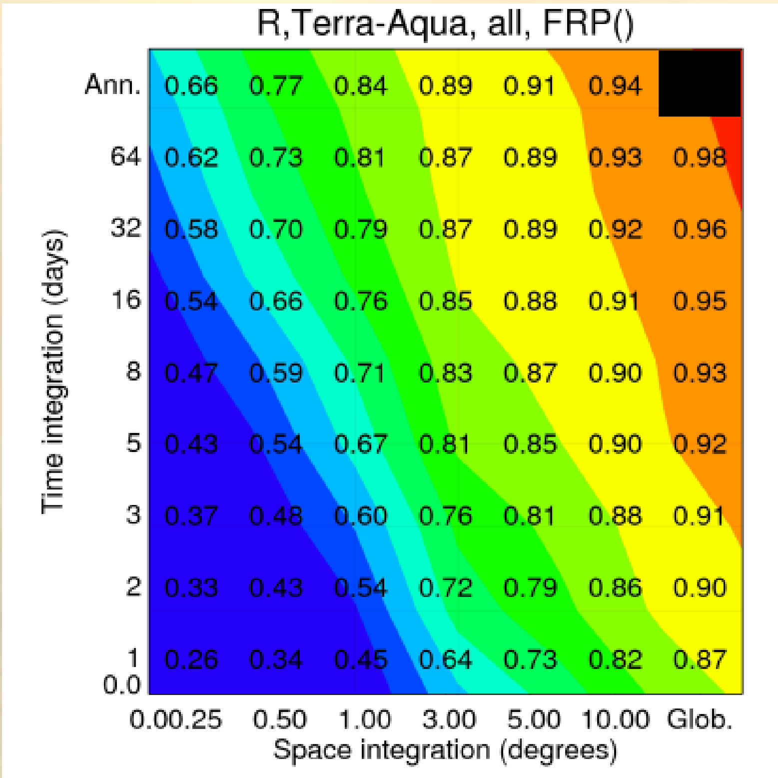
- ***Q: Do Terra and Aqua seem the same patterns of fire activity?***
- ***A: Yes, at sufficiently coarse scales***
- At **temporal scales** smaller than the orbital period, variations in MODIS detection reduce correlation
- At finer **spatial scales**, variations in fire behavior assert themselves

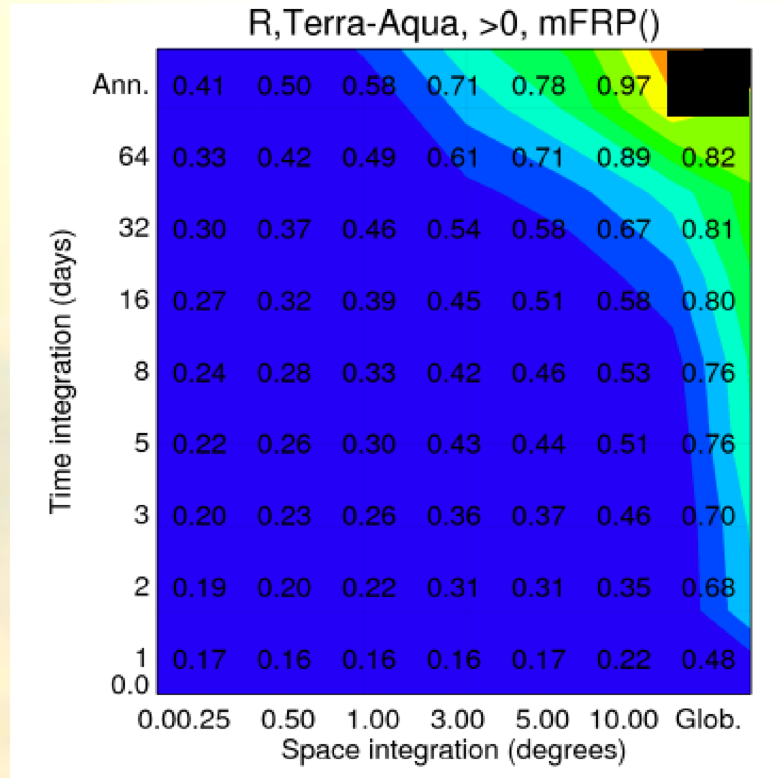
- **At scales relevant for AQ forecasting,**

Terra and Aqua see different fires



What About Fire Radiative Power?



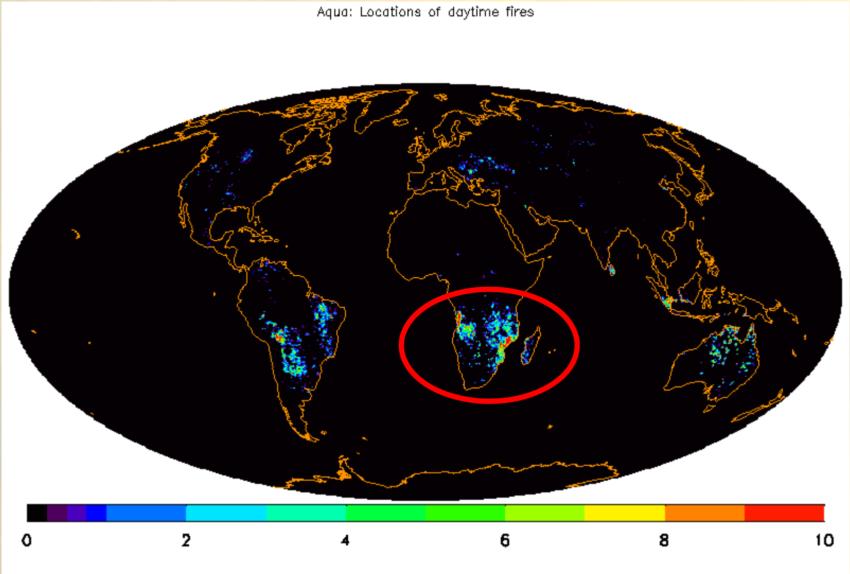


- **Total FRP is driven by fire counts**
- **At fine spatial scales, weighting by FRP reduces correlation**

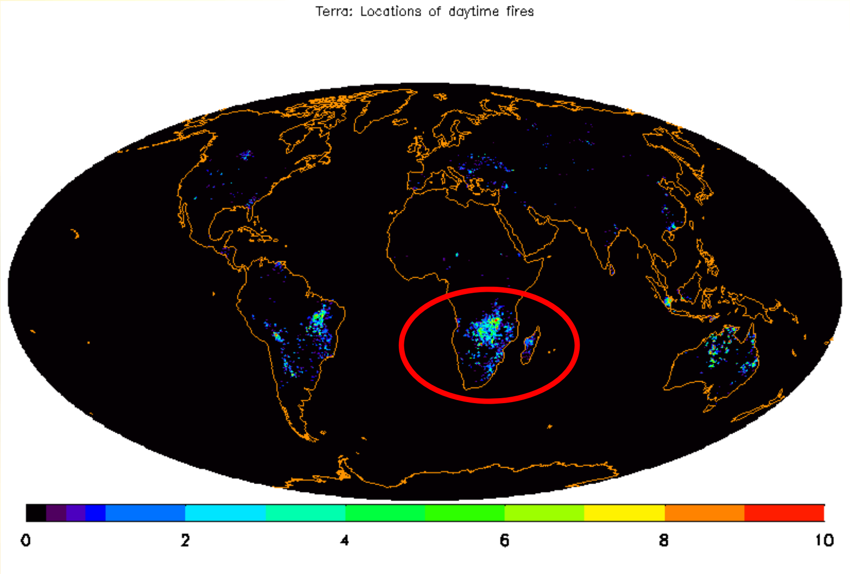
- **Mean FRP has signal, but only after extensive averaging**

A single day's fire activity seen by MODIS-Terra and -Aqua

MODIS-Aqua

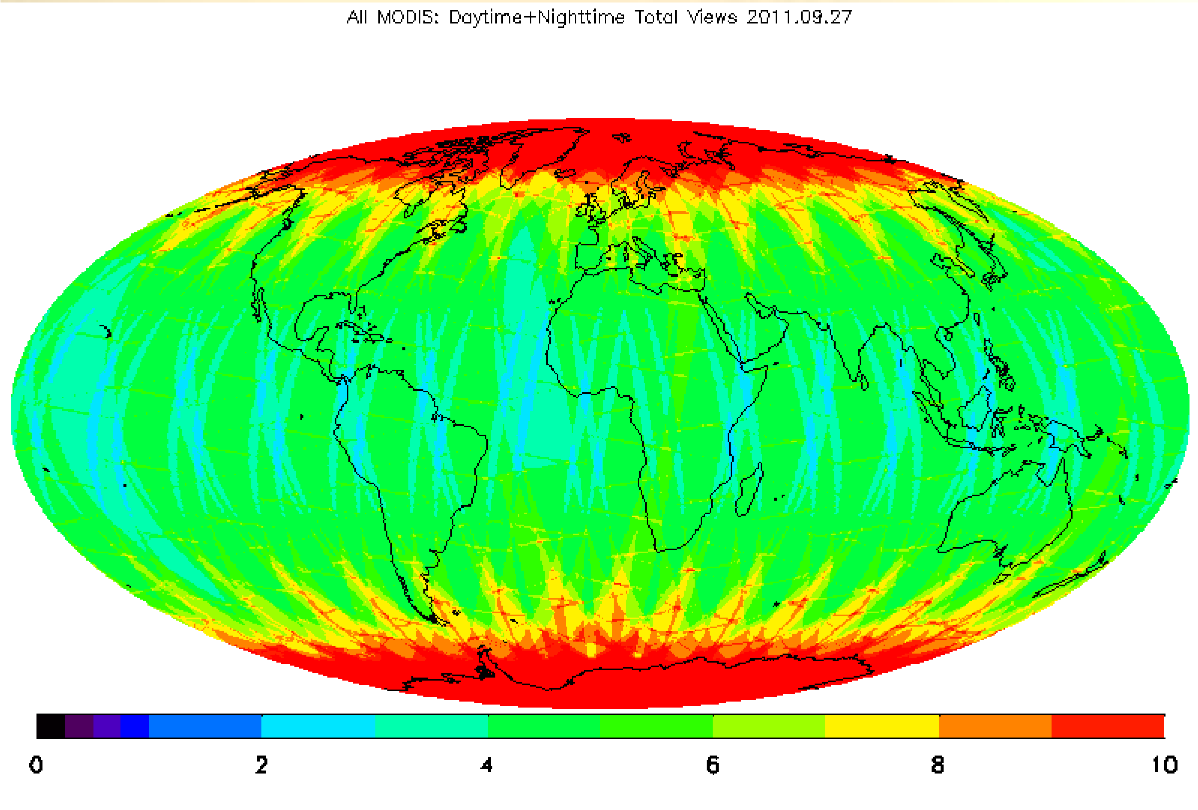


MODIS-Terra



- Daytime fires only, 2011.09.25 – there are fires in all SH continents
- Spatial patterns from Terra and Aqua are very different
- Legend = counts per half-degree grid cell
- **What are the reasons for these differences?**

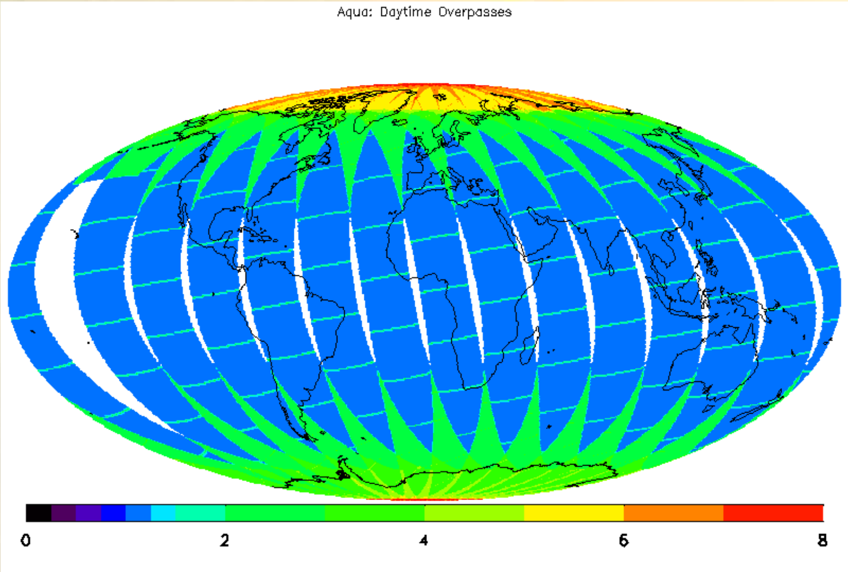
The MODIS scan pattern at face value



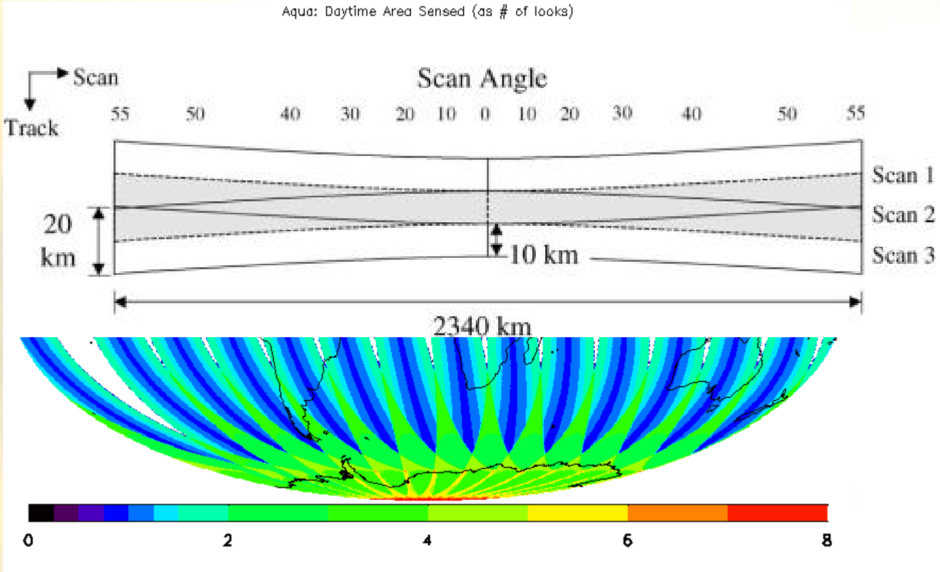
- The "face value" of MODIS coverage is 4 scans/day from Terra and Aqua
- We can see this is broadly accurate in the tropics and subtropics
- Near-global coverage is achieved with a wide swath– viewing geometry ranges to +/-65 degrees on each side of nadir

