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BASELINE UPPER AIR NETWORK (BUAN) FINAL REPORT

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U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Environmental Satellite, Data, and Information Service

NOAA TECHNICAL REPORTS

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Sounding Implementation Branch
Office of Research and Applications

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U.S. DEPARTMENT OF COMMERCE
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National Oceanic and Atmospheric Administration
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National Environmental Satellite, Data, and Information Service
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1. INTRODUCTION

Satellite measurements of spectral radiances have become an integral part of the Global Observing System of the World Weather Watch over the past 20 years. This observational capability has enabled meteorological centers to implement Numerical Weather Prediction (NWP) forecast models on a global scale. The National Oceanic and Atmospheric Administration (NOAA) computes and distributes, operationally, global soundings of atmospheric temperature and moisture based on the TIROS Operational Vertical Sounder (TOVS) measurements. This is done to satisfy national and international NWP model requirements.

Improvements in NWP forecast models over the last ten years have increased the accuracy requirement for satellite soundings. During this time, NOAA has implemented a number of modifications to provide an improved sounding product, the latest being the installation of a physical retrieval approach in 1988 which replaced the purely statistical method. Currently, international research on the sounding problem includes numerous studies to improve the complex physical models of atmospheric radiative processes applied in such approaches. Radiance classification and other techniques to compute initial estimates of the atmospheric state needed for proper initialization of the physical model are being studied. Accurate and dependable ground truth data, consisting of collocated radiosonde and radiometric measurements, are required to support the algorithm development and validation efforts associated with these studies. Furthermore, collocated data are explicitly used to adjust the physical model used to compute TOVS operational soundings. It follows that any improvement in the accuracy of such data can impact the current sounding products and supporting research, and also can lead to a sustained positive impact on sounding products through the 1990's in step with expected advances in the NWP models.

Given this premise, and based on the recommendations from several national and international groups, the Extraordinary Session of the World Meteorological Organization (WMO) Commission for Basic Systems held in 1985 agreed that a Baseline Upper Air Network (BUAN) experiment should be undertaken. The primary goal of the experiment would be to test the hypothesis, which states that an immediate improvement in satellite sounding accuracy would occur through improvements in the collocation data base used to empirically adjust the retrieval model. An important goal also was to compile a high quality data set of radiosonde and radiometric measurements to support research which could lead to long term improvements in sounding accuracy. The BUAN would optimally consist of a small, globally distributed set of radiosonde stations selected from the currently operational observing stations. A key element of the BUAN network was the requirement to take special radiosonde observations coincident with satellite overpasses, which in general are not made at the normal synoptic observation times.

The final selection of the BUAN radiosonde stations was based on many factors, including geographical location, data quality, and regularity of receipt of transmitted reports. Initially it was believed that 15 to 25 stations with excellent performance records and appropriate geographic distribution would suffice for a baseline network. However, it was later decided that it was not reasonable to expect that two special observations from all BUAN stations would be taken for six months. The list of stations, therefore, was expanded to include alternate stations to better ensure an adequate global distribution in the event of missing special observations. A total of 101 candidate stations and ships were ultimately selected to comprise the BUAN.

The United States agreed to undertake an evaluation of the impact of the BUAN hypothesis on the accuracy of TOVS operational soundings. This task was undertaken by NOAA, the parent organization of the National Environmental Satellite Data and Information Service (NESDIS) and the National Weather Service (NWS). A number of WMO Members agreed to take special radiosonde observations at stations on the candidate list during the period January 15 to July 15, 1988. NOAA provided satellite overpass information for NOAA-10 to the BUAN, and the special radiosonde observations made by participating WMO Members were transmitted on the Global Telecommunication System (GTS). The special observations, together with routine observations from the remaining candidate stations which were coincident with satellite overpass, were collected by NOAA. These observations were then collocated with satellite data, the collocated data was archived, and their impact on sounding products evaluated.

This report describes the special data collection, processing and evaluation done as part of the BUAN experiment. Section 2 describes the processing and distribution of NOAA-10 overpass information, the collection of BUAN radiosonde observations, and their collocation with satellite data. Section 3 describes the principles and components of the TOVS operational system used to test the BUAN hypothesis, and presents evaluation results. Section 4 analyzes the BUAN hypothesis with respect to the field experiment and the evaluation results, and provides recommendations to the WMO Commission for Basic Systems (CBS) on the advisability of implementation. Section 5 describes the final archive of collocated BUAN radiosonde and satellite observations compiled by NOAA.

2. SATELLITE AND BUAN RADIOSONDE OBSERVATIONS

2.1 Data

2.1.1 Satellite Overpass Schedules

Launch schedules and ephemeris information corresponding to NOAA-10 satellite overpass were generated and distributed to the operators of BUAN reporting stations and Automated Shipboard Aerological Program (ASAP) ships. Ephemeris data were also forwarded to Japan for non-ASAP ships taking radiosonde observations. NOAA typically operates two polar orbiting satellites; however, complete TOVS data from NOAA-9 were not available during the field experiment due to an instrument malfunction. NOAA-10 had local equator crossover times of approximately 0730 and 1930 during the BUAN period. Except in polar regions, satellite overpass generally coincides with the 0000 and 1200 UTC routine synoptic observations at longitudes of about 100E and 80W, and with the 0600 and 1800 UTC standard observations at about 10E and 170W.

Table 1 lists the countries and identification codes of reporting stations comprising the BUAN. Launch schedules were generated and distributed to each of these stations on the 7th and again on the 11th days of each month during the experimental period. The schedules contained two desired launch times per day for each station for the upcoming month. Each launch time corresponded to the satellite orbit for which the nadir position was closest to the station location, and varied daily at a given station due to orbit retrogression. The times listed were the predicted time of the NOAA-10 satellite overpass minus a 45 minute offset to allow the satellite data to coincide with a balloon height of about 300 hPa. Routine feedback on the receipt of launch schedules was requested by NOAA; however only a few of the countries operating BUAN stations provided such information.

Table 2 lists the countries and identification codes of ships identified for the BUAN. Ephemeris data were generated and distributed to WMO Members responsible for ASAP operations for each country on the 15th day of each month, and contained data for the following month. The ephemeris data consisted of NOAA-10 orbital track positions at two minute intervals over the North Atlantic, North Pacific, and Indian Oceans. It was recommended that the radiosonde launch occur forty-five minutes prior to the time when the position of the ship was within 500 km and directly East or West of the predicted sub-satellite position.

Table 1. Reporting stations[1] comprising the BUAN.

Country	Station Identification
Argentina	87155, 87860
Australia	89571, 89611, 94203, 94326, 94610, 94672
Barbados	78954
Brazil	82193
Canada	71124, 71600, 71913, 71924, 71925, 71957
Cape Verde	08594
Cent. African Rep.	64650
China	54511, 58457
Denmark	06011
Finland	02963
France	07145, 61996, 61998, 91938
Germany, F.R.	10868
Ivory Coast	65578
Japan	47778, 47936, 89532
Libya	62010
Mexico	76151, 76644, 76723
New Zealand	91610, 93944
Niger	61052
Norway	C7M
Peru	84628
Poland	12374
Portugal	08509
Saudi Arabia	41024
Seychelles	63985
Singapore	48698
South Africa	68512, 68588, 68842, 68906, 68994
Spain	08001, 60020
Thailand	48455
U.S.S.R.	20046, 21432, 24959, 28698, 34560, 38457, 38687, 89050, 89542, C7C
United Kingdom	03005, 08495, 61901, 89022, C7L
United States	61902, 61967, 70308, 70414, 72203, 72208, 72261, 72269, 72340, 72391, 72402, 72493, 72747, 74794, 78861, 91217, 91245, 91285, 91765, 98327, 91366
Venezuela	80413
Zimbabwe	67774
Total Number of Stations:	91

[1]Launch schedules were not distributed to stations 89050 and 21432 operated by the USSR, and station 06011 operated by Denmark. Omission of these stations was due to an oversight which was not realized until after the conclusion of the field experiment.

Table 2. Ships identified for the BUAN.

Country	Ship Identification
Canada	ZCSK
Finland	VSBV3
France	FNOR, FNOU, FNPH, FNRS
Germany, F.R.	DBBH, DBFM
United Kingdom	VPHA
Japan	JBOA
Total Number of Ships:	10

2.1.2 Collocated Radiosonde and Satellite Observations

BUAN radiosonde and satellite observations were collocated and saved each day. The general procedure was to collect pairs of radiosonde and satellite observations that were within 1 hour and 150 km of each other. All radiosonde observations from BUAN reporting stations, both special and routine synoptic, which met the collocation requirements were collected. A final archive of the collocated data was compiled and is available from NOAA (see Section 5).

The BUAN reports were obtained from the World Meteorological Center (WMC)-Washington which routinely receives radiosonde reports from the global network over the GTS. Reports were stored on four files, each containing reports for the 6-hour interval within minus three and plus two hours of the synoptic observation times.

The TOVS satellite data were obtained from the NESDIS operational files which reside on the NOAA Central Computer at Suitland, Md. The data included the raw, preprocessed and fully-processed TOVS measurements and the TOVS sounding products. Further description of the satellite data collected is given in Section 5.

The procedures to collocate the BUAN radiosonde and satellite observations included a comparison of the scheduled and reported launch times for each radiosonde observation. If the times were within one hour, then the scheduled launch time plus 45 minutes was used as the target time for collocating the satellite data. This insured that the collocated satellite data were from the single orbit corresponding to the scheduled launch time. If the reported and scheduled launch times differed by more than one hour, then the report time was used as the target for collocating the satellite data. Generally, no satellite data could be collocated in such cases except in polar regions where successive satellite orbits overlap. Both the reported and scheduled launch times were stored for radiosonde observations collected on the final archive. Further details on data collection procedures are described in Section 3.

2.2 Receipt of Radiosonde Reports

2.2.1 Introduction

An important aspect of the BUAN experiment was ensuring that the special observations that were requested and made were successfully stored in the WMC-Washington data base. Regularity of receipt of the observations from the BUAN was important in order to test the BUAN hypothesis. However, past experience with monitoring the receipt of observational data over the GTS, has revealed that many proper, scheduled observations are never received. The problem is even more complicated when irregularly scheduled observations are introduced. It is clear that some of these factors influenced the data collection and subsequent evaluation effort. Problems regarding the WMC collection process also influenced the receipt of observations. The following sub-sections summarize the observations collected and factors related to missing data.

2.2.2 Receipt Statistics

Tables 3a, 3b, and 3c list the number of radiosonde observations that were collocated with satellite data and stored in the final archive along with the mean scheduled launch times (two per day) for each reporting station. The total number of observations was highest for the region 90N to 30N (3,934 reports from 41 sites). About one-half that number were collected for the region 30N to 30S (2,029 reports from 35 sites). The number of observations was halved again for the region 30S to 90S (1,056 reports from 15 sites). The data receipt maximized during the middle of the collection period. There were, however, a number of stations for which only a small number of reports was collected.

Inferences may be made from Tables 3a, 3b, and 3c about the contributions made by participating BUAN stations and ships through both routine synoptic and special asynoptic observations. For example, stations for which the scheduled launch time was asynoptic (e.g., station 63985 at about 0300 and 1500 UTC) clearly had to make special observations. However, since the radiosonde observation times were reported to only the nearest hour, it was difficult to determine if special launches were made at stations where the satellite overpass occurred close to one hour from the normal synoptic observation times and impossible to determine if special launches occurred when the time difference was less than one hour. This complicated the task of routinely monitoring the receipt of special BUAN reports. In general, Table 3 shows a higher number of reports from stations with scheduled launch times close to the standard synoptic times.

Table 3a. Number of BUAN radiosonde reports in the final archive of collocated radiosonde and satellite observations for the latitude belt 90N to 30N.

Station Id.	Mean Scheduled Launch (UTC)	Jan	Feb	Mar	Apr	May	Jun	Jul	Total
02963	0619,1740	6	37	42	48	38	38	16	225
03005	0823,1815	1	12	15	8	3	4	2	45
06011	0835,1815	0	0	1	2	3	0	0	6
07145	0704,1734	1	6	8	9	3	6	3	36
08001	0806,1859	0	0	23	27	18	19	10	97
08509	0904,2010	0	0	0	4	7	11	3	25
10868	0644,1713	5	25	29	26	28	29	12	154
12374	0613,1647	0	34	45	2	0	0	4	85
20046	0829,1100	0	18	27	26	27	27	11	136
21432	0705,0017	3	17	20	22	19	17	7	105
24959	0904,2325	1	17	20	22	15	20	7	102
28698	0250,1309	3	11	10	9	7	8	5	53
34560	0433,1513	2	15	19	23	17	20	8	104
54511	1040,2331	4	27	35	32	31	30	11	170
58457	1028,2314	5	34	35	38	31	30	14	187
70308	0519,1907	7	37	39	45	38	36	15	217
70414	0630,2005	0	0	0	0	0	1	0	1
71124	0205,1546	0	0	0	0	6	1	0	7
71600	1128,2221	3	42	44	47	40	45	17	238
71913	1409,2338	9	30	34	35	35	34	12	189
71924	1532,2253	6	24	33	38	31	38	13	183
71925	0017,1529	9	31	36	36	37	34	14	197
71957	0202,1722	5	22	39	44	39	39	17	205
72208	2355,1235	8	24	28	32	28	26	9	155
72269	0219,1508	0	0	0	1	0	0	0	1
72340	0037,1325	5	34	37	35	31	36	16	194
72391	0310,1601	0	0	0	1	0	0	1	2
72402	0010,1310	0	18	26	33	30	25	11	143
72747	0024,1343	8	36	45	50	37	38	17	231
C7C	0945,2050	3	8	13	12	14	14	5	69
C7L	0905,2010	0	17	13	13	15	12	8	78
C7M	0810,1800	2	18	25	21	21	27	9	123
DBBH		0	0	0	13	4	0	1	18
DBFM		0	0	0	0	2	16	0	18
FNOR		0	1	0	1	0	0	0	2
FNOU		0	1	3	1	0	2	1	8
FNPH		1	2	3	3	0	3	1	13
FNRS		0	1	2	2	3	3	0	11
VPHA		1	5	7	7	4	7	3	34
ZCSK		0	0	0	5	7	3	2	17
SHIP		0	0	0	17	16	12	5	50
Total		98	604	756	790	685	711	290	3934

Table 3b. Number of BUAN radiosonde reports in the final archive of collocated radiosonde and satellite observations for the latitude belt 30N to 30S.

Station Id.	Mean Scheduled Launch (UTC)	Jan	Feb	Mar	Apr	May	Jun	Jul	Total
08594	0835,2012	0	0	0	0	1	0	0	1
47936	1003,2256	1	11	8	4	7	7	2	40
48455	1122,2339	3	24	29	26	20	21	9	132
48698	1155,2358	1	15	13	18	12	16	5	80
60020	0729,1938	0	2	8	9	3	10	3	35
61901	0717,1949	0	2	2	1	0	3	0	8
61902	0743,1956	0	1	0	1	1	0	0	3
63985	0307,1508	1	4	8	7	7	9	2	38
64650	0540,1737	0	1	3	0	0	0	0	4
68512	0525,1802	0	0	26	25	20	10	0	81
68588	0427,1704	0	0	7	17	18	0	0	42
72203	2359,1231	10	36	40	41	39	33	14	213
72261	0113,1355	4	31	27	27	27	29	9	154
74794	0045,1315	0	8	7	1	0	1	1	18
76644	0037,1307	3	8	9	10	14	7	5	56
78861	2319,1158	0	5	14	10	10	12	5	56
78954	1059,2243	3	13	4	9	16	19	8	72
80413	1129,2317	0	0	11	17	13	10	3	54
82193	1007,2208	0	2	3	8	8	5	4	30
84628	0007,1150	4	8	11	12	12	9	2	58
87155	2308,1029	2	9	14	14	14	13	6	72
91217	0904,2119	0	3	0	0	0	0	0	3
91245	0733,2001	0	6	9	9	7	10	5	46
91285	0501,1725	2	18	20	17	14	19	10	100
91366	0822,2028	0	0	1	0	0	0	0	1
91610	0717,1922	0	6	13	13	17	13	0	62
91765	0624,1808	1	13	18	19	17	13	7	88
91938	0458,1641	0	15	20	16	12	9	0	72
94203	1058,2226	0	13	17	24	20	12	0	86
94326	1013,2140	2	36	39	24	15	20	8	144
98327	1040,2256	2	27	19	10	4	2	3	67
FNOR		0	4	4	1	1	5	3	18
FNOU		0	6	5	3	4	4	2	24
FNPH		1	6	6	8	5	7	4	37
FNRS		0	2	7	8	12	2	3	34
Total		40	335	422	409	370	330	123	2029

Table 3c. Number of BUAN radiosonde reports in the final archive of collocated radiosonde and satellite observations for the latitude belt 30S to 90S.

Station Id.	Mean Scheduled Launch (UTC)	Jan	Feb	Mar	Apr	May	Jun	Jul	Total
61996	0113,1408	0	1	1	1	1	1	0	5
61998	0125,1455	0	1	2	0	2	0	0	5
68842	0443,1737	0	0	11	22	19	14	0	66
68906	0702,2003	0	0	5	7	6	0	0	18
68994	0341,1659	0	0	7	1	6	2	2	18
87860	0001,1048	3	21	24	25	23	19	10	125
89022	0613,2258	0	0	1	7	0	0	0	8
89050	2351,0940	5	16	15	20	18	18	7	99
89532	0234,1750	0	2	4	3	2	5	0	16
89542	0259,1800	0	2	3	4	4	6	2	21
89571	0003,1511	3	16	15	8	7	16	5	70
89611	1254,2207	5	25	23	20	20	28	9	130
93944	0823,1847	3	26	35	35	22	23	0	144
94610	1131,2240	0	7	15	35	25	26	10	118
94672	1002,2256	6	40	43	40	31	37	16	213
Total		25	157	204	228	186	195	61	1056

2.2.3 Verification of the Collection Process

It was not possible to determine the cause of missing scheduled reports or to determine whether the observations were in fact taken. Some problems were identified and promptly corrected during the first part of the collection period. However, a lingering question throughout the field experiment was whether missing reports had been made but somehow mishandled.

