Climate Change and the Stratosphere

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Our climate – Why be interested in the stratosphere?

H_2O CO_2 CH_4 O_3

"We go on holiday in the stratosphere!!"

- The Problem
  - Regional climate appears to be changing faster than predicted from trends in CO_2
  - E.g. Why do we not get much snow anymore?
  - Why is Greenland melting faster than Antarctica
  - We need to look elsewhere for possible causes
- Issues
  - The thin air of the stratosphere is sensitive to changes in composition
  - Changes here directly modulate the sun's radiation
  - UV changes the chemistry
  - Are we able to make our own judgement?
  - Are we being told the whole truth?

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  - *Regional impacts*
- *Are there other factors emerging?*
  - *Methane*
- *Recommendations*

What has made me suspicious about aviation?

- Travis' measurements after 9/11
- We are getting warmer nights especially in winter
  - More cloud cover and little snow
- The IPCC say "the H_2O component is shown to be very small because flight routes are close to the tropopause and reach at most into the lowermost stratosphere
  - This effluent is rapidly returned to the troposphere with little expected accumulation"
- However the stratosphere is naturally dry, stratified and therefore sensitive to water accumulation
- Water vapour is the strongest greenhouse gas
- The aviation industry
  - Doubles every 10 years with 2% of CO_2 emissions already
  - Plays down the impact of GHGs other than CO_2
- Increasing stratospheric water vapour has been observed but is hardly ever attributed to human activity

What did we find out last time?

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

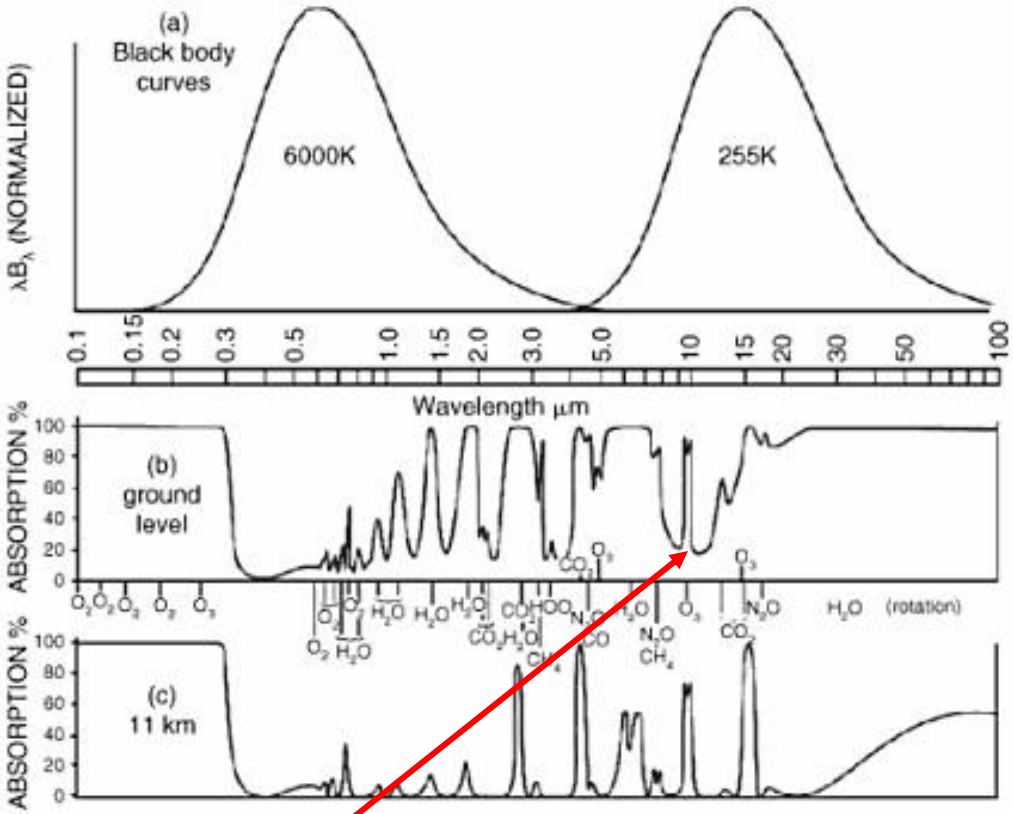


FIGURE 2.6. (a) The normalized blackbody emission spectra, $T^{-4}\lambda B_\lambda$, for the Sun ($T = 6000$ K) and Earth ($T = 255$ K) as a function of ln λ (top), where B_λ is the blackbody function (see Eq. A-2) and λ is the wavelength (see Appendix A.1.1 for further discussion). (b) The fraction 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).

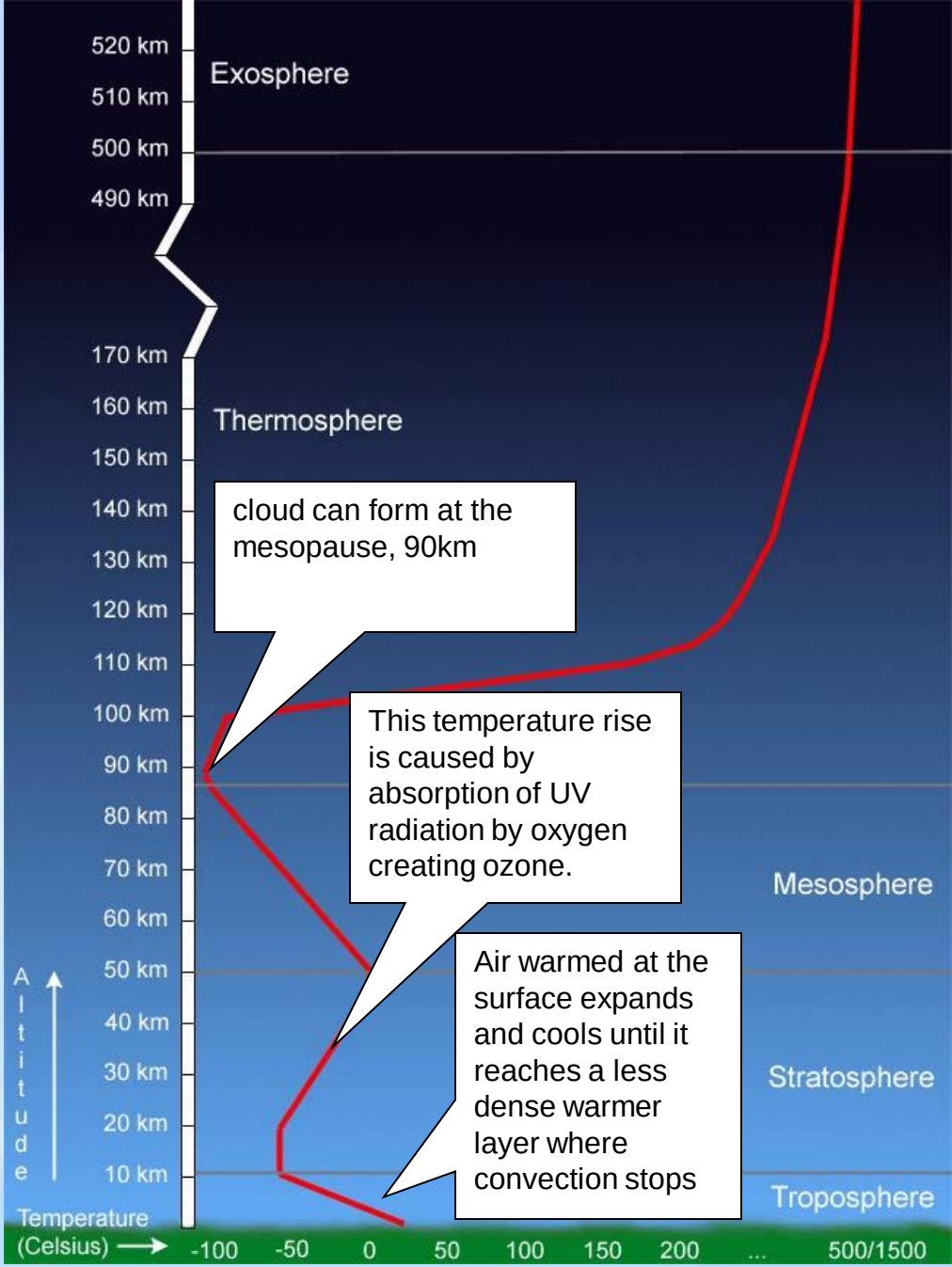
Downward radiation from the sun and upward radiation form the earth are in different bands of the electromagnetic spectrum and are in radiative (energy) equilibrium

Closure of the IR atmospheric window restricts the emission from the earth and the surface temperature increases. The 'greenhouse effect'

Clouds have a bigger potential to close the atmospheric window than the GHGs. CO_2 is already close to optical 'saturation'. Less dense GHGs can have a bigger impact if their spectra occur in the atmospheric window

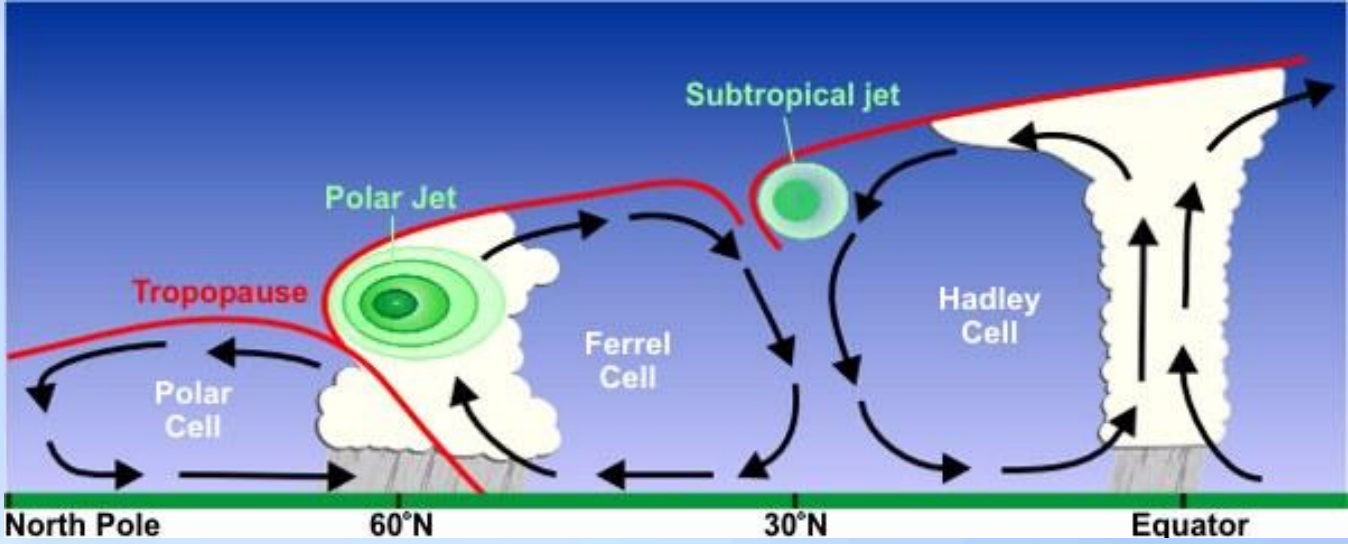
Atmospheric Layers

- "The atmosphere is thickest near the surface and thins out with height until it eventually merges with space.
- 5) The exosphere merges into space in the extremely thin exosphere. This is the upper limit of our atmosphere
- 4) The thermosphere is a layer with auroras. It is also where the space shuttle orbits
- 3) Meteors or rock fragments burn up in the mesosphere
- 2) Many jet aircrafts fly in the stratosphere because it is very stable. Also, the ozone layer absorbs harmful rays from the Sun
- 1) The troposphere is the first layer above the surface and contains 75% of the Earth's atmosphere. Weather occurs in this layer.



http://www.windows.ucar.edu/tour/link=/earth/Atmosphere/ozone_strato.html

Atmospheric Layers

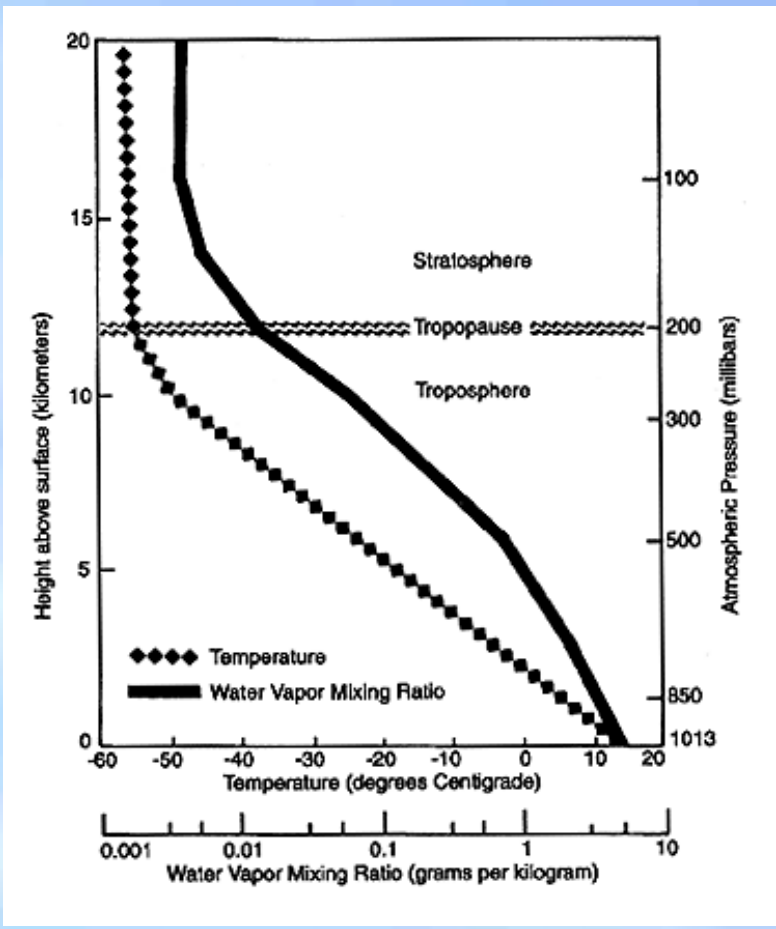


- The troposphere [1]
  - contains
    - approximately 75 percent of the atmosphere's mass and
    - 99 percent of its water vapour and aerosols.
  - Height
    - approximately 17 km in the middle latitudes
    - up to 20 km tropical regions,
    - shallower near the poles, at 7 km in summer, and indistinct in winter.
- The tropopause [2] is
  - the boundary between the troposphere and the stratosphere
  - one of the points where air ceases to cool with height, and becomes almost completely dry.
  - an inversion layer, with little mixing between the two layers.

