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ANALYSIS OF AIRCRAFT MICROWAVE MEASUREMENTS OF THE OCEAN SURFACE

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16. Abstract

A data system was developed to process, from calibrated brightness temperature to computation of estimated parameters, the microwave measurements obtained by the NASA CV-990 aircraft during the 1972 Meteorological Expedition. The microwave data, contained in ten channels, spanned the frequency range from 1.42 GHz to 58.8 GHz.

A primary objective of the study was the implementation of an integrated software system at the computing facility of NASA/GSFC, and its application to the 1972 data. This system contains modules for: (1) prediction of radiometric brightness temperatures under hypothetical atmospheric, cloud and surface conditions; (2) selection, display and formatting of data from the 1972 flights; and (3) applying the statistical inversion method both for evaluation (simulation) and data reduction.

A single test case involving measurements away from and over a heavy rain cell was chosen to examine the effect of clouds upon the ability to infer ocean surface parameters.

The results indicate substantial agreement with those of the theoretical study; namely, that the values obtained for the surface properties are consistent with available ground-truth information, and are reproducible except within the heaviest portions of the rain cell, at which nonlinear (or saturation) effects become apparent. Finally, it is seen that uncorrected instrumental effects introduce systematic errors which may limit the accuracy of the method.

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1. INTRODUCTION

The application of passive microwave remote sensing techniques to the study of atmospheric and surface properties has received rapidly increasing interest and attention in the last several years. Studies by Staelin (1966), Gaut (1967), and Gaut and Reifenstein (1970) have shown the possibility of using satellite microwave measurements to infer useful geophysical parameters. The success of the Electronically Scanning Microwave Spectrometer (ESMR) and Nimbus 5 Microwave Spectrometer (NEMS) experiments currently orbiting on the Nimbus 5 satellite has demonstrated clearly the ability to infer atmospheric water vapor, liquid water, and vertical temperature profile in real time on a global scale.

The microwave spectrum is particularly well suited for the remote sensing of terrestrial properties since the opacity of the atmosphere varies from essentially transparent to nearly opaque over the range from 1 meter to 1 millimeter. The characteristics of the surface, atmosphere, and clouds together determine the radiometric signal at any frequency, and since the interaction with electromagnetic energy for each of the contributing species exhibits a different frequency dependence, a multichannel (multifrequency) experiment may be expected to provide simultaneous information about more than one species in the pressure of the others.

The present study represents a continuation of a previous effort (Gaut, Reifenstein and Chang, 1972) supporting the development of operational techniques for recovering geophysical parameters from microwave measurements, with interest directed specifically toward the estimation of surface properties. In the cited effort, a statistical regression technique was applied and evaluated for inversion of surface temperature and wind speed, integrated water vapor and liquid water. Since there existed no "real" data corresponding to the chosen configurations, simulated noisy microwave data were derived from physical models describing the terrestrial environment and its interaction with microwave energy. The results of the study demonstrated the theoretical capability for the estimation of these parameters to an accuracy suitable, under most cloud cover situations, in many geographical applications.

Since 1967, Goddard Space Flight Center (GSFC), of the National Aeronautics and Space Administration, has operated a Convair 990 research aircraft equipped with microwave radiometers. Data acquired with a test version of the Nimbus 5

ESMR system operating at 19.35 GHz was analyzed using model-fitting techniques by Gaut and Reifenstein (1971), demonstrating the self-consistency of the physical models used. During the 1972 Meteorological Expedition, a series of flights was made using a microwave system containing 10 channels spanning the frequency range from 1.42 GHz to 58.8 GHz, providing the opportunity to test the theoretical results of the previous effort. The present report thus describes the development of the data system by which these data were processed from calibrated brightness temperatures to computation of estimated parameters. A primary objective of the study was the implementation of an integrated software system at the computing facility of NASA/GSFC, and its application to the 1972 data. This system contains modules for: (1) prediction of radiometric brightness temperatures under hypothetical atmospheric, cloud and surface conditions; (2) selection, display and formatting of data from the 1972 flights; and (3) applying the statistical inversion method both for evaluation (simulation) and data reduction. Extensive use of the system for data-processing was not within the scope of this study; however, data for one flight were selected for a detailed evaluation of the approach and the data system. A single test case involving measurements away from and over a heavy rain cell was chosen to examine the effect of clouds upon the ability to infer ocean surface parameters.

The results indicate substantial agreement with those of the theoretical study; namely, that the values obtained for the surface properties are consistent with available ground-truth information, and are reproducible except within the heaviest portions of the rain cell, at which nonlinear (or saturation) effects become apparent. Finally, it is seen that uncorrected instrumental effects introduce systematic errors which may limit the accuracy of the method.

2. THE ANALYSIS APPROACH

The approach taken in this study is the implementation of an algorithm for the inversion of data to infer geophysical parameters, and a set of physical models designed to simulate the responses of microwave radiometers to various geophysical conditions. This algorithm and the models have been extensively described in publications by Gaut (1967), Gaut and Reifenstein (1970), Reifenstein and Gaut (1971), and Gaut, Reifenstein and Chang (1972). A brief summary drawn from these reports is provided below.

2.1 The Statistical Method for Estimation of Parameters

The heart of the analysis approach is the statistical method used to infer geophysical parameters from multichannel microwave data. The method is based on the work done by Rodgers (1966), Staelin (1967), Gaut (1967), Waters and Staelin (1968), Gaut (1968), Rozenkranz (1971), and Waters (1971). The essential element of the scheme is to choose, in a statistical sense, the most probable combination of atmospheric and surface properties which produces the set of measured radiometric data values. It is a general statistical regression technique which minimizes, in the statistical sense, the mean square error between the estimated and observed values of the parameter of interest.

The formalism for the method used starts with the assumption that there exists some linear combination of data elements which will provide information about the geophysical quantity in question. That is, if p_i is the i^{th} parameter to be estimated or predicted and d_j is the j^{th} element of a column vector of measured data, thought to be related to the parameter to be estimated, then it is assumed that

$$p_i^* = \sum_{j=1}^{N} (D_{ij} \; d_j) \qquad (2\text{-}1)$$

will provide an estimate of p_i which is useful. In this case, p_i^* is the estimate of p_i, and D_{ij} is an element of a linear operator relating the d values to p_i. The problem is to define the elements of the matrix $\underline{\underline{D}}$ (subsequently referred to as the D-matrix) which relate the d_j values to p_i^* such that (and this is an arbitrarily chosen condition) $\langle (p_i^* - p_i)^2 \rangle$ is a minimum where the brackets < > indicate the expectation. That is, over an ensemble of independent measurements, the D_{ij} must be chosen to minimize the mean square error between the predicted and actual value of the parameter p_i. How well this will be done depends on the degree of correlation, and the level of complexity of the relationships, between the d_j and the p_i values.

If the error between p_i^* and p_i for each measurement is called e_i, then we wish to minimize

$$<e_i^2> = <(p_i^* - p_i)^2> = <(\sum_{j=1}^{n_d} D_{ij} d_j - p_i)^2>, \tag{2-2}$$

where

n_d is the total number of data elements.

To do this, each D_{ik} value must satisfy the condition

$$\frac{d<e_i^2>}{d D_{ik}} = 0 \tag{2-3}$$

or

$$0 = \frac{d}{d D_{ik}} <(\sum_{j=1}^{n_d} D_{ij} d_j - p_i)^2> \tag{2-4}$$

$$0 = <2(\sum_{j=1}^{n_d} D_{ij} d_j - p_i) d_k>. \tag{2-5}$$

Since D_{ij} is a constant over any ensemble, it may be removed from expectation brackets; i.e.,

$$0 = 2 \Sigma D_{ij} (<d_j d_k> - 2 <p_i d_k>) \tag{2-6}$$

or

$$\Sigma D_{ij} \cdot <d_j d_k> = <p_i d_k>. \tag{2-7}$$

In full matrix notation, Eq. (2-7) can be expressed as

$$\underline{\underline{D}} \cdot \underline{\underline{C}} (\underline{d}, \underline{d}) = \underline{\underline{C}} (\underline{p}, \underline{d}) \tag{2-8}$$

in which $\underline{\underline{C}}$ is a correlation matrix of the quantities in parentheses defined as

$$C_{ij} (\underline{x},\underline{y}) = \langle x_i \; y_j \rangle . \tag{2-9}$$

D can therefore be written as

$$\underline{\underline{D}} = \underline{\underline{C}} (\underline{p},\underline{d}) \cdot \underline{\underline{C}}^{-1} (\underline{d},\underline{d}). \tag{2-10}$$

From Eq. (2-10), it may be seen that the statistical parameter inversion method relies on a priori information defining the correlation between the prediction data vector ($\underline{d}$) and the predicted geophysical parameter vector ($\underline{p}$).

Three conditions arise which, if not treated properly, can degrade the inversion results. They are: (1) nonlinearities in the $\underline{d}$ to $\underline{p}$ relationships; (2) noise in the prediction data; and (3) correlations between elements of $\underline{C}(\underline{d},\underline{d})$ leading to a singular condition in $\underline{C}^{-1}$ $(\underline{d},\underline{d})$. These problems are discussed in detail in Gaut, Reifenstein and Chang (1972).

2.2 System Logic

A flow diagram illustrating the sequence of operations for the Statistical Parameter Inversion Method is shown in Figure 2-1. Four distinct phases are involved in the procedure. In Phase 1 a model of the physical system under study is used to generate two statistical data sets. The first consists of the ensemble $\underline{p}_o$ of parameter vectors representing the state of the system at each of a number of observations. In the present case, the model of the system consists of three submodels: (1) a model for the clear atmosphere; (2) a cloud model; and (3) a surface model.

In Phase 2 the same ensemble of models is used together with the equations describing the electromagnetic interaction with the physical system to yield an ensemble of data vectors $\underline{d}_o$, each element of which is a radiometric brightness temperature for one "channel" of the experimental configuration to be used.

In Phase 3 the data sets $\underline{p}_o$ and $\underline{d}_o$ are used to compute the correlation matrices $\underline{\underline{C}}$ $(\underline{p}_o, \underline{d}_o)$ and $\underline{\underline{C}}$ $(\underline{d}_o, \underline{d}_o)$ and to obtain the D-matrix appropriate to the experiment and the system. Gaussian noise is added to the theoretically computed brightness temperatures before computation of the correlation matrices.

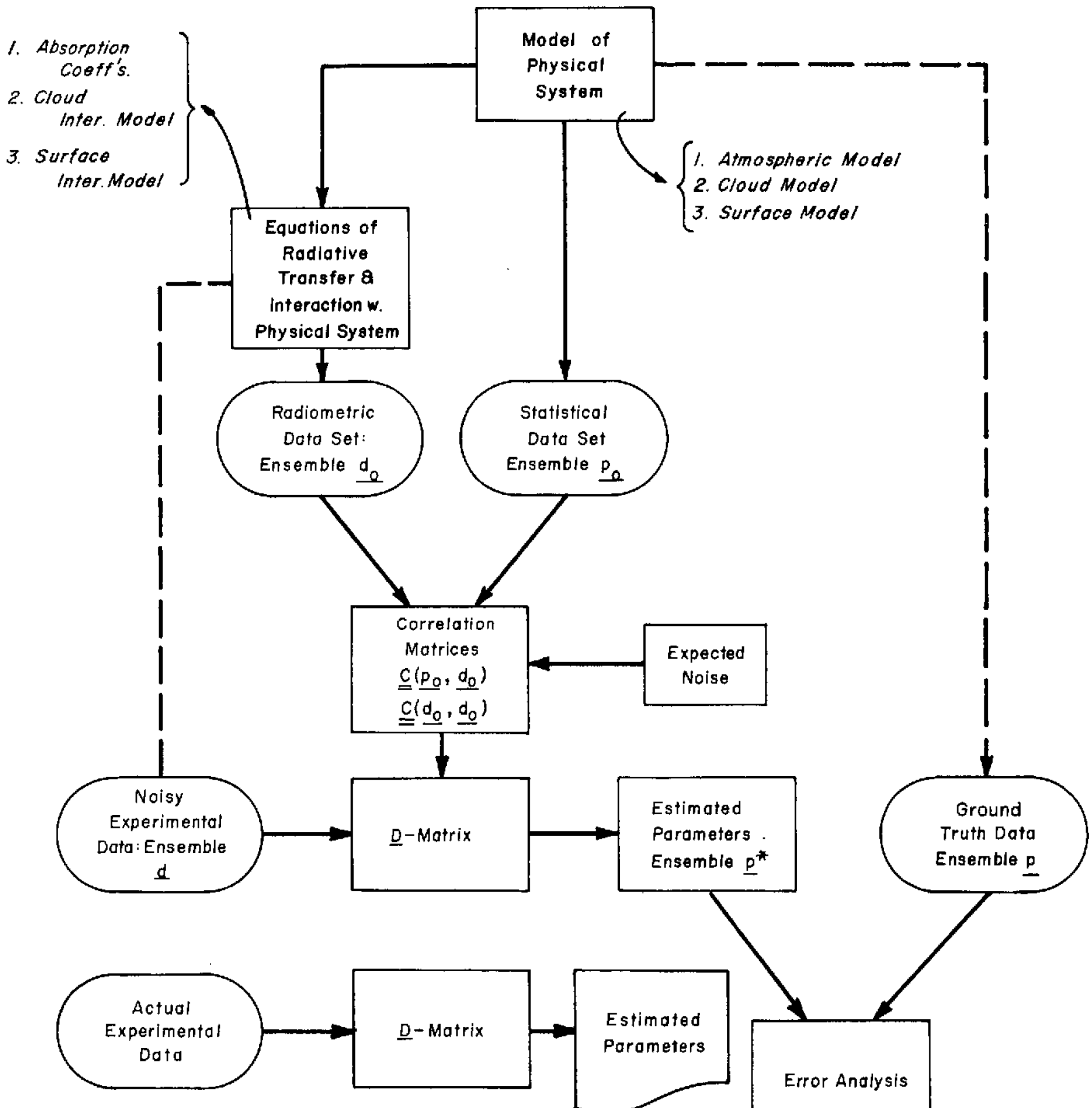

Figure 2-1 Flow Diagram for the Application of the Data Inversion Methodology to Parameter Estimation for a Radiometric Experiment

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In Phase 4 the D-matrix is used with an ensemble $\underline{d}$ of noisy data vectors representing experimental data to estimate the ensemble $\underline{p}^*$ of parameter vectors at each observation. Finally, this set of estimated parameter vectors $\underline{p}^*$ is compared, point by point, with the set of ground-truth parameter vectors $\underline{p}$ for overall error analysis.

As shown in Figure 2-1, the data inversion methodology can be applied to the inversion of real experimental data or to the evaluation of hypothetical radiometer systems. In the former case, the noisy experimental data ensemble, $\underline{d}$, is constituted from the set of real experimental measurements such as those obtained by the CV 990 microwave sensors. In the latter case, the ensemble, $\underline{d}$, can be simulated in a manner identical to that by which the ensemble, $\underline{d}_o$, is generated.

2.3 Physical Submodels

The modeling approach used to generate the ensemble of simulated radiometric data is shown in Figure 2-2. The ensemble consists of a set of "experiments." For each experiment a certain environmental configuration is specified and yields (as a result of electromagnetic interactions) a set of radiometer outputs. The simulation process essentially involves two models: the environmental model, consisting of the set of parameters defining the state of the system at the time of the experiment, and the interaction model by which these parameters affect the multichannel outputs. The environmental model is generated independently for each "experiment", using climatological statistics and Monte Carlo methods for the unknown quantities.

The desired parameters define the experimental configuration best suited for their estimation, together with the set of environmental submodels and the interaction model to be used for simulation of the experiment. In the present study, we are concerned with the properties of the terrestrial atmosphere, clouds, and surface, as determined by a multichannel microwave radiometer looking down from an aircraft platform. The environmental model is thus conveniently made up of: (1) an atmospheric gas submodel; (2) a cloud submodel; and (3) a surface model. The interaction model thus consists of the unit-volume interactions due to atmospheric water vapor, oxygen, and cloud particles and the integration of

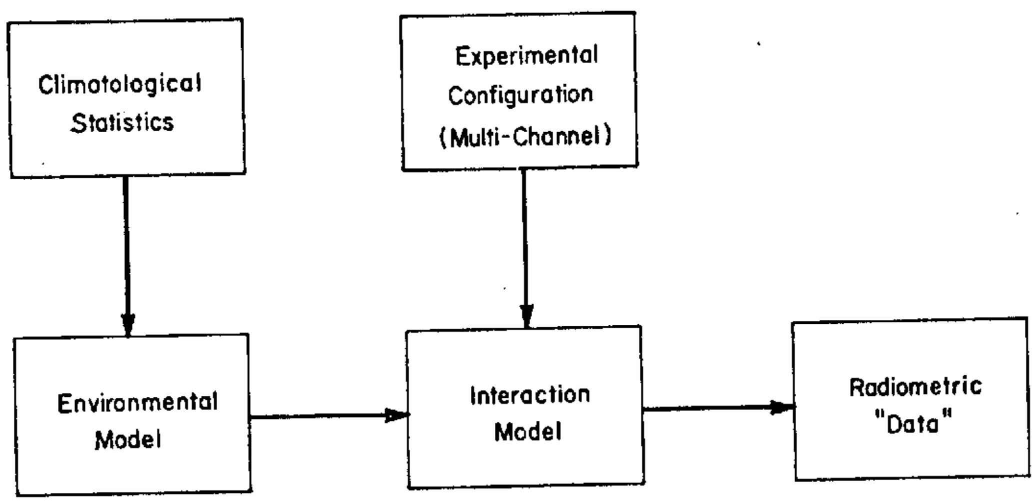

Figure 2-2 Block Diagram of the Experimental Modeling Procedure

the equation of radiative transfer in the presence of these interactions and the electromagnetic properties of the surface.

The properties of the submodels and the interaction model have been developed at length in previous studies (see, for example, Gaut and Reifenstein, 1970, 1971; Reifenstein and Gaut, 1971). They are summarized briefly as follows.

2.3.1 Atmospheric Gas Submodel

The geometry applicable to the numerical solution of the equation of radiative transfer is shown in Figure 2-3. The atmosphere is assumed to be made up of plane-absorbing layers at uniform temperature and pressure. The clear atmosphere is constructed by making use of radiosonde data to assign values of temperature, pressure and water vapor density to a set of heights above the surface. A layer is assumed to extend between two levels such that the i^{th} layer extends between level i and i+1. The intensive variables to be assigned to each layer are determined by an appropriate interpolation between values at the boundary levels. The ensemble of clear atmospheres is thus generated directly using radiosonde data taken over a period of time at a station whose climatology corresponds to the region of interest.

2.3.2 Cloud Submodel

Cloud models for the present study have been taken from the representative catalog constructed by Reifenstein and Gaut (1971) and reproduced as Table 2-1. Each model consists of one or more layers for which the composition (water cloud, ice cloud, precipitation), the mass density, and three parameters describing the drop-size distribution (Deirmendjian, 1964) are specified. Incorporation of a cloud model into a given clear atmosphere is accomplished by generating, for each layer of the cloud model, two new levels in the clear atmosphere; the temperature, pressure and water-vapor density for these levels are determined by the interpolation. Once these levels are created, the cloud properties are then assigned to those layers of the new atmosphere which fall between them. Of concern in the present study are the liquid-water mass density m, the composition index, and the droplet mode radius r_c; i.e., that radius for which the drop size number-density distribution function N(r) is maximum. In the event that adjacent

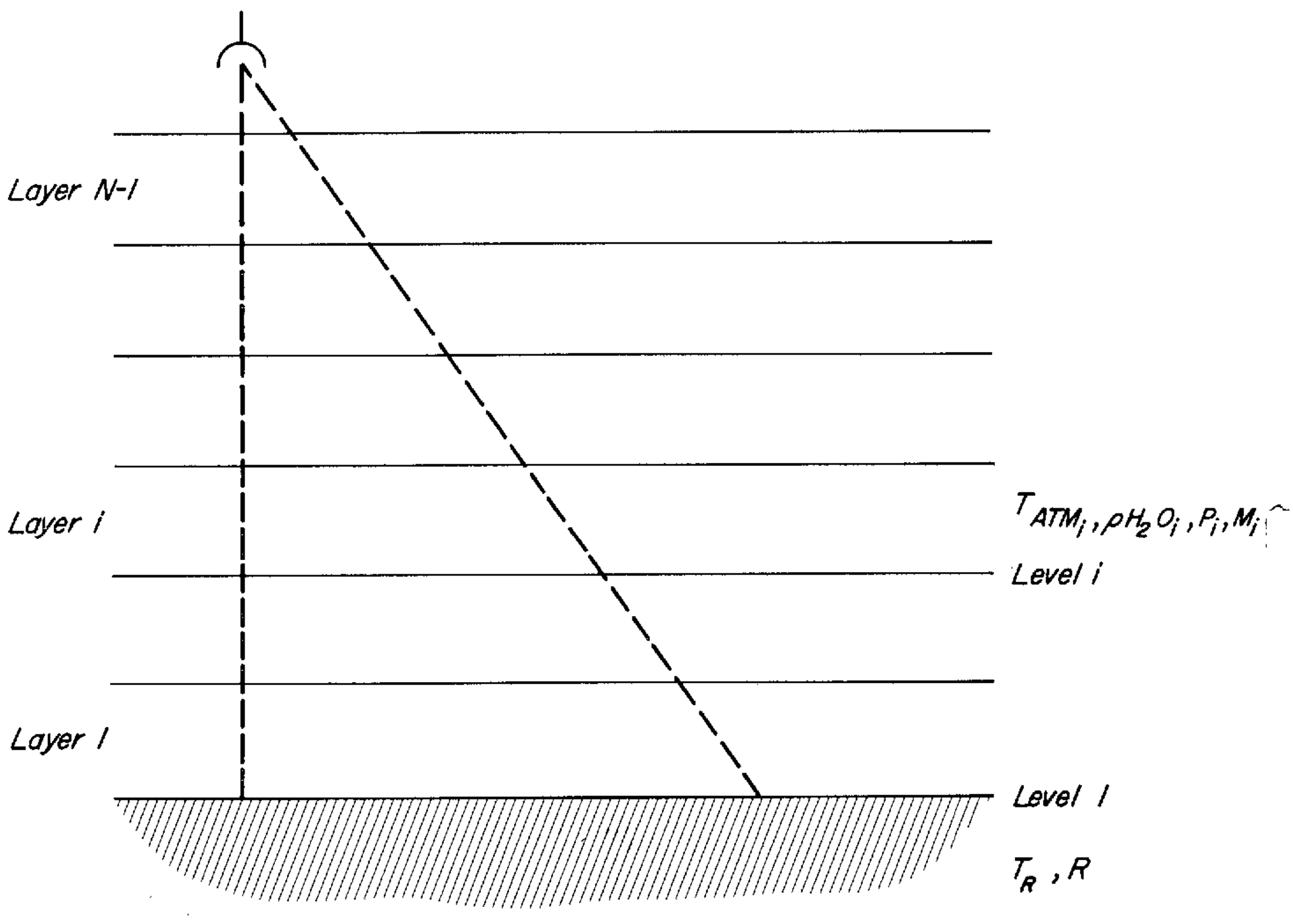

Figure 2-3 Geometries Applicable to the Solution of the Equation of Radiative Transfer in a Plane-Layered Atmosphere

TABLE 2-1

PROPERTIES OF STANDARD CLOUD MODELS

NUMBER	NAME	BASE (m)	TOP (m)	DENSITY (g/m³)	r_c (μ)	C_1	C_2	COMP.	Ref.
1-A-1	CIRROSTRATUS, ARCTIC, 12-18 kft	4000.	6000.	0.10	40.0	6.0	0.5	ICE	1,4
1-M-1	CIRRSOTRATUS, MID-LAT., 15-21 kft	5000.	7000.	0.10	40.0	6.0	0.5	ICE	1,4
1-T-1	CIRROSTRATUS, TROPICAL, 18-24 kft	6000.	8000.	0.10	40.0	6.0	0.5	ICE	1,4
10-1	ALTO CUMULUS 8000-9650 ft	2400.	2900.	0.15	10.0	6.0	0.5	WATER	1,2,3
14-1	ALTOSTRATUS 8000-9650 ft	2400.	2900.	0.15	10.0	6.0	1.0	WATER	1,2,3
20-1	LOW-LYING STRATUS 500-2000 ft	150.	650.	0.25	10.0	6.0	1.0	WATER	1,2,3
20-2	LOW-LYING STRATUS 1500-3000 ft	500.	1000.	0.25	10.0	6.0	1.0	WATER	1,2,3
20-3	FOG LAYER, GROUND TO 150 ft	0.	50.	.15	20.0	7.0	2.0	WATER	3
20-4	HAZE, HEAVY	0.	1500.	10^{-3}	0.05	1.0	0.5	WATER	1,5
21-1	DRIZZLE, 0.2 mm/hr	0. 500. 1000.	500. 1000. 1500.	1.00 2.00 1.00	20.0 10.0 10.0	6.0 6.0 6.0	0.5 0.5 0.5	RAIN WATER WATER	6
21-2	STEADY RAIN, 3 mm/hr	0. 150. 500. 1000.	150. 500. 1000. 1500.	0.20 1.00 2.00 1.00	200.0 10.0 10.0 10.0	5.0 6.0 6.0 6.0	0.5 0.5 0.5 0.5	RAIN WATER WATER WATER	6
21-3	STEADY RAIN, 15 mm/hr	0. 300. 1000. 2000.	300. 1000. 2000. 4000.	1.00 2.00 3.00 2.00	200.0 10.0 10.0 10.0	5.0 6.0 6.0 6.0	0.5 0.5 0.5 0.5	RAIN WATER WATER WATER	6
22-1	STRATOCUMULUS 1000-2000 ft	330.	660.	0.25	10.0	6.0	0.5	WATER	1,2,3
22-2	STRATOCUMULUS 2000-4000 ft	660.	1320.	0.25	10.0	6.0	0.5	WATER	1,2,3
25-1	FAIR WEATHER CU. 1500-6000 ft	500. 1000. 1500.	1000. 1500. 2000.	0.50 1.00 0.50	10.0 10.0 10.0	6.0 6.0 6.0	0.5 0.5 0.5	WATER WATER WATER	1,2,3
25-2	CUMULUS WITH RAIN 2.4 mm/hr	0. 500. 1000.	500. 1000. 3000.	0.10 1.00 2.00	400.0 20.0 10.0	5.0 6.0 6.0	0.5 0.2 0.2	RAIN WATER WATER	3,6
25-3	CUMULUS WITH RAIN 12 mm/hr	0. 400. 1000.	400. 1000. 4000.	0.50 2.00 4.00	400.0 20.0 10.0	5.0 6.0 6.0	0.5 0.2 0.2	RAIN WATER WATER	3,6
25-4	CUMULUS CONGESTUS, 3000-9000 ft	1000. 1200. 1600. 2000. 2500.	1200. 1600. 2000. 2500. 3000.	0.30 0.50 0.80 1.00 0.50	10.0 15.0 20.0 20.0 20.0	6.0 5.0 5.0 5.0 5.0	0.5 0.4 0.3 0.3 0.3	WATER WATER WATER WATER WATER	3
26-1	CUMULONIMBUS W. RAIN 150 mm/hr	0. 300. 1000. 4000. 6000. 8000.	300. 1000. 4000. 6000. 8000. 10000.	6.30 7.00 8.00 4.00 3.00 0.20	400.0 20.0 10.0 10.0 10.0 40.0	5.0 6.0 6.0 6.0 6.0 6.0	0.2 0.2 0.2 0.2 0.2 0.5	RAIN WATER WATER WATER WATER ICE	2,3,6

REFERENCES:
1. Valley, 1965
2. Fletcher, 1966
3. Mason, 1957
4. Blau, Espinola, and Reifenstein, 1966
5. Deirmendjian, 1964
6. Crane, 1966

levels of the new atmosphere have different values of the mass density, the corresponding layer is assigned the mean value. For mode radius and composition, however, the layer, assumed to be uniform in composition, is assigned that value corresponding to the level with the predominate mass density. The new model atmosphere with the cloud properties inserted is then converted to a set of layers as described above in Section 2.2.1, with one exception: the relative humidity within a cloud layer is assumed to be 100% and the water vapor density is set to the corresponding value.