During early June, 1988, a Preliminary Report, which included an initial assessment of participation in the BUAN field experiment from January 15 to April 15, was distributed. Feedback was subsequently received from three countries, two of which indicated that special observations had not been included. As a result, investigations were undertaken to compare station launch records with the data received by NOAA to track missing reports. Studies were done for two periods. The first, from April 17-30, 1988, was based on launch records received from BUAN stations operated by Spain and the United Kingdom (UK). The second, from May 15-28, 1988, was based on records received from the USSR.

Investigation results are summarized in Table 4 which identifies key elements of the radiosonde observation collection process beginning at the reporting station and ending with the data set of collocated BUAN radiosonde and satellite observations. Listed are the country, station identification number, mean scheduled launch times, number of radiosonde observations taken, and the numbers received by NOAA and collocated with satellite data. The numbers for observations taken, received and collocated are sub-divided into special and routine synoptic observations (NR indicates No Records received).

Table 4. Comparison of station launch records with radiosonde observations received by NOAA and collocated with satellite data for standard synoptic (Snpt.) and special (Spec.) observations.

Country	Ident.	Mean Scheduled Launch (UTC)	Taken		Received		Collocated	
			Snpt.	Spec.	Snpt.	Spec.	Snpt.	Spec.
Period: April 17-30								
Spain	08001	0806,1859	NR	28	-	17	-	12
	60020	0729,1938	NR	27	-	10	-	5
UK	08495	0759,1905	NR	9	-	8	-	0
	61901	0717,1949	NR	3	-	0	-	-
	89022	0613,2258	28	0	14	-	4	-
Period: May 15-28								
USSR	21432	0705,0017	42	0	42	-	9	-
	24959	0904,2325	42	0	42	-	8	-
	28698	0250,1309	28	6	28	(4)	3	0
	38457	0247,1343	56	10	53	(10?)	0	0
	38687	0303,1408	56	6	55	(6?)	0	0

Note: ( ) and (?) are explained in the text.

A summary of Table 4 indicates the following:

(a) for the 10 stations, 89 observations were taken out of a possible 280 special launches for which schedules were provided,

(b) 35 of the 67 special reports taken at stations operated by Spain and the UK were received over the GTS,

(c) 17 of the 27 special reports received from stations operated by Spain were collocated with satellite data, and

(d) none of the special reports taken at stations operated by the UK (12) and USSR (22) were collocated with satellite data.

As indicated in Section 2.2.1, there is no single explanation as to why reports, known to have been taken, were not received at the WMC over the GTS. However, of the reports received, 10 of the 27 from Spain and all eight from the UK were not collocated with satellite data. Investigation of the scheduled launch time and recorded observation time for these reports verified that in most cases the time difference was greater than one hour. Confusion may have arisen from the time constraints cited in the BUAN feasibility study circulated to WMO Members, which initially indicated that a 2-hour (instead of 1-hour) window for timeliness would be acceptable.

Gaps in the satellite data also occurred; however, cases for which collocations were not done due to gaps were rare. For example, of the 19 timely reports received from Spain only two were not collocated because of missing satellite data. Gaps in the satellite data were primarily due to processing problems which resulted in missing data. Inter-orbit gaps which occur at the lower latitudes, and the decreased density in satellite data at the outer scan angles of the sounder were also causes for missing data.

Investigation of the missing USSR reports revealed that some of the special 0300 UTC observations were received, but that the observation time was incorrectly recorded on the WMC file as 0600 UTC. This occurred for the four special observations (six were taken) received from station 28698 during the period May 15-28. It could not be determined whether any of the 16 special reports from stations 38457 and 38687 were received, but the time recorded in each case was the synoptic time of 0600 UTC. Subsequently, none of the USSR observations met the time criterion for collocation with satellite data. Further investigation indicated that the time problem was related to a shortcoming in WMC procedures which can only accommodate one report from the same station per 6-hour synoptic interval. On days when special launches were made, the three USSR stations made observations at 0300 and 0600 UTC, resulting in two reports for the 0600 UTC interval. It is not certain which reports were received over the GTS, but in any case the special observations were either lost or combined with the synoptic report when stored on the WMC file.

The reliable receipt and collection of radiosonde observations was an important criterion for the BUAN experiment. Stations were chosen to be part of the BUAN on the basis of having a good record of receipt at WMC-Washington. It was assumed that BUAN reports would be reliably taken, received over the GTS and stored in the WMC database; however during the BUAN experiment this did not always occur. Further discussion and possible impacts on the evaluation are discussed in Section 4.

3. EVALUATION OF THE BUAN HYPOTHESIS

3.1 TOVS Operational Processing System

3.1.1 The BUAN Hypothesis

As discussed in the Introduction, the BUAN hypothesis states that an immediate improvement in satellite sounding accuracy will occur through improvements in the collocation data used to empirically adjust the retrieval model.

This hypothesis was tested using TOVS data from the NOAA-10 satellite.

3.1.2 Satellite Products Generation

The TOVS operational retrieval algorithm uses a Minimum Variance-Simultaneous retrieval technique (Dey, et al.) for computing atmospheric temperature and moisture soundings. This technique can be described as one in which the solution is derived by explicit inversion of the radiative transfer equation. It is "simultaneous" in that atmospheric and surface temperatures and water vapor mixing ratios are retrieved at one time in a single solution. These profiles are converted to layer-mean virtual temperature and precipitable water profiles which are the standard sounding products distributed to users.

An important step of the NESDIS operational retrieval algorithm is the determination of initial estimates of atmospheric temperature, moisture and the associated TOVS radiance profiles. The initial estimates are important because the final solution is strongly dependent upon them. Procedures to compute the initial estimates are based on a sample of previously collocated radiosonde and satellite observations, and need to be considered carefully when testing the BUAN hypothesis. Further details are given in Section 3.1.3.

The strategy selected for testing the BUAN hypothesis was to compare the accuracy of NOAA-10 TOVS operational soundings (the "Control") to those from a second ("Test") system. The Test system was operated in a real-time mode, similar to the TOVS operational system. In most cases, the locations of the Control and Test soundings were identical, as were the TOVS radiance data used to compute each sounding. In fact, the Control and Test systems were the same in all but one respect. While the Control system used a data set compiled from conventional radiosonde and satellite observations collocated within 3 hours and 300 km to derive initial estimates and the retrieval solution, the Test system used a set compiled only from BUAN radiosonde and satellite observations collocated within 1 hour and 150 km. The use of the collocated data sets as described above is referred to as "adjustment" and is described in the next section.

3.1.3 Adjustment

Because the retrieval technique is a physical one, theoretically the retrievals can be accomplished without resorting to the radiosonde network. However, in practice the physical parameters needed are not known well enough to perform the retrievals accurately. As a consequence, empirical "adjustment" of the retrieval algorithm using collocated radiosonde and satellite observations is still required. This adjustment compensates for uncertainties in the physical parameters.

The adjustment can be explicit or implicit. Explicit adjustment occurs when a numerical adjustment is made to the radiance or to some quantity in a physical retrieval model, such as the atmospheric transmittance functions. Adjusting the retrieved profiles or initial temperature/moisture profiles toward radiosonde profiles also is an explicit adjustment. On the other hand, the adjustment is implicit when both the initial radiance and temperature/moisture approximations are based on measurements. In these cases the relationship between observed satellite radiance and temperature data is used implicitly to compensate for model errors (see Fleming, et al.).

An implicit adjustment procedure is applied operationally in the TOVS retrieval algorithm, and was the basis for testing the BUAN hypothesis. The adjustment is based on a 28-day data set of collocated radiosonde observations and satellite radiometric measurements which was updated daily. Updating of the collocated data set is needed to ensure the validity and continuity of the adjustment. The adjustment procedure is applied during the computation of the initial estimates of radiance, temperature and moisture, and in the determination of the retrieval operator (i.e., the coefficient matrix) needed to compute sounding products.

The initial estimates of the temperature/moisture vector and of the radiance vector for each sounding are determined by selecting the twenty radiance vectors in the 28-data set most closely resembling the observed radiance vector for a given sounding. The selected radiance vectors are then averaged to derive the initial radiance profile, and the corresponding temperature/moisture profiles from the radiosonde observations are averaged to derive the initial temperature/moisture profiles.

The 28-day data set is categorized by latitude, land or sea, and day or night as shown in Table 5. Each week, a single retrieval operator is calculated for each category by averaging the individual operators computed for each profile within the category. One of these operators is selected for each sounding based on the initial estimate of temperature. For details on how these operators are computed and applied when doing a retrieval, see Dey, et al.

Table 5. The TOVS geographic categories.

Latitude	Sea	Land/Day	Land/Night
90-60N	1	10	19
60-45N	2	11	20
45-30N	3	12	21
30-15N	4	13	22
15N-15S	5	14	23
15-30S	6	15	24
30-45S	7	16	25
45-60S	8	17	26
60-90S	9	18	27

3.1.4 Adjustment and Evaluation Data Sets

As stated in Section 3.1.2, two collocation data sets, one compiled using only the BUAN radiosonde observations and the other compiled using all the conventional radiosonde observations, were used to adjust the Test and Control soundings, respectively. Similar data sets also were compiled to evaluate the Test and Control soundings. The two collocation data sets were independently subjected to the same selection criteria before they were used for either adjustment or evaluation. Tests were applied to identify the following:

(a) radiosonde observations with superadiabatic lapse rate,

(b) radiosonde observations with a tropospheric temperature inversion exceeding 15 C/km,

(c) radiosonde observations with missing dewpoint depressions for reported mandatory and significant levels between the surface and 500 hPa,

(d) incomplete satellite data,

(e) questionable or bad satellite data,

(f) a large difference in terrain height between the radiosonde observation and satellite sounding locations,

(g) radiosonde observations with missing temperature data for two (or more) consecutive mandatory levels between 850 and 100 hPa,

(h) radiosonde observations for which the mandatory and significant levels with temperature data did not cover the range 850 hPa to 100 hPa,

(i) satellite soundings with superadiabatic lapse rates,

(j) satellite soundings with a tropospheric temperature inversion exceeding 15 C/km,

(k) satellite soundings with a skin temperature more than 5 C lower than the radiosonde surface temperature (if reported),

(l) satellite soundings with the retrieved temperature nearest the surface being more than 5 C lower than the corresponding radiosonde temperature,

(m) satellite soundings with the retrieved temperature at any level between the surface and 100 hPa differing by 15 C or more from the corresponding radiosonde temperatures,

(n) large differences simulated (from radiosonde observations) and measured TOVS radiance data for selected channels,

(o) cloudy satellite soundings, and

(p) radiosonde observations with multiple collocated satellite soundings.

The collocated data used for adjustment were required to pass tests (a) through (h), plus tests (k), (n), (o), and (p). For cases of radiosonde observations with multiple collocated soundings (test (p)), only the clearest and closest sounding was used. The collocation data set used for evaluation were required to pass the same tests as for adjustment, except for test (o). Except for test (p), the result of each test is stored on the final archive.

3.1.5 Data Set Characteristics

The TOVS physical retrieval algorithm requires an ample and meteorologically heterogeneous sample of collocated radiosonde observations and satellite radiometric measurements for use in adjustment. The meteorological and global representativeness of these data is important to achieving accurate TOVS physical retrievals. Success in evaluating the BUAN hypothesis was contingent on achieving a sufficiently heterogeneous sample of collocated data when limited to the BUAN reports.

The BUAN stations (and ships) for which at least one radiosonde observation was used to adjust the Test sounding system are listed in Tables 6-10. Each table represents an independent, 28-day data set, and together they span the period from February 9 to June 27. Listed, for each of the 27 geographic categories (see Table 5), are the BUAN station identification numbers and the total number of stations for the oceanic and land categories (the total number of observations for a given station can be determined from Tables 3a, 3b, and 3c). Table 11 lists the total sample sizes of collocated radiosonde and satellite observations corresponding to Tables 6-10.

Table 6. BUAN stations from which at least one radiosonde observation was used to adjust the Test soundings for the geographic categories shown in Table 5; February 2 to March 1, 1988.

Category	Station Identification
1	20046, 21432, C7M
2	70308, 71913, C7C, C7L
3	71600, FNOU, FNPH
4	47936, 60020, 72203, 74794, 76644, 78861, 91245, 91285, FNPH
5	48698, 63985, 78954, 91217, 91610
6	61901, 91938
7	
8	87860, 93944
9	89050, 89571, 89611
Total Number of Ocean Stations: 30	
10	02963, 24959, 71924, 71957
11	02963, 10868, 70308, 71600, 71913, 72747
12	54511, 72208, 72340, 72402
13	58457, 72203, 72261, 74794, 78861
14	48455, 48698, 63985, 78954, 82193, 91610, 98327
15	87155, 94203
16	87860, 94672
17	61998, 87860
18	89050, 89571, 89611
19	02963, 20046, 21432, 24959, 71924, 71925, 71957
20	10868, 28698, 70308, 71600, 71913, 72747,
21	54511, 58457, 71600, 72208, 72340, 72402
22	47936, 58457, 72203, 72261, 76644, 91245, 91285 98327
23	48455, 98327
24	
25	94672
26	
27	89050, 89611
Total Number of Land Stations: 41	

Note: Some stations appear in more than one category.

Table 7. BUAN stations from which at least one radiosonde observation was used to adjust the Test soundings for the geographic categories shown in Table 5; March 9 to April 4, 1988.

Category	Station Identification
1	21432, C7M
2	03005, 70308, 71913, C7L, C7C, SHIP, ZCSK, VPHA
3	08001, 71600, 72208, FNOU, FNPH, FNRS, ZCSK
4	47936, 60020, 72203, 74794, 76644, 78861, 91245, 91285, 98327, FNOR, FNOU, FNPH, FNRS
5	63985, 78954, 80413, 84628, 91610, 91765, 98327, DBBH
6	61901, 91765, 91938, 94203
7	68588, 68842, 68906
8	61998, 68994, 87860, 93944
9	89050, 89571, 89611
Total Number of Ocean Stations: 46	
10	02963, 20046, 21432, 24959, 71924, 71925, 71957
11	02963, 03005, 10868, 28698, 34560, 70308, 71600, 71913, 72747
12	08001, 54511, 58457, 71402, 71600, 72208, 72261, 72340
13	58457, 72203, 72261, 74794, 78861, 98327
14	48455, 48698, 63985, 78954, 80413, 82193, 91610, 98327
15	61901, 68512, 68588, 87155, 91938, 94203, 94326
16	68588, 68842, 68906, 87860, 94610, 94672
17	68994, 87860
18	89611
19	02963, 20046, 71924, 71925, 71957
20	02963, 07145, 10868, 28698, 70308, 71600, 71913, 72747
21	08001, 54511, 58457, 71600, 72208, 72340, 72402
22	47936, 58457, 60020, 72203, 72261, 76644, 91245, 91285, 98327
23	48455, 48698, 84628, 91765, 98327
24	68512, 94203, 94326
25	68512, 94610, 94672
26	68994
27	89050, 89542, 89571, 89611
Total number of Land Stations: 60	

Note: Some stations appear in more than one category.

Table 8. BUAN stations from which at least one radiosonde observation was used to adjust the Test soundings for the geographic categories shown in Table 5; April 6 to May 2, 1988.

Category	Station Identification
1	03005, 20046, 21432, C7M
2	03005, 70308, C7C, C7L, DBBH, SHIP, VPHA, ZCSK
3	08001, 08509, 71600, 72208, 72402, FNPH, SHIP, ZCSK
4	47936, 60020, 72203, 78861, 91245, 91285, FNPH, FNRS
5	48698, 61902, 63985, 78954, 84628, 91610, 91765
6	68588, 91765, 91938, 94203
7	68588, 68842, 68906
8	68994, 87860, 93944
9	89050, 89611
Total Number of Ocean Stations: 42	
10	02963, 20046, 21432, 24959, 71924, 71925, 71957
11	02963, 07145, 10868, 28698, 34560, 70308, 71600, 71913, 72747
12	08001, 08509, 54511, 58457, 71600, 72208, 72261, 72340, 72402
13	48455, 58457, 72203, 72261, 76644, 78861, 98327
14	48455, 48698, 63985, 78954, 80413, 82193, 91610, 98327
15	68512, 68588, 87155, 91938, 94203, 94326
16	68588, 68842, 68906, 87860, 94610, 94672
17	87860
18	
19	02963
20	07145, 10868, 70308, 71913, 72747
21	08001, 54511, 58457, 71600, 72208, 72261, 72340, 72402
22	47936, 58457, 60020, 72203, 72261, 76644, 91285
23	48455, 78954, 84628, 91765
24	94203, 94326
25	68588, 94610, 94672
26	
27	89022, 89050, 89571, 89611
Total number of Land Stations: 54	

Note: Some stations appear in more than one category.

Table 9. BUAN stations from which at least one radiosonde observation was used to adjust the Test soundings for the geographic categories shown in Table 5; May 3 to May 30, 1988.

