global distribution of tropospheric bro observed from satellite

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Overview: BrO in the Atmosphere

In the Stratosphere:

- Catalytically destroys O_3 with significantly higher efficiency than ClO (starts with $Br_2 + h\nu \rightarrow 2Br$)

In the Troposphere:

- Main sources of bromine in the troposphere: Bromocarbons (CH_3Br, CH_2Br_2, $CHBr_3$) and release mechanisms from sea salt
- Associated with nearly-complete ozone depletion events observed in Polar regions
- Environmental impact: BrO oxidizes gaseous mercury to reactive mercury, which leads to mercury deposition
- Changes the NO_x(NO + NO_2) and HO_x(OH + HO_2) balance towards OH, with the potential to increase CH_4 oxidation

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Overview: BrO in the Atmosphere

What we know from surface and balloon observations

- Observations of BrO in volcanic plumes, over salt lakes, and in the polar regions
- Confirmation of enhanced BrO during tropospheric ozone depletion events in the Arctic and Antarctic
- Possible tropospheric loading of ~0.5-1.2×10^{13} molec/cm^2 (1-2 ppt)

What we know from satellite observations

- Global BrO total columns have a longitudinally uniform distribution
- Latitudinal variation between ~3×10^{13} molec/cm^2 (tropics) and ~5×10^{13} molec/cm^2 (high latitudes)
- Tropospheric hotspots are observed at high latitudes in the Polar spring over fresh sea ice ("bromine explosions")
- BrO was detected in the plume of the Kasatochi eruption in August 2008

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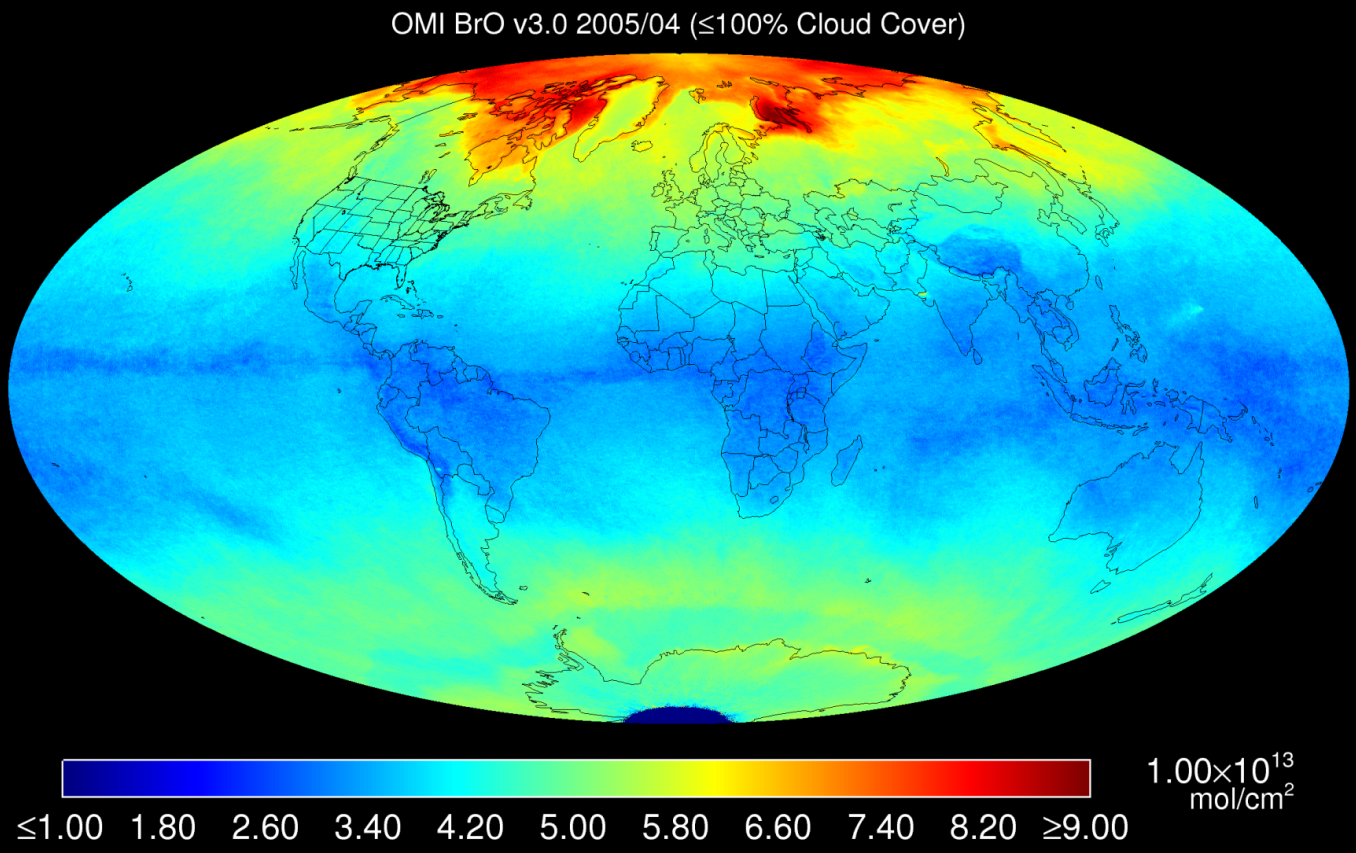
Global View: OMI BrO



