MODIS
Thermal Emissive Band
RVS Measurement Data Analysis

Outline

- Basic equations to retrieve RVS
- Drifting of the linear coefficient b_1
- Error sources and analysis in RVS retrieval
- RVS fitting equation and procedure

Basic RVS retrieval equations (1)

$$f(DN_{bcs}) = L_{bcs} \cdot RVS_{bcs} + (\tau - RVS_{bcs}) \cdot L_{sm} + \delta_{bkg} \qquad \text{(Eq.1)}$$

$$f(DN_{obc}) = \varepsilon \cdot L_{obc} \cdot RVS_{obc} + (\tau - RVS_{obc}) \cdot L_{sm} + \delta_{bkg} \qquad \text{(Eq.2)}$$

$$f(DN_{svs}) = L_{svs} \cdot RVS_{svs} + (\tau - RVS_{svs}) \cdot L_{sm} + \delta_{bkg} \qquad \text{(Eq.3)}$$

$$f(DN) = a_0 + a_1 \cdot DN + a_2 \cdot DN^2 \qquad \text{(Eq.4)}$$

where τ is the MODIS fixed optics total throughput, and L is the Planck function radiance integrated over each bandwidth.

Basic RVS retrieval equations (2)

(Eq.1) - (Eq.3) gives

$$b_1 \cdot dn_{bcs} + \left(L_{svs} - L_{sm}\right) \cdot RVS_{svs} + a_2 \cdot dn_{bcs}^2 = \left(L_{bcs} - L_{sm}\right) \cdot RVS_{bcs}$$

(Eq.5)

(Eq.2) - (Eq.3) gives

$$b_1 \cdot dn_{obc} + \left(L_{svs} - L_{sm}\right) \cdot RVS_{svs} + a_2 \cdot dn_{obc}^2 = \left(\varepsilon \cdot L_{obc} - L_{sm}\right) \cdot RVS_{obc}$$

(Eq.6)

where

$$b_1 = a_1 + 2a_2 \cdot DN_{svs}$$ (Eq.7)

Basic RVS retrieval equations (3)

(Eq.5) / (Eq.6) gives

$$\frac{RVS_{bcs}}{RVS_{obc}} = \frac{\varepsilon \cdot L_{obc} - L_{sm}}{L_{bcs} - L_{sm}} \cdot \frac{dn_{bcs}}{dn_{obc}} \cdot \left(1 + \Delta_1 + \Delta_2\right) \qquad \text{(Eq.8)}$$

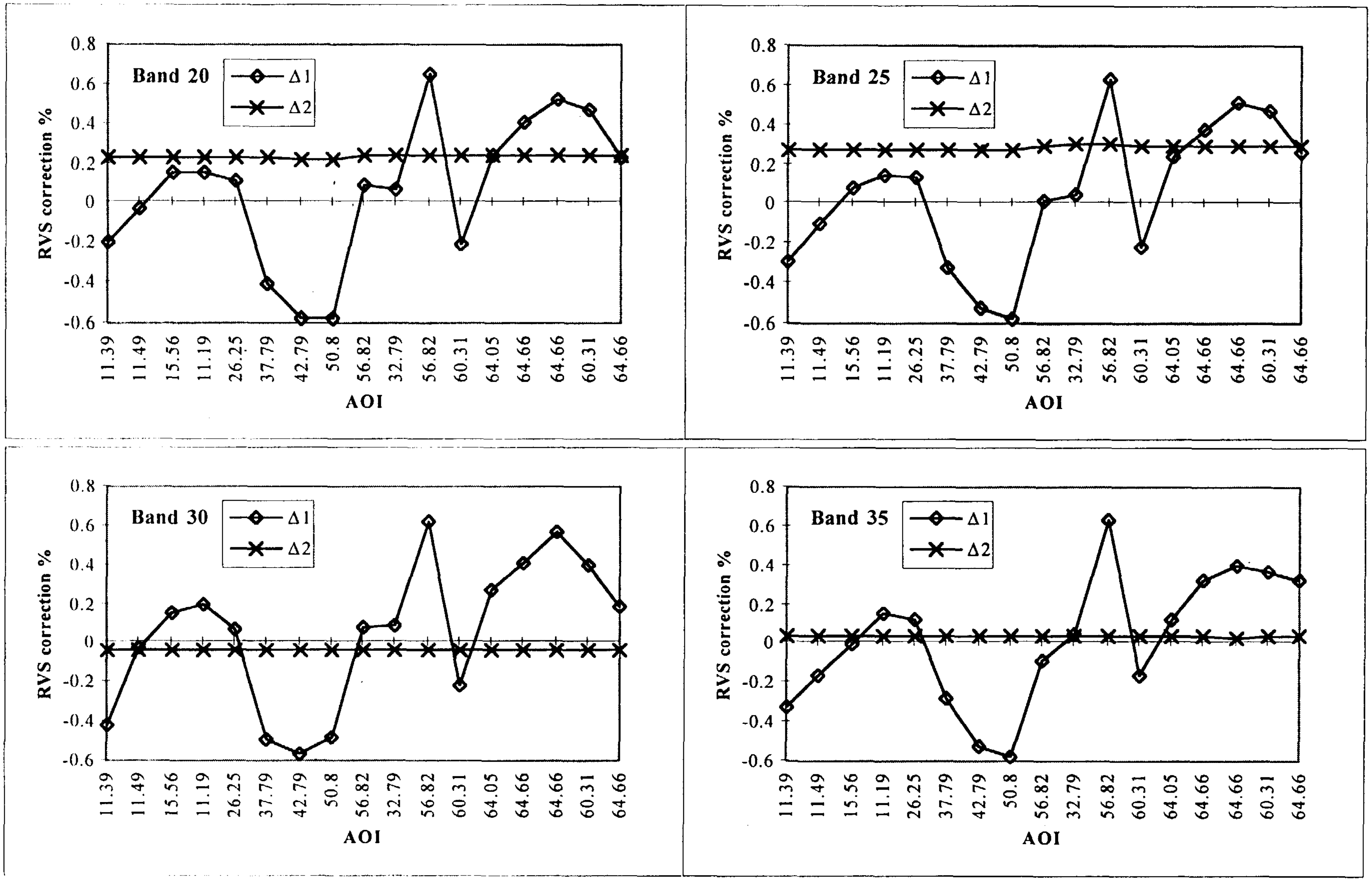
where correction due to temperature difference between sm and svs is

$$\Delta_1 = \frac{RVS_{svs} \cdot \left(L_{sm} - L_{svs}\right)}{b_1 \cdot dn_{bcs} \cdot dn_{obc}} \cdot \left(dn_{bcs} - dn_{obc}\right) \qquad \text{(Eq.9)}$$

and the correction due to non-linear term is

$$\Delta_2 = \frac{a_2}{b_1} \cdot \left(dn_{bcs} - dn_{obc}\right) \qquad \text{(Eq.10)}$$

Δ_1 , Δ_2 Evaluation



Drifting of linear coefficient b_1

As shown in (Eq.7)

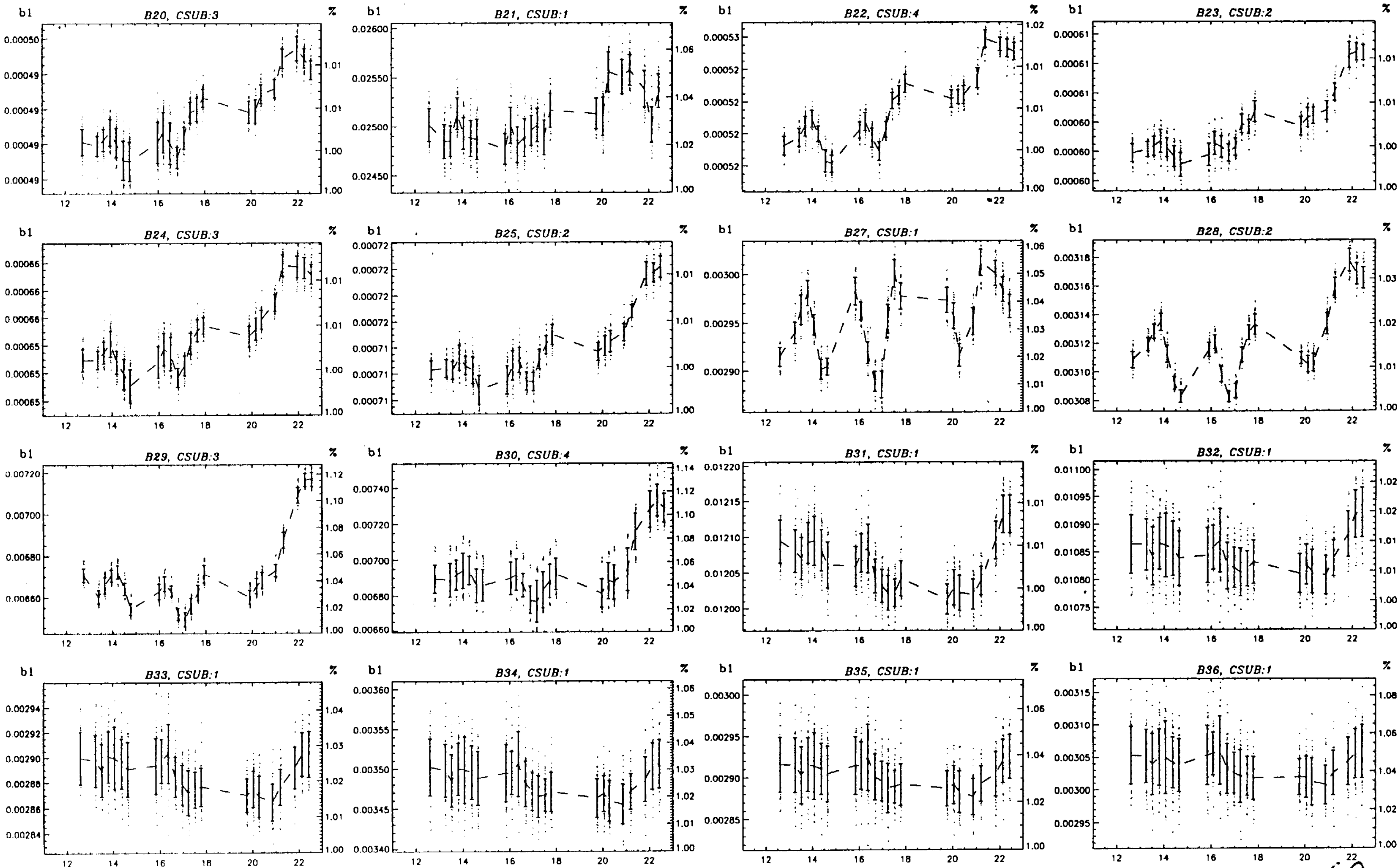
$$b_1 = a_1 + 2a_2 \cdot DN_{svs}$$

where the a_1 is a function of FPA temperature, and DN_{svs} drifts as background fluctuates, thus, b_1 will fluctuate as DN_{svs} and FPA temperature drift, and hence needs to be retrieved scan by scan as

$$b_1 = RVS_{obc} \cdot \frac{(\varepsilon \cdot L_{obc} - L_{sm})}{dn_{obc}} + \text{higher order terms}, \quad \text{(Eq.11)}$$

FM1 RVS Highbay Measurement (PC20); Data set [320_2]

Linear Gain <b1>$_{50\ frames}$ vs. Time(hours of the day; 3/30/98); ch5, 40 scans, side A; T_bcs=320K



Error sources in RVS retrieval

- Temperature measurement error in

  T_{bcs}, T_{obc}, T_{sm}, T_{svs}
- OBC effective emissivity ε_{obc}
- DN measurement errors due to

  cross-talk, finite resolution, ...

Error Analysis in RVS (1)

From (Eq.8), the complete *rvs* differential equation is (correction terms are ignored in this analysis)

$$\frac{d(rvs)}{rvs} = \frac{\partial \ln(rvs)}{\partial \varepsilon_{obc}} \Delta\varepsilon_{obc} + \frac{\partial \ln(rvs)}{\partial T_{bcs}} \Delta T_{bcs} + \frac{\partial \ln(rvs)}{\partial T_{obc}} \Delta T_{obc} + \frac{\partial \ln(rvs)}{\partial T_{sm}} \Delta T_{sm} + \frac{\partial \ln(rvs)}{\partial DN_{bcs}} \Delta DN_{bcs} + \frac{\partial \ln(rvs)}{\partial DN_{obc}} \Delta DN_{obc} + \frac{\partial \ln(rvs)}{\partial DN_{svs}} \Delta DN_{svs}$$

(Eq.12)

Error Analysis in RVS (2)

(due to the error in ε_{obc})

$$\frac{\partial \ln(rvs)}{\partial \varepsilon_{obc}} \Delta\varepsilon_{obc} = \left(\frac{L_{obc}}{\varepsilon_{obc} L_{obc} - L_{sm}} \right) \cdot \Delta\varepsilon_{obc} \qquad \text{(Eq.13)}$$

This is a systematic bias error, which is independent of the AOI. Since *rvs* will be renormalized later at a particular AOI angle, this bias error will essentially be "renormalized out" and thus will not contribute to the total *rvs* error.

Error Analysis in RVS (3)

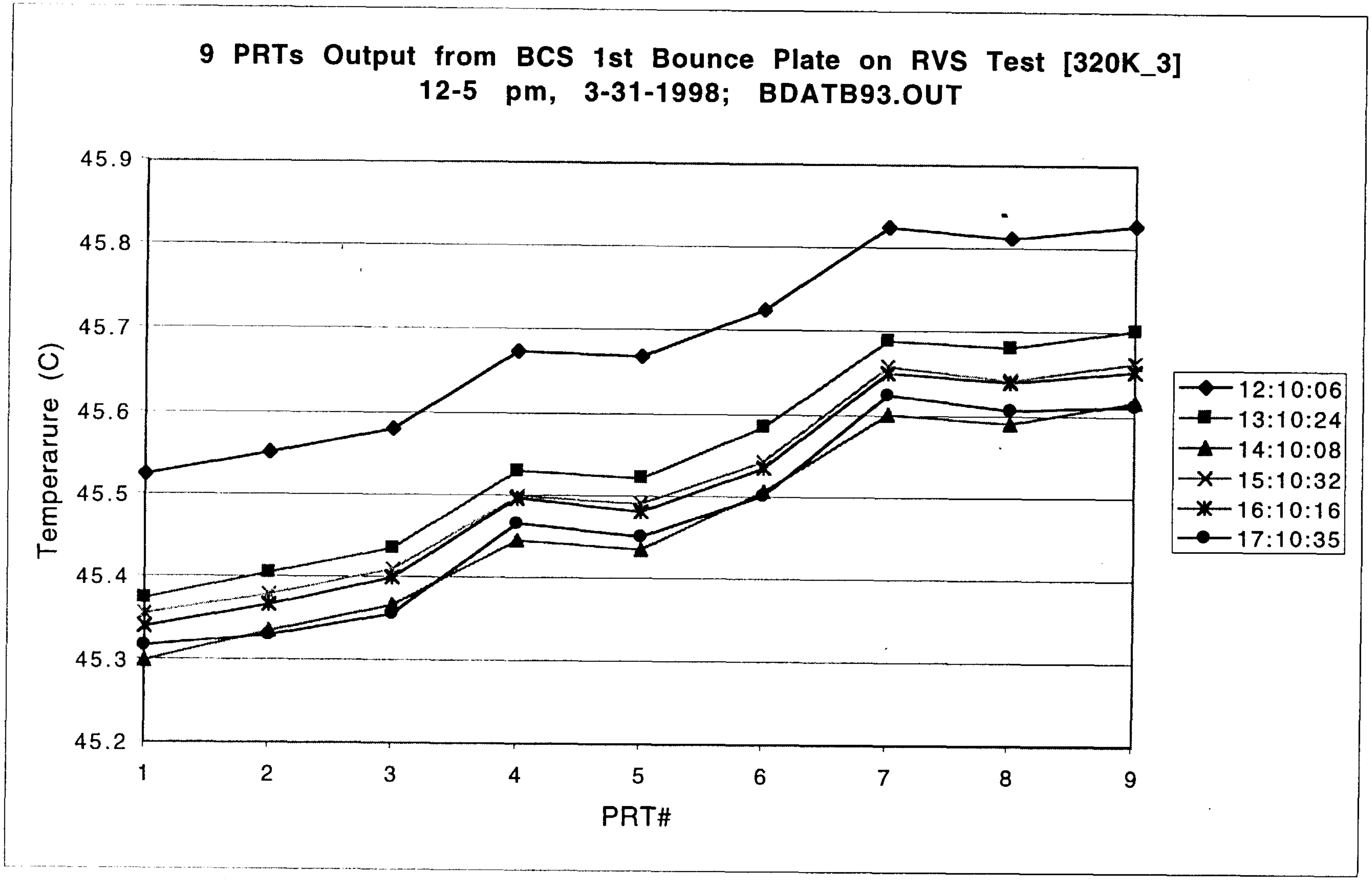
(due to the error in T_{bcs}, T_{obc}, T_{sm} measurements)

$$\frac{\partial \ln(rvs)}{\partial T_{bcs}} \Delta T_{bcs} = \left(\frac{-L'_{bcs}}{L_{bcs} - L_{sm}} \right) \cdot \Delta T_{bcs} \qquad \text{(Eq.14)}$$

$$\frac{\partial \ln(rvs)}{\partial T_{obc}} \Delta T_{obc} = \left(\frac{\varepsilon_{obc} L'_{obc}}{\varepsilon_{obc} L_{obc} - L_{sm}} \right) \cdot \Delta T_{obc} \qquad \text{(Eq.15)}$$

$$\frac{\partial \ln(rvs)}{\partial T_{sm}} \Delta T_{sm} = \left(\frac{-L'_{sm}}{\varepsilon_{obc} L_{obc} - L_{sm}} + \frac{L'_{sm}}{L_{bcs} - L_{sm}} \right) \cdot \Delta T_{sm} \qquad \text{(Eq.16)}$$

A system bias error in ΔT, combining with the terms in (..), will be constant across the AOIs, thus won't effect the renormalized *rvs*, only the local fluctuated error in ΔT will contribute to the errors in *rvs*.


9 PRTs Output from BCS 1st Bounce Plate on RVS Test [320K_3]
12-5 pm, 3-31-1998; BDATB93.OUT
45.9
45.8
45.7
45.6
45.5
45.4
45.3
45.2
Temperarure (C)
1
2
3
4
5
6
7
8
9
PRT#
12:10:06
13:10:24
14:10:08
15:10:32
16:10:16
17:10:35

Error Analysis in RVS (4)

(due to the errors in $DN_{bcs}, DN_{obc}, DN_{svs}$)

$$\frac{\partial \ln(rvs)}{\partial DN_{bcs}} \cdot \Delta DN_{bcs} = \left(\frac{1}{DN_{bcs} - DN_{svs}} \right) \cdot \Delta DN_{bcs} \qquad \text{(Eq.17)}$$

$$\frac{\partial \ln(rvs)}{\partial DN_{obc}} \cdot \Delta DN_{obc} = \left(\frac{-1}{DN_{obc} - DN_{svs}} \right) \cdot \Delta DN_{obc} \qquad \text{(Eq.18)}$$

$$\frac{\partial \ln(rvs)}{\partial DN_{svs}} \Delta DN_{svs} = \left(\frac{-1}{DN_{bcs} - DN_{svs}} + \frac{1}{DN_{obc} - DN_{svs}} \right) \cdot \Delta DN_{svs}$$

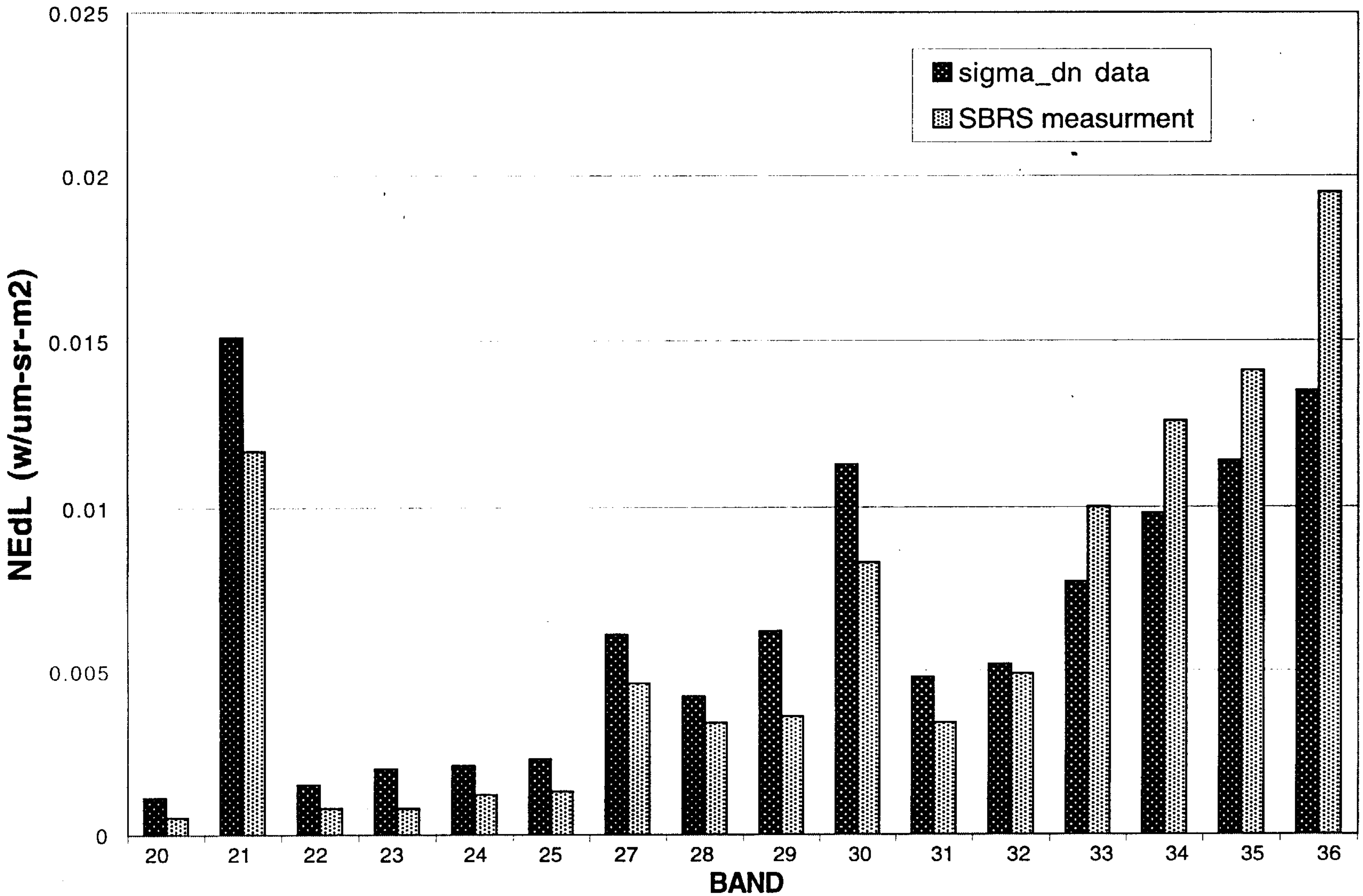
(Eq.19)

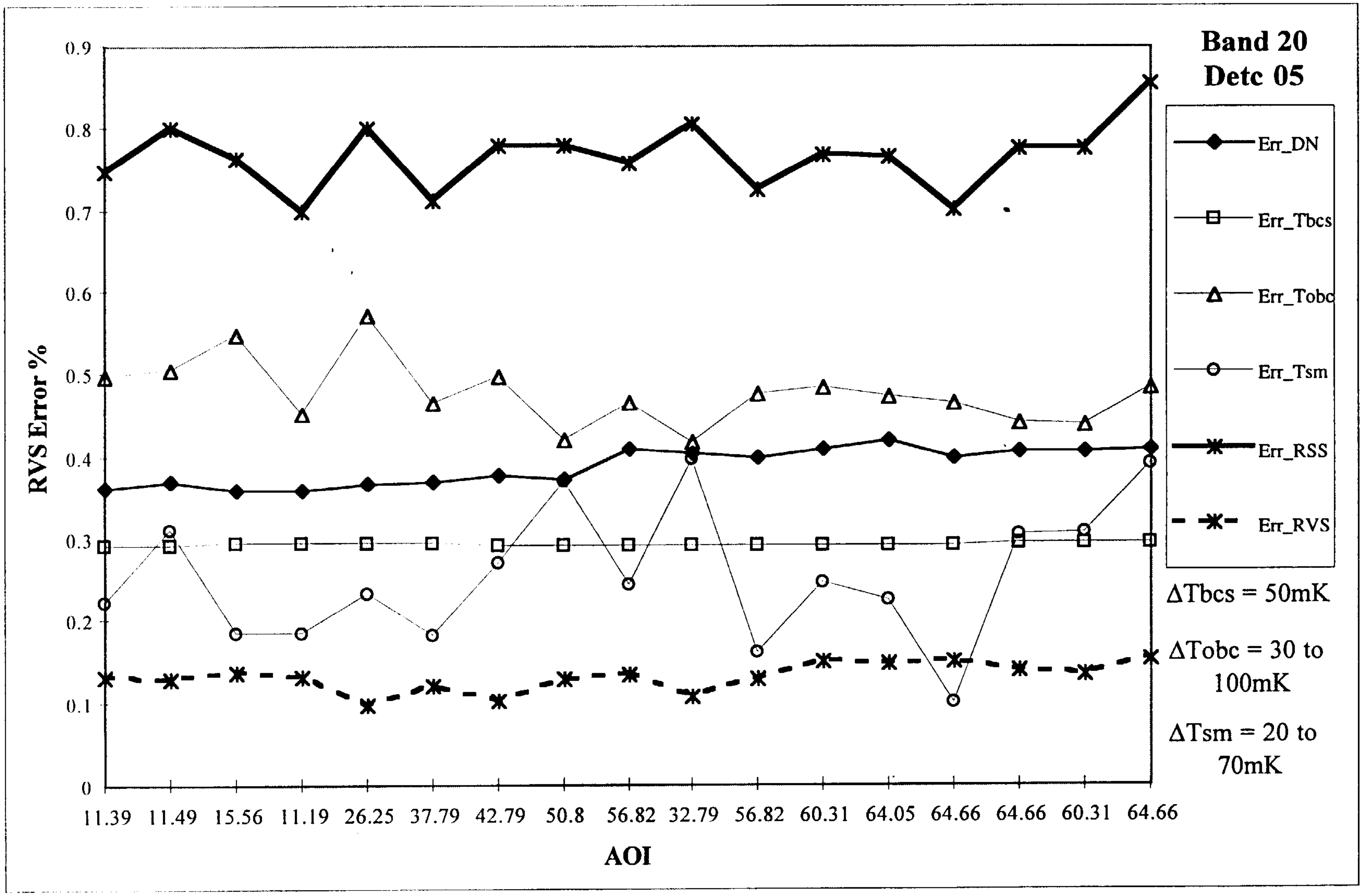
Error Analysis in RVS (5)
σ(RVS)

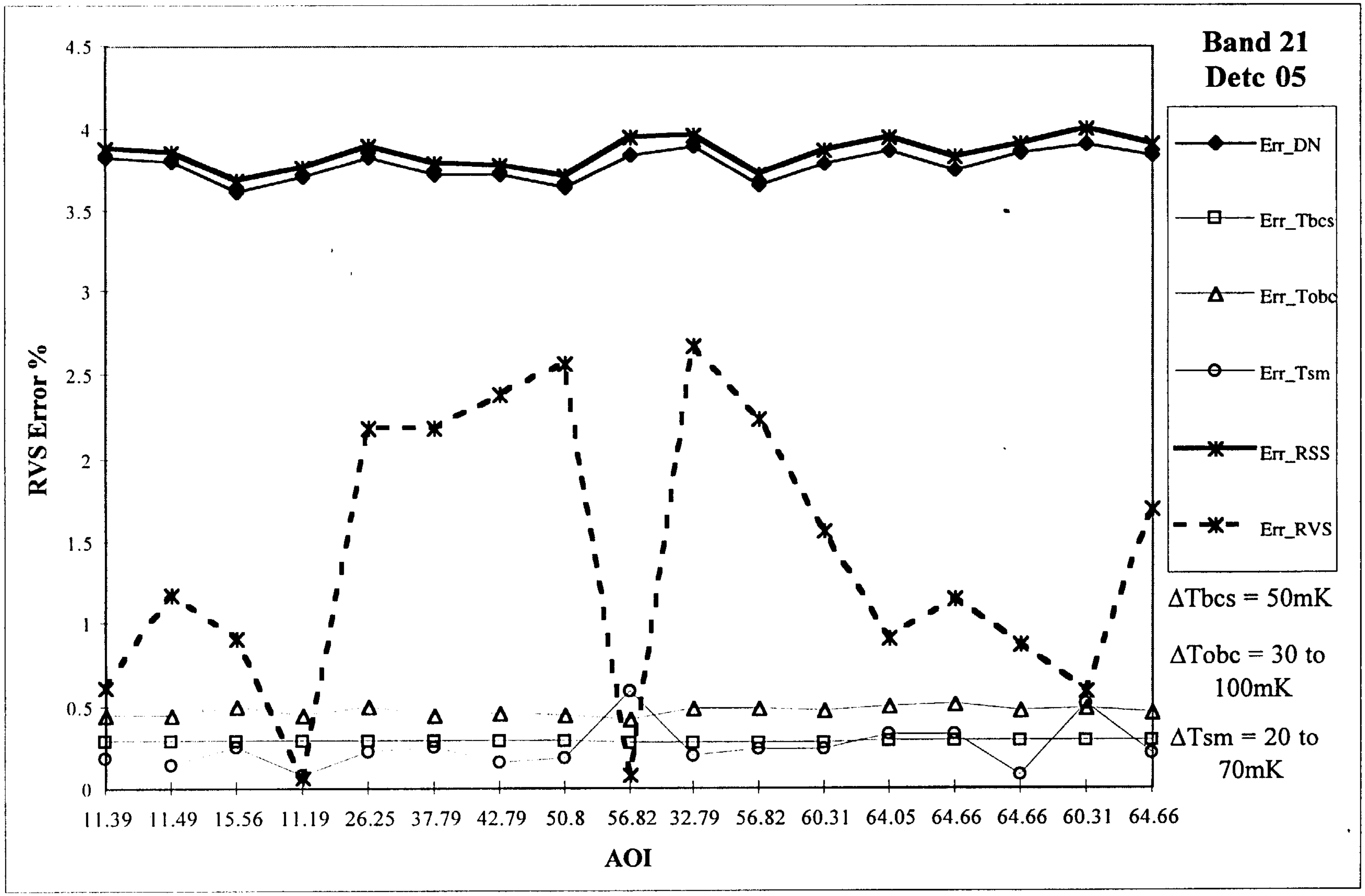
$$\sigma(rvs) = \sqrt{\sigma^2_{T_{bcs}} + \sigma^2_{T_{obc}} + \sigma^2_{T_{svs}} + \sigma^2_{DN_{bcs}} + \sigma^2_{DN_{obc}} + \sigma^2_{DN_{svs}}}$$

The RSS ignores the correlation relationship between the variables, thus will result in either over-estimating or under-estimating the total 1-sigma error in *rvs*.

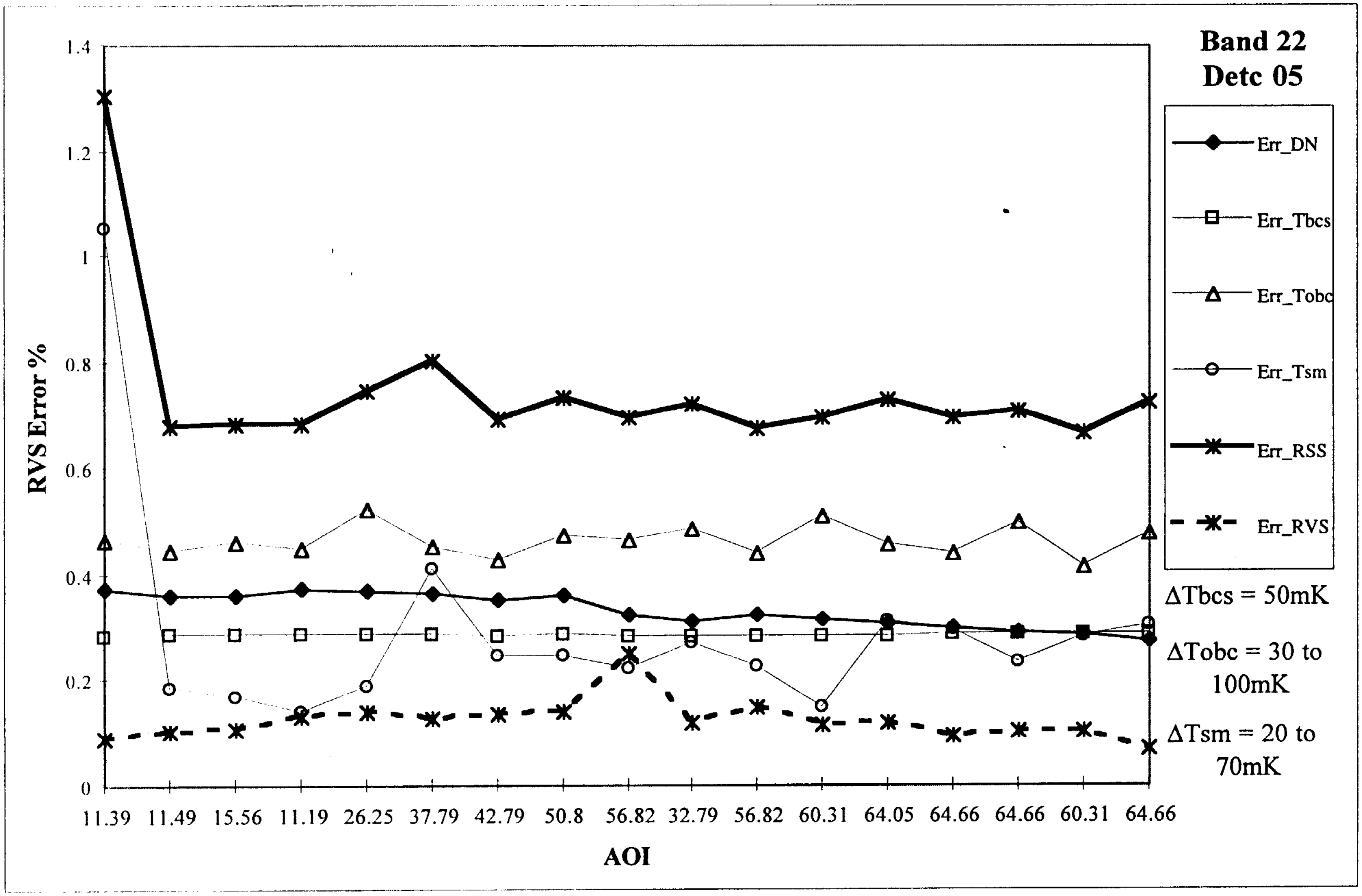
NEdL from [linear gain * σ(dn)] compared with SBRS measured value



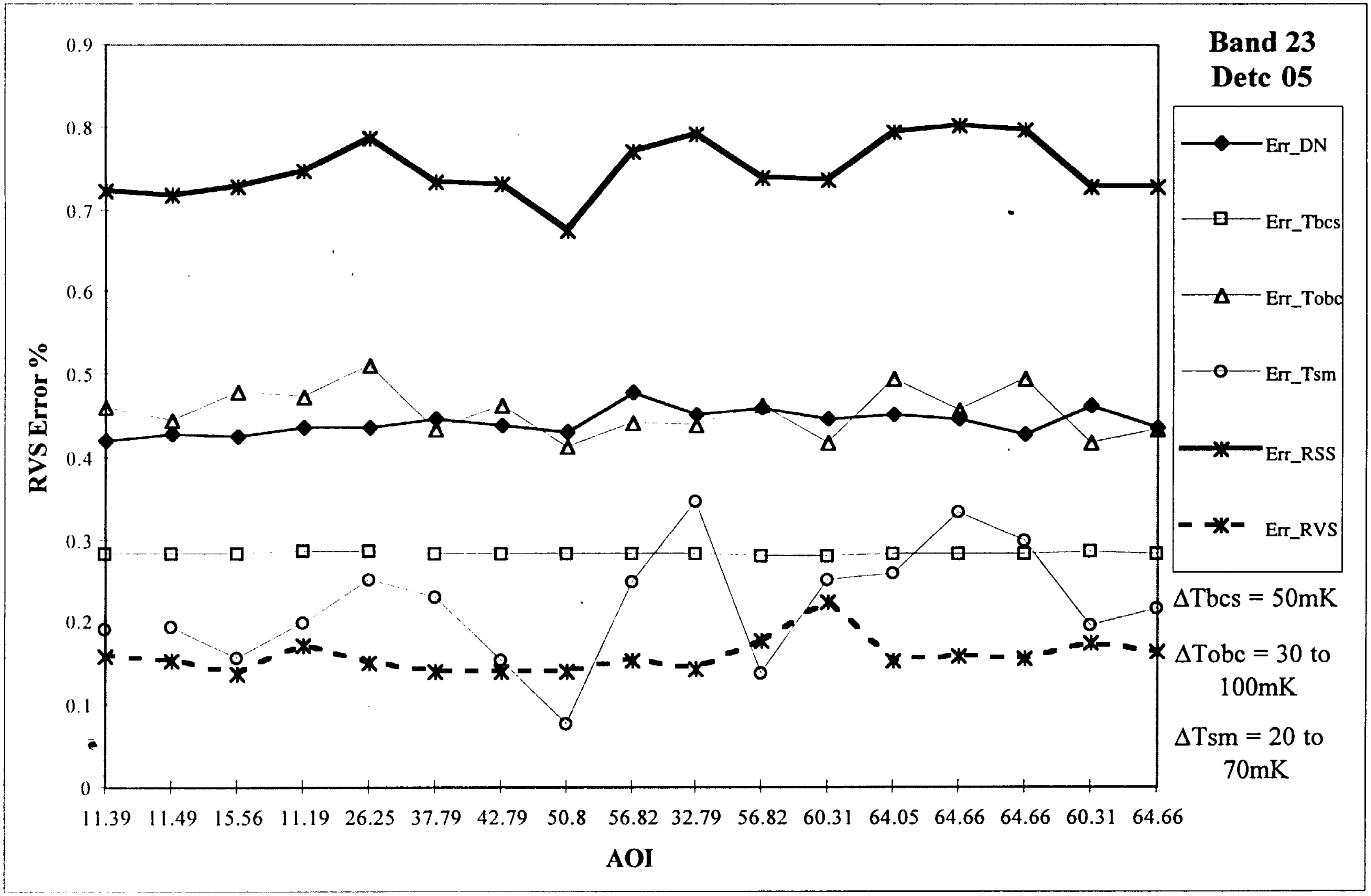

Band 20
Detc 05
Err_DN
Err_Tbcs
Err_Tobc
Err_Tsm
Err_RSS
Err_RVS
ΔTbcs = 50mK
ΔTobc = 30 to 100mK
ΔTsm = 20 to 70mK
RVS Error %
AOI
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
11.39 11.49 15.56 11.19 26.25 37.79 42.79 50.8 56.82 32.79 56.82 60.31 64.05 64.66 64.66 60.31 64.66

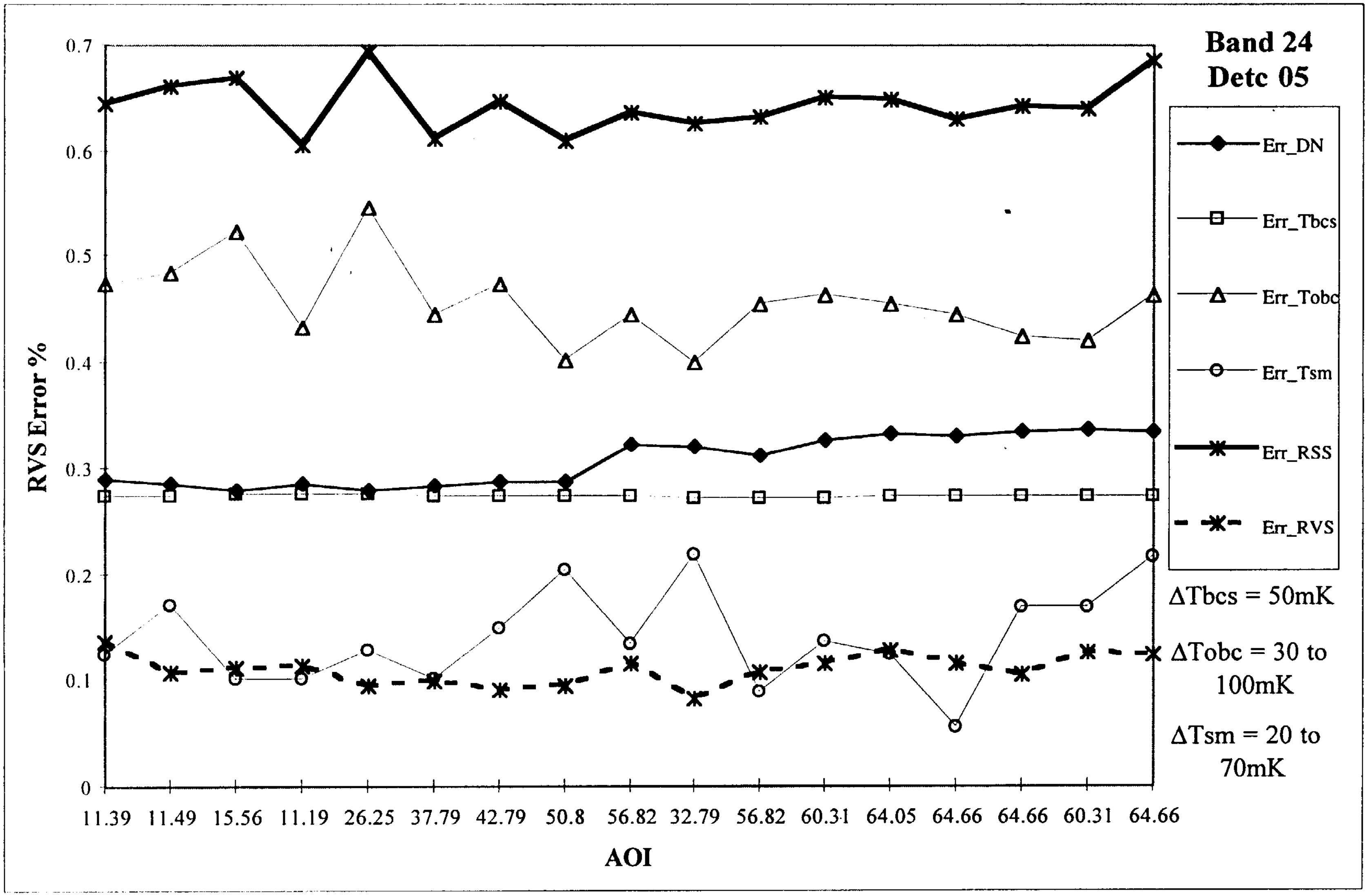


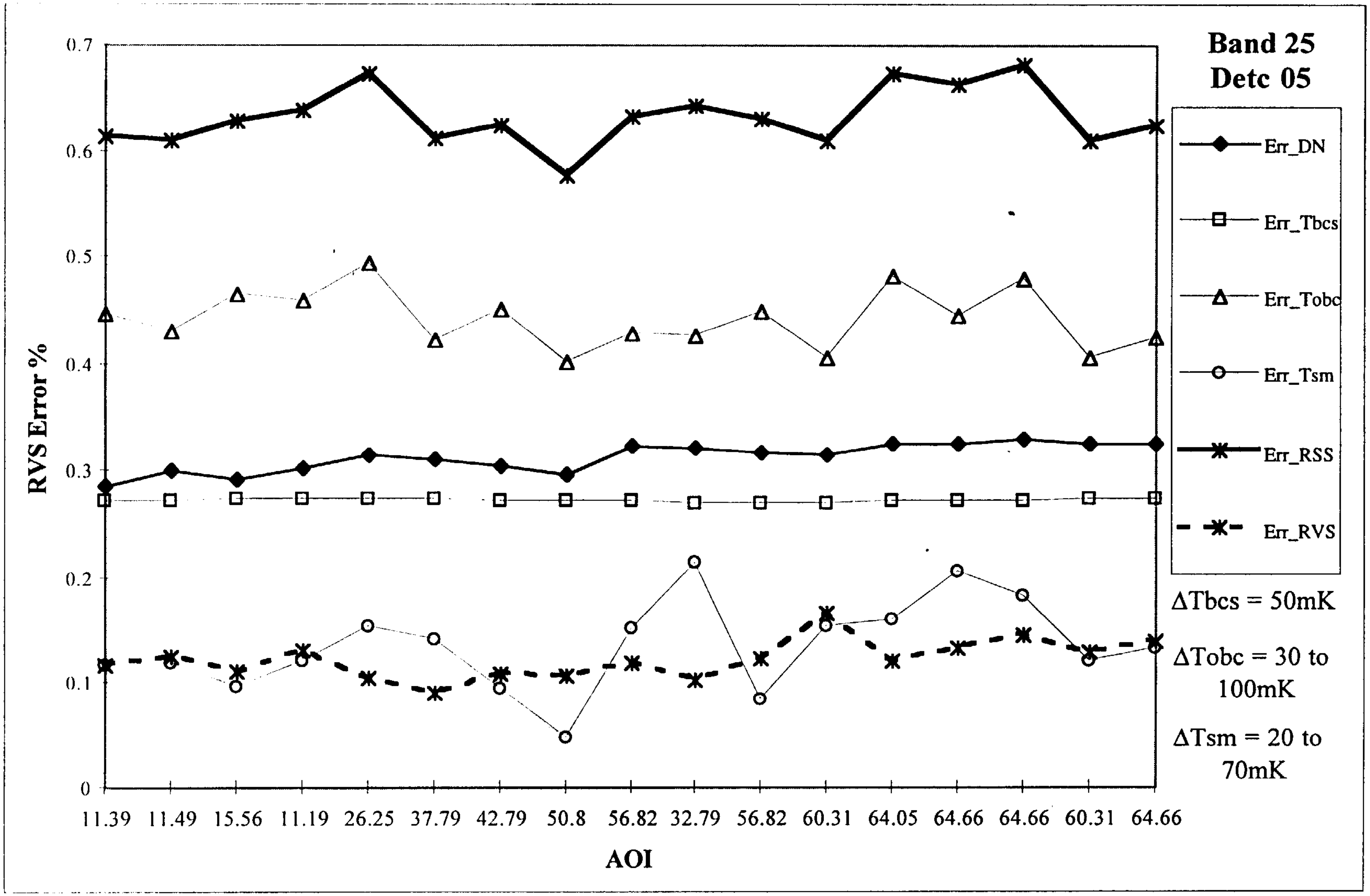
Band 21
Detc 05
RVS Error %
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
11.39 11.49 15.56 11.19 26.25 37.79 42.79 50.8 56.82 32.79 56.82 60.31 64.05 64.66 64.66 60.31 64.66
AOI
Err_DN
Err_Tbcs
Err_Tobc
Err_Tsm
Err_RSS
Err_RVS
ΔTbcs = 50mK
ΔTobc = 30 to 100mK
ΔTsm = 20 to 70mK