Category	Station Identification
1	03005, 20046, 21432, C7M, DBFM, SHIP
2	70308, 71913, C7C, C7L, DBBH, SHIP, VPHA
3	08001, 08509, 71600, 72208, 72402, FNPH, FNRS, ZCSK
4	47936, 72203, 76644, 78861, 91245, 91285, FNOR, FNPH, FNRS
5	63985, 78954, 80413, 84628, 91610, 91765
6	61901, 68588, 91765, 91938, 94203
7	68588, 68842, 68906
8	68994, 87860, 93944
9	89050, 89611
Total Number of Ocean Stations: 45	
10	02963, 03005, 20046, 21432, 24959, 71913, 71924, 71925, 71957
11	02963, 03005, 07145, 10868, 28698, 34560, 70308, 71600, 71913, 72747
12	08001, 08509, 54511, 58457, 71600, 72208, 72261, 72340, 72402
13	58457, 72203, 72261, 76644, 78861
14	48455, 48698, 63985, 78954, 80413, 82193, 91610
15	68512, 68588, 87155, 91938, 94203, 94326
16	68588, 68842, 94610, 94672
17	87860
18	
19	
20	71600, 72747
21	08001, 54511, 58457, 71600, 72208, 72261, 72340, 72402
22	47936, 58457, 72203, 72261, 76644, 91245, 91285
23	48455, 84628, 91765
24	68512, 68588, 94203, 94326
25	87869, 94610, 94672
26	68994, 87860
27	89050, 89571, 89611
Total Number of Land Stations: 54	

Note: Some stations appear in more than one category.

Table 10. BUAN stations from which at least one radiosonde observation was used to adjust the Test soundings for the geographic categories shown in Table 5; May 31 to June 27, 1988.

Category	Station Identification
1	03005, 20046, 21432, C7M, DBFM, SHIP
2	70308, C7C, C7L, VPHA
3	08001, 08509, 71600, FNPH, FNRS, SHIP
4	47936, 60020, 72203, 76644, 78861, 91245, 91285, FNOR, FNPH, FNRS
5	48698, 60020, 63985, 78954, 84628, 91610, 91765, FNOR
6	91765, 91938, 94203
7	68842, 94610
8	68994, 93944
9	89050, 89571, 89611
Total Number of Ocean Stations: 39	
10	02963, 03005, 20046, 21432, 24959, 71924, 71925, 71957
11	02963, 03005, 10868, 28698, 34560, 70308, 71913, 71600, 72747
12	08001, 08509, 54511, 58457, 71600, 72208, 72261, 72340, 72402
13	58457, 60020, 72203, 72261, 74794, 78861
14	48455, 48698, 63985, 78954, 80413, 82193, 91610
15	68512, 87155, 91938, 94203, 94326
16	68842, 94610, 94672
17	
18	
19	
20	
21	54511, 58457, 72208, 72261, 72340, 72402
22	47936, 58457, 60020, 72203, 72261, 76644, 91245, 91285
23	48455, 84628, 91765
24	94203, 94326
25	68842, 87860, 94610, 94672
26	87860
27	89050, 89542, 89571, 89611
Total Number of Land Stations: 53	

Note: Some stations appear in more than one category.

Table 11. Sample sizes of collocated BUAN radiosonde and satellite observations used for adjusting the Test soundings for the periods and geographic categories corresponding to Tables 6-10.

	Periods				
Category	2/2-3/1	3/9-4/5	4/6-5/2	5/3-5/30	5/31-6/27
1	17	28	31	36	45
2	34	47	75	43	39
3	20	24	35	45	43
4	47	75	57	58	71
5	31	52	59	46	47
6	3	16	28	19	16
7	0	15	17	13	6
8	30	31	29	22	17
9	10	7	6	10	13
TOT.	192	295	337	292	297
10	37	122	146	157	155
11	58	90	127	118	124
12	51	60	84	84	101
13	43	54	60	44	53
14	50	56	80	49	51
15	35	64	91	63	58
16	21	49	50	39	17
17	21	16	10	2	0
18	20	7	0	0	0
19	127	30	5	0	0
20	94	69	32	3	0
21	63	87	93	75	48
22	65	75	74	65	55
23	18	35	20	20	13
24	0	13	23	13	12
25	23	25	39	35	30
26	0	1	0	11	9
27	20	20	46	22	28
TOT.	745	873	980	800	754
TOTAL	937	1168	1317	1092	1041

In summary, a total of 5,555 pairs of collocated BUAN radiosonde and satellite radiometric observations were available to adjust the Test system during the periods covered by Table 11. The data sets had an acceptable latitudinal distribution of land and sea observations with the highest number of observations in the Northern Hemisphere over land. The coverage was weakest in the Southern Hemisphere polar regions. It can be seen that the number of observing stations increased after the first period. This increase is attributed to improved processing and participation as the field experiment progressed, and was most noticeable in the data sparse region between 15S and 60S.

Table 11 indicates that on any given day, the available sample size of collocated data (and therefore the sample size of individual radiosonde reports, see test (p) in Section 3.1.4) used for adjusting the Test soundings ranged from 937 to 1,317. Excluding the first period, average sample sizes of 305 collocated data from 43 oceanic (ie., coastline and ships) stations, and 852 collocated data from 55 land (ie., coastline and inland) stations, were available for adjusting oceanic and land soundings, respectively.

3.1.6 Rejected Data

The amount of collocated data rejected for adjustment use due to the failure of the tests indicated in Section 3.1.4 also was monitored. Most of the data rejected were because of cloudy satellite soundings, test (o), and radiosonde observations with multiple collocated soundings, test (p). Of the remainder, most were rejected due to failures of tests (g) and (h), which check for radiosonde report completeness. Further investigation indicated that a common cause for incomplete reports was a missing Part A of the TEMP message which contains the mandatory level data. Table 12 lists the radiosonde stations for which at least 10 incomplete reports were received during the field experiment, and shows the number of incomplete reports observed for each month.

Table 12. Number of radiosonde reports rejected each month due to missing observations from stations with at least 10 incomplete reports throughout the experiment.

Identification	J	F	M	A	M	J	J	Total
12374		35	45	2			2	84
71925	3	6	10	9	12	14	5	59
71924	1	5	2	11	10	9	3	41
94326		16	21	2				39
98327	1	16	5	3	1	2	3	31
72208	2	2	2	9	3	7		25
03005		10	7	1			1	19
34560		14	3			2		19
91938		9	4	1	1			15
07145		2	3	6	1	2		14
93944		1	4	3	1	4		13
94203		3	7	2				12
89050		1	1	2	1	6		11
84628	1			2	3	3	1	10

3.2 TOVS Operational Test

3.2.1 Procedures

The evaluation strategy for the operational test of the BUAN hypothesis was to compare corresponding soundings from the Control and Test systems to the same radiosonde sounding. The evaluation was done using two separate evaluation data sets. The first, a "Standard Evaluation Data Set", contained corresponding Test and Control satellite soundings collocated with conventional radiosonde observations. The second, a "BUAN Evaluation Data Set", contained corresponding Test and Control satellite soundings collocated with BUAN radiosonde observations (see Section 3.1.4). In this way, the differences between Test and Control satellite soundings, and also between the Standard and BUAN Evaluation Data Sets used as ground truth, could be separately analyzed.

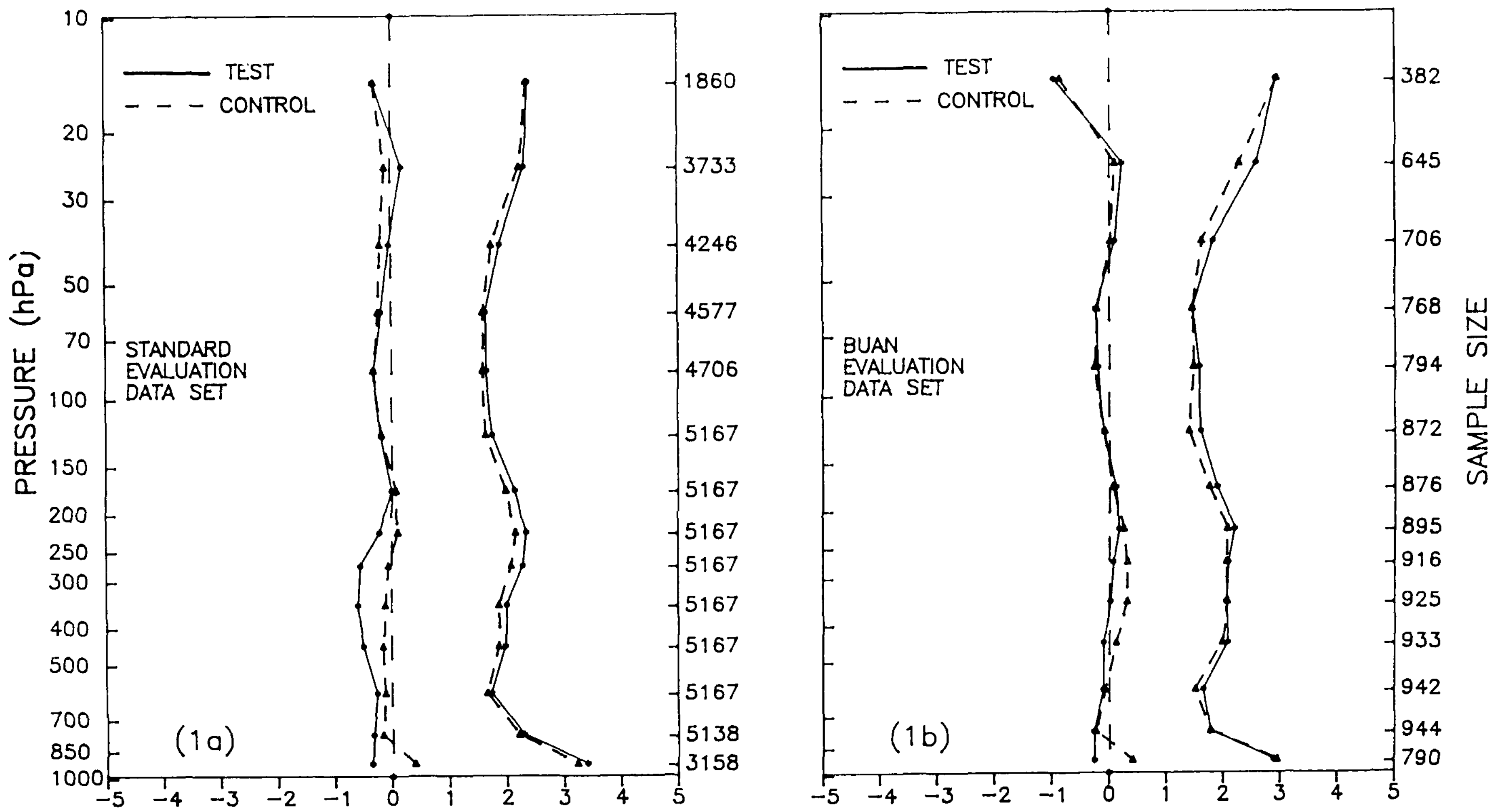
Two important aspects of the evaluation data sets should be mentioned. As indicated in Section 3.1.2, the Test and Control sounding systems were operated in parallel, therefore, the locations of the corresponding Test and Control soundings collocated with a given radiosonde report were often identical. Also, the radiosonde observations used to evaluate the soundings were always independent of those used for adjustment. Stated another way, a satellite sounding was never compared to a radiosonde observation that was used to adjust it.

Root mean square (RMS) and mean statistics of the difference in layer-mean virtual temperature between the satellite soundings and collocated radiosonde observations data (for each evaluation data set) were computed for the mandatory atmospheric layers and three global latitude regions. Figures 1a and 1b to 3a and 3b show graphs comparing the Test (solid) and Control (dashed) satellite products with the radiosonde observations. Each figure represents data averaged for 8 individual weeks, selected within the period March 8 to July 15, 1988 (graphs of the weekly statistics which were averaged are presented in the Appendix). The "a" graphs (left side) are with respect to the Standard Evaluation Data Sets while the "b" graphs (right side) are with respect to the BUAN Evaluation Data Sets. Figures 1a and 1b are for the Northern Hemisphere from 90N to 30N, Figs. 2a and 2b are for the Tropics from 30N to 30S, and Figs. 3a and 3b are for the Southern Hemisphere from 30S to 90S.

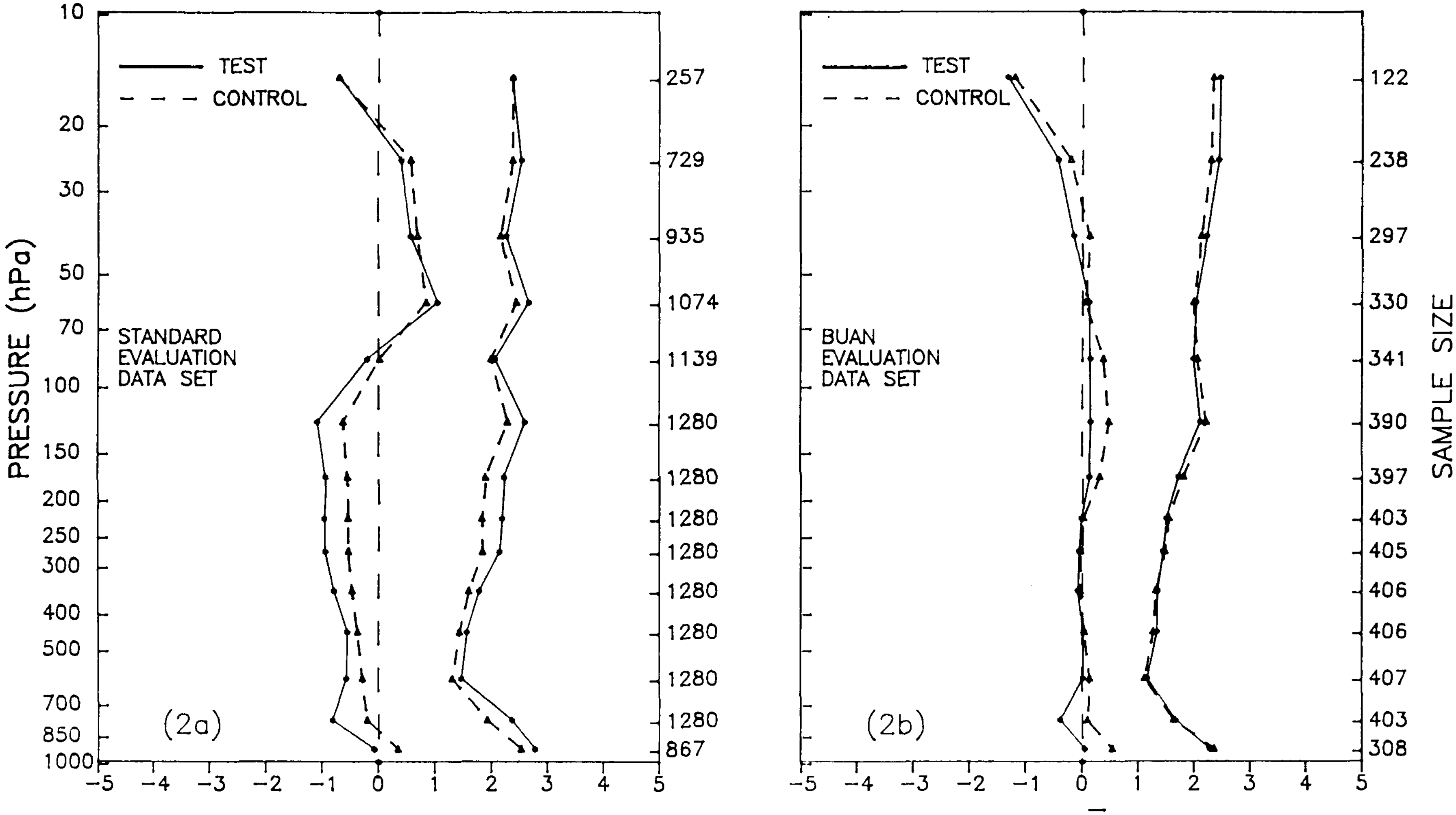
The formats of the six figures are identical. The tick marks on the left-hand axis represent the fifteen mandatory pressure levels, which bound fourteen atmospheric layers. The tick marks on the right-hand axis (located at the midpoints of the layers) represent the sample sizes for each of the layers. Below the axis across the bottom of the figure are the virtual temperature differences in degrees C.

The four curves in each of the six figures are interpreted as follows. The two dashed curves represent profiles of virtual temperature differences between the Control satellite soundings and the corresponding radiosonde soundings, while the solid curves represent differences between the Test and radiosonde soundings. Since the radiosonde soundings are assumed to be the truth, the difference curves represent error curves. The pair of dashed and solid curves that oscillate about the broken, vertical zero-error line are the mean errors, while the second pair of dashed and solid curves to the right of the first pair are the RMS errors. Note that the symbols on each of the four lines are the layer-mean values, and thus are located in the middle of the layers.

