"Introducing the Collection 6 MODIS Aerosol products"

Season III

AeroCenter Update   May 31, 2013   1

Starring: The "Dark Target" Aerosol Team

Rich Kleidman
(SSAI)

Lorraine Remer
(UMBC)

Shana Mattoo
(SSAI)

Pawan Gupta
(USRA)

Leigh Munchak
(SSAI)

Rob Levy
(GSFC)

Falguni Patadia
(USRA)
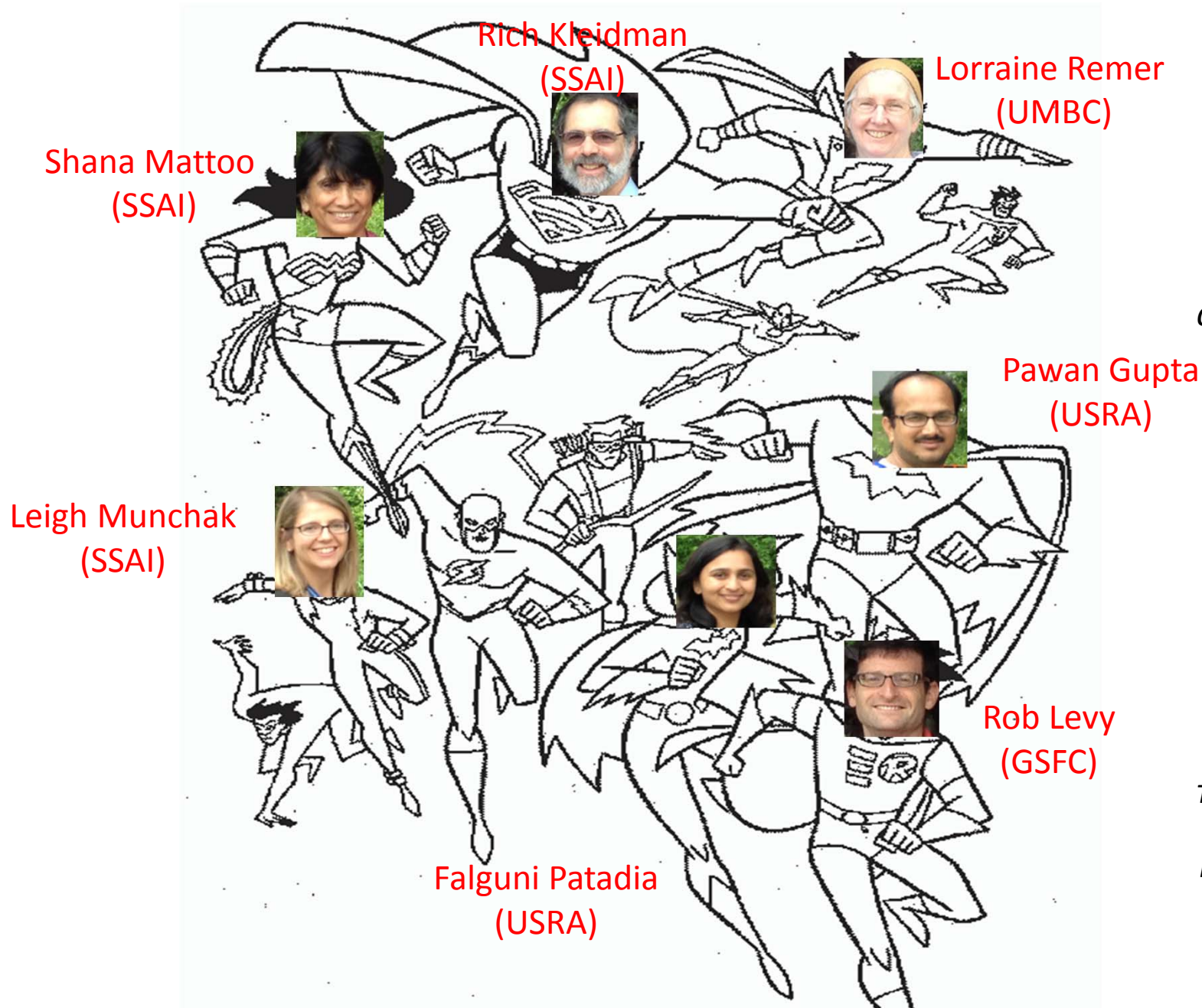
Disclaimer: Lorraine is an renegade superhero. She receives no financial contribution from the MODIS aerosol group, and does not in any way "influence the government on this particular matter on behalf of UMBC".

Telling Rob what to do, on a personal level, is perfectly legal. That's just female-male communication.

When we last saw our motley gang of heroes…

(Scenes from Season II)

AeroCenter update: May 2012

... They were promising "final" delivery of Collection 6 algorithms

- Rob was fussing with gas correction
- Leigh was fixing the cloud mask
- Shana was ordering that Version V6.0.11 was the *final* version
- Rich was evaluating DeepBlue/DarkTarget merge
- Lorraine was at UMBC, starting AirPhoton
- Falguni and Pawan had not yet joined the gang.

Now one year later…

(Scenes from Season III)

... They are still promising "final" delivery of Collection 6 algorithms

- **Rob** is answering 40 pages of AMTD comments
- **Leigh** is fixing the coastline mask
- **Shana** is insisting that Version V6.0.27 ... s the *final* version
- **Rich** is re-evaluating DeepBlue/DarkTarget merge
- **Lorraine** comes to GSFC because she misses the rest of the gang.
- **Falguni** is fussing with gas correction.
- **Pawan** is improving urban aerosol retrieval

Introducing the Collection 6 MODIS aerosol products

Subtitle: The art of the MODIS aerosol retrieval
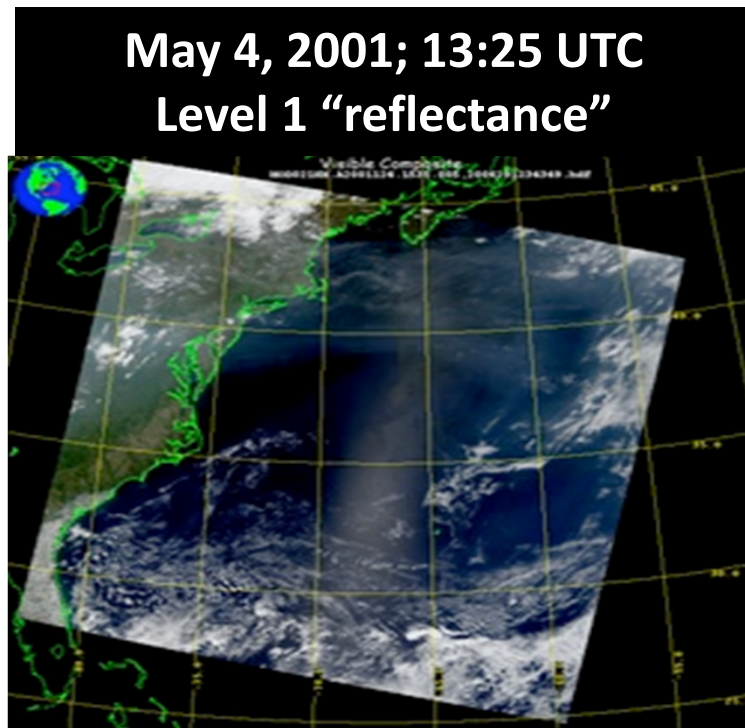
Sub-subtitle: Getting a cat into a carrier
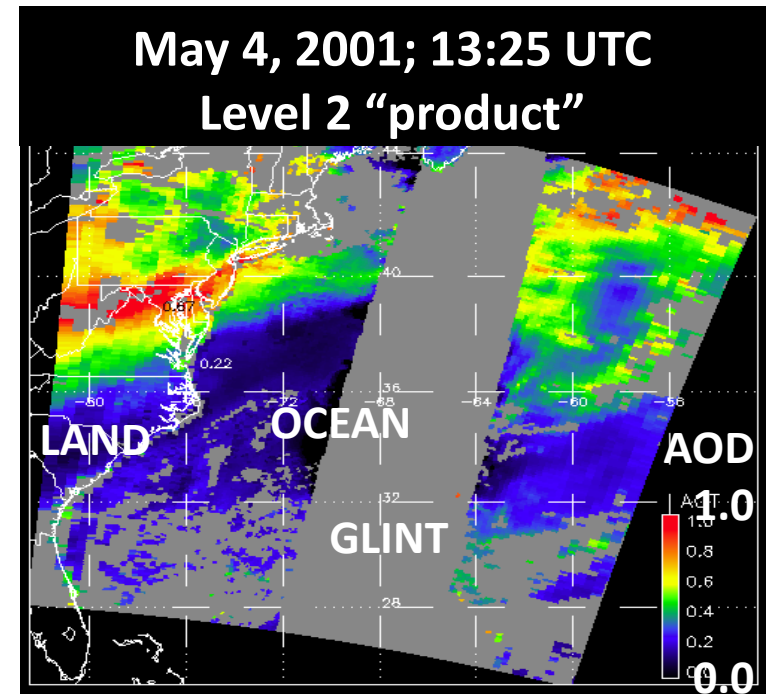
Trying to get C6 into product is like...

Video found on You-Tube
Note: no harm to cat

Aerosol retrieval from MODIS

What MODIS observes

May 4, 2001; 13:25 UTC
Level 1 "reflectance"

Attributed to aerosol (AOD)

May 4, 2001; 13:25 UTC
Level 2 "product"

LAND   OCEAN

GLINT

AOD
1.0

0.0

There are many different "algorithms" to retrieve aerosol from MODIS

1. Dark Target ("DT" ocean and land; Levy, Mattoo, Munchak, Remer, Tanré, Kaufman)
2. Deep Blue ("DB" desert and beyond; Hsu, Bettenhousen, Sayer,..)
3. MAIAC (coupled with land surface everywhere; Lyapustin, Wang, Korkin,…)
4. Ocean color/atmospheric correction (McClain, Ahmad, …)
5. Etc (neural net, model assimilation, statistical, …)
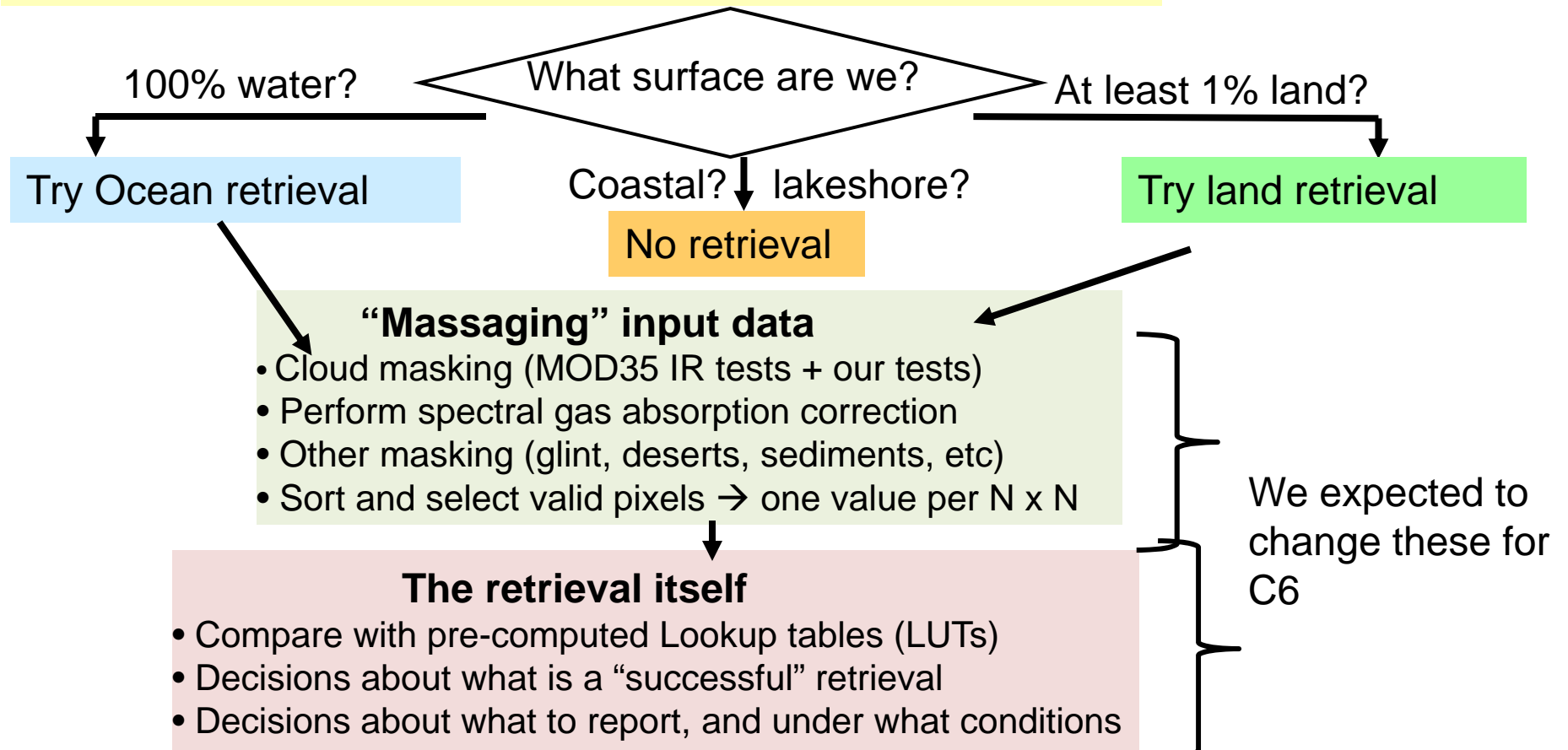6. Your own algorithm (many groups around the world)

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Generic MODIS-DT retrieval algorithm

INPUTS / UPSTREAM PRODUCTS
- MOD02 = MODIS spectral reflectance pixels (at 500 m resolution)
- MOD03 = geo-location: geometry and surface type (1 km resolution)
- MOD35 = cloud mask, including IR tests. Also has surface type
- Ancillary data: GDAS 1° ozone, water vapor, surface wind speed

Aggregate into N x N boxes

= 20x20 for 10 km

What surface are we?