Accounting for geometry effects on MODIS "detection opportunity"

Aqua, # of overpasses



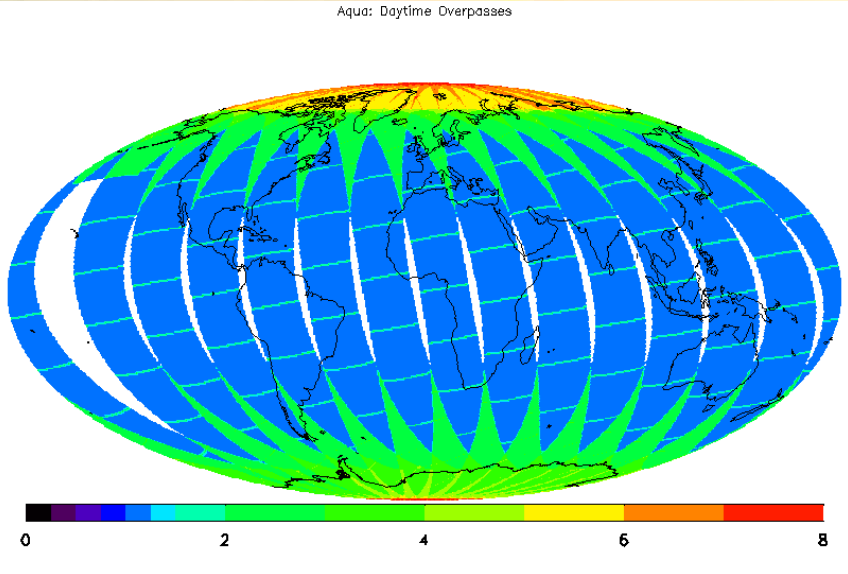
Aqua looks w/scan overlap



- Increased coverage at scan edge
- Scan centers have coverage ~1.0

Accounting for geometry effects on MODIS "detection opportunity"

Aqua, # of overpasses



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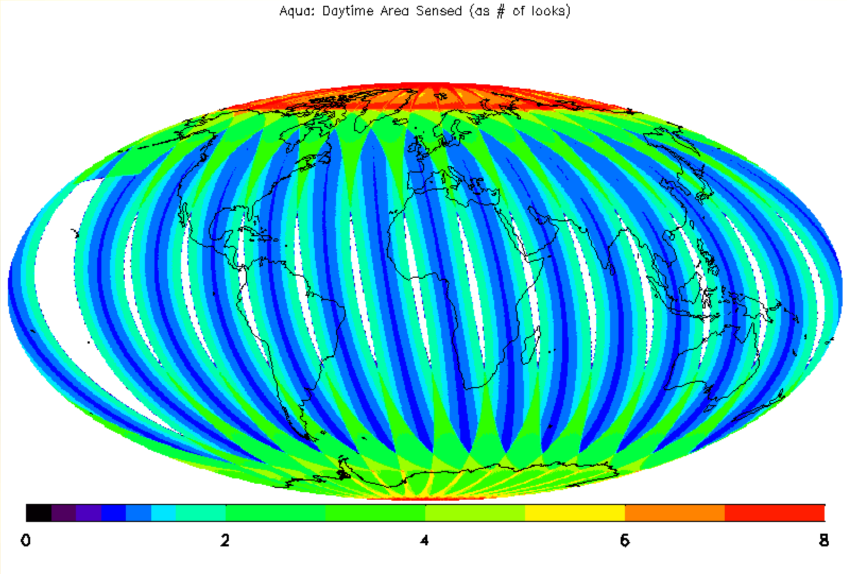
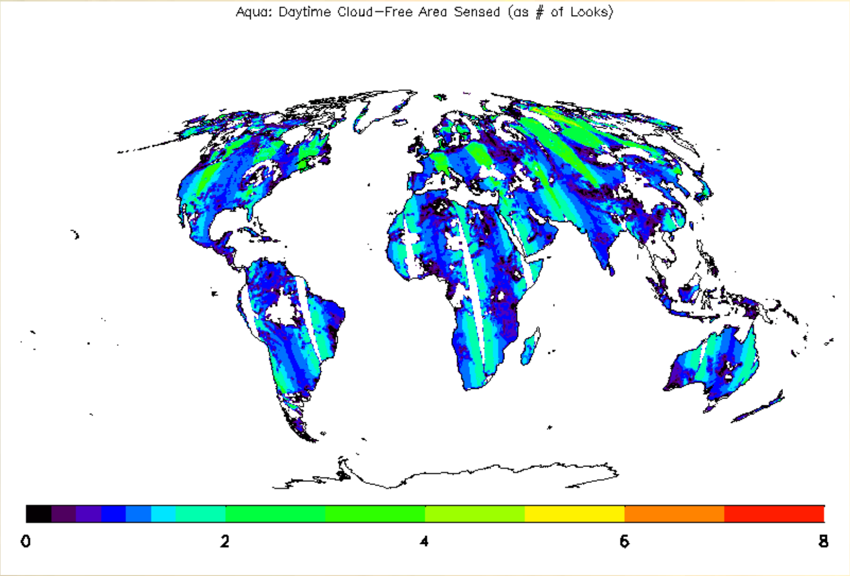


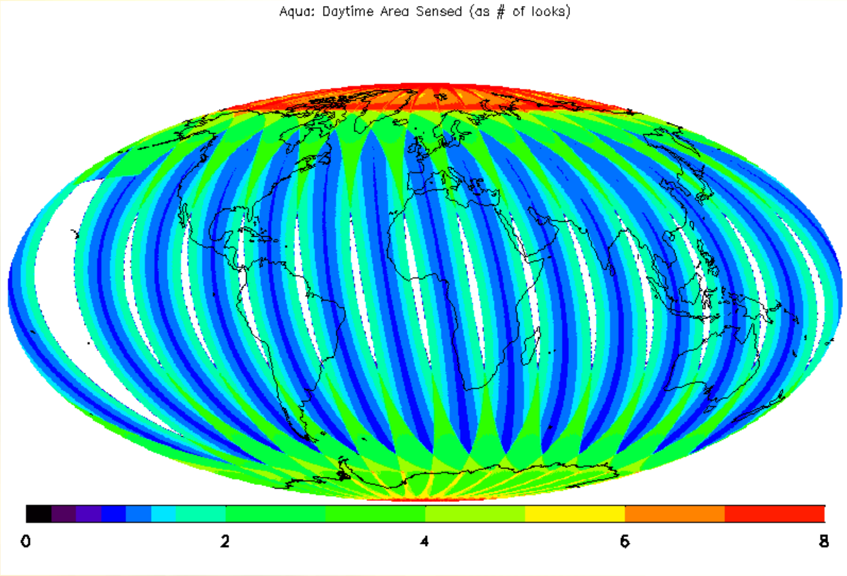
- Increased coverage at scan edge
- Scan centers have coverage ~1.0

Accounting for cloud effects on MODIS "detection opportunity"

Aqua cloud-free valid looks



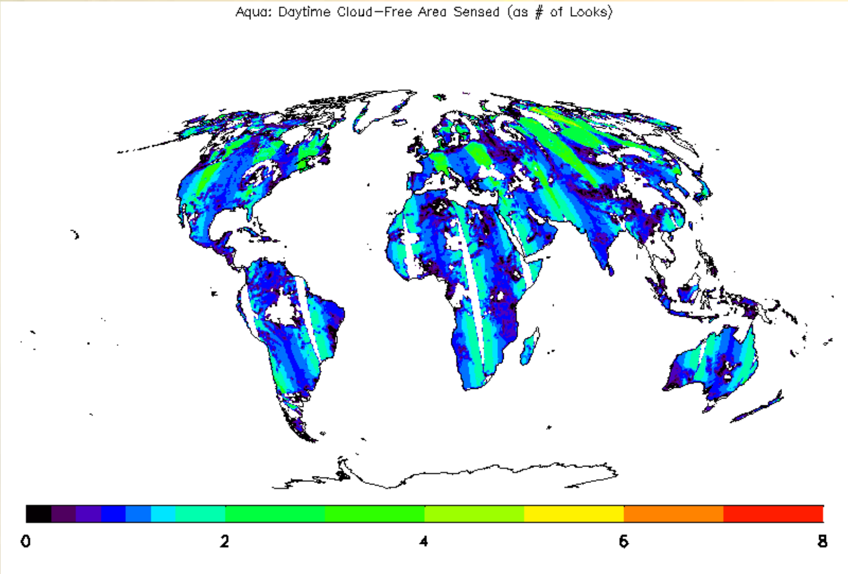
Aqua looks w/scan overlap



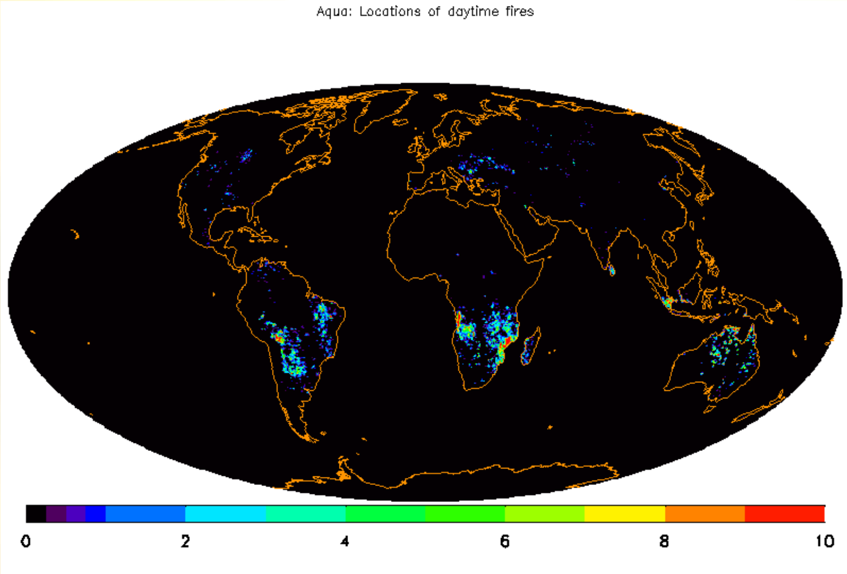
- More representative of detection opportunity

Accounting for cloud effects on MODIS "detection opportunity"

