



Optimizing data assimilation strategy for a global aerosol model with a multi-sensor constellation

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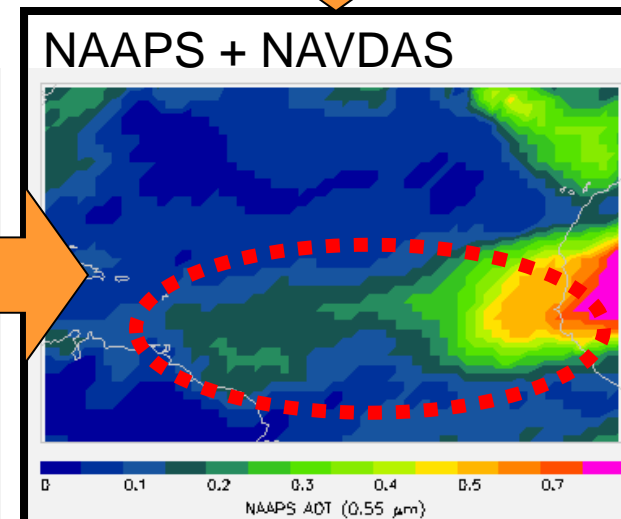
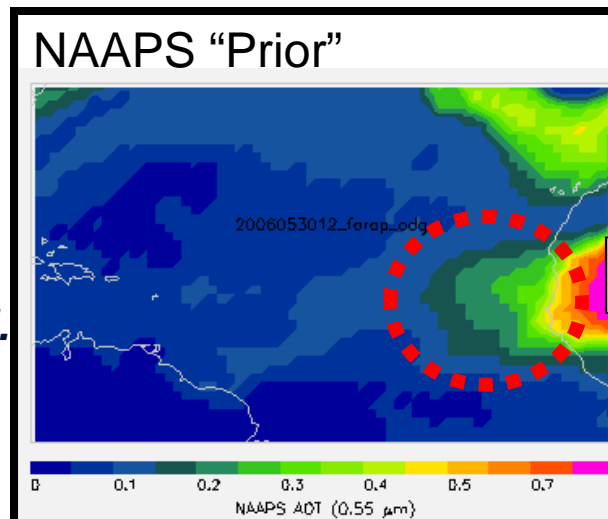
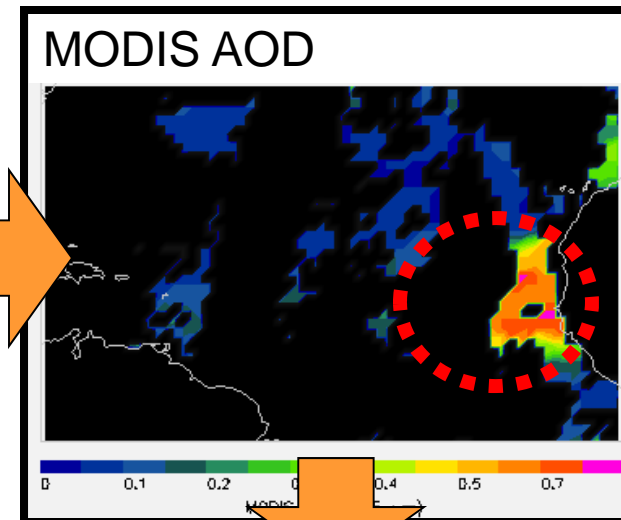
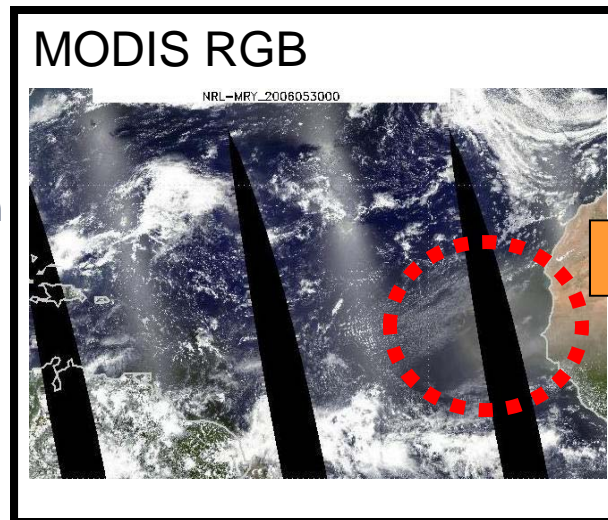
23-27 January 2017

- Data Assimilation for Navy Aerosol Forecasting
- Current constellation— coverage and limitations
- The trade space for aerosol retrieval: space/time/error
- Where can we add aerosol data?
- Limitations of 3DVAR assimilation
- Outlook for future upgrades

Data Assimilation for Navy Aerosol Forecasting

The Navy Aerosol Analysis and Prediction System (NAAPS) provides aerosol concentration and visibility forecasting 24/7/365

- Navy Variational Data Assimilation System for AOD (NAVDAS-AOD) Operational at FNMOC from September 2009
- 2009: MODIS Dark Target over ocean
- 2012: MODIS Dark Target over land
- 2016: MODIS Dark Target+Deep Blue
- 2017: AVHRR ACSPO (gap fill only)
- 2017: NOAA Enterprise
- Refs:
 - J.L. Zhang et al., “A System for Operational Aerosol Optical Depth Data Assimilation over Global Oceans”, JGR 2008.
 - Lynch et al., “An 11-year global gridded aerosol optical thickness reanalysis (v1. 0) for atmospheric and climate sciences”, *Geosci. Model Devel.* 2016.



