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A data set, first described in AFGL-TR-81-0275, Johnson (1981), which contains nearly 500 arrays representing measurements of sky and terrain radiance values, is reviewed and further illustrated with respect to naturally occurring radiance variations. The measurements were made using radiometer systems mounted on a C-130 aircraft during a series of European flights associated with the NATO Program OPAQUE, Fenn (1978) and Johnson *et al.* (1979).

20. ABSTRACT continued:

Radiance measurements throughout the 4π field surrounding the aircraft during seventeen separate flight episodes are presented and discussed with respect to their variability as a function of altitude, look angle, cloud cover and spectral band. The measurements were made in spectral bands having mean wavelengths of 478, 557, 664 and 765 nm, and under meteorological conditions ranging from fully overcast to clear and cloudfree. With appropriate caveats, examples of "typical" overcast, broken cloud and clear day radiance distributions are illustrated.

Whereas these data illustrate substantial variations in the radiance distribution from day to day, there are determinable patterns that may provide boundary conditions for a very generalized attempt of classification. Thus, as were the data displayed in the earlier companion report, Johnson (1981), these data are appropriate for use in the development of operationally useful predictive models as illustrated in Hering (1981).

AFGL-TR-81-0317

SIO 82-6

AN ANALYSIS OF NATURAL VARIATIONS IN EUROPEAN SKY AND TERRAIN RADIANCE MEASUREMENTS

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SUMMARY

A data set, first described in AFGL-TR-81-0275, Johnson (1981), which contains nearly 500 arrays representing measurements of sky and terrain radiance values is reviewed and further illustrated with respect to naturally occurring radiance variations. The measurements were made using radiometer systems mounted on a C-130 aircraft during a series of European flights associated with the NATO Program OPAQUE, Fenn (1978) and Johnson *et al.* (1979).

Radiance measurements throughout the 4π field surrounding the aircraft during eighteen separate flight episodes are presented and discussed with respect to their variability as a function of altitude, look angle, cloud cover and spectral band. The measurements were made in spectral bands having mean wavelengths of 478, 557, 664 and 765 nm, and under meteorological conditions ranging from fully overcast to clear and cloudfree. With appropriate caveats, examples of "typical" overcast, broken cloud and clear day radiance distributions are illustrated.

Whereas these data illustrate substantial variations in the radiance distribution from day to day, there are determinable patterns that may provide boundary conditions for a very generalized attempt of classification. Thus, as were the data displayed in the earlier companion report, Johnson (1981), these data are appropriate for use in the development of operationally useful predictive models as illustrated in Hering (1981).

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AN ANALYSIS OF NATURAL VARIATIONS IN EUROPEAN SKY AND TERRAIN RADIANCE MEASUREMENTS

Richard W. Johnson
Wayne S. Hering

1. INTRODUCTION

With the continuing increase in the deployment of tactically oriented electro-optical systems, it is only prudent that we devise effective methodologies insuring their optimal effectiveness. Since atmospheric effects on the transmittance of visible and infrared radiation through the lower troposphere are often severe, and thus detrimental to EO performance, it behooves us to insure full understanding of these effects. As a necessary corollary to understanding, computationally fast and accurate modelling techniques are required to predict performance degredation in adverse weather conditions as an integral part of the deployment decision process. It is in support of this general context that the Visibility Laboratory in cooperation with, and under the sponsorship of the Air Force Geophysics Laboratory has maintained an extensive program of airborne optical and meteorological measurements. Many of these data, all of which were directed toward enhancing our understanding the fundamental elements of contrast transmittance through the troposphere, have been presented in several earlier technical reports, among them being Duntley *et al.* (1976), Johnson *et al.* (1979), Johnson and Gordon (1980), Johnson (1981a), and Johnson (1981b).

Whereas the most recent of the reports referenced above have concentrated upon the documentation and modelling of the vertical structure of the atmospheric volume scattering coefficient, it is important to note that there is a substantial and valuable complementary data set associated with each of these flight episodes that has not been made readily available to the user community. This complementary data set, introduced in Johnson (1981b), includes angularly precise spectral measurements of the 4π radiance field surrounding the aircraft at several different altitudes throughout the zero to six kilometer altitude regime. These radiance data enable one to characterize a broad variety of the environmental conditions extant during the flight episode and thus lead to the development of operationally useful predictive models. The radiance data, in conjunction with their companion scattering coefficient data, are readily applicable to the determination of slant path contrast transmittances, atmospheric optical depths, aerosol directional scattering characteristics, flux divergences and their attendant determinations of turbid atmosphere single scattering albedos.

The presentation of selected sets of these 4π radiance distributions representing eighteen separate data flights, a discussion of several pertinent characteristics of the data, and their application to the modelling task are the subjects of this report. The data flights from which the radiance data appearing in this report have been selected are listed in Table 1.1. The eighteen flights listed represent a cross section of the total forty-seven flight data base which was tabulated in Johnson (1981b).

Table 1.1. Summary of Selected Data Flights

Flight No.	Date	Site	Nominal Cloud Condition	Underlying Terrain	OPAQUE Deployment	Initial Report No.
379	17 MAY 76	RB	clear	ocean	I	AFGL-TR-77-0078
401	5 DEC 76	BR	scattered	farmland	II	AFGL-TR-77-0239
419	4 AUG 77	MP	scattered	farmland	III	AFGL-TR-78-0168
422	11 AUG 77	RB	overcast	ocean	III	"
434	18 FEB 78	SG	scattered	ocean	IV	AFGL-TR-79-0159
435	23 FEB 78	BK	overcast	snowy forest	IV	AFGL-TR-79-0159
437	27 FEB 78	BK	scattered	snowy forest	IV	"
439	1 MAR 78	BK	broken	snowy forest	IV	"
444	11 MAR 78	YO	overcast	farmland	IV	"
449	18 MAR 78	YO	broken	farmland	IV	"
450B	22 MAR 78	SO	overcast	farmland	IV	"
465	14 AUG 78	MP	overcast	farmland	V	AFGL-TR-80-0207
466	15 AUG 78	MP	scattered	farmland	V	"
468	21 AUG 78	MP	clear	farmland	V	"
469	22 AUG 78	SO	scattered	farmland	V	"
471	11 SEP 78	BK	overcast	pasture/forest	V	"
475	15 SEP 78	YO	overcast	farmland	V	"
476	16 SEP 78	YO	scattered	farmland	V	"

MP: Meppen, Germany
BK: Birkhof, Germany — RB: Rodby, Denmark — SO: Soesterberg, Netherlands
BR: Bruz, France — SG: Sigonella, Sicily — YO: Yeovilton, England

Note: Nominal cloud condition may not have existed throughout entire mission. See flight description sheets.

2. DATA COLLECTION SYSTEM

The airborne data acquisition system that was used to collect the measurements presented and discussed in this report has been described previously. Each of the data reports listed in Appendix C discusses the general characteristics of the specific optical-meteorological subsystems appropriate to that report's data. Similarly, the following paragraphs, which have been extracted from the preceding companion report AFGL-TR-81-0275, Johnson (1981b) will briefly review the pertinent characteristics of the Automatic 2π Scanner Assemblies, the primary instrument related to the data presented in this report.

An annotated illustration of the total instrument system as it appeared during a 1977 deployment to Lorient, France is shown in Fig. 2-1. Attention should be drawn to the Upper and Lower Hemisphere Scanner locations and the corresponding locations of their companion camera systems. A more detailed view of an Automatic Scanner Assembly, two of which are mounted on the aircraft, is shown in Fig. 2-2. In this view the instrument has been removed from the aircraft and is attached to its ground storage rack.

As discussed in several earlier reports, Duntley *et al.* (1975 & 1978) and Johnson (1981b), the Automatic Scanner assembly is essentially an electrically driven, servo-controlled telescope assembly associated with both an optical filter changer and a photomultiplier detector. The telescope has a circular, five degree field of view which is capable of scanning a full hemisphere under either manual or automatic control. In its automatic mode, the azimuth head (the smaller upper white cylinder in Fig. 2-2) rotates 180 degrees in either one, five or ten seconds as pre-selected by the operator. At the end of each azimuth revolution, the elevation head steps up five degrees in elevation from its initial horizontal start point. The full 2π steradian scan requires 18 revolutions and thus in the 10sec/rev mode, three minutes of elapsed time. In interpreting the resulting measured radiances, as illustrated in Sections 3 and 4, one should recognize that each plot represents measurements made throughout this three minute interval and therefore along a horizontal flight track approximately 15 km in length. This time and distance effect is particularly important in the assessment of the radiance distributions associated with variable cloud and/or patchy terrain conditions.

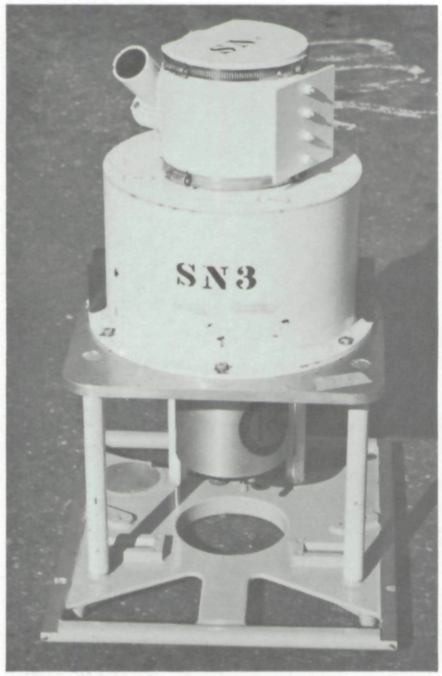


Fig. 2-2. Automatic 2π Scanner Assembly.

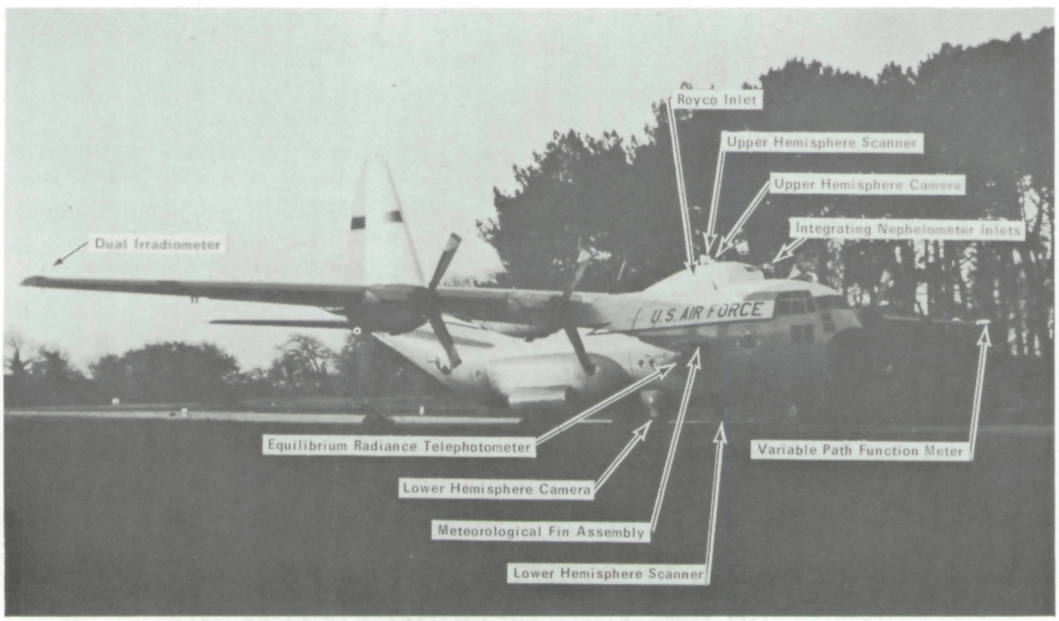


Fig. 2-1. C-130 Airborne Instrument System.

The output of the scanner's radiometer circuit was sampled sixty times per second by the on-board system data logger. For most applications, these constant zenith angle but azimuthally increasing data points were averaged to yield one radiance value for each six degrees change in azimuth. Thus the sky or terrain radiances measured by this system normally ended up in a data array wherein the 2π steradians were represented by an average radiance value every six degrees in azimuth and every five degrees in elevation, or zenith angle. The "every point" data base was retained as a back-up for diagnostic troubleshooting and special purpose displays.

The spectral characteristics of the scanner system's radiometer are illustrated in Fig. 2-3 and Table 2.1. The detector, an EMR541E series photomultiplier (S-20 spectral response) was fitted with a selection of interference and absorption filters to yield the resultant spectral responses shown in Fig. 2-3. The relative response labeled number 4 is similar to the photopic response of the human eye, and thus measurements made using this spectral response can be used to predict human performance.

Some typical atmospheric properties for the passbands illustrated in Fig. 2-3 are summarized in Table 2.1. The last row in Table 2.1 tabulates the appropriate properties for the true photopic response, for comparison with the pseudo-photopic properties associated with filter response number four. It is clear that even though responses four and nine have substantially different effective passbands, (the area under the normalized relative spectral response curve) the atmospheric properties characterizing these two responses are quite similar.

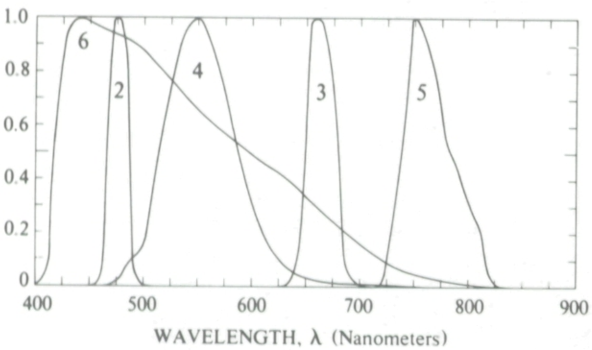


Fig. 2-3. Standard Spectral Responses. Peak Wavelengths are: 2 = 475nm Blue, 3 = 660nm Red, 4 = 550nm Photopic, 5 = 750nm N.I.R., 6 = 440nm S-20.

3. TYPICAL SKY & TERRAIN RADIANCE DISTRIBUTIONS

Partial summaries of data availability, applications, and selected display formats related to the airborne measurements conducted with the C-130 mounted system have been presented previously in each of the technical reports listed in Appendix C. The most comprehensive of these earlier reports is Duntley *et al.* (1978). For the majority of cases, however, these summaries addressed data other than the specific radiance arrays produced by the Automatic 2π Scanner Systems. Therefore, in the following sections of this report, we will address specifically these sky and terrain radiance measurements and their variabilities.

As summarized in Johnson (1981b), a library containing approximately 500 measurements of sky and terrain radiances representing nearly 50 separate flight episodes, emerged from the European flight program. Three flights have been selected from this library to illustrate several typical, or baseline, conditions against which any other set of measured or modelled radiances might be compared. The data from these flights are illustrated in Figs. 3-2 through 3-9 which are in the Composite Sky-Terrain Radiance format used in both Johnson (1981b) and Hering (1981).

In these composite plots, the radiance variations throughout the sun zenith plane, in both the up-sun and down-sun directions, are plotted as a single curve, and labeled "PHI=0 & -180". Similarly, the data in the cross-sun plane are plotted continuously and labeled "PHI=90 & -270". In all cases, a zenith view angle of 0° represents the point in the sky directly overhead, and a zenith view angle of 180° represents the point on the underlying terrain directly below. The negative signs associated with angular indices are an artifact of the computer sorting technique, and should not be rigorously interpreted. In general, the negative sign is used merely to designate the two different azimuthal directions associated with each spherical scan.

The utility of these composite plots lies in the compact visualization of the radiance field surrounding the aircraft at the time of measurement. Having the entire upper hemisphere radiance pattern presented symmetrically about the center of the plot is intuitively satisfying to most users and enhances ones association of the data display with ones concept of the real world.

Table 2.1.

Spectral Characteristics Summary for Project OPAQUE

Spectral Characteristics for Project OPAQUE				Inherent Sun Properties [Johnson (1954)]			Rayleigh Atmosphere Properties (15°C)		
Filter Code No.	Peak Wavelength (nm)	Mean Wavelength (nm)	Effective Passband	Irradiance ($w/m^2\mu m$)	Radiance ($w/\Omega m^2 \mu m$) Average	Radiance ($w/\Omega m^2 \mu m$) Center	Attenuation Length (m)	Total Scattering Coefficient (per m)	Vertical Beam Transmittance
2	475	478	19.9	2.14E+03	3.13E+07	4.07E+07	4.84E+04	2.07E-05	0.839
3	660	664	30.2	1.57E+03	2.30E+07	2.75E+07	1.86E+05	5.41E-06	0.955
4	550	557	78.5	1.90E+03	2.78E+07	3.47E+07	8.93E+04	1.15E-05	0.907
5	750	765	50.4	1.23E+03	1.80E+07	2.10E+07	3.28E+05	3.08E-06	0.974
6	440	532	183.5	1.91E+03	2.80E+07	3.55E+07	7.22E+04	1.64E-05	0.867
9	555	560	106.9	1.89E+03	2.77E+07	3.45E+07	9.22E+04	1.15E-05	0.907

As an aid to the interpretation of radiance distributions illustrated in Figs. 3-2 through 3-10, a pictorial representation of the measurement field is shown in Fig. 3-1. This artist's conception of the 4π radiance field which surrounded the aircraft is annotated with the angular notations and terminologies used in the data displays and discussions which follow.

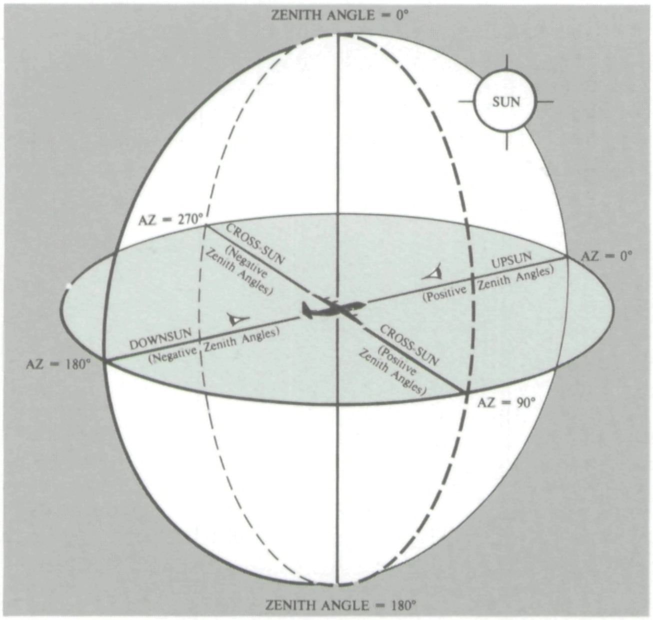


Fig. 3-1. Sky and Terrain Coordinate System.

The selection of any particular set of sky and terrain radiances as typical of a distinctly identifiable larger class is not without its hazards. The uncertainties involved in any classification will clearly be driven by the number of relatively independent variables influencing the characteristics of the radiance distribution and their occurrence within the measurement sample. The fundamental expressions for spectral sky and terrain radiance are set forth in Section 4, and a selection of influential variables addressed in the analysis of the radiance data considered in this report is summarized in Table 3.1. It is clear that some degree of artistic license must be imposed if one is to specify several distinctly "typical" classifications. Thus it is with this forewarning that data from flights C-422, C-439, and C-379 are presented as "typical" representations of overcast, broken cloud, and clear sky conditions. They might be more fairly designated as reasonable approximations for these classes of generalized conditions. In any case, they can serve as useful boundary conditions against which the comparisons of Section 4 can be assessed.

Table 3.1.

Major Variables Influencing Sky-Terrain Radiance Distributions

Variable	Optional Conditions
Viewing Azimuth Angle	Upsun, Cross-Sun, Down-Sun
Viewing Zenith Angle	Upward, Horizontal, Downward
Solar Zenith Angle	High, Intermediate, Low
Cloud Condition	Clear, Scattered, Broken, Overcast
Terrain Reflectance	Ocean, Forest, Farmland, Urban, Snow
Altitude of Observation	above or below haze boundary, between cloud decks
Spectral Band of Observation	478nm, 557nm, 664nm, 765nm

It should be noted that the radiance distributions illustrated in Fig. 3-2 through 3-10 have not been corrected for the near-sun stray light problem discussed in the preceeding companion report Johnson (1981b).

3.1 Fully Overcast Sky

At one boundary in the spectrum of meteorological possibilities lies the weather pattern typified by fully overcast skies. In this situation, where the solar disc is fully occluded, one encounters the flat, shadowless and nondirectional light field traditionally modelled by assuming Lambertian characteristics in both upper and lower hemispheres. There are only a few occurrences of this totally diffuse situation encountered during most flight episodes, and surely very few under the VFR flight conditions associated with the OPAQUE flight program. Two sets of data are included, however, which are illustrative of a highly symmetric radiance distribution in one case, and a relatively constant radiance distribution in the other. These are the data from flights C-422 and C-435.

For each of the four flights illustrated in the next several figures, *i.e.* Fig. 3-2 through 3-10, the original flight description notes have been abstracted from the earlier parent reports and, as a reader convenience, included with the graphical displays of sky and terrain radiance. Additionally, selected scenes from the photographic documentation acquired during each flight episode have been reproduced as part of the flight description. In each case, these photographs represent the 4π scene surrounding the aircraft during a specific radiometric measurement sequence. Thus each photo title includes the altitude and spectral band of the radiometric measurement with which the photo should be associated. One should be aware however that while each radiometric sequence required three minutes of elapsed time to complete, the photographic documentation was essentially instantaneous, thus the assessment of specific cloud conditions should be approached with caution. As noted in the earlier technical reports associated with this measurement program, there are photographic records coinciding with each radiance set that was acquired, even though only four per flight are included in this presentation.

Flight C-422 represents the most symmetric radiance distribution retrieved from the OPAQUE series. As illustrated in Figs. 3-2 and 3-3, the radiances in all four cardinal azimuths from the sun show nearly identical gradients as a function of zenith angle with very little sky structure. Spectral differences are trivial within the 1500m AGL set, and exhibit only minor nadir differences at300m. However, the radiance difference between the overhead sky and the underlying ocean surface is substantial.

Flight C-435 represents a similar overcast sky condition over a completely different underlying terrain. The relatively high reflectance of the snow covered plateau underlying the Birkhof flight track has produced the most directionally constant radiance levels retrieved to date. Particularly noticeable is the highly constant radiance in the photopic (Filter 4, $\bar{\lambda} = 557nm$) and the near infrared (Filter 5, $\bar{\lambda} = 765nm$) spectral bands.

The characteristics of radiance uniformity and symmetry illustrated by these two flights can be considered to represent one extreme in the overall spectrum of sky and terrain radiance distributions, and thus form one set of boundary conditions in any realistic modelling approximation.

FLIGHT C-422 - 11 AUGUST 1977 DESCRIPTION OF FLIGHT AND WEATHER CHARACTERISTICS

Filter Ident	Data Interval Start (GMT)	End (GMT)	Elapsed (hrs)	Max. Flight Altitude (m)	Average Terrain Elevation (m)
2,3	0953	1040	0.8	1560	0
4,5	1044	1120	0.6	1560	0

Filter Ident	Solar Zenith Angle Initial ST&LV (degrees)	Solar Transit (degrees)	Final V-PRO (degrees)
2,3	42.9	-	40.2
4,5	40.1	39.5	39.5

Flight Description. Flight C-422 was a morning flight. The skies were overcast with low level clouds. The approximate southeast to northwest Rodby track was located south of Lolland Island, Denmark. Typical terrain features along the nearby coast to the north of the track were flat, cultivated farmlands interspersed with occasional woods and small towns. Directly beneath the track and to the south were the relatively shallow waters of Femer Bay.

In-Flight Notes. The in-flight observer reported overcast clouds with bases at 1800 meters (6000 feet) with light precipitation. Heavy haze was present at all flight altitudes. The slant range visibility varied from 3.5 miles at 300 meters (1000 feet) to 10 miles at 1500 meters (5000 feet).

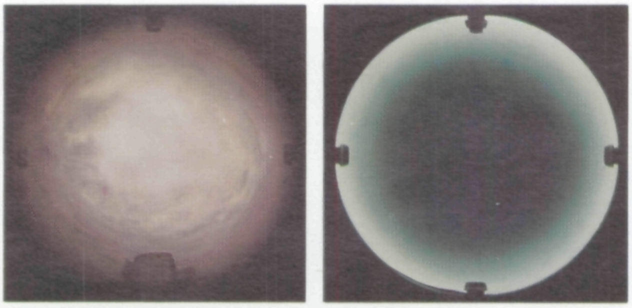
Local Weather Notes. Fehmarnbelt, 9 miles south of the track center point, reported overcast stratocumulus based at 300 meters (1000 feet) and 4.0 kilometers visibility with light fog at 0900 GMT improving to 10.0 kilometers at 1200 GMT.

Schleswig, 103 kilometers west of the track center point, reported 4/8 cumulus at 300 meters (1000 feet) decreasing to 2/8 with bases at 750 meters (2500 feet) by 1100 GMT. Stratocumulus with amounts varying from 4/8 to 3/8 were at 900 meters (3000 feet) and altostratus with 4/8 coverage at 3600 meters (12,000 feet) were also recorded. Visibility of 4.0 kilometers with light fog gradually improved to 10.0 kilometers.

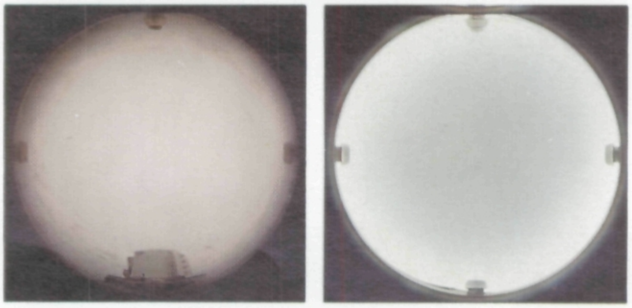
The radiosonde station at Schleswig was 103 kilometers west of the flight track and located in an airflow that was parallel with the track.

Synoptic Remarks. The surface chart showed ridging from the North Pole southward through eastern Britain. Moist air at low levels was being advected from the North Sea. At 500 millibars there was a low centered near Frankfort. The flow was southeasterly and the air mass was modified maritime polar.

FLIGHT C-422
Rodby Track



Upper and Lower Hemisphere
300m AGL Filter 3



Upper and Lower Hemisphere
1500m AGL Filter 5

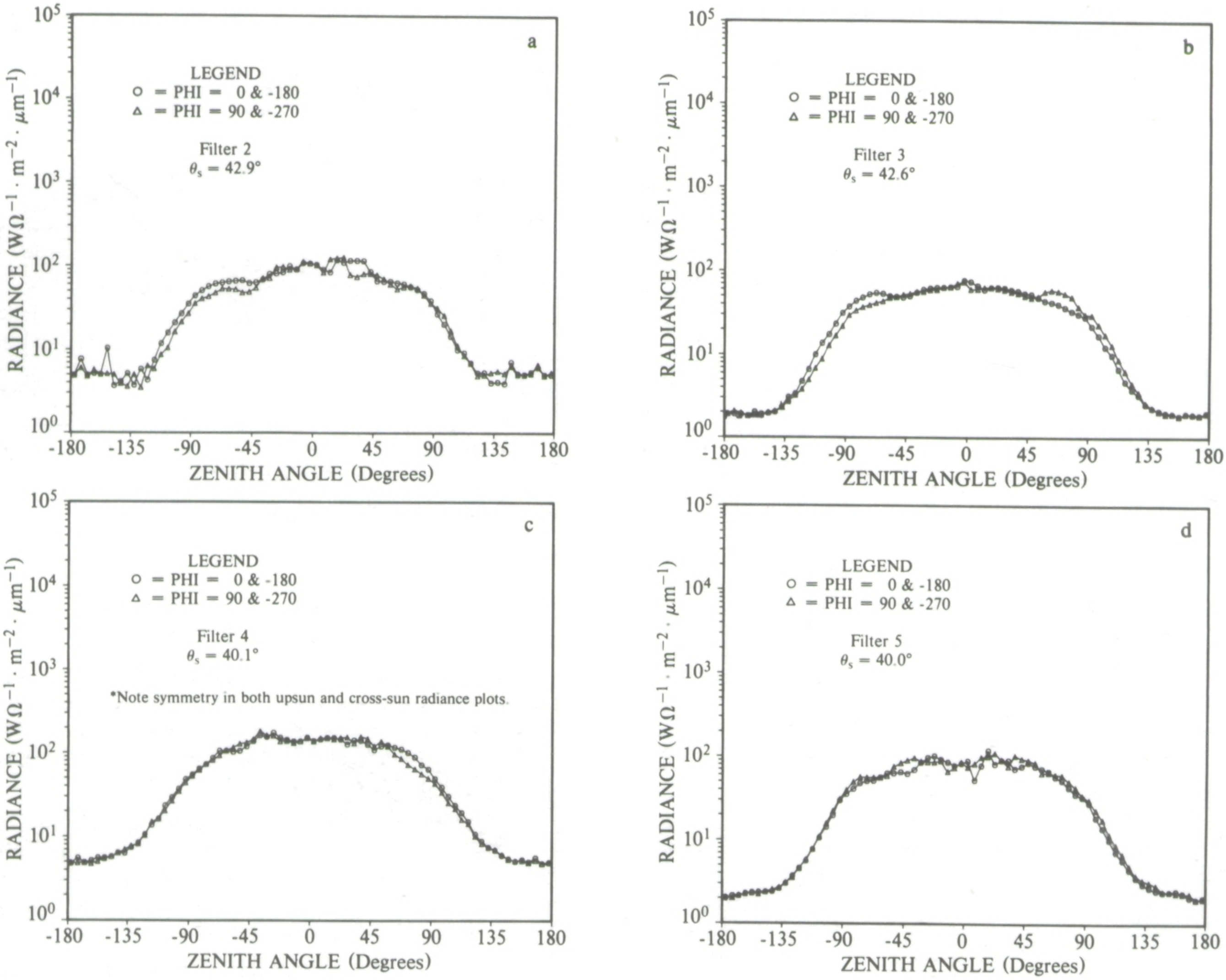


Fig. 3-2. Flight C-422 (Rodby, Denmark), Overcast Sky over Calm Ocean, 300m AGL.

