Enhancement and Testing of Hemispheric CAMx

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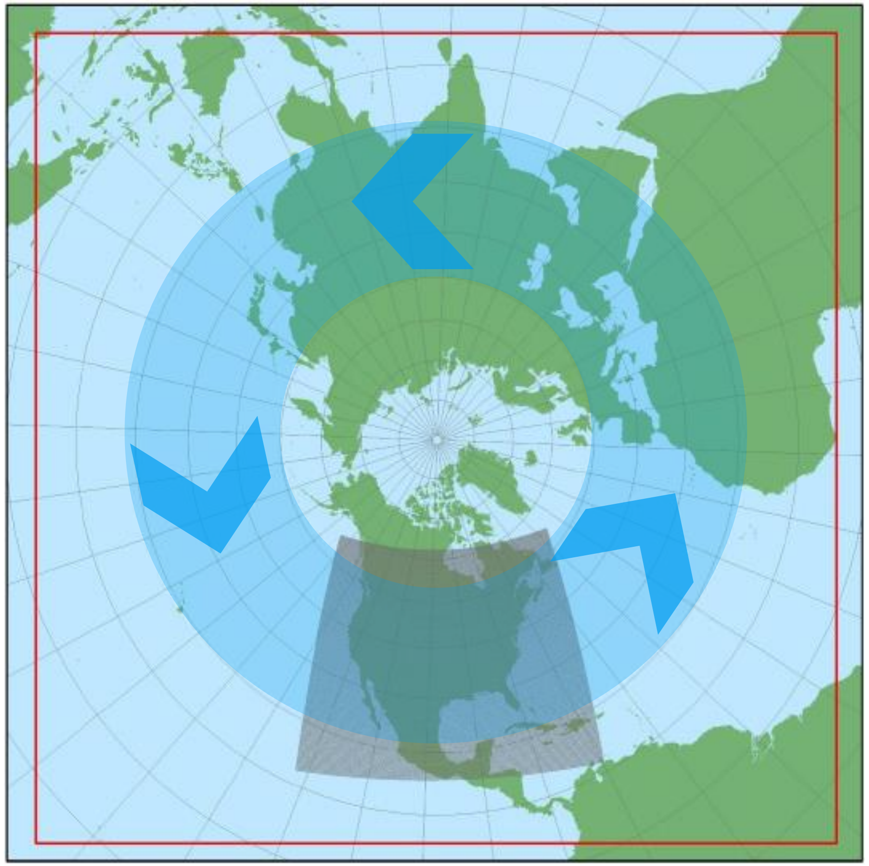
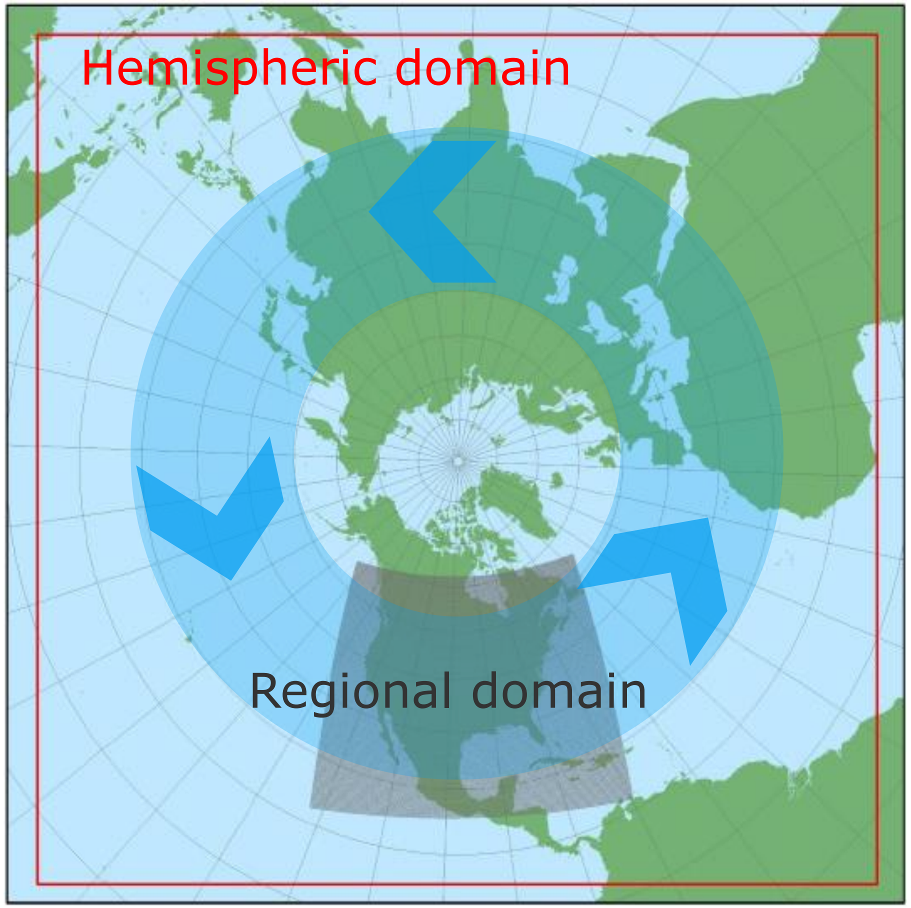


CMAS Conference, October 2020

HEMISPHERIC CAMx (PHASE I)

- Improve the characterization of "background" ozone within regional (continental) air quality simulations
- Apportion ozone in hemispheric scale simulations
- Transfer hemispheric ozone source apportionment to regional domains via boundary concentrations (BCs)



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HEMISPHERIC CAMx (PHASE II)

