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Calibration of Long Term Satellite Ozone Data Sets Using the Space Shuttle

N91-19524

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January, 1990

1. Introduction

Trends in atmospheric ozone continue to be an environmental concern. Drifts in satellite observations are the major obstacle in the detection of changes in global ozone over the long term. Careful re-analysis of satellite ozone data along with groundbased observations have more or less corroborated photochemical models which predict ozone depletion [1]. However there remains margin of error in the observations that is as large as the trend itself.

The National Plan for Stratospheric Monitoring [2] calls for monitoring global ozone for at least the next ten years employing the NOAA polar orbiting satellites. Ozone observations will be made with the Solar Backscatter Ultraviolet Spectral Radiometer Mod 2 (SBUV/2) which is a refinement of the SBUV instrument flying on NASA's Nimbus-7 satellite [3]. The first instrument in the operational series began taking data from the NOAA-9 spacecraft in February 1985. A second instrument was launched on NOAA-11 in September 1988. Both continue to operate.

Earlier attempts to calibrate satellite data relied on comparisons with ground based observations. However, differences in instrumental techniques severely complicated these efforts. This problem will be over come by regular flights, about once per year, of the Shuttle Solar Backscatter Ultraviolet radiometer (SSBUV). The data from the SSBUV instrument will be compared with nearly coincident data taken by the NOAA satellite instruments. This procedure will permit a direct calibration transfer in space [4] since the two instruments observe the same quantities thereby bypassing the inversion algorithm which converts the observations to ozone amounts.

2. Flight Instrumentation

The SSBUV payload consists of a SBUV/2 instrument that has been modified for Shuttle flight [4]. The payload is packaged into two Getaway Special canisters as shown in figure 1. One canister contains the instrument, and supporting optical systems. The second canister contains batteries and the data recording system. This stand-alone capability allows easy access to the Shuttle which affords some assurance of regular flights. The SSBUV Instrument is the engineering model to the series of SBUV/2 instruments now flying the NOAA satellites. The Nimbus and NOAA instruments employ a reflective diffuser to bring sunlight into the monochromator as the spacecraft traveled over the pole. For the solar irradiance measurement, the SSBUV employs a transmission diffuser, consisting of two ground crystalline quartz plates, which is deployed in front of the instrument entrance aperture. Therefore the solar irradiance measurement is made normal to the diffuser. SSBUV also contains a unique inflight calibration system which tracks instrument radiometric sensitivity and wavelength stability during flight.

3. Instrument Calibration

Maintaining accurate and precise instrument calibrations over the long term is a major objective of the SSBUV program. Procedures have been developed to maintain calibrations with a precision of 1 percent over the long term [4]. This precision is essential in deriving a long term ozone data set. Calibration accuracy relies on the accuracy of the radiometric standards provided by the National Institutes of Standards and Technology (NIST). The accuracy of the radiometric standards will be tracked by a laboratory reference standard spectrometer with radiometric characteristics similar to the flight instrument. A laboratory comparison program involving several other satellite and Shuttle solar irradiance experiments is now underway. This comparison program is being coordinated by NIST. Figure 2 depicts the overall elements of the SSBUV calibration program.

To date the calibration efforts have demonstrated excellent results [5,6]. Calibration repeatability tests indicate that irradiance and radiance calibration constants can be maintained to the order of 0.5 percent (1 sigma). Several other important instrument characteristics such as, linearity and gain wavelength dependence have been measured to a precision of a few tenths of a percent. These results were acquired through a series of laboratory calibrations and environmental testing. This suggests that, with careful attention to all phases of the calibration process, that a 1 percent long-term radiometric calibration precision for SSBUV is a realistic goal.

4. Overall Mission Requirements

The goal of the SSBUV is to remove the uncertainty in the SBUV/2 data set from the NOAA satellite series to value less than the expected ozone trend. The statistical uncertainty (at the 2 sigma level) remaining in the corrected data is the factor which ultimately limits the ability to detect long term ozone changes. Variables determining this uncertainty include: a) the magnitude of the ozone trend, b) the duration of the ozone monitoring period, c) the frequency of SSBUV flights, d) the number of coincident measurements between SSBUV and SBUV/2 for a given shuttle mission, e) atmospheric variability, f) instrument and measurement precision, and g) long term SSBUV calibration precision. Maintaining instrument calibration to within 1 percent is the most critical factor in performing the in orbit long term calibration [7].

Each one of these variables have been treated objectively [4] and can be combined to compute the Shuttle flight frequency needed to correct the satellite data set for a given ozone monitoring period. The results of this computation is given in figure 3. The curves correspond to heights where SSBUV observes ozone which are a function of wavelength. The dashed line helps to illustrate; for example, if the SSBUV flies every 8 months, a monitoring period of 8 years is required to correct the SBUV/2 data set at 40 km to the necessary precision. At 47 km, where the ozone trend is less, 10 years of observations are required at the 8 month flight schedule.

5. Calibration of the Satellite Data Set

Procedures for combining the SSBUV an SBUV/2 data sets are under development. Existing ozone satellite data has been used as model data sets to test these procedures [8]. The average factor, C(i,j), for correcting the SBUV/2 data set can be calculated from SSBUV and SBUV/2 coincident observations of the atmospheric albedo, A(i,j,k) where i=wavelength, j=the SSBUV flight number, and k=number of coincidences per flight.

$$C(i, j) = (1/N) \sum_{k=1}^{N} [A_s(i, j, k)/A_2(i, j, k)] \qquad (1)$$

Where $A_s(i,j,k)$ and $A_2(i,j,k)$ are the coincident observations from SSBUV and SBUV/2 respectively. One flight of the SSBUV produces one value of C(i,j) at each wavelength, i. Interpolation in time between the derived C(i,j) yields correction factors for all times during the SBUV/2 program.

6. SSBUV First Flight

The first flight of SSBUV occurred on October 19, 1989 on the Shuttle Atlantis. During that period coincident observations were taken with the SBUV on Nimbus-7 and the SBUV/2's on NOAA-9 and NOAA-11. Thirty one orbits of earth observations were obtained resulting in over 30 matchups with each of the satellite observations where a one hour window was the matchup criteria. Solar observations and in flight calibration checks were conducted at the beginning, near the middle, and at the end of the observing period. Figure 4 illustrates the one hour window matchup locations for the three satellites during the SSBUV observing period.

An initial and preliminary comparison has been performed between the solar irradiances observed by the SSBUV and the day 1 solar irradiance (March, 1985) observed by the NOAA-9 SBUV/2. For the ozone observing channels agreement was about +/- 2%.