Aqua cloud-free valid looks

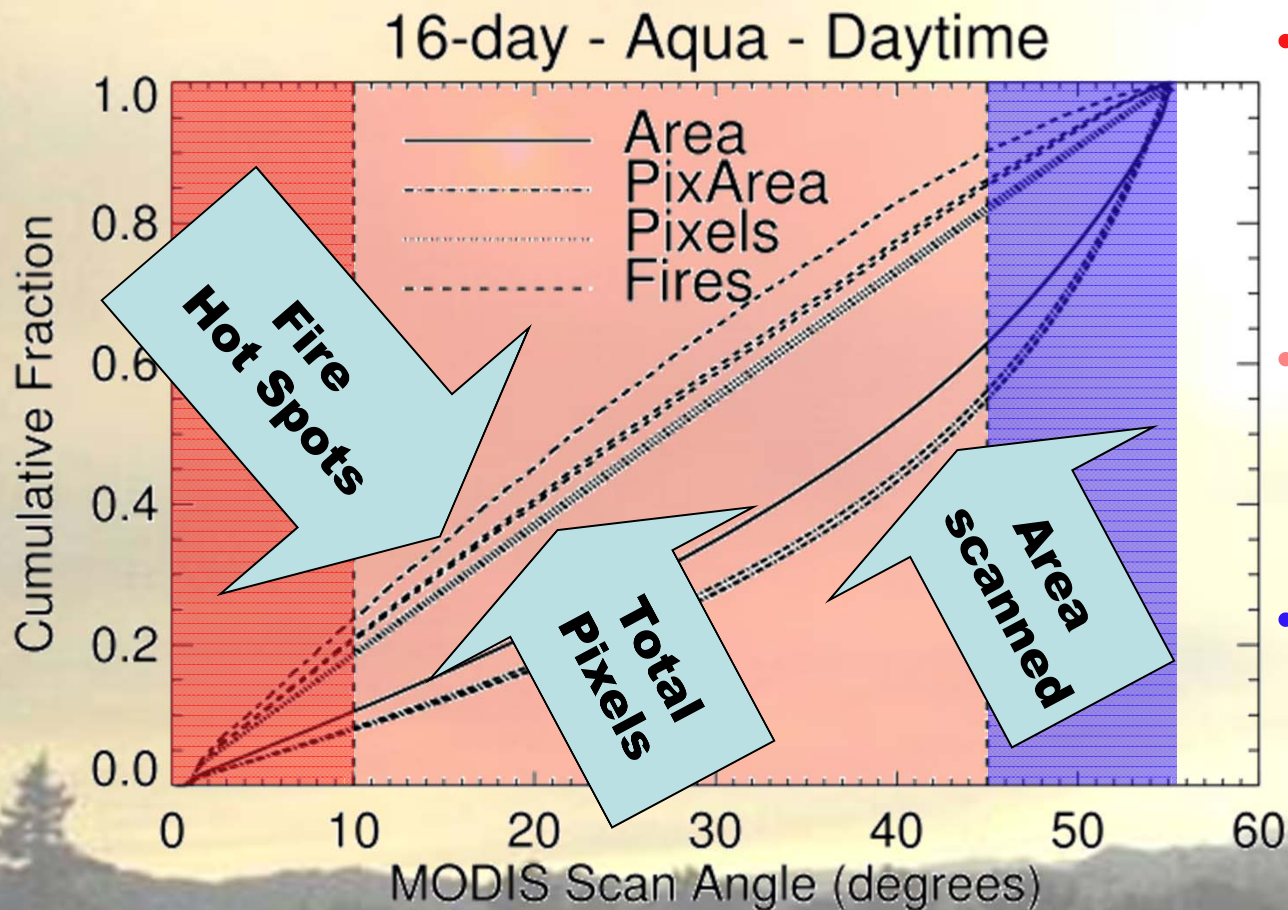


Aqua fires



- More representative of detection opportunity

What does MODIS detection look like across the scan?

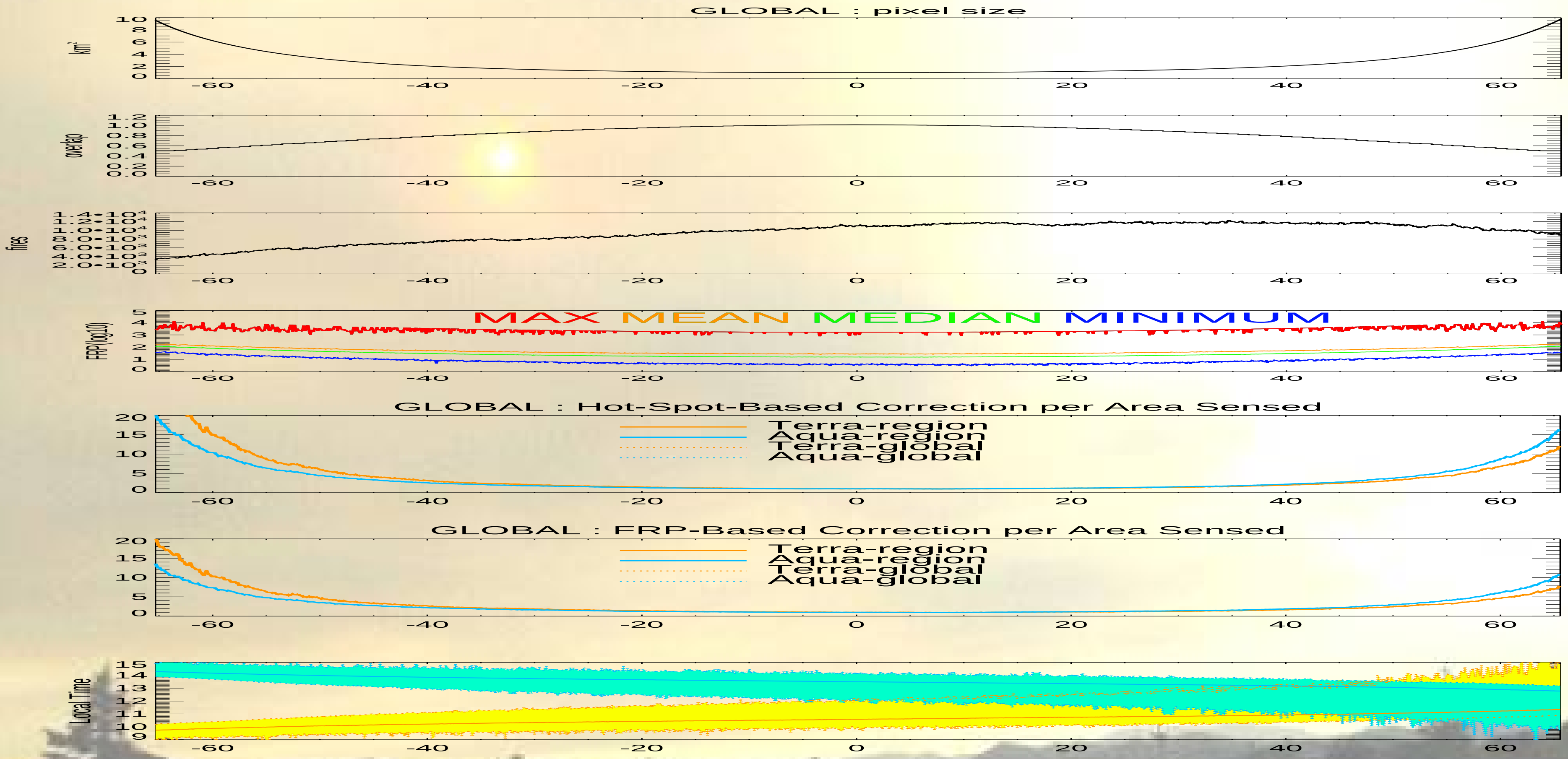


- **Left zone = nadir**
  - **15% of MODIS pixels**
  - **8% of pixel area**
  - **~20% of fires**
- **Center = mid-scan**
  - **65% of pixels**
  - **48% of pixel area**
  - **~65% of fires**
- **Right = scan edge**
  - **20% of pixels**
  - **45% of pixel area**
  - **~15% of fires**

THESE ARE VERY LARGE DIFFERENCES

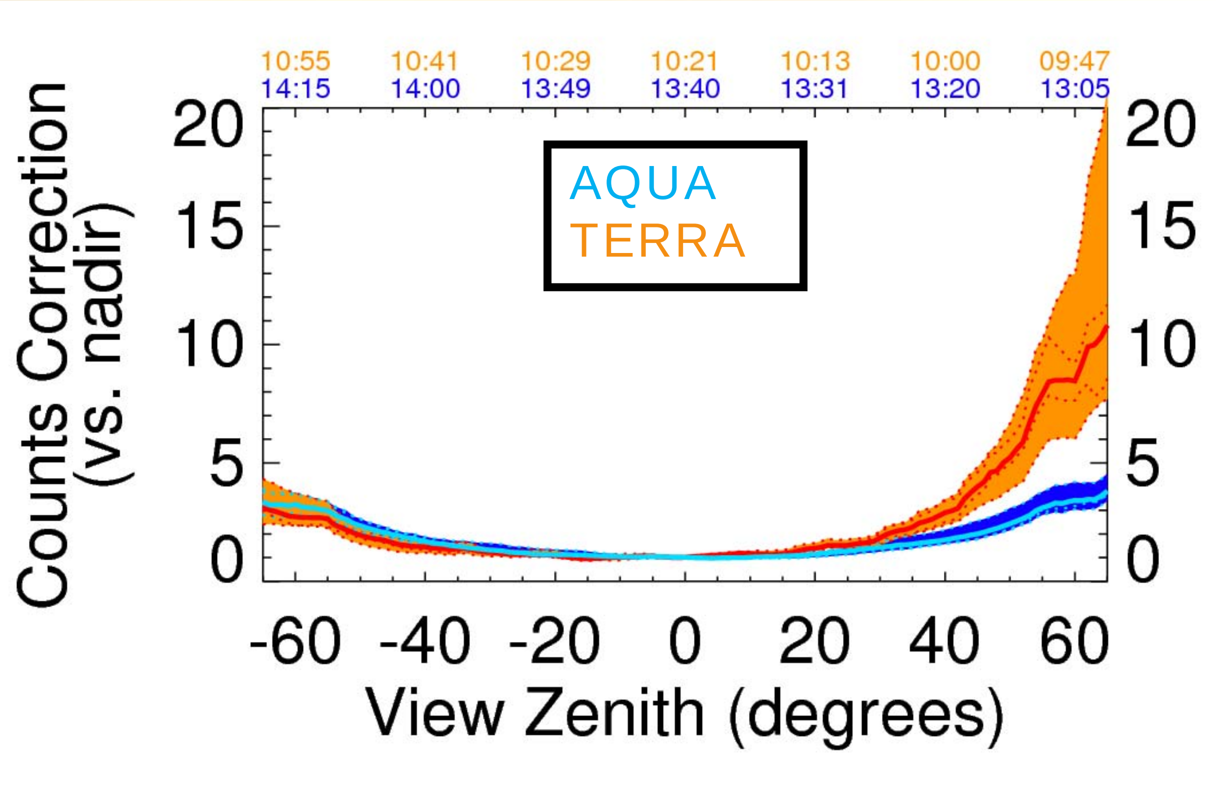
in fire detection efficiency

Competing Effects: Pixel Size and Diurnal Position



Both of these will affect fire detection efficiency

Can we construct an angular correction for fire counts?

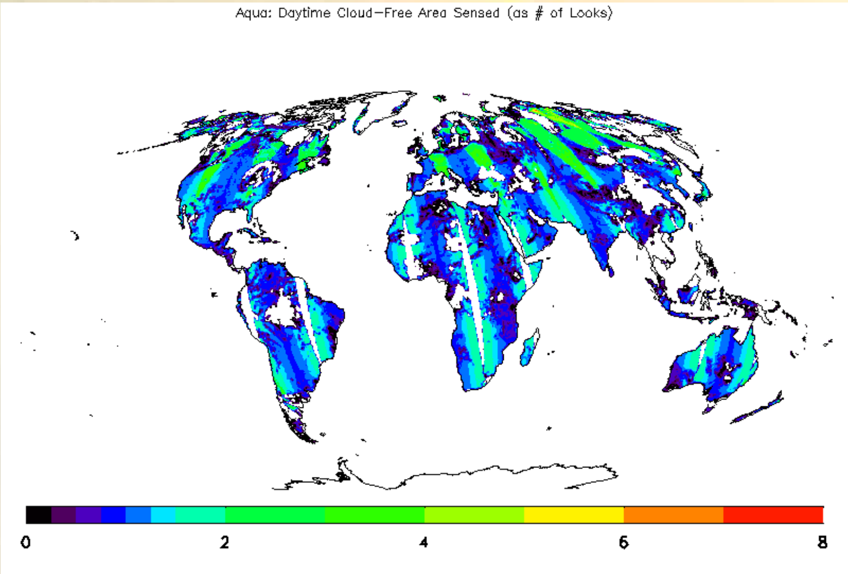


- Dashed lines show results from single years 2007-2010
- Shaded areas indicate range of single-year results
- Correction numbers include correction for pixel overlap

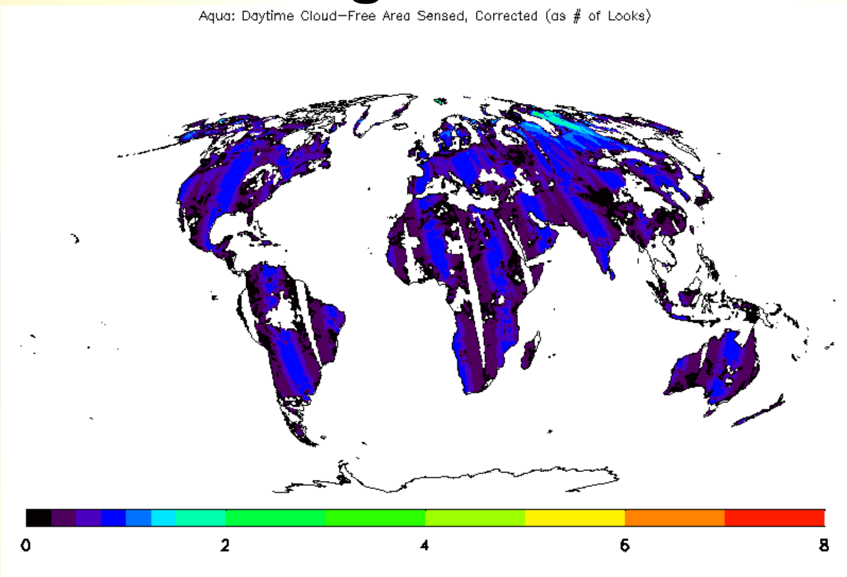
- **Aqua correction is fairly symmetrical**
- **Terra correction is extreme for the early side of the scan**
  - **0945 to 1021 local time is a steep part of diurnal curve**
- **We will use this correction to estimate "nadir-equivalent looks," which will be the denominator of our normalized fire detection**

