Climate Change Lecture: DAVE'S NOTES – more or less what I used to prep my lecture notes. (note sections in RED not required for examination purposes)

ASIC200 (PART 1)

THE EARTH IS GETTING WARMER

Let's go over a number of facts that everyone (even skeptics and denialists) are more or less on board with these days.

(VIDEO) IF YOU MIX UP WEATHER AND CLIMATE, YOU COULD GO TO PRISON (FUNNY PSA)

Weather is the set of all extant phenomena in a given atmosphere at a given time.

Climate is the average and variations of weather in a region over long periods of time.

This is important, because when folks talk about climate change prediction, they often get it mixed up with respect to predicting weather. i.e. if we suck at figuring out what the weather will be like in 3 days, how on earth can we figure out things 100 years from now.

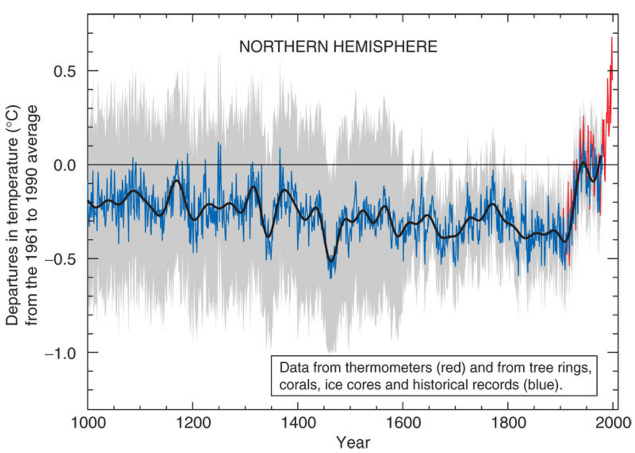
Weather knowledge, because of its emphasis on the situation "at given time" is incredibly susceptible to chaos. This is where a minor perturbation can result in a major change down the timeline. Chaos is not necessarily a random event, and can to some degree be calculated, but in order to be accurate, you have to have perfect knowledge of initial conditions.

Climate, because it's looking at period of time (nominally 30 years +) is way less sensitive to such nuances. Therefore, the predictive data produced here should be more reliable.

Talking points. Heads and Tails analogy.

Video link at http://www.youtube.com/watch?v=TQlHaGhYoF0

(GRAPHIC) HOCKEY STICK GRAPH OF TIME VERSUS TEMPERATURE



Here's an example of a figure that shows time versus temperature, which you can see demonstrates a general significant increase since around the 1850s.

A couple points to highlight here. Firstly, there's two main sections in this graph.
RED LINE: based on instrument data (i.e. a thermometer was used). We've got records as of 1659 (England), and quasi-global records as of the 1850s.
International Meteorlogical Org 1873
World Meteorological Org 1950

BLUE LINE: No instrument data. Therefore primarily relies on PROXY DATA.
Also note that the grey areas – this represents uncertainty, which essentially shows that the blue line has greater uncertainty, whereas the red line is pretty good (make's sense, since it is data obtained from instrument measurements).

WHAT IS PROXY DATA?

Definition (from wiki): "**climate proxies** are preserved physical characteristics of the past that stand in for direct measurements"
Tree Rings: (From http://www.climatedata.info/Proxy/Proxy/treerings_introduction.html)
The width of tree rings varies with, among other things, temperature. They can be used to estimate temperature for times before thermometers were in widespread use. When cross sections are taken of trees

there is a pattern of annular rings. The width of these rings is, in part, a function of temperature.
Other things which can affect ring width are:

- The age of the tree. The rate of growth varies through the life of the tree.
- Weather. In addition to temperature, ring growth is also affected by precipitation and to a lesser extent by wind speed and sunshine.
- Previous years. If a tree has grown vigorously in one year it is likely to grow vigorously in following years and vice versa.
- Atmosphere. Carbon dioxide is necessary to growth and increased levels of carbon dioxide can lead to enhanced growth.
- Competition. Other trees nearby or other plants can rob a particular tree of nutrients or light.
- Parasites. Infestation by insects or fungi can slow the growth of the tree.

To overcome the above, for temperature reconstruction the sites to be analysed are chosen so that these other factors have limited importance. For example trees might be chosen in areas where rainfall was plentiful so that water stress does not affect growth.
Even in well chosen sites it has to be recognised that ring width is not a uniform function of temperature but is biased toward the temperatures during the growing period. This is sometimes dealt with by analysing early and late growth separately.
It is not necessary to fell the tree first – normally samples are taken by boring into the tree with a hollow bit. Dozens of samples are normally taken from a group of trees.

Ice Cores: (From http://www.climatedata.info/Proxy/Proxy/icecores.html)
Ice cores are one of the most effective, though not the only, methods of recreating long term records of temperature and atmospheric gases.

Particularly in the polar region, but also at high elevations elsewhere, snow falls on an annual cycle and remains permanently. Over time, a few decades, the layers of snow compact under their own weight and become ice. By drilling through that ice, and recovering cylinders of it, it is possible to reconstruct records of temperature and of atmospheric gases for periods of hundreds of thousands of years.

Technologically the recovery of ice cores and their analysis is an amazing feat. Firstly as engineering: drilling thousands of metres in sub-zero temperatures, retrieving the cores and transporting them for analysis is a major feat. Secondly, to analyse the content of the air bubbles, and determine not only the proportion of different gases but also the proportion of specific isotopes of those gases is also technologically challenging.

Whilst ice cores allow direct measurement of atmospheric gases, like CO2 and Methane, some care is needed in interpreting the results. This is because of the fact that, while the snow is being compressed into ice, gas transfer may occur between the atmosphere and the layers of ice. Indeed, dating information is sometimes given for the “ice age” and “gas age”. Because the gases in the atmosphere are mixed and decay over time this adds another element of uncertainty. In effect, the data represent the average over a period of time, which can be several decades; a corollary of this is that data calculated from ice cores, for temperature of CO2 for example, will have less variation than the measured record.

In the case of temperature no direct measurement is possible. The temperature values are estimated from different isotopes of oxygen and hydrogen. The methodology is based on the assumption that different isotopes evaporate at different rates depending on the temperature. It is generally considered that the best estimate of temperature from ice cores is based on the use of both Oxygen-18 and Deuterium (a heavy form of hydrogen). Another complication is that ice is not stationary, which means that the ice collected at lower layers may not be the ice that was originally underneath the upper layers. Despite all of these limitations, it is generally accepted that ice cores give a good representation of temperature over very long periods. They are able to answer such questions as what drives the cycle of ice ages and warm periods and what is the role of CO2 in long-term climate change.