OMI BrO Total Columns for April 2005, on a monthly average, exhibit significant structure, particularly at lower latitudes. Is this real?

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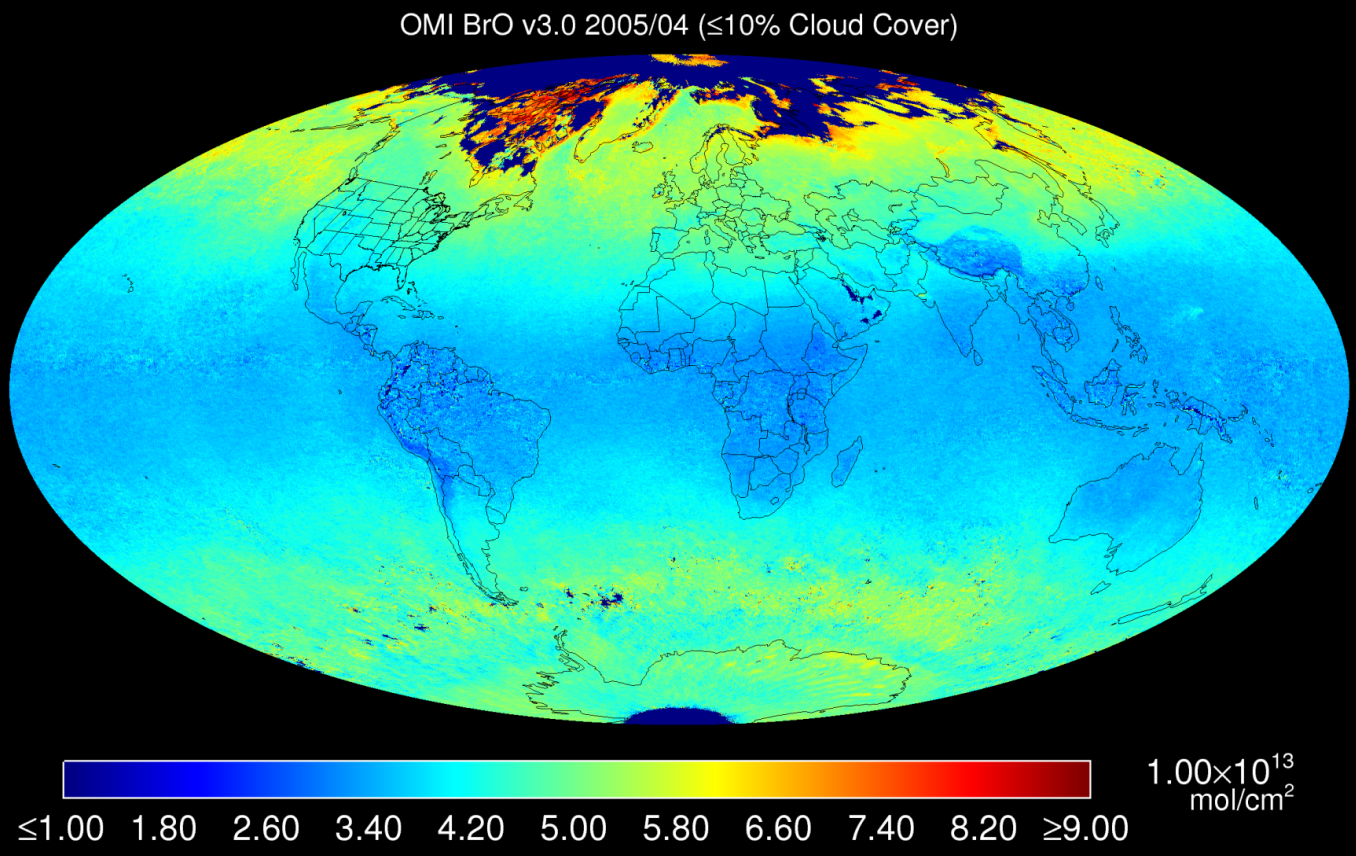
Global View: OMI BrO



OMI BrO Total Columns, as before, but now discarding OMI pixels with cloud fractions >10%: Cloud Screening removes most of the low-latitude structure in the BrO field.

