VISSR ATMOSPHERIC SOUNDER

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The major effort during the past month has been to summarize and analyze the results of the VAS simulator runs. The first report, which is included here, concerns the effects of diffraction on sounding channel retrievals. Subsequent reports will deal with location errors and window channel retrievals.

INTRODUCTION

Simulations were performed using both the line fit and the paired FOV retrieval techniques for channel 5 where sounding was expected to be most difficult. The paired FOV technique was found to be superior, and the biases caused by diffraction were separated from those due to the presence of mixed cloud types for that technique. Also the variation of sounding accuracy was studied as a function of sounding channel and of spatial resolution. Throughout this report it is assumed that the window channel clear column radiance is known exactly. It will be shown that for both the line fit and the paired FOV techniques, the contribution of window channel clear column radiance errors to sounding channel errors can be predicted and varies from channel to channel.

1. Line Fit VS. Paired FOV Retrieval

The simulator results for the line fit and paired FOV techniques are given in Table 1. The data are for the 13.42μ sounding channel which, when the window channel clear column errors are neglected, is the most difficult channel to sound. The mean and RMS errors of 10 retrievals with different random noise additions are given for each of the 90 x 90 km subgrids along with the number of clear samples/subgrid and the number of points or pairs used by both techniques. For the paired FOV technique both weighted (see appendix) and unweighted results are tabulated. The number of clear samples is included as a characterization of the difficulty of sounding the subgrids. (A clear sample was defined to be one with a

TABLE 1. Retrieval errors for Channel 5 with 2 clo types in the scene (Channel 5 NEN = .5 ergs/etc, window channel NEN = .21 ergs/etc)

SUBGRID	NO. CLEAR SOUNDER SAMPLES	LINE FIT ERRORS			PAIRED FOV ERRORS		WEIGHTED		NO. PAIRED FOV's USED
		MEAN	RMS	NO. POINTS USED	MEAN	RMS	MEAN	RMS	
1	4	+.09	.45	26	+.22	.30	+.13	.26	315
2	68	-.02	.15	82	-.06	.11	-.09	.12	340
3	6	-.14	.22	37	+.01	.18	-.06	.15	305
4	4	-.27	.53	26	+.34	.36	+.20	.23	290
5	3	-.06	.15	58	-.02	.16	-.07	.15	290
6	2	-.19	.35	40	+.12	.18	+.04	.15	275
7	0	-.38	.52	38	+.18	.22	-.05	.13	250
8	10	-.13	.36	31	-.02	.19	-.04	.19	285
9	12	+.03	.22	47	+.23	.27	+.12	.18	310
10	3	-.07	.11	63	+.11	.17	+.06	.12	325
11	0	-.07	.26	40	+.07	.18	+.05	.17	275
12	25	+.02	.09	95	-.01	.13	-.06	.12	335
13	0	-3.08	6.55	10	+.39	.59	+.40	.60	125
14	4	-.16	.24	52	+.03	.08	-.02	.07	315
15	1	-.13	.60	19	+.34	.36	+.16	.21	230
16	0	-.32	.64	19	+.15	.19	+.11	.16	235

clear area 8 mr x 4 mr about its IGFOV). The number of points fit by the line fit technique has an upper bound of 150 and the maximum number of pairs possible for the paired FOV technique is 600. These parameters are included to indicate the data use efficiency of both techniques. The sounding channel noise was chosen to be 0.5 ergs/etc so that the sounding time required for a 30 km east-west swath is approximately the same as it would be for a clear scene where spatial averaging further reduces the noise to 0.25 ergs/etc. The spatial averaging for a cloudy scene is performed by the line fit or paired FOV retrieval. The window channel noise was taken to be 0.21 ergs/etc.

