MODIS Team Responsibilities

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Photogrammetric Camera Model SW (forward/reverse)

Topographic Correction SW for land surface

Scene simulation Monte Carlo Ray-tracer SW

Global BRDF Data for land surface

Global Spectral Albedo Data for Earth surface

Global Surface Roughness Parameter Data

Global Land Cover Data-sets for Climate Models

Modelling of MODIS Sensors

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MODCAL 1991 Progress Report

- "Math Model" developed for production of synthetic satellite scenes taking into account all known interactions of electro-magnetic radiation with matter.

- uses Monte Carlo ray-tracing techniques ("ARARAT")

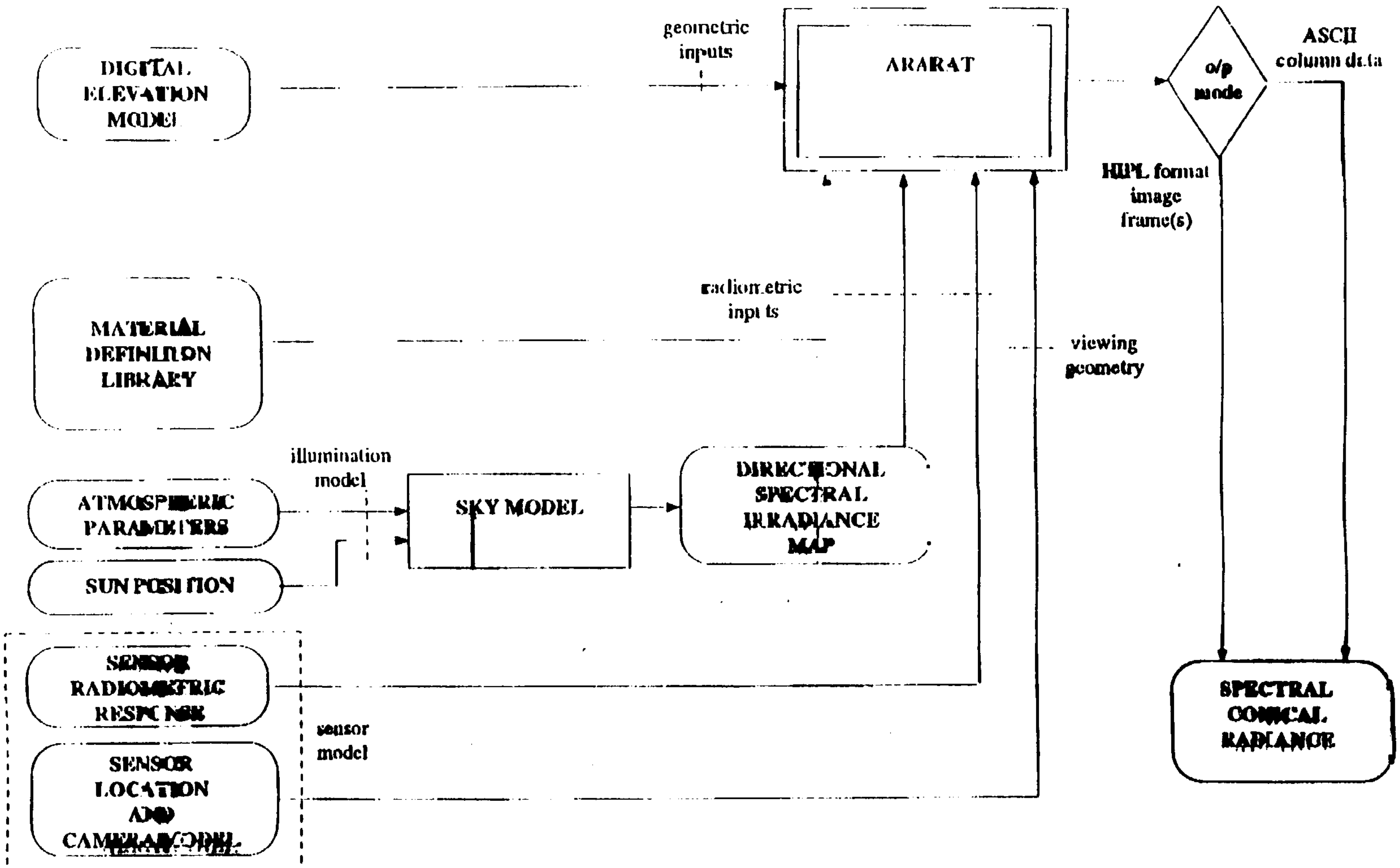
- can be applied to modelling of scene radiance from the leaf scale to the global scale. Also can be applied to ocean.

- uses Zibordi & Voss spectral sky irradiance model as 6S is still not available.

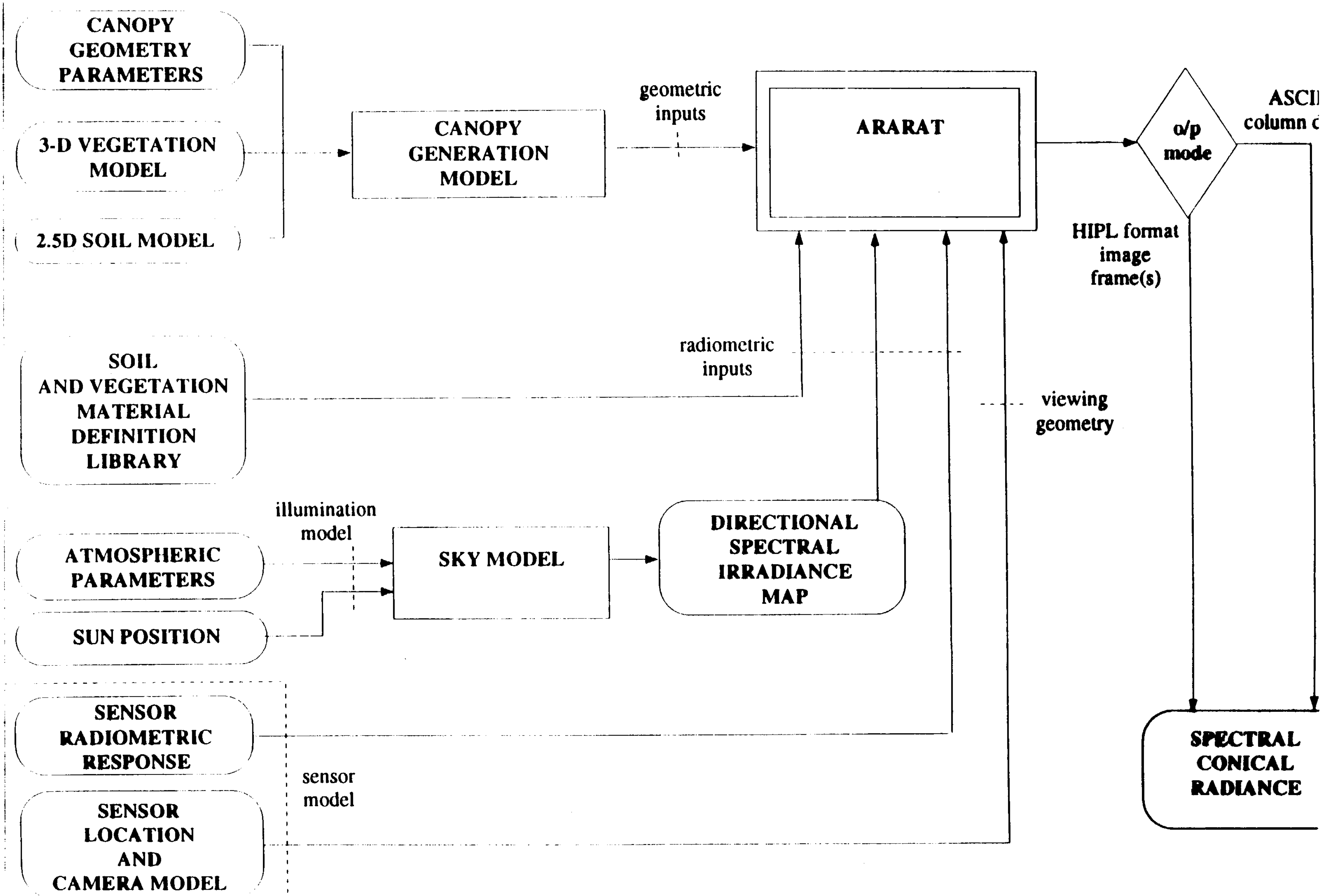
- sensitivity studies for FIFE test site started on topographic shading and shadowing effects for AVHRR and MODIS images

- currently still uses "pin-hole camera geometry" as no information has yet been supplied by MCST on MODIS camera geometry (pointing vector through focal point as a function of time in WGS84 co-ordinates).

- camera model (forward and reverse) for ASAS and MAS being developed using additional parameter approach



DIGITAL ELEVATION MODEL
geometric inputs
ARARAT
o/p mode
ASCII column data
HIPL format image frame(s)
MATERIAL DEFINITION LIBRARY
radiometric inputs
viewing geometry
illumination model
ATMOSPHERIC PARAMETERS
SKY MODEL
DIRECTIONAL SPECTRAL IRRADIANCE MAP
SUN POSITION
SENSOR RADIOMETRIC RESPONSE
sensor model
SENSOR LOCATION AND CAMERA MODEL
SPECTRAL CONICAL RADIANCE


CANOPY GEOMETRY PARAMETERS
3-D VEGETATION MODEL
2.5D SOIL MODEL
CANOPY GENERATION MODEL
geometric inputs
ARARAT
o/p mode
ASCII column
HIPL format image frame(s)
radiometric inputs
viewing geometry
SOIL AND VEGETATION MATERIAL DEFINITION LIBRARY
illumination model
ATMOSPHERIC PARAMETERS
SUN POSITION
SKY MODEL
DIRECTIONAL SPECTRAL IRRADIANCE MAP
SENSOR RADIOMETRIC RESPONSE
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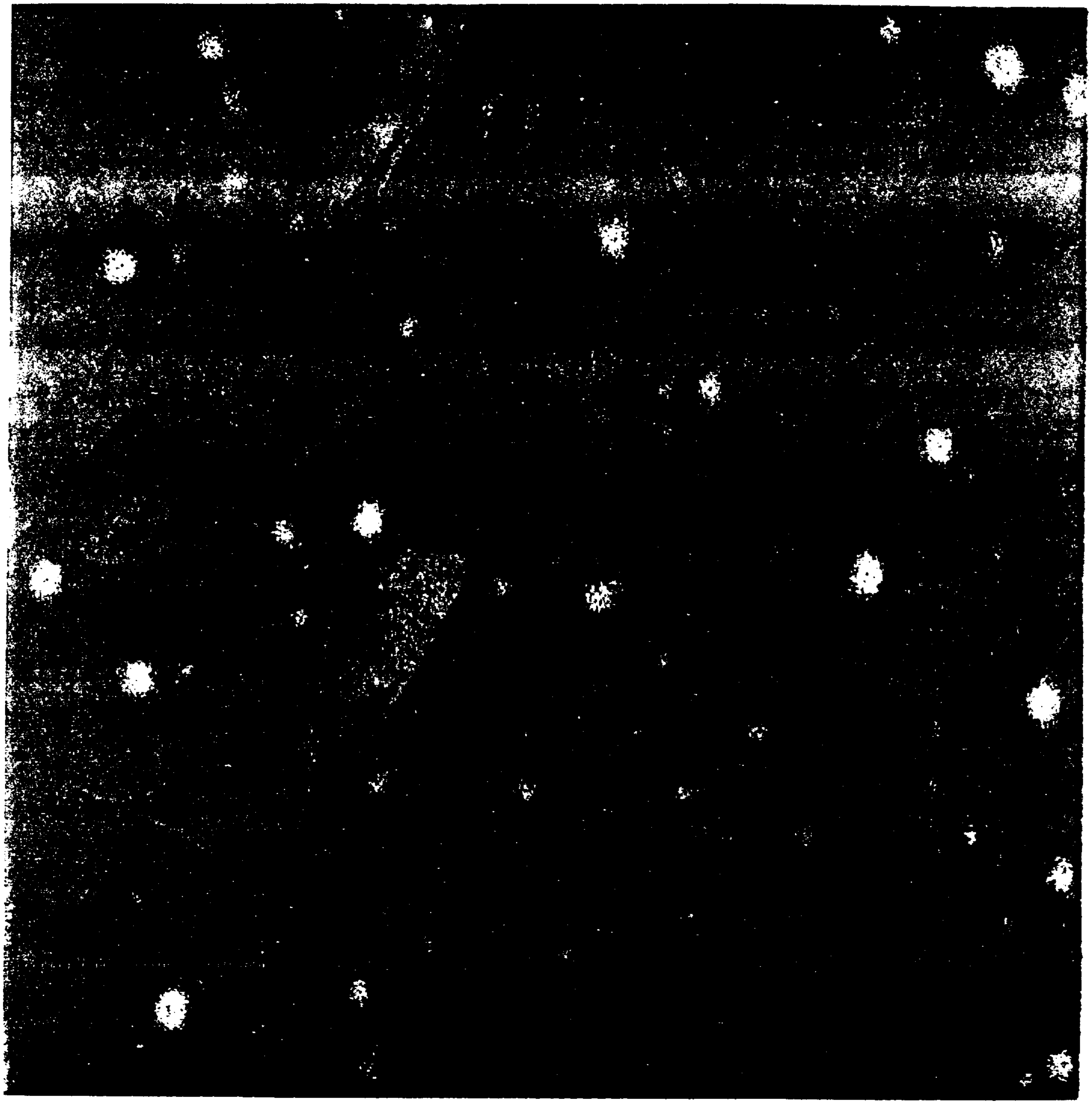


maize plant: diffuse sampling sensitivity experiment:
ray-depth: 1 diffuse-rays: 1,4,8,16