7. Summary

Detecting an ozone trend is a formidable task since our observing systems drift at a rate that is comparable to the trend itself. Satellite observations must be carefully checked to accurately reveal an ozone trend. A program is now underway in which an instrument similar to the ozone sounders on the NOAA operational satellites is flown regularly on the Space Shuttle to perform in orbit calibration checks by comparing observables. It is essential that the calibration of the Shuttle instrument be known to 1% over the long term. Tests to date demonstrate that this is an achievable goal.

8. References

[1] Watson, R. T., M. J. Prather, and M. J. Kurylo, Present State of Knowledge of the Upper Atmosphere, 1988: An Assessment Report, NASA Reference Publication 1208, 1988

[2] National Plan for Stratospheric Monitoring and Early Detection of Change, 1988-1997, U. S. Dept of Commerce/NOAA, FCM-P17-1989, July, 1989.

[3] Heath, D. F., A. J. Krueger, H. R. Roeder, B. D. Henderson, The Solar Backscatter Ultraviolet and Total Ozone Mapping Spectrometer (SBUV/TOMS) for Nimbus G, Optical Engineering, Vol. 14, pp. 323-331, 1975.

[4] Hilsenrath, E., D. Williams, and J. Frederick, Calibration of Long Term Data Sets from Operational Satellites Using the Space Shuttle, SPIE Proc., 924, 215-222, 1988.

[5] Cebula, R. P., E. Hilsenrath, B. Guenther, Calibration of the Shuttle Borne Solar Backscatter Ultraviolet Spectrometer, SPIE Proc., 1109, 205-218, 1989

[6] Cebula, R. P., E. Hilsenrath, Prelaunch Calibration of the Shuttle Solar Backscatter Ultraviolet (SSBUV) Spectrometer for STS-34, Proceedings of OSA, Feb, 1990.

[7] Frederick, J. E., X. Niu, E. Hilsenrath, The Detection and Interpretation of Long-Term Changes in Ozone from Space, Adv. Space Res., 9 (7) 317- (7) 321, 1989.

[8] Frederick, J.E., X. Nir, E. Hilsenrath, An Approach to the Detection of Long Term Trends in Stratospheric Ozone from Space, submitted to Journ. Oceanic and Atmos. Tech.

