present. The data were averaged for the two sites for the summer period May through August and the winter period November through February. Then, 3-year moving averages were computed for each of these four sets (mean maximum summer, mean maximum winter, mean minimum summer, and mean minimum winter). Separate linear regressions of temperature on time were carried out for each of these data sets for the periods before and after 1946. The resultant slopes (warming trends) with their associated standard errors of estimate (in units of degrees Fahrenheit per year) for the period prior to 1946 were as follows: maximum summer, 0.100 ± 0.020; maximum winter, 0.019 ± 0.019; minimum summer, 0.019 ± 0.018; and minimum winter, 0.059 ± 0.023; the values for the period after 1946 were as follows: maximum summer, 0.039 ± 0.020; maximum winter, 0.048 ± 0.023; minimum summer, 0.083 ± 0.026; and minimum winter, 0.175 ± 0.021.

In relating these results to air pollution, reference was made to the study by Idso and Kangieser (*4*), wherein it was shown that there is a large diurnal and yearly vertical redistribution of dust over Phoenix. In winter, inversions and shallow mixing heights confine the surface-generated aerosol to a layer only 500 to 800 m deep, whereas in summer the less frequent inversions and greater mixing heights allow the aerosol to daily mix to heights on the order of 2500 m. In both seasons the aerosol is distributed to greater heights in the afternoon as compared to the morning, as a result of the degradation of the inversions with time through the day.

From detailed data in (*4*) on the occurrence and persistence of inversions, I calculated the percentage of the total time that inversions existed at the times of the four temperature measurements (midafternoon, summer; midafternoon, winter; early morning, summer; and early morning, winter). The first instance (midafternoon, summer, or mean maximum summer) showed no indications of inversions at all. Thus, it was not expected to exhibit any dust-induced greenhouse effect; and indeed it did not. Its mean warming trend since 1946 was actually less than that prior to 1946, in good agreement with the general world cooling trend observed by Mitchell (*5*) to have begun at about the same time as the pivotal year used here.

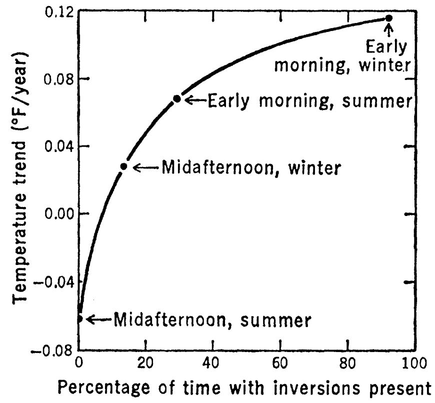

Fig. 2. Mean rate of temperature increase at Phoenix, Arizona, after 1946 relative to that prior to 1946 as a function of the percentage of the total time that inversions existed at the specific times and seasons represented by the four data points.

The changes in warming rates after 1946 relative to those prior to 1946 for all four periods are plotted as a function of the percentage of time of inversion existence in Fig. 2. A good curvilinear relation is seen to result, where the relative warming trend increases with the increasing percentage of time of inversion existence. Thus, the restriction of aerosols produced by human activity to low levels of the atmosphere does indeed appear to directly affect the climate at the earth's surface, causing mean air temperatures to rise significantly.

The final question, then, concerns the mechanism involved: Is it the solar or the thermal radiation interaction that is responsible for the apparent aerosol-induced warming effect? Two facts point to the latter mechanism. First, it has been shown experimentally that the thermal radiation interaction can indeed occur (*3*), whereas the solar radiation interaction that would cause a warming has only been theorized. Second, in postulating the solar radiation effect, Mitchell (*2*) has noted that it would be least likely to occur in "arid and urban areas," both of which conditions aptly describe Phoenix and its environs. Thus, both experiment and theory point to the thermal radiation interaction mechanism as the one responsible for the temperature effects described in this study.