Erd Sicht / Global Change Video

story: OZONE
data: TOMS daily ozone concentration. UCL ImagingBase
source: NASA GSFC

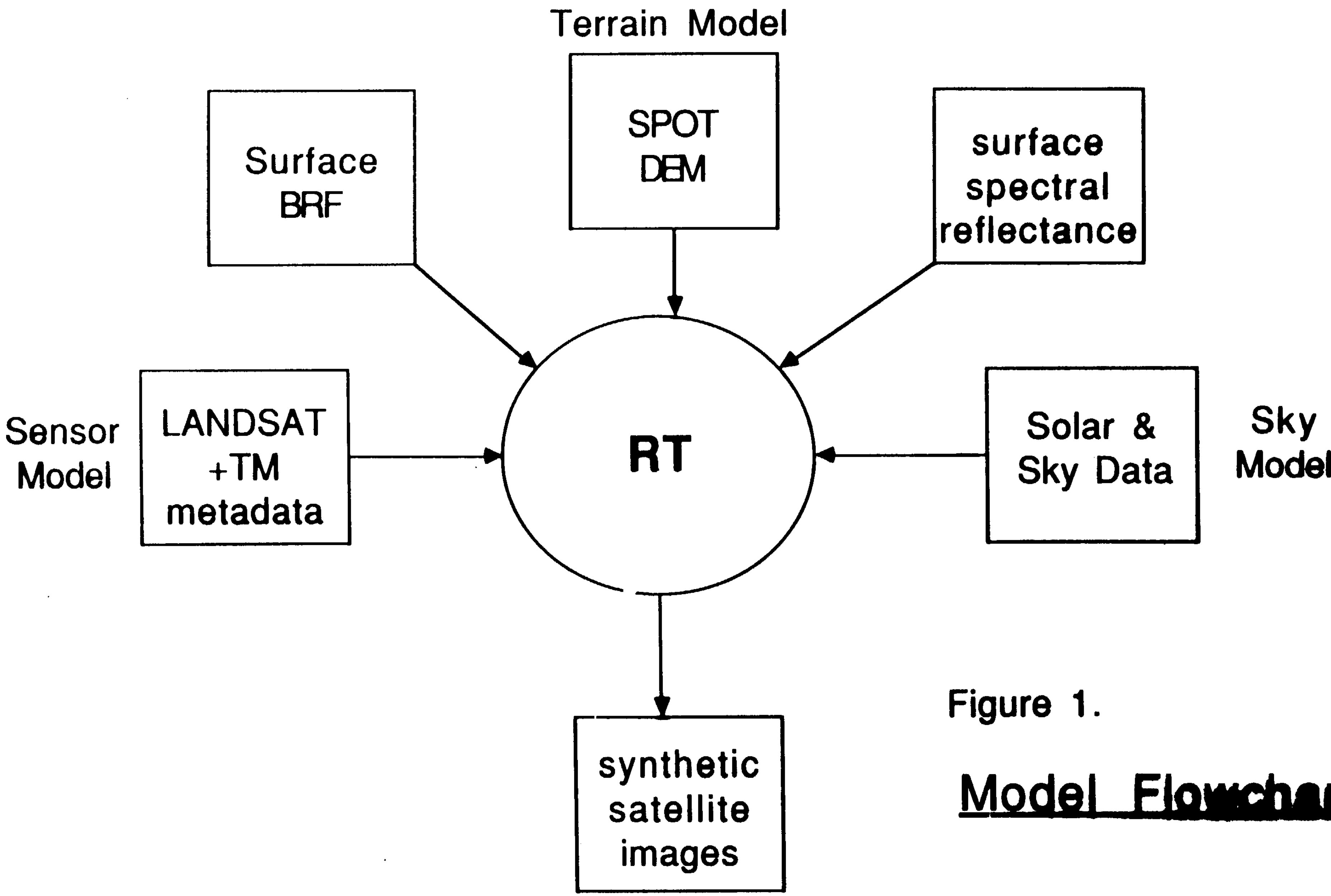
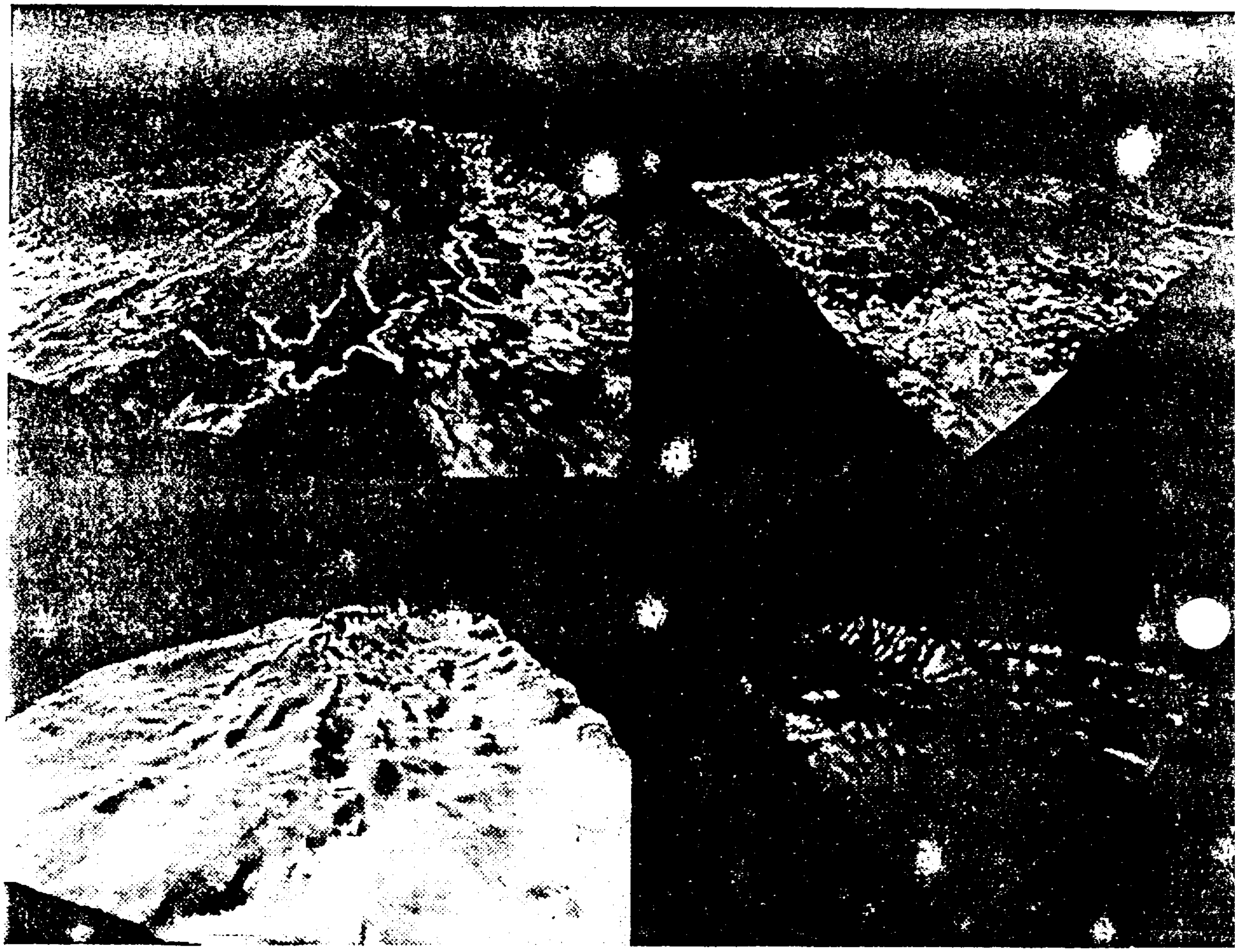
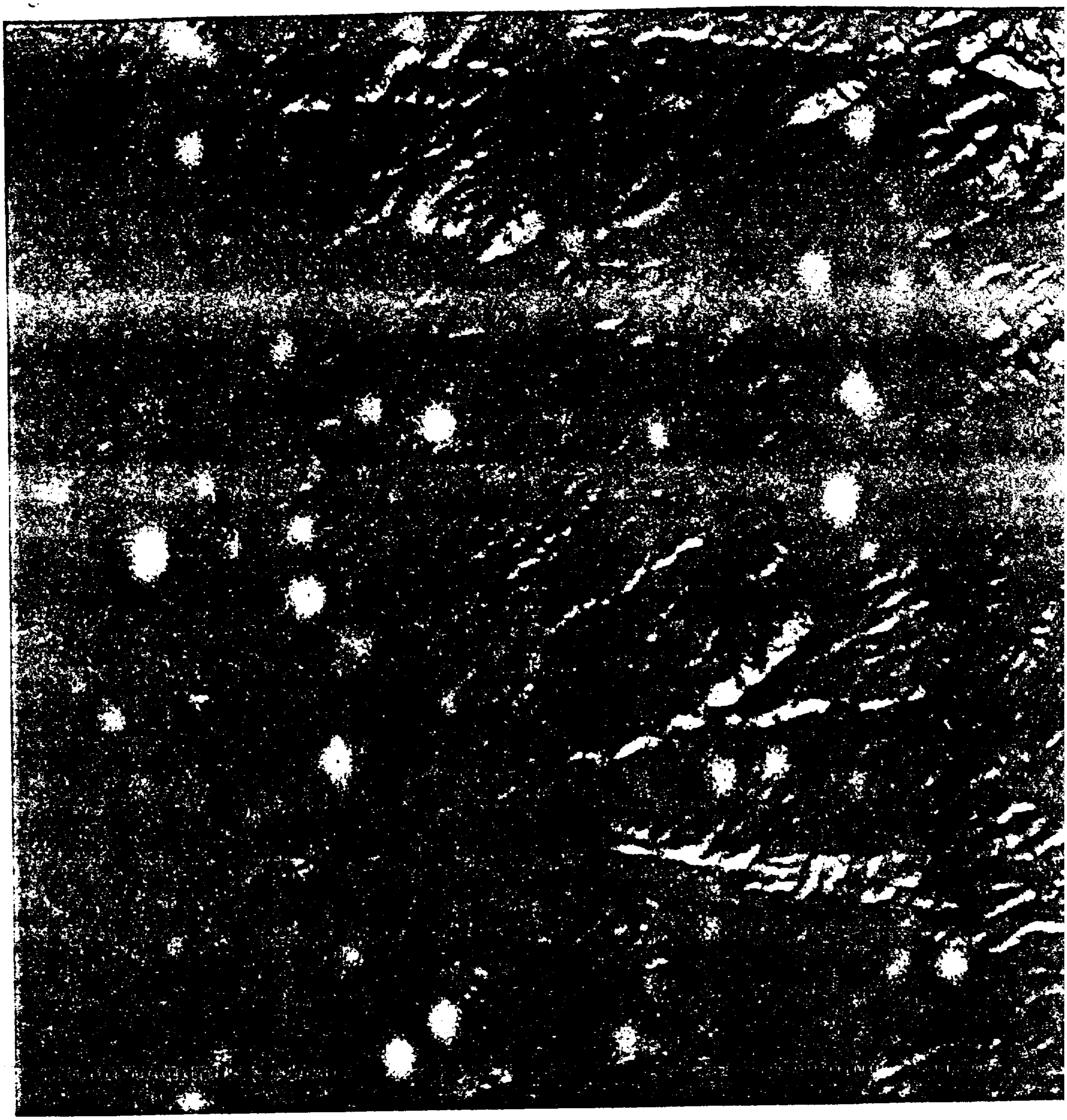


Figure 1.