100% water? → Try Ocean retrieval

At least 1% land? → Try land retrieval

Coastal? lakeshore? → No retrieval

"Massaging" input data
- Cloud masking (MOD35 IR tests + our tests)
- Perform spectral gas absorption correction
- Other masking (glint, deserts, sediments, etc)
- Sort and select valid pixels → one value per N x N

The retrieval itself
- Compare with pre-computed Lookup tables (LUTs)
- Decisions about what is a "successful" retrieval
- Decisions about what to report, and under what conditions

We expected to change these for C6

Last November we submitted Collection 6 overview paper to AMTD

Levy, R., S. Mattoo, L.A. Munchak, L.A. Remer, A.M. Sayer, and N. Hsu (2013). The Collection 6 MODIS Aerosol Products over Land and Ocean *Atmos. Meas. Tech. Disc.* (6), 159-259

- We thought it would be a service to our users to have paper out when C6 processing began.
- It was a really long paper (100 AMTD pages) describing major updates and effects on the "products"
- It received 40 pages of online criticism and comments
- Then the rug was pulled out from under us.

What happened?

The world changed
(or at least the MODIS-observed view of the world)

INPUTS / UPSTREAM PRODUCTS
- MOD02 = MODIS spectral reflectance pixels (at 500 m resolution)
- MOD03 = geo-location: geometry and surface type (1 km resolution)
- MOD35 = cloud mask, including IR tests. Also has surface type
- Ancillary data: GDAS 1° ozone, water vapor, surface wind speed

What surface are we?

100% water? → Try Ocean retrieval

At least 20% land? → Try land retrieval

Coastal? lakeshore? → No retrieval
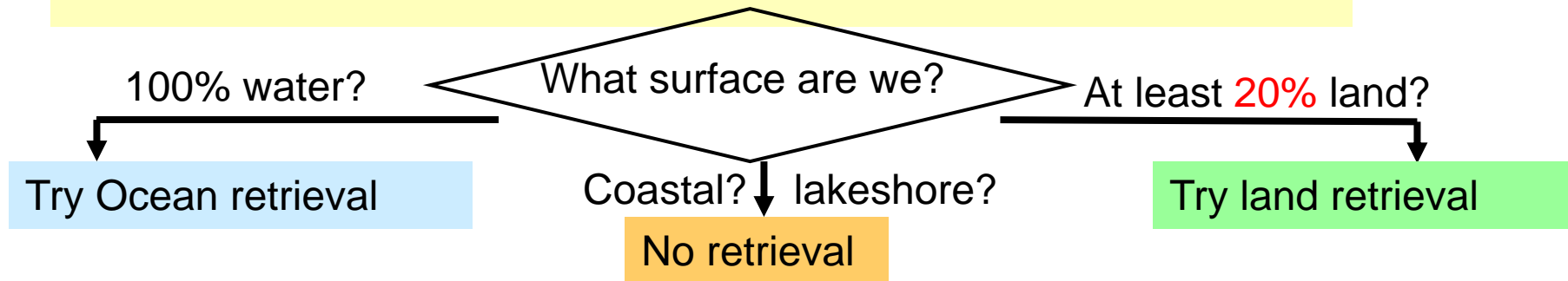
- For MOD02: Different decisions about bad/missing pixels, plus calibration
- For MOD03: Definitions of land/water/coastal were changed
- For MOD35: IR test finding high cirrus clouds was changed
- For ozone: Input stream changed from TOAST to GDAS

"Our" changes for C6 needed to be revised

Note: that "our" also refers to **ALL** MODIS products (clouds, land surface, etc) 12

"Definitions" of land/coastal/water:
C5: Used MOD35; C6: Use MOD03 (It's a long story)

This is ARCTAS region in northern Canada.

Land 'o lakes

MODIS AOD, with no coastline pixels
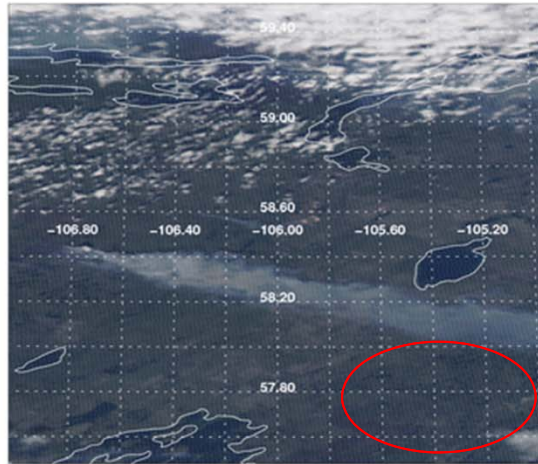
MODIS AOD, with coastline pixels
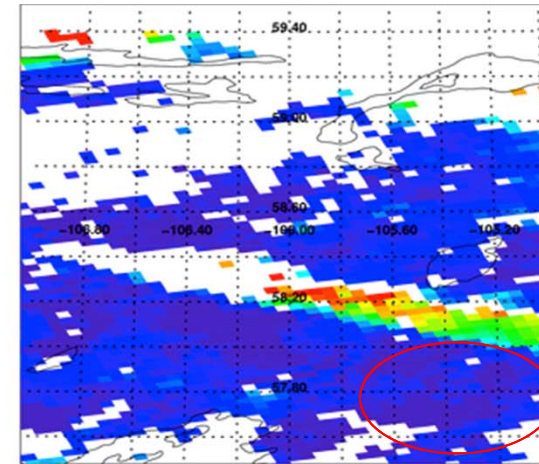
improved coverage near water
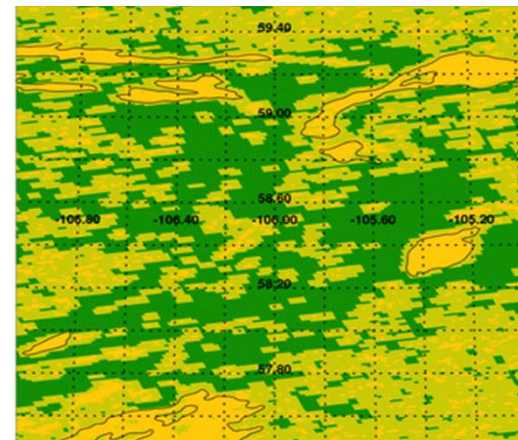
550 nm AOD

| 0.00 | 0.25 | 0.50 | 0.75 | 1.00 | 1.25 | 1.50 |
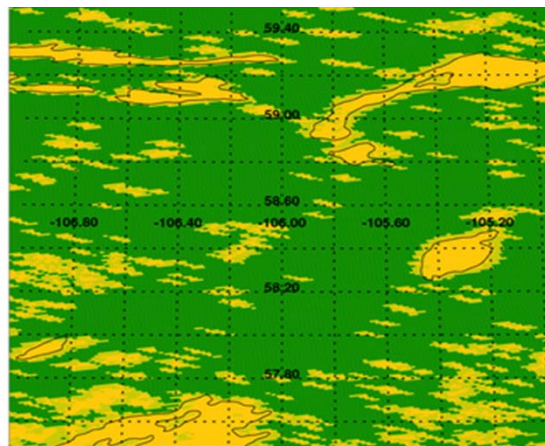
Note very little "coastal" in C5.

Clean divide between Green (land) and Yellow (Lakes)

C5 MOD03 Land/Sea Mask

C6 MOD03 Land/Sea Mask
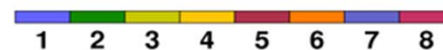
Note much more "coastal" in C6.

Lots of shorelines (lime colored) pixels that would be thrown out.

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |

… Now they are promising "final" delivery of Collection 6 algorithms

(Shana will allow NO MORE CHANGES!!!!)

OUTLINE of REST of TALK

COMING SOON

- Compensated for upstream changes!!!!!

- Better RT (gas corrections, LUTs)

- Cloud mask and pixel decision-making

- "Science" upgrades

- "Quality assurance" upgrades

- DT products (expected C6 versus C5)

- Other stuff: 3 km, DT/DB merge, etc

Better RT: Gas Corrections

- Gases (H_2O, O_3, CO_2, NO_2, etc...) absorb radiation, $T_{gas} < 1.0$
- T_{gas} varies spectrally and function of gas optical depth:
- $T_{gas} \approx 1 - \tau_{gas}$:

- The C5 assumptions were undocumented (circa 1995)
- Used modern RT code and found changes
- Changes for C6 have impacts.

Gas Corrections (cont.)

Gas Optical Depths for Mid Latitude Summer

Legend:
- H2O = 2.9 cm (blue)
- O3 = 324 DU (green dotted)
- GAS (red)

For Z=0°: $T'_{gas} \approx 1 + \tau_{gas}$
$\Delta T'_{gas} \approx 0.01 \rightarrow \Delta\rho^* \approx 0.001$

Y-axis: Gas Optical Depth (0 to 0.05)

X-axis: Version, MODIS Band

Bands: 0.645, 0.856, 0.466, 0.554, 1.242, 1.638, 2.113

Versions: C5_1, 6SE_1, LBL_1, *, C5_2, 6SE_2, LBL_2, *, C5_3, 6SE_3, LBL_3, *, C5_4, 6SE_4, LBL_4, *, C5_5, 6SE_5, LBL_5, *, C5_6, 6SE_6, LBL_6, *, C5_7, 6SE_7, LBL_7, *
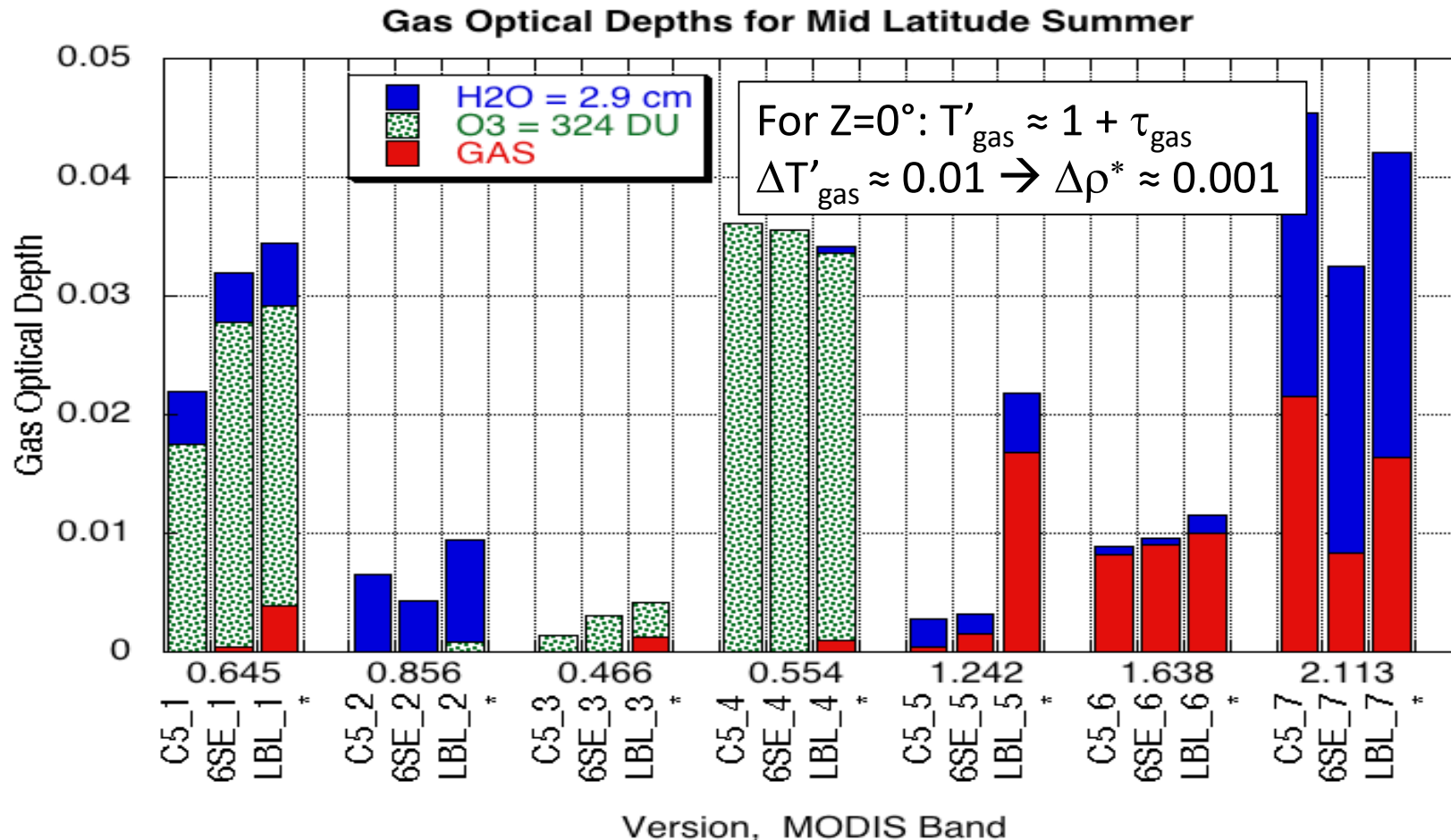
- Consistent "bias" of $\Delta\rho^* \approx 0.001 \rightarrow$ "bias" of AOD of 0.01.
- Bias is double for Z=60°.   Quadruple for two-way transmission!
- Something really weird is happening at 1.24 μm channel **(big impact on land retrieval)**
- **ACE: We want to know global AOD to ±0.01?   Not when we don't know gas!!!**

Radiative Transfer updates (applied to C5)

Jul 2008: Aqua

Recalculate "center wavelengths" from MODIS filter functions, and spectral Rayleigh optical depths

Recalculate gas absorption coefficients and optical depths for H_2O, O_3, CO_2, CH_4, O_2, etc

Extend valid solar zenith angle from 72° to 84°.

Pretty big changes, but they are justified.

