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A Condensed Global Photochemical Mechanism for Two-Dimensional Atmospheric Models

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Abstract

A condensed chemical mechanism that represents the reactions of organic compounds in the atmosphere is developed and tested using a one-dimensional model. Due to the differences between the full and condensed mechanisms, the reduced version cannot be considered an accurate predictor of globally important trace species concentrations. The condensed mechanism must be improved before it can be used with confidence in two-dimensional models.

Introduction

Presently, there are two types of well-established models that are widely used to study global atmospheric chemical and transport processes. One-dimensional models only resolve altitude and are computationally simple and affordable. Until several years ago, one-dimensional models were the primary tool available for studying global chemical cycles. Currently, they are used in modelling studies that involve very large numbers of parametric sensitivity analyses or extremely detailed chemical mechanisms that contain well over 100 chemical species and several hundred reactions. The newer two-dimensional models resolve altitude and latitude but are longitudinally-averaged. Two-dimensional models are more complex and expensive to run on computers, but do confer a distinct advantage: such models can represent the effects of dynamics in redistributing constituents in the meridional plane. These models represent the current state of the art for studying detailed chemical interactions in the atmosphere. Furthermore, the vertical boundary of the most modern two-dimensional global atmospheric models extends to the top of the stratosphere or higher.

To date, atmospheric models have used reactive organic photochemical mechanisms that are too detailed for use in two-dimensional models that extend vertically to the top of the stratosphere. When a detailed organic degradation mechanism is used, the cost of running the model becomes very expensive. The problem arises because each species (i.e. dependent variable) in the mechanism generates a corresponding species continuity equation. Therefore, in order to reduce the number of differential equations that must be solved at each model grid point, a condensed chemical mechanism for use in these two-dimensional models needs to be developed. Thus, there is an incentive to use the simplest mechanism possible that can adequately predict profiles of important species such as OH, CO, and O₃.

Discussion

Hough et al. (1991) describe the detailed photochemical mechanism used in their two-dimensional atmospheric model of the troposphere. In the same paper, these authors establish that their mechanism is capable of accurately predicting the global levels of important trace species such as CH₄, CO, and O₃. Therefore, this mechanism has been selected as a prime candidate for simplification. The full and reduced mechanisms will be compared by using a one-dimensional model to test the agreement between the predicted profiles of key species. If there is good agreement between the mechanisms, then the condensed version also can be considered adequate for predicting global levels of important trace species.

The organic chemical mechanism developed by Hough et al. includes 50 species: 12 hydrocarbons, 14 oxygenated hydrocarbon derivatives, 2 nitrogenated hydrocarbon derivatives, 16 organic radicals, and 6 inorganic species. These compounds participate in 63 thermally-activated reactions and 13 photolytic reactions. Appendix 1 contains the

complete mechanism. In order to condense the mechanism, the number of species in Hough's mechanism will have to be reduced.

Lurmann et al. (1986) develop a condensed mechanism from their detailed version and show that there is excellent agreement between the two mechanisms. Their technique consists of combining organic species with similar chemical reactivities into one representative compound. If one of the species to be lumped reacts by an unimportant minor pathway, then that reaction is excluded from the mechanism. This technique is used because it is the only method capable of significantly reducing the number of dependent variables.

By applying Lurmann's technique to Hough's mechanism, the reduced mechanism that is produced contains 39 species, 46 thermal reactions, and 10 photolytic reactions. Thus, the number of species is reduced by 11. Furthermore, 17 thermal and 3 photolytic reactions are removed. Appendix 2 contains the reduced mechanism. The species are lumped as shown in Table 1:

<i>Original Species</i>	<i>Affected Species</i>	<i>Representative Species</i>
≥C4 Alkanes	Butane, Pentane, Hexane	ALKA
≥C3 Alkenes	Propene, Isoprene	ALKE
≥C2 Aldehydes	Acetaldehyde, Methacrolein	ALD2
≥C2 Organic Peroxides	Ethyl Peroxide, Butyl Peroxide, Hexyl Peroxide, Peroxyacetic Acid	ROOH
All Ketones	Methyl ethyl ketone, Methyl vinyl ketone	KET
Peroxyacetyl and Methacrolein-peroxy Radicals	—	MCO3•
Keto-peroxy Radicals	—	KO2•
≥C3 Alkene-peroxy Radicals	—	PO2•

Table 1—The chemical species lumping scheme.

All the other species remain explicit. As mentioned previously, some of the chemical reactions are deleted if the products are not typically generated by the lumped species. For example, methacrolein is lumped into ALD2. Since it is the only aldehyde in the mechanism that reacts with ozone, that pathway is excluded.

The next step is to insert the detailed and condensed versions of Hough's mechanism into the Lawrence Livermore National Laboratory one-dimensional global atmospheric chemical-transport model. This model is described by Kinnison (1989). Once the mechanisms are entered into the model, the profiles for several important trace species can be compared to determine the degree of agreement between the detailed and condensed chemical mechanisms. In this way, the accuracy of the assumptions employed in reducing the mechanism will be evaluated.

Results

Since the purpose of this investigation is to perform a comparison between the two mechanisms, the diurnally-averaged coefficients are calculated for both versions. The

results of the one-dimensional diurnally-averaged model for the full and condensed cases are compared for CO, OH, CH₄, NO, NO₂, O₃, HO₂, and PAN. Appendix 3 contains the tabulated data for each of these species and the percent difference in the calculated mixing ratios. The profiles from the surface up to 20 kilometers are depicted in Figures (1)-(8). In each graph, the ordinate corresponds to altitude and the abscissa represents the species mixing ratio on a volumetric basis with respect to air. Overall, the reduced mechanism tends to underpredict species concentrations relative to the full set. PAN is an exception; this species is overpredicted by the reduced mechanism.

The differences are particularly evident in the lower troposphere. As shown in Appendix 3, the largest discrepancies (i.e. 20% or greater) occur in the OH, NO, NO₂, O₃, and PAN profiles in the lowest 3-5 kilometers of the model. In addition, the reduced mechanism predicts lower CO and CH₄ mixing ratios than the full mechanism throughout the model domain. Finally, there is a discrepancy of approximately 20% between the HO₂ profiles predicted in the tropopause and lower stratosphere (12-18 kilometers). These discrepancies can probably be attributed to the assumptions employed in the development of the reduction scheme.

