ERDAS Imagine

OrthoBASE

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Contents

Introduction

This is a guide to the orthorectification of aerial imagery using ERDAS Imagine OrthoBASE. OrthoBASE is PC based software. The process described is for aerial frame photography, see Appendix II for details of other types of imagery.

Orthorectification is the process of removing terrain distortion from imagery.

Three types of data are required for the orthorectification process:

1. **Digital imagery.** For example scanned aerial photography or videography, to be rectified.
2. **Ground control points (GCPs).** GCPs can be collected from Ordnance Survey data, ground survey or from global positioning system (GPS). GCP's are used for the referencing of the images to a map base.
3. **Digital elevation model.** A model of the underlying terrain is required for the removal of terrain distortion from the aerial imagery.

Sources of help and information.

- **ERDAS Field Guide.** The ERDAS Field Guide gives details of the theory aspect of photogrammetry rather than details of how to do photogrammetry.
  The ERDAS Field Guide is available in pdf format.
  \IMAGINE 8.4\help\hardcopy\FieldGuide

- **OrthoBASE Tour Guide.** The Tour Guide leads the user through the process using an example set of data. It is also available in pdf format.
  \IMAGINE 8.4\help\hardcopy\OrthoBASE_TourGuide.

- **OrthoBASE Users Guide.** The OrthoBASE Users Guide is also available in pdf format.
  \IMAGINE 8.4\help\hardcopy\UsingOrthoBASE.

Overview of Process

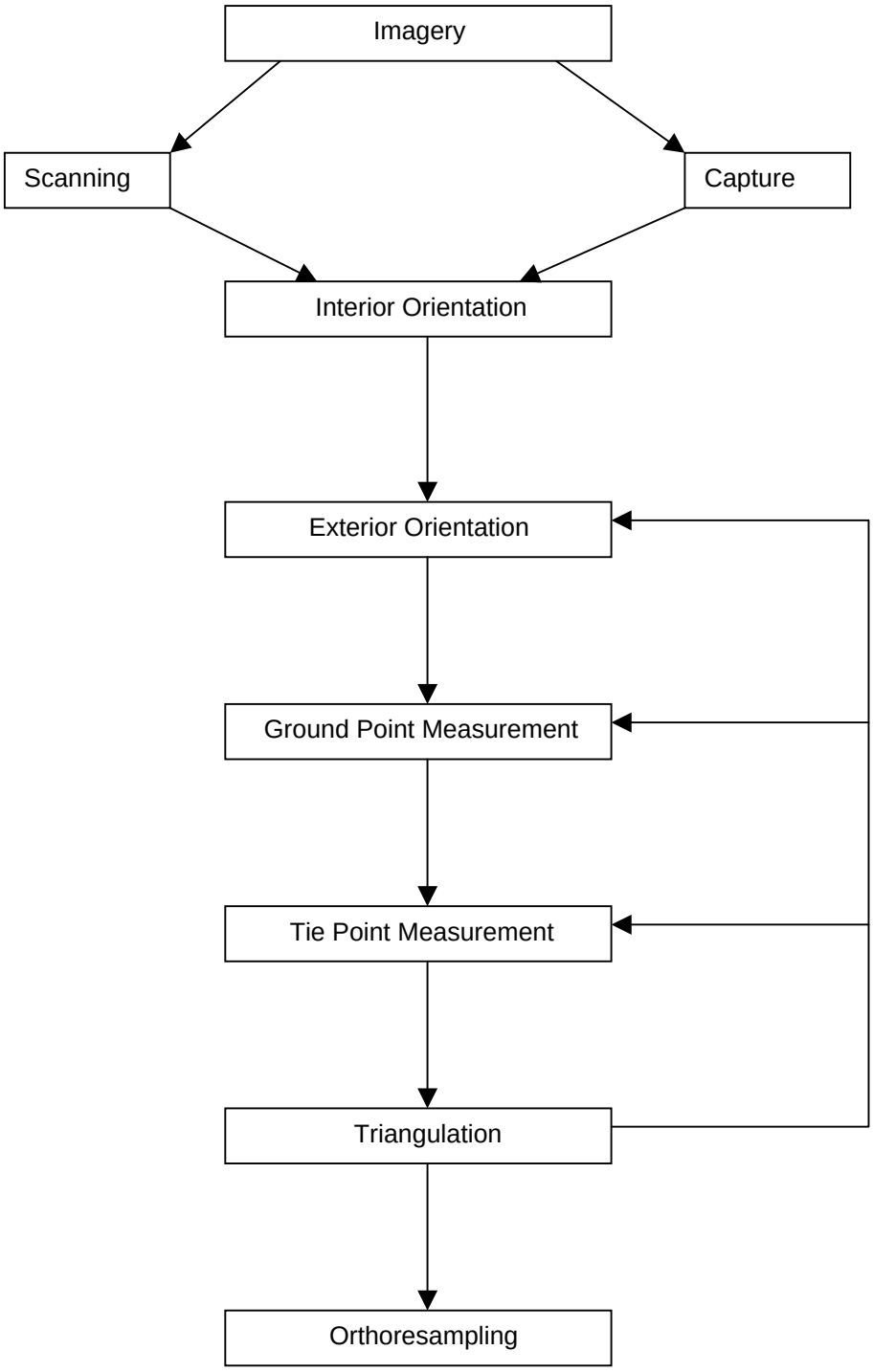

Figure 1. Schematic diagram of the OrthoBASE process

Orthorectification of frame images

A guide to the orthorectification of frame images using ERDAS Imagine OrthoBASE. For other types of images refer to Appendix II for changes to the procedure.

Step 1. Create a new OrthoBASE project

- **Select OrthoBASE from the ERDAS Imagine panel. To start a new block select *Create a new OrthoBASE project.* Click *OK.***

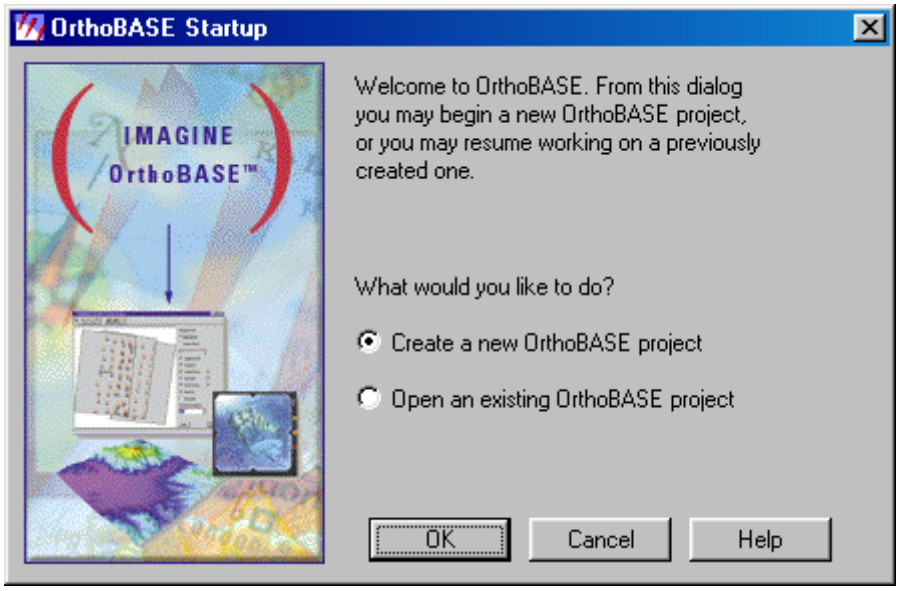

Figure 2. OrthoBASE start-up dialog.

- **Choose a location and a name for your block file.**

The block file has the extension .blk. This is a binary file containing all the block information, i.e. imagery locations, camera information, fiducial mark measurements and GCP measurements.

In creating a new block, information about the geometric model, projection system, reference units, rotation system and photo direction needs to be entered (see **Steps 2** to **5**). These steps are omitted when an existing block is opened (*Open an existing OrthoBASE project*).

Step 2. Select Geometric Model

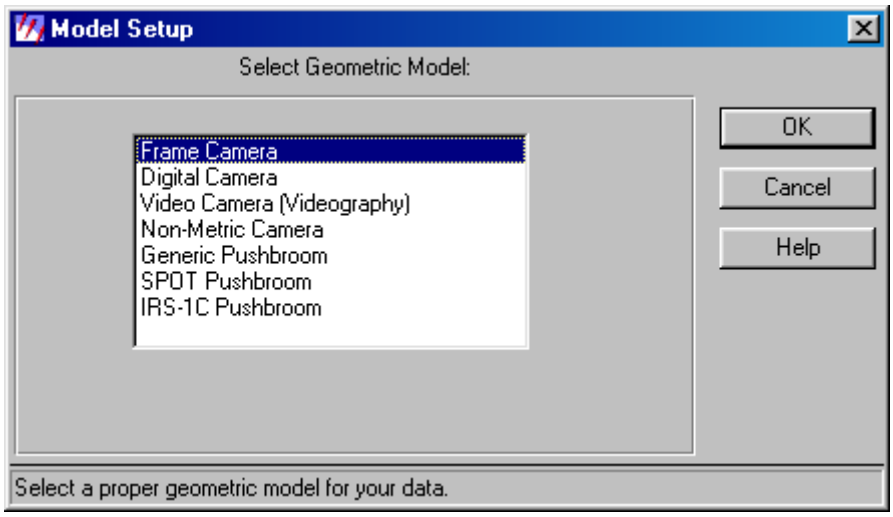

Figure 3. Select geometric model.

- **Select *Frame Camera* and click *OK*.**

Step 3. Set Reference System

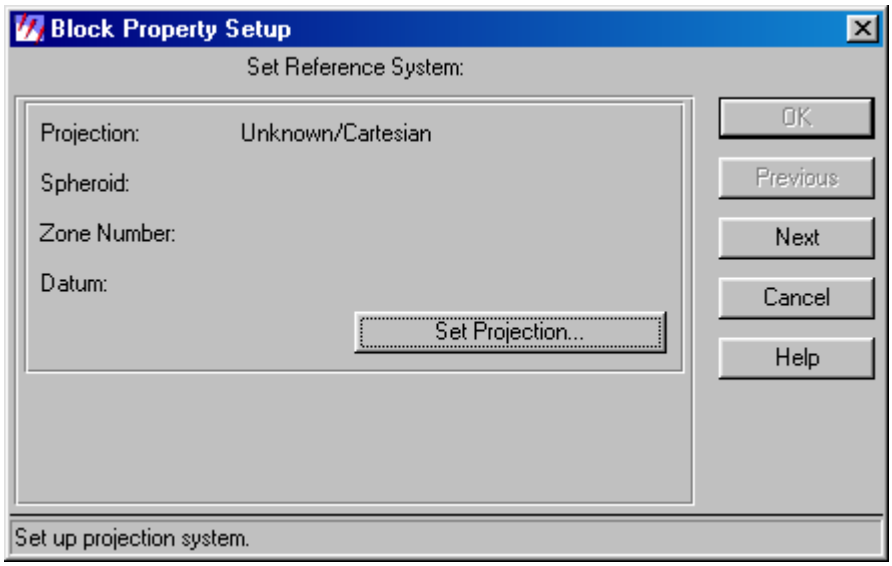

Figure 4. Set reference system.

- **Click on the *Set Projection...* button.**

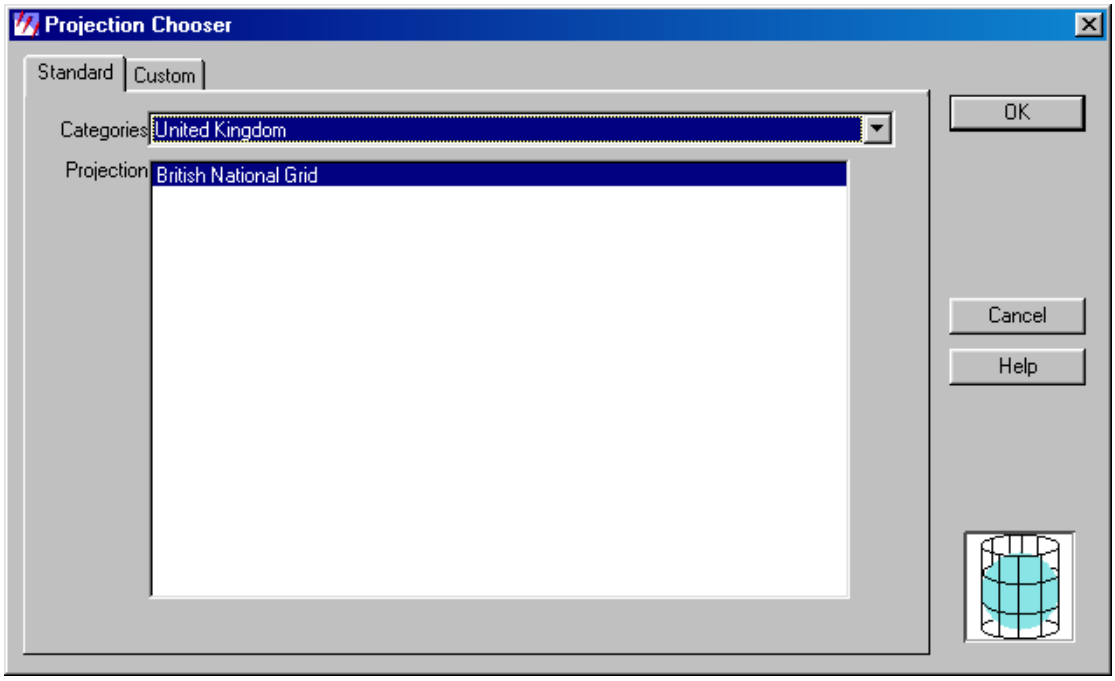

Figure 5. Projection chooser.