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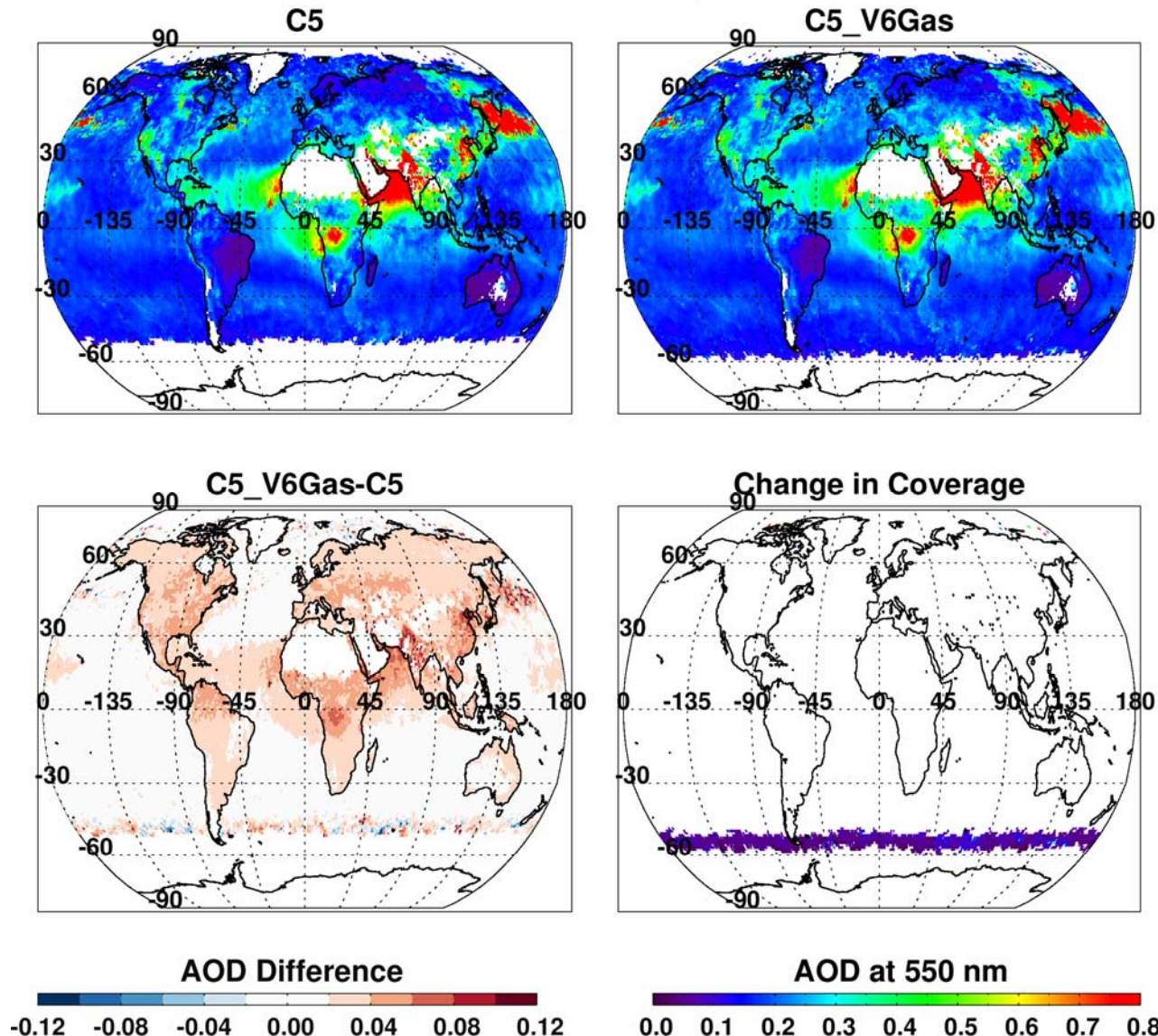
Update cloud masking (ocean & land)
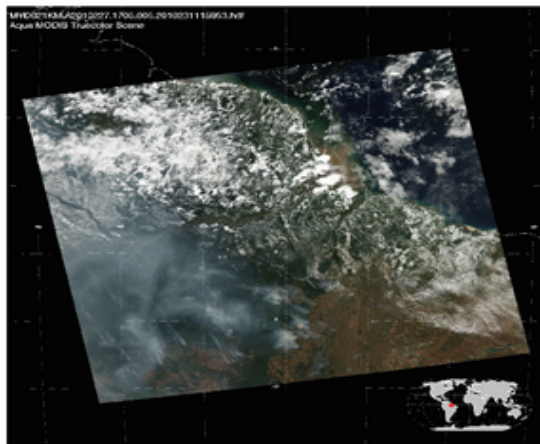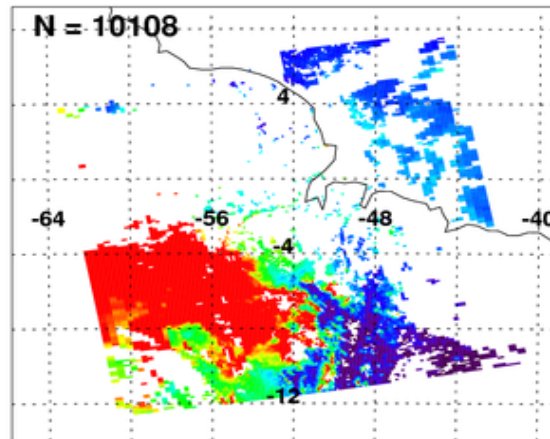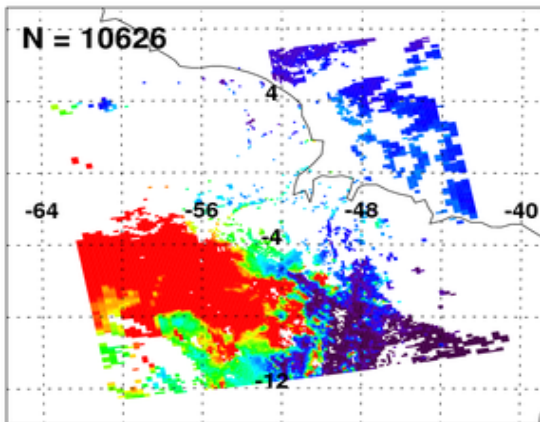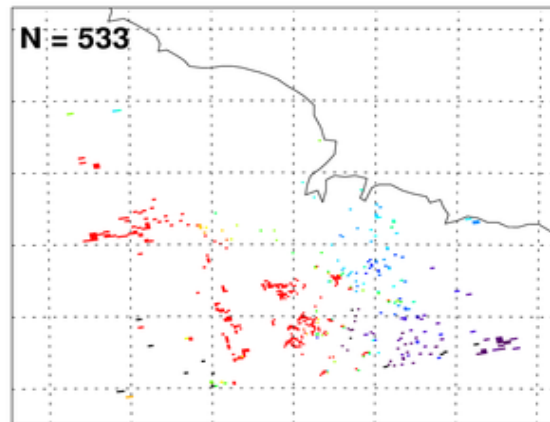
- Retrieve more "heavy smoke" cases

- Retrieve fewer "thin cirrus" cases

- Correct assignment of QAC due to clouds

Science: wind speed dependence (ocean)

MYD04_L2.A2010018.1440.hdf

NCEP winds - 6 m/s winds

One granule

AOD Difference

-0.03 -0.02 -0.01 0.00 0.01 0.02 0.03
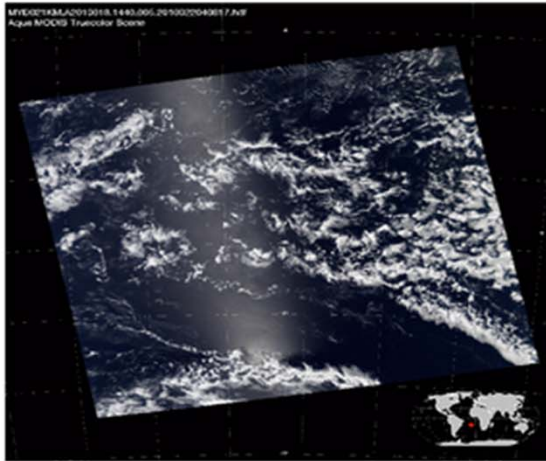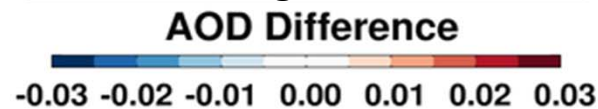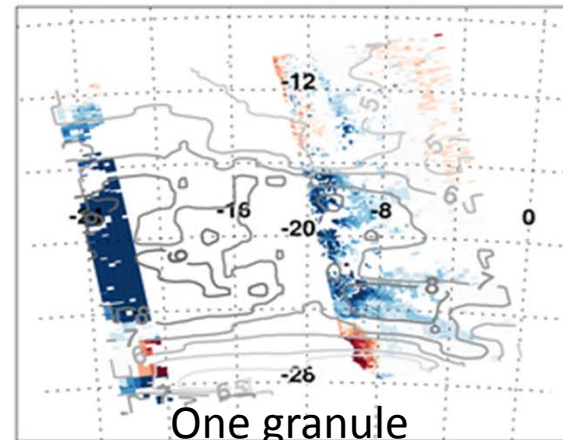
- Higher wind speeds
  → more ocean foam
  and diffused glitter
  pattern

- Aerosol LUT now
  calculated for 4 wind
  speeds

  (v=2, 6*, 10, 14 m/s)

multi_wind-only_6ms

One day

One month

AOD Difference

-0.03 -0.02 -0.01 0.00 0.01 0.02 0.03

AOD Difference

-0.12 -0.08 -0.04 0.00 0.04 0.08 0.12
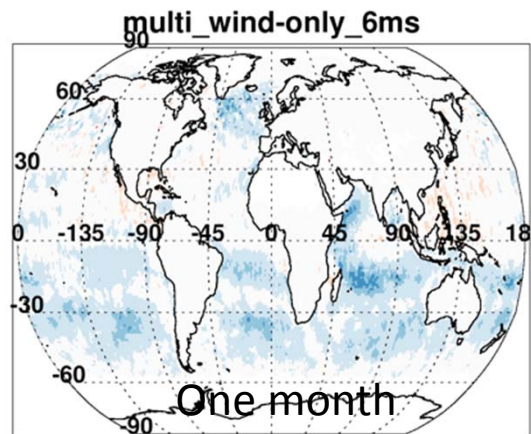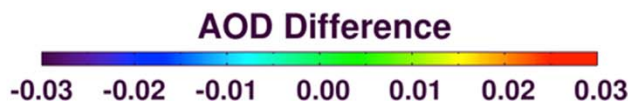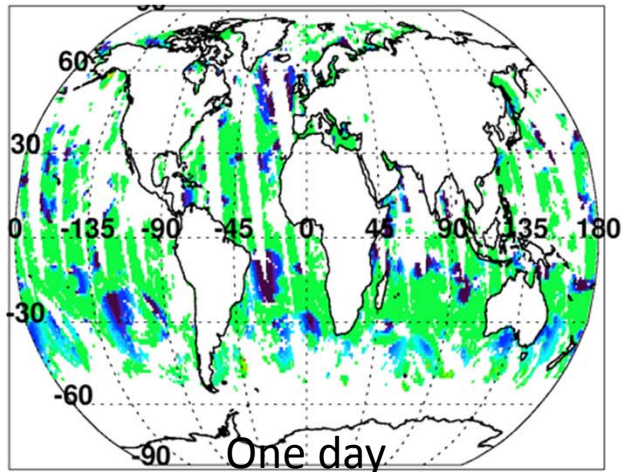
- Retrieved AOD
  reduced when v≥6

- Reduces AOD near
  40° glint mask edges
  and in "Roaring 40s"
  of southern Oceans.

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Quality Confidence "definitions"

AOD Histogram over Ocean
Aqua (6 months)

C5: N = 8.091 10^7
C6: N = 8.604 10^7

Pixel Counts

AOD at 0.55 μm
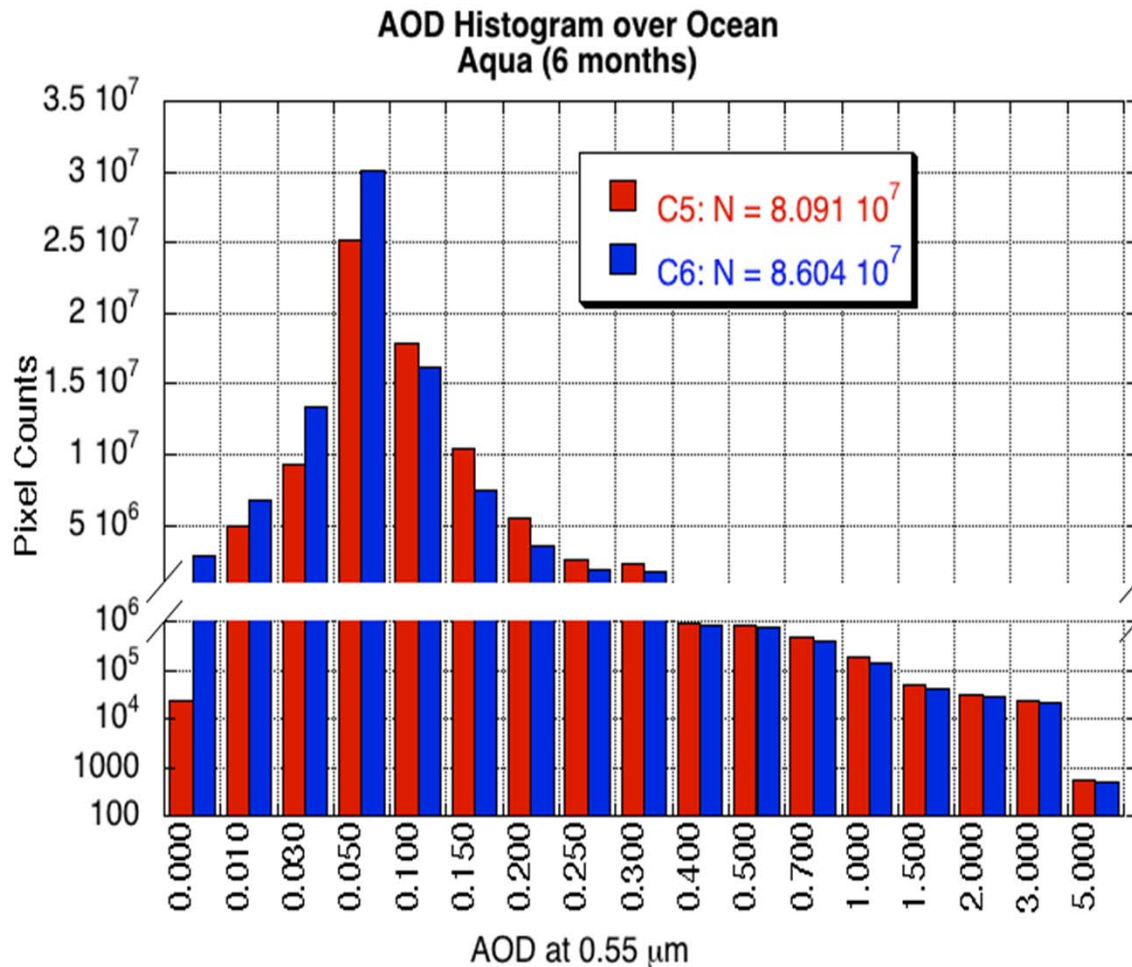
Old (C5): Quality assurance depends on success of a retrieval solution. If aerosol signal is too small, then do not include in daily/monthly statistics.
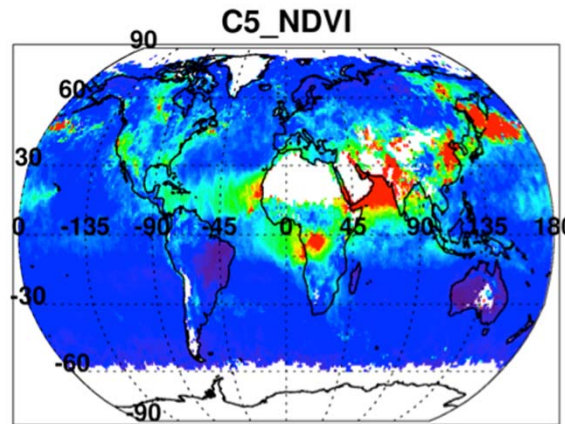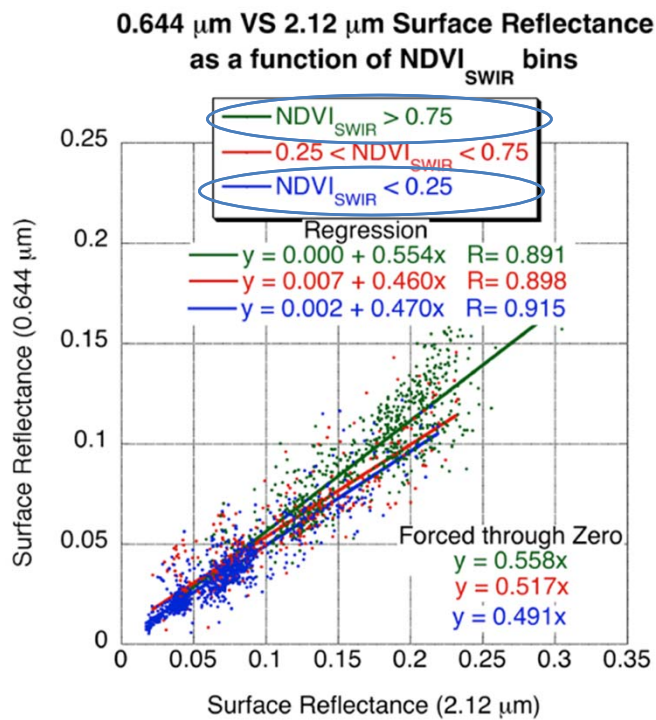
New (C6) : Sometimes signal is small, but we are confident that it is small. Include in daily/monthly statistics.

