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Final Report on Automatic AVHRR Image Navigation Software

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This is the final report describing the work done on the project entitled Automatic AVHRR Image Navigation Software funded through NASA-Washington, award NAGW-3224, Account 153-7529.

At the onset of this project, we had developed image navigation software capable of producing geo-registered images from AVHRR data. The registrations were highly accurate but required a priori knowledge of the spacecraft's axes alignment deviations, commonly known as attitude. The three angles needed to describe the attitude are called roll, pitch, and yaw, and are the components of the deviations in the along scan, along track and about center directions. The inclusion of the attitude corrections in the navigation software results in highly accurate georegistrations, however, the computation of the angles is very tedious and involves human interpretation for several steps. The technique also requires easily identifiable ground features which may not be available due to cloud cover or for ocean data.

The current project was motivated by the need for a navigation system which was automatic and did not require human intervention or ground control points. The first step in creating such a system must be the ability to parameterize the spacecraft's attitude. The immediate goal of this project was to study the attitude fluctuations and determine if they displayed any systematic behavior which could be modeled or parameterized. We chose a period in 1991-1992 to study the attitude of the NOAA 11 spacecraft using data from the Tiros receiving station at the Colorado Center for Astrodynamic Research (CCAR) at the University of Colorado.

In essence, the calculation of the attitude is the determination of a set of angles which best correct the total registration error. If sources other than attitude are contributing to this error, then the

calculated corrections will not be the actual roll, pitch and yaw. A budget of the registration error must be done to ensure that other sources of error have either been eliminated or corrected.

Along with attitude, there are three sources of registration error: 1) errors in the satellites ephemeris data, 2) errors in the time of the satellite observations due to spacecraft clock drift and 3) errors in the orbital model. The suppliers of our ephemeris data, The Naval Space Surveillance Center (NAVSPASUR), have assured us that the ephemeris data is accurate to well within the limits of our measurability (1 km) so that the ephemeris data are not a contributing source to the registration error. The timing errors due to clock drift have been computed by the University of Miami and appear in Fig 1 for the period of our study. The application of these clock corrections ensures that clock drift will not contribute to the registration error. The error in the orbital model used to predict the satellite position is displayed in Fig 2 as a function of the prediction time from the ephemeris epoch. Fig 2 shows that the orbital model error exceeds 1 km for prediction times greater than 4 days. Since our ephemeris data is supplied daily, our prediction times will always be less than 1 day and the errors due to the orbital model will always be less than 1km. The maximum resolution of the AVHRR instrument is 1km, so that any registration errors less than this are considered insignificant.

The time series for roll, pitch and yaw computed for the study period is displayed in Fig 3a, 3b, and 3c. The variations appearing in Fig 3 suggest that the means of the angles could be used as a parameterization for the attitude. Furthermore, the parameterization would be more accurate if the time period was divided into four segments. These segments are defined by the vertical lines in Fig 3. The numerical values for the means of each time segment are listed in Table 1, along with their associated standard deviations. An attitude angle of 0.001 radians corresponds to a 1km registration error

The "residual" attitude is defined as the resulting angles after the mean values have been subtracted. If the mean values are used as the apriori parameters, the residual values will produce errors in the registration which will define the accuracy of the parameterization technique. The residual attitude angles can be seen in Fig 4 and the corresponding registration error is displayed in

Fig 5 for both nadir and the edge of the scan. It should be noted that the resolution of the AVHRR instrument varies across the scan from 1 km at nadir to 6 km at the edge of the scan. The minimum size of a "significant" registration error will vary in the same way. Analysis of Fig 5 shows that for the nadir case, all the residual errors are below 1.5 km and most of the values are below 1km. The edge of scan errors are similar with respect to the minimum significant error.

The spacecraft attitude is measured on board the NOAA satellites and reported in the data stream. In the past, these values have proven to be useless to image navigation systems. A second part of this study was devoted to a comparison between the onboard values and our computed values. Onboard values are reported every 10 seconds, while our computed values are valid for the duration of the recorded data which is approximately 10 minutes. A plot of the onboard values along with our calculated values can be seen in Fig 6. Although this represents only one overpass, the comparison is typical of all other passes which were examined.

The conclusions from our study were : 1) The attitude angles can be effectively parameterized by using mean values calculated over some relatively large time period, say four months. This would mean that registrations done during this period could use the mean values for that period as apriori parameters, this would eliminate the need to calculate them for every navigation. 2) During our study period, the NOAA 11 spacecraft displayed a significant bias in the roll angle of approximately 0.0025 radians, resulting in a registration error of 2.5 satellite field of views. 3) The attitude values reported from the onboard attitude sensors do not correspond to the computed values and are not useful for geo registration purposes.

