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ATTICA

From the exhaust to ozone production and methane destruction

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With contributions from
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Impact of NOx emission on ozone and methane

Contribute to RF through:

Chemical formation of the secondary compound O_3
Reduction in CH_4 through reduced lifetime

Impact of NOx emission on O_3 (Ozone production):

$$NO + HO_2 \rightarrow NO_2 + OH$$
$$NO_2 + \text{UV-light} \rightarrow NO + O$$
$$O + O_2 + M \rightarrow O_3 + M$$

Impact of NOx emission on CH_4 (Reduced lifetime through formation of the hydroxyl radical (OH)):

$$NO + HO_2 \rightarrow NO_2 + OH$$
$$CH_4 + OH \rightarrow CH_3 + H_2O$$

Increased climate effect from O_3, reduced climate effect from methane

Aircraft emissions in the UTLS region where impact on composition and radiative forcing (RF) could be significant. Ship emissions in prestine background regions.

Emissions from aircraft and ship not included in the Kyoto protocol, but significant reductions possible

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Key reactions for ozone and methane perturbations from Nox emissions

Ozone distribution

- NOx ➔ O_3 occurs at cruise altitudes (in the UTLS region, 10 to 12 km)
- Ozone has long lifetime and is transported to other latitudes and altitudes

Formation and loss of OH

- $NO + HO_2$ ➔ $NO_2 + OH$
- $CO + OH$ ➔ $CO_2 + H$ (main loss reaction for CO and OH)
-

NOx emission from aircraft

CO is reduced aloft, trsp to low altitudes and latitudes, where OH is affected ➔ methane reduction (IPCC, 1999)

Emission index for aircraft:

NO_2 ~ 14 g/kg fuel, CO ~ 4 g/kg fuel

Large NOx emissions from ships

Surface emissions:

CO/NOx ~ 10, higher in biomass emissions

Aircraft and ship emissions have significant impact on OH (increase), and on methane (rerductions)

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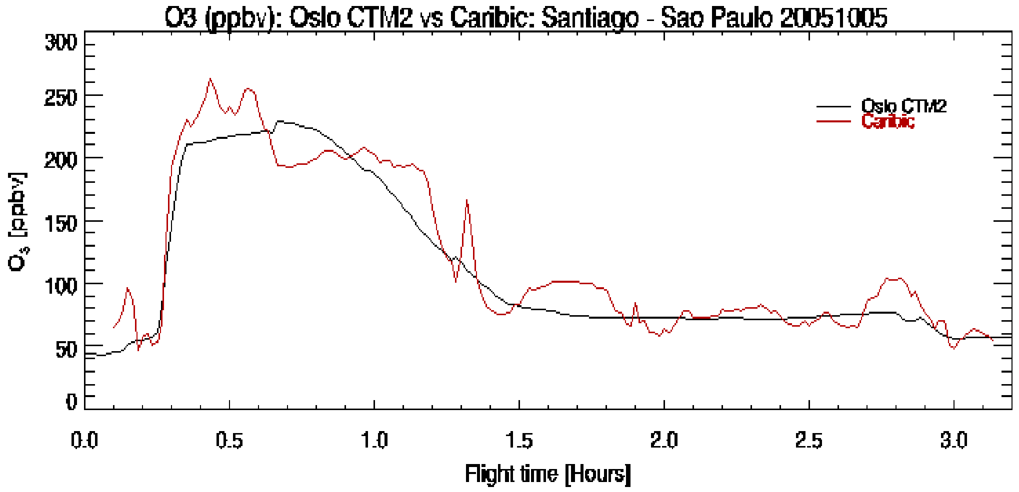
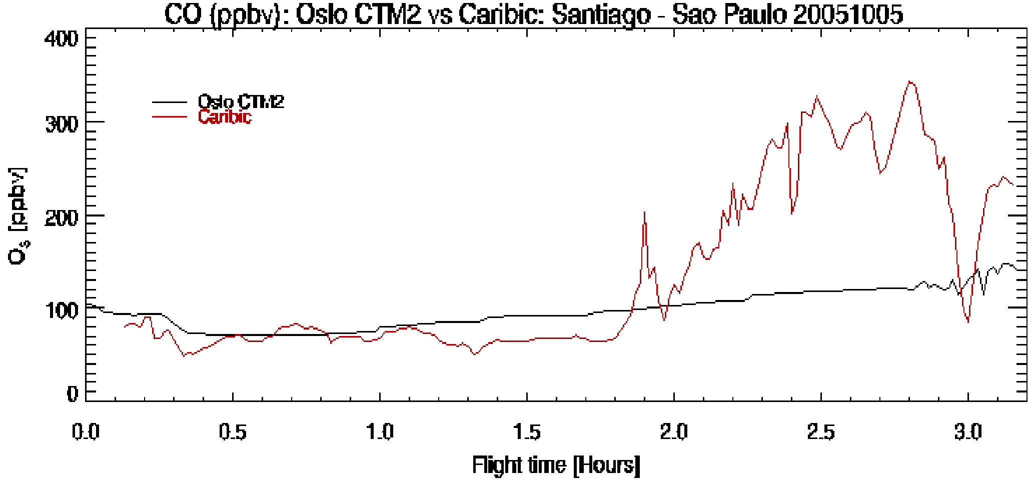
Comparison with observations on the UTLS region

Oslo CTM2 vs CARIBIC for O3 & CO



The model represents the UTLS ozone distribution well along flight tracks



The disagreement between model calculation and observation is probably due to underestimated biomass CO emissions

Could affect estimates of OH

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Comparisons of ozone columns

