Reports

Long-Term Brightness Variations of Neptune and the Solar Cycle Modulation of Its Albedo

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The visual brightness and albedo of Neptune vary periodically during the 11-year solar cycle with an amplitude of 4%, anticorrelated with the variation of solar ultraviolet output. A seasonal trend in color suggests that Neptune, like Uranus, may have a slightly reddened pole.

A CYCLIC SOLAR-PLANETARY CLIMATE effect appears to exist for the planet Neptune, whose visual brightness, monitored systematically since 1972 by using photoelectric photometry, varies during the solar cycle with an amplitude of 4%. Brightness maximum of Neptune coincides with solar minimum, and brightness minimum with solar maximum. Subtle and elusive sun-climate and sun-weather effects are suspected and sought as a high priority of terrestrial atmospheric research (*1*). Although these effects may occur in the atmospheres of other solar system bodies, for example, Titan and Uranus, the evidence for a solar cycle effect in Neptune's atmosphere is uniquely compelling.

Neptune's global atmospheric properties vary periodically, modulating the geometric albedo, the transfer of radiation through the atmosphere, and the planetary energy budget. Examination of weather systems and details of the atmospheric structure of this distant, cold planet, where the intensity of sunlight is roughly 1/900 of that on Earth, awaits the August 1989 encounter by the Voyager spacecraft.

Since the solar spectral irradiance apparently does not vary perceptibly in visible light (*2*), a causal mechanism is not immediately obvious. However, solar cycle irradiance variations are known to occur at ultraviolet wavelengths, phased fairly closely with the magnetic activity that defines the 11-year sunspot cycle and the 22-year magnetic cycle. Through a photochemical mechanism, these variations provide a periodically changing input to Neptune's climate system.

In visible light, Neptune appears as a tiny, featureless object, 2 arc seconds in diameter. However, discrete clouds have been seen in methane-band images in the near-infrared (*3*), and there is sometimes enough variegation in the atmosphere to permit a photometric determination of the rotation period, which is about 18 hours (*4*). A unique episode of "weather" on Neptune was observed in early 1976 when its brightness in the wavelength region from 1 to 4 μm was found to have more than doubled since the 1975 apparition (*5*). Over a period of several months, the brightness returned nearly to previous levels. The increase was attributed to the formation of a high-altitude aerosol cloud of micrometer-sized condensates that left the visible spectrum and brightness essentially unchanged (*6*).

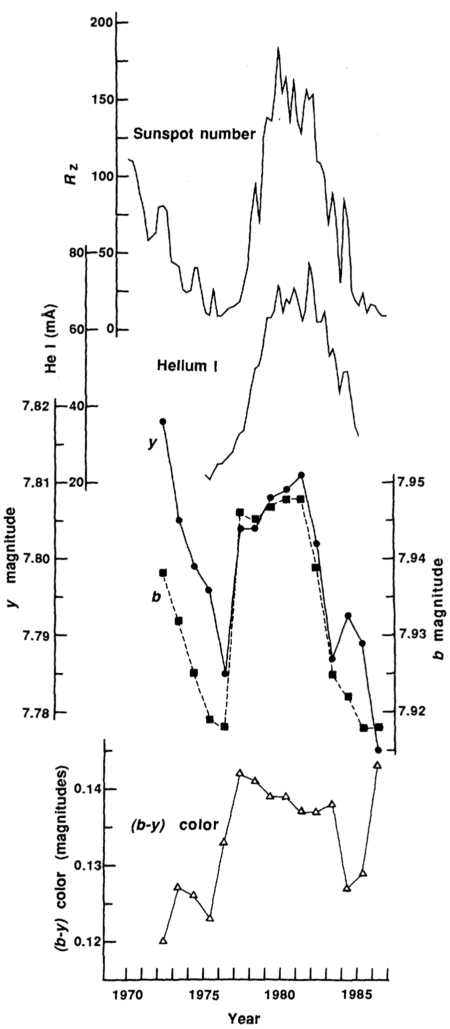

Fig. 1. Smoothed sunspot number (R_z) and strength of He I at 1083 nm; the b and y annual mean magnitudes of Neptune plotted inversely (brightness increasing downward); $(b - y)$, color of Neptune.