The results of this study are being written in a paper which will be submitted to the journal Transactions on 3 and Remote Sensing. The paper is in its final internal review and we expect to submit by the end of 1993.
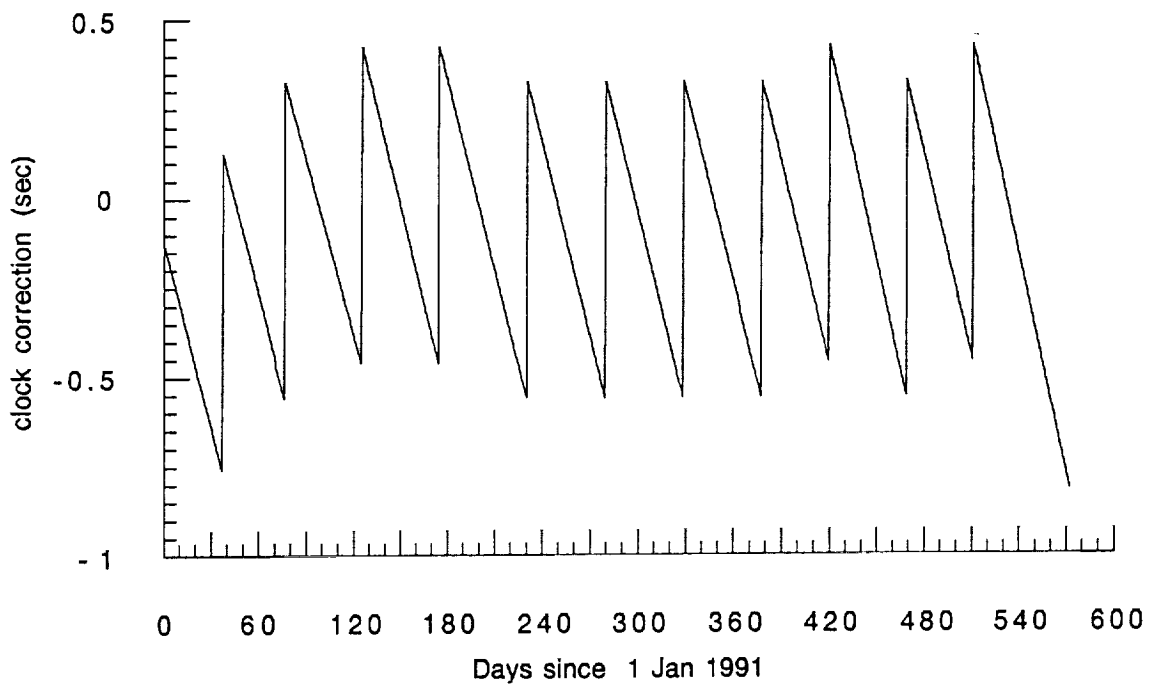
