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► **To cite this version:**

Frederick G. Finger, M. E. Gelman, J.D. Wild, Marie-Lise Chanin, Alain Hauchecorne, et al.. Evaluation of NMC Upper-Stratospheric Temperature Analyses Using Rocketsonde and Lidar Data. *Bulletin of the American Meteorological Society*, 1993, 74 (5), pp.789-800. 10.1175/1520-0477(1993)0742.0.CO;2 . insu-03598705

**HAL Id: insu-03598705**

**<https://insu.hal.science/insu-03598705>**

Submitted on 5 Mar 2022

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# Evaluation of NMC Upper-Stratospheric Temperature Analyses Using Rocketsonde and Lidar Data

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## Abstract

Daily NMC analyses, constructed from operational TOVS data since 1978, are used to monitor behavior of middle atmospheric temperature. Capability of the upper-stratospheric analyses (5, 2, 1, and 0.4 mb) to provide temporally consistent temperature fields depends on adjustments derived from ground-truth observations. These adjustments compensate for biases in the analyses caused by behavioral differences in data derived from successive operational satellite instruments and by changes in data and analysis procedures. This paper supports previous studies showing that observations from the datasonde rocket system provide ground-truth adjustments with a precision of 1°–3°C. The number of datasonde observations has diminished substantially in recent years, putting this adjustment system at risk. Falling-sphere rocket temperature data are shown to have variability in excess of that judged to be acceptable for use in the adjustment system.

The capability for Rayleigh lidar to provide high-quality temperature data needed for ground truth is examined by comparing NMC analysis temperatures, adjusted by datasonde measurements, with observational values from regularly operating lidar systems in France since 1978. Agreement between the two databases is found to be good in recent years. This is further verified by comparisons between the datasonde-computed adjustments and independent analysis adjustments derived from the lidar database. It is concluded that high-quality lidar measurements, if made available from low, medium, and high latitudes, could provide the essential data for use in the analysis adjustment system.

## 1. Introduction

Temperature information from the levels within the higher stratosphere and up into the mesosphere (from about 35 to 55 km) is required to test the validity of atmospheric models, which predict a 2°C cooling trend per decade in those layers as a result of stratospheric ozone depletion [World Meteorological Organization (WMO) 1989]. The purpose of this study is to survey the consequences of using constant-pressure

analyses, operationally derived by the National Meteorological Center's (NMC) Climate Analysis Center (CAC), for monitoring the behavior of temperature at the higher levels of the atmosphere (Gelman 1991). Such analyses must be capable of detecting small temperature trends occurring over long time periods if they are to be useful for monitoring purposes. This survey focuses on the NMC analyses of temperature for the upper stratosphere and the lower portion of the mesosphere (5, 2, 1, and 0.4 mb, or about 35, 42, 48, and 55 km) provided since 1978. We note that basic features of the system used for these analyses are similar to those methods developed earlier for use with the radiosonde database at the lower-stratospheric levels of 70, 50, 30, and 10 mb, or 18, 20, 24, and 30 km (Finger et al. 1965). This analysis system is a general adaptation of the type originally developed by Cressman (1959) for NMC operations and depends on a "first-guess" field, adjusted by successive applications of the observational database. It has been replaced for NMC operations at the tropospheric level, but the system continues to produce stable analyses useful for upper-stratospheric monitoring purposes.

The system used for analysis at levels from 5 to 0.4 mb is based on global temperature data provided by successive temperature profile satellites. Temperatures retrieved from radiances measured by the Vertical Temperature Profile Radiometer (VTPR) during the period from October 1978 to October 1980 formed the initial database for the analyses. However, for longer than a decade and at present, the satellite temperature data have been supplied by the TIROS Operational Vertical Sounder (TOVS) system (Smith et al. 1979; McMillin and Dean 1982; Dey et al. 1989). The TOVS system is composed of three instruments: the stratospheric sounding unit (SSU), the high-resolution sounder (HIRS), and the microwave sounding unit (MSU). Of the 27 spectral channels available from TOVS, nine are used for derivation of stratospheric temperature profiles.

Several different satellite temperature retrieval methods have been utilized over the years by the National Environmental Satellite and Data Information

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Service (NESDIS). Each has its own strengths and weaknesses. The most recent developments have been the TOVS statistical temperature retrieval system, initiated in October 1980, and the replacement TOVS physical system put into operation in September 1988 (see Dey et al. 1989). Both of these methods vary little in producing operational retrievals at the levels of our interest (i.e., at pressure surfaces less than 10 mb). They are, however, dependent on the use of a relatively sparse climatological dataset of rocketsonde observations taken previous to 1980. This dependency is in sharp contrast to the situation at the pressure levels greater than 10 mb, where the retrievals have the distinct advantage of being tuned with the use of near-current radiosonde reports (28 days) from each of about 200 globally located stations.

For the purposes of increasing the usefulness of the NMC analyses within the 5- to 0.4-mb layer, rocketsonde temperature measurements from the datasonde instrument reported since 1978 have been used for ground-truth evaluations (Gelman et al. 1986). These evaluations have uncovered analysis biases, many of which can be neutralized by the application of temperature adjustments. It is unfortunate, however, that the number of datasondes employed for providing the ground-truth observations has been rapidly diminishing, thus threatening the usefulness of this database. Temperatures derived from falling-sphere-type rocketsondes have also been considered for ground-truth use, but there are fewer of these observations than those from datasondes. In addition, questions have persisted regarding measurement precision and accuracy of the falling-sphere observations. We will reevaluate reported temperatures from both rocketsonde systems in order to determine whether the two may be used together to provide larger and more useful ground-truth temperature databases for determining and evaluating NMC analysis adjustments.

In view of the future needs for continued ground-truth confirmation of the NMC analyses, strong consideration is being given to the use of temperature measurements made by Rayleigh lidar. Versions of this remote sensing lidar instrument, utilizing a technique based on backscatter of pulsed laser beams by atmospheric molecules, are located at the Observatory of Haute-Provence (OHP), France (44°N, 6°E), and at the Centre D'Essai des Landes (CEL), Biscarrosse, France (44°N, 1°W). A relatively large dataset has been obtained from the observations made at the OHP site since late 1978 (Chanin and Hauchecorne 1984), while CEL operations were initiated in 1986. Additional lidar systems are in various stages of development in the United States and other countries (McGee and McIlrath 1979; McDermid 1987)

and plans are being developed for formation of the international Network for the Detection of Stratospheric Change. We will focus here on the data derived from lidars operating in France, with a view of determining the usefulness of the derived temperatures as independent sources of ground truth for the NMC analyses.