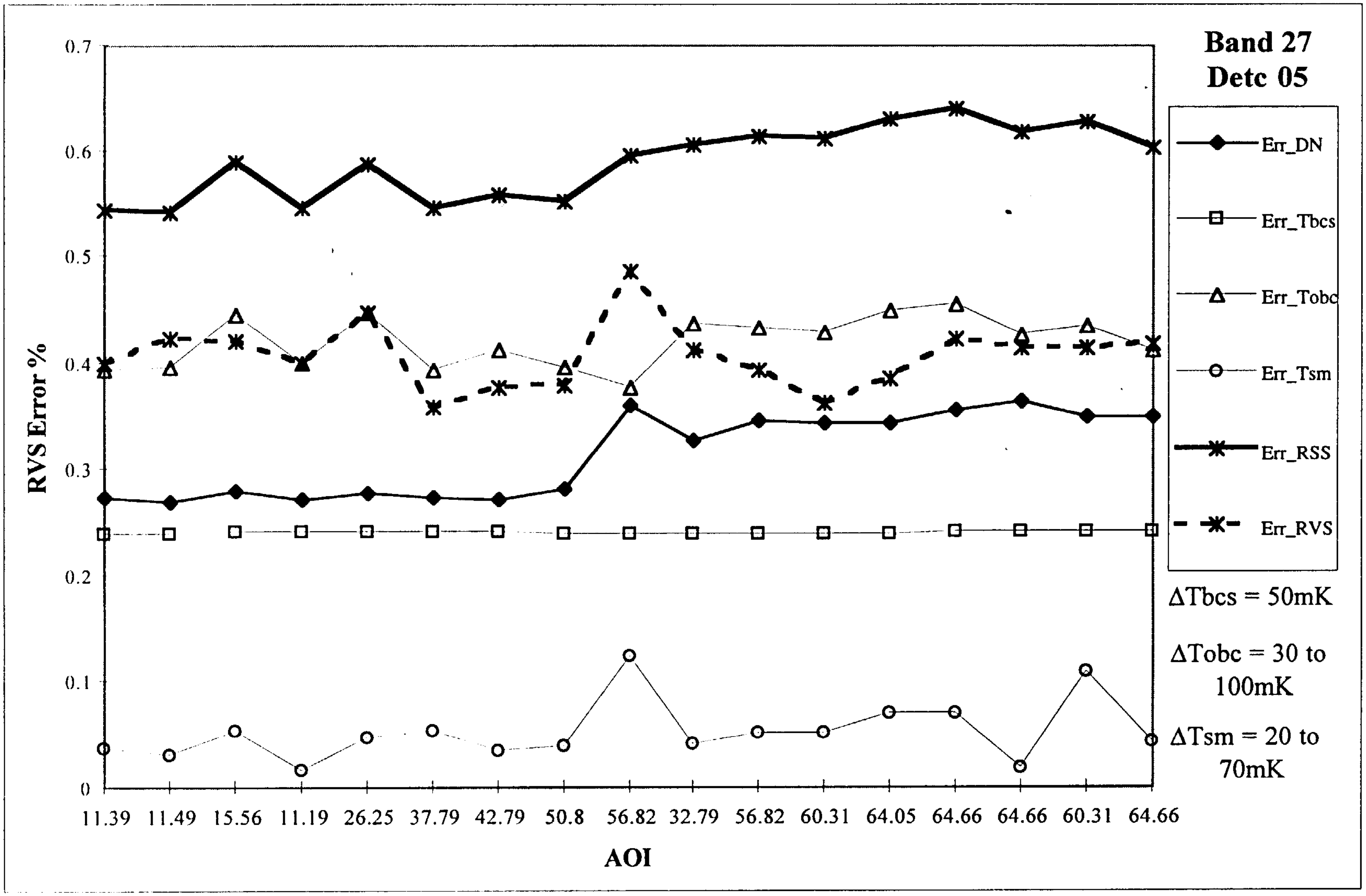
Band 22
Detc 05
Err_DN
Err_Tbcs
Err_Tobc
Err_Tsm
Err_RSS
Err_RVS
ΔTbcs = 50mK
ΔTobc = 30 to 100mK
ΔTsm = 20 to 70mK
RVS Error %
1.4
1.2
1
0.8
0.6
0.4
0.2
0
11.39 11.49 15.56 11.19 26.25 37.79 42.79 50.8 56.82 32.79 56.82 60.31 64.05 64.66 64.66 60.31 64.66
AOI

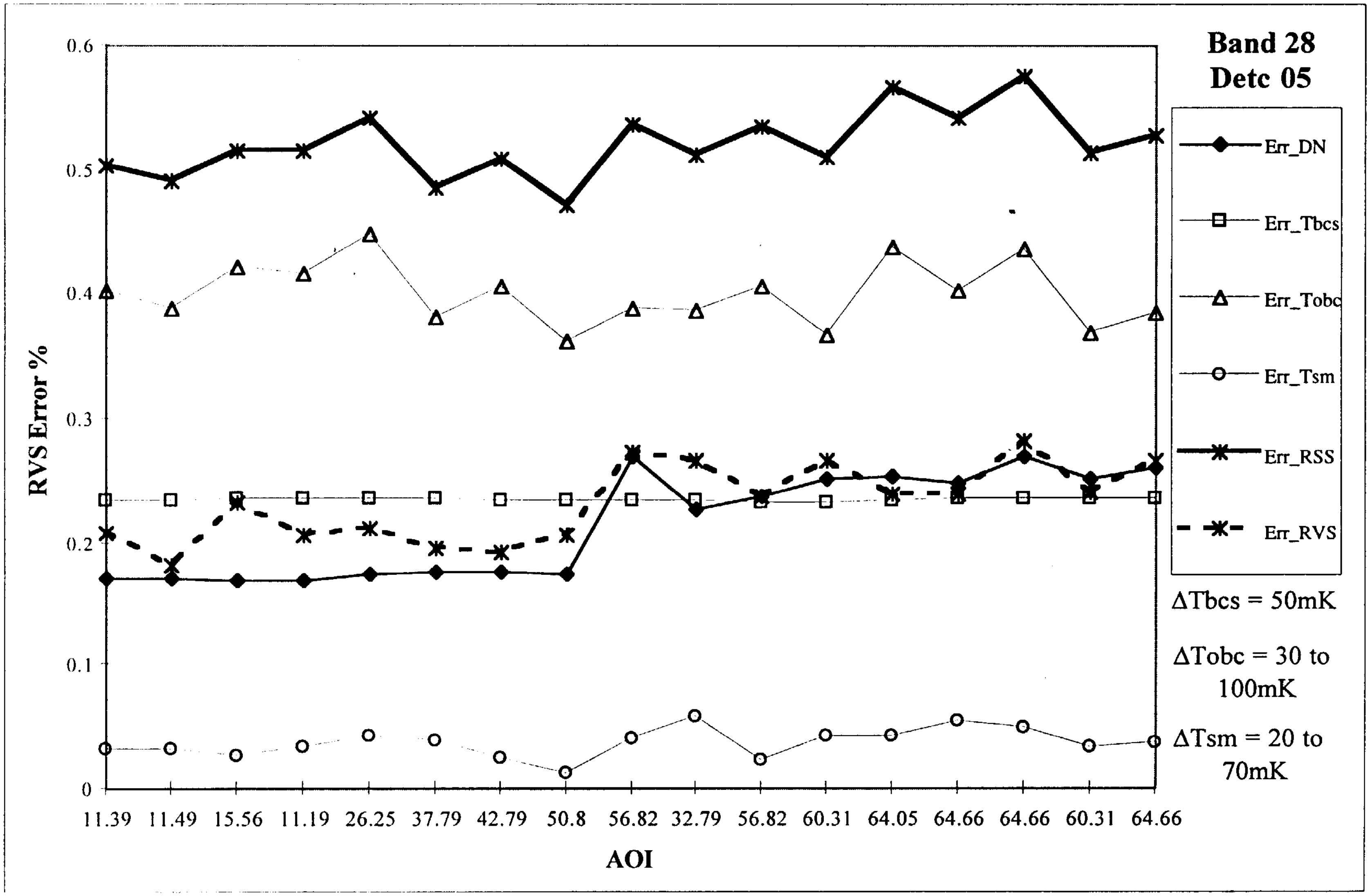

Band 23
Detc 05
RVS Error %
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
11.39 11.49 15.56 11.19 26.25 37.79 42.79 50.8 56.82 32.79 56.82 60.31 64.05 64.66 64.66 60.31 64.66
AOI
Err_DN
Err_Tbcs
Err_Tobc
Err_Tsm
Err_RSS
Err_RVS
ΔTbcs = 50mK
ΔTobc = 30 to 100mK
ΔTsm = 20 to 70mK

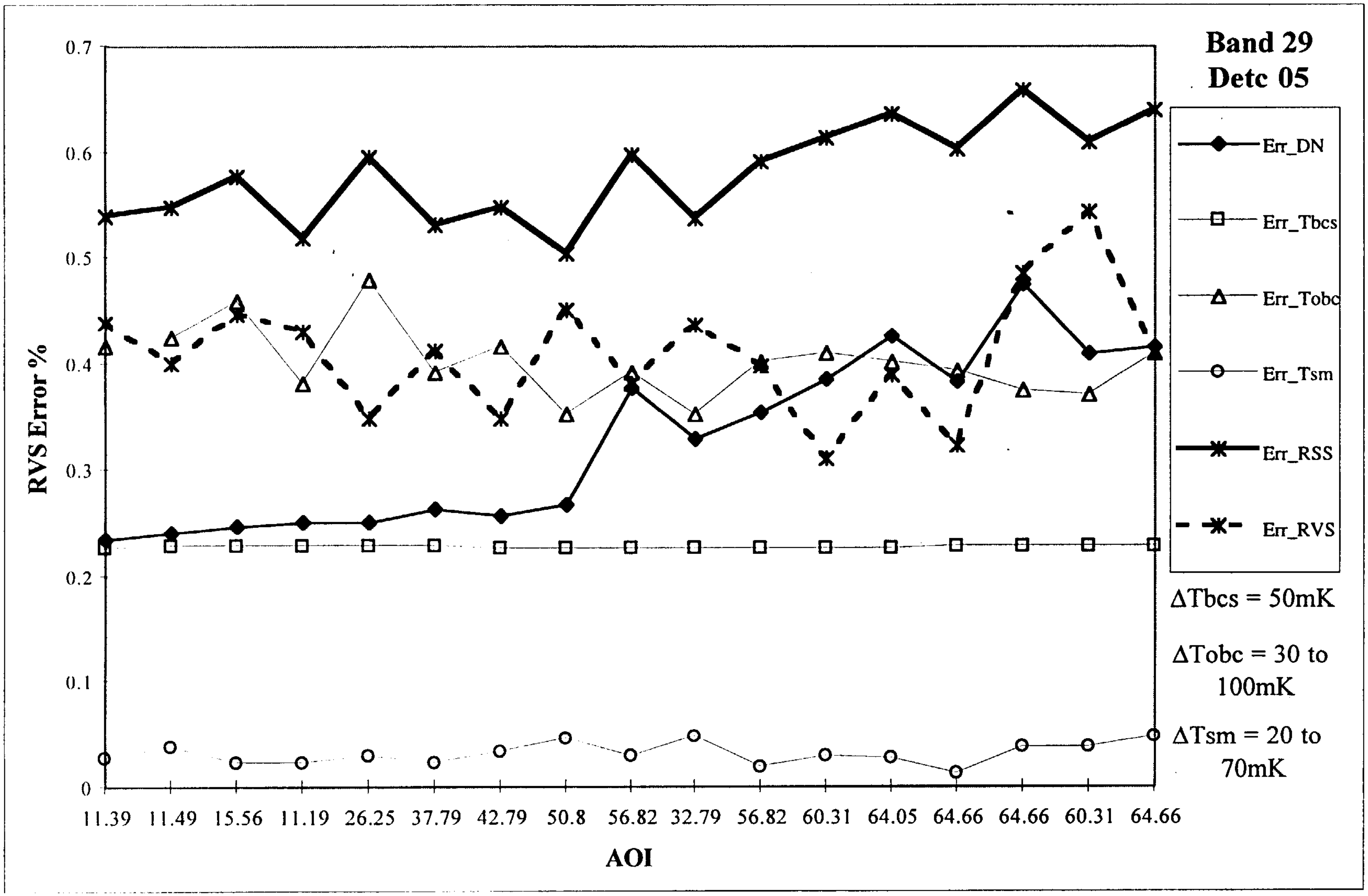

Band 24
Detc 05
Err_DN
Err_Tbcs
Err_Tobc
Err_Tsm
Err_RSS
Err_RVS
ΔTbcs = 50mK
ΔTobc = 30 to 100mK
ΔTsm = 20 to 70mK
RVS Error %
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
11.39 11.49 15.56 11.19 26.25 37.79 42.79 50.8 56.82 32.79 56.82 60.31 64.05 64.66 64.66 60.31 64.66
AOI



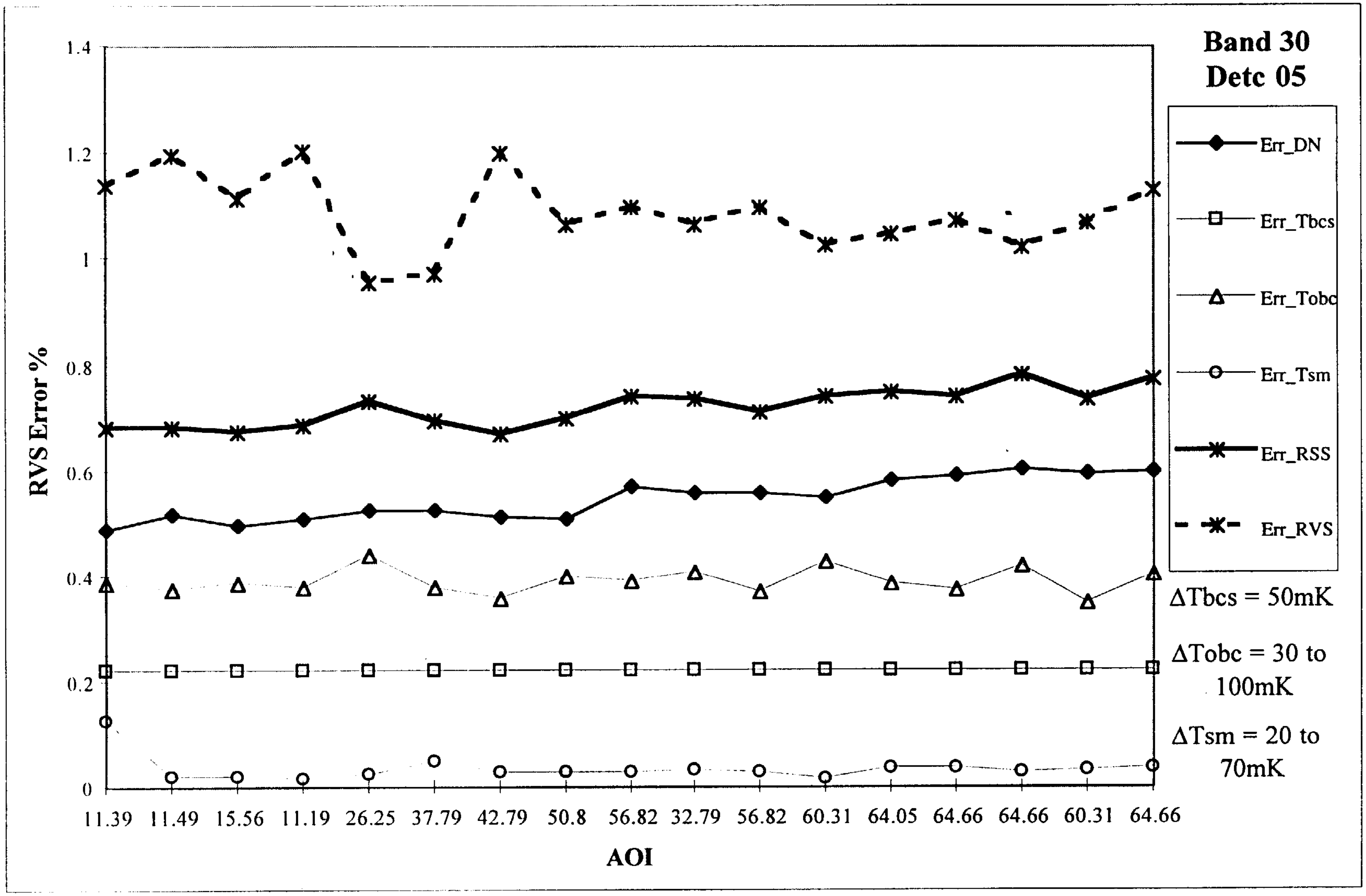
Band 25
Detc 05
RVS Error %
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
11.39 11.49 15.56 11.19 26.25 37.79 42.79 50.8 56.82 32.79 56.82 60.31 64.05 64.66 64.66 60.31 64.66
AOI
Err_DN
Err_Tbcs
Err_Tobc
Err_Tsm
Err_RSS
Err_RVS
ΔTbcs = 50mK
ΔTobc = 30 to 100mK
ΔTsm = 20 to 70mK

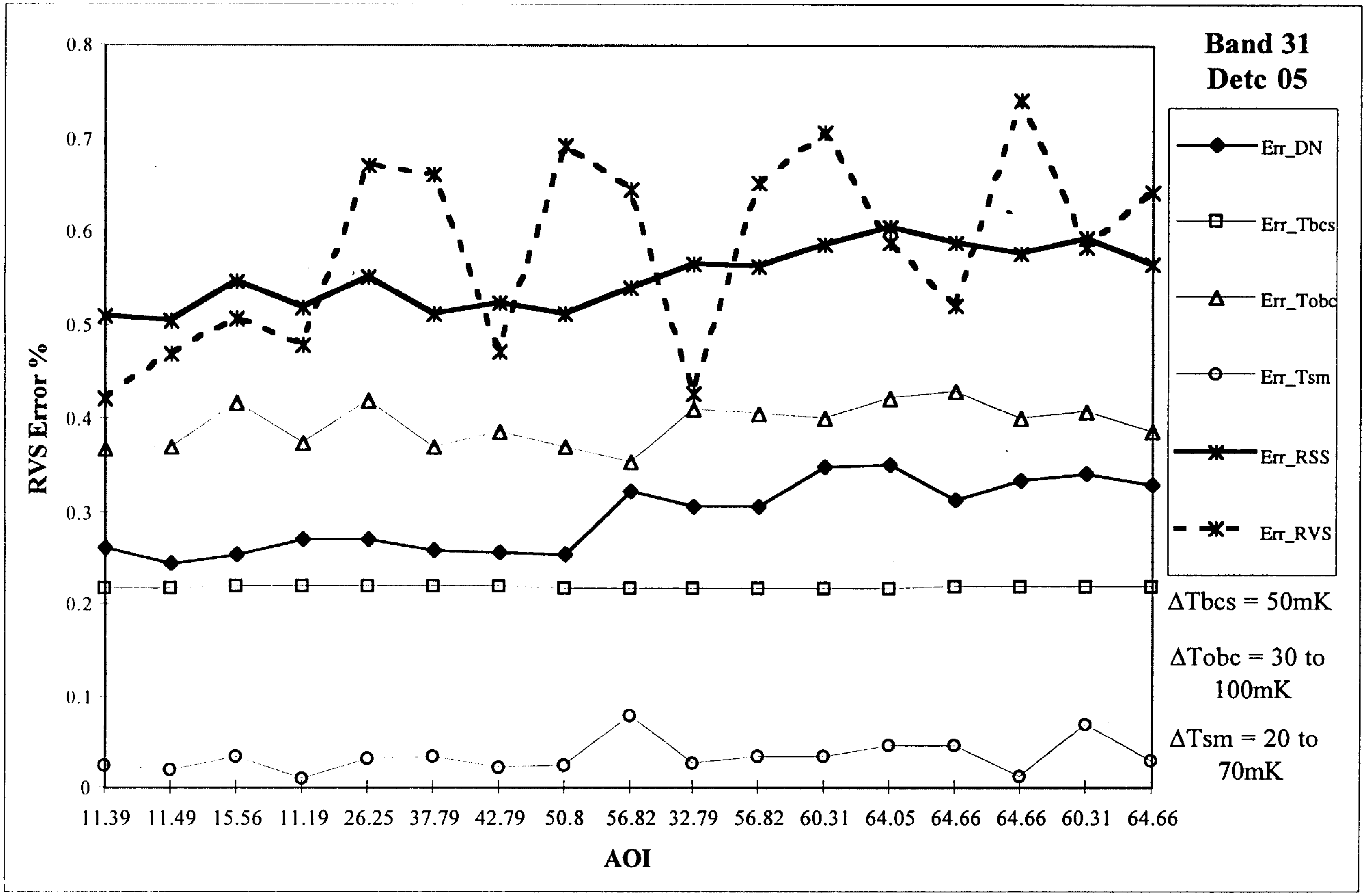

Band 27
Detc 05
Err_DN
Err_Tbcs
Err_Tobc
Err_Tsm
Err_RSS
Err_RVS
ΔTbcs = 50mK
ΔTobc = 30 to 100mK
ΔTsm = 20 to 70mK
RVS Error %
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
11.39 11.49 15.56 11.19 26.25 37.79 42.79 50.8 56.82 32.79 56.82 60.31 64.05 64.66 64.66 60.31 64.66
AOI


Band 28
Detc 05
RVS Error %
AOI
0
0.1
0.2
0.3
0.4
0.5
0.6
11.39
11.49
15.56
11.19
26.25
37.79
42.79
50.8
56.82
32.79
56.82
60.31
64.05
64.66
64.66
60.31
64.66
Err_DN
Err_Tbcs
Err_Tobc
Err_Tsm
Err_RSS
Err_RVS
ΔTbcs = 50mK
ΔTobc = 30 to 100mK
ΔTsm = 20 to 70mK

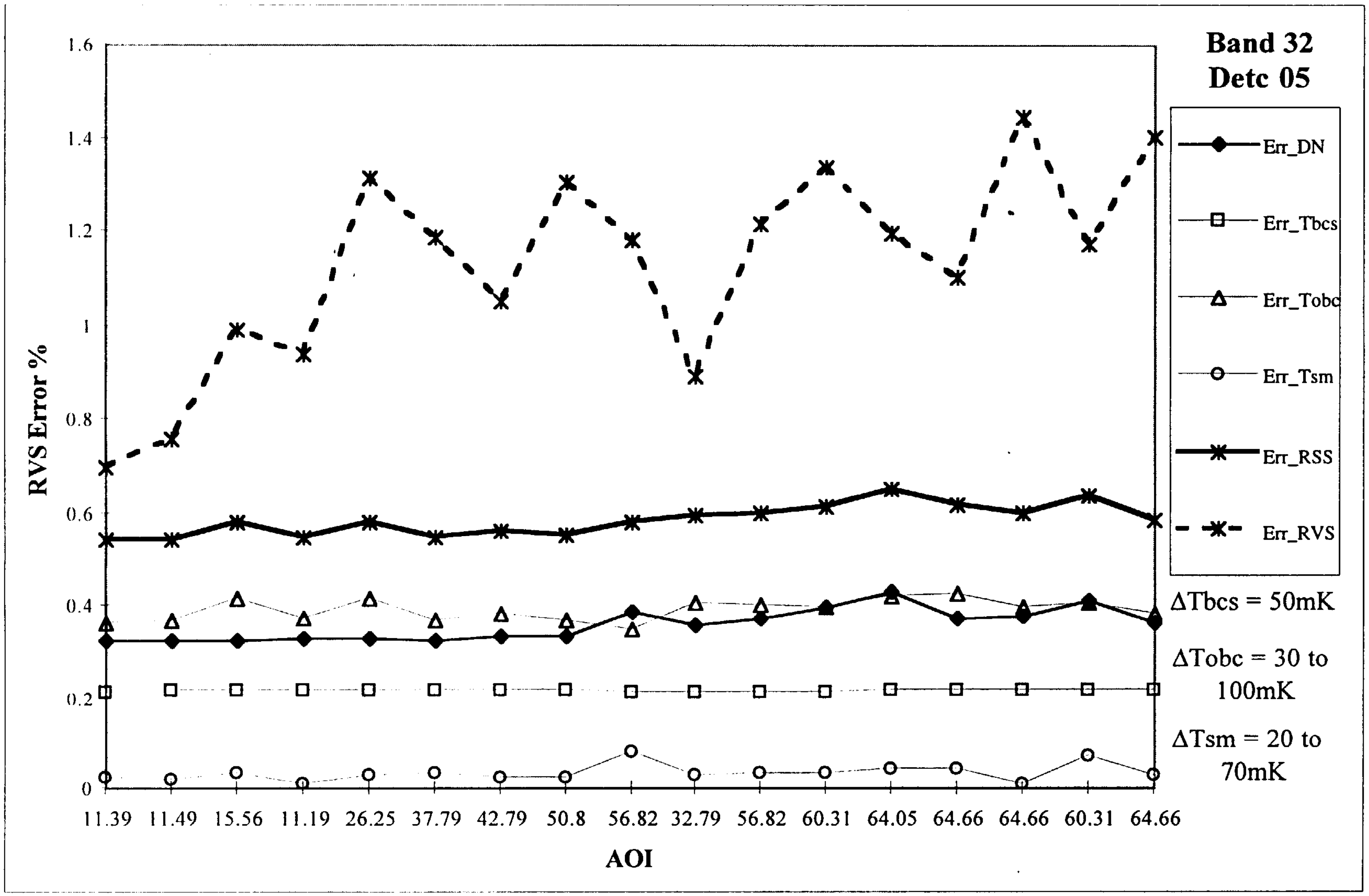


Band 29
Detc 05
RVS Error %
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
11.39 11.49 15.56 11.19 26.25 37.79 42.79 50.8 56.82 32.79 56.82 60.31 64.05 64.66 64.66 60.31 64.66
AOI
Err_DN
Err_Tbcs
Err_Tobc
Err_Tsm
Err_RSS
Err_RVS
ΔTbcs = 50mK
ΔTobc = 30 to 100mK
ΔTsm = 20 to 70mK

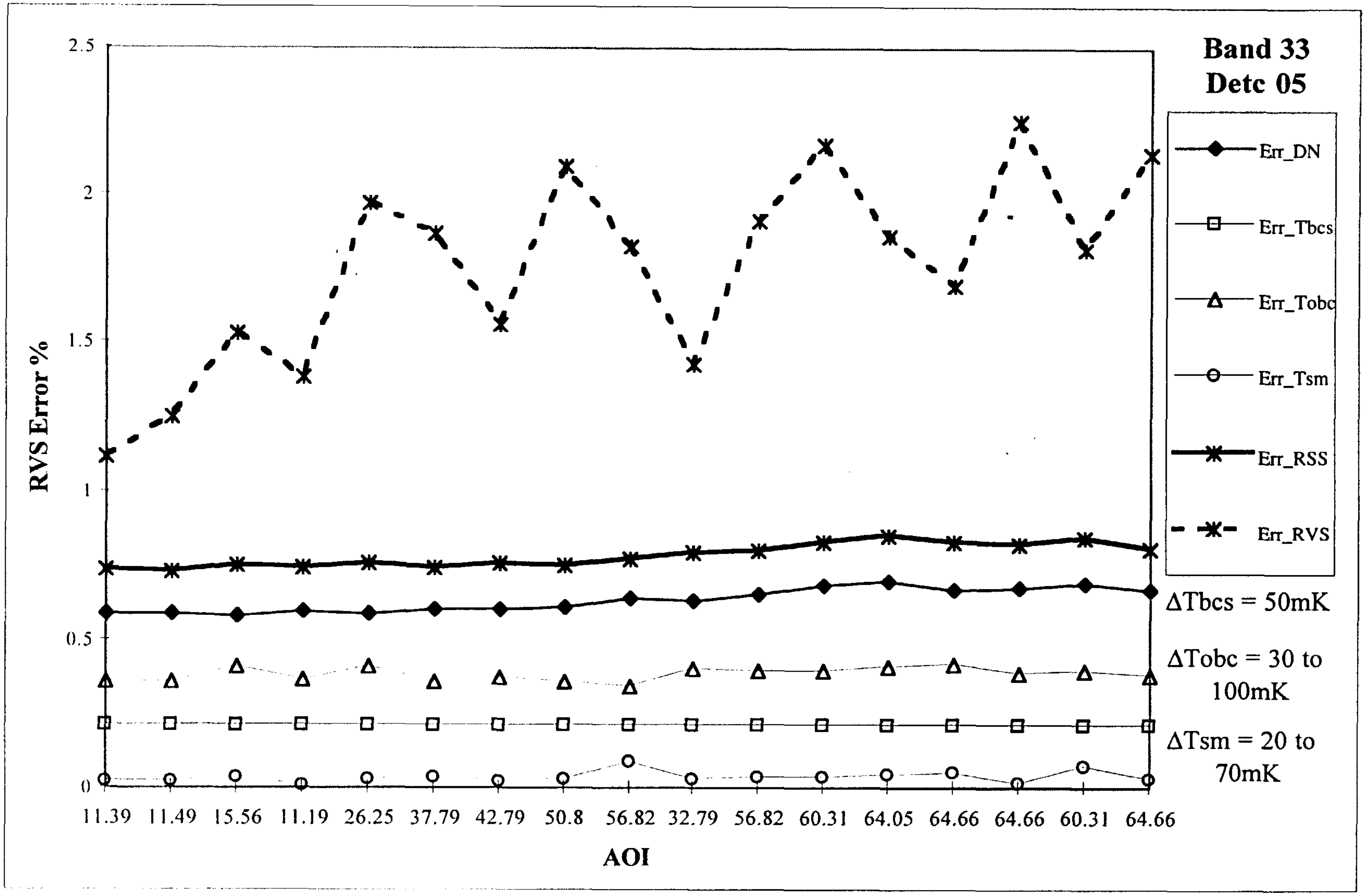

Band 30
Detc 05
RVS Error %
1.4
1.2
1
0.8
0.6
0.4
0.2
0
11.39 11.49 15.56 11.19 26.25 37.79 42.79 50.8 56.82 32.79 56.82 60.31 64.05 64.66 64.66 60.31 64.66
AOI
Err_DN
Err_Tbcs
Err_Tobc
Err_Tsm
Err_RSS
Err_RVS
ΔTbcs = 50mK
ΔTobc = 30 to 100mK
ΔTsm = 20 to 70mK

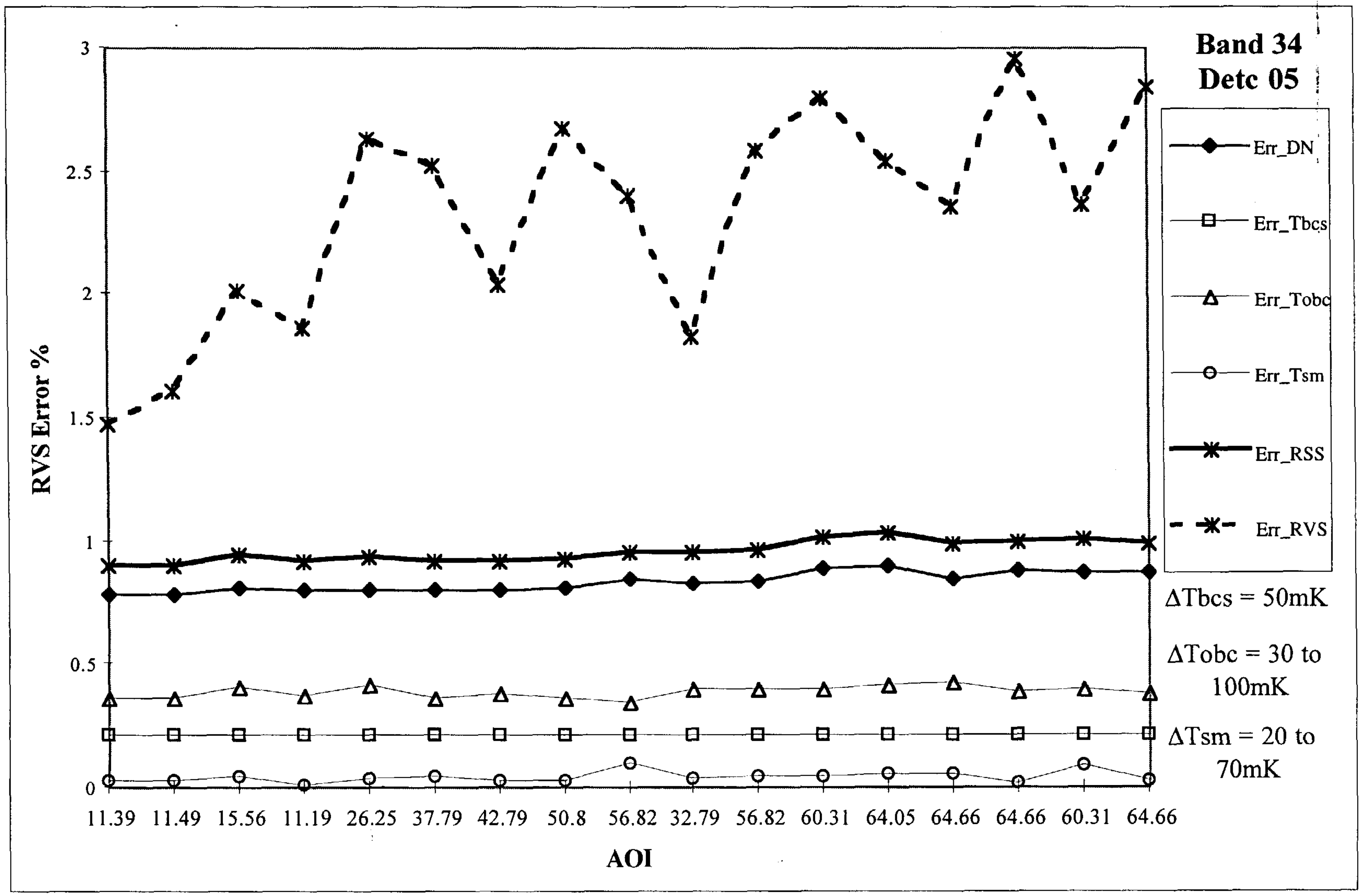


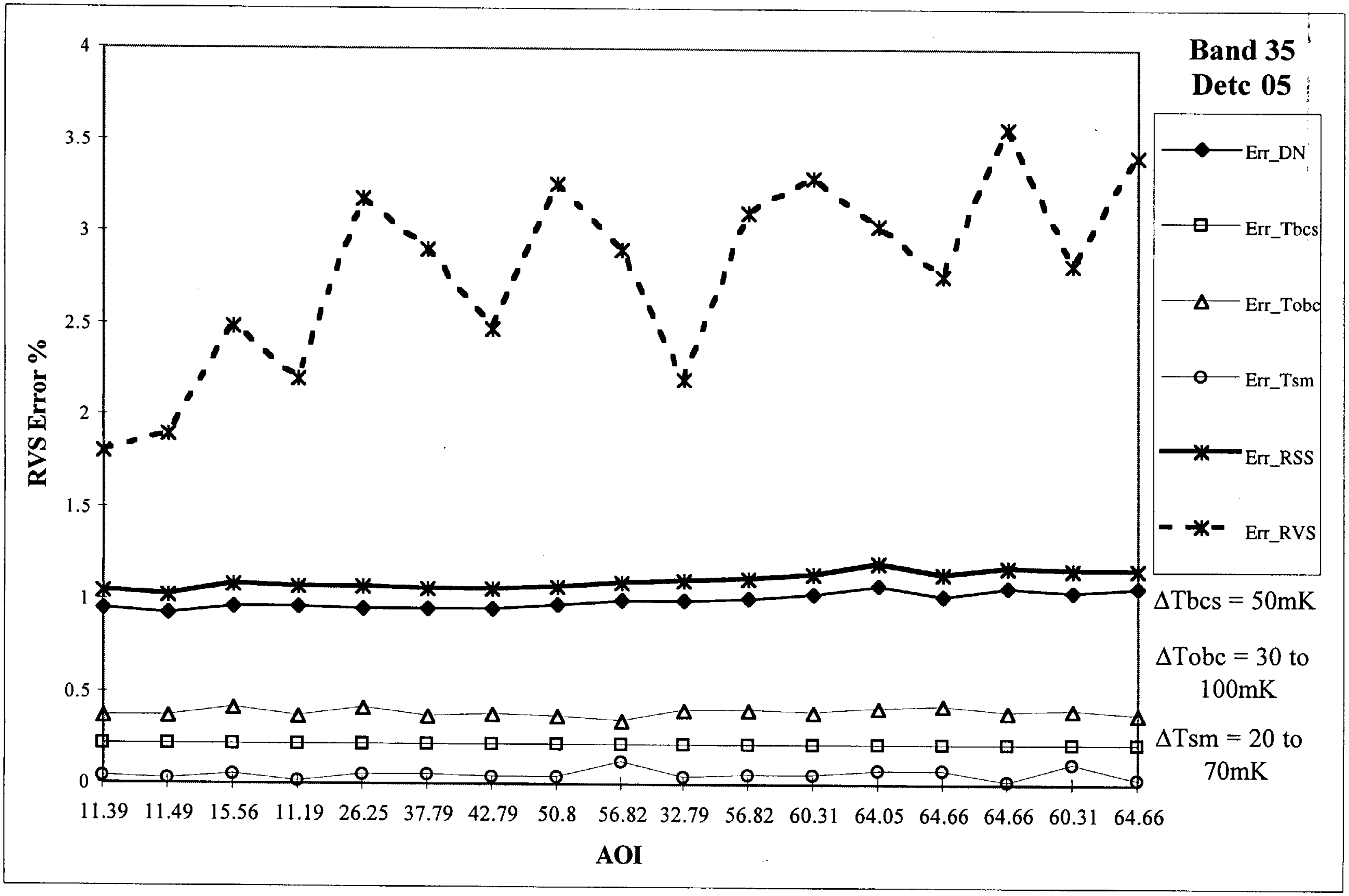
Band 31
Detc 05
Err_DN
Err_Tbcs
Err_Tobc
Err_Tsm
Err_RSS
Err_RVS
ΔTbcs = 50mK
ΔTobc = 30 to 100mK
ΔTsm = 20 to 70mK
RVS Error %
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
11.39 11.49 15.56 11.19 26.25 37.79 42.79 50.8 56.82 32.79 56.82 60.31 64.05 64.66 64.66 60.31 64.66
AOI

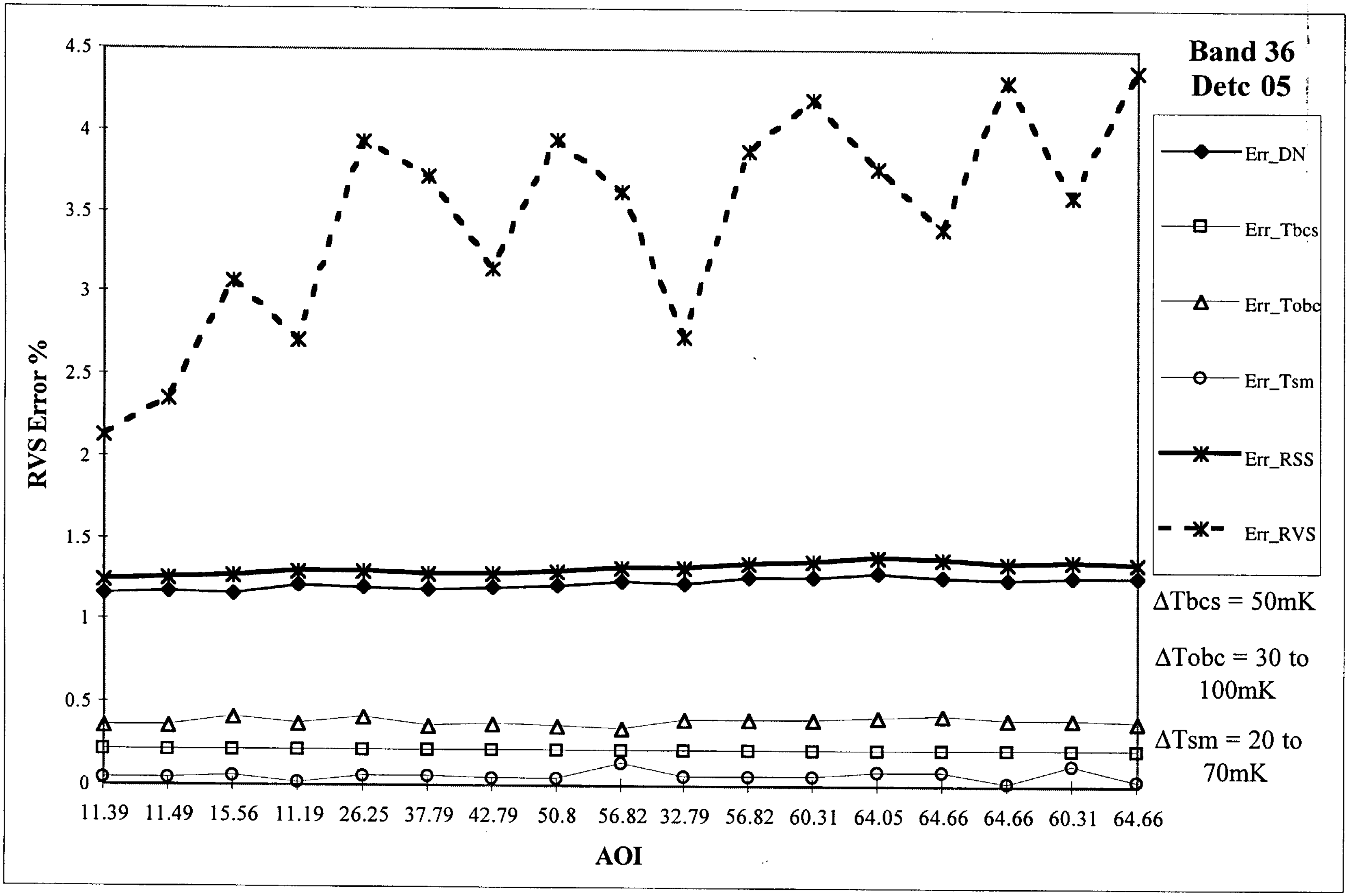


Band 32
Detc 05
RVS Error %
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
11.39 11.49 15.56 11.19 26.25 37.79 42.79 50.8 56.82 32.79 56.82 60.31 64.05 64.66 64.66 60.31 64.66
AOI
Err_DN
Err_Tbcs
Err_Tobc
Err_Tsm
Err_RSS
Err_RVS
ΔTbcs = 50mK
ΔTobc = 30 to 100mK
ΔTsm = 20 to 70mK


Band 33
Detc 05
2.5
2
1.5
1
0.5
0
RVS Error %
Err_DN
Err_Tbcs
Err_Tobc
Err_Tsm
Err_RSS
Err_RVS
ΔTbcs = 50mK
ΔTobc = 30 to 100mK
ΔTsm = 20 to 70mK
11.39
11.49
15.56
11.19
26.25
37.79
42.79
50.8
56.82
32.79
56.82
60.31
64.05
64.66
64.66
60.31
64.66
AOI


Band 34
Detc 05
Err_DN
Err_Tbcs
Err_Tobc
Err_Tsm
Err_RSS
Err_RVS
ΔTbcs = 50mK
ΔTobc = 30 to 100mK
ΔTsm = 20 to 70mK
RVS Error %
0
0.5
1
1.5
2
2.5
3
11.39 11.49 15.56 11.19 26.25 37.79 42.79 50.8 56.82 32.79 56.82 60.31 64.05 64.66 64.66 60.31 64.66
AOI


Band 35
Detc 05
RVS Error %
4
3.5
3
2.5
2
1.5
1
0.5
0
11.39 11.49 15.56 11.19 26.25 37.79 42.79 50.8 56.82 32.79 56.82 60.31 64.05 64.66 64.66 60.31 64.66
AOI
Err_DN
Err_Tbcs
Err_Tobc
Err_Tsm
Err_RSS
Err_RVS
ΔTbcs = 50mK
ΔTobc = 30 to 100mK
ΔTsm = 20 to 70mK


Band 36
Detc 05
RVS Error %
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
11.39
11.49
15.56
11.19
26.25
37.79
42.79
50.8
56.82
32.79
56.82
60.31
64.05
64.66
64.66
60.31
64.66
AOI
Err_DN
Err_Tbcs
Err_Tobc
Err_Tsm
Err_RSS
Err_RVS
ΔTbcs = 50mK
ΔTobc = 30 to 100mK
ΔTsm = 20 to 70mK

RVS fitting equations and procedure (1)

The MODIS polarization theory (Appendx A) gives

$$RVS = \tau \cdot \overline{\rho} + \eta \cdot \overline{\delta\rho} \quad \text{or,} \quad rvs = \overline{\rho} + C \cdot \overline{\delta\rho} \qquad \text{(Eq.20)}$$

where τ is the MODIS fix-optics total throughput (or A_{11} component of the fixed-optics 4x4 Mueller matrix), and η is the A_{12} component of the matrix, and *rvs* is the re-normalized RVS, and

$$\overline{\rho} = \frac{\rho_s + \rho_p}{2} \quad , \qquad \overline{\delta\rho} = \frac{\rho_s - \rho_p}{2} \qquad \text{(Eq.21)}$$

Using (Eq.12), together with *RVS* data and ρ_s and ρ_p functions fitted to the NPL scan mirror reflectivity data, τ and η can be determined by Least-Square fitting procedure, thus, completes the RVS fitting.

RVS fitting equations and procedure (2)

- This procedure assumes that reflectivity measurement accuracy is comparable or better than that of the RVS measurement. Given this presumption, this fitting procedure can be proved to be superior to the direct fitting (e.g., quadratic fitting) of the RVS data, which is primarily due to the fact that Eq.12 is an exact relationship between the RVS and scan mirror reflectivities.