Observations in visible light were made with the 0.5-m telescope and photoelectric photometer at the Lowell Observatory, usually on ten nights per season from 1972 through 1986 (*7*). Neptune's image is so small and starlike that global brightness measurements are easily made with a stellar photometer; included in the field of view is Neptune's nearby faint satellite Triton, whose additional light contribution is negligible (*8*). Interference filters about 20 nm wide at 472 and 551 nm define the blue (b) and yellow (y) magnitudes, respectively (*9*). The b filter is dominated by reflected sunlight, but the y filter also includes a weak methane band in Neptune's atmosphere at 543 nm.

In each season, differential observations were made relative to two solarlike stars of similar brightness and color to Neptune that were located nearby in the sky (within 2°). An ongoing series of separate measurements each season established the relative magnitudes of the yearly pairs of comparison stars, which now include 15 sets of stars extending along a 30° section of the ecliptic. Since two comparison stars were always measured, a comparison star that may be variable can be unambiguously identified independently of the variability of Neptune itself. Data acquisition, reduction, and analysis followed a highly standardized procedure (*10*).

Mean annual b and y magnitudes and $(b - y)$ colors of Neptune are given in Table 1 along with the internal (night-to-night) standard deviation for each season and the number of nights of observation. The nightly standard deviation of the differential observations is typically 0.003 mag (0.3%), yielding a standard deviation of the annual mean of about 0.1% (assuming that the n values are an adequate sample of the yearly variation). The year-to-year accuracy is about 0.3% (standard deviation plus all known sources of systematic error, including the interseasonal links to new comparison stars). In Table 1, the final planetary magnitudes have been adjusted to a standard heliocentric distance of 30.071 astronomical units (AU) (*11*), and to a solar phase angle of 0°, by using solar phase coefficients of +0.007 mag deg^{-1} in y and +0.004 mag deg^{-1} in b (*7*). Because the maximum attainable solar phase angle of Neptune viewed from Earth is only 2°, the solar phase correction is quite small, and its uncertainty is

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Table 1. Annual mean magnitudes of Neptune.

Year	n*	y	SD	b	SD	$(b - y)$	SD
1972	12	7.818	0.002	7.938	0.002	0.120	0.003
1973	18	7.805	0.004	7.932	0.004	0.127	0.004
1974	20	7.799	0.004	7.925	0.003	0.126	0.004
1975	8	7.796	0.005	7.919	0.004	0.123	0.004
1976	9	7.785	0.005	7.918	0.004	0.133	0.004
1977	11	7.804	0.002	7.946	0.003	0.142	0.003
1978	20	7.804	0.003	7.945	0.004	0.141	0.004
1979	15	7.808	0.005	7.947	0.004	0.139	0.004
1980	9	7.809	0.007	7.948	0.006	0.139	0.005
1981	10	7.811	0.004	7.948	0.003	0.137	0.003
1982	6	7.802	0.006	7.939	0.002	0.137	0.006
1983	7	7.787	0.004	7.925	0.004	0.138	0.006
1984	7	7.795	0.003	7.922	0.004	0.127	0.005
1985	7	7.789	0.007	7.918	0.007	0.129	0.004
1986	9	7.775	0.009	7.918	0.007	0.143	0.005

*Number of nights of observation.

completely negligible, as is the correction for changing heliocentric and geocentric distances.

The photometric observations date from 1972, midway down the declining phase of solar cycle 20, and include nearly all of cycle 21, which will probably end in 1987. Minimum solar activity marking the start of cycle 21 occurred in 1976, and the maximum was reached in late 1979. During the most active years of cycle 21, calibrated ultraviolet fluxes of the sun were obtained at 205 nm by the solar-backscattered ultraviolet instrument on board the Nimbus 7 spacecraft. The comparison of contemporaneous ground-based measurements of the chromospheric He I absorption line at 1083 nm, made at the Kitt Peak National Observatory since 1974, showed that this line is an excellent predictor of the ultraviolet solar output (*12*). The He I measurements continued on a near-daily basis, providing a proxy record of ultraviolet output for all of solar cycle 21, during which the 205-nm flux was estimated to vary by 13%.

