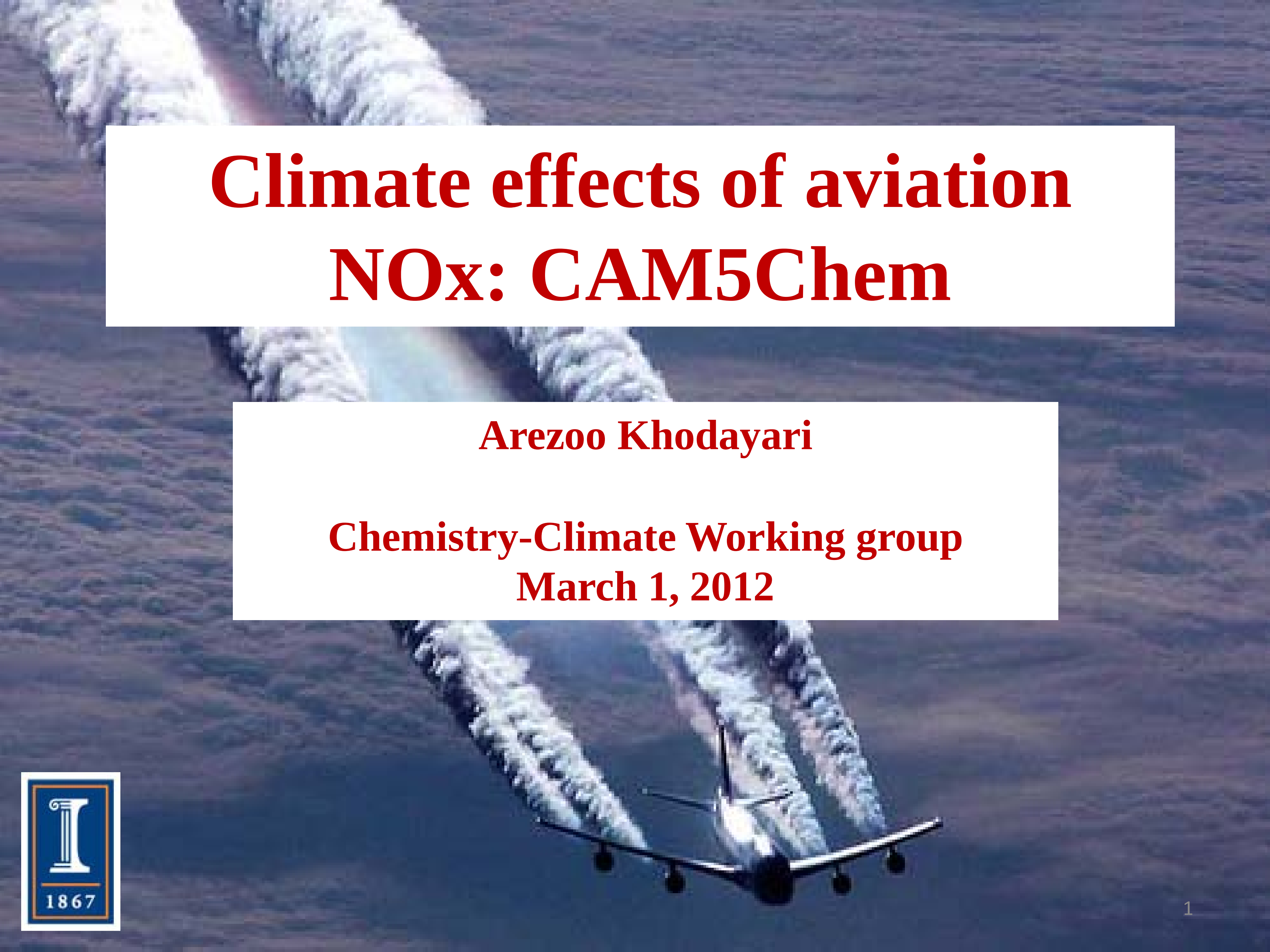

Climate effects of aviation NOx: CAM5Chem

Arezoo Khodayari

Chemistry-Climate Working group
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NCAR Scientists: Dr. Simone Tilmes , Dr. Jean-Francois Lamarque, Dr. Francis Vitt and Dr. Andrew Gettelman