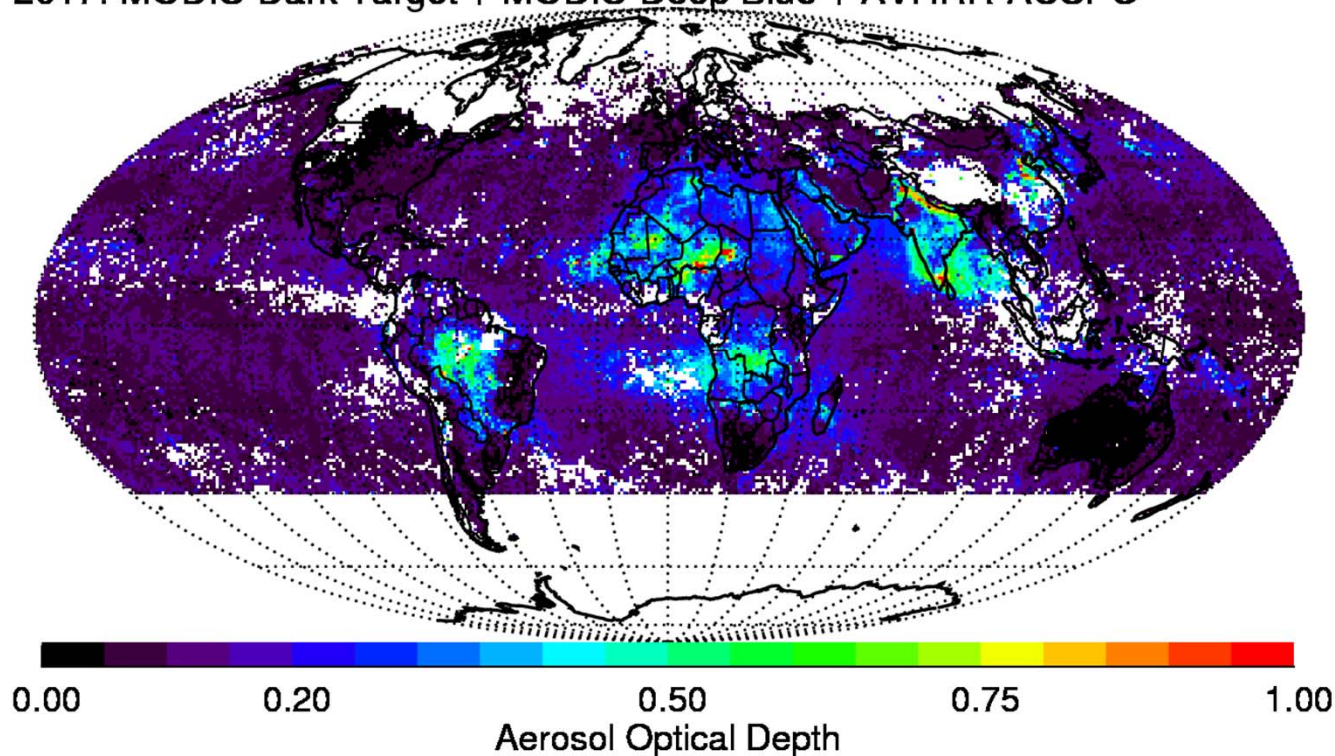
Aerosol Operational Constellation Evolution

10/15 – 11/1/2016 (16 days)

NAAPS operational obs

- 2009: MODIS over ocean (Dark Target retrieval)
- 2012: MODIS global Dark Target
- 2016: MODIS Dark Target + Deep Blue (C6)
- 2017: MODIS + AVHRR ACSPO (ocean only)

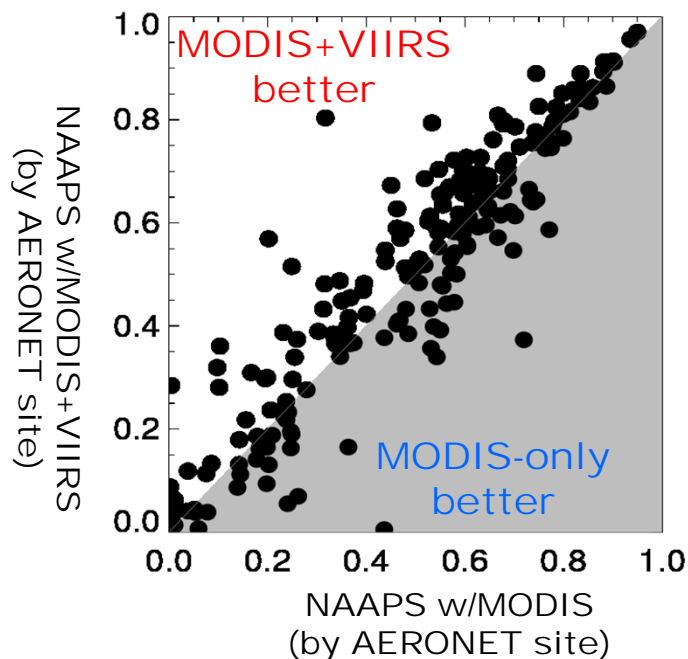
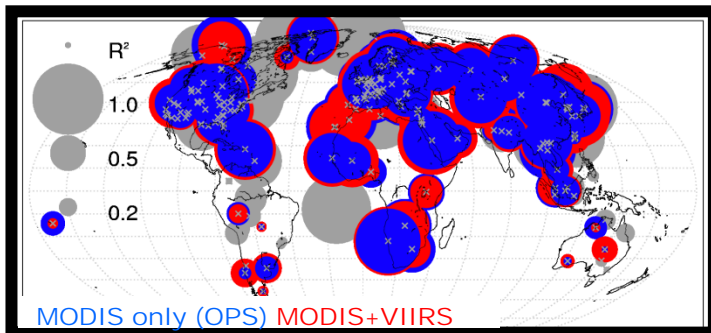
2017: MODIS-Dark Target + MODIS-Deep Blue + AVHRR-ACSPO



- Southern Ocean is a challenging environment with limited validation for retrievals
- Polar Ice+Snow requires a different method of retrieval
- *Where else can we add data?*