Conclusions

Additional work is warranted in order to better parameterize the reduction scheme so that closer agreement can be achieved in the species profiles. Due to the differences between the full and condensed mechanisms, this version of the reduced chemical mechanism cannot be considered an accurate predictor of globally important trace species. Thus, the species lumping scheme employed in the condensed mechanism must be improved before it can be used in future two-dimensional modelling studies of the atmosphere. Therefore, the full chemistry set will be used in the two-dimensional model until the reduced mechanism is refined.

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References

Hough, A.M. and C. Johnson (1991): *The Development of a Two-Dimensional Global Tropospheric Model: The Model Chemistry*. **Journal of Geophysical Research**, Vol. 96, No. D4, pp. 7325-7362.

Lurmann, F.W. and A.C. Lloyd (1986): *A Chemical Mechanism for Use in Long-Range Transport/Acid Deposition Computer Modeling*. **Journal of Geophysical Research**, Vol. 91, No. D10, pp. 10905-10936.

Kinnison, D.E. (1989): *Effects of Trace Gases on Global Atmospheric Chemical and Physical Processes*. **Ph.D. Thesis, Department of Chemistry, University of California, Berkeley.**

Appendices

Appendix 1–Full Mechanism

PHOTOLYSIS REACTIONS

1. $\text{CH}_3\text{OOH} = \text{HCHO} + \text{HO}_2 + \text{OH}$
2. $\text{CH}_3\text{O}_2\text{NO}_2 = \text{CH}_3\text{O}_2 + \text{NO}_2$
3. $\text{CH}_3\text{CHO} = \text{CH}_3\text{O}_2 + \text{CO} + \text{HO}_2$
4. $\text{CH}_3\text{CHO} = \text{CH}_4 + \text{CO}$
5. $\text{C}_2\text{H}_5\text{COCH}_3 = \text{C}_2\text{H}_5\text{O}_2 + \text{CH}_3\text{COO}_2$
6. $\text{HCOCHO} = 0.13\text{HCHO} + 0.87\text{H}_2 + 1.87\text{CO}$
7. $\text{CH}_3\text{COCHO} = \text{CH}_3\text{COO}_2 + \text{HO}_2 + \text{CO}$
8. $\text{C}_2\text{H}_5\text{OOH} = \text{CH}_3\text{CHO} + \text{HO}_2 + \text{OH}$
9. $\text{C}_4\text{H}_9\text{OOH} = \text{C}_2\text{H}_5\text{COCH}_3 + \text{HO}_2 + \text{OH}$
10. $\text{C}_6\text{H}_{13}\text{OOH} = \text{C}_2\text{H}_5\text{COCH}_3 + \text{C}_2\text{H}_5\text{O}_2 + \text{OH}$
11. $\text{CH}_3\text{COO}_2\text{H} = \text{CH}_3\text{O}_2 + \text{OH}$
12. $\text{PAN} = \text{CH}_3\text{COO}_2 + \text{NO}_2$
13. $\text{HCOCHCHCHO} = \text{HCOCHCHCOO}_2 + \text{HO}_2$

THERMAL REACTIONS

1. $\text{CH}_3\text{O}_2 + \text{HO}_2 = \text{CH}_3\text{OOH} + \text{O}_2$
2. $\text{CH}_3\text{O}_2 + \text{CH}_3\text{O}_2 = 1.27\text{HCHO} + .7\text{HO}_2$
3. $\text{CH}_3\text{O}_2 + \text{NO}_2 = \text{CH}_3\text{O}_2\text{NO}_2$
4. $\text{CH}_3\text{O}_2\text{NO}_2 = \text{CH}_3\text{O}_2 + \text{NO}_2$
5. $\text{OH} + \text{CH}_3\text{OOH} = 0.6(\text{CH}_3\text{O}_2 + \text{H}_2\text{O}) + 0.4(\text{HCHO} + \text{H}_2\text{O} + \text{OH})$
6. $\text{HCHO} + \text{NO}_3 = \text{CO} + \text{HO}_2 + \text{HNO}_3$
7. $\text{C}_2\text{H}_6 + \text{OH} = \text{C}_2\text{H}_5\text{O}_2$
8. $\text{C}_3\text{H}_8 + \text{OH} = 0.33\text{C}_2\text{H}_5\text{O}_2 + 0.58\text{C}_4\text{H}_9\text{O}_2$
9. $\text{C}_4\text{H}_{10} + \text{OH} = 0.28\text{C}_2\text{H}_5\text{O}_2 + 0.59\text{C}_4\text{H}_9\text{O}_2 + 0.18\text{C}_6\text{H}_{13}\text{O}_2$
10. $\text{C}_5\text{H}_{12} + \text{OH} = 0.25\text{C}_2\text{H}_5\text{O}_2 + 0.66\text{C}_4\text{H}_9\text{O}_2 + 0.31\text{C}_6\text{H}_{13}\text{O}_2$
11. $\text{C}_6\text{H}_{14} + \text{OH} = 0.24\text{C}_2\text{H}_5\text{O}_2 + 0.71\text{C}_4\text{H}_9\text{O}_2 + 0.45\text{C}_6\text{H}_{13}\text{O}_2$
12. $\text{C}_2\text{H}_5\text{O}_2 + \text{NO} = 0.985\text{CH}_3\text{CHO} + 0.985\text{HO}_2 + 0.985\text{NO}_2$
13. $\text{CH}_3\text{CHO} + \text{OH} = \text{CH}_3\text{COO}_2$
14. $\text{CH}_3\text{CHO} + \text{NO}_3 = \text{CH}_3\text{COO}_2 + \text{HNO}_3$
15. $\text{CH}_3\text{COO}_2 + \text{NO}_2 = \text{PAN}$
16. $\text{PAN} = \text{CH}_3\text{COO}_2 + \text{NO}_2$
17. $\text{PAN} + \text{OH} = \text{HCHO} + \text{NO}_2$
18. $\text{CH}_3\text{COO}_2 + \text{NO} = \text{CH}_3\text{O}_2 + \text{NO}_2$
19. $\text{C}_4\text{H}_9\text{O}_2 + \text{NO} = 0.91\text{C}_2\text{H}_5\text{COCH}_3 + 0.91\text{NO}_2 + 0.91\text{HO}_2$
20. $\text{C}_2\text{H}_5\text{COCH}_3 + \text{OH} = \text{CH}_3\text{CH}(\text{O}_2)\text{COCH}_3$
21. $\text{CH}_3\text{CH}(\text{O}_2)\text{COCH}_3 + \text{NO} = 0.92\text{CH}_3\text{CHO} + 0.92\text{CH}_3\text{COO}_2 + 0.92\text{NO}_2$
22. $\text{C}_6\text{H}_{13}\text{O}_2 + \text{NO} = 0.96\text{C}_2\text{H}_5\text{O}_2 + 0.96\text{C}_2\text{H}_5\text{COCH}_3 + 0.96\text{NO}_2$
23. $\text{C}_2\text{H}_4 + \text{OH} = \text{C}_2\text{H}_5\text{O}_3$
24. $\text{C}_2\text{H}_5\text{O}_3 + \text{NO} = f_a\text{HCHO} + f_b\text{CH}_3\text{CHO} + \text{HO}_2 + \text{NO}_2$
25. $\text{C}_2\text{H}_4 + \text{O}_3 = \text{HCHO} + .42\text{CO} + .12\text{H}_2 + .12\text{HO}_2$
26. $\text{C}_3\text{H}_6 + \text{OH} = \text{CH}_3\text{CH}(\text{O}_2)\text{CH}_2\text{OH}$
27. $\text{CH}_3\text{CH}(\text{O}_2)\text{CH}_2\text{OH} + \text{NO} = \text{CH}_3\text{CHO} + \text{HCHO} + \text{HO}_2 + \text{NO}_2$
28. $\text{C}_3\text{H}_6 + \text{O}_3 = 0.525\text{HCHO} + 0.5\text{CH}_3\text{CHO} + 0.06\text{CH}_4 + 0.06\text{H}_2 + 0.33\text{CO} + 0.23\text{HO}_2 + 0.095\text{OH} + 0.215\text{CH}_3\text{O}_2$
29. $\text{C}_2\text{H}_2 + \text{OH} = \text{HCOCHO} + \text{OH}$
30. $\text{C}_6\text{H}_6 + \text{OH} = 0.64\text{ARO}_2$
31. $\text{C}_7\text{H}_8 + \text{OH} = 0.76\text{ARO}_2$

