Towards a consistent global fire emissions product: Estimating and correcting for fire observability

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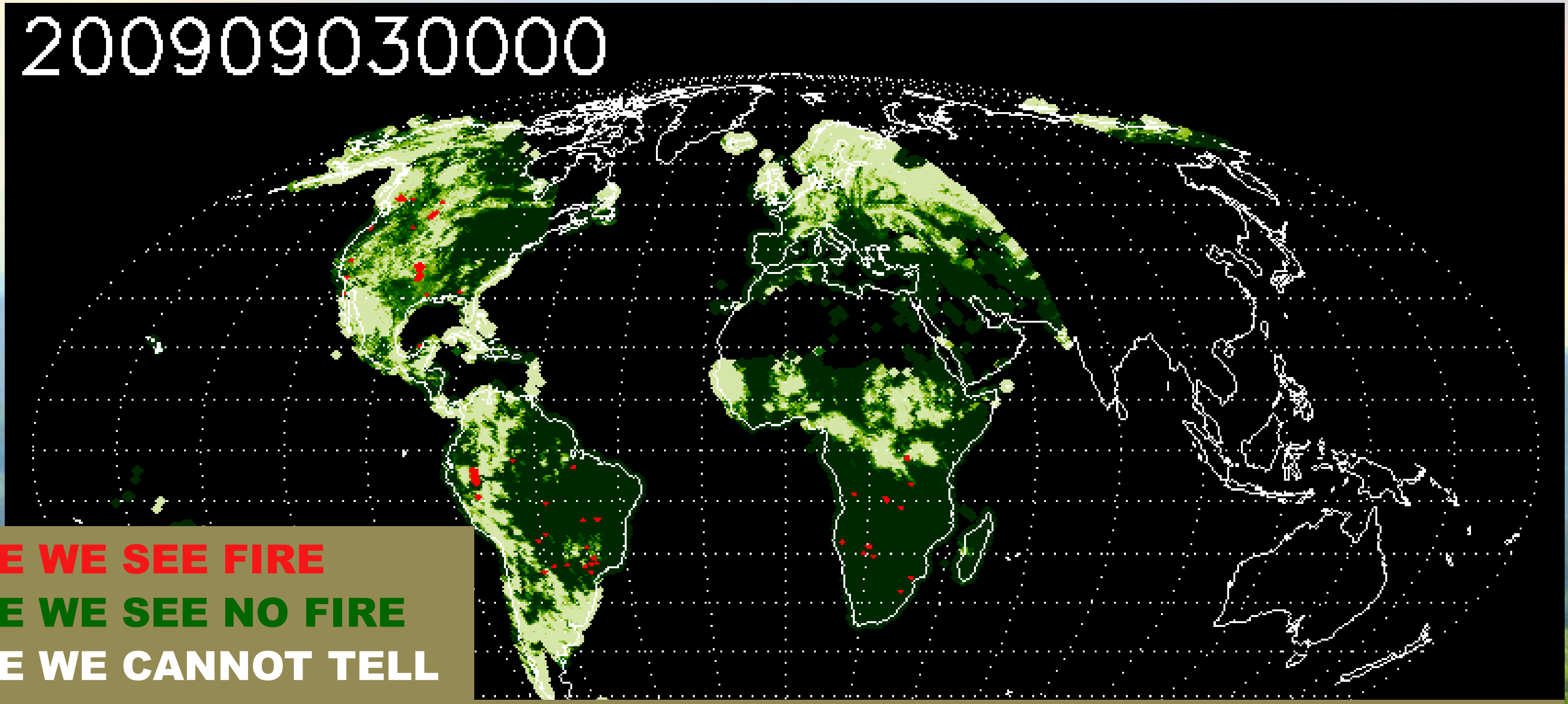
5th Technical Interchange Meeting
Tsukuba, Japan 5-8 November

In this talk

- Orientation of FLAMBE and design goals
- Data sources
- Data flows: ingest and processing
- Data products
- Fire observability results
- Next steps

Orientation of FLAMBE

- Constellation of fire detection satellites
  - Polar and geostationary
  - Varying sensitivity, **within and between sensors**



HERE WE SEE FIRE
HERE WE SEE NO FIRE
HERE WE CANNOT TELL

- Coverage masks from MODIS + Global WF_ABBA geostationary
- **CLEAR, CLOUDY, FIRE**

FLAMBE design goals

- **Spatially and temporally consistent estimation of smoke sources**
- **Capture of spatial/temporal patterns**
- **Facilitate scaling to obtain accurate atmospheric loadings**
- **Accommodate changes in satellite constellation**
- **Don't miss fires– give AOD assimilation a chance!**

What are we up against?

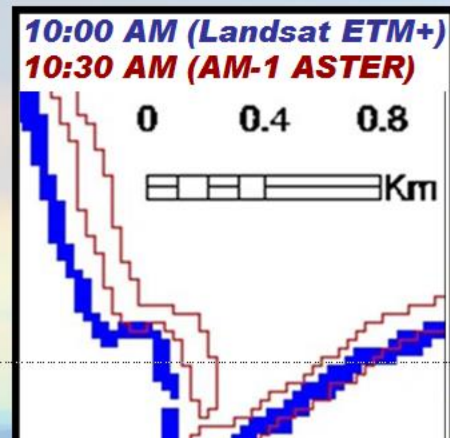
- Fire is a highly variable phenomenon relative to the spatial and temporal sampling of current observations
- Here is the “countdown of challenges,” the top 3 limitations of the current observation system

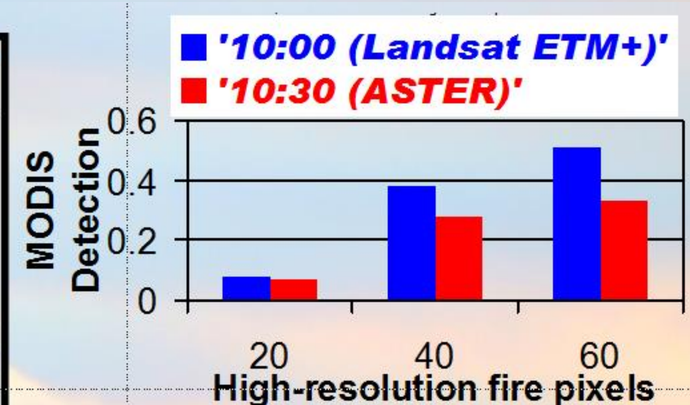
3) Temporal Sampling is too slow

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

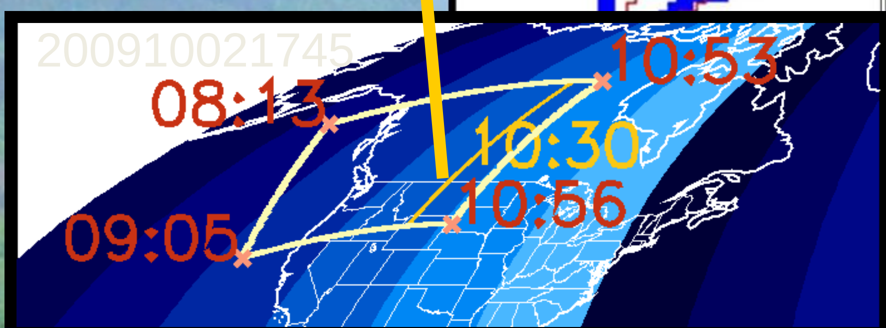
Nominal overpass time ≠ center of scan

Scan Angle and Overpass Time Interact to Determine Detection Efficiency





Csiszar and Schroeder, JSTARS 2008



- Fire fronts have significant movement across landscape in 30 minutes
- Fire activity at 1030 local is substantially (~20-40%) greater than at 1000

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

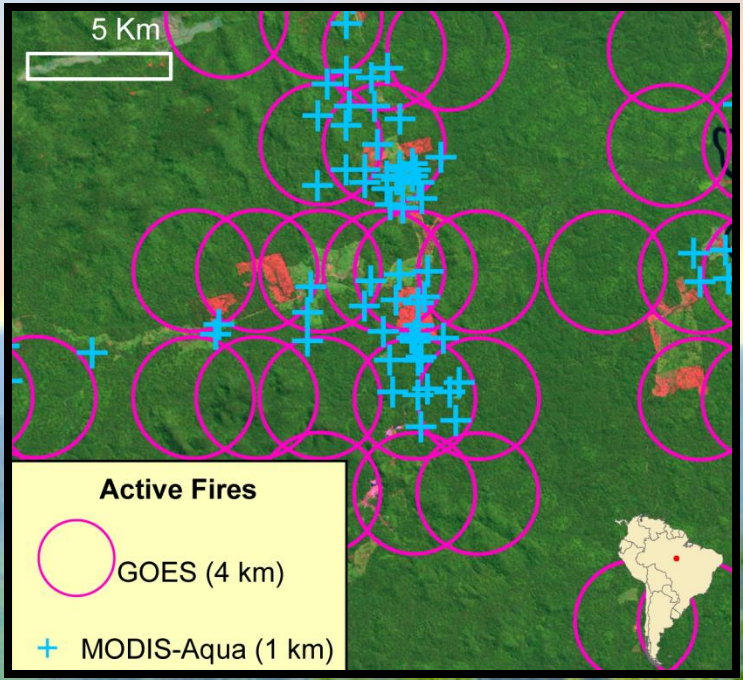
•Spatial resolution of sensors does not allow 100% attribution of fuels in mixed landscapes

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

•Random error that disrupts spatial/temporal pattern of emissions

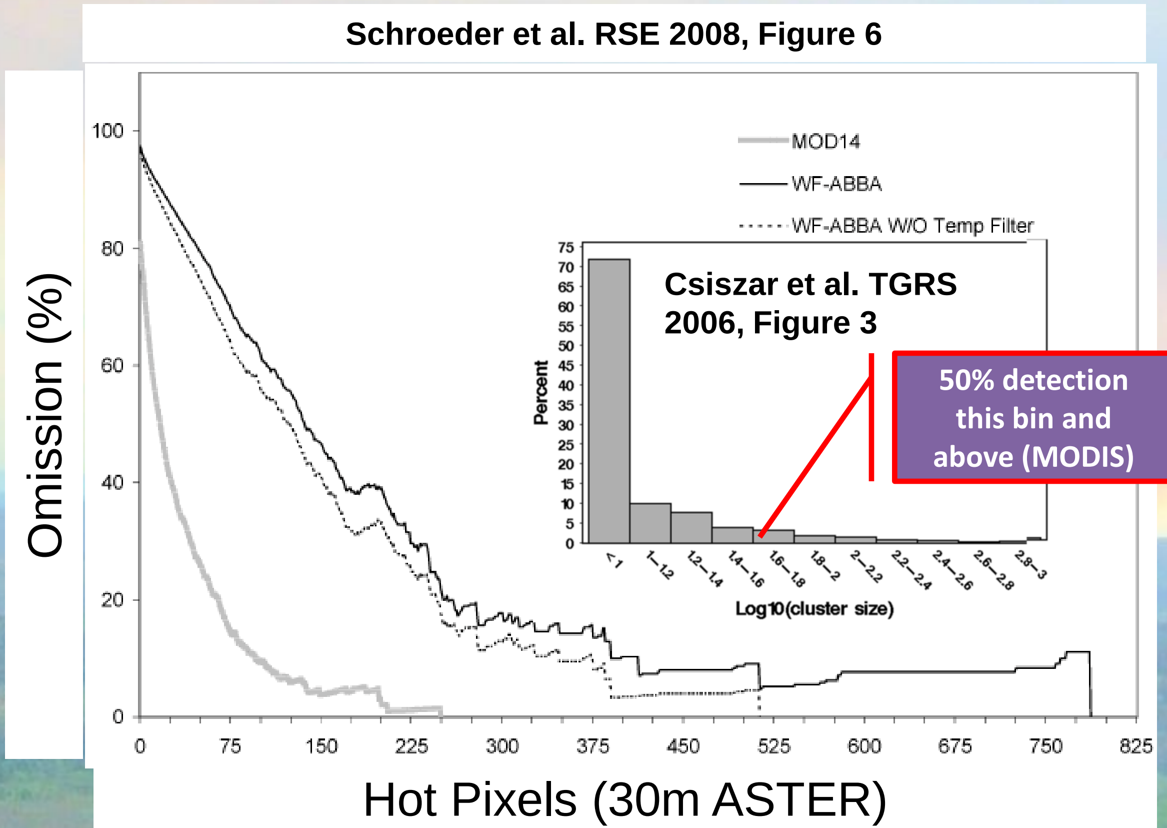
•Aliasing/overlap issues abound:

- Current contextual algorithms exclude fractions of fire FRP that spill into adjacent pixels



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
- Covariance of fires means that scaling can be effective at coarse scales

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

Implications of these limitations for smoke emission estimation

1. Omission errors dominate, so don’t discard data
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

Implications of these limitations for smoke emission estimation

1. Omission errors dominate, so don't discard data
2. Scaling will be necessary: observations cannot 'close the loop' of fire energy
3. Satellite overpasses are best treated as independent snapshots
   – Spatial scale of obs and speed of changes in fire behavior preclude modeling evolution

Implications of these limitations for smoke emission estimation

1. Omission errors dominate, so don’t discard data
2. Scaling will be necessary: observations cannot ‘close the loop’ of fire energy
3. Satellite overpasses are best treated as independent snapshots
4. Observations must be considered in terms of the diurnal cycle

So, how are we going about this?

FLAMBE inputs

- MODIS data from NASA LANCE
  - Terra and Aqua
  - MOD14
    - Fire detections
    - FRP
    - Detection mask (as seen in animation)
    - 576 files/day, 130MB
  - MOD03
    - Geolocation
    - Required to use MOD14 mask
    - 576 files/day, 16GB
  - NPP VIIRS (data from UW PEATE) would be similar

- Geostationary data from University of Wisconsin CIMSS
  - WF_ABBA v6.5
  - ASCII files
    - Fire detections
    - FRP
    - Retrieved size/temperature
  - AREA files (binary)
    - Header for navigation
    - Detection mask

WF_ABBA data volumes (all values are per 24 hours)

- ASCII files
  - GOES-13
    - 250 files (125 with and without temporal filter)
    - 1.8MB
  - GOES-15
    - 300 files, 1.5MB
  - MTSAT-1R (10/22 – 12/19/2013)
    - 112 files, 1.3MB
  - Meteosat-10
    - 130 files, 3.8MB
- AREA files (.gz compressed)
  - GOES-13: 15MB
  - GOES-15: 9MB
  - MTSAT-1R: 7MB
  - Meteosat-10: 30MB
- 12 months of FLAMBE inputs = ~100GB + MOD03
  - **MOD03 is >90% of total data volume**
  - **Potential solution: add lat/lon fields to MOD14**

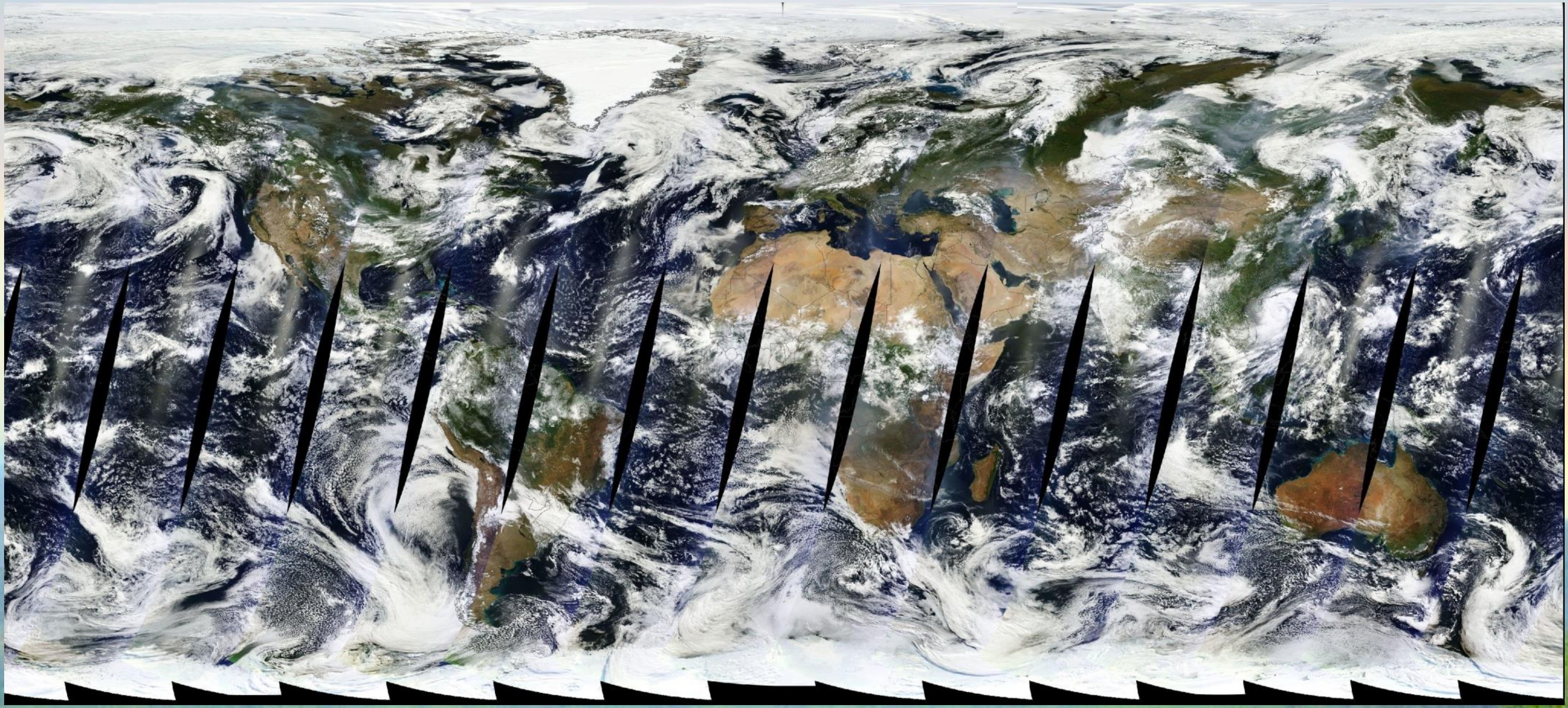
Goals of processing these data

- Generate a spatially and temporally consistent analysis of fire activity
- Account for known variation in fire detection efficiency
- Normalize data from sensors to a common benchmark

