Sunny Days On Other Worlds

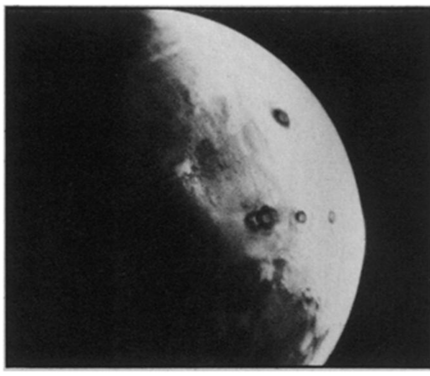
The sunshine that drives the earth's weather systems also has significant effects on the outer planets

BY JONATHAN EBERHART

During the summer of 1974, some 4,000 people from about six dozen countries spent 14 weeks conducting the mammoth field operations of GATE, first major project in the years-long Global Atmospheric Research Program, or GARP. Yet their labors were far from global. Instead, the GATE forces were concentrated in a swath across the Atlantic, extending only 20°N and 10°S of the equator.

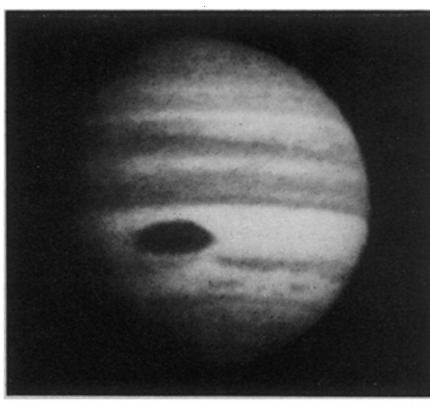
Half of all the solar radiation reaching the earth falls on the tropics, from there to be carried poleward as heat by the oceans and the atmosphere. So great is the latitudinal difference in incoming solar energy, that the GATE researchers knew that no such global study could be meaningful without an emphasis on the region of the "heat engine" that drives the world's weather. Equatorial currents, midlatitude storms and circumpolar winds are only a few of the phenomena related to the differing angles with which the sun shines on different parts of the world.

The same effect is true for other planets with atmospheres. Although the effect is sharply reduced with increasing distance from the sun, it is still a contributing factor to the climate, weather and global circulation of the outer worlds in the solar system. For this reason, Joel S. Levine of the NASA Langley Research Center, together with David R. Kraemer and William R. Kuhn of the University of Michigan, have calculated the latitudes and seasonal effects in the amount of sunshine reaching the tops of the atmospheres of the five major planets beyond the earth.



Viking 1/NASA

Atmosphere affects sunshine on Mars.



Pioneer 11/NASA

Self-warming Jupiter hardly needs sun.

The calculations themselves, Levine says, are easy. Back-of-an-envelope stuff. Thus it's a little strange, but apparently true, he says, that they've never before been published. All the stranger, perhaps, considering the wide range of planetary studies to which they could make a difference.

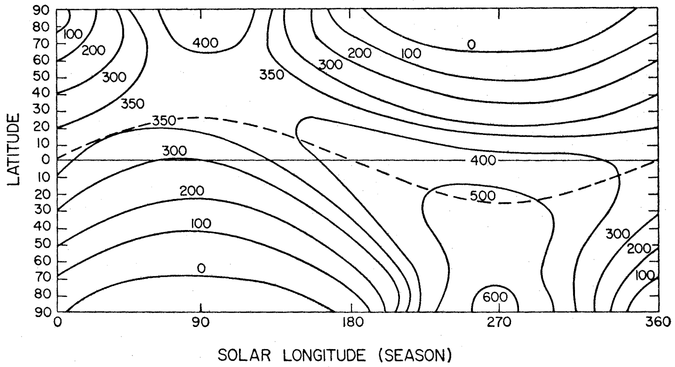
When the oblateness of the Martian atmosphere, for example, was calculated from a stellar occultation, the earth-Mars-sun geometry was such that the star disappeared behind a dark limb of the planet (as seen from earth) but reemerged from behind an illuminated limb. This could have been reason to worry that the asymmetry of the solar input might distort the shape of the atmosphere, but careful study of a 1971 stellar occultation by Jupiter with a similar asymmetry showed no such effect. Oblateness measurements, however, are critically dependant on knowing the latitudes of the star's disappearance and reemergence. A look at Levine and colleagues' data shows: (1) that the solar input to the top of the atmosphere is much greater for Mars at *any* latitude, possibly amplifying diurnal effects, and (2) that the ratios of solar input at different latitudes are different for the two planets, making interplanetary comparisons complicated.