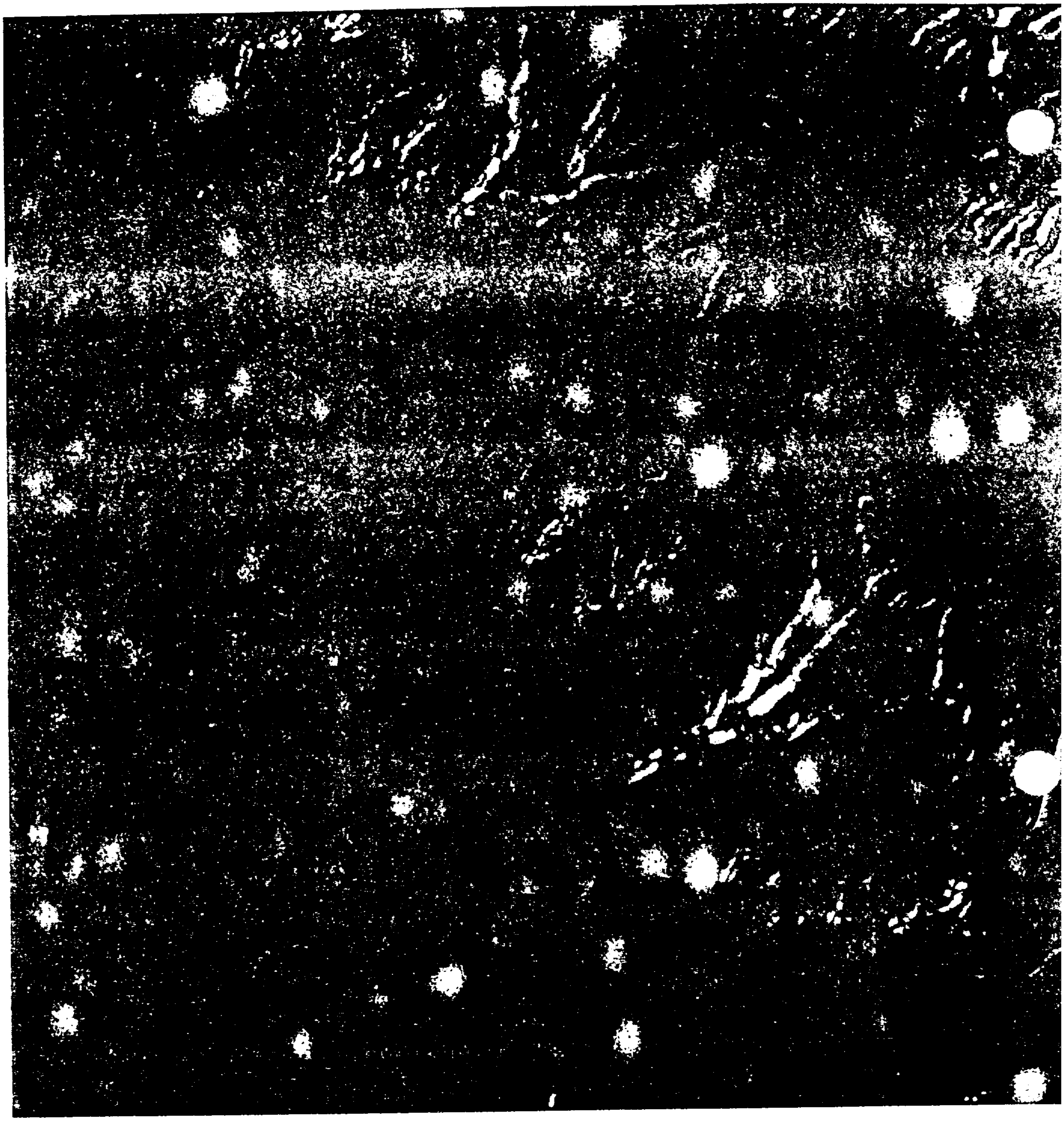
Model Flowchart





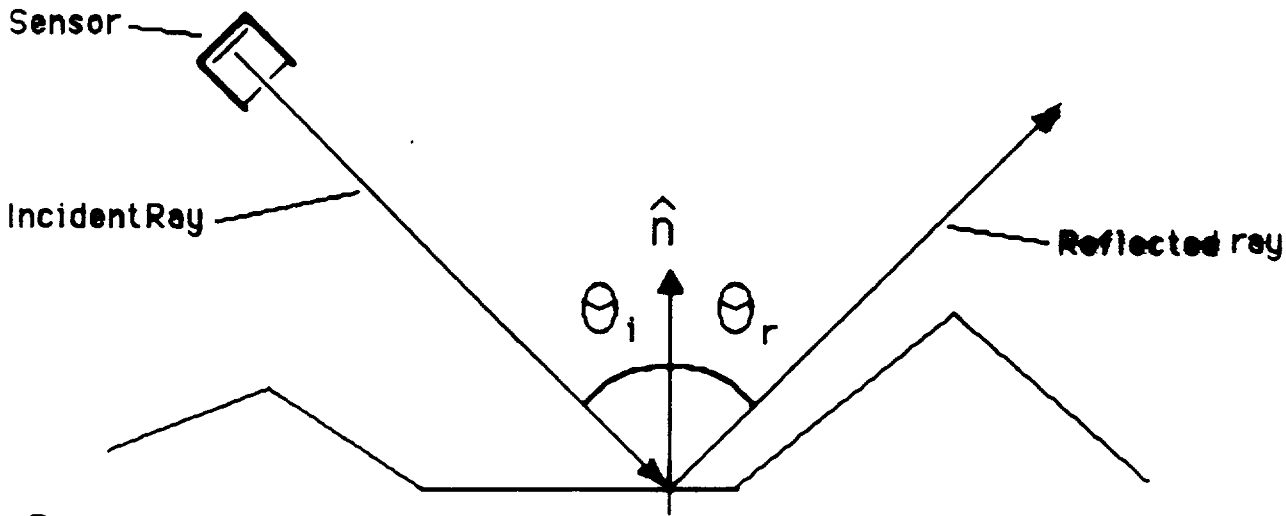
False Colour Composite of bands 7,3,1 as RGB. This area was extracted to match the area of the DEM used to generate the synthetic images.

FCC 731 RGB of Frontier Sandstone Synthetic images: [illegible]



False Colour Composite of bands 7,3,1 as RGB. This area was extracted to match the area of the DEM used to generate the synthetic images.

Figure 2. **Ray Propagation: Specular Reflectance**



Θ_i - Angle of Incidence

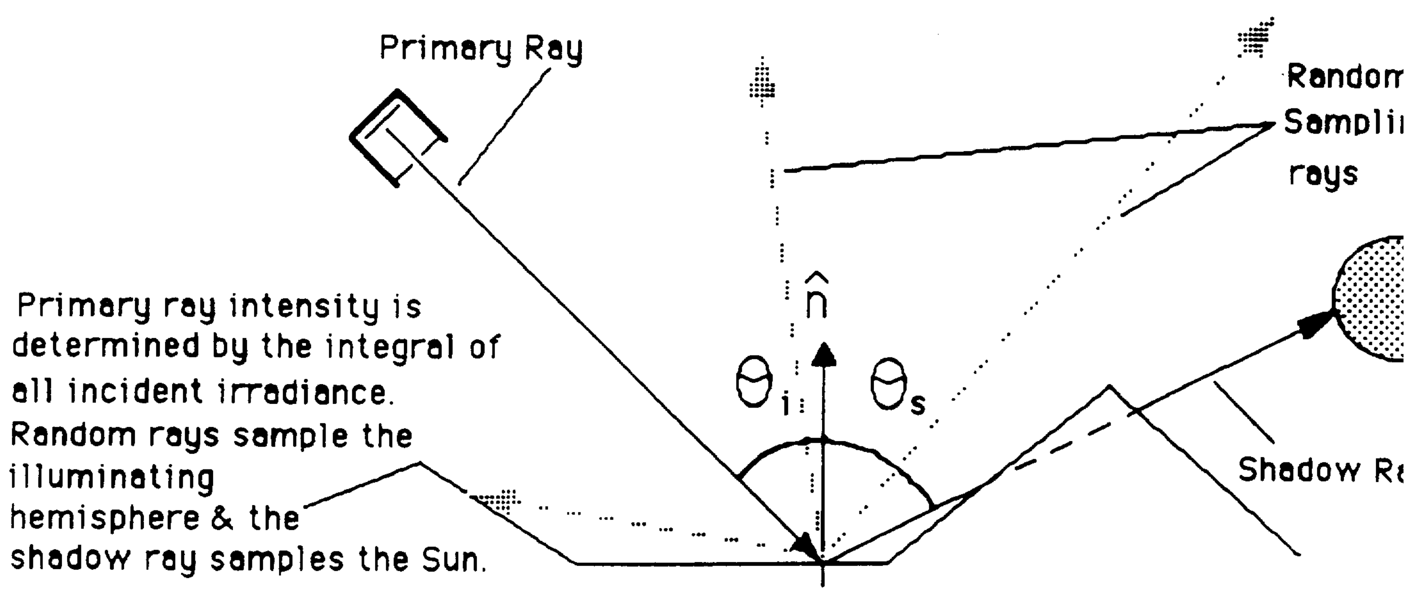
Θ_r - Angle of reflectance

$\hat{n}$ - Normal Vector

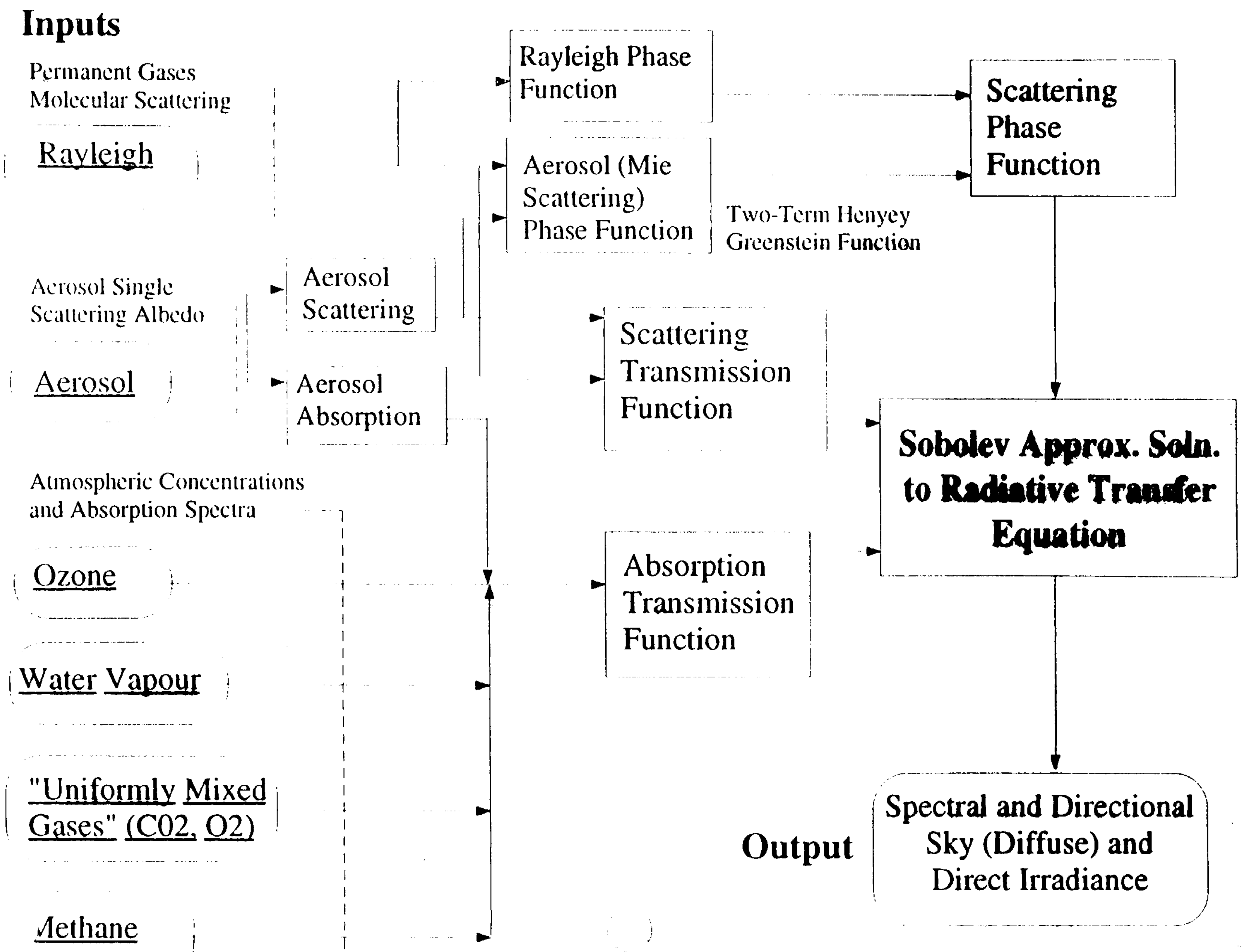
Θ_s - Sun Angle

A single reflected ray can determine the intensity to assign to the incident ray.

