The Next-generation Berkeley High Resolution NO_2 (BEHR NO_2) Retrieval: Design and Preliminary Emissions Constraints

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Introduction

- The Ozone Monitoring Instrument (OMI) is a satellite instrument that provides global measurements of NO_2 with good spatial resolution, but the retrieval requires *a priori* knowledge of NO_2 profiles.
- Simulating this is computationally expensive, so standard global retrievals do so at coarse spatial resolution.
- Version 2 of our retrieval, BEHR, has been used to measure NO_2 trends and constrain NO_x emissions by ourselves[1] and other groups.[2;3]
- We have shown the importance of **lightning** and **daily, high resolution** NO_2 profiles when constraining emissions.[4;5]
- **Here, we present improvements in v3.0 of the BEHR retrieval, and show the potential to infer changes in urban NO_x lifetime during the OMI data record.**

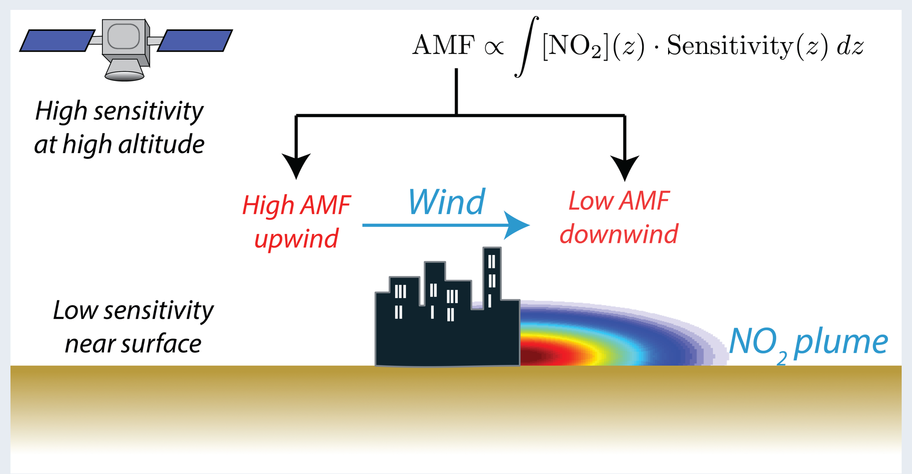

Figure 1: Illustration of why daily profiles are important especially around emissions sources.

WRF-Chem daily profiles

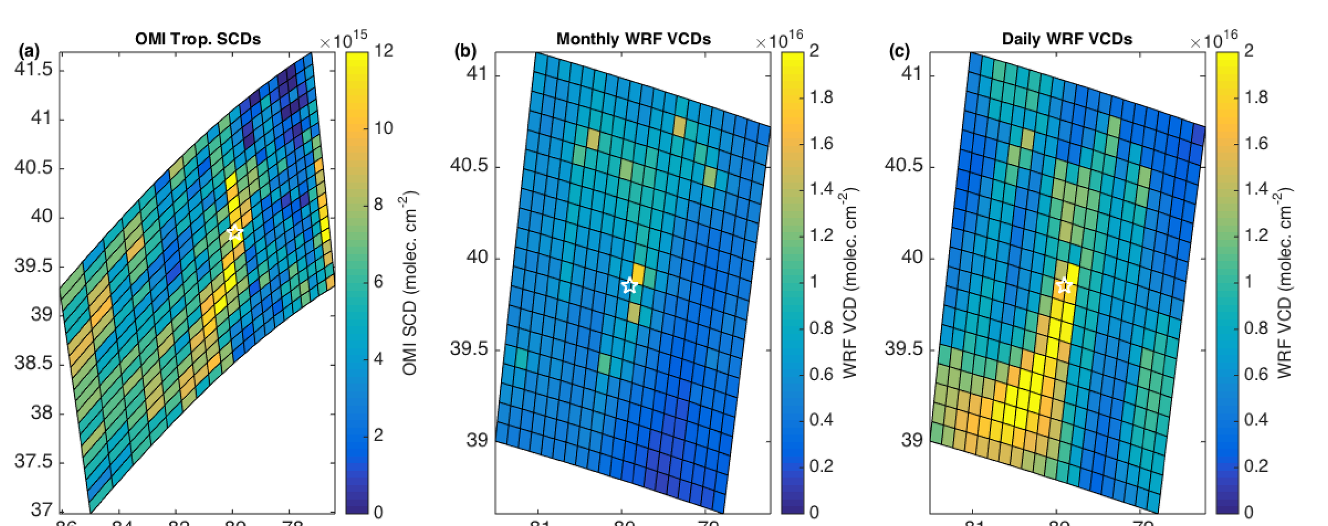

Figure 3: (a) OMI slant column densities (SCDs), (b) monthly average WRF-Chem NO_2 vertical column densities (VCDs), (c) daily WRF-Chem VCDs. The white star marks the Hatsfield Ferry power station.

