Studying the Co-benefits of Global and Regional GHG Mitigation on U.S. Air Quality at Fine Resolution with Dynamical Downscaling Methods

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Motivation

- Air quality is sensitive to climate change, although the influences for $PM_{2.5}$ are less clear as for ozone (Jacob and Winner, 2009; Fiore et al. 2012).
- Actions to mitigate greenhouse gas (GHG) emissions will not only slow climate change, but will also bring co-benefits for improved air quality, through two mechanisms: reductions in co-emitted air pollutants, and slowing climate change and its effect on air quality (Fig 1).

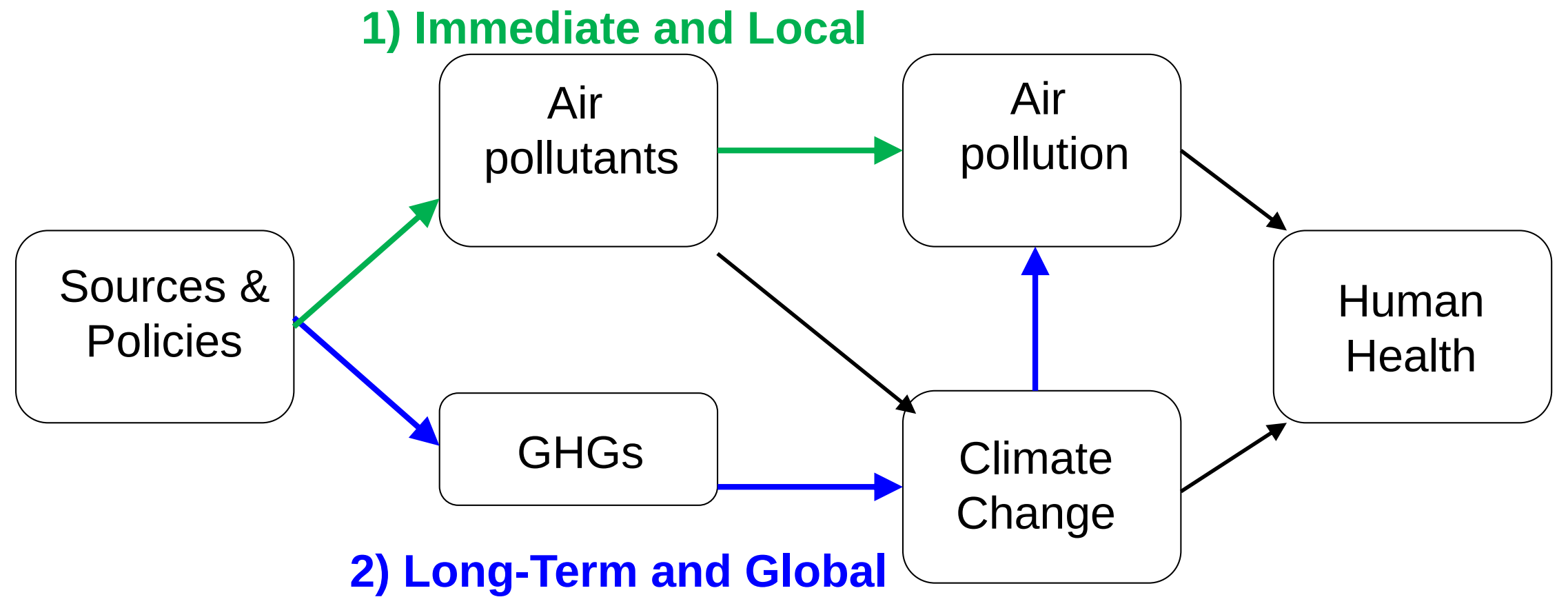


Fig 1: Co-benefits for air quality and human health from GHG mitigation via two mechanisms

- Previous studies have focused on the local and regional co-benefits of GHG reductions, but tend not to analyze global effects in projected future scenarios.
- West et al. (2013) studied the co-benefits of global GHG mitigations on surface air quality and human health both globally and regionally using a global CTM. They found that global GHG mitigation avoids 2.2±0.8 million premature deaths in 2100 from both O_3 and $PM_{2.5}$, and that the reduced co-emitted air pollutants are much more important than climate change for air quality. However, the estimated co-benefits are limited due to the coarse resolution (2˚x2.5˚).