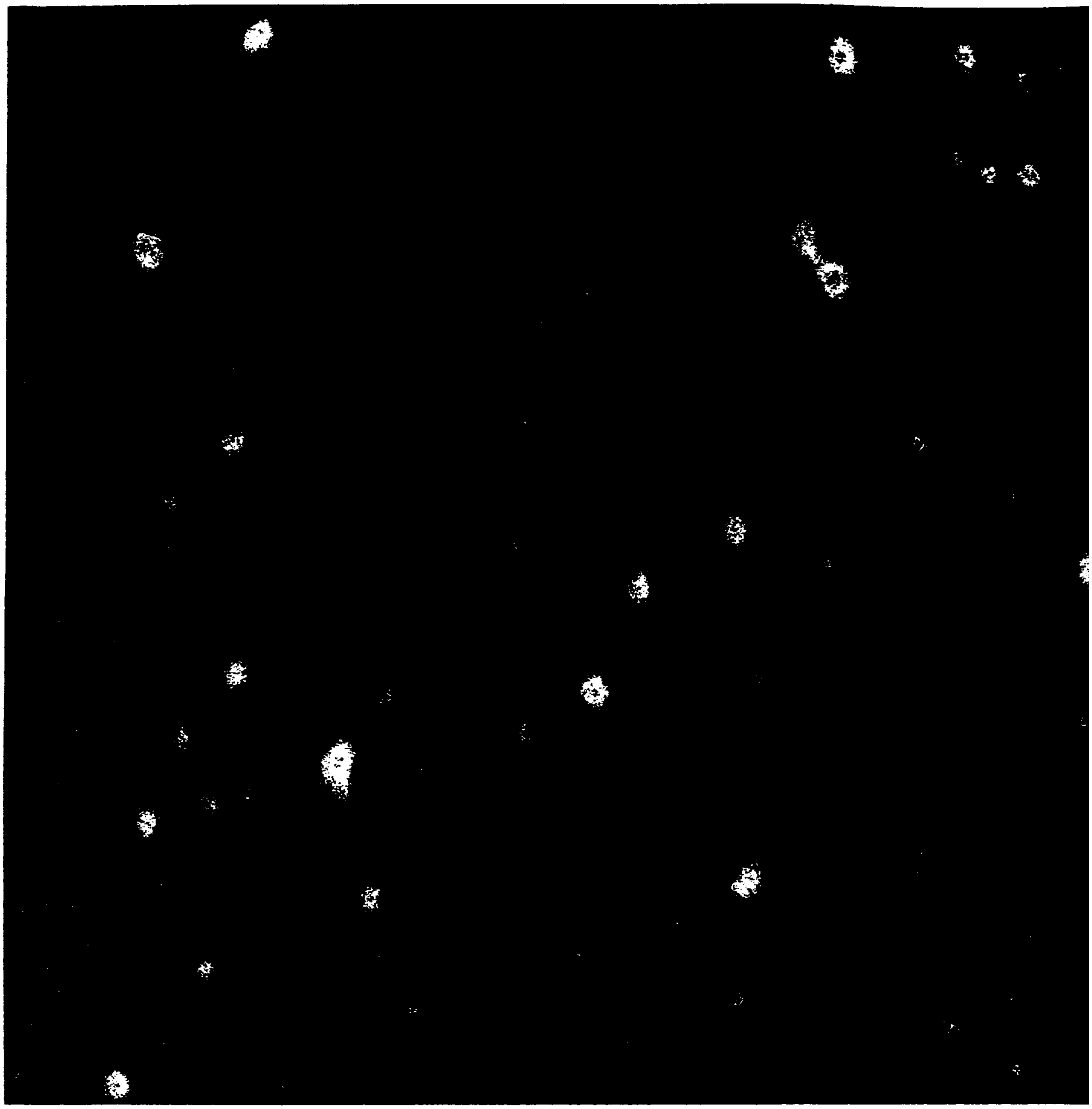
Figure 3. **Ray Propagation: Lambertian Reflectance**



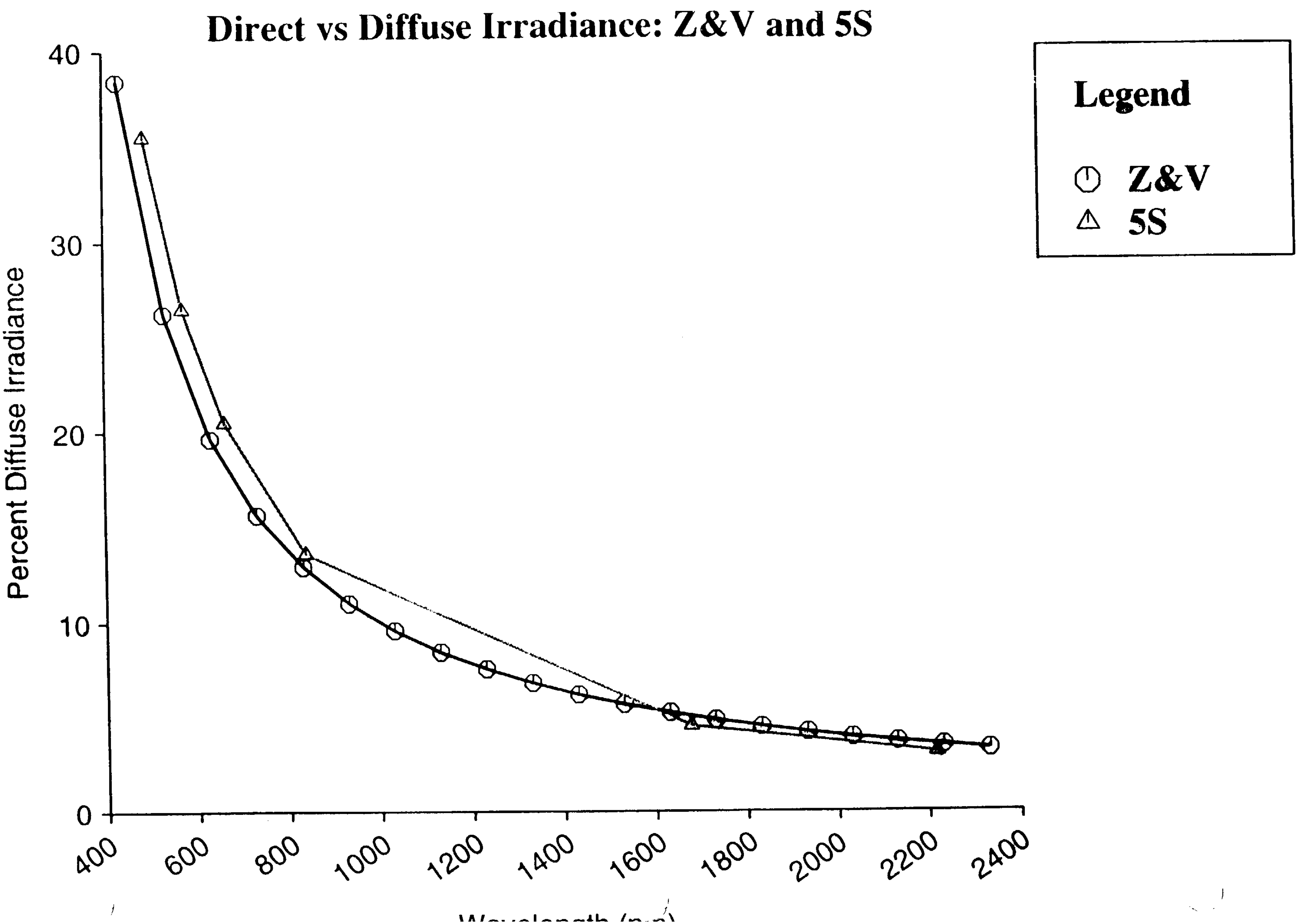
Spectral and Directional Sky Radiance Model (Zibordi and Voss 1989)

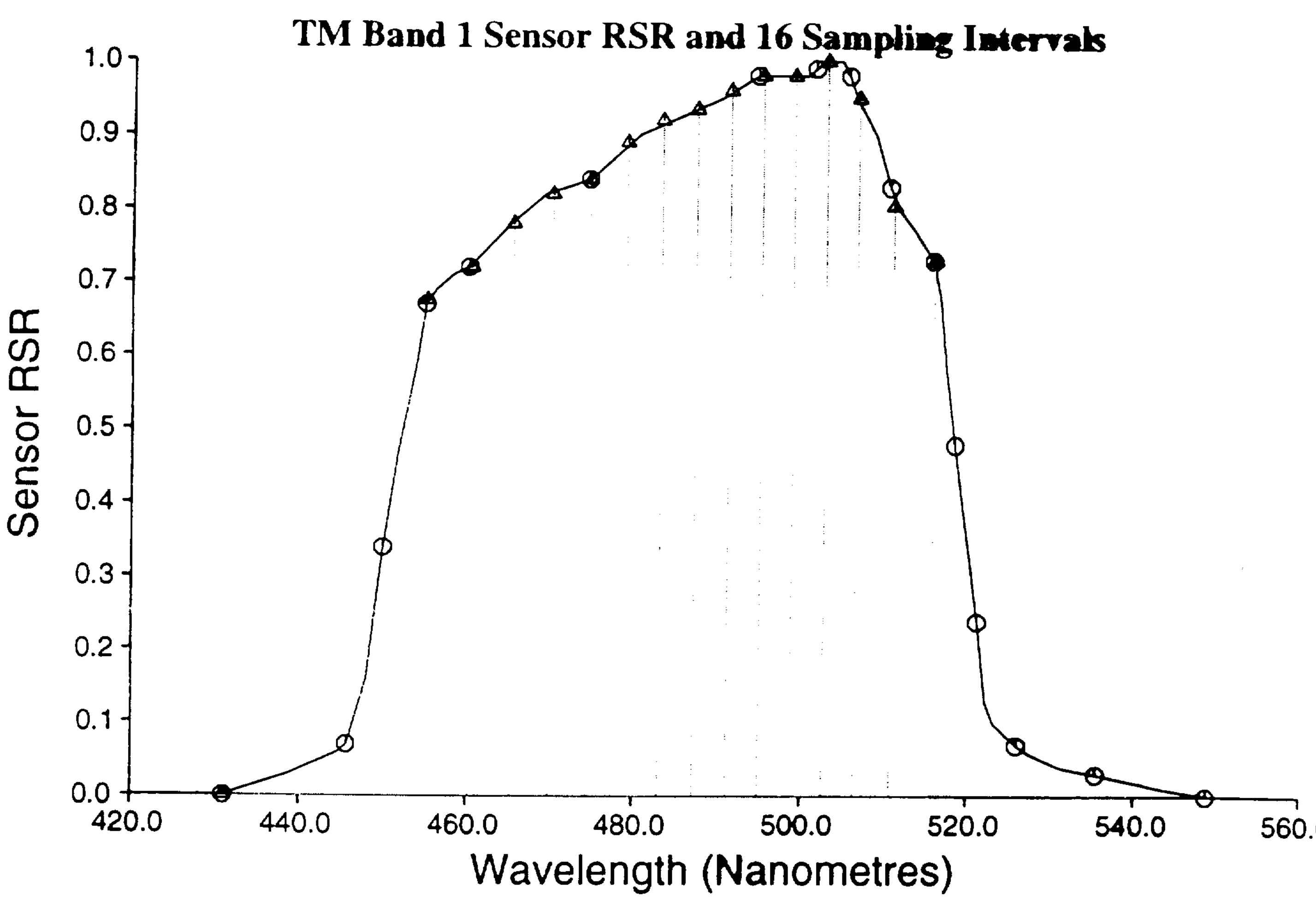


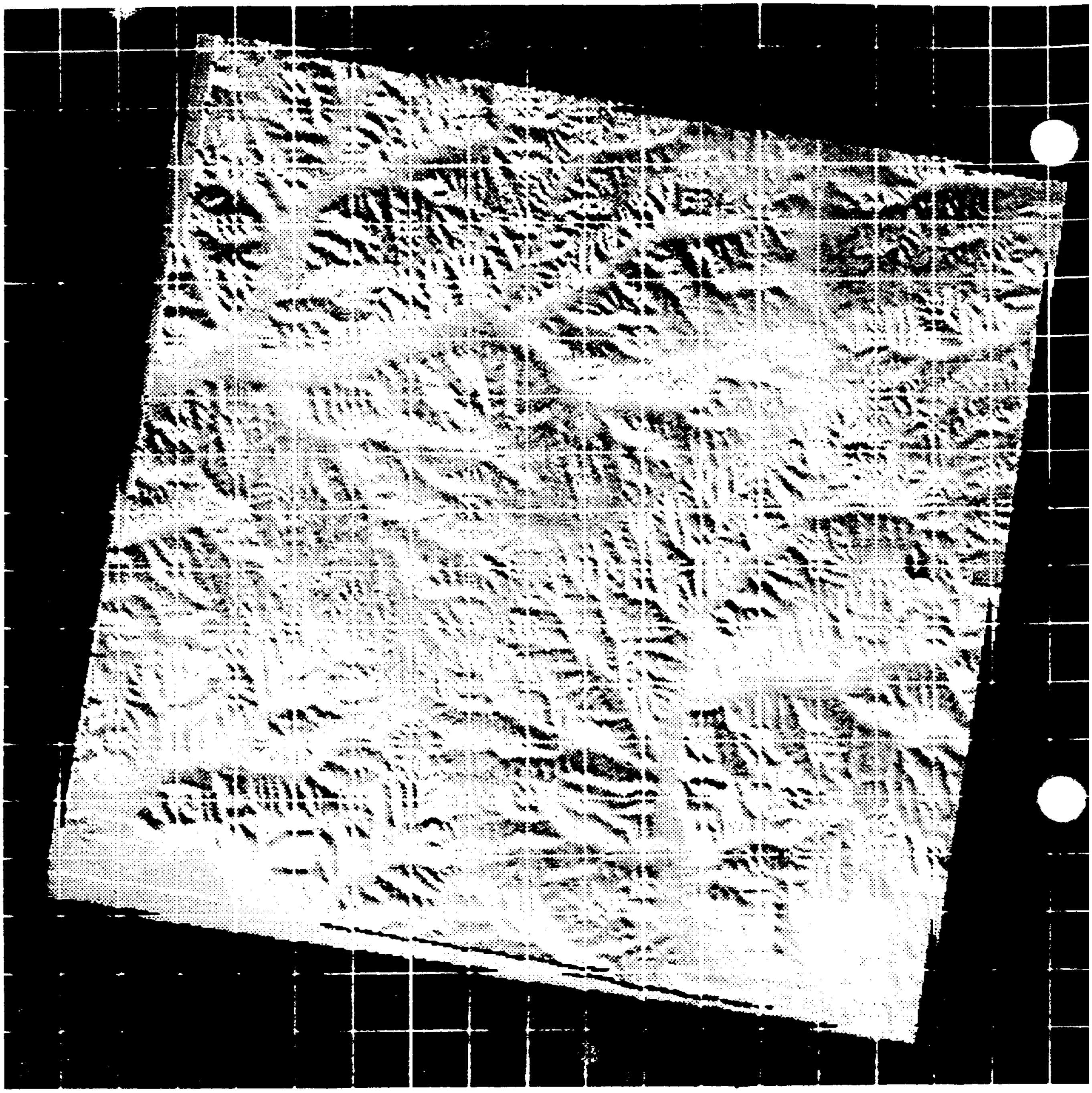
Ziborda and Voss model : Blue Sky



Zibordi and Voss sky irradiance model:
standard atmospheric parameters
nominal RGB wavelengths (nm) : 800, 600, 500
computed at 1 degree intervals
24-bit to QMS


