Climate Change - The Basics

How much do we 'believe' and how much do we understand?

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The aim of this presentation is to investigate some basic physics we need to understand to give us confidence that our changes to a low carbon lifestyle are justified.
It is also intended to be a primer for a second talk on the effects of emissions into the stratosphere-a layer where humans can cause even more havoc.

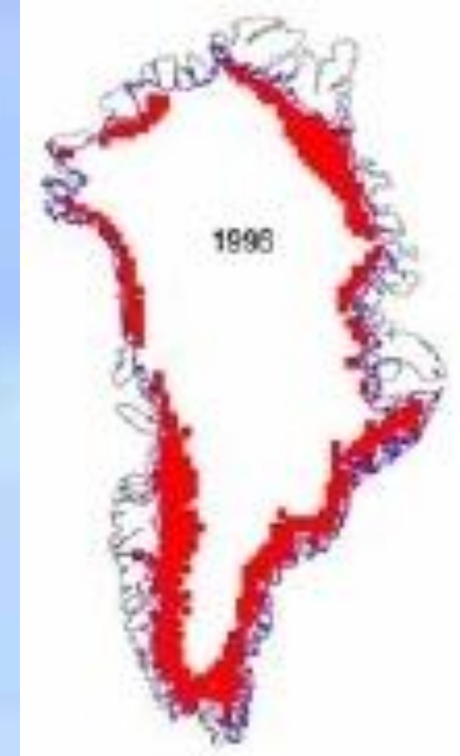
Contents

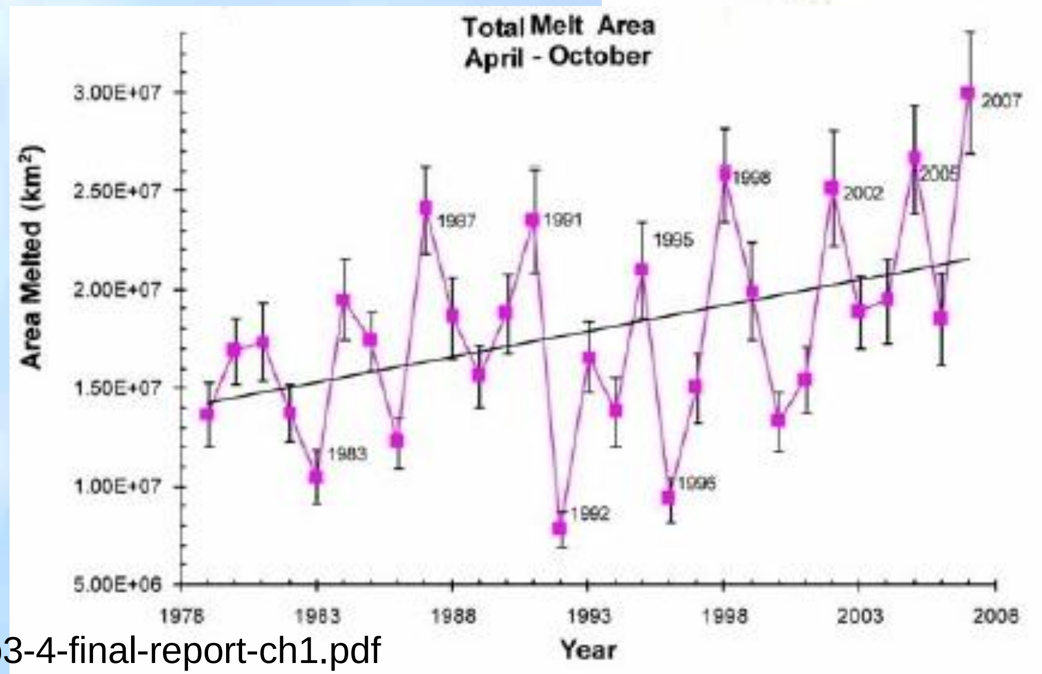
Background, Recent Evidence

Abrupt Changes in the Earth’s Climate System 1995

- “Ongoing and projected growth in global population and its attendant demand for carbon-based energy is placing human societies and natural ecosystems at ever-increasing risk to climate change (IPCC, 2007).
- In order to mitigate this risk, the United Nations Framework Convention on Climate Change (UNFCCC) would stabilize greenhouse gas (GHG) concentrations in the atmosphere at a level that would prevent “dangerous anthropogenic interference” with the climate system (UNFCCC, 1992, Article 2)”.

“There has been a significant increase in meltwater runoff from the Greenland Ice Sheet for the 1978-2007 period compared to the previous three decades (Fig. 1.3)”.





http://downloads.climatescience.gov/sap/sap3-4/sap3-4-final-report-ch1.pdf

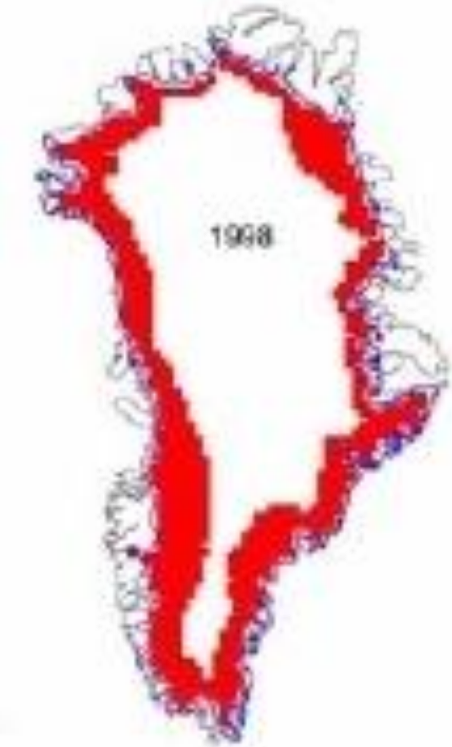
Background, Recent Evidence

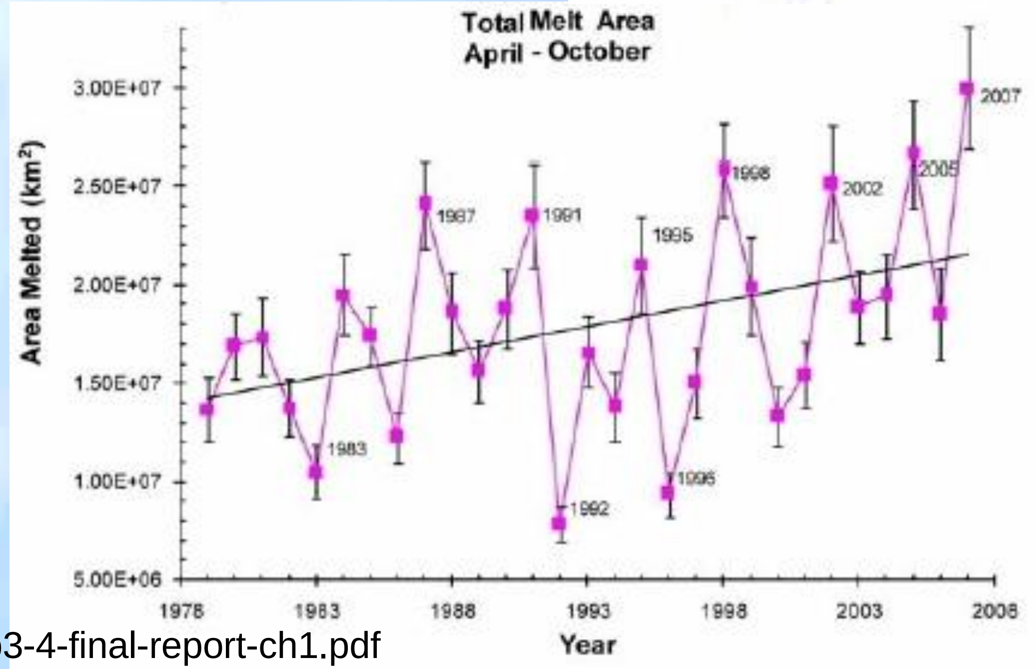
Abrupt Changes in the Earth’s Climate System 1998

- “Ongoing and projected growth in global population and its attendant demand for carbon-based energy is placing human societies and natural ecosystems at ever-increasing risk to climate change (IPCC, 2007).
- In order to mitigate this risk, the United Nations Framework Convention on Climate Change (UNFCCC) would stabilize greenhouse gas (GHG) concentrations in the atmosphere at a level that would prevent “dangerous anthropogenic interference” with the climate system (UNFCCC, 1992, Article 2)”.

“Recent data from Greenland show a high correlation between periods of heavy surface melting and an increase in glacier speed”

A possible cause for this relation is rapid drainage of surface meltwater to the glacier bed, where it enhances lubrication and basal sliding”.





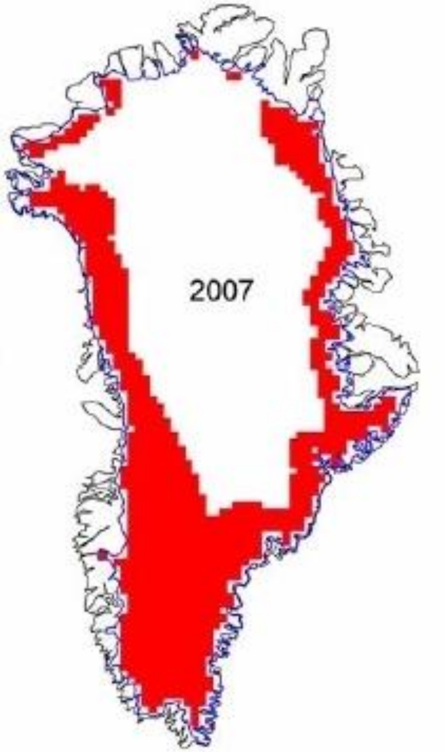
http://downloads.climatescience.gov/sap/sap3-4/sap3-4-final-report-ch1.pdf

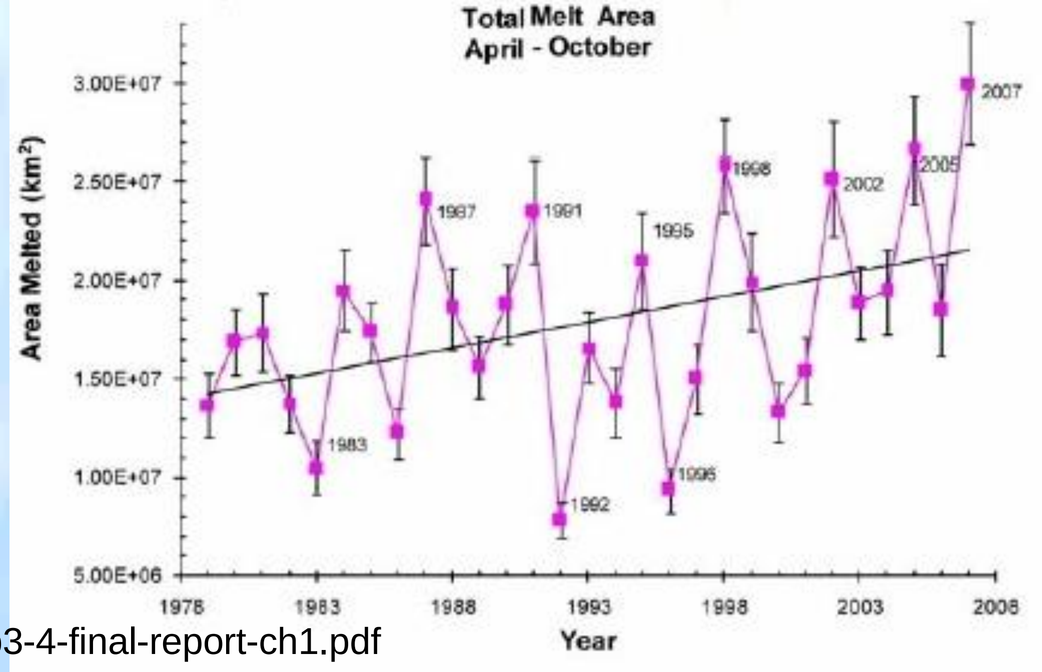
Background, Recent Evidence

Abrupt Changes in the Earth's Climate System 2007

- 50% Greenland has begun to melt
- September 2009 NE passage opens to shipping
  - May be kept open all winter in future (BBC radio World Service 17 Sept 2009)

"Total melt area is continuing to increase during the melt season and has already reached up to 50% of the Greenland Ice Sheet; further increase in Arctic temperatures will very likely continue this process and will add additional runoff.

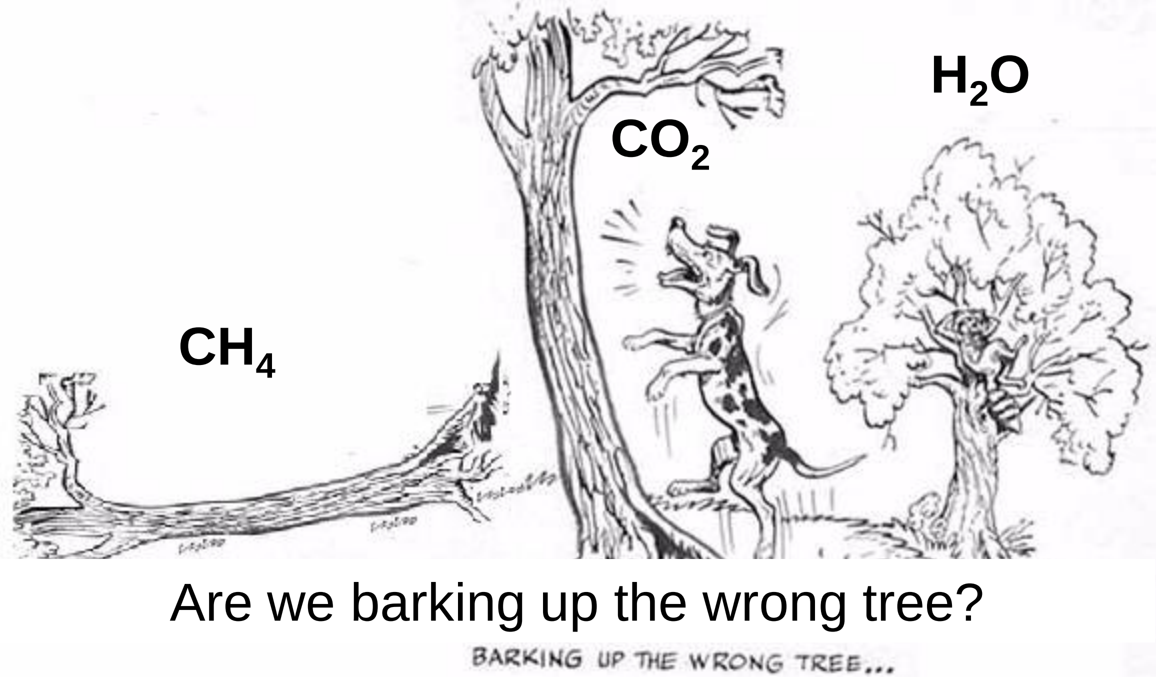




http://downloads.climatescience.gov/sap/sap3-4/sap3-4-final-report-ch1.pdf

Our climate –
Why be interested in how it works?