Selection of a cloud model to be used for any given "day" is accomplished using Monte Carlo techniques. First, a probability of occurrence is assigned to an appropriate subset of the catalog, with this occurrence based upon available climatological data for the region of interest. Second, a relative rms variability is assigned to each model, again determined from climatological data. On each day a uniformly distributed random number is used to select one of the cloud models on the basis of probability of occurrence. If no cloud is selected, clear conditions are assumed and the atmosphere of Section 2.2.1 is used as is.

For the selected cloud model, the mass density is uniformly scaled by a second random number - this one is Gaussian-distributed with unit mean and variance determined by the specified rms variability. The result of this process is the actual cloud-cover submodel which is inserted into the clear atmosphere.

2.3.3 Surface Submodel

The geometry of Figure 2-3 represents the terrestrial surface as a horizontal plane characterized by uniform composition and temperature and an effective (specular) reflectivity. In actual fact, a real terrestrial surface is far more complicated: it is neither flat nor uniform, nor can it generally be described by an effective reflectivity. The present approach thus involves several assumptions concerning the nature of the surface, considered necessary to preserve the generality of the study method and, at the same time, to minimize the computation time required.

For the purposes of the present and related studies, the generalized surface submodel is considered to be a rough horizontal plane surface characterized by three gaussian random variables from which an effective specular reflectivity may be calculated. This surface model can be either a land or ocean model, with the land model specified by a temperature and a reflectivity. In the present study, an ocean surface model has been used with temperature, surface wind speed, and salinity as the three variables.

In computing the effective reflectivity, surface roughness is taken into account as a first-order correction to the smooth-plane approximation. The surface is considered to be made up of elemental slopes distributed as a gaussian random process, with the distribution parameters correlated with the wind speed. This approach is based upon the model of Stogryn (1967) and has been described in detail by Reifenstein and Gaut (1971). Essentially, the given temperature and salinity are used to obtain the specular reflectivities at both polarizations as a function of angle. The effects of roughness are then introduced by performing a weighted average over the incidence angle, and a weighted average of the two polarizations as shown in Figure 2-4. In the former case, the down-welling sky radiation incident at the surface is convolved with a Gaussian weighting function centered on the geometrical angle of incidence and, in the latter, a wind-dependent mixing function centered on the polarization angle of the radiometer. In addition, the porous dielectric foam model of Rosenkrantz (1971) is used with precipitable foam content

$$F = \rho \cdot Q \cdot D = 0.004 \text{ g/cm}^2 \qquad (2\text{-}11)$$

where

ρ is the density of sea water

Q is the volumetric mixing ratio of foam

and

D is the layer thickness.

The values of these parameters were to force agreement between model calculations at 19.35 GHz and the observations of foam patches reported by Nordberg et al (1970).

Selection of surface properties for any given "day" of the simulated experiment is accomplished using Monte Carlo techniques. Specified means and standard deviations for surface temperature, windspeed, and salinity are used with a Gaussian-distributed random number generator to arrive at the "actual" values appropriate to the day.

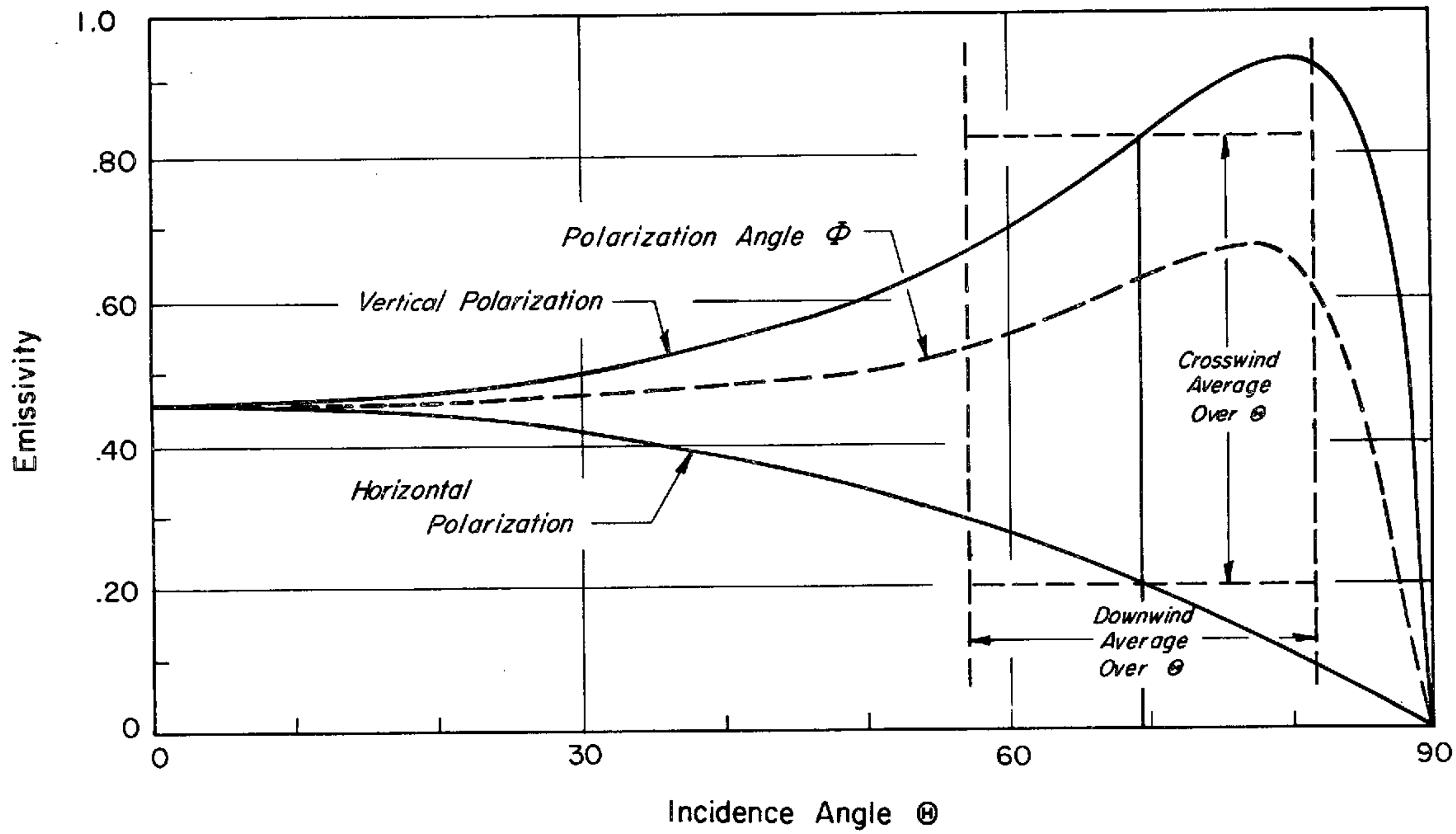

Figure 2-4 Schematic Representation of the Effects of Downwind and Crosswind Distributions of Slopes for the Determination of the Effective Specular Reflectivity

2.3.4. Interaction Model

Once the layered model of the atmosphere with its inserted cloud layers has been constructed, the extinction coefficients for water vapor, oxygen and clouds are computed for each layer at the radiometer frequencies.

The absorption coefficient for water-vapor in the vicinity of the 22 GHz and 183 GHz lines is computed using expressions of Gaut (1968). The method makes use of the Van-Vleck-Weisskopf (1945) collision-broadened line shape with an empirical correction term for the wings of the line. The absorption coefficient of oxygen is computed using the expressions of Lenoir (1968). Cloud and precipitation layers are treated as uniformly absorbing (Rayleigh scattering) media. In this limit, the absorption coefficient for water clouds is simply proportional to the mass density, and has been computed using an approximation formula of Staelin (1966). No distinction has been made between water, ice, and rain layers in the use of this approximation formula.

The formal relation which describes the passage of radiation through a material medium is the equation of radiative transfer. The following discussion of the numerical procedure for solution of the equation of radiative transfer follows that of Reifenstein and Gaut (1971). The brightness temperature seen by a space-based radiometer looking down at the earth's surface at an incidence angle ϕ is (Gaut, 1968):

$$T_B = T_{B_1} + \{(1 - R)\, T_G + R\, T_{B_2}\} \exp(-\tau) \qquad (2\text{-}12)$$

where

T_{B_1} = upward <u>emission</u> from the atmosphere alone $^{\circ}K$

R = effective specular reflectivity

T_G = surface temperature $^{\circ}K$

T_{B_2} = downward emission from the atmosphere plus the attenuated sky background emission $^{\circ}K$

τ = total opacity of the atmosphere along the line of sight, nepers

The quantities T_{B_1} and T_{B_2} are in fact integrals of the equation of radiative transfer carried as follows:

$$T_{B_1} = \int_0^H T(z)\ \gamma(z)\ \exp\left[-\int_z^H \gamma(z')\ \sec\theta\ dz'\right] \sec\theta\ dz \qquad (2\text{-}13)$$

$$T_{B_2} = T_{sky}\ e^{-\tau} + \int_0^H T(z)\ \gamma(z)\ \exp\left[-\int_0^z \gamma(z')\ \sec\theta\ dz'\right] \sec\theta\ dz$$

where

$$\tau = \int_0^H \gamma(z)\ \sec\theta\ dz.$$

H is the height of the atmosphere, and γ is the total extinction coefficient at height z above the surface, representing the sum of terms due to water, vapor, oxygen and cloud particles. Since the continuously variable atmosphere has been replaced by a set of N-1 uniform layers, the integrals of Eq. (2-13) are replaced by summations over the layers:

$$T_{B_1} = \sum_{i=1}^{N-1} \bar{T}_i\ \exp\left[-\tau+\tau_{i+1}\right]\ \{1 - \exp\left[-\tau_{i+1} + \tau_i\right]\}$$

$$T_{B_2} = \sum_{i=1}^{N-1} \bar{T}_i\ \exp\left[-\tau_i\right] \{1 - \exp\left[-\tau_{i+1} + \tau_i\right]\} + T_{sky}\ \exp\left[-\tau\right] \qquad (2\text{-}14)$$

where

τ_i is the total opacity from the surface to the i^{th} <u>level</u> (bottom of the i^{th} <u>layer</u>):

$$\tau_i = \int_0^{z_i} \gamma(z')\ \sec\ \theta dz' = \sum_{j=2}^{i} \gamma_j\ \sec\ \theta\{z_j - z_{j-1}\}. \qquad (2\text{-}15)$$

The relationship between the incidence angle θ and the nadir angle Ψ for a satellite depends upon its height above the surface, h, the level height, z, and the radius of curvature, R, of the earth as shown in Figure 2-5, with

$$\sin \theta = \frac{R+h}{R+z} \sin \psi . \qquad (2\text{-}16)$$

For $\Psi = 45^{\circ}$, $R = 6.4 \times 10^3$ km (4000 miles), and $z = 0$, we have $\Theta = 55^{\circ}$ Note that the error made by assuming a "flat earth" in the determination of the path length through any atmospheric layer is negligible except at extreme nadir angles since the atmosphere is itself confined to less than 100 km.

2.3.5. Limitations to the Model

The following limitations to the modeling procedure as implemented in the present study are worthy of note:

1) The procedure for cloud selection and insertion may in fact over estimate the amount of water vapor present in cloudy atmospheres as a result of the 100% humidity assumption, which neglects the effects of partial cloud cover within the antenna beam. In addition, the presence of clouds in the original radiosonde data (assumed to be cloudless) tends to over-estimate the water vapor content on so-called "clear" days.

2) The surface model as presently implemented, require further investigation with regard to the relationship between surface roughness and surface winds, foam coverage and surface winds, and experimental verification of the frequency dependence of the foam interaction model.

3) In the determination of the absorption coefficient due to clouds, neither the cloud composition nor the drop-size distribution have been considered, but instead the simple Rayleigh approximation formula has been used, with the result that ice absorption is substantially over-estimated, and the effect of rain layers under-estimated.

These limitations represent sources of error in the modeling of absolute microwave responses to an assumed set of environmental parameters, since they introduce false correlations between the parameters and the data to be inverted. This error is self cancelling in the case of simulated inversions, since the simulated "data" behaves in the same manner as the statistics. In the application to real data, however, this is no longer the case, and hence a divergence occurs between the theoretical and observed performance (e.g. for the mode radius of the cloud drop distribution).

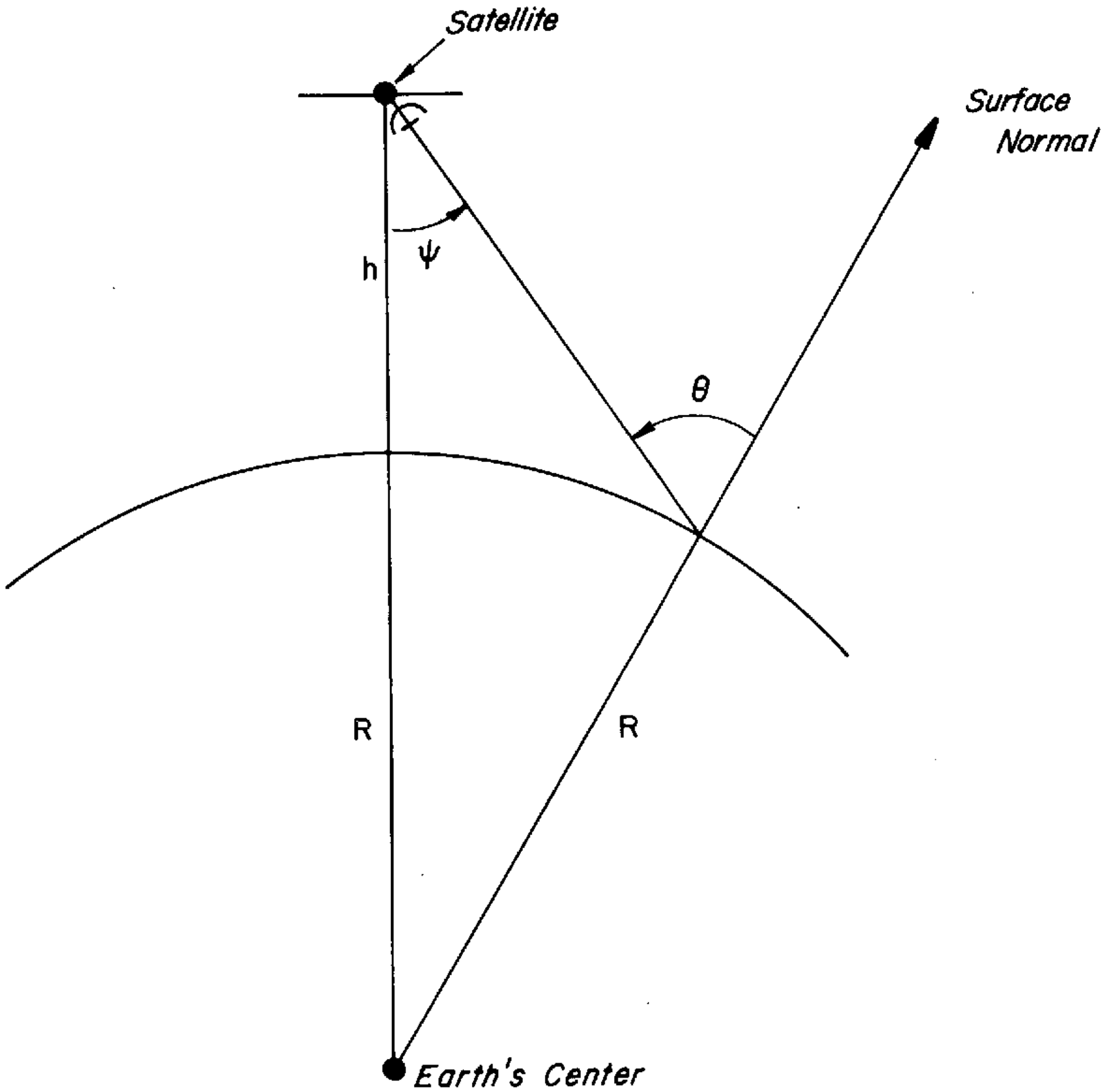

Figure 2-5 Geometry for Relating the Surface Incidence Angle to the Nadir Angle of a Satellite at Height h above the Earth's Surface

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3. IMPLEMENTATION OF THE METHODOLOGY

The implementation of the methodology previously described for the analysis of the CV-990 data is made through the software system shown in Figure 3-1. This system consists of computer programs and their associated data sets which together carry out the computation and analysis steps indicated schematically in Figure 2-1. In this section, the operation of these programs is briefly described using as an example, the application of these programs to the data obtained by CV-990 flights over the Gulf of Mexico.

3.1 Simulation Programs

The generation of the radiometric data set $\underline{d}_o$ (and also $\underline{d}$ in evaluation of hypothetical systems) is achieved through the three major programs identified as NWRC, NWRST, and RAPID GABTAWF. The first two programs create an environmental data set (atmosphere, clouds and surface) having statistics similar to those under which the experimental data were obtained. The last program, RAPID GABTAWF, operates on this environmental data set, through a radiation interaction model, to obtain the required data set $\underline{d}_o$.

3.1.1 The Radiosonde Data (NWRC)

Historical radiosonde data are used to create the environmental data set representative of clear sky conditions. To create the set of data corresponding to the conditions over the Gulf of Mexico, radiosonde data from Tampa, Florida were selected. These radiosondes were available from the extensive data library of the MIT General Circulation Project, to which ERT has access; however, as that data library was created from the data provided by the National Weather Records Center, the soundings are equivalent to soundings provided by the Center.

For the test case, the program NWRC input all 00Z radiosondes available in this library for March 1958, 1959, 1961, and 1962 and for February 1961. Each sounding contained height, temperature, relative humidity, and winds at 50 mb intervals from the surface to 100 mb. The processing resulted in a tape (Tape A in Figure 3-1) containing 140 vertical profiles of temperature, height, and moisture. To provide surface statistics, NWRC also generated a mean and standard deviation of surface moisture and wind speed.

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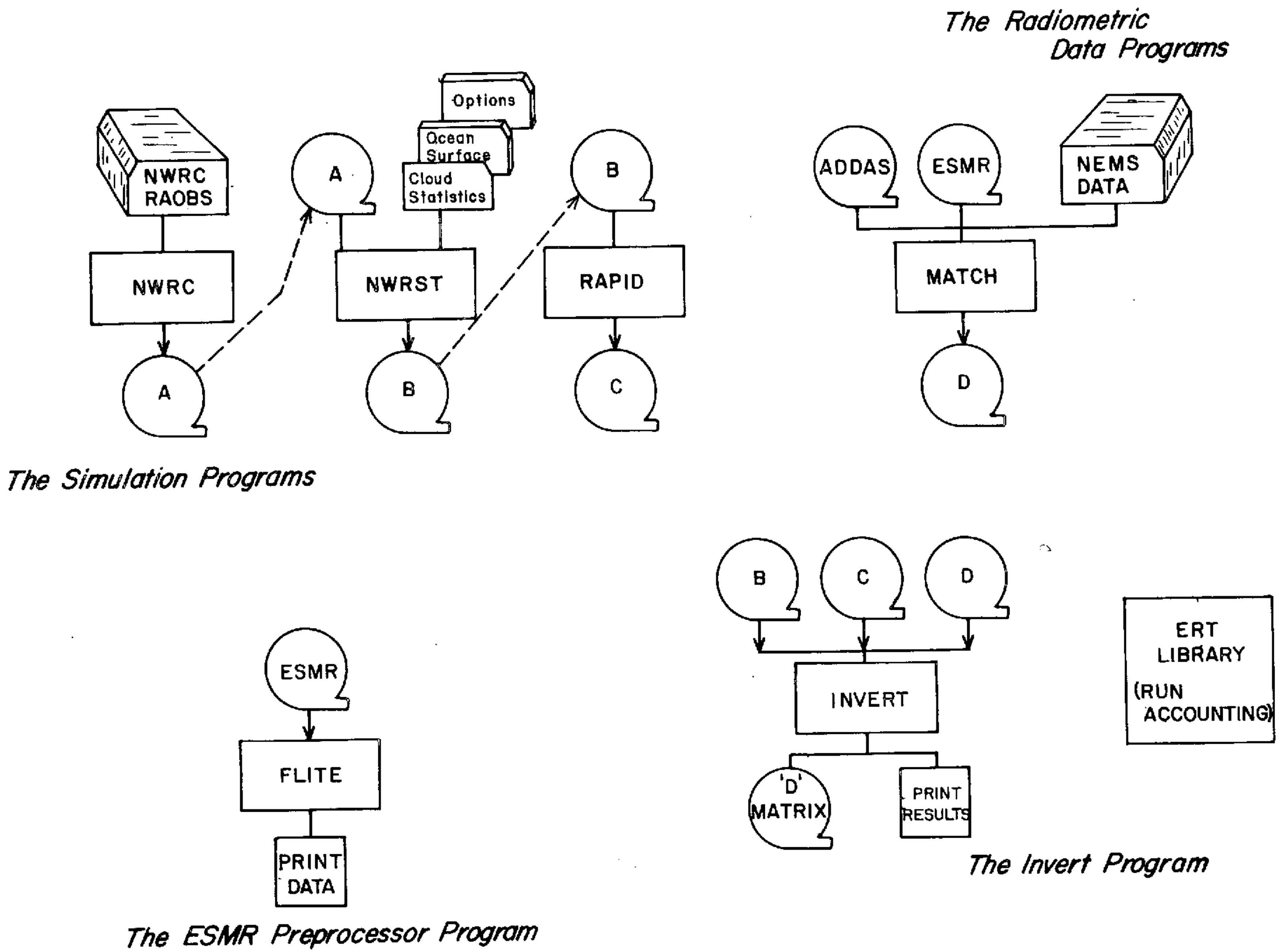

Figure 3-1 Flow Diagram of the Radiometric Data Inversion Software Package

3.1.2 The Atmospheric Models (NWRST)

The radiosonde data set generated by NWRC provides a simple layered atmosphere, without clouds or surface data. Since any realistic atmospheric simulation must include this information, the NWRST program is designed to add such data to the soundings and to generate complete atmospheric models.

The cloud statistics used by NWRST were taken from a study by Chang and Willand (1972) which presents detailed statistics on the global distribution of cloud cover and cloud type. These statistics are based on 5 to 10 years of surface and satellite observations, and are tabulated for each month of the year, at three hour intervals, for each of twenty-nine climatological regions. Cloud region 4, defined in the study, is representative of conditions over the Gulf of Mexico. Its hourly statistics were combined into daily statistics for the month of March, and the appropriate cloud model was chosen for each cloud type represented. Table 3-1 shows the selected cloud models, their microphysical parameters, and their probabilities of occurence. These cloud models were input from cards to the computer program, and a table of their probabilities of occurence was established for future Monte Carlo processing.

The only surface model used by this study was the ocean surface model, since all the data to be analyzed were taken over the Gulf of Mexico. The mean and standard deviation of surface temperature, surface wind speed and salinity were derived from the climatological data (Crutcher and Meserve, 1970) available for the Gulf of Mexico (Table 3-2). Parameters applicable to the radiosonde station were then input: the station name (Tampa, Florida), the station WMO number (72211), and the station elevation (3 meters).

Using the cloud and surface statistics, NWRST converted the soundings to atmospheric models. For each radiosonde sounding prepared by NWRC, checks were performed for missing surface values, coding errors, and large gaps in the observations. If the sounding showed any of these defects, it was eliminated. Layer values of temperature, height, pressure and water vapor were then computed from the values given at the surface and at the constant pressure levels. A cloud model was then selected by a Monte Carlo procedure based on the cloud's probability of occurrence, its liquid water content scaled by a random number chosen from a Gaussian distribution, and the resulting parameters inserted into the layered atmosphere. If the cloud model contained greater vertical detail than that given by the original

TABLE 3-1

CLOUD STATISTICS FOR THE GULF OF MEXICO

CLOUD TYPE	NAME	BASE (m)	TOP (m)	DENSITY (g m^{-3})	Rc (μm)	C_1	C_2	COMP.	SIGMA	PROBABILITY
1-T-1	Cirrostratus Tropical	6000	8000	0.10	40.0	6.0	0.5	Ice	.5	.242
10-1	Altocumulus	2400	2900	0.15	10.0	6.0	0.5	Water	.5	.113
14-1	Altostratus	2400	2900	0.15	10.0	6.0	1.0	Water	.5	.023
20-2	Low-lying Stratus	500	1000	0.25	10.0	6.0	1.0	Water	.5	.087
21-2	Steady Rain 3 mm/hr	0	150	0.20	200.0	5.0	0.5	Rain	.5	.141
		150	500	1.00	10.0	6.0	0.5	Water		
		500	1000	2.00	10.0	6.0	0.5	Water		
		1000	1500	1.00	10.0	6.0	0.5	Water		
22-2	Stratocumulus	660	1320	0.25	10.0	6.0	0.5	Water	.5	.192
25-1	Fair Weather Cumulus	500	1000	0.50	10.0	6.0	0.5	Water	.5	.080
		1000	1500	1.00	10.0	6.0	0.5	Water		
		1500	2000	0.50	10.0	6.0	0.5	Water		
26-1	Cumulonimbus	0	300	6.30	400.0	5.0	0.2	Rain	.5	.014
		300	1000	7.00	20.0	6.0	0.2	Water		
		1000	4000	8.00	10.0	6.0	0.2	Water		
		4000	6000	4.00	10.0	6.0	0.2	Water		
		6000	8000	3.00	10.0	6.0	0.2	Water		
		8000	10000	0.20	40.0	6.0	0.5	Ice		

TABLE 3-2

OCEAN SURFACE PARAMETERS FOR THE GULF OF MEXICO

Parameter	Mean	Standard Deviation
Surface Temperature (°k)	297.0	2.0
Wind Speed (m sec^{-1})	5.8	2.0
Salinity (moles/liter)	0.66	0.0

sounding, the altitudes affected were broken down into smaller layers and all appropriate values were recomputed. Finally, the water vapor density values in all the cloud layers were set to saturation. In cases where no cloud was chosen, clear skies were assumed and the sounding was left unchanged.