Assimilation Testing of VIIRS Enterprise Aerosol product

AOD Correlation (r^2) at AERONET stations



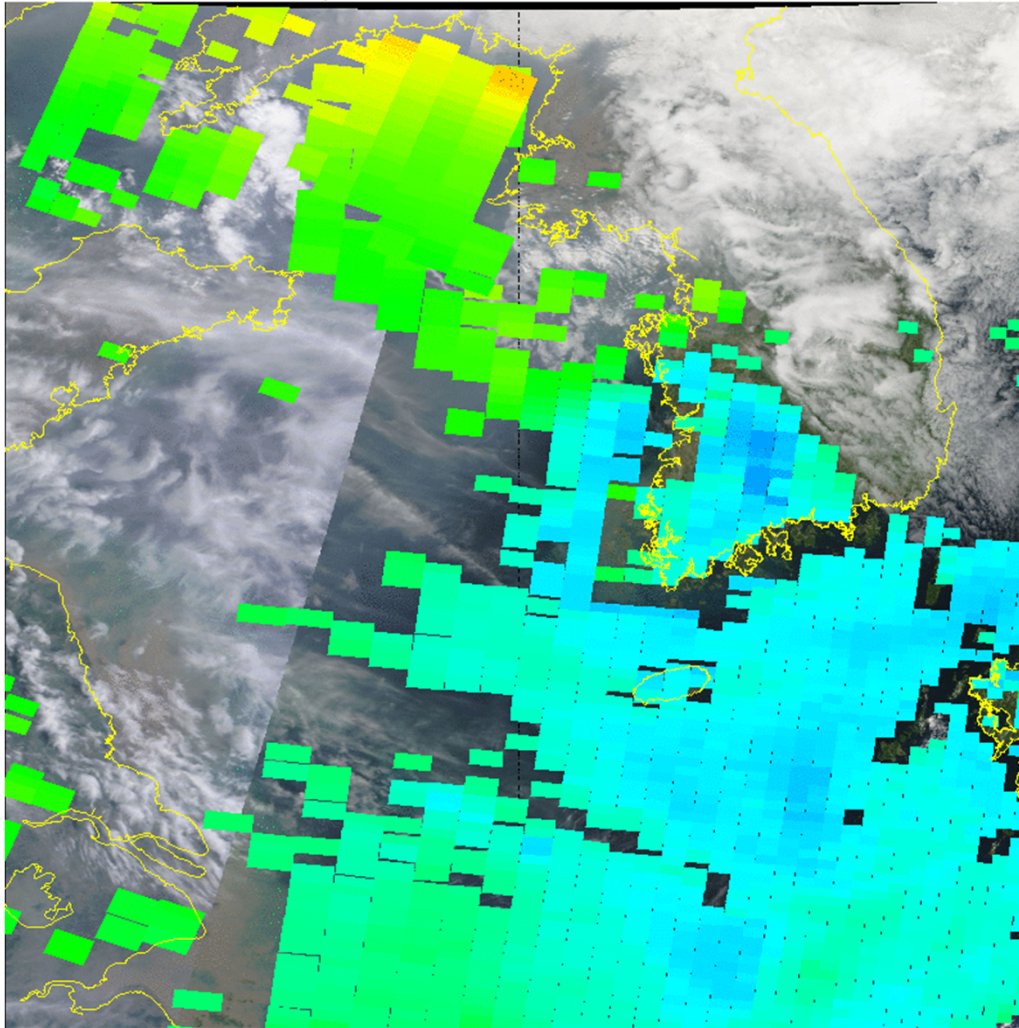
NAAPS assimilation testing of VIIRS Enterprise Aerosol

- Global VIIRS data processed 201505-201507 (90 days)
- Prep for data assimilation:
 - All in-granule quality flags
 - NO Buddy check, cloud proximity check, textural filtering
 - Aggregate to 1 degree (min 500 valid AOD per grid)
 - Uncertainty estimates based on AERONET, e.g.:
 - LAND_NIR: $\text{MAX}(0.22 \cdot \text{AOD} + 0.02, 0.05)$
 - LAND_SWIR: $\text{MAX}(0.42 \cdot \text{AOD} - 0.03, 0.067)$
- NAAPS analysis results: **VIIRS+MODIS better than MODIS only**
- Global correlation improved from $r^2=0.68$ (MODIS-only) to $r^2=0.74$ (MODIS+VIIRS)
- Global RMSE decreased from $RMSE=0.12$ (MODIS-only) to $RMSE=0.11$ (MODIS+VIIRS)
- Correlation (r^2) vs AERONET L2.0 increased at 132 of 208 stations
 - Colored symbols on map indicate r^2 difference > 0.05
- Site-by-site RMSE more mixed: 199 sites with $\Delta RMSE > 0.02$:
 - RMSE better at 111/199, worse at 88/199
- **Better results can likely be achieved with additional filtering**

A new constellation of geostationary observations: upgrades in every parameter

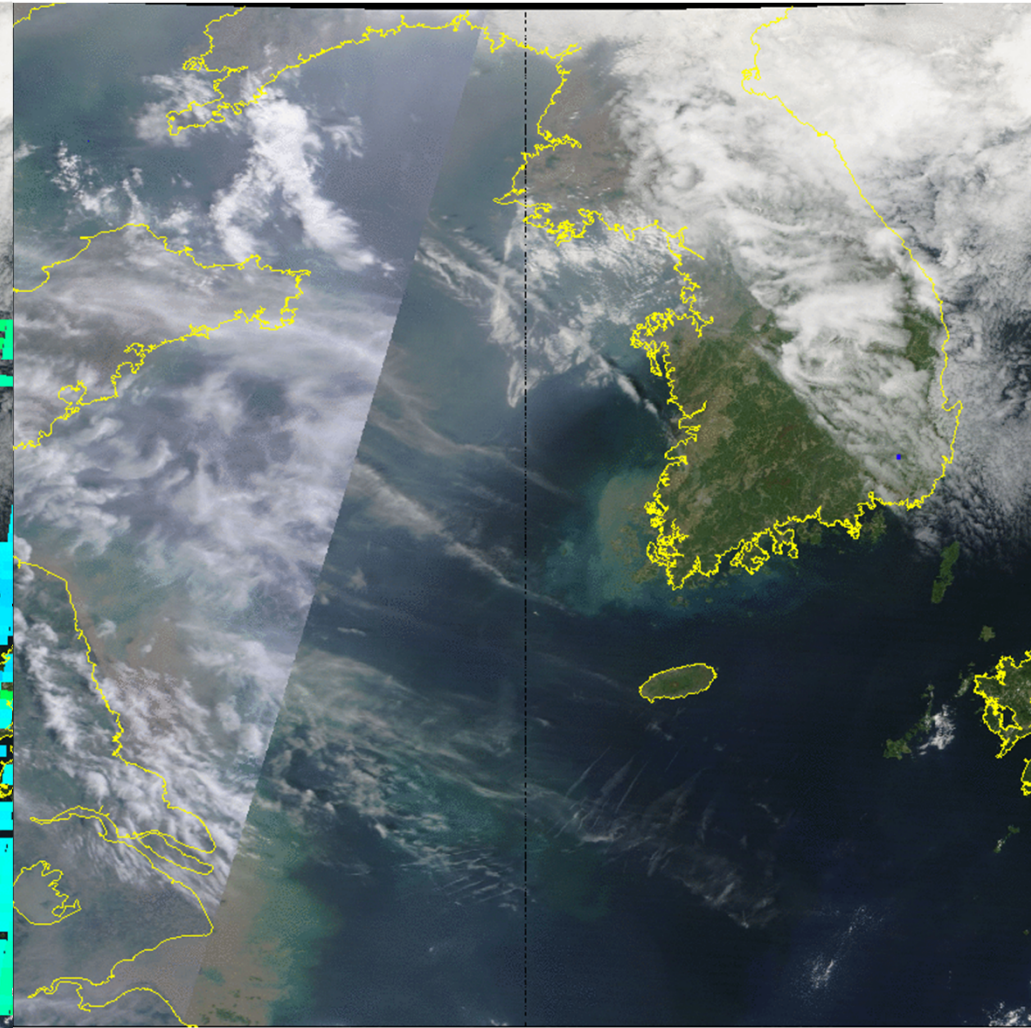
MOD04 Terra c6 Dark Target AOD 201605010153 (0151-0332)
Basemap = MODIS Terra RGB+Fires 20160501

To this!



