DEVELOPMENT STUDIES TOWARDS AN 11-YEAR GLOBAL GRIDDED AEROSOL OPTICAL THICKNESS REANALYSIS FOR CLIMATE AND APPLIED APPLICATIONS

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BOTTOM LINE UP FRONT

- An 11-yr long (200301-201309) global 1x1 degree and 6-hrly 550nm modal aerosol optical thickness (AOT) reanalysis product was generated.

  http://usgodae.org/cgi-bin/datalist.pl?dset=nrl_naaps_reanalysis&summary=Go

- This product is based on the application of multi satellite aerosol, fire and precipitation products in the NAAPS model.
- Validating with AERONET observations
  - the global mean RMSE is ~ 0.1 for both fine and coarse mode AOTs and ~0.14 for the total AOT. RMSE decreases 50% in monthly averaged modal AOTs.
  - Captures the regional and seasonal AOT variations to various degrees of skill.
  - Performs better in the long-range transport regions than the source regions.
- Despite the use of non-trending source functions, the reanalysis developed reasonable decadal trends that match other observations.
- Recommendations for the application of the AOT reanalysis product.

WHY AEROSOL REANALYSES?

- Like meteorological reanalyses, we expect aerosol and chemistry reanalyzes to be a dominant data source for most earth system science applications.
- While standalone satellite and model aerosol products see wide utilization, there is a significant need in climate and applied applications for a best available, contiguous, fused product on a regular grid.
- Aerosol reanalyses combine advantages of data accuracy from satellite products and data consistency from modelling. The data is gridded and has good spatial and temporal coverage.
- Weighting and error can be controlled, or at least characterized relative to the environmental state.
- Aerosol reanalysis are being pursued at nearly all major NWP centers because of the ability to integrate meteorological analyses and thus context.

But there is a lot to do!
Lets start with simple AOT

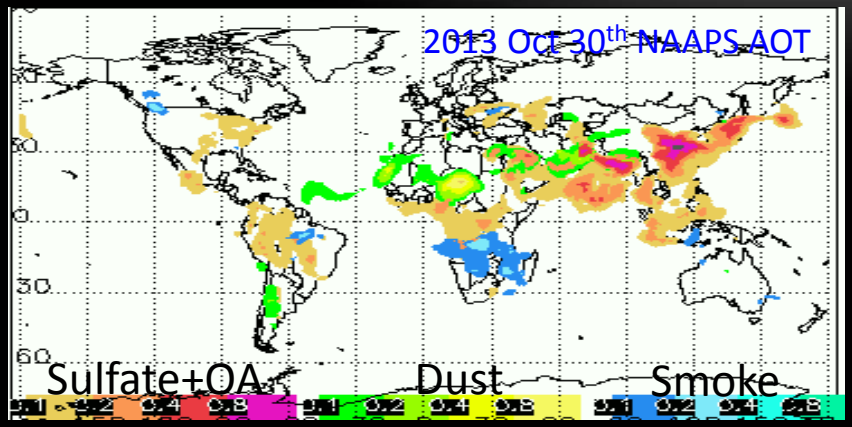
Abrams's Advice: When eating an elephant, take one bite at a time.

THINGS MUST BE CONSIDERED IN AOT REANALYSIS

- Errors in satellite products, caused by cloud contamination, errors in wind and aerosol microphysics in retrieval algorithm, etc. (Zhang and Reid, 2006, 2009, Shi et al., 2011; Hyer et. al. , 2011)
- There are differences in satellite AOT products, sometimes covarying errors between them.
- Bias still exist in quality assured satellite products.
- Errors in aerosol models, resulting from uncertainties in aerosol sources, representation of chemical processes, wet/dry removal, transport.
- Errors/bias in meteorological model.
- Data consistency in time in satellite products and meteorological models.

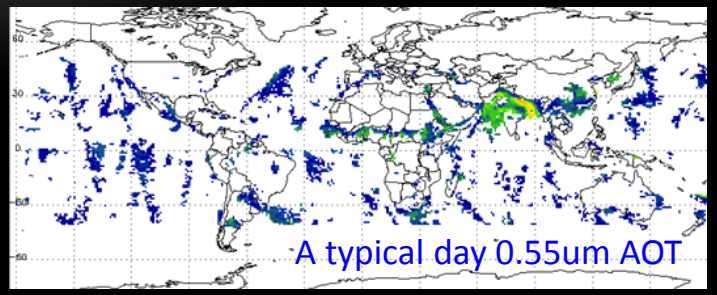
COMPONENTS OF AOT REANALYSIS

1.



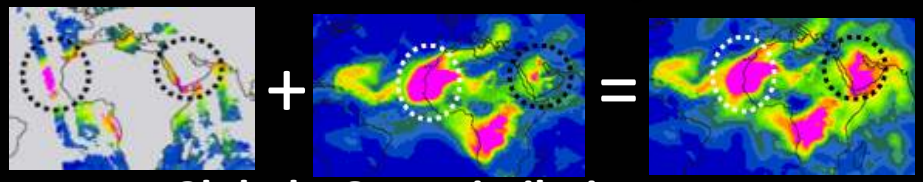
NAAPS chemical Transport model w/ NOGAPS NWP analysis fields

2.

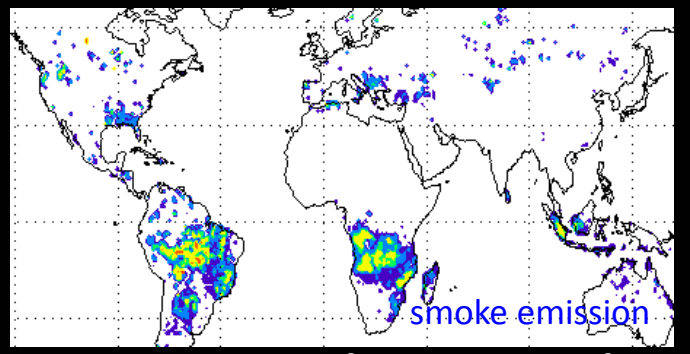


MODIS+MISR Fused AOT product

3.