Another important factor is the amount of the sun's radiation that actually gets into the depths of the atmosphere rather than reflecting away or being absorbed by dust particles or aerosols. Levine's group

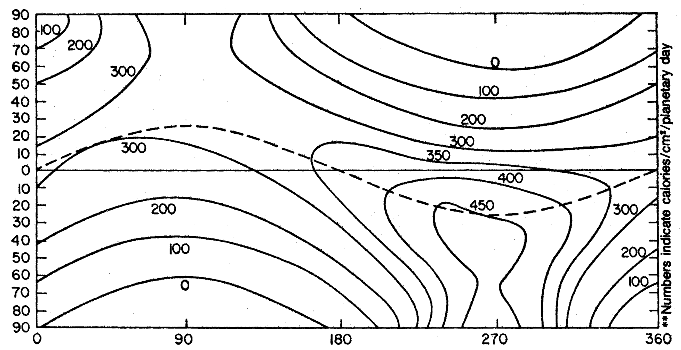
Lat.	Mars: Top of atmosphere	Surface ($\tau = 0.1$)	Surface ($\tau = 0.35$)	Surface ($\tau = 2.0$)	Jupiter	Saturn	Uranus	Neptune
85	0.167×10^3	0.118×10^3	0.559×10^2	0.877	0.128×10^1	0.191×10^1	0.108×10^1	0.279
80	0.170×10^3	0.121×10^3	0.599×10^2	0.143×10^1	0.239×10^1	0.194×10^1	0.107×10^1	0.283
75	0.176×10^3	0.128×10^3	0.666×10^2	0.232×10^1	0.352×10^1	0.200×10^1	0.106×10^1	0.289
70	0.185×10^3	0.137×10^3	0.759×10^2	0.352×10^1	0.463×10^1	0.208×10^1	0.105×10^1	0.299
65	0.198×10^3	0.150×10^3	0.871×10^2	0.501×10^1	0.571×10^1	0.219×10^1	0.103×10^1	0.311
60	0.217×10^3	0.167×10^3	0.997×10^2	0.677×10^1	0.675×10^1	0.236×10^1	0.101×10^1	0.330
55	0.238×10^3	0.186×10^3	0.114×10^3	0.874×10^1	0.774×10^1	0.256×10^1	0.987	0.355
50	0.259×10^3	0.206×10^3	0.129×10^3	0.109×10^2	0.867×10^1	0.277×10^1	0.960	0.381
45	0.279×10^3	0.225×10^3	0.144×10^3	0.132×10^2	0.954×10^1	0.297×10^1	0.932	0.408
40	0.297×10^3	0.243×10^3	0.158×10^3	0.156×10^2	0.103×10^2	0.316×10^1	0.901	0.433
35	0.315×10^3	0.260×10^3	0.172×10^3	0.180×10^2	0.110×10^2	0.334×10^1	0.871	0.456
30	0.330×10^3	0.275×10^3	0.185×10^3	0.204×10^2	0.117×10^2	0.350×10^1	0.839	0.477
25	0.344×10^3	0.288×10^3	0.196×10^3	0.227×10^2	0.122×10^2	0.364×10^1	0.808	0.496
20	0.355×10^3	0.299×10^3	0.206×10^3	0.247×10^2	0.127×10^2	0.375×10^1	0.778	0.511
15	0.364×10^3	0.308×10^3	0.213×10^3	0.264×10^2	0.130×10^2	0.384×10^1	0.752	0.523
10	0.370×10^3	0.314×10^3	0.219×10^3	0.277×10^2	0.133×10^2	0.391×10^1	0.730	0.532
5	0.374×10^3	0.318×10^3	0.222×10^3	0.285×10^2	0.134×10^2	0.395×10^1	0.717	0.537
0	0.375×10^3	0.319×10^3	0.223×10^3	0.288×10^2	0.135×10^2	0.396×10^1	0.714	0.539