- **Within the *Projection Chooser* dialog box select the *Category* required, e.g. for the United Kingdom select United Kingdom, then for the *Projection* select British National Grid.**

- **Select the *Custom* tab to check or alter the details of the projection chosen. For example, if the British National Grid projection is chosen the dialog box should be filled in as follows.**

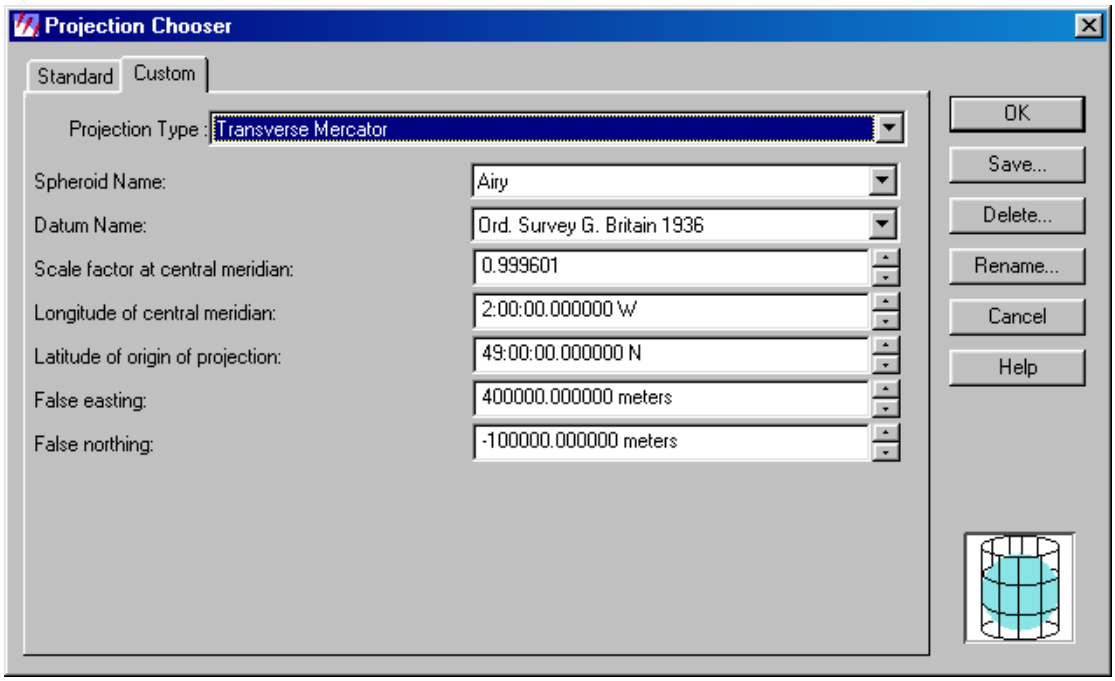

Figure 6. Defining details of the projection.

- **Click *OK* to return to the *Block Property Setup* and then click *Next* to move onto the next stage.**

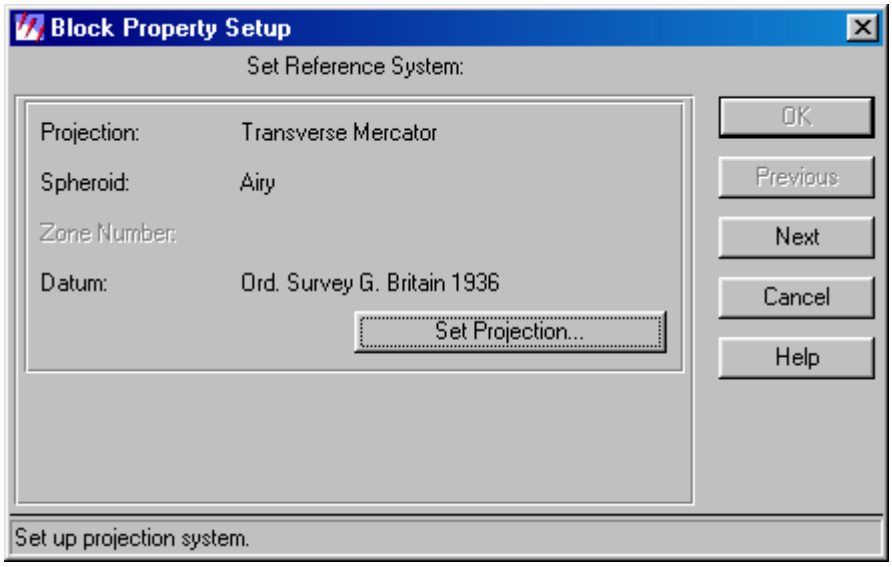

Figure 7. The defined reference system.

Step 4. Set Reference Units

- **The units for the British National Grid are meters for horizontal and vertical units and degrees for angle units.**

Other projections may have different units. Check the ERDAS Field Guide for detailed descriptions of projections and units.

- **Click *Next* to move onto the next stage.**

Step 5. Set Frame Specific Information

For most frame photography the following applies. Exception would be oblique photography, for which you would choose *Y-axis for close range images.*

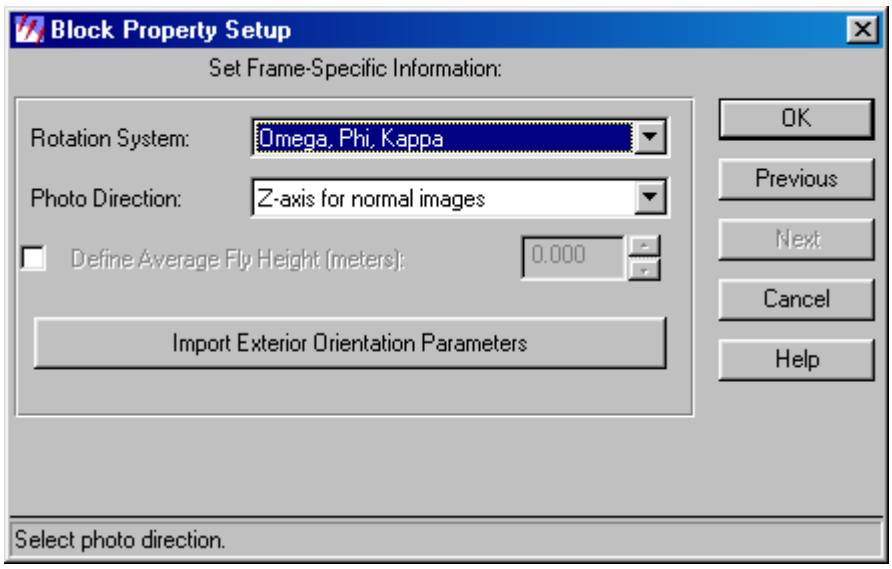

Figure 8. Setting frame specific information.

- **Clicking *OK* completes the block setup process and brings up the main OrthoBASE dialog box.**

Information entered in this process can not be altered once *OK* has been clicked.

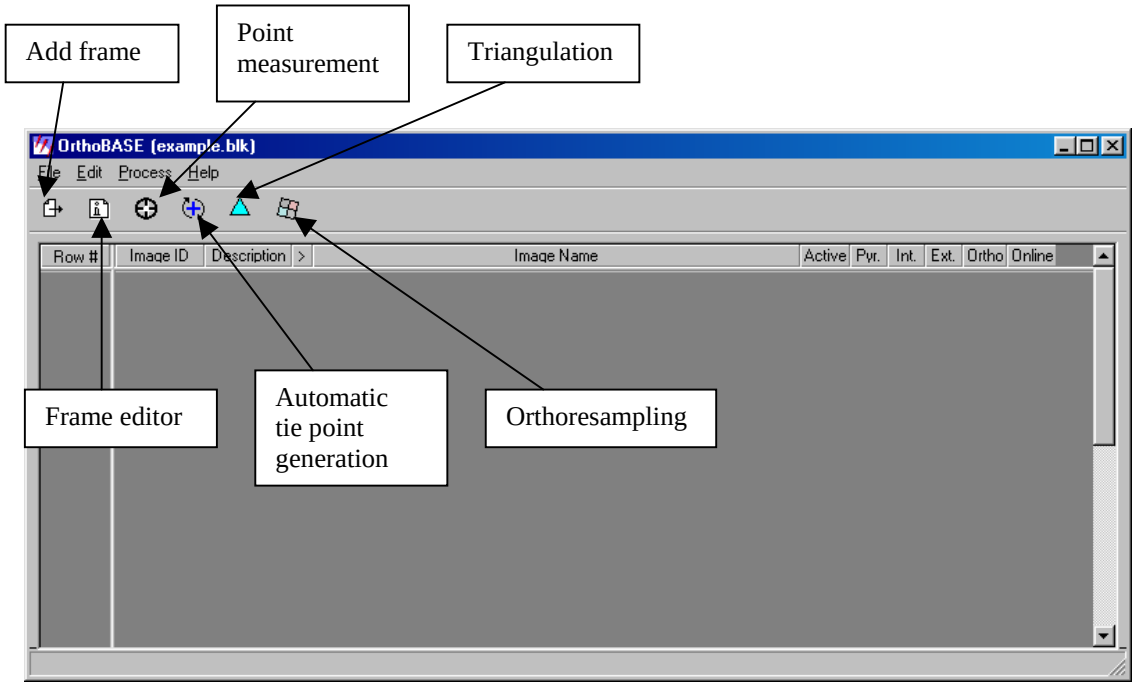

Figure 9. The main OrthoBASE dialog box.

Work logically through this box from left to right, i.e. Add Frame, Frame Editor, Point Measurement, Automatic Tie Point Generation, Triangulation and finally Orthoresampling.

Row#	Left click on a row or rows within this column to select an image or images specifically for use within OrthoBASE, e.g. computing of pyramid layers.
>	Designates which image is currently active.
Active	X indicates which images are to be used in OrthoBASE processes such as automatic tie point generation, triangulation and orthoresampling.
Image Name	Indicates the name and location of the image.
Pyr.	Presence (green) or absence (red) of pyramid layers. OrthoBASE performs more efficiently if pyramid layers are present.
Int.	A green box indicates that the interior orientation parameters of the images have been calculated.
Ext.	Green indicates that the exterior orientation parameters have been calculated. These values are not calculated until triangulation has been run and accepted.
Online	Green indicates that the images are in the correct locations.

Step 6. Adding images to the block

- **To add images into the block select the *Add images* button. Select the image required in the file list and click *OK*. Repeat for all images required.**

- **To add multiple images, select the *Add options* tab within the file chooser. Select the *Add Selected File Plus* radio button and specify a string in the *Files Matching* box. For example, specifying *.img adds all .img files in the folder to the block.**

File types recognised include IMAGINE, TIFF, MrSID and JPEG. Refer to the Online Help documentation for a full list of supported file types.