Gaussian-distributed random numbers were also used to select the surface properties of temperature, wind speed, and salinity needed to complete the atmospheric model. The model, with its identifying record number and data, was then output to tape (Tape B in Figure 3-1) and a new sounding was input for processing. This procedure continued until the desired number of atmospheric models had been established for use in the radiometric simulation and in the inversion procedure.

3.1.3 The Radiometric Models (RAPID)

The third simulation program is RAPID GABTAWF, the version of GABTAWF (Generalized Atmospheric Brightness Temperatures and Weighting Functions) which computes brightness temperatures for selected microwave channels for each atmospheric model generated by NWRST. This program contains the models and submodels of radiative transfer which were discussed in Section 2; the reader is referred to that section for a detailed presentation of the equations of radiative transfer.

For the test case, RAPID read the general parameter specifications such as the radiometer altitude (i.e., the Convair 990 altitude), the output print options, and the background atmospheric temperature. In general, RAPID allows the use of more than one radiometer height in a run; however, the inversion procedure does not. This necessitated separate runs for passes at 7620 m (25000 ft) and at 1524 m (5000 ft) corresponding to selected aircraft flight altitudes. (In cases where the radiosonde sounding did not reach to the altitude specified, the processing of that model terminated at the top of the atmosphere and no attempt was made to extrapolate to the sensor altitude.) Whenever the brightness temperatures were to be written on tape, that output parameter had to be set to TRUE. Without this parameter specification, no results could be saved for further processing.

The program then input the radiometric specifications. First, the channel configuration applicable to the entire experiment was specified. For this study, this included all the EOS, ESMR and NEMS channels which were flown on the Convair 990 and used for the determination of atmospheric and surface parameters. The selected frequencies, angles, and polarizations are given in Table 3-3 with their assigned channel numbers. These channel numbers were fixed for all processing in the radiometric and statistical programs, and were used to internally reference the computed brightness temperatures.

The channels specified for processing during the run were then selected from the set of 32 channels. This set was a subset (possibly an inclusive subset) of the overall channel configuration. Additional information concerning the beam width and channel name were also provided along with rms noise values, (see Section 3.4), and offsets and scale factors (see Section 3.3). The channels selected for analysis included the entire channel configuration. Note, however, that if only the EOS system was to be studied, this procedure makes it possible to specify just the desired set of channels, to avoid unnecessary processing.

With the completion of the channel selection, station information was read, and the program began processing the atmospheric models generated by NWRST. First each sounding was read from tape and the radiometer height and surface properties initialized. Then the program proceeded through the requested microwave channels computing the absorption coefficients for each layer of the model atmosphere for each frequency look angle and polarization. The equations given in Section 2.2.4 were used to compute the contributions of the surface, sky background radiation, water vapor, liquid water and clouds to the total brightness temperature generated for each channel. Values of opacity and total transmission were also computed and terms

TABLE 3-3

CONVAIR 990 MICROWAVE CHANNEL CONFIGURATION

Channel	Frequency	Angle	Polarization
1	1.420	0.0	H
2	4.990	38.00	V
3	4.990	38.00	H
4	10.690	38.00	V
5	10.690	38.00	H
6	31.400	0.0	V
7	37.000	38.00	V
8	37.000	38.00	H
9	19.350	0.0	H
10	19.350	2.30	H
11	19.350	4.60	H
12	19.350	6.90	H
13	19.350	9.20	H
14	19.350	11.50	H
15	19.350	13.80	H
16	19.350	16.20	H
17	19.350	18.60	H
18	19.350	21.00	H
19	19.350	23.50	H
20	19.350	26.00	H
21	19.350	28.60	H
22	19.350	31.20	H
23	19.350	33.90	H
24	19.350	36.70	H
25	19.350	39.60	H
26	19.350	42.70	H
27	19.350	45.90	H
28	19.350	49.30	H
29	22.230	0.0	V
30	53.650	0.0	V
31	54.900	0.0	V
32	58.800	0.0	V

printed for the user's reference. Finally, computed brightness temperatures were output for each model atmosphere to tape (Tape C in Figure 3-1).

3.1.4 The Simulation Results

The data sets generated by the three programs just discussed permit simulation of the atmospheric and radiometric properties in the Gulf of Mexico for the month of March. Since the data set generated by NWRC is used only by NWRST, the atmospheric models created by NWRST, and the radiometric values computed by RAPID GABTAWF, are the data sets which are used in the inversion procedure. The first set supplies the parameter vectors $\underline{p}_0$ and the second is used as the data vectors $\underline{d}_0$ (see Section 2.1). It is the relationship between these two data sets which is used both to generate the D-matrices and to evaluate the expected inversion error. However, since the purpose of this study was not the evaluation of radiometric systems, but rather the interpretation of radiometric data, a description of the data sets, and the data handling programs, precedes a discussion of the inversion procedure.

3.2 The Radiometric Data Programs

Three microwave systems were carried on the NASA Convair 990 aircraft for the flights made in March 1972. The ADDAS system (Airborne Digital Data Acquisition System), also known as the EOS system (Earth Observational Satellite), contained microwave channels ranging in frequency from 1.42 GHz to 37.0 GHz, and in look angle from 38° behind the aircraft to 38° ahead of the aircraft. The system also contained an infrared channel in the 11-12 μm range. Data from this sensor were not used in this study. The NEMS system (Nimbus E Microwave Spectrometer) had five down looking sensors, one at 22.235 GHz, one at 31.4 GHz, and three in the oxygen band. Finally the ESMR system (Electronically Scanning Microwave Radiometer) scanned from 49.3° at the left of the aircraft to 49.3° at the right of the aircraft with a frequency of 19.35 GHz permitting a map of the track followed by the aircraft. Figure 3-2 presents schematically the areas viewed by the microwave systems.

It is clear that the combined radiometer package covers the range of sensitivities to water vapor, liquid water and oxygen. However, it is also clear that the various sensors view the same spot at different times, and

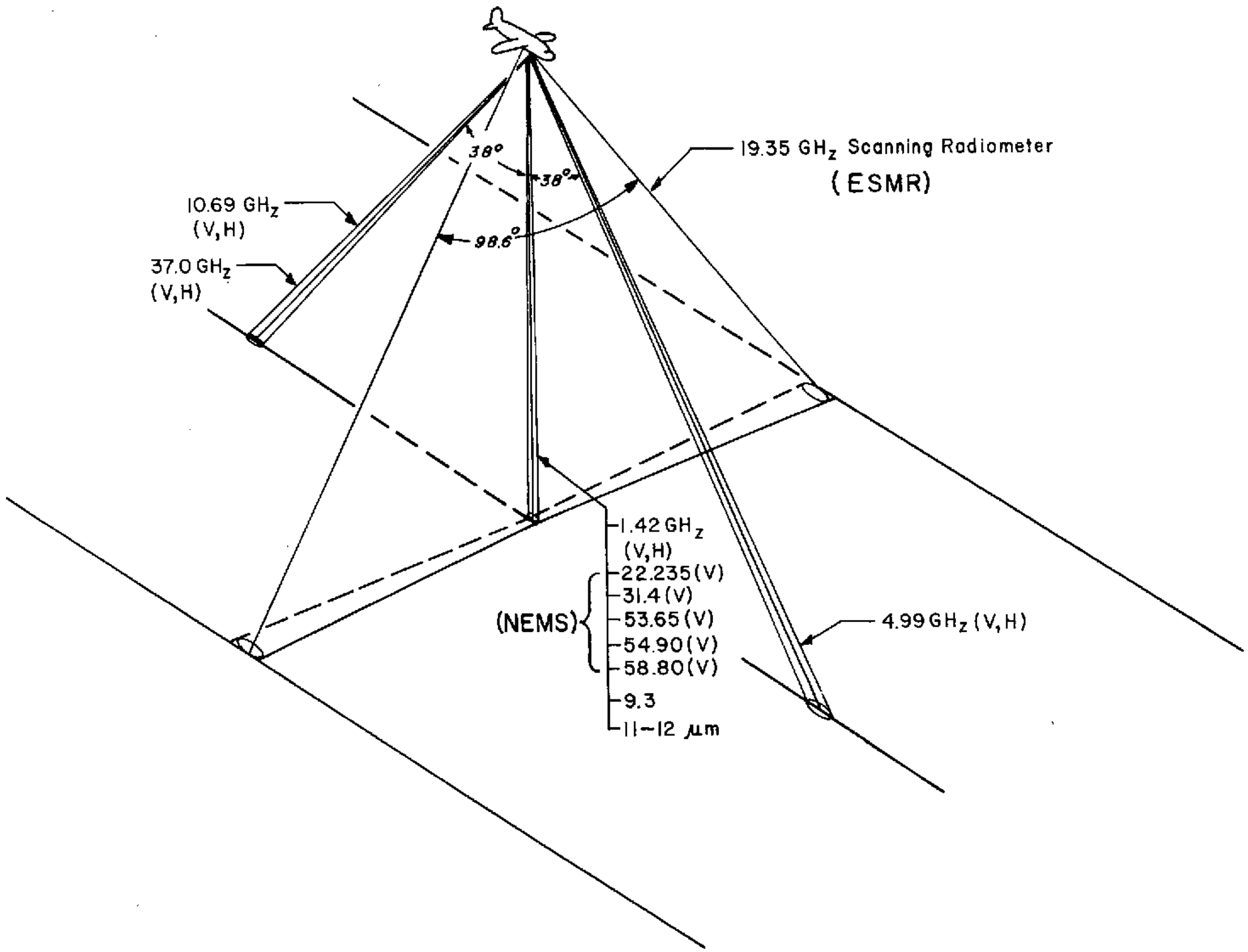

Figure 3-2 Schematic Representation of the Areas Viewed by the Convair 990 Microwave Systems

and that some locations are seen by only one sensor; thus the data must be carefully matched in space coordinates before they can be considered to form a multi-channel package.

3.2.1 The Data Preparation Program (MATCH)

Program MATCH was written to take the data from the three microwave systems and combine them in such a fashion that they could be input to the inversion program and used to obtain information on atmospheric and surface properties. Each system provided a separate data source; these can be summarized as follows:

- One tape of ADDAS data for each flight made by the Convair 990 containing digitized values of brightness temperature for each microwave channel shown in Figure 3-2 at a rate of 20 values per second. With these values were given the navigational data (e.g. pressure height, pitch, roll, air speed). Each second of data was represented by a separate record.
- One tape of ESMR data for each flight containing digitized brightness temperatures at 29 angles along one scan line, recorded at two second intervals with time and position identifiers.
- Printouts of the NEMS data showing brightness temperature for each of the five microwave channels. These values were given as averages across 16 second intervals, and were punched on computer cards for program input.

Separate input routines were necessitated by these differences in format and time intervals; in fact, it was necessary to make the data values consistent before aligning them geographically. Certain constraints on the number of data samples were necessitated for efficient computer processing. Thus, a maximum of 11 minutes was defined as the processing segment and an 18 x 660 array was established to contain all of the CV-990 data measured during that time interval. In actuality, the conversion from time to space coordinates eliminated some of the data input so that only a 10 minute segment was processed in each job step.

The program began by reading a computer card requesting a start time and an end time for the data to be processed, and a second card specifying the use (or nonuse) of NEMS data and the time interval (in seconds) for averaging. The ADDAS tape was then positioned at the start time, and one second's worth of navigational and radiometric data was read. The values were checked for flags indicating missing or questionable data, and the erroneous values directly following the polarization switching in 10.69 GHz channels were eliminated. When it had been established that all the remaining values were legitimate, the data values were averaged for that one second and stored in the 18 x 660 array.

The distance traveled by the aircraft from its position at the start time was then computed, and adjusted to distance traveled by the forward, downward, and backward looking sensors. The computations involved were the following:

Forward Looking:	$D = H \tan (38.0 + P) + Sdt$	(3-1)
Downward Looking:	$D = H \tan (P) + Sdt$	(3-2)
Backward Looking:	$D = H \tan (-38.0 + P) + Sdt$	(3-3)

where

D = the distance traveled

H = the aircraft altitude

P = the pitch of the aircraft

S = the average air speed computed from the true air speed at the current and previous observation times

and

dt = the observation time t_n - the start time t_o.

In the case of the first record, when dt = 0 and the pitch = 0, equations gave a negative value for the backward looking sensors, a zero value for the down looking sensors, and a positive value for the forward looking sensors. These three distance values were also stored in the data array.

The reading and processing of the ADDAS data continued in this fashion until all data requested for a time period had been input and averaged for one second intervals, and stored in the large array. Then the program began to match the sensors by the location sensed. A distance computed for the downviewing sensors was selected, and the array scanned for matching distances in the backviewing and forward viewing sensors. If, and when, these were found, the appropriate data were moved to the positions in the array corresponding to the time of the selected down viewing sensors. A new distance was then selected and the search and rearrangement repeated until all of the data corresponding to a particular location had been grouped together. Frequently, because of the drift in the aircraft or changes in direction, the spot viewed differed slightly for the three sets of sensors. Little error was introduced by these small discrepancies because of the large amount of overlap expected by the MATCH program, and because of the areal homogeneity of most atmospheres and surfaces sensed. Data values from some sensors were always lost because of the view angle; these values were usually from the back viewing sensors at the beginning of the time period, and from the forward viewing sensors at the end.

The ESMR data were then read scan line by scan line. For each scan line, the temperatures measured on the left side of the aircraft were averaged with the appropriate temperatures measured on the right side of the aircraft (e.g. the temperature for 2.3°L with the temperature for 2.3°R); only the down looking value remained the same. This averaging again involved an assumption of areal homogeneity, an assumption which was generally supported by visual analysis of the ESMR data (see Section 3.2.2). The average data value for each look angle was stored in the array with the ADDAS data measured at the same time as the scan line. Since the ESMR scan lines were recorded at 2 second intervals, every other second of ADDAS data had missing values stored for the ESMR channels.

While the ESMR data was being processed, the computer program checked to see if the requested time interval for averaging had been completed. For example, if the averaging interval specified was ten seconds, ten seconds of ESMR data were read and processed in the above fashion, then a ten second average was found for all values stored for the navigational parameters, the ADDAS channels and the ESMR channels. These averages were stored in an output array appropriate for input to the inversion procedure, and the processing of the ESMR was repeated for another ten seconds. Thus, at the completion of the ESMR processing, not only were all the ADDAS and ESMR microwave channel values combined by the location sensed, but they were also averaged for the requested time intervals and ready for output to tape (Tape D in Figure 3-1) and printer. If the NEMS data were not desired, this output followed directly and the program terminated.

In runs which requested NEMS data, the 16 second averaged values for the entire time period were read from cards and stored in a separate array. Since the 16 second time interval was generally longer than the time interval requested (e.g. 10 seconds), the values were interpolated to the desired times, rather than averaged as the ADDAS and ESMR values were. The resulting brightness temperature values were stored in the output array with the values from the other channels. Finally the entire array was printed and written on tape.

3.2.2 The Data Display Program (FLITE)

To permit examination of the brightness temperatures recorded by the ESMR radiometer, a program (FLITE) was written to read and display the radiometric values. This program is quite independent of the other programs discussed in this report and its use is not required by any aspect of the inversion procedure. However FLITE was written as part of the preprocessing package to facilitate the selection of homogeneous areas, and the evaluation of the 19.35 GHz measurements.

Basically the program reads the ESMR tape, displays each scan line on the printer and finds the mean and standard deviation of the brightness temperatures for each look angle. These statistics are then plotted on the printer providing a clear picture of the temperature range at various parts of the scan line, and of the noise inherent in the system. Since the roll of the aircraft changes the look angles of the radiometer and hence the temperature values recorded, these plots also provide an interesting presentation of the CV-990's flight pattern.

A computer card specified the date, the start and end time of processing, and a print option. If the print was suppressed, only the statistics for the time period, and the resulting plot, were printed. Otherwise the scan line from 49.3° left to 49.3° right was printed with a code and the last two digits of temperature. In this fashion 129° was shown as -29, 229° was shown as 29, and 329° appeared as +29. Each line of printout showed one scan line and a series of these lines across time created a map of brightness temperatures. Since the 19.35 GHz is highly sensitive to changes in surface temperature, the resulting map delineated land-sea boundaries, islands and, often, ocean currents. If clouds were encountered, they were also seen quite clearly. As the result, ESMR tapes were mounted, and proposed time segments examined for areal homogeneity or interesting atmospheric or terrestrial features, before any attempt was made to infer geophysical parameters.

Several time segments could be selected merely by setting up a request card for each time period desired, in chronological order. The program printed, averaged, and plotted for each card read, then read a new card and continued. An entire tape was mapped in this fashion without the use of any expensive peripheral equipment.

3.3 The Inversion Program (INVERT)

The large amounts of data processing and analysis represented by the programs just discussed created three important data sets, one representing the atmosphere, one representing theoretical radiometric values, and one representing measured data. Although each of these data sets provides significant information to individuals concerned with atmospheric parameters and/or microwave observations, none of them permits the derivation of atmospheric parameters from microwave observations. This step is accomplished by the inversion program INVERT, which establishes the statistical relationship between the observations and the desired parameters, and then applies this relationship for inversion of observed data. This program has two separate phases: one to create the D-matrix and the other to use it. Each phase will be described in a separate section, but they should be regarded as one unit of processing.

3.3.1 The Generation of the D-Matrix

The first phase of INVERT is similar to that described in previous reports (Gaut, Reifenstein and Chang, 1972; Gaut, Reifenstein, Chang and Blinn, 1973); that is, it uses the atmospheric models generated by NWRST, and the simulated radiometric data generated by RAPID GABTAWF to create and evaluate a D-matrix. The statistical principles underlying this approach were given earlier; it should be remembered that the $\underline{p}_o$ vector of Figure 2-1 is generated directly from the atmospheric data set, and the $\underline{d}_o$ vector from radiometric values computed from the atmospheric data set.

INVERT began by specifying the microwave channels to be used. The entire Convair 990 microwave system was defined as given in Table 3-3.

This was identical to the system specified at the start of RAPID GABTAWF to permit accurate referencing of the brightness temperatures generated by the simulation. The precise channels selected for the desired inversion were then read, and a check was made to determine that those channels had been previously simulated. If the channels had not been simulated, the program terminated. Frequency, look angle and polarization were all defined. In addition, a value of system noise was input to be added to the simulated data. An offset and a scale factor for each sensor was also read and saved to alter the measured values in phase two.

The number of channels and the specific channels requested differed from run to run and permitted easy evaluation of the usefulness of various microwave channel combinations. Within a run, however, the channel specifications applied to all processing, both in the generation of the D-matrix and in the inversion of the measured data. The microwave channel specification terminated with a computer card indicating the order of array elements generated by MATCH corresponding to the channel order in the Goddard channel package. This card, like the cards in the Goddard channel package, did not change throughout the experiment (Table 3-4). Again the information given by this card was not used in the generation of the D-matrix, but rather was saved to input the measured values.

Run parameters were specified next: the number of observations to be used in generating the D-matrix, the number of elements in a parameter vector, the number of elements in a data vector, and other such values. The number of data ($\underline{d}_o$ vector) elements had to match the number of channels requested and could vary from run to run. The number of parameter ($\underline{p}_o$ vector) elements had to match the number of parameters defined in the program (nine), and could not vary at all. Other run parameters specified included a random number seed and options for outputting, and inputting, in phase two, the D-matrix. These parameters are described in more detail in Section 5.4.

A data card then specified aircraft height and four altitudes delimiting layers of water vapor density. As stated in Section 3.1.3, the aircraft height was constant for each run. No attempt was made to infer water vapor density above the aircraft. When the aircraft height fell within a layer, the aircraft altitude replaced the specified layer altitude. With this one exception, no changes were made in the elements of the parameter vector

TABLE 3-4

RELATIONSHIP BETWEEN THE GODDARD CHANNEL NUMBER AND THE MEASURED DATA ARRAY ELEMENTS

Channel Number*	Array Element	Frequency
1	3	1.42
2	4	4.99
3	5	4.99
4	8	10.69
5	7	10.69
6	33	31.4
7	11	37.0
8	10	37.0
9	12	19.35
10	13	19.35
11	14	19.35
12	15	19.35
13	16	19.35
14	17	19.35
15	18	19.35
16	19	19.35
17	20	19.35
18	21	19.35
19	22	19.35
20	23	19.35
21	24	19.35
22	25	19.35
23	26	19.35
24	27	19.35
25	28	19.35
26	29	19.35
27	30	19.35
28	31	19.35
29	32	22.235
30	34	53.65
31	35	54.9
32	36	58.8

*See Table 3-3 for further detail.

throughout the study. (If changes were desired the subroutine PVECT, but only subroutine PVECT, would have to be rewritten.) Table 3-5 lists the parameters for which the inversion was performed. From tape B (Figure 3-1), atmospheric models were read up to the number of observations specified. From each model the surface temperature, surface wind speed and cloud drop mode radius were taken unchanged and stored in the $\underline{p}_o$ vector array, and the layered values of liquid water density and water vapor density were used to compute the parameters of integrated water vapor, integrated liquid water and water vapor density in each of the four layers. These values filled the remaining elements of each $\underline{p}_o$ vector, and the resulting vectors were printed with their identifying dates and record numbers.

Radiometric data values were read next, and brightness temperatures for the requested channels were stored in the appropriate elements of the $\underline{d}_o$ vector array. System noise was added at this time. For each channel a random number was drawn selecting a noise value from a zero-mean Gaussian distribution, with a standard deviation corresponding to the system noise specified in the channels package. The resulting $\underline{d}_o$ vectors were printed in format similar to that used by the $\underline{p}_o$ vectors and the D-matrix computed according to the equations of Section 2.1, achieving the primary objective of phase 1. If output of the D-matrix had been requested, it was now written on tape along with the number of parameters, the number of data elements and the average values of the data in each of the channels used (e.g. the mean brightness temperature for 19.35 GHz at 0^o look angle).

INVERT could be terminated at this point (for example, when the D-matrix had been written on tape for future processing). Otherwise, an evaluation of the expected inversion error was usually performed. Run parameters were again specified, differing from the previous parameters only in the number of observations to be read. For evaluation purposes, the simulated "data" should represent the same statistics as those of the D-matrix. For a discrete set of simulated inversions, a conservative estimate of the expected error can be obtained using data sets statistically equivalent (but not identical) to those used in generation of the D-matrix. For this reason, the input from the parameter and data tapes continued from the point at which the earlier reading had ceased. The combined number of observations for the D-matrix generation and evaluation thus had to be less than or equal to the total number of observations, 140.

TABLE 3-5

ELEMENTS OF THE PARAMETER ($\underline{P}_o$) VECTORS

Number	Parameter	Unit
1	Surface Temperature	°K
2	Wind Speed	mps
3	Integrated Water Vapor	g cm^{-2}
4	Integrated Liquid Water	g cm^{-2}
5	Cloud Droplet Mode Radius	μm
6	Mean Water Vapor Density 0 - 500 m	g m^{-3}
7	Mean Water Vapor Density 500 - 1500 m	g m^{-3}
8	Mean Water Vapor Density 1500 - 3500 m	g m^{-3}
9	Mean Water Vapor Density 3500 - 7620 m	g m^{-3}

The evaluation procedure consisted of reading a $\underline{d}_o$ vector of simulated microwave data, multiplying this by the elements of the D-matrix to generate atmospheric parameters, then comparing these parameter values to the parameter values given by the $\underline{p}_o$ vector derived from the original atmospheric model. The same input parameters were also compared with the mean of the atmospheric parameters computed from the $\underline{p}_o$ vectors used in the generation of the D-matrix. A ratio of the error in the mean value to the error in the inferred value was then found and called the figure of merit; this value should be greater than unity in order to demonstrate that the inversion process provided a better meteorological estimate than did the climatological mean. As expected, this was usually the case.

When the number of observations requested had been read and analyzed, the error statistics for the total evaluation data set were computed. These statistics permitted an estimation of the optimum expected accuracy of a large set of inversion results.

3.3.2 The Inversion of the Data

The second phase of INVERT used the D-matrix in conjunction with CV-990 measurements of microwave data (Tape D in Figure 3-1). This phase can directly follow the generation or the evaluation of the D-matrix. It can also form an entirely separate run in those cases where the D-matrix has been output to tape. This latter approach is useful for inverting several independent sets of data with similar characteristics; for example, all measurements made by the aircraft at 500 m in clear skies over a warm ocean. In this study, however, the use of the D-matrix always followed the evaluation of the D-matrix in the same computer run, and hence it will be assumed that the run parameters and channel configuration were specified in phase one.

Using the number of observations specified by the evaluation procedure, INVERT began reading the measured brightness temperatures from the tape generated by MATCH (see Section 3.2.1). The desired channel values were extracted from the input array according to the relationship shown in Table 3-4, and the selected brightness temperatures were adjusted by the offsets and scale factors given on the channel cards. These adjustments permitted calibration corrections as the data was being used, and enabled the measured values to be brought in line with the simulated values, if a noticeable difference existed.

The corrected brightness temperatures formed $\underline{d}_o$ vectors which were multiplied by the D-matrix array to infer the actual geophysical parameters existing at the time of the Convair 990 flight. If any element of the $\underline{d}_o$ vector was missing (e.g. the mean brightness temperature for the 10.69 GHz channel at vertical polarization), no multiplication was performed. All elements of the $\underline{p}_o$ vector were set to zero as though no data was available for that time period. The $\underline{d}_o$ vectors and the parameters resulting from the inversion of the $\underline{d}_o$ vectors were then printed creating the final product of the processing. The results of this procedure are discussed in Section 4.

4. ANALYSIS OF THE RESULTS

Although the discussions in the previous sections summarized the statistical approach to microwave inversion, and the data sources and computer programs used to implement that approach, no attempt was made to justify the underlying assumption that the meteorological parameters listed in Table 3-5 could, in reality, be derived from the microwave channels listed in Table 3-3. This section will discuss the various microwave channels in light of their sensitivity to surface temperature, liquid water, and water vapor, then present an example of the information derived from the inversion of measured microwave data.

4.1 The Individual Channel Responses

The thirty-two microwave channels flown on the Convair 990 cover a wide range of sensitivities to various atmospheric constituents and surface properties. Some, such as 22.235 GHz channel, are highly sensitive to total water vapor and to liquid water contents. Others, such as the 58.8 GHz channel, are sensitive only to the amount of oxygen contained in the atmosphere. Since the application of microwave channels to geophysical studies is of primary interest in this analysis, the information to be obtained from these channels will be discussed here.