- **The Problem**
  - **Things are changing faster than predicted**
  - **Changes affect our environment**
  - **Food and water supplies are at risk**
- **Issues**
  - **Are we getting the right story?**
  - **Are we able to make our own judgement?**
  - **Are we being told the whole truth?**



Are we barking up the wrong tree?

Balancing the sun’s and earth’s radiation

Black Body Radiation #1

A concept used in physics to understand radiation from objects

“Hotter objects give off more heat”

“A black body (when heated) emits a temperature-dependent spectrum” [1]

If the black body is hot enough it emits light (e.g. the Sun)

If it is cooler it gives out infra-red energy like the embers in a dying fire

[1] http://en.wikipedia.org/wiki/Black_body

Black Body Radiation #2

"…a black body (when heated) emits a temperature-dependent spectrum of light" [1].

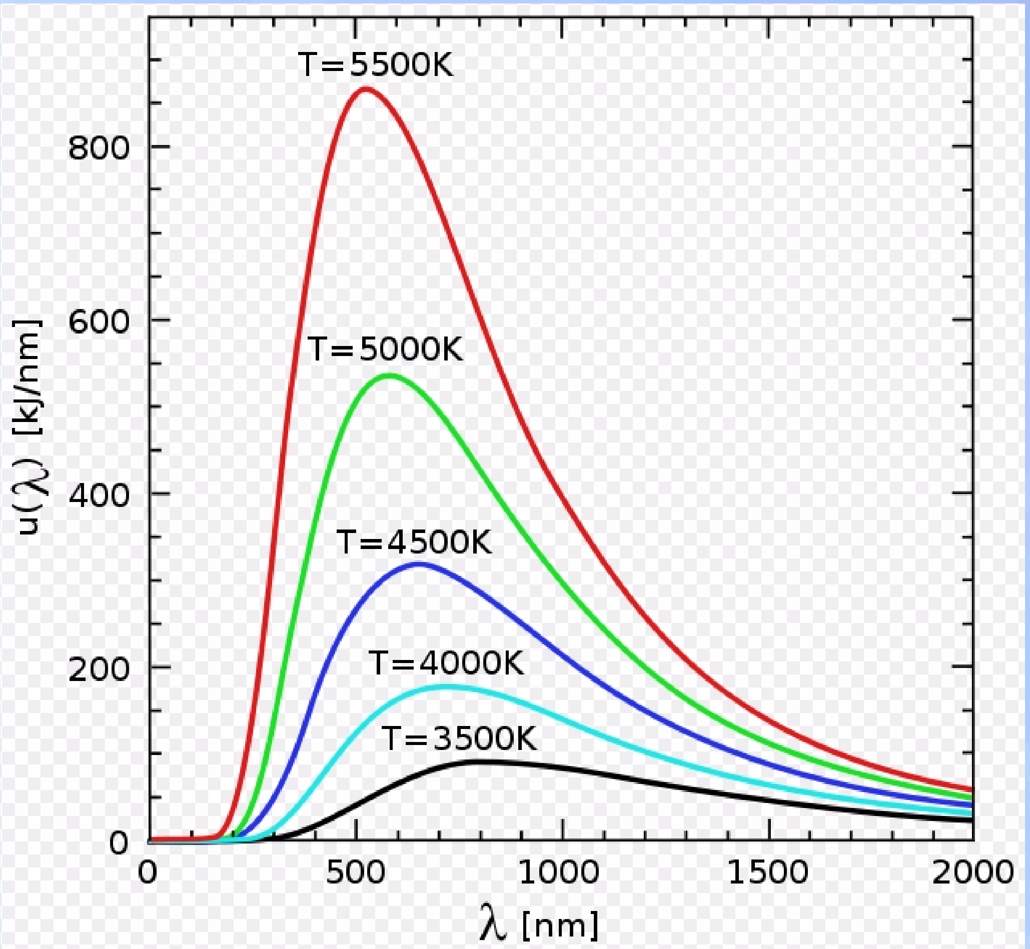
The intensity of radiation (u = shape of curve) is a function of wavelength (λ) as given by Planck's law [2] with parameter T

$u(\lambda) = a/\lambda^5[\exp(b/ \lambda T)-1]$
where a= and b are constants

T (sun) = 5780K,   [cf. T (earth) =255K]

"Wien's law gives the wavelength of maximum intensity as = 0.29/T (cm)"[3]

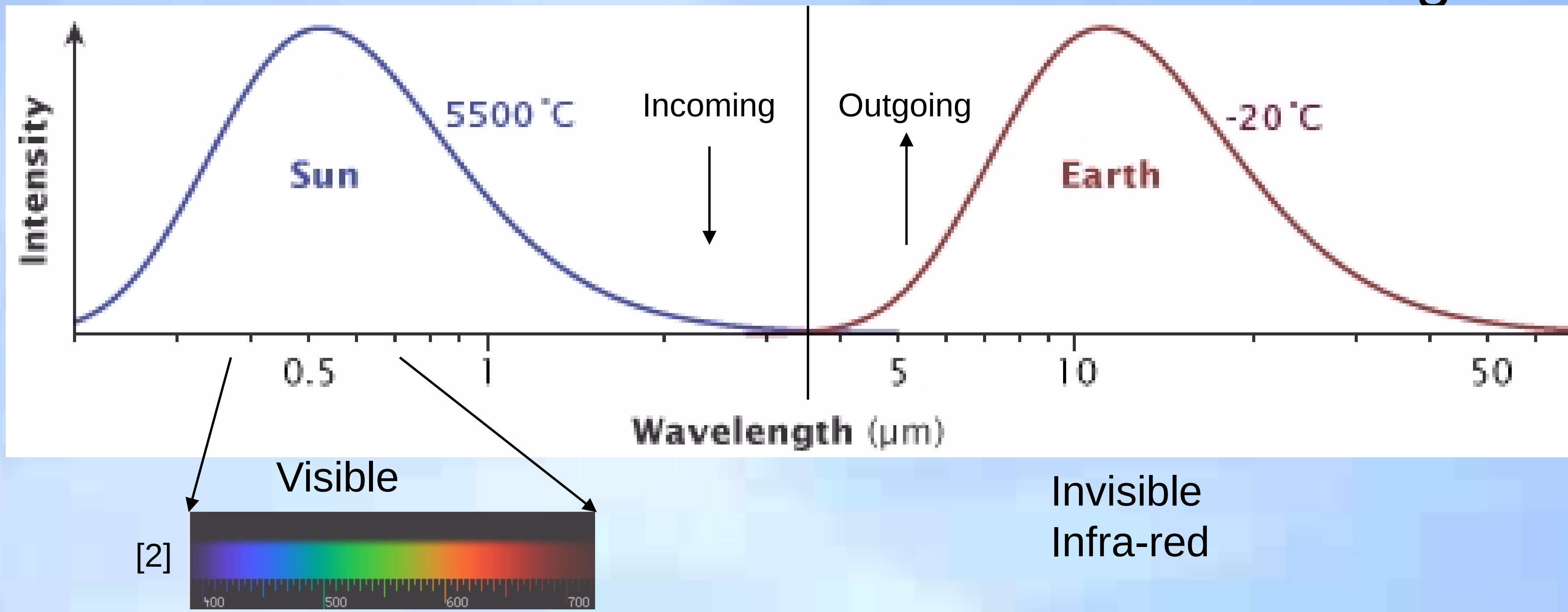
λ (sun) = 518nm   [cf. λ (earth) = 11.4μm]



[1] http://en.wikipedia.org/wiki/Black_body
[2] http://en.wikipedia.org/wiki/Planck's_law
[3] http://www.astro.cornell.edu/academics/courses/astro201/wiens_law.htm

Balancing the sun's and earth's radiation

Sun and Earth 'Transmit' on Different Wavelengths



The total emission, the area under each curve, is given by the Stefan-Bolzmann law as

$E = \sigma_{SB} T^4$

Where T is the temperature (K) and σ_{SB} =is the Stefan-Bolzmann constant [3]

For the earth (at 255K) the radiation into space is 240 W/m^2

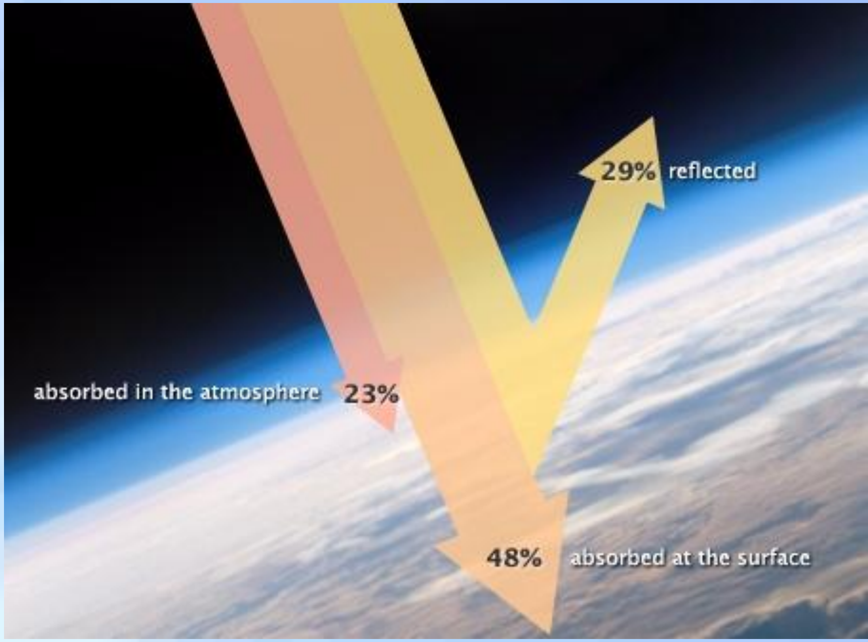
The incoming radiation from the sun is equal to the outgoing radiation from the earth

[1] http://earthobservatory.nasa.gov/Features/EnergyBalance/page2.php.
[2] http://en.wikipedia.org/wiki/Color
[3] "Meteorlogy for Scientists and Engineers", Ed 2–Roland B Stull, pp 30-31, Pub. Brooks/Cole

Balancing the sun's and earth's radiation

Where does the Sunlight go?

- "About 29 percent of the solar energy that arrives at the top of the atmosphere is **reflected** back to space by
  - clouds,
  - atmospheric particles,
  - bright ground surfaces like sea ice and snow.
  - This energy plays no role in Earth's climate system.
- About 23 percent of incoming solar energy is **absorbed in the atmosphere** by
  - water vapour, dust, and ozone
- 48 percent passes through the atmosphere and is **absorbed by the surface.**
- Thus, about 71 percent of the total incoming solar energy is **absorbed by the Earth system".**



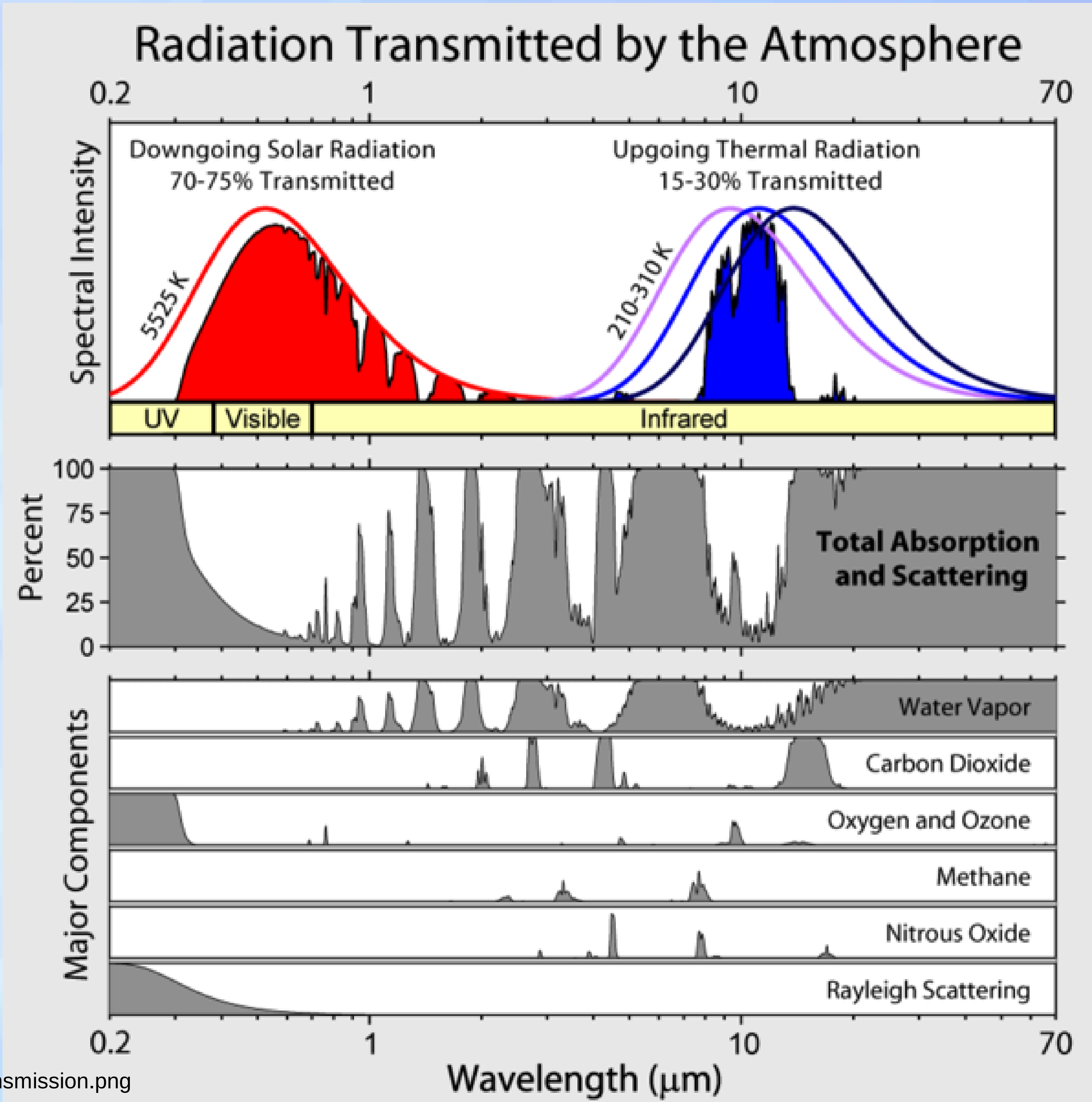
http://earthobservatory.nasa.gov/Features/EnergyBalance/page4.php