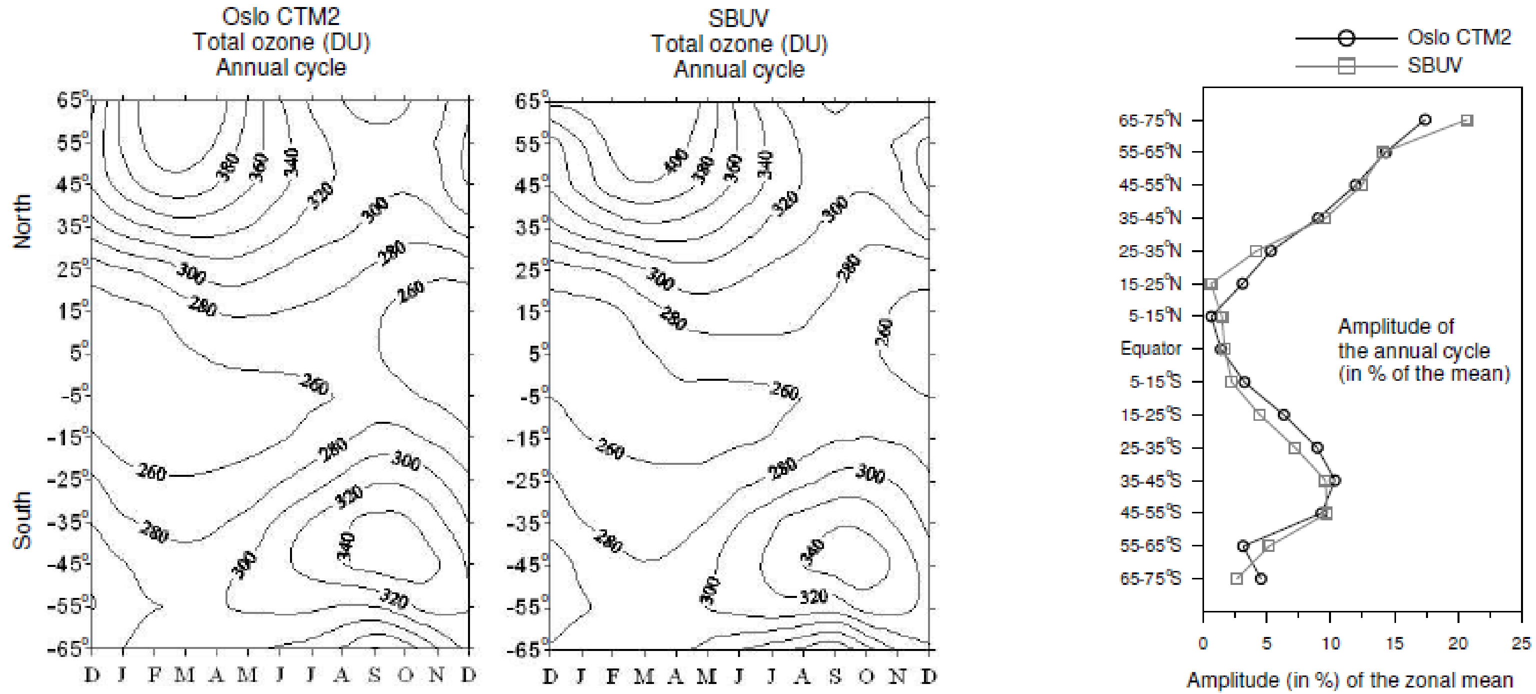
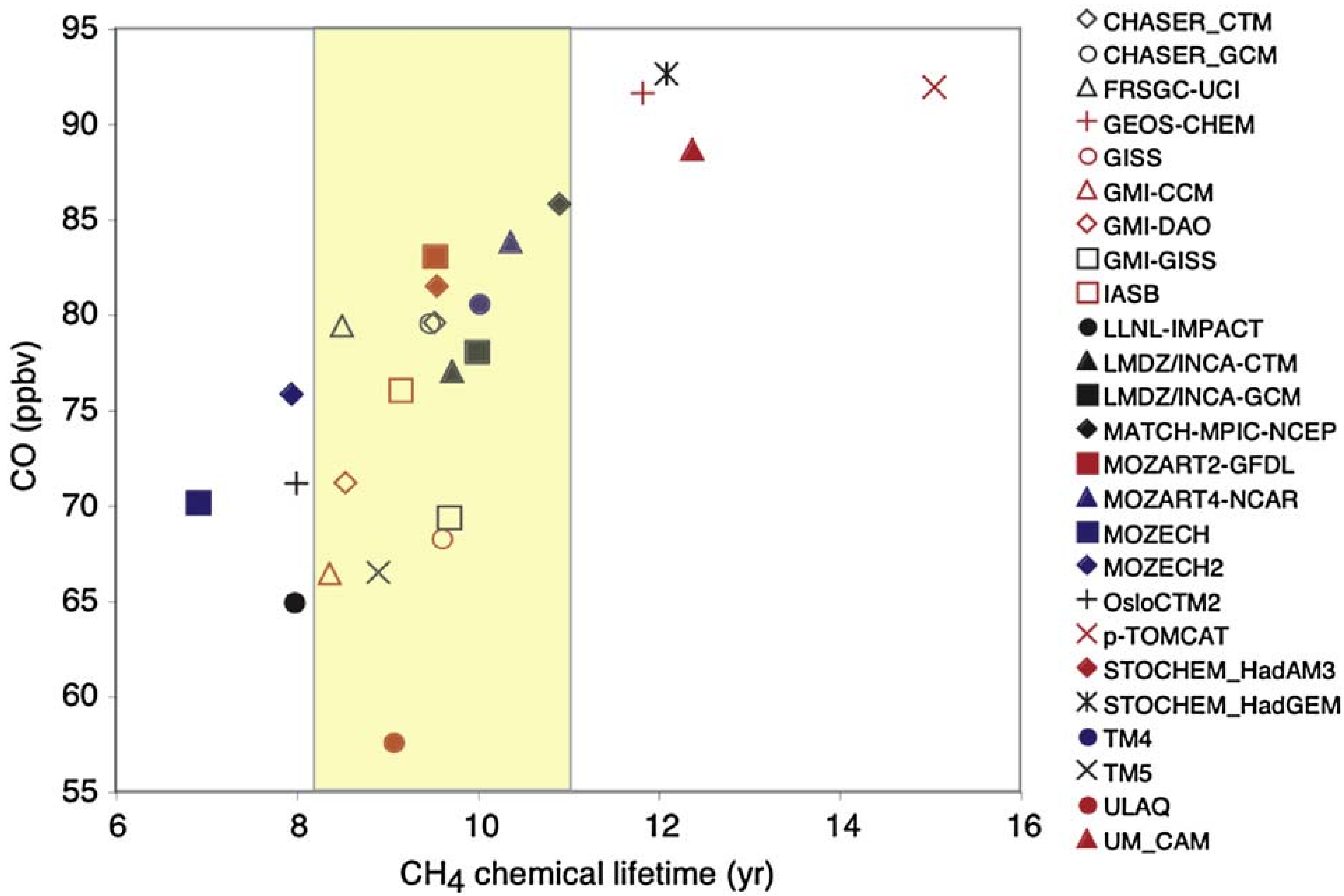