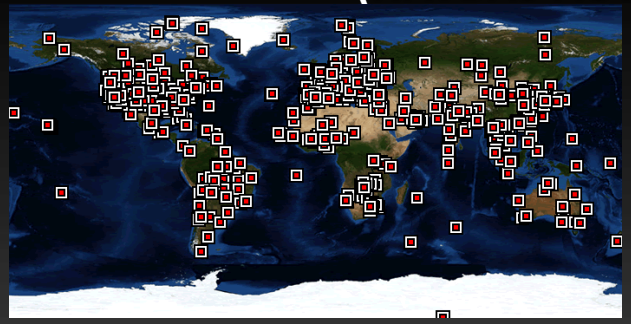


Global AOT Assimilation system (NAVDAS-AOT)

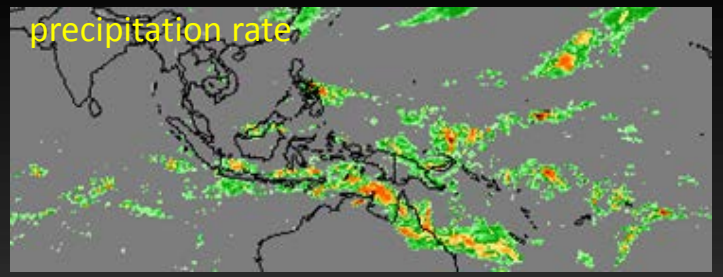


FLAMBE Fire (MODIS-Only)

4.