Accounting for angular effects on MODIS "detection opportunity"

Aqua cloud-free valid looks



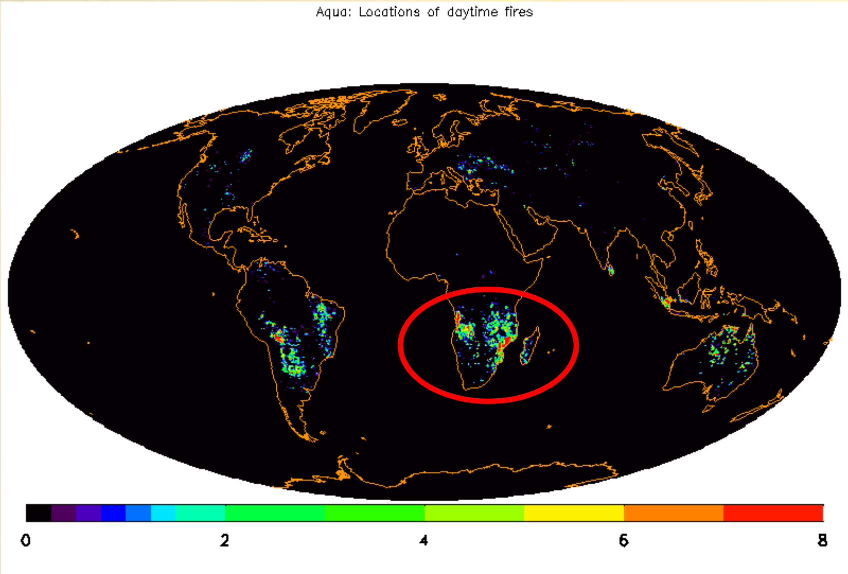
looks w/angular correction



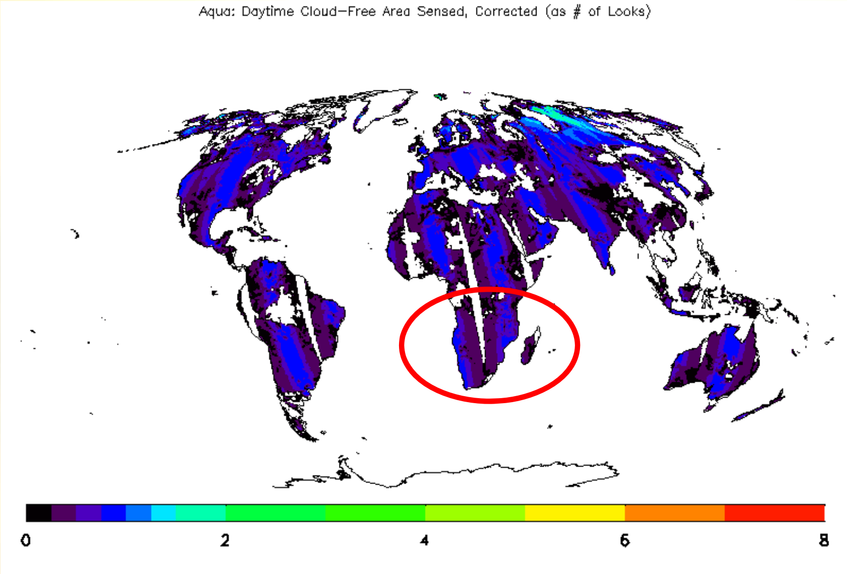
- More representative of detection opportunity
- Most area sensed falls short of nadir detection opportunity
- **"Nadir-Equivalent looks" becomes our coverage correction metric**
  - **For FLAMBE2, per half-degree grid cell per 24 hours**

MODIS “detection opportunity” and MODIS fire detection

Aqua fires



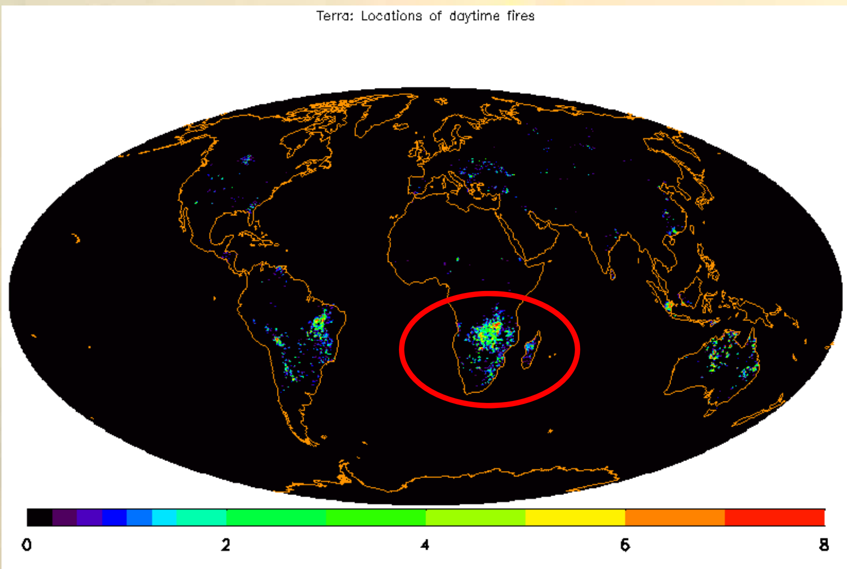
“nadir-equivalent” Aqua looks



- Legend = counts per half-degree grid cell
- More looks => more fires

Terra-Aqua differences follow "detection opportunity"

Terra fires



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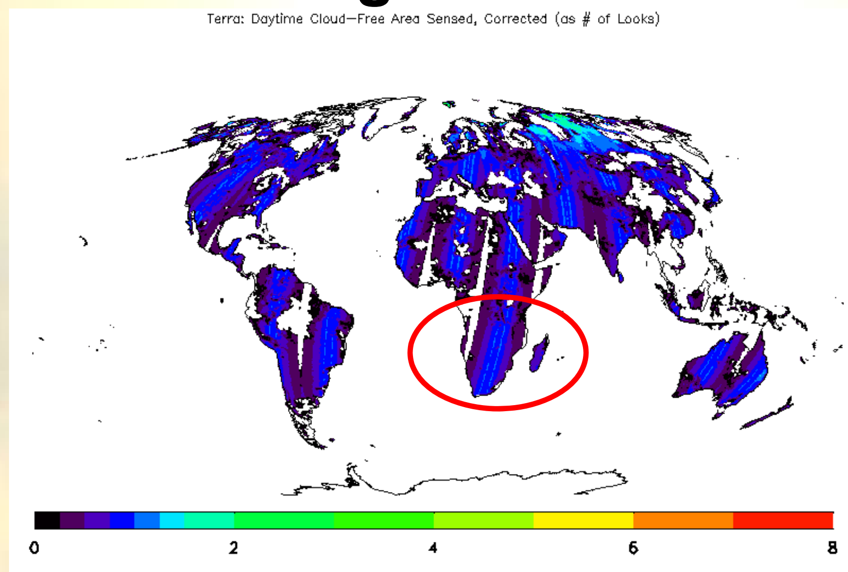
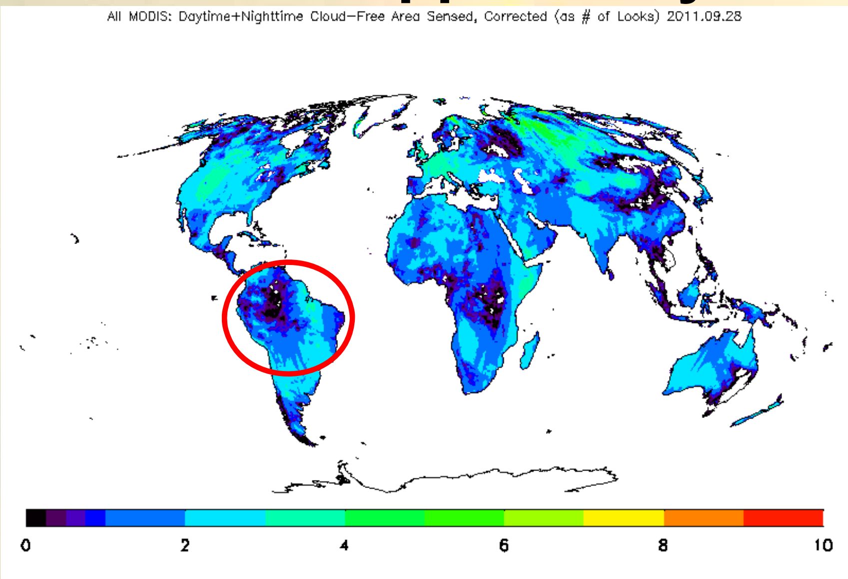


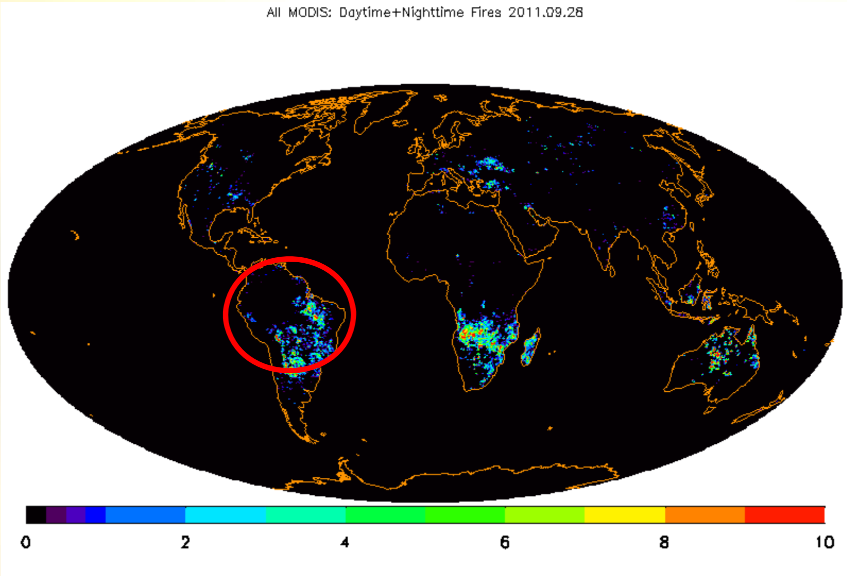
- Legend = counts per half-degree grid cell
- More looks => more fires

Variation in detection opportunity is large from day to day

2011.09.28 opportunity



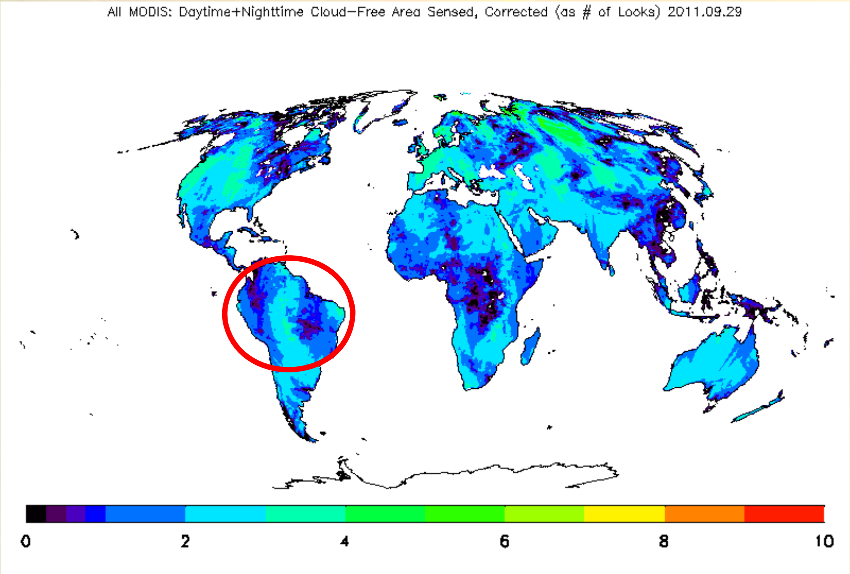
2011.09.28 fires



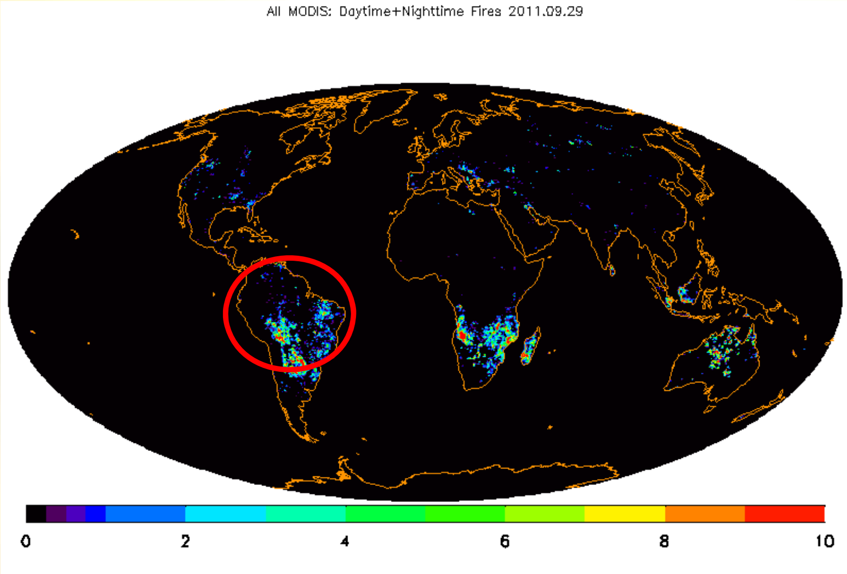
- Terra+Aqua MODIS, daytime and nighttime overpasses
- More looks => more fires

