N87-17146

A SCANNING RADAR ALTIMETER FOR MAPPING CONTINENTAL TOPOGRAPHY

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Topographic information constitutes a fundamental data set for the earth sciences. For example, temperature, rainfall, rain runoff, evaporation rate and soil moisture are often critical parameters in botany, hydrology and other ecosystem sciences, and can exhibit a strong dependence on elevation, local slope and slope aspect. In the geological and geophysical sciences, topography combined with gravitational information provides an important constraint on the structure and rheologic properties of the crust and lithosphere. Detailed topography data can also be used to map offsets associated with faulting and to reveal the effects of tectonic deformation. In the polar regions, elevation data form a crucial but as yet largely unavailable resource for studying ice sheet mass balance and ice flow dynamics. The vast Antarctic ice sheet is the largest fresh water reservoir on earth and is an important influence on ocean circulation and global climate. However, our knowledge of its stability is so limited that we cannot even specify whether the Antarctic ice sheet is growing or shrinking. It is clear that there is need for high quality global topography data. A summary of potential applications with their resolution requirements is shown in Figure 1.

Global continental topography is poorly and unevenly known at all but the coarsest resolution (Figure 2). Topographic data of moderate to high resolution is generally available for small, local areas in the form of topographic maps, consisting of hand or machine drawn contours around unevenly distributed spot height measurements. Unfortunately, for many areas coverage is limited, inaccurate or nonexistent. Mountain belts, deserts, tropical rain forests and polar areas, critical sites for a variety of earth science research, suffer from topographic coverage that is highly inadequate, reflecting difficulties in physical access.

Even if topographic maps exist, they may be generated in such a way as to preclude many types of studies. The distribution of horizontal and vertical control points across a map sheet may be quite uneven, resulting in variable accuracy within the map. Even maps which are internally consistent (precise) cannot be assembled to generate good regional coverage. Lack of uniformity for the individual map datum (reference level) compromises the integrity of world topographic data. For example, the United Nations lists 18 separate reference ellipsoids in the world's countries. This lack of standardization effectively limits the scope of any regional or global study where topography is an important parameter.

Regional or global studies require the manipulation of large data sets. These studies benefit greatly from the availability of digital data. Unfortunately this form of topographic data is extremely limited in terms of world-wide coverage. High resolution (1:250,000 or better) digital topography exists only for the U.S., Australia, and Western Europe (Figure 2). The best global coverage has only 18 km resolution. Moreover, digital elevation data are usually generated by digitizing contour maps, and hence suffer from the same problems that afflict the original data set, particularly in terms of long wavelength (long spatial scale) integrity.

It is clear that there is a great need for high resolution global topographic data, preferably in a digital, machine-readable format. Such data can only be acquired in a cost effective manner by space-borne techniques.

Several technological approaches now exist for space-based acquisition of topographic data. The most promising of these is a narrow beam, scanning synthetic aperture radar altimeter. This system is capable of generating moderate to high resolution (250-500 m horizontal and 2-5 m vertical) global topographic data. It can be deployed on the space shuttle, promising a relatively low cost experiment. GPS tracking of the shuttle would be required to ensure accurate recovery of the elevation data. Global coverage can be achieved with two or three shuttle flights if at least one flight has a polar orbit.

Conventional wide-beam ("pulse limited") altimeters are not well suited for mapping the high relief continental areas (Figure 3). Reflections from cross-track topography can be confused with the nadir echo, rendering such data difficult if not impossible to interpret. Topographic mapping of the continents with radar altimetry therefore requires small radar footprints to achieve adequate feature resolution. This implies the use of large antennas (large D in Figure 3), high frequencies, or some combination of both characteristics. The proposed system is sketched in Figure 3. The antenna consists of a long rail with an array of individual antenna elements. Scanning of the beam from side to side is achieved by electronic beam steering of the phased array. Swath widths up to 100 km are envisioned. The rail is long in the cross-track direction ensuring a narrow radar footprint in this dimension. Such an antenna, while having good cross-track resolution, has large footprints in the along-track dimension. However, doppler information in the reflected pulse can be used to distinguish the precise along-track position of a particular part of the reflected echo, synthesizing the effect of a large antenna in this dimension. Such synthetic aperture techniques have been widely employed in the more difficult problem of radar imaging. Extension of these techniques to an altimeter is straightforward.

The high effective resolution achieved by this approach satisfies a wide range of scientific requirements, and promises to provide an important global data set.