Direct vs Diffuse Irradiance: Z&V and 5S
Percent Diffuse Irradiance
0
10
20
30
40
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
Legend
Z&V
5S


TM Band 1 Sensor RSR and 16 Sampling Intervals
Sensor RSR
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
420.0
440.0
460.0
480.0
500.0
520.0
540.0
560.0
Wavelength (Nanometres)

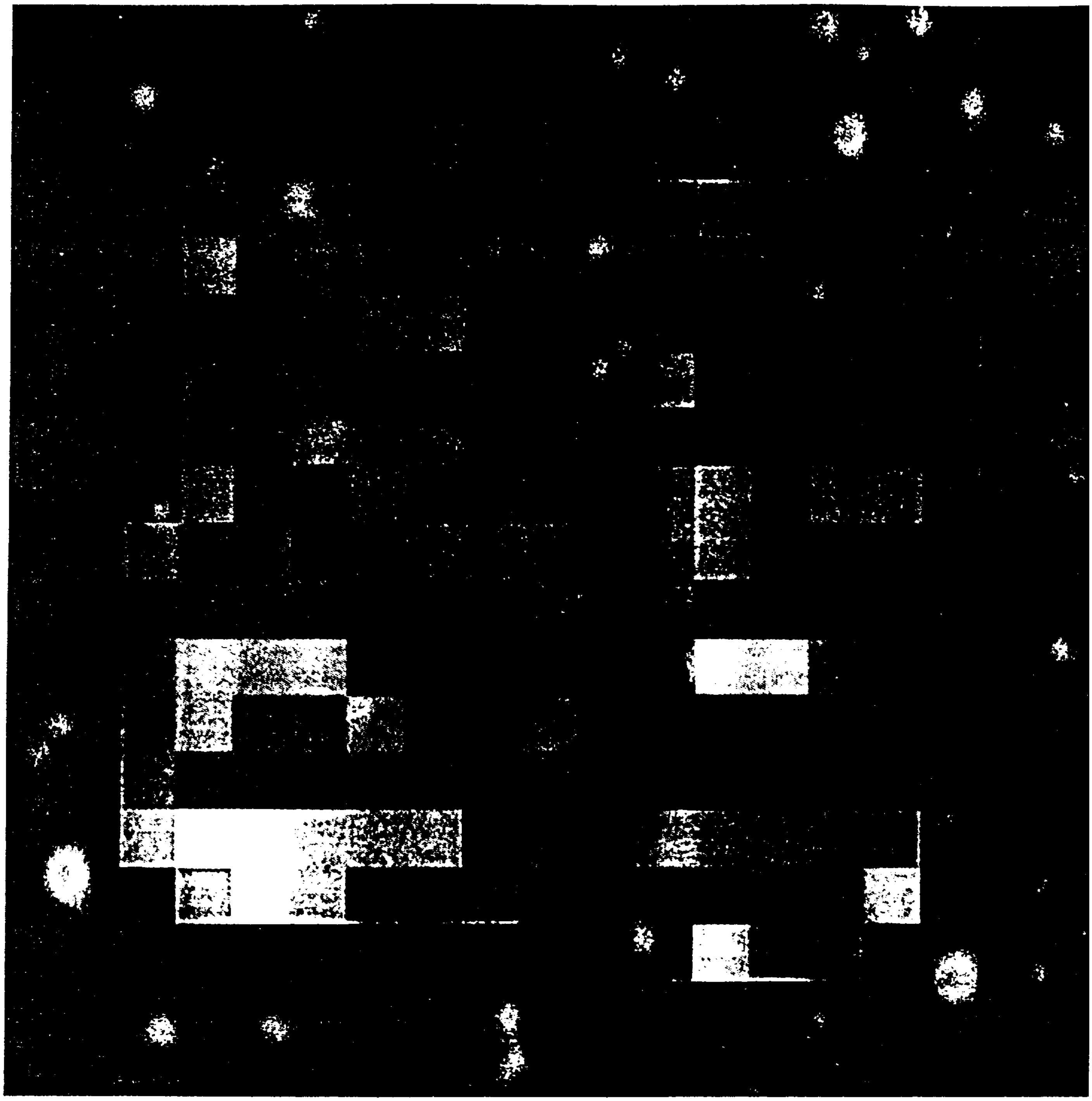


AVHRR band 1 simulation of FIFE DEM with PVD sugarbeet model

- 19x19 pixel AVHRR scenewith sub-pixel contents -

simulated with no diffuse sampling (direct irradiance only) (DN range maps to reflectance 0.024 to 0.032)

FIFE AVHRR Channel 1 Simulation 1



AVHRR channel 1 simulated Radiance:

FIFE Site August 7th 1989, 19.57 GMT;

Imaging Parameters: View Azimuth 260.2, View Zenith 17.5

Irradiance Parameters: Solar Azimuth 225.5, Solar Zenith 29.2

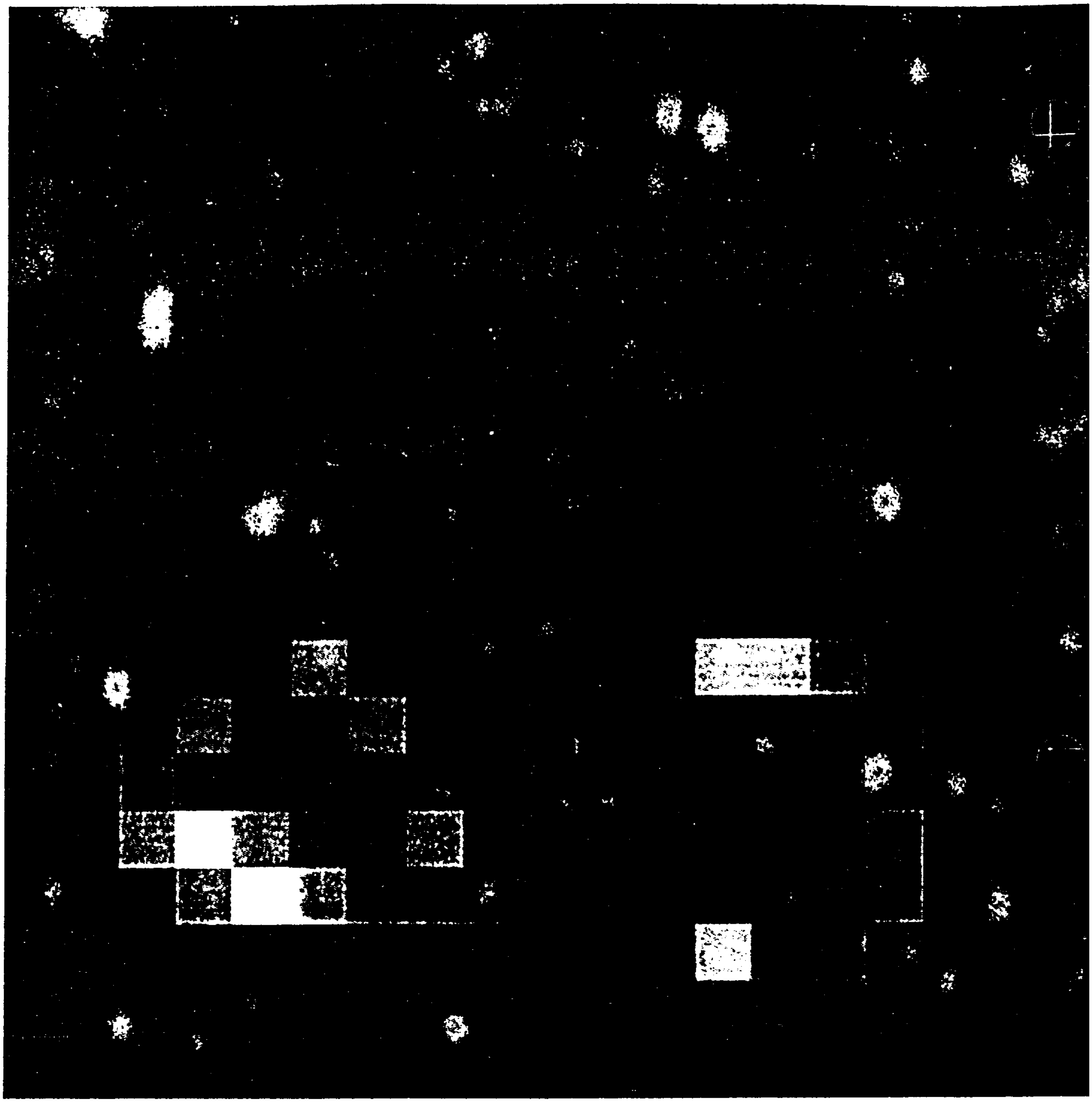
Simulation Parameters: 100x100x4 primary rays per AVHRR IFOV

Convergence to 1% in radiance per pixel

Range: max = 39.37, min = 37.05, (W m^-2 um^-1)

BRDF: PVD Model "Soybean" (from PVD, JGR Vol 95, July 1990)

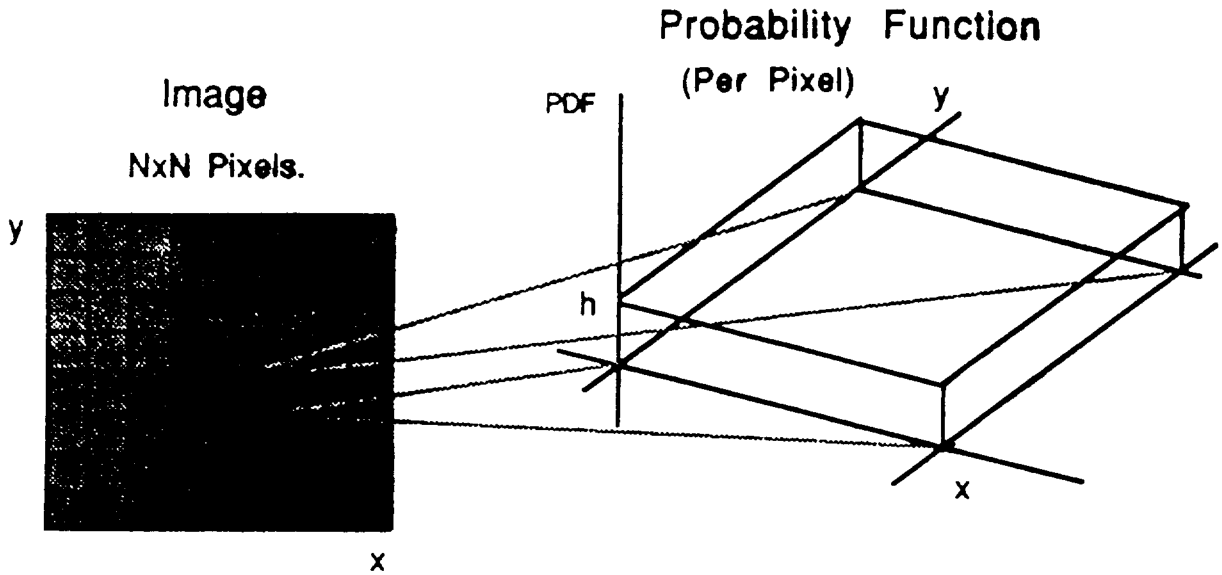
FIFE AVHRR Channel 2 Simulation ..



AVHRR channel 2 simulated Radiance:
FIFE Site August 7th 1989, 19.57 GMT;
Imaging Parameters: View Azimuth 260.2, View Zenith 17.5
Irradiance Parameters: Solar Azimuth 225.5, Solar Zenith 29.2
Simulation Parameters: 100x100x4 primary rays per AVHRR IFOV
Convergence to 1% in radiance per pixel
Range: max = 344.4, min = 324.1, (W m^-2 um^-1)
BRDF: PVD Model "Soybean" (from PVD, JGR Vol 95, July 1990)

Figure 4.

