MODIS DATA STUDY

TEAM PRESENTATION

July 20, 1990

AGENDA

1. Format Update for Level-1A and -1B MODIS Data (Ardanuy, Schols)
2. Platform and MODIS Data Requirements (McKay, Blaisdell, Ardanuy)

FORMAT UPDATE FOR LEVEL-1A AND -1B MODIS DATA

1. Definition of Scan Cube: 1 scan from MODIS-N or -T containing all radiometric data (on Earth, internal calibration, or deep space). Packets should start and stop with each scan.

2. A concept of data packetization and a scan cube needs to be developed for MODIS data taken while not in scan mode.

3. Level-1A data will be packed (i.e., not expanded to 16-bit words) unless done automatically within the DAAC upon storage.

4. Level-1A data will be handled and sent to archive in relatively large (less than a day, more than a minute) groups of scan cubes; tentative definition of these groups will be volumes.

5. Level-1A data will be stored as sequentially as possible during processing, with processing control tables locating the individual scan cubes for the storage media. As volumes are assembled for archive, all scans cubes will be sequentially retrieved.

6. At Level-1B, the scan cubes will be limited to on-Earth radiometric data only. All other radiometric data will be archived separately via the MCST support product.

7. Calibration processing will likely be performed for entire orbits at a time. This will dictate a first pass through the data to obtain offsets, and then a second pass through the data to apply the calibration.

8. Possible minimum grouping of scan cubes to be processed would be N scans, where N is the number of processors in the IDPGF machine.

9. Possibly at Level-1B (and definitely at Level-2), MODIS data will be archived in volumes (or scenes) which are some moderate segment of an orbit. This scenario is not driven by any direct processing requirement. Rather, the motivation is to reduce the number of granules of MODIS data which must be independently tracked (e.g., about 85,000 scan cubes per day for MODIS-N versus 15 orbits or perhaps 300 scenes).

For MODIS-N (MODIS-T) a scene cube contains
[36 wavelengths * 12 b]/pixel * 1582 pixels/line * 8 lines/scan *
5841 scans/orbit / 20 = 200 MB
[34 wavelengths * 13 b]/pixel * 1007 pixels/line * 30 lines/scan *
625 scans/orbit / 20 = 52 MB
of 1.1 km * 1.1 km resolution data.

PLATFORM AND MODIS DATA REQUIREMENTS

1. Meeting with the EOS Platform Personnel

On Tuesday, 18 July a very productive meeting was held with Jerry Kull to exchange information on platform and MODIS data requirements. Ed Chang was also present at the meeting. This memorandum summarizes salient subjects reviewed.

The most recent documentation describing the platform, as seen by the instruments, is the "General Instrument Interface Specification for the EOS Observatory," dated 15 January 1990. An update to this document will be issued late in 1990. Any comments which we may have on the contents of this document, particularly on the ancillary data required to meet MODIS requirements, should be forwarded through Jerry Kull.

There are a number of areas of interest where final requirements have not yet been determined but are actively being worked. These include the following:

- Control accuracy. The estimated control accuracy requirement will be in the range of 100 - 200 arcseconds. There is currently a requirement of control within 7.2 arcseconds per 1000 seconds for jitter. Jitter for a 1 second interval is expected to be less than 1 arcsecond. Control requirements for longer and shorter time periods are yet to be established.

- Time delays. Requirements for the maximum time delays between readout of data and the time they are made available on the platform are not yet established but are expected to be short. A platform location and attitude prediction capability may be provided on the platform so that platform parameters can be provided in real-time on the platform. Data filters or other smoothing techniques may be applied to the platform parameters to limit the effect of individual read-out errors. Such techniques, if they are applied, will be a part of the platform-based position processing and will not need to be developed or applied by the individual payload instruments.