A "nominal" fire detection system

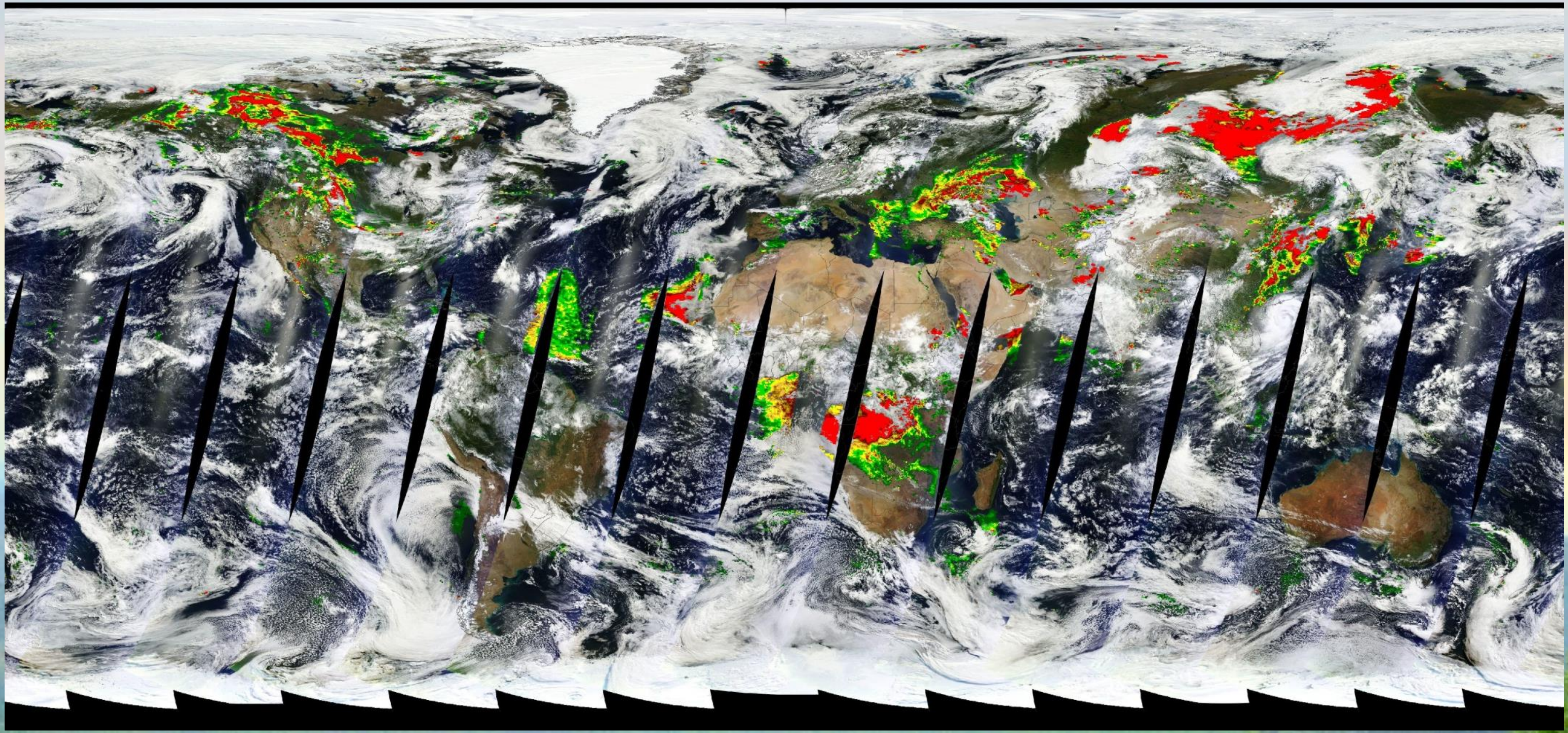
- A thought experiment based on current weather satellites
- This system would:
  - Observe the entire globe every hour;
    - GEO sensors do better than this in many locations;
  - Have a pixel resolution of 1x1km;
    - This is MODIS at nadir; GEO are coarser
  - Be capable of detecting fires under cloud;
    - Not possible with detection based on thermal contrast
- FLAMBE2 translates observations from a polar/GEO constellation into expected fire activity observed by this nominal system
- This nominal system exceeds current capability, but is nowhere near FRE closure! Scaling still required!

A single day: 13 August 2013



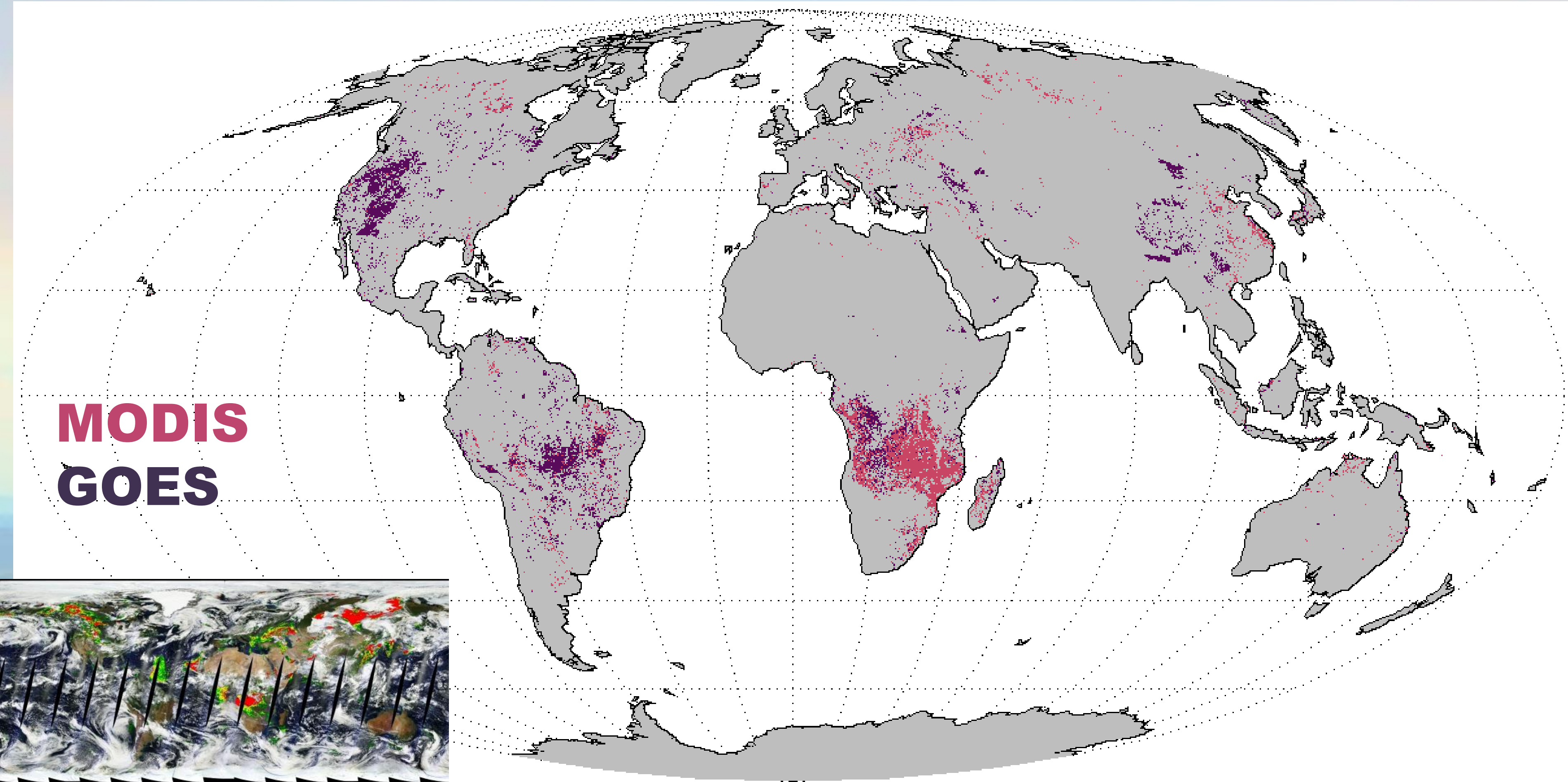
MODIS Terra RGB Image from LANCE Worldview

A single day: 13 August 2013



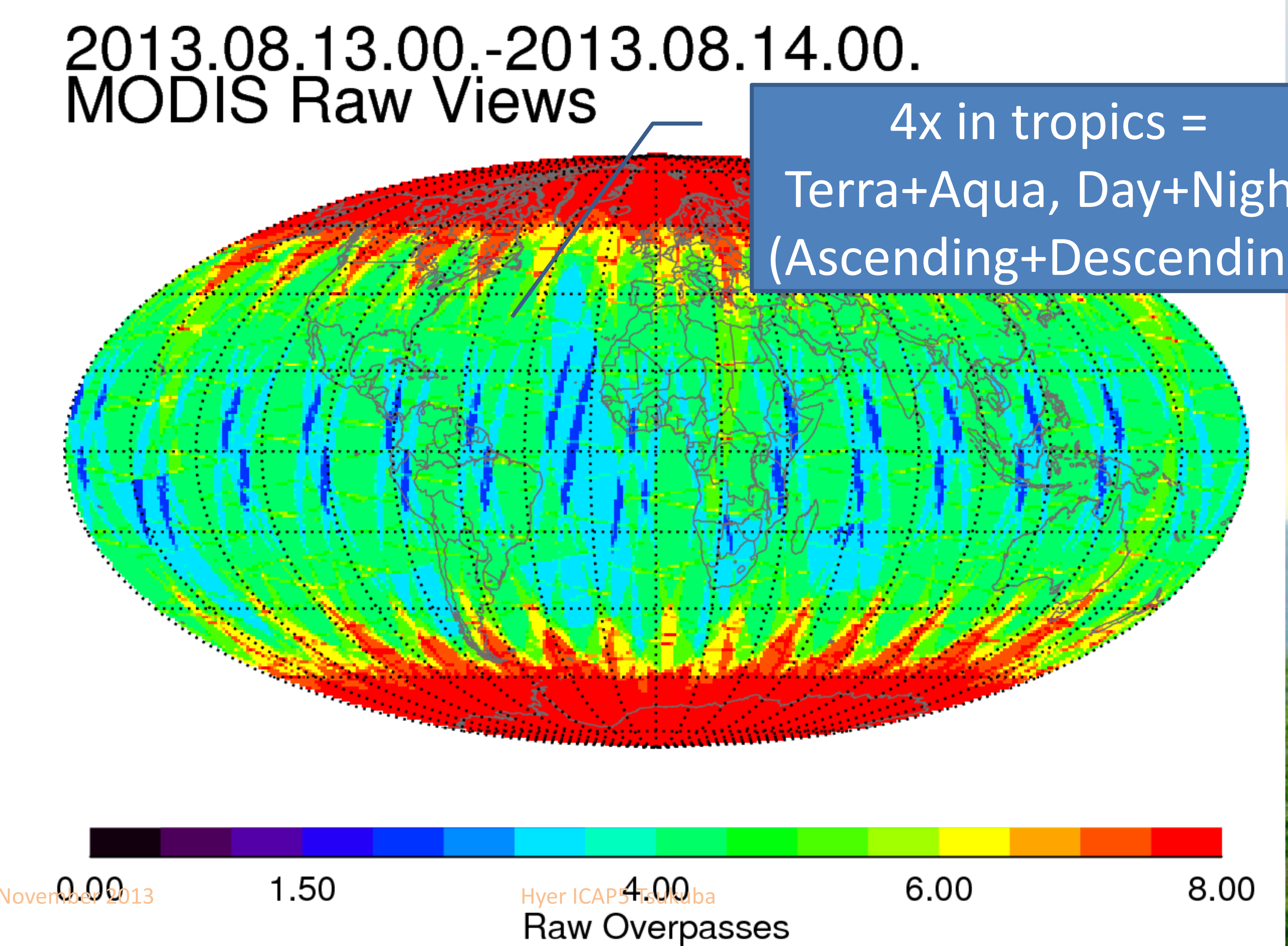
MODIS Terra RGB Image from LANCE Worldview
MOD04_L2 Dark Target AOD (min=0.27, red=0.7+)

A single day: 13 August 2013



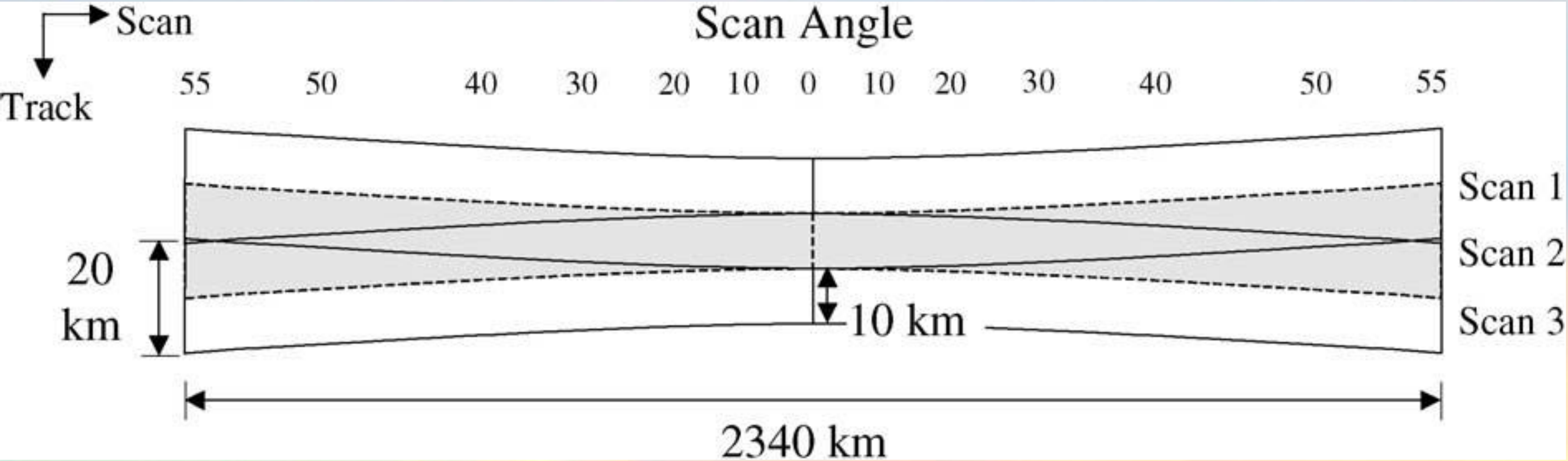
MOD14 fires from MODIS Terra and Aqua
WF_ABBA fires from GOES-12, GOES-13, GOES-15, Meteosat-10, and MTSAT-2

MODIS coverage for one day



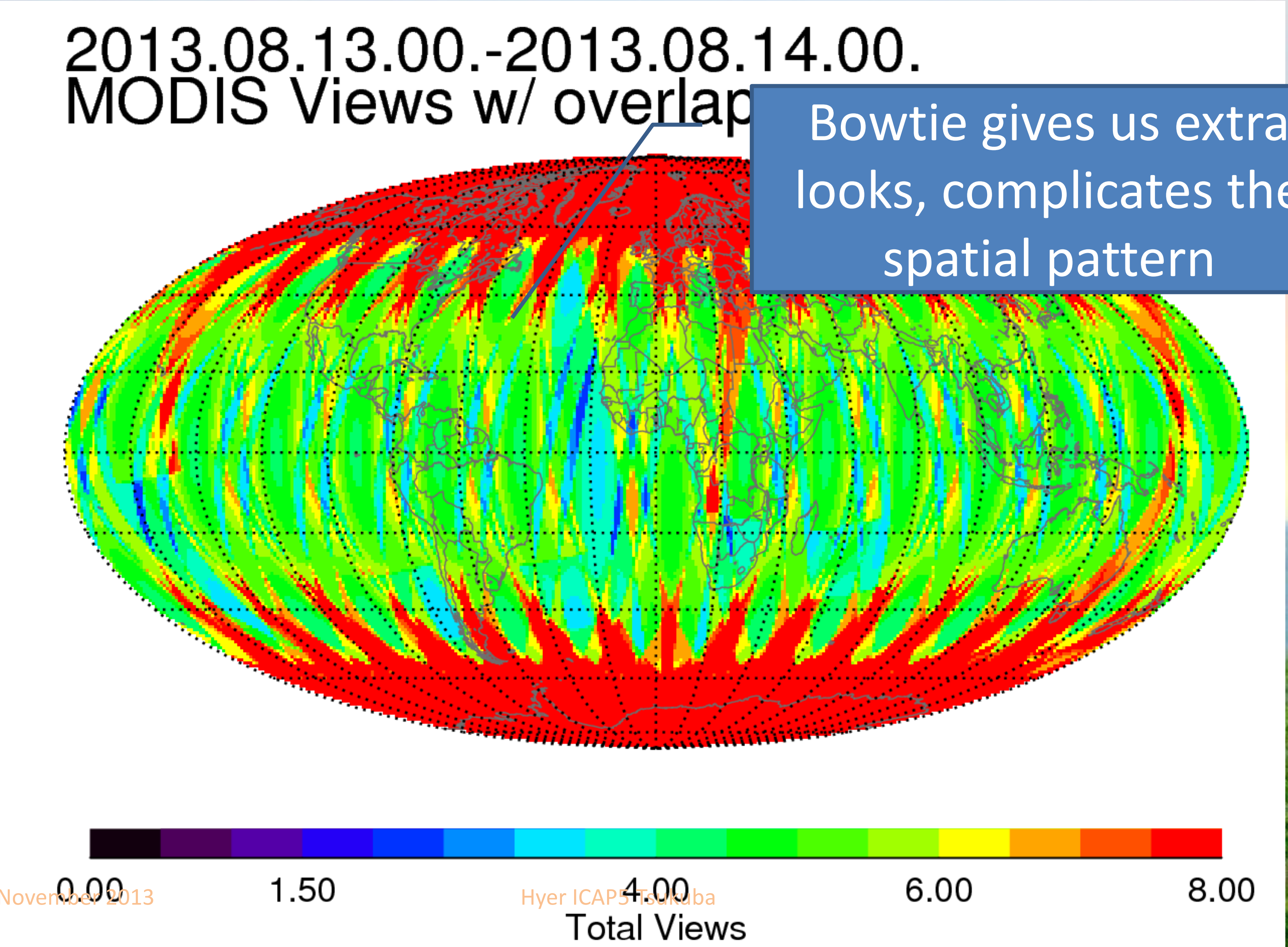
4x in tropics = Terra+Aqua, Day+Night (Ascending+Descending)

Overpasses ≠ Looks: Bowtie Effect



- Every point on the ground at the edge of the scan is actually observed twice each time MODIS passes overhead

