Global Sources of North American Ozone

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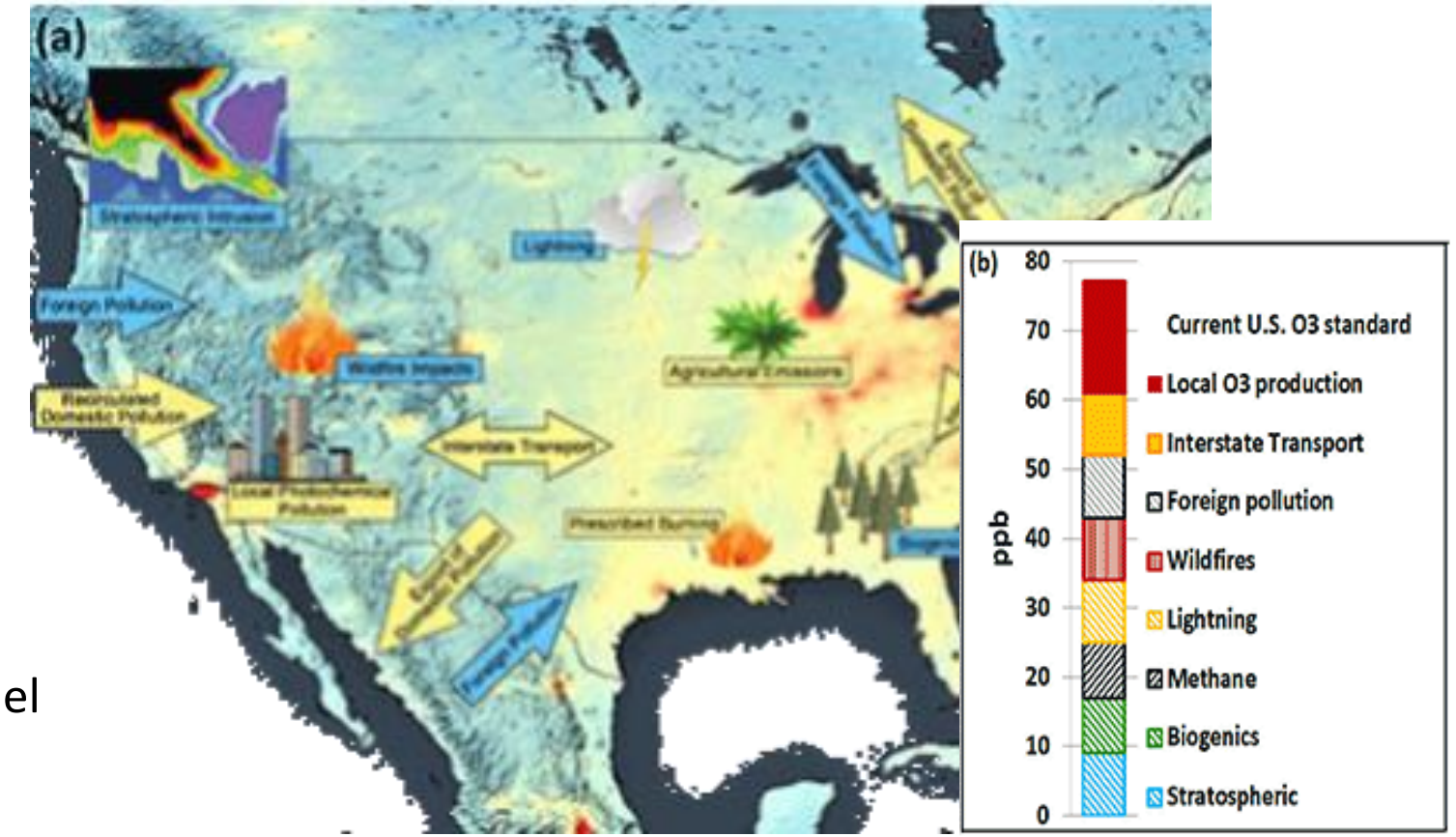
***Disclaimer**: The views expressed in this presentation are those of the authors and do not necessarily reflects the views or policies of the U.S. Environmental Protection Agency.*

What are background concentrations?

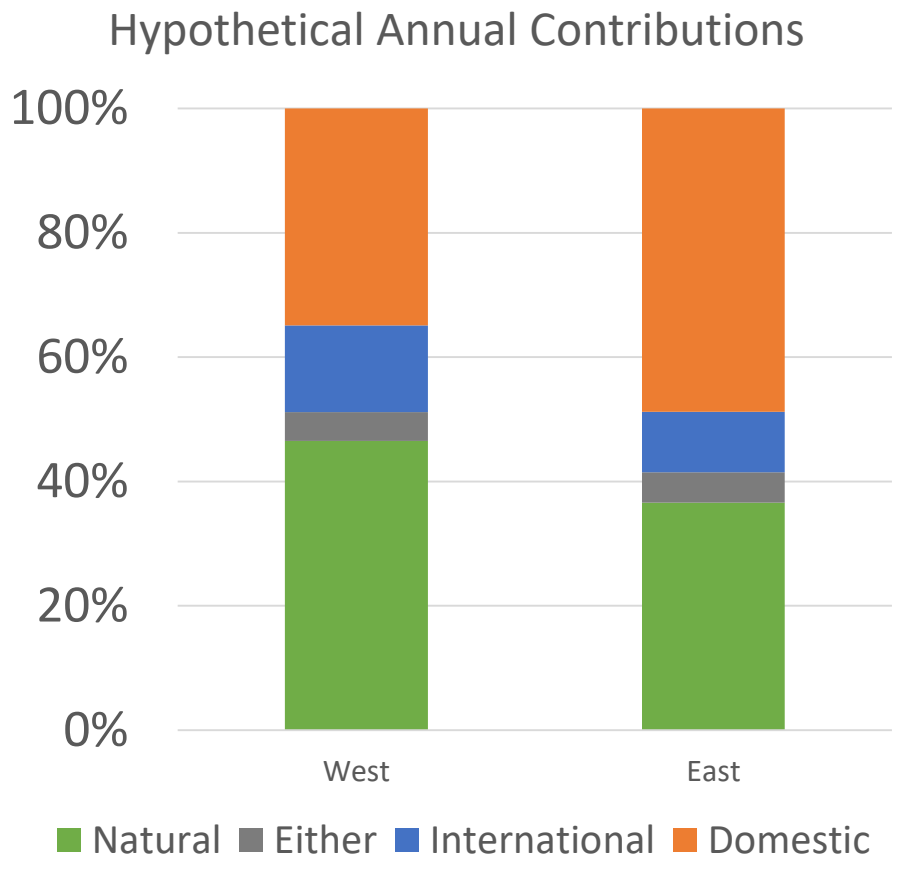
- Jaffe et al. (2018) uses a source oriented definition
  - Non-Controllable *Ozone* Sources contribute to background ozone.
  - What is controllable, to some extent, depends on context.
- "Non-Controllable" Ozone Sources
  - Stratosphere
  - Lightning NOx
  - Wildfires, Biogenics
  - Seasonal uncertainty ±10 ppb
- "Controllable"
  - Depends on Context…
  - Non-Attainment Area
  - State, Country
  - International?
- ***Ambient air has all sources***
  - NCOS can be important
  - NCOS vary from year to year
  - NCOS vary from model to model

doi: 10.1525/elementa.309



Zero-out estimates of ozone contributions

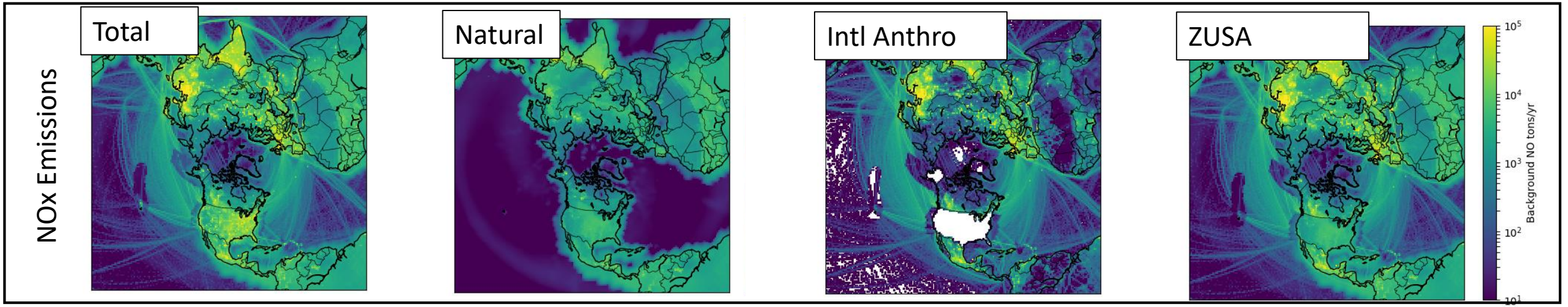
- *Motivations:*
  - Interannual variability (e.g., Lin et al., 2017)
  - Modeling system (e.g., Huang et al. 2017)
  - 2016 platform (α)
- *New Estimates:*
  - *Northern Hemispheric:* **Natural**
  - International anthropogenic: **Intl**
  - Domestic anthropogenic: **USA**
  - And either: **Residual**…
- Long range transport and aloft results
  - At 108km & Separating China and India
- Surface results
  - 108km and 12 km nested from 108 km LBC
  - Natural, Intl, USA



Estimates of 2016 Ozone Components

- **Predictions** = *F*(*M, E*)
  - Total : *E* = sum({*nat, usa, sum(intl)*})
  - Natural : *E* = sum({*nat*}); *soil NOx and methane are treated as natural*
  - ZINTL : *E* = sum({*nat, usa*}); *Prescribed fires are treated as anthropogenic*
  - ZUSA aka USB : E = sum({nat, sum(intl)}); Others…

Evaluations: Henderson CMAS 2018; IGC9 2019; CMAS-SA 2019



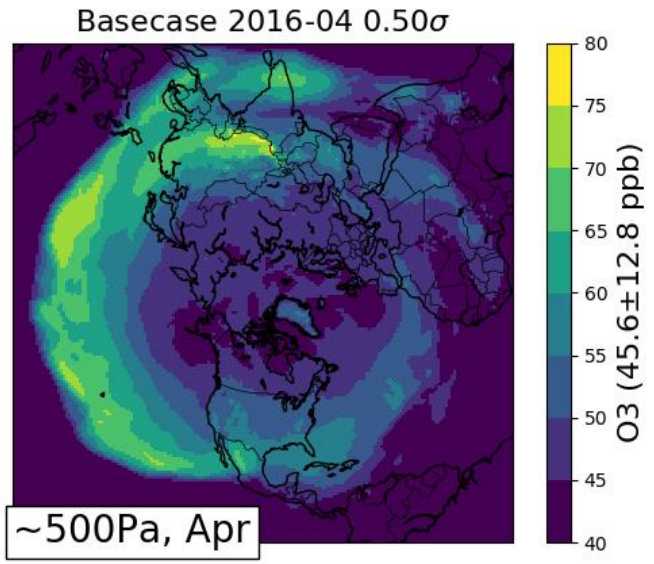
Contributions

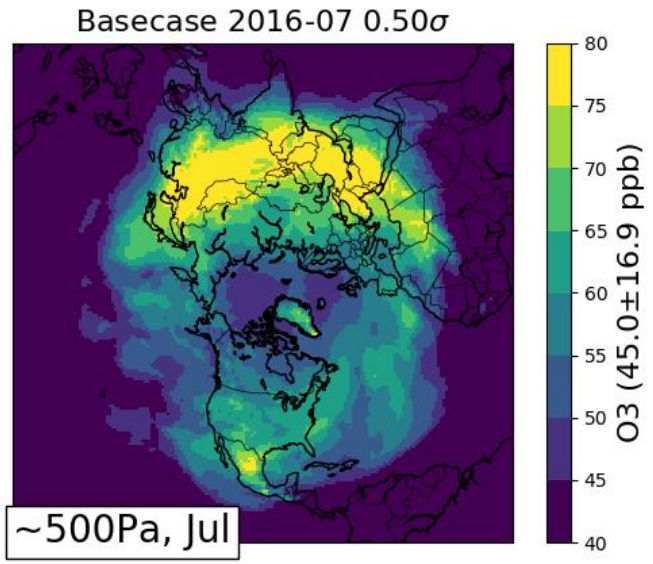
- Natural = ZANTH
- USA = Total - ZUSA
- Intl = Total - ZINTL
- RES* = Total - USA - INTL – NAT

International Parts

- CHN = Total - ZCHN
- SHIP = Total - ZSHIP
- IND = Total - ZIND
- CANMEX = Total – ZCANMEX
- OTHER = Intl - CHN - IND - SHIP - CANMEX