[1] http://en.wikipedia.org/wiki/Troposphere
[2] http://en.wikipedia.org/wiki/Tropopause

Atmospheric layers
Water Vapour

- "The atmosphere's water vapour contributes only about 0.25% by weight of all the gases[1]". (CO_2 is 0.0582% [2])
- "If all the water vapour in the air at a particular time were to condense and fall as rain, it would be only 2.5 cm deep.
  - 5 cm near the equator
  - less than 5mm at the poles.
  - The average precipitation over the globe is about 1 m annually, so there must be a rapid turnover of water in the air; the average water molecule spends about 9 days in the air before precipitating back to the surface.
- Water vapour is distributed unevenly in the atmosphere, not only horizontally but vertically as well.
  - The figure shows the mean vertical distribution of temperature and the mixing ratio of water vapour in the atmosphere.
  - The lower scale shows that water vapour decreases rapidly with height as the atmosphere gets colder.
  - Nearly half the total water in the air is between sea level and about 1.5 km above sea level.
  - Less than 5-6% of the water is above 5 km, and
  - less than 1% is in the stratosphere, nominally above 12 km"
  - **(DF 250µm column depth)**
- **"Despite the small amount of water vapour in the upper troposphere (above about 5 km) and stratosphere, recent research has shown that upper tropospheric water vapour is very important to the climate".**



[1] http://www.agu.org/sci_soc/mockler.html **Recommended**
[2] http://micpohling.wordpress.com/2007/03/30/math-how-much-co2-by-weight-in-the-atmosphere/

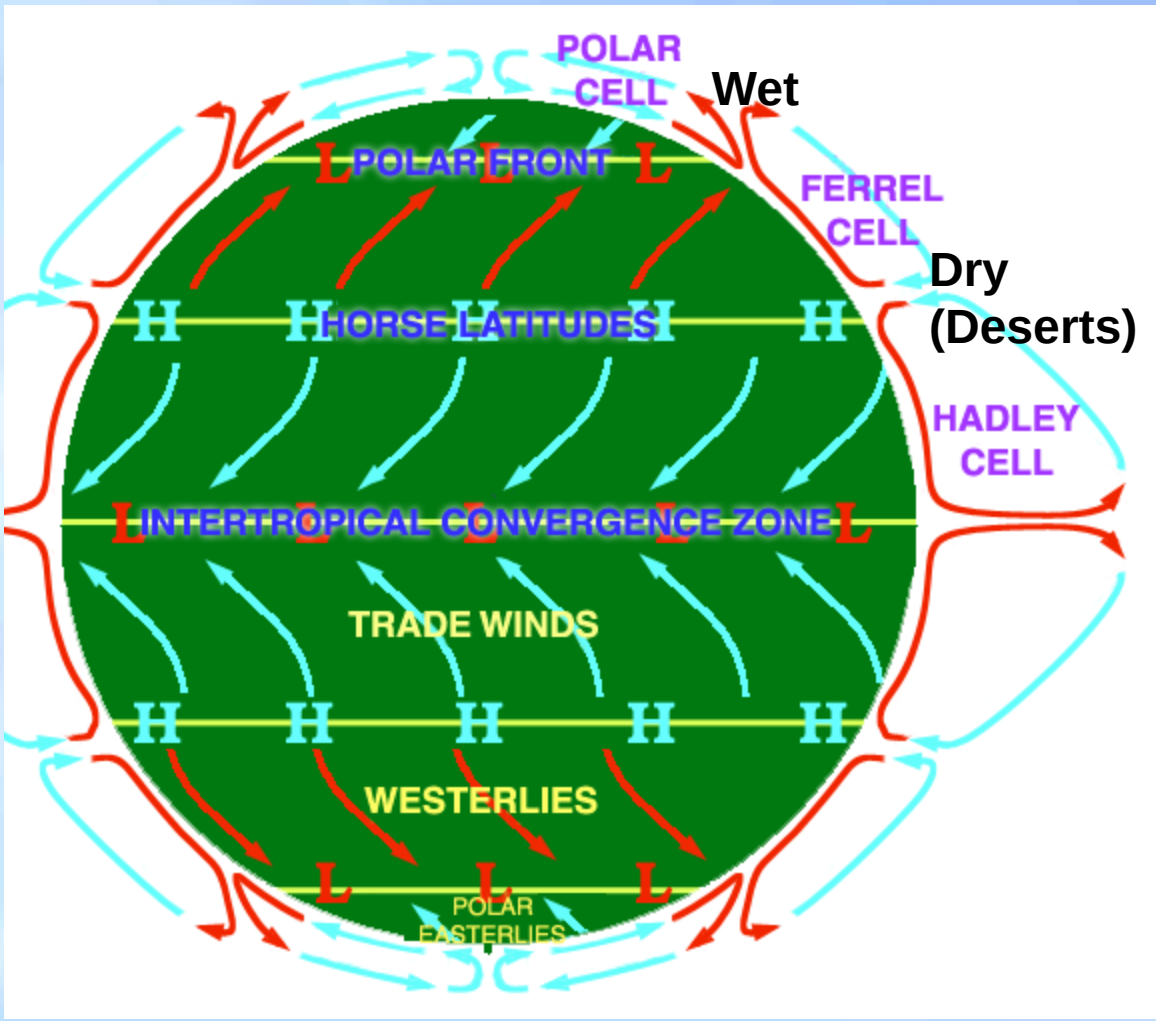
Atmospheric Circulation

"Atmospheric circulation is the large-scale movement of air, and the means (with ocean circulation) by which heat is distributed around the Earth.

Jet streams are found at the polar and horse latitudes.

The polar front is characterised by low pressure systems and often passes over the UK during the summer nowadays.

GCMs take account of heat transfer by the oceans and the atmosphere from tropics to poles



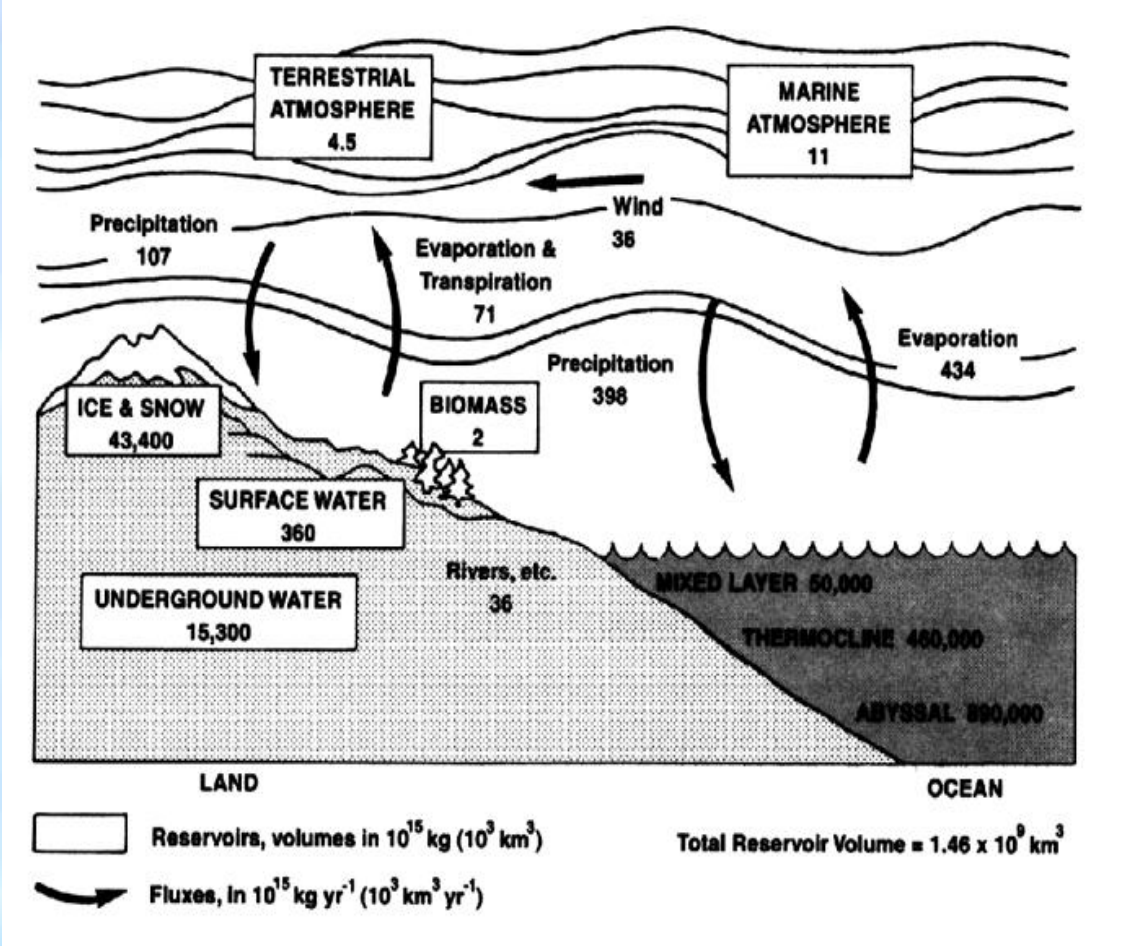
http://en.wikipedia.org/wiki/File:AtmosphCirc2.png

Hydrologic Cycle

- "Rivers carry water from land to oceans, from which we infer that there must be more precipitation than evaporation over land. To achieve balance, there must then be more evaporation than precipitation over oceans. The excess water vapor is transported from oceanic to continental areas and precipitates".

- tropospheric water is in long term dynamic equilibrium

- ***"There are some aspects of the role of water vapor as a greenhouse gas that are not well understood, again mainly because we lack the necessary observations to test theoretical models".***



http://www.agu.org/sci_soc/mockler.html.

Characteristics of stratosphere and troposphere

- The troposphere contains what we call ‘the weather’ with convective mixing
  - Dominated by the oceans
  - Water spends on average 9 days in the troposphere and so washes out pollution

- The stratosphere has very little water content and is sensitive to small changes
  - Water vapour reaches its convective limit at the tropopause
  - Requires energy to enter the stratosphere (kinetic/chemical)
  - The time water spends in the stratosphere can be months or years[1]
  - Any water in the stratosphere may be outside of the weather systems and have additional impact on atmospheric window
  - The stratosphere height drops to zero at the poles
  - Let’s examine some stratospheric effects…

http://www.areco.org/Global%20Warming%20Potential%20of%20Green%20House%20Gas%20Release%20at%20Different%20Altitudes.pdf

Sources of stratospheric water vapour

- Annual input
  - Volcano [A] } 40 MT
  - Tropical storm [A]
  - Oxidation of methane [A] 40 MT
  - Aviation (2004) 290 MT
    - assuming an average of 10% of the total 320MT from fuel is burnt during the climb [B]
    - Assuming that most flights take place in northern latitudes (i.e. above 20,000ft in the stratosphere)

[A] http://www.eci.ox.ac.uk/research/energy/downloads/methaneuk/chapter02.pdf

[B] http://www.boeing.com/commercial/aeromagazine/articles/qtr_4_08/article_05_1.html

Impact of volcanoes on climate

- The most abundant gases typically released into the atmosphere from volcanic systems are [A]
  - water vapour (H_20),
  - carbon dioxide ($C0_2$) and
  - sulphur dioxide ($S0_2$).
- "climate simulations from the Pinatubo eruption yielded
  - a general cooling of the global troposphere but
  - winter warming over northern hemisphere continents. [B]
- Discussion. Would the warming have been more general if the sulphur dioxide was absent?

