Contrails reduce daily temperature range

A brief interval when the skies were clear of jets unmasked an effect on climate.

The potential of condensation trails (contrails) from jet aircraft to affect regional-scale surface temperatures has been debated for years[1–3], but was difficult to verify until an opportunity arose as a result of the three-day grounding of all commercial aircraft in the United States in the aftermath of the terrorist attacks on 11 September 2001. Here we show that there was an anomalous increase in the average diurnal temperature range (that is, the difference between the daytime maximum and night-time minimum temperatures) for the period 11–14 September 2001. Because persisting contrails can reduce the transfer of both incoming solar and outgoing infrared radiation[4,5] and so reduce the daily temperature range, we attribute at least a portion of this anomaly to the absence of contrails over this period.

We analysed maximum and minimum temperature data[6] from about 4,000 weather stations throughout the conterminous United States (the 48 states not including Alaska and Hawaii) for the period 1971–2000, and compared these to the conditions that prevailed during the three-day aircraft-grounding period. All sites were inspected for data quality and adjusted for the time of observation.

Because the grounding period commenced after the minimum temperatures had been reached on the morning of 11 September and ended before maximum temperatures were attained on 14 September (at noon, Eastern Standard Time), we staggered the calculation of the average diurnal temperature range (DTR) across adjacent days (for example, 11 September maxima minus 12 September minima). We repeated this procedure for the three-day periods immediately before and after the grounding period, and also for the same periods (8–11, 11–14 and 14–17 September) for each year from 1971 to 2000.

DTRs for 11–14 September 2001 measured at stations across the United States show an increase of about 1.1 °C over normal 1971–2000 values (Fig. 1). This is in contrast to the adjacent three-day periods, when DTR values were near or below the mean (Fig. 1). DTR departures for the grounding period are, on average, 1.8 °C greater than DTR departures for the two adjacent three-day periods.

This increase in DTR is larger than any during the 11–14 September period for the previous 30 years, and is the only increase greater than 2 standard deviations away from the mean DTR (s.d., 0.85 °C). Moreover, the 11–14 September increase in DTR was more than twice the national average for regions of the United States where contrail coverage has previously been reported to be most abundant (such as the midwest, northeast and northwest regions)[7].

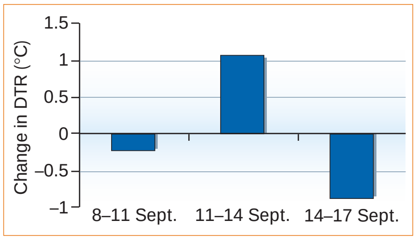

Figure 1 Departure of average diurnal temperature ranges (DTRs) from the normal values derived from 1971–2000 climatology data for the indicated three-day periods in September 2001. These periods included the three days before the terrorist attacks of 11 September; the three days immediately afterwards, when aircraft were grounded and there were therefore no contrails; and the subsequent three days.

Day-to-day changes in synoptic atmospheric conditions can affect regional DTRs[8]. In particular, a lack of cloud cover helps to increase the maximum (and reduce the minimum) temperature. Maps of the daily average outgoing long-wave radiation (OLR)[9,10] — a proxy for optically thick clouds — show reduced cloudiness (that is, larger OLR) over the eastern half of the United States on 11 September, but more cloud (smaller OLR) over parts of the west. Cloud cover subsequently decreased in the west and increased over much of the eastern half of the country during the next two days, producing predominantly negative three-day OLR changes in the east and positive values in parts of the west.

Our findings indicate that the diurnal temperature range averaged across the United States was increased during the aircraft-grounding period, despite large variations in the amount of cloud associated with mobile weather systems (Fig. 2). We argue that the absence of contrails was responsible for the difference between a period of above-normal but unremarkable DTR and the anomalous conditions that were recorded.

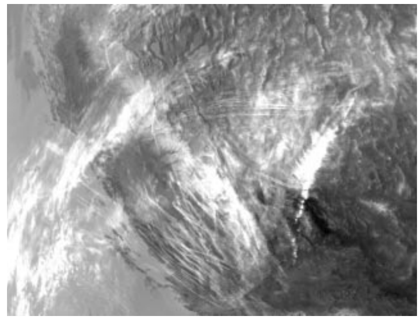

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Figure 2 Flight lines: jet contrails can clearly be seen as thin streaks in this satellite image of the southwestern United States.

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Animal behaviour

Male parenting of New Guinea froglets

Male parental care is exceptionally rare in nature, although one of the most fascinating aspects of New Guinea's biodiversity is the evolution of male care in the frog family Microhylidae[1]. Here I report a new mode of parental care: transport of froglets by the male parent, which was recently discovered in two species of microhylid frogs from the mountains of Papua New Guinea. As the offspring jump off at different points, they may benefit from reduced competition for food, lower predation pressure and fewer opportunities for inbreeding between froglets, which may explain why this unusual form of parental care evolved.

