Effect of NO_x emission controls on the long-range transport of ozone air pollution and human mortality

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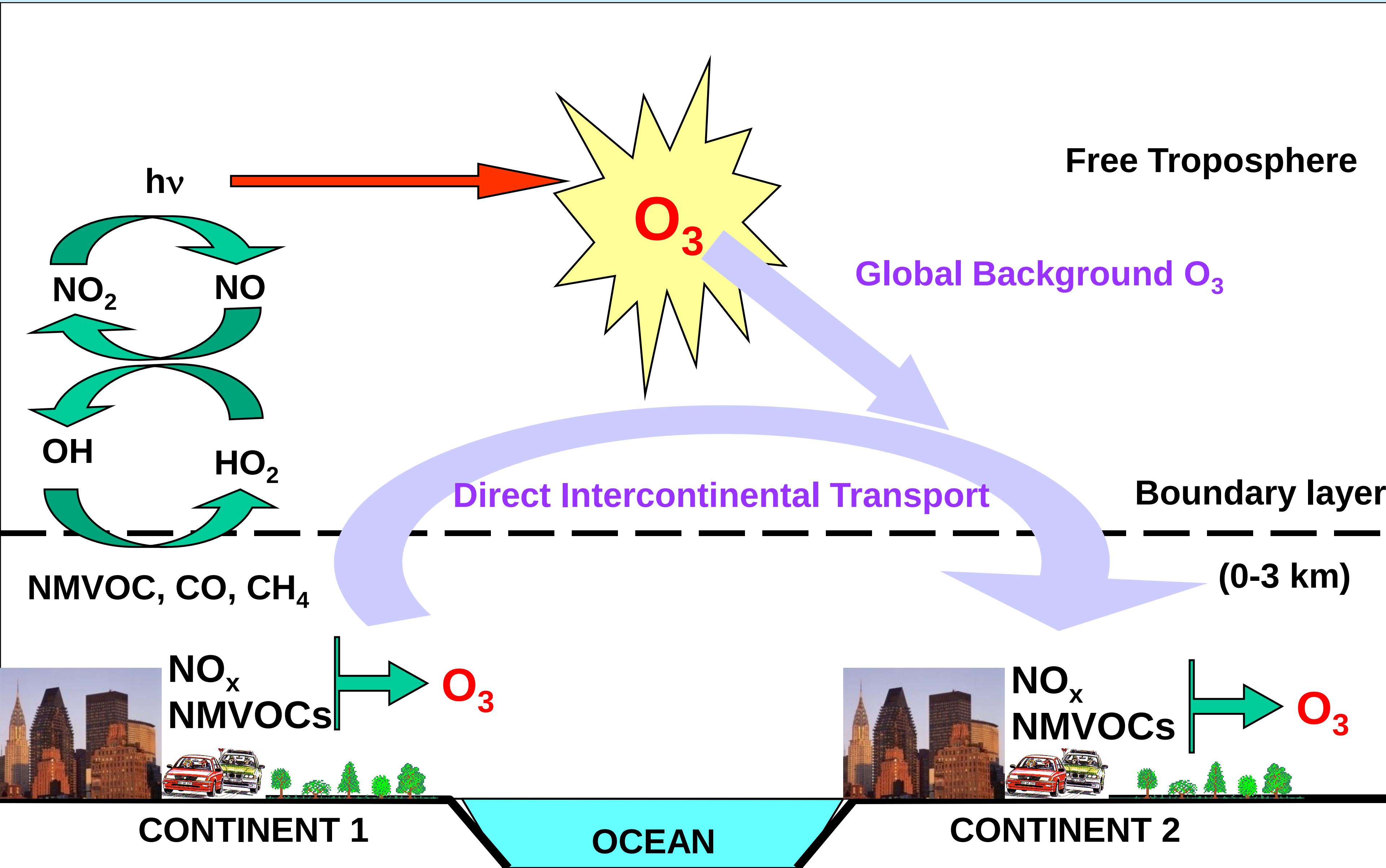
Ozone Precursors Affect Both Ozone Air Quality and Climate Forcing



hν

NO_2

NO

OH

HO_2

NMVOC, CO, CH_4

O_3

Free Troposphere

Global Background O_3

Direct Intercontinental Transport

Boundary layer

(0-3 km)