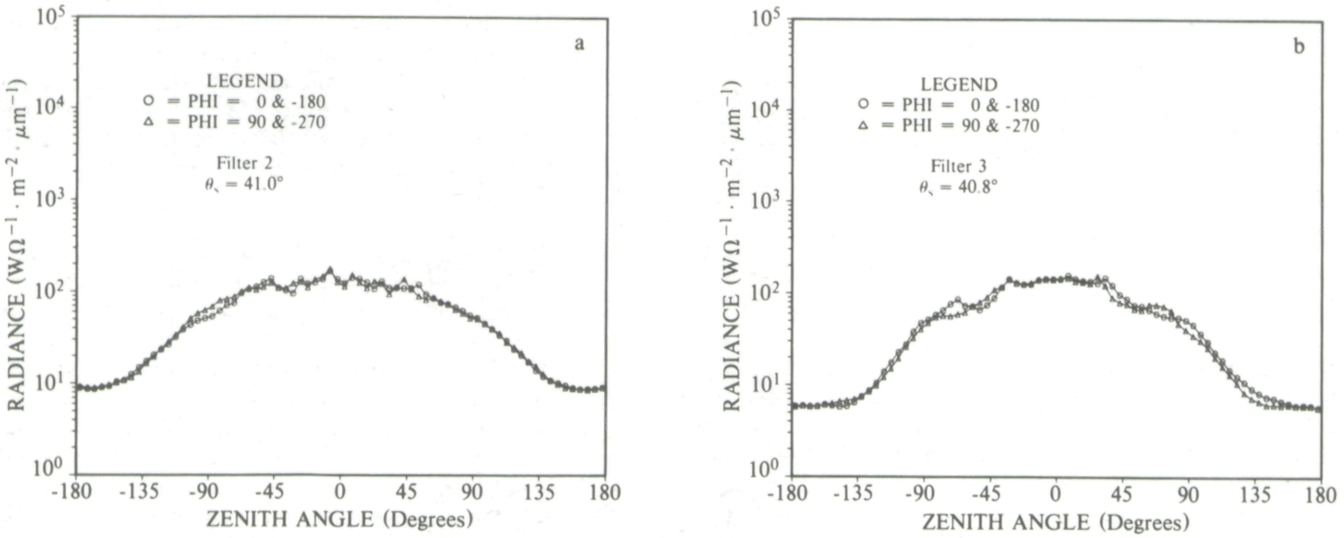


Fig. 3-3. Flight C-422 (Rodby, Denmark), Overcast Sky over Calm Ocean, 1500m AGL.

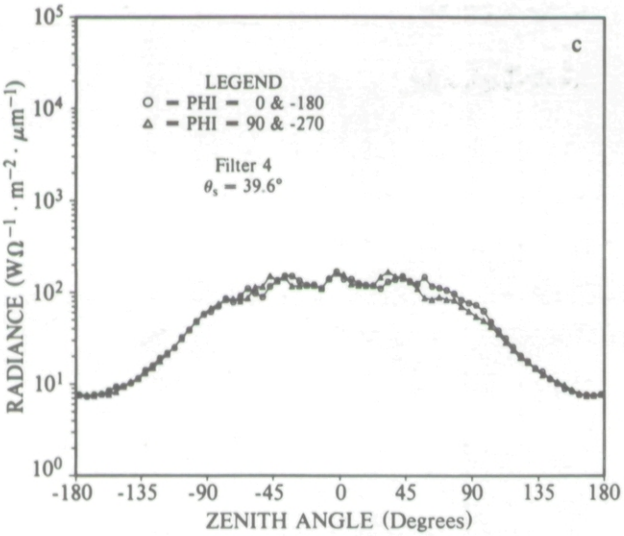


Fig. 3-3 (con't.). Flight C-422 (Rodby, Denmark), Overcast Sky over Calm Ocean, 1500m AGL.

FLIGHT C-435 - 23 FEBRUARY 1978 DESCRIPTION OF FLIGHT AND WEATHER CHARACTERISTICS

Filter Ident	Data Interval Start (GMT)	End (GMT)	Elapsed (hrs)	Max. Flight Altitude (m)	Average Terrain Elevation (m)
2,3	0832	0921	0.82	2310	762
4,5	0927	1015	0.80	2280	762

Filter Ident	Solar Zenith Angle Initial ST&LV (degrees)	Solar Transit (degrees)	Final V-PRO (degrees)
2,3	71.0	-	65.2
4,5	64.8	-	60.9

Flight Description. Flight C-435 was a morning flight with take off at 0800 and landing at 1045 GMT. There were overcast altostratus clouds. The approximate west to east Birkhof track in southwest Germany was over a plateau surrounded by forest and some small villages. Typical terrain features were forest cover with intermittent snow covered fields and valleys that presented a black and white contrast.

In-Flight Notes. The in-flight observer reported overcast altostratus with the flight conducted under the cloud layer. There were foehn conditions and it was very clear below the cloud layer. On the V-PRO's there was very uniform light haze and thin fog in the valleys. Slant visibilities were usually 48 kilometers (30 miles) except at 0938 GMT at 1200 kilometers (4000 feet) it was 32 kilometers (20 miles) and at 0955 GMT at 3000 meters (10,000 feet) it lowered to 24 kilometers (15 miles).

Local Weather Notes. Freudenstad, 53 kilometers west of the track center, reported varying amounts of cumulus from 2/8 to 6/8 at 720 to 780 meters (2400 to 2600 feet) and 8/8 to 7/8 altocumulus at 3000 meters (10,000 feet). Visibility was 30 to 40 kilometers.

Spaichinger, 28 kilometers southwest of the track center, reported 1/8 to 3/8 cumulus at 1050 meters (3500 feet), 5/8 to 8/8 altocumulus at 2700 to 3300 meters (9000 to 11,000 feet) and 7/8 cirrus at 6000 meters (20,000 feet). Visibility was 70 to 75 kilometers.

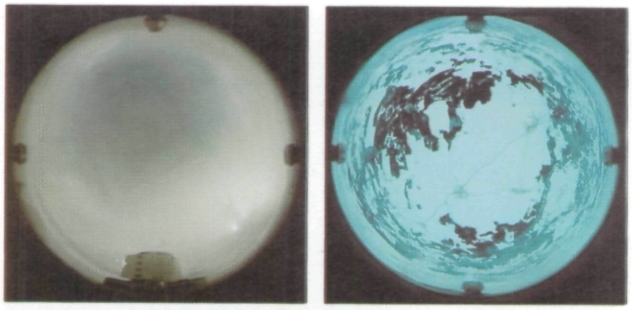
Ulm, 68 kilometers eastnortheast of the track center, reported ceiling zero, visibility zero in fog until 1100 GMT when conditions improved to 7/8 stratus at 210 meters (700 feet) and visibility 1.0 kilometers in fog.

The radiosonde station at Neuchatel was 225 kilometers southwest and upstream from the track. The vertical cross section for 1200 GMT showed 8/8 clouds at 1300 meters, 7/8 at 2000 meters, 6/8 from 3000 to 4400 meters, 8/8 coverage from 5500 to 6500 meters and 5/8 cloud at 800 meters. These conditions also prevailed to the east and west.

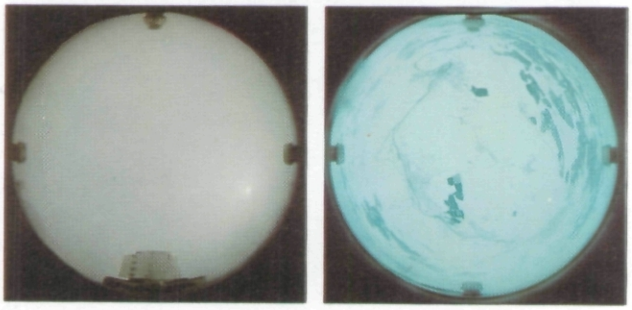
Synoptic Remarks. The surface charts showed an occlusion south of Iceland that extended east and southeast through western France and eastern Spain into Africa and then westward to another storm in the eastern Atlantic. This chart had widespread fog that was advected by southwesterly flow from the Mediterranean in advance of the frontal system in Europe. The 500 millibars chart showed ridging from Tunisia and eastern Algeria northward through western Germany to the North Sea. The upper flow was southwesterly and the air mass was stable maritime polar.

FLIGHT C-435
Birkhof Track

Upper and Lower Hemisphere
2200m AGL   Filter 3



Upper and Lower Hemisphere
2200m AGL   Filter 5



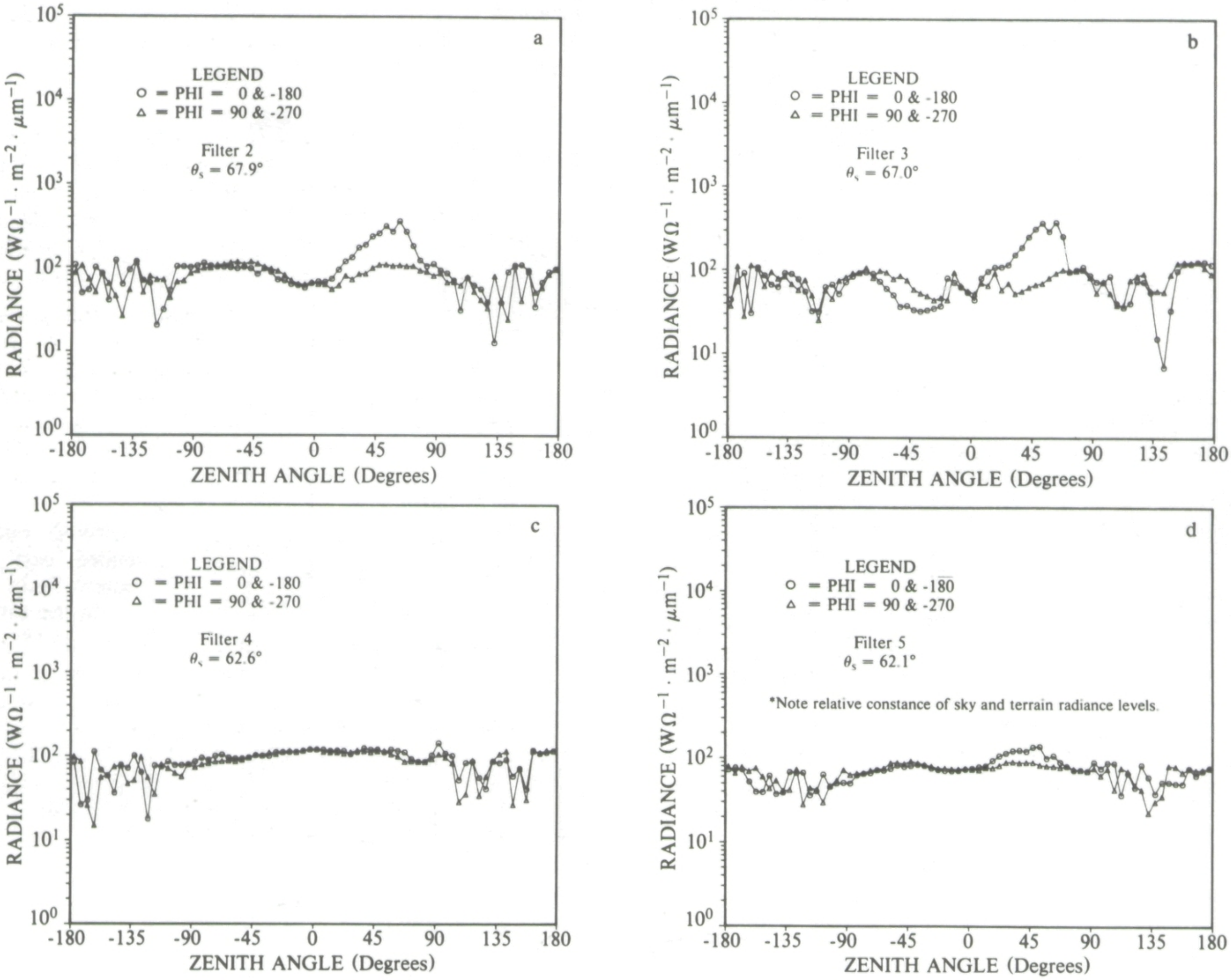


Fig. 3-4. Flight C-435 (Birkhof, Germany), Overcast Sky over Snow Covered Plateau, 2200m AGL.

3.2 Broken Cloud Conditions

The most difficult condition to specify within the context of "typical" sky and terrain radiance distributions are those characterized by broken clouds, in either single or multiple decks. Under broken cloud conditions both sky and terrain radiances become highly variable with respect to both time and path of sight. Background radiance patterns become highly irregular and can induce severe variations in contrast transmittance determinations as illustrated in Hering (1981).

A good example of these variabilities is provided in the data from flight C-439, illustrated in Figs. 3-5 and 3-6. In each of these illustrations, the data in the pairs a & b were measured approximately five minutes apart in time, as were the data in the pairs c & d. The appearance and disappearance of the high radiance sun peaks are clearly illustrated as the sky radiance distributions vary from highly directional, 3-5 a & c to moderately directional 3-6a, b & c, to relatively flat and uniform 3-5b & d and 3-6d.

In each spectrally matched pair *i.e.* 3-5a & 3-6a, etc., the reduced variance in the terrain radiance patterns induced by the degree of solar occultation and the increased altitude is readily discernible.

It is clear that these variable radiometric conditions can severely test the analyst in his attempts to establish a "typical" condition, much less develop a simple, generalized model for operational predictions. It is however, within this turbid atmospheric regime that reliable predictive methodologies are most needed, and thus where substantially increased modelling efforts should be concentrated.

FLIGHT C-439 - 1 MARCH 1978
DESCRIPTION OF FLIGHT
AND WEATHER CHARACTERISTICS

Filter Ident	Data Interval: Start (GMT)	End (GMT)	Elapsed (hrs)	Max. Flight Altitude (m)	Average Terrain Elevation (m)
2,3	1257	1342	0.75	1650	762
4,5	1352	1433	0.68	1620	762

Filter Ident	Solar Zenith Angle: Initial ST&LV (degrees)	Solar Transit (degrees)	Final V-PRO (degrees)
2,3	58.6	-	62.3
4,5	63.3	-	68.0

Flight Description. Flight C-439 was an afternoon flight with take off at 1213 and landing at 1510 GMT. There were scattered to broken middle clouds and broken to overcast high clouds. The approximate west to east Birkhof track in southwest Germany was over a plateau surrounded by forest and some small villages. Typical terrain features were forest cover with intermittent snow covered fields and valleys that presented a black and white patchwork.

In-Flight Notes. The in-flight observer reported scattered altostratus at 3000 meters (10,000 feet) and broken to overcast cirrostratus at 6000 meters (20,000 feet). By 1310 GMT the altostratus had increased to broken and became denser and sometimes overcast. The altostratus moved in from the south and data were taken below the deck. Slant range visibilities were 24 to 40 kilometers (15 to 25 miles) at 1200 and 2400 meters (4000 and 8000 feet) becoming 24 kilometers (15 miles) by 1335 GMT at all altitudes.

Local Weather Notes. Freudenstad, 53 kilometers west of the track, observed 7/8 to 4/8 altocumulus at 1800 meters (6000 feet) with 1/8 to 3/8 stratocumulus at 1500 meters (5000 feet) after 1500 GMT and 6/8 thin cirrus at 6000 meters (20,000 feet) after 1500 GMT. Visibilities were 50 to 65 kilometers.

Spaichinger, 28 kilometers southwest of the flight track, had three levels of clouds. There were 1/8 to 3/8 stratocumulus at 1500 meters (5000 feet), 6/8 to 7/8 altocumulus at 3600 meters (12,000 feet) lowering to 2700 meters (9000 feet) and 7/8 cirrostratus at 6900 meters (23,000 feet). Visibility was 60 to 75 kilometers.

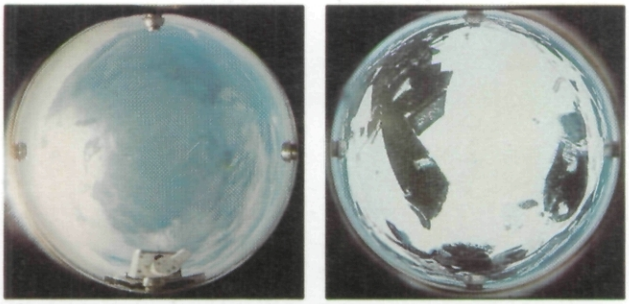
Ulm, 68 kilometers eastnortheast of the track center, had an obscured sky with a ceiling of 90 meters (300 feet) and visibility of 0.8 kilometers in fog at 1300 GMT. Conditions gradually improved with 1/8 to 2/8 stratus at 90 to 150 meters (300 to 500 feet), 4/8 altocumulus at 3000 meters (10,000 feet) and 7/8 cirrus at 7200 meters (24,000 feet). Visibility improved to 1.8 kilometers in light fog.

The radiosonde station at Neuchatel was 225 kilometers southwest and upstream from the track. There was no appropriate vertical cross section.

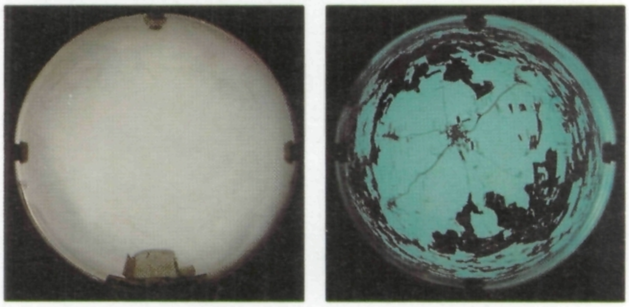
Synoptic Remarks. The surface chart showed that an occluded front extended from the Irish Sea to Belgium then as a cold front southward through eastern France into Algeria and then westward into the Atlantic to an advancing complex system. There was widespread fog in advance of the frontal system in Europe. At 500 millibars there was slight ridging from Sicily to Belgium and south-southwesterly flow. The air mass was modified stable maritime polar.

FLIGHT C-439
Birkhof Track

Upper and Lower Hemisphere
507m AGL Filter 2



Upper and Lower Hemisphere
1612m AGL Filter 5



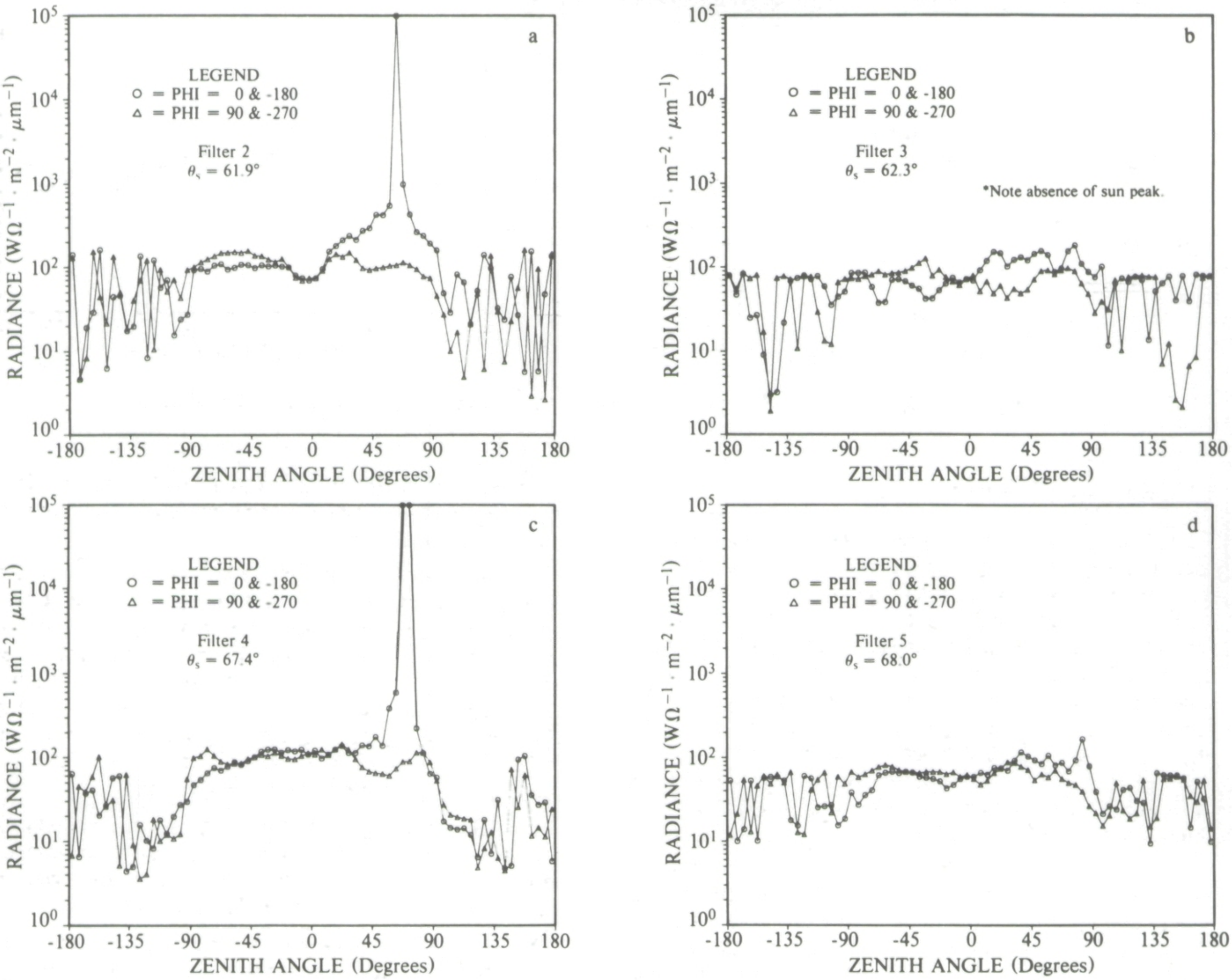


Fig. 3-5. Flight C-439 (Birkhof, Germany), Broken Cloud over Forest with Snow, 500m AGL.

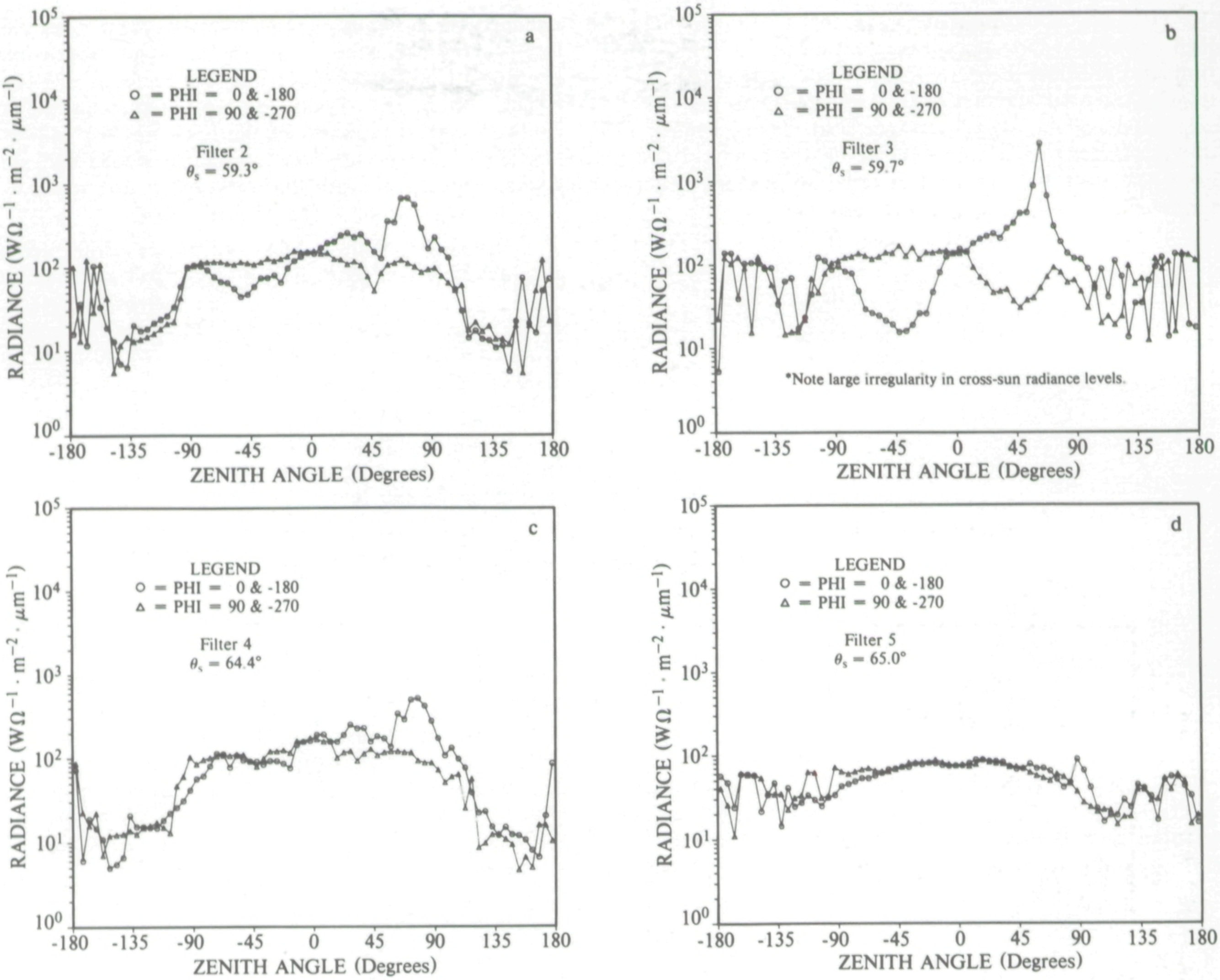


Fig. 3-6. Flight C-439 (Birkhof, Germany), Broken Cloud over Forest with Snow, 1600m AGL.

3.3 Clear Sky Conditions

Just as the fully overcast conditions illustrated in Section 3.1 represent one end of the meteorological spectrum, the clear sky conditions of flight C-379 represent the other. Under such clear sky conditions, radiance patterns are well behaved and tell a consistent story with respect to upper and lower hemisphere characteristics, both as a function of observational wavelength and altitude. The driving forces of direct solar irradiance upon the atmospheric volume scattering function and the underlying terrain reflectance characteristics predominate in establishing the radiance distributions as evidenced by the modelled comparisons in Hering (1981).

These consistent clear day radiance patterns are shown in Figs. 3-7 through 3-10 which are chosen for illustration since they contain a variety of easily discerned characteristics. The uniformity in the radiance distribution relationships between the through-sun and cross-sun measurements is clear, both spectrally and as a function of altitude. The bright horizons and highly asymmetric up-sun and down-sun sky radiance levels are consistent and readily discernible.

The uniformity of the down-sun and cross-sun sea surface radiances is well illustrated, as is the obvious glitter pattern which appears as a broad high radiance peak in the up-sun terrain (sea surface) radiance measurements at all altitudes and in all spectral bands. The relatively high radiance of the nearby shore line gradually appears in the down-sun terrain radiance measurements as the altitude of observation increases. These terrain effects are particularly noticeable in Figs. 3-9b, c, and d.

The excellent fidelity with which operationally effective modelling approximations can be used to characterize the radiance distributions typified by these clear day conditions is well illustrated by Hering (1981).

It should be recalled that the radiance distributions illustrated in Figs. 3-2 through 3-10 have not been corrected for the near sun stray light problem discussed in the preceding companion report Johnson (1981b). The high near-sun radiance peaks illustrated in Figs. 3-7 through 3-10 have been reproduced unaltered as illustrations of the solar aureoles relative importance in any characterization of the overall radiance field. In the comparative illustrations of Section 4, however, the near sun radiance data have been deleted in order to preclude misinterpretation.

FLIGHT C-379 - 17 MAY 1976
DESCRIPTION OF FLIGHT AND WEATHER CHARACTERISTICS

Filter Ident	Data Interval Start (GMT)	End (GMT)	Elapsed (hrs)	Max. Flight Altitude (m)	Average Terrain Elevation (m)
2,3	0957	1138	1.7	6270	0
4,5	1143	1332	1.8	6270	0

Filter Ident	Solar Zenith Angle Initial ST&LV (degrees)	Solar Transit (degrees)	Final V-PRO (degrees)
2,3	38.0	35.3	35.7
4,5	35.8	-	44.3

Flight Description. Flight C-379 was a midday flight spanning local apparent noon. Nearby areas reported clear skies during the morning, with thin cirrus and scattered cumulus developing in the afternoon, although the in-flight pictures indicated clear skies along the track throughout the flight. The approximate southeast to northwest track was located south of Lolland Island, Denmark. Typical terrain features along the nearby coast to the north of the track was flat cultivated farmlands interspersed with occasional woods and small towns. Directly beneath the track and to the south were the relatively shallow waters of Femer Bay.

In-Flight Notes. The in-flight observer reported clear skies early in the flight with some scattered high thin cirrus beginning at 1045 GMT and increasing to 4/8 at 7500 meters (25,000 feet) by 1145 GMT. Scattered cumulus (1/8) formed at 1200 meters (4000 feet) after 1200 GMT.

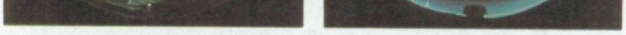
Local Weather Notes. At Fehmarnbelt, 10 kilometers south of the track center point, no clouds were reported on the three-hourly observations. Visibility was reported as 20 kilometers.

Kegnaes, 80 kilometers westnorthwest of the track center point, reported 1/8 of cirrus at 6000 meters (20,000 feet) on the 1200 and 1500 GMT observations. Visibility was reported from 15 to 30 kilometers.

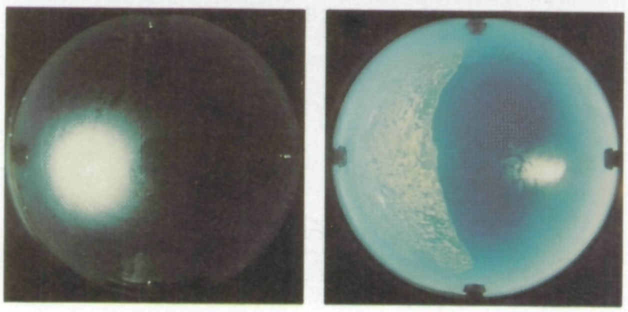
The radiosonde station at Schleswig was 106 kilometers west and downstream from the flight track center point.

Synoptic Remarks. The surface chart for 1200 GMT shows a closed high cell centered near Kiel Bay. A cold front was moving from Ireland to Britain through the Irish Sea. At 500 millibars there was weak ridging from Sardinia to Sweden with light northwesterly winds. The air mass was stable maritime polar.