Variation in detection opportunity is large from day to day

2011.09.29 opportunity



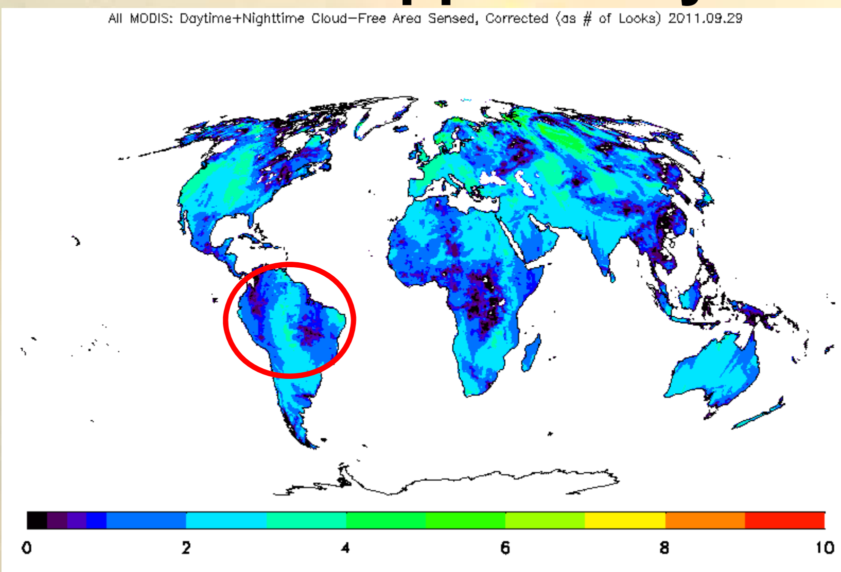
2011.09.29 fires



- Terra+Aqua MODIS, daytime and nighttime overpasses
- More looks => more fires
- Day-to-day variation is mostly artifact of coverage

Variation in detection opportunity is large from day to day

2011.09.29 opportunity



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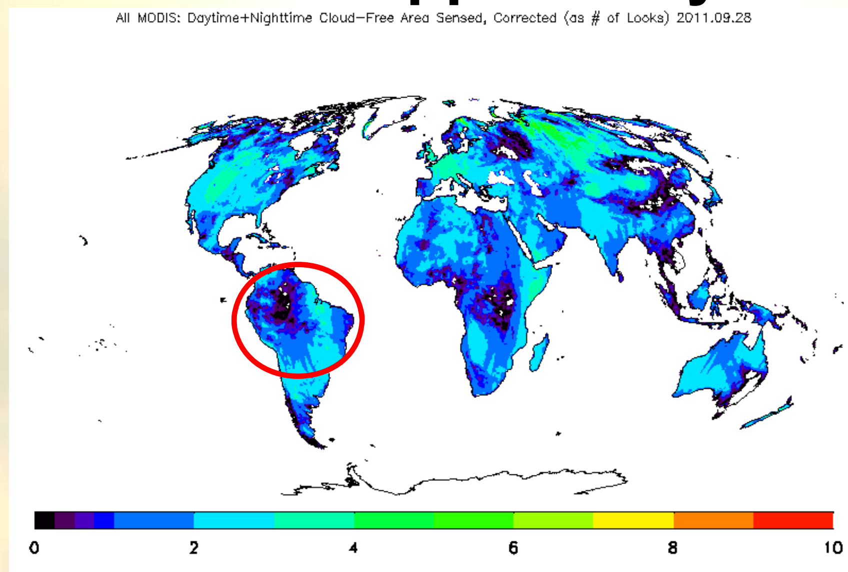
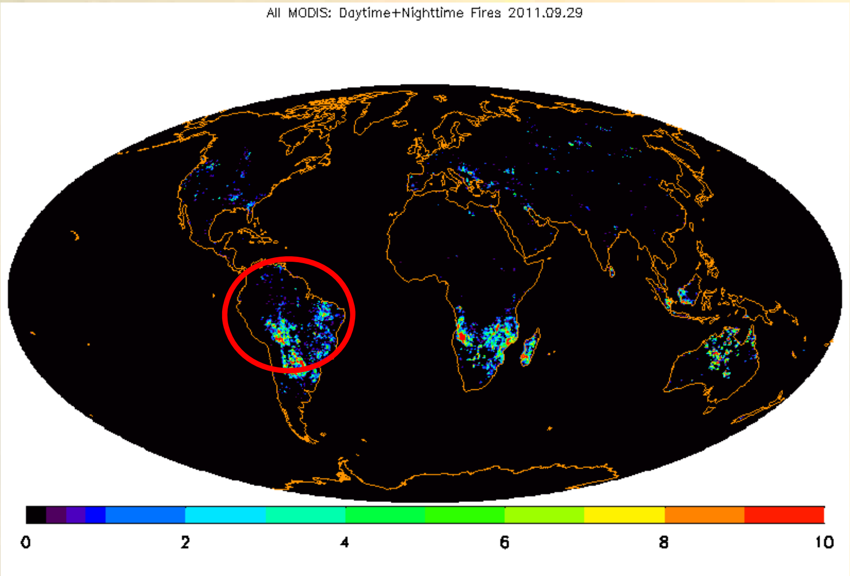


- More looks => more fires

Variation in detection opportunity is large from day to day

2011.09.29 fires



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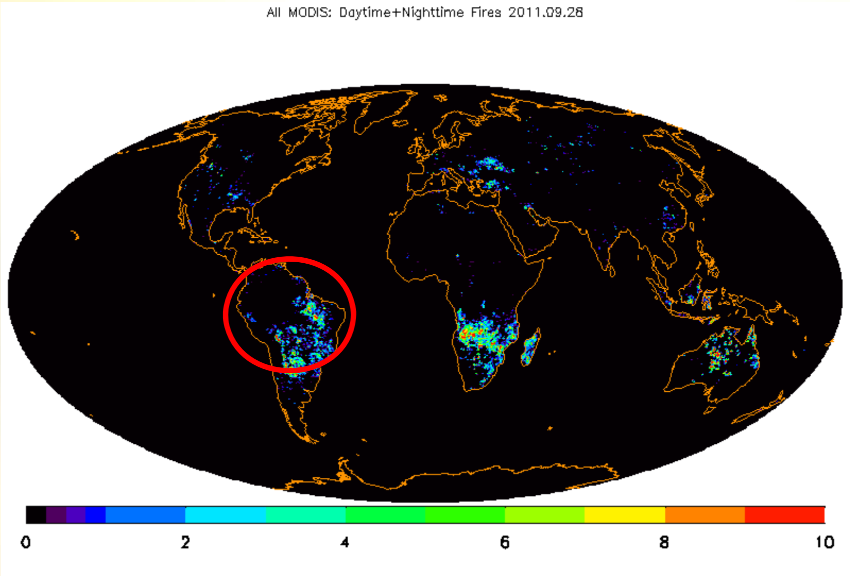

- Legend = counts per half-degree grid cell
- More looks => more fires

Variation in detection opportunity is large from day to day

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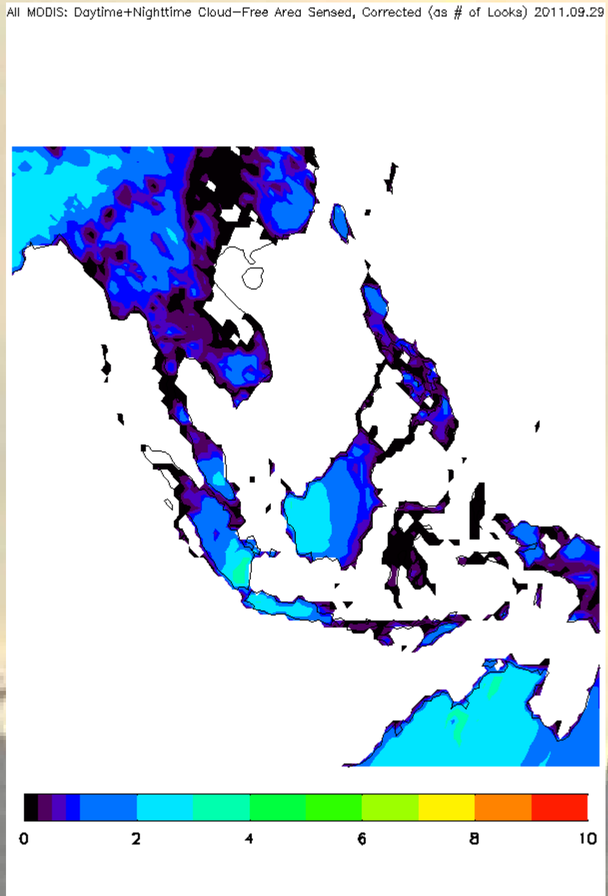

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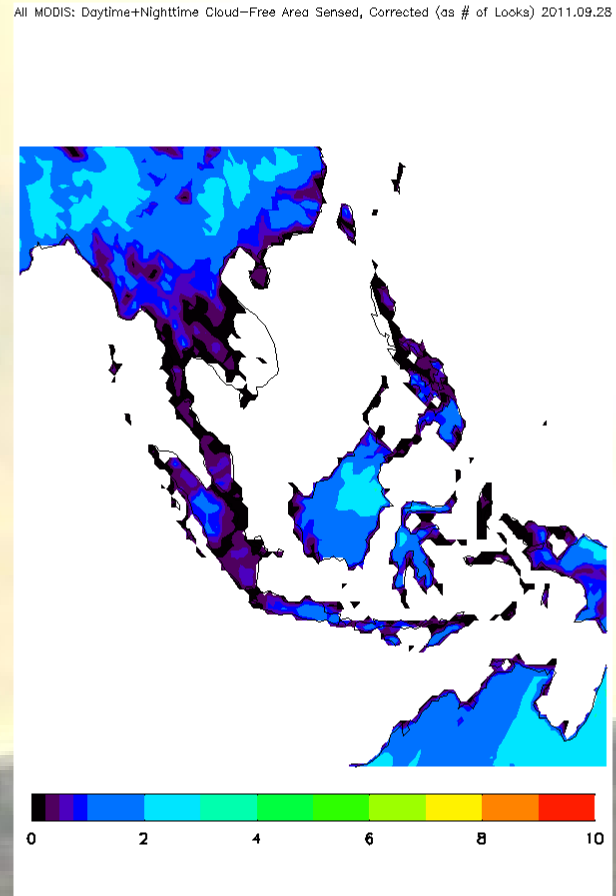
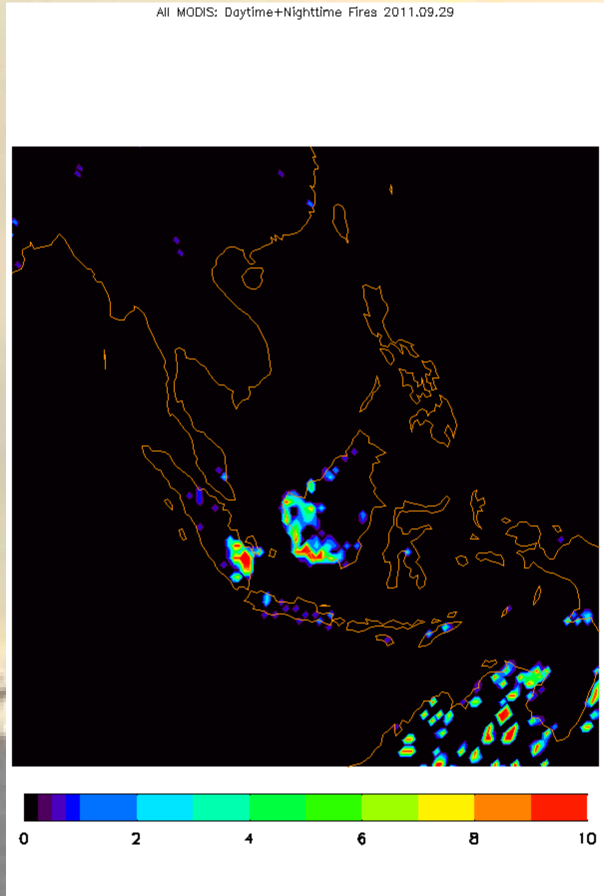
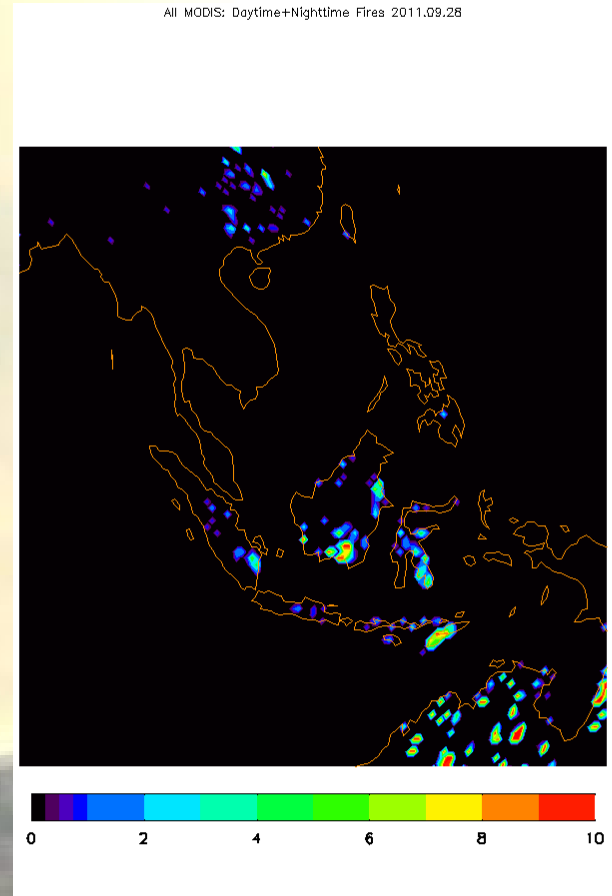


