

NASA CONTRACTOR REPORT

RESULTS OF A ROCKET-NIMBUS SOUNDER COMPARISON EXPERIMENT

**CASE FILE
COPY**

Alvin J. Miller and Frederick G. Finger

Prepared under Purchase Order No. P-48606(G) by
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NATIONAL METROLOGICAL CENTER
Hillcrest Heights, Md. 20031

June 1972

Prepared for
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WALLOPS STATION
Wallops Island, Va. 23337

RESULTS OF A ROCKET-NIMBUS SOUNDER COMPARISON EXPERIMENT

by Alvin J. Miller and Frederick G. Finger

Prepared under Purchase Order No. P-48606(G) by
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NATIONAL METEOROLOGICAL CENTER
Hillcrest Heights, MD 20031

For
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WALLOPS STATION
Wallops Island, VA 23337

RESULTS OF A ROCKET-NIMBUS SOUNDER COMPARISON EXPERIMENT

by

Alvin J. Miller and Frederick G. Finger

NOAA, National Meteorological Center

Hillcrest Heights, Md.

ABSTRACT

Stratospheric temperature data obtained from instrumentation on board Nimbus 3 and 4 are compared with conventional rocket soundings to determine the compatibility of measurements.

A carefully controlled cooperative experiment was organized by the National Aeronautics and Space Administration which involved the joint efforts of NASA, National Oceanic and Atmospheric Administration (NOAA), and Oxford University, England. It was carried out at Wallops Island, Virginia (38°N, 76°W) and included the launching of various meteorological rockets at the same time that satellites, Nimbus 3 and 4, passed near Wallops Island.

The Arcasonde 1A and Datasonde were the primary rocketsondes used, but acoustic grenade and pitot probe soundings were also involved. Observed temperature profiles and computed radiances obtained from rocket soundings are compared with 15- μ data provided by the Satellite Infrared Spectrometers (SIRS A and SIRS B), the Infrared Interferometer Spectrometer (IRIS), and the Selective Chopper Radiometer (SCR) on board the satellites. A reasonable agreement between the rocket and satellite data is indicated, but variations are noted which are related to the sounding techniques chosen for comparison. Of major interest are several inconsistencies within the numerical results, which suggest unknown instrumental changes in some of the systems.

CONTENTS

ABSTRACT	ii
INTRODUCTION	1
FORM OF COMPARISONS.	6
RADIANCE DIFFERENCES	8
TEMPERATURE DIFFERENCES.	15
SUMMARY.	23
ACKNOWLEDGEMENTS	24
REFERENCES	25

RESULTS OF A ROCKET-NIMBUS SOUNDER COMPARISON EXPERIMENT

by

Alvin J. Miller and Frederick G. Finger

NOAA, National Meteorological Center
Upper Air Branch
Hillcrest Heights, Md.

INTRODUCTION

As is true for any new observational system, before its full potential can be realized, it must be compared and evaluated against those systems already in use. Thus, with the advent of successful temperature profile determinations from satellite-borne sounding instruments, it was natural that the question should arise as to the compatibility of the data from the various in situ measurements obtained from rocketsondes and rawinsondes. In order to gain some answers, an experiment was organized for the period June-September 1970 when stratospheric variations are small and the temperature gradients are weak. During this period, different types of meteorological rocketsondes were launched at Wallops Island, Virginia (37.8°N, 75.5°W) at such times when the Nimbus 3 and Nimbus 4 satellites were within $\pm 5^\circ$ longitude and as they passed overhead, about local noon. The basic goals of this experiment were to determine the following:

- (1) The sign and magnitude of any errors in the temperature determination of the radiosondes, meteorological rocketsondes, and data from acoustic grenade and pitot probe soundings.
- (2) Any possible errors in the numerical values of the atmospheric transmission functions used for conversion of measured infrared radiances to temperatures for the various satellite systems.
- (3) The usefulness of satellite data for at least supplementing rocketsonde data for atmospheric research in the stratosphere and mesosphere.
- (4) The compatibility between meteorological data derived from the various satellite instruments.

The satellite sounders included the Satellite Infrared Spectrometer on board Nimbus 3 (SIRS A), (Wark, 1970) a similar instrument with a scanning capability on board Nimbus 4 (SIRS B), the Infrared Interferometer Spectrometer (IRIS) (Hanel et al, 1970)

and the Selective Chopper Radiometer (SCR) (Houghton and Smith, 1970) both also on Nimbus 4. Data from these systems were compared with that of the Arcasonde 1A and Datasonde meteorological rocketsondes, as well as data derived from the larger acoustic grenade and pitot systems, along with the support rawinsonde in each instance (Bollermann, 1970).

The orbital characteristics of Nimbus 4 were such that there were three suitable meteorological rocket launch days during each week of the experimental period with the approximate tracks depicted in Figure 1 by the curved line segments. Wallops Island is denoted by the filled circle. The track in the middle occurred on Monday of each week, that to the west of Wallops on Wednesday, and that to the east on Thursday. While the orbits precess slightly westward, each of the above tracks remained within the 5° longitude criterion of spatial separation employed in this study. Ephemerides of the satellite positions, obtained throughout the experiment from the Nimbus Project Office, made it possible to time all rocket launches to within about one hour of the satellite overpass. The orbit of Nimbus 3 was such that occasionally it passed within 5° longitude of Wallops Island in rather close proximity to Nimbus 4 such that comparisons could then be made between data from the two satellites.

Guided by the above constraints, three priority levels were assigned for the rocket launch schedule. Highest priority was given to those days on which the larger, more expensive grenade and pitot experiments were launched. Arcasonde and Datasonde rockets were also launched on those days for comparison purposes. In addition, these priority experiments (total of 6 grenades and pitot soundings) were scheduled only on days when both Nimbus 3 and 4 were in close proximity to Wallops. The second priority for launch schedule was given to those days when Nimbus 3 and 4 were in approximate conjunction over Wallops so that as many comparisons as possible could be made between the various satellite instruments. Finally, whenever possible, meteorological rockets were launched every Monday, Wednesday, and Thursday so that emphasis was placed on the rocketsonde-Nimbus 4 comparisons.

It was expeditious to treat the rocketsonde and satellite temperature data as a function of pressure rather than height for all comparisons. Thus, each rocketsonde observation required a base rawinsonde pressure for all pressure computations at higher levels (a common procedure for rocketsonde observations). In the case of Wallops Island, the general practice is to merge the two systems between 100 and 50 mb (~ 16 -20 km). This practice was adhered to during the experiment, so that our results would be representative of the typical results from the site. As the satellite computer programs required data up to 0.01 mb (~ 80 km), temperatures linearly interpolated to Wallops Island from the Supplemental Standard Atmosphere (1966) were simply added to fill

