

# Atmospheric chemistry of trans-CF<sub>3</sub>CH=CHF: products and mechanisms of hydroxyl radical and chlorine atom initiated oxidation

M. S. Javadi<sup>1</sup>, R. Søndergaard<sup>1</sup>, O. J. Nielsen<sup>1</sup>, M. D. Hurley<sup>2</sup>, and  
T. J. Wallington<sup>2</sup>

<sup>1</sup>Department of Chemistry, University of Copenhagen, Universitetsparken 5, 2100  
Copenhagen, Denmark

<sup>2</sup>System Analytics and Environmental Sciences Department, Ford Motor Company, Mail Drop  
RIC-2122, Dearborn, MI 48121-2053, USA

Received: 4 December 2007 – Accepted: 5 December 2007 – Published: 23 January 2008

Correspondence to: O. J. Nielsen (ojn@kiku.dk)

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

## Abstract

Smog chamber/FTIR techniques were used to study the products and mechanisms of OH radical and Cl atom initiated oxidation of trans-CF<sub>3</sub>CH=CHF in 700 Torr of N<sub>2</sub>/O<sub>2</sub> diluent at 295±1 K. Hydroxyl radical initiated oxidation leads to the formation of CF<sub>3</sub>CHO and HC(O)F in yields which were indistinguishable from 100% and were not dependent on the O<sub>2</sub> partial pressure. Chlorine atom initiated oxidation gives HC(O)F, CF<sub>3</sub>CHO, CF<sub>3</sub>C(O)Cl, and CF<sub>3</sub>C(O)CHFCl. The yields of CF<sub>3</sub>C(O)Cl and CF<sub>3</sub>C(O)CHFCl increased at the expense of HC(O)F and CF<sub>3</sub>CHO as the O<sub>2</sub> partial pressure was increased over the range 5–700 Torr. The results are discussed with respect to the atmospheric chemistry and environmental impact of trans-CF<sub>3</sub>CH=CHF.

## 1 Introduction

Recognition of the adverse environmental impact of chlorofluorocarbon (CFC) release into the atmosphere (Molina et al., 1974; Farman et al., 1985) has led to an international effort to replace these compounds with environmentally acceptable alternatives. Saturated hydrofluorocarbons (HFCs) have become widely used CFC replacements. For example, CF<sub>3</sub>CH<sub>2</sub>F (HFC-134a) is used as the working fluid in all modern vehicle air conditioning systems. Hydrofluorocarbons do not contain chlorine and hence do not contribute to the well established chlorine based catalytic ozone destruction cycles (Wallington et al., 1994). The atmospheric lifetime of HFCs is determined by their reactivity towards OH radicals. HFC-134a has a direct global warming potential of 1440 over a 100 y time horizon; a factor of 8 lower than the CFC-12 that it replaced (World Meteorological Organization, 2007).

Unsaturated hydrofluorocarbons are a class of compounds, which are potential replacements for CFCs and saturated HFCs in air conditioning units. In general, unsaturated hydrofluorocarbons react more rapidly with OH radicals, have shorter atmospheric lifetimes, and have lower global warming potentials than saturated hy-

ACPD

8, 1069–1088, 2008

## Atmospheric chemistry of trans-CF<sub>3</sub>CH=CHF

M. S. Javadi et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

EGU

drofluorocarbons. Prior to their large-scale industrial use an assessment of the atmospheric chemistry, and hence environmental impact, of these compounds is needed. The present paper provides information concerning the atmospheric oxidation products of trans-CF<sub>3</sub>CH=CHF. Specifically, smog chamber/FTIR techniques were used to determine the products of the OH radical and Cl atom initiated oxidation of trans-CF<sub>3</sub>CH=CHF. The present work builds upon a recent kinetic study in which values of  $k(\text{Cl}+\text{trans-CF}_3\text{CH=CHF})=(4.64\pm 0.59)\times 10^{-11}$  and  $k(\text{OH}+\text{trans-CF}_3\text{CH=CHF})=(9.25\pm 1.72)\times 10^{-13}\text{ cm}^3\text{ molecule}^{-1}\text{ s}^{-1}$  in 700 Torr total pressure at 296 K were determined (Søndergaard et al., 2007).

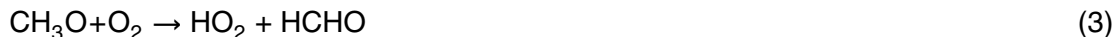
## 2 Experimental

Experiments were performed in a 140-liter Pyrex reactor interfaced to a Mattson Sirius 100 FTIR spectrometer (Wallington and Japar, 1989). The reactor was surrounded by 22 fluorescent blacklamps (GE F15T8-BL), which were used to photochemically initiate the experiments. The products of the atmospheric oxidation of trans-CF<sub>3</sub>CH=CHF were investigated by irradiating trans-CF<sub>3</sub>CH=CHF/CH<sub>3</sub>ONO/O<sub>2</sub>/N<sub>2</sub> and trans-CF<sub>3</sub>CH=CHF/Cl<sub>2</sub>/O<sub>2</sub>/N<sub>2</sub> mixtures. All samples of trans-CF<sub>3</sub>CH=CHF used in this work were supplied by Honeywell International Inc. at a purity >99.9% and were used without further purification.

Chlorine atoms were produced by photolysis of molecular chlorine,



OH radicals were produced by photolysis of CH<sub>3</sub>ONO in the presence of NO in air,



Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

CH<sub>3</sub>ONO was synthesized by the drop wise addition of concentrated sulfuric acid to a saturated solution of NaNO<sub>2</sub> in methanol. Other reagents were obtained from commercial sources at purities >99%. Experiments were conducted in 700 Torr total pressure of N<sub>2</sub>/O<sub>2</sub>, or air diluent at 295±1 K.

5 Concentrations of reactants and products were monitored by FTIR spectroscopy. IR spectra were derived from 32 coadded interferograms with a spectral resolution of 0.25 cm<sup>-1</sup> and an analytical path length of 27.1 m. Unless stated otherwise, quoted uncertainties are two standard deviations from least squares regressions.