MODIS coverage for one day

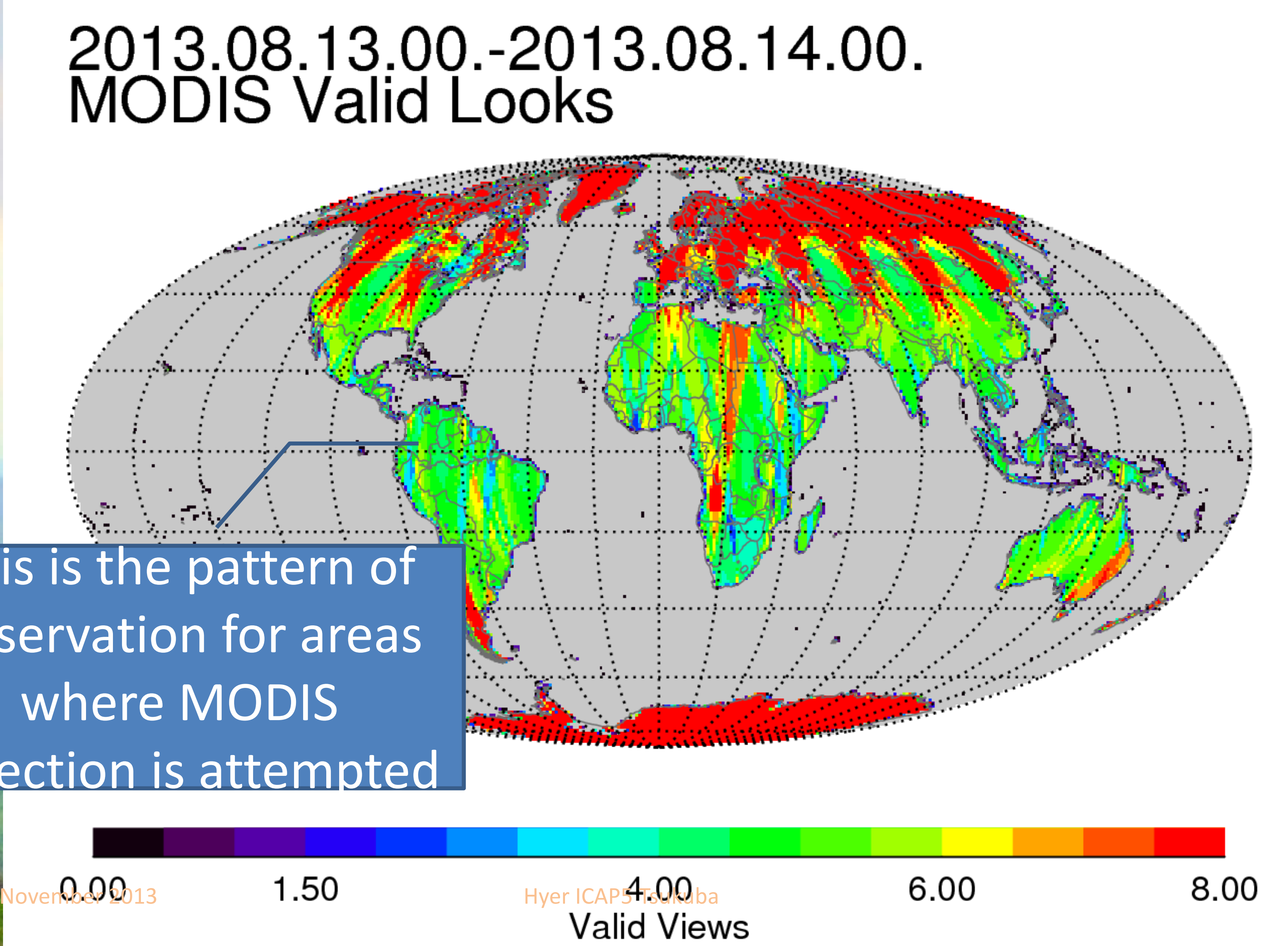


Bowtie gives us extra looks, complicates the spatial pattern

Not everywhere MODIS looks is suitable for detection

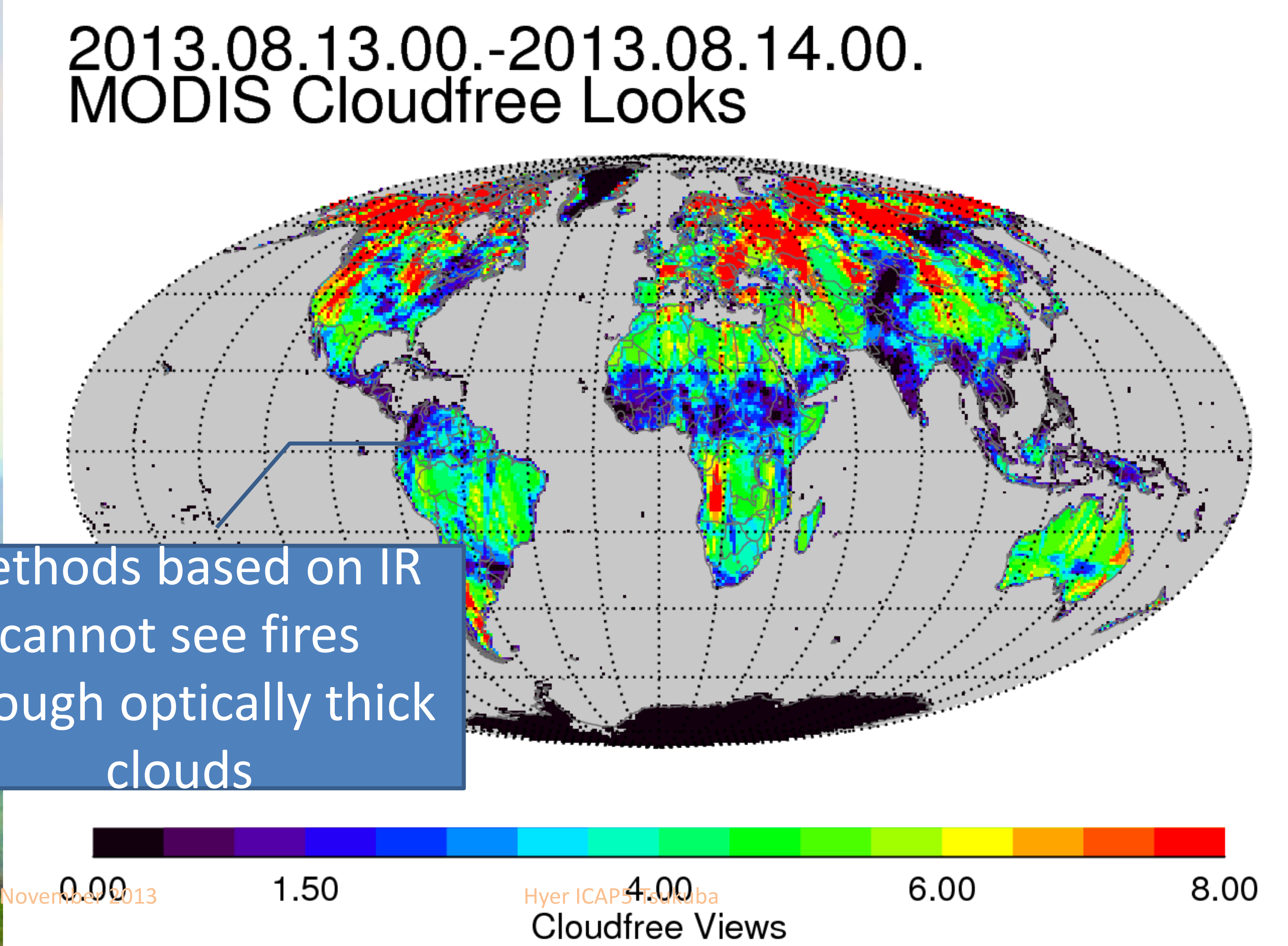
- Water mask excludes pixels with/near inland water and coastlines
- Observing conditions may make detection impossible
  – Less of an issue for MODIS;
  – WF_ABBA has solar, glint, and temperature blockouts

MODIS coverage for one day



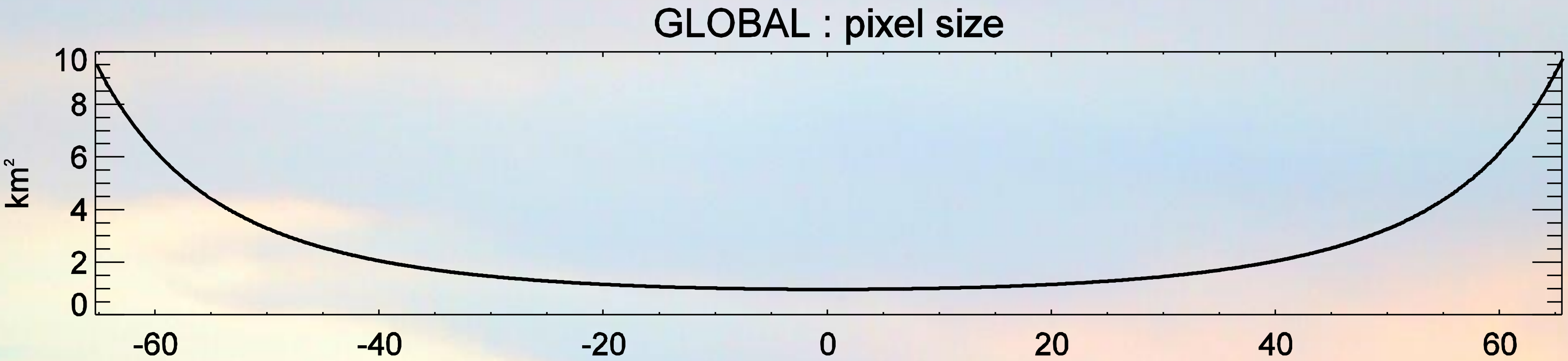
This is the pattern of observation for areas where MODIS detection is attempted

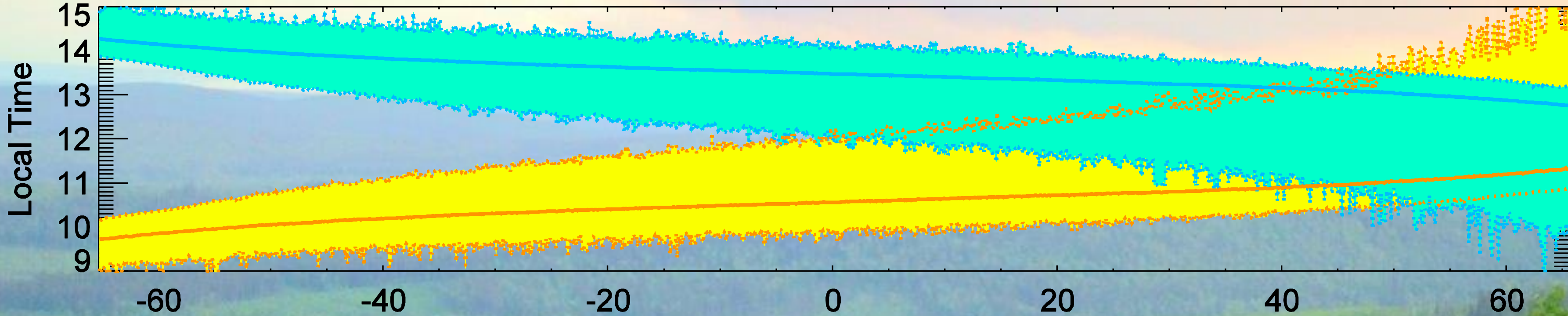
MODIS cloud-free coverage



Methods based on IR cannot see fires through optically thick clouds

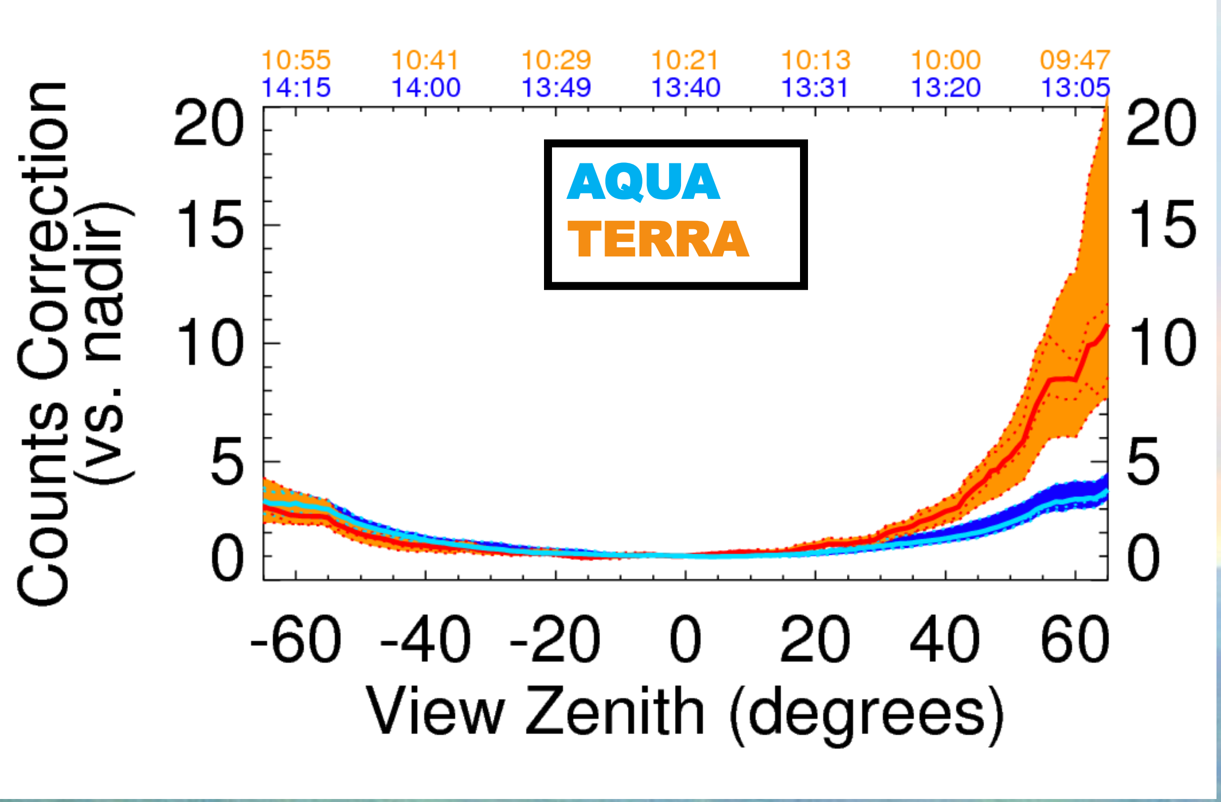
MODIS detection efficiency varies across the scan





Both of these will affect fire detection efficiency

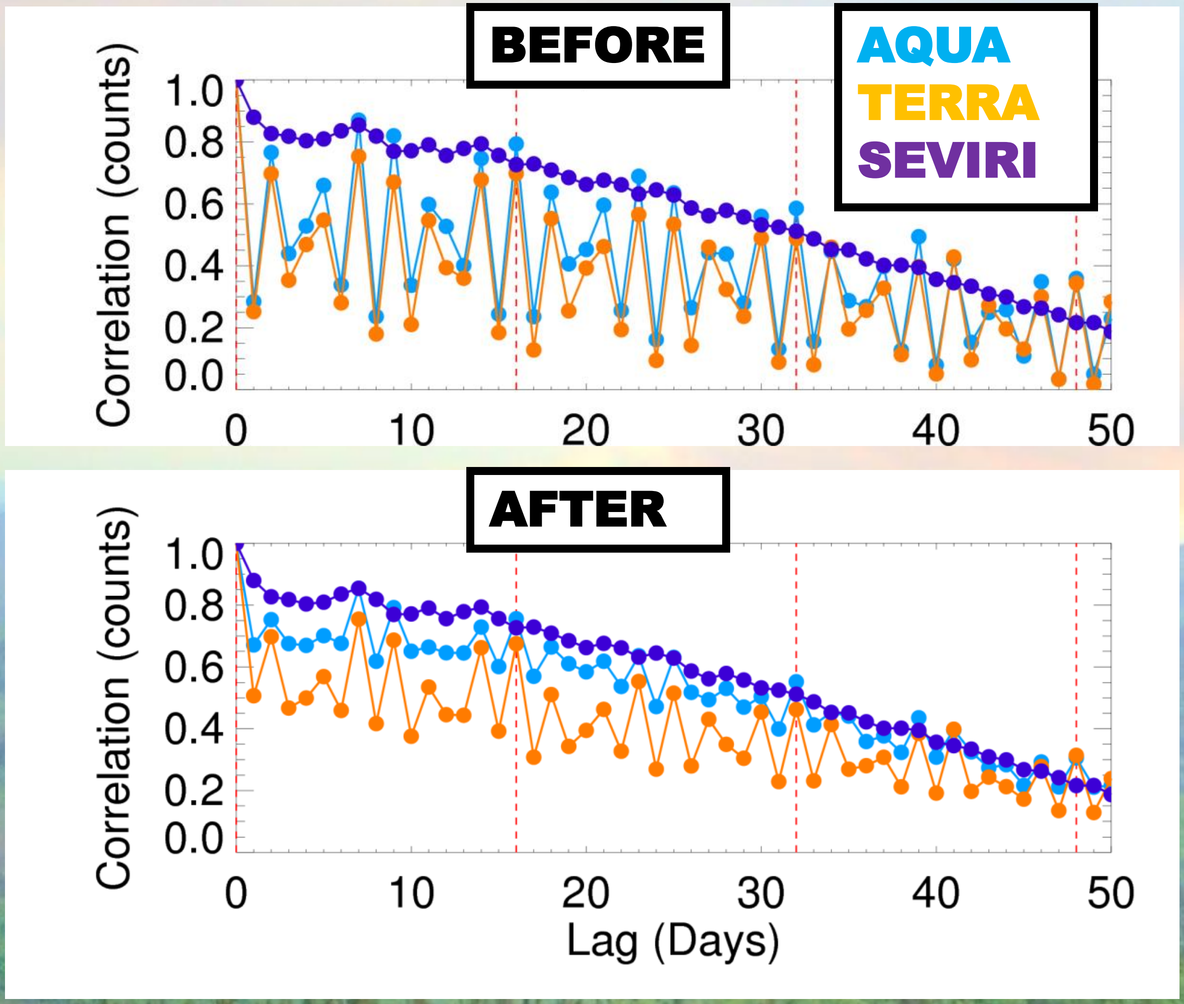
Can we construct an angular correction for fire counts?