32. $\text{ARO}_2 + \text{NO} = \text{CH}_3\text{COCHO} + \text{HCOCHCHCHO} + \text{HO}_2 + \text{NO}_2$
33. $\text{HCOCHCHCHO} + \text{OH} = \text{HCOCHCHCOO}_2$
34. $\text{HCOCHCHCOO}_2 + \text{NO} = \text{HCOCHO} + 3\text{NO}_2 - 2\text{NO} + \text{HO}_2$
35. $\text{HCOCHO} + \text{OH} = \text{HO}_2 + 2\text{CO}$
36. $\text{CH}_3\text{COCHO} + \text{OH} = \text{CH}_3\text{COO}_2 + \text{CO}$
37. $\text{C}_2\text{H}_5\text{O}_2 + \text{HO}_2 = \text{C}_2\text{H}_5\text{OOH}$
38. $\text{C}_4\text{H}_9\text{O}_2 + \text{HO}_2 = \text{C}_4\text{H}_9\text{OOH}$
39. $\text{C}_6\text{H}_{13}\text{O}_2 + \text{HO}_2 = \text{C}_6\text{H}_{13}\text{OOH}$
40. $\text{CH}_3\text{COO}_2 + \text{HO}_2 = \text{CH}_3\text{COO}_2\text{H}$
41. $\text{CH}_3\text{CH}(\text{O}_2)\text{COCH}_3 + \text{HO}_2 = \text{CH}_3\text{CHO} + \text{CH}_3\text{COO}_2 + \text{OH}$
42. $\text{CH}_3\text{CH}(\text{O}_2)\text{CH}_2\text{OH} + \text{HO}_2 = \text{CH}_3\text{CHO} + \text{HCHO} + \text{HO}_2 + \text{OH}$
43. $\text{C}_2\text{H}_5\text{O}_3 + \text{HO}_2 = f_a\text{HCHO} + f_b\text{CH}_3\text{CHO} + \text{HO}_2 + \text{OH}$
44. $\text{ARO}_2 + \text{HO}_2 = \text{SINK}$
45. $\text{HCOCHCHCOO}_2 + \text{HO}_2 = \text{SINK}$
46. $\text{CH}_3\text{O}_2 + \text{CH}_3\text{COO}_2 = \text{HCHO} + .5\text{CH}_3\text{O}_2 + .5\text{HO}_2$
47. $\text{CH}_3\text{COO}_2 + \text{CH}_3\text{COO}_2 = 2\text{CH}_3\text{O}_2$
48. $\text{C}_2\text{H}_5\text{OOH} + \text{OH} = 0.75\text{CH}_3\text{CHO} + 0.75\text{OH} + 0.25\text{C}_2\text{H}_5\text{O}_2$
49. $\text{C}_4\text{H}_9\text{OOH} + \text{OH} = \text{C}_2\text{H}_5\text{COCH}_3 + \text{OH}$
50. $\text{C}_6\text{H}_{13}\text{OOH} + \text{OH} = \text{C}_6\text{H}_{13}\text{O}_2$
51. $\text{CH}_3\text{COO}_2\text{H} + \text{OH} = \text{CH}_3\text{COO}_2$
52. $\text{ISOPRENE} + \text{OH} = \text{ISOPO}_2$
53. $\text{ISOPO}_2 + \text{NO} = 0.9\text{NO}_2 + 0.9\text{HCHO} + 0.45\text{MVK} + 0.45\text{MAC}$
54. $\text{ISOPO}_2 + \text{HO}_2 = 2.75\text{CO} + 0.9\text{H}_2$
55. $\text{ISOPRENE} + \text{O}_3 = 0.5\text{HCHO} + 0.2\text{MVK} + 0.3\text{MAC} + 0.2\text{CO} + 0.06\text{HO}_2 + 0.06\text{H}_2$
56. $\text{MVK} + \text{OH} = \text{MVKO}_2$
57. $\text{MVKO}_2 + \text{NO} = 0.9\text{NO}_2 + 0.6\text{CH}_3\text{COO}_2 + 0.6\text{CH}_3\text{CHO} + 0.3\text{HO}_2 + 0.3\text{HCHO} + 0.3\text{CH}_3\text{COCHO}$
58. $\text{MVKO}_2 + \text{HO}_2 = 1.8\text{CO} + 0.6\text{H}_2$
59. $\text{MVK} + \text{O}_3 = 0.5\text{HCHO} + 0.21\text{HO}_2 + 0.15\text{CH}_3\text{CHO} + 0.15\text{CH}_3\text{COO}_2 + 0.5\text{CH}_3\text{COCHO} + 0.2\text{CO} + 0.06\text{H}_2$
60. $\text{MAC} + \text{OH} = \text{MACRO}_2$
61. $\text{MACRO}_2 + \text{NO} = 0.9\text{NO}_2 + 0.9\text{HO}_2 + 0.9\text{HCHO} + 0.9\text{CH}_3\text{COCHO}$
62. $\text{MACRO}_2 + \text{HO}_2 = 2.2\text{CO} + 0.6\text{H}_2$
63. $\text{MAC} + \text{O}_3 = 0.65\text{HCHO} + 0.36\text{HO}_2 + 0.5\text{CH}_3\text{COCHO} + 0.35\text{CO} + 0.06\text{H}_2 + 0.15\text{NO}_2 - 0.15\text{NO}$