### 3 Results

#### 10 3.1 Products of OH radical initiated oxidation of trans-CF<sub>3</sub>CH=CHF

To investigate the products and mechanism of the reaction of OH radicals with trans-CF<sub>3</sub>CH=CHF reaction mixtures consisting of 8.3–34.9 mTorr trans-CF<sub>3</sub>CH=CHF, 82.3–117.3 mTorr CH<sub>3</sub>ONO, 15.1–19.6 mTorr NO, and 126–700 Torr O<sub>2</sub> in 700 Torr total pressure of N<sub>2</sub> diluent were introduced into the chamber and subjected to UV irradiation. Figure 1 shows IR spectra at 1750–1950 cm<sup>-1</sup> obtained before (a) and after (b) 15 subjecting a mixture containing 34.9 mTorr trans-CF<sub>3</sub>CH=CHF, 82.3 mTorr CH<sub>3</sub>ONO, 19.6 mTorr NO, and 126 Torr O<sub>2</sub> in 700 Torr of N<sub>2</sub> diluent to 6 min of UV irradiation. The consumption of trans-CF<sub>3</sub>CH=CHF was 6%. Subtraction of IR features attributable to CF<sub>3</sub>CH=CHF, H<sub>2</sub>O, NO, and HCHO (product of CH<sub>3</sub>ONO photolysis) from panel (b) 20 gives the product spectrum shown in panel (c). Comparison of the IR features in panel (c) with the reference spectra of HC(O)F and CF<sub>3</sub>CHO in panels (d) and (e) shows the formation of these products.

HC(O)F and CF<sub>3</sub>CHO were the only identified carbon containing products of the OH radical initiated oxidation of trans-CF<sub>3</sub>CH=CHF. Figure 2 shows a plot of the observed 25 formation of HC(O)F and CF<sub>3</sub>CHO versus loss of trans-CF<sub>3</sub>CH=CHF. The yields of HC(O)F and CF<sub>3</sub>CHO were indistinguishable. For low consumptions (<1 mTorr) the

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

**Atmospheric  
chemistry of  
trans-CF<sub>3</sub>CH=CHF**

M. S. Javadi et al.

linear least squares fit to the combined data sets has a slope =  $0.93 \pm 0.08$  indistinguishable from 100%. For consumptions of CF<sub>3</sub>CH=CHF greater than 1 mTorr the observed yields of HC(O)F and CF<sub>3</sub>CHO are less than 100% indicating that either the efficiency of conversion of trans-CF<sub>3</sub>CH=CHF into HC(O)F and CF<sub>3</sub>CHO is lower, or there are significant losses of these products at higher trans-CF<sub>3</sub>CH=CHF conversions, or both. To test for heterogeneous loss of HC(O)F and CF<sub>3</sub>CHO, reaction mixtures were allowed to stand in the dark for 15 min; there was no discernable loss (<2%) of either compound. For the 2–14% conversions of trans-CF<sub>3</sub>CH=CHF in the data shown in Fig. 2, loss of HC(O)F and CF<sub>3</sub>CHO via secondary reactions with OH radicals should be of minor importance as their reactivity with OH is less than that of trans-CF<sub>3</sub>CH=CHF;  $k(\text{OH} + \text{trans-CF}_3\text{CH=CHF}) = (9.25 \pm 1.72) \times 10^{-13}$  (Søndergaard et al., 2007),  $k(\text{OH} + \text{HC(O)F}) < 4 \times 10^{-15}$  (Wallington et al., 1993), and  $k(\text{OH} + \text{CF}_3\text{CHO}) = (6 \pm 1.2) \times 10^{-13} \text{ cm}^3 \text{ molecule}^{-1} \text{ s}^{-1}$  (IUPAC, 2007). It seems likely that the curvature in Fig. 2 reflects a lower yield of both HC(O)F and CF<sub>3</sub>CHO with increased consumption of CF<sub>3</sub>CH=CHF. A possible explanation of this effect is the reaction of NO<sub>2</sub> (which increases in concentration with consumption of trans-CF<sub>3</sub>CH=CHF) with the alkoxy radicals formed in the system leading to the formation of small amounts of nitrates. In the atmosphere such reactions will not be of any significance and we did not pursue the origin of the curvature further.

By analogy to the well established oxidation mechanism of propene (IUPAC, 2007), the reaction of OH radicals with trans-CF<sub>3</sub>CH=CHF is expected to proceed via addition to the >C=C< double bond. The mechanism of the OH radical initiated oxidation of trans-CF<sub>3</sub>CH=CHF which explains the observed formation of HC(O)F and CF<sub>3</sub>CHO as shown in Fig. 3. The results from the present work indicate that irrespective of whether the OH radicals add to the terminal, or central carbon atom, the subsequent reactions lead to the formation of one molecule of both HC(O)F and CF<sub>3</sub>CHO.

[Title Page](#)[Abstract](#)[Introduction](#)[Conclusions](#)[References](#)[Tables](#)[Figures](#)[◀](#)[▶](#)[◀](#)[▶](#)[Back](#)[Close](#)[Full Screen / Esc](#)[Printer-friendly Version](#)[Interactive Discussion](#)

### 3.2 Products of Cl atom initiated oxidation of trans-CF<sub>3</sub>CH=CHF

The products of the Cl atom initiated oxidation of trans-CF<sub>3</sub>CH=CHF were studied using the UV irradiation of trans-CF<sub>3</sub>CH=CHF/Cl<sub>2</sub>/O<sub>2</sub>/N<sub>2</sub> mixtures. Mixtures consisting of 6.6–8.4 mTorr trans-CF<sub>3</sub>CH=CHF, 102.9–134 mTorr Cl<sub>2</sub> and 5–700 Torr of O<sub>2</sub> in 700 Torr total pressure of N<sub>2</sub> diluent were introduced into the reaction chamber and subjected to UV irradiation. Figures 4 and 5 show IR spectra at 675–1000 cm<sup>-1</sup> and 1650–2000 cm<sup>-1</sup>, respectively, obtained before (a) and after (b) subjecting a mixture containing 6.6 mTorr trans-CF<sub>3</sub>CH=CHF and 109 mTorr Cl<sub>2</sub> in 700 Torr air diluent to 20 s of UV irradiation. Comparison of the IR features formed in low and high [O<sub>2</sub>] experiments revealed that four products were formed in the chamber; HC(O)F, CF<sub>3</sub>CHO, CF<sub>3</sub>C(O)Cl, and a product with a broad absorption feature in the carbonyl stretching region centered at 1801 cm<sup>-1</sup> which we attribute to the ketone CF<sub>3</sub>C(O)CHFCl. We do not have a calibrated reference spectrum for CF<sub>3</sub>C(O)CHFCl. The concentration of this compound in the chamber was estimated by assuming that the carbonyl stretching band integrated absorption cross section at 1780–1820 cm<sup>-1</sup> is the same as that in CF<sub>3</sub>C(O)CH<sub>2</sub>Cl (1.06 × 10<sup>-17</sup> cm molecule<sup>-1</sup>, Nakayama et al., 2007).