- But "major" influence on estimating regional and global mean AOD

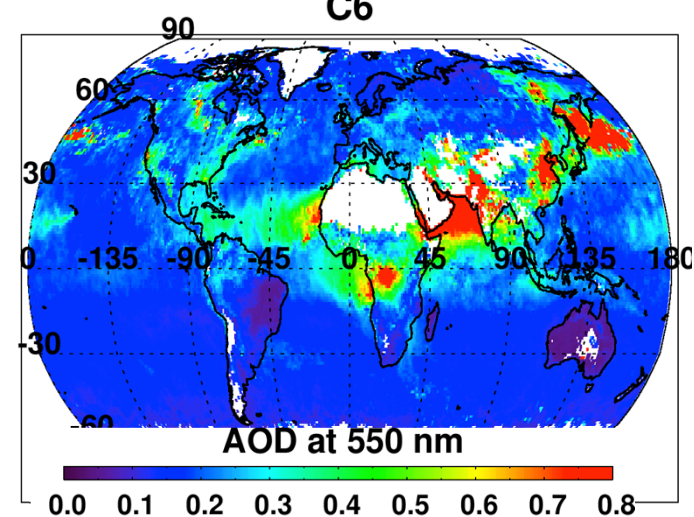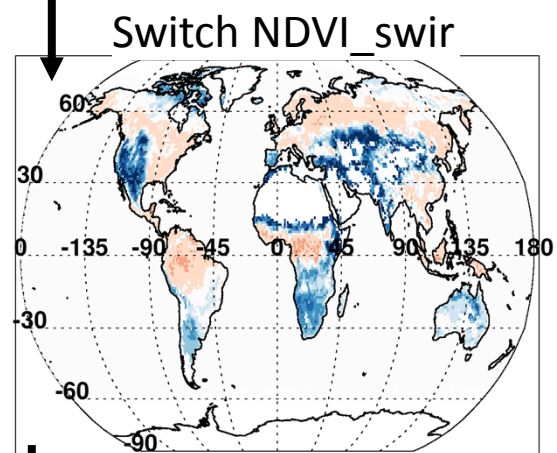# Major bug fix: surface reflectance relationship to NDVI_swir

0.644 μm VS 2.12 μm Surface Reflectance as a function of NDVI$_{SWIR}$ bins

— NDVI$_{SWIR}$ > 0.75
— 0.25 < NDVI$_{SWIR}$ < 0.75
— NDVI$_{SWIR}$ < 0.25

Regression
— y = 0.000 + 0.554x   R= 0.891
— y = 0.007 + 0.460x   R= 0.898
— y = 0.002 + 0.470x   R= 0.915

Forced through Zero
y = 0.558x
y = 0.517x
y = 0.491x

Surface Reflectance (0.644 μm)
Surface Reflectance (2.12 μm)

Jul 2008

C5_NDVI

C6_NDVI-C5_NDVI

AOD Difference
-0.12 -0.08 -0.04 0.00 0.04 0.08 0.12
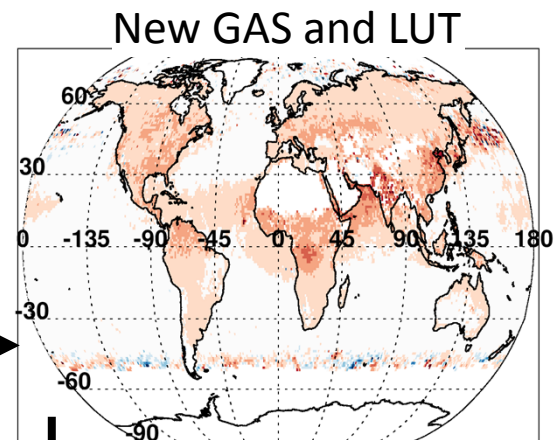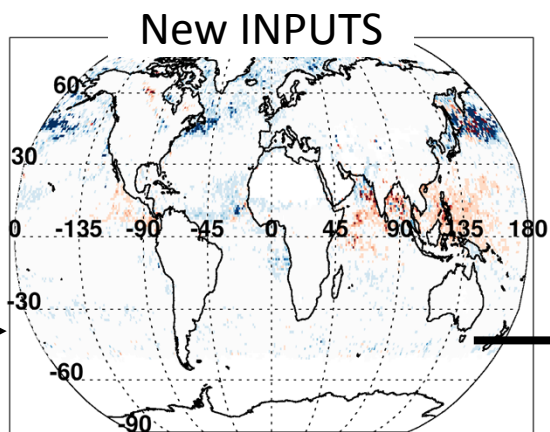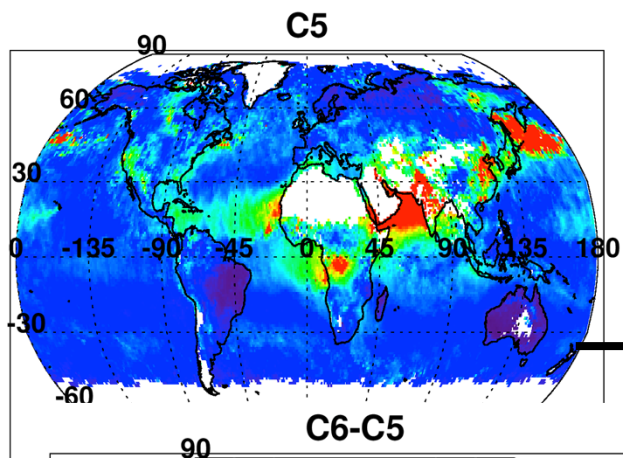
These labels were reversed
Resulting in coding error

- Coding error from C5 continued to C6

- Surface reflectance dependence on NDVI_swir was reversed

- New: Reduces super-high bias for semi-arid regions.

C5

C6-C5

AOD Difference

-0.12 -0.08 -0.04 0.00 0.04 0.08 0.12

C6

AOD at 550 nm

0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8

New INPUTS

New GAS and LUT

Degrade coastal QA

Switch NDVI_swir

Fix cirrus bug over land

Add wind speed dep.
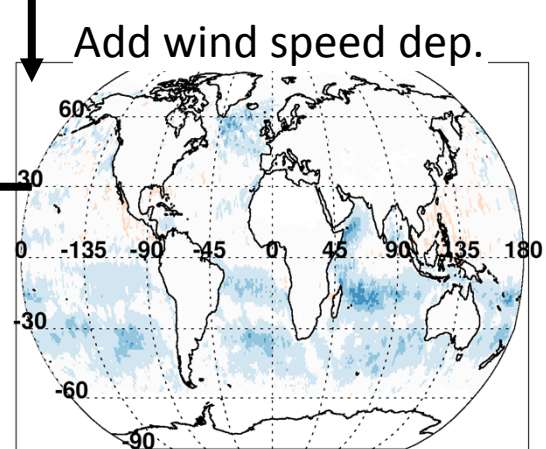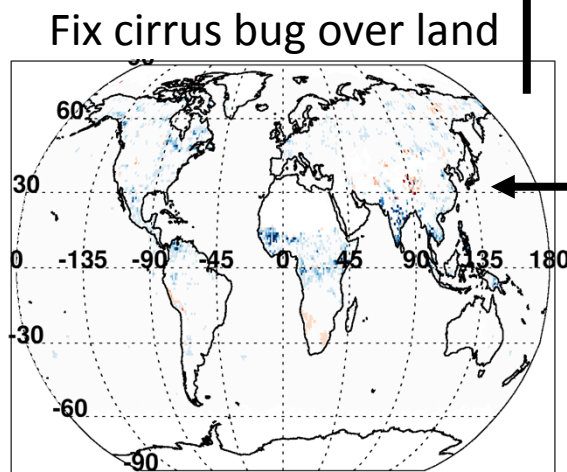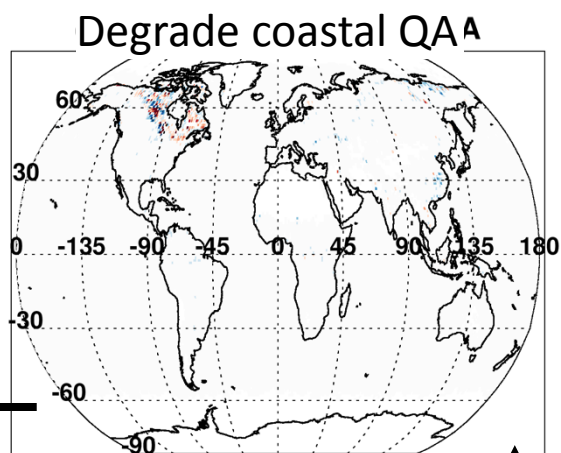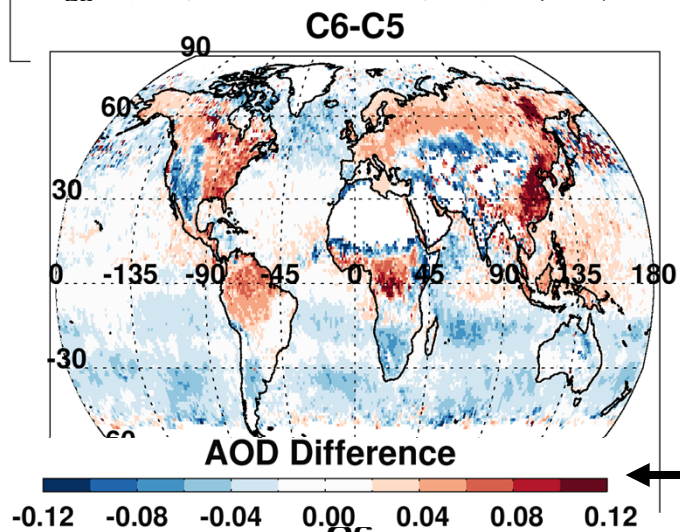
Results from *ALL* changes

Jul 2008: Aqua

C5   C6

Version 6.0.27

C6-C5   Change in Coverage
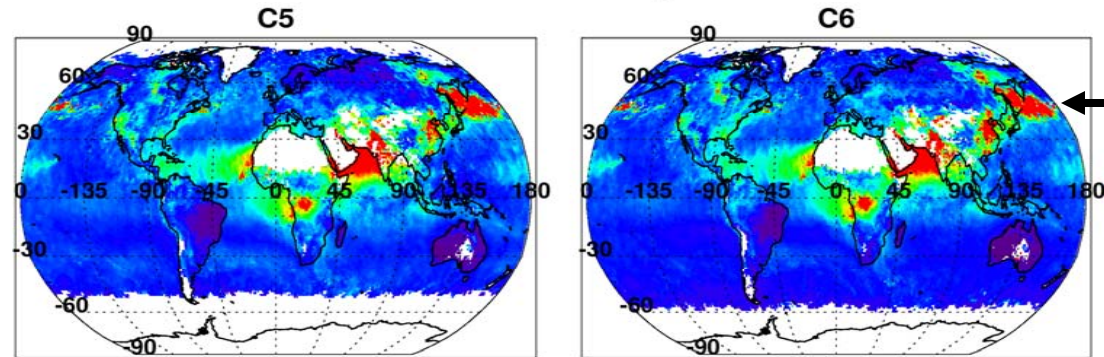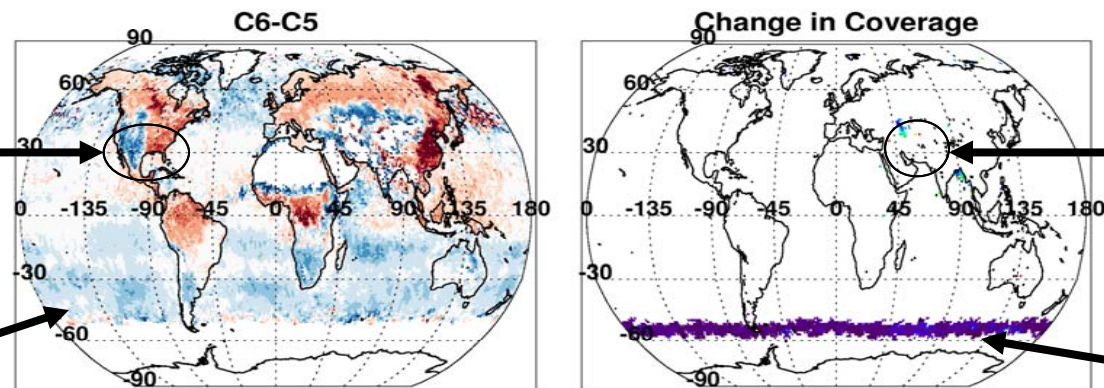
NDVI switch