- Evaluate and develop use of satellite data to derive lateral and top boundary conditions
- Test effects of improved vertical resolution and use of CAMx "cloud-in-grid" (CiG) convective sub-model
- Comprehensive model performance for entire 2016 year vs. GEOS-Chem and H-CMAQ

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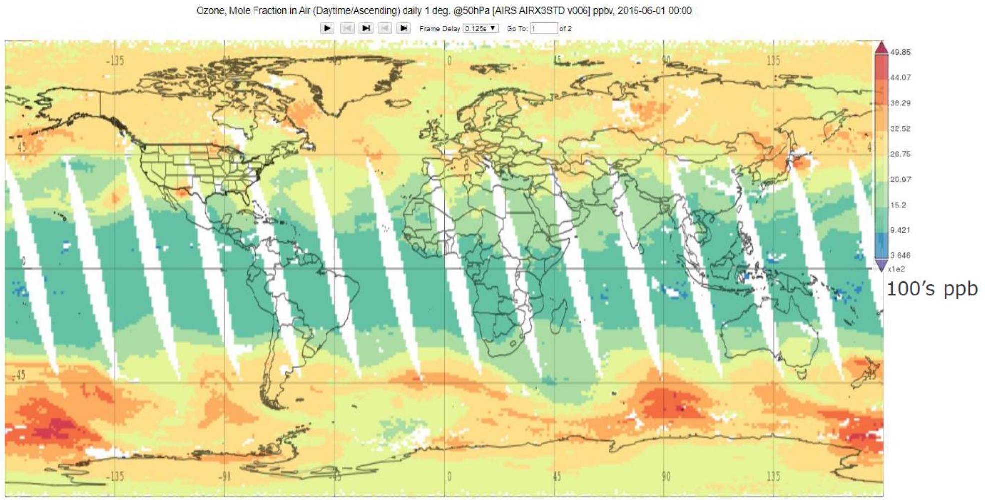
SATELLITE O_3 FOR CAMx TOP BC

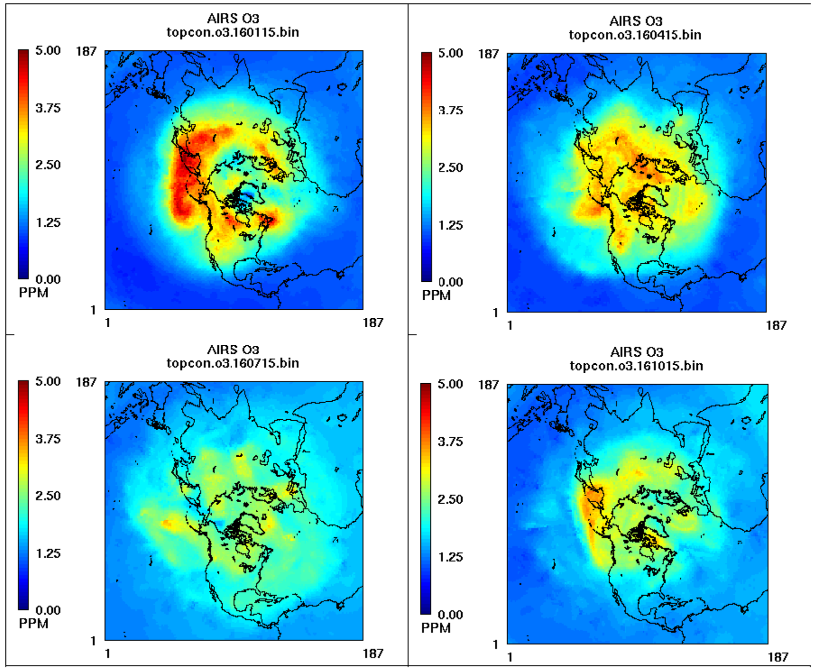
- NASA-AIRS V6 product includes ozone, CO and methane
    - Good for stratospheric concentrations
    - Poor in the lower and mid troposphere

- Use to characterize spatial and temporal variations of ozone at the top of the model

- **AIRS2CAMxTC**: new tool generates top BC from daily global AIRS ozone data
    - Easily adaptable to AIRS-OMI when available



AIRS V6/L3 ozone fields at 50 hPa (mb) pressure altitude



Daily H-CAMx ozone top concentrations derived from AIRS ozone retrievals

MULTI-YEAR INITIAL/BOUNDARY CLIMATOLOGY

- Initializing from simple profile assumptions require excessive model spin-up to achieve chemically equilibrated atmosphere
- AIRS has little tropospheric temporal and zonal variability (monthly climatological a-priori dominates), limited chemical species
- Developed a library of monthly-averaged, spatially-varying IC/BC for all CAMx species from 2016 GEOS-Chem
- Can be used to represent a recent global climatology within a reasonable interval (arguably ±5 years) from 2016
- Shortens model spin-up times from IC (~1 month to 1 season)

HEMISPHERIC WRF SIMULATIONS

- Key WRF sensitivity tests:

  1) Vertical resolution:

  - Increase in mid-troposphere through lower stratosphere
  - Improve winds for long-range transport and stratospheric intrusion?
  - 9 additional layers (from 44 to 53)

  2) Convective submodel:

  - Use Multi-scale Kain-Fritsch (MSKF) cumulus option that supports CAMx cloud-in-grid (CiG) convective submodel

WRF runs

Scenario	Description
Run0	EPA's WRF output
Run1	Replicate EPA's setup but parallelize over 5.5-day sections (speed up WRF)
Run2	53 layers
Run3	MSKF cumulus

WRF physics options used in Run0 through Run3

WRF Physics	Run0/1/2	Run3
Surface Layer Physics	P-X	MM5
PBL	ACM2	YSU
Sub-Grid Convection	K-F	MSKF