The data clearly show that the paired FOV technique is superior. The most convincing evidence for this conclusion is the size of the RMS errors. As we will see in the next sections, the bias errors due to mixed cloud types help to cancel the bias errors due to diffraction for the paired FOV technique in this sounding channel. Therefore, the comparison of mean error differences is somewhat deceiving here. The bias caused by mixed cloud types in a FOV are actually much smaller for the line fit technique than for the paired FOV technique. However, when mixed cloud type biases are eliminated by making both clouds in the scene identical, the paired FOV technique is still superior as shown in Table 2.

We can see from a geometrical interpretation of the retrieval techniques why these results are reasonable. Plots of the sounding channel radiance versus the window channel radiance are illustrated in Figures 1a and 1b. Figure 1a shows that the line fit procedure determines the sounding channel clear column radiance by least square fitting all data points from registered sounding and window channel measurements which have window channel radiances within a certain distance of the clear column window

TA'.E 2. Retrieval errors for channel 5 with 1 clo type in the scene
(Channel 5 NEN = .5 ergs/etc window channe NEN = .21 ergs/etc)

		LINE FIT ERRORS			PAIRED FOV ERRORS				
							WEIGHTED		
UBGRID	NO. CLEAR SOUNDER SAMPLES	MEAN	RMS	NO. POINTS USED	MEAN	RMS	MEAN	RMS	NO. PAIRED FOV's USED
1	4	-.10	.32	33	+.01	.10	-.03	.11	300
2	68	+.10	.16	83	+.03	.10	-.04	.10	335
3	6	+.07	.20	61	-.12	.18	-.11	.15	300
4	4	-.02	.20	57	-.06	.15	-.07	.14	260
5	3	+.03	.20	49	-.15	.20	-.12	.20	275
6	2	-.05	.13	64	-.09	.15	-.11	.17	255
7	0	-.20	.46	39	-.07	.20	-.13	.25	220
8	10	+.05	.23	40	+.02	.12	+.02	.12	275
9	12	+.01	.15	49	-.03	.15	-.06	.14	295
10	3	-.06	.18	80	-.10	.16	-.13	.17	315
11	0	+.05	.29	48	-.05	.16	-.09	.18	250
12	25	-.03	.14	92	+.01	.13	-.02	.12	330
13	0	-.39	1.00	12	-.15	.33	-.16	.30	125
14	4	-.11	.21	51	-.10	.15	-.14	.18	310
15	1	-.26	.63	25	-.07	.17	-.11	.16	195
16	0	-.21	.38	44	-.13	.16	-.13	.16	220

channel radiance. This technique was designed to minimize biases caused by FOV's containing mixed cloud types and it accomplishes this end. However, since the number of data points used is restricted to avoid bias, the RMS error is quite large because of the detector noise.

The paired FOV technique, is quite susceptible to mixed cloud type biases. To restrict its susceptibility only FOV's which are spatially close together are used for projection to obtain a clear column sounding channel radiance. The pairs used for projection are also restricted to include only those separated sufficiently in radiance to allow accurate projection. The projections obtained for a given subgrid are weighted as described in the Appendix and the average is the retrieved sounding channel radiance. A larger amount of the data for cloudy FOV's is used in this case than in the line fit technique; so one expects a smaller RMS error due to detector noise.

It should also be pointed out that from the plots of Figure 1 it is evident how errors in the clear column window channel radiances effect sounding channel retrievals. The product of the mean slope of the cloud lines and the clear column window channel error is the error contribution to the sounding retrieval. The channels most sensitive to clouds are most affected by this error. The cloud line slopes for the simulated scene are shown in Table 3.

