Impact of Satellite Viewing Swath Width on Global and Regional Aerosol Optical Thickness Statistics and Trends

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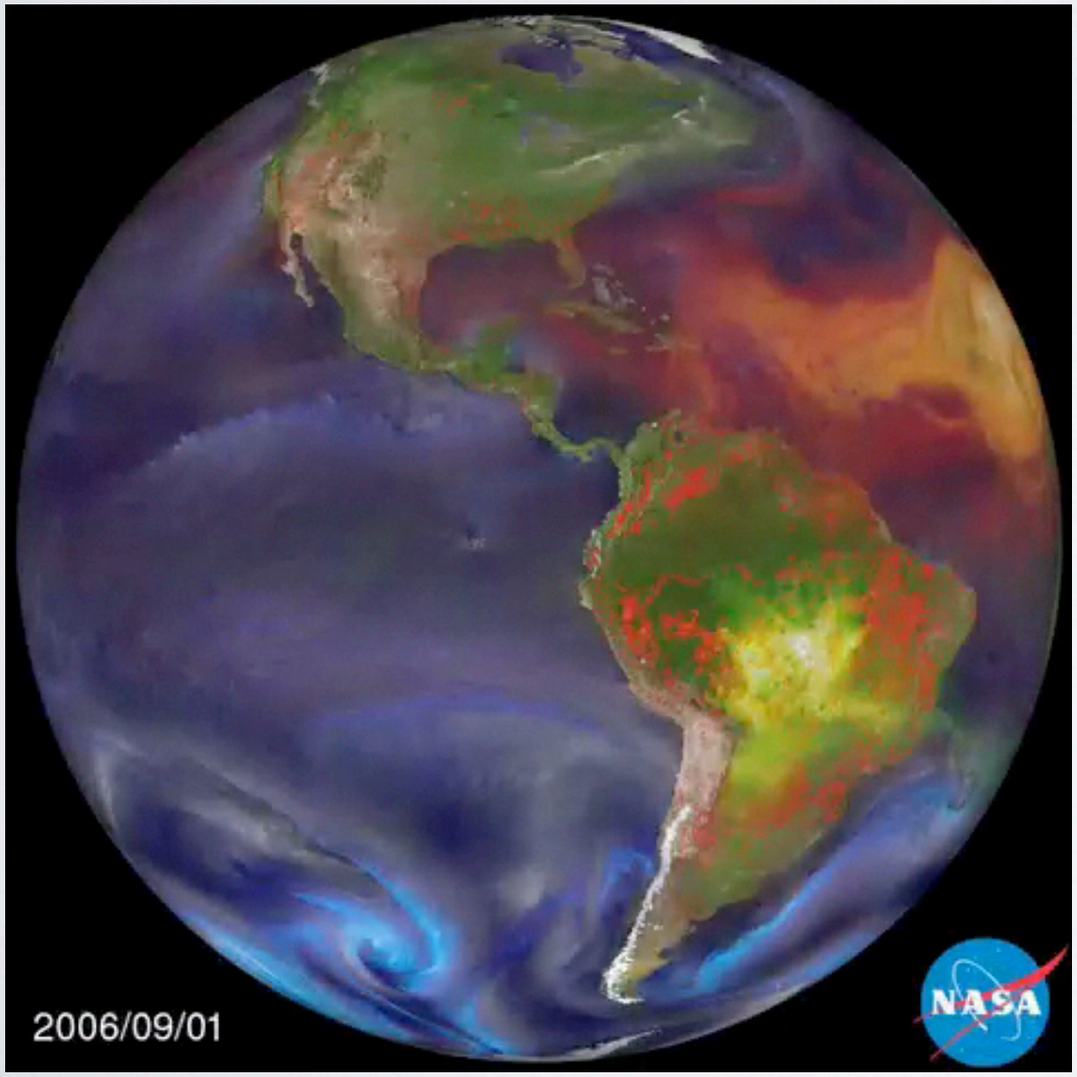
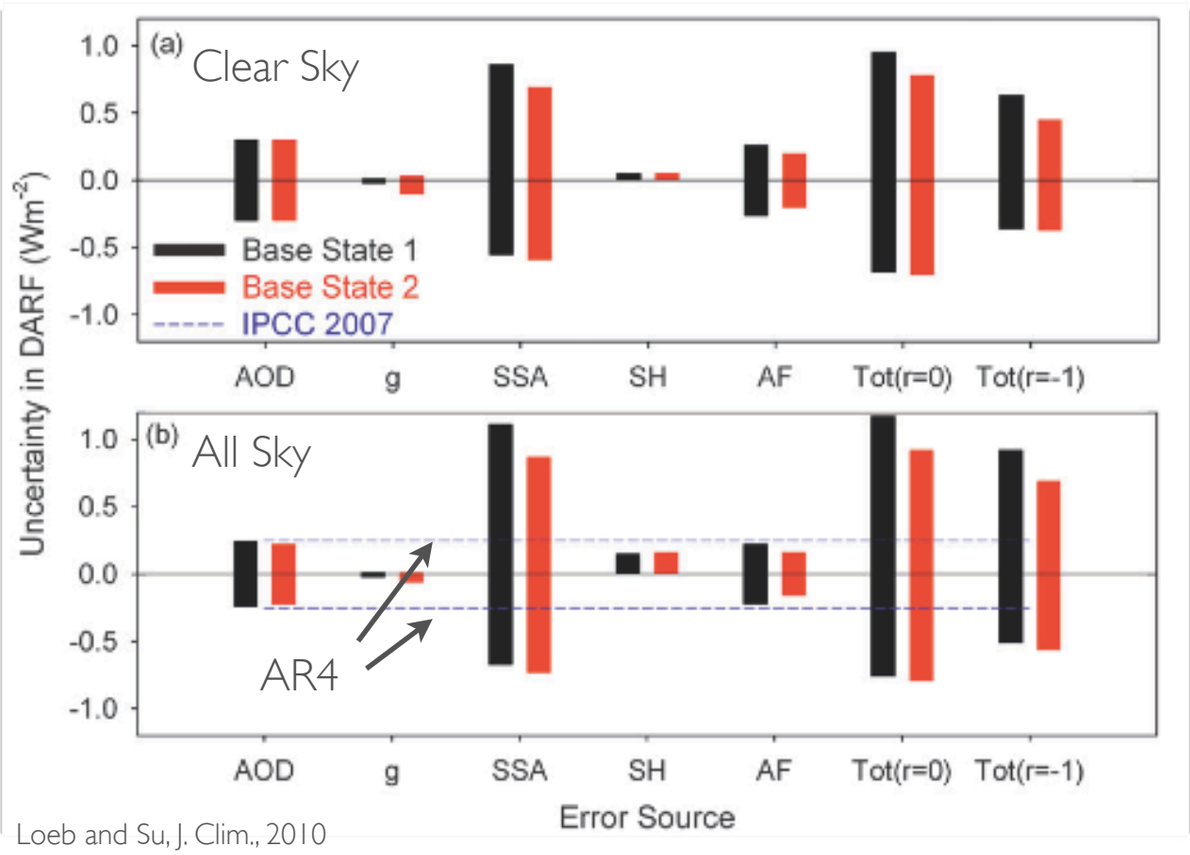
Motivation

Aerosols (dust, sulfate, carbon, etc.) influence climate by scattering and absorbing radiation, and by affecting the properties of clouds

They are spatially, temporally, and compositionally heterogeneous in the atmosphere

Despite more than a decade of observation from advanced satellite platforms there remains considerable uncertainty in their climate impact





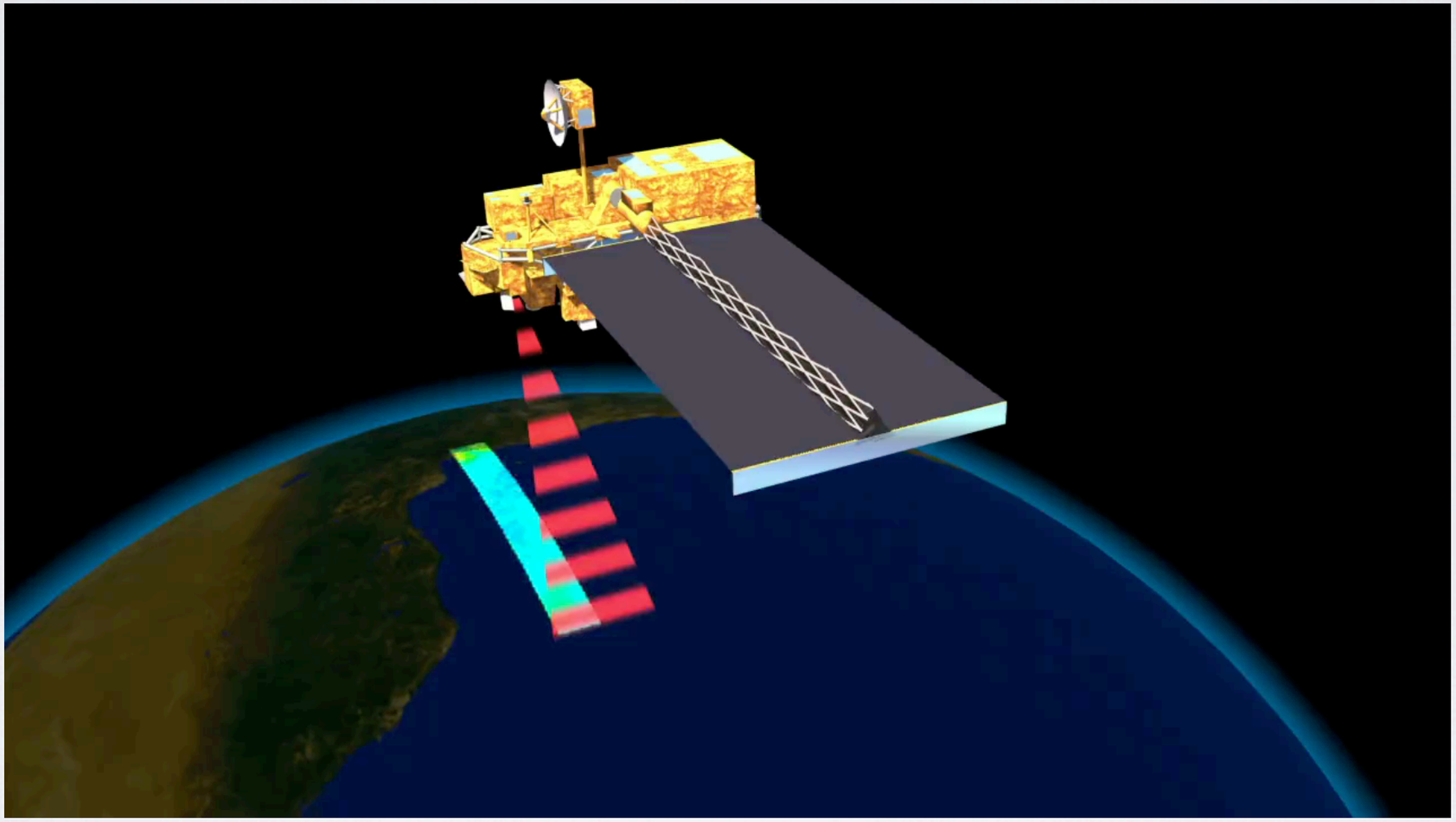
Loeb and Su, J. Clim., 2010

Reduction of uncertainties will require new observing systems and models

Consideration of Coverage

A polar orbiting satellite will “paint” a picture of Earth with numerous overpasses

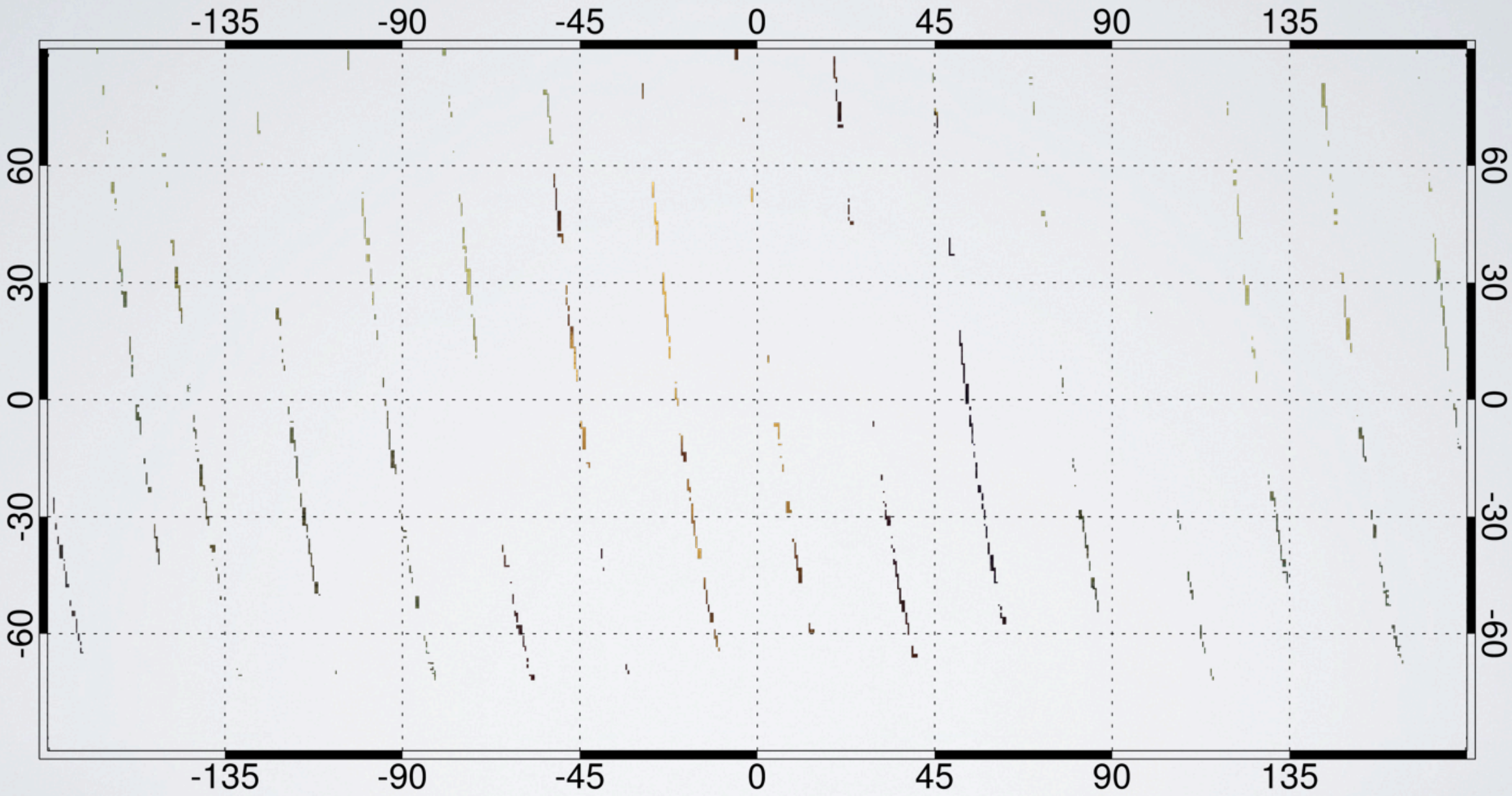
Often there is a trade-off between spatial coverage and instrument capability



How does a reduction of spatial coverage impact the statistics related to aerosols?

An Illustration of the Problem

Without wide-swath sampling you don’t see the whole picture, but you also don’t know what you aren’t seeing



CALIOP-like sampling

An Illustration of the Problem

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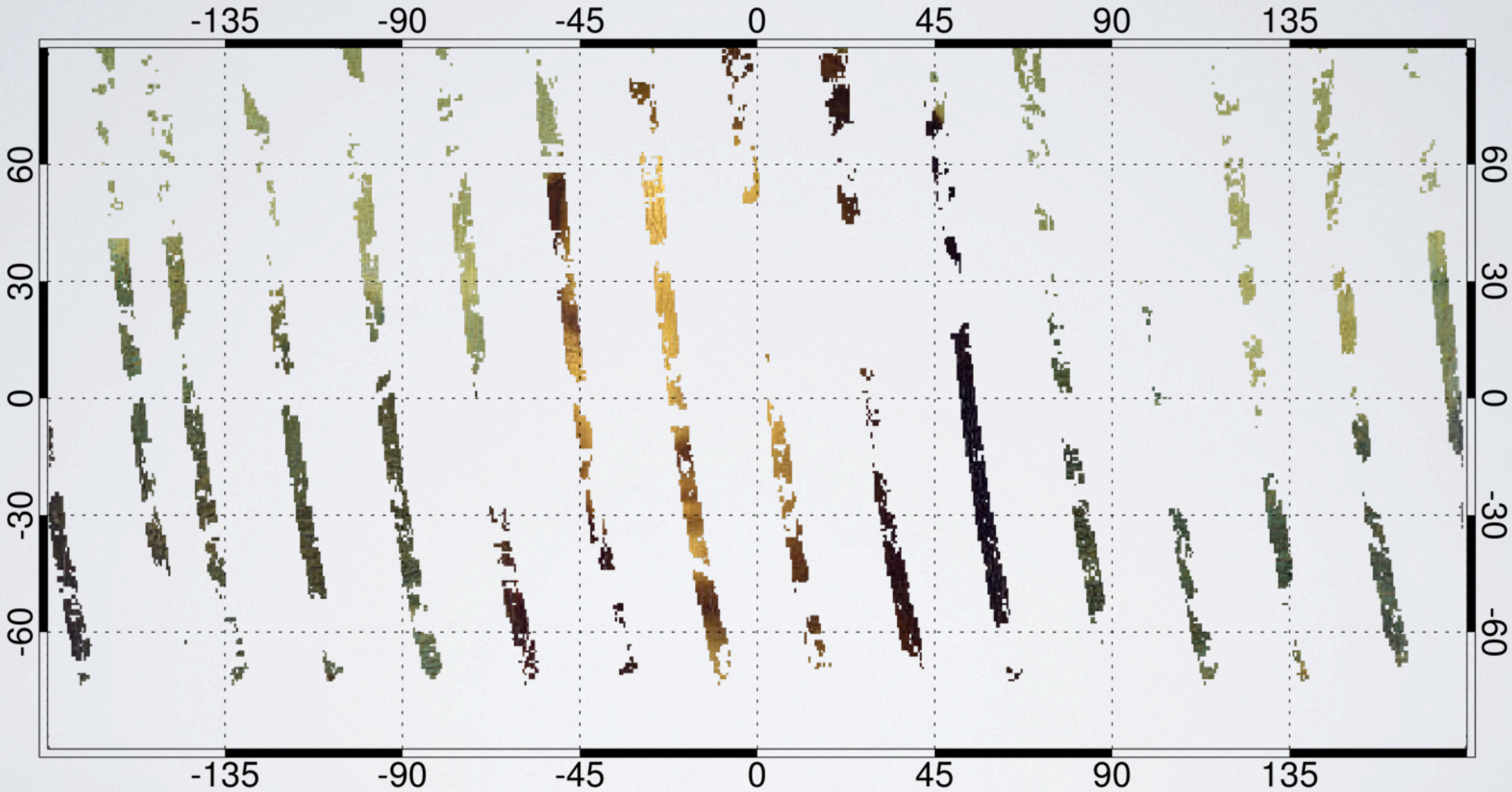
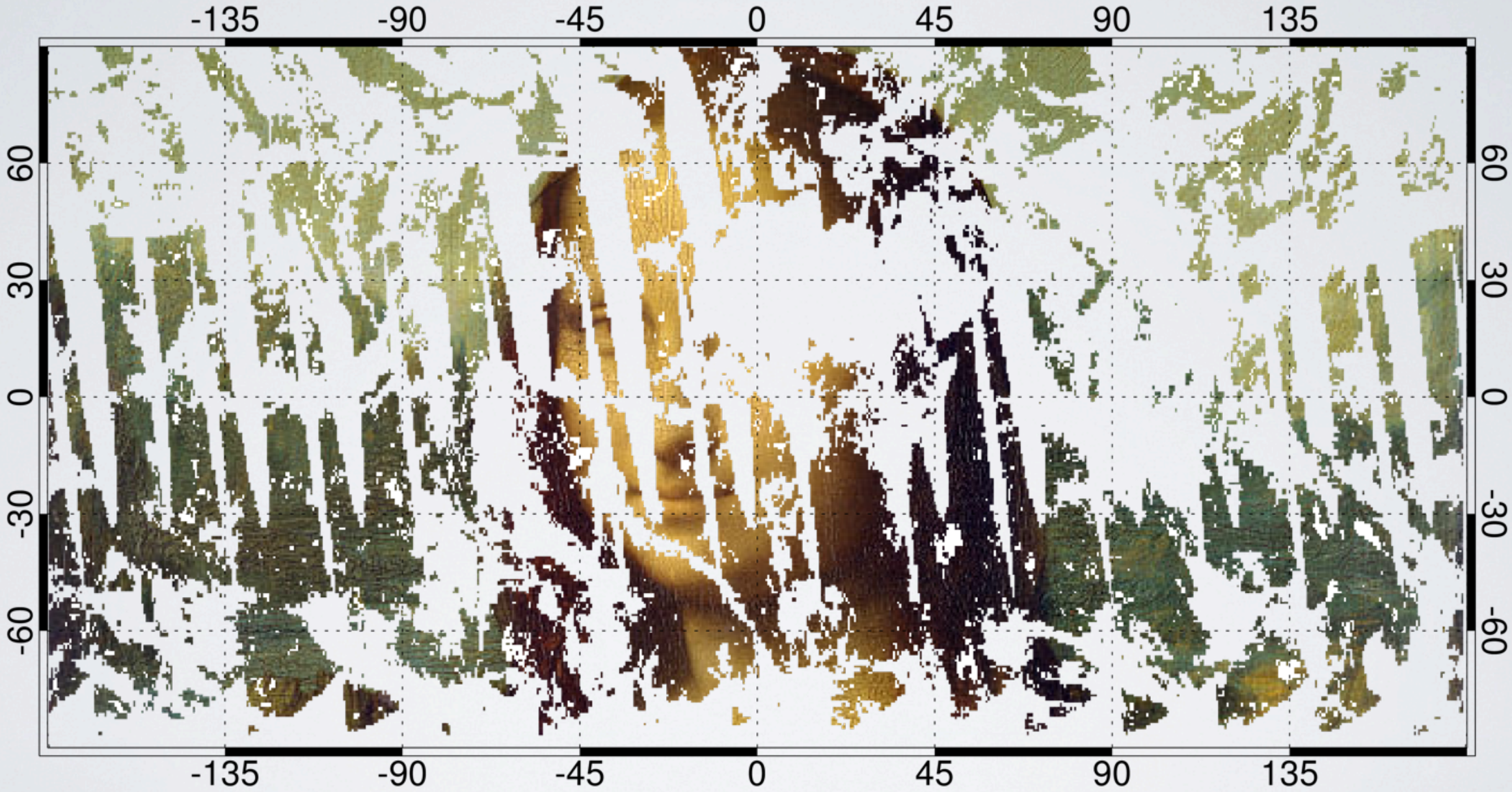


MISR-like sampling (~380 km)

An Illustration of the Problem

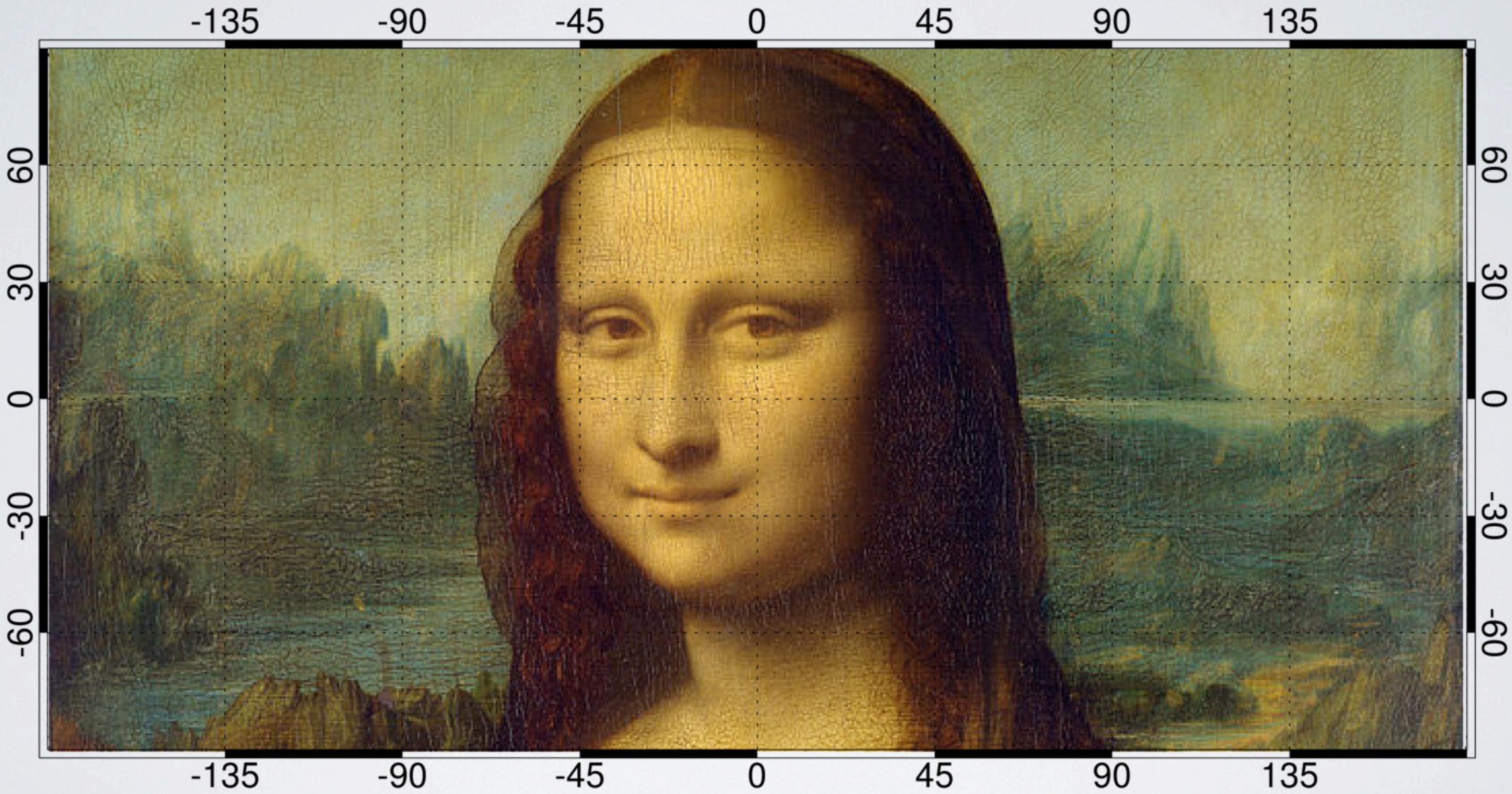
Without wide-swath sampling you don’t see the whole picture, but you also don’t know what you aren’t seeing



MODIS-like sampling (~2300 km)

An Illustration of the Problem

Without wide-swath sampling you don’t see the whole picture, but you also don’t know what you aren’t seeing



What kind of sampling is needed to complete the picture?