Monthly average ozone illustrate transport





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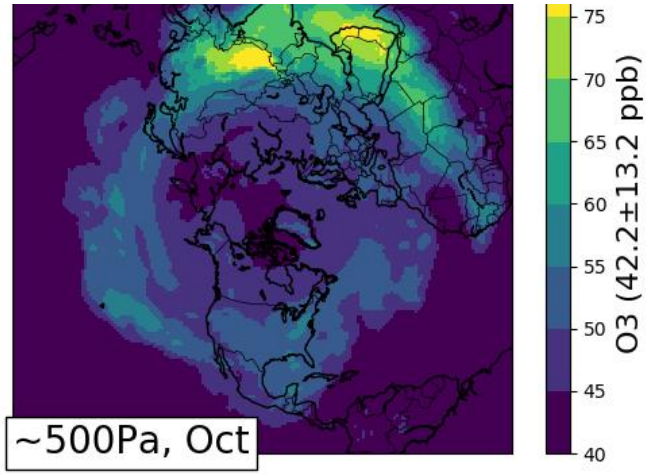
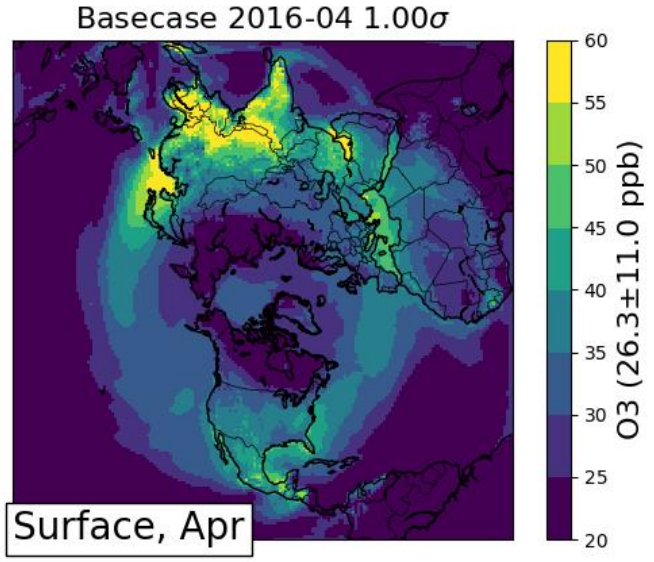
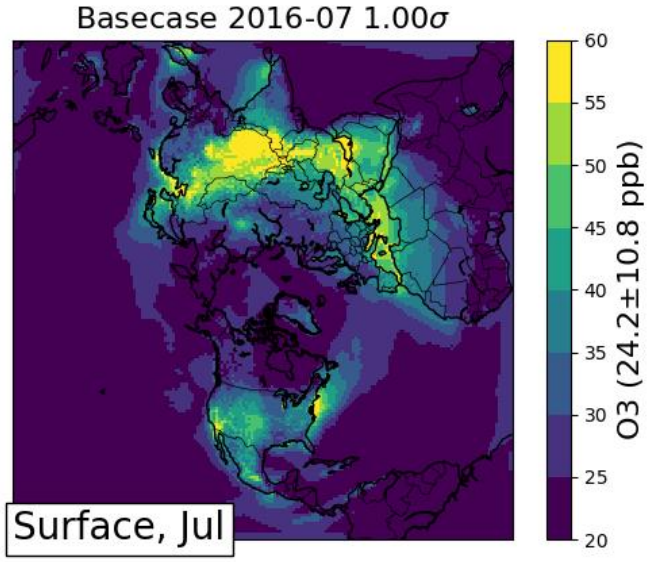
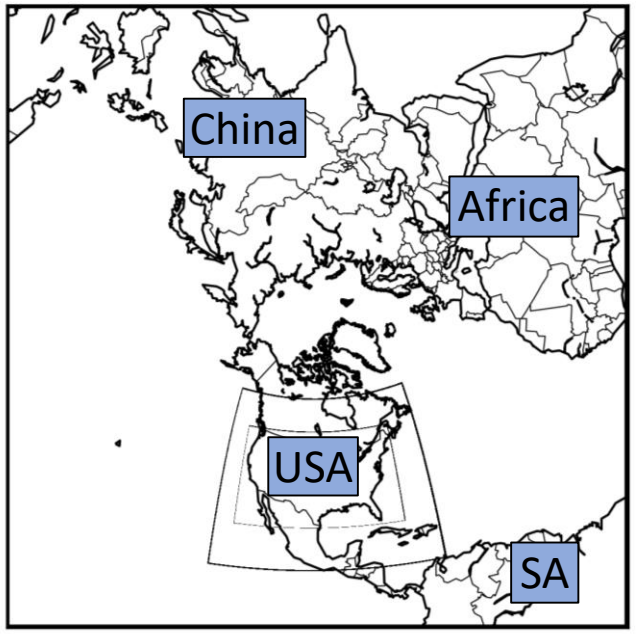
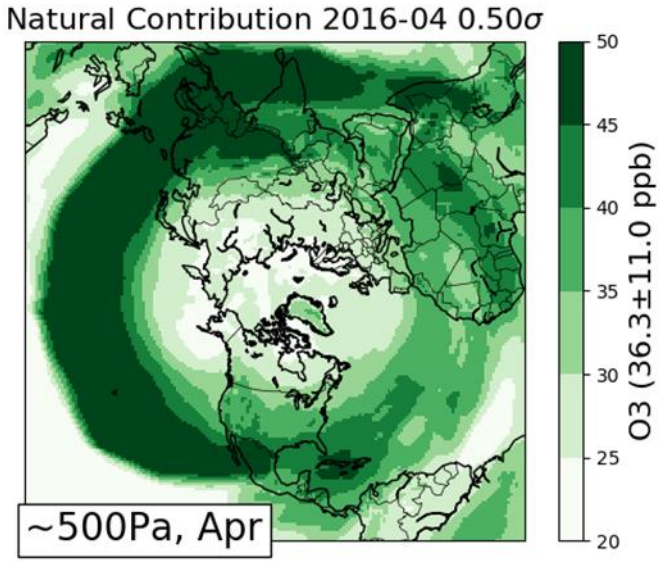


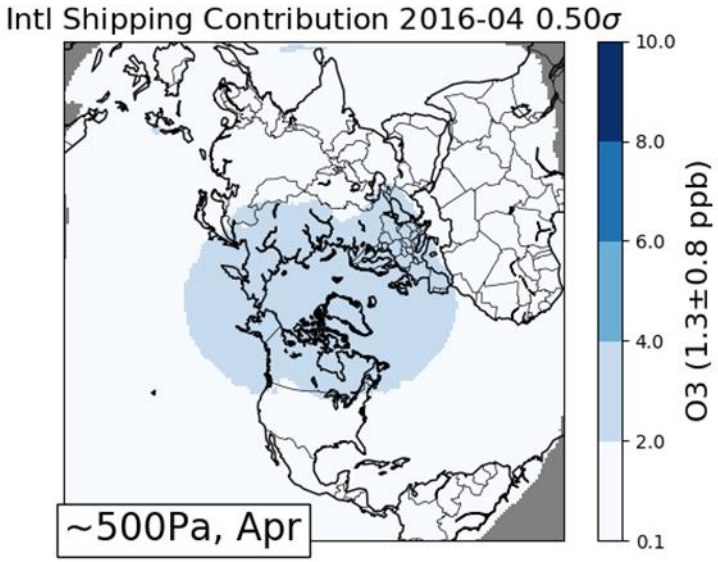


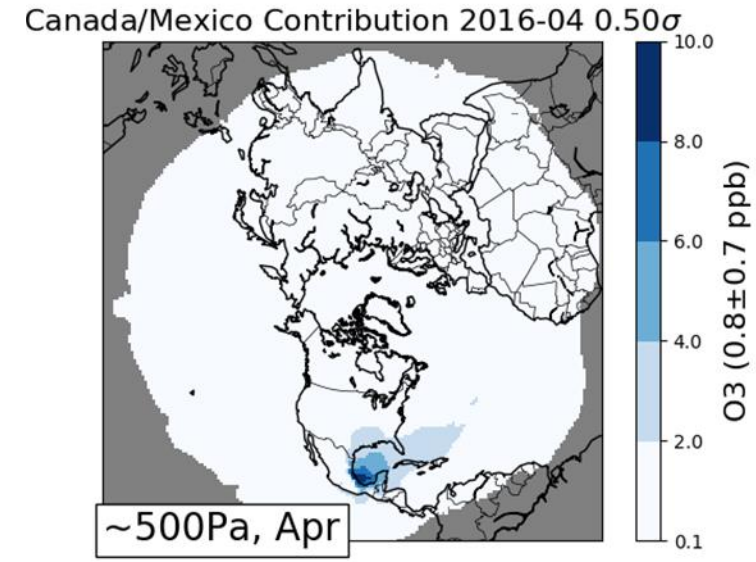


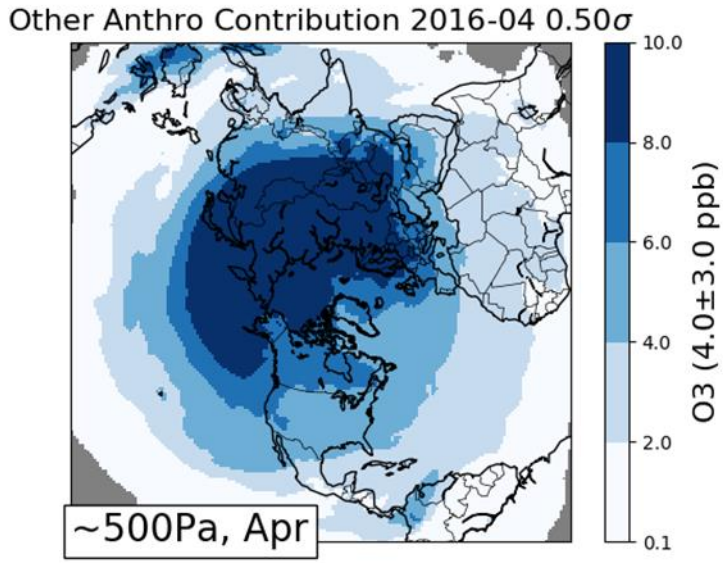


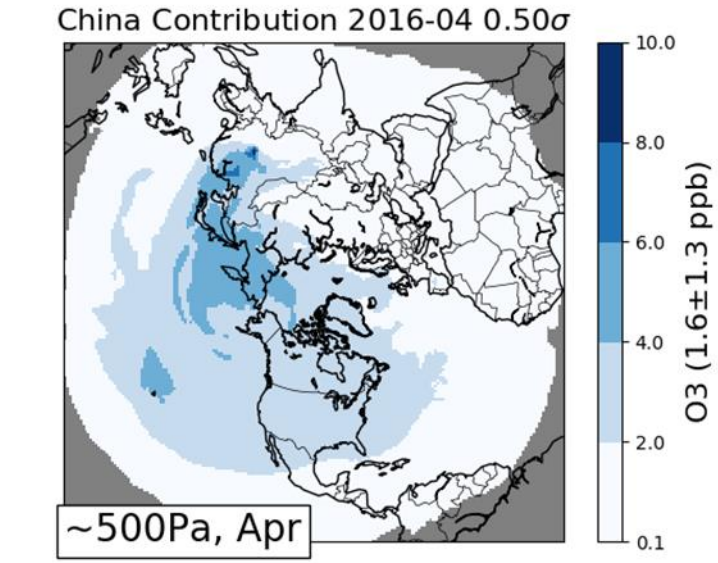
Ozone source contributions in April aloft

