Introductory Astronomy

Week 3: Solar System(s)

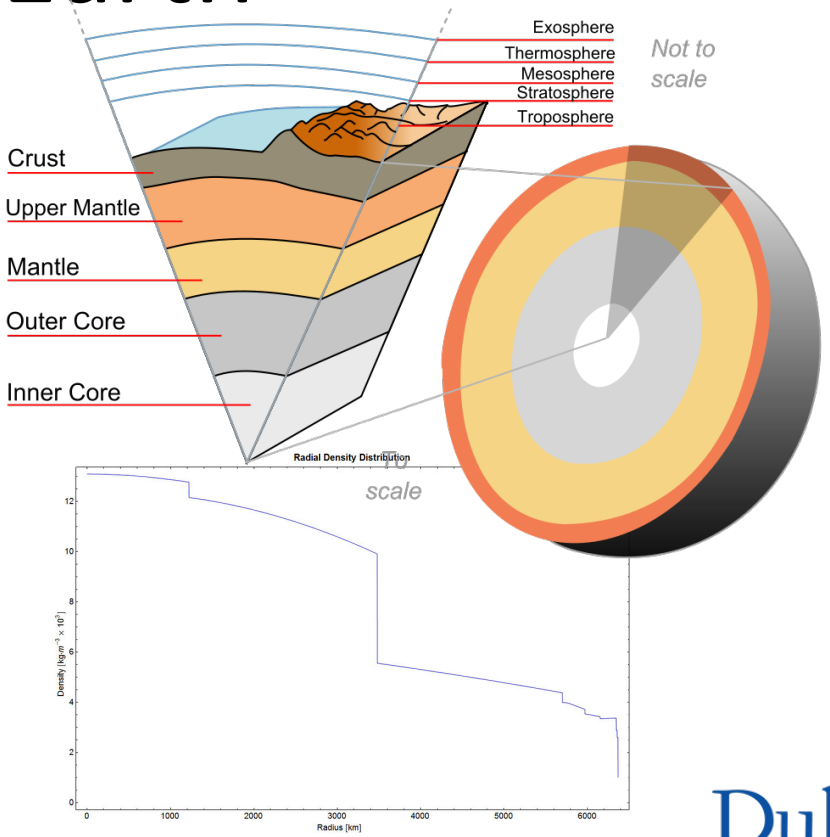
Clip 6: Earth is a Planet

On the Surface

- 71% of Earth covered with water
- Above this is atmosphere of (mostly) N_2, O_2
- Surface is rocky (Si) crust

Inside Earth

- In molten Earth chemical differentiation. Fe, Ni rich core, Si crust and mantle
- Density 5500 kg/m^3
- Pressure, density, temperature increase with depth
- Internal structure studied via seismology



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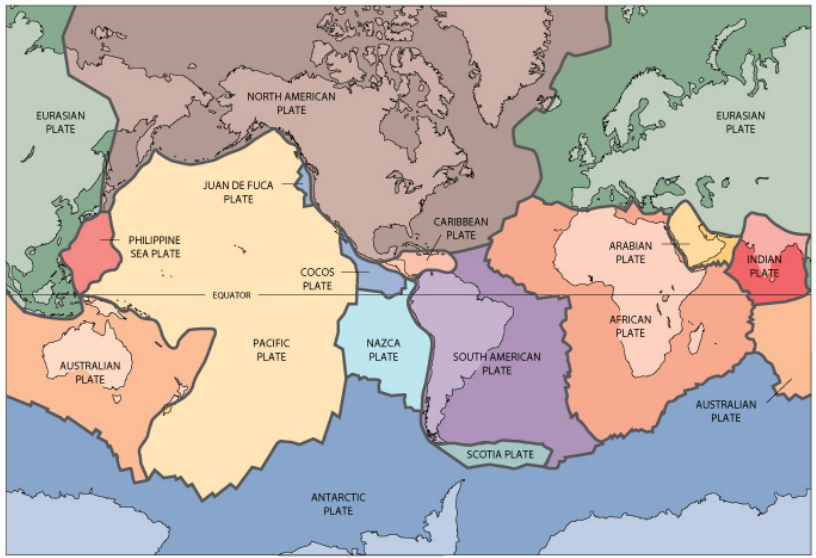
Internal Heat