Objectives

- Quantify the **total co-benefits** for air quality (O_3 and $PM_{2.5}$) in the U.S. in 2050 from global GHG mitigation, at fine resolution.
- Separate the co-benefits on U.S. air quality into contributions from the two mechanisms: **co-emitted Air pollutants** and changes via **future slowing climate**.
- Separate the co-benefits of **domestic GHG mitigation** from those from **foreign countries' GHG reduction**.
- Study the air quality co-benefits of GHG reductions from **different U.S. sectors**.
- Analyze the co-benefits on **human health (premature mortality)** in U.S. through those changes above.

Approach

We develop a comprehensive model framework to study the regional co-benefits via the two mechanisms.

- **Experimental design:** We use RCP4.5 as a global GHG mitigation scenario (Table 1), and its associated reference scenario (REF) as a base scenario, following West et al. (2013). These two scenarios differ only in the application of a climate policy.

Table 1: List of CMAQ Simulations for this study.

Years	Scenario Name	Emissions	Meteorology	BCs & CH_4[1]
2000	**S_2000**	2000	2000	MZ4[2] 2000
2050 (2049, 2050, 2051, 2052)	**S_REF**	REF[3]	RCP8.5	MZ4 Ref & CH_4 (2267ppbv)
	S_RCP45	RCP4.5	RCP4.5	MZ4 RCP4.5 & CH_4 (1833ppbv)
	S_Dom	RCP4.5 for U.S. REF for Can, Mex	RCP8.5	MZ4 Ref & CH_4 (2267ppbv)
	S_Emis	RCP4.5	RCP8.5	MZ4 e45m85 & CH_4 (1833ppbv)

[1]CH_4: Fixed global methane concentration in CMAQ depending on scenarios. [2]MZ4: MOZART-4 simulations as conducted by West et al. (2013).
[3]REF: Reference scenario, based on which the RCP4.5 was developed using GCMA model.

S_RCP45 — S_REF: **Total co-benefits** for U.S. air quality from global GHG mitigation.
S_Emis — S_REF: Co-benefits from **global reductions in co-emitted air pollutants**.
S_RCP45 — S_Emis: Co-benefits from **slowing climate change** alone..
S_Dom — S_REF: Co-benefits from **domestic GHG reduction** only.
S_RCP45 — S_Dom: Co-benefits from **foreign countries' GHG reduction**.

- **Emissions**: SMOKE v3.5 is used to **directly process** the global anthropogenic emissions of the RCP4.5 and REF scenarios from 0.5º to the regional scale at 36 km for CONUS domain. This approach differs from the traditional method of mapping the ratio of emissions in RCP scenarios to present day U.S. NEI emissions, which has higher uncertainties and neglects changes in the spatial distributions of emissions. Emissions of black carbon and organic carbon are used to estimate the total primary PM emissions (both fine and coarse) making use of PM speciation profiles from the EPA, definitions of emission sectors, and Xing et al. (2013) (Table 2).