2. Separation of Biases Due to Diffraction and Mixed Cloud Types

In order to gain a better understanding of the effect of misregistration caused by diffraction, it is useful to separate it from cloud type biases. To do this a number of simulations were performed with "ideal" radiometer

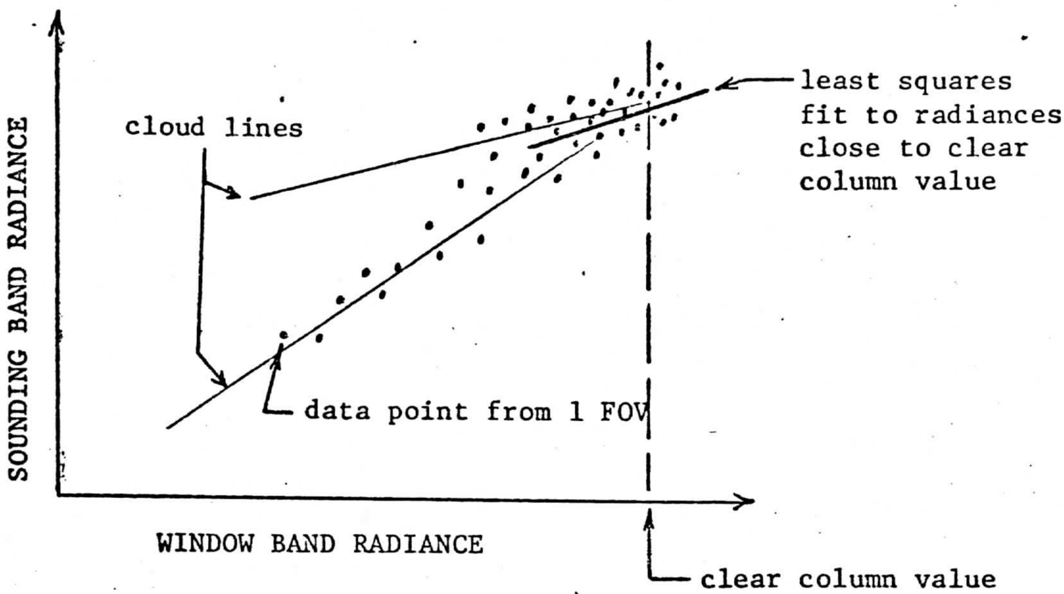

Figure 1a. Geometrical representation of the line fit procedure.

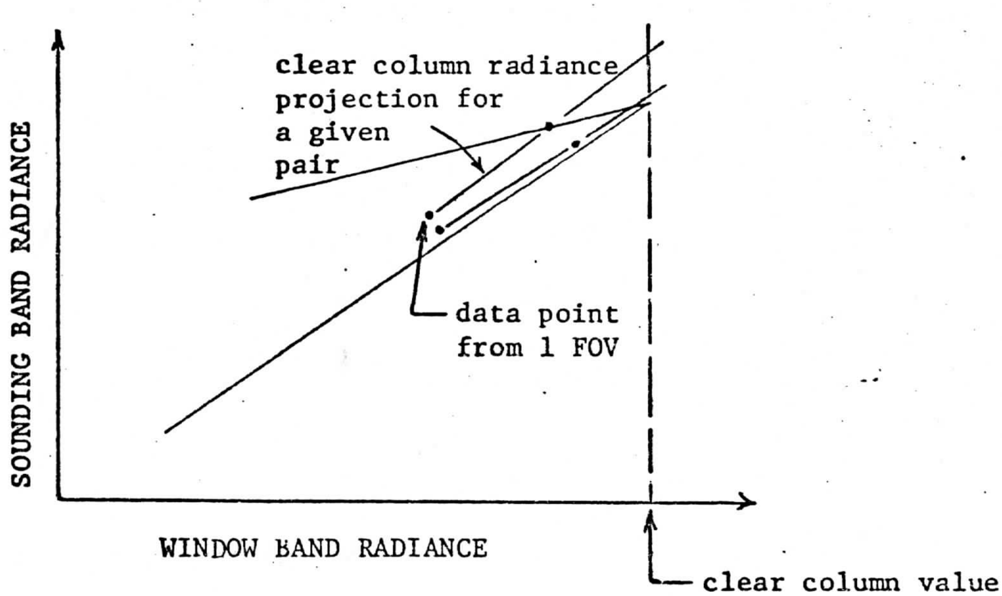

Figure 1b. Geometrical representation of the paired FOV procedure.