NRL: created on Tue May 03 23:20:00 2016

From this...

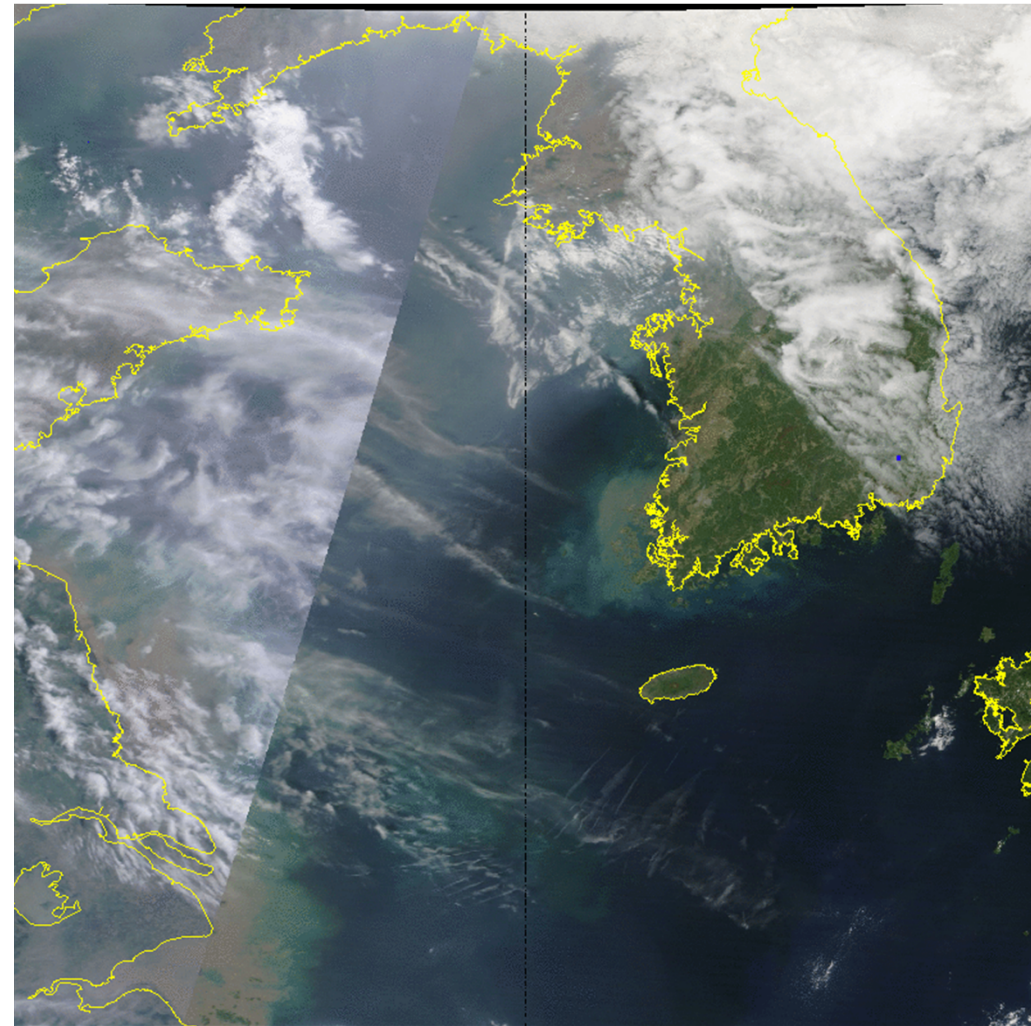


Himawari-8 AOD (QA=3)201604302100
Basemap = MODIS Terra RGB+Fires 20160501
NRL: created on Wed Dec 07 19:17:44 2016

A new constellation of geostationary observations: upgrades in every parameter

- **COMS-GOCI**
- **Himawari-8 AHI**
- **GOES-R ABI**
- **TEMPO**
- **Sentinel-4**
- What can we expect to observe with this new capability?
- How do we need to modify our existing modeling and data assimilation systems to accommodate these new data?

To this!

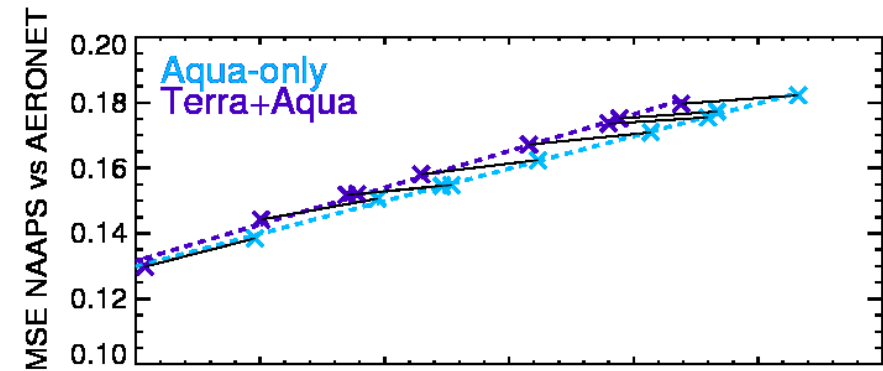
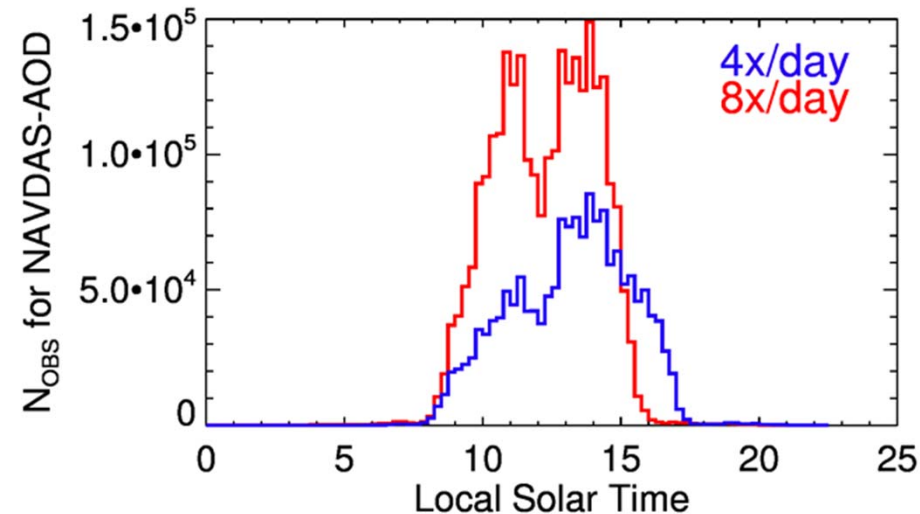