Appendix 2–Reduced Mechanism

PHOTOLYSIS REACTIONS

1. $\text{CH}_3\text{OOH} = \text{HCHO} + \text{HO}_2$
2. $\text{CH}_3\text{O}_2\text{NO}_2 = \text{CH}_3\text{O}_2 + \text{NO}_2$
3. $\text{ALD2} = \text{CH}_3\text{O}_2 + \text{CO} + \text{HO}_2$
4. $\text{ALD2} = \text{CH}_4 + \text{CO}$
5. $\text{KET} = \text{C}_2\text{H}_5\text{O}_2 + \text{MCO}_3$
6. $\text{HCOCHO} = 0.13\text{HCHO} + 0.87\text{H}_2 + 1.87\text{CO}$
7. $\text{CH}_3\text{COCHO} = \text{MCO}_3 + \text{HO}_2 + \text{CO}$
8. $\text{ROOH} = \text{ALD2} + \text{HO}_2 + \text{OH}$
9. $\text{PAN} = \text{MCO}_3 + \text{NO}_2$
10. $\text{HCOCHCHCHO} = \text{HCOCHCHCOO}_2 + \text{HO}_2$

THERMAL REACTIONS

1. $\text{CH}_3\text{O}_2 + \text{HO}_2 = \text{CH}_3\text{OOH} + \text{O}_2$
2. $\text{CH}_3\text{O}_2 + \text{CH}_3\text{O}_2 = 1.27\text{HCHO} + .7\text{HO}_2$
3. $\text{CH}_3\text{O}_2 + \text{NO}_2 = \text{CH}_3\text{O}_2\text{NO}_2$
4. $\text{CH}_3\text{O}_2\text{NO}_2 = \text{CH}_3\text{O}_2 + \text{NO}_2$
5. $\text{OH} + \text{CH}_3\text{OOH} = 0.6(\text{CH}_3\text{O}_2 + \text{H}_2\text{O}) + 0.4(\text{HCHO} + \text{H}_2\text{O} + \text{OH})$
6. $\text{HCHO} + \text{NO}_3 = \text{CO} + \text{HO}_2 + \text{HNO}_3$
7. $\text{C}_2\text{H}_6 + \text{OH} = \text{C}_2\text{H}_5\text{O}_2$
8. $\text{C}_3\text{H}_8 + \text{OH} = 0.33\text{C}_2\text{H}_5\text{O}_2 + 0.58\text{C}_4\text{H}_9\text{O}_2$
9. $\text{ALKA} + \text{OH} = 0.28\text{C}_2\text{H}_5\text{O}_2 + 0.59\text{C}_4\text{H}_9\text{O}_2 + 0.18\text{C}_6\text{H}_{13}\text{O}_2$
10. $\text{C}_2\text{H}_5\text{O}_2 + \text{NO} = 0.985\text{ALD2} + 0.985\text{HO}_2 + 0.985\text{NO}_2$
11. $\text{ALD2} + \text{OH} = \text{MCO}_3$
12. $\text{ALD2} + \text{NO}_3 = \text{MCO}_3 + \text{HNO}_3$
13. $\text{MCO}_3 + \text{NO}_2 = \text{PAN}$
14. $\text{PAN} = \text{MCO}_3 + \text{NO}_2$
15. $\text{PAN} + \text{OH} = \text{HCHO} + \text{NO}_2$
16. $\text{MCO}_3 + \text{NO} = \text{CH}_3\text{O}_2 + \text{NO}_2$
17. $\text{C}_4\text{H}_9\text{O}_2 + \text{NO} = 0.91\text{KET} + 0.91\text{NO}_2 + 0.91\text{HO}_2$
18. $\text{KET} + \text{OH} = \text{KO}_2$
19. $\text{KO}_2 + \text{NO} = 0.92\text{ALD2} + 0.92\text{MCO}_3 + 0.92\text{NO}_2$
20. $\text{C}_6\text{H}_{13}\text{O}_2 + \text{NO} = 0.96\text{C}_2\text{H}_5\text{O}_2 + 0.96\text{KET} + 0.96\text{NO}_2$
21. $\text{C}_2\text{H}_4 + \text{OH} = \text{C}_2\text{H}_5\text{O}_3$
22. $\text{C}_2\text{H}_5\text{O}_3 + \text{NO} = f_a\text{HCHO} + f_b\text{ALD2} + \text{HO}_2 + \text{NO}_2$
23. $\text{C}_2\text{H}_4 + \text{O}_3 = \text{HCHO} + .42\text{CO} + .12\text{H}_2 + .12\text{HO}_2$
24. $\text{ALKE} + \text{OH} = \text{PO}_2$
25. $\text{PO}_2 + \text{NO} = \text{ALD2} + \text{HCHO} + \text{HO}_2 + \text{NO}_2$
26. $\text{ALKE} + \text{O}_3 = 0.525\text{HCHO} + 0.5\text{ALD2} + 0.06\text{CH}_4 + 0.06\text{H}_2 + 0.33\text{CO} + 0.23\text{HO}_2 + 0.095\text{OH} + 0.215\text{CH}_3\text{O}_2$
27. $\text{C}_2\text{H}_2 + \text{OH} = \text{HCOCHO} + \text{OH}$
28. $\text{C}_6\text{H}_6 + \text{OH} = 0.64\text{ARO}_2$
29. $\text{C}_7\text{H}_8 + \text{OH} = 0.76\text{ARO}_2$
30. $\text{ARO}_2 + \text{NO} = \text{CH}_3\text{COCHO} + \text{HCOCHCHCHO} + \text{HO}_2 + \text{NO}_2$
31. $\text{HCOCHCHCHO} + \text{OH} = \text{HCOCHCHCOO}_2$
32. $\text{HCOCHCHCOO}_2 + \text{NO} = \text{HCOCHO} + 3\text{NO}_2 - 2\text{NO} + \text{HO}_2$
33. $\text{HCOCHO} + \text{OH} = \text{HO}_2 + 2\text{CO}$
34. $\text{CH}_3\text{COCHO} + \text{OH} = \text{MCO}_3 + \text{CO}$