Figure 6 shows a plot of the concentrations of HC(O)F, CF<sub>3</sub>CHO, CF<sub>3</sub>C(O)Cl, and CF<sub>3</sub>C(O)CHFCl versus the loss of trans-CF<sub>3</sub>CH=CHF observed following the UV irradiation of a mixture of 6.61 mTorr trans-CF<sub>3</sub>CH=CHF and 109 mTorr Cl<sub>2</sub> in 700 Torr of air diluent. As seen from Fig. 6 the formation of HC(O)F, CF<sub>3</sub>C(O)H, CF<sub>3</sub>C(O)Cl and CF<sub>3</sub>C(O)CHFCl scaled linearly with the loss of trans-CF<sub>3</sub>CH=CHF over the range of trans-CF<sub>3</sub>CH=CHF consumption of 10–95%. The linearity of the formation of HC(O)F, CF<sub>3</sub>CHO, CF<sub>3</sub>C(O)Cl and CF<sub>3</sub>C(O)CHFCl suggests that loss of these compounds via secondary reactions is not significant. This observation is consistent with the fact that Cl atoms react much more slowly with these products than with the parent trans-CF<sub>3</sub>CH=CHF compound;  $k(\text{Cl} + \text{trans-CF}_3\text{CH=CHF}) = (4.64 \pm 0.59) \times 10^{-11}$  (Søndergaard et al., 2007),  $k(\text{Cl} + \text{HC(O)F}) = (1.9 \pm 0.2) \times 10^{-15}$  (Meagher et al., 1997), and  $k(\text{Cl} + \text{CF}_3\text{CHO}) = (1.85 \pm 0.26) \times 10^{-12}$  cm<sup>3</sup> molecule<sup>-1</sup> s<sup>-1</sup> (Sulbaek Andersen et al.,

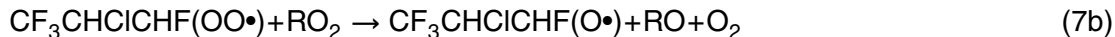
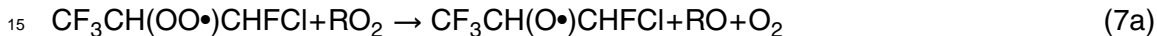
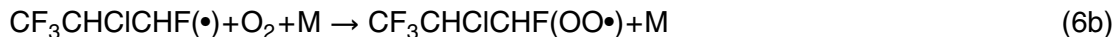
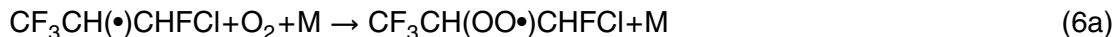
[Title Page](#)[Abstract](#)[Introduction](#)[Conclusions](#)[References](#)[Tables](#)[Figures](#)[⏪](#)[⏩](#)[◀](#)[▶](#)[Back](#)[Close](#)[Full Screen / Esc](#)[Printer-friendly Version](#)[Interactive Discussion](#)

2004). Previous work has shown that  $\text{CF}_3\text{C}(\text{O})\text{Cl}$  is not lost by heterogeneous processes, photolysis, or reaction with Cl atoms in the chamber (Møgelberg et al., 1995).

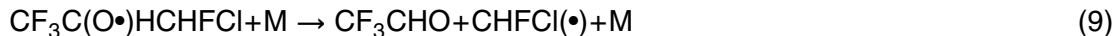
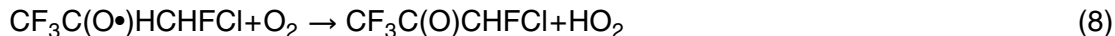
As shown in Fig. 7, the yields of  $\text{HC}(\text{O})\text{F}$ ,  $\text{CF}_3\text{CHO}$ ,  $\text{CF}_3\text{C}(\text{O})\text{Cl}$  and  $\text{CF}_3\text{C}(\text{O})\text{CHFCl}$  varied with  $[\text{O}_2]$ . In experiments with high  $[\text{O}_2]$  the yields of  $\text{CF}_3\text{C}(\text{O})\text{Cl}$  and  $\text{CF}_3\text{C}(\text{O})\text{CHFCl}$  increased at the expense of  $\text{HC}(\text{O})\text{F}$  and  $\text{CF}_3\text{CHO}$ . As in the case of the OH radical attack, the reaction of Cl atoms with  $\text{trans-CF}_3\text{CH}=\text{CHF}$  is expected to proceed via electrophilic addition to the terminal and central carbon atoms:



The radicals produced in Reaction (5) will react with  $\text{O}_2$  to give peroxy radicals which will undergo self- and cross-reaction to give the corresponding alkoxy radicals (in the equations below M represents a third body):



Decomposition via C-C bond scission or reaction with  $\text{O}_2$  are likely fates of the alkoxy radicals. The observed formation of the ketone  $\text{CF}_3\text{C}(\text{O})\text{CHFCl}$  in a yield which varies with  $[\text{O}_2]$  shows that  $\text{CF}_3\text{C}(\text{O}\bullet)\text{HCHFCl}$  radicals undergo reaction with  $\text{O}_2$  and decomposition via C-C bond scission:



Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

[Title Page](#)
[Abstract](#)
[Introduction](#)
[Conclusions](#)
[References](#)
[Tables](#)
[Figures](#)
[Back](#)
[Close](#)
[Full Screen / Esc](#)
[Printer-friendly Version](#)
[Interactive Discussion](#)

The CHFCl(•) radicals formed in Reaction (9) will add O<sub>2</sub>, undergo reaction with other peroxy radicals in the system to give CHFCl(O•) radicals, and decompose via Cl atom elimination to give HC(O)F (Tuazon et al., 1993). The data in Fig. 7 contain information concerning the rate constant ratio  $k_8/k_9$ . The yield of CF<sub>3</sub>C(O)CHFCl,  $Y_{CF_3C(O)CHFCl}$ , can be described by the expression  $Y_{CF_3C(O)CHFCl} = Y_{CF_3CH(O•)CHFCl} (k_8[O_2]/(k_8[O_2]+k_9)) + C$ , where  $Y_{CF_3CH(O•)CHFCl}$  is the yield of CF<sub>3</sub>CH(O•)CHFCl radicals in the system,  $k_8$  and  $k_9$  are the rate constants for Reactions (8) and (9), and C is the [O<sub>2</sub>] independent yield of CF<sub>3</sub>C(O)CHFCl (e.g., from self-reaction of CF<sub>3</sub>CH(OO•)CHFCl peroxy radicals).