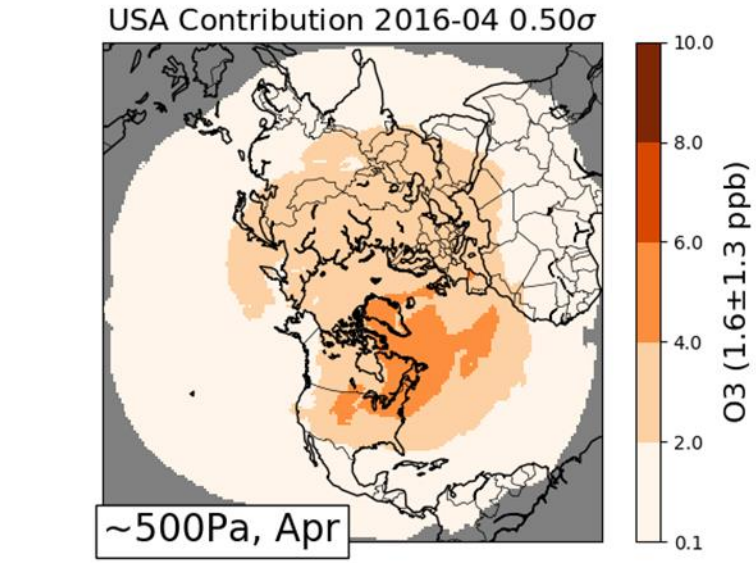




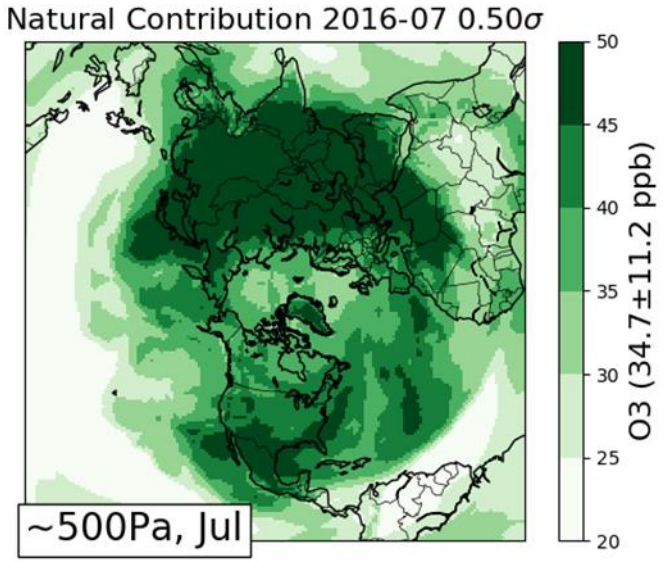


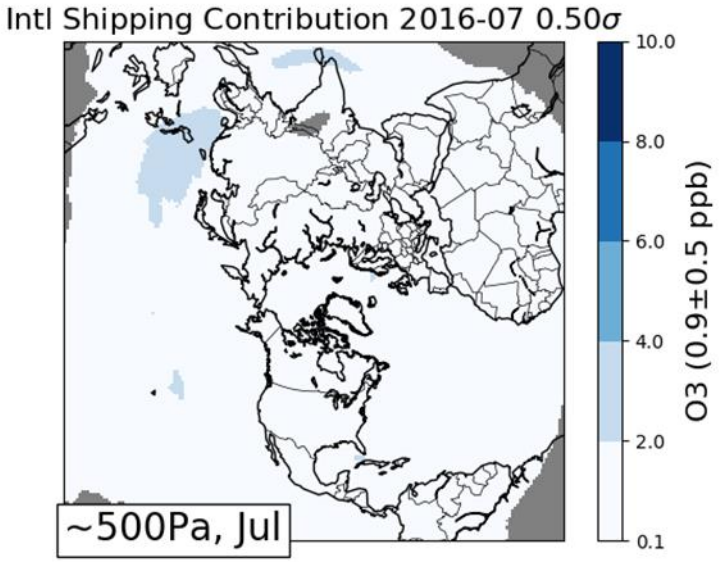


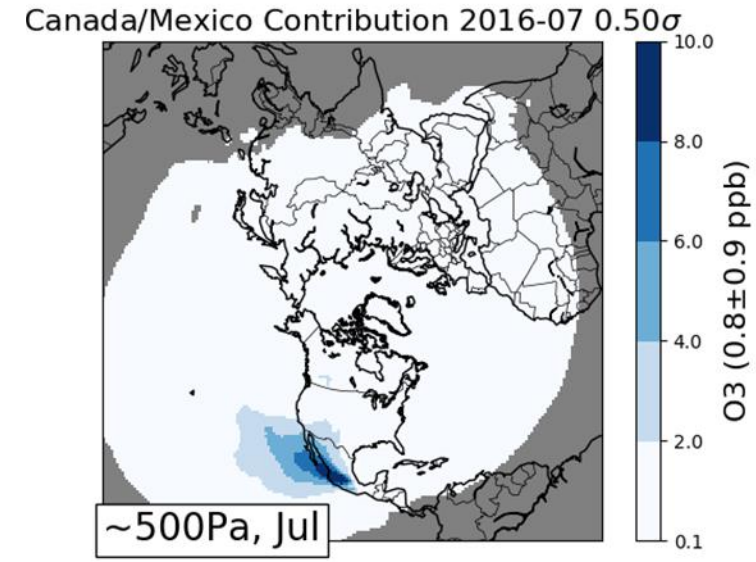


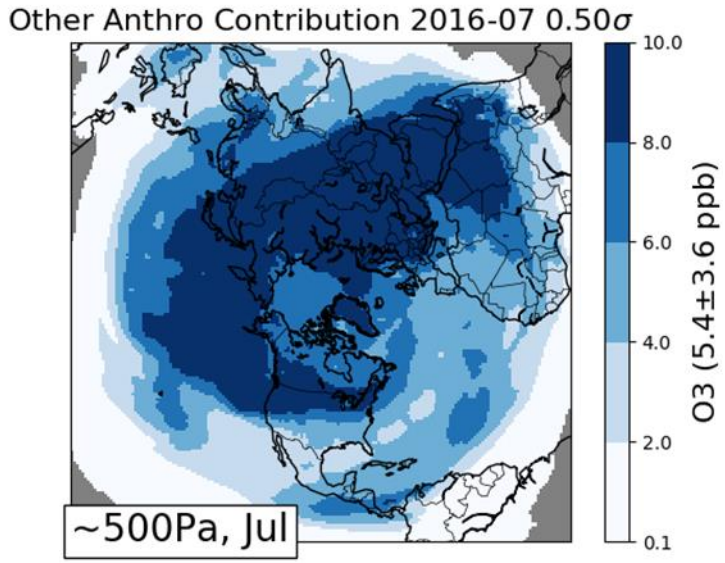


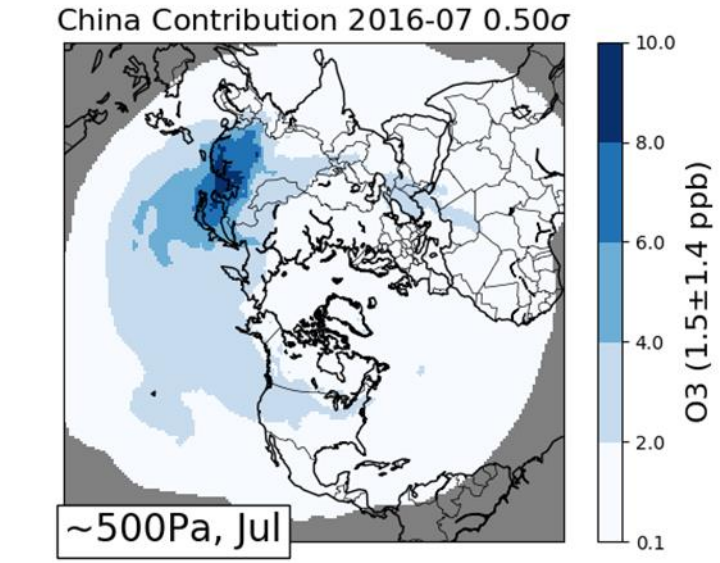
Ozone source contribution in July aloft

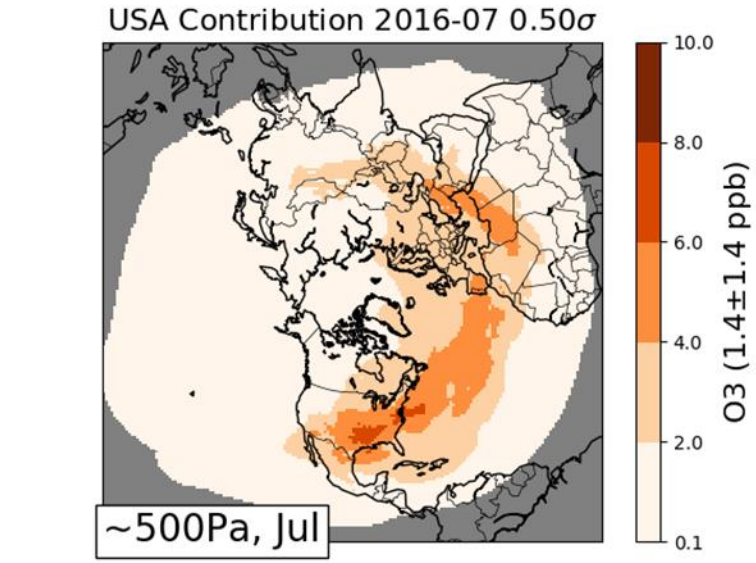






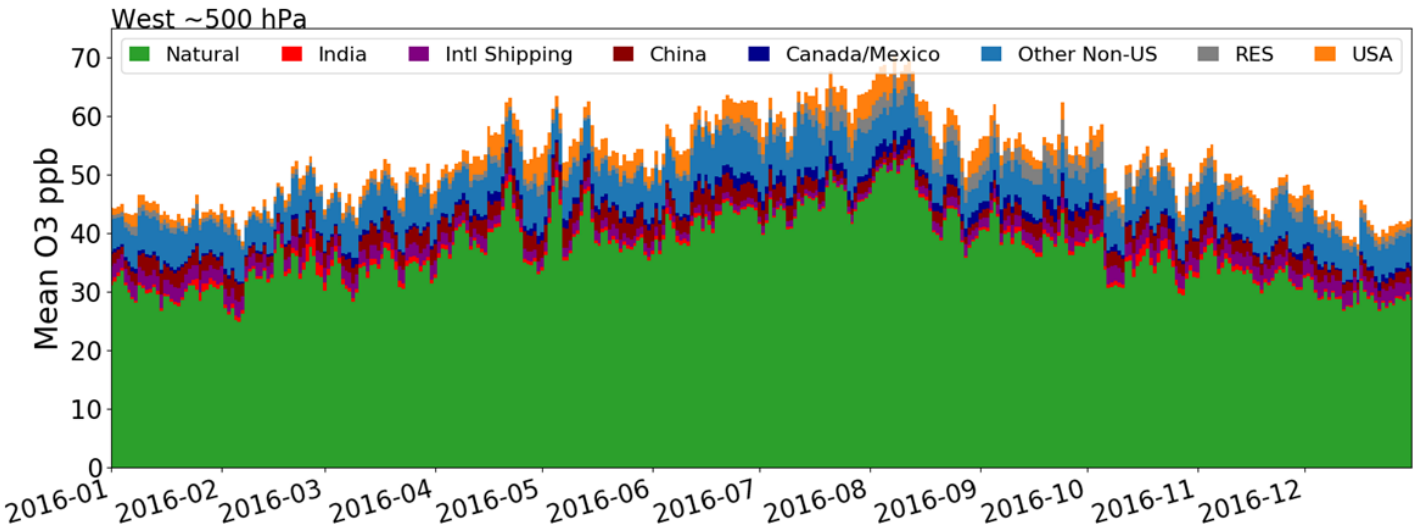


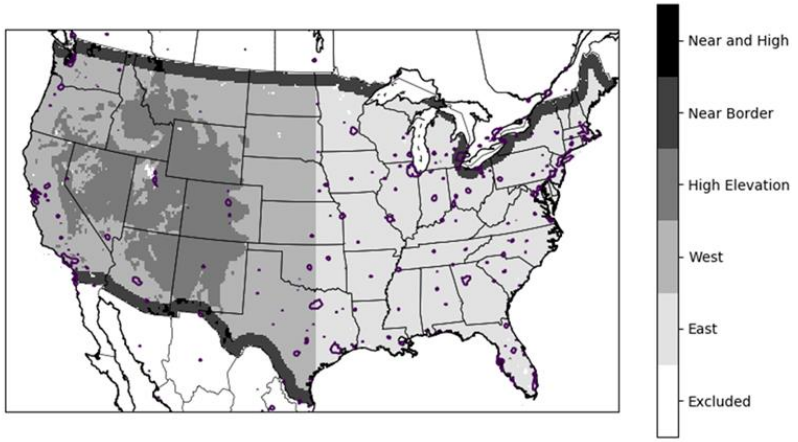




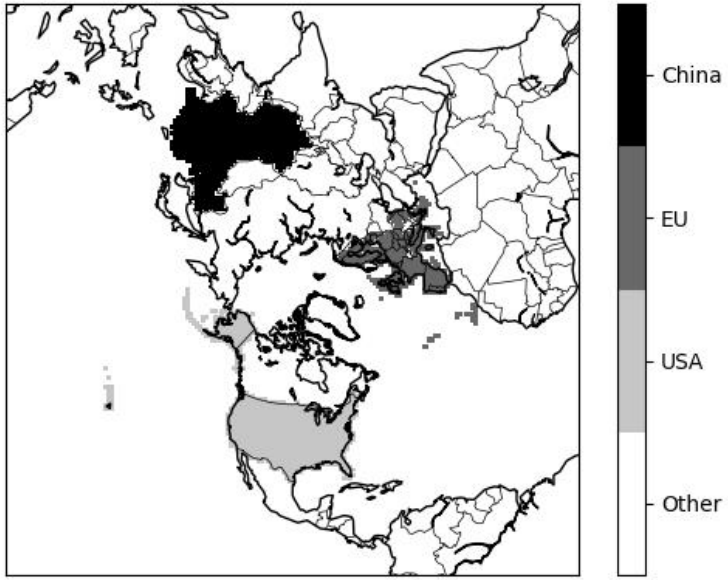
Difference between West and East aloft (108km)