## 2. Rocketsonde data

The datasonde rocket system has been used since the early 1970s. It has played a vital role in providing a dependable and many times an only source for high-level temperature observations. Nearly all of the ground truth for the NMC analyses has also been provided by this system, as we will show subsequently. The datasonde includes an instrumented thermistor package and parachute, which are ejected from the rocket at apogee and tracked by radar during descent. In situ measured temperatures are provided as functions of geometric height from about 60 km down to near 25 km. Constant-pressure data from the datasonde are derived with the use of support radiosonde observations that supply the needed base "tie-on" values. Experimental studies of the system have indicated temperature measurement precision (repeatability) of 1°–3°C (Schmidlin 1981).

The sharp reduction in the number of observations made with datasondes each year since 1979 is illustrated in Fig. 1. Greatest reduction can be noted during the first half of the 1980s. Much of this initial reduction was due to the termination in 1982 of several of the higher-latitude (above 40°N) stations operated by the United States. Locations of the 12 rocket sites operational at that time are listed in Table 1.

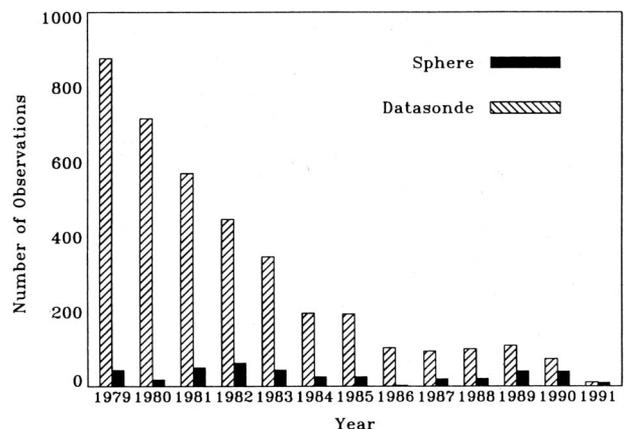


FIG. 1. Number of datasonde and falling-sphere observations used each year for study.

TABLE 1. Rocketsonde station location and instrument type used (d = datasonde; s = falling sphere).

Station name	Latitude	Longitude	Instrument	Symbol
Ascension Island, AFB	8.0°S	14.4°W	d,s	■
Barking Sands, Hawaii	22.0°N	159.8°W	d,s	▲
Cape Canaveral, Florida	28.5°N	80.5°W	d,s	◆
Point Mugu, California	34.1°N	119.1°W	d,s	▼
Wallops Island, Virginia	37.8°N	75.5°W	d,s	●
Kwajalein, Marshall Islands	8.7°N	167.7°E	d	
Antigua, British West Indies	17.2°N	61.8°W	d	
White Sands, New Mexico	32.4°N	106.5°W	d	
Shemya, Alabama	52.7°N	174.1°E	d	
Primrose Lake, Canada	54.8°N	110.1°W	d	
Churchill, Canada	59.0°N	93.8°W	d	
Thule, Greenland	76.6°N	68.8°W	d	

Although the number of sphere temperature observations has always been relatively small, these data might possibly be used along with those from datasondes, thus providing important additions to the ground-truth information base. Spheres have been used at the five stations noted in Table 1, and these five stations also regularly launched datasondes for a number of years. The sphere system consists of an inflatable mylar balloon, tracked by high-precision radar as the balloon descends from rocket apogee. Atmospheric density from approximately 90 km down to about 30 km is derived from the fall velocity of the sphere, assuming zero vertical atmospheric motion. Temperatures are derived from the density changes, along with the use of a "guess" value at the top of the profile.

A study by Quiroz and Gelman (1976) found differences between sphere and datasonde to be as much as 6°C at about 50 km, with sphere temperatures lower (colder). Schmidlin et al. (1991), using a limited sample of more recent observations, suggest improved agreement. They report average differences of less than 3°C between 60 and 30 km. We note that sphere procedures were updated during the period between the two studies with a view of refining operational accuracy. A decrease in differences between datasonde and sphere was also noted by Angell (1991), who found that biases between the two systems at the levels of concern were 3.6°C during the mid-1970s and about 1.5°C in the mid-to-late 1980s (sphere temperatures lower in each case).

### 3. Datasonde adjustments for NMC analyses

The need to apply temperature adjustments to NMC analyses for the upper stratosphere stems primarily from inconsistencies within the TOVS-derived temperature database. A significant portion of this mainly temporal instability problem can be related to the differences in the behavior of the various satellite instruments used to provide operational data. Other contributing factors are related to changes in NMC data and analysis procedures (Gelman et al. 1983, 1986; Geller et al. 1983). Temperature bias arising from replacement of operational satellites is one of the more difficult problems, since precise instrumental intercalibration demands considerable study. In cases where single channels of an instrument fail, operational data derived from the reduced number of channels may exhibit different characteristics than information derived from all the channels. Unfortunately, the

data from the period of instrumentation overlap necessary for determining characteristics of datasets derived before and after such changes may not be available.

In this section we will review the present system of using datasonde-measured temperatures as ground-truth observations for application to the upper-stratospheric analyses. This application is intended to minimize biases within the analysis sequences that result from the aforementioned problems.

Figure 2 shows NMC analysis temperatures (unadjusted), interpolated to the location of Wallops Island, Virginia (37.8°N, 75.5°W), along with datasonde observations taken at the midlatitude site. The period of record for both datasets is from 1978 through 1991. Even though rocketsonde observations provide many fewer values than do daily NMC interpolations, variations of temperature through the years are outlined consistently by both datasets. During some of the winter periods, sharp and rapid changes associated with stratospheric warmings can be seen. Also quite evident in Fig. 2 are biases between analysis and rocketsonde values. These biases are different at each level. It is obvious that rocketsonde-measured temperatures are higher (warmer) than analysis-derived temperatures at 1 mb. The opposite is the case at 0.4 mb.