LATEST RECONSTRUCTED TEMPERATURE VERSUS TIME GRAPH (i.e. BERKELEY EARTH PROJECT - GRAPHIC)

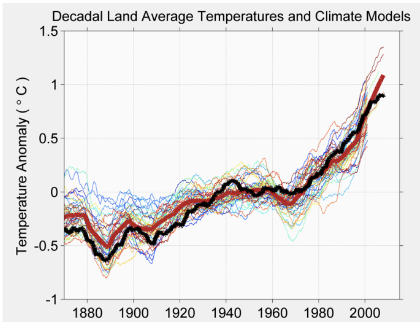


Figure 9. The above figure shows a comparison between Berkeley Earth Surface Air Temperature and a collection of GCM results from AR4. The GCM results are created by sampling the entire GCM field at the same locations and times as the Berkeley Earth average. The GCM average is shown in red and the Berkeley average is shown in black

Think how difficult it is to get a truly "global mean temperature" i.e. ice cores might be a great way to get proxy data, but then you're limited to places with consistent snow fall over many many years. Therefore, how good can proxy data be, when it's ultimately representative of a limited number of locales?

Even direct measurements have some caveats. From Berkeley Earth Surface Temperature Project. Good recap from the Economist (http://www.economist.com/node/21533360) Anyway, this study by Berkeley is trying to assess validity of direct measurements (use example of most instrument temperature records derived from airport readings which tend to be tarmacked and therefore could be considered heat sinks). Berkeley Earth Surface Temperature Project is especially newsworthy, because the lead investigator is a well known climate change skeptic (Richard Muller), which was also why funding for this project came from notable places (such as the Koch Foundation). In any respect, the main finding is that even a skeptic has had to admit that the data is looking pretty good and that the earth has been warming in an unusual manner.

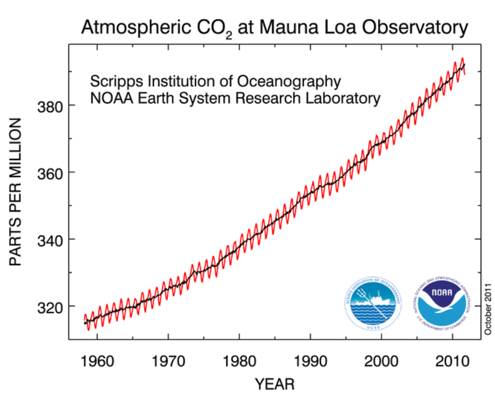
06 STRIKING ANIMATION OF TEMPERATURE CHANGES SINCE LATE 1800s
NASA Goddard Institute for Space Studies analyzis of global temperature data. (up to 2014)
http://svs.gsfc.nasa.gov/cgi-bin/details.cgi?aid=4252

Note: WMO (world meteorology organization) had calculated 2015 is likely to be the hottest in recorded history (global mean)

Figure from IPCC SPM, Fig SPM.1. Observed change in surface temperature 1901 to 2012.

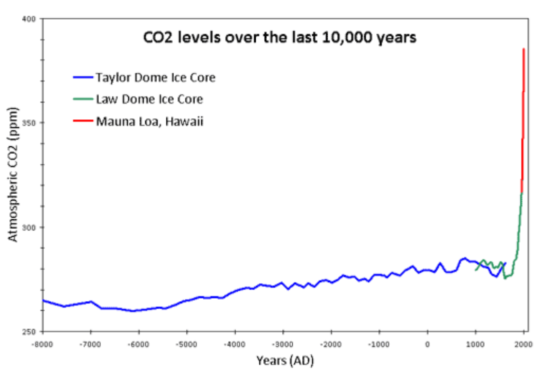
FACT – THERE IS MORE CO2 IN THE EARTH'S ATMOSPHERE. MUCH OF THIS IS DUE TO HUMAN ACTIVITY
Now that we've demonstrated the first fact (that the world is, indeed, getting hotter) – let's move to the second fact.

CO2 HISTORICAL TRENDS – LONGTERM AND SHORTTERM GRAPHS



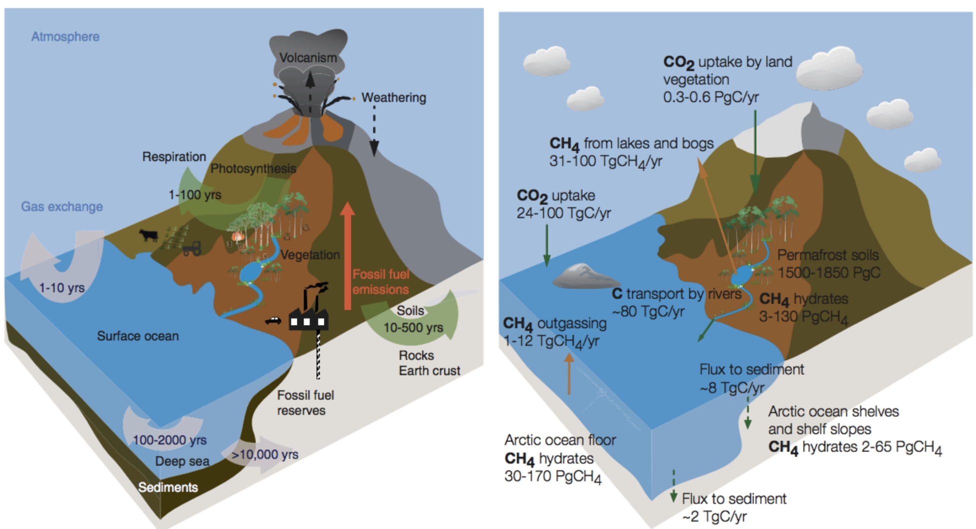
SHORTTERM (more about Mount Loa at Wiki)
Instrument readings from Mauna Loa Observatory. Note the up and down swing for each individual year. Lots of environmentalists refer to this as the "breathing" of the planet Earth.

Basically, most foliage is found in the Northern Hemisphere. Therefore, there are more plants in full photosynthetic state every summer. Consequently, you would see a "dip" in the atmospheric CO2 amounts (i.e. the plants are taking in more CO2 than say in the winter). Note that as of December, 2015, the ppm CO2 is equal to 401.85. When we last taight ASIC200 (2 years ago), it was 396.81



LONGTERM. (Note the red data is taken from Mt Loa) Blue and Green represent two different Proxy sets from two different Ice CORES (see section above on Temp Proxys).

10 CARBON CYCLE + HOW DO WE KNOW BURNING OF FOSSIL FUELS IS THE CULPRIT?



This carbon cycle image is essentially to show how carbon generally moves around on our planet. As such, any carbon being emitted into the air will eventually make its way to other parts of the cycle. Note that the numbers you see in the figure on the right are from calculations shown in the IPCC AR5 specifically for ice terrain scenarios (2013) – to illustrate CH4 nuances from permafrost loss. Also note that the timescale for carbon to move around can be very long for certain components (in the thousands of years). This is to say that it takes a long time for any carbon dioxide we emit into the atmosphere to spread itself out into the other places.