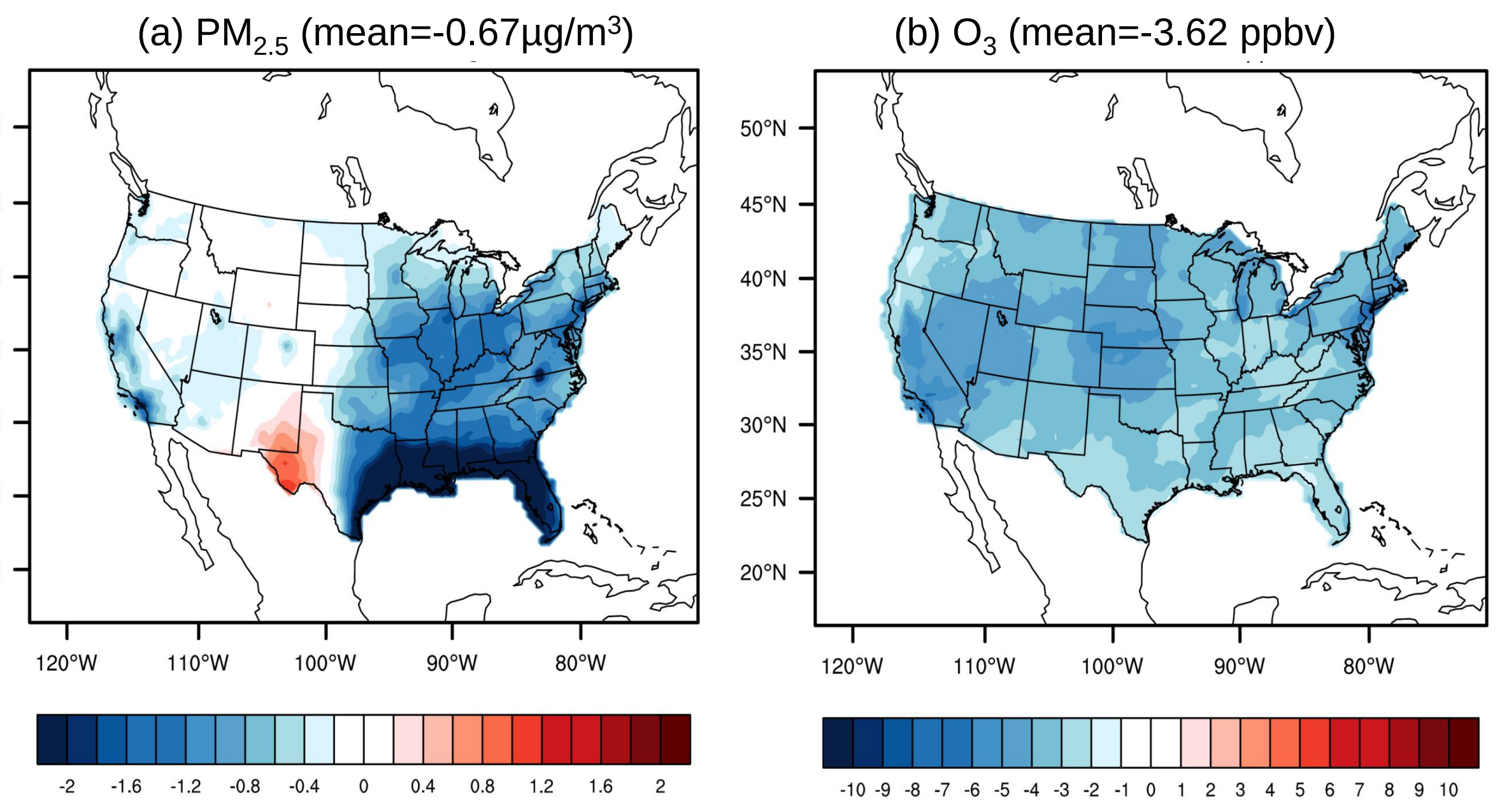
Table 2 Anthropenic emissions in U.S. after regridding (Tg/yr)

	2000	REF_2050	RCP45_2050	Relative Diff[1]
CO	92.74	11.42	11.25	-1.48
NH_3	3.34	4.56	4.30	-5.56
SO_2	14.84	2.46	1.75	-28.78
NO_X	19.57	4.40	3.92	-10.93
PEC	**0.42**	**0.22**	**0.21**	**-7.59**
POC	**0.71**	**0.35**	**0.33**	**-6.17**
$PM_{2.5}$[2]	**4.14**	**1.87**	**1.57**	**-15.80**
PMC[2]	**11.02**	**5.50**	**4.63**	**-15.80**
NMVOC	15.23	8.07	7.16	-11.21

[1]Relative Diff: (RCP4.5 - REF)/REF*100
[2]$PM_{2.5}$ and PMC are not reported in IPCC RCPs but are included in CMAQ input, increasing inorganic PM emissions based on SMOKE emission profiles.

- **Meteorology:** We downscale the global climate simulations of GFDL AM3 for 2000 and for the 2050 RCP4.5 and RCP8.5 scenarios. We use WRF v3.4.1 through **analysis nudging** at 36km for CONUS domain for five years consecutively with the first year as initiation. We resolve the Great Lakes issues by applying the land/sea mask modification approach as discussed by Gao et al. (2012). The WRF downscaling results are comparable with the GCM for geopotential height, temperature and surface precipitation, while the skin temperature is biased higher in the southern U.S. during summer. Hourly WRF outputs are processed through MCIP (4.1) to provide inputs for CMAQ.
- **BCs**: **Dynamical BCs** are developed from the global MOZART-4 model simulations of West et al. (2013).
- **Regional CTM**: CMAQ v5.0.1 is adopted to run the regional simulation (CONUS domain) at 36km resolution for 40 months consecutively for each scenario (Table 1), with the first four months as spin-up. We turn on the in-line options for the **lighting, biogenic emissions, soil, sea salt and wind-blown dust emissions**, which all change in response to climate change.