- Heat generated in interior by
  - Radioactive decay
  - Kelvin-Helmholtz
- Drives convection in mantle
- Crust broken into plates dragged by mantle
- Heat loss $87\,\mathrm{W/m^2}$



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Energy Balance

- Surface temperature nearly constant
- Absorb energy as radiation from Sun, with small contribution from internal heat
- Lose energy by radiation to space
- In equilibrium, these rates are equal

If Earth were Black

$$I_{\rm in} = b_\odot \pi R_\oplus^2 = \frac{1}{4} L_\odot \left(\frac{R_\oplus}{D_\odot}\right)^2 = \pi R_\odot^2 \sigma T_\odot^4 \left(\frac{R_\oplus}{D_\odot}\right)^2$$

$$I_{\rm out} = 4\pi R_\oplus^2 F = 4\pi R_\oplus^2 \sigma T_\oplus^4$$

- Set them equal

$$T_\oplus = T_\odot \left(\frac{R_\odot}{2D_\odot}\right)^{1/2} = 278K$$

It's Blue?

- Earth reflects about 0.367 of the radiation
- This fraction is Earth's albedo
- So

$$I_{\text{abs}} = (1-a)I_{\text{in}} = (1-a)\pi R_{\odot}^2 \sigma T_{\odot}^4 \left(\frac{R_{\oplus}}{D_{\odot}}\right)^2$$

- Hence

$$T_{\oplus} = (1-a)^{1/4} T_{\odot} \left(\frac{R_{\odot}}{2D_{\odot}}\right)^{1/2} = 248K$$

The Greenhouse Effect

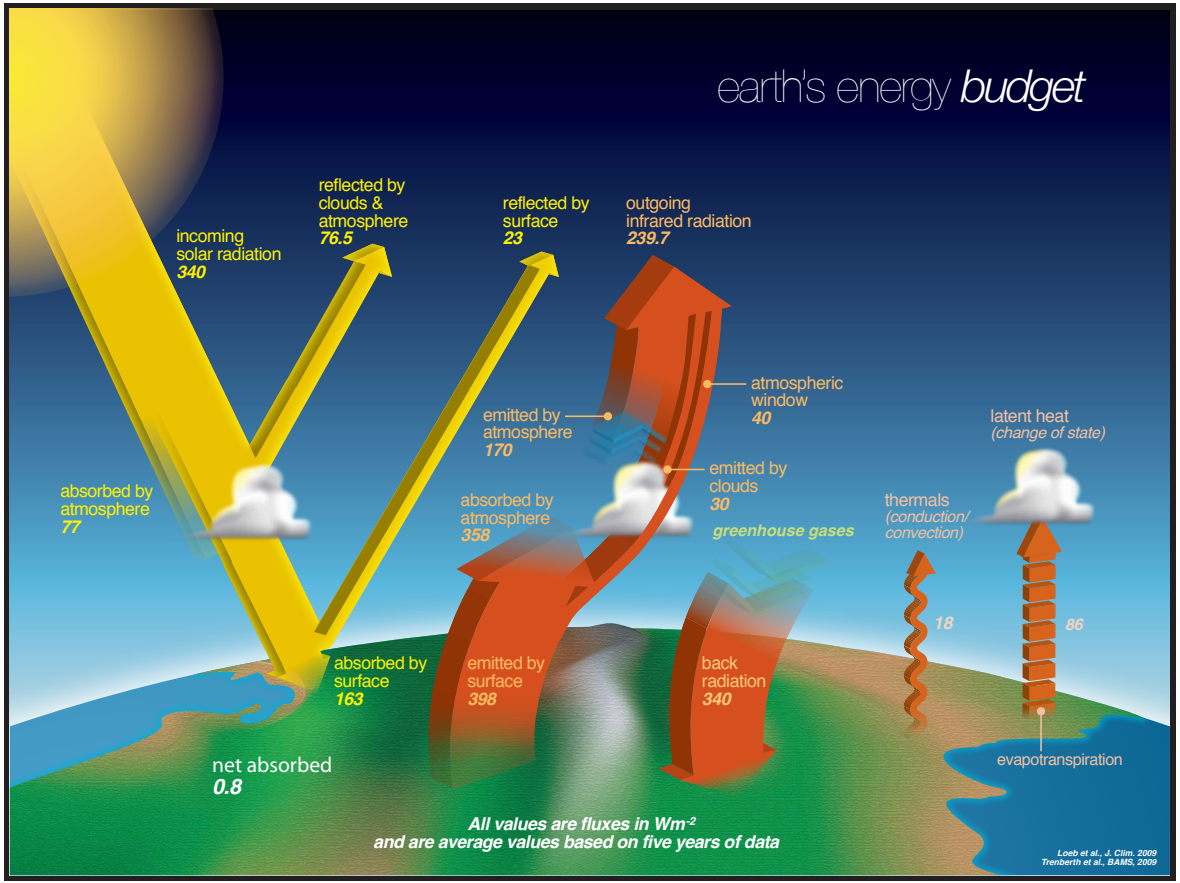
- Incoming Sunlight (visible) absorbed by surface through transparent atmosphere
- Radiated light (infrared) absorbed by molecules in atmosphere, heating this.
- Absorbed heat reradiated
- Surface warmer than equivalent blackbody