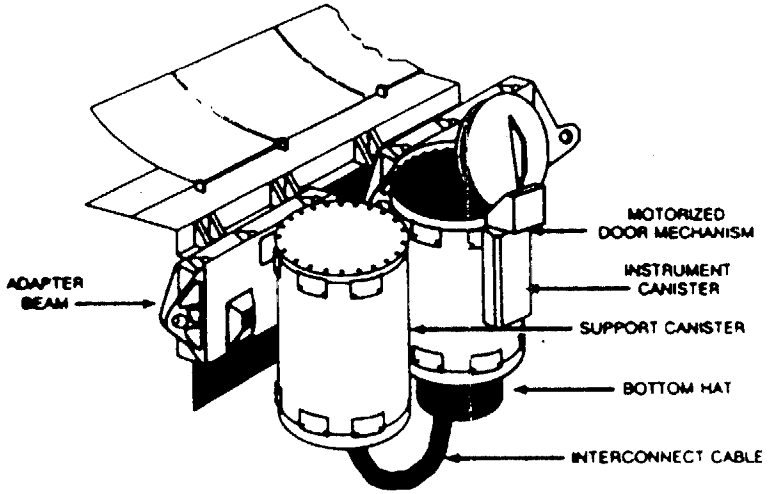


Figure 1. SSBUV Flight Configuration

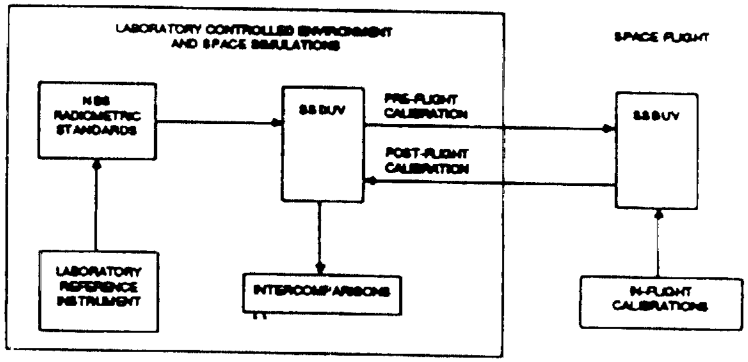


Figure 2. SSBUV Calibration Program

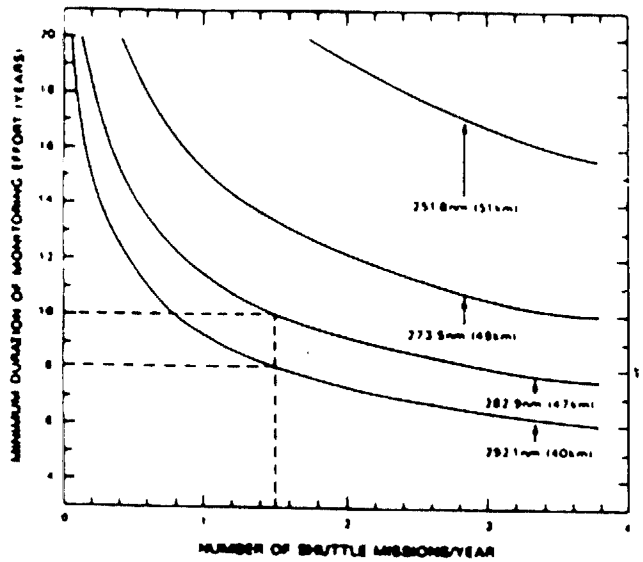


Figure 3. SSBUV Flight Requirements

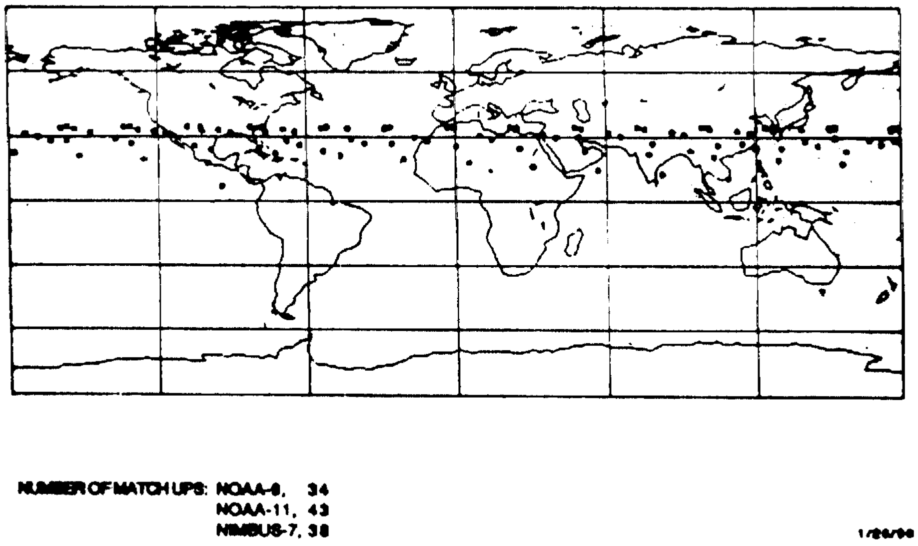
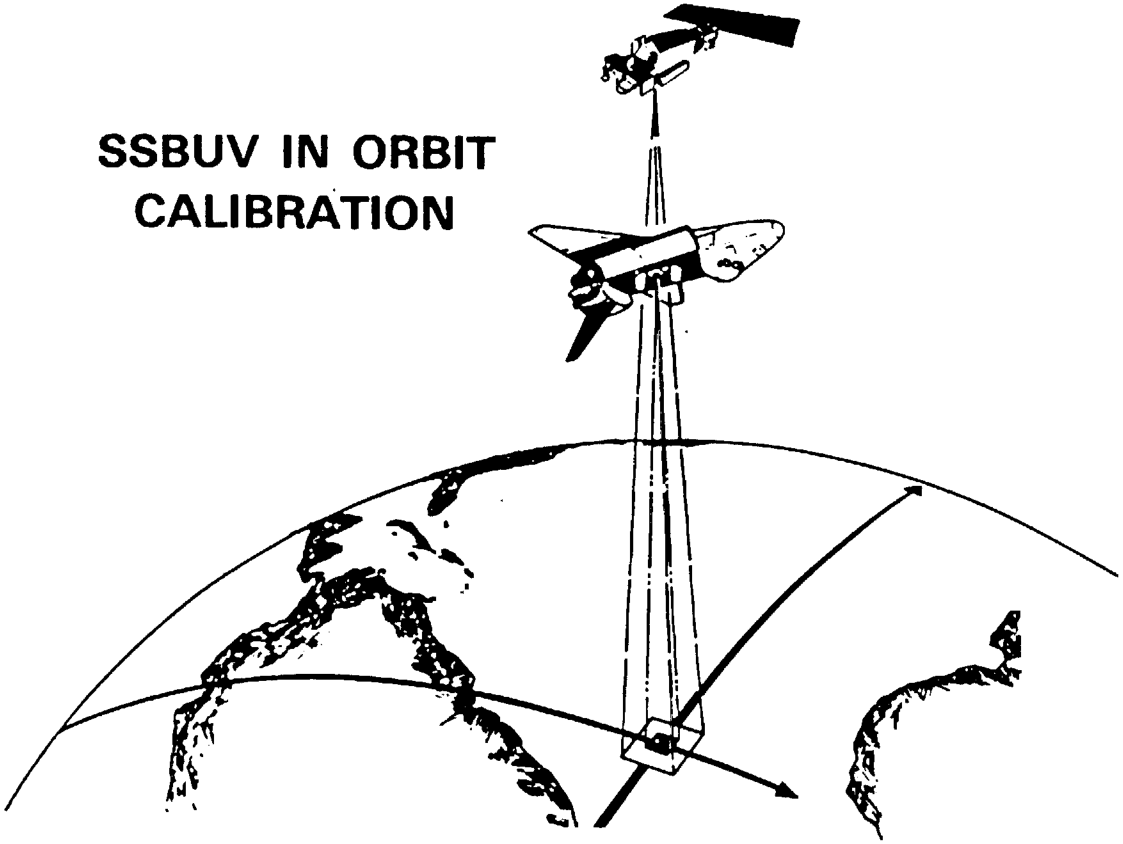


Figure 4. Orbit Intersections for STS-34

SHUTTLE SOLAR BACKSCATTER ULTRAVIOLET (SSBUV)

NOAA-9 SBUV/2 SUMMARY MEETING
JANUARY 28, 1990



SSBUV IN ORBIT
CALIBRATION

SHUTTLE SOLAR BACKSCATTER ULTRAVIOLET SPECTROMETER
(SSBUV)

SHUTTLE ATTACHED, SELF-CONTAINED PAYLOAD TO MEASURE TOTAL AMOUNT AND HEIGHT DISTRIBUTION OF OZONE IN UPPER ATMOSPHERE

PROVIDE HIGHLY ACCURATE AND RELIABLE OZONE MEASUREMENTS TO AID CALIBRATION OF OPERATIONAL OZONE INSTRUMENTS ON NOAA SATELLITES

PERIODIC SAMPLING, LONG-TERM DATA SET FOR TREND ANALYSIS

COMPARE OBSERVABLES, BYPASSING ALGORITHM

UNIQUE CHARACTERISTIC: CALIBRATION CONCEPT - PRE & POST LAUNCH AND ON-ORBIT

FLIGHTS: AT LEAST ONCE PER YEAR, THROUGH 1990'S
FIRST FLIGHT IN OCTOBER 1989

PRINCIPAL INVESTIGATOR: E. HILSENRATH
NASA/GODDARD SPACE FLIGHT CENTER

CO-INVESTIGATORS: NASA AND NOAA

EXPERIMENT MANAGER: D. E. WILLIAMS
NASA/GODDARD SPACE FLIGHT CENTER

1/25/90

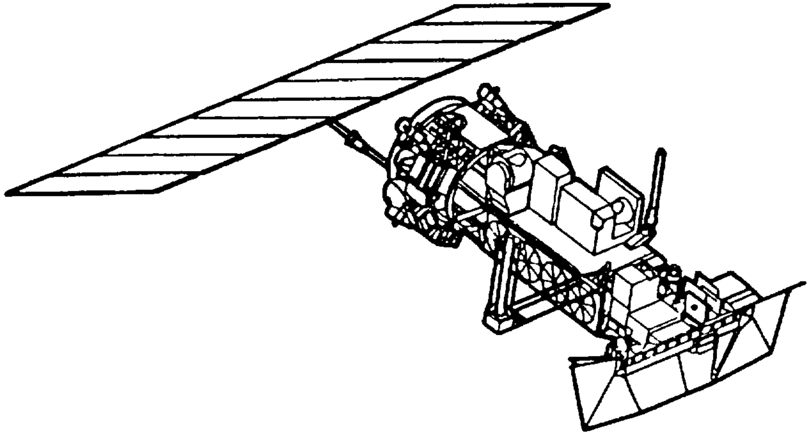
U.S. DEPARTMENT OF COMMERCE / National Oceanic and Atmospheric Administration