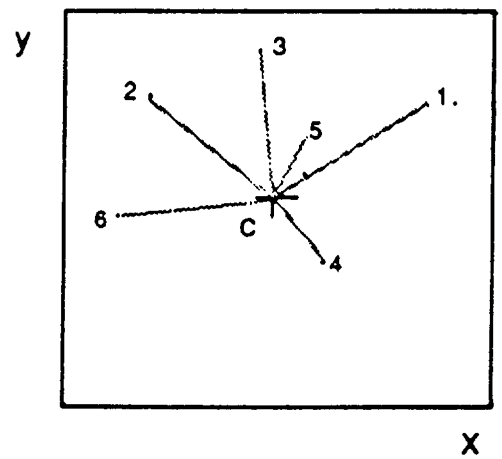
Spatial Sampling. (for ray origin).



h = 1/n ; n samples per pixel.

Classical Monte Carlo sampling.

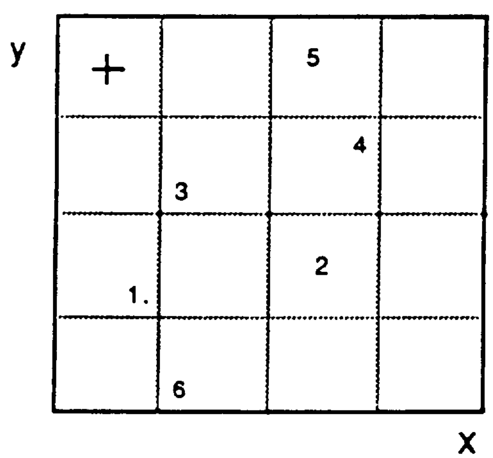
(One Pixel).



Sample Origins chosen by Random Offsets from Pixel Centre.

Importance sampling.

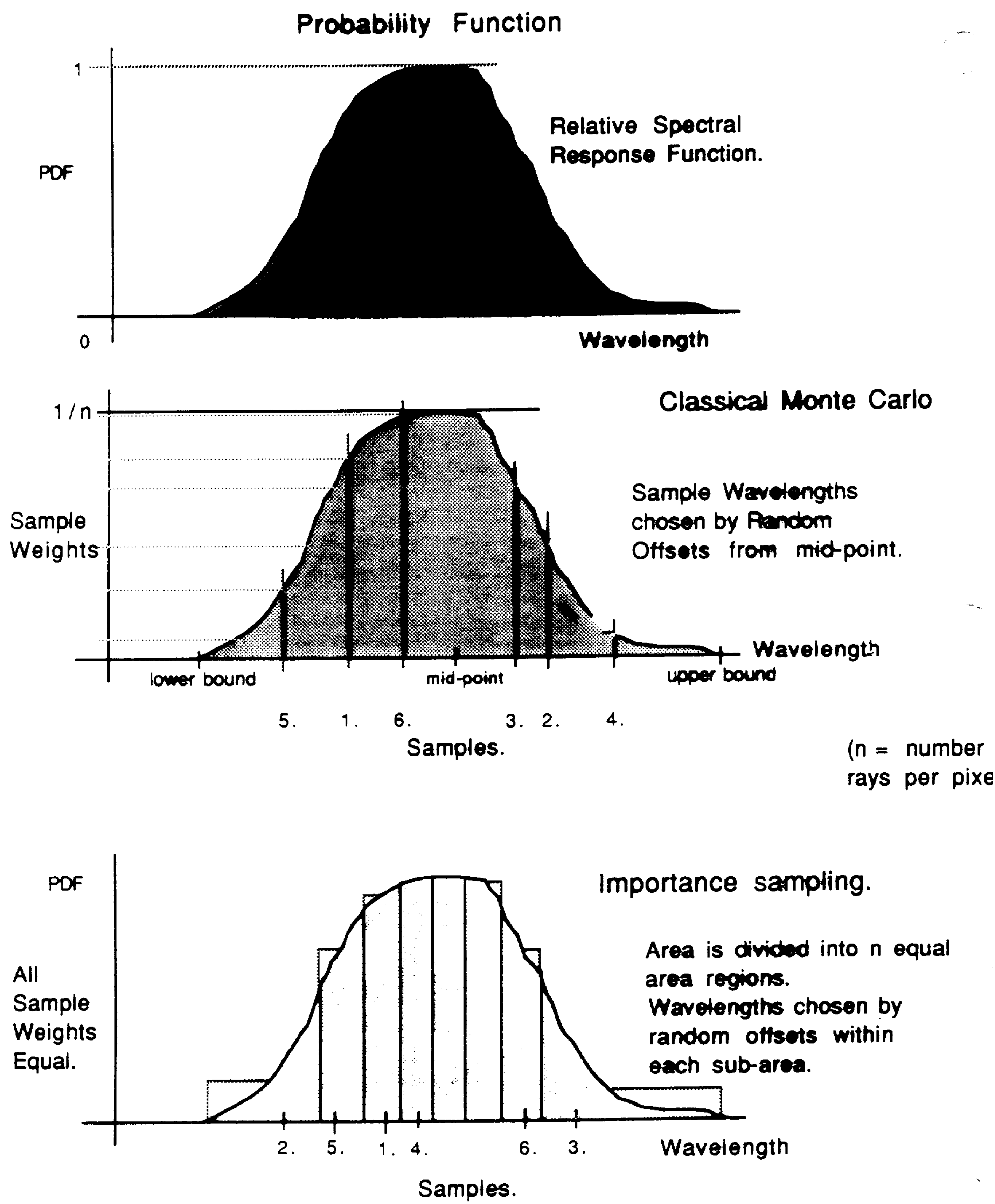
(One Pixel).



Origins chosen by random offsets within each sub-pixel area.

Wavelength Sampling.

Figure 5.



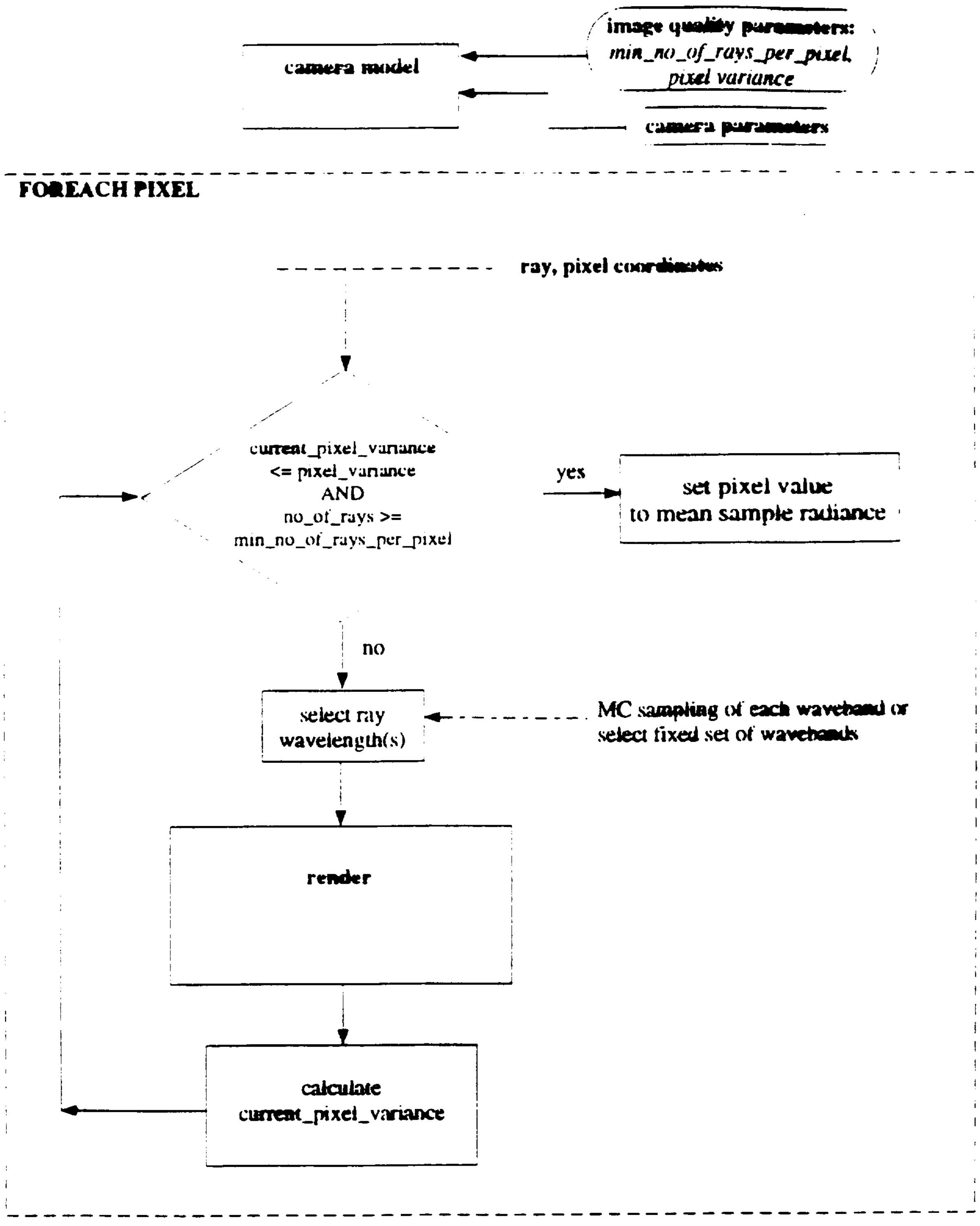


figure 1. flow diagram of ARARAT - origination and processing of primary rays

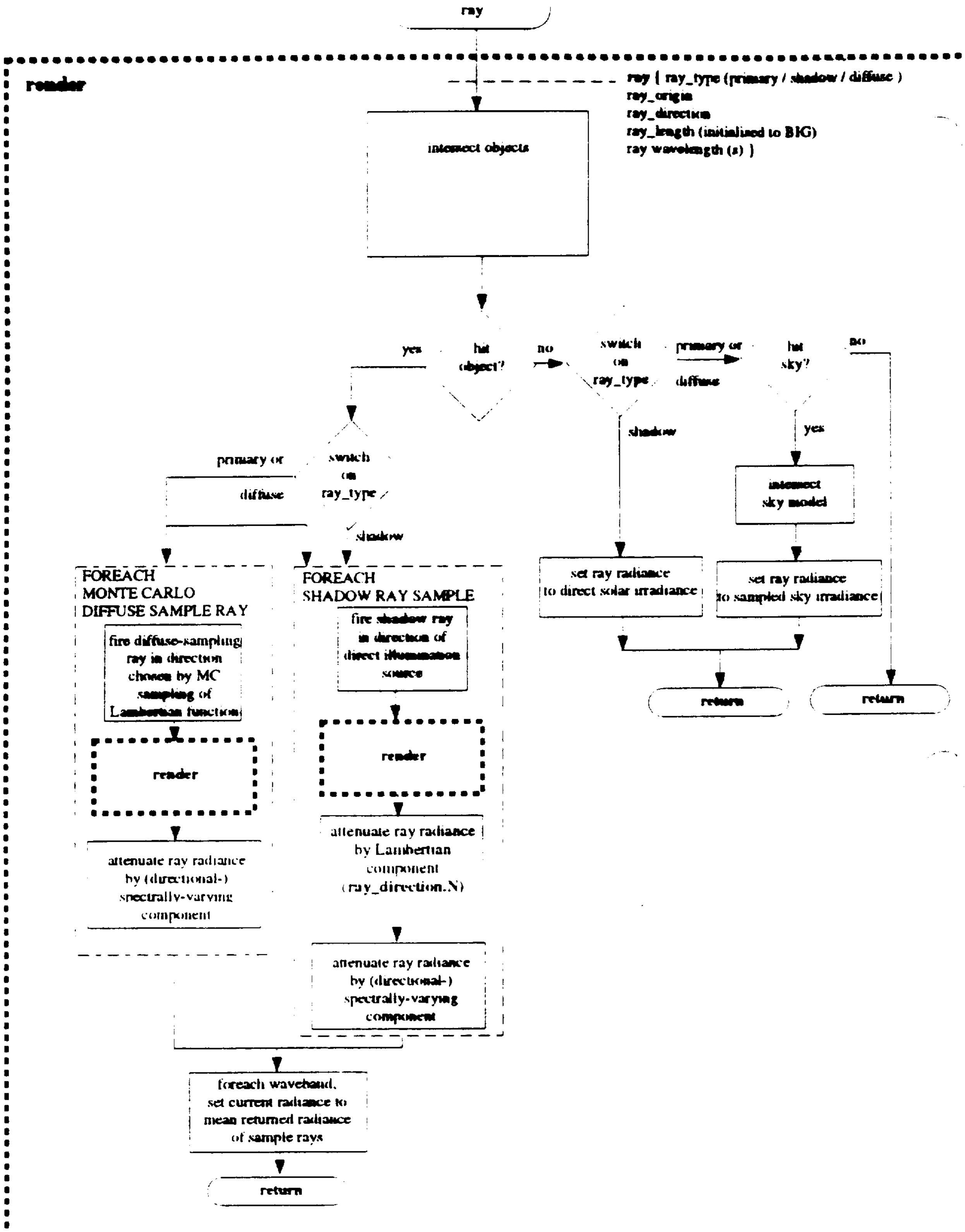
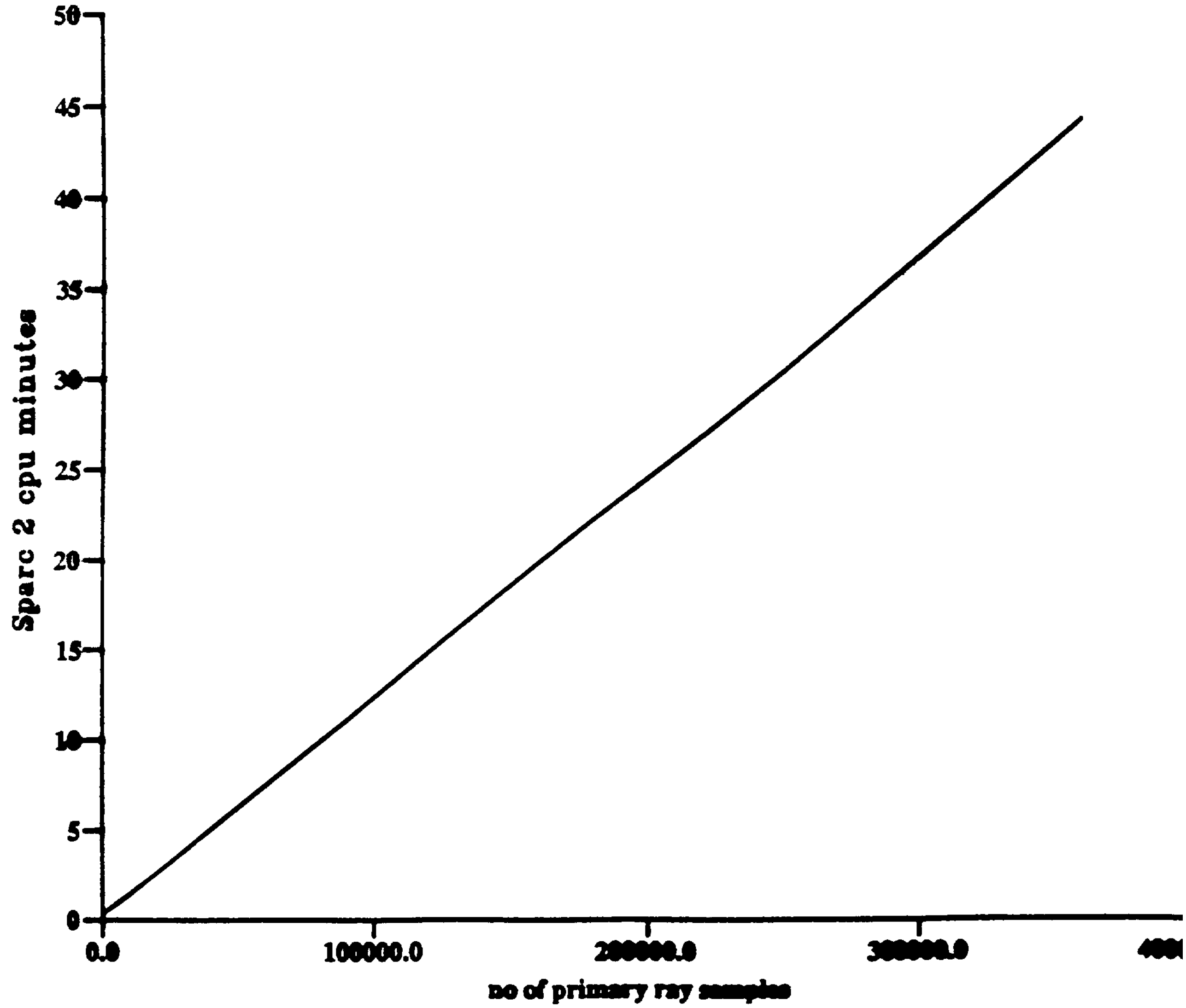


