Evaluation of a regional air quality forecast model using OMI/AURA tropospheric NO_2 and preliminary tropospheric O_3 (and AIRS CO)

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Atmospheric Composition Constellation (ACC) Workshop on Air Quality

ESRIN, Frascati, Italy, June 16, 2009

PRESENTATION OUTLINE:

1. Introduce AIRPACT-3 and OMI
2. Discuss limitations and methods for column integration of species while comparing satellite products with an AQ forecast
3. Discuss seasonal variation in AIRPACT - OMI tropospheric NO2 biases
4. Discuss use of OMI tropospheric NO2 measurements for evaluation and adjustment of the AIRPACT-3 emission inventory.
5. Discuss preliminary tropospheric ozone columns (provided by Xiong Liu) from OMI as compared to AIRPACT-3.
6. Discuss Carbon Monoxide retrievals as a potential adjustment for boundary conditions in AIRPACT

WASHINGTON STATE UNIVERSITY

AIRPACT-3 http://lar.wsu.edu/airpact-3/

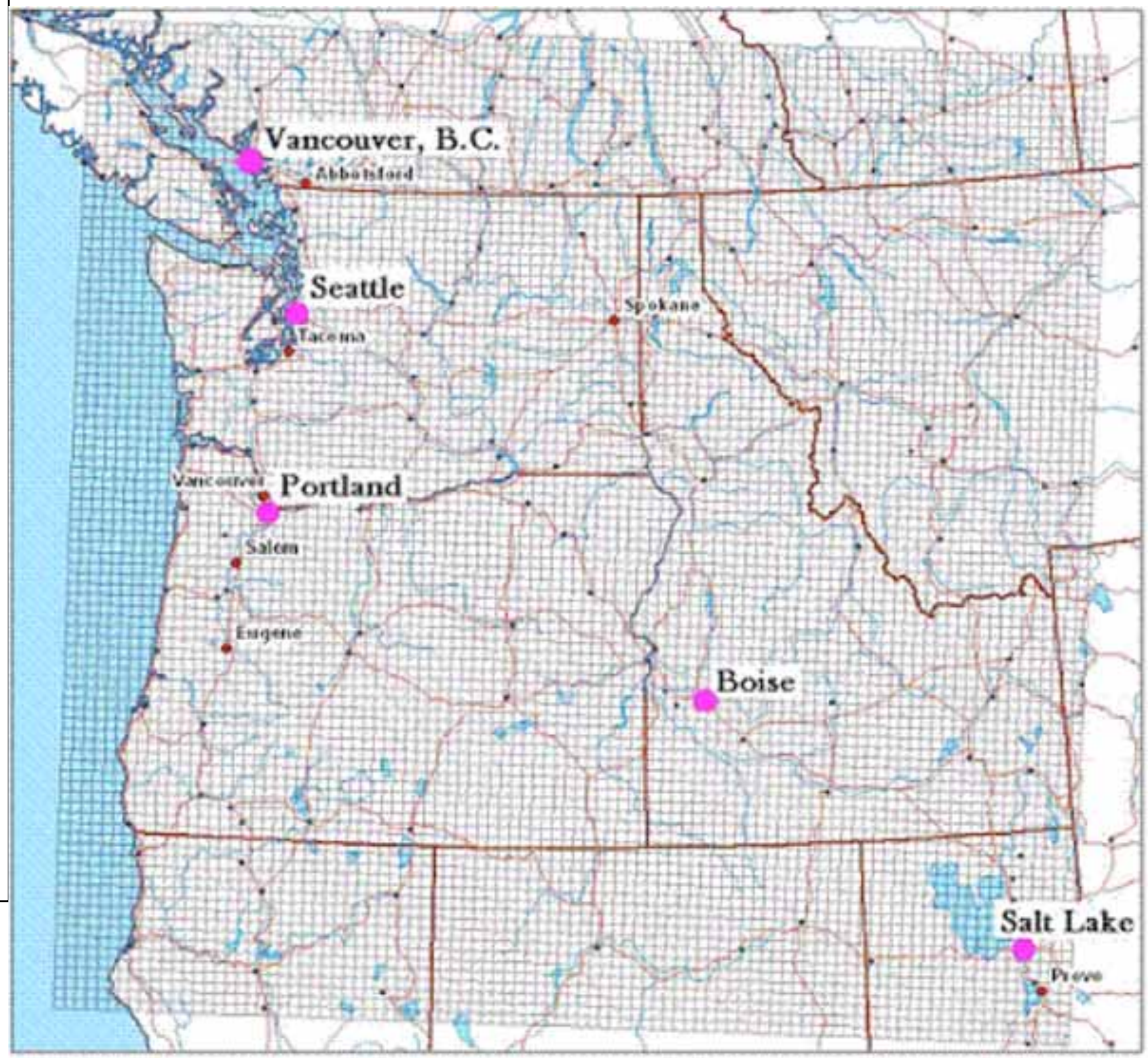
Air Indicator Report for Public Access and Community Tracking v3

AIRPACT is an air quality forecast system that uses community modeling software: WRF (meteorology), SMOKE (emissions), & CMAQ (chemistry & physics) for simulating air pollution. (95 x 95 x 21 Grid, 12 km x 12km x Eta Level).

The goal of the AIRPACT project is to provide timely air quality (AQ) information to people in the Pacific Northwest region, from both model results and monitoring stations.

AIRPACT has been developed with support from US EPA Region 10, the WA Department of Ecology, the Oregon & Idaho Departments of Environmental Quality, and the Puget Sound Clean Air Agency, among others.

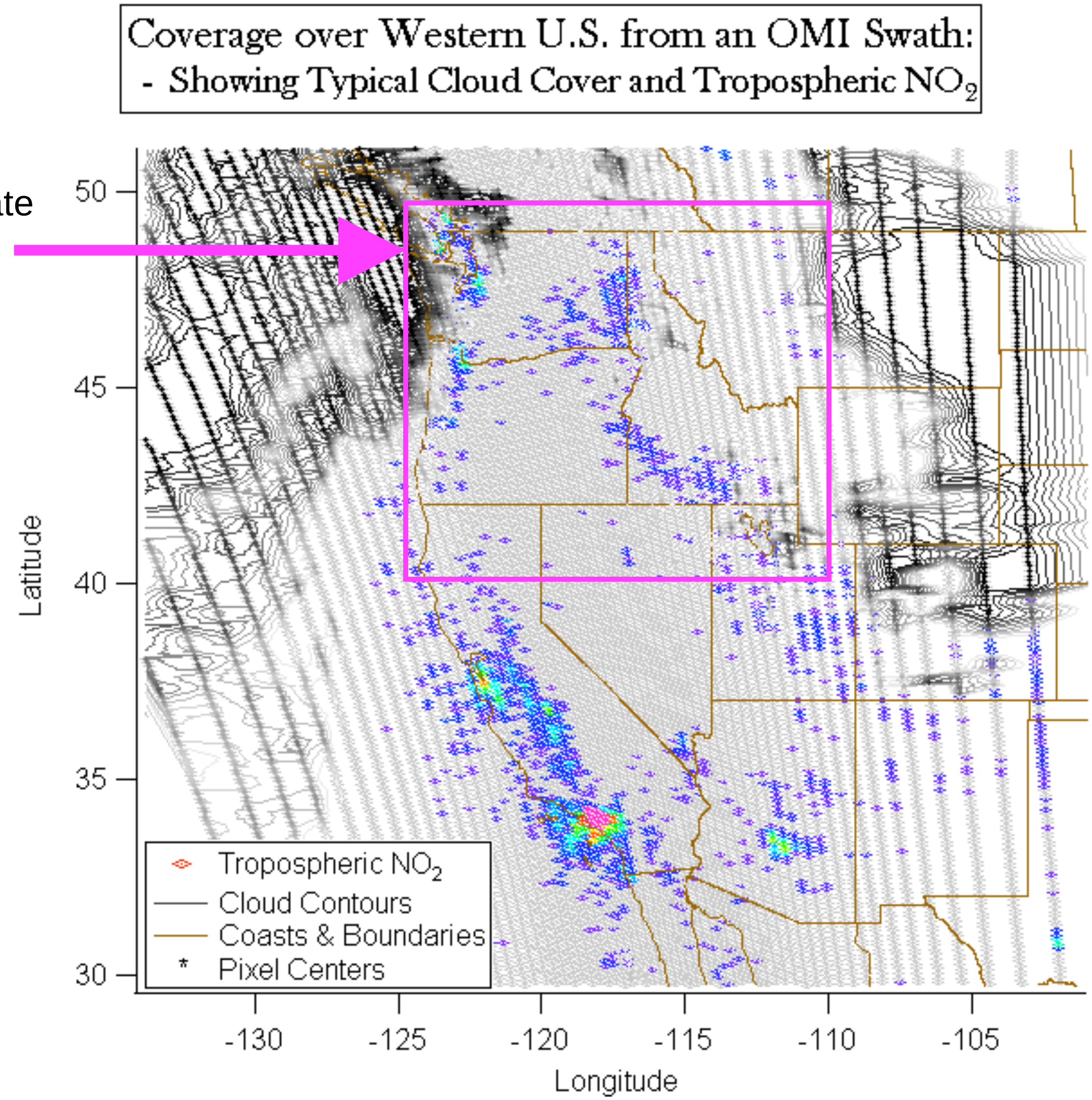
The AIRPACT DOMAIN (Pacific NW):



OMI *Ozone Monitoring Instrument* http://aura.gsfc.nasa.gov/

KNMI (Dutch) Instrument aboard Aura (NASA) Satellite retrieving daily global tropospheric and stratospheric chemistry of NO_2, O_3, AOD, SO_2, & HCHO. The following analyses utilize US OMI Level 2 NO_2 (Collection 3). 13 x 24 km2 footprint at swath center

Approximate AIRPACT domain



OVERALL GOAL:

To improve the AIRPACT air-quality forecast system using NASA satellite retrievals of trace gases.

LIMITATIONS:

1. A high cloud fraction in the pacific northwest limits the amount of high quality tropospheric data available.

2. The time lag before satellite data is available (approximately 1.5 days).

3. The ability of satellites to detect trace gases at or near the surface is severely limited, but the surface layer is the most important region for air quality decision support systems.

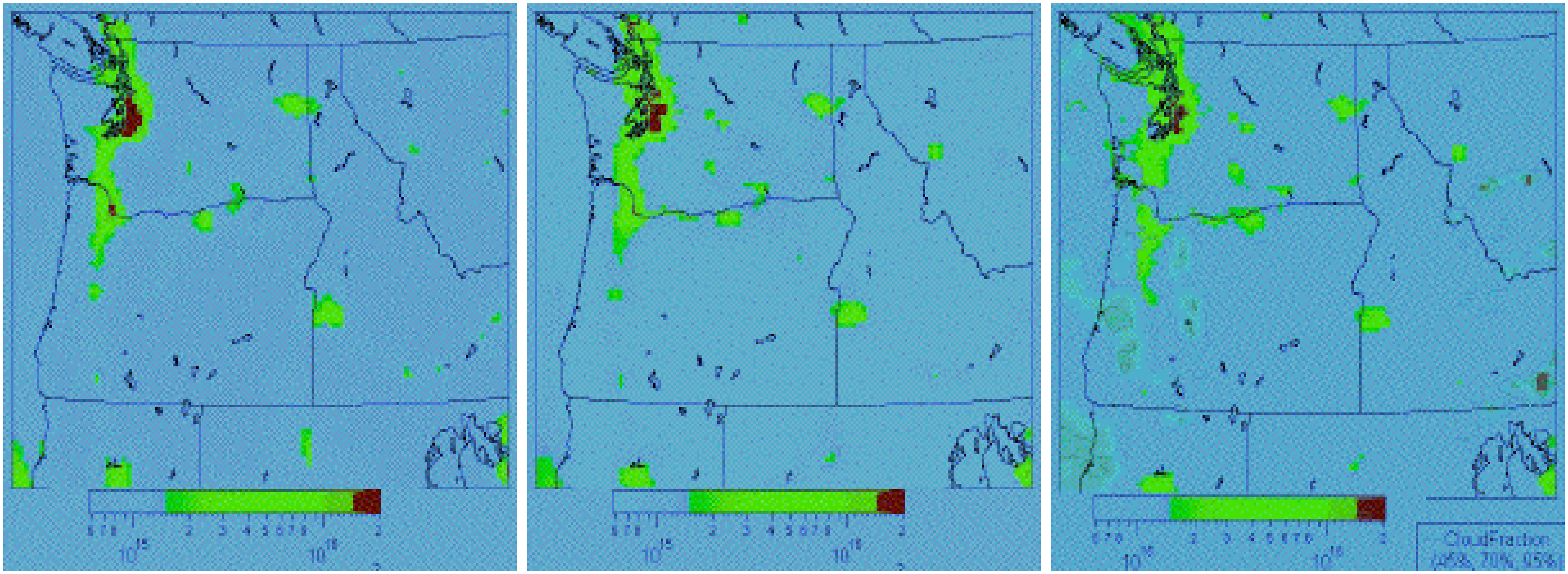
4. There is generally only one satellite retrieval per geo-location per day to be used for a more temporally and spatially resolved air quality forecast system.

5. There are very few surface monitors for species such as NOx in the Pacific Northwest, making validation very difficult (except for PM and O3).

<u>What is the effect of applying the OMI NO_2 Averaging Kernel to AIRPACT Forecasts?</u>

The results of three methods for column integration of AIRPACT NO_2 (October 1, 2008 is shown):

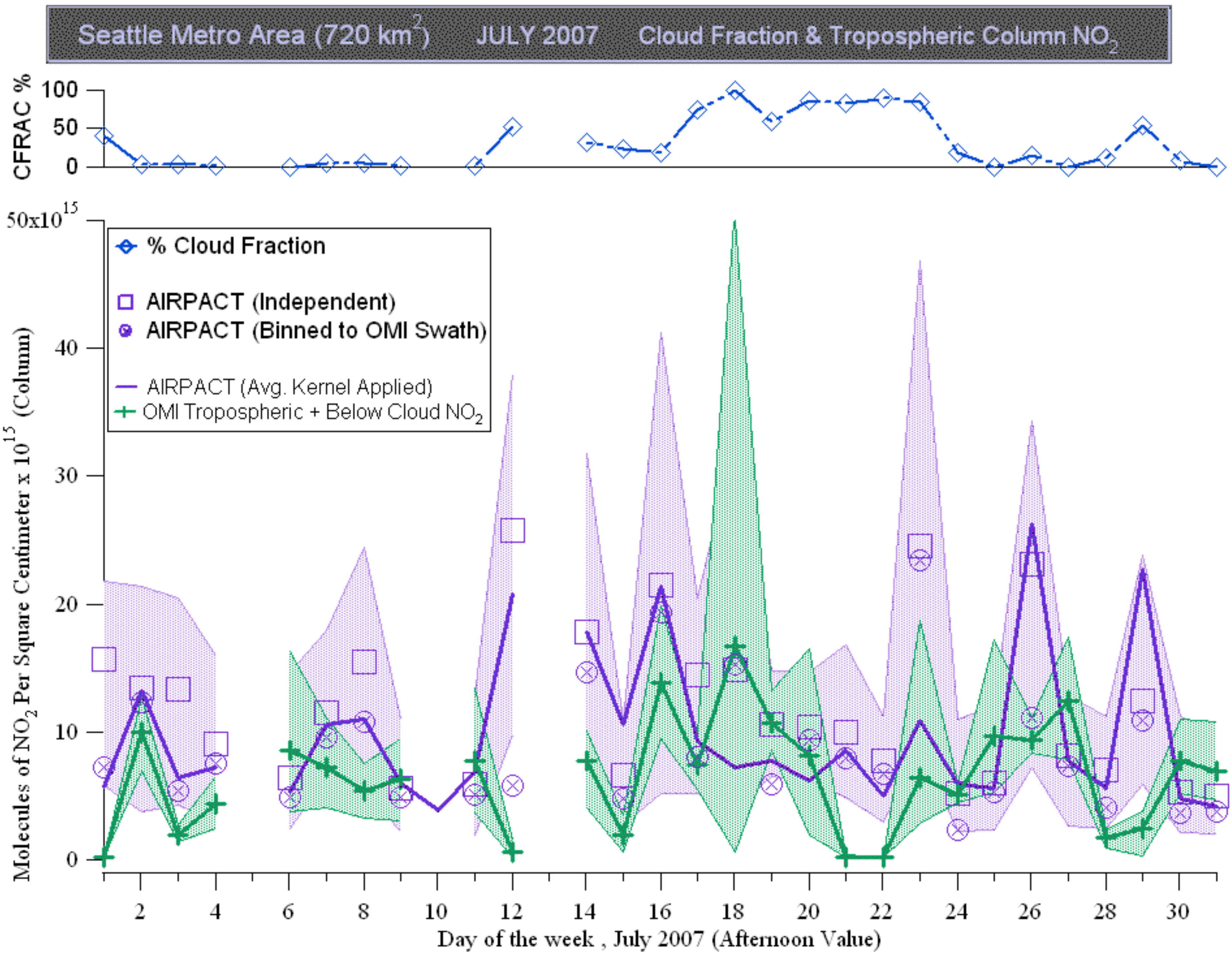
1) <u>Independent Integration</u> 2) <u>Binned & Averaged to OMI Grid</u> 3) <u>OMI Averaging Kernel Applied</u> (with cloud mask)



The effect of applying the averaging kernel is apparent when comparing images (2) and (3). The largest discrepancies are where there is high cloud fraction in the OMI retrieval (mostly masked). (Cloudy pixels, over 35%, are excluded from all AIRPACT analyses.)