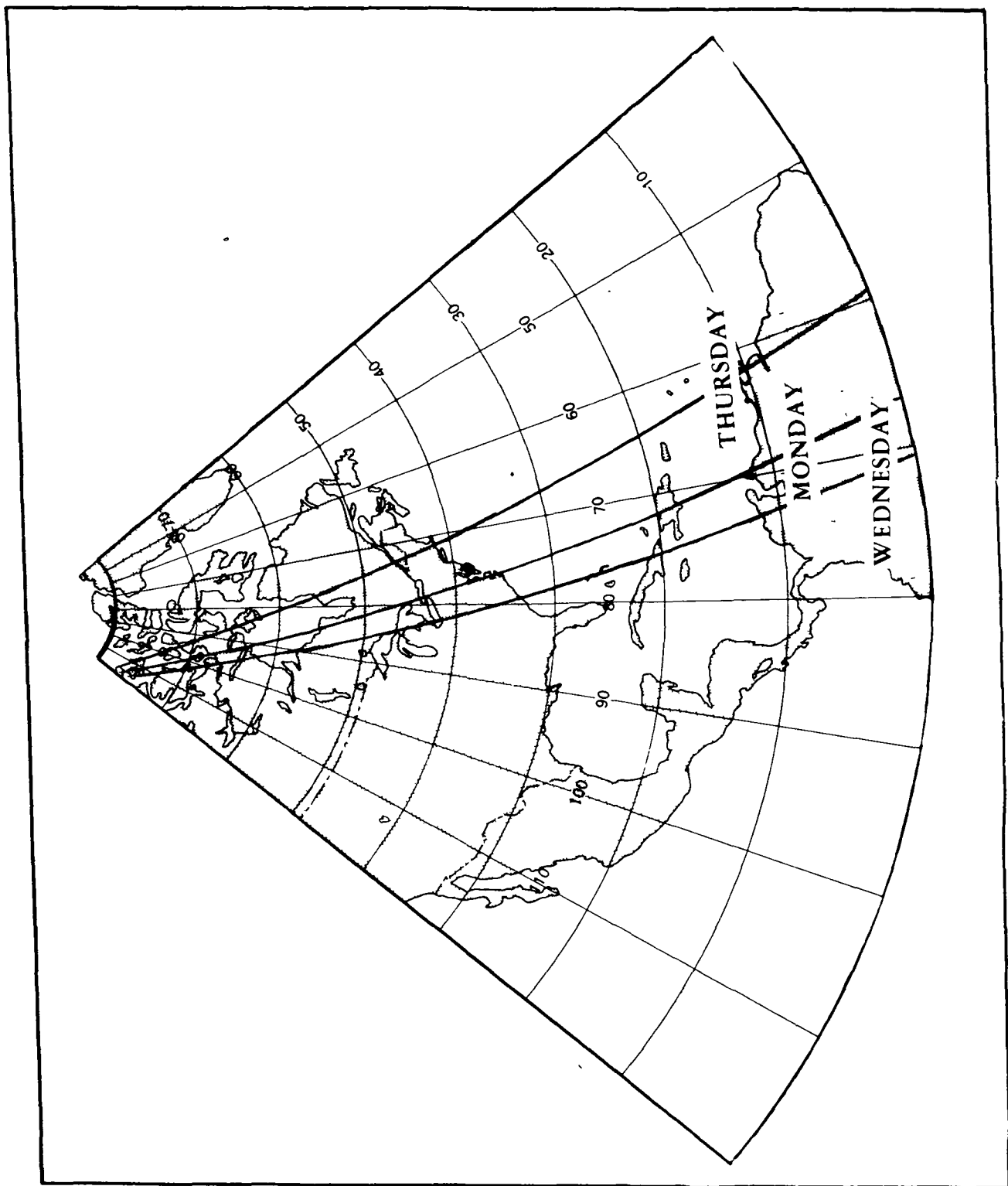


Figure 1. Relative location of SIRS B track with respect to Wallops Island, Virginia (filled circle).

in the gap from the top of the rocketsonde sounding, about 55-60 km. As will be shown below, no appreciable error was caused by this data merge.

It has long been recognized that adjustments are needed to the rawinsonde and small meteorological rocketsonde temperatures to account for solar radiation, dynamic heating, etc. For the rawinsonde used in this experiment, the U.S. NOAA instrument, an adjustment due to Finger *et al* (1965) was added that lowered the observed temperatures by about one degree at 100 and 50 mb. The adjustment factor utilized for the Arcasonde 1A was that derived by Drews (1966) and is presented in Figure 2. The negative adjustment represents a lowering of the observed temperatures. Basically, we see that this technique involves an adjustment of about 8°C at 58 km which decreases almost linearly to zero at 40 km. Also depicted in this figure is the average temperature adjustment calculated from a technique devised by Staffanson (1971) for nine individual soundings. Since results for this latter technique were not available for the entire series of Arcasonde observations, we employed only Drews' technique in this study. The effect of the difference between the two systems will be discussed below. To our knowledge no such adjustment technique has yet been accepted for the Datasonde instrument. In the case of the grenade and pitot results, only the rawinsonde adjustment was added to the observed profile. When applicable, both adjusted and non-adjusted profiles are compared against the satellite data.

As mentioned above, the small meteorological rocketsondes included the Arcasonde 1A and the Datasonde instruments. In practice, however, there were two types of Datasonde instruments available during the comparisons. Although both were of the same fundamental loop mount design, that which was available up to the end of July 1970 we designated Datasonde I. This variation had the 10 mil bead thermistor placed flush against the mylar substrate mount. The system available after that date, for our purposes designated Datasonde II, is distinguished by the fact that the thermistor was lifted off the mylar substrate. While the latter design is the present operational configuration, the former mode has been used at various sites. Consequently, both types were included in this study.

It should be mentioned at this point that the major impetus for modification of the Datasonde I was the general observation that the temperatures of this instrument were consistently warmer than those of the support rawinsonde by 4-5° in the overlap region (e.g. Miller and Schmidlin, 1971). Hence, the Datasonde II configuration was introduced by the manufacturer in an attempt to reduce this discrepancy.

The selection of satellite data for comparison contained an additional spectrum of problems. One major problem was selecting the satellite data point along the path which would be most applicable to the various *in situ* measurements. Ultimately, it was decided to employ the data point physically closest to Wallops

ROCKETSONDE TEMPERATURE ADJUSTMENT

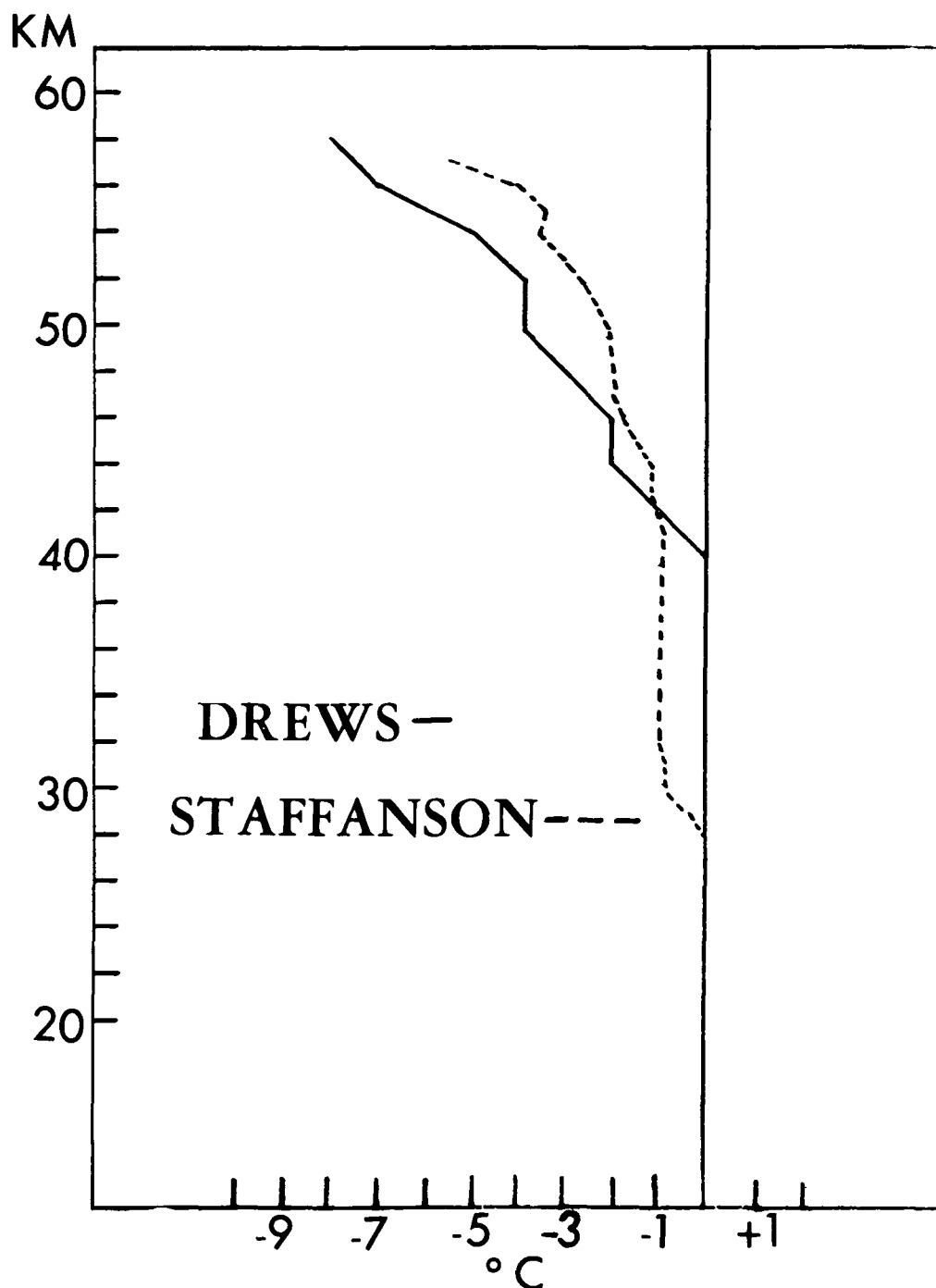


Figure 2. Arcasonde 1A temperature adjustment as depicted by Dreds (1966) and Staffanson (1971). Negative adjustment represents a cooling of the observed temperature.

Island. In addition, for the SIRS B system which contained a side scanning capability, this feature was turned off north of 30°N for the appropriate orbit so that the nadir points would be more closely resolved in space. Experiments were conducted to test the representativeness of this data set and the results will be indicated below.