Solar extreme ultraviolet fluxes, measured by the AE-E satellite between 1977 and 1980 at wavelengths below 185 nm (including the He I line at 58.4 nm and the H I Lyman β line at 102.6 nm), likewise follow the He I 1083-nm variations, but vary by a factor of 2 or more depending on the wavelength (*13*). This spectral region is important in the photochemistry of planetary atmospheres because ultraviolet photons below 145 nm photolyze methane (*14*). Although the ultraviolet output follows fairly closely the conventional indices of solar activity, such as the sunspot number, significant differences occur—ultraviolet minimum preceded the 1976 magnetic minimum by about 1 year, and ultraviolet maximum was delayed about 2 years after the 1979 magnetic maximum.

Figure 1 shows the variation of the sunspot number and the equivalent width of He I smoothed by a 3-month median. The b and y magnitudes, plotted inversely (with brightness increasing downward), illustrate the anticorrelation between the brightness of Neptune and the two indices of solar activity. A cross-correlation of planetary magnitudes and solar indices peaks at 0 years lag for both the proxy solar ultraviolet output and magnetic activity. Near solar maximum, however, the shape of the planetary light curves favors an association with ultraviolet output—the sunspot number peaked steeply in 1979, while He I and the 205-nm flux trended upward through 1981, corresponding to a slow decrease in the brightness of Neptune. However, around the 1976 solar minimum, Neptune's brightness more closely followed the declining sunspot number rather than the sharp rise in He I strength. On both occasions, the 0.3% errors of the photometry preclude drawing firm conclusions about the relative phasing of the light curve and solar indices.

The increase in Neptune's brightness in cycle 20 from 1972 to 1976 was apparently delayed relative to solar activity, while the comparable increase in cycle 21 from 1981 to 1986 is coincident. This delay may be an artifact of a superposed additional random or seasonal trend in the albedo of Neptune. Solar cycle 20 attained a much lower ultimate sunspot number than cycle 21, but we do not know if the ultraviolet variations in cycle 20 were similarly lower and similarly phased with respect to magnetic activity. The rising branch of the planetary light curve repeated after 9 years, whereas the corresponding phases of the solar cycles are separated by 11 years, the nominal solar cycle length. Evidently, the two phenomena are imperfectly phase-locked if the solar ultraviolet output in cycle 20 behaved as in cycle 21.

The 2% decrease in Neptune's brightness between 1976 and 1977 preceded the corresponding increase in solar activity, possibly an aftereffect related to the 1976 infrared brightening and the subsequent decay of the putative high-altitude cloud. In 1976, we observed a barely significant 1% linear decrease in visual brightness during the 2-month observing season (May to July); this decrease paralleled the decrease in the infrared (*5, 6*), which was 50 times as large.

Perhaps by chance, 1977 was also the year in which infrared observations first revealed a brightness modulation leading to the photometric determination of the rotation period of Neptune (*4*). Thus, in 1977 the atmosphere of Neptune was not completely homogeneous, and its visual brightness may have been temporarily perturbed, although the night-to-night variation was similar to that of other years.

The color of Neptune has also undergone a slight change during the course of our observing program, as shown by the 0.02 mag increase in $(b - y)$ color from 1972 to 1986 (Table 1 and Fig. 1). This subtle but statistically significant reddening trend appears unrelated to the solar cycle and may be evidence for long-term atmospheric changes. However, as Neptune's equator is inclined 28° to its orbit, a seasonal effect may be involved; the sub-Earth latitude on Neptune is currently $-26°$ and increasing as southern hemisphere summer approaches. Thus, Neptune may have a slightly reddened pole, as does Uranus (*15*).

A photochemical mechanism triggered by ultraviolet variations acting on the upper atmosphere of Neptune to produce or modify haze layers may explain the observed brightness variations, since methane can be photolyzed in the upper atmosphere of Neptune, producing a variety of condensates (*14*). The varying flux of solar wind particles and the accompanying modulation of galactic cosmic rays may also be important, but relevant in situ measurements at the distance of Neptune do not exist.