Investigation

We want to investigate coverage using data from the MODIS instrument, for which there is a long time series of aerosol observations (i.e., aerosol optical thickness, AOT) with a wide swath instrument

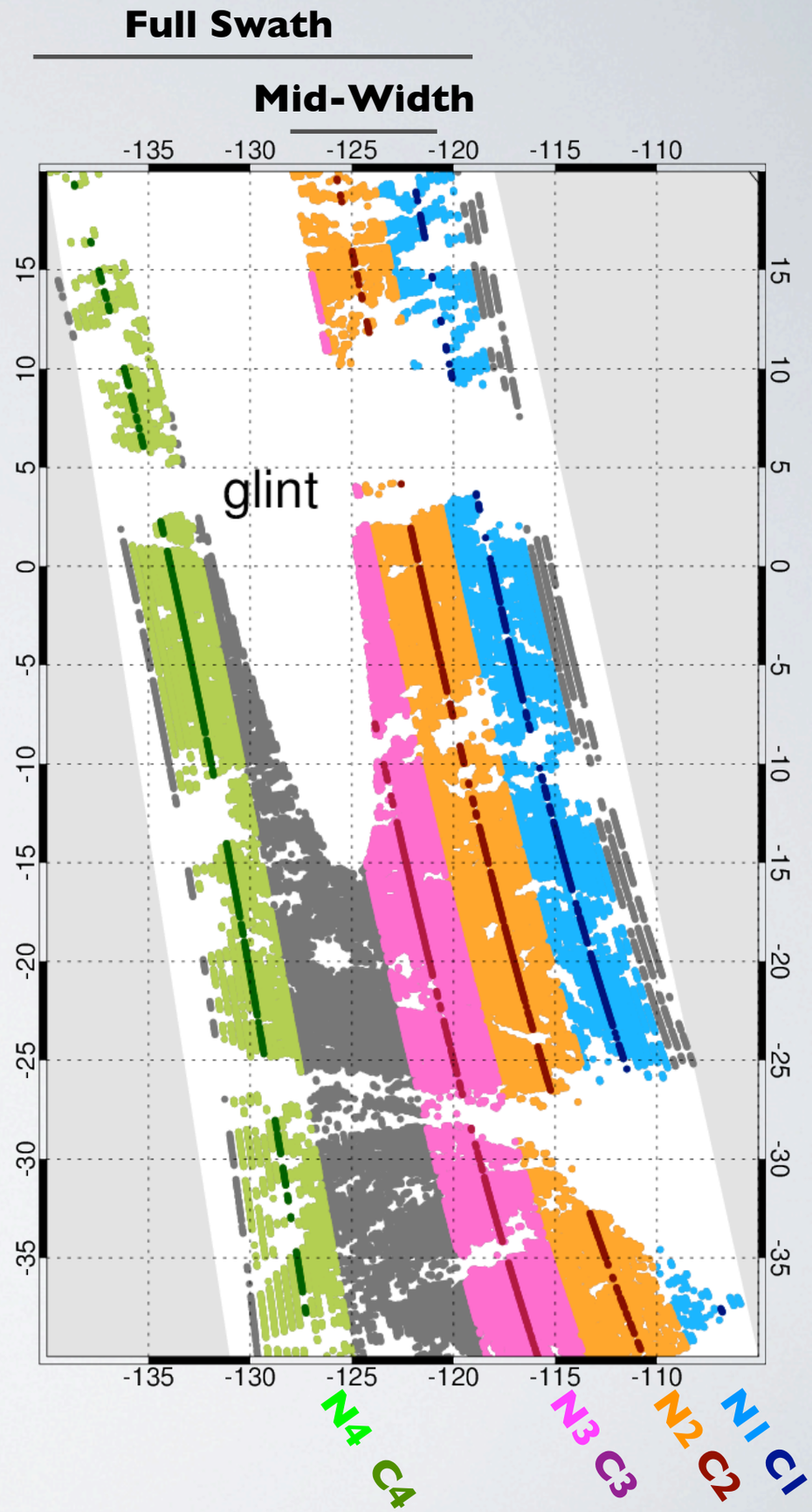
We subsample the MODIS data (collection 5) along candidate narrower swaths similar to other existing instruments (e.g., MISR, CALIOP)

MODIS Aqua

- 10 x 10 km^2 (nadir) aerosol retrieval product
- global land (QA=3) and ocean (QA > 0), QA- and number-weighted means generated
- Sample by flying notional instrument track through full data set:

  Full Swath (~2330 km)
  4 x Narrow (~380 km, N1, N2, N3, N4)
  4 x Curtain (along-track, C1, C2, C3, C4)
  Mid-Width (~760 km, MW)

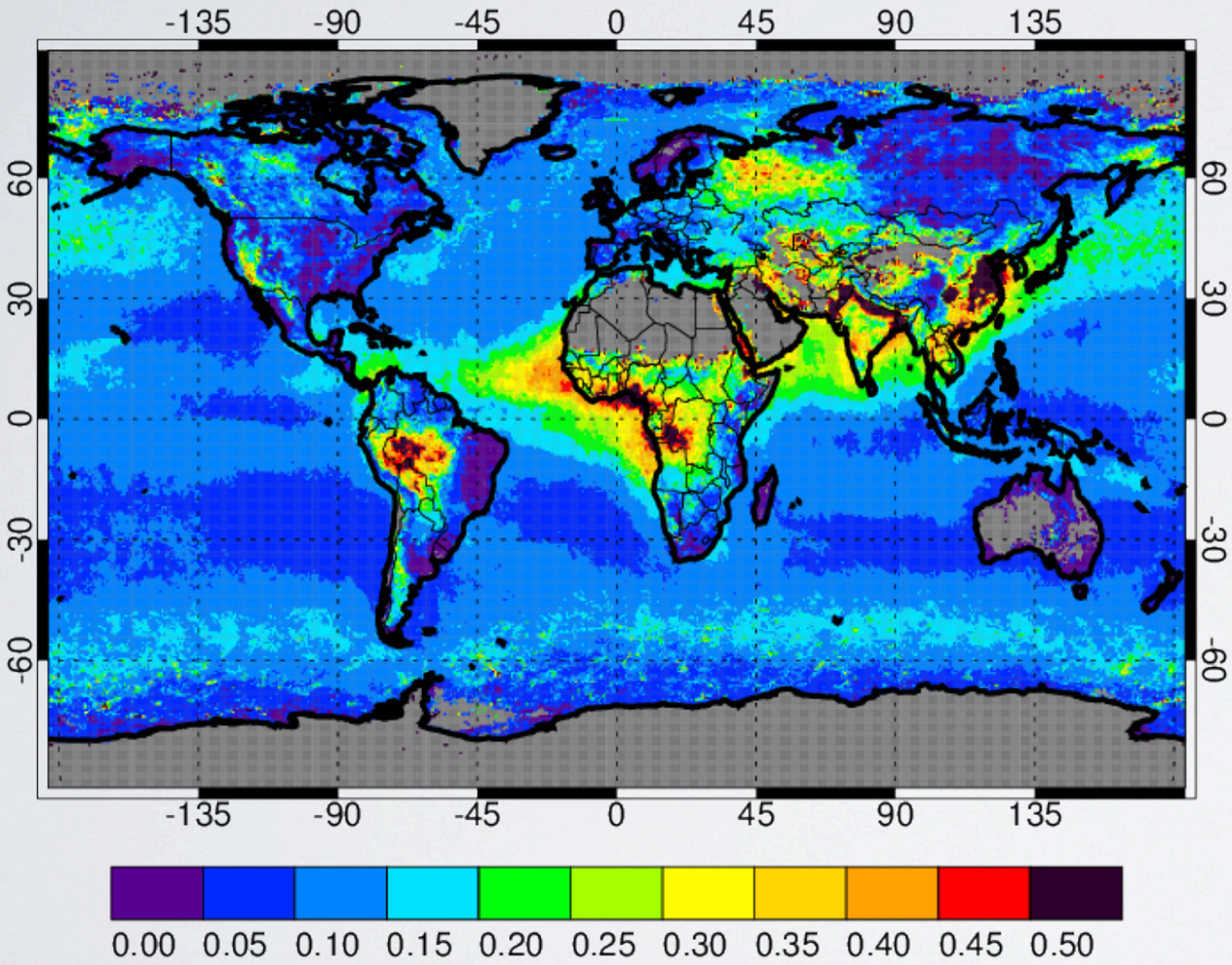
- This is done for 2003 - 2012
- Note: MODIS only retrieves AOT under daylight and cloud free conditions



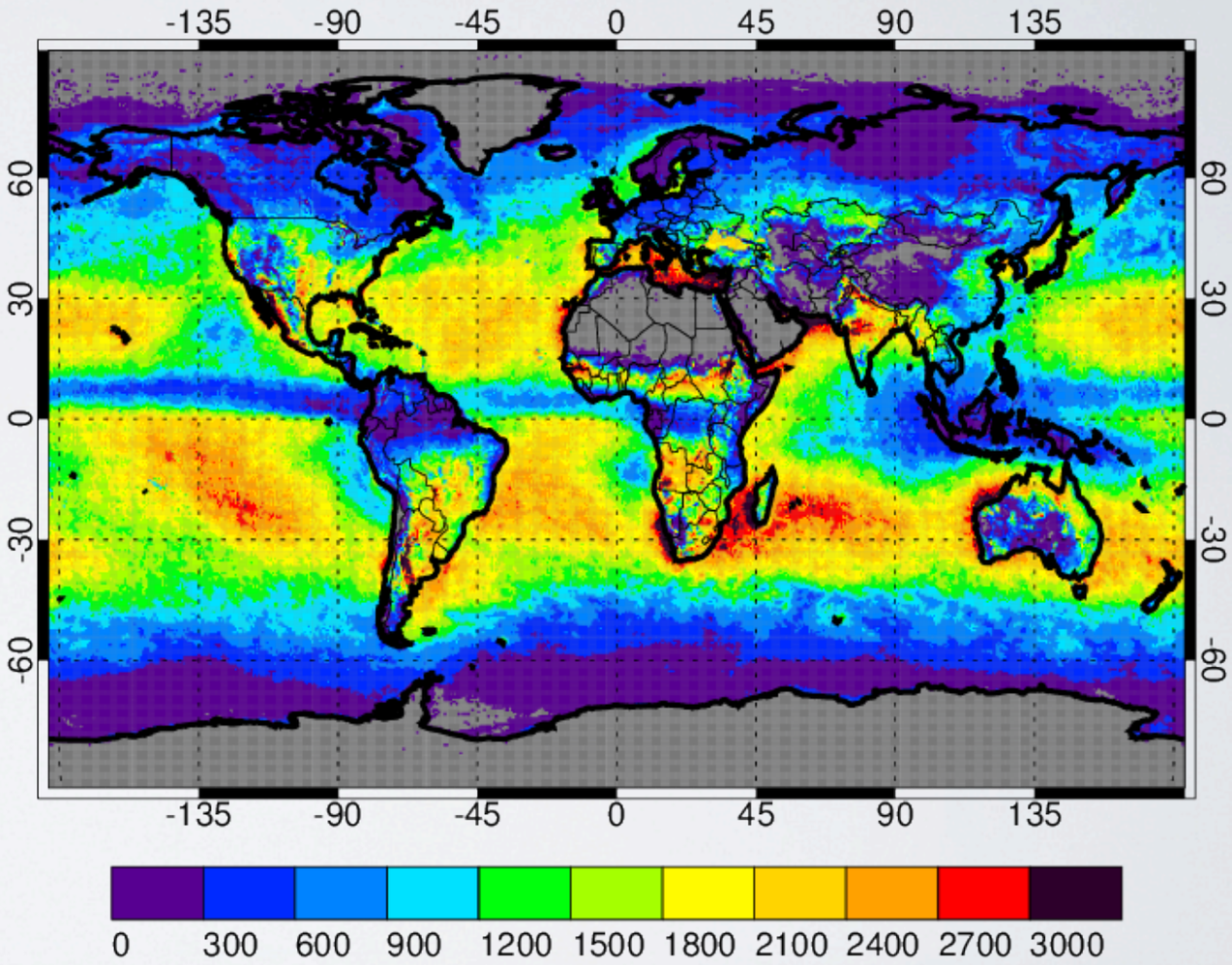
What is the global annual mean AOT?

