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The influence of increased jet airline traffic on the amount of high level cloudiness in Alaska

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With 4 Figures

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Summary

The high level cloudiness has increased over Alaska during the second half of this century, a period for which reliable data exist. This increase is most pronounced in areas close to the much traveled air routes from Europe to Anchorage which could be demonstrated by a comparison with two remote stations in western Alaska. This might be taken as an indication that the observed high cloudiness increase is caused by jet contrails. Seasonally, summer and spring give the greatest increases. Cloudiness is, of course, an important parameter for climatic change, and increased high level cloud amount in arctic and subarctic areas would lead to warmer temperature; these have been observed in Alaska.

1. Introduction

Nearly 5 decades ago, jet air traffic became a reality. These planes fly typically around the 10,000 m level, close to the tropopause. In the tropics, where the tropopause is higher, they fly in the upper troposphere, but in subarctic and arctic Alaska they fly mostly in the lower stratosphere, where the conditions are much more stable and vertical mixing is reduced (Graßl, 1990).

In 1958, the first commercial airline, Scandinavian Air System (SAS), started regular flights over Alaska. Increased traffic from Europe to Japan and other places in Asia made a stop in Anchorage essential. As Russian air space was at that time restricted, this represented the shortest route. In the following decades, this air traffic increased substantially, as most European and Asian airlines participated in this development. About a decade ago, passenger air traffic dropped, as the Russian air space opened and planes extended their range without having to refuel, and could hence fly non-stop from Europe to Asia or vice versa. However, the decrease in passenger planes was compensated by an increase in cargo traffic. Large Boing 747, heavily loaded, fly daily from Asia to Europe and normally refuel in Anchorage. Due to their heavy loads, it is more economic for these planes to refuel than fly non-stop, which would reduce substantially the amount of cargo they would be able to carry.

In Fig. 1, the annual numbers of jet take-offs from International Airport at Anchorage are presented as an indication of the air traffic for the time period 1970 to 1997, a time period for which we were able to obtain these data. During this time period, the number increased more than 3-fold. We were unable to obtain the amount of jet fuel used, however, we found data on the total amount of freight handled at the airport, which are also presented in Fig. 1; an increase above 400% can be observed.

2. Background

Studies of jet contrails go back a long time. This is understandable, as they can be so striking against

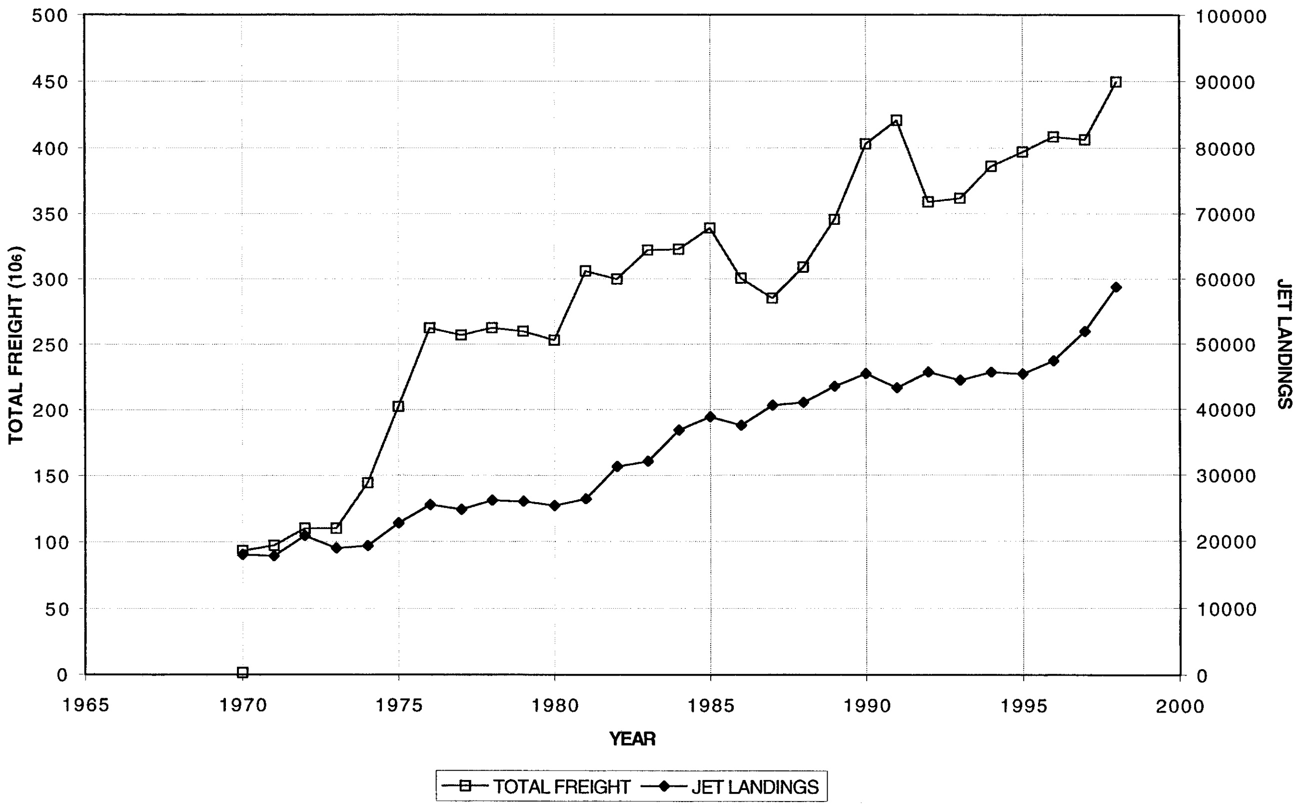


Fig. 1. The number of annual landings of jet planes and the cargo handled at the International Airport in Anchorage for the time period 1970 to 1997. Note the strong increase in the number of planes (3 times) and in the cargo (4 times)

the blue sky and everyone has observed them. Even to a casual observer, there can be large differences in occurrence: some of them disappear after a few seconds, other ones last for longer time periods and might drift with the winds aloft, and some others might spread over part or the whole sky, covering it eventually with a thin cirrus cloud cover. Appleman (1953) was one of the earlier investigators and since than a large amount of literature has been accumulated. As the water vapor saturation pressure of air is a logarithmic function of the temperature, cold air masses are especially susceptible for the formation of contrails (e.g. Schrader, 1997). At very low temperatures, contrails can form in relatively dry air. However, they will only persist if the ambient air temperature is moist and with respect to ice supersaturated. Naturally the type of the aircraft (fuel consumption) will also play a major role as does the sulfur content of the fuel (Busen and Schumann, 1995). For spreading over larger parts of the sky, a strong wind shear aloft combined with supersaturation in respect to ice are essential. Observations of contrails have been carried out by ground based observers, by all sky cameras and also from satellites (Carleton and Lamb, 1986) and modeling efforts were done by Travis et al. (1997). Recently, a comprehensive study (IPCC, 1999) discusses the growing concern air traffic might have on the structure of the atmosphere and the climate of the earth.

Clouds have, of course, a strong influence on radiation budget and are hence a major factors in climate change (Seinfeld, 1998). In the short wave region of the solar spectrum, cirrus contrails tend to scatter the incoming radiation (mostly forward) and to a much lower percentage, absorb some of the radiation (e.g. Gayet et al., 1996). In the infrared region they contribute to the back radiation of the atmosphere. Kuhn (1970) carried out an early investigation on the infrared radiation, while Smith et al. (1998) performed more recent studies. Combined, they can contribute either to cooling or warming, depending on the time of the day, season and latitude. However, integrated over the whole Earth and the annual cycle, they contribute to warming (Seinfeld, 1998).

Changnon (1981) carried out a systematic study on cloudiness trends in the mid-western region of the United States since 1901, and he found for areas in which the air traffic has increased the most, the largest increase in the amount of fractional cloud cover. While this might be convincing at first appearance, the areas with the larger amount of air traffic are also those in which the most industrial development has taken place. Industrial production normally puts more aerosols into the atmosphere which might act as condensation nuclei. This might also influence the cloud formation, and with it, the amount of cloud cover. A distinction between these two processes is not easily made. However, in a recent study, Boucher (1999) gives convincing evidence that the cirrus cloudiness has increased by analyzing the 1982 to 1991 data set for the northern hemisphere. He found a mean increase for the decade of 1.1% for land and 3.5% for ocean, with higher increases over the principle flight corridors.

In Alaska there is no heavy industry with the exception of the oil fields close to Prudhoe Bay; the development of the latter occurred in the last two decades. Hence, changes in the amount of cloud cover can not easily be attributed to industrial development. Therefore, we believe that this remote, sparsely populated area might be well suited for such an investigation.

Most of the jet traffic over Alaska is international, more specifically from Europe to Asia or vice versa. In most cases, Anchorage serves as a refueling station. In Fig. 2, we plotted the great circle (shortest) routes these planes are taking from Anchorage to the major metropolises in Europe. One can see from this figure, that the planes fly over the Central Interior (Fairbanks) and cross from Alaska to the Arctic Ocean in the area of Barter Island. Two other stations, namely McGrath and Barrow are situated at similar latitudes, but about 500 km to the west of the flight corridor. They have experienced over the last decades a much less drastic increase in jet traffic. All four stations are first class weather stations with the highest standard of data quality. These stations are manned 24 hour daily by trained personnel of National Weather Service and cloud observations are carried out visually in 3 hourly intervals. It might be worthwhile to point out that in recent years, automatic cloud observing devices (ASOS) have been installed. These are not directly comparable to the old visual measurements, as the field of view (zenith) is different, and further, they do not see above 5000 m, hence, do not see cirrus clouds. Visual observation have been or will be discontinued, hence an extension of the time series will also not be possible in the future.

3. Data analyses and results

The mean annual course of the total cloudiness is similar for both Interior and Northern Alaska. The minima occur in winter or early spring, when the atmosphere is cold and dry; monthly long term minima in cloud cover of 59, 62, 54, and 49% were observed for Fairbanks, McGrath, Barter Island, and Barrow, respectively. Maxima occur in August or September with values of 81, 85, 86 and 92% respectively. At Barrow, the Arctic stratus in late summer is semi-permanent, and on average, only two clear days are observed each August and each September.

Cloud observations are carried out every 3 hours for up to 4 layers of the atmosphere. From these different parameters can be calculated; on the data tapes we utilized, total and opaque cloudiness are available from sunrise to sunset and from midnight to midnight. Our main emphasis is on the change in the amount of high cloudiness, which is well approximated by the difference in the amount of total and opaque cloudiness. Total cloudiness is defined as "the amount of the celestrial dome covered by clouds or obscuring phenomena" (NCDC, 1975), while opaque clouds is defined as "an extensive cloud patch, sheet or layer, the greater part of which is sufficient opaque to mask completely the sun or the moon. This term applies to altocumulus, altostratus, stratocumulus and stratus" (WMO, 1992). The difference represents high level cloudiness to a good degree of accuracy and consists mostly of cirrus, cirrocumulus or cirrostratus. Even though the amount of high level cloudiness in this paper is derived as the relatively small difference of two larger numbers, this method was only used for convenience sake, as these two quantities were easily available in digital format. Actually, the amount of high level cloudiness is not a deduced quantity but was observed.

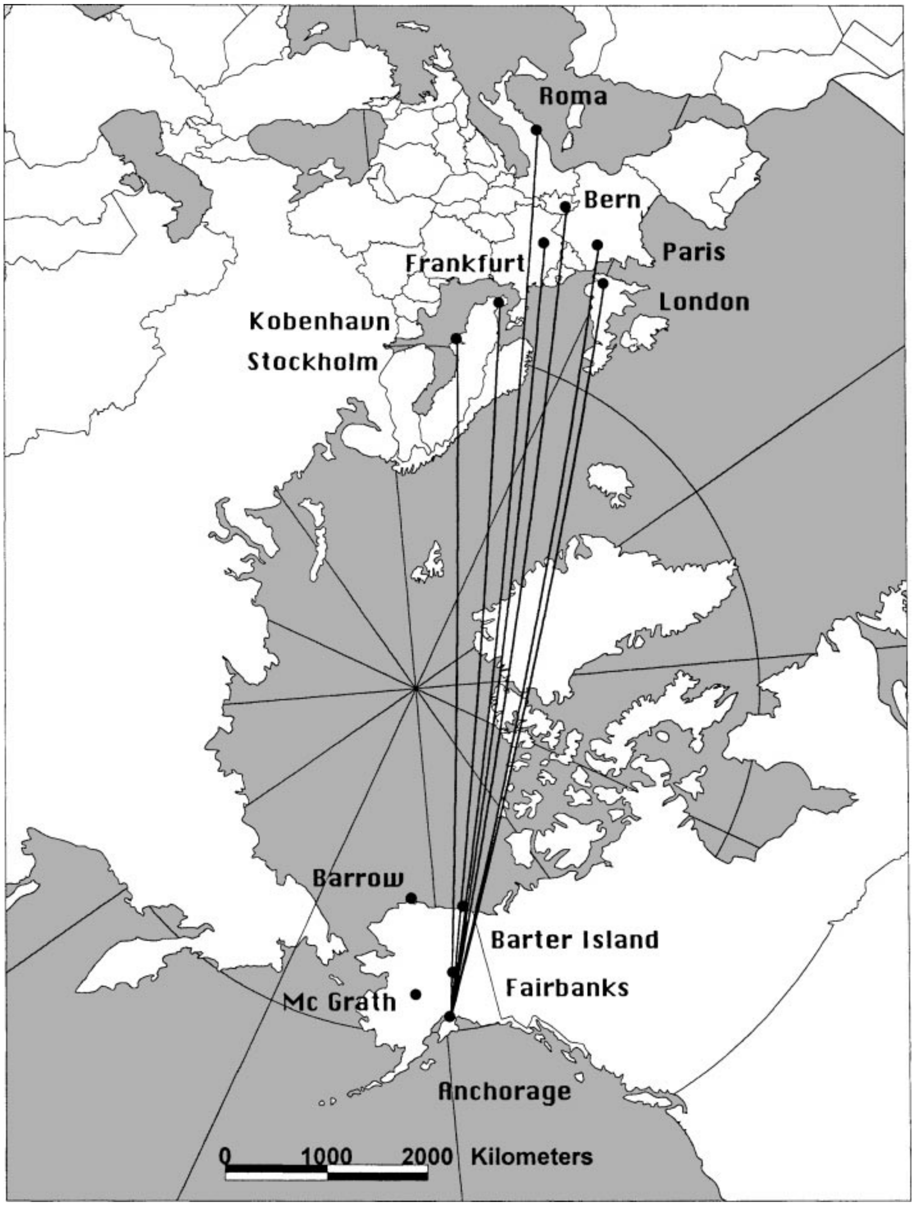
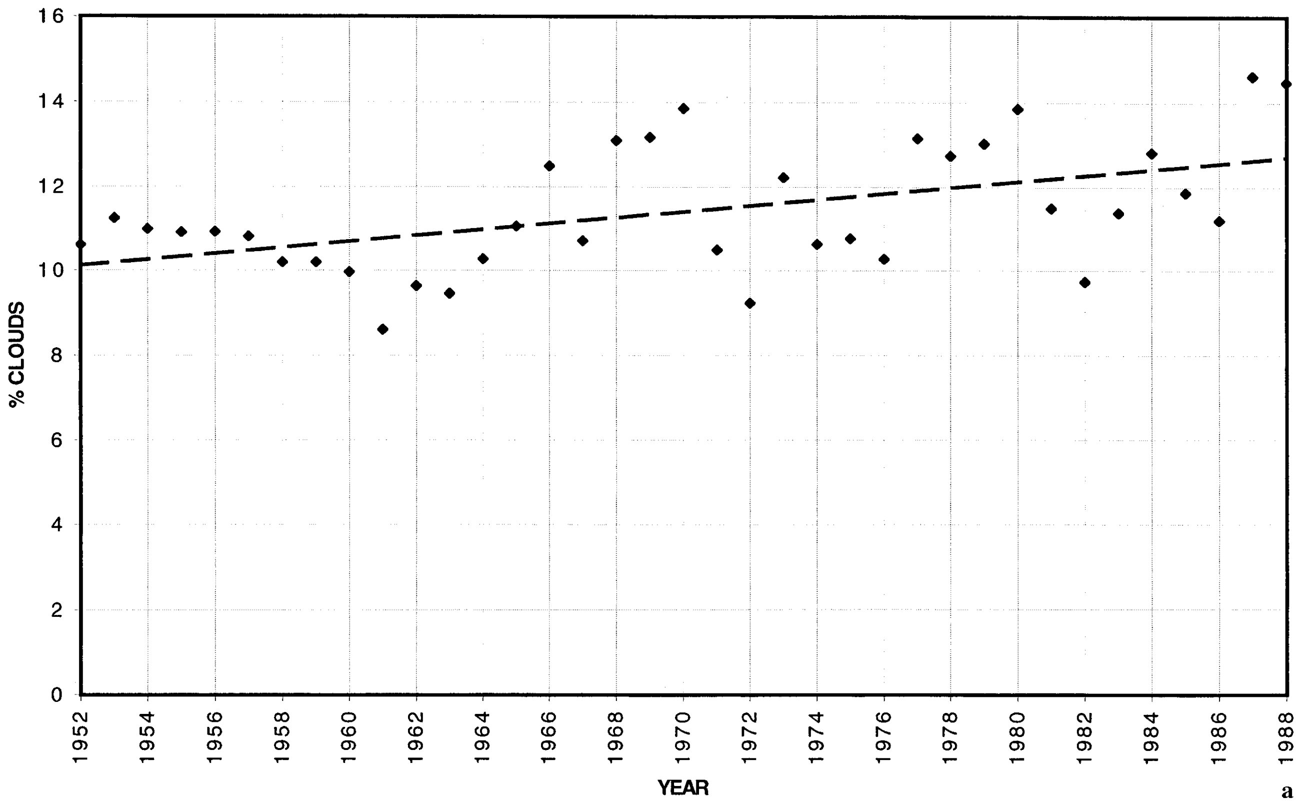


Fig. 2. Flight path (great circle route) between Anchorage, Alaska and major European airports. Note, that Fairbanks and Barter Island lie below the much traveled flight routes, while McGrath and Barrow lie to the west of them

There are several concerns when using this method. High clouds might be obscured by lower level clouds. Hence, a change in low level cloud amount will also affect the amount of high clouds observed, even if this amount has stayed constant. We looked at trends in the low level cloud amounts, and indeed there has been a change (Curtis et al., 1998). We will discuss this effect later.

Another concern worth addressing is the quality of the data. All cloud observations are, of course, subjective as they depend on the observer. The observers at first class weather stations are professionals, trained and employed by the National Weather Service. At each stations there are a minimum of three observers, and we estimate that during the time period and for the four stations used in this study, some 100 observers would have participated in these measurements, minimizing the effect of a single biased observer. Further, we improved the quality of the data set by utilizing only observations during day light hours. At night, especially in the absence of the moon, cloud observations are difficult and hence less reliable.

When looking at the high level cloudiness trends, a strong increase in the amount can be observed for both Fairbanks and Barter Island. In Fig. 3 the mean annual values of the two stations are presented for the time period of 1952 to 1988; the observations at Barter Island stopped in 1989



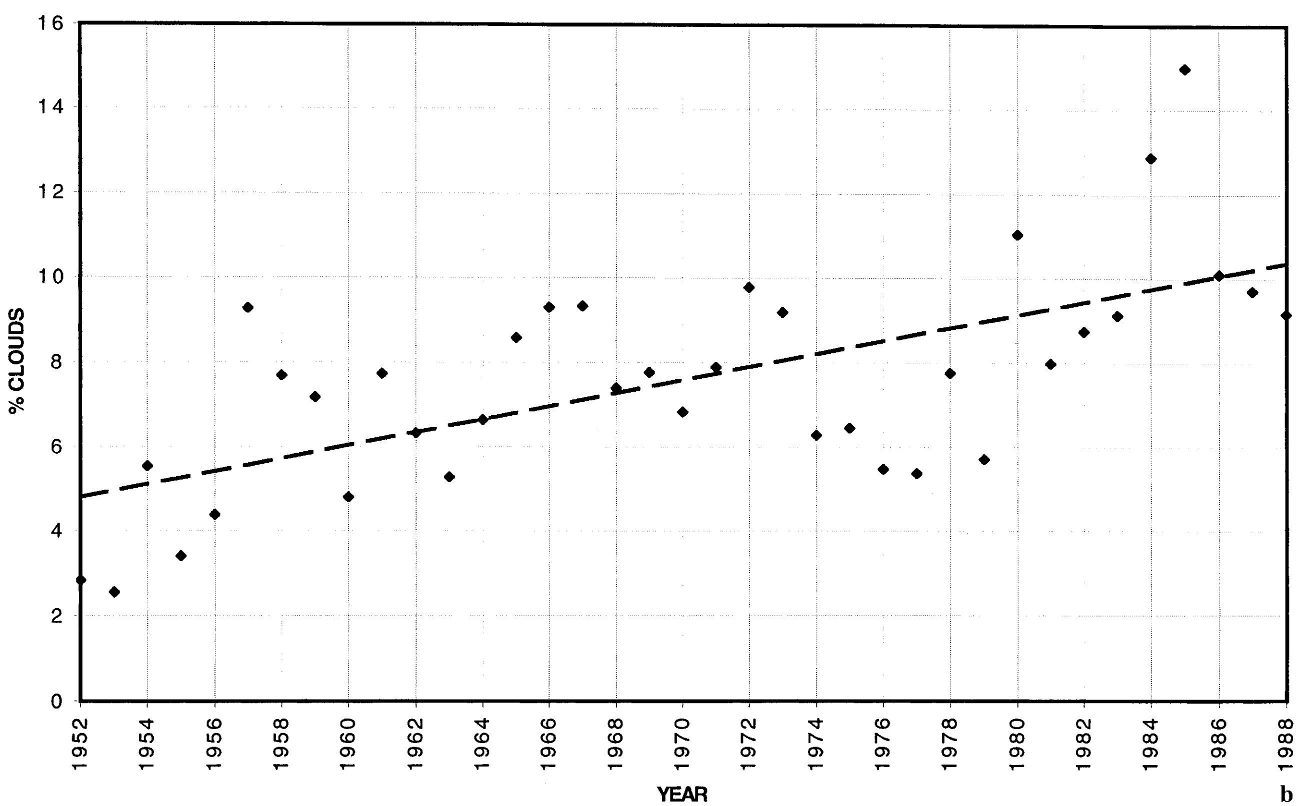


Fig. 3. Time series of the mean annual values of high level cloud amount for Fairbanks (**a**) and Barter Island (**b**) from 1952–1988. Note, that the cloud amount for Fairbanks increased by more than 25%, and for Barter Island it nearly doubled

and we present the data for identical time periods. However, if we extent the time series for Interior Alaska, a similar trend can be observed. Assuming a linear increase with time, the high cloud amount increased from 10.1% to 12.8% for Fairbanks (Fig. 3a), a relative and substantial increase of 27% for the 37 year time period. There are some indications of periodic variations in the increase, however the time series is too short to carry out a meaningful Fourier analyses. A variance of 0.26 was calculated, which makes the increase significant at the 99% confidence level. Barter Island (Fig. 3b) displayed an even more substantial increase from 5.0% to 10.0%, doubling the amount of high level cloud amount over the 37 year period. The variance was higher (0.39), again being significant at the 99% confidence level.

Looking at the increases over the course of the years, both stations showed an increase in high level cloud amount for all seasons. These increases for Barter Island were significant at the 99% confidence level for all seasons. However in Fairbanks only summer showed such a high confidence level. In spring a confidence level above 95% was observed, but in fall and winter the observed increases were too small to be significant. The detailed values are presented in Table 1. Looking at even shorter time periods, monthly values showed an increase in the amount of high level cloudiness for all months at Barter Island, and for 10 out of 12 months for Fairbanks. In late fall/early winter, hardly any trend could be observed for Fairbanks. This is also the time period of the year at which temperature trends are in poor agreement with their annual values (Stafford et al., 2000).

Table 1. Variance of and confidence level of the change in the amount of high level cloudiness with time under the assumption of a linear trend from 1952 to 1988 for Fairbanks and Barter Island. Seasonal and annual values are presented

	Fairbanks	Barter Island
Spring	0.176	0.229
Summer	0.393	0.430
Autumn	0.004	0.264
Winter	0.023	0.303
Annual value	0.260	0.390

Confidence level

> 99% > 95% < 95%

Not only increased jet traffic, but also other parameters like circulation changes or global warming might have an effect on the high level cloud amount. Furthermore, a change in the amount of low level cloudiness affects the ability to obverse high level clouds. To isolate the potential impact of jet traffic, we compared the two stations located in the area of substantial air traffic with those more remotely located. There are only a few first class weather stations in Alaska, at which cloud observations for the last 5 decades have been carried out. On the other hand, we did not want to use second class climatological stations, as observers are less trained and the observations are frequently more sporadic.

Interior Alaska is bordered to the south by the Alaska Range and to the north by the Brooks Range. McGrath, located some 400 km to the west of Fairbanks, is situated in the same climatic zone (subarctic continental). Statistical methods (Stafford et al., 2000) showed the climate within this area to be similar. North of the Brooks Range, there is besides Barter Island only one other first class climatological station with a long term record, namely Barrow. Barrow is as Barter Island located at the edge of the Beaufort Sea, but some 500 km to the west. Again, Barter Island and Barrow are located in the same climatic zone (Arctic tundra) (Curtis et al., 1998). Their exact location can be seen from Fig. 2.

For the comparison to be valid, we investigated first the opaque cloudiness of the four stations. Most of them displayed a decrease, however, the changes were similar for each of the two stations in the two climatic zones. We also verified that the decrease for Fairbanks was not larger than the one at McGrath as well as the decrease at Barter Island was less than the one at Barrow. If this would not be the case, then the observed relative increase in high level cloudiness in the flight corridor could have been due to the more frequent ability to see the higher levels of the atmosphere.

For the time period 1952 to 1988, for which we have data for all 4 stations, McGrath showed no variation in the amount of high level cloudiness, while Barrow's values increased, but less so than the ones of Barter Island. There is a further indication, that in recent years (after 1988) also the values of McGrath are increasing. It is interesting to note, that the increase in high cloudiness at the two stations outside the flight corridor from

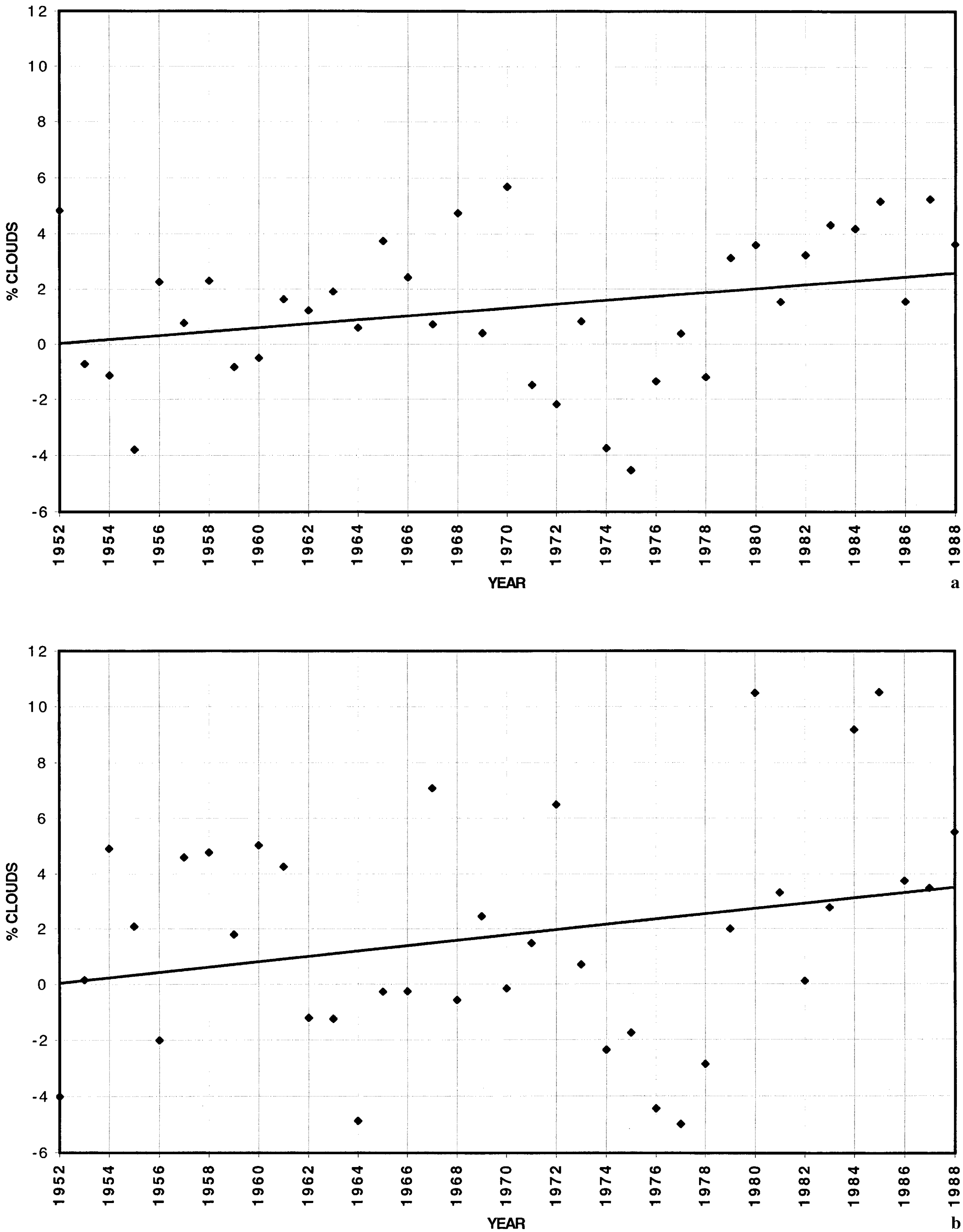


Fig. 4. Time series of the relative differences in high level cloud amount for two station pairs, one located in the continental climate of Interior Alaska (**a** Fairbanks – McGrath), the other one located in the Arctic climate of the North Slope of Alaska (**b** Barter Island – Barrow) for the spring season

Table 2. Change (%) in the amount of high level cloudiness for 1952–1988. Note the greater increase in the areas of increased jet traffic. Further, the standard deviation (SD) from the best linear fit in the relative increase in high level cloudiness between the flight corridor and more remote areas is also presented (F = Fairbanks, M = McGrath, BI = Barter Island, BA = Barrow, SD = standard deviation)

	F	M	Δ F-M	SD F-M	BI	BA	Δ BI-BA	SD BI-BA
Spring	3.96	1.33	2.63	2.7	5.55	2.00	3.55	4.1
Summer	4.70	2.52	2.18	2.2	5.92	5.44	0.48	3.0
Fall	0.74	0.00	0.78	2.0	4.40	4.33	0.07	3.2
Winter	1.22	0.04	1.18	2.7	6.88	2.55	4.33	3.7
Year	**2.66**	**0.30**	**2.44**	**1.7**	**5.03**	**3.59**	**1.44**	**2.8**

Anchorage to Europe is quite different. One possible explanation might be that different climatic zones have reacted differently to the climatic change which has occurred in Alaska. Another one being that the general development (and with it the amount of air traffic) on the North Slope of Alaska has increased substantially with the discovery and production of the largest oil field in the USA, while western interior Alaska is quite remote with little industrial development.

To carry out a quantitative comparison, we deducted the values of McGrath, the less affected station, from Fairbanks and the values of Barrow, the less affected station, from Barter Island, respectively. A positive trend can be taken as an indication that the stations in the more traveled flight corridor had an increase in the amount of high level cloud amount when compared to the more remote stations in the same climatic zone. In Fig. 4 the data for the spring season (March, April, May) are presented. There is a large amount of scatter in the data points, however, both station pairs show a positive trend, a result to be expected. The numerical value for the interior station pair is 2%, which could be attributed to increased jet traffic; this represents an increase of about 15% in the amount of high level cloudiness. The arctic station pair, the relative increase was some 3%, representing a relative increase in high level cloudiness of about 30%.