- Position accuracy. The military GPS data will be received according to current plans and will provide maximum position errors in the range of 30 - 50 meters. (NOTE: "Secure mode" GPS data vice "military" GPS data). Backup system requirements are still being worked. TONS 1 and 2 from the TDRSS system may backup, supplement, or even replace the GPS data except in cases where subsequent quality control procedures identify gross errors in the initially-provided platform position and attitude, improved values for these parameters will not be available days or weeks after the initial estimates were provided. The best available estimates for these quantities will be provided in real-time or near-real-time on the platform. Ground-loaded ephemerides are a backup option with substantially poorer accuracy.

- Backup attitude system requirements. The installation of a fine Sun sensor is being considered.

Requirements are in place for many important interface features. The position and attitude will be available on board via propagation from GPS and the attitude sensors. The platform position will be available as x,y,z data in a coordinate system TBD. Besides x,y,z coordinate data, GPS can provide a very accurate time reference provided the full constellation of GPS satellites is available. The platform attitude is determined on board from star sensors and the position data and is read out as angular deviation from the nadir (Earth center) and rotation about nadir. These data will be available to the instruments on board and will also be transmitted to EOSDIS (**not** CDOS). EOSDIS is anticipated to perform some crude checking and make the data available within 3 - 6 hours. The Flight Dynamics Facility will perform quality control on a weekly basis but will not be involved in the production data stream. The position, attitude, and velocity will be available at a 10 Hz rate.

The platform attitude knowledge requirement is 108 arcseconds on each of the three axes as a worst case for **each** instrument (NOTE: 108 arcseconds is a 3 sigma deviation and not a "worst case"). There is no expectation for these errors to be correlated. Platform distortions are expected to be smaller than launch shifts, but there is no on-orbit measurement capability of instrument alignments. There is some concern that the 108 arcsecond requirement may not be achievable. An area yet to be addressed is the requirements for coalignment of instruments to achieve the overall attitude requirement.

Since the use of ground control points will be difficult for MODIS, a suggestion was made that the ground truth determined for HIRIS (mounted near MODIS) may be considered for making attitude bias corrections to MODIS Earth location data. If ground control data can be developed for several instruments located in different sections of the platform, observation offset data may be developed independently for each section of the platform. Differences in offset for the various sections of the platform might be used as the basis for a platform distortion model.

Only small attitude excursions are expected during the operation of the platform, even for calibrations, because the platform operational attitude is only metastable against gravity gradient torques. Large attitude excursions run the risk of saturation of reaction wheels and excessive use of propellant.

2. <u>First Order Error Analysis</u>

Nadir IFOV Location Accuracy (Method 1):

Maximum GPS Position Errors:	50 m
Maximum Platform Attitude Error (per axis):	105 arc seconds
Maximum MODIS Pointing Error (per axis):	90 arc seconds
Nominal Platform Altitude:	705 km

Approximate nadir position error due to imperfect platform attitude knowledge = 359 m

Approximate nadir position error due to imperfect MODIS pointing knowledge = 308 m

Approximate nadir position error due to imperfect platform position knowledge = 50 m

Assuming that the individual errors are "three-sigma," then the corresponding three standard deviation total nadir position error (assuming no cross-correlations) is $[(359\ m)^2 + (308\ m)^2 + (50\ m)^2]$ = 476 m, which is 56% of the largest (856 m) MODIS-N IFOV, 41% of the largest (1,100 m) MODIS-T IFOV, and 222% of the present smallest MODIS-N IFOV.

At higher scan (and tilt) angles, the spatial errors will be greater, though the relative errors to the IFOV will remain approximately the same.

Occcasionally, the errors will all act in the same direction. Under these conditions, the total error will exceed the three-sigma uncorrelated value to give a simple sum = 717 m.