Balancing the sun's and earth's radiation

Radiation from the sun (red) warms the earth and atmosphere (sunny side only)

Radiation from the earth (blue curve)is lost into space by day and night

Substances in the atmosphere absorb some radiation and warm up the atmosphere:- the 'greenhouse' effect



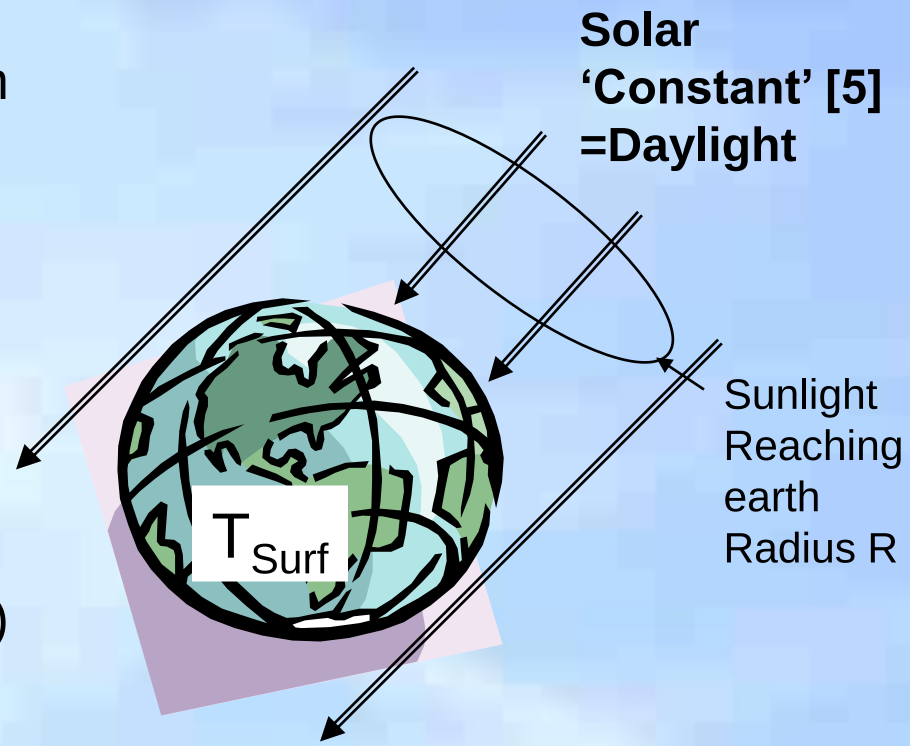
http://en.wikipedia.org/wiki/File:Atmospheric_Transmission.png

Calculating the incoming radiation

First apply the Stefan-Boltzmann law to calculate the sun's incoming radiation

$I_R = (1 - A)S.\pi.R^2$

Where A=Albedo (Reflectivity) (0.3)
R= radius of earth (cancels later)
S=Solar constant (daylight) =1367 W/m^2 [4,5]



[1] "Meteorology for Scientists and Engineers", Ed 2–Roland B Stull, Pub Brooks/Cole
[2] "Atmosphere, ocean, and climate dynamics: an introductory text" By John Marshall, R. Alan Plumb", Elsevier Academic Press 2008. See p 14 on Google books
[3] Introduction to circulating atmospheres By Ian N. James, Cab Uni Press see pp. 63/64 on google books
[4] http://www.answers.com/topic/solar-constant
[5] http://wattsupwiththat.com/2009/04/01/nasa-headline-deep-solar-minimum/

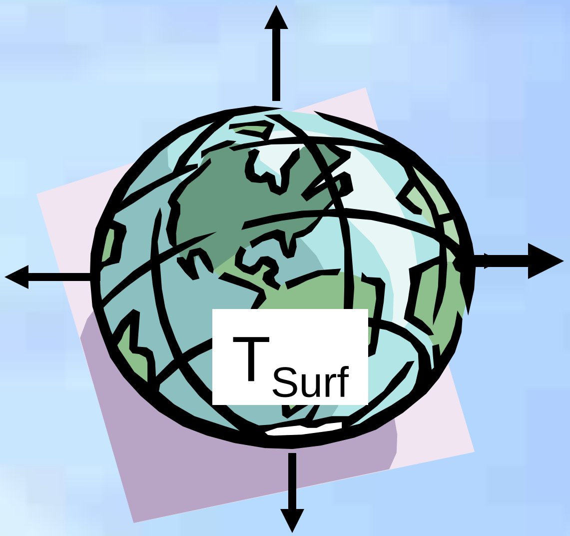
Recommended

Calculating the outgoing radiation

Next apply the Stefan-Boltzmann Law to calculate the IR radiation out

$I_o = 4\pi R^2 \, \sigma_{SB} T_{Surf}^4$

where $4\pi R^2$ is the surface area
σ_{SB} is the Stefan Boltzmann constant
T_{Surf} is the surface temperature which is the same as the earth system when there is no atmosphere



The earth emits IR day and night

[1] "Atmosphere, ocean, and climate dynamics: an introductory text" By John Marshall, R. Alan Plumb", Elsevier Academic Press 2008. See p 14 on Google books
[2] "Meteorology for Scientists and Engineers", Ed 2–Roland B Stull, Pub Brooks/Cole
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Balancing the sun's and earth's radiation

Calculating the earth's temperature (no atmosphere)

Balance the two equations

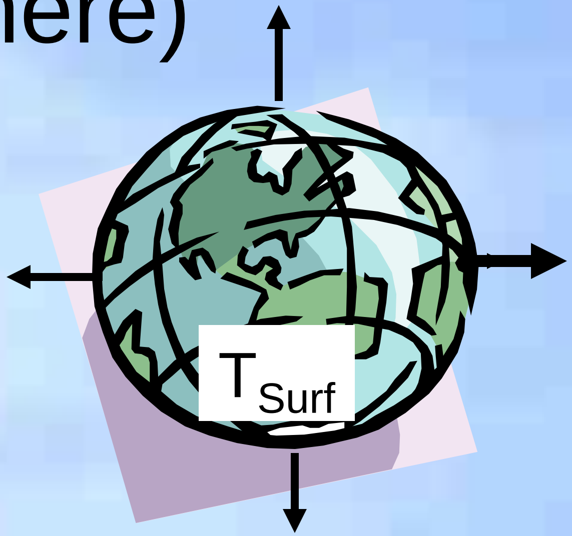
$I_R = I_O$ and rearrange for T_{Surf}

$$T_{Surf} = [(1-A)S/4\sigma_{SB}]^{1/4}$$

(assuming earth is a perfect black body emitter)

Applying the numbers we get **255K (–18^{O}C)** for the earth.

But this is colder than the real average observed at the surface…..



NB. This temperature T_{Surf} =T_{ES} = 255K should be constant for the earth system viewed from space averaged over a year if there is no change in incoming sunlight (radiation) or albedo (reflectivity).

If we add layers such as the atmosphere or cloud the average will be the same

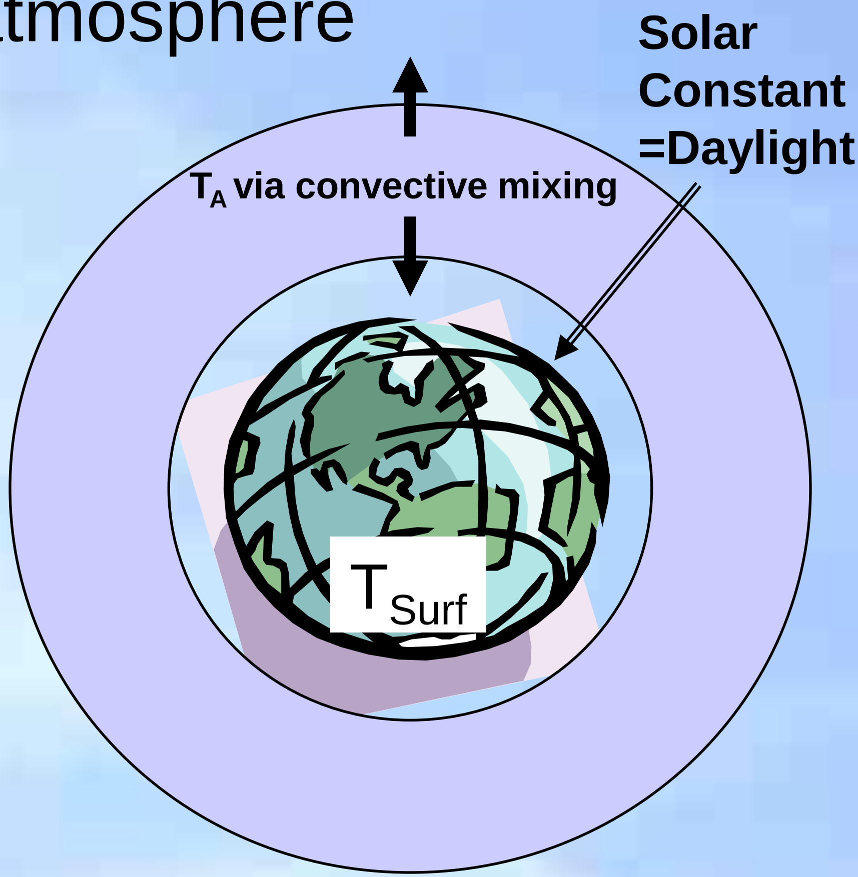
Some of the graphs shown later show only a local surface temperature (e.g. over the tropics or poles)

[1] "Atmosphere, ocean, and climate dynamics: an introductory text" By John Marshall, R. Alan Plumb", Elsevier Academic Press 2008. See p 14 on Google books

[2] "Meteorology for Scientists and Engineers", Ed 2–Roland B Stull, Pub Brooks/Cole

[3] Introduction to circulating atmospheres By Ian N. James, Cab Uni Press see pp. 63/64 on google books

Balancing the sun's and earth's radiation
Calculating the Earth's temperature- Adding the atmosphere



Next add a theoretical atmosphere that is transparent to incoming sunlight but opaque to infra red. Radiation from earth heats the atmosphere to temperature T_A = 255K

The atmosphere is assumed to radiate equally outwards and inwards (like a black body radiation).

Hence the radiation reaching the surface has two equal components one from the sun (mostly visible) and one from the atmosphere (IR)

$$\sigma_{SB} T_{Surf}^4 = 2.\ \sigma_{SB} T_A^4$$

$$T_{Surf} = 2^{1/4}.\ T_{ES} = 30.1^oC$$

This warming is known as the **greenhouse** effect

Discussion. This simple model does not apply for Venus at 735K. The temp of the Venus system is approximately the same as earth's and 2 $^{1/4}$ is too small a multiplier. There must be some important physics missing.

[1] "Atmosphere, ocean, and climate dynamics: an introductory text" By John Marshall, R. Alan Plumb", Elsevier Academic Press 2008. See p 14 on Google books
[2] "Meteorology for Scientists and Engineers", Ed 2–Roland B Stull, Pub Brooks/Cole
[3] Introduction to circulating atmospheres By Ian N. James, Cab Uni Press see pp. 63/64 on google books

Balancing the sun's and earth's radiation

Calculating the Earth's surface temperature

The atmospheric window

$+30.1^{O}C$ is warmer than we observe but illustrates what would happen if the atmosphere was truly opaque to IR .