35. $\text{C}_2\text{H}_5\text{O}_2 + \text{HO}_2 = \text{ROOH}$
36. $\text{C}_4\text{H}_9\text{O}_2 + \text{HO}_2 = \text{ROOH}$
37. $\text{C}_6\text{H}_{13}\text{O}_2 + \text{HO}_2 = \text{ROOH}$
38. $\text{KO}_2 + \text{HO}_2 = \text{ALD2} + \text{MCO}_3 + \text{OH}$
39. $\text{PO}_2 + \text{HO}_2 = \text{ALD2} + \text{HCHO} + \text{HO}_2 + \text{OH}$
40. $\text{C}_2\text{H}_5\text{O}_3 + \text{HO}_2 = f_a\text{HCHO} + f_b\text{ALD2} + \text{HO}_2 + \text{OH}$
41. $\text{ARO}_2 + \text{HO}_2 = \text{SINK}$
42. $\text{HCOCHCHCOO}_2 + \text{HO}_2 = \text{SINK}$
43. $\text{CH}_3\text{O}_2 + \text{MCO}_3 = \text{HCHO} + .5\text{CH}_3\text{O}_2 + .5\text{HO}_2$
44. $\text{MCO}_3 + \text{MCO}_3 = 2\text{CH}_3\text{O}_2$
45. $\text{ROOH} + \text{OH} = 0.75\text{ALD2} + 0.75\text{OH} + 0.25\text{C}_2\text{H}_5\text{O}_2$
46. $\text{MCO}_3 + \text{HO}_2 = \text{ROOH}$

Appendix 3–Species Profile Comparison

Key
<i>Full Mechanism</i> = Concentration of species in mixing ratios as predicted by the full mechanism
<i>Reduced Mechanism</i> = Concentration of species in mixing ratios as predicted by the reduced mechanism
<i>Percent Change</i> = Percentage difference between the full and reduced mechanism, relative to the full mechanism

Carbon Monoxide Comparison

Altitude (km)	Full Mechanism	Reduced Mechanism	Percent Change
0	1.386E-07	1.221E-07	-11.90%
1	1.321E-07	1.152E-07	-12.79%
2	1.262E-07	1.090E-07	-13.63%
3	1.210E-07	1.036E-07	-14.38%
4	1.164E-07	9.898E-08	-14.97%
5	1.124E-07	9.496E-08	-15.52%
6	1.088E-07	9.141E-08	-15.98%
7	1.055E-07	8.829E-08	-16.31%
8	1.026E-07	8.554E-08	-16.63%
9	1.000E-07	8.318E-08	-16.82%
10	9.807E-08	8.137E-08	-17.03%
11	9.159E-08	7.563E-08	-17.43%
12	8.279E-08	6.808E-08	-17.77%
13	7.289E-08	5.995E-08	-17.75%
14	6.229E-08	5.150E-08	-17.32%
15	5.237E-08	4.371E-08	-16.54%
16	4.374E-08	3.693E-08	-15.57%
17	3.655E-08	3.117E-08	-14.72%
18	3.107E-08	2.670E-08	-14.07%
19	2.749E-08	2.371E-08	-13.75%
20	2.519E-08	2.176E-08	-13.62%
21	2.380E-08	2.055E-08	-13.66%
22	2.305E-08	1.988E-08	-13.75%
23	2.260E-08	1.945E-08	-13.94%
24	2.226E-08	1.913E-08	-14.06%
25	2.197E-08	1.885E-08	-14.20%
26	2.171E-08	1.860E-08	-14.33%
27	2.144E-08	1.836E-08	-14.37%
28	2.118E-08	1.813E-08	-14.40%
29	2.093E-08	1.792E-08	-14.38%
30	2.071E-08	1.774E-08	-14.34%
31	2.053E-08	1.759E-08	-14.32%
32	2.042E-08	1.752E-08	-14.20%
33	2.040E-08	1.751E-08	-14.17%
34	2.037E-08	1.751E-08	-14.04%
35	2.034E-08	1.750E-08	-13.96%
37.5	2.024E-08	1.746E-08	-13.74%
40	2.039E-08	1.763E-08	-13.54%
42.5	2.093E-08	1.813E-08	-13.38%
45	2.176E-08	1.888E-08	-13.24%
47.5	2.233E-08	1.940E-08	-13.12%
50	2.240E-08	1.948E-08	-13.04%
52.5	2.233E-08	1.943E-08	-12.99%
55	2.206E-08	1.920E-08	-12.96%