TABLE 3. Cloud Line Slopes

CHANNEL	λ	SLOPES CLOUD A	CLOUD B
1	14.71	0	.0012
2	14.45	.0045	.037
3	14.22	.055	.164
4	13.99	.143	.272
5	13.42	.674	.778
6	13.16	1.027	1.050
7	12.66	1.099	1.094
8	11.17	-	-
9	7.25	.391	.387
10	6.71	.295	.289

weightings where the spatial weighting function is uniform over the IGFOV and with single cloud types present in the scene. We use the following notation to label the cases considered.

R: "real" detector spatial weighting functions including both diffraction and the filter impulse response function.

I: "ideal" detector spatial weighting function.

2: 2 cloud types present in the scene.

1: 1 cloud type present in the scene.

The resolution considered was the 90 x 90 km subgrid and the detector noise was not included in these simulations. The results for cases R1, R2 and I2 are given in Table 4. Case R1 displays the diffractive misregistration bias directly because the case I1 is the simulator test case and the mean errors are essentially zero. The mean diffractive bias error over the 16 subgrids is -.05 (retrieved radiances are too small) with a standard deviation of 0.03. An estimate in agreement with this can be obtained from the difference of the mean errors for cases R2 and I2. The negative sign of this bias depends both on the fact that the spatial weighting function of the sounding channel is more smeared out than it is for the window channel (longer wavelength - more diffraction) and on the common scene characteristic that nearly clear FOV's are more frequent than any other type. Also, the paired FOV technique weights pairs with one nearly clear FOV more heavily than pairs with no nearly clear FOV's.

The mixed cloud type bias can be determined by comparing cases R1 and R2. The result is a positive mean bias of +0.13 ergs/etc over the 16 subgrids with a standard deviation of 0.08 ergs/etc. The positive bias occurs because cold clouds generally are higher in the atmosphere and have larger

TABLE 4. Paired FOV Biases (No Detector Noise Included)

SUBGRID	NO. CLEAR SOUNDER SAMPLES	CASE R1 MEAN ERROR	CASE R1 WEIGHTED MEAN ERROR	CASE R2 MEAN ERROR	CASE R2 WEIGHTED MEAN ERROR	CASE I2 MEAN ERROR	CASE I2 WEIGHTED MEAN ERROR
1	4	-.05	-.05	+.17	+.12	+.28	+.18
2	68	-.01	-.01	+.01	+.01	+.03	+.03
3	6	-.05	-.05	+.04	+.02	+.10	+.07
4	4	-.05	-.05	+.31	+.19	+.41	+.27
5	3	-.06	-.06	+.04	-.01	+.10	+.06
6	2	-.03	-.03	+.17	+.10	+.26	+.14
7	0	-.09	-.08	+.23	+.05	+.34	+.13
8	10	-.07	-.06	+.01	-.02	+.15	+.09
9	12	-.07	-.06	+.14	+.04	+.23	+.11
10	3	-.06	-.05	+.11	+.08	+.25	+.15
11	0	-.04	-.04	+.12	+.09	+.17	+.13
12	25	-.02	-.02	+.01	-.01	+.04	+.02
13	0	-.12	-.13	+.30	+.27	+.54	+.44
14	4	-.04	-.04	+.02	+.02	+.14	+.10
15	1	-.07	-.06	+.29	+.14	+.46	+.22
16	0	-.07	-.07	+.14	+.11	+.26	+.19

size than warm clouds. Therefore, since the window channel is more sensitive to low altitudes than the sounding channel, the warm cloud line slopes are larger than cold cloud line slopes in plots of the type shown in Figure 1. This results in projections of pairs having mixed cloud types generally giving sounding channel clear column radiances that are too large.