Results

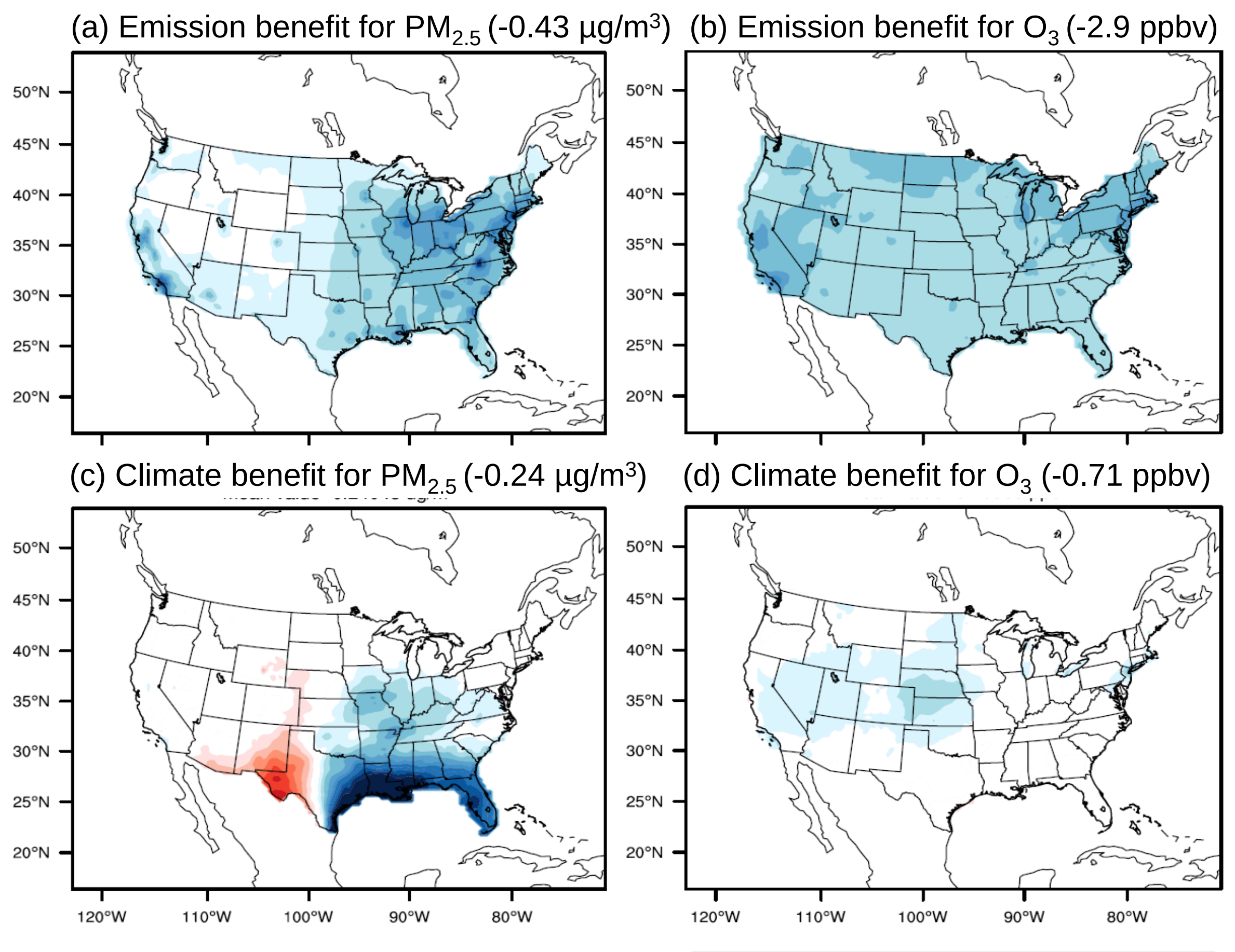


(a) $PM_{2.5}$ (mean=-0.67µg/m³) (b) O_3 (mean=-3.62 ppbv)

Fig 2: Total co-benefits (S_RCP45 - S_REF) for the annual average $PM_{2.5}$ on left, and 6-month ozone-season average of 1-hr daily maximum O_3 on the right (avg. of three years). Negative values indicate an air quality improvement.

a) Air quality co-benefits over the U.S. are significant for both $PM_{2.5}$ and O_3, with domain average decreases of **0.67 µg/m3 and 3.11 ppbv**, though $PM_{2.5}$ increases near the NM-TX border.