- If we assume that the fixed-optics parameter C is the same for both the FM1 and PFM, then PFM RVS can be retrieved from the PFM scan mirror reflectivity measurement from NPL as

$$rvs_{PFM} = \bar{\rho}_{PFM} + C_{FM1} \cdot \overline{\delta\rho}_{PFM} \qquad \text{(Eq.22)}$$

Appendix A: MODIS Polarization Theory (1)

$$S = \mathbf{D} \cdot \mathbf{A} \cdot \mathbf{M} \cdot \mathbf{L}$$

S = at-detector radiance (a scalar quantity)
D = [D,0,0,0] is the detector vector
A = the Mueller matrix for the fixed optics
M = the Mueller matrix for the rotating scan mirror
L = the Stokes vector for the at-aperture radiance field

$$S_{ev} = \mathbf{D} \cdot \mathbf{A} \cdot \mathbf{M}(\rho_{ev}) \cdot \mathbf{L}_{ev} + \mathbf{D} \cdot \mathbf{A} \cdot \mathbf{M}(\varepsilon_{ev}) \cdot \mathbf{L}_{sm} + \delta_{bkg}$$

$$S_{sv} = \mathbf{D} \cdot \mathbf{A} \cdot \mathbf{M}(\varepsilon_{sv}) \cdot \mathbf{L}_{sm} + \delta_{bkg}$$

$$\Delta S_{ev} = \mathbf{D} \cdot \mathbf{A} \cdot \mathbf{M}(\rho_{ev}) \cdot \mathbf{L}_{ev} + \mathbf{D} \cdot \mathbf{A} \cdot \mathbf{M}(\varepsilon_{ev}) \cdot \mathbf{L}_{sm} - \mathbf{D} \cdot \mathbf{A} \cdot \mathbf{M}(\varepsilon_{sv}) \cdot \mathbf{L}_{sm}$$

Appendix A: MODIS Polarization Theory (2)

$$\mathbf{L}_{ev} = \left[L_{ev}, 0, 0, 0\right]^T \qquad \mathbf{L}_{sm} = \left[L_{sm}, 0, 0, 0\right]^T$$

$$\Delta S_{ev} = D\left\{\sum_{j=0}^{3} A_{0j} M_{j0}(\rho_{ev})\right\} L_{ev} + D\left\{\sum_{j=0}^{3} A_{0j}\left[M_{j0}(\varepsilon_{ev}) - M_{j0}(\varepsilon_{sv})\right]\right\} L_{sm}$$

$$\Delta S_{ev} = RVS_{ev} L_{ev} + \left(RVS_{sv} - RVS_{ev}\right) L_{sm}$$

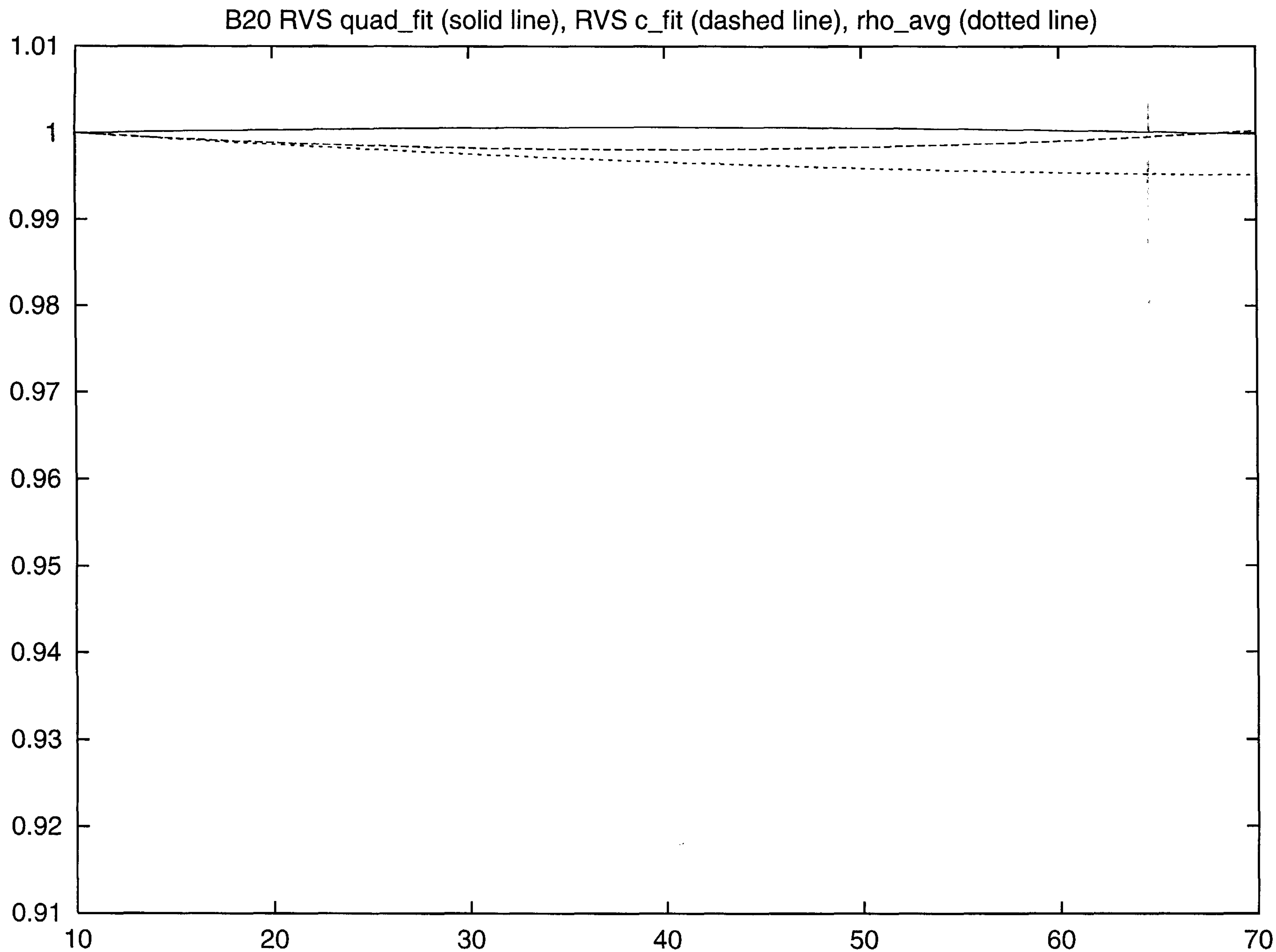
$$RVS = D\sum_{j=0}^{3} A_{0j} M_{j0}(\rho)$$

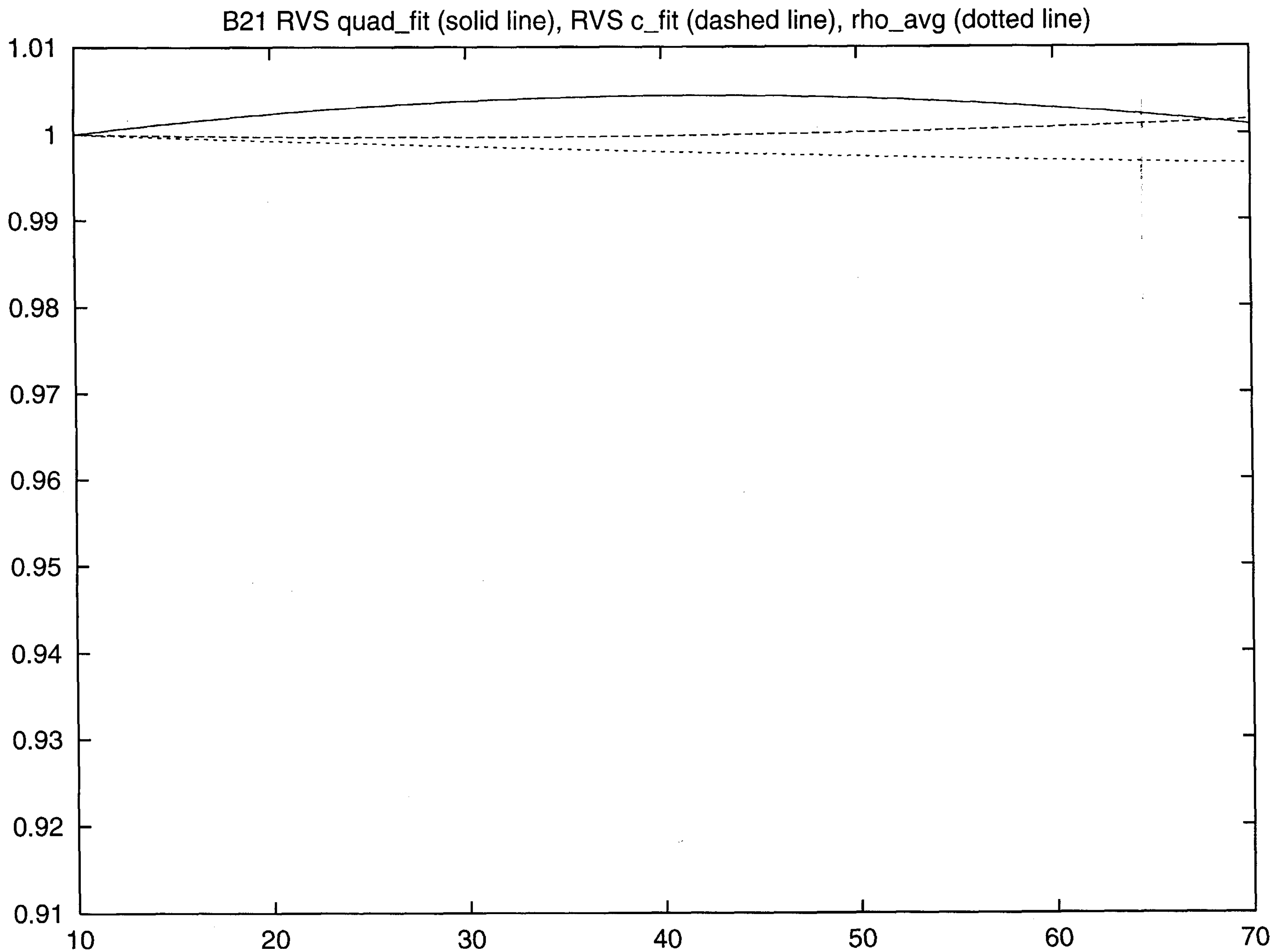
$$M_{10} = \frac{1}{2}\left(\rho_s - \rho_p\right) \qquad M_{00} = \frac{1}{2}\left(\rho_s + \rho_p\right)$$

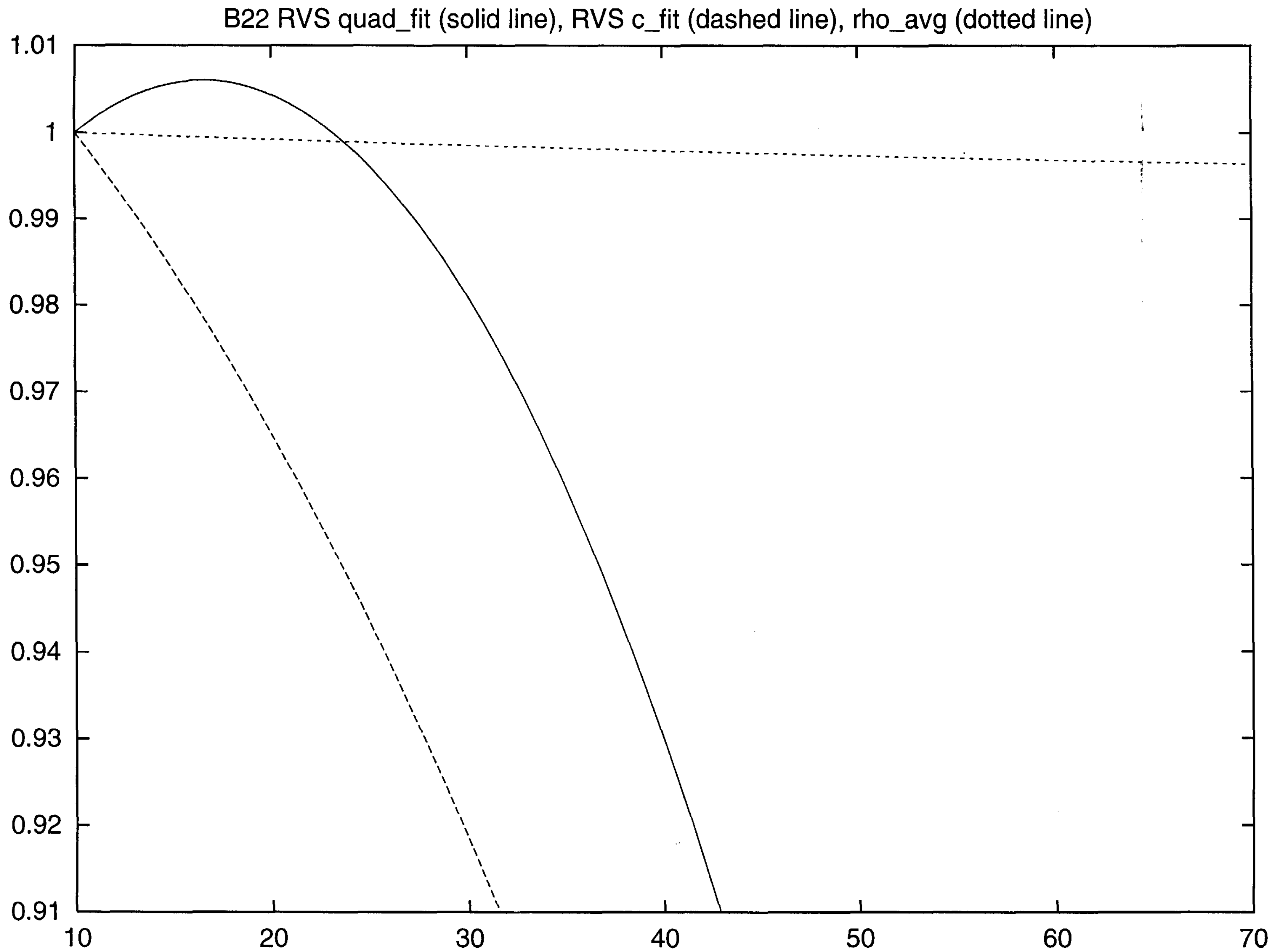
$$RVS = A_{00}\left[\frac{\rho_s + \rho_p}{2}\right] + A_{01}\left[\frac{\rho_s - \rho_p}{2}\right] = \tau_{fix}^{pol} \cdot \overline{\rho} + A_{01} \cdot \delta\overline{\rho}$$

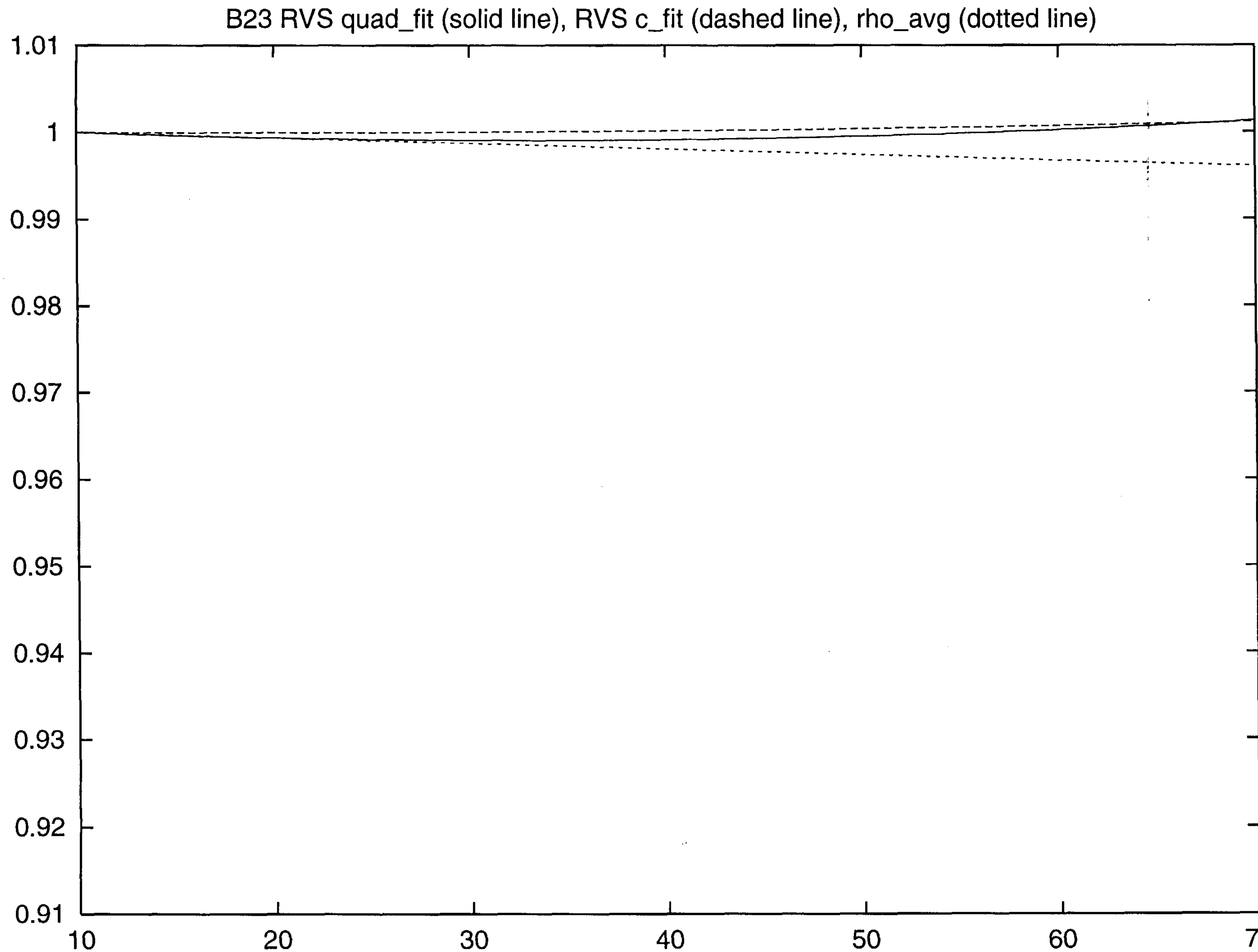
Comparison of Highbay polarized RVS, quadratic fit to Highbay RVS and quadratic fit to NPL average reflectance data

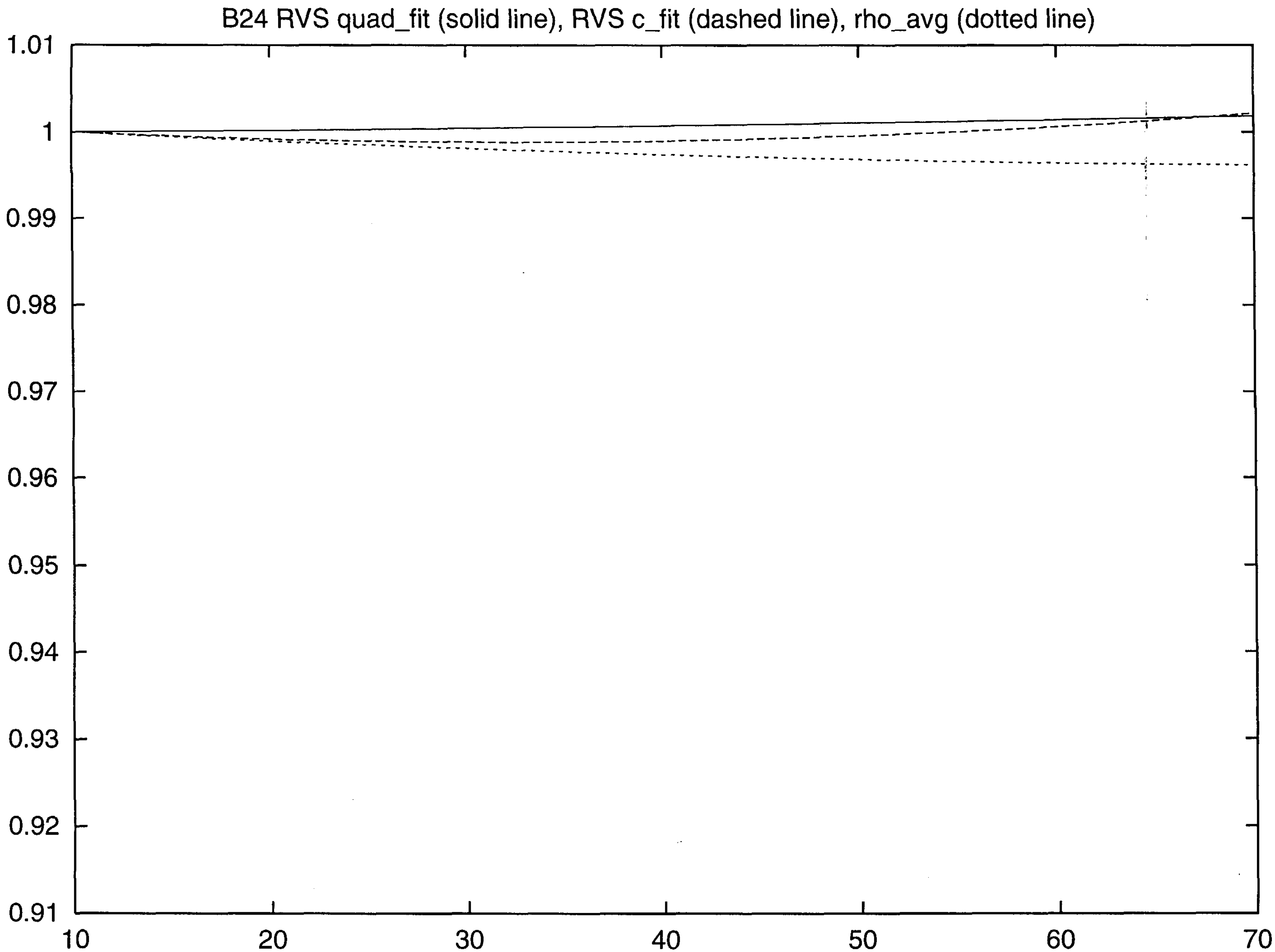
9B

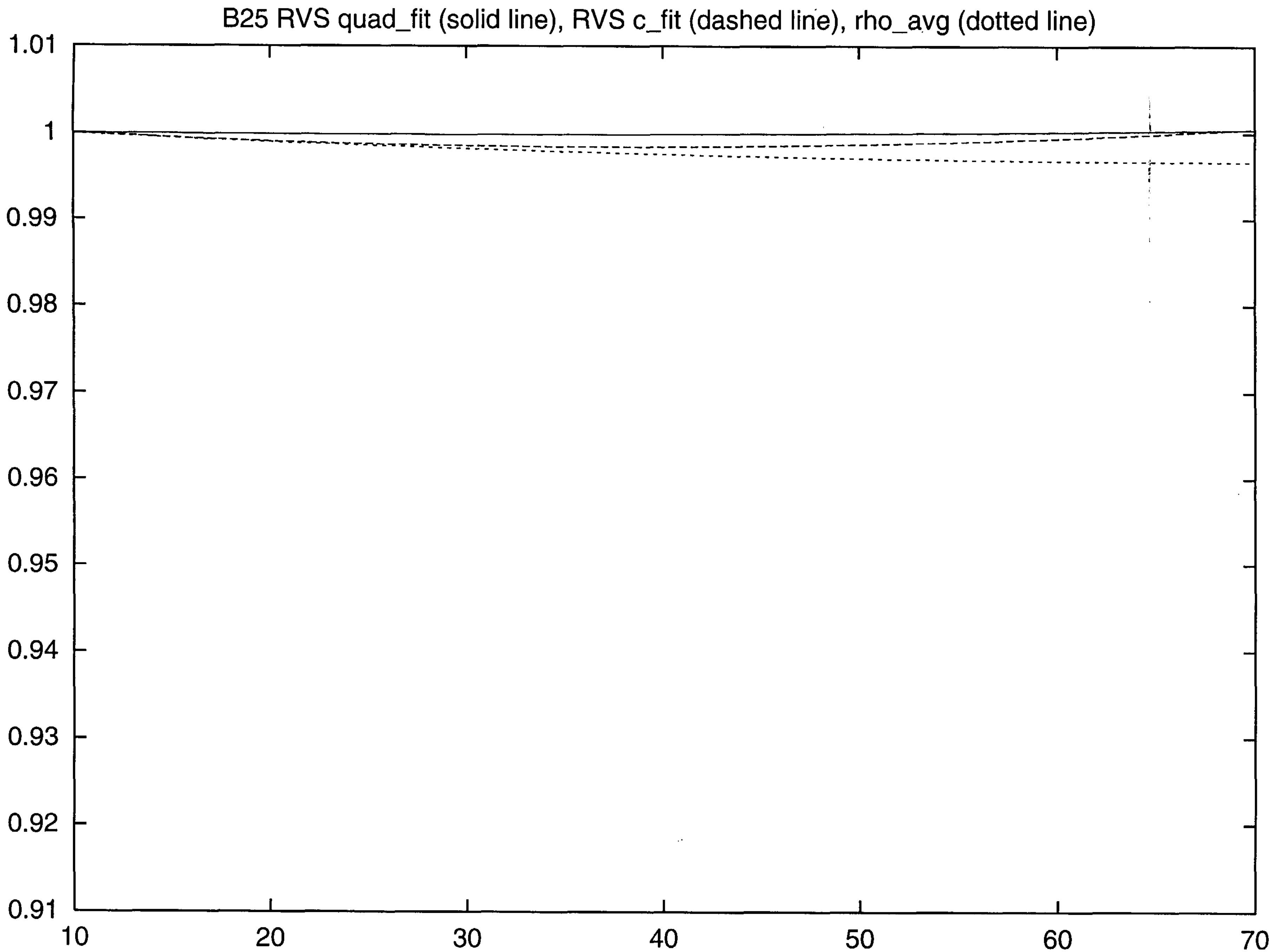

B20 RVS quad_fit (solid line), RVS c_fit (dashed line), rho_avg (dotted line)
1.01
1
0.99
0.98
0.97
0.96
0.95
0.94
0.93
0.92
0.91
10
20
30
40
50
60
70

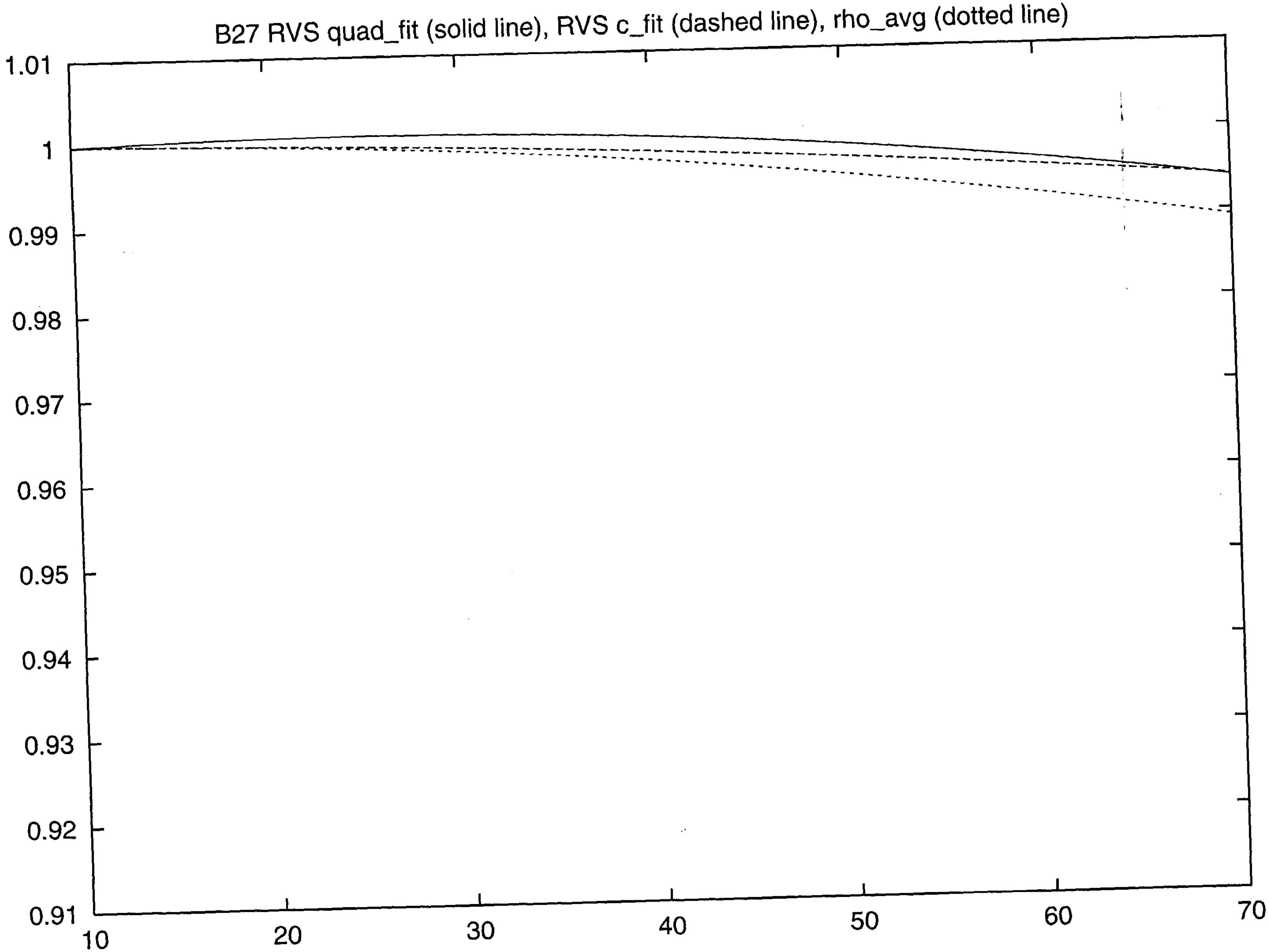

B21 RVS quad_fit (solid line), RVS c_fit (dashed line), rho_avg (dotted line)
1.01
1
0.99
0.98
0.97
0.96
0.95
0.94
0.93
0.92
0.91
10
20
30
40
50
60
70

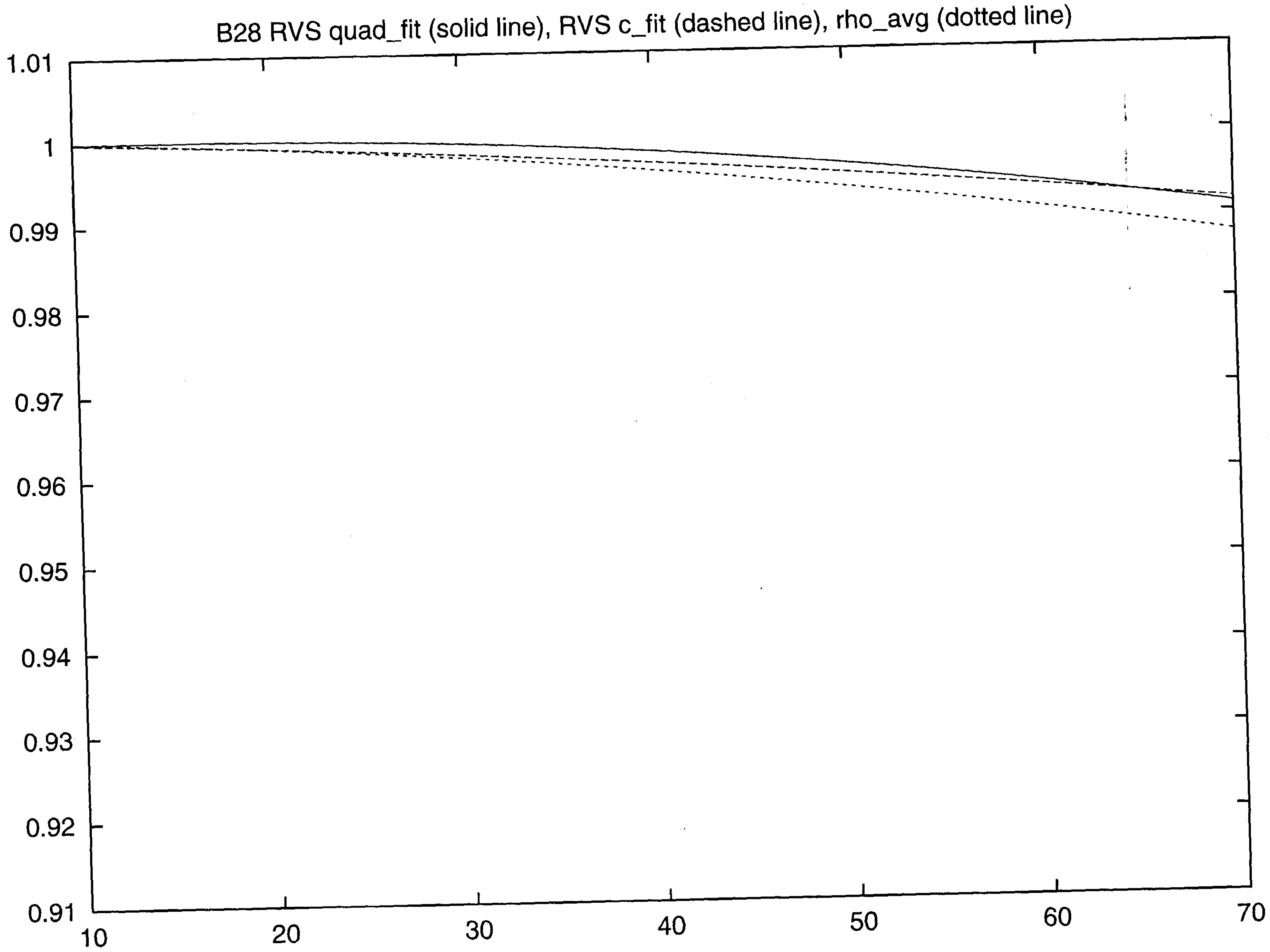

B22 RVS quad_fit (solid line), RVS c_fit (dashed line), rho_avg (dotted line)
1.01
1
0.99
0.98
0.97
0.96
0.95
0.94
0.93
0.92
0.91
10
20
30
40
50
60
70

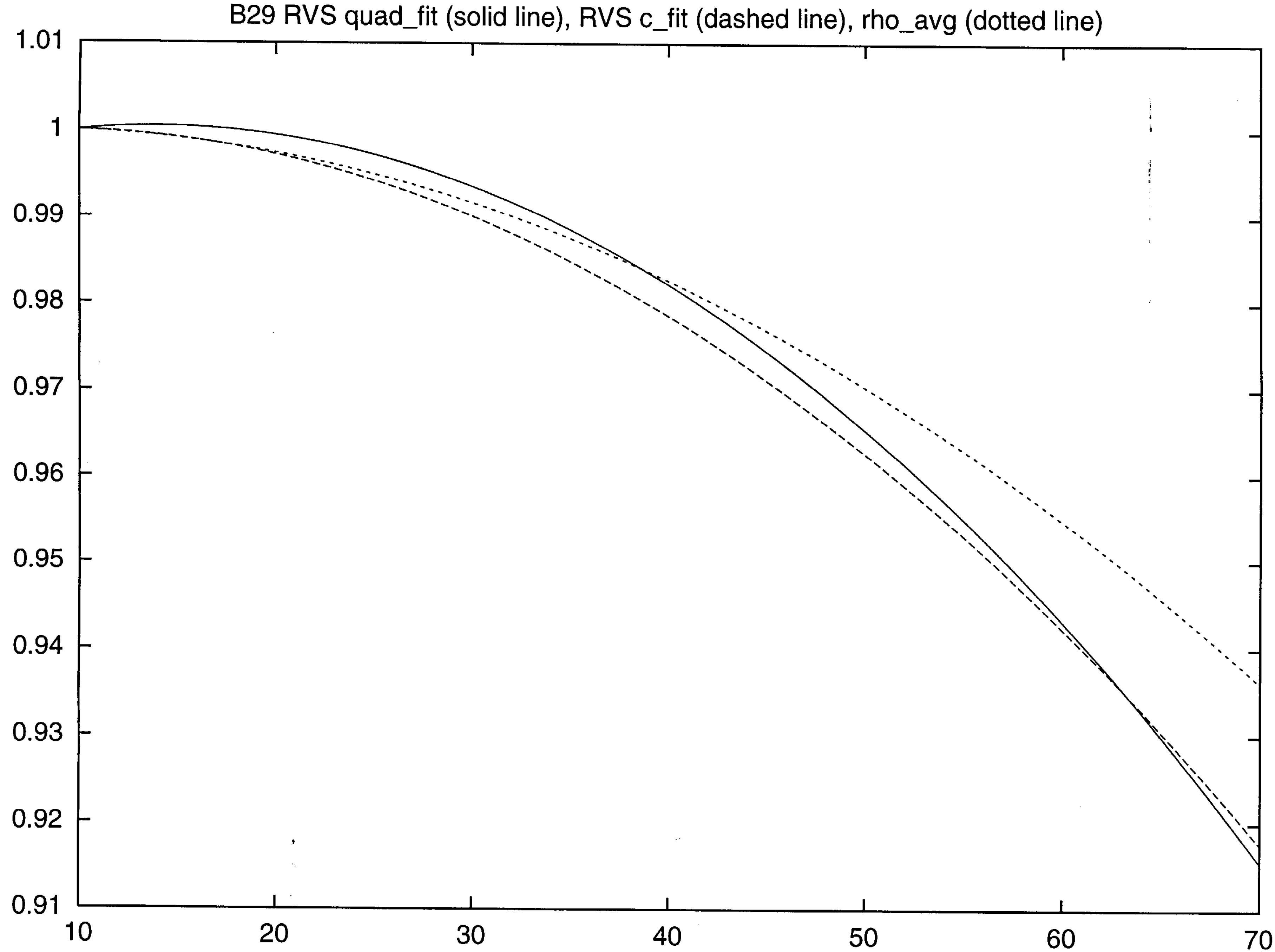

B23 RVS quad_fit (solid line), RVS c_fit (dashed line), rho_avg (dotted line)
1.01
1
0.99
0.98
0.97
0.96
0.95
0.94
0.93
0.92
0.91
10
20
30
40
50
60
70

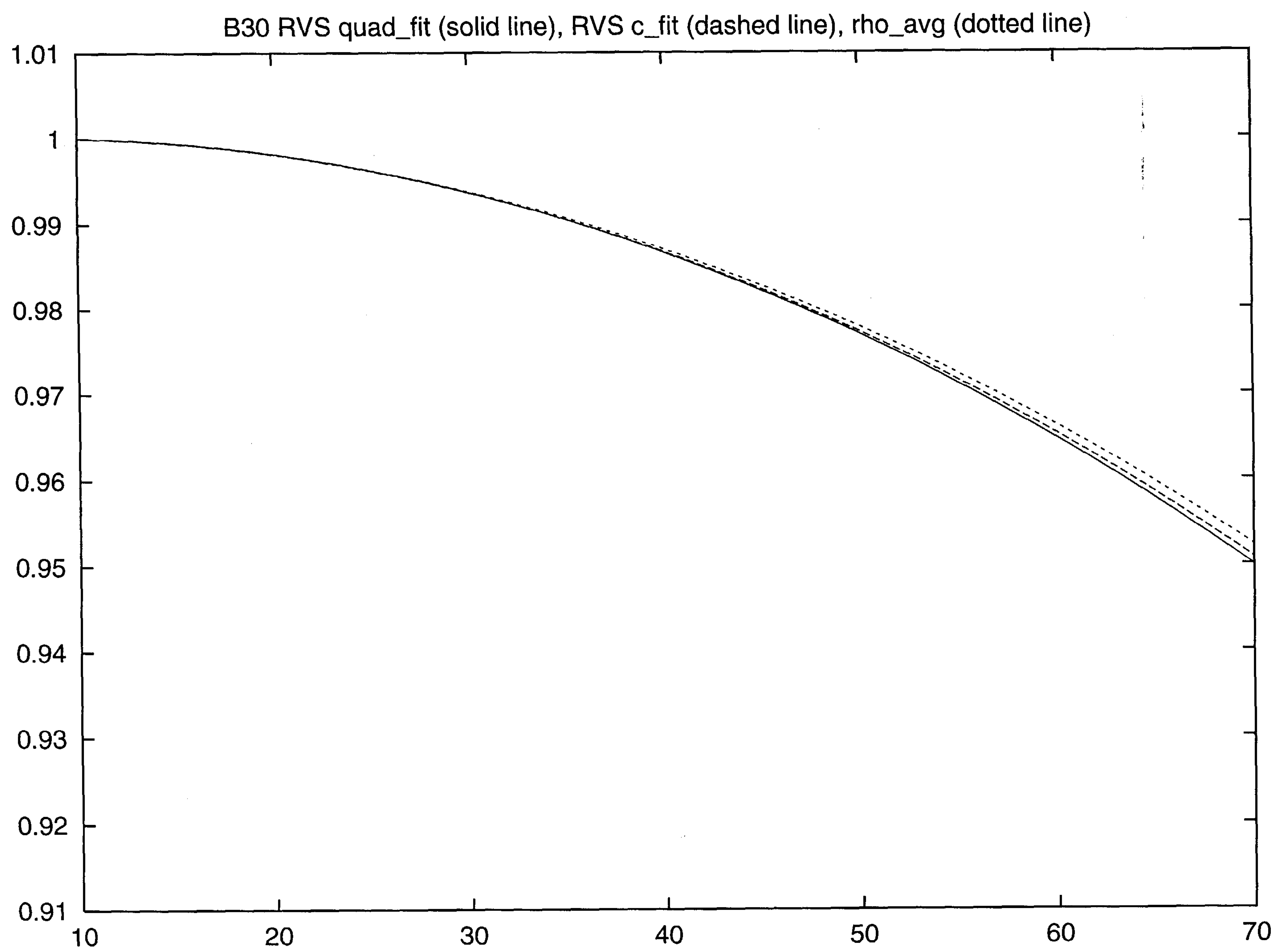

B24 RVS quad_fit (solid line), RVS c_fit (dashed line), rho_avg (dotted line)
1.01
1
0.99
0.98
0.97
0.96
0.95
0.94
0.93
0.92
0.91
10
20
30
40
50
60
70

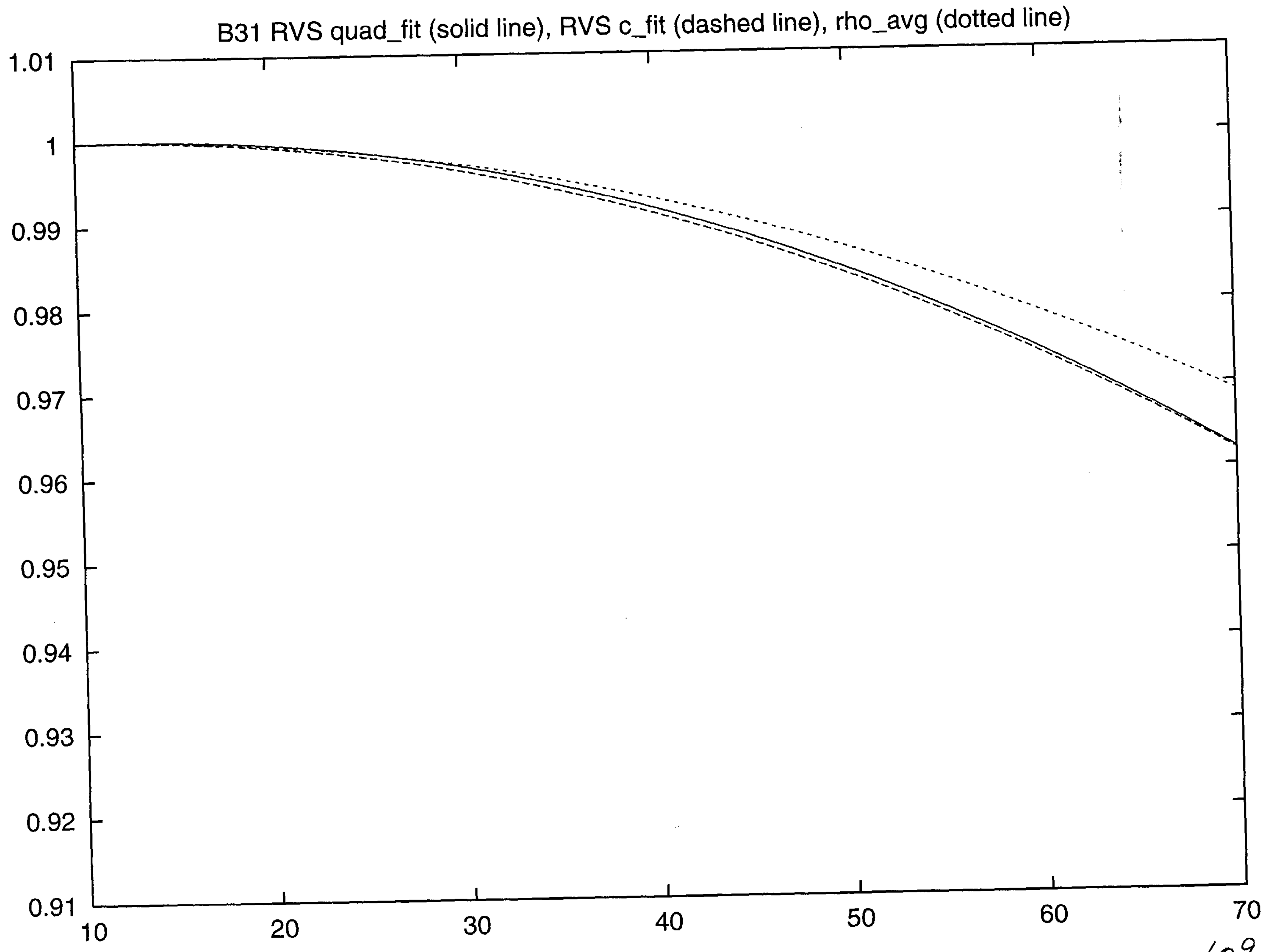

B25 RVS quad_fit (solid line), RVS c_fit (dashed line), rho_avg (dotted line)
1.01
1
0.99
0.98
0.97
0.96
0.95
0.94
0.93
0.92
0.91
10
20
30
40
50
60
70