West Contributions

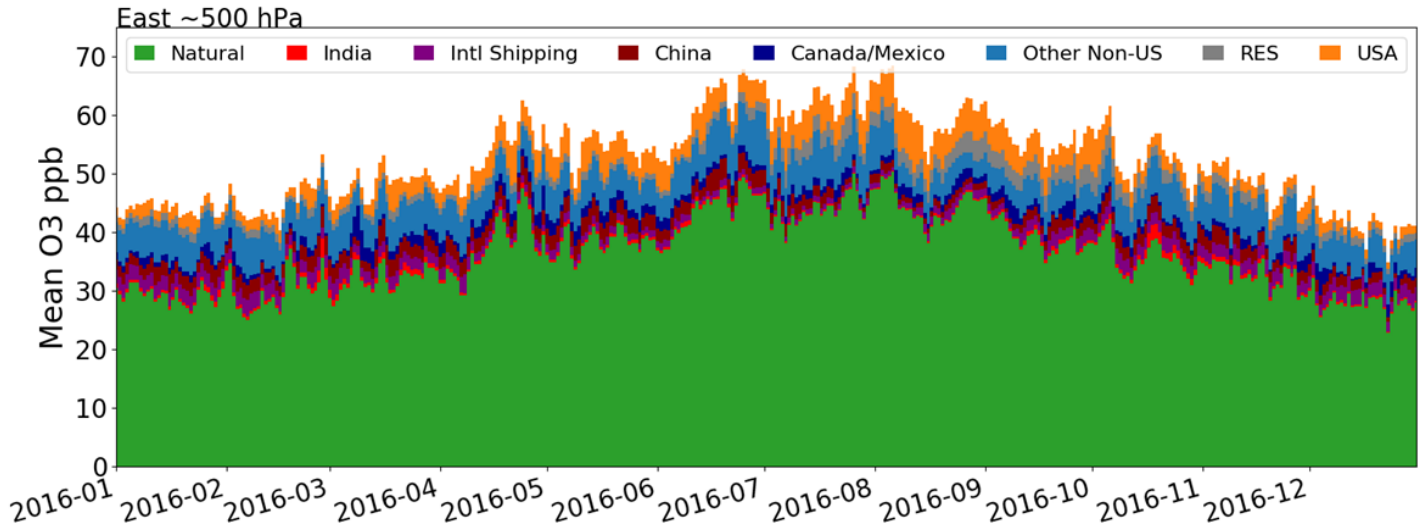




Other countries 10-15 ppb

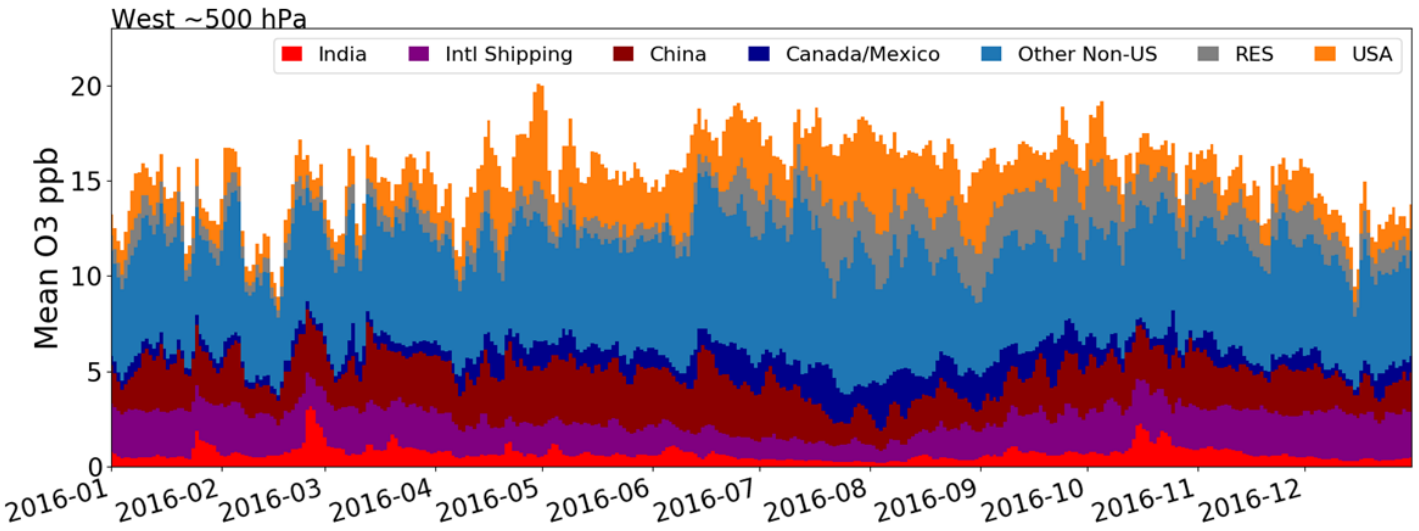


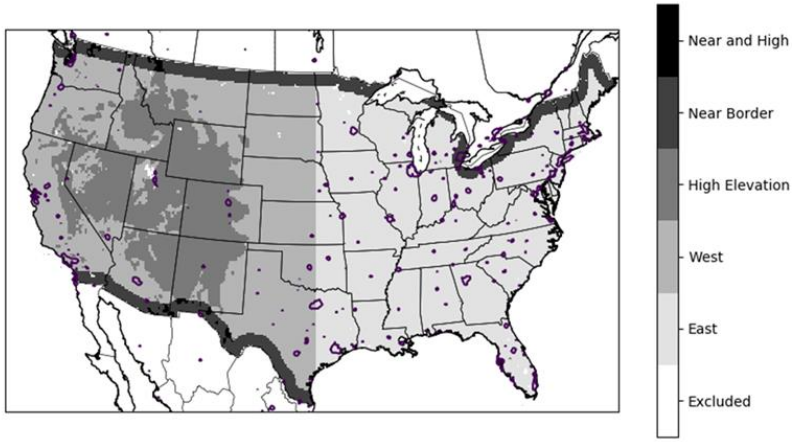
East Contributions



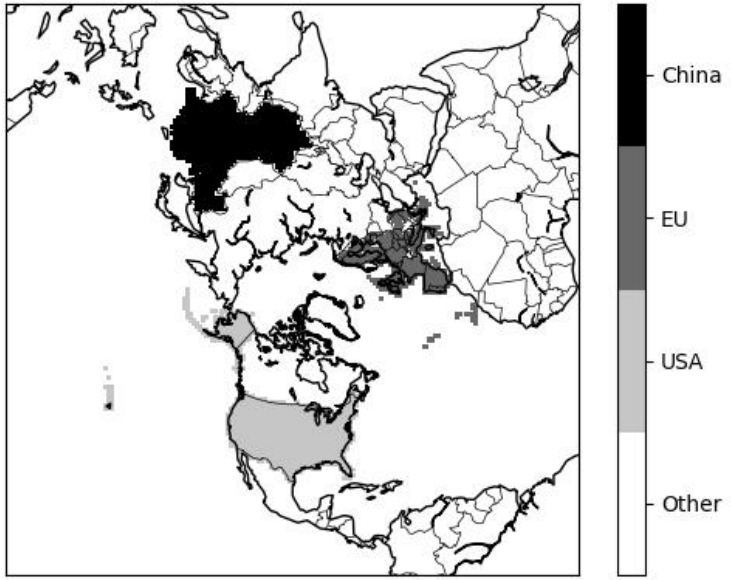
Difference between West and East Aloft (108km)

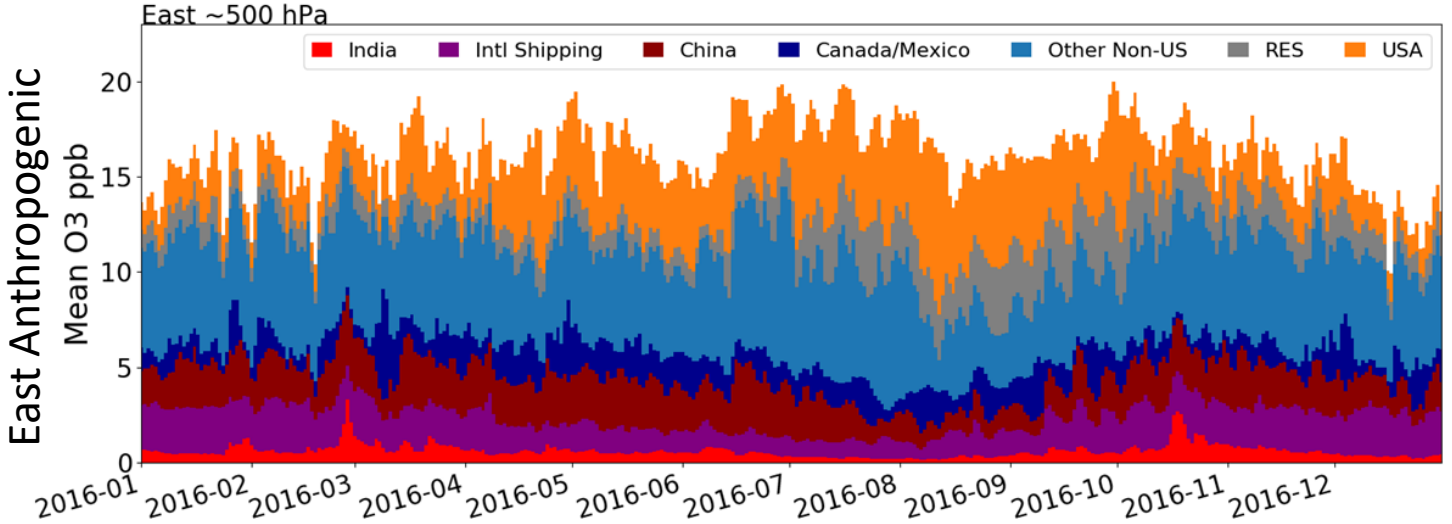
West Anthropogenic





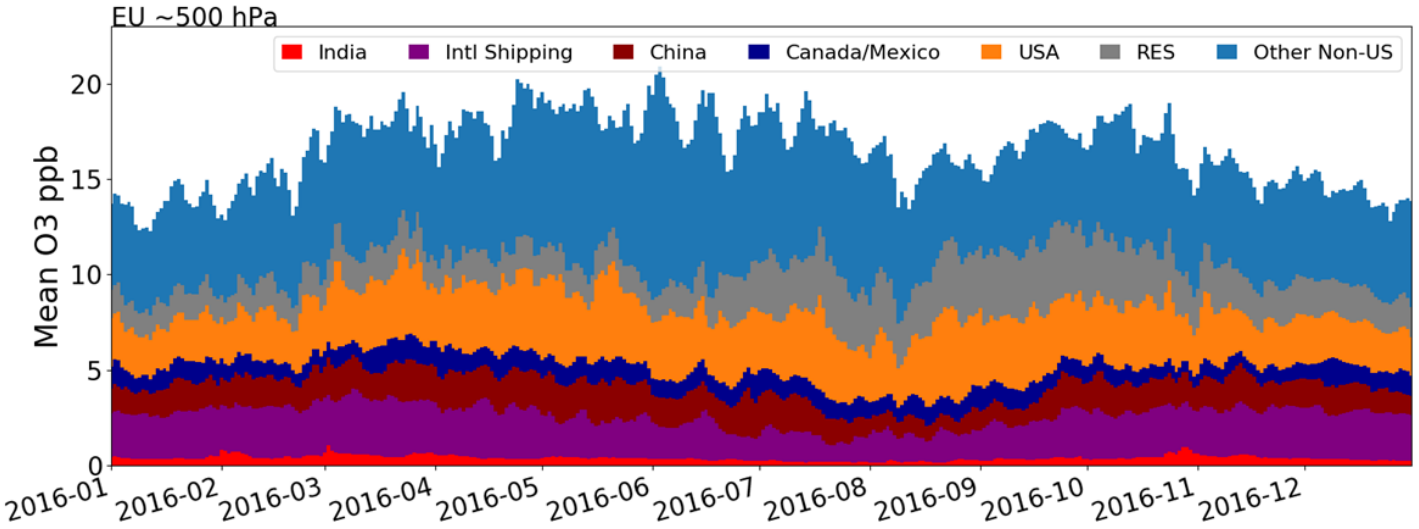
Other countries 10-15 ppb



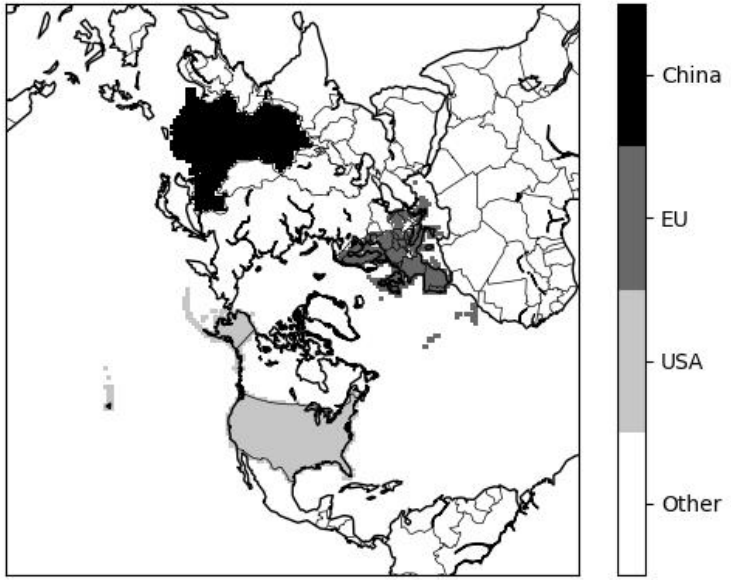


China and the European Union (108km)

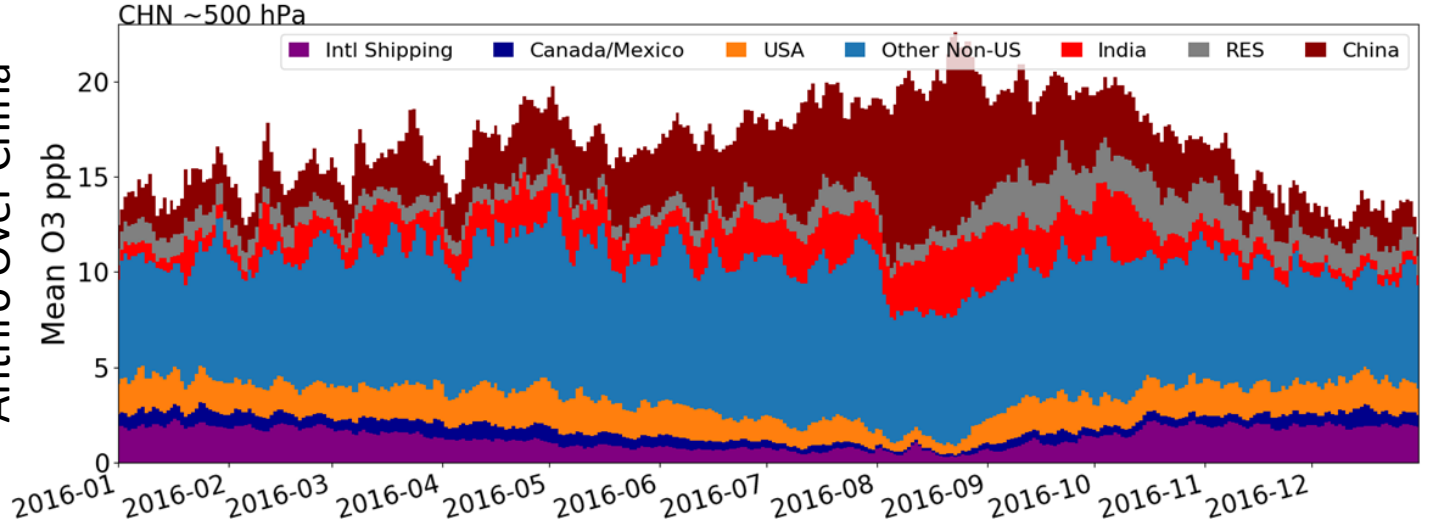
Anthro over the EU
(*UK in EU at time of writing*)



Other Non-US is not all EU, but this gives us a sense that upwind contributions similar in the EU as in the West.