3. Two-Dimensional Solution for MODIS Nadir-Looking Errors

MODIS processing will associate a set of geodetic Earth coordinates (i.e. latitude, longitude, and radius) with each observation pixel. Geolocation of pixels requires precise knowledge of the MODIS platform location and attitude at the instant when the observation was made. Errors associated with this process may be related either to uncertainties in instrument location or instrument attitude. The look direction of the MODIS instrument is the resultant of the basic platform navigation base attitude modified by any platform distortion between the navigation base and the MODIS mounting baseplate, and further modified by the line of sight of the MODIS instrument referenced with respect to the instrument baseplate. Errors are associated with the determination of each of these quantities.

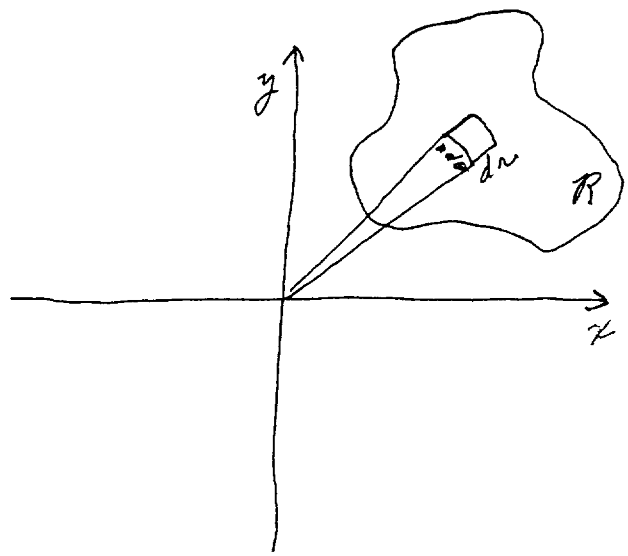
The error model to be used in this analysis will include the error terms listed in Table 1. Two sets of results will be presented: according to the current specification (January 15, 1990), the combined effect of navigation base attitude uncertainty and platform uncertainty will not exceed 105 arcseconds for each axis. One set of results will apply if this specification can be met. Because of uncertainties as to whether the specification can actually be met, a second set of calculations were done that include separate terms for navigation base uncertainty and platform distortion, as listed in Table 1. The platform distortion limit given in this table is a rough estimate based, for the moment, on the idea that if the specification is not met, navigation base uncertainty and platform distortion might each roughly equal the originally intended combined effect. Table 1 also lists the assumed platform altitude, 705 kilometers.

TABLE 1

THREE SIGMA ERROR LIMITS ASSOCIATED WITH GEOLOCATION PARAMETERS

Assumed platform altitude	705 kilometers
Platform location	50 meters/each direction
[Assuming platform meets current specification draft]	
Platform attitude uncertainty	105 arcseconds/each axis
Instrument look uncertainty	90 arcseconds/each axis
[Assuming platform does not meet current specification draft]	
Navigation base attitude	105 arcseconds/each axis
Platform distortion	105 arcseconds/each axis
Instrument look uncertainty	90 arcseconds/each axis

For analysis purposes, it will be assumed that each error quantity is Gaussian distributed with zero mean. If errors about each axis (or in each direction) are assumed independent of errors about the other axes, the joint probability density function for errors distributed in two-dimensional space is the product of the individual probability density functions (assumed Gaussian). If one asks what is the probability $P\{\mathcal{R}\}$ of errors occuring within an arbitrary region $\mathcal{R}$ as shown in Figure 1,



one obtains

$$P\{\mathcal{R}\} = \iint_{\mathcal{R}} \frac{1}{\sqrt{2\pi}\,\sigma_x} e^{-\frac{x^2}{2\sigma_x^2}} \frac{1}{\sqrt{2\pi}\,\sigma_y} e^{-\frac{y^2}{2\sigma_y^2}} \, dx\,dy \qquad (1)$$