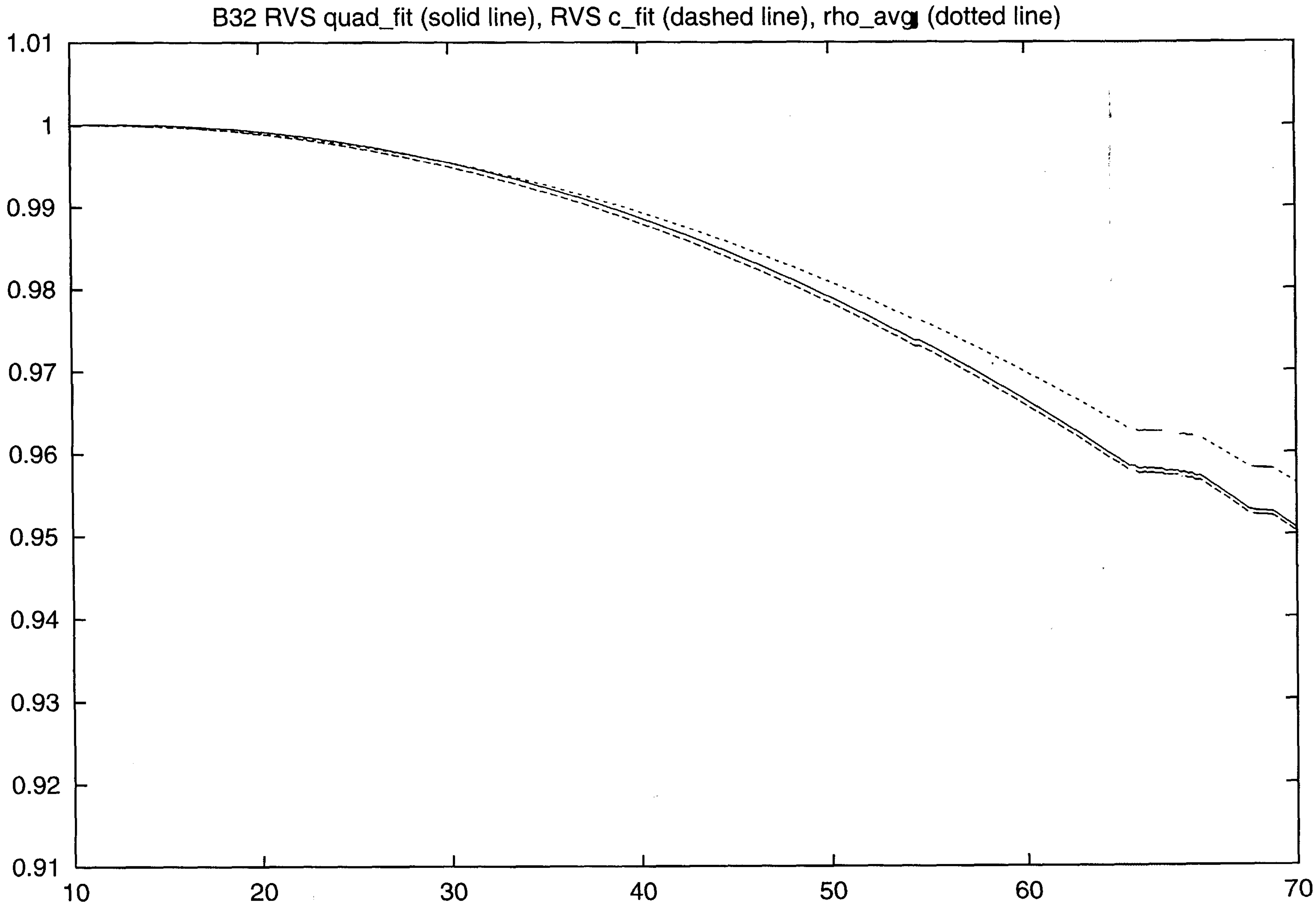

B27 RVS quad_fit (solid line), RVS c_fit (dashed line), rho_avg (dotted line)
1.01
1
0.99
0.98
0.97
0.96
0.95
0.94
0.93
0.92
0.91
10
20
30
40
50
60
70


B28 RVS quad_fit (solid line), RVS c_fit (dashed line), rho_avg (dotted line)
1.01
1
0.99
0.98
0.97
0.96
0.95
0.94
0.93
0.92
0.91
10
20
30
40
50
60
70


B29 RVS quad_fit (solid line), RVS c_fit (dashed line), rho_avg (dotted line)
1.01
1
0.99
0.98
0.97
0.96
0.95
0.94
0.93
0.92
0.91
10
20
30
40
50
60
70

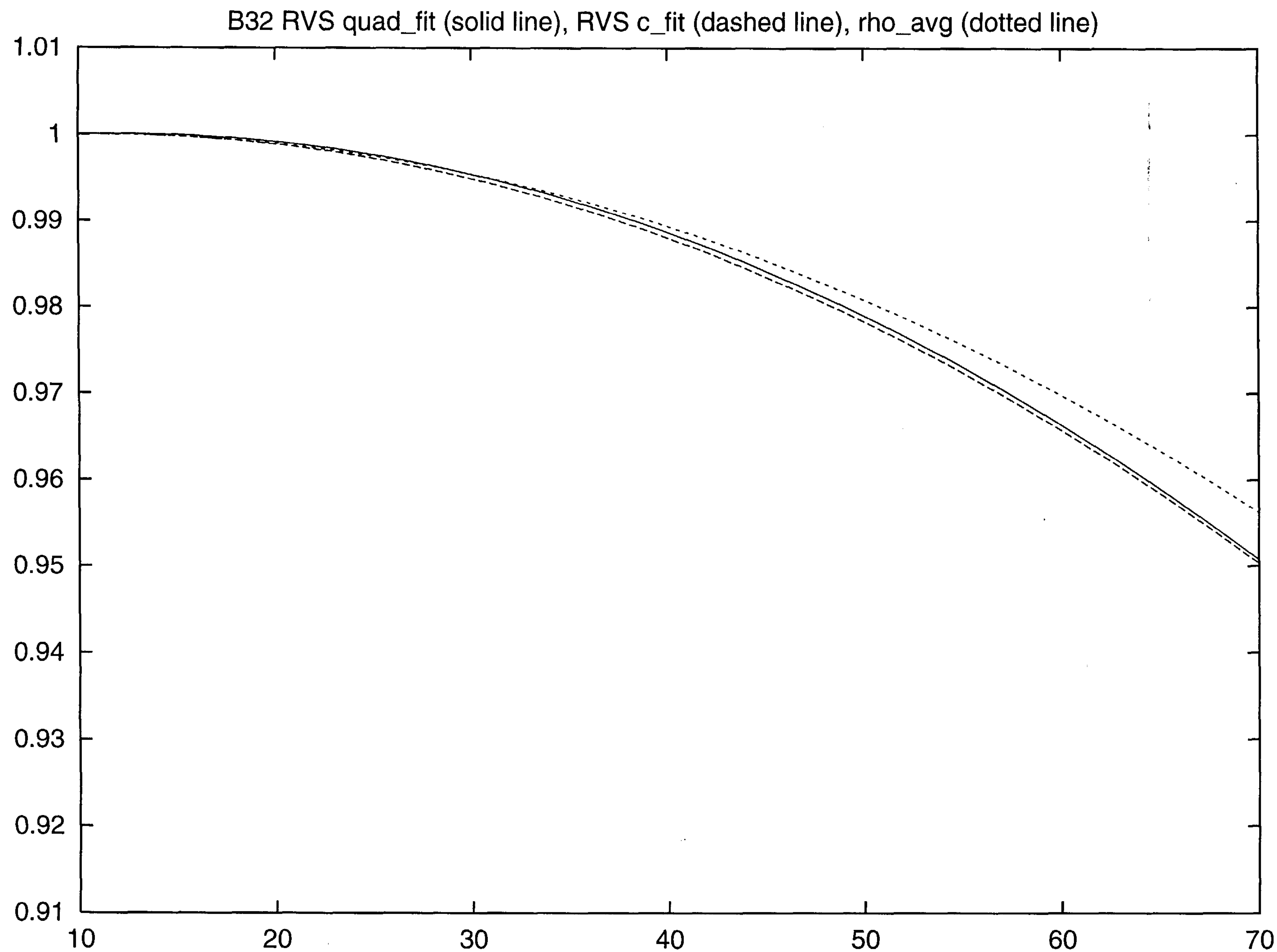

B30 RVS quad_fit (solid line), RVS c_fit (dashed line), rho_avg (dotted line)
1.01
1
0.99
0.98
0.97
0.96
0.95
0.94
0.93
0.92
0.91
10
20
30
40
50
60
70


B31 RVS quad_fit (solid line), RVS c_fit (dashed line), rho_avg (dotted line)
1.01
1
0.99
0.98
0.97
0.96
0.95
0.94
0.93
0.92
0.91
10
20
30
40
50
60
70

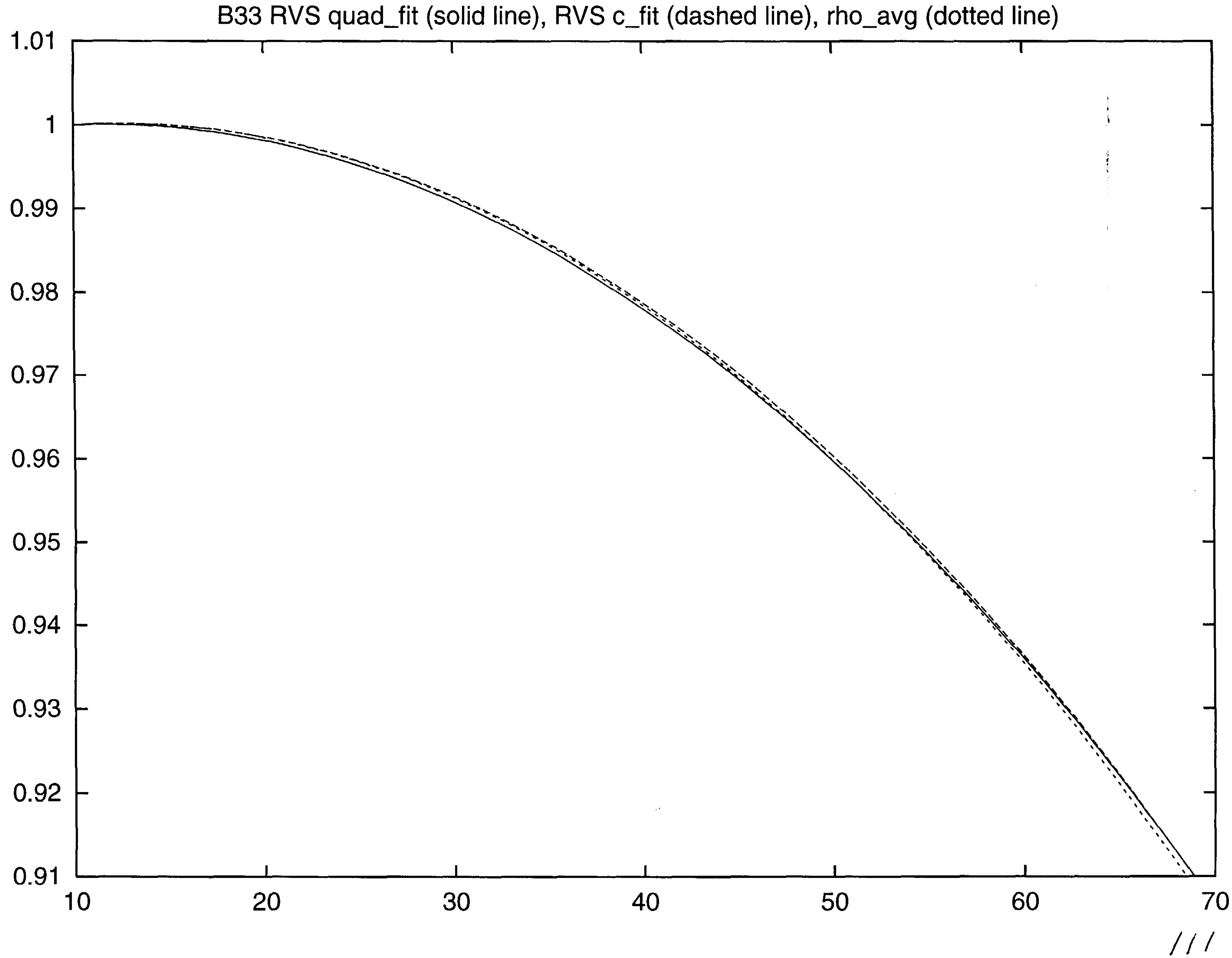


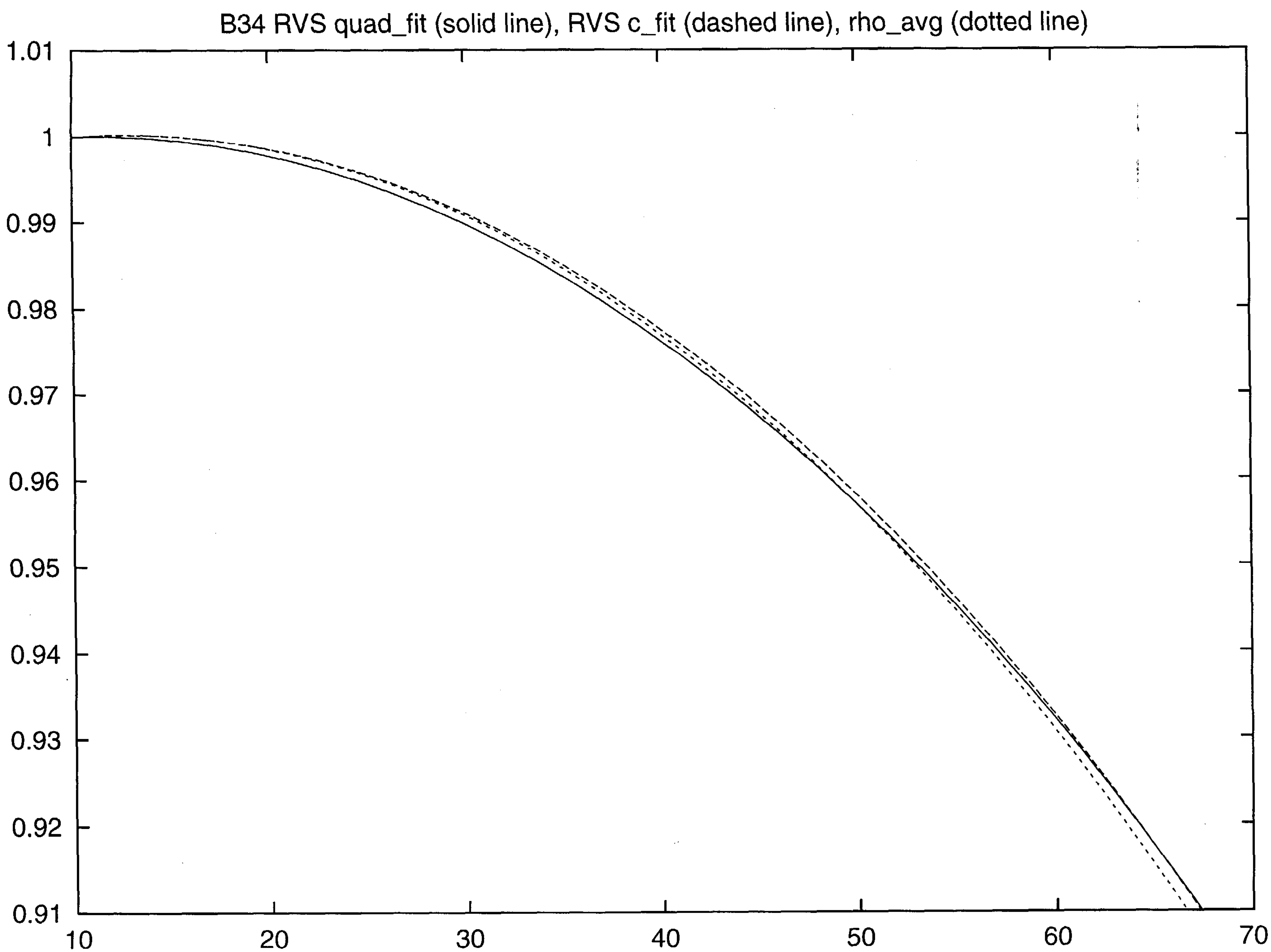
B32 RVS quad_fit (solid line), RVS c_fit (dashed line), rho_avg (dotted line)
1.01
1
0.99
0.98
0.97
0.96
0.95
0.94
0.93
0.92
0.91
10
20
30
40
50
60
70

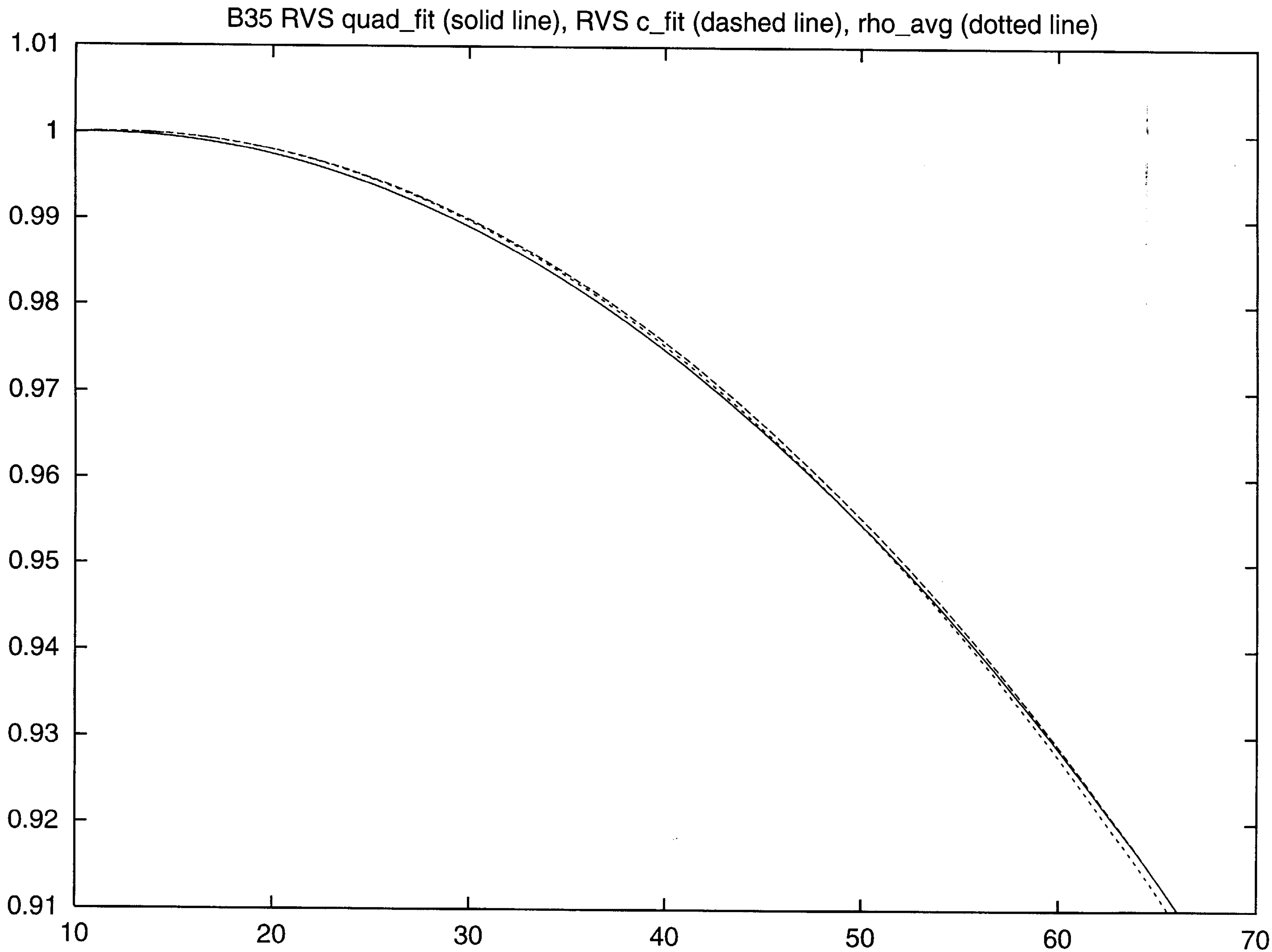
110



B32 RVS quad_fit (solid line), RVS c_fit (dashed line), rho_avg (dotted line)
1.01
1
0.99
0.98
0.97
0.96
0.95
0.94
0.93
0.92
0.91
10
20
30
40
50
60
70


B33 RVS quad_fit (solid line), RVS c_fit (dashed line), rho_avg (dotted line)
1.01
1
0.99
0.98
0.97
0.96
0.95
0.94
0.93
0.92
0.91
10
20
30
40
50
60
70


B34 RVS quad_fit (solid line), RVS c_fit (dashed line), rho_avg (dotted line)
1.01
1
0.99
0.98
0.97
0.96
0.95
0.94
0.93
0.92
0.91
10
20
30
40
50
60
70


B35 RVS quad_fit (solid line), RVS c_fit (dashed line), rho_avg (dotted line)
1.01
1
0.99
0.98
0.97
0.96
0.95
0.94
0.93
0.92
0.91
10
20
30
40
50
60
70

Scan Mirror brightness temperatures (Tsm=270K)

These temperatures are determined from the scan mirror absolute radiance emission, i.e., not the net radiance difference between the Earth View scan mirror emission and the Cold Space View scan mirror emission.

t =

AOI= 10.5	15.5	20.5	25.5	30.5	35.5	40.5	45.5	50.5	55.5	60.5	65.5	
203.4	203.4	203.4	203.4	203.5	203.6	203.9	204.4	205.3	206.8	208.9	211.6	20
199.6	199.6	199.6	199.6	199.7	199.8	200.1	200.7	201.7	203.3	205.6	208.6	21
199.8	199.8	199.8	199.9	199.9	200.1	200.4	201	202	203.6	205.9	208.8	22
198.7	198.7	198.7	198.8	198.8	199	199.3	200	201.1	202.8	205.2	208.3	23
193.5	193.5	193.5	193.6	193.7	194	194.6	195.5	196.9	198.8	201.2	204.1	24
192.6	192.6	192.6	192.7	192.9	193.2	193.7	194.6	196	197.9	200.4	203.3	25
172.9	172.9	173	173.1	173.5	174.1	175.1	176.7	178.8	181.6	184.9	188.7	27
169	169	169	169.2	169.4	169.9	170.8	172.2	174.2	176.8	180.1	184	28
162.8	163.5	164.7	166.7	169.4	172.7	176.5	180.7	185	189.5	194	198.4	29
155.1	155.6	156.6	158.2	160.5	163.5	167.1	171.1	175.3	179.8	184.4	189	30
142.6	143	143.8	145.2	147.1	149.6	152.5	155.9	159.5	163.4	167.4	171.5	31
137.9	138.2	139	140.2	142	144.3	147.1	150.3	153.8	157.6	161.5	165.6	32
130.3	131.6	133.7	136.5	139.9	143.8	148	152.3	156.7	161.2	165.6	170	33
127.8	129.5	132	135.3	139.1	143.3	147.7	152.2	156.8	161.4	165.8	170.3	34
127.9	129.5	132.1	135.3	139.1	143.3	147.7	152.2	156.8	161.4	165.9	170.4	35
126.5	128.2	130.7	134	137.9	142.1	146.6	151.2	155.9	160.6	165.2	169.7	36

Preliminary Estimated Scan Mirror Signal-to-Noise Ratios (SNRs)

(for radiance emitted from the scan mirror for 1 minute data collect based on T/V measured SNRs; assumes Tsm=270K and T_fpa constant at 83K)

M036 =

Band	20	21	22	23	24	25	27	28	29	30	31	32	33	34	35	36	AOI =
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10.5°
	0	0	0	0	0	0	0	0	1	0	1	0	1	1	1	0	15.5°
	0	0	0	0	0	0	0	0	3	1	2	1	2	2	2	1	20.5°
	0	0	0	0	0	0	0	0	7	3	3	3	3	3	3	2	25.5°
	0	0	0	0	0	0	0	1	13	5	6	5	6	5	5	3	30.5°
	0	0	0	0	0	0	1	1	21	9	10	9	8	7	7	5	35.5°
	1	0	1	1	1	1	2	2	32	13	16	13	12	11	10	7	40.5°
	1	0	1	1	1	1	3	4	45	19	23	20	17	14	14	10	45.5°
	1	0	1	1	2	2	6	8	60	27	32	27	22	19	18	12	50.5°
	1	0	1	2	3	2	9	13	78	37	43	37	28	24	23	16	55.5°
	2	1	2	3	4	4	13	20	99	47	56	48	35	29	28	20	60.5°
	3	1	3	4	6	5	19	28	124	60	71	61	42	35	34	24	65.5°

Highbay Response vs Scan Angle (RVS)

(Test Results, PFM Retrieval Methodology and On-orbit Validation Issues)

Presented to MODIS Science Team

December 14, 1998

Outline

1) Introduction
2) Highbay RVS measurement approach
3) Scan mirror witness sample polarized reflectance measurements
4) Unpolarized equations used for test data processing results
5) Raw data analysis, corrections and fitting results
6) Summary of SBRS Highbay RVS results
7) Summary of polarized equations used for test data processing
8) Polarized response fitting results
9) RVS Uncertainty Approach and Analysis
10) On-orbit RVS Determination via S/C Maneuver Issues
11) Discussion of phenomenological based RVS retrieval approaches
12) Discussion

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Data Analysis Contributors

- Kwo Fu "Vincent" Chiang
- Tim Dorman
- Gerry Godden
- Shi-Yue Qiu
- Xindong Wang
- Jack Xiong

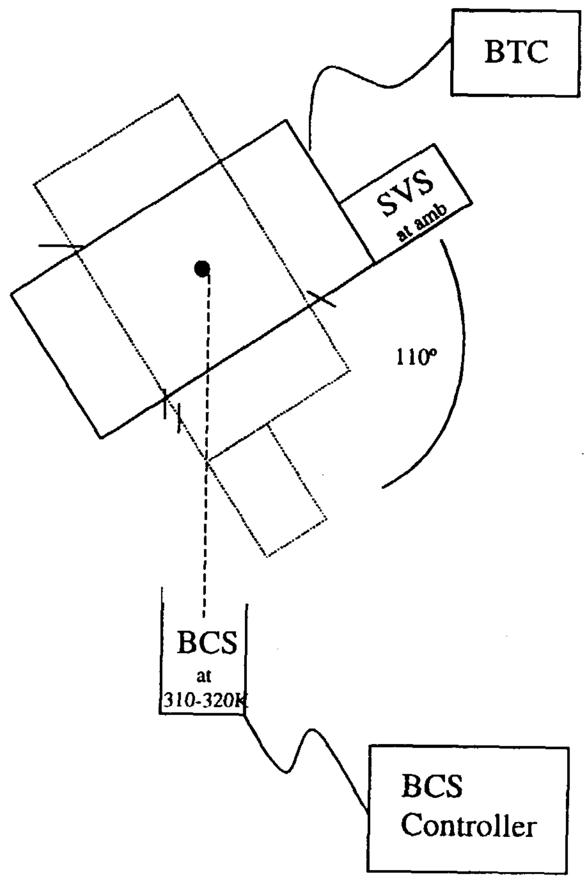
- SBRS Systems Engineering and Test Staffs

Overview of Highbay RVS Measurement Approach

Highbay RVS Test Key Features

- Test configuration:
  - MODIS aligned on rotary table (ROTAB)
  - Cold FPAs cooled with BTC
  - OBC Blackbody maintained at 310K
  - MWIR and LWIR PV detectors operated with "optimum CSUB" setting (not applicable for PC detectors)
  - SVS positioned at SVP; operated at ambient temperature
  - BCS aligned and operated at one of two temperature settings (310K and 320K)
- 3 data collects taken (310K_1, 320K_2, and 320K_3)
  - Data collects spanned 8 to 10 hours, each

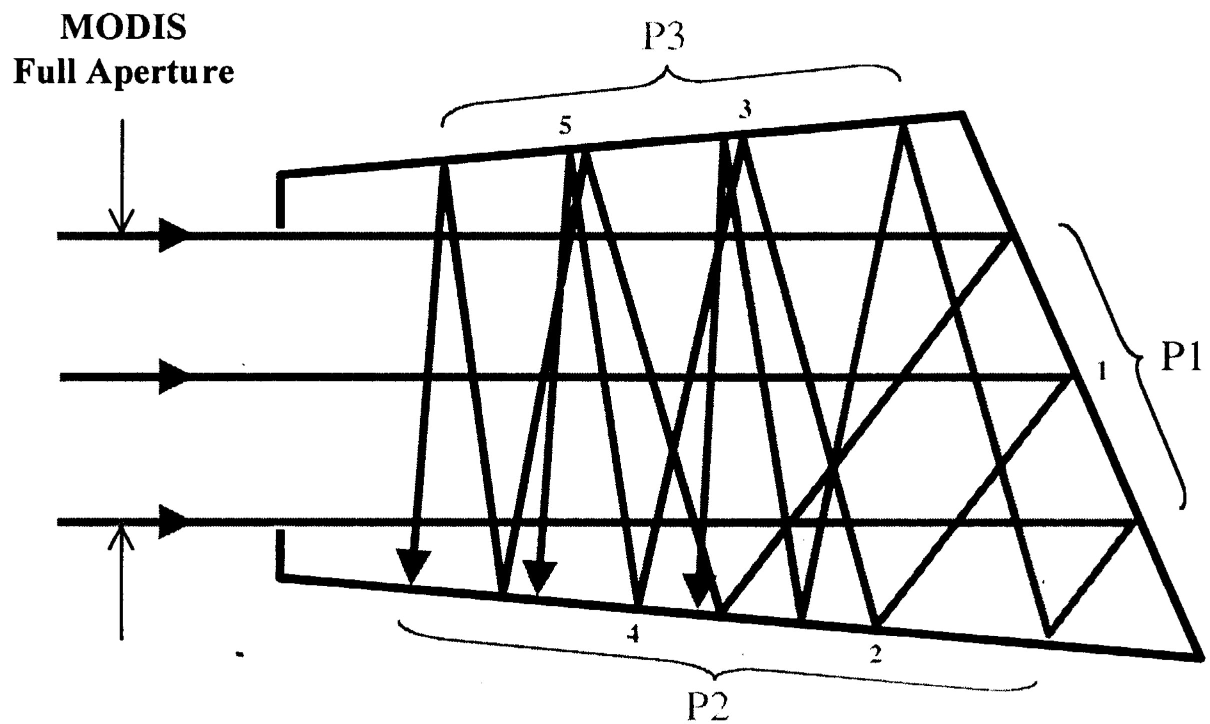
FM1 Highbay RVS Test Configuration



Summary of FM1 Highbay RVS Measurement Angles for 320K_3 Data Set

Collect #	Scan Angle (Degrees)	AOI (Degrees)
18	-53.62	11.19
1	-53.21	11.39
2	-53.01	11.50
3	-44.88	15.56
5	-23.50	26.25
10	-10.41	32.80
6	-0.41	37.80
7	9.59	42.80
8	25.61	50.80
9	37.64	56.82
11	37.64	56.82
12	44.63	60.32
16	44.63	60.32
13	52.11	64.06
14	53.33	64.67
15	53.33	64.67
17	53.33	64.67

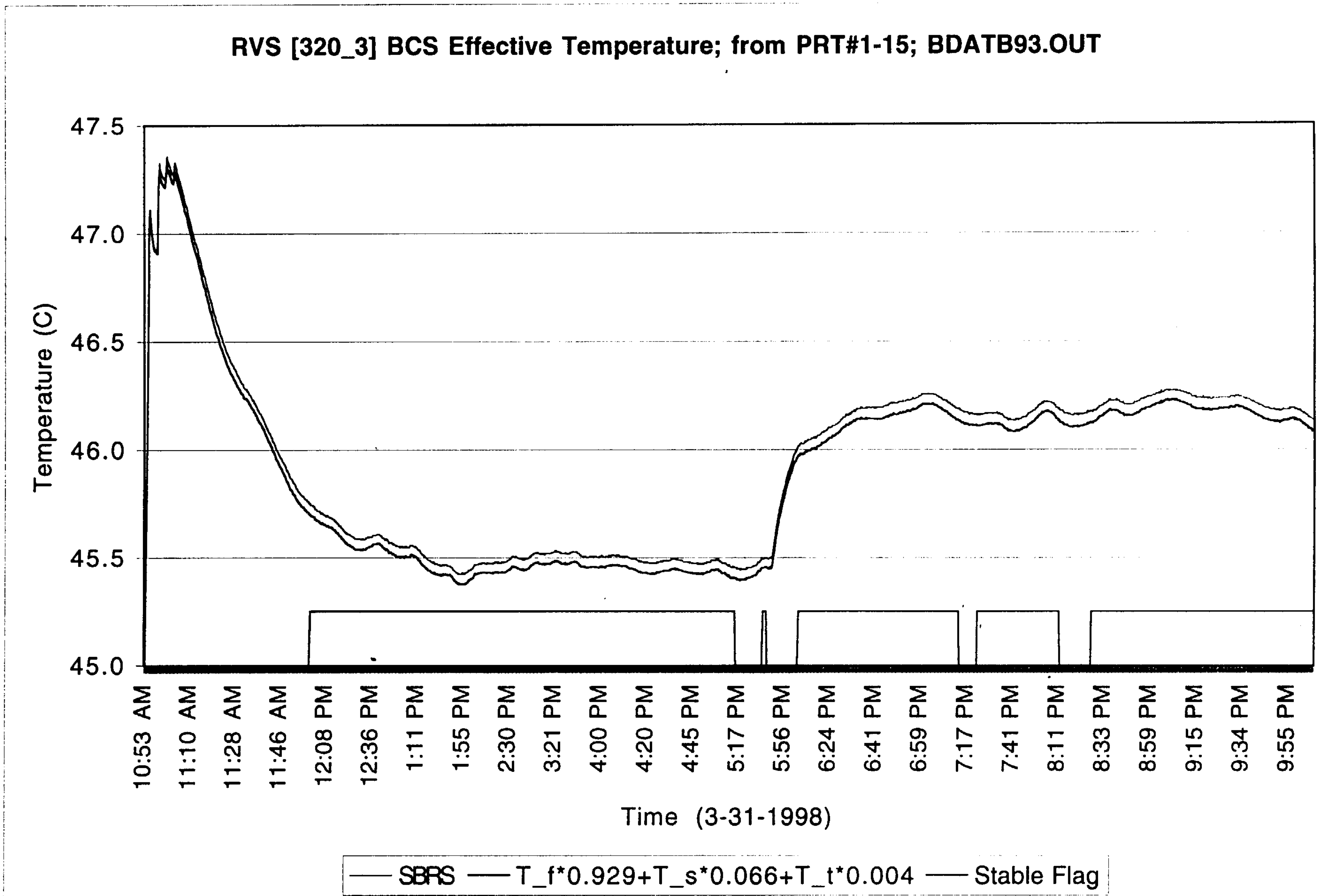
Blackbody Calibration Source (BCS)



$$L_{BCS} = W_{P1} \cdot L(\lambda, T_{P1}) + W_{P2} \cdot L(\lambda, T_{P2}) + W_{P3} \cdot L(\lambda, T_{P3})$$

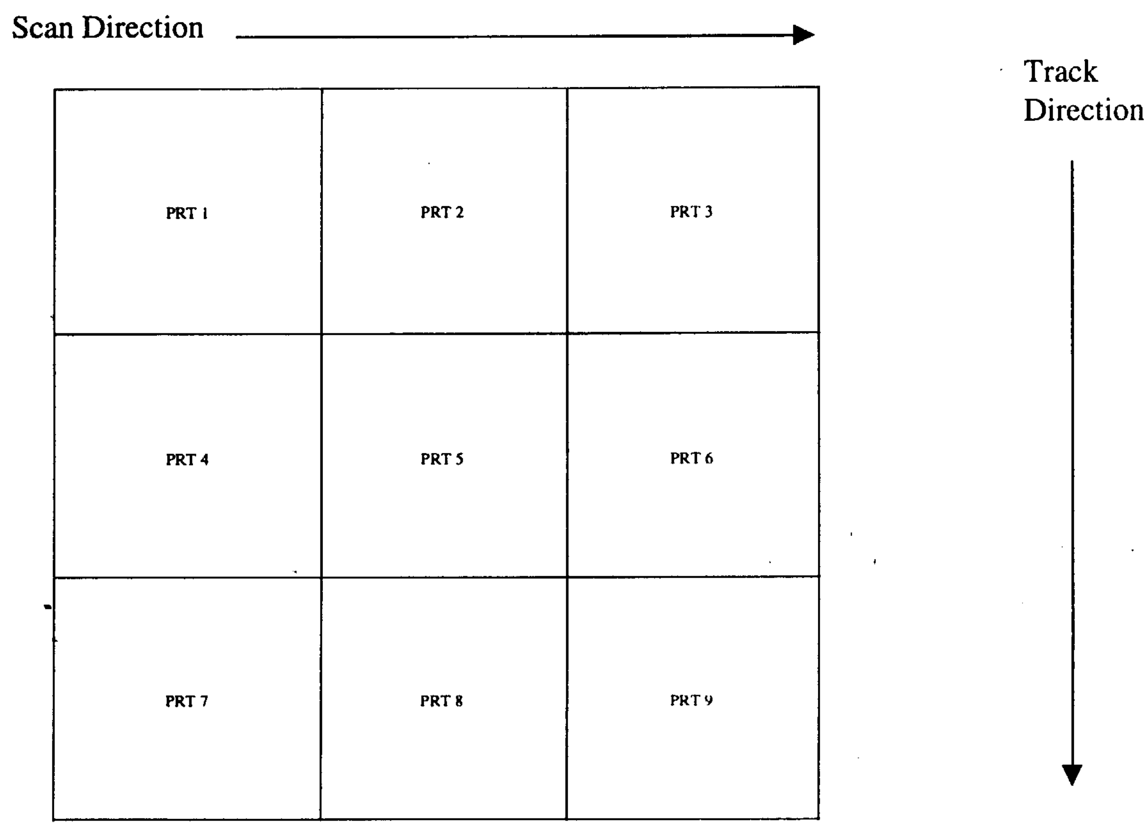
BCS Trapezoid Configuration Achieves > 0.998 Emissivity (From SBRS)

6a


RVS [320_3] BCS Effective Temperature; from PRT#1-15; BDATB93.OUT
47.5
47.0
46.5
46.0
45.5
45.0
Temperature (C)
10:53 AM
11:10 AM
11:28 AM
11:46 AM
12:08 PM
12:36 PM
1:11 PM
1:55 PM
2:30 PM
3:21 PM
4:00 PM
4:20 PM
4:45 PM
5:17 PM
5:56 PM
6:24 PM
6:41 PM
6:59 PM
7:17 PM
7:41 PM
8:11 PM
8:33 PM
8:59 PM
9:15 PM
9:34 PM
9:55 PM
Time (3-31-1998)
SBRS
T_f*0.929+T_s*0.066+T_t*0.004
Stable Flag

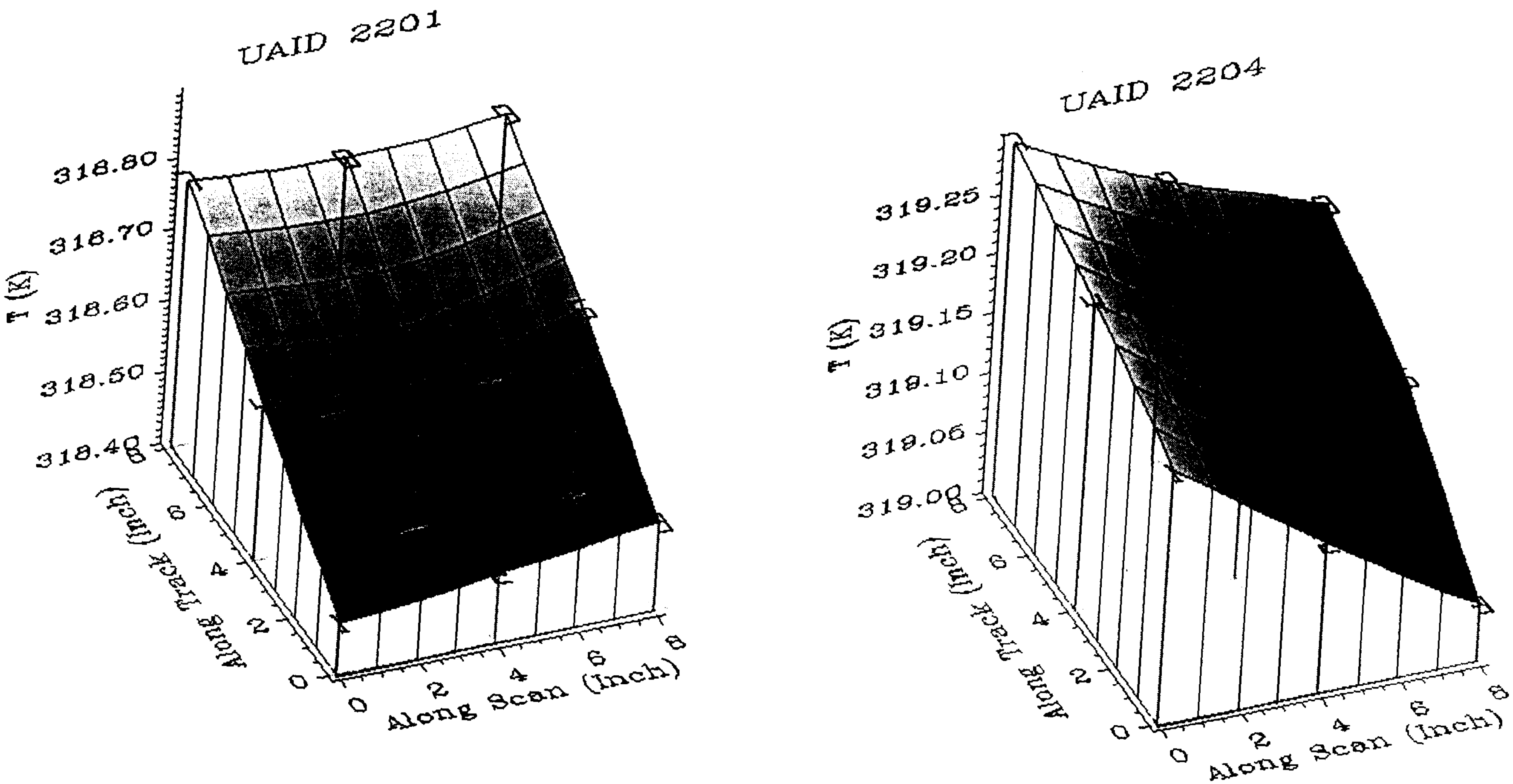
7

BCS First Bounce Plate Temperature Sensor Arrangement



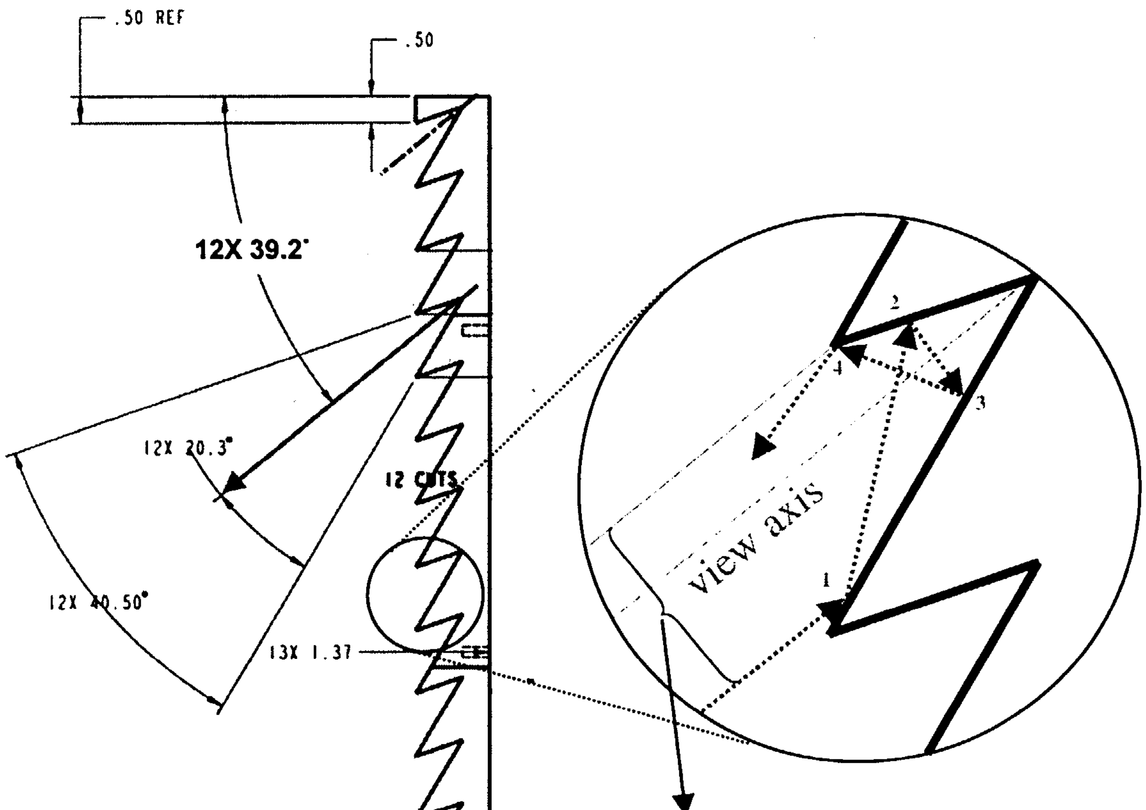
View is back of BCS

BCS First Bounce Plate 9 PRTs Interpolated Temperature Gradients
(Before and After 18:00 Hrs for 320K_3 Collect)