Overall, binning and averaging to the OMI grid has a more significant change on our analysis than applying the averaging kernel itself.

Note: Applying the averaging kernel is equivalent to calculating a theoretical AIRPACT slant column and dividing by the OMI air mass factor based on *a priori* profiles.



Seattle Metro Area (720 km2) JULY 2007 Cloud Fraction & Tropospheric Column NO2
CFRAC %
100
50
0
50x10^15
40
30
20
10
0
Molecules of NO2 Per Square Centimeter x 10^15 (Column)
% Cloud Fraction
AIRPACT (Independent)
AIRPACT (Binned to OMI Swath)
AIRPACT (Avg. Kernel Applied)
OMI Tropospheric + Below Cloud NO2
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
Day of the week , July 2007 (Afternoon Value)

Data Flow for Tropospheric NO_2 Column Comparisons using spatial averaging

*Note: Trop. Ozone steps are essentially the same (Except # of layers).

OMI Preparation:

1. Nearest HDF orbit file to domain is downloaded from NASA
2. “Below Cloud NO2” & “Tropospheric NO2” are summed
3. Lambert Equal Area Projection of pixel center coordinates
4. Data array interpolated to a latitudinally parallel grid using Delaunay triangulation

AIRPACT Preparation:

1. Press, Temp, NO_2 (VMR), & Height are extracted from AIRPACT
2. VCD = VMR x N(p,T) x H (at 2 p.m.) per layer
3. AIRPACT pixels are binned to the daily OMI pixel locations and averaged
4. All 21 layers are summed to a “Tropospheric Column”
5. Lambert Equal Area Projection of pixel center coordinates
6. Data array interpolated to a latitudinally parallel grid using Delaunay triangulation

Processing Steps:

1. Both grids are masked from areas where OMI Cloud Fraction > 35%
2. Domain averages, bias, ratio, & correlation calculated on a per month basis.
3. Results analyzed to identify areas where NOx emissions should be adjusted

Preliminary Emissions Adjustment Procedure: (for retrospective analyses and testing)

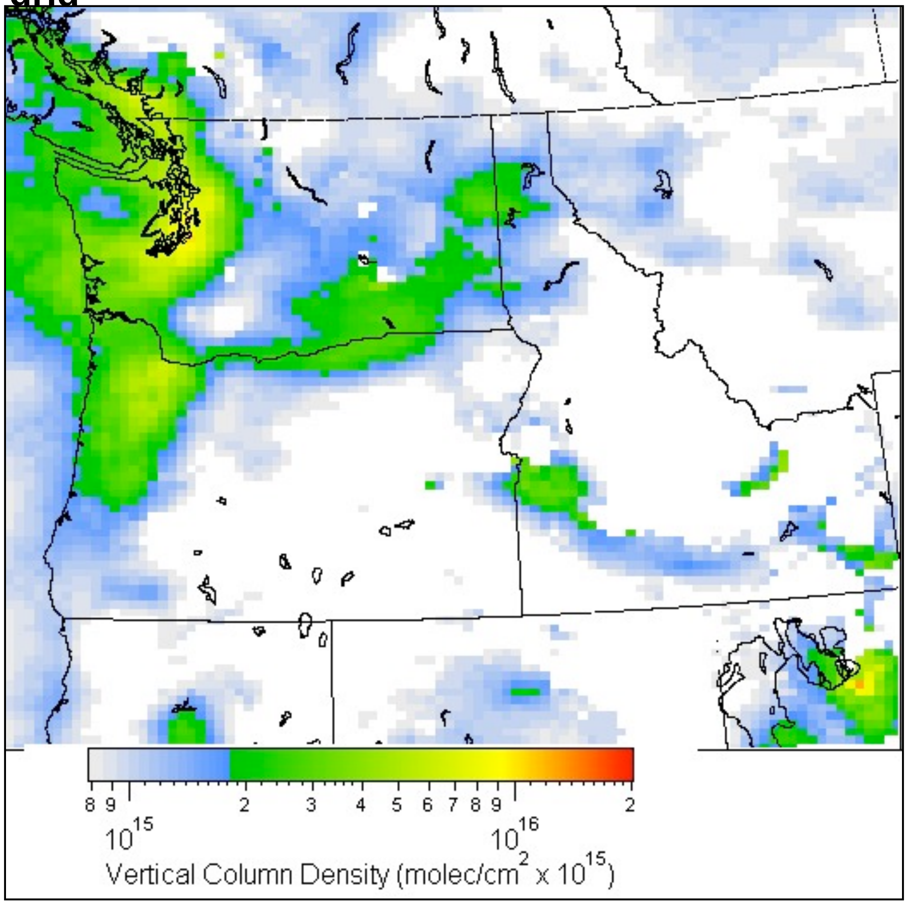
1. Calculate OMI / AIRPACT NO2 ratio for use as a NOx multiplier matrix. (Monthly Avg.)
2. Each day, process the AIRPACT emissions and multiply the AIRPACT NOx emission rates by the OMI/AIRPACT NO2 ratio (Other methods— i.e. Kalman filters are of interest)

*Note: Future Emissions Adjustments for operational forecasts may use immediately past OMI retrievals

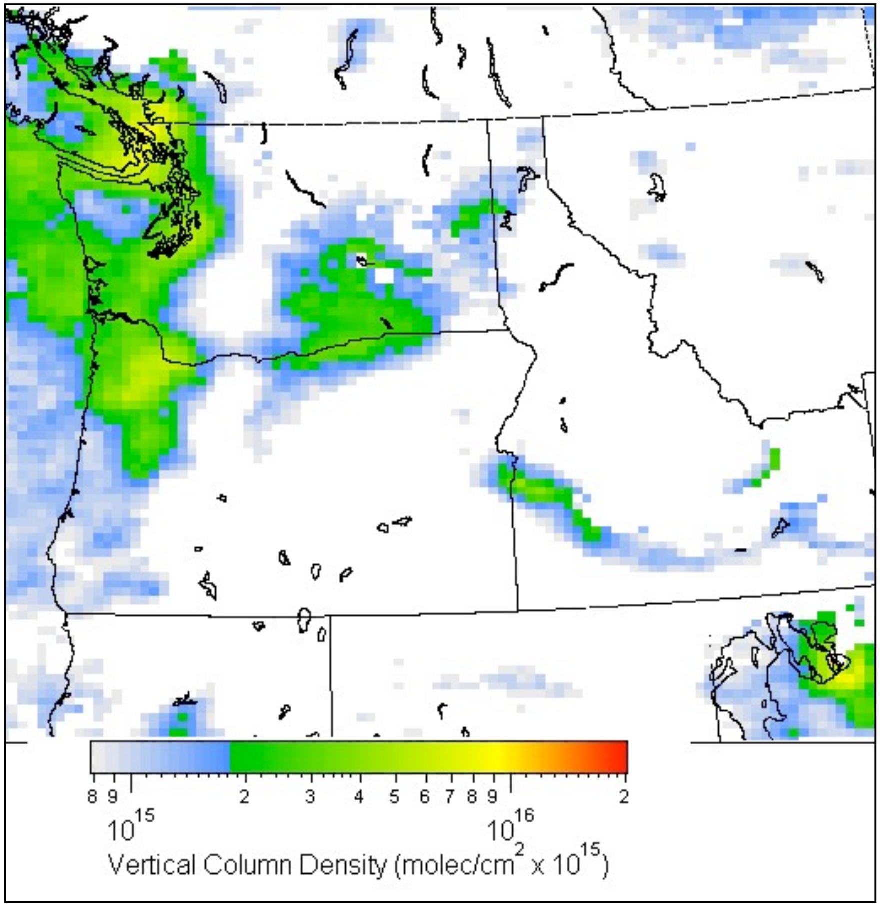
An example comparison for AIRPACT vs OMI

January 2008 Tropospheric NO_2 Monthly Averages (Winter)

AIRPACT Tropospheric NO_2 VCD
"Binned and Averaged" to the L2 OMI daily grid



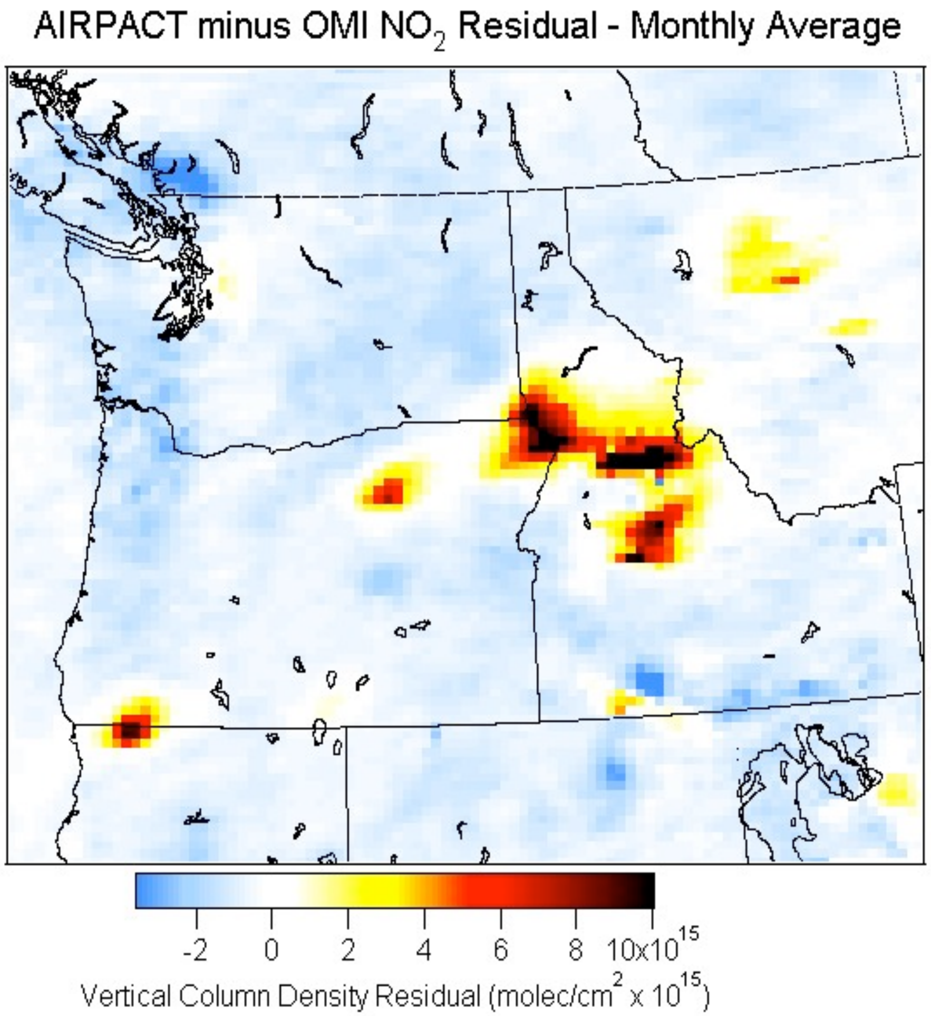
L2 OMI Tropospheric NO_2 VCD



Tropospheric NO_2 Monthly Average Biases (seasonality)

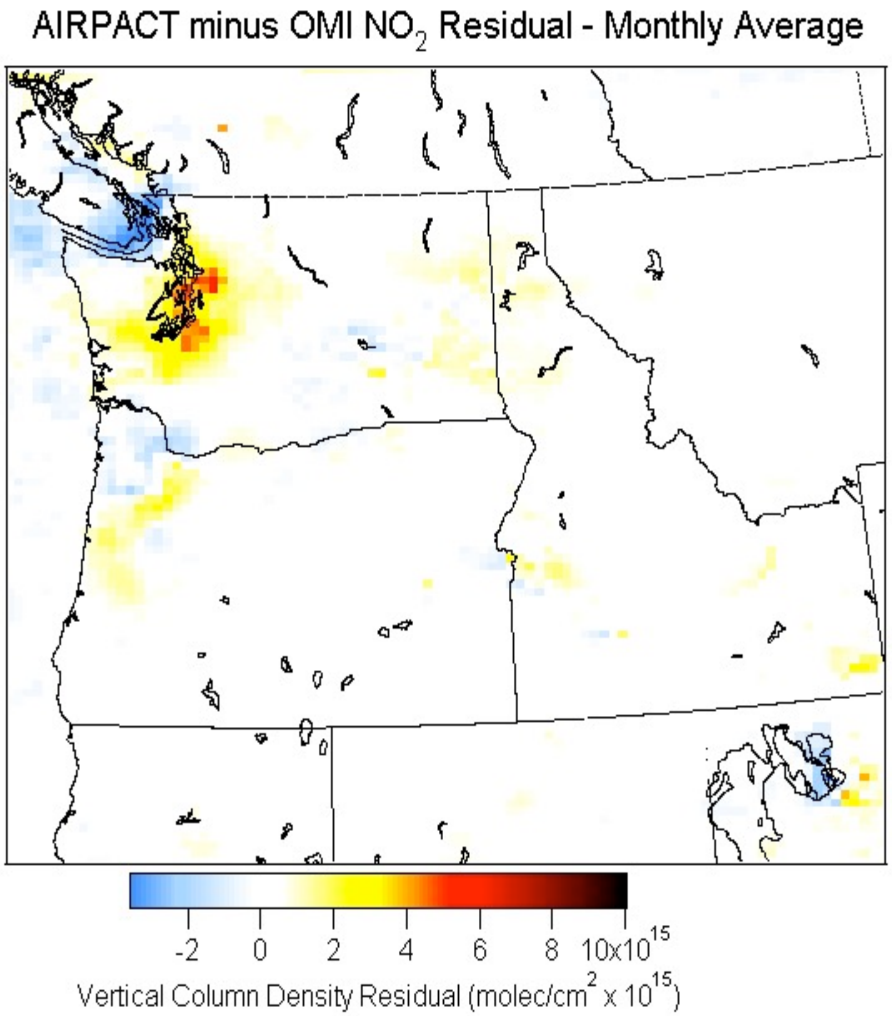
July 2007 – (Summer)

Good urban area accuracy
Poor wildfire area accuracy
much of the domain biased towards OMI