A Simple Model

- If atmosphere ideally transparent to V and absorbs a fraction g of IR
- Surface and atmosphere in equilibrium

- Surface $\sigma T_\oplus^4 = \sigma T_A^4 + F_{\rm in}$
- Atmosphere $2\sigma T_A^4 = g\sigma T_\oplus^4$

$$(1-g/2)\sigma T_\oplus^4 = F_{\rm in} \quad T_\oplus = (1-g/2)^{-1/4} T_{\rm no\,gh}$$

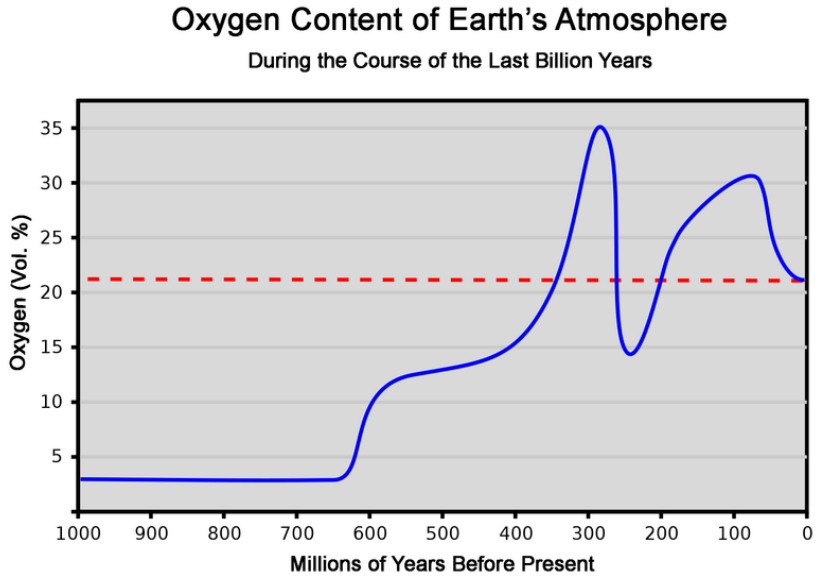

earth's energy budget
incoming solar radiation 340
reflected by clouds & atmosphere 76.5
reflected by surface 23
outgoing infrared radiation 239.7
atmospheric window 40
emitted by atmosphere 170
emitted by clouds 30
greenhouse gases
absorbed by atmosphere 77
absorbed by atmosphere 358
latent heat (change of state)
thermals (conduction/ convection)
18
86
absorbed by surface 163
emitted by surface 398
back radiation 340
evapotranspiration
net absorbed 0.8
All values are fluxes in Wm-2
and are average values based on five years of data
Loeb et al., J. Clim. 2009
Trenberth et al., BAMS, 2009

More Greenhouse Effect

- We found $T_\oplus = T_\odot \left(\frac{(1-a)}{4(1-g/2)} \right)^{1/4} \left(\frac{R_\odot}{D_\odot} \right)^{1/2}$
- With $a = 0.367, g = 0.21$ we find $T_\oplus = 292K$
- Atmospheric greenhouse effect crucial to making Earth inhabitable
- Changes in a, g can alter climate drastically

Atmosphere?

