The Scientific Significance of Contrails and

Why it is Necessary for us to Study Them.

The Aims of this Study.

The Science and the Issues Surrounding Contrails.

The aviation industry is an industry experiencing rapid growth, which is not expected to halt or slowdown in the foreseeable future. In fact, due to technological advances and increased fuel efficiency, it is expected to grow. For such an important industry, that is central to many of our lives, it is important to fully understand the environmental impacts that may result. Although research has been conducted into the environmental impacts of aircraft there is still much uncertainty about just how aviation impacts on the environment, particularly on the climate. The most comprehensive research has been compiled by the IPCC in their 1999 report Aviation and the Global Atmosphere, the first report written by the IPCC for a specific industrial sub-sector.

There are two main areas of concern over the impacts of aircraft. Firstly, there is concern over the pollution emitted by the aircraft which is thought to impact on the ozone layer, and secondly, there is concern over the formation of contrails (condensation trails) behind the exhausts of planes, which can in turn increase the amount of cloudiness and thus impact on climate. In this current study, which is being conducted as part of an MSc degree at Lancaster University, it is the latter of these concerns which is to be studied.

During flight aircraft emit a number of pollutants which have varying effects on the environment, the main ones being:

Carbon Dioxide

Nitrogen Oxides

Sulphate and soot aerosols

Water vapour

Concerning the formation of contrails the main pollutants are water vapour and aerosol particles (soot, nitric acid and hydrocarbons).

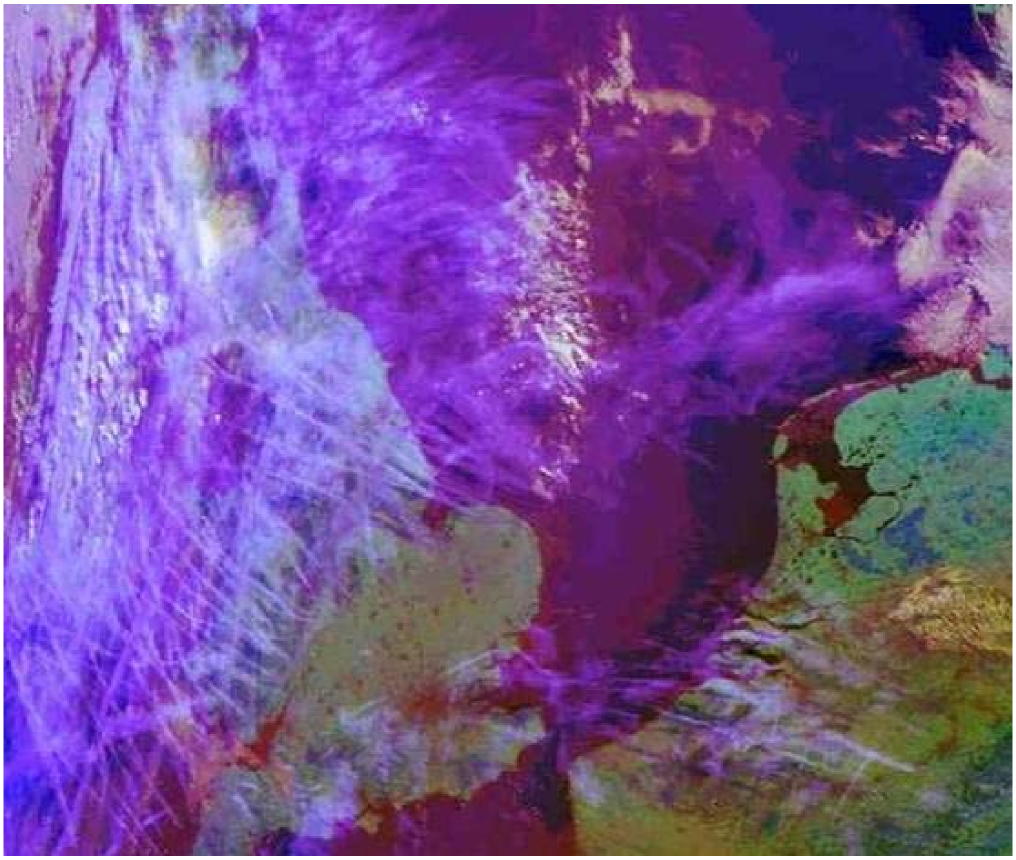
Aircraft contrails form in the upper troposphere, where temperatures are cold, therefore contrails consist of ice particles, in which respect they are similar to cirrus clouds. Generally, for a contrail to form, there must be water vapour present and aerosol particles, such as soot, for the water vapour to condense on, and the ambient atmospheric conditions must also be suitable. The relative humidity (RH) of the surrounding air must be high enough (supersaturated) or the water vapour emitted by the aircraft will increase the saturation to the point where condensation occurs. If the ambient air is already at super saturation then it is likely that other clouds will also be present, if however super saturation is reached by the input of water vapour from the aircraft then it is likely that only contrail related cloud will be present.

