Light & Radiation – Contemporary Environmental Issues

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Using Information from EM Radiation in Astrobiology

• Most information from space comes from EM radiation
• EM radiation passes through Earth’s atmosphere – and it leaves a fingerprint
• Examples of spectra
  - MKO as an observing site
  - Aurorae
  - Solar system and ISM spectra
  - Earth at many λ
• Applications
  - Ozone problem
  - Greenhouse Effect
  - Global warming Consequences

Summary of the Lecture

• Light’s wave properties characterized by c = λf
  - Wavelength, λ (γ to radio)
  - Frequency, f (Hz)
  - Travels at c = 3 x 10⁸ km/s
• Light carries energy, E=hf

• Atomic properties
  - Nucleus, protons, neutrons, electrons, isotopes
  - # protons → chemistry
  - n orbits quantized

• EM Interaction with matter
  - Absorption, emission, continuous (BB) spectrum

• Applications
  - Most spectra are a complex combination of types
  - Spectra give T, and possibly composition . . . But it is complex to detangle

The Ozone problem

• High E radiation γ, X, UV harmful to life
  - E = hf,
  - Energy > molec. Bond E

• Primary absorbers
  - O₂ (far UV) O₃ (0.1-0.3 μm)
  - X, γ rays – cascade

• Biomarker
  - O, O₂, O₃ very reactive → constant production

Atmospheric Chemistry

• Normal cycle
  - O₂ + hf → O + O
  - O + O₂ + M → O₂ + M
  - O₃ + hf → O + O₂

• Manmade Destruction
  - Cl + O₃ → ClO + O₂
  - ClO + O → Cl + O₂

• Normal environment
  - Balance between creation and destruction of O₂

• Destruction
  - Chlorine atoms → catalyst
  - Chlorofluorocarbons: A/C, aerosols
  - O₃ combines with NOx from:
    - High altitude aircraft exhaust
    - Fertilizers: nitrates
    - Nuclear weapons
    - Shuttle launches
Ozone Distribution

[Image: http://www.esrl.noaa.gov/gmd/dv/spo_oz/movies/index.html]

Recovery time for ozone depends on altitude

Why is the ozone hole bigger in the South?

Ozone Destruction

- Buildup of Cl₂ during winter
  - Observed by loss of CIONO₂
- Destruction needs Cl, not Cl₂
  - Cl forms when sunlight returns (Feb – Mar)
  - Cl₂ + hv → Cl + Cl
  - Loss of O₃ is sudden

CIONO₂, Slimcat 3D Model. 26 Nov 1994

3D simulation of CIONO₂

Ozone Summary

- The Process
  - O₃ is the only molecule protecting us at certain UV λ's
  - Natural balance of creation and destruction of O₃
  - Man-made chemicals act as catalysts for O₃ destruction
- Many Complications
  - Complex chemical interactions
  - Depends on atm circulation
  - Timescales for recovery long & variable

Polar Stratospheric Clouds

- Cl compounds stable
  - Breakdown needs surface reactions
- Winter → no sun
  - Strong circumpolar wind develops
  - Isolates air over pole
  - When Air T is < -80°C
  - Clouds form of nitric acid & H₂O

HCl+ClONO₂ → HNO₃+Cl₂
ClONO₂+H₂O → HNO₂+HOCI
HCl+HOCl → H₂O+Cl₂
H₂O₂+HCl → HNO₃+CIONO
N₂O₅+H₂O → 2 HNO₃
The Greenhouse Effect

- Atm Transparent windows on Earth: optical, radio
- Visible (& radio) radiation passes through atmosphere
- Energy heats surface
- Re-Radiated energy in IR \( \rightarrow \) traps Energy (heating lower atm)

![Graph showing radiation with wavelengths (micrometers)]

Energy has to get in
- It does not matter what wavelength
- Short wavelengths are most effective (most energy)
- The energy heats the surface of the planet (how much depends on albedo)

Infrared radiation (heat) has to be trapped
- Much or all of IR region of atmosphere has to be blocking light

Green House Effect: 2 Key Points

ManMade Greenhouse Gases

<table>
<thead>
<tr>
<th>Gas</th>
<th>Pre-industry Amount (ppb)</th>
<th>1994 Amount (ppb)</th>
<th>Atm Life (yrs)</th>
<th>Man made sources</th>
<th>Global warming potential</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon dioxide (CO₂)</td>
<td>278,000</td>
<td>368,000</td>
<td>Variable</td>
<td>Fossil fuels, land use, cement</td>
<td>1</td>
</tr>
<tr>
<td>Methane (CH₄)</td>
<td>700</td>
<td>1721</td>
<td>12</td>
<td>Fossil fuels, waste, livestock</td>
<td>21</td>
</tr>
<tr>
<td>Nitrous oxide (N₂O)</td>
<td>275</td>
<td>311</td>
<td>120</td>
<td>Fertilizer, shuttle launch</td>
<td>310</td>
</tr>
<tr>
<td>CFC-12</td>
<td>0</td>
<td>0.5</td>
<td>102</td>
<td>Coolants</td>
<td>&gt; 6000</td>
</tr>
<tr>
<td>HCFC-22</td>
<td>0</td>
<td>0.105</td>
<td>12</td>
<td>Coolants</td>
<td>1300</td>
</tr>
<tr>
<td>Per fluoro methane</td>
<td>0</td>
<td>0.07</td>
<td>50,000</td>
<td>Al production</td>
<td>6500</td>
</tr>
<tr>
<td>Sulfur hexa fluoride</td>
<td>0</td>
<td>0.032</td>
<td>3200</td>
<td>Dielectrics</td>
<td>23,900</td>
</tr>
</tbody>
</table>
Relative Sources of Greenhouse Gases