- Day-to-day changes in wind affect how NO_2 is transported from emissions sources; capturing this in the retrieval is important to get the downwind VCDs right.
- We compared OMI SCDs (which do not rely on the NO_2 profile) to monthly-average and daily WRF-Chem VCDs (Fig. 3). Based on the transport of NO_2 , the daily WRF profiles simulate the downwind plume much better than the monthly average.

Data access

- BEHR data is available at `behr.cchem.berkeley.edu`
- Retrievals using daily profiles are available for 2005, 2007, 2012, and 2013. Additional years added as WRF-Chem simulations complete.

Upgrades to version 3

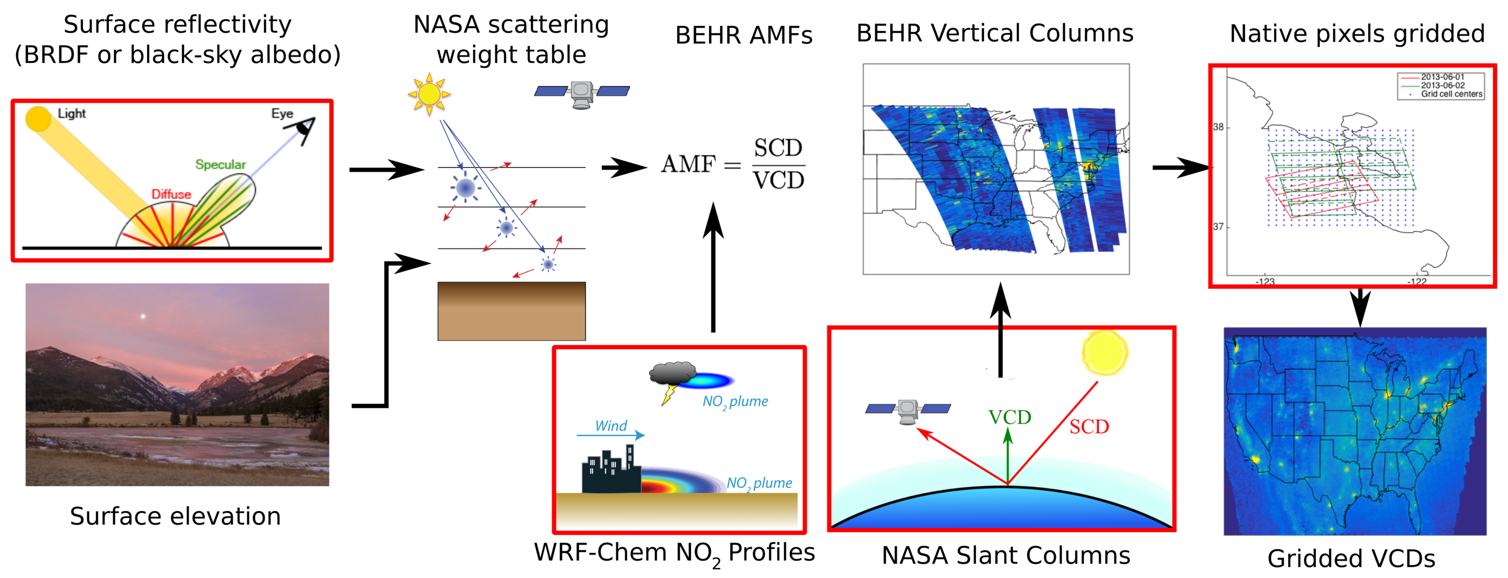

Figure 2: Flowchart outlining the major components of the BEHR retrieval. Red boxed elements were upgraded in version 3.

- BEHR calculates a custom air mass factor (AMF) to retrieve tropospheric NO_2 vertical column densities (VCDs) over the continental US using 12 km WRF-Chem NO_2 profiles, high resolution (30 arc sec) MODIS surface reflectance, and high resolution (1 km) surface elevation data over the continental US.
- Changes in version 3.0:
  - Update to NASA v3.0 slant column densities (SCDs)
  - Surface reflectance upgraded from black-sky albedo to BRDF
  - Daily, 12 km NO_2 profiles that include lightning NO_2
  - Gridding now uses the constant value method from Kuhlmann et al., 2014[6] (`https://github.com/gkuhl/omi`).