FLIGHT C-379
Rodby Track



Upper and Lower Hemisphere
282m AGL Filter 4



Upper and Lower Hemisphere
6265m AGL Filter 4

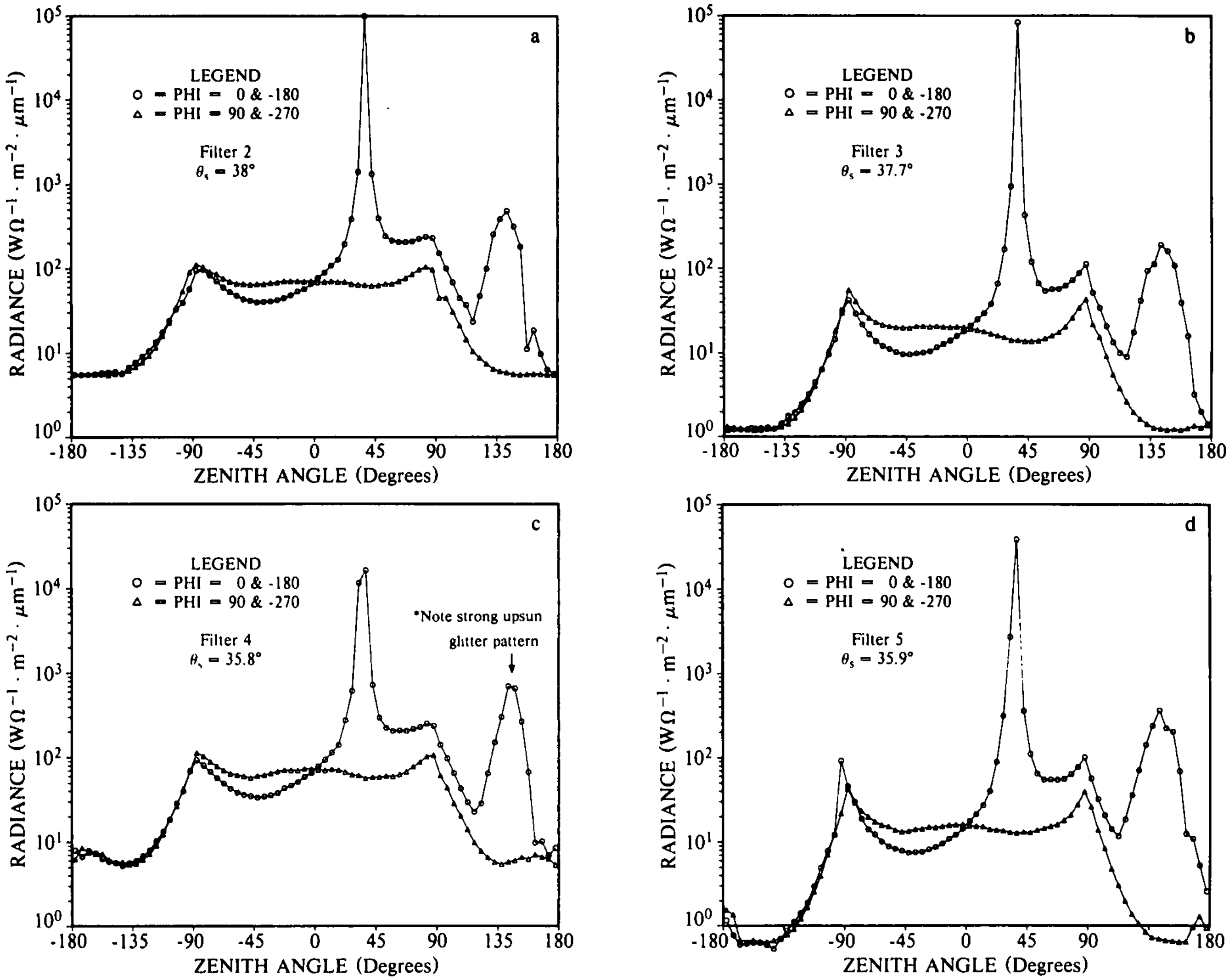


Fig. 3-7. Flight C-379 (Rodby, Denmark), Clear Sky over Ocean with Glitter, 300m AGL.

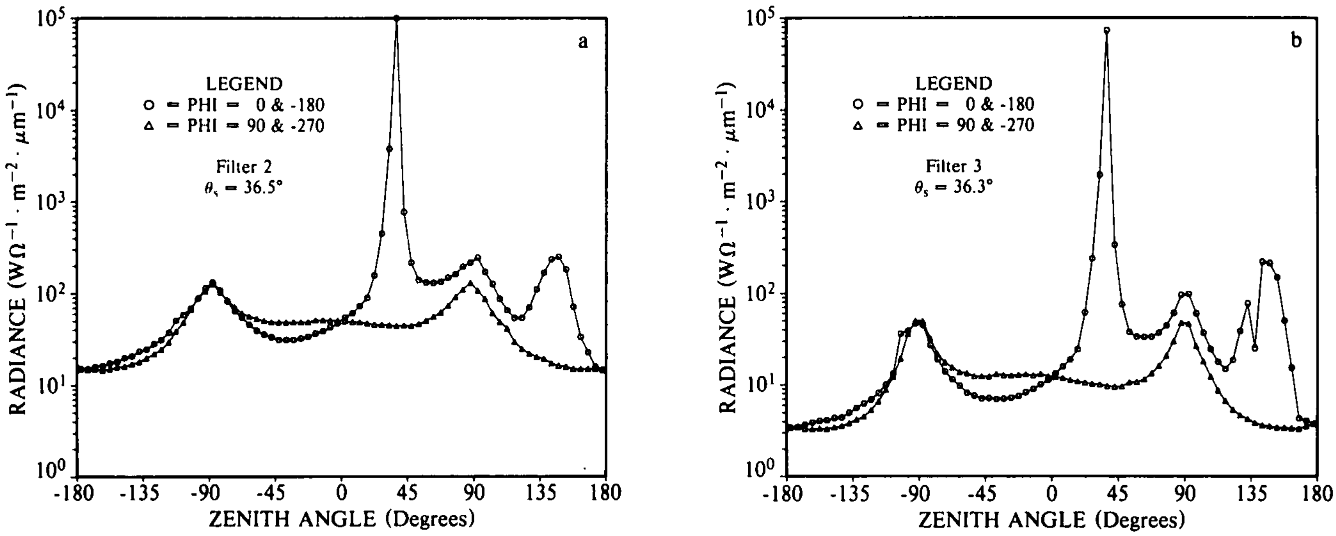


Fig. 3-8. Flight C-379 (Rodby, Denmark), Clear Sky over Ocean with Glitter, 1600m AGL.

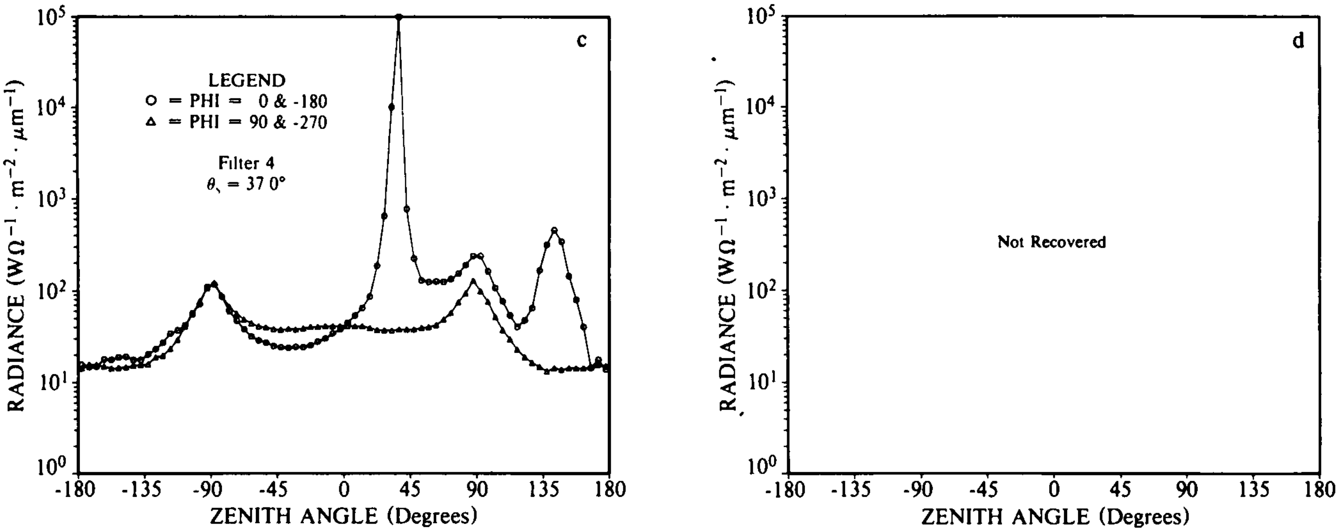


Fig. 3-8 (con't.). Flight C-379 (Rodby, Denmark), Clear Sky over Ocean with Glitter, 1600m AGL.

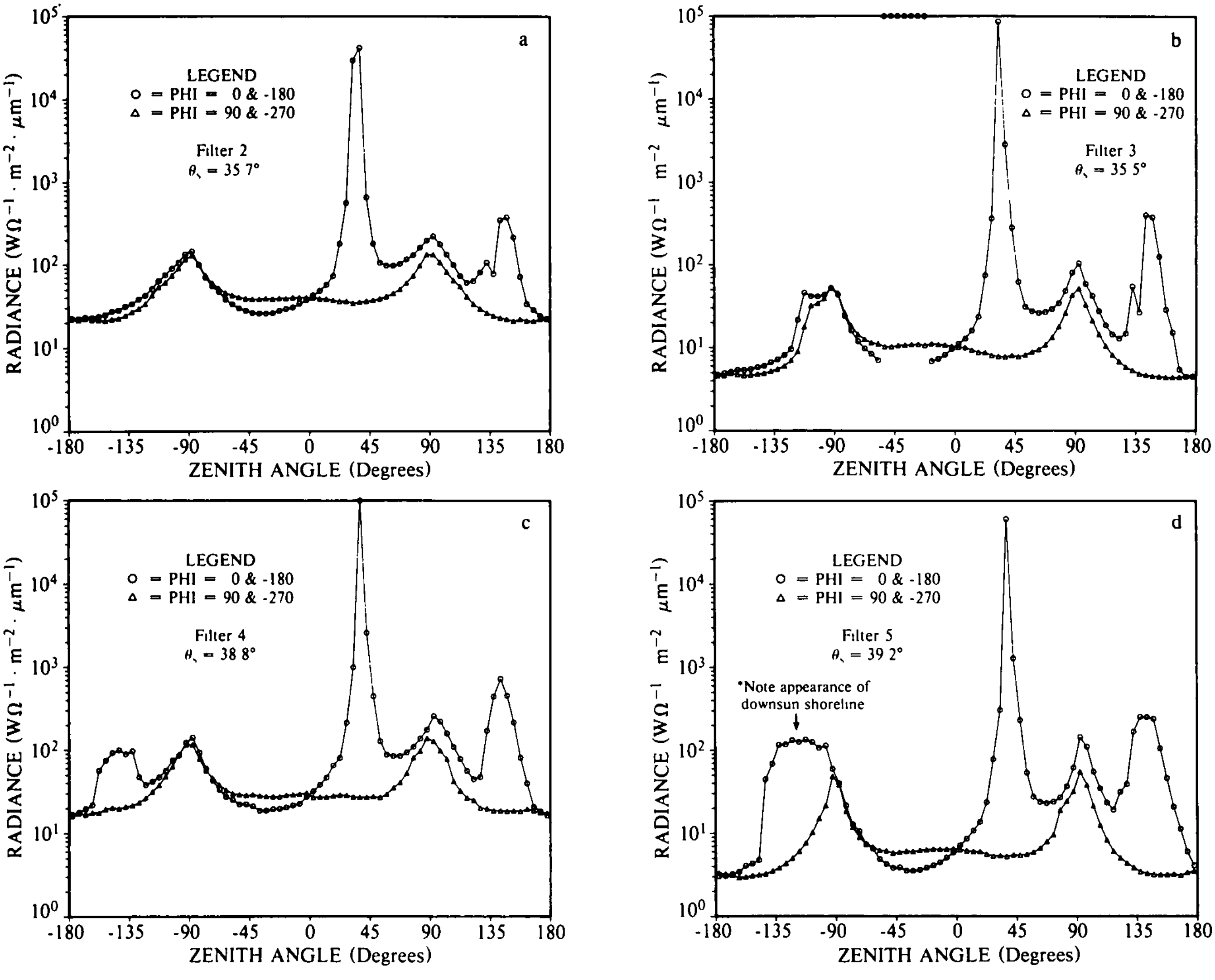


Fig. 3-9. Flight C-379 (Rodby, Denmark), Clear Sky over Ocean with Glitter, 3000m AGL

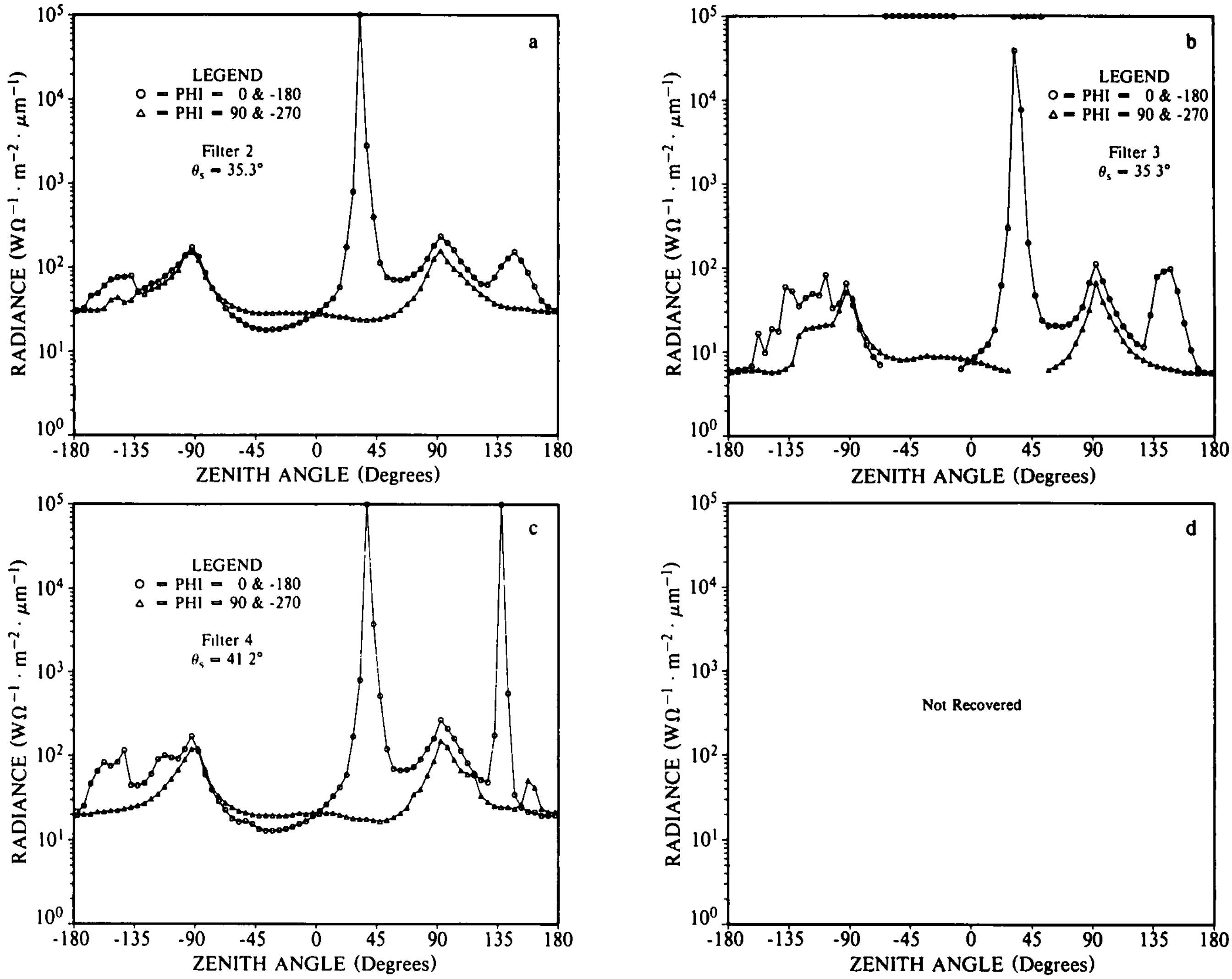


Fig. 3-10. Flight C-379 (Rodby, Denmark), Clear Sky over Ocean with Glitter, 6000m AGL.

4. RADIANCE COMPARISONS AND ANALYSIS

In this section we will take a closer, quantitative look at some of the natural variations in sky and terrain radiance through a series of composite analyses of selected experimental flight data. Comparative measurements were chosen to illustrate in more detail some of the characteristic changes in the radiance structure as a function of wavelength, altitude, cloud cover, surface reflectance, and solar zenith angle. As a convenient reference for the interpretation of the comparative measurements, the fundamental expressions for the apparent spectral sky and terrain radiance are presented and discussed briefly below.

4.1 Expressions for Sky and Terrain Radiance

The (monochromatic) apparent radiance of the sky or terrain background for an horizontally uniform atmosphere at altitude z and for a viewing path of length r, zenith angle θ and azimuthal angle ϕ is (Duntley *et al.*, 1957)

$$ {}_bL_r(z,\theta,\phi) = T_r(z,\theta,\phi)\, {}_bL_o(z_t,\theta,\phi) + L_r^*(z,\theta,\phi) \; . \quad (1)$$

The first term on the right hand side of Eq. (1) is the residual contribution of the inherent background radiance of the underlying surface, cloud, etc., which can be expressed,

$$ {}_bL_o(z_t,\theta,\phi) = E(z_t,180-\theta,\phi+180)\; R(z_t,\theta,\phi)/\pi \; , \quad (2)$$

where $E(z_t,180-\theta,\phi+180)$ is the downwelling radiance on a flat plate oriented normal to the path of sight, $R(z_t,\theta,\phi)$ is the inherent spectral reflectance of background, and $T_r(z,\theta) = \exp - \int_0^r \alpha(z)dr$ is the path transmittance. As emphasized in Section 3, natural variations in the reflectivity pattern of the underlying terrain have a strong impact on the radiance field fluctuations for downward paths of sight, particularly at low altitudes (short path lengths) where the path radiance contribution tends to be small.

The path radiance, or last term in Eq. (1), is given by

$$L_r^*(z,\theta,\phi) = \int_0^r L_*(z',\theta,\phi)\,T_r'(z,\theta)\,dr' , \qquad (3)$$

where $L_*(z',\theta,\phi)$ is path function. It is the point function component of the path radiance generated by the directional scattering of light reaching that point of the path. The expression for the path function can be written (Gordon, 1969) in terms of its separate contributions resulting from primary scattering of the direct solar scalar irradiance, $\epsilon_s(z,\theta_s)$ and from the directional scattering of the incident diffuse sky and terrain radiance field, $L_D(z,\theta',\phi')$, as follows:

$$L_*(z,\theta,\phi) = \epsilon_s(z)P(z,\beta_s)s(z) + \int_{4\pi} L_D(z,\theta',\phi')P(z,\beta)s(z)\,d\Omega' \qquad (4)$$

where $s(z)$ is the total volume scattering coefficient and $P(z,\beta)$ is the phase function for single scattering that gives the probability that light will be scattered at angle β between the direction of the source light and the path of sight.

We note from Eq. (3) and (4) that path radiance increases in proportion to the optical scattering thickness of the path, $\tau_s = \int_0^r s(z)dr$, hence the tendency for the increased brightness of horizon sky relative to more overhead paths of sight for sunlit atmospheres. It also follows from Eq. (3) and (4) that the path radiance generated by aerosol particle scattering is enhanced for paths of sight close to the sun as opposed to the backscattering direction due to the asymmetry in the single scattering phase function, $P(z,\beta)$.

For cloud free paths of sight, the apparent radiance field of the sky hemisphere is given by $L_r^*(z,\theta,\phi)$ since the inherent background radiance, ${}_bL_o$, near the upper limit of the atmosphere tends to zero. Furthermore for cloud free atmospheres, the primary scattering of the direct solar irradiance (first term on the right hand side of Eq. (4)) is the major determinant of the path function, $L_*(z,\theta,\phi)$ and the sky radiance, ${}_bL_r(z,\theta,\phi)$.

4.2 Radiance Variations With Altitude

Comparative measurements of the radiance distributions as a function of altitude are shown in Figs. 4-1 through 4-8. As indicated in the descriptions of the flight and weather characteristics, both experimental flights were carried out over open farmland with scattered cirrus clouds present at high altitude. The first set of measurements (Figs. 4-1 through 4-4) for flight C-466 were made near noon in the summer in northwestern Germany with an average solar zenith angle near 45 degrees. By contrast, the second set of measurements for flight C-401 (Figs. 4-5 through 4-8) were made with a much lower sun elevation (average zenith angle near 70 degrees). Flight C-401 was carried out in northwestern France in early December.

As indicated by Eqs. (1) through (4) the radiance fields have significant systematic variations with altitude and with viewing angle. On the other hand, the expressions indicate that the ratio of the measured sky radiance fields (upper hemisphere) for any pair of altitude levels should be rather uniform with respect to variations in the paths of sight, although some variation can be expected due to such factors as horizontal inhomogeneity and changes in the shape of the single scattering phase function with altitude. From Figs. 4-1 through 4-8 we observe that,

a. The percent change in the measured sky radiance (upper hemisphere) between specific altitude levels tends to be much the same over a wide range of viewing paths for flight C-466 and again for flight C-401. A similar tendency is evident in the apparent terrain radiance measurements (lower hemisphere), except that large fluctuations are superimposed which are caused by abrupt changes in the reflectivity of small scale terrain features. Both experimental flights were made under conditions of light to moderate haze in the lower troposphere. It should be noted that increasing the tropospheric aerosol load would increase the altitude dependence of the observed radiances. The high frequency reflectivity variations are more prominent in the measurements at low altitude (200 to 500m).

b. Sky radiance altitude ratios are similar for Filter 2 (475 nm) and Filter 3 (660 nm) for flight C-466 and again for flight C-401.

c. Due largely to the differences in the solar irradiance profiles, the measured ratio of sky radiance between specific altitudes are significantly smaller for flight C-401 (low sun) than for flight C-466 (higher sun).

d. The average rate of increase of apparent terrain radiance (lower hemisphere) with increasing altitude is relatively small for the Filter 3 ($\lambda = 660m$) measurements for both experimental flights. In other words, the gain due the generation of path radiance tends to be balanced by the transmission loss of the inherent background radiance.

Note: See Appendix B for Flight Descriptions.
Flight C-466 see p.42, Flight C-401 see p.34.
Figs. 4-1 through 4-8 see pp.17-20.

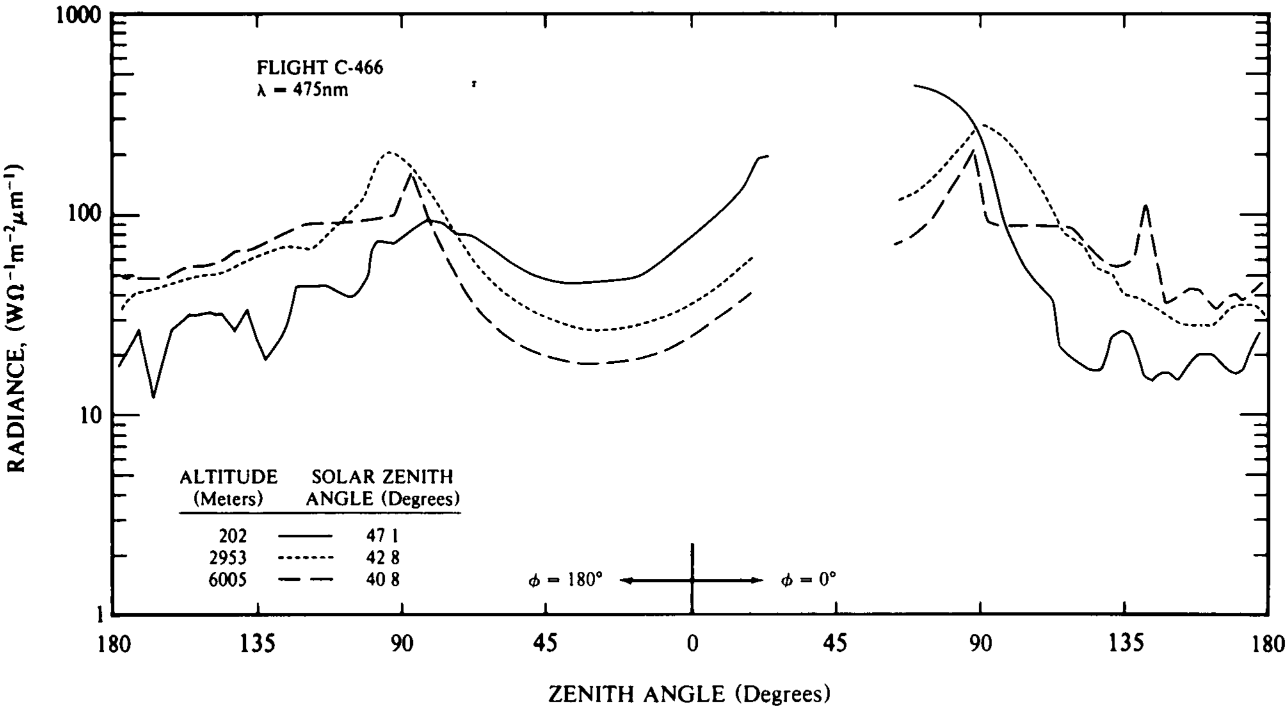


Fig. 4-1. Variation of Radiance Field with Altitude, Flight C-466, λ = 475 nm, φ = 0°/180°.

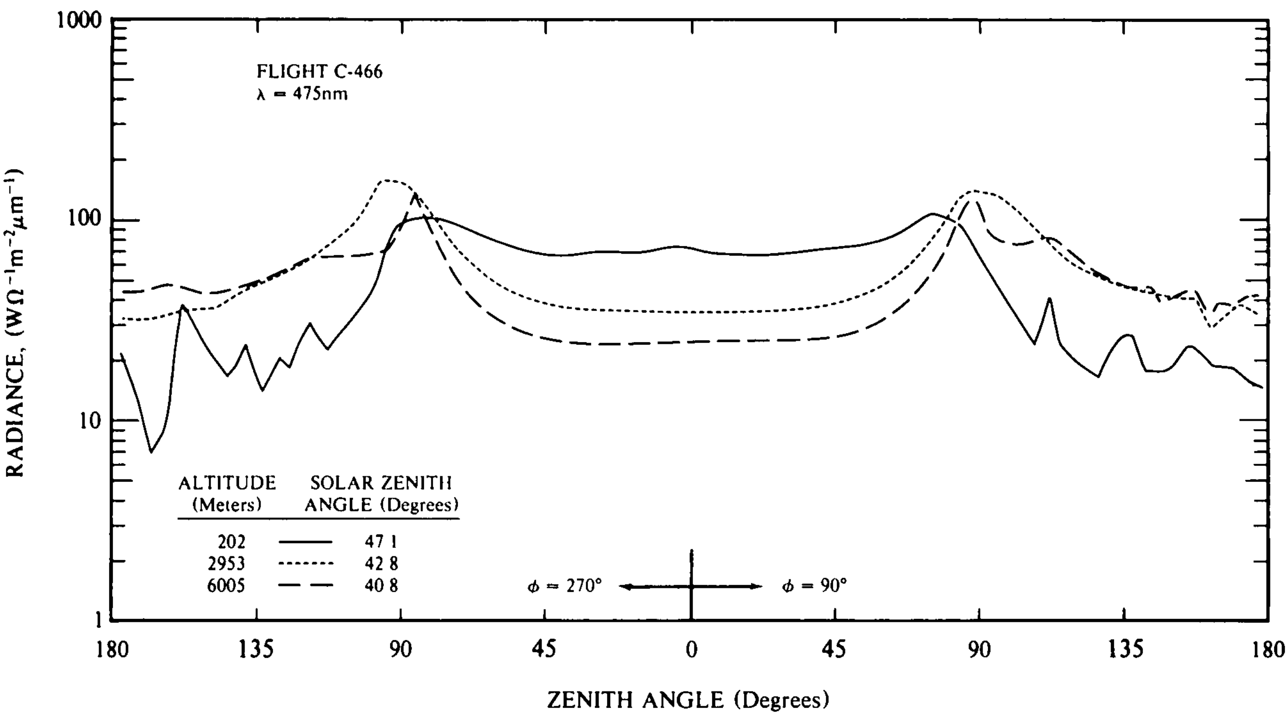


Fig. 4-2. Variation of Radiance Field with Altitude, Flight C-466, λ = 475 nm, φ = 90°/270°.

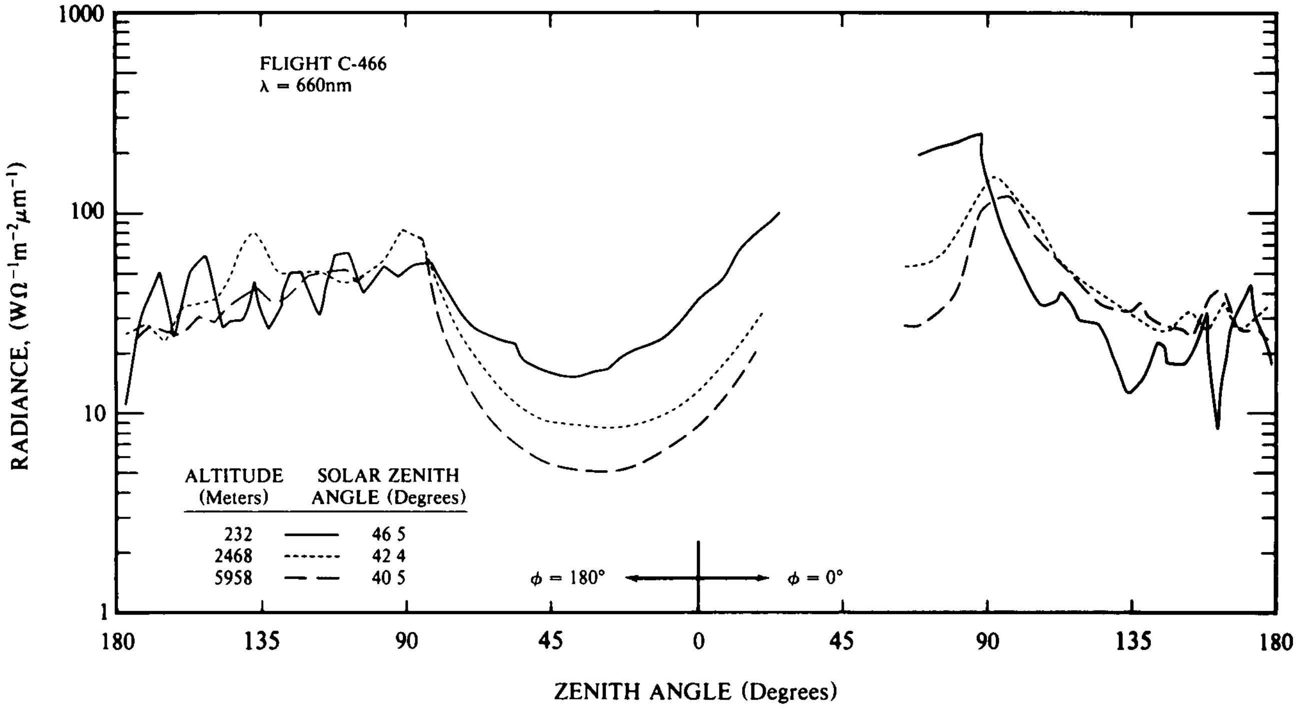


Fig. 4-3. Variation of Radiance Field with Altitude, Flight C-466, λ = 660 nm, ϕ = 0°/180°.