- Where did gases and water come from?
- N_2, CO_2 released from minerals in volcanic outgassing
- H_2O imported from asteroid belt during heavy bombardment
- Rain creates oceans which dissolve CO_2 and fix it in sediments – accelerated by emergence of continents
- Plants release O_2 initially taken up by Fe, S



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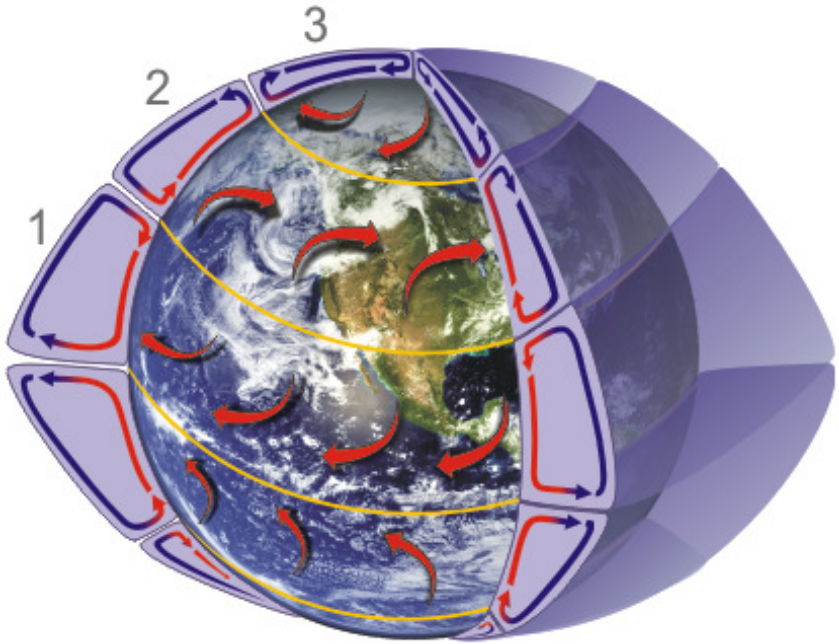
Atmospheric Physics

- Heated surface heats lower atmosphere driving convection
- Differential heating guides convection cells
- Rotation twists vertical motion to global winds



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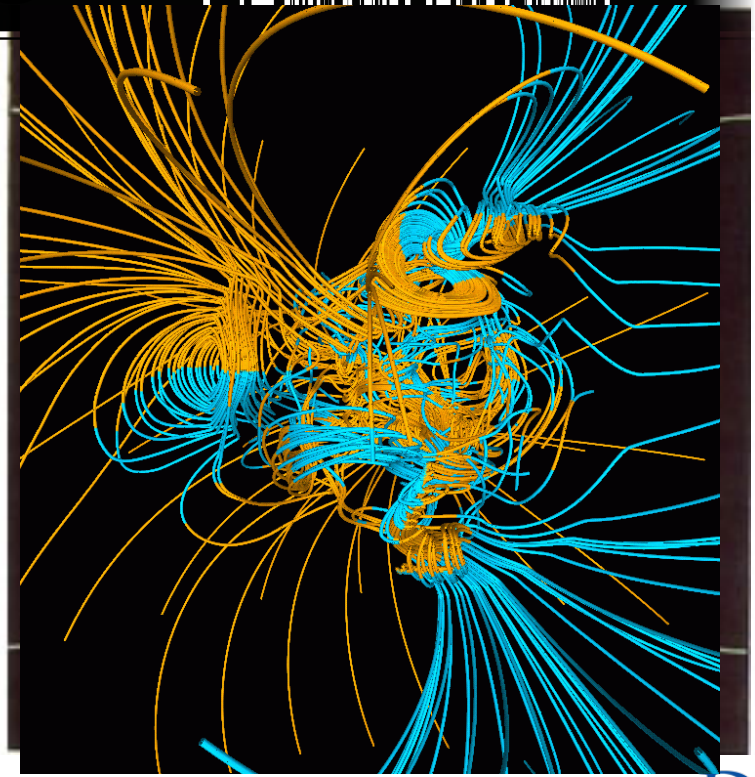
Earth's Magnetism

- Earth is a magnet roughly aligned with rotation axis
- Dynamo: convective flow of conducting outer core powered by heat of core and ongoing chemical differentiation and directed by rotation
- Field reverses polarity unpredictably