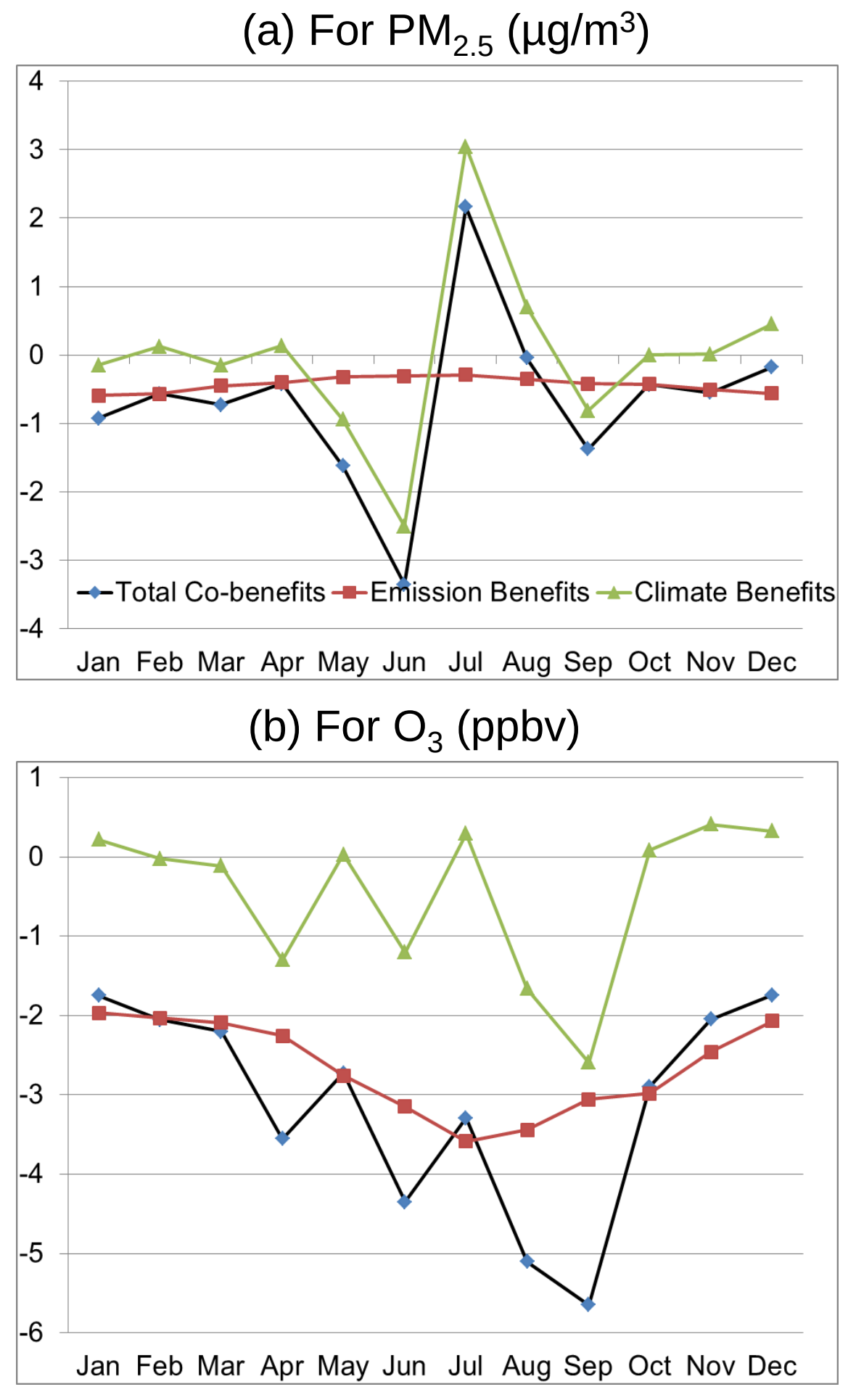
b) The total co-benefits for **PM2.5 are more striking in the east**, especially in the southeast, while the benefits for O_3 are consistent over U.S. $PM_{2.5}$ benefits are influenced mainly by **domestic air pollutant** emission reductions, while O_3 is strongly affected by **global methane reductions and intercontinental transport.**