2010 Full Swath Mean Values

AOT



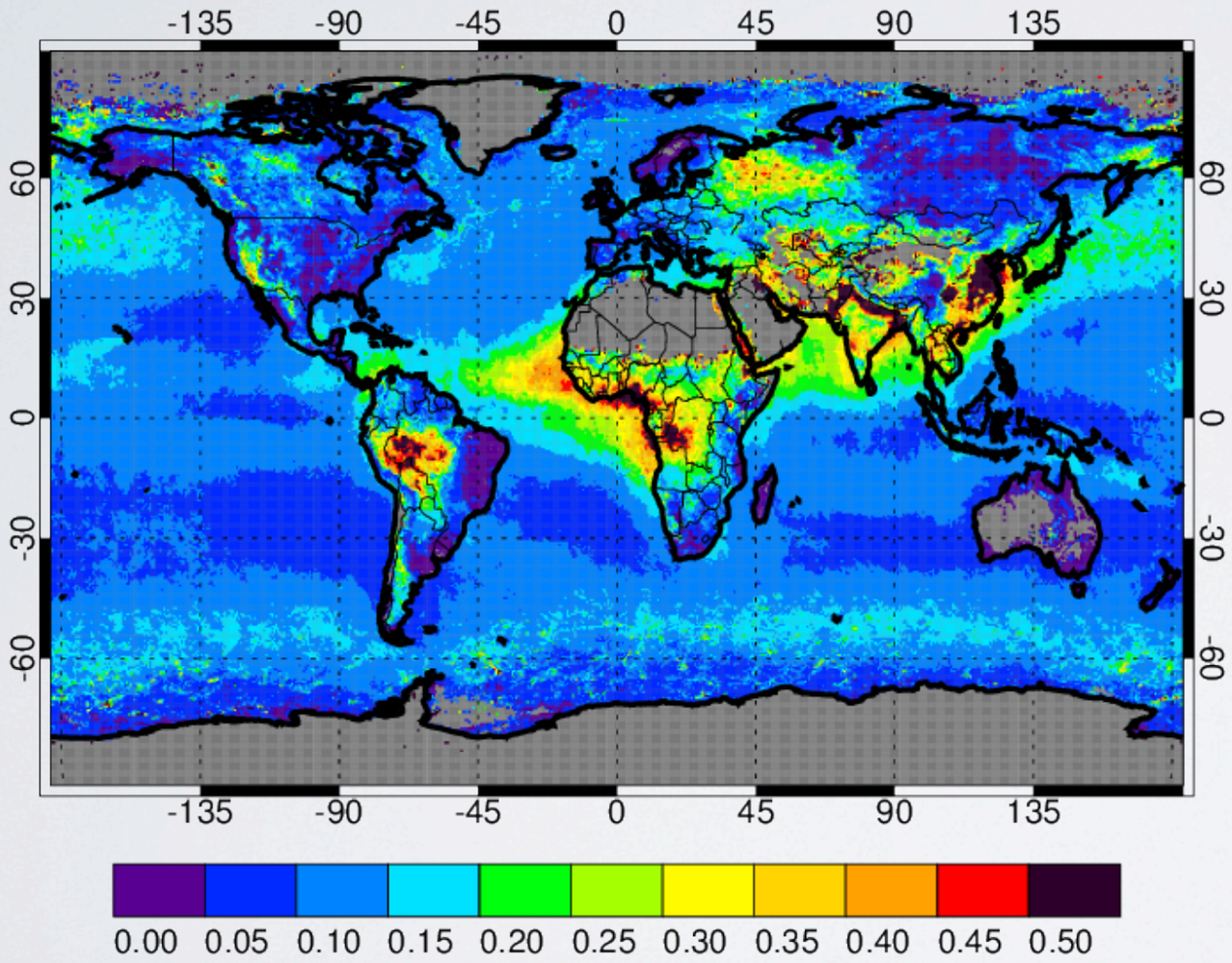
Number of AOT Retrievals



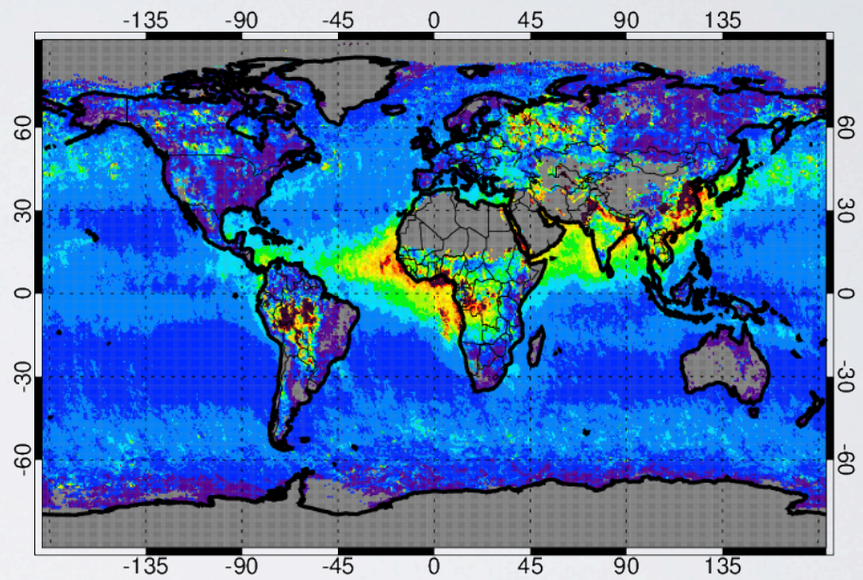
Impact of coverage on annual mean AOT

Narrow Swath versus Full Swath Sampling

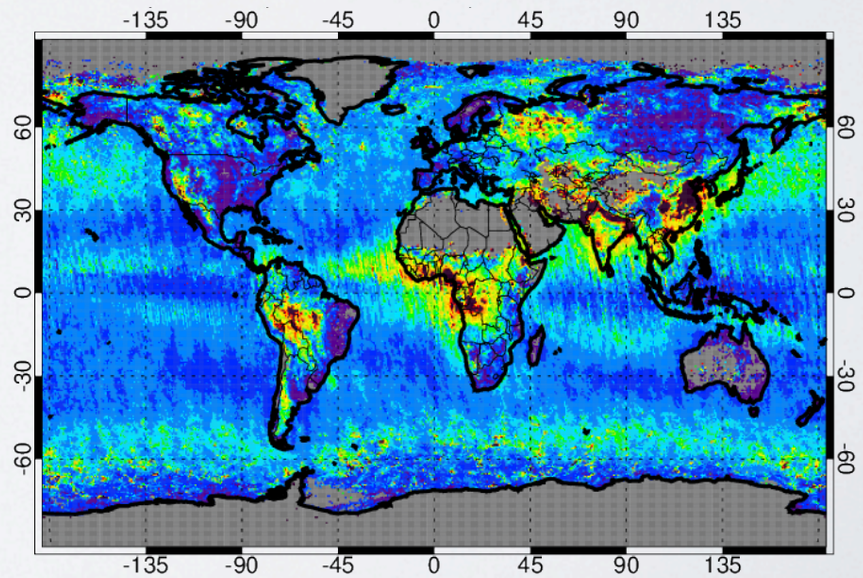
Full Swath



2010 Mean



N1

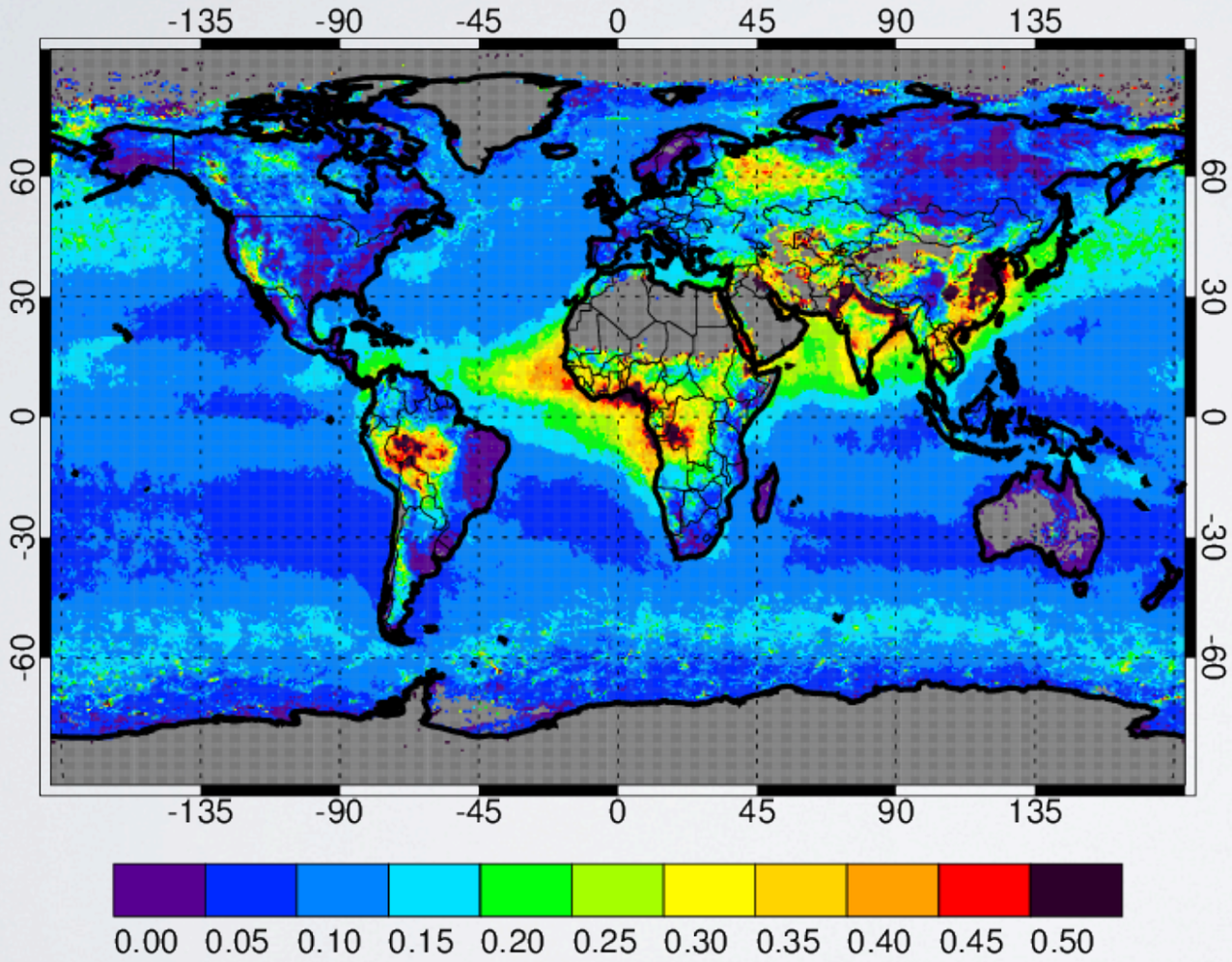


N3

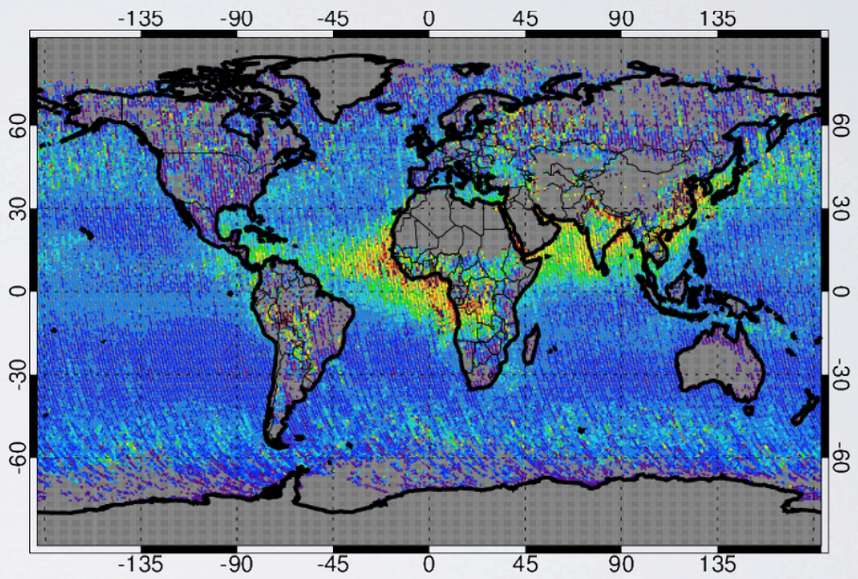
Impact of coverage on annual mean AOT

Curtain versus Full Swath Sampling

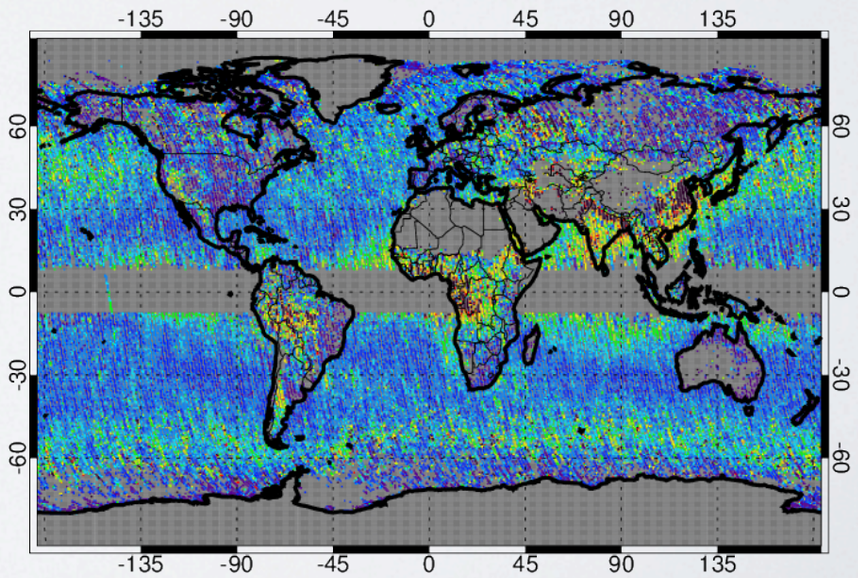
Full Swath



2010 Mean



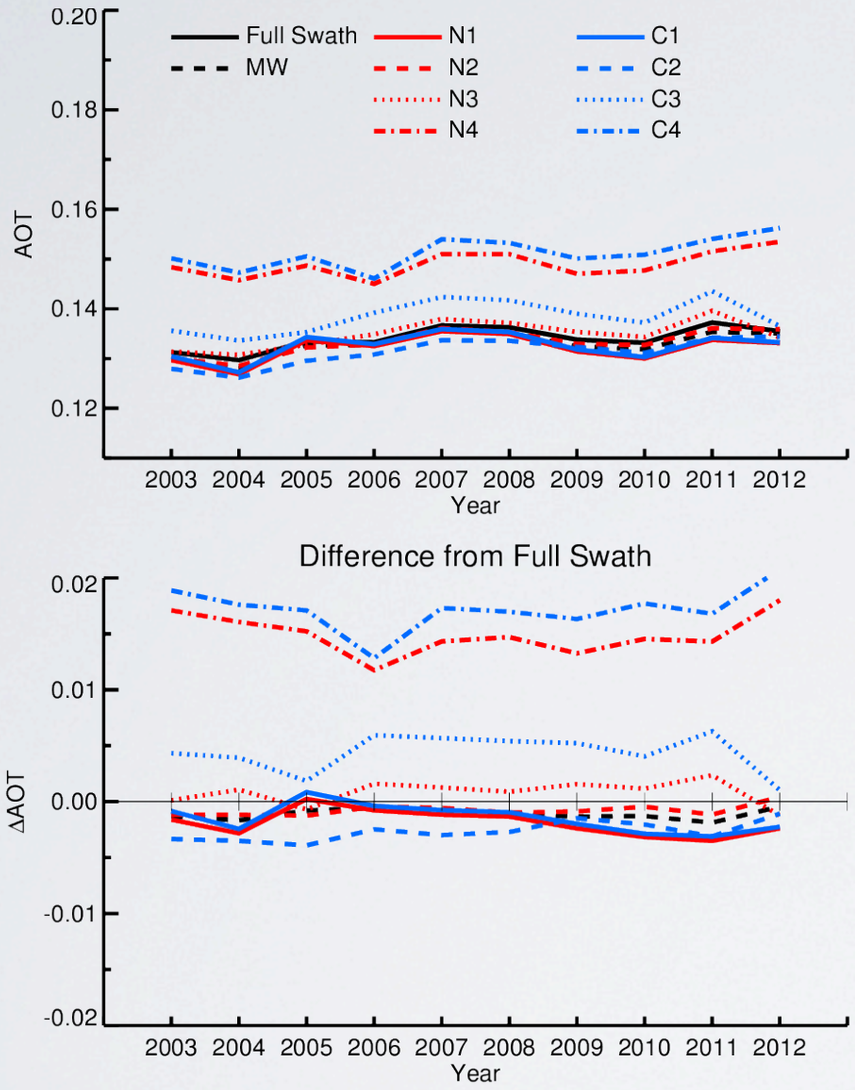
C1



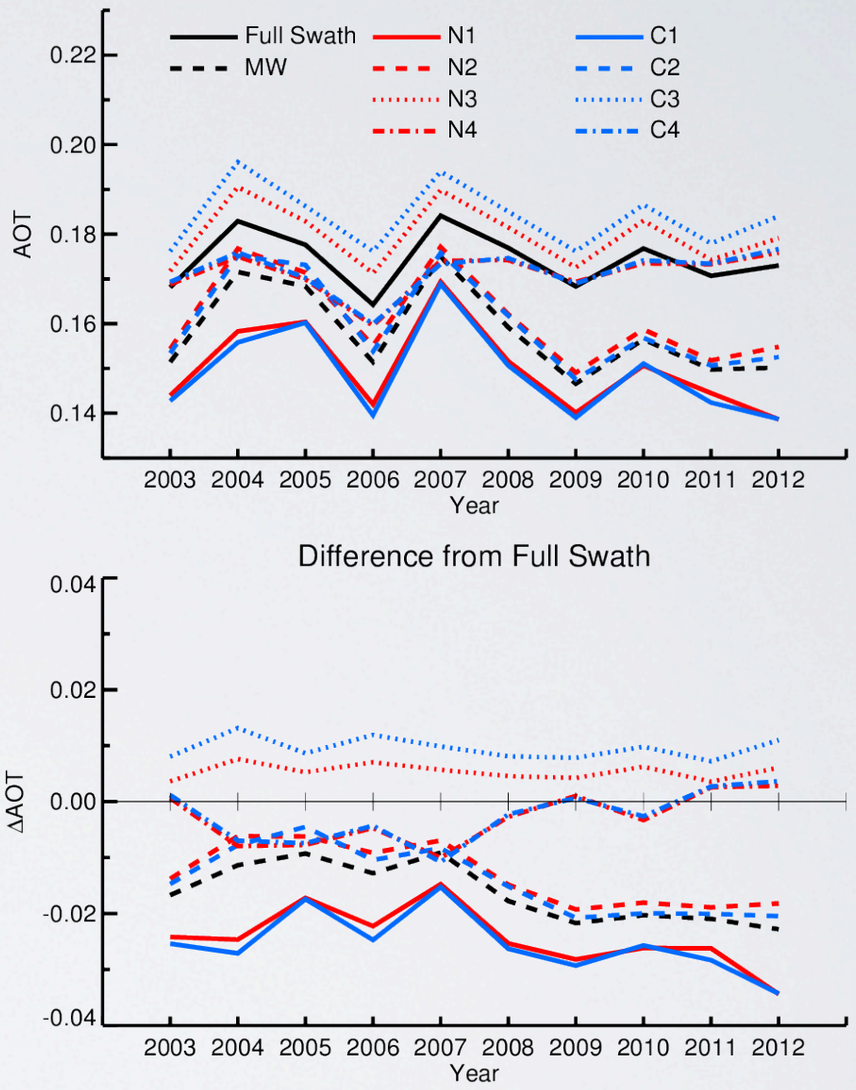
C3

What is the global annual mean AOT?

Ocean



Land



Caveat:

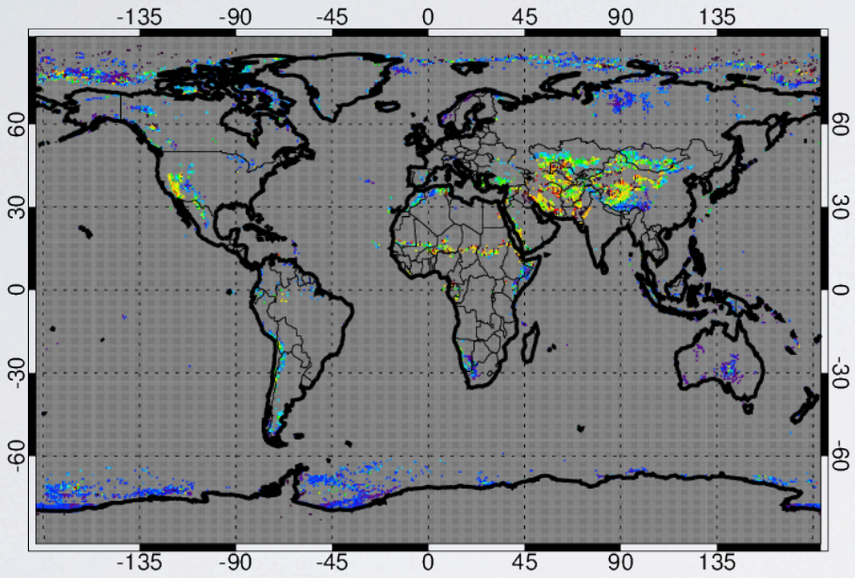
- We know that MODIS has a scan angle bias in its AOT retrievals.
- Our sub-samples are individually preferential to certain ranges of scan angle.
- We tried to correct this using collocated sun photometer observations, but could not develop robust statistics.

Observability

2010 Full Swath AOT unobserved by sub-sample

There are many places on Earth never observed under certain samplings

NI



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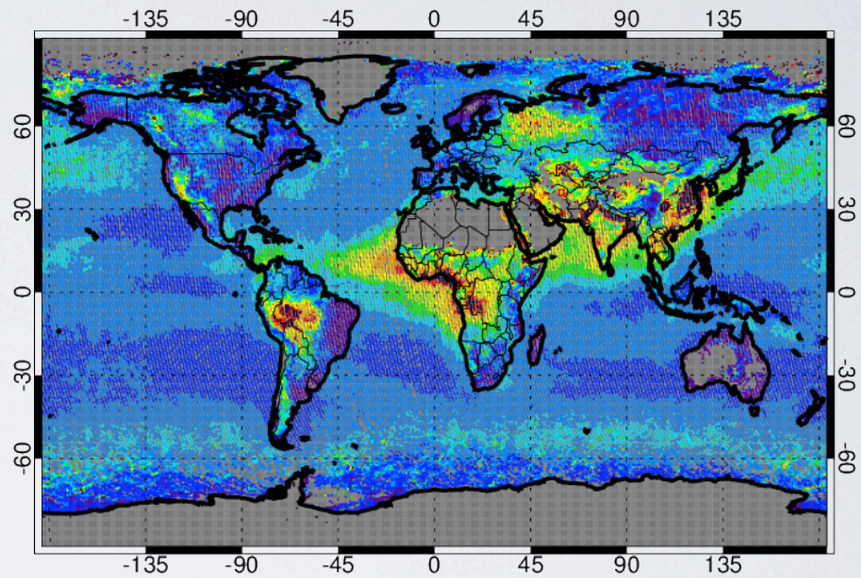
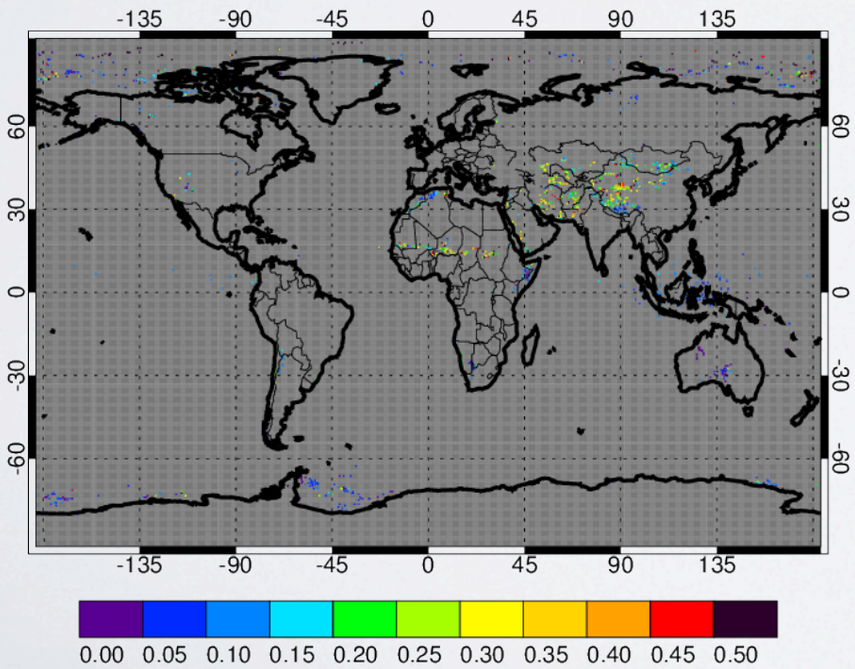


N3



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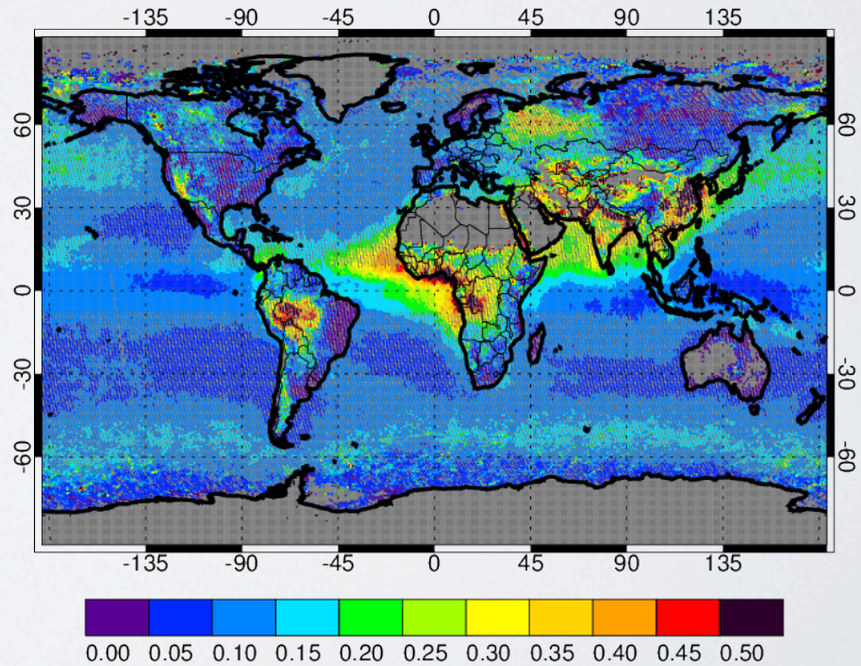
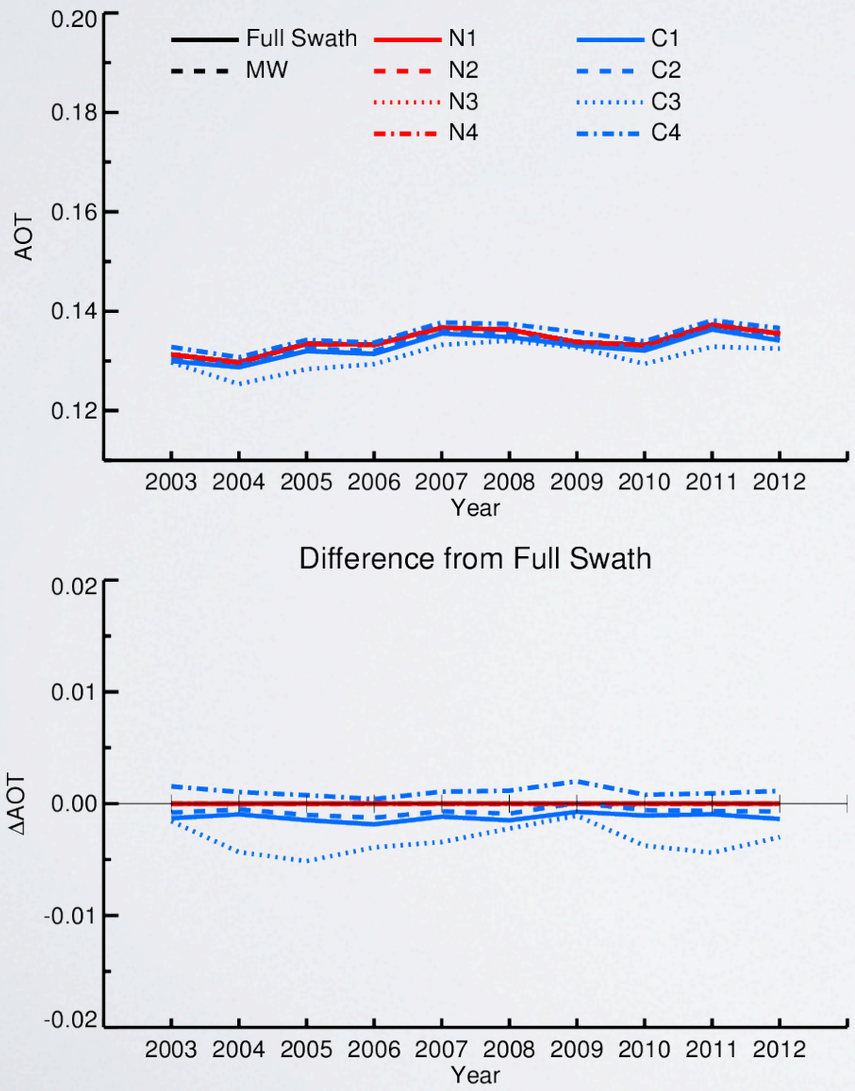


Impact of Observability on Global AOT

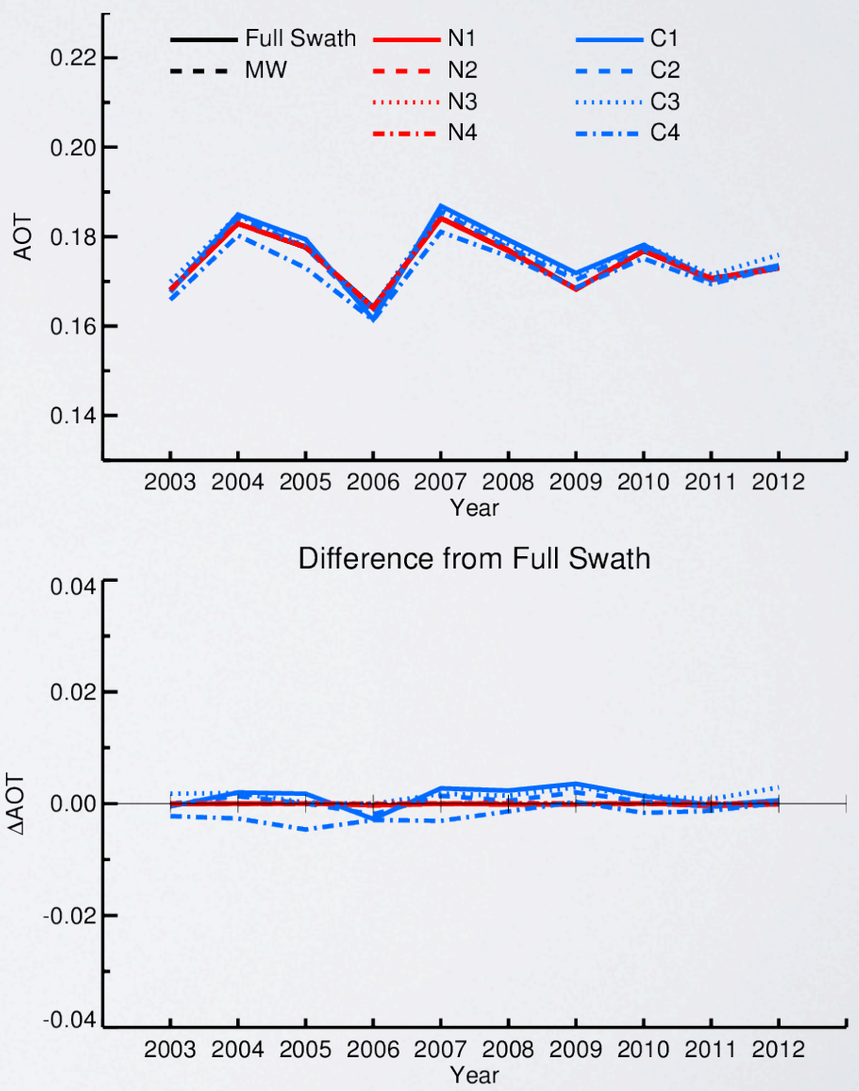
Average-then-Mask Approach

- *Global, annual average AOT composed from the full swath means **excluding** points where the indicated sub-sample **never** retrieved AOT*
- *This averages out the view angle dependency since all full swath data are used, but gives much better sampling then the reduced swath would ever actually experience*

Ocean



Land



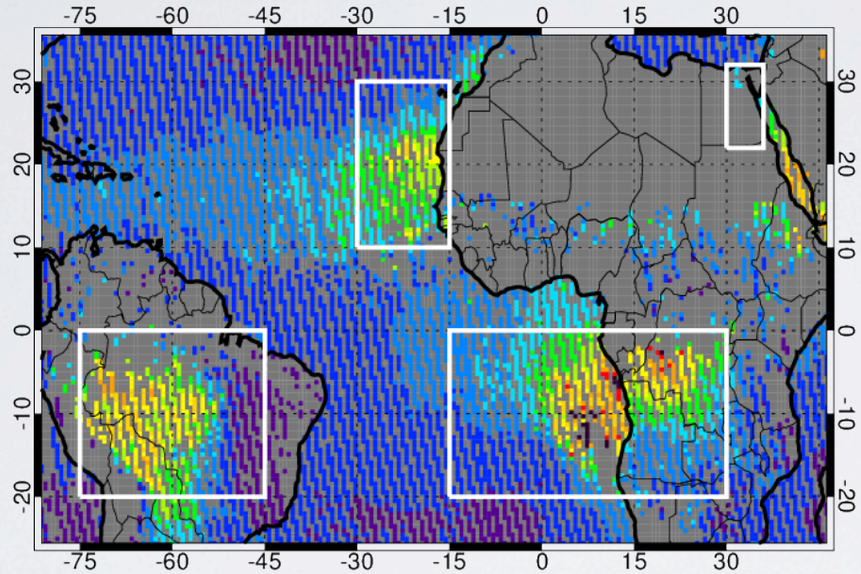
Impact of Observability on Regional AOT

Regional AOT sampling is important because of air quality issues--inherently a regional problem--and because aerosol forcing is a convolution of loading and surface reflectivity, both of which vary regionally

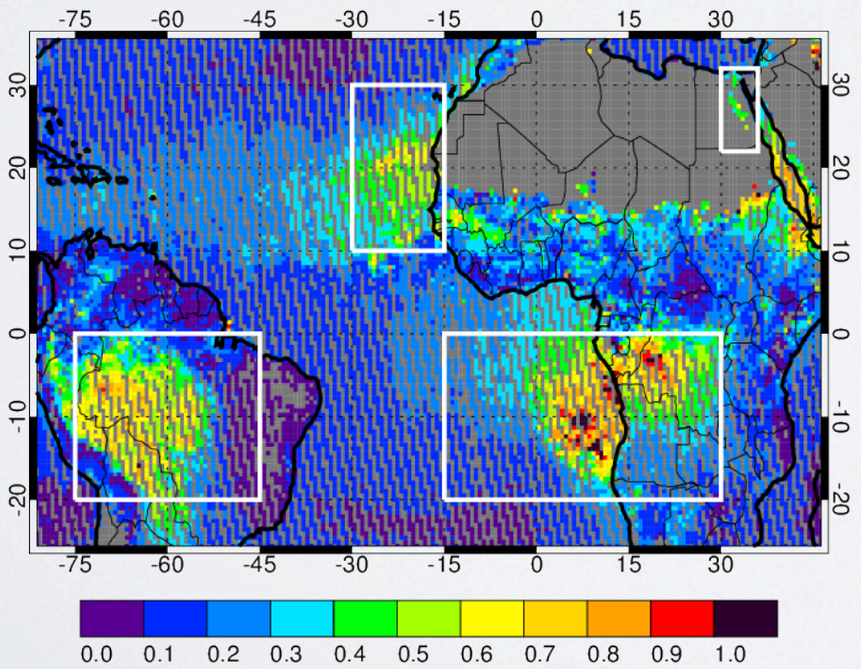
Full swath JAS 2010 AOT where C1 does and does not observe

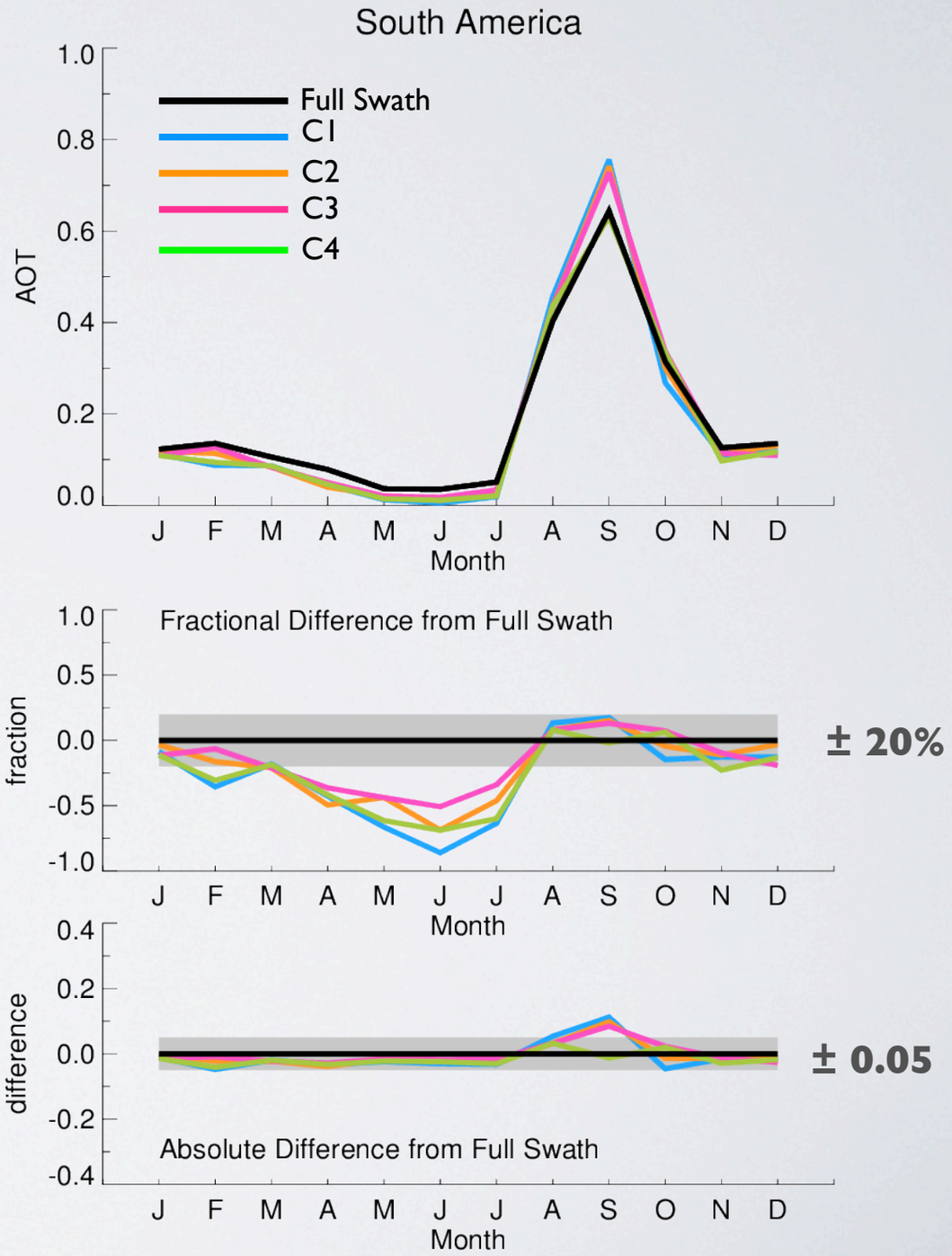
C1

Observed



Unobserved





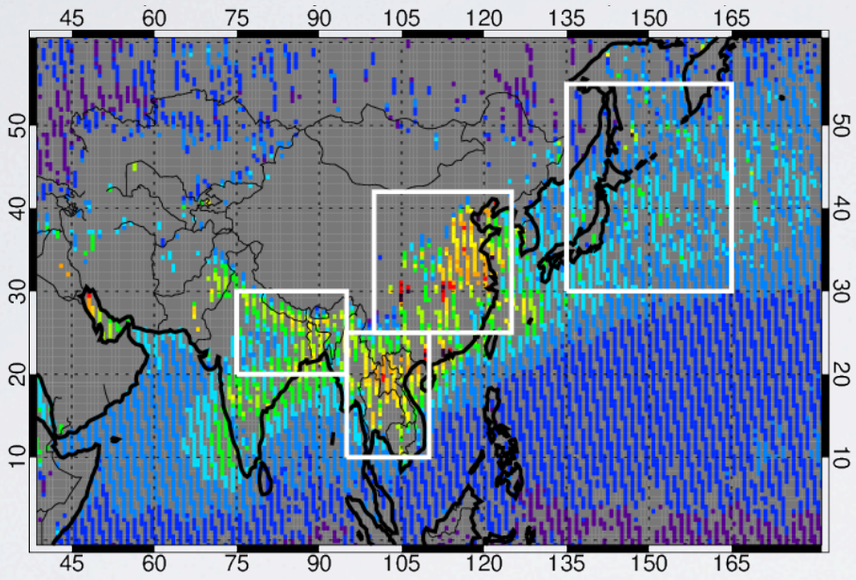
Impact of Observability on Regional AOT

Regional AOT sampling is important because of air quality issues--inherently a regional problem--and because aerosol forcing is a convolution of loading and surface reflectivity, both of which vary regionally