Now the integration over the region $\mathcal{R}$ may be done in any desired coordinate system. Since we ultimately want to examine the probability of error within a circle centered at the origin and with radius R, we shall use radial coordinates. The conversion equations are

$$x = r\cos\theta$$
$$y = r\sin\theta \qquad (2)$$

To permit further simplification, and because the condition is satisfied by the postulated error distributions, we shall assume

$$\sigma = \sigma_x = \sigma_y \qquad (3)$$

For $P\{\mathcal{R}\}$ we then obtain

$$P\{\mathcal{R}\} = \iint_{\mathcal{R}} \frac{1}{\sqrt{2\pi}\,\sigma} e^{-\frac{r^2\cos^2\theta}{2\sigma^2}} \frac{1}{\sqrt{2\pi}\,\sigma} e^{-\frac{r^2\sin^2\theta}{2\sigma^2}} r\,d\theta\,dr \qquad (4)$$

But considering that $\cos^2\theta + \sin^2\theta = 1$ Equation 4 can be simplified.

$$P\{\mathcal{R}\} = \frac{1}{2\pi\sigma^2} \iint_{\mathcal{R}} e^{-r^2/2\sigma^2} r\,d\theta\,dr \qquad (5)$$

Note that the simplified integrand does not explicitly involve θ. Let the region of integration $\mathcal{R}$ be a circle $\mathcal{C}$, centered at the origin with radius R. Then we can explicitly carry out the integration in θ and r and we obtain

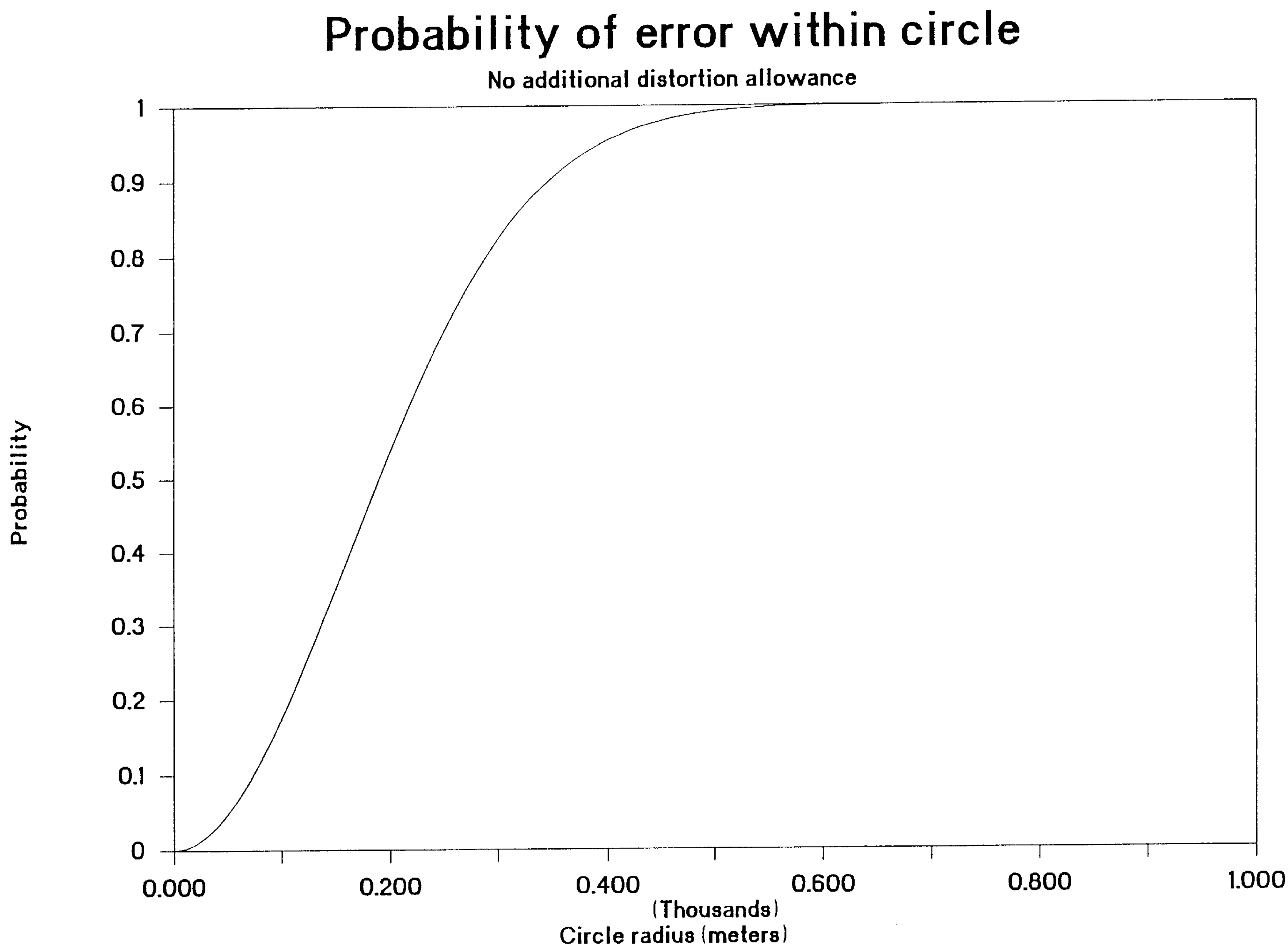
$$P\{C\} = \frac{1}{\sigma^2} \int_0^R e^{-\frac{r^2}{2\sigma^2}} r\,dr = 1 - e^{-\frac{R^2}{2\sigma^2}} \qquad (6)$$