Himawari-8 AOD (QA=3)201604302100
Basemap = MODIS Terra RGB+Fires 20160501
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Motivation: Repeat Observations and AOD data assimilation

- Navy Aerosol Analysis and Prediction System (NAAPS) assimilates AOD using 3DVAR technique 4x/day (0,6,12,18Z, blue curve)
- For KORUS-AQ, NAAPS was run with a 3-hourly data assimilation cycle (8x/day, red curve)
- This improved the forecast in two ways:
 - More observations assimilated (Aqua supercedes Terra in the 4x/day run [blue])
 - Observations hit earlier in the day

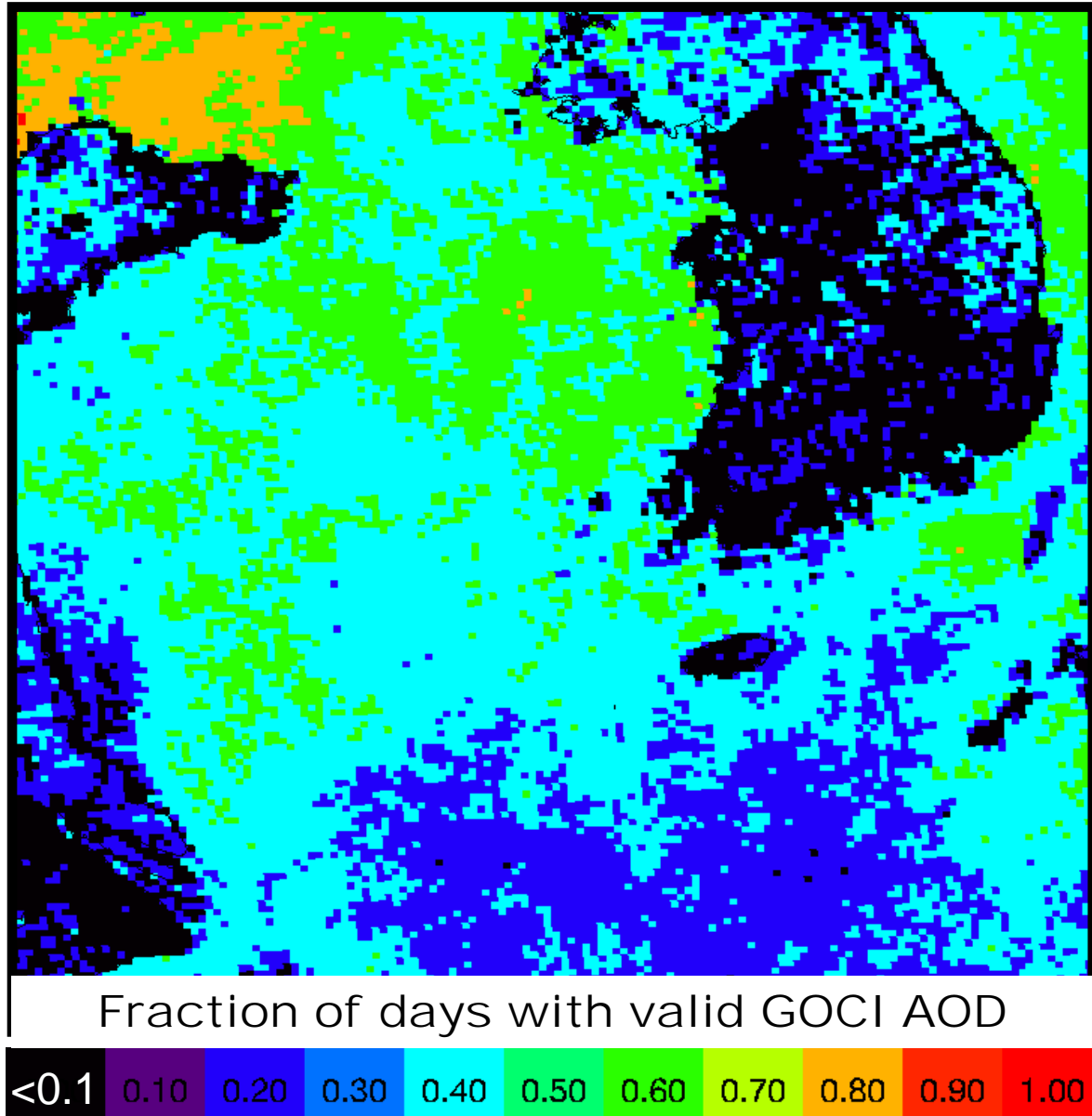
With geostationary AOD, we have potentially a lot more observations several hours sooner



For our current modeling system, model error increases linearly with time-since-last-observation