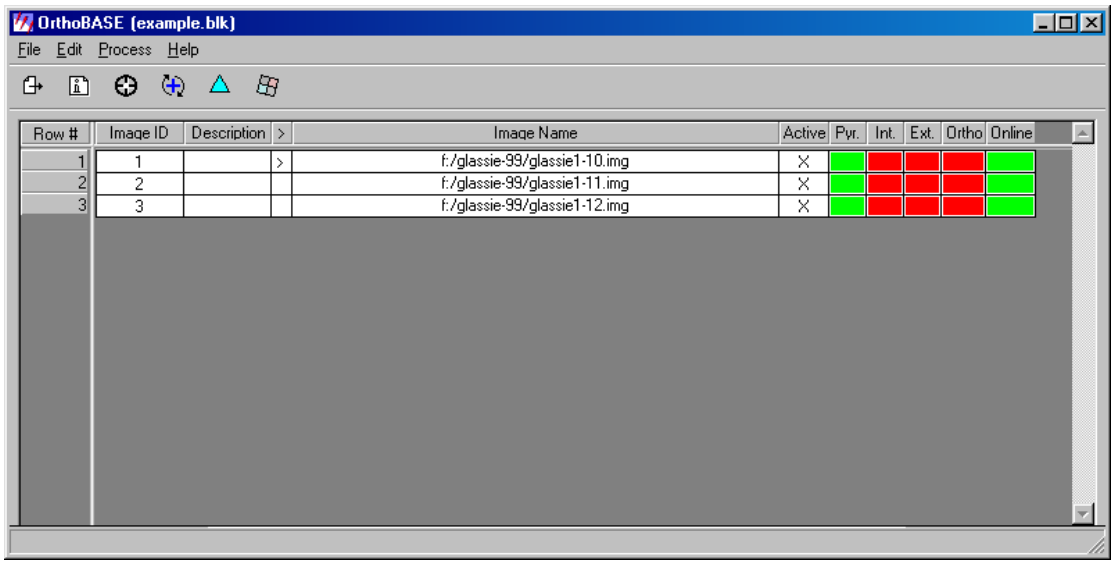

Figure 10. Images added to the block.

In Figure 10, the images have pyramid layers associated and are in the correct location.

To compute pyramid layers. Select *Edit* and then *Compute Pyramid Layers….* Choose the applicable radio button and click *OK.*

To alter image location. Select the frame editor button. Under the *Sensor* tab click on *Attach,* reselect the location of the images and click *OK.* If any measurements have already been made to the images e.g. interior orientation or ground point measurement, then these will remain.

Step 6. Defining the sensor.

- **Click on the *Frame Editor* button. Within the frame editor select the *Sensor* tab.**

Information is required about the camera that obtained the images. The more information that is available the more accurate the calculations and therefore the end result will be.

- **Click on *New…* to enter the specification of the camera.**

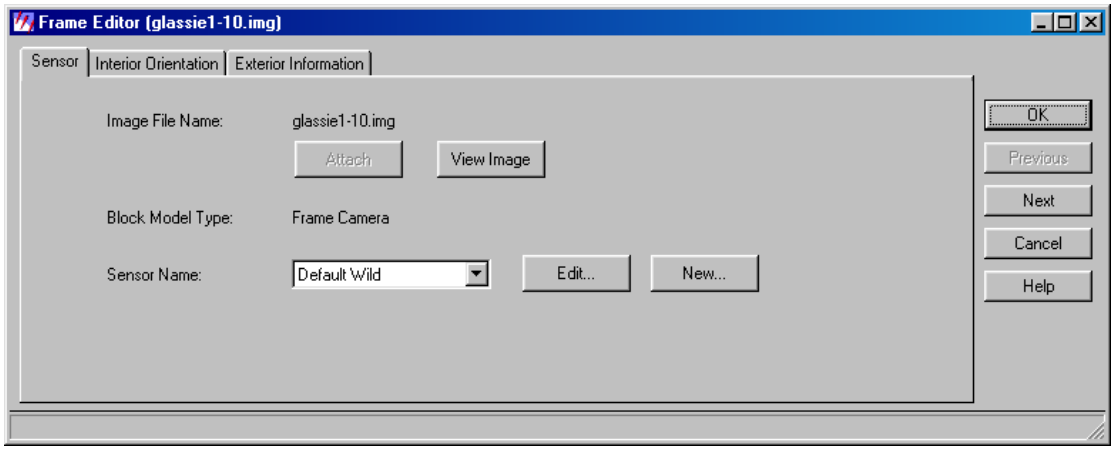

Figure 11. Specifying the sensor used to capture the imagery.

Information required:

General tab	Camera Name: Description: Focal length: Principal point xo (mm): Principal point yo (mm):
Fiducials tab	Required information is the number of fiducials and the location of them on the film.
Radial Lens Distortion tab	Enter if information is available.

For the specifications of certain cameras see Appendix III.

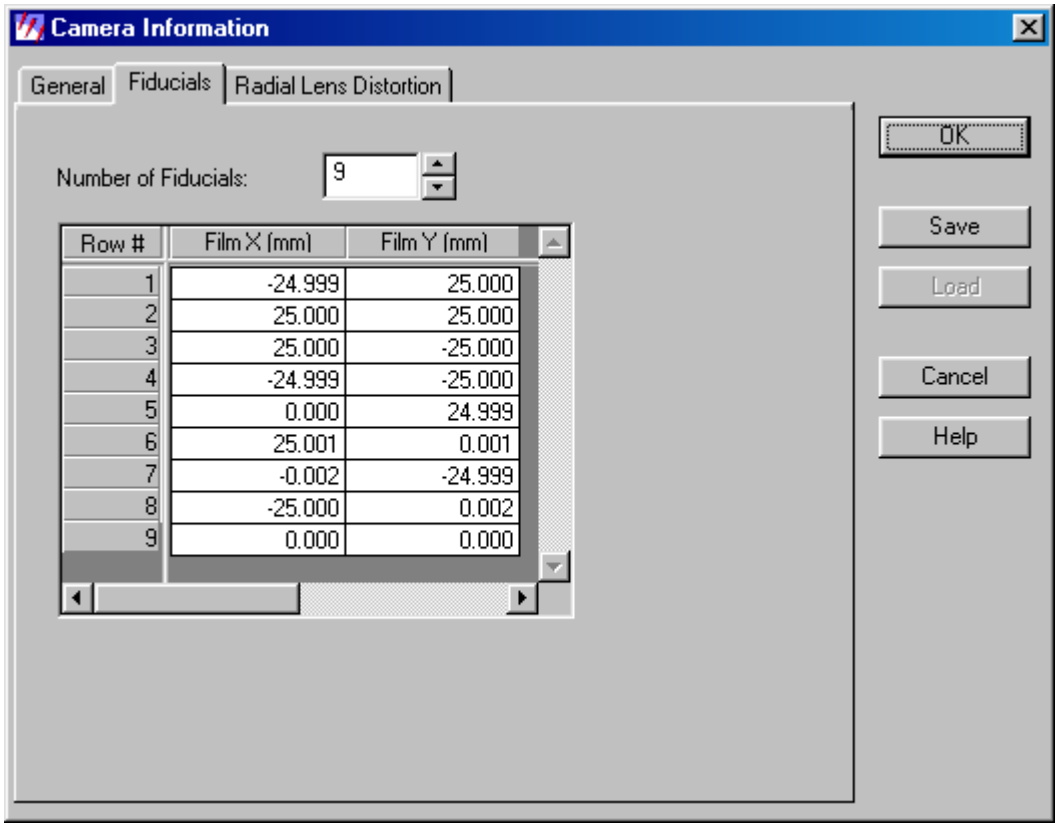

Figure 12. Entering fiducial information associated with the sensor.

- **Click *Save* to save the camera to a .cam file that can be loaded into other blocks. Click *OK* to return to the Frame Editor.**

Step 7. Interior Orientation

This process determines the internal geometry of the camera that captured the imagery. The calculation requires principal point, focal length, fiducial marks and lens distortion.

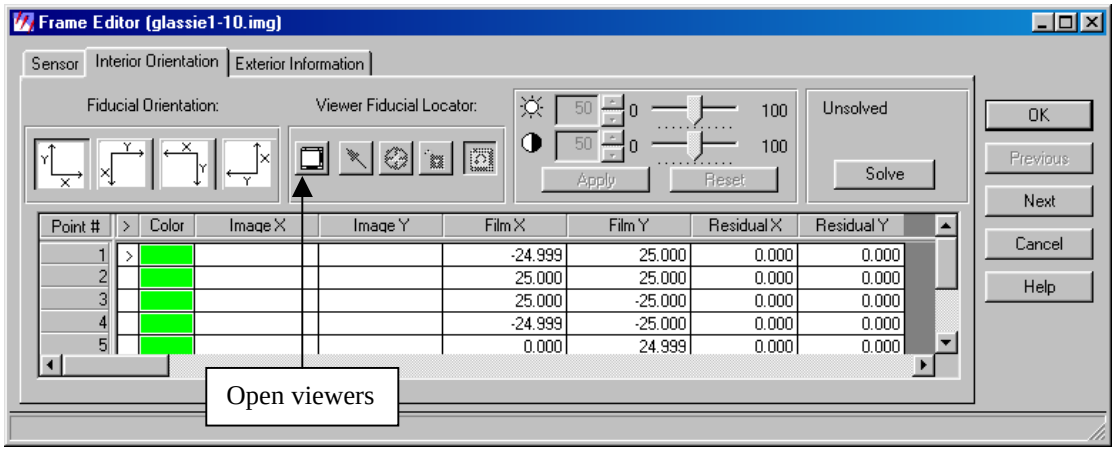

Figure 13. Interior orientation.

Three different views are brought up when the open viewer icon is selected, an overview, a main viewer and a detailed view.

Locating fiducials. Film X=0mm, Film Y=0mm is the centre of the image, therefore the location of the fiducials can be worked out from this point. See Appendix ?? for an example.

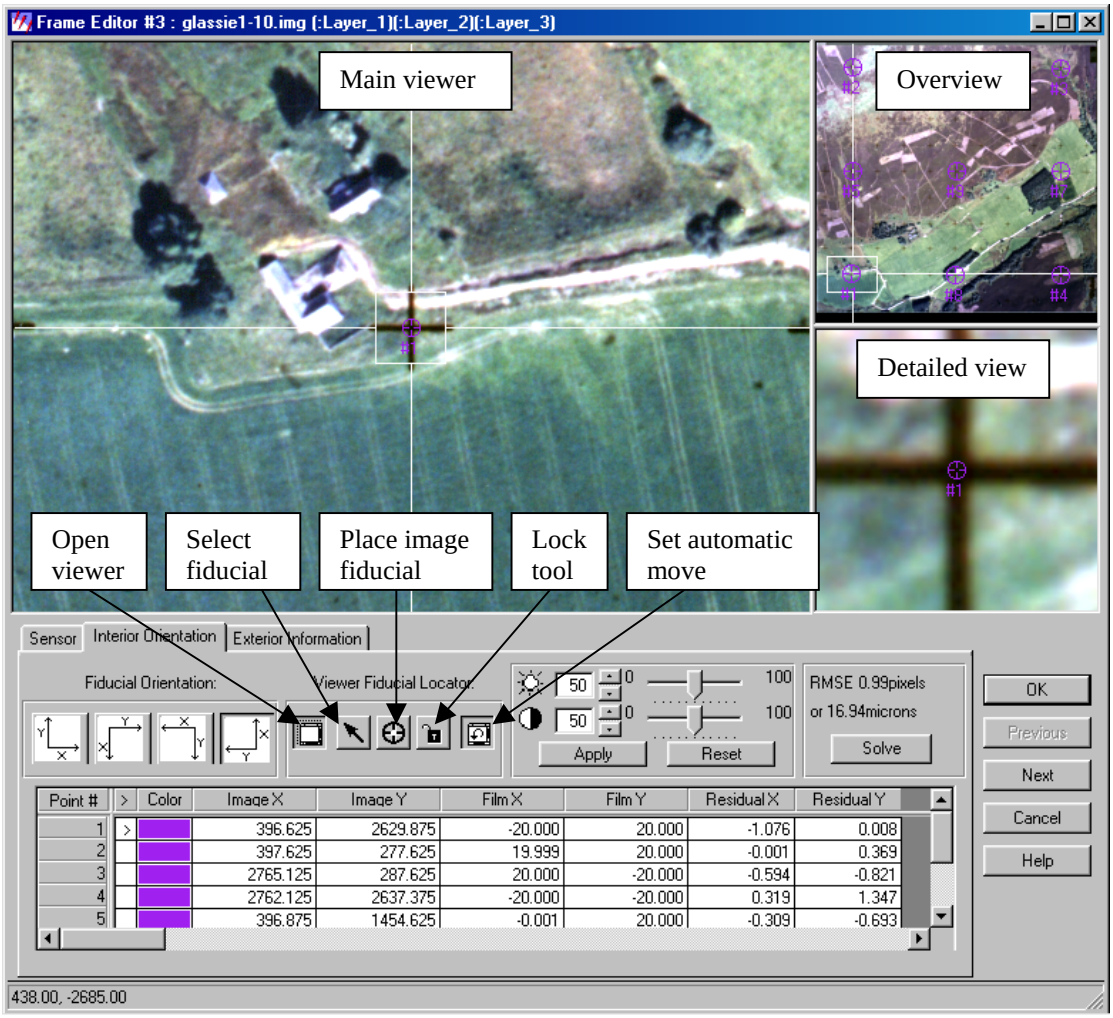

Figure 14. Locating image fiducials.