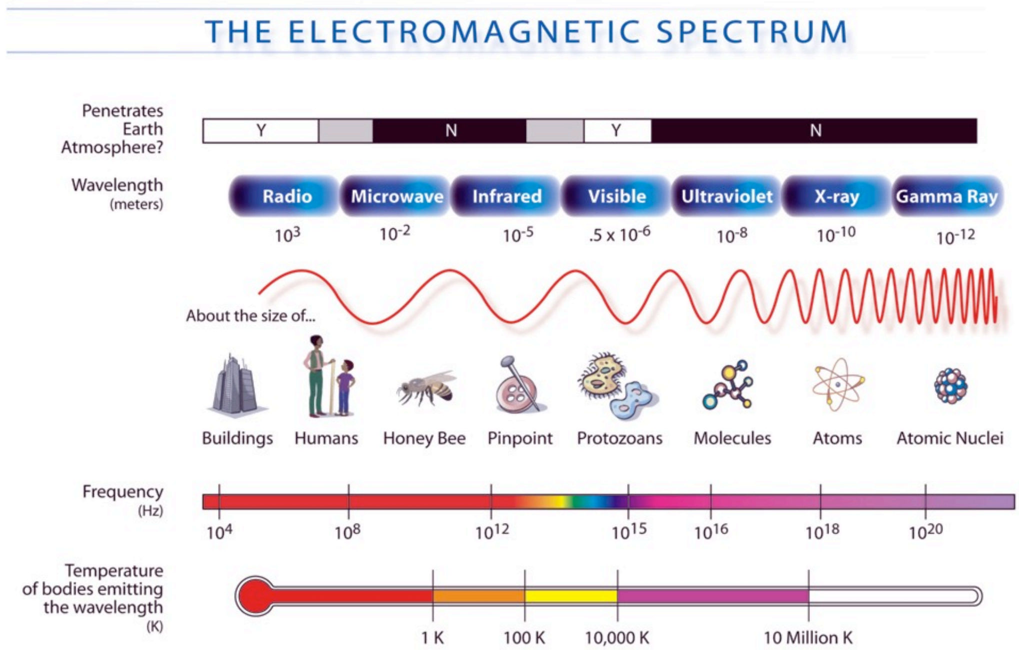
And how do we know that the rise in atmospheric CO2 is due to fossil fuel emissions? Well, this is because we can monitor the type of Carbon in the air. Like the Oxygen in the ice core scenario, there are different isotopes of Carbon. Turns out, plants prefer to take in a certain ratio of different carbons, and we can use this to calculate the amount of carbon from fossil fuel burning (i.e. fossil fuel like coal or oil, etc is almost all based from what was once plant material. You can read more about this at this piece - http://www.realclimate.org/index.php/archives/2004/12/how-do-we-know-that-recent-cosub2sub-increases-are-due-to-human-activities-updated/

END OF VIDEO PART ONE:
START OF VIDEO PART TWO

FACT – CO2 IS A GREENHOUSE GAS
I.E. CO2 is great at retaining heat energy. But what is energy exactly, and what kinds are there?

IT STARTS WITH THE SUN
So what do you think powers the Earth's climate? That's right – THE SUN!

ELECTROMAGNETIC RADIATION + QUANTA + ABSORPTION
From the Sun, this starts off as Hydrogen atoms fusing to become Helium, and with that comes a release of a whole load of energy, in the form of electromagnetic radiation initially gamma rays.



What is electromagnetic radiation. See figure (no need to memorize) Technically, any form of radiant energy that is made via some electromagnetic processes. Includes a number of different forms, and the discrepancies in these forms is more important for us (rather than a proper technical understanding of em radiation).

Note that gamma is at the far right. On the continuum of different types of electromagnetic radiations, it is the highest frequency, and highest energy type. Note also that you can get different types of radiation, which get less energetic as you move towards the left.

WARNING, there'll be a bit about QUANTUM STUFF as it relates to ABSORPTION.
Note the quantum (how everything at the atomic level likes to deal with discrete packets) stuff is unavoidably going to sound confusing - it's essentially a non-intuitive phenomenon. Still, will try to talk about it so as to initiate a discussion on absorption.

Energy in a vacuum will go along its merry way, but what if there's "stuff" in the way. 4 possible events. (1) misses stuff – keeps going through vacuum, (2) Reflection, (3) Refraction or (4) Absorption.

We'll focus on absorption

Absorption -> some or all energy is taken up by the stuff. Allows the stuff to achieve a different state as determined by the quanta (amount) of energy it absorbs. Note that the stuff absorbing energy will inevitably need to re-emit (or else it will just keep collecting collecting and collecting energy). When it re-emits it can do so at radiation of longer wavelengths (less energetic). From a tangible view, this can look like energy being sucked up, and then re-emitted in smaller portions. i.e. gamma goes in, a few ultraviolets come out, or ultraviolet goes in, and a whole bunch of infrared comes out. (thermal radiation). This also implies that matter can have different energy states (different based on things like where the electrons are flinging around, or how it wiggles <- each of these different states have distinct and discrete energy amounts associated with them, so knocking a molecule up or down these energy states requires absorption of a specific frequency or the emittance of a specific frequency.

Obvious examples of absorption include: white light from the sun (which is a mix of all different colours of visible light), hitting your sweater. Most of it gets absorbed, but some gets reflected. The reflected stuff is the same frequency that determines the colour you see. Eventually, the energy that was absorbed will get emitted out – here, it tends to do so as one of the lower energy forms (which often looks like thermal – re: heat – radiation).

ANYWAY… The whole point of a greenhouse gas, is that this is a gas that can absorb this lower energy thermal radiation. i.e. it can take in **heat** energy.

SETTING UP THE GRAPHIC THAT HIGHLIGHTS CHANGES IN ELECTROMAGNETIC RADIATION ENERGY FROM SUN TO EARTH.
We introduce my desktop, and showcase a few icons, representing gamma, uv/xray, visible, and thermal radiation.

Tracking the pathway of energy leaving the sun and on its way to our planet. In short, the Sun produces gamma rays, but by the time they leave the surface of the sun, they've been absorbed and re-emitted so much, that significantly less gamma rays actually leave the surface of the sun (they are now UV and X-Rays and visible and thermal, etc).

So imagine all three of these radiant energies hurtling towards Earth. Most of this is through the vacuum of space, so they continue – when they get to the Earth, they start hitting atoms in the atmosphere. Essentially, whenever they hit something absorption can happen. BUT absorption is special because the specific atom being hit can only absorb very specific frequencies of the electromagnetic radiation (kind of like a shirt will only absorb certain frequencies of colour, and reflect specific frequencies of colour). This absorbed energy in turn must eventually leave the atom, and sometimes leaves in the exact same amount, but more often leaves in increments (also in discrete amounts). If it leaves in increments, then by default it leaves in multiple "spurts" of lower energy forms.

ONE WAY TO LOOK AT IT: is why we see colours: visible light is actually a spectrum too, an infinity number of different colours (the rainbow if you like) that when mixed altogether make something that looks like "white." Think of the visible tshirt as actually a composite of lots of different tshirts of specific colours.