Hydroxyl Comparison

Altitude (km)	Full Mechanism	Reduced Mechanism	Percent Change
0	4.510E-14	6.890E-14	52.77%
1	4.313E-14	5.712E-14	32.44%
2	3.816E-14	4.987E-14	30.69%
3	3.525E-14	4.599E-14	30.47%
4	3.323E-14	4.263E-14	28.29%
5	3.311E-14	4.183E-14	26.34%
6	3.520E-14	4.305E-14	22.30%
7	3.900E-14	4.679E-14	19.97%
8	4.363E-14	5.169E-14	18.47%
9	4.851E-14	5.682E-14	17.13%
10	5.184E-14	6.029E-14	16.30%
11	6.060E-14	7.014E-14	15.74%
12	6.904E-14	7.752E-14	12.28%
13	8.041E-14	8.393E-14	4.38%
14	1.015E-13	9.970E-14	-1.77%
15	1.210E-13	1.127E-13	-6.86%
16	1.355E-13	1.226E-13	-9.52%
17	1.478E-13	1.334E-13	-9.74%
18	1.657E-13	1.511E-13	-8.81%
19	1.975E-13	1.824E-13	-7.65%
20	2.481E-13	2.312E-13	-6.81%
21	3.278E-13	3.078E-13	-6.10%
22	4.505E-13	4.257E-13	-5.50%
23	6.329E-13	6.002E-13	-5.17%
24	9.003E-13	8.582E-13	-4.68%
25	1.293E-12	1.236E-12	-4.41%
26	1.860E-12	1.782E-12	-4.19%
27	2.668E-12	2.564E-12	-3.90%
28	3.807E-12	3.662E-12	-3.81%
29	5.386E-12	5.187E-12	-3.69%
30	7.546E-12	7.269E-12	-3.67%
31	1.045E-11	1.007E-11	-3.64%
32	1.435E-11	1.382E-11	-3.69%
33	2.062E-11	1.986E-11	-3.69%
34	2.716E-11	2.612E-11	-3.83%
35	3.472E-11	3.334E-11	-3.97%
37.5	6.577E-11	6.287E-11	-4.41%
40	1.152E-10	1.094E-10	-5.03%
42.5	1.782E-10	1.687E-10	-5.33%
45	2.438E-10	2.314E-10	-5.09%
47.5	3.046E-10	2.904E-10	-4.66%
50	3.595E-10	3.445E-10	-4.17%
52.5	4.138E-10	3.979E-10	-3.84%
55	4.708E-10	4.532E-10	-3.74%

Methane Comparison

Altitude (km)	Full Mechanism	Reduced Mechanism	Percent Change
0	2.902E-06	2.340E-06	-19.37%
1	2.897E-06	2.335E-06	-19.40%
2	2.893E-06	2.331E-06	-19.43%
3	2.889E-06	2.328E-06	-19.42%
4	2.886E-06	2.326E-06	-19.40%
5	2.884E-06	2.323E-06	-19.45%
6	2.881E-06	2.322E-06	-19.40%
7	2.879E-06	2.320E-06	-19.42%
8	2.877E-06	2.318E-06	-19.43%
9	2.875E-06	2.317E-06	-19.41%
10	2.873E-06	2.315E-06	-19.42%
11	2.866E-06	2.310E-06	-19.40%
12	2.853E-06	2.301E-06	-19.35%
13	2.833E-06	2.286E-06	-19.31%
14	2.803E-06	2.264E-06	-19.23%
15	2.761E-06	2.232E-06	-19.16%
16	2.701E-06	2.186E-06	-19.07%
17	2.615E-06	2.120E-06	-18.93%
18	2.502E-06	2.033E-06	-18.75%
19	2.375E-06	1.933E-06	-18.51%
20	2.233E-06	1.821E-06	-18.45%
21	2.082E-06	1.700E-06	-18.35%
22	1.945E-06	1.591E-06	-18.20%
23	1.818E-06	1.488E-06	-18.15%
24	1.697E-06	1.390E-06	-18.09%
25	1.586E-06	1.300E-06	-18.03%
26	1.482E-06	1.216E-06	-17.95%
27	1.383E-06	1.135E-06	-17.93%
28	1.289E-06	1.058E-06	-17.92%
29	1.200E-06	9.852E-07	-17.90%
30	1.115E-06	9.160E-07	-17.85%
31	1.035E-06	8.500E-07	-17.87%
32	9.590E-07	7.880E-07	-17.83%
33	8.875E-07	7.293E-07	-17.83%
34	8.155E-07	6.701E-07	-17.83%
35	7.464E-07	6.134E-07	-17.82%
37.5	6.016E-07	4.944E-07	-17.82%
40	4.901E-07	4.027E-07	-17.83%
42.5	4.056E-07	3.331E-07	-17.87%
45	3.479E-07	2.853E-07	-17.99%
47.5	3.124E-07	2.558E-07	-18.12%
50	2.925E-07	2.393E-07	-18.19%
52.5	2.831E-07	2.314E-07	-18.26%
55	2.815E-07	2.301E-07	-18.26%