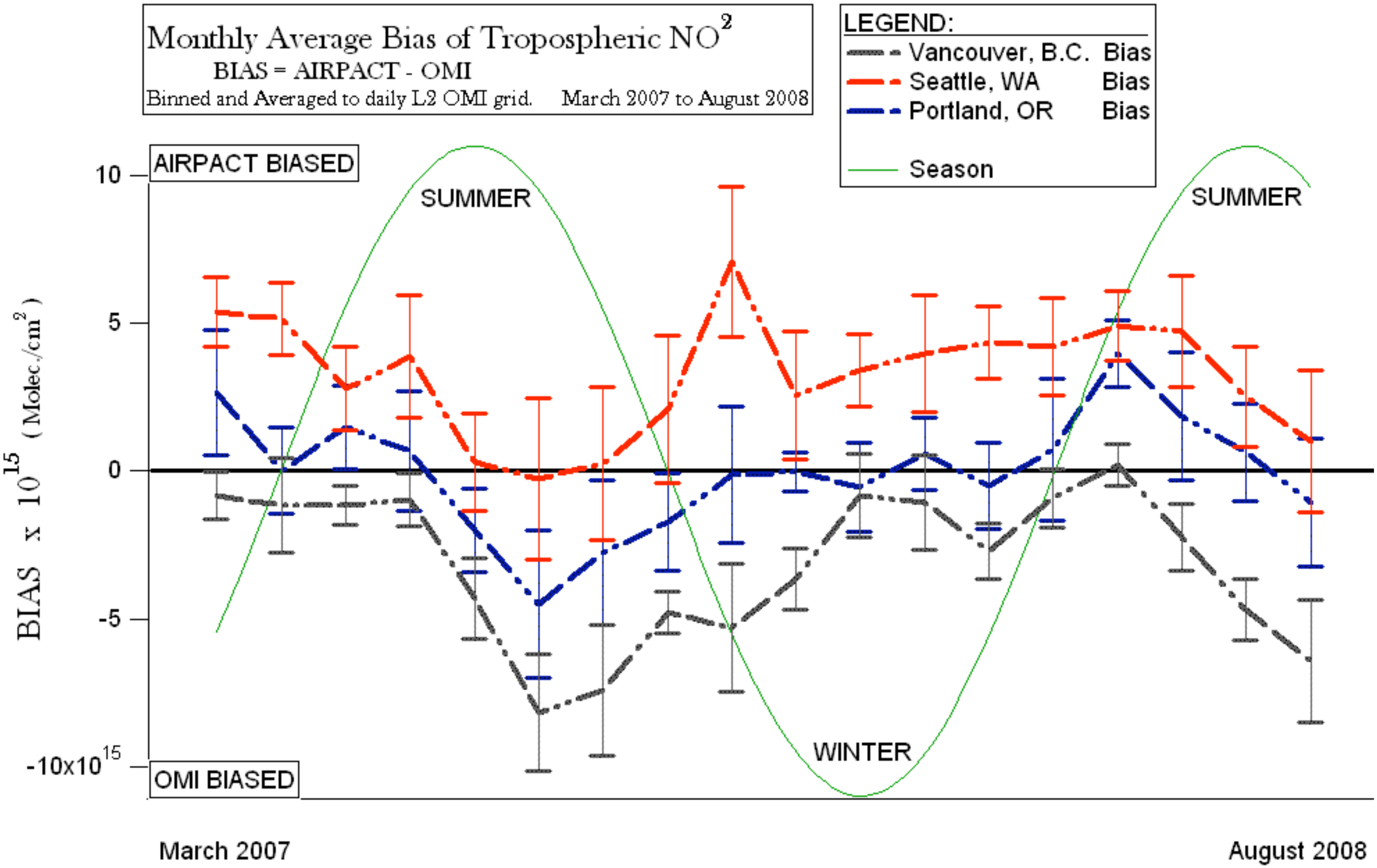


January 2008 – (Winter)

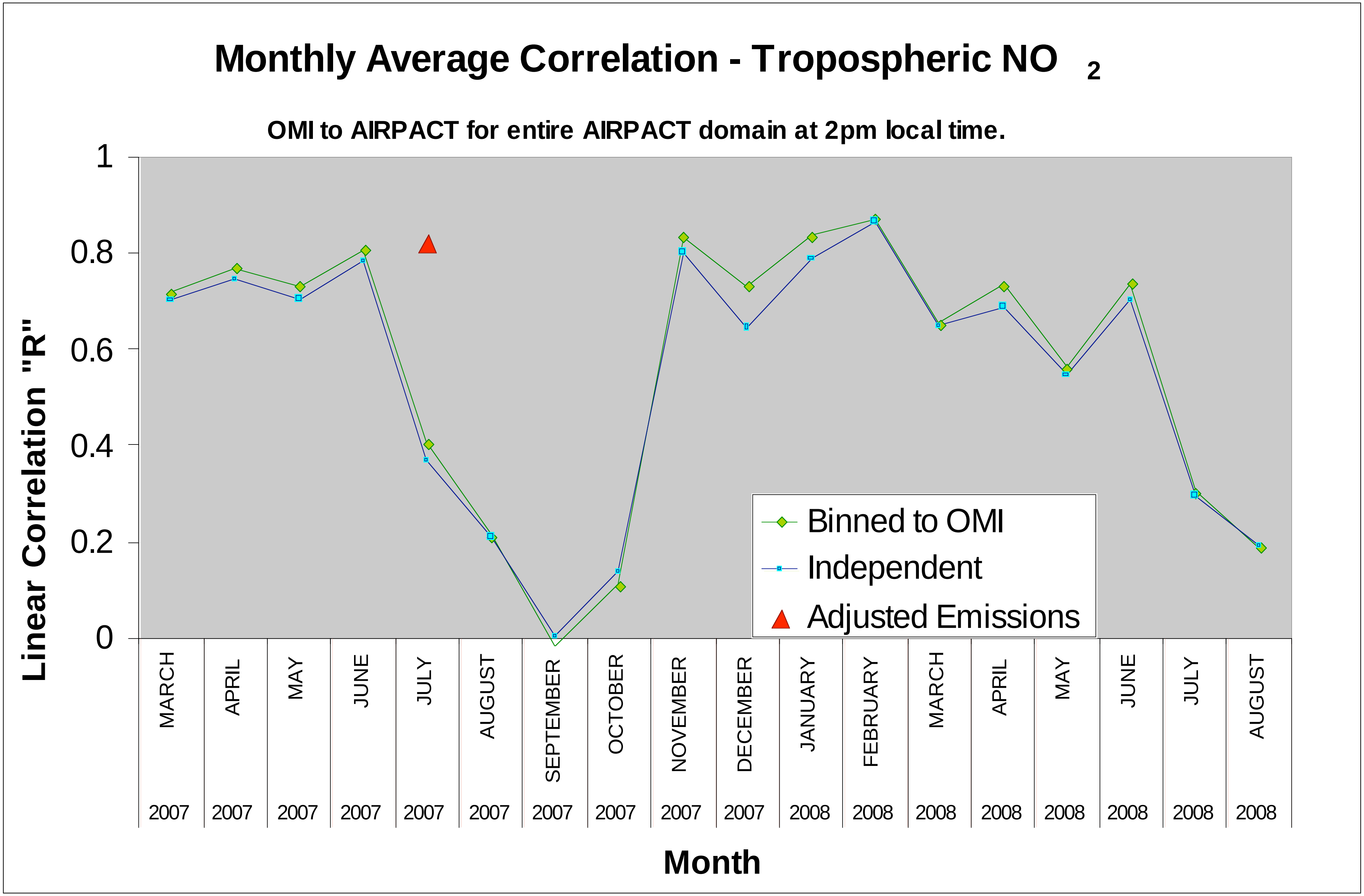
Many urban areas biased towards AIRPACT
Good agreement over much of the domain



Tropospheric NO_2 Monthly Average Biases in Urban Areas



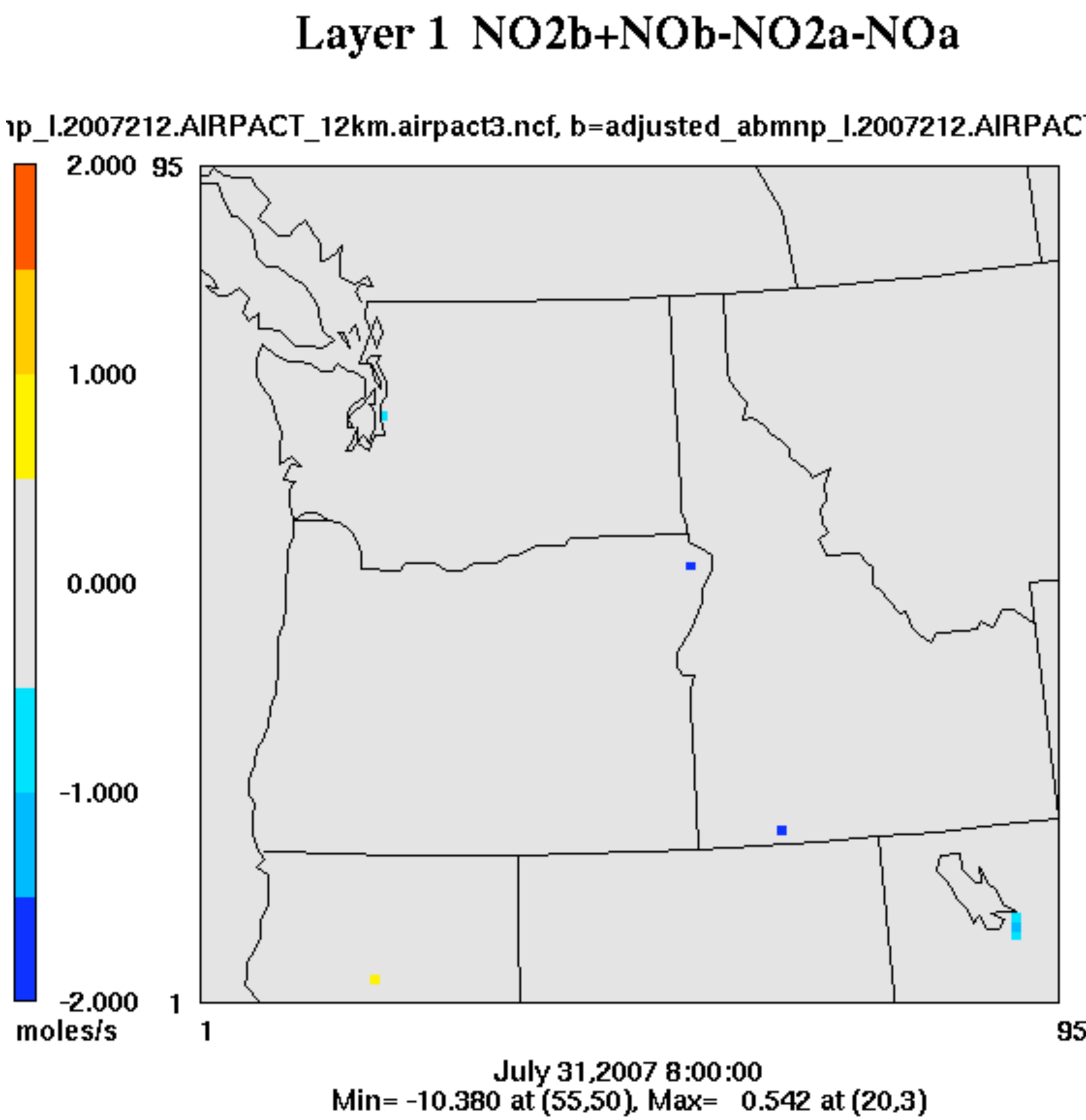
The seasonal swing in NO2 concentrations retrieved by OMI has been attributed to the annual average of stratospheric NO2 used in the tropospheric NO2 algorithm. This is not a problem with the KNMI algorithm and should be fixed in the next NASA algorithm.



**** Note: large drop in correlation during wildfire (summer) seasons.***

AIRPACT emissions adjustment for summer NOx (July 31, 2007)

Based on the Monthly Average of OMI to AIRPACT



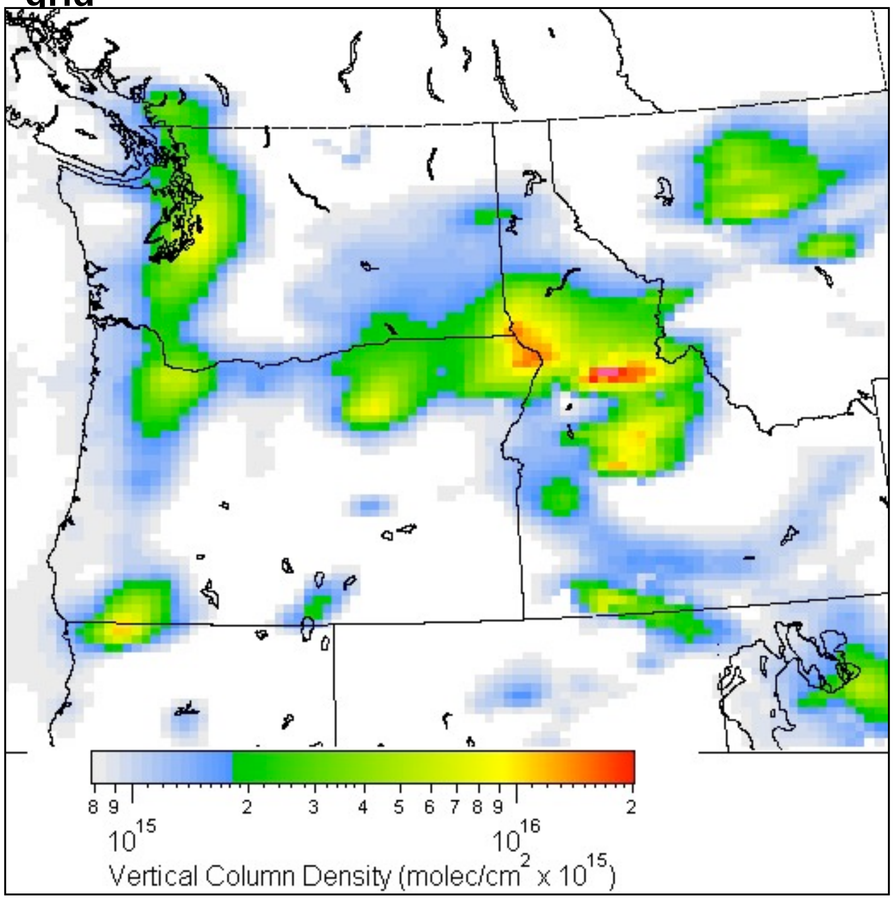
Note: many AIRPACT pixels do not have a strong emission source on inventory and so those locations have little to no NOx emissions adjustment.

July 2007 Tropospheric NO_2 Monthly Averages (Summer)

