Effects of Ozone Depletion

201114
Environmental Science in Today’s World
The Discovery

In 1985, using satellites, balloons, and surface stations, a team of researchers had discovered a balding patch of ozone in the upper stratosphere, the size of the United States, over Antarctica.

Team who discovered the hole 1985.
From left: Joe Farman, Brian Gardiner, and Jonathan Shanklin

British Atlantic Survey Research station, Holly Bay, Antarctic coast
Total Ozone Mapping Spectrometer (TOMS)

- Used by NASA to measure ozone concentrations
- TOMS – a satellite-borne instrument
- TOMS launched in 1996 – makes 35 measurements every 8 seconds
- Levels of ozone are measured in Dobson units (DU), where 100 DU is equivalent to a 1 millimeter thick layer of pure ozone

Artist's view of the QuikTOMS spacecraft (image credit: NASA)
**The ozone layer**

- Ozone is a triatomic form of oxygen (O₃) found in Earth’s upper and lower atmosphere.

- The ozone layer, situated in the stratosphere about 15 to 30 km above the earth's surface.

- Ozone protects living organisms by absorbing harmful ultraviolet radiation (UVB) from the sun.

- The ozone layer is being destroyed by CFCs and other substances.

- Ozone depletion progressing globally except in the tropical zone.
Hole Formation Based on Two different mechanisms:

- Meteorological mechanism
  - Movement of air from one place to another in the upper stratosphere
  - Cold temperature in the upper atmosphere causes nitric acid to freeze into crystals forming wispy pink clouds
  - Forms a vortex of tightly twisted winds thus forming a hole in the upper atmosphere

- No sun
  - Thermal radiation to space
  - Subsiding air
  - Chemistry of the stratospheric air
  - Isolation from other latitudes
Different chemicals are responsible for the destruction of the ozone layer

- Topping the list:
  - chlorofluorocarbons (CFC’s)
  - man-made, non-toxic and inert in the troposphere
  - In the stratosphere are photolysed, releasing reactive chlorine atom that catalytically destroy ozone
A combination of low temperatures and elevated chlorine and bromine concentrations are responsible for the destruction of ozone in the upper stratosphere thus forming a “hole”. (Kerr, 1987)
Ozone levels over North America (USEPA, March 1994)

- Comparing the colors of the bands over a particular city, such as Seattle, shows lower ozone levels in 1994 than in 1979.

- Over the U.S., stratospheric ozone levels are about 5 percent below normal in the summer and 10 percent below normal in the winter.

(U.S.E.P.A. 1994)
Stratospheric Ozone and Ultraviolet Radiation (UVR)

- **Ultra-violet radiation (UVR)** high energy electromagnetic wave emitted from the sun. It is made up of wavelengths ranging from 100nm to 400nm.

- **UV radiation includes UV-A**, the least dangerous form of UV radiation, with a wavelength range between 315nm to 400nm, **UV-B** with a wavelength range between 280nm to 315nm, and **UV-C** which is the most dangerous between 100nm to 280nm. UV-C is unable to reach Earth’s surface due to stratospheric ozone’s ability to absorb it. (Last, 2006)
Too much ultra-violet light can result in:

- Skin cancer
- Eye damage such as cataracts
- Immune system damage
- Reduction in phytoplankton
- Damage to the DNA in various life-forms
  - this has been as observed in Antarctic ice-fish that lack pigments to shield them from the ultra-violet light (they've never needed them before)
- Possibly other things too that we don't know about at the moment
Effects of UV radiation on biological organisms

- **DNA damage**
  - Maximum effect on small and single cell organisms

- **Impaired growth and photosynthesis**
  - Poor crop yields

- **Phytoplankton**
  - Reduced uptake of CO2
  - Mortality
  - Impaired reproductive capacity

- **Nitrogen-fixing soil bacteria**
  - Reduced, damaged

- **Human health effects**
  - Suppressed immune system
  - Enhanced susceptibility to infection
  - Increase risk of Cancer
  - Sunburn
  - Loss of skin elasticity (Premature aging)
  - Photosensitivity
  - Melanocytic (malignant melanoma)
  - Squamous cell skin – cancer
  - Basal skin – cancer
  - Still questionable if causes lip cancer or cancer of the salivary glands
  - Cataract
  - Pterygium