The curve through the CF<sub>3</sub>C(O)CHFCl data in Fig. 7 is a fit of the expression above to the data which gives  $k_8/k_9 = (8.0 \pm 2.6) \times 10^{-19} \text{ cm}^3 \text{ molecule}^{-1}$ . This value can be compared to the analogous rate constant ratio  $k_{O_2}/k_{diss} = (3.8 \pm 1.8) \times 10^{-18} \text{ cm}^3 \text{ molecule}^{-1}$  measured for CF<sub>3</sub>CH(O•)CH<sub>2</sub>Cl radicals (Nakayama et al., 2007). The increased importance of decomposition as an atmospheric fate of CF<sub>3</sub>CH(O•)CHFCl compared to CF<sub>3</sub>CH(O•)CH<sub>2</sub>Cl radicals is consistent with theoretical work showing that the barrier to C-C bond scission decreases as the degree of fluorine substitution on the two carbon atoms becomes more even and the bond becomes less polar (Somnitz et al., 2001). The limiting value for the CF<sub>3</sub>C(O)CHFCl yield reached at high [O<sub>2</sub>] provides a measure of  $k_{5a}/(k_{5a}+k_{5b}) = 47 \pm 7\%$ .

Figure 8 shows the mechanism of Cl atom initiated oxidation of trans-CF<sub>3</sub>CH=CHF which is consistent with our experimental observations. From  $k_8/k_9 = (8.0 \pm 2.6) \times 10^{-19} \text{ cm}^3 \text{ molecule}^{-1}$  it can be calculated that in 700 Torr of O<sub>2</sub> the reaction with O<sub>2</sub> accounts for 92% of the CF<sub>3</sub>CH(O•)CH<sub>2</sub>Cl radicals with decomposition accounting for the remaining 8%. Given the estimate of  $k_{5a}/(k_{5a}+k_{5b}) = 47 \pm 7\%$  we then expect a 4% HC(O)F yield resulting from addition of Cl atoms to the terminal carbon atom (left hand side of Fig. 8). Hence, we can attribute the bulk of the approximately 40% HC(O)F yield in experiments in 700 Torr of O<sub>2</sub> to the decomposition of CF<sub>3</sub>CHClCHF(O•) radicals. Decomposition via C-C bond scission is the dominant fate of CF<sub>3</sub>CHClCHF(O•) radicals. Finally, the increase in the yield of CF<sub>3</sub>C(O)Cl



[Title Page](#)
[Abstract](#)
[Introduction](#)
[Conclusions](#)
[References](#)
[Tables](#)
[Figures](#)
[⏪](#)
[⏩](#)
[◀](#)
[▶](#)
[Back](#)
[Close](#)
[Full Screen / Esc](#)
[Printer-friendly Version](#)
[Interactive Discussion](#)

with [O<sub>2</sub>] evident in Fig. 7 is consistent with the expected competition between reaction with O<sub>2</sub> and decomposition for the available CF<sub>3</sub>CHCl(O•) radicals. The yield of CF<sub>3</sub>C(O)Cl, Y<sub>CF<sub>3</sub>C(O)Cl</sub>, can be described by the expression  $Y_{CF_3C(O)Cl} = Y_{CF_3CHCl(O\bullet)} (k_{10}[O_2]/(k_{10}[O_2]+k_{11})) + C$ , where Y<sub>CF<sub>3</sub>CHCl(O•)</sub> is the yield of CF<sub>3</sub>CHCl(O•) radicals in the system, k<sub>10</sub> and k<sub>11</sub> are the rate constants for Reactions (10) and (11), and C is the [O<sub>2</sub>] independent yield of CF<sub>3</sub>C(O)Cl.



The curve through the CF<sub>3</sub>C(O)Cl data in Fig. 7 is a fit of the expression above to the data which gives  $k_{10}/k_{11} = (4.6 \pm 1.9) \times 10^{-19} \text{ cm}^3 \text{ molecule}^{-1}$ . This result is larger than the previous more direct determination of  $k_{10}/k_{11} = (2.1 \pm 0.4) \times 10^{-19} \text{ cm}^3 \text{ molecule}^{-1}$  (Møgelberg et al., 1995). A likely explanation for this discrepancy lies in the indirect and complex route by which CF<sub>3</sub>CHCl(O•) radicals are formed in the present system. As indicated in Fig. 8, decomposition and reaction with O<sub>2</sub> are possible competing fates for CF<sub>3</sub>CHClCHF(O•) radicals. Increased loss of CF<sub>3</sub>CHClCHF(O•) via reaction with O<sub>2</sub> at high [O<sub>2</sub>] will lead to a decreased yield of CF<sub>3</sub>CHCl(O•) radicals and hence CF<sub>3</sub>C(O)Cl. The net effect will be to cause the CF<sub>3</sub>C(O)Cl yield to plateau at a lower [O<sub>2</sub>] which will lead to an overestimation of k<sub>10</sub>/k<sub>11</sub>. To investigate this effect further would require the use of [O<sub>2</sub>] levels higher than 700 Torr where a decrease in the yield of CF<sub>3</sub>C(O)Cl would be expected with increased loss of CF<sub>3</sub>CHClCHF(O•) via reaction with O<sub>2</sub>. Such experiments are beyond the scope of the present work.