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

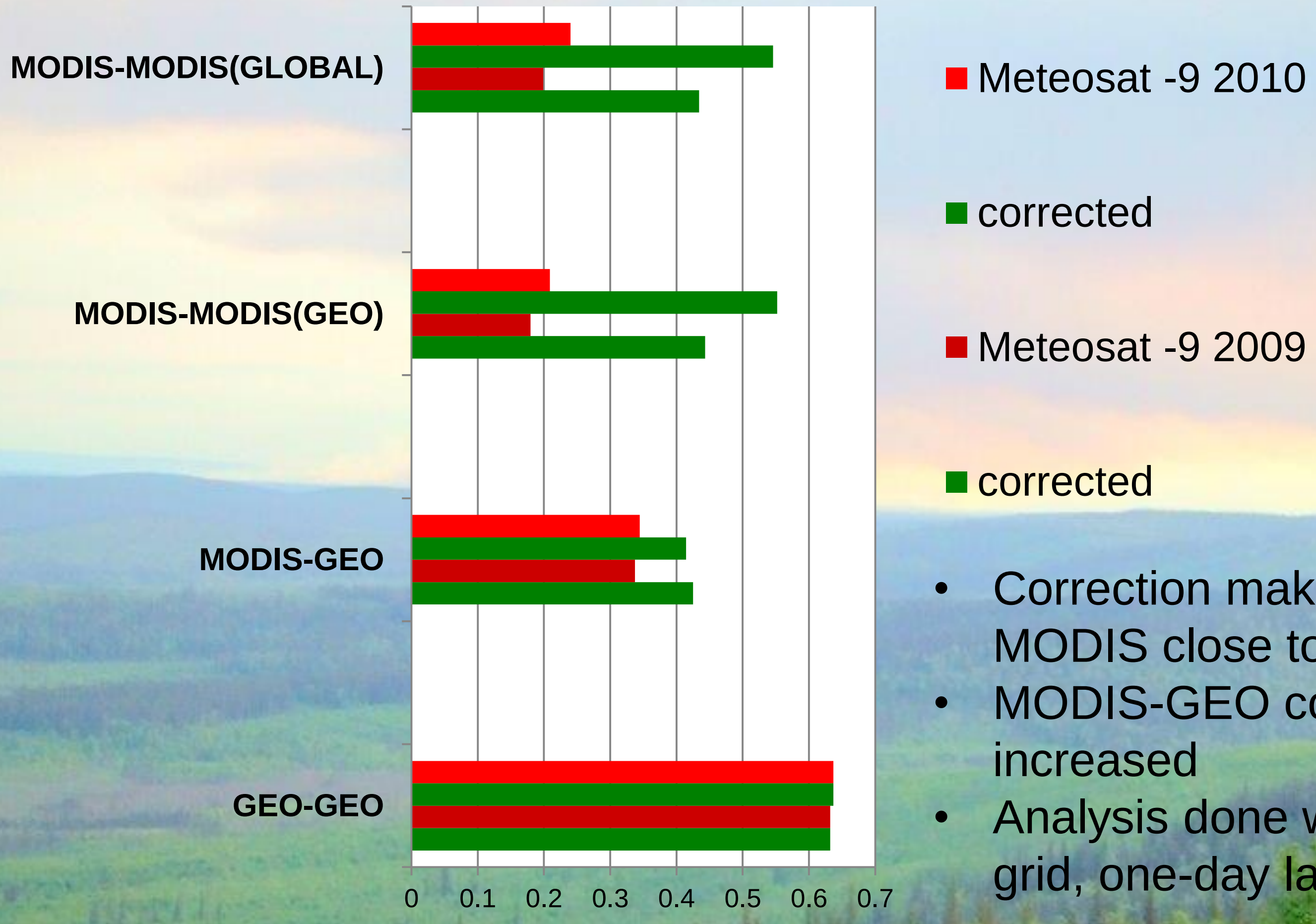
- **Aqua correction is fairly symmetrical**
- **Terra correction is extreme for the early side of the scan**
  - **0945 to 1021 local time is a steep part of diurnal curve**
- **We will use this correction to estimate "nadir-equivalent looks," which will be combined with diurnal cycle information to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

Testing angular correction: lag correlation



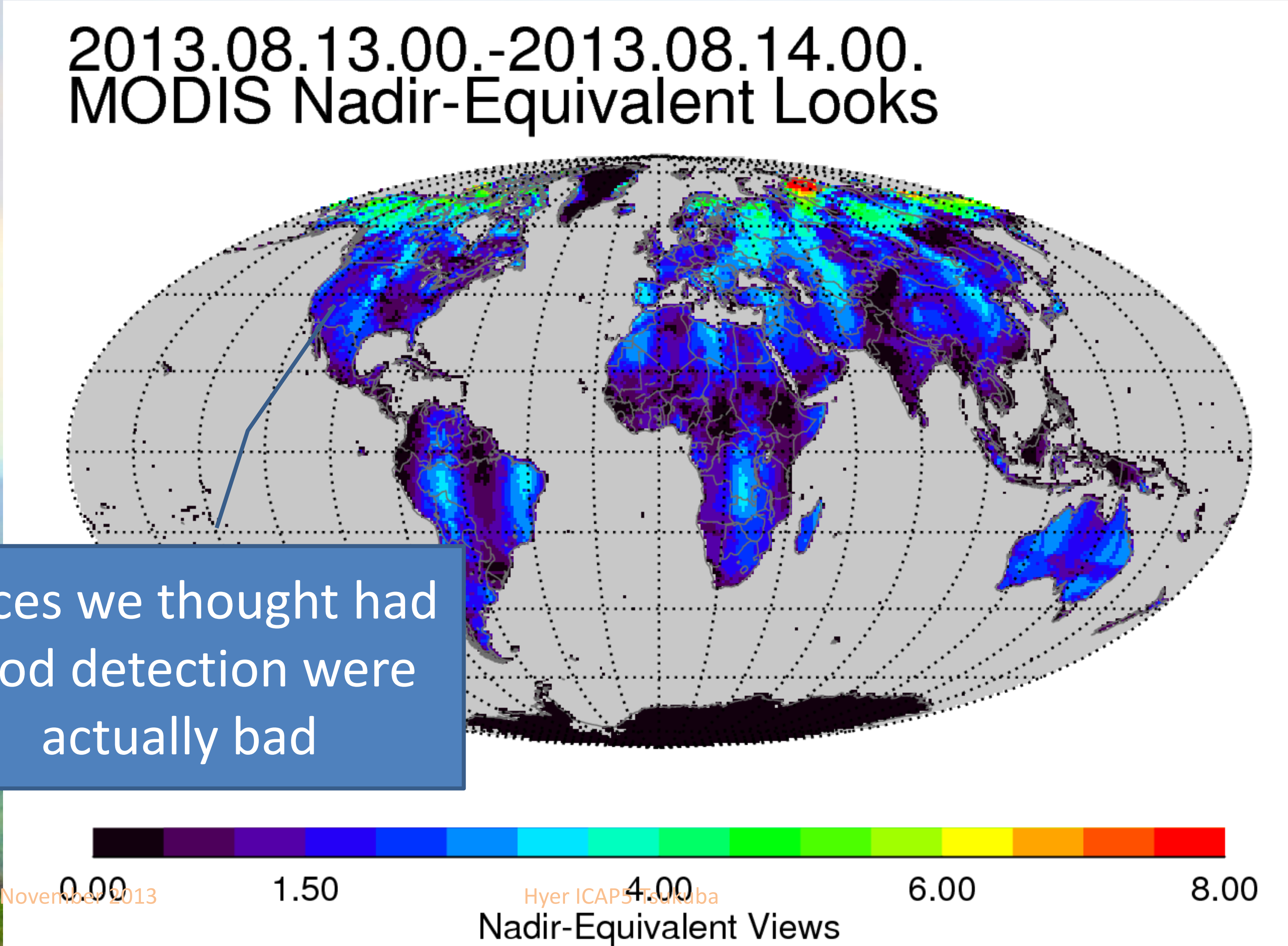
- Correction makes lag correlation decay more like GEO
- Variation with orbital period not completely eliminated

Testing angular correction: 1-day lag correlation



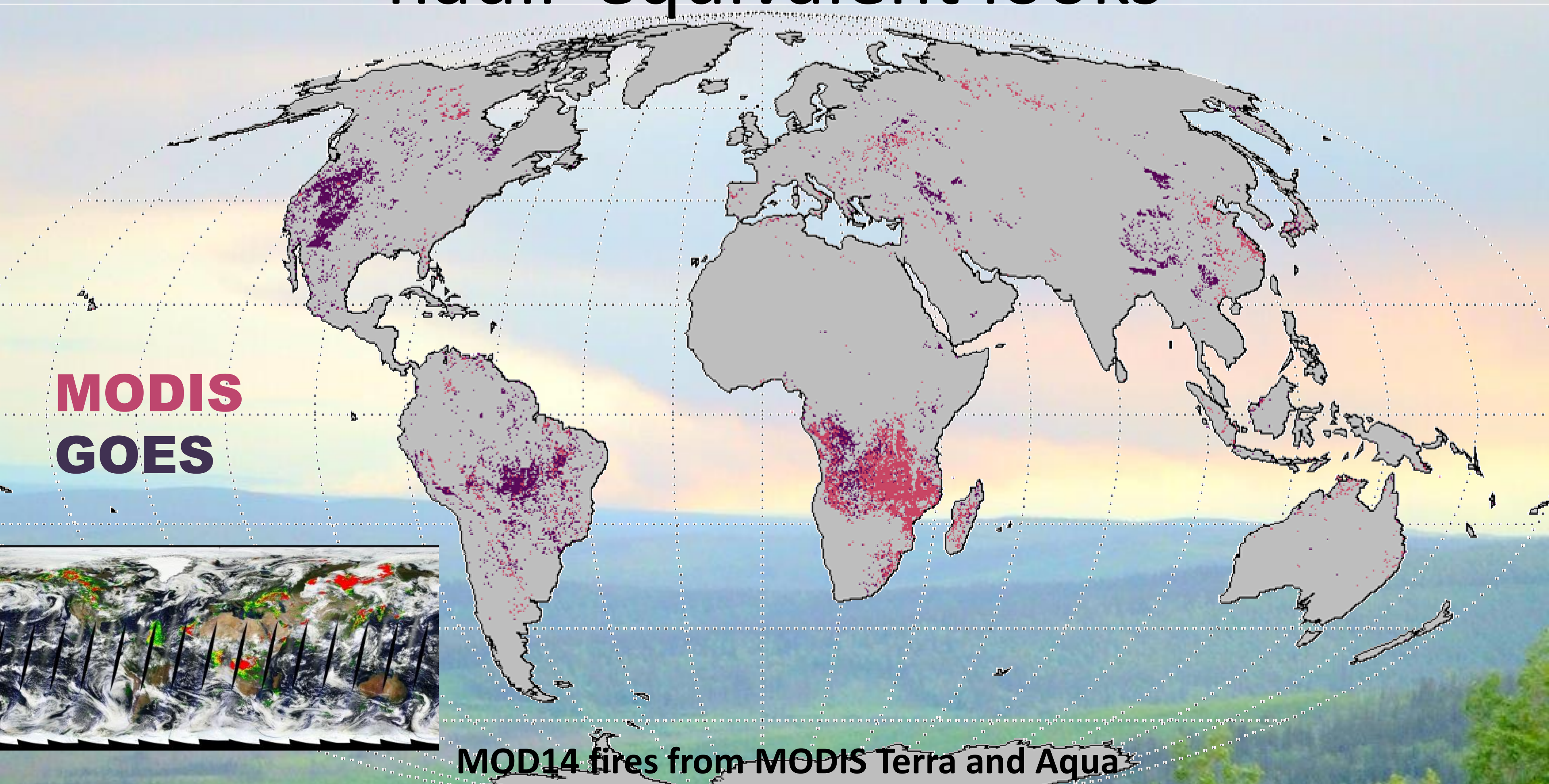
- Correction makes MODIS-MODIS close to GEO-GEO
- MODIS-GEO correlation is also increased
- Analysis done with 2-degree grid, one-day lag

MODIS “nadir-equivalent” coverage



Places we thought had good detection were actually bad

MODIS fire locations are explained by "nadir-equivalent looks"



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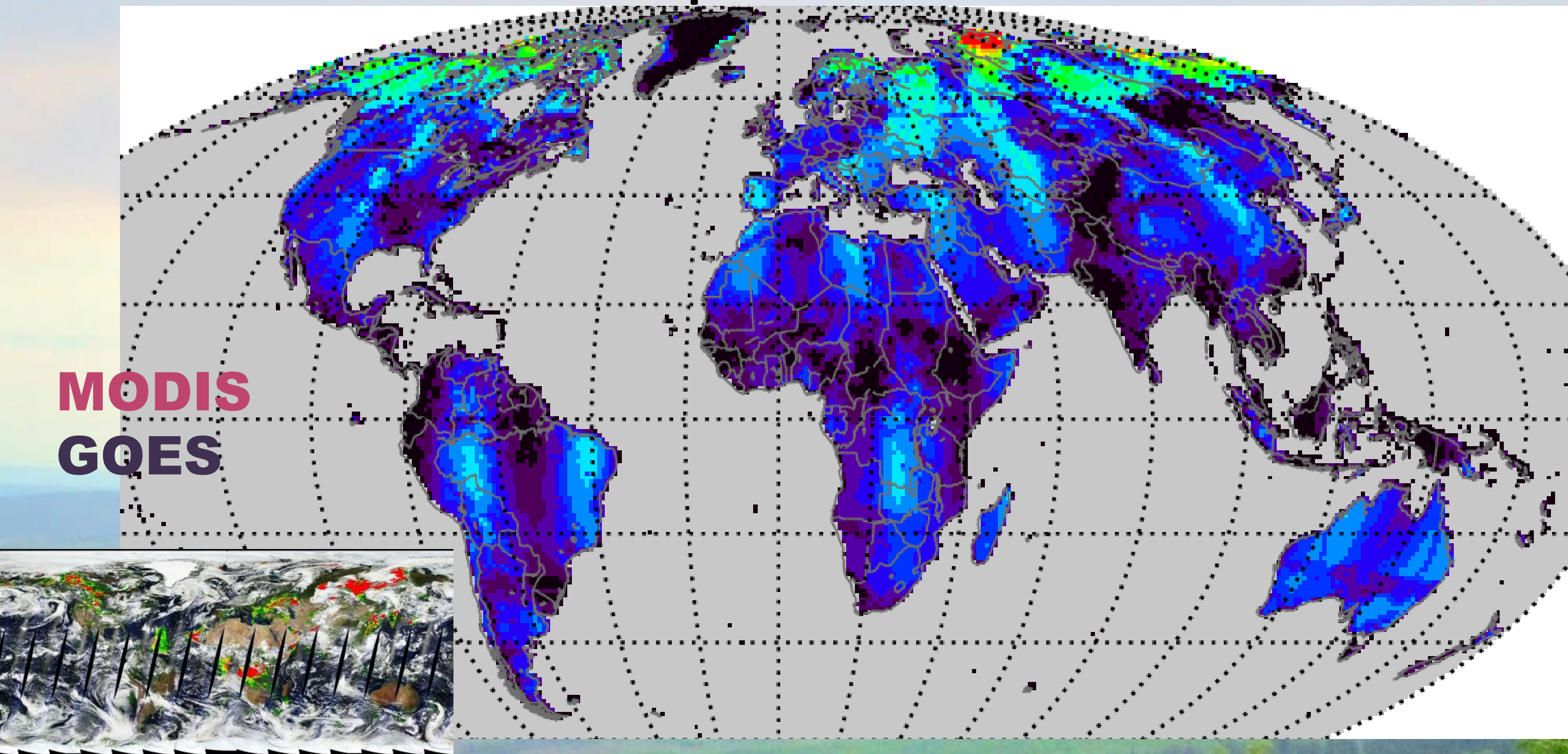


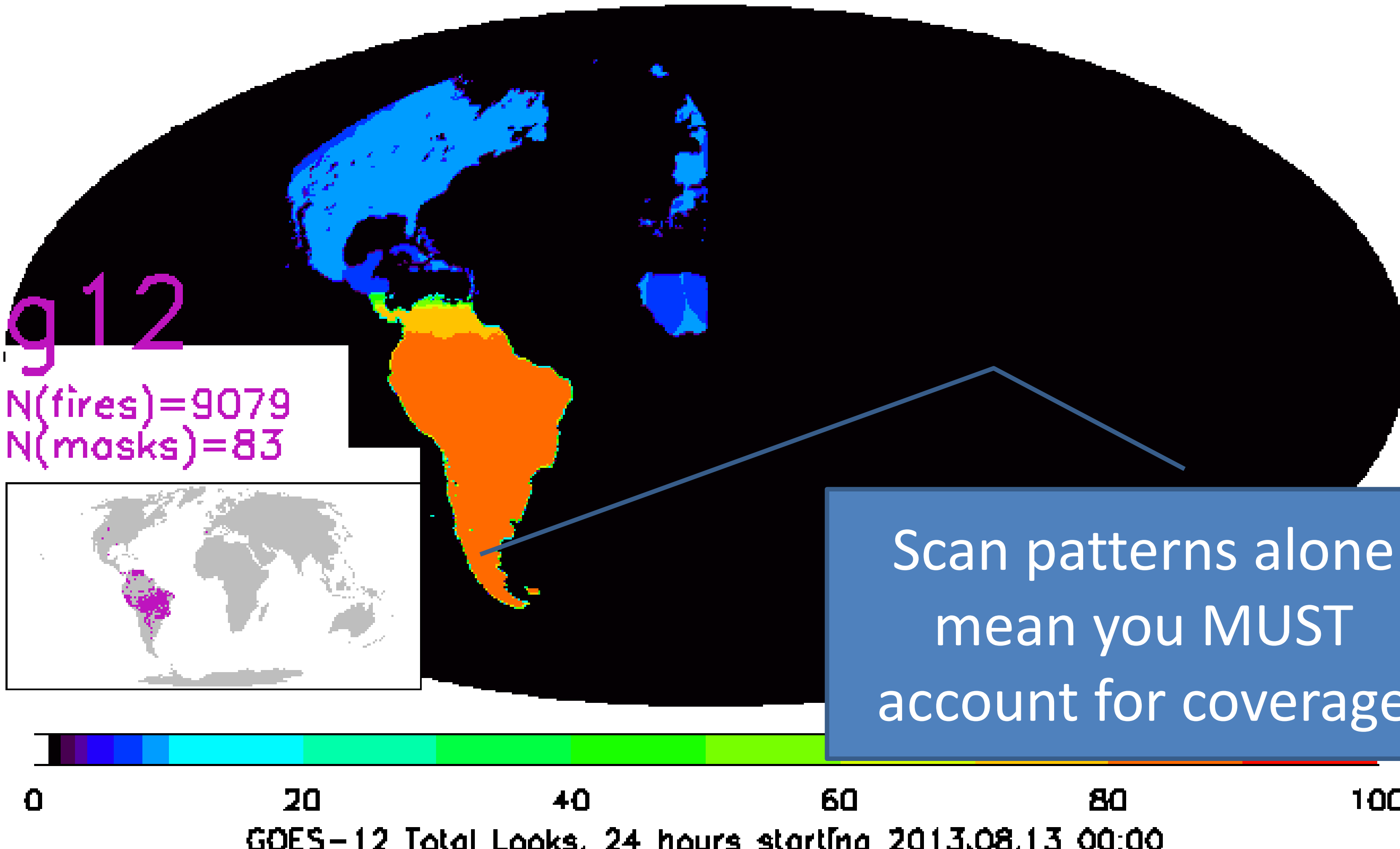
MODIS
GOES

These looks are still not created equal– some of them are in the morning, some in the afternoon, and some are at night! To fully normalize, we need to include the diurnal cycle.