OFCM

OFFICE OF THE FEDERAL COORDINATOR FOR
METEOROLOGICAL SERVICES AND SUPPORTING RESEARCH

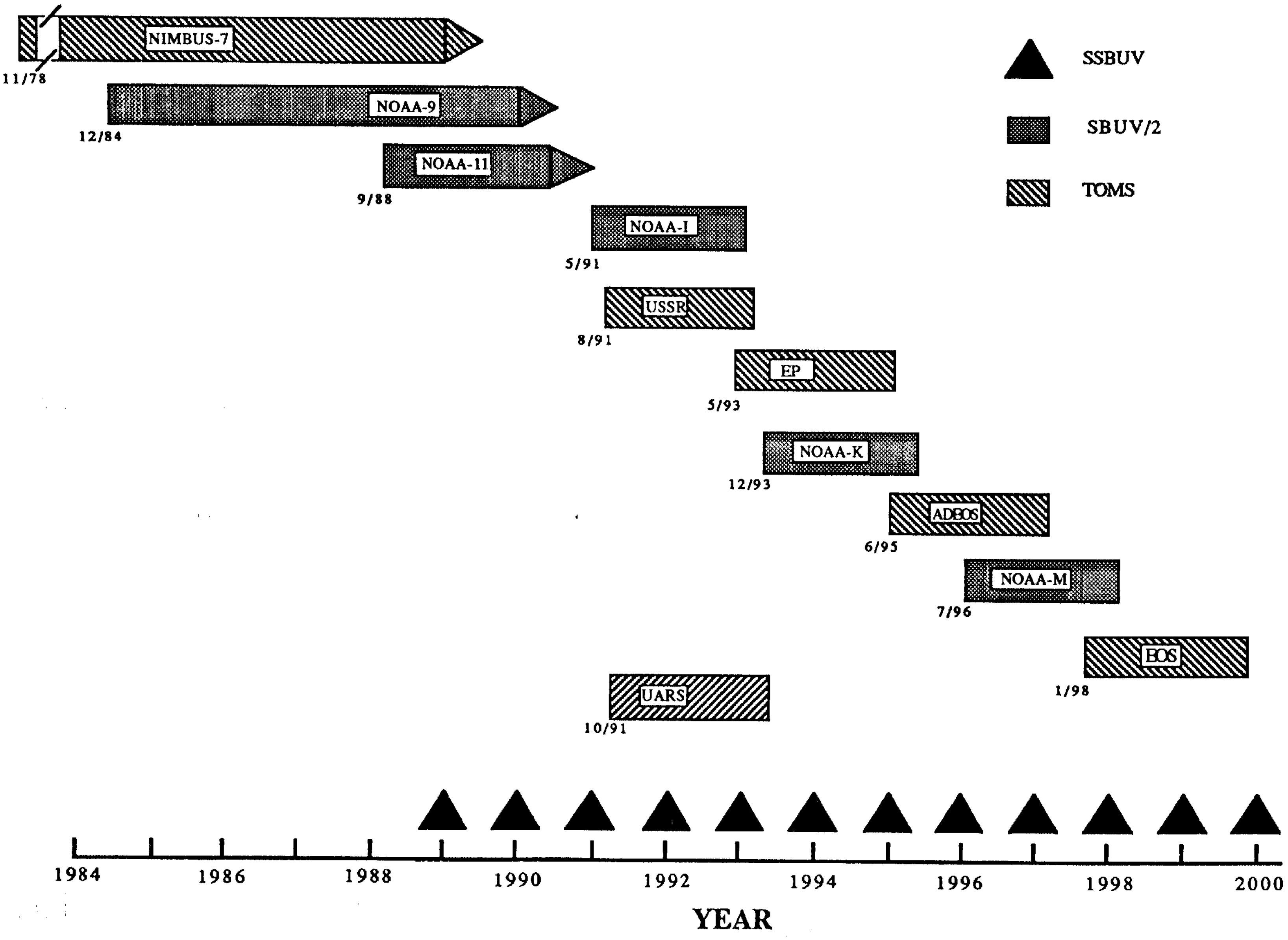
National Plan for Stratospheric Monitoring, 1988 - 1997

FCM-P17-1989



Washington, D.C.
July 1989

NATIONAL PLAN FOR OZONE MONITORING



APPLICATION OF SSBUV DATA TO SATELLITE OBSERVATIONS

PROBLEM

THE STATISTICAL UNCERTAINTY REMAINING IN THE TREND DERIVED FROM A CORRECTED DATA SET IS THE FACTOR WHICH ULTIMATELY LIMITS OUR ABILITY TO DETECT A TREND.

REQUIREMENT

ACHIEVE AN UNCERTAINTY IN THE SATELLITE DATA DRIFT THAT IS SMALLER, AT THE 2 SIGMA LEVEL, THAN THE PREDICTED OZONE (ALBEDO) TREND

VARIABLES

MAGNITUDE OF OZONE TREND

ATMOSPHERIC "NOISE"

MEASUREMENT PRECISION

REPEATABILITY (CONSTANCY) OF CALIBRATION

NUMBER OF COINCIDENCES PER MISSION

FREQUENCY OF SHUTTLE MISSIONS

DURATION OF MONITORING PERIOD

CALIBRATION - 1% (1 SIGMA) LONG TERM REPEATABILITY REQUIRED

RADIOMETRIC STANDARDS AND CALIBRATIONS ARE PROVIDED BY THE NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY (FORMALLY NBS)