Variation in detection opportunity is large from day to day

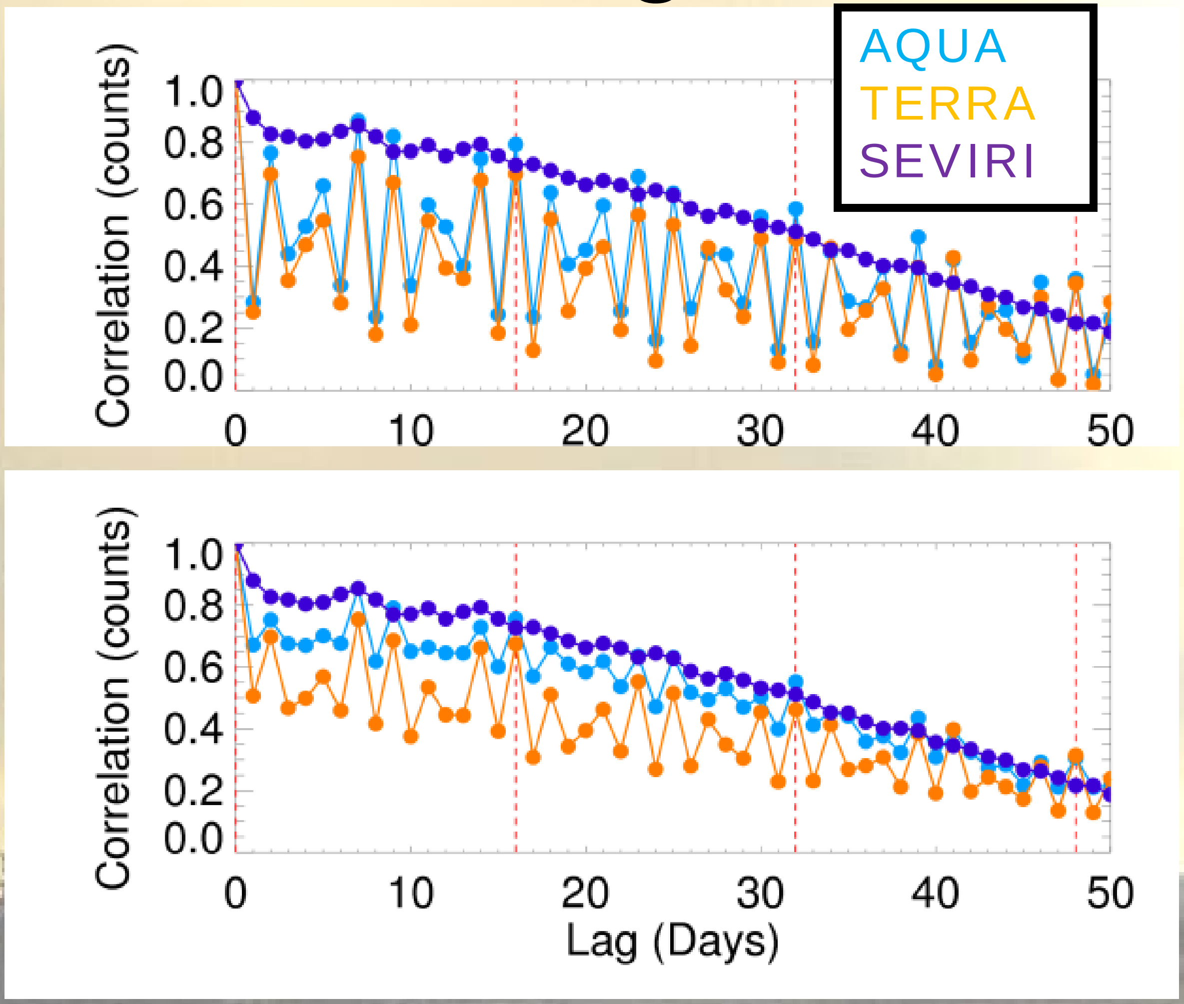
2011.09.29 fires



2011.09.28 fires

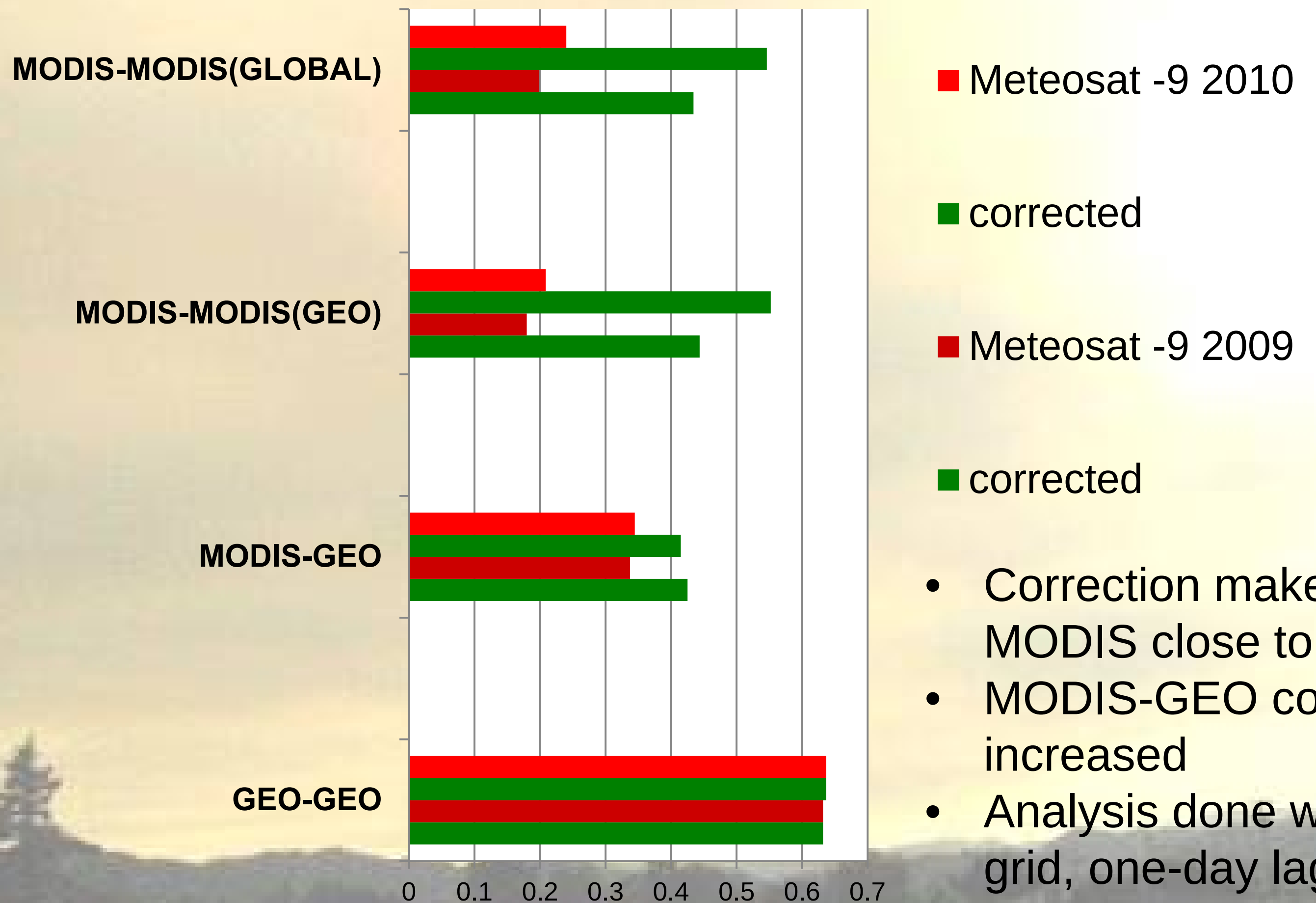


Testing this correction: lag correlation



- Correction makes lag correlation decay more like GEO
- Variation with orbital period not completely eliminated