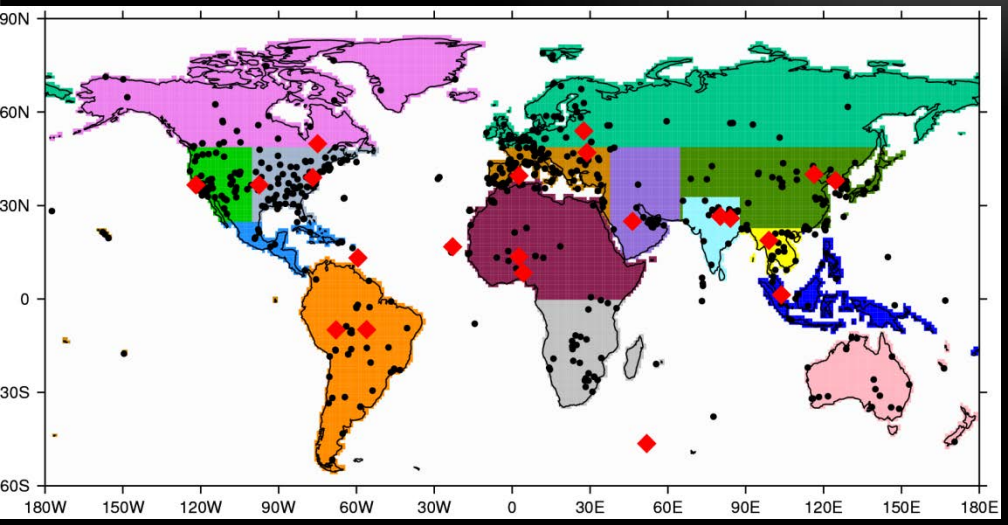


Validation with AERONET

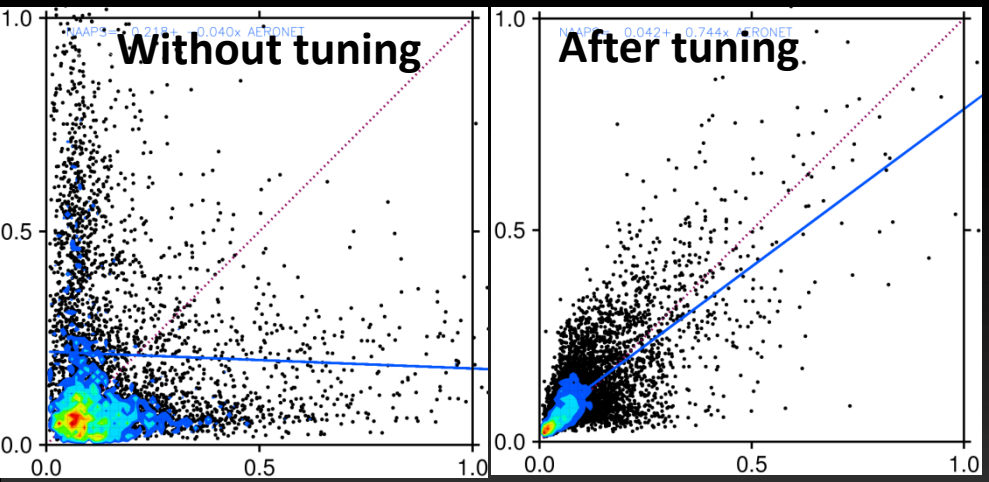


CMORPH Tropical Precip: 30 S-30 N

REGIONAL TUNING OF AEROSOL SOURCES AND REMOVALS



Model vs. AERONET : South America

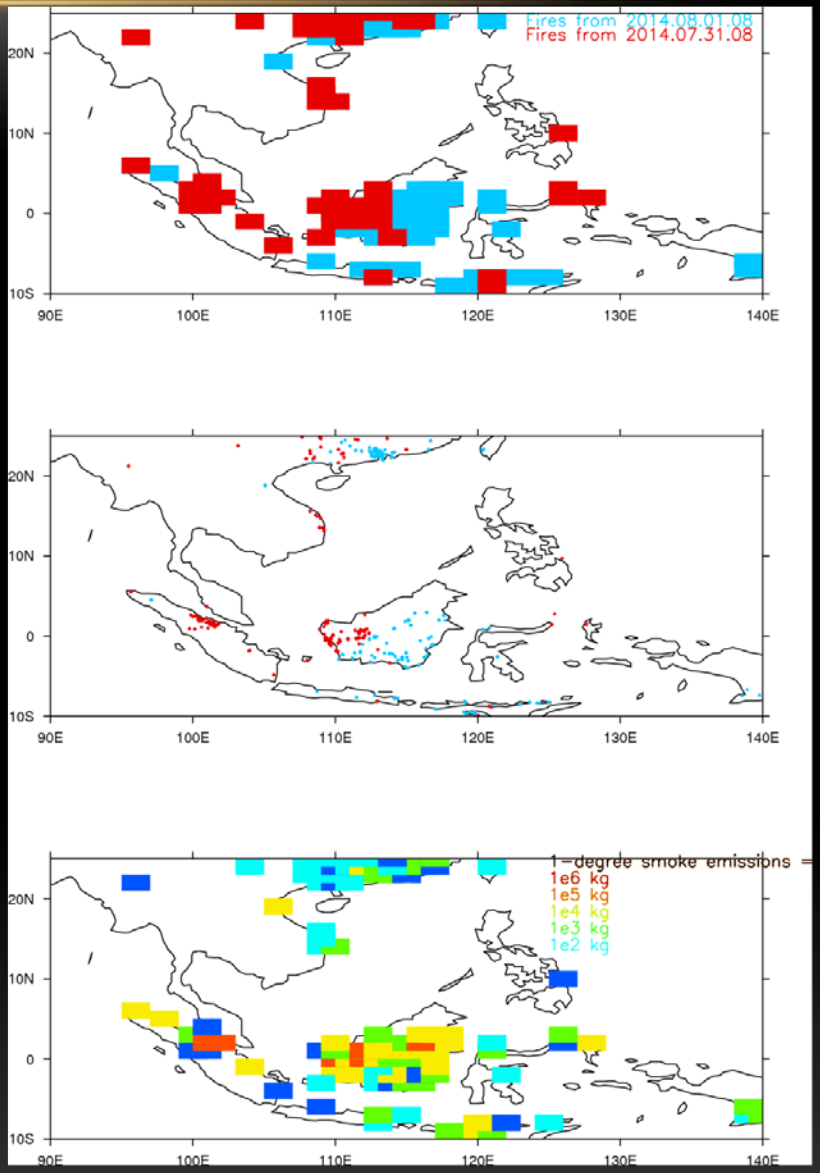


- The whole globe is divided into 16 regions, with each having its own distinct aerosol characteristics.
- Pairing fine/coarse AOT for the model versus AERONET along two major seasons: JJASON, DJFMAM.
- Regional smoke and dust emission factors are applied based on multiple sensitivity test runs.
- Organic aerosols are tuned along with smoke.
- Removal parameters are tuned using AOT assimilation correction fields over water.

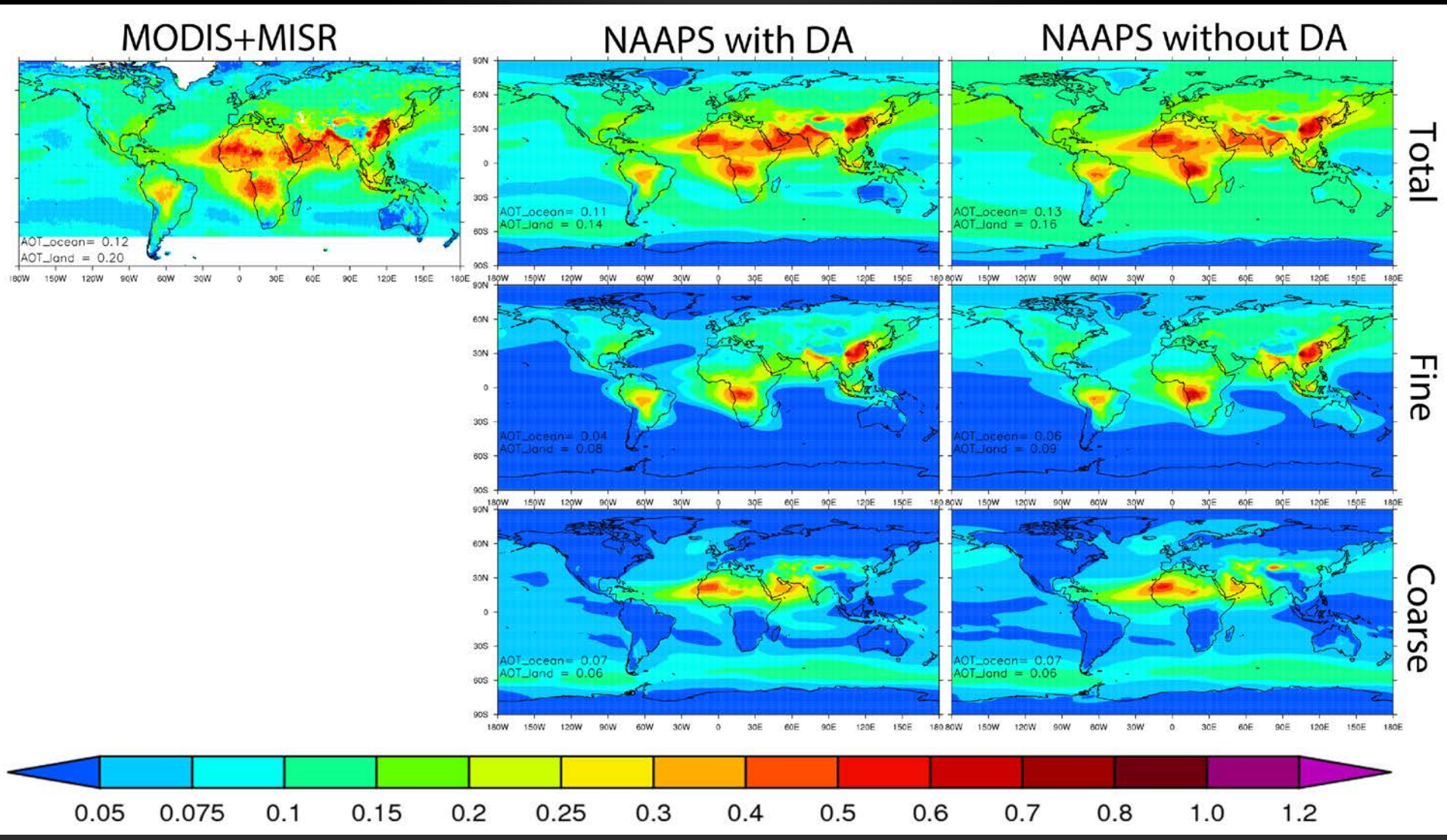
IMPROVEMENT ON SMOKE EMISSION

- Adopted the satellite active fire hotspot based approach through the FLAMBE (Reid et al. 2009; Hyer et al., 2013).
- For time consistency, a MODIS-only version of FLAMBE1.0 is created.
- Used a two day maximum (previous day and present day) fire signal to minimize MODIS orbital effects (i.e., day-to-day shift in orbital pattern).

Note: fire hotspots are often clustered in a large area in one day and then disappear for the next day, which is a reflection of detection issue.