When visible light (this spectrum and therefore looking whiteish) from the sun hits an object on Earth, that object (being composed of a LOT of atoms, and LOTS of DIFFFERENT atoms), is often capable of absorbing all sorts of energy levels of the visible spectrum. How some of these energy levels however are accounted for by what the atoms can absorb, and therefore get reflected back. In other words, this is what you "see." The types of electromagnetic radiation that didn't get absorbed (and that our eyes can pick – which happens to be the "visible spectrum.")

(GRAPHIC) PICTURE OF CO2 AND DIAGRAM OF TYPES OF ENERGY COMING FROM SUN VERSUS TYPES OF ENERGY LEAVING THE SURFACE OF THE EARTH.
Doesn't CO_2 look like the head of a fly?
In any event, when the energy from the sun (mostly in the form of visible electromagnetic radiation by the time it hits the earth), the ground will absorb most of it (some of it does get reflected back – like if it hits something like snow or white clouds on the way in), which in turn will be predominantly remitted as thermal radiation.
Without greenhouse gases, this thermal radiation would bee-line back out into space. However, due to the presence of greenhouse gases (like CO_2, methane, water, etc), it gets absorbed, then reemitted in a random direction, reabsorbed, etc
Overall, all of this energy will eventually make its way back to space, but the point is that the greenhouse gas will effectively delay that event, causing heat to be retained in the earth atmosphere. Think of it as delaying the heat to stick around longer.
Regardless, that CO_2 is a greenhouse gas and capable of doing this type of thing is a FACT.

RECAP OF THREE FACTS COVERED
(1) The Earth is getting warmer.
(2) There is more CO_2 in the Earth's atmosphere. Much of this is due to human activity.
(3) CO_2 is a greenhouse gas.

END OF VIDEO PART 2.
START OF VIDEO PART 3.

HYPOTHESIS:
The increase in temperature is largely due to the anthropogenic production of CO_2.

Segues: pirates versus global warming (from the Flying Spaghetti Monster Religion), and planet building (the perfect experience to test effect of human fossil fuel emissions is to have a negative control planet!).

This is point out that we have a number of FACTS, but the hypothesis in this slide infers and relies on a causation. Very different from a correlation.

THERMODYNAMICS: The laws of thermodynamics are to science what Shakespeare is to literature. (variation of a C.P. Snow quote)
"A theory is the more impressive the greater the simplicity of its premises, the more different kinds of things it relates, and the more extended its area of applicability. Therefore the deep impression that classical thermodynamics made upon me. It is the only physical theory of universal content which I am convinced will never be overthrown, within the framework of applicability of its basic concepts."
-A. Einstein.

"Lisa, get in here. In this house we obey the laws of thermodynamics!"
-Homer Simpson.

THE FIRST LAW OF THERMODYNAMICS: A DESCRIPTIVE TAKE
Thermodynamics is a branch of science, which more or less looks at things like temperature, pressure, and volume, particularly as they relate to a mathematical representation of things like energy or motion.

A more simplistic view is to think of thermodynamics as really a field that takes a close look at something like heat, and how that relates to something like energy,

In fact from a strictly scientific vantage, the term "heat" can be defined as a "movement of energy." Think of what happens when you put a burning coal next to an ice cube – there is clearly a change of temperature in both players as the energy is transferred from one to the other - that energy in transit is referred to heat.

We'll focus on the first law, because in many respects, it represents a good glimpse of how a lot of climate science is surveyed. Here, the **first law of thermodynamics** can be expressed in a number of different ways.

If you were running a PR firm you might go with:
We are all about the conservation of energy.
Which, well like a lot of PR, is a bit on the vague side.
Here's an interesting sidebar – the PR take can also be stated as:
"Energy can be neither created nor destroyed"
...although it can be converted from one form to another. It's such a central tenant of science that often this first law gets the limelight as one of the most important "laws of nature." (Use the word "bookkeeping" to illustrate what you can do with the 1^{st} law of thermodynamics – i.e. energy must always be accounted for, must always add up).

Another key to using the 1^{st} law of thermodynamics is that it must be stated clearly, where exactly you are looking at these energy calculations (i.e. setting the physical boundaries). Because of this we need to talk a bit about the properties and layers of the atmosphere as that terminology helps explain what the "system" is when IPCC talks about what is happening to energy on the planet.

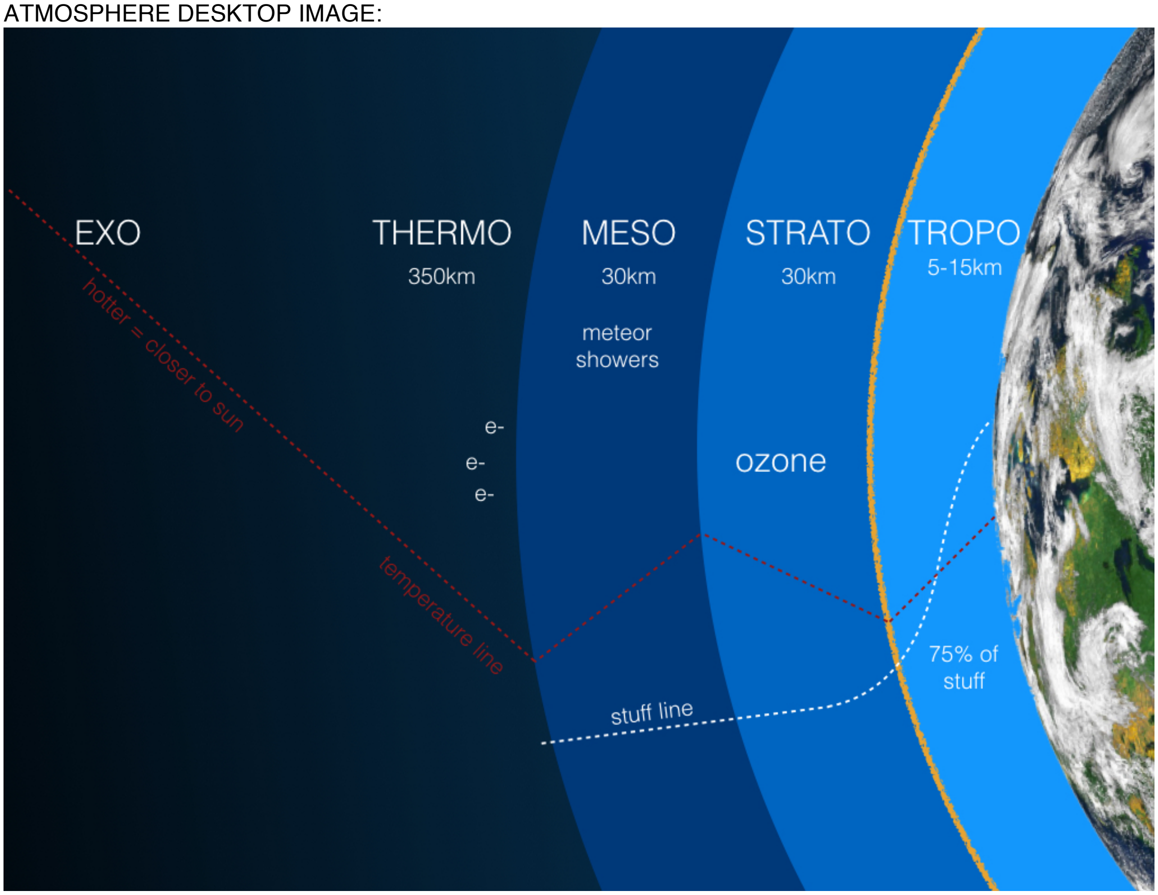
THE ATMOSPHERE (General knowledge to explain what the layers are and why the heat changes occur is required for the exam).
The Inverse Square Law (right image on slide)