We therefore assume that some radiation (25%) escapes into space via the **'atmospheric window'**

This gives an absorptivity '(a)' of around 75%

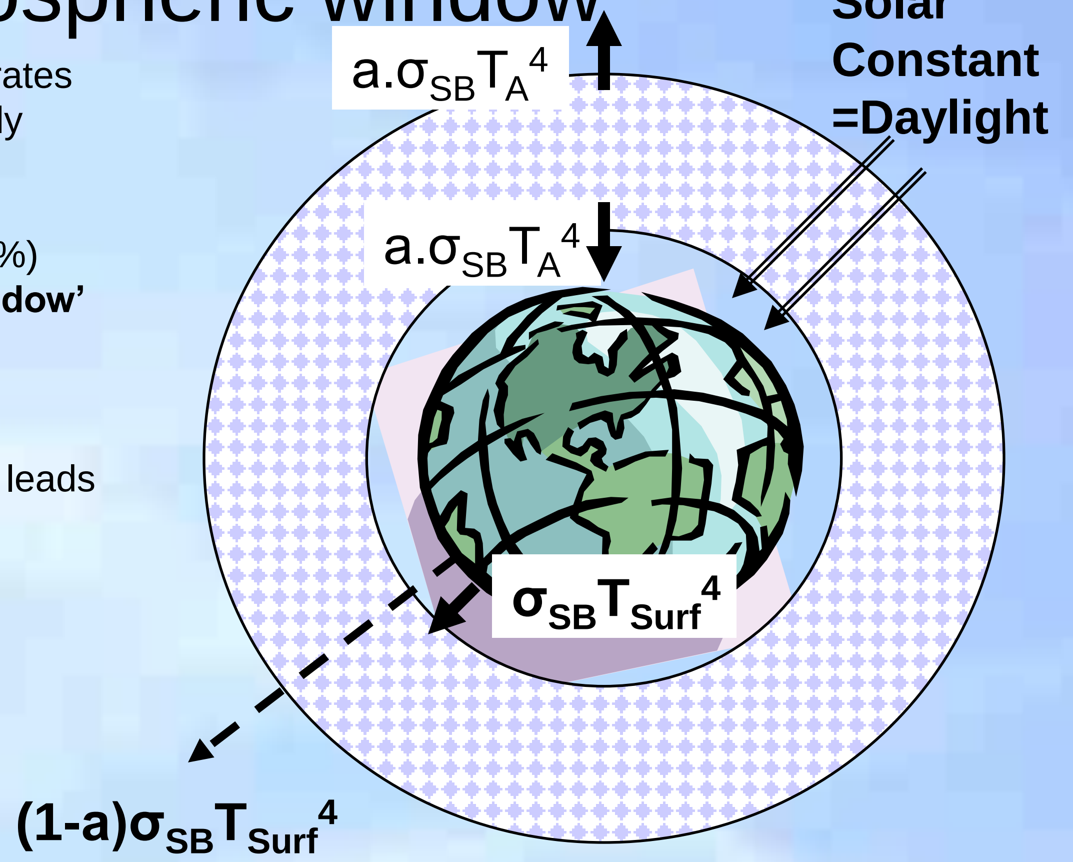
Balancing the radiation equations and solving leads us to a more realistic estimate of the average surface temperature [1]

$$T_{Surf}^4 = 2.\ \sigma_{SB} T_{ES}^4 / (2-a)$$

(where T_{ES} = the average earth system temperature observed from space =255K)

$=288K = (15^{o}C)$

A 'true value' is 287K [2]



[1] "Atmosphere, ocean, and climate dynamics: an introductory text" By John Marshall, R. Alan Plumb", Elsevier Academic Press 2008. See p 14 on Google books

[2] "Meteorology for Scientists and Engineers", Ed 2–Roland B Stull, Pub Brooks/Cole

[3] Introduction to circulating atmospheres By Ian N. James, Cab Uni Press see pp. 63/64 on google books

The atmospheric windows

- There are two ‘windows’
  - One allows radiation in (e.g. visible light)
  - One allows radiation out (infra-red)
- Clouds give spatial variability affecting both windows
  - absorbing IR
  - blocking incoming light
  - (On average about 60% earth is covered in cloud)
  - Discussion: Is this an average value- part cloud and partly clear?
- The various gases and particulates in the atmosphere have selective spectral absorption
  - Can affect one or both windows
  - Some gases have positive radiative forcing and some negative

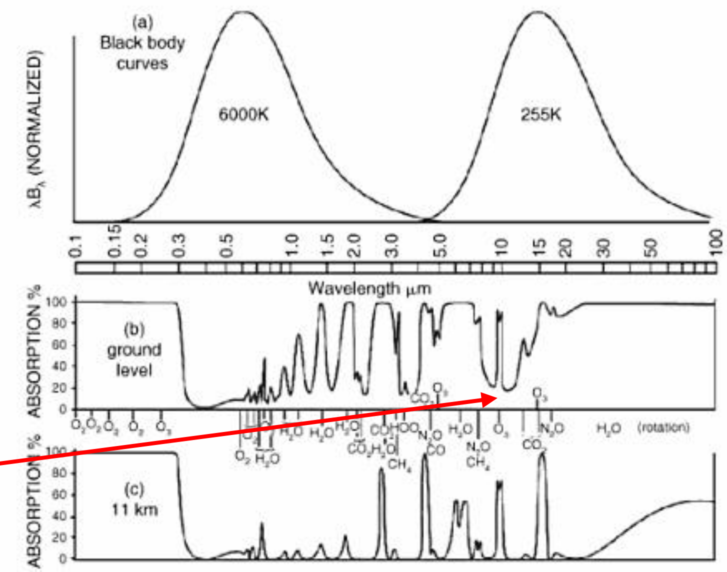


FIGURE 2.6. (a) The normalized blackbody emission spectra, $T^{-4}\lambda B_\lambda$, for the Sun ($T = 6000$ K) and Earth ($T = 255$ K) as a function of $\ln \lambda$ (top), where B_λ is the blackbody function (see Eq. A-2) and λ is the wavelength (see Appendix A.1.1 for further discussion). (b) The fraction of radiation absorbed while passing from the ground to the top of the atmosphere as a function of wavelength. (c) The fraction of radiation absorbed from the tropopause (typically at a height of 11 km) to the top of the atmosphere as a function of wavelength. The atmospheric molecules contributing the important absorption features at each frequency are also indicated. After Goody and Yung (1989).

“Atmosphere, ocean, and climate dynamics: an introductory text” By John Marshall, R. Alan Plumb”, Elsevier Academic Press 2008, see p18 on Google books

Balancing the sun's and earth's radiation

What does this simple model tell us?

$$T_{Surf}^4 = 2.\ \sigma_{SB} T_{ES}^4 /(2-a)$$
$$= (1-A)S/2\ (2-a)$$

- The earth's surface temperature is sensitive to
  - Sunlight and its reflection (S and A)
  - How much IR energy is radiated from the surface into space (1-a)
  - The sensitivity is moderated by a power ¼
    - often quoted as a 'negative feedback' (a stabilising influence)
- These can change over time (e.g. averaged year to year)
  - This leads to 'climate change'
- To reach the maximum +30.1ºC for a single layer model the IR window needs to close
  - Apart from water vapour (and resultant clouds) carbon dioxide has been identified as a blocker of IR radiation into space
  - To avoid climate change we must do everything possible to avoid changing the IR atmospheric window
    - So that the earth can radiate from the surface directly into space to as it has done for millions of years

What are the limitations of this model?

- It is a single slab model
  - The surface temperature depends upon the number of 'opaque' layers which can be included in the model (depending upon optical depth)
- It does not explain **how** IR energy is radiated through the atmospheric window
  - In the absence of clouds, there is the gap in the IR spectrum which allows earth's surface heat to be radiated
- It is a global average and does not account for temperature variation with latitude
  - What is happening at the poles?
  - This could be widely more extreme than the average
- It does not account for altitude
  - Different layers having different temperatures
  - What is happening on mountain glaciers?
- It does not allow for different surface features (land, ocean, snow)

  (General Circulation Models (GCMs) running on supercomputers are needed to take account of these and other effects
  - Plus research into the effects of water vapour, cloud and ice)

Balancing the sun's and earth's radiation

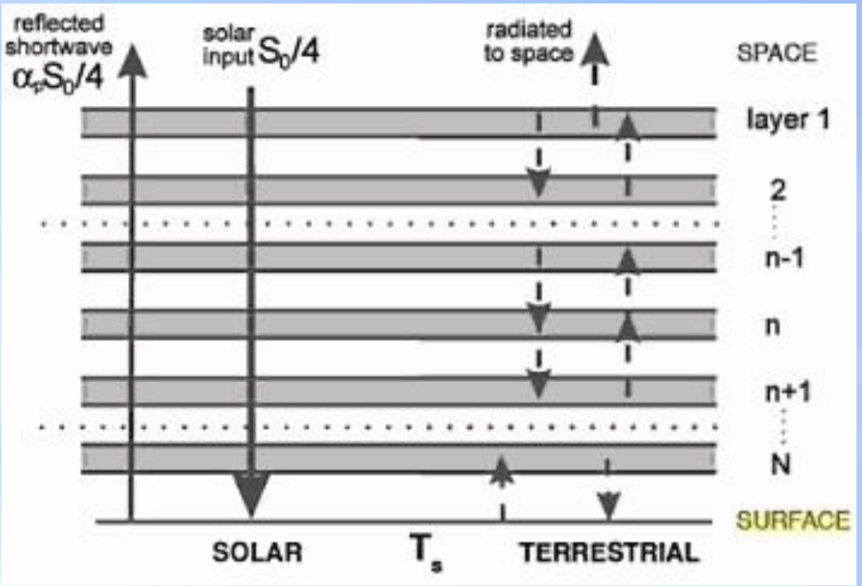
N-Slab Model

- The surface temperature can be better estimated according to the formula

$$T_s = (N+1)^{1/4}\, T_{es}$$

T_{es} = average temperature of the planet viewed from space
N = the number of layers

- From the surface upwards every layer is cooler than the one below
  - If the atmospheric IR window 'closes' in each layer these surface temperatures will be met



An atmosphere made up of N slabs each of which is completely absorbing in the IR window[1]

	Earth Surface	
N	C	
0	-18	
1	30.25	
2	62.6	
3	87.62	
4	108.3	

"Atmosphere, ocean, and climate dynamics: an introductory text" By John Marshall, R. Alan Plumb", Elsevier Academic Press 2008 (See page 21 on Google books for this reference example)

What is the significance of the N-Slab model

- It forms the basis of 'radiative transfer modelling [1]'
  - using calculus and / or
  - General Circulation Models (GCMs)
- It demonstrates how the earth's surface temperature could rise above 30^{o}C
  - If layers are opaque
- It can be used to estimate the surface temperature of Venus (480^{o}C)
  - With 90 times denser atmosphere (96% is CO_2)
  - The famous astronomer Carl Sagan published on this in 1967
  - A key question is how many 'layers' to apply. Optical depth is a key factor…..

http://www.ericweisstein.com/research/thesis/node40.html

Optical Depth and Absorption

- "Optical depth, or optical thickness is a measure of transparency
  - Defined as the negative logarithm of the fraction of radiation (or light) that is scattered or absorbed on a path.
  - One way of visualizing optical depth is to think of a fog.
    - The fog between you and an object that is immediately in front of you has an optical depth of zero.
    - As the object moves away, the optical depth increases until it reaches a large value and the object is no longer visible [1]".
  - Used to estimate the 'thickness' of clouds

- Seen in IR from space, clouds and GHGs mask the radiation from earth
  - Space radiometers detect the cold temperature of the cloud tops
  - CO_2 and other GHGs also radiate from the top of the atmosphere into space

- CO_2 absorption in the first 100m meters from the surface appears to be dominant [2]
  - Intuitively yes. However radiative transfer models are needed to compute the total effect throughout many small atmospheric layers to obtain the accuracy needed

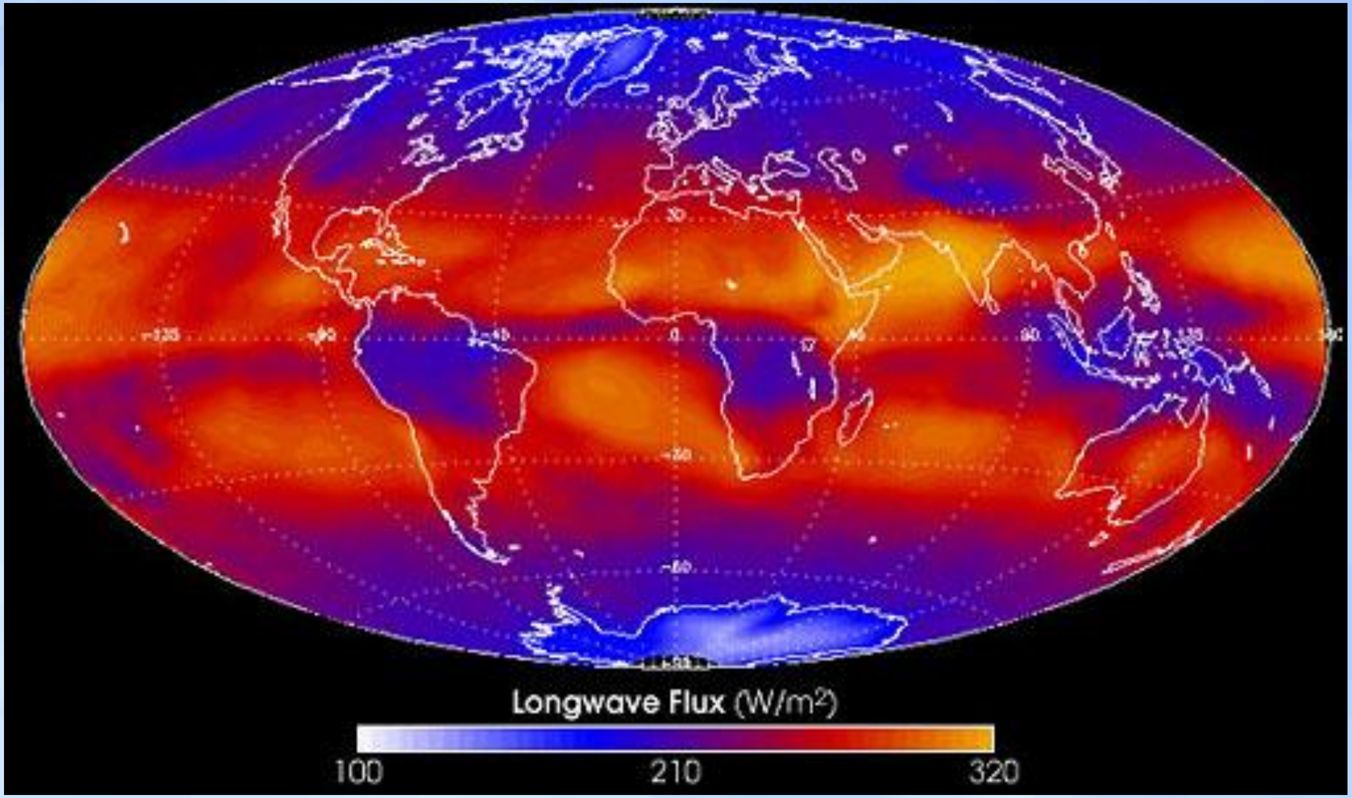
[1] http://en.wikipedia.org/wiki/Optical_depth
[2] http://www.warwickhughes.com/papers/barrett_ee05.pdf

Next

Earth's radiation seen from space

Earth's radiation seen from space

What does earth's IR emissions look like from space?