Physical data needed to create realistic atmospheric models will not be available until the 1989 Voyager encounter. However, photochemical models have been used to explain the temporal brightness changes of Titan, Saturn's satellite; these models are based on the photolysis of methane in an atmosphere composed mainly of nitrogen (*16*). They are of little applicability to Neptune, where the intensity of sunlight is less than 1/10 that at Titan, and where the principal atmospheric constituent is molecular hydrogen, as on Uranus.

A change in global albedo influences the overall planetary energy budget slightly, even though the thermal radiation from Neptune's internal heat source exceeds the solar energy deposition into its atmosphere by a factor of 2.5 (*17*). The periodicity of albedo variations appears to provide an input to global planetary weather systems on a short time scale relative to Neptune's 164-year period of revolution around the sun. Neptune's orbit is almost perfectly circular, so its changing distance from the sun caused only an insignificant 0.5% decrease in total insolation since 1972. What appears remarkable is the extraordinary sensitivity of Neptune's atmosphere to the modulation of the solar output.

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$$F_{205} = 8.56 + 0.0185 W_{1083} \text{ W cm}^{-3}$$

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A Novel Human Gene Closely Related to the *abl* Proto-Oncogene

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A DNA sequence related to the *abl* proto-oncogene was identified in human placenta. Molecular cloning and nucleotide sequence analysis revealed two putative exons whose predicted amino acid sequence was most homologous to the corresponding sequences of c-*abl* and v-*abl* but was related to other tyrosine kinase genes as well. The new sequence was localized by in situ hybridization and somatic cell genetic analysis to human chromosome 1q24–25, which differs from the location of any previously identified tyrosine kinase gene. The detection of a novel 12-kb transcript by this gene in human normal and tumor cells establishes it as a new member of the tyrosine kinase family that is closely related to but distinct from c-*abl*.

Proto-oncogenes are the normal counterparts of the oncogenes of acute transforming retroviruses (*1*). The normal functions of some of these genes are becoming increasingly better understood. Chain 2 of platelet-derived growth factor is encoded by the human *sis* proto-oncogene (*2*). A truncated version of the receptor for epidermal growth factor (EGF) is encoded by v-*erb*B (*3*), and the product of the *fms* proto-oncogene appears to be related to the receptor for macrophage colony-stimulating factor (CSF-1) (*4*). Both v-*erb*B and v-*fms*, as well as several growth factor and hormone receptors, are members of a family of tyrosine kinase–encoding genes (*5, 6*).

There are several examples of genetic alterations affecting members of the tyrosine kinase family in human tumors (*7–10*), including the specific translocation of the c-*abl* locus in chronic myelogenous leukemia (CML). Because of the significance of c-*abl* in neoplasia, we embarked on a search for other human tyrosine-kinase genes closely related to c-*abl*.

Additional members of some proto-oncogene families have been identified by finding their related sequences sufficiently amplified in particular tumors to allow detection (*9, 11, 12*). In order not to rely upon the fortuitous identification of tumor cells carrying amplified c-*abl*–related sequences, we attempted to detect such sequences in normal human DNA by molecular hybridization with a v-*abl* probe under conditions of low stringency. The tyrosine kinase–encoding domain of v-*abl* was selected as the probe, since this region is well conserved among members of the tyrosine kinase gene family.

Hybridization of the v-*abl* probe under stringent conditions with DNA prepared from human placenta revealed two Eco RI fragments (Fig. 1A, lane 2) that contained c-*abl* sequences, as expected (*13*). However, when hybridization was conducted under conditions of low stringency, an additional 12.5-kbp fragment was identified (Fig. 1A, lane 4). This 12.5-kbp fragment was not amplified in DNA from K562 (Fig. 1A, lane 3), a CML line that contains an amplified copy number of c-*abl*, further suggesting that the additional fragment did not represent c-*abl*.

To clone the 12.5-kbp fragment, an Eco

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