There are layers here, labeled due to temperature trends which are primarily determined by the stuff present and what it does with the incoming energy from the sun (remember it's a variety of different wavelengths in the ultraviolet and visible light ranges), as well as energy bouncing or re-emitted back from the earth. Where stuff settles is basically dependant on a number of different things.

1. (Density) of stuff. (relates to the Earth's gravitational pull). This layering also creates strata of pressure (high at the bottom, and low at the top). The gravity of the moon also has a diurnal and lunar effect.
2. Temperature of stuff. (relates to energy as supplied from the sun coming in, as well as energy supplied by thermal radiation emitted from various parts of the earth/sky). Heat energy is capable of moving things, and can thus effect where certain things choose to settle.
3. And the movement of stuff in general will determine where things are going to settle – momentum from atmospheric tides, an effect from both the movement of the earth, as well as weather systems. Coriolis effect

Bottom line is that the stratification is quite severe. This stuff does tend to equilibriate to discernable layers. As far as terminology is concerned the common labeling of layers relates to temperature changes (getting hotter to getting cooler and vice versa) in the atmosphere.

ATMOSPHERE DESKTOP IMAGE:



Thermosphere: Hardly any stuff. Temperature gradient from hot (top) to cold (bottom), largely due to small amount of oxygen absorbing ultraviolet energy from the sun –near the top individual gas molecules can reach a temperature of 2000K. Still, you don't actually feel this because there's so little of it around. Some of the oxygen that gets smacked here from incoming UV light to the point, releases an electron to fly off. -> ionosphere (aurora).

Mesosphere: catching the tail end of atmospheric tides. Throws a bit of stuff into this region, such that you're starting to see that gradient of material (more closer to the earth, less further away from the earth). Consequently, you have a temperature gradient as seen due to more stuff able to absorb energy at the lower part of this layer. Enough material in this part of the atmosphere to create the friction necessary to burn out any falling object coming through to the earth (this is where meteor showers happen).

Stratosphere: Now we're seeing more of the stuff pluming up from below, but the stratosphere is notable because it is also where the vast majority of the atmosphere's ozone settles. Since ozone is a strong absorber of ultraviolet, this layer in particular takes in a lot of that energy. You see a reverse gradient here, because UV light essentially gets filtered out so that less and less makes it through to the lower levels to create that heat. (hence the temperature gradient from hot at the top to colder at the bottom).

Then we get into the troposphere.

THE TROPOSPHERE (OR BELOW THE TROPOPAUSE) AS OUR "SYSTEM."
In thermodynamics, the "system" defines the boundaries in space where we choose to do our bookkeeping. i.e. if you were an accountant, your "system" might just be the financial details of "one person." Or perhaps the system would be bigger, say the entire family. In thermodynamics, we need to consider where we're doing our energy math. For Climate Change investigations, most of the things talked about in the IPCC deal with energy at the planetary scale, specifically in that first layer of our atmosphere.

Precise definitions of TROPOSPHERE and TROPOPAUSE:
What is the troposphere? In a nutshell, the troposphere is the lowest portion of Earth's atmosphere comprising about 75% of the total mass of the atmosphere. It's here that almost all of its water vapor and aerosols are present. The size varies between the poles and the equator, primarily due to this water vapor – i.e equator has a lot, the cold poles not so much. Therefore, the equator has a troposphere as large as 15 or so km. Whereas at the poles, it can be as small as about 5km in thickness.

O.K. This part is important. The boundary of the troposphere and the stratosphere is called the TROPOPAUSE. It represents the place, where the temperature gradients do the first flip flop from the surface of the Earth, since that seen from the stratosphere is due to the incoming solar (ultraviolet/visible) radiation from the sun, and that seen from the troposphere is due to the outgoing thermal radiation coming back from the earth. The idea here is that folks often say that if the earth had no greenhouse effect, in order for the energy to balance out (incoming solar = out going thermal), calculations suggest that the average temperature of the earth should be about –19C. Obviously, it's not (because of the greeenhouse effect). However, this -19C mark can be observed at the TROPOPAUSE – therefore it represents a place where that "balance" is seen.

Another way to look at this is to realize that climate essentially happens below the tropopause.

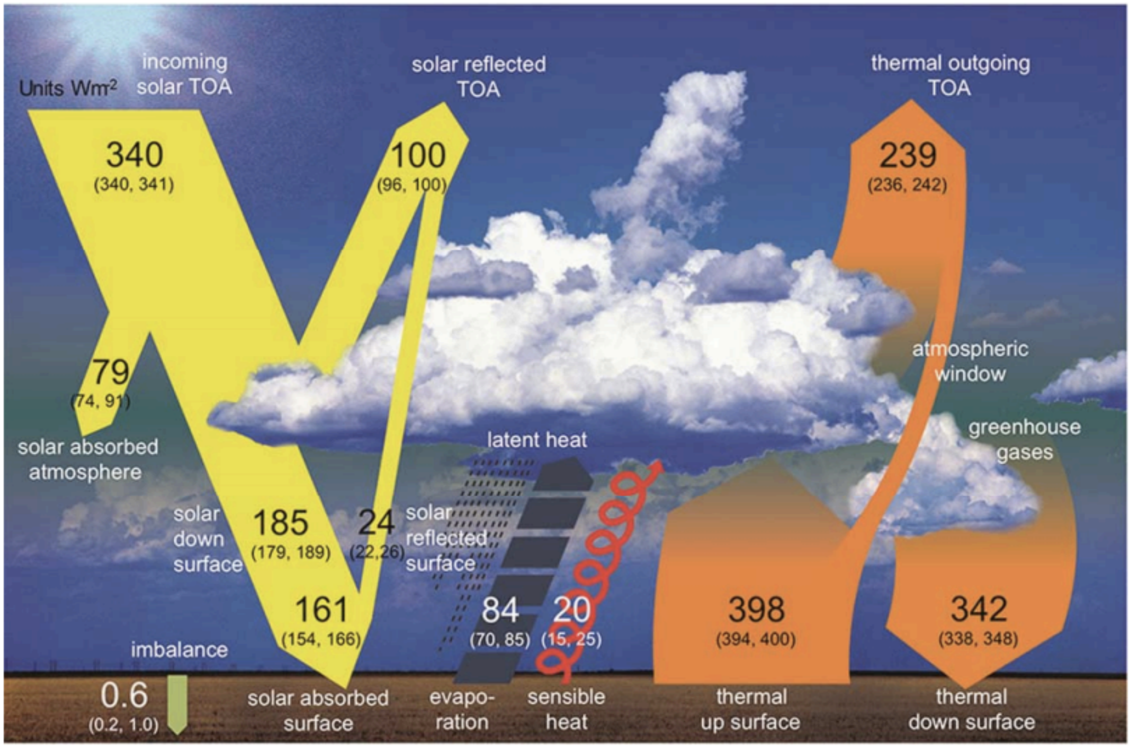
SOME HULK PHYSICS
Essentially a run down of what some of the units of energy are. In particular, we'll derive what a "Joule" (a unit of work energy) is, and also what a "Watt" is (a unit of power) – these are the most common units that come up in policy reports.