Figure 3 illustrates differences between 1-mb temperatures interpolated from NMC analyses (unadjusted) and datasonde measurements taken at Wal-

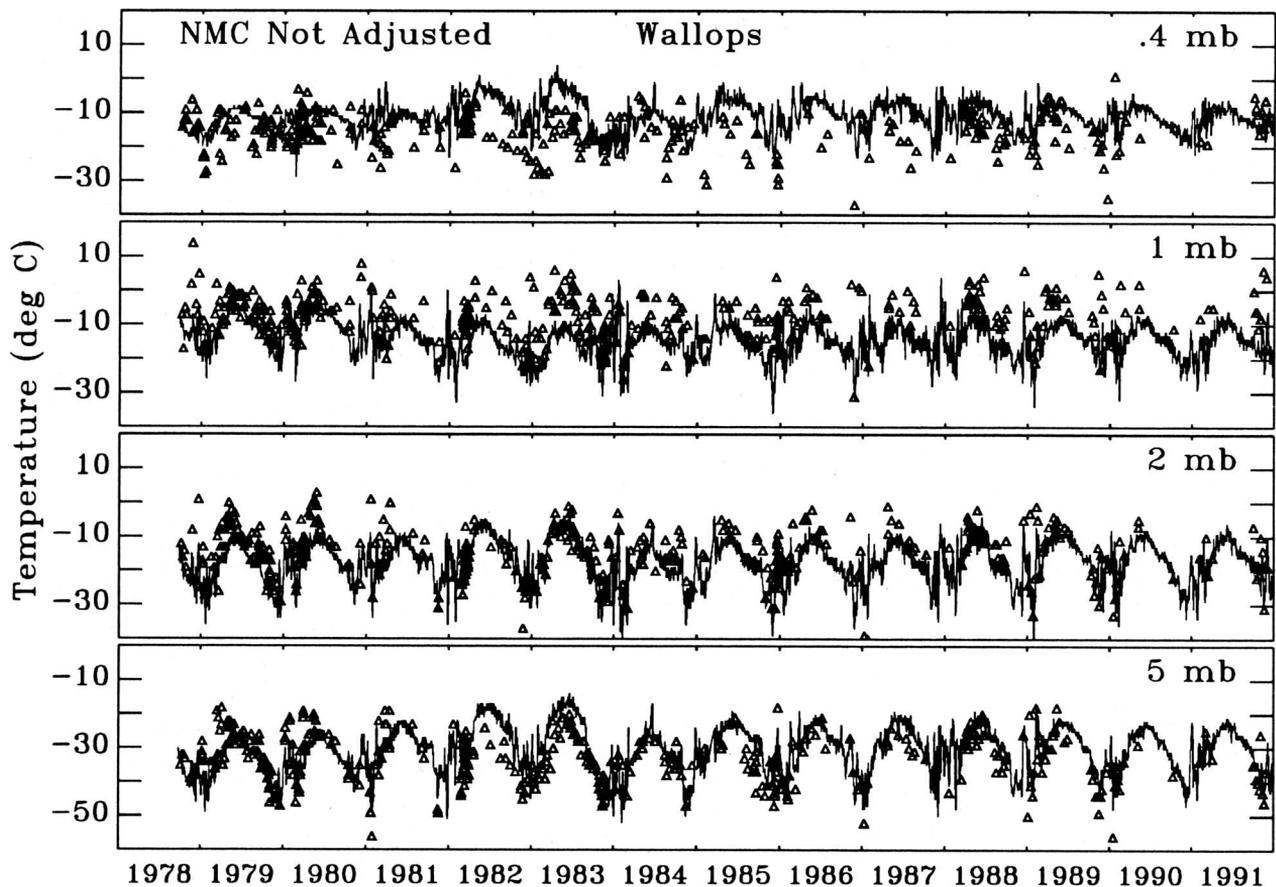


FIG. 2. Daily NMC analysis temperatures (unadjusted) for years 1978 through 1991, interpolated to Wallops Island, VA (solid lines). Included are temperature reports from Wallops Island observations using datasondes (triangles).

Wallops Island (shown in Fig. 2). These temperature differences clearly define an overall bias, with temperatures from NMC analyses lower (colder) than Wallops Island datasonde observations. Bias is even more apparent from the comparison shown in the bottom of Fig. 3, which illustrates differences between 1-mb temperatures interpolated from analyzed values at the locations of all 12 stations and datasonde observations from those stations.

An additional and very important feature of Fig. 3 is the partitioning of the overall database (late 1978 through 1991) into ten distinct periods. Boundaries of these periods were specifically defined by identifying dates of changes in use of satellite instruments, or by important changes in data or analysis procedures (for detailed information regarding the recorded changes, see Gelman et al. 1986). It is apparent from Fig. 3 that abrupt changes in values of differences do occur at some of the period boundaries. One change, especially evident in the information for all 12 stations, occurs at the boundary between periods 5 and 6. Computations of mean differences for these periods indicate a shift of about 3°C in the overall values.

The averages of differences between daily NMC analyses values at each of the pressure surfaces and for periods 4–10 are shown in Fig. 4 (periods 1–3 are discussed separately below). These biases represent the adjustments necessary to achieve compatibility between datasonde measurements and NMC analysis values. Application is accomplished by subtracting the computed adjustment value from the NMC analysis temperature. Figure 4 indicates that shapes of adjustment profiles are quite similar for periods 4–10. Most adjustment values are positive at 5 and 0.4 mb and negative at 2 and 1 mb. The adjustment value for each level and for each period has been calculated using data from all stations, and these single adjustments are applied globally.

With regard to periods 1–3, an adjustment system (Gelman et al. 1983) was developed using a best-fit linear-regression equation of the form  $a + bI$ , where  $a$  is the computed adjustment at the equator and  $b$  is the slope of the adjustment values with the absolute value of the latitude ( $I$ ). This latitudinally varying adjustment system, however, produced values beginning in period 4 that were not statistically significant, perhaps

because of the radical reduction in the number of rocketsonde stations at high latitudes. Further investigation into the possibilities of latitudinal influence is planned through comparisons with other independent data sources [e.g., the Upper Atmosphere Research Satellite (UARS)].

Values of all adjustments needed for user application to the NMC basic analyses, from 1978 to the present, are given in Table 2. This table is a continuation of that presented by Gelman et al. (1986). As indicated, the user must subtract the adjustment value at all analysis locations. We stress that this adjustment is not applied at the time of analysis and that application is a user prerogative.