NO_x
NMVOCs

O_3

NO_x
NMVOCs

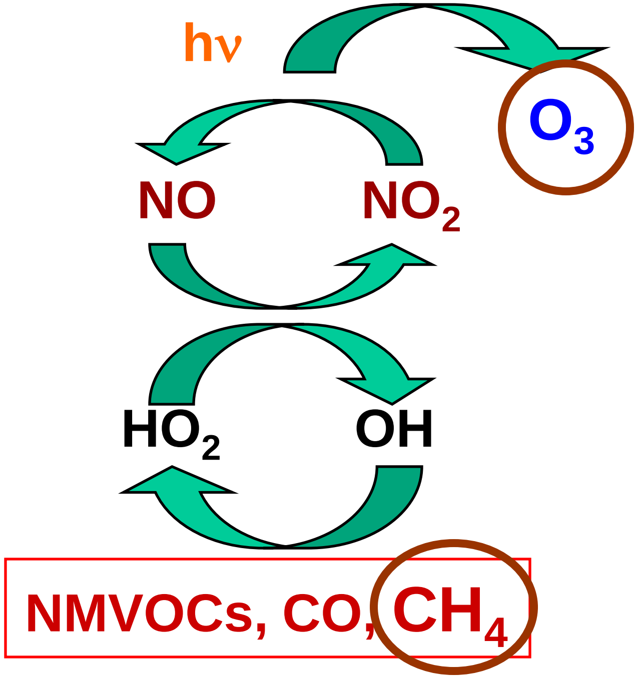
O_3

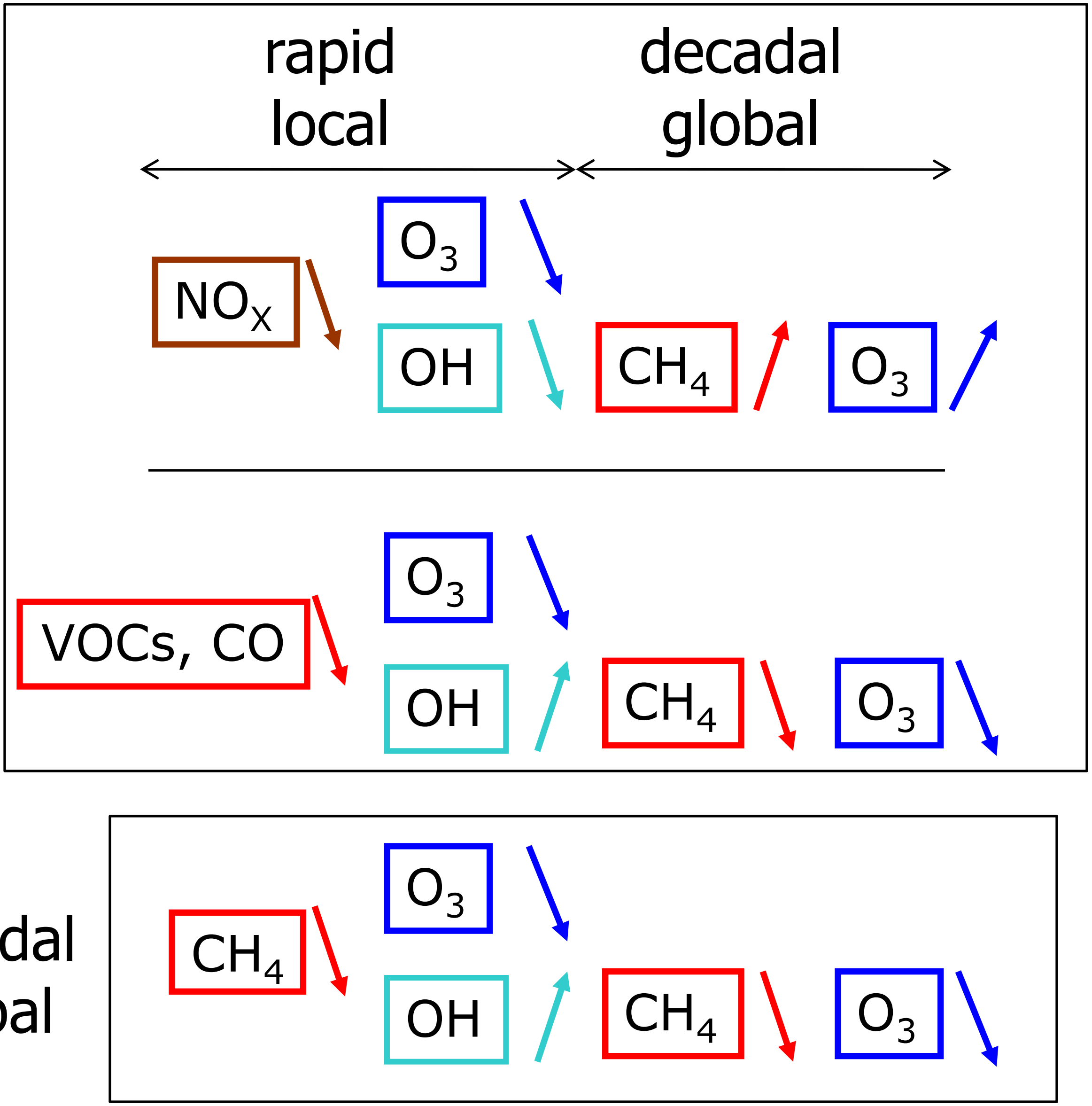
CONTINENT 1

OCEAN

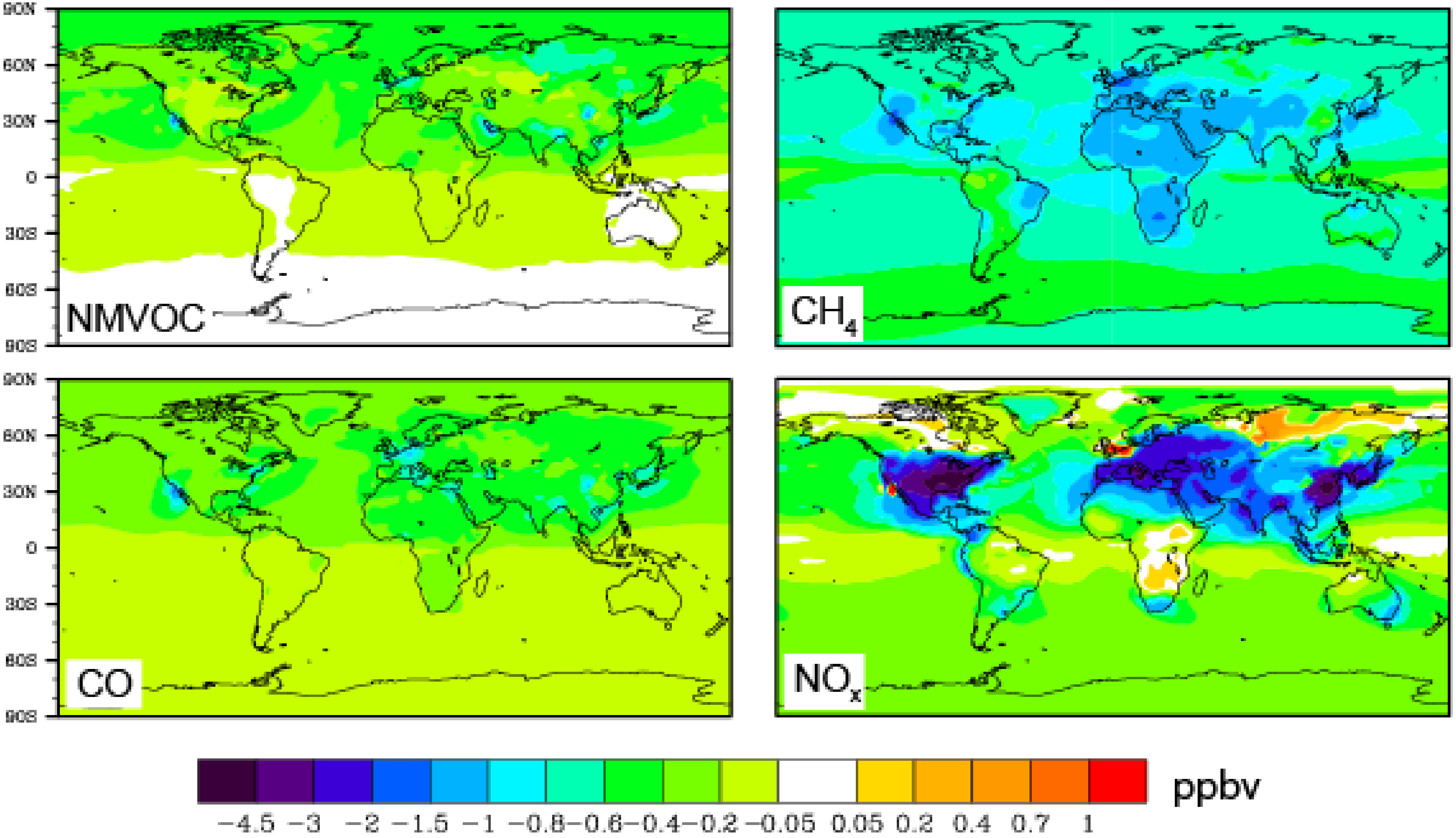
CONTINENT 2

Ozone Precursors Affect Both Ozone Air Quality and Climate Forcing





Surface ozone changes due to 20% anthropogenic reductions

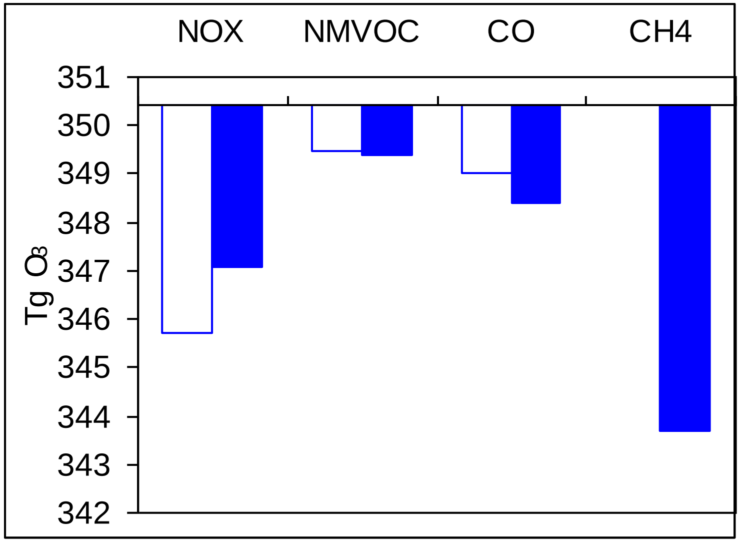


Effect of global 20% anthropogenic emission reductions on 8-hr daily maximum surface O_3, averaged over 3 month period with highest O_3, at steady state (MOZART-2).

