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The problem of AVHRR image navigation revisited

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Abstract. In this study, Earth location errors in AVHRR satellite data and methods for their correction are examined with particular application to oceanic regions far removed from ground control. A general correction procedure, using landmarks or Ground Control Points (GCPs) and taking into account landmark uncertainties, is presented. Correction functions are derived as expansions for any complete basis. Operationally-available estimates of Earth location are used as a first-guess in developing the correction procedure. In particular, polynomial expansions are used to represent the correction functions which provide the basis for renavigating the satellite data. The coefficients of the polynomial expansions are obtained using the method of least-squares. The stability of the correction procedure with respect to local errors in navigation, (i.e. within a scene) and how to select the correct order of the correction polynomials are examined. Uncertainty in extrapolating navigation corrections over remote regions is examined and quantified. The importance of landmark uncertainty in degrading renavigation accuracy is also addressed. Several parameters are introduced to optimize the choice of GCPs and their distributions. The procedures which are developed are then applied to simulated and actual AVHRR imagery. Finally, the impact of local errors in navigation, which most likely arise from rapid variations in spacecraft attitude, on renavigation accuracy is emphasized and one possible solution proposed.

1. Introduction

The Advanced Very High Resolution Radiometer (AVHRR) is a high-resolution, multi-channel scanning radiometer that has been flown aboard NOAA's TIROS-N polar-orbiting satellites since 1978. Satellite imagery from this instrument has been used extensively to study a variety of oceanic features based on their thermal manifestations at the surface. As the oceanographic applications for AVHRR data have become more sophisticated, the need for greater Earth location accuracy has likewise increased. For example, by measuring the displacements experienced by selected thermal features between successive images, it is often possible to infer the apparent advective motion that transports these features. Such feature-tracking methods place stringent requirements on Earth location accuracy since the associated displacements may not be large compared to the uncertainties in the navigation. Although careful co-registration of successive images in coastal regions usually produces close alignment near coastlines which are often used as a common reference in the co-registration process, there is no guarantee that close alignment will occur between the images for oceanic locations far-removed from land. Thus, we are motivated to reexamine the question of Earth location accuracy as new applications for AVHRR satellite imagery arise which continue to place greater reliance on earth location accuracy.

In navigating AVHRR satellite data, two basic approaches are used. The first employs an ephemeris model to predict the orbital elements which are then used to calculate Earth locations for the satellite data; the second involves the use of landmarks that provide a basis for relocating AVHRR image pixels which are usually first navigated approximately using an ephemeris model (e.g., Emery *et al.* 1989). Our primary interest in this study involves the use of landmarks, and a number of issues arise in their use that significantly influence the quality of the renavigated data. They include the number and distribution of landmarks, landmark uncertainty, and the mathematical procedures that are used to relocate the satellite data. These issues are examined in some detail.

Since the mid-1970s, a number of studies has addressed the problem of navigation for data acquired from polar-orbiting satellites. The various types of geometric errors and methods for their correction for Landsat data were outlined by Bernstein and Ferneyhough (1975). Malhotra and Rader (1975) described the two basic approaches for Earth-locating remotely-sensed data using (1) an ephemeris model to determine the orbital position and attitude of a spacecraft as a function of time, and (2), landmarks or Ground Control Points (GCPs) as known reference points on the Earth's surface as a basis for relocating the entire field of image elements or pixels. Legeckis and Pritchard (1976) developed an algorithm to correct satellite data from the Very High Resolution Radiometer (VHRR) for geometric distortions due to Earth curvature, Earth rotation and rolling motions of the spacecraft. A method for assigning geographical coordinates to digital satellite imagery from the VHRR was given by Kirkham and Stevenson (1976). McConaghy (1980) presented a technique for analytically determining the geographic location of individual pixels in VHRR satellite data to an accuracy of 0·1° or less, in latitude and longitude.

According to Clark and LaViolette (1981), AVHRR data from TIROS-N could be reliably registered on to a geographical grid using two-dimensional, third-order polynomials. The remapped data were useful for tracking the movements of oceanic fronts. Freidman *et al.* (1983) were able to reduce the computational effort involved in obtaining precise geometric corrections for Landsat data by reducing the required number of GCPs from an average of 15 to 4, through (1) the processing of multiple scenes, and (2), physically modelling the motions of the spacecraft. Two methods for geometrically correcting AVHRR data were compared by Emery and Ikeda (1984). One method included Earth oblateness and the second assumed a circular orbit for the satellite. Both methods used GCPs as a final step in the Earth location process. Significantly fewer GCPs were required to achieve a specified degree of Earth location accuracy for the case where Earth oblateness was included. Brunel and Marsouin (1987) presented a method for navigating AVHRR data in real time based on an extrapolation of the satellite's orbital elements which were calculated from the ARGOS Data Collection and Location System. The mean navigational error using this method was 4·7 km. Cracknell and Paithoonwattanakij (1989) were apparently able to achieve subpixel accuracy in renavigating AVHRR data by combining AVHRR and Landsat images using the method of Torlegard (1986). The NOAA/