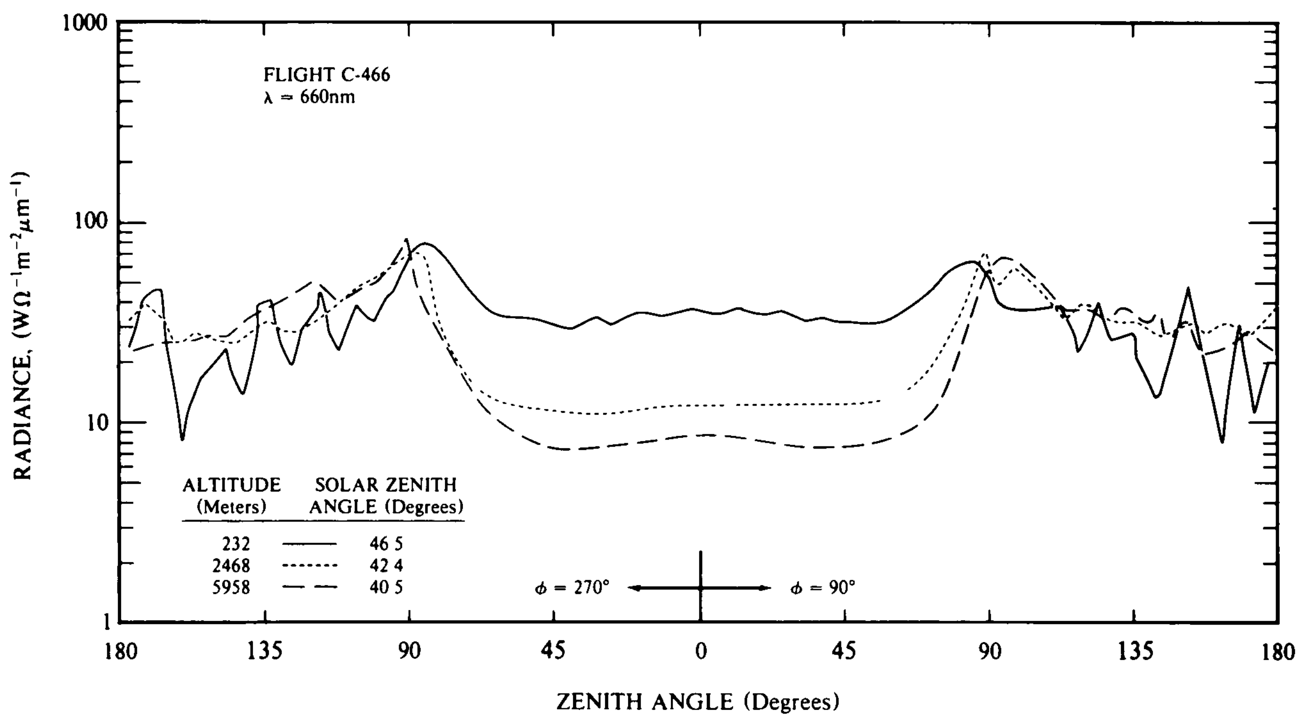


Fig. 4-4. Variation of Radiance Field with Altitude, Flight C-466, λ = 660 nm, ϕ = 90°/270°.

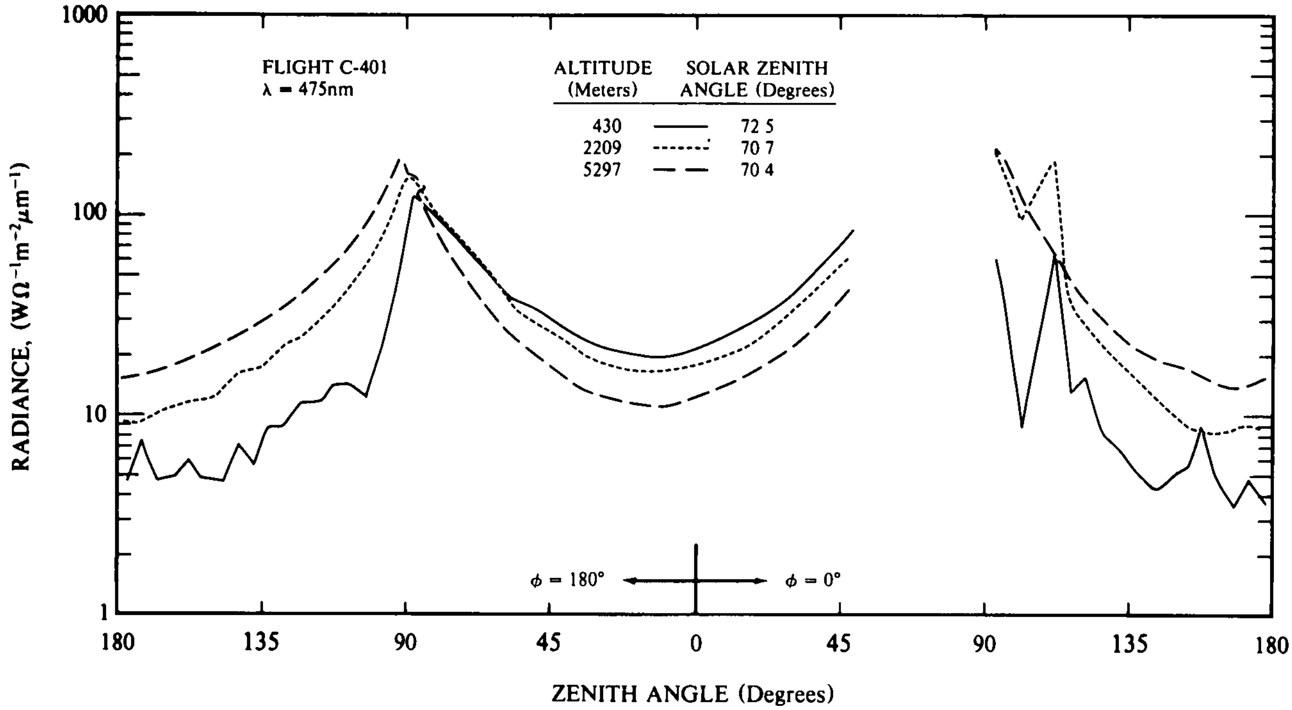


Fig. 4-5. Variation of Radiance Field with Altitude, Flight C-401, λ = 475 nm, ϕ = 0°/180°.

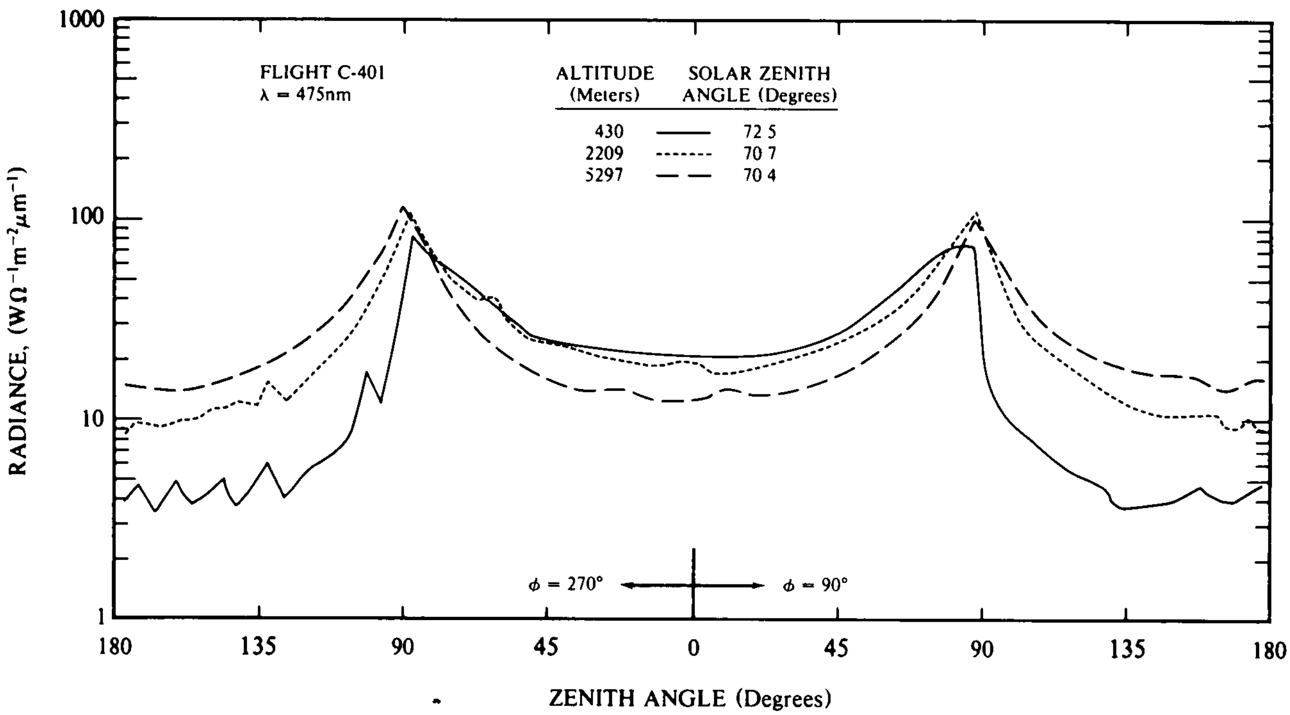


Fig. 4-6. Variation of Radiance Field with Altitude, Flight C-401, λ = 475 nm, ϕ = 90°/270°.

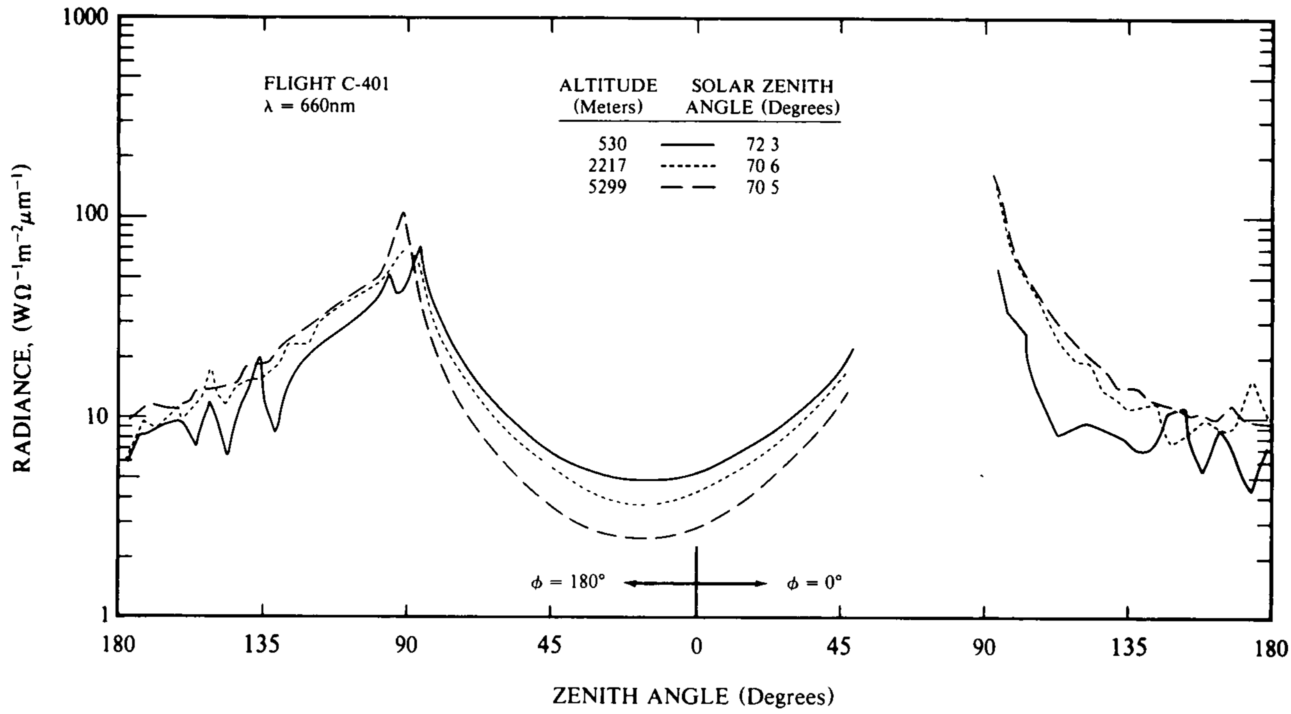


Fig. 4-7. Variation of Radiance Field with Altitude, Flight C-401, λ = 600 nm, ϕ = 0°/180°.

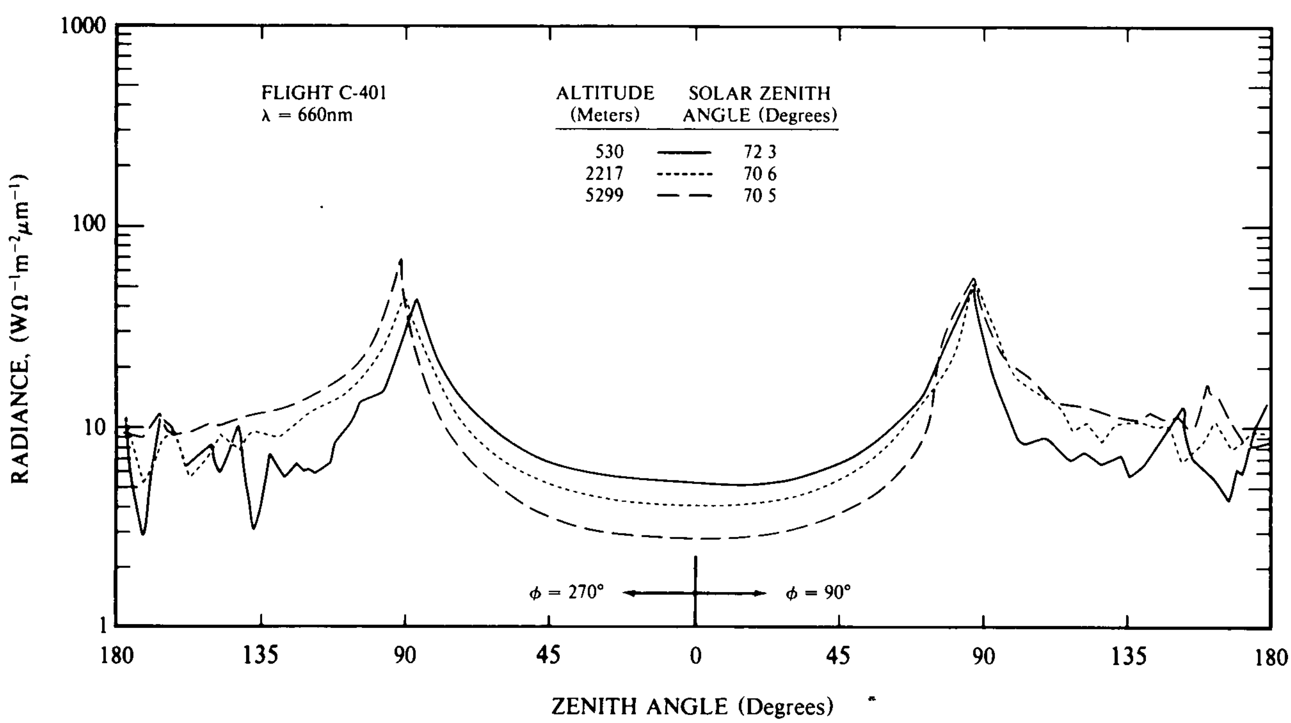


Fig. 4-8. Variation of Radiance Field with Altitude, Flight C-401, λ = 600 nm, ϕ = 90°/270°.

4.3 Radiance Variations with Wavelength

Comparative measurements of the radiance fields as a function of wavelength for the same two experimental flights, C-466 and C-401, are shown for two altitude levels in Figs. 4-9 through 4-16. Since the coefficient for Rayleigh scattering varies as the -4th power of wavelength (λ) and the Mie scattering coefficient varies roughly in the range $\lambda^{-0.5}$ to $\lambda^{-1.5}$, the radiance field has a strong spectral dependence. Thus, we see in Figs. 4-9 through 4-16 a very pronounced decrease in sky radiance with increasing wavelength in the visible spectrum. But as indicated by Eqs. (1) through (4), at any given altitude within a flight, and for any given view angle, the ratios between the various spectral measurements of clear sky radiance remain relatively constant.

Note also in Figs. 4-9 through 4-16 that the spectral variations (475 to 660 nm) of the measured apparent terrain radiance (lower hemisphere) is much less than the spectral variation of the corresponding sky radiance (upper hemisphere) measurements. Again, much of the observed variation in measured terrain radiance is due to small scale fluctuations in surface reflectivity. However, a prominent feature of the apparent terrain radiance measurements is the relatively large lower hemisphere radiance values for Filter 5 (750 nm), which result from the characteristically large surface reflectance for rural farm and wooded areas in the near infrared portion of the spectrum.

Note: See Appendix B for Flight Descriptions.

Flight C-401, page 34
Flight C-466, page 42

Figs. 4-9 through 4-16 are shown on pages 22-25.

4.4 Radiance Fluctuations with Variable Cloud Cover

Composite plots of cloudy day radiance fields as measured during several experimental flights are illustrated in Figs. 4-17 through 4-22. These plots are shown to illustrate some of the radiance fluctuations observed under a relatively broad selection of variable cloud conditions. As discussed briefly in Section 3, the association of a specific cloud category, *i.e.* scattered ⦶, broken ⦷ or overcast ⊕, with any particular plot is somewhat subjective even though the category assigned each plot in Figs. 4-17 through 4-22 has been validated by examining its specific companion photograph.

Figures 4-17 and 4-18 illustrate measurements collected during flights C-444, C-450B, C-468 and C-475 in the blue spectral band (Filter 2), and at relatively low altitude. Flights C-444, C-450B, and C-475 were carried out in the presence of multiple layers of scattered to broken clouds where the overall effect was overcast (see descriptions of weather characteristics). Shown for comparison is the radiance field for flight C-468 which was conducted in essentially clear sky conditions (few high cirrus clouds). All measurements were in the 200-350m altitude range over rural areas with light to moderate haze in the boundary layer and the solar zenith angle in the range 49 to 55 deg. We note that the measured sky and terrain radiances for the cloudy cases tends to fluctuate both above and below the radiance distribution for the clear sky reference case depending upon the scattering and reflectance properties of the clouds, haze and terrain as a function of viewing path. The measured cloudy sky radiance is a factor of two or more larger in some instances, but in general remains within about ± 50 percent of the clear sky radiance for the corresponding upward path of sight for these atmospheres and wavelength (475 nm).

A second series of flights illustrating variable cloud conditions is shown in Figs. 4-19 and 4-20. These five flight episodes represent a broader variety of conditions, ranging from clear to overcast, as measured in the photopic spectral band, and at an intermediate altitude. The solar zenith angles for this series ranged between 50 and 65 degrees, similar to those in the preceeding example. With the generally more cluttered sky and terrain conditions illustrated in Fig. 4-19 and 4-20 we note even larger fluctuations in the radiance distributions than shown earlier. One should keep in mind the difference in the terrain characteristics in these examples. *i.e.* 3 flights over cultivated farmland, and 2 flights over snowy forest, and its influence upon associated path radiances.

The final examples of cloudy day measurements are shown in Figs. 4-21 and 4-22. The plots in these figures represent measurements made in the blue spectral band, as in the initial cloudy day example, but in this second case at maximum flight altitude. At this altitude, the relatively thin cloud coverages show only small influences upon the upper hemisphere radiance distributions, although the underlying decks still contribute to a significant variation in the apparent terrain radiances.

Note:

See Appendix B for Flight Descriptions.

Flight C-444, page 38
Flight C-450B, page 40
Flight C-468, page 43
Flight C-475, page 46

Figs. 4-17 through 4-22 are shown on pages 26-28.

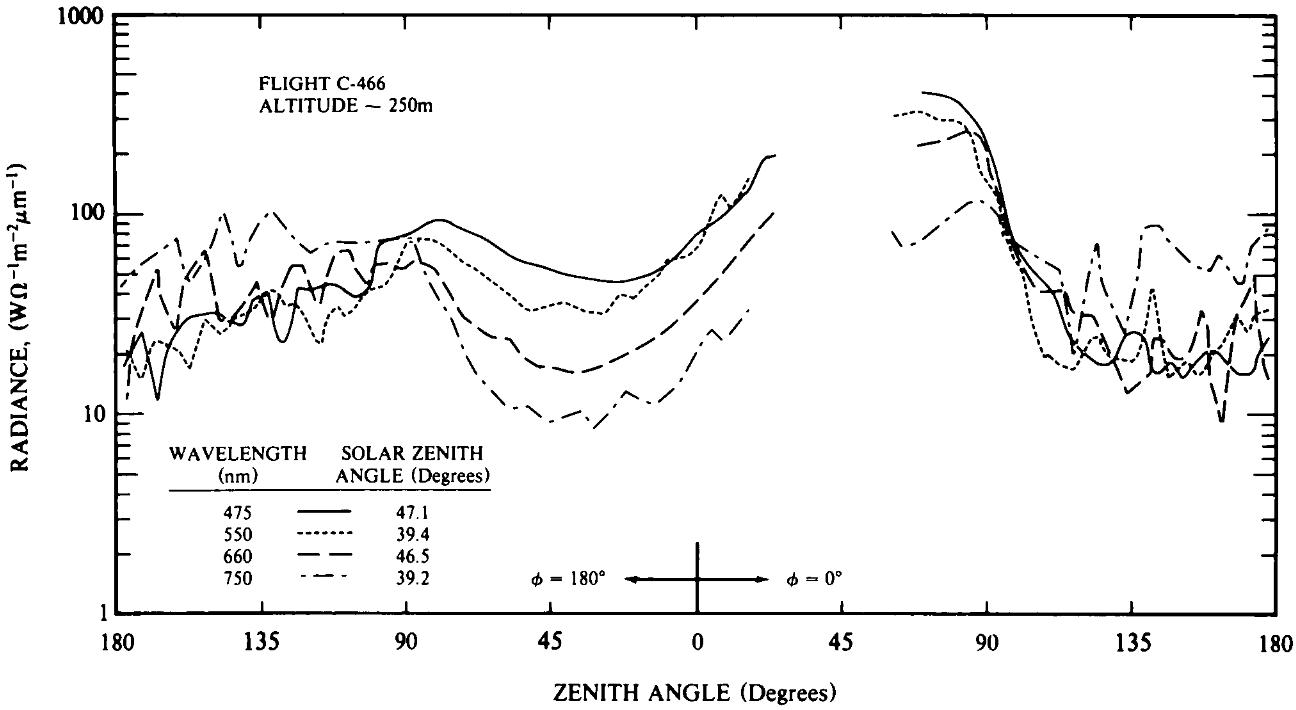


Fig. 4-9. Variation of Radiance Field with Wavelength, Flight C-466, $z \approx$ 250m AGL, ϕ = 0°/180°.

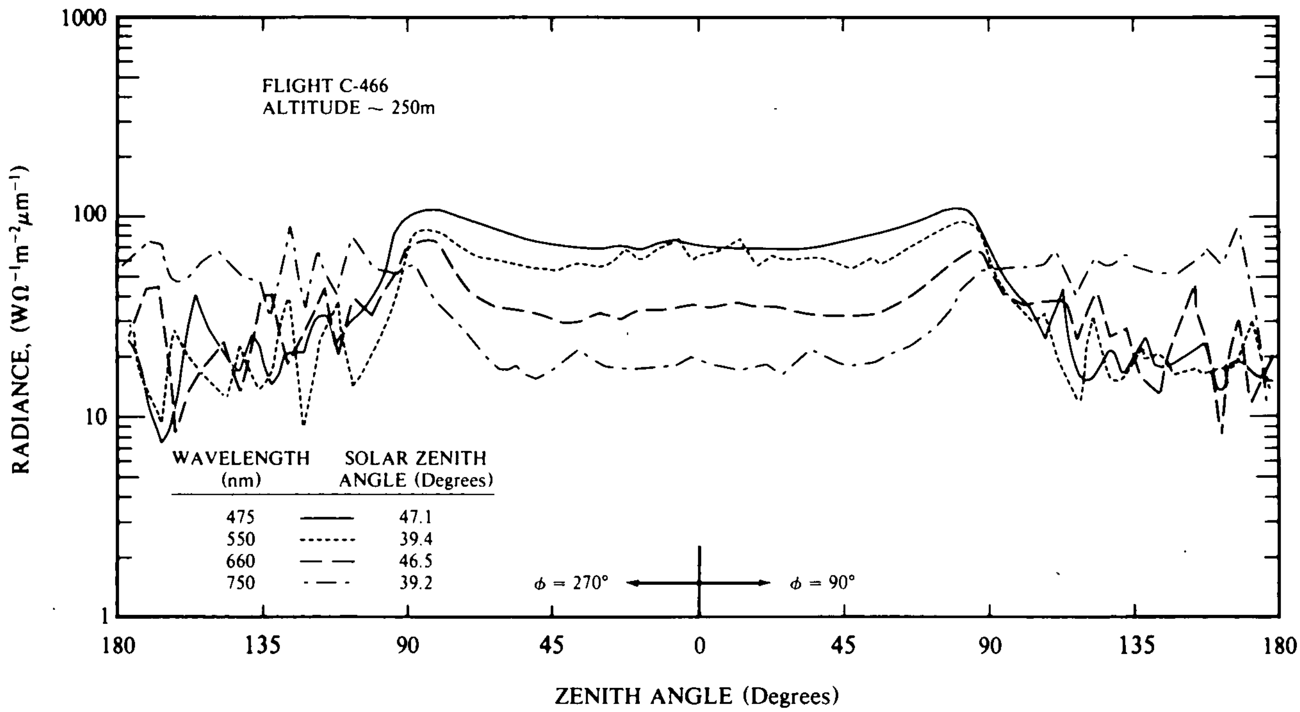


Fig. 4-10. Variation of Radiance Field with Wavelength, Flight C-466, $z \approx$ 250m AGL, ϕ = 90°/270°.

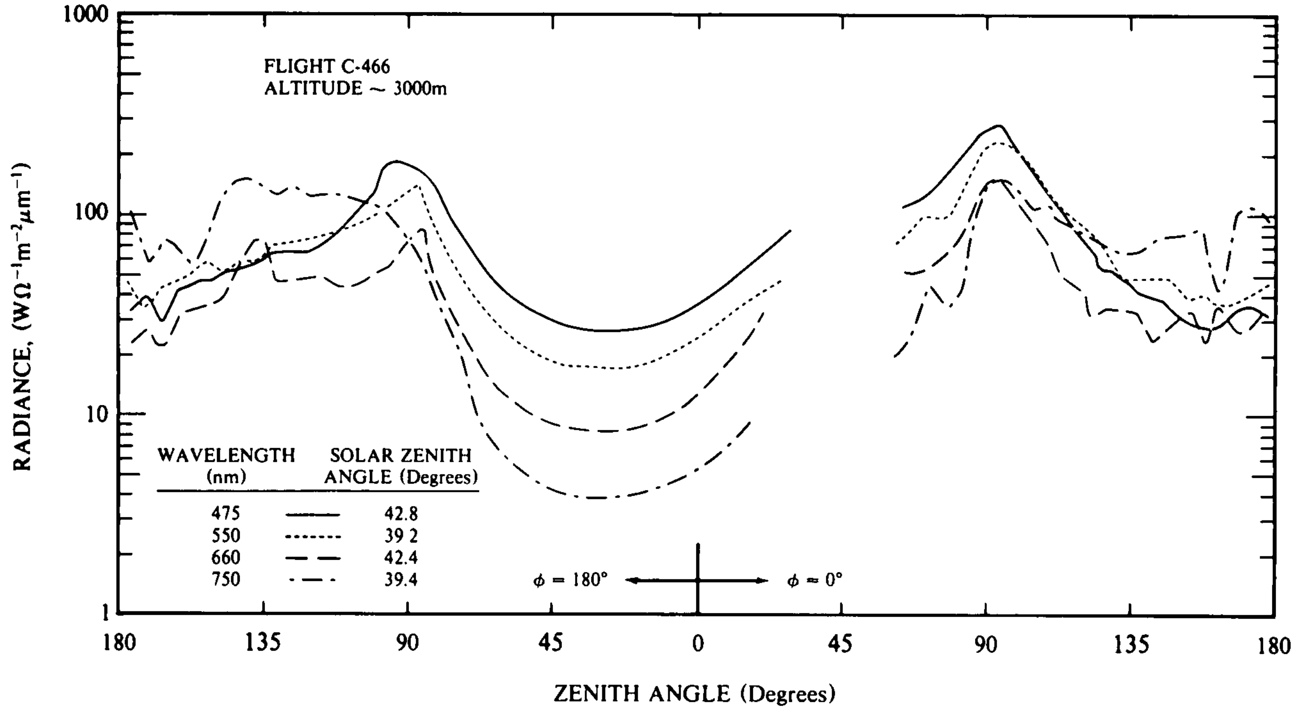


Fig. 4-11. Variation of Radiance Field with Wavelength, Flight C-466, $z \approx$ 3000m AGL, ϕ = 0°/180°.