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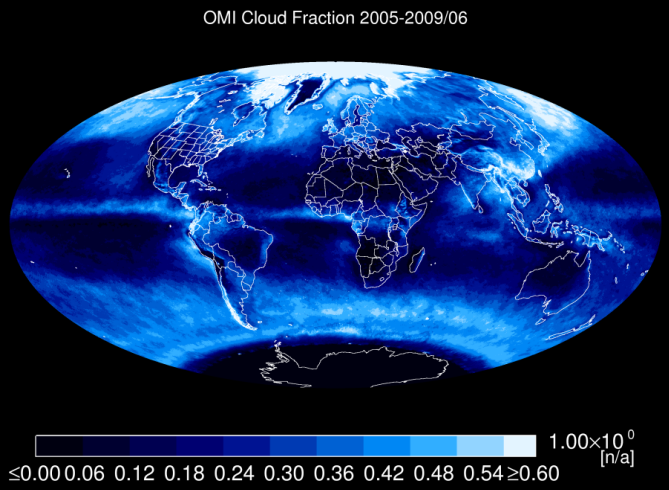
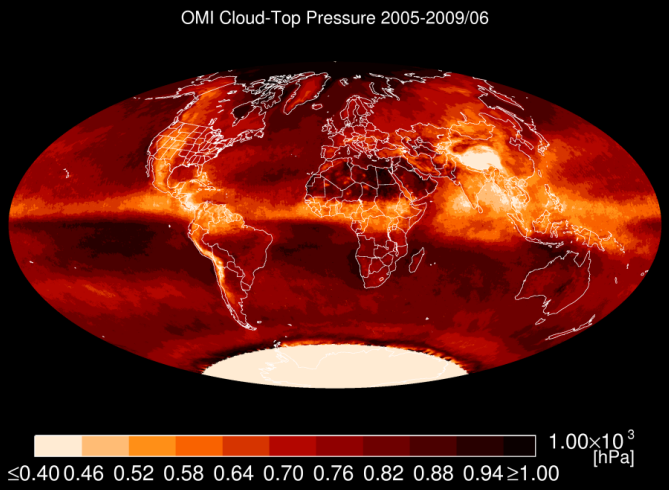
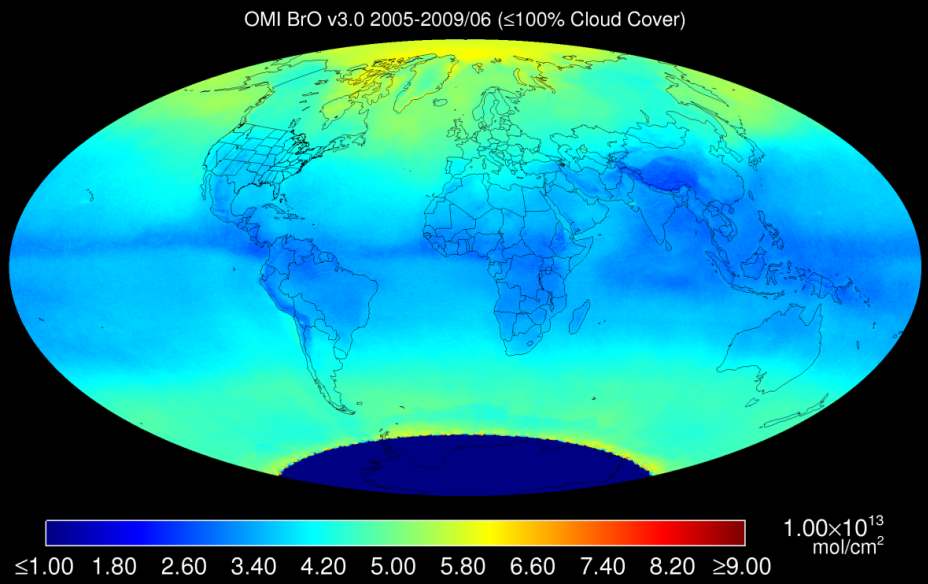
BrO – Cloud Comparison





Cloud Fraction: Lower BrO VCDs over areas of high cloud cover.



Cloud-Top Pressure: Lower BrO VCDs over areas of high-altitude clouds.

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Interpretation of BrO/Cloud Correlation

Decrease in BrO VCD with increasing cloud fraction

- At first glance, this is counter-intuitive! Bright surfaces increase sensitivity to BrO above it. Since cloud effects are not considered in the retrieval, cloud covered pixels should show an increase in BrO, not a decrease.

Decrease in BrO VCD with increasing cloud-top height

- This provides a first clue as to what might be going on: OMI is sensitive to tropospheric BrO, and consistently high clouds mask a portion of that, leading to a decrease in overall signal.

but then …

- … it could be something else entirely.

