Ozone Production in Global Tropospheric Models: Quantifying Errors due to Grid Resolution

Oliver Wild[1,2] and Michael Prather[3]

Contact: Oliver.Wild@atm.ch.cam.ac.uk

[1] Frontier Research Center for Global Change, JAMSTEC, Japan; [2] now at Centre for Atmospheric Science, University of Cambridge, UK
[3] Earth System Science, University of California, Irvine, California

AGU Fall Meeting 2005
Poster No. A13B-0911

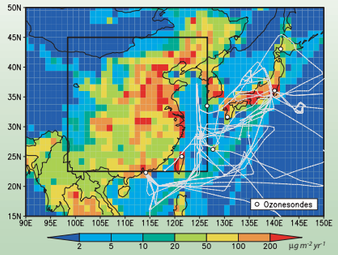
1. Introduction

Ozone production in global chemical models is dependent on model resolution because ozone chemistry is inherently nonlinear, the timescales for chemical production are short, and precursors are artificially distributed over the spatial scale of the model grid.

Here we examine the sensitivity of ozone, its precursors, and its production to resolution by running a global chemical transport model at four different resolutions: T21 (5.6˚x 5.6˚), T42 (2.8˚x 2.8˚), T63 (1.9˚x 1.9˚) and T106 (1.1˚x1.1˚) under the same conditions and then by quantifying the errors in regional and global budgets.

2. Model Studies

We use the FRSGC/UCI CTM [*Wild and Prather,* 2000] to study the global impacts of model resolution and consider East Asia to provide a regional focus. Measurements from the NASA TRACE-P campaign in Spring 2001 allow a detailed assessment of model performance.



Surface NO_x emissions over East Asia in March 2001 at T106 resolution. Ozonesonde launch sites and NASA DC-8 and P-3B aircraft flight tracks during the TRACE-P campaign are indicated; the region used for diagnostics is highlighted.

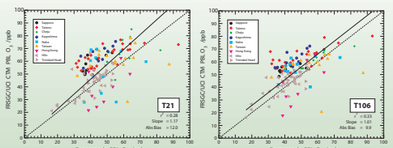
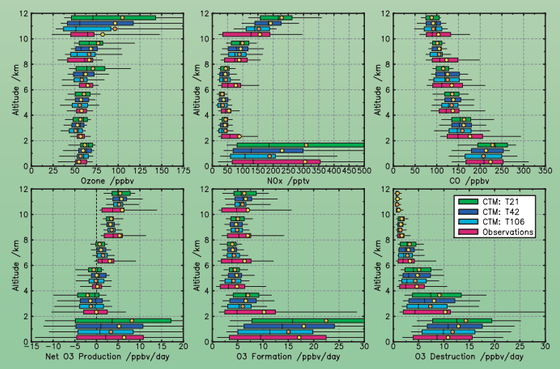


Table 1. CTM vs. Ozonesonde Comparisons

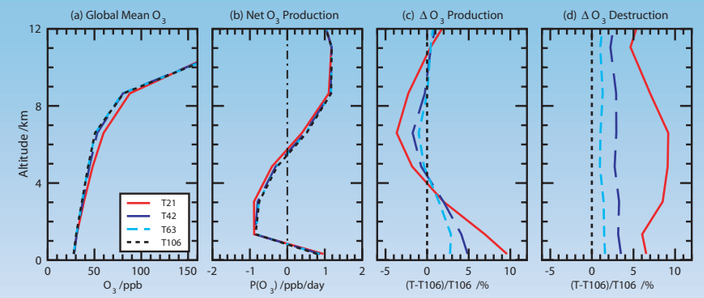
	r	Slope	Mean Bias	Abs Bias
T21	0.526	1.17	7.05	12.03
T42	0.567	1.11	7.15	11.20
T63	0.574	1.04	6.41	10.52
T106	0.578	1.01	5.95	9.87

Comparison of boundary layer O_3 below 800 hPa with data from 137 ozonesondes over the Western Pacific in Spring 2001, showing correlation coefficient (r), slope of linear regression and mean and absolute biases (in ppb).



TRACE-P aircraft measurements over the Western Pacific during Spring 2001 compared with CTM data sampled along flight tracks. Distributions over each 2-km altitude bin are given by the mean (circles), median (vertical bar), quartiles (defining box) and 10th/90th percentiles (horizontal lines). Observed tendencies derived with a photochemical steady-state box model driven by observations.

3. Global O_3 Production



*Impacts of resolution on the global O_3 budget for March/April 2001 showing **(a)** the mean O_3 profile, **(b)** the net chemical tendency, **(c)** the change in gross production relative to the T106 simulation, and **(d)** the change in gross destruction relative to T106.*

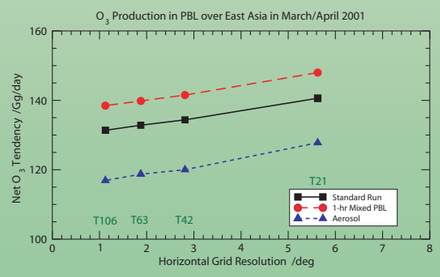
Table 2. Global Oxidant Budgets for March/April 2001