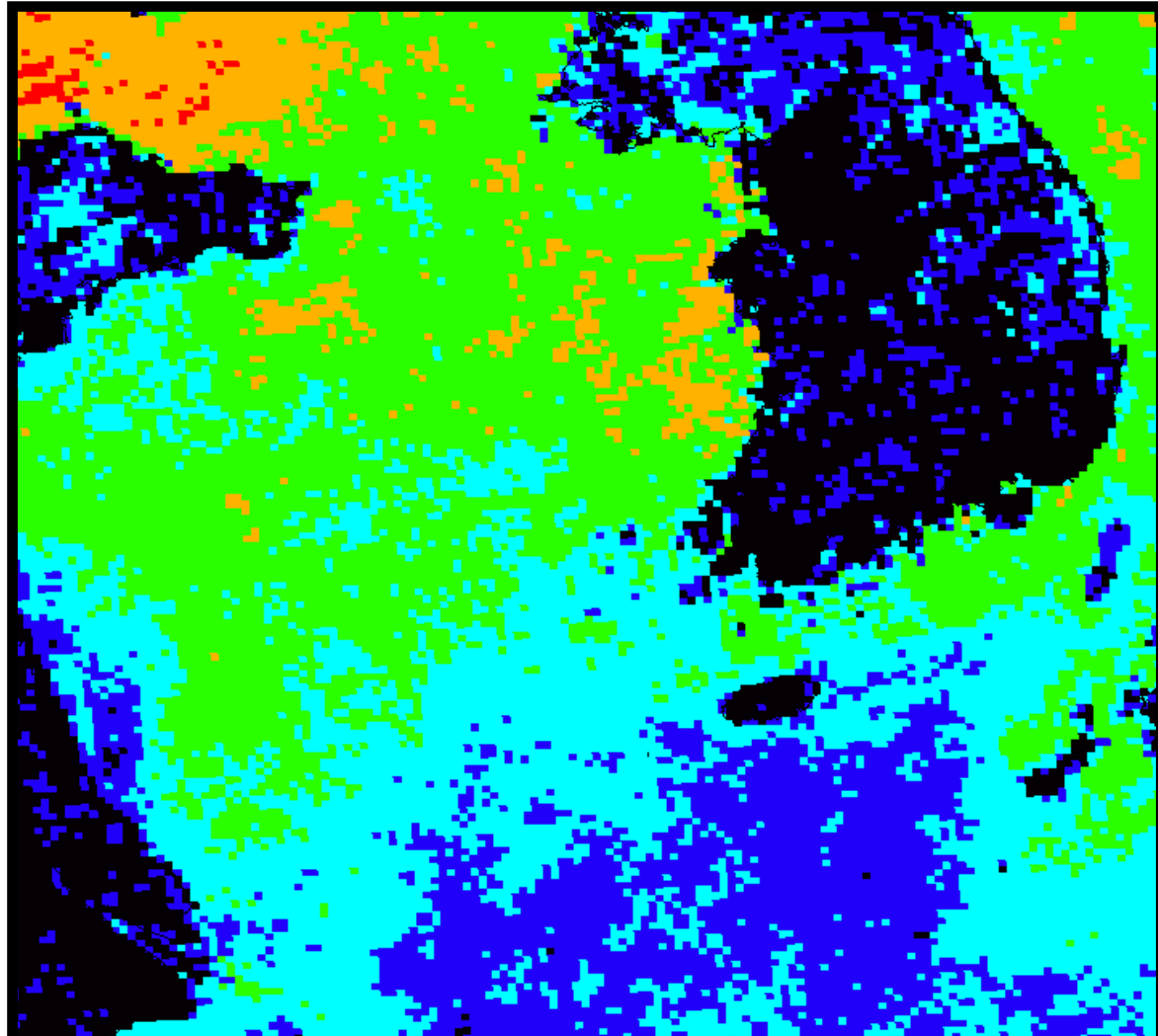
GOCI gives an indication of cloud-free viewing opportunities from geostationary

- May-July 2016
- GOCI scenes from 1Z
- 1000 local time
- Left: fraction of days with valid GOCI AOD at Terra overpass time

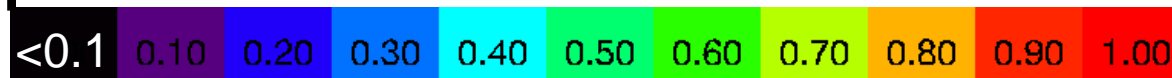


GOCI gives an indication of cloud-free viewing opportunities from geostationary

- May-July 2016
- GOCI scenes from 4Z
- 1300 local time
- Left: fraction of days with valid GOCI AOD at Aqua overpass time
 - Terra sees more land
 - Aqua sees more ocean