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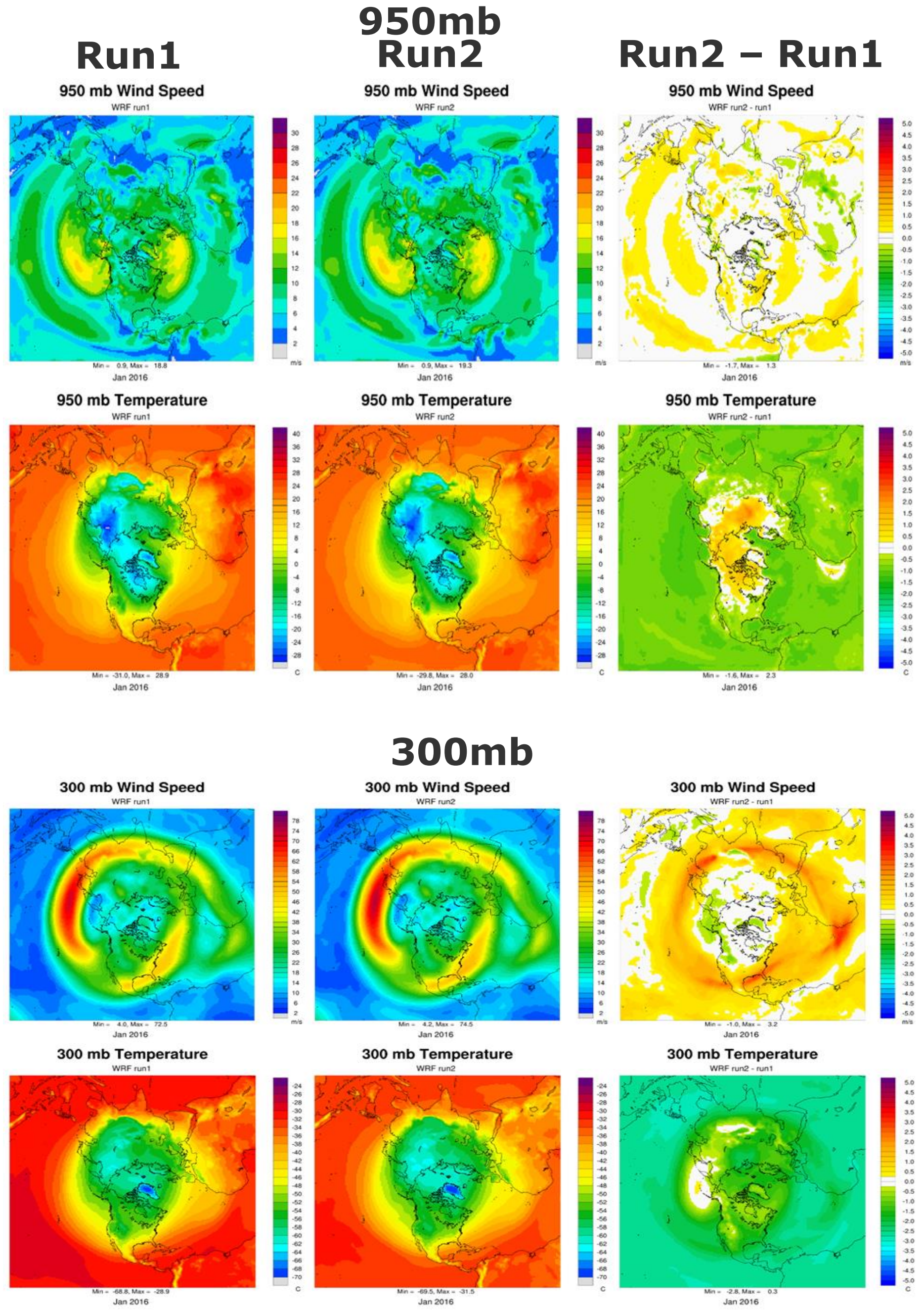
VERTICAL RESOLUTION SENSITIVITY (RUN 2)

- Near-surface fields are cooler and drier, whereas high latitude areas are warmer

- Near-surface winds are slightly stronger in equatorial and mid-latitude regions

- Better resolution of the jet stream's vertical structure and hence higher speeds

- Improved resolution of temperature profile near the tropopause, leading to lower temperatures