4.1.1 Water Vapor

Channel 29, at 22.235 GHz, is the most sensitive channel to total water vapor, as it is located at the lowest frequency rotational water vapor line. The brightness temperatures measured by it are thus highly dependent upon the total water vapor sensed; however, the same water vapor content can result in different brightness temperatures because of the effects of pressure broadening. If the water vapor is concentrated at low levels with high pressures, the line will be broad and the peak brightness temperature low. If the same water vapor amount occurs at lower pressures (higher altitudes), the line will be narrowed and the peak temperature higher. Thus this channel does not show a unique correspondence between brightness temperature and water vapor. Other channels are needed to provide information on the shape of the water vapor line. In the current channel configuration, the 19.35 GHz channels and the 31.4 GHz channel are the nearest to the 22.235 GHz line, and are thus the most useful in indicating the line shape, and in assisting in the derivation of total water vapor. The other frequencies present on the CV-990 are too far below the water vapor line to provide significant information. (See Figure 4-1).

The same information that enables one to determine the shape of the water vapor line permits an evaluation of the vertical distribution of water vapor. Thus the 19.35 GHz channels, the 22.235 GHz channel, and the 31.4 GHz channel are expected to provide the maximum possible information on the density of water vapor at various altitudes. Water vapor weighting (Figure 4-2) functions derived for these channels (Gaut, 1967; 1973) show that the 19.35 GHz channels are most sensitive to water vapor near the surface, the 22.235 GHz channel to water vapor above the troposphere, and the 31.4 GHz channel to water vapor at the surface. While this combination allows some estimation of the vertical distribution, it gives little information about changes in the mid-troposphere for which a channel near 21.00 GHz (see Figure 4-2) would be useful. Since the CV-990 did not fly such a channel, inversion results for water vapor density in selected layers are not expected to approximate the optimum possible from any microwave configuration, but rather the optimum possible results for the given CV-990 microwave configuration.

4.1.2 Integrated Liquid Water

The integrated liquid water measured by the Convair 990 represents the precipitable water contained in cloud water droplets along the radiometer path. At microwave frequencies less than 30 GHz the wavelength of the radiation field is much longer than the largest cloud drop radius associated with most types of clouds. For this reason, cloud particles may be considered to be Rayleigh scatterers, exhibiting an inverse wavelength squared dependence in their absorption coefficient.

Comparison of the resulting dependence of brightness temperature on integrated liquid water shows a smooth temperature increase across a range of 0-3.6 g cm^{-2} at the lower frequencies such as 4.99 GHz and 10.69 GHz (Figure 4-3) and a very sharp increase to saturation at .6 g cm^{-2} at

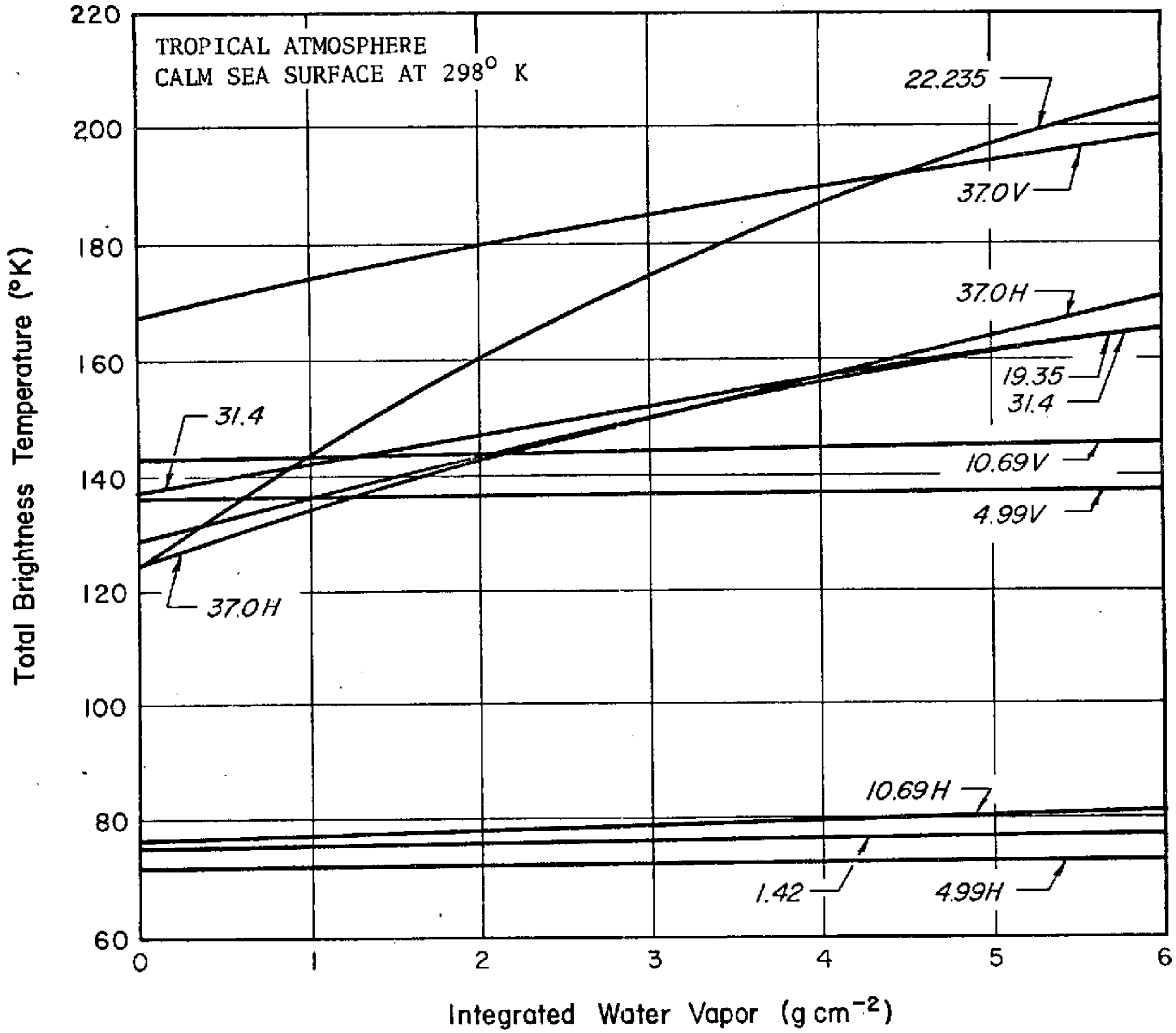

Figure 4-1 Integrated Water Vapor

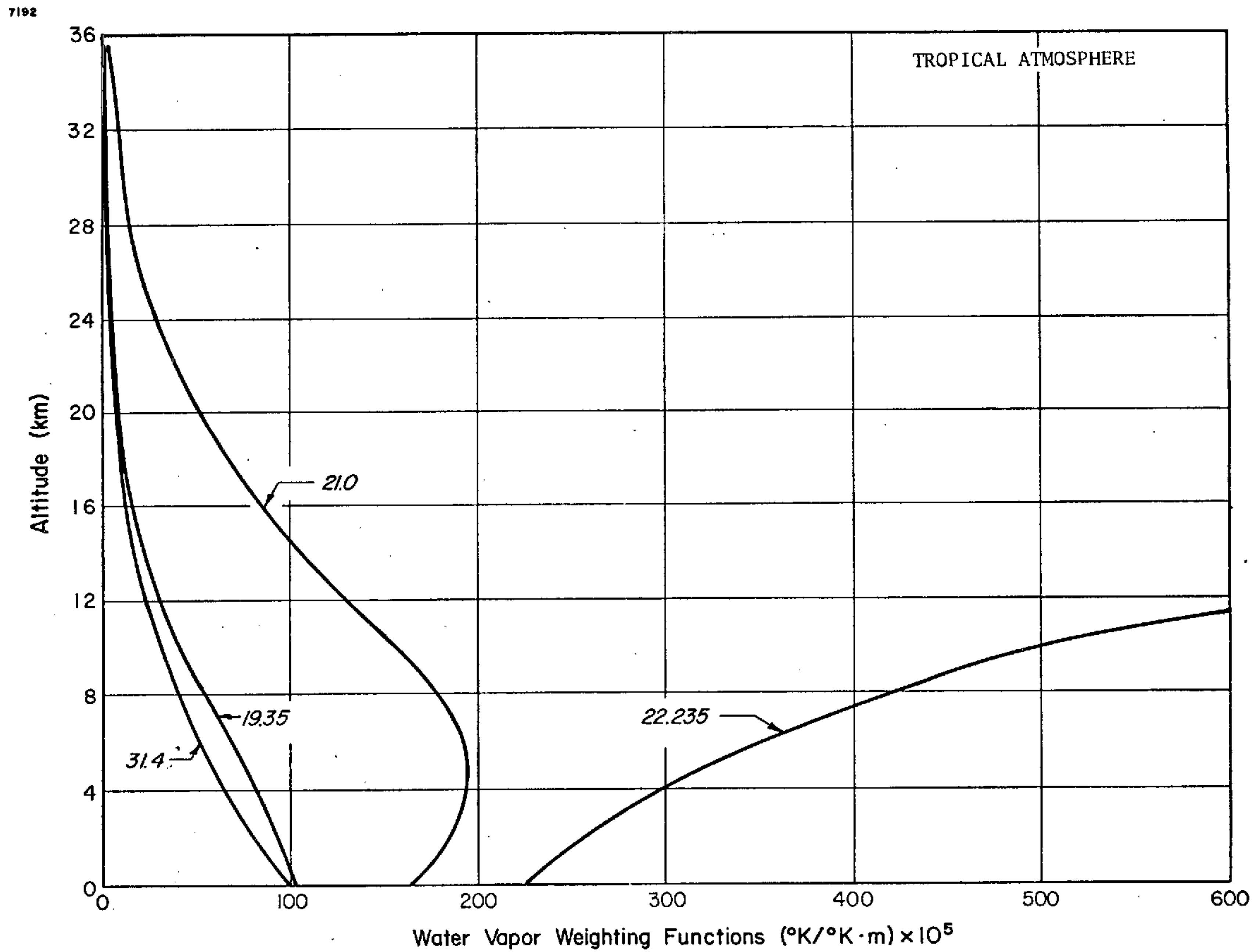

Figure 4-2 Water Vapor Weighting Functions

frequencies near 31.4 GHz (Gaut et al, 1973). A judicious combination of all these channels can thus well define the total liquid water content of the atmosphere. The lower frequency channels (4.99 GHz, 10.69 GHz but not 1.42 GHz), although relatively insensitive to thin clouds of low water content, can accurately portray the liquid water in the heavy clouds; they can also penetrate these clouds to provide surface information when the other channels have become saturated. On the other hand, the 22.235 GHz channel combined with the 31.4 GHz channel can provide significant information about clouds whose liquid water contents are in the 0-1.2 g cm^{-2} range while estimating the total water vapor.

The cloud drop mode radius is an interesting parameter as a potential indicator of precipitation cloud layers. Detailed computation of the unit volume extinction coefficient for rain-bearing cloud distributions have been performed by Gaut and Reifenstein (1971). The results for a three-layer cloud, taken from that study are shown in Figure 4-4, and indicate that the extinction coefficient in the rain layer increases more rapidly from 1 to about 20 GHz than predicted by the λ^{-2} dependence used by the Rayleigh approximation, and then tapers off above 20 GHz. This departure from the Rayleigh dependence is correlated with the mode radius of the cloud distribution, and hence, the latter may in principle be inferred by three channels covering the range from 1 to 60 GHz. Since the interaction model of the present study uses only the Rayleigh approximation, this signature is not detectable, although a weak correlation exists between mode radius and total liquid water content for heavy precipitation-bearing clouds. For this reason, therefore, effective inversion for mode radius must await correction to the interaction model to account for the effect of large drops.

4.1.3 Surface Temperature and Wind Speed

Reflection and emission of microwave energy by the background surface has an important effect on the total amount of energy received by the microwave sensors. In the case of an ocean surface this reflection is highly dependent upon the surface wind speed and the resulting roughness and foam cover; both the reflection and emission are also highly dependent on the surface temperature. Brightness temperatures resulting from these effects also differ with changes in polarization (see Figure 2-4) and with

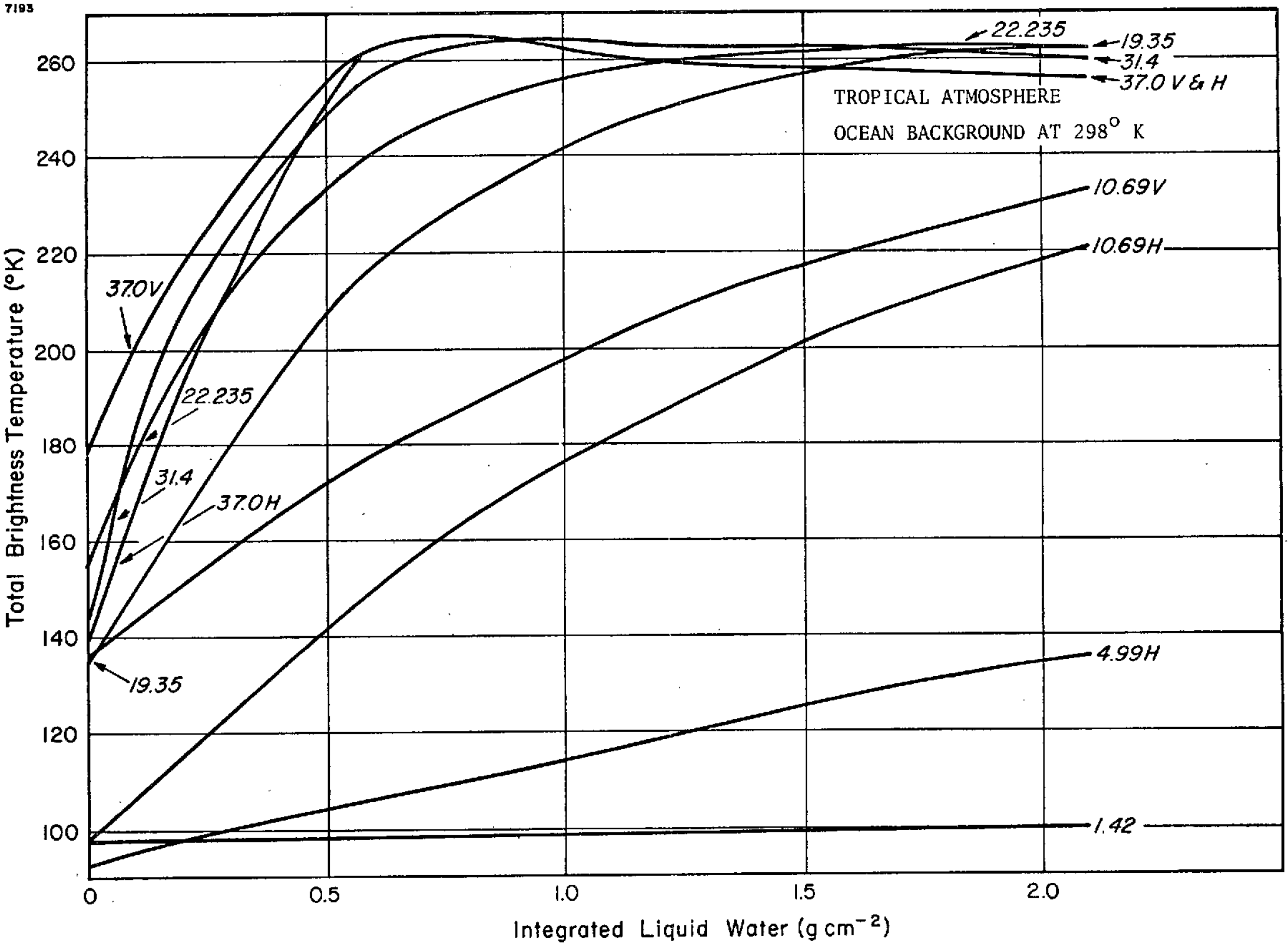

Figure 4-3 Integrated Liquid Water

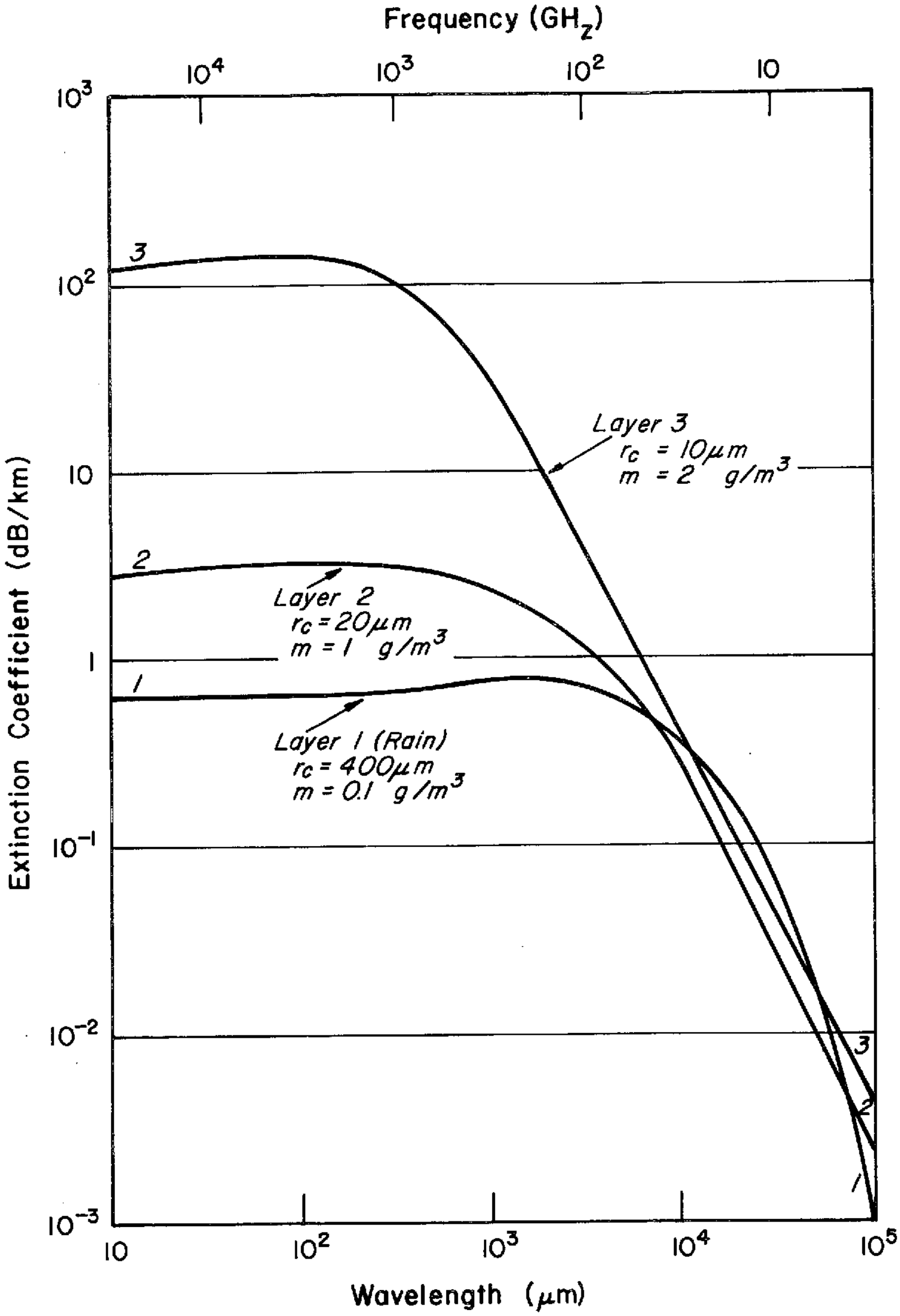

Figure 4-4 Extinction Coefficient for Three Layers of a Rain Bearing Cumulus Cloud Computed as a Function of Wavelength (After Gaut and Reifenstein, 1971)

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changes in viewing angles; judicious channel selection can thus yield much information on the surface conditions.

The Convair 990 microwave channel configuration is well suited for the examination of surface parameters. First, the 19.35 GHz radiometer provides information at twenty different look angles permitting a wide range of brightness temperatures from the same surface. Since the water vapor sensed at this frequency is near the surface, the surface can usually be sensed quite clearly under clear sky conditions, and much can be derived about the surface temperature and wind speed from the changes in brightness temperature with angle.

Considerable information can also be derived from the dual-polarized channels at 4.99 GHz and 10.69 GHz and the channel at 1.42 GHz since water vapor is not highly absorbing at these frequencies, and most liquid water concentrations are not optically dense below 10.69 GHz. Thus in clear skies, or in the presence of most clouds, these channels are useful in inferring surface characteristics. Since the 31.4 GHz channel's water vapor weighting function peaks near the surface, this channel can also provide information. This is especially true in conjunction with the above channels since it has a 0° look angle (vs. 38° for the others).

4.1.4 Vertical Profile of Temperature

The remaining three channels at 53.65 GHz, 54.9 GHz, and 58.8 GHz provide information on the vertical distribution of temperature in the atmosphere. Channel 30 is most sensitive to oxygen near 4 km, channel 31 to oxygen near 13.5 km and channel 32 to oxygen near 17.6 km. Since oxygen content is temperature dependent, these three channels can be used to infer a temperature profile. Such a profile was not desired in this study and these channels were not used. The distribution of water vapor and its microwave interaction are related to temperature, however, and thus the use of these channels might improve results for the water vapor profile in future studies.

4.2 Test Case - Flight Five

4.2.1 Background Information

To test the validity of the assumptions on the microwave interaction with the atmosphere and to evaluate the use of the statistical inversion procedure with measured data, a test case was selected for analysis. The data set chosen was measured between 1737 GMT and 1745 GMT on March 16, 1972 during Flight 5 of the Gulf of Mexico experiment. The total flight path and the segment studied are shown in Figure 4-5A. The aircraft altitude was 7620 meters (25000 ft) in an area of cloudiness associated with a cold front heading southeast (see Figure 4-5B). During the first three minutes of the time segment selected, the aircraft was flying over a multilayered cloud bank 50 miles from the edge of the frontal system. Then a large area of precipitation was encountered with the data showing two pronounced rain cells one noticeable between 17:41:43 and 17:42:24, and a second one, much larger, visible between 17:43:04 and 17:44:44. Since it is not clear whether these cells are two precipitation regions within one cloud, or two entirely separate clouds, they will be analyzed separately.

Ground truth applicable to the surface data have been assembled from 1200 and 1800 GMT ship reports, as shown in Figures 4-6A and 4-6B. On the basis of these reports, a surface temperature of 298 ± 1 °K and surface wind speed of 10 ± 2 mps were adopted as ground truth values appropriate to the inversion for these parameters.

4.2.2 The Radiometric Data

Two subsets of the Convair 990 channel configuration were chosen for analysis. The first consisted of 10 channels, the characteristics of which are summarized in Table 4-1. The assignment of rms noise values for each channel was accomplished by a study of measured data in portions of the same flight for which the mean signals were relatively constant. The values used were injected into the simulated radiometric data during the creation of the D-matrix, and represented one-half the (ten-second) standard deviation observed in the measured segment. (The factor of one-half allows for the contribution of parameter variability to the fluctuation in observed signals).