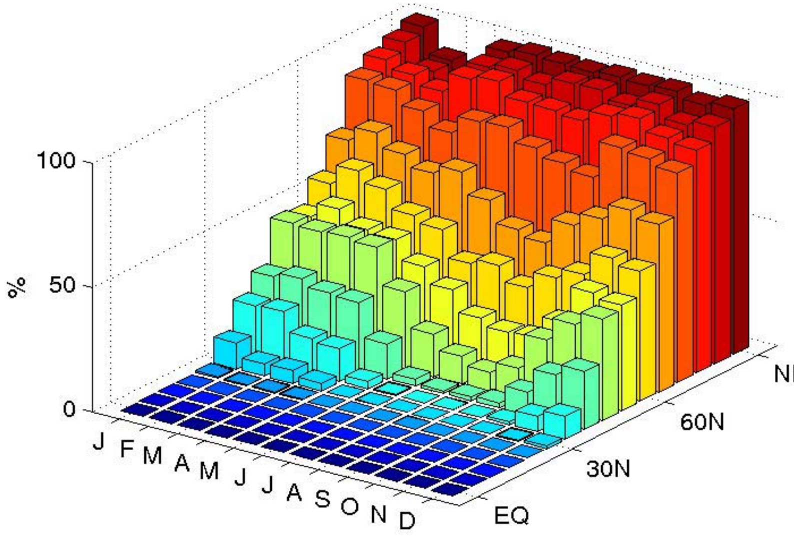
Figure 4. Comparison between the latitudinal distribution of the annual cycles of total ozone from Oslo CTM2 model calculations and SBUV satellite data. Right panel: comparison between the amplitudes of the annual cycles per latitude zone in percent (%) of the zonal mean.



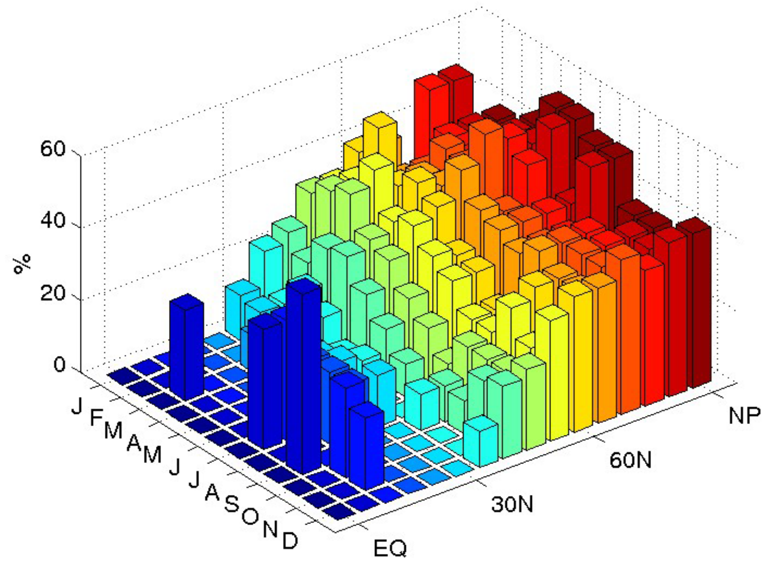
Annual average methane chemical lifetime versus CO in the broad 500 hPa MOPITT retrieval level. Methane lifetime is inversely proportional to OH; all models used the same prescribed methane values, with only a very small deviation due to temperature differences between models. The shaded area indicates the IPCC-TAR lifetime derived from observations and modeling. Reprinted from Shindell et al. (2006).

Stratospheric impact of aircraft emissions

Fraction of aircraft emissions emitted in the stratosphere [%]

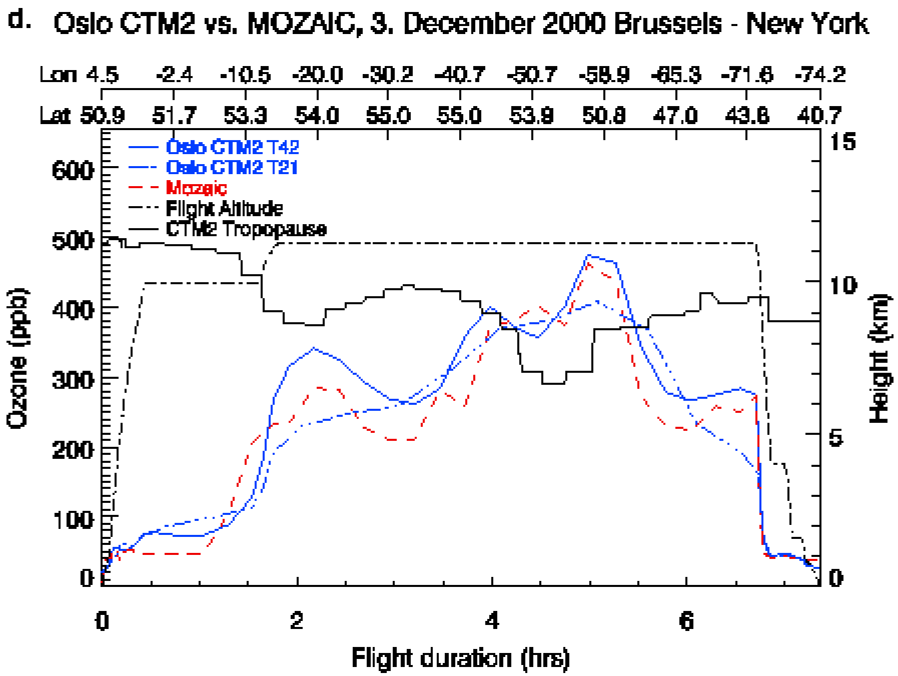


How much of the total ozone column change occurs in the stratosphere?



A major part of emission and ozone column perturbations at high northern latitudes occur in the stratosphere

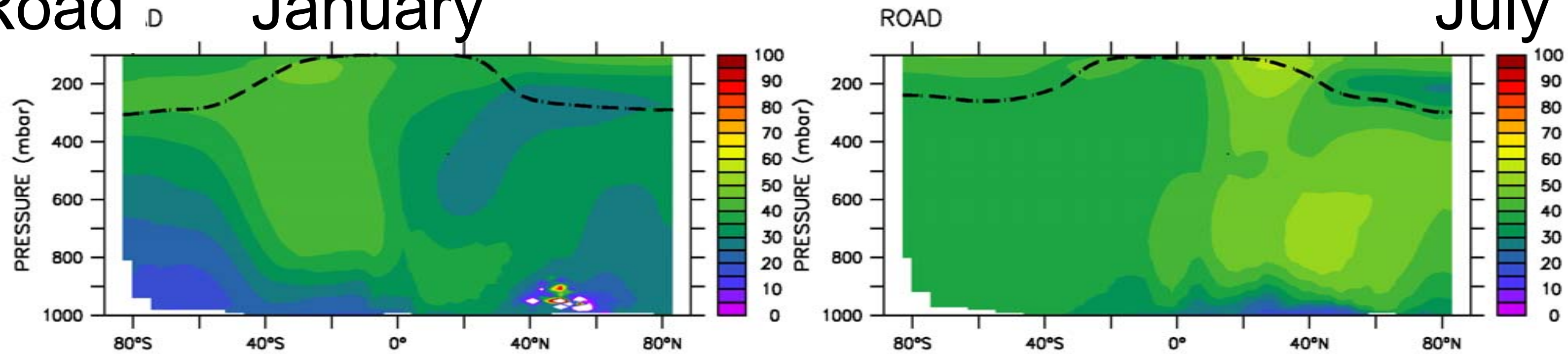
Oslo CTM2 vs Mozaic : O3 – Effect of model resolution