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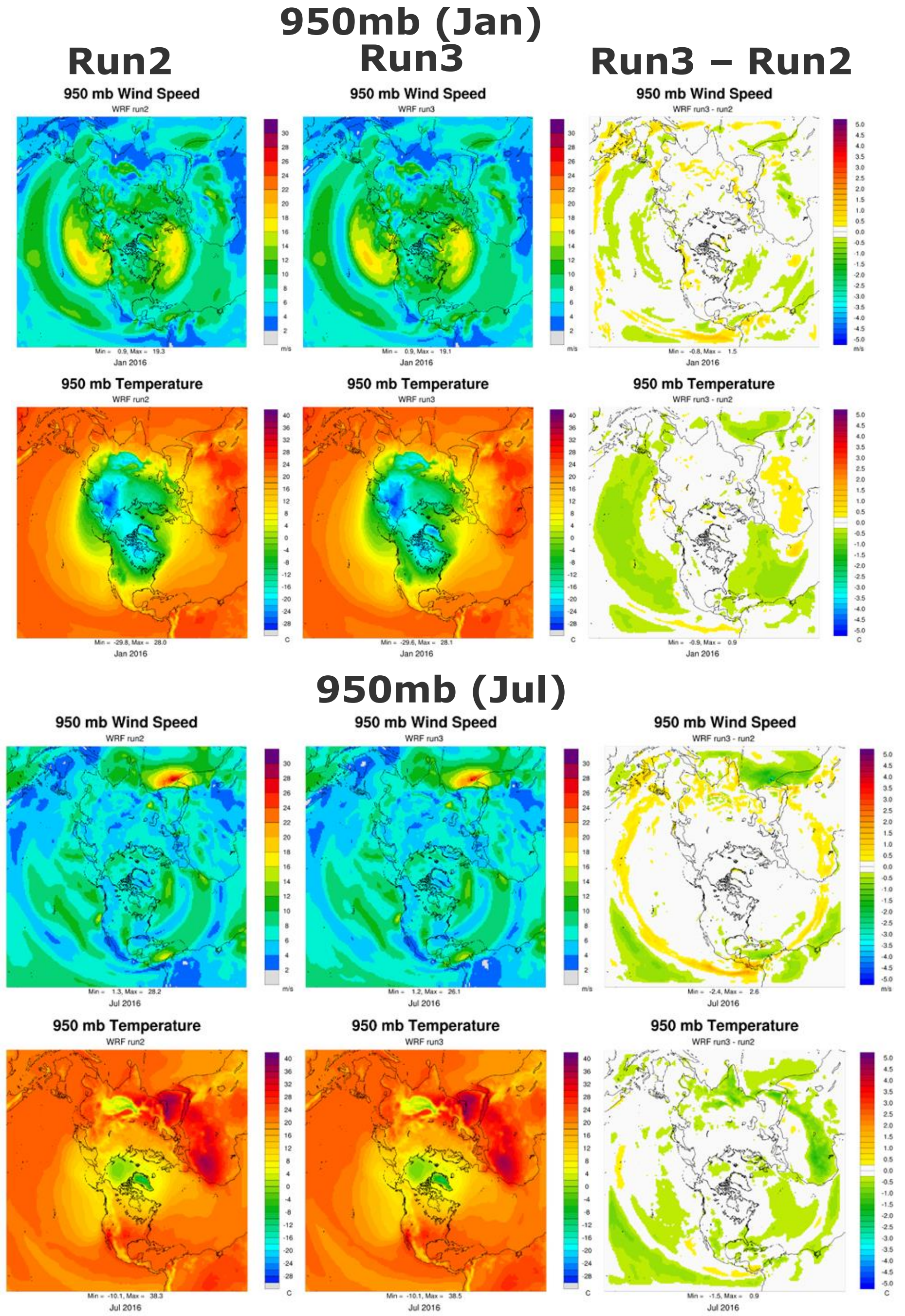
CUMULUS SENSITIVITY (RUN 3)

- Slightly stronger winds in equatorial convergence zone in both seasons, slightly weaker mid-latitude winds in winter

- Cooler winter temperatures over the subtropical oceans and warmer over Saharan Africa

- Cooler summer subtropical temperatures globally (especially Africa and India)
  - Higher humidity in same areas and in both seasons

- Little impact in mid/high latitudes and at tropopause
  - Low-altitude/low-latitude sensitivity to PBL and cumulus mixing



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H-CAMx SIMULATIONS

Meteorology, Emissions, IC/BC/TC

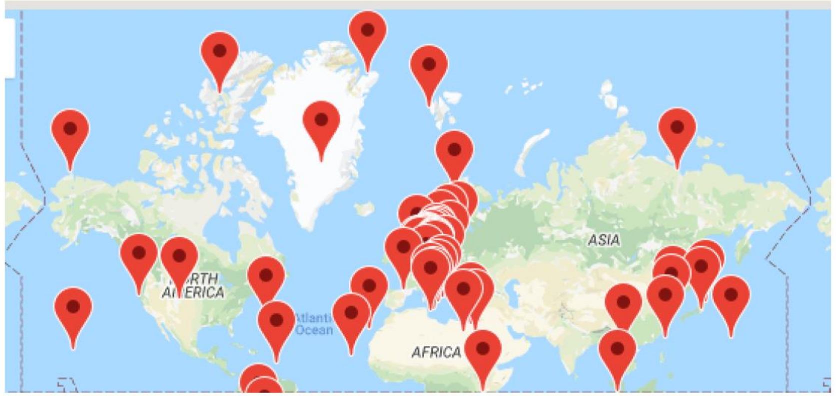
Scenario	Description
Run0	EPA WRF and most emissions (Mathur et al., 2017) Oceanic & wind blown dust, day specific GEOS-Chem IC/BC/TC V1 H-CAMx stratospheric ozone parameterization
Run1	WRF replication, monthly IC/BC, daily satellite TC, updated natural emissions V2 H-CAMx stratospheric ozone parameterization to reduce ozone bias above 10km
Run2	WRF with 53 layers, re-extracted monthly IC/BCs
Run3	WRF with MKSF/YSU/MM5 schemes CAMx cloud-in-grid convective mixing scheme