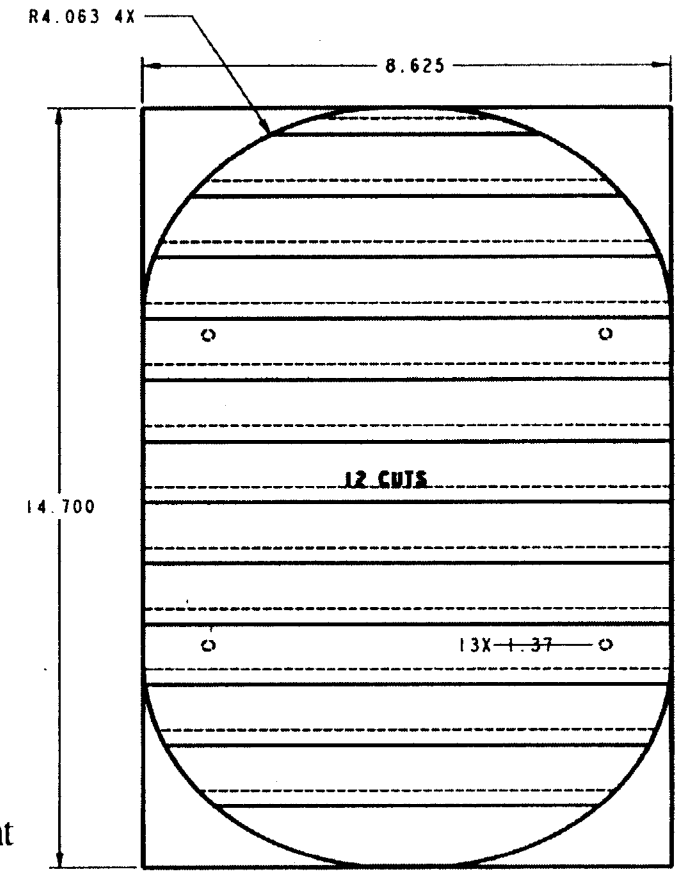


9a

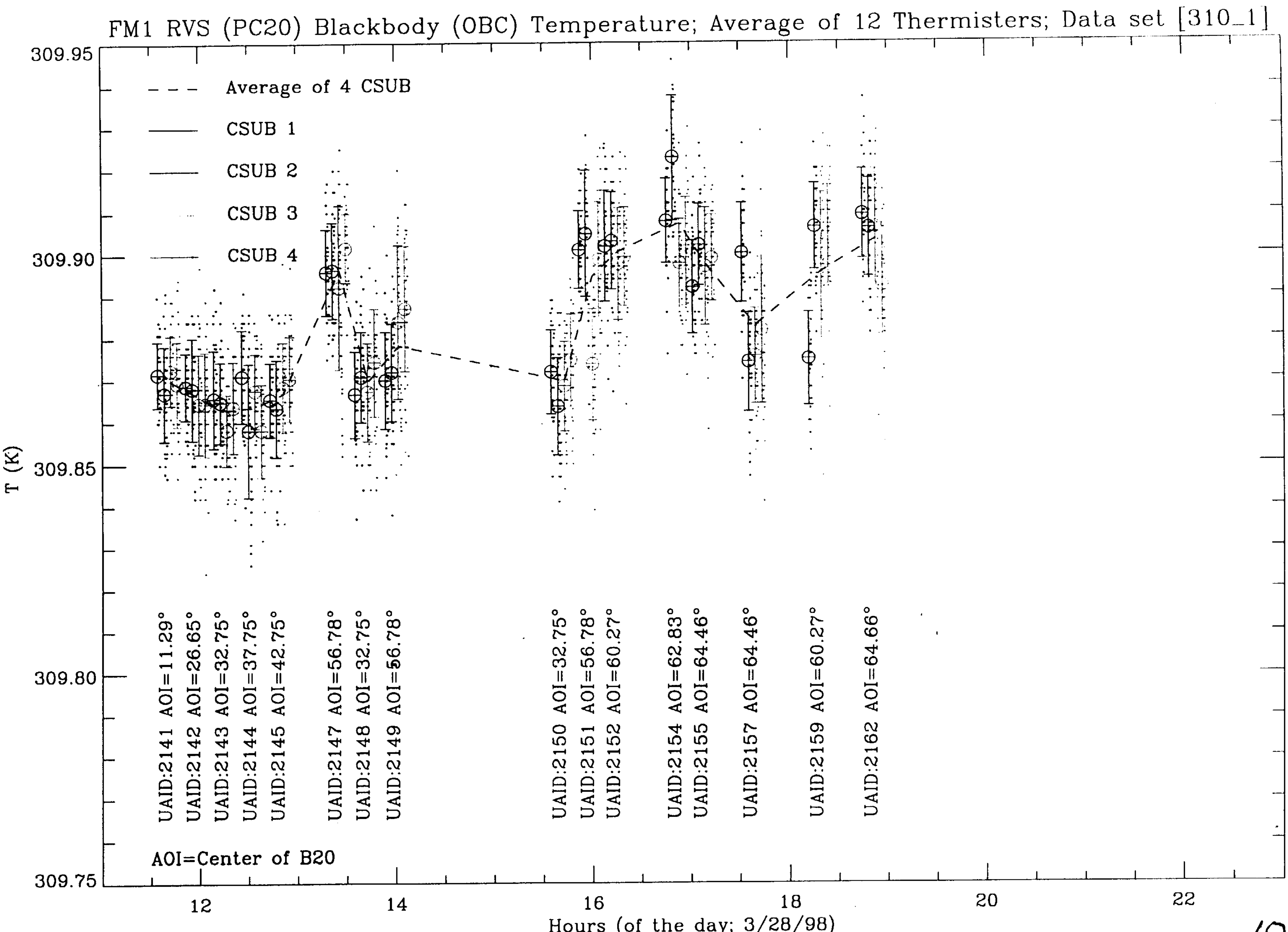
The MODIS On-Board Calibrator (OBC) Blackbody



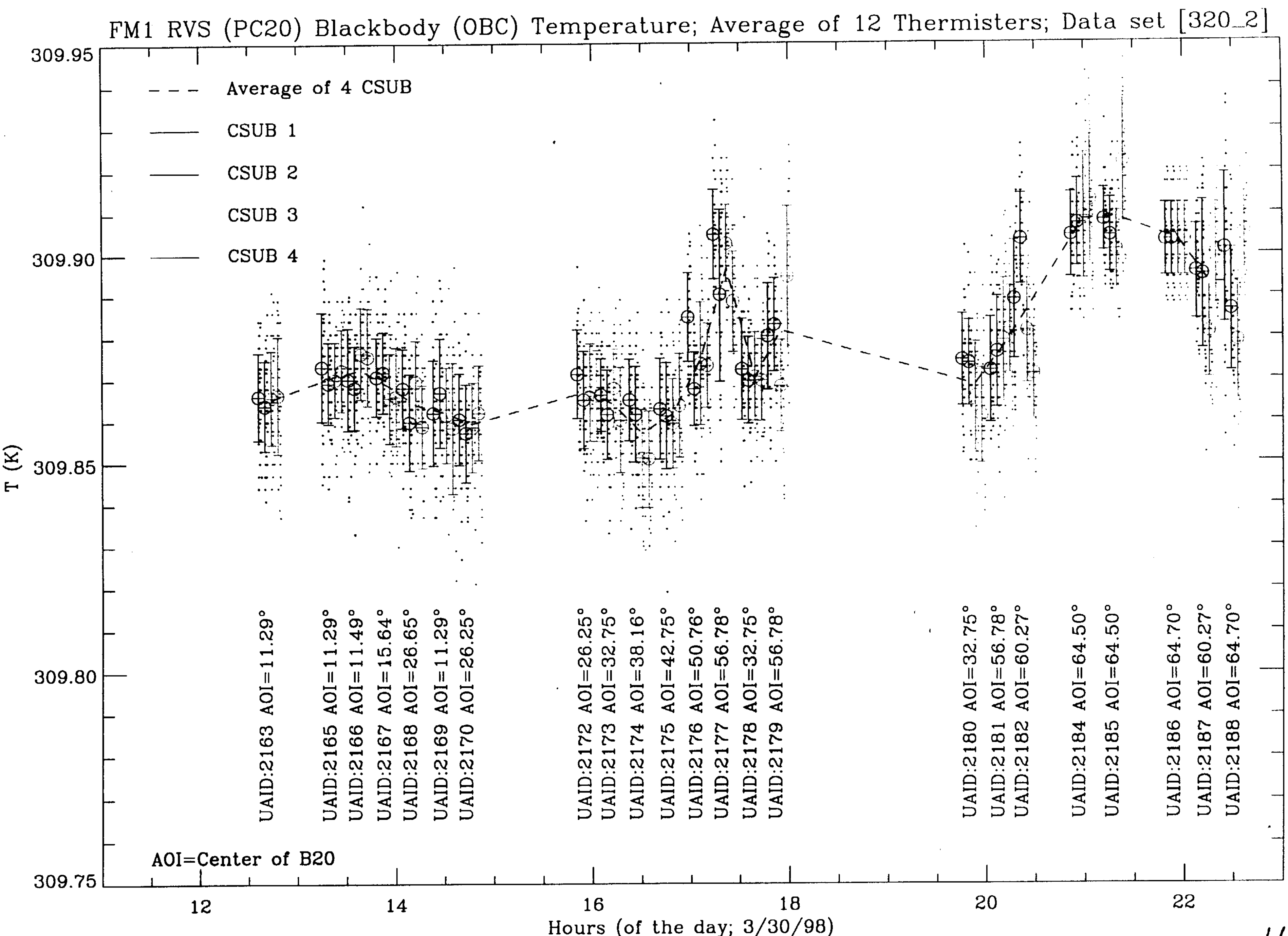
More than 90% of the reflected light undergoes at least four specular reflections to achieve > 0.992 emissivity

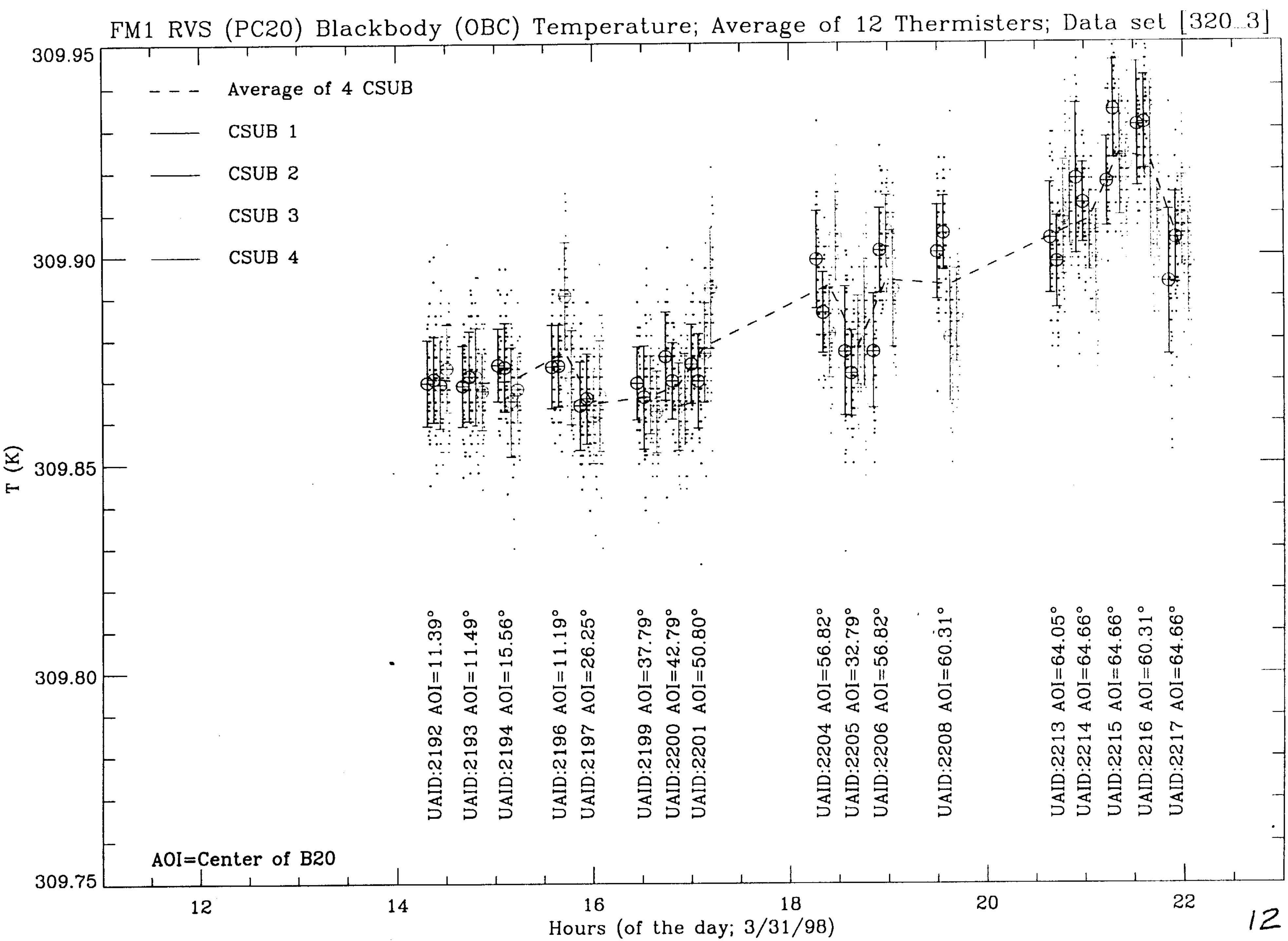


Dimensions: Inches



FM1 RVS (PC20) Blackbody (OBC) Temperature; Average of 12 Thermisters; Data set [310_1]
Average of 4 CSUB
CSUB 1
CSUB 2
CSUB 3
CSUB 4
309.95
309.90
309.85
309.80
309.75
T (K)
UAID:2141 AOI=11.29°
UAID:2142 AOI=26.65°
UAID:2143 AOI=32.75°
UAID:2144 AOI=37.75°
UAID:2145 AOI=42.75°
UAID:2147 AOI=56.78°
UAID:2148 AOI=32.75°
UAID:2149 AOI=56.78°
UAID:2150 AOI=32.75°
UAID:2151 AOI=56.78°
UAID:2152 AOI=60.27°
UAID:2154 AOI=62.83°
UAID:2155 AOI=64.46°
UAID:2157 AOI=64.46°
UAID:2159 AOI=60.27°
UAID:2162 AOI=64.66°
AOI=Center of B20
12
14
16
18
20
22
Hours (of the day; 3/28/98)

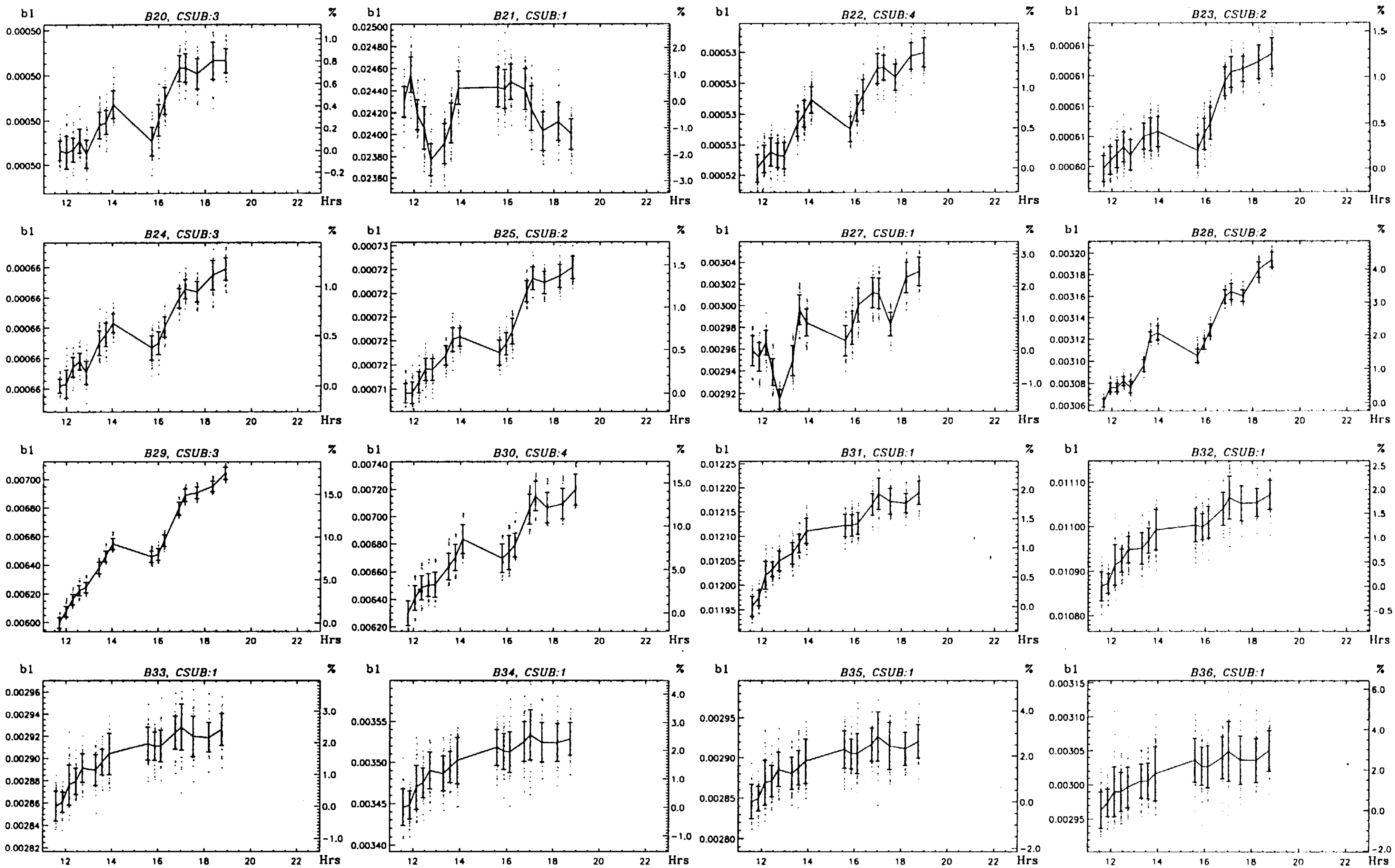

FM1 RVS (PC20) Blackbody (OBC) Temperature; Average of 12 Thermisters; Data set [320_2]
Average of 4 CSUB
CSUB 1
CSUB 2
CSUB 3
CSUB 4
309.95
309.90
309.85
309.80
309.75
T (K)
UAID:2163 AOI=11.29°
UAID:2165 AOI=11.29°
UAID:2166 AOI=11.49°
UAID:2167 AOI=15.64°
UAID:2168 AOI=26.65°
UAID:2169 AOI=11.29°
UAID:2170 AOI=26.25°
UAID:2172 AOI=26.25°
UAID:2173 AOI=32.75°
UAID:2174 AOI=38.16°
UAID:2175 AOI=42.75°
UAID:2176 AOI=50.76°
UAID:2177 AOI=56.78°
UAID:2178 AOI=32.75°
UAID:2179 AOI=56.78°
UAID:2180 AOI=32.75°
UAID:2181 AOI=56.78°
UAID:2182 AOI=60.27°
UAID:2184 AOI=64.50°
UAID:2185 AOI=64.50°
UAID:2186 AOI=64.70°
UAID:2187 AOI=60.27°
UAID:2188 AOI=64.70°
AOI=Center of B20
12
14
16
18
20
22
Hours (of the day; 3/30/98)



FM1 RVS (PC20) Blackbody (OBC) Temperature; Average of 12 Thermisters; Data set [320_3]
Average of 4 CSUB
CSUB 1
CSUB 2
CSUB 3
CSUB 4
309.95
309.90
309.85
309.80
309.75
T (K)
UAID:2192 AOI=11.39°
UAID:2193 AOI=11.49°
UAID:2194 AOI=15.56°
UAID:2196 AOI=11.19°
UAID:2197 AOI=26.25°
UAID:2199 AOI=37.79°
UAID:2200 AOI=42.79°
UAID:2201 AOI=50.80°
UAID:2204 AOI=56.82°
UAID:2205 AOI=32.79°
UAID:2206 AOI=56.82°
UAID:2208 AOI=60.31°
UAID:2213 AOI=64.05°
UAID:2214 AOI=64.66°
UAID:2215 AOI=64.66°
UAID:2216 AOI=60.31°
UAID:2217 AOI=64.66°
AOI=Center of B20
12
14
16
18
20
22
Hours (of the day; 3/31/98)

Channel 5 Linear Gain $\langle b1_{OBC} \rangle_{50\ frames}$ for 40 Scans vs Experiment Time (Hours)

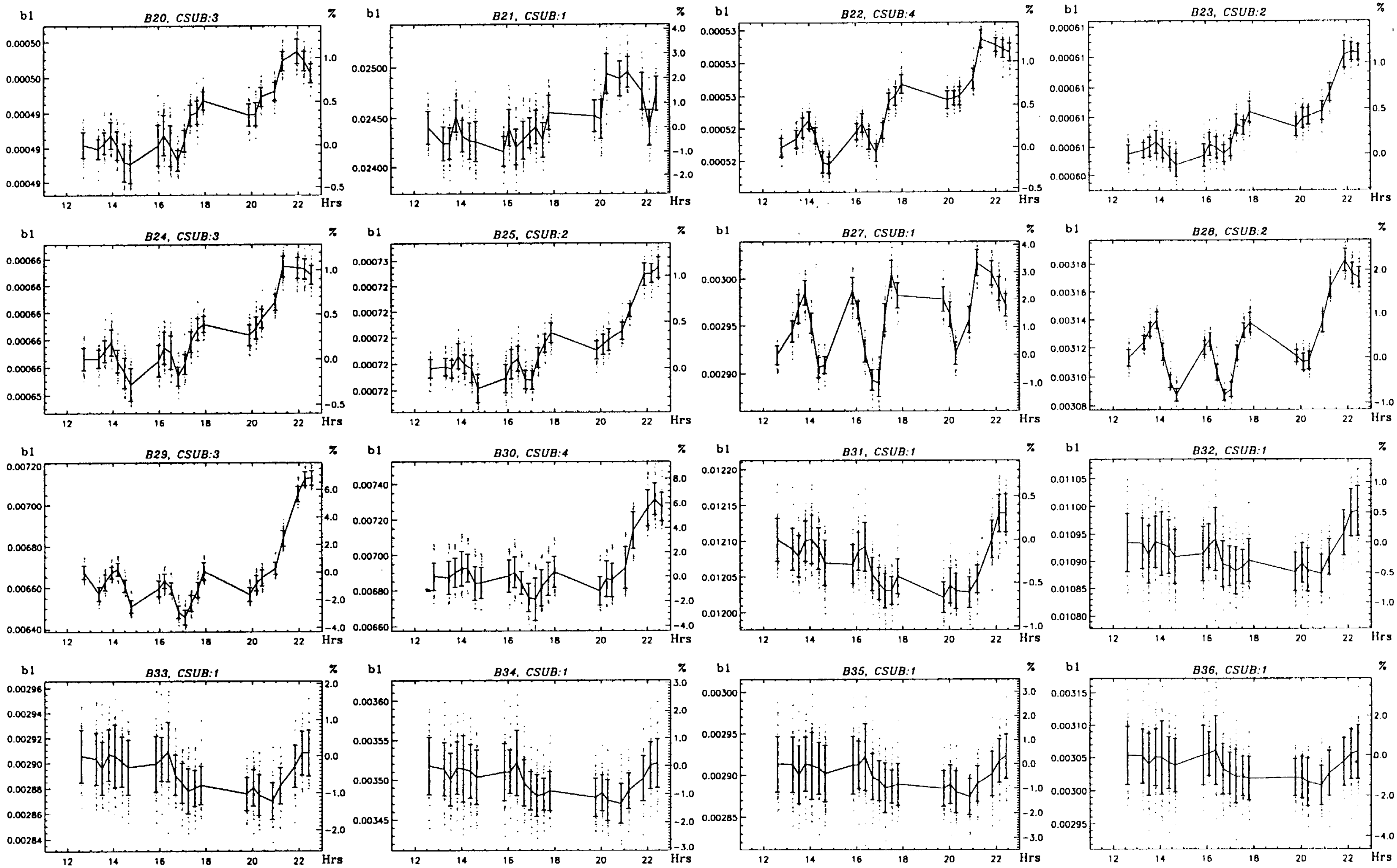
(310K_1 Data Set; Mirror A; w/50frame×40scan Average and 1−σ Error Bars; % Change from 1st Average Noted on Right Axis)



Note: $b1=(L_{OBC}-L_{SVS})/dn_{OBC}$

Channel 5 Linear Gain $\langle b1_{OBC} \rangle_{50\ frames}$ for 40 Scans vs Experiment Time (Hours)

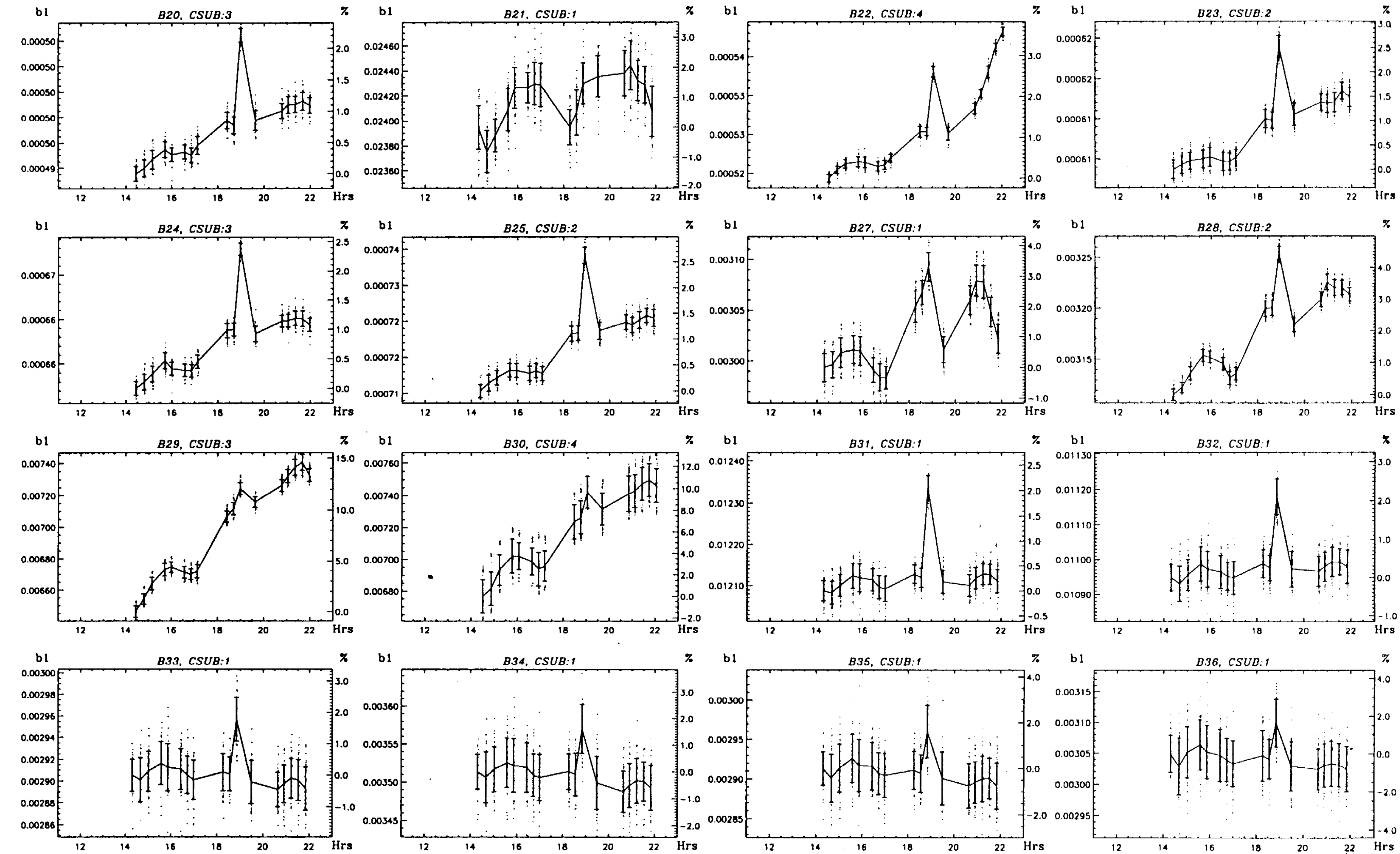
(320K_2 Data Set; Mirror A; w/50frame×40scan Average and 1-σ Error Bars; % Change from 1st Average Noted on Right Axis)



Note: $b1=(L_{OBC}-L_{SVS})/dn_{OBC}$

Channel 5 Linear Gain $<b1_{OBC}>_{50\ frames}$ for 40 Scans vs Experiment Time (Hours)

(320K_3 Data Set; Mirror A; w/50frame×40scan Average and 1−σ Error Bars; % Change from 1st Average Noted on Right Axis)



Note: $b1=(L_{OBC}-L_{SVS})/dn_{OBC}$

Unpolarized Equations Used for Analysis of Highbay RVS Test Data

RVS Equations

Relationship between the BCS path radiance and the detector's response

$$RVS_\theta \cdot L_{BCS(\theta)} + (\tau - RVS_\theta) \cdot L_{SM} + L_{BKG} = DN^{o}_{BCS} + b_1 \cdot DN^{s}_{BCS} \qquad (1)$$

RVS_θ - RVS at AOI = θ

$L_{BCS(\theta)}$, L_{SM}, L_{BKG} - Radiance of BCS, Scan Mirror, and Background

τ - system effective transmittance

b_1 - detector linear response

DN - instrument digital number $DN = DN^{O} + DN^{S}$ (offset term + signal term)

RVS Equations (cont'd)

Relationship between the BCS path radiance and the detector's response

$$RVS_{\theta} \cdot L_{SVS(\theta)} + (\tau - RVS_{\theta}) \cdot L_{SM} + L_{BKG} = DN^{o}_{SVS} + b_1 \cdot DN^{s}_{SVS} \qquad (2)$$

From Equations (1) and (2)

$$RVS_{BCS(\theta)} \cdot (L_{BCS(\theta)} - L_{SM}) = b_1 \cdot (DN_{BCS} - DN_{SVS}) + RVS_{SVS} \cdot (L_{SVS} - L_{SM}) \qquad (3)$$

For highbay test $T_{SM} \approx T_{SVS}$. For $T_{BCS} = 320K$, the second term on the RHS of Equation (3) is ~ 0.1%, then

$$RVS_{BCS(\theta)} = b_1 \cdot \frac{DN_{BCS} - DN_{SVS}}{L_{BCS(\theta)} - L_{SVS}} \qquad (4)$$

RVS Equations (cont'd)

Using the On Board Calibrator (OBC) to correct detector's scan to scan response fluctuation, Equation (4) becomes

$$RVS_{BCS(\theta)} = \underbrace{RVS_{OBC} \cdot \frac{L_{OBC} - L_{SVS}}{DN_{OBC} - DN_{SVS}}}_{b_1} \cdot \frac{DN_{BCS} - DN_{SVS}}{L_{BCS(\theta)} - L_{SVS}} \qquad (5)$$

The normalized RVS (to AOI = 10.75°)

$$RVS^{Norm}(\theta) = \frac{RVS_{BCS(\theta)}}{RVS_{BCS(\theta=10.75^\circ)}} = f(DN_S, \lambda, T_S, \varepsilon_{OBC}, \theta) \qquad (6)$$

RVS Uncertainty

Approach 1

$$RVS^{Norm}(\theta) = \frac{f(DN_S, \lambda, T_S, \varepsilon_{OBC}, \theta)}{f(DN_S, \lambda, T_S, \varepsilon_{OBC}, \theta = 10.75^\circ)} = \frac{f(x_i, \theta)}{f(y_i, \theta = 10.75^\circ)} \qquad (7)$$

$$\frac{\Delta RVS^{Norm}(\theta)}{RVS^{Norm}(\theta)} = \sqrt{\sum \left(\frac{\partial f(x_i, \theta)}{\partial x_i} \cdot \frac{\Delta x_i}{f(x_i, \theta)} \right)^2} \qquad (8)$$

Approach 2

Computer $RVS^{Norm}(\theta)_i$ for Measurement i (=1, 2, 3)
(frame, scan, channel average)

$$\Delta RVS^{Norm}(\theta) = \mathrm{stdev}\{RVS^{Norm}(\theta)_1, RVS^{Norm}(\theta)_2, RVS^{Norm}(\theta)_3\} \qquad (9)$$

Scan Mirror Witness Sample Reflectance Measurements

Summary of NPL Scan Mirror Witness Sample Polarized Reflectance Measurements

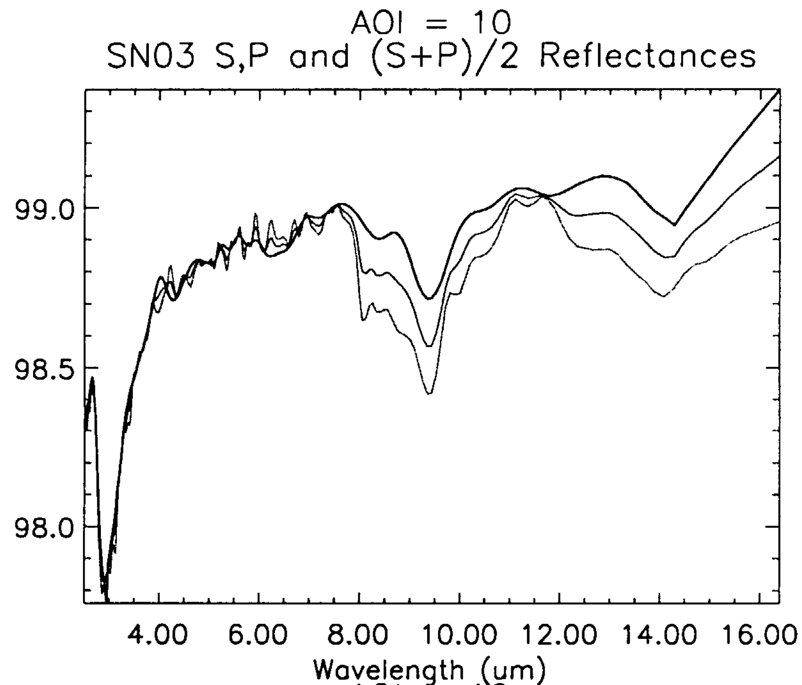
- 2 witness samples from PFM scan mirror (SN03 and SN04), and 2 witness samples from FM1 scan mirror (SN08 and SN16)
  - SN03 and SN04 samples previously measured by Lincoln Laboratory on two separate occasions
- Measured s and p polarization reflectance of 4 witness samples over 2.50 to 15.15 micron wavelength region, in 10 cm^{-1} increments, for 10°, 26.7°, 38.0°, 50.0° and 65.5° Angles-of-Incidence (AOIs).
- NPL estimated 95% confidence level uncertainties quoted at:

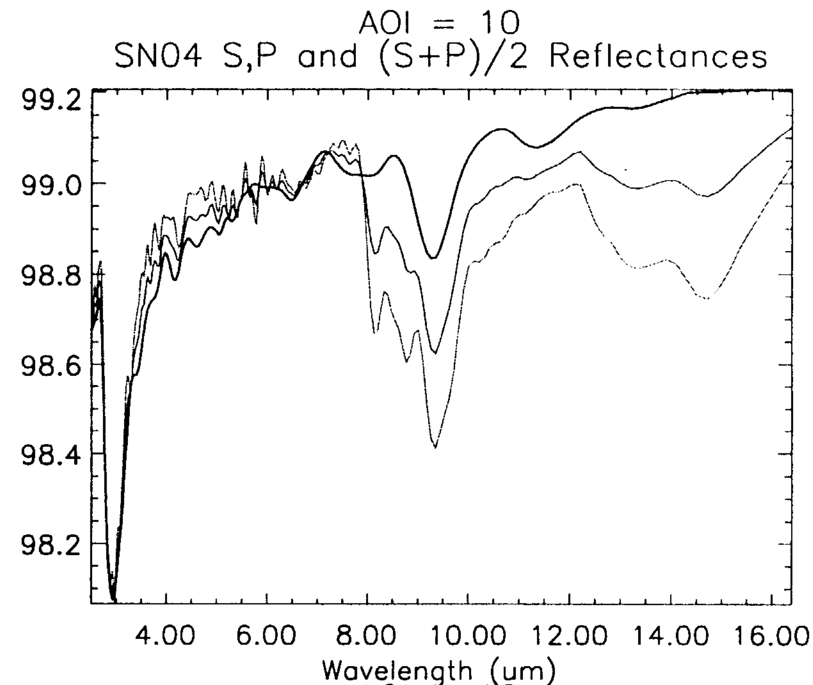
  ±0.4% for s-polarization for 2.5 to 12.5 microns range, rising to ±0.4% to ±0.7% between 12.5 and 15.15 microns. Except ±0.3% for 10° AOI over the whole wavelength range.

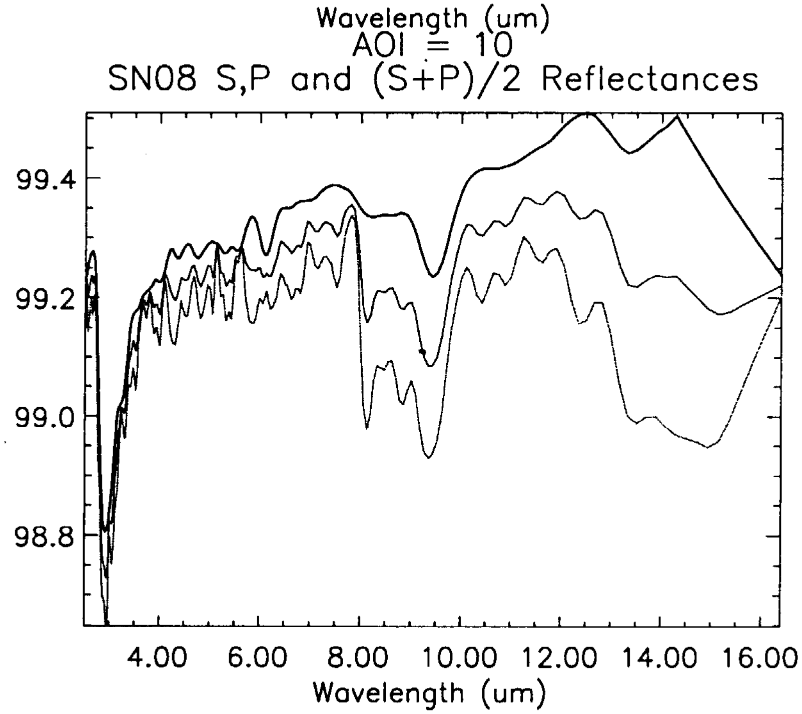
  ±0.3% for p-polarization
- Average reflectance results compare to within ±1% with Lincoln Laboratory measurements for SN03 and SN04 samples
- Significant differences between PFM and FM1 samples exist

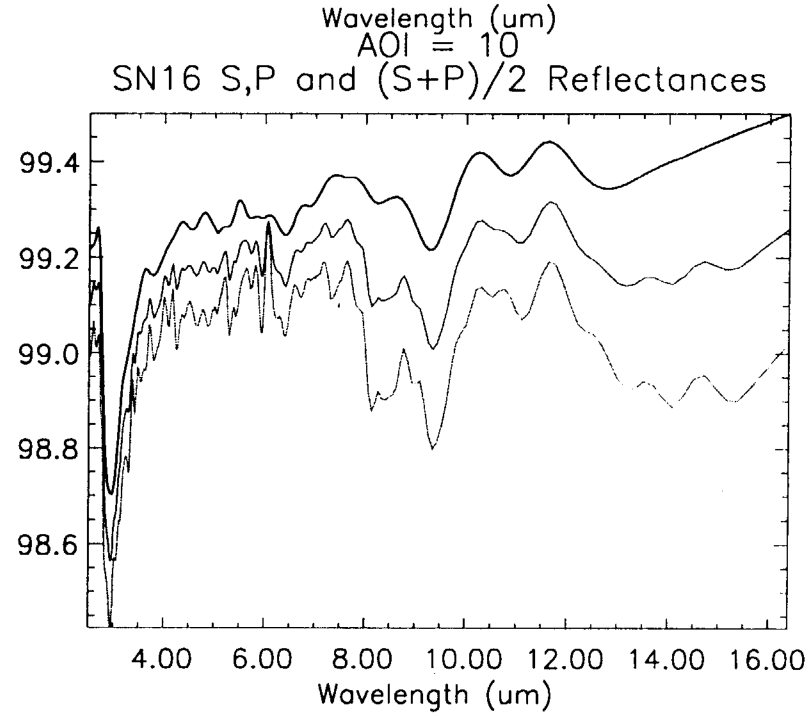
Summary of Scan Mirror Witness Sample Polarized Reflectance Measurements

- Graph Summaries Provided for:
  - NPL S, P and Average reflectances for SN03, SN04, SN08 and SN16 samples at 6 AOIs
  - Comparisons of LL and NPL SN03 and SN04 measurements
  - Sample-to-sample variations for PFM SN03/SN04 and FM1 SN08/SN16 samples
  - FM1 and PFM Average Reflectances versus wavelength
  - FM1 and PFM Polarization Factors versus wavelength
  - FM1 Band-weighted Average Reflectances versus AOI
- Table of FM1 Band's Band-weighted S, P and Average Reflectances for 6 AOIs

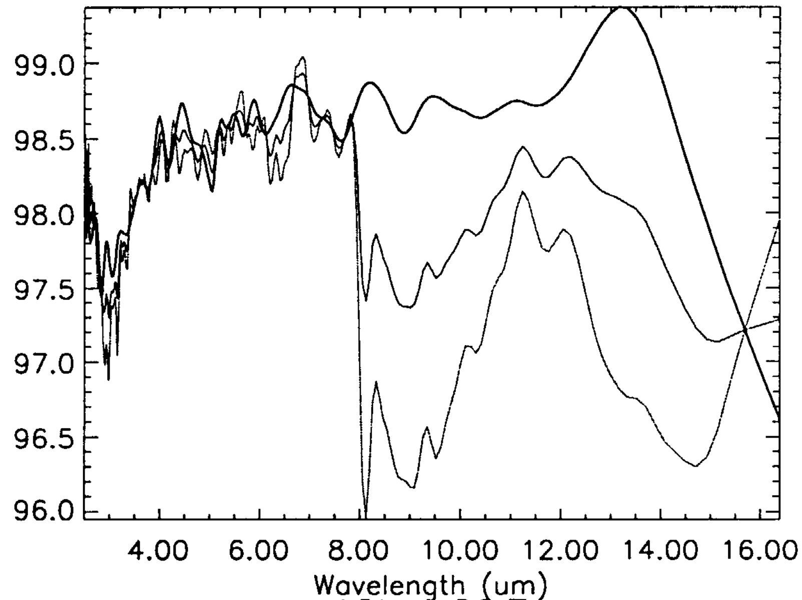

AOI = 10
SN03 S,P and (S+P)/2 Reflectances
99.0
98.5
98.0
4.00 6.00 8.00 10.00 12.00 14.00 16.00
Wavelength (um)


AOI = 10
SN04 S,P and (S+P)/2 Reflectances
99.2
99.0
98.8
98.6
98.4
98.2
4.00 6.00 8.00 10.00 12.00 14.00 16.00
Wavelength (um)

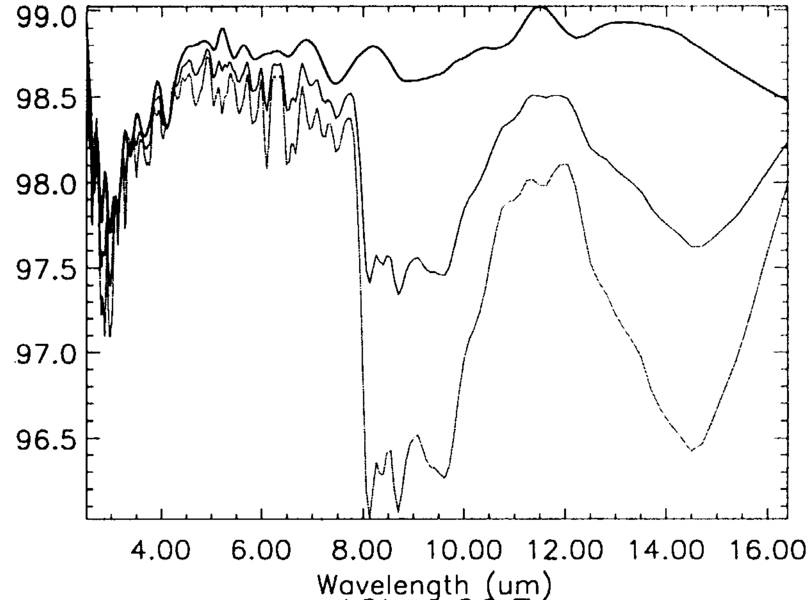

AOI = 10
SN08 S,P and (S+P)/2 Reflectances
99.4
99.2
99.0
98.8
4.00 6.00 8.00 10.00 12.00 14.00 16.00
Wavelength (um)


AOI = 10
SN16 S,P and (S+P)/2 Reflectances
99.4
99.2
99.0
98.8
98.6
4.00 6.00 8.00 10.00 12.00 14.00 16.00
Wavelength (um)

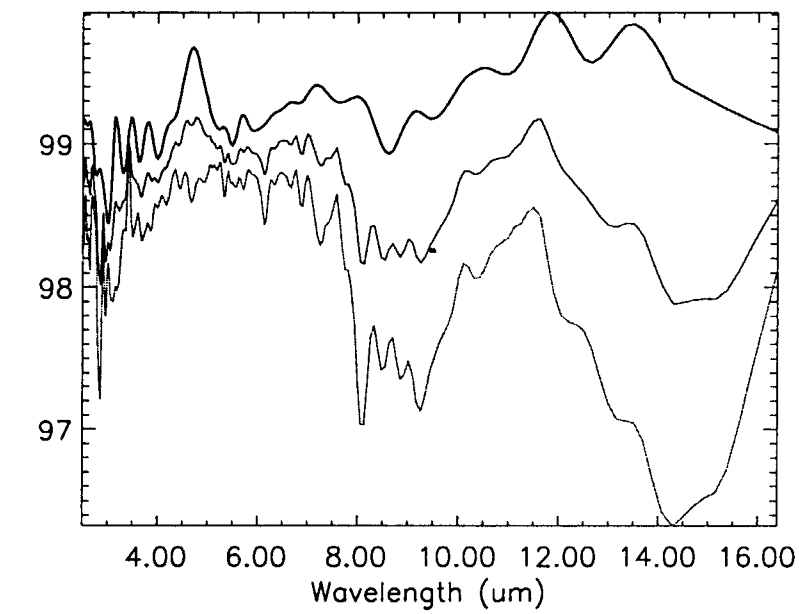
AOI = 26.7
SN03 S,P and (S+P)/2 Reflectances



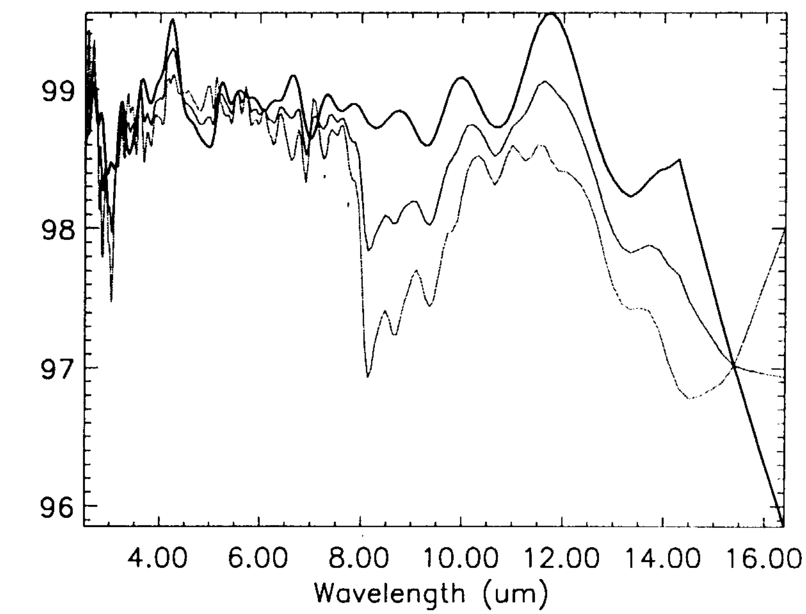
AOI = 26.7
SN04 S,P and (S+P)/2 Reflectances