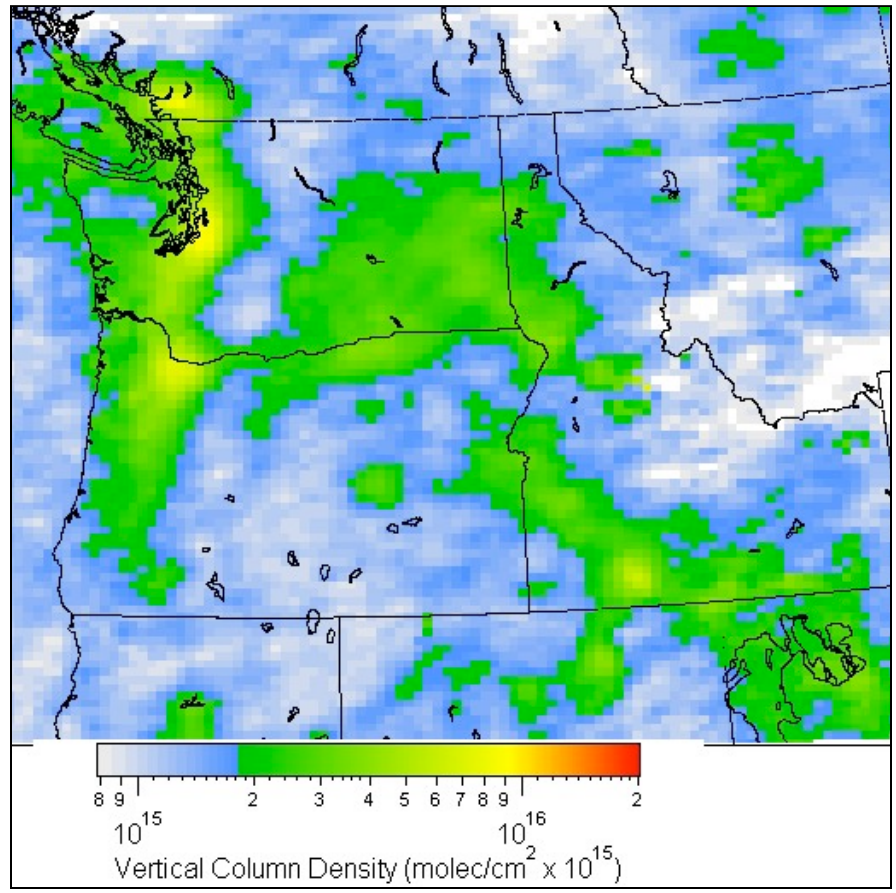
Before Adjusted NOx Emissions

R=0.41

AIRPACT Tropospheric NO_2 VCD
"Binned and Averaged" to the L2 OMI daily grid



L2 OMI Tropospheric NO_2 VCD

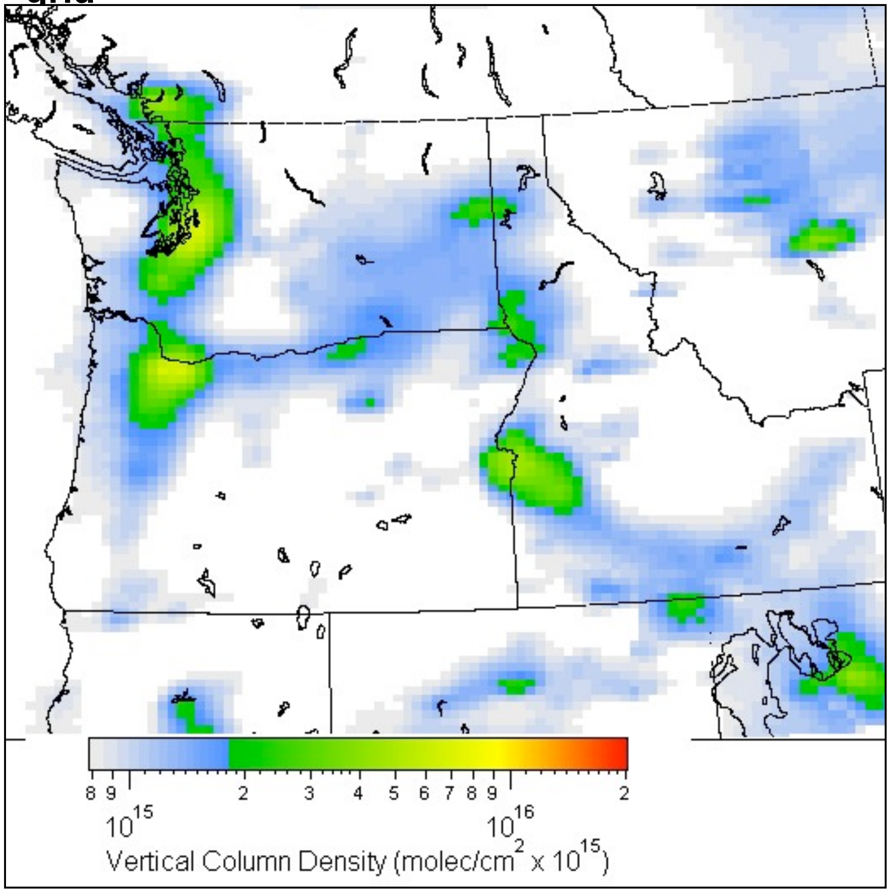


July 2007 Tropospheric NO_2 Monthly Averages (Summer)

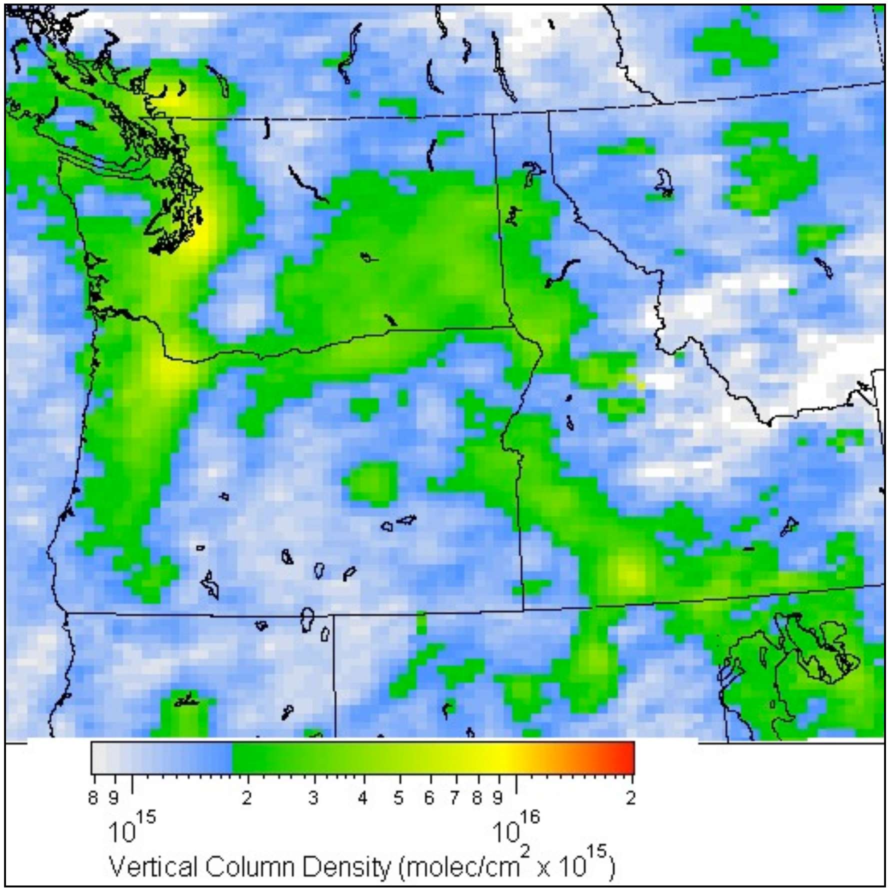
After Adjusted NOx Emissions

R=0.82

AIRPACT Tropospheric NO_2 VCD
"Binned and Averaged" to the L2 OMI daily grid

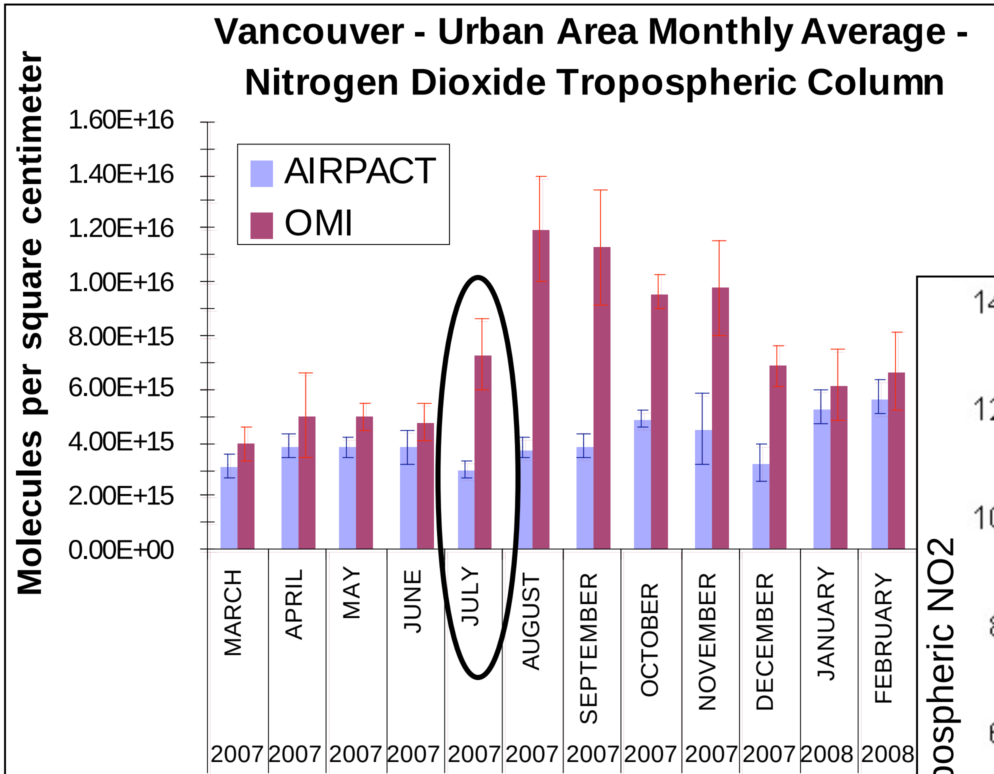


L2 OMI Tropospheric NO_2 VCD

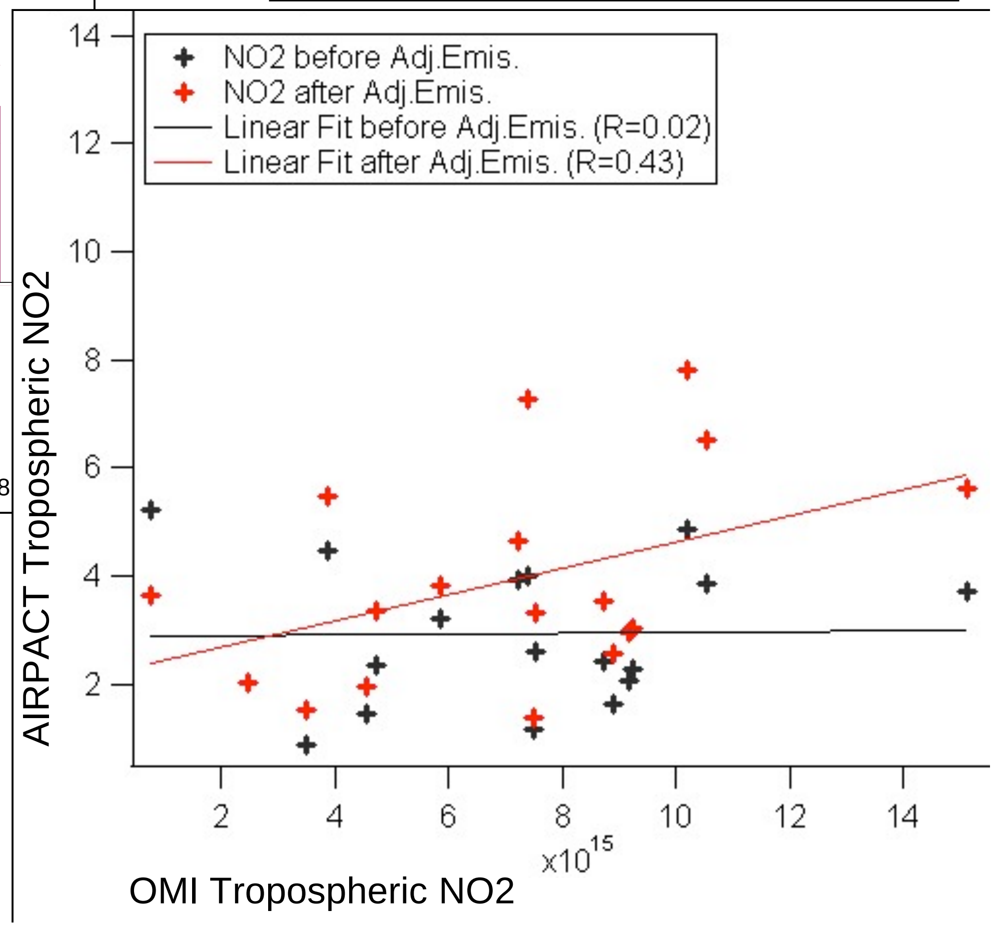


Vancouver, B.C., Canada

An example of urban NOx emission adjustment



Change in AIRPACT Trop. NO_2 VCD from Emis.Adj.
Cloud Free Days – July 2007:



(Urban Area Example – daily)

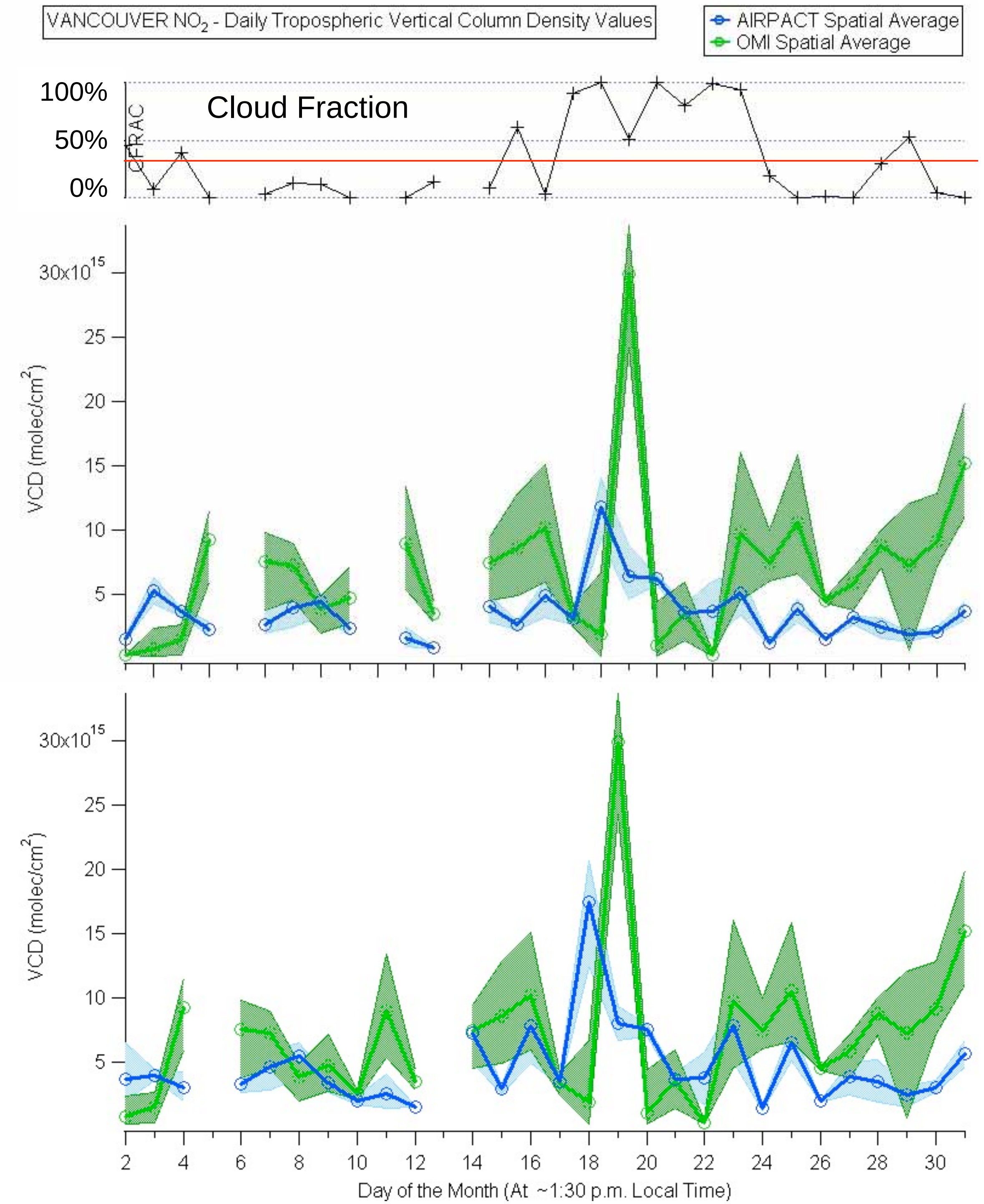
JULY 2007 –

Vancouver, B.C., Canada.