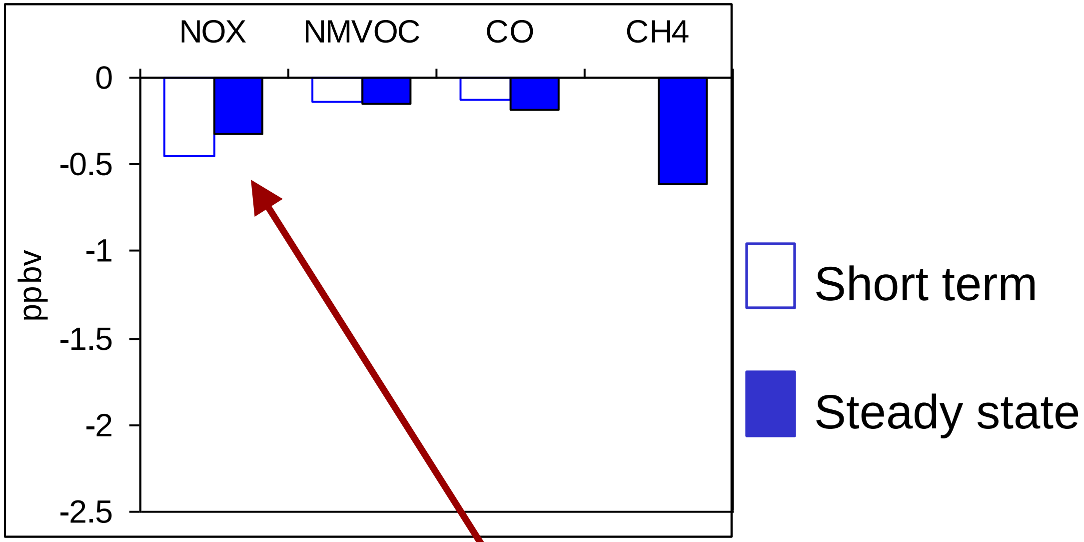
Ozone changes

Effects of 20% reductions in anthropogenic emissions

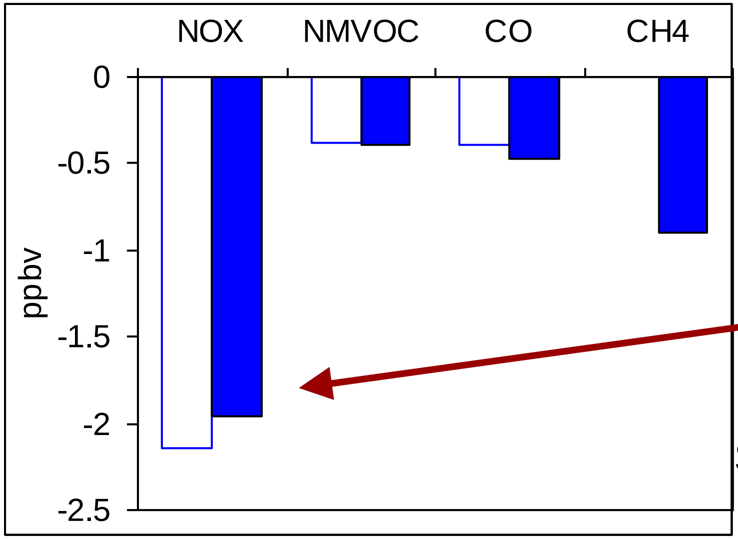
Tropospheric O_3 burden

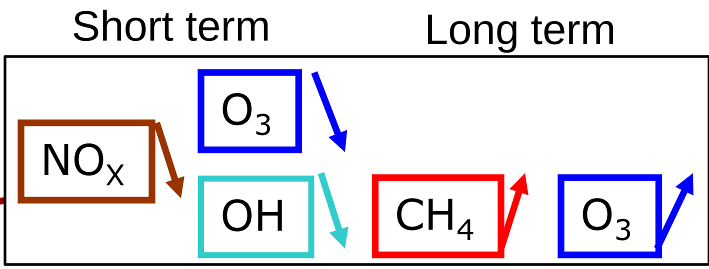


ΔO_3^{srf} annual average



ΔO_3^{srf} global population-weighted 8hr. 3-month

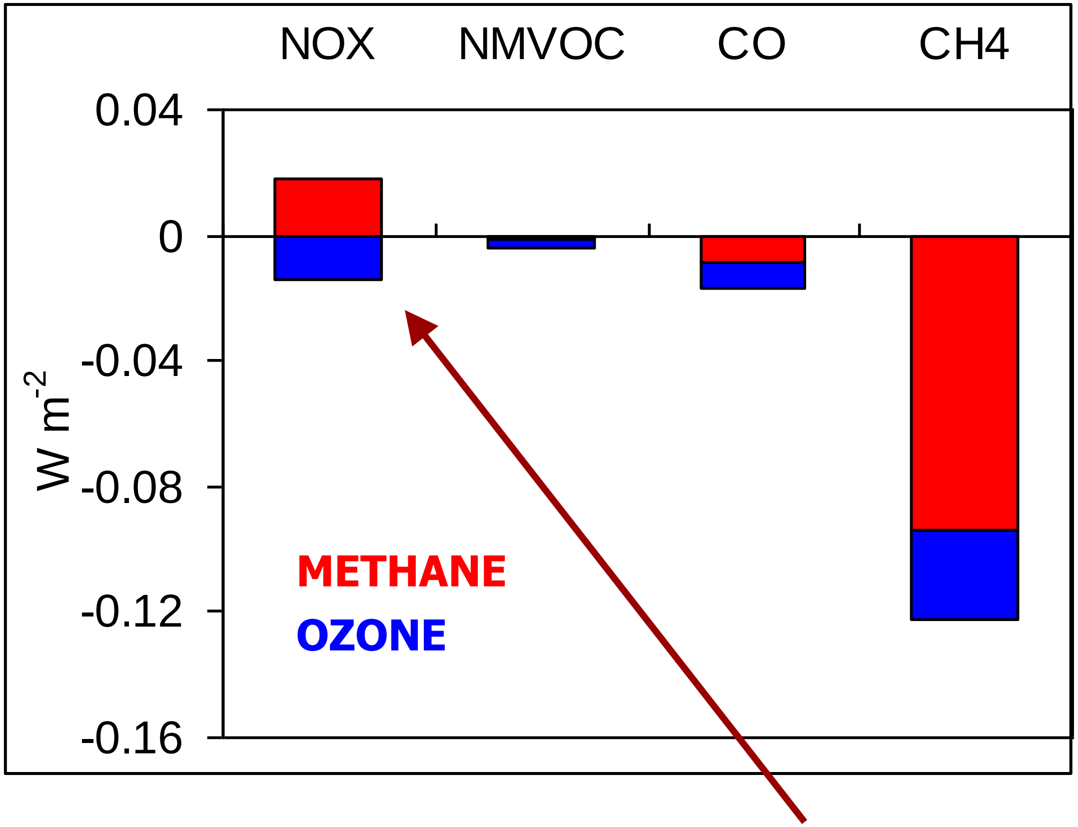


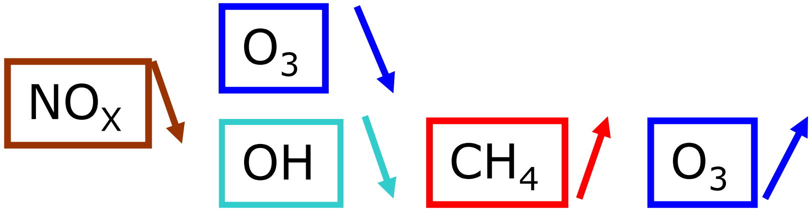


Steady state = Short term + Long term

Radiative forcing

Effects of 20% reductions in anthropogenic emissions



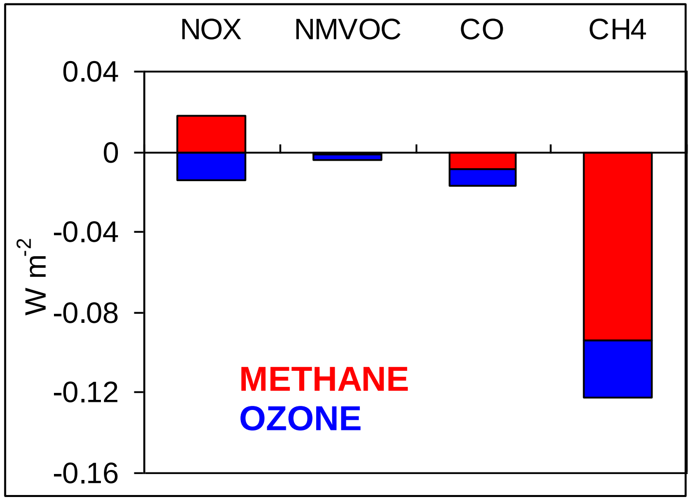


CH_4 forcing estimated using Ramaswamy *et al.* (2001), O_3 forcing using GFDL AM2 radiative transfer model.