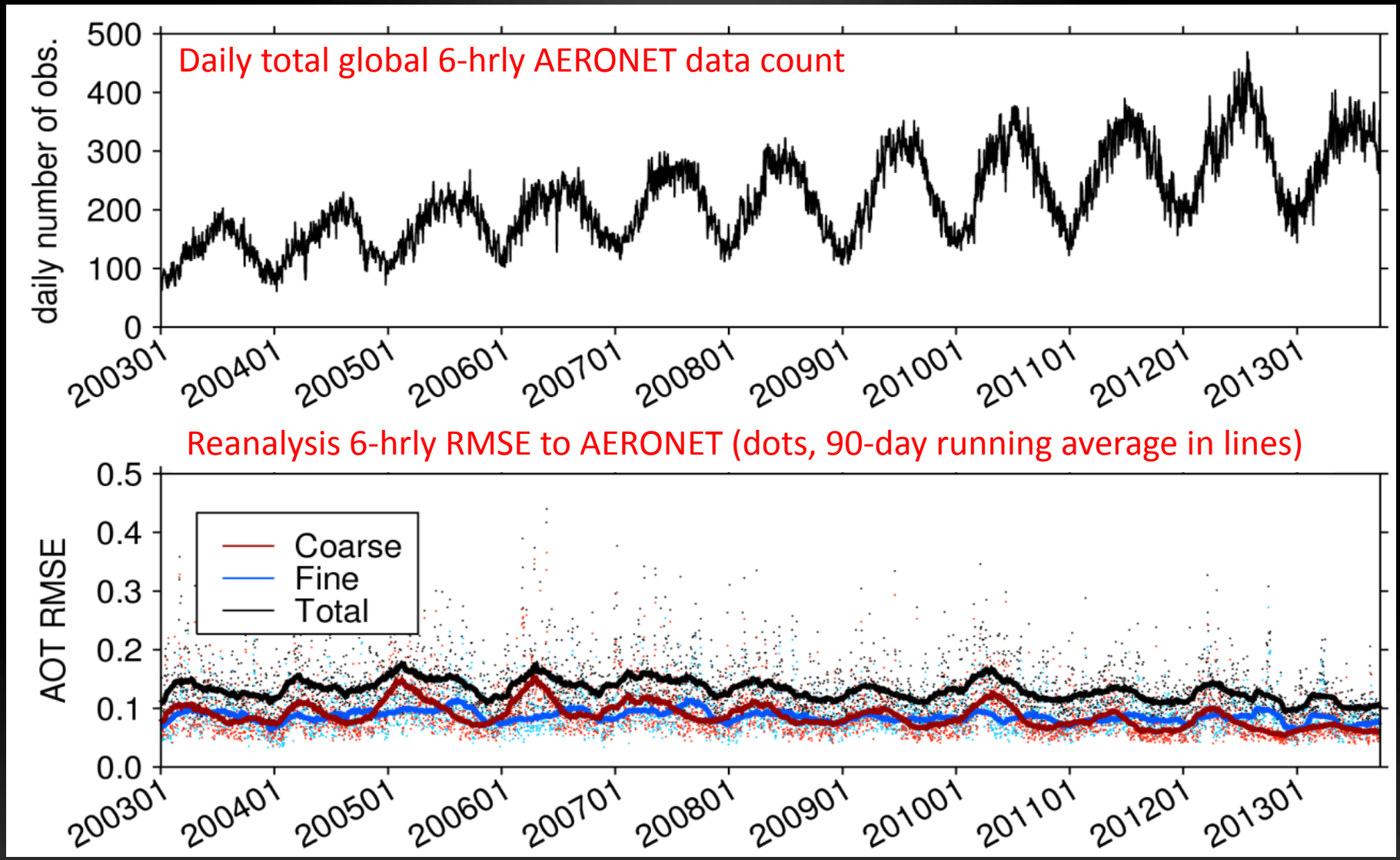


AOT CLIMATOLOGY-JJASON MEAN: GOOD RESEMBLANCE AMONG THE THREE



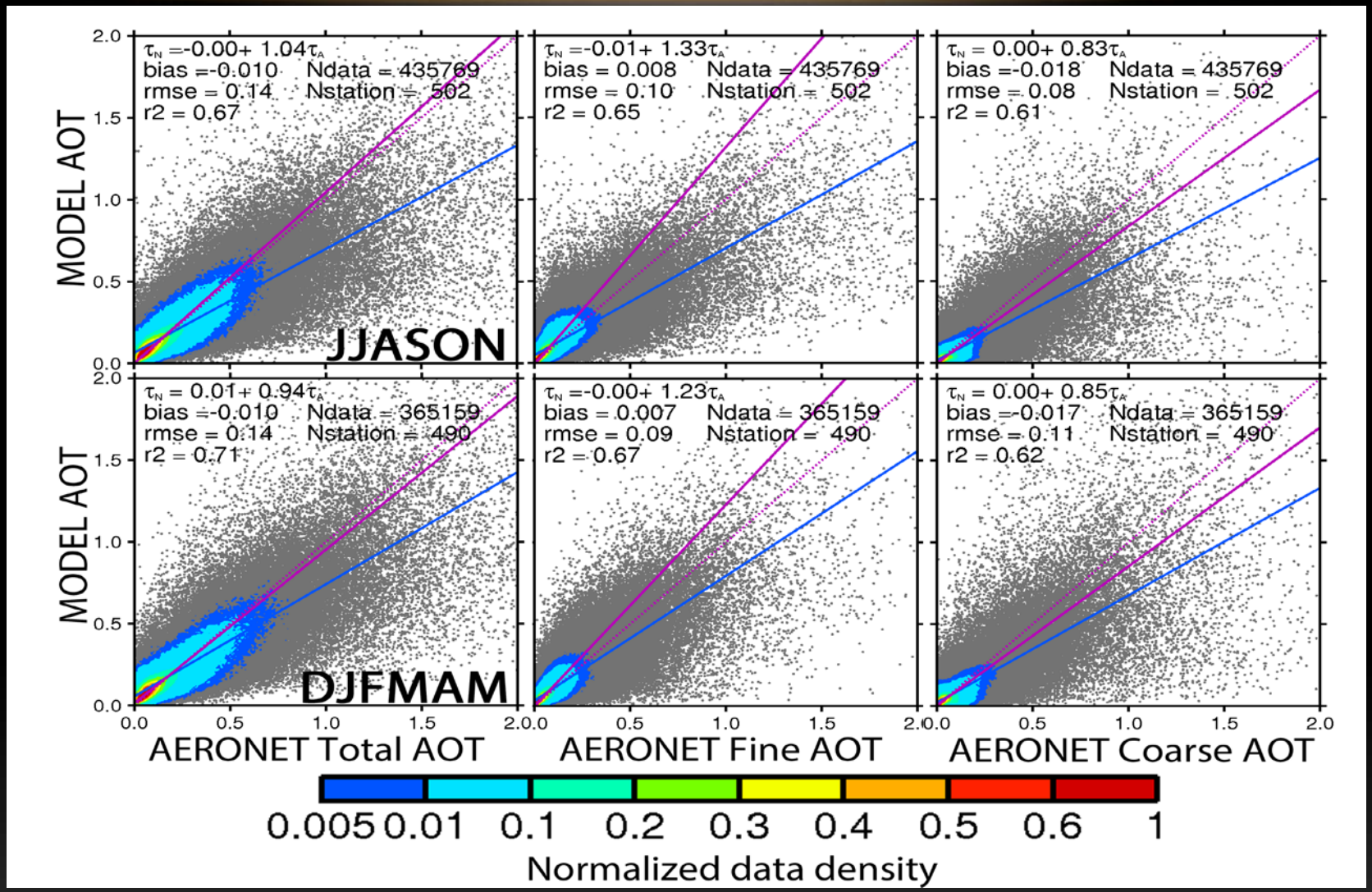
Aerosol Optical Thickness, 550 nm