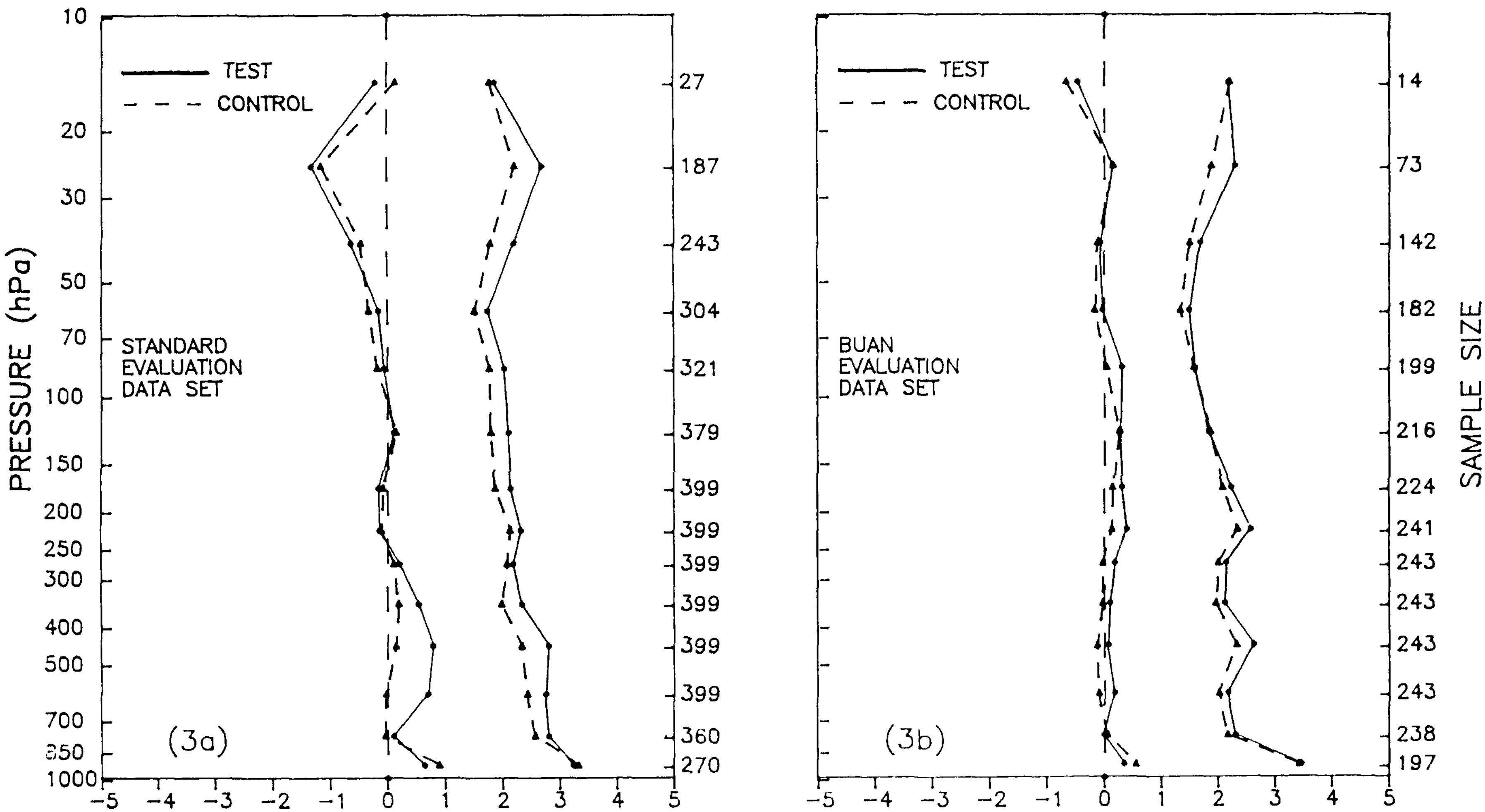
The variances of the radiosonde temperature data, for mandatory pressure levels also were analyzed and are plotted in Figures 4a and 4b for the BUAN (solid) and Standard (dashed) Evaluation Data Sets. Fig. 4a is for the region 90N to 30N, and Figure 4b is for the region 30N to 30S. Radiosonde observations for three weekly periods, corresponding to the 3rd, 5th and 6th weeks in the Appendix, were combined to compute the variances. Figures 5a and 5b show the reporting frequency as a function of longitude for the Standard and BUAN radiosonde reports, respectively, associated with the curves in Fig. 4a. Figures 6a and 6b show the reporting frequency as a function of longitude for the Standard and BUAN reports, respectively, associated with the curves in Fig. 4b. Each point in Figs. 5a through 6b denotes a station location and the total number of reports collected for the three weeks.



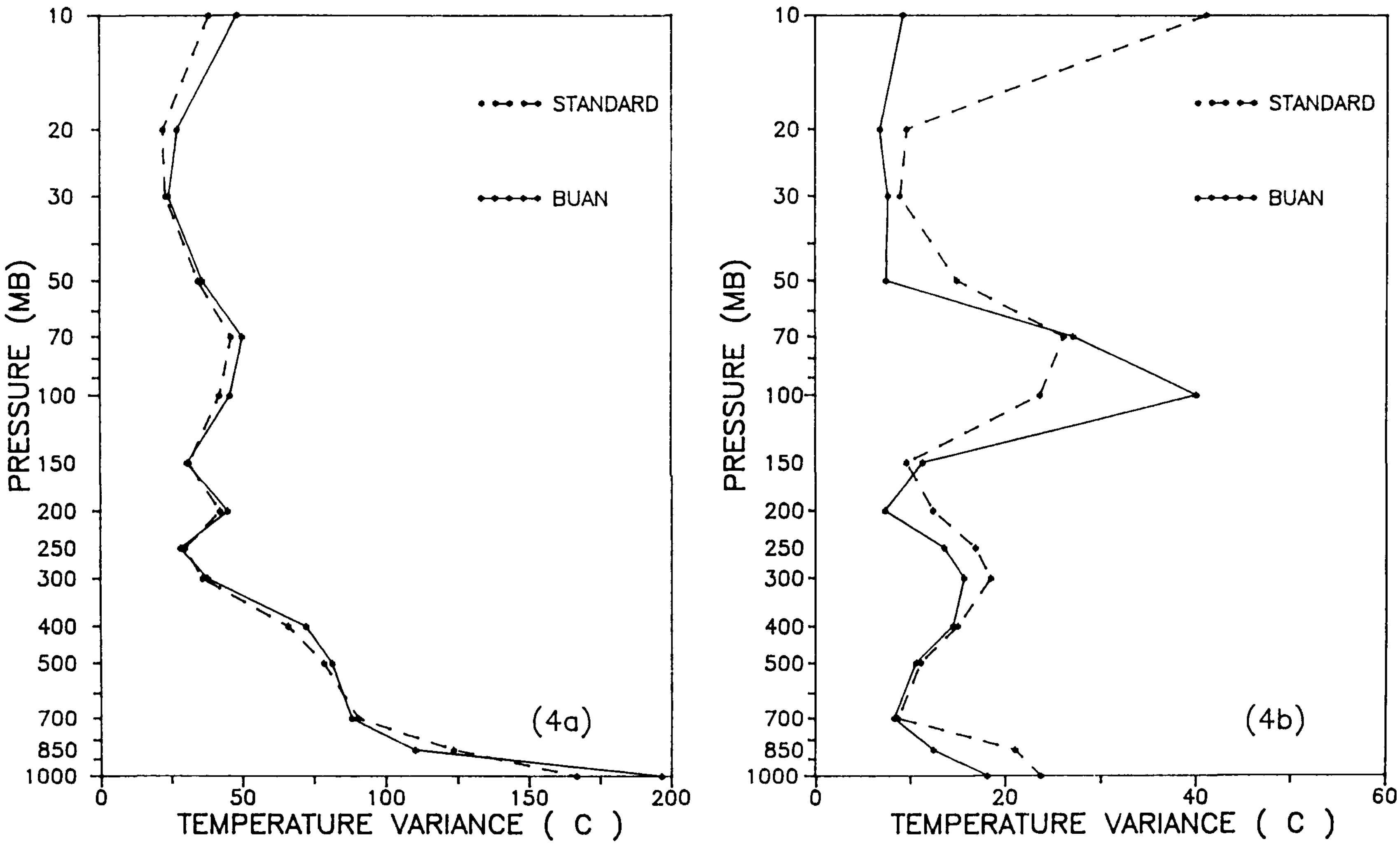
Figures 1a and 1b. Mean and RMS differences of layer-mean virtual temperature (C) between satellite soundings and radiosonde observations for the region 90N to 30N, for Test (solid) and Control (dashed) soundings using Standard (Fig. 1a) and BUAN (Fig. 1b) Evaluation Data Sets, averaged for eight weeks within the period 3/8/88 to 7/15/88; the total sample size for each layer is indicated on the right-hand axis.



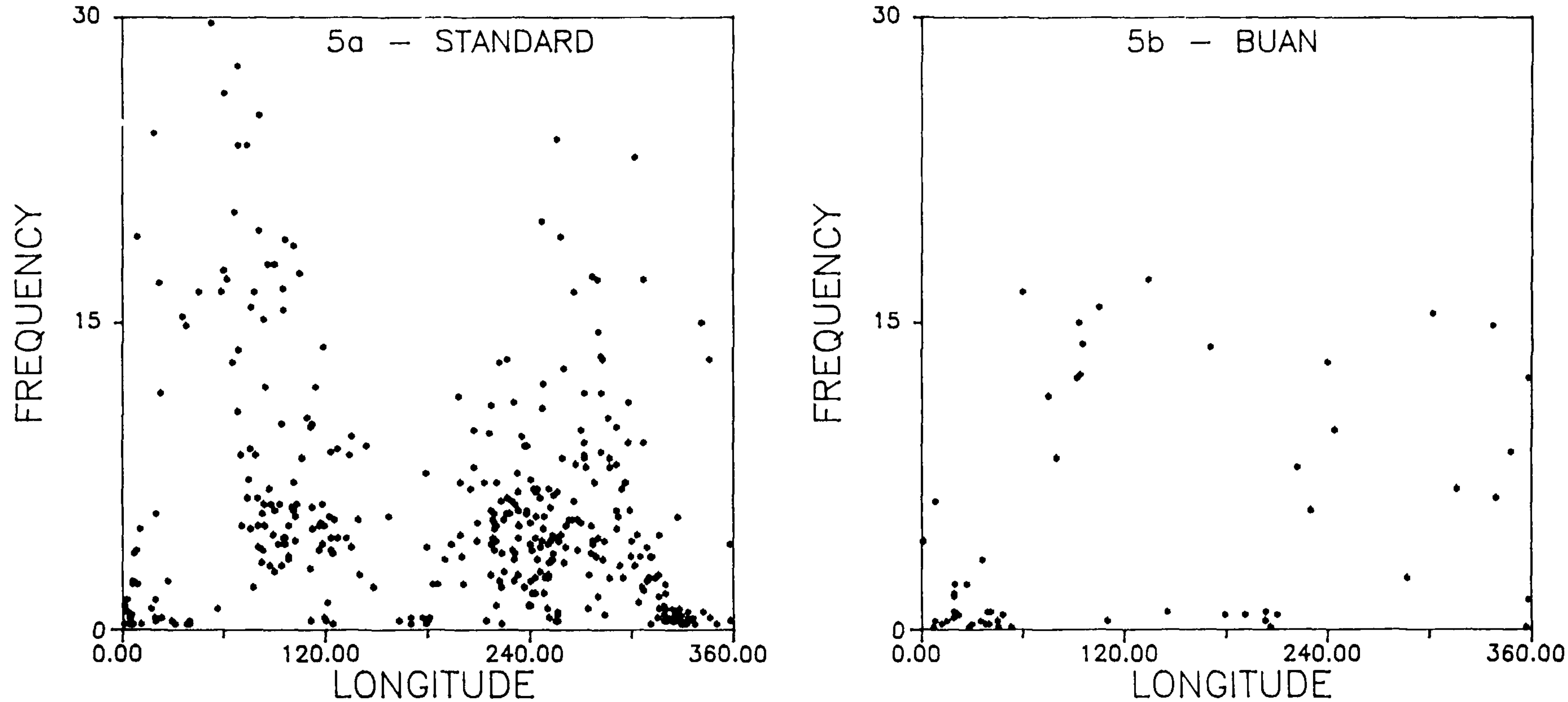
Figures 2a and 2b. Mean and RMS differences of layer-mean virtual temperature (C) between satellite soundings and radiosonde observations for the region 30N to 30S, for Test (solid) and Control (dashed) soundings using Standard (Fig. 2a) and BUAN (Fig. 2b) Evaluation Data Sets, averaged for eight weeks within the period 3/8/88 to 7/15/88; the total sample size for each layer is indicated on the right-hand axis.



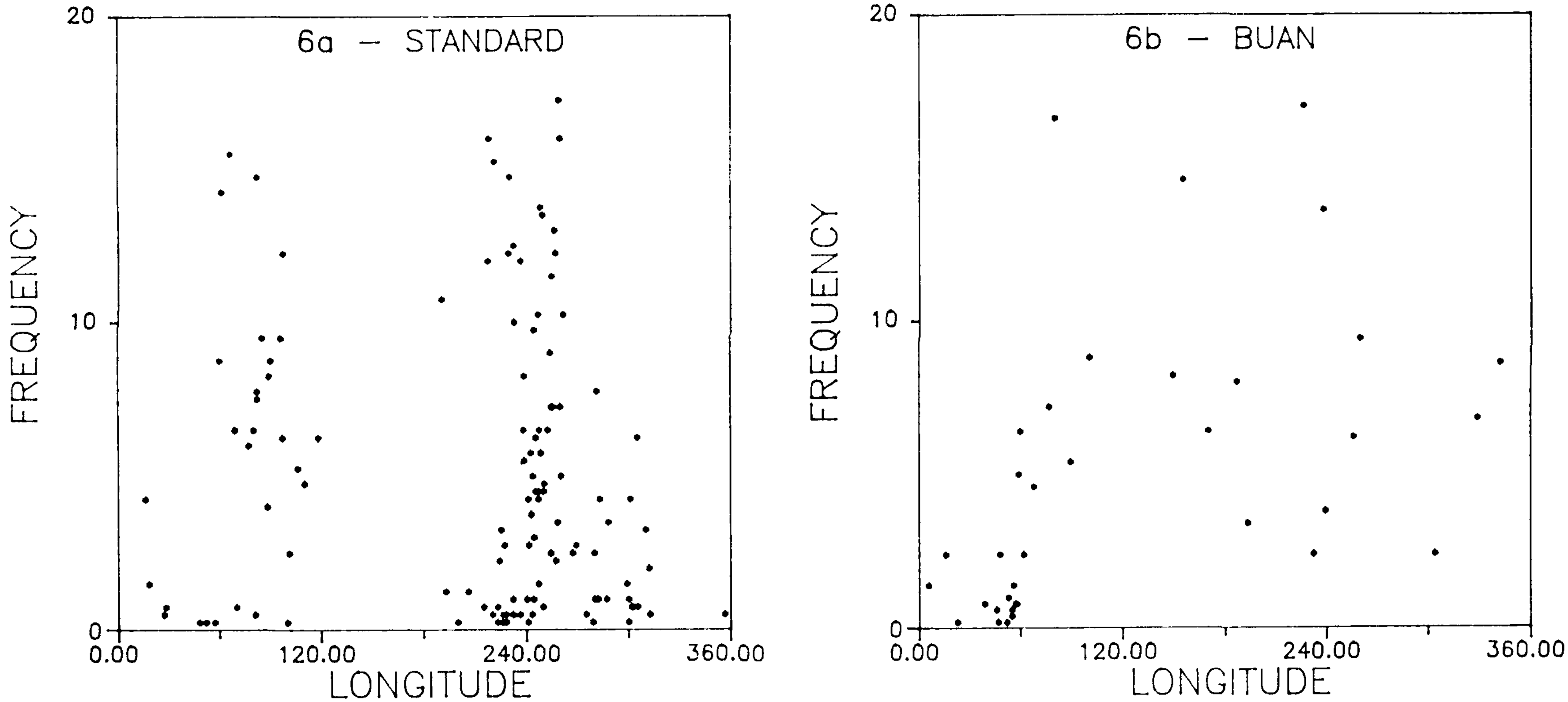
Figures 3a and 3b. Mean and RMS differences of layer-mean virtual temperature (C) between satellite soundings and radiosonde observations for the region 30S to 90S, for Test (solid) and Control (dashed) soundings using Standard (Fig. 3a) and BUAN (Fig. 3b) Evaluation Data Sets, averaged for eight weeks within the period 3/8/88 to 7/15/88; the total sample size for each layer is indicated on the right-hand axis.



Figures 4a and 4b. Variance in radiosonde temperature data comprising the BUAN (solid) and Standard (dashed) Evaluation Data Sets for three weekly periods, for the regions 90N to 30N (Fig. 4a) and 30N to 30S (Fig. 4b).



Figures 5a and 5b. Number of reports as a function of longitude in the region 90N to 30N (associated with Fig. 4a), for radiosonde observations contained in the Standard (Fig. 5a) and BUAN (Fig. 5b) Evaluation Data Sets.



Figures 6a and 6b. Number of reports as a function of longitude in the region 30N to 30S (associated with Fig. 4b), for radiosonde observations contained in the Standard (Fig. 6a) and BUAN (Fig. 6b) Evaluation Data Sets.

3.2.2 Results

Figures 1a and 1b through 3a and 3b are studied collectively for the purpose of answering two questions:

(1) Is the BUAN Evaluation Data Set a better ground truth data set than the Standard Evaluation Data Set?

(2) Are the temperature retrievals from the Test system more accurate than those from the Control system, as predicted by the BUAN hypothesis?

An affirmative answer to Question 1 would indicate that there is an apparent improvement in sounding accuracy because the verification data used to evaluate the results are more accurate. An affirmative answer to Question 2 would indicate that there is a real improvement in sounding accuracy, thereby verifying the BUAN hypothesis with respect to the NOAA-10 results.

To answer the first question, the accuracy of each of the "a" curves was compared with that of the corresponding "b" curve. A single accuracy judgement is made for the entire vertical extent of the error profile, except for the topmost 10 to 20 hPa layer, which is treated separately. The following results were found to hold, first for the mean errors and then for the RMS errors.