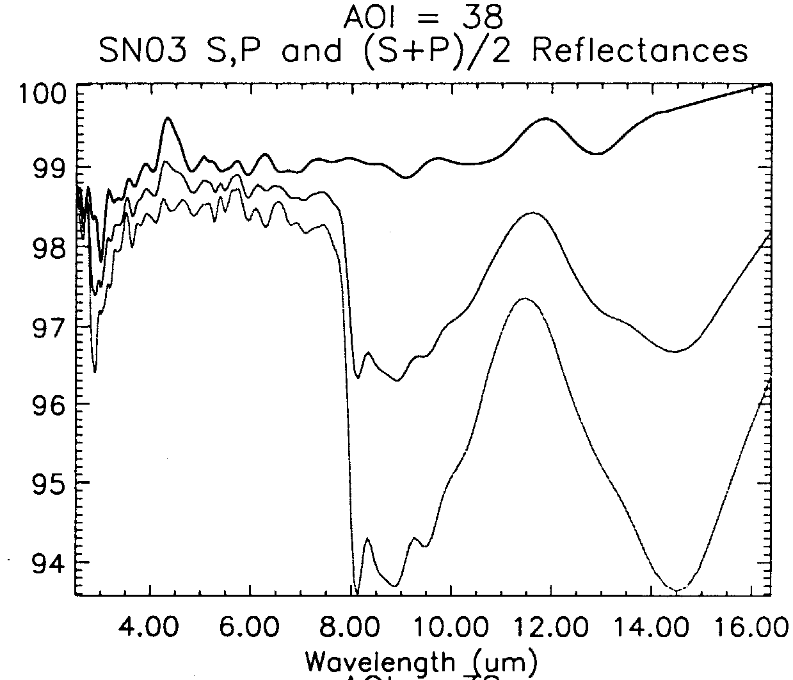


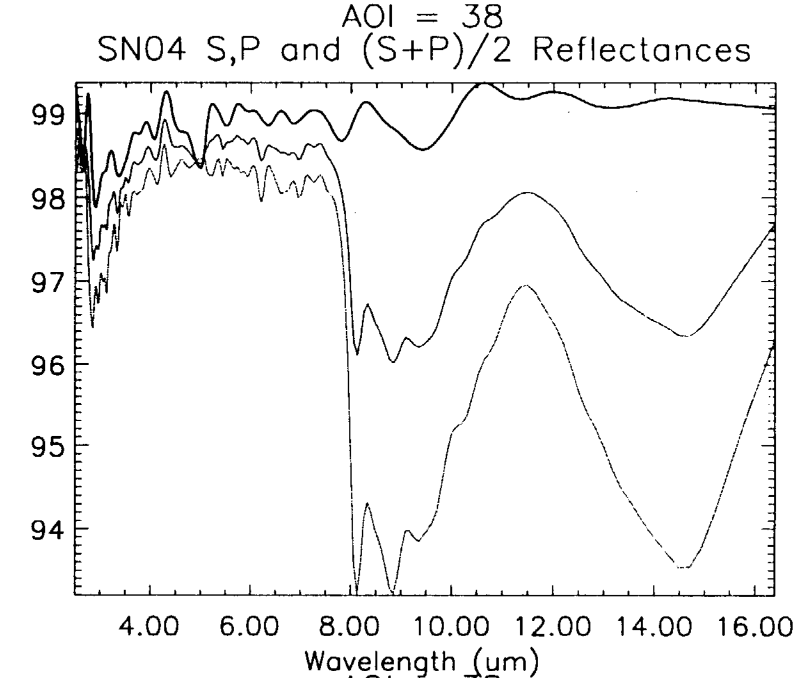
AOI = 26.7
SN08 S,P and (S+P)/2 Reflectances

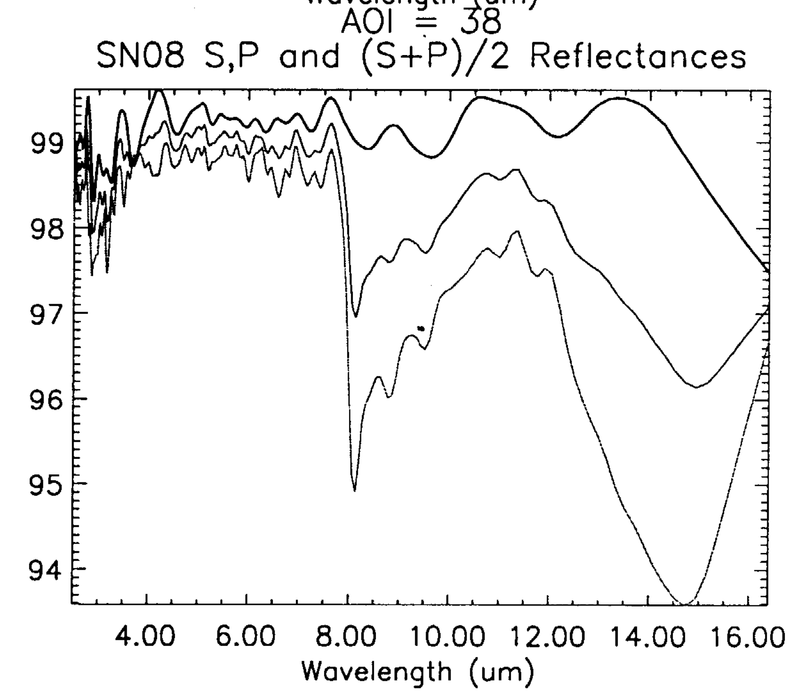


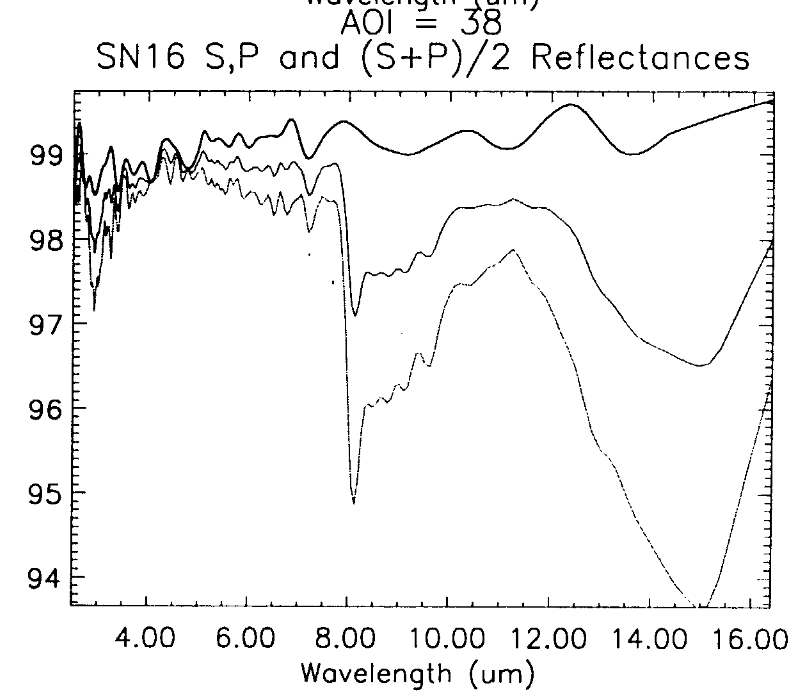
AOI = 26.7
SN16 S,P and (S+P)/2 Reflectances

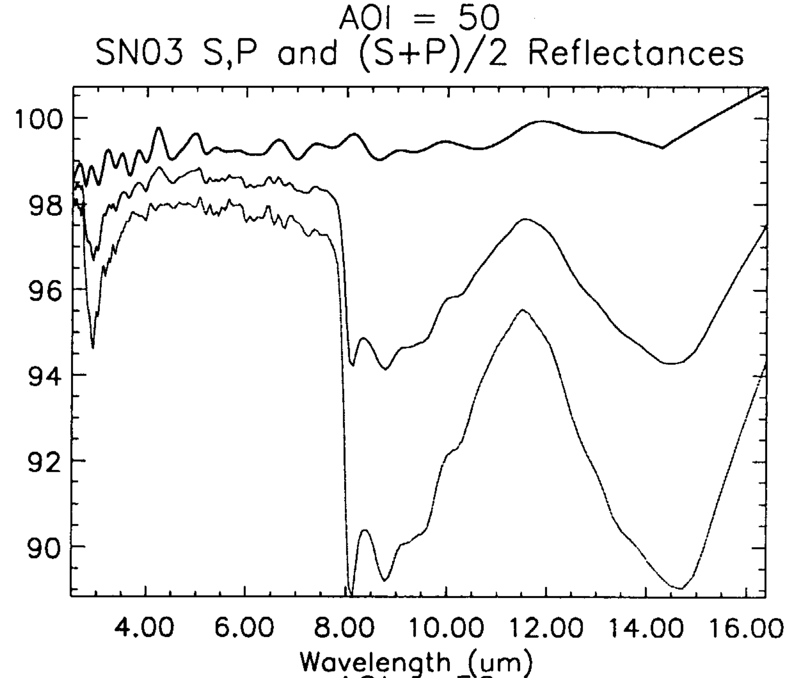


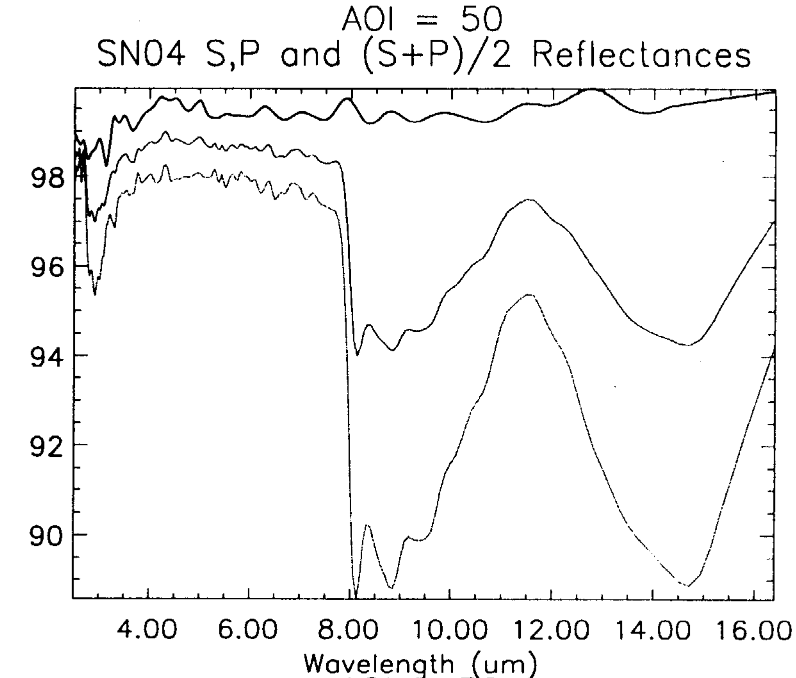

AOI = 38
SN03 S,P and (S+P)/2 Reflectances
100
99
98
97
96
95
94
4.00
6.00
8.00
10.00
12.00
14.00
16.00
Wavelength (um)

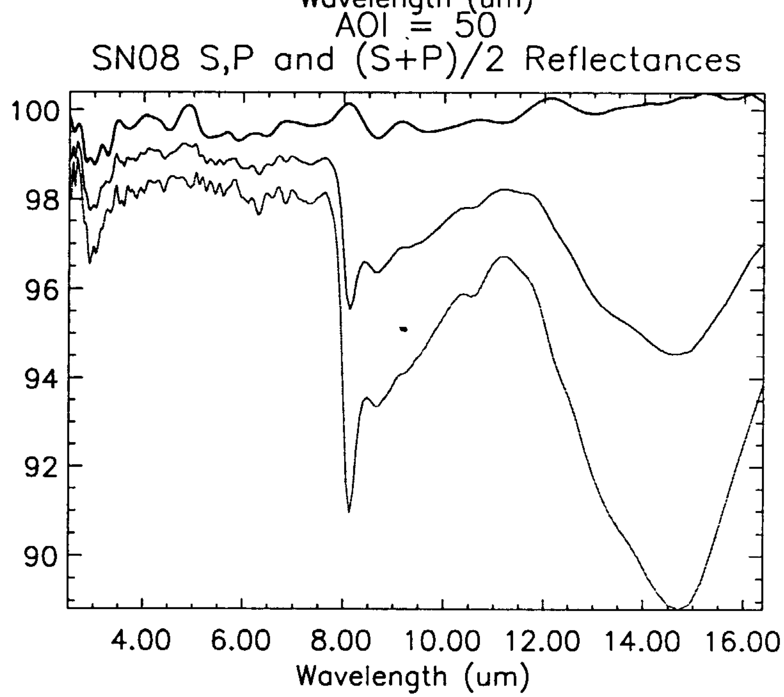

AOI = 38
SN04 S,P and (S+P)/2 Reflectances
99
98
97
96
95
94
4.00
6.00
8.00
10.00
12.00
14.00
16.00
Wavelength (um)

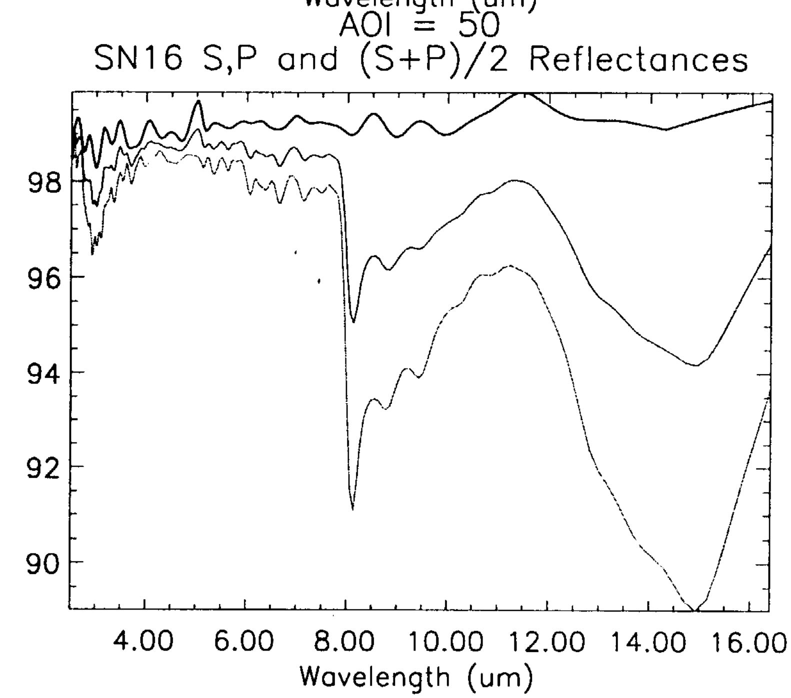

AOI = 38
SN08 S,P and (S+P)/2 Reflectances
99
98
97
96
95
94
4.00
6.00
8.00
10.00
12.00
14.00
16.00
Wavelength (um)

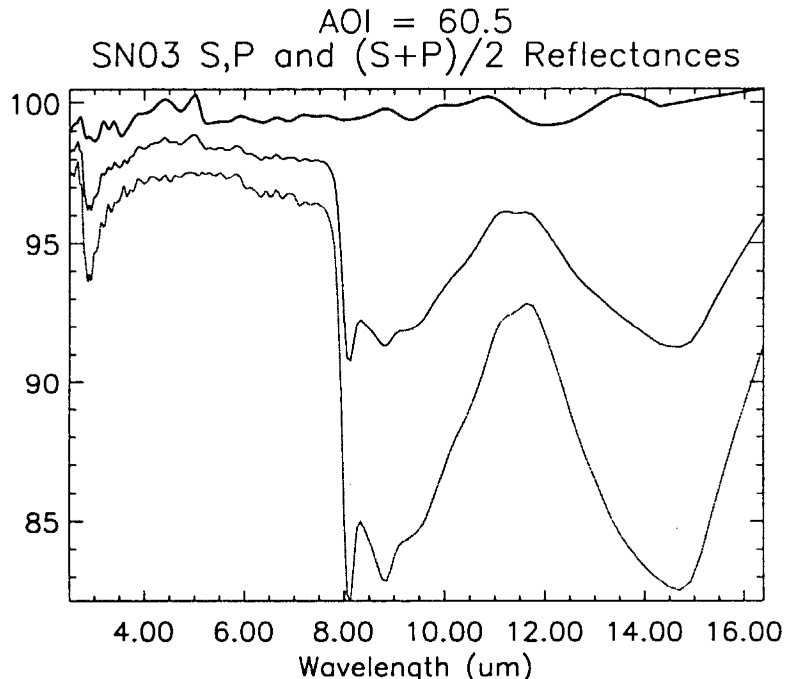

AOI = 38
SN16 S,P and (S+P)/2 Reflectances
99
98
97
96
95
94
4.00
6.00
8.00
10.00
12.00
14.00
16.00
Wavelength (um)

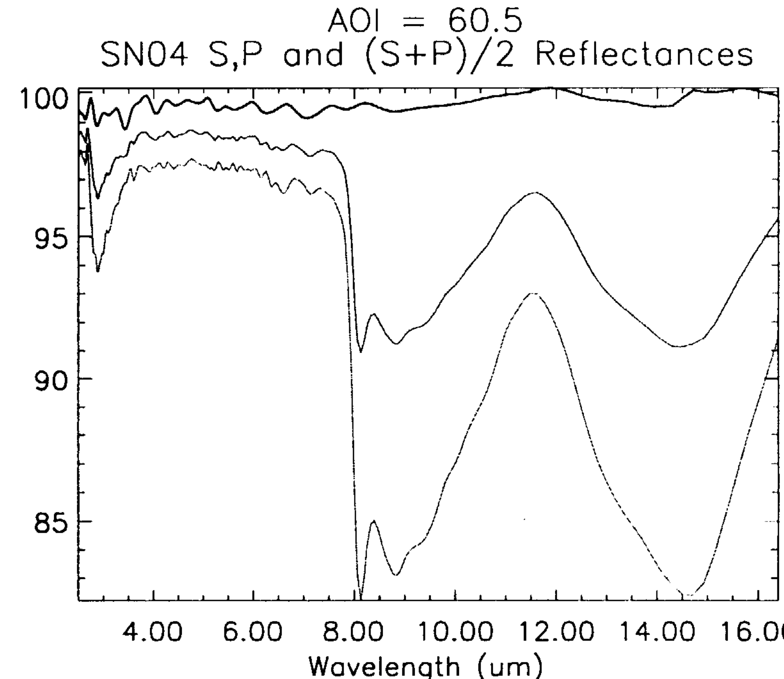

AOI = 50
SN03 S,P and (S+P)/2 Reflectances
100
98
96
94
92
90
4.00
6.00
8.00
10.00
12.00
14.00
16.00
Wavelength (um)

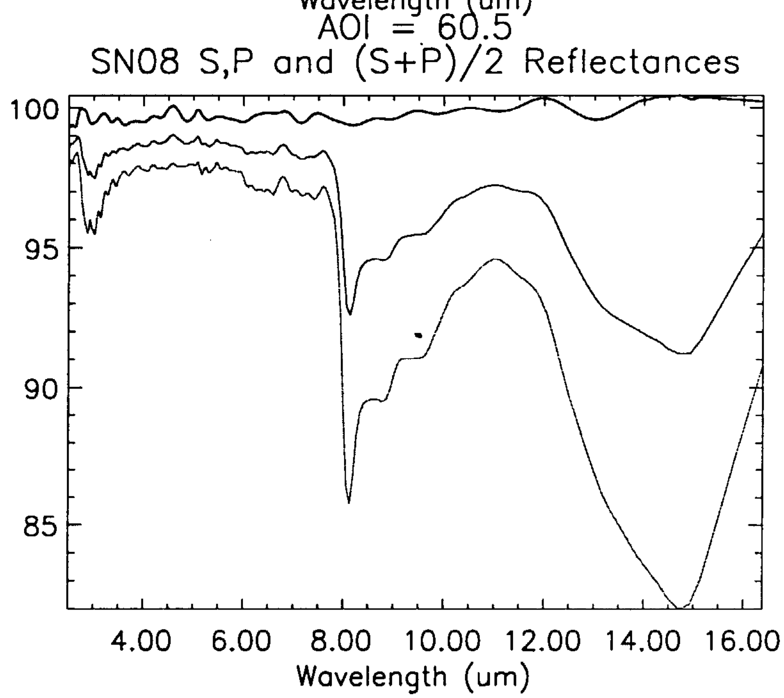

AOI = 50
SN04 S,P and (S+P)/2 Reflectances
98
96
94
92
90
4.00
6.00
8.00
10.00
12.00
14.00
16.00
Wavelength (um)

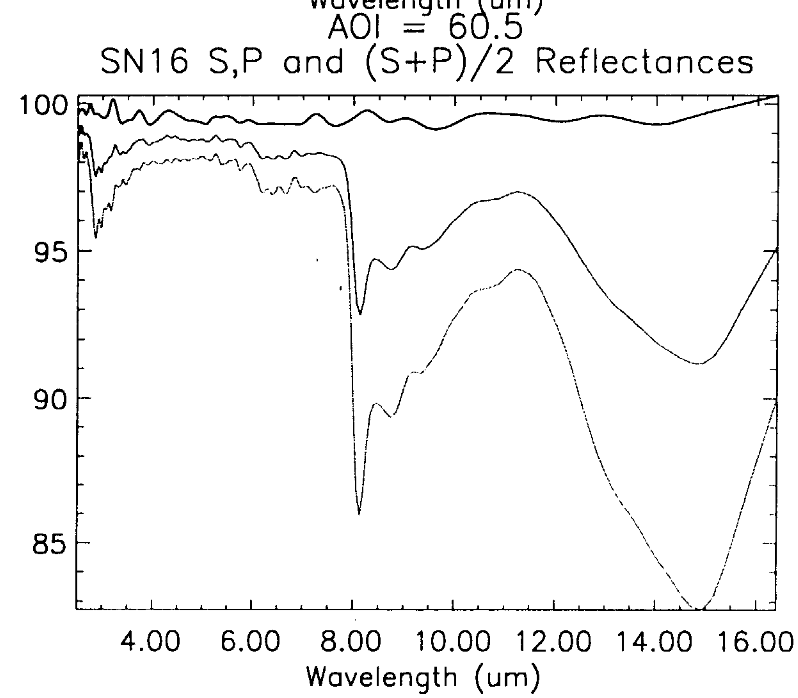

AOI = 50
SN08 S,P and (S+P)/2 Reflectances
100
98
96
94
92
90
4.00
6.00
8.00
10.00
12.00
14.00
16.00
Wavelength (um)

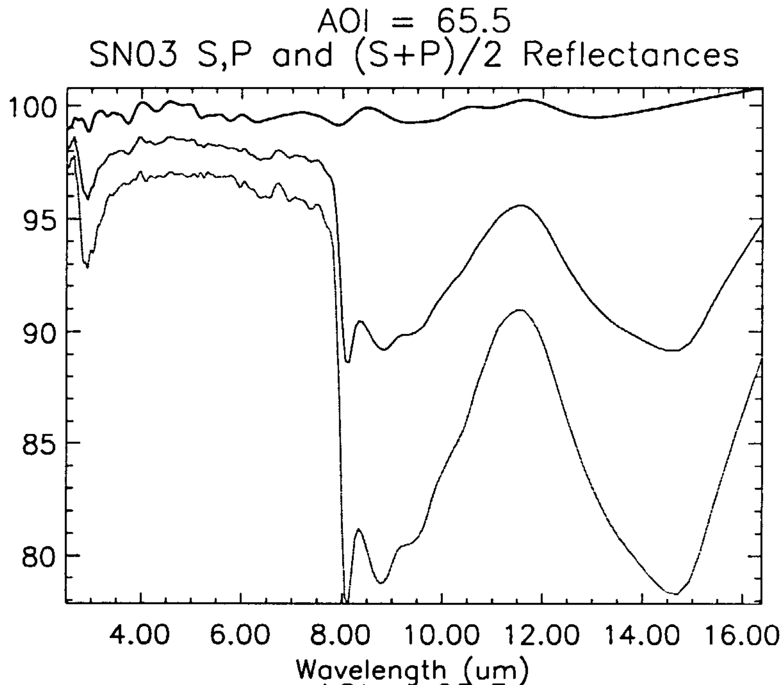

AOI = 50
SN16 S,P and (S+P)/2 Reflectances
98
96
94
92
90
4.00
6.00
8.00
10.00
12.00
14.00
16.00
Wavelength (um)

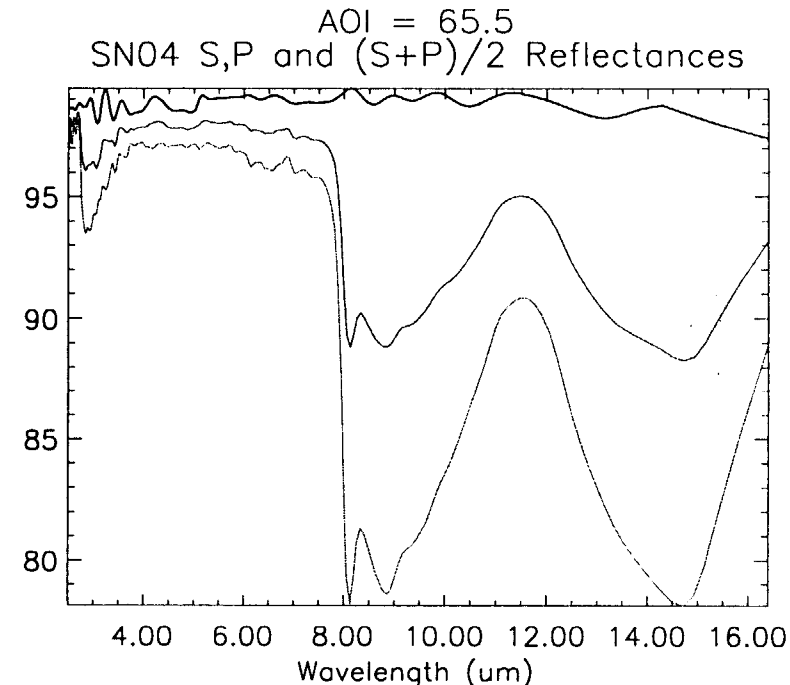

AOI = 60.5
SN03 S,P and (S+P)/2 Reflectances
100
95
90
85
4.00
6.00
8.00
10.00
12.00
14.00
16.00
Wavelength (um)

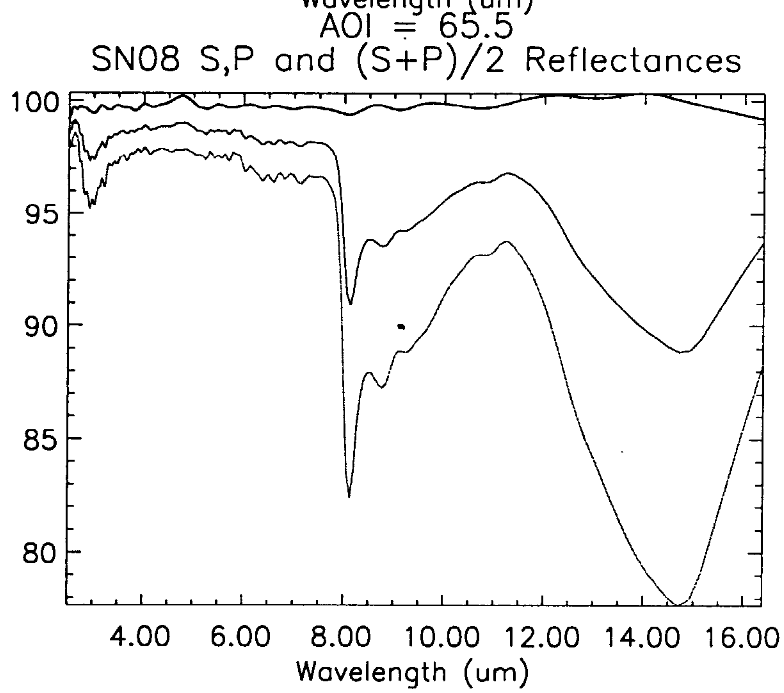

AOI = 60.5
SN04 S,P and (S+P)/2 Reflectances
100
95
90
85
4.00
6.00
8.00
10.00
12.00
14.00
16.00
Wavelength (um)

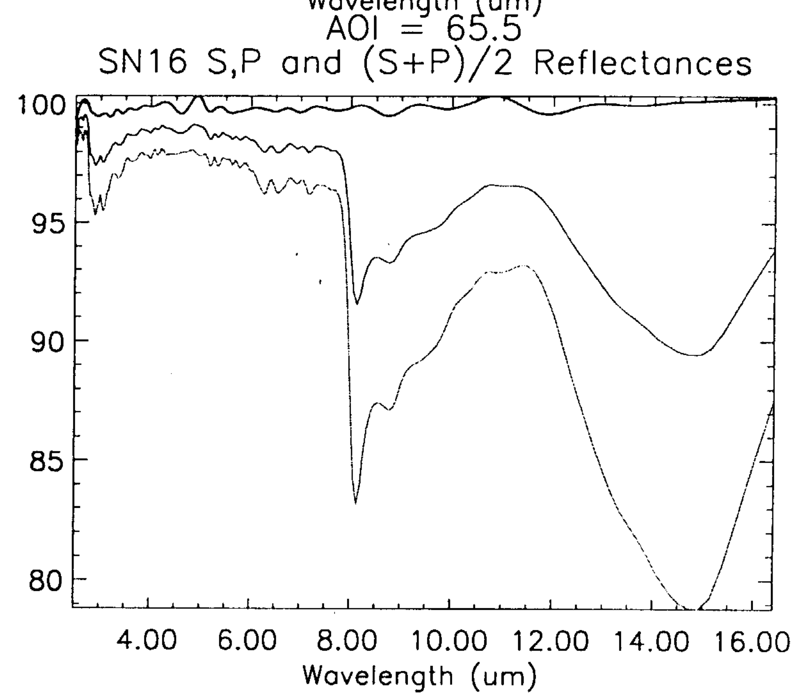

AOI = 60.5
SN08 S,P and (S+P)/2 Reflectances
100
95
90
85
4.00
6.00
8.00
10.00
12.00
14.00
16.00
Wavelength (um)


AOI = 60.5
SN16 S,P and (S+P)/2 Reflectances
100
95
90
85
4.00
6.00
8.00
10.00
12.00
14.00
16.00
Wavelength (um)

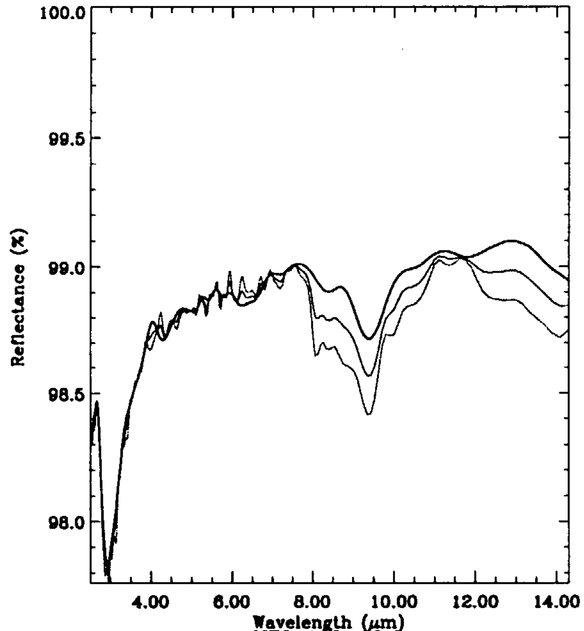

AOI = 65.5
SN03 S,P and (S+P)/2 Reflectances
100
95
90
85
80
4.00
6.00
8.00
10.00
12.00
14.00
16.00
Wavelength (um)


AOI = 65.5
SN04 S,P and (S+P)/2 Reflectances
95
90
85
80
4.00
6.00
8.00
10.00
12.00
14.00
16.00
Wavelength (um)

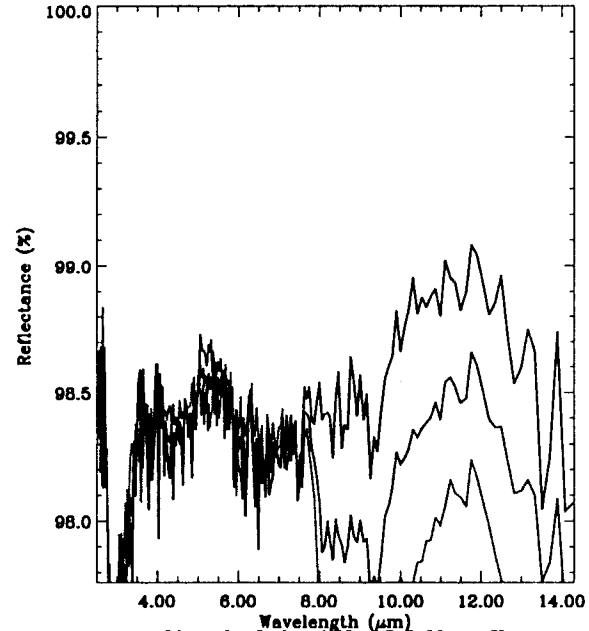

AOI = 65.5
SN08 S,P and (S+P)/2 Reflectances
100
95
90
85
80
4.00
6.00
8.00
10.00
12.00
14.00
16.00
Wavelength (um)


AOI = 65.5
SN16 S,P and (S+P)/2 Reflectances
100
95
90
85
80
4.00
6.00
8.00
10.00
12.00
14.00
16.00
Wavelength (um)

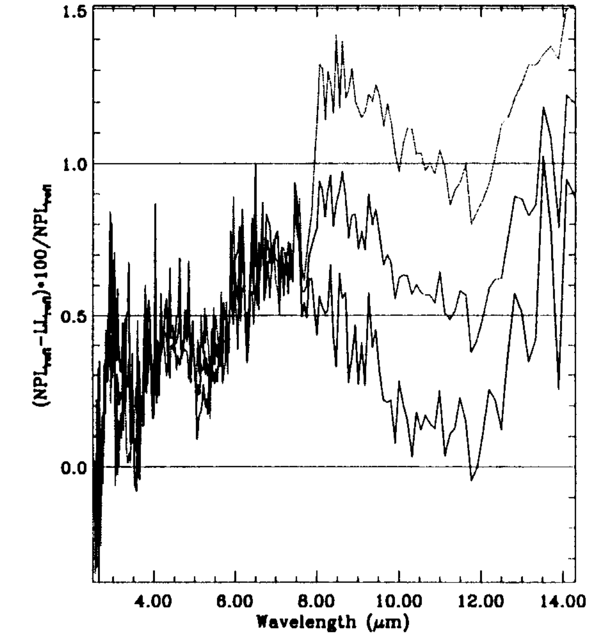
NPL AOI=10.0
SN03 S,P and (S+P)/2 Reflectances



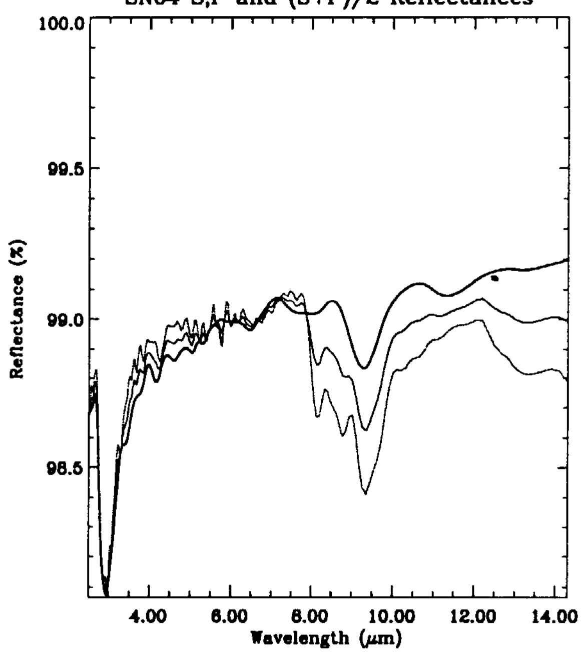
Lincoln Labs AOI=19.0 Meas II
SN03 S,P and (S+P)/2 Reflectances



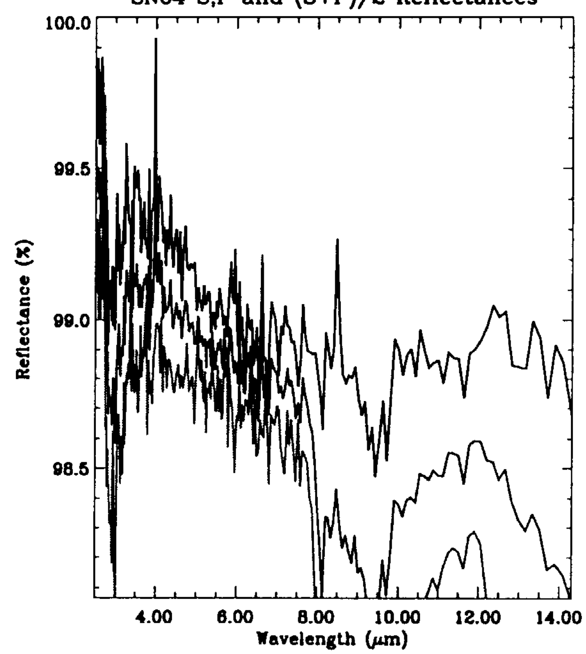
Percent Difference of LL and NPL Ave Reflectaces



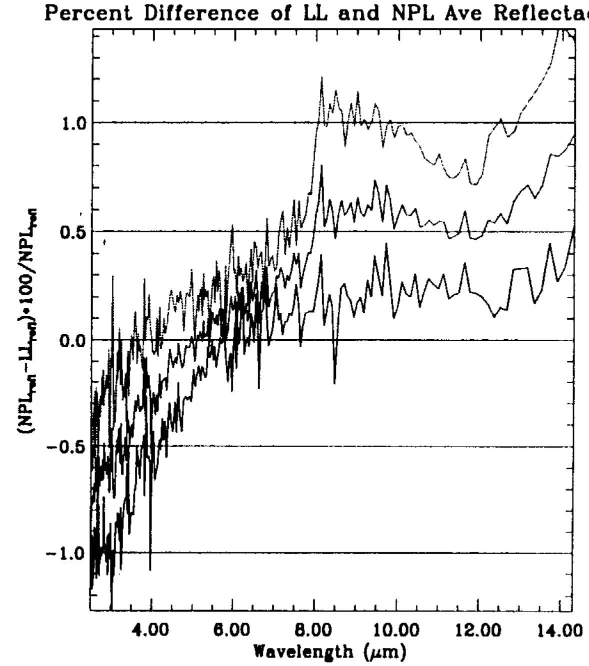
NPL AOI=10.0
SN04 S,P and (S+P)/2 Reflectances



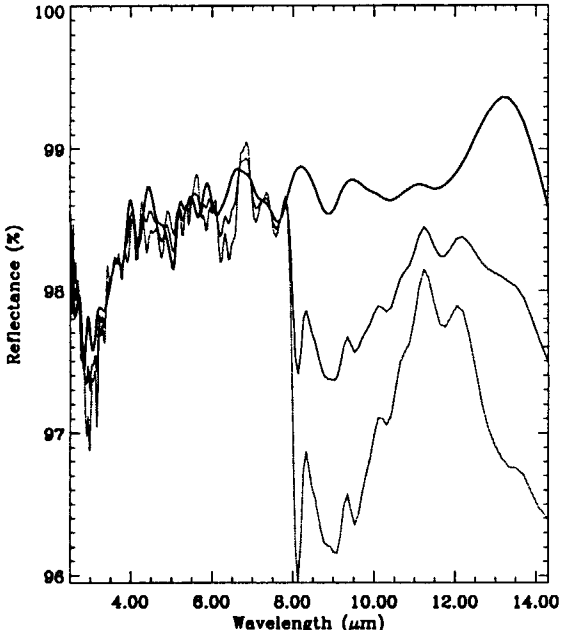
Lincoln Labs AOI=19.0 Meas II
SN04 S,P and (S+P)/2 Reflectances



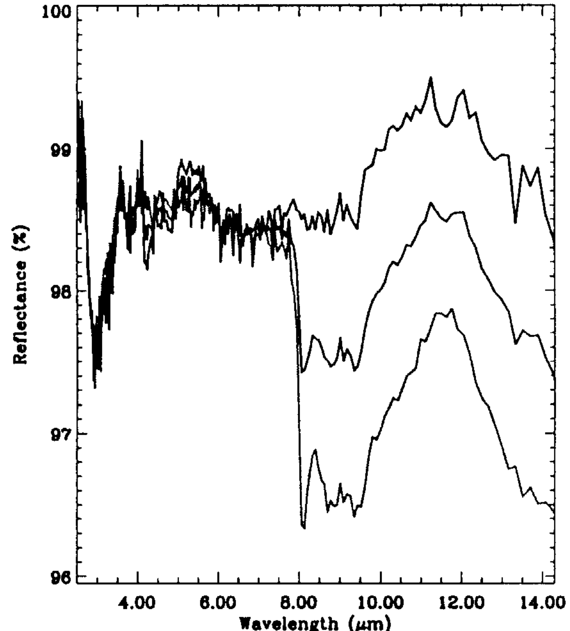
Percent Difference of LL and NPL Ave Reflectaces



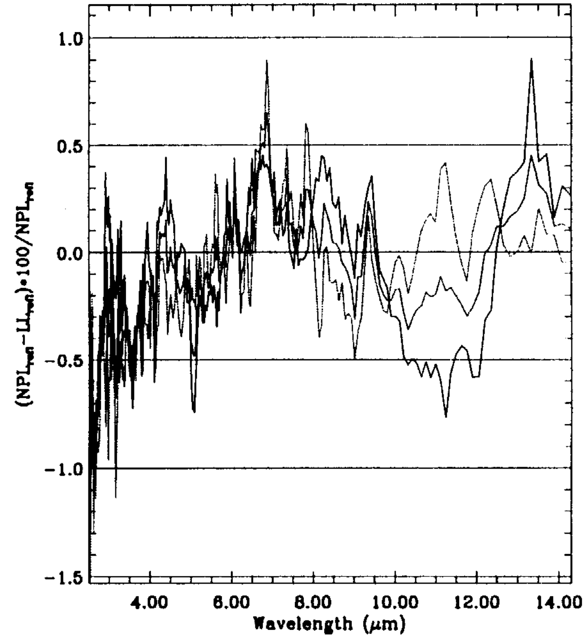
NPL AOI=26.7
SN03 S,P and (S+P)/2 Reflectances



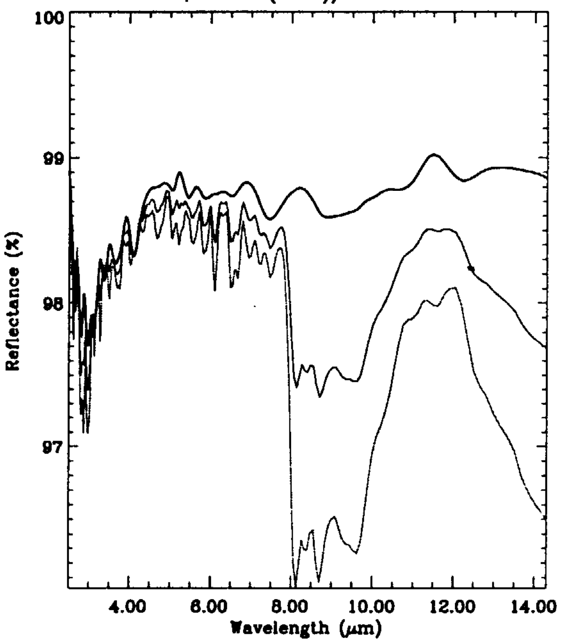
Lincoln Labs AOI=26.0 Meas II
SN03 S,P and (S+P)/2 Reflectances



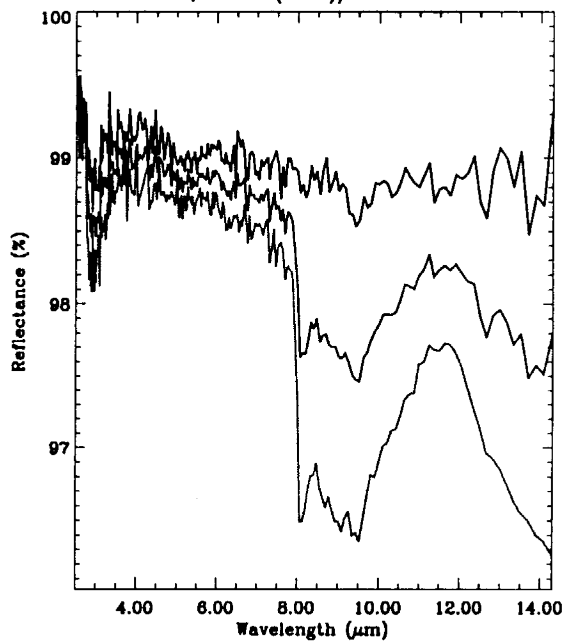
Percent Difference of LL and NPL Ave Reflectaces



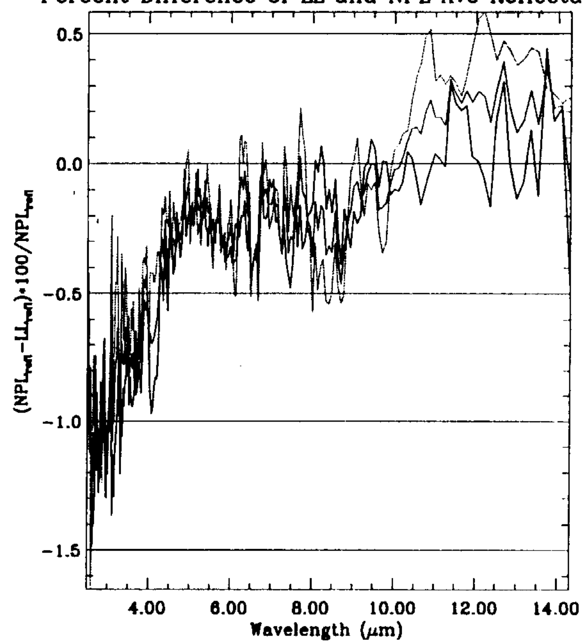
NPL AOI=26.7
SN04 S,P and (S+P)/2 Reflectances