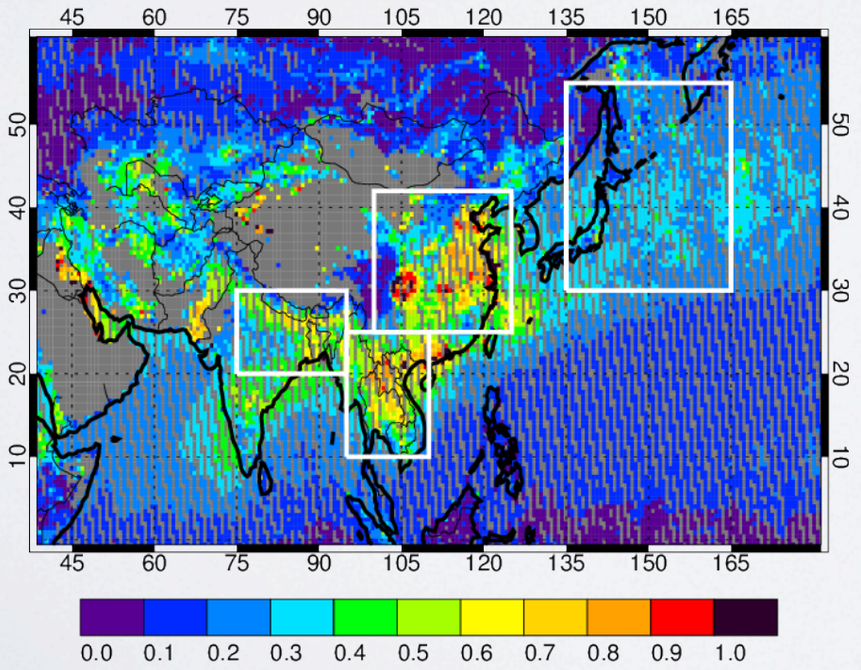
Full swath MAM 2010 AOT where C1 does and does not observe

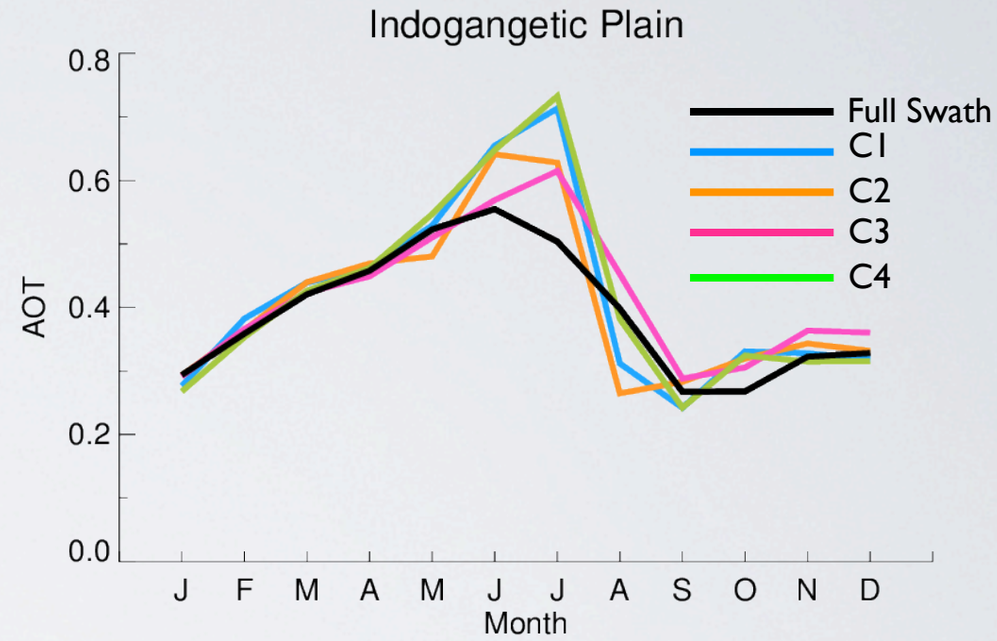
C1

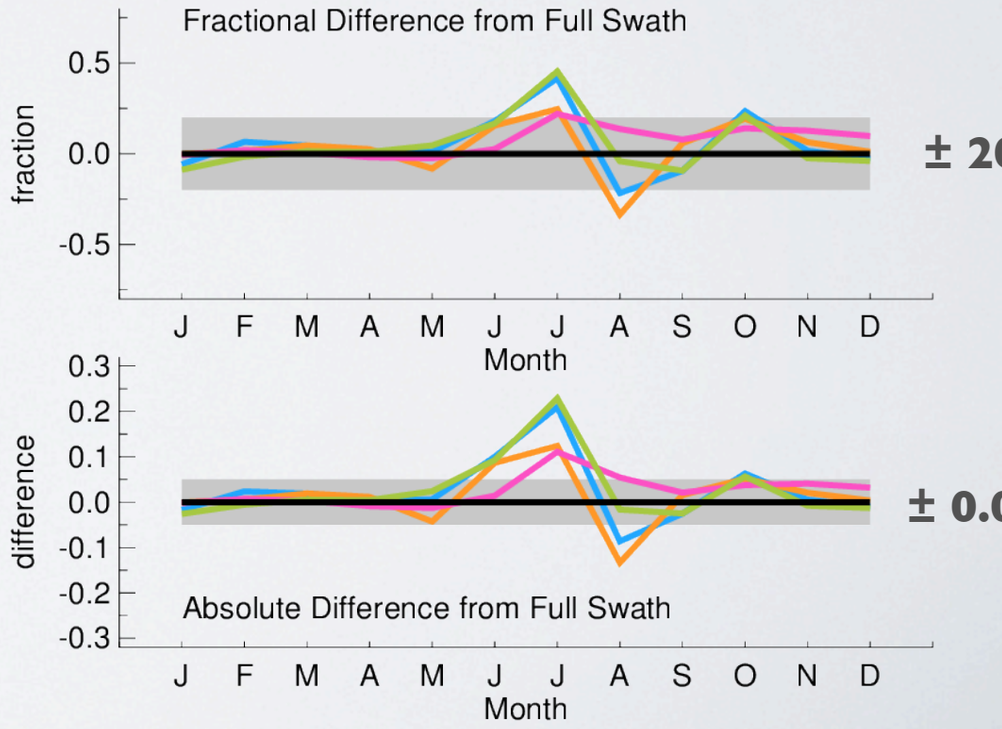
Observed



Unobserved







Regional spatial sampling artifact ΔAOT

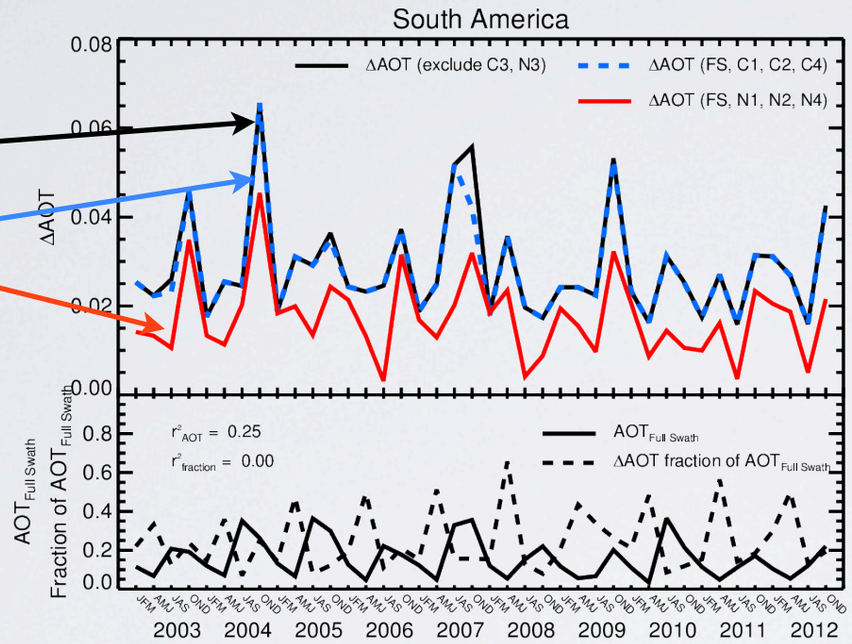
Tropical Atlantic Regions

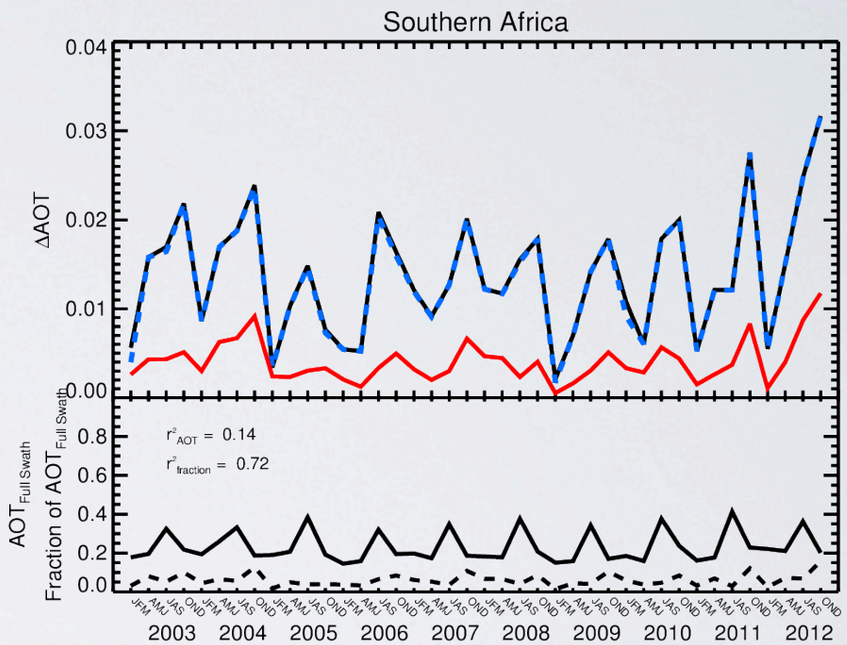
- *ΔAOT is the range of seasonal-regional mean AOT among sampling strategies using "average-then-mask" approach*

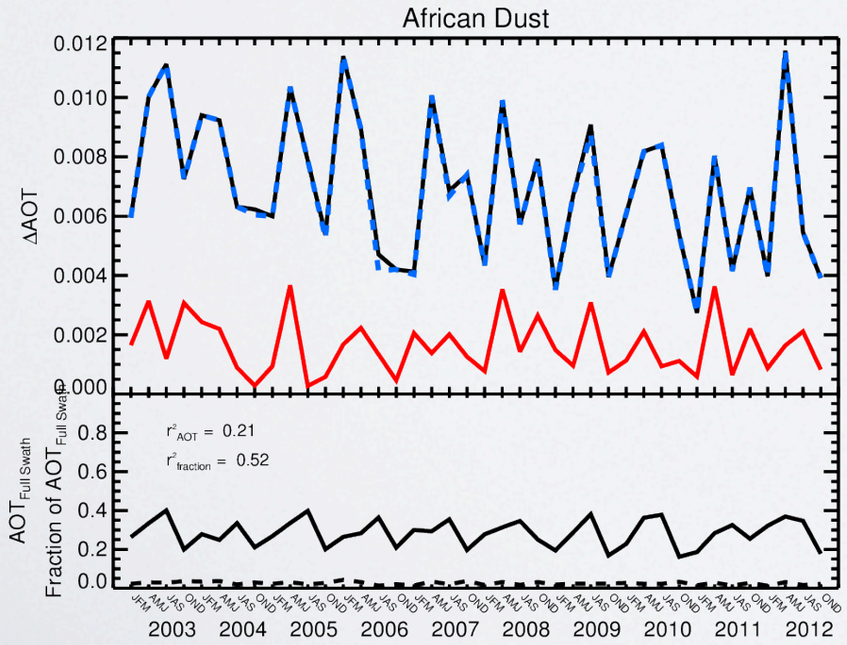
All Samples Except Glint

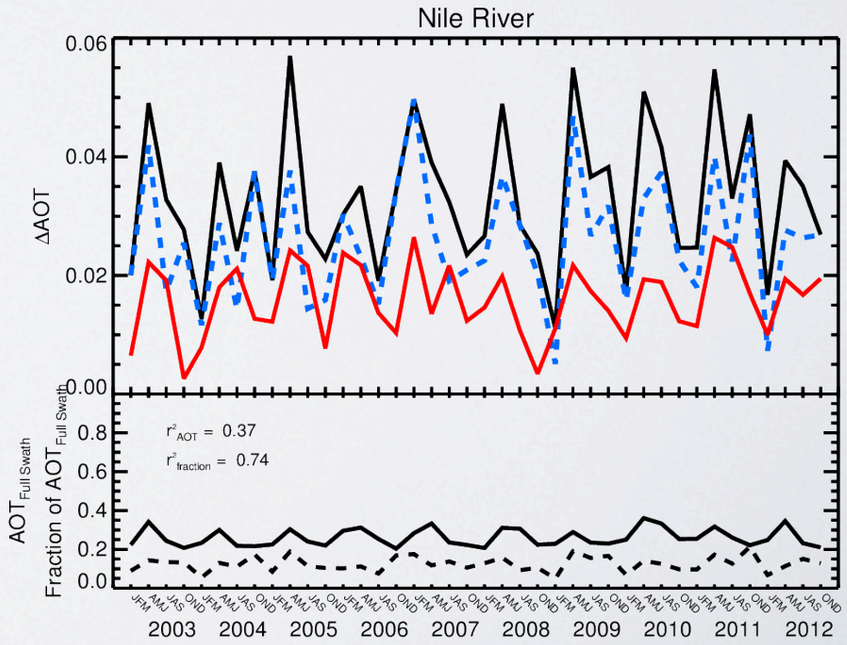
Curtain vs. Full

Narrow vs. Full









Regional spatial sampling artifact ΔAOT

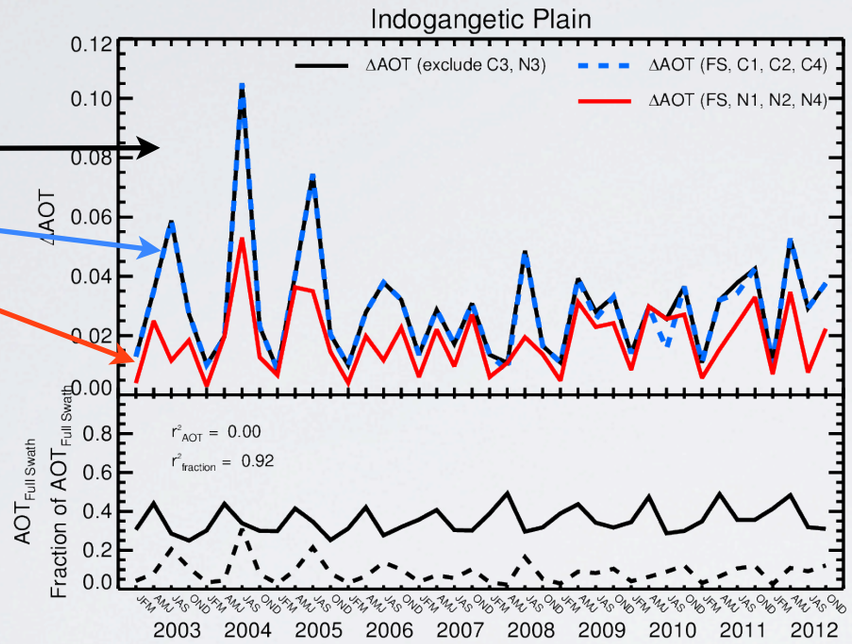
Asian Regions

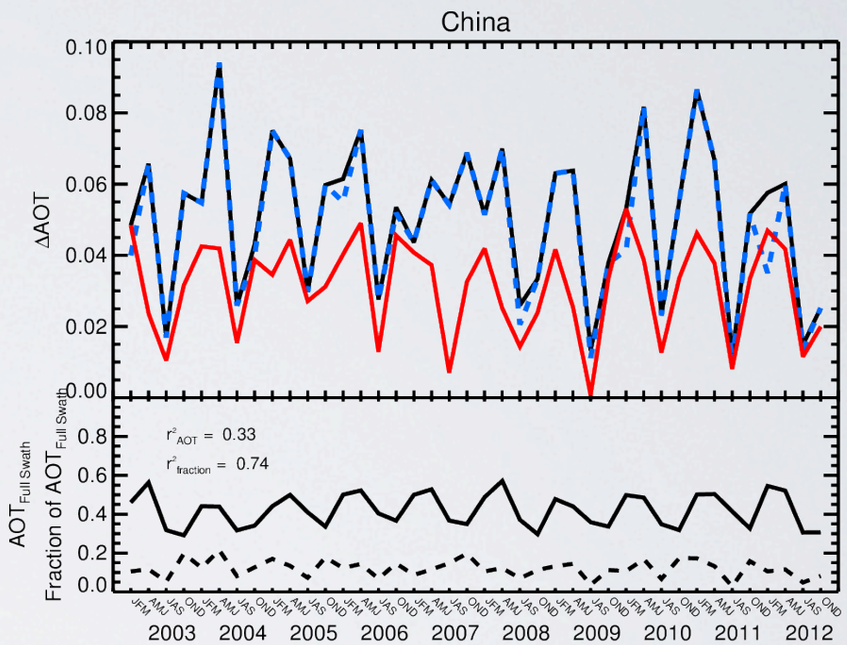
ΔAOT is the range of seasonal-regional mean AOT among sampling strategies using "average-then-mask" approach

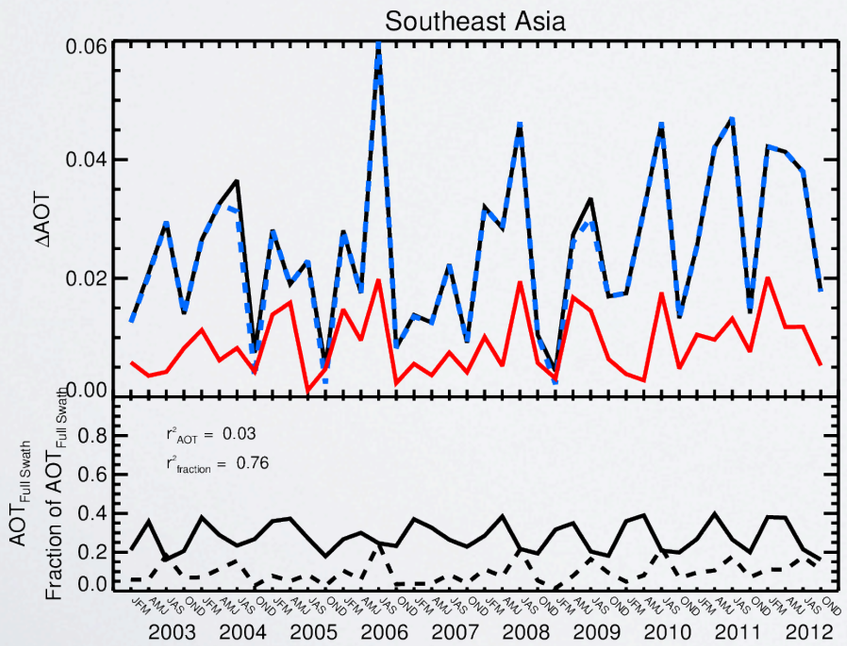
All Samples Except Glint

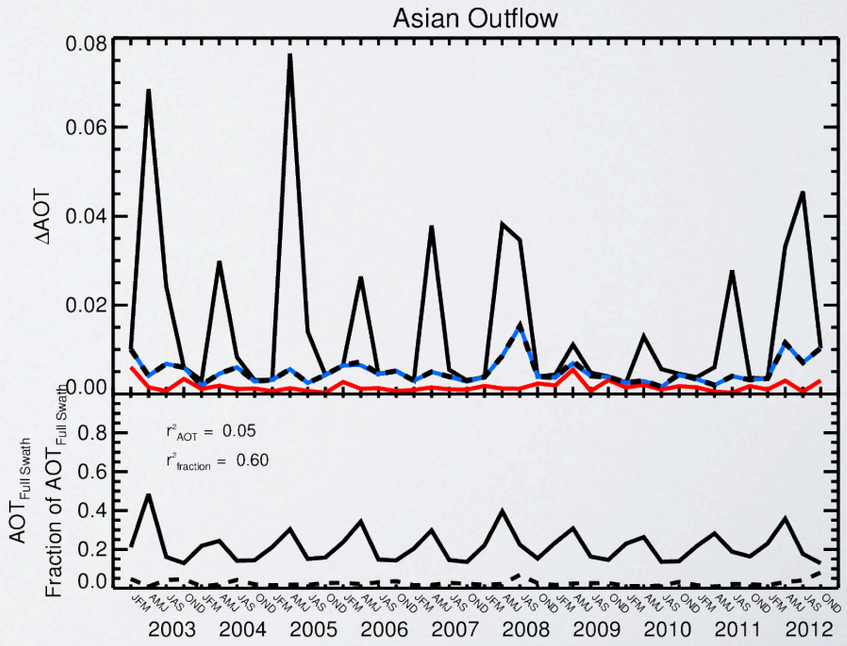
Curtain vs. Full

Narrow vs. Full









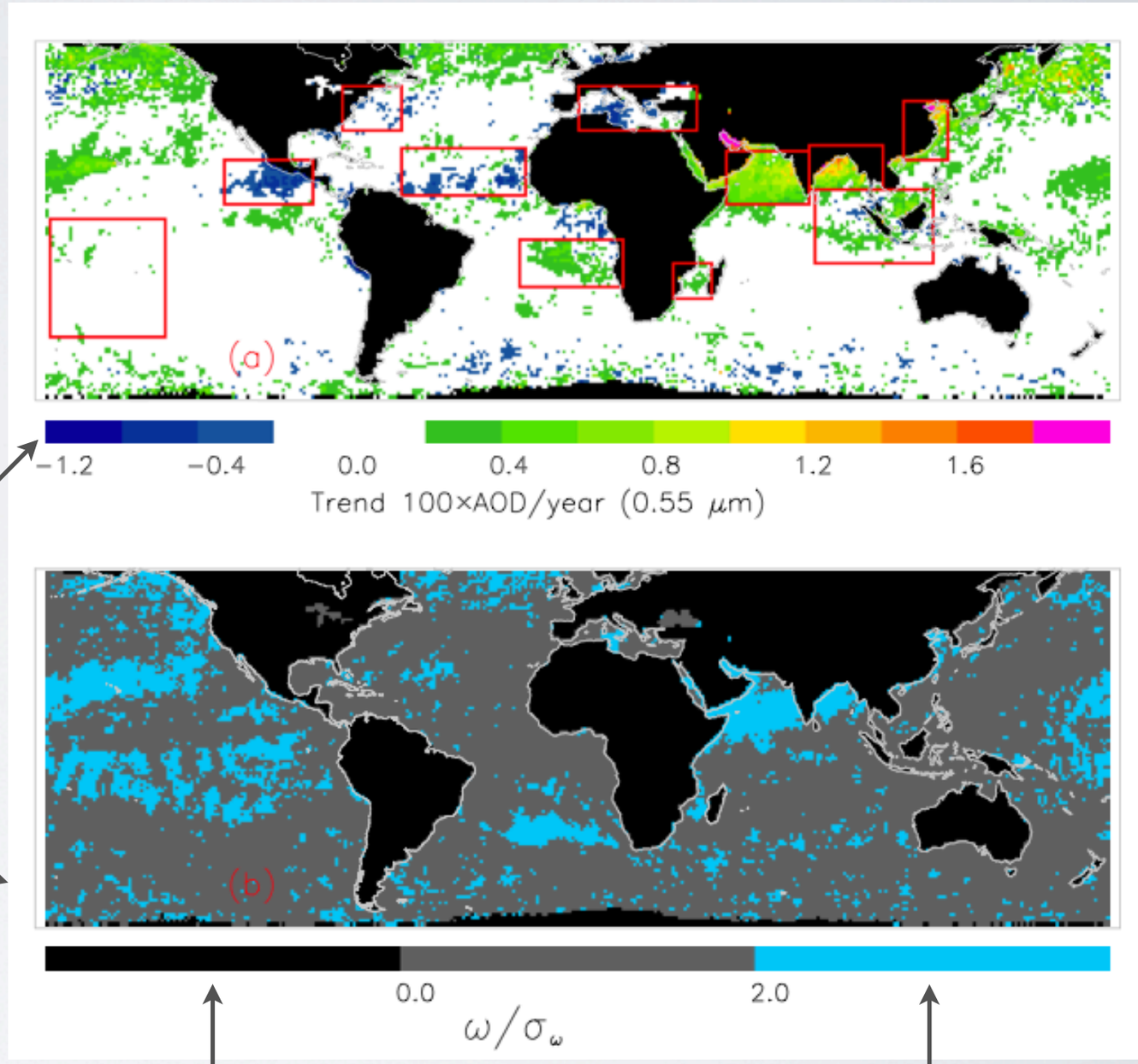
Impact of Swath on Trend Detection

Zhang and Reid (ACP, 2010) investigated the suitability of MODIS observations to detect decadal-scale trends in AOT