3. Channel Dependence

Simulations were performed for channels 1,5,7 and 10 and the results are shown in Tables 5 - 8. Since both the bias caused by diffraction and mixed cloud types depends on the cloud line slopes in a plot of sounding channel radiance vs. window channel radiance, both biases become very small for channel 1 which is insensitive to clouds. The diffractive misregistration bias of channel 7 and 10 are about the same magnitude as for channel 5; however, the channel 10 bias is positive because its wavelength is shorter than that for the window channel. The cloud type bias of channels 7 and 10 becomes small because, for the scene simulated, the two cloud slopes become very nearly the same. The RMS errors of channel 1 are quite large; however, since this channel is only sensitive to high altitudes (where temperature variations are small) a lower resolution than 90 x 90 km can be used to reduce the RMS errors.

4. Resolution Dependence

Up to this point we have presented results for an intermediate resolution of 90 x 90 km. Two other cases have been studied, the whole

TABLE 5. Paired FOV error for Channel 1 at Subgrid resolution
(Channel 1 NEN = 2.0 ergs/etc, window channel NEN = .21 ergs/etc)

SUBGRID	MEAN	RMS	WEIGHTED MEAN	WEIGHTED RMS
1	+.04	+.43	+.06	.38
2	+.07	.24	+.08	.28
3	+.22	.65	+.26	.60
4	-.01	.51	-.08	.45
5	-.04	.70	-.33	.68
6	-.10	.51	-.08	.47
7	+.03	.57	+.03	.61
8	-.10	.43	-.08	.55
9	-.31	.59	-.42	.63
10	-.21	.52	-.18	.53
11	-.17	.72	-.26	.71
12	+.06	.59	+.06	.59
13	+.19	1.07	+.14	.92
14	+.38	.70	+.34	.68
15	-.16	.35	-.08	.41
16	+.27	.53	-.21	.49

scene grid which is about 360 x 260 km and a high resolution which is somewhat smaller than 30 x 30 km.

For the whole grid an improvement is realized over the intermediate resolution results because of the added spatial averaging. Table 9 gives the results for sounding channels 1,5,7 and 10. The weighted results are not much better than the unweighted results for channels 1,7 and 10 where mixed cloud type errors are small; for channel 7 where the diffractive registration errors dominate the weighted results are actually somewhat worse. On the other hand, results for channel 5, where mixed cloud type errors dominate, are dramatically improved by the weighting procedure.

High resolution retrievals were made over the whole grid using 5 samples/retrieval. Since the samples overlap, their IGFOV's occupy an area about 30 km north-south and 20 km east-west. The grid average of the mean error absolute values and of the RMS errors are shown in Table 10. It is not too surprising that the errors are large since no attempt is made to select areas that are largely clear. If largely clear areas are selected by viewing visible or window channel (11.2μ or 3.7μ) grids the results can be greatly improved. Figure 2 shows the whole Canary Islands grid and indicates 18 areas approximately 36 x 36 km which have large percentages of clear area. Averaging the high resolution retrievals over these areas gives the results shown in Table 11. Many of these retrievals are satisfactory. The averages are very sensitive to fairly small amounts of clouds in the selected areas (see areas 9, 14 and 15) and in one case to cold clouds near the selected area (area 4).

TABLE 6. Paired FOV errors for Channel 5 at subgrid resolution (Channel 5 NEN = .5 ergs/etc, window channel NEN = .21 ergs/etc)

SUBGRID	MEAN	RMS	WEIGHTED MEAN	WEIGHTED RMS
1	+.22	.30	+.13	.26
2	-.06	.11	-.09	.12
3	+.01	.18	-.06	.15
4	+.34	.36	+.20	.23
5	-.02	.16	-.07	.15
6	+.12	.18	+.04	.15
7	+.18	.22	-.05	.13
8	-.02	.19	-.04	.19
9	+.23	.27	+.12	.18
10	+.11	.17	+.06	.12
11	+.07	.18	+.05	.17
12	-.01	.13	-.06	.12
13	+.39	.59	+.40	.60
14	+.03	.08	-.02	.07
15	+.34	.36	+.16	.21
16	+.15	.19	+.11	.16