#### 4 Atmospheric chemistry and environmental impact of trans-CF<sub>3</sub>CH=CHF

The present work improves our understanding of the atmospheric chemistry of trans-CF<sub>3</sub>CH=CHF. The atmospheric lifetime of trans-CF<sub>3</sub>CH=CHF is dictated by its reaction with OH radicals (Søndergaard et al., 2007) and has been estimated at approximately 2

**Atmospheric  
chemistry of  
trans-CF<sub>3</sub>CH=CHF**

M. S. Javadi et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

weeks. The OH initiated oxidation of trans-CF<sub>3</sub>CH=CHF gives CF<sub>3</sub>CHO and HC(O)F in yields of approximately 100%. CF<sub>3</sub>CHO is removed from the atmosphere via photolysis and, to lesser extents, reaction with OH radicals (Chiappero et al., 2006) and addition of water to give the hydrate (Sulbaek Andersen et al., 2006). Photolysis gives CF<sub>3</sub> and HCO radicals (Chiappero et al., 2006) while reaction with OH gives CF<sub>3</sub>CO radicals. CF<sub>3</sub> radicals will add O<sub>2</sub> to give CF<sub>3</sub>O<sub>2</sub> radicals which are then converted into COF<sub>2</sub> (Wallington et al., 1994) which hydrolyzes to give CO<sub>2</sub> and HF. CF<sub>3</sub>CO radicals will add O<sub>2</sub> to give CF<sub>3</sub>C(O)O<sub>2</sub> radicals, the majority of which will be converted into COF<sub>2</sub>, with a small fraction converted into CF<sub>3</sub>C(O)OH (Hurley et al., 2006) via reaction with HO<sub>2</sub> radicals. The hydrate, CF<sub>3</sub>CH(OH)<sub>2</sub> is lost via reaction with OH radicals to give CF<sub>3</sub>C(O)OH (Sulbaek Andersen et al., 2006). The available data suggest that while CF<sub>3</sub>C(O)OH is not a natural component of the freshwater environment (Nielsen et al., 2001), it is a natural component of the background oceanic environment (Frank et al., 2002), and any additional burden associated with trans-CF<sub>3</sub>CH=CHF oxidation will be of negligible environmental significance. We conclude that the products of the atmospheric oxidation of trans-CF<sub>3</sub>CH=CHF will have negligible environmental impact.

*Acknowledgement.* M. S. Javadi, R. Søndergaard and O. J. Nielsen acknowledge financial support from the Danish Natural Science Research Council for the Copenhagen Center for Atmospheric Research (CCAR).

**References**

- Chiappero, M. S., Malanca, F. E., Argüello, G. A., Wooldridge, S. T., Hurley, M. D., Ball, J. C., Wallington, T. J., Waterland, R. L., and Buck, R. C.: Atmospheric chemistry of perfluoroaldehydes (C<sub>x</sub>F<sub>2x+1</sub>CHO) and fluorotelomer aldehydes (C<sub>x</sub>F<sub>2x+1</sub>CH<sub>2</sub>CHO): quantification of the important role of photolysis, *J. Phys. Chem. A*, 110, 11 944–11 953, 2006.
- Farman, J. D., Gardiner, B. G., and Shanklin, J. D.: Large losses of total ozone in Antarctica reveal seasonal ClO<sub>x</sub>/NO<sub>x</sub> interaction, *Nature*, 315, 207–210, 1985.
- Frank, H., Christoph, E. H., Holm-Hansen, O., and Bullister, J. L.: Trifluoroacetate in ocean waters, *Environ. Sci. Technol.*, 36, 12–15, 2002.

**Atmospheric  
chemistry of  
trans-CF<sub>3</sub>CH=CHF**

M. S. Javadi et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

- Hurley, M. D., Ball, J. C., Wallington, T. J., Sulbaek Andersen, M. P., Nielsen, O. J., Ellis, D. A., Martin, J. W., and Mabury, S. A.: Atmospheric chemistry of  $n$ -C<sub>x</sub>F<sub>2x+1</sub>CHO ( $x=1, 2, 3, 4$ ): fate of  $n$ -C<sub>x</sub>F<sub>2x+1</sub>C(O) radicals, *J. Phys. Chem. A*, 110, 12443–12447, 2006.
- IUPAC, available at: <http://www.iupac-kinetic.ch.cam.ac.uk>, 2007.
- 5 Meagher, R. J., McIntosh, M. E., Hurley, M. D., and Wallington, T. J.: A kinetic study of the reaction of chlorine and fluorine atoms with HC(O)F at 295±2K, *Int. J. Chem. Kinet.*, 29, 619–625, 1997.
- Molina, M. J. and Rowland, F. S.: Stratospheric sink for chlorofluoromethanes: chlorine atom catalysed destruction of ozone, *Nature*, 249, 810–812, 1974.
- 10 Møgelberg, T. E., Nielsen, O. J., Sehested, J., and Wallington, T. J.: Atmospheric chemistry of HCFC-133a: the UV absorption spectra of CF<sub>3</sub>CClH and CF<sub>3</sub>CClHO<sub>2</sub> radicals, reactions of CF<sub>3</sub>CClHO<sub>2</sub> with NO and NO<sub>2</sub>, and fate of CF<sub>3</sub>CClHO radicals, *J. Phys. Chem.*, 99, 13437–13444, 1995.
- Nakayama, T., Takahashi, K., Matsumi, Y., Sulbaek Andersen, M. P., Nielsen, O. J., Waterland, R. L., Buck, R. C., Hurley, M. D., and Wallington, T. J.: Atmospheric chemistry of CF<sub>3</sub>CH=CH<sub>2</sub> and C<sub>4</sub>F<sub>9</sub>CH=CH<sub>2</sub>: products of the gas-phase reactions with Cl atoms and OH radicals, *J. Phys. Chem. A*, 111, 909–915, 2007.
- Nielsen, O. J., Scott, B. F., Spencer, C., Wallington, T. J., and Ball, J. C.: Trifluoroacetic acid in ancient freshwater, *Atmos. Environ.*, 35, 2799–2801, 2001.
- 20 Somnitz, H. and Zellner, R.: Theoretical studies of the thermal and chemically activated decomposition of CF<sub>3</sub>CY<sub>2</sub>O (Y=F, H) radicals, *Phys. Chem. Chem. Phys.*, 3, 2352–2364, 2001.
- Sulbaek Andersen, M. P., Nielsen, O. J., Hurley, M. D., Wallington, T. J., Stevens, J. E., Marten, J. W., Ellis, D. A., and Mabury, S. A.: Atmospheric chemistry of  $n$ -C<sub>x</sub>F<sub>2x+1</sub>CHO ( $x=1, 3, 4$ ): reaction with Cl atoms, OH radicals and IR spectra of C<sub>x</sub>F<sub>2x+1</sub>C(O)O<sub>2</sub>NO<sub>2</sub>, *J. Phys. Chem. A*, 108, 5189–5196, 2004.
- 25 Sulbaek Andersen, M. P., Toft, A., Nielsen, O. J., Hurley, M. D., Wallington, T. J., Chishima, H., Tonokura, K., Mabury, S. A., Martin, J. W., and Ellis, D. A.: Atmospheric chemistry of perfluorinated aldehyde hydrates ( $n$ -C<sub>x</sub>F<sub>2x+1</sub>CH(OH)<sub>2</sub>,  $x=1, 3, 4$ ): hydration, dehydration, and kinetics and mechanism of Cl atom and OH radical initiated oxidation, *J. Phys. Chem. A*, 110, 9854–9860, 2006.
- 30 Søndergaard, R., Nielsen, O. J., Hurley, M. D., Wallington, T. J., and Singh, R.: Atmospheric chemistry of trans-CF<sub>3</sub>CH=CHF: kinetics of the gas-phase reactions with Cl atoms, OH radicals, and O<sub>3</sub>, *Chem. Phys. Lett.*, 443, 199–204, 2007.