ω = de-seasonalized linear trend

σ_ω = variance in linear trend

Trend is significant at the 95% level if linear trend $\omega/\sigma_\omega > 2$



Trend

Statistical Significance

No Data

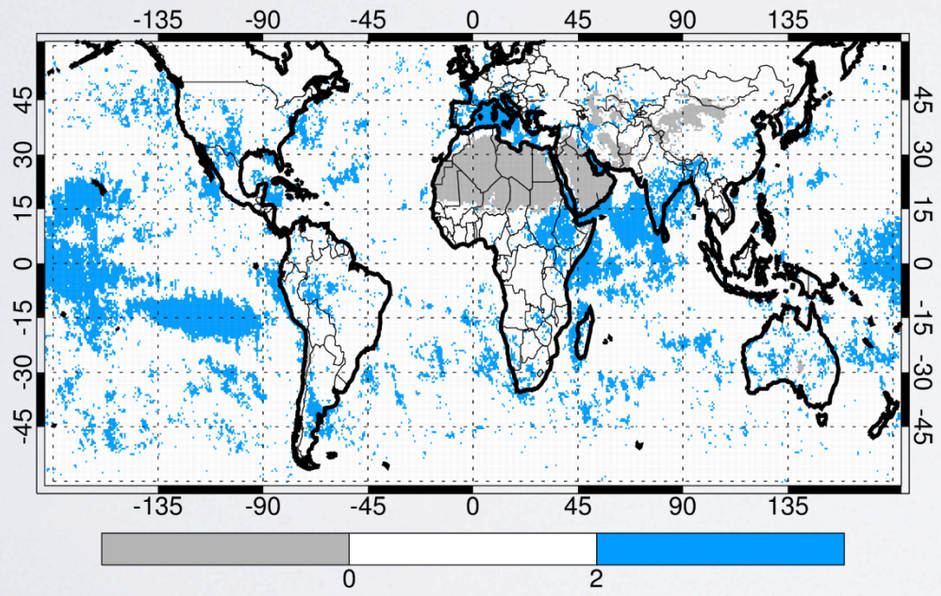
Significant Trend

Impact of Swath on Trend Detection

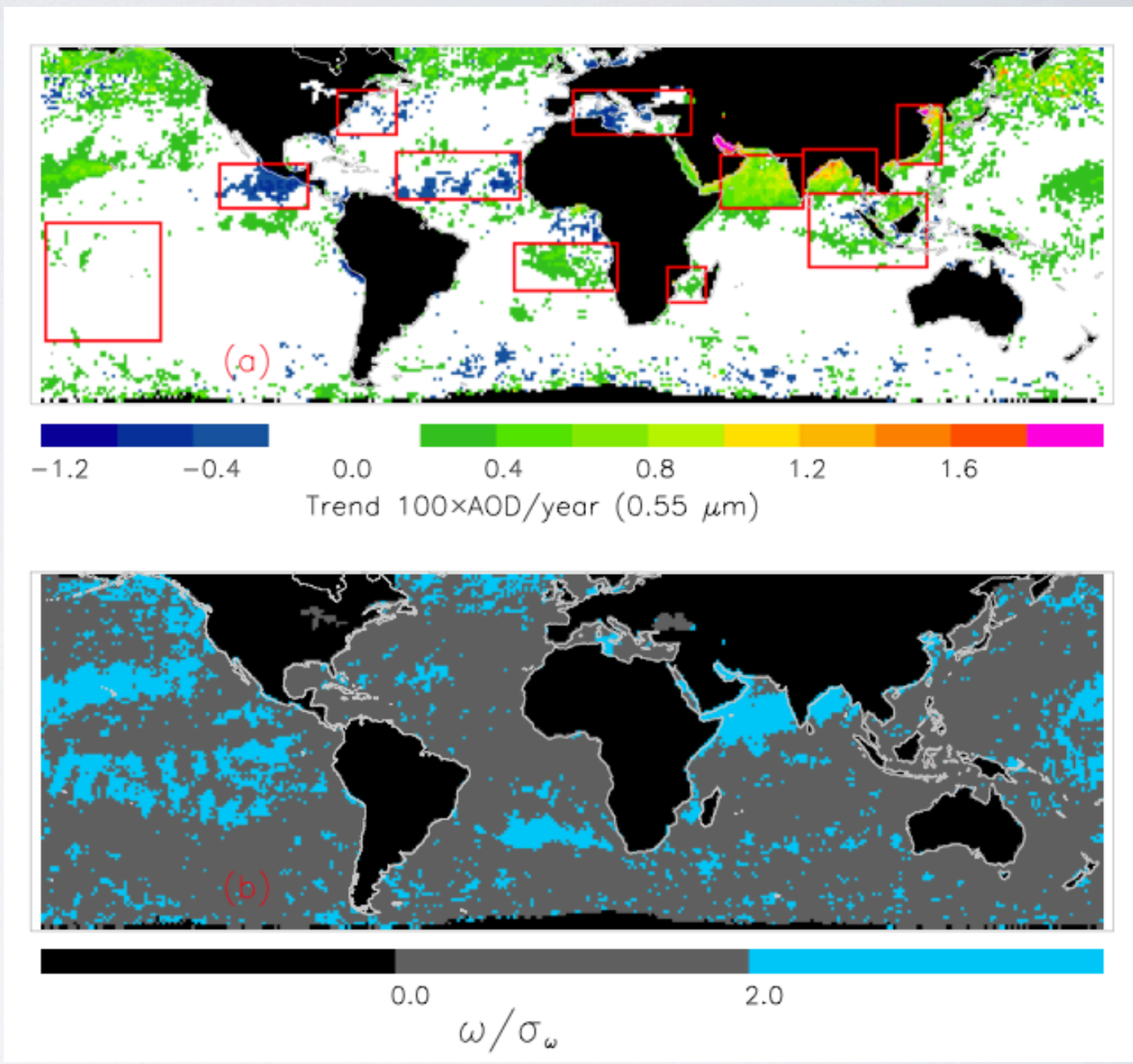
We calculated trends in our dataset following the procedure in Zhang and Reid (2010)

Trend
100*AOT yr^{-1}

Significance



Full Swath

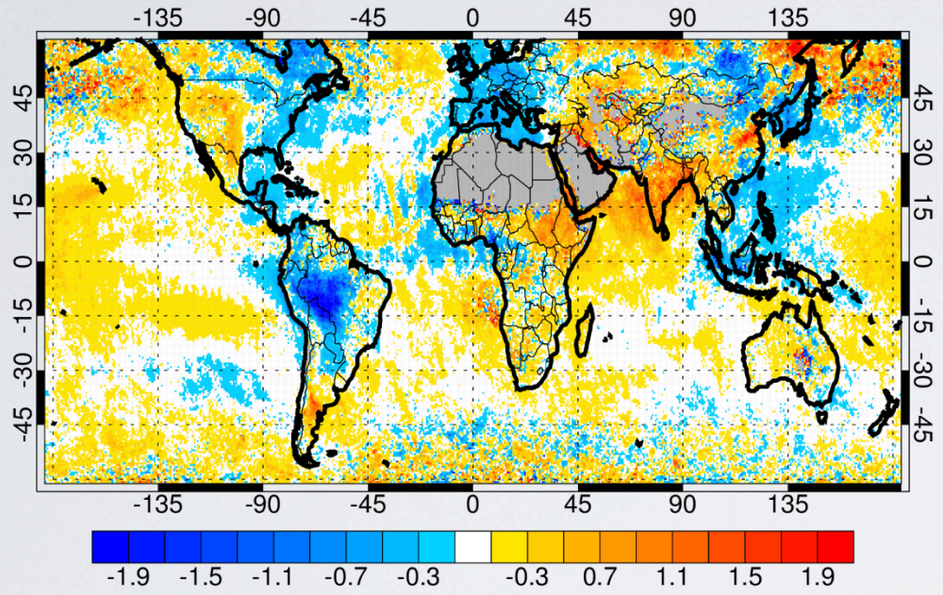


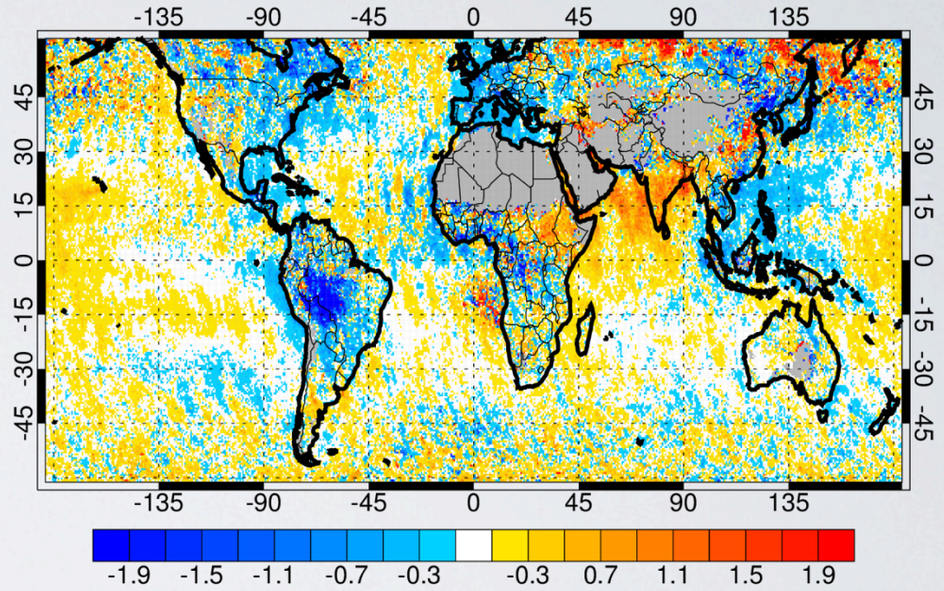
Zhang and Reid (2010)

Impact of Swath on Trend Detection

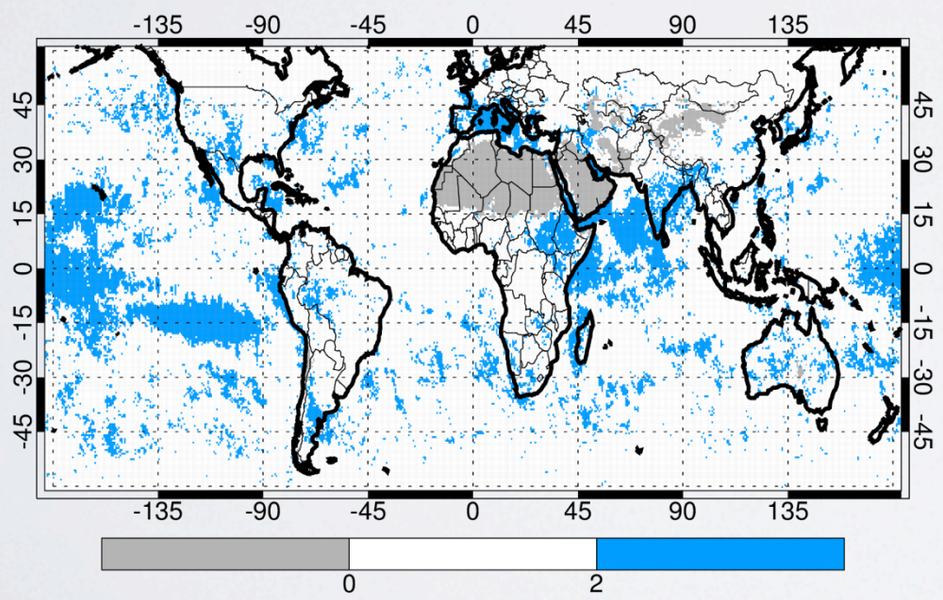
Narrow Swath versus Full Swath Sampling

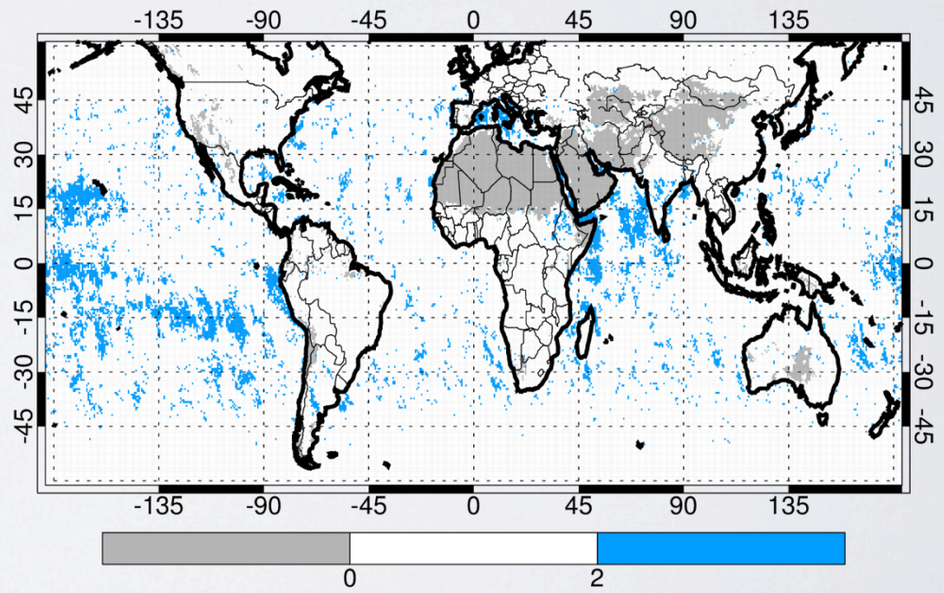
Trend
100*AOT yr^{-1}





Significance





Full Swath

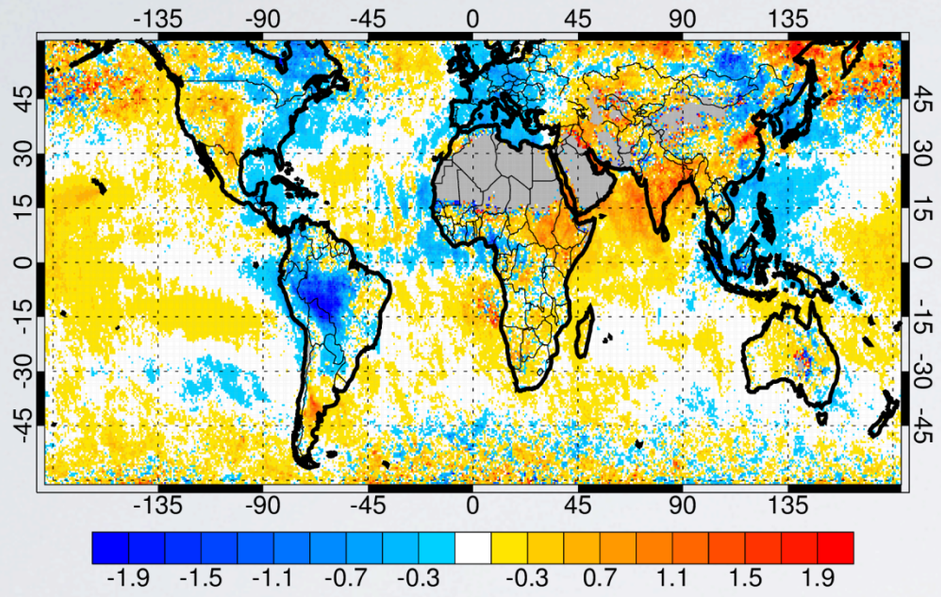
N1

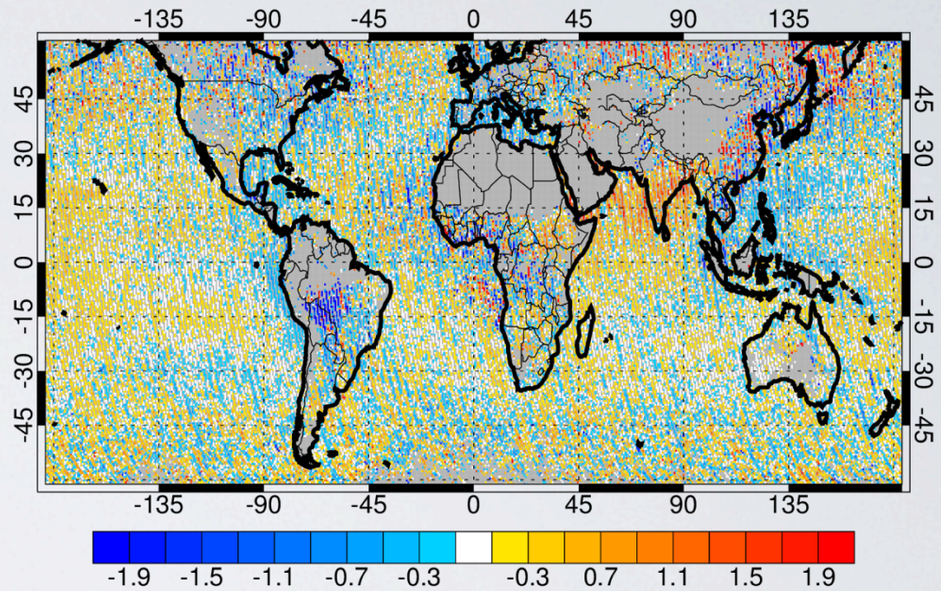
Impact of Swath on Trend Detection

Curtain versus Full Swath Sampling

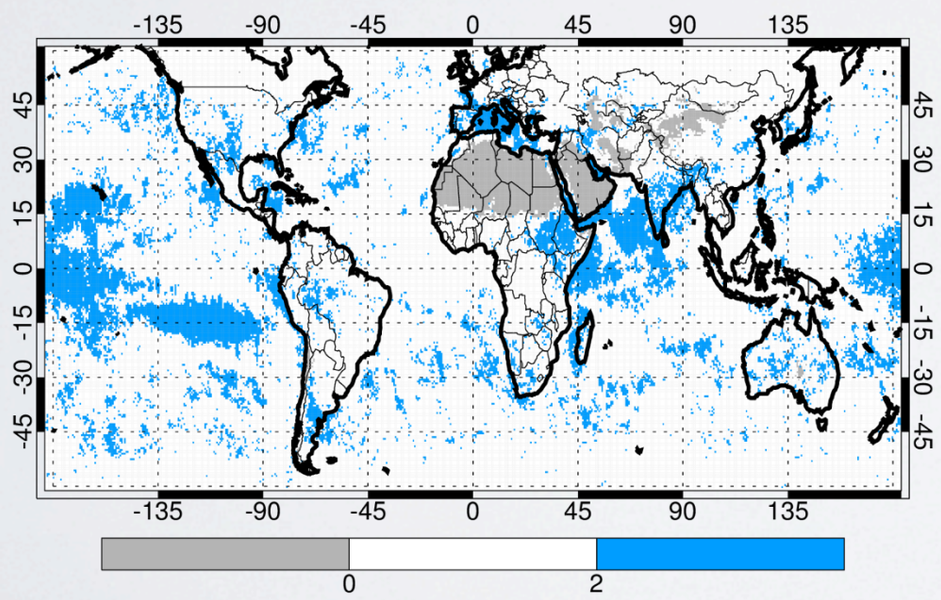
Trends muted relative to full swath, and significance is not well established