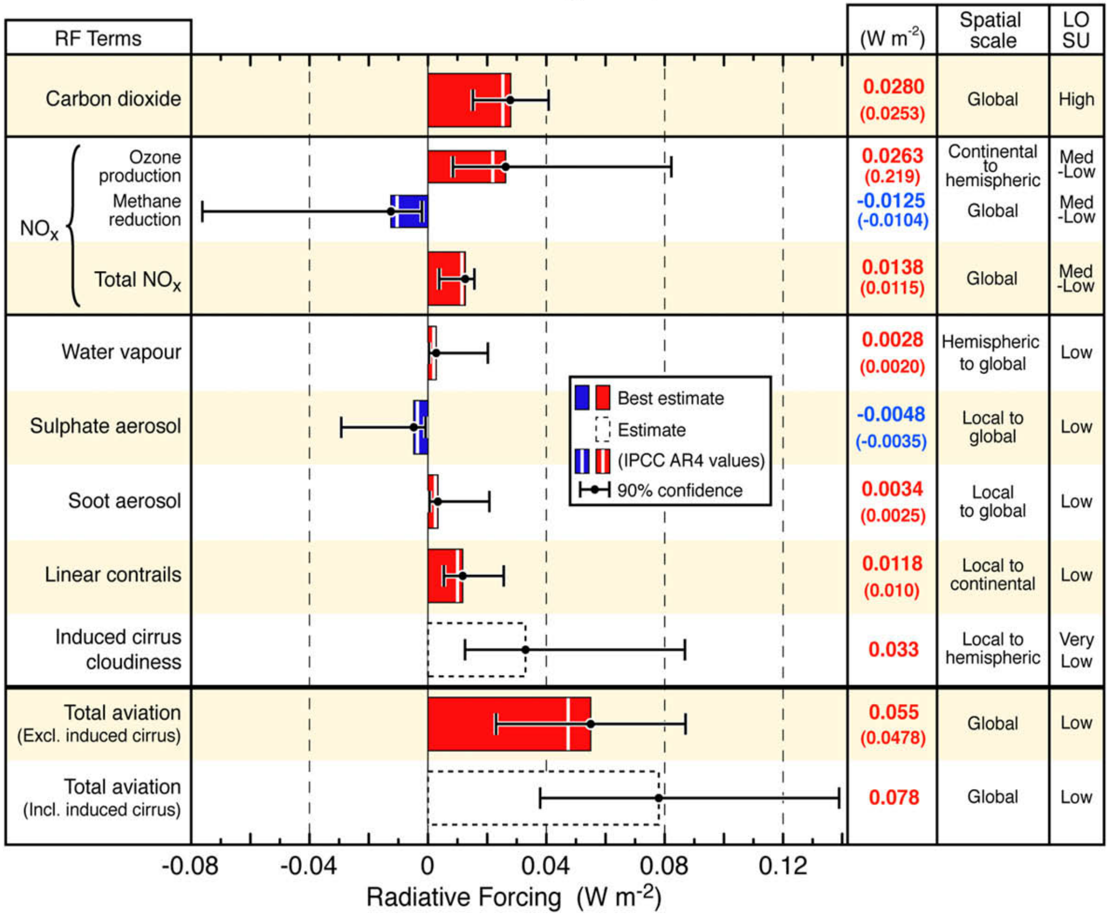
PhD advisor: Professor Donald Wuebbles

Dr. Seth Olsen and Dr. Kenneth Patten

Aviation Climate Effects

Aircraft emissions and climate change

Aviation Radiative Forcing Components in 2005



Aviation contributed approximately 3.5% (5%) of the total human-made radiative forcing (RF) on climate for the year 2005, excluding (including) effects on cirrus clouds

Aviation radiative forcing in 2005 [Lee et al., 2009]

CAM5chem Study: Climate effects of aviation NOx Motivation and Objectives

Large uncertainty in the net RF associated with aviation NOx emissions:

Level of scientific understanding : “medium-low”

Use 3-D Community Earth System Model (CESM) model, CAM5-chem to quantify the aviation NOx effects on climate. The results from this study are going to be further used to update the representation of aviation NOx effects in SCMs.

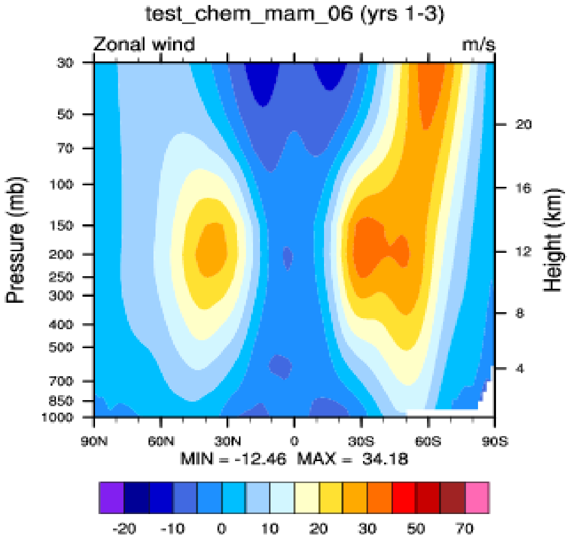
Relevant Improvements in CAM5chem

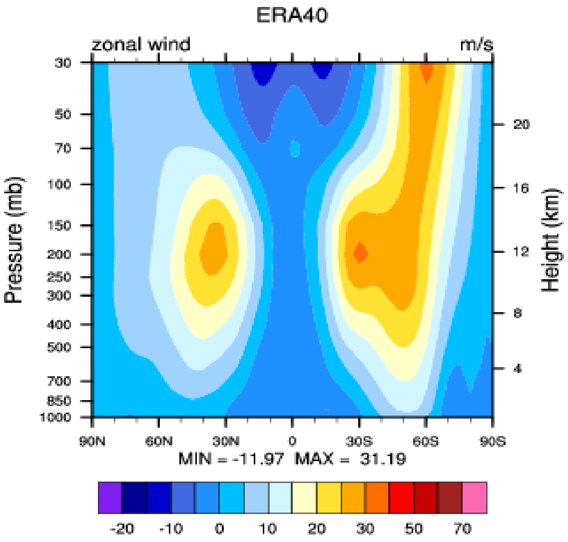
- Enhancement in physical parameterizations that makes it possible to simulate aerosols-cloud interactions such as cloud droplet activation by aerosol, precipitation processes due to particle size dependence and explicit radiative interaction of cloud particles. 3-modal distribution for secondary organic aerosols and sulphate aerosols, bulk treatment for black carbon. Addition of Convective Momentum Transport (CMT) to adjust to the deep convection algorithm, transition to the finite volume dynamical core.

http://www.cesm.ucar.edu/models/cesm1.0/cam/

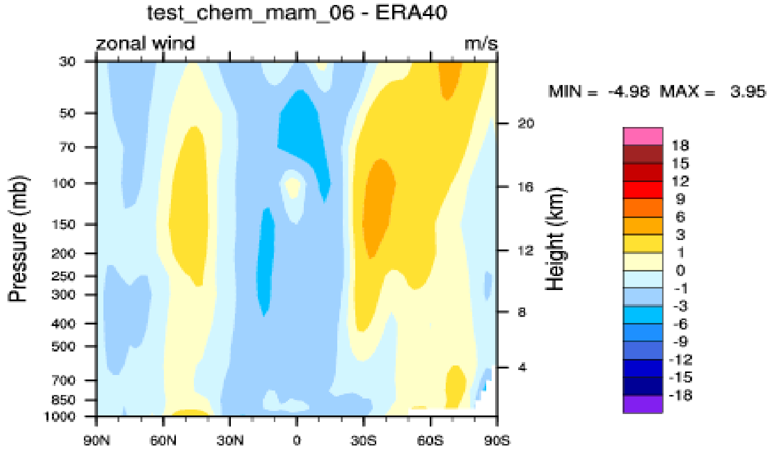
Model Evaluation
Dynamic Diagnostic Tests

Zonally-averaged CAM5-chem modeled zonal winds compared to ERA40 1980-2001 Reanalysis