Mostly wind speed upgrades

Decisions about land/sea/coastal

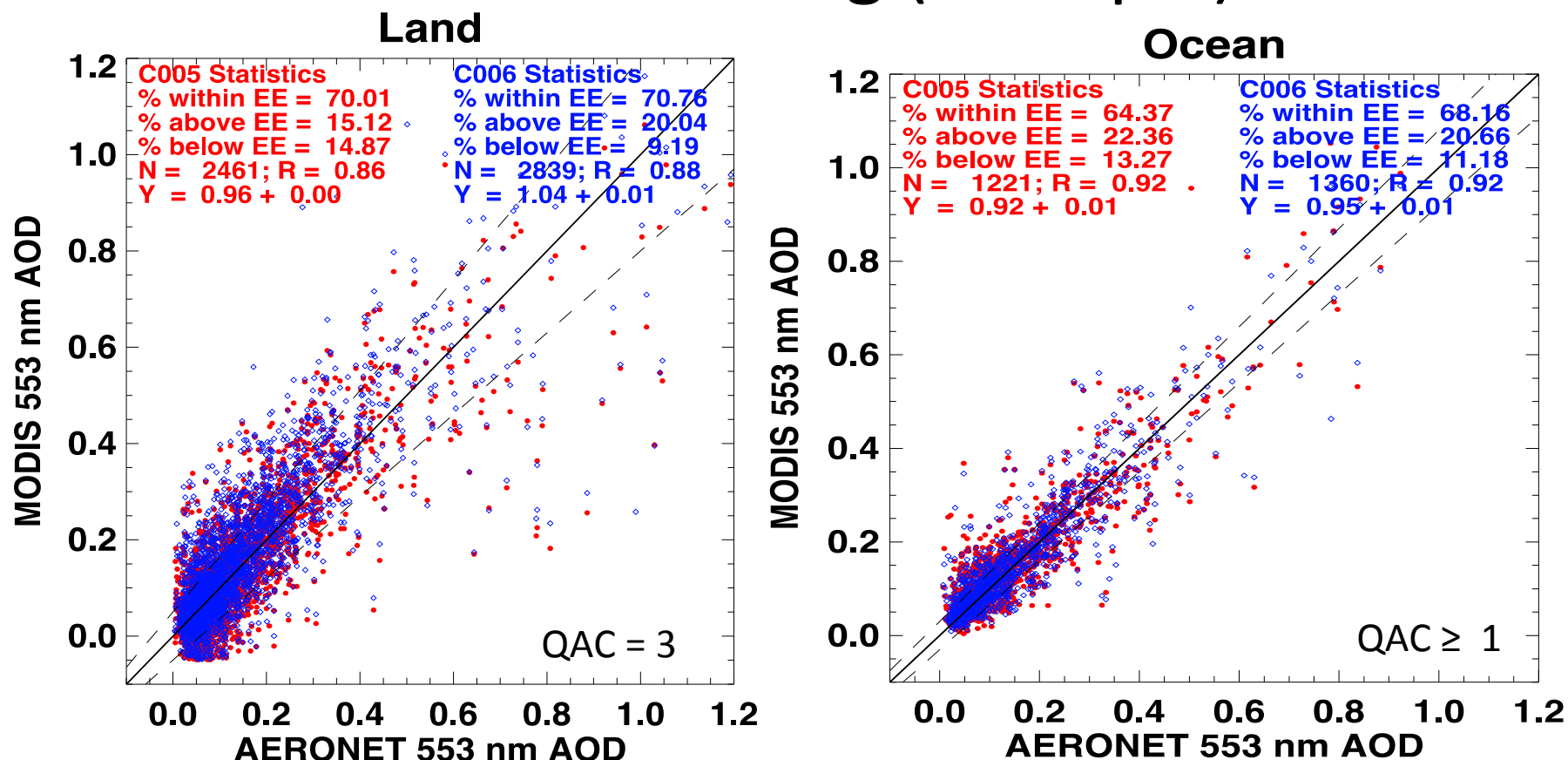Higher zenith angle valid

AOD Difference
-0.12 -0.08 -0.04 0.00 0.04 0.08 0.12

AOD at 550 nm
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8

- lower AOD over ocean, but significantly lower over southern oceans
- Higher AOD over most land, but lower in semi-arid regions.
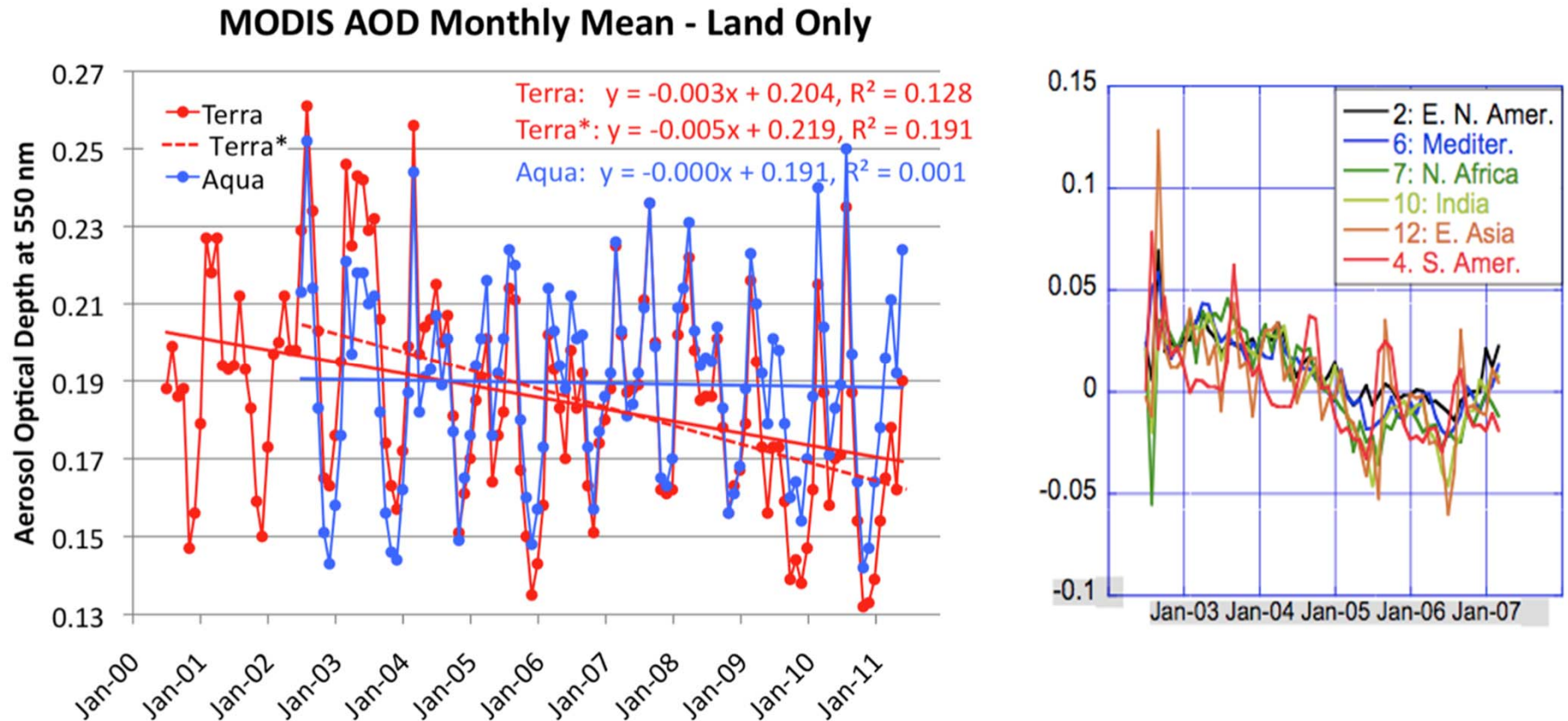- Changes in decisions to retrieve (see Aral sea).

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Preliminary "validation" of C6
6 months testing (on Aqua)

Land

Ocean

- No dramatic changes, but 10-20% more valid collocations with AERONET
- C6 algorithm has slightly better (68% vs 64%) retrieved over ocean
- C6 will have more of a high bias over land, but slightly better correlation. 24

C5: Trends Terra ≠ Aqua

MODIS AOD Monthly Mean - Land Only

Terra: $y = -0.003x + 0.204$, $R^2 = 0.128$
Terra*: $y = -0.005x + 0.219$, $R^2 = 0.191$
Aqua: $y = -0.000x + 0.191$, $R^2 = 0.001$

- Terra
- Terra*
- Aqua

Legend:
- 2: E. N. Amer.
- 6: Mediter.
- 7: N. Africa
- 10: India
- 12: E. Asia
- 4. S. Amer.

- Over land, Terra *decreases* (-0.04/decade), Aqua *constant*
- Terra / Aqua divergence is the same everywhere on the globe!
- **Artificial Terra trend traced to degrading of Terra's calibration**

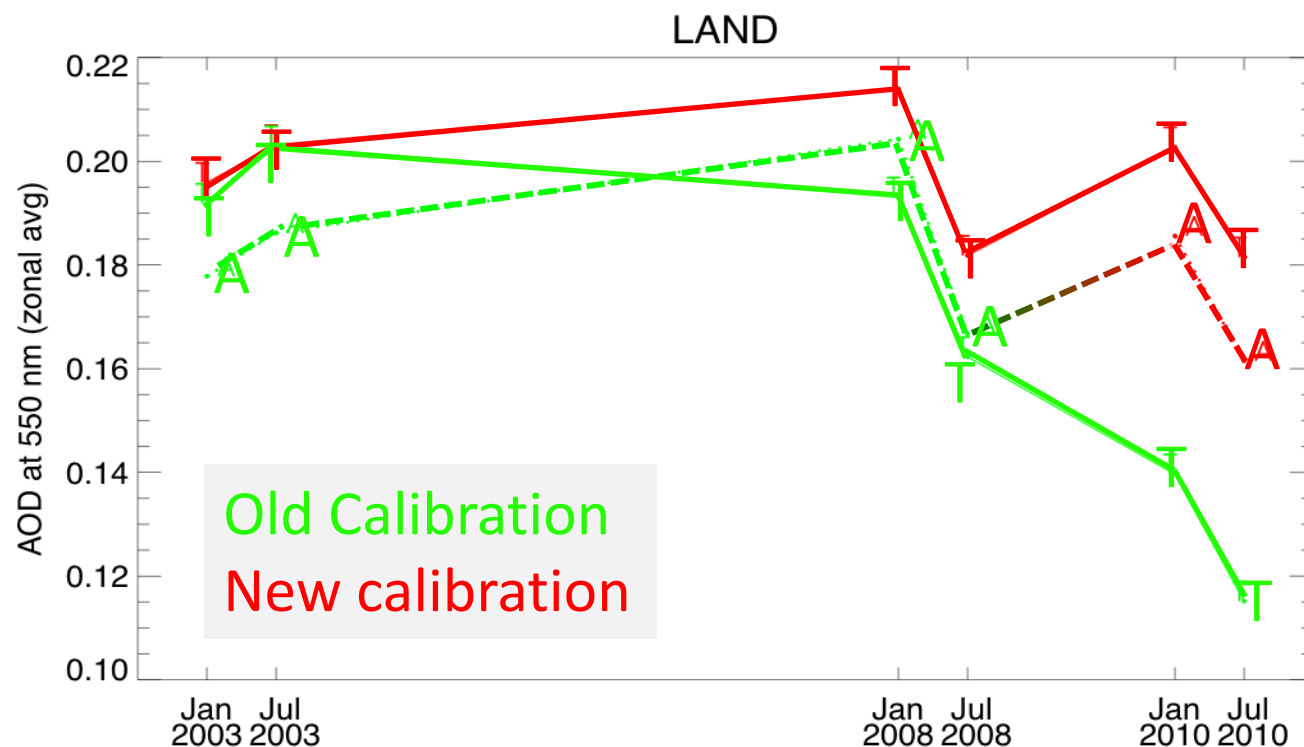# C6: Impact of New Terra calibration

Jul 2008: Terra
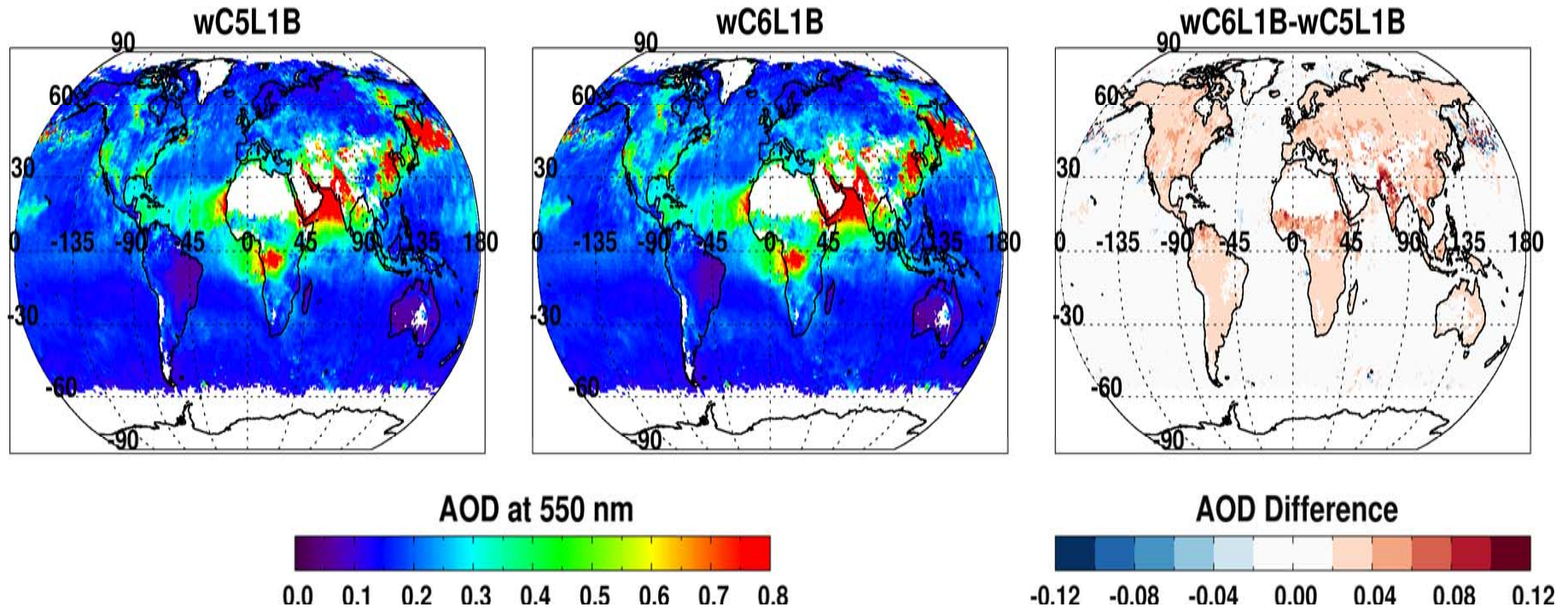
- Main impacts over land
  - Global increase by 0.02 (for this particular month)
- Impact over ocean is small
  - Global increase by 0.004 (for this particular month)

