Regional trend analysis of surface ozone observations from monitoring networks in eastern North America, Europe and East Asia

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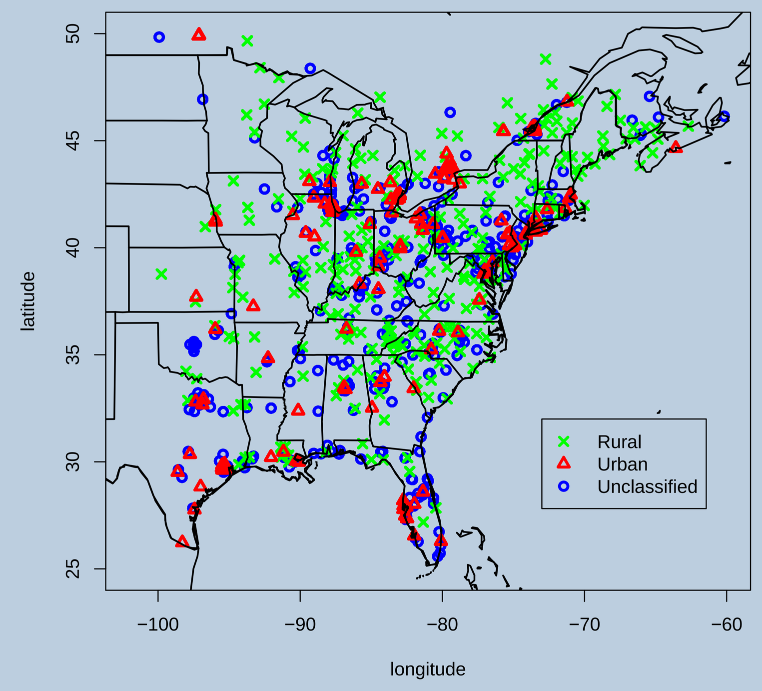
Background

Surface ozone is a greenhouse gas and pollutant detrimental to human health and crop and ecosystem productivity. The Tropospheric Ozone Assessment Report (TOAR)[1] is designed to provide the research community with an up-to-date observation-based overview of tropospheric ozone's global distribution and trends. We conducted a spatial and temporal trend analysis using the TOAR database of global surface ozone observations for different regions and for several metrics in summertime (April-September) over 2000-2014.



Ozone metric

We study the seasonal, interannual and spatial variabilities with 4 ozone metrics: (1)**Daytime average**; (2)**DMA8** (Daily maximum 8-hr average); (3)**AOT40** (cumulative ozone exposure over a threshold of 40 ppb, related to the impacts of ozone exposure on vegetation); (4)**NVGT070** (the number of days per summertime period in which DMA8 exceeds 70 ppb, related to the human health).

Method

The subject of the research is of importance for TOAR project because it addresses many challenging issues in assessment of trends over multiple observational sites: (1) data temporal inhomogeneity; (2) the irregularity of the spatial distribution of stations; and (3) interruptions in observational records.

Let $y(t)$ be the ozone value at time t, the *generalized additive mixed model* (GAMM) decomposes the obs. as

$$y(t) = f_1(seasonal) + f_2(interannual) + f_3(spatial) + \epsilon(t),$$

where each component is estimated by nonlinear smooth basis functions:

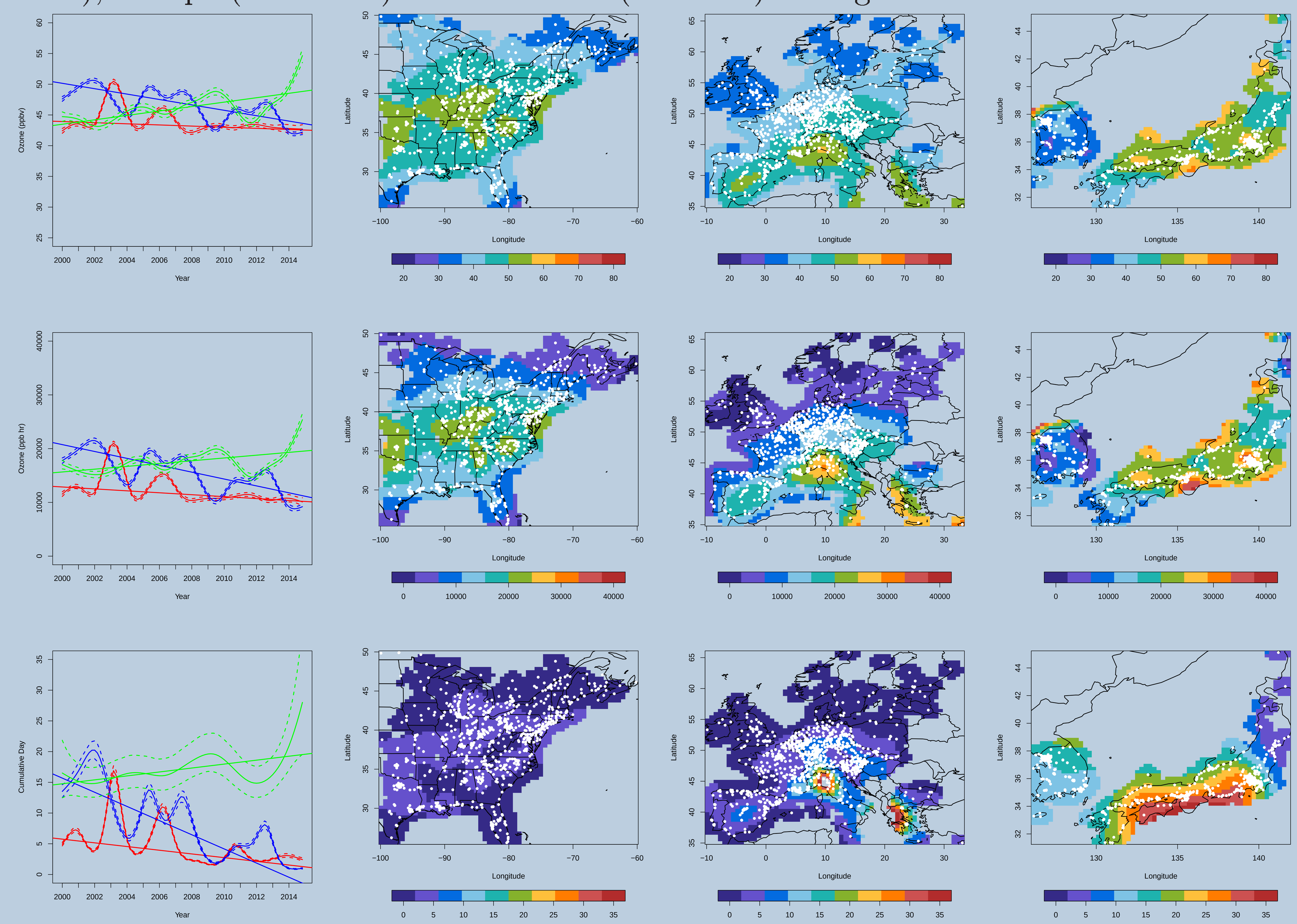
- $f_1(seasonal)$: regression **cyclic cubic splines** (assumed with periodic nature)
- $f_2(interannual)$: regression **cubic splines** (provided a convenient basis for computational efficiency)
- $f_3(spatial)$: **Gaussian process/kriging splines** (interpolated values at places where it's not observed);
- $\epsilon(i, t)$: AR(1) process for residual

Reference

[1] Schultz MG, Schroeder S, Lyapina O, Cooper OR, et al. 2017. *Tropospheric Ozone Assessment Report: Database and metrics data of global surface ozone observations.* Elementa (2017)

Result

Summertime mean of DMA8 (ppb), AOT40 (ppb hr) & NVGT070 (day) over eastern North America (756 sites), Europe (1007 sites) and East Asia (556 sites) during 2000-2014:



Trends in eastern North America (blue), Europe (red) and East Asia (green) for DMA8 (upper), AOT40 (middle) & NVGT070 (lower). The white points indicate the locations of monitoring sites.

The "regional mean approach" reports the mean (SD) of all individual trend estimates. In cases when the slopes from the GAMM and regional mean approaches are similar, we conclude that the station network is well covered in this region, and a sophisticated statistical approach might not be required to assess the regional trend.

Region	DMA8	GAMM approach Intercept	Slope	p-value	Regional mean approach Intercept	Slope
Eastern North America	Overall	50.15	-0.43	< 0.01	49.37(6.63)	-0.43(0.30)
	Rural	50.85	-0.52	< 0.01	50.10(6.66)	-0.52(0.26)
	Urban	46.57	-0.25	< 0.01	45.79(6.99)	-0.21(0.33)
Europe	Overall	43.87	-0.08	< 0.01	44.63(7.34)	-0.14(0.34)
	Rural	47.14	-0.21	< 0.01	47.51(6.29)	-0.25(0.31)
	Urban	41.17	-0.05	0.13	41.25(7.92)	-0.03(0.32)
East Asia	Overall	43.72	0.37	< 0.01	43.38(9.50)	0.37(0.66)
	Rural	46.83	0.23	< 0.01	46.25(6.01)	0.20(0.66)
	Urban	42.37	0.48	< 0.01	42.11(10.81)	0.49(0.63)

Summary

- **Eastern North America**:
  (1) Ozone has decreased strongly (although daytime average at urban sites is less certain).
  (2) The summertime mean of DMA8 shows a larger decrease than daytime average.
  (3) AOT40 is reduced by roughly half (from ~20,800 to ~11,200 ppb hr).
  (4) The average modeled value of NVGT070 decreased to less than 1 day in 2014.
- **Europe**:
  (1) Significant decreases of daytime average and DMA8 are only detectable in rural sites.
  (2) AOT40 and NVGT070 decreased significantly in both rural and urban sites.
  (3) The spatial distributions estimated from different metrics display a similar result: lower values in western and northern Europe and higher value in southern Europe.
- **East Asia**:
  (1) All the metrics indicate that surface ozone increased, with statistically significant trends of 0.40 and 0.37 ppb yr^{-1} estimated for daytime average and DMA8, respectively.
  (2) AOT40 also reveals a significant increase of 260 ppb hr yr^{-1}.
  (3) The linear regression predicts the NVGT070 value reached 20 days in summertime 2014.
  (4) All the trends show a steep increase from 2011-2014.
- The monitoring network is well covered and developed in eastern North American and East Asia, assessed by several metrics. A consistent result in Europe is difficult to achieve due to relatively limited monitoring sites over northern and astern Europe.