AIRPACT and OMI VCD Tropospheric NO_2 before NOx emissions adjustment

AIRPACT and OMI VCD Tropospheric NO_2 after a daily NOx emissions adjustment

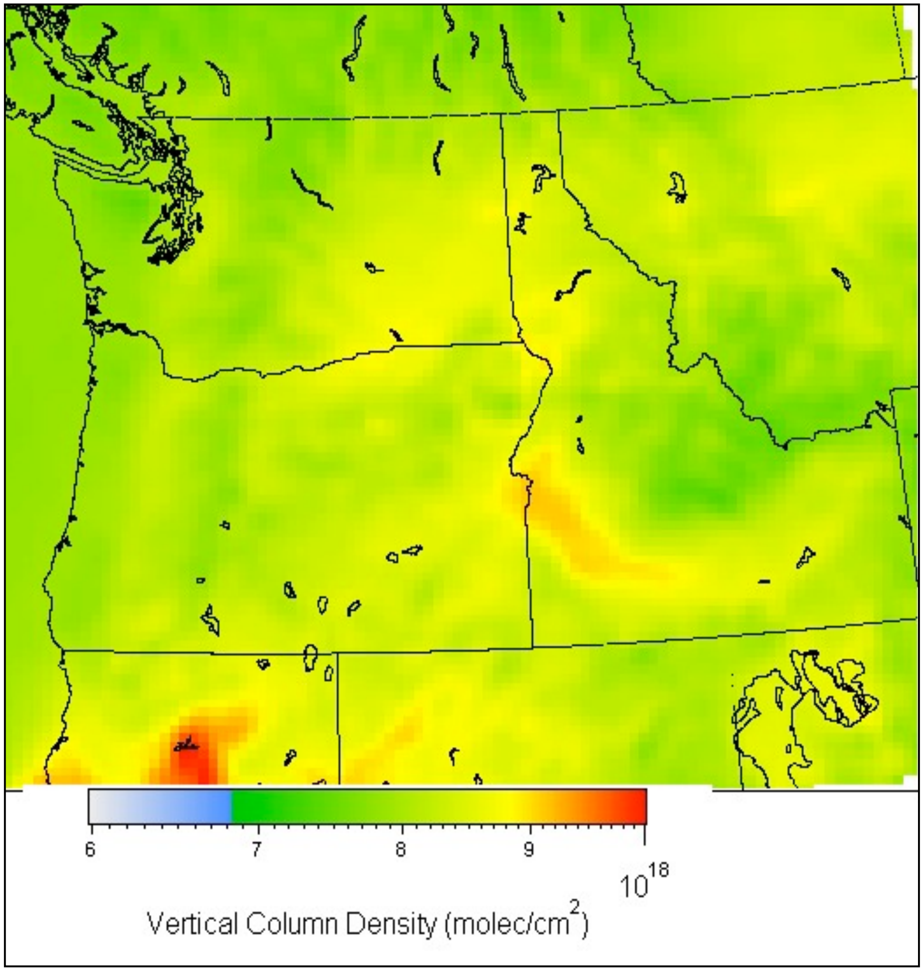
(based on the NO2 monthly average OMI/AIRPACT ratio)



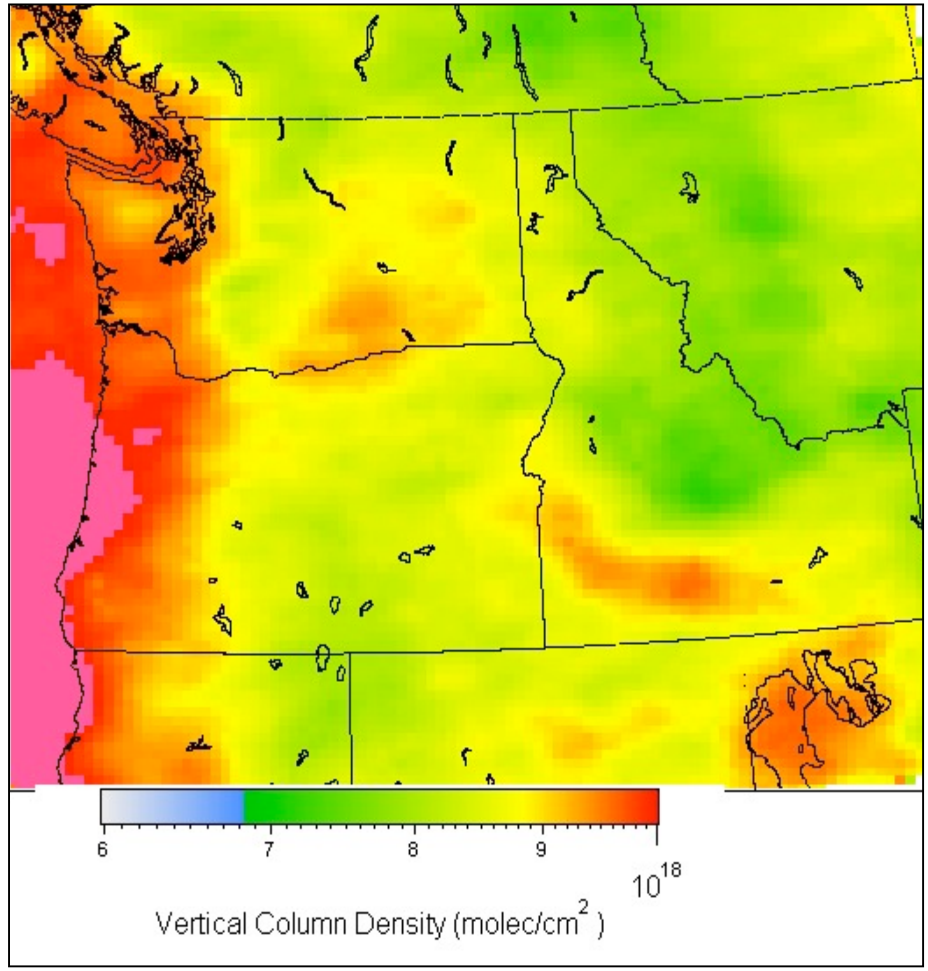
July 2007 Tropospheric O_3 Monthly Averages (Summer)

Independent Comparison (Not spatially averaged to OMI swath)

AIRPACT Tropospheric O_3 VCD



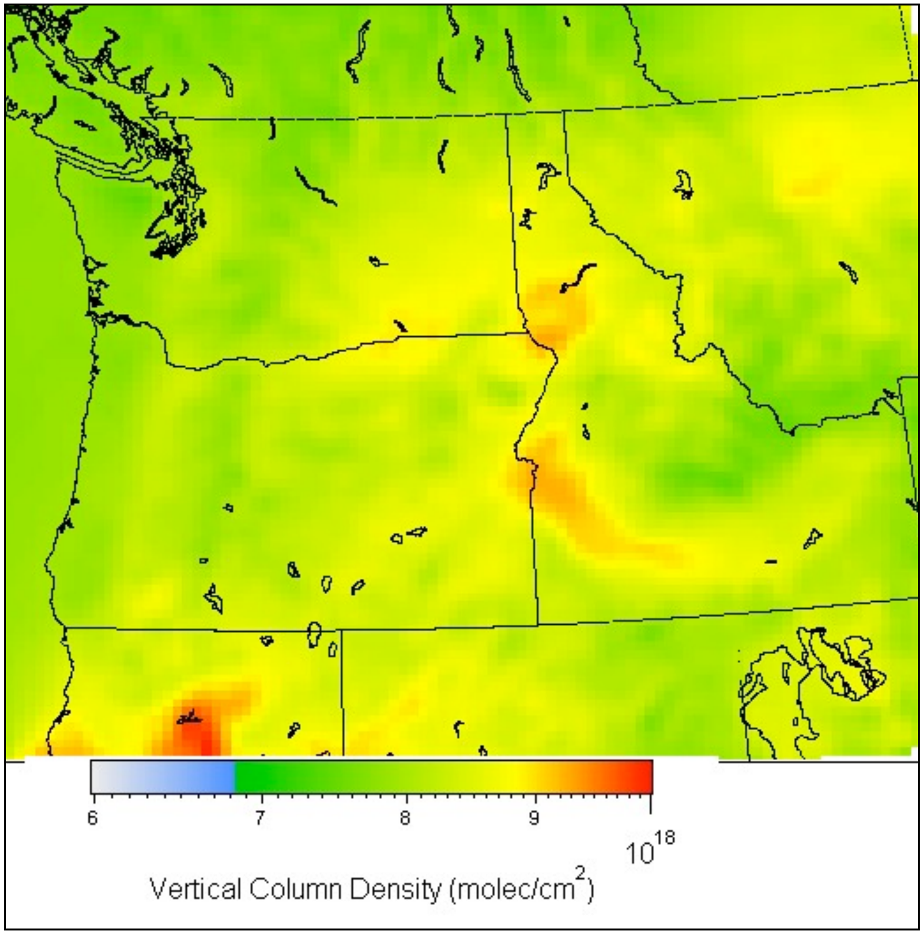
L2 OMI Tropospheric O_3 VCD (Xiong Liu)



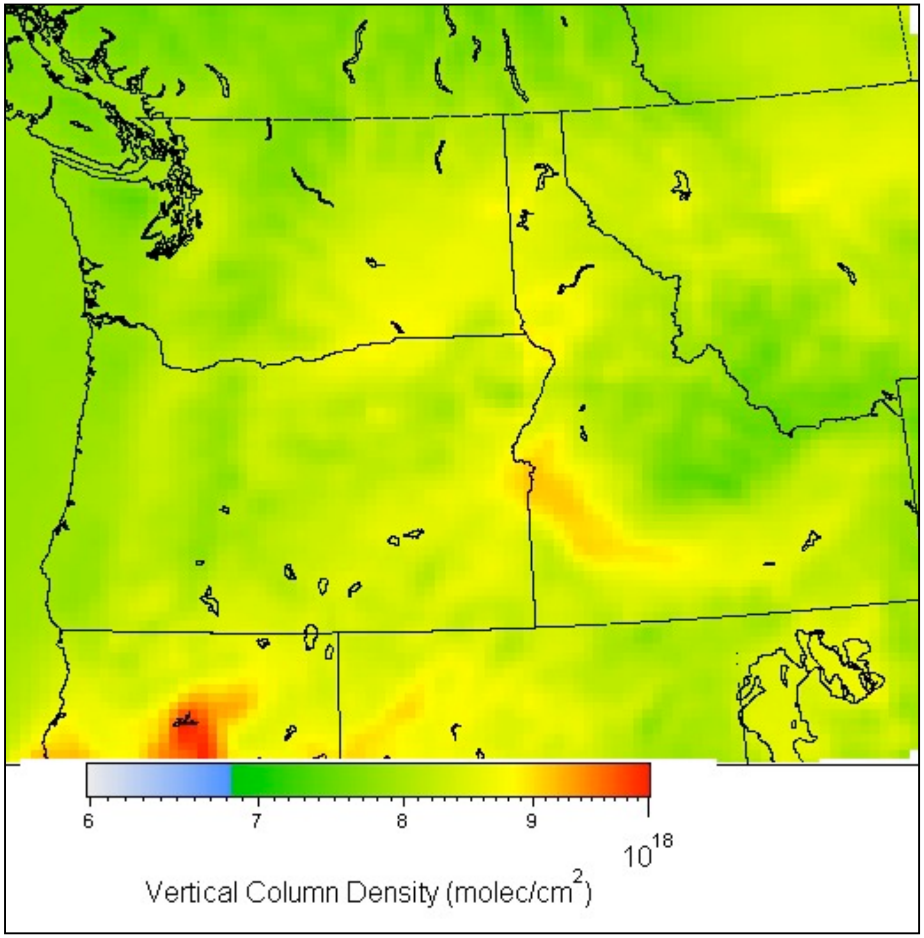
"Given the ozone burden above the boundary layer and the very weak sensitivity to boundary tropospheric ozone especially at mid-latitude, it is very difficult to see urban signatures. So future comparisons should be of free tropospheric ozone." – Xiong Liu

July 2007 Tropospheric O_3 Monthly Averages (Summer)

Independent AIRPACT Tropospheric O_3 VCD



Independent AIRPACT Tropospheric O_3 VCD
After Adjusted NOx Emissions



NOTE: When accounting for spatial averaging, NOx emissions adjustments raised AIRPACT – OMI Tropospheric Ozone correlation from 0.30 to 0.37

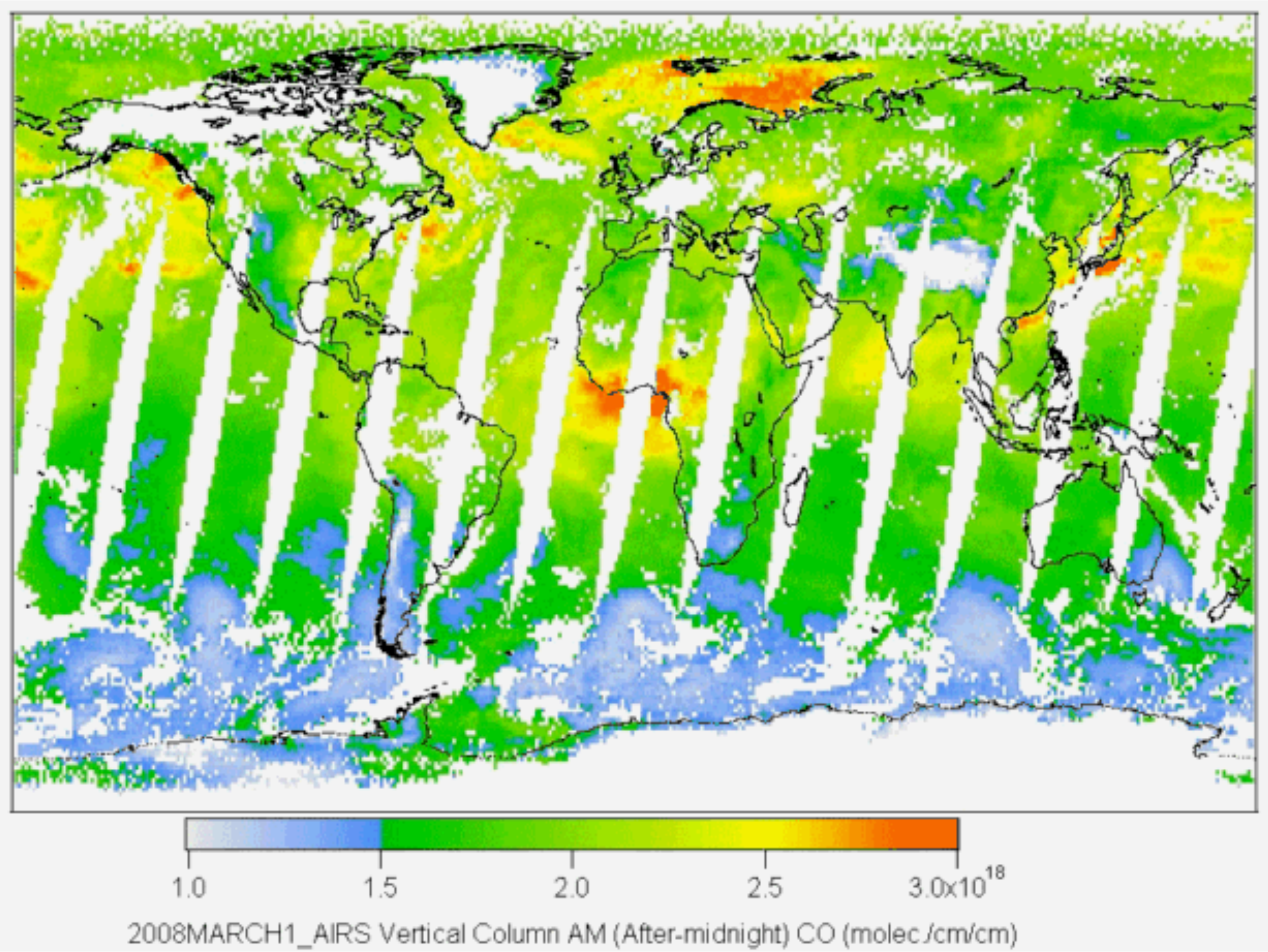
AIRS-AQUA – Carbon Monoxide Retrievals

Atmospheric Infra-Red Sounder http://www-airs.jpl.nasa.gov/

AIRS Carbon Monoxide Columns – March 2008

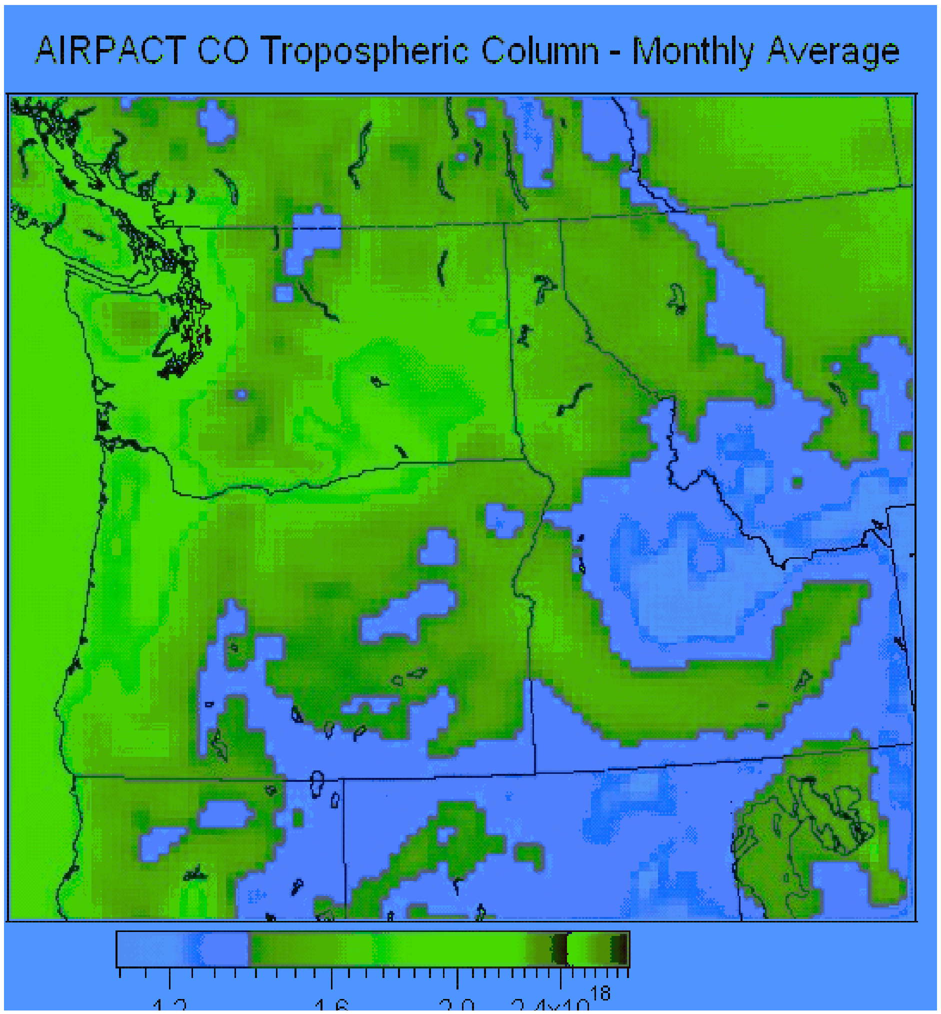
As an Infra-Red sounder, AIRS is able to provide both day and night data for ~1:30 local time, unlike most instruments in the A-Train that utilize visible & U.V. spectral bands and provide data only for the afternoon.