Figure 5 reveals that application of derived temperature adjustments to the unadjusted Wallops Island and 12 station datasets (previously shown in Fig. 3) has essentially reduced the overall bias to zero. At the same time, period-by-period consistency has been significantly improved. However, variability of differences within any given period is not affected by this procedure. A troubling aspect relating to the variability is the considerable number of individual differences that are situated well beyond the mass of the data points. Many of these outliers are associated with low- and high-latitude stations, such as

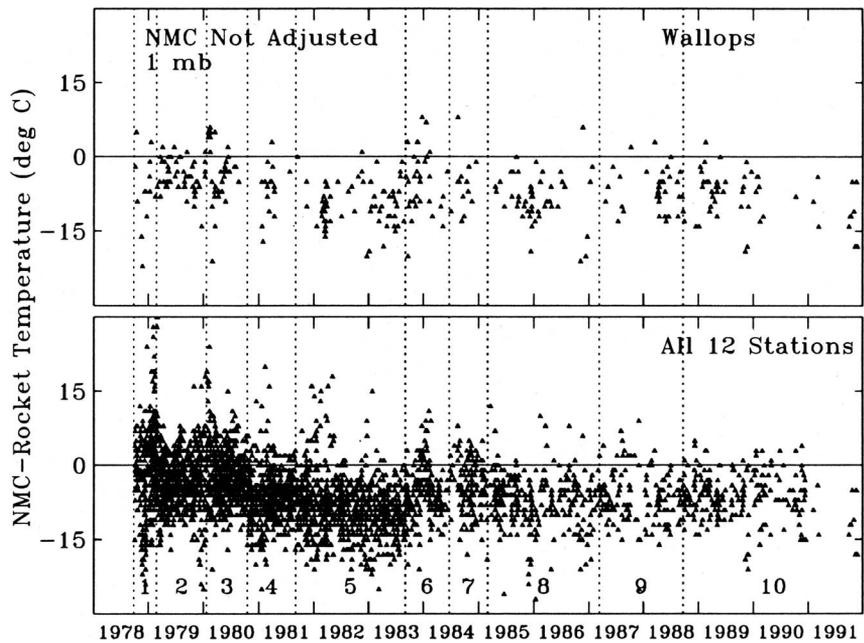


FIG. 3. Computed 1-mb temperature differences between NMC analyses (unadjusted) and datasonde observations made at Wallops Island (top) and at the 12 stations listed in Table 1 (bottom). Differences derived only for days with available datasonde observations. Boundaries for the periods 1–10 show dates of changes in satellite instruments or in NMC procedures.

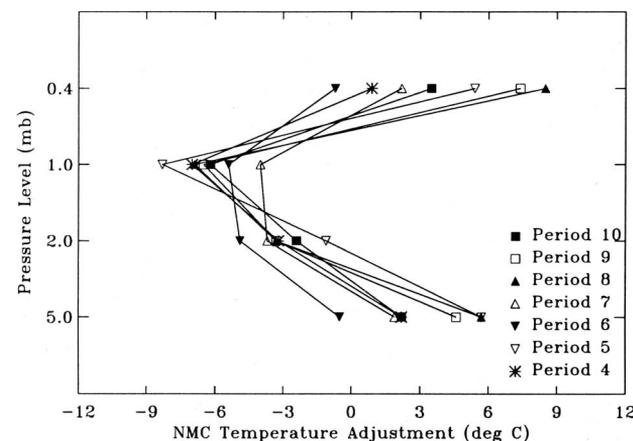


FIG. 4. Derived NMC analysis temperature adjustments as functions of pressure for periods 4–10. Value should be subtracted from the NMC analysis temperature globally.

Ascension Island, Shemya, Fort Churchill, and Thule. We further note that many reports from high-latitude stations were available only for the early period of the database. Variability among stations will be shown subsequently, as part of evaluating the adjustments.

The strategy outlined for derivation and application of ground-truth datasonde adjustments has resulted in diminishing biases and improving temporal consistency of the temperature fields used by the NMC analyses during the time period 1978–1991. However, an objective definition of the improvement in analysis accuracy and of the uncertainty in the derived adjustments is much more difficult. For this evaluation, we will use independent data in an attempt to corroborate perceived benefits from the application of adjustments. As indicated earlier, there are two other systems presently available that might possibly supply ground truth. These systems include the falling-sphere rocketsonde and ground-based lidar.

#### 4. Compatibility between datasonde-adjusted NMC analyses and falling-sphere temperatures

Rocketsonde observations derived from falling spheres have provided relatively few temperatures

(Fig. 1), especially in terms of measurements made nearly simultaneously with datasonde observations. Results of the relatively few direct comparisons by others have been discussed previously. Our comparisons will utilize temperature values interpolated from NMC analyses, along with sphere temperature observations.

Average temperature differences between adjusted NMC analysis values and sphere observations for each of the five stations supplying measurements are shown in Fig. 6. Overall biases for all stations (not shown) range from about 2° to 3°C at the 0.4-, 2-, and

5-mb levels, with NMC temperatures higher (warmer). In contrast, at 1 mb the overall sphere bias is negative and less than 1°C. Individual station biases shown for the various pressure levels differ from the overall biases (mentioned above) by ±1° to 2°C, except for the Ascension Island data at 5 and 0.4 mb. This odd Ascension Island behavior (but there are similar issues with datasonde observations from that station) cannot be untangled, and we will not consider the problem at this time.

Figures 7 and 8 allow comparisons of mean temperature differences for the five individual stations where both rocket systems were used (see Table 1 for definition of these stations). Figure 7 illustrates the scatter for the datasonde stations. Since derived adjustments have already been applied to the NMC analyses, the interperiod biases have been accounted for. Remaining scatter between individual station mean differences within the periods (intraproduct) ranges up to about 6°C, but in a few cases extends to nearly 10°C. The standard errors for the computed differences range from 0.2° to 0.8°C.

Scatter of datasonde differences shown in Fig. 7 can be visually compared with that indicated for sphere data (Fig. 8). The scatter within the periods is considerably larger for sphere data, and differences between individual stations range to more than 10°C in a number of cases and up to nearly 15°C in some. A portion of this larger variability may be due to the much smaller number of sphere observations available from each station. Standard errors are also larger for the sphere and range from 0.5° to 3.3°C.

Figure 8 also illustrates that the overall mean biases of up to about 3°C between adjusted analyses and sphere data at 5, 2, and 0.4 mb (shown in Fig. 6) stem from individual station difference values that are consistently of the same sign, period by period. An exception can be seen at the 1-mb level, which provides mean bias values closest to zero. Adjustments might be applied to sphere data in order to improve their usefulness along with the datasonde observations. However, the sparsity of this database and the relatively large scatter of differences between the datasonde and sphere diminishes the advantages that may be gained from such a decision.

TABLE 2. Temperature adjustments for application to NMC upper-stratosphere analyses. Adjustment values for periods 1 to 3 are based on the equation  $(a + b|l|)$ , where  $(a)$  is the adjustment at the equator and  $(b)$  is the slope of the adjustment with the absolute value of latitude  $(l)$ . Standard errors (SE) are also shown.