Overall, the Control system mean errors are comparable for the Standard and BUAN Evaluation Data Sets in the 90N to 30N region. However, the Test system mean errors are decidedly smaller when the BUAN Evaluation Data Set is used as the ground truth. This last statement holds as well for the 30N to 30S and 30S to 90S regions for both the Control and Test system mean errors. The net result, on the basis of the mean errors, is that the BUAN Evaluation Data Set is a better ground truth data set than is the Standard Evaluation Data Set.

When comparisons of the more important RMS error curves are made between the "a" and "b" figures, the results are even more conclusive than for the mean errors. For both the Control and Test systems, the BUAN Evaluation Data Sets yield lower overall RMS errors than do the Standard Evaluation Data Sets in all three latitudinal regions. In the region 30N to 30S the improvements at some levels approach 1C, while in the region 30S to 90S the differences at many levels are of the order of 0.5C.

In the layer 10 to 20 hPa the conclusion is just the opposite, i.e., for both the mean and RMS errors and for both the Control and Test systems, the Standard Evaluation Data Sets consistently yield substantially smaller errors than do the BUAN Evaluation Data Sets in all three latitudinal regions. This result will be dealt with in Section 4.1 as a separate consideration with respect to Question 1.

It is possible that the BUAN Evaluation Data Sets yield lower overall RMS errors (except in the 10 to 20 hPa layer) than the Standard Evaluation Data Sets because they have less variance (since they are smaller and more restrictive). This, however, is not the case. Fig. 4a clearly shows the two sets to have similar variances in the region 30 to 90N. Fig. 4b, which covers the region 30N to 30S, also shows that the variances are not too dissimilar except in the vicinity of the tropopause, around 100 hPa, where the BUAN Set has almost twice the variance of the Standard Set.

Figs. 5a through 6b illustrate the frequency and global distribution of the radiosonde reports for each Data Set. As expected, the density of the distributions is higher for the "a" (i.e., the Standard Set) than for the "b" (i.e., the BUAN Set) figures. However, while the longitudinal distributions are just as varied and complete in Fig. 5b as in 5a (i.e., the N. Hemisphere), there is a better longitudinal distribution in Fig. 6b than in Fig. 6a (i.e., the Tropics).

If one relates the two previous paragraphs to the results shown in Figs. 2a and 2b, particularly near the tropopause, the improved retrieval accuracies for the BUAN Evaluation Data Set become more significant because the temperatures retrieved there have more variance and a better global distribution. This improvement in the "apparent" accuracy is even more significant when one realizes that the tropopause structure is normally very difficult to retrieve.

From the foregoing it is concluded that the answer to Question 1, is a definite "yes"; the BUAN Evaluation Data Set is a better ground truth data set than is the Standard Evaluation Data Set. An important goal was to compile a high quality data set of radiosonde and radiometric measurements to support research which could lead to long-term improvements in sounding accuracy. This has been accomplished (see Section 5, Archive). Furthermore, when seeking an answer to Question 2, only the results for the BUAN Evaluation Data Set (i.e., only the "b" figures) will be examined.

In answering Question 2, the mean errors are considered first. In the 30N to 90N region the Test system is somewhat more accurate than the Control system in the middle troposphere; otherwise, the two systems have essentially the same overall accuracy. The two systems also have essentially the same overall accuracy in the region 30N to 30S, with the Test system being somewhat more accurate around 100 hPa, while the Control system is more accurate above 50 hPa. In the region 30S to 90S the Control system is somewhat more accurate overall than the Test system. Thus, from the point of view of the mean errors, the answer to Question 2 is mixed.

When the RMS errors for the "b" figures are considered, the results are more consistent than those for the mean errors. The Control system accuracies are better than, or equal to those of the Test system. Specifically, in the Equatorial region the RMS accuracies are essentially the same, but in the Northern and Southern Hemispherical regions the Control system retrievals range from around one tenth to a few tenths of a degree more accurate than the Test system retrievals at almost every pressure level.

The foregoing analyses of the errors clearly indicate that the answer to Question 2 is "no", i.e., the BUAN hypothesis has not been confirmed relative to the NOAA-10 results. In other words, for TOVS operational retrievals, it cannot be concluded that the temperature retrievals adjusted using the BUAN data set were more accurate than those adjusted using the Standard data.

Global, horizontal fields of retrieved level temperature and moisture data also were produced and compared for the Test and Control systems, but are not presented in this report. Overall, no significant differences between these fields were observed, which is consistent with the other results of this section. This means that the global sounding products from the Test system were not degraded due to the smaller and more restrictive Data Sets used for adjustment. Overall, the fields were relatively smooth, indicating that neighboring vertical profiles were consistent with one another.

4. CONCLUSIONS

4.1 The BUAN Hypothesis

For reference, the BUAN hypothesis is repeated here, namely, that an immediate improvement in satellite sounding accuracy will occur through improvements in the collocation data base used to empirically adjust the retrieval model.

The superiority of the BUAN Evaluation Data Set used for ground truth over the Standard Evaluation Data Set is confirmed (Conclusion 1). Generally positive results for the mean error and consistently positive results for the RMS error when using the BUAN data set to evaluate both the Control and Test systems were seen. The improvement gained by using the BUAN data set is primarily due to the better time and space coincidence of the radiosonde and satellite observations collected specifically for the BUAN test.

On the other hand, based on the results shown in this report, the BUAN hypothesis has not been confirmed relative to the NOAA-10 results (Conclusion 2). In other words, using TOVS data and current NOAA operational procedures, it cannot be concluded that the temperature retrievals adjusted using the BUAN set were more accurate than those adjusted using the Standard set.

Although we do not know the reasons for the inability to confirm the BUAN hypothesis, it is suggested that a primary reason may be due to the retrieval algorithm. The retrieval algorithm used in the test derives its first guess temperature/moisture profile and radiance vector from the so-called "library search technique". Briefly, this technique involves finding the first guess profiles in a historical library of collocated radiosonde and satellite radiance observations. The search is for the radiance vector in the library that is most similar to the measured ambient radiance vector and then the associated library temperature/moisture profile is used for the first guess profile. In practice, a subset of twenty of the most similar radiance vectors (rather than the most similar vector) is found and averaged (to minimize noise) to produce the first guess radiance vector. Then the associated twenty temperature/moisture profiles are averaged to produce their first guess profile. This is an implicit adjustment procedure as explained in Section 3.1.3. Note that the library is the 28-day data set described in Section 3.1.3.

Since there are separate libraries for the Control and Test systems, the library search technique should work best for the library that contains the largest amount of collocated data. This is because the largest library is likely to be the most heterogeneous one and because when the twenty "most similar" radiance vectors and associated temperature/moisture profiles are averaged, the average profiles are likely to be more representative of the ambient condition. Consequently, the results shown may be due, at least in part, to the fact that the (Standard) library used to produce the Control curves was larger, by almost a factor of two, than the (BUAN) library used for the Test curves (see Figs 5a to 6b). This appears to be at least as important as the countervailing fact that the collocated data for adjusting the Test system library are closer in time and distance and are presumably of better quality than those in the Control system library.

The discussion concerning the retrieval algorithm indicates that the outcome of our tests may be algorithm dependent. Since many different types of adjustments to the retrievals are possible it is conceivable that a different retrieval algorithm could satisfy the BUAN hypothesis. For example, an algorithm that utilizes the BUAN collocated data differently to establish its initial profiles (e.g., air mass classification) might produce solutions that are more accurate.

Finally, the consistent superiority of the Standard Evaluation Data Set over the BUAN Set as ground truth in the layer 10 to 20 hPa, in both the mean and RMS errors and for both the Control and Test systems, is a surprising development for which no explanation is readily available. However, there are major reductions in sample sizes in going from any layer below the 10 to 20 hPa layer to that layer. Thus, the apparent contradiction may be related to this large reduction in sample size.

4.2 Lessons Learned

Lessons were learned from carrying out the various aspects of the BUAN. The following comments make clear that field station performance, data processing, and administrative tasks also require much thought and attention, and have a major bearing on the operational implementation.

(a) Having operational stations provide the specific observations needed for the BUAN study proved difficult to achieve. In light of the difficulties experienced in making special radiosonde observations at times which varied from one day to the next, while maintaining routine observations at synoptic times, it is remarkable that the participation by BUAN stations was as high as it was (see Tables 3 and 4). Nonetheless, fewer stations than expected were able to participate fully when special observations were required. Fortunately, the number of observations utilized in the test was increased by including those (from Tables 1 and 2) whose routine synoptic observations were coincident with satellite overpasses.

(b) In a number of cases the radiosonde observations in the BUAN failed to meet the quality selection criteria listed in Section 3.1.4. This led to an additional reduction in sample size for the BUAN.

(c) Monitoring the station participation and the quality of the BUAN data turned out to be a sizeable effort. A very important part of this effort involved providing feedback to the operating stations in near-real-time, which could not consistently be achieved.

(d) Feedback from the stations also was needed, i.e., without notification from the stations there was no way to confirm that a radiosonde station had taken a special BUAN radiosonde observation, if the report was not received on the GTS. Also, routine feedback was requested on the receipt of launch schedules, but only a few countries provided such information.

(e) Because the radiosonde reports provide observation times only to the nearest hour, it could not always be determined whether a BUAN observation was within the tight BUAN time-difference window between satellite and radiosonde observations of one hour.

(f) The instructions sent to the participating stations need to be clear and unambiguous. For example, there was some confusion in a limited number of cases of the interpretation of the plan with respect to release times.

(g) A number of problems in the real-time data handling, storing, and processing systems were uncovered. End-to-end testing of these systems is an important approach in recognizing data loss problems.

(h) Archiving and documenting the data set of collocated BUAN radiosonde and satellite data for further study also turned out to be sizable efforts. In terms of time, effort, and funds, the archival effort was very significant.

(i) In the absence of a network having uniform equipment (e.g., the same radiosonde type), intercomparison studies applied to all types of radiosondes used in the existing network become indispensable to achieving uniform measurements, and hence to achieving consistently high accuracy. No adjustments were made to the BUAN data to account for biases between radiosondes of different types.

(j) Solar and longwave radiation corrections for radiosonde instruments of participating countries are not known with sufficient accuracy to obtain globally-consistent results.

(k) The TOVS adjustment procedure could be achieved equally well using the current operational method and the standard radiosonde network but with improved coincidence and library generation specifications (see Sections 3.1.3 and 4.1). NOAA implemented these new procedures during November, 1989.

4.3 Recommendations to CBS

The original request from CBS was to have the U.S. evaluate the feasibility of the BUAN. This has been done. Both general and specific recommendations follow.

4.3.1 General

(1) It is recommended that CBS not consider implementation of the Baseline Upper Air Network (BUAN) at this time based upon scientific, operational, and financial considerations.

(2) Further study by the scientific community of the procedures to improve satellite temperature retrievals through the BUAN archived data set is recommended. A high quality data set of radiosonde and radiometric measurements has been archived (see Section 5) to support research.

(3) While it is recognized that international radiosonde observation intercomparison tests already have taken place, additional efforts are needed. It is recommended that intercomparison studies of the remaining radiosonde types be completed, and that adjustments be proposed to assure compatibility of measurements from all types of radiosondes.

(4) Since current and planned retrieval algorithms will continue to require initial and periodic adjustment, it is recommended that Members of CBS pay special attention to providing high quality (i.e., accurate, timely, and high-ascent) operational synoptic radiosonde observations, particularly in the Tropics and the Southern Hemisphere.

4.3.2 Operational

(1) The TEMP Code should be modified to include launch time in hours and minutes.

(2) The CBS Working Group on Data Management should focus on elaborating procedures to provide end-to-end monitoring of data.

5. ARCHIVE

5.1 Introduction

The collocated BUAN radiosonde and satellite observations which were collected each day, including those which were not acceptable for adjustment or evaluation (see Section 3.1.3), were compiled into an archive which is available to the research community. Archive directory information and printed listings also were compiled. The final BUAN archive is separated into three parts:

(A) Radiosonde observations and fully-processed satellite radiometric data,

(B) Radiosonde observations and preprocessed satellite radiometric data, and

(C) Radiosonde observations and raw satellite radiometric data.

Together, the complete archive is stored on six, 6250 bpi magnetic tapes. Part A data for the period February 1 to July 15, 1988, is stored on one tape, which is designated as Tape 1. Part B data for the period February 1 to July 15, 1988, is stored on a total of three tapes, which are designated as Tapes 2, 3, and 4. Part C data for the period May 23 to July 15 is stored on one tape, designated as Tape 5. Part A and Part B data for the period January 18 to 31, 1988, are stored on a single tape, designated as Tape 6. The final two files on each of the six tapes contain a sub-directory of the data stored and rocketsonde data (from the standard network) corresponding to the period of record.

The radiosonde observations stored in the archive are the same for Parts A, B, and C, and basically consist of the reported mandatory and significant level data. However, two sets of mandatory and significant level temperature data are stored. One set contains the temperature and geopotential height data "as received" by WMC-Washington over the GTS. The other set contains these data "as adjusted" using the WMC radiation adjustment data (McInturff, et al.). Depending on the station, the radiosonde observations received may or may not have already been corrected at the station. However, WMC adjustments are applied to all incoming radiosonde observations (and understandably are smaller for radiosondes already corrected at the stations). The adjusted radiosonde observations were the data used in the BUAN Evaluation Data Set reported in this document. Software to unpack the two sets of radiosonde data and to replace the "adjusted data" was also compiled and is stored on magnetic tape, designated as Tape 7.

The satellite data stored in Parts A, B, and C of the BUAN archive are different and are described in Sections 5.2 through 5.4. The archive directory, available listings and a review of the directory information are presented in Section 5.5. The availability of the seven magnetic tapes, the directory listings and documentation is described in Section 5.6.

5.2 Radiosonde and Fully-Processed Satellite Observations

Part A of the BUAN archive contains the collocated data sets of BUAN radiosonde reports and the fully-processed satellite data. The fully-processed satellite data include the temperature and moisture soundings and the fully-processed TOVS measurements. The TOVS soundings consist of atmospheric temperature profiles at 40 pressure levels ranging from 1000 hPa to 0.1 hPa and water mixing ratio profiles at 15 pressure levels ranging from 1000 hPa to 300 hPa. Note that the soundings stored are not the standard products of layer-mean virtual temperature which are distributed to users and evaluated in Section 3.2. Three types of soundings are computed depending on cloud conditions; they are designated as either clear, partly cloudy or cloudy.

The fully-processed TOVS measurements incorporate all the corrections and adjustments described later in Sections 5.3 and 5.4, plus additional adjustment of the High-resolution InfraRed Sounder (HIRS) data to remove the effects of clouds. These are referred to as the TOVS "clear-column" brightness temperatures. The clear-column brightness temperatures are the TOVS data used to compute sounding products, and the data stored depends on the sounding type. For clear and partly-cloudy soundings, processed measurements for 20 HIRS, 4 Microwave Sounding Unit (MSU) and 3 Stratospheric Sounding Unit (SSU) channels are stored; whereas, for cloudy soundings only 3 "stratospheric" HIRS channels, 4 MSU channels and 3 SSU channels are stored.

A single clear-column profile of TOVS brightness temperatures is stored for each collocated data record. The clear-column profile stored for clear and partly cloudy soundings correspond to the single HIRS field of view (FOV) used to compute the sounding. For cloudy soundings, the clear-column profile is an average of nine HIRS FOVs comprising a 3 by 3 array centered on the sounding location.

5.3 Radiosonde and Preprocessed Satellite Observations

Part B of the BUAN archive contains the collocated data sets of BUAN radiosonde reports and preprocessed TOVS data. Processing limitations occasionally prevented the collection of preprocessed satellite data for a given radiosonde report. Missing data are indicated in the directory.

The preprocessed TOVS data are the calibrated and initially adjusted satellite radiometric data. The initial adjustments include limb correction of all TOVS channels, water vapor attenuation correction of the HIRS channels 8, 18, and 19, and asymmetric scan bias and antenna pattern corrections of the MSU data. The MSU data have also been screened for precipitation contamination, with all contaminated MSU and corresponding HIRS data removed. After screening, the MSU data are interpolated to the HIRS FOV resulting in a 24 channel radiance vector of combined HIRS and MSU data for each HIRS FOV; SSU data are not included.

A total of 99 HIRS FOVs, corresponding to an 11 by 9 array which includes the FOV(s) used to compute the sounding, are stored for each collocated data record. The 99 FOVs are those in the vicinity of the location of the satellite sounding, which generally also surround the location of the radiosonde observation. However, the radiosonde location may occasionally lie outside the area covered by the 99 FOVs.

5.4 Radiosonde and Raw Satellite Observations

Part C of the BUAN archive contains the collocated data sets of BUAN radiosonde reports and raw TOVS data. As indicated, these data were saved only for the period May 22 to July 15. Again, it was not possible to store raw satellite data in all cases due to processing limitations. Missing data are indicated in the directory.

The raw TOVS data contain the calibrated HIRS and MSU brightness temperatures computed at each HIRS FOV; SSU data are not included. The calibration algorithm applied is the current operational method which uses either the preceding or succeeding calibration data depending on which is closer within the orbit. The MSU data are interpolated to the HIRS FOVs after calibration, resulting in a single radiance vector for each HIRS FOV which contains 20 HIRS channels and 4 MSU channels. Ninety-nine HIRS FOVs, corresponding to the 11 by 9 array described in Section 5.3, are stored for each collocated data record.