Processing WF_ABBA data to constrain diurnal cycle

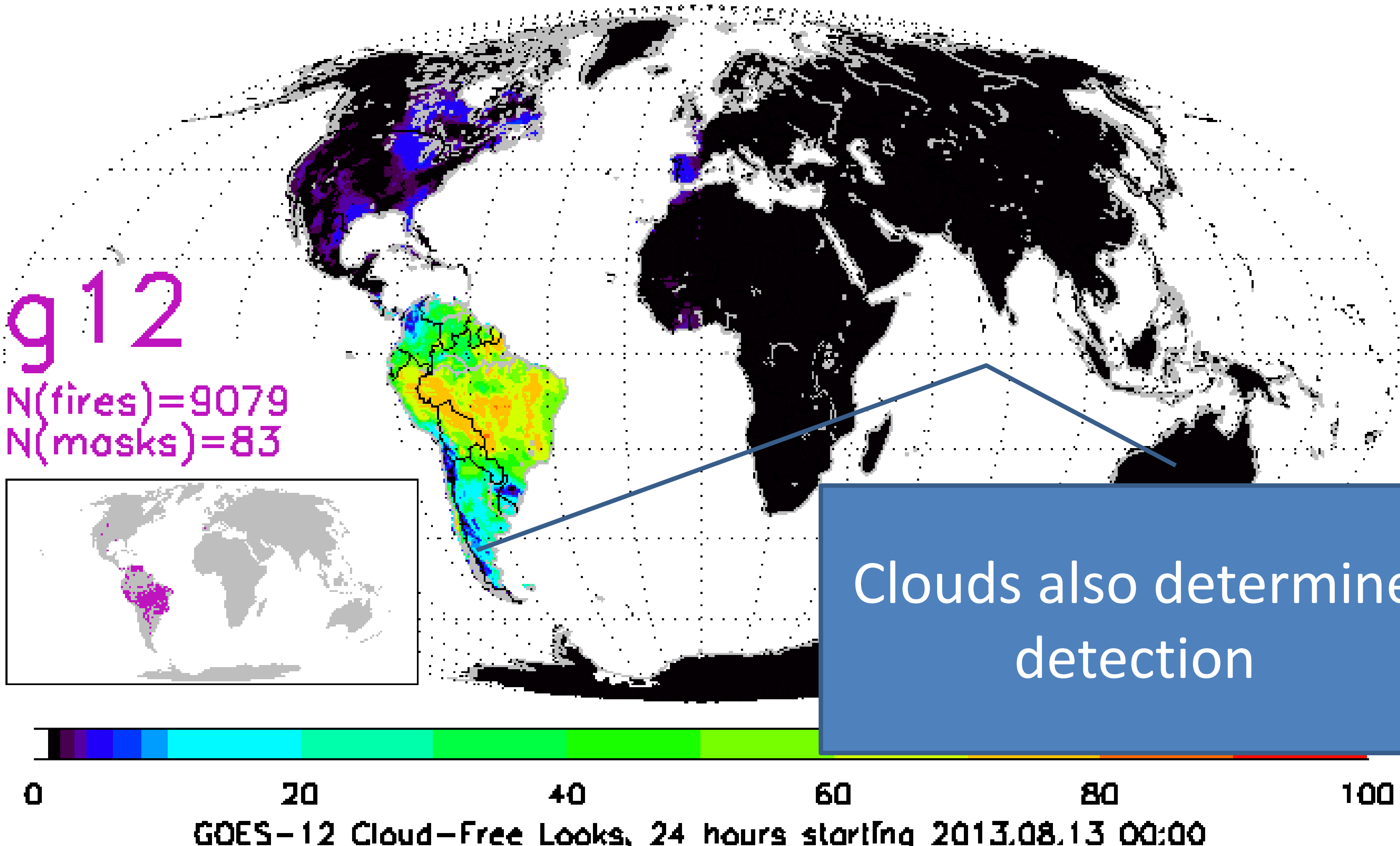
- All processing done on 0.5 degree grid
- Calculate hourly “fires per area sensed”
- Merge with climatological diurnal cycle
- Apply to MODIS to get correction to “nominal fire observing system”
- Re-apply to get hourly emissions

WF_ABBA coverage



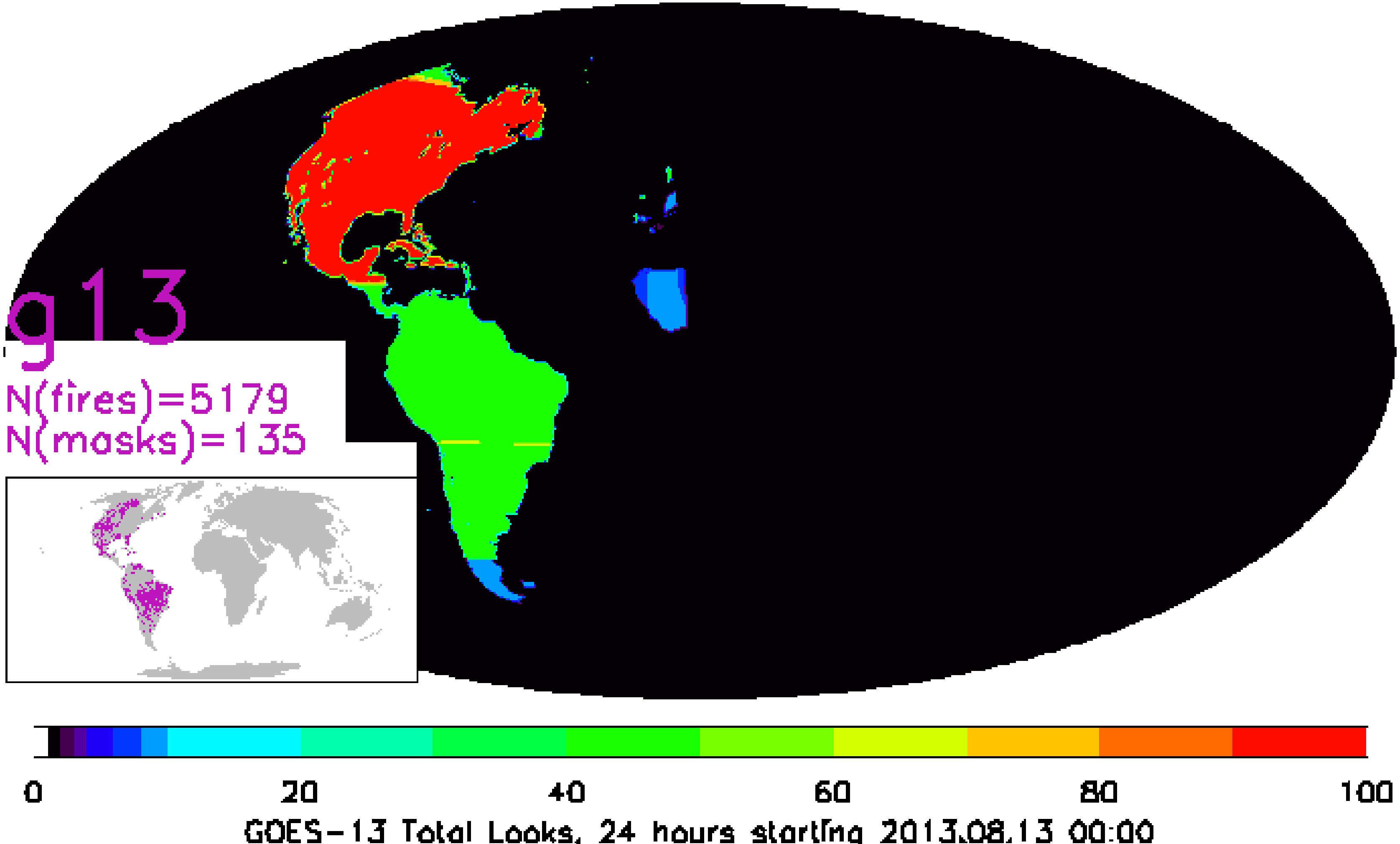
Scan patterns alone mean you MUST account for coverage

WF_ABBA coverage

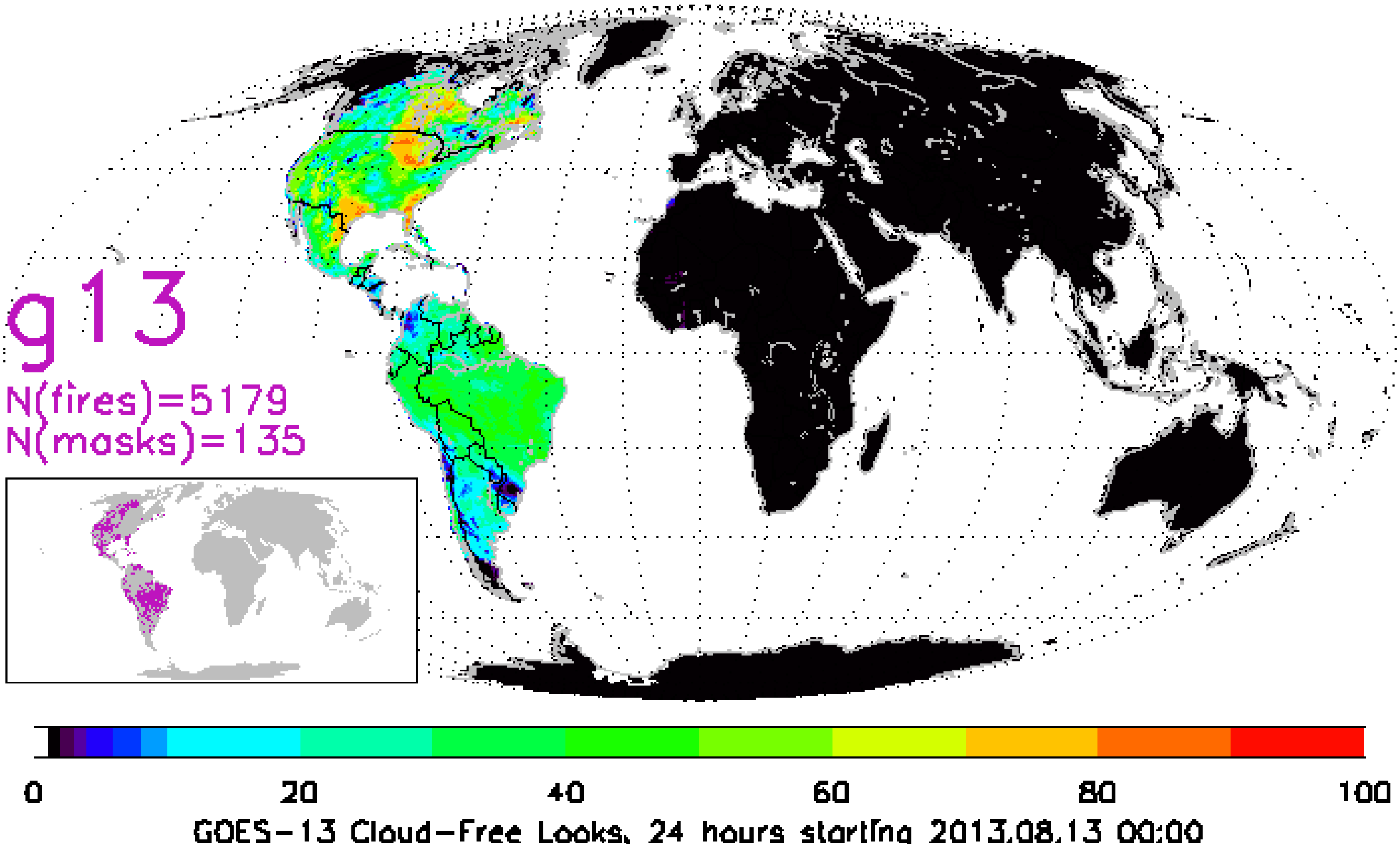


Clouds also determine detection

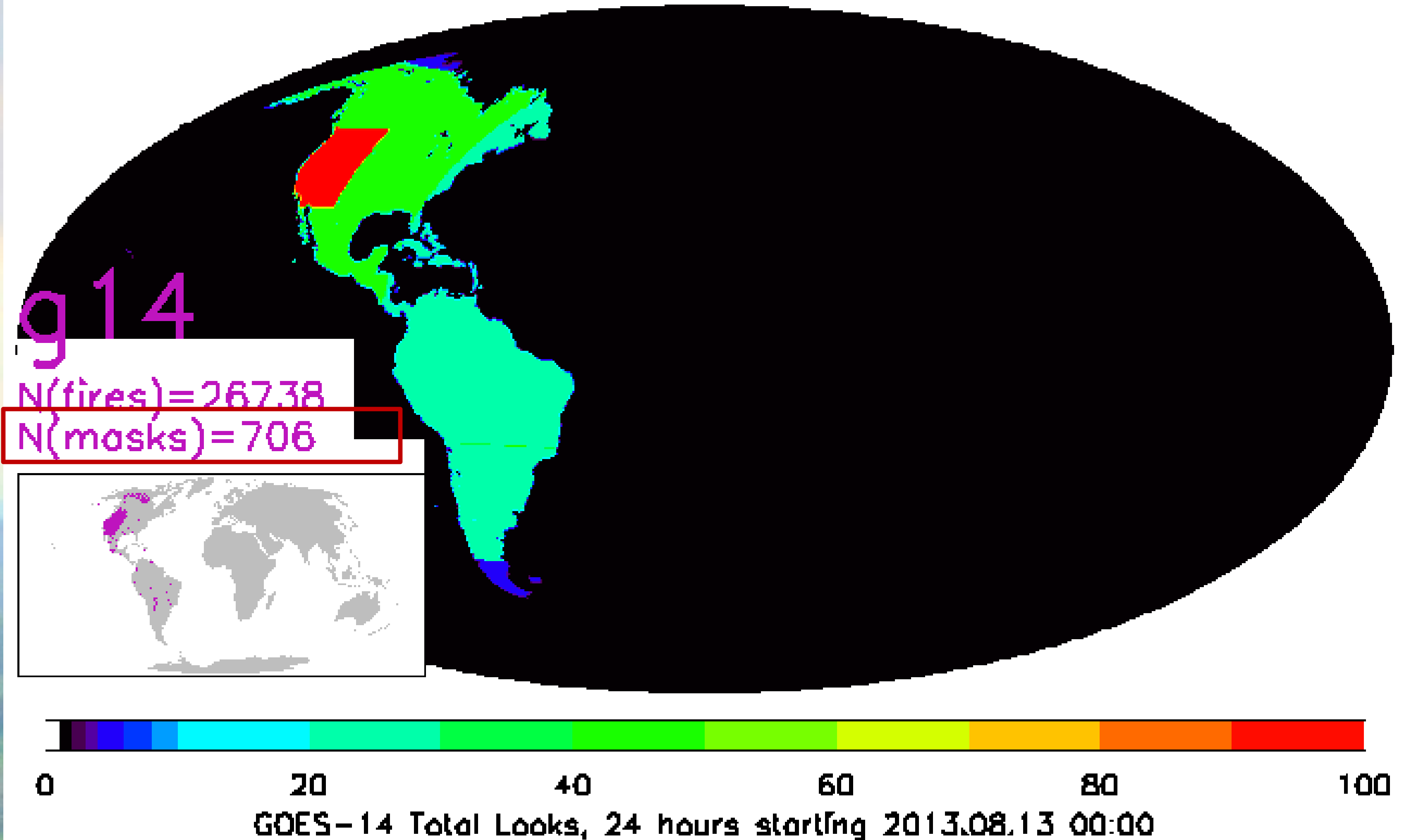
WF_ABBA coverage



WF_ABBA coverage

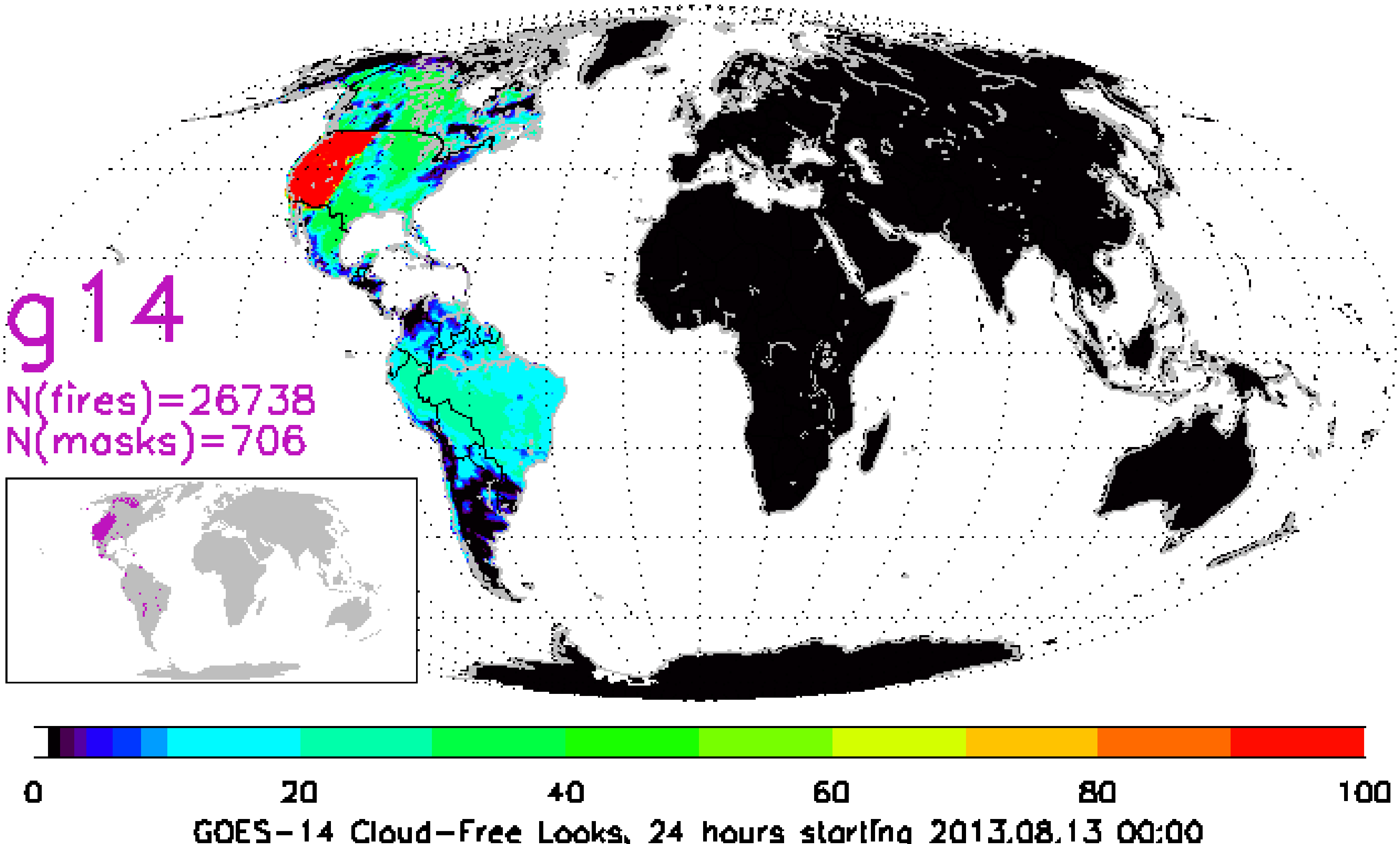


WF_ABBA coverage



700+ looks! This is GOES Super Rapid Scan operations. Even a small level of false positives can add up over 700 looks!

