Weather and Climate

Peter Watson

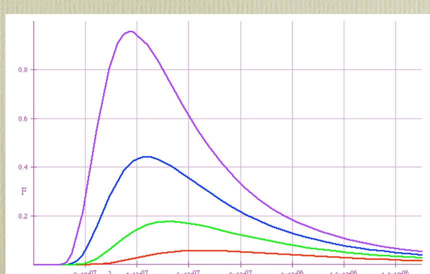
- Two fundamental laws:
- Stefan- Boltzmann law
- Total Power radiated/unit area

$$U = \sigma T^4, \sigma = 5.67 \times 10^{-8} Wm^{-2} K^{-4}$$

- (remember: must work in absolute temp, K not °C)
- i.e double the temp, 16 times the energy

Text

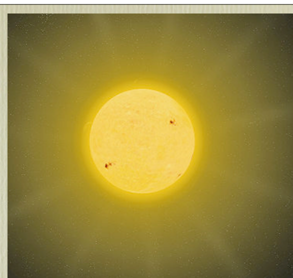
- Wien's law: $\lambda_{max} = \frac{B}{T}, B = 2.9 \times 10^{-3} mK^{-1}$
- Wavelength of peak i.e. as we heat up objects, they go
- black ⇒ red ⇒ orange ⇒ yellow ⇒ white

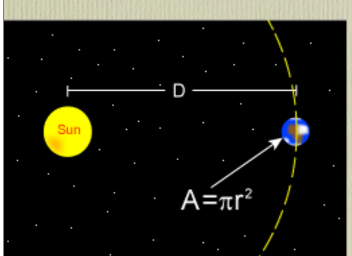


Can use this to figure out how hot the earth should be

- Our model: both earth and sun are perfect black bodies
- Sun is 7x10⁵ km in radius, temp. of 5800 K. How much energy does it radiate?
- How much is absorbed by earth?
- What temp. would earth be at to re-radiate this?

•Sun produces radiation
Each square metre produces σT_{sun}^4, so total power output (luminosity) is
$L = 4\pi R_{sun}^2 \sigma T_{sun}^4$

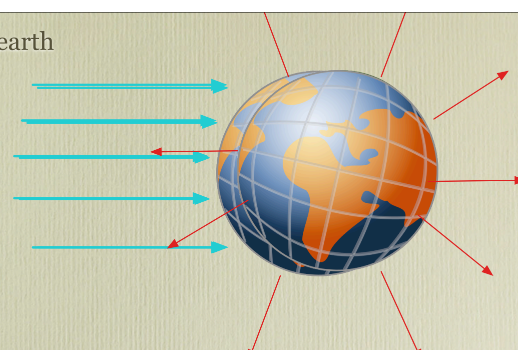




- This gets emitted into space,
- spreads out over an area $4\pi D^2$

Wikimedia

•absorbed by earth



Earth then re-emits energy at a lower temp T_{earth}

Wikimedia, PW

Inflow from sun must balance outflow

Inflow $$\frac{4\pi R_{sun}^2 \sigma T_{sun}^4}{4\pi D^2}\pi R_{earth}^2$$

Outflow $$4\pi R_{earth}^2 \sigma T_{earth}^4$$

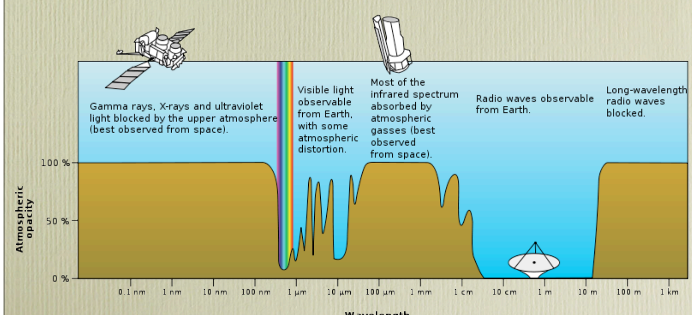
Must be equal (First Law!)