figure 2. flow diagram of the function **render**
(note the recursive call to function render)



ARARAT PROCESSING TIMES:
25M DEM, DIFFUSE SAMPLING

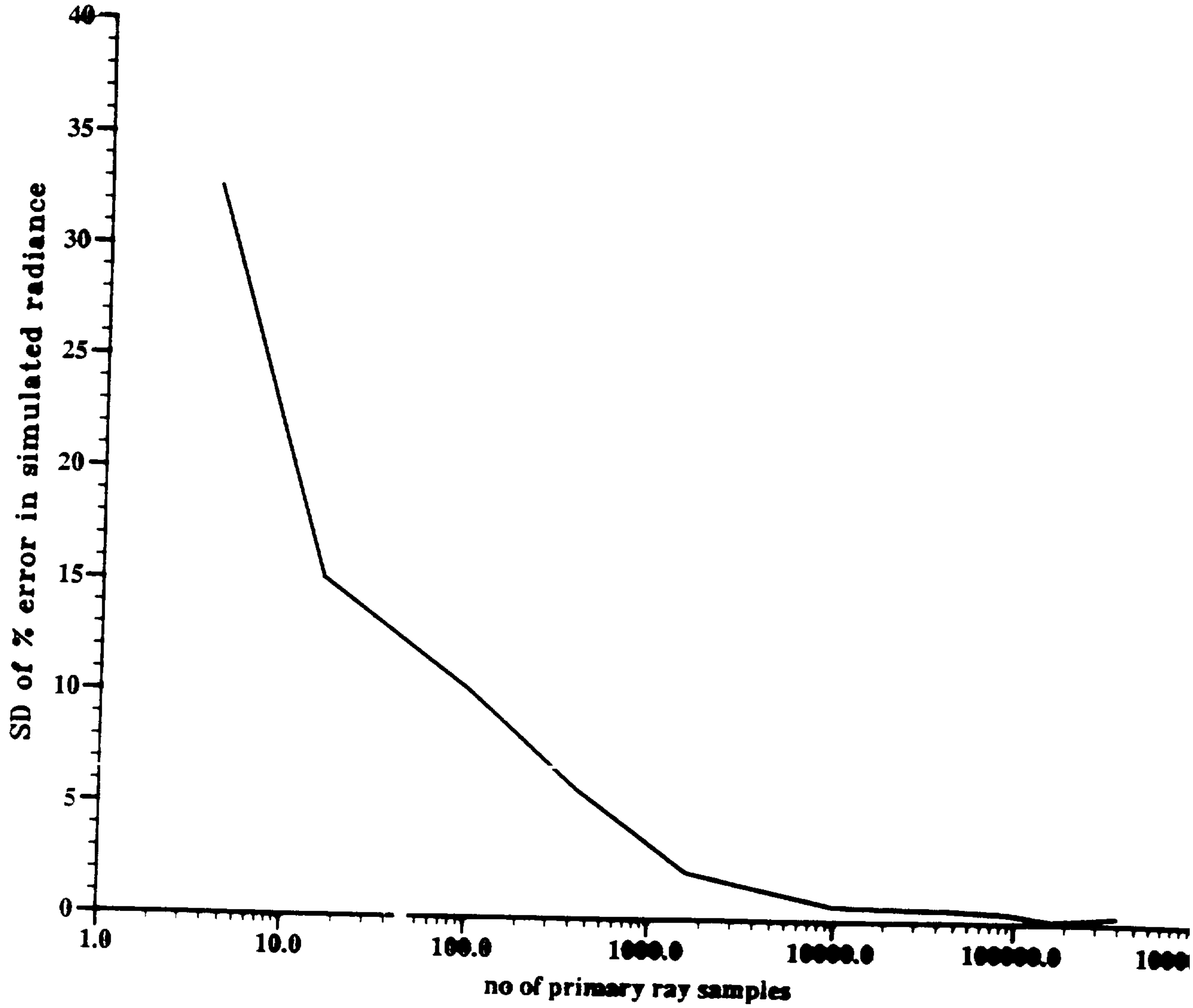
ARARAT PROCESSING TIMES
(FLAT PLANE - DIFFUSE SAMPLING)

machine type	processing time (cpu secs)
SGI powers series VGX	107
SPARCstation 2	239
SPARCstation 1+	260
SPARCstation IPC	265
SGI personal IRIS-4D	306
SPARCstation 1	321
SPARCstation SLC	341

Table 1 processing times for processing 500000 diffuse samples

machine type	relative processing time
SGI powers series VGX	0.45
SPARCstation 2	1.00
SPARCstation 1+	1.09
SPARCstation IPC	1.11
SGI personal IRIS-4D	1.28
SPARCstation 1	1.34
SPARCstation SLC	1.43

Table 2 processing times relative to SPARCstation 2



Pixel Integral Convergence with N samples.
Single AFE AVHRR pixel simulation with PVD
BRDF model, 2 bands & Vis Sky + AFE DEM

Possible Models

1) polynomial collinearity model (PCM)

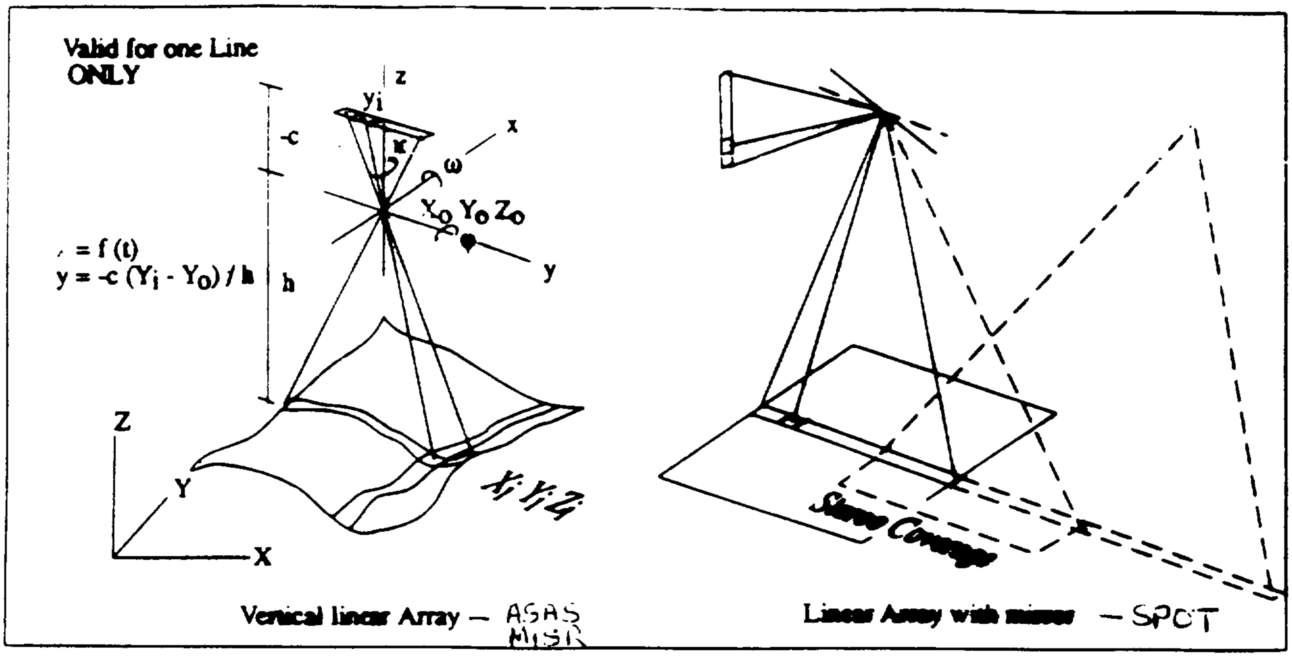
2) equivalent photography model (EPM)

3) additional parameter model (APM)

...they are all adaptations of the collinearity approach.

APM (3) is chosen as the best approach to ASAS and MISR because it handles image deformation better than the others.