[A] http://sandmc.pwv.gov.za/comp/Gases.htm
[B] http://earthobservatory.nasa.gov/Features/Volcano/

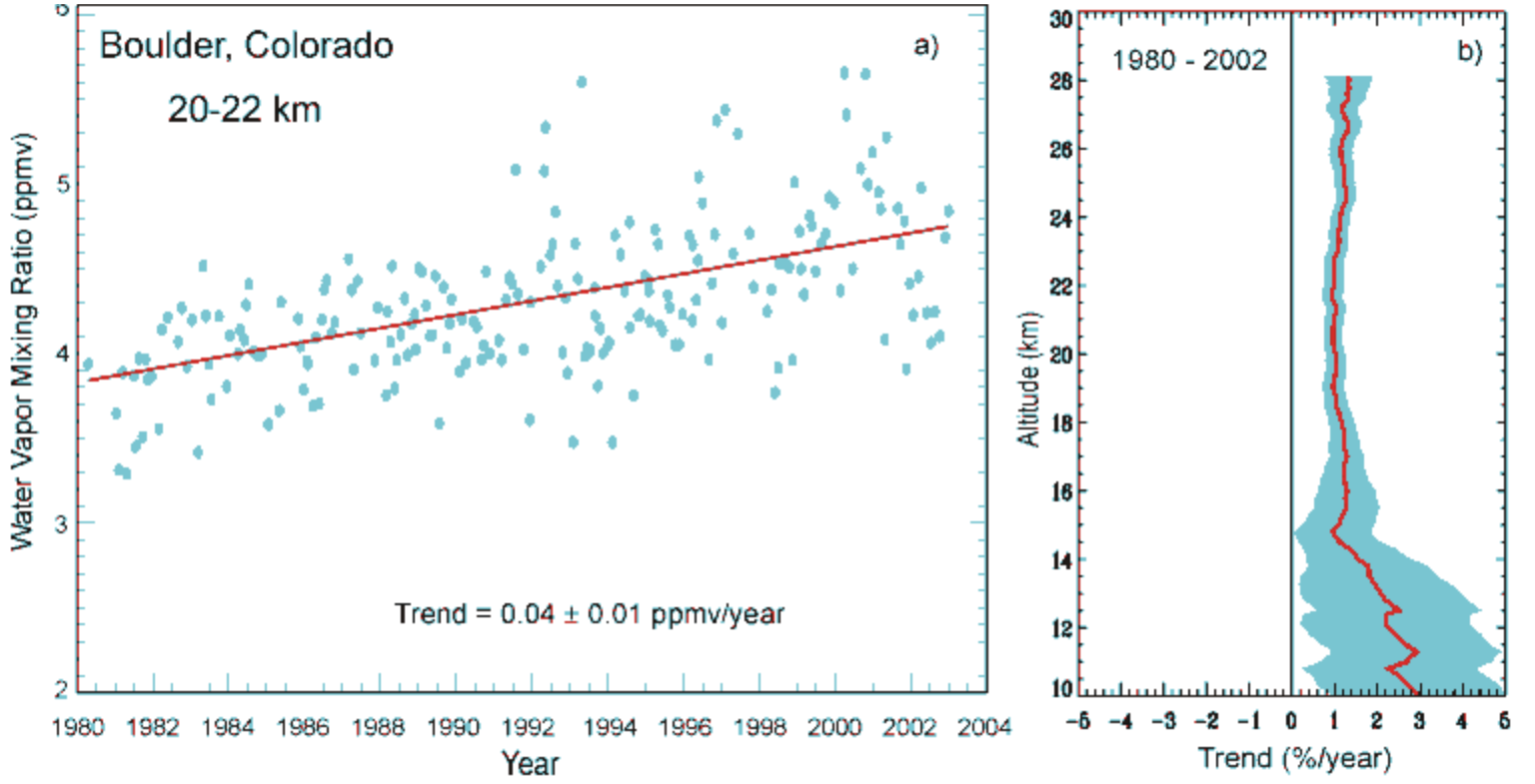
Aircraft Emissions

- Aircraft traffic doubling every 10 years [A]
- 75% of northern corridor flights are in stratosphere/tropopause [B]
  - Up to half are likely to be east-west in the jet streams
- A total 240MT kerosene was burnt for freight and passenger in 2004 [C]
  - 240MT kerosene combusts to form 320MT water and 744MT carbon dioxide [C]
- If 90% of H20 is emitted in the stratosphere (288MT) it exceeds that from natural sources (160MT) at this altitude [D]
  - Natural sources of stratospheric water vapour include storm cloud, volcanoes and solar breakdown of methane
- A molecule of water in the stratosphere has been quoted as high as **200** times worse GHG than a molecule of carbon dioxide and destroys ozone in the stratosphere [B]
  - It is very difficult to find an accurate figure for this. Water has many phases
  - For the year 2000 calculations suggest that the overall effect of all emissions [H20, NOx] is **36** times greater than those of the CO_2 emissions [E]

    The Royal Commission report [F] gives a figure of **10 times CO_2**

[A] http://www.tyndall.ac.uk/publications/working_papers/wp84.pdf
[B] http://space.newscientist.com/article/mg14219232.100-saving-ozone-with-a-nogo-zone-jumbo-jets-are-spending-
[C] http://www.after-oil.co.uk/runways.htm
[D] http://www.eci.ox.ac.uk/research/energy/downloads/methaneuk/chapter02.pdf
[E] www.eci.ox.ac.uk/research/energy/downloads/predictanddecide.pdf
[F] http://www.rcep.org.uk/avreport.htm

Increase of stratospheric water vapour



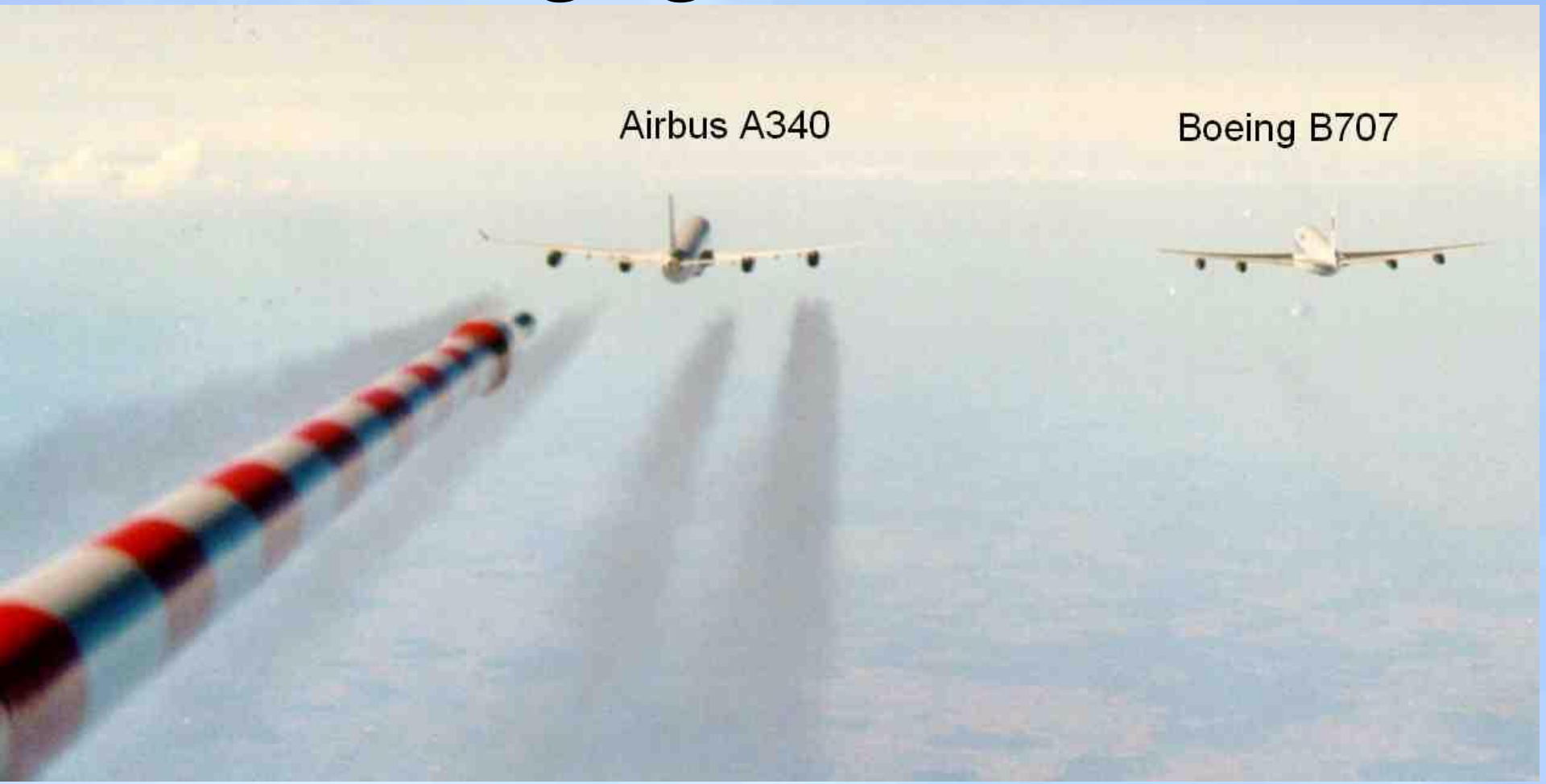
- "1% pA at Boulder, Colorado, since 1980. 30% may be due to increased methane [A].
- Besides implications for climate change, increased water vapor can affect the rate of chemical ozone loss, for example, by increasing the incidence of polar stratospheric clouds. Satellite measurements of water vapour, although not of adequate length for accurate trend determination, suggest that the increase may extend to other latitudes
  - plays a role both in cooling the lower stratosphere and in depleting ozone through chemical interactions, thereby contributing to climate processes.
  - However, the water vapour trends are not fully defined, nor are their cause understood"

NB This accumulation appears to be mainly at the altitude of civil aviation!!

[A] http://en.wikipedia.org/wiki/File:BAMS_climate_assess_boulder_water_vapor_2002.png

Stratospheric water vapour

Changing the Climate?



Schumann et al., 2000

www.eumetnet.eu/.../Sausen_Climate_impact_by_aviation_070503.ppt

Airbus has a more efficient engine which emits exhaust at a cooler temperature.
The water condenses more readily than the Boeing's.
Both are emitting H_2O but we do not know which provides the 'best' nucleation

Stratospheric water vapour

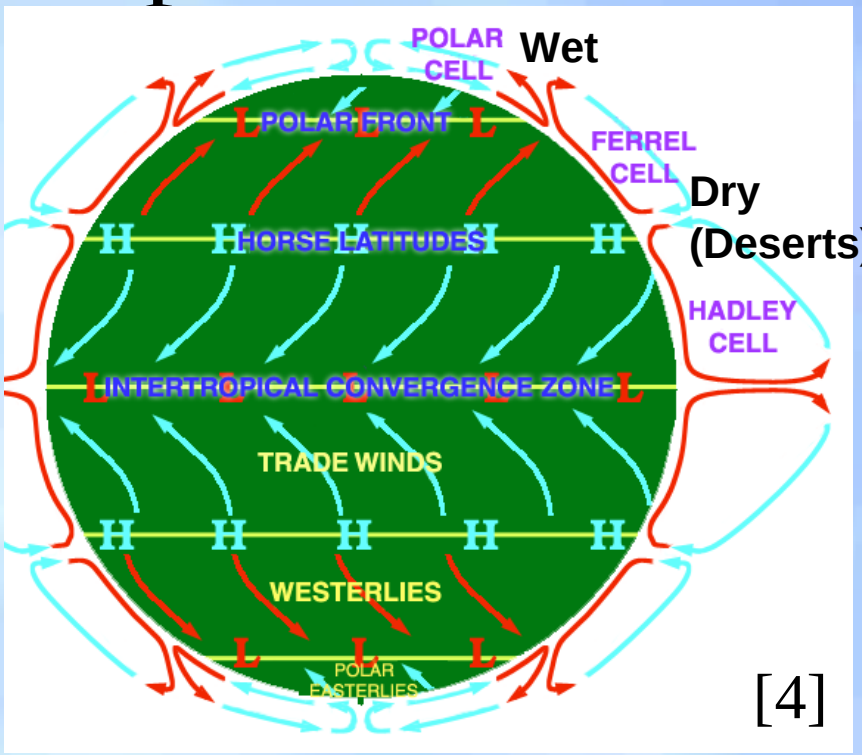
Concerns about aviation as the dominant source of stratospheric water

- During 9/11 grounding David Travis measured 1% increase in diurnal temperature variation because of absence of air traffic [A]
  - He was waiting for an opportunity to test his theory
- "Coverage of persistent, spreading contrails (contrail-cirrus) may be global
  - infra-red radiative forcing might be underestimated by an order of magnitude or more, but large uncertainties remain [B]".
  - Cirrus (ice) cloud has lower reflectivity to sunlight than tropospheric (water) clouds and to have higher IR reflectivity and /or absorption than water cloud
    - Hence a positive forcing of temperature
- "water vapour breaks down to produce the reactive radicals OH and HO_2 , known collectively as HOx . The HOx radicals react catalytically with ozone (O_3) [C] :
  - NB Ozone is a greenhouse gas contributing 3-7% to global warming [C,D,E]
  - This is the greatest single loss process for ozone in the lower stratosphere (10-25 km altitude).
  - NB. High altitude water vapour may originate from methane rather than aviation
- Globally the accumulation my be around 8μm pA but regionally much more
  - It would take 30 years at today's rate to double the stratospheric H_2O

[A] http://ams.allenpress.com/perlserv/?request=get-document&doi=10.1175%2F1520-0442(2004)017%3C1123%3ARVIUDT%3E2.0.CO%3B2
[B] http://web.mit.edu/aeroastro/partner/reports/climatewrksp-rptsummary-0806.pdf
[C] http://www.es.lancs.ac.uk/casestud/case13.htm (may be removed now ask DF for text)
[D] http://en.wikipedia.org/wiki/Greenhouse_gas
[E] http://www.giss.nasa.gov/research/briefs/shindell_05/

How is water vapour removed from the stratosphere?