Testing this correction: 1-day lag correlation

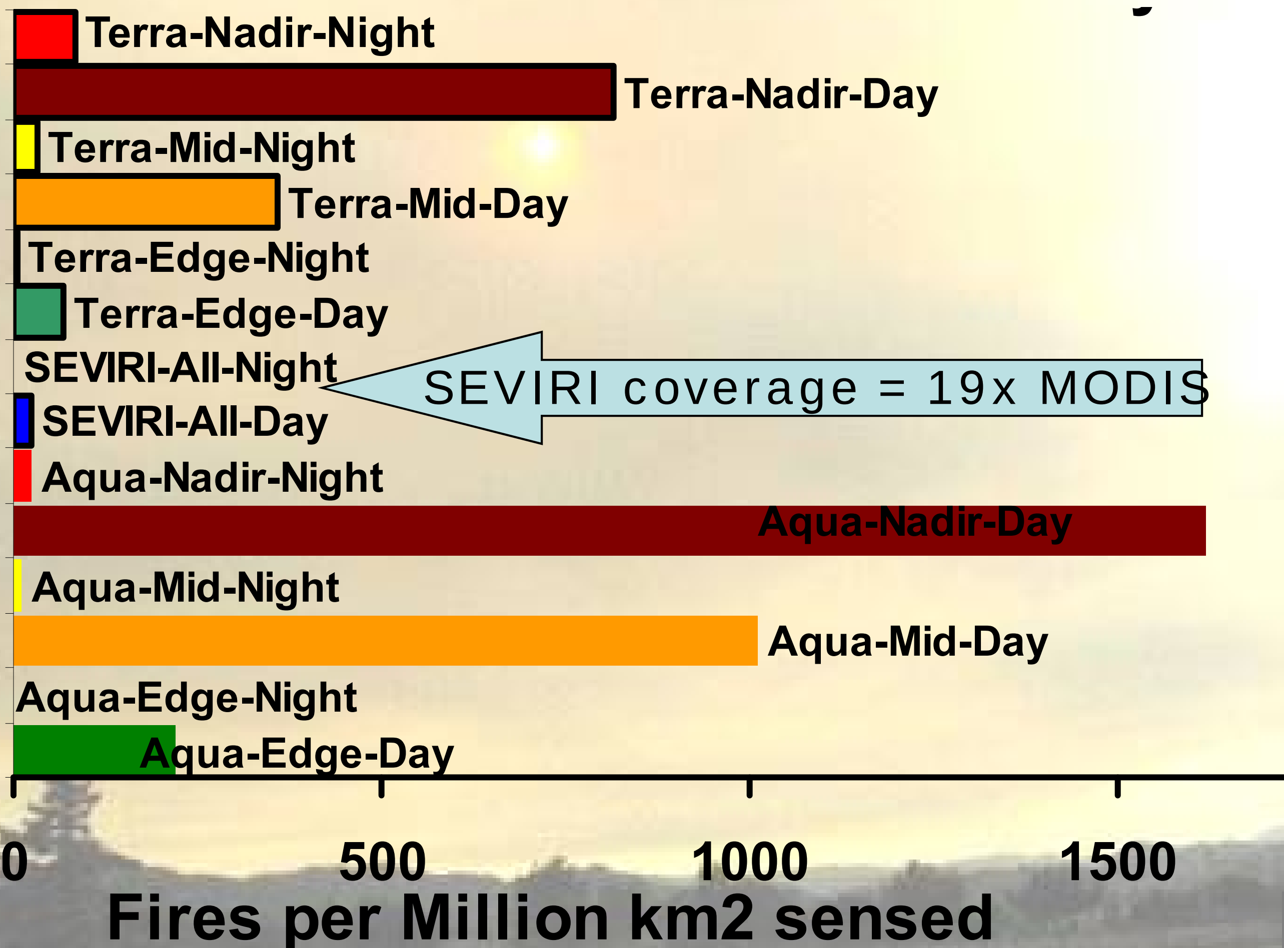


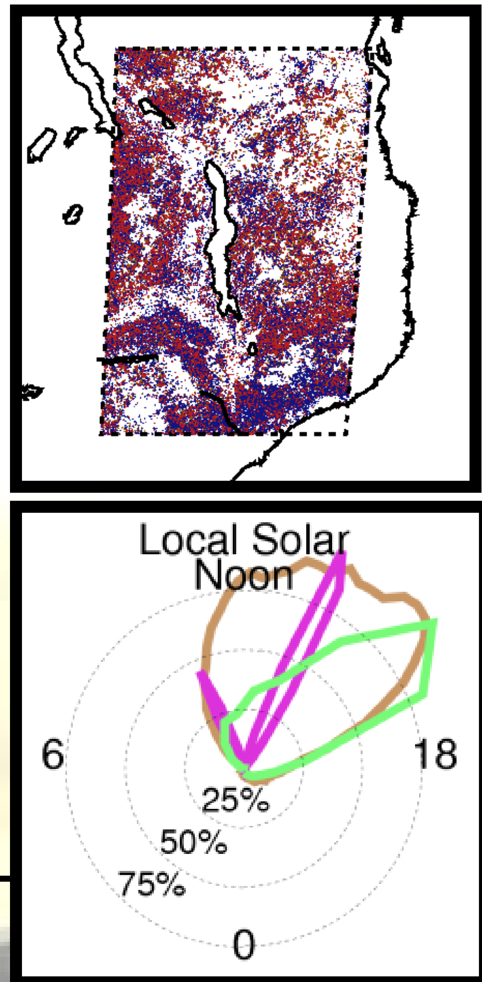
- Correction makes MODIS-MODIS close to GEO-GEO
- MODIS-GEO correlation is also increased
- Analysis done with 2-degree grid, one-day lag

Wrap Part 1: Detection Opportunity and Detection

1. Spatial patterns of daily fire detection relate as much to coverage as to fire activity on the ground
2. A metric of “nadir-equivalent looks” can be used to correct estimated fire activity, with
   1. Angular detection efficiency correction
   2. Cloud cover correction
   3. MODIS scan overlap correction
3. This metric is gridded, but does not require discarding fire location information
4. **Cloud cover correction involves an assumption about fire-under-cloud**
   - **For FLAMBE-SEAC4RS, the assumption is “for a given half-degree grid cell where a fire is observed during a 24-hour period, fires in that grid cell during that 24-hour period are assumed to be as active under cloud as under clear sky.”**

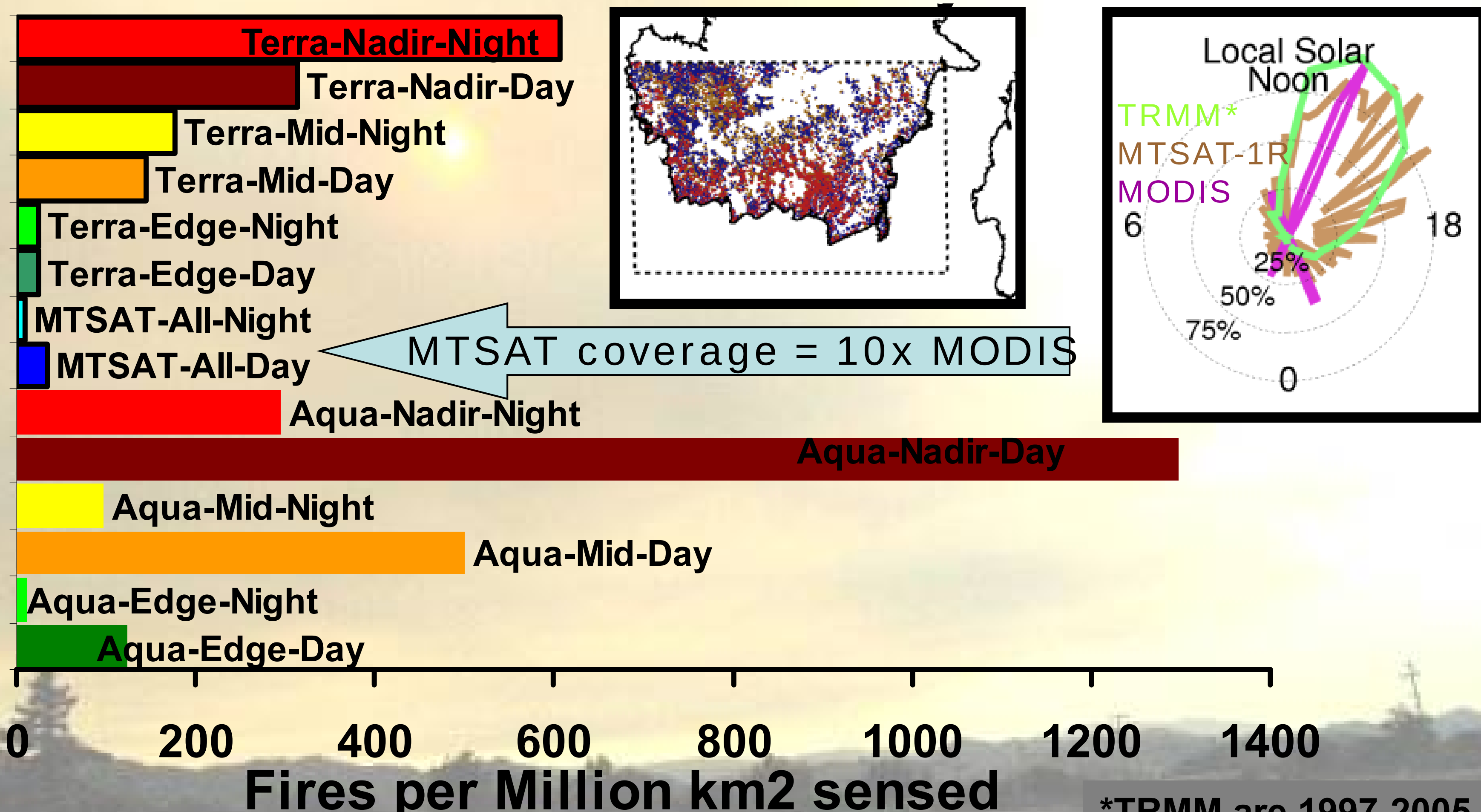
Detection Efficiency of MODIS + GEO: SE Africa





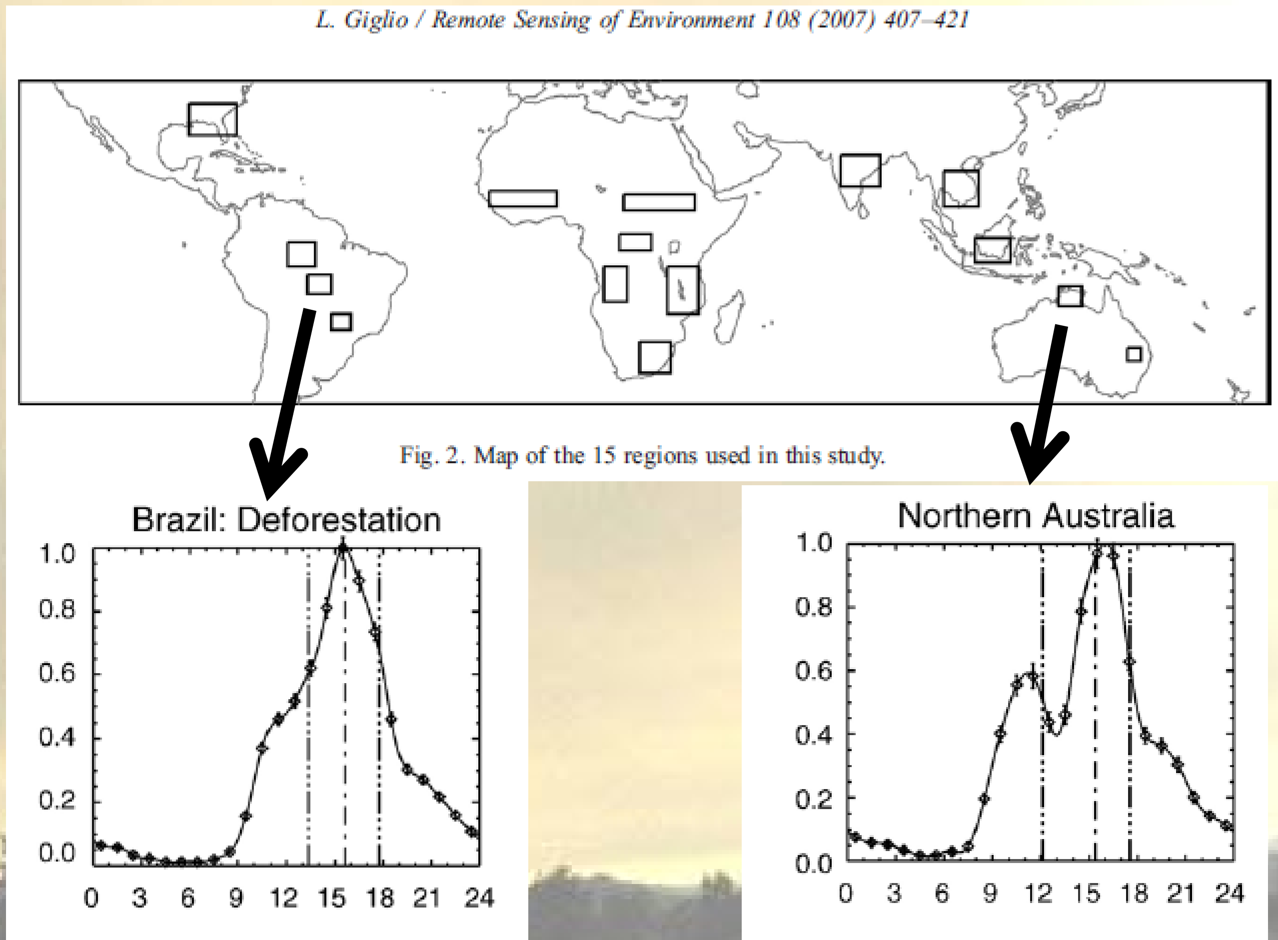
***TRMM are 1997-2005 data (Giglio, *RSE* 2007)**

Detection Efficiency of MODIS + GEO: Borneo



*TRMM are 1997-2005 data (Giglio, *RSE* 2007)