- Tuazon, E. C. and Atkinson, R.: Tropospheric transformation products of a series of hydrofluorocarbons and hydrochlorofluorocarbons, *J. Atmos. Chem.*, 17, 179–199, 1993.
- Wallington, T. J. and Hurley, M. D.: Atmospheric chemistry of formyl fluoride: reaction with hydroxyl radicals, *Environ. Sci. Technol.*, 27, 1448–1452, 1993.
- 5 Wallington, T. J. and Japar, S. M.: Fourier transform infrared kinetic studies of the reaction of HONO with HNO<sub>3</sub>, NO<sub>3</sub> and N<sub>2</sub>O<sub>5</sub> at 295 K, *J. Atmos. Chem.*, 9, 399–409, 1989.
- Wallington, T. J., Schneider, W. F., Worsnop, D. R., Nielsen, O. J., Sehested, J., DeBruyn, W., and Shorter, J. A.: The environmental impact of CFC replacements-HFCs and HCFCs, *Environ. Sci. Technol.*, 28, 320A–326A, 1994.
- 10 World Meteorological Organization, Scientific Assessment of Ozone Depletion: 2006, Geneva, 2007.

---

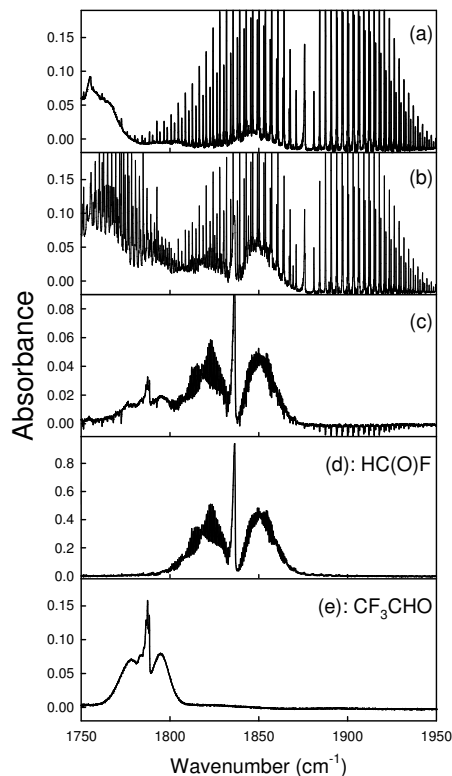
**Atmospheric  
chemistry of  
trans-CF<sub>3</sub>CH=CHF**M. S. Javadi et al.

---

[Title Page](#)[Abstract](#)[Introduction](#)[Conclusions](#)[References](#)[Tables](#)[Figures](#)[◀](#)[▶](#)[◀](#)[▶](#)[Back](#)[Close](#)[Full Screen / Esc](#)[Printer-friendly Version](#)[Interactive Discussion](#)

Atmospheric  
chemistry of  
 $\text{trans-CF}_3\text{CH=CHF}$ 

M. S. Javadi et al.

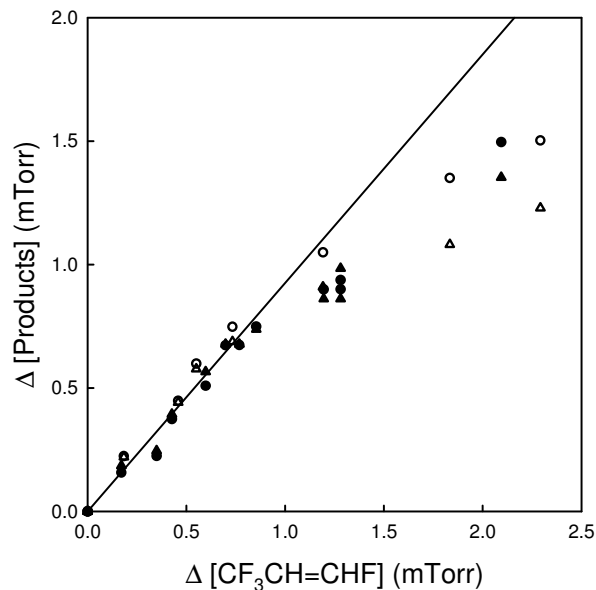


**Fig. 1.** Infrared spectra acquired before **(a)** and after **(b)** UV irradiation of mixtures 34.9 mTorr  $\text{trans-CF}_3\text{CH=CHF}$ , 82.3 mTorr  $\text{CH}_3\text{ONO}$ , 19.6 mTorr  $\text{NO}$  and 126 Torr  $\text{O}_2$  in 700 Torr total pressure of  $\text{N}_2$  diluent. Panel **(c)** show the residual IR features after subtraction of features attributable to  $\text{trans-CF}_3\text{CH=CHF}$ ,  $\text{H}_2\text{O}$ ,  $\text{NO}$ , and  $\text{HCHO}$  from panel (b). Panels **(d)** and **(e)** show reference spectra of  $\text{HC(O)F}$  and  $\text{CF}_3\text{CHO}$ , respectively.