"..This picture was constructed from images gathered over a one-month period during March 2000. The orange-red areas of this image show heat being emitted from relatively cloud-free bands north and south of the equator. .."

"The dark blue areas over the tropics show high clouds which are colder at their surface. Heat is being trapped underneath."

Most heat is lost through cloud free regions in the tropics and subtropics.

http://www.exploratorium.edu/climate/atmosphere/data1.html

How is energy selectively radiated through the atmosphere?

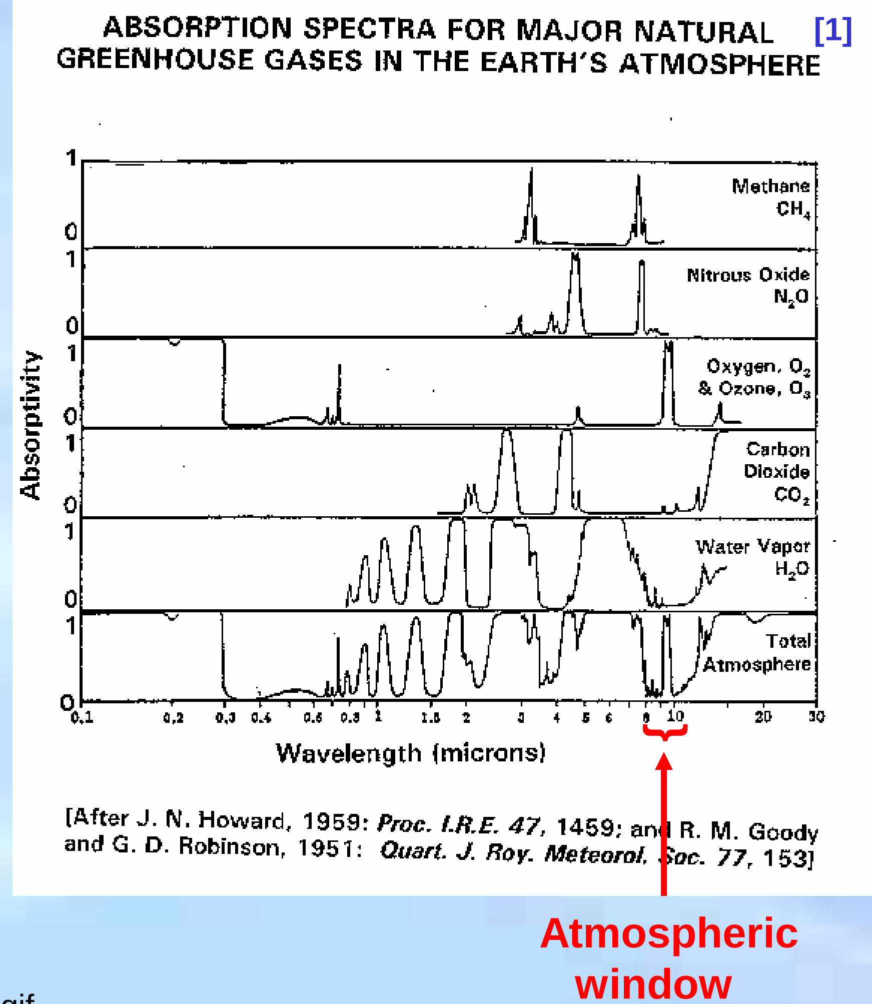
- Greenhouse gases absorb radiation by characteristic molecular resonances
- The composite transmission/absorption is calculated from the individual absorption spectra and their densities according to the Beer-Lambert law.

  [2] "The absorption bands (wavelength regions) for carbon dioxide are nearly saturated, but those for other gases (CH_4, N_2O) are not, so one additional molecule makes a larger impact"

- Clouds close the IR window if they are 'thick' enough

  [3] "Tiny liquid droplets are good absorbers of IR but poor absorbers of sunlight. Clouds even absorb the wavelengths between 8 and 11µm which are otherwise 'passed up' by water vapour and CO_2. Thus they have the effect of enhancing the greenhouse effect by closing the atmospheric window".

  – Clouds also partially close the solar window



[1] http://www.iitap.iastate.edu/gccourse/forcing/images/image7.gif
[2] http://www.iitap.iastate.edu/gccourse/forcing/effects.html
[3] "Essentials of Meteorology" ,C. Donald Ahrens 5th edition, pub Thompson, Brooks/Cole p.36-37

Earth’s radiation seen from space

Let’s look at some spectra-
models of earth's radiation viewed from space

Earth's radiation seen from space
What does earth's spectrum look like from space?

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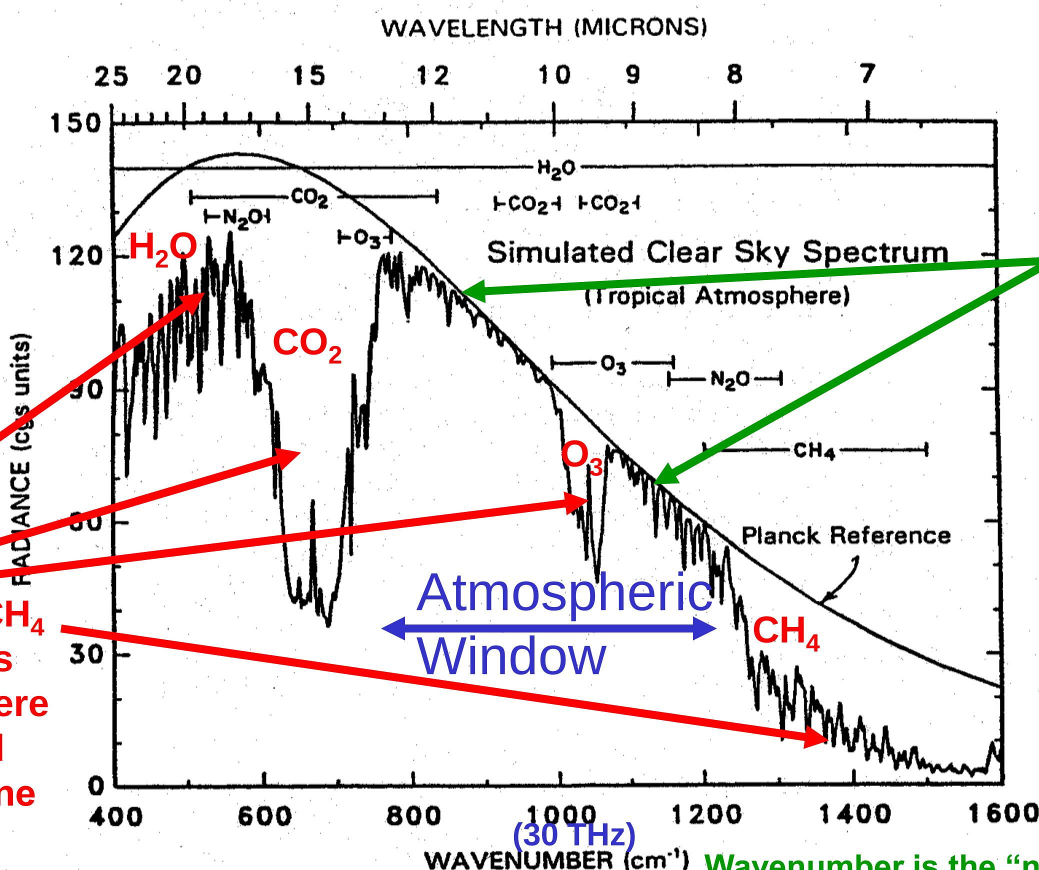


Radiation from the surface escaping directly into space

The Planck reference here is shown for the tropics with a hotter surface than the average earth system.

This hides any average surface temperature rises due to global warming.

H_2O, CO_2, O_3, CH_4 and other gases in the atmosphere are high up and Cold. They 'shine less brightly' than the surface

Wavenumber is the "number of cycles per centimetre"

Fig. 10.1. Clear sky spectrum at 3 cm^{-1} (IRIS) resolution. The spectral locations of the principal absorption features are identified.

From

10. Michelson Interferometer (MINT)

Andrew Lacis and Barbara Carlson, NASA Goddard Institute for Space Studies

http://map.nasa.gov/documents/CLARREO/7_07_presentations/Michelson%20Interferometer.pdf

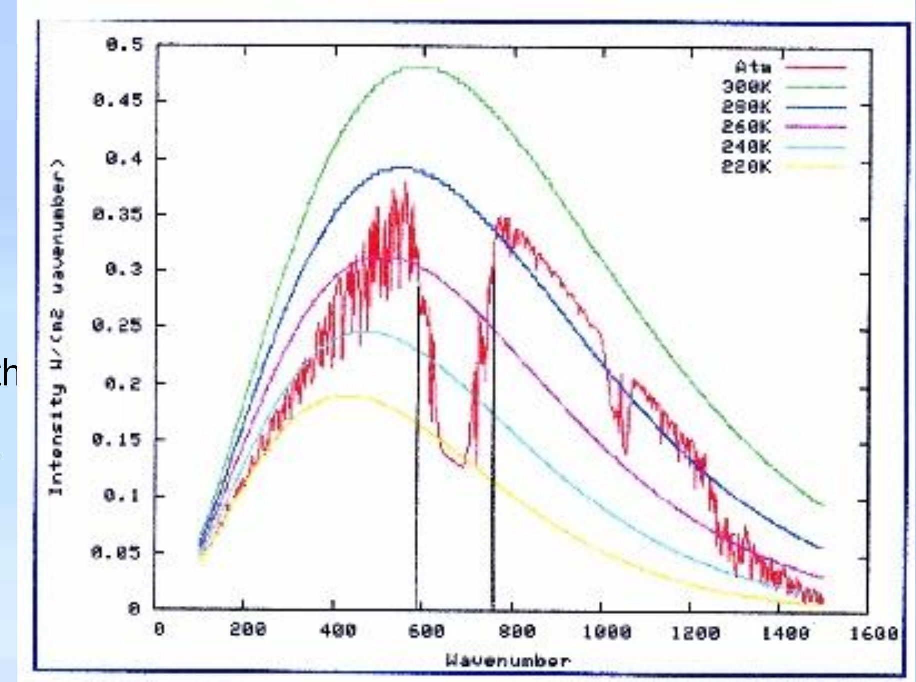
Next

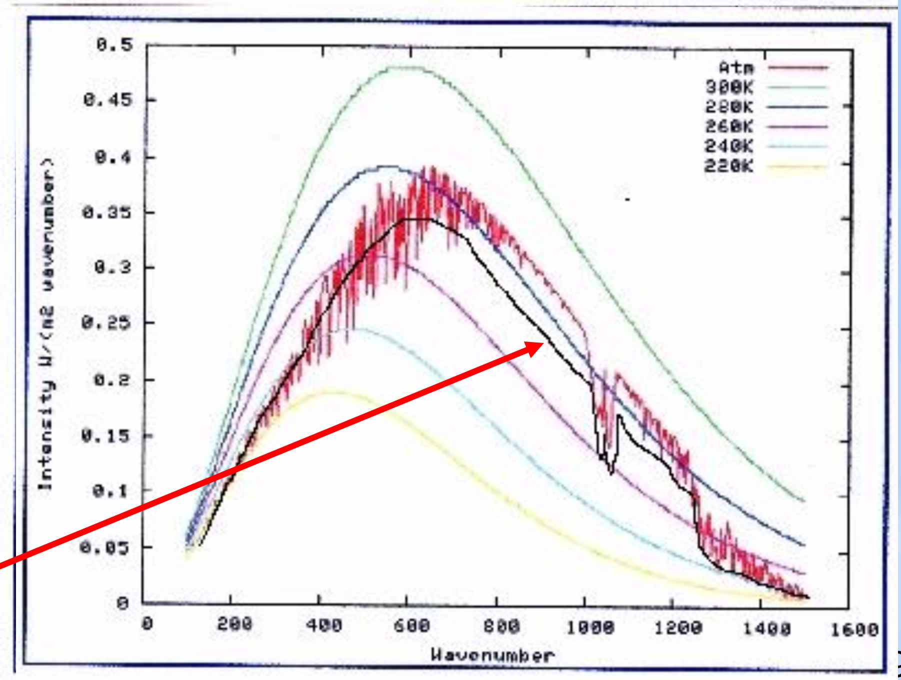
How important is CO_2?

How important is CO_2?