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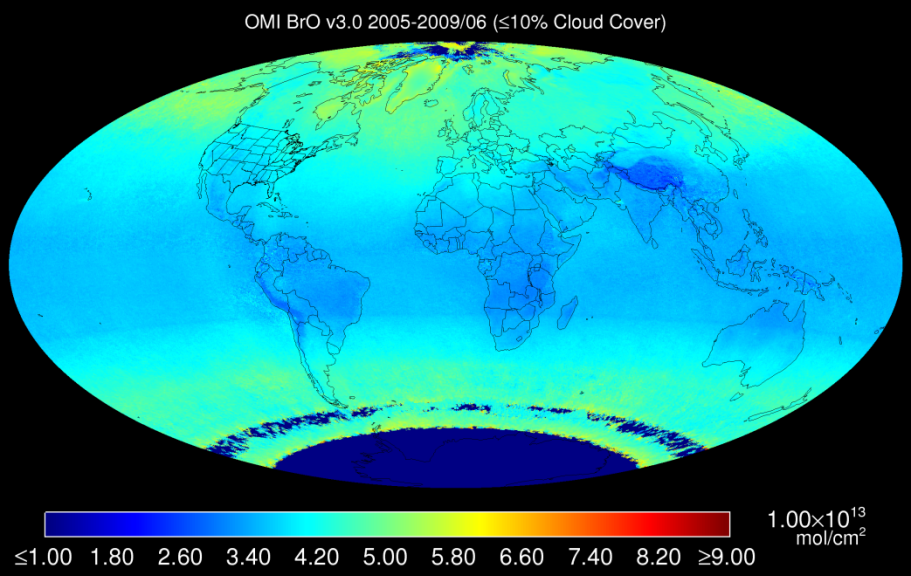
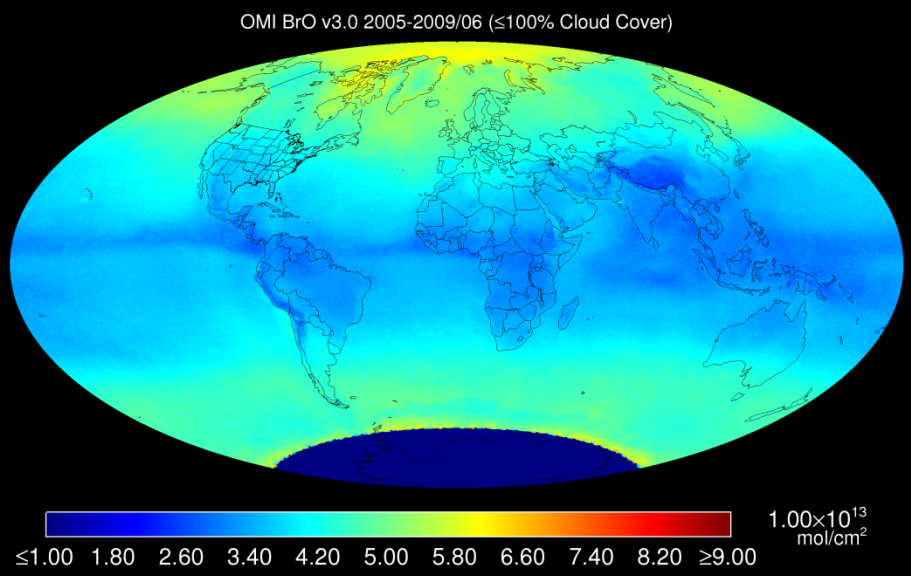
BrO Cloud Slicing – A First Look





Simple Cloud Slicing:

- Take a global monthly BrO average screened for ≤10% cloud cover (left image)
- Take another global monthly BrO average unscreened (≤100% cloud cover, right)