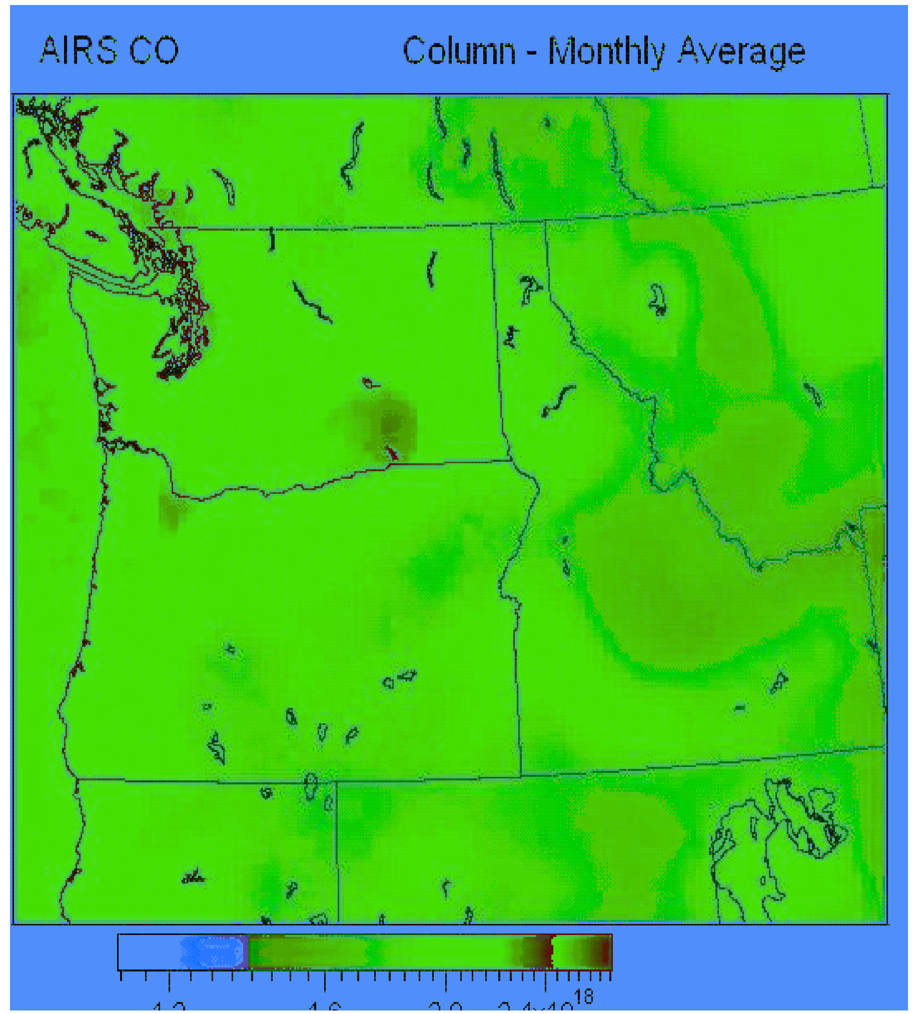
Note: incoming air masses from Asia bring significant CO into the AIRPACT domain.



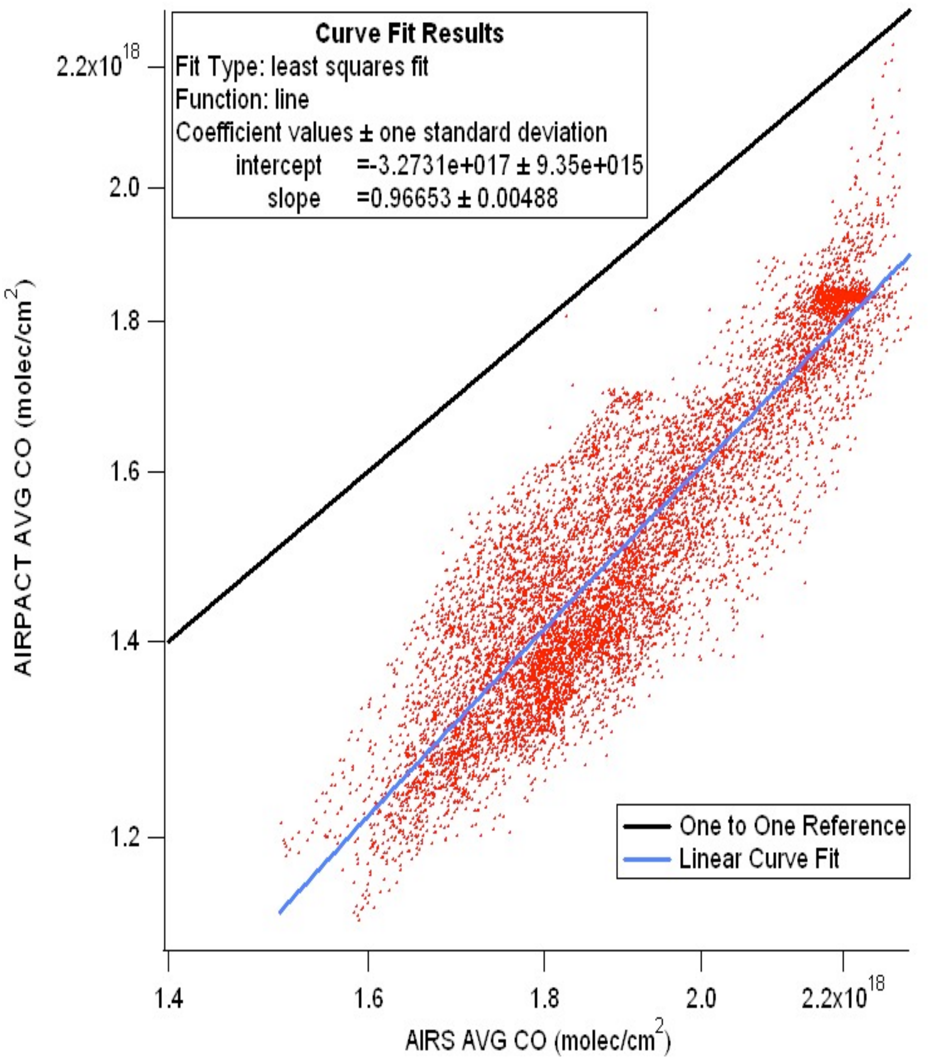
Carbon Monoxide Vertical Columns

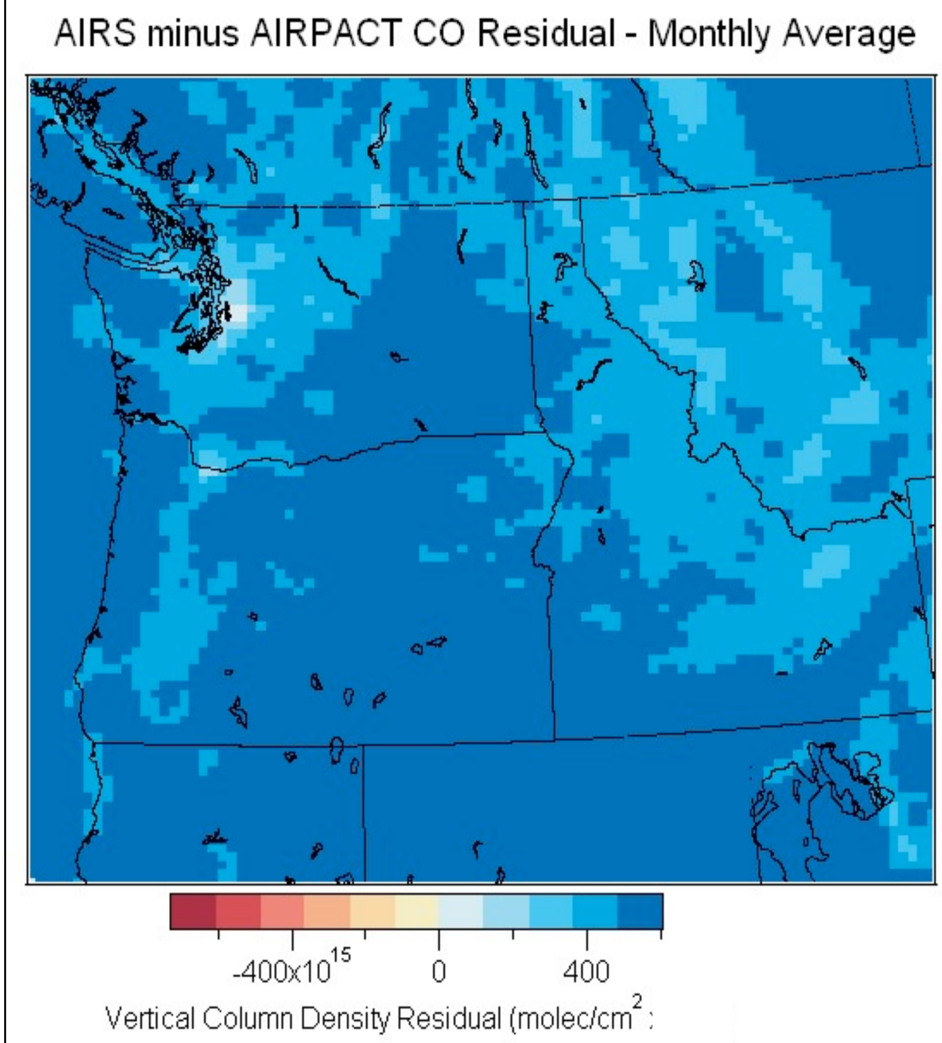
Comparisons of AIRPACT and AIRS carbon monoxide columns show that AIRPACT is biased low. Some researchers have discussed results that show AIRS CO to be sometimes positively biased over MOPITT measurements (i.e. Waner, 2007 & Yurganov, 2008). (Feb. 2008 shown)





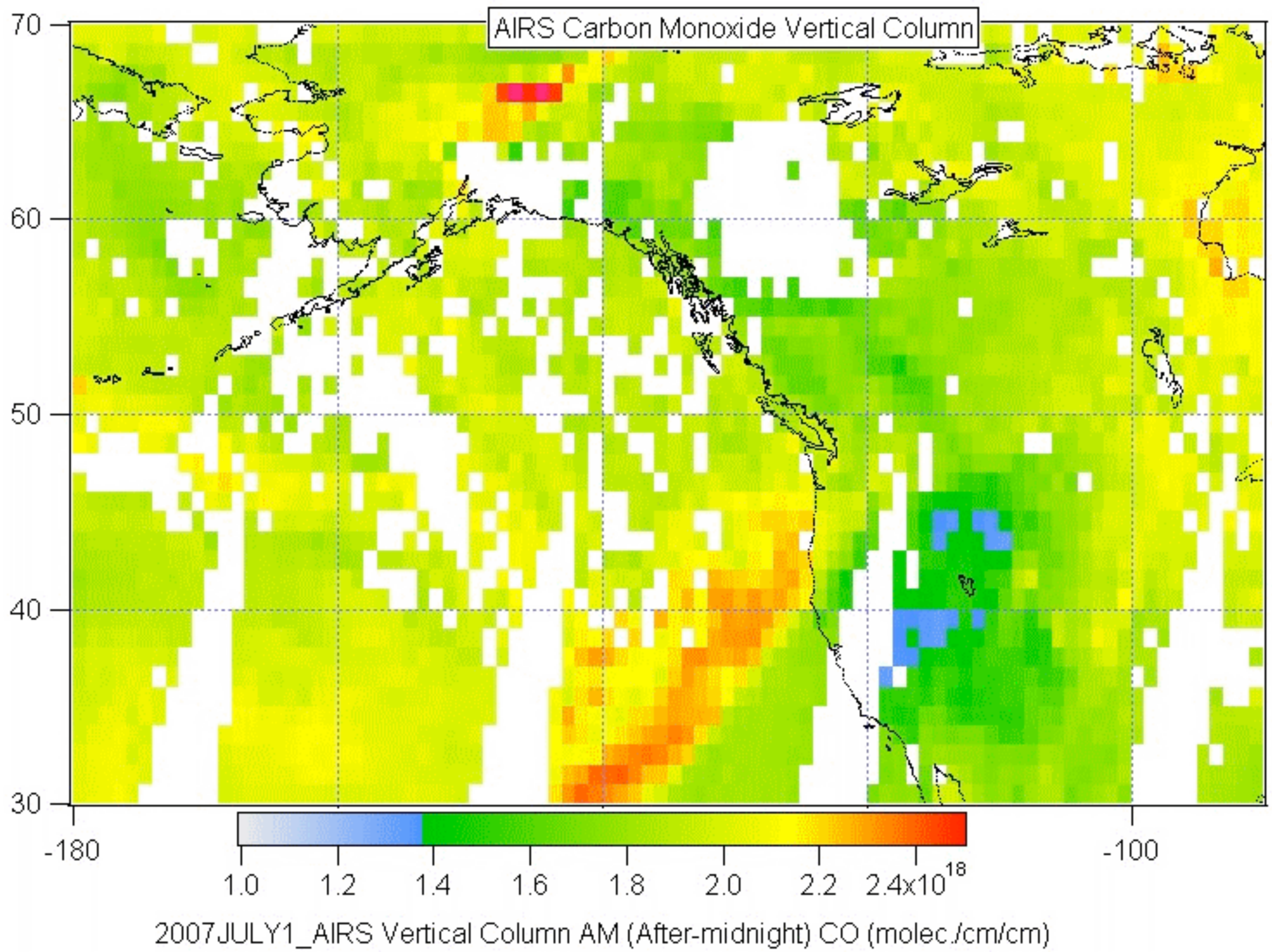
Monthly averages of carbon monoxide show good correlation between AIRS and AIRPACT, and a strong bias. Monthly averages of AIRPACT are ~ 5 x 10^{17} molec./cm^2 (~ 25%) lower than AIRS over most of the domain. (Feb. 2008 shown)