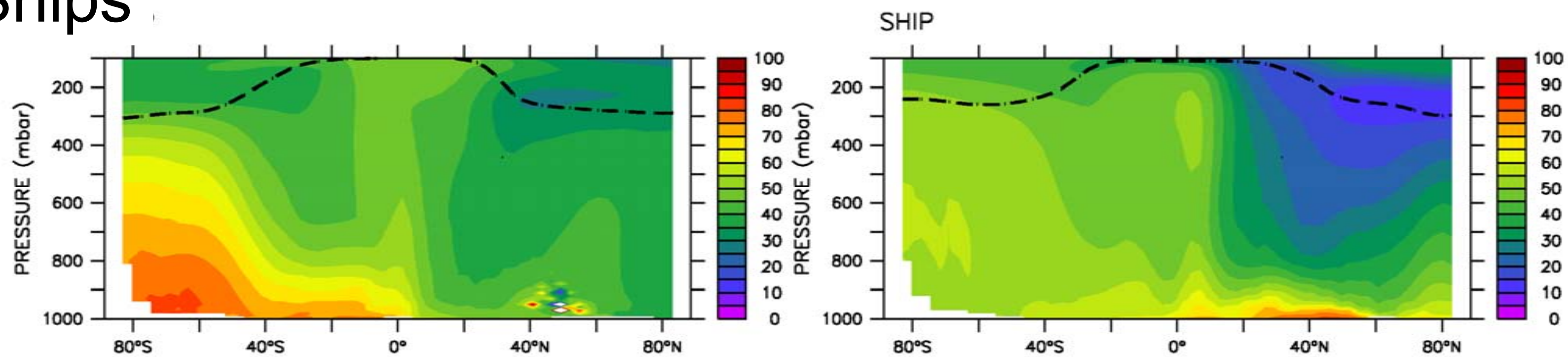
The comparisons demonstrate the importance of model resolution in representing distributions in the UTLS region

ozone perturbation: case/(road+ship+air)