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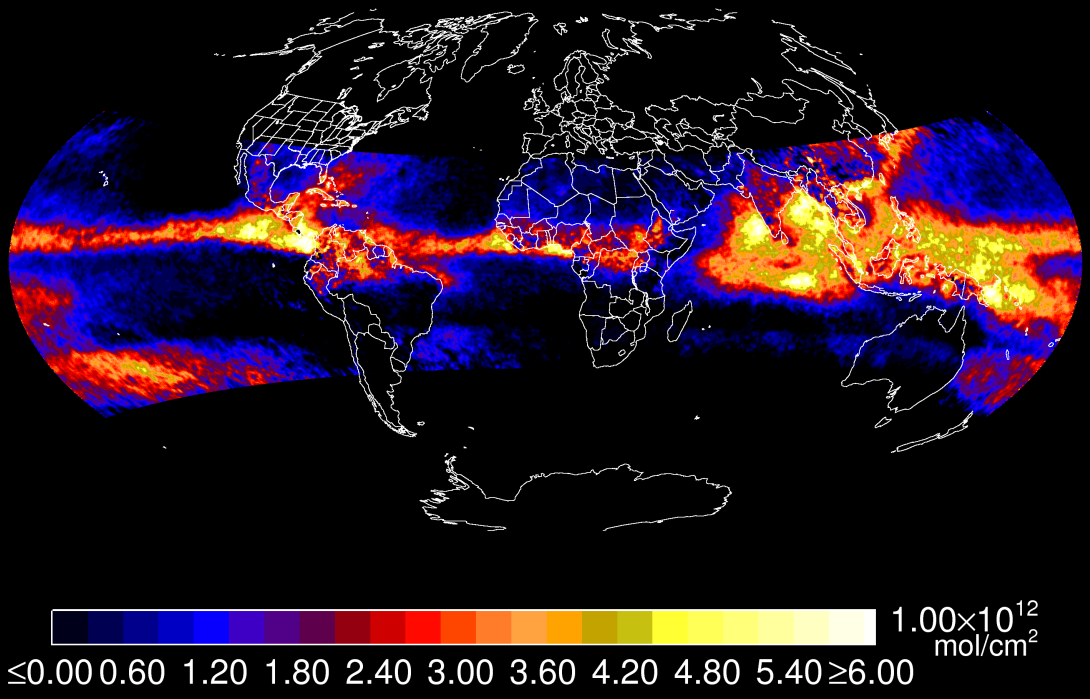
BrO Cloud Slicing – A First Look

OMI BrO Tropospheric Residual 2005-2009/06 ("≤10%" - "≤100%" Cloud Cover)



Simple Cloud Slicing:

- Take a global monthly BrO average screened for ≤10% cloud cover
- Take another global monthly BrO average unscreened (≤100% cloud cover)
- Subtract one from the other: "≤10% cc" – "≤100% cc" and focus on the region of ±35˚ latitude

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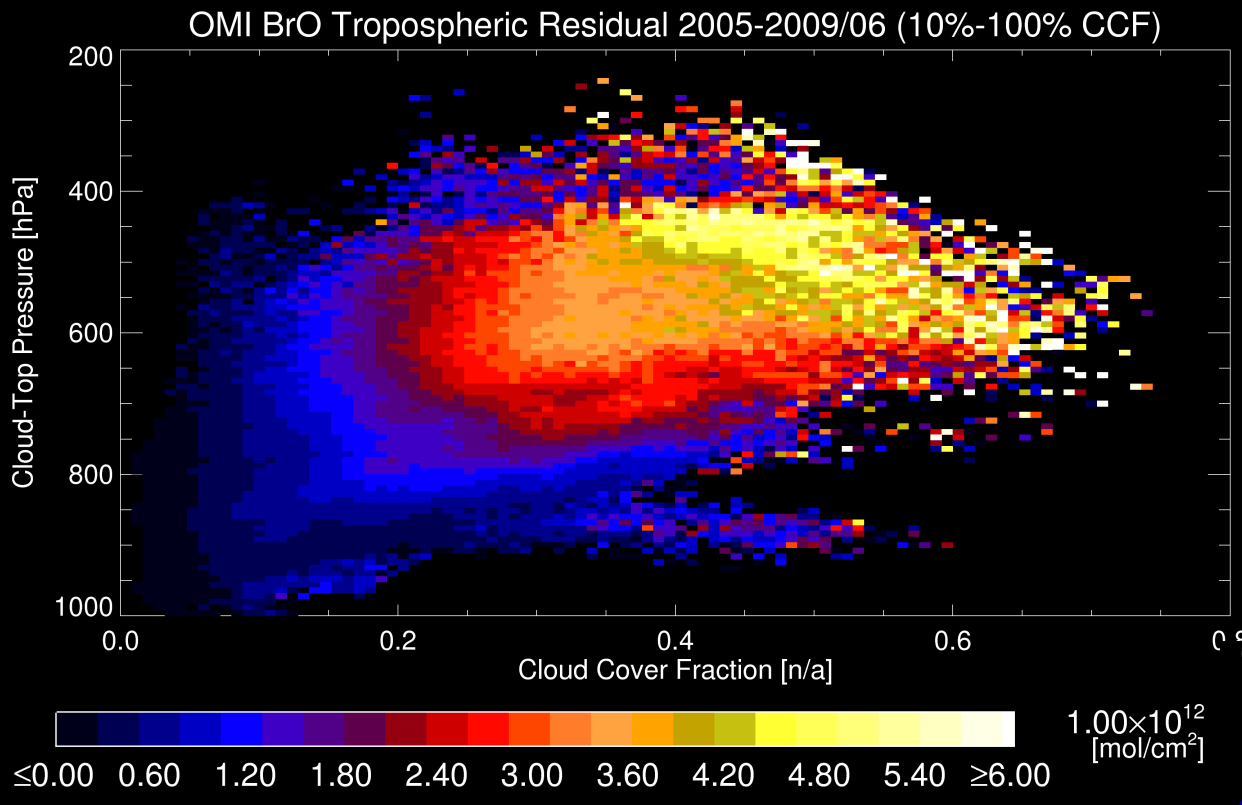
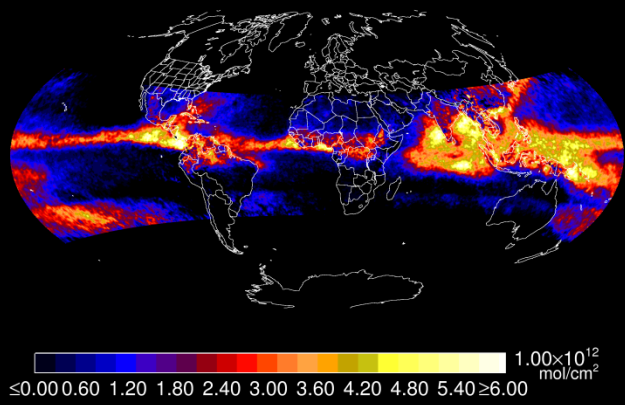
BrO Cloud Slicing – A First Look (all surfaces)