LINEARITY - PRINCIPAL OF SUPERPOSITION

WAVELENGTH AND BANDPASS - 3 LINE SOURCES

IRRADIANCE - QUARTZ HALOGEN (FEL) AND DEUTERIUM LAMPS

RADIANCE - ABOVE LAMPS AND $BaSO_4$ DIFFUSER PLATES

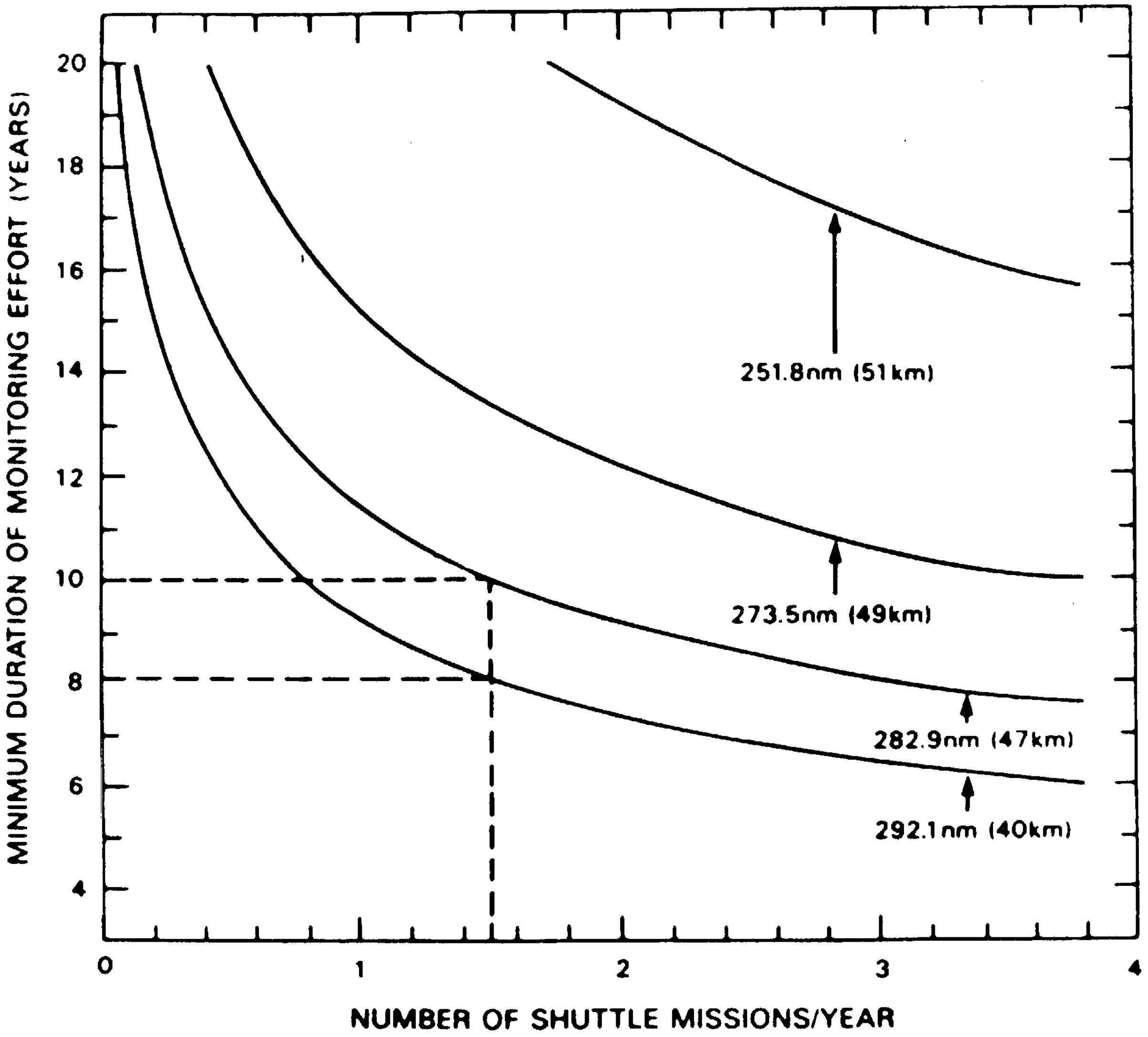
DATES:

OCTOBER 1988, FEBRUARY 1989, APRIL 1989

RESULTS (1 SIGMA):

LINEARITY	- 1% OVER ENTIRE DYNAMIC RANGE AND CHARACTERIZED TO 0.1%
WAVELENGTH	- ABSOLUTE ACCURACY, 0.014NM PRECISION, 0.013NM
IRRADIANCE	- ESTIMATED ABSOLUTE ACCURACY, 2-3% PRECISION, 0.2% REPEATABILITY, 0.3%
RADIANCE	- ESTIMATED ABSOLUTE ACCURACY, 3-5% PRECISION, 0.1% REPEATABILITY, 0.2%
ALBEDO	- < 0.3%

SSBUV MISSION FREQUENCY REQUIREMENTS



EXAMPLE

REQUIRES A MONITORING PERIOD OF:

8 YEARS FOR THE TREND AT 40km
10 YEARS FOR THE TREND AT 47km

Correction factor which normalizes the SBUV/2 albedos to the SSBUV albedos.

$$C(\lambda, j) = \frac{1}{N} \sum_{k=1}^{N} \frac{A_2(\lambda, j, k)}{A_s(\lambda, j, k)}$$

λ = wavelength
j = shuttle mission
k = number of coincidences

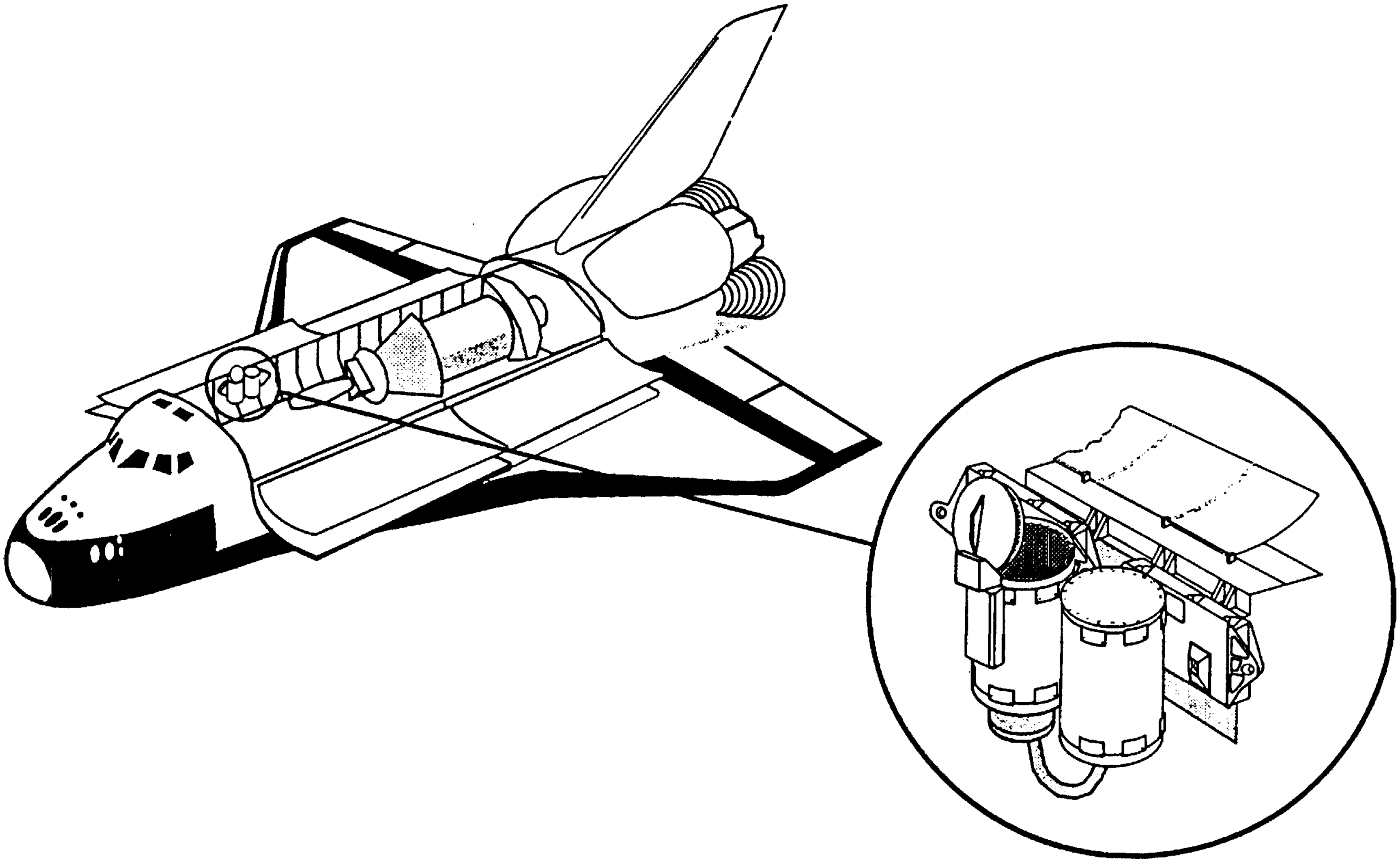
Correcting actual SBUV data with a given trend with simulated SSBUV data results in a long term data set that is less than (±2 sigma) the expected trend due to anthropogenic by-products.