WRF-Chem lightning

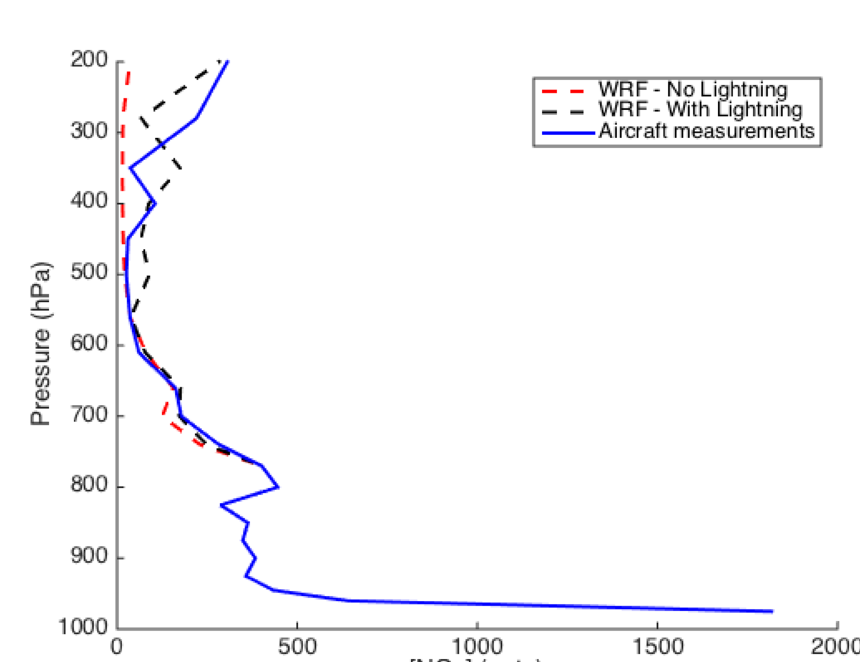

Figure 4: Average NO_2 profile from the DC3 aircraft campaign compared against WRF-Chem data (above 750 hPa) sampled along the aircraft flight path.

Profile	Average AMF
Aircraft	1.59
No lightning	1.04
With lightning	1.51

- Lightning strongly affects the upper tropospheric NO_2 profile, where OMI is most sensitive to tropospheric NO_2 .
- We compared various WRF-Chem configurations against aircraft measurements of thunderstorm chemistry by calculating AMFs with the profiles in Fig. 4 and 27,000 scattering weight vectors.
- The average AMFs show that, without lightning, the AMF is biased low by $\sim 35\%$, but with lightning is within 6%.[5]

Acknowledgments

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References

[1] Russell, A.R. et al. *ACP*, 12, 12197, 2012.
[2] Travis, K.R. et al. *ACP*, 16, 13561, 2016.
[3] Parker, L. et al. *Final Report Hood County NOx Trends* Ramboll Environ, Contract #582-16-60185, 2017.
[4] Laughner, J.L. et al. *ACP*, 16, 15247, 2016.
[5] Laughner, J.L. and Cohen, R.C. *AMT*, 10, 4403, 2017.
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[8] Beirle et al. *Science*, 333, 1737, 2011.
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The EMG method

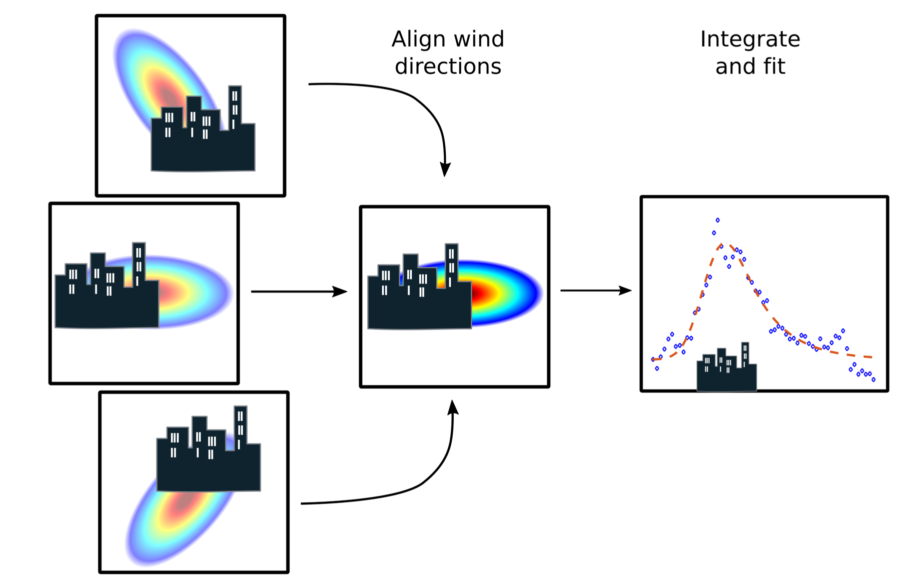

Figure 5: The EMG approach. VCDs are rotated to align wind directions; the plume is integrated perpendicular to the wind to yield a line density. That is fit with an exponentially-modified Gaussian function.

- The EMG method infers NO_x lifetime (and emissions) by fitting line densities with an exponentially-modified Gaussian function.[7–9]
- The characteristic length of the exponential (one of the fitting parameters) divided by the average wind speed yields the effective lifetime.