Jack Xiong,
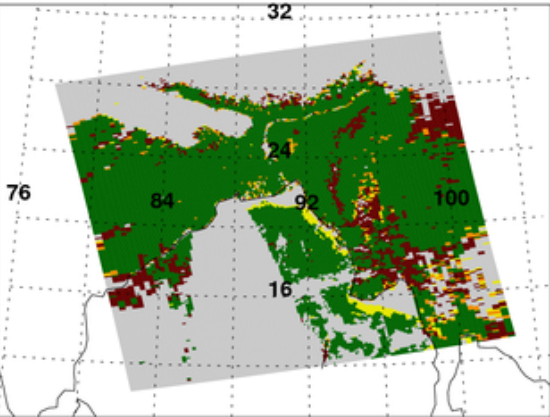Junqing Sun and
MCST

C6: Impact of new calibration on trend?

LAND

Old Calibration
New calibration

- 6 months processed with same dark-target aerosol algorithms
- Terra (T) now "in sync" with Aqua (A) time series
- (Terra-Aqua) offset remains 0.01 (ocean) and 0.015 (land)
- **New calibration → Terra/Aqua divergence removed for C006!**
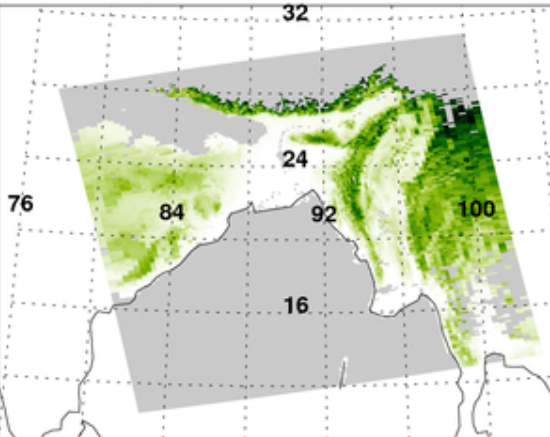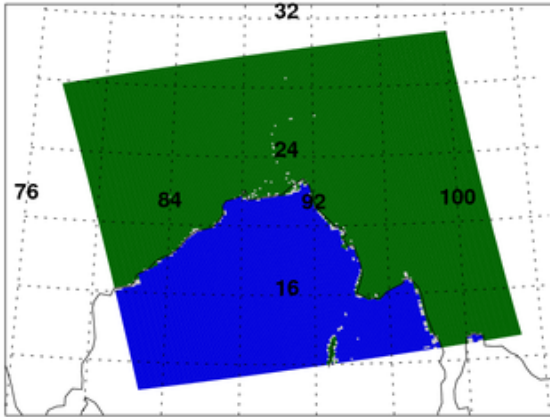
What else for C6 Level 2?

New Diagnostic SDSs
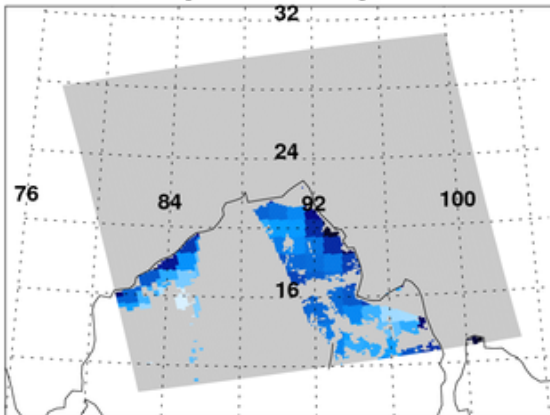
Cloud and Aerosol SDSs

Aerosol_Cldmask_Land_Ocean

Clear | Cloudy

Distance to Cloud

Distance to Cloud [pixels]

0   4   8   12   16   20
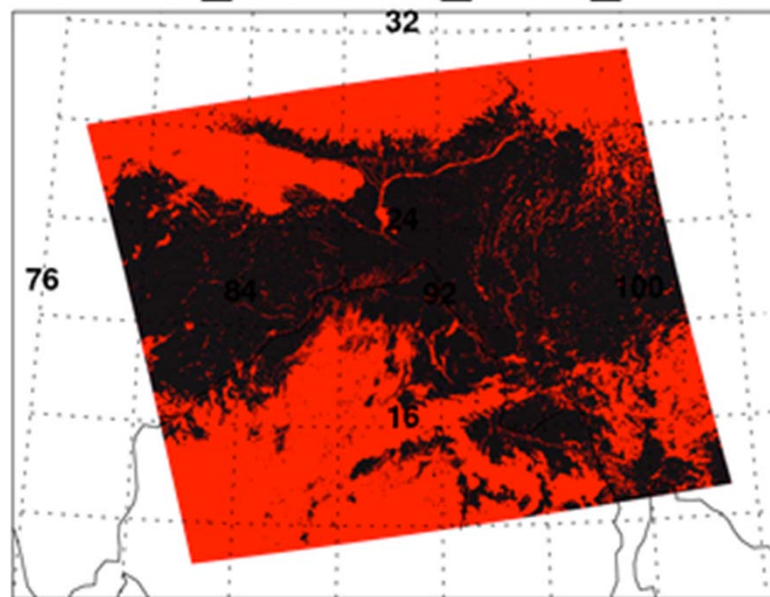
500 meter resolution cloud mask used in aerosol retrieval. Can be (at times, significantly) different than MOD35
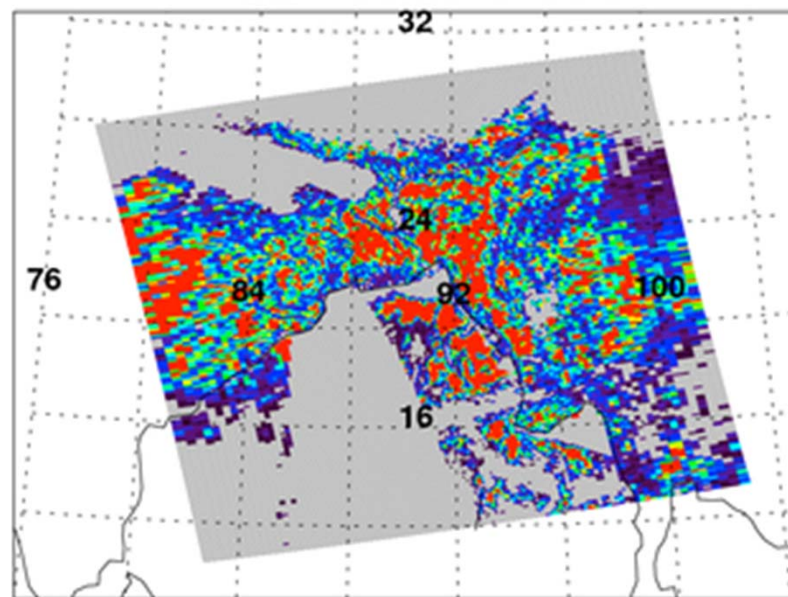
**Number of pixels between an aerosol retrieval and the closest cloud. Not thoroughly validated yet.**

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The Deep/Dark merge

Jan 21 2010 at 13:40 UTC
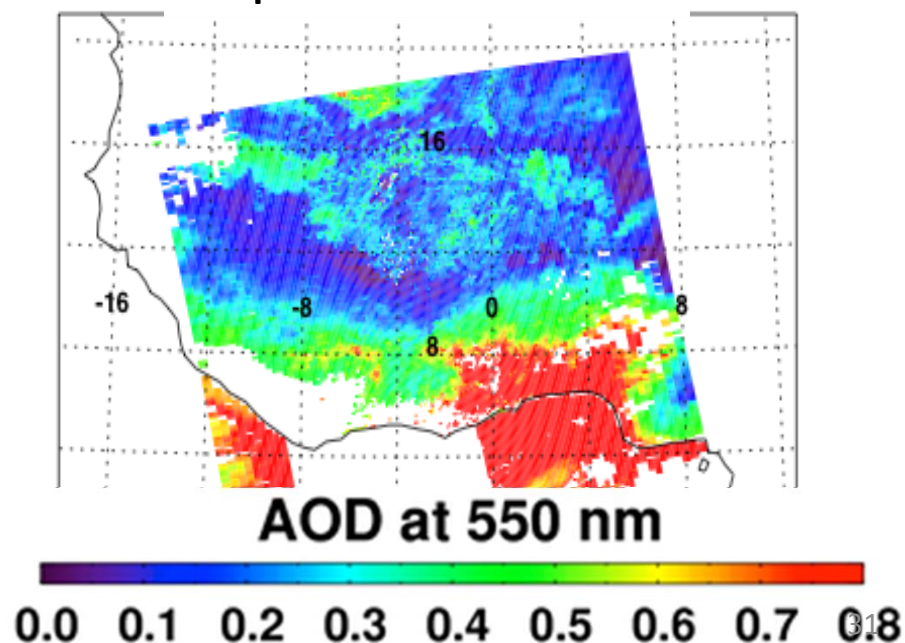

- **Dark**, **bright**, and **transitional** regions are identified by monthly mean NDVI
- In **Dark** regions, value from dark-target retrieval is used
- In **bright** regions, deep-blue is used
- In **transition** regions, AOD is merged, dependent on QA of retrievals
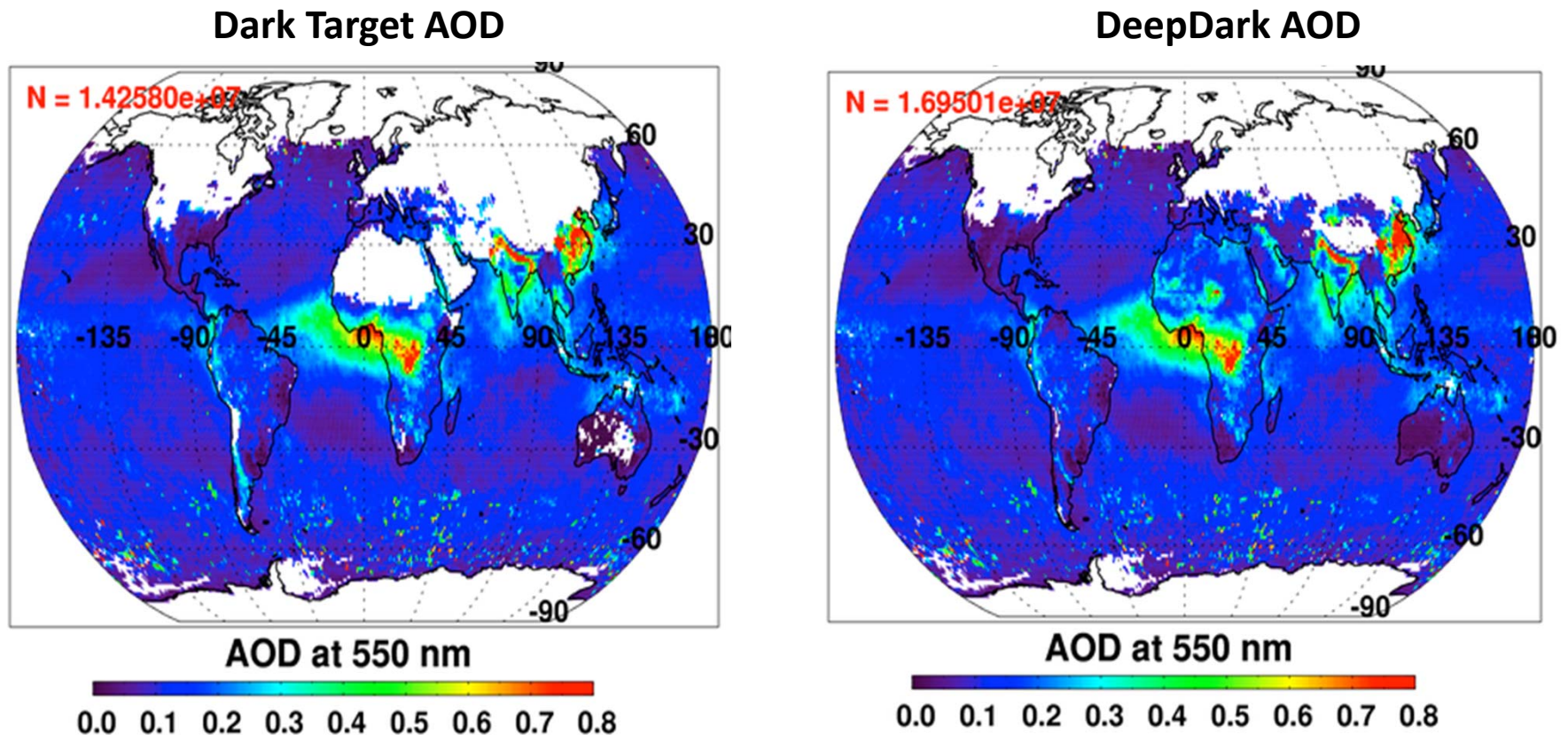
DeepDark Algorithm Flag

0: Dark Target   1: Deep Blue   2: Mixed

DeepDark 550 nm AOD

AOD at 550 nm

0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8
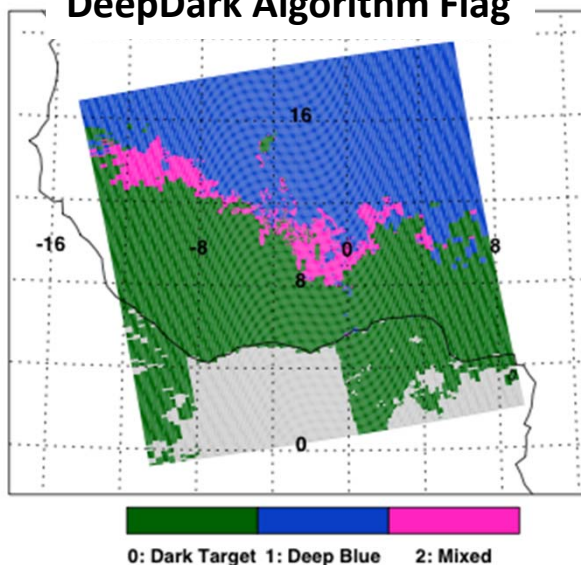
C. Hsu, A. Sayer, C. Bettenhousen, S. Mattoo, L. Munchak, R. Kleidman, et al.,

Monthly mean AOD for Aqua, January 2010

Dark Target AOD

DeepDark AOD

AOD at 550 nm

0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8

Merging deep blue & dark target produces best global coverage
- Deep blue is land-only; need dark target for oceans
- Deep blue introduces coverage over Australian outback, Sahara desert and Arabian peninsula
- Still no coverage over snow (see: most of Northern Hemisphere).