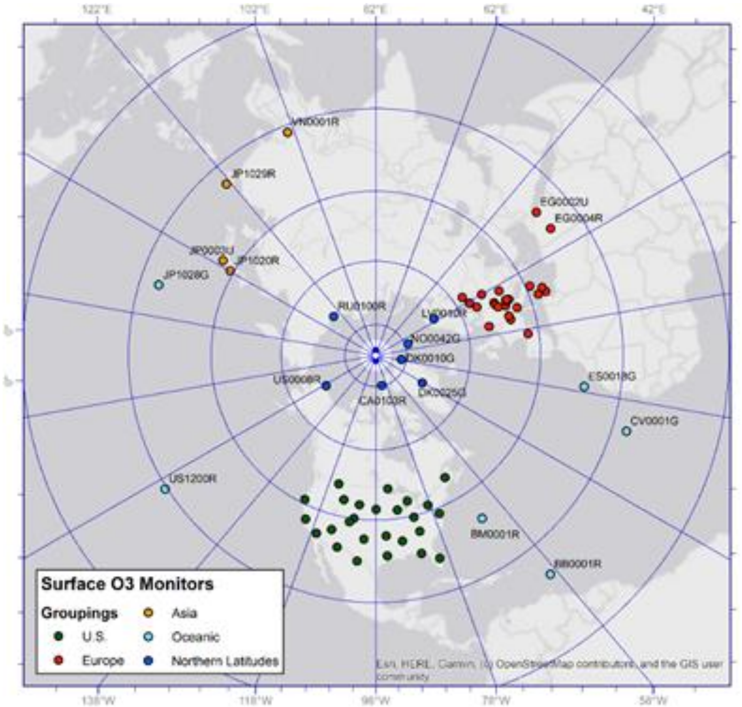
H-CAMx Run	Run Duration	Run Dates (Total # Days)
Run0	4 days, 11 hr, 46 mins	12/22/2015 - 12/30/2016 (375 days)
Run1	5 days, 3 hr, 46 mins	10/01/2015 - 12/31/2016 (458 days)
Run2	5 days, 23 hrs 21 mins	10/01/2015 - 12/31/2016 (458 days)
Run3	6 days, 9 hr, 15 mins	10/01/2015 - 12/31/2016 (458 days)

Parallelization: 9 MPI x 6 OMP

GLOBAL SURFACE MEASUREMENT DATA

World data center for reactive gases (WDCRG) ozone monitor locations for 2016





US CASTNET sites

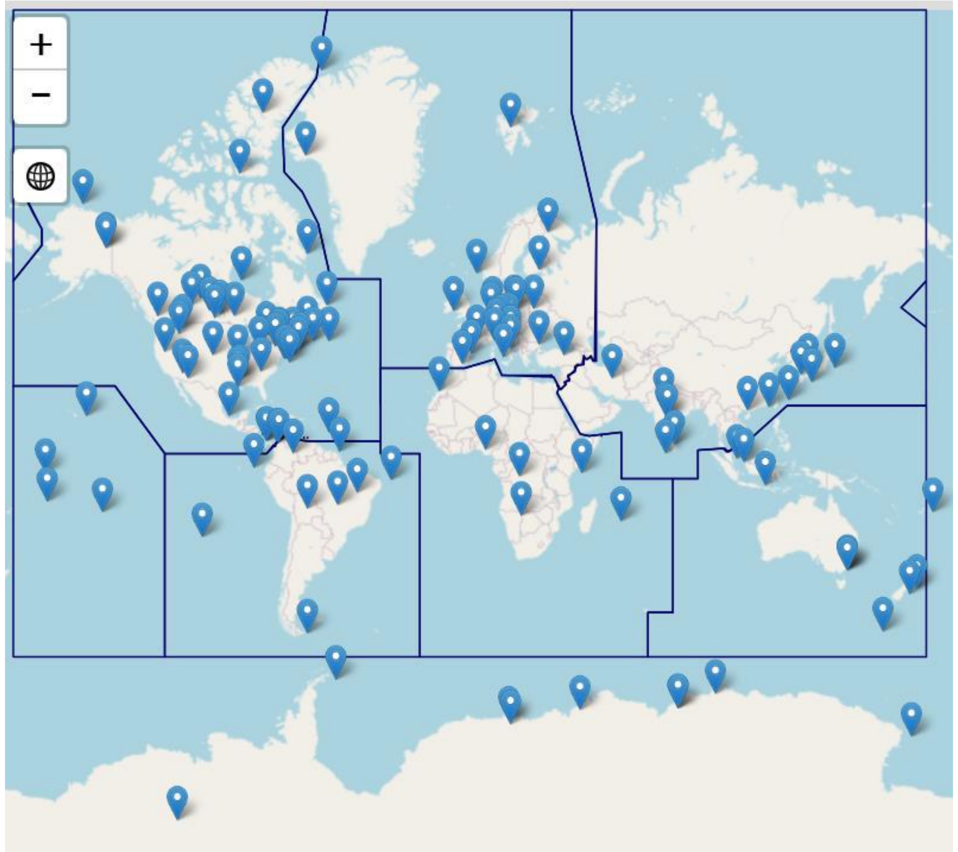
(Source: https://www3.epa.gov/castnet/docs/CASTNET2016/AR2016-main.htm#chapter1-3)

All surface monitors for 2016:

- Europe (26 sites)
- US (24 sites)
- Asia (4 sites)
- Northern Latitudes (7 sites)
- Oceanic (6 sites)