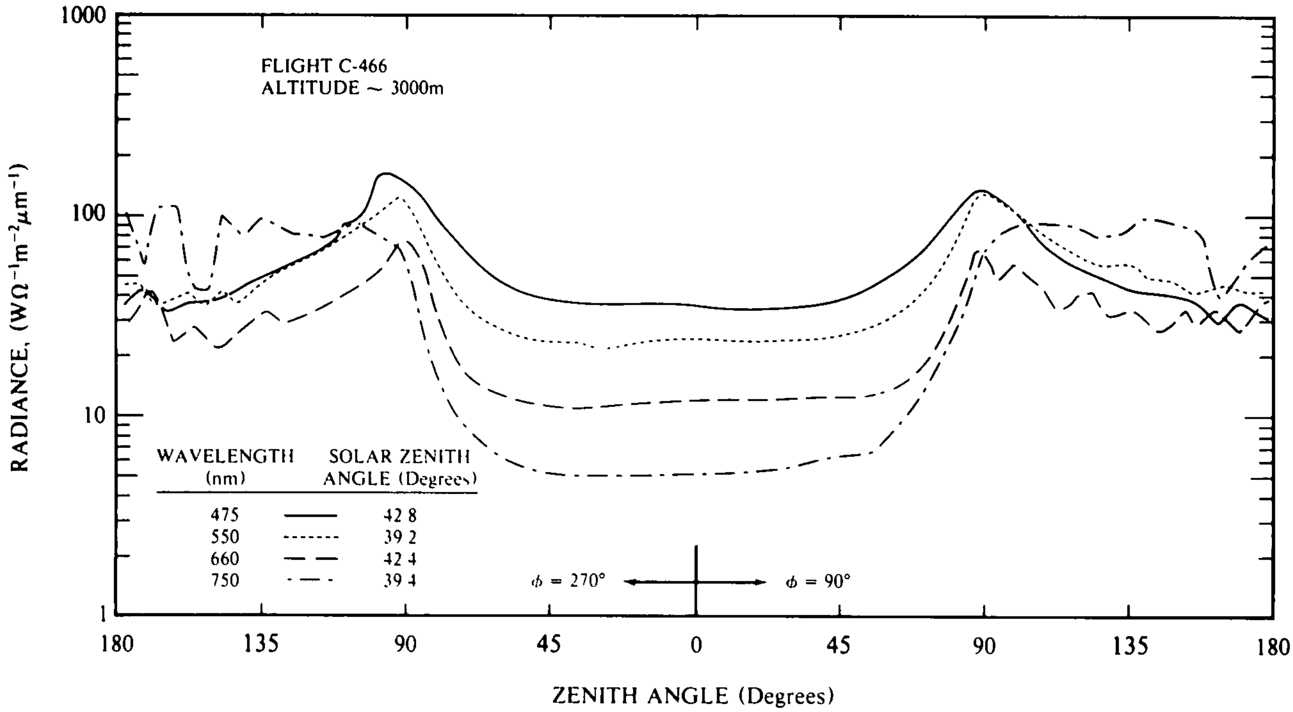


Fig. 4-12. Variation of Radiance Field with Wavelength, Flight C-466, $z \approx$ 3000m AGL, ϕ = 90°/270°.

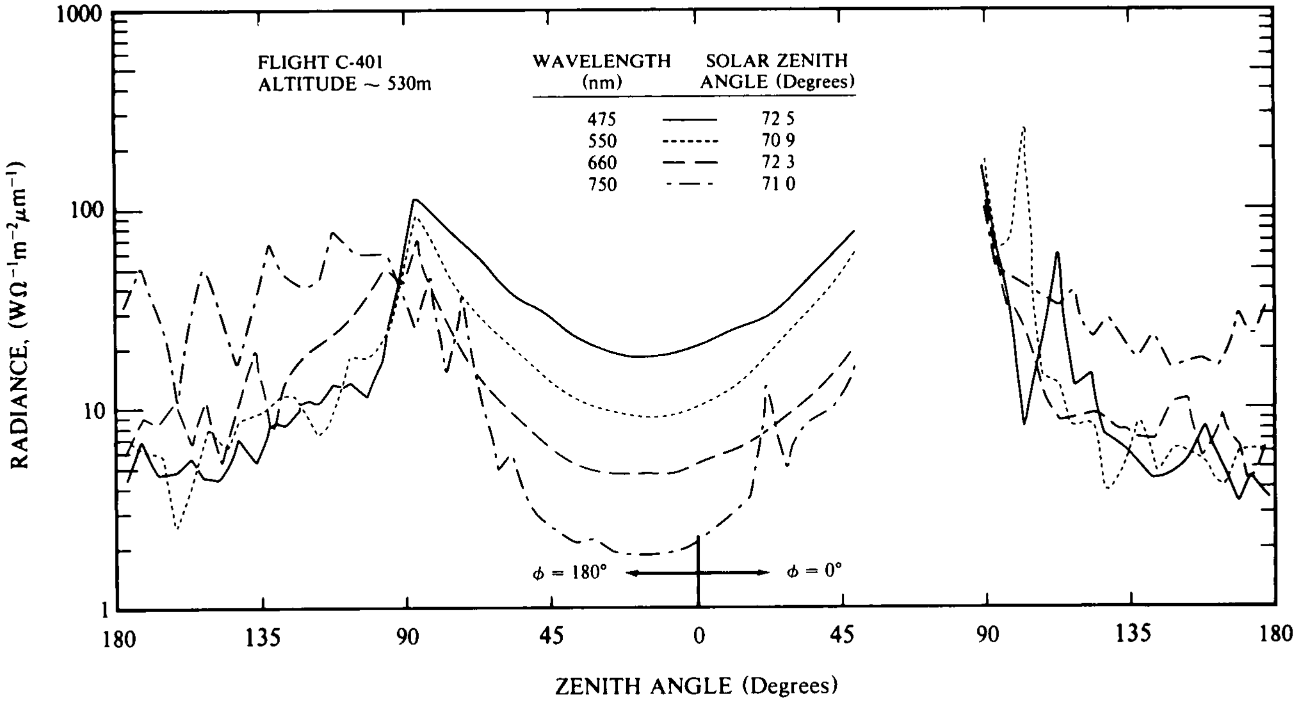


Fig. 4-13. Variation of Radiance Field with Wavelength, Flight C-401, $z \approx$ 530m AGL, ϕ = 0°/180°.

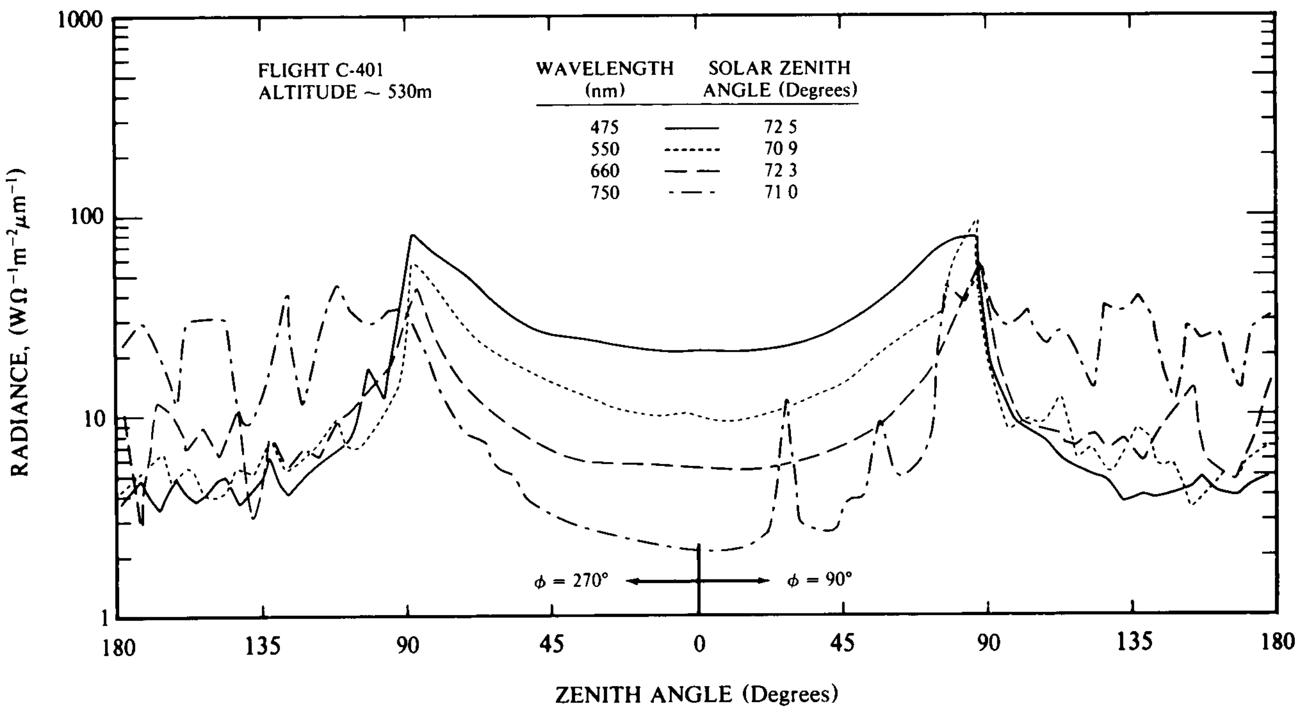


Fig. 4-14. Variation of Radiance Field with Wavelength, Flight C-401, $z \approx$ 530m AGL, ϕ = 90°/270°.

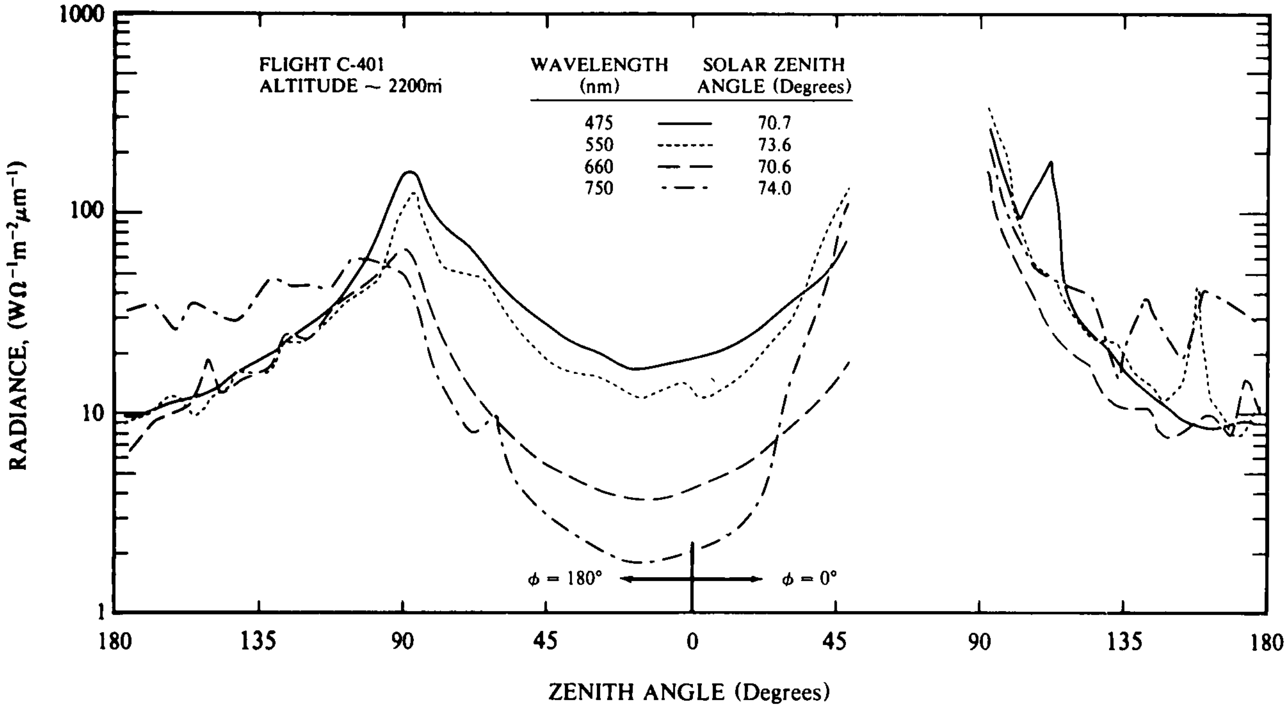


Fig. 4-15. Variation of Radiance Field with Wavelength, Flight C-401, $z \approx$ 2200m AGL, ϕ = 0°/180°.

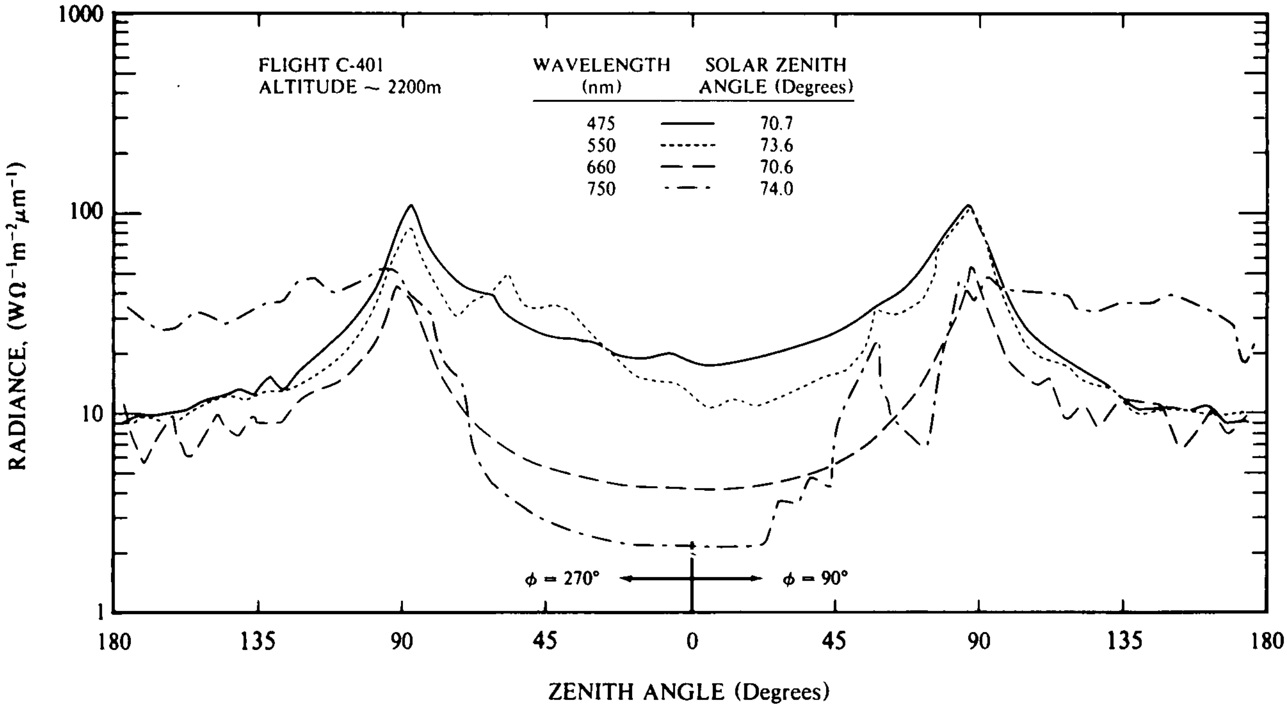


Fig. 4-16. Variation of Radiance Field with Wavelength, Flight C-401, $z \approx$ 2200m AGL, ϕ = 90°/270°.

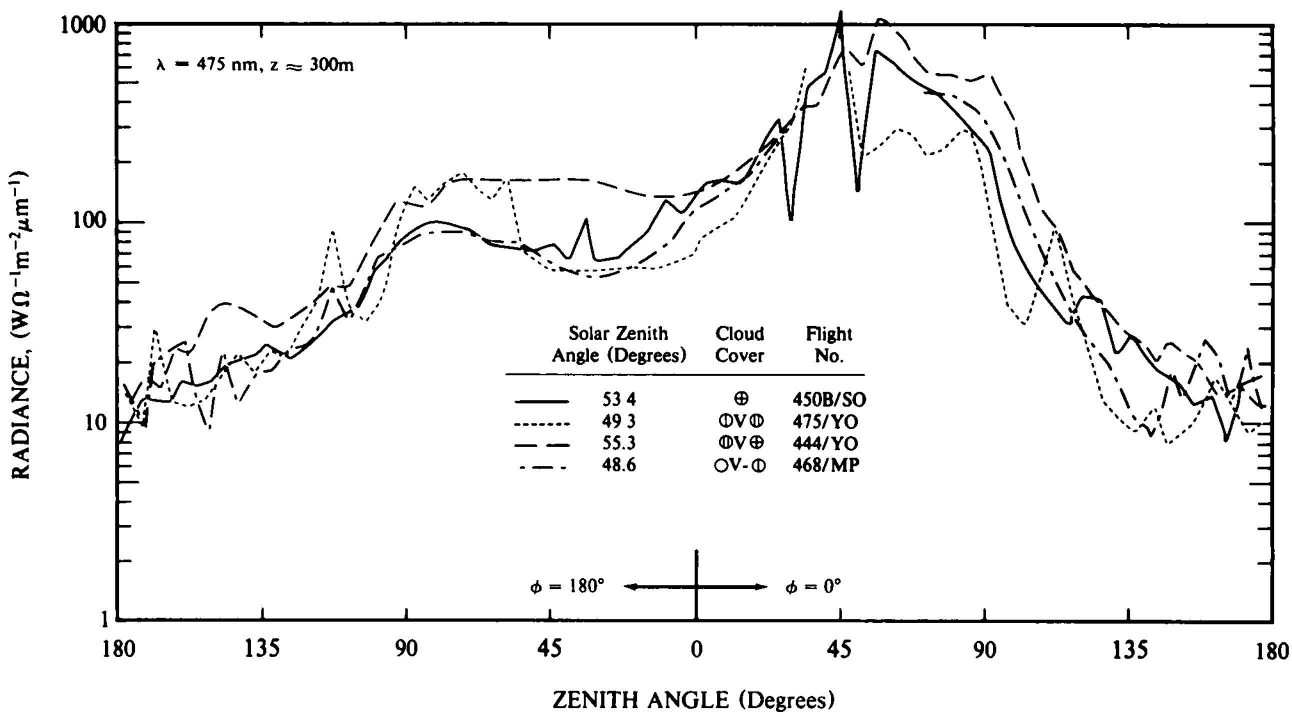


Fig. 4-17. Comparison of Radiance Measurements for Selected Flights with Variable Cloud Cover, λ = 475 nm, $z \approx$ 300m AGL, ⓘV⊕, ϕ = 0°/180°

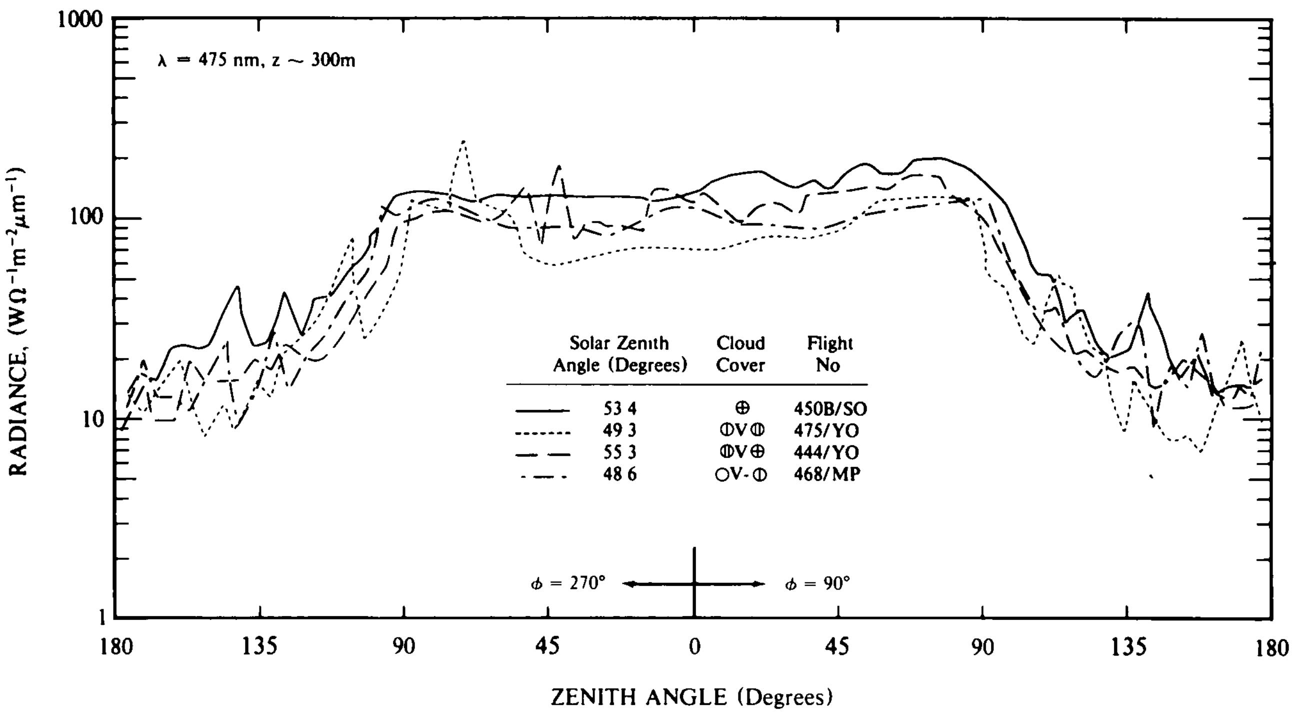


Fig. 4-18. Comparison of Radiance Measurements for Selected Flights with Variable Cloud Cover, λ = 475 nm, $z \approx$ 300m AGL, ⓘV⊕, ϕ = 90°/270°

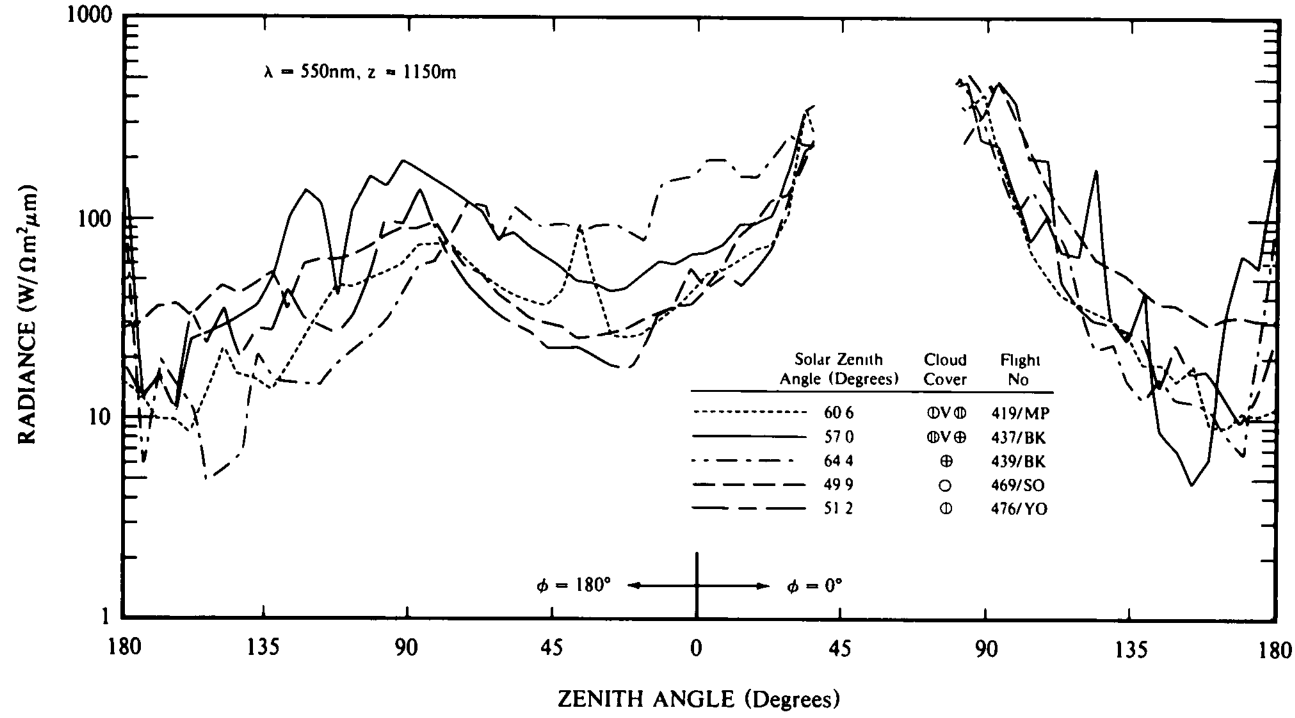


Fig. 4-19. Comparison of Radiance Measurements for Selected Flights with Variable Cloud Cover, λ = 557 nm, $z \approx$ 1500m AGL, OV⊕, ϕ = 0°/180°

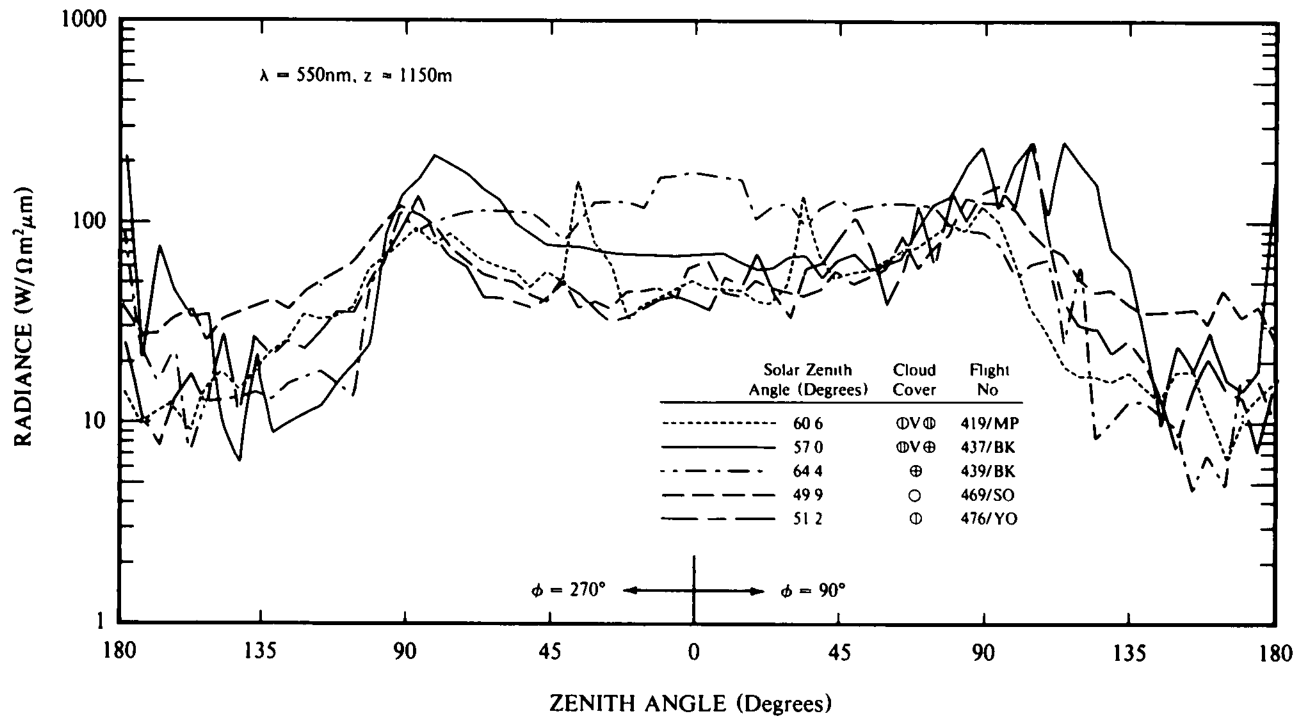


Fig. 4-20. Comparison of Radiance Measurements for Selected Flights with Variable Cloud Cover, λ = 557 nm, $z \approx$ 1500m AGL, OV⊕, ϕ = 90°/270°

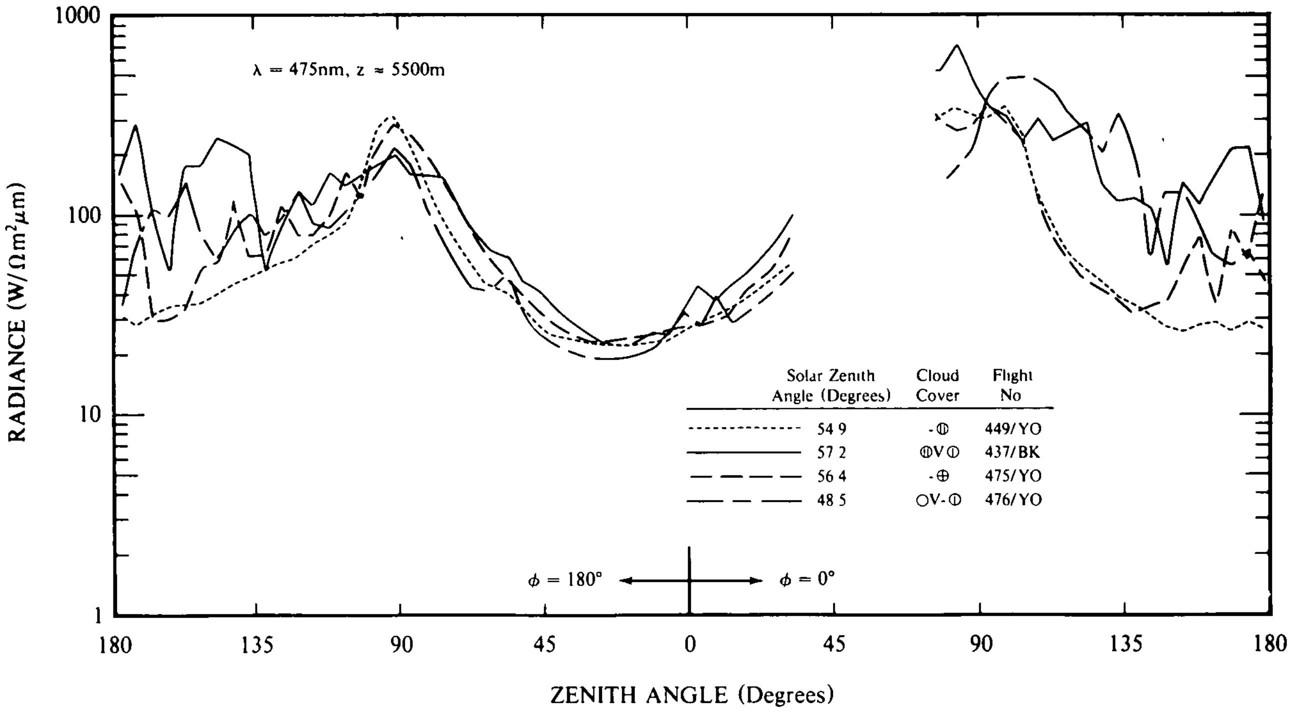


Fig. 4-21. Comparison of Radiance Measurements for Selected Flights with Variable Cloud Cover, λ = 475 nm, $z \approx$ 5000m AGL, ○V◑, ϕ = 0°/180°