- **Use the white box in the overview to locate the area of the fiducial.**
- **Drag the white box over the fiducial in the main viewer to bring it up in the detailed view.**
- **Use the *Place image fiducial* button to place a measurement in the centre of the fiducial. If the *Set automatic move* button is selected then OrthoBASE will jump to the next fiducial in the list. Check that this is the correct fiducial.**
- **Repeat the process for the remainder of the fiducials.**
- **Click on *Solve*. Aim for an RMSE of less than 1 pixel.**
- **To correct or remove any measurements, select the required fiducial in the table. To remove the measurement right click the mouse and select *Delete selected.* To alter a measurement use either the *Select fiducial* tool to drag the measurement to a new location or use the *Place image fiducial* tool to place**

the measurement again. Ensure that the correct fiducial is selected in the table.

- **Click *Next* to repeat the process for other images.**
- **Once all images have been completed select the *Exterior Information* tab.**

Step 8. Exterior Information

- **Select the *Exterior Orientation* tab within the Frame Editor. Enter any known information.**

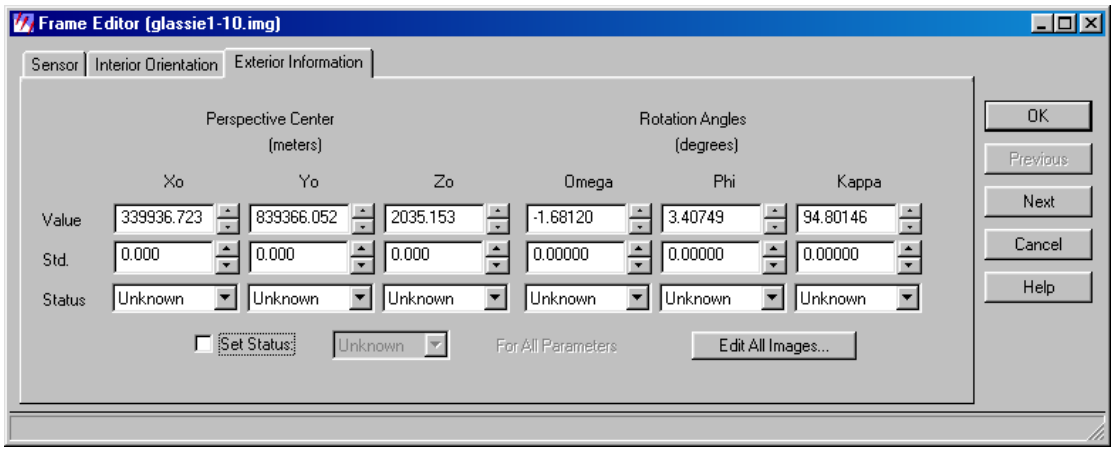

Figure 15. Specifying exterior orientation information.

- **The quality of the information given needs to be specified in the *Status* row.**

  Fixed. If the values available are accurate select *Fixed.* The values will not be altered during triangulation.

  Initial. If the values available are an approximation select *Initial.* The values will be modified during triangulation.

  Unknown. If no information about the exterior orientation parameters of the camera is available then select *Unknown.* OrthoBASE will calculate initial approximations.

Step 9. Ground Point Measurement

The purpose of this part of the process is to attach map coordinates and height information to the images by selecting points which are common to two or more images in the block.

- **Select the Point Measurement button in the main OrthoBASE dialog box.**

Ground control points can either be *Full* (X, Y and Z values), *Horizontal* (X and Y values) or *Vertical* (Z values only).

GCPs can be obtained from theodolite survey, GPS data, planimetric and topographic maps, digital orthorectified images and digital elevation models.

Minimum number of GCPs. Theoretically, the minimum number of GCPs is three, two full (X, Y and Z) and one vertical (Z only). It is recommended that for a strip of images there are two GCPs for every third image. It also increases the accuracy of the triangulation if there are three GCPs at the corner edges of the strip.

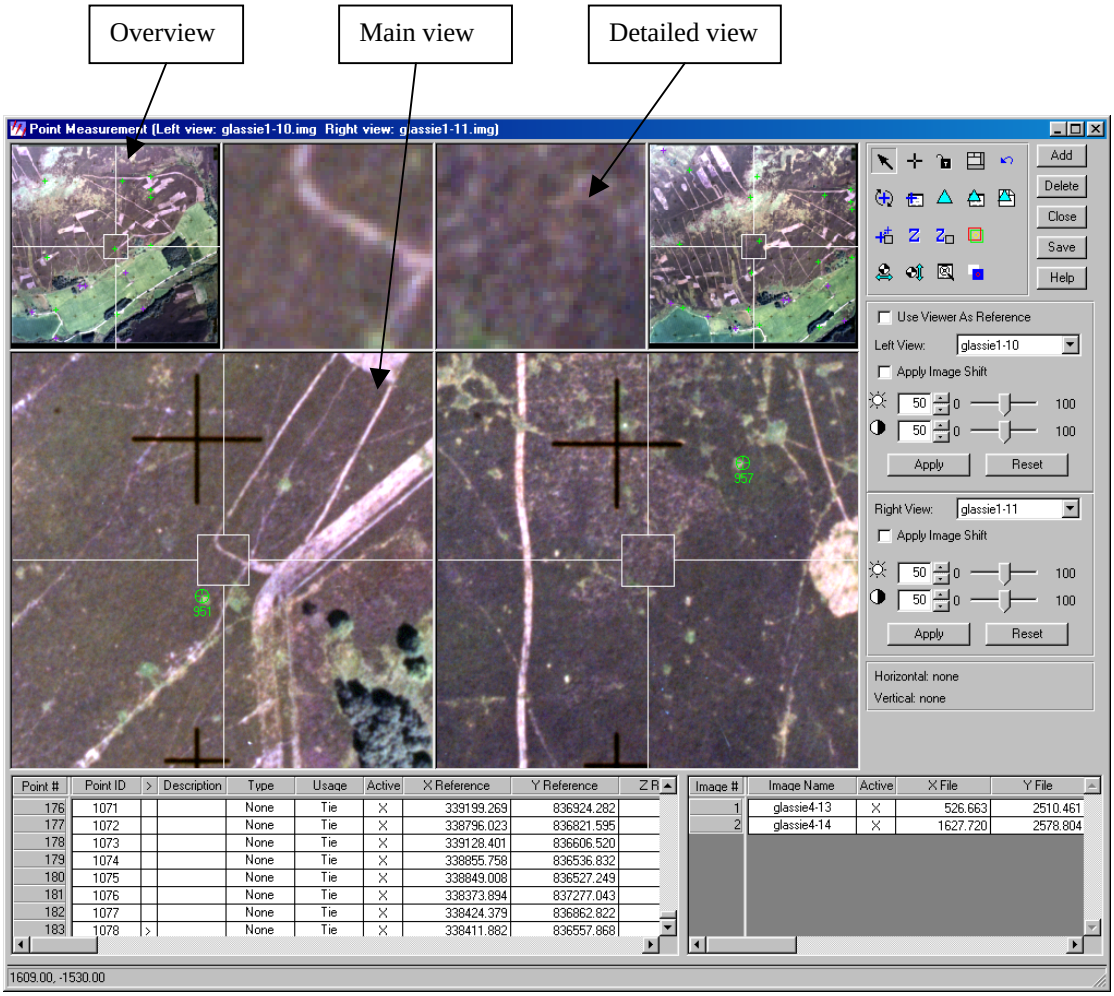

Figure 16. Point measurement tool.

Select point. This is the default tool.

Create point. Points can be placed in either the main view or the detailed view.

Keep current tool. Select this to keep the tool being used, stops the tool being defaulted back to the select point tool.

Reset screen.

Undo point measurement. Click to undo edits made, multiple edits can be undone.

Perform automatic tie generation.

 **Automatic tie properties.**

 **Perform triangulation.**

 **Triangulation properties.**

 **Report triangulation results.**

 **Set automatic (x, y) drive.** This tool automatically moves the viewing area in the right viewer to the approximate location of the point being measured in the left viewer. For this tool to work 3 GCPs in the overlap of the two images have to have already been measured. Clicking on this tool locks it, to unlock click on it again.

 **Update Z values on selected points.** For points selected the Z value will be updated using the vertical reference source specified, e.g. DEM.

 **Set automatic Z value updating.** Clicking on this tool locks the Z value updating function. Therefore for every X and Y coordinates the Z value will be obtained automatically from the vertical reference source specified.

 **Select points which are common to both left and right viewers.** Highlights points in the table which are common to both viewers.

 **Reset horizontal reference source.** Click to select the source of X and Y coordinates.

 **Reset vertical reference source.** Click to select the source of Z values.

 **Viewing properties.** Click to change the viewing properties of the block.

 **Show graphic.** Click to open the OrthoBASE Graphic Status Display. The OrthoBASE graphic display shows graphically the arrangement of the images, tiepoints and ground control points. It is useful in showing the distribution of tiepoints and ground control points.

Example: Adding ground control points collected from Ordnance Survey digital LandLine data.

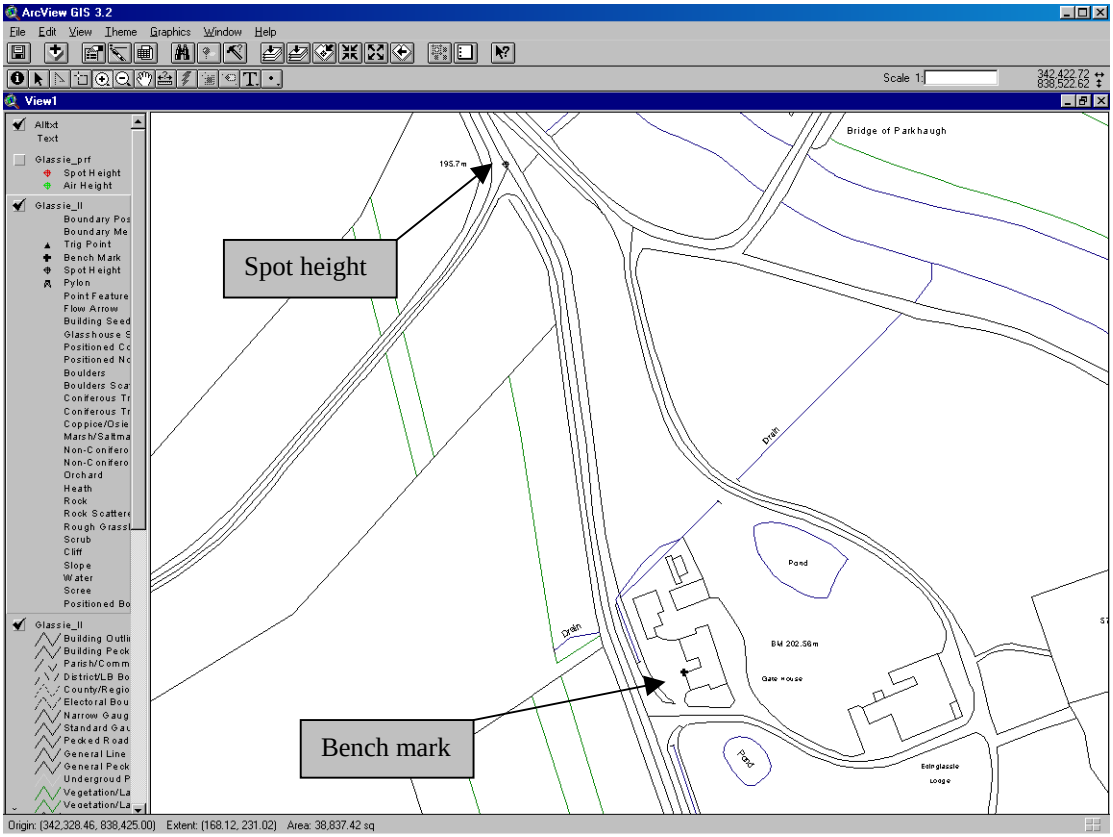

Figure 17. Ordnance Survey digital LandLine data.

Figure 16 shows a section of Ordnance Survey LandLine data loaded into ArcView GIS. A spot height and a bench mark are visible.