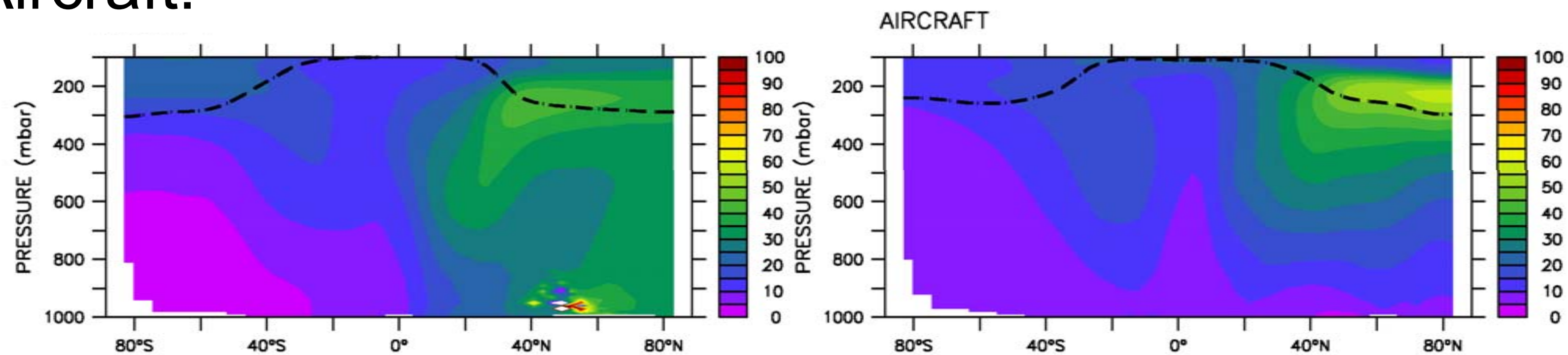
Road January July



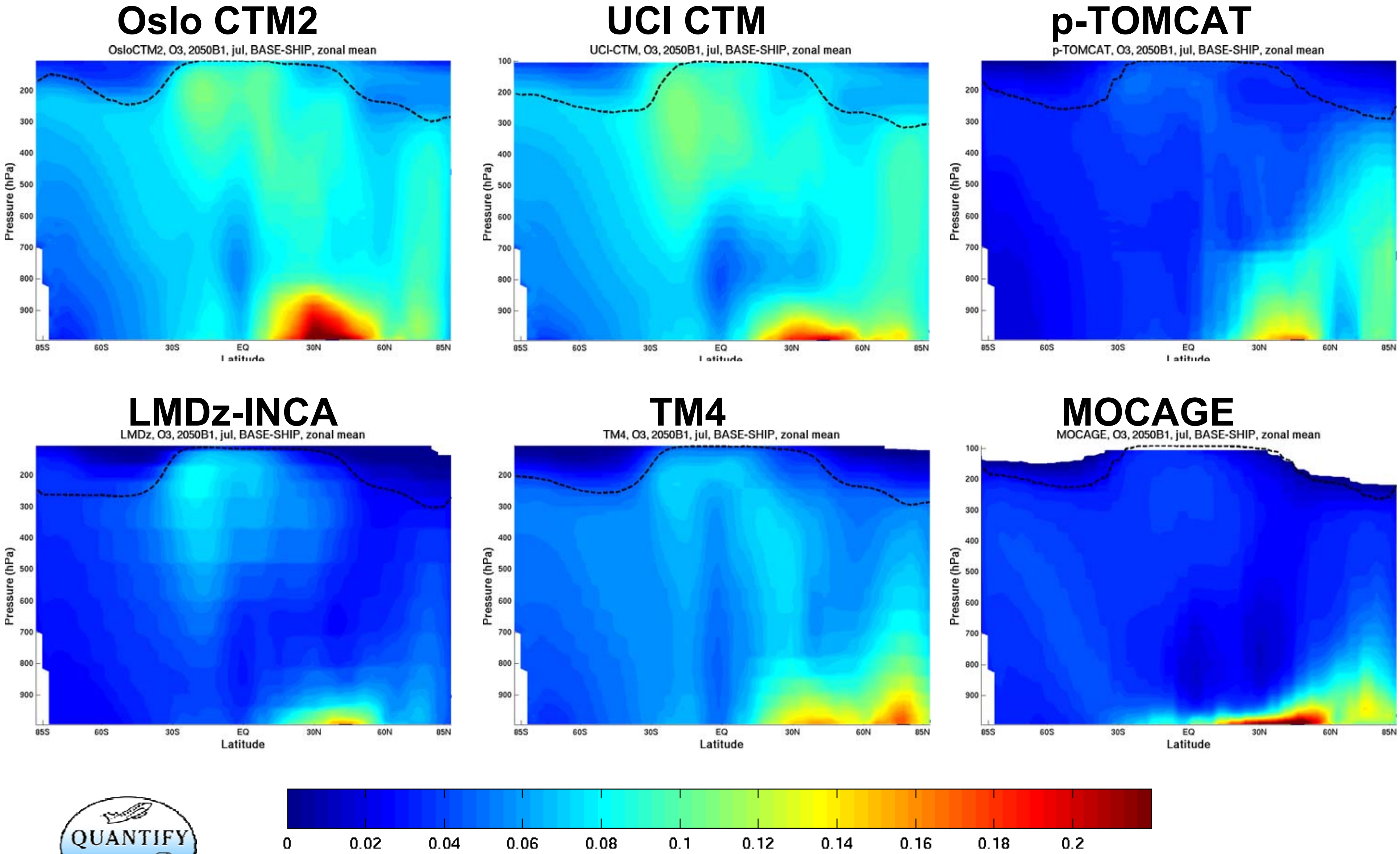
Ships



Aircraft:



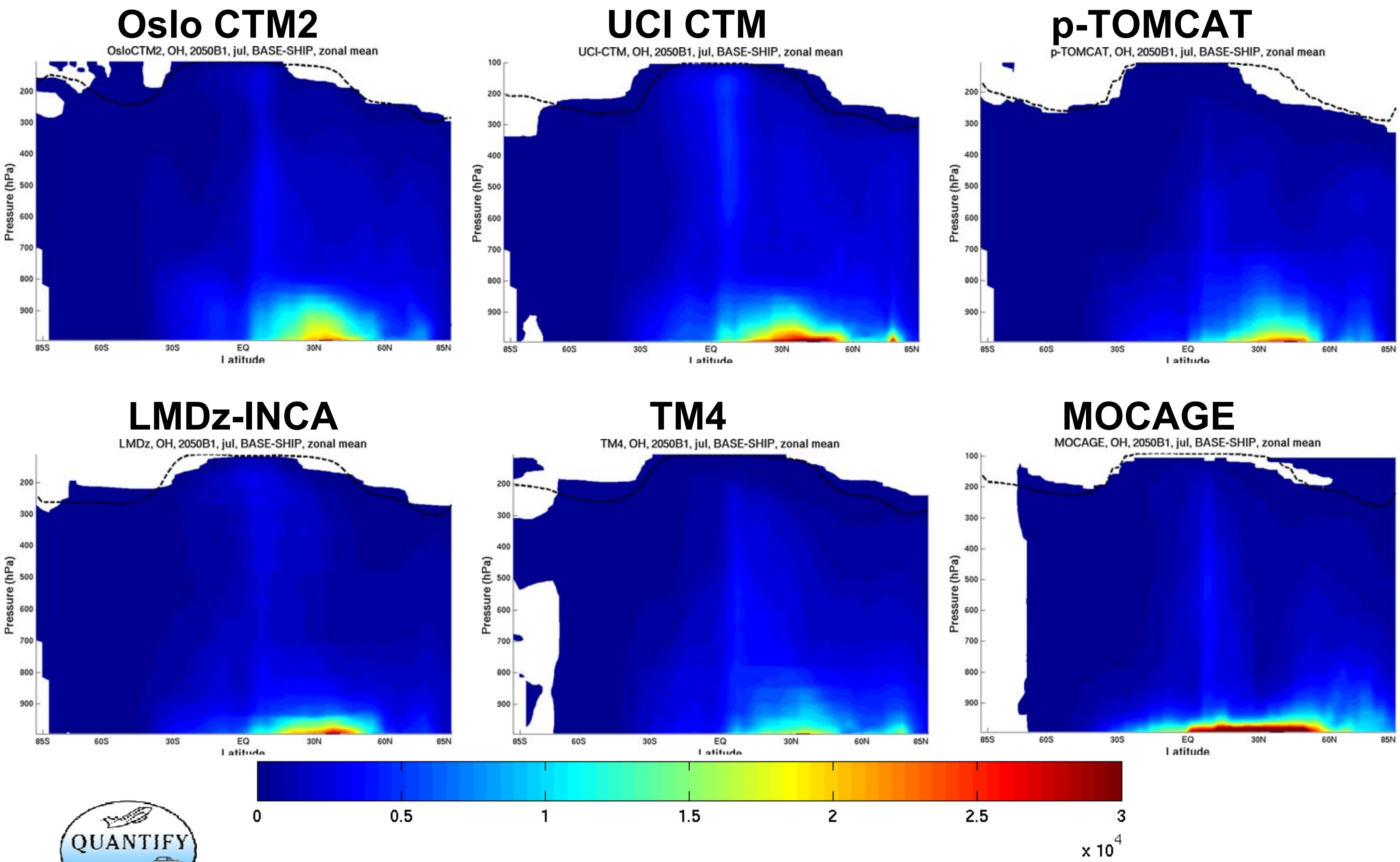
ΔO$_3$ (ppbv), zonal mean. 2050 B1 scenario. July.
5 % perturbation of ship emissions.



Hodnebrog et al., in preparation

ΔOH (molec/cm³), zonal mean. 2050 B1 scenario. July.