TABLE 7. Paired FOV errors for Channel 7 at subgrid resolution (Channel 7 NEN = .5 ergs/etc, window channel NEN = .21 ergs/etc)

SUBGRID	MEAN	RMS	WEIGHTED MEAN	WEIGHTED RMS
1	-.01	.14	-.07	.15
2	-.06	.11	-.10	.13
3	-.12	.20	-.17	.22
4	-.12	.20	-.14	.21
5	-.10	.19	-.11	.18
6	+.10	.13	+.07	.13
7	-.04	.12	-.16	.19
8	-.09	.22	-.12	.23
9	-.12	.15	-.11	.15
10	-.13	.18	-.16	.19
11	-.13	.19	-.18	.21
12	-.16	.18	-.21	.22
13	+.11	.35	+.03	.33
14	-.07	.12	-.11	.15
15	+.01	.12	-.01	.10
16	-.19	.21	-.22	.24

TABLE 8. Paired FOV errors for Channel 10 at subgrid resolution (Channel 10 NEN = .2 ergs/etc, window channel NEN = .21 ergs/etc)

SUBGRID	MEAN	RMS	WEIGHTED MEAN	WEIGHTED RMS
1	+.05	.07	+.03	.06
2	-.01	.04	-.02	.04
3	+.01	.04	-.01	.04
4	+.03	.04	+.03	.04
5	+.05	.07	+.02	.04
6	+.02	+.04	+.01	.03
7	+.05	.07	+.04	.08
8	+.07	+.09	+.06	.09
9	+.04	.08	+.03	.06
10	+.04	.06	+.03	.05
11	+.01	.08	+.01	.09
12	+.01	.04	-.01	.05
13	+.07	.11	+.07	.10
14	+.05	.07	+.03	.05
15	+.04	.06	+.01	.05
16	+.02	.07	+.01	.07

TABLE 9. Paired FOV errors for Channels 1, 5, 7, and 10 at whole grid resolution (Window channel NEN = .21 ergs/etc)

CHANNEL	NEN	MEAN	RMS	WEIGHTED MEAN	WEIGHTED RMS
1	2.0	-.05	.15	-.07	.14
5	0.5	+.12	.13	+.03	.05
7	0.5	-.08	.10	-.12	.13
10	0.2	+.03	.04	+.02	.02

TABLE 10. Paired FOV errofrs for Channels 1, 5, 7 and 10 at high resolution averaged over the whole grid (NEN/s are the same as those shown in TABLE 4).

CHANNEL	AVERAGE OF MEAN ABSOLUTE VALUES	AVERAGE OF WEIGHTED MEAN ABSOLUTE VALUES	AVERAGE OF RMS ERRORS	AVERAGE OF WEIGHTED RMS ERRORS
1	.73	.70	2.83	2.74
5	.26	.25	.84	.82
7	.25	.25	.78	.75
10	.08	.08	.30	.29