VALIDATION AND PERFORMANCE STATISTICS



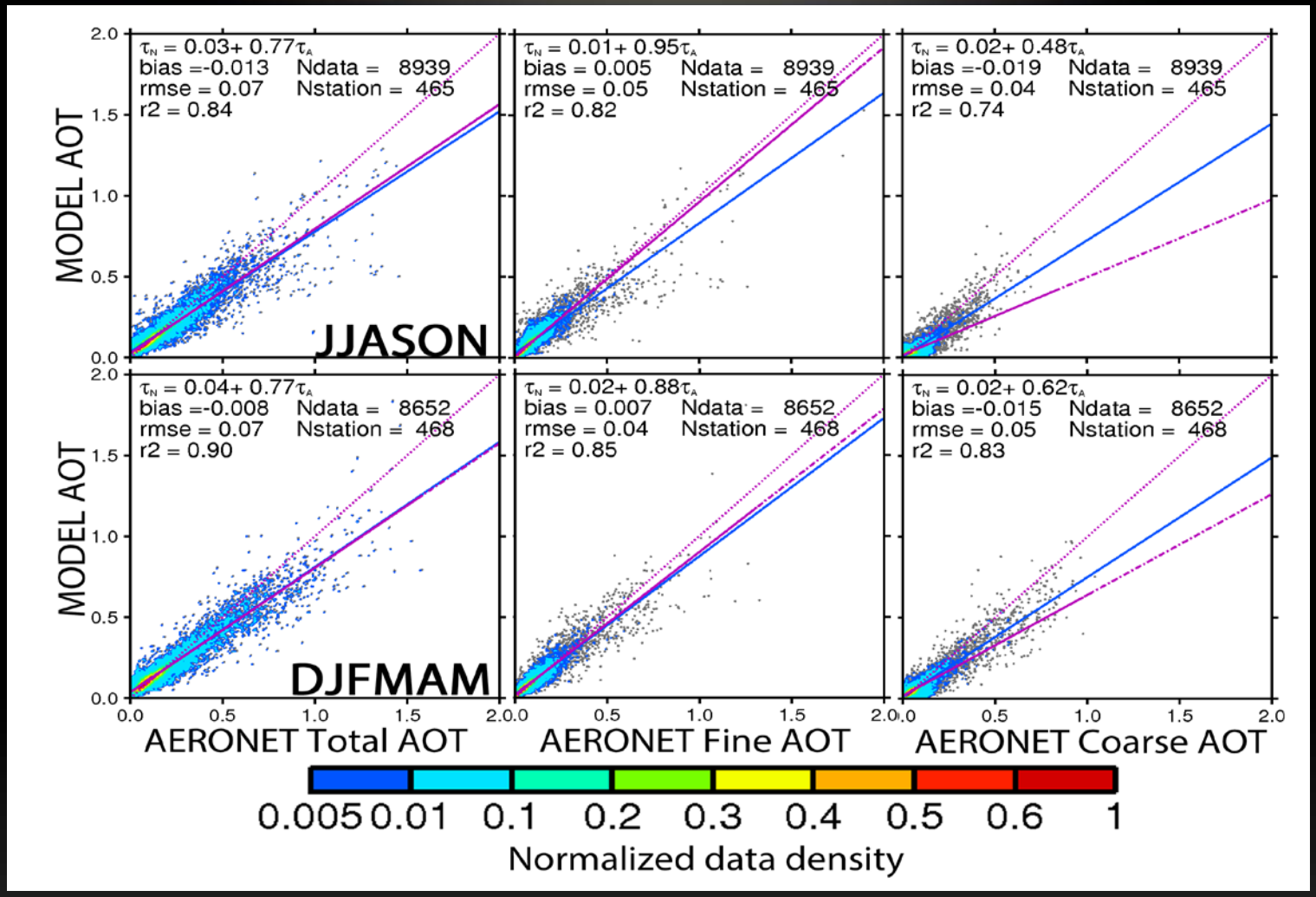
- The RMSE of reanalysis AOTs is quite stable through the time.

VALIDATION WITH AERONET (6-HRLY)



