



Research Article

Time Integrated Radiative Forcing from North American NO_x Emissions: Climate Effect over 20- and 100-year Time Scales

Richard Damoah* 

Climate Science Division, Morgan State University, Baltimore, United States

Abstract

The distribution of tropospheric ozone (O₃) globally depends on the emission of precursors (e.g., NO_x), chemistry, and transport. In this study, we quantify the response of radiative forcing over 20- and 100-year time scales, to O₃ and methane (CH₄) perturbations caused by a marginal increase (0.1 Tg N) in anthropogenic emissions of NO_x in January and July from 21 (10° × 10° grid) geographical locations in North America. Changes in the perturbations have been calculated with the global climate-chemistry transport model STOCHEM. Addition of NO_x emissions led to an initial increase in global O₃ burdens up to 0.9 Tg, which decayed after 4 months. Global CH₄ burdens decreased (by increasing OH) by up to −0.7 Tg and decayed gradually after 6 months. Global radiative forcings resulting from the regional emission increases were calculated, accounting for changes in both O₃ (using an offline radiation code) and CH₄ (using a simple conversion of 0.37 mW m^{−2} ppb^{−1}, assuming that CH₄ is well mixed in the atmosphere). Our results revealed that O₃-induced time-integrated radiative forcings exhibit both positive (initial) and negative (long-term) phases in the two (20- and 100-year) time horizons. For the positive phase, both the 20- and 100-year time periods peaked at 0.454 mW m^{−2} yr; however, for the negative phase, the 20-year peaked at −0.246 mW m^{−2} yr and the 100-year peaked at −0.300 mW m^{−2} yr. CH₄, on the other hand, showed a single negative phase which peaked at −1.070 mW m^{−2} yr for the 20-year time period and −1.302 mW m^{−2} yr for the 100-year time period. The total net radiative forcings (assuming a linear additive for relatively small perturbations) of the CH₄ term and the two O₃ terms over a 100-year time period from all 21 locations produce a net climate cooling effect (negative forcings), irrespective of the season of the emission pulses. However, over a 20-year time period in winter, some emission pulses at low latitudes produce a net climate warming effect (positive forcings). Both the O₃ and CH₄ burdens and the associated radiative forcings depend strongly on the geographical location as well as the season of the emission pulses. They are most sensitive to emissions from low latitudes and least sensitive to emissions from mid-latitudes and high latitudes.

Keywords

Radiative Forcing, Ozone, Methane, Chemistry Transport Model, Climate Model, Nitrogen Oxides, Lagrangian Model

*Correspondence: Richard Damoah (Richard.Damoah@morgan.edu)

Received: 21 February 2026; Accepted: 18 March 2026; Published: 30 March 2026



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1. Introduction

Apart from the Kyoto-regulated gases, there are several other short-lived gases (e.g., oxides of nitrogen, NO_x) that significantly affect anthropogenic radiative forcing of the climate by changing the concentrations of ozone (O_3) and methane (CH_4) [1]. Tropospheric ozone is known to have caused a radiative forcing since pre-industrial times that is comparable in magnitude to CH_4 [1]. Due to lack of adequate measurement data of the ozone changes numerical models are used to simulate the ozone changes making this forcing uncertain. Furthermore, the emissions of ozone precursors such as NO_x and CO also affect the oxidizing capacity of the atmosphere, mainly through perturbations of the hydroxyl (OH) radical. The concentrations of OH in the troposphere are likely to have led to changed lifetimes and concentrations of various Kyoto gases such as CH_4 and O_3 [2-4]. These perturbations especially CH_4 sometimes can be well-mixed globally and decay away longer (1.4-1.5 times) than the atmospheric lifetime [3].

The climate impact of short-lived gases varies according to their emission locations. For example, the magnitude of changes in ozone and OH concentrations due to emissions of short-lived species depends on meteorological/physical (e.g., UV radiation, temperature, humidity, albedo, convection, clouds) and chemical (in particular the NO_x and VOC levels) background in a non-linear way [2, 5-7], hence, varying the radiative forcing from these changes according to location. Studies have shown that changes in upper tropospheric ozone concentrations lead to a larger radiative forcing [8, 9] than changes near the surface, and changes in the tropics and subtropics causes larger (up to a factor of 2) impact on radiative forcing than changes at high latitudes [10].

In previous studies, radiative forcings due to aircraft NO_x emissions [11] and surface CO, NO_x , and CH_4 [4] have been investigated using the global chemistry climate model STOCHEM. However, in this study, the changes in concentrations of CH_4 , O_3 , and OH due to additional emission of surface NO_x in North America have been analyzed. We have employed an approach similar to previous studies to examine CH_4 and O_3 radiative forcings due to surface NO_x emissions. We have focused on the spatial and seasonal variations in the emissions and their relationship to radiative forcing over 20- and 100-year time scales.

2. Model Description and Experimental Design

2.1. Model Description

In this study, we have used a Lagrangian chemistry transport model STOCHEM [12]. STOCHEM has been validated extensively in previous studies [12, 24-30]. We utilized STOCHEM version that divides the atmosphere into 50,000 air parcels which are mapped after each advection time-step

to a $5^\circ \times 5^\circ$ resolution grid and 9 vertical layers up to 100 hPa. The Lagrangian cells are advected every 3 hours using meteorological input from the Met Office numerical weather prediction models as analysis fields, which are based on a resolution of 1.25° longitude and 0.83° latitude and on 12 vertical levels, extending to 100 hPa [12].