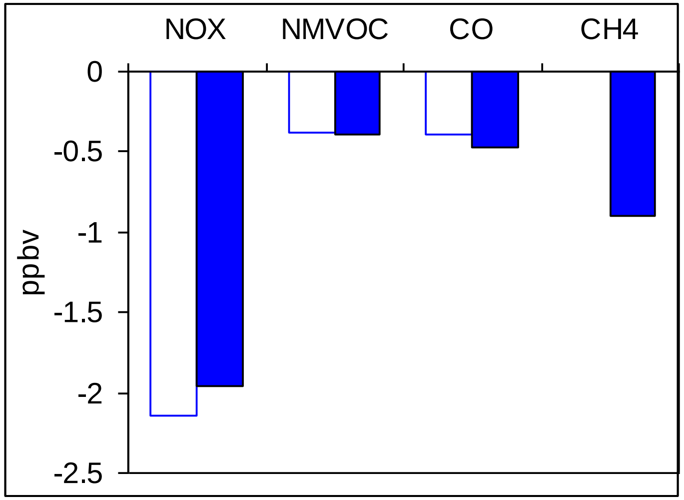
Radiative Forcing and Ozone Air Quality

Effects of 20% reductions in anthropogenic emissions

Radiative Forcing

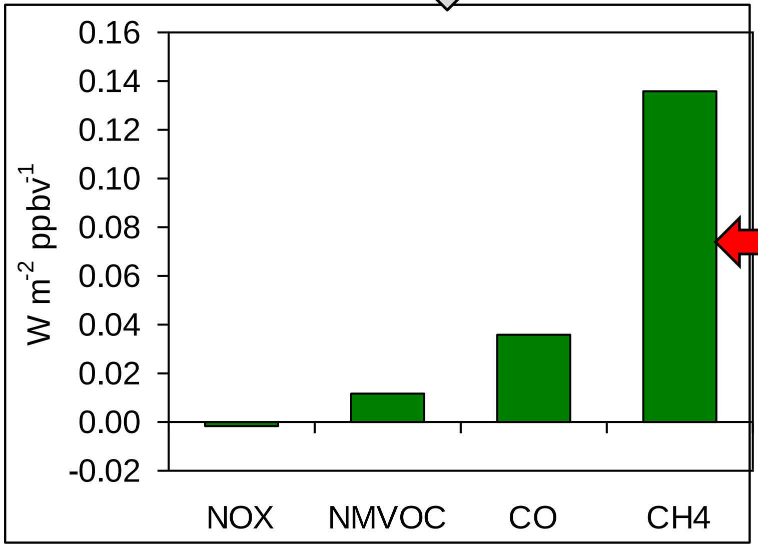


Ozone air quality



ΔO_3^{srf} global population-weighted 8hr. 3-month

$\Delta \mathrm{RF}_{net} / \Delta \mathrm{O}_3^{srf}$

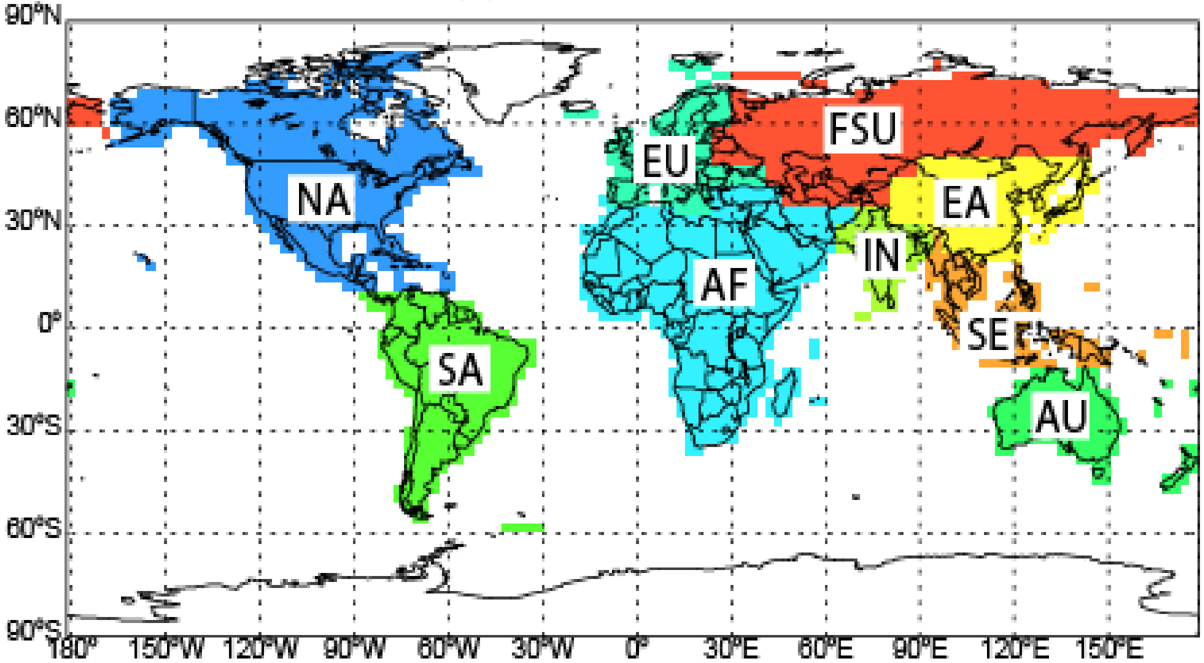


Reducing methane emissions causes the greatest reduction in RF per unit improvement in O_3 air quality.

West et al. (2007) *GRL*

What is the effect of NO_x reductions in one region, on ozone in all other world regions?

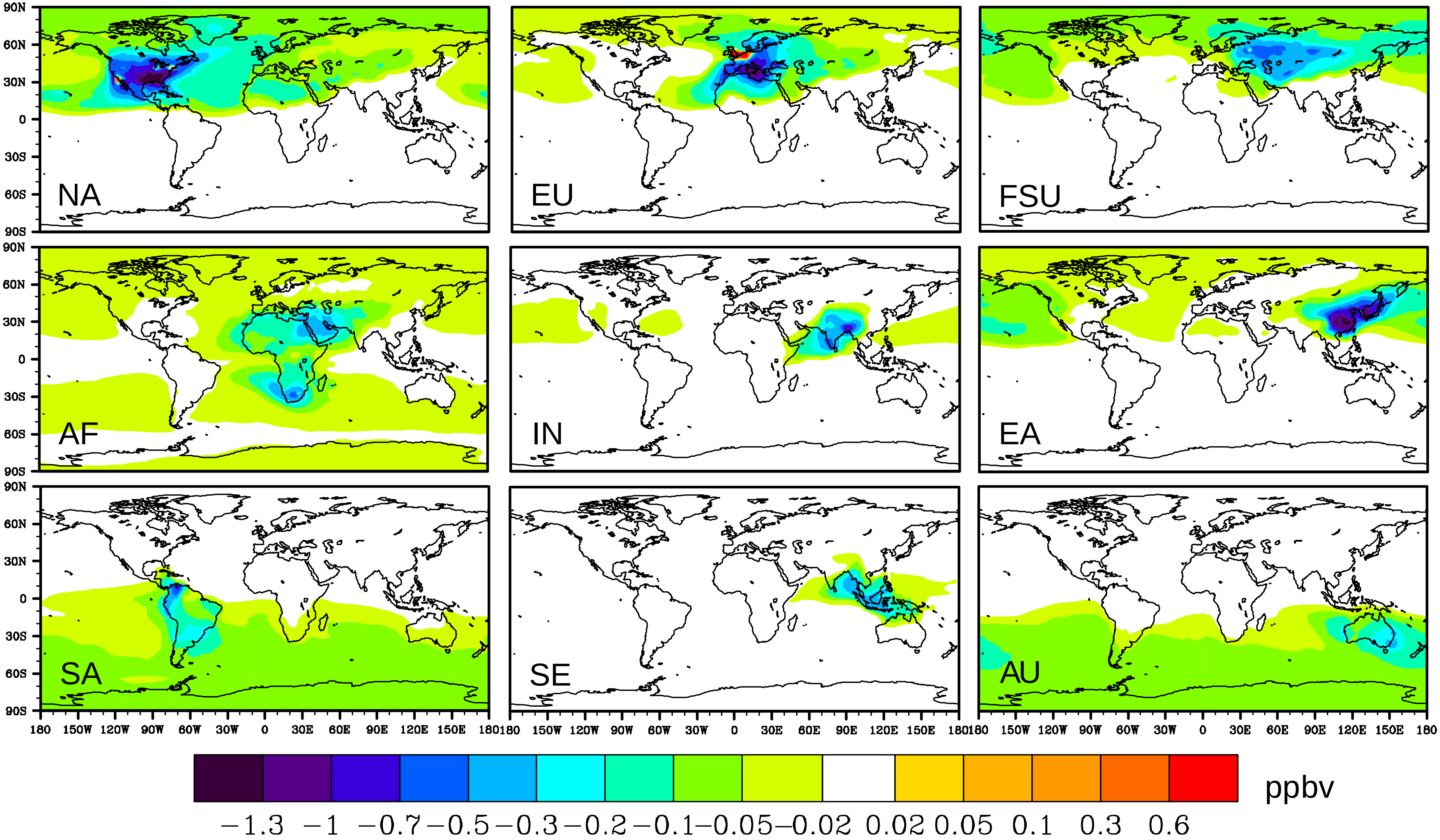
Reduce anthropogenic NO_x emissions by 10% in each of 9 world regions, in the MOZART-2 global CTM (MACCM3 meteorology, EDGAR emissions for 1990s).



Naik *et al.* (JGR, 2005) used these simulations to show that NO_x reductions in each region increase net RF.

Surface O_3

Change from 10% regional NO_x reductions



Change in surface O_3 (ppb), averaged over the 3-month period with highest population-weighted O_3 in source region.