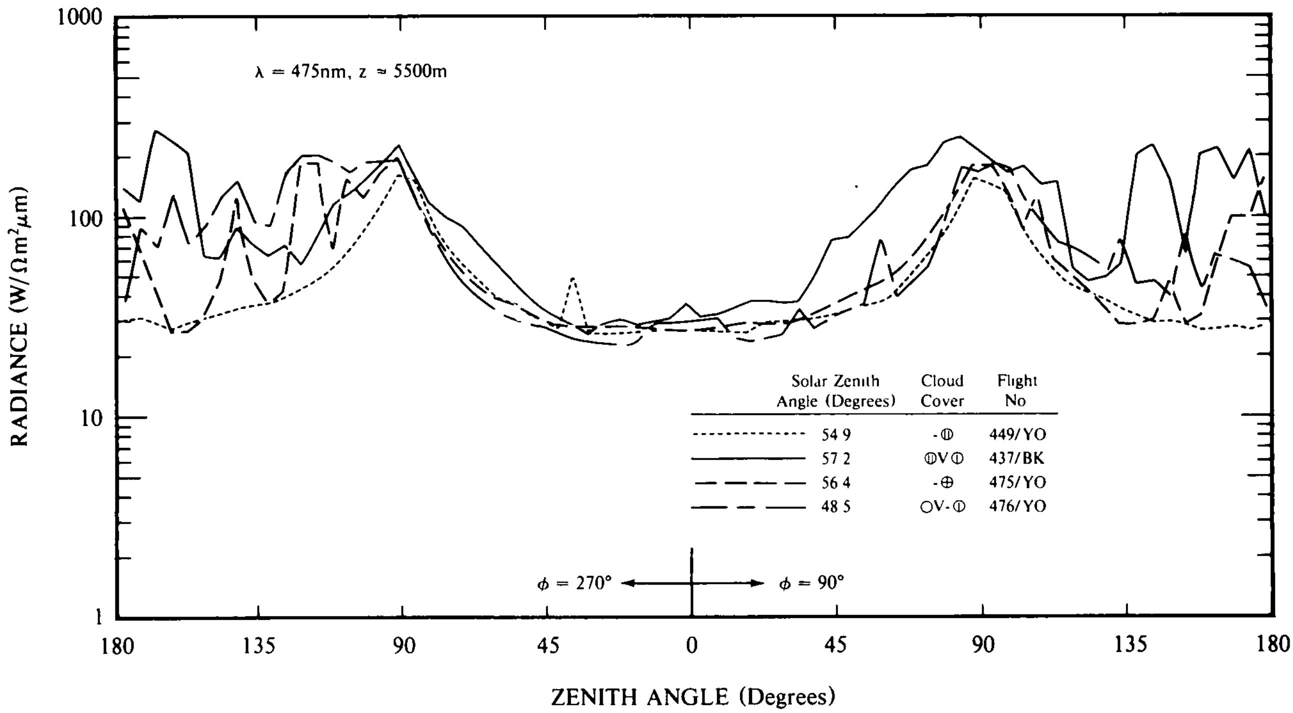


Fig. 4-22. Comparison of Radiance Measurements for Selected Flights with Variable Cloud Cover, λ = 475 nm, $z \approx$ 5000m AGL, ○V◑, ϕ = 90°/270°

4.5 Radiance Variations with Overcast Sky Conditions

Figure 4-23 shows a comparison of radiance fields as measured during a series of three experimental flights under low overcast conditions with the ceiling 1800m or less. As discussed in the descriptions of flight and weather characteristics, the haze conditions in the lower atmosphere varied from light to moderate (C-471, C-465) to heavy (C-422). The measured upper hemisphere radiance fields below the overcast tend to have only a slight dependence upon azimuthal angle and a rather uniform and systematic variation with the zenith angle, such that the zenith radiance is roughly a factor of 2 to 3 larger than the horizon radiance. Thus, the distributions correspond in general to the analytic expression given by Middleton (1952) Eq. (6-8),

$$L(z,\theta) = L(z,90)[1+m \cos\theta] , \qquad (5)$$

where m for these data is in the range of 1 to 2.

The variation of the radiance field as a function of wavelength for one of the cloud cases (C-465) is shown in Fig. 4-24. Again, we note that the variation in upper hemisphere radiance is rather uniform and systematic with respect to zenith angle for the measurements with all 4 band pass filters, ranging from the narrow band blue (475 nm) to the near infrared band (750 nm). The changes in upper hemisphere radiance with wavelength tend to be small and of the same magnitude as the fluctuations due to temporal variations in the optical thickness of the overcast. Similarly, the measured terrain radiances (lower hemisphere) show only small variations with wavelength in the visible portion of the spectrum for the cloud case. However, the apparent terrain radiance for the near infrared band (750 nm) is much larger due to enhanced reflectance of the underlying surface at this wavelength, as discussed in Section 4.3.

Note: See Appendix B for Flight Descriptions.

Flight C-422, page 35
Flight C-465, page 41
Flight C-471, page 45
Flight C-434, page 36
Flight C-437, page 37

Figs. 4-23 & 4-24 are shown on page 30.

Figs. 4-25 & 4-26 are shown on page 31.

4.6 Radiance Variations due to Changes in Surface Reflectance

Finally, one additional example in this series of composite graphs is given to illustrate further the strong influence of surface reflectance upon the apparent terrain radiance. Two radiance fields are depicted in Figs. 4-25 and 4-26. The first (flight C-434) was carried out in February over the Mediterranean Sea near Sicily. The second (flight C-437) was over snow covered fields and forest areas in February near Birkhof in southwest Germany. As given in the flight descriptions, scattered or scattered to broken light clouds were present during both flights, with excellent visibility. The contrast in terrain radiance is clearly evident in Figs. 4-25 and 4-26. Over water, the lower hemisphere radiance is uniformly low except for the prominent sun glitter in the upsun (ϕ=0) direction. In contrast, the snow covered terrain radiance is at least an order of magnitude larger than the sea surface radiance and shows very large fluctuations as the scanner passes alternately over the snow covered fields and deep wooded areas. Note also that the horizon radiance for flight C-434 (over water) is a order of magnitude larger than the zenith and nadir radiances.

5. SUMMARY

A data set, first described in AFGL-TR-81-0275, Johnson (1981), which contains nearly 500 arrays representing measurements of sky and terrain radiance values is reviewed and further illustrated with respect to naturally occurring radiance variations. The measurements were made using radiometer systems mounted on a C-130 aircraft during a series of European flights associated with the NATO Program OPAQUE, Fenn (1978) and Johnson *et al.* (1979).

Radiance measurements throughout the 4π field surrounding the aircraft during seventeen separate flight episodes are presented and discussed with respect to their variability as a function of altitude, look angle, cloud cover and spectral band. The measurements were made in spectral bands having mean wavelengths of 478, 557, 664 and 765 nm, and under meteorological conditions ranging from fully overcast to clear and cloudfree. With appropriate caveats, examples of "typical" overcast, broken cloud and clear day radiance distributions are illustrated.

Whereas these data illustrate substantial variations in the radiance distribution from day to day, there are determinable patterns that may provide boundary conditions for a very generalized attempt of classification. Thus, as were the data displayed in the earlier companion report, Johnson (1981), these data are appropriate for use in the development of operationally useful predictive models as illustrated in Hering (1981).

6. ACKNOWLEDGEMENTS

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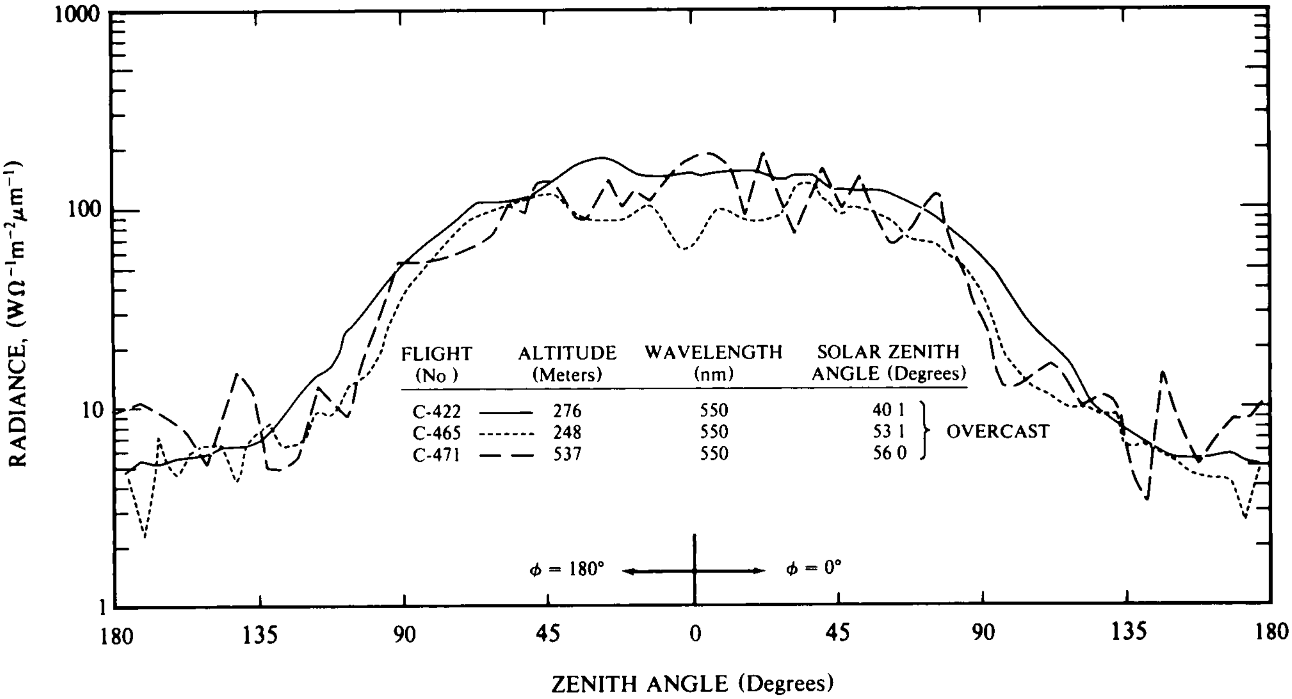

Fig. 4-23. Comparison of Radiance Measurements for Selected Flights with Fully Overcast Sky, $\lambda = 550$ nm, $z \approx 250$m AGL, , $\phi = 0°/180°$.

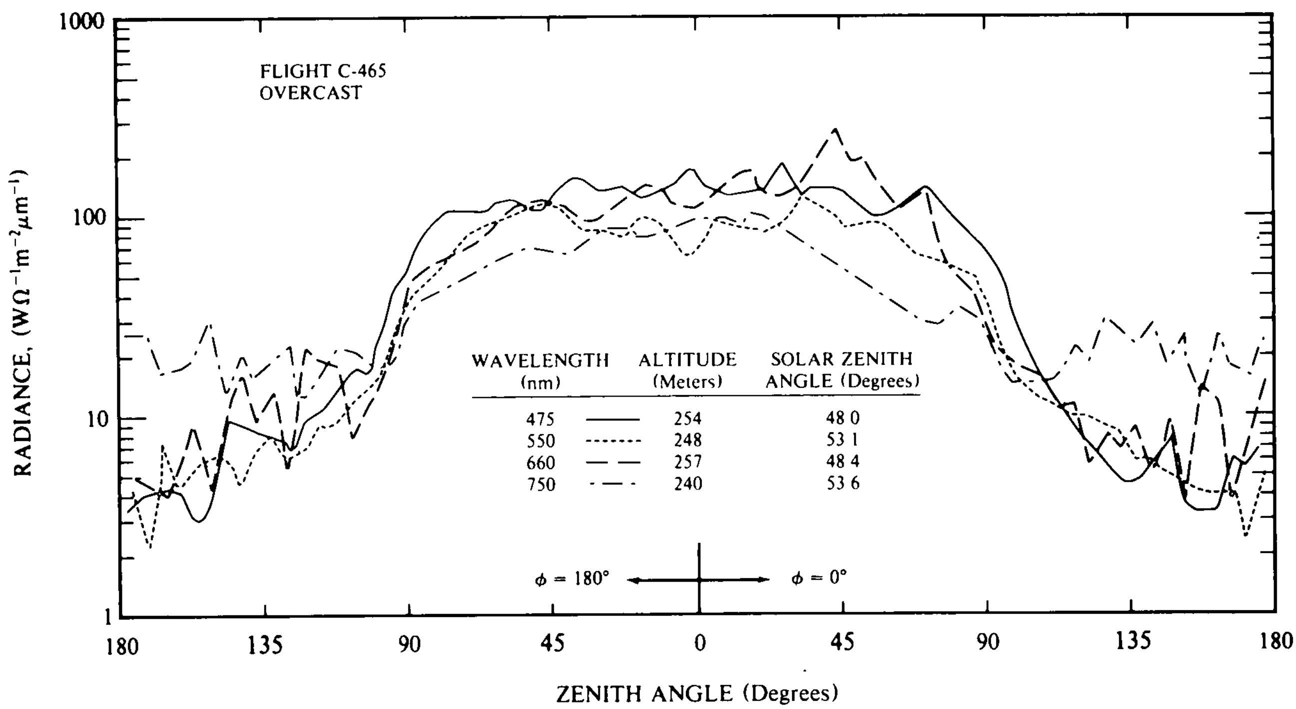

Fig. 4-24. Radiance Distribution as a Function of Wavelength for Overcast Sky Conditions, Flight C-465, $z \approx 250$m AGL, $\phi = 0°/180°$.

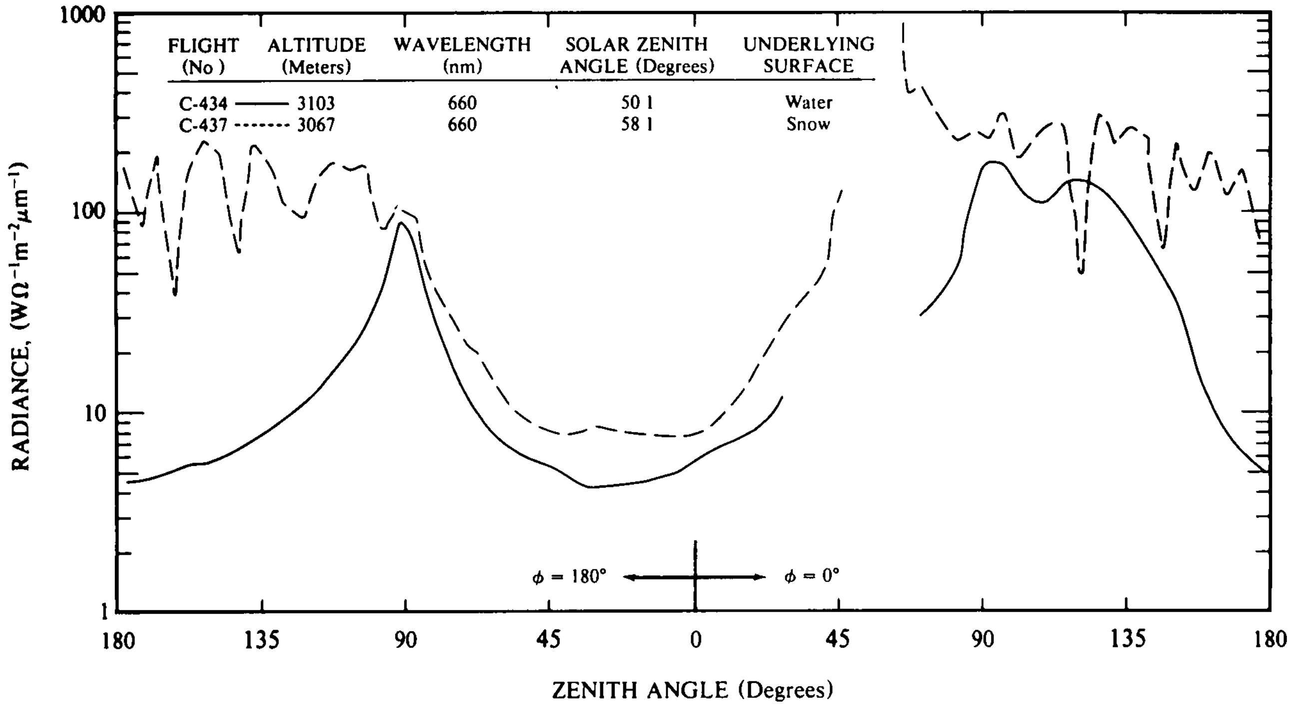

Fig. 4-25. Comparison Between Terrain Radiance Distributions Measured Over Sea Surface and Snow Covered Land Surface, $\lambda = 660$ nm, $z \approx 3000$m AGL, $\phi = 0°/180°$

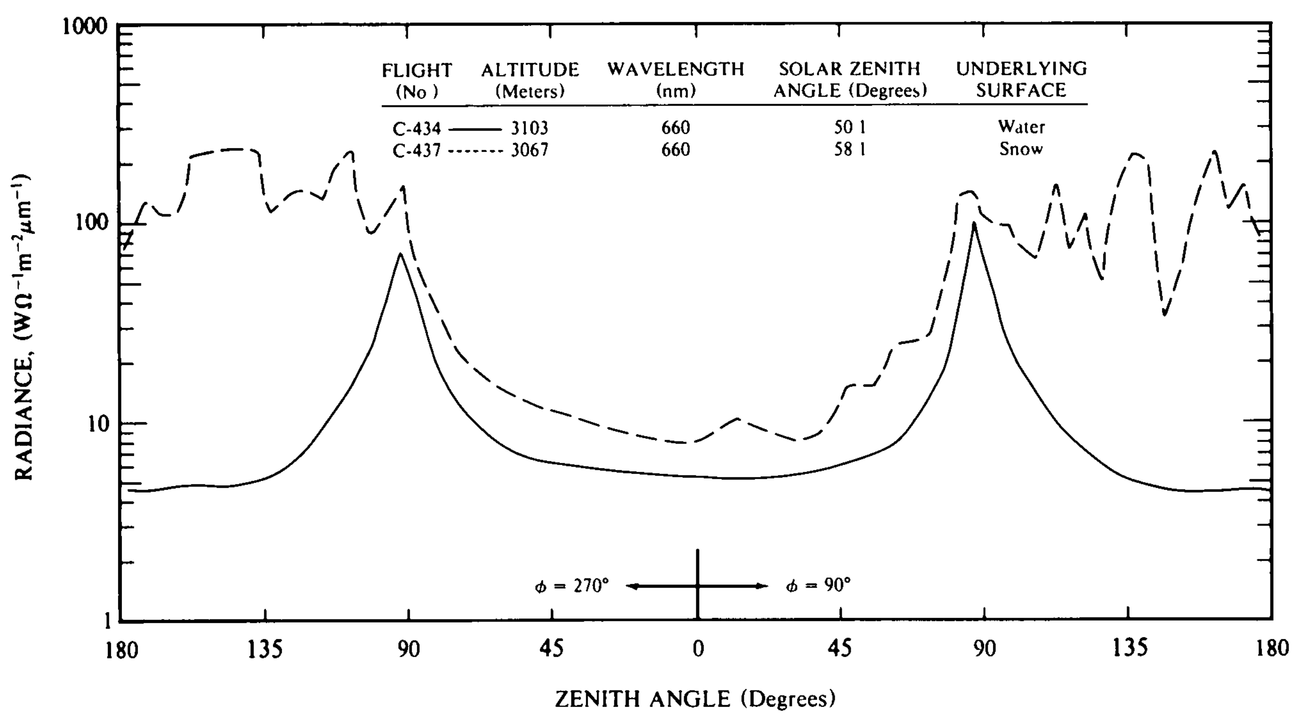

Fig. 4-26. Comparison Between Terrain Radiance Distributions Measured Over Sea Surface and Snow Covered Land Surface, $\lambda = 660$ nm, $z \approx 3000$m AGL, $\phi = 90°/270°$.

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APPENDIX A: Meteorological Glossary & Abbreviations

SKY AND CEILING

Sky cover symbols are in ascending order. Figures preceding symbols are heights in hundreds of feet above station. Sky cover symbols are:

- ○ Clear: less than 0.1 sky cover
- ⦶ Scattered: 0.1 to less than 0.6 sky cover
- ⦷ Broken: 0.6 to 0.9 sky cover
- ⊕ Overcast: more than 0.9 sky cover
- \- Thin (when prefixed); light (when suffixed)
- -- Very light (when suffixed)
- -X Partial obscuration: 0.1 to less than 1.0 sky hidden by precipitation or obstruction to vision (bases at surface)
- X Obscuration: 1.0 sky hidden by precipitation or obstruction to vision (bases at surface)

Letter preceding height of layer identifies ceiling layer and indicates how ceiling height was obtained. Thus:

- A Aircraft
- B Balloon (pilot or ceiling)
- D Estimated height of cirriform clouds on basis of persistency
- E Estimated height of noncirriform clouds
- M Measured
- R Radiosonde balloon or radar
- U Height of cirriform ceiling layer unknown
- V Immediately following numerical value indicates a varying ceiling (also used with varying visibility)
- W Indefinite, sky obscured by surface base phenomenon. e.g. fog, blowing dust, snow

RELATIVE HUMIDITY (RH)

Reported in percent and computed from temperature and dewpoint.

VISIBILITY (VV)

Reported in kilometers.

WEATHER AND OBSTRUCTION TO VISION SYMBOLS

A	Hail	IF	Ice fog
AP	Small hail	K	Smoke
BD	Blowing dust	L	Drizzle
BN	Blowing sand	R	Rain
BS	Blowing snow	RW	Rain showers
D	Dust	S	Snow
E	Sleet	SG	Snow grains
EW	Sleet showers	SP	Snow pellets
F	Fog	SW	Snow showers
GF	Ground fog	T	Thunderstorms
H	Haze	ZL	Freezing drizzle
IC	Ice crystals	ZR	Freezing rain

CLOUD ABBREVIATIONS

Ac	Altocumulus	Cs	Cirrostratus
As	Altostratus	Cu	Cumulus
Cb	Cumulonimbus	Ns	Nimbostratus
Cc	Cirrocumulus	Sc	Stratocumulus
Ci	Cirrus	St	Stratus

WIND

Direction in ten's of degrees from true north, speed in meters per second (mps). A "0000" indicates calm. A "G" indicates gusty. A "Q" indicates squall. Peak speed of gusts, when reported, follows G or Q. The contraction WSHFT in remarks followed by time group (GMT) indicates wind shift and its time of occurrence.

Examples: 0109 is 010 degrees, 9 mps.
3607G11 is 360 degrees, 7 mps, peak speed in gusts of 11 mps.

MSG: Data missing in original source.

FLIGHT C-379 - 17 MAY 1976 - DESCRIPTION OF FLIGHT AND WEATHER CHARACTERISTICS

Filter Ident	Data Interval Start (GMT)	End (GMT)	Elapsed (hrs)	Max. Flight Altitude (m)	Average Terrain Elevation (m)
2,3	0957	1138	1 7	6270	0
4,5	1143	1332	1 8	6270	0

Filter Ident	Solar Zenith Angle Initial ST&LV (degrees)	Solar Transit (degrees)	Final V-PRO (degrees)
2,3	38 0	35 3	35 7
4,5	35 8	-	44 3

Flight Description. Flight C-379 was a midday flight spanning local apparent noon. Nearby areas reported clear skies during the morning, with thin cirrus and scattered cumulus developing in the afternoon, although the in-flight pictures indicated clear skies along the track throughout the flight. The approximate southeast to northwest track was located south of Lolland Island, Denmark. Typical terrain features along the nearby coast to the north of the track was flat cultivated farmlands interspersed with occasional woods and small towns. Directly beneath the track and to the south were the relatively shallow waters of Femer Bay.

In-Flight Notes. The in-flight observer reported clear skies early in the flight with some scattered high thin cirrus beginning at 1045 GMT and increasing to 4/8 at 7500 meters (25,000 feet) by 1145 GMT. Scattered cumulus (1/8) formed at 1200 meters (4000 feet) after 1200 GMT.

Local Weather Notes. At Fehmarnbelt, 10 kilometers south of the track center point, no clouds were reported on the three-hourly observations. Visibility was reported as 20 kilometers.

Kegnaes, 80 kilometers westnorthwest of the track center point, reported 1/8 of cirrus at 6000 meters (20,000 feet) on the 1200 and 1500 GMT observations. Visibility was reported from 15 to 30 kilometers.

The radiosonde station at Schleswig was 106 kilometers west and downstream from the flight track center point.

Synoptic Remarks. The surface chart for 1200 GMT shows a closed high cell centered near Kiel Bay. A cold front was moving from Ireland to Britain through the Irish Sea. At 500 millibars there was weak ridging from Sardinia to Sweden with light northwesterly winds. The air mass was stable maritime polar.

FLIGHT C-401 - 5 DECEMBER 1976 - DESCRIPTION OF FLIGHT AND WEATHER CHARACTERISTICS

Filter Ident	Data Interval Start (GMT)	End (GMT)	Elapsed (hrs)	Max Flight Altitude (m)	Average Terrain Elevation (m)
2,3	1040	1227	1 8	5190	46
4,5	1233	1428	1 9	5190	46

Filter Ident	Solar Zenith Angle Initial ST&LV (degrees)	Solar Transit (degrees)	Final V-PRO (degrees)
2,3	72 5	70 4	70 8
4,5	70 9	-	78 2

Flight Description. Flight C-401 was a midday flight spanning local apparent noon. Scattered cumulus and scattered thin cirrus did not interfere with collection of data. The approximate east to west Bruz track was centered south of Rennes in northwestern France. Typical terrain features were green fields interspersed with some brown areas and dark green trees.

In-Flight Notes. The in-flight observer noted thin scattered cirrus throughout the flight with scattered cumulus at 900 to 1050 meters (3000 to 3500 feet) forming after 1230 GMT. Multiple haze layers present in the morning became more dense in the afternoon.

Local Weather Notes. Rennes/St. Jacques, north of the center of the track, reported 1/8 cumulus at 600 meters (2000 feet) and 1/8 to 2/8 thin cirrus at 7500 meters (25,000 feet) throughout the period. Visibility was 11.2 to 35 kilometers.

St. Nazaire-Montoir, south of the track, reported 1/8 cumulus and stratocumulus at 600 meters (2000 feet) and 11.2-kilometer visibility at 0900 GMT. There were no other observations reported from this station.

Nantes-Chateau Bougon, south of the track, had 1/8 cumulus at 750 meters (2500 feet), 1/8 altocumulus at 4500 meters (15,000 feet) and 1/8 thin cirrus at 7500 meters (25,000 feet). Visibility ranged from 11.2 to 30 kilometers.

Anbers/Arville, southeast of the track, had 1/8 cumulus at 750 meters (2500 feet) and 1/8 thin cirrus at 7500 meters (25,000 feet). Visibilities were 11.2 to 20 kilometers.

The radiosonde station at Brest was approximately 200 kilometers westnorthwest of the center of the track. The upper winds flowed from the region of the radiosonde station toward the track.

Synoptic Remarks. The surface chart for 1200 GMT showed that a complex low dominated northern Europe and the northern Atlantic. A 960-millibar low had an occlusion oriented 4 degrees west of the Irish coast and 8 degrees from western France. There was an open 995-millibar low located near Paris. Some weak ridging between the two lows occurred over the area of Rennes. At 500 millibars there was a low north of Bergen together with weak ridging off France and into southeastern Ireland and Great Britain. This pressure combination produced moderate northwesterly flow over the flight region. The air mass was unstable maritime polar.