Boundary layer mixing is accomplished by randomly redistributing air parcels vertical coordinates over the boundary layer height [13]. The height of the boundary layer is estimated in two ways based on earlier study [13]: the dry adiabatic method (convective situations) and the Richardson number method (stable situations). Small-scale (i.e., smaller than can be resolved on the gridded wind data) convection is achieved by randomly mixing a fraction of the air parcels between the surface and the cloud top, while, advection uses a fourth order Runge-Kutta method described previously [13]. The chemistry in the model uses 70 species including the main trace gas species thought to influence the tropospheric ozone budget. These species take part in 174 photochemical gas and aqueous phase reactions. The concentration of each chemical species is updated using a backward Euler solver with a chemical time step of 5 minutes. Wet deposition uses scavenging coefficients, and dry deposition uses a resistance approach. O_3 and NO_y upper boundary conditions are prescribed into the top layer of the model at 100 hPa [14, 15].

We used emission fields for anthropogenic trace gases for the year 2000 from the International Institute for Applied Systems Analysis (IIASA) [16]. Emissions of isoprene from vegetation were set at 500 Tg yr^{-1} . NO_x from lightning and aircraft were also set at 5.0 Tg N yr^{-1} and 0.5 Tg N yr^{-1} , respectively. SO_2 and NO_x emissions from international shipping were from EDGAR v3.2 data for 1995 [17], with 1.5% growth rate applied per year between 1995 and 2000 [16]. Emissions of methane from wetlands, tundra, and rice paddies were set at 260 Tg yr^{-1} .

2.2. Experimental Design

The model uses an initial set of trace gas mixing ratios from 1st October 1997 and analyzed wind fields to run through to 30th June 1998. At that point, three model runs were initiated. The first model run, the base case, continued on from the annual cycle without change until 30th June 1999. In the second and third model runs, the transient cases, NO_x emission pulses of 0.1 Tg N were added in each of the $21 \times 10^\circ \times 10^\circ$ grid boxes shown in Figure 1 for the months of January and July 1998. They were then reset to the base case value and allowed to continue until 30th June 1999. Changes in the concentration of CH_4 , OH, and O_3 were normalized to 1 Tg of emission pulse to make them comparable and then followed by taking the differences between the base and transient cases. Similar applications have been employed [4] to CH_4 , CO, H_2 , and NO_x and to VOCs [23].

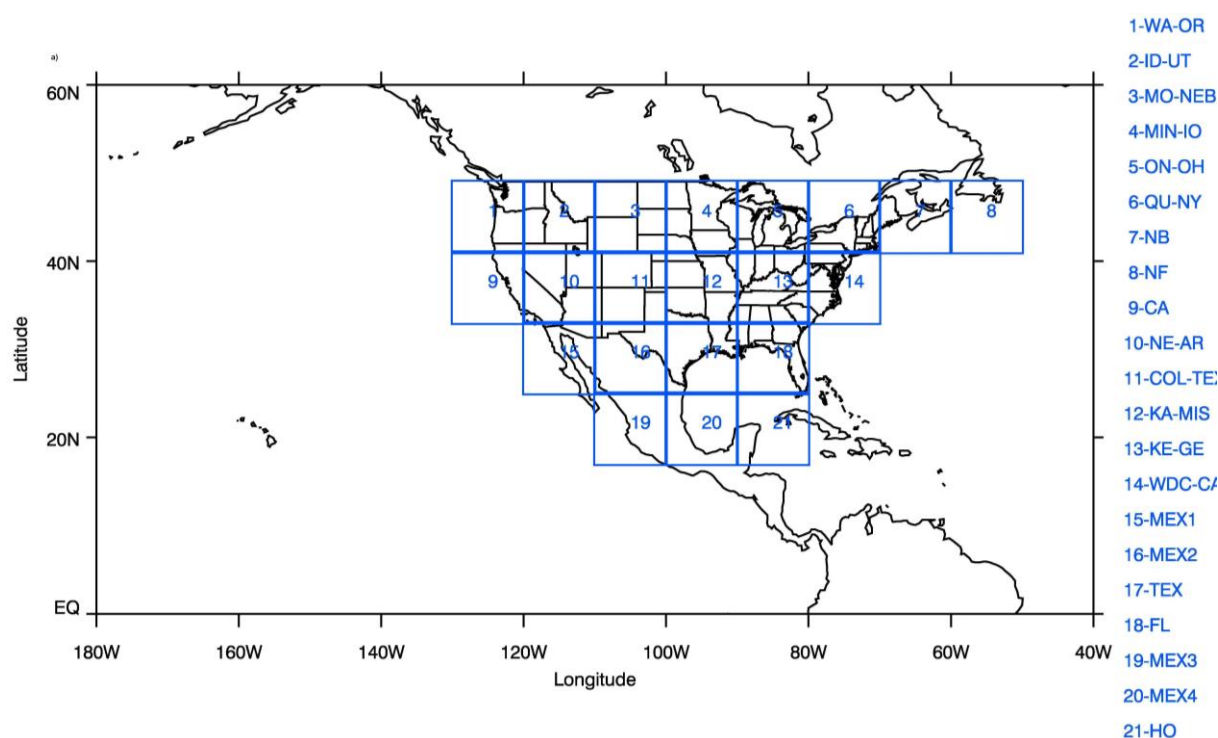


Figure 1. Map of North America showing all the $21\ 10^\circ \times 10^\circ$ grid emission locations.

Time-integrated radiative forcing calculations for CH_4 and O_3 perturbations over 20 and 100-year time periods [4, 18], as explained in previous study [11], were employed to estimate the overall climate forcing from the NO_x emissions. Due to the long-lived CH_4 perturbation, the radiative forcing calculations for CH_4 become simple because they are well-mixed throughout the atmosphere. Time-integrated CH_4 deficits in ppbv yr are converted into radiative forcing using $0.37\ \text{mW m}^{-2}\ \text{ppb}^{-1}$ [19]. The O_3 forcing calculations used an off-line radiation code taking into account stratospheric temperature adjustment, which reduces the forcing by about 22% [11].