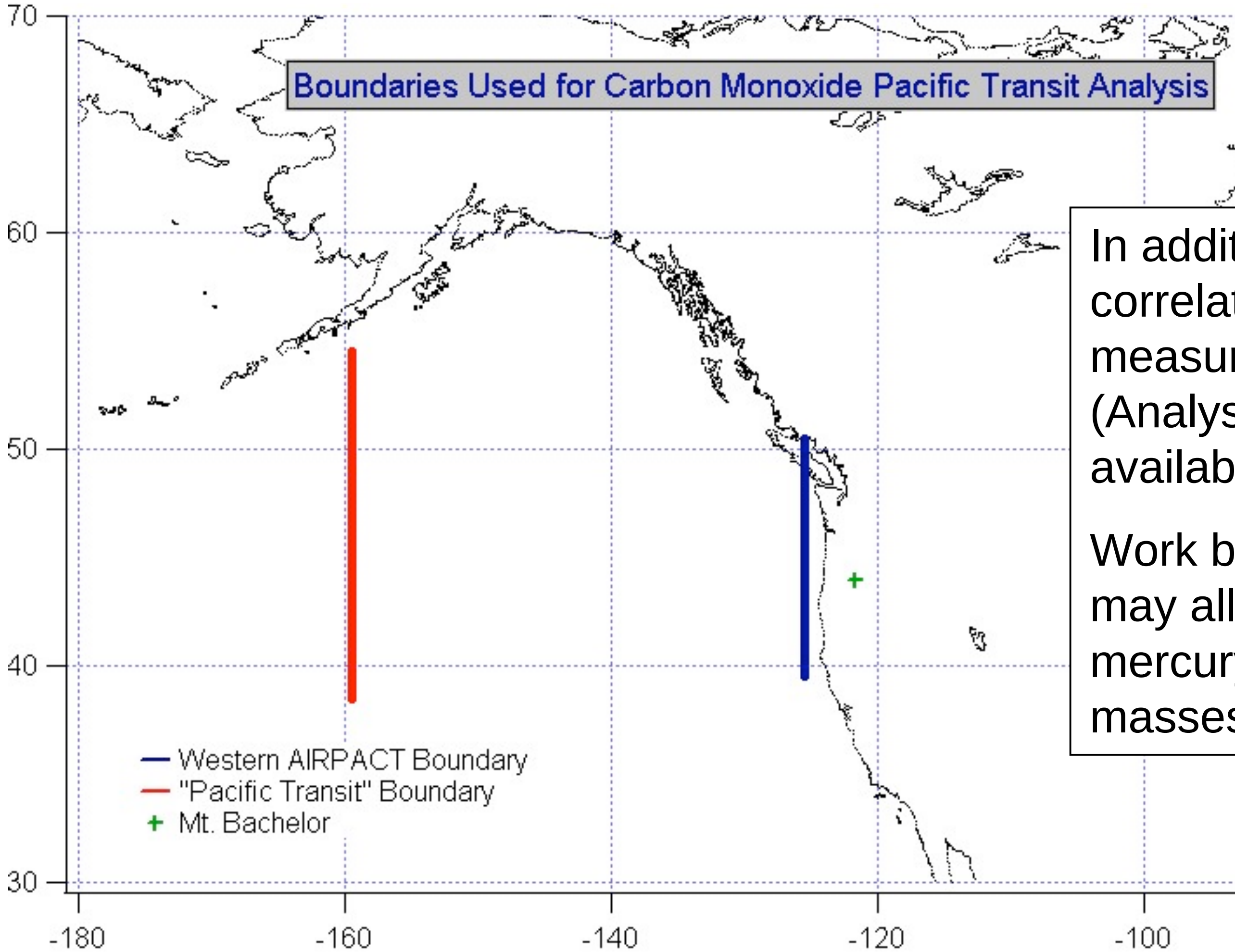
Asian air masses influencing the Pacific Northwest

Boundary conditions for AIRPACT are taken from MOZART global model results, but do not reflect incoming polluted air masses from Asia. Episodes of carbon monoxide influencing the western boundary of AIRPACT from Asia can explain part of the bias that we see.



JULY 2007 Shown, 12 hour time steps

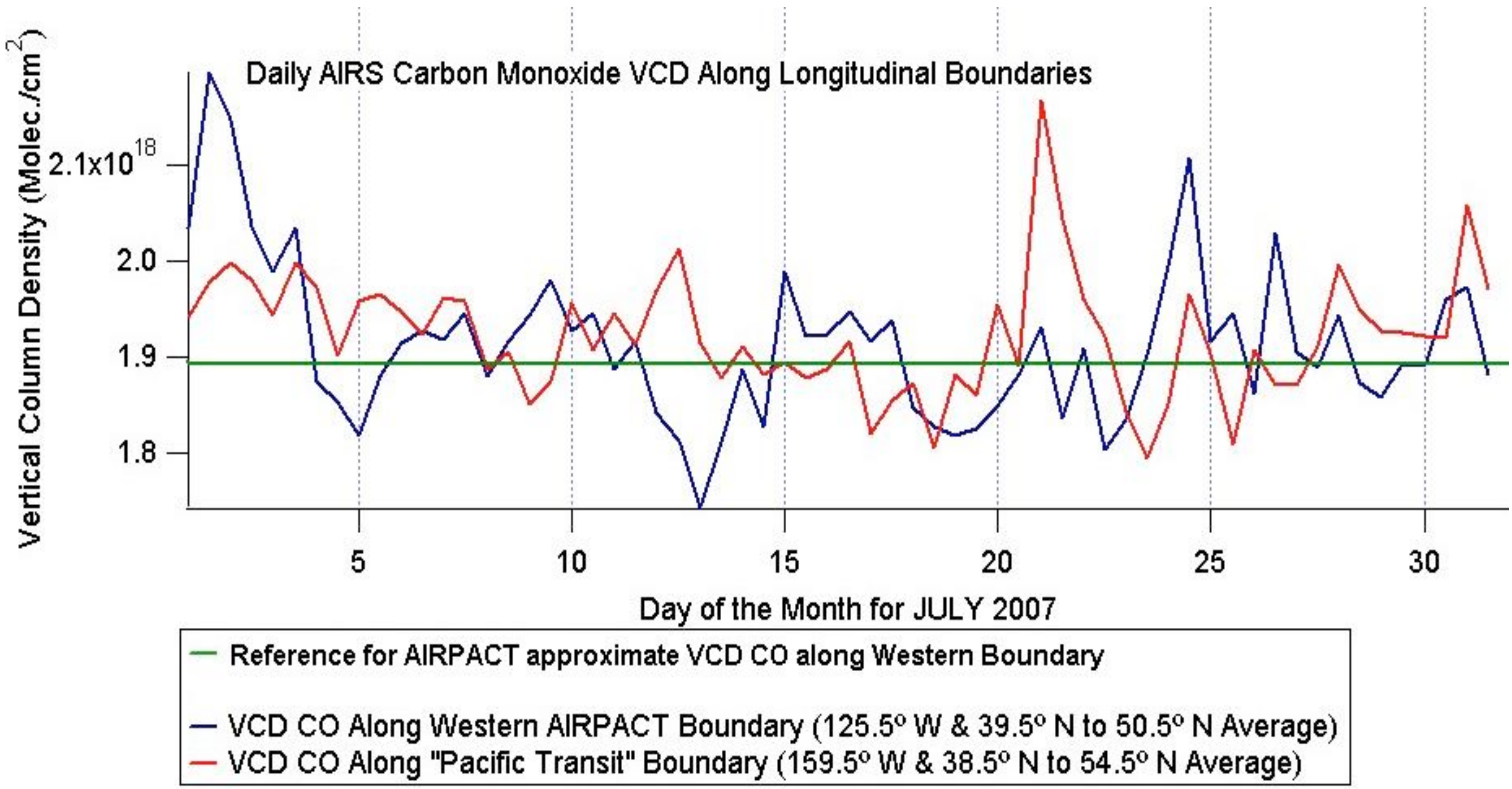
The time lag between retrieval and data availability requires a projection of incoming air masses to use AIRS data in operational AIRPACT forecasts. This is being refined to choose the closest usable "projection boundary" and may be pressure level dependent. The best solution will utilize wind fields to project location and time of the approaching air masses.



In addition, AIRS shows good correlation with Mt. Bachelor measurements of CO. (Analysis not shown here but available from LAR).

Work by Jaffe Research Group may allow us to infer incoming mercury levels with Asian air masses.

Looking at a month of AIRS CO that has crossed the Pacific, we can see that a typical month may have 3 or more episodes of needed boundary condition adjustment.



Implications for the Future

OMI NO_2 for AIRPACT Emissions Inventory:

•Tropospheric NO2 satellite products provide a worthwhile source for evaluation and adjustment of air quality forecast model emission inventories.

•A dynamic NOx emissions adjustment scenario is currently being developed for the AIRPACT forecast system. Preliminary reruns with emissions adjustments increases correlation between OMI and AIRPACT for both NO2 and O3

OMI Tropospheric O_3 vs. AIRPACT:

•More work is needed to make this data available for forecasting assimilation and is best suited for retrospective analysis.

•A very clear signature of urban ozone is seen using Xiong Liu's TO3, but this work should be refined to strictly address free tropospheric ozone.

AIRS CO for AIRPACT Boundary Conditions:

•Time lag between retrieval and data availability necessitates projection of incoming air masses for AIRPACT forecasts. The closest usable "boundary" will be chosen and should utilize wind fields to project location and time of the approaching air mass.

• Projecting CO to the western AIRPACT boundary appears to be suitable in the middle to upper troposphere (not shown).

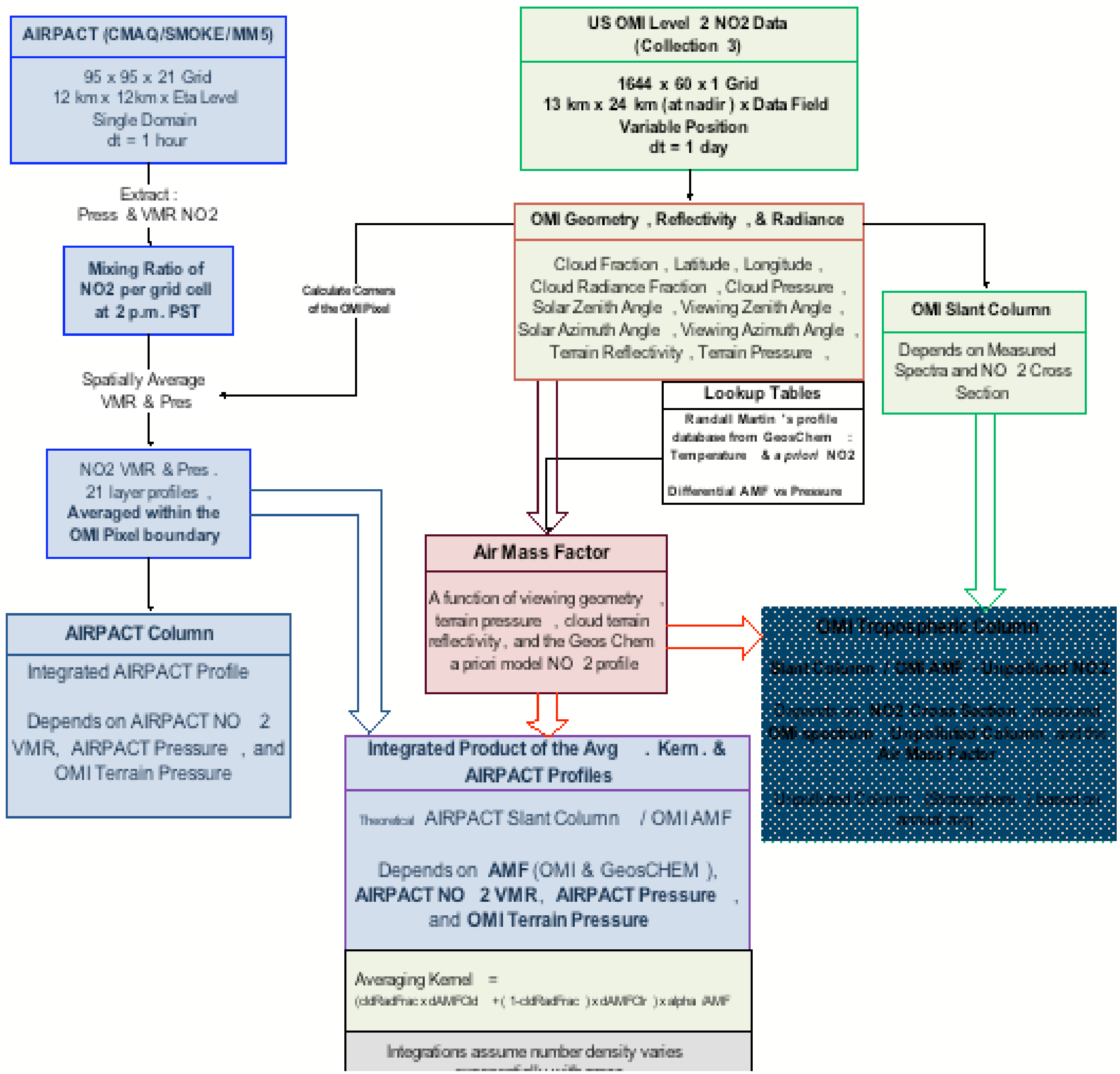
•Availability of day & night retrievals makes InfraRed retrievals particularly attractive

The authors would like to thank Eric Bucsela and Xiong Liu at UMBC for their contributions to this work.

Extra Slides

- The following are unused slides

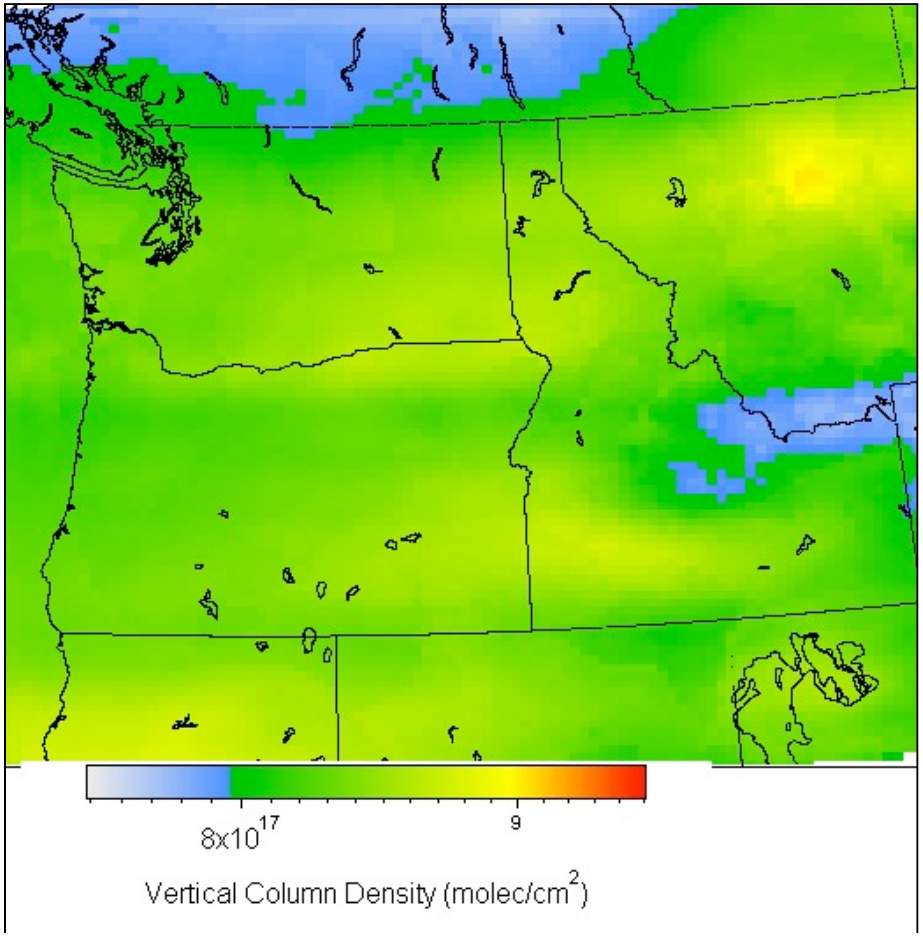
Data Flow for Tropospheric Column Comparisons using the Averaging Kernel