	T21	T42	T63	T106
Mean O_3 Burden (Tg)	294	284	278	275
Gross Production (Gg/day)	12290	12130	12040	11880
Gross Destruction (Gg/day)	12120	11650	11450	11290
Net O_3 Production (Gg/day)	169	480	594	583
O_3 Deposition (Gg/day)	2090	2210	2250	2300
O_3 Strat/Trop Exch. (Gg/day)	2000	1760	1670	1730
O_3 Chemical Lifetime[a] (days)	24.25	24.34	24.25	24.34
CH_4 Lifetime vs. OH (years)	8.06	8.32	8.44	8.57

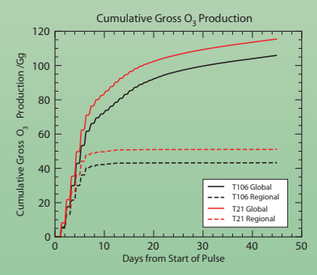
[a] Lifetime defined as burden divided by gross destruction.

*Increasing resolution from T21 (5.6˚) to T106 (1.1˚) leads to **(a)** reduced chemical O_3 production and destruction, **(b)** reduced descent from stratosphere, **(c)** reduced global O_3 burden, and **(d)** increased surface deposition. Net chemical production of O_3 is higher, and the lifetime of CH_4 is longer. These reflect changes in geographical location for O_3, its production and removal.*

4. Regional O_3 Production



*Net O_3 production over East Asia in springtime is 7-8% less at T106 than at T21, largely due to reduced distribution of emitted precursors. Alternative model formulations: **(1)** more rapid PBL mixing (greater mixing, higher O_3 production) and **(2)** climatological aerosol loading (reduced photolysis, slower production) both show similar impacts due to resolution.*



Isolate impacts of resolution on chemical evolution by applying a 5-day pulse of industrial NO_x, CO and NMHC emissions over East Asia at each resolution. Find greater export of NO_y at high resolution, but subsequent O_3 production in the global troposphere is little affected.

5. Quantifying Resolution Errors

Quantify the errors due to resolution (ε) by deriving values for the limit of infinite resolution (T_∞) based on the convergence T42-T63-T106, and assume that the absolute error is proportional to some power (*N*) of the grid size (*h*), i.e., $\varepsilon \propto h^N$ (Richardson extrapolation).

Table 3. Convergence and Resolution Errors in Oxidant Budgets

	Budgets						Estimated Errors			
	T21	T42	T63	T106	T_∞	N	ε_{21}	ε_{42}	ε_{63}	ε_{106}
Global Budgets from All Global Emissions										
Global gross production (Gg/yr)	12286	12130	12043	11877	11710	1.0	578	422	335	169
Global O_3 burden (Tg)	294	284	278	275	273.6	2.2	20.2	10.0	4.1	1.3
CH_4 lifetime (years)	8.06	8.32	8.44	8.57	8.73	1.0	-0.7	-0.4	-0.3	-0.2
Production from East Asian Industrial Emissions Only										
Regional net production (Gg/yr)	58.8	49.2	47.3	45.5	43.0	1.0	15.8	6.2	4.3	2.5
Regional gross production (Gg/yr)	102.1	90.3	88.7	86.6	84.1	1.8	18.0	6.2	4.5	2.5
Regional O_3 burden (Tg)	27.4	22.3	21.1	20.9	20.8	2.9	6.6	1.4	0.3	0.1
Global gross production (Gg/yr)	231.0	223.1	215.4	211.9	210.4	2.3	20.6	12.8	5.0	1.5
Global O_3 burden (Tg)	56.2	52.9	51.0	50.0	49.6	2.1	6.6	3.4	1.4	0.5

The O_3 production terms and burdens are generally well-behaved, with $N \approx 2$, so that the resolution error $\varepsilon \propto h^2$. For some quantities such as the net stratospheric flux or O_3 lifetime the sequence is not monotonic, but in these cases the errors are usually small.

Note that the convergence and error terms calculated here are based on emissions supplied at 0.5˚x 0.5˚ resolution (about 50 x 50 km), and that sub-grid-scale processes occurring at the smaller scales associated with urban plumes are not considered here. Even neglecting these small scales, significant errors remain at T106 (120 km scale).

6. Conclusions

(1) Boundary layer O_3 production is less at higher resolution
emissions less smeared, production lower, precursor export greater; agreement with aircraft/sonde measurements better at higher resolution

(2) Global O_3 production is less affected by resolution
chemical changes buffered by changes in deposition and distribution and by poorer representation of strat-trop exchange at T21

(3) Demonstrate convergence with increasing resolution
geometric convergence occurring for T42-T63-T106 sequence

(4) Large errors in regional O_3 production still present at T106
For East Asian industrial sources regional production is overestimated by 27% at T21, 13% at T42, 9% at T63, and 5% at T106

Suggests that assessments of source-receptor relationships with current CTMs focusing on climate or air quality are significantly biased; further work will be required to address these issues.

References

Wild, O., and M.J. Prather, *Excitation of the primary chemical mode,* J. Geophys. Res. 105, 24647-24660, 2000
Wild, O., and M.J. Prather, *Quantifying errors due to grid resolution,* under revision for J. Geophys. Res.