3. Results

3.1. Time Development of CH_4 , OH, and O_3 Burdens from NO_x Emission Pulses

The time behavior of important trace gases associated with NO_x emission pulses shows systematic variations in their mixing ratios according to the reactions below:

- 1) $\text{NO}_2 + \text{O}_3 \rightarrow \text{NO}_3 + \text{O}_2$
- 2) $\text{NO} + \text{HO}_2 \rightarrow \text{OH} + \text{NO}_2$
- 3) $\text{NO}_2 + \text{solar radiation} \rightarrow \text{NO} + \text{O}$

- 4) $\text{O} + \text{O}_2 + \text{M} \rightarrow \text{O}_3 + \text{M}$
- 5) $\text{O}_3 + \text{solar radiation} \rightarrow \text{O}(^1\text{D}) + \text{O}_2$
- 6) $\text{O}(^1\text{D}) + \text{H}_2\text{O} \rightarrow \text{OH} + \text{OH}$
- 7) $\text{CH}_4 + \text{OH} \rightarrow \text{CH}_3 + \text{H}_2\text{O}$

The responses of O_3 and OH mixing ratios in sign to the NO_x emissions strongly depend on the location of the pulses. According to the left panel of top row in Figure 2, shortly after pulses are emitted in January at high latitudes, a decrease in O_3 mixing ratio is observed at the location due to reaction (1) above. This then led to a decrease in OH concentrations (middle panel of row 1) by suppressing reactions (5) and (6), whereas downwind in nearby regions an increase in the transient case is observed. However, at low latitudes, as shown in the last two rows of Figure 2, there is systematic build-up of both O_3 and OH in the region due to high solar radiation, which enhances reactions (2), (3), and (4). The build-up of OH led to a deficit in CH_4 according to reaction (7), which is evident in the last column of Figure 2. These monthly anomalies steadily decay away at the location of the pulses within 2–3 months for O_3 , 4–6 months for OH, and after 6 months for CH_4 . The monthly time development for perturbations resulting from winter pulses is similar to that of summer pulses; however, the latter show the highest magnitude.

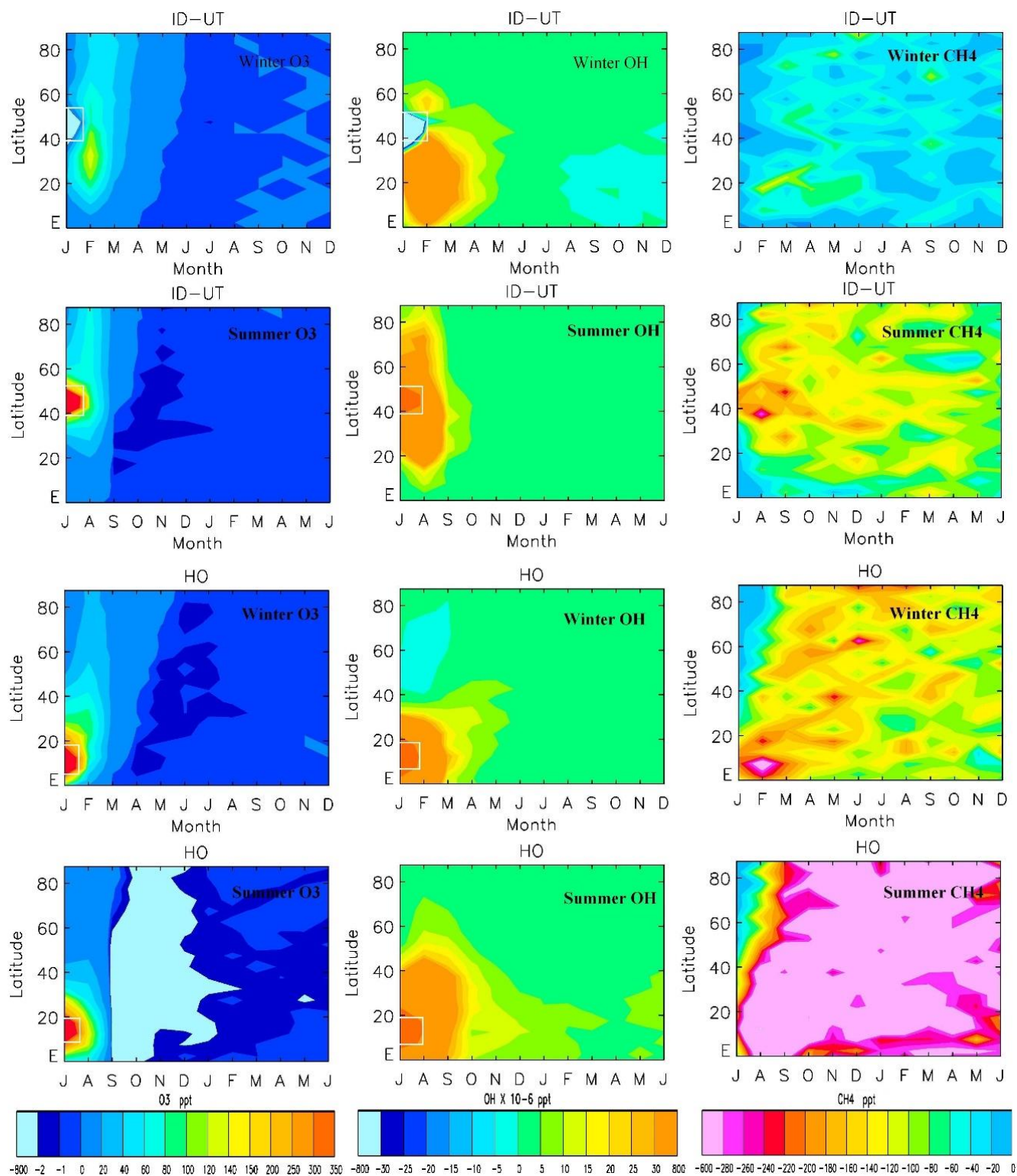


Figure 2. Time development of monthly mean O_3 (left column), OH (middle column), and CH_4 (right column) anomalies. The first two rows from the top are for Idaho pulses in January and July, and the last two rows are for Honduras emission pulses. The white rectangles show the locations of the emission pulses.