APM = collinearity model for linear array sensors + additional parameters



$$\begin{bmatrix} X_i \\ Y_i \\ Z_i \end{bmatrix} = \begin{bmatrix} X_o \\ Y_o \\ Z_o \end{bmatrix} + \Delta * R * \begin{bmatrix} x_i \\ y_i \\ -c \end{bmatrix}$$

$$\begin{bmatrix} x_i \\ y_i \\ -c \end{bmatrix} = 1 / \Delta_i * A \begin{bmatrix} X_i - X_o \\ Y_i - Y_o \\ Z_i - Z_o \end{bmatrix}$$

R = 3 Dimensional Orthogonal Rotation Matrix $A = R^{-1} = R^{t}$

$$A = \begin{bmatrix} \cos\kappa & \sin\kappa & 0 \\ -\sin\kappa & \cos\kappa & 0 \\ 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} \cos\varphi & 0 & \sin\varphi \\ 0 & 1 & 0 \\ -\sin\varphi & 0 & \cos\varphi \end{bmatrix} \cdot \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\omega & \sin\omega \\ 0 & -\sin\omega & \cos\omega \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix}$$

direct equations

$$0 = -c \frac{a_{11}(X_i - X_o) + a_{12}(Y_i - Y_o) + a_{13}(Z_i - Z_o)}{a_{31}(X_i - X_o) + a_{32}(Y_i - Y_o) + a_{33}(Z_i - Z_o)}$$

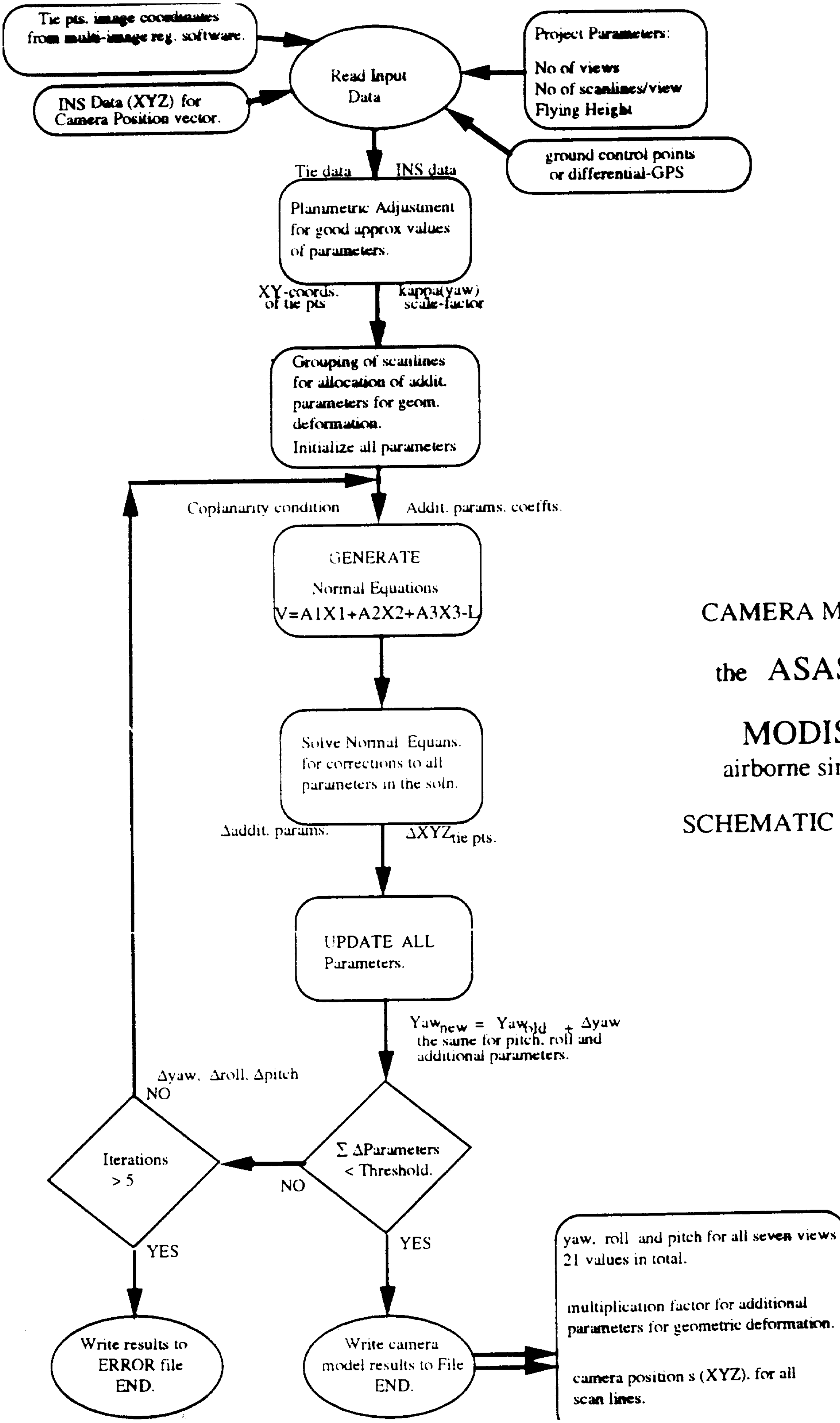
$$y_i = -c \frac{a_{21}(X_i - X_o) + a_{22}(Y_i - Y_o) + a_{23}(Z_i - Z_o)}{a_{31}(X_i - X_o) + a_{32}(Y_i - Y_o) + a_{33}(Z_i - Z_o)}$$

inverse equations

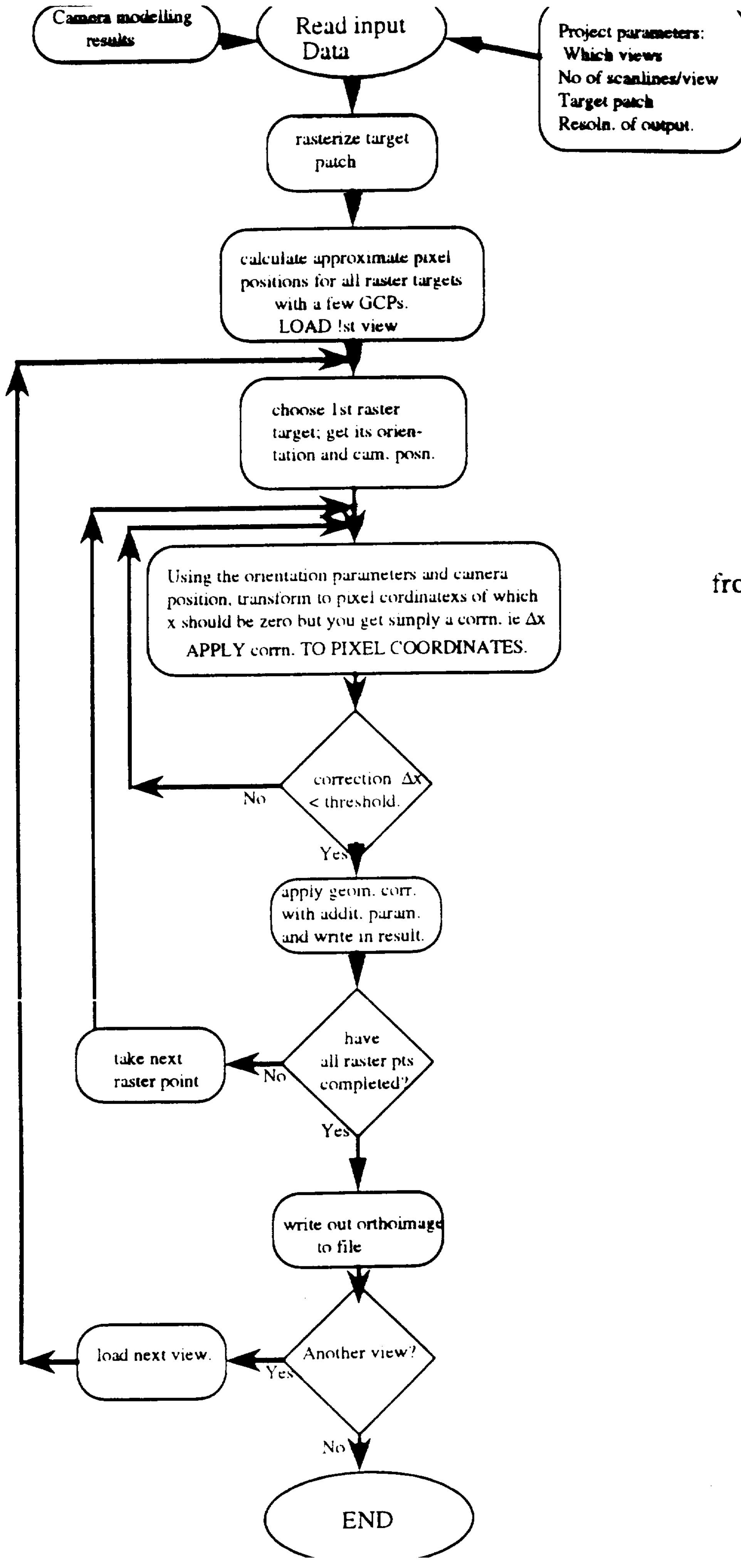
$$(X_i - X_o) = (Z_i - Z_o) \frac{a_{21} y_i - a_{31} c}{a_{23} y_i - a_{33} c}$$

$$(Y_i - Y_o) = (Z_i - Z_o) \frac{a_{22} y_i - a_{32} c}{a_{23} y_i - a_{33} c}$$

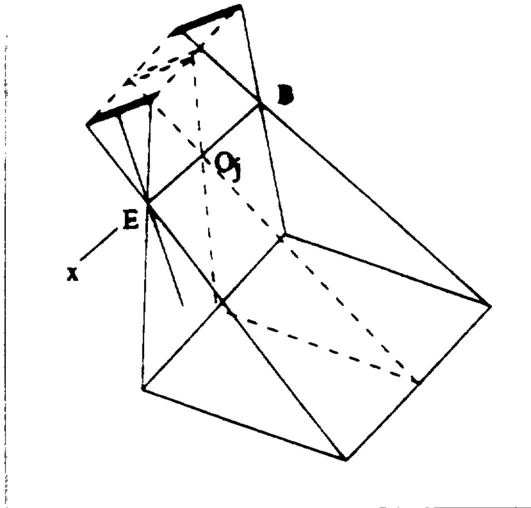
Colinearity Equations for



CAMERA MODEL of the ASAS and MODIS-N airborne simulator SCHEMATIC DIAGRAM



ORTHOPHOTO
GENERATION
from images of linea
array sensor



$$\begin{bmatrix} x_{oj} \\ y_{oj} \\ z_{oj} \end{bmatrix} = \begin{bmatrix} x_{oB} \\ y_{oB} \\ z_{oB} \end{bmatrix} + d_j / d_{BE} \begin{bmatrix} X_{oE} - X_{oB} \\ Y_{oE} - Y_{oB} \\ Z_{oE} - Z_{oB} \end{bmatrix}$$

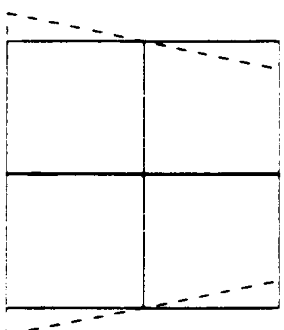
The colinearity equation is valid for each line.

$$\begin{bmatrix} x_i \\ y_i \\ z_i \end{bmatrix} = 1/\lambda_i \quad A \begin{bmatrix} X_i - X_{oj} \\ Y_i - Y_{oj} \\ Z_i - Z_{oj} \end{bmatrix}$$

The central $\kappa\ \varphi\ \omega$ is chosen A instead of A_j

Choice of additional parameters :

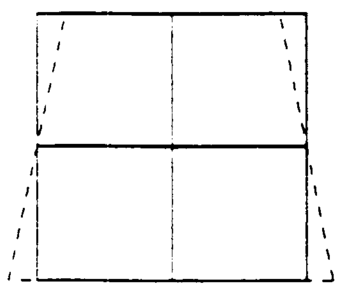
κ change



$Vx = b3(2x^2 - 4b^2)/3$

$Vy = b3\ (xy)$

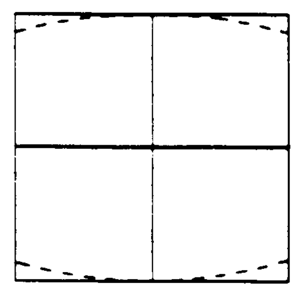
φ change



$b4(xy)$

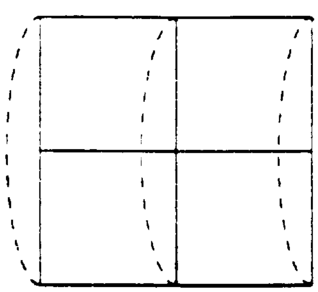
$b4(2y^2 - 4b^2)/3$

φ change



$b5(x^2 - 2b^2)/3$

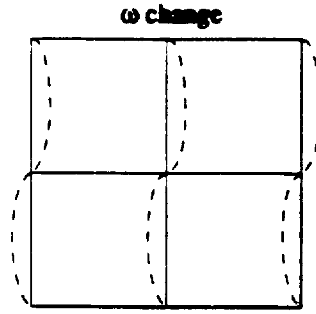
ω change



$Vx =$

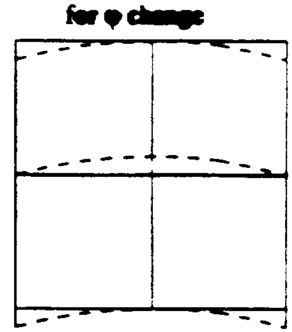
$Vy = b1(y^2 - 2b^2/3)$

ω change



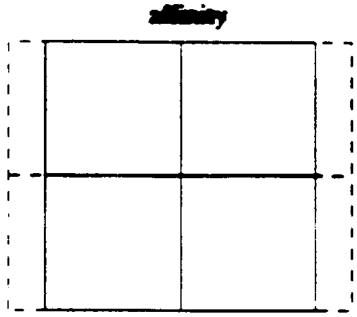
$b2(2b^2 - y^2)\ /2y^2$

earth curvature for φ change



$b6(x - 2b)/3$

affinity



$Vx = b7\ (x)$

$Vy = b7'(y)$

Additional Parameters Model

MODCAL 1992 Work Plan

- "ARARAT" imaging geometry extended to MODIS, AVHRR and ATSR

- "ARARAT" ported to parallel transputer array and multi-processor SGI workstation to enable larger simulation experiments to be run

- "ARARAT" to be tested over a wider variety of different sites where DEMs are available or UCL can generate from supplied stereo-optical data (HAPEX-SAHEL, BOREAS)

- "ARARAT" to be extended to clouds using DEMs and internal cloud droplet distributions from ATSR & JERS-1

- Simulations to study topographic requirements, sensitivity to different atmospheric correction schemes, effect of different calibration accuracies.

- Comparisons to be made with use of simulated MODIS imagery from LANDSAT-TM imagery (jointly with GSFC?)

- Continuing severe difficulties with funding this program from UK sources.