FORM OF COMPARISONS

For a nonscattering cloudless atmosphere in local thermodynamic equilibrium, the spectral radiance observed at the top of the atmosphere, $N(\nu)$, is given by

$$N(\nu) = B[\nu, T(P_s)] \tau(\nu, P_s) - \int_{P=0}^{P=P_s} B[\nu, T(P)] \frac{d\tau}{d \ln P}(\nu, P) d \ln P \quad (1)$$

where $B[\nu, T(P)]$ is the Planck function at wave number ν and temperature T , P is pressure and $\tau(\nu, P)$ is the fractional transmittance of the atmosphere between level P and the top of the atmosphere. The subscript (s) refers to surface values. The term $d\tau/d \ln P$ is commonly labeled the weighting function of the Planck radiance and determines the amount that a specific atmospheric layer contributes to the integral.

Presented in Figure 3 are the weighting functions for the SIRS A instrument. Note that the maximum information content on the atmospheric structure is contained below 10 mb although some high-level information is inherent in the topmost channel. The weighting functions for the SIRS B instrument are very similar to the SIRS A (Smith *et al*, 1971). The weighting functions for the IRIS instrument (Conrath *et al*, 1970) are somewhat similar to those of the SIRS instruments. The SCR instrument (Ellis *et al*, 1970), on the other hand, provides information to much higher altitudes as the stratospheric weighting functions peak at about 2.5, 15, 60, and 90 mb.

Given $N(\nu)$ as measured by the satellite, temperature profiles may be obtained by solving the integral equation (Equation 1) for B and hence T as a function of pressure. However, because there is no unique temperature profile that balances the measured radiances, the accuracy of the actual retrieved profiles is very much dependent on the solution technique and the season of the year. Consequently, the summer period, which exhibits the least stratospheric variability, was chosen for study as the relative invariance of the actual temperature profiles enhanced the chance for compatible results between the various retrieval techniques. For the SIRS data, the retrieval process employed is that outlined by Strand and Westwater (1969); in the case of the IRIS, the technique is that described by Conrath *et al* (1970), while that for the SCR is given by Rodgers (1970). In all cases, the

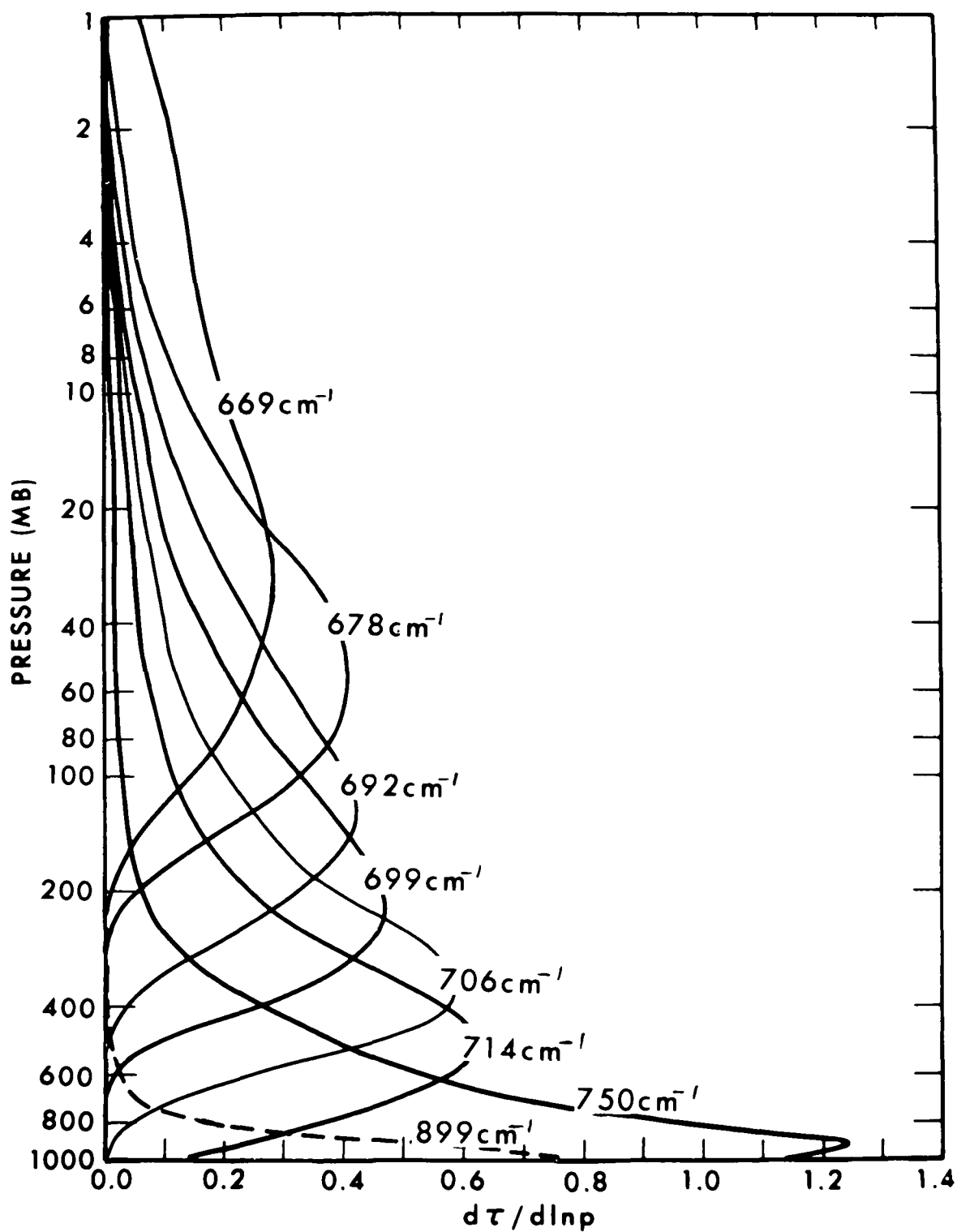


Figure 3. Weighting functions, $d\tau/d\ln P$, for the SIRS A instrument. Channels are numbered from ground up so that channel 1 is 899 cm^{-1} and channel 8 is 669 cm^{-1} .

various retrieval processes were made as consistent with one another as possible. For example, the same initial assumption was used by both the SIRS and IRIS groups.

In view of the above, it was realized that a comparison procedure that would circumvent the retrieval problem would be highly desirable as it would allow evaluations to be made over longer time periods. At the same time it was recognized that as we have observations of T(P) from the rocketsonde-rawinsonde systems, it is possible to work the problem in reverse order. That is, if we calculate from the observed temperatures the spectral radiance that the satellite should have seen (Equation 1) and then compare that value with what was actually measured, the retrieval process would be circumvented and the number of variables for consideration reduced. Within this latter technique, if the two numbers disagreed, the investigation to resolve the differences would center on the calibration of the measured satellite radiances, the "correctness" of the observed temperature profile, and finally the values of the transmittance (τ) used.

For the study, the final evaluations are presented both for the radiance and the temperature differences and for both adjusted and non-adjusted temperature profiles. In the case of the radiance comparisons, a difference of $1 \text{ erg/cm}^2\text{-sec-strdn-(cm}^{-1}\text{)}$ hereafter referred to as erg/ , is approximately equivalent to a difference of 1°C in effective black body temperature.

The results presented in this paper are an extension of those discussed during a Workshop Meeting conducted at Wallops Island on March 23-24, 1971 (NASA, 1972).

RADIANCE DIFFERENCES

The first differences (defined as the radiance computed from the rocketsonde temperature profiles minus that observed) to be discussed are between the SIRS A measured radiances and those computed for the Arcasonde 1A and Datasonde I rockets (Table 1). For these particular systems several additional comparisons were available for the period following the launch of Nimbus 3 and prior to that of Nimbus 4, April 1969-March 1970. For this early period it can be seen that the Arcasonde 1A unadjusted radiance differences are positive (rocketsonde-measured temperatures are relatively high compared to satellite system) with the greatest disparity in channel 8. In all cases, the numbers in parentheses represent the 95% confidence limits of the mean values. Adding the adjustment lessens the discrepancy in each channel, but does not account for the large difference in channel 8. The results for June-September 1970, however, surprisingly indicate an overall downward shift in the differences of about 2 ergs/ . An inspection of the individual temperature

Δ R (ROCKETSONDE - SIRS A)

	<u>UNADJUSTED</u>				<u>ADJUSTED</u>			# OBS.
	8	7	6	8	7	6		
<u>ARCAS 1A</u>								
4/69-3/70	3.50 (1.33)	1.11 (1.11)	0.52 (1.06)	2.51 (1.32)	0.58 (1.12)	0.18 (1.06)	14	
6/70-9/70	1.00 (0.66)	-1.11 (0.48)	-1.11 (0.55)	0.02 (0.61)	-1.55 (0.49)	-1.49 (0.51)	10	
<u>DATAS I</u>								
4/69-3/70	5.92 (4.42)	2.64 (3.53)	1.57 (2.81)				4	
6/70-7/70	7.40 (3.35)	3.70 (3.74)	2.10 (2.46)				3	
<u>DATAS II</u>								
7/70-9/70	2.90 (0.78)	-0.03 (0.74)	-0.20 (0.72)				5	

9

Table 1. Mean radiance differences of rocketsonde minus SIRS A.