NOTE students do not need to memorize or do the math, but working through the math definitely helps with understanding the concepts, and why the energy calculations are express in units of Watts.

Although you won't need to derive the definition of a Watt, you should know what a Watt is essentially measuring (i.e. it's a unit of power, or amount of energy produced per second).

WHAT HAPPENS BELOW THE TROPOPAUSE: HOW ENERGY MOVES.
Note that numbers are given in Watts per Metre squared. Watts is a measure of power which is defined as the amount of energy produced each second. (i.e. the sun emits a certain amount of energy per second – at about 342W worth on a one metre by one metre square. Note also that this number is an average since the equator receives more and the poles would receive less, etc).

This below figure is actually one of the most central things in the IPCC reports (but evidently too complicated to present in the policy maker summary).



This is where the numbers might get a little confusing, because its not like when energy is absorbed, it gets re-emitted back out past the tropopause instantly – rather some of it does, but some of it takes its time, it lingers, it loiters (this actually is the greenhouse effect).

Will walk through the figure a bit – note this is to essentially show that our first law of thermodynamics holds true (it all adds up and can be tracked). No need to memorize this chart, but if presented with it, and I were to ask you a question about what's going on here, then you should be able to figure that part out (with the exception of "evaporation", "sensible heat" and "latent heat" concepts).

The net effect of this series of flowcharts is to realize that there specific places where this energy moves to and from. If we affect any part of it, that change will feedback on the entire system. For instance, say our greenhouse gases are increased, this will unduly affect the net absorption of thermal radiation in the atmosphere, which in turn can be emitted back down to the surface – overall this creates an effect where the overall presence of thermal radiation in either the troposphere or the surface is increased (i.e. it lingers, loiters, even longer – net average temperature goes up – global warming).

Example of how you can alter that flowchart. A second sun! (Star Wars, tatooine movie file).

RADIATIVE FORCING
This "below the tropopause" is an important place to focus on because it includes talk about RADIATIVE FORCING. This receives a lot of attention in things like the IPCC reports.

"radiative forcing" - IPCC definition.

The radiative forcing of the **surface-troposphere*** system due to the perturbation in or the introduction of an agent (say, a change in greenhouse gas concentrations) is the change in net irradiance (solar plus long-wave; in **Wm-^{2}**) at the **tropopause** AFTER allowing for stratospheric temperatures to readjust to radiative equilibrium, but with surface and tropospheric temperatures and state held fixed at the unperturbed values.

What does this gobbledegook mean? Basically, radiative forcing is something that can change the energy movement calculations in the IPCC figure. For instance, a goofy example would be the addition of a second sun. This would obviously effect the 342W/m2 number, thereby affecting the rest of the figure.

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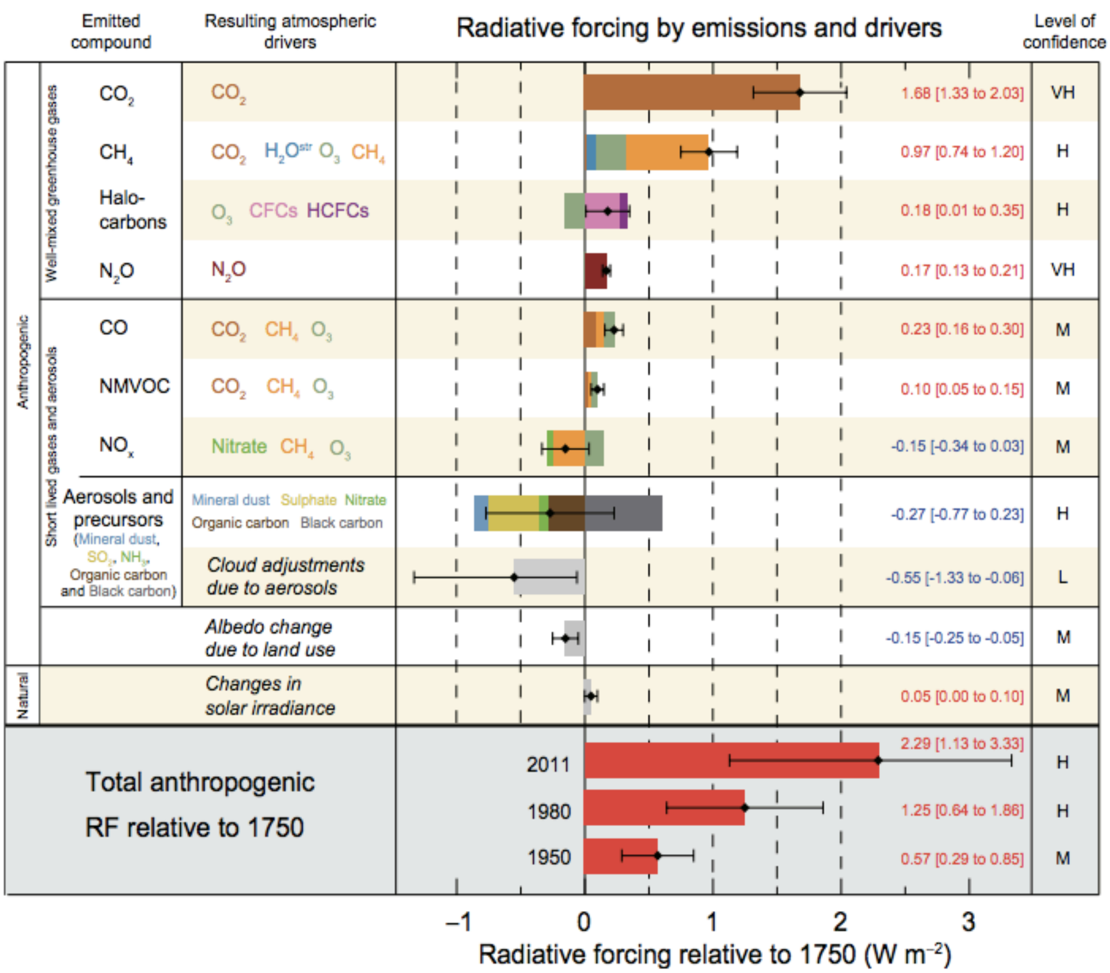
> Likewise, think about what would happen if cloud formation is altered due to the conditions of the atmosphere. Think of what would happen to this system if land albedo changes. Think of what may happen if you have an ozone hole over the stratosphere (which means more UV light can get to the troposphere – more energy, and also energy that can affect the make up of the troposphere). In all, everything is connected to everything else, so trying to project changes is having the models take these things into account.