Now for independent error processes

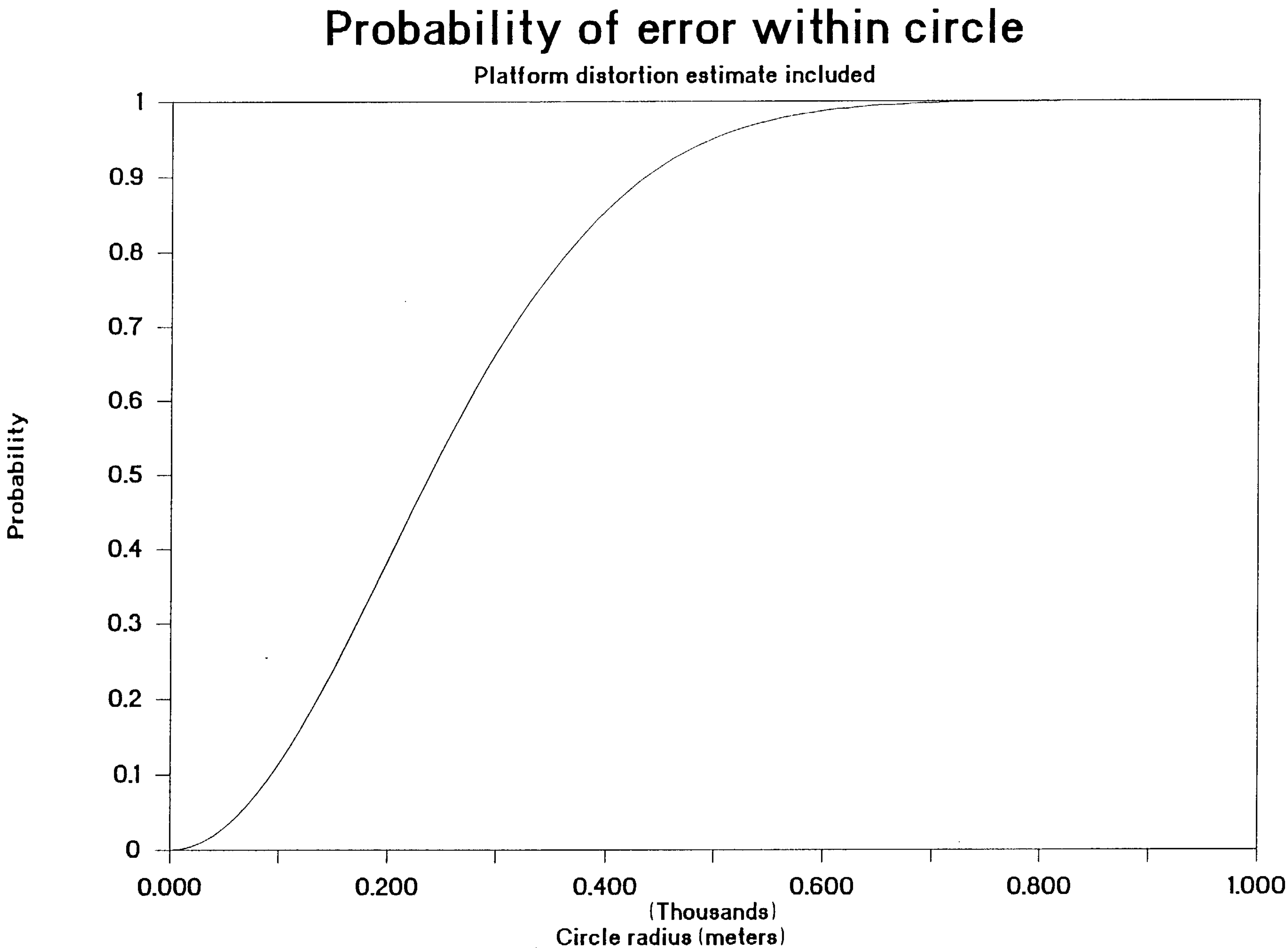
$$\sigma = \sqrt{\sigma_\ell^2 + \sigma_a^2 + \sigma_d^2 + \sigma_i^2}$$