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The Spiral Interplanetary Magnetic Field: A Polarity and Sunspot Cycle Variation

Abstract. *Spacecraft observations near the earth of the average direction of the interplanetary magnetic field during the sunspot maximum year 1968 showed a deviation from the spiral field of Parker's classical description. The included angle between the average field direction when the field polarity was away from the sun and the average direction when the field polarity was toward the sun was 168°, rather than 180° as predicted by Parker. This effect appears to have a sunspot cycle variation.*

The solar magnetic field is stretched out away from the sun by the solar wind plasma. Parker (*1*) has pointed out that the resulting interplanetary magnetic field should, on the average, have the form of an Archimedean spiral because of the combined effects of the radially flowing solar wind and a twisting induced by solar rotation. Near the earth the average radial solar wind velocity is approximately 400 km/sec, which is approximately equal to the azimuthal velocity of the solar rotation ΩR, where Ω is the sun's angular velocity and R is the distance from the sun to the earth, so that the average spiral angle α is about 45°.

Early spacecraft observations [reviewed by Wilcox (*2*)] showed that, on the average, the interplanetary magnetic field configuration was close to that described by Parker, and this theoretical picture is now widely accepted. In a recent investigation utilizing the several years of spacecraft observations of the interplanetary magnetic field that are now available, we have uncovered a variation in α observed near the earth having a dependence on the polarity of the field (away from or toward the sun) and on the time within the 11-year sunspot cycle. This effect may be considered as a perturbation of the basic description of Parker (*1*).

The effect may be described with reference to Fig. 1, in which the earth is at the center of the coordinate system and the direction of the earth's orbital velocity is toward the right. The average spiral angle of about 45° as described by Parker is represented by the dashed line. During the sunspot maximum year 1968 the observed average field directions were qualitatively as shown by the solid lines labeled "away" and "toward"; that is, the average spiral field direction was different when the polarity of the interplanetary field was away from the sun from what it was when the polarity was toward the sun. The included angle δ was about 168° rather than the expected 180°. The away and toward average field directions were symmetrically displaced from the 45° spiral line; that is, the average of α_A and α_T was approximately 45°.

The variation of this effect through a portion of a sunspot cycle is shown in Fig. 2B. The angle δ represents the yearly average of δ shown in Fig. 1, and points are plotted for each year. The spacecraft with which the observations were made is identified in the inset of Fig. 2B, and generally a few thousand hours of data go into each average. In the years 1967 and 1968 Explorer 33 and Explorer 35 observed essentially the same value of δ. This tends to reduce the possibility that the observed effect is an artifact, because the orbits and spin directions of these two spacecraft were very different. Explorer 33 was orbiting the earth with its spin axis nearly parallel to the ecliptic plane; Explorer 35 was orbiting the moon with its spin axis nearly perpendicular to the ecliptic plane. The probable error for Explorer 33 observations during 1968 is $\pm 1°$, and the probable errors for the other years are comparable.

Figure 2A shows the yearly averages of α, which is computed from hourly averages of α_A and α_T. The value of α remains within 1° or 2° of 45°, thus showing that the effect that we discuss tends to be symmetric about the Parker spiral angle (*1*), and also indicating that our numerical analysis has a re-

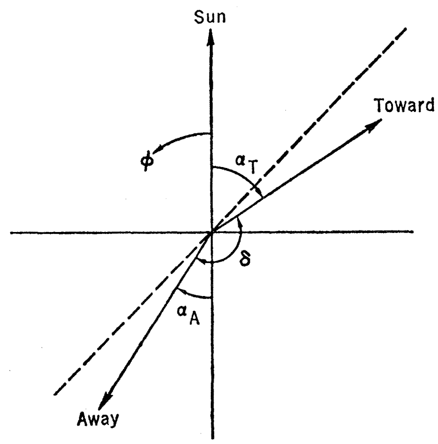

Fig. 1. Geometry of the interplanetary magnetic field. The earth is at the center of the coordinate system, and its orbital velocity is toward the right. The angles are defined in the text.

sulting scatter of only 1° or 2° as compared with a range in δ of almost 20° as shown in Fig. 2B.

We will now discuss possible physical explanations of this effect for the sunspot maximum year 1968, when the amplitude of the effect was the largest. Analogous considerations may be applied to the other years.