Units: $\text{ergs-cm}^{-2}\text{-ster}^{-1}\text{-sec}^{-1}\text{-(cm}^{-1})^{-1}$. Channels 8,

7 and 6 refer to the curves 669 cm^{-1} , 678 cm^{-1} and

692 cm^{-1} of Fig. 3 respectively. Numbers in parentheses

represent 95% confidence limits.

and radiance observations for the period June-September 1969 versus 1970 clearly showed that the rocketsonde-rawinsonde temperatures are lower by about 1°C while the SIRS A radiances increased by about 1 erg/. The reason for this discrepancy is unexplained at this time.

The results for the Datasonde I instrument indicate that temperatures reported by this system are considerably higher than those of Arcasonde 1A. This was suspected from earlier research (e.g., Miller and Schmidlin 1971). In addition, for the Datasonde I there are significant differences between the results for the two time periods, but opposite in sign to those of the Arcasonde. However, the number of observations involved is insufficient for serious consideration. While the number of Datasonde II comparisons is also relatively small, it is clear that the differences for this instrument are considerably smaller than those of the Datasonde I.

Unfortunately, radiance data for SIRS A were not acceptable on one day when both grenade and pitot experiments were launched and discussion on these instruments is deferred to the SIRS B comparisons when all data were available.

The results for SIRS B are presented in Table 2. In contrast to SIRS A, the Arcasonde results are more consistent between channels 8 and 7 with both the unadjusted and adjusted results generally close to zero. The results also suggest that the Datasonde I and II both yield higher temperatures than the Arcasonde, with the greatest differences involving Datasonde I at the highest levels. It should be mentioned that the SIRS B channel 6 could not be employed for the study since that particular channel had not been usable from the time of Nimbus 4 launch.

Conclusions that may be drawn from the above mentioned results are 1) that the weighting functions for SIRS B are more internally consistent (i.e. from channel to channel) than those for SIRS A, and 2) that the Datasonde instruments appear to report temperatures significantly higher than the Arcasonde. The Datasonde II appears less biased than the Datasonde I.

It should be re-emphasized at this point that in all cases it was impossible to gain complete simultaneity of observations in time and space. As stated previously, no attempt was made to select satellite observation points in terms of the exact in-situ measurement locations (i.e. the exact position of the descending sonde). Instead, radiance measurements on the satellite path physically closest to Wallops Island were employed. As a test for stability, these single values were compared with radiance values averaged over a 4° latitude band along the path and centered at the latitude of Wallops Island. The results agreed to within a few tenths of an erg/. Secondly, since the summer-time temperature gradients are in the north-south direction, the horizontal displacements of the satellite points (i.e. Monday,

ΔR (ROCKETSONDE -SIRS B)

<u>ARCAS 1A</u>	<u>UNADJUSTED</u>		<u>ADJUSTED</u>		# OBS.
	8	7	8	7	
6/70-9/70	0.36 (0.46)	-0.17 (0.39)	-0.54 (0.46)	-0.59 (0.37)	20
<u>DATAS I</u>					
6/70-7/70	4.53 (1.36)	3.15 (1.28)			9
<u>DATAS II</u>					
7/70-9/70	2.30 (0.57)	0.83 (0.37)			13
<u>GRENADE</u>					
6/70-9/70	0.90 (0.31) [0.08]	-0.03 (0.62) [-0.38]	0.65 (0.52) [-0.81]	-0.31 (0.74) [-0.75]	3
<u>PITOT</u>					
8/70-9/70	-0.40 (1.37) [1.01]	-0.39 (1.41) [0.01]	-0.66 (1.17) [-0.08]	-0.76 (1.09) [-0.58]	3

Table 2. Mean radiance differences of rocketsonde minus SIRS B. Units: ergs-cm⁻²-ster⁻¹-sec⁻¹-(cm⁻¹)-⁻¹. Channels 8 and 7. Numbers in parentheses represent 95% confidence limits. Numbers in brackets represent mean values for Arcasonde-SIRS B differences on same day as grenade and pitot observations.

Wednesday, Thursday, Figure 1) were expected to inject minimal complications. This effect was tested by comparing differences with respect to the various satellite paths. Again the results agreed to within a few tenths of an erg/. It may be concluded, then, that the radiance comparisons are truly representative.

The grenade and pitot experiments are primarily designed to measure above the altitudes of the small meteorological rockets and in this study their data extended down only to about 5 mb (~35 km). This necessitated a merge of these systems with the Arcasonde-rawinsonde measurements of the same day. Thus, to about 35 km, the grenade and pitot soundings are identical to the Arcasonde profiles for those days. Presented in Table 2 are the radiance differences between the grenade and pitot, and SIRS B measurements. Also shown in brackets are the differences obtained for the same days using only Arcasonde observations. In the case of the adjusted results, only the rawinsonde adjustment was included.

Results of the grenade comparisons, although few in number, suggest that their measured temperatures are higher than the same-day Arcasondes, and this disparity is increased by the adjustments. As suggested above, the greatest differences occur in the highest SIRS B channel. The pitot experiments, in contrast, exhibit lower radiances than the same-day Arcasondes although in this case the adjustments tend to bring the two measurements more into coincidence.

With this small sample of observations, it is difficult to make definite statements concerning these systems, but the results suggest that the grenade temperatures tend to be higher while the pitots tend to be slightly lower than those of the Arcasonde.

The fact that the IRIS radiances are measured with greater spectral resolution than the SIRS radiances allowed us to treat the former in a slightly different fashion. That is, from the detailed IRIS data we computed the radiances that IRIS would have seen in the SIRS B channels and compared the radiances with what was observed by SIRS B. The results are summarized in Table 3 and indicate virtually no difference in channel 8, but a disparity of over 4 ergs/ in channel 7. This agreement in channel 8, however, is considered to be more fortuitous than real; because of the two channels, the comparisons for channel 7 are most likely the more accurate. In addition, there appears to be a trend in the data that is verified by consideration of the individual observations. The reasons for this result, however, are not known at this time.

Although certain operational difficulties with the SCR instrument have reduced the number of rocketsonde comparisons, the results are indicated in Table 4. The Arcasonde radiances are relatively low with respect to the SCR and hence the adjustment

	ΔR (SIRS B - IRIS)		
	8	7	#OBS.
6/70	-0.48	3.60	6
7/70	-0.02	3.70	5
8/70	0.60	4.63	6
9/70	1.02	4.50	5
AV.	0.27 (± 0.19)	4.11 (± 0.31)	22

Table 3. Mean radiance differences of SIRS B minus IRIS. Units: $\text{ergs-cm}^{-2}\text{-ster}^{-1}\text{-sec}^{-1}\text{-(cm}^{-1}\text{)}^{-1}$. Numbers in parentheses represent 95% confidence limits.

A R (ROCKETSONDE- SCR)

<u>ARCAS 1A</u>	<u>UNADJUSTED</u>				<u>ADJUSTED</u>			# OBS.
	A	B	C	D	A	B	C	
6/70-9/70	-3.13(1.46)	-3.55(0.78)	-3.02(0.66)	-0.92(0.42)	-5.50(1.35)	-4.35(0.77)	-3.41(0.59)	-1.30(0.65) 16
<u>DATAS I</u>								
6/70-7/70	1.74(4.34)	0.54(1.84)	1.70(5.13)	1.82(1.95)				5
<u>DATAS II</u>								
7/70-9/70	-0.29(2.70)	-1.49(1.44)	-1.86(1.03)	-0.11(0.87)				7

Table 4. Mean radiance differences of rocketsonde minus SCR.

Units. ergs-cm⁻²-ster⁻¹-sec⁻¹-(cm⁻¹)⁻¹. Channels A, B, C,

D refer to the topmost channel downward respectively.

