1 Ozone Depletion in the Stratosphere

EVPP 111 Lecture

Dr. Largen

2 Ozone Depletion in the Stratosphere

- Ozone and ozone layer
- Thinning of ozone layer
- What causes ozone depletion
  - chlorofluorocarbons
  - other ozone depleting compounds
- Seasonal thinning over the poles
- Why should we care about ozone depletion
- solutions: protecting the ozone layer

3 Ozone Depletion in the Stratosphere

- Ozone and ozone layer
- Thinning of ozone layer
- What causes ozone depletion
  - chlorofluorocarbons
  - other ozone depleting compounds
- Seasonal thinning over the poles
- Why should we care about ozone depletion
- solutions: protecting the ozone layer

4 Ozone and ozone layer

- **Ozone (O_3)**
  - structure
  - forms and breaks down naturally in stratosphere
    - via reaction of O_2 with UV radiation
      - breaks O_2 into O which react with O_2 to reform O_3
        - » process absorbs ~99% of UV
    - creates layer in lower stratosphere
      - altitude of ~10-16 miles

5 Ozone and ozone layer

- **Ozone (O_3)**
  - "good" ozone
    - stratospheric ozone
  - "bad" ozone
    - tropospheric ozone, "ground level" ozone
    - secondary air pollutant
      - component of photochemical smog
        - » irritates respiratory tissue
        - » causes permanent lung damage
        - » damages plants

» reduces agricultural yields

6 Ozone Depletion in the Stratosphere

- Ozone and ozone layer
- Thinning of ozone layer
- What causes ozone depletion
  - chlorofluorocarbons
  - other ozone depleting compounds
- Seasonal thinning over the poles
- Why should we care about ozone depletion
- solutions: protecting the ozone layer

7 Thinning of the ozone layer

- **Ozone concentration in stratosphere**
  - determination
    - balloons, aircraft, satellites

8 Thinning of the ozone layer

- **Ozone concentration in stratosphere**
  - depleted seasonally over
    - Antarctica and Arctic
  - lower overall thinning of layer
    - everywhere except over tropics

9 Thinning of the ozone layer

- **Ozone depletion in stratosphere**
  - considered a
    - serious long-term threat
      - humans
      - many other animals
      - primary producers

10 Ozone Depletion in the Stratosphere

- Ozone and ozone layer
- Thinning of ozone layer
- What causes ozone depletion
  - chlorofluorocarbons
  - other ozone depleting compounds
- Seasonal thinning over the poles
- Why should we care about ozone depletion
- solutions: protecting the ozone layer

11 Ozone Depletion in the Stratosphere

- Ozone and ozone layer
- Thinning of ozone layer
- What causes ozone depletion
  - chlorofluorocarbons

- other ozone depleting compounds
- Seasonal thinning over the poles
- Why should we care about ozone depletion
- solutions: protecting the ozone layer

12 What causes ozone depletion

- Certain chemicals
  - destroy ozone in stratosphere
    - primarily
      - chlorofluorocarbons (CFCs)
      - other chlorine-containing compounds

13 What causes ozone depletion

- **Chlorofluorocarbons (CFCs)**
  - discovered in 1930
    - General Motors chemist, Thomas Midgley
  - other chemists
    - made similar compounds
      - creating family of highly useful CFCs

14 What causes ozone depletion

- **Chlorofluorocarbons (CFCs)**
  - two most widely used
    - known by trade name - Freons
      - CFC-11 (trichloromethane, CCl_3F)
      - CFC-12 (dichlorodifluoromethane, CCl_2F_2)

15 What causes ozone depletion

- **Chlorofluorocarbons (CFCs)**
  - originally considered “dream chemicals”
    - because of characteristics
      - chemically stable (nonreactive)
      - odorless
      - nonflammable
      - nontoxic
      - noncorrosive
  - became popular for many uses

16 What causes ozone depletion

- **Chlorofluorocarbons (CFCs)**
  - uses included
    - coolants in air conditioners and refrigerators
      - replacing toxic sulfur dioxide and ammonia
    - propellants in aerosol spray cans
    - cleaners for electronic parts (computer chips)
    - sterilants for hospital instruments
    - fumigants for granaries and ship cargo holds