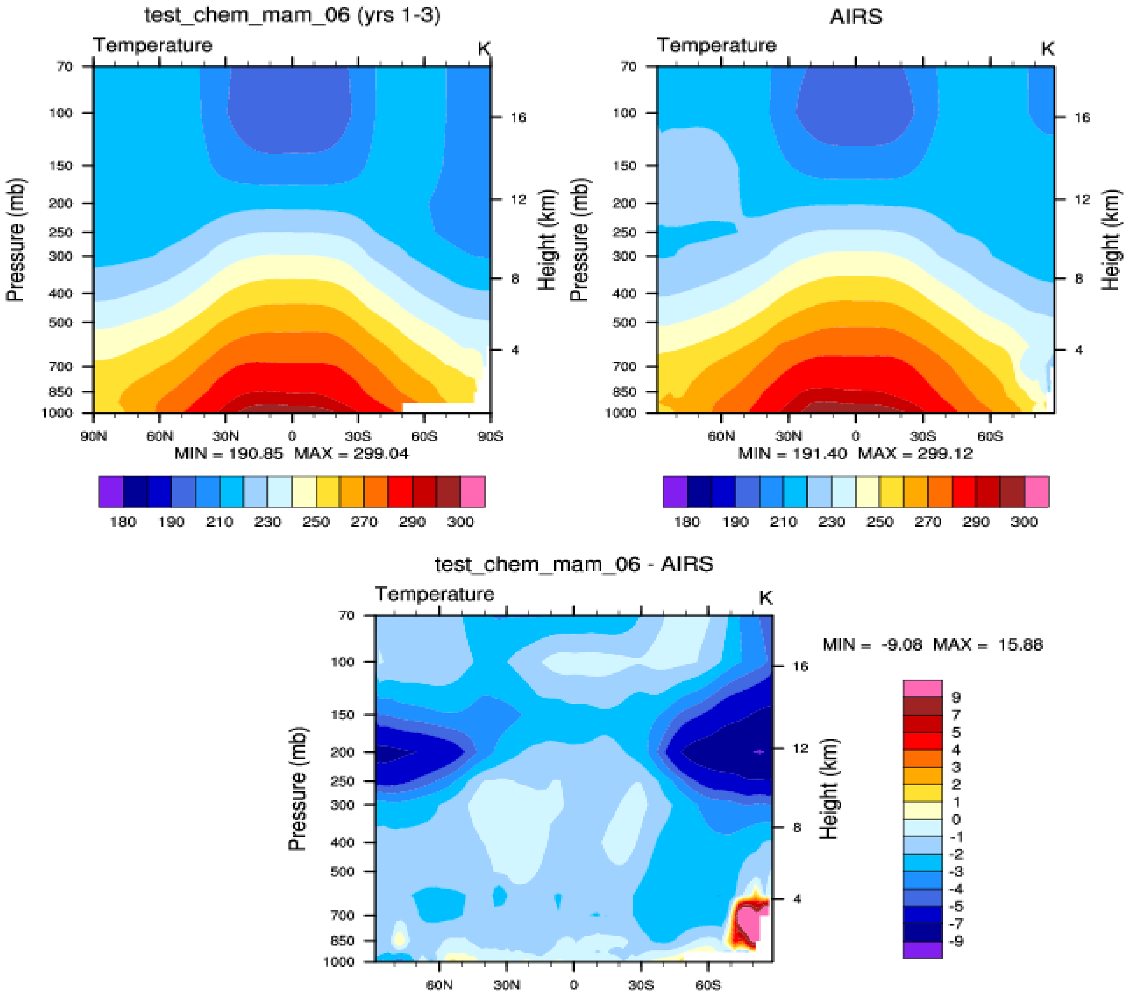
Model agrees well with reanalysis



ERA-40: reanalysis of meteorological observations from September 1956 to August 2002, conducted by the European Centre for Medium-Range Weather Forecasts

Model Evaluation
Dynamic Diagnostic Tests

CAM5-chem modeled zonally-averaged temperatures compared to AIRS IR 2002-06 Sounder

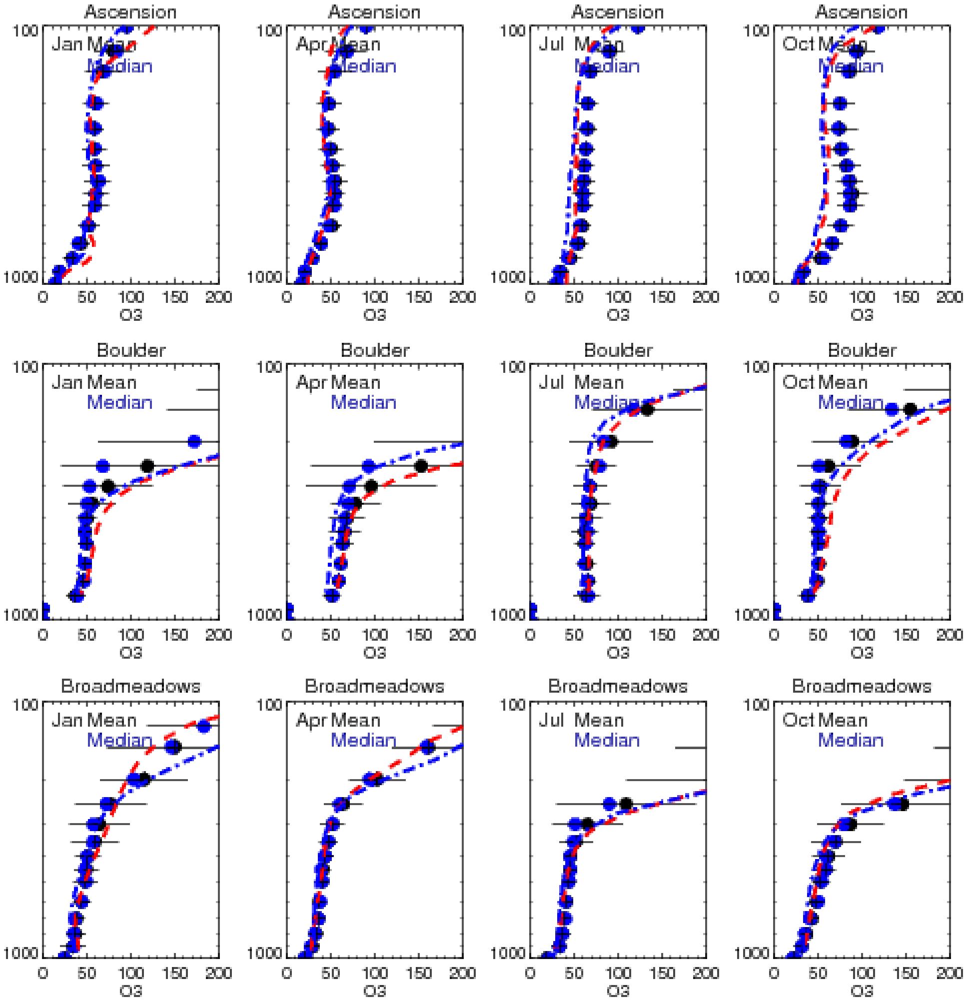


Model agrees well with reanalysis

Model Evaluation

Chemistry Diagnostic Tests

CAM5-chem modeled O_3 compared seasonally to O_3 sondes data for Ascension, Boulder and Broadmeadows stations