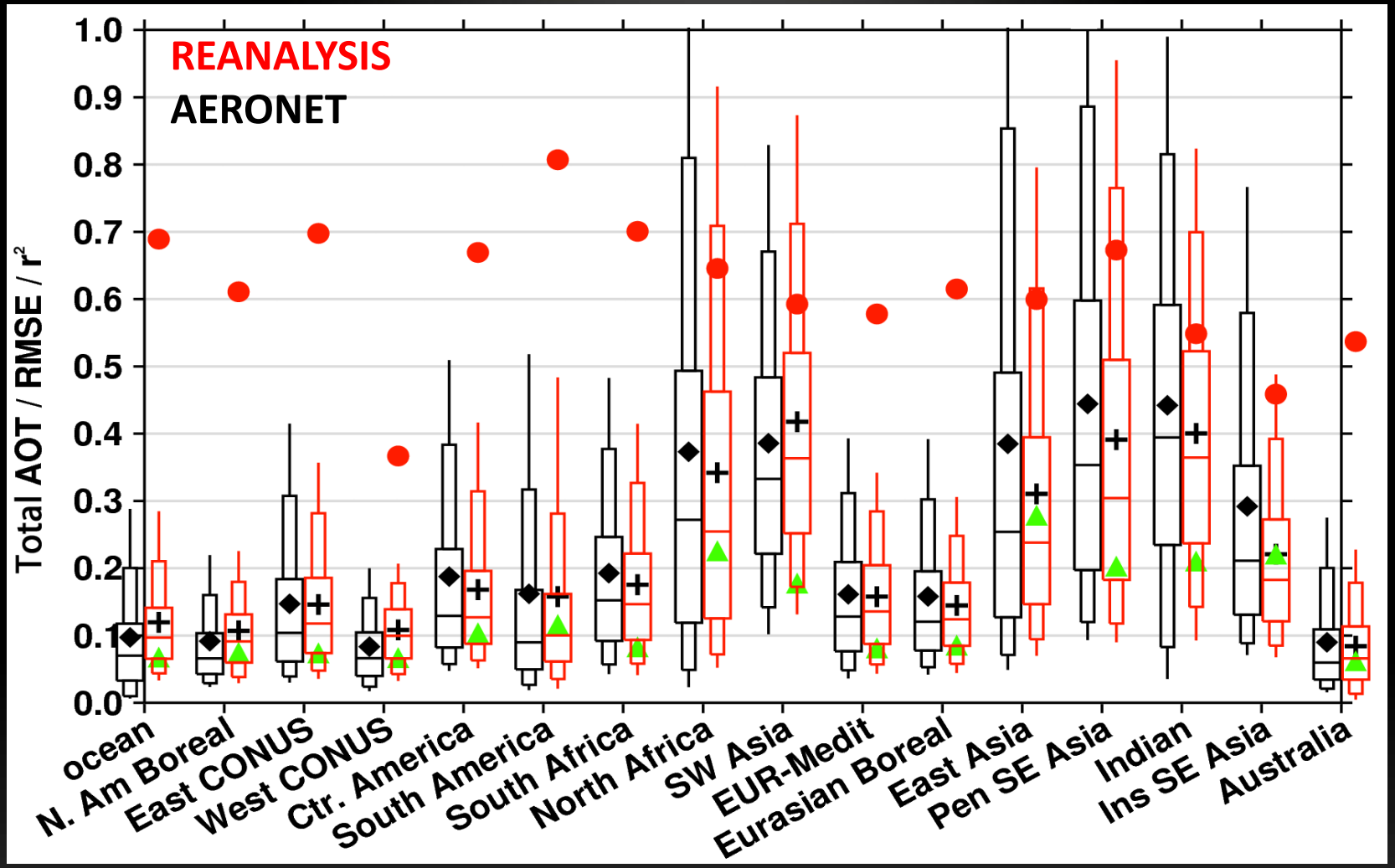
- Globally, total AOT is in good agreement with AERONET for both seasons.
- Fine mode AOT is slightly more in line with AERONET than the coarse mode AOT.

VALIDATION WITH AERONET (MONTHLY)



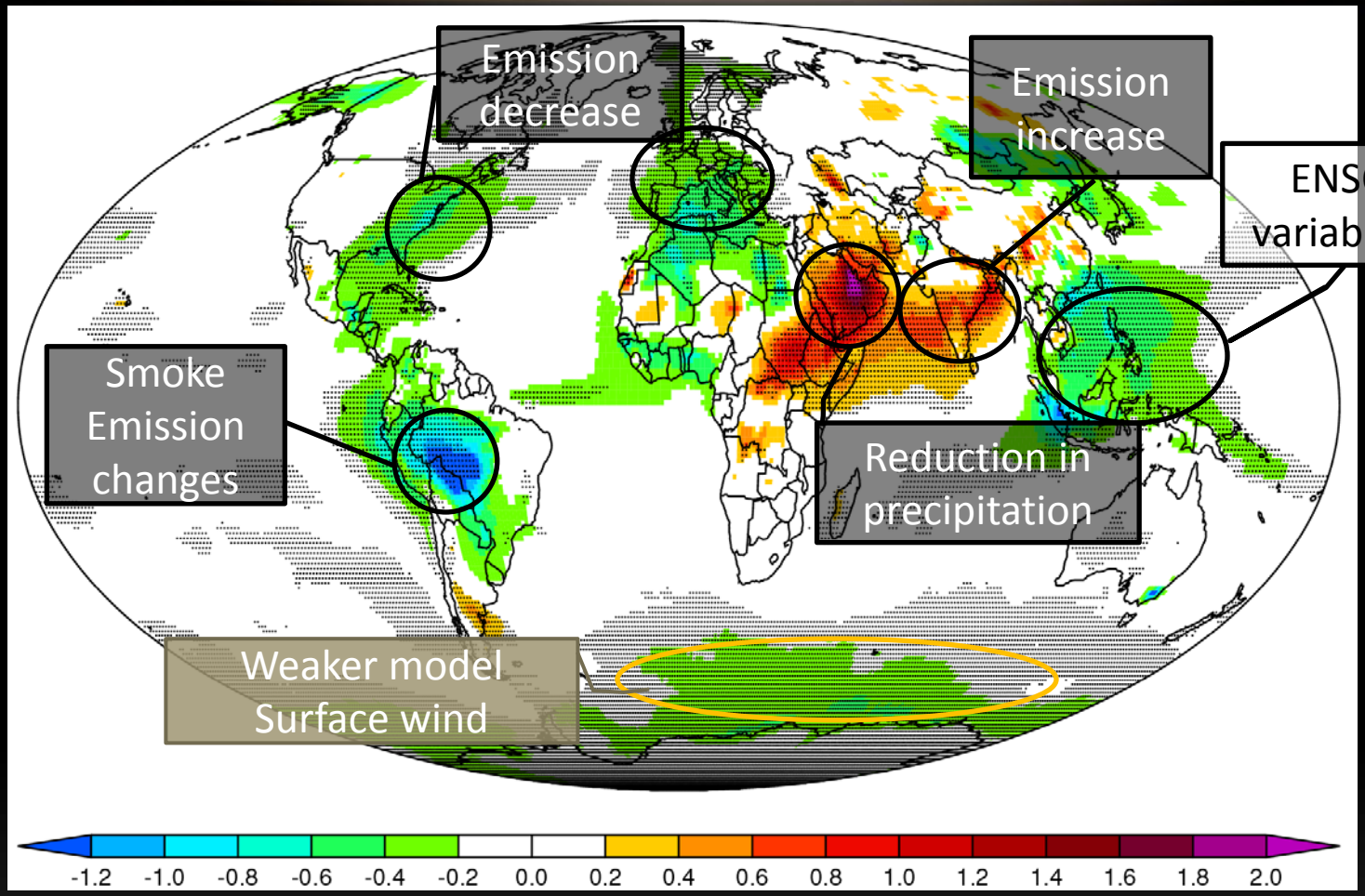
- Different data sampling methods result in quite different validation results.
- By resampling the data into monthly average, Bias is unchanged, but rmse decreases ~50%, r2 increases from ~0.6 to ~0.8.