Paper submitted JOAT, Frederick and Hilsenrath

SSBUV SHUTTLE MANIFEST - JUNE 1989

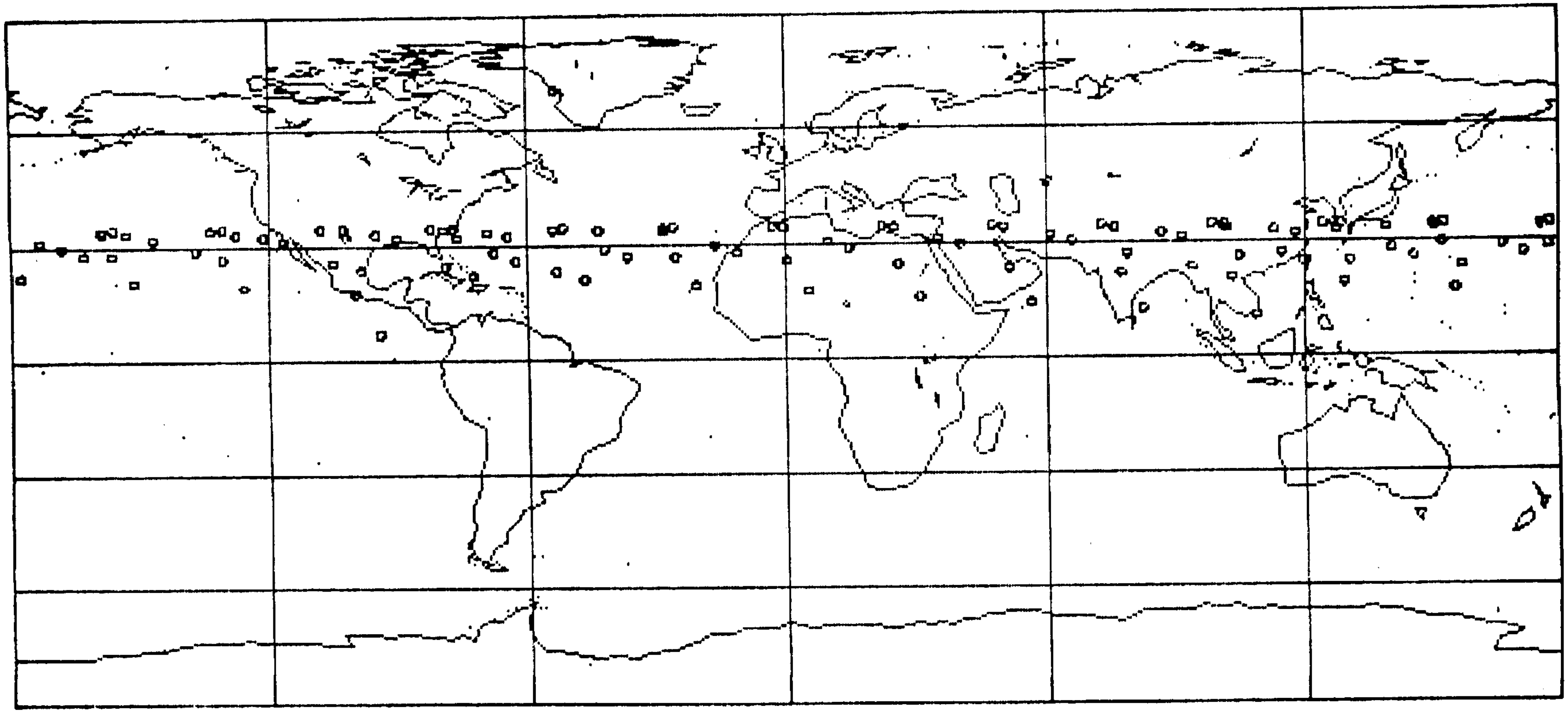
	STS #	DATE	PAYLOAD
SSBUV-1	34	10/89	GALILEO
SSBUV-2	37	11/90	GRO
SSBUV-3	43	1/91	TDRSS-E
SSBUV-4	51	1/92	SPACEHAB
SSBUV-5	57	7/92	ATLAS-2
SSBUV-6	62	12/92	TDRSS-F
SSBUV-7	70	5/93	ATLAS-3
SSBUV-8	81	4/94	ATLAS-4
SSBUV-9	87	10/94	TDRSS-H
SSBUV-10	99	9/95	ATLAS-5