MERGE LOOKS REASONABLE, BUT NOT VALIDATED YET!!!! (Kleidman et al)

What about C6 Level 3?

Calculating mean AOD
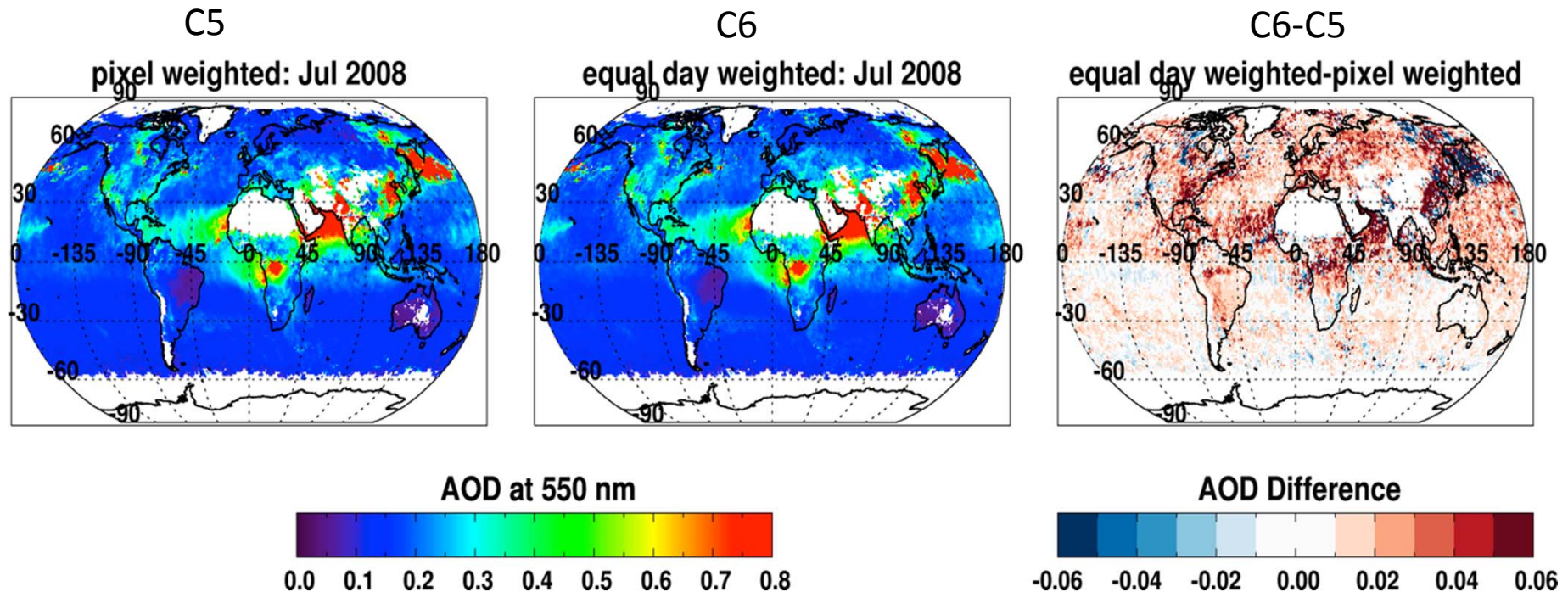

Daily data?

Monthly data?

LAND

Daily
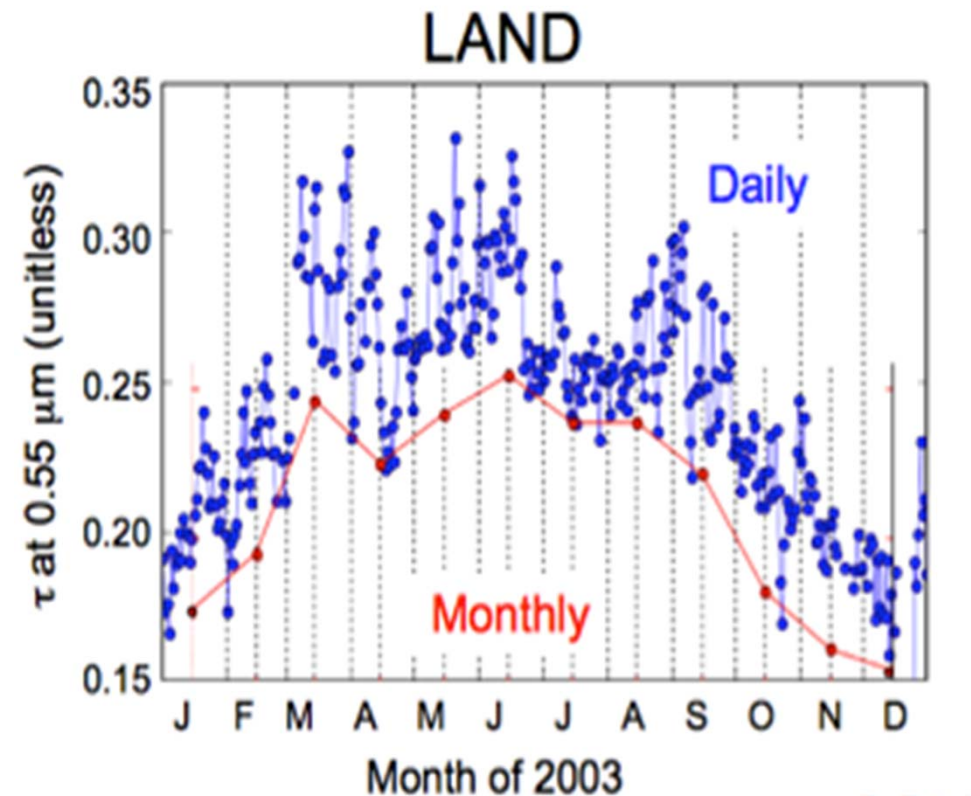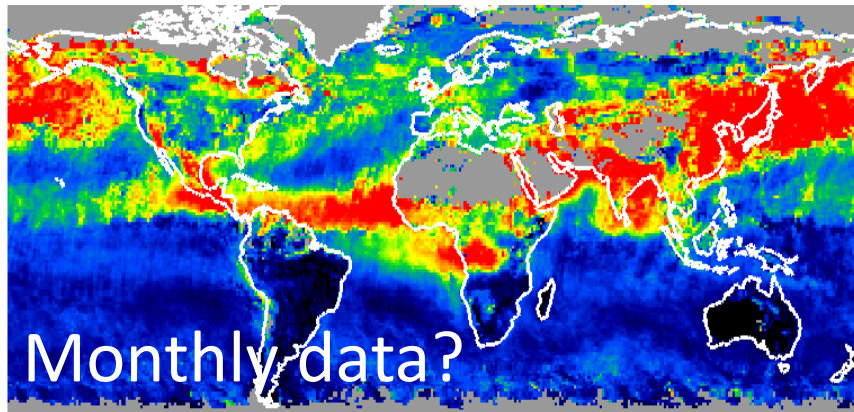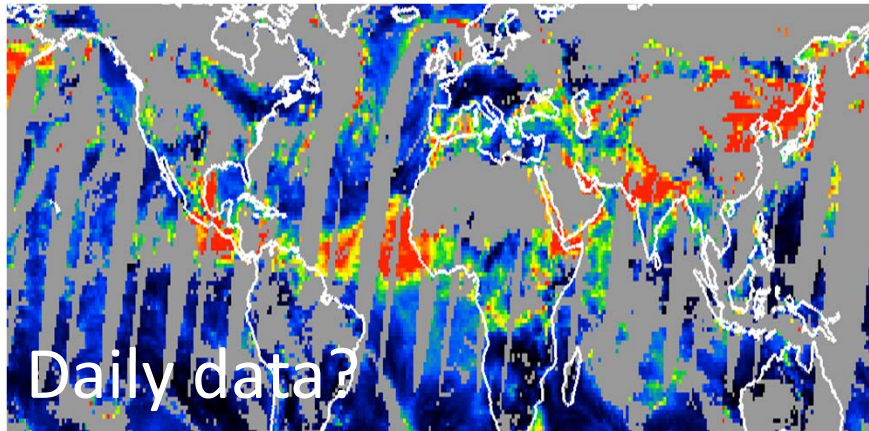
Monthly

Levy et al., TRGS, 2009

- It depends on the post-processing path
- Many choices for aggregation and weighting
- Accentuate different limitations of original (L2) sampling

Changes to Level 3: monthly

- Pixel weighting for monthly data is removed
- Replaced by "equal day" weighting (assuming at least 5 observations per day).
- → Increase monthly mean AOD over land, and ocean

Global → Local

- Nominal resolution (e.g. 10 km) cannot resolve higher scale (e.g. urban, neighborhood) variability

- Air Quality community has been asking (no, *pleading!*) for higher resolution data

- We have been afraid to lose the advantage (pixel statistics) of the 10 km.

3 km algorithm

In two AMT-Discussion Papers (in revision for AMT)

- Munchak, L., R.C. Levy, S. Mattoo, L.A. Remer, B.N. Holben, J.S. Schafer, C.A. Hostetler, and R.A. Ferrare (2013). MODIS 3km Aerosol Product: applications over land in an urban/suburban region, Atmos. Chem. Phys. Dis, 6, 1683-1716 doi:10.5194/amtd-6-1683-2013

- Remer, L., S. Mattoo, R.C. Levy, and L. Munchak (2013). MODIS 3km Aerosol Product: Algorithm and Global Perspective, Atmos. Meas. Tech. Disc., (6), 69-112 doi:10.5194/amtd-6-69-2013

- J. M. Livingston, J. Redemann, Y. Shinozuka, R. Johnson, P. B. Russell, Q. Zhang, S. Mattoo, L. Remer, R. Levy, L. Munchak, and S. Ramachandran, (2013). Comparison of MODIS 3-km and 10-km resolution aerosol optical depth retrievals over land with airborne Sunphotometer measurements during ARCTAS summer 2008, Atmos. Chem. Phys. Dis, (submitted last week).

MODIS 3 km product over suburban (MD) landscape (summer 2010)