Features from which GCPs can be derived:-

Full	Spot heights, bench marks and trig points.
Vertical	Spot heights, bench marks and trig points.
Horizontal	E.g. Road junctions, field corners and building corners.

- **Note the X and Y and/or Z values of the point of interest.**
- **Click *Add* within the point measurement tool. A new entry will appear in the table.**
- **Fill in the details of the point in the table.**

Point#	Use this column to select a point, e.g. for re-measurement.
Point ID	OrthoBASE automatically assigns an ID to the point. This field can be edited.
Description	Enter a description for the point, for example building corner, road junction.
Type	Specify the type of point by clicking in the box and choosing from the menu. Choose from *Full* (X, Y and Z values), *Horizontal* (X and Y values), *Vertical* (Z values only) or *None* (tie points).

Usage	Specify either *Tie* (no values associated with the point), *Control* (points with X, Y and/or Z values that are to be used in triangulation) or *Check* (points with X, Y and/or Z values that are to used as comparisons when triangulation is run).
Active	X in the relevant box indicates that the point will be used e.g. in triangulation.
X Reference	Input the X coordinate (in metres) of the point if it is known.
Y Reference	Input the Y coordinate (in metres) of the point if it is known.
Z Reference	Input the Z coordinate (in metres) of the point if it is known.

- **Select the create point tool and place the point in the two images.**
- **Repeat for other GCPs.**
- **To remove a point, make it inactive by removing the X from the *Active* column.**
  Removing suspicious points and running triangulation, enables the user to see what effect the point(s) has on the triangulation results.
- **To alter a point, select the required point then either retake the measurement using the create point tool or move the measurement using the select point tool.**

Step 10. Automatic Tie Point Measurement

Tie points are points which are visible on more than one image but they do not have X, Y or Z values associated with them. Block triangulation usually requires a minimum of nine tie points in each image.

The process can be run either from the main OrthoBASE dialog box or from the point measurement tool.

- **Specify the properties of automatic tie point measurement. From the main OrthoBASE panel select *Edit* then *Auto. tie point generation properties.* From the point measurement tool select the *Automatic tie properties* button.**

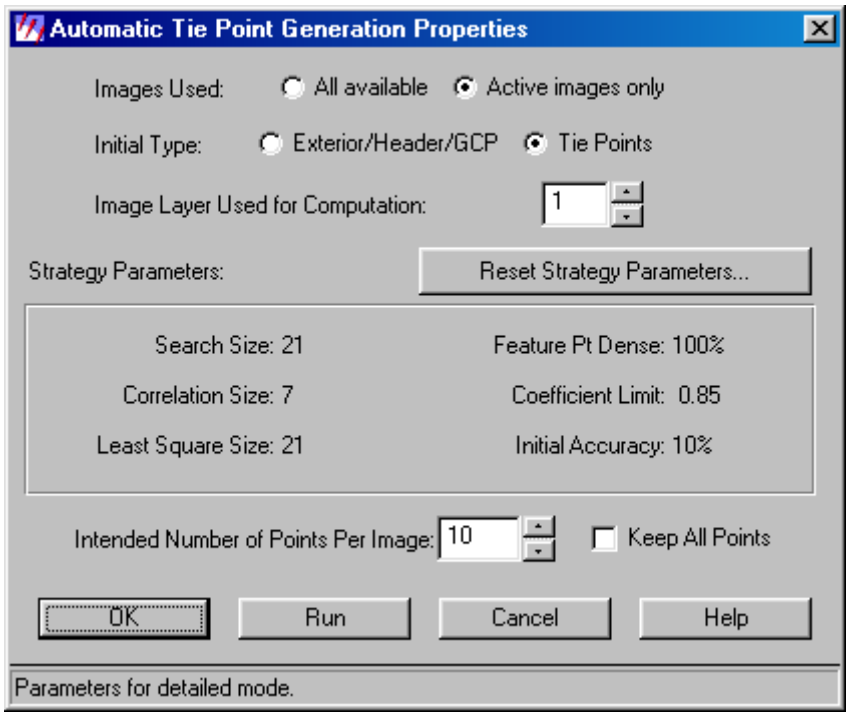

Figure 18. Automatic tie point generation properties.

- **Select *Active images only* and *Tie Points*.**

By selecting Active images only, automatic tie point generation will be performed only on those images marked (X) as active in the main OrthoBASE panel. If there are a lot of images in the block OrthoBASE may return an error due to a lack of memory. If this occurs, perform automatic tie point generation on a few images at a time by making some images inactive in the main OrthoBASE panel.

- **Specify the required number of tie points per image.**
- **Click *OK*.**
- **Select the Perform Automatic Tie Generation button from either the main OrthoBASE panel or the Point Measurement tool.**

Step 11. Triangulation

Once all the points have been entered, triangulation can be run.

- **Select the Perform Triangulation button from either the main OrthoBASE panel or the Point Measurement tool.**

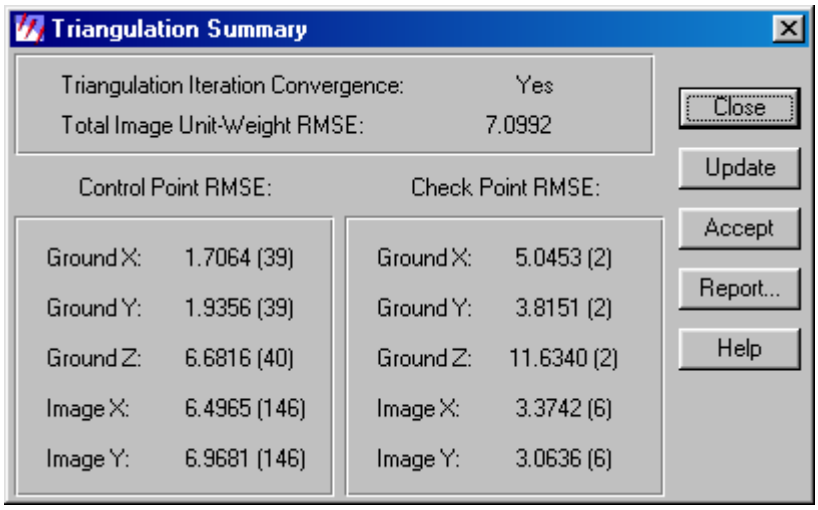

Figure 19. Triangulation summary.

During triangulation OrthoBASE estimates the exterior parameters of the images and the X, Y and Z values of the tie points. These values are then used to compute new image coordinate values. The new image coordinate values are then subtracted from the original image coordinate values. The differences are referred to as the x and y image coordinate residuals. Triangulation is an iterative process and computes new image coordinate values after each iteration. The coordinates from the latest iteration are subtracted from the coordinates from the previous iteration. If these differences are greater than the convergence value the iterations continue.

- **Check that Triangulation Iteration Convergence = Yes.**
- **Check the Total Image Unit-Weight RMSE.**
- **Check the Control Point RMSEs. Figures in brackets refer to the number of points contributing, e.g. in the example above 39 points have X values.**
- **For more detailed results click *Report.***

For a more detailed description of the triangulation report see the online help.

- **If the Triangulation Iteration Convergence = No or high RMSEs (greater than 5) are obtained check the following:**
  - There are enough ground control points (Minimum – 2 full and 1 vertical per block but more than this is usually required) and tie points (Minimum – 9 per image).
  - Typing errors (X, Y and Z reference).
  - Points placed in the wrong area.
  - Within the triangulation report check the residuals of the control points. Look for high positive or negative values. Try inactivating these points and re-running triangulation to see what effect they have on the results.

The residuals of the control points

Point ID	rX	rY	rZ
3	1.5009	3.0214	2.1724
4	0.9184	-0.4119	-6.1148
5	-0.2294	0.0139	0.5685
6	-0.7518	-0.4529	2.3241
27	0.5421	0.3611	5.5348
29	1.5567	0.2313	0.4284
10	-1.1486	0.0405	
11	-1.3804	1.8145	
12	1.0760	-2.1970	
13	-2.2279	-0.4136	
14	-0.1003	1.8349	
15	1.4946	-2.5647	
16	-1.6088	-2.0725	
17	0.5586	0.3197	
18	-0.8044	-0.8017	
19	-1.0555	0.0520	
20	-1.2832	-0.1049	
21	0.4822	-1.0359	
22	0.1771	1.3830	
24	1.0989	0.4080	
25	-0.6125	2.6665	
26	3.7632	1.6007	
9	0.4502	-0.1863	
30	-1.8242	-0.2195	
158	1.3736	4.2147	
279	-0.6746	2.1913	
931	0.3333	1.8131	
932	3.4308	1.8884	

Figure 20. Control point residual section of the triangulation report.

- **Once acceptable triangulation results have been obtained, click *Update* and *Accept.***

Update and accepting the triangulation results attributes X, Y and Z values to both tie points and to ground control points with missing information.

Step 12. Orthoresampling

- **Select the Orthoresampling button from the main OrthoBASE panel.**
- **Ensure that all images to be orthorectified are active in the main OrthoBASE panel.**

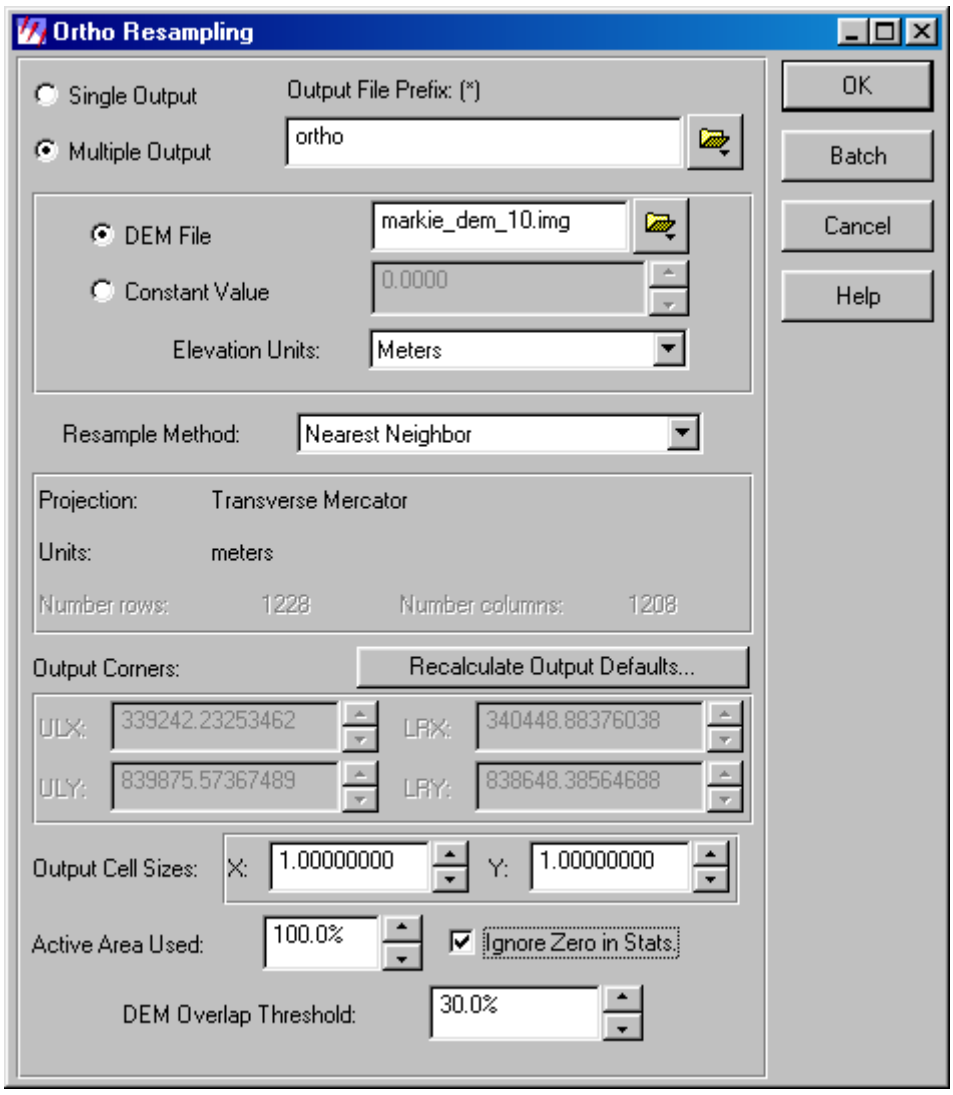

Figure 21. Defining orthoresampling properties.