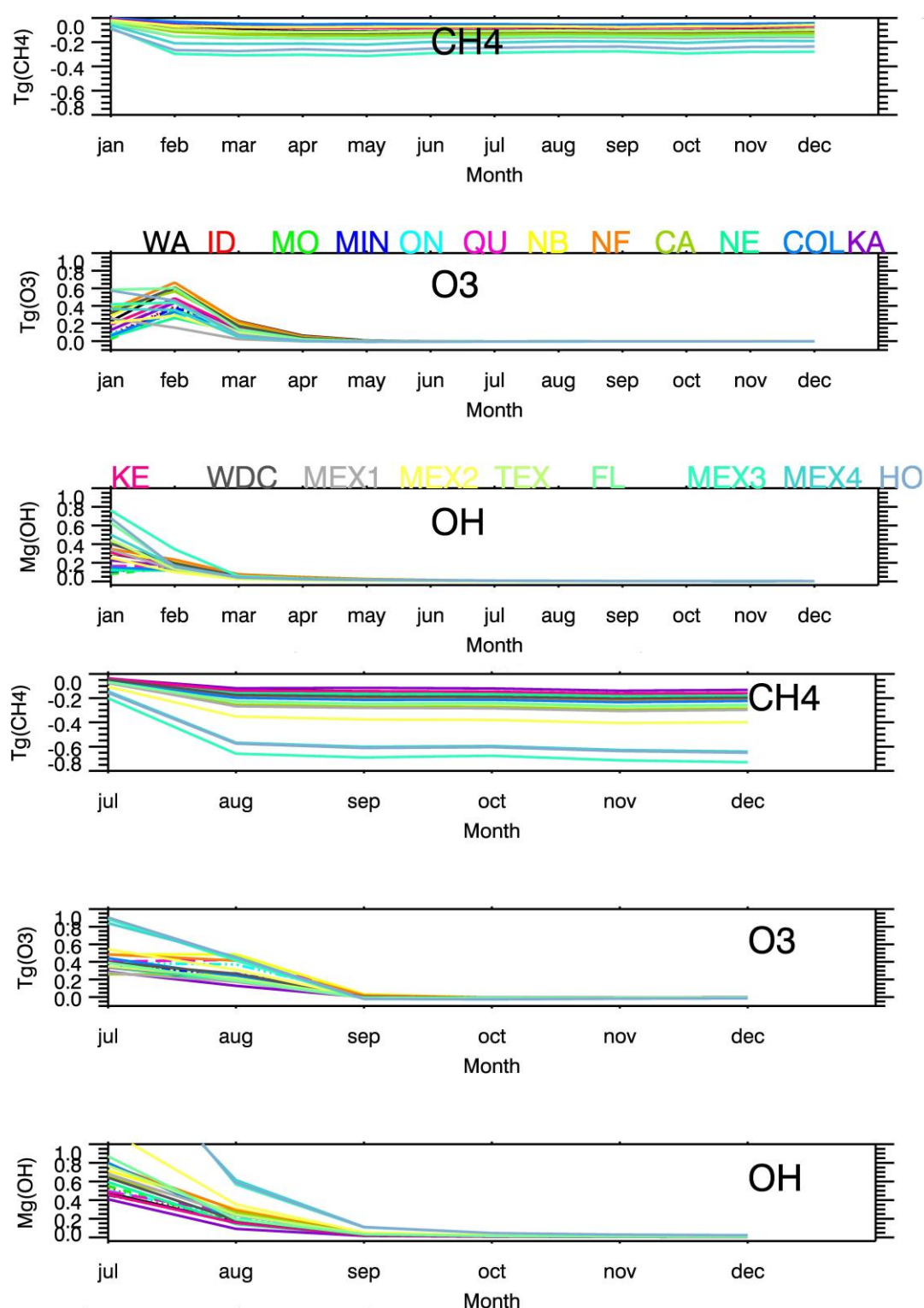


Figure 3. Time development of global CH_4 , O_3 , and OH anomalies due to the NO_x emission pulses. The colors show the various locations of the pulses, ranging from Washington to Honduras. The first three panels from the top are CH_4 , O_3 , and OH anomalies for winter pulses, and the bottom three panels are for summer pulses.

For the globally integrated anomalies shown in Figure 3, the monthly time development of O_3 and OH burdens are somewhat different. Excess O_3 and OH downwind in nearby areas tend to suppress the O_3 and OH deficit observed at high latitudes, leaving positive burdens within the first 6 months

irrespective of the location and season of the NO_x emissions. Excess O_3 burdens peak between 0.2 Tg and 0.9 Tg during the first two months, with the maximum and minimum peaks resulting from July Honduras and January Montana emission pulses, respectively. The peaks then decay rapidly after the

fourth month. The decay continued within the fifth month and produced an O₃ deficit after the sixth month. This deficit remained constant during the rest of the year before decaying. Previous studies have found that this decay is associated with CH₄ deficits and that the O₃ deficit decays with the same 10–15-year timescale as the CH₄ deficit [11]. Anomalies in OH exhibit similar features, with peaks spanning from 0.2 Mg (2.0×10^{-7} Tg) to more than 2.0 Mg (20×10^{-7} Tg). The deficit in the global CH₄ burdens increased steadily to about 0.3 Tg for January pulses and 0.7 Tg for July pulses and stabilized in magnitude during the first 4–6 months before gradually decaying. In all cases, summer emission pulses led to higher perturbations in magnitude compared to winter pulses, highlighting the important role solar radiation plays in tropospheric chemistry.