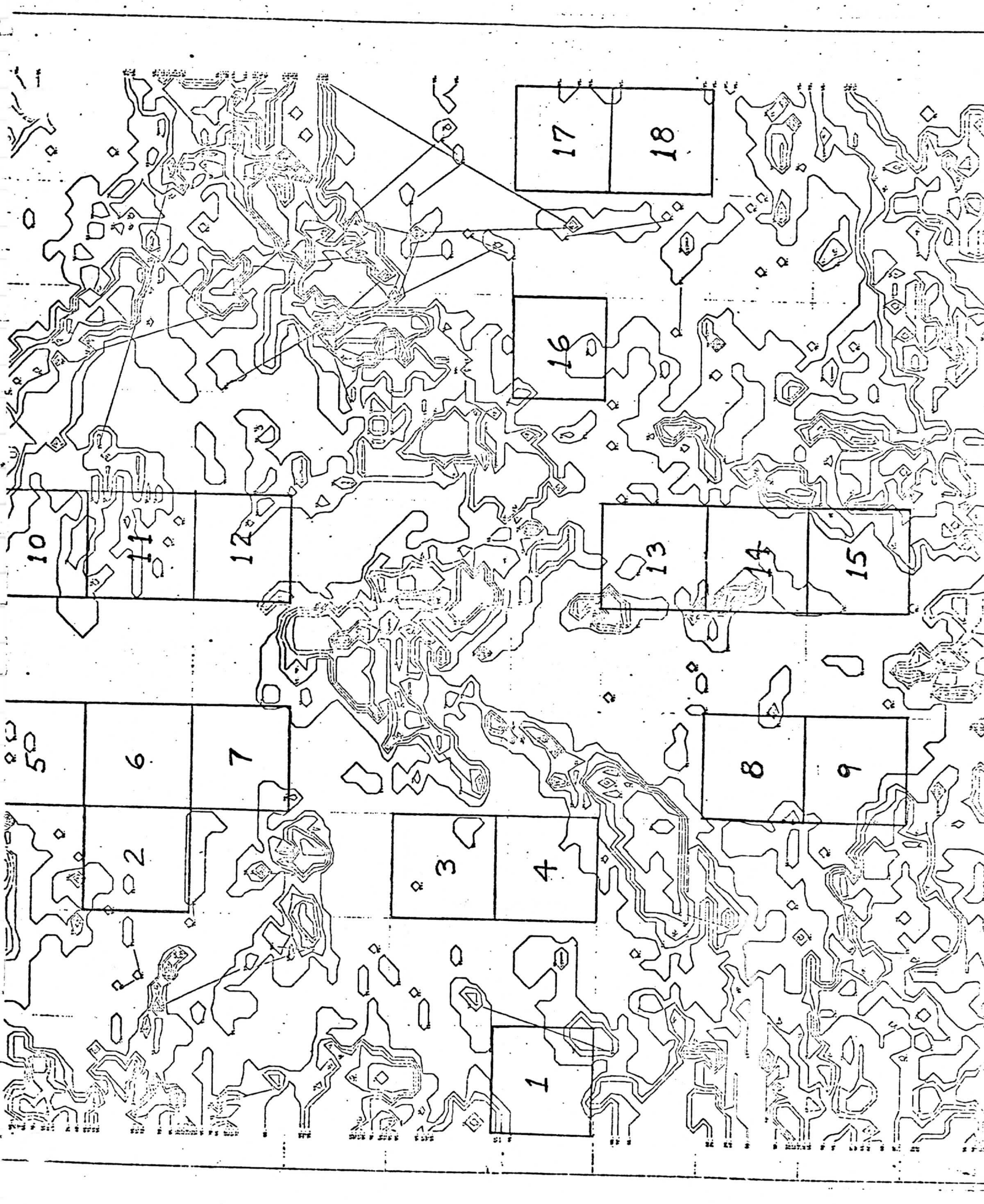

FIGURE 2. Selected Areas for High Resolution Averages

TABLE 11. Paired FOV errors for Channel 5 at high resolution averaged over selected 36 x 36 km areas
(Channel 5 NEN = .5 ergs/etc, window channel NEN = .21 ergs/etc)

AREA NO.	AVERAGE MEAN	AVERAGE MEAN ABSOLUTE VALUE	AVERAGE RMS ERRORS
1	-.11	.15	.28
2	-.09	.15	.21
3	-.07	.17	.21
4	+.12	.33	.50
5	+.02	.09	.13
6	-.04	.13	.15
7	-.07	.14	.19
8	-.13	.16	.19
9	+.21	.33	.44
10	+.06	.19	.24
11	-.03	.15	.20
12	-.01	.20	.24
13	-.06	.19	.24
14	+.13	.31	.43
15	+.04	.32	.59
16	-.17	.19	.23
17	-.01	.13	.17
18	-.09	.13	.20