WF_ABBA coverage



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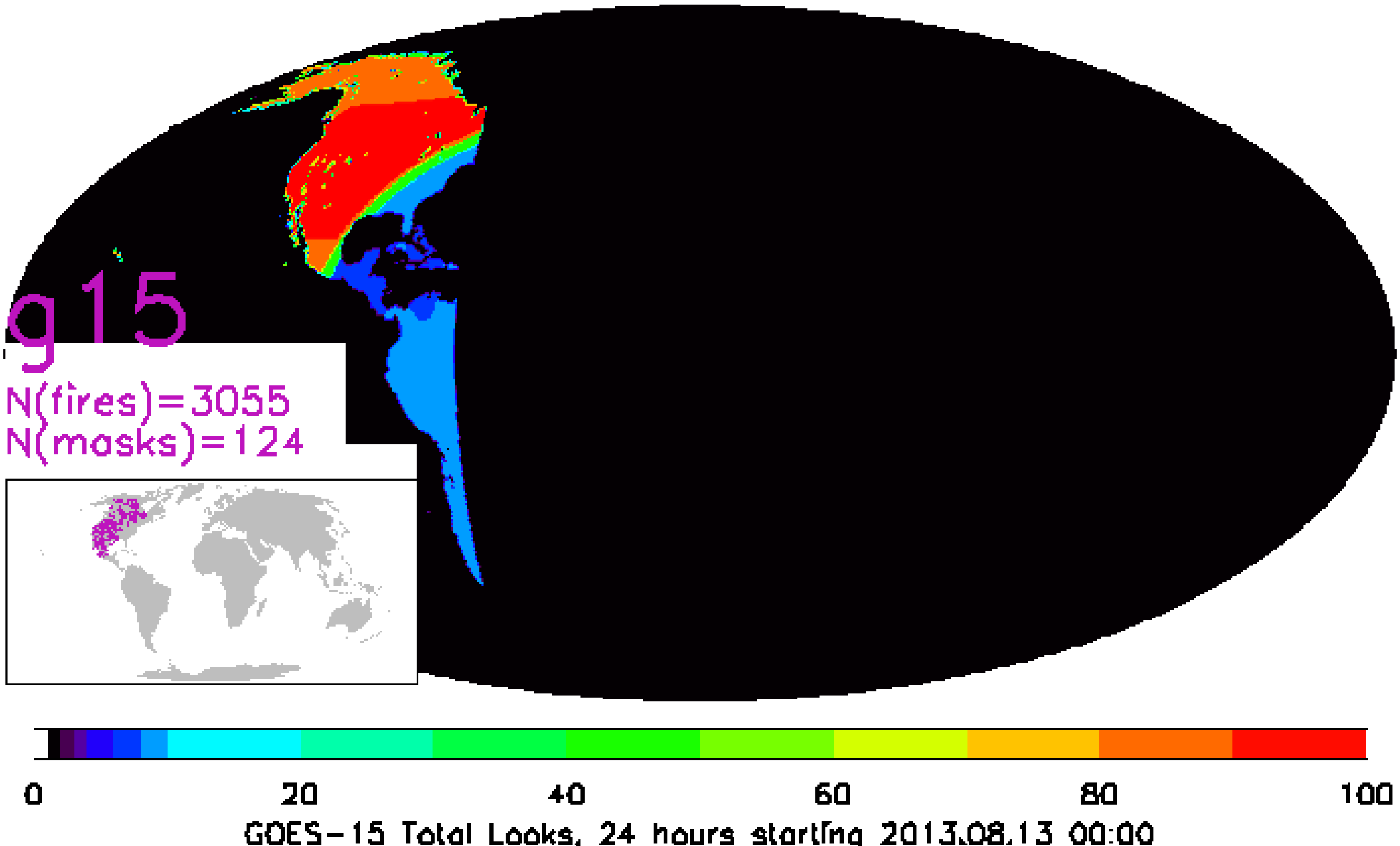

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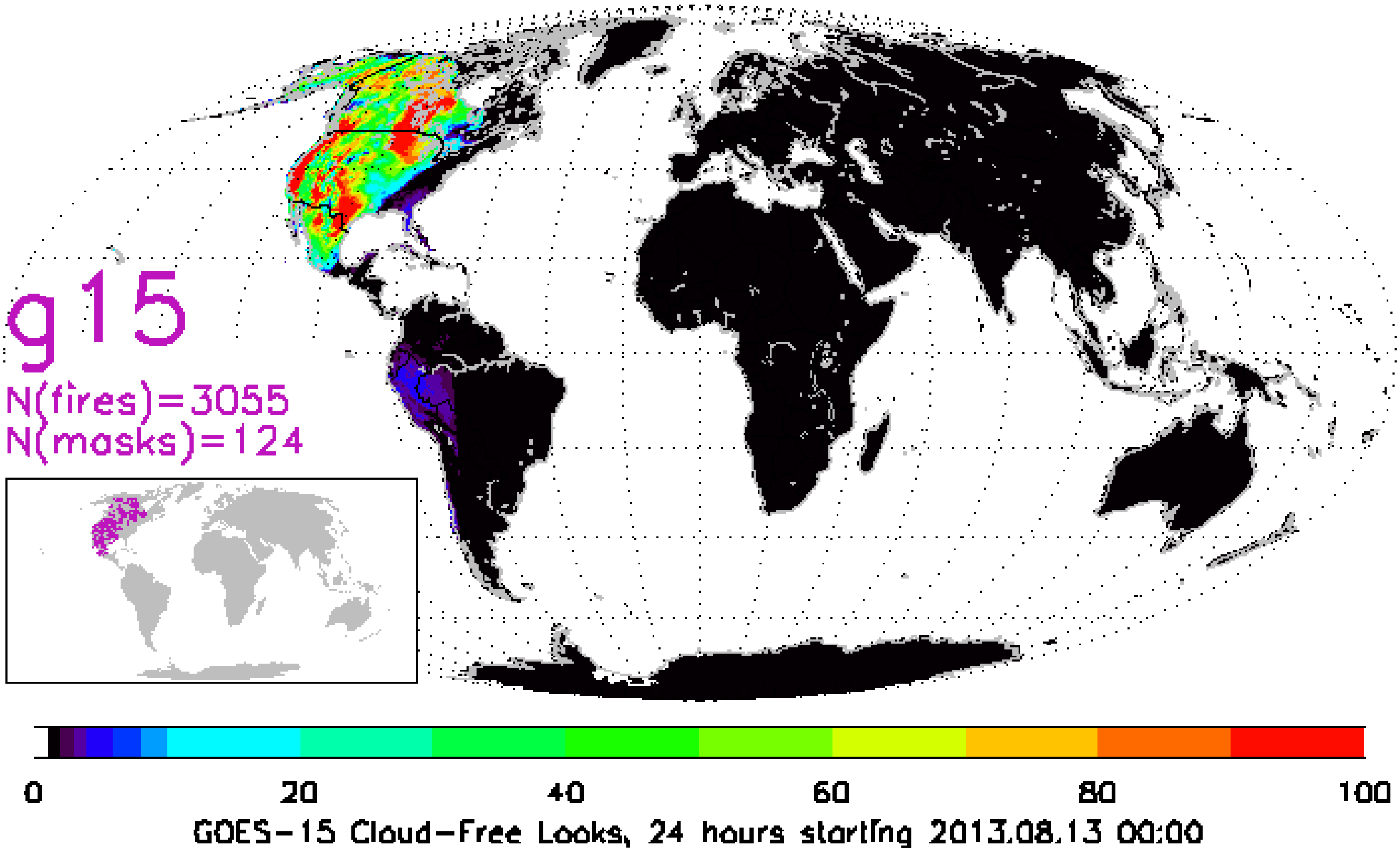

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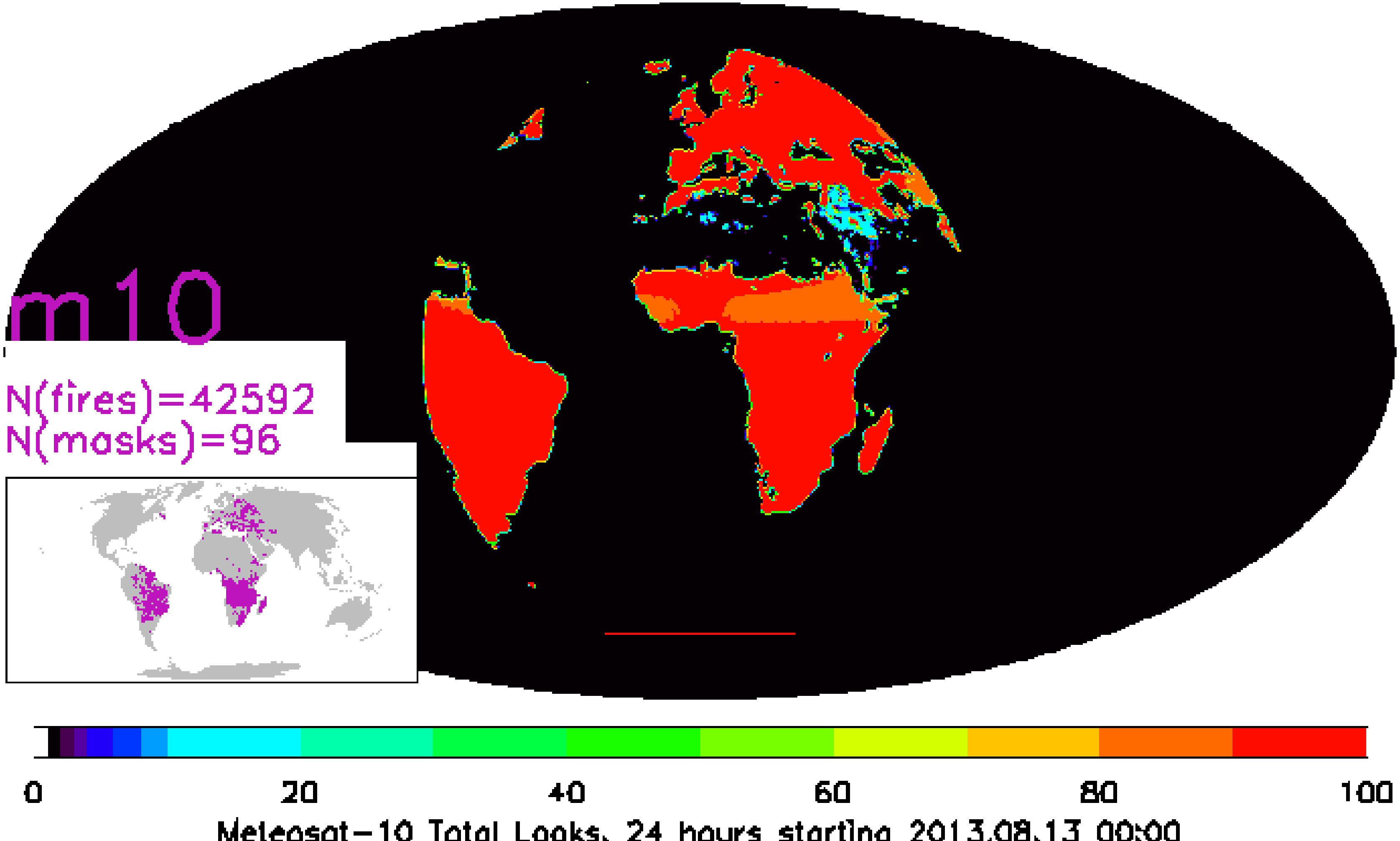
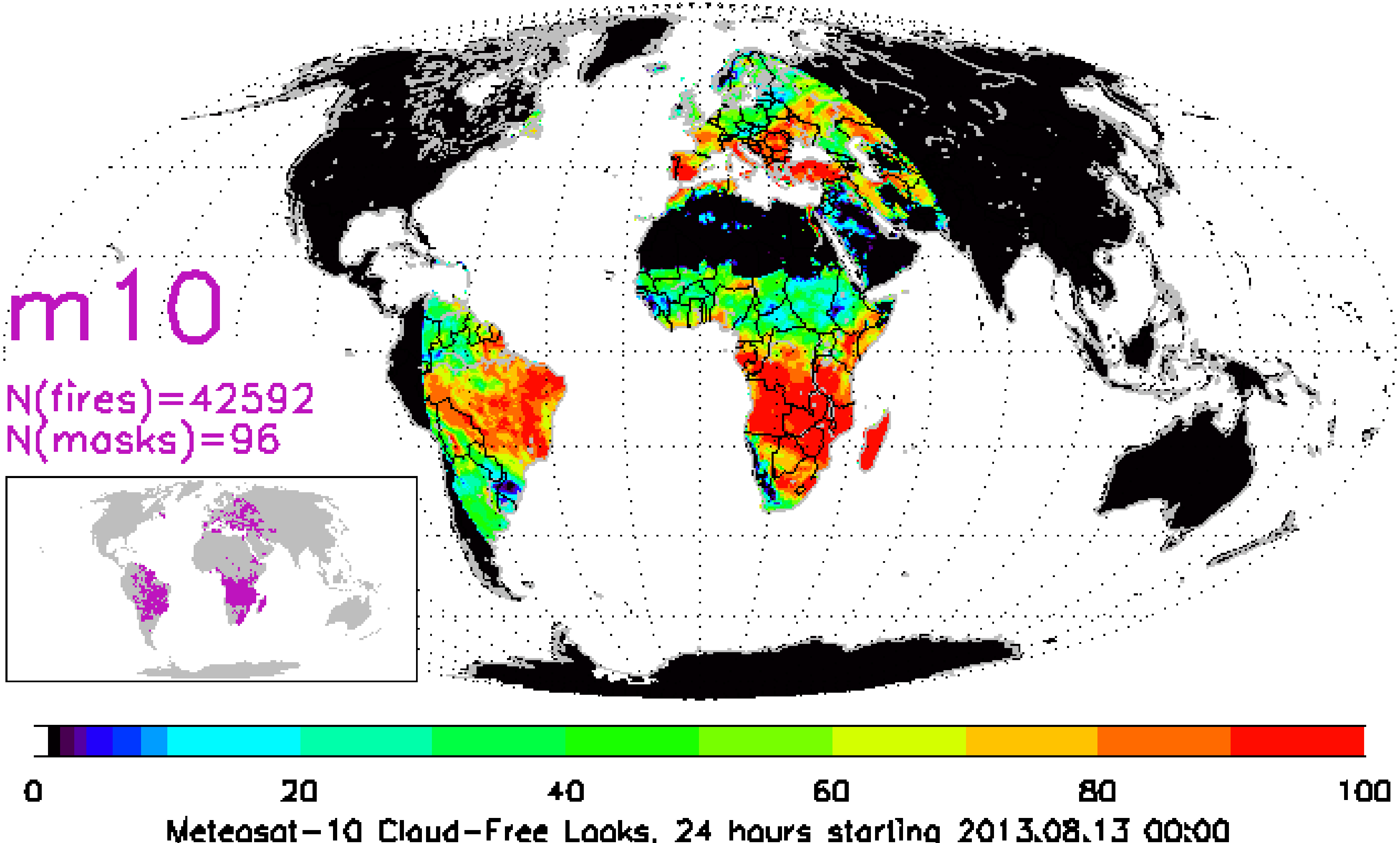