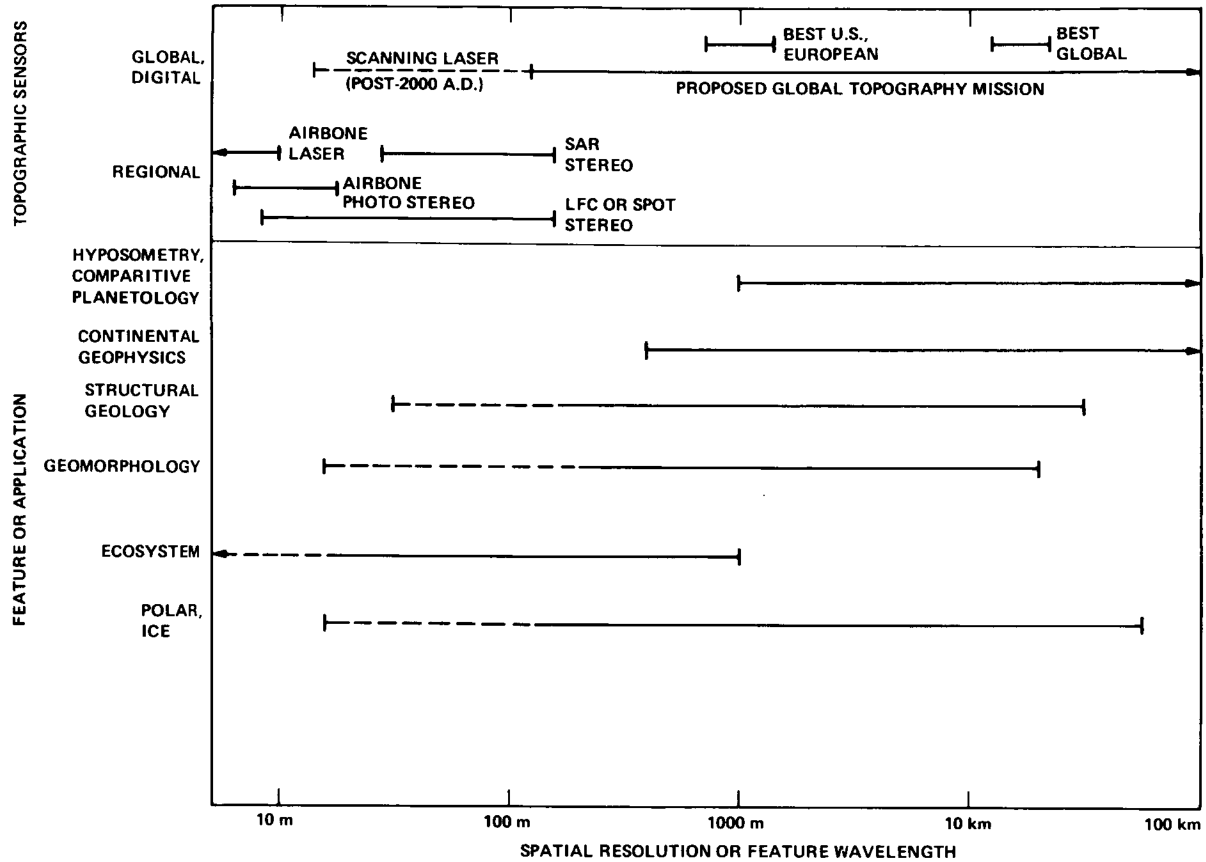

Figure 1. Potential applications of topographic data as a function of feature size (bottom), and various topographic techniques versus their respective resolution (top).