FLIGHT C-419 - 4 AUGUST 1977 - DESCRIPTION OF FLIGHT AND WEATHER CHARACTERISTICS

Filter Ident	Data Interval Start (GMT)	End (GMT)	Elapsed (hrs)	Max Flight Altitude (m)	Average Terrain Elevation (m)
2 3	1436	1518	0 7	750	18
4 5	1524	1608	0 7	750	18

Filter Ident	Solar Zenith Angle Initial ST&LV (degrees)	Solar Transit (degrees)	Final V PRO (degrees)
2 3	50 1		56 0
4 5	56 8		63 4

Flight Description. Flight C-419 was an afternoon flight There were scattered cumulus clouds in the process of dissipation and scattered cirrus The approximate northeast to southwest Meppen track was located between Oldenburg and Lathen in northwestern Germany Typical terrain features were heavily cultivated low lying flat farmlands interspersed with occasional dark woods and small towns

In-Flight Notes The in-flight observer reported scattered cloud bases at 1050 meters (3500 feet) These clouds were in the dissipation stage gradually becoming less There was moderate haze at all flight altitudes The slant range visibility was 5 to 7 miles at 300 meters (1000 feet) and 6 miles at 750 meters (2500 feet)

Local Weather Notes. Oldenburg, 42 kilometers east-northeast of the flight track center, reported 2/8 to 1/8 cumulus based at 1050 meters (3500 feet) and 4/8 to 3/8 cirrus at 7500 meters (25,000 feet) Visibility was observed as 6 0 to 7 0 kilometers in haze

Ahlhorn, 43 kilometers eastsoutheast of the flight track center, reported two layers of cumulus with 1/8 based at 750 meters (2500 feet) and 3/8 based at 1050 meters (3500 feet) early in the afternoon At 1544 GMT the observation was 2/8 cumulus at 1050 meters (3500 feet) Visibility of 6 0 kilometers in haze improved to 11 2 kilometers by 1544 GMT

Meppen, 39 kilometers southwest of the flight track center, had 4/8 cumulus based at 1200 meters (4000 feet) and 11 2 kilometers visibility

The radiosonde station at Rheine/Waldhugel was 82 kilometers south and located in a prevailing airflow that was parallel to the track

Synoptic Remarks. The surface chart showed ridging with a weak gradient across western Europe A cold front was approaching the Irish coast At 500 millibars there was an open low in eastern Spain with a trough south to Algiers There was slight ridging through western Germany, Netherlands and Denmark The airflow was westerly and the air mass was unstable maritime polar

FLIGHT C-422 - 11 AUGUST 1977 - DESCRIPTION OF FLIGHT AND WEATHER CHARACTERISTICS

Filter Ident	Data Interval Start (GMT)	End (GMT)	Elapsed (hrs)	Max Flight Altitude (m)	Average Terrain Elevation (m)
2 3	0953	1040	0 8	1560	0
4 5	1044	1120	0 6	1560	0

Filter Ident	Solar Zenith Angle Initial ST&LV (degrees)	Solar Transit (degrees)	Final V PRO (degrees)
2 3	42 9		40 2
4 5	40 1	39 5	39 5

Flight Description. Flight C-422 was a morning flight The skies were overcast with low level clouds The approximate southeast to northwest Rodby track was located south of Lolland Island, Denmark Typical terrain features along the nearby coast to the north of the track were flat cultivated farmlands interspersed with occasional woods and small towns Directly beneath the track and to the south were the relatively shallow waters of Femer Bay

In-Flight Notes. The in-flight observer reported overcast clouds with bases at 1800 meters (6000 feet) with light precipitation Heavy haze was present at all flight altitudes The slant range visibility varied from 3 5 miles at 300 meters (1000 feet) to 10 miles at 1500 meters (5000 feet)

Local Weather Notes. Fehmarnbelt, 9 miles south of the track center point, reported overcast stratocumulus based at 300 meters (1000 feet) and 4 0 kilometers visibility with light fog at 0900 GMT improving to 10 0 kilometers at 1200 GMT

Schleswig, 103 kilometers west of the track center point, reported 4/8 cumulus at 300 meters (1000 feet) decreasing to 2/8 with bases at 750 meters (2500 feet) by 1100 GMT Stratocumulus with amounts varying from 4/8 to 3/8 were at 900 meters (3000 feet) and altostratus with 4/8 coverage at 3600 meters (12,000 feet) were also recorded Visibility of 4 0 kilometers with light fog gradually improved to 10 0 kilometers

The radiosonde station at Schleswig was 103 kilometers west of the flight track and located in an airflow that was parallel with the track

Synoptic Remarks. The surface chart showed ridging from the North Pole southward through eastern Britain Moist air at low levels was being advected from the North Sea At 500 millibars there was a low centered near Frankfort The flow was southeasterly and the air mass was modified maritime polar

FLIGHT C-434 - 18 FEBRUARY 1978 - DESCRIPTION OF FLIGHT AND WEATHER CHARACTERISTICS

Filter Ident	Data Interval Start (GMT)	End (GMT)	Elapsed (hrs)	Max. Flight Altitude (m)	Average Terrain Elevation (m)
2,3	0940	1126	1.77	6120	Sea Level
4,5	1132	1325	1.88	6150	Sea Level

Filter Ident	Solar Zenith Angle Initial ST&LV (degrees)	Solar Transit (degrees)	Final V-PRO (degrees)
2,3	53 7	49 1	49 2
4,5	49 3	-	58 1

Flight Description. Flight C-434 was a midday flight spanning local apparent noon with take off at 0913 and landing at 1510 GMT. There were scattered middle and high clouds. The approximate east to west Sigonella track was located east of Sigonella NAF on the east side of Sicily. Typical terrain features along the nearby coast were cultivated lowlands with fields of brown and green. Directly beneath the track were the relatively deep waters of the Mediterranean. The track was slid 64 kilometers (40 miles) to the east to stay in the clear at 1045 GMT.

In-Flight Notes. The in-flight observer noted 1/8 to 3/8 cirrus and 1/8 to 3/8 altostratus clouds. Slant visibility was 40 to 48 kilometers (25 to 30 miles). Haze was uniform to the cloud base at 1700 meters (5500 feet) and another haze layer was visible from 2300 to 2600 meters (7500 to 8500 feet).

Local Weather Notes. Trapani, 254 kilometers northwest of the flight track, reported 1/8 to 2/8 cumulus at 450 meters (1500 feet) and 3/8 to 7/8 cirrus at 5700 to 6000 meters (19,000 to 20,000 feet). Visibility was 9.0 kilometers in light fog and improved to 11.2 kilometers by 1300 GMT.

Pantelleria, 304 kilometers southwest of the flight track, reported 5/8 fractostratus at 150 meters (500 feet) becoming 2/8 cumulus at 450 meters (1500 feet) by 1100 GMT. Cirrus clouds at 6000 meters (20,000 feet) decreased from 7/8 to 2/8 by 1300 GMT. Visibility was 5.0 kilometers in light fog and improved to 7.0 kilometers by 1200 GMT.

The radiosonde station at Trapani was northwest and upstream from the track. The vertical cross section at 1200 GMT at a location west of the track showed 6/8 coverage of clouds from 400-650 meters, another location south of the track showed 6/8 cloud from the surface to 250 meters, 2/8 at 650 meters, 7/8 cloud from 2000 to 3000 meters, and 3/8 cloud at 8000 meters.

Synoptic Remarks. The surface synoptic chart indicated that the area containing Sicily was in a col at 1200 GMT. There was a warm front in the Pyrenees and a cold front off the coast of Portugal extended northward to southern Ireland. The track was in a col between two storm systems. The 500 millibars chart showed ridging from Morocco to Spain to Britain combined with a trough from Poland to Greece. Sicily was between these systems and in a northwesterly flow. The air mass was unstable maritime polar.

FLIGHT C-435 - 23 FEBRUARY 1978 - DESCRIPTION OF FLIGHT AND WEATHER CHARACTERISTICS

Filter Ident	Data Interval Start (GMT)	End (GMT)	Elapsed (hrs)	Max Flight Altitude (m)	Average Terrain Elevation (m)
2,3	0832	0921	0 82	2310	762
4,5	0927	1015	0 80	2280	762

Filter Ident	Solar Zenith Angle Initial ST&LV (degrees)	Solar Transit (degrees)	Final V-PRO (degrees)
2,3	71 0	-	65 2
4,5	64 8	-	60 9

Flight Description. Flight C-435 was a morning flight with take off at 0800 and landing at 1045 GMT. There were overcast altostratus clouds. The approximate west to east Birkhof track in southwest Germany was over a plateau surrounded by forest and some small villages. Typical terrain features were forest cover with intermittent snow covered fields and valleys that presented a black and white contrast.

In-Flight Notes. The in-flight observer reported overcast altostratus with the flight conducted under the cloud layer. There were foehn conditions and it was very clear below the cloud layer. On the V-PRO's there was very uniform light haze and thin fog in the valleys. Slant visibilities were usually 48 kilometers (30 miles) except at 0938 GMT at 1200 kilometers (4000 feet) it was 32 kilometers (20 miles) and at 0955 GMT at 3000 meters (10,000 feet) it lowered to 24 kilometers (15 miles).

Local Weather Notes. Freudenstad, 53 kilometers west of the track center, reported varying amounts of cumulus from 2/8 to 6/8 at 720 to 780 meters (2400 to 2600 feet) and 8/8 to 7/8 altocumulus at 3000 meters (10,000 feet). Visibility was 30 to 40 kilometers.

Spaichinger, 28 kilometers southwest of the track center, reported 1/8 to 3/8 cumulus at 1050 meters (3500 feet), 5/8 to 8/8 altocumulus at 2700 to 3300 meters (9000 to 11,000 feet) and 7/8 cirrus at 6000 meters (20,000 feet). Visibility was 70 to 75 kilometers.

Ulm, 68 kilometers eastnortheast of the track center, reported ceiling zero, visibility zero in fog until 1100 GMT when conditions improved to 7/8 stratus at 210 meters (700 feet) and visibility 1.0 kilometers in fog.

The radiosonde station at Neuchatel was 225 kilometers southwest and upstream from the track. The vertical cross section for 1200 GMT showed 8/8 clouds at 1300 meters, 7/8 at 2000 meters, 6/8 from 3000 to 4400 meters, 8/8 coverage from 5500 to 6500 meters and 5/8 cloud at 800 meters. These conditions also prevailed to the east and west.

Synoptic Remarks. The surface charts showed an occlusion south of Iceland that extended east and southeast through western France and eastern Spain into Africa and then westward to another storm in the eastern Atlantic. This chart had widespread fog that was advected by southwesterly flow from the Mediterranean in advance of the frontal system in Europe. The 500 millibars chart showed ridging from Tunisia and eastern Algeria northward through western Germany to the North Sea. The upper flow was southwesterly and the air mass was stable maritime polar.

FLIGHT C-437 - 27 FEBRUARY 1978 - DESCRIPTION OF FLIGHT AND WEATHER CHARACTERISTICS

Filter Ident	Data Interval Start (GMT)	End (GMT)	Elapsed (hrs)	Max Flight Altitude (m)	Average Terrain Elevation (m)
2 3	0925	1126	2 02	5160	762
4 5	1133	1326	1 88	5130	762

Filter Ident	Solar Zenith Angle Initial ST&LV (degrees)	Solar Transit (degrees)	Final V PRO (degrees)
2 3	63 6		56 7
4 5	56 6	56 6	61 6

Flight Description. Flight C-437 was a midday flight spanning local apparent noon with take off at 0900 and landing at 1359 GMT There were scattered to broken cirrus clouds The approximate west to east Birkhof track in southwest Germany was over a plateau surrounded by forest and some small villages Typical terrain features were forest cover with intermittent snow covered fields and valleys that presented a black and white contrast

In-Flight Notes. The in-flight observer reported 3/8 to 4/8 cirrus that was thin at the start of flight increased in density and amount becoming 6/8 to 1135 GMT and overcast at 1310 GMT Heavier cirrus moved in from the west at heights of 6000 meters (20,000 feet) There was fog in the valleys but the slant range visibility was unlimited

Local Weather Notes. Freudenstad, 53 kilometers west of the track center, reported 5/8 to 6/8 cirrus at 6900 meters (23,000 feet) gradually lowering to 6300 meters (21,000 feet) 1/8 cumulus formed at 600 meters (2,000 feet) by noon Visibility was 40 to 50 kilometers

Spaichinger, 28 kilometers southwest of the track center, reported 6/8 to 7/8 cirrus at 6900 meters (23,000 feet) with 1/8 to 2/8 cumulus at 600 meters (2000 feet) after 1300 GMT Visibility was observed as 70 to 75 kilometers

Ulm, 68 kilometers eastnortheast of the track center, had fog with a ceiling of 30 meters (100 feet) and visibility of 0 2 kilometers at 0900 GMT Cirrus clouds gradually increased from 1/8 to 6/8 with bases at 6900 meters (23,000 feet) and visibilities gradually improved to 15 kilometers

The radiosonde station at Neuchatel was 225 kilometers southwest and upstream from the track The vertical cross section for 1200 GMT showed 6/8 cloud from 1400 to 2000 meters

Synoptic Remarks. The surface chart had an occluded front off the east coast of Spain with a dissipating warm front from the southern Balearics to Algeria The cold front part of this system extended from the Balearics southwest through Morocco into the Atlantic The surface flow was southwesterly with widespread fog and stratus in advance of the occlusion At 500 millibars there was a low in northeastern Yugoslavia with a minor trough from central West Germany to eastern Turkey The upper flow was southwesterly and the air mass was modified stable maritime polar

FLIGHT C-439 - 1 MARCH 1978 - DESCRIPTION OF FLIGHT AND WEATHER CHARACTERISTICS

Filter Ident	Data Interval Start (GMT)	End (GMT)	Elapsed (hrs)	Max Flight Altitude (m)	Average Terrain Elevation (m)
2 3	1257	1342	0 75	1650	762
4 5	1352	1433	0 68	1620	762

Filter Ident	Solar Zenith Angle Initial ST&LV (degrees)	Solar Transit (degrees)	Final V PRO (degrees)
2 3	58 6		62 3
4 5	63 3		68 0

Flight Description. Flight C-439 was an afternoon flight with take off at 1213 and landing at 1510 GMT There were scattered to broken middle clouds and broken to overcast high clouds The approximate west to east Birkhof track in southwest Germany was over a plateau surrounded by forest and some small villages Typical terrain features were forest cover with intermittent snow covered fields and valleys that presented a black and white patchwork

In-Flight Notes. The in-flight observer reported scattered altostratus at 3000 meters (10,000 feet) and broken to overcast cirrostratus at 6000 meters (20,000 feet) By 1310 GMT the altostratus had increased to broken and became denser and sometimes overcast The altostratus moved in from the south and data were taken below the deck Slant range visibilities were 24 to 40 kilometers (15 to 25 miles) at 1200 and 2400 meters (4000 and 8000 feet) becoming 24 kilometers (15 miles) by 1335 GMT at all altitudes

Local Weather Notes. Freudenstad, 53 kilometers west of the track, observed 7/8 to 4/8 altocumulus at 1800 meters (6000 feet) with 1/8 to 3/8 stratocumulus at 1500 meters (5000 feet) after 1500 GMT and 6/8 thin cirrus at 6000 meters (20,000 feet) after 1500 GMT Visibilities were 50 to 65 kilometers

Spaichinger, 28 kilometers southwest of the flight track, had three levels of clouds There were 1/8 to 3/8 stratocumulus at 1500 meters (5000 feet), 6/8 to 7/8 altocumulus at 3600 meters (12,000 feet) lowering to 2700 meters (9000 feet) and 7/8 cirrostratus at 6900 meters (23,000 feet) Visibility was 60 to 75 kilometers

Ulm, 68 kilometers eastnortheast of the track center, had an obscured sky with a ceiling of 90 meters (300 feet) and visibility of 0 8 kilometers in fog at 1300 GMT Conditions gradually improved with 1/8 to 2/8 stratus at 90 to 150 meters (300 to 500 feet), 4/8 altocumulus at 3000 meters (10,000 feet) and 7/8 cirrus at 7200 meters (24,000 feet) Visibility improved to 1 8 kilometers in light fog

The radiosonde station at Neuchatel was 225 kilometers southwest and upstream from the track There was no appropriate vertical cross section

Synoptic Remarks. The surface chart showed that an occluded front extended from the Irish Sea to Belgium then as a cold front southward through eastern France into Algeria and then westward into the Atlantic to an advancing complex system There was widespread fog in advance of the frontal system in Europe At 500 millibars there was slight ridging from Sicily to Belgium and southsouthwesterly flow The air mass was modified stable maritime polar

FLIGHT C-444 - 11 MARCH 1978 - DESCRIPTION OF FLIGHT AND WEATHER CHARACTERISTICS

Filter Ident	Data Interval Start (GMT)	End (GMT)	Elapsed (hrs)	Max. Flight Altitude (m)	Average Terrain Elevation (m)
2,3	1259	1411	1.20	2190	60
4,5	1415	1521	1.10	2460	60

Filter Ident	Solar Zenith Angle Initial ST&LV (degrees)	Solar Transit (degrees)	Final V-PRO (degrees)
2,3	55.3	-	59.6
4,5	60.0	-	66.9

Flight Description. Flight C-444 was an afternoon flight with take off at 1203 and landing at 1630 GMT. There were multiple cloud layers with the overcast cirrus at the highest level. The approximate east to west Yeovilton track was located between Bournemouth Hurn and Yeovilton near the south central coast of England. Typical terrain features were rolling green fields and woods interspersed with occasional brown fields and small towns.

In-Flight Notes. The in-flight observer reported that an approaching weak frontal system over Eire was pumping substantial cirrus into southern England area and that there were some areas of altocumulus clouds. There was dense low level haze with tops at 610 meters (2000 feet). Scattered to broken stratocumulus clouds were at 610 meters (2000 feet), scattered variable broken altostratus at 2700 meters (9000 feet) and overcast cirrus at 7600 meters (25,000 feet). Slant range visibility ranged from 3.2-13 kilometers (2 to 8 miles). The cirrus deck over the western half of the track was heavier than over the eastern half. The stratocumulus layer moving in from the west forced the track to be moved 8 kilometers (5 miles) to the east.

Local Weather Notes. Boscombe Down, 55 kilometers northeast of the track center, observed 5/8 stratus at 150 meters (500 feet) at 1200 GMT. These clouds dissipated and there were 2/8 to 4/8 cumulus at 450 to 750 meters (1500 to 2500 feet), 3/8 to 5/8 altocumulus at 2700 meters (9000 feet) and 6/8 to 7/8 cirrus and cirrostratus at 6600-7500 meters (22,000 to 25,000 feet). Visibility of 3.5 kilometers gradually improved to 7 kilometers in haze.

Yeovilton, 15 kilometers northwest of the track center, reported 1/8 stratocumulus at 1500 meters (5000 feet) gradually increasing to 5/8 and lowering to 1050 meters (3500 feet), 2/8 to 3/8 altocumulus at 3000 meters (10,000 feet), and 6/8 to 7/8 cirrus at 7500 meters (25,000 feet). Visibility was 4 kilometers in haze.

Bournemouth Hurn, 46 kilometers eastsoutheast of the flight track center, observed 1/8 to 2/8 altocumulus at 3000 meters (10,000 feet) gradually increasing to 5/8 and lowering to 1800 meters (6000 feet) by 1600 GMT. There was a 6/8 to 7/8 layer of cirrus and cirrostratus at 7500 meters (25,000 feet). Visibility was 4.0 to 4.7 kilometers in haze.

The radiosonde station at Crawley was 157 kilometers east and in an airflow parallel to the track. There was no appropriate vertical cross section.

Synoptic Remarks. The surface chart had a low centered near Reykjavik with an occlusion eastsoutheastward and a warm front southeast through the Orkney Islands into the North Sea, then as a cold front eastward into Russia. A cold front also extended from the occlusion southward through the Irish Sea and Scilly Islands into Portugal. The flight path was in the warm sector of the storm with southerly flow and stable conditions. At 500 millibars there was ridging from northern Spain to the North Sea. The flow was southwesterly at this level. The air mass was stable maritime polar.

FLIGHT C-449 - 18 MARCH 1978 - DESCRIPTION OF FLIGHT AND WEATHER CHARACTERISTICS

Filter Ident	Data Interval Start (GMT)	End (GMT)	Elapsed (hrs)	Max Flight Altitude (m)	Average Terrain Elevation (m)
2,3	0945	1122	1 62	4590	60
4,5	1126	1316	1 83	6180	60

Filter Ident	Solar Zenith Angle Initial ST&LV (degrees)	Solar Transit (degrees)	Final V PRO (degrees)
2,3	61 3	-	53 2
4,5	53 1	51 9	53 4

Flight Description. Flight C-449 was a midday flight spanning local apparent noon with take off at 0858 and landing at 1420 GMT There were multiple layers of broken clouds The approximate east to west Yeovilton track was located between Bournemouth Hurn and Yeovilton near the south central coast of England Typical terrain features were rolling green fields interspersed with occasional brown fields and small towns The track was shifted after the first 1100 meter (3500 foot) level to avoid a cumulus field The last 6100 meter (20,000 foot) run was along the coast with water to the south and land to the north

In-Flight Notes. The in-flight observer noted at 0936 GMT that cumulus was forming rapidly over the highlands to the east At 0945 GMT there were scattered cumulus at 610 meters (2000 feet) in mid track, thin broken cirrus at 6100 meters (20,000 feet) and light haze with slant visibility 16 kilometers (10 miles) At 1008 GMT there were scattered cumulus at 760 meters (2500 feet) from the middle to the eastern end of the track as well as broken cirrus at 6100 meters (20,000 feet), slant range visibility was 24 kilometers (15 miles) At 1025 GMT the track was shifted to the west over a clear area with altostratus to the west at 1500 meters (5000 feet) and visibility 40 kilometers (25 miles) At 1055 GMT altostratus to the north was sliding south and cumulus east and south was forcing the flight to be squeezed into a clear narrow band between the decks At 1130 GMT the flight was back on track but at 1150 GMT the track was rotated 24-06 orientation between two lines of clouds Haze top was 1500 meters (5000 feet) and the layers above were very thin At 1215 GMT the flight was between altostratus to the north and cumulus to the south with the clear area decreasing At 1315 GMT the cloud layer had bases at 1200 meters (3800 feet) and tops at 1300 meters (4200 feet) with haze below

Local Weather Notes. Boscombe Down, 55 kilometers northeast of the track center, reported 3/8 to 7/8 cirrus at 7500 meters (25,000 feet) with cumulus forming after 1100 GMT and increasing to 5/8 by 1400 GMT with bases at 1350 meters (4500 feet) Visibility was 8 to 30 kilometers

Yeovilton, 15 kilometers northwest of the track center, observed cumulus and stratocumulus in amounts varying from 4/8 to 7/8 and bases varying from 600 to 750 meters (2000 to 2500 feet), and 5/8 to 6/8 cirrus at 6000 meters (20,000 feet) Visibility was 10 to 14 kilometers in haze

Bournemouth Hurn, 46 kilometers eastsoutheast of the track center, reported 1/8 cumulus at 1200 meters (4000 feet) increasing to 5/8 and bases lowering to 1050 meters (3500 feet) at 1300 GMT There was also 4/8 to 6/8 cirrus at 7500 meters (25,000 feet) Visibility of 6 to 8 kilometers in haze improved to 18 to 30 kilometers by 1100 GMT

The radiosonde station at Crawley was 157 kilometers east and in an airflow that was generally parallel to the track Data from a vertical cross section were not available for this area

Synoptic Remarks. The surface chart showed a low centered in northern Italy that had no associated frontal system Ridging from the Atlantic continued from Spain to Great Britain and western Germany Over the flight path the flow was westsouthwest from the North Atlantic At 500 millibars there was increasing ridging in the Irish Sea with a strong northnorthwesterly flow at this level The air mass was unstable maritime polar

FLIGHT C-450B - 22 MARCH 1978 - DESCRIPTION OF FLIGHT AND WEATHER CHARACTERISTICS

Filter Ident	Data Interval Start (GMT)	End (GMT)	Elapsed (hrs)	Max Flight Altitude (m)	Average Terrain Elevation (m)
2 3	1100	1136	0 60	1080	6
4 5	1140	1227	0 78	1140	6

Filter Ident	Solar Zenith Angle Initial ST&LV (degrees)	Solar Transit (degrees)	Final V PRO (degrees)
2 3	52 2		51 4
4 5	51 3	51 3	52 1

Flight Description. Flight C-450B was the second third of a triple mission It was a continuation of a morning flight with data taking commencing about 1100 GMT and ending about 1244 There were multiple layers of scattered to broken clouds with broken cirrus at the highest level The overall effect was overcast at low altitude The approximate east to west Soesterberg track was located between Deelen and DeBilt in central Netherlands Typical terrain features were green fields interspersed with occasional brown fields and small towns

In-Flight Notes. The in-flight observer noted that an approaching frontal system was moving mid level clouds into the area rapidly and would bring rain in a few hours Over the area there were scattered cumulus at 460 meters (1500 feet), broken altostratus at 4000 meters (13,000 feet), and broken cirrus at 7600 meters (25,000 feet) There was moderate haze to 460 meters (1500 feet) and light haze to 2100 meters (7000 feet) Slant visibility was 9 6 kilometers (6 miles) At 1005 GMT cumulus bases were at 520 meters (1700 feet) and tops at 940 meters (3100 feet), slant visibility was 24 kilometers (15 miles) At 1100 GMT the flight was occasionally over a large cumulus cell and the cumulus coverage increased by 1125 GMT By 1210 GMT there was increasing density in the altostratus layer overhead and the cumulus field was being suppressed in the heavier shadow Slant range visibility decreased to 11 kilometers (7 miles) by 1210 GMT

Local Weather Notes. DeBilt, 32 kilometers northwest of the track center, reported 2/8 to 3/8 cumulus at 450 to 600 meters (1500 and 2000 feet), 3/8 to 4/8 altocumulus at 3000 meters (10,000 feet), and 6/8 to 7/8 cirrus at 6000 meters (20,000 feet) Visibility of 5 kilometers in fog improved to 7 to 10 kilometers in haze

Soesterberg, 30 kilometers northwest of the track center, reported 2/8 to 5/8 cumulus varying in altitude from 360 to 600 meters (1200 to 2000 feet), 4/8 to 6/8 altocumulus at 3000 meters (10,000 feet), and 7/8 cirrus at 6000 meters (20,000 feet) Visibility was 11 2 to 16 kilometers

Deelen, 26 kilometers northeast of the track center, recorded 4/8 cumulus with bases from 60 to 900 meters (200 to 3000 feet) and 6/8 to 7/8 thin cirrus at 6000 meters (20,000 feet) Visibility of 4 7 kilometers in fog improved to 10 to 15 kilometers

The radiosonde station at DeBilt was northwest and downstream from the track Vertical cross section data were not available for the area

Synoptic Remarks. The surface chart showed an occlusion that extended southsoutheast from a low south of Iceland to Dundee, Cardiff, then as a warm front from Cardiff to Perigueux The cold front part of this system extended from Cardiff to Brest and southwest into the Atlantic There was southwesterly flow over the flight track at the surface in the pre-warm frontal conditions AT 500 millibars there was slight ridging from France to Norway with northwesterly flow at this level The air mass was stable maritime polar

FLIGHT C-465 - 14 AUGUST 1978 - DESCRIPTION OF FLIGHT AND WEATHER CHARACTERISTICS

Filter Ident	Data Interval Start (GMT)	End (GMT)	Elapsed (hrs)	Max Flight Altitude (m)	Average Terrain Elevation (m)
2,3	1358	1434	0 60	1500	18
4,5	1440	1510	0 50	1290	18

Filter Ident	Solar Zenith Angle Initial ST&LV (degrees)	Solar Transit (degrees)	Final V-PRO (degrees)
2,3	48 0	-	52 5
4,5	53.1	-	57 4

Flight Description. Flight C-465 was an afternoon with tape commencing about 1355 and landing at 1536 GMT. This was the second of two data packages collected on this date. Earlier in the afternoon data were collected over the Soesterberg track. The flight was conducted under overcast skies. The approximate northeast to southwest Meppen track was located between Oldenburg and Lathen in northwestern Germany. Typical terrain features were green and brown fields interspersed with occasional dark woods and small towns.

In-Flight Notes. The in-flight observer noted at 1400 GMT at 300 meters (1000 feet) an overcast stratus deck at 1650 meters (5500 feet) with slant range of 16 kilometers (10 miles) in moderate haze. It was very uniform under the 1500 meter (5000 feet) overcast - nice - no virga visible. At 1413 GMT on the climb the top of the surface based haze was about 900 meters (3000 feet); appears lighter than (less dense) haze at Soesterberg. Gray appearance, low level clouds were moving in from the west. At 1420 GMT patches of cloud penetrated in last 20 seconds of first filter; second filter was entirely clear. Also at 1420 GMT at 1500 meters (5000 feet) there was overcast stratus at 1650 meters (5500 feet) and slant range of 16 kilometers (10 miles) in light haze. At 1440 GMT at 300 meters (1000 feet) overcast stratus deck was at 1500 meters (5000 feet) and slant range of 32 kilometers (20 miles) in moderate haze. Visibility had improved - seems darker - perhaps time of day but probable overcast density. At 1450 GMT haze top had increased slightly to 990 meters (3300 feet). Note - burning field to south of midpoint of track may appear on 300 meters (1000 feet) data. At 1500 GMT at 1350 meters (4500 feet) there was a broken stratofractus deck at 1500 meters (5000 feet) and an overcast stratus deck at 1650 meters (5500 feet), slant range was 16 to 24 kilometers (10 to 15 miles) in light haze. On the last descent there definitely appeared to be a region from 300 to 450 meters (1000 to 1500 feet) where visibility was much less than either above or below.

Local Weather Notes. Bremerhaven, 87.1 kilometers northeast of the track center, reported overcast stratocumulus at 600 meters (2000 feet) with visibility of 4.5 kilometers in light rain at 1400 GMT and 7.0 kilometers in light fog at 1500 GMT.

Emden, 45.7 kilometers southwest of the track center, recorded 4/8 stratocumulus at 450 meters (1500 feet) and overcast altostratus at 3000 meters (10,000 feet) with visibility 4.0 kilometers in light rain during the flight period.

Bremen, 79.3 kilometers east of the track center, reported 5/8 stratocumulus at 900 meters (3000 feet) and overcast altostratus at 3000 meters (10,000 feet) with visibility 11.2 kilometers at 1320 GMT. Conditions improved gradually becoming 2/8 stratocumulus at 1260 meters (4200 feet) 7/8 altocumulus at 3000 meters (10,000 feet) and 18 kilometers visibility by 1500 GMT.

The radiosonde station at Bergen was 149 kilometers east and downstream from the track. The sounding was colder and moister than the one at DeBilt, the station nearer to the Soesterberg track.

Synoptic Remarks. The surface chart for 0000 GMT indicated a weak ridge of the Atlantic High extended through northern France and southern Germany. There was an occluded front that extended from south of Iceland southeastward to northern Ireland then south and southwest as a cold front through western Ireland into the Atlantic. A warm front, part of this same system, extended from northern Ireland southward into the Irish Sea. There was also a 1016 millibar low centered in the northern Adriatic. At 1200 GMT there was a high centered near Berlin with the 1016 millibar isobar enclosing most of continental Europe. An occluded front extended from south of Iceland southeastward to Scotland, then as a cold front southward through the eastern Irish Sea into the Atlantic. The warm front part of this system extended from Scotland southeastward to the North Sea. There was light westerly surface flow over the track. The 500 millibar chart for 0000 GMT had ridging from the Bay of Biscay to Scotland with the track on the leading side with moderate northwesterly winds. At 1200 GMT there was ridging from Algeria northward through the North Sea. The track had moderate westnorthwesterly winds at this level. The air mass was maritime polar. The satellite map was difficult to define with clouds over most of Europe except for southern France, Sardinia and Sicily. The computer printout maps showed broken to overcast cumulus, stratocumulus, altocumulus and cirrus over the area.