Numbers in parentheses represent 95% confidence limits.

factors only tend to increase the disparity. This result is considerably different than for the SIRS B and points out rather dramatically the difference between the satellite systems. As may be expected from the previous SIRS comparisons, the Data-sonde I system shows more general agreement with SCR than with SIRS while the Datasonde II appears relatively colder than the Datasonde I.

At the time of this writing, SCR radiances were not computed for several of the grenade and pitot observations and discussion of these profiles is deferred to the section on temperature comparisons.

TEMPERATURE DIFFERENCES

Inasmuch as the rocketsonde temperature profiles indicate small-scale perturbations that cannot be determined by the satellite retrievals, all comparisons were made by taking differences in mean-layer temperatures for the regions; 100-10 mb (~16-31 km) and 10-1.0 mb (~31-49 km). These layers were chosen for evaluation as the SIRS and IRIS instruments have their maximum stratospheric information in the 100-10 mb layer and because the relative invariance of the summertime stratosphere should allow the possibility of relatively accurate temperature determinations up to the stratopause (about 1.0 mb). For the SCR the additional layer of 1.0-0.6 mb (~49-53 km) was added for comparison, 0.6 mb being the lowest pressure level generally reached by this series of Arcasonde instruments.

The results for the unadjusted Arcasonde 1A instrument are presented in Figure 4 along with the 95% confidence limits. The numbers in parentheses represent the sample size of the individual comparisons. In the 100-10 mb layer, the Arcasonde-SIRS B difference is very close to zero with the SIRS A and IRIS temperature retrievals slightly higher and lower respectively. From 10-1.0 mb, all three retrievals are relatively low, the SIRS B again exhibiting the least difference. In contrast, the SCR temperature retrievals are consistently high with respect to the Arcasonde temperatures, with the difference over 3° in each layer. It should be emphasized that these differences are computed over substantial atmospheric layers and a temperature bias in this region can result in significant errors in the computed pressures. For example, a three degree positive bias between 100 and 10 mb would result in a computed pressure at 10 mb that would be about 3% in error. If this same bias is inherent up to 1 mb, the computed pressure error increases to about 6%.

Adjusting the Arcasonde-rawinsonde profiles by the techniques described earlier results in a relative reduction of the in-situ temperatures as shown in Figure 5. As a result, all differences shift to the left by the amount of the adjustments. In the bottom

$\Delta T(\text{ARCAS 1A} - \text{SATELLITE})$

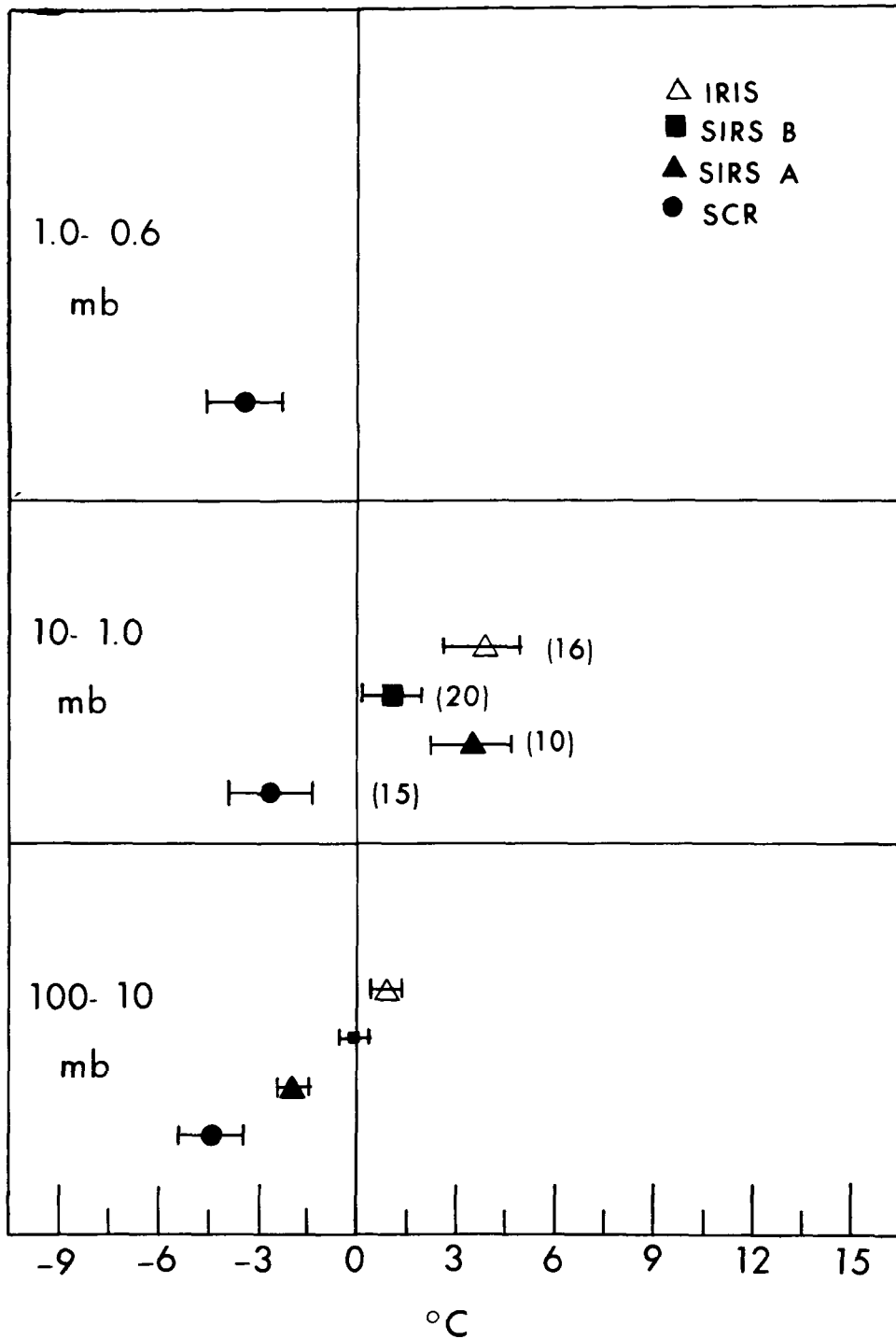


Figure 4. Mean temperature differences of Arcasonde 1A minus satellite retrievals with 95% confidence limits. Numbers in parentheses indicate number of observations.