STS-34 GALILEO/SSBUV



G66.001

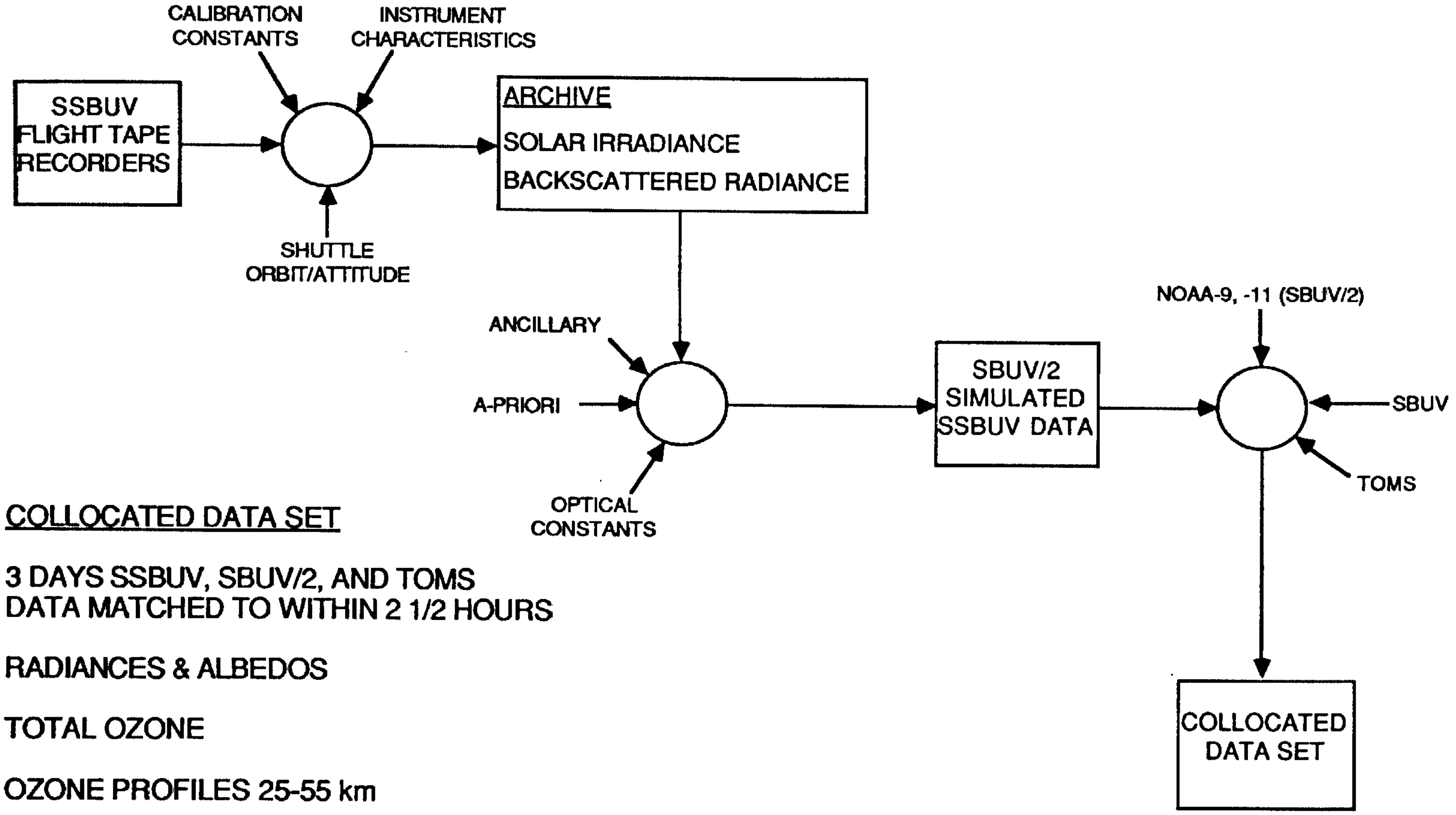
ORBIT INTERSECTIONS FOR PROBLEM SET STS-34
SYSTEM: SBUV/2



NUMBER OF MATCH UPS: NOAA-9, 34
NOAA-11, 43
NIMBUS-7, 38

1/26/90

SSBUV DATA PROCESSING



SSBUV FLIGHT TAPE RECORDERS

CALIBRATION CONSTANTS

INSTRUMENT CHARACTERISTICS

SHUTTLE ORBIT/ATTITUDE

ARCHIVE

SOLAR IRRADIANCE

BACKSCATTERED RADIANCE

ANCILLARY

A-PRIORI

OPTICAL CONSTANTS

SBUV/2 SIMULATED SSBUV DATA

NOAA-9, -11 (SBUV/2)