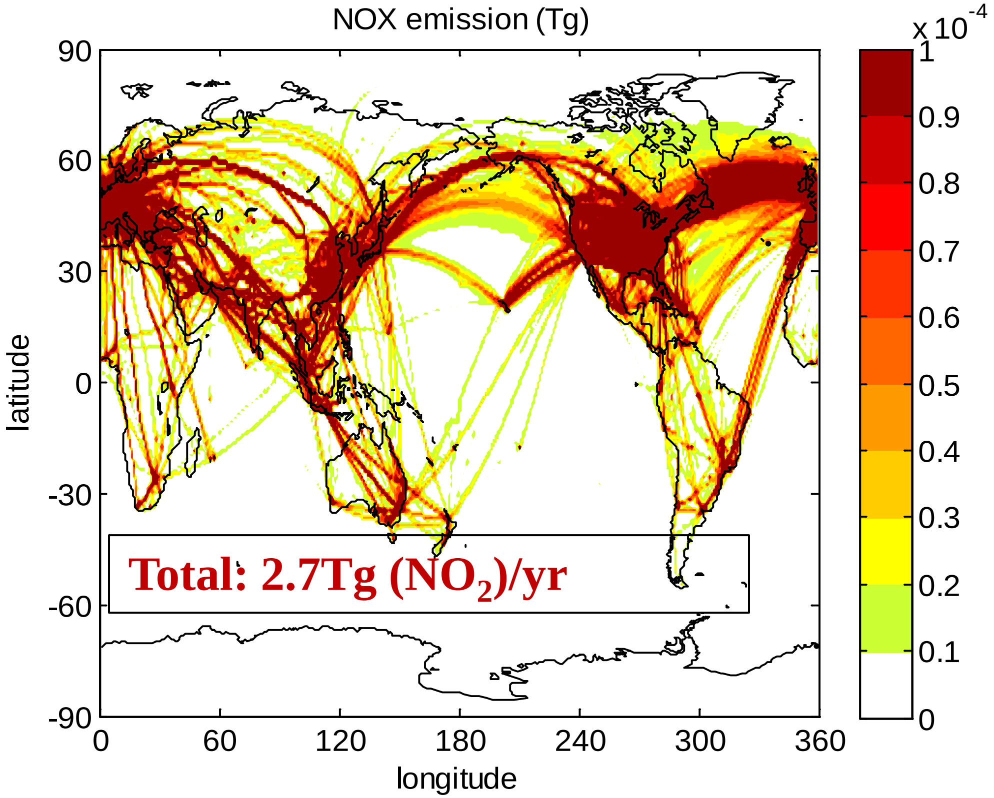


O_3 profiles are well reproduced

2006 Aircraft Emission Inventory

Regional mass distributions of aviation NOx emissions

1° latitude by 1° longitude by 150 m



Total: 2.7Tg (NO_2)/yr

Simulations

5 years spin up to get the chemistry right

Two 10-year simulations: one simulation considered all NOx emissions including aviation NOx, and the other simulation had no aviation NOx

Aviation Climate Change Research Initiative year 2006 hourly emissions

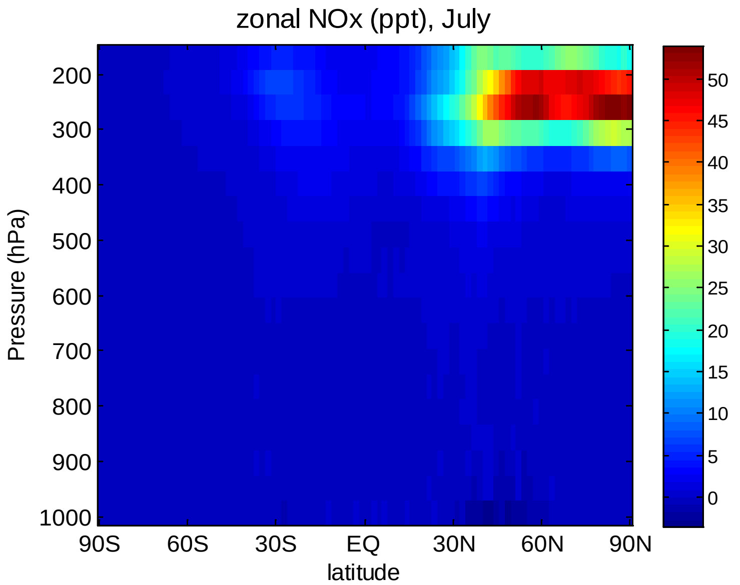
1.9° lat × 2.5° lon, 30 levels, top ~ 40 km

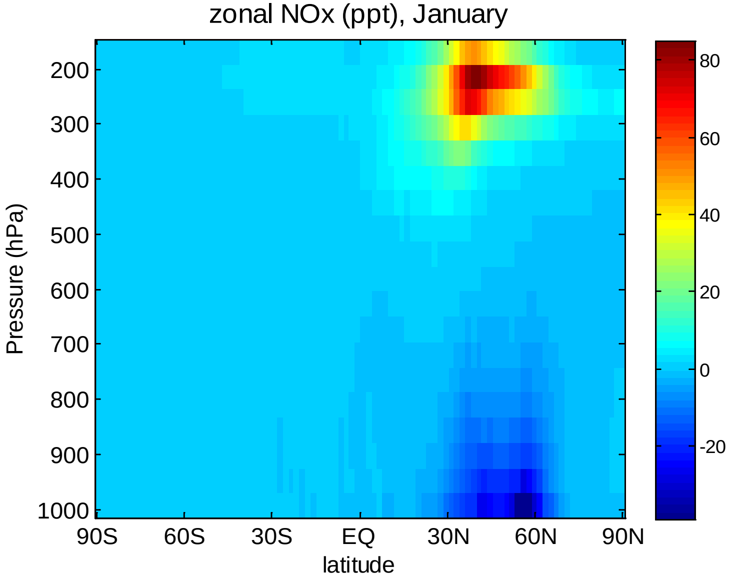
Mode: specified dynamics; Present day CAM5 climatology

Specified dynamic mode advantages over a free mode:

(1) possible to pick out aviation signal
(2) consistent simulations between the two runs
(3) calculated effects are just due to the changes in chemistry and are not impacted by the changes in dynamic

Monthly Zonal Mean Perturbations of NOx (pptv) Caused by 2006 Aviation NOx Emissions





At high altitude:

*more actinic flux at high latitude,
more O(1D) to oxidize H_2O and produce OH

*Higher OH in July
$NO_2 + OH + M \rightarrow 2\ HNO_3 + M$
=>Less NOx perturbation compared to Jan