2003-2013 REGIONAL AERONET AND REANALYSIS AOT COMPARISON (6-HRLY)



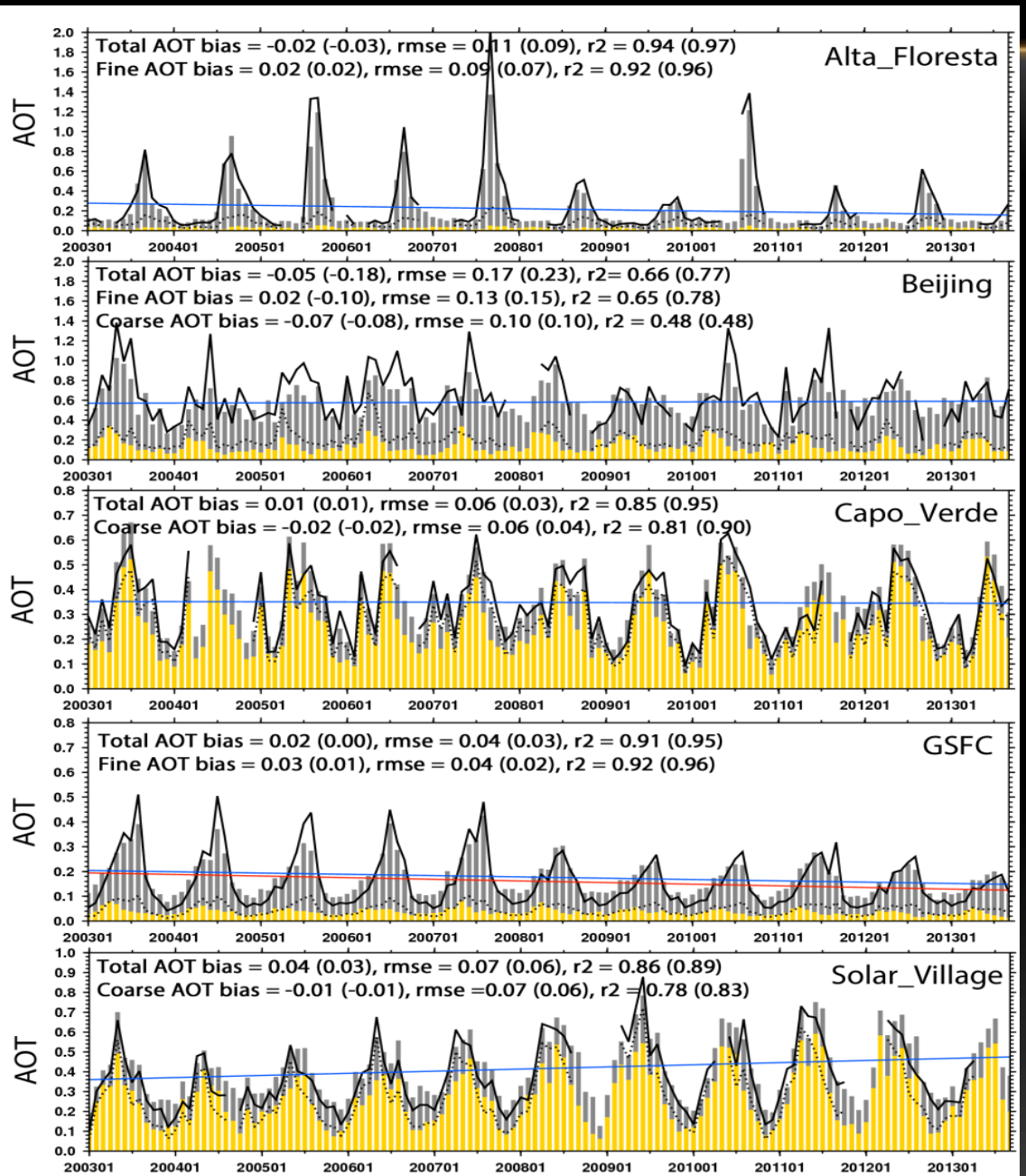
- Regionally, the reanalysis follows the AOT variations appeared in AERONET.
- Reanalysis tends to have slight low bias and spread overall.

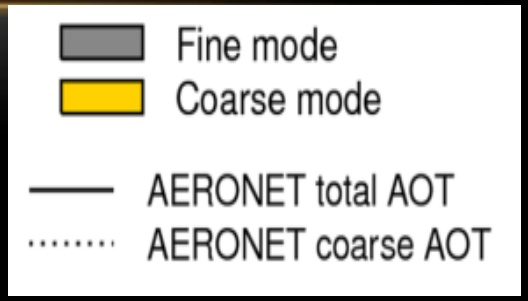
2003-2013 AOT TREND (DESEASONALISED)



- Trends over Indian Bay of Bengal, east coast of North America, Europe are a result of emission changes.
- Trends over Arabian Peninsula/Sea, South China Sea are a result of change in meteorology.
- Trends are consistent with Zhang and Reid's (2010), Hsu et al. (2012)'s study using stand alone satellite products.