Fig 1 NOAA-11 clock drift corrections (secs) from for 1991-1992 period of study. Values obtained from Univ of Miami.
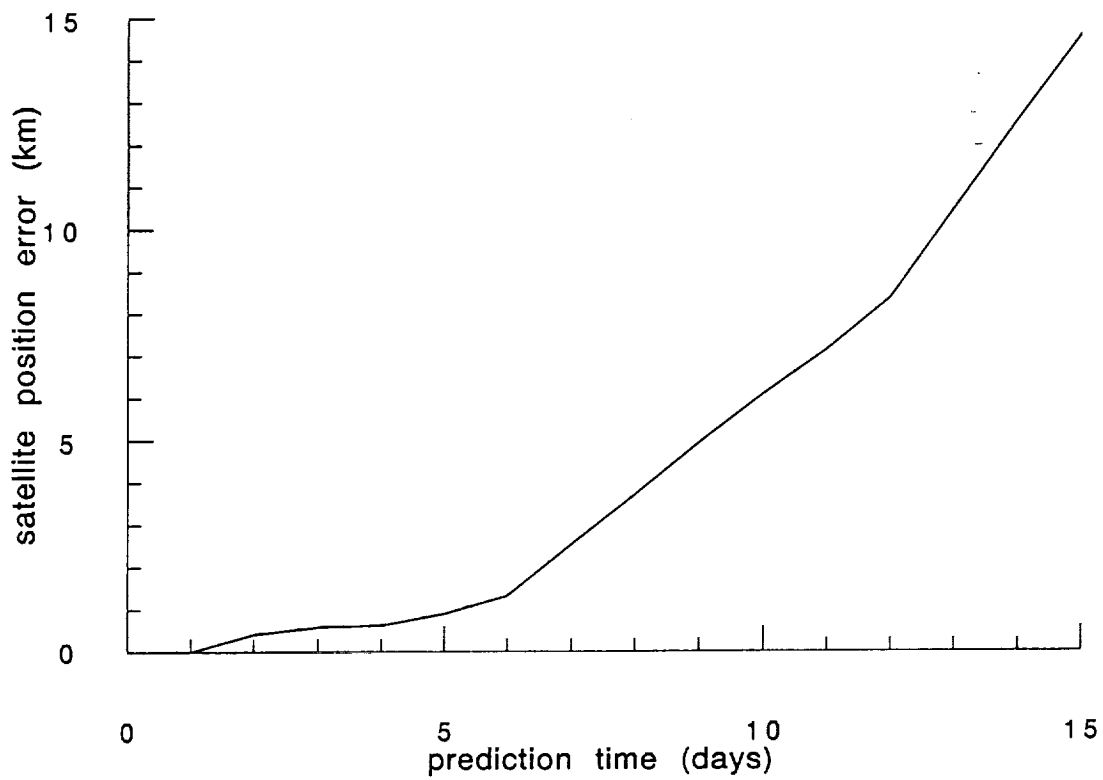
Fig 2 Satellite ground track position error (km) as a function of prediction time from ephemeris epoch (days)
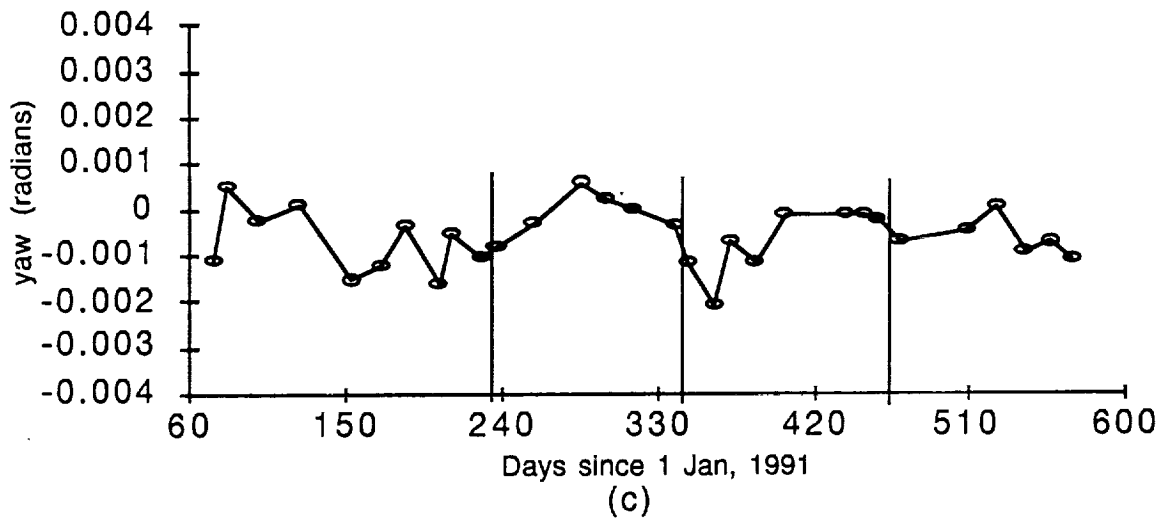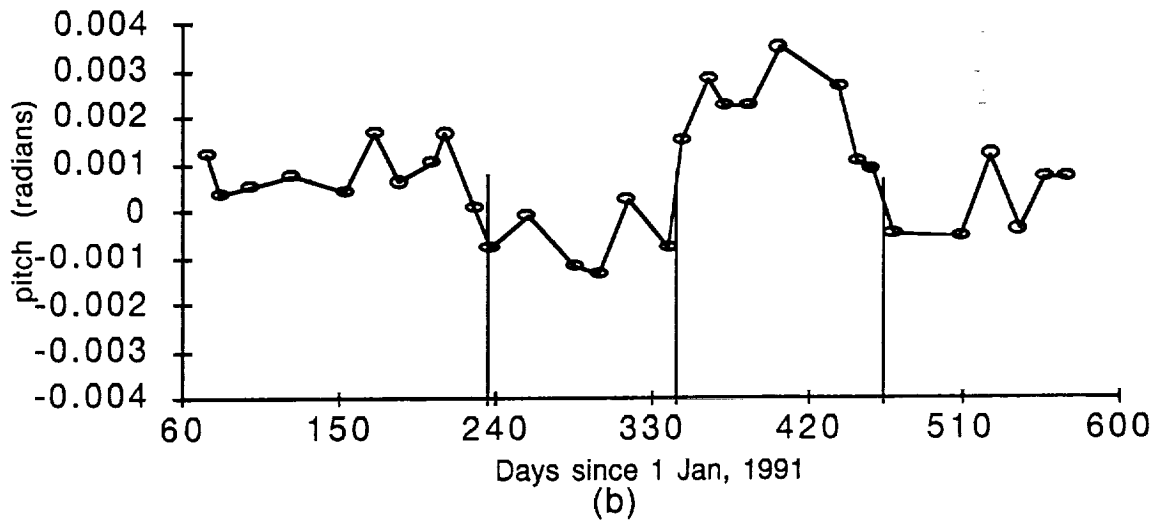