Changes in lifetime

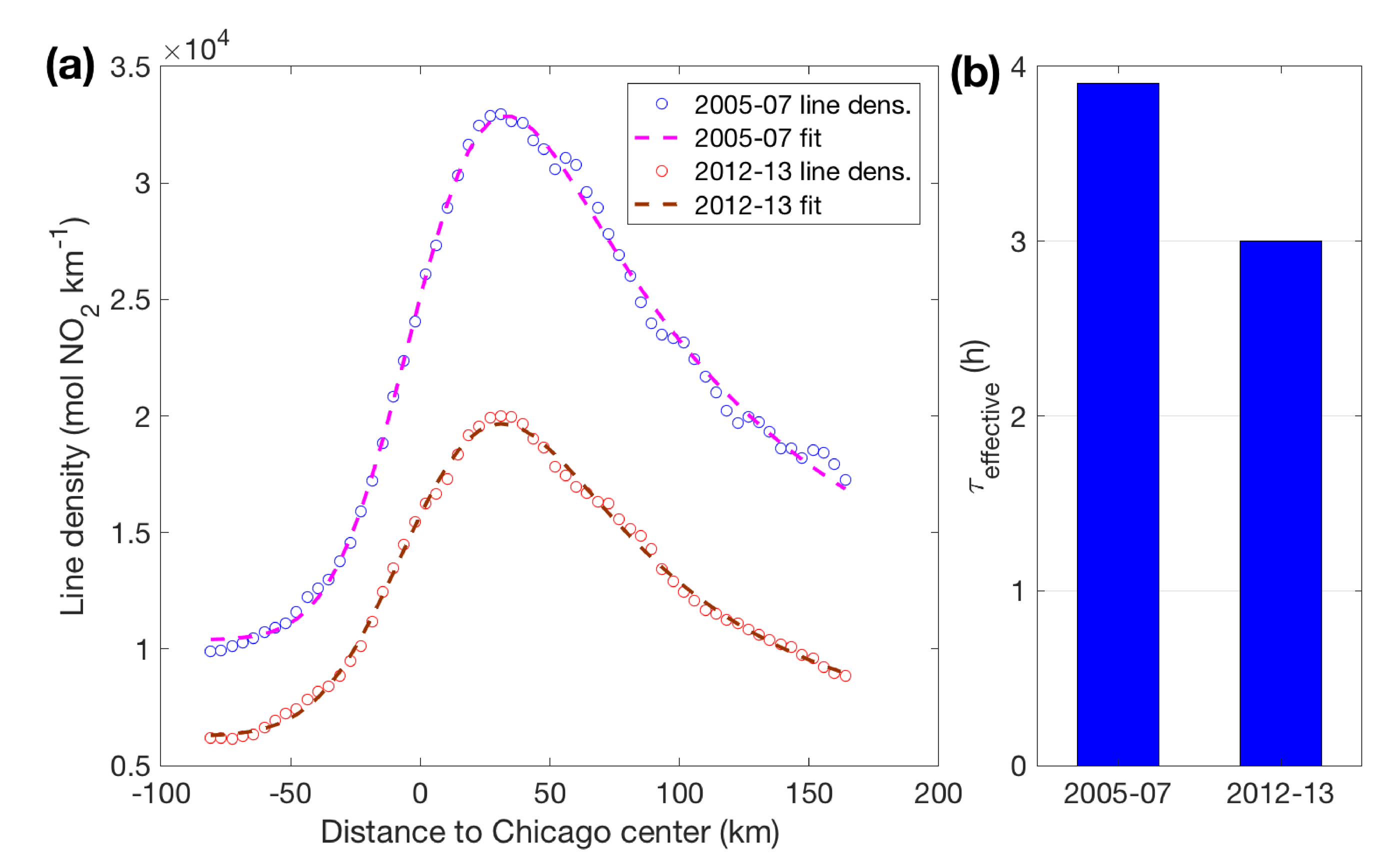

Figure 6: **(a)** Line densities and EMG fits for Chicago, IL, USA from 2005/07 and 2012/13 (using Apr.–Sept. weekday data). **(b)** EMG-derived lifetimes for Chicago.

- Weekday (Tue.–Fri.) EMG-derived lifetimes for Chicago, IL show a 25% decrease between 2005–07 and 2012–13.
- This suggests a change in chemical regime, possibly that Chicago is leaving the NO_x-suppressed regime

Conclusions

- BEHR v3.0 uses daily WRF-Chem profiles that better represent the NO_2 distribution than monthly average profiles
- With this retrieval, we observe a 25% decrease in NO_x lifetime in Chicago between 2005 and 2013.
- We plan to expand this analysis to other cities as well as investigate whether we can predict the efficacy of future NO_x emissions reductions in Chicago on NO_x concentrations and ozone production between 2007 and 2014.