I also highlighted the word AVERAGE a couple times, because the other point is that the troposphere, the earth's surface and how the solar irradiance hits the earth's surface, varies greatly depending on where on the earth, you're talking about.

i.e. in the Northern Poles – thinner troposphere, less water vapor, less solar irradiance coming in, high albedo.



RECENT ENERGY CALCULATIONS: Note that the recent AR5 states. At least half of the earth's temperature rise is very likely (>90%) attributed to human activity.

Highlight a paper that suggests that at least 74% of the climate change we see is due to human activity. (Late 2011) I.e. humans as a central cause of radiative forcing (note however, this research also calculates in things such as deforestation, land use, etc – i.e. not just CO2 emissions). http://www.nature.com/news/at-least-three-quarters-of-climate-change-is-man-made-1.9538

END OF VIDEO PART THREE
START OF VIDEO PART FOUR

ANOTHER HYPOTHESIS These greenhouse gas amounts and increases in temperature will lead to predictable (and bad) effects to the planet and its inhabitants.

TIME TRAVEL! The perfect experiment to address this hypothesis.
Time machine would also be great to check in with our future projection studies. I.e. a lot of the IPCC report is about trying to predict the future effects of our carbon emissions.
See http://arxiv.org/abs/1312.7128 (time travel paper!)

DU = DQ – DW
How exactly would you test for this: Basically, you rely on climate models. How do you do this? You rely on mathematical representations of universal physical laws. For instance, the first law of thermodynamics can also be stated in mathematical terms.

DU = DQ - DW

DU = Internal energy (i.e. how much the molecules or atoms hold in energy – in their bonds, where electrons are, how they vibrate, how they hold together – actually quite a complex concept but, one simple example is the amount of energy it holds because of its because of its state – gas versus liquid versus solid <- this is sort of true – but don't worry about it for this course).
DQ = heat energy
DW = energy in the form of WORK.

Now, in science speak, it may come out:
The first law of thermodynamics defines the internal energy as equal to the difference of the heat transfer into a system and the work done by the system.
Which is kind of confusing.

But the equation is just an elegant way of saying that this first law is (as mentioned before) akin to a form of bookkeeping – which is why sometimes, there is the notion of conservation of energy in this law.

Bookkeeping with this equation allows you to make calculations, and calculations can be especially powerful because they provide predictive possibilities, more so when you can include other physical laws into the mix.

PUT ANOTHER WAY. IF radiative forcing dictates that dQ (heat) goes up, then that increase in energy must be accounted for. More importantly, this might take the form as something as basic as "temperature goes up" OR maybe some of that heat energy gets converted into Work OR energy being taken up and presented in matter as an increase in internal energy. Regardless, it all needs to add up.

These changes in heat and the movement of energy into different forms can lead to effects (at least at the intuitive level).

ADJUSTING LEVELS OF WORK - AIR, WATER, EVEN LAND.
Air in the atmosphere doing work could be thought of as wind, and water doing work could be thought of as currents, waves, etc. A fairly obvious example of air and water together doing a lot of work is something like a hurricane.
Make sure to also highlight why a single hurricane event can't be attributed to climate change, as the earth can also exhibit localized temperature extremes regardless of climate change. However, you can get a sense of whether the increase in global mean temperature causes these kinds of things by looking at total numbers of extreme weather events.
There is even a bit of evidence that frequencies and magnitudes of earthquakes may be increasing slightly because of climate change. (i.e. land doing more work). Read http://boingboing.net/2011/08/04/climate-change-and-earthquakes-its-complicated.html

ADJUSTING LEVELS OF INTERNAL ENERGY. STATES OF MATTER EXAMPLE -> ICE MELTING, SEA LEVELS, TROPIC BANDS. CHANGE IN CHEMICAL REACTIONS
If there is an increase in internal energy, then that could lead to things like water changing states (from solid to liquid, from liquid to gas). This equates to things like ice melting, water evaporating. Ice melting can lead to sea levels rising, water evaporating could lead to changes in the locales of the tropics (i.e. shifting the areas of dry places). -
http://www.sciencemuseum.org.uk/ClimateChanging/ClimateScienceInfoZone/ExploringEarthsclimate/1point1/1point1point3.aspx

MOVING FROM THE INTUITIVE: HOW CALCULATIONS CAN LEAD TO PRETTY GOOD PREDICTIONS.

Some time with Boyle's Law! (the specific not required for the exam -> take home point is the predictive power of a finely worked out physical science law)

PV=NRT

LIQ NITROGEN + BALLOON I DRY ICE + TUBE
Here's one worth knowing– it's called the Ideal Gas Law. Wait, let's bold that even. **The Ideal Gas Law**. Benoît Paul Émile Clapeyron in 1834 came up with that one. It's really quite pretty and states that:

pV = nRT

Where:
p is the absolute pressure [Pa], (Pressure (symbol: 'P') is the force per unit area applied on a surface in a direction perpendicular to that surface.)
V is the volume (in cubic meters) of the vessel containing *n* moles of gas
n is the amount of substance of gas (in moles again – not the animal, a unit of "numbers" of molecules)
R is a constant, specifically the gas constant. It is equal to 8.314472 $m^3 \cdot Pa \cdot K^{-1} \cdot mol^{-1}$.
T is the temperature in kelvins (a unit of temperature, like a shifted over version of celcius)

If you reflect on this, hopefully you nail home the point that things like temperature can affect volume, and pressure. i.e. if you have a vessel and you know the volume, and you put a gas in it (and you're able to measure how much), and you play around with the temperature of the vessel – you can mathematically work out the pressure in that vessel. And in effect, things like pressure and a change in volume can "move" things and ultimately enact a degree of work.

MORE IMPORTANTLY, this allows us to make pretty good predictions about the behaviour of the balloon. Actually, we can make very precise predictions (due to the mathematical representation of behaviour of gas).