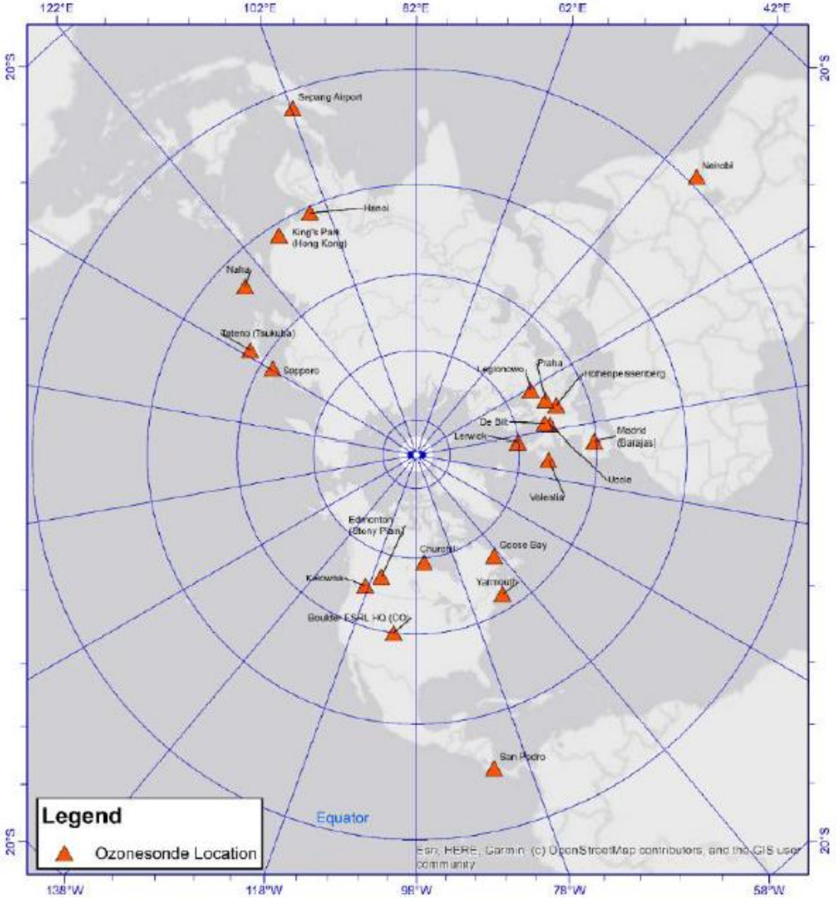
OZONESONDE MEASUREMENTS

Global ozonesonde launch sites in 2016



Source: https://woudc.org/data/explore.php

Ozonesonde locations selected for H-CAMx Evaluation