- **To orthorectify multiple files, select *Multiple File Output* and specify a prefix to be added to the beginning of the original image file name.**
- **Select *DEM File* and specify the DEM to be used.**
- **For the resample method choose one of the following*:-***

  Bilinear Interpolation. Use this method if the resolution of the DEM is greater than the resolution of the image or if the output area of the orthorectified image is covered entirely by the DEM.

  Nearest Neighbour. Use this method if the resolution of the DEM and the image is approximately the same or if the output orthorectified image is not covered entirely by the DEM.

- **Enter the required output cell sizes. For example, entering 1 in the X and Y fields would produce a 1m orthorectified image.**
- **Click *OK* to begin the orthorectification process.**

Figure 22. Orthoresampling process monitor.

- **Click *OK* once the *Job State* is *Done* for all the images selected for orthoresampling.**

Appendix I
Example Frame Imagery

LCS88 Aerial Photography

Scale 1:24000
Camera. Wild RC20 (for more information see Appendix III.)
Fiducials Marked by purple circles
Scanned 256 level grey
400 dpi

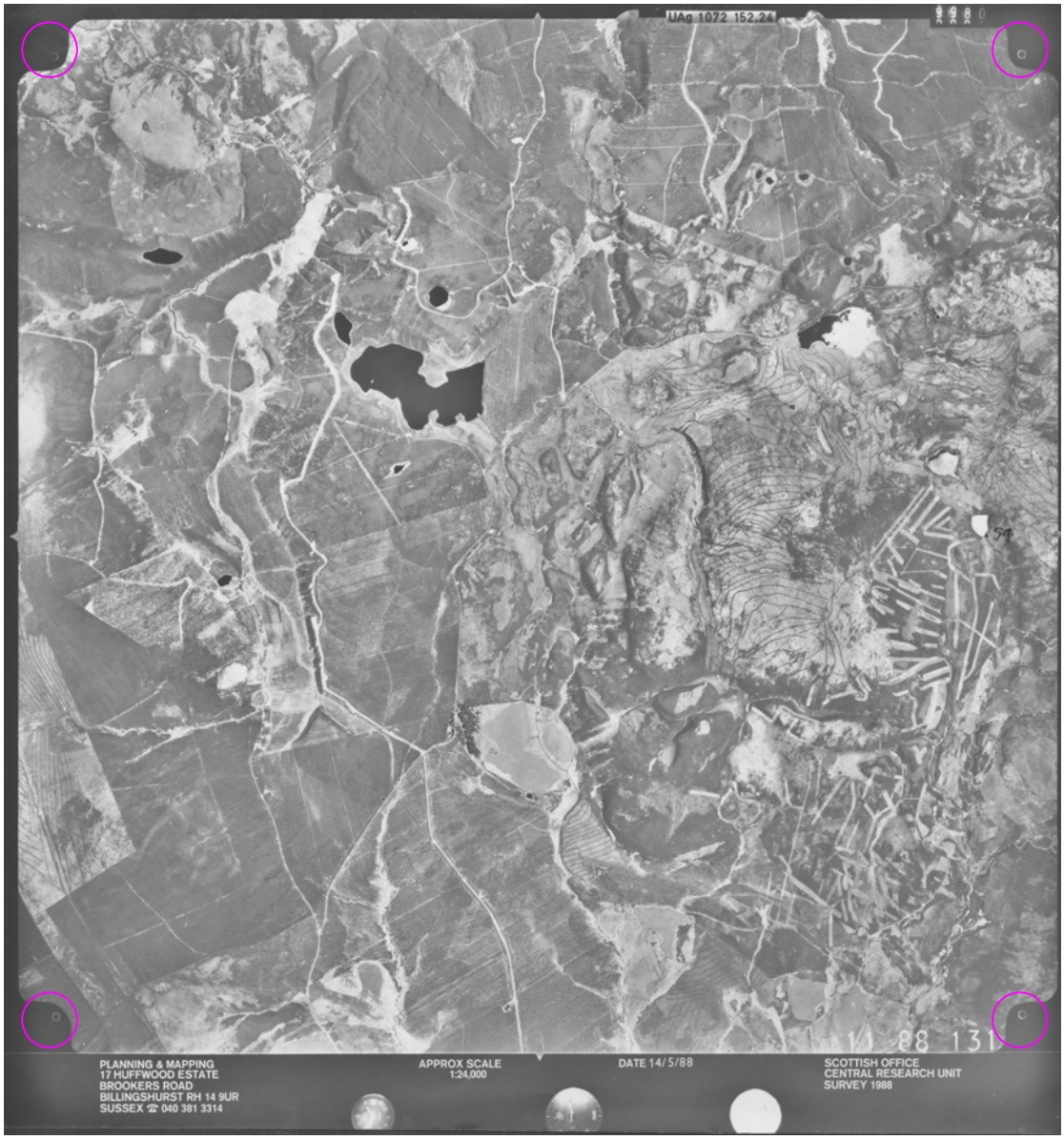

Figure 23. LCS88 aerial photography.

Colour frame photography

Scale. 1:5000
Camera. Rolleiflex 6006 (for more information see Appendix III.)
Fiducials. Marked by purple circles
Scanned. 24 bit colour
600 dpi

Figure 24. Colour frame photography.

Appendix II
Other Types of Imagery

Videography

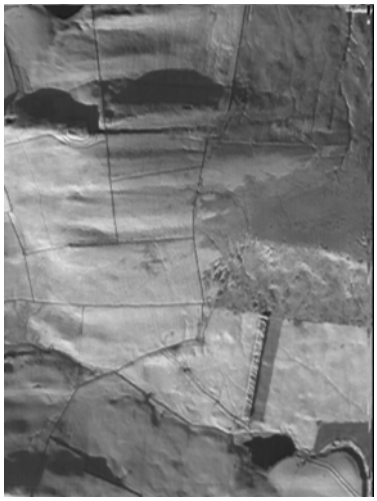

Figure 25. Infra red videography.

Figure 23 shows 1:5000 infra red videography. The imagery was captured using a video camera, individual frames of the imagery were then captured to be orthorectified. This type of imagery can also be orthorectified within OrthoBASE.

- **Follow the procedure laid out for frame photography with the following exceptions.**

Step 2. Select geometric model

- **Select *Video Camera (Videography)* and click *OK.***

Step 6. Defining the sensor

The same information is required under the sensor tab as was for the frame camera. It is however advantageous to have as much information as possible as a video camera is not as accurate as a photogrammetric camera.

Specification for video camera used to capture Figure 23 IR videography

Focal Length (mm)	8.54
Principal Point xo (mm)	0.00
Principal Point yo (mm)	0.00

Radial Lens Distortion

Radial Dist	Distortion (microns)	Residual (microns)
0	0	0
1.74	-17.44	0.98
2.79	-54.78	-1.85
3.50	-105.12	1.37
4.23	-169.04	-0.32

Step 7. Interior Orientation

Video cameras are non-metric cameras, therefore they do not have fiducial marks. Instead the pixel size of the imagery must be defined.

- **Define the *Pixel size in x direction (microns)*.**
- **Define the *Pixel size in y direction (microns)*.**

For example, for the imagery in Figure 23:

Pixel size in x direction (microns) = 11.4583
Pixel size in y direction (microns) = 11.4583

Appendix III
Sensor Specifications

Wild RC20

Camera Name	Wild RC20
Focal Length (mm)	153.23
Principal Point xo (mm)	0.00
Principal Point yo (mm)	0.00

Fiducials

	Film X (mm)	Film Y (mm)
1	106.004	-106.008
2	-105.999	-105.998
3	-106.004	106.005
4	106.002	106.002
5	0.003	-109.992
6	-109.996	0.003
7	-0.004	109.997
8	109.998	-0.002

Rolleiflex 6006

Camera Name	Rolleiflex 6006
Focal Length(mm)	80.11
Principal Point xo (mm)	0.1300
Principal Point yo (mm)	0.2900

Fiducials

	Film X (mm)	Film Y (mm)
1	-24.999	25.000
2	25.000	25.000
3	25.000	-25.000
4	-24.999	-25.000
5	0.000	24.999
6	25.001	0.001
7	-0.002	-24.999
8	-25.000	0.002
9	0.000	0.000

Appendix IV
Example Triangulation Report

```
  The Triangulation Report With OrthoBASE

  The output image x, y units:     pixels
  The output angle unit:      degrees
  The output ground X, Y, Z units: meters

       The Input Image Coordinates
              image ID = 1
Point ID            x            y
      1         1519.375     3735.875
      3         2017.875     2863.125
      4         1749.875     2696.375
      5         2150.875     1895.625
      6         2555.375     2949.125
      7         2576.125     1724.125
      8         1992.125     3589.125
      9         2511.385      494.622
     10         1490.643      541.323
     11          580.031      571.566
     12         1486.756     1512.508
     13         2483.160     1517.131
     14          488.567     1547.937
     15         2534.312     2533.349
     16          498.628     2537.495
     17         1521.037     2536.842
     18         1412.723     3417.528
     19         2461.938     3446.785
     20          475.368     3528.835

 Affine coefficients from file (pixels) to film (millimeters)
   A0          A1          A2          B0          B1          B2
-128.3387   0.063582   -0.000374    127.2615   -0.000339   -0.063255

              image ID = 2
Point ID            x            y
      1         2316.125     3690.375
      3         2825.625     2828.125
      4         2559.625     2655.125
      5         2970.375     1860.375
      6         3367.375     2926.875
      7         3401.125     1696.625
      8         2786.375     3553.125
      9         3383.436      452.596
     10         2341.647      475.185
     11         1408.169      483.392
     12         2316.146     1457.323
     13         3315.094     1485.759
     14         1318.398     1470.029
     15         3360.523     2509.951
     16         1319.779     2466.851
     17         2326.324     2489.807
     18         2217.419     3370.356
     19         3274.915     3422.208
     20         1278.302     3457.657
     21          581.125     1479.875
     22         1848.375     1730.875
     23         2761.296     2011.809
     24          548.085     2581.584
```

Each image is listed in turn. The points that are measured on the image are listed along with the image coordinates.

The affine coefficients are used to transform the pixel coordinates of the ground point into image coordinates.

25	922.335	2212.276
26	530.057	2961.144
27	1219.973	3045.746
28	402.998	369.852
29	2040.063	379.362
30	1123.948	447.625
31	2608.514	525.128
32	429.693	1163.743
33	2642.365	1207.550
34	1185.392	1216.432
35	2007.685	1235.668
36	2759.129	1961.019
37	2024.367	1995.693
38	1161.097	2001.059
39	404.770	2025.434
40	2038.031	2783.690
41	1213.844	2800.919
42	2694.310	2811.848
43	533.431	2956.053
44	554.658	3249.249
45	766.157	3253.502
46	794.266	3349.697
47	2714.570	3389.352
48	642.909	3445.632
49	771.367	3518.452
50	1987.620	3554.483
51	1147.312	3631.226
52	2727.112	2109.896

Affine coefficients from file (pixels) to film (millimeters)

A0	A1	A2	B0	B1	B2
-131.1987	0.063598	-0.000203	125.0123	-0.000168	-0.063261

image ID = 3

Point ID	x	y
1	3487.125	3576.875
21	1688.625	1395.125
4	3710.125	2544.625
22	2969.579	1624.780
23	3895.776	1891.254
24	1687.033	2505.576
25	2049.056	2129.017
26	1674.988	2883.038
27	2382.730	2957.153
28	1479.184	262.471
29	3153.133	229.731
30	2192.395	324.876
31	3749.911	365.782
32	1529.890	1077.680
33	3778.048	1071.728
34	2300.920	1112.802
35	3138.907	1115.336
36	3894.313	1839.839
37	3152.391	1889.795
38	2290.598	1912.302
39	1531.441	1950.592
40	3179.979	2682.001
41	2371.848	2712.822
42	3849.422	2699.346
43	1677.346	2877.475
44	1718.383	3166.124