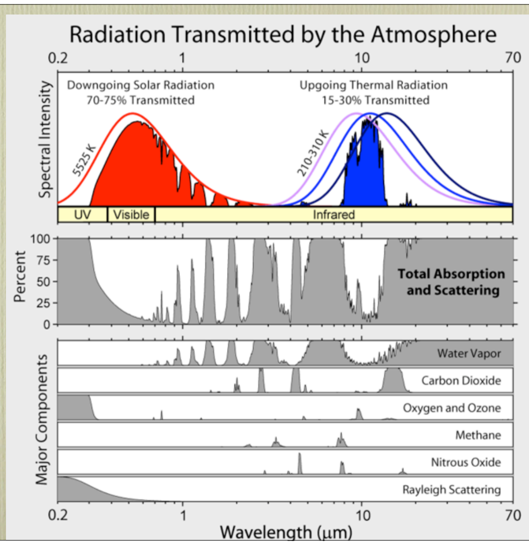
Predicts

Temp of Earth is $$T_{earth} = \left(\frac{R_{sun}^2}{4D^2}\right)^{1/4} T_{sun}$$

- This gives ~ 278K
- ~ 5°C
- Note this is an average: is it reasonable?
- A bit cool (actually, about 20°C)
- Why?
- Note the earth is cool, so re-radiated heat is at a much lower temp
- Incident energy is (mostly) visible
- re-radiated is infra-red

- Atmosphere is mostly opaque except to visible light & radio waves





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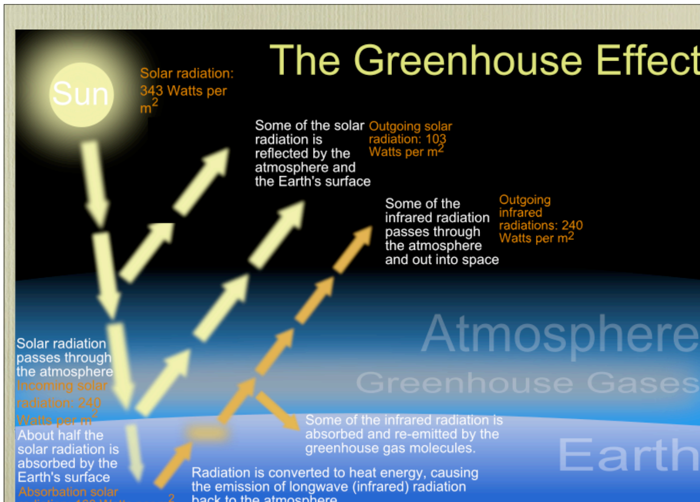
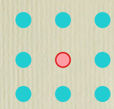
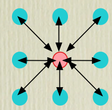


Weather

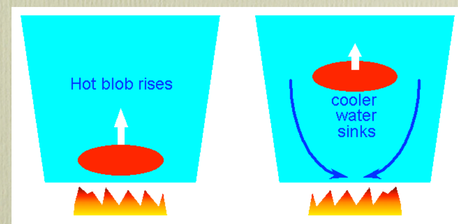
- "Primitive Equations" for weather written down by L F Richardson (1922). Can't be solved without computer
- Assume we know everything (temperature, pressure, humidity, radiation inflow...) at some points in space.
- Each point will affect it's neighbour, so can figure out how it will change
- Need to know how the energy can be transferred





Convection

- Most fluids expand when heated
- Hot water is less dense than cold, so rises

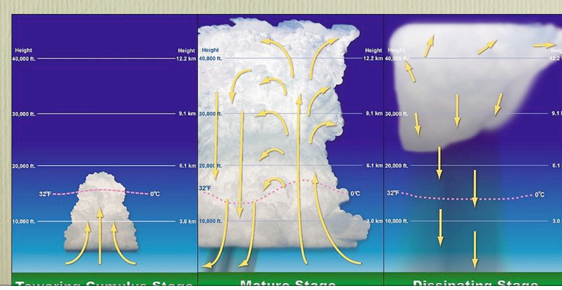


- In atmosphere:
- ground is heated by sun,
- transfers energy to air
- produces updraft
- in summer, humid air is heated, lifts upwards
- cools, water condenses out as cloud