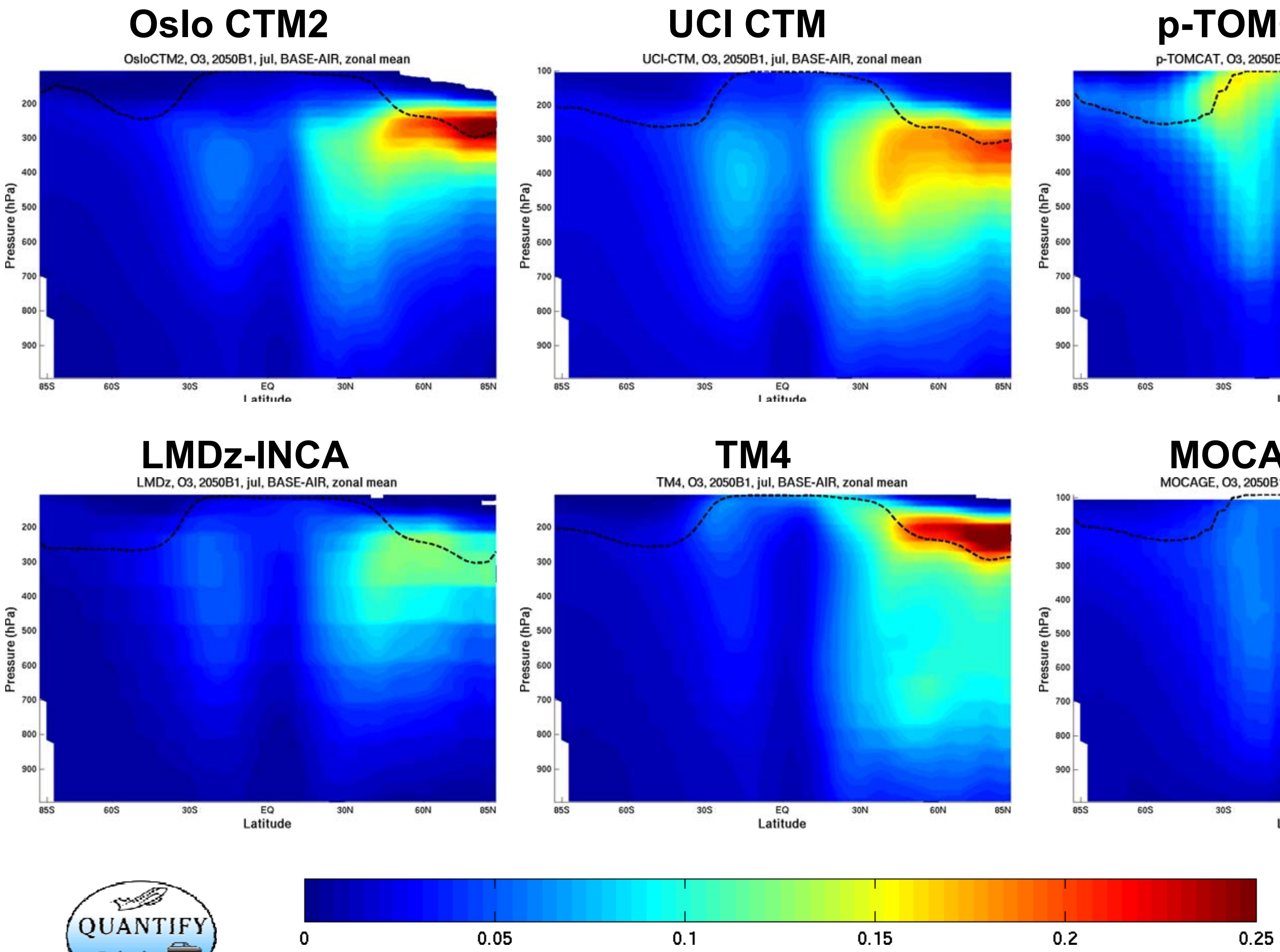
5 % perturbation of ship emissions.



Hodnebrog et al., in preparation

ΔO_3 (ppbv), zonal mean. 2050 B1 scenario. July.

5 % perturbation of aircraft emissions.



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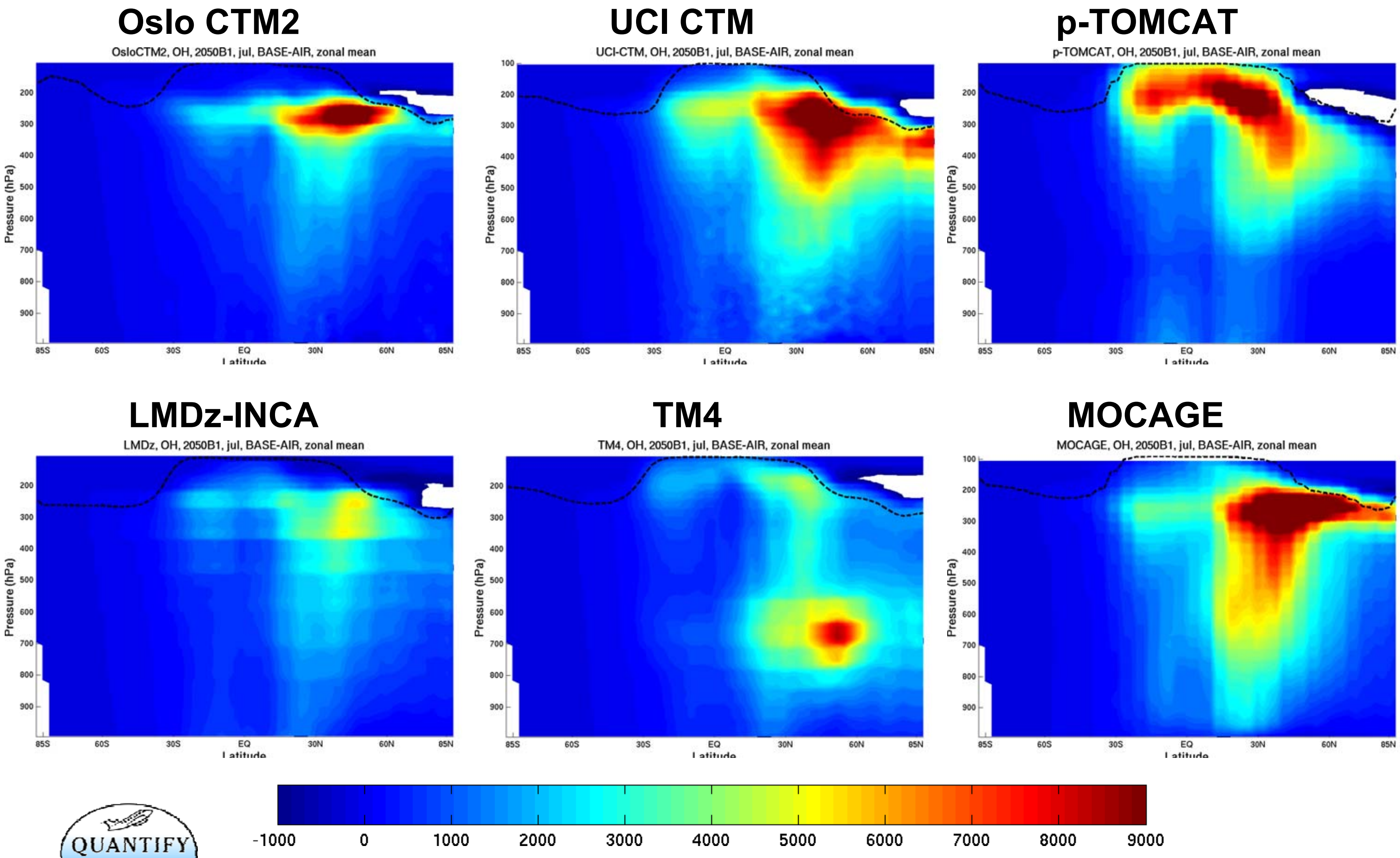