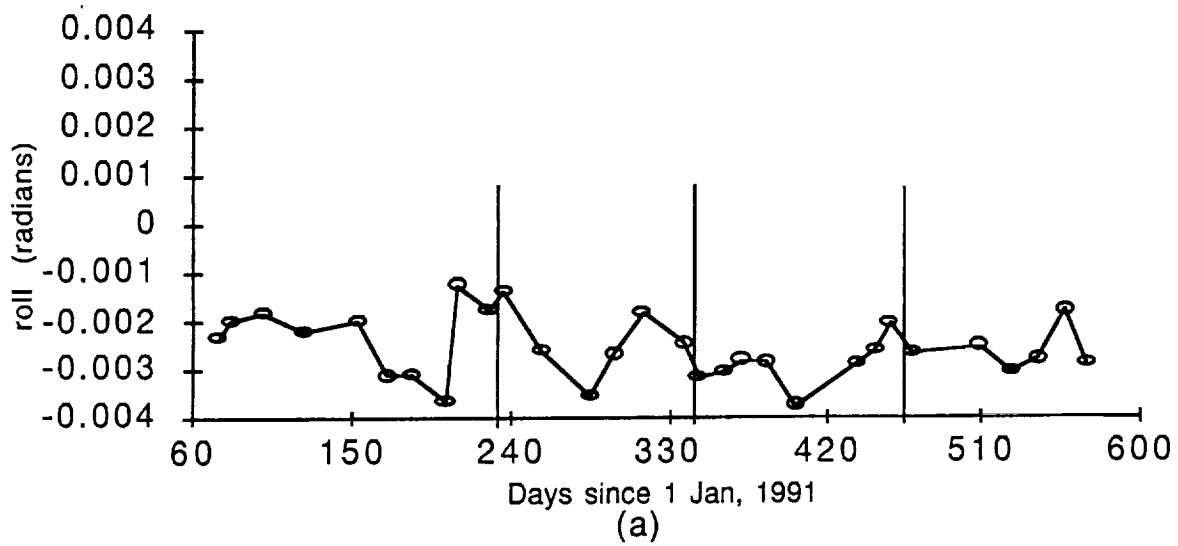
Fig 3 Time series of calculated attitude angles (radians) for NOAA-11 satellite for 1991-1992 time period. Vertical lines delineate four time segments. A value of 0.001 radians corresponds to a deviation of one satellite FOV. (a) roll, (b) pitch, (c) yaw