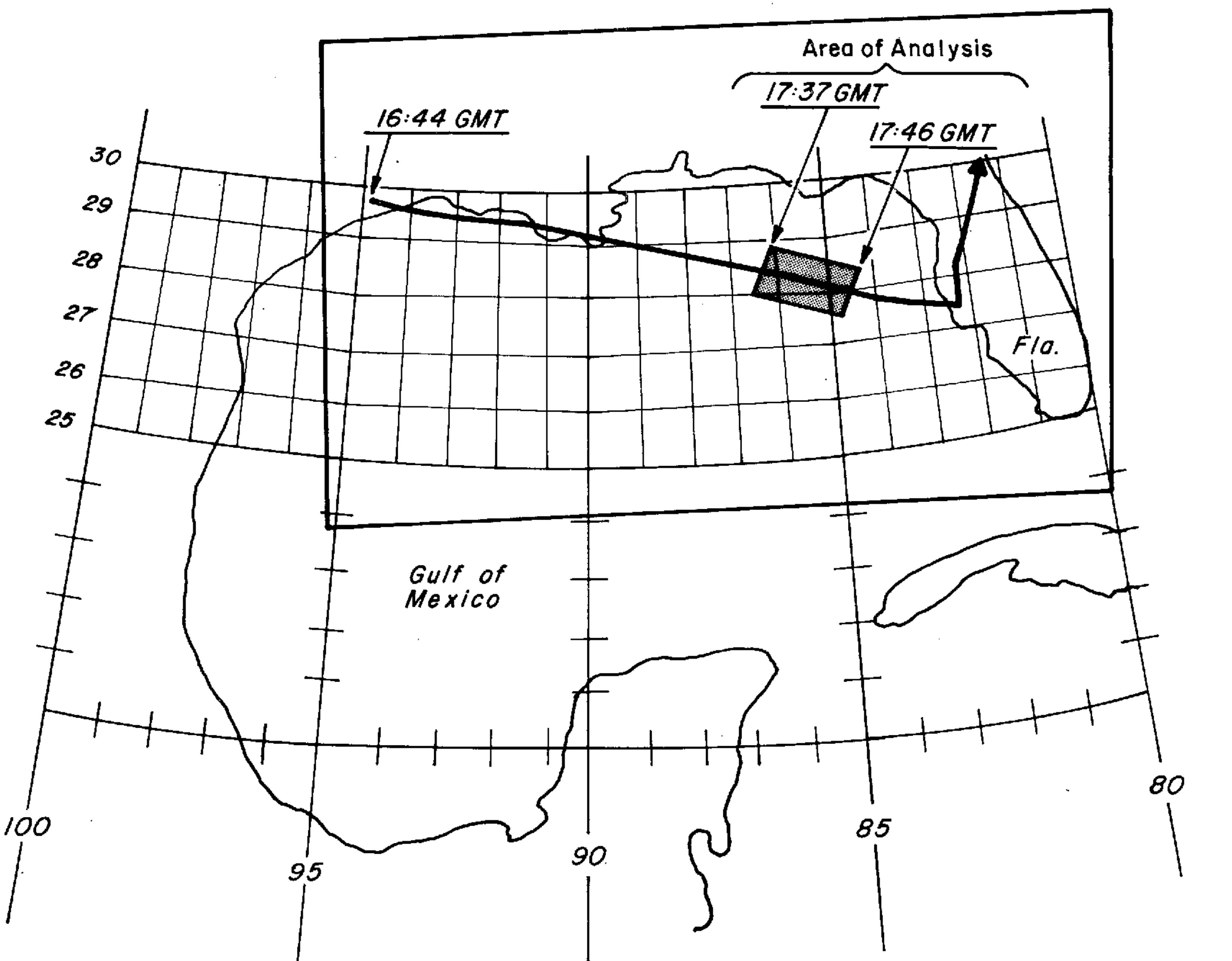

Figure 4-5A Convair 990 Flight Path, 16 March 1972

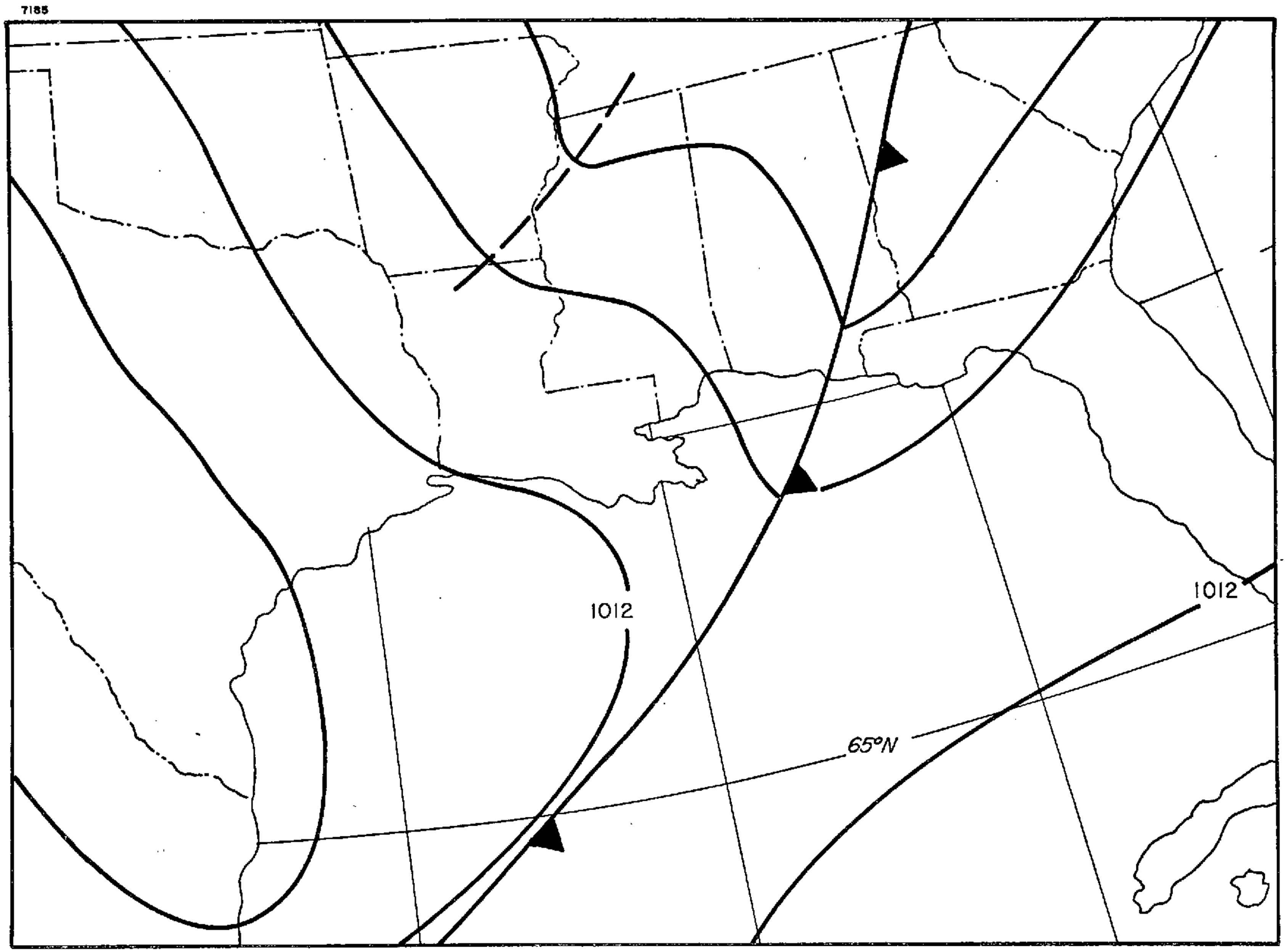

Figure 4-5B Surface Analysis for 1800 GMT, 16 March 1972

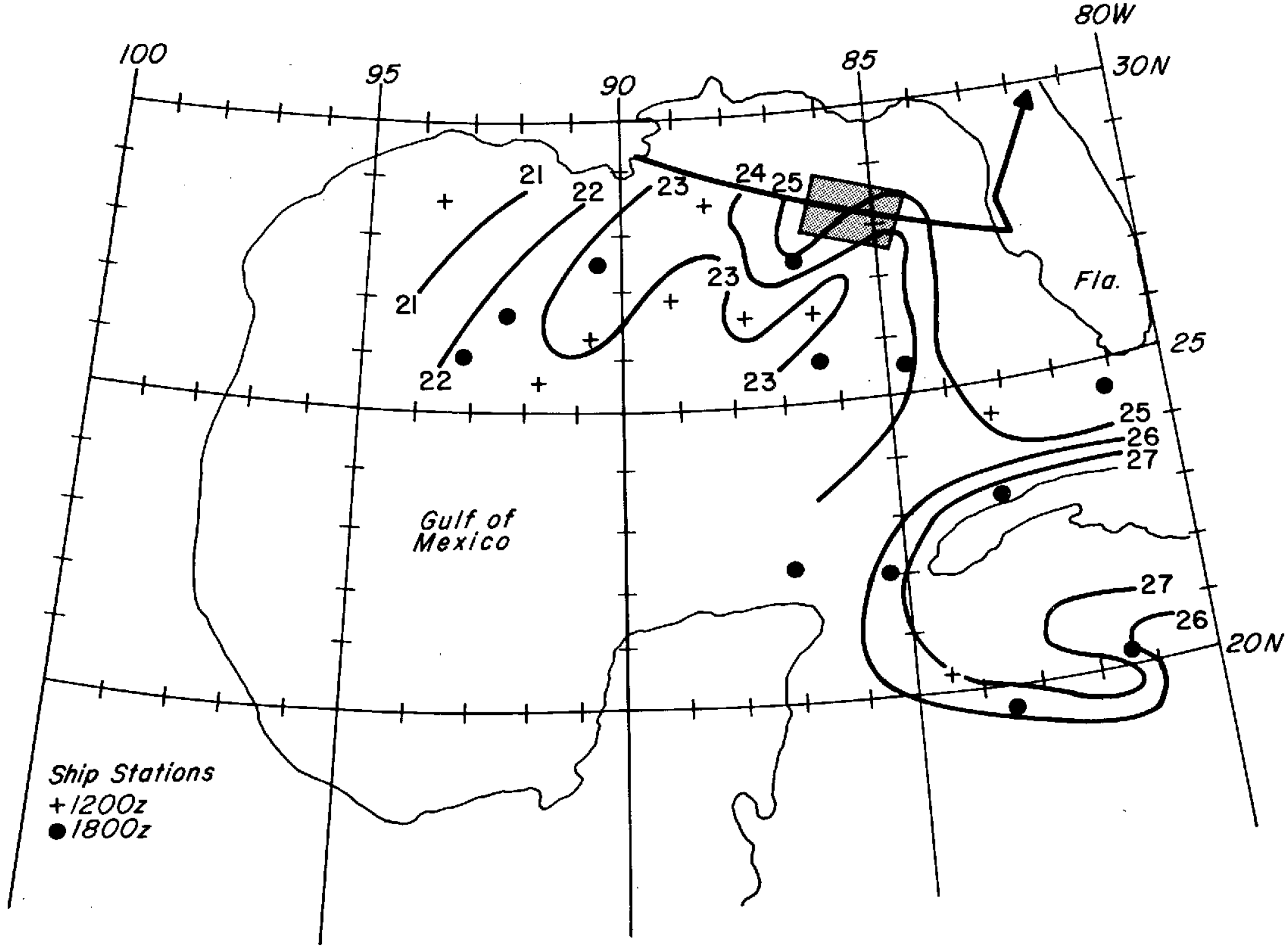

Figure 4-6A Sea Surface Temperature Map (March 16, 1972)
Composited from 1200 and 1800 GMT Ship Reports

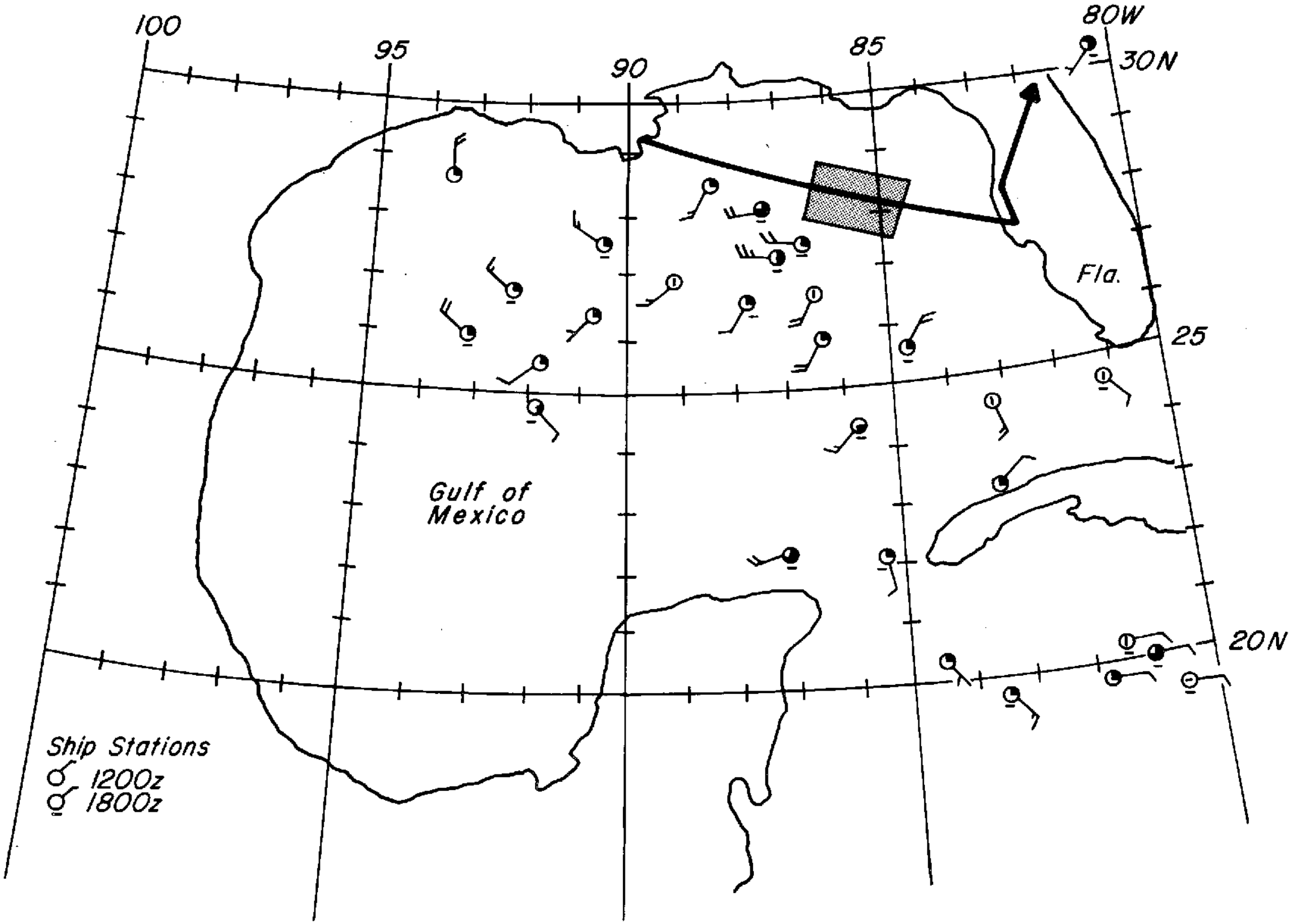

Figure 4-6B Composite Map of Sky Cover, Wind Speed and Wind Direction March 16, 1972

TABLE 4-1

CONVAIR 990 CHANNELS

Frequency (GHz)	Angle (deg)	Polarization	rms Noise (°K)	Offset (°K)
1.42	0	H	2.0	-36
4.99	38	V	1.0	10
4.99	38	H	1.0	21
10.69	38	V	0.5	-25
10.69	38	H	0.5	-19
19.35	0	H	1.0	-12
22.235	0	V	0.5	0
31.4	0	V	1.0	-2
37.0	38	V	1.0	-1
37.0	38	H	1.0	-3

The assignment of instrumental offsets is a particularly critical part of the data preparation process, since "offsets" can represent not only instrumental effects (which must be taken out), but also true departures from parameter values used in generation of the statistics (which are to be measured). To obtain the best estimate of the instrumental offset, mean values of brightness temperatures used in the generation of the D-matrix were compared with measured values over ensembles for which the statistics were as close as possible to those assumed in the D-matrix. The resulting offsets (to be added to measured values) are given for each channel in Table 4-1. Some of the offsets are substantial, and are indicative of instrumental difficulties experienced during the flight (particularly apparent in the 1.42 and 10.69 GHz channels).

Brightness temperatures, corrected for offsets, for the 10-channel configuration are shown for the eight-minute study period in Figures 4-7 and 4-8. The first 20 (ten-second) observations include clouds with no significant precipitation. Observations 21-35 were taken over the first rain cell, and 35-50 represent the larger, second cell. The varying sensitivities to liquid water are clearly seen with rain cells showing a pronounced effect on all channels but the 1.42 GHz. The smaller rain cell is not visible in the 1.42 or 4.99 GHz channels, and has only a slight effect on the 10.69 GHz channels; its effect on the other five channels is shown by a clear maximum in brightness temperatures near 1742 GMT.

The larger rain cell completely saturates all the channels whose frequencies are greater than 10.69 GHz. In fact, the brightness temperatures attained between 17:43:53 and 17:44:44 reach 260°K, the cloud top temperature indicated by the infrared sensor carried by the aircraft. High temperatures are also reached by the 10.69 GHz channels, which remain however, unsaturated. Serious degradation of the inversion results is expected due to the opacity of this cloud at frequencies above 10.69 GHz. This degradation reflects the fact that saturated channels can add no information regarding parameters associated with the surface or the atmosphere, since the signal effectively originates at the top of the cloud. It was for this reason that a second system was chosen, consisting only of those channels for which saturation effects were absent; i.e., the 4.99 and 10.69 GHz channels, again using the characteristics of Table 4-1. The 1.42 GHz channel was eliminated from the second configuration due to the fact that this frequency is less sensitive

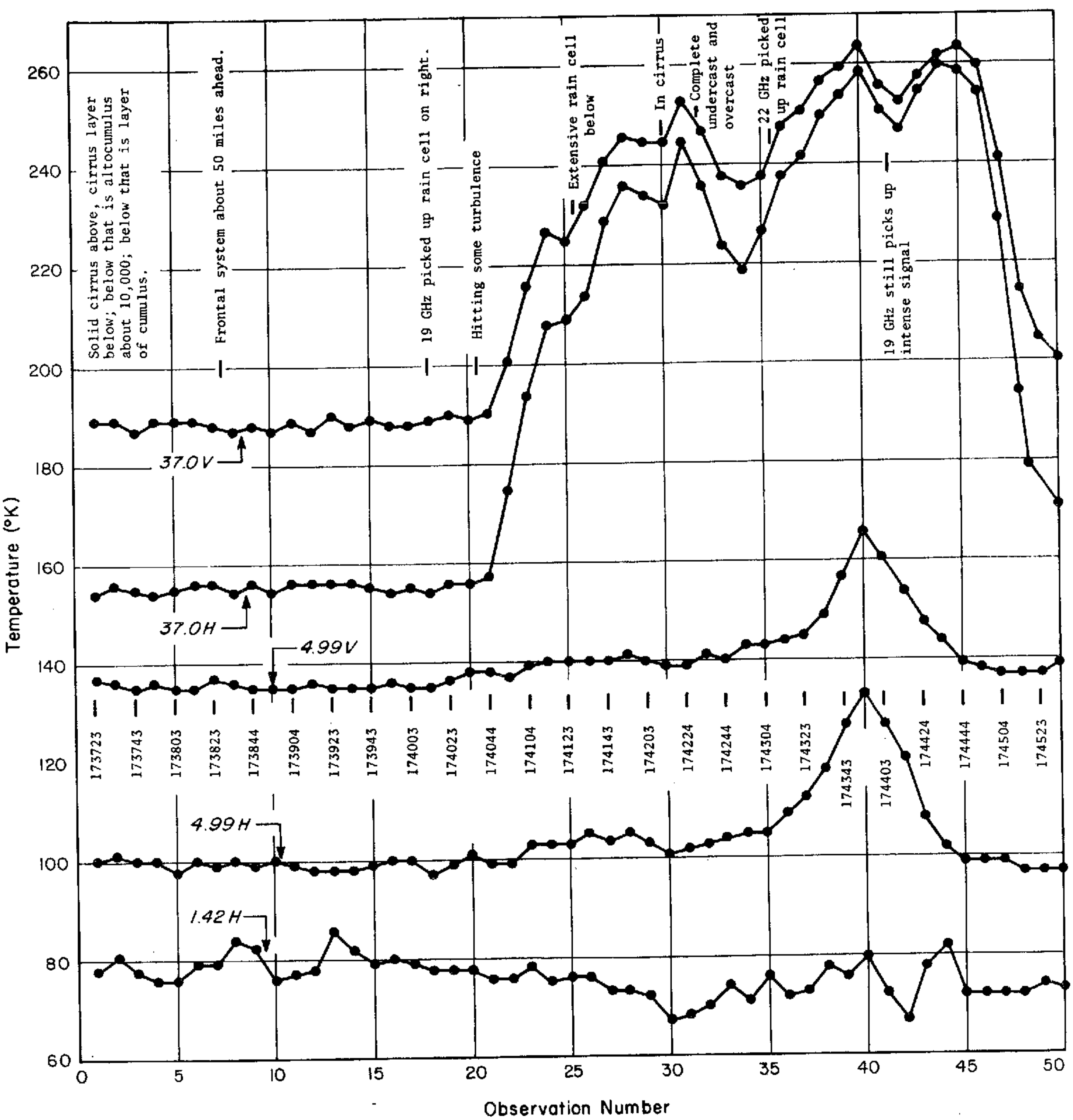

Figure 4-7 Brightness Temperatures (T_b) Measured by the Indicated Channels over Target Site.

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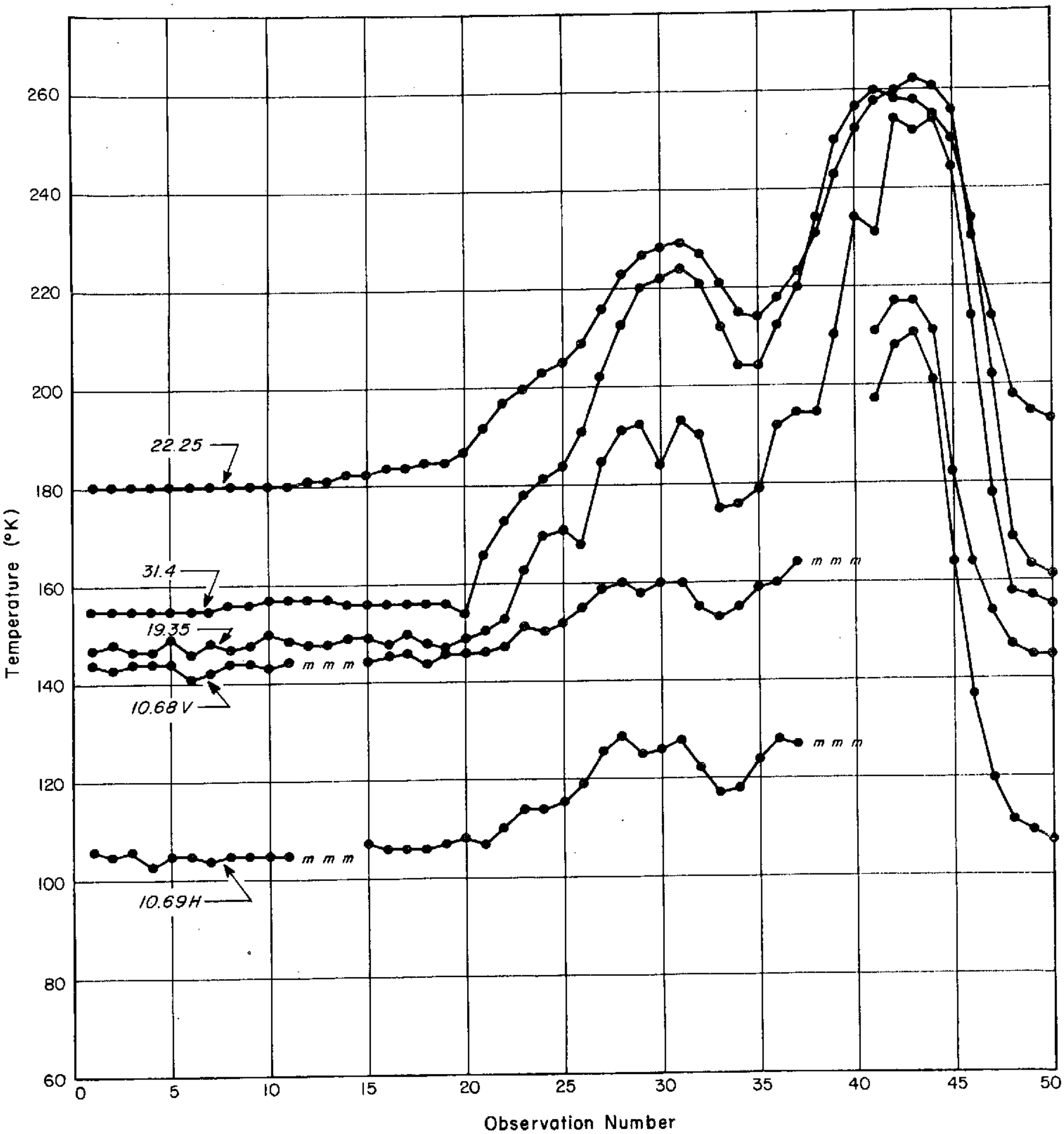

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Figure 4-8 Brightness Temperature (T_b) Measured by the Indicated Channels over Target Site.

to surface temperature than 4.99 GHz, and insensitive to water vapor and liquid, and that the instrumental problems evident in this channel tended to make it a source of noise rather than of added information.

4.2.3 Simulated Inversion Results

Inversion matrice were generated and evaluated for both the 10-channel and 4-channel systems, using 52 atmospheres for the D-matrix and 50 for simulated inversion. The results of the simulated inversion are given in Table 4-2. The results indicate comparable performance (measured in terms of rms error) by the two systems in estimation of the surface parameters, and show improvement on the part of the 10-channel system in estimation of integrated water vapor and liquid water, and vertical distribution of water vapor. These results are to be expected for clear skies or "normal" cloud cover conditions as represented in the statistics, and are a measure of the added sensitivity of the higher frequencies to water vapor and liquid in an atmosphere which is semi-transparent for all channels. They also demonstrate that the inversion procedure can, in principle, correctly compensate for atmospheric effects in the estimation of the surface properties.

4.2.4 Data Inversion Results

Using the D-matrices generated for the two radiometer configurations, the measured data values, corrected for offsets, were inverted. An overall summary of inversion results for the two surface parameters and the two integrated water quantities is given in Table 4-3, and plotted in Figures 4-9 and 4-10 for all fifty observations. In Table 4-3, the first two rows summarize the statistical information input to the inversion of the four parameters. The a priori values as specified in the Monte Carlo procedure are given for the surface quantities, and climatogical values as reported by Spiegler and Fowler, 1972, are given for the integrated water vapor. The second row gives the mean values and standard deviations as represented in the D-matrix itself. The agreement of these two sets of values measures the degree to which the D-matrix (generated from a finite ensemble) agrees with the climatological statistics (generated from a large quantity of data). This agreement is seen to be close, with the largest deviation corresponding to about 6% for surface wind speed.

TABLE 4-2

EVALUATION OF INVERSION SIMULATION RESULTS

	Mean	Standard Deviation	10 Channel Error	4 Channel Error
Surface Temperature (°K)	296.71	2.1213	1.7574	1.7834
Wind Speed (m sec^{-1})	5.58	2.8344	1.6246	1.6091
Integrated Water Vapor (g cm^{-2})	2.61	0.8858	0.1932	1.0140
Integrated Liquid Water (g cm^{-2})	0.04	0.0700	0.0125	0.0186
Water Vapor Density Sfc-500 m (g m^{-3})	11.46	3.94	2.4269	4.3039
Water Vapor Density 500-1500 m (g m^{-3})	10.05	3.45	1.9964	3.5557
Water Vapor Density 1500-3500 m (g m^{-3})	3.63	1.93	1.1313	2.1734
Water Vapor Density 3500-7260 m (g m^{-3})	0.73	0.38	0.3348	0.4889

TABLE 4-3

INVERSION RESULTS FOR THE 10-CHANNEL AND 4-CHANNEL SYSTEMS FOR SURFACE PROPERTIES AND INTEGRATED WATER

		Surface Temperature (°K)		Wind Speed (m/sec)		Intergrated Water Vapor (gm cm^{-2})		Intergrated Liquid Water (gm cm^{-2})	
		Mean	σ	Mean	σ	Mean	σ	Mean	σ
A Priori Value		297.00	2.00	5.80	2.00	2.50	1.00	--	--
D-Matrix		297.24	1.89	6.14	3.31	2.55	0.97	0.04	0.07
Ground Truth		298.00	1.00	10.00	2.00	--	--	--	--
Inversion									
"clear"	10	301.00	0.70	8.50	1.50	3.50	0.10	0.02	0.02
1-20	4	298.20	0.30	5.50	1.20	2.00	0.10	0.04	0.02
Inversion									
"first rain cell"	10	305.20	1.80	9.00	1.70	4.50	≤0.20	0.20	≤0.20
25-31	4	298.20	0.70	8.00	1.30	4.50	≤0.50	0.20	≤0.20
Inversion									
"second rain cell"	10	--	--	--	--	3.00	≤0.70	0.85	≤0.50
40-45	4	--	--	--	--	--	--	0.90	≤0.50

The remaining rows of Table 4-3 summarize the actual inversion itself. First, the available ground truth values are given for the surface properties, as discussed in Section 4.2.1. Mean values of estimated parameters are then given for each configuration in three selected portions of the study period: the initial cloud area (observations 1-20); the first rain cell (observa- 25-31); and, the second, larger rain cell (observations 40-45). The observation limits for each were chosen to minimize the contamination of the results due to changing parameter values. Since the cells exhibited substantial structure on a scale comparable to the resolution of the antennas, the effect of structure is significant and therefore water vapor and liquid water rms error values are shown as upper limits. The results of Table 4-3 in general support the conclusions reached with the simulated results, with the observation that inversion for the surface quantities deteriorates with both configurations upon entry into the first rain cell, and breaks down completely in the second. Rms variabilities for all parameter estimates increase in the transition from the clear region to the center of the second cell, although again, these variabilities for the integrated water quantities contain effects due to structure of the cells.