- bubbles in plastic foam used for insulation and packaging

17 What causes ozone depletion

- **Chlorofluorocarbons (CFCs)**
  - production rose sharply between 1960 and early 1990's

18 What causes ozone depletion

- **Chlorofluorocarbons (CFCs)**
  - in 1974
    - research by two University of California-Irvine chemists, Sherwood Rowland and Mario Molina
      - indicated that
        - » **CFCs were lowering average concentration of ozone in stratosphere**

19 What causes ozone depletion

- **Chlorofluorocarbons (CFCs)**
  - Rowland and Molina
    - shocked scientific community and $28 billion per year CFC industry
      - called for immediate ban on CFCs in spray cans

20 What causes ozone depletion

- **Chlorofluorocarbons (CFCs)**
  - Rowland and Molina
    - concluded that
      - large quantities of CFCs were being released into troposphere
      - mostly from
        - » use of CFCs as propellants in spray cans
        - » leaks from refrigeration and air conditioning equipment
        - » production and burning of plastic foam products

21 What causes ozone depletion

- **Chlorofluorocarbons (CFCs)**
  - Rowland and Molina
    - concluded that
      - CFCs remain in troposphere due to
        - » insolubility in water
        - » chemical unreactivity
      - over period of 11-20 years, CFCs rise into stratosphere through
        - » convection
        - » random drift
        - » turbulent mixing in troposphere

22 What causes ozone depletion

- **Chlorofluorocarbons (CFCs)**
  - Rowland and Molina
    - concluded that
      - in stratosphere, CFC molecules break down

» under influence of high-energy UV radiation
» releasing highly reactive chlorine atoms

23

24 What causes ozone depletion

- **Chlorofluorocarbons (CFCs)**
  - Rowland and Molina
    - concluded that
      - each CFC can last in stratosphere for 65-385 years (most widely used, 75-111 years), depending on its type
        - » each chlorine atom released from CFC molecule can convert up to 100,000 molecules of ozone to oxygen

25 What causes ozone depletion

- **Chlorofluorocarbons (CFCs)**
  - Rowland and Molina
    - concluded that
      - **"dream molecules" (CFCs) had turned into global ozone destroyers**

26 What causes ozone depletion

- **Chlorofluorocarbons (CFCs)**
  - CFC industry, led by Dupont Company
    - attacked Rowland and Molina's conclusion
    - was powerful, well-funded with lots of profits and jobs at stake

27 What causes ozone depletion

- **Chlorofluorocarbons (CFCs)**
  - Rowland and Molina held their ground against industry
    - explaining their calculations to other scientists, elected officials, media
  - in 1988, 14 years after Rowland and Molina's study
    - DuPont officials acknowledged that CFCs were depleting ozone layer
      - agreed to stop producing them once they found substitutes

28 What causes ozone depletion

- **Chlorofluorocarbons (CFCs)**
  - in 1995
    - Rowland and Molina won Nobel Prize in Chemistry for work on CFCs and ozone layer

29 Ozone Depletion in the Stratosphere

- Ozone and ozone layer
- Thinning of ozone layer
- What causes ozone depletion
  - chlorofluorocarbons
  - other ozone depleting compounds
- Seasonal thinning over the poles
- Why should we care about ozone depletion
- solutions: protecting the ozone layer

30 What causes ozone depletion

- **Other ozone depleting compounds (ODC)**
  - include
    - halons and HBFCs
      - used in fire extinguishers
    - methyl bromide(CH_3Br)
      - widely used fumigant
    - carbon tetrachloride (CCl_4)
      - cheap, highly toxic solvent

31 What causes ozone depletion

- **Other ozone depleting compounds (ODC)**
  - include
    - methyl chloroform ($C_2H_3Cl_3$)
      - cleaning solvent
      - propellant
    - hydrogen chloride (HCl)
      - emitted into stratosphere by US space shuttles

32 What causes ozone depletion

- **other ozone depleting compounds**
  - natural sources of
    - oceans and volcanic eruptions
      - release chlorine and bromine

33 Ozone Depletion in the Stratosphere

- Ozone and ozone layer
- Thinning of ozone layer
- What causes ozone depletion
  - chlorofluorocarbons
  - other ozone depleting compounds
- Seasonal thinning over the poles
- Why should we care about ozone depletion
- solutions: protecting the ozone layer