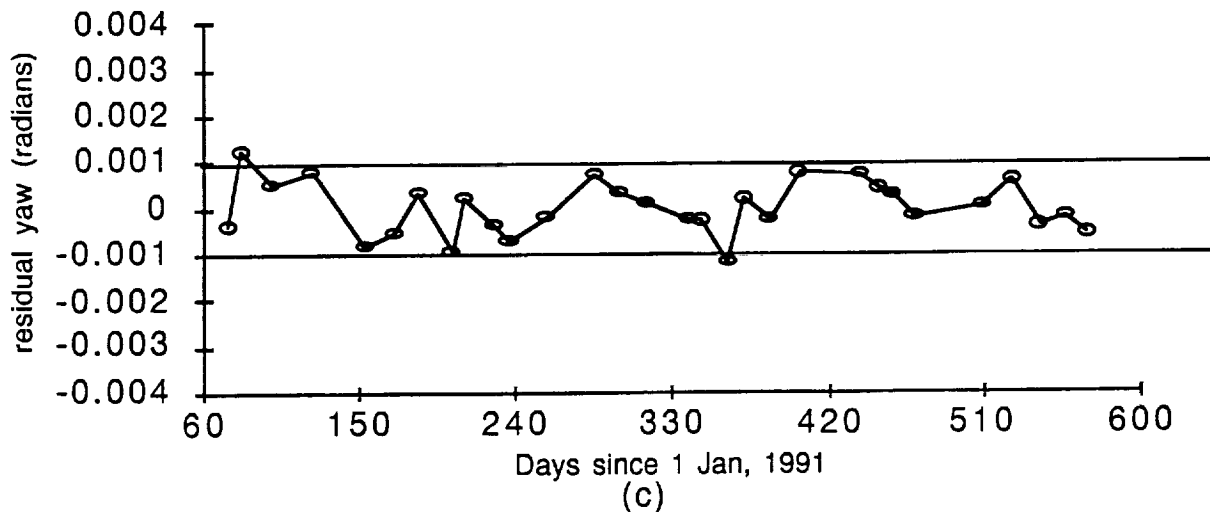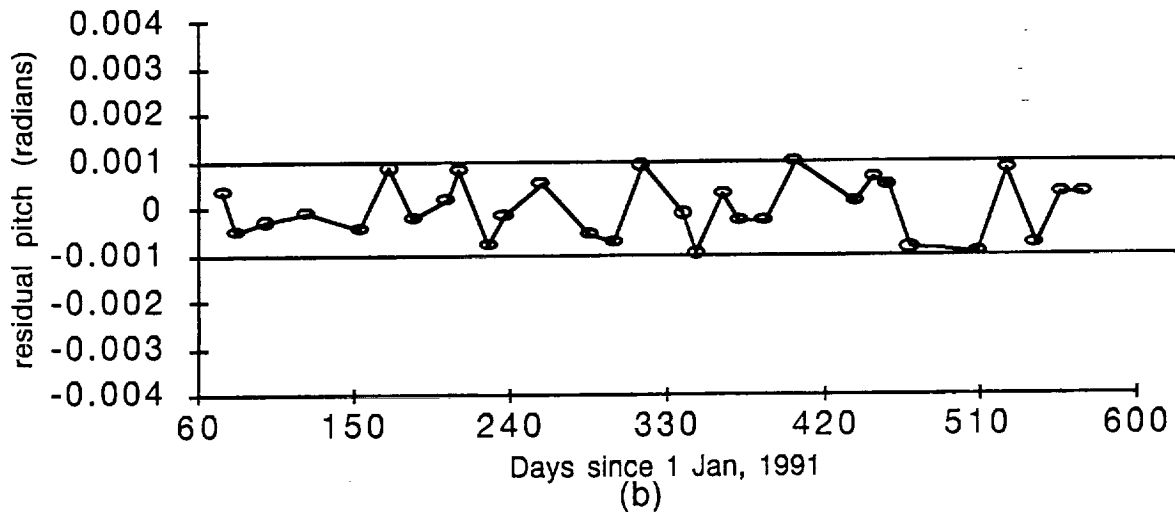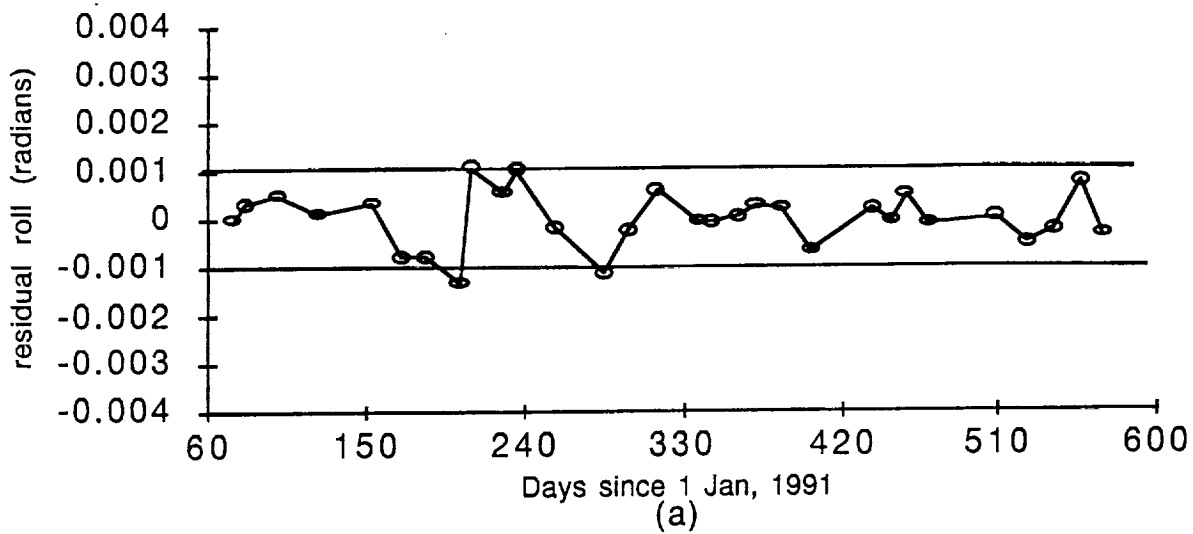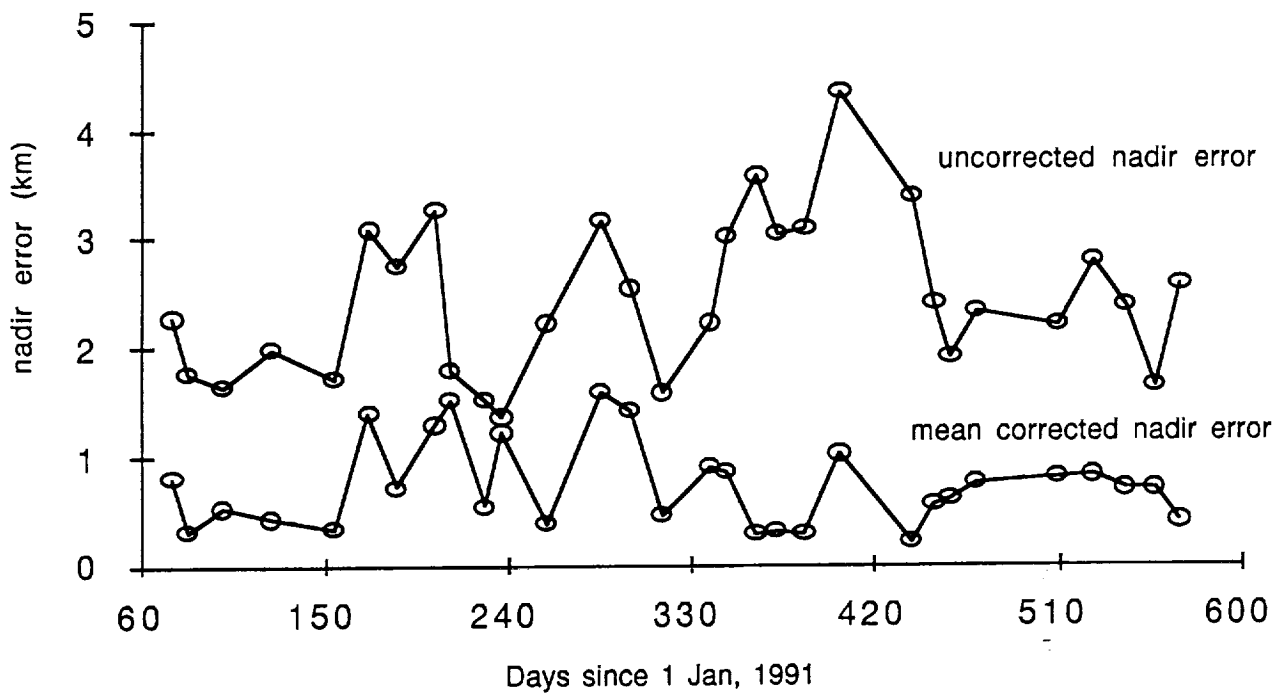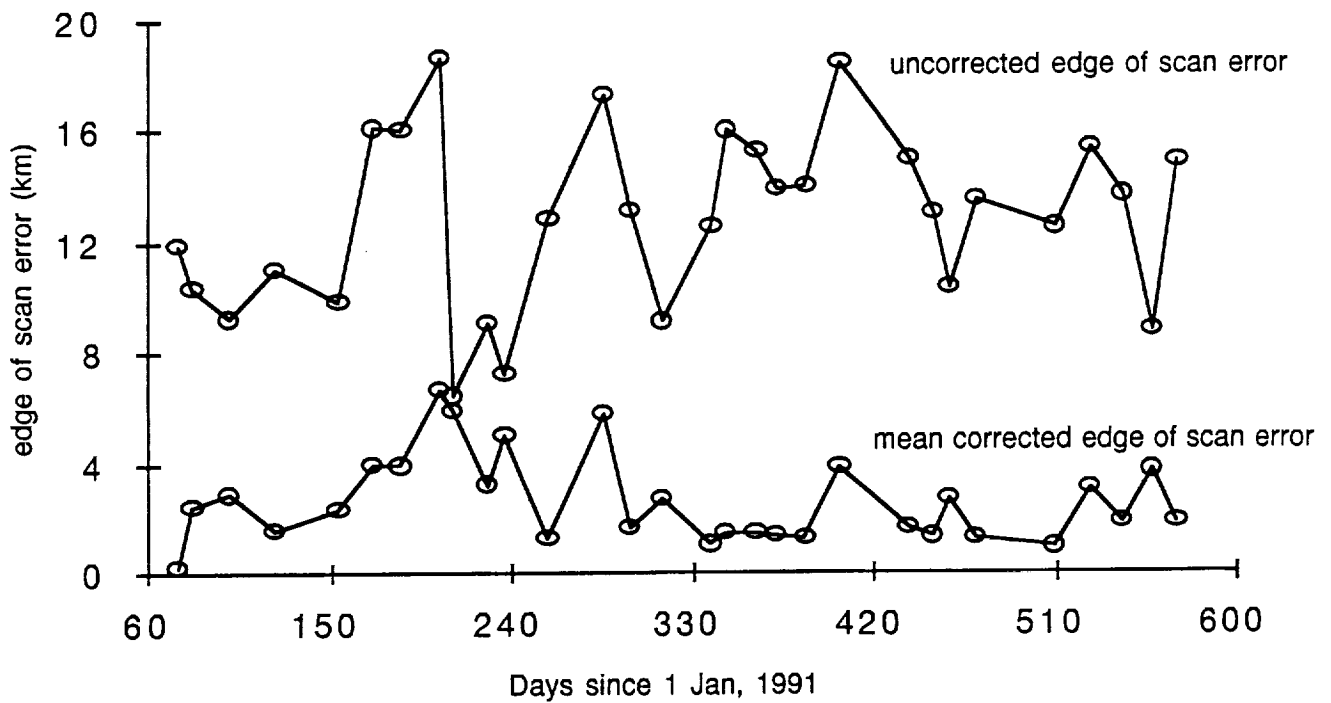
Fig 4 Time series of residual attitude angles (radians) resulting from of the mean