Earth's outgoing radiation simulated with and without CO_2

- "These are two MODTRAN generated emission spectra, the higher one is for the full atmosphere with 380 ppmv of CO_2 and the lower one is exactly the same except for the removal of all the CO_2. The two spectra make obvious the overlapping of the water and CO_2 spectra in the 600-750 cm^{-1} range".
- "Much of the CO_2 emission originates from the atmosphere at a temperature of about 218 K [-55C]. This part of the atmosphere is around 15 km altitude and is known as the tropopause"
- Barrett calculates the change in radiation to be "39.1 W/m^2. Using S-B law this turns out to be 10.4^{o}C cooler than the surface would be in the presence of the CO_2. It is a 'greenhouse gas'"
- Discussion: "The area under the red curve has changed. The earth is no longer in radiative equilibrium. More heat is escaping into space. The earth's surface must be cooling from today's 288K". The line I sketched in black should be the new Planck intensity curve for **277.6K** surface temp.
- MODTRAN should show this! However it is a transmission model (not a GCM)



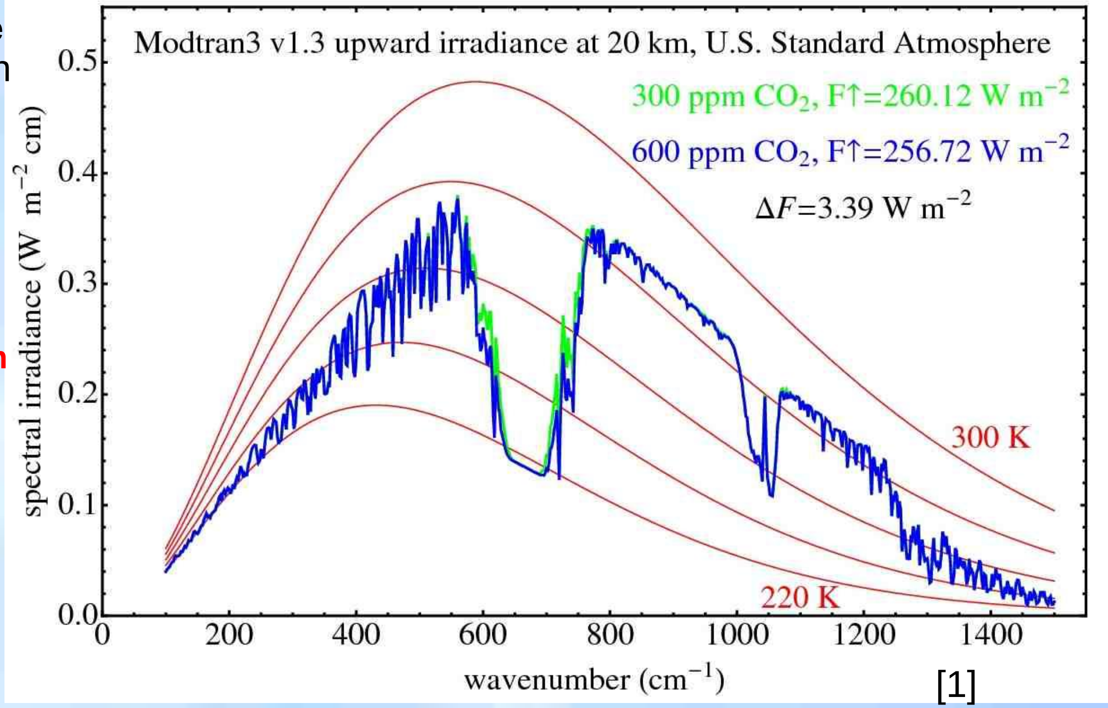


http://www.barrettbellamyclimate.com/page17.htm

How important is CO_2?

Doubling the CO_2

- Here the author also used MODTRAN. "The green spectrum is for CO_2 at 300 ppm which has a total outgoing energy flow is 260.12 W/m^2
- The blue spectrum is for CO_2 at 600 ppm which has a total outgoing energy flow of 256.72 W/m^2 [1]
  - **NB the earth is not in radiative equilibrium the blue curve needs to move up slightly**
- The difference is 3.39 W/m^2; close to that obtained by the more precise calculations used in the literature [2] (Myhre 1998 [3])
- Weak absorption modes either side of the main one comes into play as the CO_2 concentration doubles
- Myhre calculated an energy flow change of 3.71W/ m^2"
- This corresponds with 1.1^{O}C warming (without feedback effects and is the lower estimate of the IPCC/consensus)



[1]

[1] http://en.wikipedia.org/wiki/Radiative_forcing
[2] http://www.physicsforums.com/showthread.php?t=307685
[3] http://www.agu.org/pubs/crossref/1998/98GL01908.shtml

Discussion: Is 3.71W/ m^2 at the end of the century enough to melt the Greenland ice sheet today? Should we be looking for something more compelling to explain what is going on today?

How important is CO_2?

Demonstration of the spectral effect of doubling CO_2

- This demo needs to be done in the visible rather than infra-red part of the spectrum
  - It's a wavelength shifted demo. It is convenient because you can see the results
- Equipment
  - The laser pointer emits monochromatic light
    - Let's say it transmits on the CO_2 wavelength like a very strong atmospheric 'probe'
    - It is not like black body radiation
  - The bike headlamp emits white light
    - It is more like black body radiation
    - Lets say it represents the IR from the earth's surface
  - The red, green and blue films are for stage spotlights
    - They let through one colour each
- Procedure
  - Put the green filter in front of the laser. No light gets through
    - "The CO_2 is blocking it"
  - Put the green filter in front of the headlamp. Green light gets through
    - This is the atmospheric window (the red light in the CO_2 band has gone)
  - Put two green filters in front of the headlamp. Only half of the green light gets through.
    - This is like doubling the CO_2
  - Put a blue filter in front of the green one. No light gets through
    - This is like another GHG or cloud that closes the window completely
- This is a very crude demo and may be an exaggeration or an underestimate.
  - We do not know how well these filters represent CO_2 in the atmosphere.
- Discussion: Think what happens to a 500W stage spot-lamp when filters are added!
  - This is global warming (do not cover car headlamps!!)

How important is CO_2?

Feedback effects

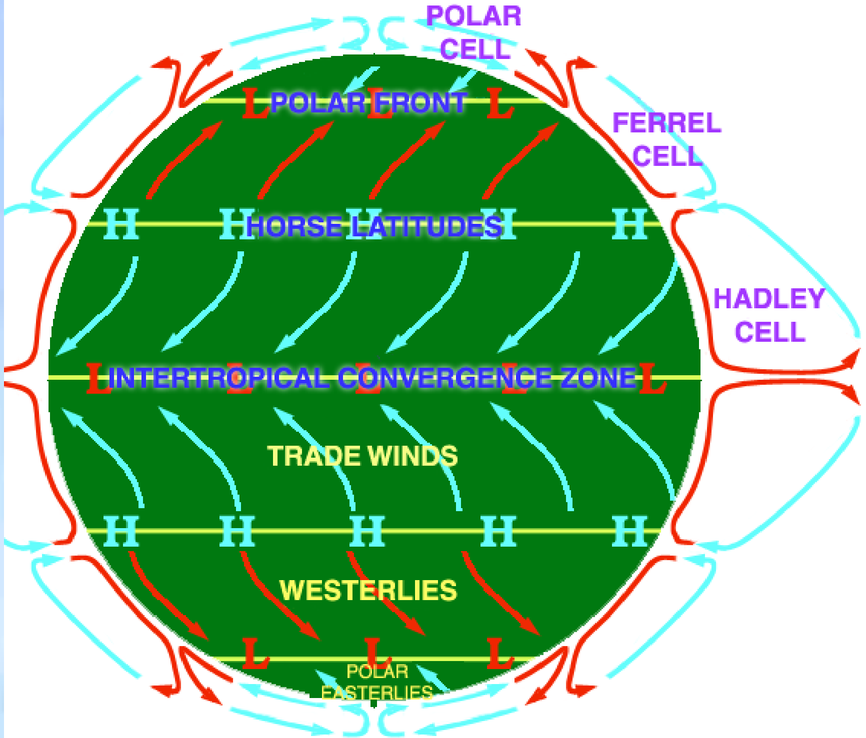
- Ice/Snow reflectivity (albedo) feedback at the poles
  - When the ice melts the land/sea reflects less light and so the surface temperature rises
- Water vapour feedback
  - If the temperature is perturbed upwards (e.g. by CO_2) the atmosphere can hold more moisture
  - H_2O is a strong greenhouse gas, so its increasing concentration adds to global warming by partial closure of the atmospheric window
    - However, clouds form and are assumed to have a negative feedback
  - Climate modellers cite water vapour feedback as an explanation for the higher than expected temperature rises obtained with increasing CO_2 alone
    - Stull [1] discusses a 1 degree rise by CO_2 and a further 2 degree rise when ‘indirect sensitivities’ including water are included
    - GCMs are used to evaluate these feedback sensitivities….

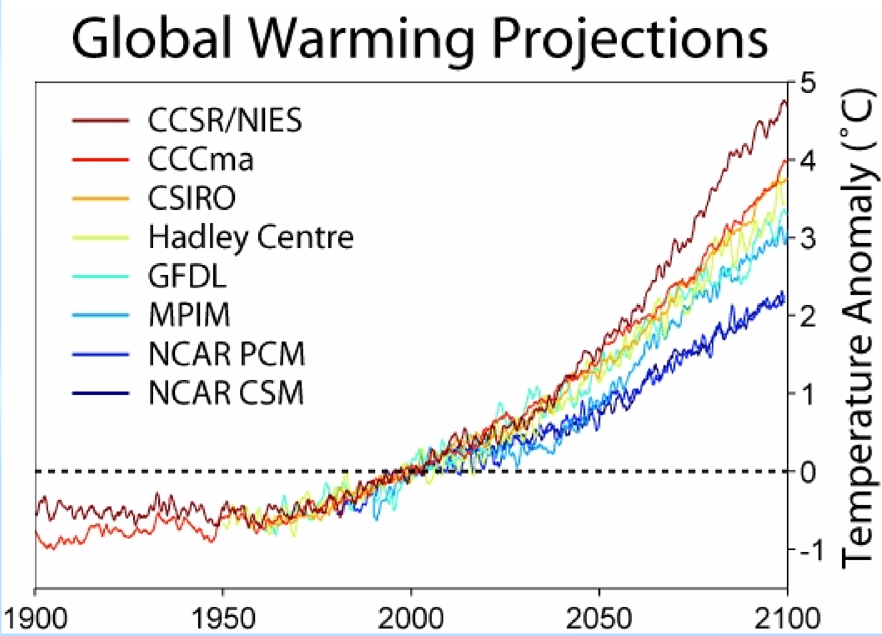
[1] “Meteorlogy for Scientists and Engineers”, Ed 2–Roland B Stull, p.408, Pub. Brooks/Cole

General Circulation Models (GCMs)

- "A General Circulation Model (GCM) is a mathematical model of the planetary atmosphere or ocean based on the Navier-Stokes equations on a rotating sphere with thermodynamic terms for various energy sources (radiation, latent heat)"

- "Earth system models couple ice sheet models for the dynamics of the Greenland and Antarctic ice sheets, and one or more chemical transport models (CTMs) for species important to climate.
  - This approach allows accounting for inter-system feedback
  - e.g. chemistry-climate models allow the possible effects of climate change on the recovery of the ozone hole to be studied".





http://en.wikipedia.org/wiki/File:AtmosphCirc2.png
http://en.wikipedia.org/wiki/Global_climate_model
http://en.wikipedia.org/wiki/File:Global_Warming_Predictions.png

How important is CO_2?

How important is the IPCC 4th Assessment report?

- It is widely accepted by policymakers as the source of information about GHGs and expected climate change
  - 4th Assessment 2007 “World temperatures could rise by between 1.1 and 6.4 °C during the 21st century”
- It majors on CO_2
  - “Carbon dioxide (CO_2) is the most important anthropogenic GHG.”
  - It calibrates all other GHGs in terms of CO_2
    - “These warming influences may be expressed through a common metric based on the radiative forcing of CO_2”.
    - “CO_2-equivalent emission”
- “Includes only carbon dioxide (CO_2), methane (CH4), nitrous oxide (N2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphurhexafluoride(SF6), whose emissions are covered by the UNFCCC”.
- “Water vapour changes represent the largest feedback affecting equilibrium climate sensitivity and are now better understood than in the TAR (third assessment report). Cloud feedbacks remain the largest source of uncertainty”.

http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr.pdf

How important is CO_2? Summary of findings

- IPCC 4th Assessment 2007 “World temperatures could rise by between 1.1 and 6.4°C (2.0 and 11.5 °F) during the 21st century [1]
  - This based on the output of world class GCMs
  - They judge that: global mean surface air temperature has increased by 0.3-0.6^{O}C over the last 100 years
- My concern is that the GCMs are underestimating the risks we run from our emissions
  - The changes are happening now, not at the end of the century
  - The biggest concern I have is the aviation induced contrail and resulting cirrus cloud which adds to the warming
  - This is likely to be missing from all climate models (see appendix 2)

Recommended literature

[1] http://en.wikipedia.org/wiki/Intergovernmental_Panel_on_Climate_Change
[3] Meteorology for Scientists and Engineers, Ed 2–Roland B Stull, p,408, Pub Brooks/Cole
[5] “Atmosphere, ocean, and climate dynamics: an introductory text” By John Marshall, R. Alan Plumb”, Elsevier Academic Press 2008

Next

Impact of water vapour and clouds

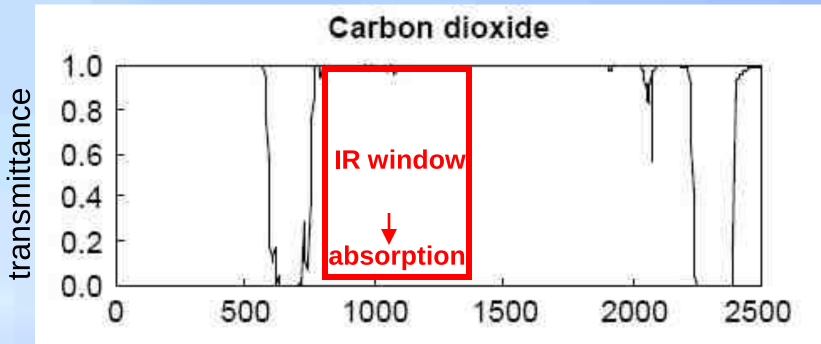
Other factors leading to a Greenhouse Effect

- "Concerning the impact of GHGs, overall we get
  - Water vapour = 60%
  - CO_2 = 26%
  - Other gases =14%
  - NB. CFC-12 absorbs in the 8-11μm atmospheric window and is 10000 times more potent than CO_2
  - These filter the sun's energy (sunlight) causing the two potentially largest and least understood feedbacks
    - clouds (e.g. absorption reflection and emission)
    - oceans (e.g. reflectivity of sea ice and plankton)
- These effects will cause global scale changes in climate over the century [1]"

[1] "Essentials of Meteorology" ,C. Donald Ahrens 5th edition, pub. Thompson, Brooks/Cole p.38