I quantified the parental care behaviour of several species of microhylid frog at the Crater Mountain Biological Research Station, Chimbu Province, Papua New Guinea (6° 43′ S, 145° 05′ E), which is located on the largest tropical island in

Figure 1 A male *Liophryne schlaginhaufeni* transporting froglets. Eleven froglets are visible (out of 22 in total) on the lateral and dorsal surfaces of the adult. The froglet located on top of the father's head is preparing to jump off.

remote rainforest at 800–1,350 m, where the topography and rainfall (6.4 m per year)[2] are extreme. All microhylid frogs on New Guinea are thought to develop directly from eggs, skipping the aquatic tadpole stage and hatching as miniature versions of the adults[3].

Among the many (more than 20) microhylid species at this site, I discovered that, in addition to guarding eggs, males of at least two species (*Liophryne schlaginhaufeni* and *Sphenophryne cornuta*) transport the froglets after they have hatched (Fig. 1). I observed 23 froglet-transport events: 9 in *S. cornuta* and 14 in *L. schlaginhaufeni*. In all of the 19 cases for which the sex of the transporting individual was ascertained, froglets were transported by the male.

Five entire transport-clutches (from eggs to independent froglets) were seen in *L. schlaginhaufeni*, with males carrying froglets for three to nine nights (mean $\pm$ s.d., 6.6 ± 2.6; $n = 5$) and travelling 0–17 metres each night (7.6 ± 4.19; $n = 29$) through herbaceous vegetation, and seeking refuge under the leaf litter of the forest floor during the day. Total transportation distances ranged from 34 to 55 m (44.4 ± 8.7 m; $n = 5$).

The regular dispersal pattern of froglets has potential benefits. Froglets distributed themselves evenly over time (fewer than seven froglets dispersing per night; 3.6 ± 1.7; $n = 49$) and space (between 0.4 and 5.5 m; 3.3 ± 0.7 m; $n = 49$) by individually jumping off the transporting male. The rewards accrued by the froglets might include less competition for food, a lower chance of predation and a decreased potential for inbreeding because they are widely dispersed.

Male parental care in other frog families includes both attendance and transport of eggs and tadpoles, but not froglet transport[4]. Froglet transport has only been reported for females in a single species, the Jamaican cave-breeding frog *Eleutherodactylus cundalli*[5], and has either not been observed in New Guinean frogs[6] or has been only briefly described without identification of the species or sex of the caring adult[7].

Uniparental male care is extremely rare in terrestrial vertebrates[8]. Even in groups with male care, most species display maternal or biparental care, or no care at all. The microhylid frogs of New Guinea are the only known large group (over 150 species in about 20 genera) of terrestrial vertebrates in which male care predominates. Comparative cost–benefit analyses should provide insights into the evolution of this behaviour and the role of parental care in the radiation of microhylid frogs on New Guinea, adding to our understanding of the environmental and/or historical conditions under which male parental care evolves.

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Cosmology

Black holes constrain varying constants

There is evidence to suggest that the fine-structure constant, α — a measure of the strength of the electromagnetic interaction between photons and electrons — is slowly increasing over cosmological timescales[1–4]. As $\alpha = e^2/\hbar c$ (where e is the electronic charge, $\hbar$ is Planck's constant and c is the speed of light), this would call into question which of these fundamental quantities are truly constant. Here we consider black-hole thermodynamics as a test of which constants might actually be variable, discounting those that could lead to a violation of the generalized second law of thermodynamics.

Observational evidence suggests that there has been a variation of $\Delta\alpha/\alpha = -0.72 \pm 0.18 \times 10^{-5}$ over the past 6–10 billion years[1]. This result could be interpreted as supporting some non-standard cosmological theories that invoke varying the speed of light[5–7] or the electronic charge[8]. It has been shown[9] that a varying-c cosmology, through changes to standard units, can be rephrased as a varying-e theory, similar to the one proposed earlier[8]. If attention is restricted to electromagnetic phenomena, there is no observational difference between the theories, and either c or e could account equally well for the variation in α. However, there may be fundamental theoretical reasons concerned with gravitation to favour varying c over varying e.

One way to introduce gravitation into the discussion is through the theory of black-hole thermodynamics. Entropy is associated with the area of a black hole's event horizon[10,11], leading to a generalized second law of thermodynamics in which the event horizon's area may only decrease if there is a corresponding increase in the conventional entropy of the black hole's environment[10,11].

In the case of a non-rotating black hole with electric charge Q and mass M, the area of its event horizon, A_H, is obtained in conventional general-relativity theory from the Reissner–Nordström solution of Einstein's field equations

$$A_H = 4\pi r^2 \qquad (1)$$

where

$$r = \frac{G}{c^2}[M + \sqrt{M^2 - Q^2/G}] \qquad (2)$$

The entropy of a black hole is given by $S_H = (kc^3/G\hbar)A_H/4$, which becomes

$$S_H = \frac{k\pi G}{\hbar c}[M + \sqrt{M^2 - Q^2/G}]^2 \qquad (3)$$

where k is Boltzmann's constant.