values. Data is from NOAA-11 satellite for 1991-1992 Horizontal lines show + and - 0.001 radian levels which correspond an error of one satellite field of view.
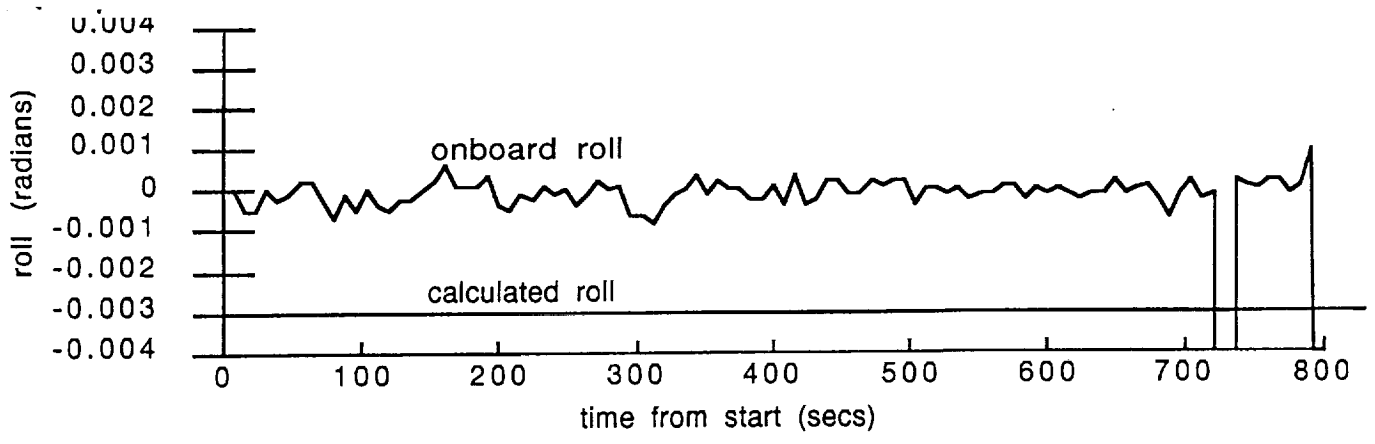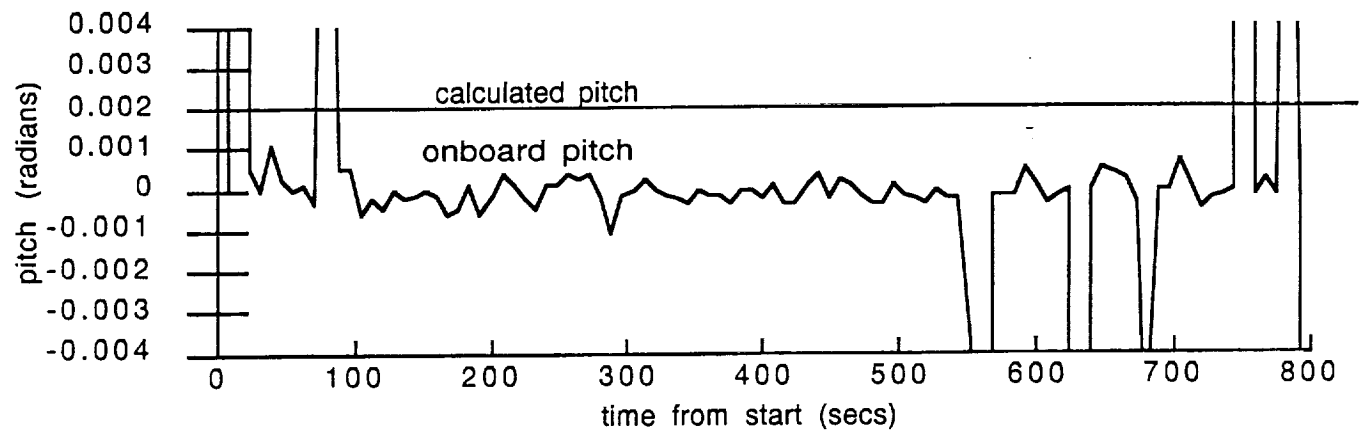(a) residual roll, (b) residual pitch, (c) residual yaw.

