Global and regional emissions estimates for HCFC-22

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Importance of HCFC-22 (CHClF$_2$)

- Major Greenhouse Gas
  - Global Warming Potential: 1810

- Ozone-Depleting Substance: Regulated by the Montreal Protocol
  - Developed countries already started regulation (cease production by 2030, 99.5% by 2020)
  - Developing countries start in 2013

- Atmospheric lifetime: 11.9 years (primary sink - OH)

- Used for commercial refrigeration, air conditioning, and foam industries.
HCFC-22 Mixing Ratio Increasing

- No atmospheric mixing ratio in pre-industrial times

Source: AGAGE, NOAA, CGAA, and THD air samples
Source and Magnitude of HCFC-22 Emissions

- **Source:** Only anthropogenic

Source: McCulloch et al., 2003

![HCFC-22 global emissions estimate graph](image)

Source: Eri Saikawa

Global and regional emissions estimates for HCFC-22
Methods

- Global 3-dimensional chemical transport model MOZART v4
- Conducted 2 simulations:
  - 1st simulation: Global, 1995-2009
  - Horizontal resolution: 5° latitude x 5° longitude
  - 2nd simulation: Regional, 2005-2009
  - Horizontal resolution: 1.9° latitude x 2.5° longitude
- 56 vertical levels from the surface to approximately 2mb
- Meteorological field: MERRA
- Bayesian weighted least-squares:
  - Minimizing the following cost function with respect to $x$:
    \[ J = (y - Hx)^T W^{-1} (y - Hx) + x^T S^{-1} x \] (1)
A priori emissions

- McCulloch et al. (2003): 1995-2000.
- Consumption data submitted to United Nations: 2001-2009.

Source: UNEP
10 Regions used for the inversion

- Canada & Alaska
- US West
- US Midwest
- US East
- Central & South America
- Europe
- Africa & Middle East
- North Asia
- Article 5 Asia
- Oceania
Observational Data

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Global HCFC-22 emissions estimated from inversion

- Optimized emissions (this study)
- Polynomial fit prior (this study)
- "Raw" prior (this study)
- Bank emissions estimate (IPCC/TEAP, 2005; UNEP, 2007)
- "Bottom-up" emissions estimate (UNEP/TEAP, 2006)
- 12-box model emissions estimate (Wang)
- 1-box model emissions estimate (Montzka et al., 2009)

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Results: Regional Emissions

(a) US East

prior emissions
optimized (AGAGE + NOAA flasks + NOAA tower)
optimized (AGAGE + NOAA flasks)
optimized (AGAGE only)
optimized (NOAA flasks only)

uncertainty reduction (%)

optimized (AGAGE + NOAA flasks + NOAA tower)
optimized (AGAGE + NOAA flasks)
optimized (AGAGE only)
optimized (NOAA flasks only)
Results: Regional Emissions

(b) US Midwest

Global and regional emissions estimates for HCFC-22
Results: Regional Emissions

(c) US West
Results: Regional Emissions

(d) North Asia

(e) Article 5 Asia
Global HCFC-22 emissions (Gg year$^{-1}$)

- AFEAS (1997): 225 Gg year$^{-1}$ in 1995
- This study: 169±45.69 Gg year$^{-1}$ in 1995
Comparison with other models - Global

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- Stohl et al. (2009): 333 Gg year\(^{-1}\) for 2005 and 2006
- This study: 272±78 Gg year\(^{-1}\) for 2005 and 2006
- Montzka et al. (2009) - global emissions increasing by 93 Gg from 2004-2007 & emissions shift towards low latitude in NH
- This study: 251±13.3 Gg year\(^{-1}\) in 2004 to 368±15.9 Gg year\(^{-1}\) in 2007.
Comparison with other models - Regional

- United States HCFC-22 emissions (Gg year$^{-1}$)
  - Miller et al. (2009): 46 Gg year$^{-1}$ for 2005 and 2006
  - EPA bottom-up estimates: 83Gg year$^{-1}$ in 2004
  - This study: 67.9±20.6 Gg year$^{-1}$ for 2005 and 2006
Comparison with other models - Regional

- Regional HCFC-22 emissions for 2005 and 2006 (Gg year\(^{-1}\))
  - This study:
    - North America: 75±35 Gg year\(^{-1}\)
    - Europe: 7.3±2.0 Gg year\(^{-1}\)
    - Asia: 121±31 Gg year\(^{-1}\)
    - Oceania: 1.5±0.4 Gg year\(^{-1}\)
  - Stohl et al., 2010:
    - North America: 80 Gg year\(^{-1}\)
    - Europe: 24 Gg year\(^{-1}\)
    - Asia: 149 Gg year\(^{-1}\)
    - Australia: 12 Gg year\(^{-1}\)
Conclusion

- We conducted a global and a regional inversion study for estimating HCFC-22 emissions.
- Our model results indicate an increase in global emissions from 1995 to 2009, with a large growth from 1999 to 2001 and from 2004 to 2006.
- In recent years, emissions are mostly flat in developed countries.
- We find a rapid emissions increase in Asia in the recent years.
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