FLIGHT C-466 - 15 AUGUST 1978 - DESCRIPTION OF FLIGHT AND WEATHER CHARACTERISTICS

Filter Ident	Data Interval			Max Flight Altitude (m)	Average Terrain Elevation (m)
	Start (GMT)	End (GMT)	Elapsed (hrs)		
2 3	0919	1056	1 62	6000	18
4 5	1104	1303	1 98	5910	18

Filter Ident	Solar Zenith Angle		
	Initial ST&LV (degrees)	Solar Transit (degrees)	Final V PRO (degrees)
2 3	47 1		39 6
4 5	39 4	38 9	42 8

Flight Description. Flight C-466 was a midday flight spanning local apparent noon with take off at 0833 and landing at 1342 GMT There were scattered cirrus clouds and a low level haze layer The approximate northeast to southwest Meppen track was located between Oldenburg and Lathen in northwestern Germany Typical terrain features were green and brown fields interspersed with occasional dark woods and small towns

In-Flight Notes. The in-flight observer generalized that there were muted horizontal blue-gray striations and isolated contrails On the climbout from Wunstorf the surface based haze layer top is 1350 meters (4500 feet) in the Wunstorf area with a clear layer to 1800 meters (6000 feet) and a similar haze layer from 1800 meters (6000 feet) to an unknown upper altitude Isolated patches of altocumulus at above 4200 meters (14,000 feet) with scattered thin cirrus at much higher altitude On the descent, top of the haze layer was 1350 meters (4500 feet), apparent best altitudes 300, 1200, 3000 and 6000 meters (1000, 4000, 10,000 and 20,000 feet) Beautiful day, only thin cirrus are a hindrance At 0920 GMT at 300 meters (1000 feet) scattered cirrus at 9000 meters (30,000 feet) slant range 16 kilometers (10 miles) in moderate haze At 0945 GMT and 1200 meters (4000 feet) slant range 19 2 kilometers (12 miles) At 0955 GMT on the climb the haze top was 1350 to 1500 meters (4500 to 5000 feet), clear layer 1500 to 1950 meters (5000 to 6500 feet), mostly clear to 2400 meters (8000 feet), distinct top at 2700 meters (9000 feet), thin layer at 2940 meters (9800 feet) At 1005 GMT and 3000 meters (10,000 feet) scattered cirrus at 9000 meters (30,000 feet) with isolated cumulus starting and slant range 24 kilometers (15 miles) in light haze On the climb from 3000 to 6000 meters (10,000 to 20,000 feet) there were multiple thin layers visible from 3000 to 5100 meters (10,000 to 17,000 feet) with a distinct layer visible from 4650 to 2950 meters (15,500 to 16,500 feet) During the remainder of the flight the cirrus continued with cumulus at 900 meters (3000 feet) on the west end of the track Visibility improved during the course of the mission with the haze still moderate and the top remaining at 1350 meters (4500 feet) The flight at 6000 meters (20,000 feet) was not above the highest haze layer

Local Weather Notes. Bremerhaven, 87 1 kilometers northeast of the track center, reported 1/8 altocumulus at 4500 meters and 3/8 to 4/8 high thin cirrus with visibility 7 to 18 kilometers

Emden, 45 7 kilometers northwest of the track center, recorded 1/8 high thin cirrus with 3/8 stratocumulus at 1050 meters (3500 feet) at the 1400 GMT observation Visibility varied from 6 kilometers in haze to 15 kilometers

Bremen, 79 3 kilometers east of the track center, reported 1/8 altocumulus at 4500 meters (15,000 feet) before 1000 GMT with 1/8 to 2/8 high thin cirrus through the day Visibility, when reported varied from 11 2 to 18 kilometers

The radiosonde station at Bergen was 149 kilometers east and downstream from the track The sounding indicated that lower level winds were moderate southerly becoming southwest above 800 millibars The sounding was fairly dry and much warmer at lower levels than 24 hours ago

Synoptic Remarks. The surface chart for 0000 GMT had an occlusion north of Scotland into the North Sea A cold front extended from the North Sea southsouthwest through Leeds to Plymouth and then southwest into the eastern Atlantic The warm front part of the system extended south-southeast from the North Sea to northern Denmark There was a 1021 millibar high centered in the Ukraine that dominated most of the European continent and western Russia except for a small low in eastern Spain At 1200 GMT the occlusion in the North Sea with the cold front extending southsouthwest was approaching the coast of The Netherlands and then extended southwest through northwestern France and into the Atlantic The track was in southwesterly surface flow in advance of the front At 500 millibars at 0000 GMT there was ridging from Algeria northnortheast to southern Scandinavia The track had light to moderate northwesterly winds There was also a closed low west of northern Ireland By 1200 GMT there was ridging from Tunisia to southern Scandinavia and the low center continued west of northern Ireland At this level flow over the track was moderate westerly The air mass was modified maritime polar The satellite map showed clouds over most of Europe except thin clouds over the low countries and Italy

FLIGHT C-468 - 21 AUGUST 1978 - DESCRIPTION OF FLIGHT AND WEATHER CHARACTERISTICS

Filter Ident	Data Interval Start (GMT)	End (GMT)	Elapsed (hrs)	Max Flight Altitude (m)	Average Terrain Elevation (m)
2 3	0920	1058	1 63	5820	18
4 5	1102	1244	1 70	6210	18

Filter Ident	Solar Zenith Angle Initial ST&LV (degrees)	Solar Transit (degrees)	Final V PRO (degrees)
2 3	48 6		41 4
4 5	41 3	40 9	43 3

Flight Description. Flight C-468 was a midday flight spanning local apparent noon with take off at 0847 and landing at 1320 GMT There were scattered high thin cirrus clouds The approximate northeast to southwest Meppen track was located between Oldenburg and Lathen in northwestern Germany Typical terrain features were green and brown fields interspersed with occasional dark woods and small towns

In-Flight Notes. The in-flight observer noted that there was very muted horizontal banding in haze and cirrus above - gradual clearing of haze left relatively clear cirrus layers against blue sky A weak frontal passage last night has left cirrus A new frontal system to the northwest is causing more cirrus to move in from the northwest slowly At 0920 GMT at 300 meters (1000 feet) there was scattered cirrus at 6000 meters (20,000 feet) with 8 kilometers (5 miles) slant range down sun On the climb from 1350 to 3000 meters (4500 to 10,000 feet) the low altitude haze top was 1860 meters (6200 feet) with a thin clearer layer and lighter haze above Distinct haze top of all haze at 2400 meters (8000 feet) Areas of cloud are visible to the north and south At 1005 GMT at 3000 meters (10,000 feet) scattered cirrus at 6000 meters (20,000 feet) with scattered cumulus far to north, light haze with slant range 16 kilometers (10 miles) Cirrus appears to come down to 3600 to 4500 meters (12,000 to 15,000 feet) in places On the climb to 6000 meters (20,000 feet) some cirrus trails were heavy to below 4500 meters (15,000 feet), cirrus are in bands with 20 to 30 nautical mile separation Other cirrus extend up to 10500 meters (35,000 feet), basic layer is at 6000 meters (20,000 feet) At 1130 GMT at 1350 meters (4500 feet) there was scattered altostratus at 1500 meters (5000 feet) and scattered cirrus at 9000 meters (30,000 feet) with moderate to heavy haze and slant range 6 4 to 8 kilometers (4 to 5 miles) At 1145 GMT on the climb to 3000 meters (10,000 feet) it was noted that cumulus were beginning Cirrus was present during the first half with a moderate wall to the south A new band of cirrus was moving in from the north at a higher altitude than previously The cumulus tended to blend into bright haze in the up sun direction On the final descent the cumulus field was developing further along and to the south of the west end of the track Cumulus tops were 2700 meters (9000 feet) and the haze top was now closer to 2100 meters (7000 feet) Visibility at the top of the haze layer was very poor Visibility below 2700 meters (3000 feet) seems lower than previous

Local Weather Notes. Bremerhaven, 87 1 kilometers northeast of track center, reported scattered high thin cirrus clouds becoming broken at 6900 meters (23,000 feet) by 1300 GMT Visibility of 5 kilometers in haze improved to 9 kilometers by 1300 GMT

Emden, 45 7 kilometers northwest of the track center, recorded 1/8 to 2/8 high thin cirrus becoming 5/8 broken at 6900 meters (23,000 feet) at 1200 GMT Visibility of 4 5 kilometers in haze improved to 9 kilometers by 1000 GMT and decreased to 8 kilometers at 1200 GMT

Bremen, 79 3 kilometers east of the track center, reported 3/8 decreasing to 1/8 high thin cirrus with visibility 8 to 15 kilometers

The radiosonde station at Bergen was 149 kilometers east and downstream from the track The raob showed a warming trend below 400 millibars and cooler above than the sounding taken six hours earlier

Synoptic Remarks. The surface chart for 0000 GMT showed an occluded front that extended from north of the Arctic Circle southeast and south to near Oslo then as a cold front southsouthwest through the North Sea to Belgium and off the west coast of Morocco with a wave near Madrid The front was approaching the flight track and there was southwesterly flow over the track At 1200 GMT the cold front had passed over the track and was on a line from southern Norway, Bremen, Offenbach, Avignon to Fes There was a weak cell of high pressure centered two degrees west of Brest Flow over the track was westsouthwesterly At 500 millibars at 0000 GMT there was weak ridging from northern Italy to northern Scandinavia and a closed low just southeast of Iceland At 1200 GMT there was ridging from Spain northeastward to Latvia The track had weak northwesterly flow at this level The air mass was modified maritime polar The satellite maps for 1259 and 1309 GMT showed thin clouds over all of western Europe and a frontal system approaching Great Britain

FLIGHT C-469 - 22 AUGUST 1978 - DESCRIPTION OF FLIGHT AND WEATHER CHARACTERISTICS

Filter Ident	Data Interval Start (GMT)	End (GMT)	Elapsed (hrs)	Max Flight Altitude (m)	Average Terrain Elevation (m)
2 3	1158	1337	1 65	5820	6
4 5	1342	1527	1 75	5880	6

Filter Ident	Solar Zenith Angle Initial ST&LV (degrees)	Solar Transit (degrees)	Final V PRO (degrees)
2 3	41 5		48 3
4 5	48 6		62 1

Flight Description. Flight C-469 was an afternoon flight with take off at 1102 and landing at 1615 GMT There were scattered to broken cumulus clouds Track was gradually slipped south to 260-080 track from east end turn point The approximate east to west Soesterberg track was located between Deelen and DeBilt in central Netherlands Typical terrain features were green fields interspersed with occasional brown fields and small towns

In-Flight Notes. The in-flight observer noted that on the let downs the haze top was 900 meters (3000 feet) with isolated cumulus trying to form at the top of haze The haze was very dense on the east end and slightly less dense on the west end of the track At 1200 GMT and 300 meters (1000 feet) there were isolated cumulus at 900 meters (3000 feet) and heavy haze with slant range 4 8 kilometers (3 miles) At 1216 GMT we were trying run at 750 meters (2500 feet) at the same altitude as incipient clouds at top of haze We were just below the haze top The haze was still very dense at this altitude On the climb to 2400 meters (8000 feet) the haze top was 900 meters (3000 feet), there was a second dense layer with base at 1200 meters (4000 feet) top at 1500 meters (5000 feet) and more thinner layers above to 2100 meters (7000 feet) At 1245 GMT at the start there was a solid cumulus field to the north by 6 4 kilometers (4 miles) angling sharply away from the track at the east At 1315 GMT at 5700 meters (19,000 feet) at the start broken cumulus line to the north are greater than 75° from nadir and it was clear below On the descent to 300 meters (1000 feet) there was very light haze down to 1950 meters (6500 feet) At 1950 meters start entering significant haze, clear layer 1650 to 1200 meters and relatively uniform below 1200 meters At 1340 GMT at 300 meters (1000 feet) it was clear with moderate to heavy haze and a slant range of 9 6 kilometers (6 miles) The haze was brown in color and a line of broken cumulus was slowly sliding down from the north but we were staying ahead of them At 1405 GMT at 900 meters it was clear to the south, cumulus clouds still to the north and west of the west end of the track with bases at 1050 meters (3500 feet) On the climb to 2400 meters the haze top was 1390 meters (4300 feet) and light haze was still visible above There was a clear layer from 1200 to 1500 meters then into light haze again Cumulus line to the north was still pressing south At 1500 GMT at 5700 meters (19,000 feet) scattered variable broken cumulus to the northwest, north and northeast Horizon is indistinct in light haze At the start of straight and level the line of cumulus was just north of the track On the descent from 6000 meters it was clear down to light haze top at 2700 meters, this was south of the cumulus to the north, denser haze at 1950 meters, clear from 1500 to 1290 meters, and in heavy low level haze at 1290 meters Visibility was still less than 8 kilometers (5 miles) in haze

Local Weather Notes. DeBilt, 32 1 kilometers northwest of track center, reported 1/8 to 5/8 cumulus at 900 meters (3000 feet) with visibility 6 to 7 kilometers in light fog and haze

Soesterberg, 30 3 kilometers northwest of track center reported cumulus increasing from 3/8 to 7/8 at 1050 to 1140 meters (3500 to 3800 feet) and visibility 7 kilometers in haze

Deelen, 26 3 kilometers northeast of track center, recorded 1/8 to 2/8 cumulus at 1050 meters (3500 feet) and visibility 4 8 kilometers in haze gradually improving to 10 kilometers

The radiosonde station at DeBilt was 32 1 kilometers northwest and in a flow parallel to the track The sounding showed a warming trend at all levels except from 470 to 300 millibars The winds aloft backed from 320° to 240-260°

Synoptic Remarks. The surface chart for 0000 GMT showed a weakening cold front was east of the track along the Oslo-Rostock-Bamberg line A weak high pressure cell was centered west of Brest and there was a weak gradient over the track At 1200 GMT a low centered at 68°N 5°E had a trough southsouthwest over the track area with surface flow light westerly The weakening cold front continued to move east and was in western Russia The weak high continued west of Ireland and France The 500 millibar chart for 0000 GMT showed weak ridging from Spain to the Gulf of Bothnia, with a low centered at 65°N 5°W At 1200 GMT the low was located at 67 5°N 1°W with troughing southward to the Irish Sea There was weak ridging from southern France to western Poland The track had moderate westerly flow at this level The air mass was maritime polar The satellite map for 1309 GMT had clear skies or thin scattered clouds over all of western Europe

FLIGHT C-471 - 11 SEPTEMBER 1978 - DESCRIPTION OF FLIGHT AND WEATHER CHARACTERISTICS

Filter Ident	Data Interval			Max Flight Altitude (m)	Average Terrain Elevation (m)
	Start (GMT)	End (GMT)	Elapsed (hrs)		
2,3	0739	0812	0 55	540	762
4,5	0818	0849	0 50	540	762

Filter Ident	Solar Zenith Angle		
	Initial ST&LV (degrees)	Solar Transit (degrees)	Final V-PRO (degrees)
2,3	64 0		59 0
4,5	58 4	-	54 0

Flight Description. Flight C-471 was a morning flight with take off at 0706 and landing at 0935 GMT This flight was first of three data packages collected over the same track on this date There were overcast altostratus clouds which became broken near the end of the flight The approximate east to west Birkhof track in southwest Germany was over plateau surrounded by forest and some small villages Typical terrain features were forest cover with intermittent green fields and valleys

In-Flight Notes. The in-flight observer noted at 0735 GMT at 900 meters MSL and 300 meters (1000 feet) above the ground that there was an overcast deck of altostratus at 1500 meters (5000 feet) and slant range visibility of 24 kilometers (15 miles) The overcast prevented multi levels over the high ground of the Swabische Alps Dual 2+2 were possible if done in one filter legs in the western half of the track At 0745 GMT at 1350 meters MSL the overcast remained unchanged and there were clouds on the horizon Slant range was 48 kilometers (30 miles) with light haze At 0819 GMT at 900 meters MSL cloud cover was unchanged but the slant range had decreased to 24 to 32 kilometers (15 to 20 miles) The overcast was slightly less uniform At 0830 GMT and 1350 meters MSL the altostratus deck was broken variable overcast with bases at 1500 meters (5000 feet) and slant range of 40 kilometers (25 miles) in light haze The flight broke into a hole midway through the 2nd filter The broken variable overcast layer was starting to break up from the north

Local Weather Notes. Freudenstad, 52 9 kilometers west of the track center, reported 3/8 to 2/8 stratocumulus at 900 meters (3000 feet) with 25 to 28 kilometers visibility At the 0900 GMT observation there was also 3/8 altocumulus at 3000 meters (10,000 feet)

Spaichinger, 27 8 kilometers southwest of the track center, observed 4/8 to 5/8 stratocumulus at 900 to 1050 meters (3000 to 3500 feet) and 5/8 to 7/8 altocumulus at 3000 meters (10,000 feet) Visibility was 30 to 35 kilometers

Ulm, 68 2 kilometers eastnortheast of the track center, reported 5/8 stratocumulus at 1290 meters (4300 feet), 7/8 altocumulus at 3000 meters (10,000 feet) and visibility 28 to 35 kilometers in the early morning By 0900 GMT there were 3/8 cumulus and stratocumulus at 1020 meters (3400 feet) and 40 kilometers visibility

The radiosonde station at Neuchatel was 225 kilometers southwest of the track and in an airflow that was parallel to the track The sounding at 1200 GMT was colder at all levels above 700 millibars and at some levels below than it was at 0000 GMT Also it was more moist above 550 millibars than it had been

Synoptic Remarks. The surface chart for 0000 GMT showed that from a low in the Gulf of Bothnia an occluded front extended southsoutheast and then as a cold front passed through the Baltic and then westward along 55°N to a wave near Belfast and thence southwest into the Atlantic At 1200 GMT there was a cold front with waves, part of a more extensive system, that extended from northwestern Russia southward to and through northern Poland and then west through Berlin and Hannover and southwest through France to the Atlantic The track was in westerly flow in advance of the front The 500 millibar chart for 0000 GMT showed weak ridging from southern France northeastward to western Poland There were moderate westerly winds At 1200 GMT there was ridging from eastern Spain to central Poland The track continued with moderate westerly winds The air mass was modified maritime polar The satellite map for 1309 GMT showed the front north of the track with clouds It was clear over Italy, Sicily and southern France

FLIGHT C-475 - 15 SEPTEMBER 1978 - DESCRIPTION OF FLIGHT AND WEATHER CHARACTERISTICS

Filter Ident	Data Interval Start (GMT)	End (GMT)	Elapsed (hrs)	Max Flight Altitude (m)	Average Terrain Elevation (m)
2,3	1301	1458	1.95	6180	60
4,5	1506	1652	1.77	6150	60

Filter Ident	Solar Zenith Angle Initial ST&LV (degrees)	Solar Transit (degrees)	Final V-PRO (degrees)
2,3	49 3	-	60 1
4,5	61 0	-	76 5

Flight Description. Flight C-475 was an afternoon flight with take off at 1155 and landing at 1750 GMT. There were scattered variable broken stratocumulus clouds and thin broken variable thin overcast cirrus. The resulting effect was overcast. The approximate east to west Yeovilton track was located between Bournemouth Hurn and Yeovilton near the south central coast of England. Typical terrain features were rolling green fields and woods interspersed with occasional brown fields and small towns.

In-Flight Notes. The in-flight observer noted that they were working basically the main track which was extended to the east and west as necessary. At 1303 GMT at 360 meters (1200 feet) there was scattered stratocumulus at 1050 meters (3500 feet) and high thin broken cirrus. The stratocumulus were dissipating with about 1/8 to 2/8 coverage and the cloud base distinguished the top of the haze. At 1324 GMT at 960 meters (3200 feet) scattered stratocumulus was at 1050 meters (3500 feet) and high thin broken cirrus. Track was running very close to the cloud base and on occasion we passed very near or directly under a cloud. Cloud cover is increasing now up to 2/8 to 3/8 and becoming troublesome. On the climb possible cloud debris at 1170 meters (3900 meters), cloud tops 1290 meters (4300 feet) and clear above. At 1355 GMT at 3000 meters (10,000 feet) high thin overcast cirrus with scattered variable broken stratocumulus below. Stratocumulus is broken along entire track at this time - mostly clear areas exist north and south. Cirrus is tending to increase in intensity. The sun is shining brightly through the cirrus but occasional areas of heavier cirrus are in the area. On the climb thin layers of haze are distinguishable to above 3600 meters (12,000 meters). About 1510 GMT at 360 meters (1200 feet) flown in eastern third and farther to east in clear air area as the track is becoming heavy in cloud. At 1535 GMT at 690 meters (3200 feet) right at top of haze layer and in clear away from stratocumulus. Climb started between patches of cloud and out of haze completely almost immediately. At 1600 GMT stratocumulus below appears to be trying to dissipate with large holes - second filter was over clear area. At 1625 GMT at 6000 meters (20,000 feet) high thin overcast cirrus with broken stratocumulus (overcast immediately below) slant range 32 kilometers (20 miles). Sc below now appears to be more dense than previous for first filter, second filter broken variable scattered Sc near end of filter. Last descent top of haze was 900 meters (3000 feet) with very muted haze layers above. Boundary layer has been strongly suppressed by cold air flow and high pressure influence.

Local Weather Notes. Yeovilton, 14.8 kilometers northwest of track center, reported 3/8 to 5/8 cumulus and stratocumulus at 540 to 600 meters (1800 to 2000 feet) and 5/8 to 6/8 high cirrus with 25 to 30 kilometers visibility.

Portland, 46.3 kilometers south of the track center, reported 2/8 cumulus and stratocumulus at 450 meters (1500 feet) increasing to 4/8 by 1500 GMT and to 6/8 at 600 meters (2000 feet) by 1700 GMT. There was also 4/8 cirrostratus until 1400 GMT. Visibility was 16 kilometers decreasing to 10 kilometers at 1500 GMT.

Bournemouth Hurn, 46.4 kilometers eastsoutheast of track center, recorded 1/8 cumulus and stratocumulus at 1050 meters (3500 feet) with 6/8 to 7/8 cirrus at 7500 meters (25,000 feet) and visibility 30 kilometers.

The radiosonde station at Crawley was 160 kilometers east and in an airflow parallel to the track. The 1200 GMT sounding was warmer and drier below 560 millibars than at 0000 GMT.

Synoptic Remarks. The surface chart for 0000 GMT had a high pressure cell centered at 46.5°N 16°W with the track in the northeastern quadrant with westnorthwesterly flow. From a low south of Iceland, an occluded front extended eastsoutheast then as a warm front from the triple point to Northern Ireland. The cold front part of the system extended southwest in the Atlantic. By 1200 GMT the occlusion had moved eastward and was located on the border of Norway and Sweden. The cold front part of the system extended from the triple point southwest to the North Sea then westward through Newcastle-on-Tyne to Belfast, into Donegal Bay and the Atlantic where it was stationary. A 1028 millibar high was located 3° west of Brest. The track had light westerly flow with the high center southwest. At 0000 GMT the 500 millibar chart showed zonal westerlies with moderate to strong westnorthwesterly flow over the track. The situation showed little change at 1200 GMT and the strong westnorthwesterly flow continued. The air mass was modified maritime polar. The 1310 GMT satellite map indicated that the cold front was in the English Channel.

FLIGHT C-476 - 16 SEPTEMBER 1978 - DESCRIPTION OF FLIGHT AND WEATHER CHARACTERISTICS

Filter Ident	Data Interval Start (GMT)	End (GMT)	Elapsed (hrs)	Max. Flight Altitude (m)	Average Terrain Elevation (m)
2,3	1050	1255	2.08	6180	60
4,5	1301	1451	1.83	6150	60

Filter Ident	Solar Zenith Angle Initial ST&LV (degrees)	Solar Transit (degrees)	Final V-PRO (degrees)
2,3	49.6	48 3	50 5
4,5	50 8	-	62.1

Flight Description. Flight C-476 was a midday flight with take off at 0944 and landing at 1544 GMT. There were scattered to broken cumulus and stratocumulus clouds and high thin scattered cirrus. The track was gradually displaced to the north as stratus moved in from the channel to the south of the track. The approximate east to west Yeovilton track was located between Bournemouth Hurn and Yeovilton near the south central coast of England. Typical terrain features were rolling green fields and woods interspersed with occasional brown fields and small towns.

In-Flight Notes. The in-flight observer noted at 1053 GMT at 360 meters (1200 feet) scattered stratus at 450 meters (1500 feet) and high scattered clouds. Slant range was 24 kilometers (15 miles). Morning stratus was still in the area but it was predominantly clear above with less than 1/8 of higher cloud. The first low level run was below 2/8 to 3/8 of dissipating stratus but with high sun angle it was generally clear above with short periods of being beneath a patch of stratus. At 1110 GMT at 1050 meters (3500 feet) there was scattered variable broken stratocumulus at 450 meters (1500 feet) and scattered cirrus at 7500 meters (25,000 feet). The first filter was taken over predominantly broken stratocumulus in the last half. The second filter was over predominantly scattered stratocumulus. Haze does not show a marked break at cloud elevation, but haze extends up to about 1050 to 1200 meters (3500 to 4000 feet). On the climb to 3000 meters (10,000 feet) the haze top was sharp at 1170 meters (3900 meters). There were layers of haze above but we were in the clear from 1170 to 1410 meters (3900 to 4700 feet); in light haze 1440-1590 meters (4800 to 5300 feet); thin layer at 2100 meters (7000 feet), another at 2550 meters (8500 feet), also 2850 to 3000 meters (9500 to 10,000 feet). At 1145 GMT at 3000 meters (10,000 feet) scattered stratocumulus at 450 meters (1500 feet), and 2/8 cirrus greater than 7500 meters (25,000 feet), light haze with slant range 32 kilometers (20 miles). We may be in a layer of haze at this level that is very thin. At 1225 GMT at 6000 meters (20,000 feet) horizon was indistinct in gray haze, slant range was 56 kilometers (35 miles). On the descent light haze began about 1350 meters (4500 feet) and was more dense at 1050 meters (3500 feet). It appeared to be more sharply depressed by high pressure subsidence than earlier. Turbulence began at 600 meters (2000 feet). At 1303 GMT at 300 meters (1000 feet) we were right at the bases of stratus and stratocumulus; first filter was under most broken areas but second filter was better. At 1330 GMT slant range was 16 kilometers (10 miles) and at 1355 GMT it was 24 to 32 kilometers (15 to 20 miles) in light haze. At 1335 GMT set up on line over scattered stratocumulus. Thin layers of haze visible but generally below - above not distinguished during westward climb. Second filter was run under area of thin broken cirrus. At 1430 GMT at 6000 meters (20,000 feet) there was no discernible difference between 3000 and 6000 meter haze condition. Horizon was actually sharper at 3000 meters possibly indicating more haze at 6000 meters or at least more scattering. On the descent a white band existed above the horizon below 6000 meters whereas, looking west, the white band was at the elevation of the horizon at 6000 meters (haze layer?). The white band is "airlift" not cirrus in the distance. Base of this "layer" may be in the vicinity of 4800 meters (16,000 feet). Start losing definition due to steep look angle below 4500 meters (10,000 feet).

Local Weather Notes. Yeovilton, 14.8 kilometers northwest of track center, reported 4/8 cumulus and stratocumulus at 450 to 600 meters (1500 to 2000 feet) decreasing to 2/8 by 1500 GMT. There were also 4/8 altocumulus at 3000 meters (20,000 feet) reported only at 1400 GMT and 3/8 to 1/8 high cirrus. Visibility was 15 kilometers.

Portland, 46.3 kilometers south of track center, recorded 4/8 to 8/8 stratocumulus at 600 to 750 meters (2000 to 2500 feet) with visibility 25 kilometers decreasing to 16 kilometers by 1200 GMT.

Bournemouth Hurn, 46.4 kilometers eastsoutheast of the track center, reported 5/8 to 3/8 cumulus at 600 to 660 meters (2000 to 2200 feet) increasing to 6/8 to 7/8 and lowering to 330 to 390 meters (1100 to 1300 feet) after 1400 GMT. Visibility was 20 to 25 kilometers lowering to 18 kilometers at 1400 GMT and to 10 kilometers at 1600 GMT.

The radiosonde station at Crawley was 160 kilometers east and in a flow parallel to the track. The sounding showed more moisture below 480 millibars and less above at 1200 GMT than it did at 0000 GMT.

Synoptic Remarks. The 0000 GMT surface chart indicated that the high cell had moved eastward with the center located near Brest, France. A cold front extended from Kiel westward through Newcastle-on-Tyne and Belfast into the Atlantic. At 1200 GMT the high had continued to move eastward with the center now located near Orleans, France. The track was in the northwestern quadrant of the high with light southwesterly winds. A cold frontal system was approaching the Irish coast. The 500 millibar chart for 0000 GMT showed weak ridging through Spain to Great Britain. The track had moderate to strong northwesterly flow. At 1200 GMT there was weak ridging from northeastern Spain to the North Sea. There was moderate westerly flow over the track at this level. The air mass was modified maritime polar. There were no satellite maps for this day.

APPENDIX C

VISIBILITY LABORATORY CONTRACTS AND RELATED PUBLICATIONS

Previous Related Contracts:
F19628-73-C-0013, F19628-76-C-0004

PUBLICATIONS:

Duntley, S. Q., R. W. Johnson, J. I. Gordon, and A. R. Boileau (1970), "Airborne Measurements of Optical Atmospheric Properties at Night", University of California at San Diego, Scripps Institution of Oceanography, Visibility Laboratory, SIO Ref. 70-7, AFCRL-70-0137.

Duntley, S. Q., R. W. Johnson, and J. I. Gordon (1972a), "Airborne Measurements of Optical Atmospheric Properties in Southern Germany", University of California at San Diego, Scripps Institution of Oceanography, Visibility Laboratory, SIO Ref. 72-64, AFCRL-72-0255.

Duntley, S. Q., R. W. Johnson, and J. I. Gordon (1972b), "Airborne and Ground-Based Measurements of Optical Atmospheric Properties in Central New Mexico", University of California at San Diego, Scripps Institution of Oceanography, Visibility Laboratory, SIO Ref. 72-71, AFCRL-72-0461.

Duntley, S. Q., R. W. Johnson, and J. I. Gordon (1972c), "Airborne Measurements of Optical Atmospheric Properties, Summary and Review", University of California at San Diego, Scripps Institution of Oceanography, Visibility Laboratory, SIO Ref. 72-82, AFCRL-72-0593.

Duntley, S. Q., R. W. Johnson, and J. I. Gordon (1973), "Airborne Measurements of Optical Atmospheric Properties in Southern Illinois", University of California at San Diego, Scripps Institution of Oceanography, Visibility Laboratory, SIO Ref. 73-24, AFCRL-TR-73-0422.

Duntley, S. Q., R. W. Johnson, and J. I. Gordon (1974), "Airborne and Ground-Based Measurements of Optical Atmospheric Properties in Southern Illinois", University of California at San Diego, Scripps Institution of Oceanography, Visibility Laboratory, SIO Ref. 74-25, AFCRL-TR-74-0298.

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