Tropospheric BrO Residual:

Large tropospheric BrO residual over areas of (on average) high cloud cover fraction and low cloud-top pressure.

Scatter Plot



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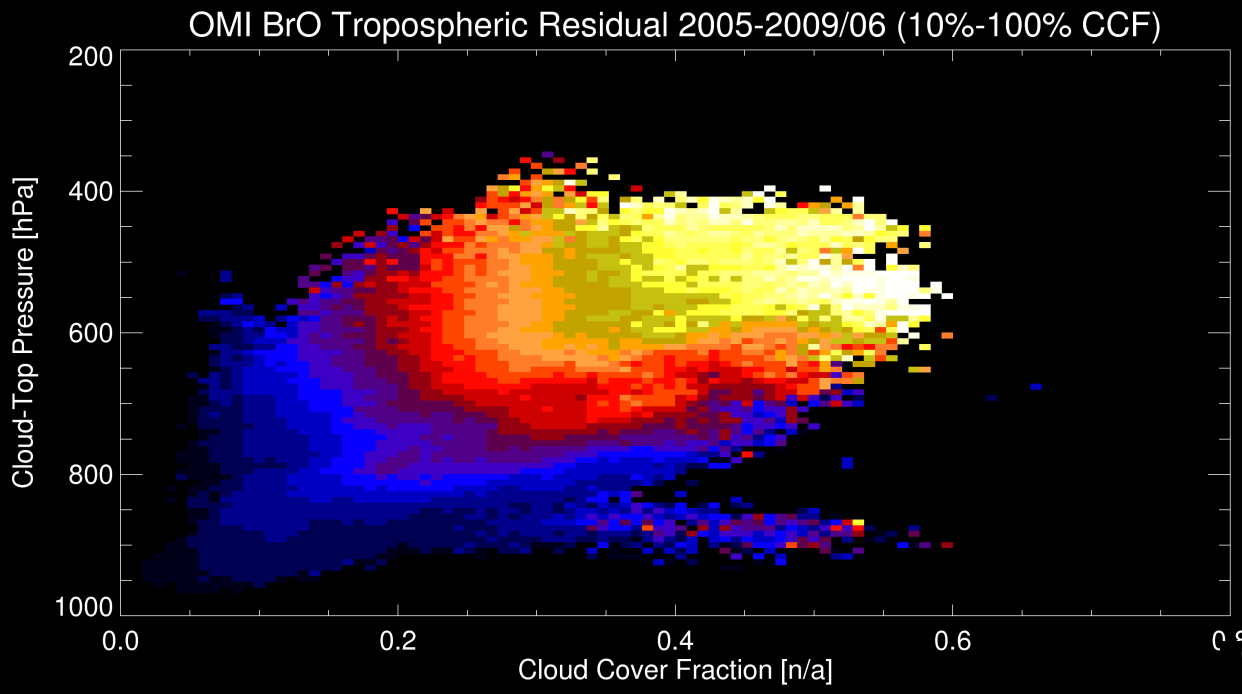
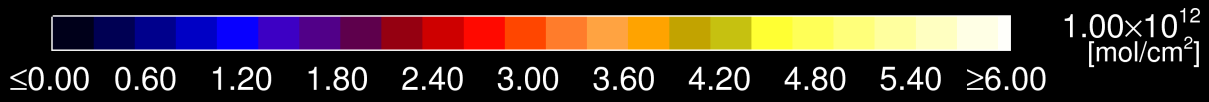
BrO Cloud Slicing – A First Look (ocean only)