$\Delta T(\text{ADJUSTED ARCAS 1A} - \text{SATELLITE})$

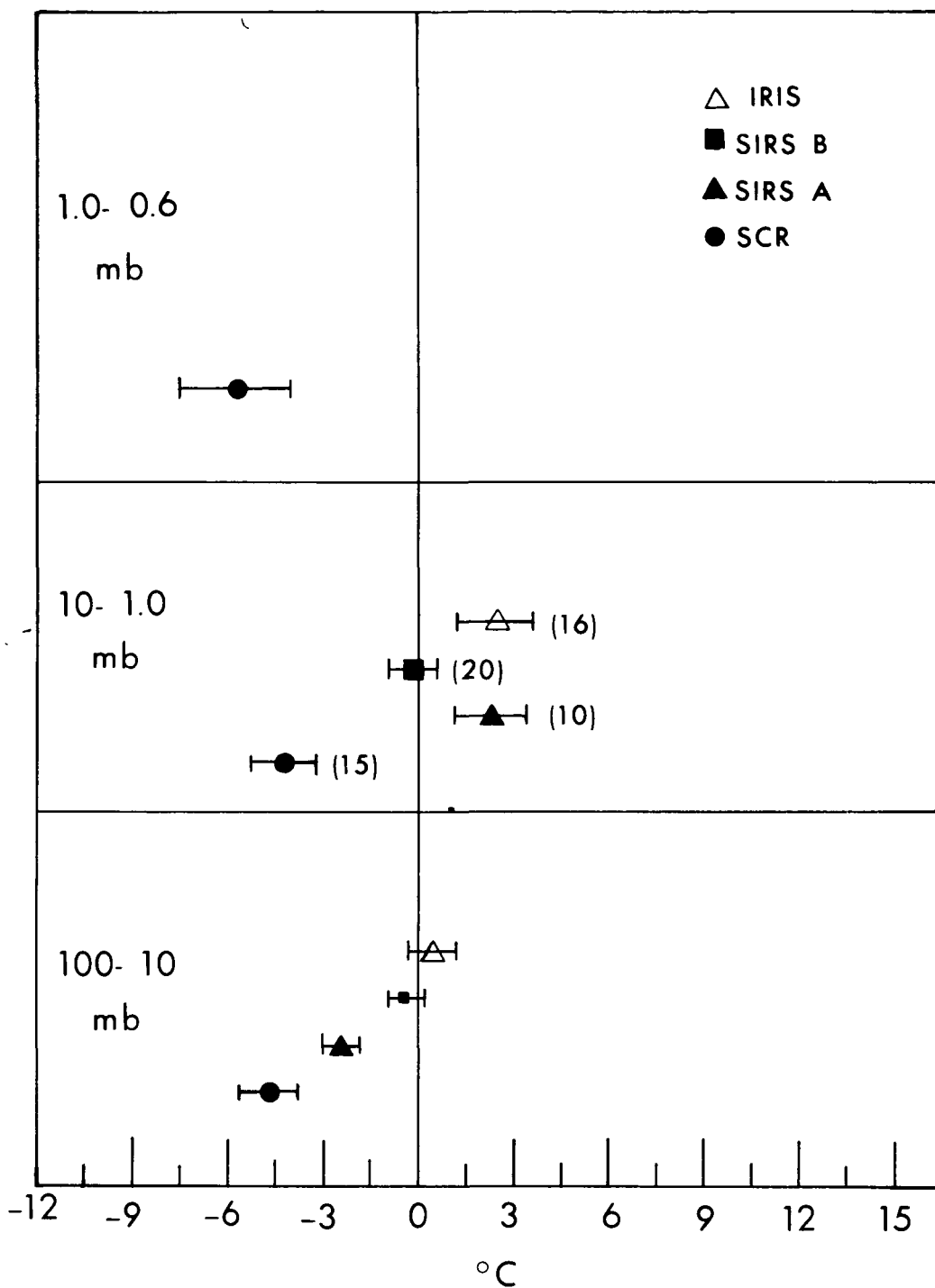


Figure 5. Mean temperature differences of adjusted Arcasonde 1A minus satellite retrievals with 95% confidence limits. Numbers in parentheses indicate number of observations.

layer, the differences shift by less than 0.5°C , at 10-1.0 mb the temperatures are about 1.2°C lower while in the highest layer the shift is about 4.0°C . We note that for SIRS B the differences are not significantly different from zero in both atmospheric layers. Comparing the rocketsonde adjustments scheme utilized (Drews, 1966) with that recently derived by Staffanson (1971), the latter procedure would result in lower layer temperatures (the layer from 100-10 mb) cooled still further by about 0.15°C , the intermediate layer (10-1.0 mb) cooled additionally by about 0.4°C , and the top layer (1.0-0.6 mb) warmed by about 1.5°C . In the case of the SCR, neither set of temperature adjustments can decrease the observed disparity.

The results for the Datasonde I instrument are shown in Figure 6 and again as might be anticipated from the previous radiance results, the rocketsonde temperatures are relatively warm with respect to SIRS A, SIRS B, and the IRIS instruments. This difference exceeds 3° in the lower layer and 6° in the intermediate layer. In contrast, the results for the SCR instrument indicate virtually zero difference although the confidence limits are considerably expanded over the other instruments.

In Figure 7 we see that the Datasonde II design results in relatively lower temperatures in the two lower levels, but the change in the 1.0-0.6 mb region is toward higher temperatures. This ambiguity is probably due to the high noise level of the observed data in that region. In all layers, however, the Datasonde II temperatures still appear to be relatively high compared to the Arcasonde. This latter point is substantiated by a subset of this complete data set consisting of 8 days in August and September during which both Arcasonde and Datasonde II instruments were launched in conjunction with the Nimbus 4 satellite overpass.

In the overall sense, we see that while the Arcasonde tended to agree with the SIRS B and Datasonde I with the SCR, there does not appear to be any consistent agreement between the Datasonde II and any of the satellite systems. The best agreement is with the SCR in the two upper levels, but between 100-10 mb the difference exceeds 3° .

Looking next at the results for the grenade and pitot comparisons in Figures 8 and 9 respectively, we should first re-emphasize that in the 100-10 mb layer the observed temperature profile is that of the support Arcasonde and rawinsonde and is included mainly for completeness. In the intermediate level, the grenade observations appear warm compared to the SIRS A, SIRS B, and IRIS measurements and also to the pitot observations. The average difference between the grenade-satellite and pitot-satellite in this layer is about 4° . The reason for this disparity is not resolved at this time. In the uppermost layer, both the grenade and pitot measurements appear cold with respect to the SCR, as they do below, but in this case the confidence levels are

$\Delta T(\text{DATAS I}-\text{SATELLITE})$

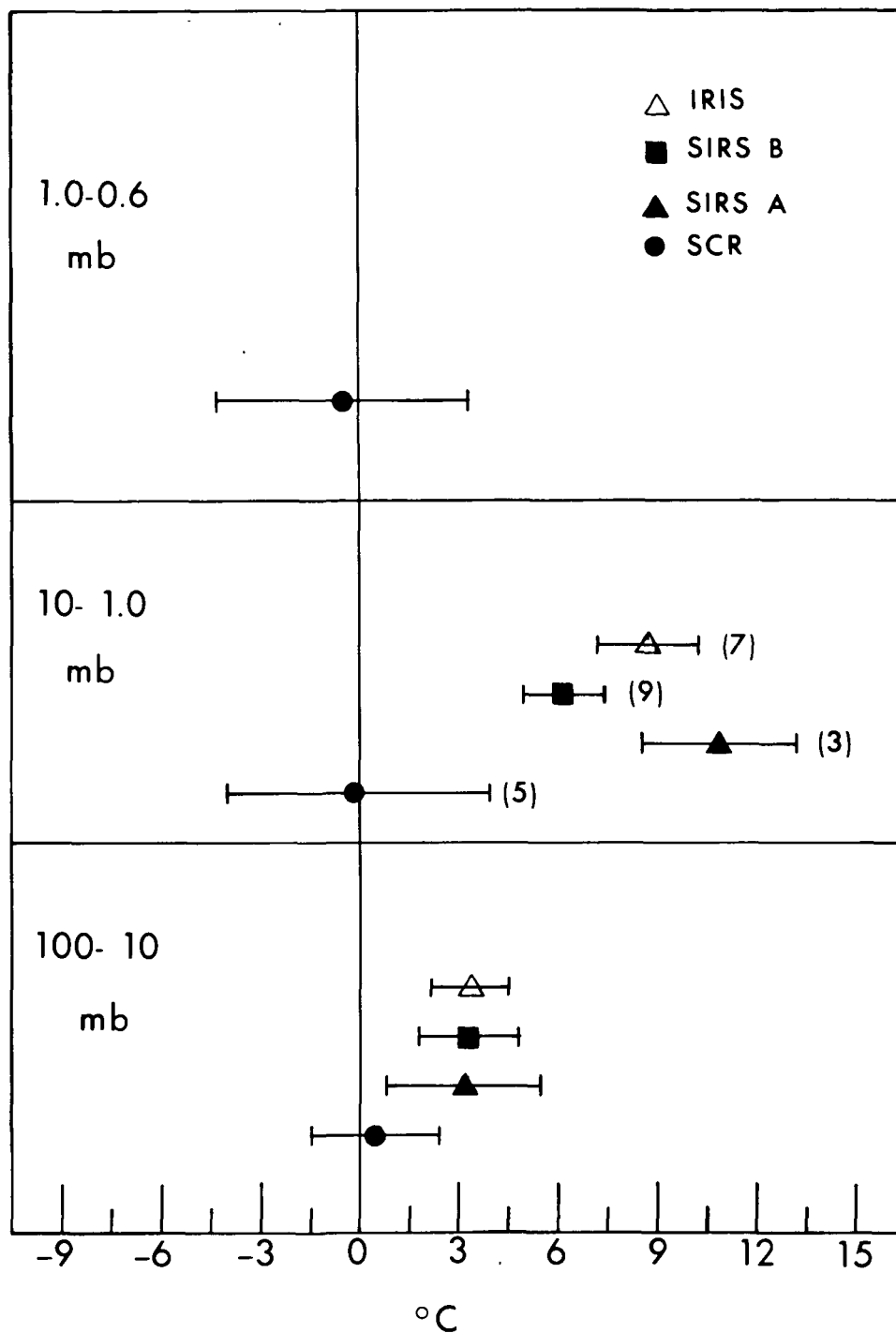


Figure 6. Mean temperature differences of Datasonde I minus satellite retrievals with 95% confidence limits. Numbers in parentheses indicate number of observations.