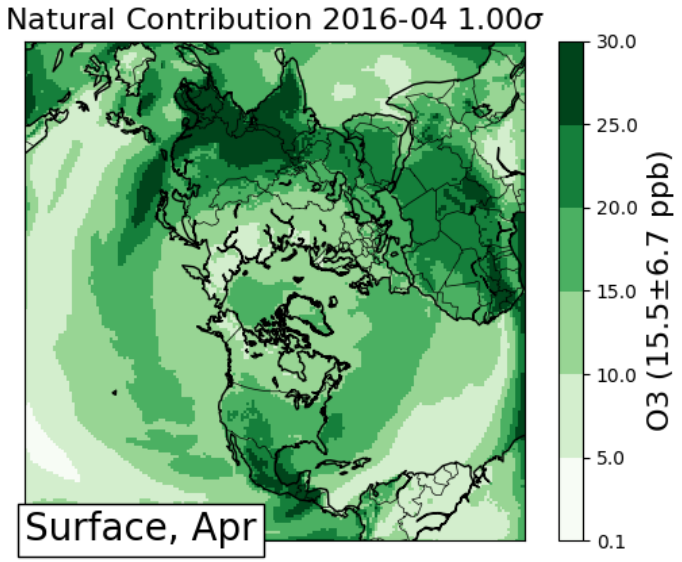


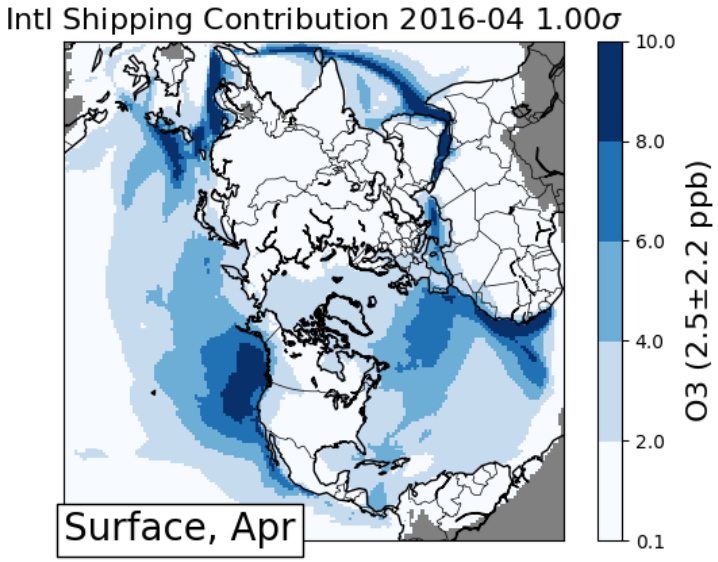
Anthro Over China

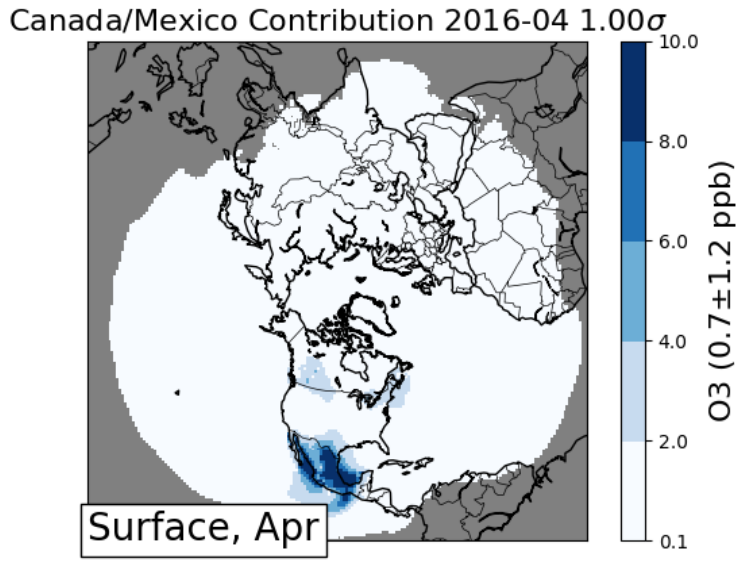


China Aloft ozone from other countries is 10-15 ppb

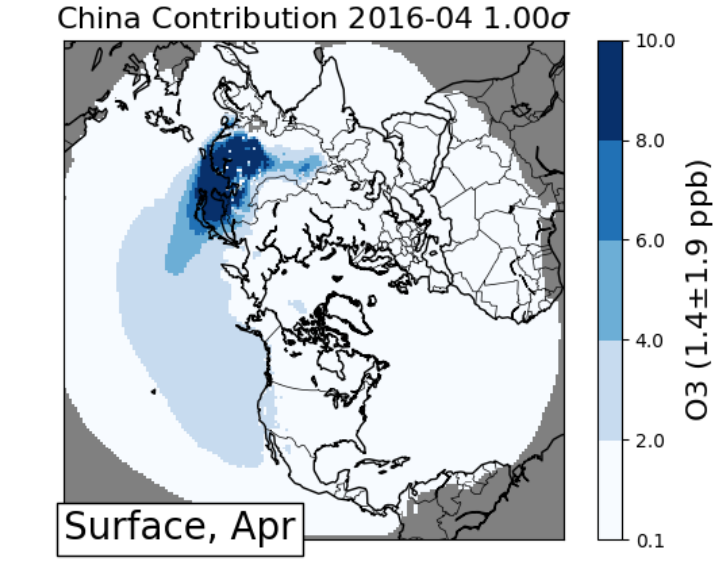
Ozone source contributions in April at the Surface

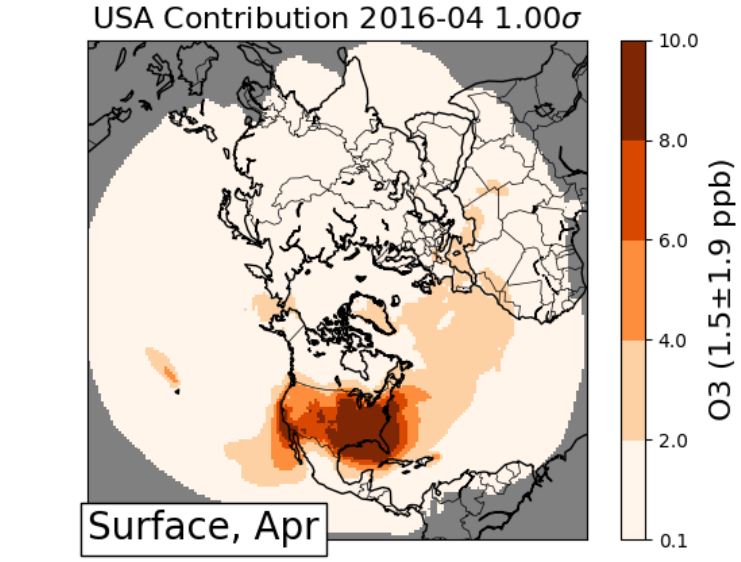




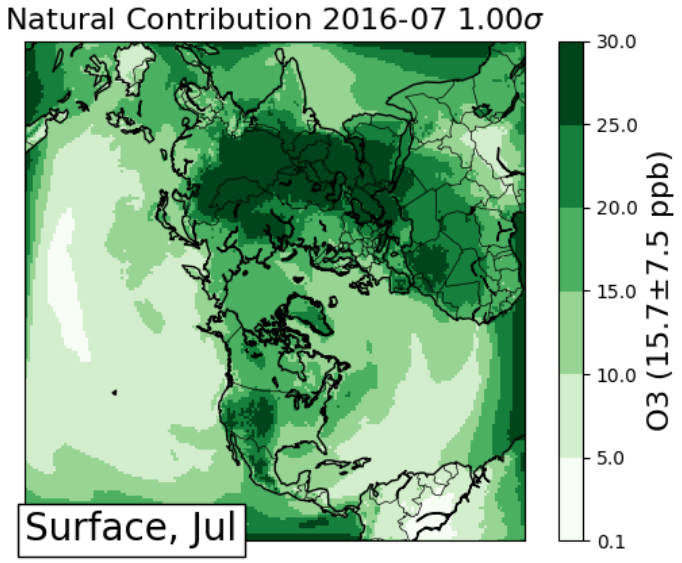


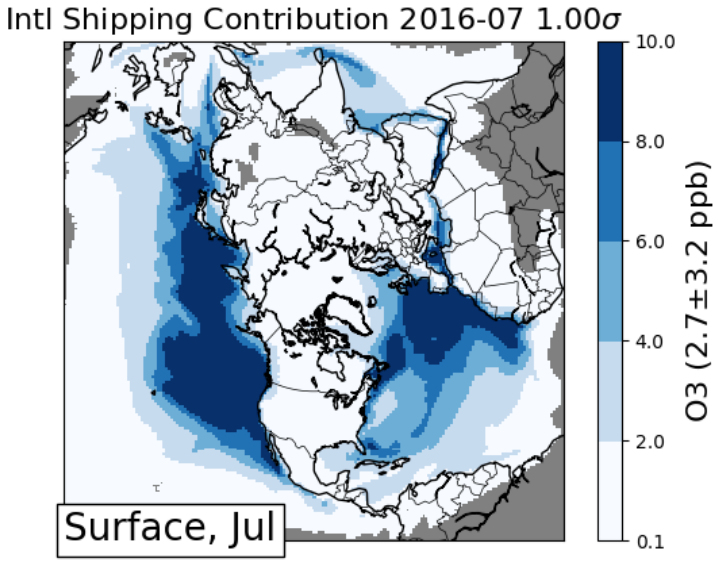
"The only reliable quantitative ozone measurements from the late 19th century were made at Montsouris near Paris where ozone averaged 11 ± 2 ppbv from 1876 to 1910." ... "While these measurements indicate that late 19th century ozone in western Europe was much lower than today, there is no way to know if these values were representative of other surface locations in the NH." - Cooper et al., 2014. doi: 10.12952/journal.elementa.000029

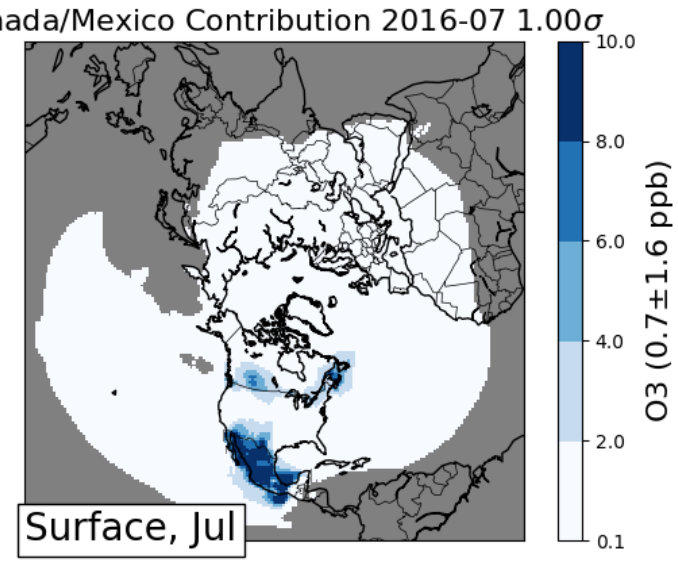


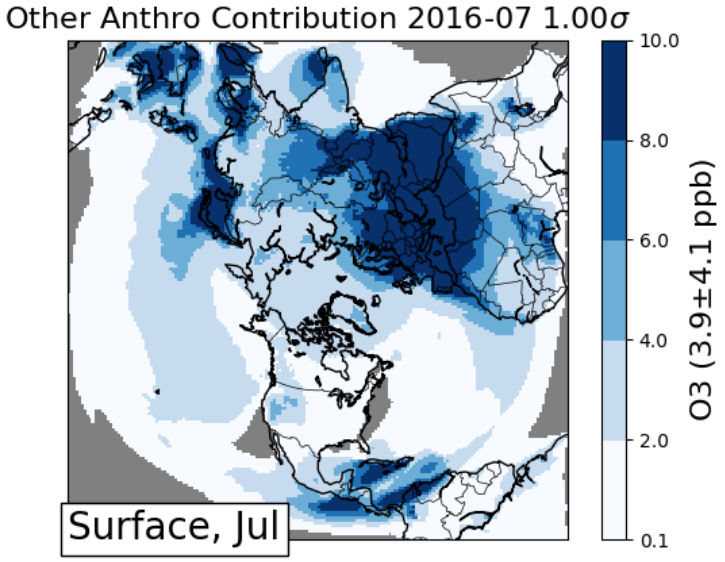


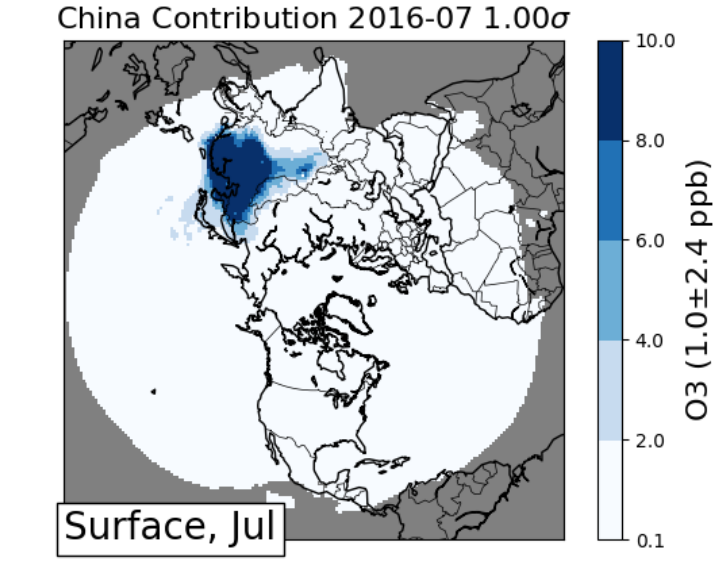
Ozone source contributions in July at the Surface