The most obvious possibility would be that the average solar wind velocity was considerably larger when the interplanetary field was directed away from the sun than when it was toward the sun, since in Parker's description (*1*) α is given by $\tan \alpha = \Omega R / V_S$, where V_S is the solar wind velocity. However, to explain the effect in this way during 1968 would require an extremely large difference in the two solar wind veloci-

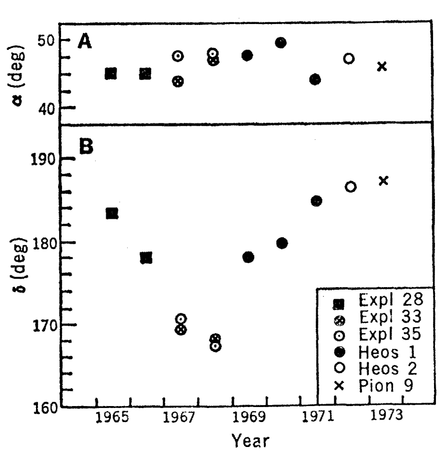

Fig. 2. (A) The average spiral angle α, which is equal to the average of α_A and α_T. (B) Yearly averages of the included angle δ defined in Fig. 1 through a portion of a sunspot cycle. The spacecraft with which the observations were made is identified in the inset.

ties. When the interplanetary field was away from the sun the average velocity would have to be 530 km/sec, and when the field was toward the sun the average velocity would have to be 350 km/sec. During the year July 1967 to July 1968 (the limits are set by spacecraft launch and failure of the instrument) the Massachusetts Institute of Technology solar wind plasma experiment on Explorer 35 had a computed average solar wind velocity of 470 km/sec while the field polarity was away from the sun and a computed average solar wind velocity of 455 km/sec while the field polarity was toward the sun. Thus the effect cannot be explained in terms of the average solar wind velocity.

Deflections in the direction of the solar wind velocity at the interface between steady corotating solar wind streams were predicted by Carovillano and Siscoe (*3*) and observed by Ness *et al.* (*4*). Such deflections would appear to be averaged out in the yearly averages considered here and should not contribute to the effect.

If magnetic reconnection were occurring only between a preceding sector in which the field polarity was away from the sun and a following sector in which the field polarity was toward the sun, the effect might be explained. But then δ would be very different near a boundary in which the field polarity changed from toward to away as compared with near a boundary in which the field polarity changed from away to toward. An analysis computing values of δ for 2-day intervals centered on sector boundaries showed that δ was the same within 2° irrespective of the direction of the polarity change across the boundary. The possibility of explaining the effect through magnetic reconnection is an attractive one, but it appears that the observations rule out any simple application of this explanation.

The effect is formally equivalent to a constant field of magnitude approximately one-fifth the spiral field directed normal to the usual spiral direction. Near the sun this would be equivalent to an azimuthal field that could be produced by an electric current flowing approximately along the sun's rotation axis from the nearby interstellar medium into the southern solar hemisphere and out of the northern solar hemisphere into the interstellar medium. We are not aware of any evidence for such a current, although Schatten and Wilcox (*5*) have discussed the possibility of magnetic reconnection between the solar polar magnetic field and the nearby interstellar magnetic field.

Another observed deviation from the Parker model was reported by Ness *et al.* (*4*), who found no trace of the variation in average magnetic field direction as a function of velocity that would be expected from the equation $\tan \alpha = \Omega R / V_S$. A similar result was found by Neugebauer and Snyder (*6*).

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Phosphate Release and Sorption by Soils and Sediments: Effect of Aerobic and Anaerobic Conditions

Abstract. *Anaerobic soils released more phosphate to soil solutions low in soluble phosphate and sorbed more phosphate from soil solutions high in soluble phosphate than did aerobic soils. The difference in behavior of phosphate under aerobic and anaerobic conditions is attributed to the change brought about in ferric oxyhydroxide by soil reduction. The probably greater surface area of the gel-like reduced ferrous compounds in an anaerobic soil results in more soil phosphate being solubilized where solution phosphate is low and more solution phosphate being sorbed where solution phosphate is high.*

The amount of dissolved inorganic orthophosphate in flooded soils, swamp and marsh sediments, and shallow bodies of water depends on the capacity of the soil or sediment to release orthophosphate-P to a solution low in P and to sorb it from a solution high in P. Soils and sediments thus tend to have a buffering effect on solution P. These reactions help determine whether the P concentration in the interstitial and overlying water is adequate for the nutritional requirements of plants and whether the soils and sediments can remove enough P from solutions high in P to influence eutrophication.