It is under these conditions that there is most concern over the occurrence of contrails as it produces a situation where clouds are formed anthropogenically in a sky that would otherwise have been cloud free. This situation is clearly demonstrated in Figure 1a where thick contrail cover (linear formation) can be seen over central Europe in a sky where no other cloud types are present, and Figure 1b where a similar sight is seen over the UK.

Figure 1a. Contrails over Europe.

Contrails over central Europe. 0943 UTC 4 May 1995, based on NOAA-12 AVHRR satellite data (from Mannstein, 1997). From: Aviation and the Global Atmosphere, IPCC (1999).

Figure 1b. Contrails observed over the UK.



From: [Pedersen, H.]

Although it has been stated (IPCC, 1999) that aerosol particles are necessary for the formation of contrails they can also form in some situations, without the presence of particle emissions, by homogeneous nucleation, however they form more commonly by heterogeneous nucleation where water vapour condenses onto a solid surface, such as a soot particle, and therefore these particles often become incorporated into the ice crystal. It is often found therefore that there are soot particles present in the ice crystals of contrails, which will in turn affect the radiative properties of the contrail.

Contrails do not have a standard form, in fact the size of the ice particles do not only vary between contrails but also within each individual contrail. The particle sizes are found to be larger on the outside of a contrail and smaller within a contrail. This is because as the water vapour condenses to form the first ice crystals the saturation of the air is reduced, limiting further condensation. At the edges of the contrail however the super saturation is maintained by the surrounding ambient air and so condensation of particles can continue, thus the ice crystals are able to grow to much greater sizes than within the contrail (300 micrometers. IPCC, 1999). These large particles at the edge of contrails are within the same size range of those particles within natural cirrus cloud, therefore large dispersed contrails have very similar particle sizes and optical properties as natural cirrus and are often very difficult to distinguish form this natural cloud cover (this can make the observations of contrails problematic once the contrails are old and dispersed). The typical particle size distribution of the ice crystals within newly formed contrails is around 0.5 to 1 micrometer radius while after 2 minutes the size is 2 to 5 micrometers.

There is concern over contrails because it is believed they influence climate by affecting the global radiative balance, although just how they affect climate is not fully understood (due to their similarity to cirrus clouds they are likely to affect climate in much the same way however). Contrails affect climate both directly and indirectly; directly by scattering and absorbing insolation and reflected long wave radiation from the earths surface, and indirectly by affecting the formation of clouds and their radiative properties. For example, if a contrail consists of ice crystals containing soot particles their radiative properties are affected so that they are more likely to absorb insolation and long wave radiation, whereas pure ice crystals have a higher albedo/reflective effect, the radiative properties of contrails also depend on the sizes of the ice crystals.

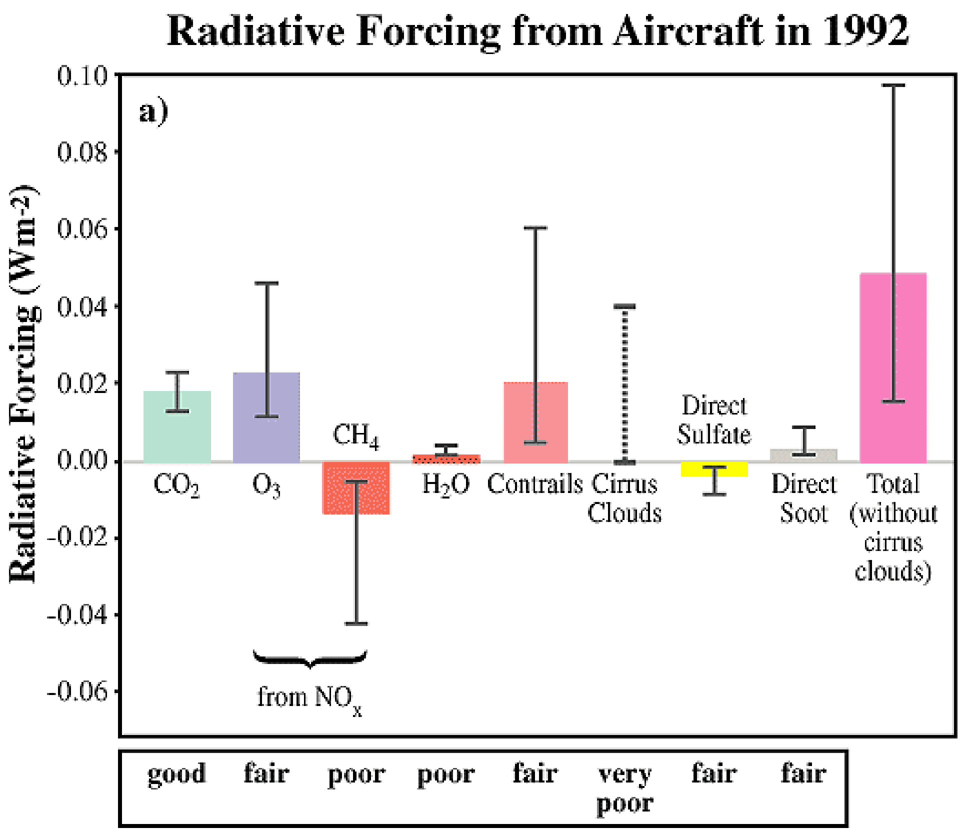
Currently there are few places in the world that study or observe contrails, and so there is still much research to be done. There are 19 locations in the USA where data is available from 1993 to 1994. In this data there are peaks in the frequency of contrail occurrence in February and March and a minimum in July. Contrails over the former Soviet Union have been reported to be most common in spring and winter and less so in summer. Data from Salt Lake City in the USA has also shown an apparent seasonal cycle with a maximum in autumn and winter and a minimum in July.(IPCC, 1999.)

In Europe data from the AVHRR (Advanced Very High Resolution Radiometer) satellite has shown a mean contrail cover of 0.5% with a seasonal cycle where the maximum in contrail occurrence is shifted southward during the winter months and the maximum occurs in summer, especially along the route of the North Atlantic flight corridor. This maximum is a coverage of around 2%. In a study by Mannstein et al (1999) the maximum contrail coverage over Europe was found to be during winter and spring with contrail coverage being greatest in the daytime (nighttime contrail coverage is one third of that at midday). (IPCC, 1999.) This may however be due to the greater occurrence of flights in the daytime rather than simply being due to atmospheric conditions. The IPCC (1999) report that contrails are seen to occur in clusters, in cold humid areas. Such air masses have been estimated to cover 10 to 20% of Europe (Mannstein et al, 1999), and so a growth in the aviation industry would be of most concern to climate if it occurred in these regions.

The most important contrails as regards the concerns over climate are those which are persistent and dispersed (p+d). Contrails grow much more rapidly horizontally than they do vertically and so can rapidly cover large areas but not actually be thick enough to block insolation and for this reason it is generally assumed that contrails warm the lower atmosphere. However, as shown in Figure 2 this is still a very uncertain area. One of the main problems in studying the affects contrails have on climate is that any occasion when contrails are present in an area but then totally absent for a period are very rare and so comparisons between these two situations in one location are rare. However, a chance to test such an occurrence arose in 2001 during the three day period after the September 11th attacks in the USA when all aircraft were grounded. During this time an increase in the difference between the day and night time temperatures was reported, suggesting that clouds insulate the earth at night, trapping heat, and cool during the day by reflecting insolation back out into space. The fact this occurred after the grounding of aircraft suggests that this is caused by aircraft induced clouds.

Figure 2. Estimates of the globally and annually averaged radiative forcing (Wm-2).

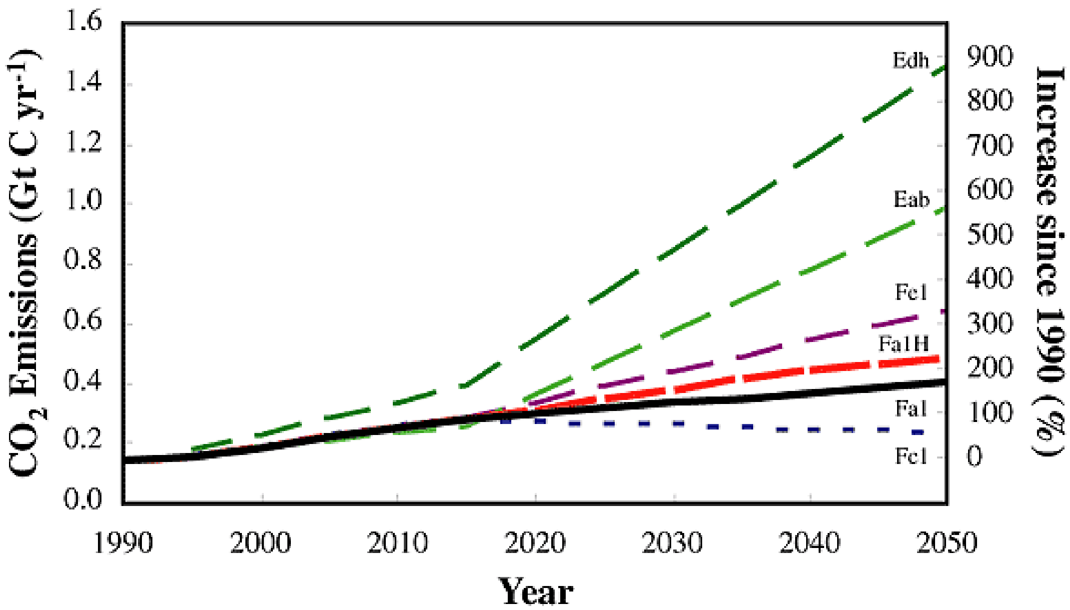
Below each graph (e.g. good, poor etc) is the level of scientific understanding. Notice the different scales.



From: [Aviation and the Global Atmosphere. IPCC (1999)]

The idea that aircraft induced cloud affects the radiative balance is not disputed but just how it affects the balance is, however it is believed that thin cloud, such as contrails and cirrus have a greater impact on the upward flux of terrestrial long wave radiation than on the solar flux, thus leading to an increase in temperature. Therefore if the aviation industry continues to grow, as is expected, the impact on climate can also be expected to increase. The IPCC has devised various projections (scenario IS92a-f)in the growth of aviation based on assumptions of population and economic growth, land use, technological changes, energy availability and fuel mix (IPCC, 1999) (Figure 3). Passenger traffic has grown at a rate of nearly 9% per year since 1960, which is 2.4 times the average Gross Domestic Product (GDP) growth rate (IPCC, 1999). The growth in air travel is expected to be at a rate of 5% per year between 1990 and 2015 (IPCC, 1999), while in Britain alone the industry is expected to increase from 180 million passengers per year to more than 500 million by 2030 (Leake, J. The Sunday Times 30/11/2003). Figure 4 demonstrates this increase in aviation in England from 2000 to 2030 (roll cursor over the image) and shows that the main increase is expected to be around the North Atlantic flight route, down the middle of the country. The original of Figure 4 can be obtained from the CPRE web site in their leaflet 'Flying to Distraction'.

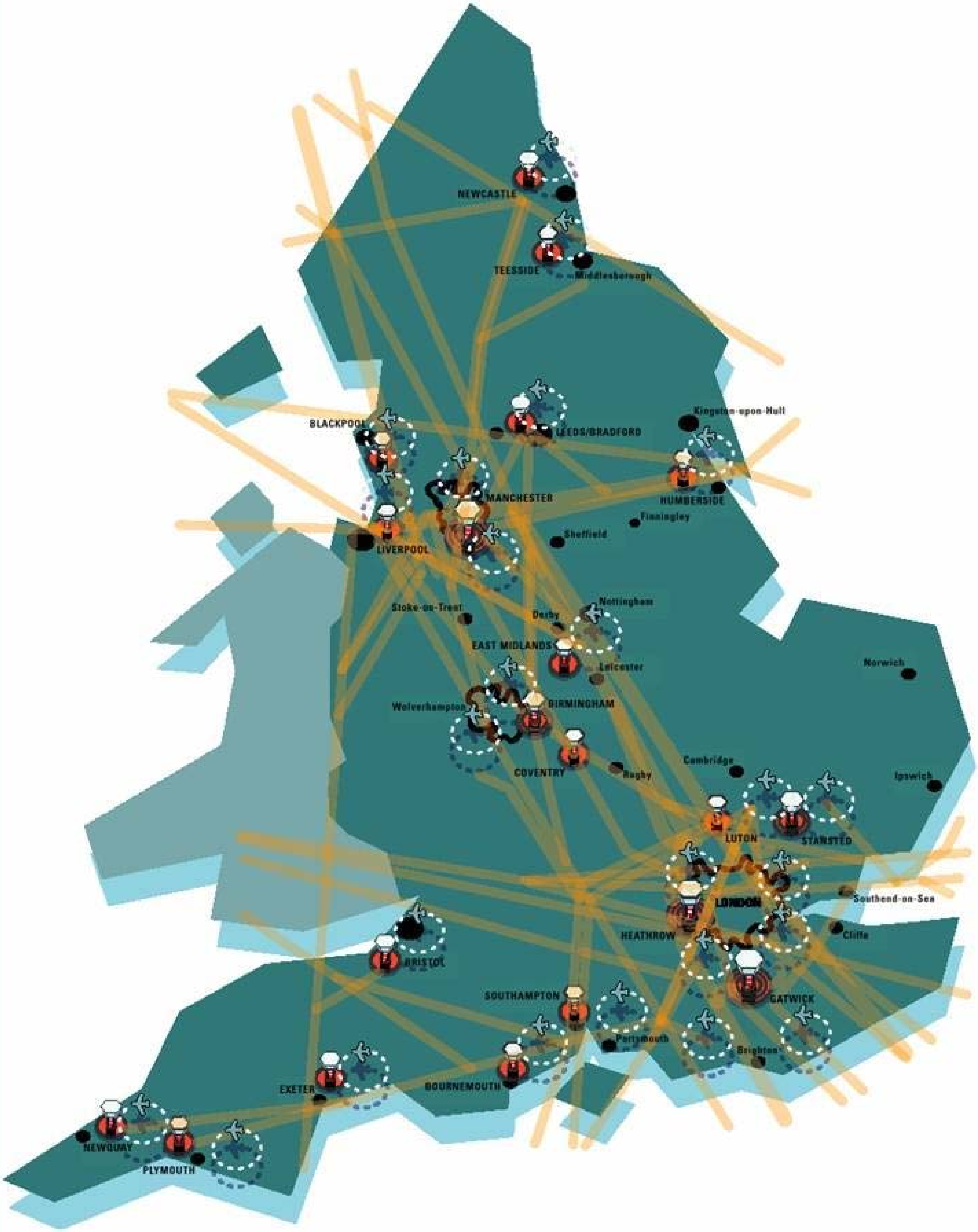
Figure 3. Carbon dioxide emissions from six different scenarios of aviation growth.



From: Aviation and the Global Atmosphere. IPCC (1999)

Figure 4. Governments Projected Growth in Aviation by 2030.

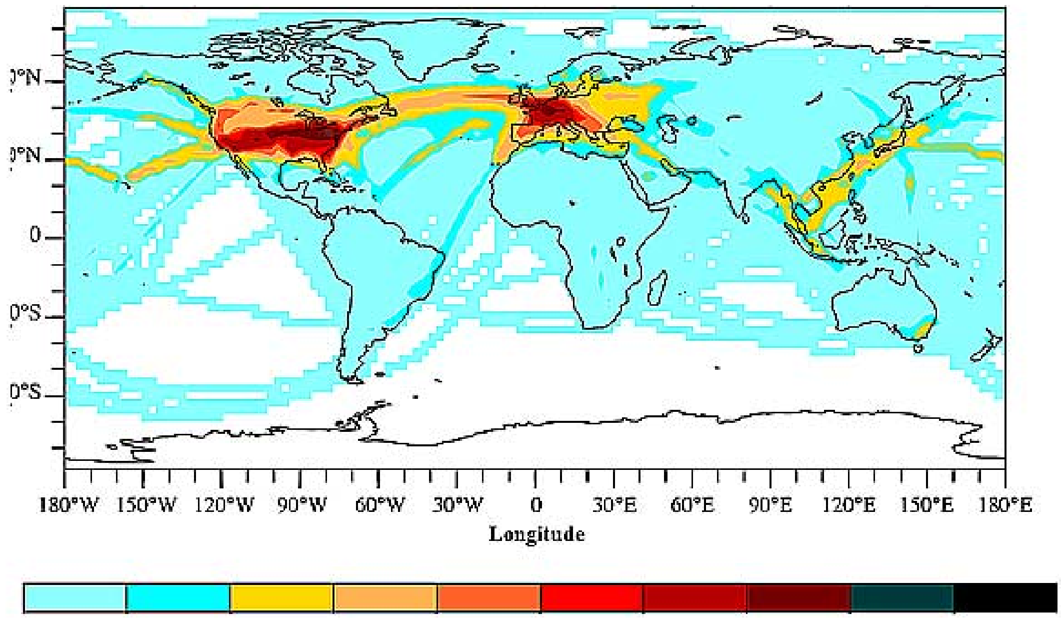
2000


NEWCASTLE
TEESSIDE
Middlesborough
BLACKPOOL
LEEDS/BRADFORD
Kingston-upon-Hull
MANCHESTER
HUMBERSIDE
Finningley
LIVERPOOL
Sheffield
Stoke-on-Trent
Nottingham
Derby
EAST MIDLANDS
Leicester
Norwich
Wolverhampton
BIRMINGHAM
COVENTRY
Rugby
Cambridge
Ipswich
LUTON
STANSTED
LONDON
Southend-on-Sea
HEATHROW
Cliffe
BRISTOL
SOUTHAMPTON
GATWICK
Portsmouth
Brighton
EXETER
BOURNEMOUTH
NEWQUAY
PLYMOUTH

From: CPRE. Campaign to Protect Rural England.