3.2. Time-Integrated Global Burdens

Time-integrated changes for both CH₄ and O₃ burdens were

calculated due to their impact on radiative forcing. The calculations, expressed in ppbv yr, comprised of two contributions: the first from the initial short-term phase estimated from the model results in the first year; the second from the long-term phase obtained by extrapolating the model results from the end of December 1998 onwards using the CH₄ adjustment time constant of 11.5 years as described in detailed in previous studies [4, 11]. The 11.5 years methane lifetime used were dynamically derived.

For the time-integrated perturbations to the O₃ burdens, the two contribution signs were opposite. A short-term positive, mainly due to the NO_x-driven perturbation and a long-term negative, mainly due to the CH₄-driven perturbation. According to Table 1 (20-year) and Table 2 (100-year), the NO_x-driven O₃ responses spanned from 0.005 ppbv yr to 0.015 ppbv yr for winter pulses and approximately similar magnitudes for summer pulses. In contrast, CH₄-driven O₃ responses spanned a maximum factor of about 8 times less than the NO_x-driven responses for winter pulses and about 3 times less for summer pulses.

Table 1. 20-year integrated perturbations to O₃ and CH₄ resulting from pulses emitted in January (left) and July (right).

Region	D-CH ₄ ppbv yr	D-O ₃ (short) ppbv yr	D-O ₃ (long) ppbv yr
Washington	-0.412, -0.637	0.012, 0.005	-0.002, -0.002
Idaho	-0.227, -0.681	0.007, 0.007	-0.001, -0.003
Montana	-0.211, -0.743	0.006, 0.007	-0.001, -0.003
Minnesota	-0.229, -0.658	0.007, 0.007	-0.001, -0.003
Ontario	-0.203, -0.715	0.006, 0.008	-0.001, -0.003
Quebec	-0.285, -0.733	0.008, 0.009	-0.001, -0.003
New Brunswick	-0.447, -0.862	0.013, 0.011	-0.002, -0.003
Newfoundland	-0.522, -0.893	0.014, 0.010	-0.002, -0.003
California	-0.544, -1.153	0.013, 0.006	-0.002, -0.004
Nevada	-0.222, -0.723	0.005, 0.006	-0.001, -0.003
Colorado	-0.202, -0.933	0.006, 0.007	-0.001, -0.004
Kansas	-0.270, -0.530	0.008, 0.004	-0.001, -0.002
Kentucky	-0.316, -0.636	0.009, 0.006	-0.001, -0.002
Washington DC	-0.456, -0.811	0.012, 0.007	-0.002, -0.003
Mexico 1	-0.653, -1.206	0.005, 0.005	-0.003, -0.005
Mexico 2	-0.279, -1.626	0.006, 0.009	-0.001, -0.006
Texas	-0.430, -1.086	0.011, 0.006	-0.002, -0.004
Florida	-0.623, -1.051	0.015, 0.006	-0.002, -0.004
Mexico 3	-1.159, -2.893	0.010, 0.014	-0.004, -0.011
Mexico 4	-0.802, -2.545	0.008, 0.014	-0.003, -0.010
Honduras	-0.999, -2.582	0.012, 0.014	-0.004, -0.010

Table 2. 100-year integrated perturbations to O_3 and CH_4 resulting from pulses emitted in January (left) and July (right).

Region	D- CH_4 ppbv yr	D- O_3 (short) ppbv yr	D- O_3 (long) ppbv yr
Washington	-0.502, -0.775	0.012, 0.005	-0.002, -0.003
Idaho	-0.277, -0.828	0.007, 0.007	-0.001, -0.003
Montana	-0.257, -0.904	0.006, 0.007	-0.001, -0.003
Minnesota	-0.278, -0.801	0.007, 0.007	-0.001, -0.003
Ontario	-0.247, -0.871	0.006, 0.008	-0.001, -0.003
Quebec	-0.347, -0.892	0.008, 0.009	-0.001, -0.003
New Brunswick	-0.544, -1.049	0.013, 0.011	-0.002, -0.004
Newfoundland	-0.635, -1.087	0.014, 0.010	-0.002, -0.004
California	-0.662, -1.403	0.013, 0.006	-0.003, -0.005
Nevada	-0.270, -0.880	0.005, 0.006	-0.001, -0.003
Colorado	-0.246, -1.135	0.006, 0.007	-0.001, -0.004
Kansas	-0.329, -0.645	0.008, 0.004	-0.001, -0.002
Kentucky	-0.384, -0.774	0.009, 0.006	-0.001, -0.003
Washington DC	-0.554, -0.987	0.012, 0.007	-0.002, -0.004
Mexico 1	-0.794, -1.468	0.005, 0.005	-0.003, -0.006
Mexico 2	-0.339, -1.978	0.006, 0.009	-0.001, -0.008
Texas	-0.523, -1.322	0.011, 0.006	-0.002, -0.005
Florida	-0.758, -1.279	0.015, 0.006	-0.003, -0.005
Mexico 3	-1.409, -3.520	0.010, 0.014	-0.005, -0.014
Mexico 4	-0.975, -3.097	0.008, 0.014	-0.004, -0.012
Honduras	-1.214, -3.143	0.012, 0.014	-0.005, -0.012

Time-integrated perturbations to the CH_4 had the two contributions being negative. Across latitudes (north to south), the time-integrated CH_4 global perturbations spanned from -0.246 ppbv yr to -1.409 ppbv yr for winter pulses and -0.645 ppbv yr to -3.520 ppbv yr for summer pulses (100-year values). On average, the CH_4 response in summer is about 3 times higher in magnitude than that of winter pulses.