The sorption and release of P is affected by, among other factors, the oxidation-reduction status of the soil or sediment. Mortimer (*1*) showed that the disappearance of dissolved oxygen and the subsequent reduction of the sediment resulted in a severalfold increase of dissolved P in a freshwater lake. Oxygenation of the sediment reversed this condition and decreased the P concentration. A higher amount of solution P in equilibrium with soils and sediments under anaerobic (reducing) conditions compared with aerobic (oxidizing) conditions has also been shown in flooded rice soils (*2*). These cited studies dealt with the equilibrium between P in solution and in the solid phase under conditions where the P concentration was low in both phases. Of equal or greater importance is the capacity of soils and sediments to sorb and release P under conditions where the P concentration is high in one or both phases. Little is known about the effect of anaerobic conditions on P sorption and release in interstitial water and overlying floodwater containing relatively high concentrations (5 μg/ml or more) of dissolved P.

Although the mechanism by which P is removed from solutions by sediments is not clearly understood, it is thought to be a sorption process rather than a precipitation process (*3*). Shukla *et al.* (*4*) and Williams *et al.* (*5*) attributed P sorption to a gel complex consisting largely of hydrated iron oxide. In soils and sediments exposed to free oxygen the active iron is in the Fe^{3+} form, probably as ferric oxyhydroxide (*6*), but under anaerobic conditions most of the active iron is in the Fe^{2+} form, with some occurring as ferrous hydroxide gel complex (*5*). Marked differences have been observed in the nature of Fe in aerobic and anaerobic soils. Anaerobic soils and sediments have much more Fe in solution—approximately 50 to 100 parts per million (ppm) compared to less than 1 ppm in aerobic soils—as well as a much greater amount of Fe adsorbed on the exchange complex (*7*). The oxidation state of the iron compounds apparently affects the phosphate equilibrium between solid and solution. Phosphate coprecipitated or occluded in ferric oxyhydroxide in an aerobic soil does not exchange with solution phosphate as readily as in an anaerobic soil.

The apparent relation of P sorption and release to hydrated iron oxide and the known effect of reducing conditions on ferric oxyhydroxide motivated the experiments reported here. These experiments were designed (i) to determine the effect of oxidizing and reducing soil conditions on P sorption and release in the presence of both low and high concentrations of P in solution and (ii) to determine whether release of P to a solution low in P and sorption of P from a solution higher in P in flooded soils could be related to the reduction of ferric oxyhydroxide to ferrous hydroxide brought about by anaerobic conditions.

Five soils which normally undergo differing conditions of oxygen depletion were used in this study. These were Commerce silt loam, Mhoon silt loam, and Sharkey silty clay loam from the Mississippi River floodplain, Moreland silty clay from the Red River floodplain, and Crowley silt loam from the rice-growing Prairie Terrace area of Louisiana. The first four soils are fertile alluvial soils with a high P-supplying capacity, whereas Crowley soil is low in both total P and P available to plants and requires additions of P for adequate plant growth. The Mhoon, Sharkey, and Moreland soils usually undergo seasonal oxygen depletion, and the Crowley soil is flooded during the summer months for rice production.

In the first of two experiments samples of the Commerce, Sharkey, Moreland, and Crowley soils were incubated for 17 days under aerobic and anaerobic conditions. Each soil was then equilibrated with a solution containing 0.01M $CaCl_2$ and P (0 or 100 μg/ml) as $Ca(H_2PO_4)_2$. Care was taken not to expose the anaerobic samples to atmospheric oxygen or to oxygenated solutions. The solution was