Effect of 10% regional NO_x reductions

Receptor Region

Source Region

	NA	EU	FSU	AF	IN	EA	SA	SE	AU
NA	-512	-63	-46	-44	-44	-8	-11	-10	-3
EU	-8	-194	-184	-73	-13	-9	1	-3	1
FSU	-14	-55	-401	-16	-16	-27	0	0	0
AF	-4	-9	-15	-176	-50	-1	-8	-8	-17
IN	-4	0	-2	-6	-482	-16	-2	-32	-1
EA	-16	-7	-16	-6	-6	-930	-1	-105	0
SA	-6	1	1	-4	-4	1	-252	-5	-34
SE	0	2	1	-2	-15	-38	-9	-265	-11
AU	0	0	0	-1	0	0	-13	-3	-179

Change in population-weighted O_3 (ppt), averaged over the 3-month period with highest O_3 in the receptor region.

Normalized source-receptor matrix

Receptor Region

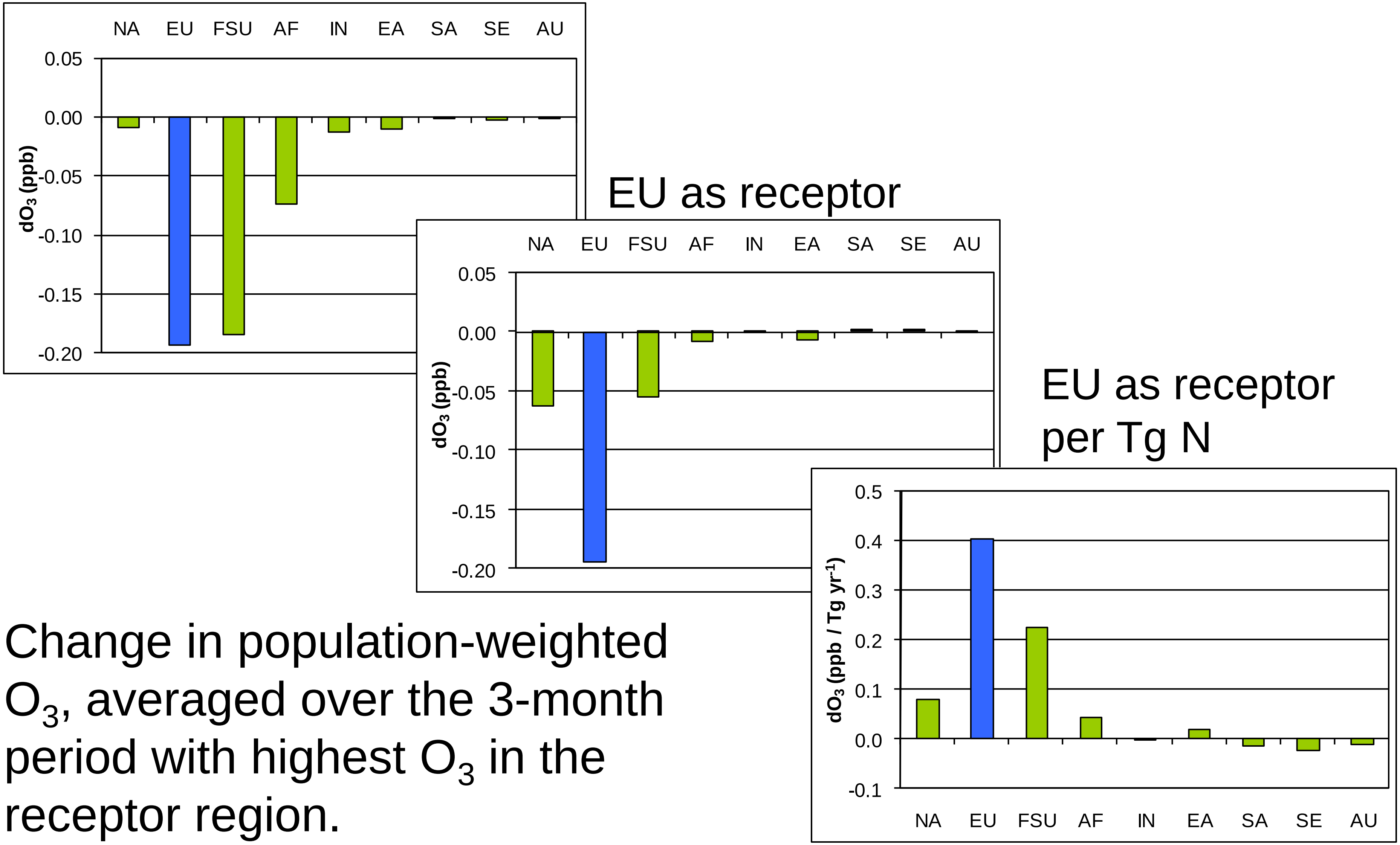
Source Region

	NA	EU	FSU	AF	IN	EA	SA	SE	AU
NA	0.64	0.08	0.06	0.06	0.05	0.01	0.01	0.01	0.00
EU	0.02	0.40	0.38	0.15	0.03	0.02	0.00	0.01	0.00
FSU	0.06	0.22	1.62	0.07	0.06	0.11	0.00	0.00	0.00
AF	0.02	0.04	0.07	0.89	0.25	0.00	0.04	0.04	0.08
IN	0.04	0.00	0.02	0.05	4.19	0.14	0.02	0.28	0.01
EA	0.04	0.02	0.04	0.02	0.02	2.33	0.00	0.26	0.00
SA	0.07	-0.02	-0.01	0.05	0.05	-0.01	3.07	0.06	0.41
SE	0.00	-0.02	-0.01	0.04	0.23	0.58	0.13	4.05	0.16
AU	-0.01	-0.01	-0.01	0.02	0.02	-0.01	0.34	0.08	4.70

Change in 3-month population-weighted average O_3 per unit change in NO_x emissions (ppb (Tg N yr^{-1})$^{-1}$).