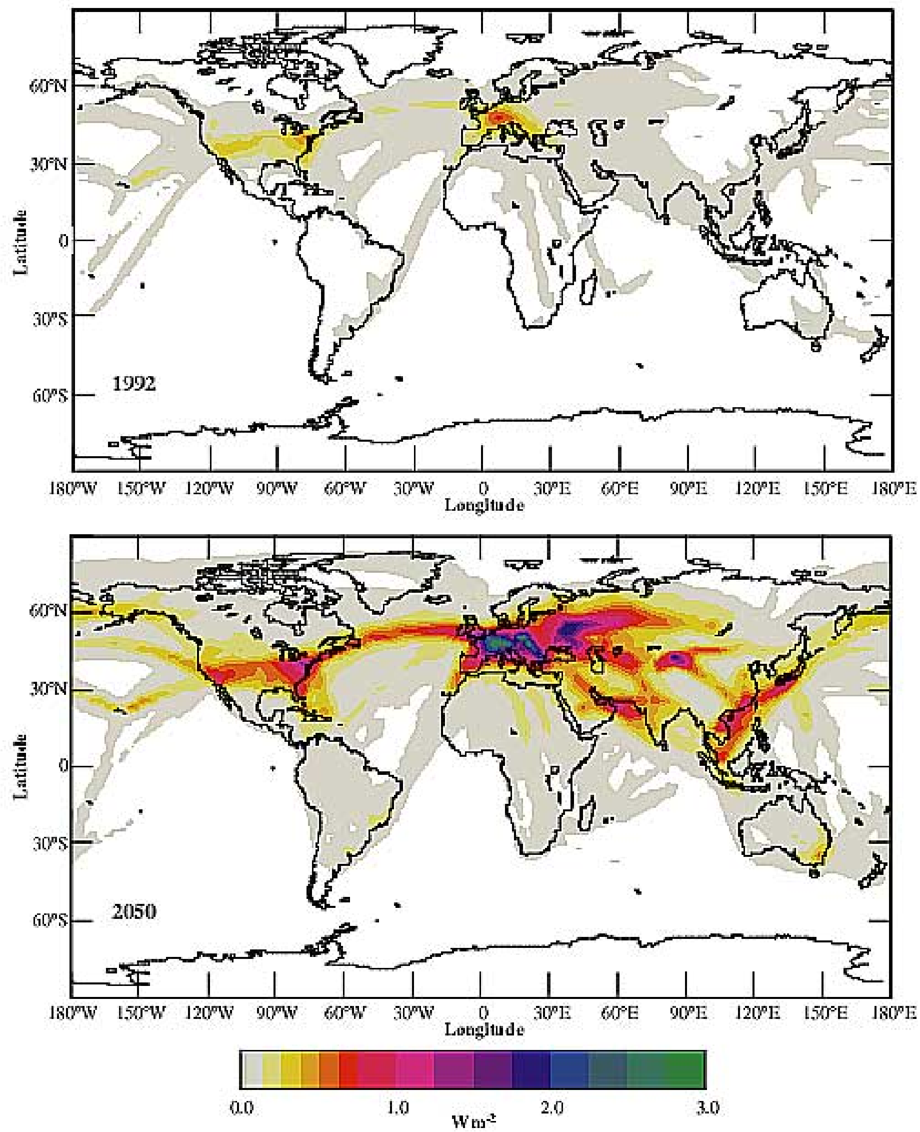
Figure 5 clearly demonstrates the impact the predicted growth in aviation will have on the percentage of contrail cover (roll cursor over the image) and Figure 6 shows the associated impacts on the net radiative forcing.

Figure 5. Persistent contrail cover (%) for 1992. Roll the cursor over the image for the 2050 projection.



From: Aviation and the Global Atmosphere. IPCC (1999)

Figure 6.Global distribution of net radiative forcing at the top of the atmosphere.



From: Aviation and the Global Atmosphere. IPCC (1999)

The importance of the aviation industry and its influence on climate is undoubtedly an important area of research, especially due to the current levels of uncertainty and therefore continued research in this area is vital. The aims of this study are therefore:

Aims

The purpose of this research project is to increase our understanding of the conditions under which contrails form and therefore increase our understanding of how contrails may influence future climate. It is also hoped that it will clarify how many stations are needed to study contrails in the UK; if contrail formation is a nationwide phenomenon then only one or two stations are needed, but if the formation of contrails occurs on a more local scale then many stations will be needed to provide a representative picture of the pattern of contrails over the UK.

There are three main research areas within this study:

> To look at the number of contrails observed on each day at each stations and see if there are any nationwide patterns or more local patterns of contrail occurrence/formation. This has been carried out by looking at a case study of December 18th 2003.
>
> To study the cluster of stations in the North East of England (Bishop Auckland, Consett and Stokesley) to test whether or not these stations are indeed a 'cluster' (if so their observations of the number of contrails should relate more closely to each other than to any other station in the UK).
>
> To look at the possibility of there being a seasonal cycle of contrail occurrence, as suggested by Ledson (2003), through analysis of the monthly averages of the number of contrails observed at each station.

The National Contrail Network. Front Page.

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