[Title Page](#)[Abstract](#)[Introduction](#)[Conclusions](#)[References](#)[Tables](#)[Figures](#)[◀](#)[▶](#)[◀](#)[▶](#)[Back](#)[Close](#)[Full Screen / Esc](#)[Printer-friendly Version](#)[Interactive Discussion](#)

Atmospheric  
chemistry of  
 $\text{trans-CF}_3\text{CH=CHF}$ 

M. S. Javadi et al.



**Fig. 2.** Formation of  $\text{HC(O)F}$  (triangles) and  $\text{CF}_3\text{CHO}$  (circles) versus loss of  $\text{trans-CF}_3\text{CH=CHF}$  observed following the UV irradiation of mixtures of 8.32–9.18 mTorr  $\text{trans-CF}_3\text{CH=CHF}$  and 109.1–113.8 mTorr  $\text{CH}_3\text{ONO}$  in 700 Torr total pressure of air diluent at  $296 \pm 1$  K. The open symbols are results obtained in the absence of  $\text{NO}$ .

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

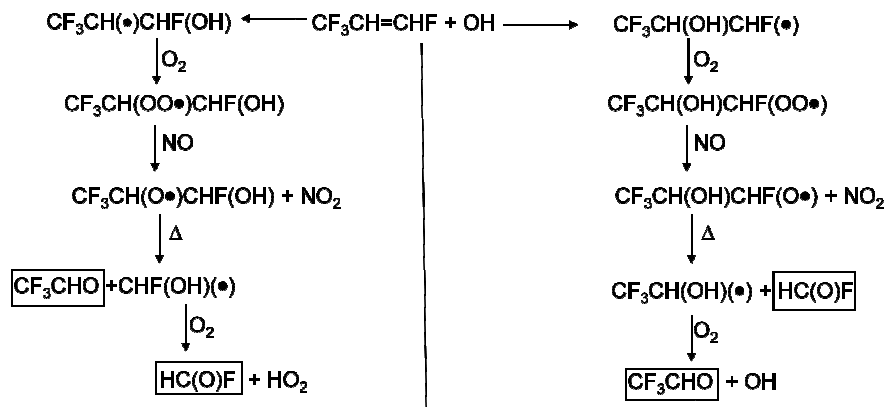
Full Screen / Esc

Printer-friendly Version

Interactive Discussion

## Atmospheric chemistry of trans-CF<sub>3</sub>CH=CHF

M. S. Javadi et al.



**Fig. 3.** Mechanism of OH radical initiated oxidation of trans-CF<sub>3</sub>CH=CHF, boxes indicate observed products.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

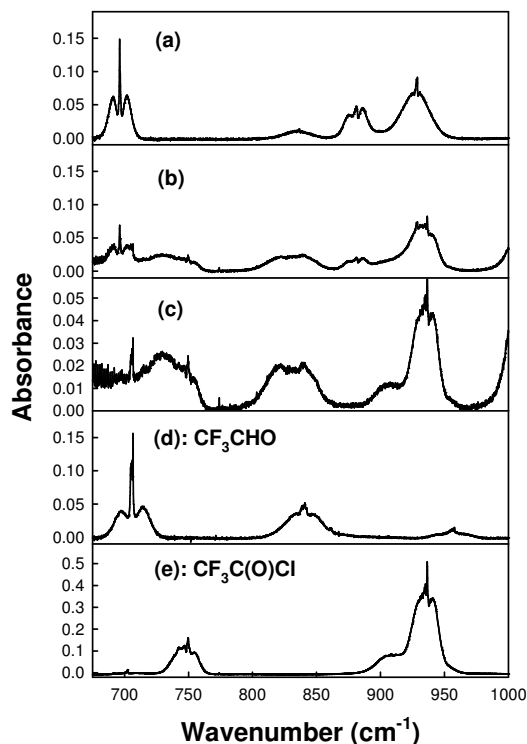
Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Atmospheric  
chemistry of  
 $\text{trans-CF}_3\text{CH=CHF}$ 

M. S. Javadi et al.



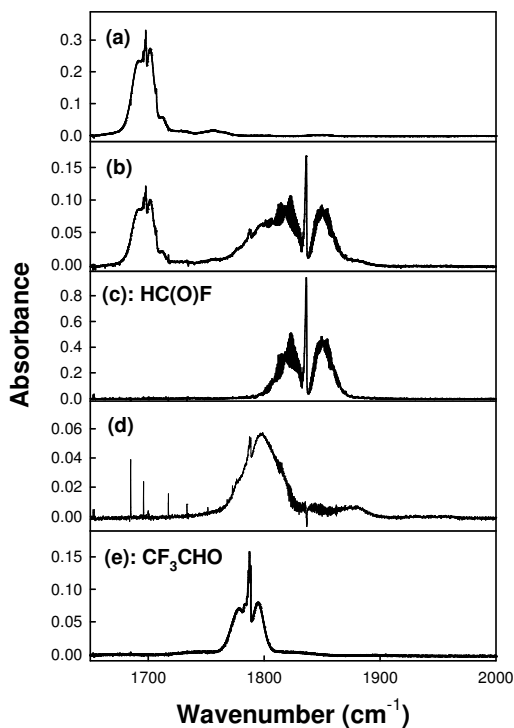
**Fig. 4.** Infrared spectra acquired before **(a)** and after **(b)** UV irradiation of 6.6 mTorr  $\text{trans-CF}_3\text{CH=CHF}$  and 109 mTorr  $\text{Cl}_2$  in 700 Torr of air diluent. Panel **(c)** show the residual IR features after subtraction of  $\text{trans-CF}_3\text{CH=CHF}$  from panel **(b)**. Panels **(d)** and **(e)** show reference spectra of  $\text{CF}_3\text{CHO}$  and  $\text{CF}_3\text{C(O)Cl}$ , respectively.