where σ is the combined standard deviation in each dimension, σ_ℓ is the standard deviation of platform location errors, σ_a is the standard deviation of platform navigation base errors, σ_d is the standard deviation of platform distortion errors, and σ_i is the standard deviation of instrument pointing errors. For attitude errors as specified in the current platform specification, σ = 161 meters. With added platform distortion, σ = 203 meters.

The basic behavior of $P\{\mathcal{C}\}$ is shown in Figures 2 and 3 for the two cases. Table 2 shows details of the behavior for larger radius values. One case of particular interest we shall here call the "three sigma" case, where $P\{\mathcal{C}\}$ = 0.0026 (0.0026 is the probability of exceeding a 3 σ separation from the mean in a standard Gaussian distribution). Solving Equation 6 for R/ corresponding to this probability, we see that for the distribution function given in Equation 6, R/σ = 3.44, i.e. the radius corresponding to the "three sigma" probability is actually 3.44 σ for the two dimensional geometry considered in this analysis. The corresponding circle radius is 554 meters for the specified platform errors and 697 meters with added platform distortion.



Probability of error within circle
No additional distortion allowance
Probability
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.000
0.200
0.400
0.600
0.800
1.000
(Thousands)
Circle radius (meters)



Probability of error within circle
Platform distortion estimate included
Probability
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.000
0.200
0.400
0.600
0.800
1.000
(Thousands)
Circle radius (meters)

TABLE 1

TABULAR LISTING OF ERROR PROBABILITIES

As specified (15 Jan 90)		With added platform distortion	
Circle radius (meters)	Probability of error within circle	Circle radius (meters)	Probability of error within circle
100	0.175362458	100	0.114618319
200	0.537563176	200	0.385499661
300	0.823653063	300	0.665670433
400	0.954269112	400	0.857410184
500	0.991935498	500	0.952328009
600	0.999032899	600	0.987506068
700	0.999921134	700	0.997433176
800	0.999995626	800	0.999586616
900	0.999999835	900	0.999947812
1000	0.999999996	1000	0.999994835