Period	Date		5 mb	2 mb	1 mb	0.4 mb
1	24/09/78 to 22/02/79	(a)	-0.189	0.299	-0.162	-1.365
		SE (a)	0.681	0.593	0.928	0.900
		(b)	-0.033	-0.057	-0.019	0.037
		SE (b)	0.017	0.015	0.237	0.023
2	25/02/79 to 20/01/80	(a)	-4.052	-4.713	-1.818	6.831
		SE (a)	0.275	0.291	0.401	0.395
		(b)	0.069	0.017	-0.057	-0.170
		SE (b)	0.007	0.007	0.010	0.010
3	21/01/80 to 16/10/80	(a)	-5.142	-6.043	-0.917	8.829
		SE (a)	0.308	0.398	0.438	0.442
		(b)	0.084	0.061	-0.040	-0.203
		SE (b)	0.007	0.010	0.011	0.011

Temperature adjustments (Diff.) and standard errors (SE) for periods 4 to 10, derived with use of datasondes.

4	17/10/80 to 01/09/81	Diff.	2.2	-3.2	-7.0	0.9
		SE	0.4	0.5	0.5	1.1
5	02/09/81 to 01/09/83	Diff.	5.7	-1.1	-8.3	5.4
		SE	0.6	0.3	0.4	0.8
6	02/09/83 to 18/06/84	Diff.	-0.5	-4.9	-5.4	-0.7
		SE	0.6	0.5	0.4	1.1
7	19/06/84 to 26/02/85	Diff.	1.9	-3.7	-4.0	2.2
		SE	1.3	1.2	1.4	0.8
8	27/03/85 to 10/03/87	Diff.	5.7	-3.3	-6.9	8.5
		SE	0.4	0.4	0.5	0.6
9	11/03/87 to 19/09/88	Diff.	4.6	-3.3	-6.5	7.4
		SE	0.3	0.4	0.4	0.5
10	20/09/88 to 1992	Diff.	2.2	-2.4	-6.2	3.5
		SE	0.3	0.3	0.3	0.4

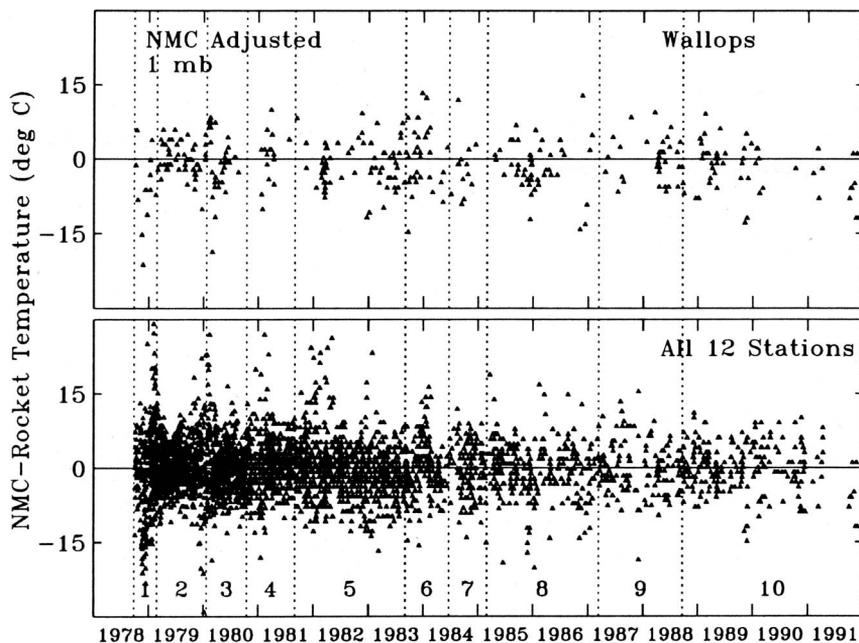


FIG. 5. Computed 1-mb temperature differences between NMC analyses (adjusted) and datasonde observations made at Wallops Island (top) and 12 stations (bottom).

## 5. Compatibility between datasonde-adjusted NMC analyses and lidar temperatures

Studies of lidar-derived temperature (Chanin and Hauchecorne 1984), of upper-atmospheric climatology based on lidar data (Hauchecorne et al. 1991), and of the definition of instrumental measurement accuracy and precision (Keckhut et al. 1992) have provided considerable information on lidar systems. In addition, initial results of comparisons of lidar observations with data used for the NMC analyses were given by Chanin and Gelman (1989). In this section we will use temperatures derived from lidar observations taken at OHP and CEL (France) with a focus on corroborating the NMC adjustments that have been derived from the reported datasonde temperatures. In addition, we will evaluate the possibility of using lidar measurements to supplement and eventually replace the datasonde as the ground-truth system.

NMC analyses cannot be compared directly with lidar observations, since NMC temperatures are given for pressure surfaces while lidar values are derived with respect to geometric height. Considering the necessity to convert one of the sets, we chose to interpolate the lidar temperatures to the height given for each pressure level of the NMC analyses. Lidar data are presented in 1-km increments and NMC

pressure surfaces are spaced in approximately 7-km layers. Thus, this conversion procedure generates less potential for error than a method based on interpolation of NMC temperature at given pressure, to lidar geometric height levels.

Individual differences between temperatures interpolated from adjusted NMC analyses and OHP measurements for the period of lidar record (1978–1991) are shown in Fig. 9. This initial view shows varying period-to-period differences between the analysis values and the OHP observational dataset. In some cases it appears that differences vary with period boundaries. Such a relationship would not be expected, since adjustments have already been applied to the analyses and should have reduced period-to-period biases to near zero. A most obvious change in difference values can

be noted between period 7 and 8 at all levels except 0.4 mb. Whether this behavior is a function of the adjusted analyses or of the OHP lidar data is not readily apparent from this view. It is important to try to pinpoint the problem, since stability of the dataset may be involved. We will pursue this further in discussing subsequent figures.

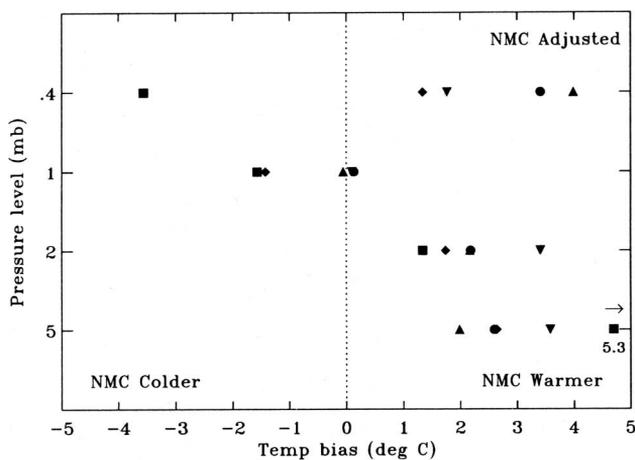


FIG. 6. For the five stations using spheres (see Table 1), individual station mean biases between NMC (adjusted) temperatures and available sphere observations 1978 through 1991. Mean values for all stations at the various pressure levels can be estimated by visual inspection.