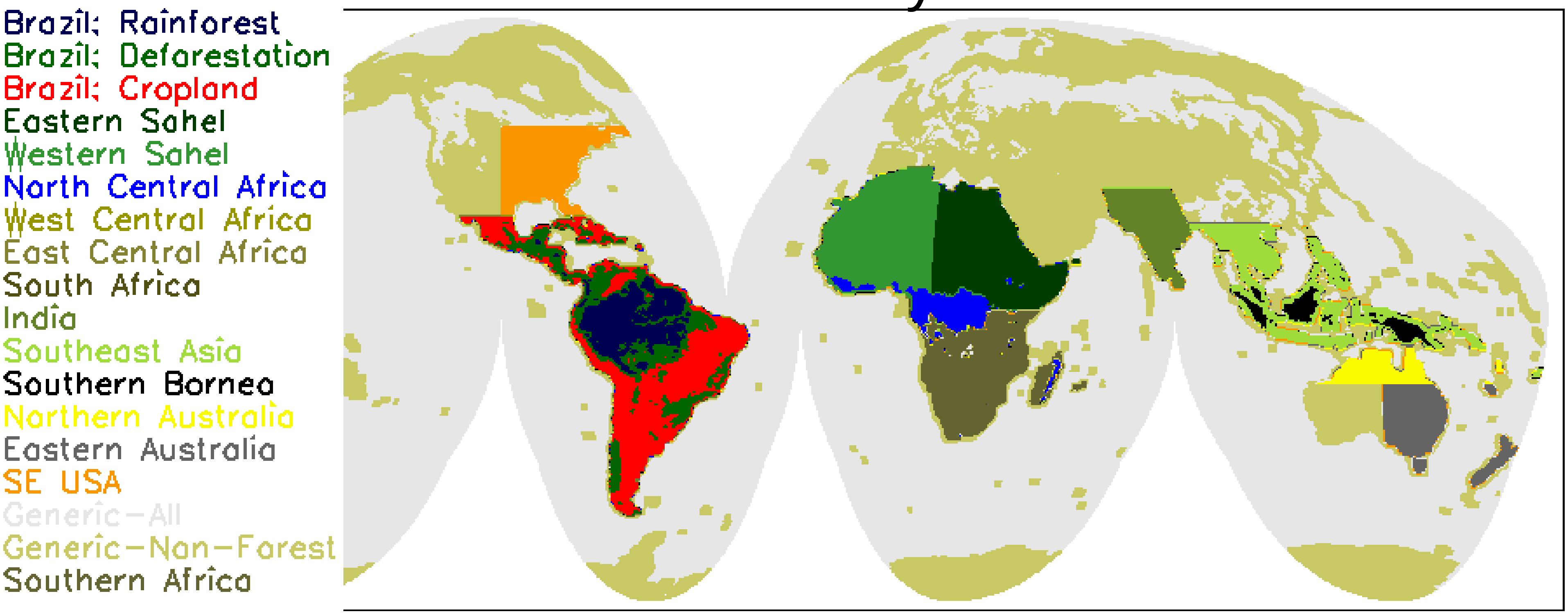
Diurnal Cycle Climatology



- Giglio RSE 2007
- Fire activity vs local solar time
- Based on TRMM

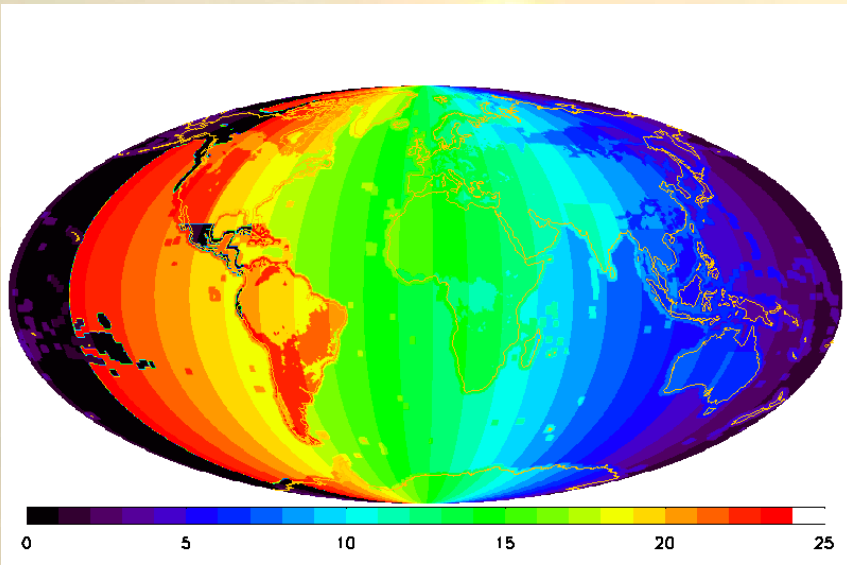
Diurnal Cycle Climatology

- Limited temperate, no boreal data
- Some DC are vegetation-specific, others are regional
- “generic” and “generic non-forest” created by averaging G2007 cycles

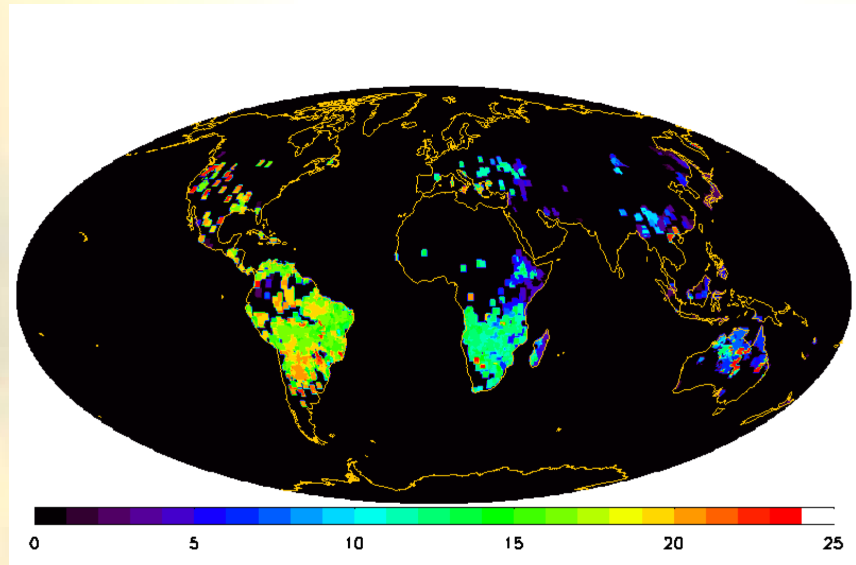


Climatology vs GEO obs.

Peak hour of burning (UTC): Climatology



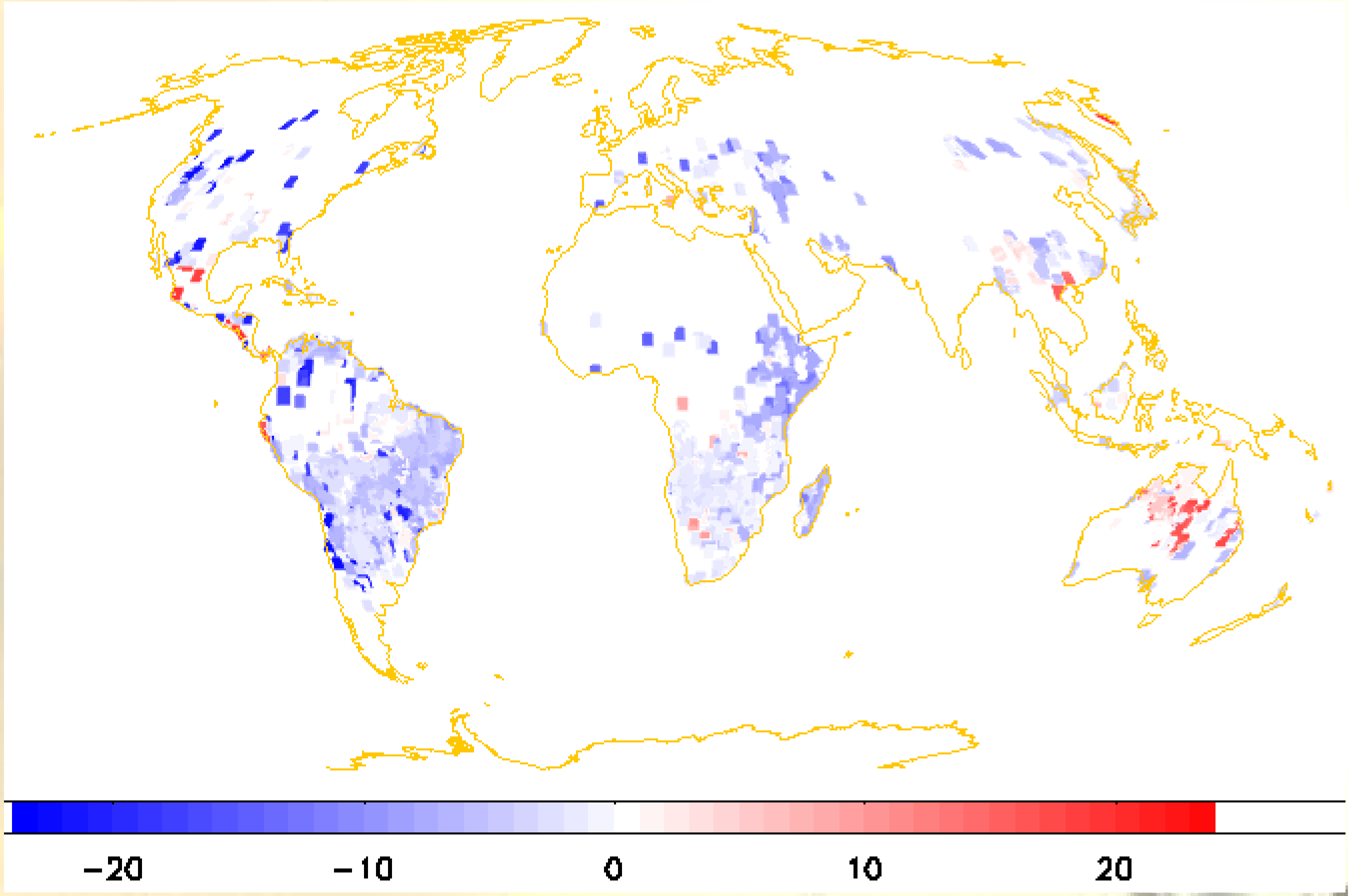
Peak hour of burning (UTC): Geostationary



- Geostationary diurnal cycles use all GEO obs in a 5x5 window of 0.5-degree grid cells
- Calculated separately for each GEO sensor
- Assigned according to largest number of looks
- **For several dates tested, GEO data was used for >80% of MODIS fires**
  - **Climatology used mostly in NH**

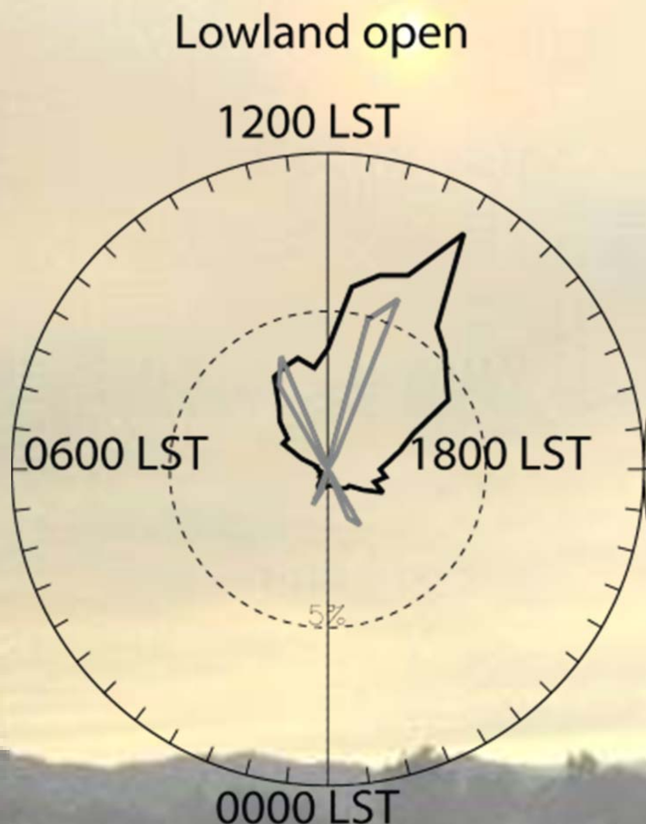
Climatology vs GEO obs.

- Hour of peak burning, GEO-CLIM
- GEO is earlier over SA, NA, E. Africa
- GEO is later over Australia
- **For several dates tested, climatology was used for <20% of MODIS fires**
  - **Mostly in NH**

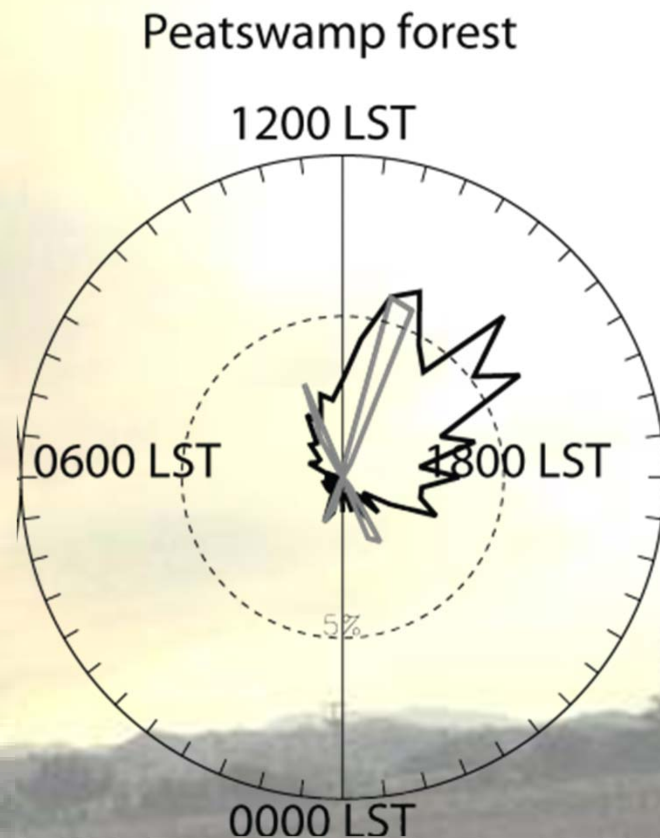


Diurnal Cycles also vary by vegetation type within a region

Indonesia– Lowland Open



Indonesia – Peatswamp



Perspective

1. Correction for detection opportunity is just one piece of the puzzle
2. A quantitative model of detection opportunity and detection efficiency is necessary for a robust emissions estimate, even from a single sensor
3. Multiple sensors must be normalized after detection opportunity correction
4. Diurnal cycles of fire are very strong, and affect emissions estimation at several points in the processing chain
5. GEO and TRMM diurnal cycles have differences that need to be investigated

Thanks!

- WF_ABBA team at CIMSS
  - Chris Schmidt & Elaine Prins
- MODIS Fire Team
  - Louis Giglio, SSAI
- FLAMBE team at NRL