Near the surface:

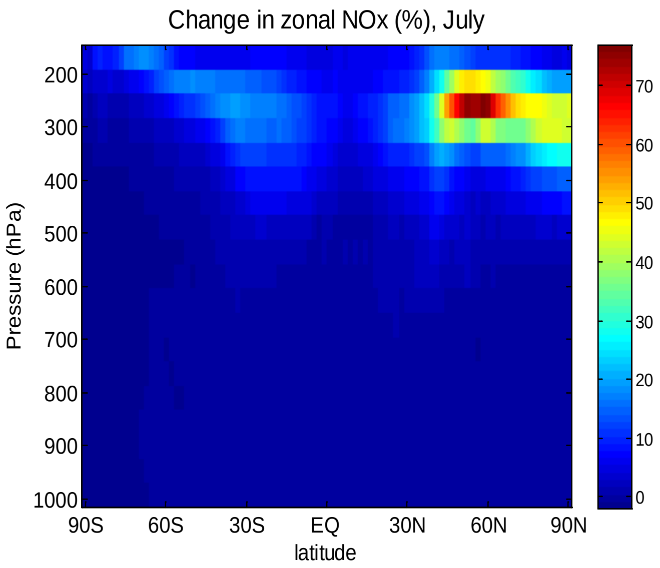
* ozone perturbation propagated to the surface can react with background NOx
*less actinic flux at high latitude in Jan, less photolysis of NO_3 back to NO_2
$NO_2 + O_3 \rightarrow NO_3$

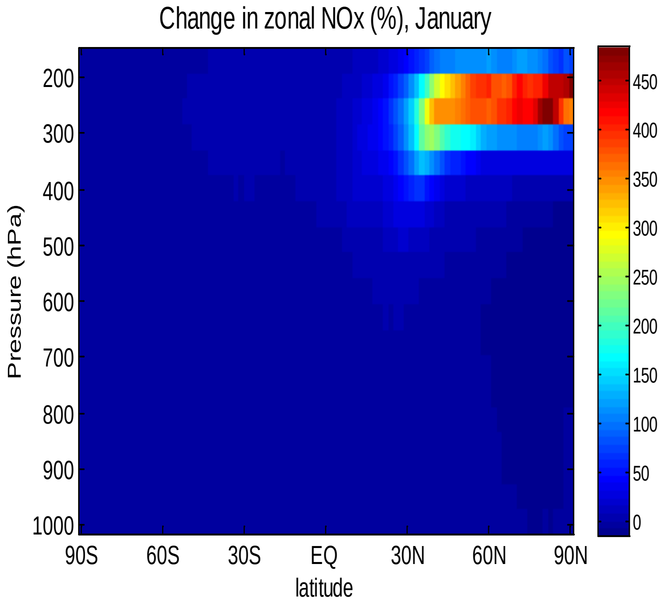
$NO_3 + NO_2 \rightarrow N_2O_5$
More aerosols near the surface and between 30-60^o N; heterogeneous reactions on aerosols:

$N_2O_5 \rightarrow 2\ HNO_3$
$NO_3 \rightarrow HNO_3$
$NO_2 \rightarrow 0.5 * (OH + NO + HNO_3)$

=> Higher decrease in pre-existing NOx compared to July

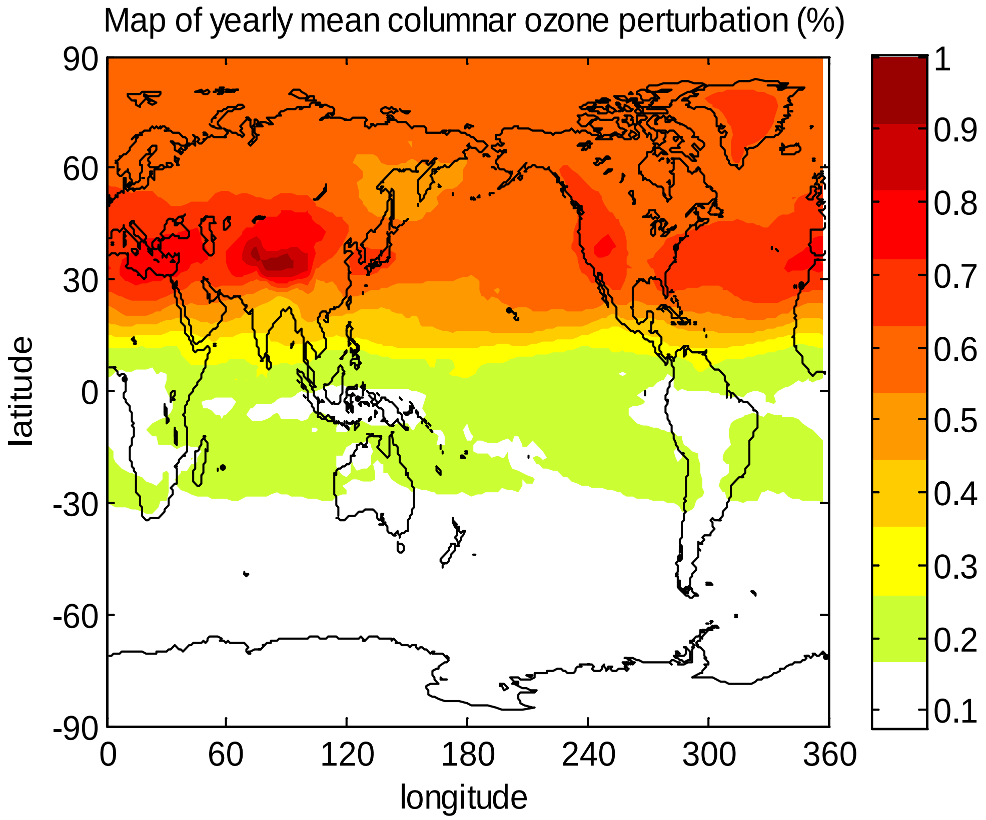
Monthly Zonal Mean Perturbations of NOx (%) Caused by 2006 Aviation NOx Emissions


Change in zonal NOx (%), July


Change in zonal NOx (%), January

- Lower background NOx at the cruise altitude in January as air is more stable =>higher aviation perturbation relative to background
- Higher background NOx near the surface in January which makes it hard to see the NOx decrease near the surface in a relative term, but it was noticeable in previous slide (absolute change in NOx)

Yearly Mean Perturbations of Ozone Column (ΔDU, Change in Ozone in Dobson Units) due to 2006 Aviation NOx


Map of yearly mean columnar ozone perturbation (%)