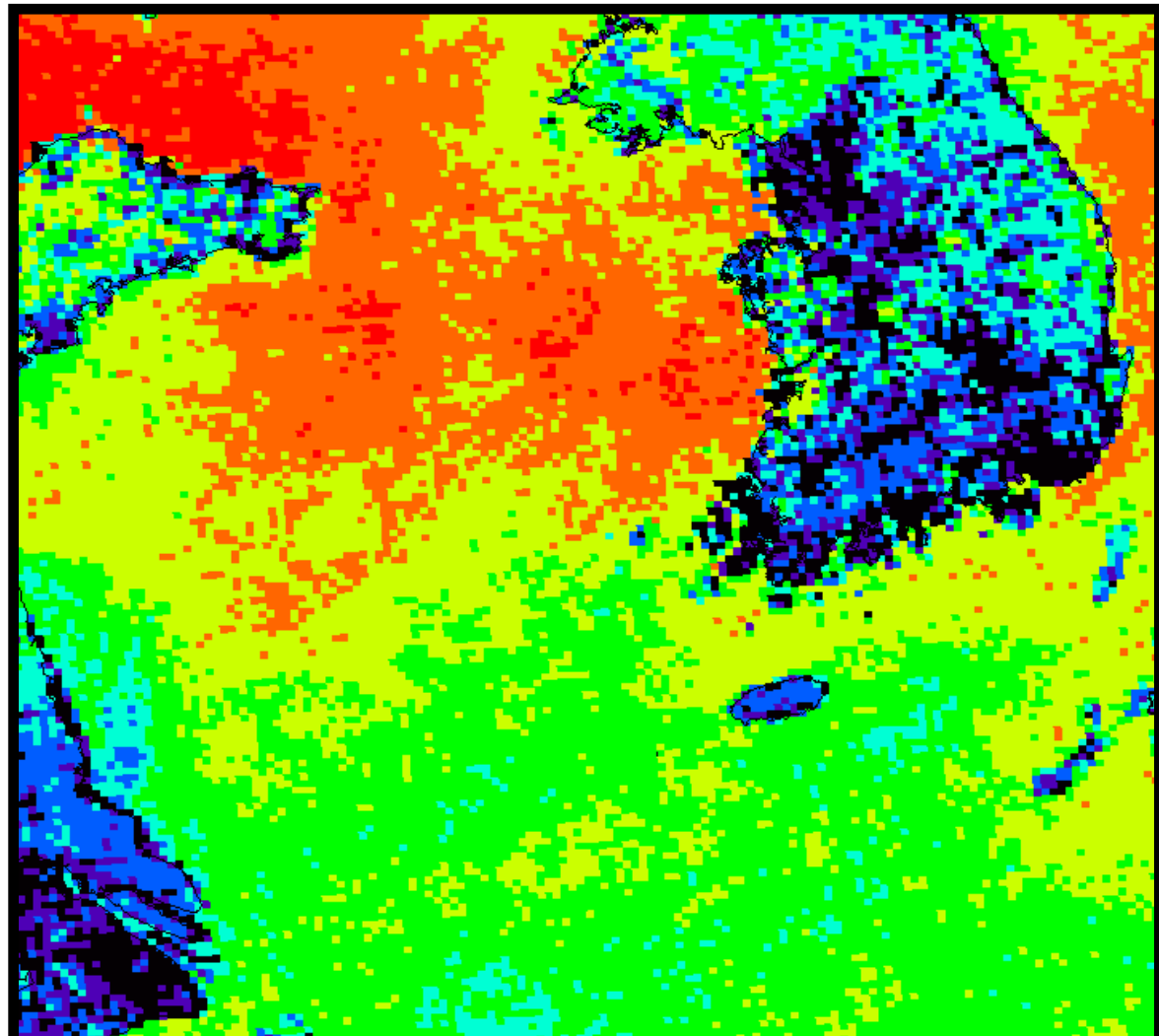


Fraction of days with valid GOCI AOD

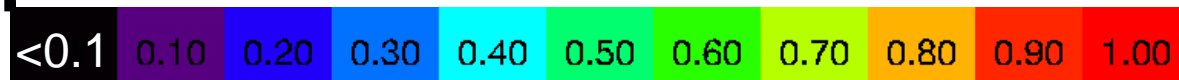


GOCI gives an indication of cloud-free viewing opportunities from geostationary

- May-July 2016
- GOCI scenes from 0-8Z
- 9-17 local time
- Left: fraction of days with 1+ valid GOCI AOD
 - Terra sees more land
 - Aqua sees more ocean
 - Imaging over the diurnal cycle greatly expands the area observed each day!



Fraction of days with valid GOCI AOD



NRL Satellite AOD Intercomparison page

http://www.nrlmry.navy.mil/aerosol/modis_geo_aod_compare/korea/html_files/modis_geo_aod_compare_frame.html

The problem:

- AOD products are multiplying
- Many are new algorithms
- Visualization capabilities are dispersed around the internet
- **Some products do not have a NRT visualization (that I know of)**

Our solution:

- **Consistent legend for all AOD products**
- **Nearest-time matching for MODIS vs GEO comparison**
- **RGB imagery for context**
- **L2 and L3 aerosol products**



NRL Satellite AOD Intercomparison page

http://www.nrlmry.navy.mil/aerosol/modis_geo_aod_compare/korea/html_files/modis_geo_aod_compare_frame.html

MODIS (Terra and Aqua)

- Dark Target C5.1 and C6
- Deep Blue C5.1 and C6
- NRL/UND L3 0.5-degree product

VIIRS (NPP)

- IDPS product (via UW-CIMSS/Navy FNMOC)
- L3 1-degree product

AVHRR (NOAA-18, NOAA-19, MetOp-A, MetOp-B)

- Air-Sea Clear-Sky Processor for Ocean (ACSPO) product from NESDIS

AHI (Himawari-8)

- AOD product from JAXA

GOCI (COMS-01)

- AOD from Yonsei University

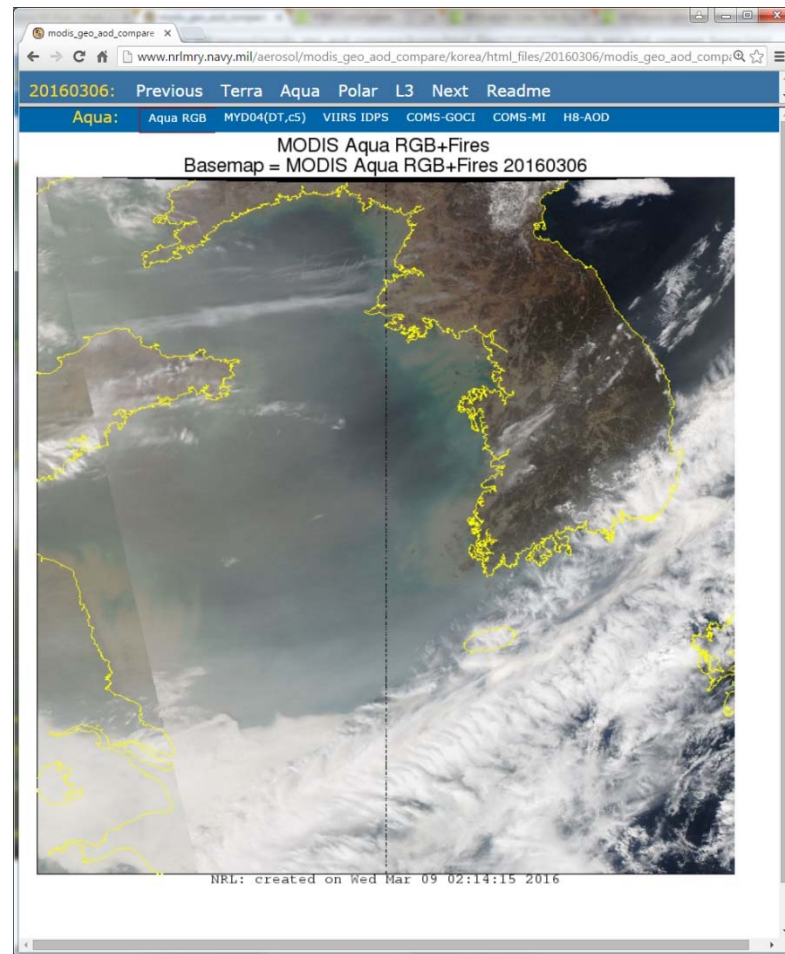
MI(COMS-01)