- Precipitation as ice crystals into the troposphere
  - With possible 'seeding' of rain clouds below [1,2]
    - and consequent drying of air in other regions
  - Needs a 'seed' particle
    - Water can exist as a droplet to –40^{o}C
- Circulation cells
  - Down-welling over the [horse latitudes/Jet stream]
  - Down-welling over the poles
  - 3-5 months tropics to poles (Brewer-Dobson) [3]

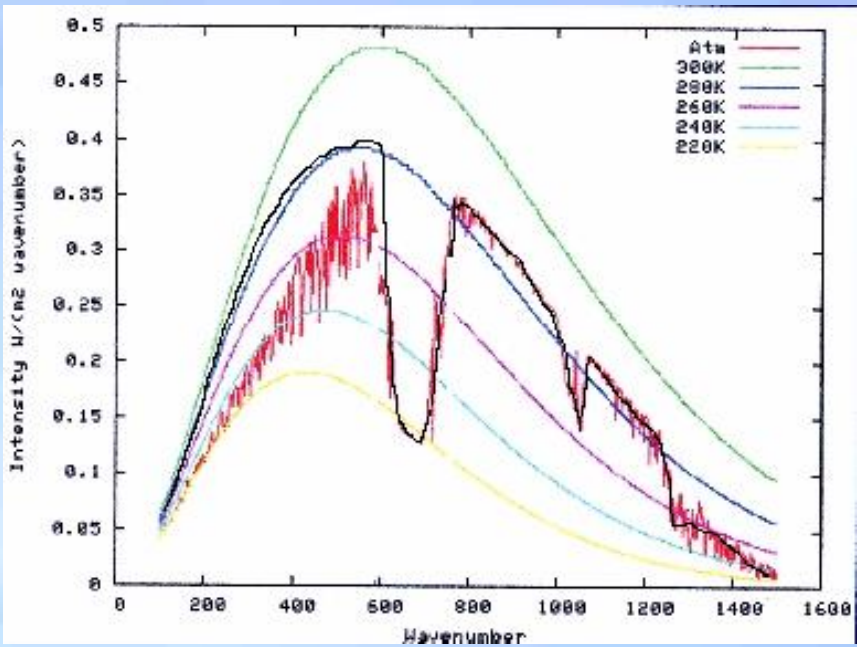


[1] "Essentials of Meteorology" ,C. Donald Ahrens 5th edition, pub Thompson, Brooks/Cole p.125
[2] http://www.extremegb.com/articles/cloud_formations.aspx
[3] http://www.easternuswx.com/bb/lofiversion/index.php/t137229.html
[4] http://en.wikipedia.org/wiki/File:AtmosphCirc2.png

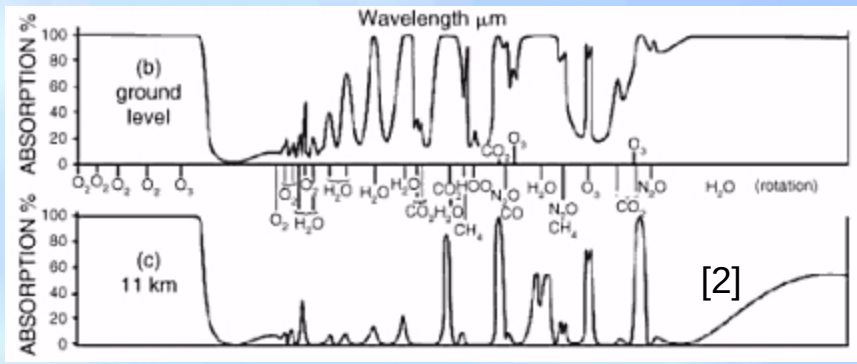
Impact of water vapour on climate

Removal of water vapour from an atmospheric model

- When we discussed the hypothetical removal of CO_2 (previous talk) in the red curve
  - the temp decreased by 10.4^{O}C
- The black line is my sketch of what might be expected if water vapour is similarly removed
  - The temp would again decrease by around 10^{O}C (area under curve)
- This may be the REAL situation in the stratosphere [1] over desert or poles [2] where the humidity is naturally low
- Discussion.
  - Could aviation emission be causing water vapour to be significantly increased in dry regions and so warming the surface below?



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

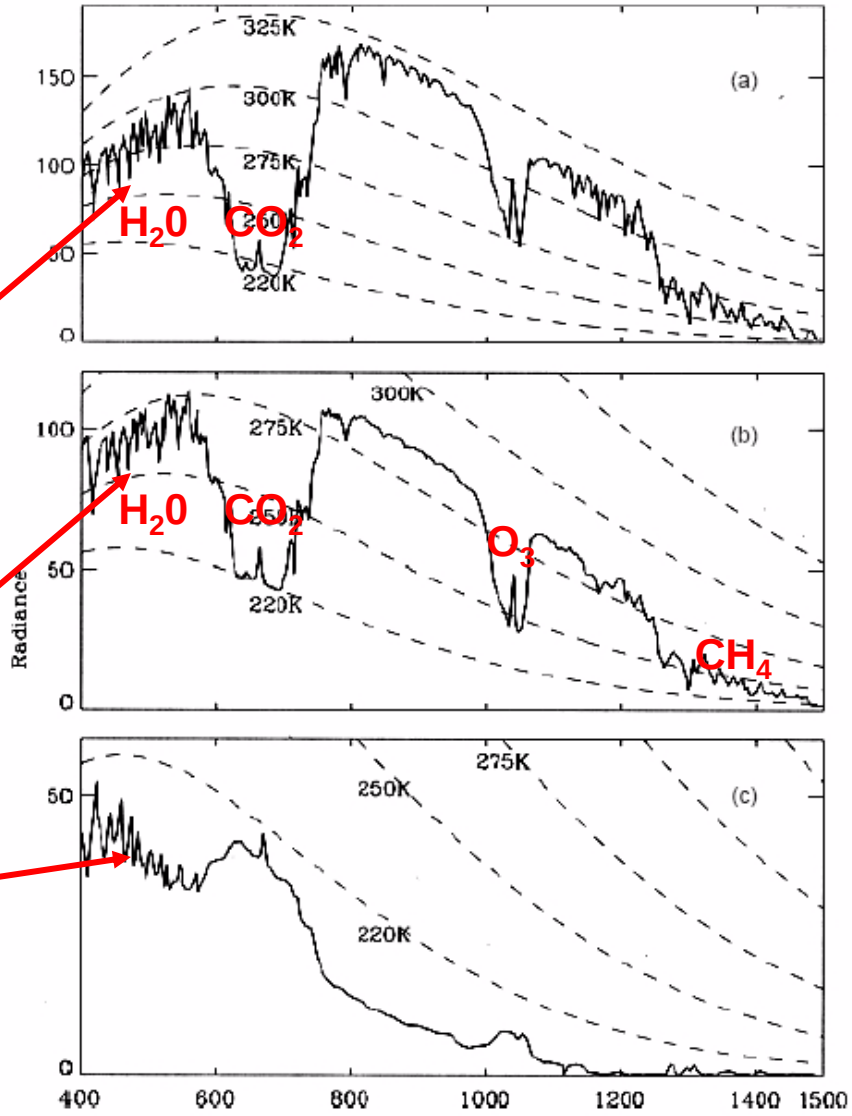


[1] The humidity in the Sahara desert is normally in the range of only 4 to 5%
And is potentially sensitive to additional sources of water vapour
http://wiki.answers.com/Q/What_is_the_average_humidity_in_the_Sahara_desert

[2] "Atmosphere, ocean, and climate dynamics: an introductory text" By John Marshall, R. Alan Plumb", Elsevier Academic Press 2008, see p13 on Google books

Measured IR emissions over different regions

- The water vapour over Sahara is 40^{o}C cooler than the surface
  - High altitude
- The water vapour over the Med is 20^{o}C cooler than the surface
- In the Antarctic the surface is colder than the CO_2. Water vapour may be absent or close to the surface temperature



Sahara

Mediter-ranean

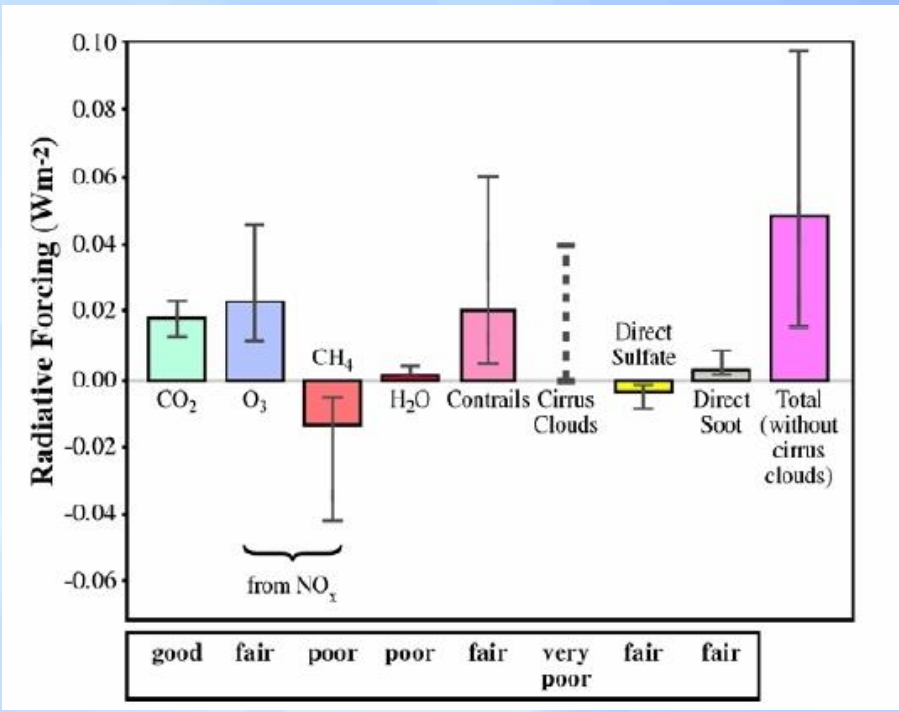
Antarctic

Figure 9: Emission spectra of the Earth taken by the Nimbus 4 satellite. The radiance units are milliWatts per square metre per cm^{-1} per steradian. Spectrum (a) is measured over the Sahara Desert, spectrum (b) over the Mediterranean, and spectrum (c) over the Antarctic

Recommended read → http://www.warwickhughes.com/papers/barrett_ee05.pdf

IPCC- Aviation as a source of GHG

- IPCC calculate the change in radiative forcing of aviation emissions since pre-aviation times to be 0.049 W/m^2. This corresponds to a radiative forcing index of **2.7** times that of CO_2 alone (0.018 W/m^2) [A]
- However, a recent study (TRADEOFF9) has proposed a value of 1.9 as the best-quantified estimate of radiative forcing index of aviation emissions [B]
- Cirrus has positive forcing
  - "The limits on cirrus are questionable
  - The effect of cirrus is not understood"
- Note that the H_20 component is shown to very small because "flight routes are close to the tropopause and reach at most into the lowermost stratosphere, This effluent is rapidly returned to the troposphere with little expected accumulation" [C]
  - **Why does the IPCC not say flights are mostly in the stratosphere especially in northern latitudes?**
  - **E.g. See this reference "In contrast, the UT-LS around the tropopause is a region of relative vertical stability, and emissions here will change altitude very slowly and can remain there for months or years [D]"**



from [A]

[A] http://www.grida.no/climate/ipcc/aviation/083.htm#661
[B] http://www.climatecare.org/media/documents/pdf/Aviation_Emissions_&_Offsets.pdf
[C] http://www.grida.no/climate/ipcc/aviation/076.htm#635
[D]http://www.areco.org/Global%20Warming%20Potential%20of%20Green%20House%20Gas%20Release%20at%20Different%20Altitudes.pdf