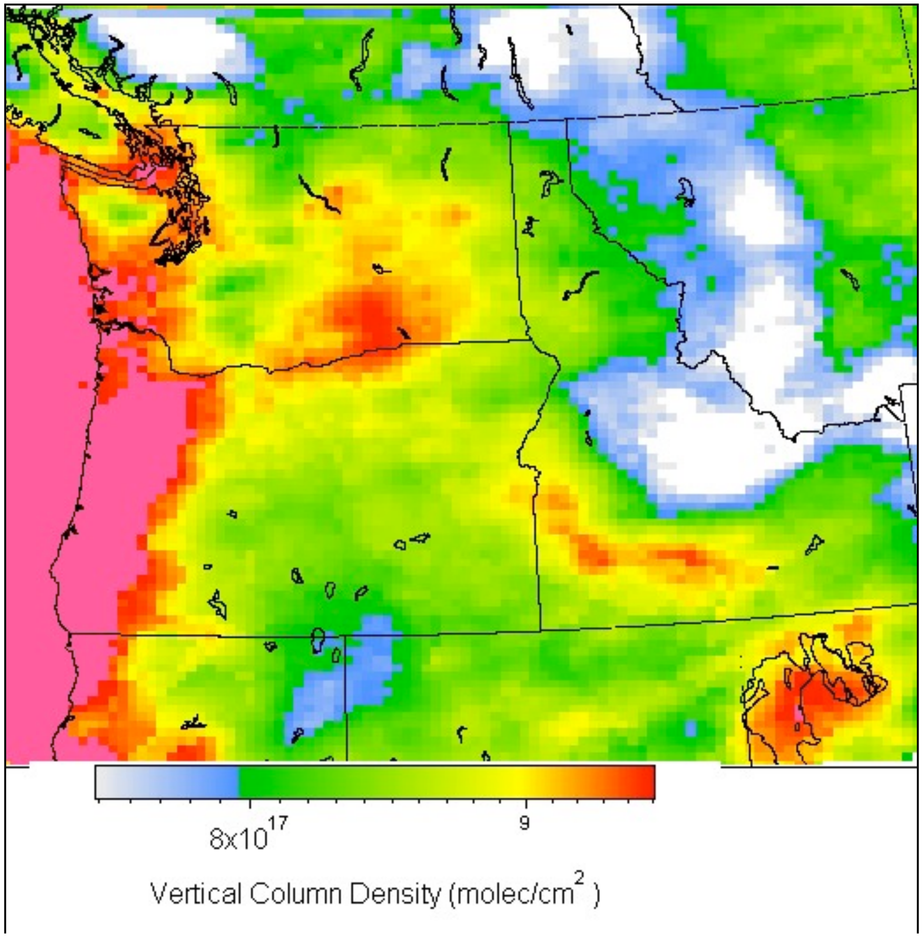
July 2007 Tropospheric O_3 Monthly Averages (Summer)

R=0.30

AIRPACT Tropospheric O_3 VCD
"Binned and Averaged" to the L2 OMI daily grid



L2 OMI Tropospheric O_3 VCD

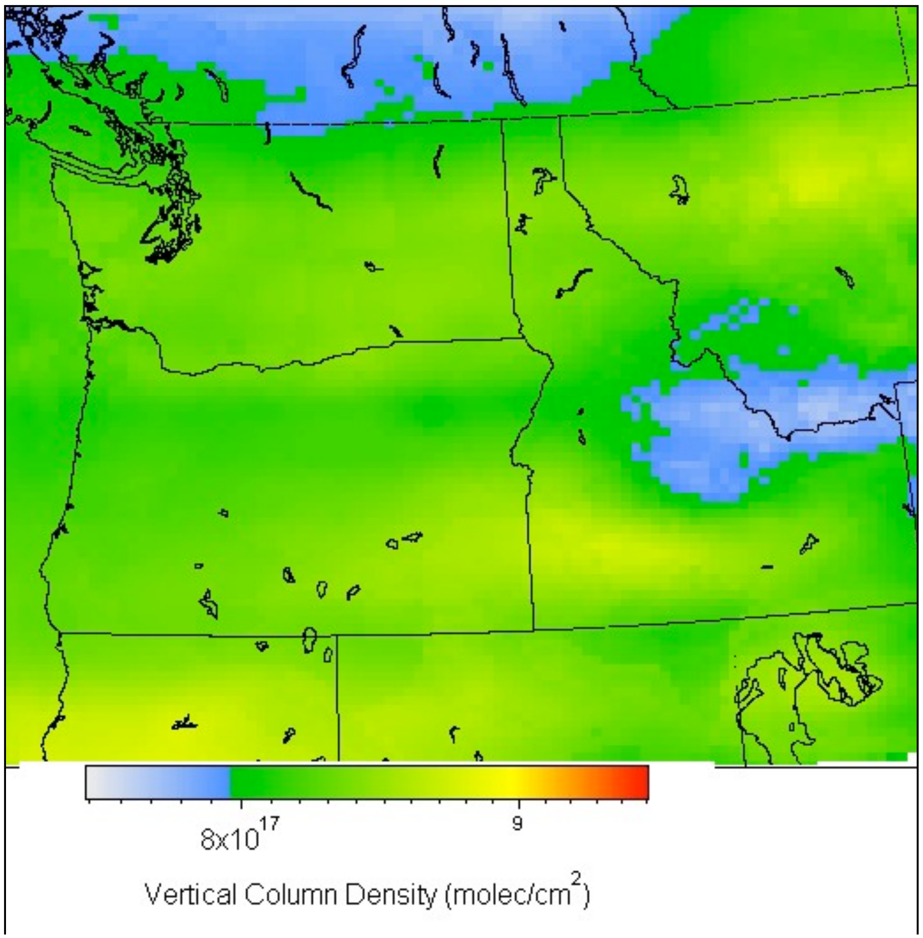


<u>July 2007 Tropospheric O_3 Monthly Averages (Summer)</u>

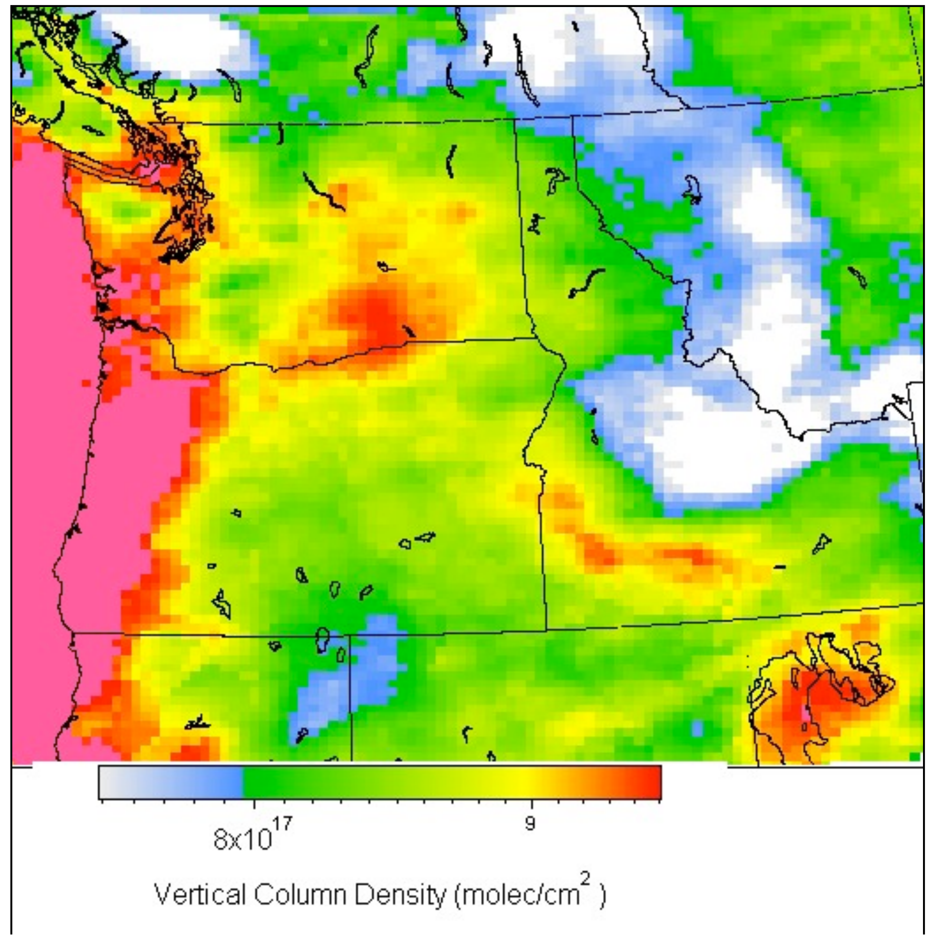
Adjusted NOx Emissions for AIRPACT based on OMI to AIRPACT ratio

R=0.37

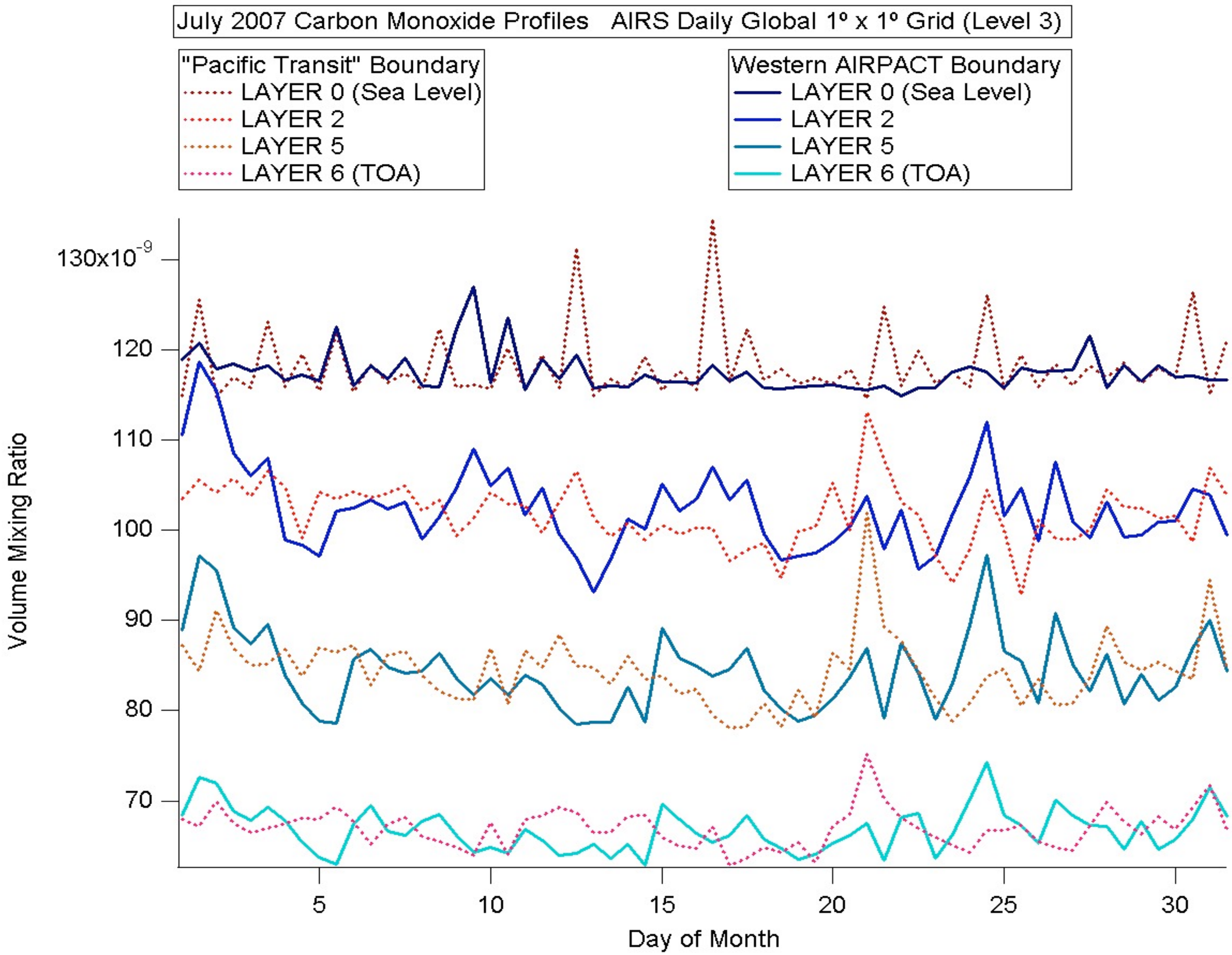
AIRPACT Tropospheric O_3 VCD
"Binned and Averaged" to the L2 OMI daily grid



L2 OMI Tropospheric O_3 VCD



Time lag correlation of CO between the two boundaries decreases as the layer retrieved approaches the surface. This is most likely due to the fact that:
1) error from the retrieval increases as layers approach the surface,
2) there is active chemistry near the surface (and therefore shorter CO lifetimes).

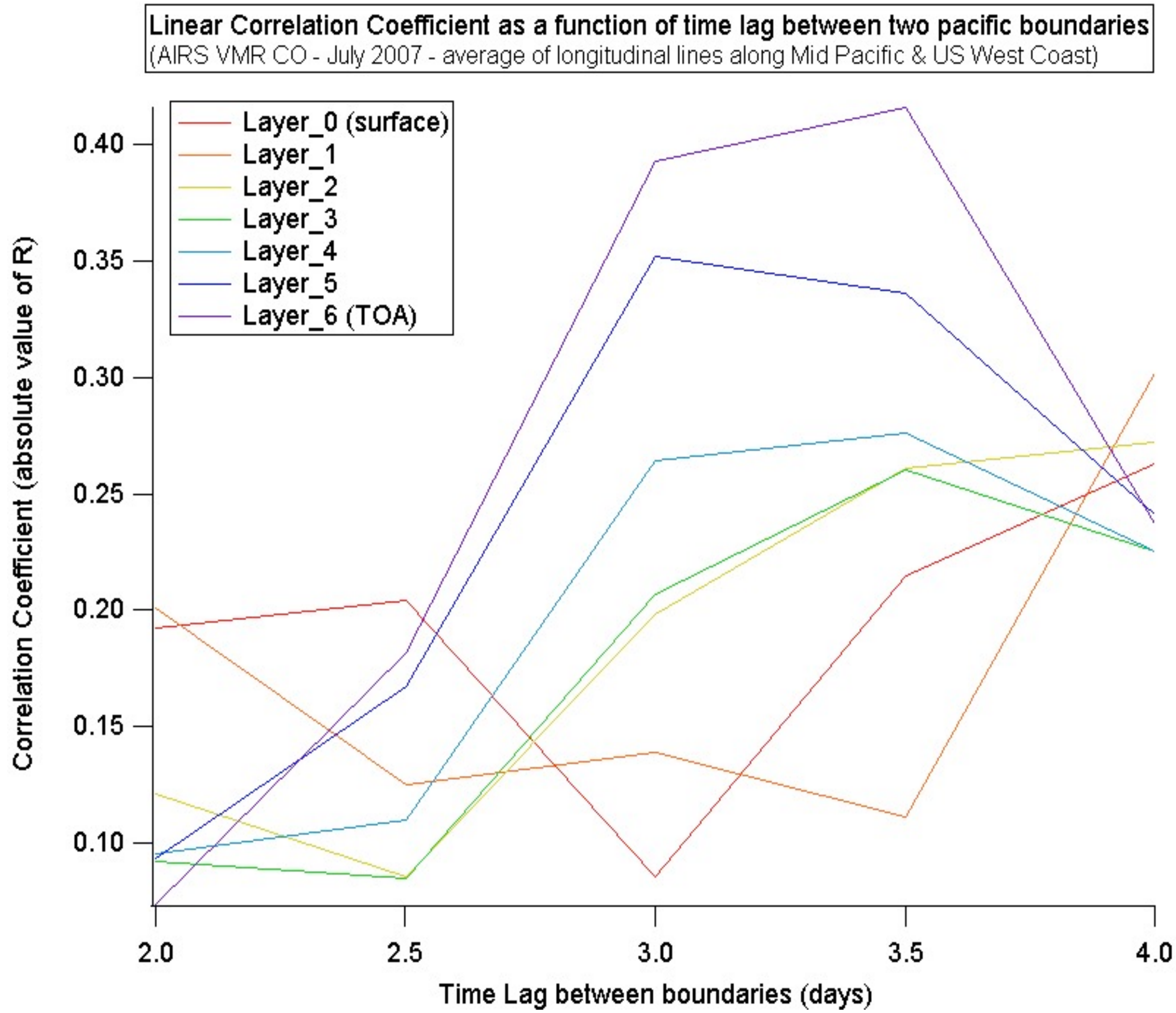


Linear correlation of air masses across the two boundaries

(as a function of time lag)

This analysis shows us that the average time lag between incoming CO across the chosen pacific boundaries is about 3.5 days.

Since data is available from NASA ~1.5 days after retrieval, a closer boundary should be used for AIRPACT.



Notice that the maximum time lag correlation occurs later near the surface (presumably from lower mean wind speeds).