Example: Europe

EU as source

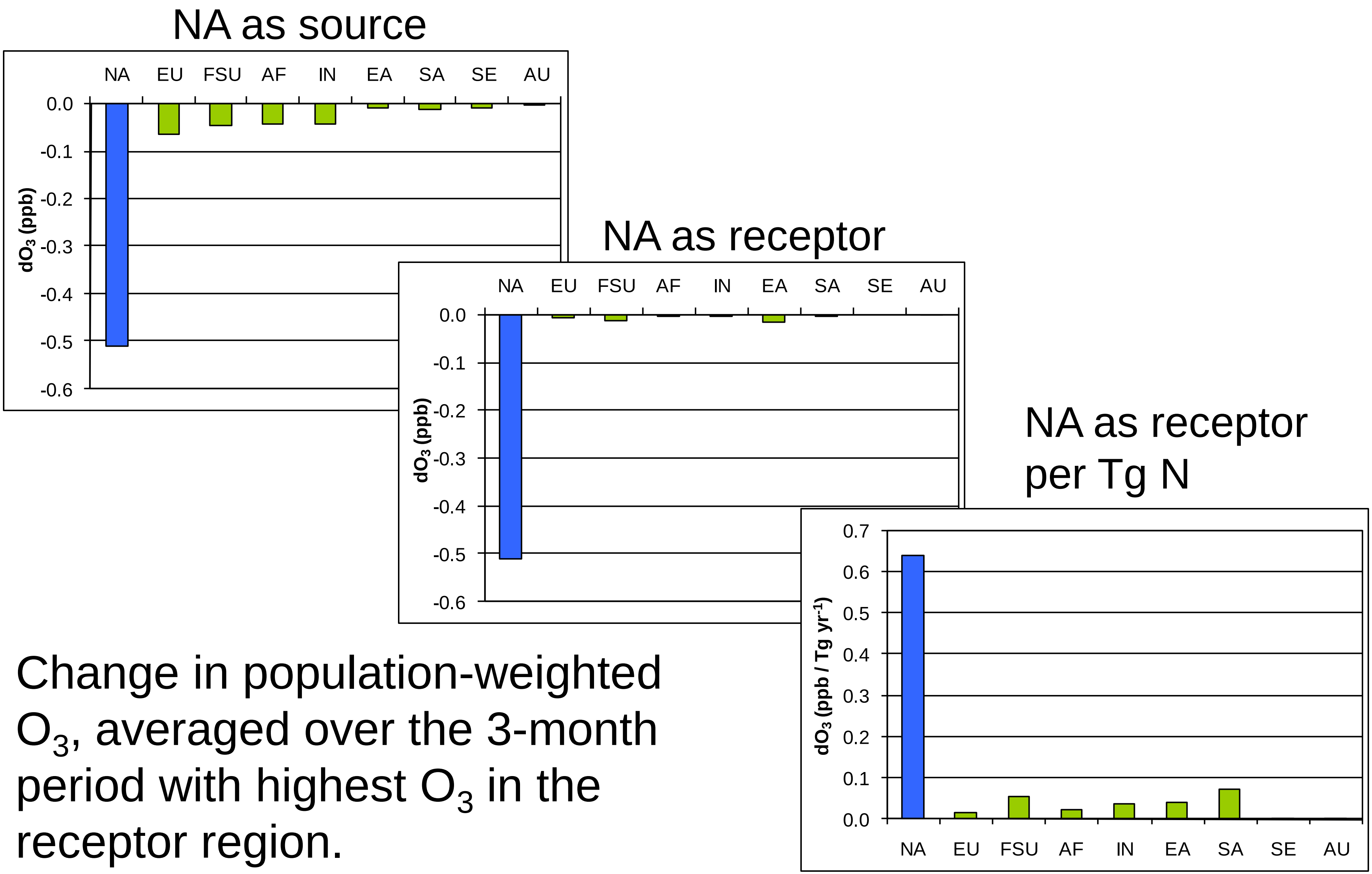


EU as receptor

EU as receptor
per Tg N

Change in population-weighted O_3, averaged over the 3-month period with highest O_3 in the receptor region.

Example: North America

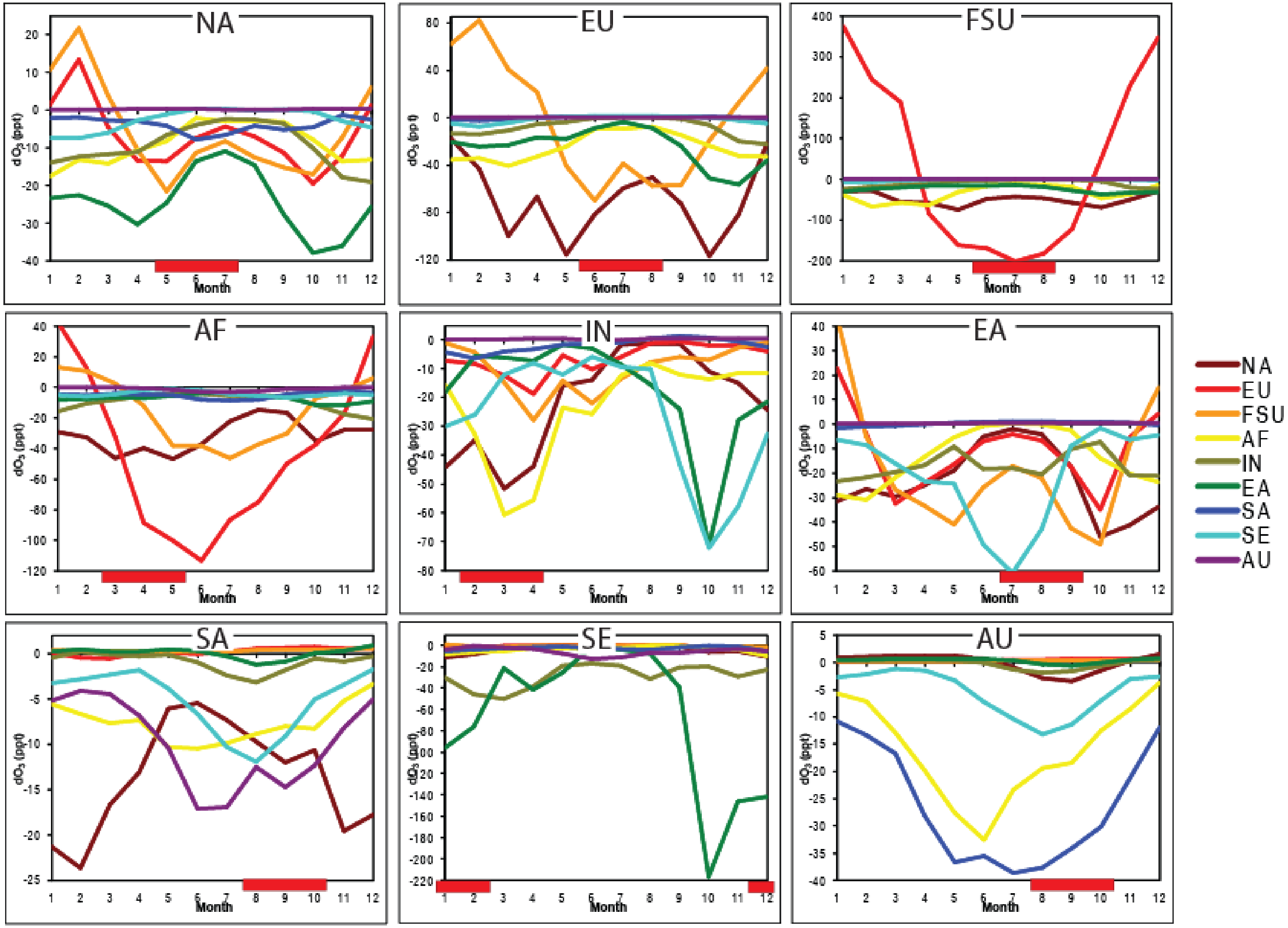

NA as source

NA as receptor

NA as receptor per Tg N

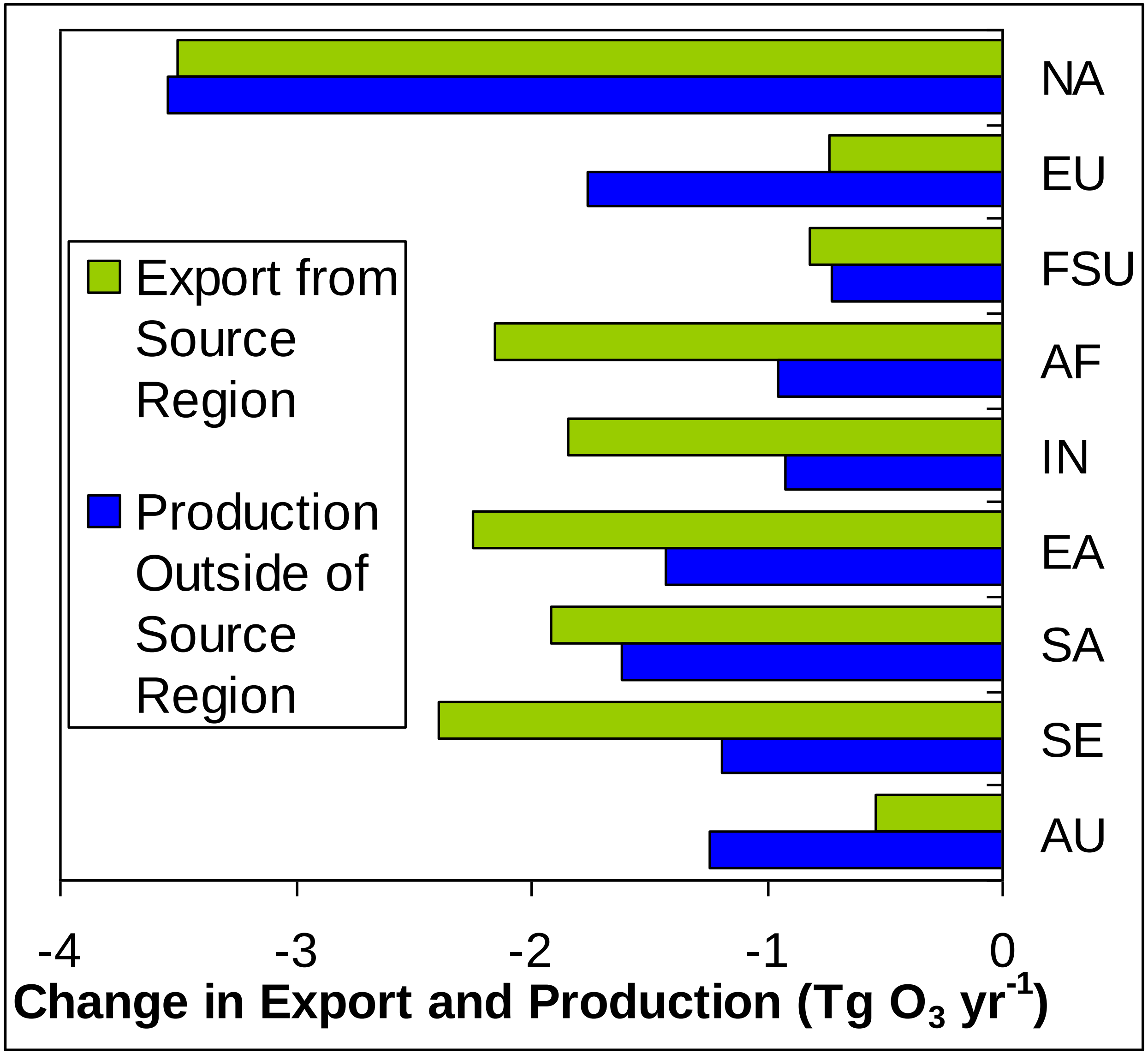
Change in population-weighted O_3, averaged over the 3-month period with highest O_3 in the receptor region.