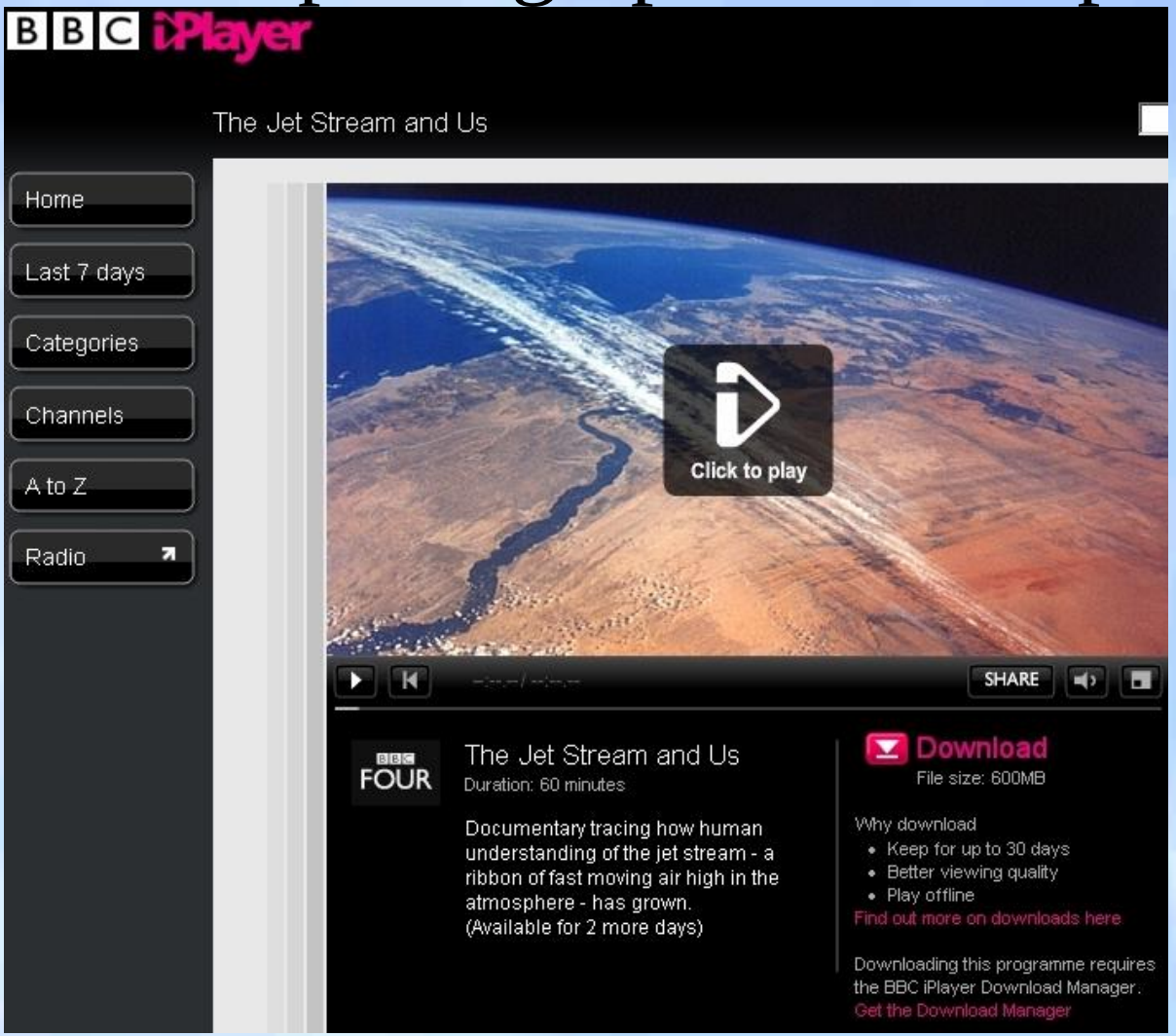
Recent Literature about Aviation and Climate

- "Questions have been raised about what uplift factor should be applied.
  - Recent studies indicate that the appropriate uplift factor could range between 1.7 and 5.1 times aviation CO_2 emissions depending on the timescales of the analysis (Sausen et al. 2005; Forster et al. 2005).
  - If the purpose is to provide an approximation of CO2-e using a 100-year timeframe, an uplift factor of 1.7 appears to be the best estimate, although it is subject to considerable uncertainty" [1]
- "Variations between lower and upper bounds for estimates of radiative forcing are relatively low for carbon dioxide, around 131% to 800% for cirrus clouds effects, and 1044% for soot".
  - Advances in climate research, particularly in the area of contrail and cloud effects, has led to some revision of the 1999 IPCC estimates1, and demonstrates that the research community is actively working to further understand the underlying science [2]
- "Simulations (of cirrus cloud) show
  - smallest longwave cloud forcing (26.22W/m2) and the
  - smallest shortwave cloud forc-ing (50.65W/m2) because it has the lowest ice crystal number concentration" [3]

[1] http://www.aef.org.uk/uploads/International_aviation_emissions_to_2025___Macintosh_1.pdf
[2] http://www.raes.org.uk/aero_journal.asp
[3] http://www.atmos-chem-phys-discuss.net/9/16607/2009/acpd-9-16607-2009.pdf

Possible aviation impact on climate

Jet-stream photographed from space[A]



Jet streams are most commonly found between latitudes 30°N and 70°N
(pilots remember that like birds, they go north in the summer and south in the winter)

[A] http://www.bbc.co.uk/iplayer/page/item/b00909b0.shtml

Possible aviation impact on climate

Contrail Outbreak

- During 9/11 grounding David Travis measured 1% increase in diurnal temperature variation because of absence of air traffic [A]
  - –Warmer nights trapping heat
  - –The Royal Commission cite it [B]
  - –Others have refuted it [C]

[A]http://ams.allenpress.com/perlserv/?request=get-document&doi=10.1175%2F1520-0442(2004)017%3C1123%3ARVIUDT%3E2.0.CO%3B2

[B]http://www.rcep.org.uk/avreport.htm

[C] http://ams.allenpress.com/perlserv/?request=get-document&doi=10.1175%2F1520-0442(2004)017%3C1123%3ARVIUDT%3E2.0.CO%3B2&ct=1

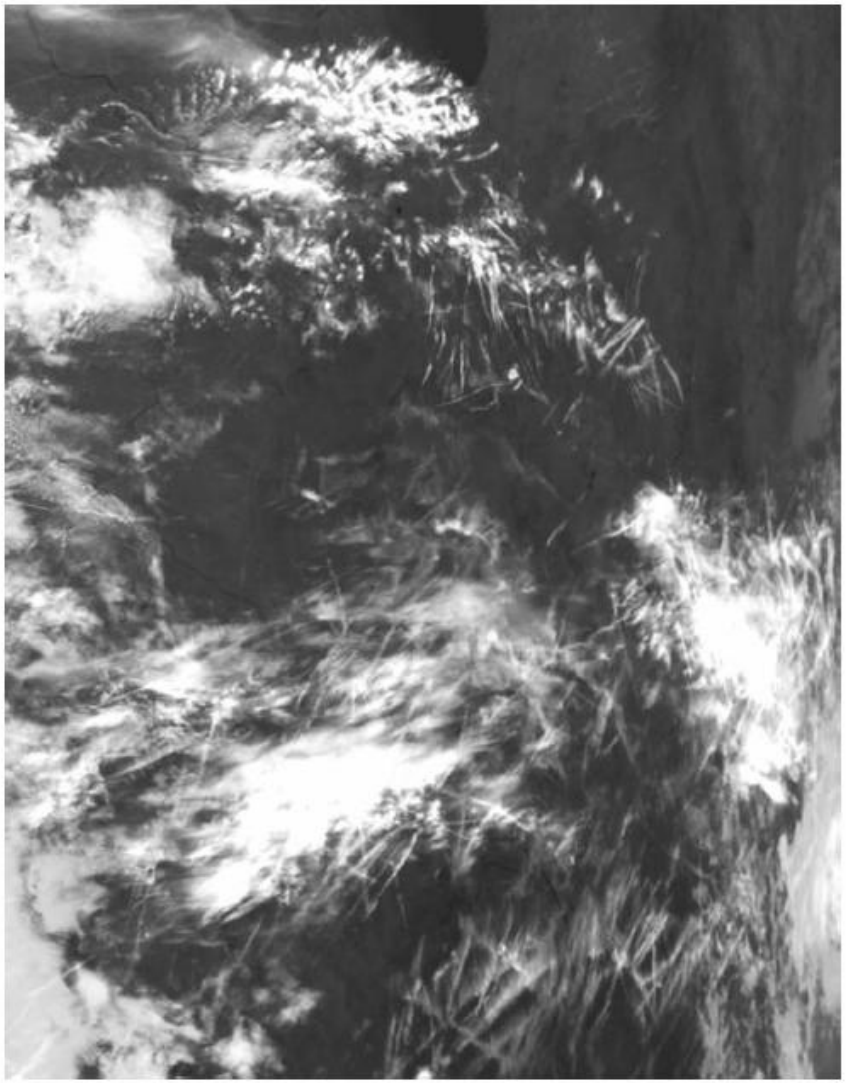
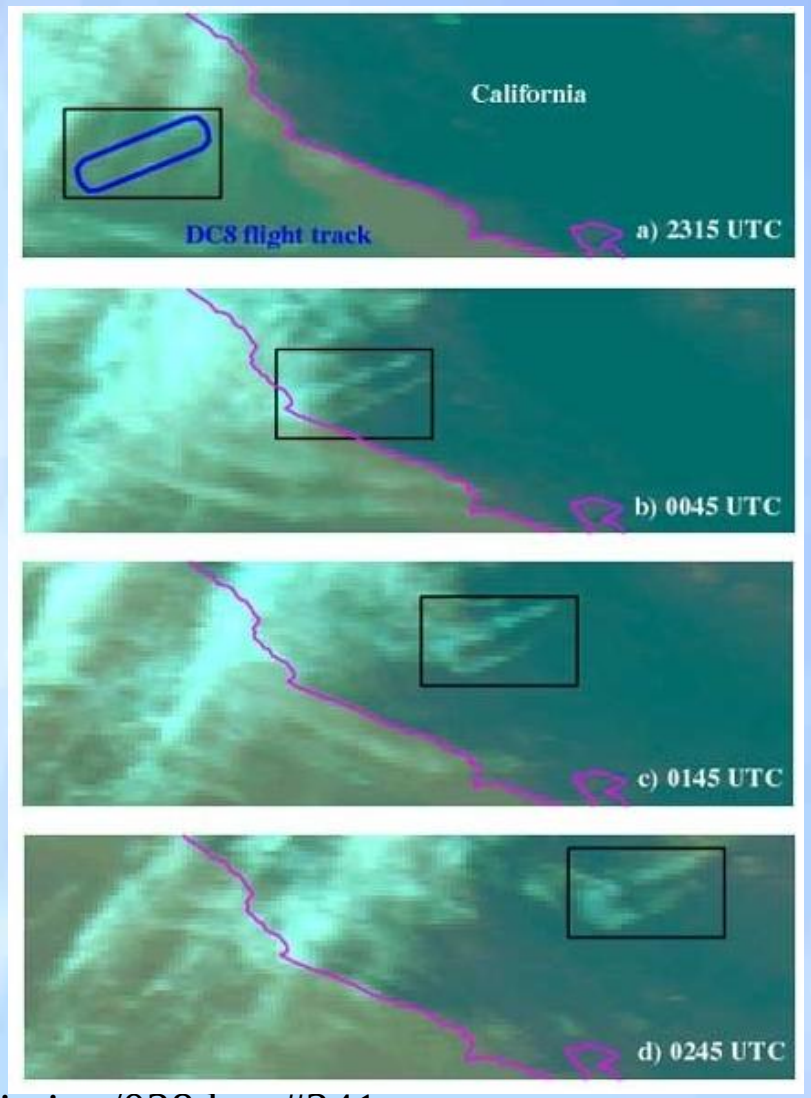


FIG. 1. AVHRR thermal IR (band 4) image (at 1.1-km resolution) of a contrail "outbreak" over the Midwest taken at 1000 UTC 11 Sep 1995. The southern tip of Lake Michigan can be seen at the top of the image.

Clouds from aircraft drift eastwards

- Figure 3-13[A]: Time series of GOES-8 satellite images showing the evolution of a contrail from an initial oval shape to extensive cirrus clouds (from Minnis et al., 1998a).
  - The NASA DC-8 flew an oval flight pattern several times off the coast of California on 12 May 1996 (a),
  - resulting in a visible contrail 15 minutes later (b).
  - This contrail spread as it was advected (DF blew) over California (c),
  - until it no longer resembled its initial shape 3 hours later (d) (DF Yes it did!)
- Satellite photographs courtesy of L. Nguyen of AS&M, Inc., Hampton, VA, USA [B].



[A] http://www.grida.no/climate/ipcc/aviation/038.htm#341
[B] http://www.grida.no/climate/ipcc/aviation/avf3-13.htm

When do contrails matter?