5.5 Directory Information

5.5.1 Listings

A data directory is installed near the end of each tape. The directory summarizes the collocated data stored on a given tape in the order that it appears on the tape. For example, the directory for Tape 1, which contains Part A data for the period February 1 to July 15, 1988, contains 28,106 entries corresponding to each collocated radiosonde and satellite observation stored. The following information is listed for each directory entry:

(a) radiosonde station identification number,

(b) date and time of radiosonde observation,

(c) highest and lowest pressure level for radiosonde observation,

(d) distance between radiosonde station and satellite sounding,

(e) time difference between radiosonde and satellite sounding,

(f) date and time of satellite sounding,

(g) latitude and longitude of satellite sounding,

(h) satellite sounding type (clear, partly cloudy, or cloudy),

(i) other ancillary information for satellite sounding,

(j) availability of preprocessed satellite data, and

(k) availability of raw satellite data.

A "condensed directory listing", for which multiple collocations were removed (see Section 3.1.4), also was compiled and printed and is described in Section 5.5.2.

5.5.2 Data Summary

Examination of the directory data reveals the following information during the effective period of the BUAN test, 18 January to 15 July 1988:

(a) There are a total of 7,019 radiosonde observations and 383 pilot balloon observations.

(b) There are a total of 28,106 fully-processed TOVS data sets collocated with the radiosonde observations and 1,382 collocations with pilot balloon observations.

(c) Associated with the 7,019 radiosonde reports, and using the criteria of the clearest and nearest satellite sounding in the case of multiple collocated satellite data, there are:

- o 4,545 clear conditions,
- o 1,396 partly cloudy conditions, and
- o 1,078 cloudy conditions.

A condensed data listing, containing the 7,019 radiosonde reports with the associated collocated satellite data as selected above, was compiled and printed. The listing is in numerical order according to the station identification number, with the reports for each station listed chronologically. See Section 5.6 for information on receiving this listing.

Table 13 presents a summary of the directory information relative to the radiosonde observations stored. Shown are the numbers of radiosonde reports having initial and final levels for 15 pressure ranges.

Table 13. Numbers of reports on the BUAN Archive with temperature data within the range of the indicated starting and ending pressure ranges (hPa).

	Last level (hPa)														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
First	850	700	500	400	300	250	200	150	100	70	50	30	10	7	0
level	1042	849	699	499	399	299	249	199	149	99	69	49	29	9.9	
1	7	16	17	40	44	42	53	72	426	163	338	748	4753	7	2
2		-	1	-	2	1	1	2	4	-	1	12	28	-	-
3			-	-	-	-	-	1	1	-	-	-	-	-	-
4				38	-	-	-	5	1	-	175	-	-	-	-
5					-	-	-	-	-	-	-	-	-	-	-
6						1	-	-	-	-	-	-	-	-	-
7							1	-	-	-	-	-	-	-	-
8								1	-	-	-	-	-	-	-
9									-	-	-	1	-	-	-
10										-	-	3	6	-	-
11											-	-	-	-	-
12												-	1	-	-
13													4	-	-
14														-	-
15															383

Some conclusions may be drawn on the quality of the radiosonde observations from the data in Table 13, and additional information contained in the archive data Directory:

(1) There are 6,009 radiosonde reports with first levels 850 hPa or greater and last levels less than 100 hPa; these are the most useful soundings.

(2) Of the 6,009, 48 begin at 850 hPa and 498 begin at 1000 hPa. There are 44 and 451, respectively, ending at a standard level. This suggests that most of these 546 radiosonde reports contain only standard levels, lacking significant levels including the surface.

(3) Considering (1) and (2) above, about 5,463 soundings, 78 percent of the total, cover the range from the surface to a pressure level less than 100 hPa and have both standard and significant levels (i.e., they are complete and satisfy many needs).

(4) The 1,008 reports not included in Item 1, are of little benefit, although the 435 with first and last levels in the ranges 850-1042 and 100-149 hPa may find some other applications.

(5) There are 369 soundings ending at 100 hPa, indicating that there are about this number lacking the upper portion, Part D, of the reports. All but five of these began at pressures greater than or equal to 850 hPa.

(6) There are 383 pilot balloon reports, which are indicated in the directory by lower and upper pressure levels of zero.

5.6 Availability

The seven, 9-track, 6250 bpi magnetic tapes, containing the BUAN archive data and software to unpack the radiosonde data are available from NOAA/NESDIS. A printed listing of the condensed directory, as described in Section 5.5.2, also is available. All data sets and software have complete documentation which will be included with all requests. Printed directory listings will be included upon request. A fee to cover processing, magnetic tapes and delivery costs can be expected. For further information contact:

NOAA/NESDIS
National Climatic Data Center
Satellite Data Services Division
User Services Branch
Princeton Executive Square, Room 100
Washington D.C., 20233

Telephone Number: (301) 763-8400

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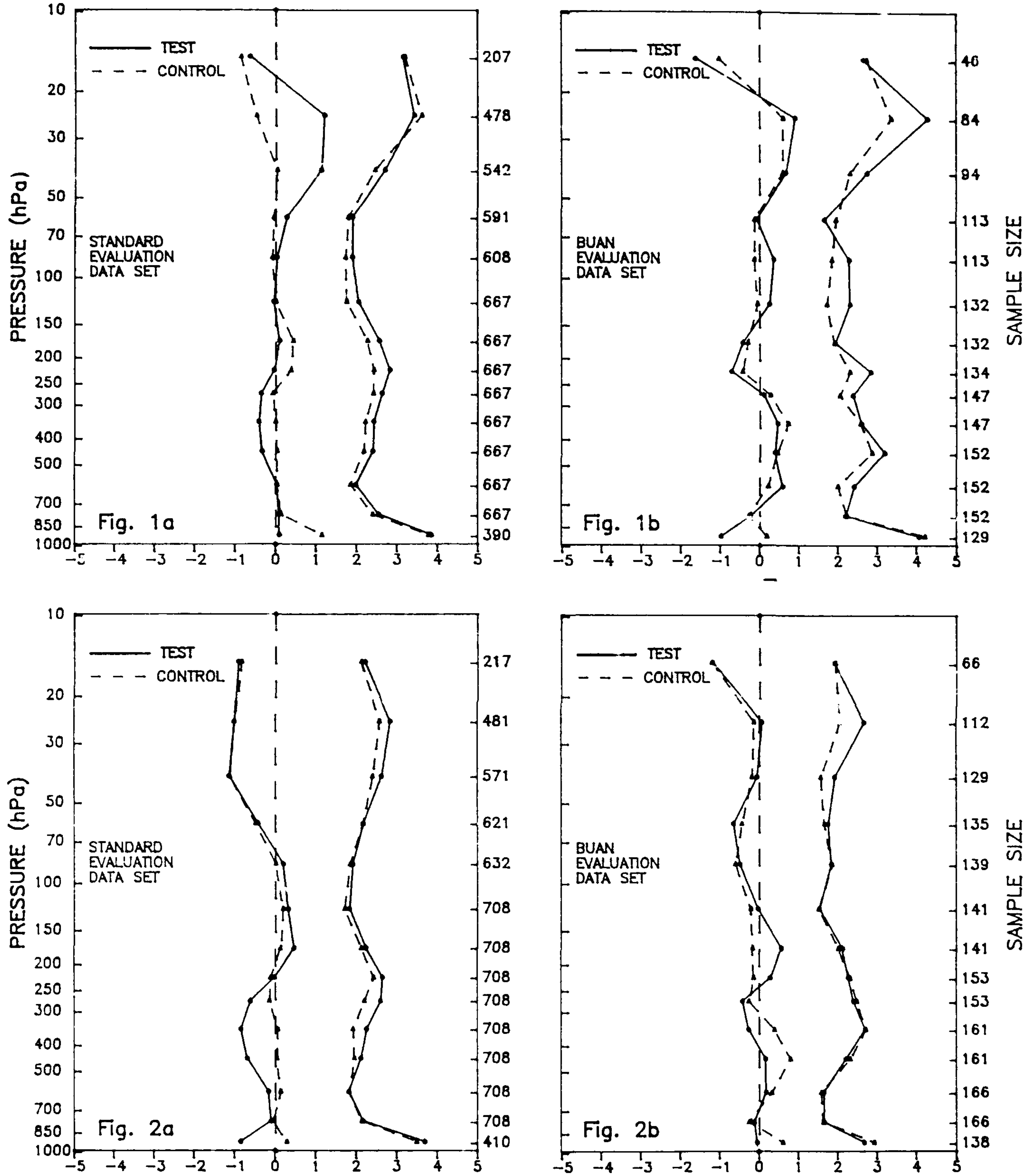
Fleming, H.E., D.S. Crosby, and A.C. Neuendorffer, "Correction of Satellite Temperature Retrieval Errors Due to Errors in Atmospheric Transmittances", J. Climate Appl. Meteor., vol. 25, No. 6, June 1986, pp. 869-882.

McInturff, R., F. Finger, K. Johnson, and J. Laver, "Day-Night Differences in Radiosonde Observations of the Stratosphere and Troposphere", NOAA Technical Memorandum NWS NMC 63, Washington, D.C., September 1979, 47 pp. (NTIS, 5285 Port Royal Road, Springfield, VA 22161).

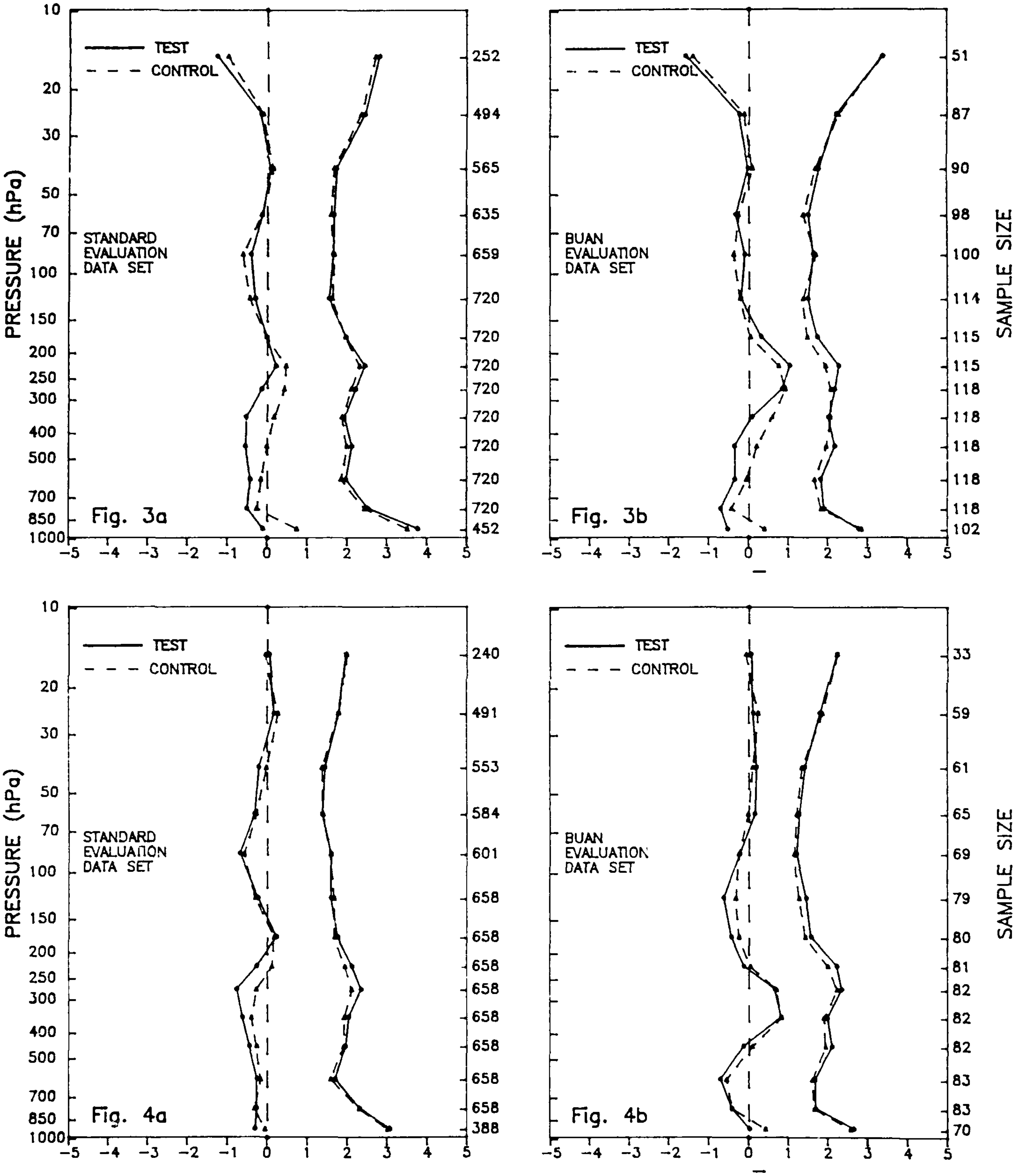
APPENDIX

Weekly Evaluation Results

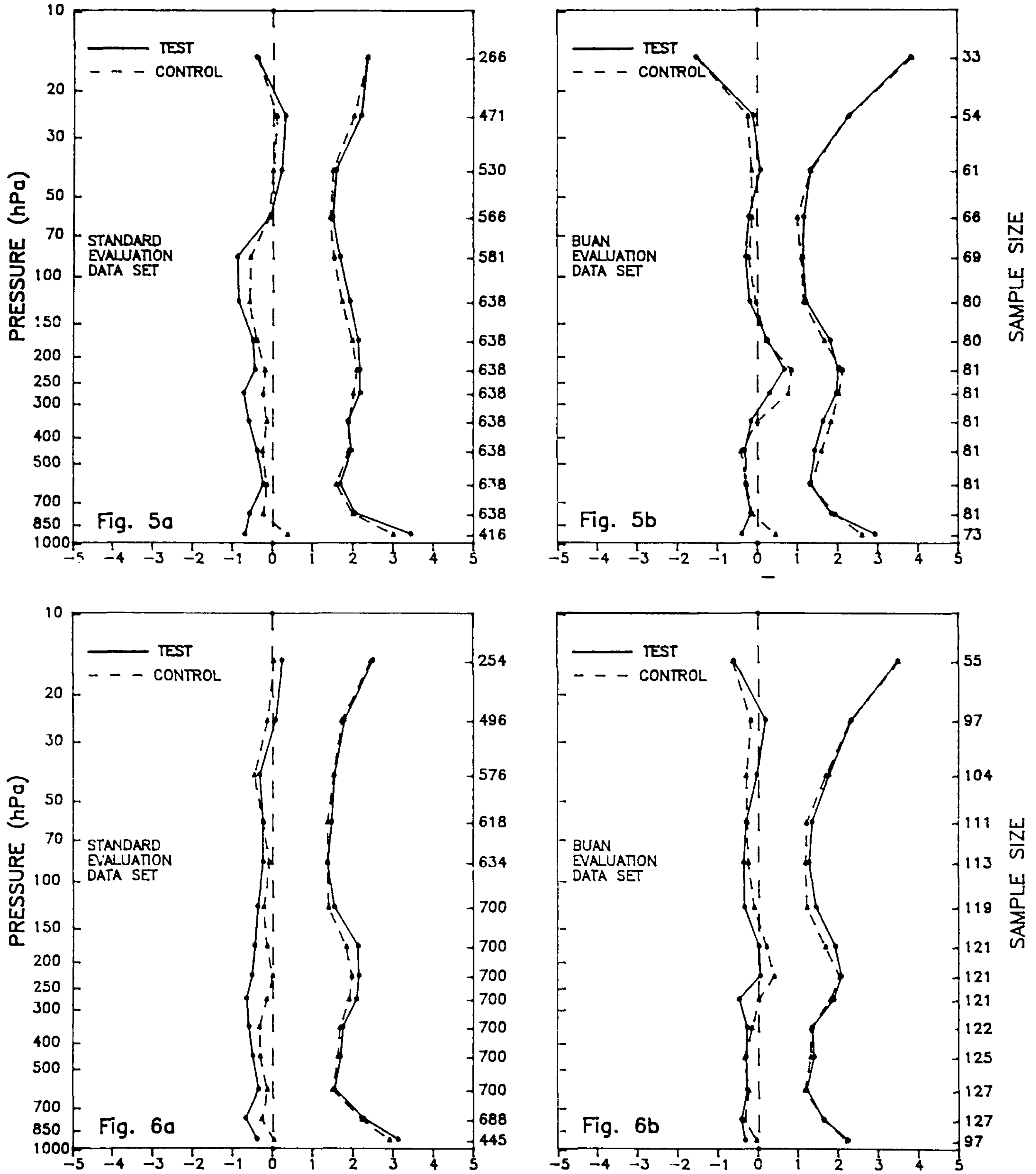
Shown are 48 plots labelled Figures A-1a to A-24b. Figs. A-1a to A-8a are the eight weekly plots which are averaged in Fig. 1a, and Figs. A-1b to A-8b are the eight weekly plots averaged for Fig 1b (see Section 3.2.2). Similarly, Figs. A-9a to A-16b are the eight weekly plots corresponding to Figures 2a and 2b, respectively, and Figures A-17a to A-24b are the weekly plots corresponding to Figures 3a and 3b.