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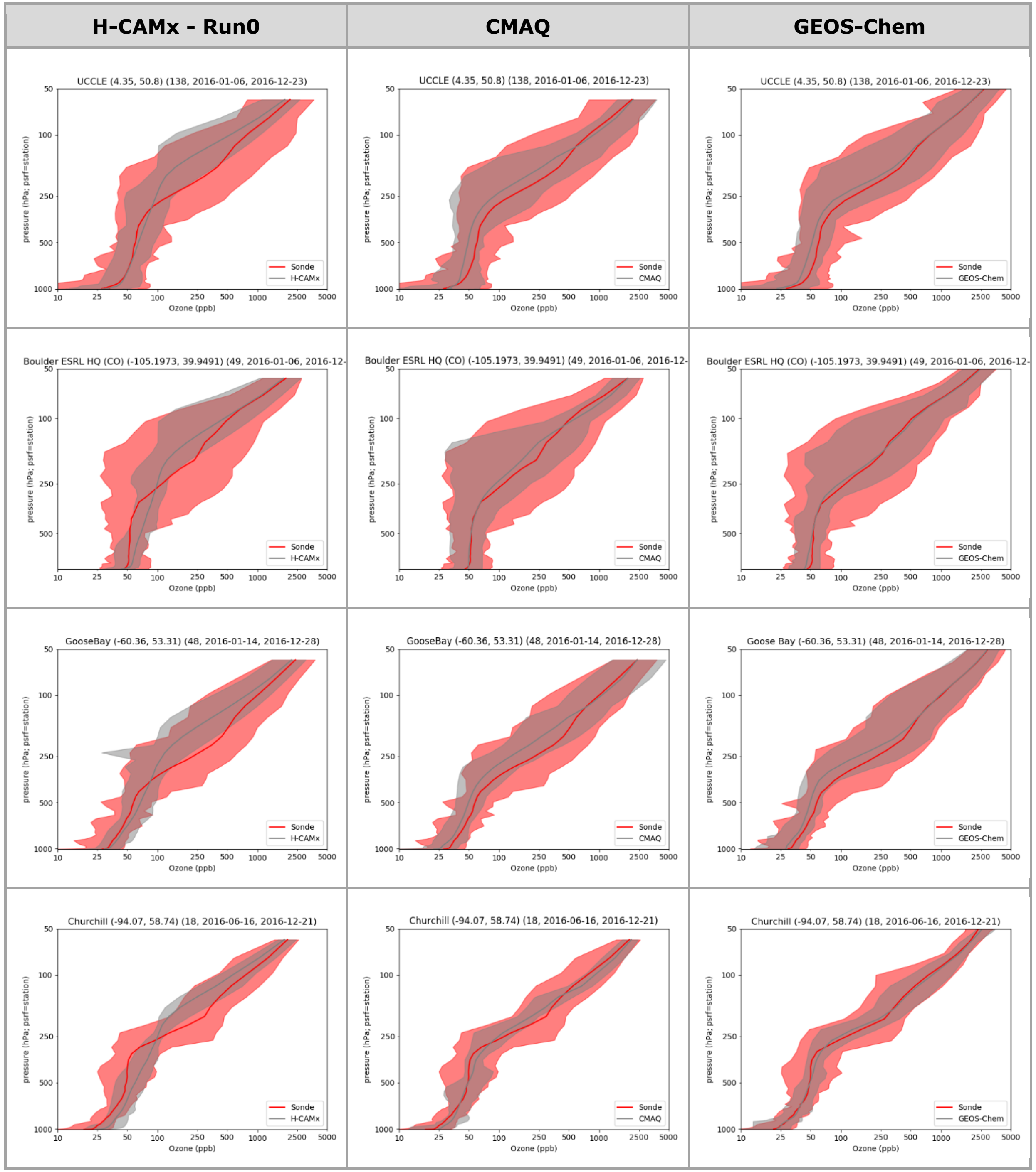
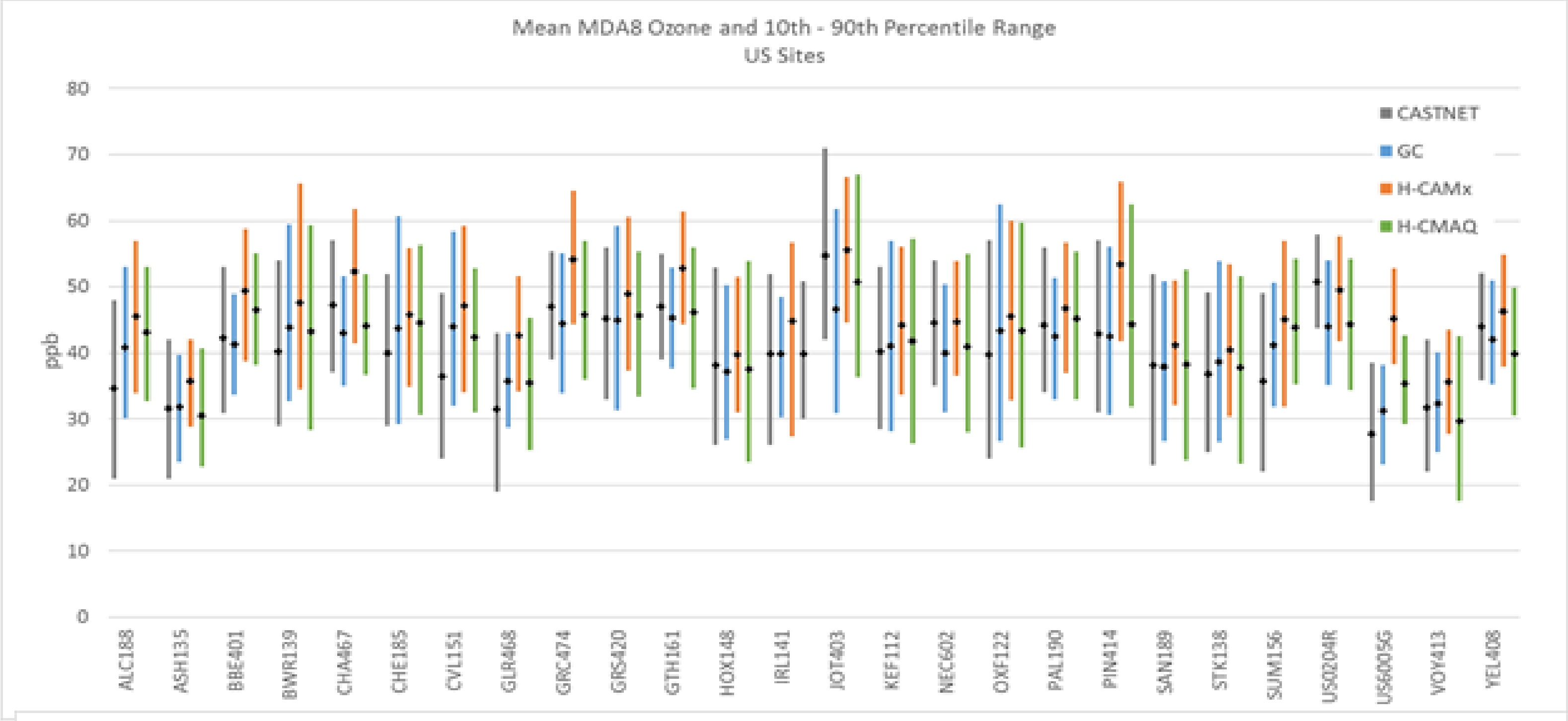
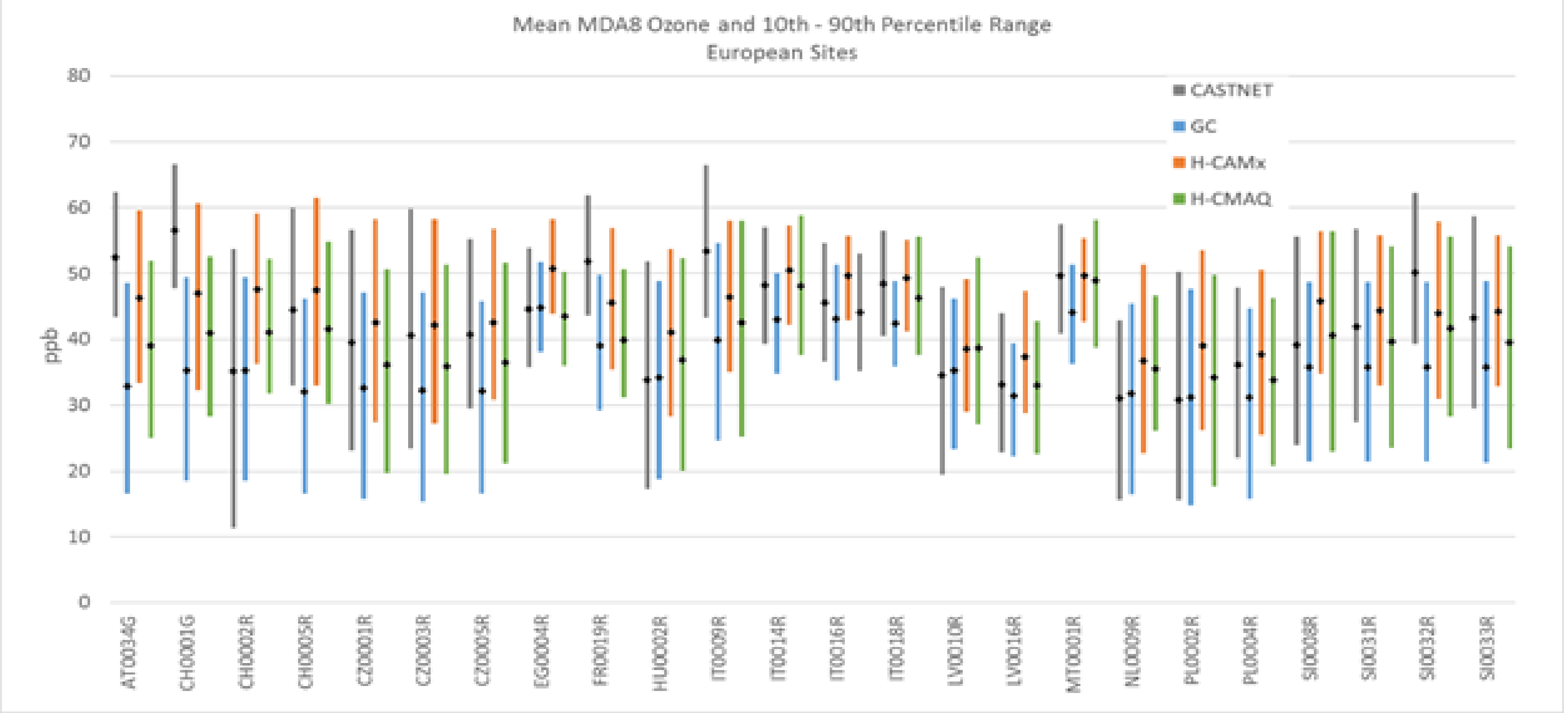
INTER-MODEL PERFORMANCE COMPARISON