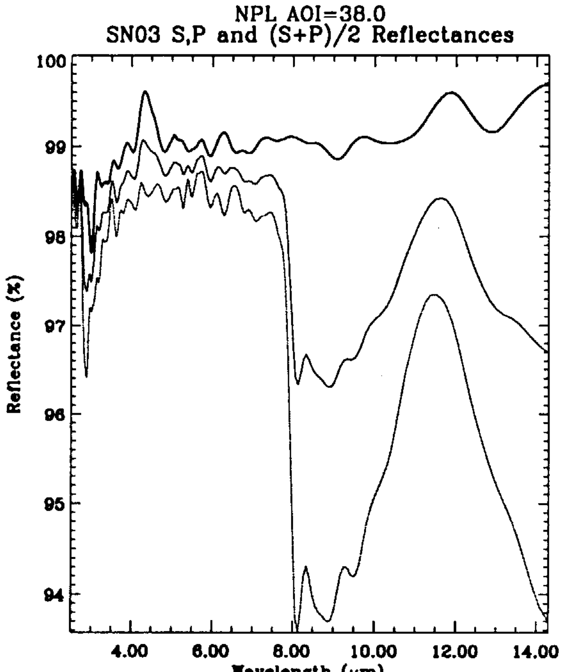


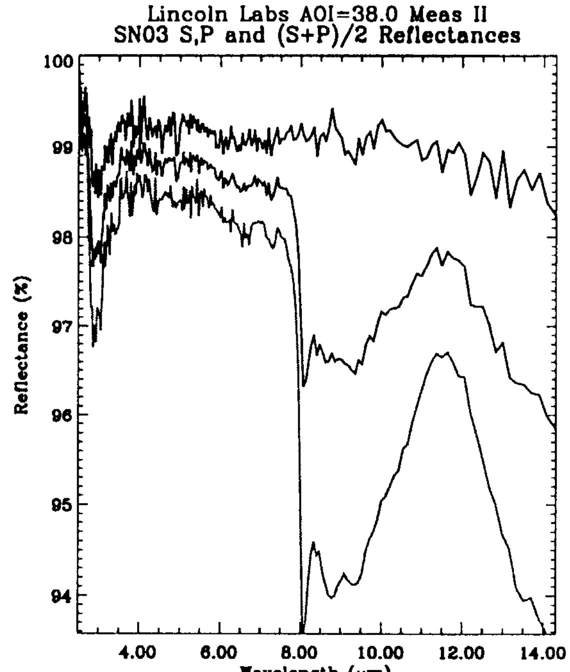
Lincoln Labs AOI=26.0 Meas II
SN04 S,P and (S+P)/2 Reflectances

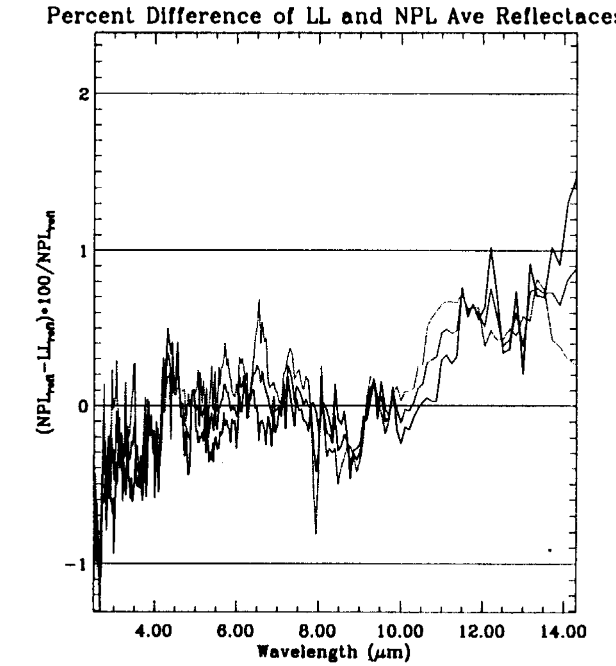


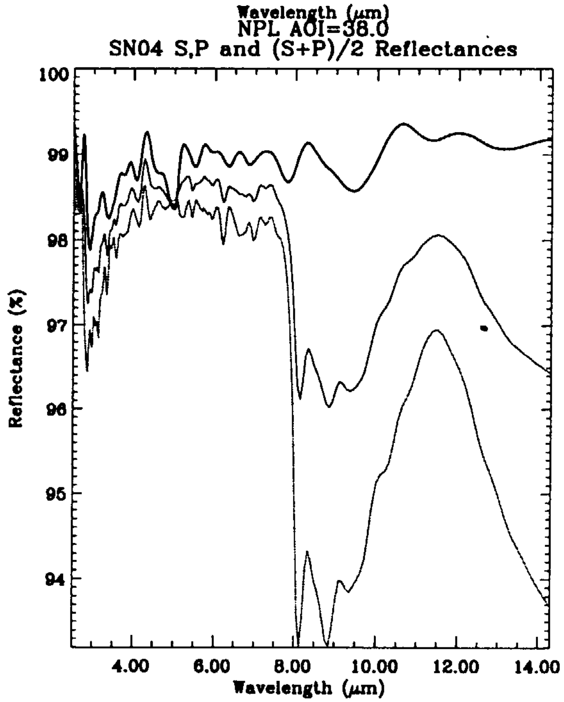
Percent Difference of LL and NPL Ave Reflectaces

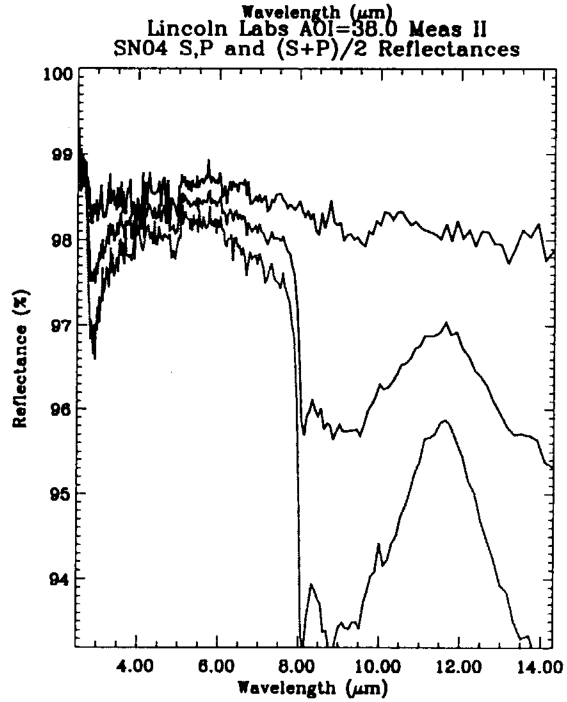


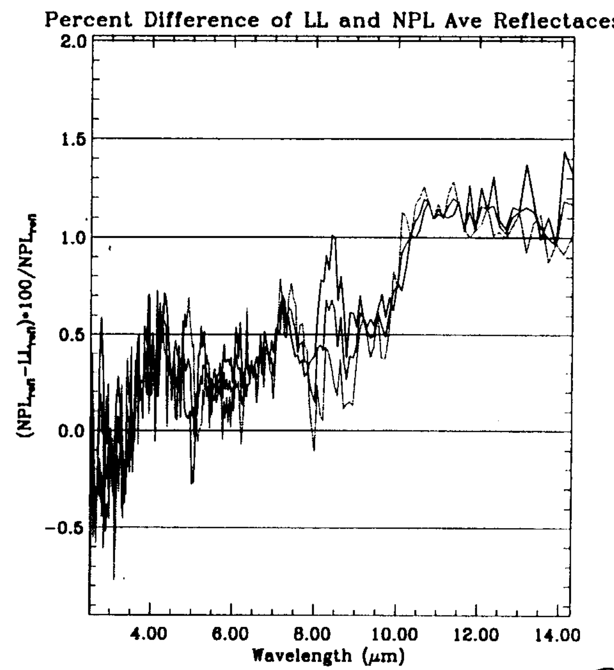

NPL AOI=38.0
SN03 S,P and (S+P)/2 Reflectances
Reflectance (%)
Wavelength (μm)

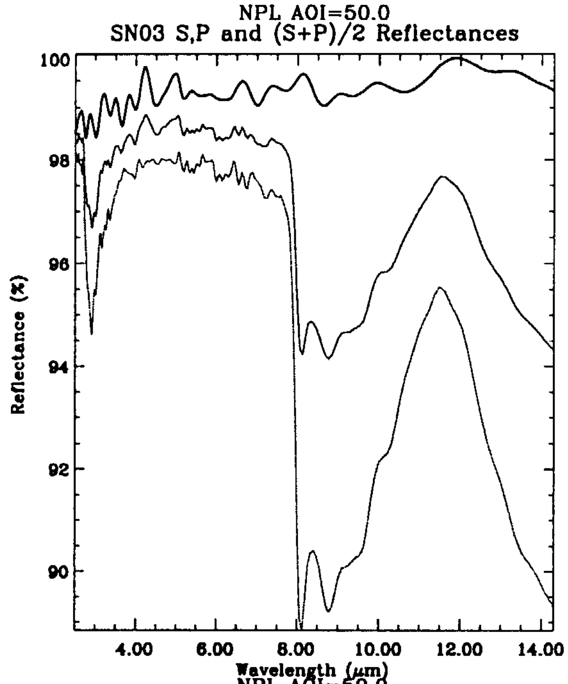

Lincoln Labs AOI=38.0 Meas II
SN03 S,P and (S+P)/2 Reflectances
Reflectance (%)
Wavelength (μm)

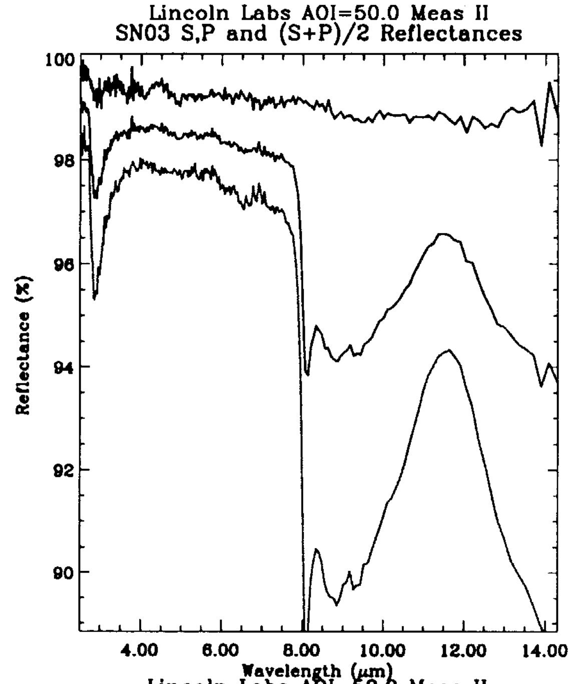

Percent Difference of LL and NPL Ave Reflectaces
$(NPL_{refl}-LL_{refl})\cdot100/NPL_{refl}$
Wavelength (μm)

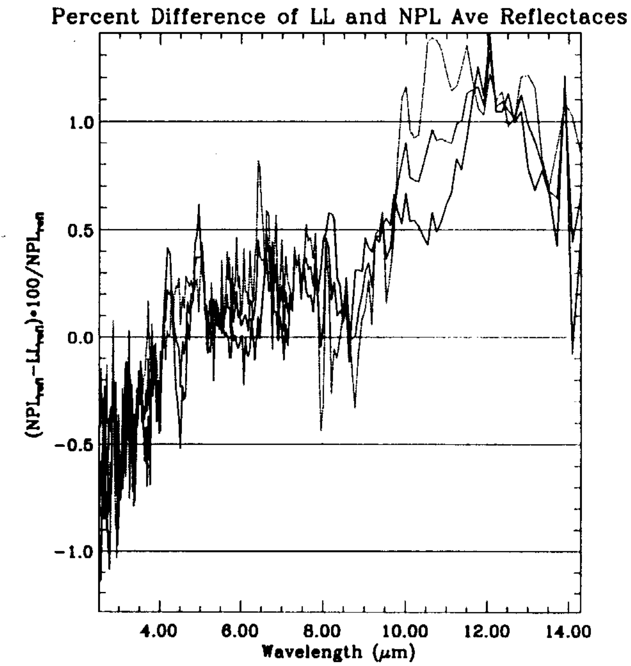

NPL AOI=38.0
SN04 S,P and (S+P)/2 Reflectances
Reflectance (%)
Wavelength (μm)

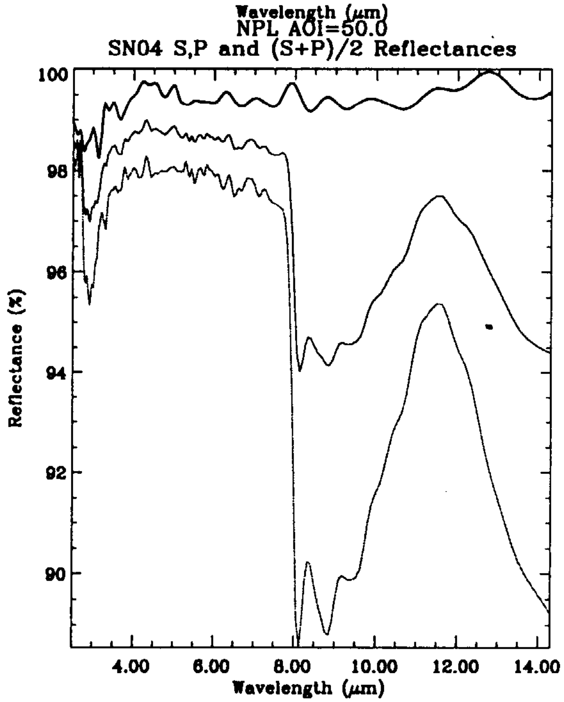

Lincoln Labs AOI=38.0 Meas II
SN04 S,P and (S+P)/2 Reflectances
Reflectance (%)
Wavelength (μm)

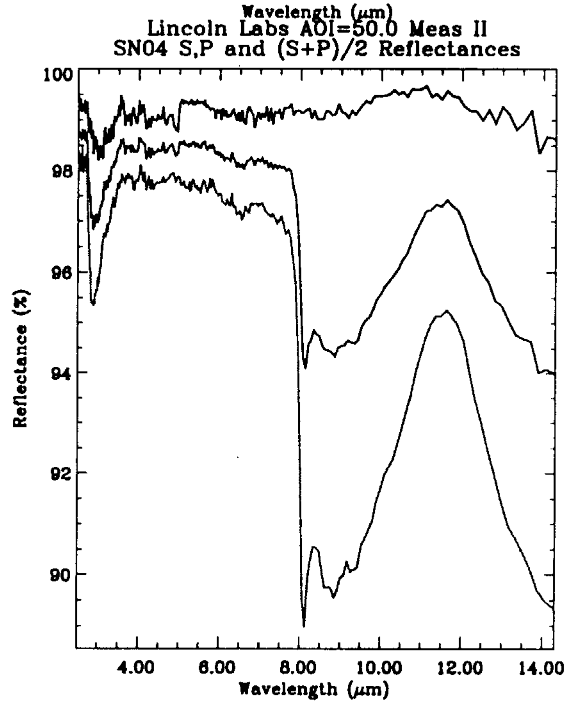

Percent Difference of LL and NPL Ave Reflectaces
$(NPL_{refl}-LL_{refl})\cdot100/NPL_{refl}$
Wavelength (μm)

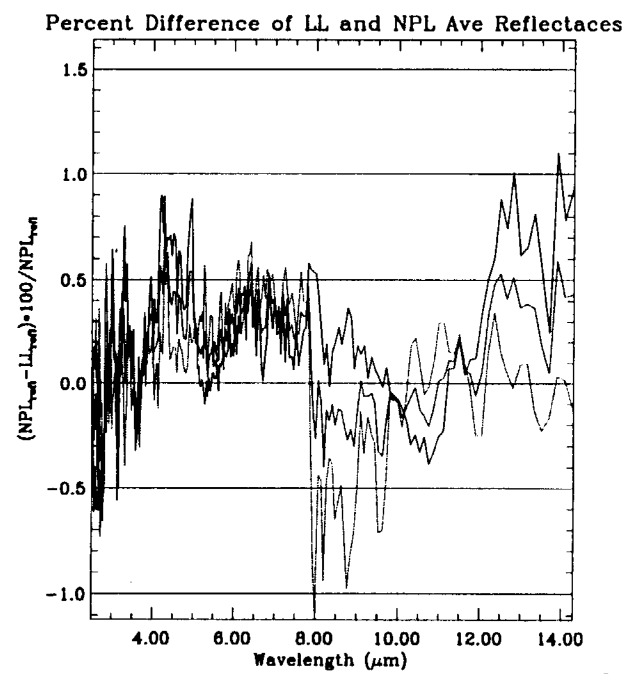

NPL AOI=50.0
SN03 S,P and (S+P)/2 Reflectances
Reflectance (%)
Wavelength (μm)
100
98
96
94
92
90
4.00
6.00
8.00
10.00
12.00
14.00


Lincoln Labs AOI=50.0 Meas II
SN03 S,P and (S+P)/2 Reflectances
Reflectance (%)
Wavelength (μm)
100
98
96
94
92
90
4.00
6.00
8.00
10.00
12.00
14.00

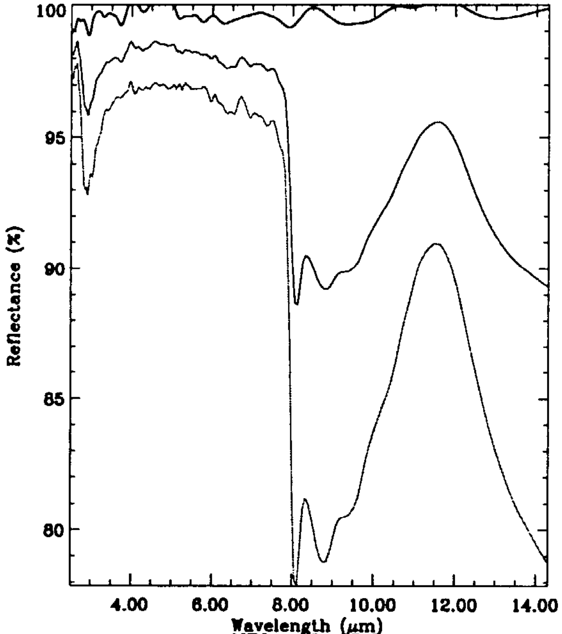

Percent Difference of LL and NPL Ave Reflectaces
(NPL_refl − LL_refl)*100/NPL_refl
Wavelength (μm)
1.0
0.5
0.0
-0.5
-1.0
4.00
6.00
8.00
10.00
12.00
14.00


NPL AOI=50.0
SN04 S,P and (S+P)/2 Reflectances
Reflectance (%)
Wavelength (μm)
100
98
96
94
92
90
4.00
6.00
8.00
10.00
12.00
14.00

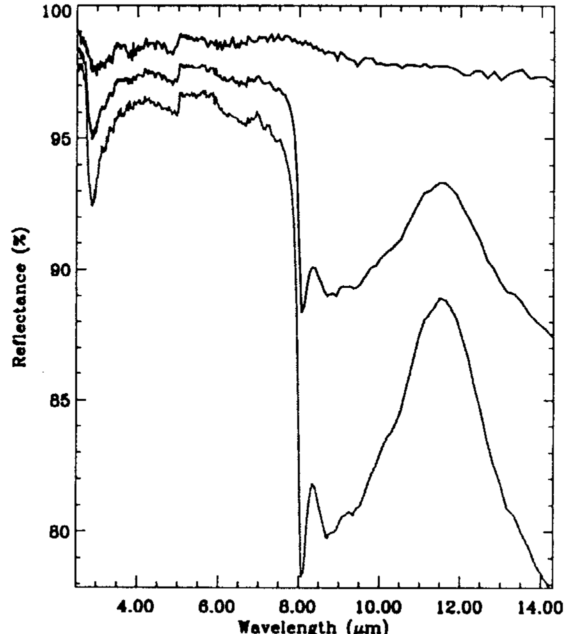

Lincoln Labs AOI=50.0 Meas II
SN04 S,P and (S+P)/2 Reflectances
Reflectance (%)
Wavelength (μm)
100
98
96
94
92
90
4.00
6.00
8.00
10.00
12.00
14.00


Percent Difference of LL and NPL Ave Reflectaces
(NPL_refl − LL_refl)*100/NPL_refl
Wavelength (μm)
1.5
1.0
0.5
0.0
-0.5
-1.0
4.00
6.00
8.00
10.00
12.00
14.00

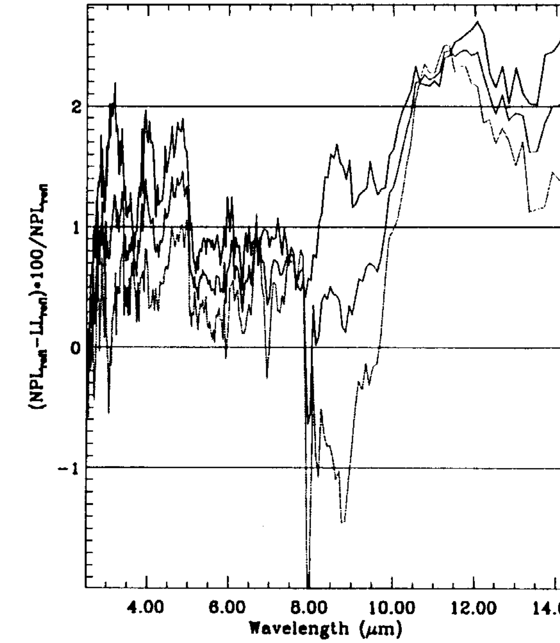
NPL AOI=65.5
SN03 S,P and (S+P)/2 Reflectances



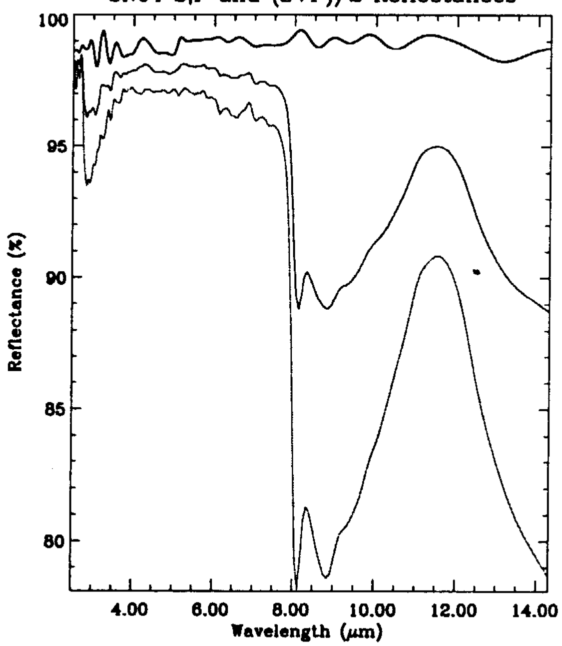
Lincoln Labs AOI=65.5 Meas II
SN03 S,P and (S+P)/2 Reflectances



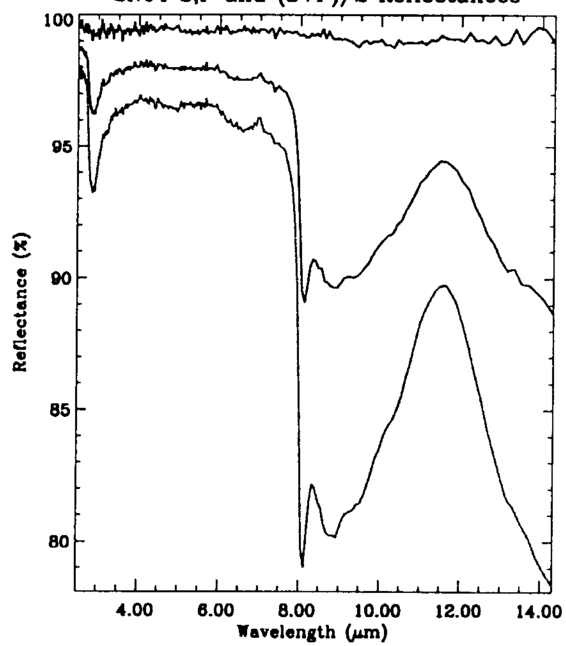
Percent Difference of LL and NPL Ave Reflectaces



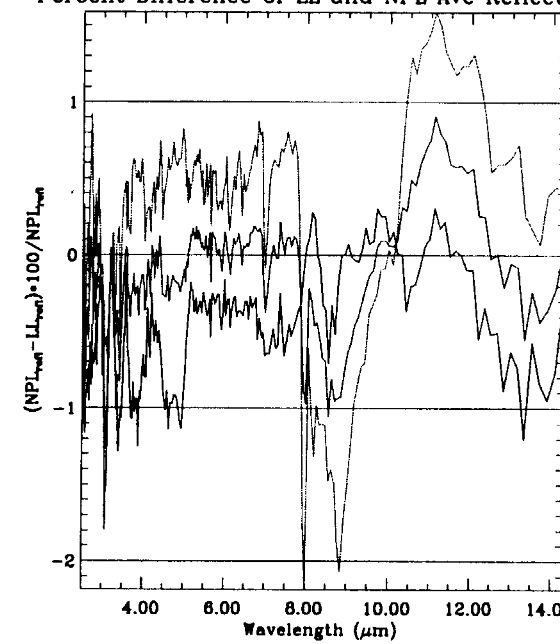
NPL AOI=65.5
SN04 S,P and (S+P)/2 Reflectances

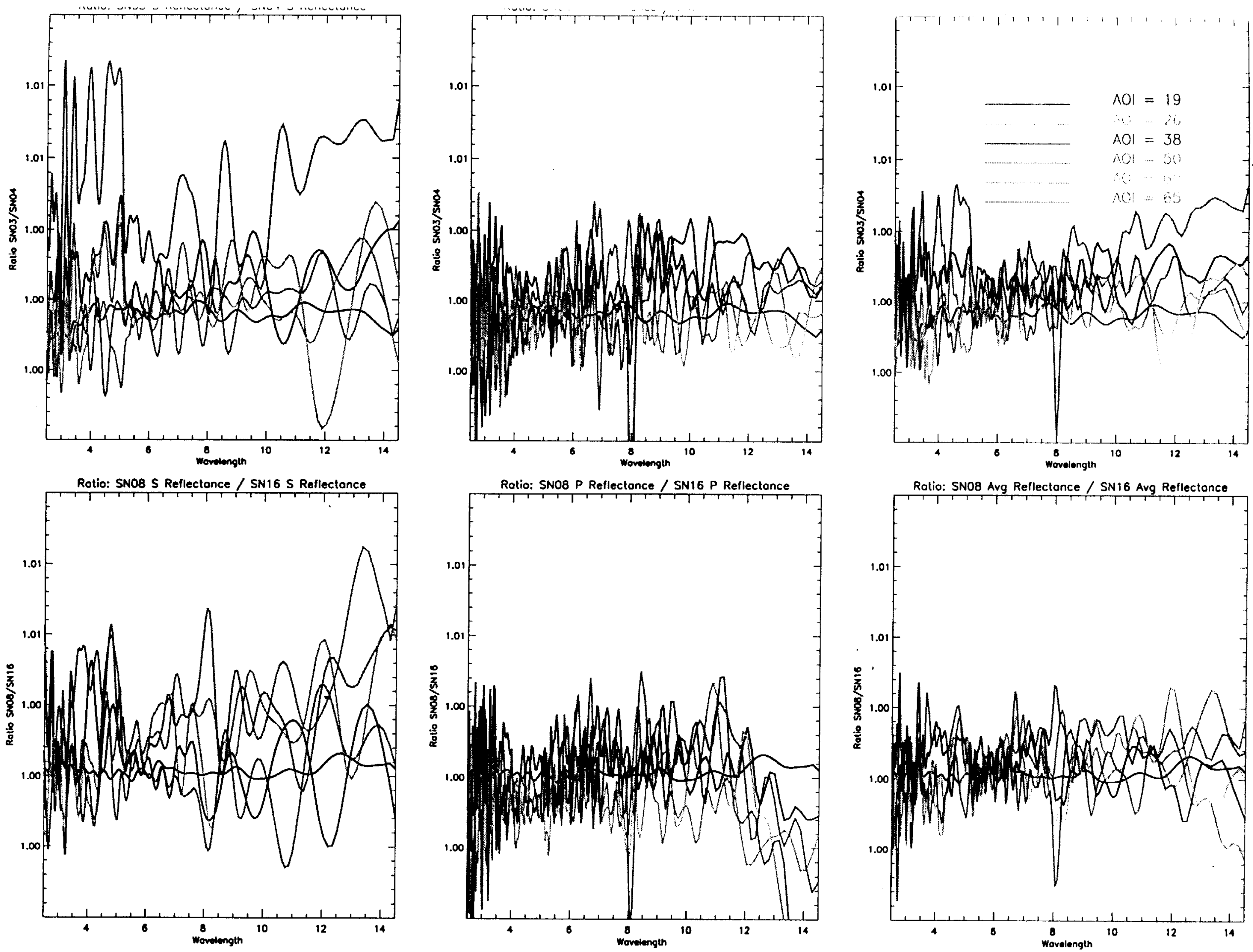


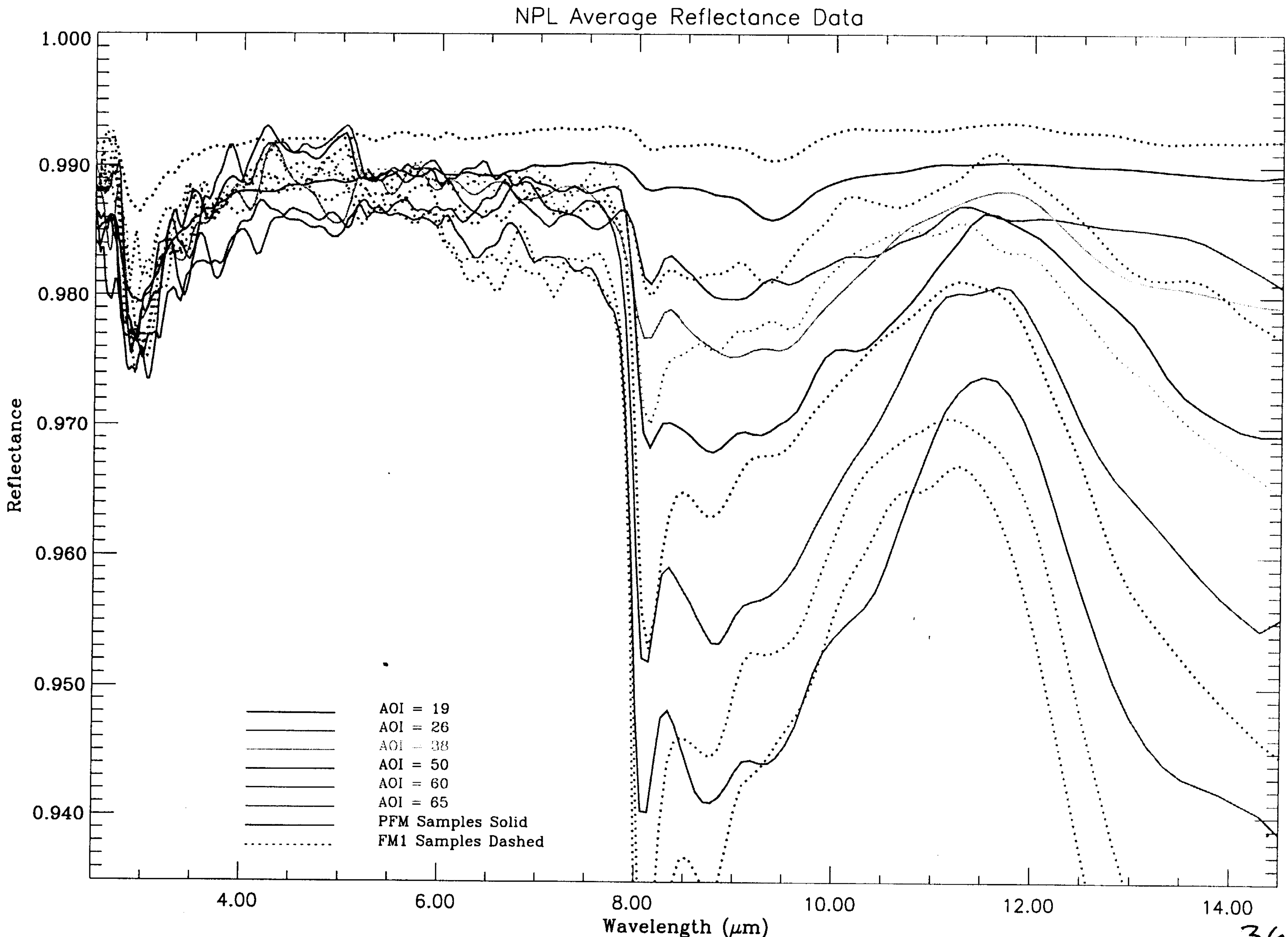
Lincoln Labs AOI=65.5 Meas II
SN04 S,P and (S+P)/2 Reflectances



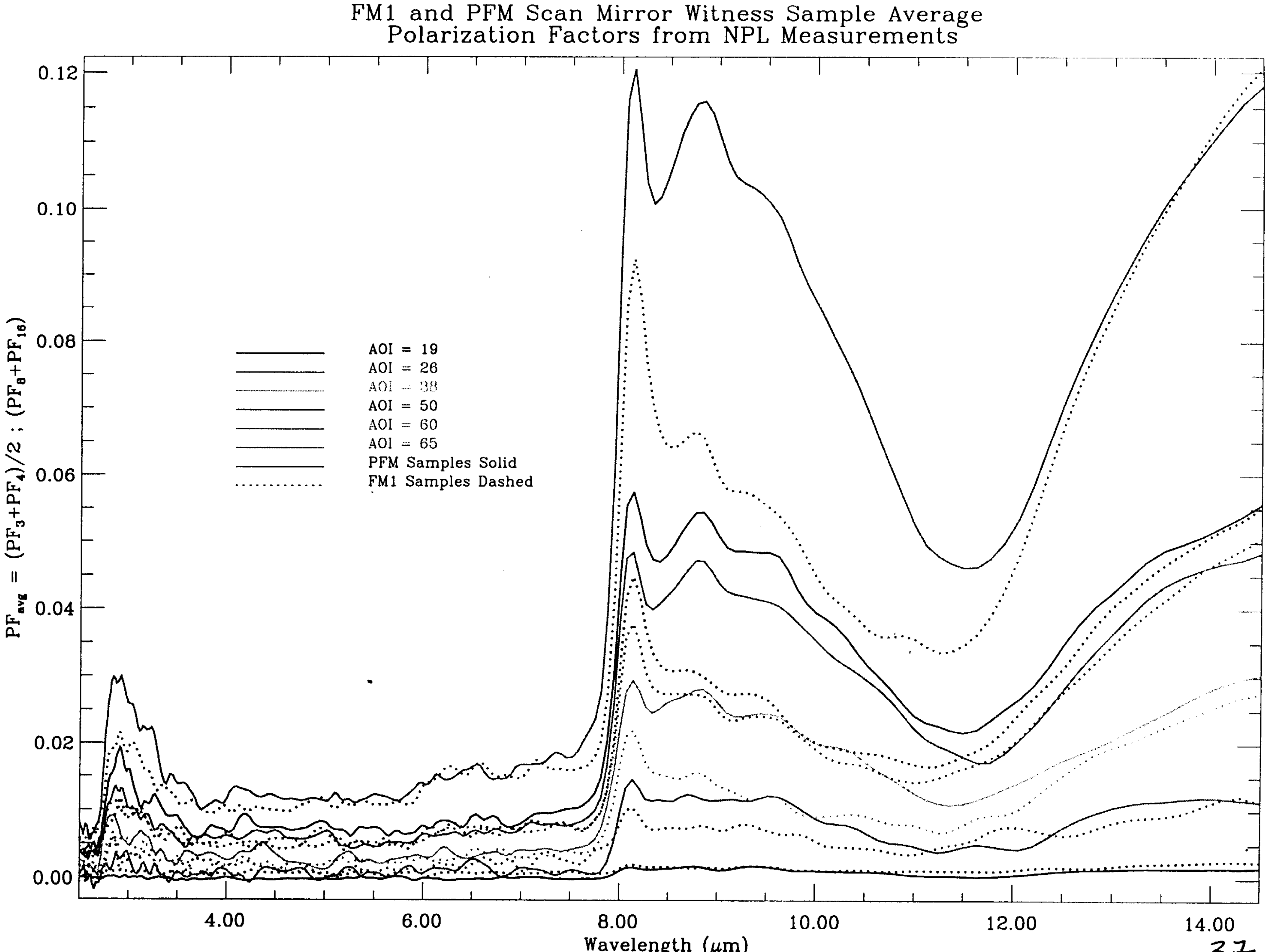
Percent Difference of LL and NPL Ave Reflectaces



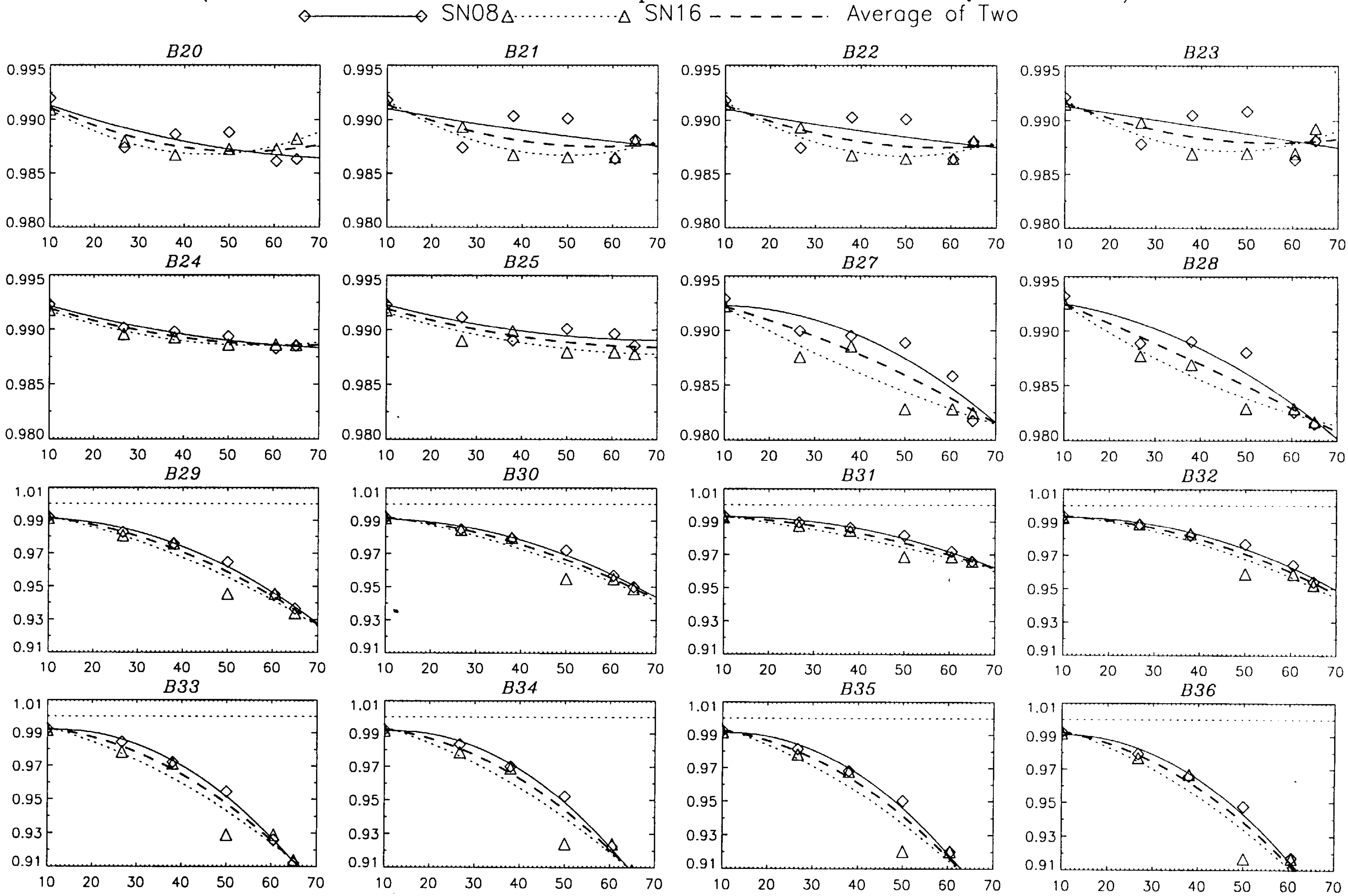

Ratio SN03/SN04
1.01
1.00
Wavelength
4
6
8
10
12
14
AOI = 19
AOI = 38
AOI = 50
AOI = 65
Ratio: SN08 S Reflectance / SN16 S Reflectance
Ratio: SN08 P Reflectance / SN16 P Reflectance
Ratio: SN08 Avg Reflectance / SN16 Avg Reflectance
Ratio SN08/SN16


NPL Average Reflectance Data
1.000
0.990
0.980
0.970
0.960
0.950
0.940
Reflectance
4.00
6.00
8.00
10.00
12.00
14.00
Wavelength (μm)
AOI = 19
AOI = 26
AOI = 38
AOI = 50
AOI = 60
AOI = 65
PFM Samples Solid
FM1 Samples Dashed

36


FM1 and PFM Scan Mirror Witness Sample Average
Polarization Factors from NPL Measurements
0.12
0.10
0.08
0.06
0.04
0.02
0.00
PF_{avg} = $(PF_3+PF_4)/2$; (PF_8+PF_{16})
AOI = 19
AOI = 26
AOI = 38
AOI = 50
AOI = 60
AOI = 65
PFM Samples Solid
FM1 Samples Dashed
4.00
6.00
8.00
10.00
12.00
14.00
Wavelength (μm)

FM1 Scan Mirror Witness Sample Average Polarization Reflectances vs AOI
(NPL Measurements of Witness Samples SN08 and SN16 with Quadratic Fit)



Summary of Highbay RVS Measurements

Summary of Data Analysis

- Raw (not-normalized) RVS data results
  - 16 bands, 10 channels*, 3 RVS data collects (310K_1, 320K_2, and 320K_3)
  - data points averaged over 40 scans and ~50 frames†, with 1-sigma error bars
  - data collected at 10 AOIs; repeated measurements at 4 AOIs
  - corrected for drift (via b1 changes), and T_svs ≠ T_sm effect
- Normalized RVS fitted results
  - raw RVS data averaged over: 40 scans; 50 BCS frames† (with a few exceptions regarding # of frames to assure all data in BCS sweet spot)
  - averaged data preliminarily fitted to a Normalized Best-Fit Quadratic (NBFQ) function on channel-by-channel basis
  - RVS data normalized to average response (40 scans; 50 BCS frames†) at BCS AOI=10.75°

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* B22, channels 1-7, and B36, Channel 6 deleted due to obvious saturation/noise problems

† some exceptions to 50 BCS frames depending on location of BCS sweet spot on band-by-band basis

Summary of Data Analysis

(continued)

- Normalized Best Fit Quadratic chart series provided:
  1) Normalized RVS vs AOI - channel dependent (averaged over 40 scans and 50 BCS frames†; for 16 bands and 3 data collects)
  2) Normalized RVS vs AOI - data collect dependent (averaged over 40 scans, 50 BCS frames† and 10 channels*; for 16 bands)
  3) Normalized RVS vs AOI - grand average (averaged over 40 scans, 50 BCS frames†, 10 channels* and 3 datasets; for 16 bands)

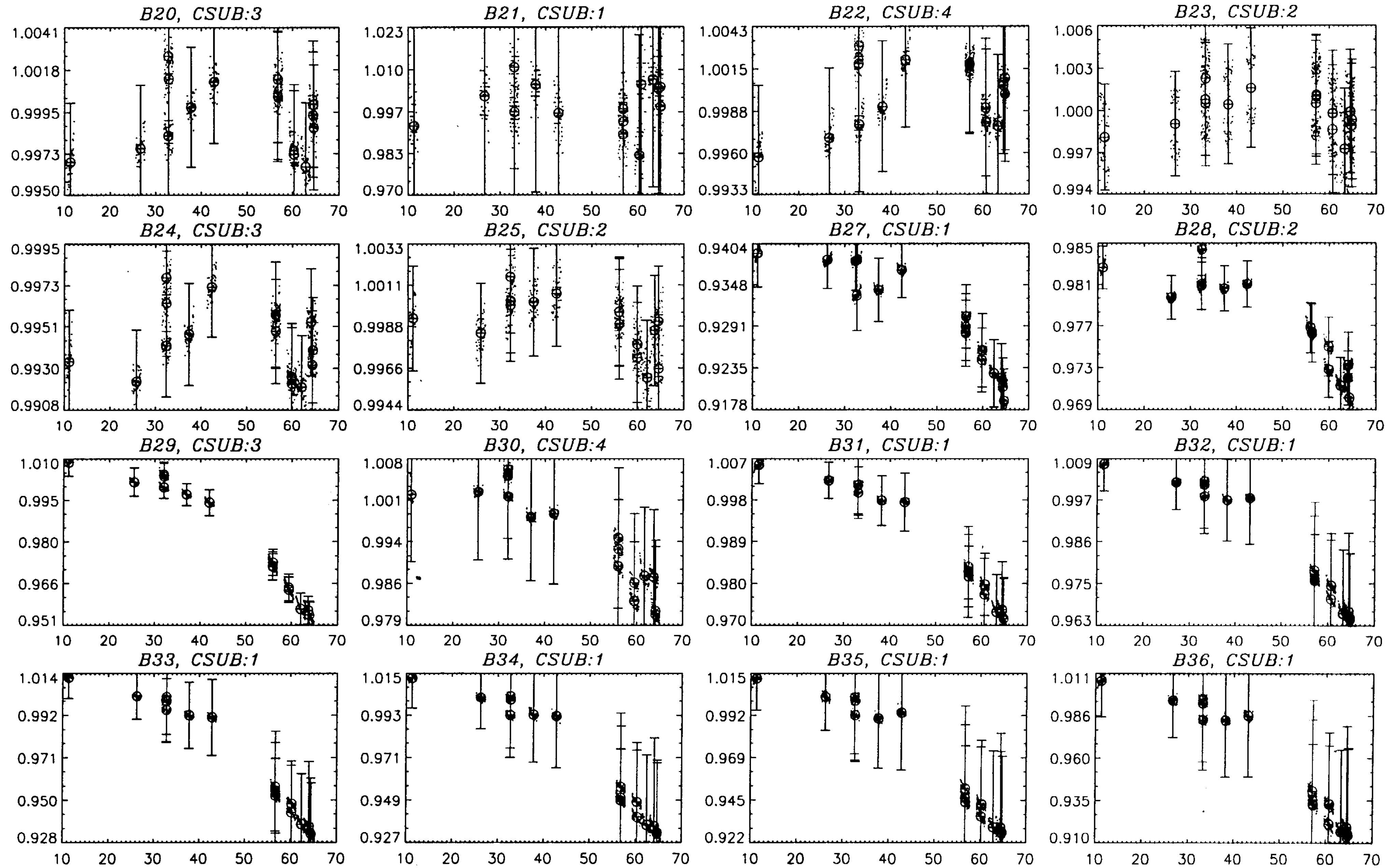
Channel-by-Channel
Highbay RVS Raw Data Results