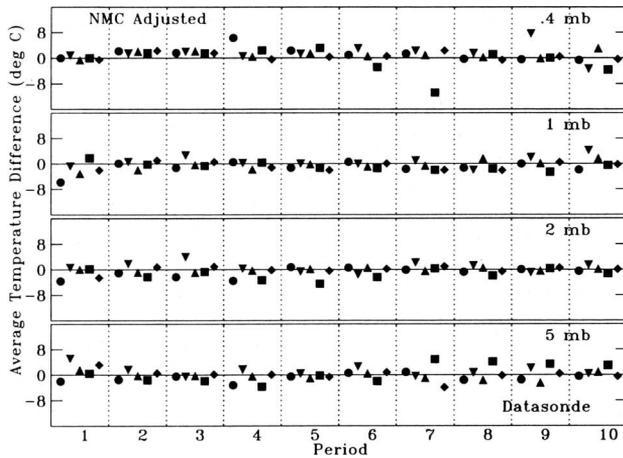


FIG. 7. Mean temperature differences (NMC adjusted analyses minus datasonde observations), at each period and pressure surface, for the five individual rocketsonde stations that used both datasondes and sphere systems (see Table 1).

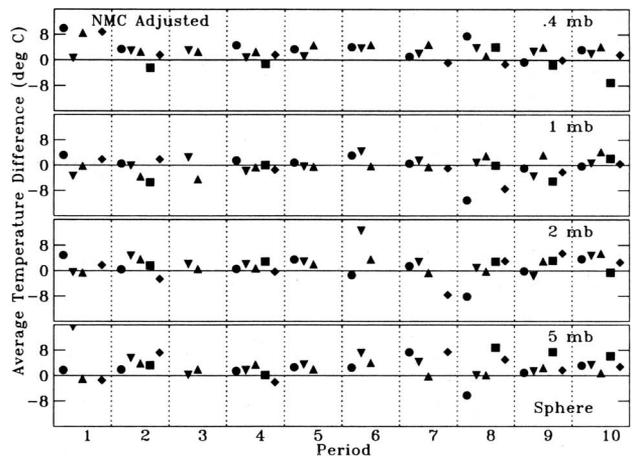


FIG. 8. Same as in Fig. 7 but for sphere observations. Note that in some periods there were no observations.

Overall biases between adjusted NMC analyses and OHP lidar temperature data for the entire record (NMC–OHP 78–91) are included in Fig. 10. NMC analyses are indicated to be lower (colder) by about 1°C at 5 mb and 1.5°C at 2 mb, and higher (warmer) by less than 1°C at 1 mb and about 4°C at 0.4 mb. These bias values can be compared with those given for the sphere (see Fig. 6). Note that the NMC analyses are higher (warmer) than sphere observations at

5, 2, and 0.4 mb. Relatively small bias at 1 mb is evident between all systems.

Operations of the lidar at CEL beginning in 1986 provided an additional dataset for periods 8–10 that should behave in a similar manner to OHP. Figure 10 shows that both NMC–CEL 86–91 and NMC–OHP 86–91 biases do vary with pressure in a similar manner, but are offset by 1° to 2°C degrees. This apparent bias between OHP and CEL needs further clarification.

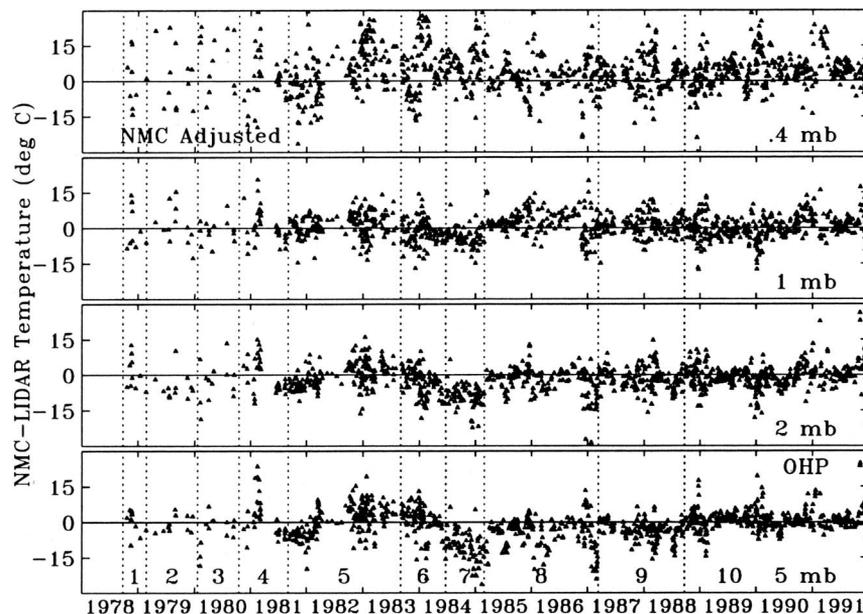


FIG. 9. Differences between (adjusted) NMC analysis temperatures and OHP lidar data for 0.4, 1, 2, and 5 mb.

Figure 11 extends the comparison of the NMC adjusted analysis temperatures with those observed by lidar at both OHP and CEL by showing computed period-by-period biases. Rather large standard error values shown for the first several periods are mainly reflections of the relatively sparse dataset obtained during initial operations at OHP. Signs of the period-to-period biases throughout most of the database are generally consistent with the sense of the overall biases previously shown in Fig. 10. This agreement is most evident at 2 mb, where the signs are predominantly minus, and at 0.4 mb, where the signs are predominantly plus.