Residual uncorrected instrumental offset effects are evident in the systematic disagreement between the two configurations. The fact that the 10-channel predicts higher values for all parameters except liquid water leads to the conclusion that one or both of the "liquid water" channels was actually reading too low, forcing the procedure to attribute values in the other channels to higher surface temperature, surface wind and integrated water vapor. The close agreement of the surface temperature estimated by the 4-channel system with the 298°K ground truth value supports this conclusion.

With the exception of the 10-channel estimates of surface temperatures, both systems show reasonable progressive changes in the parameters as the storm is entered. Both indicate an increase in surface roughness (wind speed), an increase in integrated water vapor, and in integrated liquid water. The performance of the 10-channel system (measured in terms of rms variability) agrees with the simulated results in improvement over the 4-channel system for water vapor in the presence of the cloud system. The 4-channel system, however, exhibits significant improvement over the 10-channel system in measurement of the surface quantities, in disagreement

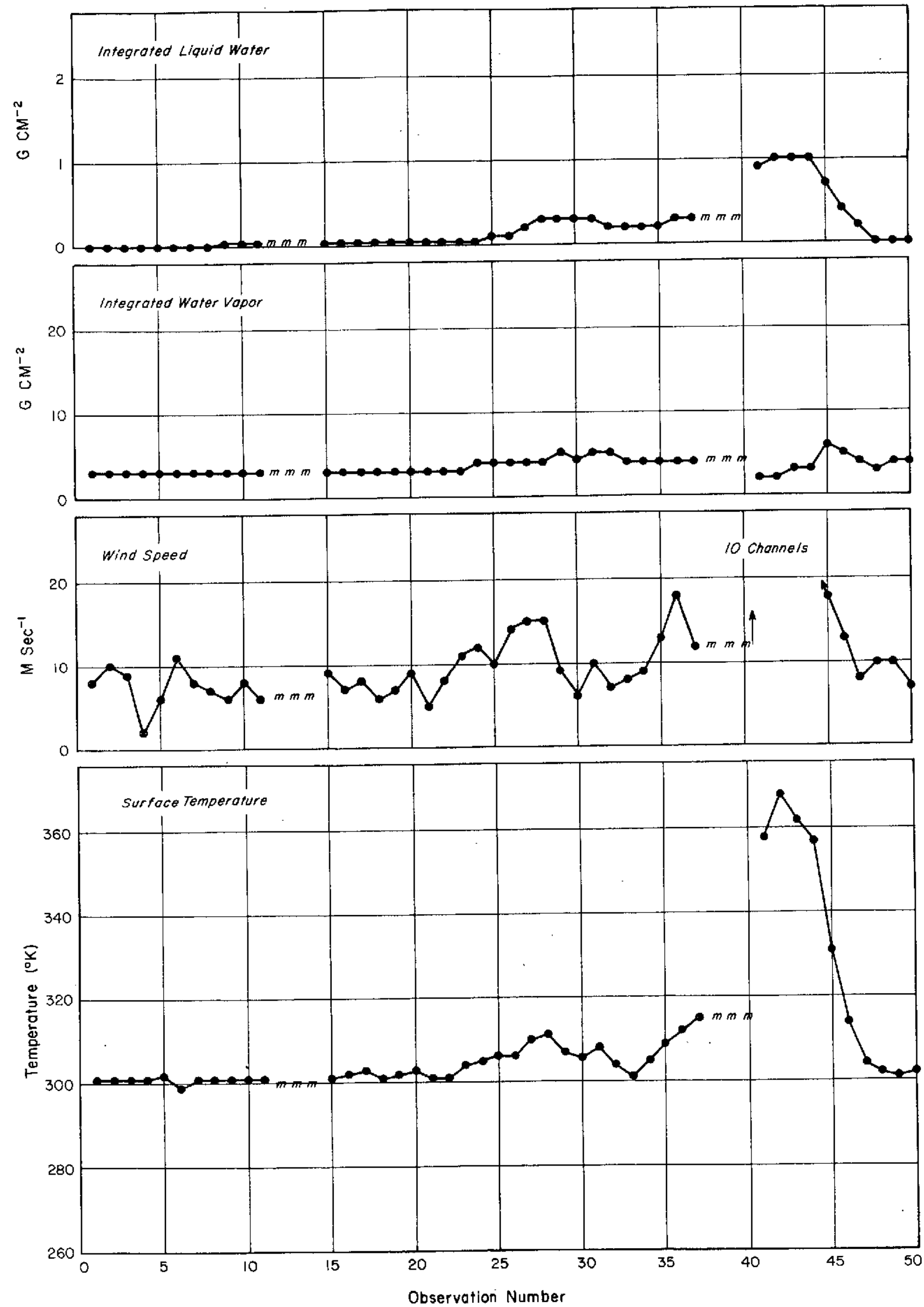

Figure 4-9 10-Channel Inversion Results for Surface Temperature and a Wind Speed, and Integrated Water (Vapor and Liquid)

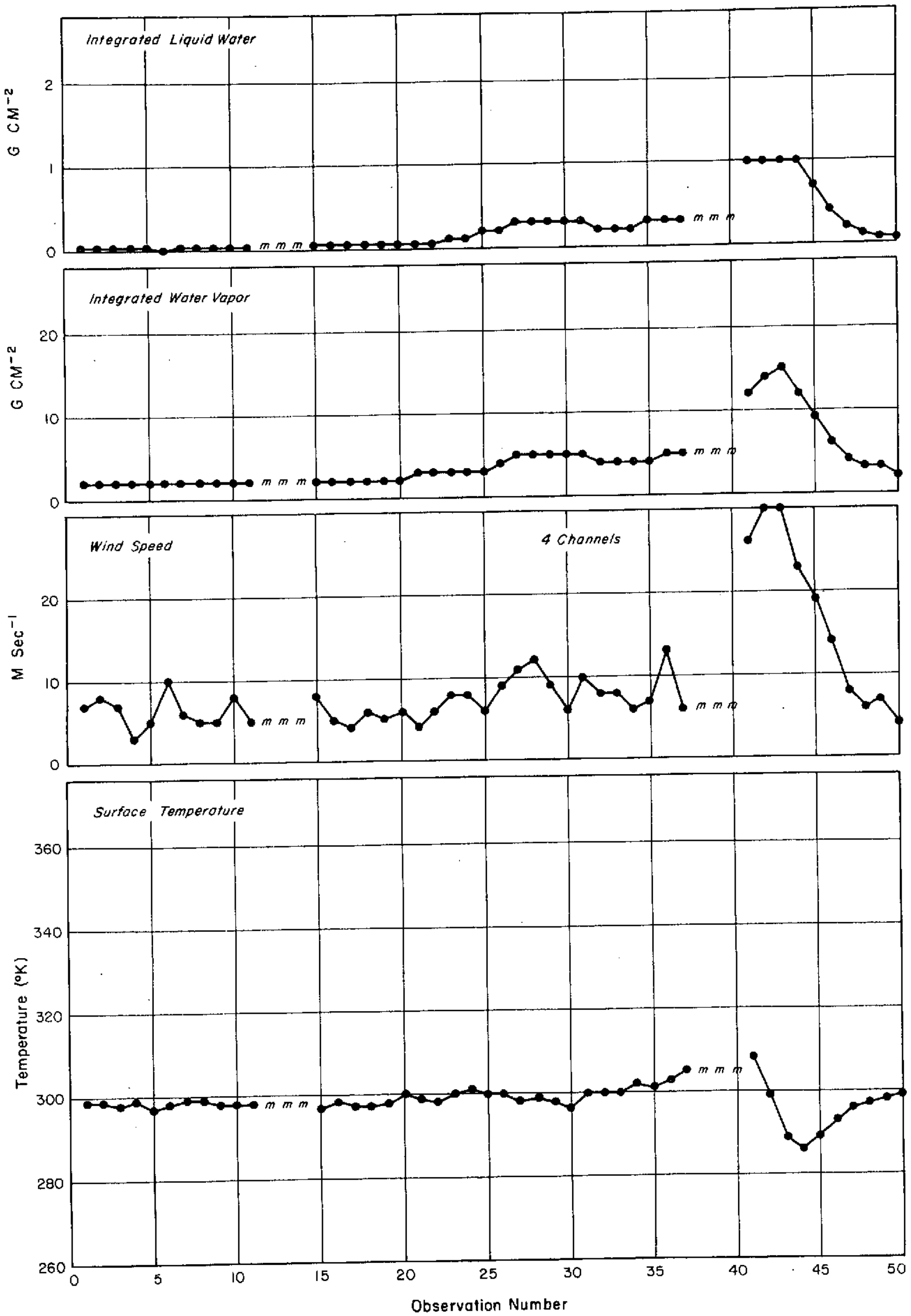

Figure 4-10 4-Channel Inversion Results for Surface Temperature and Wind Speed and Integrated Water (Vapor and Liquid) with the simulated results. This result is a measure of the added noise sources inherent in the use of the higher frequencies for correcting the real atmospheric effects in the estimation of surface parameters which are not present in the self-consistent "model" world represented by the D-matrix and the simulation results. Different antenna resolutions, actual parameter fluctuations, signal noise in excess of that assumed by the D-matrix, and residual deficiencies in the physical interaction models are examples.

The inversion results for vertical water vapor distribution, summarized in Table 4-4, are plotted for the same 50 observations in Figures 4-11 and 4-12. These results are less satisfactory than those for the surface and integrated parameters since neither channel configuration is optimum for vertical water vapor distribution. As seen in Figure 4-2 the water vapor weighting functions for all channels except that on the water line peak at the ground, and the 22.235 GHz channel peaks at the top of the atmosphere. The ability to estimate the water vapor profile is therefore largely determined by the correlation of water-vapor distribution with other quantities which are measurable by the actual radiometer configuration. According to the simulated results of Table 4-2, this is indeed what happens in the case of the 10-channel system, for some improvement (measured by rms error over the evaluated ensemble relative to the a priori variability) is evident in each of the four layers. In the case of the 4-channel system, there is no meaningful correlation, and all inversion errors are greater than the a priori variabilities.

The results of Table 4-4 do however show a general increase in water vapor in all four layers as the rain cell is entered, with total deterioration except for the upper two layers in the second, larger rain cell. Based on the simulation results, the 10-channel system is expected to provide the better estimates of the water vapor profile, and this expectation is confirmed by the generally better agreement of the 10-channel "clear" profile with the mean profile represented by the D-matrix (except in the lowest layer). Conclusions in addition to regarding the inversion for water vapor profile are not justified by the radiometer configuration.

TABLE 4-4

INVERSION RESULTS FOR THE 10-CHANNEL AND 4-CHANNEL SYSTEMS FOR VERTICAL WATER VAPOR PROFILE

		Surface to 500 M		500 M to 1500 M		1500 M to 3500 M		3500 M to 7620 M	
		Mean	σ	Mean	σ	Mean	σ	Mean	σ
A priori Value		9.81	1.40	7.98	1.03	5.10	0.74	1.0	0.25
D-Matrix		10.96	4.15	8.93	3.49	3.74	2.15	0.94	0.58
Inversion "clear"	10	7.0	0.9	10.8	0.7	5.5	0.3	1.0	0.3
1 - 20	4	7.5	0.7	7.0	0.3	3.5	0.2	1.0	< 0.1
Inversion "first rain cell"	10	8.5	0.9	15.0	1.5	9.0	1.3	1.2	0.3
25 - 31	4	20.5	0.7	16.0	1.2	6.5	0.3	1.5	0.2
Inversion "second rain cell"	10	--	--	--	--	14.0	≤ 2.5	3.5	≤ 0.6
40 - 45	4	--	--	--	--	20.0	≤ 1.5	3.0	≤ 0.3

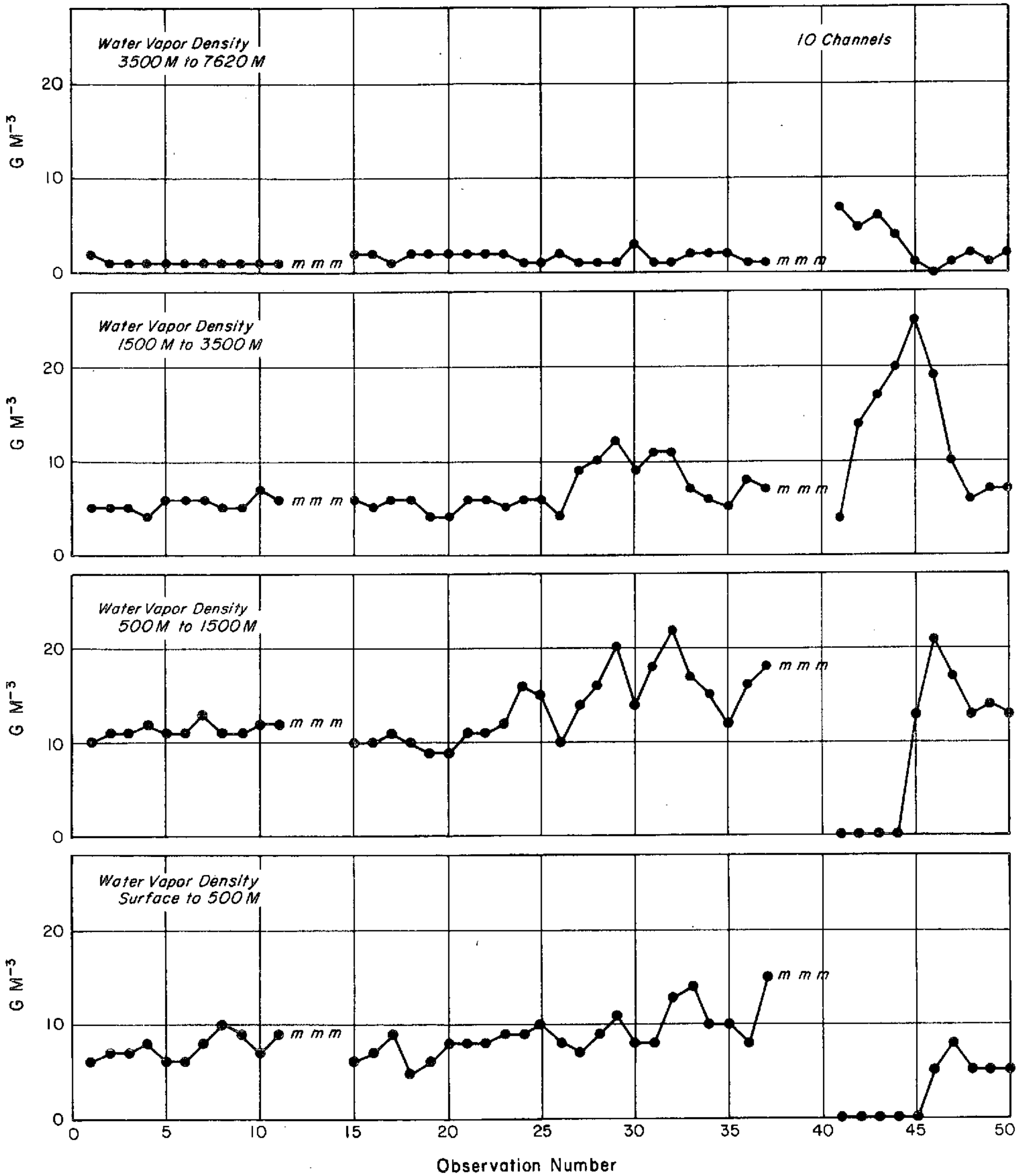

Figure 4-11 10-Channel Inversion Results for Mean Water Vapor Density in Four Altitude Ranges.

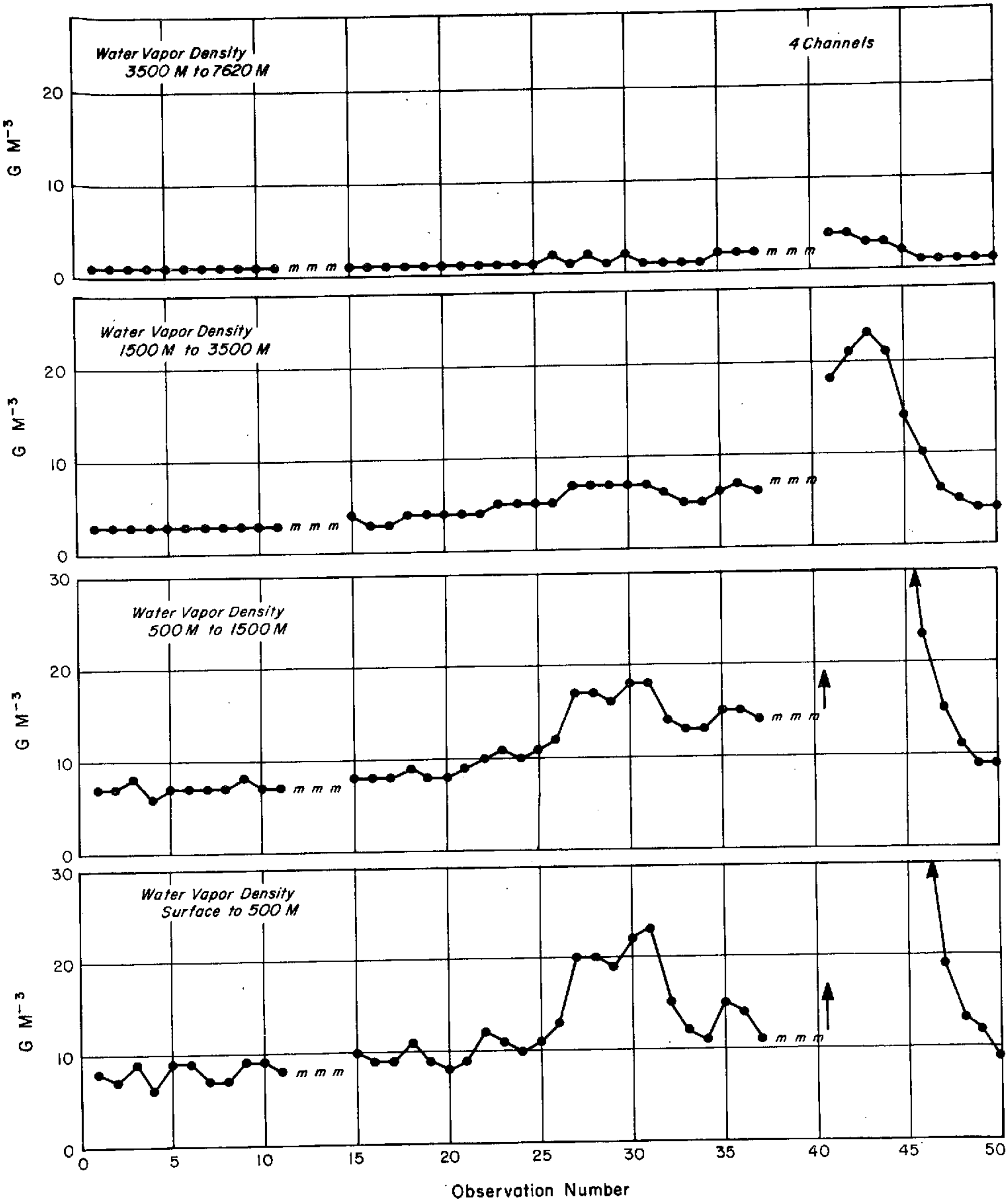

Figure 4-12 4-Channel Inversion Results for the Water Vapor Density in Four Altitude Ranges.

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4.2.5 Conclusion

The test serves as an example of the application of the data analysis system developed partly during this study, partly through previous NASA sponsored studies, and partly through internal company funds. The single case study, which was used as an example to illustrate the data analysis system, provides the basis for certain conclusions about the system when used to derive atmospheric surface parameters. Several of these conclusions are set forth below:

1) It is clear from the simulation results that the statistical parameter inversion method may be used to simulate derived information about atmospheric water vapor, liquid water and surface temperatures from properly chosen microwave channels and that this information is quantitatively better than the best climatological guess. It is also probably true that information can be obtained about surface wind speed.

2) It is not clear from the case study how closely the theoretical accuracy established from the simulation results can be approached when real radiometric data is inverted for the parameters listed under clear or cloudy conditions.

3) It can be concluded that the use of different beam widths, different look angles, and different integration between channels in the inversion to estimate atmospheric parameters will degrade the results. Furthermore, as the atmosphere and surface becomes more heterogeneous with respect to beam width (as occurred in the case study over the cloudy and rainy areas), the effects of the noise introduced into the results increases drastically.

4) The variability of the estimated surface temperature for the test case and for all of the assumptions embodied in the D-matrix used for the test case inversion results are less than 1°K under clear conditions and 2°K under moderately cloudy conditions for both channel configurations. The rms variabilities of the estimated wind speed are less than 2 meters/sec under both clear and moderately cloudy conditions. These results, however, were obtained using large corrections for apparent offsets-corrections which are based solely upon consistency checks derived from theoretical considerations.

5) Absolute errors based on the best available ground truth information for the test case are less than 4°K for surface temperature under clear conditions and 5 meter/sec for surface wind despite the large estimated offset and non-congruent beams of the various radiometers used in the experiment. However, because of the close match between mean a priori and observed conditions at the surface the significance of these absolute errors cannot be ascertained until further and better experimental results are available.

6) The rms variabilities for integrated water vapor in the test case are less than 0.1 g/cm^2 under "clear" conditions and less than 0.5 g/cm^2 under moderately cloudy conditions for both channel configurations. The relationship between these values and actual prevailing conditions is unknown.

7) The absolute departures from the a priori mean values for integrated water vapor in the test case are within 0.5 g/cm^2 under clear conditions. This departure is equivalent to 50% of the deviations in the a priori values. The significance of these numbers with respect to the actual prevailing conditions could not be determined however because no independent measurements were available.

8) The 4 channel system will probably provide a better estimate of the surface properties than the 10 channel system in the presence of clouds. This is reasonable because the lower frequencies are relatively more sensitive to surface temperatures and roughness (wind speed) and the correction for atmospheric water vapor is not critical. Furthermore, saturation does not occur in these channels except in the presence of the most extreme rainy and cloudy conditions, and only then at the highest frequency channel. Under these conditions non-linear effects and saturation in some channels destroy the ability to estimate surface parameters using the 10 channel system.

9) The estimated value for liquid water vapor in the test case shows a general increase to peak mean value of 0.9 g/cm^2 in the second rain cell, with close agreement between both channel configurations. These are reasonable values but their relationship to actual values within the cloud is unknown.

10) Statistical inversion errors with actual data can be expected to strictly approach theoretical values only when the observational data system and radiometric channels exhibit statistics similar to those used in the derivation of inversion D-matrix.

11) Inversion results using statistical inversion procedures derived from physical interaction models are limited by the validity of those models. It is clear from this study and others that both the surface roughness models and precipitation and interaction models should be studied further in order to increase the sensitivity of the method.

12) Optimum sets of microwave frequencies exist for the inference of each geophysical parameter. An optimum set will change depending upon a number of factors including the following:

a) The range of values for the various geophysical parameters which affect the radiometric observations.

b) The noise level in each microwave channel

c) The residual offset in each microwave channel

d) The degree of coincidence of the beam of each channel

e) The interdependence of data from channel to channel. The optimum set will consist of those channels which have a maximum sensitivity to the parameters of interest.

5. USER'S GUIDE

The preceding sections of this report have described the analysis and inversion methodology applicable to the study of microwave data obtained with the NASA Convair 990 research aircraft. The physical basis for the models used has been summarized in Section 2, and an overview of the computation steps discussed in Section 3. Finally, an example of the application of the system has been seen in Section 4.

The remainder of this report is devoted to a description of the software modules themselves, as implemented for NASA GSFC, and their use in carrying out their intended functions.

The data flow pattern of the system is shown schematically in Figure 3-1. Each of the programs making up the system is supplied as a FORTRAN card deck consisting of software modules, many of which are common to several programs.

For convenience, this discussion is organized by program and the following information is given for:

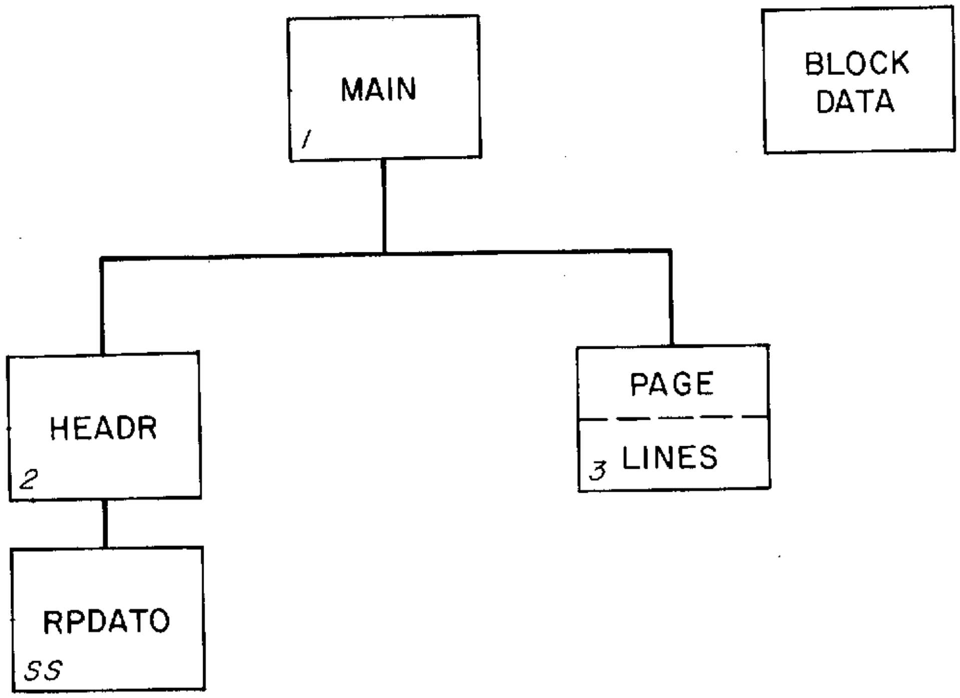
1) interdependence of program sub-modules shown as a schematic;
2) data set descriptions;
3) card deck setups for typical runs;
4) card formats for input cards;
5) supporting reference information as required;
6) sample input; and
7) sample output.

5.1 PROGRAM NWRC

Program NWRC was designed to process long periods of record of radiosonde data from selected stations. The main source of data is that contained on card deck 645 which is maintained and obtainable at the National Climatic Center (NCC). A complete description of card deck 645 is included.