Table and diagrams: J.S. Levine et al./Icarus

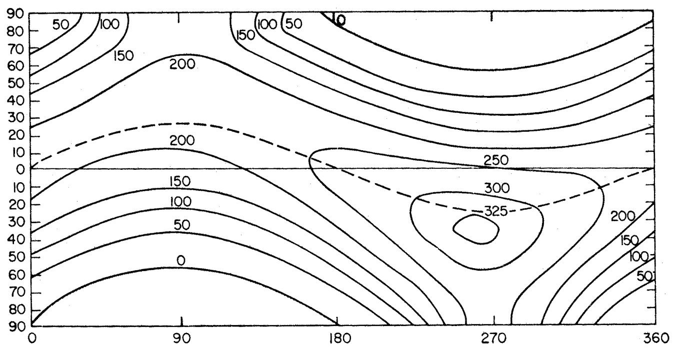
Mean annual daily solar radiation, in calories per square centimeter per planetary day, reaching the top of the Martian atmosphere, the Martian surface under different atmospheric opacities, and the tops of the atmospheres of the four major outer planets.



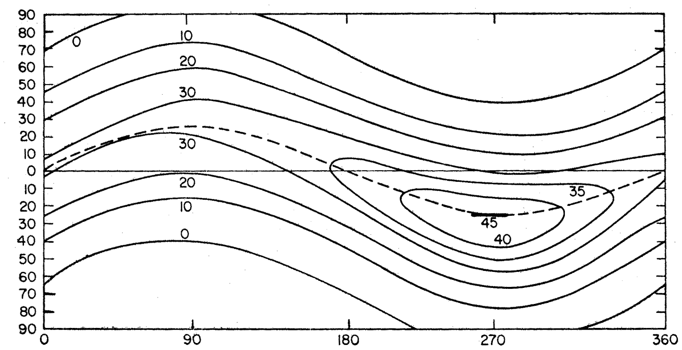
Mars: *Southern half shows hotter summer, colder winter.*



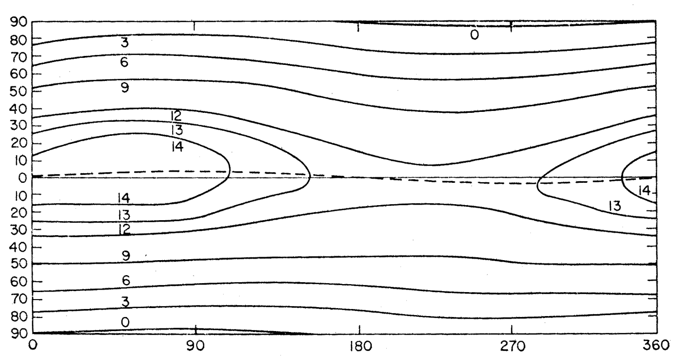
A little haze (optical depth 0.1) cuts surface temperatures.