Wikipedia

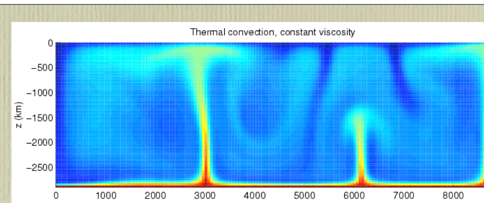
Evaporation & Condensation

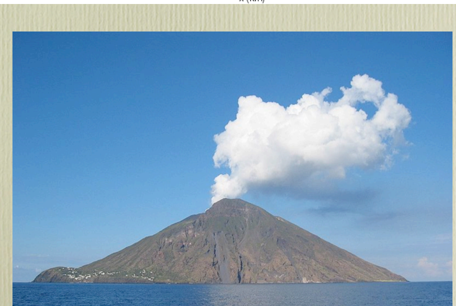
- Evaporation requires a lot of energy
- e.g boiling one litre of water takes ~ 2.3 MJ (million joules)
- Condensation gives the energy back



- Thunderclouds are evaporation-convection-condensation cycle

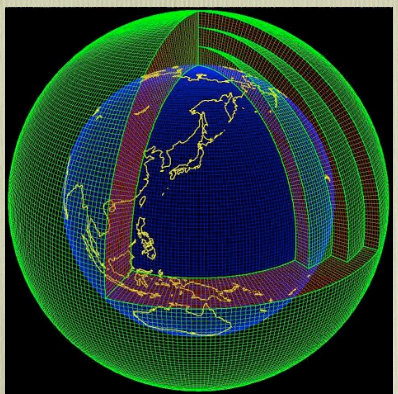
Text





Text

Weather

- For the earth, need a huge grid of points
- 

But

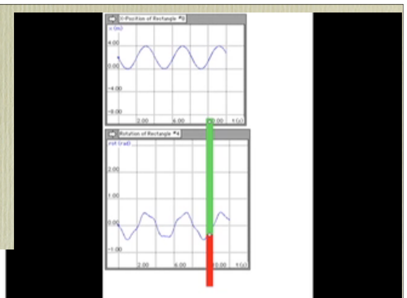
Butterfly effect found in 1950's: arbitrarily small perturbation of initial conditions have unpredictably large consequences.

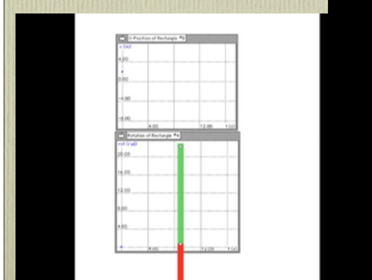
- The "Lorentz" equations: very simplified version of the "weather " equations, give rise to chaotic behaviour.

Double pendulum

- Small swings are predictable,

Medium swings are quasi-periodic





Large ones are chaotic

Weather is also chaotic

- You cannot predict the future weather precisely.
- However, buried in this are some predictable elements. e.g. we <u>cannot</u> predict an "el Nino" event, but we <u>can</u> predict the consequences once it has happened.
- Note "weather" prediction and "climate" prediction are (almost) unrelated

- Can predict globally, not locally
Can predict how fast a river will flow

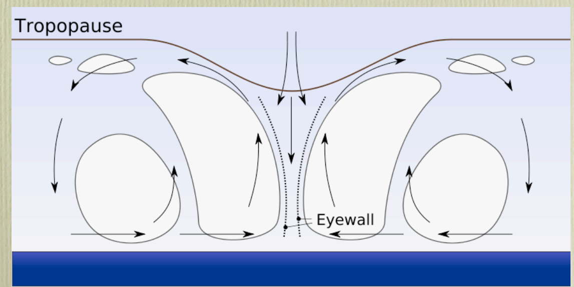
- But not how it will behave on small scale

PW

Hurricanes

NASA picture

- Driven by same set of processes
- Warm water in Caribben is easy to evaporate,
- energy transferred from ocean to upper atmosphere
- converts to mechanical energy (i.e. wind)

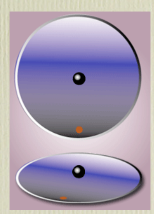


NASA

- Energy release ~ 10^{20} J/day
- power is 1PW = 10^{15} W ~ 100 times total power consumption of humanity

Hurricanes rotate anti-clockwise and drift west & north because of Coriolis force