Nitric Oxide Comparison

Altitude (km)	Full Mechanism	Reduced Mechanism	Percent Change
0	2.660E-11	3.800E-11	42.86%
1	8.478E-12	1.064E-11	25.50%
2	3.817E-12	4.806E-12	25.91%
3	2.206E-12	2.859E-12	29.60%
4	1.675E-12	2.073E-12	23.76%
5	1.745E-12	2.041E-12	16.96%
6	2.487E-12	2.666E-12	7.20%
7	3.651E-12	3.876E-12	6.16%
8	4.962E-12	5.367E-12	8.16%
9	6.397E-12	7.122E-12	11.33%
10	7.315E-12	8.455E-12	15.58%
11	1.085E-11	1.328E-11	22.40%
12	1.672E-11	2.118E-11	26.67%
13	2.795E-11	3.525E-11	26.12%
14	4.520E-11	5.552E-11	22.83%
15	6.921E-11	8.276E-11	19.58%
16	1.023E-10	1.191E-10	16.42%
17	1.457E-10	1.649E-10	13.18%
18	1.970E-10	2.176E-10	10.46%
19	2.528E-10	2.742E-10	8.47%
20	3.149E-10	3.373E-10	7.11%
21	3.842E-10	4.072E-10	5.99%
22	4.657E-10	4.891E-10	5.02%
23	5.674E-10	5.914E-10	4.23%
24	6.960E-10	7.209E-10	3.58%
25	8.584E-10	8.834E-10	2.91%
26	1.060E-09	1.085E-09	2.36%
27	1.306E-09	1.331E-09	1.91%
28	1.602E-09	1.625E-09	1.44%
29	1.949E-09	1.971E-09	1.13%
30	2.349E-09	2.365E-09	0.68%
31	2.793E-09	2.806E-09	0.47%
32	3.268E-09	3.278E-09	0.31%
33	3.776E-09	3.777E-09	0.03%
34	4.312E-09	4.307E-09	-0.12%
35	4.853E-09	4.843E-09	-0.21%
37.5	6.159E-09	6.138E-09	-0.34%
40	7.242E-09	7.212E-09	-0.41%
42.5	7.902E-09	7.852E-09	-0.63%
45	8.077E-09	8.034E-09	-0.53%
47.5	8.026E-09	7.990E-09	-0.45%
50	7.892E-09	7.873E-09	-0.24%
52.5	7.858E-09	7.847E-09	-0.14%
55	7.978E-09	7.964E-09	-0.18%

Nitrogen Dioxide Comparison

Altitude (km)	Full Mechanism	Reduced Mechanism	Percent Change
0	1.545E-10	2.482E-10	60.65%
1	3.859E-11	5.524E-11	43.15%
2	1.503E-11	2.096E-11	39.45%
3	7.826E-12	1.103E-11	40.94%
4	5.489E-12	7.283E-12	32.68%
5	5.625E-12	6.954E-12	23.63%
6	7.439E-12	8.329E-12	11.96%
7	8.950E-12	9.830E-12	9.83%
8	1.005E-11	1.109E-11	10.35%
9	1.136E-11	1.285E-11	13.12%
10	1.199E-11	1.402E-11	16.93%
11	1.736E-11	2.135E-11	22.98%
12	2.767E-11	3.504E-11	26.64%
13	4.940E-11	6.223E-11	25.97%
14	8.766E-11	1.071E-10	22.18%
15	1.487E-10	1.768E-10	18.90%
16	2.462E-10	2.848E-10	15.68%
17	3.991E-10	4.493E-10	12.58%
18	6.103E-10	6.711E-10	9.96%
19	8.600E-10	9.296E-10	8.09%
20	1.155E-09	1.233E-09	6.75%
21	1.502E-09	1.587E-09	5.66%
22	1.882E-09	1.972E-09	4.78%
23	2.323E-09	2.417E-09	4.05%
24	2.846E-09	2.943E-09	3.41%
25	3.452E-09	3.551E-09	2.87%
26	4.144E-09	4.245E-09	2.44%
27	4.916E-09	5.016E-09	2.03%
28	5.757E-09	5.854E-09	1.68%
29	6.635E-09	6.728E-09	1.40%
30	7.512E-09	7.602E-09	1.20%
31	8.360E-09	8.441E-09	0.97%
32	9.123E-09	9.204E-09	0.89%
33	9.776E-09	9.849E-09	0.75%
34	1.029E-08	1.036E-08	0.68%
35	1.062E-08	1.068E-08	0.56%
37.5	1.063E-08	1.068E-08	0.47%
40	1.012E-08	1.016E-08	0.40%
42.5	9.392E-09	9.421E-09	0.31%
45	8.727E-09	8.753E-09	0.30%
47.5	8.165E-09	8.188E-09	0.28%
50	7.671E-09	7.684E-09	0.17%
52.5	7.217E-09	7.222E-09	0.07%
55	6.793E-09	6.800E-09	0.10%

Ozone Comparison

Altitude (km)	Full Mechanism	Reduced Mechanism	Percent Change
0	2.153E-08	2.636E-08	22.43%
1	2.336E-08	2.849E-08	21.96%
2	2.417E-08	2.907E-08	20.27%
3	2.531E-08	2.994E-08	18.29%
4	2.726E-08	3.163E-08	16.03%
5	3.011E-08	3.428E-08	13.85%
6	3.377E-08	3.781E-08	11.96%
7	3.812E-08	4.208E-08	10.39%
8	4.300E-08	4.692E-08	9.12%
9	4.830E-08	5.220E-08	8.07%
10	5.342E-08	5.730E-08	7.26%
11	7.532E-08	7.906E-08	4.97%
12	1.144E-07	1.177E-07	2.88%
13	1.763E-07	1.786E-07	1.30%
14	2.722E-07	2.730E-07	0.29%
15	4.129E-07	4.120E-07	-0.22%
16	6.194E-07	6.169E-07	-0.40%
17	9.286E-07	9.244E-07	-0.45%
18	1.354E-06	1.348E-06	-0.44%
19	1.857E-06	1.849E-06	-0.43%
20	2.446E-06	2.435E-06	-0.45%
21	3.112E-06	3.097E-06	-0.48%
22	3.757E-06	3.739E-06	-0.48%
23	4.396E-06	4.375E-06	-0.48%
24	5.036E-06	5.013E-06	-0.46%
25	5.644E-06	5.620E-06	-0.43%
26	6.214E-06	6.189E-06	-0.40%
27	6.734E-06	6.708E-06	-0.39%
28	7.189E-06	7.161E-06	-0.39%
29	7.562E-06	7.530E-06	-0.42%
30	7.839E-06	7.803E-06	-0.46%
31	8.023E-06	7.977E-06	-0.57%
32	8.115E-06	8.058E-06	-0.70%
33	8.146E-06	8.076E-06	-0.86%
34	7.834E-06	7.753E-06	-1.03%
35	7.310E-06	7.211E-06	-1.35%
37.5	6.165E-06	6.052E-06	-1.83%
40	4.991E-06	4.892E-06	-1.98%
42.5	3.986E-06	3.924E-06	-1.56%
45	3.143E-06	3.122E-06	-0.67%
47.5	2.492E-06	2.501E-06	0.36%
50	2.011E-06	2.037E-06	1.29%
52.5	1.665E-06	1.698E-06	1.98%
55	1.438E-06	1.471E-06	2.29%