WF_ABBA coverage



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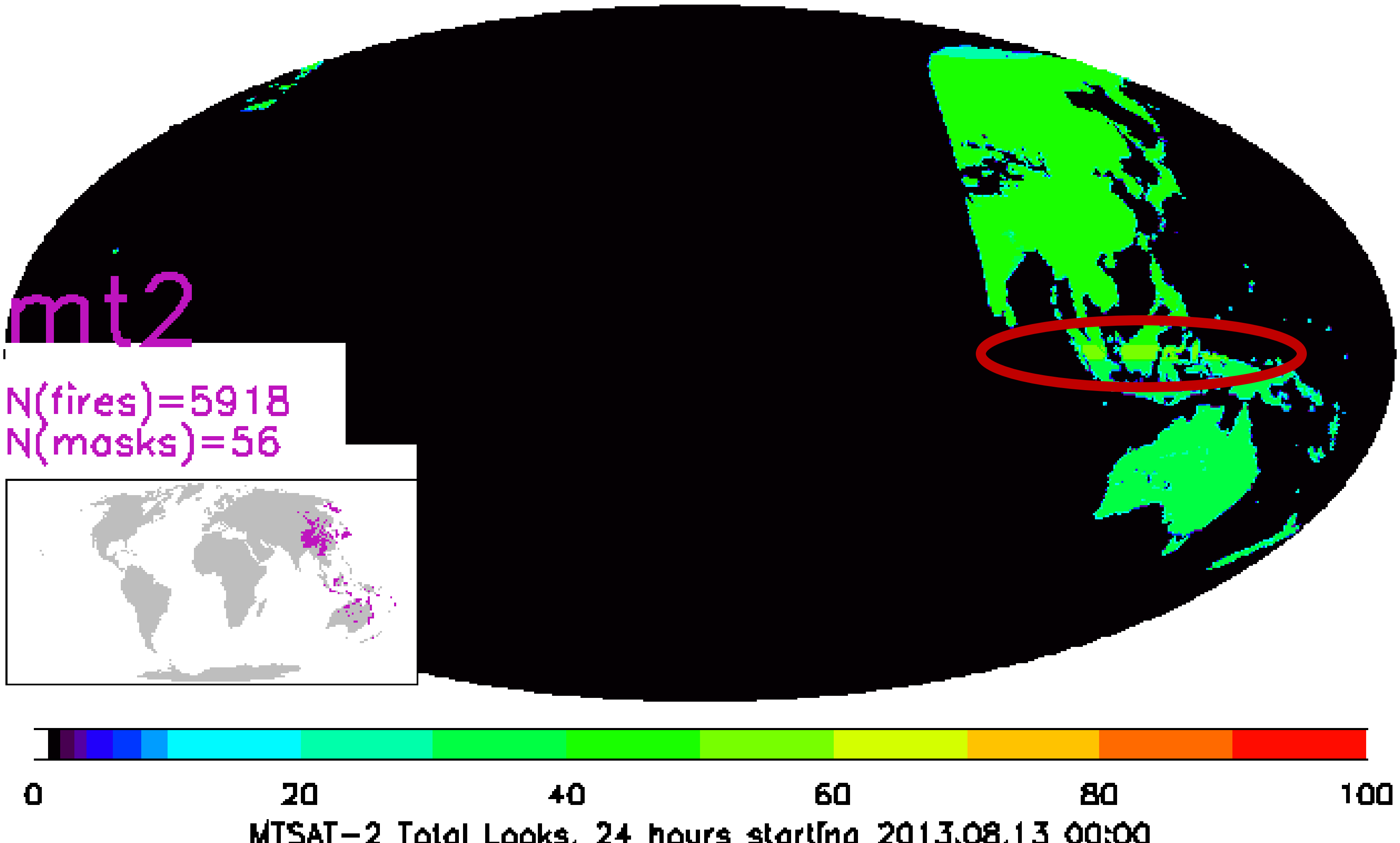
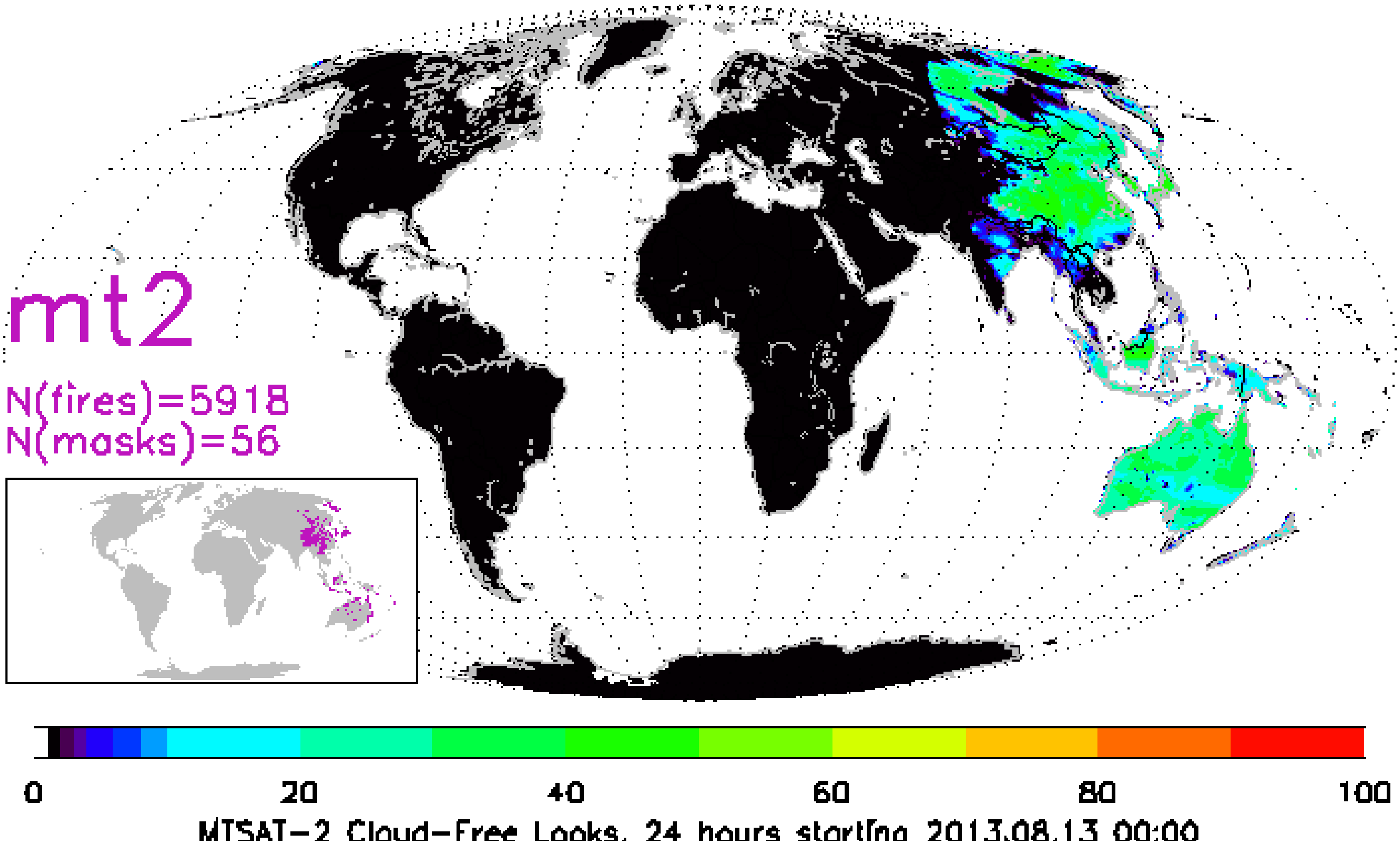


Bonus detection in Borneo+Sumatra! North+South hemisphere scans have 10° overlap.

WF_ABBA coverage



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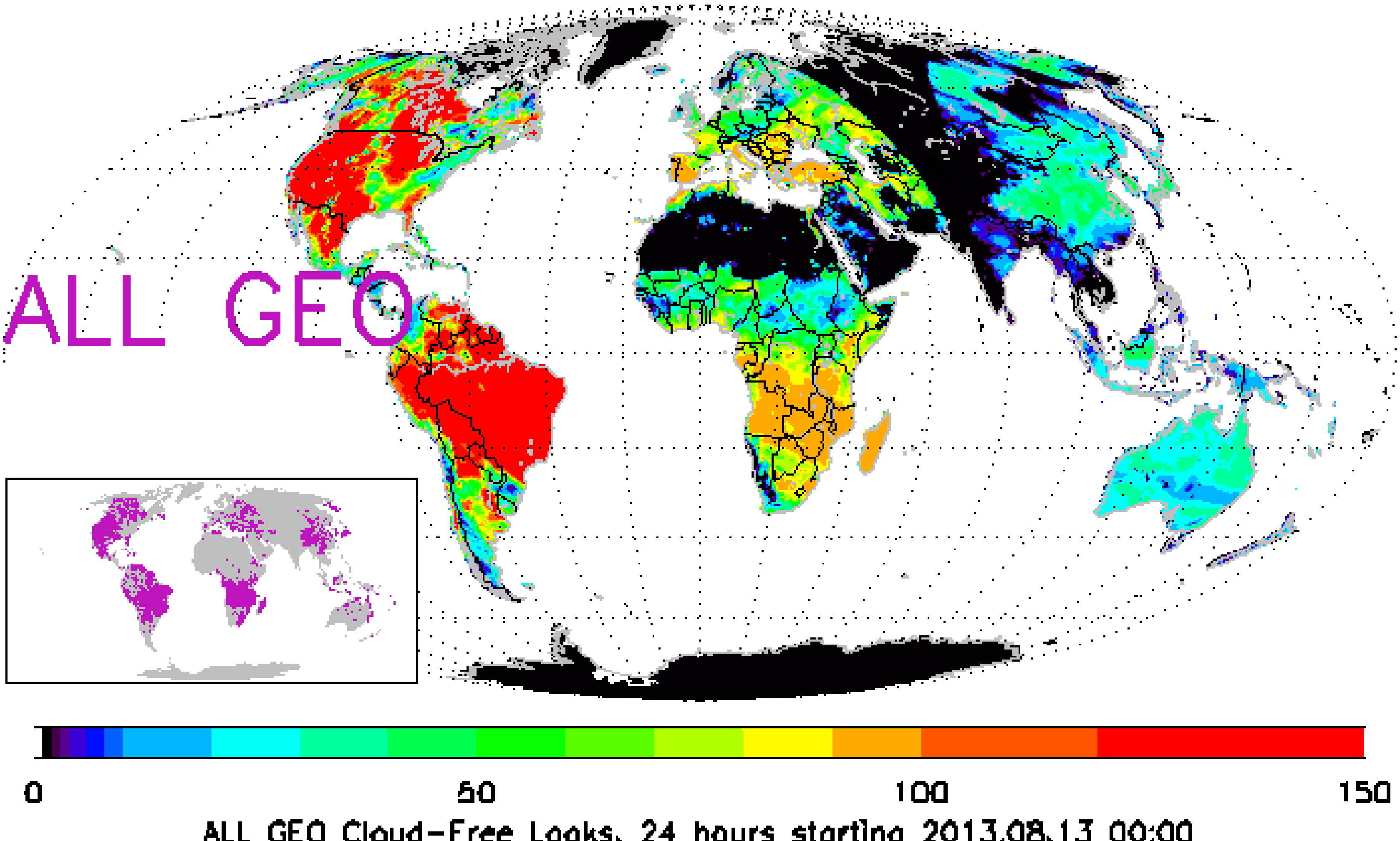
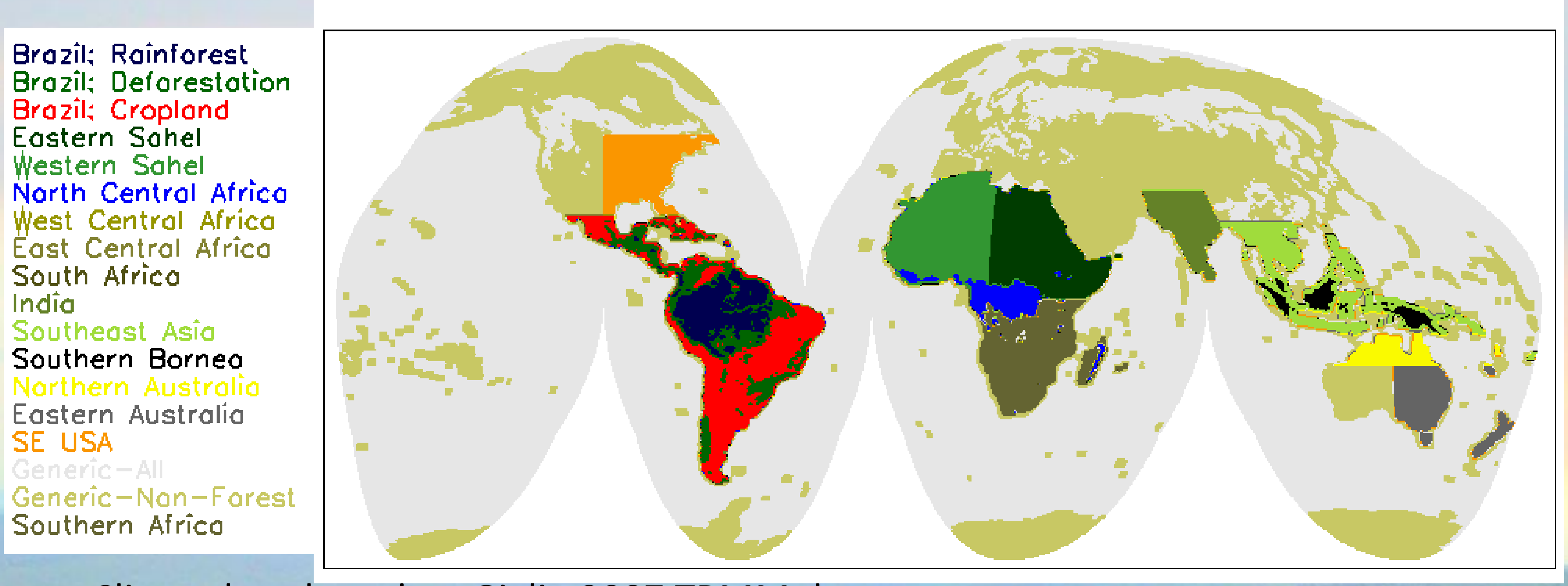
WF_ABBA coverage



This is a very approximate "fire observability" from WF_ABBA. It ignores differences in sensitivity between sensors, and angular variation in detection efficiency.

Using WF_ABBA to dynamically constrain diurnal cycles of fire activity

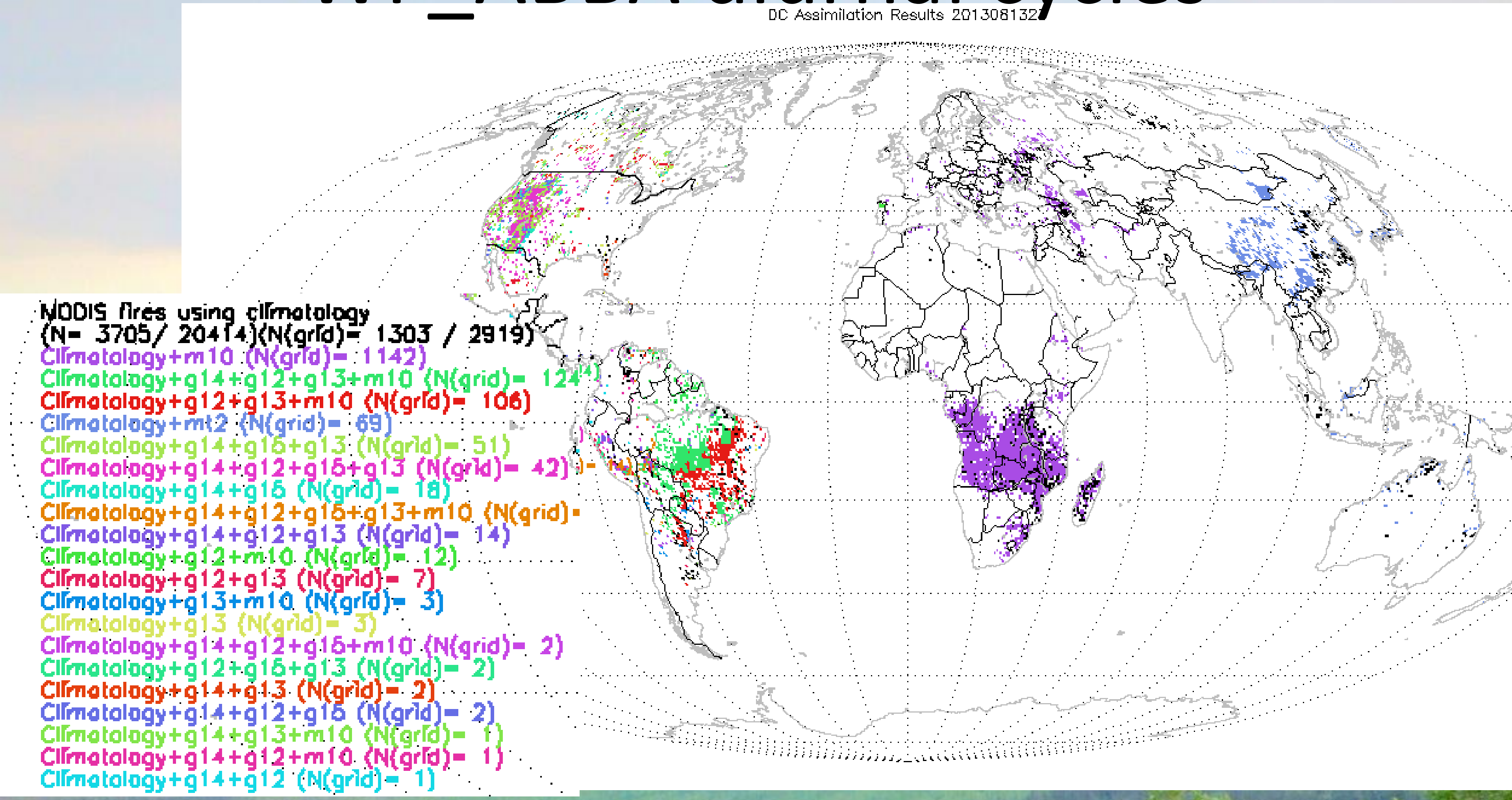


- Climatology based on Giglio 2007 TRMM data
- TRMM diurnal cycles are based on small regions, I extend them based on geography and land cover
- Two generic diurnal cycles (overall and non-forest) are used outside the tropics
- Diurnal cycles are 24 hourly values that sum to 1:
  - "fraction of 24-hour fire activity at each hour"
- This climatology is a prior; GEO observations are added where available