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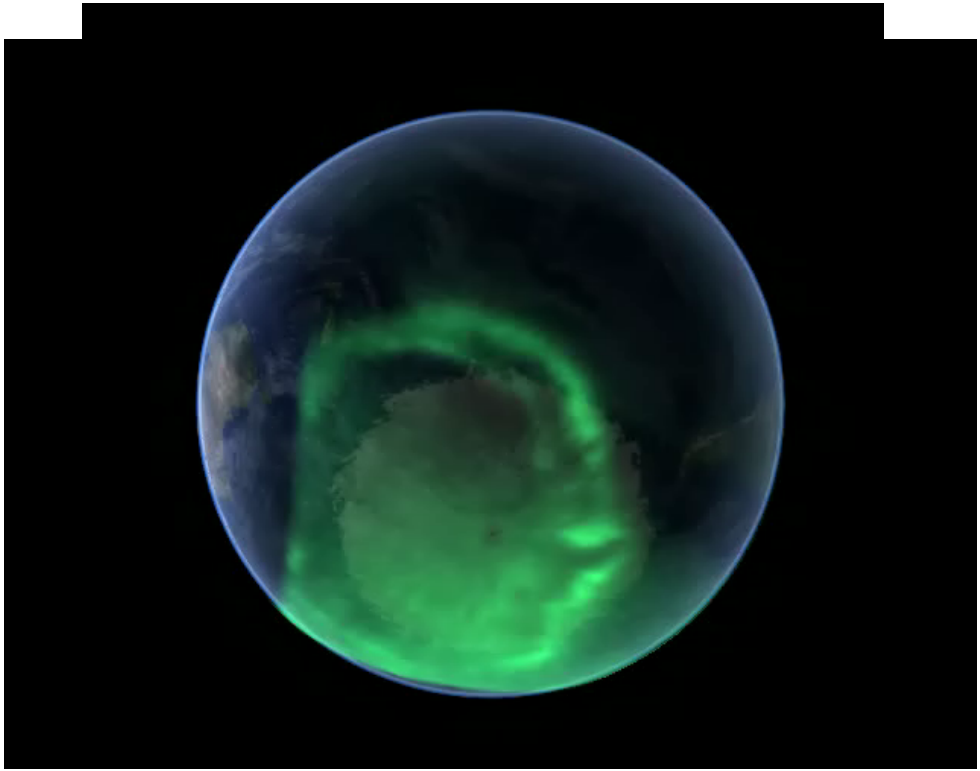
What the Field Does

- Charged particles of Solar wind trapped by field lines into radiation belts
- Solar wind deforms field
- During Solar storms some particles break through to atmosphere – visible by ionization



Summary

- Features of Earth as a planet we know well can serve as benchmarks for comparison
  - Tectonics/Geological Activity
  - Atmosphere/Temperature
  - Magnetic Field
- Geologically active Earth erases past. Less active bodies like Moon provide better data

Credits

- Earth: NASA http://solarsystem.nasa.gov/multimedia/display.cfm?IM_ID=9643
- Earth Interior: Wikimedia Commons http://en.wikipedia.org/wiki/File:Earth-crust-cutaway-english.svg
- Earth Density: Wikimedia Commons http://en.wikipedia.org/wiki/File:RadialDensityPREM.jpg
- Mantle Convection: Wikimedia Commons http://en.wikipedia.org/wiki/File:RadialDensityPREM.jpg
- Plates: USGS http://pubs.usgs.gov/publications/text/slabs.html
- Energy Budget : NASA Educational Materials http://www.nasa.gov/audience/foreducators/topnav/materials/listbytype/Earths_Energy_Budget.html
- Global Winds: NOAA http://www.srh.noaa.gov/jetstream/global/circ.htm
- Magnetic Field Schematics: USGS http://www.usgs.gov/faq/index.php?action=artikel&cat=11&id=477&artlang=en
- Magnetic Field Model: Dr. Gary A. Glatzmaier - Los Alamos National Laboratory - U.S. Department of Energy http://www.es.ucsc.edu/~glatz/geodynamo.html
- Radiation Belts: NASA/T. Benesch, J. Carns http://www.nasa.gov/mission_pages/rbsp/news/electric-atmosphere.html
- Magnetosphere Animation: NASA/T. Benesch, J. Carns http://www.nasa.gov/mission_pages/rbsp/news/electric-atmosphere.html
- Aurora: NASA/UC Berkeley http://www.nasa.gov/vision/universe/solarsystem/aurora1110.html