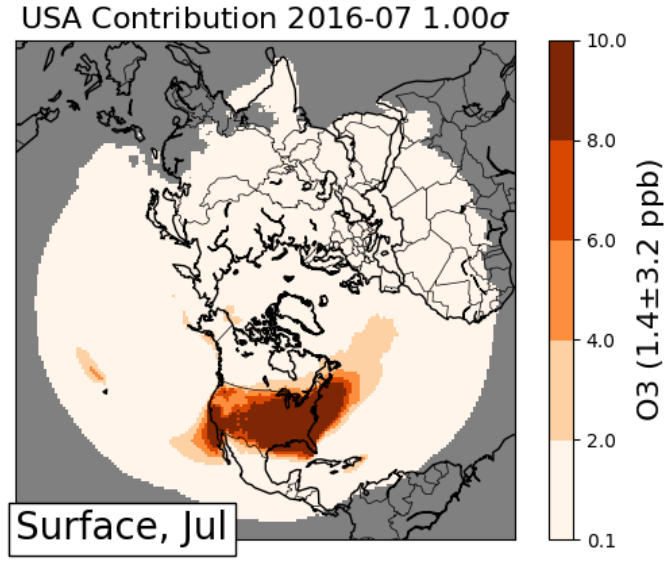






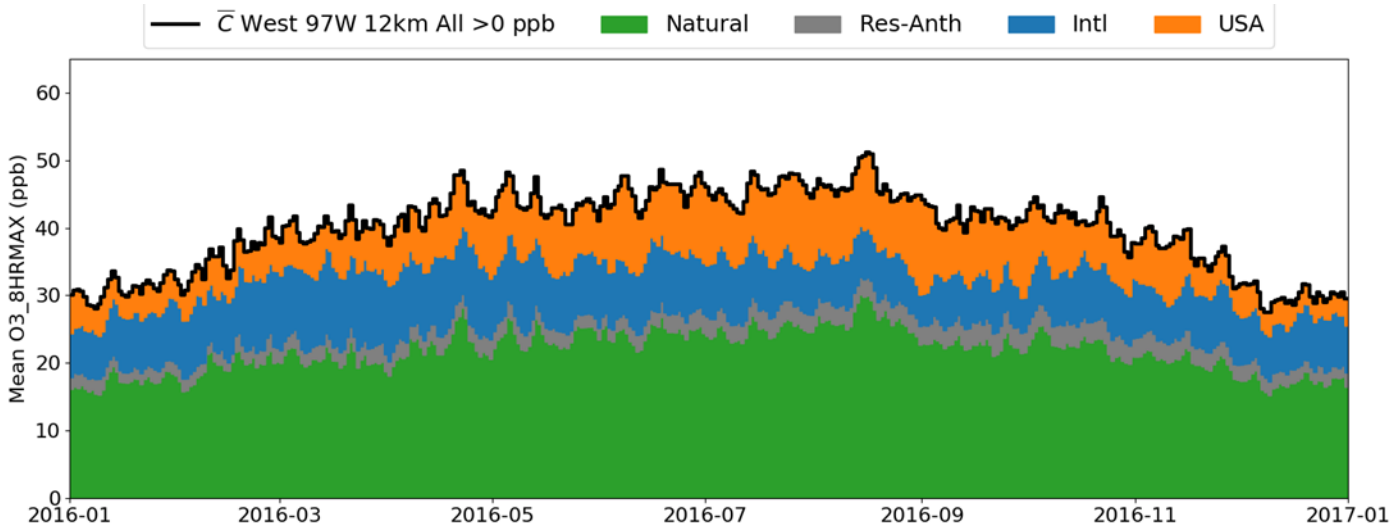


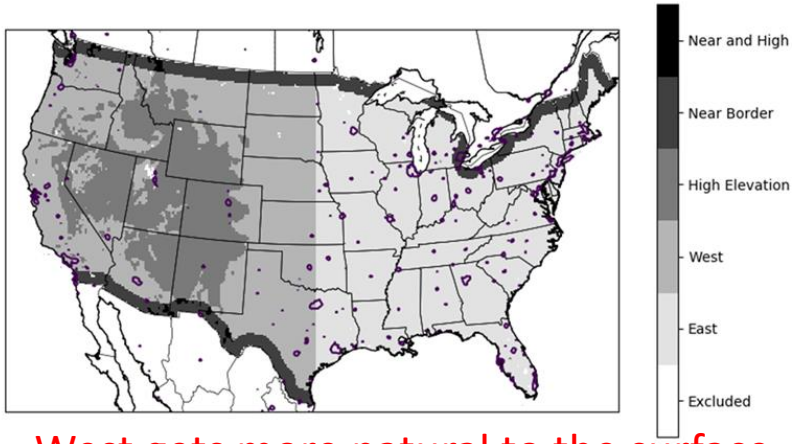




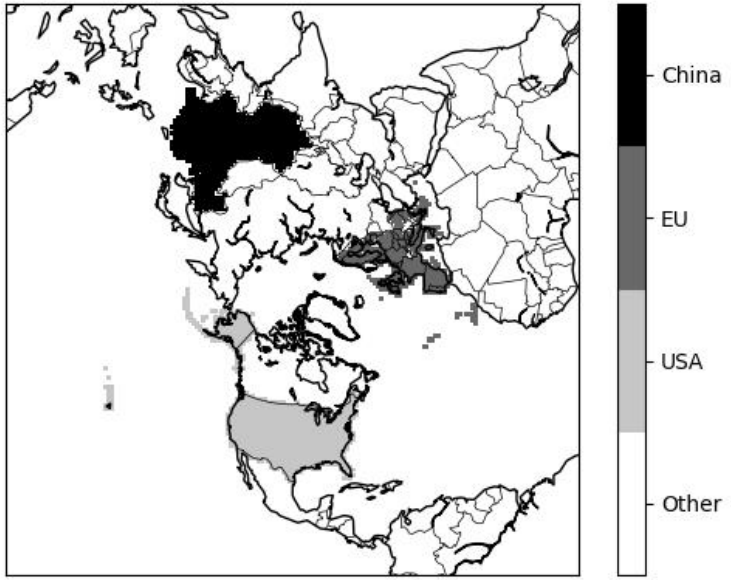
Difference between West and East Surface (12km)

West Contributions

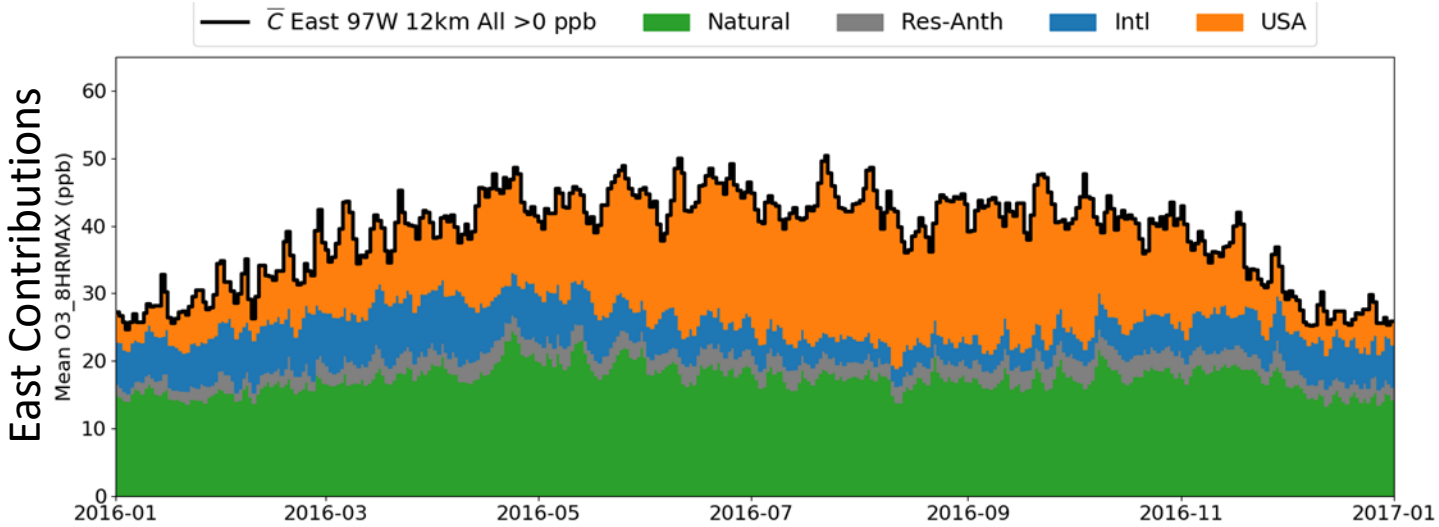




West gets more natural to the surface; think stratosphere.

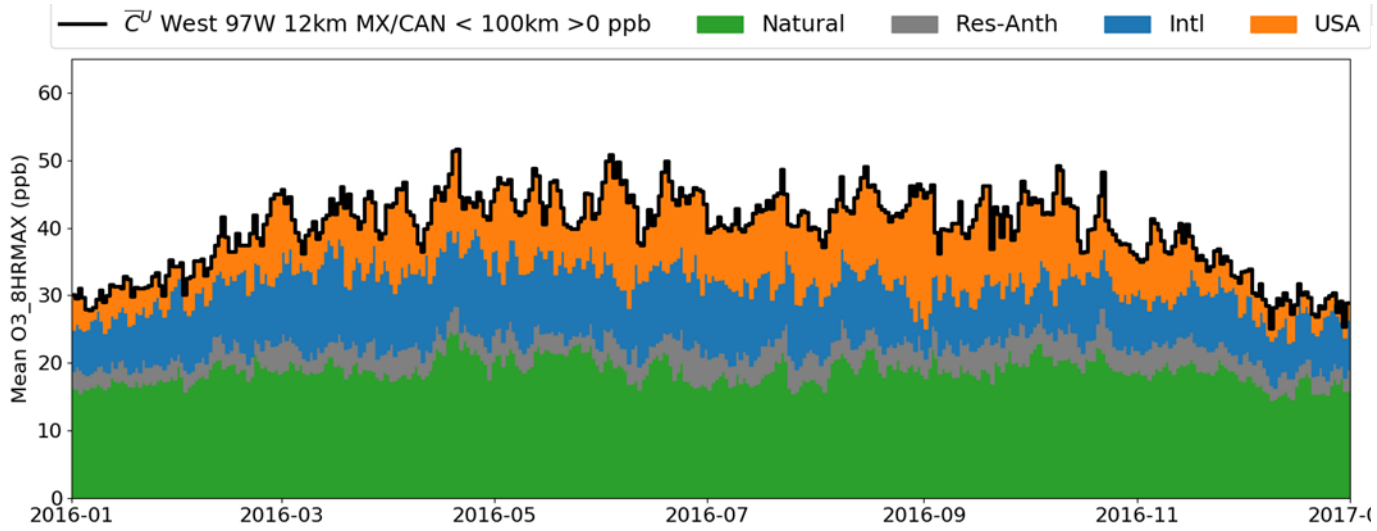


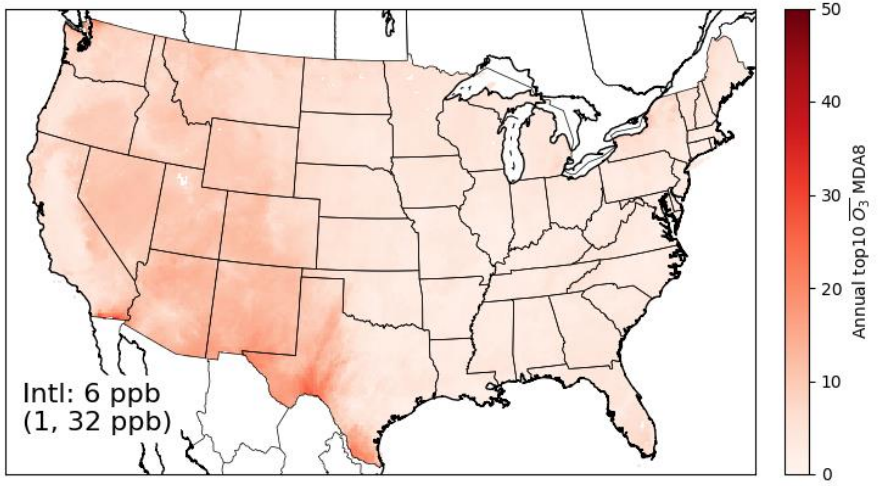
East Contributions

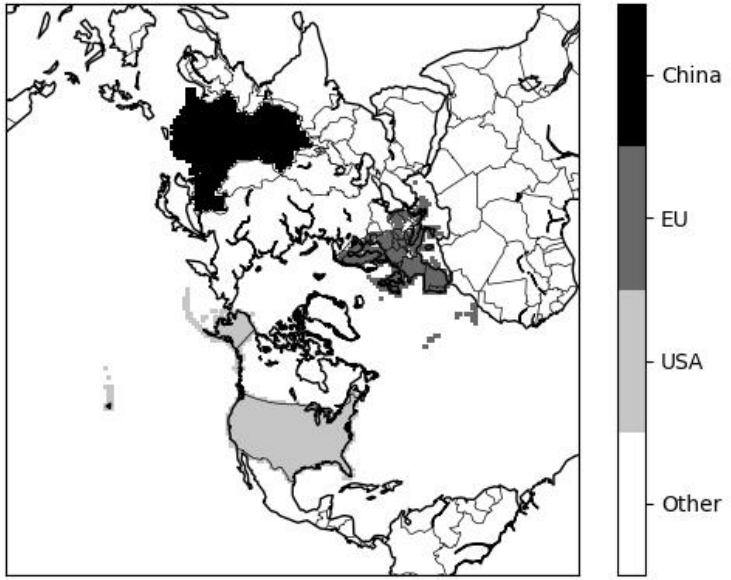


Differences within the West at the Surface (12km)