$\Delta T(\text{DATAS II} - \text{SATELLITE})$

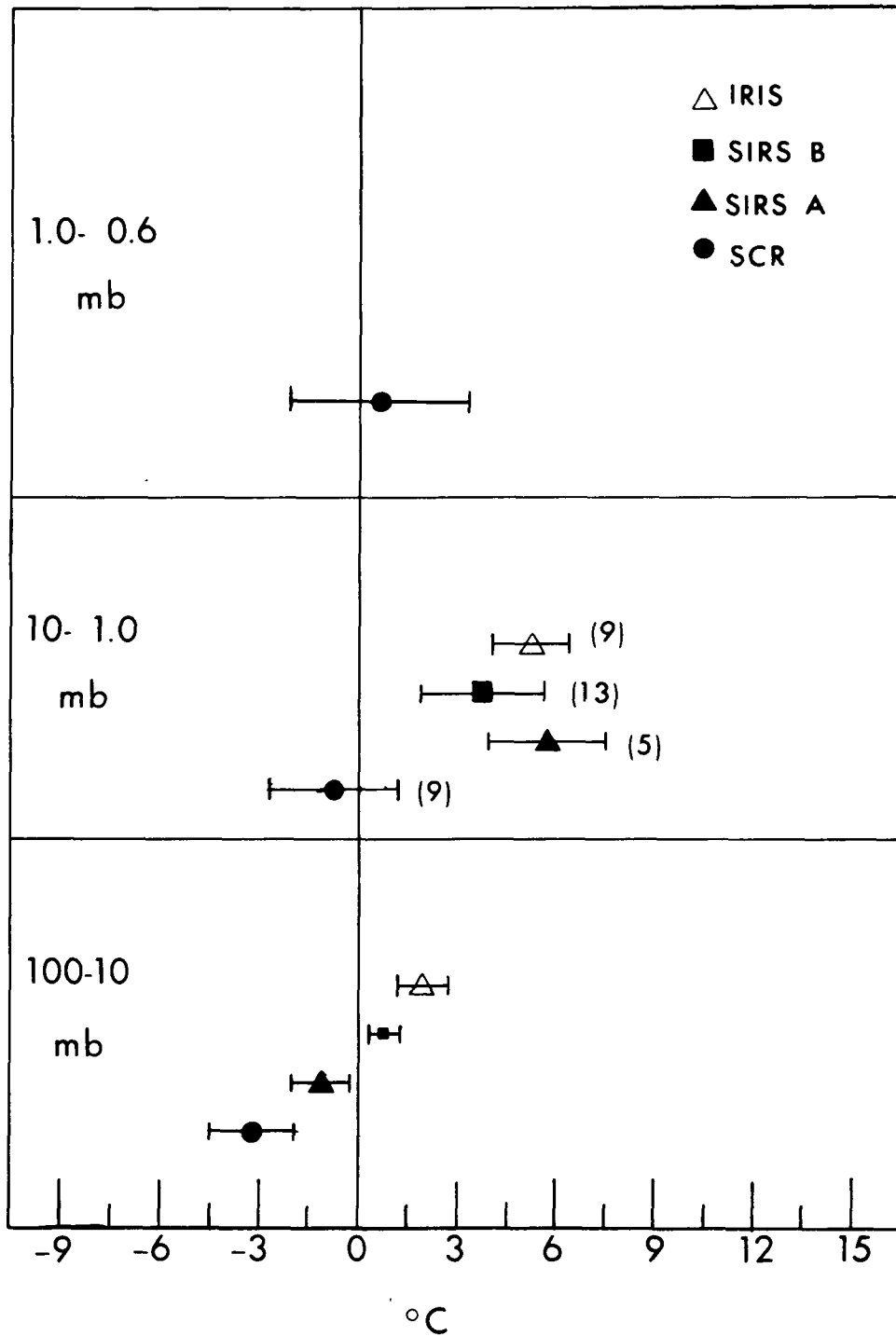


Figure 7. Mean temperature differences of Datasonde II minus satellite retrievals with 95% confidence limits. Numbers in parentheses indicate number of observations.

$\Delta T(\text{GRENADE} - \text{SATELLITE})$

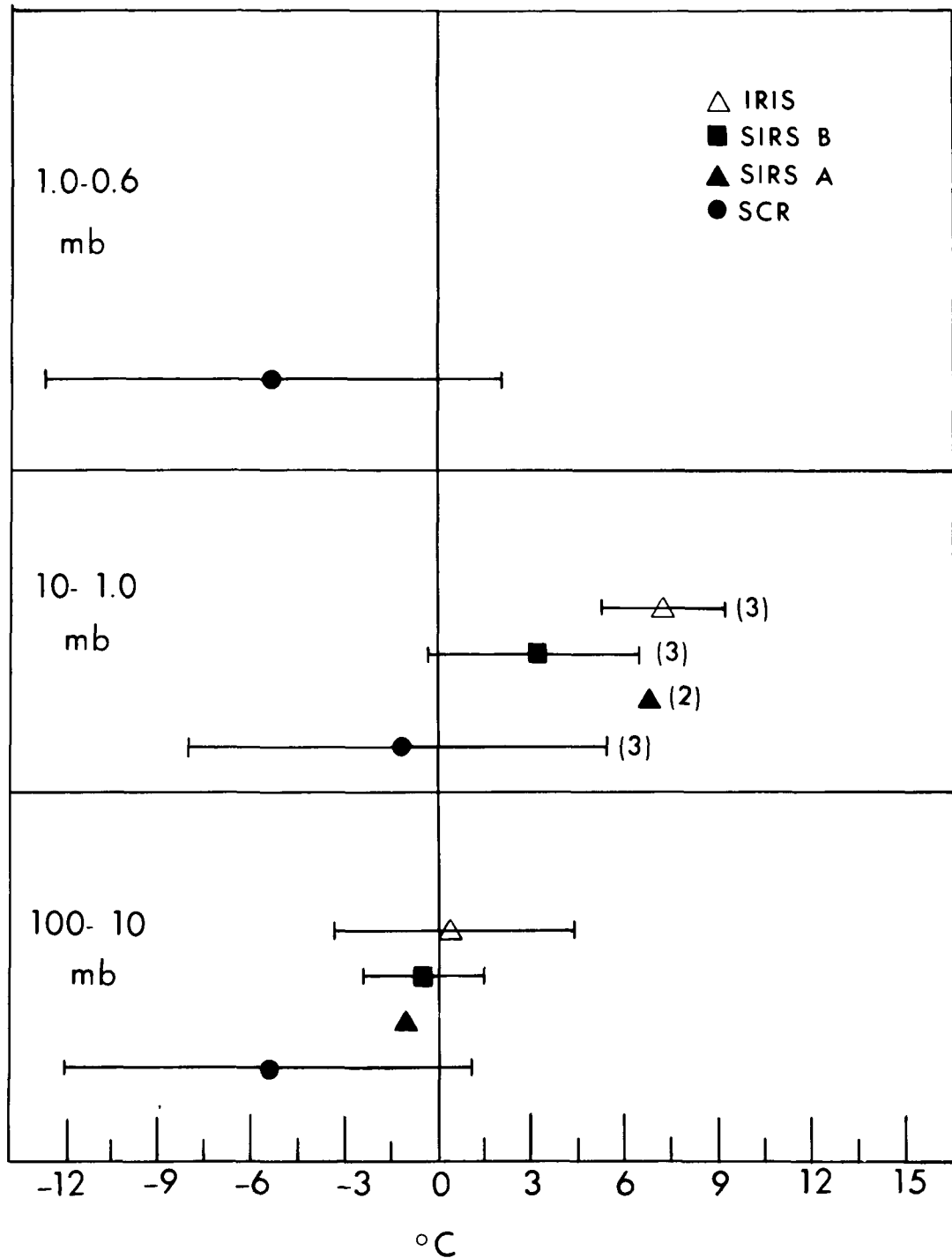


Figure 8. Mean temperature differences of grenade experiments minus satellite retrievals with 95% confidence limits. Numbers in parentheses indicate number of observations.