Merging climatological and observed diurnal fire cycles

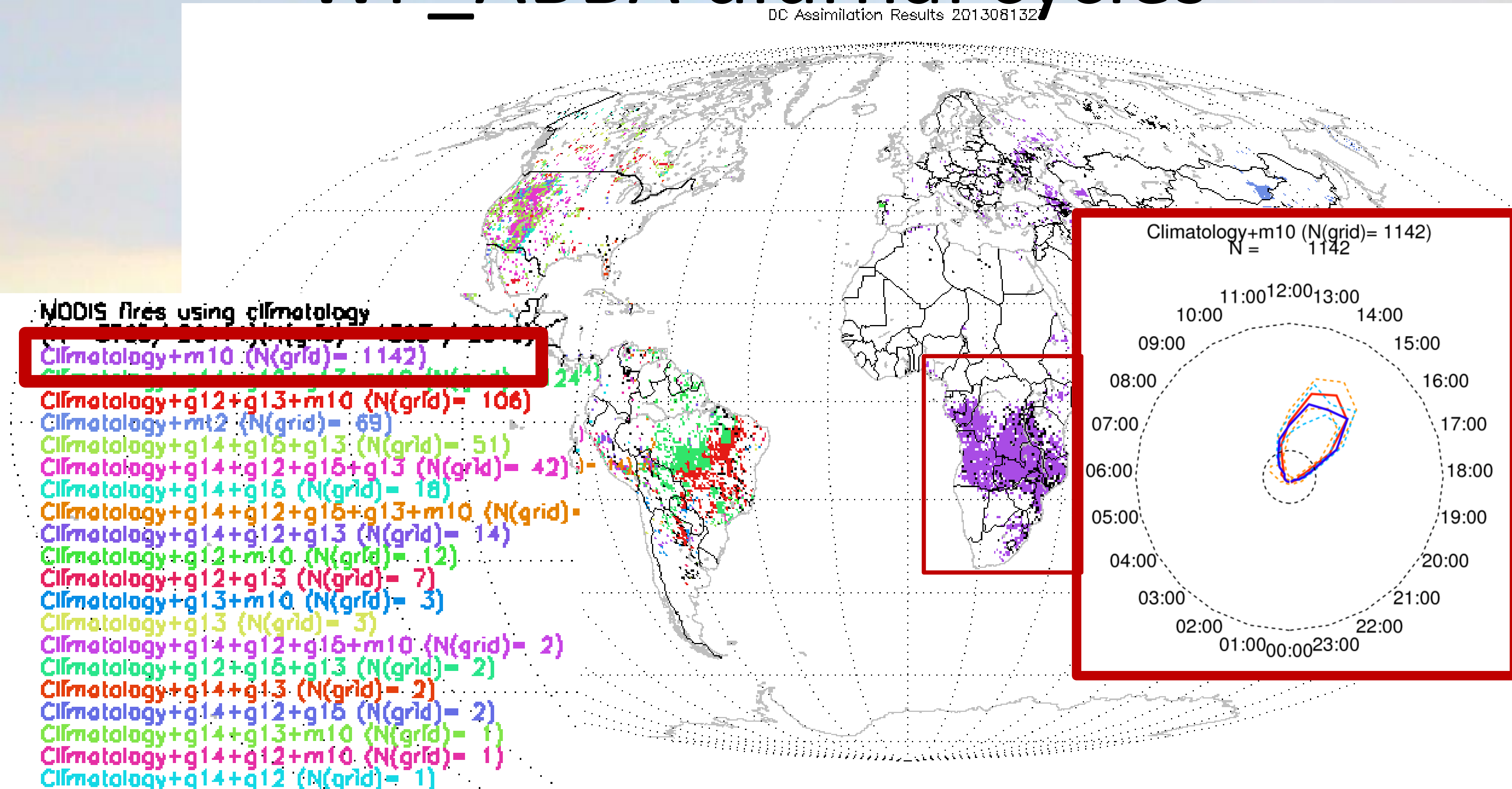
- Climatology gives 24 hourly fractions of total daily activity
- WF_ABBA data are normalized to “fires per area sensed”
- fractions of total activity are calculated for each grid cell for each observation with data
- Optimal interpolation is used to create analyzed diurnal cycle
- After all obs are assimilated, diurnal cycles are truncated to 1% per hour minimum

WF_ABBA diurnal cycles



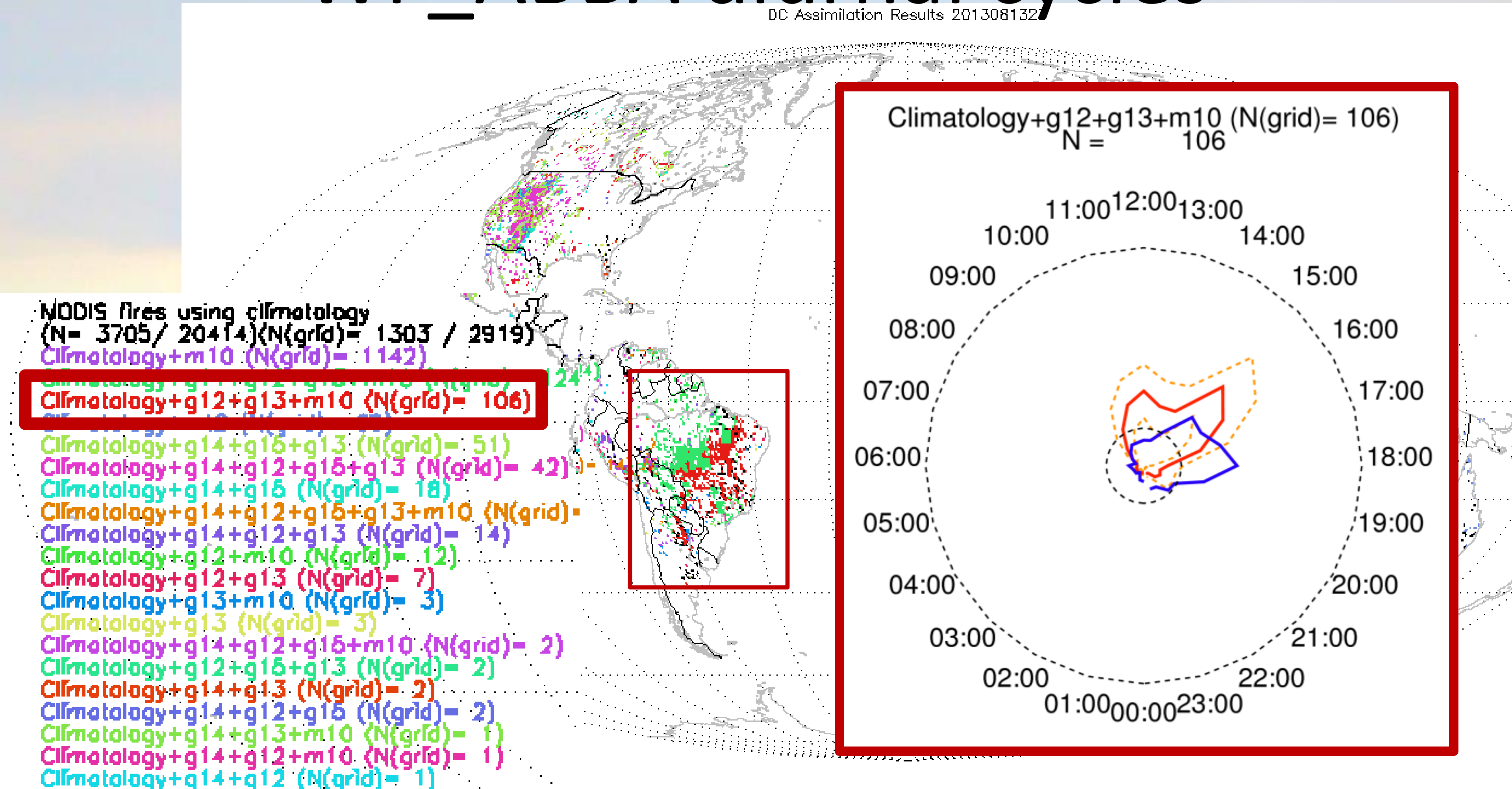
80% of MODIS fires have modified diurnal cycle applied to them from WF_ABBA.

WF_ABBA diurnal cycles



Meteosat-10 WF_ABBA data agree with climatological diurnal cycle in Africa, but introduce variability by location.

WF_ABBA diurnal cycles

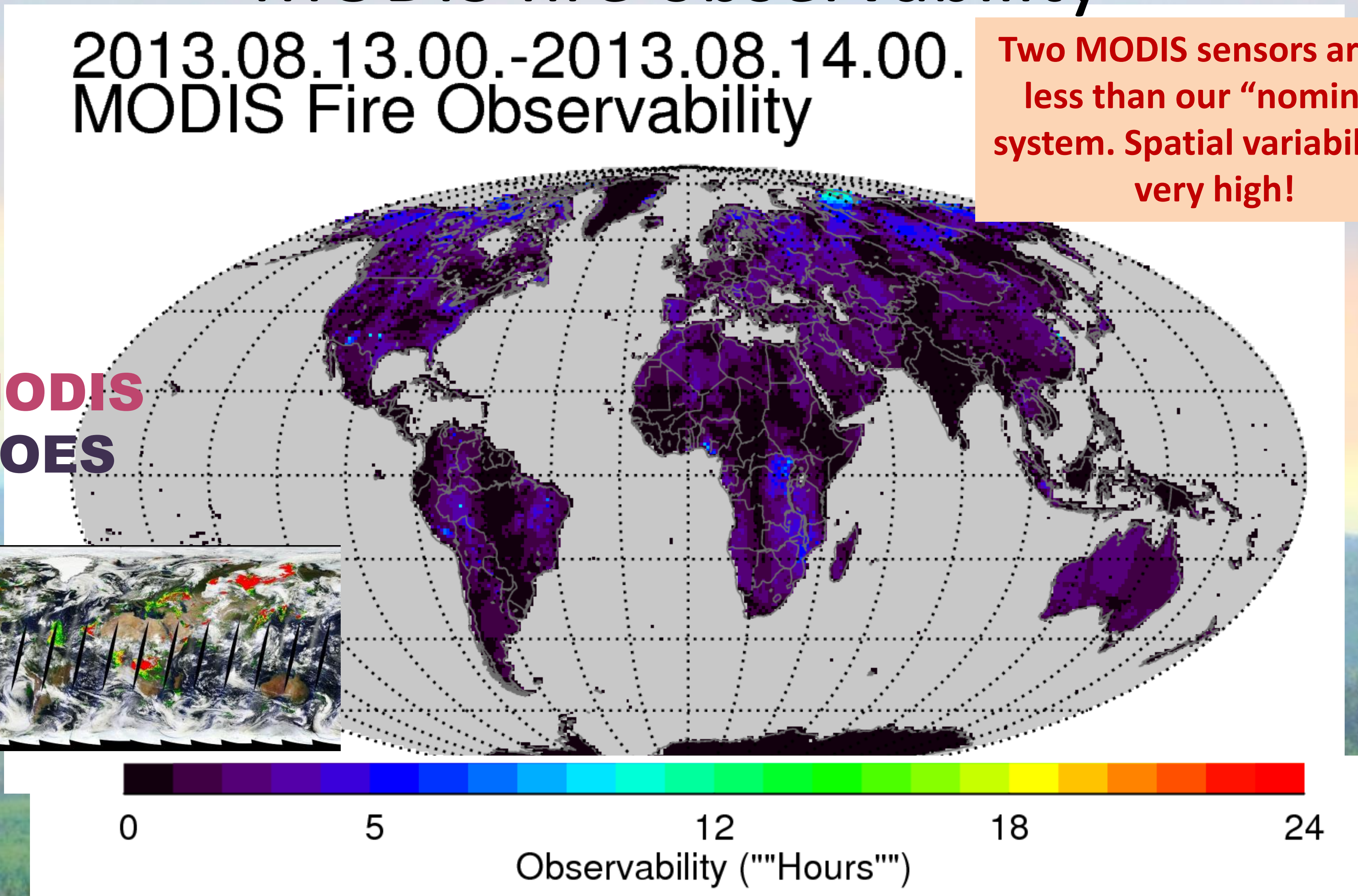


WF_ABBA data is shifting diurnal cycle earlier in the day vs. climatology for these South American locations where 3 GEO sensors were available

Applying WF_ABBA diurnal cycles to get MODIS fire observability

- For each observation, “what is the fraction of 24-hour fire activity captured by an observation this hour?”
- This is the last step to transform our MODIS observations into an estimate of what our “nominal” system would observe
- The net multiplier is the MODIS observability for that time period
- We can show it in hours (x/24)

MODIS fire locations are explained by MODIS fire observability

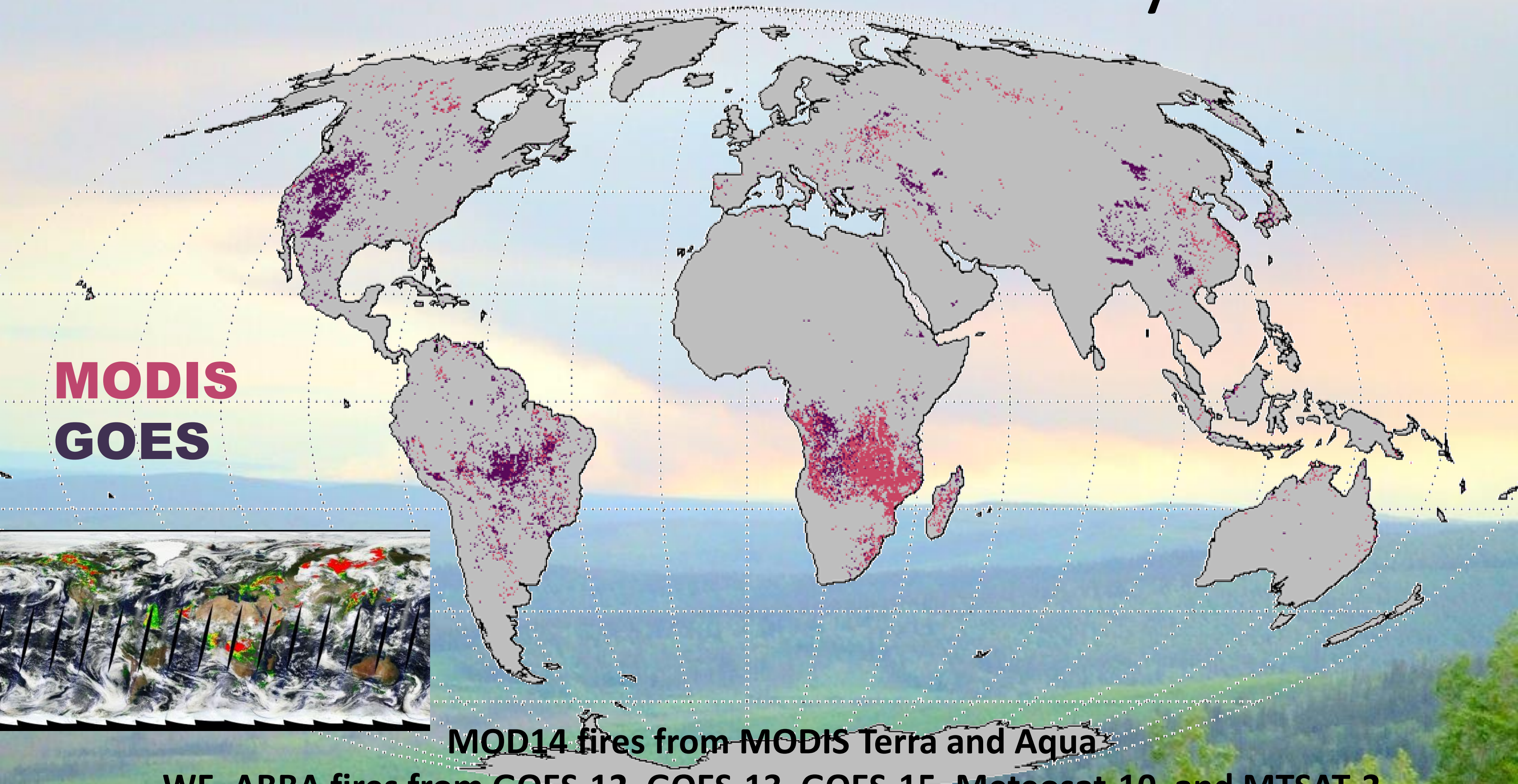


Two MODIS sensors are far less than our "nominal" system. Spatial variability is very high!

MODIS

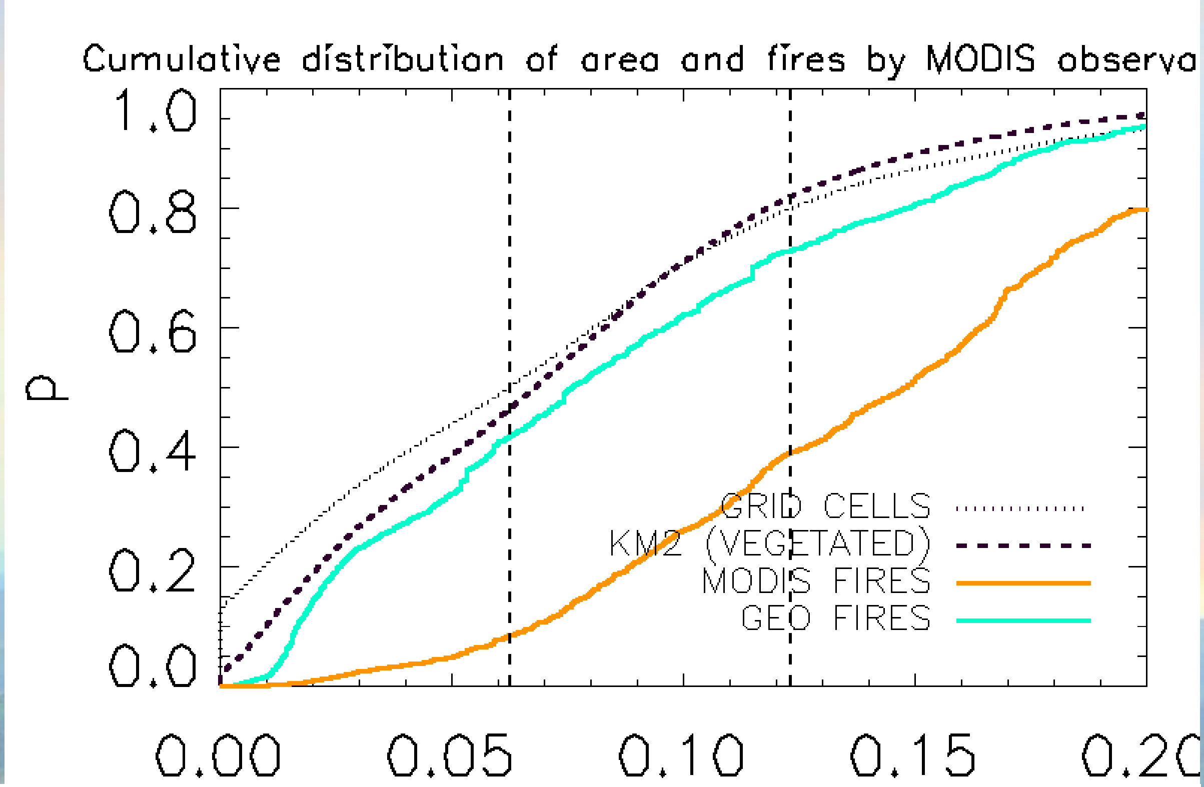
GOES

MODIS fire locations are explained by MODIS fire observability



MOD14 fires from MODIS Terra and Aqua
WF_ABBA fires from GOES-12, GOES-13, GOES-15, Meteosat-10, and MTSAT-2

MODIS fire observability tracks closely to fire detections



MODIS observability from FLAMBE

- GEO fires (blue) track total vegetated area
- MODIS fires (orange) are heavily weighted to observability > 0.05 (~1 “hour”)
- Almost 50% of vegetated area is poorly observed by MODIS in 24 hours
- **Observability correction can be done, and improves MODIS-GEO spatial correlation, but only for observability > 0.05**

Perspective

1. Correction for detection opportunity yields improvements in both spatial and temporal description of fires
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. Incorporating all of these effects into a single model has not yet been accomplished

Thanks!

- WF_ABBA team at CIMSS
  - Chris Schmidt
  - Jay Hoffman
  - Elaine Prins
- MODIS Fire Team
  - Louis Giglio, UMD
  - Wilfrid Schroeder, UMD
- FLAMBE team at NRL

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