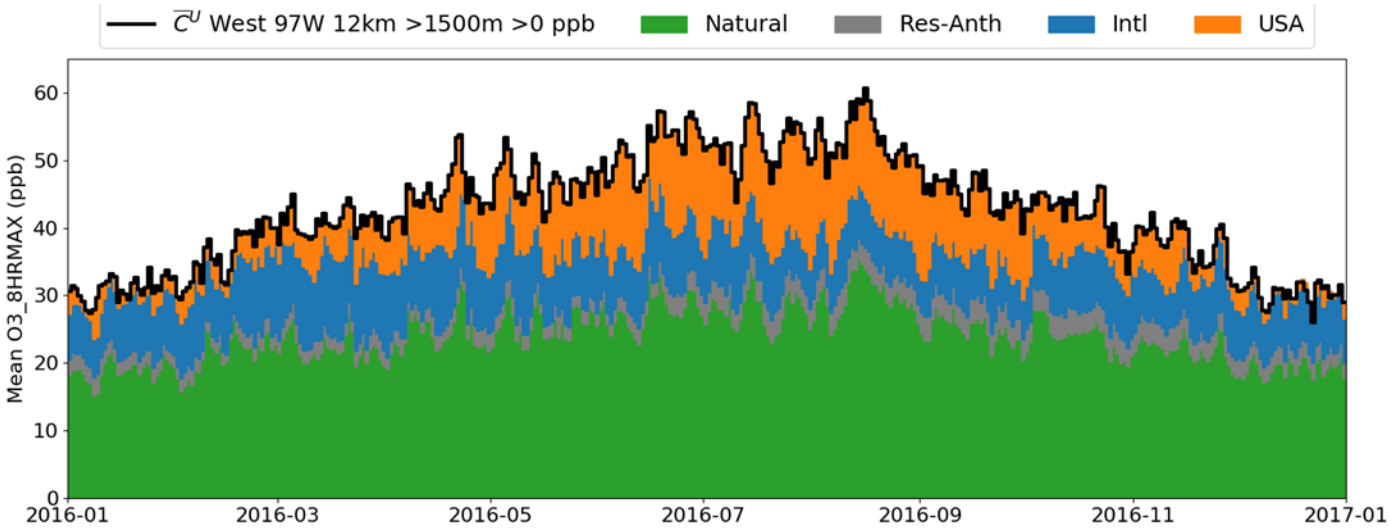
Near Border has consistent international





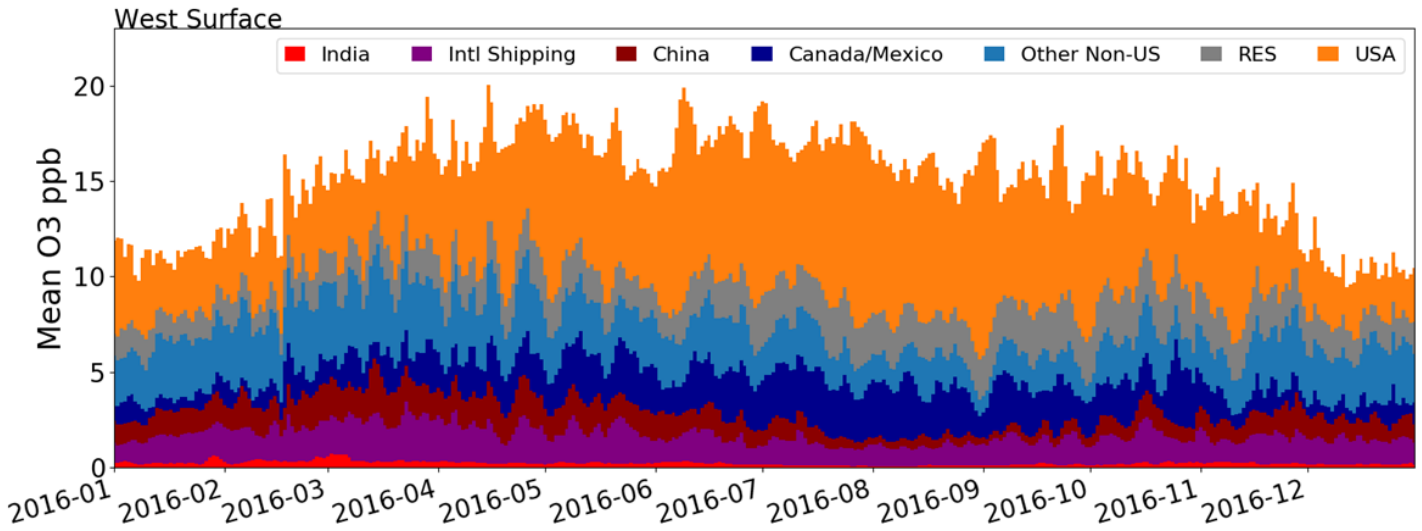


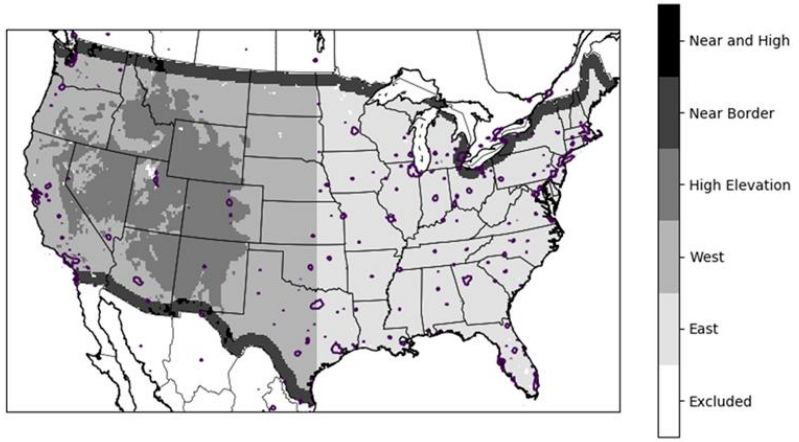
High Elevation more Natural



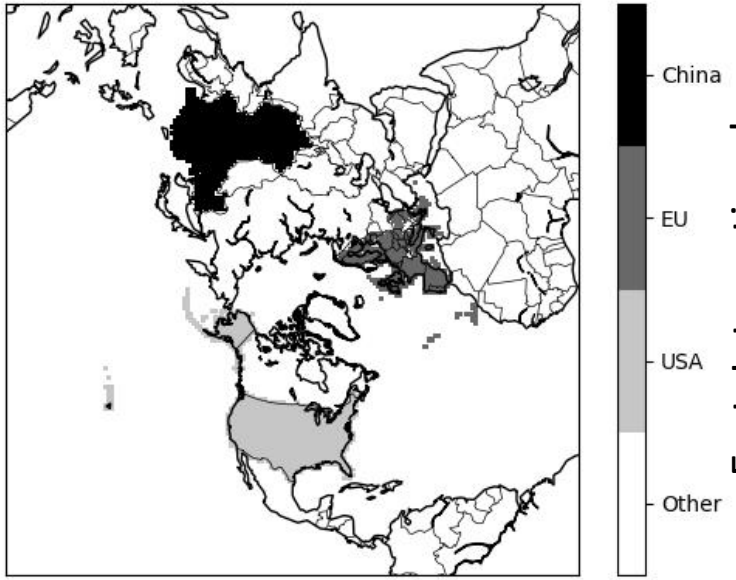
Difference between West and East Surface (108km)

West: Canada increases as long-range decrease

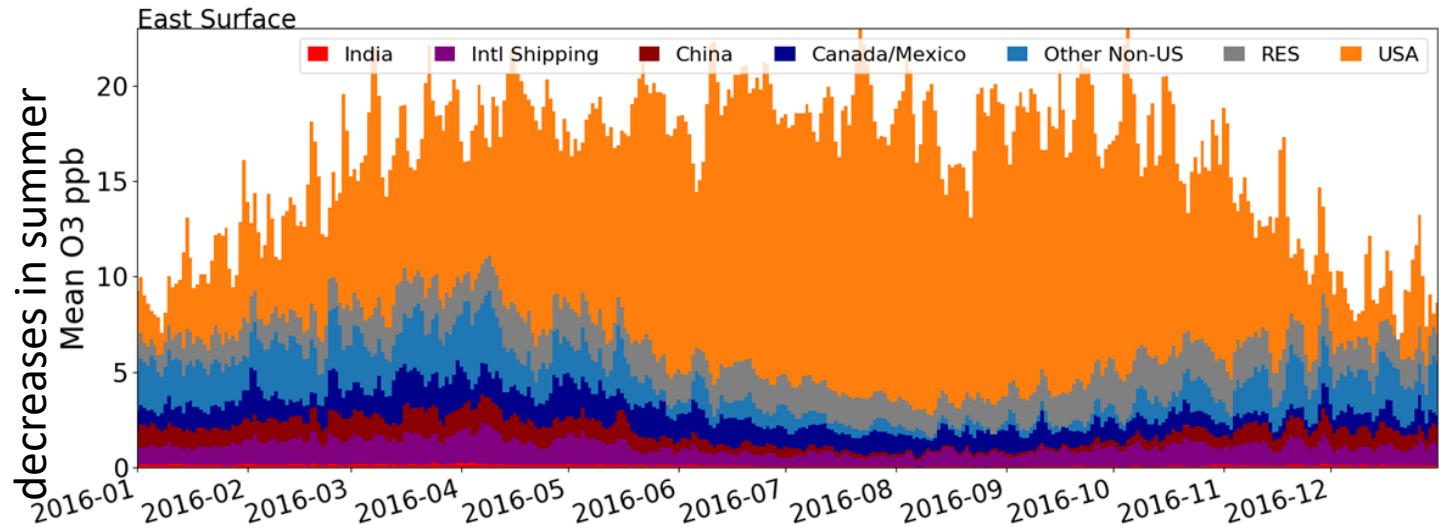




Other countries 2-5 ppb on average



East: International decreases in summer

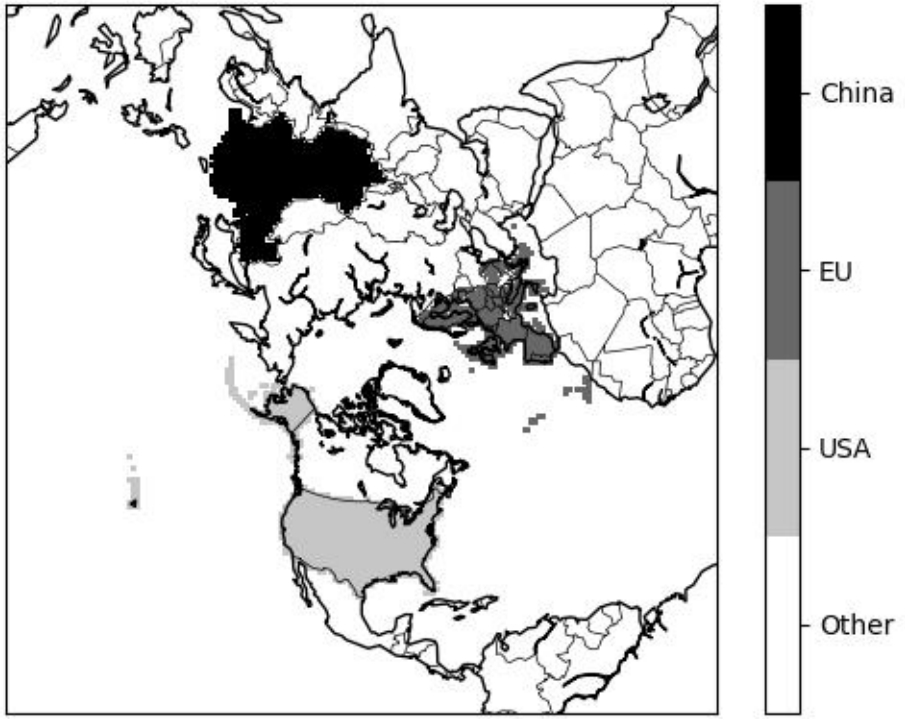


India/China pop-weighted impact higher, but consistent with West, Horowitz, Fiore doi:10.5194/acp-9-6095-2009, see supplement Tables S1

Summary

- Zero-out simulations provide estimates of contributions
  - Global Natural, International Anthropogenic, Domestic Anthropogenic
  - India, China, International Shipping, more to come
- Generally consistent with the literature
  - HTAP Phase I and Phase II; Jaffe et al. (2018)
  - USB is higher in the West than in the East, USB can be a significant contributor on high ozone days.
  - Long-range transport contributes more in the spring than summer
  - Canada and Mexico operate as short-range transport to most of the West
- Largest West/East difference at the surface was natural
- International Contribution on top 10 days at the surface
  - Summer most places: 1-15 ppb
  - Near-border: up to 30 ppb (no bias correction)
  - Eastern US decreases from all sources in summer
  - Western US increases from Canada/Mexico