(after correction for drift via reference to OBC blackbody)

- Channel 8 charts processed w/Tsm=Tsvs
- Channel 8 chart for 320K_3 w/Tsm≠Tsvs
- Channel 8 chart comparing Tsm=Tsvs results with Tsm≠Tsvs correction

Channel 8 Raw $\langle RVS \rangle_{40\ scans}$ vs AOI for 50 BCS Frames

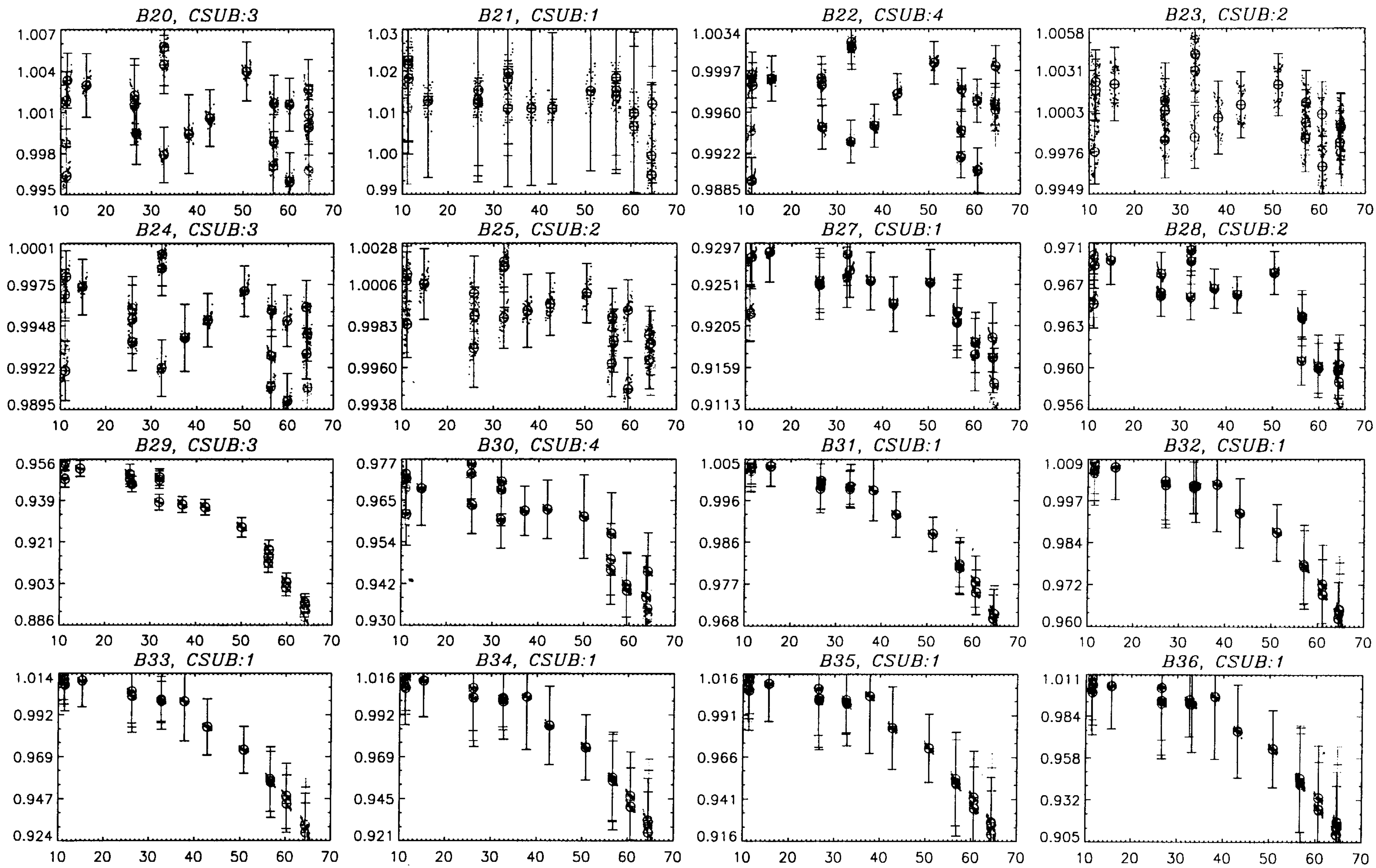
(310K_1 Data Set; Mirror A; w/50frame×40scan Average and 1-σ Error Bars; Optimum CSUB; Repeat AOIs in Color)



Instrument & Source Drift Corrected via OBC b1 (1st order); $T_{SM} \neq T_{SVS}$ Term Excluded)

Channel 8 Raw $\langle \mathrm{RVS} \rangle_{40\ \mathrm{scans}}$ vs AOI for 50 BCS Frames

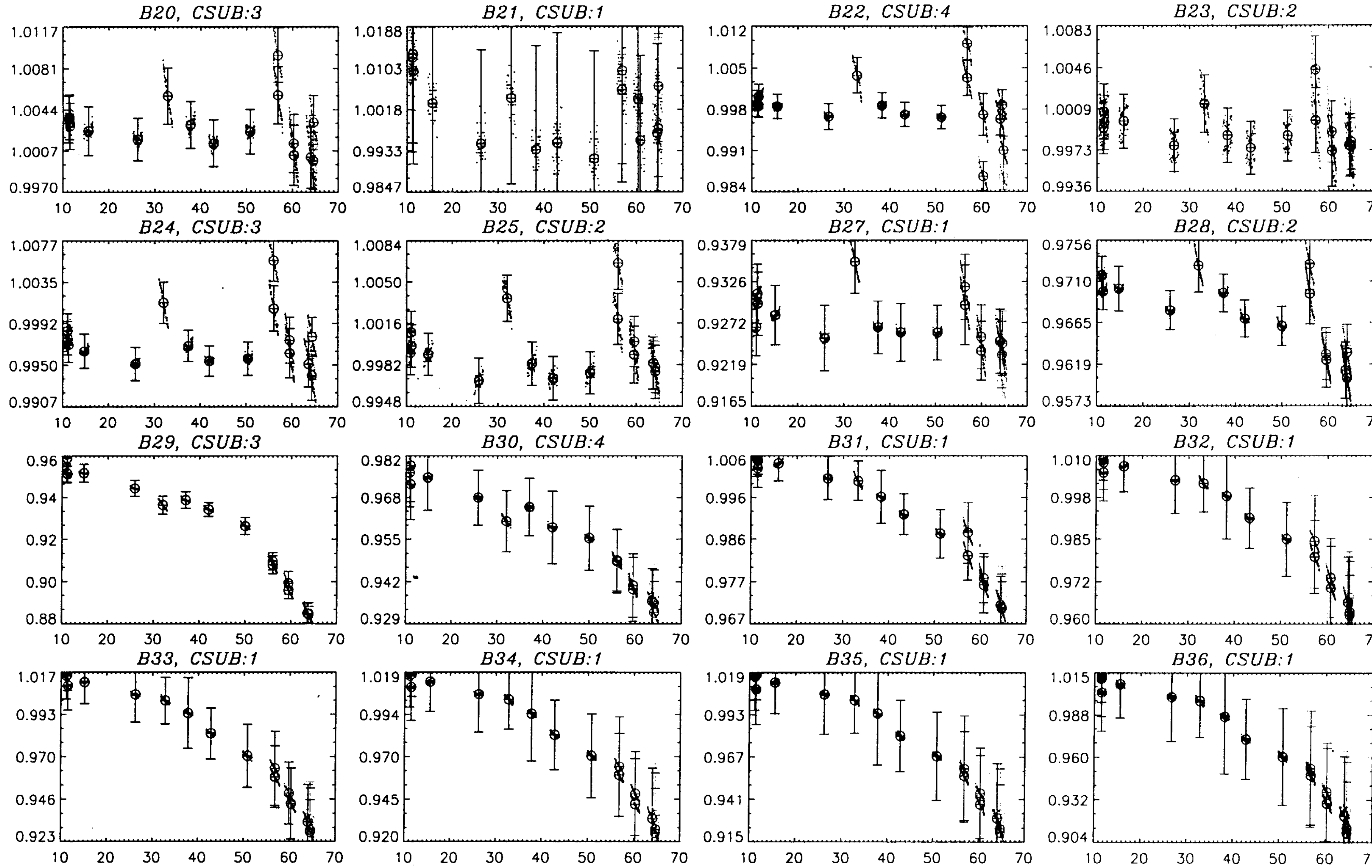
(320K_2 Data Set; Mirror A; w/50frame×40scan Average and 1−σ Error Bars; Optimum CSUB; Repeat AOIs in Color)



Instrument & Source Drift Corrected via OBC b1 (1st order); $T_{SM} \neq T_{SVS}$ Term Excluded)

Channel 8 Raw <RVS>$_{40\ scans}$ vs AOI for 50 BCS Frames

(320K_3 Data Set; Mirror A; w/50frame×40scan Average and 1-σ Error Bars; Optimum CSUB; Repeat AOIs in Color)

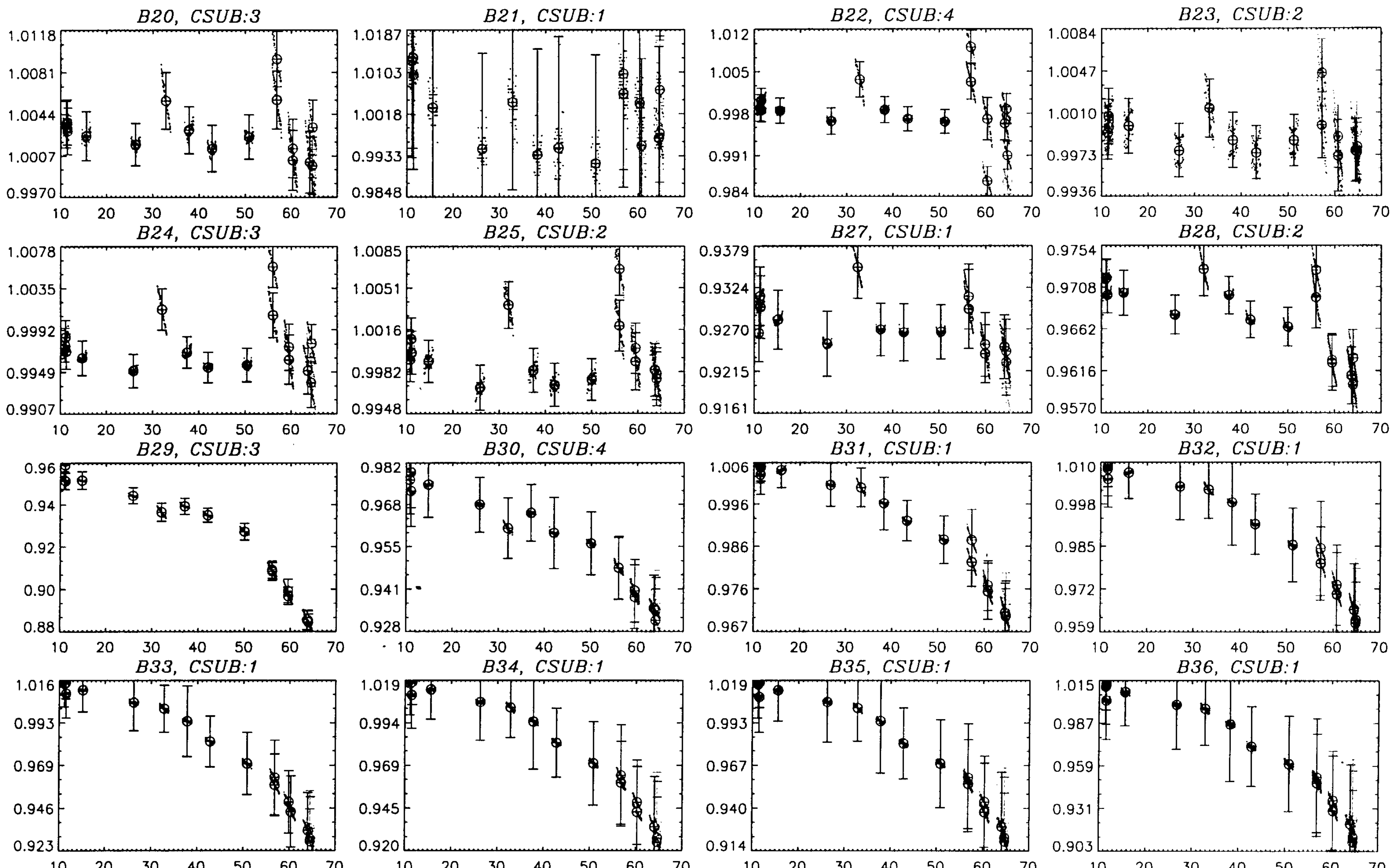


45

Instrument & Source Drift Corrected via OBC b1 (1st order); $T_{SM} \neq T_{SVS}$ Term Excluded)

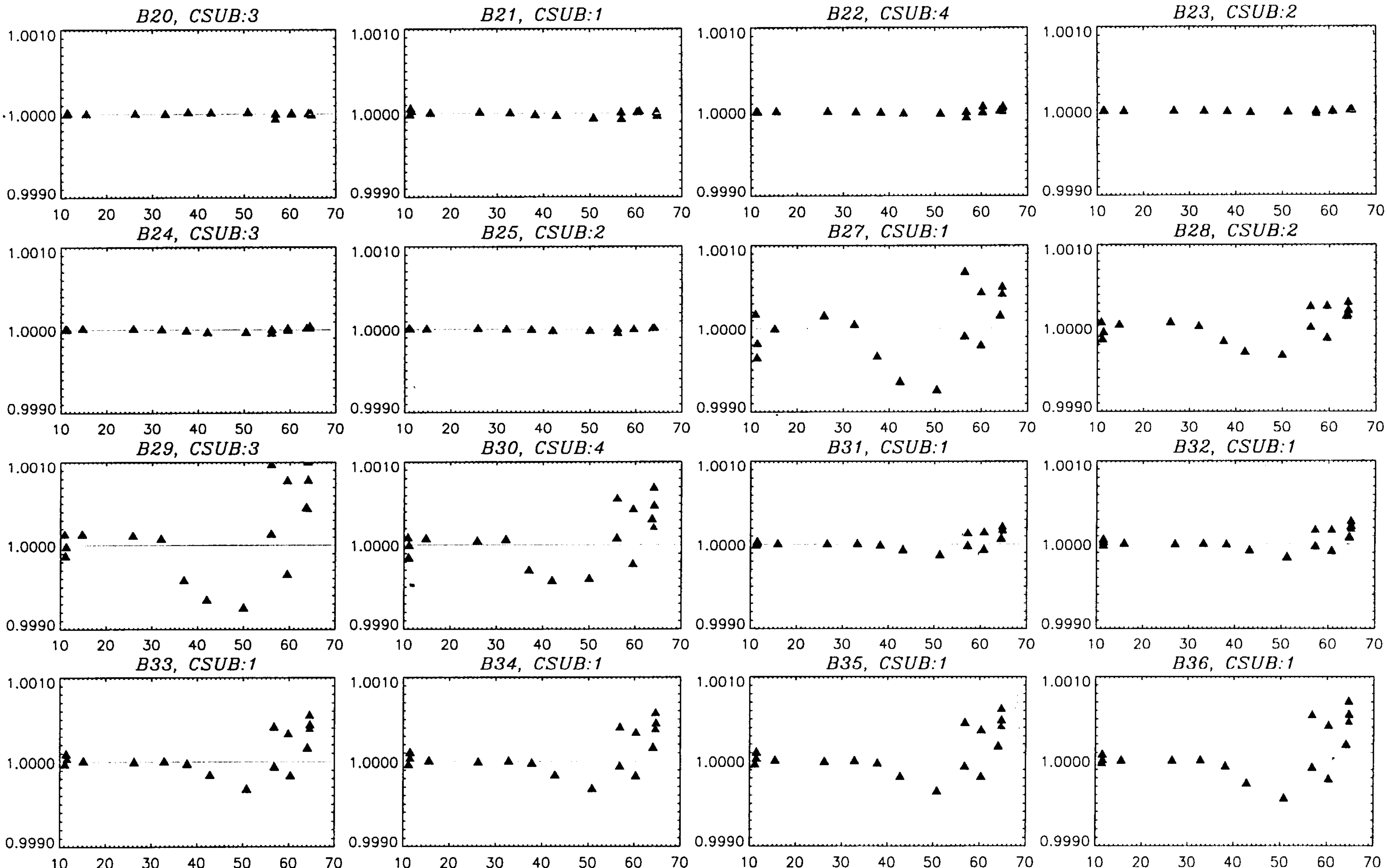
Channel 8 Raw <RVS>$_{40\ scans}$ vs AOI for 50 BCS Frames

(320K_3 Data Set; Mirror A; w/50frame×40scan Average and 1−σ Error Bars; Optimum CSUB; Repeat AOIs in Color)



Note: Instrument & Source Drift Corrected via OBC b1 (1st order); $T_{SM} \neq T_{SVS}$ Term Included

Channel 8 $\langle RVS\rangle_{T_{SM}=T_{SVS}} / \langle RVS\rangle_{T_{SM}\neq T_{SVS}}$ vs AOI for Data Set:[320K_3]
(Mirror A; w/50frame×40scan Average; Repeat AOIs in Color)

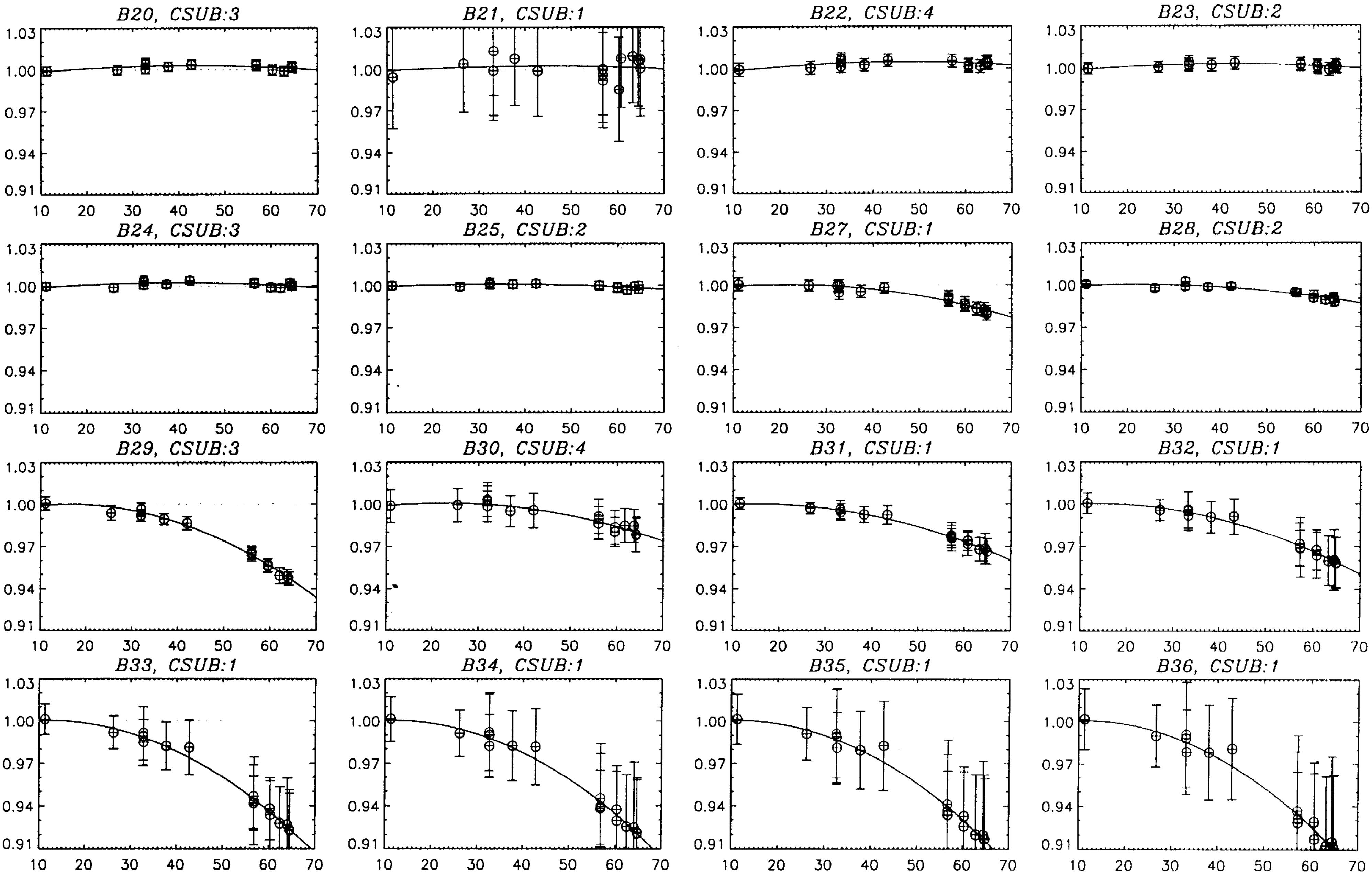


Normalized RVS with weighted quadratic fit

- Quadratic function normalized at 10.75° AOI
- Channel 8 processed assuming Tsm=Tsvs
- Channel 8 for 320K_3 data collect with Tsm≠Tsvs correction

Channel 8 Normalized <RVS>$_{40\ scans}$ @ 10.75° vs AOI for 50 BCS Frames with Quadratic Fit

(310K_1 Data Set; Mirror A; w/50frame×40scan Average and 1-σ Error Bars; Optimum CSUB; Repeat AOIs in Color)

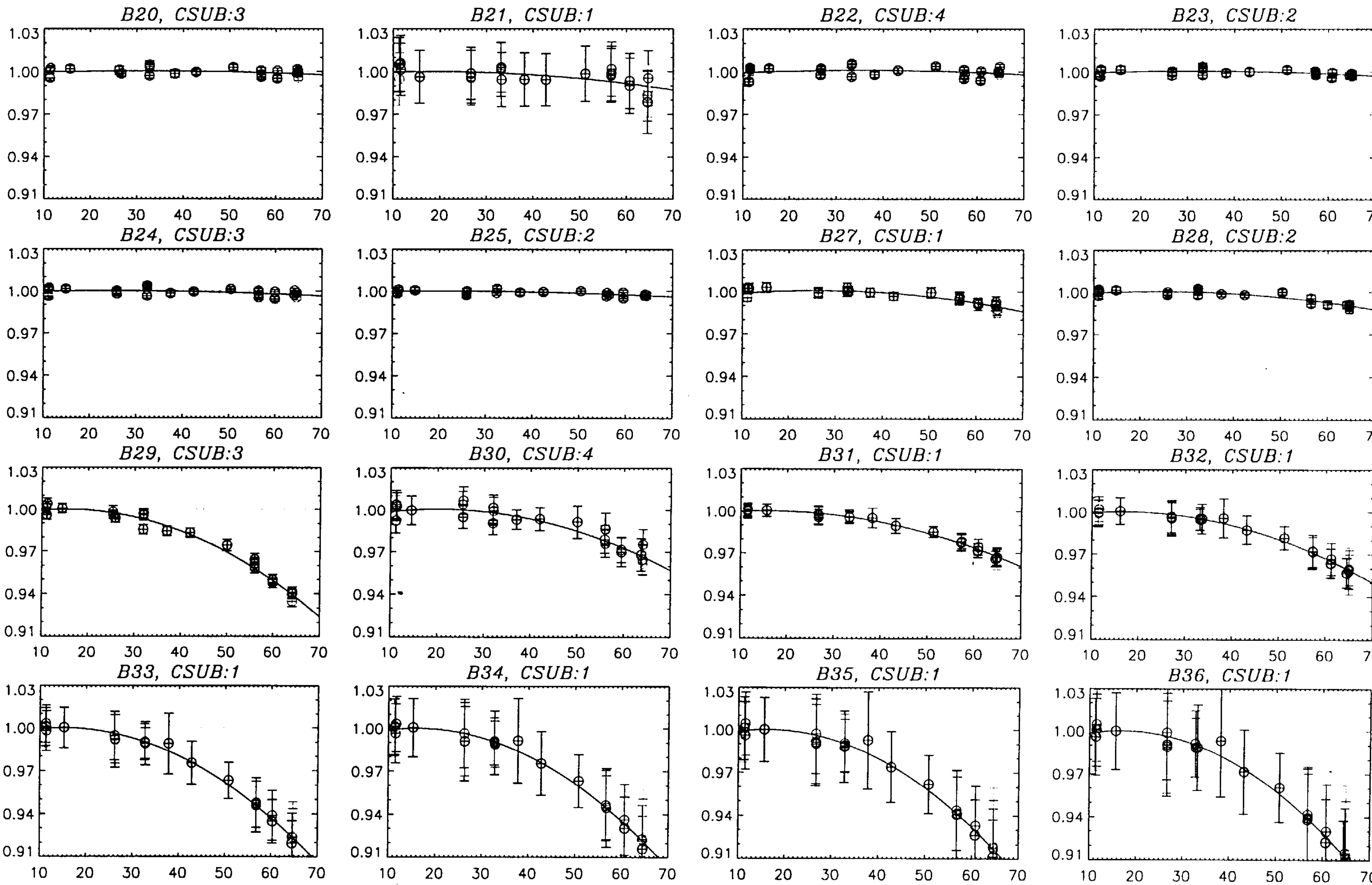


49

Note: Instrument & Source Drift Corrected via OBC b1 (1st order); $T_{SM} \neq T_{SVS}$ Term Excluded

Channel 8 Normalized <RVS>$_{40\ scans}$ @ 10.75° vs AOI for 50 BCS Frames with Quadratic Fit

(320K_2 Data Set; Mirror A; w/50frame×40scan Average and 1-σ Error Bars; Optimum CSUB; Repeat AOIs in Color)

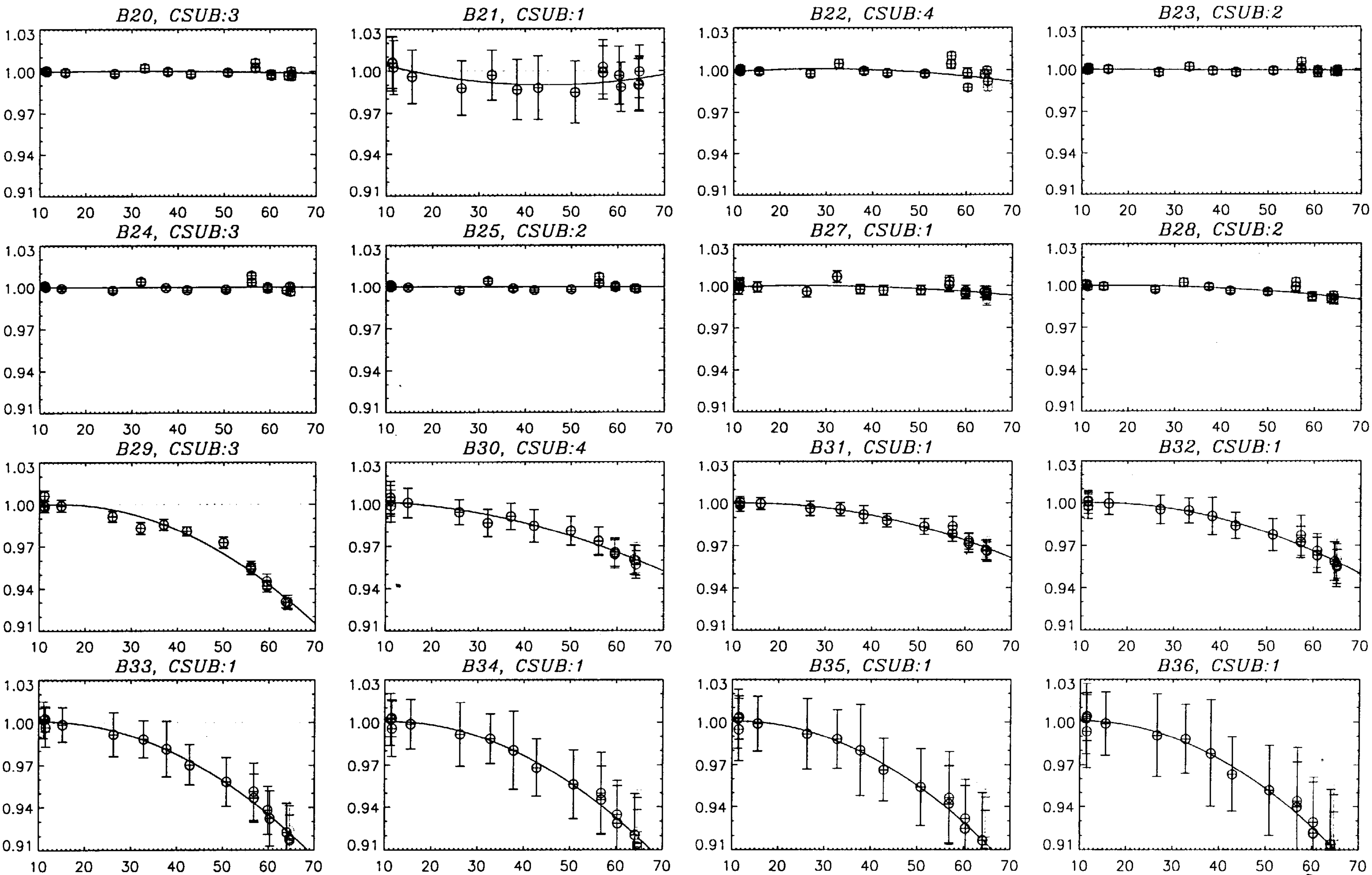


50

Note: Instrument & Source Drift Corrected via OBC b1 (1st order); $T_{SM} \neq T_{SVS}$ Term Excluded

Channel 8 Normalized <RVS>$_{40\ scans}$ @ 10.75° vs AOI for 50 BCS Frames with Quadratic Fit

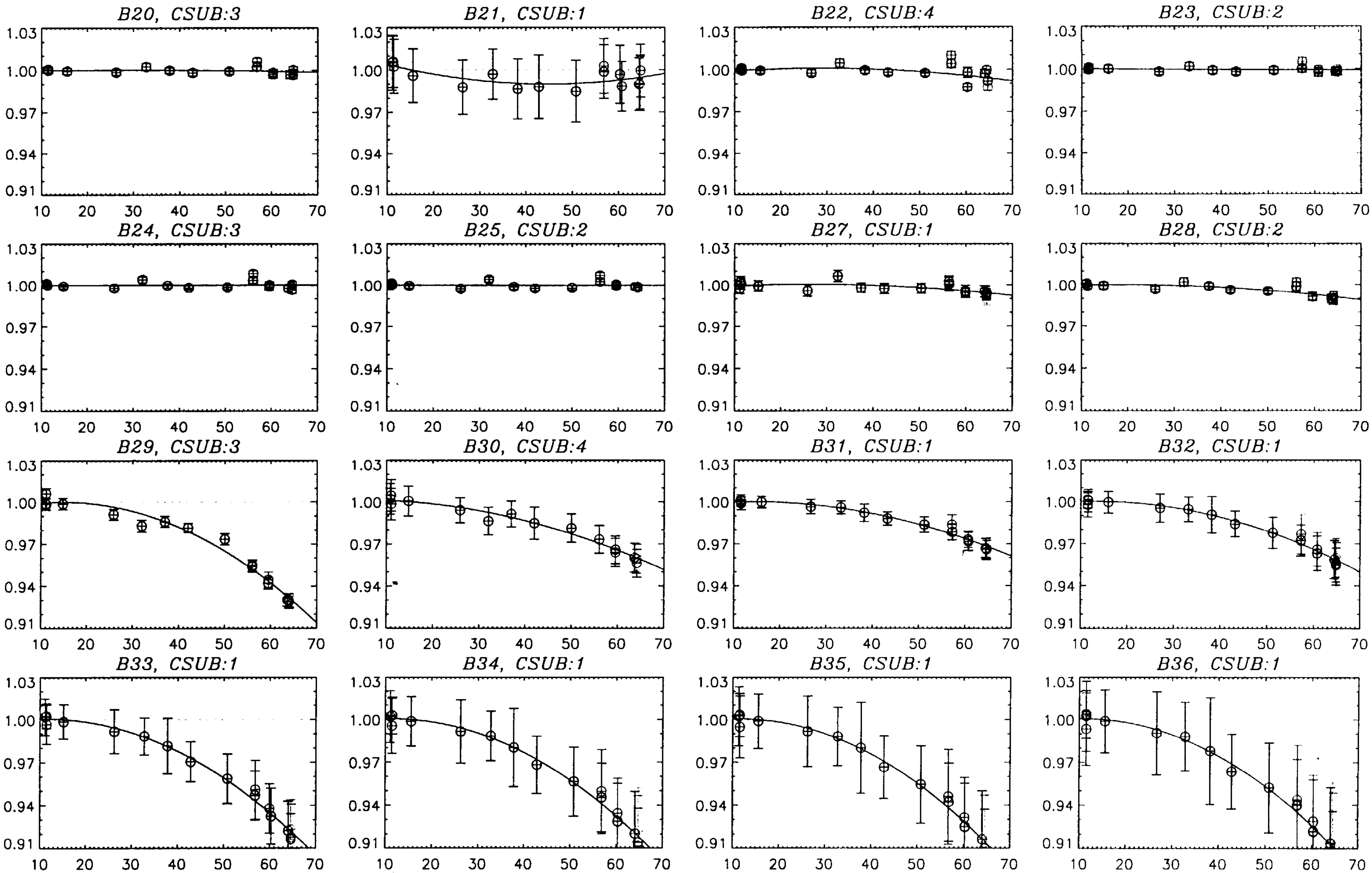
(320K_3 Data Set; Mirror A; w/50frame×40scan Average and 1-σ Error Bars; Optimum CSUB; Repeat AOIs in Color)



Note: Instrument & Source Drift Corrected via OBC b1 (1st order); $T_{SM} \neq T_{SVS}$ Term Excluded

Channel 8 Normalized <RVS>$_{40\ scans}$ @ 10.75° vs AOI for 50 BCS Frames with Quadratic Fit

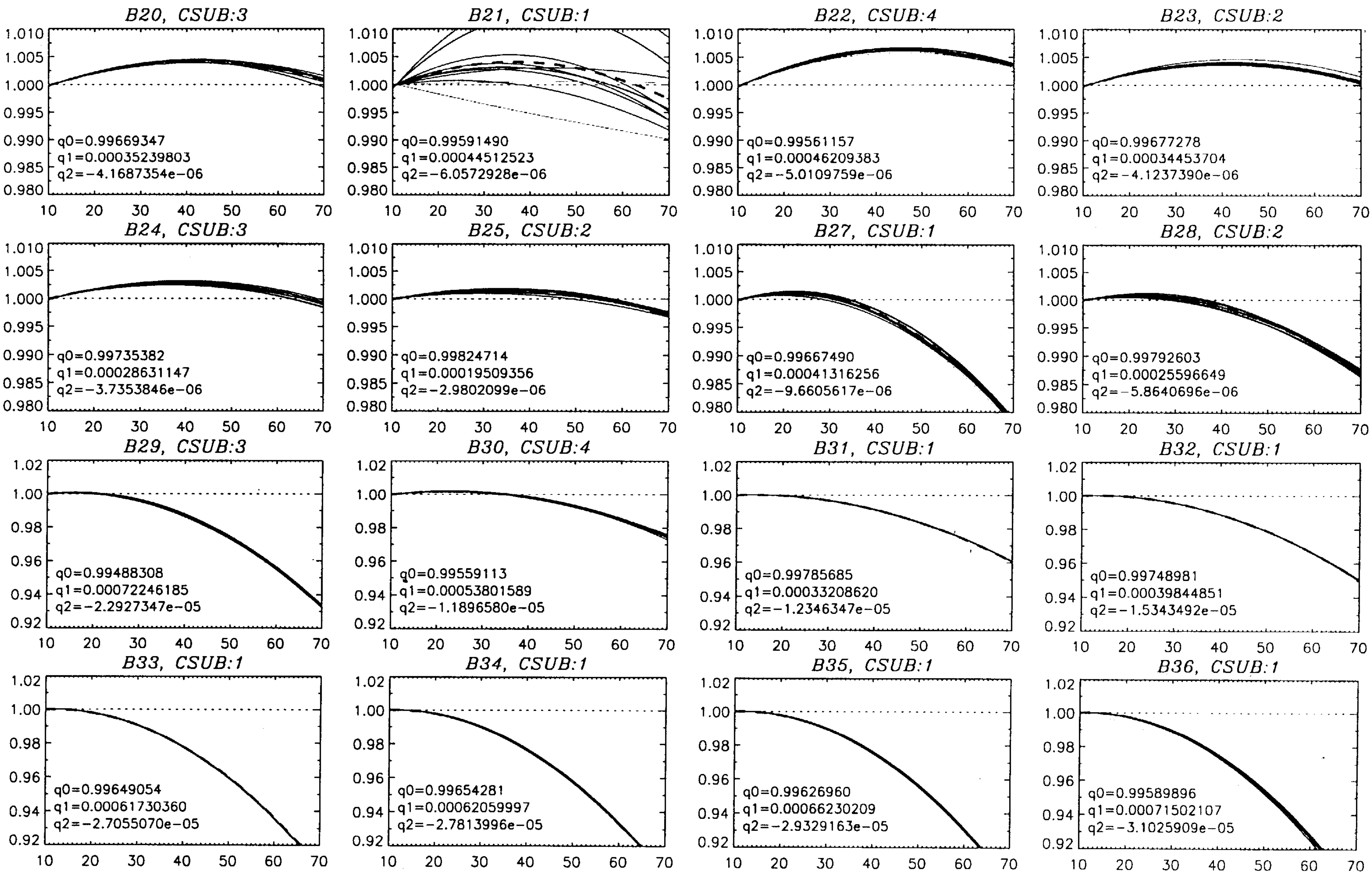
(320K_3 Data Set; Mirror A; w/50frame×40scan Average and 1−σ Error Bars; Optimum CSUB; Repeat AOIs in Color)



Note: Instrument & Source Drift Corrected via OBC b1 (1st order); $T_{SM} \neq T_{SVS}$ Term Included

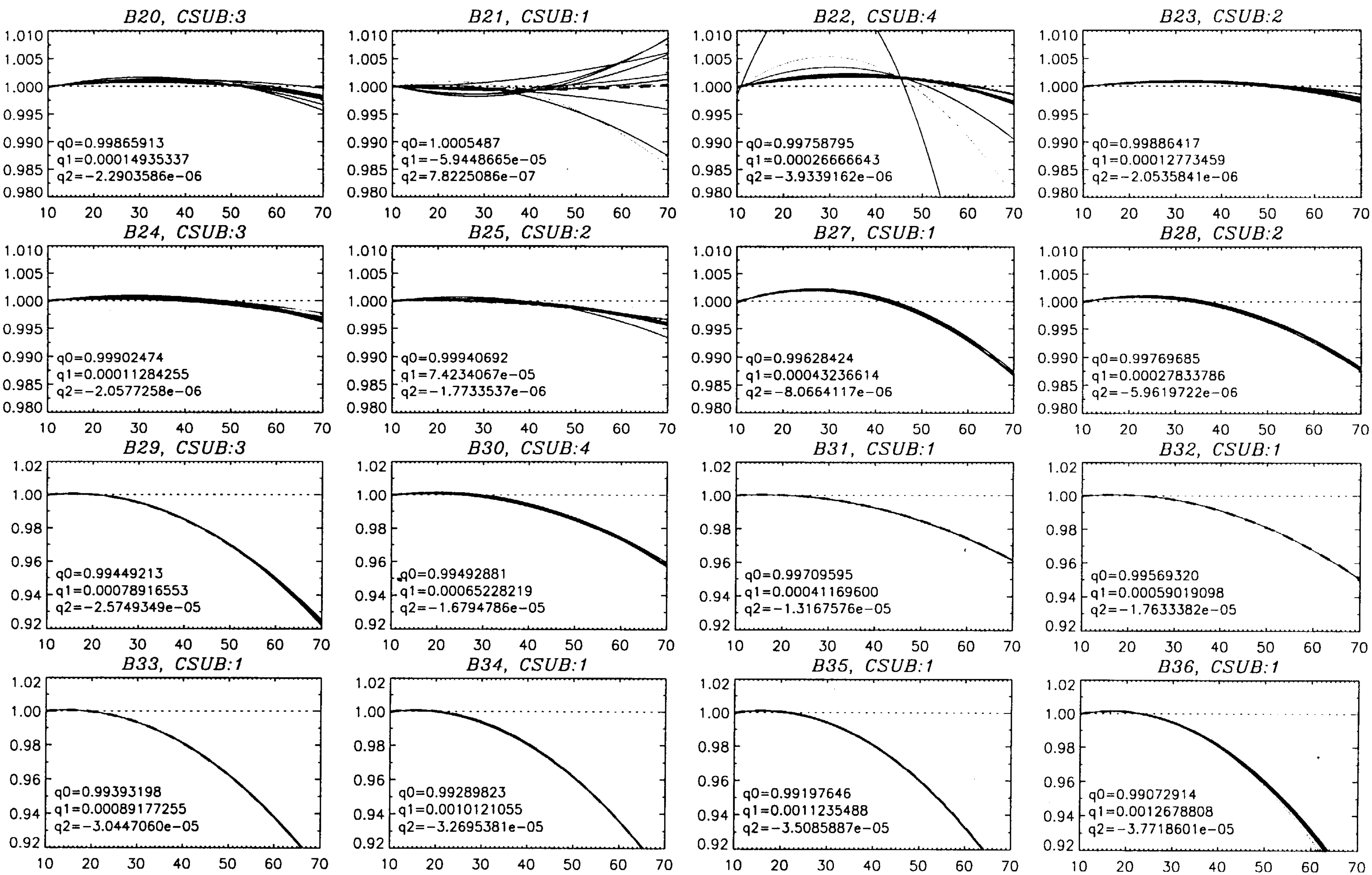
Normalized RVS (@ 10.75°) and Quadratic Fit vs AOI of 10 Channels for 310K_1 Data Set; Mirror A

Polynomial coefficients result from the average (dashed line) of unsaturated channels



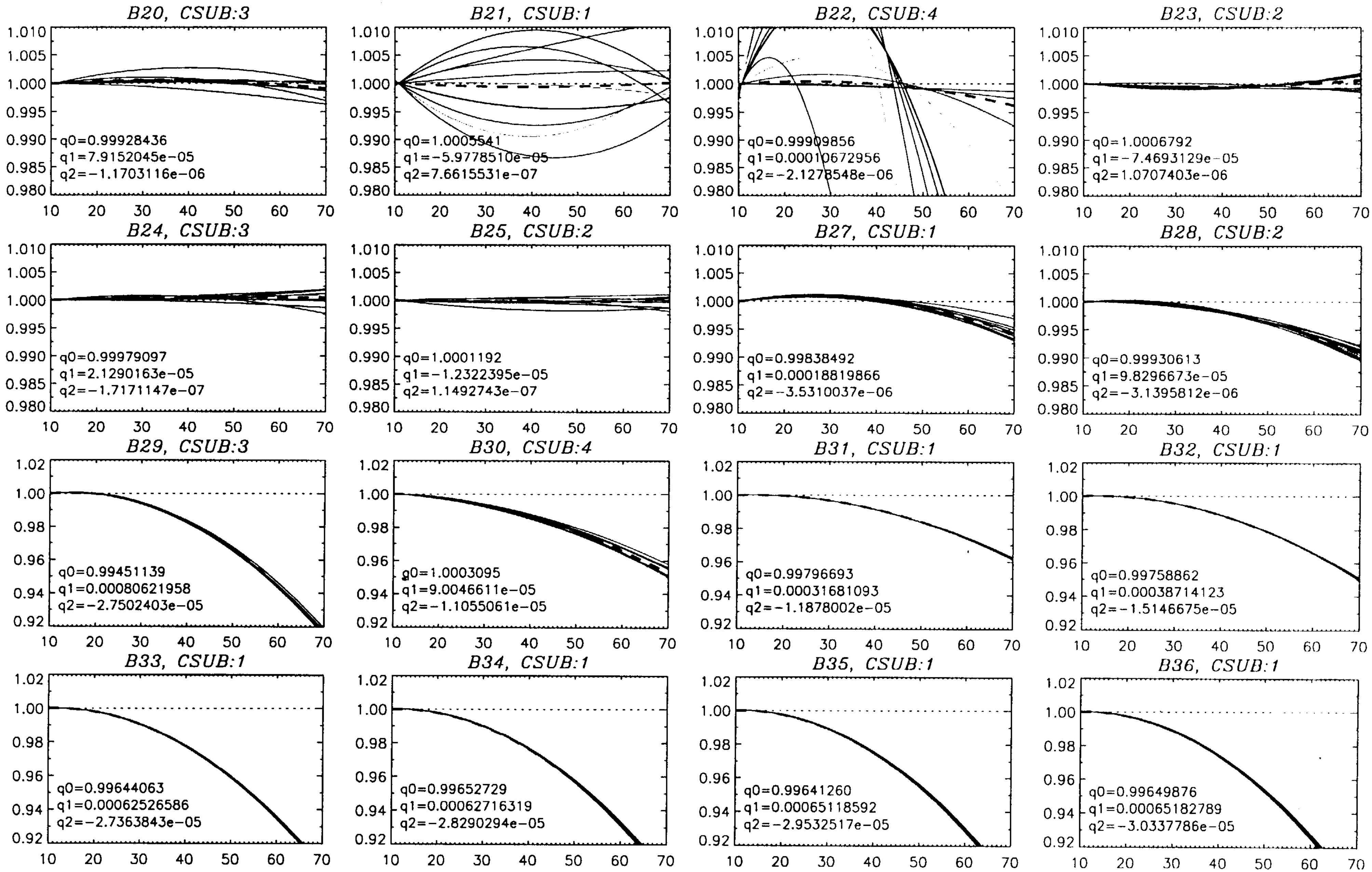
Normalized RVS (@ 10.75°) and Quadratic Fit vs AOI of 10 Channels for 320K_2 Data Set; Mirror A

Polynomial coefficients result from the average (dashed line) of unsaturated channels



Normalized RVS (@ 10.75°) and Quadratic Fit vs AOI of 10 Channels for 320K_3 Data Set; Mirror A

Polynomial coefficients result from the average (dashed line) of unsaturated channels



Quadratic Fit of Normalized RVS (@ 10.75°) of Unsaturated Channels vs AOI; Mirror A