SBUV

TOMS

COLLOCATED DATA SET

COLLOCATED DATA SET

3 DAYS SSBUV, SBUV/2, AND TOMS
DATA MATCHED TO WITHIN 2 1/2 HOURS

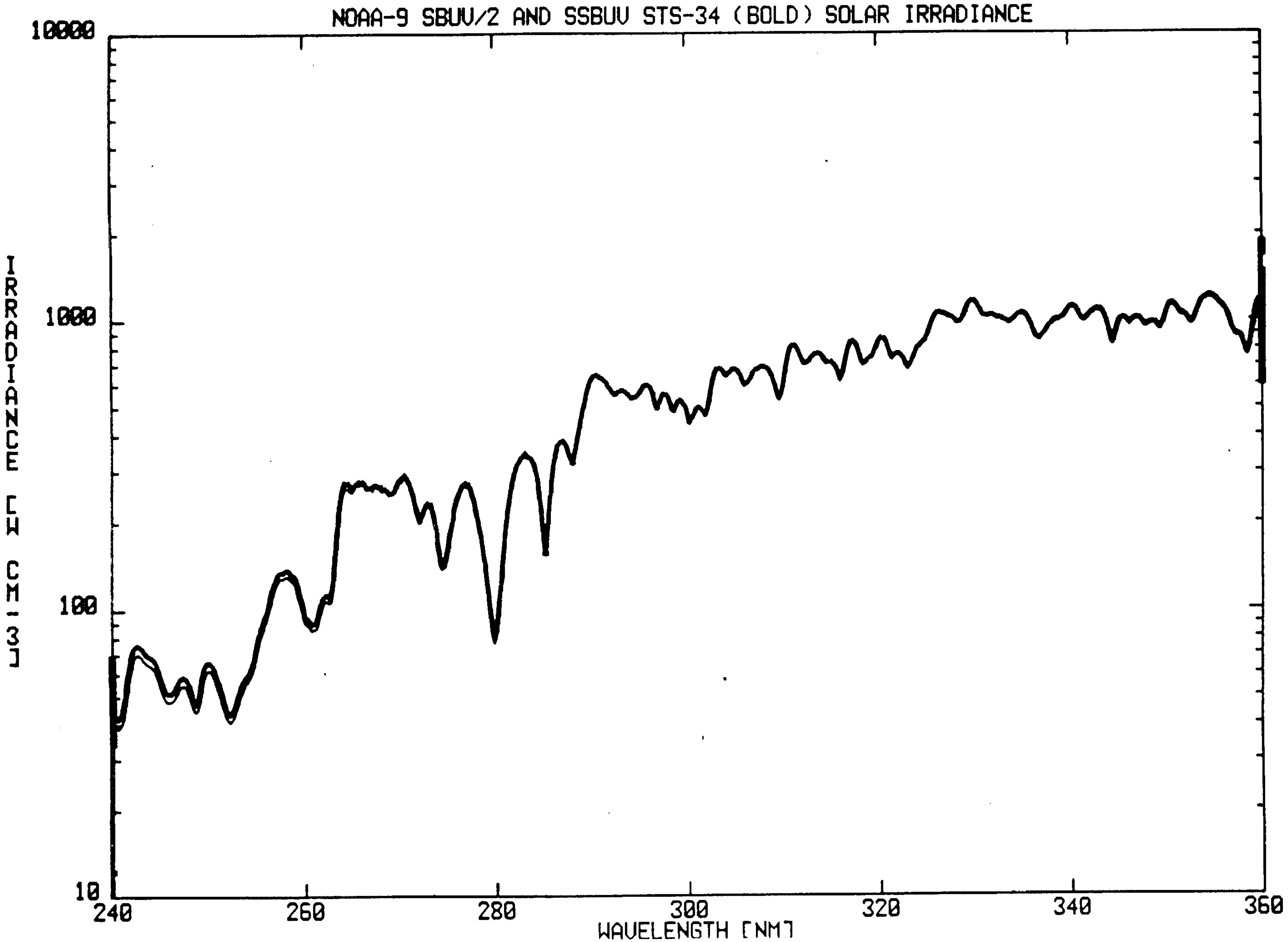
RADIANCES & ALBEDOS

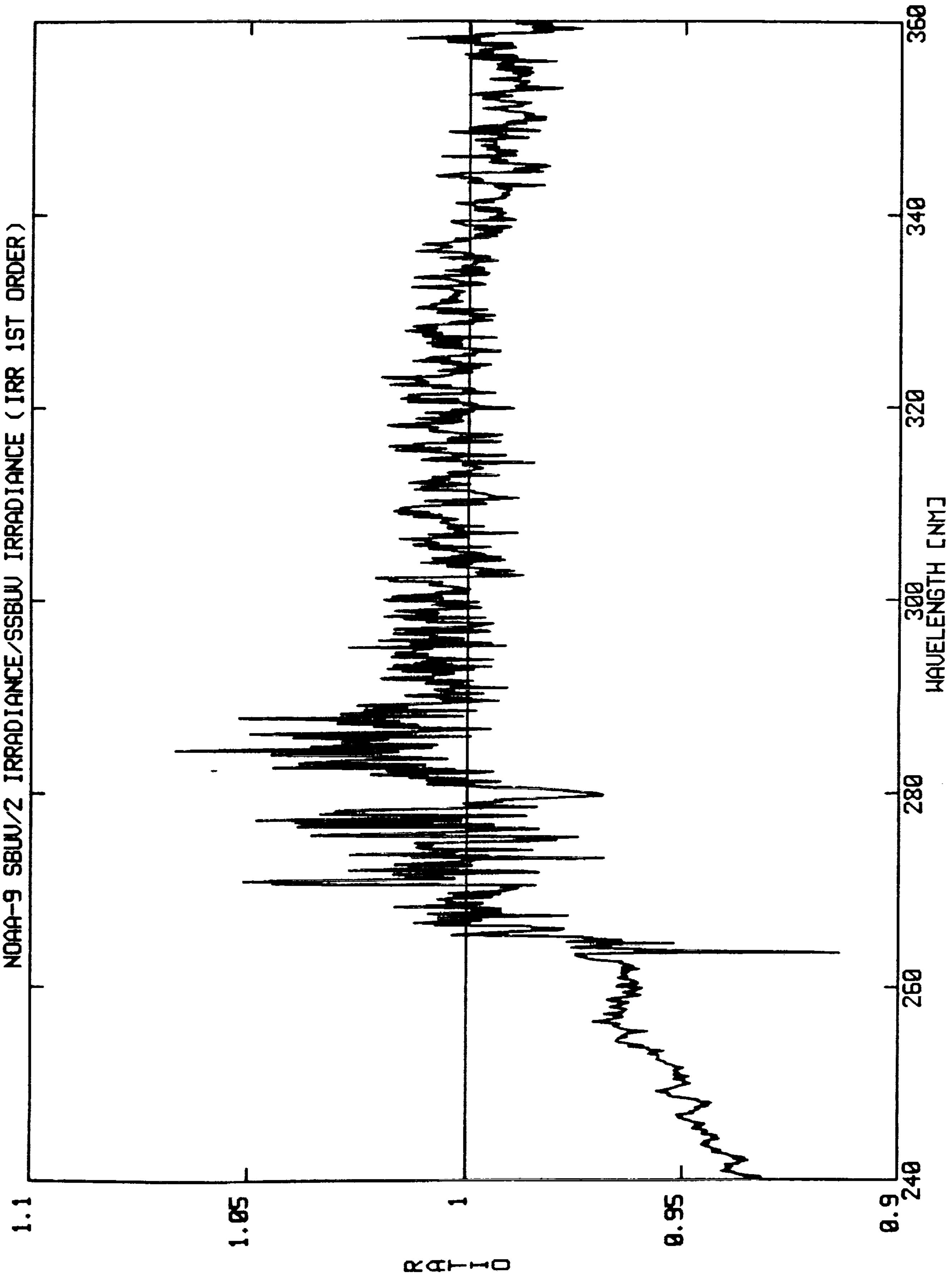
TOTAL OZONE

OZONE PROFILES 25-55 km

SOLAR IRRADIANCE, 180 - 400 nm, 1.1 nm RESOLUTION

1/25/90


NOAA-9 SBUV/2 AND SSBUV STS-34 (BOLD) SOLAR IRRADIANCE
IRRADIANCE [W CM-3]
10000
1000
100
10
240
260
280
300
320
340
360
WAVELENGTH [NM]


NOAA-9 SBUV/2 IRRADIANCE/SSBUV IRRADIANCE (IRR 1ST ORDER)
RATIO
1.1
1.05
1
0.95
0.9
240
260
280
300
320
340
360
WAVELENGTH [NM]

Attachment 11

Total Ozone Ozonesonde and Umkehr Observations for Satellite Ozone Data Validation

W.O. Komhyr, R.D. Grass, and G.L. Koenig
NOAA/ERL-CMDL
R.D. Evans, P. Franchois, and R.L. Leonard
University of Colorado, CIRES