The program reads in the cards for each radiosonde observation and reformats the data for output to magnetic tape. Each reformatted record that is processed is printed out in the form shown in the sample output for NWRC, where N is the level number up to and including 40 levels; T is the temperature (^{o}K) multiplied by 10; H is the height of the standard pressure level (GPM); and RH is the percent relative humidity at height H. All are in integer format.

At the completion of each run, NWRC will print out the station's mean and standard deviation of the surface wind speed and temperature. These parameters can be used with NWRST runs.



SS System Subroutine

Figure 5-1 Interdependence of Program Elements for NWRC

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```
//GO.FT03F001 DD DSNAME=K3.S1TCC.S1035.DLOGDATA,DISP=OLD
//GO.FT04F001 DD UNIT=2400-9,LABEL=(,NL),DISP=NEW,
//             DCB=(RECFM=VBS,LRECL=508,BLKSIZE=5084),
//             VOL=SER=A
//GO.DATAS DD *
```

(A) ATMOSPHERIC DATA SET FOR INPUT TO NWRST

Data Sets for Program NWRC

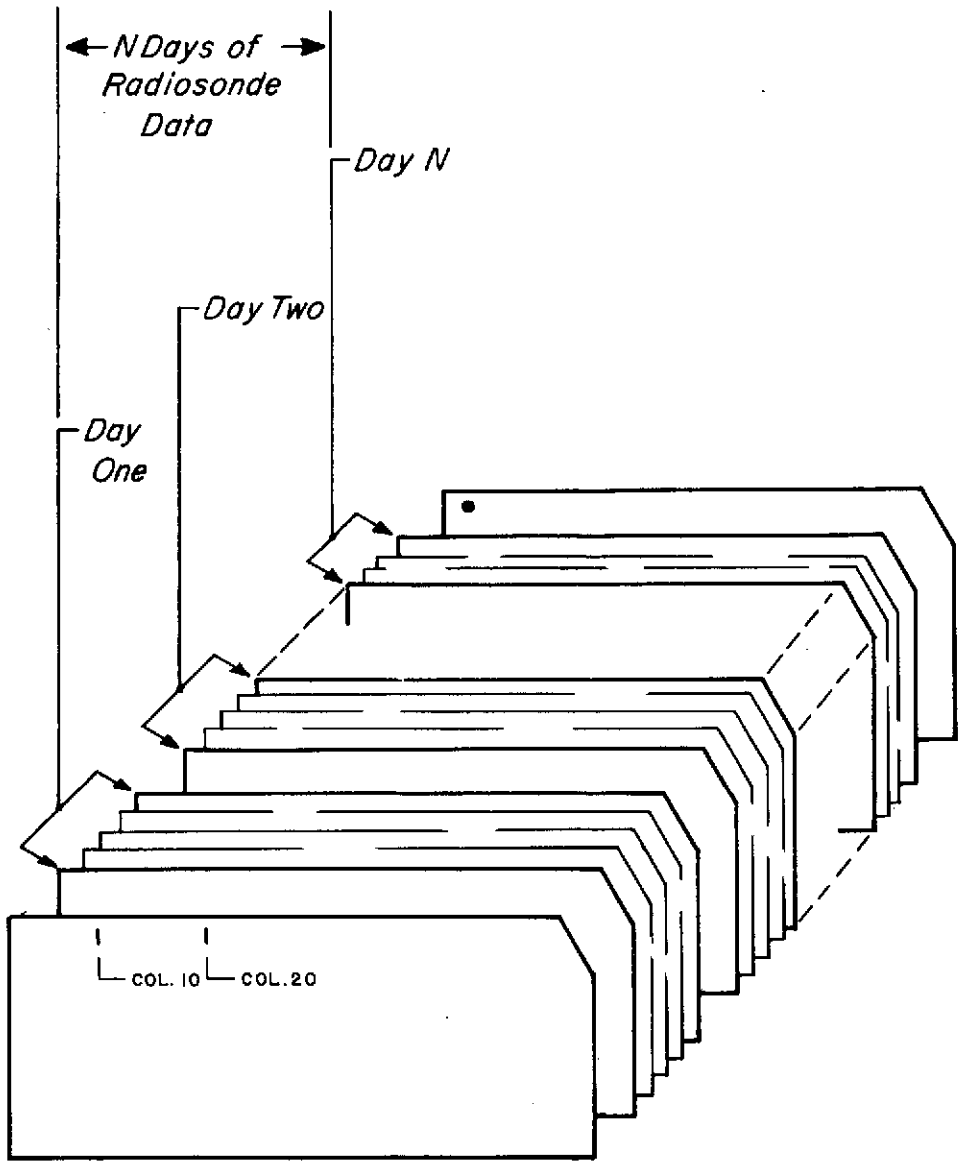

Figure 5-2 Deck Setup for a Typical NWRC Run

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Card Formats for Use with Program NWRC

FIRST CARD

Column	Variable	Format	Meaning
1-10	ISAVE	I10	Day of first sounding
11-20	IREC	I10	1 - begin a new file 0 - space to end of file N - begin with Nth record
21-30	ISELCT	I10	1 - print contents of file 4 0 - normal processing

SECOND AND FOLLOWING CARDS

The second and following cards are those obtained from NCC containing radiosonde data in the 645 card deck format described below.

NUMBERED ERROR MESSAGES

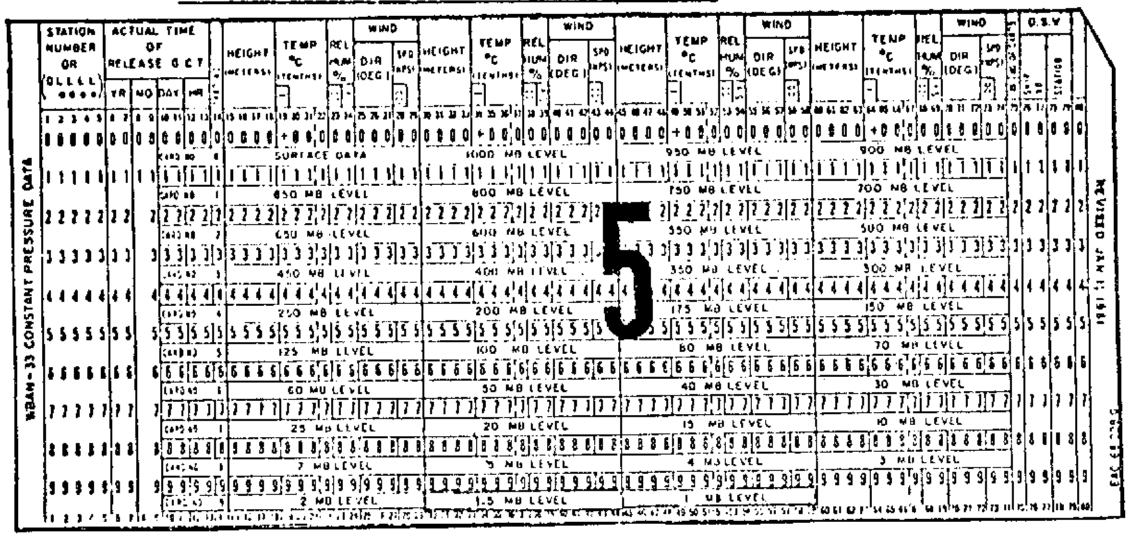
Program NWRC

Routine	Number	Cause
	None	

```
          1          1
7221159 3 1 001011 16895 55 4 101 16588 50 5 530 14680 1010 992 12184331127
7221159 3 1 011471  9589330 91976  9596208 82510  7398203133081  46 0192147
7221159 3 1 023680  14 0202154328  -798189185010 -448820725576B -9573218297
7221159 3 1 036580-15266214327458-21453222358426-29453        9506-38444     7
7221159 3 1 04 730-492          2155-594                      3947-619       7
7221159 3 1 05                  6403-696                          -700       7
7221159 3 1 06                   547-628                                     7
7221159 3 2 001008 15091250 9  76 1419325410 510 1109526714 956  8095        5
7221159 3 2 011425  5095        1918  2390     2430  -685     2987 -2663     5
7221159 3 2 023570 -4546        4199 -8640     4870-13437     5585-19932     5
7221159 3 2 036380-21132        7232-23428     8191-30323     9269-395 !     5
7221159 3 2 04 487-511          1930-542                      3761-585       5
                                    .
                                    .
                                    .
7221163 330 001019 24341 20 8 172 22845 35 8 600 18653 46111074 14262 48116
7221163 330 011553  4770 39 92054  5077 26 72550  1869  7 73134  -914  8116
7221163 330 023730 -441M 17174348 -791M 17175030-1041L  4275751-12111353366
7221163 330 036550-1791N34836/416-25210348338368-3271N343359433-409  338386
7221163 330 04 643-505  348372073-565  34231                  3873-620  317306
7221163 330 05                  6354-636  31320                              6
```

Sample Data Cards for Program NWRC

CARD DECK 645 RAOB CONSTANT PRESSURE LEVELS



Format U. S. STATIONS Jan 61 - to include 1.5 mb and 1.0 mb levels. . Card No. 9, beginning Jan 68 was expanded Format for CANADIAN STATIONS is on page 2.

AREA COVERAGE: The data included in this deck constitutes a coverage of Air Force, Weather Bureau, Navy Land and Ships, Canadian, Foreign Cooperative, and Signal Corps Stations; United States controlled Ocean Weather Stations (OSV's) and Military Sea Transport Ships (MSTS) that take radiosonde observations.

PERIOD OF RECORD: Jan 61 - Canada: Jan 61 - Dec 67.
Other card decks containing similar data prior to Jan 61 and their period of record are as follows:
Card Deck 542 Jan 46-Jun 49; Card Deck 544 Jul 49-Dec 55; Card Deck 545 Jan 56-Dec 60.

Refer to supplementary note A for levels punched in above decks with changes and additions to the pressure levels on page 9.

OBSERVATION TIME: GMT 00, 06, 12, 18. (Most observations in this deck are 00 & 12) These are scheduled observation hours. Observations within one and 1/2 hours of these times are punched the scheduled hour. Special or delayed observations are punched to the nearest hour of release time.

OBSERVATION TIME: (continued) For Canadian stations the scheduled hour is punched for all observations where the release has been effected between one hour previous to and two hours after the scheduled hour. Observations outside these limits are not punched.

SOURCE: This card deck is produced from radiosonde observations recorded in the data blocks on Adiabatic Charts, forms MF 3-31A, B and C (prior to 1 Jul 69, WBAN 31A, B and C) and output cards from a digital computer for the Automatic RAOB stations.

CODE: 1960 WMO 3300, Octant of Globe.

MISSING DATA: If an element (s) is doubtful or missing within an observation, the card columns for that element (s) are left blank. If an entire observation is missing, Card No. 0 will contain punches only in Cols. 1-14 for land stations, and Cols. 1-14 and 76-79 for Ocean Weather Vessels "on-station." No identification cards are punched for missing observations for Military Sea Transport Ships, Navy Ships, Ocean Weather Vessels "off-station" and AWS stations effective 1 Mar 61. Canada: Refer to sup. note D on page 2.

COLUMNS AND ELEMENTS PUNCHED: Cols. 1-75 for U. S. land stations; Cols. 1-79 for OSV's, ships, and Canadian stations; Cols. 1-80 for digital computer output cards are punched.

Elements punched are:

Pressure at Surface

At Surface and Standard Pressure Levels Aloft

- Temperature
- Relative Humidity
- Wind Direction and Speed

Heights for Standard Pressure Levels

CORRECTIONS: Any errors detected in this manual should be called to the attention of the Director, National Climatic Center, Environmental Data Service, ESSA; or Chief, Data Processing Division, Environmental Technical Applications Center, USAF. Please give specific instances of error, and correct information if available.

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CARD CONTENT

COLUMN	ITEM OR ELEMENT	SYMBOLIC LETTER	CARD CODE	CARD CODE DEFINITION	REMARKS
14-79	Missing Data		Blank	Missing or doubtful data	Cols. 76-79 are blank for land stations except Canada. For Canadian stations, Cols. 25, 40, 55, and 70 (high order position of wind direction field) are punched "X" to indicate a missing data stratum and that the data resume at a higher level.
			X/Cols. nn	X overpunch in Cols. noted	
1-5	Station Number or Ship Position (Q$L_aL_aL_oL_o$		00000-99999	WBAN Number (Land Stations)	WBAN Number: The first digit represents a modified octant, as shown below; the second digit is the tens position of latitude; the third digit is the tens position of longitude; and the last two digits are consecutively assigned within the ten degree square defined by the first three digits. The octant code is as follows: Octant / Northern Hemisphere / Octant / Southern Hemisphere 1 / 0° to 100° West / 5 / 0° to 100° West 2 / 100° to 180° West / 6 / 100° to 180° West 3 / 0° to 100° East / 7 / 0° to 100° East 4 / 100° to 180° East / 8 / 100° to 180° East 9 is used as the first digit for identifying the second hundred stations within a ten degree square. 0 is used for identifying the third hundred stations. A list of stations with their numbers, coordinates and period of record is maintained at the National Climatic Center.
1	Octant of Globe	Q	Octant	North Latitude 00°00'-90°00'	Code 1, modified 1960 WMO Code 3300.
			0	00°00' - 89°59' W Longitude	
			1	90°00' -180°00' W	
			2	179°59' - 90°00' E	
			3	89°59' - 00°01' E	
				South Latitude 00°01'-90°00'	
			5	00°00' - 89°59' W Longitude	
			6	90°00' -180°00' W	
			7	179°59' - 90°00' E	
			8	89°59' - 00°01' E	
2-3	Latitude	L_aL_a	00-99	0° - 90° Latitude	North or South Latitude is determined by Octant, Col. 1.
4-5	Longitude	L_oL_o	00-99 00-80	0° - 99° Longitude 100° - 180° Longitude	East or West is determined by Octant, Col. 1. Hundreds position of Longitude is omitted, determined by Octant. Prior to 1 Jul 64, Latitude and Longitude were punched to the nearest whole degree (30' or more rounded off to next degree). Effective 1 Jul 64, the minutes entry is ignored when punching.

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CARD CONTENT

COLUMN	ITEM OR ELEMENT	SYMBOLIC LETTER	CARD CODE	CARD CODE DEFINITION	REMARKS
6-7	Year		61-	Last two digits of year	
8-9	Month		01-12	Jan - Dec	
10-11	Day	YY	01-31	Day of Month	
12-13	Hour		00 06 12 18 00-23	0000 GMT (GCT) 0600 GMT (GCT) 1200 GMT (GCT) 1800 GMT (GCT) 0000-2300 GMT (GCT)	Observations one and 1/2 half hours or less before or after these scheduled times are punched these hours; Canada within one hour before and two hours after these hours. Observations outside the above limits are punched hour of release.
14	Card Number		0-9 (see below)	Field #No. And Columns (see below)	Col. 14 is punched 0 and Cols. 15-75 left blank when no observation. Card number punched indicates that the card contains data for the mb levels shown when available. Card 9, field 2, 1.5 mb and field 3, 1.0 mb, began with Jan 68 data.
15-18	Surface Pressure	PPPP	0600-1100	600 - 1100 millibars (whole)	Col. 14 punched 0, surface level.
15-18	Height of Standard Pressure Level in Geopotential Meters (gpm) (Mean Sea Level)	hhhh	0000-9999	0 - 49,999 gpm Last four digits of height	Ten thousands digit omitted. Refer to supplementary note B, U.S. Standard Atmosphere, as an aid in verifying the correct digit. Heights for standard pressure levels below the station level are computed and will not accompany any other data for that particular level. Canada: The ten thousand digit of height in Cards 4-9 (Col. 14) is punched in Cols. 76-79 for Fields 1-4, respectively. In Cards Nos. 0-3, Cols. 76-79 are left blank. In Cols. 15-18, the height of 850 mb is punched in Card No. 1, 650 mb in 2, 450 mb in 3, 250 mb in 4, 125 mb in 5, 60 mb in 6, 25 mb in 7, 7 mb in 8, and 2 mb in 9.

Card Number (Col. 14) — Field #No. And Columns

Card Code	#1 15-29	#2 30-44	#3 45-59	#4 60-74
0	SFC	1000	950	900
1	850	800	750	700
2	650	600	550	500
3	450	400	350	300
4	250	200	175	150
5	125	100	80	70
6	60	50	40	30
7	25	20	15	10
8	7	5	4	3
9	2	1.5	1	

TABLE OF ELEMENTS AND CARD COLUMNS

Element	Field 1	Field 2	Field 3	Field 4
Height (Sfc Pres. Card 0)	15-18	30-33	45-48	60-63
Temperature	19-22	34-37	49-52	64-67
Relative Humidity	23-24	38-39	53-54	68-69
Wind Direction	25-27	40-42	55-57	70-72
Wind Speed	28-29	43-44	58-59	73-74

CARD CONTENT

COLUMN	ITEM OR ELEMENT	SYMBOLIC LETTER	CARD CODE	CARD CODE DEFINITION	REMARKS
19-22	Temperature	TTTT	0000-0999 X001-X999	0.0°C thru 99.9°C Degrees Celsius and Tenths -0.1°C thru -99.9°C (minus)	Temperature at the height of the pressure levels listed in the Remarks for Cols. 15-18. Refer to Remarks for Cols. 19-22. Canada: Effective Jan 64 interpolated and extrapolated temperatures are punched to the nearest whole degree with an X punch in the low order (tenths) positions of the temperature fields (X in Cols. 22, 37, 52, and 67).
23-24	Relative Humidity		01-99 $\frac{X}{00}$ $\frac{X}{12} - \frac{X}{22}$	1% - 99% 100% (X overpunch Col. 23) Statistical Values 12% - 22% (X/Col. 24) Used when humidity element "motorboats" due to very low humidity.	Relative Humidity at pressure levels indicated in Cols. 15-18. RH is not generally evaluated at temperatures below -40.0°C. For exceptions, refer to supplementary note C on page 9. TABLE OF STATISTICAL VALUES Mean values of relative humidity (over water) for use at various temperatures, when electric hygrometer is below operating range. (see table below)

Temp. °C Range	RH %	Temp. °C Range	RH %	Temp. °C Range	RH %
40.0 thru 11.5	12	-10.5 thru -15.4	16	-29.5 thru -33.4	20
11.4 " 2.5	13	-15.5 " -20.4	17	-33.5 " -36.4	21
2.4 " -4.4	14	-20.5 " -25.4	18	-36.5 " -40.0	22
-4.5 " -10.4	15	-25.5 " -29.4	19		

COLUMN	ITEM OR ELEMENT	SYMBOLIC LETTER	CARD CODE	CARD CODE DEFINITION	REMARKS
23-24 (cont.)	Relative Humidity				At WB stations when radiosondes were equipped with carbon hygristors statistical values were discontinued. (Phased in: 1961-1965)
			$\frac{X}{00} - \frac{X}{99}$ $\frac{XX}{00}$	00% thru 99% (X/Col. 24) 100% (XX/Cols. 23-24) "Statistical" RH values in cards with 12/1 in Col. 80	For AWS Auto-RAOBS (the cards have a 12/1 punch in Col. 80) "statistical" values for the entire range of RH may be encountered. These values represent values assigned for computational purposes, or values interpolated using one or more such values.
25-27	Wind Direction	ddd	000 001-360	Calm 1° - 360°	Wind direction at the pressure levels indicated in Cols. 15-18. Canada: An "X" punch in the high order position of the wind direction fields (Cols. 25, 40, 55, and 70) indicates a missing data stratum (data resume at a higher level).
28-29	Wind Speed	ff	00 01-99 $\frac{X}{00} - \frac{X}{99}$	Calm 1 - 99 meters per second 100 - 199 mps (X/Col. 28)	Wind speed at the pressure levels indicated in Cols. 15-18.
30-33	Height of Standard Pressure Level in Geopotential Meters (Mean Sea Level)	hhhh	0000-9999 X001-	Last four digits of height 0 - 49,999 gpm gpm below Mean Sea Level (X in Col. 30)	Refer to Remarks for Cols. 15-18. In Cols. 30-33 the Height of 1000 mb is punched in Card No. 0, 800 mb in 1, 600 mb in 2, 400 in 3, 200 in 4, 100 in 5, 50 mb in 6, 20 mb in 7, 5 mb in 8, and 1.5 mb in 9.

CARD CONTENT

COLUMN	ITEM OR ELEMENT	SYMBOLIC LETTER	CARD CODE	CARD CODE DEFINITION	REMARKS
34-37	Temperature	TTTT	0000-0999 X001-X999	0.0°C thru 99.9°C -0.1°C thru -99.9°C	Temperature at the height of the pressure levels listed in the Remarks for Cols. 30-33. Refer to Remarks for Cols. 19-22.
38-39	Relative Humidity		01-99 X 00 X X 12 - 22 X/Col. 39 XX/Cols. 38-39	1% - 99% 100% Statistical Values (X/Col.39) 12% - 22% 00% thru 99% 100%	Relative humidity at pressure levels indicated in Cols. 30-33. Refer to Remarks in Cols. 23-24. "Statistical" RH values in cards with 12/1 in Col. 80. Refer to Remarks on AWS Auto-RAOBS in Cols. 23-24.
40-42	Wind Direction	ddd	000 001-360	Calm 1° - 360°	Wind Direction at the pressure levels indicated in Cols. 30-33. Refer to Remarks in Cols. 25-27 for Canada.
43-44	Wind Speed	ff	00 01-99 X X 00 - 99	Calm 1 - 99 meters per second 100 - 199 mps (X/Col. 43)	Wind Speed at the pressure levels indicated in Cols. 30-33.
45-48	Height of Standard Pressure Level in Geopotential Meters (Mean Sea Level)	hhhh	0000-9999 X001-	Last four digits of height 0 - 49,999 gpm gpm below Mean Sea Level (X in Col. 45)	Refer to Remarks for Cols. 15-18 on tens thousands digit. In Cols. 45-48 the Height of 950 mb is punched in Card No. 0, 750 mb in 1, 550 mb in 2, 350 in 3, 175 in 4, 80 mb in 5, 40 mb in 6, 15 mb in 7, 4 mb in 8, and 1 mb in 9.
49-52	Temperature	TTTT	0000-0999 X001-X999	0.0°C thru 99.9°C -0.1°C thru -99.9°C	Temperature at the height of the pressure levels listed in the Remarks for Cols. 45-48. Refer to Remarks for Cols. 19-22.
53-54	Relative Humidity		01-99 X 00 X X 12 - 22 X/col. 54 XX/Cols. 53-54	1% - 99% 100% Statistical Values(X/Col.54) 12% - 22% 00% thru 99% 100%	Relative Humidity at pressure levels indicated in Cols. 45-48. Refer to Remarks in Cols. 23-24. "Statistical" RH values in cards with 12/1 in Col. 80. Refer to Remarks on AWS Auto-RAOBS in Cols. 23-24.
55-57	Wind Direction	ddd	000 001-360	Calm 1° - 360°	Wind Direction at the pressure levels indicated in Cols. 45-48.
58-59	Wind Speed	ff	00 01-99 X X 00 - 99	Calm 1 - 99 meters per second 100 - 199 mps (X/Col. 58)	Wind Speed at the pressure levels indicated in Cols. 45-48.

CARD CONTENT

COLUMN	ITEM OR ELEMENT	SYMBOLIC LETTER	CARD CODE	CARD CODE DEFINITION	REMARKS
60-63	Height of Standard Pressure Level in Geopotential Meters (Mean Sea Level)	hhhh	0000-9999 X001—	Last four digits of height 0 - 49,999 gpm gpm below Mean Sea Level (X in Col. 60)	Refer to Remarks for Cols. 15-18 on tens thousands digit. In Cols. 60-63, the Height of 900 mb is punched in Card No. 0, 700 mb in 1, 500 mb in 2, 300 mb in 3, 150 mb in 4, 70 mb in 5, 30 mb in 6, 10 mb in 7, 3 mb in 8.
64-67	Temperature	TTTT	0000-0999 X001-X999	0.0°C thru 99.9°C -0.1°C thru -99.9°C	Temperatures at the height of the pressure levels listed in the Remarks for Cols. 60-63. Refer to Remarks for Cols. 19-22.
68-69	Relative Humidity		01-99 X $\overline{00}$ X $\overline{12}$ - X $\overline{22}$ X/Col. 69 XX/Cols. 68-69	1% - 99% 100% Statistical Value (X/Col.69) 12 - 22 % 00% thru 99% 100%	Relative Humidity at pressure levels indicated in Cols. 60-63. Refer to Remarks in Cols. 23-24. "Statistical" RH values in cards with 12/1 in Col. 80. Refer to Remarks on AWS Auto-RAOBS in Cols. 23-24.
70-72	Wind Direction	ddd	000 001-360	Calm 1° - 360°	Wind Direction at the pressure levels indicated in Cols. 60-63. Refer to Remarks in Cols. 25-27 for Canada.
73-74	Wind Speed	ff	00 01-99 X $\overline{00}$ - X $\overline{99}$	Calm 1 - 99 meters pre second 100 - 199 mps (X/Col. 73)	Wind Speed at the pressure levels indicated in Cols. 60-63.
75	Number of Cards in Observation		Blank 1-9, X	Observation missing 1-9, 10 Number of cards required to punch an observation	Canada: For missing observations an "8" was punched in Col. 75 from 1 Jan 61 - 31 Dec 66 and a "1" beginning 1 Jan 67; refer to supplementary note C on page 2. The number punched in Col. 75 is one higher than the number in Col. 14 of the last card required to punch the observation.
76-79	Not used for U. S. land Stations Ocean Vessel and Ocean Weather Station Number MSTS and Navy Ship Number				Canada: See Remarks for Cols. 15-18 on ten thousands digit of height which is punched in these columns.

CARD CONTENT

COLUMN	ITEM OR ELEMENT	SYMBOLIC LETTER	CARD CODE	CARD CODE DEFINITION	REMARKS
76-77	Ocean Station Vessel or MSTS Number		00 01-99	No ship on station Ship Number	Lists of Ocean Weather Ships and Military Sea Transport Ships are maintained at the National Climatic Center
78-79	Ocean Weather Station Number		00 01-99	Ship off station Station Number	The number assigned to the fixed position at which the weather ships are located. A list of stations with their coordinates, numbers and period of record is maintained at the National Climatic Center
76-79	Navy Ship Number		X001-X999	Ship Number	
80	Indicator		Blank 12/1	Conventional RAOB data Automatic RAOB data	Data source are adiabatic charts. 12 over 1 (A) punch in Col. 80 indicates that the data are derived from the digital computer. This punch appears in AWS card only.

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Supplementary Note A: PRESSURE LEVELS IN DECKS 542, 544, 545, 645, and 933.

C.D. 933 Prior to 1 Jan 61 Card No. Columns 10 14	WBAN NO. 5 CARD DECKS (C.D.) C.D. 542, 544, 545 Card No. Column 14	C.D. 542 Jun 46 - Jun 49 Level Mbs.	C.D. 544 Jul 49 - Dec 55 Level Mbs.	Card Deck 545 Jun 56-Jun 57 Level Millibars	Card Deck 545 Jul 57-Dec 60 Level Millibars	C.D. 645 Jan 61- Level	C.D. 645 Card No. Col. 14	C.D. 933 Beginning 1 Jan 61 Card No. Columns 10 14
8 1	1	Sfc. 1000	Sfc. 1000	Sfc. 1000	Sfc. 1000	Sfc. 1000	0	8 0
9 1	1	950 900	950 900	950 900	950 900	950 900	0	9 0
8 2	2	850 800	850 800	850 800	850 800	850 800	1	8 1
9 2	2	750 700	750 700	750 700	750 700	750 700	1	9 1
8 3	3	650 600	650 600	650 600	650 600	650 600	2	8 2
9 3	3	550 500	550 500	550 500	550 500	550 500	2	9 2
8 4	4	450 400	450 400	450 400	450 400	450 400	3	8 3
9 4	4	350 300	350 300	350 300	350 300	350 300	3	9 3
8 5	5	250 200	250 200	250 200	250 200	250 200	4	8 4
9 5	5	175 150	175 150	175 150	175 150	175 150	4	9 4
8 6	6	125 100	125 100	125 100	125 100	125 100	5	8 5
9 6	*6	80 60	80 60	80 60	80 60	80 *70	5*	8 6
8 7	*7	50 40	50 40	50 40	50 40	60 50	6*	8 6
9 7	*7	30 20	30 20	30 20	30 *25	40 30	6*	9 6
8 8	*8	10 Not punched above the 10 mb. level	15 10	15 10	20 15	25 20	7*	8 7
9 8	*8		7 5	7 5	10 7	15 10	7*	9 7
8 9	*9		4 3	4 3	5 4	7 5	8*	8 8
9 9	*9		2	2	3 2	4 3	8*	9 8
						2	9*	8 9
						1.5 1	9*	

*Indicates change of pressure levels

Note change of card number in deck 645; for Card No. 9, the 1.5 mb and 1 mb levels began Jan 68.

Deck 933 contains Monthly Summary cards for Weather Bureau and Navy stations for varying periods, generally from Feb 51 to Mar 69. AWS stations include only the period indicated in the Reference Manual for Deck 933. (Card Deck 933 to tape Apr 69-)

NOTE: When using above decks, refer to applicable Reference Manuals.

Supplementary Note B: UNITED STATES STANDARD ATMOSPHERE

As an aid in determining the ten thousand digit of height, which is not punched for U.S. stations, the U. S. Standard Atmosphere is shown below. Heights are rounded to the nearest ten meters at the standard pressure levels above 10 mb:

Pressure Millibars	Geopotential Meters
1080	-541
1013.2	0
1000	111
950	540
900	988
850	1457
800	1949
750	2466
700	3012
650	3591
600	4206
550	4865
500	5574
450	6344
400	7185
350	8117
300	9164
250	10363
234	10788*

*Average Tropopause

Pressure Millibars	Geopotential Meters
200	11784
175	12631
150	13608
125	14765
100	16180
80	17595
70	18442
60	19419
50	20576
40	22000
30	23849
25	25029
20	26481
15	28368
10	31055
7	33410
5	35780
4	37390
3	39430
2	42440
1.5	44640
1	47800

Supplementary Note C: RELATIVE HUMIDITY AT TEMP. BELOW -40.0°C

Beginning in 1961, at a few special project stations operated or were operated by the WB evaluated relative humidity at temperatures below -40.0°C. These are: WBO, Wallops Station, Va., WBO, Point Arguello, Cal., WBAS, Eniwetok and WBAS, Kwajalein, Marshall Is., Pacific; and Pacific Missle Range Ships.

At AWS stations, Jan 62 - May 68, relative humidity was evaluated at conventional and automated stations at temperatures below -40.0°C, after May 68 it was continued only at automated stations.

NWS stations evaluated RH at temperatures below -40.0°C beginning in 1961 when radiosondes were equipped with carbon hygristors.

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RECORD NUMBER 1 STATION 72211 59/ 3/ 1 TIME 0

N	T	H	RH	N	T	H	RH	N	T	H	RH	N	T	H	RH
1	2900	1011	95	11	2688	5010	88	21	0	0	0	31	0	0	0
2	2897	101	88	12	2637	5768	73	22	2036	6403	0	32	0	0	0
3	2878	530	80	13	2580	6580	66	23	0	0	0	33	0	0	0
4	2853	992	84	14	2518	7458	53	24	2032	0	0	34	0	0	0
5	2827	1471	89	15	2438	8426	53	25	0	0	0	35	0	0	0
6	2827	1976	96	16	2348	9506	44	26	2104	547	0	36	0	0	0
7	2805	2510	98	17	2240	730	0	27	0	0	0	37	0	0	0
8	2778	3081	0	18	2138	2155	0	28	0	0	0	38	0	0	0
9	2746	3680	0	19	0	0	0	29	0	0	0	39	0	0	0
10	2725	4328	98	20	2113	3947	0	30	0	0	0	40	0	0	0

RECORD NUMBER 2 STATION 72211 59/ 3/ 2 TIME 0

N	T	H	RH	N	T	H	RH	N	T	H	RH	N	T	H	RH
1	2882	1008	91	11	2598	4870	37	21	0	0	0	31	0	0	0
2	2873	76	93	12	2533	5585	32	22	0	0	0	32	0	0	0
3	2842	510	95	13	2521	6380	32	23	0	0	0	33	0	0	0
4	2812	956	95	14	2498	7232	28	24	0	0	0	34	0	0	0
5	2782	1425	95	15	2429	8191	23	25	0	0	0	35	0	0	0
6	2755	1918	90	16	2337	9269	0	26	0	0	0	36	0	0	0
7	2726	2430	85	17	2221	487	0	27	0	0	0	37	0	0	0
8	2706	2987	63	18	2190	1930	0	28	0	0	0	38	0	0	0
9	2687	3570	46	19	0	0	0	29	0	0	0	39	0	0	0
10	2646	4199	40	20	2147	3761	0	30	0	0	0	40	0	0	0

RECORD NUMBER 3 STATION 72211 59/ 3/ 3 TIME 0

N	T	H	RH	N	T	H	RH	N	T	H	RH	N	T	H	RH
1	2851	1017	64	11	2622	4940	14	21	0	0	0	31	0	0	0
2	2838	149	64	12	2565	5678	15	22	2083	6258	0	32	0	0	0
3	2804	570	64	13	2503	6450	15	23	0	0	0	33	0	0	0
4	2800	1018	12	14	2426	7310	14	24	2083	0	0	34	0	0	0
5	2804	1487	12	15	2345	8243	0	25	0	0	0	35	0	0	0
6	2794	1985	12	16	2271	9284	0	26	2118	0	0	36	0	0	0
7	2772	2500	12	17	2193	475	0	27	0	0	0	37	0	0	0
8	0	3069	28	18	2232	1917	0	28	0	0	0	38	0	0	0
9	2687	3660	26	19	0	0	0	29	0	0	0	39	0	0	0
10	2654	4283	14	20	2143	3762	0	30	0	0	0	40	0	0	0

RECORD NUMBER 4 STATION 72211 59/ 3/ 4 TIME 0

N	T	H	RH	N	T	H	RH	N	T	H	RH	N	T	H	RH
1	2906	1019	72	11	2600	5000	12	21	0	0	0	31	0	0	0
2	2894	168	70	12	2540	5731	12	22	0	0	0	32	0	0	0
3	2863	600	69	13	2472	6490	30	23	0	0	0	33	0	0	0
4	2844	1056	74	14	2404	7347	34	24	0	0	0	34	0	0	0
5	2824	1532	19	15	2343	8277	54	25	0	0	0	35	0	0	0
6	2809	2034	12	16	2263	9317	0	26	0	0	0	36	0	0	0
7	2778	2560	13	17	2183	504	0	27	0	0	0	37	0	0	0
8	2744	3122	13	18	2156	1912	0	28	0	0	0	38	0	0	0
9	2703	3700	13	19	0	0	0	29	0	0	0	39	0	0	0
10	2655	4343	14	20	2140	3723	0	30	0	0	0	40	0	0	0

Sample Output from Program NWRC

5.2 PROGRAM NWRST

This program (National Weather Record Statistics) combines input NWRST radiosondes with selected surface characteristics and cloud models to create a set of atmospheres useful for radiometric computations. Several data sources are used as input:

1. The radiosonde soundings contained on a magnetic tape generated by program NWRC (Keyword = NWRC)
2. The selected cloud models with their probabilities of occurrence contained on cards (Keyword = CLOUD)
3. The surface statistics contained on cards (Keyword = SURFACE)
   a. Surface type (ocean, soil, etc.)
   b. Mean surface temperature and its standard deviation
   c. For the ocean case only:
      V1 = Mean surface wind and its standard deviation
      V2 = Mean salinity and its standard deviation
   d. For the land case only:
      V1 = Mean reflectivity and its standard deviation

Each radiosonde is assumed to represent one day. Through the use of Monte Carlo techniques, a surface temperature, a surface wind (if appropriate), and a cloud type (or clear-sky condition) are selected to be combined with each sounding. The input variables are then converted to the desired units (e.g., relative humidity becomes absolute humidity) and the water vapor of the cloud levels is set to saturation. Mean values of all parameters are then computed for each desired output layer, these layers being specified by an input parameter (Keyword = NWRC), or determined by the pressure levels of the original sounding and the bases and heights of the cloud model.

The following variables, with the appropriate record number and date, are printed and output to magnetic tape (Unit 12).

Variable Name	Units	Definition
Z	meters	Height of the base of the layer
ZBAR	meters	Average height of the layer
TBAR	°K	Average temperature of the layer
PBAR	mb	Average pressure of the layer
RHOBAR	$g\ m^{-3}$	Average water vapor of the layer
CLBAR	$g\ m^{-3}$	Average liquid water of the layer
RCBAR	μm	Average modal drop size of the layer
C1BAR		Drop size distribution coefficients for the layer
C2BAR		Drop size distribution coefficients for the layer
ICOMP		Type of droplet in the layer
TSUR	°K	Surface temperature
V1	$m\ sec^{-1}$	Wind speed for ocean surface or Reflectivity for land surface
V2	moles/ liter	Salinity for ocean surface or Unused for land surface

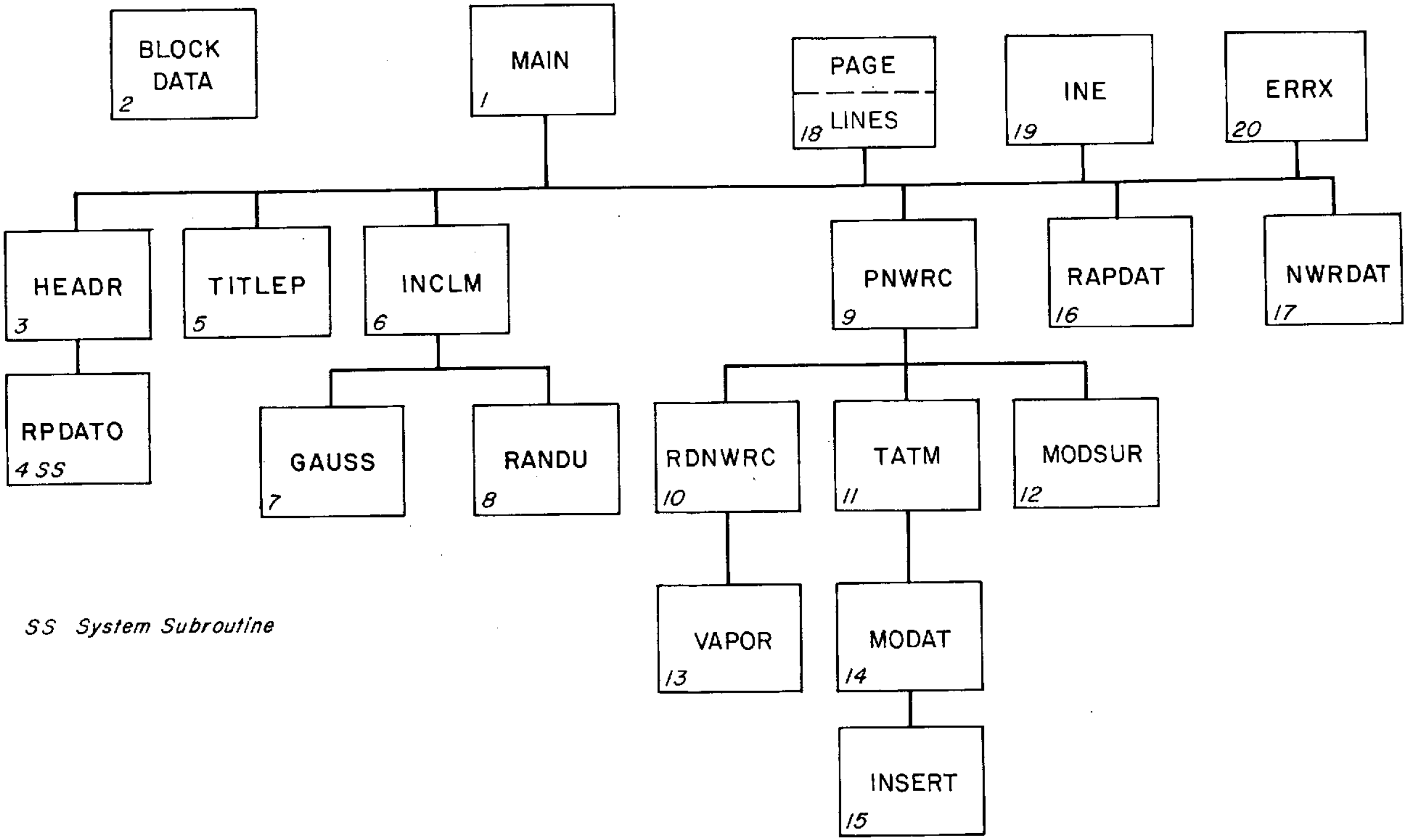

Figure 5-3 Interdependence of Program Elements for NWRST