Monthly O_3 changes in each receptor region



Panels for receptor regions, showing effects of 10% NO_x reductions in each source region, for population-weighted monthly average O_3.

Is ozone exported or NO_y?



Export greater

Effects on Metropolitan Regions

Receptor

Source Region

	Los Angeles	Toronto	London	Athens	Moscow	Tehran	Delhi	Hong Kong	Bangkok
NA	-411	-572	-123	-49	-39	-82	-71	-28	-14
EU	-12	-12	801	-656	-254	-112	-24	-14	-5
FSU	-23	-23	0	-87	-393	-323	-38	-10	-1
AF	-1	0	-24	-135	-1	-198	-83	-14	-7
IN	-8	-1	-8	-2	0	-6	-363	-25	-21
EA	-46	-17	-26	-13	-8	-13	-10	-583	-232
SA	0	1	0	1	1	0	-3	0	-3
SE	1	1	-2	1	1	0	-5	-7	-243
AU	1	0	0	1	0	0	0	1	0

Change in 3-month population-weighted average O_3 (ppt).

Human Health Effects of Ozone and PM

- Time-series studies: relate short-term (day-to-day) changes in concentration to daily mortality rates
- Cohort studies: relate community-level exposures over multiple years to annual mortality
- Relative Risk (RR) = the ratio of the probability of health outcome in exposed group vs. unexposed group

Mortality effects of ozone in short-term time-series studies:

	RR for a 10 ppb increase in O_3 concentration
Non-accidental	1.005 (1.003-1.008)
Cardiopulmonary	1.006 (1.003-1.010)

Bell *et al.*, 2004

Mortality effects of PM in long-term cohort studies:

	RR for a 10 μg/m^3 increase in $PM_{2.5}$ concentration
All-cause	1.06 (1.02-1.11)
Cardiopulmonary	1.09 (1.03-1.16)
Lung Cancer	1.14 (1.04-1.23)

Pope *et al.*, 2002

Avoided Mortalities (annual)

Receptor Region

Source Region

	NA	EU	FSU	AF	IN	EA	SA	SE	AU	TOT
NA	251	148	59	162	133	106	11	7	0	876
EU	12	-289	89	250	39	54	0	2	0	158
FSU	12	53	50	67	62	89	0	1	0	333
AF	12	49	36	938	134	58	4	5	5	1238
IN	13	13	10	53	3012	80	1	56	0	3238
EA	38	45	25	34	107	1154	0	124	0	1527
SA	3	-1	0	33	9	-1	203	3	1	251
SE	3	1	1	29	149	100	4	417	0	704
AU	-1	-1	0	7	-2	-2	5	7	7	20
TOT										8344

Mortality based on Bell et al. (2004)
Intra-regional avoided mortalities: 5744; Inter-regional: 2600

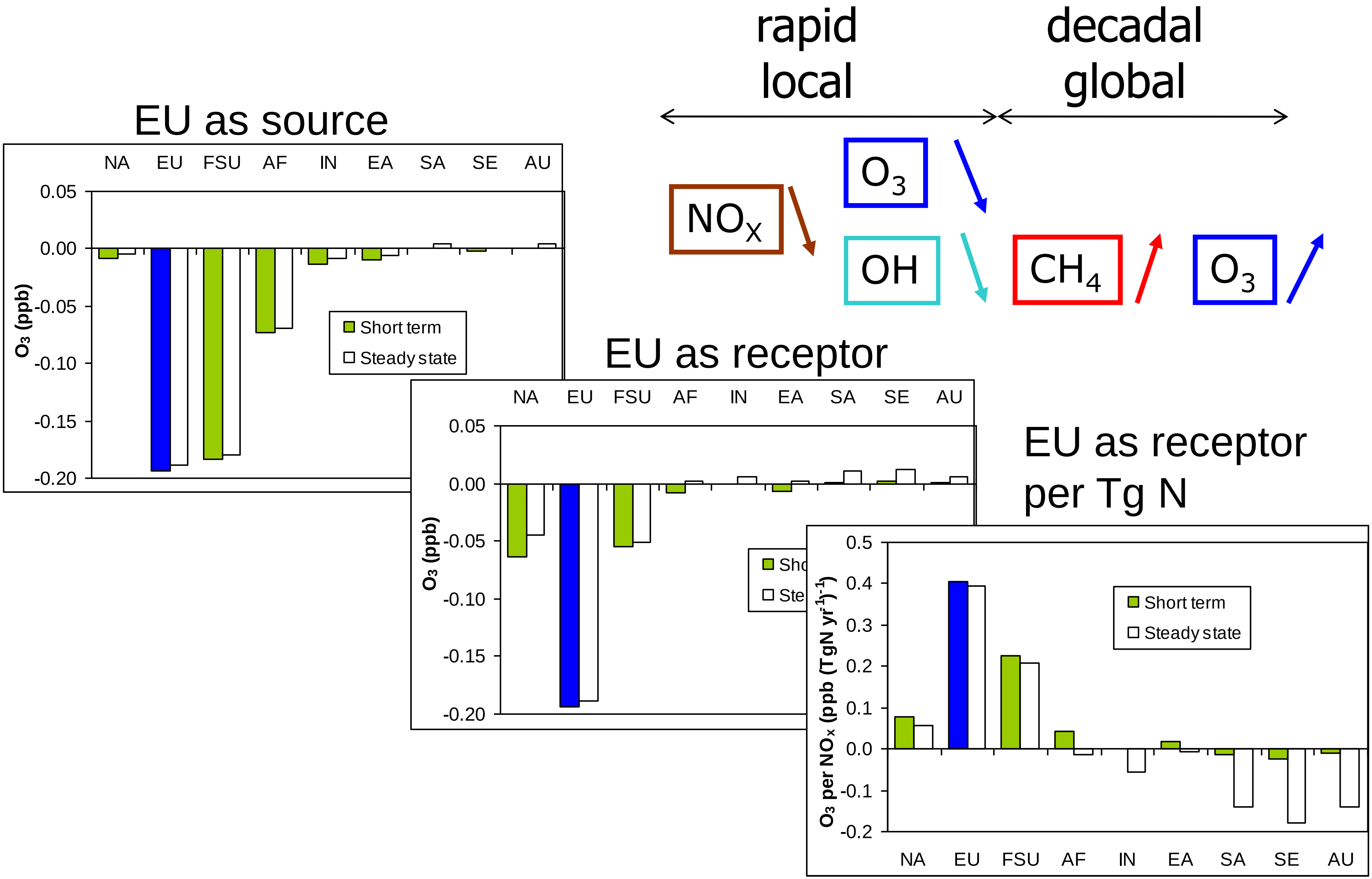
Avoided Mortalities (annual) per Tg N yr^{-1}

Receptor Region

Source Region

	NA	EU	FSU	AF	IN	EA	SA	SE	AU	TOT
NA	32	18	7	20	17	13	1	1	0	110
EU	3	-60	18	52	8	11	0	4	0	33
FSU	5	21	20	27	25	36	0	0	0	135
AF	6	25	18	472	68	29	2	0	0	623
IN	12	11	8	46	2621	70	1	3	0	2818
EA	10	11	6	8	27	290	0	49	0	383
SA	4	-1	0	40	12	-1	248	31	1	306
SE	5	2	1	44	227	152	6	637	0	1076
AU	-1	-2	-1	18	-6	-4	13	17	19	52
TOT										345