3.3. Time-Integrated Radiative Forcings

The radiative forcings resulting from time-and globally integrated perturbations of both O_3 and CH_4 for January and July pulses are shown in Figure 4 (20 year) and Figure 5 (100 year). It is evident that the geographical and seasonal influences on the radiative forcing as a result of the NO_x emission pulses are reasonably significant. The short-term phase showed O_3 radiative forcings ranging from $0.082 \text{ mW m}^{-2} \text{ yr}$ to $0.293 \text{ mW m}^{-2} \text{ yr}$ for January pulses and from $0.123 \text{ mW m}^{-2} \text{ yr}$ to $0.454 \text{ mW m}^{-2} \text{ yr}$ for the pulses in July. The largest forcing was from Honduras ($10^\circ\text{N} - 20^\circ\text{N}$) pulse in July while the smallest was

from Nevada ($20^\circ\text{N} - 30^\circ\text{N}$) pulse in January. The CH_4 -driven O_3 forcings were negative in sign and varied by a factor of approximately 15 from $-0.021 \text{ mW m}^{-2} \text{ yr}$ to $-0.300 \text{ mW m}^{-2} \text{ yr}$ for pulses emitted at Ontario ($40^\circ\text{N} - 50^\circ\text{N}$) and Mexico 3 ($10^\circ\text{N} - 20^\circ\text{N}$), respectively. The radiative forcings induced by CH_4 responses gave values that are approximately in the same order in terms of magnitude with those of NO_x -driven O_3 forcing but opposite in sign. However, the spatial and seasonal distributions of CH_4 forcings are similar to CH_4 -driven O_3 forcings. Spatially, the CH_4 forcings varied through a range from $-0.91 \text{ mW m}^{-2} \text{ yr}$ to $-0.521 \text{ mW m}^{-2} \text{ yr}$ for January pulses and $-0.239 \text{ mW m}^{-2} \text{ yr}$ to $-1.302 \text{ mW m}^{-2} \text{ yr}$ for July pulses. The two peaks are from Ontario emission pulses similar to CH_4 -driven O_3 forcing which also peak with Ontario pulses. The total net forcing of CH_4 and the two O_3 forcing terms (last row) showed completely negative values, assuming completely additivity of the global mean radiative forcing terms because it is assumed that the forcing from one do not significantly affect the efficiency of the forcing of the other due to the relatively small nature of the pulses [4, 11]. This is because

there is a great deal of cancellation between O_3 short-term phase (positive) and CH_4 forcings (negative), therefore the negative values of long-term CH_4 -driven O_3 forcings mainly dominating in the total net forcing values. The total net time-integrated radiative forcings for winter and summer pulses

spanned a factor of 34 and 6, respectively, signifying the high variability in radiative forcings from winter NO_x emission pulses. However, the average summer total net forcing is approximately 4 times higher than winter forcing.