45	1935.166	3167.900
46	1968.528	3262.204
47	3869.313	3274.031
48	1819.690	3357.986
49	1953.303	3428.188
50	3171.006	3447.520
51	2325.657	3534.249
52	3862.596	1991.580
54	950.320	1529.529
56	1970.016	351.930
57	1198.052	381.646
58	2785.460	438.956
59	407.279	507.958
60	736.714	1015.833
61	2806.325	1239.786
62	1986.540	1251.261
63	651.009	1259.179
64	1195.727	1263.751
65	740.093	1265.549
66	695.008	1330.306
67	627.911	1515.862
68	444.699	1976.114
69	2009.817	1994.295
70	1182.185	2018.766
71	2768.181	2018.731
72	445.869	2826.782
73	2731.172	2836.017
74	1192.926	2845.641
75	2043.463	2839.681
76	740.377	3251.097
77	746.921	3296.048
78	2620.695	3566.379
79	1999.469	3598.292
80	1268.781	3639.271
81	564.934	177.723
82	878.158	292.419
83	1988.798	296.642
84	596.573	293.020
85	2621.168	301.607
86	1127.567	396.675
87	1032.307	405.548
88	487.770	517.570
89	529.253	537.197
90	461.398	545.431
91	543.933	541.369
92	434.423	591.931
93	609.415	629.481
94	467.313	692.560
95	826.853	777.163
96	2525.125	815.364
97	1932.877	818.987
98	1436.859	844.336
99	877.506	1094.035
100	1415.229	1380.453
101	2546.705	1397.535
102	2027.489	1462.111
103	862.693	1567.987
104	554.788	1699.258
105	925.670	1997.269
106	1417.955	2001.802
107	2589.251	2065.677

108	2585.311	2603.196
109	383.142	2601.695
110	1485.410	2618.182
111	2039.492	2617.191
112	823.248	2624.725
113	560.599	2917.842
114	2041.010	3110.576
115	2598.733	3152.113
116	1374.081	3176.414
117	923.621	3229.651
118	1052.297	3649.770
119	1413.728	3696.801
120	2006.314	3714.035
121	2496.813	3712.573
122	1400.727	2935.548
124	484.023	1110.637
125	1675.624	1313.618
126	1155.456	1262.765

Affine coefficients from file (pixels) to film (millimeters)

A0	A1	A2	B0	B1	B2
-134.4256	0.063583	-0.000457	123.1679	-0.000410	-0.063259

image ID = 4

Point ID	x	y
21	2714.625	1447.875
24	2741.284	2570.579
25	3093.310	2178.728
26	2733.807	2953.071
27	3471.448	3009.038
54	1945.446	1605.175
56	2954.894	382.170
57	2203.456	436.012
58	3794.023	443.012
59	1367.739	591.820
60	1730.330	1093.138
61	3847.705	1255.256
62	3018.958	1291.871
63	1626.225	1343.227
64	2193.763	1328.993
65	1721.658	1345.525
66	1675.149	1412.227
67	1609.567	1601.820
68	1451.438	2072.119
69	3058.778	2044.424
70	2224.109	2092.915
71	3822.536	2047.016
72	1515.230	2929.581
73	3815.405	2877.454
74	2249.398	2930.269
75	3115.156	2899.363
76	1829.237	3350.678
77	1837.242	3396.225
78	3729.312	3620.489
79	3102.915	3668.553
80	2352.600	3729.692
81	1516.909	252.189
82	1872.681	356.663
83	2976.570	325.079
84	1566.114	367.004
85	3622.005	308.915

86	2132.343	453.591
87	2036.190	465.760
88	1459.187	598.057
89	1505.166	616.651
90	1429.604	627.344
91	1521.620	620.300
92	1405.434	675.389
93	1593.505	707.550
94	1444.915	776.140
95	1834.586	847.835
96	3553.498	833.349
97	2946.684	856.037
98	2451.043	896.427
99	1873.054	1167.083
100	2421.947	1440.975
101	3593.627	1422.378
102	3073.686	1503.911
103	1856.880	1646.675
104	1543.070	1789.143
105	1965.610	2078.356
106	2458.085	2069.381
107	3641.797	2099.557
108	3672.044	2645.027
109	1442.684	2704.491
110	2541.379	2690.802
111	3091.192	2674.412
112	1877.064	2717.197
113	1628.035	3018.860
114	3124.859	3173.870
115	3691.971	3200.909
116	2446.617	3260.231
117	2011.848	3324.994
118	2135.066	3745.477
119	2509.169	3784.516
120	3115.706	3785.998
121	3610.636	3772.144
122	2462.954	3014.736
124	1460.128	1198.539
125	2700.083	1365.607
126	2154.105	1328.711

Affine coefficients from file (pixels) to film (millimeters)

A0	A1	A2	B0	B1	B2
-134.3869	0.063586	0.000013	127.0052	0.000045	-0.063262

```
THE OUTPUT OF SELF-CALIBRATING BUNDLE BLOCK ADJUSTMENT

the no. of iteration =1    the standard error =  1.0287
the maximal correction of the object points = 176.46666

the no. of iteration =2    the standard error =  1.0174
the maximal correction of the object points =   2.03745

the no. of iteration =3    the standard error =  1.0176
the maximal correction of the object points =   0.00604

the no. of iteration =4    the standard error =  1.0176
the maximal correction of the object points =   0.00002
```

The calculations are redone until the *maximal correction of the object points* is less than 0.001 (the convergence value). In this example it has taken four iterations. The *standard error* is a global indicator of quality.

The exterior orientation parameters

image ID	Xs	Ys	Zs	OMEGA	PHI	KAPPA
1	342626.1828	839279.9113	4174.6864	1.6073	1.1402	1.6777
2	341340.1026	839232.2968	4171.6558	1.2362	1.0662	2.8898
3	339632.8642	839152.6748	4166.9242	0.0168	1.4430	2.0738
4	337959.6896	839105.1744	4164.6899	-0.0100	1.7130	0.0143

Estimated exterior orientation parameters.

The interior orientation parameters of photos

image ID	f(mm)	xo(mm)	yo(mm)
1	152.2400	0.0000	0.0000
2	152.2400	0.0000	0.0000
3	152.2400	0.0000	0.0000
4	152.2400	0.0000	0.0000

The interior orientation parameters (focal length and principal point) remain as inputed.

The residuals of the control points

Point ID	rX	rY	rZ
1	2.4358	-0.6450	-0.7271
3	0.1541	0.6455	-1.6778
6	0.8140	0.8453	-0.9678
7	1.0846	1.6680	2.5452
21	3.0184	-2.3048	0.3643
23	0.6543	-0.1429	-3.3105
54	-2.0225	2.4939	-1.3090
125	1.4557	-1.4018	0.8862
126	-1.4303	0.4299	1.4235
5	-1.7202	0.2516	
24	0.2169	4.1949	
25	1.9107	-2.0056	
26	4.4972	3.5971	
27	-3.4050	-4.1109	
8	-2.5899	3.8657	
122	-1.3011	-1.9714	
124	-6.6115	4.4751	
4	-0.6436	-2.1176	
22	-2.9674	-0.3853	

In the process new control coordinates are calculated. Control point residuals represent the difference between the original control point coordinates and the estimated control point coordinates.

aX	aY	aZ
-0.3395	0.3885	-0.3081
mX	**mY**	**mZ**
2.5690	2.4392	1.7119

aX, aY and aZ are the average residuals for the control point coordinates.

mX, mY and mZ are the root mean square errors (standard deviation).

All the control points are listed X, Y and Z values. Those values that were inputed remain the same, those that were unknown have been estimated. Tie points are also listed with estimated X, Y and Z values.

The coordinates of object points

Point ID	X	Y	Z	Overlap
1	341791.2000	836594.5000	265.1200	3
3	342560.8000	837989.9000	231.4100	2
6	343435.3000	837880.2000	233.7800	2
7	343443.3000	839871.3000	184.4000	2
21	338799.6800	839997.7200	324.4000	3
23	342412.3000	839306.6000	194.8000	2
54	337570.5000	839758.0100	261.1100	2
125	338777.2000	840125.7000	329.3100	2
126	337911.2000	840199.7000	284.4200	2
5	342745.0000	839569.9000	200.6021	2
24	338848.9000	838208.0000	310.1316	3
25	339412.9000	838836.7000	285.7046	3
26	338838.2000	837591.4000	287.4224	3
27	339994.2000	837540.9000	323.1814	3
8	342549.6000	836823.9000	222.7657	2
122	338406.7100	837506.8000	319.9132	2
124	336777.3000	840423.3000	269.4953	2
4	342117.3000	838250.0000	237.0913	3
22	340888.2000	839692.4000	248.7536	2
9	343277.6484	841859.4845	314.8575	2
10	341597.8564	841772.6725	297.3594	2
11	340050.5223	841724.8943	262.4435	2
12	341631.6416	840171.3005	263.0642	2
13	343280.1413	840209.5177	209.1129	2
14	340016.4360	840062.5263	338.6576	2
15	343383.4914	838553.3286	266.9977	2
16	340111.0604	838470.4468	354.3184	2
17	341728.4186	838491.0214	217.6815	2
18	341611.0267	837100.2609	284.9889	2
19	343291.2595	837114.3803	283.7301	2
20	340121.0220	836897.8034	325.7788	2
28	338420.1955	841786.7168	360.9048	2
29	341096.2969	841911.9184	300.0207	2
30	339563.4723	841777.5236	246.1940	2
31	342034.0447	841698.9383	311.7661	2
32	338535.7842	840493.5947	346.1251	2
33	342148.5852	840609.7671	250.7049	2
34	339774.9140	840465.9633	333.8041	2
35	341111.4342	840499.8223	306.8290	2
36	342404.5171	839389.5336	196.8402	2
37	341195.1160	839273.0991	238.2453	2
38	339796.2467	839195.5580	308.0531	2
39	338576.6643	839097.6027	337.0819	2
40	341278.7432	837994.0872	231.4867	2

41	339961.7577	837926.5571	330.1923	2
42	342346.6528	838006.9591	233.6315	2
43	338844.8914	837601.5634	282.6550	2
44	338932.6154	837155.9872	320.6671	2
45	339284.3223	837176.7346	336.3683	2
46	339342.8378	837033.2358	344.4289	2
47	342426.3358	837070.3893	202.2192	2
48	339108.7214	836869.9336	344.6673	2
49	339326.9141	836774.1674	354.0642	2
50	341258.2682	836816.3593	329.1610	2
51	339926.2245	836615.0871	325.4701	2
52	342362.8424	839142.4001	193.7755	2
56	339201.3447	841718.8123	260.3811	2
57	337988.0975	841563.5143	400.3786	2
58	340531.7162	841599.0342	255.9053	2
59	336621.7545	841412.5567	282.7002	2
60	337227.4033	840572.1924	327.3468	2
61	340594.4874	840296.2219	288.3053	2
62	339278.0386	840234.3491	336.9249	2
63	337037.4451	840198.3334	236.6882	2
64	337973.9828	840201.2289	279.9879	2
65	337199.2632	840187.6530	253.8924	2
66	337120.4959	840081.3385	244.5887	2
67	337009.4474	839772.8627	234.5391	2
68	336764.2164	839001.1613	293.1212	2
69	339348.2960	839050.2549	316.4418	2
70	338022.3420	838972.2317	361.6277	2
71	340576.7859	839046.8388	257.4300	2
72	336908.7223	837663.7960	431.7828	2
73	340548.8524	837735.5405	283.6632	2
74	338063.9840	837637.9188	325.8858	2
75	339441.3191	837695.4615	306.5804	2
76	337405.0049	837016.3757	435.3028	2
77	337417.6049	836945.9685	435.3216	2
78	340400.9542	836573.2488	306.5536	2
79	339407.9175	836502.7540	345.5154	2
80	338228.7950	836373.5614	335.0779	2
81	336865.7424	841964.9867	275.6276	2
82	337466.0840	841700.5622	396.5903	2
83	339231.0484	841799.2354	275.3517	2
84	336960.3360	841741.1901	326.9904	2
85	340259.2249	841815.1814	259.6281	2
86	337876.4076	841536.8662	402.3644	2
87	337725.3102	841518.3718	405.9542	2
88	336783.4203	841379.0132	317.4522	2
89	336861.8626	841341.2563	329.0470	2
90	336730.8281	841340.3687	304.1703	2
91	336890.0670	841331.9834	334.1287	2
92	336693.5915	841259.3252	311.5737	2
93	337009.1286	841185.5819	343.3830	2
94	336761.8691	841090.0030	322.8795	2
95	337406.1537	840928.9058	397.3077	2
96	340120.7144	840955.1138	315.0657	2
97	339169.7680	840929.7158	320.2149	2
98	338380.0269	840855.4248	363.5971	2
99	337456.6245	840455.1218	315.1781	2
100	338342.7107	840018.6948	280.8939	2
101	340181.3691	840027.2710	318.7995	2
102	339355.2141	839895.3317	360.2644	2
103	337423.0483	839693.6117	258.9381	2
104	336901.6806	839464.1123	245.0537	2

105	337612.6188	838994.7290	377.3896	2
106	338394.9909	839009.7109	337.0540	2
107	340288.9055	838962.7052	264.6306	2
108	340295.9296	838113.1281	331.7469	2
109	336791.3261	838012.9249	424.6848	2
110	338529.4737	838022.2080	323.5499	2
111	339421.8823	838038.0564	257.2479	2
112	337471.1102	837984.4875	369.2134	2
113	337081.4811	837516.4875	407.2074	2
114	339450.7222	837268.3825	322.2554	2
115	340348.7171	837227.2685	296.8019	2
116	338377.9917	837121.9704	334.1617	2
117	337690.0706	837054.2787	421.3042	2
118	337881.9054	836349.5796	347.8596	2
119	338474.3308	836310.0104	358.8189	2
120	339424.6659	836325.5058	354.0198	2
121	340207.5518	836342.2192	322.5158	2

The total object points = 122

The residuals of image points

Point	Image	Vx	Vy
1	1	-1.565	0.519
1	2	-1.519	-0.361
1	3	-1.251	-0.676

Point	Image	Vx	Vy
3	1	-0.131	0.490
3	2	0.192	0.992

Point	Image	Vx	Vy
6	1	-0.396	0.445
6	2	-0.218	1.014

Point	Image	Vx	Vy
7	1	-0.998	0.731
7	2	-1.529	1.664

Point	Image	Vx	Vy
21	2	-1.709	-1.313
21	3	-1.548	-1.085
21	4	-2.085	-1.854

Point	Image	Vx	Vy
23	2	0.149	-0.886
23	3	1.057	0.621

Point	Image	Vx	Vy
54	3	0.752	0.886
54	4	1.171	1.915

Point	Image	Vx	Vy
125	3	-0.753	-0.392
125	4	-1.053	-1.085

Point	Image	Vx	Vy
126	3	1.225	-0.113
126	4	0.918	1.142

Point	Image	Vx	Vy
5	1	1.035	0.332

The residuals of image points represent the difference between the original image coordinates and the estimated image coordinates.