Peroxy radicals (RO_2 and HO_2) produced through CO and VOC oxidation react with NO:

$HO_2 + NO \longrightarrow OH + NO_2$

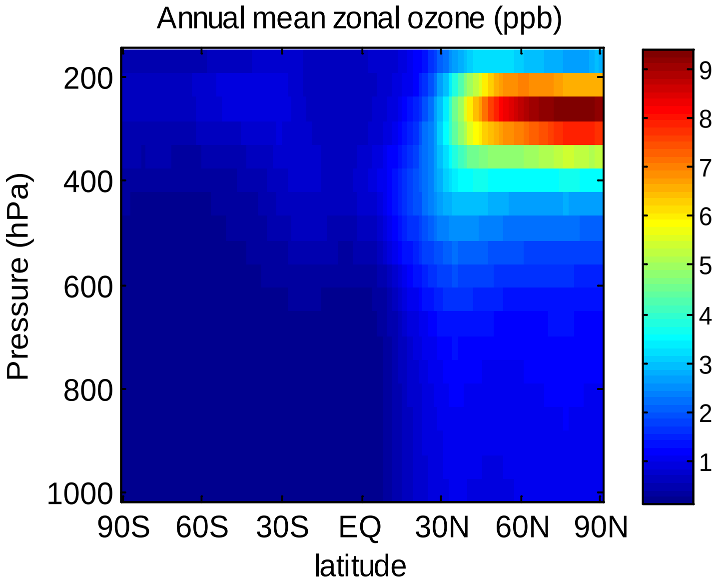
$NO_2 + h\nu \longrightarrow NO + O$

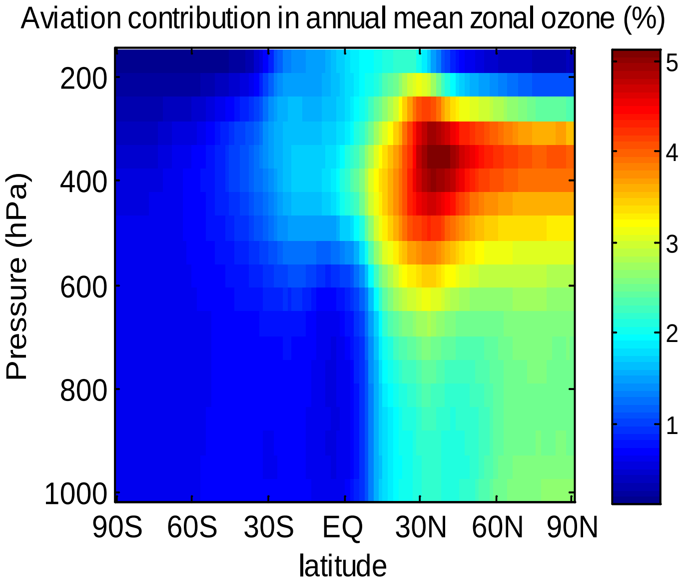
$O + O_2 + M \longrightarrow O_3 + M$

maximum of 1% change in columnar ozone that is equivalent to 2.5 Dobson Unit change in column O_3

Dobson Unit (DU) that is a measure of the columnar density of ozone overhead.

Annual Average Zonal Mean Perturbations of Ozone (ppbv) Caused by 2006 Aviation NOx

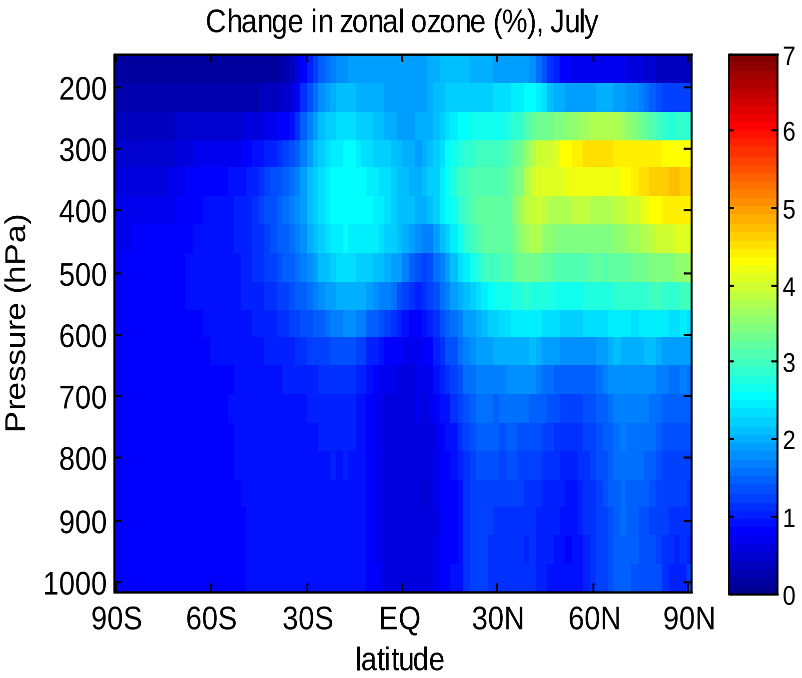

Annual mean zonal ozone (ppb)

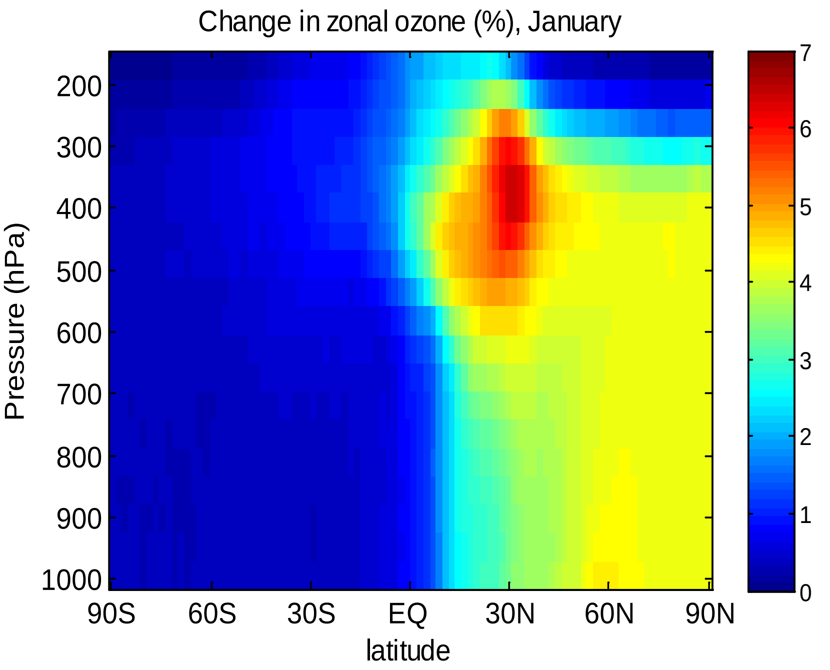

Aviation contribution in annual mean zonal ozone (%)

Maximum north of 30°N and between 200-300 hPa where most of the flights operate.