- “Night flights account for only 22% of Britain's annual air traffic but contribute between 60 - 80% of the greenhouse effect from contrails [A]
- Flights between December and February contribute half of the annual mean climate warming, even though they account for less than a quarter of annual air traffic," says Nicola Stuber.
- Although there are fewer flights during the winter months, the conditions needed to form contrails - the right temperature, amount of moisture in the air and aircraft altitude - are found more often then
- When they join up to produce a blanket of cirrus”

[A] http://www.abc.net.au/science/news/stories/s1663637.htm

Impact of cirrus cloud on Atmospheric window

Cirrus clouds are formed of ice and are typically thin in both the visible and IR windows.

They exist near the tropopause at –15^{O}C.

Particulates are required to act as nucleation for the ice crystal which grows and falls to make rainfall (or evaporates)

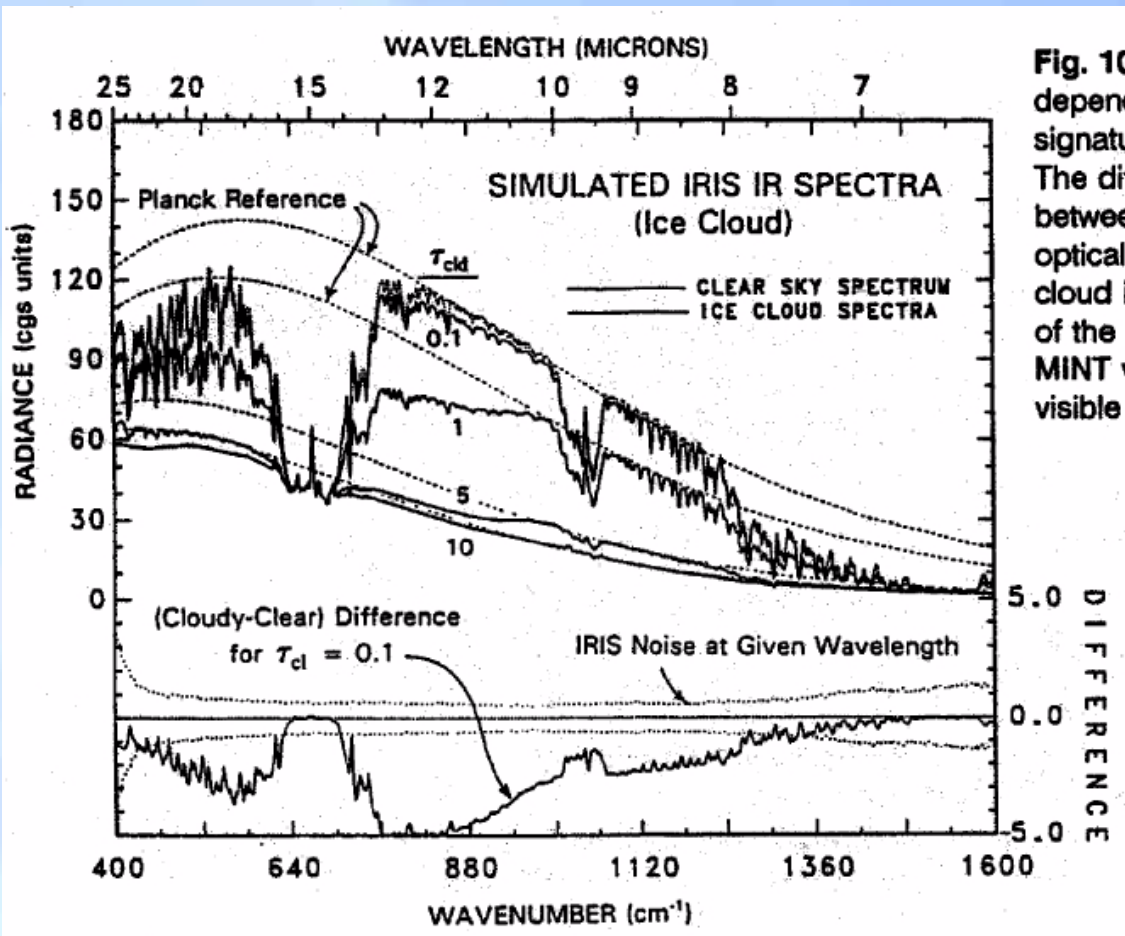


Fig. 10.3. Optical depth dependent spectral signatures of ice clouds. The difference spectrum between clear sky and optically thin (τ = 0.1) ice cloud in the lower portion of the figure shows that MINT will detect sub-visible cirrus.

When the cirrus cloud is thick enough it closes the IR atmospheric window halving the outgoing emission

But may be also closing the incoming visible atmospheric window

[A] http://www.abc.net.au/science/news/stories/s1663637.htm

UK IR and visible images on 23 August 1600

The top image is a negative. Hotter surfaces are blacker.

At this time Martlesham was covered by blanketing cirrus with long lasting contrail (lower image looking east)

Cirrus clouds do not show up as particularly cold in the top image even though they are highest.

The surface is radiating through this thin cloud. Even so they are both letting in sunlight and trapping heat by absorption and reflection. The surface temperature was 24ºC

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.

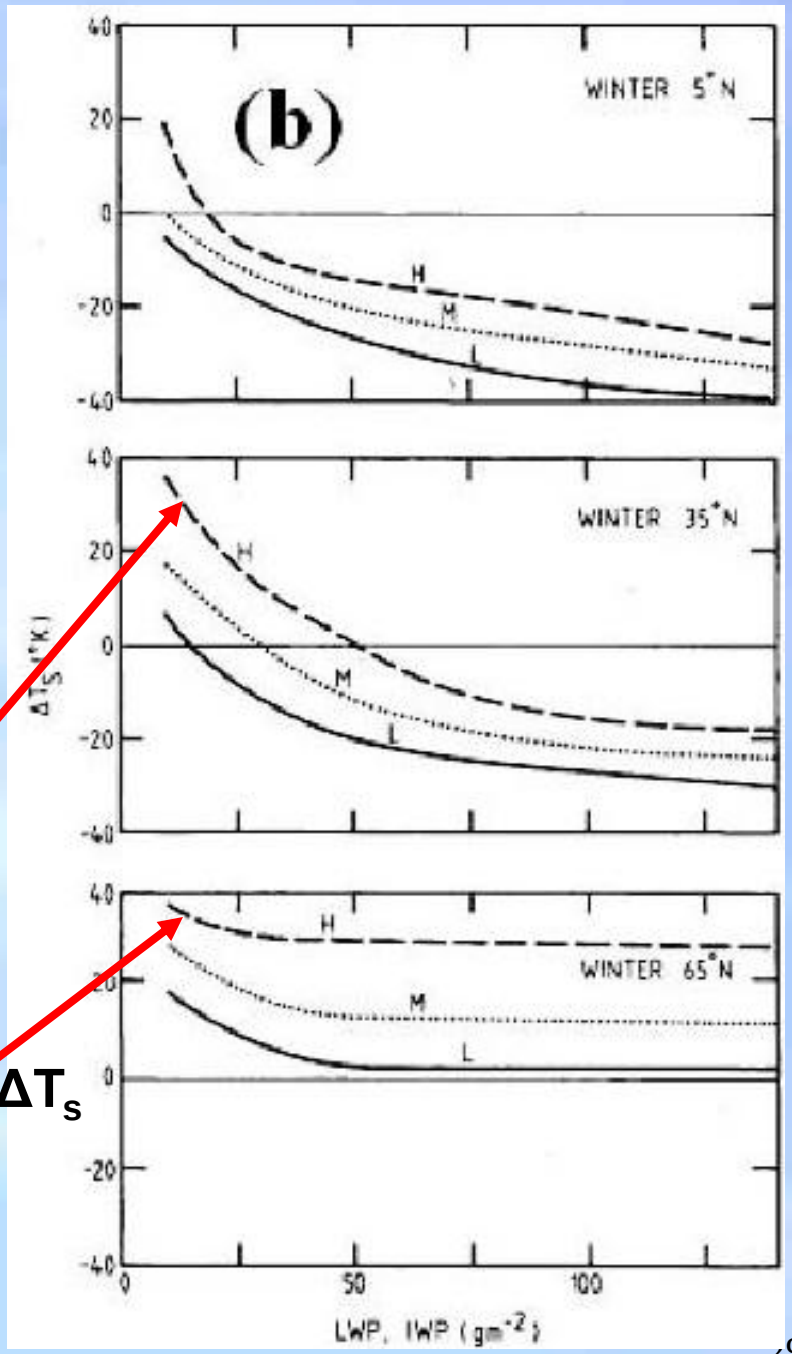
Lighter areas of cloud show where the cloud tops are cooler and therefore where weather features like fronts and shower clouds are. The advantage of infrared images is that they can be recorded 24 hours a day. However, low cloud, having similar temperatures to the underlying surface, are less easily 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.

Thin Cirrus Cloud

Fig (b) The change in equilibrium surface temperature as a function of cloud LWP and IWP for low (L), middle (M) and high (H) clouds (Stephens and Webster 1981).

liquid water path= LWP
Ice water path =IWP

- "…it is not the thicker cirrus that produces a surface heating but rather the thin cirrus, Fig-(b)".
  - (DF with shorter water path)
- In the figure the high cloud (H) appears to cause the largest winter temperature change at latitude 65^{o}N (Iceland) with >30^{o}C



http://irina.eas.gatech.edu/EAS_spring2006/Stephens2005.pdf

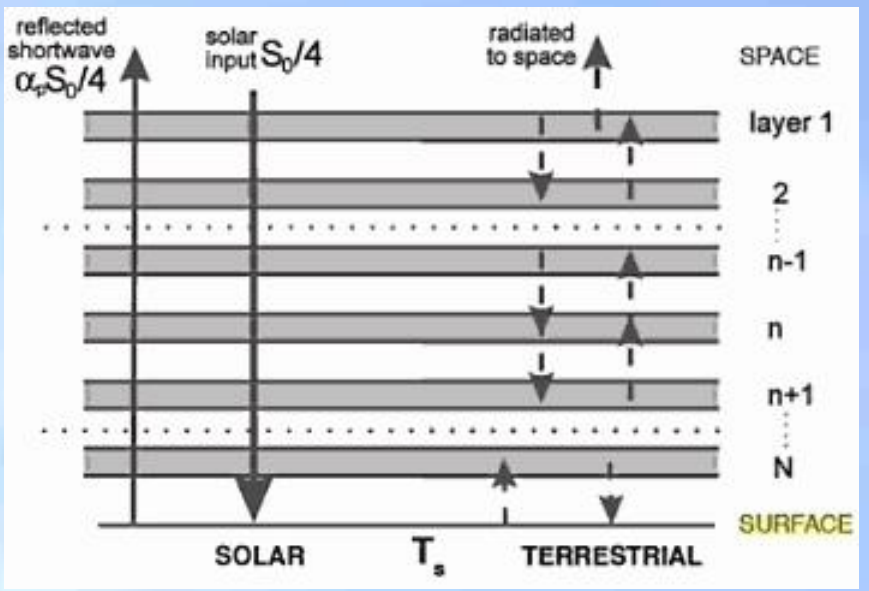
Where could a +30°C rise come from?

- The temperature rise can be calculated according to the formula

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

T_{es} = average temperature of the planet viewed from space
N = the number of opaque 'slabs', layers in the model

- From the surface upwards every layer is cooler than the one below
- Discussion- Could stratospheric water /ice be a new layer in this model
  - the troposphere could be represented by N=1
  - The resulting cirrus cloud could be either
    - pushing us towards full opacity for N=1 with a maximum temperature of 30°C
    - Or a new maximum temperature for N=2 of 62.6°C
  - cirrus coverage averages 30%,
    - what if it is increasing year on year towards 100%?
    - (by 2050 the stars will no longer be visible from Cambridge)



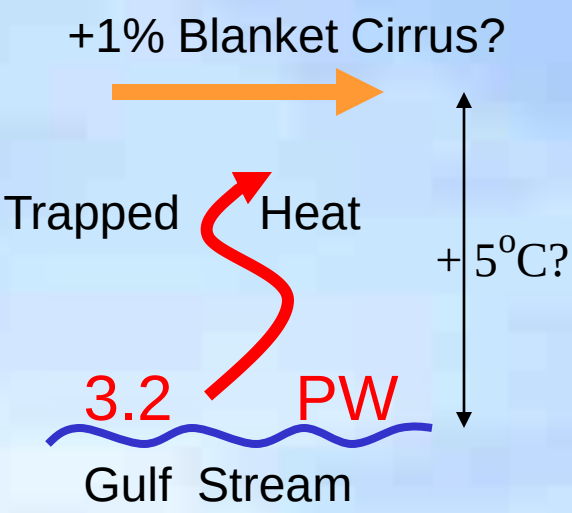
An atmosphere made up of N slabs each of which is completely absorbing in the IR window[1]

	Earth Temp	
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)

Flight paths over USA[A] and Europe[B]

[A]



[B]

- Does easterly drift of winter cirrus affect temperatures in EU and Siberia?
- What is the warming from the Gulf Stream under this additional cloud? [C]
  - **If only 1% extra heat is trapped (32TW), this would be double the power of all fossil fuels burnt in a year**
  - **Could this effect be a large multiplier due to aviation?**
  - **Temperature rises creating a blanket of tropospheric warm air not just at ground level**
  - **A strong regional effect flowing towards the pole making the NW passage navigable**