Period-by-period biases between NMC adjusted analyses and both the OHP and CEL lidar datasets (shown in Fig. 11) range

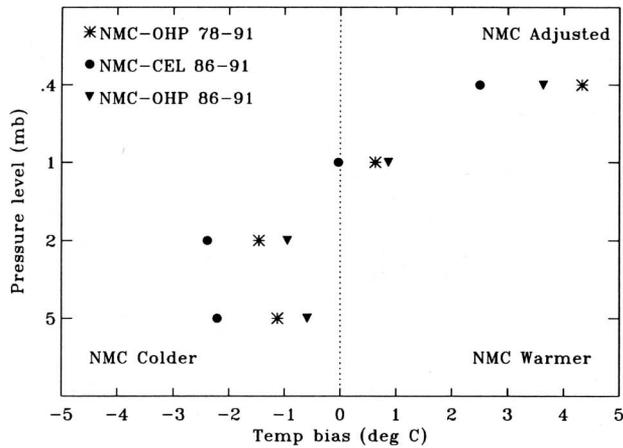


FIG. 10. Mean temperature differences for 0.4, 1, 2, and 5 mb between the NMC (adjusted) temperatures and the OHP lidar dataset [NMC-OHP 78–91]; between the NMC analyses and the limited OHP dataset [NMC-OHP 86–91]; and between the NMC analysis and the CEL dataset [NMC–CEL 86–91].

within 5°C, except for a few larger values at 0.4 mb and especially the values shown for period 7. In hope of explaining this anomaly, we further investigated the 5-mb temperature database for 1983, 1984, and 1985 (years including and surrounding periods 6 and 7). The OHP lidar dataset revealed a sudden temperature increase (warming) of 5° to 10°C, not related to a period boundary and developing within a time span of a few days in late May 1984. Differences between the lidar temperatures and NMC analyses indicate that this was not a transient change, as the lidar values remained at higher levels with respect to the analyses until late winter 1985, nearly one year later. Results of a recent study by Hauchecorne et al. (1991) using OHP lidar data for upper-atmosphere climatological purposes, indicated a significant anomaly at 5 and 2 mb over southern France during this time period. The reality of this climatological change is suspect, as the lidar changes are not supported by similar changes in the NMC adjusted analyses. In addition, reported lidar values during this time frame are considerably higher than are indicated during any other summer in the full database. Keckhut et al. (1992) discussed systematic differences of several degrees between OHP and CEL temperatures observed during the summers of 1987 and 1988, which they acknowledge could stem from lidar alignment problems. Similar problems may also have played a role in the 1984–1985 time periods.

An important feature of Fig. 11 is the general reduction of bias values between NMC adjusted analyses and OHP lidar datasets during the last three periods, and especially during period 10. This period encompasses the time frame from late 1988 through

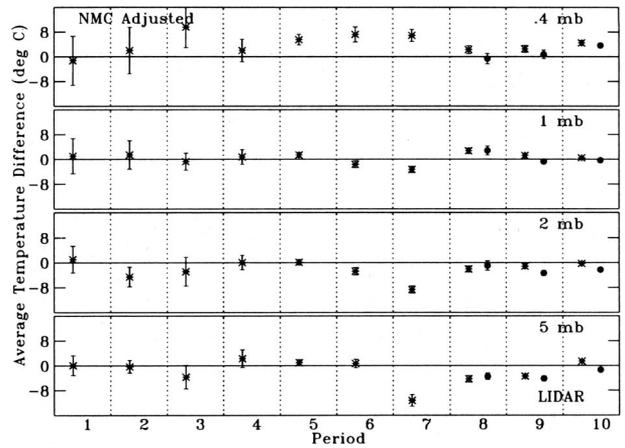


FIG. 11. Average period temperature differences (NMC minus lidar) between NMC analyses (adjusted) and lidar observation values for OHP (asterisk) and CEL (filled circle), for 0.4, 1, 2, and 5 mb. Vertical bars represent values of two standard errors about the means. Larger error bars for OHP in early years are mainly the result of small numbers of observations.

1991, for which the biases between NMC analyses and OHP lidar at 5, 2, 1, and 0.4 mb are, respectively, 1.7°, -1.2°, -1.0°, and 2.5°C. Such significant improvement in compatibility with time increases the prospect of using the two datasets together. Differences between the analyses and CEL lidar during this same period 10 are also less than 3°C, but the small average temperature differences between the two lidar datasets mentioned previously (see Fig. 10) can still be detected.

Our evaluations of the agreement between the NMC adjusted analyses and the OHP and CEL lidar data have had positive results for the last three periods and particularly for period 10. Although we emphasize that absolute truth is still unknown, the evaluation indicates that datasonde and lidar observations subsequent to period 7 may be used together for NMC analysis adjustment purposes with a degree of confidence. Problems associated with the period 7 anomaly and some additional concerns regarding the lidar database during earlier periods suggest that caution is needed in the use of the datasets together previous to period 8.

## 6. Adjustments derived from lidar data

In contrast to the sparsity of sphere observations, relatively abundant lidar temperature data allow independent computations of NMC analysis adjustments in a similar manner to that used for datasondes. As a final test, we have derived period adjustments for both OHP and the abbreviated CEL datasets. These ad-

justments are shown in Fig. 12 along with those originally produced for the datasonde (from Table 2). We emphasize that this figure shows the sign and magnitude of independently computed adjustments, as distinct from the temperature differences between analyses that are dependent on datasonde observations, as were presented in previous figures.

An ideal result from comparing the various adjustments shown in Fig. 12 would be the complete agreement, period by period, between values derived from the three sources. It is obvious that there is no such unanimity. As would be expected from information already given, the period 7 anomaly is very prominent in Fig. 12. Several of the other less conspicuous biases shown in Fig. 11 may also be noted in Fig. 12.

Even in light of differences between adjustments derived from the three independent datasets, the consistency of signs is gratifying. All three measurement systems overwhelmingly indicate the satellite-derived temperature values to be too high (warm) at 0.4 and 5 mb (except for period 7) and too low (cold) at 1 and 2 mb. Most conspicuous is the compatibility between adjustment values computed for both datasonde and OHP lidar for period 10 (see Fig. 12). At 2 and 1 mb, for example, the adjustments computed for both systems are within 1°C of each other. The greatest adjustment difference is about 2.5°C at 0.4 mb. Adjustments computed for CEL also match those of the datasonde within 3°C.

Results of the comparisons between NMC analysis temperatures and those temperatures from lidar observations support the conclusion that lidar datasets can be employed along with those from datasondes to enhance the database used for analysis adjustment derivations. This conclusion is founded primarily on

the close agreement between the datasonde and lidar temperature values for the past several years, and especially since 1988.

## 7. Conclusions

NMC analyses provide upper-stratospheric temperature data needed to verify important atmospheric variations. Unaccounted-for biases can seriously limit the temporal precision of the analyses and thus degrade their monitoring usefulness. The NMC analysis adjustment system, presently based on ground-truth datasonde observations, has been developed to minimize these biases. We have discussed the present status and future prospects of this system, and the following conclusions have been reached.

1) The datasonde rocket system has provided a ground-truth dataset for the NMC analysis adjustment system, with an uncertainty of 2° to 3°C. This uncertainty will allow determination of temperature trends with suitable confidence over a time period of several decades. However, continued use of the datasonde for ground-truth purposes cannot be maintained because of cutbacks in the rocket program.