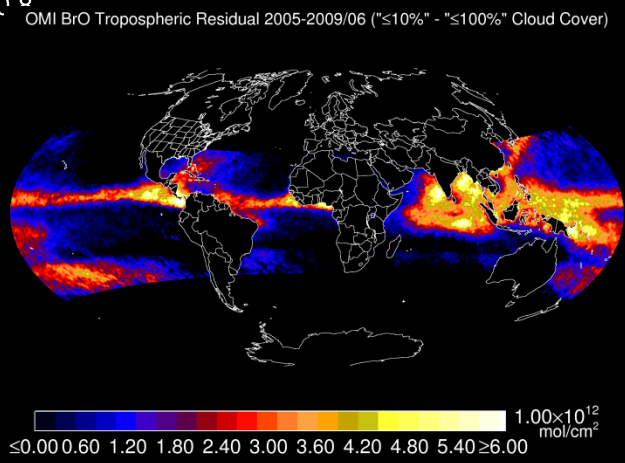




Tropospheric BrO Residual:

Large tropospheric BrO residual over areas of (on average) high cloud cover fraction and low cloud-top pressure.

"Ocean Only" improves the pattern due to the uniform surface.



The Question Is:

Can we untangle the cloud fraction/cloud-top pressure signatures to derive information on vertical distribution of BrO in the troposphere?

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BrO Cloud Slicing – Vertical Profiling

Construct sets of cloud-screened BrO averages:

1. Define a "Stratospheric Reference" (SR):
   Cloud Cover ≥90% and low cloud-top pressure ≤300 hPa
2. Create a set of high-cloud-cover screened averages:
   Cloud cover ≥90% and ctp ≥200 hPa, 300 hPa, …, 900 hPa
3. Try a "boundary layer" case:
   Cloud cover ≥90% and any ctp (needs more thought!)
4. Subtract the Stratospheric Reference from the cloud-screened sets
5. For each ctp, average all qualifying pixels into a single value and plot as a function of ctp

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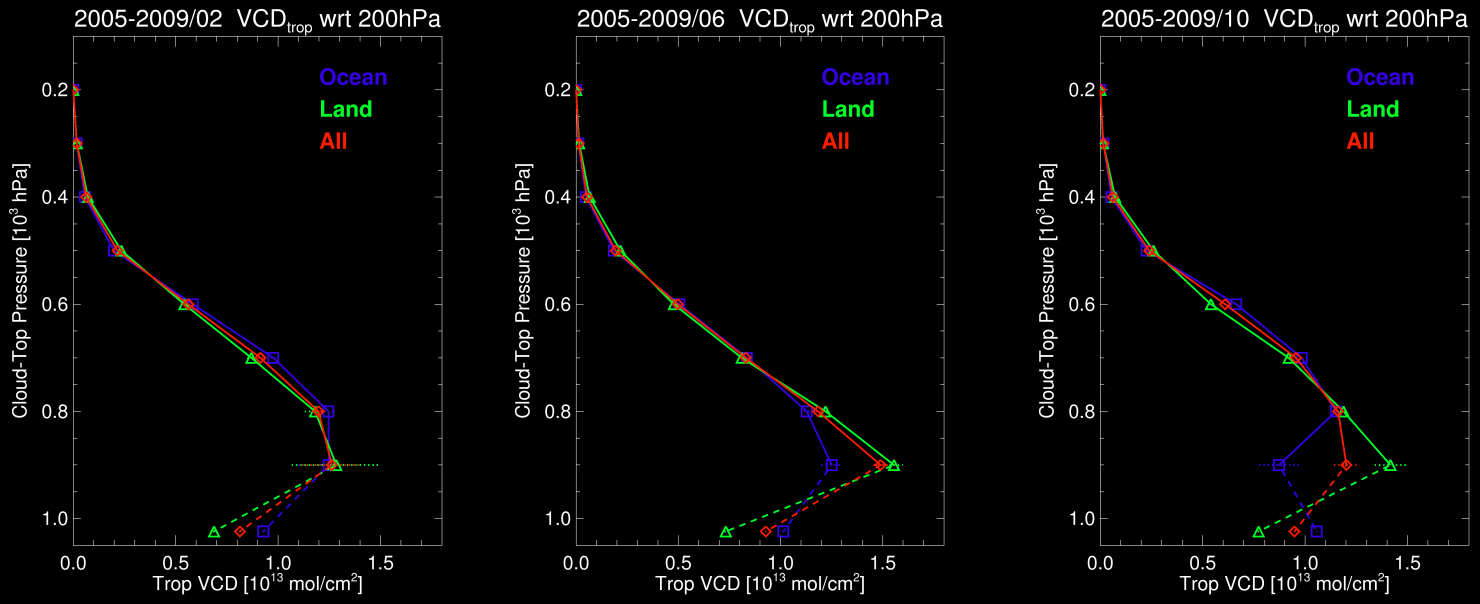
BrO Cloud Slicing – Vertical Profiling



Multi-year average examples for February, June, October – relative to 200 hPa

Cumulative tropospheric BrO VCD: ~1.2×10^{13} molec/cm^2

This is at the upper limit of ground-based DOAS measurements over Lauder, NZ, which reported 0.6-1.2×10^{13} mol/cm^2 (Schoefield *et al.*, 2004).