- AOD from Yonsei University



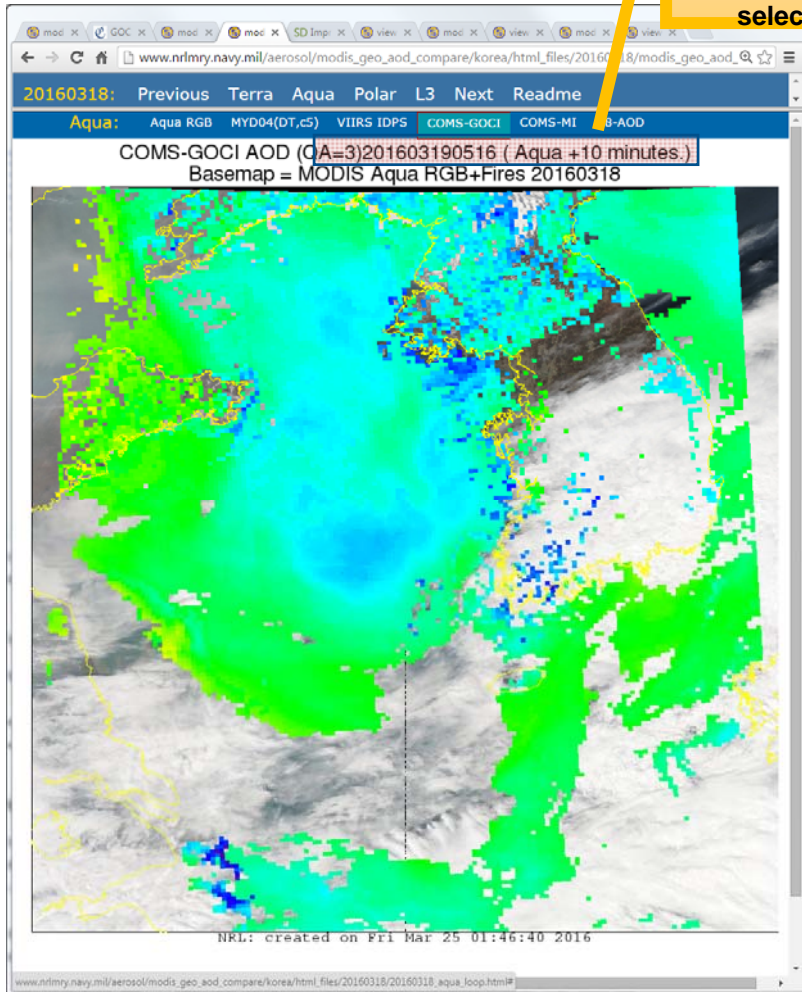
How do we support NRT users?

- Daily maps of AOD products
- **Produced in NRT**
- **Easy access to recent archive**
- **Consistent comparison of products**
- **Easy back-and-forth comparison**



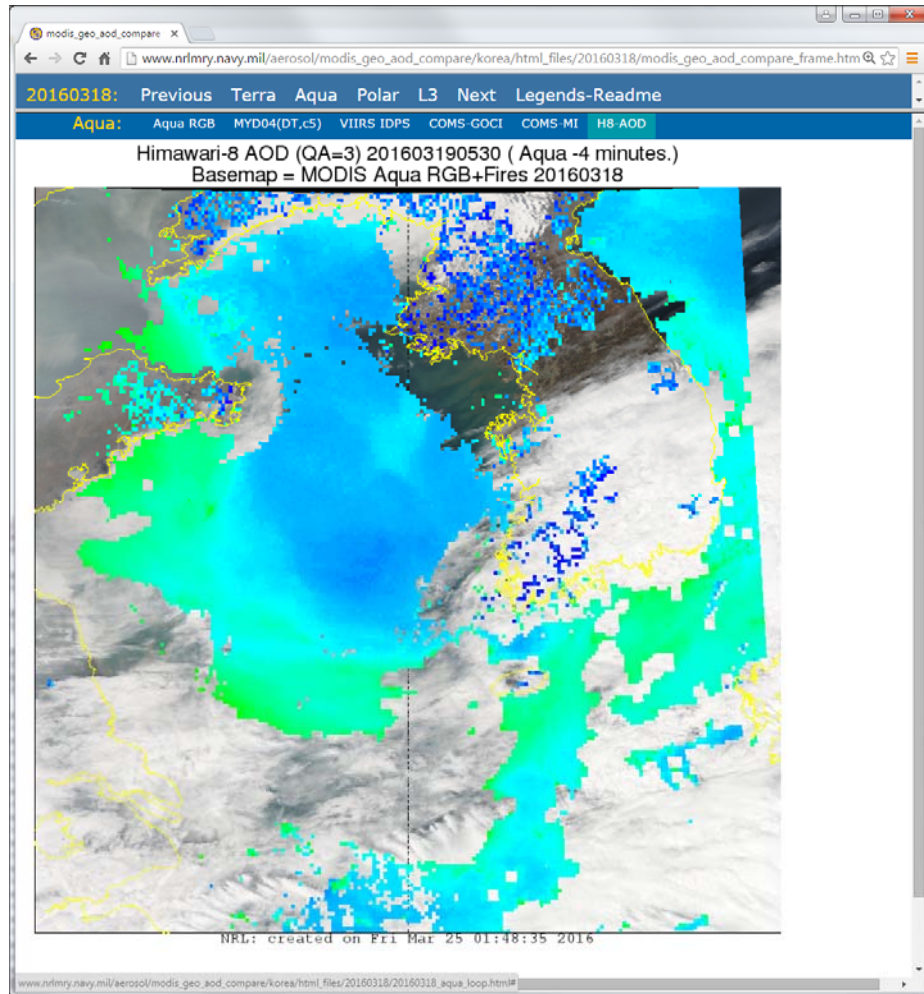
COMS-GOCI Geostationary AOD

Granule closest
to MODIS
overpass time
selected.



- AOD retrieval from Geostationary Ocean Color Imager on Korea COMS-1
- **Produced by Yonsei University**
- **500m VIS and NIR used to retrieve AOD at 6km resolution**
- On 'Aqua' and 'Terra' pages
- Granules matched to closest MODIS overpass; RGB basemap from MODIS used.
- QA used: QA=3 (GOCI AOD QA)
- Algorithm and validation details in Choi et al. AMT 2016: <http://www.atmos-meas-tech.net/9/1377/2016/>
- **Recently upgraded to Version 2!**

Himawari-8 AOD



- AOD retrieval from Advanced Himawari Imager on Himawari-8
- **BETA developmental product: new version just coming available, publications soon!**
- Produced by JAXA
- Available from JAXA Himawari Monitor : <http://www.eorc.jaxa.jp/ptree/index.html>
- 500m VIS and NIR used to retrieve AOD at 0.05-degree resolution
- Granules matched to closest MODIS overpass; RGB basemap from MODIS used.
- QA used: QA='very good' including cloud, sunglint, sun angle tests
- Algorithm described in Higurashi and Nakajima GRL 2002: <http://onlinelibrary.wiley.com/doi/10.1029/2002GL015357/full>
- Validation details in Fukuda et al. JGR 2013: <http://onlinelibrary.wiley.com/doi/10.1002/2013JD020090/full>

Observations based on this preliminary look at the data

- **Our modeling system is far from data-saturated**
- **However, changes to assimilation methods are required to avoid diminishing returns**
- **New geostationary products will radically change the landscape**
- **We will continue to need aerosol data from polar orbit**
- **We know a lot about the benefits and consequences of spatial averaging**
 - and spatial variation-based screening
- **We need to work on exploitation of high-frequency data**
 - Potential to screen for bad observing conditions while preserving spatial resolution
 - Potential to exploit minutes-vs-hours differences in variability (current methods exploit hours-vs-weeks differences)

Acknowledgements

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THANK YOU!



**U.S. NAVAL
RESEARCH
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