(a) Emission benefit for $PM_{2.5}$ (-0.43 µg/m³) (b) Emission benefit for O_3 (-2.9 ppbv)

(c) Climate benefit for $PM_{2.5}$ (-0.24 µg/m³) (d) Climate benefit for O_3 (-0.71 ppbv)

Fig 3: Benefits of co-emitted air pollutants versus slowing climate change for $PM_{2.5}$ (a, c) and O_3 (b, d).



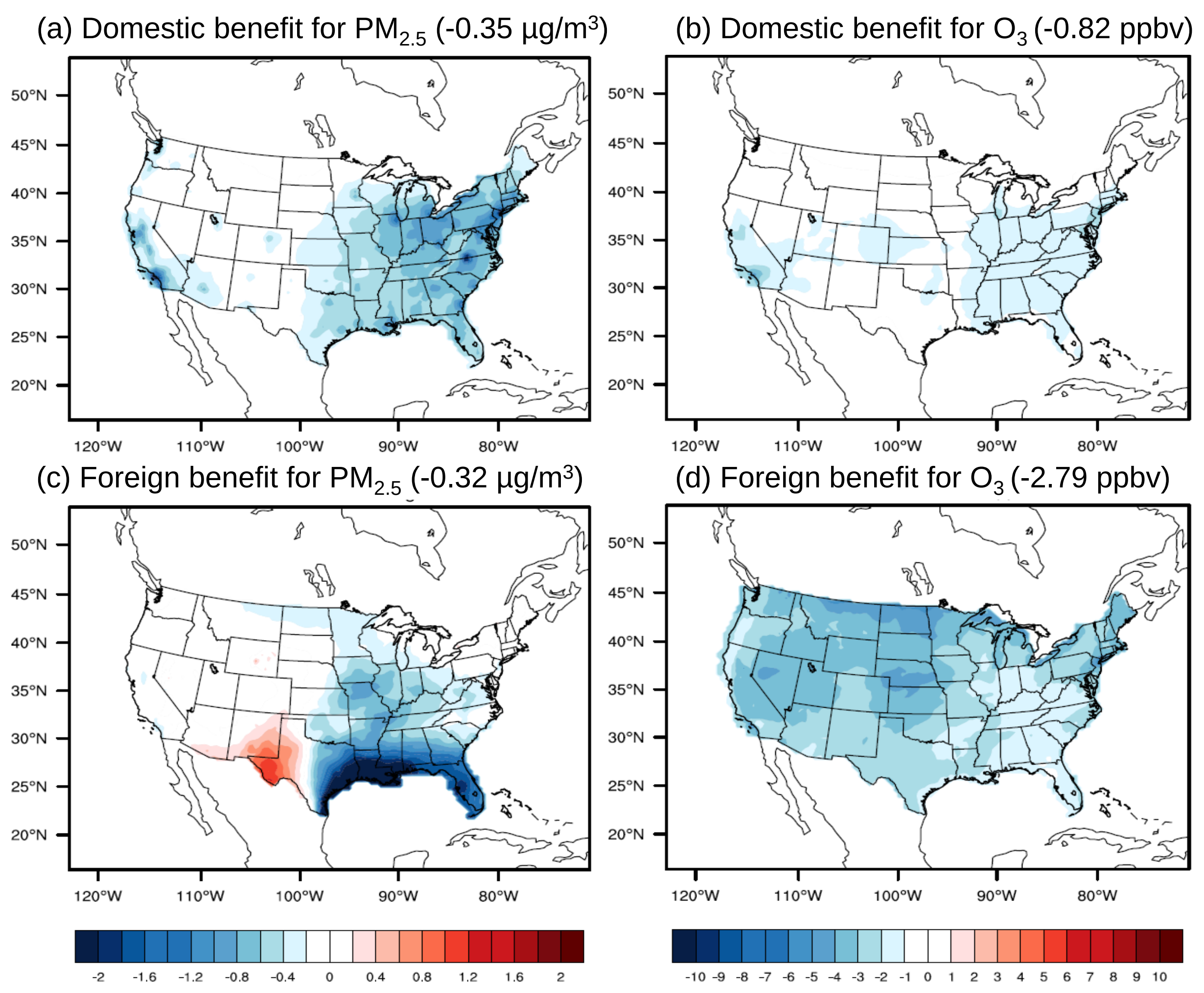
(a) For $PM_{2.5}$ (µg/m³)