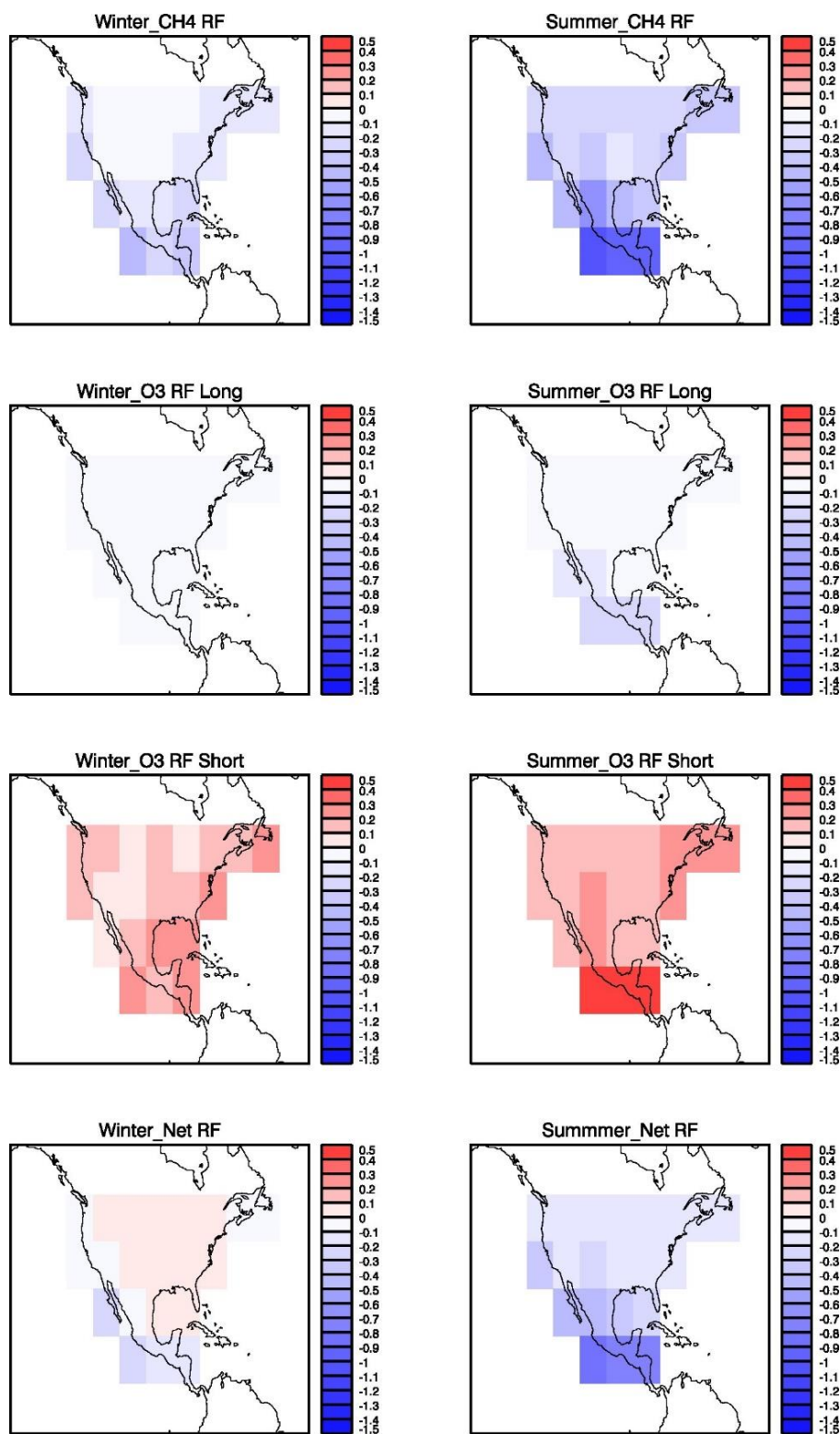


Figure 4. 20-year time-integrated radiative forcing (in $mW\ m^{-2}\ yr$) due to CH_4 (first row), O_3 long-term (second row), O_3 short-term (third row), and total net (fourth row) responses to NO_x emission pulses emitted at all 21 locations in winter (left column) and summer (right column) seasons.

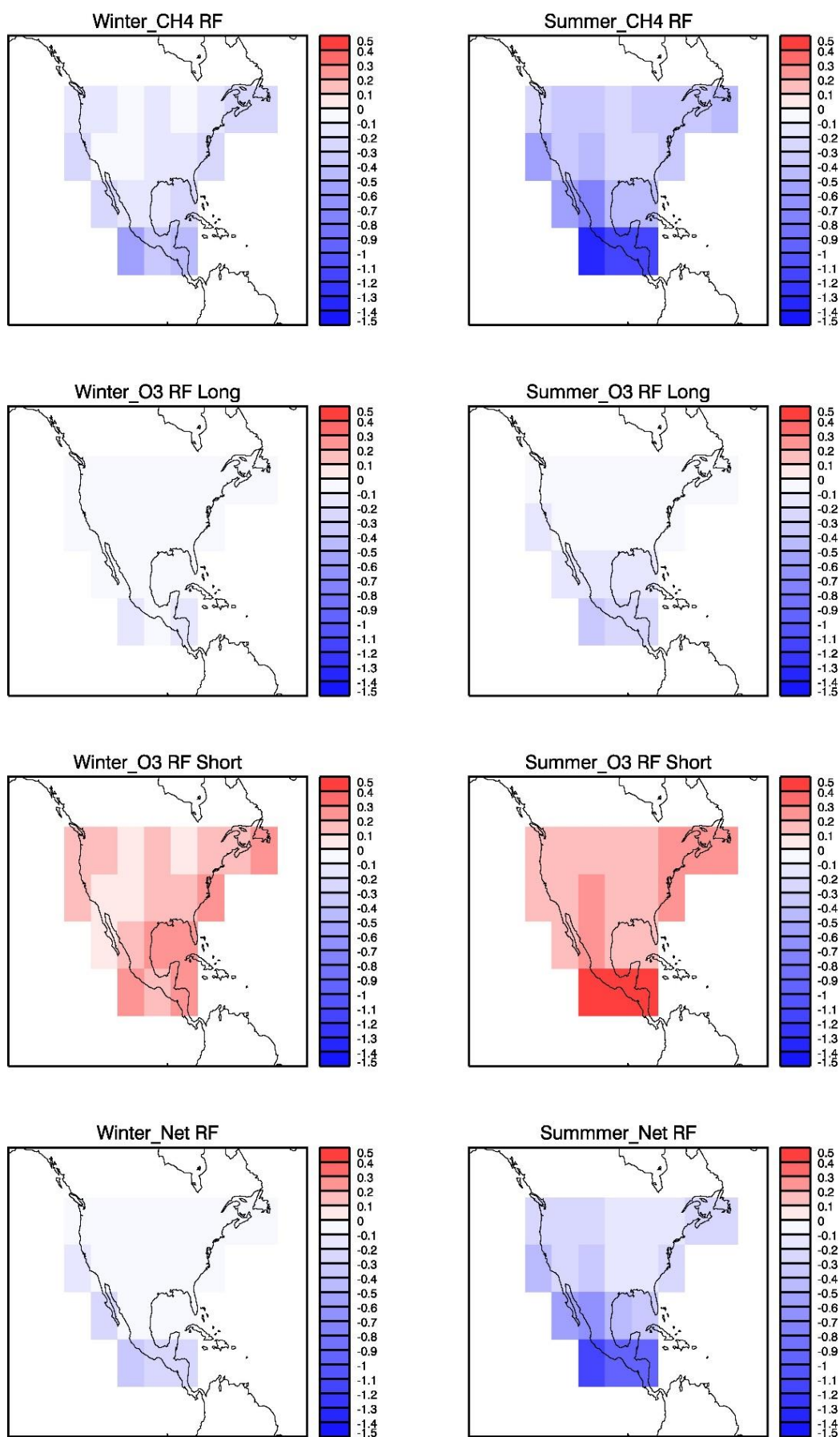


Figure 5. 100-year time-integrated radiative forcing (in $\text{mW m}^{-2} \text{yr}$) due to CH_4 (first row), O_3 long-term (second row), O_3 short-term (third row), and total net (fourth row) responses to NO_x emission pulses emitted at all 21 locations in winter (left column) and summer (right column) seasons.