Fig 5 Time series of registartion errors (km) for uncorrected registrations and registrations corrected by mean attitude angles. Data is from NOAA-11 satellite in 1991-1992 time period.
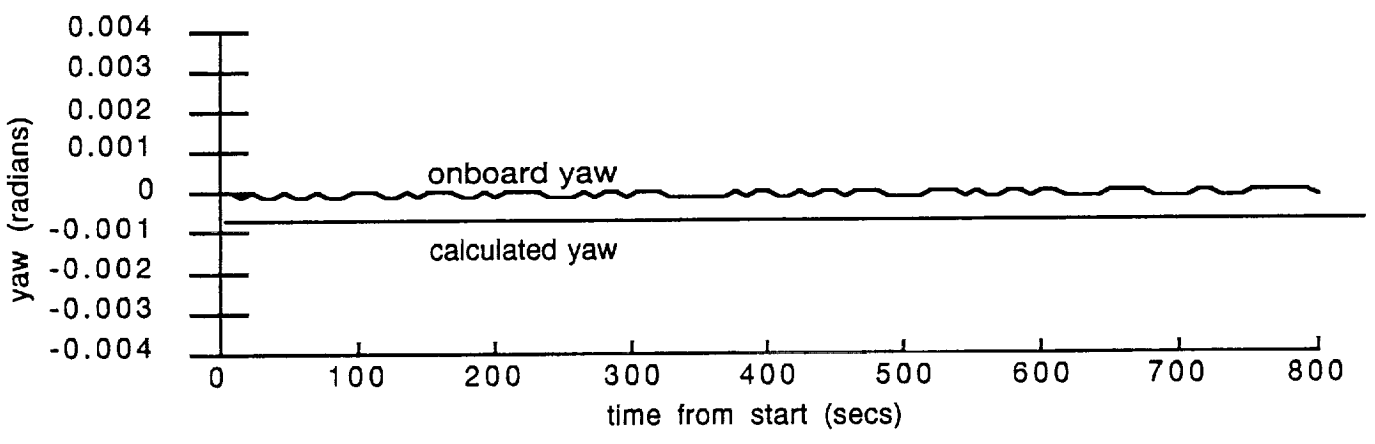(a) Nadir registration errors (km),
(b) edge of scan registration errors (km)