FIRST LAW OF THERMODYNAMICS + IDEAL GAS/BOLYE'S LAW = FIRST LAW OF THERMODYNAMICS FOR THE ATMOSPHERE

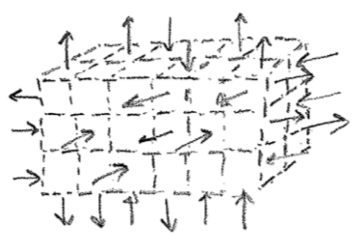
Because the ideal gas law is also a way to look at how air can do work, we can fancy up our first law of thermodynamics. More specifically, by combining the two equations, we get (no need to memorize!):

$$dq = c_{v,m}\, dT + \frac{p_a dV}{M_a}$$

This is actually a more formal rendition of the first law of thermodynamics for the atmosphere, and here's the thing (so so important), many of the variables and constants denoted in this new expression can be measured and/or modeled.

Think of it like this. How much heat energy is being transferred in this packet of air? Well if I know that the temperature is just so, and that the pressure is also just so, I should be able to fit those values in to figure out my *dq*. You might even be confident enough to do some back of the envelope calculations for that single packet of air- you know this one (since the equation is really just a bunch of multiplication and addition – nothing too crazy hard):

But what about this:



(whoa)

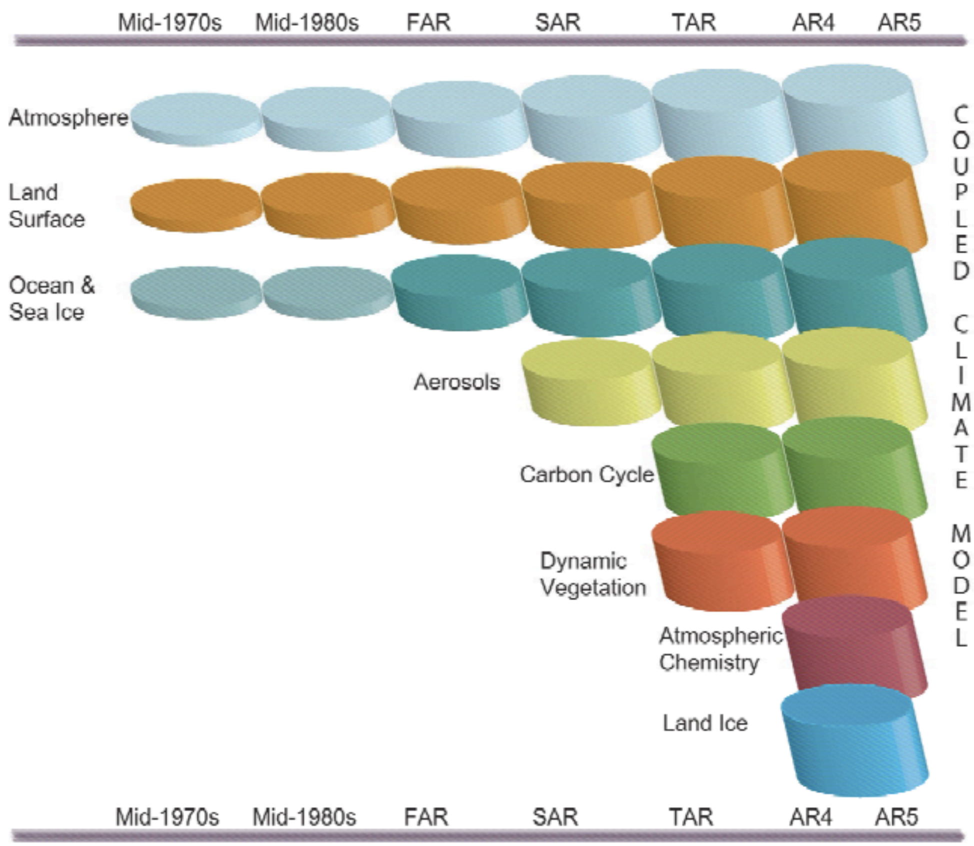
Here the transfer of heat and work between packets are obviously going to affect each other. Clearly, this isn't a back of the envelope calculation anymore, but it could be one that a computer can handle. That's really what a climate model is trying to look at. It uses these derivations of physical law, in tandem with probabilities calculated of more complex phenomenon (things still too complicated for a straight up formula that are instead defined from statistical observations) to compose a simulation that can hopefully have predictive value.

MODELS CAN BE PRETTY FANCY

"Models are composed of algorithms (a step by step calculation), which in turn are based on processing mathematical expressions, which in turn may be derived from physical laws, which in turn are derived from the things people see and do and measure everyday and throughout history."

The above equation only looks at things like movement of gases in the atmosphere. These days models can be pretty sophisticated, looking at all sorts of things (after all, whether it's a rain drop or cloud formation, or ocean currents, they're still subject to physical laws that can be defined by equations). Computational power can also allow us to start combining several of these things. Hence the figure showing how nuanced and complex these models have become over time.

Slides showing how more sophisticated things have become over the years. (no need to memorize)



IPCC SCENARIOS: Just a hat tip to say that model constructions can be so nuanced such that the IPCC report presents a number of different emissions scenarios or representative concentration pathways. (Again no need to memorize, but you do need to understand why they are important) – This is a way to standardize models, so that the data can be collaborative in nature.
See AR5 SPM

O.K. MODELS ARE COOL, BUT HOW DO YOU KNOW THEY ARE RIGHT?
A.k.a. How exactly do you "validate" a climate model (simple or complex)

"**Firstly**, it can be run for a number of years over simulated time and the climate generated by the model compared in detail to the current climate."
Here, a valid model is one where average distribution and season variations of appropriate parameters such as surface pressure, temperature and rainfall compare well. As well, noted variability in the model should coincide well with variability in the observed situation as well.

"**Secondly**, models can be compared against simulations of past climates when distribution of key variables was substantially different than at present."
An example would be about 9000 years ago, where the Earth's orbit in relation to the sun was slightly different. The axis of rotation was basically tilted 24o rather than the current 23.5o. Enough, however, to obviously affect the distribution of solar energy to the surface of the planet. Now meteorological data is obviously weaker for those type of timescales but there is data that (ice core data, vegetation fossilization patterns, etc).

"**Thirdly**, a model can be validated by usage in predicting the effect of large perturbations on the climate."

i.e. El Nino, large volcanic eruptions... (like mount Pinatubo 1991 / second largest eruption in 20^{th} century).
- - -

Emphasize the fact that constructing a good model is not always easy to do. It's a tricky endeavour because sometimes the nuances involved in the system are so multifaceted and so complicated.

Related to this - Be aware that the best model, is not always the most sophisticated – it ultimately is the one that best reflects reality. In this respect, one needs to consider whether too much complexity may increase the likelihood for an off prediction (due either to unknown behaviour not accounted for by the physical laws, which do tend to describe observations under very controlled circumstances, or that this variation in behaviour has just too much a computational load – errors made, takes for freaking ever because computers still not fast enough, etc).

As a result of this nuance, not all models are fancy – some are quite simple, choosing to focus on only certain elements, at very specific physical locales (only this layer of the atmosphere), under very broad timelines. Many go through phases of "tweaking" or "best fitting."

END OF VIDEO PART 4