

not fully explain the cause of geoelectric and geomagnetic activity" (Sanders, 1961), while Winckler *et al.*, (1959), in discussing a 2650-V drop across a transatlantic cable produced during a magnetic storm (see below) concluded "... either the current circuit [in the Atlantic] is in the horizontal plane or the currents are not the result of the induced emf."

The mathematical modeling of telluric currents, unlike the understanding of their physical causes, is still far from a satisfactory solution. As far as Earth currents are concerned, the investigations have been for the most part carried out on a local or limited regional scale.

In contrast, the understanding of oceanic telluric currents (which cover a considerable fraction of the Earth's surface) has, since the Ashour (1950) estimate of their decay time in an ocean (order of a few hours), undergone substantial progress. The state of the art of ocean-current modeling now takes into account coastlines, although the ocean bottom is usually assumed flat—either nonconducting (although with a conducting mantle; see e.g., Parkinson, 1975; Hobbs and Brignall, 1976; Hobbs and Dawes, 1980; Beamish *et al.*, 1980; Fainberg, 1980, and references therein) or conducting (Hewson-Browne, 1981; Hewson-Browne and Kendall, 1981; Kendall and Quinney, 1983). The ocean currents and their related geomagnetic effects have been investigated by, for example, Barber and Longuet-Higgins (1948), Fraser (1965), Peckover (1973), Klein *et al.*, (1975), and Semevskiy *et al.* (1978). Malin (1970, 1973), in considering the lunar tidal harmonic component M_2 (which is the most important one both in the atmosphere and in the sea, with a period of half a lunar day), succeeded in separating the effect of direct electromagnetic induction from the ionosphere from the currents produced by oceanic tidal flow. He assumed that the geomagnetic variation associated with the tidal component should always be observed, independent of local time, whereas the ionosphere component should be negligible at midnight. In fact, he found that at Irkutsk, the geomagnetic observatory farthest from any ocean, the ocean-produced effect is negligible, unlike the situation at several other observatories closer to a coast, where the ocean component is present.

No equivalently sophisticated modeling, even for long-period geomagnetic variations, can usually be found for Earth currents. This situation exists principally because of the frustrating indeterminacies introduced by local Earth conductivity anomalies. The basic difficulty arises because of the nonuniqueness of the "inversion problem," that is, the nonuniqueness of the evaluation of the underground conductivity structure in terms of the surface geoelectromagnetic recordings. Therefore, the problem is usually tackled in terms of the

"forward problem": an external-origin electromagnetic field is assumed to impinge on an underground conducting structure of given geometrical shape, with only the conductivities left to be optimized by a numerical fitting of the model with the actual observational records. The procedure can be worked out only for reasonably simple geometrical shapes (Porstendorfer, 1976) for the conducting bodies, which implies substantial limitations to any attempt to extend such investigations to wider spatial scales (see e.g., Rokityansky, 1982; Hohmann, 1983; Parker, 1983; Varentsov, 1983).

In terms of planetary-scale currents, Gish (1936a, 1936b) presented the results of Figure 16.1, which he deduced for the daytime western hemisphere from diurnal variation (24-h period) recordings of orthogonal Earth current measurements collected during the second International Polar Year (1932-1933) at a number of sites around the world. The directions of current flow were determined by taking the vector sum of the N-S and E-W currents measured at the various sites. Large errors could be expected because of the sparse number of stations and the need, therefore, for large interpolations.

A more recent picture has been provided by Matsushita and Maeda (1965a, 1965b; see also Matsushita, 1967) from analyses of the worldwide geomagnetic field on a planetary scale. These authors performed a standard separation (by means of Gauss' spherical harmonic expansion) of the external- and internal-origin field. Some of the results are presented in Figure 16.2. Notice the obvious, substantial differences compared to the currents of Figure 16.1. However, even the more recent work is obviously unable to recognize the effects, where important, of localized anomalous conductors, such as mid-oceanic ridges, or even the differences between ocean basins and continents. In fact, spherical harmonics vary too smoothly to be able to account for such localized features, particularly if a reasonably limited number of terms is used in the expansion (for recent reviews of spherical harmonic techniques, see Winch, 1981; Fainberg, 1983).

The first 75 to 100 years of Earth current work produced considerable debate as to causes and disagreements among researchers as to the magnitude of the effect at given times. Gish (1936a, 1936b) noted that better agreement between independent measurements often occurred when relatively long lengths of wire were used. Today it is clear that such a situation could easily arise from experimental procedures such as improper grounding of a wire and an insufficiently high impedance in the measuring system (e.g., see Hessler, 1974). For example, in the work of Airy (1868) the wires were grounded to water pipes, which themselves obviously