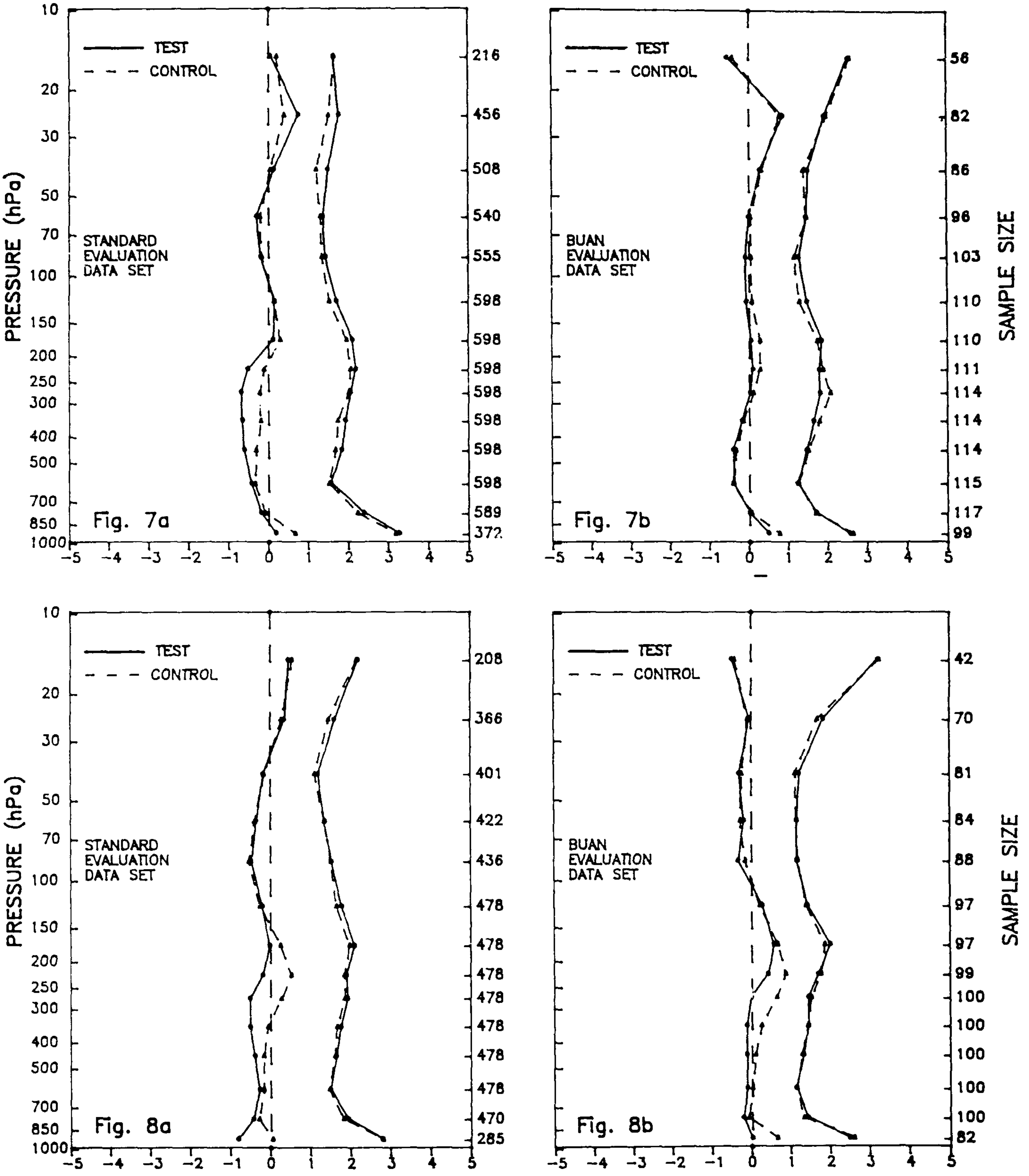
Figures A-1a to A-2b. Mean and RMS differences in layer-mean virtual temperature (C) between satellite soundings and radiosonde observations for the region 90N to 30N, for Test (solid) and Control (dashed) soundings using Standard (left) and BUAN (right) Evaluation Data Sets for the periods March 8-15 (upper), and March 22-29 (lower), 1988; the sample size for each layer is indicated on the right-hand axis.



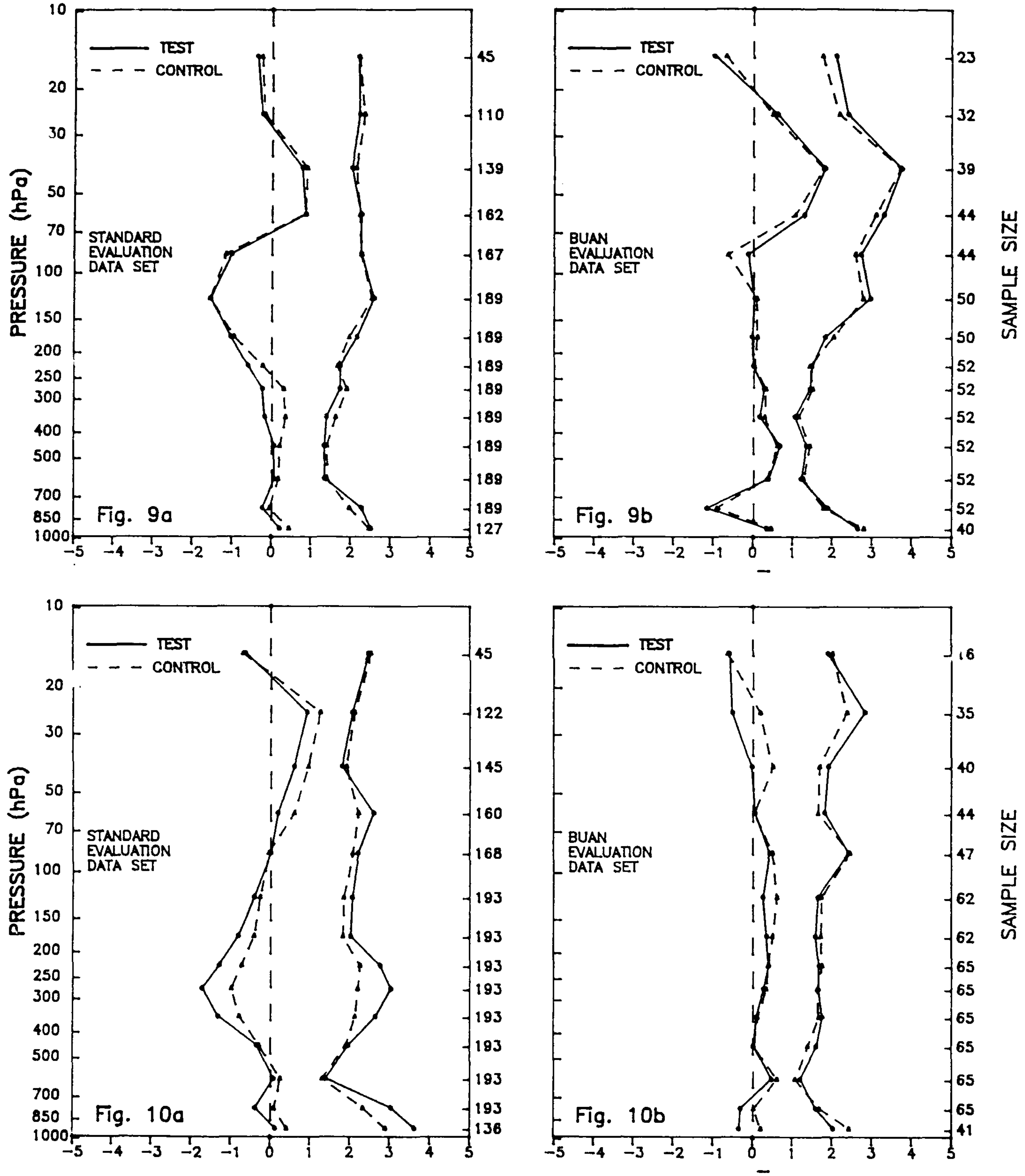
Figures A-3a to A-4b. Same as Figs. A-1a to A-2b except for the periods April 5-12 (upper), and April 19-26 (lower).



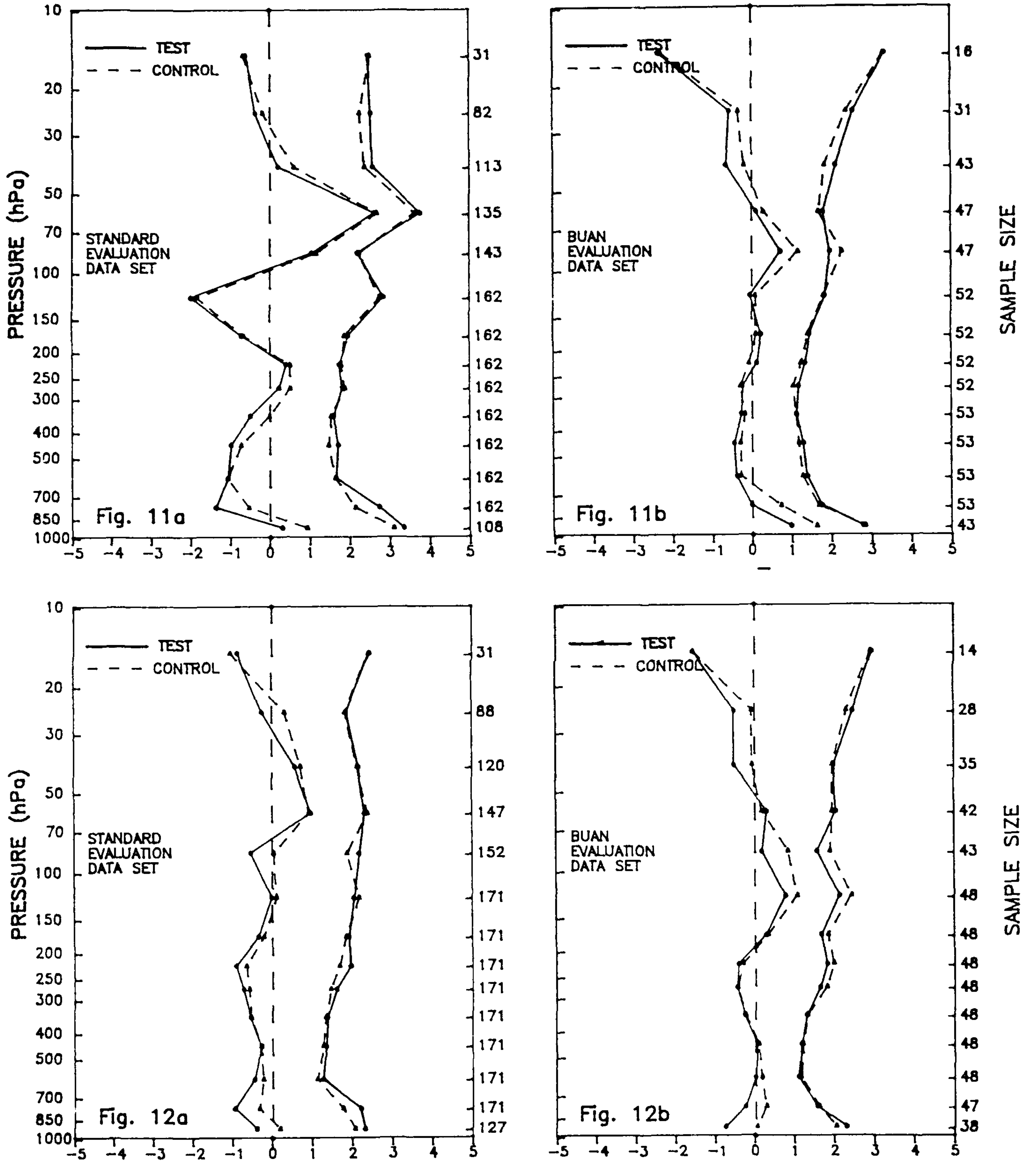
Figures A-5a to A-6b. Same as Figs. A-1a to A-2b except for the periods May 3-10 (upper), and May 24-31 (lower).



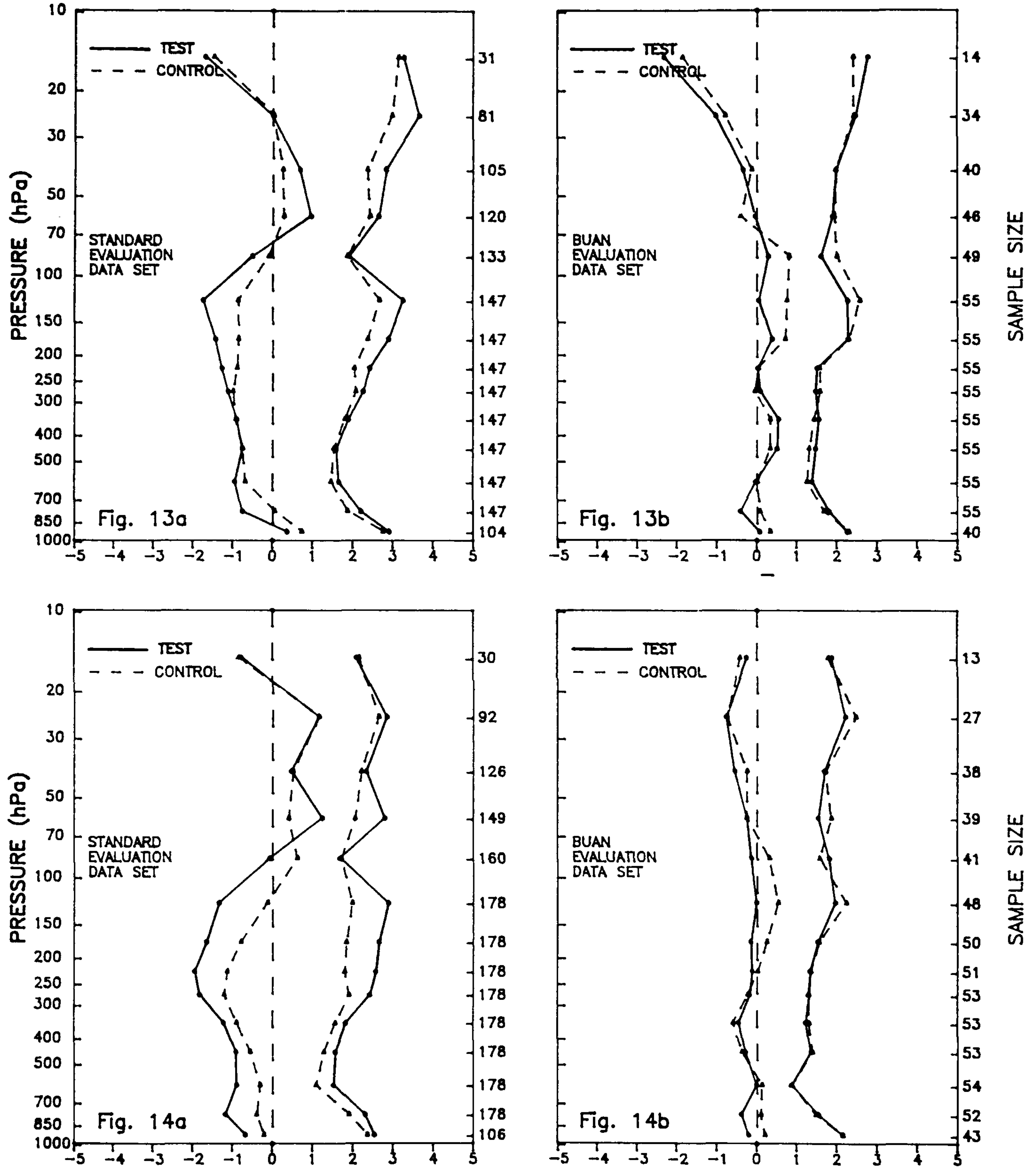
Figures A-7a to A-8b. Same as Figs. A-1a to A-2b except for the periods June 7-14 (upper), and July 9-15 (lower).



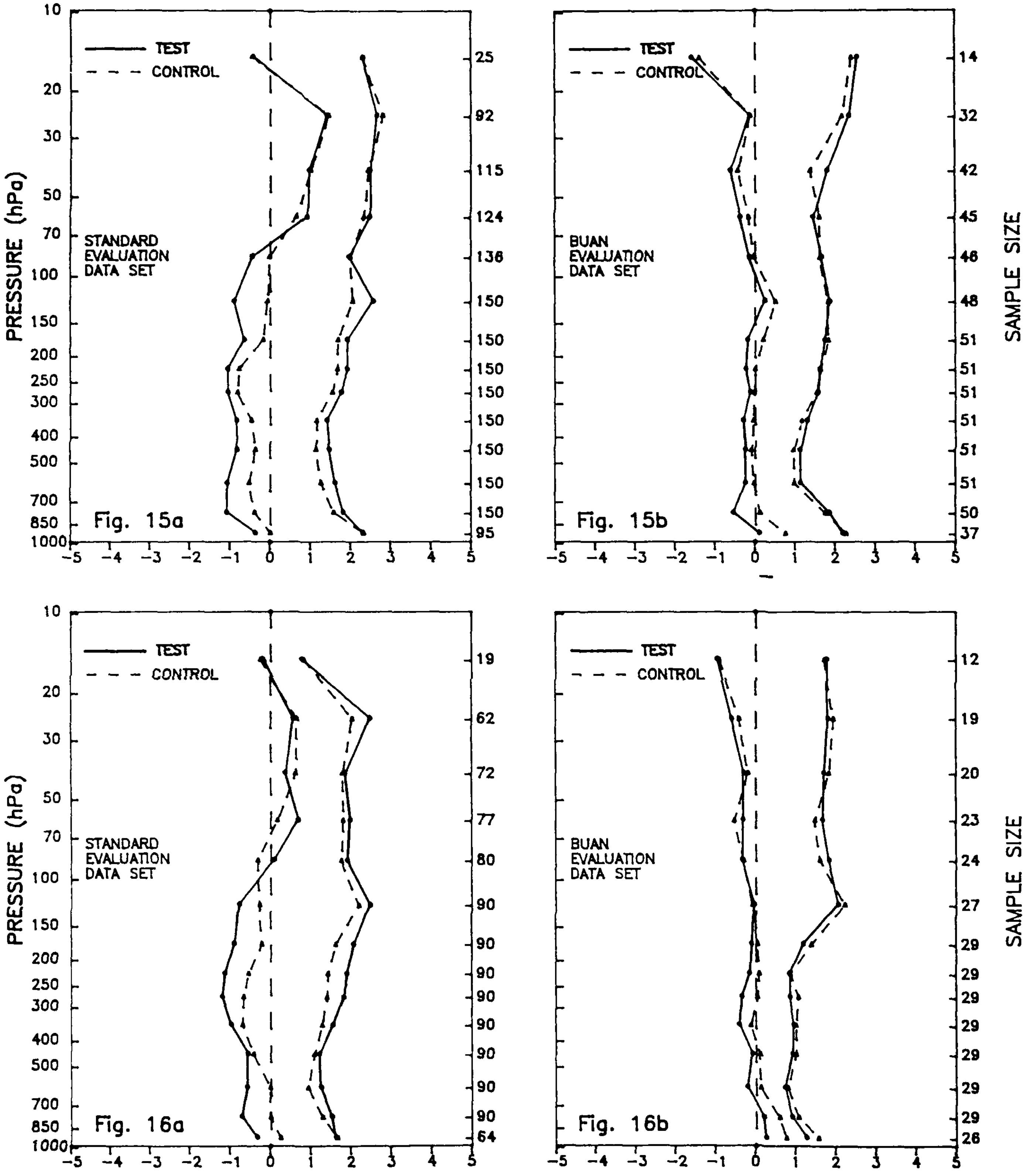
Figures A-9a to A-10b. Same as Figs. A-1a to A-2b except for the region 30N to 30S.