Maximum change in zonal mean ozone concentration of about 10 ppbv that corresponds to about a 5% of background O_3.

Monthly Zonal Mean Perturbations of Ozone (ppbv, %) Caused by 2006 Aviation NOx Emissions


Change in zonal ozone (%), July

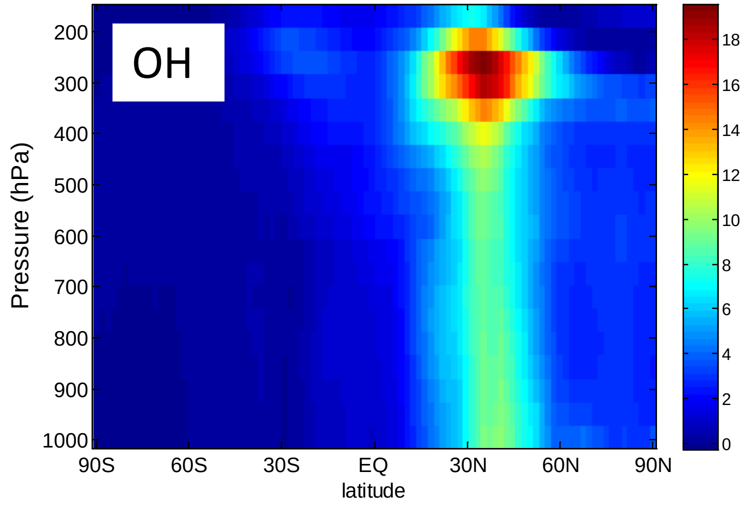

Change in zonal ozone (%), January

O_3 reach a maximum of about 5% change in July and a maximum of about 7% change in January.

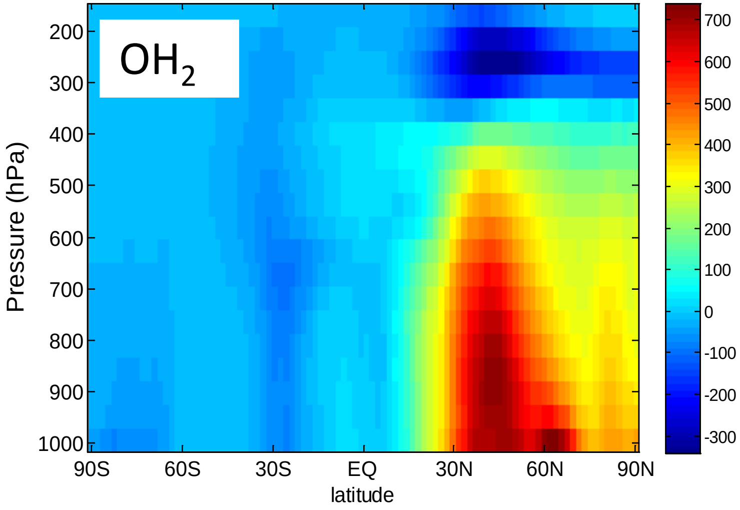
Higher in July in relationship to the available sunlight for photochemistry.

Annual Average Zonal Mean Perturbations of OH and HO_2 (Δmolecules/cm^3) Caused by 2006 Aviation NOx Emissions

Aviation contribution in annual mean zonal OH (10^4 Δmolecules/cm^3)



Aviation contribution in annual mean zonal HO_2 (10^4 Δmolecules/cm^3)



There is up to 27% increase in OH relative to background (~3 times the O_3 perturbation)

There is an increase in OH at cruise altitude:

$O_3 + h\nu \longrightarrow O_2 + O(^1D)$

$O(^1D) + M \longrightarrow O + M$

$O(^1D) + H_2O \longrightarrow 2OH$

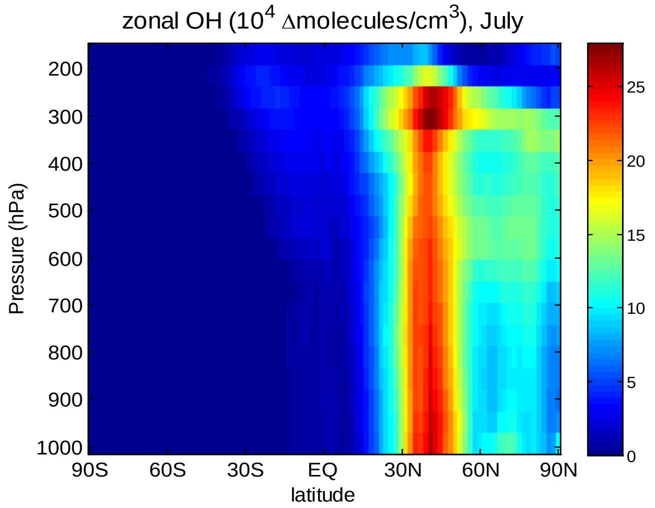
Increase in OH below cruise altitude due to O_3 transport

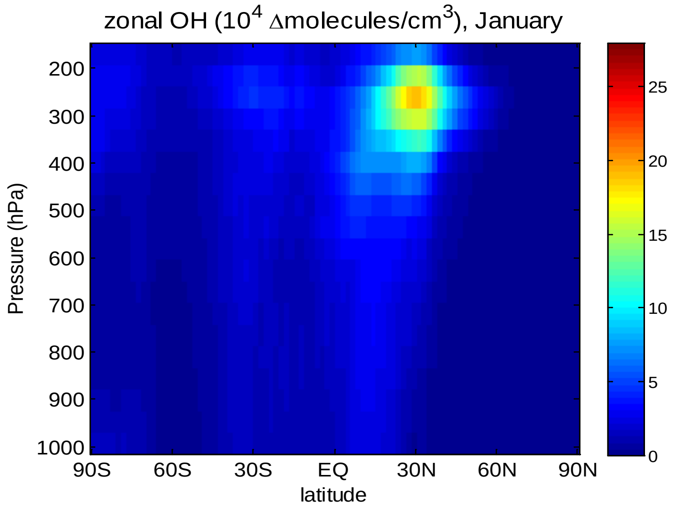
and decrease in HO_2 at cruise altitude: dominant reaction:

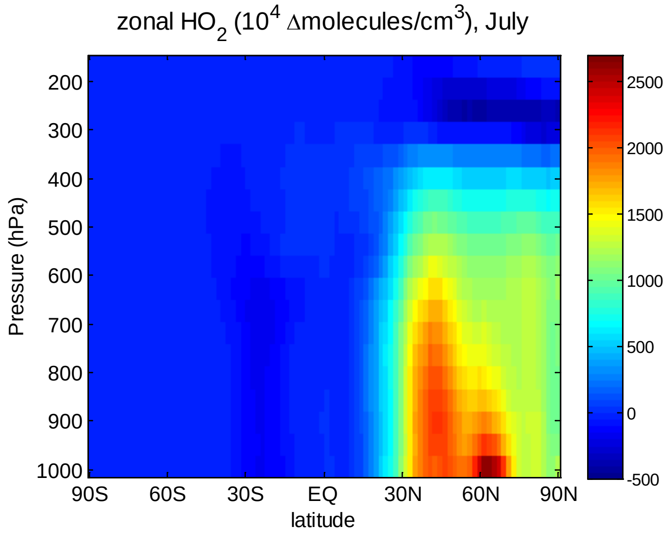
$HO_2 + NO \longrightarrow OH + NO_2$

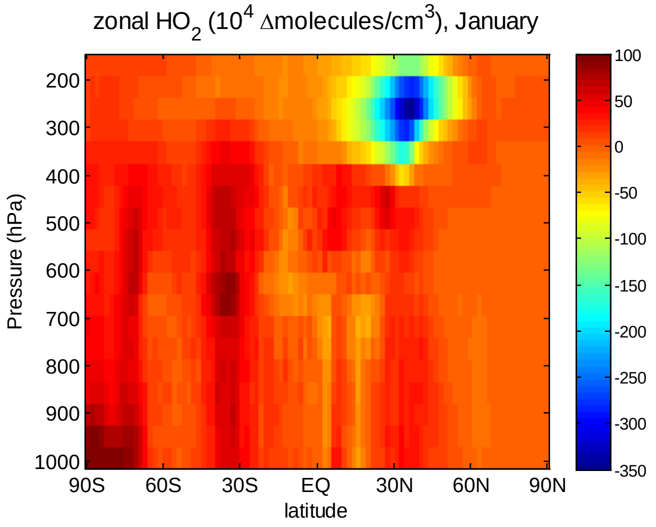
and increase in HO_2 below cruise altitude due to higher H_2O mixing ratio and higher produced OH, and higher tropospheric CO and VOC that reacts with OH and through oxidation result in higher HO_2

Monthly zonal mean perturbations of OH (Δmolecules/cm^3) caused by 2006 aviation NOx


zonal OH (10^4 Δmolecules/cm^3), July


zonal OH (10^4 Δmolecules/cm^3), January


zonal HO_2 (10^4 Δmolecules/cm^3), July


zonal HO_2 (10^4 Δmolecules/cm^3), January

Changes in Methane Lifetime due to Aviation NOx Emissions

(1) find the change in methane concentration using Fuglestvedt et al. [1999] equation :

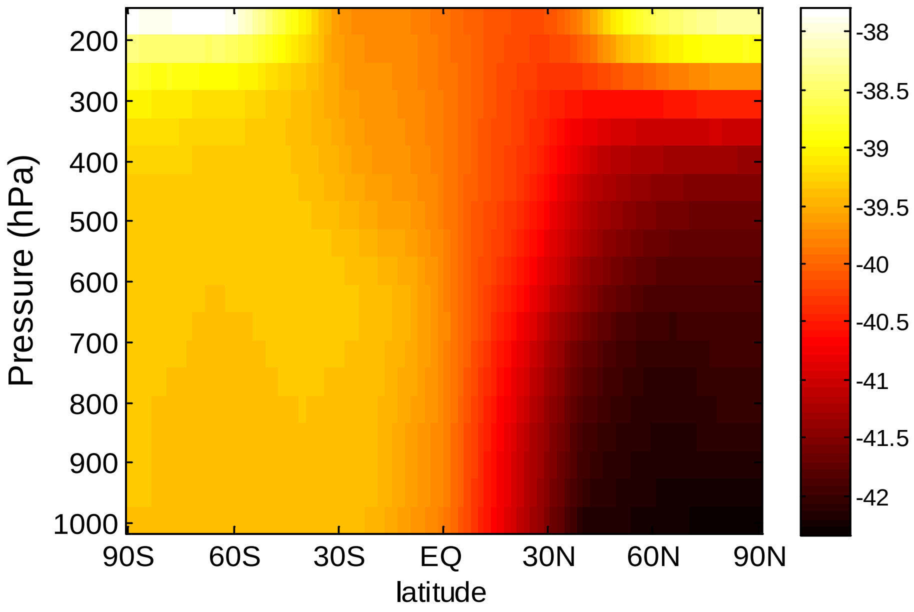
$[CH_4]_{ss} = [CH_4]_{ref} \times (1\text{-}1.4\times\Delta\tau_0/\Delta\tau_{ref})$

where $\Delta\tau_0 = \Delta\tau_{per} - \Delta\tau_{ref}$

$[CH_4]_{ref:}$ global annual mean methane concentration in reference run with no perturbation

$[CH_4]_{ss:}$ steady state global annual mean CH_4 concentration due to perturbation

Perturbation in zonal annual mean CH_4 (ppb)



1.64% decrease in CH_4 lifetime due to the year 2006 aviation NOx emissions

Hoor et al. [2009] reported 1.04(±0.40)% decrease in CH_4 lifetime due to the year 2000 aviation NOx emissions

Key Findings

- Maximum change of about 55 ppt in zonal mean NOx in July and about 80 ppt in Jan
- Up to 40 ppt decrease in NOx near the surface between 30-60^o N in Jan

- Maximum annual mean zonal ozone increase of ~ 5.2% (~ 9 ppb)
- 4.8% in CAM4chem
- ~ 10 ppb for 7.3 Tg NO_2 in the year 2050 from Sovde et al. [2007]
- ~ 7% for 7 Tg NO_2 in the year 2050 from Grewe et al. [1999]

- Maximum annual mean zonal OH increase of ~ 27%

- 1.64% decrease in CH_4 lifetime, excluding CH_4 feedback on its lifetime; 1.04(±0.40)% decrease in Hoor et al. [2009] study; in response to 2.2 Tg NO_2
- 1.3(±0.30)% decrease in Hodnebrog et al. [2011] study; in response to 2.7 Tg NO_2