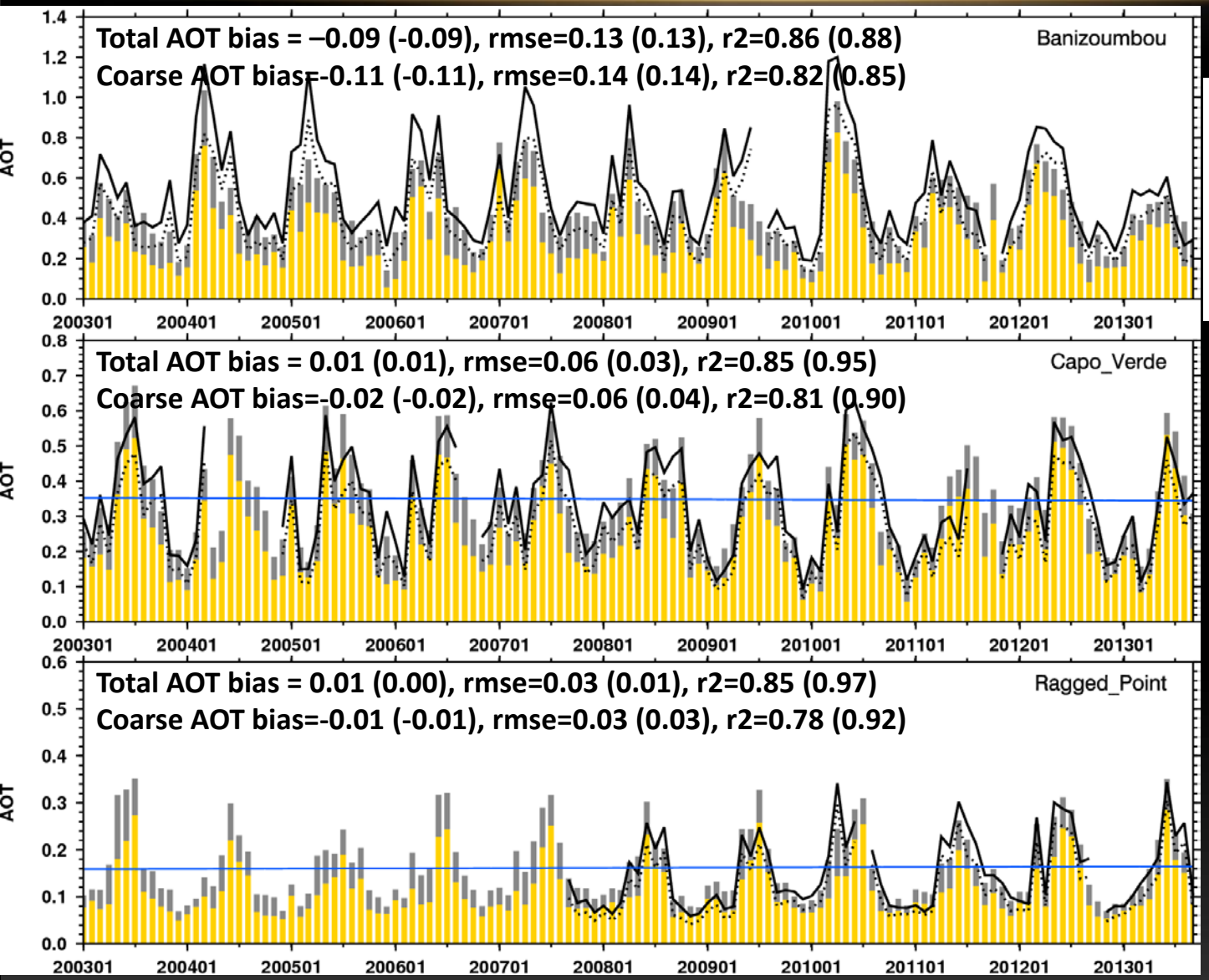
Monthly AOT time series: reanalysis vs. AERONET

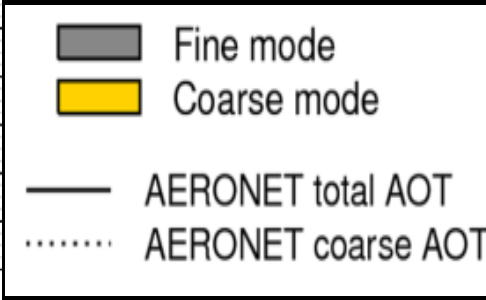




- It captures the AOT seasonal and annual variations well.
- Performs less well at Beijing site.
- AOT trend is also reflected.

Monthly AOT time series: reanalysis vs. AERONET





It performs better in the long-range transport regions than the source regions.

SUMMARY

- An 11-yr long (200301-201309) global 1x1 degree and 6-hrly modal aerosol optical thickness (AOT) reanalysis product was generated.
- Validating with AERONET observations
  - the global mean RMSE is around 0.1 for both fine and coarse mode AOTs and ~0.14 for the total AOT. RMSE decreases 50% in monthly averaged modal AOTs.
  - Captures the regional and seasonal AOT variations to various degrees of skill.
  - Performs better in the long-range transport regions than the source regions.
- AOT trend is robust in many regions.
- Recommended applications
  - Ideal for quick and consistent identification of large aerosol events globally or regionally.
  - To provide global and regional AOT climatologies.
  - Can be used in different scale analysis, from daily to inter-annual.

ICAP Advice to satellite product providers (and some friendly advice)

- Most importantly be honest with yourself and the community in regard to what your objectives are and how good your product really is. Big errors are ok, as long as when we know they are big. Keep good notes.
- For process studies and data assimilation we need a de-biased products with a residual point wise error estimate. That is, we need an error model for bias and root mean square deviation.
- Feel free to pack in as much environmental metadata as is reasonable (cloud fraction, snow, aggregated radiance or reflectance). It helps us develop our own error models and select the right data to use.
- Categorical aerosol models such as "dust, polluted dust, etc." can be difficult to implement in data assimilation and process studies. Index of refraction of a complex mixture is not easily relatable. More generally, unless we can clearly define an observation operator, an observable cannot be effectively assimilated. Great uncertainties in observation operators --> specification of large observation errors --> less impact.
- Data needs to be easy to get and parse. Be consistent with a few major upgrades being preferable to lots of incremental changes.
- Consider the niche market and keep the global constellation in mind. Every product does not need to do everything.
- Take advantage of newer status-take the good and don't be bound by bad conventions. Level 2g/level 3 methods? Aggregated radiances?

An Error Model as Metadata (requires lots of data to pull out)

- **Can be as simple as RMSE as a function of AOD**
  - AOD can be from AERONET (diagnostic) or own AOD (prognostic).
  - But, RMSE is symmetric nor does it address massive outliers which are often the problem
- **Terms include:**
  - Differential Signal to Noise: Lower boundary minus total, including view angle/optical path length.
  - Lower Boundary Condition:
    - Ocean: Wind/glint/whitecap, class 2 waters, sea ice
    - Land: Surface reflectance model, snow, view angle/BRDF/hotspot
  - Cloud mask
  - Microphysical: Fine coarse/partition, $P(\theta)/g$, ω_o, AOD
- **Biases are often folded into "random" error models. If they are known, why not correct for them?**
- **Radiance Calibration: Individual wavelengths propagate non-linear through retrievals and are not easy to incorporate.**
- **<u>Verification! You need to verify your error model so we believe you.</u>**