34 Ozone depletion

- Of observed ozone losses in stratosphere since 1976
  - ~75-85% are attributed to compounds released into atmosphere by human activities beginning in 1950s

35 Figure: Erosion of Earth's ozone shield: Thickness of the ozone layer

36 Seasonal ozone thinning over poles

- In mid-1980s
  - researchers discovered that ~40-50% of ozone over Antarctica was being destroyed during

- Antarctic spring and summer (September-December)

37 Figure: Erosion of Earth's ozone shield: The ozone hole over the Antarctic

38

39 Seasonal ozone thinning over poles

- seasonal loss of ozone over Antarctica was incorrectly dubbed ***ozone hole***
  - actually ozone thinning
    - degree of depletion varies with altitude and location
- total area of atmosphere above Antarctica that suffers from ozone thinning varies from year to year
  - in 2000, seasonal thinning above Antarctica was largest ever

40 Seasonal ozone thinning over poles

- Why is loss of ozone over Antarctica seasonal
  - during winter
    - its sunless
    - steady winds blow in circular pattern over earth's poles
    - creates polar vortex
      - swirling mass of very cold air that is isolated from rest of atmosphere
        - » until sun returns a few months later

41 Seasonal ozone thinning over poles

- Why is loss of ozone over Antarctica seasonal
  - during winter
    - water droplets in clouds enter polar vortex
      - form tiny ice crystals which collect CFCs and other ODCs on their surfaces
        - » serve as catalysts for speeding up chemical reactions that release Cl & ClO
        - » Cl and ClO react with each other to form Cl_2O_2
        - » in dark of winter Cl_2O_2 molecules can't react with ozone so they accumulate in polar vortex

42 Seasonal ozone thinning over the poles

- Why is loss of ozone over Antarctica seasonal
  - during spring
    - when sunlight returns (October)
    - Cl_2O_2 molecules are broken apart by UV light
      - releasing large numbers of Cl atoms
        - » which begin reacting with ozone
    - sunlight
      - gradually melts ice crystals
      - breaks up vortex of trapped polar air
      - allows trapped air to begin mixing with rest of atmosphere

43 Seasonal ozone thinning over poles

- Why is loss of ozone over Antarctica seasonal
  - during spring
    - within weeks

- 40-50% of ozone above Antarctica is destroyed

44 Seasonal ozone thinning over poles

- Why is loss of ozone over Antarctica seasonal
  - during spring
    - when vortex breaks up
      - huge masses of ozone depleted air above Antarctica flows northward
        - » lingers for few weeks over Australia, New Zealand, South America, South Africa
        - » resulting in increases of 3-20% levels of biologically damaging UV-B radiation

45 Seasonal ozone thinning over poles

- Ozone thinning over the Arctic
  - in 1988
    - scientists discovered similar but less severe ozone thinning over Arctic
      - during Arctic spring/summer (February-June)
        - » producing a seasonal loss of 11-38% (compared with ~50% loss in Antarctic)

46

47 Ozone Depletion in the Stratosphere

- Ozone and ozone layer
- Thinning of ozone layer
- What causes ozone depletion
  - chlorofluorocarbons
  - other ozone depleting compounds
- Seasonal thinning over the poles
- Why should we care about ozone depletion
- solutions: protecting the ozone layer

48 Why should we care about ozone loss

- Less ozone in stratosphere
  - results in more biologically damaging UV-A and UV-B radiation reaching surface
    - impact on humans
      - worse sunburns
      - more eye cataracts
      - more skin cancers

49 Why should we care about ozone loss

- According to UNEP estimates
  - additional UV-B radiation reaching surface would cause 10% annual loss of global ozone leading to
    - 300,000 aditional cases of squamous cell and basal cell cancer
    - 4500-9000 additional cases of potentially fatal malignant melanoma
    - 1.5 million new cases of cataracts

50 Why should we care about ozone loss

- Other effects of increased UV exposure include
  - immune system suppression
  - increase in acid deposition

- increase in photochemical smog
- lower yields of key crops (corn, rice, soybeans, wheat, etc.)
  - estimated losses totaling ~2.5 billion/ year
- decline in forest productivity
- increased degradation and breakdown of materials such as plastics, paints