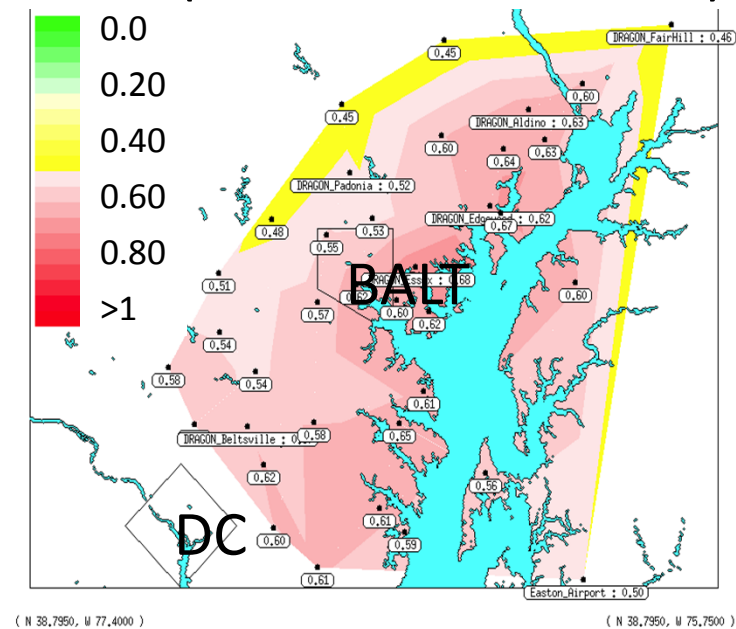Aqua: Day 209 2010 — 10 km — 3 km

Terra: Day 219 2010 — 10 km — 3 km
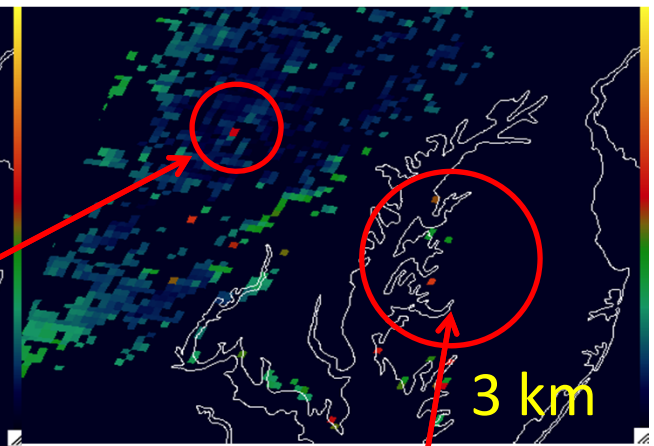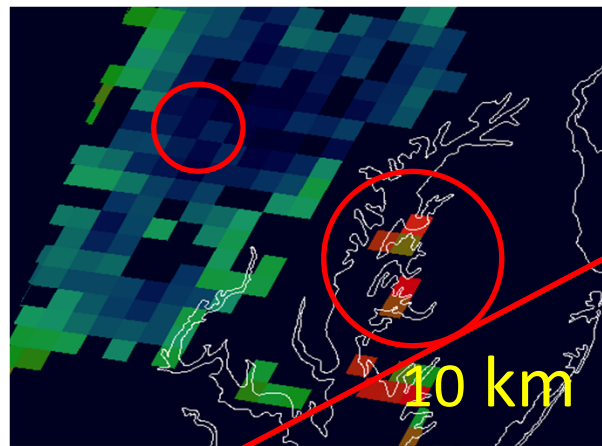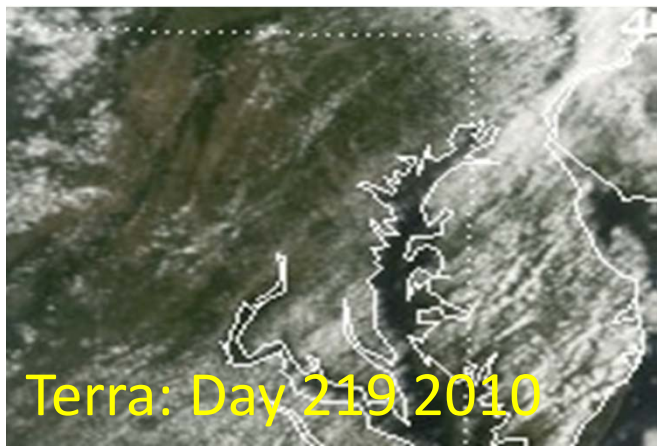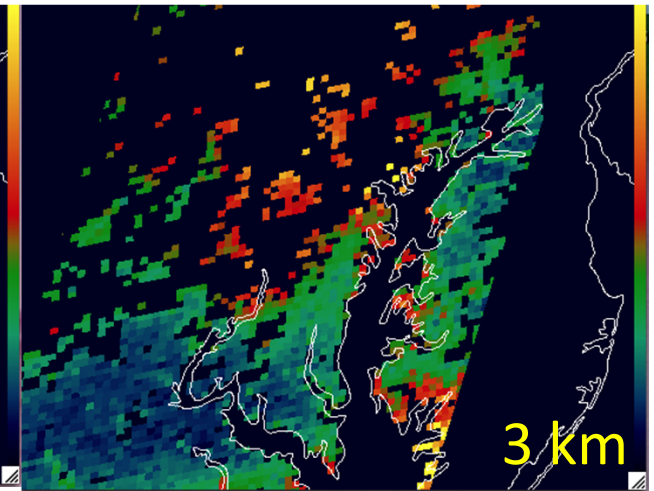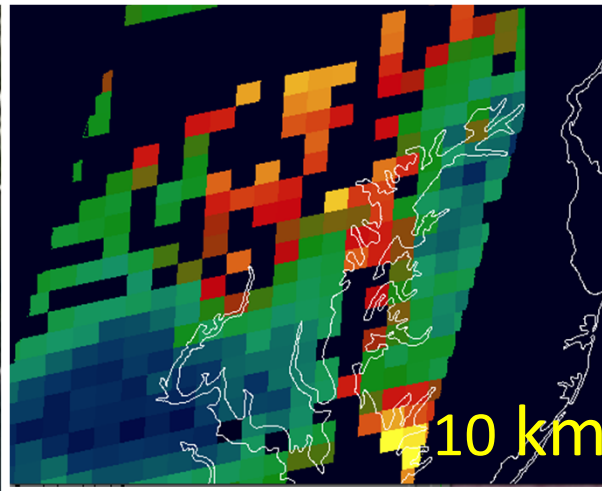
- 3 km mirrors 10 km product (pattern and magnitude)
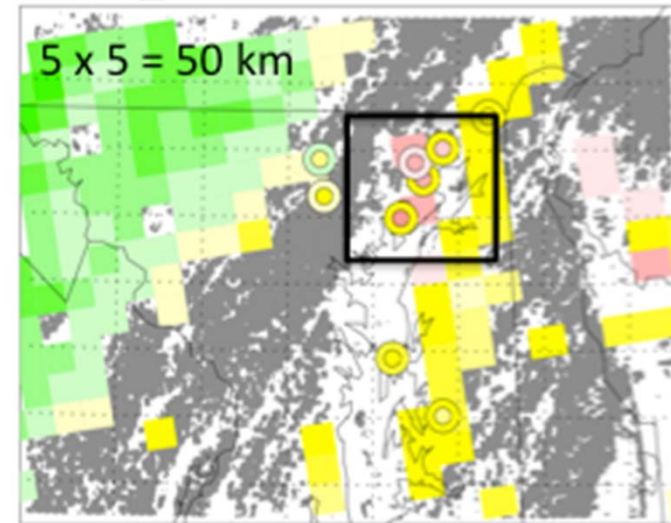- 3 km introduces noise, but also can reduce spatial impact of outliers

MODIS vs DRAGON
July 21, 2011

AOD (AERONET: DRAGON)
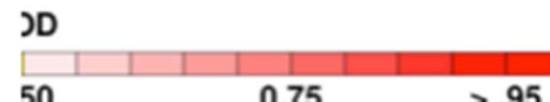

(N 38.7950, W 77.4000)　　　　(N 38.7950, W 75.7500)

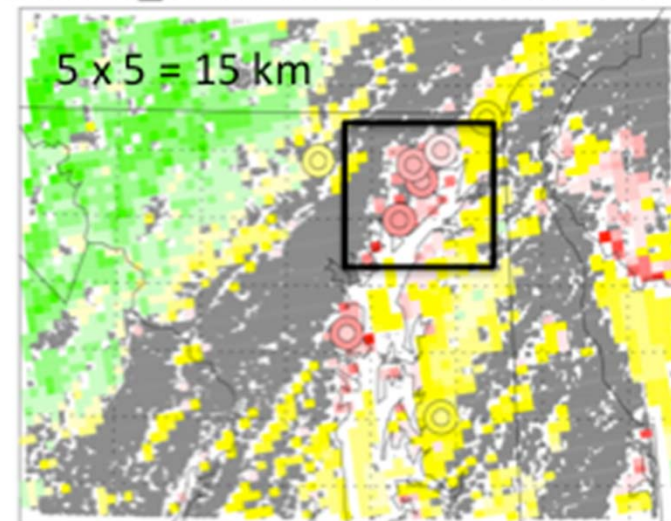- DRAGON = Many AERONET over Maryland during DISCOVER-AQ experiment, July 2011
- For MODIS plots, QA=3 only
  - Circle Center = AERONET ±2 hours
  - Circle Outer = MODIS 5 x 5 box
- 3km (bottom) resolves Baltimore maxima
- Gray is MODIS-Aerosol cloud mask
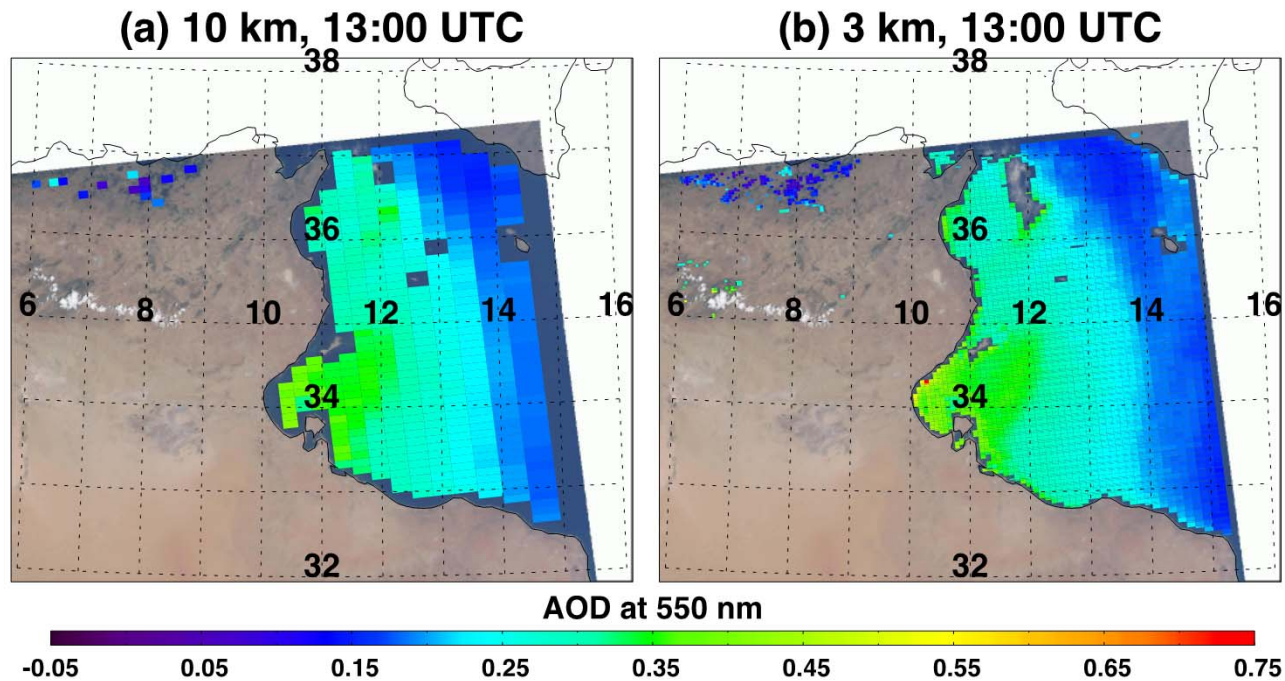- 3km also resolves aerosol over Ches. Bay

MYD04_10km 550 um 2011202 18:30

5 x 5 = 50 km

MYD04_03km 550 um 2011202 18:30

5 x 5 = 15 km

39

L. Munchak

(a) 10 km, 13:00 UTC   (b) 3 km, 13:00 UTC

AOD at 550 nm

-0.05   0.05   0.15   0.25   0.35   0.45   0.55   0.65   0.75

MODIS 3 km product (operational for C006)

- Algorithm structurally identical to standard "10 km" retrieval
- Results will be in new files, *'MOD04_3K'*
- Over land and ocean, (but no Deep Blue yet).
- Both MOD04_L2 and MOD04_3K will be available

S. Mattoo, L. Munchak, M. Martins, L. Remer, B. Holben, et al

Summary (1)

- Dark-target algorithm/products are updated for C6, but only "modest" changes (no major science updates).

- "Modest" is relative... Many difficult decisions about seemingly small things that actually were significant. (e.g. Gas Correction, Cloud Mask, Quality Assurance etc).

- Upstream changes (L1B and MOD35) meant we had to re-analyze, over and over.

- Not superhero like, but there were mistakes (bugs carried over from C5) that needed re-analysis.

- Dark-target and Deep-blue products are merged, leading to more global coverage

Summary (2)

- MODIS aerosol retrieval was intended for *global* climate applications
  - Air quality events are sometimes on urban and local scales
  - Aerosol properties change near clouds
  - → The MODIS dark-target team is offering 3 km operational aerosol data.
  - Issues in land/sea/coastal are ACCENTUATED!

Trying to get C6 into product is like…

… Being Sisyphus
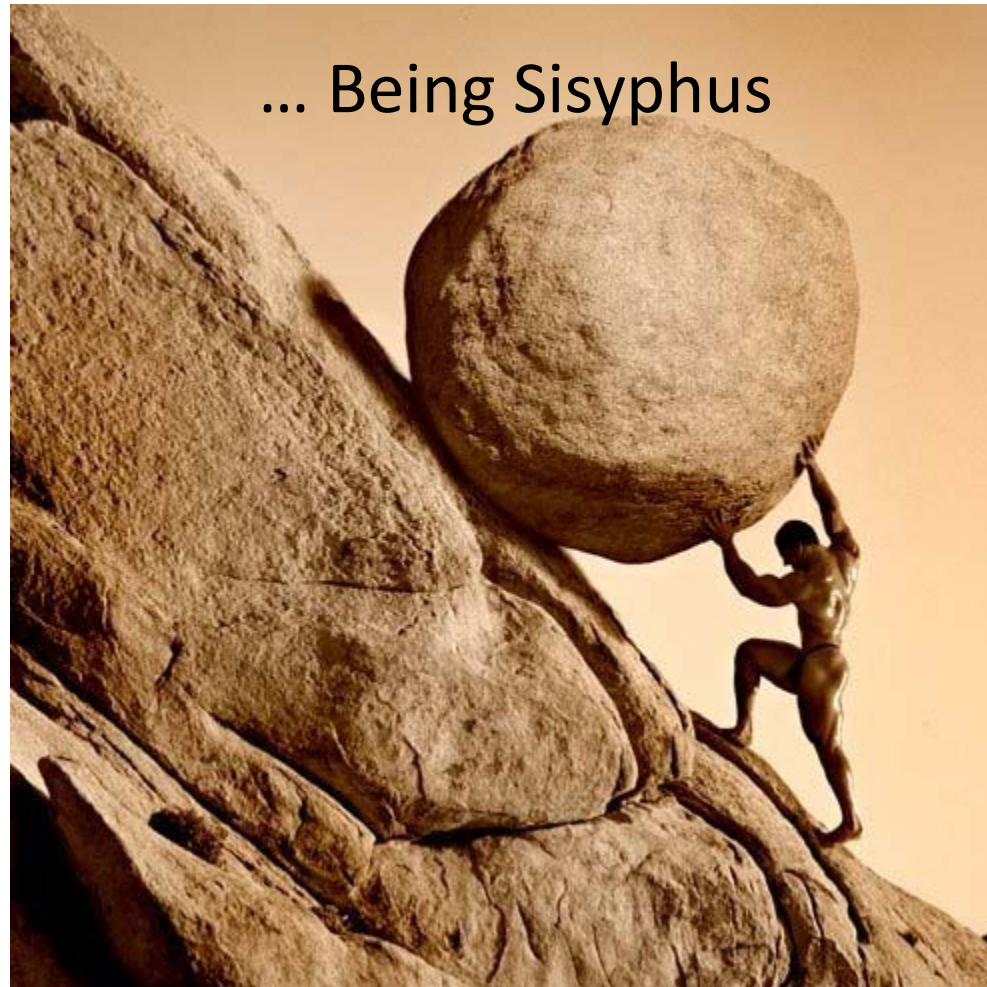
Hopefully, there will be no season IV for "Introducing Collection 6 products"

On towards Collection 7!

At the Yoram memorial tree outside of Bldg #33

- Proper per-pixel error products

- Better urban retrievals

- Use IR information for dust detection

- Etc: It's proposal season!

THANK YOU FOR YOUR ATTENTION !!!