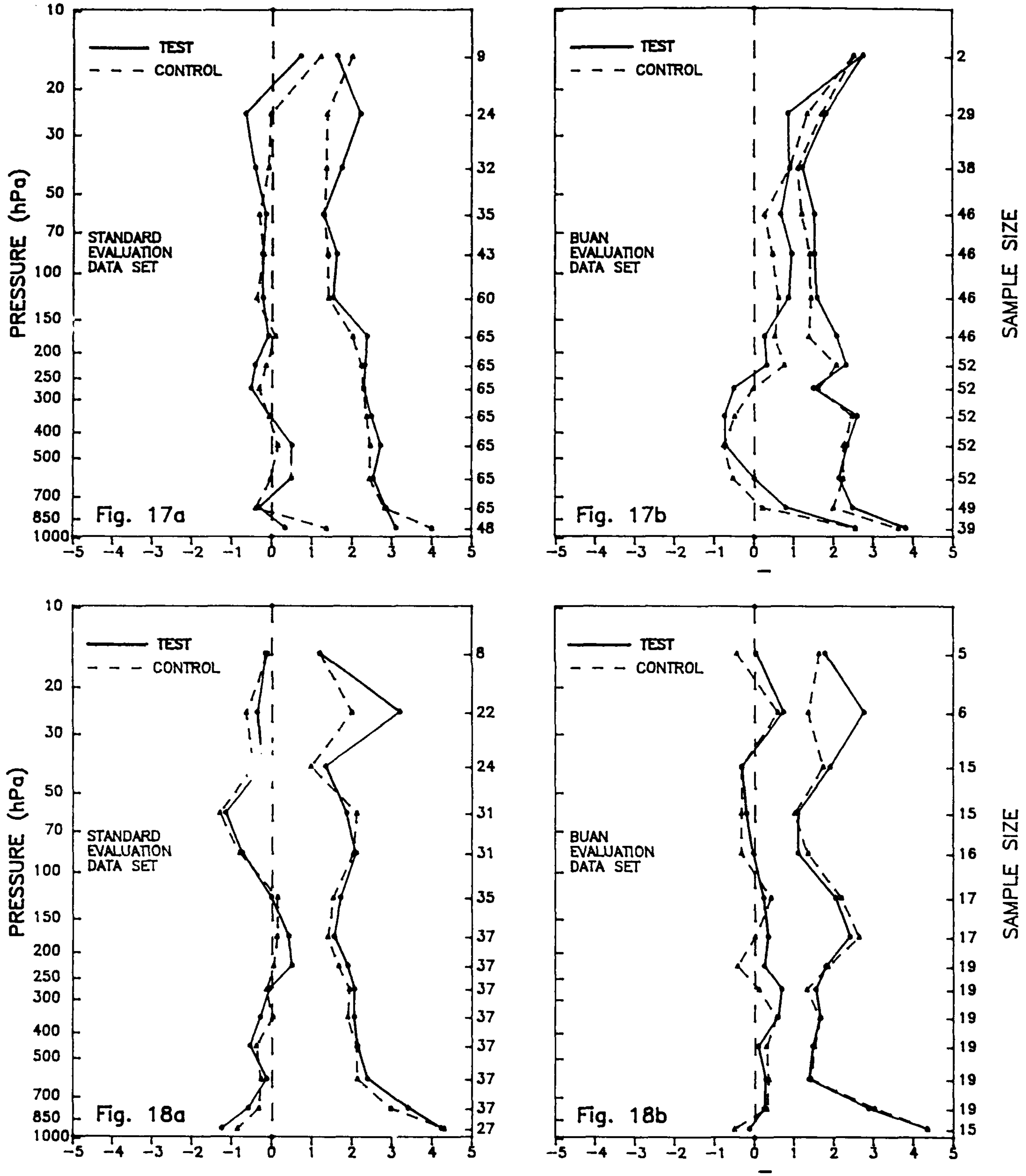
Figures A-11a to A-12b. Same as Figs. A-9a to A-10b except for the periods April 5-12 (upper), and April 19-26 (lower).



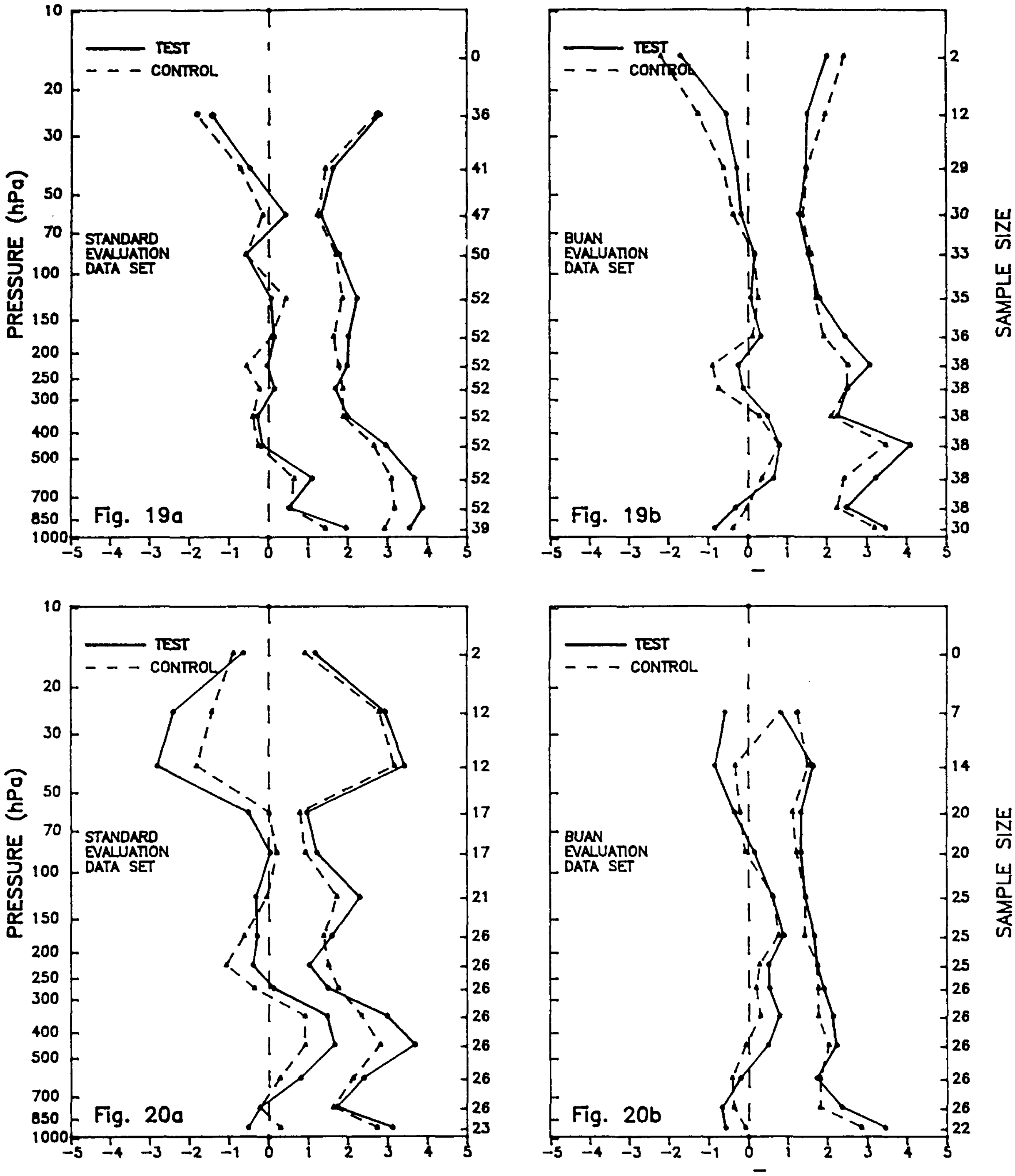
Figures A-13a to A-14b. Same as Figs. A-9a to A-10b except for the periods May 3-10 (upper), and May 24-31 (lower).



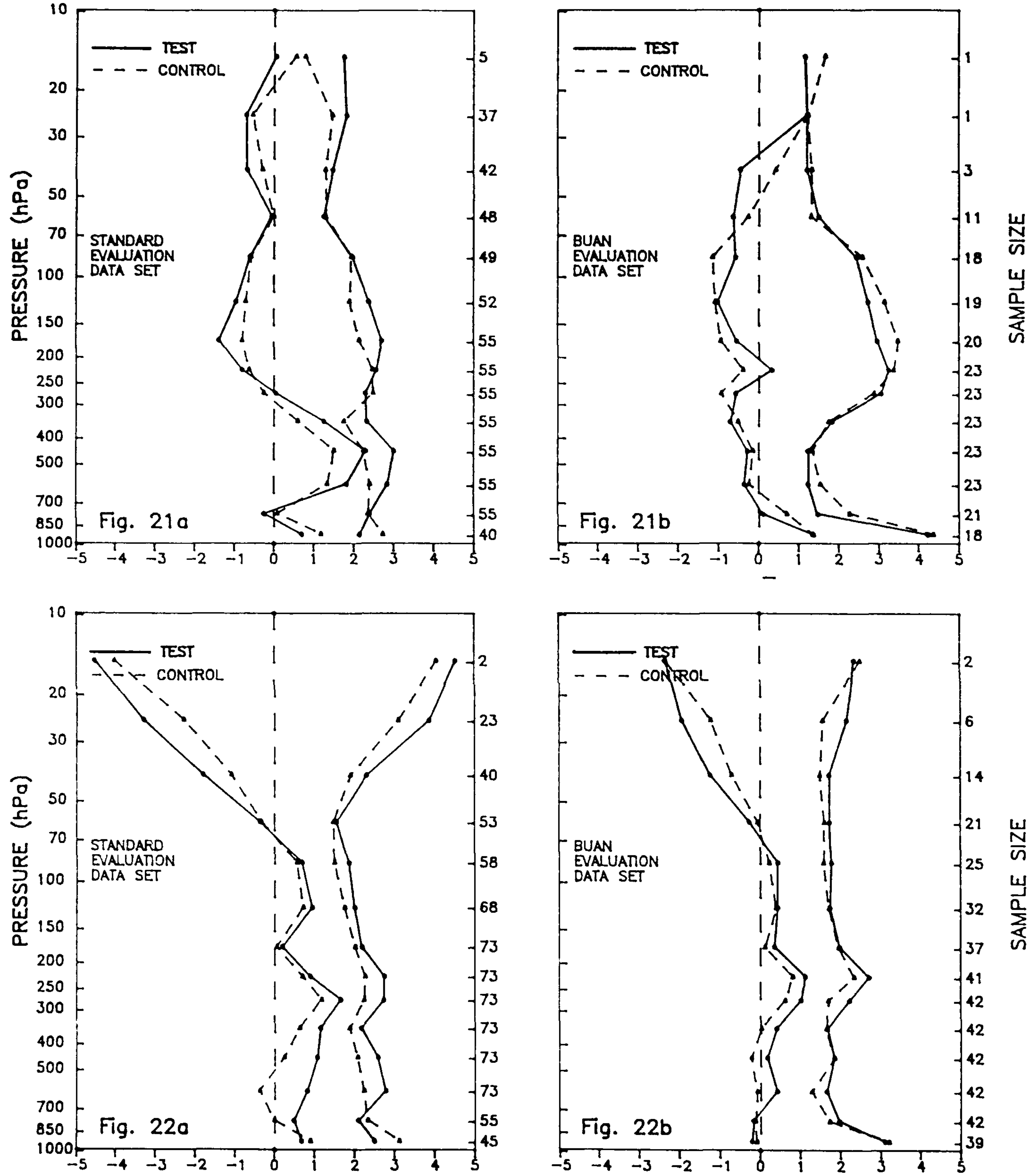
Figures A-15a to A-16b. Same as Figs. A-9a to A-10b except for the periods June 7-14 (upper), and July 9-15 (lower).



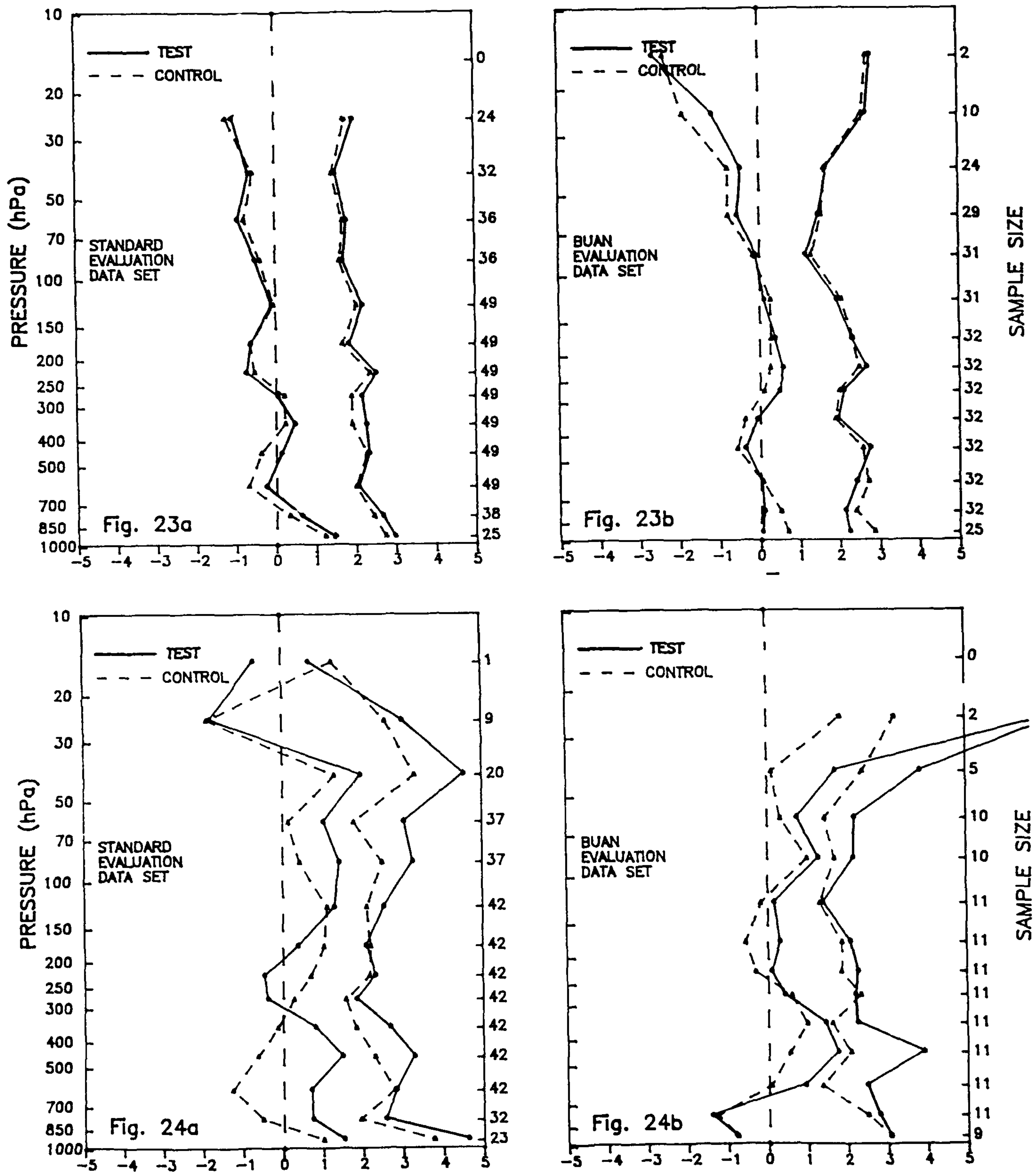
Figures A-17a to A-18b. Same as Figs. A-1a to A-2b except for the region 30S to 90S.



Figures A-19a to A-20b. Same as Figs. A-17a to A-18b except for the period April 5-12 (upper), and April 19-26 (lower).



Figures A-21a to A-22b. Same as Figs. A-17a to A-18b except for the period May 3-10 (upper), and May 24-31 (lower).



Figures A-23a to A-24b. Same as Figs. A-17a to A-18b except for the period June 7-14 (upper), and July 9-15 (lower).

(continued from inside cover)

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