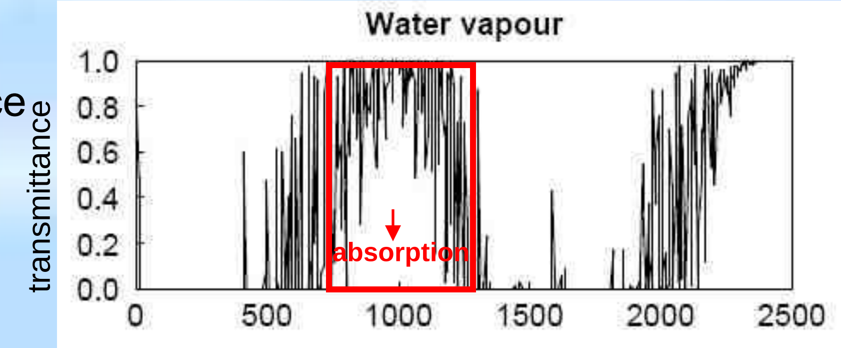
Impact of water vapour

- So far I have not been able to explain how increasing CO_2 alone would lead to closure of the atmospheric window shown in red
  - Its absorption spectra would need to expand and join up between
    - 667 cm^{-1}, 15.0 μm and
    - 1288 cm^{-1},7.76 μm
- CO_2 needs a lot of 'help' from other GHGs to 'drive' global warming to the +6^{o}C extreme often quoted in the press
  - Next we will explore the impact of H_2O and cloud….
  - Here H_2O has absorption in the IR window, enough to act as 'positive feedback', and hence 2^{o}C additional warming but probably not enough to completely close the IR window



Infrared spectra of the greenhouse gases as calculated using the HITRAN data base1; Transmission is plotted against wavenumber (reciprocal cm)

http://www.warwickhughes.com/papers/barrett_ee05.pdf



Lets look at clouds in more detail

- "Tiny liquid droplets are good absorbers of IR but poor absorbers of sunlight.
- Clouds even absorb the wavelengths between 8 and 11 μm which are otherwise 'passed up' by water vapour and CO_2.
- Thus they have the effect of enhancing the greenhouse effect by closing the atmospheric window" [1].

[1] "Essentials of Meteorology" ,C. Donald Ahrens 5th edition, pub. Thompson, Brooks/Cole p.38

Impact of Clouds
Effect of Water Cloud

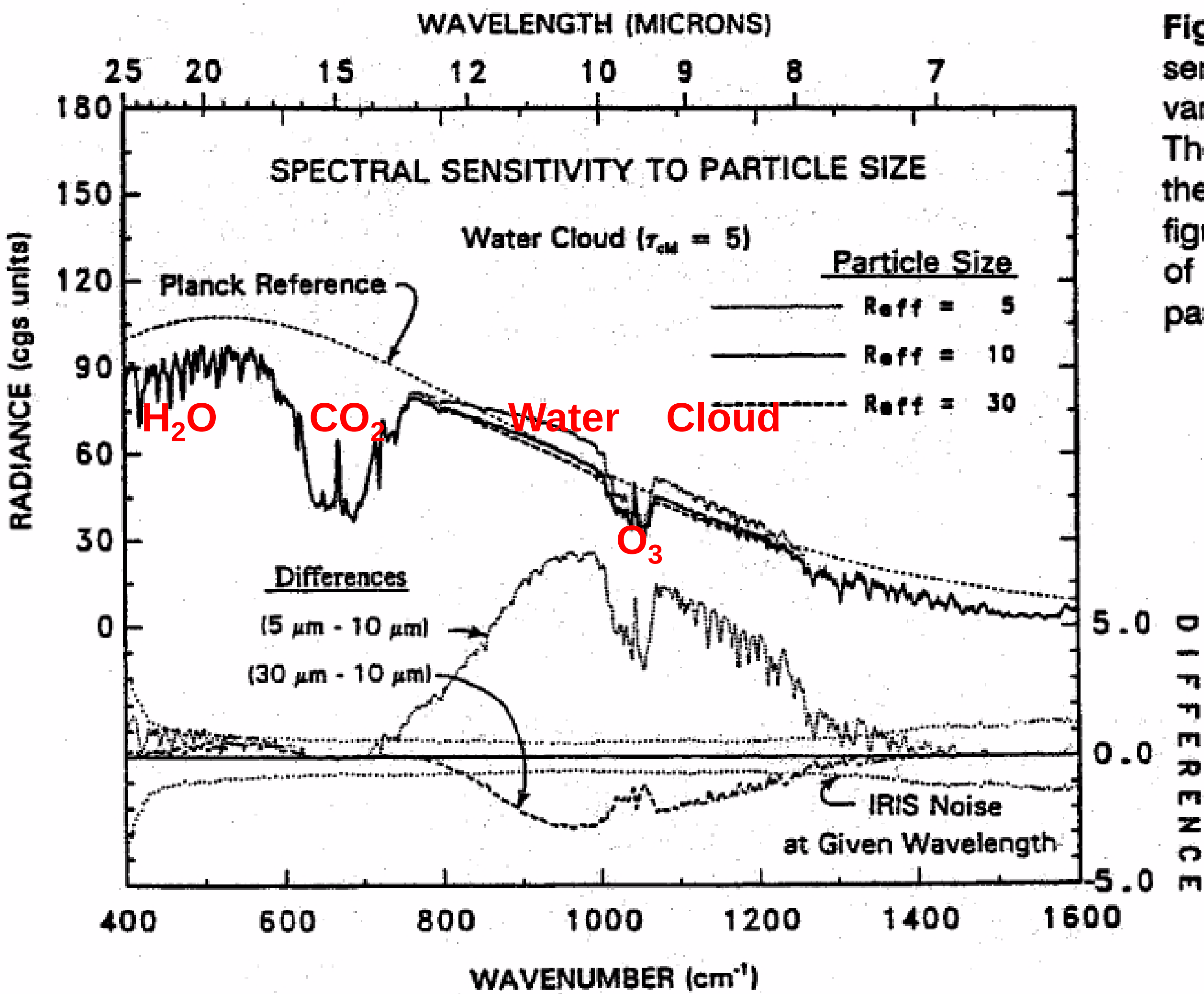


Fig. 10.4. Spectral sensitivity to particle size variations in a water cloud. The difference spectra in the lower portion of the figure shows the feasibility of MINT retrieval of cloud particle size.

"The relatively clear window region from 8-12 µm contains information on tropospheric water vapour distribution and is also the region where the spectral signature of clouds is most apparent"…
"Clouds are detected by the degree of departure from the Planck spectrum"

Here the atmospheric system radiates most when the particle size is 5-10µm (resonance in the atmospheric window)

http://map.nasa.gov/documents/CLARREO/7_07_presentations/Michelson%20Interferometer.pdf

Impact of Clouds

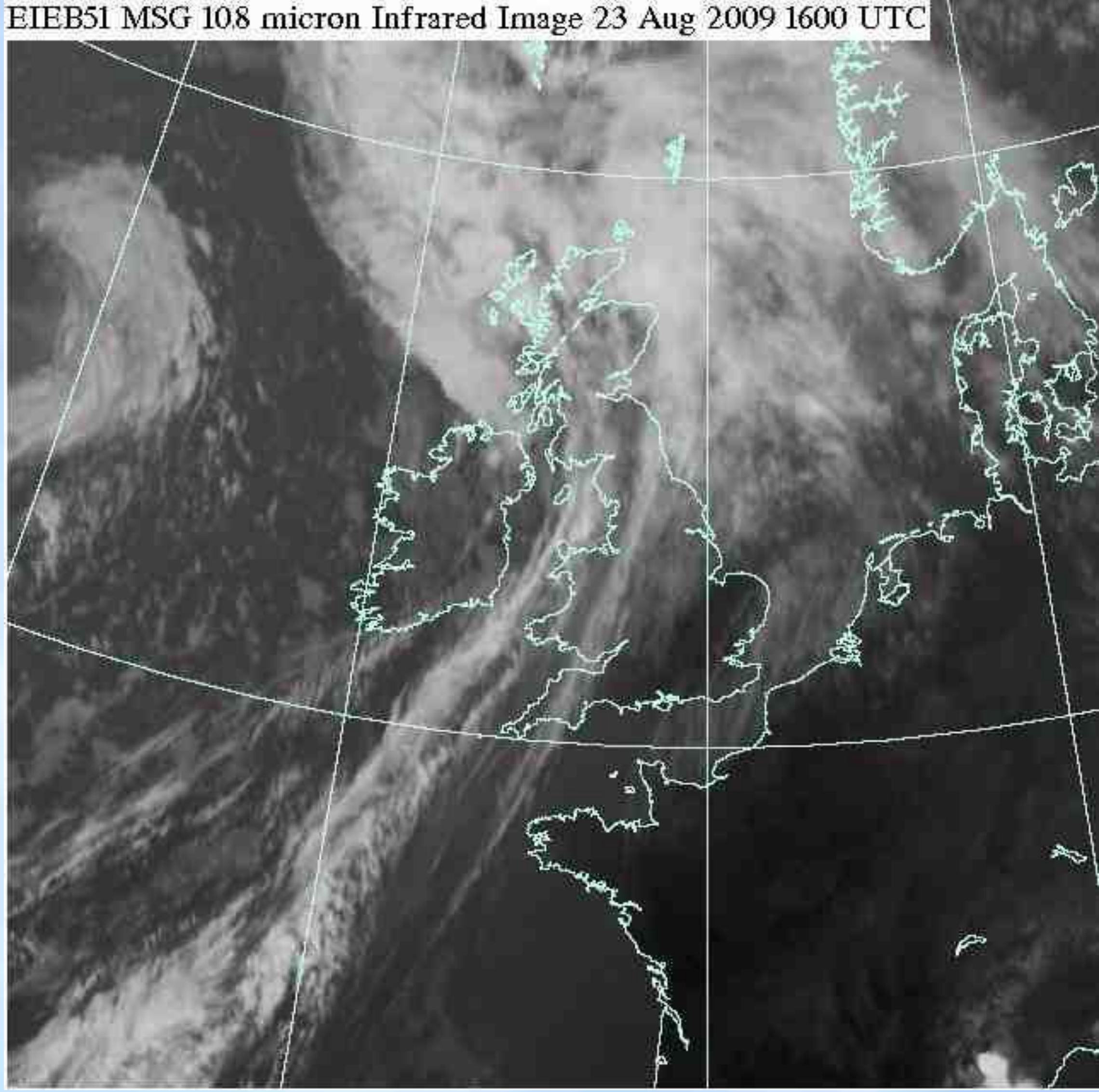
UK IR image on 23 August

This image is a negative. Hotter surfaces are blacker.

At this time Martlesham was covered by cirrus and contrail (background).

These do not show up as particularly cold even though they are higher.

The surface is likely to be radiating through this thin cloud. Even so the cirrus and contrail must be trapping some heat



Note. We cannot tell from this type of image whether Martlesham was covered in low thick cloud or high thin cloud. In fact it was a hot day with high thin cloud…

http://www.metoffice.gov.uk/satpics/latest_uk_ir.html

These images come from satellites which remain above a fixed point on the Earth (i.e. they are "geostationary"). The infrared image shows the invisible infrared radiation emitted directly by cloud tops and land or ocean surfaces. The warmer an object is, the more intensely it emits radiation, thus allowing us to determine its temperature. These intensities can be converted into greyscale tones, with cooler temperatures showing as lighter tones and warmer as darker.

Lighter areas of cloud show where the cloud tops are cooler and therefore where weather features like fronts and shower clouds are. The advantage of infrared images is that they can be recorded 24 hours a day. However, low cloud, having similar temperatures to the underlying surface, are less easily discernable. Coast-lines and lines of latitude and longitude have been added to the images and they have been altered to northern polar stereographic projection.

Martlesham Heath on 23 August at 16:33
Cirrus with persistent contrails

- "Cirrus clouds trap and reflect infrared radiation (heat) beneath them (greenhouse effect)"[1]

  Conservation of energy must apply [2]

  Reflection + Absorption + Transmission = 1
- If **reflection** occurs in the infrared the surface temperature will be different from the single slab model showing a temperature of 30.1^{o}C of page 15
  - This assumed perfect absorption for the single slab atmosphere model
  - **Discussion/homework. Could cirrus cloud act as an IR mirror? What would the surface temperature be if cirrus turns out to be a near perfect reflector of IR?**
  - **What would the surface temperature be if cirrus turns out to be a 50% reflector 25% absorber and 25% transmitter?**