2) Falling-sphere observations are not sufficient in number to be used independently for the NMC analysis adjustments. In addition, use of both spheres and datasondes would be complicated by the larger variability of the sphere data and by the biases of about 3°C between the two at 0.4, 2, and 5 mb. In contrast, there is a surprising degree of compatibility (near-zero bias) between the two rocketsonde systems at the 1-mb level. Even so, the large variability problem of sphere-derived temperature values remains.

3) Lidar systems operating in France have produced databases suitable for ground-truth use. Sparsity of lidar observations at the beginning of the period of data availability, as well as the effects of a few substantial data inconsistencies (especially 1984 and 1985), requires special care in the use of the entire OHP database for ground truth. However, continued development of the system and procedures since 1988 have resulted in database improvements, as indicated by our various comparisons of lidar data with datasonde observations. These present results support the use of the two datasets together, with a good level of confidence. Results for CEL lidar during the same time period were also good.

4) Global NMC analyses, derived from operational satellite information, must continue to be compared with datasets capable of supplying ground truth. Furthermore, derived adjustments must be applied to the NMC upper-stratosphere analyses to ensure long-term consistency. To this end, it is strongly recom-

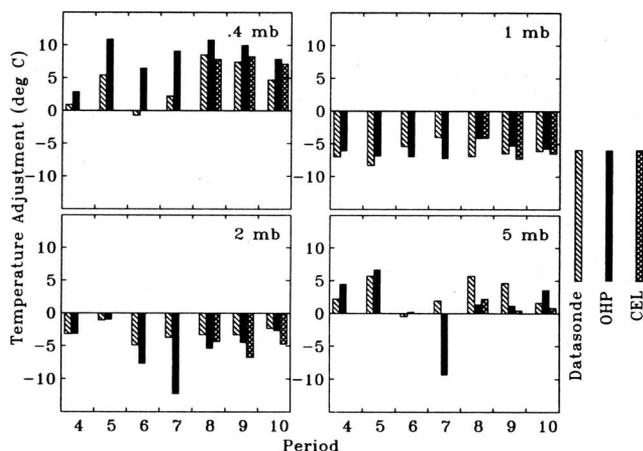
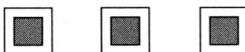


FIG. 12. Temperature adjustments for application to the NMC unadjusted analyses as computed for each period from the datasonde and from the independent OHP and CEL lidar datasets. The CEL computations are restricted to periods 8, 9, and 10.

mended that the Network for the Detection of Stratospheric Change be expedited, so that the adjustment system includes data from lidar stations in various latitude regions.

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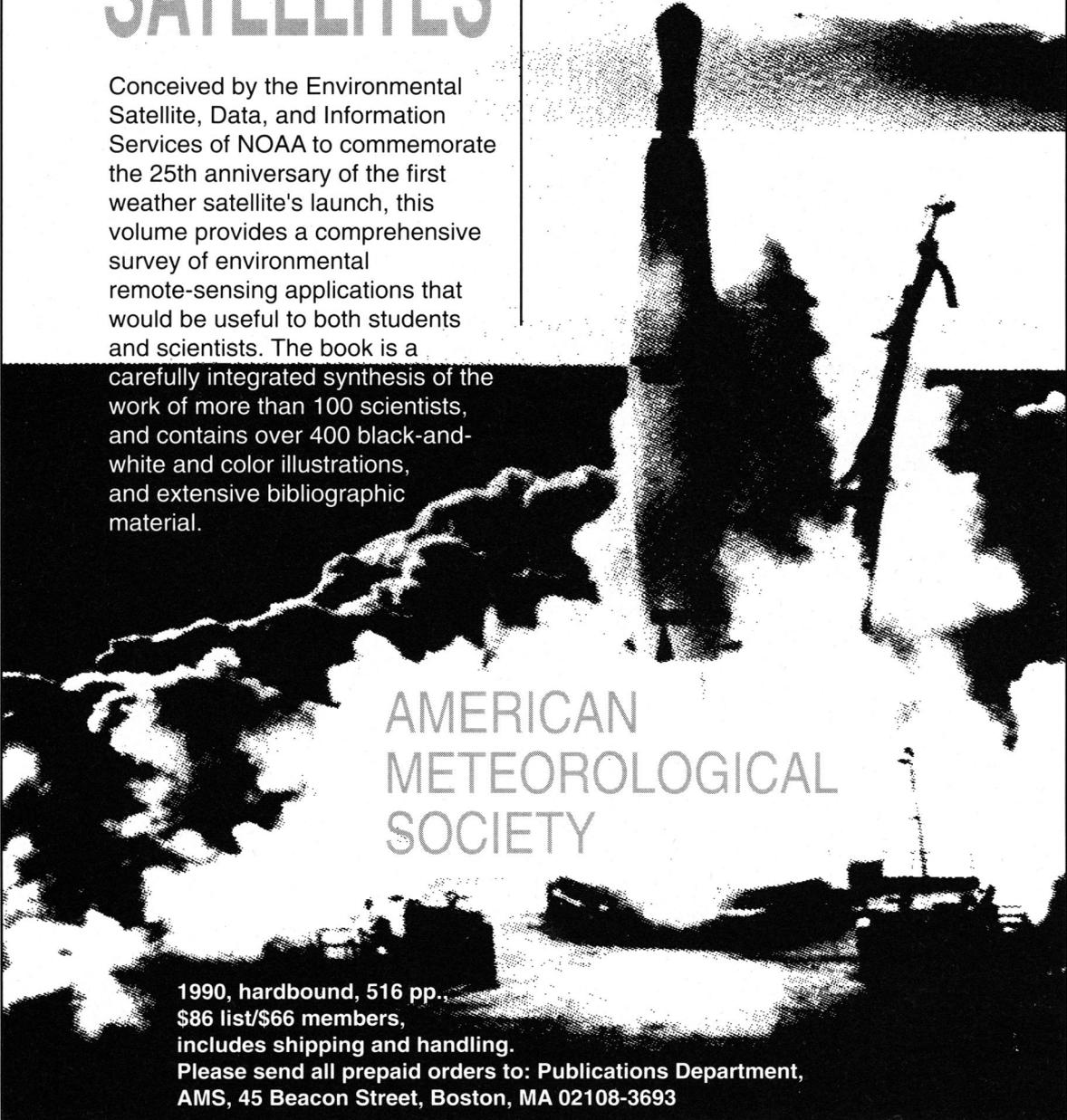
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