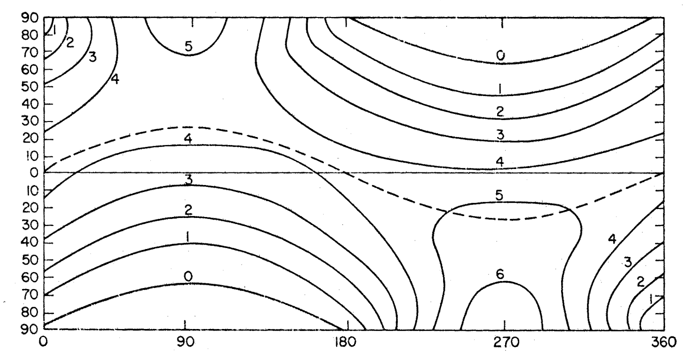
Small opacity increase (to 0.35) cools surface substantially.



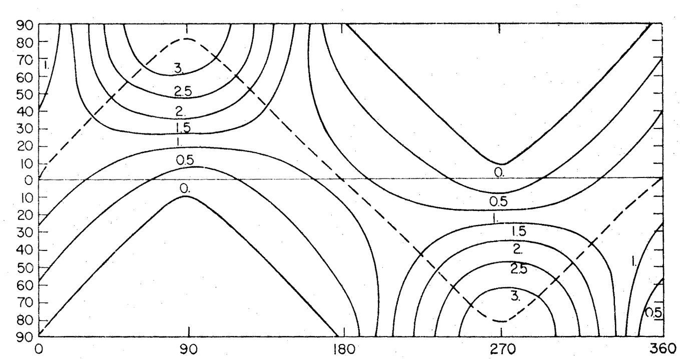
Martian dust storm (2.0) brought wintry chills everywhere.



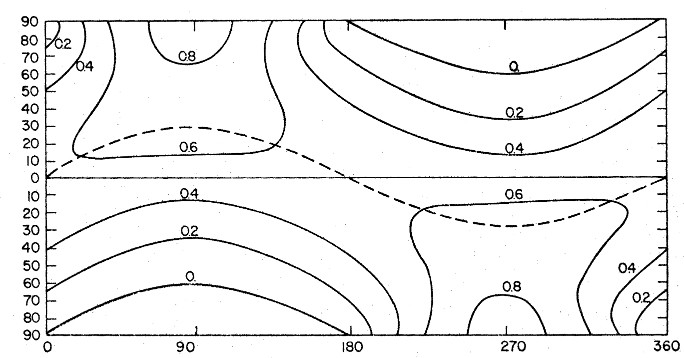
Jupiter: *Upright axis, internal heat create balanced seasons.*



Saturn: *Mars-like axial tilt makes similar seasonal patterns.*



Uranus: *Near-horizontal axis yields half-year-long seasons.*



Neptune: *If weather varies, it's probably not from the sun.*

calculated the amount reaching the surface of Mars for different atmospheric opacities, or "optical depths," and the differences are striking.

At 45° latitude, for example, 279 calories of solar energy strike each square centimeter of the top of the atmosphere in one Martian day. If the atmosphere is clear enough for 90 percent of this energy to reach the surface from directly overhead (an optical depth of 0.1), only 225 calories will get there at 45°. A relatively slight increase in opacity (to an optical depth of 0.35), allowing 70 percent of the radiation through, yields only 144 calories. At the time of the huge Martian dust storm of 1971, the optical depth rose to 2.0, Levine says, letting through only 14 percent of the radiation. As a result, just 13.2 of those 279 calories were reaching the ground. In fact, the researchers report in ICARUS (31:136), others have calculated that the solar radiation absorbed by windblown dust during the storm was enough to increase the temperature of the lower atmosphere by 25°K (45°F) in a day. For the aerosol-rich atmosphere of Jupiter, it could be equally important to take optical depths into account, and the numbers are undoubtedly different.

