experiments in 1984. An interesting sidenote is that Shiva was operational 1 month after the earthquake in Livermore and suffered only minor damage to the optical system. At Los Alamos, the current scenario for the Antares CO_2 laser facility envisages the construction of two of the previously proposed six beam lines so that 40 kJ of CO_2 laser energy can be provided for target experiments in 1983. Recent improvements in the triple-pass amplifiers of the Helios system at Los Alamos will increase their energy on target from 5 to 10 kJ by early summer. The light-ion-beam facility at Sandia Laboratories (PBFA-1) is scheduled for completion this year and will provide 1 MJ and 30 TW. The upgrade of this facility, PBFA-II, will deliver 3.5 MJ at 100 TW and will be available for experiments in 1986. A 10-kJ heavy-ion-beam target physics facility has been proposed for construction and operation by 1984. As mentioned previously the programme for new laser development is emphasizing short wavelength lasers. The present candidates are the rare gas halide lasers KrF, XeC1, and XeF. All these require a pulse compression technique to obtain pulses in the neighbourhood of 20 ns. Papers at this meeting showed the feasibility of both Raman compression and pulse stacking (angular multiplexing) to achieve shorter pulses. A major drawback of these short-wavelength systems is the low damage threshold of the optical components and the resulting high cost of the optical system. This problem has not been adequately addressed. Since the tradeoffs between these systems will depend very strongly on the results of future laser-target coupling experiments, the option to use longer-wavelength lasers has not been eliminated. □

Thunderstorms and substorms: any connection?

from D. J. Southwood

IT is a familiar fact that substantial electric fields are produced in the atmosphere during a thunderstorm. As well as a steady (d.c.) field being present, thunderstorm lightning flashes are a source of transient a.c. electromagnetic signals over a wide frequency range. A less familiar electromagnetic storm phenomenon is the magnetospheric substorm, a disturbance of the ionosphere and magnetosphere in the tenuous outer ionized layers of the Earth's atmosphere. The substorm's most dramatic manifestation is in intense auroral displays. The aurora results from the strong electric coupling between the magnetosphere and the ionosphere below, a process which can require strong currents to flow between them. The aurora occurs when the currents are carried by energetic electron beams which give rise to light as they strike the denser lower ionosphere.

The ionosphere and magnetosphere are very good electrical conductors while the troposphere, the lowest layer of the atmosphere and the one in which thunderstorms occur, is insulating. There have been few attempts to consider whether there could be any significant electrical coupling between the troposphere and the outermost regions except by those workers (Markson *Nature* **273**, 103; 1978; Herman & Goldberg *J. Atmos. Terr. Phys*, **40**, 121; 1978) looking at "sun-weather relationships". The search is for causal links between activity in the tenuous outer layers of the atmosphere and the much denser bottom 5-10 km where the weather occurs. Any such connection must be subtle. The energy associated with tropospheric motions far exceeds that associated with any magnetospheric effect. Electric coupling (Markson *op. cit*) is one possible connection.

Data from a recently reported balloon flight (Bering *et al. J. geophys. Res.* **85**, 55; 1980) in northern Canada that took place during the simultaneous occurrence of a thunderstorm and a magnetospheric substorm has permitted a direct look at some interrelations between these apparently disparate disturbances in very different regions. The balloon was some 10-20 km above the top of the thunderstorm activity (at $\sim$ 10 km) but some 60 to 70 km below the bottom of the E region ionosphere. The thunderstorm was localised and centred some 30-40 km north-west of the balloon launch site in Roberval, Quebec. In contrast the substorm was a worldwide event. Magnetograms from the USSR, Alaska, Canada and Greenland showed that magnetic perturbations due to the magnetospheric substorm were present all around the auroral zone. The balloon was instrumented to measure vertical and horizontal electric fields, electrical conductivity and X-ray emissions. The latter provide information on energetic electrons precipitated from the magnetosphere but which are stopped at much higher altitudes than the balloon's flight height. On the ground VLF (very low frequency) radio receivers, goniometers and other equipment for support measurements were deployed.

The d.c. electric field at the balloon was dominated by the presence of the thunderstorm. There are uncertainties in extrapolating the observed field upwards to the ionosphere. On this flight a reasonable estimate suggests the thunderstorm charge distribution should produce a field of 10^{-7} V m^{-1} in the ionosphere. In contrast the detection of echoes by the Cornell University auroral radar which was operating during the flight shows the actual ionospheric field must have exceeded 10^{-2} V m^{-1}. It seems safe to say the thunderstorm electric field had no effect on the magnetosphere and ionosphere.

Thunderstorms are a strong source of a.c. signals in the atmosphere and these can penetrate upwards far more effectively. Lightning flashes associated with the storm generate ULF (ultra low frequency) and VLF electromagnetic noise. In the 1-30 kHz VLF band lightning-flashes have long been known as a source of whistler mode plasma waves in the magnetosphere. A complicated interaction between magnetosphere and atmosphere can then be envisaged because lightning-launched whistler mode signals can interact with the magnetospheric energetic electron population. In particular, waves can scatter electrons onto orbits which bring them down into the atmosphere or lower ionosphere along the Earth's magnetic field. Here they experience collisions and in particular generate secondary X rays. The X-ray emissions seen on the balloon flight were of the microburst type, short bursts ($<$ 1 s) which characteristically occur during substorms. A key question thus was, were any microbursts caused by lightning-induced VLF? The authors argue there were. Their test is to look at how many microbursts occur within 1.5 s of a lightning flash. 62 out of 95 nearby flashes appeared to have closely correlated bursts of electron precipitation following them. The authors estimate a 1% probability of this being chance.

The flashes also produce substantial power in the much lower ULF band ($<$ 1 Hz). They conclude this could have a substantial effect in the ionosphere and suggest the thunderstorm-induced ionospheric ULF field could considerably exceed the substorm-induced ULF fields in the ionosphere. Whether this is of significance in magnetospheric terms is another matter. No measurements were made of magnetospheric parameters that could have been directly affected (such as ion precipitation).

The authors' most surprising measurement is that of the local electrical conductivity. It is about half its fair weather value. This certainly contradicts electrical coupling mechanisms between atmosphere and magnetosphere which invoke a substorm-induced conductivity enhancement as a trigger in a coupling mechanism.

All in all the report cuts down our ability to speculate on electric coupling of magnetosphere and atmosphere. D.C. coupling seems unimportant. The conductivity measurement is a puzzle. It does seem ULF and VLF phenomena can couple but such coupling should not be of dynamic significance in either region. The hard fact is we seem no nearer a substantive connection. □

D.J. Southwood is in the Blackett Laboratory, Imperial College, London.

0028-0836/80/17599-02$01.00