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B1 ACARE

Mitigation scenario for aviation. Probably presents the lowest estimate of impact.

Very optimistic, but feasible scenario

Assumes same traffic demand as in B1.

Assumes excellent fuel efficiency and NO_X improvements

ACARE* targets achieved in 2020 and continuing improvements beyond 2020. Means that all new aircrafts entering the fleet after 2020 are ACARE-compliant.

* Advisory Council for Aeronautics Research in Europe

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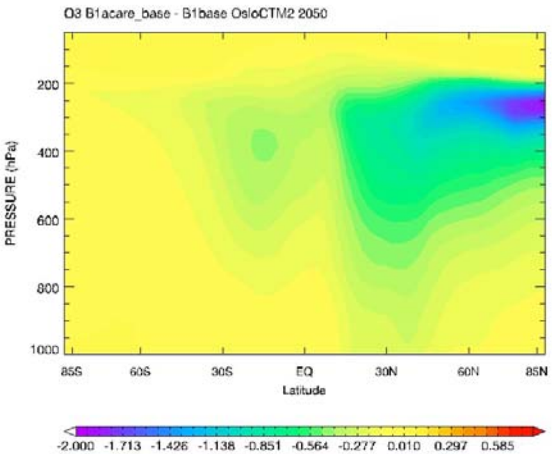
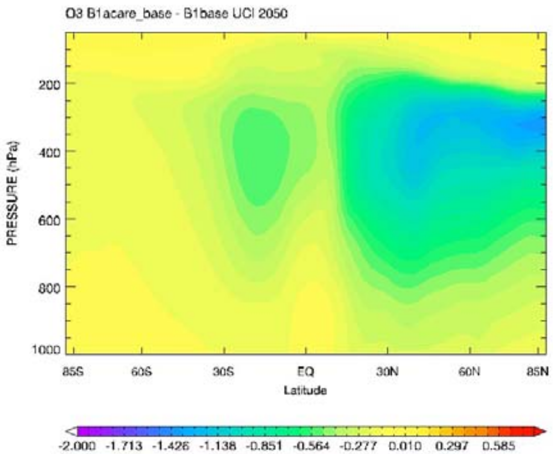
O_3 (ppbv), 2050B1ACARE–B1, zonal mean