Changing CO₂ and Other G.H. Gases

Measuring Past Global Temps: Ice Cores
- Isotopes
  - different # neutrons
  - Chemically the same, different mass

Isotope Behavior
- Water (H₂O) has 9 isotope combinations:
  - Light isotopes evaporate easier
  - Heavier isotopes rain out faster
- Relation between amount of ¹⁸O (H₂¹⁸O) and T

δ notation: isotope enrichment

Measuring Global Temps: Ice Cores

Is the Increase Real?
- Strong correlation of greenhouse gas and climate
- Is the increase man-made?
  - T & CO₂ vary a lot over time from natural causes
  - Recent rise in CO₂ > than any time in 650,000 yr
  - But... caution over presentation of data
  - Temp & CO₂ levels vary from natural causes too
Carbon Cycle On Earth

- Life of the Carbon Atom
  - CO2 in atmosphere
  - Plants ingest CO2, stripping off oxygen
  - Carbon becomes organic carbon in the leaf
  - Leaves fall to soil
    - bacteria transform organic C to CO2
  - Sediment buried, no oxygen
  - Plate tectonics recycles this C to surface, erosion can liberate it into atmosphere.

<table>
<thead>
<tr>
<th>Reservoir</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atmosphere</td>
<td>800 billion tons</td>
</tr>
<tr>
<td>Soils</td>
<td>1600 billion tons</td>
</tr>
<tr>
<td>Oceans</td>
<td>40000 billion tons</td>
</tr>
<tr>
<td>Sedimentary rocks, Limestones</td>
<td>Vast</td>
</tr>
</tbody>
</table>

Carbon Silicate Cycle

- Formation of Limestone
  - Calcium combines with carbonic acid (H2CO3)
  - Ca++ from weathering of rocks
  - H2CO3 from weathering of silicate rocks

- The Silicate Cycle
  - Higher CO2 → warmer atmosphere
  - Warmer atm → more precipitation
  - More rain → rocks erode (weather) faster
  - Erosion frees chemicals → makes limestone
  - More H2CO3 → faster removal of CO2
  - Removal of CO2 → atmosphere cools
  - Cooler atm → weathering slows

- Rocks, Air, Water & Life have interacted to regulate Earth Atmospheric Temperature

Complex Models

- Earth is a system
  - We cannot consider one aspect in isolation
  - Models are very complex
  - We don’t understand all the variables
  - Complex systems don’t behave predictably
  - Interdisciplinary Approaches are needed
  - Astrobiology is key

Carbon-Silicate Weathering: 250Myr in The Future

- Plate Tectonics (Paleomap Project)
  - Atlantic & Indian oceans closed
  - N America collided with Africa, S. America wrapped around Africa

- Massive single continent
  - Changes ocean circulation → oceans may become unmixed
  - Oceans stratification, C cycle will radically change →
    - Oceans become like the Black sea → Anoxic (storing greenhouse gases)
  - Plate tectonic recycling may slow
  - Climate in interior of large continent harsher

Consequences of Global Warming

- Rapid polar ice melting → habitat change
- Sea level rising
- Sea Temperature rise – less nutrients
- Changes in ocean circulation
- Changes in ocean chemistry
- Changes in severe weather
- Hotter weather – shift where crops grow

Collapse of Antarctic Larsen Ice Shelf

- 2002 Collapse related to climate change
  - Occurs over a 35 day period
  - 3200 sq km of ice collapses
  - This region had experienced 2.5°C warming over past 50 years (higher than global average)

MODIS satellite images
Greenland & Sea Ice

- Largest island in the world
- Ice sheet thickness ~ 3 km
- Important reserve of fresh H_2O
- Melting rapidly
- Rate could raise sea level by 6m by 2100
- Sea ice melt increasing
- Similar to warming period 129,000 years ago

Sea Level changes

- Measurements show sea level changes
- Models are run to extrapolate to the future
- Models are complex
- Models most accurate for near term

Sea Level changes

- 500m rise
- 150m rise

Global Temperature Change: Measurements & Models

- Climate Ocean Conveyor System
- Basic Physics
  - Salt water denser than fresh H_2O
  - Cold water denser than warm H_2O
- Thermohaline circulation
  - Evaporation in tropics → water becomes more salty, warms up
  - Warm water carried North
  - Ocean releases heat to colder atm
  - Cold water sinks
  - This draws more warm salty water from tropics
- Disruption of cycle
  - If too much fresh water dilutes surface waters, inhibits sinking
  - Poles cool fast

Ocean Conveyor & Climate Change

- Paleoclimate
  - 8200 years ago – ice cores
  - Avg annual T dropped 5°
  - Younger Dryas = 12,700 yr ago
  - Collapse of thermohaline circulation
  - AT = 27° in Greenland
  - Duration 1000 yrs
- Primary Effects
  - Drought in key agricultural centers
  - Intensively winter storms
- Current Conditions

Synopsis: Leading to Other worlds

- Earth is a Complex System
- Interdisciplinary approach needed
- Don’t understand all feedback systems
- Models only as good as input data
- What are implications for our “space ship?”

Two Physical Effects

- Ozone Hole
  - UV creates and destroys O_3 in atm
  - Natural balance disturbed by man-made chemicals
- Green House Effect
  - Energy has to get to Earth’s surface
  - Heat (IR) is blocked by atm
  - Causes an increase in T

Other worlds

- Venus – once had oceans
  - Runaway Greenhouse
- Mars – once had liquid surface water
  - Global cooling