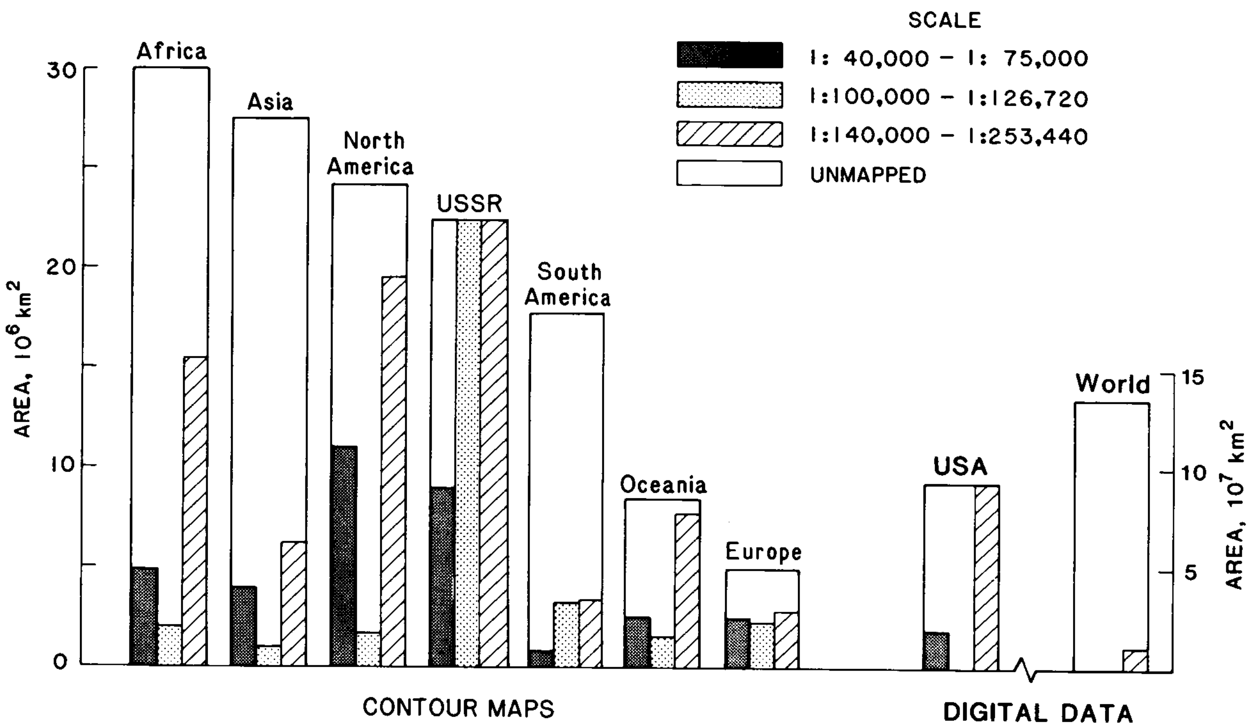

Figure 2. Availability of world-wide topographic data. Only Europe, the USSR, and North America are adequately covered by high-resolution (better than 1:100,000) topographic contour maps. No continent is adequately covered by digital topographic data.

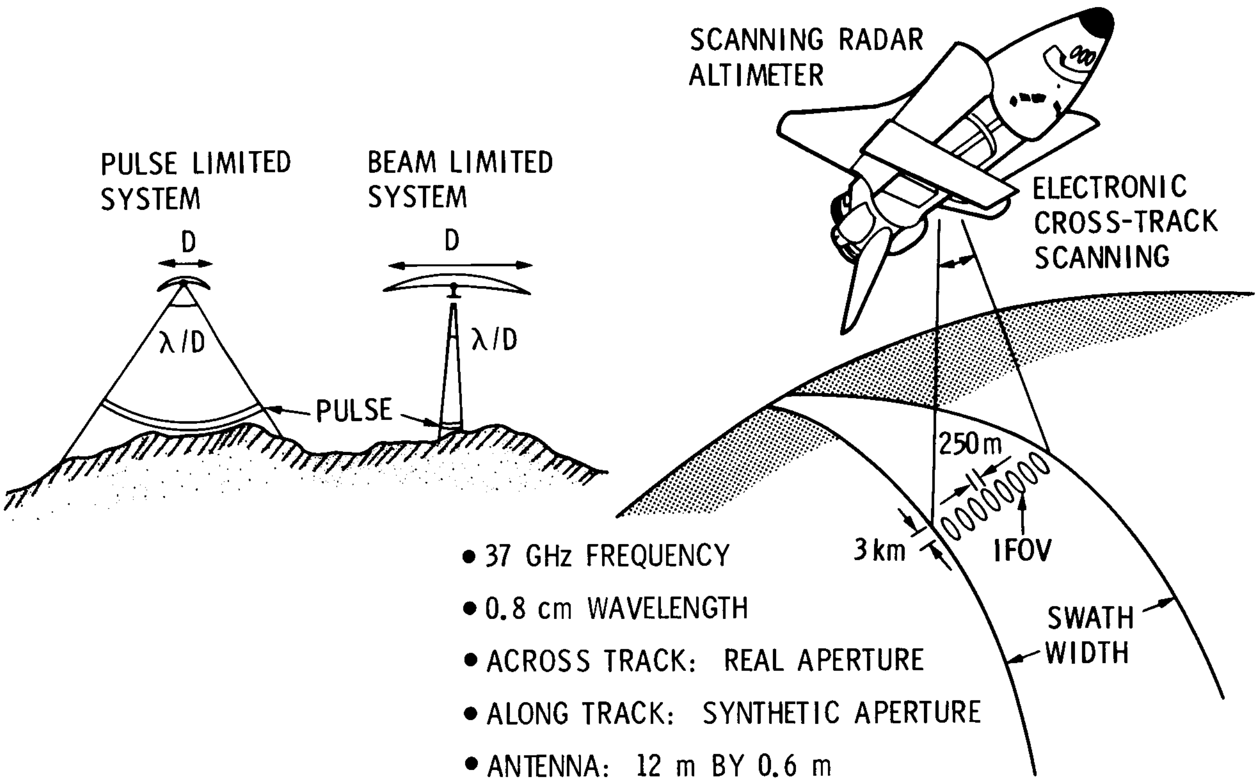

Figure 3. A possible system design to obtain high-resolution continental topographic data. Conventional radar altimeters (pulse limited systems) produce a wide footprint, unsuitable for altimetric measurement in high-relief continental terrain. However, the combination of a large antenna and high frequency would enable narrow-beam, small-footprint altimetry suitable for continental mapping. A proposed hybrid system would operate at relatively high frequency (37 GHz) and would utilize an antenna large in one dimension, giving cross-track resolution at 250 m. Synthetic aperture techniques allow recovery of along-track resolution of similar dimensions, even though the instantaneous field of view (IFOV) would be of order 3 km. Electronic scanning of individual antenna elements would generate the required swath width.