July

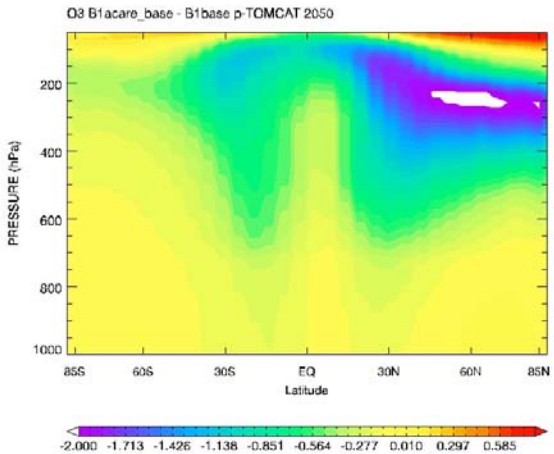
Oslo CTM2



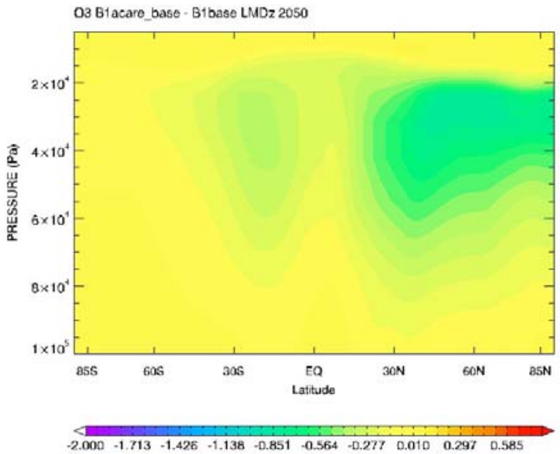
UCI CTM



p-TOMCAT



LMDz-INCA



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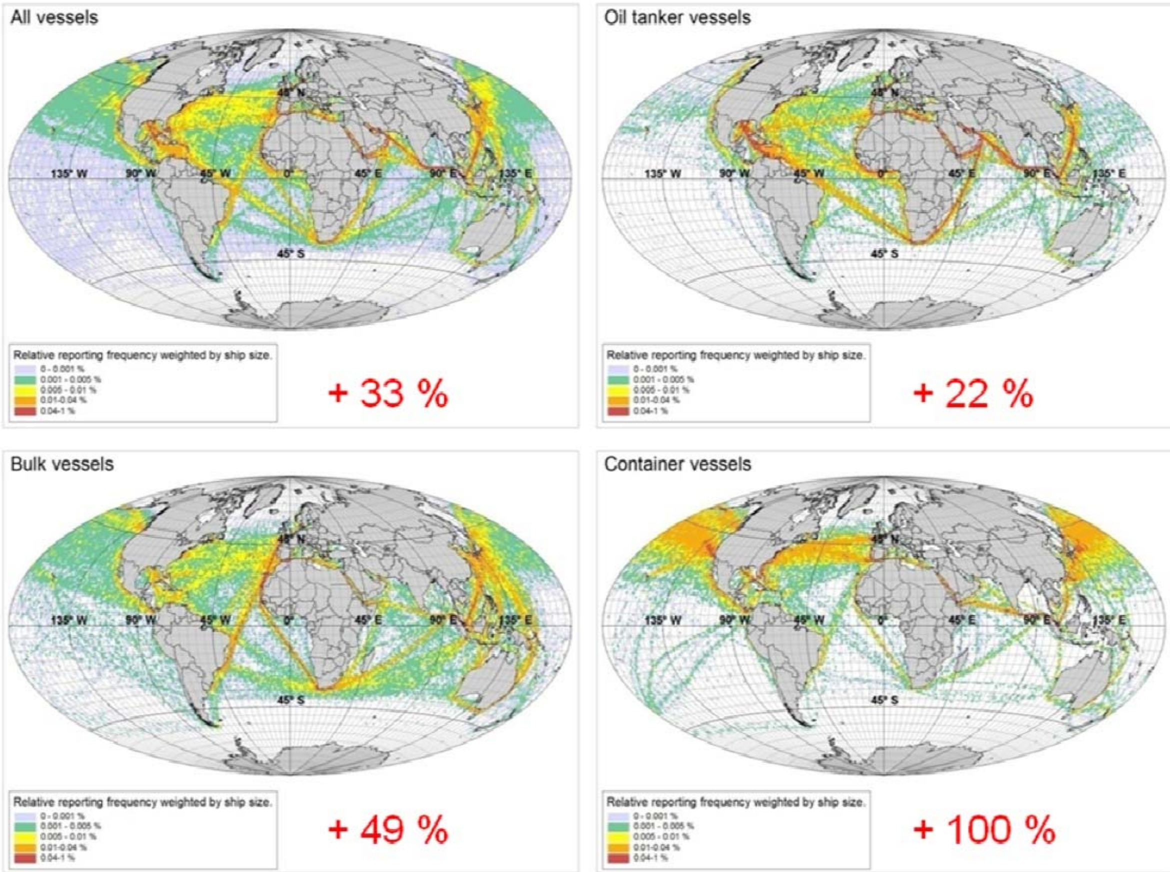
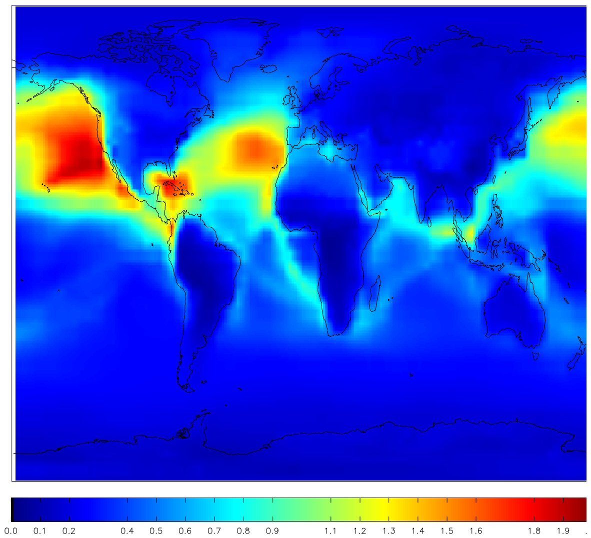
Vessel traffic densities (relative number of observations per grid cell) for year 2001/2002 based on the AMVER (2005) data



Impact on surface ozone from increased ship emissions



Yearly average increase (ppbv) in surface ozone due to increase in ship emissions 2000-2007

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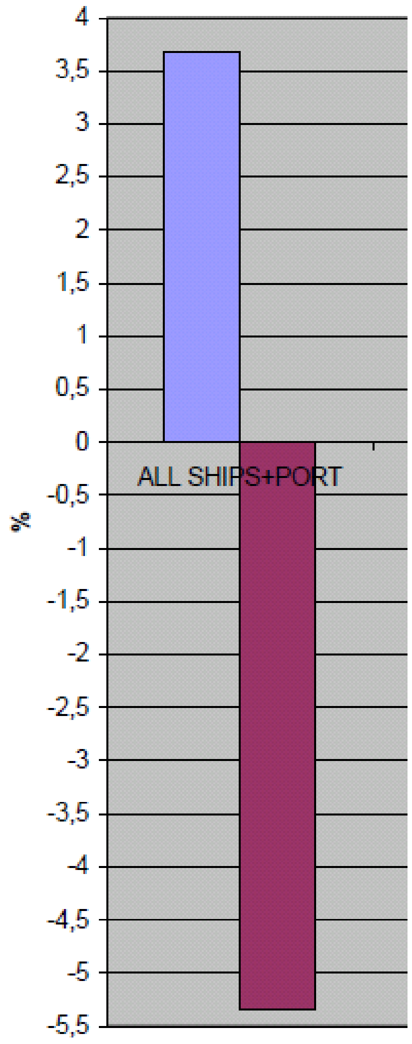
Changes in global average OH and CH_4 lifetime from ship emissions (2000)



Comparison of efficiency of ozone production for NOx emission from the transport sector for 5 CTMs

	TM4	UiO	LMDz	UCI	pTOM	meen
Road	0.31	0.44	0.34	0.35	0.25	0.33
Ship	0.47	0.65	0.46	0.57	0.57	0.54
Aircraft	1.32	1.22	1.45	1.39	2.78	1.63

Global annual average ozone burden change per annual integrated NOx-emission of each respective transport sector (Molecules(O3)/molecules(NOx-emission)

Efficient ozone production from aircraft
Large model to model differences

Model differences in estimates of methane lifetime impact from the transport sector

	TM4	OSLO	LMDz	UCI	TOMCAT
BASE (yr)	7.2	8.5	10.2	7.6	11.4
ROAD (%)	1.9	1.4	1.9	1.3	1.6
SHIP (%)	3.2	3.7	4.1	3.5	6.4
AIR (%)	0.8	0.7	1.1	1.0	1.8

Methane lifetime in years for the BASE case and relative changes due to traffic emissions

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Hoor et al. (2009)

Conclusions

Some key issues with the global modeling studies in QUANTIFY:

- New emission scenarios for 2000, 2025, and 2050 for the aviation, shipping and land transport sectors
- Extensive and consistent comparison of the impact from the transport sectors
- New results for current and future impact on ozone and methane lifetime
- Focus on mitigation options
- Provide input to forcing calculations

Significant differences between models in estimates on aircraft impact
point to the UTLS region as a region where research is needed

Research needs (improve our estimates of transport impact)

- STE (Stratospheric-Tropospheric-exchange), inter-hemispheric exchange
- Impact on the stratosphere, including sulfate from aircraft
- Upper tropospheric processes, impact of convection
- Methane lifetime/OH perturbations and trend
- Constrain on models by observations (in particular satellite observations)
- Regional differences in emissions/composition changes/impact
- Focus on sectors differences and impact
- Inclusion of plume processing
- Model evaluation to reduce uncertainties

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