APPENDIX. Procedure for Weighting Retrievals from Individual FOV Pairs to Obtain Sounding Channel Clear Column Radiances When Using the Paired FOV Technique

The clear column radiance for a pair of FOV's with cloud fractions N_1 and N_2 is given by:

$$I_{cl} = \frac{I_1 - N^* I_2}{1 - N^*} \quad (1)$$

$$N^* = \frac{N_1}{N_2} = \frac{I_1^{\,w} - I_{cl}^{\,w}}{I_2^{\,w} - I_{cl}^{\,w}} \quad (2)$$

where I_{cl} : retrieved clear column sounding radiance for the pair

I_1, I_2 : sounding channel radiance measurements for FOV 1 and 2

$I_{cl}^{\,w}$: window channel clear column radiance

$I_1^{\,w}, I_2^{\,w}$: window channel radiance measurements for FOV 1 and 2.

The retrievals from individual pairs should be averaged in a fashion which weights the samples with the smallest errors most heavily. To determine the proper weighting, we consider a weighted average of N individual pair retrieval radiances x_i as follows:

$$\tilde{x} = \sum_{i=1}^{N} a_i x_i \Big/ \sum_{i=1}^{N} a_i \, . \quad (3)$$

We now enforce the condition that the proper weighting is that for which the variance of $\tilde{x}$ from the true value x is a minimum, i.e. the expectation value $E(\tilde{x} - x)^2$ is a minimum. The expectation value can be written as:

$$E(\tilde{x} - x) = \frac{E \sum_{i=1}^{N} \sum_{j=1}^{N} a_i a_j e_i e_j}{\left(\sum_{i=1}^{N} a_i \right)^2} = \frac{\sum_{i=1}^{N} a_i^{\,2} \sigma_i^{\,2}}{\left(\sum_{i=1}^{N} a_i \right)^2} \quad (4)$$

where $e_i = (x_i - x)$ and $\sigma_i = E(e_i)^2$ and where it has been assumed that the errors e_i are random and uncorrelated. Minimizing $E(\tilde{x} - x)^2$ by setting its derivative with respect to a_i to zero yields the condition:

$$a_i = \frac{1}{\sigma_i^2} \tag{5}$$

where an arbitrary normalization of the a_i has been chosen. Therefore, we see that I_{cl} for each pair should be weighted by $\sigma^{-2}(I_{cl})$ when averages are calculated. The variance of I_{cl} can easily be found by differentiation of Equation 1 combined with Equation 2 as follows:

$$\sigma^2(I_{cl}) = \sum_{i=1}^{2} \left(\frac{\partial I_{cl}}{\partial I_i}\right)^2 \sigma^2(I_i) + \sum_{i=1}^{2} \left(\frac{\partial I_{cl}}{\partial I_i^w}\right)^2 \sigma^2(I_i^w) + \left(\frac{\partial I_{cl}}{\partial I_{cl}^w}\right)^2 \sigma^2(I_{cl}^w) \tag{6}$$

where it has been assumed that the errors of I_i, I_i^w, and I_{cl}^w are independent and random. The result is:

$$\sigma^2(I_{cl}) = \left(\frac{1 + N^*}{1 - N^*}\right)^2 \left[\sigma^2(I) + \left(\frac{I_1 - I_2}{I_1^w - I_2^w}\right)^2 \sigma^2(I^w)\right] + \left(\frac{I_1 - I_2}{I_1^w - I_2^w}\right)^2 \sigma^2(I_{cl}^w) \tag{7}$$

$\sigma(I)$ is the sounding channel NEN, $\sigma(I^w)$ is the window channel NEN, and $\sigma^2(I_{cl}^w)$ is the variance of the window channel clear column retrieved radiance.