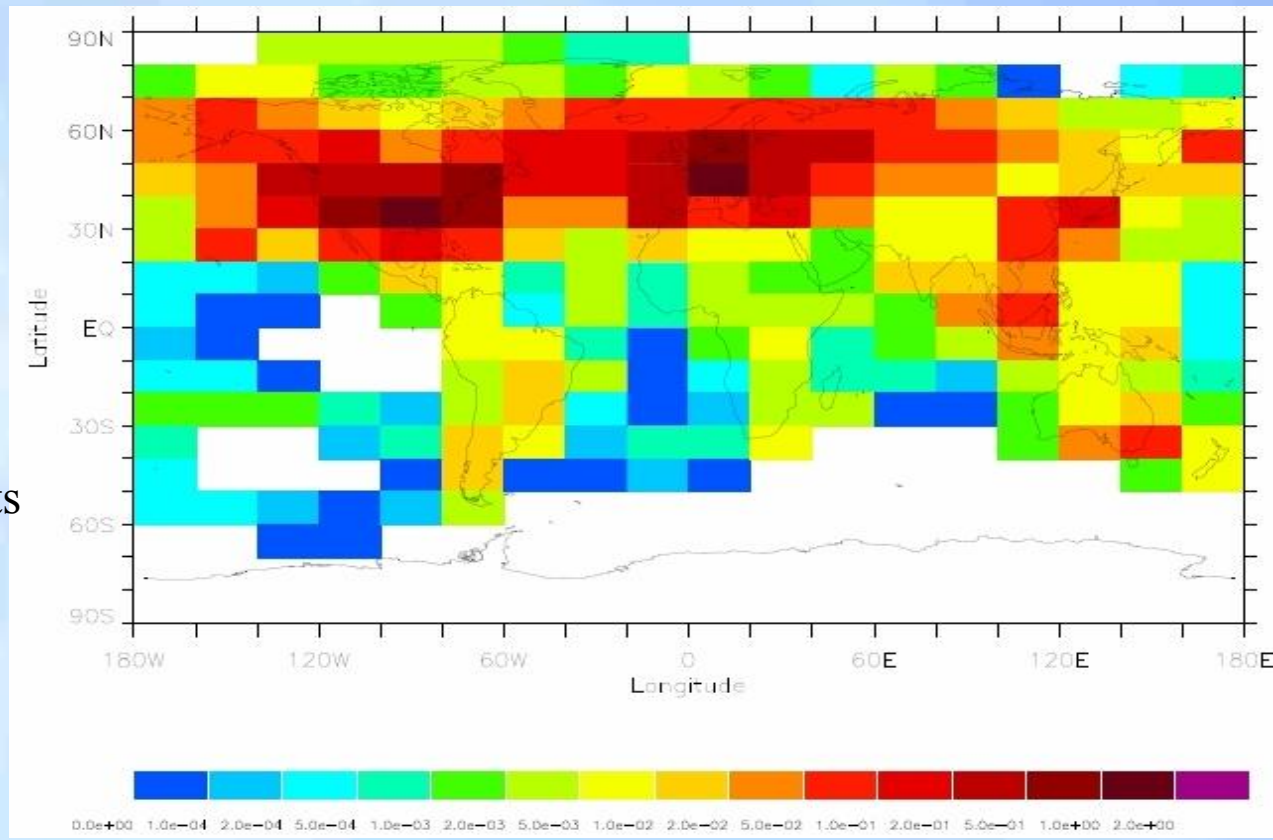
[A] http://www.youtube.com/watch?v=H2qTwvaQ_F4
[B] http://www.canso.org/NR/rdonlyres/BE6737B0-7E61-4D3C-9E72-5D1458550327/0/1TowardsaGlobalATMConceptttheEuropeanContributionVictorAguadoEurocontrol.ppt
[C] http://www.ocean.washington.edu/courses/oc400/Lecture_Notes/CHPT2App.pdf

Periodic and seasonal effects
Are contrails and tropospheric temperatures linked?

- **Note here that flight paths are densest over the north atlantic**
- **annual** diurnal mean contrail cover, in percent. Note the logarithmic scale [A]
- Exercise: overlay this on previous and following slides

Very dark red =100%
Dark red =10%
Red=1%
Yellow=0.1%
Green=0.01%
Dark blue=0.001%

NB. In this report "The effects of aviation induced cirrus clouds are uncertain"

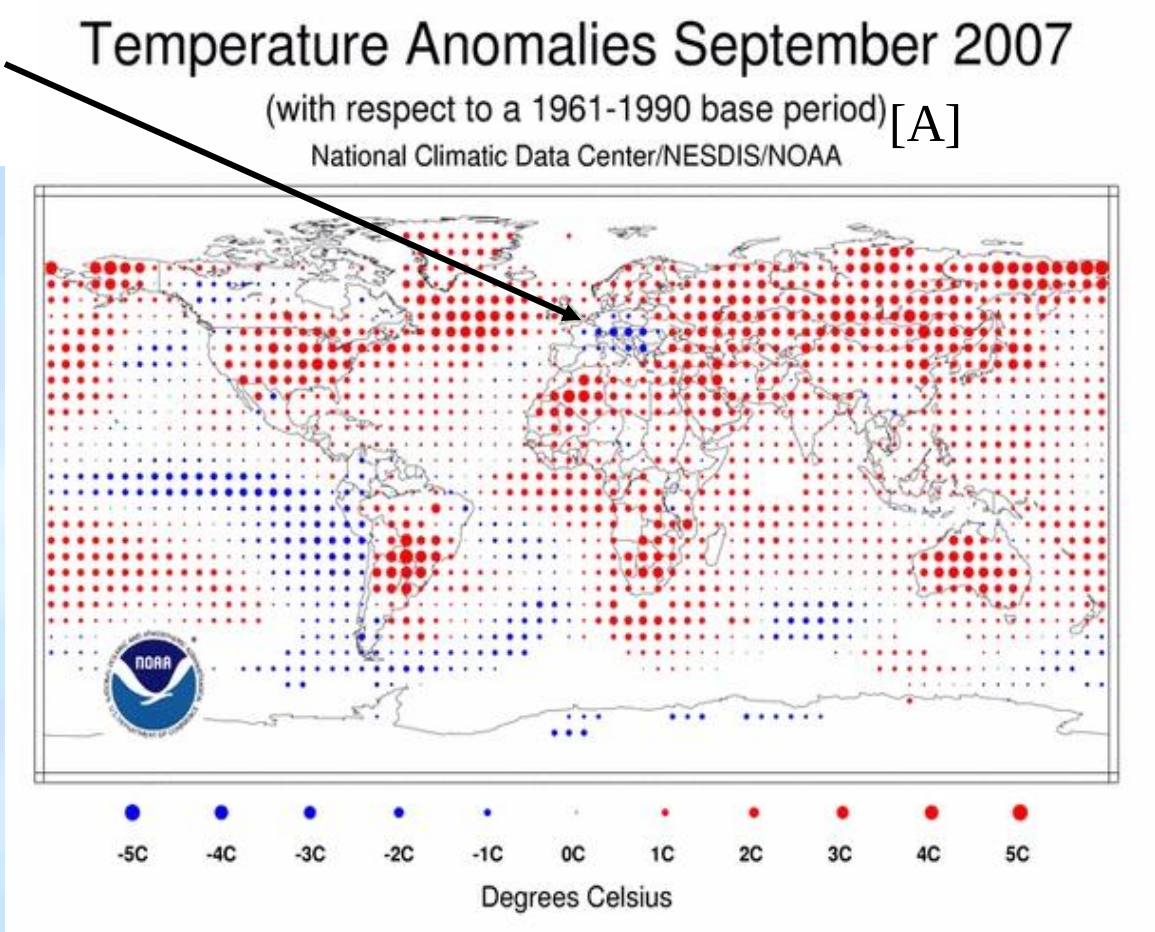


[A] trafficwww.atmos-chem-phys-discuss.net/6/9123/2006/acpd-6-9123-2006-print.pdf -

Periodic and seasonal effects

#3 Summer 07

Note that this area coincides with max contrail on previous page



- European summer 2007
- Cold spot over Europe coincided with deluges and unusual track of jet stream
- Discussion. Could water or particulates from aviation in the jet stream lead to higher than normal summer rainfall?
- Note that this pattern changes from year to year following El Nino events

[A] http://www.ncdc.noaa.gov/oa/climate/research/2008/feb/global.html
[B] http://www.realclimate.org/index.php/archives/2005/12/methane-hydrates-and-global-warming/

Are there other factors emerging?

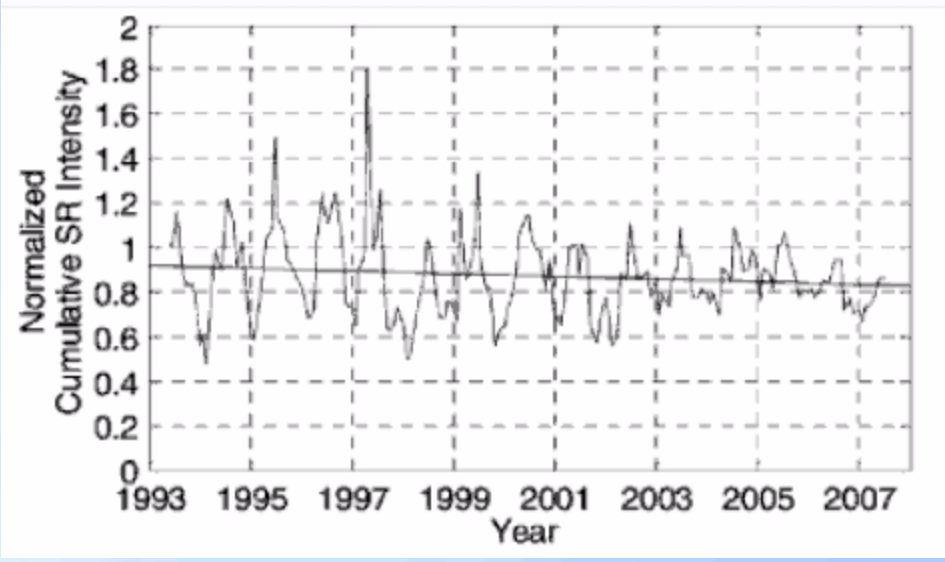
- Measurements with aircraft in the tropopause has found a thin invisible blanket layer of cirrus [A]
- High altitude measurements have found additional H_2O which is not part of the nucleation [B]
- Two temperature inversion layers have been observed over Pittsburg[C]
- Seattle researchers have discovered that warming of the Earth's atmosphere seems to be shoving jet streams out of their normal tracks, a change that could expand deserts and profoundly affect the world's weather patterns [D]
- The number of clear nights in SE England is reported to have dropped from 122 to 70 nights per annum since 1945 [E]
  - Cambridge University astronomer, Dr. Gerry Gilmore, predicts that by 2050, the telescope will be a redundant tool because the skies will be blanketed with clouds formed by contrails.
- Lightning is decreasing [F]
- Methane is increasing [G]
- Emissions Trading to Include Aviation in Europe from 2012 [H]

[A] "Dehydration Of The Upper Troposphere And Lower Stratosphere By Subvisible Cirrus Clouds Near the Tropical Tropopause2 http://imk-aida.fzk.de/workshops/uth2007/uth_workshop_karlsruhe_brochure.pdf
[B] Supersaturations in cirrus: field and laboratory measurements
[C] http://www.oco.noaa.gov/gcosworkshop/Bill_Randel.ppt.
[D] http://seattletimes.nwsource.com/html/localnews/2003019908_jetstreams26m.html
[E] http://www.bbc.co.uk/insideout/southeast/series10/week2.shtml
[F] http://books.google.co.uk/books?id=U6lCL0CIolYC&pg=PA380&lpg=PA380&dq=global+lightning+trend+europe+-lighting&source=bl&ots=93Fsu0MwuN&sig=YtLSYvDJRRQj9v_StArHDUdWHsc&hl=en&ei=qVidSrrIMoKhjAeSzOmWAg&sa=X&oi=book_result&ct=result&resnum=5#v=onepage&q=&f=false
[G] http://zipcodezoo.com/Trends/Trends%20in%20Atmospheric%20Methane.asp
[H] http://www.greenaironline.com/news.php?viewStory=210

Are there other factors emerging?