[Title Page](#)[Abstract](#)[Introduction](#)[Conclusions](#)[References](#)[Tables](#)[Figures](#)[◀](#)[▶](#)[◀](#)[▶](#)[Back](#)[Close](#)[Full Screen / Esc](#)[Printer-friendly Version](#)[Interactive Discussion](#)



Atmospheric  
chemistry of  
trans-CF<sub>3</sub>CH=CHF

M. S. Javadi et al.

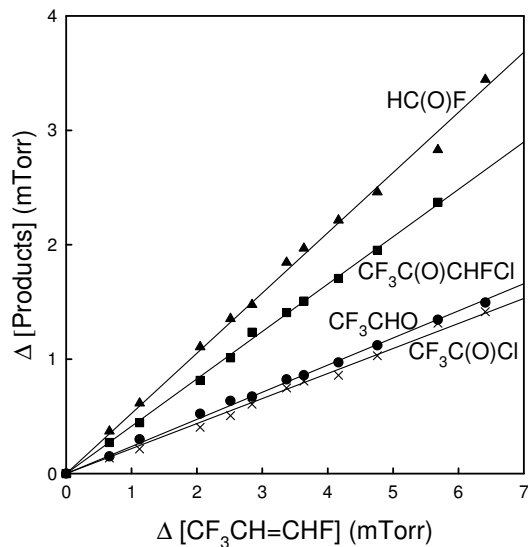


**Fig. 5.** Infrared spectra acquired before **(a)** and after **(b)** UV irradiation of 6.6 mTorr trans-CF<sub>3</sub>CH=CHF and 109 mTorr Cl<sub>2</sub> in 700 Torr of air diluent. Panel **(c)** show a reference spectrum of HC(O)F. Panel **(d)** show the residual IR features after subtraction of trans-CF<sub>3</sub>CH=CHF and HC(O)F from panel (b). Panel **(e)** shows a reference spectrum of CF<sub>3</sub>CHO.

[Title Page](#)[Abstract](#)[Introduction](#)[Conclusions](#)[References](#)[Tables](#)[Figures](#)[◀](#)[▶](#)[◀](#)[▶](#)[Back](#)[Close](#)[Full Screen / Esc](#)[Printer-friendly Version](#)[Interactive Discussion](#)

Atmospheric  
chemistry of  
 $\text{trans-CF}_3\text{CH=CHF}$ 

M. S. Javadi et al.



**Fig. 6.** Formation of  $\text{HC(O)F}$  (triangles),  $\text{CF}_3\text{C(O)CHFCl}$  (squares),  $\text{CF}_3\text{CHO}$  (circles) and,  $\text{CF}_3\text{C(O)Cl}$  (crosses) versus loss of  $\text{trans-CF}_3\text{CH=CHF}$  observed following the UV irradiation of a mixture of 6.6 mTorr  $\text{trans-CF}_3\text{CH=CHF}$  and 109 mTorr  $\text{Cl}_2$  in 700 Torr of air diluent.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

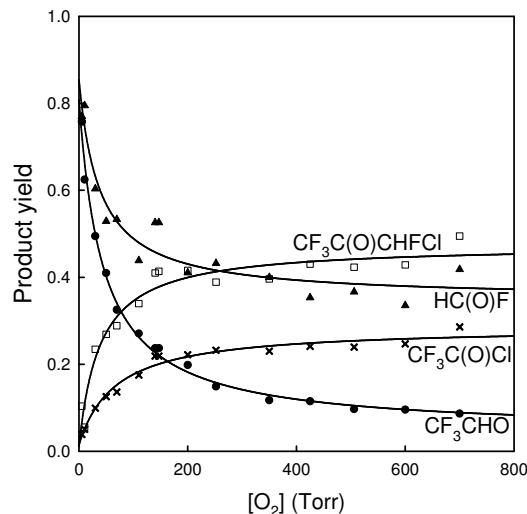
Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Atmospheric  
chemistry of  
 $\text{trans-CF}_3\text{CH=CHF}$ 

M. S. Javadi et al.

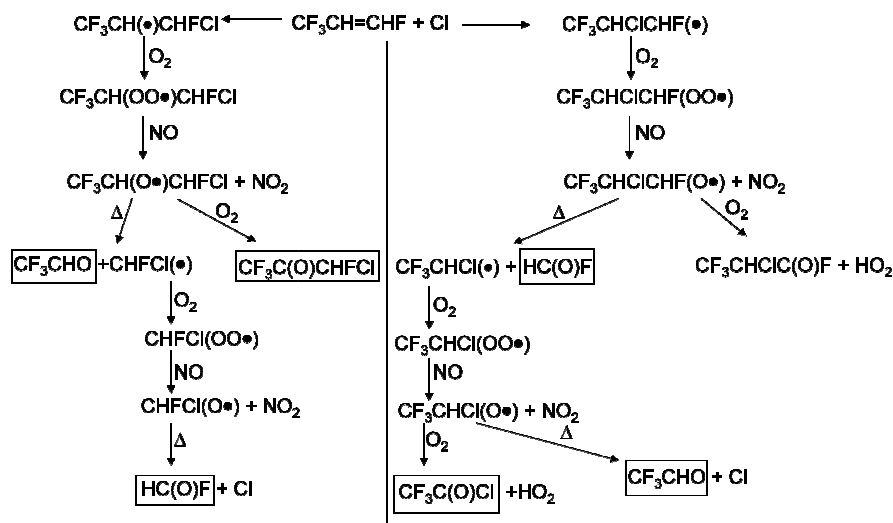


**Fig. 7.** Observed molar yields of  $\text{HC(O)F}$  (triangles),  $\text{CF}_3\text{CHO}$  (circles),  $\text{CF}_3\text{C(O)Cl}$  (crosses) and  $\text{CF}_3\text{C(O)CHFCl}$  (squares) versus the  $\text{O}_2$  partial pressure following the UV irradiation of  $\text{trans-CF}_3\text{CH=CHF/Cl}_2/\text{N}_2/\text{O}_2$  mixtures at 700 Torr total pressure. Curves through the  $\text{CF}_3\text{C(O)CHFCl}$  and  $\text{CF}_3\text{C(O)Cl}$  are fits to the data using the expressions described in the text. The curves through the  $\text{HC(O)F}$  and  $\text{CF}_3\text{CHO}$  data are polynomial fits to aid visual inspection of data trends.

[Title Page](#)[Abstract](#)[Introduction](#)[Conclusions](#)[References](#)[Tables](#)[Figures](#)[◀](#)[▶](#)[◀](#)[▶](#)[Back](#)[Close](#)[Full Screen / Esc](#)[Printer-friendly Version](#)[Interactive Discussion](#)

## Atmospheric chemistry of trans-CF<sub>3</sub>CH=CHF

M. S. Javadi et al.



**Fig. 8.** Mechanism of Cl atom initiated oxidation of trans-CF<sub>3</sub>CH=CHF, boxes indicate observed products.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion