THE EFFECT OF SOLAR PARTICLE EVENTS AT AIRCRAFT ALTITUDES

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ABSTRACT

The Mullard Space Science Laboratory of University College London is collaborating with Virgin Atlantic Airways, the Civil Aviation Authority and the National Physical Laboratory in a programme investigating the aircrew exposure to cosmic radiation. The study has been undertaken as a result of the EU *Directive 96/29* [1] that took effect on the 13th May 2000 and requires the assessment of the level of aircrew exposure to cosmic radiation. The programme of measurements started on January 2000. To date measurements have been made on over 200 flights on Virgin Atlantic aircraft around the globe.

The cosmic radiation is measured using a Tissue Equivalent Proportional Counter (TEPC) manufactured by Far West Technology. The instrument is designed to mimic human tissue providing a measure of the dose equivalent to a few micro-metres of tissue. Measurements are recorded every minute during each flight and later integrated with the aircraft's flight data (including time, latitude, longitude and flight level), allowing us to obtain an accurate measure of the radiation dose throughout each flight. In particular, we are able to show how the radiation levels vary during the flight in response to changes in the aircraft's position and more importantly to changes in the cosmic ray flux as a consequence of solar activity. One of the main aims of this study is to assess the effect that Solar Particles Events (SPEs) have at aircraft altitude. In the following paper we present a comparison of flight doses measured during and after the 14th July 2000 X-class flare that was accompanied by a major solar particle event. The results highlight the importance of a range of external factors that can strongly influence the effect of SPEs at aircraft altitudes

1. IN FLIGHT MEASUREMENTS

Measurements were made using the same TEPC monitor on two flights from London to Hong Kong following the eruption of an X-class flare at ~09:00 UT on 14th July 2000. The first flight began at ~21:00 UT on 14th July, ~11 hrs after the flare. The second flight flew to Hong Kong a week later, taking-off at ~21:00 UT on 21st July. The similarity of the two flight routes is shown in Figure 1. The flights both took-off at ~21:00 Local Time (LT) and pass through local midnight ~2 hours later, crossing the daytime meridian (06:00 LT) ~5 hours after take-off. The route also gradually moves to lower latitudes from 23:00 UT onwards.

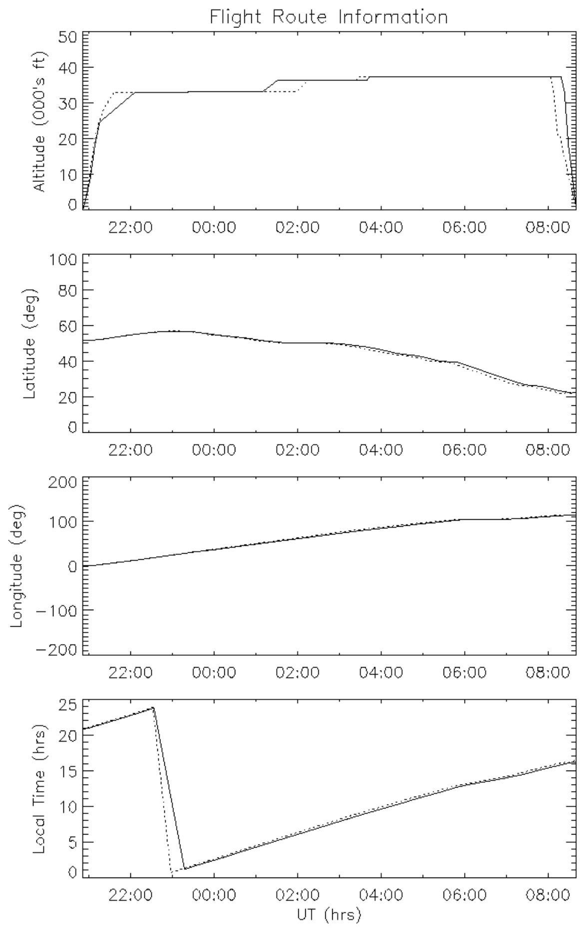

Fig. 1. Summary of the London to Hong Kong flight routes for the 14th and 21st July represented by the solid and dotted lines respectively.

2. THE SOLAR FLARE

The solar flare started at 09:03 UT and peaked at 09:24 UT on the 14th July. The X-rays detected by the GOES-10 satellite registered an X5.9 class flare. This was immediately followed by a very strong SPE, the largest in 6-years. Figure 2 shows the increase in the GOES-10 proton flux measurements for energies from 370 MeV to > 850 MeV. The red and blue lines depict the time intervals during which the 14th and 21st July flights were airborne respectively. During the earlier flight there is a significant enhancement of the proton flux across all the energy channels. In contrast by the 21st July the flux has returned to background levels.

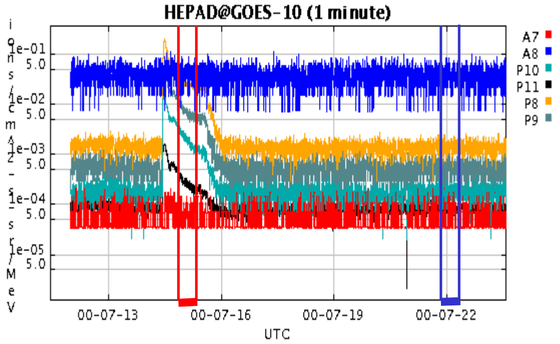

Fig. 2. GOES/HEPAD measurements of solar protons and He^{+}. The 14th and 21st July flights are indicated by the red and the blue intervals respectively.

A7: (He^{+}) 630 - 850 MeV
A8: (He^{+}) > 850 MeV
P10: 640 - 850 MeV
P11: > 850 MeV
P8: 370 - 480 MeV
P9: 480 - 640 MeV

3. COMPARISON OF FLIGHT DOSES

In order to identify differences in the measured dose as a result of SPEs associated with solar flares it is first necessary to take into account variations in the dose due to changes in altitude and latitude. This is achieved by comparing doses during intervals when the two flights are at the same flight level and magnetic latitude. Because flights tend to follow a generic flight route comparisons like this are possible. Figure 3 shows the results at four different flight levels, each for a different duration. The doses are plotted as a function of magnetic latitude and longitude. The red and green lines represent measurements made on-board the 14th July and the 21st July respectively. The one-minute integrated measurements of the dose were smoothed using a running boxcar averaging technique using a 9-minute window.

Our analysis shows that there is no significant difference between the doses measured on-board the flight during the SPE and a week later when the solar

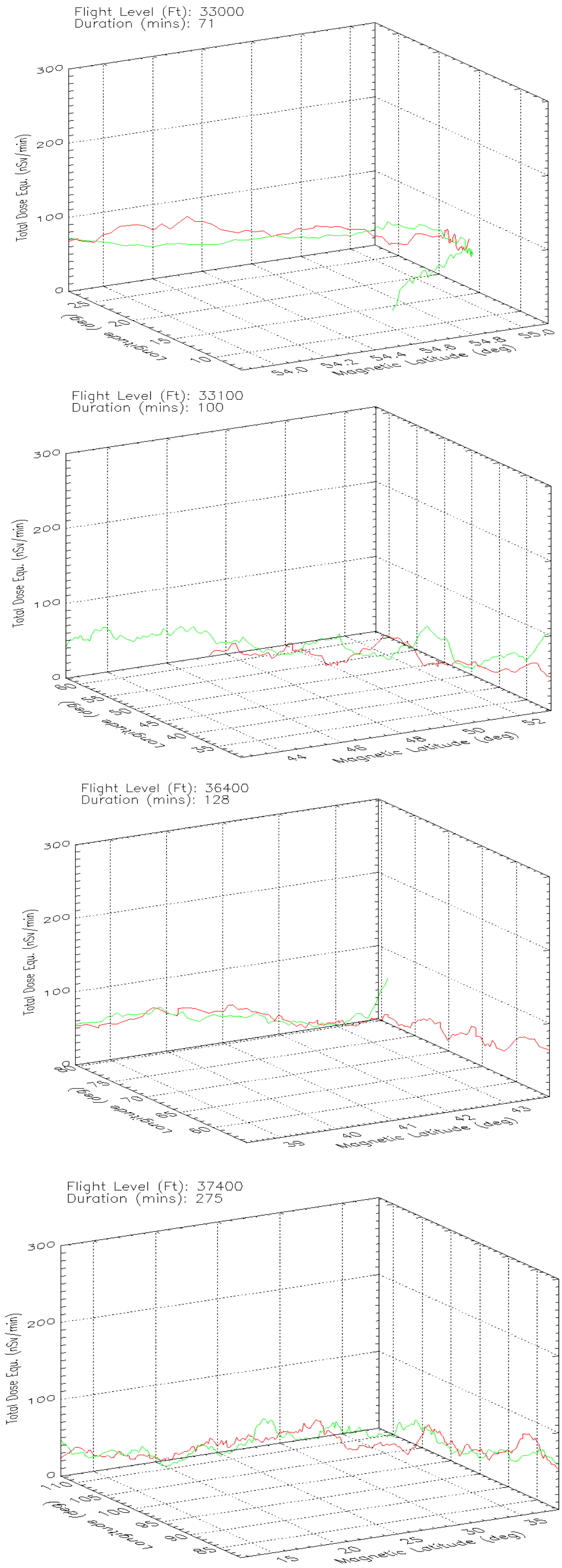

Fig. 3. Total dose equivalent measured by the TEPC from London to Hong Kong plotted as a function of magnetic latitude and longitude at four different flight levels. The red and green traces represent the 14th and 21st July flights respectively.

energetic particle fluxes have returned to background levels measured at GOES. A marginal increase in the dose is observed within the first hour of the 14th July flight at 33,000 ft. However, it is not a statistically significant enhancement with similar magnitude deviations also occurring later during the flight in the positive and negative direction. The minimal difference between the measurements made on the two flights may partially be caused by the shielding effect of the Earth. During the first ~5 hours of both flights the aircraft are on the nightside of the Earth (see Figure 1). This may hamper detection of the solar flare particles earlier in the flight when the particle spectrum is hardest (i.e. the more energetic the particles the earlier they will arrive at the Earth). By the time the 14th July flight enters local daytime the solar particle spectrum will have become much softer and as a consequence the solar particles may not be energetic enough to penetrate down to aircraft altitudes.

In addition to the day/night location of a flight there are also a number of further factors that may influence the effectiveness of a SPE at aircraft altitudes. Further investigation of the flight route, interplanetary solar wind conditions and ground based measurements shed more light on the effect of some of these factors.

4. INTERPLANETARY CONDITIONS

The interplanetary conditions, including the solar wind speed, solar wind density, magnitude of the interplanetary magnetic field (IMF) and the IMF-B_z component observed at ACE are shown in Figure 4. The observations suggest the arrival of a CME at ACE a day prior to the SPE. The abrupt increase in the solar wind speed, proton density and the magnitude of the magnetic field indicate the arrival of a CME associated shock (dotted vertical line). This is significant, as it would result in a Forbush decrease prior to the 14th July flare leading to an overall decrease in the galactic cosmic ray dose at Earth.

5. GROUND LEVEL MONITORING

Figure 5 shows the flight route and the location of ground-based neutron monitors over-plotted on a contour map of the ground level cosmic ray effective cut-off rigidities in GeV. In addition Figure 6 shows the ground-based measurements at the four different neutron monitors around the World. The vertical red and blue lines correspond to when the 14th July and 21st July flights respectively cross the same longitude as the first three ground stations.

The decrease in the neutron measurements observed at all the ground stations in Figure 6 confirms the presence of a Forbush decrease on the 13th July, the day prior to the flare. The arrival of the SPE is then seen as spike in the counts observed at the ground stations at Kiel, Moscow and Calgary, all located at latitudes ≥ 50º. In contrast there is no clear signal at Beijing that is at a latitude of ~40º and as a consequence has a ground level cut-off rigidity of ~ 9 GeV compared < 3 GeV at the other ground stations. Due to the Forbush decrease the increase in counts due to the SPE detected at the Kiel and Moscow ground stations on the flight route do not exceed the normal background level. The duration of the increase at ground level is also only ~ 4-6 hours and is therefore over before the 14th July Virgin began.

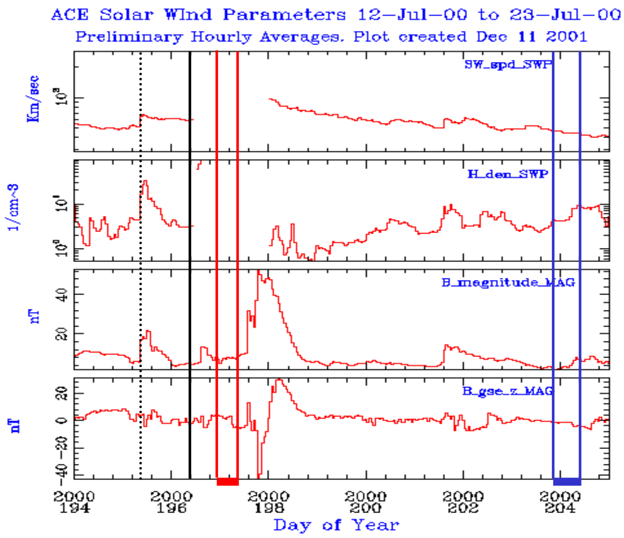

Fig. 4. The solar wind speed, proton density, magnitude of the interplanetary magnetic field (IMF) and the IMF-B_z component measured at ACE. The dotted vertical line indicates the arrival of an interplanetary shock and the solid vertical line is when the flare erupts. The intervals between the red and blue lines represent the 14th and 21st July flights respectively.