$\Delta T(\text{PITOT}-\text{SATELLITE})$

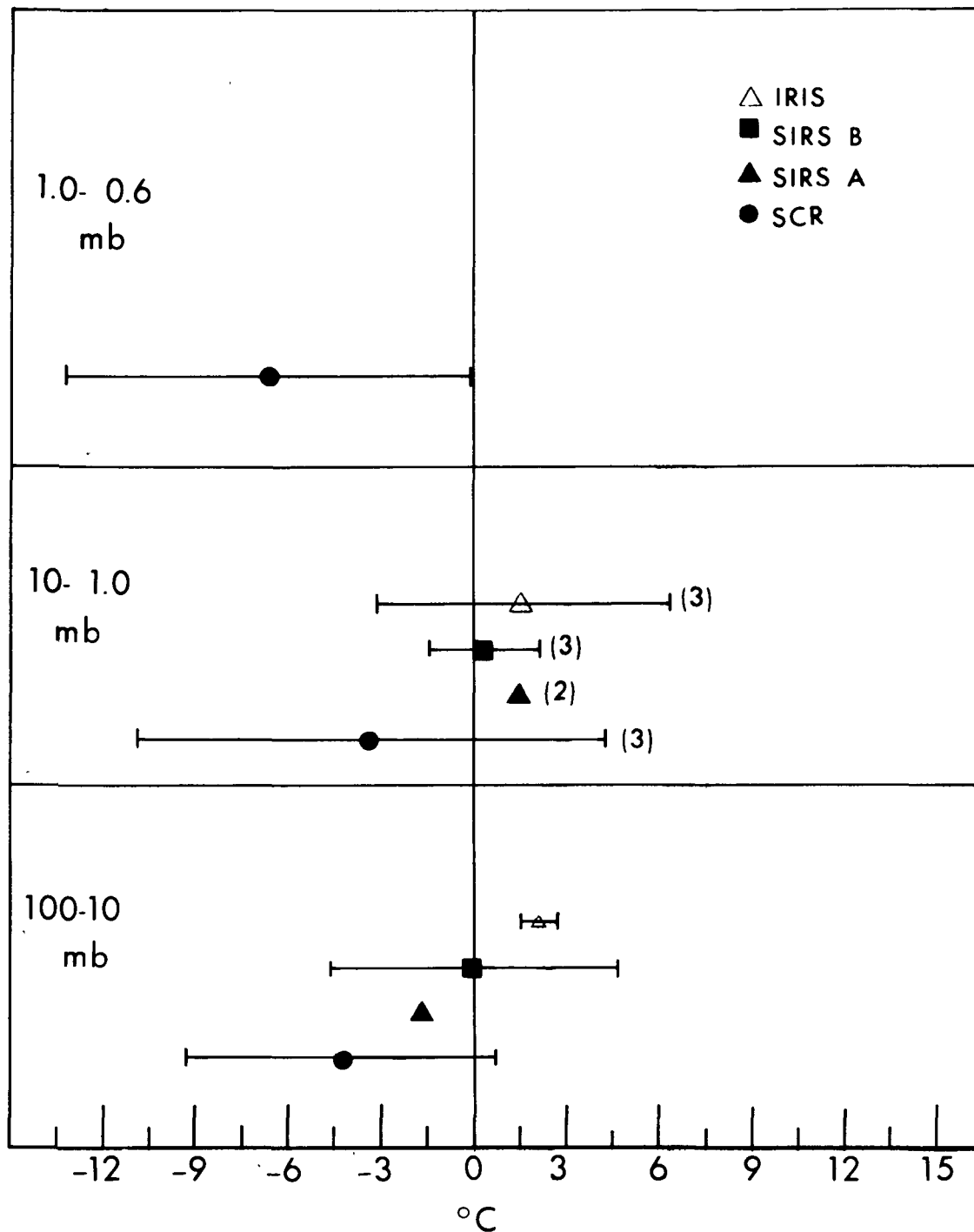


Figure 9. Mean temperature differences of pitot experiment minus satellite retrievals with 95% confidence limits. Numbers in parentheses indicate number of observations.

so great that the 1.5° difference between the data pairs cannot be considered significant.

SUMMARY

It was not the intent of this study to assign "correctness" to any specific system but rather to compare the various systems for overall compatibility. With this in mind we may summarize our findings:

1. The SIRS A radiance differences were not constant over the period of a year, indicating a possible shift in either the rocketsonde or satellite or both instrument calibrations.

2. Though the two SIRS instruments are similar in nature, the weighting functions for SIRS B appear to be more internally consistent for the highest channels than do those for SIRS A.

3. SIRS B and IRIS radiances differed by as much as 4 ergs/, although this difference is somewhat compensated for in the temperature retrieval process.

4. The Datasonde I-measured temperatures are considerably higher than those from either the Arcasonde 1A or Datasonde II.

5. The Datasonde II-measured temperatures are slightly higher than those from the Arcasonde 1A.

6. The grenade soundings appear to yield temperatures which are higher than those from the Arcasonde 1A.

7. The pitot temperatures are slightly lower than those from the Arcasonde 1A.

8. The SCR temperature data are consistently higher than SIRS A, SIRS B, and IRIS although the relative differences between the various rocketsonde systems appear to be maintained.

9. In the 10-1.0 mb region the temperatures were determined to be in the following approximate order toward warmer values:

IRIS-SIRS A-SIRS B-Pitot-Arcasonde 1A-Datasonde II-
Grenade-SCR-Datasonde I.

ACKNOWLEDGEMENTS

This study is only one part of the cooperative effort to determine the compatibility between satellite sounder and in situ type atmospheric measurements. Many others have been involved including: Dr. M. Tepper; Messrs. W. C. Spreen and J. F. Spurling; Drs. R. A. Hanel and B. J. Conrath; Messrs. G. J. Delio, R. Ormsby, R. M. Henry, W. S. Smith, D. U. Wright, J. S. Theon, all of NASA; Dr. D. Q. Wark, Messrs. H. E. Flemming, R. C. Luebbe, J. Lienesch, F. J. Schmidlin of NOAA; Mr. M. J. Horvath of the University of Michigan; Dr. F. L. Staffanson of the University of Utah; and Dr. J. T. Houghton and colleagues of the University of Oxford.

Funds for this research have been made available by the National Aeronautics and Space Administration.

REFERENCES

1. Bollermann, B., 1970: A Study of 30 km to 200 km Meteorological Rocket Sounding Systems, Vol. 1, NASA Contractor Report, NASA CR-1529, National Aeronautic and Space Administration, Washington, D. C., 426 pp.
2. Conrath, B. J.; Hanel, R. A.; Kunde, V. G.; Prabhahara, C., 1970: The Infrared Interferometer Experiment on Nimbus 3, Journal of Geophysical Research, Vol. 75, No. 30, pp. 5831-5857.
3. Drews, W. A., 1966: A Thermistor Arrangement to Improve Temperature Measurement at High Altitude, NASA Contract Report, NASA CR-533, National Aeronautics and Space Administration, Washington, D. C., 29 pp.
4. Ellis, P. J.; Peckham, G.; Smith, S. D.; Houghton, J. T.; Morgan, C. G.; Rogers, C. D.; and Williamson, E. J., 1970: First Results from the Selective Chopper Radiometer on Nimbus 4, Nature, Vol. 228, pp. 139-143.
5. Finger, F. G.; Woolf, H. M.; and Anderson, C. E., 1965: A Method for Objective Analysis of Stratospheric Constant-Pressure Charts, Monthly Weather Review, Vol. 93, No. 10, pp. 619-638.
6. Hanel, R. A.; Schlachman, B.; Clark, F. D.; Prokesh, C. H.; Taylor, J. B.; Wilson, W. M.; and Chaney, G., 1970: The Nimbus III Michelson Interferometer, Applied Optics, Vol. 9, No. 8, pp. 1767-1774.
7. Houghton, J. T., and Smith, S. D., 1970: Remote Sounding of Atmospheric Temperature from Satellites, Proceedings Royal Society London A, Vol. 320, pp. 23-33.
8. Miller, A. J., and Schmidlin, F. J., 1971: Rocketsonde Repeatability and Stratospheric Variability, Journal of Applied Meteorology, Vol. 10, No. 2, pp. 320-327.
9. National Aeronautics and Space Administration, 1972: Rocket/-Nimbus Sounder Comparison (RNSC) Workshop Meeting, NASA SP (to be published).
10. Rodgers, D. D., 1970: Remote Sounding of the Atmospheric Temperature Profile in the Presence of Cloud, Quarterly Journal of the Royal Meteorological Society, Vol. 96, pp. 654-666.

11. Smith, W. G.; Woolf, H. M., and Fleming, H. E.: Retrieval of Atmospheric Temperature Profiles from Satellite-Measurements for Dynamical Forecasting, submitted to Journal of Applied Meteorology.
12. Staffanson, F. T., 1971: Mathematical Model of the Film-Mounted Rocketsonde Thermistor, Journal of Applied Meteorology, Vol. 10, No. 4, pp. 825-832.
13. Strand, O. N. and E. R. Westwater, 1969: Minimum - RMS Estimation of the Numerical Solution of a Fredholm Integral Equation of the First Kind, SIAM Journal Numerical Analysis, Vol. 5, pp. 287-295.
14. U. S. Committee on Extension to the Standard Atmosphere: U. S. Standard Atmosphere Supplements, 1966, Government Printing Office, Washington, D. C., 289 pp.
15. Wark, D. Q., 1970: SIRS, an Experiment to Measure the Free Air Temperature From a Satellite, Applied Optics, Vol. 9, No. 8, pp. 1761-1766.