Many of those using Levine et al.'s tables will also have to take another factor into account: a planet's own contribution to the heating of its atmosphere. Data from the Pioneer 10 and 11 spacecraft indicate that Jupiter, for example, emits 1.9 (±0.2) times as much energy as it receives from the sun. For the earth, which lacks massive Jupiter's extreme gravitational heating, the number is only about 0.0001, and Mars, according to Viking scientist Hugh Kieffer of UCLA, is probably in a similar or even lower range. Estimates for Saturn are diverse, but they are in a range that one might expect for a gas-giant planet—about 1.4 to 2.5. There is no evidence for internal heating on Uranus, says David Morrison of NASA, but Neptune, which is still farther from the sun, has at least been reported to emit more strongly than Uranus at thermal infrared wavelengths. That far away, even a small internal contribution might have a real effect on the atmosphere.

Levine, Kraemer and Kuhn based their calculations on the solar constant (taken to be 1.94 calories per square centimeter per minute) at the mean distance from the sun to the earth. To plot seasonal variations, they had to include each planet's angle of inclination, orbital semimajor axis, eccentricity and direction of perihelion. These combine to show, for instance, how each planet is tilted when it is closest to the sun.

The measurements are expressed as solar input per *planetary* day for each planet, which meant that rotational period had to be involved. But for two of the planets, this introduces a problem. The authors assign Uranus a 10.82-hour day, a commonly used estimate that dates back some 40 years. In 1975, however, one research team reported it to be 12.3 hours, based on Fraunhofer line broadening (SN: 6/28/75, p. 410). Early in 1977, another group used spectral-line "tilt" to conclude that a day on Uranus is somewhere between 21 and 25 hours long (SN: 1/22/77, p. 58). The same technique resulted in an 18-to-26-hour day for Neptune, quite different from the 15.8 hours cited by the Levine group's source. Fortunately, there is an easy way out. For any of the solar input measurements, it is a simple matter of multiplying the number by the ratio between the chosen rotational period and the suspect one. If the length of the day doubles, so does the daily solar input.

One of the striking features visible in the data is the difference in seasonal effects for each planet, due to rotational and orbital characteristics. Mars has a longer, colder winter in the south than in the north, but also a warmer summer. Jupiter has almost no such hemispherical asymmetry, the authors point out, since it has a much less extreme axial tilt. (They add that the solar radiation absorbed by the Jovian atmosphere probably varies much less with latitude than does the amount merely reaching the cloud tops, since low- and midlatitude clouds would reflect a signficant amount of at least visible radiation.)

Saturn's insolation pattern is far different from Jupiter's, and much like that of Mars. Some researchers, in fact, have cited the insolation difference between Saturn and Jupiter as evidence for significant internal heating on the ringed planet, since similar cloud patterns—horizontal banding—show on both worlds. The true distribution of incoming solar radiation atop the atmosphere of Saturn is probably more complicated, Levine's group points out, since the shadow of the rings almost certainly has an effect.

Uranus is the true eccentric of the solar system. Tilted 98° to the ecliptic, the planet has its "northern" hemisphere (defined by direction of rotation) slightly below the ecliptic and the "southern" hemisphere above. In fact, since the axis of rotation is so close to the plane, one might almost say that Uranus has east and west poles instead of north and south. Even those terms are troublesome, however, since the rotation axis, like those of other, less-tilted planets, is fixed relative to the star background, not to the sun. A year on Uranus is about 84 earth-years long, which means that some parts of the planet are in perpetual darkness (or light) for 42 years at a time. If the tiny amount of insolation that gets out to Uranus has any effect at all, it must be a strange one, since there would be decades for temperature (and resulting condensate) differences to build up between the light and dark hemispheres.

Neptune is more conventional, with perihelion occuring close to the vernal equinox so that there is little if any seasonal asymmetry. It has been reported, however, that Neptune brightened appreciably in the 1-to-4 micron band from early 1975 through early 1976 (SN: 1/29/77, p. 72)—a finding that was described as the first observation of "weather" on Neptune. So at least something is going on.

"Climatology" may seem a strange word to use in connection with distant, gaseous worlds such as Jupiter and Saturn, but many of the same forces that affect the climate and weather of earth are also at work on the remote planets of the solar system. □