Long-term changes in O_3 via CH_4



rapid local

decadal global

NO_X

O_3

OH

CH_4

O_3

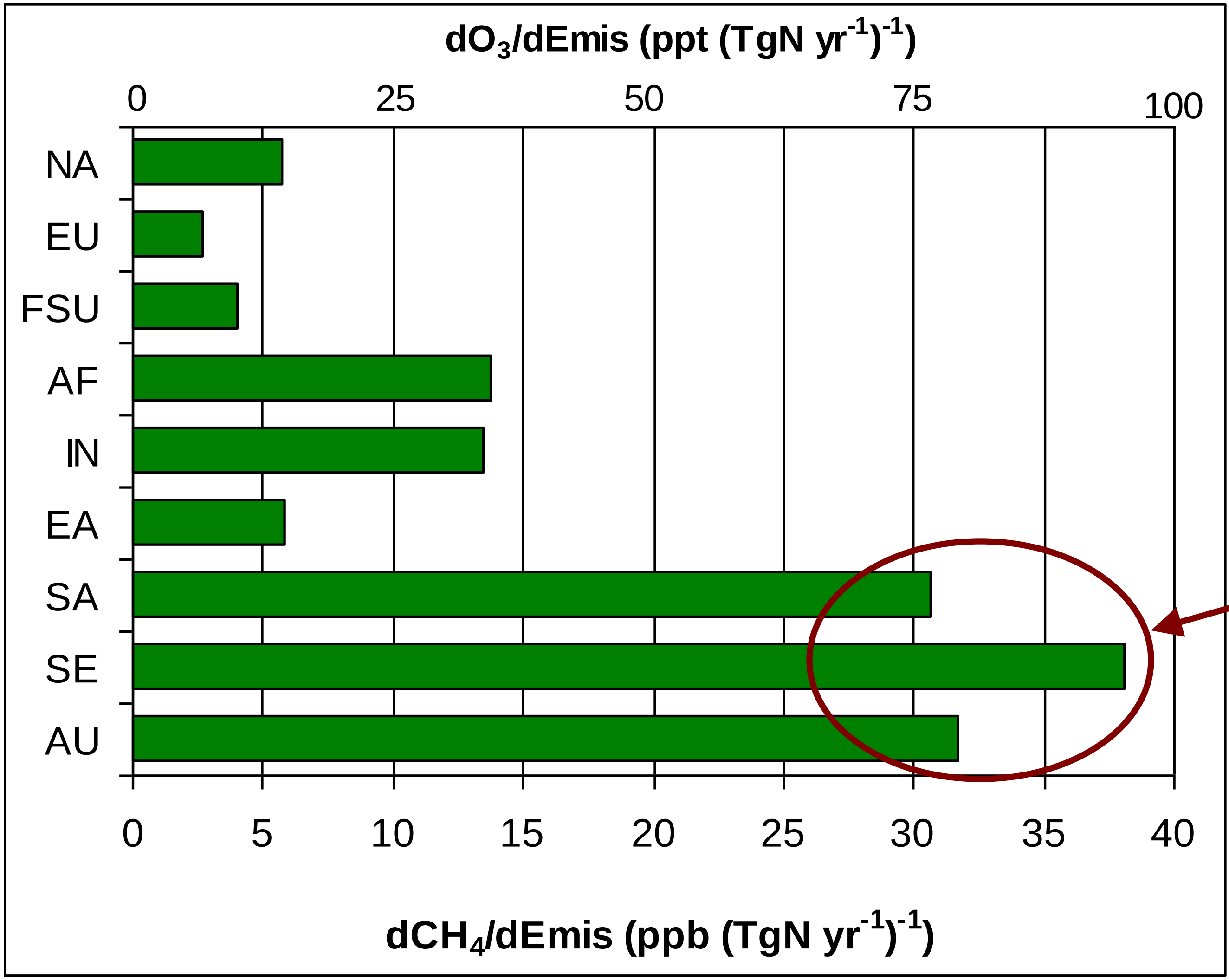
EU as source

EU as receptor

EU as receptor per Tg N

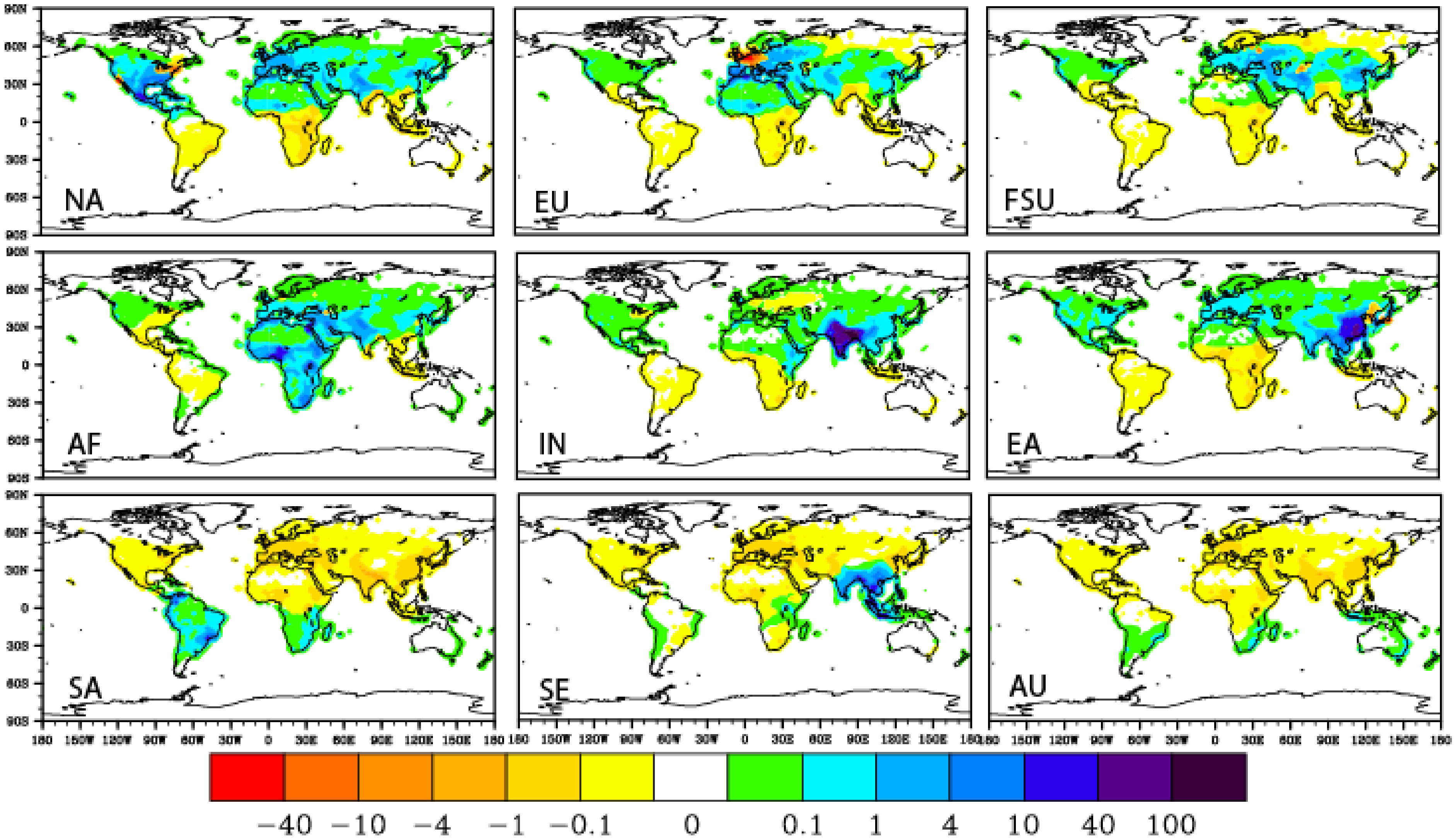
Long-term changes in O_3 via CH_4

CH_4 and long-term O_3 increase per unit NO_x decrease
(global annual average surface O_3 change)



Tropical and SH regions have much greater effect on CH_4 and long-term O_3 per ton NO_x reduced

Avoided Mortalities at Steady-state



NO$_x$ reductions cause mortalities to increase in opposite hemisphere.

Conclusions

Based on 10% regional anthropogenic NO_x emission reductions:

- Inter-continental effects are ~10x smaller than effects within a region.
  - Largest impact is Europe on the Former Soviet Union.
  - Control costs would need to be ~10% of within-region cost for overseas reductions to be cost-effective.
- Tropical regions cause a greater ΔO_3 per ton NO_x reduced, than temperate regions.
- Avoided mortalities are greater outside of NA, EU, and FSU than within.
- Long-term changes in O_3 (via CH_4) roughly cancel the short-term O_3 reduction for some region pairs.