Lightning is decreasing

- Over dinner I remarked that if aviation induced cirrus is seeding rainfall, storms should be weaker
- Julia has noticed fewer thunderstorms in recent years
  - She hates them!
- Google came up with this following trend [D, previous page]
- SR is Schumann Resonance 5-60Hz radio waves



The trend is negative but is not statistically significant. The downward trend is noteworthy in light of ongoing analyses with the NASA LIS and OTD observations, also suggesting negative trends over the past decade (W. Petersen, presentation at the 2008 AMS Annual Meeting, New Orleans, and personal communication). We have no plausible explanation for declining trends in global lightning in a period when the global surface air temperature is increasing, and when the global tropical temperature is increasing (Hansen and Lebedeff, 1995). At the time of this writing,

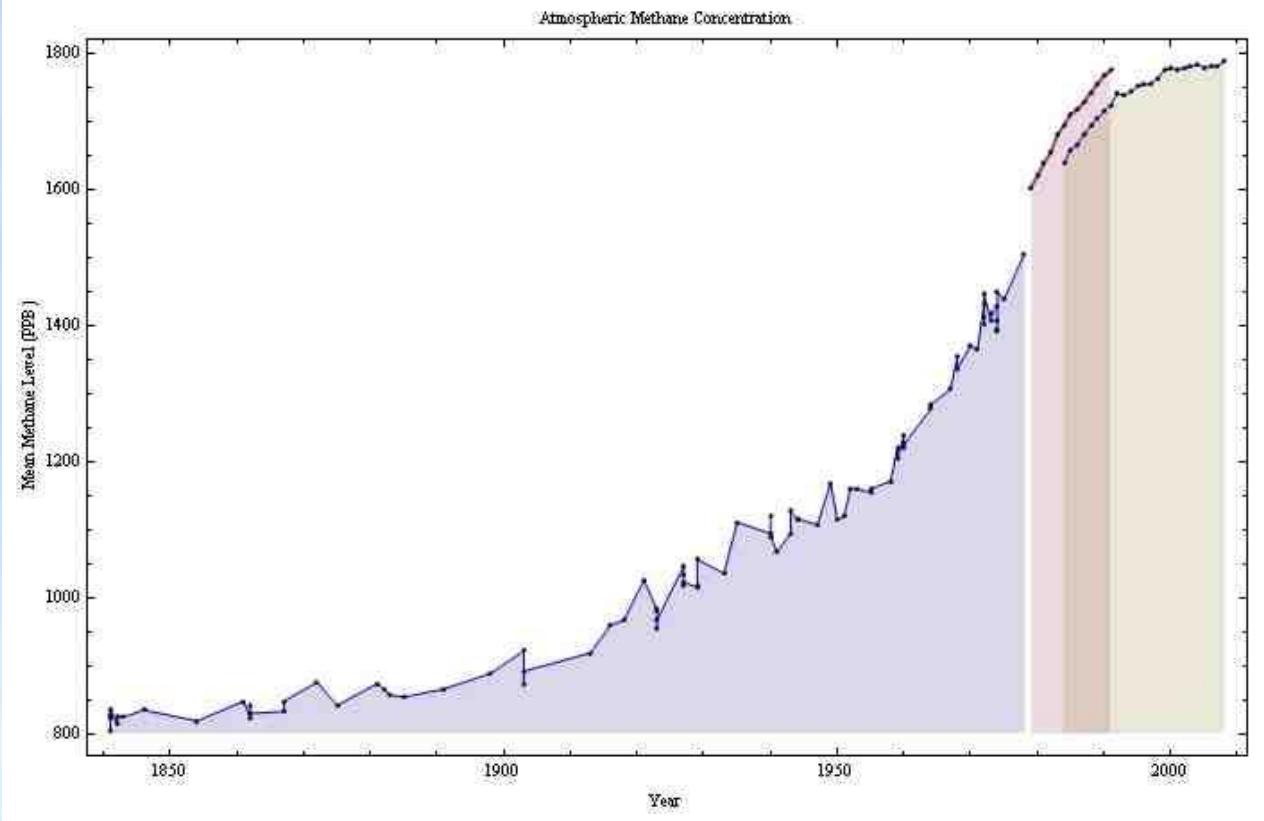
http://books.google.co.uk/books?id=U6lCL0CIolYC&pg=PA380&lpg=PA380&dq=global+lightning+trend+europe+-lighting&source=bl&ots=93Fsu0MwuN&sig=YtLSYvDJRRQj9v_StArHDUdWHsc&hl=en&ei=qVidSrrIMoKhjAeSzOmWAg&sa=X&oi=book_result&ct=result&resnum=5#v=onepage&q=&f=false

Are there other factors emerging?

Methane

Absorbs radiation at 13μm at the edge of the IR atmospheric window. (on next slide)

Breaks down to water vapour which can form cloud which closes the atmospheric window



”Atmospheric methane levels of the past 150 years far higher than those of the previous 420,000 years, and are currently 2.5 times as high as any previous level [A]”.

The rate of increase is slowing even in the stratosphere [B] may be due to better emissions control at refineries

Some good news - but beware…

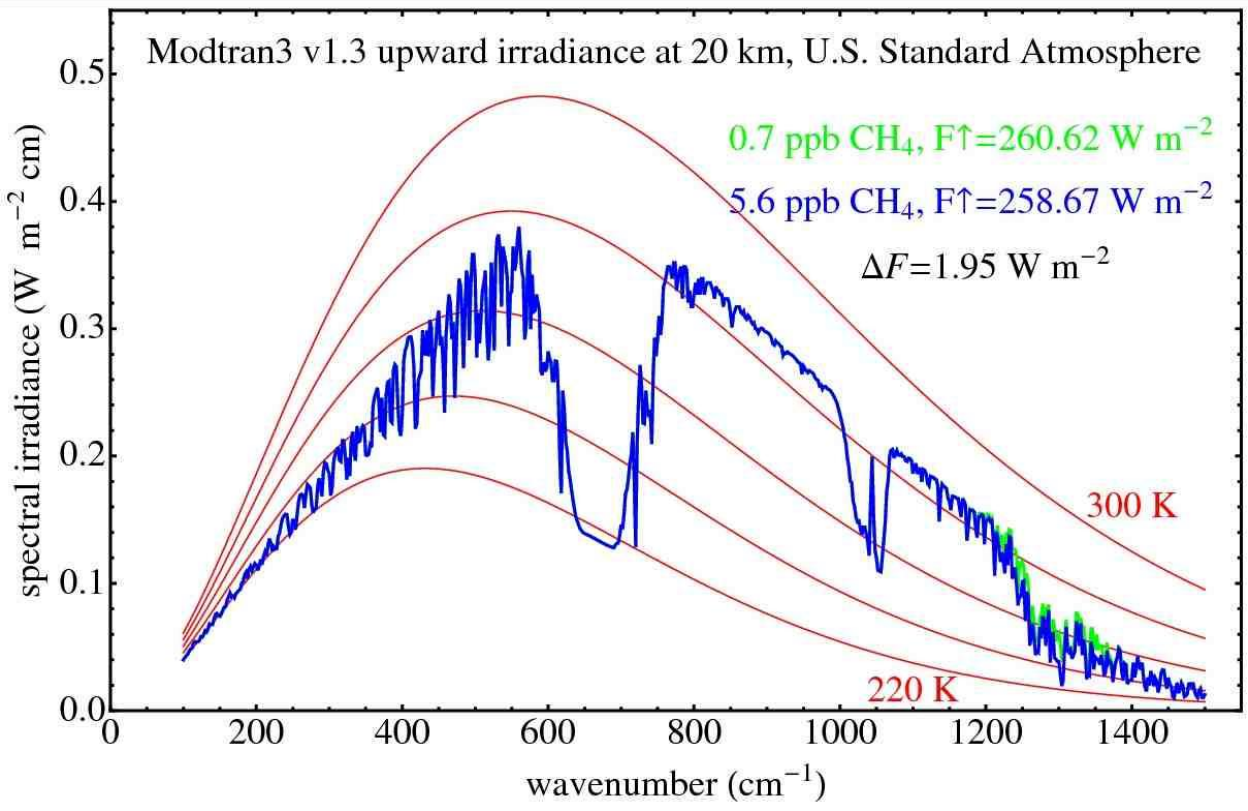
[A] http://zipcodezoo.com/Trends/Trends%20in%20Atmospheric%20Methane.asp
[B] http://www.ace.uwaterloo.ca/publications/Rinsland-CH4trend2009.pdf

Are there other factors emerging?

Methane

This simulation shows the effect of increasing methane concentration 8-fold

The hypothetical radiative forcing is 1.95W/m^2 (about 0.5^{o}C) [B]



”Atmospheric methane levels of the past 150 years are far higher than those of the previous 420,000 years, and are currently 2.5 times as high as any previous level [A]”.

“The direct radiative forcing (warming) due to the CH_4 concentration increase in the industrial era (after 1750) is 0.48 W/m² (Forster et al., 2007). Increasing methane concentration also contributes a radiative forcing indirectly, through tropospheric interactions that influence ozone concentrations, increasing stratospheric water vapor (of which it is the main source)[DF-not any more!], as well as providing a small additional source of CO_2 (methane, in its destruction, is oxidized to CO_2). If these indirect effects are taken into account, the radiative forcing due to anthropogenic (from human origin) methane increase is estimated at ~ 0.85 W/m² , as compared to 1.66 W/m² for CO_2 (Forster et al., 2007)” [C].

[A] http://zipcodezoo.com/Trends/Trends%20in%20Atmospheric%20Methane.asp
[B] http://en.wikipedia.org/wiki/Radiative_forcing
[C] http://co2now.org/index.php?option=com_content&task=view&id=64&Itemid=50

Are there other factors emerging?

What is Methane Hydrate?

- Methane hydrate (clathrate or fire ice), is a solid form of water that contains a large amount of methane within its crystal structure [A]
- Extremely large deposits of methane clathrate have been found under sediments on the ocean floors
- The permafrost reservoir has been estimated at up to 400 GT in the Arctic
  - cf 40MT annual stratospheric methane
  - cf 576 MT all annual atmospheric methane (from [B])
  - 750-950 GT of organic carbon are thought to be locked in permafrost (globally UN)
- Will positive feedback from release of methane give massive accelerated global warming?
  - (Ironically methane from hydrate is proposed by NASA as an alternative aviation fuel [C])

No higher resolution available.

Burning_hydrate_inlay_US_Office_Naval_Research.jpg

[A] http://en.wikipedia.org/wiki/Methane_clathrate
[B] http://www.cbc.ca/technology/story/2007/06/05/tech-scienceunicesnowreport-20070605.html
[C] amelia.db.erau.edu/nasacds/200712Disc1/research/20070038170_2007037800.pdf –

Are there other factors emerging?

Study finds Siberia's permafrost melting rapidly: Jan 18, 2008 [A].

- A Japanese researchers, have observed the frozen soil in eastern Siberia, Russia, since 1997.
  - Permafrost started melting rapidly 5 years ago, and that more than 2 meters melted in one summer, compared with one meter and 20 to 30 centimetres in previous years.
  - Underground temperatures have risen sharply over the past several years, with those of 2006 hitting a record high of minus 1.5 degrees Celsius.
    - More than one degree higher than the average for the past 3 decades.
  - Melting permafrost soaks the ground surface, hampering plant growth and turning forests brown.
  - They attribute the rapid melting to climate change, calling for recognition of the whole situation as soon as possible.
- Agency Program Director Tetsuo Ohata warned that methane trapped in the permafrost could be released into the atmosphere and accelerate global warming.

[A] http://www.libertypost.org/cgi-bin/readart.cgi?ArtNum=213495&Disp=85

Are there other factors emerging?

Importance of aviation and methane on climate

- Both can have similar effects on climate via the stratosphere
  - Water is added to the stratospheric system
  - Water vapour is a GHG leading to
  - ice cloud which has a positive radiative forcing leading to
  - precipitation from underlying cloud
- Aviation appears to dominate now
- Could aviation be triggering positive feedback from the permafrost?
  - Methane's breakdown to water vapour will then mask emissions from aviation
  - A runaway situation could (may already) exist pushing us towards N=2, 62.6^{o}C

In Conclusion

Our Attitude to Aviation

- Think of aviation as similar to an annual volcanic eruption but without the sulphates (yet?) producing
  - A net increase in surface temperature
- Consider your part in ‘saving the planet’
  - Avoid putting yourself in a situation where you might consider air travel
    - For business or pleasure
  - Use alternative transport
- Lobby for aviation fuel to be taxed
  - Like it is for cars
- Lobby for flights to be limited to the troposphere
- Lobby for more **independent** research on the impact of aviation and climate to be carried out with focus on H_2O, its accumulation in the stratosphere and its impact on cirrus cloud cover
  - Do not let the CO_2 and GHG debate mask this issue

Changing the Climate

"Jester" I failed the emissions test on water droplet. "Maverick" has a 'lock' on me

Airbus A340

Boeing B707

No sweat "Iceman". I'll let go with sulfur dioxide. That'll fix it

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

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

Thank you for listening

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

Possible topics for discussion

- **Are you concerned that water vapour from aviation might be contributing more to climate change than CO_2?**
- **Do you think that the information we get about aviation and climate change is 'watered down'?**
- **Are you happy for aviation to increase 16 fold by 2050?**
  - **as we enjoy even more exotic holidays**
  - **as developing nations come on stream**
- **Is it easier to control emissions from aviation than from CO_2 generally?**
- **If we cut aviation emissions would the UK survive economically?**
  - **Per head the UK uses aviation more than any other country**
- **Would you be happy to cut your household CO_2 emissions to zero to make room for more aviation?**
  - **(50% of UK citizens have never even flown and would be paying for the rest to benefit)**