Trend
100*AOT yr^{-1}

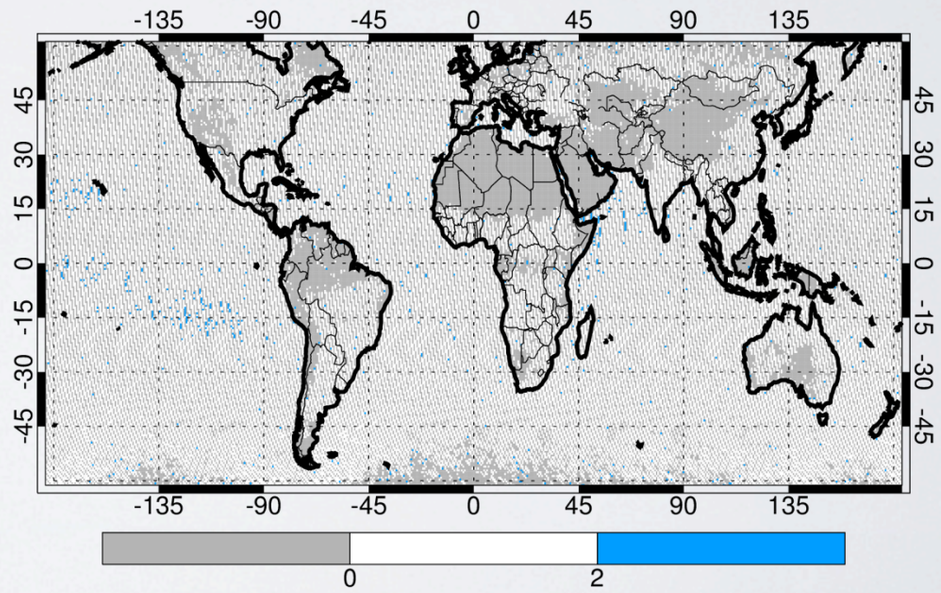




Significance



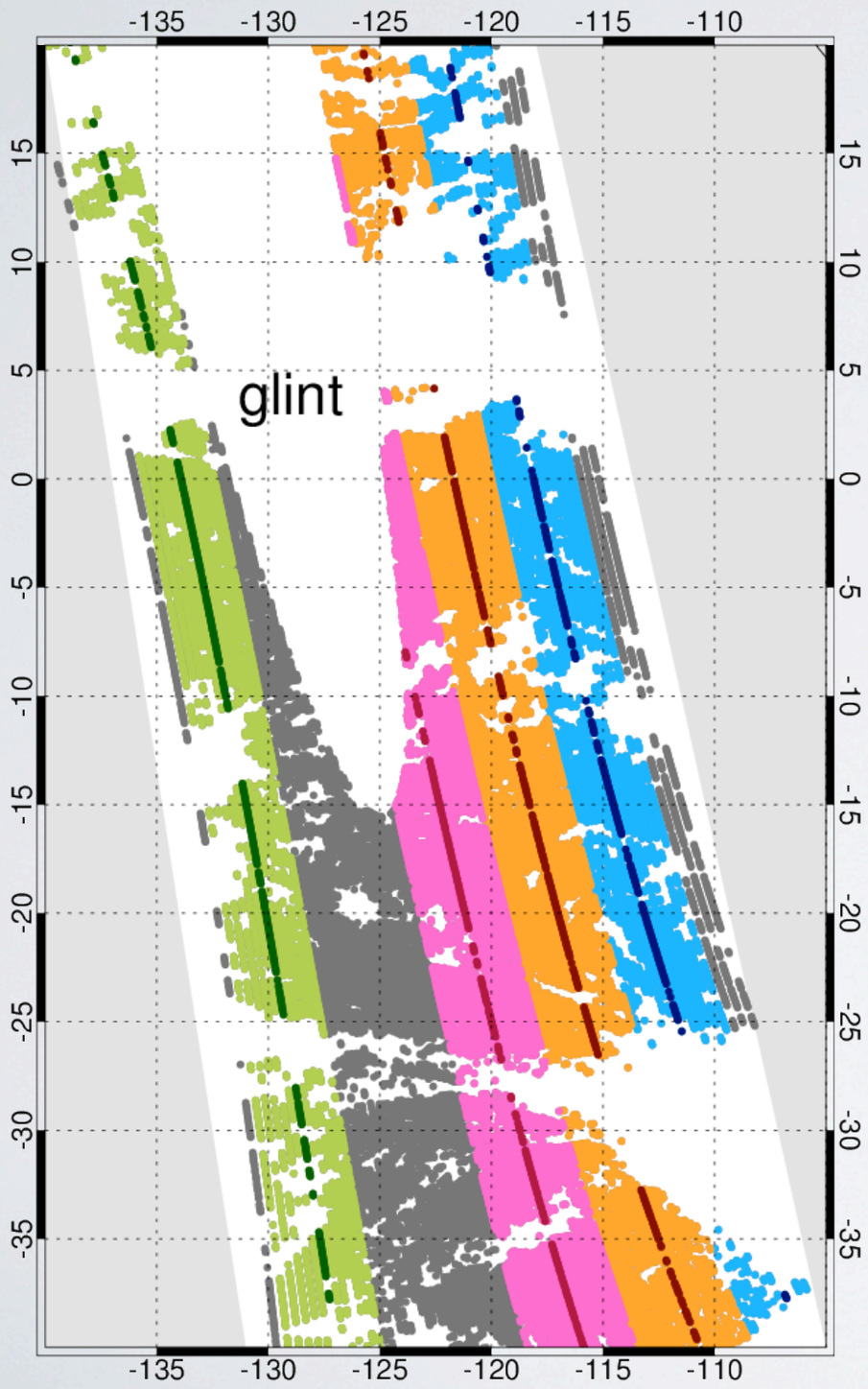
Full Swath

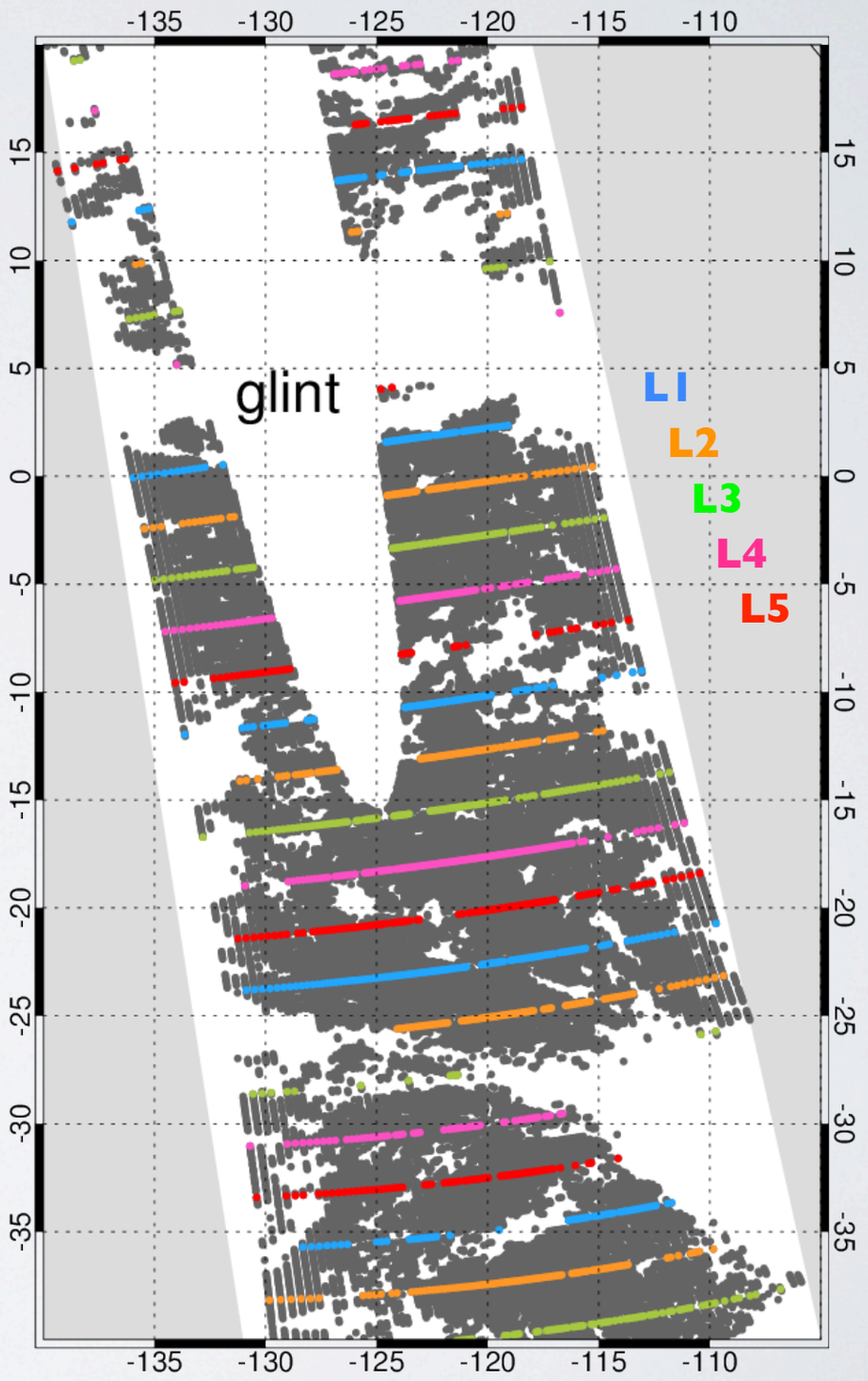


C1

An Alternative Sampling Strategy

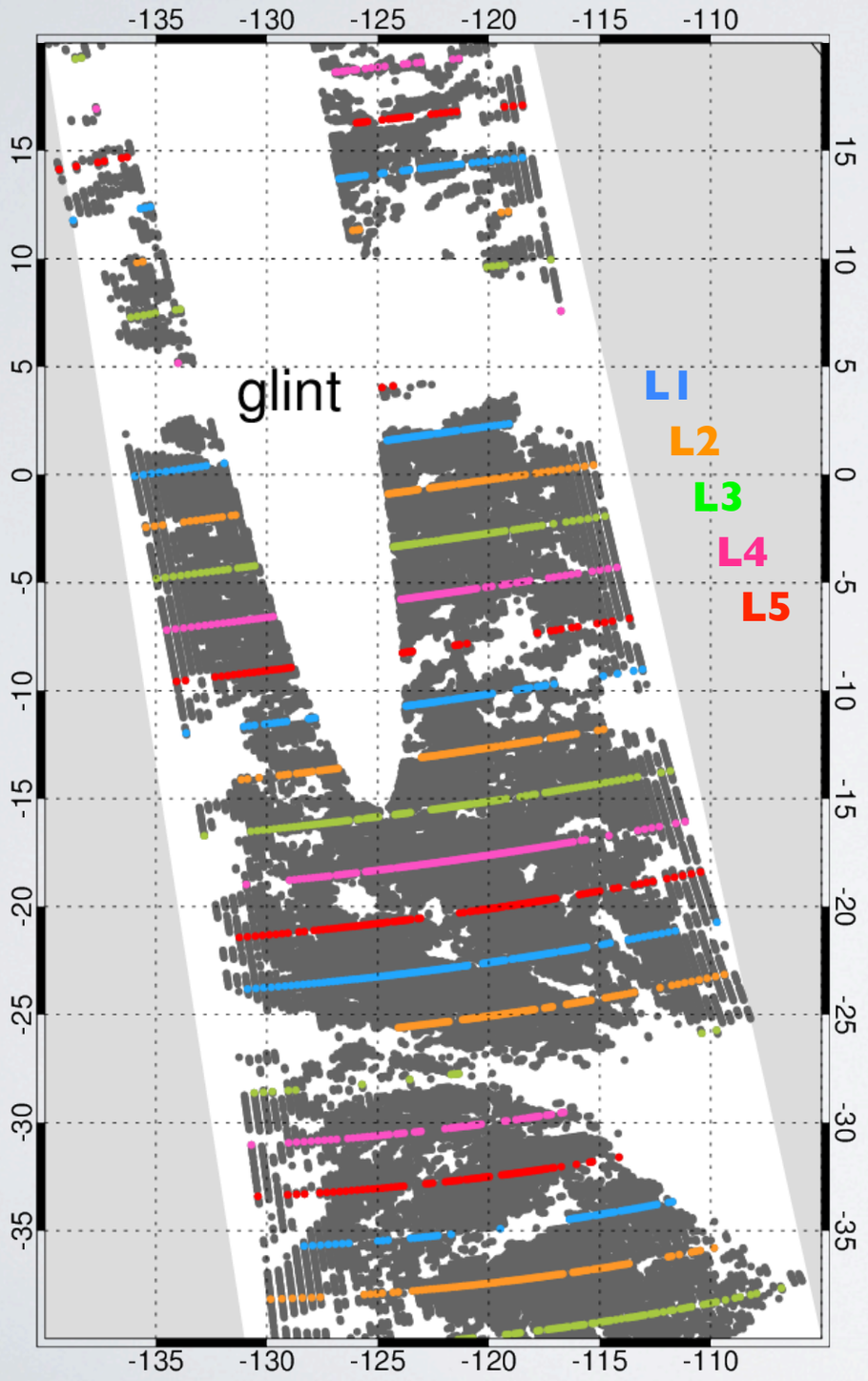
- *We considered along-track sampling to be more like a real instrument*
- *Geogdzhayev et al. (2013) considered across-track sampling to try and beat down MODIS scan angle biases*



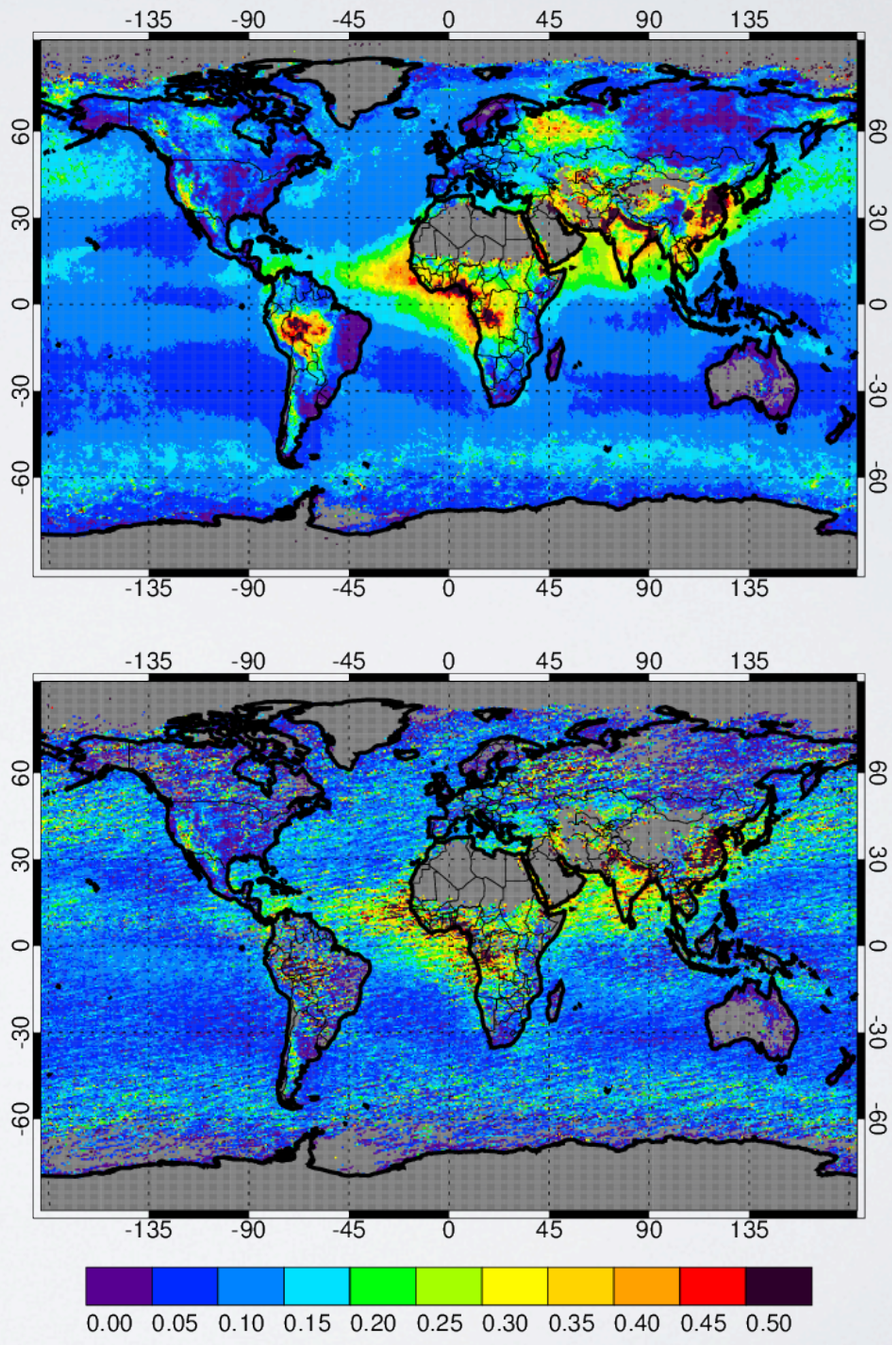


Across-track Sampling Strategy

Across-track sampling provides approximately global coverage, but temporal sampling is reduced



2010 Annual Mean AOT

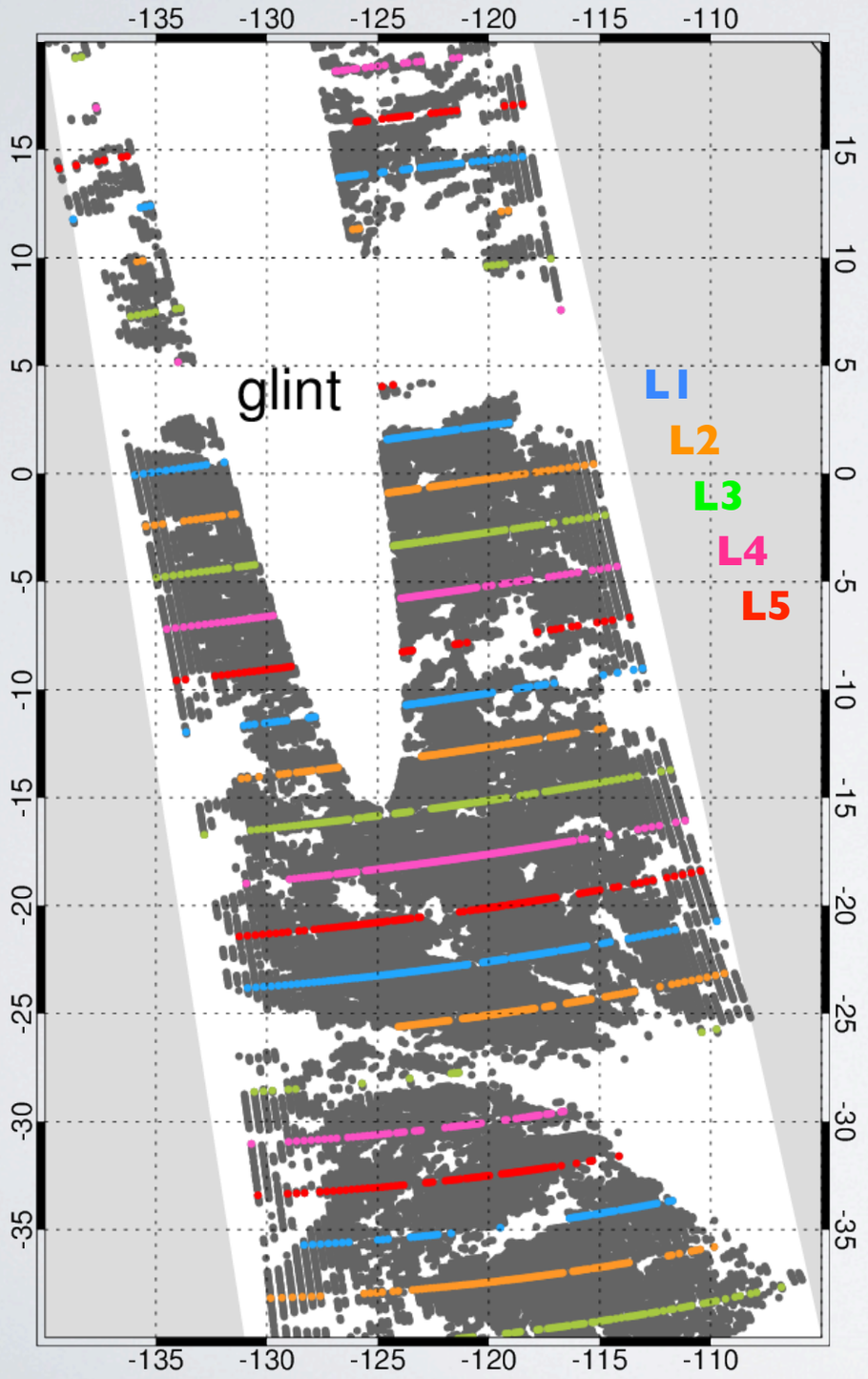


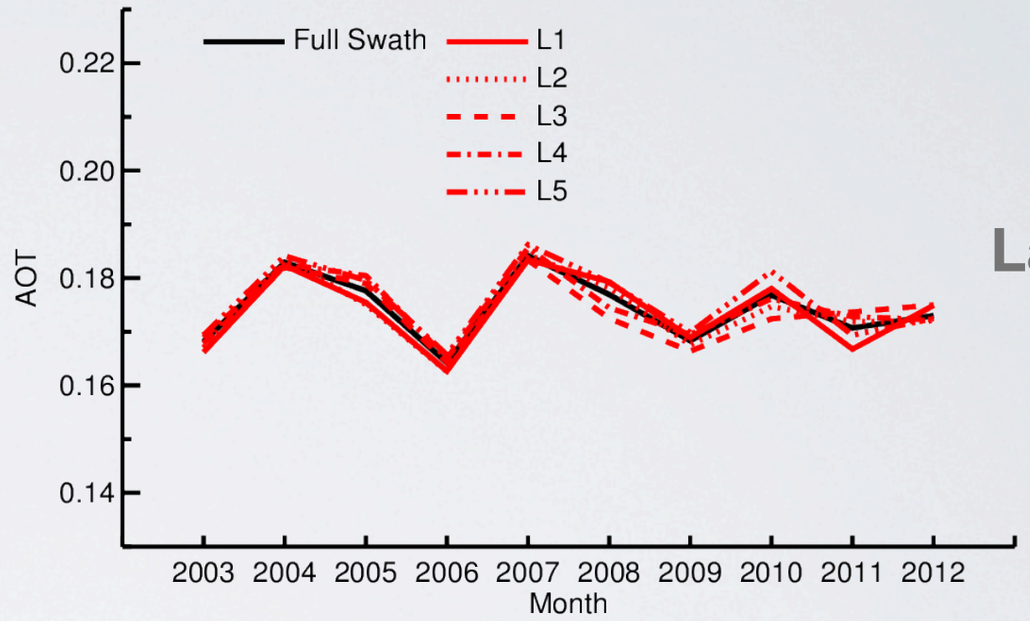
Full Swath

L1

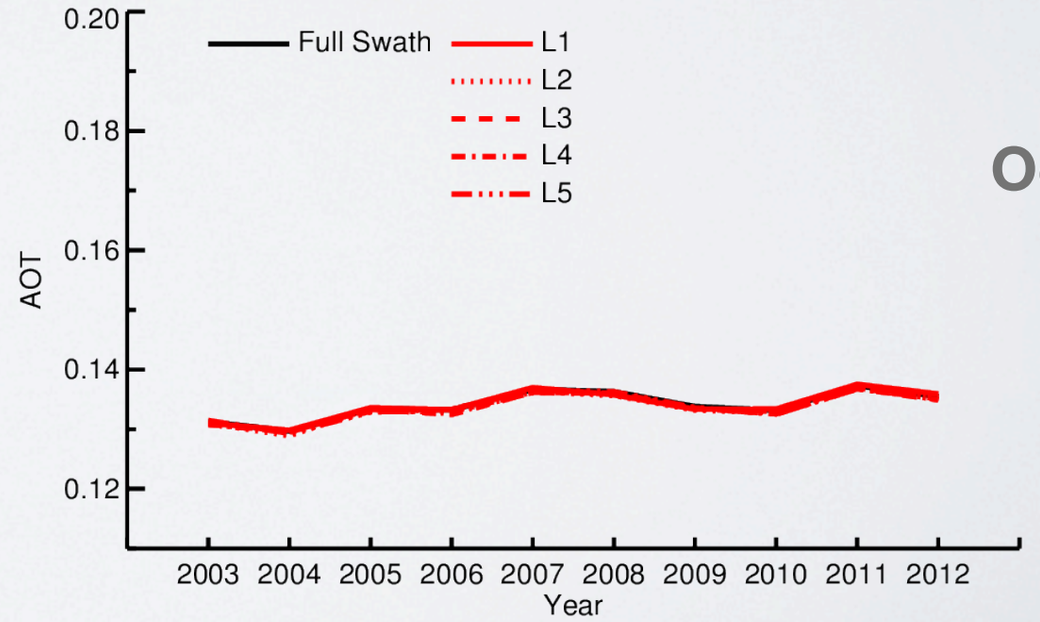
Across-track Sampling Strategy

For sufficiently long-enough time averaging and broad enough spatial averaging, the across-track sampling indeed converges to the full swath mean





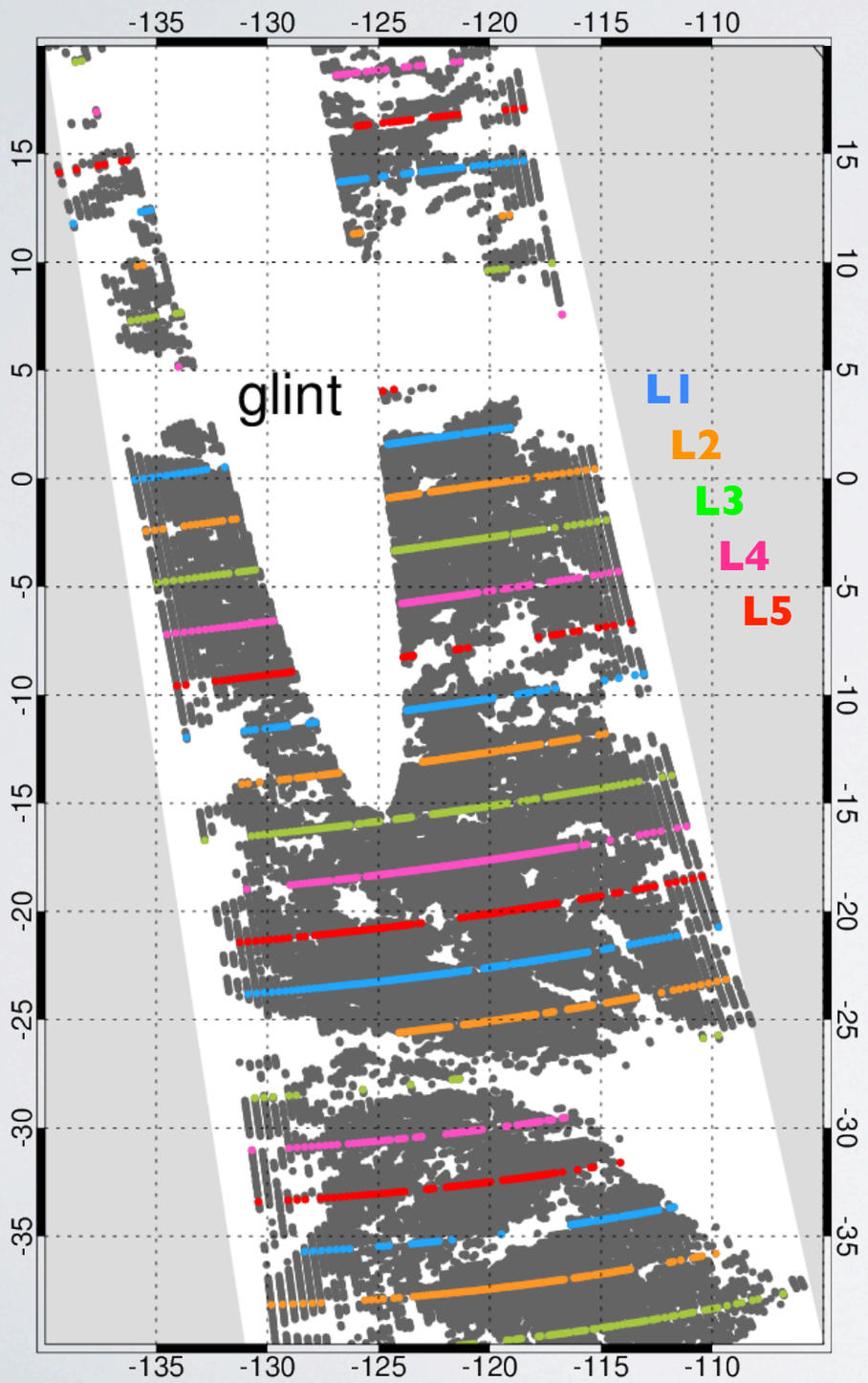
Land



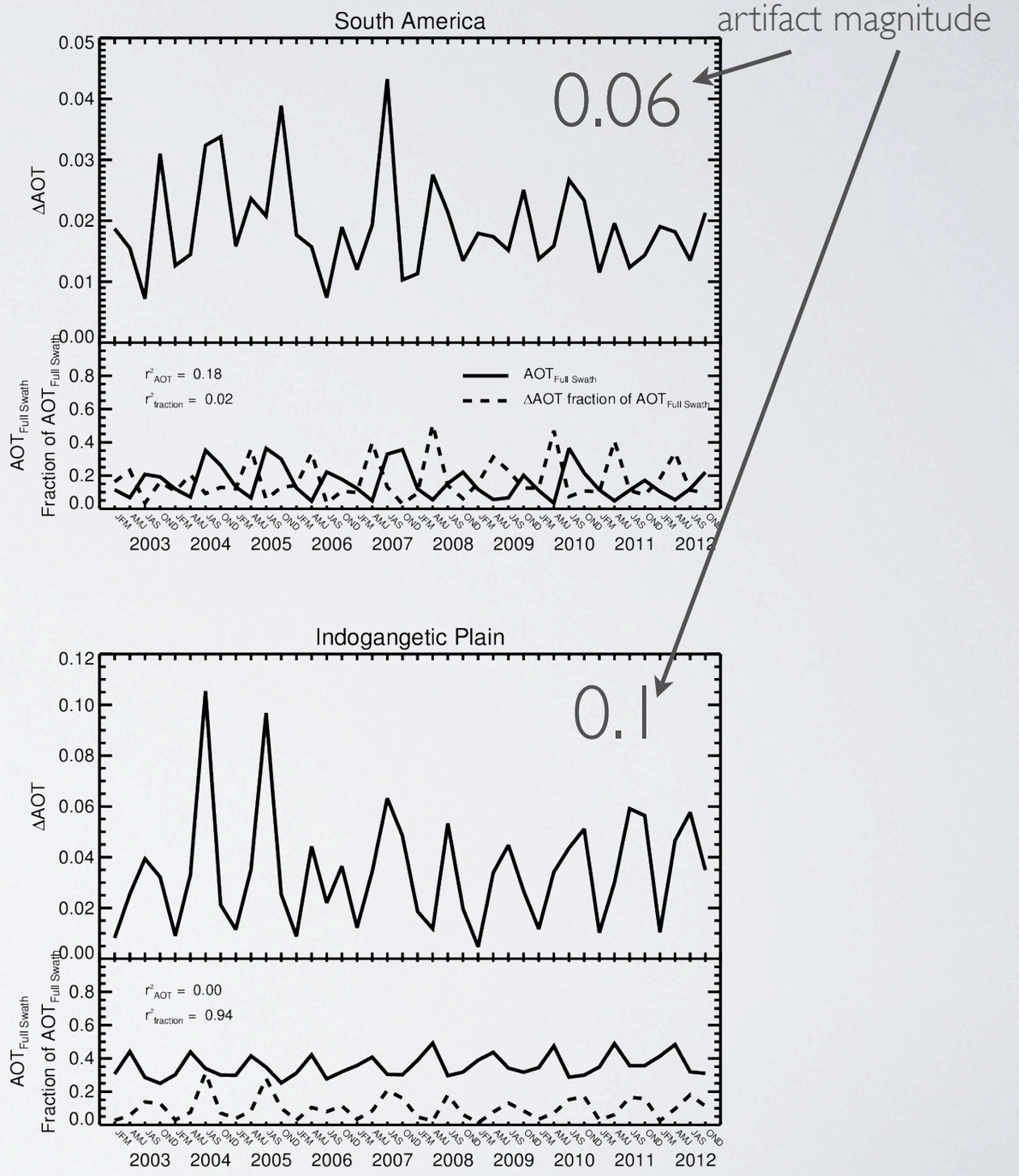
Ocean

Across-track Sampling Strategy

Reduced temporal sampling, however, still permits sizable sampling artifact. Here we apply the same "average-then-mask" approach as our along-track results