FIG. 6

Time series for onboard attitude angles (radians) from ACS for a 13 minute segment of NOAA-11 descending node data on March 13, 1992, starting at 10:08:00 UT. Also shown are the calculated attitude angles during the time period. (a) onboard roll, (b) onboard pitch,(c) onboard yaw

| | (a) Segment 1 | | (b) Segment 2 | | (c) Segment 3 | | (d) Segment 4 | | (e) June 1991 | | (f) Feb 1992 | |
	mean	stdev	mean	stdev	mean	stdev	mean	stdev	mean	stdev	mean	stdev
roll	-0.0023	0.0007	-0.0024	0.0007	-0.0031	0.0003	-0.0025	0.0004	-0.0021	0.0003	-0.0025	0.0004
pitch	0.0008	0.0005	-0.0006	0.0006	0.0025	0.0006	0.0003	0.0004	0.0007	0.0008	0.0023	0.0006
yaw	-0.0007	0.0007	-0.0001	0.0005	-0.0009	0.0007	-0.0005	0.0004	-0.0007	0.0009	-0.0015	0.0006

Table 1   Means and standard deviations for the calculated roll, pitch and yaw for different time periods and different sampling frequencies. Units are radians.
(a) Segment 1 from 03/16/91 to 08/16/91   sampling approx 20 days
(b) Segment 2 from 08/25/91 to 12/05/91   sampling approx 20 days
(c) Segment 3 from 12/30/91 to 03/13/92   sampling approx 20 days
(d) Segment 4 from 03/24/92 to 07/23/92   sampling approx 20 days
(e) June, 1991 from 05/31/91 to 06/30/91 sampling approx 3 days
(f) Feb, 1992   from 02/01/92 to 02/27/92 sampling approx 3 days