(last. 1993)
Aquatic Ecosystems

Phytoplankton and Zooplankton

Dinoflagellate
Coccolithophorid
Diatom
Copepod

Krill

oceancolor.gsfc.nasa.gov/..phyto_zoo.jpg

www.ciesin.org/docs/011-558/011-558.html
Phytoplankton

- UV-B penetrates water columns to depths of 30m

- Increased UV-B exposure
  - Reduces productivity by interfering with processes of photosynthesis
  - Damages DNA
  - Alters nitrogen metabolism
  - Inhibits mobility

- Studies (1993) conducted in the Weddle Sea
  - Evaluated effects of photosynthesis to UV exposure in the presence of vertical mixing, found:
    - photosynthesis by phytoplankton was strongly inhibited near the surface of the water
    - rapid mixing, photic zone is extended, severe inhibition of photosynthesis
- **Play critical role in aquatic system**
  - **Decomposers** - absorb dissolved organic carbon and recycle it back into the environment
  - **Primary producers** – found at the center of food web

- **Prone to UV-B stress**
  - Inhibits growth
  - Interferes with mechanisms for nitrogen fixation and carbon dioxide fixation
  - High mortality

- **Effects dependent on:**
  - Where found in the water column
  - Amount of exposure
  - Amount of protection when moving from one mixing layer to another

- **Adaptive Strategy:**
  - Pigmentation – absorb more than 90% of UV-B before it penetrates to the genetic material
  - Form external filaments which protect them from excess UV-B
Macroalgae and Seagrasses

- Are sessile and restricted to growth site
- Have diverse habitats
  - Above tidal zones
  - Intertidal zones
  - Some never exposed to air
- Have adapted to varying solar exposure
  - Able to protect themselves from excessive radiation using mechanisms of phototinhibition
    - mechanisms (electron transport) decrease photosynthesis during excessive radiation
Plants
The influence of the UV-B radiation on plant process.
DNA & UV-B

- DNA absorbs UV-B radiation
- Changes shape in DNA
  - Changes in the DNA molecule mean that enzymes cannot “read” the DNA code
  - Results in mutated cells or the cells die
- Cells have developed the ability to repair DNA
  - A special enzyme arrives at the damage site
  - Removes the damaged section of DNA
  - Replaces it with the proper components
- This makes DNA somewhat resilient to damage by UV-B
Higher Plants

- Experiments were done to determine if increased UV-B is a threat to terrestrial vegetation:
  - Found
    - High UV-B exposure does induce some inhibition of photosynthesis

**However….**

- Studies found no significant effects on photosynthetic productivity
- Some researchers have concluded that ozone depletion and increase of UV-B not a direct threat to photosynthetic productivity of crops and natural vegetation (Allen, 1998)
Difficult to Unmask UV-B Effects

- Limitations in controlled and field studies include:
  - Large differences in temperature, precipitation, soil types from year to year and in different locations
  - UV-B radiation masked by other stresses of land plants such as drought
- Drought produces large reductions in photosynthesis and growth masking the effects of UV-B
- Water stressed plants produce a high concentration of leaf flavonoids (for pigmentation) providing greater UV-B protection
Flowering

- UV-B radiation can alter both the time of flowering as well as the number of flowers in certain species.

- Differences in timing of flowering may have important consequences for the availability of pollinators.

- The reproductive parts of plants, such as pollen and ovules are well shielded from solar UV-B radiation.
Can plants protect themselves against increased UV-B?

**Plant adaptation:**
- Have UV shielding
- Only a small proportion of the UV-B radiation striking leaf penetrates into the inner tissues
- When exposed to increasing amounts of UV-B, many species of plants can increase the UV-absorbing pigments in their tissues

**Other adaptations include:**
- Increased thickness of leaves reducing the proportion of inner tissues exposed to UV-B radiation
- Have repair mechanisms in plants
  - includes repair systems for DNA damage

Amphibians
Global Decline Seen In Amphibians

Range of explanations as to why amphibians are declining, which include:

- Habitat destruction
- Disease
- Parasites
- Introduction of exotic species
- Environmental contaminants and other aspects of global climate change
UV-B radiation is still high on the list for the decline in amphibians seen around the world

- Causes damage to many species of amphibians at every stage of their life cycle, from egg to adult
- Affects growth and development in larvae
- Causes
  - Changes in behavior
  - Deformities
  - Make amphibians more vulnerable to disease and death
  - In adults, causes retinal damage and blindness
UV-B Effects on Human Effects
Effects on Human Health