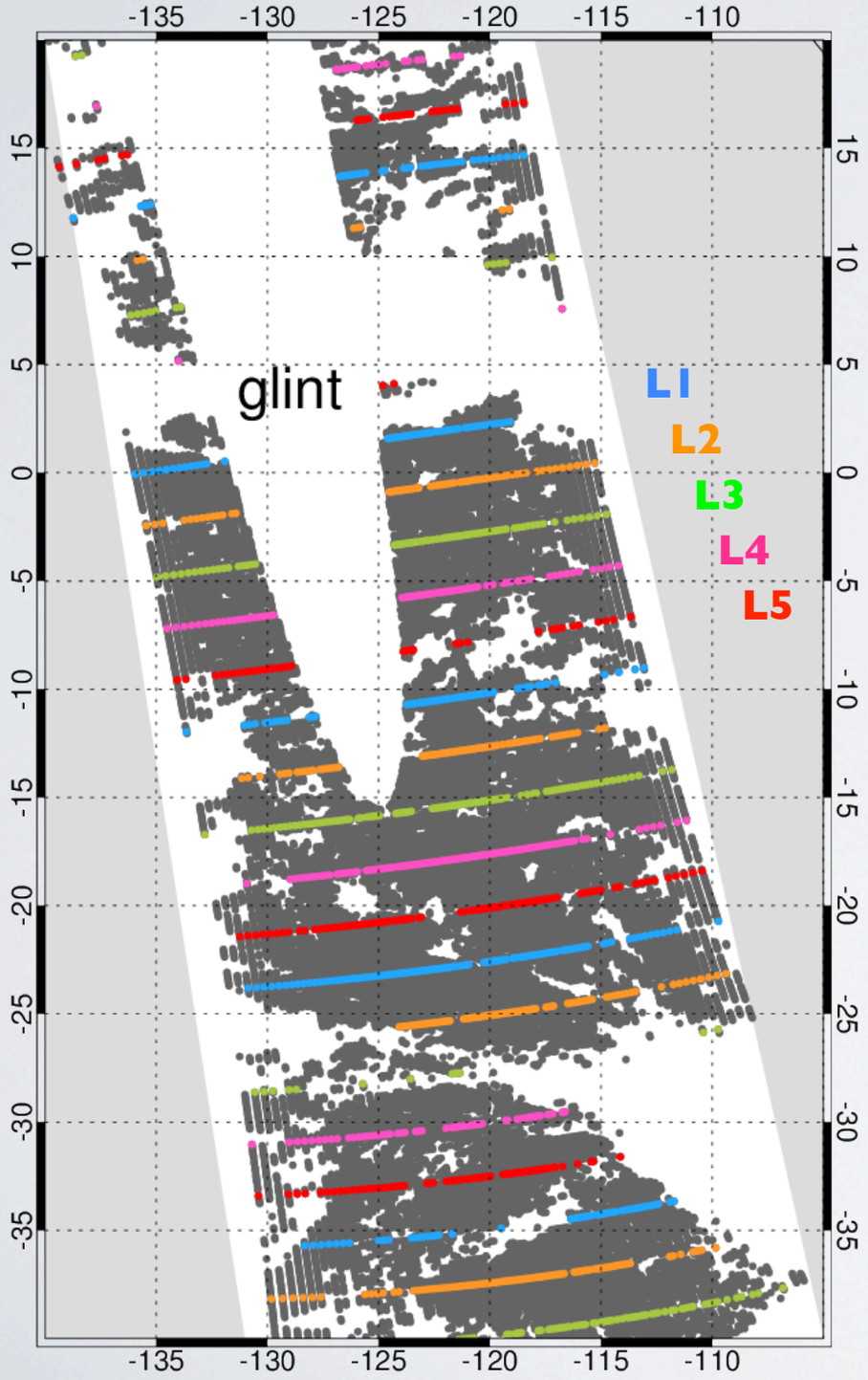


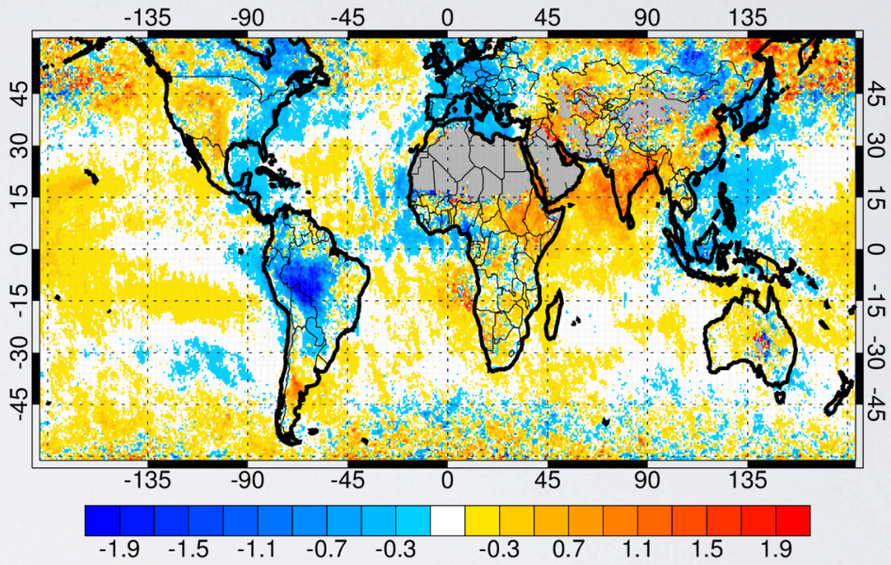
Along-track sampling artifact magnitude



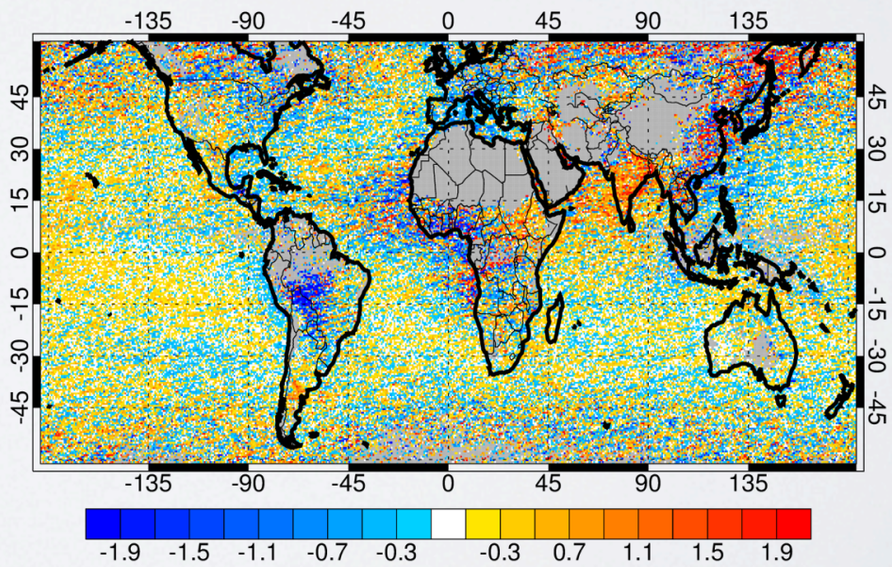
Across-track Sampling Strategy

Trend magnitude and significance of detection are compromised.





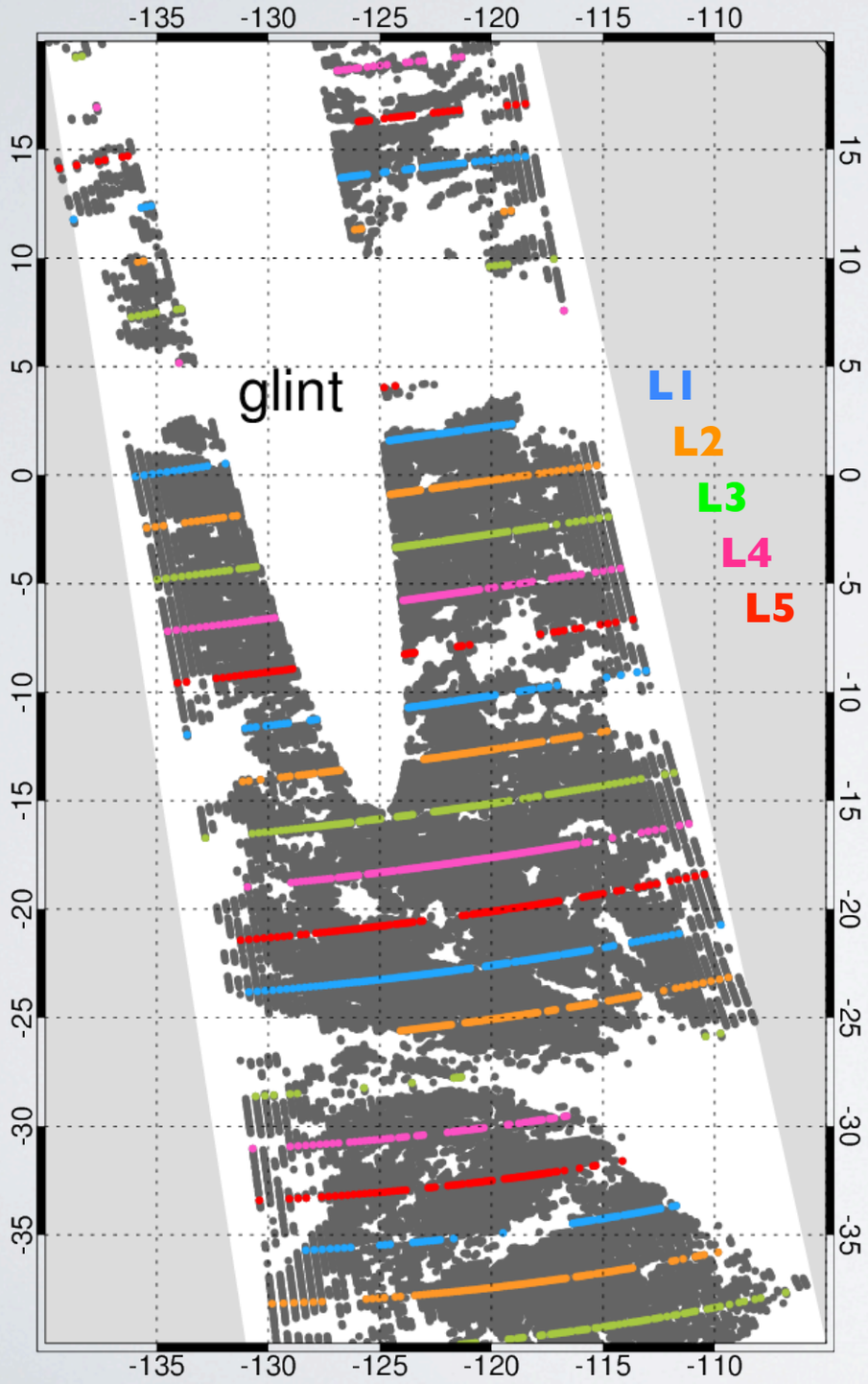
Full Swath
Trend
100*AOT yr^{-1}

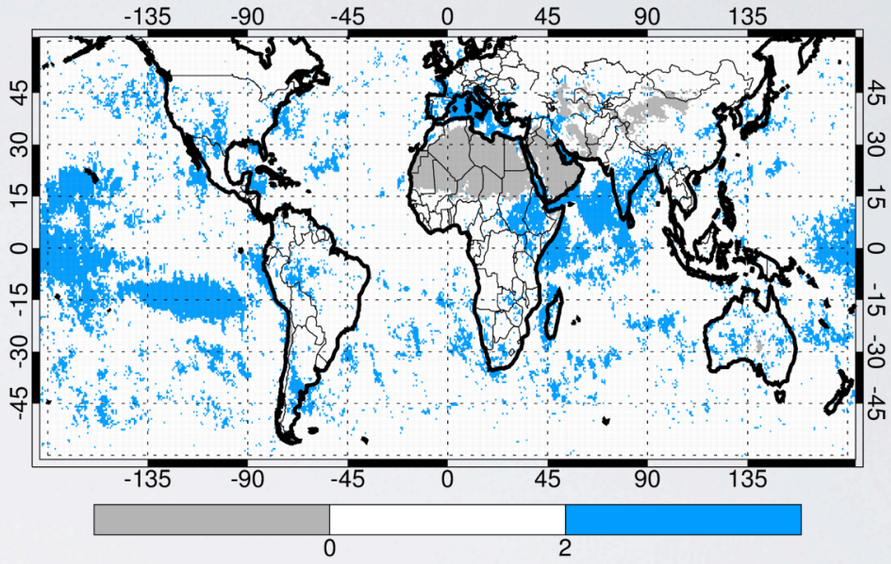


L1 Trend
100*AOT yr^{-1}

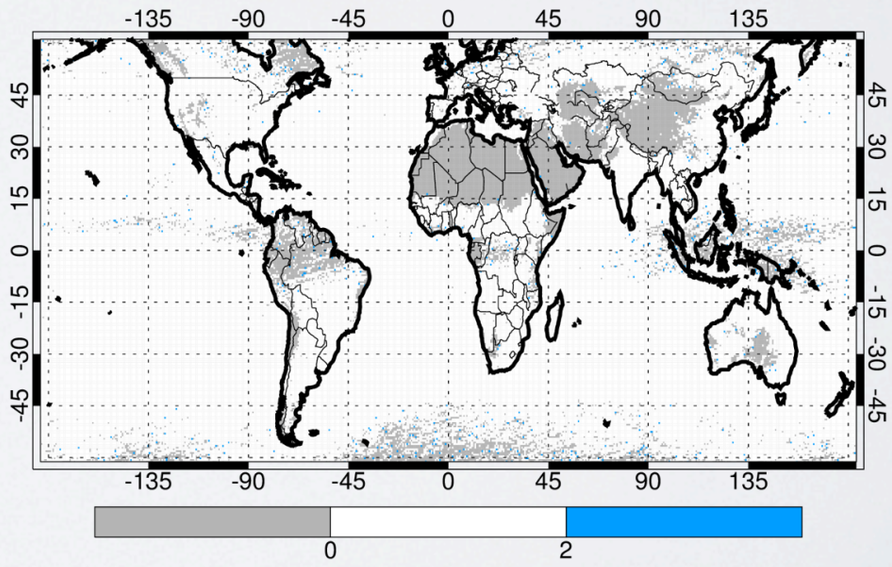
Across-track Sampling Strategy

Trend magnitude and significance of detection are compromised.





Full Swath
Trend
Significance



L1 Trend
Significance

Sampling a Global Aerosol Transport Model

MODIS represents the best available combination of broad swath, high quality, and long running coverage of satellite-based aerosol properties at our disposal

For all of that, we know MODIS has significant issues (e.g., cloud contamination, scan angle biases, surface boundary conditions, etc.)

What can we learn about sampling importance from global models, which presumably do not suffer these same issues?

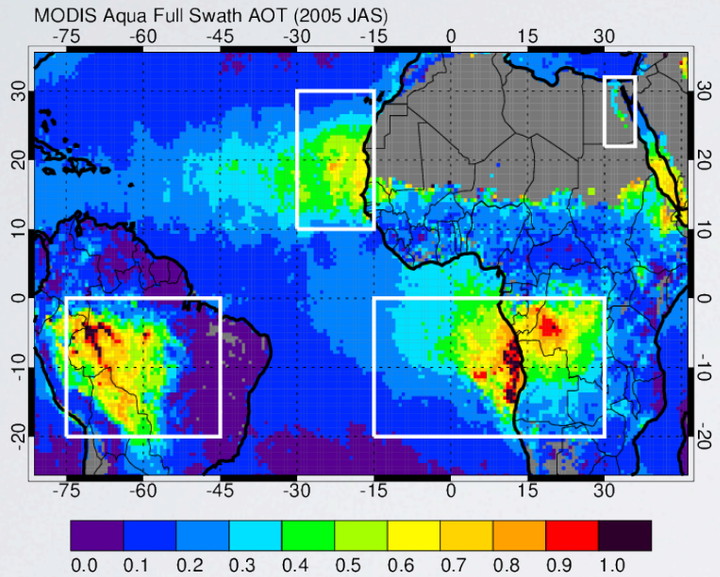
Note that whatever their virtues, there are significant issues with tackling this problem in a global model:

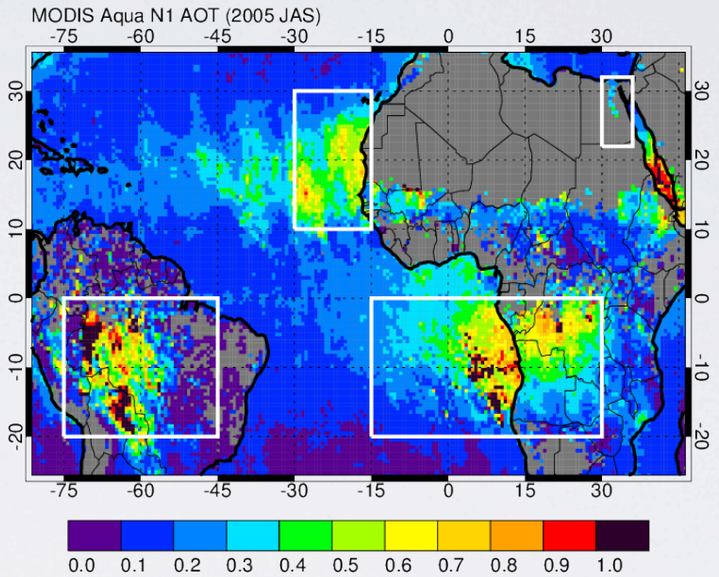
- *how is the model AOT biased relative to reality?*
- *how does the model spatial and temporal variability compare to reality?*

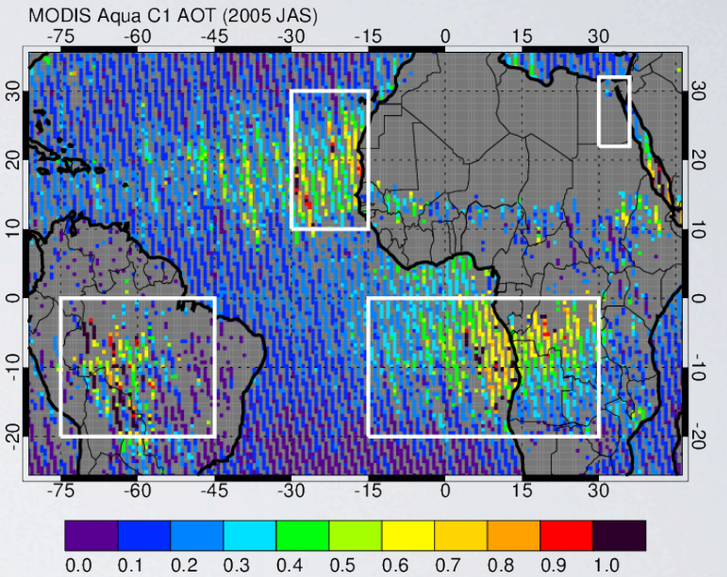
Sampling a Global Aerosol Transport Model

For this we use *climate model* simulation ("Nature Run") of GEOS-5 with GOCART aerosols run at global 10 km spatial resolution. We have results for period June 2005 - March 2007.

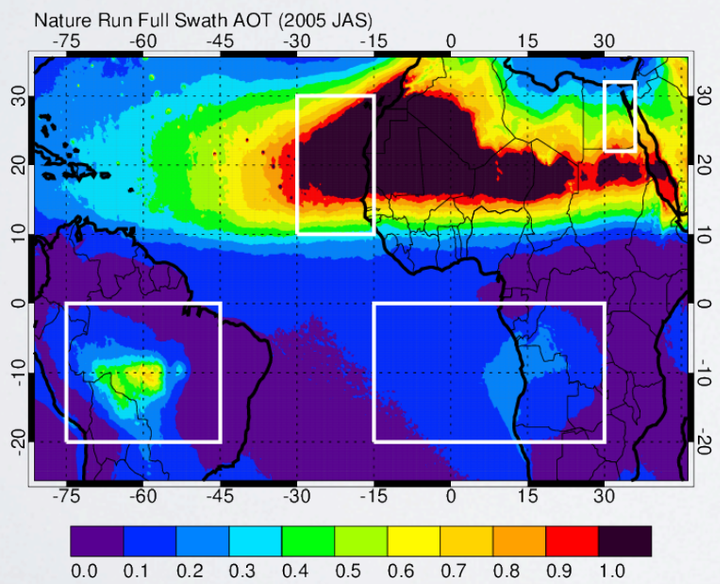
MODIS

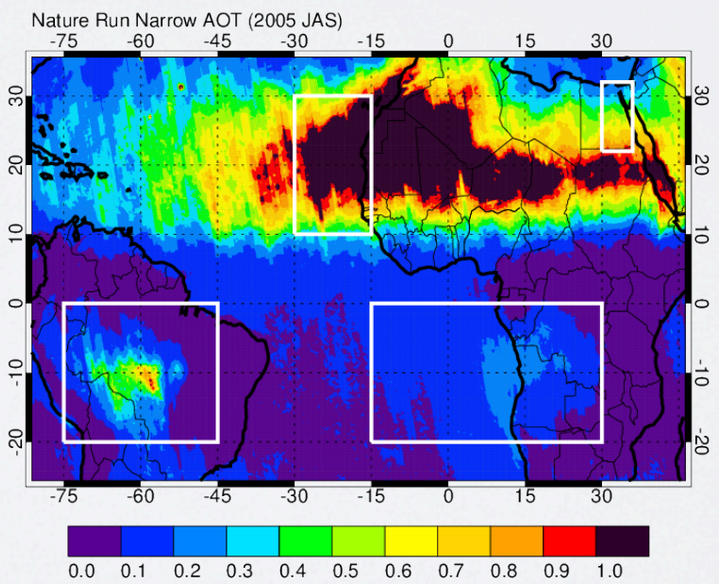


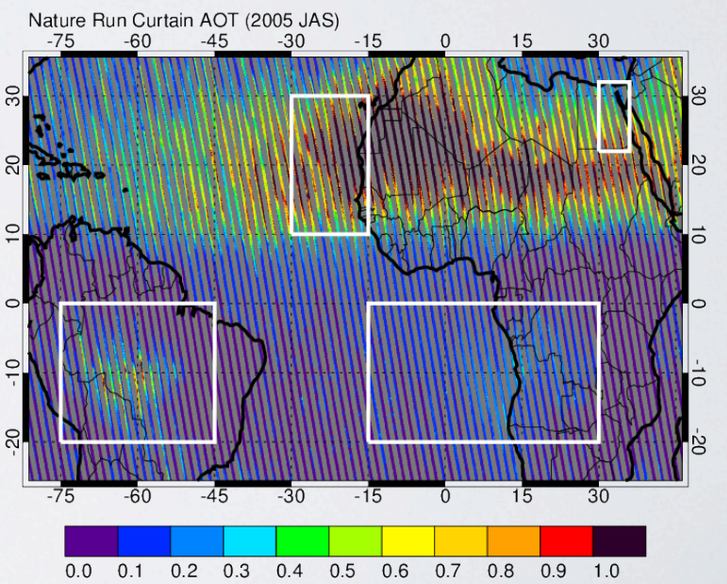




Nature Run







Full Swath

Narrow Swath

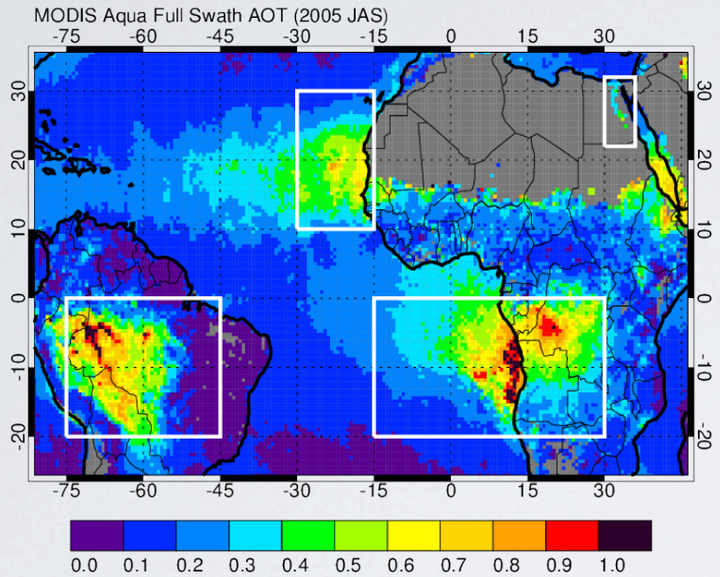
Curtain

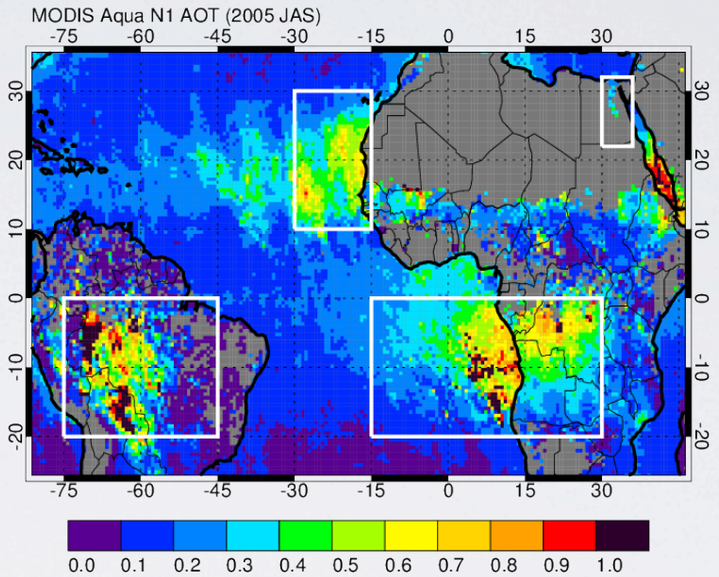
Sampling a Global Aerosol Transport Model

