cated on an overriding island arc near the Japan Trench; and on the South American Plate at Arequipa, Peru (SLR) [*Smith et al.*, 1990; *Harrison and Robaudo*, 1990].

On a more global scale, relative motions between SLR sites located well within the interiors of plates, which are therefore presumably free of plate margin deformation, show a correlation with the NUVEL-1 plate motion model predictions of about 0.95. This indicates that the geologic record provides a good indication of present-day broad-scale plate motion. The progress made in hardware, software, and analysis techniques with regard to the VLBI and SLR measurement systems has improved estimates of the kinematic behavior of the tracking sites.

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Upper Atmosphere

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Theoretical understanding of the upper atmosphere and the complex physical processes responsible for its composition, dynamics, and thermal behavior has improved to the point where reasonable three-dimensional, time-dependent models of the atmosphere above about 100 km exist. These models have been extensively refined through comparisons with experimental data from coordinated, multistation ground-based investigations. Theoretical calculations using a state-of-the-art model of the upper atmosphere indicate that over the next century, the anthropogenic production of CO_2, which is anticipated to warm the lower atmosphere, will also cool the upper atmosphere. The model predicts that doubling atmosphere CO_2 cools the mesosphere (80–100 km) by about 10°C and the thermosphere (above 100 km) by about 50°C.

Studies of noctilucent clouds (known technically as polar mesospheric clouds, or PMCs) imply that those, too, are anthropogenic—in this instance the result of increased methane. An historical survey indicates that PMCs were not observed prior to the Industrial Revolution. Calculations indicate that PMCs, presently confined to the polar regions, might spread to lower latitudes as methane levels rise, changing the thermal properties of the upper atmosphere in undetermined ways.

Extensive sets of ground-based radar measurements have provided the first climatologies of the upper atmosphere in the 60- to 100-km region, where dynamics are dominated by semidiurnal and diurnal tides. For the first time, the characteristic phase and amplitudes of these tides have been systematically charted. This effort is ongoing and involves major multinational coordination of observations.

LIDAR and radar measurements have demonstrated a prevalent, highly complicated spectrum of waves in the region between 80- and 100-km altitude. These waves, having typical wavelengths of tens of kilometers and typical periods of tens of minutes, appear to play a major role in establishing the thermal and momentum budgets of the region. The new LIDAR techniques have also revealed fascinating small-scale dynamic phenomena and composition variations in the upper atmosphere, such as sporadic, small-scale sodium layers that come and go suddenly, and may correspond to the passages of individual meteors.

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Crustal Deformation

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One of the lessons of geology, and now one of the tenets of plate tectonics theory, is that most of the Earth's crust does not deform very much. Most of the deformation takes place along the relatively narrow plate boundaries. Working out the details of how this deformation takes place, and the physics of the Earth revealed by it, is a major research enterprise, particularly because the slow deformation between the plates creates the elastic energy released in earthquakes.

Recent developments in measurement and laboratory studies are beginning to bring our picture of crustal deformation into better focus. Since the motion along most plate boundaries is less than 10 cm/year over a width (on the continents) of 100 km or more, the rates of strain to be measured rarely approach 10^{-6}/yr, and are often much less (except when earthquakes occur). Conventional surveying techniques have precisions of 10^{-5}, so that any motion can only be measured over many decades. Space geodesy, most notably measurements of signals from Global Positioning System (GPS) satellites operated by the U.S. Department of Defense, represent a significant advance over conventional techniques. The precision of GPS appears to be within a few millimeters over distances of hundreds of kilometers, so that rates of deformation can now be measured in a few years.

Measurements are achieved with equipment weighing only tens of kilograms and costing only tens of thousands of dollars. The wide availability of this equipment has led to an explosion of research expeditions to measure the rates and mode of deformation over plate boundaries from California to Tonga to Tibet. In a few years we may expect to see many data on present-day plate rates to compare with the long-term models derived from marine magnetic anomalies, and have much more detail on how the deformation takes place.

Studies of the earthquake process are also beginning to benefit from the kind of precise deformation measurements that GPS can make, and also from improvements in the continuous measurement of Earth strain.

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