High values can be a good indication of inaccurate placement of points.

5	2	1.044	0.048

Point	Image	Vx	Vy
24	2	-0.412	2.729
24	3	0.033	2.118
24	4	-0.249	2.987

Point	Image	Vx	Vy
25	2	-0.695	-1.605
25	3	-1.911	-1.688
25	4	-0.805	-0.552

Point	Image	Vx	Vy
26	2	-3.001	2.203
26	3	-2.536	1.641
26	4	-2.947	2.558

Point	Image	Vx	Vy
27	2	2.283	-1.512
27	3	2.109	-3.120
27	4	2.232	-2.935

Point	Image	Vx	Vy
8	1	1.538	2.112
8	2	1.501	2.917

Point	Image	Vx	Vy
122	3	0.831	-1.043
122	4	0.815	-1.374

Point	Image	Vx	Vy
124	3	3.843	3.401
124	4	3.971	2.107

Point	Image	Vx	Vy
4	1	0.634	-1.408
4	2	0.093	-1.354
4	3	0.595	-1.139

Point	Image	Vx	Vy
22	2	1.809	-0.323
22	3	1.854	-0.021

Point	Image	Vx	Vy
9	1	-0.008	-0.292
9	2	0.001	0.288

Point	Image	Vx	Vy
10	1	-0.001	-0.033
10	2	0.000	0.033

Point	Image	Vx	Vy
11	1	0.000	0.010
11	2	-0.000	-0.010

Point	Image	Vx	Vy
12	1	-0.005	-0.283
12	2	-0.001	0.280

Point	Image	Vx	Vy
13	1	-0.009	-0.468

13	2	-0.002	0.464

Point	Image	Vx	Vy
14	1	0.005	0.273
14	2	0.002	-0.270

Point	Image	Vx	Vy
15	1	-0.002	-0.211
15	2	-0.003	0.210

Point	Image	Vx	Vy
16	1	0.002	0.258
16	2	0.004	-0.257

Point	Image	Vx	Vy
17	1	0.001	0.097
17	2	0.001	-0.097

Point	Image	Vx	Vy
18	1	-0.000	0.521
18	2	0.012	-0.521

Point	Image	Vx	Vy
19	1	-0.001	-0.422
19	2	-0.009	0.423

Point	Image	Vx	Vy
20	1	-0.001	-0.584
20	2	-0.012	0.584

Point	Image	Vx	Vy
28	2	0.012	1.098
28	3	-0.037	-1.059

Point	Image	Vx	Vy
29	2	-0.003	-0.259
29	3	0.009	0.249

Point	Image	Vx	Vy
30	2	0.003	0.295
30	3	-0.010	-0.285

Point	Image	Vx	Vy
31	2	-0.014	-1.044
31	3	0.037	1.003

Point	Image	Vx	Vy
32	2	0.003	0.685
32	3	-0.018	-0.670

Point	Image	Vx	Vy
33	2	-0.007	-0.924
33	3	0.026	0.899

Point	Image	Vx	Vy
34	2	-0.004	-0.521
34	3	0.014	0.509

Point	Image	Vx	Vy
35	2	-0.002	-0.280
35	3	0.007	0.273

Point	Image	Vx	Vy
36	2	-0.001	-0.719
36	3	0.014	0.708

Point	Image	Vx	Vy
37	2	0.000	-0.244
37	3	0.004	0.241

Point	Image	Vx	Vy
38	2	-0.000	0.275
38	3	-0.005	-0.272

Point	Image	Vx	Vy
39	2	-0.000	0.090
39	3	-0.002	-0.089

Point	Image	Vx	Vy
40	2	0.000	-0.048
40	3	0.000	0.048

Point	Image	Vx	Vy
41	2	-0.002	0.192
41	3	-0.002	-0.193

Point	Image	Vx	Vy
42	2	0.001	-0.094
42	3	0.001	0.094

Point	Image	Vx	Vy
43	2	-0.001	0.055
43	3	-0.000	-0.056

Point	Image	Vx	Vy
44	2	0.003	-0.280
44	3	0.001	0.284

Point	Image	Vx	Vy
45	2	-0.001	0.061
45	3	-0.000	-0.062

Point	Image	Vx	Vy
46	2	-0.000	0.015
46	3	-0.000	-0.015

Point	Image	Vx	Vy
47	2	-0.001	0.054
47	3	-0.000	-0.055

Point	Image	Vx	Vy
48	2	0.004	-0.351
48	3	0.001	0.357

Point	Image	Vx	Vy
49	2	0.002	-0.127
49	3	0.000	0.130

Point	Image	Vx	Vy
50	2	-0.002	0.161
50	3	0.000	-0.163

Point	Image	Vx	Vy
51	2	-0.002	0.107
51	3	0.000	-0.109

Point	Image	Vx	Vy
52	2	0.000	-0.616
52	3	0.011	0.608

Point	Image	Vx	Vy
56	3	0.000	0.007
56	4	-0.000	-0.007

Point	Image	Vx	Vy
57	3	0.001	0.056
57	4	-0.003	-0.055

Point	Image	Vx	Vy
58	3	-0.004	-0.242
58	4	0.011	0.238

Point	Image	Vx	Vy
59	3	0.006	0.400
59	4	-0.018	-0.396

Point	Image	Vx	Vy
60	3	0.001	0.054
60	4	-0.002	-0.054

Point	Image	Vx	Vy
61	3	0.000	0.008
61	4	-0.000	-0.008

Point	Image	Vx	Vy
62	3	-0.000	-0.060
62	4	0.002	0.059

Point	Image	Vx	Vy
63	3	0.002	0.378
63	4	-0.013	-0.374

Point	Image	Vx	Vy
64	3	-0.003	-0.402
64	4	0.015	0.397

Point	Image	Vx	Vy
65	3	-0.002	-0.231
65	4	0.008	0.228

Point	Image	Vx	Vy
66	3	-0.002	-0.329
66	4	0.012	0.325

Point	Image	Vx	Vy
67	3	-0.001	-0.311
67	4	0.010	0.308

Point	Image	Vx	Vy
68	3	0.000	-0.043
68	4	0.001	0.042

Point	Image	Vx	Vy
69	3	-0.000	0.069
69	4	-0.002	-0.068

Point	Image	Vx	Vy
70	3	0.000	-0.106
70	4	0.003	0.105

Point	Image	Vx	Vy
71	3	0.000	-0.025
71	4	0.001	0.024

Point	Image	Vx	Vy
72	3	0.004	-0.366
72	4	0.006	0.362

Point	Image	Vx	Vy
73	3	-0.002	0.215
73	4	-0.003	-0.211

Point	Image	Vx	Vy
74	3	-0.006	0.529
74	4	-0.008	-0.523

Point	Image	Vx	Vy
75	3	0.002	-0.184
75	4	0.003	0.182

Point	Image	Vx	Vy
76	3	0.002	-0.123
76	4	0.001	0.121

Point	Image	Vx	Vy
77	3	-0.000	0.028
77	4	-0.000	-0.028

Point	Image	Vx	Vy
78	3	0.001	-0.058
78	4	0.000	0.057

Point	Image	Vx	Vy
79	3	0.005	-0.281
79	4	0.002	0.277

Point	Image	Vx	Vy
80	3	-0.001	0.054
80	4	-0.000	-0.053

Point	Image	Vx	Vy
81	3	-0.002	-0.084
81	4	0.004	0.083

Point	Image	Vx	Vy
82	3	0.004	0.205
82	4	-0.010	-0.202

Point	Image	Vx	Vy
83	3	-0.002	-0.119
83	4	0.006	0.117

Point	Image	Vx	Vy

Point	Image	Vx	Vy
84	3	-0.001	-0.059
84	4	0.003	0.058
85	3	-0.005	-0.301
85	4	0.015	0.296
86	3	0.002	0.093
86	4	-0.004	-0.092
87	3	0.002	0.145
87	4	-0.007	-0.143
88	3	0.003	0.187
88	4	-0.009	-0.185
89	3	0.005	0.317
89	4	-0.014	-0.314
90	3	0.004	0.250
90	4	-0.011	-0.247
91	3	0.004	0.304
91	4	-0.014	-0.301
92	3	0.005	0.396
92	4	-0.018	-0.392
93	3	0.007	0.533
93	4	-0.023	-0.527
94	3	0.007	0.550
94	4	-0.023	-0.544
95	3	-0.002	-0.137
95	4	0.006	0.135
96	3	0.001	0.069
96	4	-0.003	-0.068
97	3	0.001	0.086
97	4	-0.004	-0.085
98	3	-0.003	-0.251
98	4	0.011	0.247
99	3	-0.003	-0.344

99	4	0.013	0.340

Point	Image	Vx	Vy
100	3	-0.000	-0.040
100	4	0.001	0.040

Point	Image	Vx	Vy
101	3	-0.002	-0.349
101	4	0.012	0.344

Point	Image	Vx	Vy
102	3	-0.001	-0.123
102	4	0.004	0.121

Point	Image	Vx	Vy
103	3	-0.002	-0.544
103	4	0.018	0.538

Point	Image	Vx	Vy
104	3	-0.001	-0.310
104	4	0.010	0.306

Point	Image	Vx	Vy
105	3	0.000	-0.232
105	4	0.006	0.229

Point	Image	Vx	Vy
106	3	-0.000	0.088
106	4	-0.002	-0.087

Point	Image	Vx	Vy
107	3	0.000	-0.179
107	4	0.005	0.176

Point	Image	Vx	Vy
108	3	-0.001	0.142
108	4	-0.003	-0.140

Point	Image	Vx	Vy
109	3	0.001	-0.152
109	4	0.003	0.150

Point	Image	Vx	Vy
110	3	0.001	-0.103
110	4	0.002	0.102

Point	Image	Vx	Vy
111	3	0.001	-0.161
111	4	0.003	0.158

Point	Image	Vx	Vy
112	3	-0.006	0.600
112	4	-0.010	-0.594

Point	Image	Vx	Vy
113	3	0.002	-0.183
113	4	0.003	0.182

Point	Image	Vx	Vy
114	3	0.002	-0.124
114	4	0.002	0.122

Point	Image	Vx	Vy
115	3	0.002	-0.131
115	4	0.002	0.129

Point	Image	Vx	Vy
116	3	-0.012	0.745
116	4	-0.008	-0.737

Point	Image	Vx	Vy
117	3	-0.005	0.300
117	4	-0.003	-0.297

Point	Image	Vx	Vy
118	3	0.003	-0.153
118	4	0.001	0.151

Point	Image	Vx	Vy
119	3	-0.005	0.265
119	4	-0.001	-0.262

Point	Image	Vx	Vy
120	3	0.001	-0.072
120	4	0.000	0.071

Point	Image	Vx	Vy
121	3	-0.001	0.062
121	4	-0.000	-0.061