- GEOS-Chem qualitatively best replicates stratospheric ozone, negative bias in the troposphere
- H-CMAQ is similar to GEOS-Chem but consistently more negatively biased
  - Occasional ozone gaps around the tropopause at low-latitudes
- H-CAMx has negative stratospheric bias and positive tropospheric bias
- All models exhibit narrower minimum-to-maximum ranges than the observations







- US/CASTNET:
  - Models exhibit little NMB and a range of 10-20% NME
  - GEOS-Chem and H-CMAQ exhibit the lowest bias
  - H-CAMx has consistent positive bias, large deviations from the other models at few sites
- Europe:
  - Performance trends similar to US
  - GEOS-Chem negatively biased
  - H-CMAQ and H-CAMx bias is rather good
  - H-CAMx has consistent positive bias while H-CMAQ has a slight negative bias

INTER-MODEL PERFORMANCE COMPARISON

Site-averaged annual bias (NMB, %), gross error (NME, %) and correlation coefficient (R) over five global monitoring groups for each model.

Monitor Group	GEOS-Chem NMB	H-CAMx NMB	H-CMAQ NMB	GEOS-Chem NME	H-CAMx NME	H-CMAQ NME	GEOS-Chem R	H-CAMx R	H-CMAQ R
US	2%	15%	4%	16%	20%	18%	0.65	0.67	0.59
Europe	-14%	6%	-5%	20%	17%	17%	0.76	0.74	0.73
Asia	-8%	16%	13%	21%	25%	27%	0.78	0.74	0.76
Oceanic	-19%	9%	19%	21%	18%	23%	0.71	0.72	0.62
Polar	-20%	-3%	-25%	24%	15%	30%	0.68	0.43	0.22

Color coded according to whether **they meet (green)** or **exceed (orange)** ozone statistical performance criteria recommended by Emery et al. (2016) for regional photochemical modeling (NMB ≤ ±15%; NME ≤ 25%, R > 0.50).

- 15 metrics listed for each model (3 statistics over 5 monitoring regions)
- Performance is generally good among most models/regions (esp. US and Europe)
  - GEOS-Chem tends toward negative bias
  - H-CAMx Run0 tends toward positive bias
  - H-CMAQ statistics are mixed

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H-CAMx SENSITIVITY RESULTS

Site-averaged annual bias (NMB, %), gross error (NME, %) and correlation coefficient (R) over five global monitoring groups for each H-CAMx run.

Monitor Group	Run1 NMB	Run2 NMB	Run3 NMB	Run1 NME	Run2 NME	Run3 NME	Run1 R	Run2 R	Run3 R
US	16%	20%	21%	21%	24%	25%	0.64	0.64	0.63
Europe	6%	8%	12%	17%	17%	19%	0.74	0.71	0.69
Asia	17%	20%	25%	26%	28%	31%	0.74	0.74	0.73
Oceanic	4%	7%	4%	21%	23%	22%	0.64	0.61	0.59
Polar	-4%	-3%	-2%	14%	13%	14%	0.54	0.59	0.59

Color coded according to whether **they meet (green)** or **exceed (orange)** ozone statistical performance criteria recommended by Emery et al. (2016) for regional photochemical modeling (NMB ≤ ±15%; NME ≤ 25%, R > 0.50).

- Higher ozone in all sensitivity cases relative to Run0: upward shifts in NMB and NME over all regions
- Poor Run0 correlation in the Polar group is improved substantially in all sensitivity cases
- Bias and error performance over US and Asia degrade to outside benchmark criteria
- High bias among the Asia group is driven by higher ozone at Hanoi, Vietnam (an apparent emission issue discussed with EPA)

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CONCLUDING REMARKS

- Developed daily H-CAMx ozone TCs from AIRS satellite data at 50 mb
- Monthly spatially-varying IC/BCs provide best balance between flexibility and representativeness, allow for a shortened spin-up period
- Modified layer structure influenced resolution of the boundary layer, and temperature and wind profiles at jet stream altitudes, minor effect on tropospheric ozone
- Implementing cumulus convection had little impact meteorologically and increased tropospheric ozone
- Comparison to GEOS-Chem and H-CMAQ indicates:
  - H-CAMx tends to under predict stratospheric ozone profiles, over predict tropospheric profiles
    - Stratospheric scheme adjustment improves stratospheric ozone, slightly exacerbates tropospheric ozone
  - GEOS-Chem is best overall performer globally
  - H-CMAQ tends to slightly under predict tropospheric profiles, has most performance variability of the three models