Caution: Statistics get progressively worse towards lower cloud altitudes

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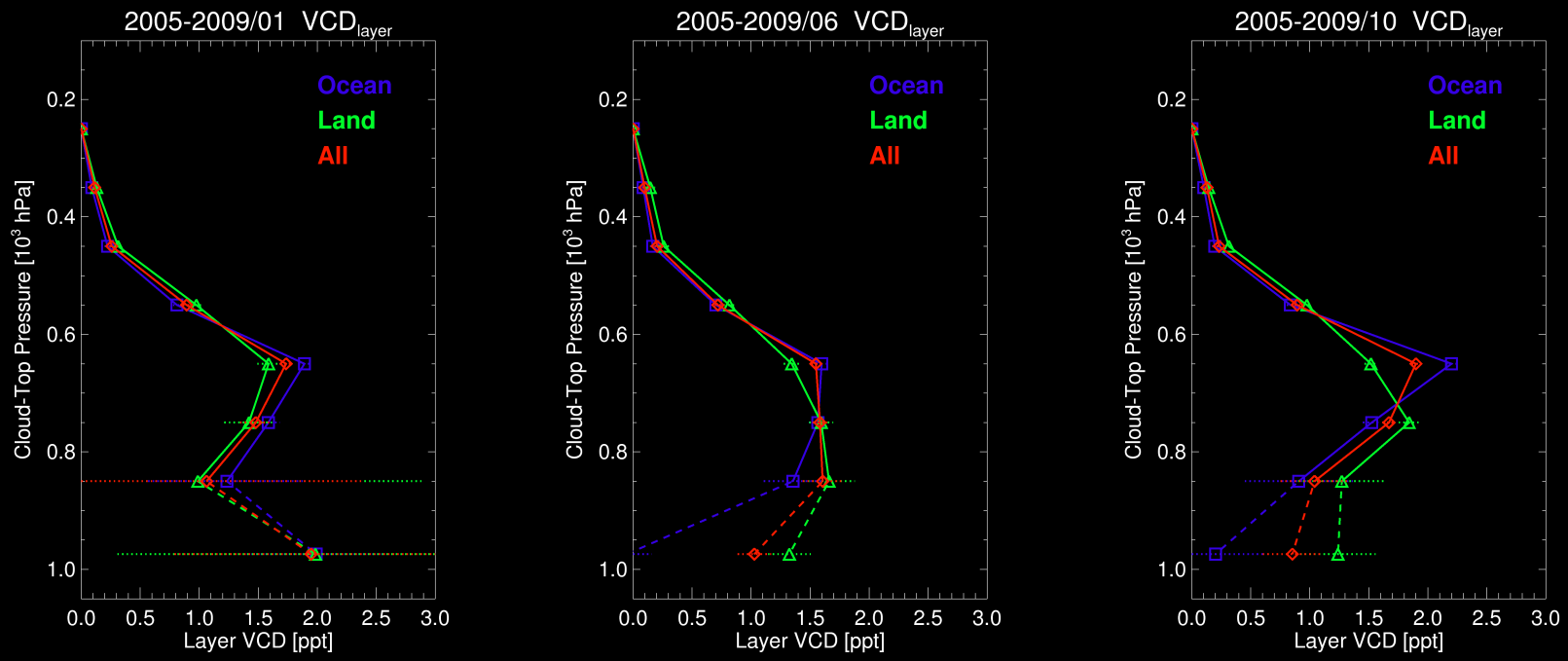
Tropospheric BrO VMR



Convert differential BrO layer optical thickness to VMR:

BrO VMR in the free troposphere ~1—2 ppt

This is consistent with balloon measurements reported by Dorf *et al*. [2008]

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Tropospheric BrO from Cloud Slicing … What could Possibly Go Wrong?

- Sensitivity of the BrO retrievals to O_2-O_2 – potentially a show-stopper
- Uncertainties in the cloud product (Raman or O_2-O_2? MODIS IR?)
- BrO Air Mass Factor – OMI BrO currently uses a stratospheric AMF only
- Stratospheric reference – chemical modeling is most likely required

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