51 ## Why should we care about ozone loss

- Other effects of increased UV exposure include
  - reduction in productivity of surface-dwelling phytoplankton resulting in
    - disruption of aquatic food chains
    - decrease in yields of seafood eaten by humans
    - possible acceleration of global warming by decreasing oceanic uptake of carbon dioxide

52

53

54 ## Ozone Depletion in the Stratosphere

- Ozone and ozone layer
- Thinning of ozone layer
- What causes ozone depletion
  - chlorofluorocarbons
  - other ozone depleting compounds
- Seasonal thinning over the poles
- Why should we care about ozone depletion
- Solutions: protecting the ozone layer

55 ## Solutions: Protecting the ozone layer

- scientific consensus of researchers
  - **immediately stop producing all ozone-depleting chemicals**
    - substitutes available for most CFCs
    - additional substitutes are being developed

56 ## Solutions: Protecting the ozone layer

- Is there a possibility of a quick fix from technology that would allow us to keep using CFCs?
  - Some strange proposals have been floated
    - blimps
    - lasers

57 ## Solutions: Protecting the ozone layer

- strange “technofix” proposals
  - blimps
    - inject electrons into stratosphere
      - which would react with and remove chlorine atoms

58 ## Solutions: Protecting the ozone layer

- strange “technofix” proposals
  - lasers
    - “blast” CFCs out of atmosphere before they could reach stratosphere

59 Solutions: Protecting the ozone layer

- Efforts to reduce ozone depletion
  - Montreal Protocol, a treaty
    - developed in 1987
    - cut emissions of CFCs by ~35% -50% between 1989 and 2000

60 Solutions: Protecting the ozone layer

- Efforts to reduce ozone depletion
  - new protocol was adopted following meetings in 1990 & 1992 of representative from 93 countries
    - in response to news in 1989 about seasonal thinning of ozone layer over Antarctica

61 Solutions: Protecting the ozone layer

- Efforts to reduce ozone depletion
  - to date, landmark international agreements
    - signed by 175 nations
      - illustrate global response to a serious global environmental problem

62 Solutions: Protecting the ozone layer

- Efforts to reduce ozone depletion
  - according to 1998 study by World Meteorological Organization (WMO)
    - ozone layer
      - will continue to be depleted for several decades
      - will return to 1980 levels by ~2050 and to 1950 level by ~2100 if certain assumptions hold
      - depletion has resulted in cooling of troposphere

63 Solutions: Protecting the ozone layer

- Efforts to reduce ozone depletion
  - according to 1998 WMO study, ozone layer
    - will continue to be depleted for several decades because
      - 11-20 year time lag between release of ODCs and their arrival in stratosphere
      - ODCs persist in stratosphere for decades

64 Solutions: Protecting the ozone layer

- Efforts to reduce ozone depletion
  - according to 1998 WMO study, ozone layer
    - will return to 1980 levels by ~2050 and to 1950 levels by ~2100, assuming
      - international agreements are followed
      - no major volcanic eruptions

- or, to rephrase
  - if all ozone use was stopped today, it would take ~47 years for concentrations to return to 1980 levels and ~97 years to return to “safe” levels of 1950s

65 ## Solutions: Protecting the ozone layer

- Efforts to reduce ozone depletion
  - according to 1998 WMO study
    - depletion of ozone in stratosphere has resulted in
      - cooling of troposphere
        - » possibly offset or disguised as much as 30% of global warming caused by greenhouse gas emissions
    - restoration of ozone layer could lead to an increase in global warming

66 ## Solutions: Protecting the ozone layer

- As result of Montreal Protocol and other international agreements
  - CFC emissions dropped ~87% from their peak in 1988
- in 1991
  - DuPont announced development of new refrigerants that don’t harm ozone layer
- in 1996
  - US stopped producing CFCs

67

68 ## Solutions: Protecting the ozone layer

- Some substitutes/replacements include
  - new coolant for air conditioners
  - soapy water and hot air for circuit boards
  - sound waves for cooling
  - helium gas for refrigeration
  - liquid nitrogen (-196°C) and supercooled CO2 (-60°C; dry ice) for shipping

69 ## The End