APPENDIX

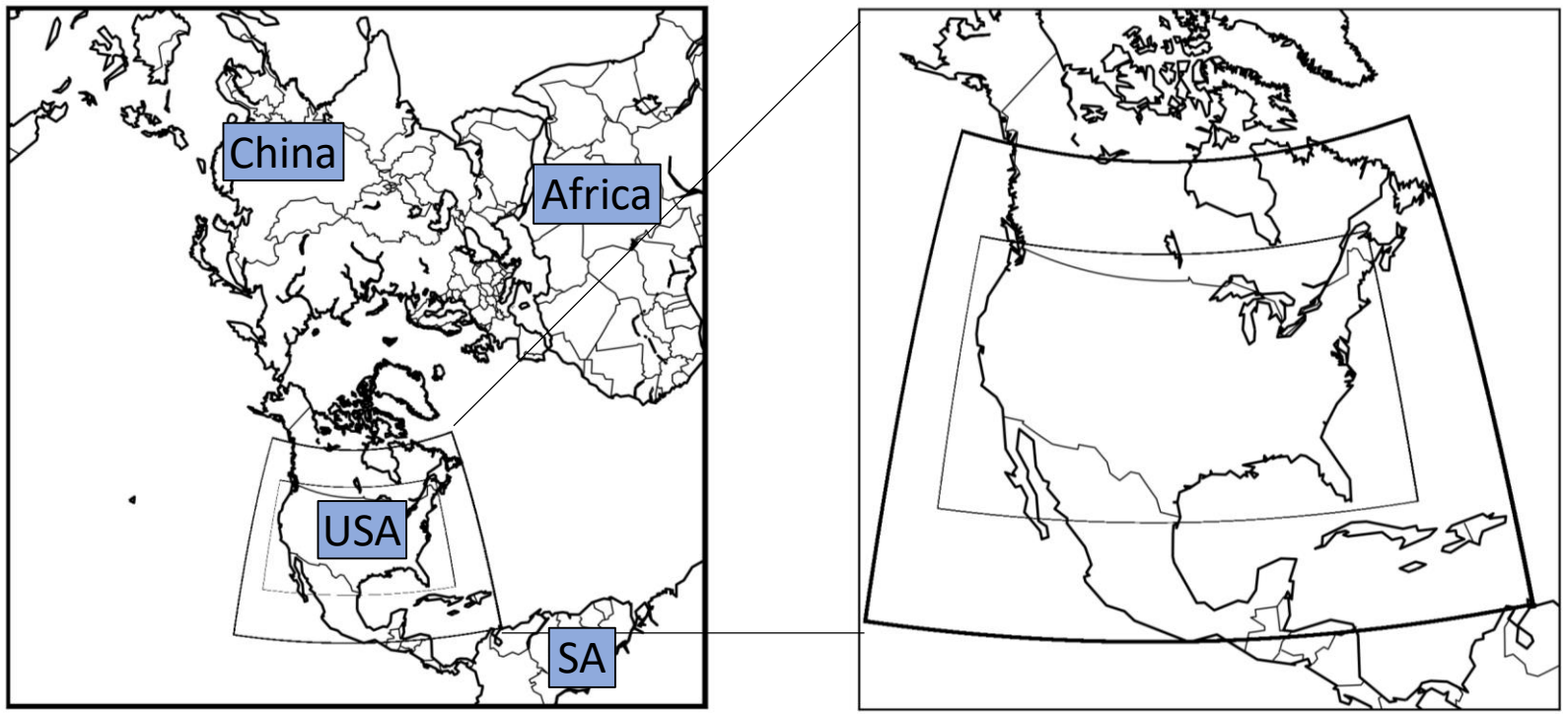


Coupled at multiple scales

- v5.2.1 (IPV, dust, halogens)
- 8 month spinup period
- Polar stereographic (~1x1 deg)
- 44 Layers up to 50mb
- Weather Research and Forecasting

- Hemispheric 108km, 44 layers – ***today***
- North America 36km, 35 layers
- United States+ 12km , 35 layers

sigma	Z (m)	DZ (m)	hPa
0.000	20162	1757	59
0.019	18406	1419	77
0.039	16987	1193	96
0.060	15794	1050	116
0.082	14744	953	137
0.105	13791	879	159
0.129	12912	822	182
0.154	12089	778	207
0.181	11311	739	232
0.209	10572	712	259
0.238	9860	685	287
0.269	9175	666	316
0.301	8509	649	347
0.335	7860	635	380
0.371	7225	621	414
0.408	6604	582	449
0.445	6022	547	483
0.483	5475	517	518
0.520	4958	490	553
0.557	4468	466	588
0.595	4002	446	623
0.632	3556	425	658
0.669	3131	407	693
0.707	2724	391	728
0.744	2333	359	762
0.780	1975	301	793
0.810	1674	255	820
0.837	1419	216	844
0.861	1202	184	865
0.881	1018	158	883
0.899	861	135	898
0.914	725	116	912
0.928	609	100	923
0.939	509	86	934
0.949	423	74	943
0.958	348	65	950
0.966	284	55	957
0.972	228	48	963
0.978	180	41	968
0.983	139	36	973
0.988	102	31	976
0.991	71	27	980
0.995	44	24	983
0.998	20	20	985



sigma	Z (m)	DZ (m)	hPa
0.000	19799	3865	73
0.050	15934	2398	118
0.100	13536	1751	164
0.150	11785	1387	210
0.200	10397	1165	255
0.250	9232	1016	301
0.300	8216	907	347
0.350	7308	822	392
0.400	6486	753	438
0.450	5733	696	484
0.500	5037	647	529
0.550	4390	605	575
0.600	3786	568	621
0.650	3218	536	666
0.700	2682	407	708
0.740	2275	294	740
0.770	1981	285	767
0.800	1696	185	790
0.820	1511	181	808
0.840	1330	177	827
0.860	1153	174	845
0.880	979	171	863
0.900	808	84	877
0.910	724	83	886
0.920	641	83	895
0.930	558	82	904
0.940	476	81	914
0.950	395	80	923
0.960	315	80	932
0.970	235	79	941
0.980	156	39	948
0.985	117	39	953
0.990	78	39	957
0.995	39	19	961
0.998	19	19	963

Natural Emissions

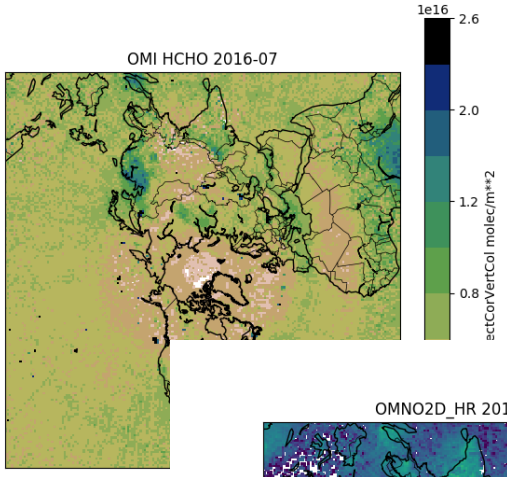
- Biogenics (plants and soils):
  - **Global:** Model of Emissions of Gases and Aerosols from Nature (MEGAN) v2.1
  - **North America:** Biogenic Emission Inventory System (BEIS)
- Wild and Prescribed Fires:
  - **Global:** FINN v1.5
  - **North America:** 2016 platform (α)
- Lightning: GEIA climatological
  - averages by latitude & season
- Inline Dust: Inline CMAQ algorithm
- Sea Salt: similar in-line schemes

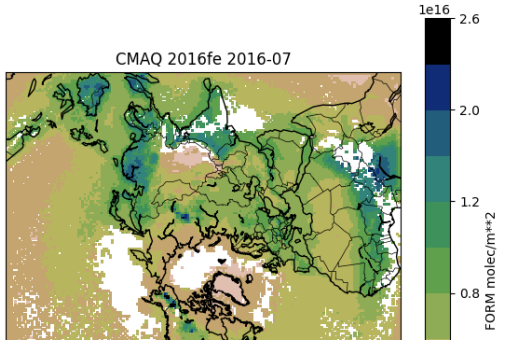
Anthropogenic Emissions

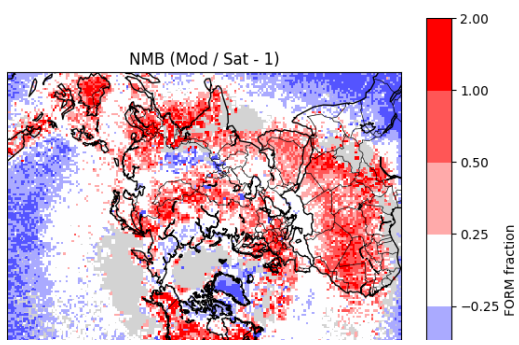
- Global
  - EDGAR-HTAP base year 2010
  - ***Interpolated to 2014 by CEDS sector/country scalars***
  - Includes shipping and aircraft
- North America : 2016fe Platform
- Asia (non-China): MIXv1
- ***China: Tsinghua University (THU)***

More in Vukovich et al. CMAS 2018

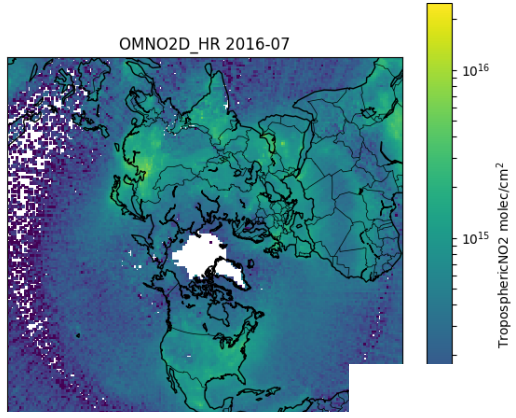
Satellites and Sondes Evaluation avail elsewhere

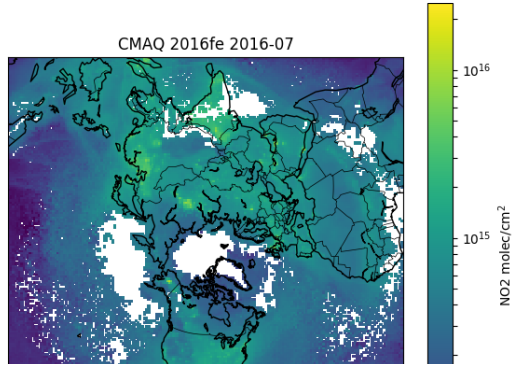


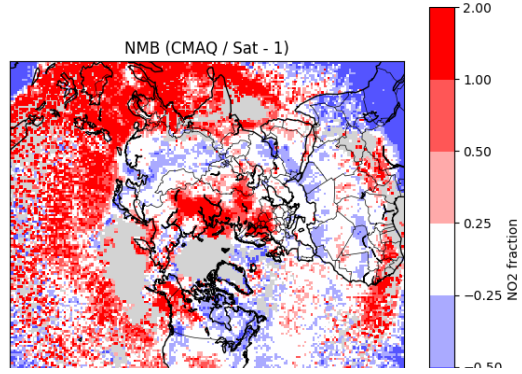




SAO Formaldehyde
(González Abad et al., 2015)

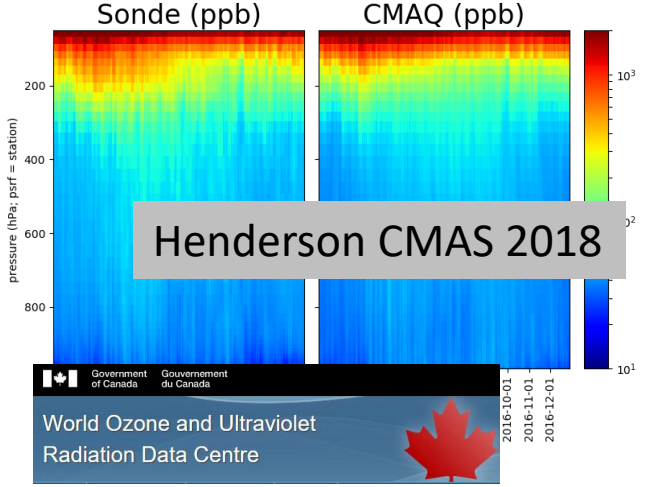


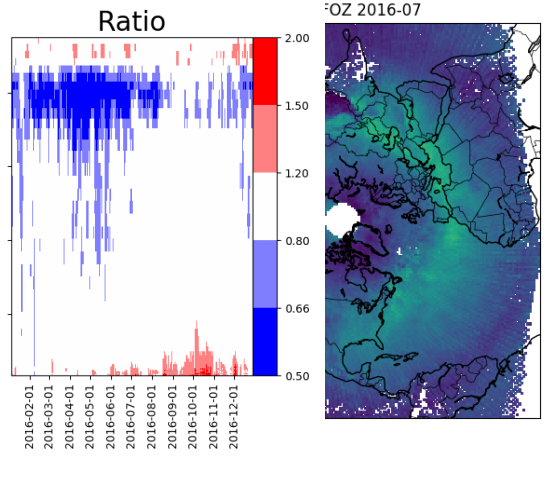


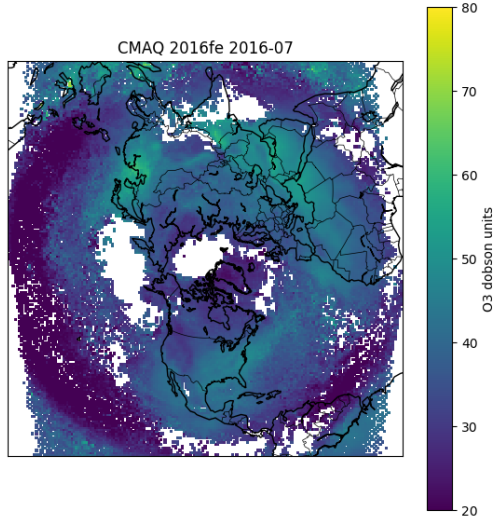


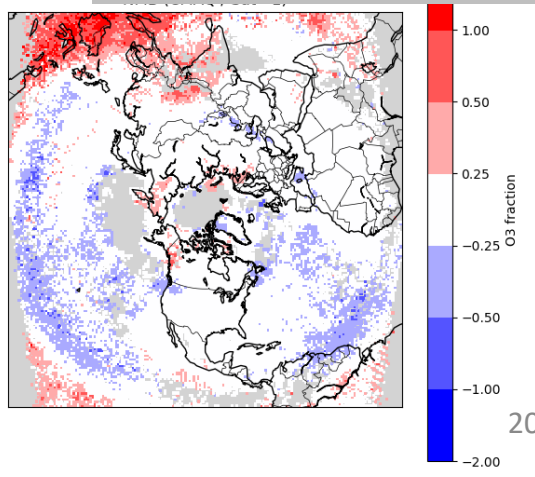
NASA Nitrogen Dioxide
(Krotkov et al., 2017,
Lamsal OMNO2D_HR)

SAO Ozone Profiles
(Huang et al., 2017))









Henderson CMAS 2018

Government of Canada Gouvernement du Canada
World Ozone and Ultraviolet Radiation Data Centre