4. Discussion

Our study demonstrates that the climate impact of NO_x emissions is highly dependent on both emission location and season. The stronger response to low-latitude summer emissions arises from three primary factors: (1) enhanced photochemical activity due to higher solar flux, (2) greater OH production efficiency, and (3) longer atmospheric residence times of secondary pollutants in the warmer tropical troposphere. The latitudinal sensitivity we find is consistent with previous work showing that tropical emission sources have disproportionately large global climate impacts [7, 20].

The temporal evolution of forcing, with initial O₃ warming transitioning to net cooling dominated by CH₄ reductions, has important policy implications. While the short-term positive O₃ forcing occurs rapidly, the long-term negative forcing persists for decades due to the extended lifetime of CH₄ perturbations. This suggests that NO_x emission increases may have a delayed cooling effect that is not immediately apparent.

The results are consistent with IPCC AR6 assessments [22] of short-lived climate forcers, which identify NO_x as an indirect climate forcer exerting a net cooling effect on multi-decadal timescales. The dominance of methane-mediated cooling and the strong dependence on emission latitude and season highlight the need for spatially resolved assessments of NO_x impacts.

5. Conclusions

In this study, we quantified both the spatial and temporal changes in tropospheric O₃ and CH₄ burdens and the associated radiative forcing resulting from emissions of the O₃ precursor NO_x over the North American region. We evaluated the response of O₃ and CH₄ to additions of anthropogenic NO_x emission pulses in both winter and summer for 21 geographical locations. We employed the 3D chemistry-climate model STOCHEM, which has been used in similar experiments over the Asian region [21].

It is evident from our findings that O₃ and CH₄ responses and the associated radiative forcing show both spatial and temporal variations. The responses and forcings reveal a clear latitudinal gradient from north to south, peaking with pulses emitted in the south. We find that from all 21 locations, increases in NO_x emissions led to a deficit in global CH₄ burdens, which in turn resulted in negative forcing (climate cooling). O₃ burdens show short-term excess and long-term deficit. The short-term positive phase, mainly driven by the initial NO_x emissions, led to a positive forcing (climate warming), but decayed after 6 months. The long-term (negative) phase is CH₄-driven and produces a negative radiative forcing (climate cooling). Total net radiative forcing of the CH₄ term and the two O₃ terms from all 21 pulse locations shows a net cooling effect (negative forcings) over 100 years. We also find that July pulses produce a stronger negative (4 times higher) net

radiative forcing compared with January pulses; however, January pulses show the highest variability (a factor of about 34) in net forcing with location.

Critically, over a 20-year time period, some low-latitude winter emission pulses produce net positive forcing, highlighting the importance of time horizon in climate policy analysis. These findings are in agreement with previous studies [20, 21] and suggest that increases in surface NO_x emissions at low latitudes, especially in summer, can have a significant impact on net climate forcings from O₃ and CH₄.

6. Policy Implications

Mitigation strategies targeting NO_x emissions should account for spatial and seasonal heterogeneity. Reductions in regions with high photochemical efficiency can yield disproportionate climate benefits, supporting integrated air quality and climate policies.

Abbreviations

O ₃	Ozone
NO _x & NO _y	Nitrogen Oxides
CH ₄	Methane
OH	Hydroxyl Radical
Tg	Teragram
IPCC	Intergovernmental Panel on Climate Change
CO	Carbon Monoxide
SO ₂	Sulfur Dioxide
H ₂	Hydrogen
UV	Ultraviolet
VOC	Volatile Organic Compounds
IIASA	International Institute for Applied Systems Analysis
NASA	National Aeronautics and Space Administration
EDGAR	Emissions Database for Global Atmospheric Research
ppbv	Parts Per Billion by Volume

Acknowledgments

Computational resources were provided by the Edinburgh Compute and Data Facility (ECDF). We thank Dr. William Collins (UK Met Office), Dr. David Stevenson (University of Edinburgh) and Martin Chipperfield (University of Leeds) for their technical support with STOCHEM.

Author Contributions

Richard Damoah: Data curation, Formal Analysis, Meth-

odology, Visualization, Writing – original draft, Writing – review & editing

Funding

This work was supported by UK Natural Environment Research Council (NERC) Fellowship and National Aeronautics Space Administration (NASA) (Grant No. 80NSSC26K0103).

Data Availability Statement

The model output data supporting this study are available from the corresponding author upon reasonable request. The STOCHEM model code is proprietary to the UK Met Office but may be available for collaborative research under license agreement.

The model output data used in this study are available from the corresponding author upon reasonable request.

Conflicts of Interest

The author declares that he has no competing interests.

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Biography



Richard Damoah is Assistant Professor in the Climate Science Division at Morgan State, International Research Associate at the Latin American Technical University in El Salvador and the Director of All Nations University Space Systems Technology Laboratory in Ghana. He has more than 20 years' experience in chemistry climate modeling, radiative transfer modeling, trajectory modeling, pollution measurement and data analysis with strong programming skills. Before joining Morgan Dr. Damoah had worked at (1) NASA Goddard Space Flight Center in Maryland as Associate Research Scientist under the GESTAR program, (2) University of Waterloo in Ontario, Canada as Research Fellow and (3) University of Edinburgh in UK as a Postdoc. Dr Damoah graduated with Bsc in Physics at University of Cape-Coast in Ghana, Msc in Environmental Physics at University of Bremen in Germany and PhD in Natural Sciences specializing in Air Pollution Transport Modeling, at Technical University of Munich also in Germany.

Research Field

Richard Damoah: Air Quality, Climate Change, Climate Modeling, Climate and Public Health, Atmospheric Pollution, Air Pollution Transport, Atmospheric Trajectory Modeling