(b) For O_3 (ppbv)

Fig 4: Seasonal plots for the benefits from co-emitted air pollutants versus slowing climate for $PM_{2.5}$ (a) and O_3 (b)

a) Overall **the reduction in co-emitted air pollutants has a greater effect** than slowing climate change, accounting for **80% of the total O_3 decrease and 60% of the total $PM_{2.5}$ decrease**, consistent with global results (West et al., 2013). For the emission benefit on $PM_{2.5}$, it is more significant in urban areas where the anthropogenic emissions are greatly reduced in U.S. (not shown), while for O_3 the emission benefit is pretty uniform over the U.S., emphasizing the influence of background ozone changes.

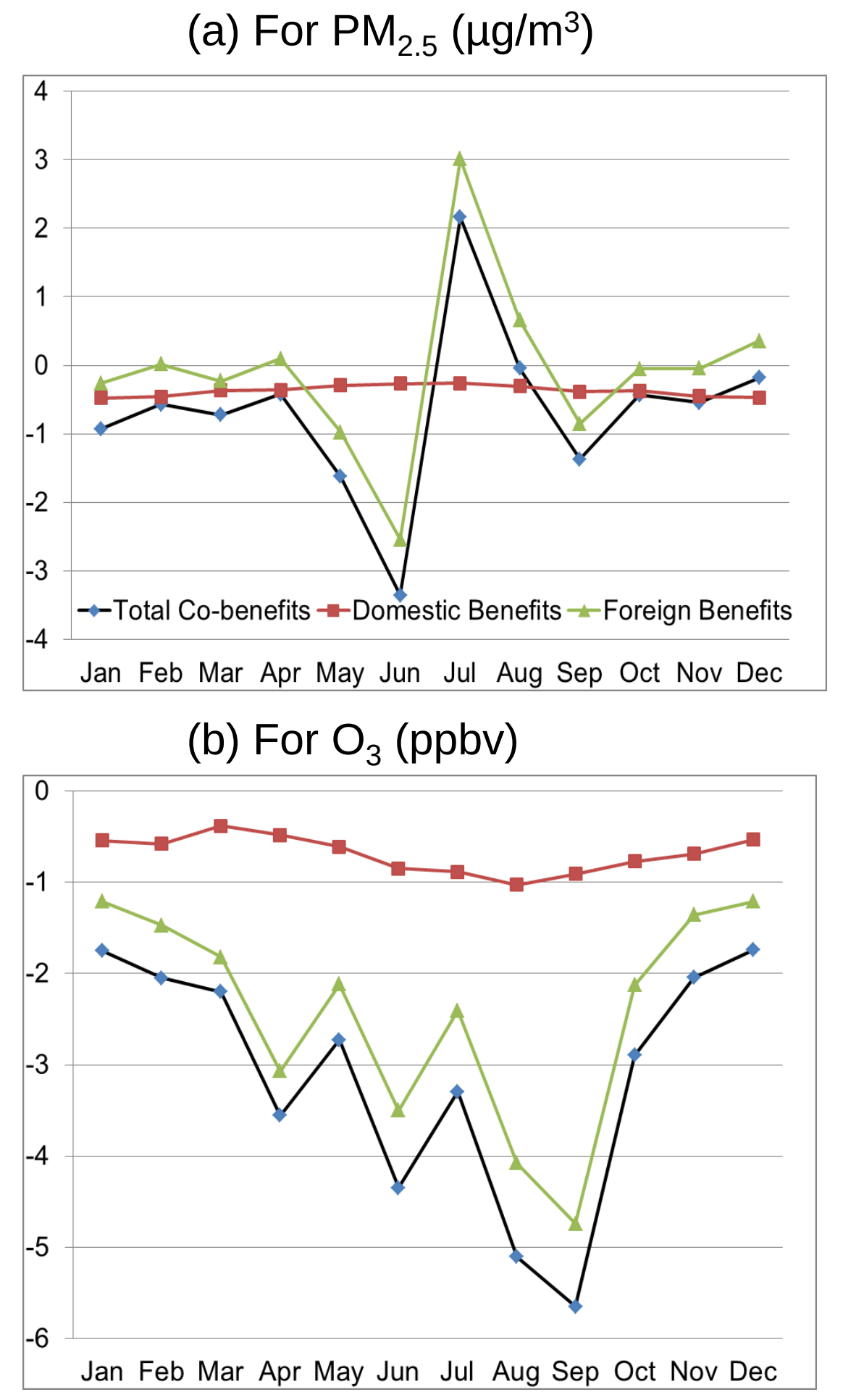
b) The benefits of slowing climate change vary from space and time. For $PM_{2.5}$ it shows strong positive and negative influences in the southern U.S., especially in summer. Analyzing the components of $PM_{2.5}$, we find that **these influences are dominated by trace metal species and unspeciated fine PM**, which are likely are related to the meteorological changes over the Gulf of Mexico, and the modeled sea salt and windblown dust emissions.