In Table 2 the data are presented for all seasons and for the year. First, the slope of the change in high level cloud amount for two interior and two northern stations for the time period 1952–1988 was calculated, for which the best linear regression fit was applied. The differences between the slopes of the two station pairs are also given. It can be seen from the table, that both station pairs give for all seasons as well as for the year a positive value, which means that there was a relative increase in the amount of high level cloud concentration in the flight corridor when compared to more remote areas. While the trend lines of the differences were by themselves not statistically significant, the likelihood that all four seasons and two station pairs show by chance the same positive trend is lower than 1%, under the assumption that the data are independent from each other.

Seaver and Lee (1987) reported that the number of cloudless days have decreased in the continuous United States. We did not find this. However, the observed decrease in low level cloudiness might have had bigger effect on the number of clear days than the increase in high level cloudiness. An interesting scenario for the decreased opaque cloudiness was pointed out by one of our unknown reviewers: The observed temperature warming in Alaska over the last decades (Stafford et al., 2000) might have lead to increased convective activity and with it a decrease in low level cloudiness.

4. Conclusion

The amount of high level cloudiness has increased in Alaska over the last half century. This increase was higher in areas of increased jet traffic than in remote areas, making us believe that contrails might have contributed to this trend. Further, Alaska has experienced during the same time period a temperature increase, which might, at least in part, be caused by this higher amount of high level cloudiness.

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