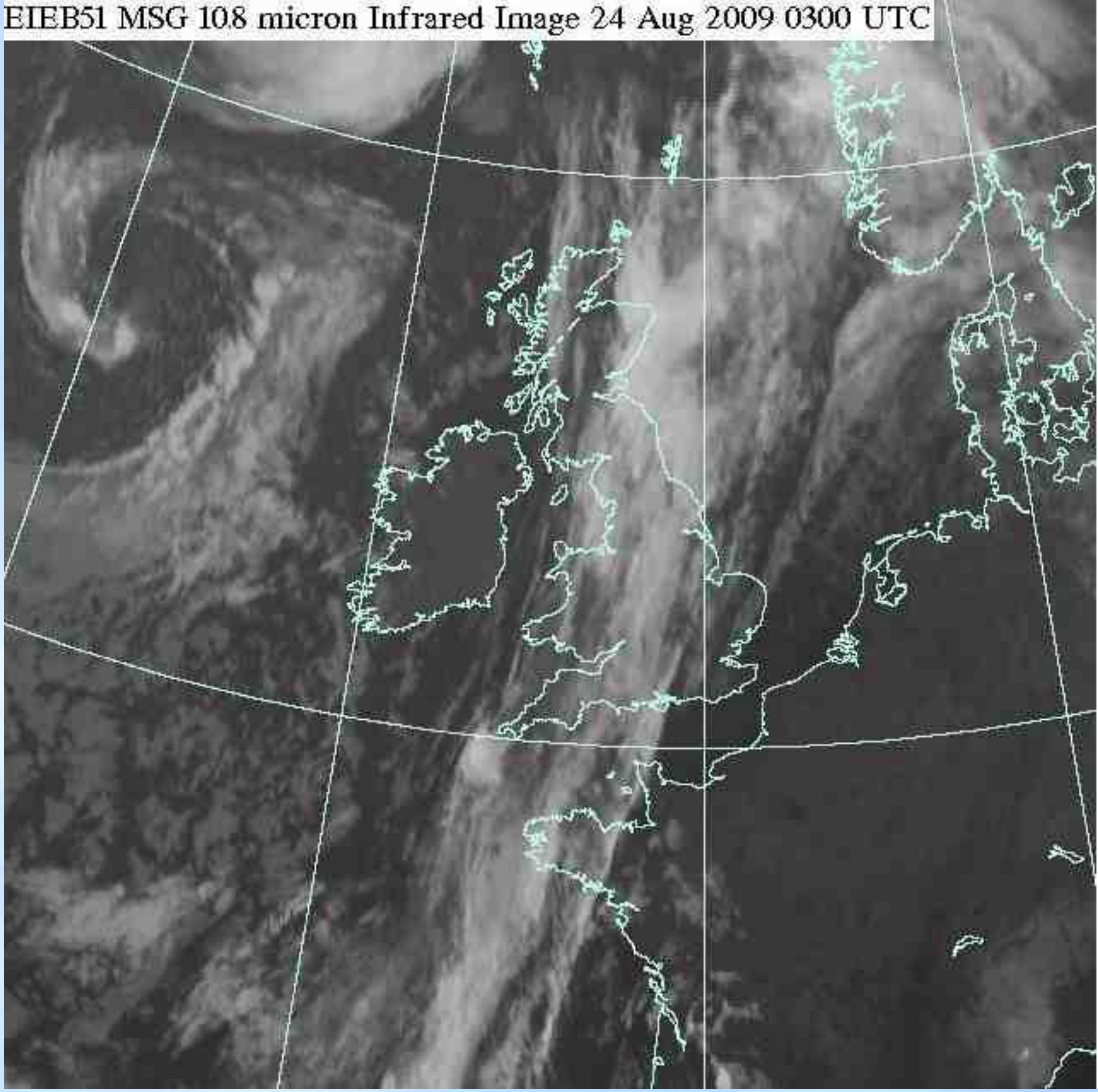
[1] http://www.absoluteastronomy.com/topics/Cirrus_cloud
[2] http://www.comet.ucar.edu/class/satmet/schmit/11.html

Impact of Clouds

UK IR image on 24 August (night)

Note. That night much of France appears to have remained cloud free. The sea is radiating more than the land which cools more rapidly

If global warming progresses towards 30.1°C the IR atmospheric window would be closed and it would no longer be possible to photograph surface features in the IR 10.8 μm band



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Next

A global average with regional chaos?

How significant regional impact?

- The IPCC judge that: global mean surface air temperature has increased by 0.3-0.6 ^{o}C over the last 100 years
  - The radiative forcing contribution (since 1750) from increasing concentrations of well-mixed GHGs is estimated to be +2.64 Watts per square meter - over half due to increases in CO2 [1]
- "The increase in global average temperature comes inordinately from an increase in average night temperatures in the winter in central Siberia and northwest Canada.
  - These are areas in which the water vapor content of the air is low due to low precipitation and effective distance from areas of humidity.
  - *As Vladimir Putin has said, "an increase of two or three degrees wouldn't be so bad for a northern country like Russia*" [2]
- **Discussion:** Do you agree with the statement in *italics* above?
- **Discussion:** Can you think of any factors which might change the water vapour component over central Siberia and Northwest Canada?
- This brings us back to the problem of accelerated melting over Greenland shown at the beginning of this talk

[1] http://www.epa.gov/climatechange/science/recentac.html
[2] http://www.sjsu.edu/faculty/watkins/radiativeff.htm

Summary

Climate Change-where do we go from here?

- If CO_2 cannot close the atmospheric window what can?
  - Ice cloud?
  - Water cloud?
  - Water vapour?
  - A cocktail of other GHGs Ozone etc?
    - (but these may affect only parts of the spectrum)
    - E.g. "One kilogram of sulphur hexafluoride will, for example, cause as much warming as 23 tonnes of carbon dioxide over 100 years [1]"
  - Aerosols (usually have a cooling effect – unless it includes ice)

- In the next talk we will explore the impact in the stratosphere of aviation, methane and volcanoes

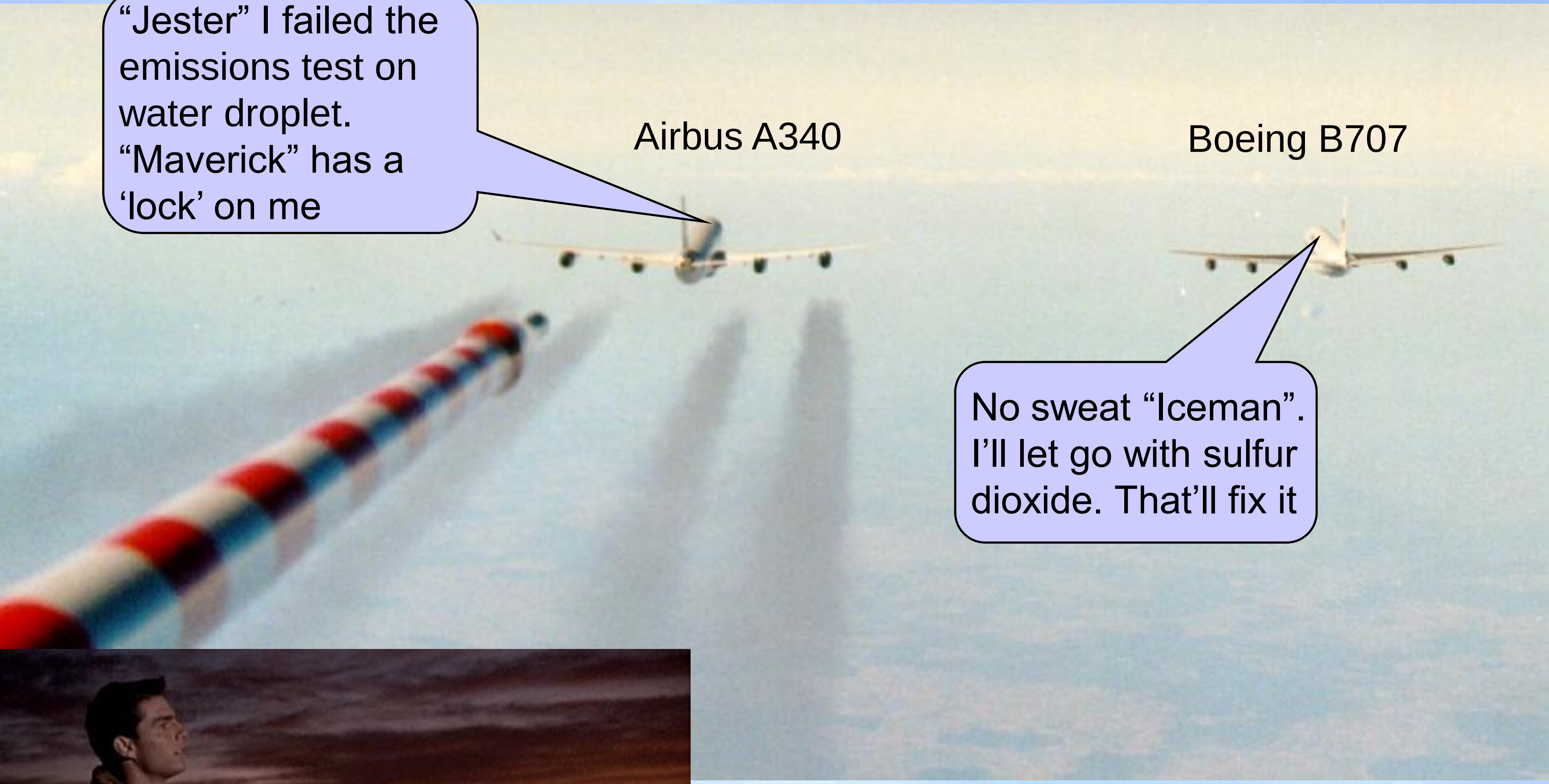
http://www.absoluteastronomy.com/topics/Atmospheric_window#encyclopedia

Conclusion

How much do I understand about climate change?

- *I think the climate has already changed dramatically at the poles, in desert and glacier regions (plenty of evidence is reported)*
  - *I think I understand 60% of the basic (textbook) science associated with climate change (not including the weather)*
  - *I think that scientific knowledge is only 50% along the way to understanding how humans are causing climate change*
    - **More investigations are needed, elsewhere than CO_2, to find more immediate problems**
    - **Regional variations (e.g. at the poles) are more important than the global average**
  - *Current theory does not seem to explain the observed changes today*
    - *The IPCC is looking 100 years ahead in their scenarios*
    - *I think an important factor is missing*
    - *We need to examine more closely possible ways of closing the atmospheric window*
- How important is it to save emissions of CO_2?
  - It would help to avoid
    - *At least 1^{o}C warming this century by doubling CO_2 (3^{o}C with feedback)*
    - *Possible pollution of the environment (e.g. acidification land, sea and air)*
    - *Wasting fossil fuels to generate energy which are key resources for future generations*

Next Talk-Changing the Climate



"Top Gun" Maverick contemplating his next duty - climate change

www.eumetnet.eu/.../Sausen_Climate_impact_by_aviation_070503.ppt
http://en.wikipedia.org/wiki/Top_Gun_(film)

Apologies to "Top Gun" Sausen, Schumann et al., 2000

Thank you

For a copy of this talk contact dav1dfaulkner@yahoo.com

Suggestions for Discussion

1. Is a global average temperature change of 0.3-0.6 degrees over the last 100 years [1] and an estimated increased forcing of 2.43 W/m^2 [2] since pre industrial times enough to account for the rapid melting of the Greenland ice sheet today?

Compare this with the average surface temperature 15C and heat loss of 240 W/m^2

Should we be looking for something more compelling to explain what is going on today?

2. Why is Greenland melting faster than Antarctica?

3. Vladimir Putin has said, "an increase of two or three degrees wouldn't be so bad for a northern country like Russia”.

Do you agree with this statement?

4. Don’t forget to do the Demo

[1] [1] http://en.wikipedia.org/wiki/Intergovernmental_Panel_on_Climate_Change
[2] http://retro.enes.org/reports/D5-2_final.pdf

Appendices

Appendix 1
Arrhenius-the ‘father’ of the greenhouse effect

- “In its original form, Arrhenius' greenhouse law reads as follows:
  - if the quantity of carbonic acid increases in geometric progression, the augmentation of the temperature will increase nearly in arithmetic progression.
- This simplified expression is still used today:
  - $\Delta F = \alpha \ln(C/C_0)$
  - (DF this is the radiative forcing in W/m^2 which is widely used to show the climate sensitivity of different gases)
- Arrhenius' high absorption values for CO_2, however, met criticism by Knut Ångström in 1900, who published the first modern infrared spectrum of CO_2 with two absorption bands. Arrhenius replied strongly in 1901 (Annalen der Physik), dismissing the critique altogether”….

- “**Arrhenius** estimated that halving of CO_2 would decrease temperatures by 4 - 5 °C (Celsius) and a doubling of CO_2 would cause a temperature rise of 5 - 6 °C[4
  - In his 1906 publication, Arrhenius adjusted the value downwards to 1.6 °C (including water vapour feedback: 2.1 °C).
  - Recent (2007) estimates from IPCC say this value (the Climate sensitivity) is likely to be between 2 and 4.5 °C”.

http://en.wikipedia.org/wiki/Svante_Arrhenius

Discussion: Is this right law to explain climate change? Would you trust it?
What might have happened if Arrhenius had taken account of Ångström’s spectral theory?
What would he have made of the atmospheric window?

Appendix 2

GCMs What factors are being included?

- “The Met Office Hadley Centre model is unique among climate models in that it is used with more regional detail to produce the weather forecasts every day
- current state-of-the-art climate models include fully interactive clouds, oceans, land surfaces and aerosols, etc. Some models are starting to include detailed chemistry and the carbon cycle.
- Clouds affect the heating and cooling of the atmosphere
  - Cirrus clouds
    - High level clouds let sunlight through and trap infra-red radiation. Their dominant effect is to warm surface climate
  - Cumulus clouds
    - Low level clouds reflect sunlight and trap little infra-red radiation. Their dominant effect is to cool surface climate
- The Gulf Stream in the north Atlantic Ocean brings warm water from the tropical Atlantic up to northern Europe, and has a strong effect on the temperatures that the UK experiences.
- The land surface influences how much radiation is absorbed at the surface
  - An area that is covered in trees will be dark and will heat up more by absorbing more radiation. Areas covered in ice, or at the opposite extreme desert, will both reflect more radiation and absorb less heat.
- Aerosols
  - such as sulphate and black carbon that are produced naturally from volcanoes and forest fires, as well as by humans from fossil fuel power stations and other industrial activities.
  - They generally have a cooling effect on climate, by reducing the amount of sunlight reaching the surface (the so-called global dimming effect) and by changing the properties of clouds. The presence of man-made aerosols is reducing global warming in the short term.
- Chemistry and the carbon cycle determine how much carbon dioxide remains in the atmosphere
  - Currently the biosphere (plants, soils, phytoplankton) absorbs half of the carbon dioxide that man produces.
- The latest Hadley Centre model, HadGEM1 (which is typical of current state-of-the-art models), uses 135km boxes with 38 levels in the vertical, and includes all of the complexity of the climate system outlined above.

- **But according to some experts, the drive for ever more computing power misses a far more basic problem with current climate models. They argue that the models are still too crude to be reliable, lacking subtle effects that can have a profound impact on the Earth’s climate”.**

http://news.bbc.co.uk/1/hi/sci/tech/6320515.stm
http://www.bbcfocusmagazine.com/feature/environment/climate-gamble.