Earth rotates, so it is a non-inertial frame of reference



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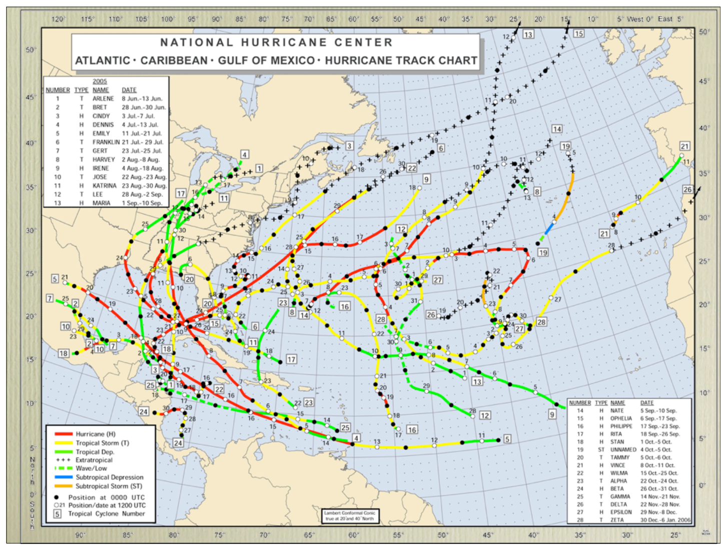
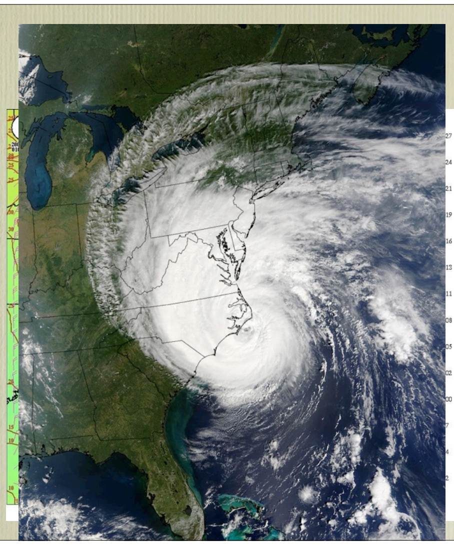


Can do it over the short term Hurricane Isabelle



Jesse Brown

-If the earth were to start spinning in the opposite direction would that change the climate?

- I know the rotation of the earth causes night and day but does the rotation also have an effect on the climate?

- 3) I'm sure it can be explained but I don't believe it is a simple answer

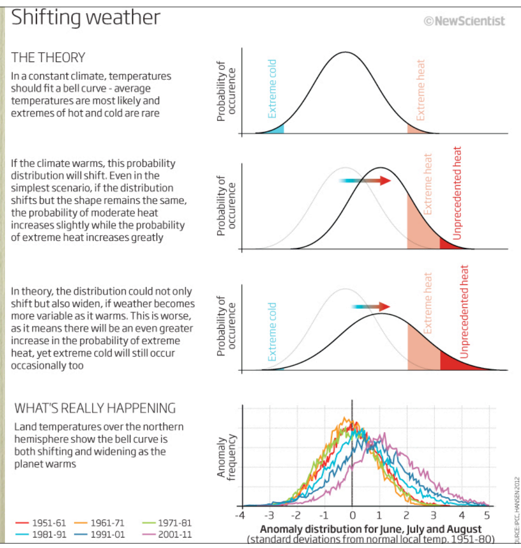
Interesting!

1. Globally, no change, but ....
2. Hurricanes rotate anti-clockwise and drift west & north because of Coriolis force (effect of the earth being non-inertial frame of reference)
3. Now they would rotate clockwise and drift east,
4. California and Spain would become hurricane areas!

Text

Weather and global warming

- Global warming does **not** imply that all temperatures will just shift upwards.
- The range of conditions will become more extreme
- e.g Pellston Mich. had previous temp record for March 22nd 2012 broken by 17° (New Scientist)
- Snow at Coliseum in Rome!



New Scientist
09 July 2012 by Stephen Battersby

- e.g summer of 2010 lies totally outside expected range
- extra heating is likely to increase number and strength of hurricanes

The Hot Summer of 2010: Redrawing the Temperature Record Map of Europe
Originally published in Science Express on 17 March 2011, doi: 10.1126/science.1201224
Science 8 April 2011:
vol. 332 no. 6026 220–224