Peroxy Radical Comparison

Altitude (km)	Full Mechanism	Reduced Mechanism	Percent Change
0	4.585E-12	4.804E-12	4.78%
1	6.183E-12	6.611E-12	6.92%
2	5.876E-12	6.250E-12	6.36%
3	5.468E-12	5.741E-12	4.99%
4	5.116E-12	5.303E-12	3.66%
5	4.935E-12	5.021E-12	1.74%
6	4.905E-12	4.892E-12	-0.27%
7	4.837E-12	4.727E-12	-2.27%
8	4.556E-12	4.373E-12	-4.02%
9	4.201E-12	3.932E-12	-6.40%
10	3.901E-12	3.548E-12	-9.05%
11	3.206E-12	2.768E-12	-13.66%
12	2.482E-12	2.012E-12	-18.94%
13	1.824E-12	1.378E-12	-24.45%
14	1.463E-12	1.078E-12	-26.32%
15	1.212E-12	8.858E-13	-26.91%
16	1.034E-12	7.667E-13	-25.85%
17	9.492E-13	7.405E-13	-21.99%
18	9.719E-13	7.859E-13	-19.14%
19	1.113E-12	9.376E-13	-15.76%
20	1.375E-12	1.189E-12	-13.53%
21	1.822E-12	1.608E-12	-11.75%
22	2.474E-12	2.220E-12	-10.27%
23	3.360E-12	3.047E-12	-9.32%
24	4.533E-12	4.161E-12	-8.21%
25	6.062E-12	5.611E-12	-7.44%
26	7.994E-12	7.456E-12	-6.73%
27	1.038E-11	9.743E-12	-6.14%
28	1.326E-11	1.249E-11	-5.81%
29	1.663E-11	1.574E-11	-5.35%
30	2.043E-11	1.940E-11	-5.04%
31	2.466E-11	2.346E-11	-4.87%
32	2.951E-11	2.810E-11	-4.78%
33	3.689E-11	3.519E-11	-4.61%
34	4.176E-11	3.973E-11	-4.86%
35	4.613E-11	4.377E-11	-5.12%
37.5	5.987E-11	5.683E-11	-5.08%
40	7.670E-11	7.267E-11	-5.25%
42.5	1.004E-10	9.516E-11	-5.22%
45	1.318E-10	1.250E-10	-5.16%
47.5	1.664E-10	1.583E-10	-4.87%
50	1.973E-10	1.892E-10	-4.11%
52.5	2.239E-10	2.155E-10	-3.75%
55	2.467E-10	2.370E-10	-3.93%

PAN Comparison

Altitude (km)	Full Mechanism	Reduced Mechanism	Percent Change
0	1.425E-11	4.505E-11	216.14%
1	3.618E-11	1.163E-10	221.45%
2	3.849E-11	1.162E-10	201.90%
3	4.142E-11	1.157E-10	179.33%
4	4.583E-11	1.167E-10	154.64%
5	5.039E-11	1.187E-10	135.56%
6	5.426E-11	1.199E-10	120.97%
7	5.717E-11	1.200E-10	109.90%
8	5.909E-11	1.192E-10	101.73%
9	6.016E-11	1.178E-10	95.81%
10	6.060E-11	1.163E-10	91.91%
11	6.055E-11	1.102E-10	82.00%
12	5.938E-11	1.009E-10	69.92%
13	5.625E-11	8.945E-11	59.02%
14	5.105E-11	7.635E-11	49.56%
15	4.441E-11	6.305E-11	41.97%
16	3.712E-11	5.032E-11	35.56%
17	2.986E-11	3.862E-11	29.34%
18	2.356E-11	2.890E-11	22.67%
19	1.890E-11	2.196E-11	16.19%
20	1.542E-11	1.696E-11	9.99%
21	1.273E-11	1.332E-11	4.63%
22	1.073E-11	1.083E-11	0.93%
23	9.046E-12	8.905E-12	-1.56%
24	7.529E-12	7.296E-12	-3.09%
25	6.196E-12	5.951E-12	-3.95%
26	5.025E-12	4.806E-12	-4.36%
27	4.019E-12	3.837E-12	-4.53%
28	3.173E-12	3.029E-12	-4.54%
29	2.481E-12	2.371E-12	-4.43%
30	1.926E-12	1.842E-12	-4.36%
31	1.483E-12	1.420E-12	-4.25%
32	1.136E-12	1.089E-12	-4.14%
33	8.617E-13	8.266E-13	-4.07%
34	6.639E-13	6.369E-13	-4.07%
35	5.069E-13	4.860E-13	-4.12%
37.5	2.441E-13	2.336E-13	-4.30%
40	1.078E-13	1.031E-13	-4.36%
42.5	4.798E-14	4.586E-14	-4.42%
45	2.905E-14	2.790E-14	-3.96%
47.5	2.347E-14	2.246E-14	-4.30%
50	1.960E-14	1.908E-14	-2.65%
52.5	1.577E-14	1.560E-14	-1.08%
55	1.211E-14	1.168E-14	-3.55%

Index of Terms

Term	Definition	Page
ALD2	Lumped species representing $\geq C_2$ aldehydes	2
ALKA	Lumped species representing $\geq C_4$ alkanes	2
ALKE	Lumped species representing $\geq C_3$ alkenes	2
Isoprene	A naturally produced alkene of the monoterpene family	2
KET	Lumped species representing all the ketones	2
KO2•	Lumped species representing the keto-peroxy radicals	2
MAC	Methacrolein	7
MCO3•	Lumped species representing peroxyacyl radicals	2
meridional	Of or relating to a great circle on the surface of the earth passing through the poles	1
MVK	Methylvinylketone	7
PO2•	Lumped species representing the alkene-peroxy radicals	2
ROOH	Lumped species representing $\geq C_2$ peroxides	2
stratosphere	The portion of the atmosphere located approximately from 10-55 kilometers above the surface of the earth	1

Figures

Figure 7: HO₂ Profiles

Figure 8: PAN Profiles

END

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