- Over exposure may:
  - Increase risk of non-melanoma and malignant melanoma skin cancer
  
  - Higher risks of malignant melanoma from severe sunburns – especially in childhood
  
  - Risk of malignant melanoma has increased 10%
  
  - Risk of nonmalignant melanoma has increased 26%

www.ldeo.columbia.edu/.../lectures/ozone_health/
Over Exposure

- Suppress immune system
- Accelerate aging of skin due to high exposure
- Cause an outbreak of rash in fair skinned people due to photo allergy – can be severe
Skin Protection

- Protect the skin against the solar radiation using skin creams with SPF
  - The greater the numerical value of the SPF the greater the protection
- Use lip balm with SPF
- Cover up
Over Exposure to UV-B....

- Increases the risk of cataracts
  - Induces type of protein that provokes cleaving (splitting) in the lens
  - Leading cause of blindness
  - The prevalence of cataract after age 30 is doubling each decade

- Causes pterygium
  - A wedge-shaped growth over the central cornea
Manifestations of...

- Cataracts
- Cancer
- Pterygium

brought on by over exposure to UV-B
Protection

- Sunglasses with 100% UV block
- Wrap around sunglasses
- Eye protection for children
- Hats
What Is Being Done to Counter the Effects of Ozone Depletion?

- **Montreal Protocol** (adopted in 1987) – panel of experts was formed to investigate substances responsible for hole formation
  - Established policies that prevent future use of certain types of chemicals
  - Stipulated that the production and consumption of compounds contributing towards depletion of ozone in the stratosphere were to be phased out by the year 2000 (2005 for methylchloroform)
The Environmental Protection Agency (EPA)

- Responsible for enforcing the Montreal Protocol within the U.S.
  - The EPA has several programs in place;
    - Regulating and enforcing on-road car and truck air-conditioning systems
    - Regulating most air-conditioning and refrigeration appliances
    - Technician certification
    - Service equipment
Signs of Recovery???
There have been some signs of recovery

- 1997 satellite showed a decline of several known ozone-depleting gases
- Satellite images show some slowing down of ozone loss

However….

Recovery is slow
Images of Antarctica Taken Indicate A Slow Recovery

10 Years of Ozone Hole Monitoring by GOME and SCIAMACHY

1999  2000  2001  2002
2003  2004

Total Ozone Mean - September

DLR
Understanding the future

Researchers would like to see:

- Stations that measure levels of ozone and surface radiation changes in relation to incidence rate of skin cancer and cataracts - installed in urban areas and in remote regions far from populations

- More studies to determine biological effects (including human) on UVR exposure

- Research on protective creams and ointments and their efficiency in preventing skin cancer and malignant melanoma

- More surveillance of UV-related damage to other species living in high latitudes for example…..
Reports of Sheep in Iceland developing eye disease – no research to support

(Last, 1993)
Future Evolution of Ozone

- **Remains unclear**
  - Current models are unable to reproduce ozone variability accurately
  - Rates of future increases in greenhouse gases are not yet established
  - Interactions between ozone depletion and climate change not yet fully understood

- **Continued monitoring of ozone and ozone-depleting substances is essential**
  - Ozone layer recovery expected by 2050
  - Hinges on the complete elimination of atmospheric ozone-depleting substances
  - Replacements for HCFCs, methyl bromide, and halons are still being sought, and studies of the new compounds must continue

The Ozone is Earth’s only defense against harmful UVR

Studies indicate ozone thinning throughout the globe due to 2 mechanisms:
- Meteorological
- Chemical

Research indicates microorganisms, are extremely sensitive to increasing UV-B levels

There is a lot of uncertainty and debate among researchers as to the degree in which land plants are affected by UV-B

There is debate in the scientific community in the role UV-B radiation plays on the decline of amphibians seen globally

In the last decade, there has been an increase in skin cancer and cataracts all related to increase UV-B exposure
Efforts Need to Be Continued

- Create reliable models
  - To gain a better understanding of the effects ozone depletion has on organisms living within different ecosystems

- Enforcement of Montreal Protocol
  - To reduce concentrations of chemicals responsible for ozone depletion

- Monitoring chemicals being emitted

- Gain a better overall understanding on just how ozone depletion is affecting our planet

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