(a) Domestic benefit for $PM_{2.5}$ (-0.35 µg/m³) (b) Domestic benefit for O_3 (-0.82 ppbv)

(c) Foreign benefit for $PM_{2.5}$ (-0.32 µg/m³) (d) Foreign benefit for O_3 (-2.79 ppbv)

Fig 5: Co-benefits of domestic versus foreign GHG reductions for $PM_{2.5}$ (a, c) and O_3 (b, d)



(a) For $PM_{2.5}$ (µg/m³)

(b) For O_3 (ppbv)

Fig 6: Seasonal plots for the benefits from domestic GHG mitigation versus that from foreign countries' GHG reductions for $PM_{2.5}$ (a) and O_3 (b)

a) For $PM_{2.5}$, **domestic GHG mitigation has larger effect** over the East and CA, while the benefit from foreign countries GHG reductions is significant in the Southeast. Over the whole U.S., The benefit from domestic GHG mitigation accounts for **52% of the total $PM_{2.5}$ decrease**. The benefit from foreign emissions is similar to that in Fig 3(c), which is because climate change is accounted for as foreign emissions (GHG reductions).

b) **Foreign countries' GHGs mitigation has a larger influence** on the U.S. O_3 decreases (accounting for **77% of the total decrease**), compared with 23% from domestic GHG mitigation, highlighting the importance of global methane reductions and the intercontinental transport of air pollutants.

Conclusions

1) The total co-benefits on **O_3 are fairly uniform** across the U.S. at 2-4 ppb, while $PM_{2.5}$ co-benefits are higher in the east (1-3 µg/m³), with strong positive and negative influences in the Southeast.

2) **Reductions of co-emitted air pollutants** have a greater influence on both $PM_{2.5}$ (60% of total) and O_3 (80% of total) than the second co-benefits mechanism via slowing climate change, consistent with West et al., (2013) .

3) **Foreign countries' GHGs mitigation** has a larger influence on the U.S. ozone decreases (77% of the total), compared with 23% from domestic GHG mitigation only, highlighting the importance of methane reductions and the intercontinental transport of air pollutants. For $PM_{2.5}$ the benefits of domestic GHG control are greater (52% of total).

Uncertainties

- ❖ We didn't account for the feedbacks of changes from land use and vegetation cover on climate and air quality in the future simulations.
- ❖ Where we attribute effects on air quality from climate change, those results are based on 3 years of simulations and may reflect influences of climate variability. We assume that the GHG reductions in the U.S. do not influence global climate, such as through aerosol forcing. We also assume that the GHG reductions in the U.S. do not influence global climate, such as through aerosol forcing, and this will affect our results on the co-benefits from domestic GHG mitigation.

Future work

- ❖ Run sensitivity simulations to see the benefits of emissions reductions from **different U.S. sectors.**
- ❖ Use BenMAP to analyze the **health co-benefits** due to these changes in concentration.

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