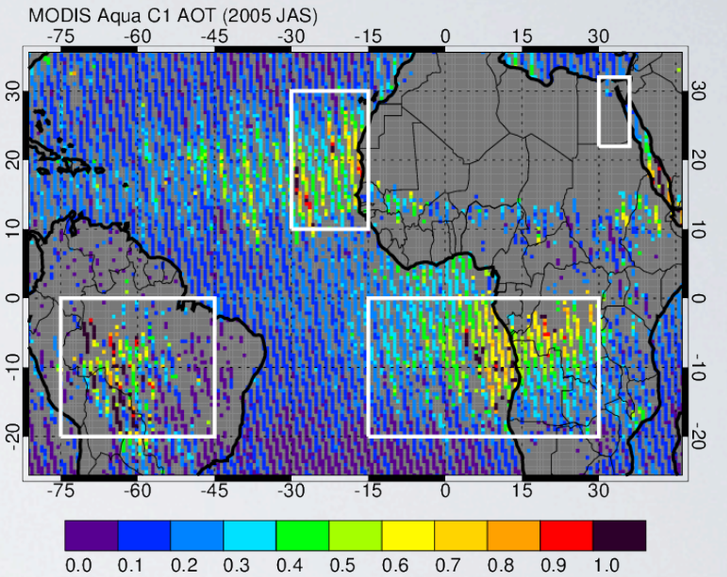
Model has higher dust AOT and lower smoke AOT than MODIS observes

A future "Nature Run" is underway which has addressed some of these biases

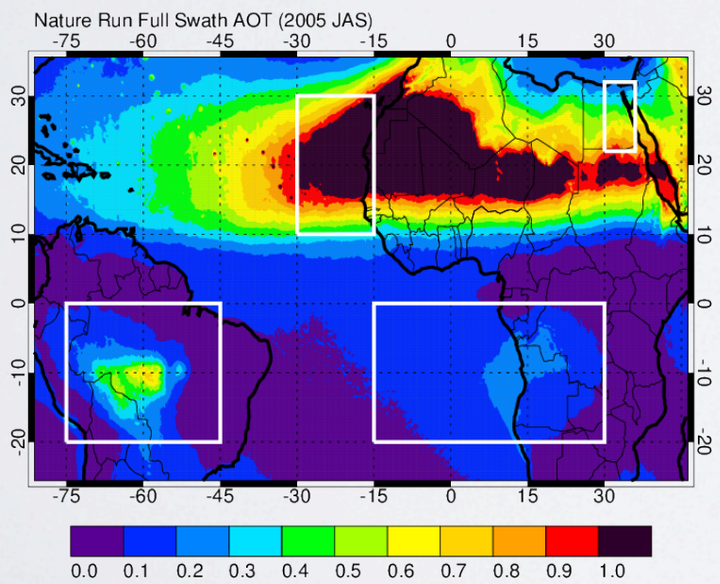
MODIS

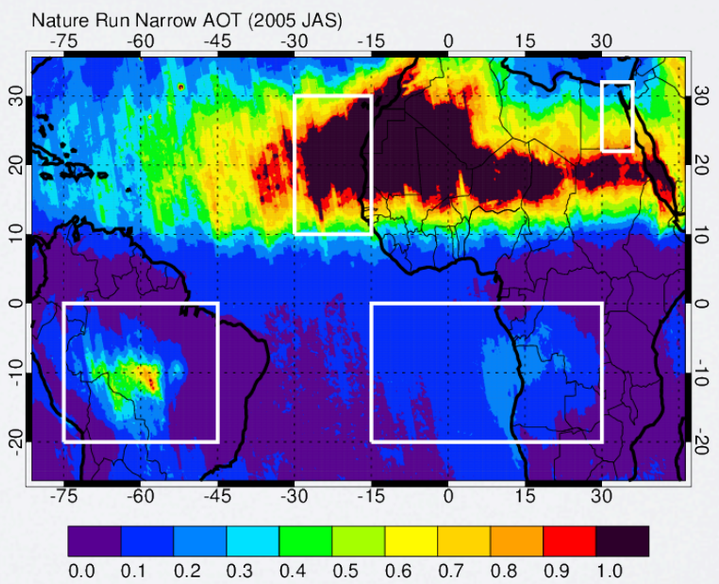


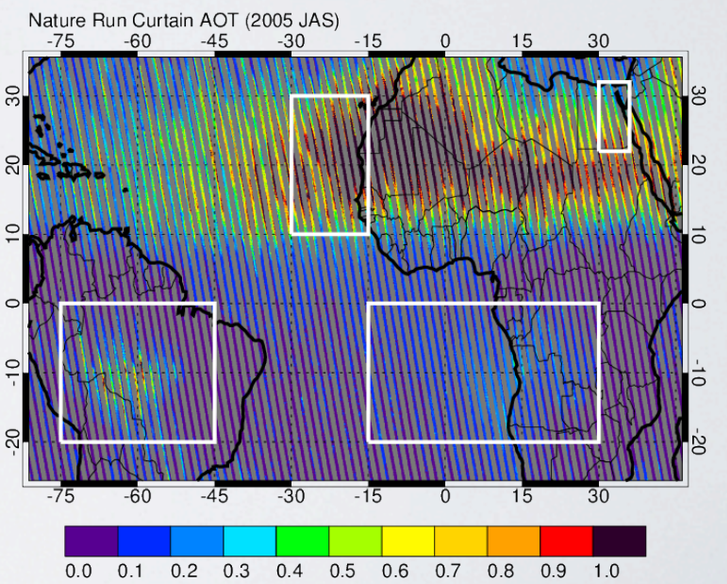




Nature Run







Full Swath

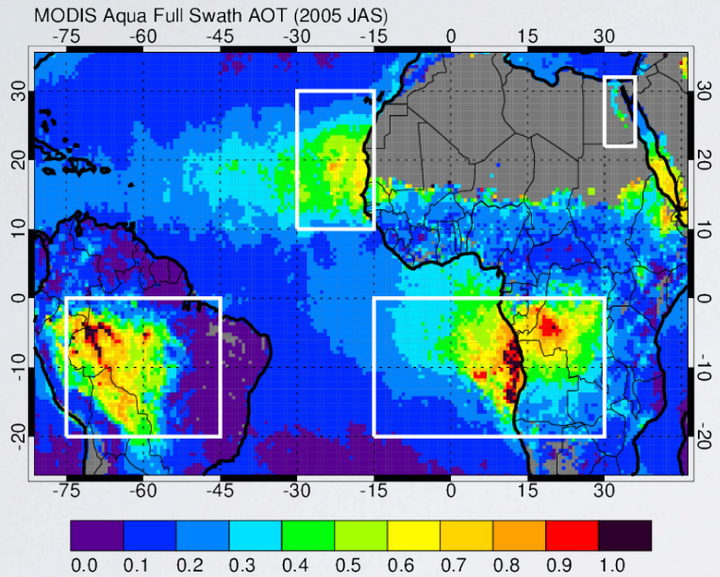
Narrow Swath

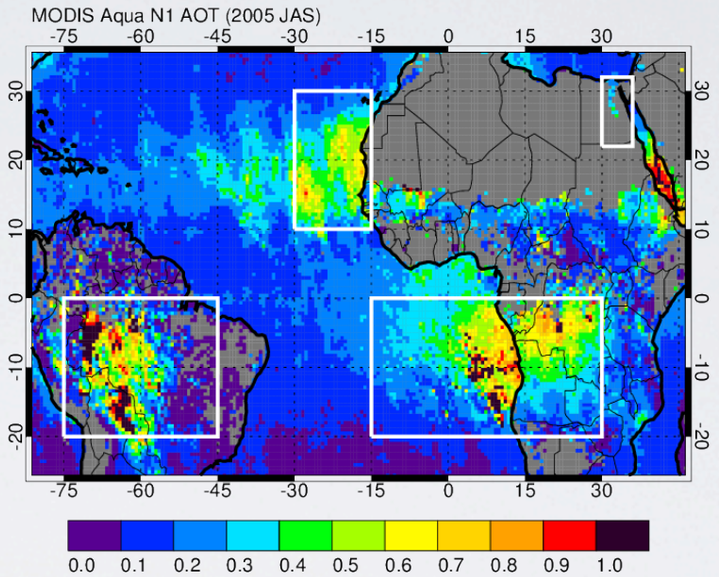
Curtain

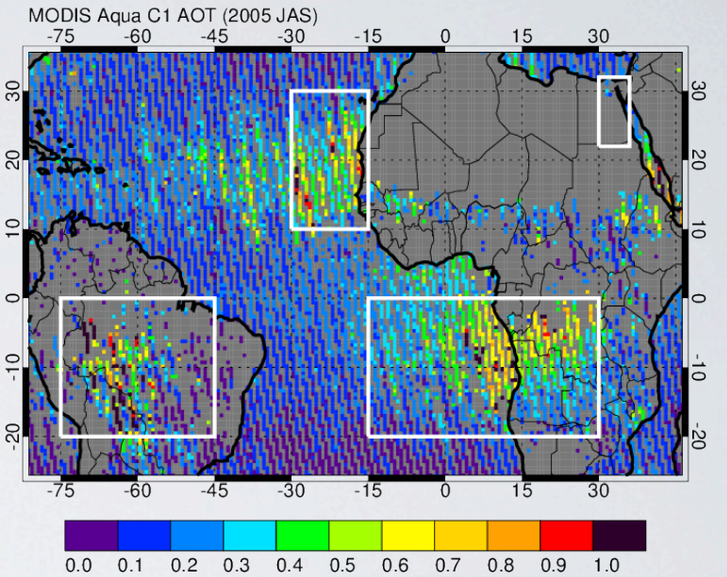
Sampling a Global Aerosol Transport Model

Not much changes when only less cloudy model grid cells are chosen

MODIS

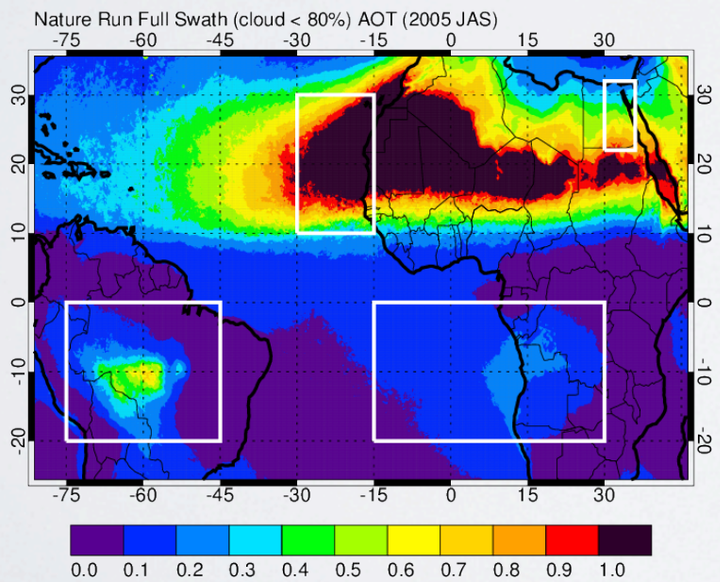


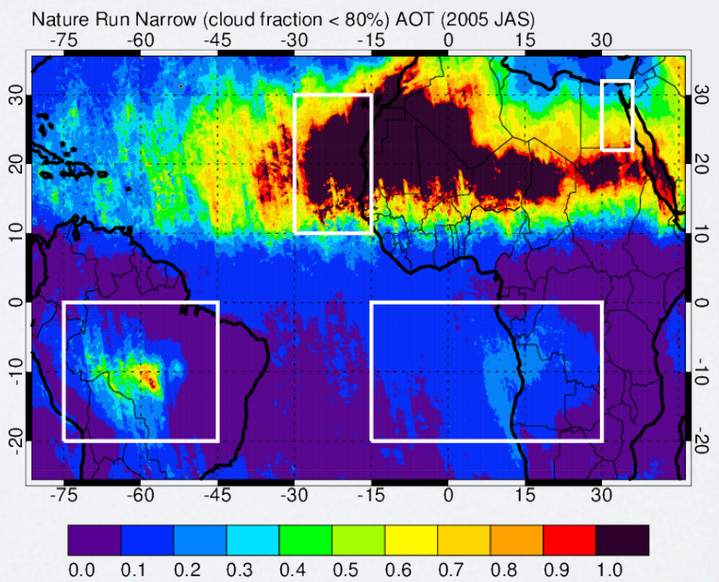


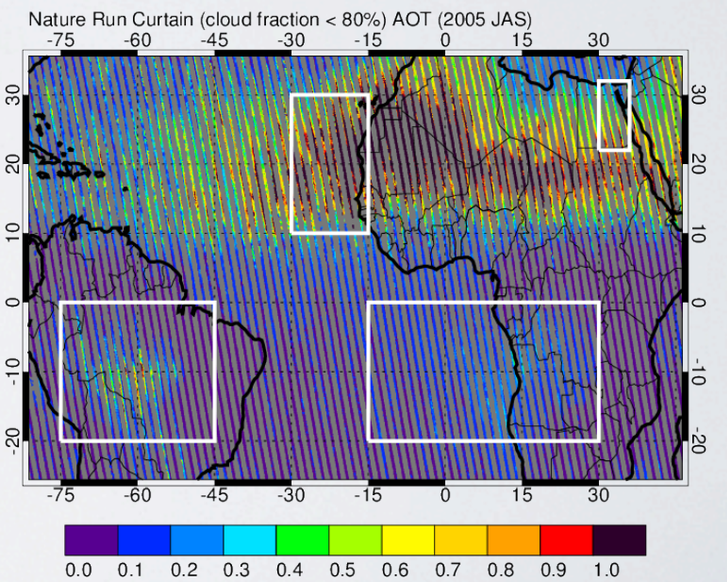


Nature Run

Only grid cells with cloud fraction < 80%







Full Swath

Narrow Swath

Curtain

Sampling a Global Aerosol Transport Model

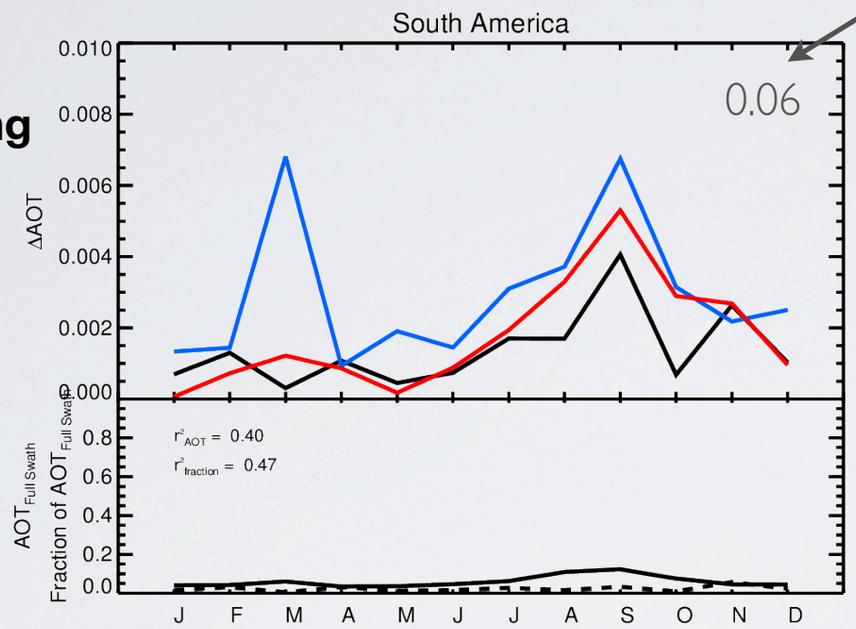
Tropical Atlantic: 2006 monthly sampling artifact (ΔAOT)
Also shown is approximate maximum value of sampling artifact from MODIS

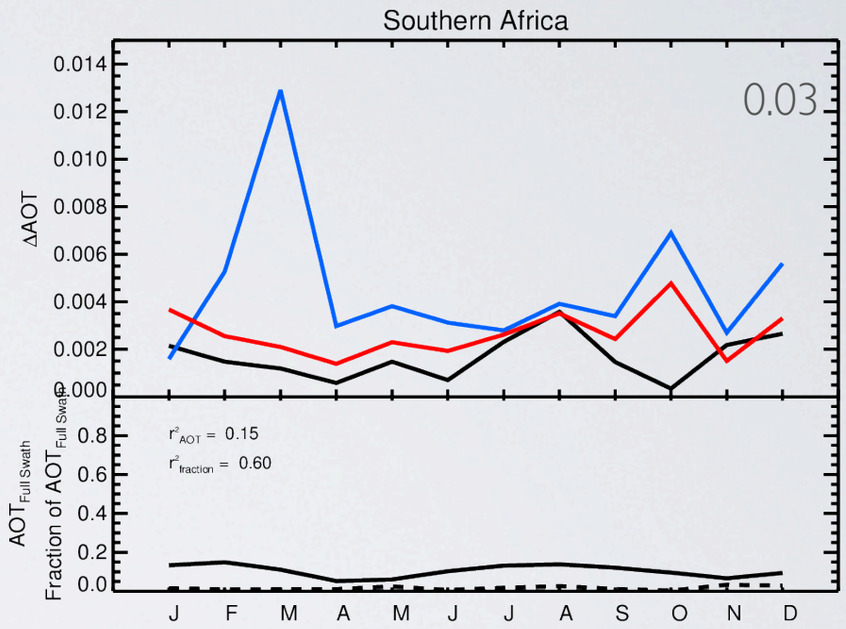
No Cloud Clearing

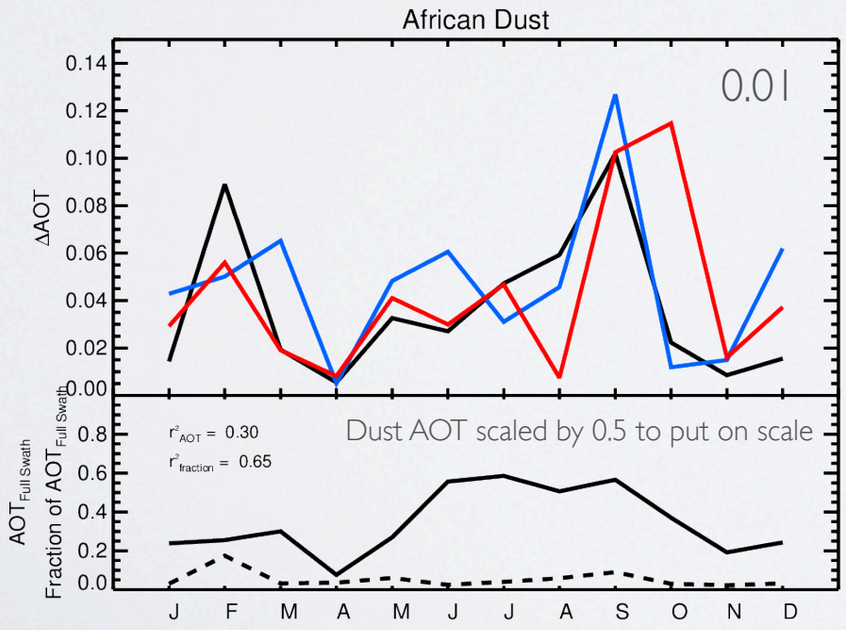
Retain cloud fraction < 80%

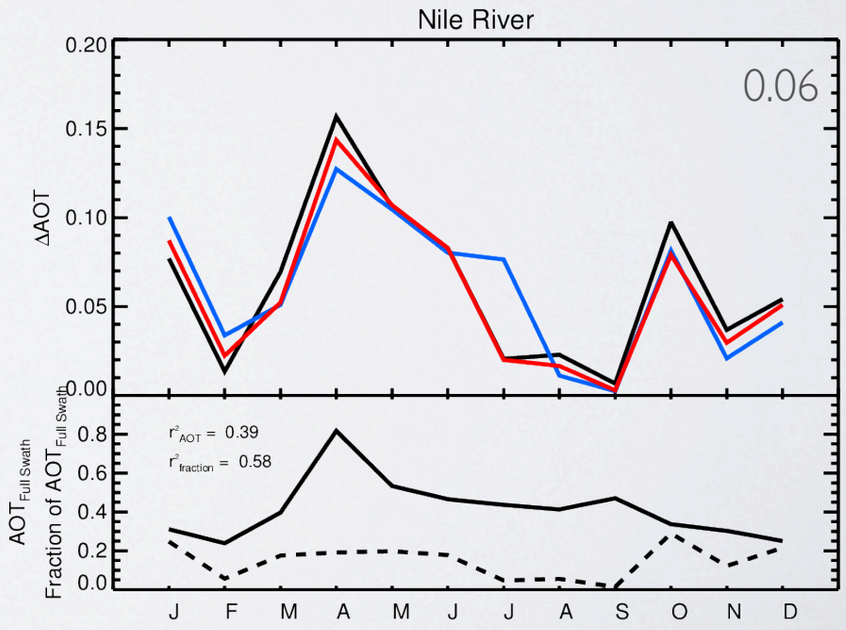
Retain cloud fraction < 50%

Maximum sampling artifact from MODIS analysis









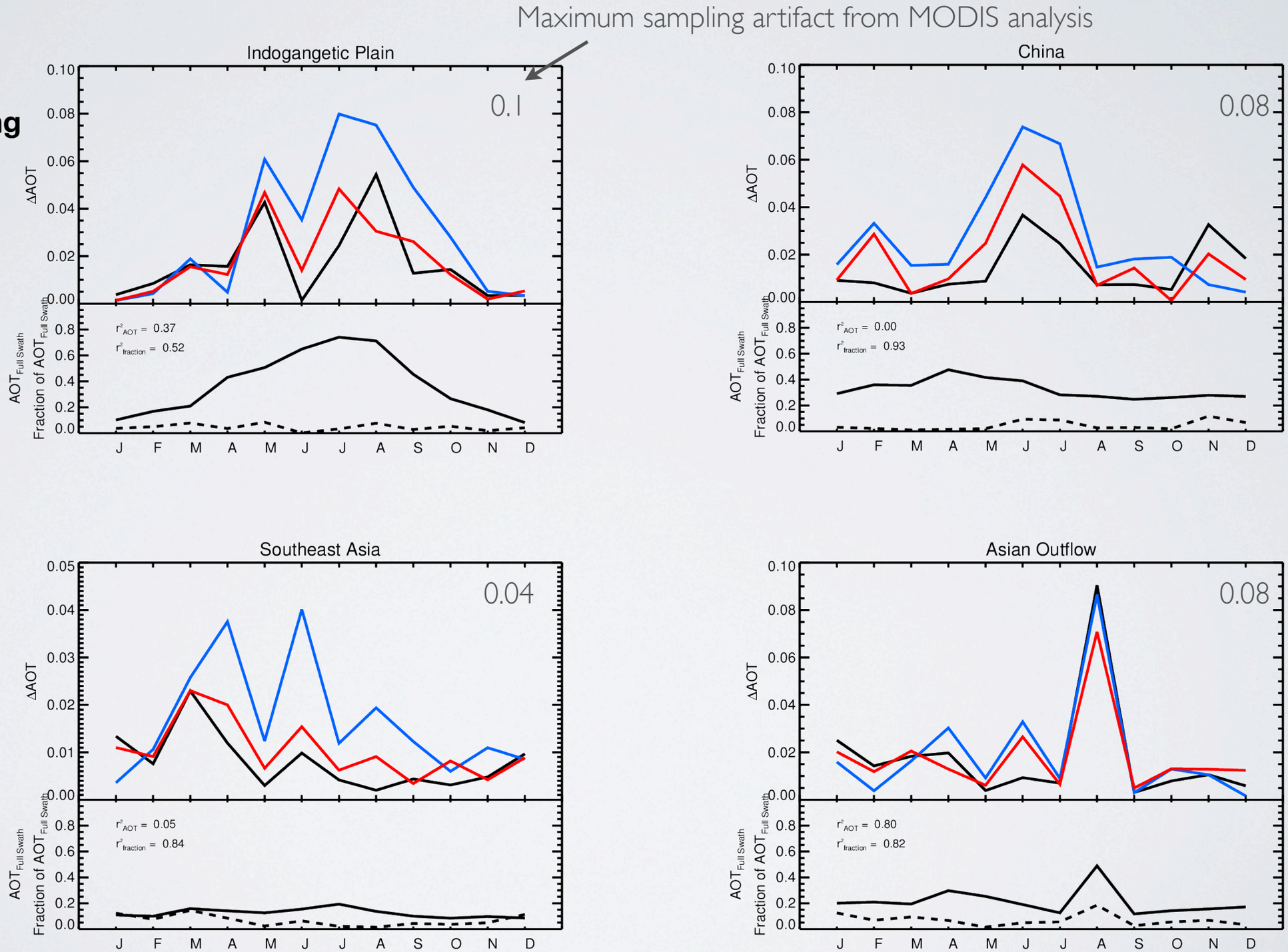
Sampling a Global Aerosol Transport Model

Asia: 2006 monthly sampling artifact (ΔAOT)
Also shown is approximate maximum value of sampling artifact from MODIS

No Cloud Clearing

Retain cloud fraction < 80%

Retain cloud fraction < 50%



Conclusions

Swath width--sampling--is an important consideration for future satellite missions

We investigate this by sub-sampling the full swath MODIS Aqua aerosol observations along several candidate narrower swaths

Our results are that:

(1) There are significant differences in the global, annual mean AOT for our different subsamples

- ➡ Scan angle biases in the MODIS retrievals complicates untangling what part of this signal is retrieval error and what part is truly spatial sampling

(2) Focusing instead on observability--where the sub-sample could or could not ever make an observation--the global, annual mean AOT is much more similar to the full swath, but there remain important regional differences

- ➡ Air quality is a regional issue
- ➡ Aerosol direct forcing is convolution of loading and surface albedo, so regional variability matters

(3) The ability to detect trends in AOT is seriously compromised by sampling issues, with the narrow swath curtain-like sampling revealing a very different picture of trend significance than the full swath observations

- ➡ narrow swath sampling highlights significant trends similar to full swath
- ➡ curtain-like sampling trends are muted
- ➡ without the context of the full swath you cannot discern what part of the curtain-like and even the narrow swath sampling to believe

Future Directions

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Future Directions

(1) What does this look like with cleaned up versions of MODIS products?
- Do results change for DA-quality version?
- How will results change for Collection 6?

(2) What does this look like in updated version of Nature Run?
- What is the impact of retuned aerosol emissions and loss processes?
- How does model spatial variability compare to real variability?
- What is calculated aerosol radiative forcing in model for different swaths?

(3) Is there a role or interest here for ICAP?
- ICAP OSSE?
- Data denial studies: What is impact of reduced swath data assimilation on forecast skill?