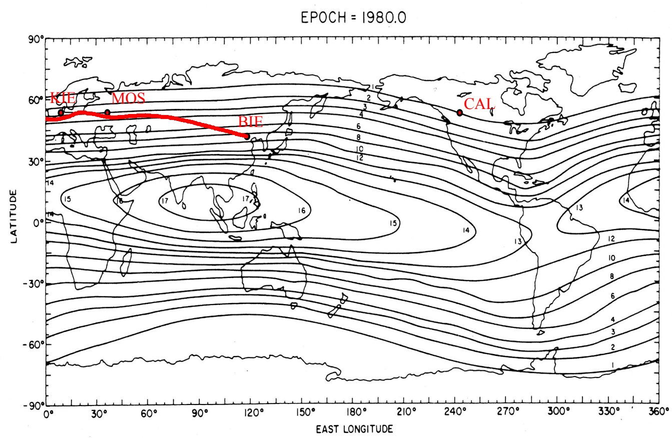

Fig. 5. Iso-rigidity contours of vertical cosmic ray effective ground level cut-off in GeV. Over-plotted is the London-Hong Kong flight route and the location of the ground level neutron monitors at Kiel, Moscow, Beijing and Calgary [2].

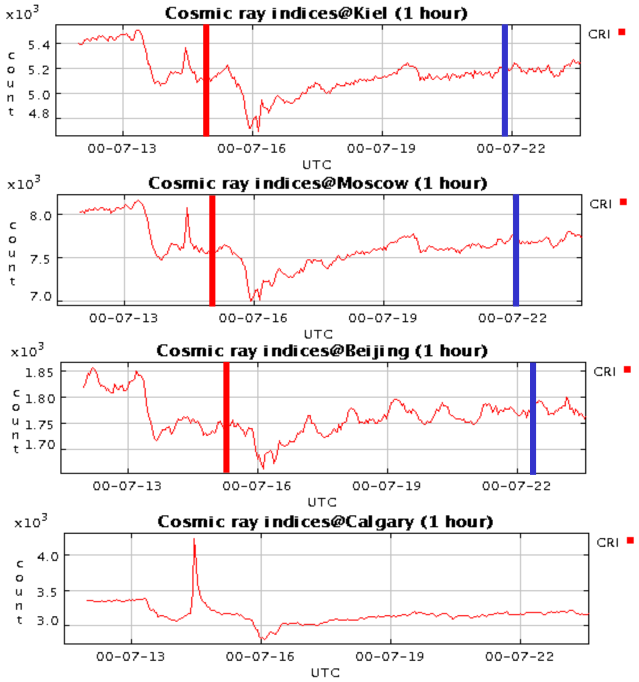

Fig. 6. Measurements made at the cosmic ray ground stations at Kiel, Moscow, Beijing and Calgary. The red and blue lines on the top three panels indicate when the 14th and 21st July flights respectively crossed the same longitude as the ground stations.

6. DISCUSSION

The observations suggest that only the most energetic flare particles that are present at the leading edge of the SPE can penetrate deep enough into the atmosphere to produce a significant increase in the cosmic ray count at ground level. This does not rule out the less energetic flare particles that arrive in the trailing edge of the SPE having an effect at aircraft altitudes where the cut-off rigidities are much lower. For example, note the much larger increase in the cosmic ray counts due to the SPE measured at the Calgary ground station, which has a cut-off rigidity of ≤ 1 GeV.

It is difficult to conclude much about the effects of SPEs at aircraft altitudes based on the measurements made during the 14th July event alone. The insignificant differences between the measurements taken on the two flights may be due to a number of factors such as the night-side location of the aircraft during the earlier part of the flare, the Forbush decrease and the increasing cut-off rigidity during the flight as it moves to lower latitudes. However, these preliminary results do suggest that the trailing edge of the 14th July SPE did not have a significant effect on the dose measured at aircraft altitudes.

The results imply that the leading edge of a SPE, where the spectrum is much harder, poses the most serious threat to aircrew that may result in a brief but significant increase in the measured dose at aircraft altitudes. However, without direct measurement of such an event at aircraft altitudes it is not possible to estimate how the dose may change. Note also that the spectrum of SPEs is not consistent and thus some flares may have little effect at aircraft altitudes whereas others may significantly add to the measured dose.

7. CONCLUSIONS

In this case the energetic (> 850 MeV) solar flare particles arrive almost immediately and persist for up to 4-6 hours at ground level. The radiation risk to aircrew is therefore relatively brief but almost immediate following the SPE. When considering radiation alerts to airlines [3] or to estimate and model any alterations in the radiation exposure to aircrew it is necessary to consider a number of factors:

1. The interplanetary conditions

2. The location of the planes for the next few hours;
   - Dayside/nightside
   - Magnetic latitude

3. Hardness of the flare particles

Although we present only preliminary results they display the complexity of the problem and the need to further investigate the possible effects of SPEs at aircraft altitudes. Without better understanding of the effects of SPEs the annual exposure to aircrew cannot at present be accurately determined.

8. ACKNOWLEDGEMENTS

Space Physics Interactive Data Resource (http://spidr.ngdc.noaa.gov/spidr/)

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9. REFERENCES

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