```
//GO.FT03F001 DD DSNAME=K3.S1TCC.S1035.DLOGDATA,DISP=OLD
//GO.FT04F001 DD UNIT=2400-9,LABEL=(,NL),DISP=OLD,
//             DCB=(RECFM=VBS,LRECL=508,BLKSIZE=5084)
//             VOL=SER=A
//GO.FT12F001 DD UNIT=2400-9,LABEL=(,NL),DISP=NEW,
//             DCB=(RECFM=VBS,LRECL=4056,BLKSIZE=4060),
//             VOL=SER=B
//GO.DATA5 DD *
```

(A) Atmospheric Data Set from Program NWRC

(B) Atmospheric Data Set (Output)

Data Sets for Program NWRST

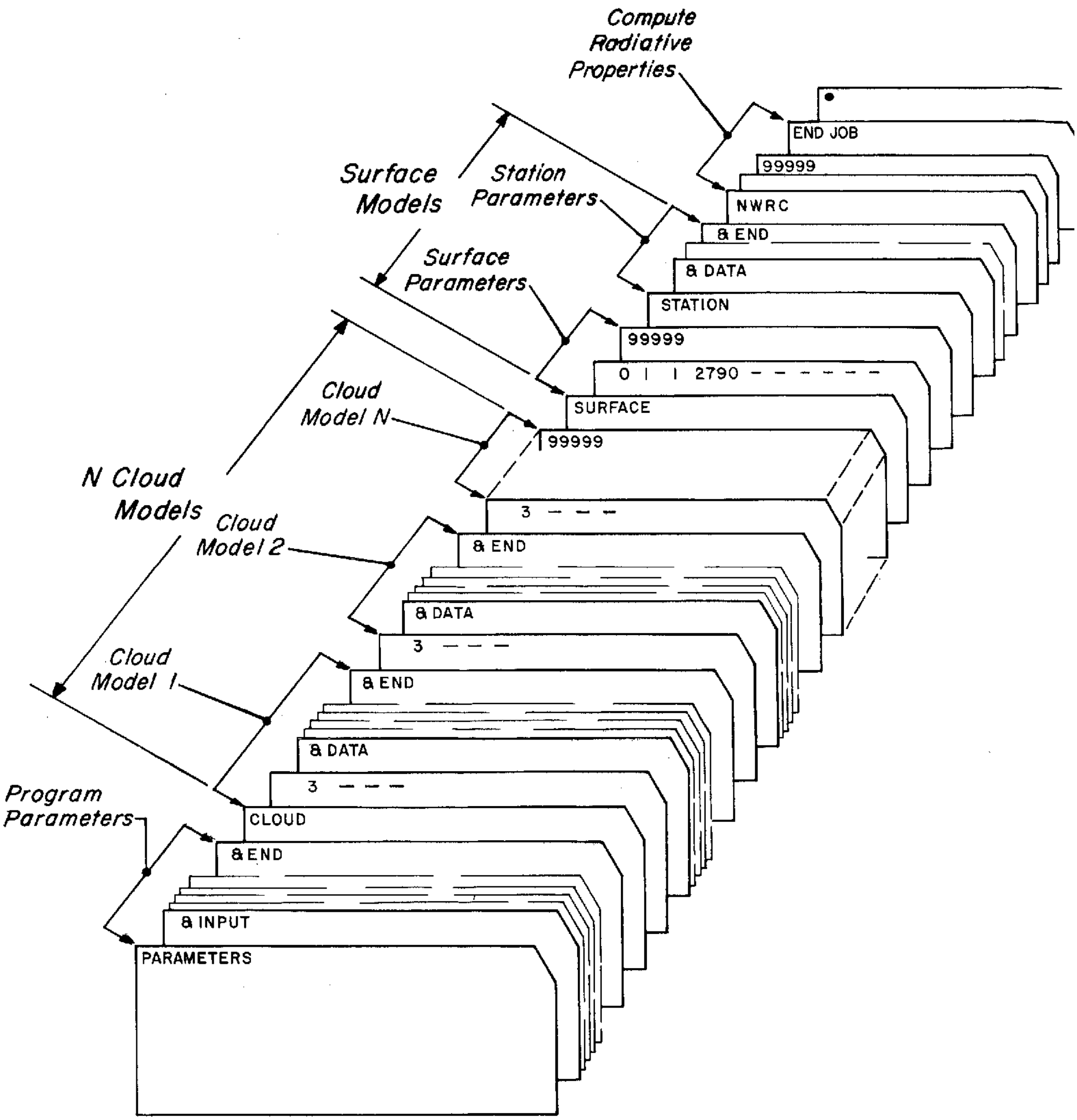

Figure 5-4 Deck Setup for a Typical NWRST Run

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Card Format for Program NWRST

Reads in program parameters via NAMELIST format.

FIRST CARD

Column	Variable	Format	Meaning
1-10	PARAMETERS		Keyword
21-70	TITLE	12A4,A2	Title for printing

SECOND CARD

2-7	&INPUT
9-72	NAMELIST assignments (see list of NAMELIST variables)

3rd AND FOLLOWING CARDS

2-72	NAMELIST assignments

LAST CARD

2-72	NAMELIST assignments, terminated by &END.

NAMELIST VARIABLES: (level 730515)

Name	Type	Dimension	Default	Meaning
RFACT	R	1	1.0	Scales water vapor content of atmosphere
CFACT	R	1	1.0	Scales liquid water content of cloud layers
HUMID	R	1	100.0	Scales relative humidity of cloud layers
IX	I	1	117755	Random number seed (odd integer)

Name	Type	Dimension	Default	Meaning
PRINT	L	1	.TRUE.	(not used)
PUNCH	L	1	.FALSE.	(not used)
TAB(PLOT)	L	1	.FALSE.	If .TRUE., NWRC sounding is printed for each "day".

'CLOUD'

Reads in cloud parameters via NAMELIST format.

FIRST CARD

Column	Variable	Format	Meaning
1-10	CLOUD		Keyword
21-70	TITLE	12A4,A2	Title for printing

SECOND CARD

Column	Variable	Format	Meaning
1-5	IREF	I5	Delimeter check word
6-10	MCODE	I5	Type of standard cloud model
21-28	CNAME	A8	Cloud name
31-80	TITLE	12A4,A2	Title of cloud for printing

THIRD CARD

2-6 &DATA

7-72 NAMELIST assignments (see list of NAMELIST variables)

FOURTH AND FOLLOWING CARDS

2-72 NAMELIST assignments.

LAST CARD

2-72 NAMELIST assignments terminated by &END.

IREF equal to 99999 on second card terminates cloud NAMELIST input.

NAMELIST VARIABLES (Level 730515)

Name	Type	Dimension	Default	Meaning
ZBASE(J)	R	10	None	Altitude (m) of base of j'th layer
ZTOP(J)	R	10	None	Altitude (m) of top of j'th layer
DENS(J)	R	10	None	Density (g cm^{-3}) of j'th layer
RC(J)	R	10	None	Model radius (μm) of droplets in j'th layer
C1(J)	R	10	None	Shape factor of drop size distribution
C2(J)	R	10	None	Shape factor of drop size distribution
ICOMP(J)	I	10	None	Composition of non-vapor H_2O in j'th layer. 1 = liquid, 2 = rain, 3 = ice.

Name	Type	Dimension	Default	Meaning
NLAYER	I	1	None	Number of layers in cloud model
SIGD	R	1	None	Standard deviation of liquid water content
OCCUR	R	1	None	Probability of occurrence of cloud type

'NWRC'

Reads desired NWRC data, assembles atmosphere, cloud model, and surface property data. Writes NWRST data set records on unit 12.

FIRST CARD

Columns	Variable	Format	Meaning
1-10	NWRC		Key word
21-70	Title	12A4,A2	Title for printing
SECOND AND FOLLOWING CARDS			
1-5	ID	I5	Station identification
6-10	IR1	I5	First NWRC record number requested
7 - 15	IR2	I5	Last NWRC record number requested
16-17	JMI	I2	Month of 1st NWRC record requested
18-19	JD1	I2	Day of 1st NWRC record requested
20-21	JY1	I2	Year of 1st NWRC record requested
22-23	JM2	I2	Month of last NWRC record requested
24-25	JD2	i2	Day of last NWRC record requested
26-27	JY2	I2	Year of last NWRC record requested
28-29	JHR	I2	Hour (GMT) of requested soundings
31-35	IOPT(1)	I5	.EQ.1 → Rewind File 12; .EQ.2 → Start at end of File 12.
36-40	IOPT(2)	I5	File 12 record pointer offset (.EQ.0)
41-45	IOPT(3)	I5	(0) Use normal output heights
			(1) Read card specifying output height intervals
			(>1) Read specified output heights up to IOPT (3)
46-50	IOPT(4)	I5	not used
LAST CARD			
1 - 5	'99999'		Denotes end of package

'STATION'

Reads in station parameters via NAMELIST format.

FIRST CARD

Columns	Variable	Format	Meaning
1-10	STATION		Keyword
21-70	Title	12A4,A2	Title for printing

SECOND CARD

2-6	&DATA
9-72	NAMELIST assignments (see list of NAMELIST variables)

THIRD AND FOLLOWING CARDS

2-72	NAMELIST assignments

LAST CARD

2-72	NAMELIST assignments, terminated by &END.

NAMELIST VARIABLES: (Level 730515)

Name	Type	Dimension	Default	Meaning
ISTAT	I	7	03131, 23114, 23169, 23230, 93104, 93116, 93214	Station code number (for catalogued stations)
NAME	I	21	San Diego, etc.	Station name (for catalogued station)
ZSUR	R	7	124.,724.,660., 6.,666.,1740., 100.	Station elevation (m) for catalogued stations

'SURFACE'

Reads in cards containing surface parameters.

FIRST CARD

Columns	Variable	Format	Meaning
1-10	SURFACE		Keyword
21-70	Title	12A4,A2	TITLE for printing

SECOND AND FOLLOWING CARDS

Columns	Variable	Format	Meaning
1-5	N1	I5	Assigns surface properties to cloud number N1. Must be .EQ.0 for constant surface
8-10	ISUR	I3	= 0 uses SURFACE card temperature (randomly distributed) for surface value. = 1 uses actual sounding surface value
11-70	FIELD	6G10.5	(see below)
11-20	FIELD (1)	G10.5	Surface temperature (°K) mean
21-30	FIELD (2)	G10.5	Standard deviation of surface temperature
31-40	FIELD (3)	G10.5	Wind speed (m sec^{-1}) mean (ocean) Reflectivity mean (land)
41-50	FIELD (4)	G10.5	Standard deviation of wind speed Reflectivity standard deviation (land)
51-60	FIELD (5)	G10.5	Surface salinity mean (mole/liter) (ocean)
61-70	FIELD (6)	G10.5	Standard deviation of salinity (ocean)

LAST CARD

Columns	Variable	Format	Meaning
1-5	'99999'		Denotes end of package

'LIST'

Prints out data from the NWRST atmospheric data set.

FIRST CARD

Columns	Variable	Format	Meaning
1-4	LIST	A4	Keyword
4-7	KWRD(2)	A4	'ALL', print out entire atmospheric data set
			'LAST', print out last record only
			'SOME', print out specified records

If Columns 4-7 equal 'SOME', use the following card formats to specify which records to list.

1-5	IR1	I5	First record number
11-15	IR2	I5	Last record number
16-17	JM1	I2	First month
18-19	JD1	I2	First day
20-21	JY1	I2	First year
22-23	JM2	I2	Last month
24-25	JD2	I2	Last day
26-27	JY2	I2	Last year
28-29	JHR	I2	Not used

LAST CARD

1-5	99999		Denotes end of package

'ENDJOB'

Key word card to end the job.

FIRST AND FINAL CARD

Columns	Variable	Format	Meaning
1-6	ENDJOB	A4	End of job

Numbered Error Messages

Program NWRST

Routine	Number	Cause
MAIN	30	Unidentified key word card
TITLEP	10	End file while reading namelist cards
INCLM	4	Number of CLD layers .LT.1 or.GT.10
PNWRC	15	Number of SNDG output layers > 100
	18	Max Z of input SNDG < Max Z requested
	40	End file encountered while reading SNDGS
	30	End file encountered when reading height specs.
MODSUR	800	Error encountered when reading surface card
	900	End file encountered when reading surface card
	55	Incorrect surface parameters
DUMMY	999	An entry to a dummy subroutine occurred
MODAT	185	Number of CLD layers > 10
RAPDAT	400	End file encountered while reading SNDGS
	120	Error encountered while reading SNDGS
	205	→ Never called ←
	320	Error encountered while reading SNDGS
	350	Month-day-year is 0.

```
PARAMETERS              GULF OF MEXICO - TAMPA, FLORIDA
 &INPUT
 PUNCH=.FALSE.,IX=62597,TAB=.TRUE.,
 &END
CLOUD
        3           25-1       FAIR WEATHER CU. 1500-6000 FT
 $DATA    NLAYER=3,
 ZBASE= 500., 1000., 1500.,
 ZTOP= 1000., 1500., 2000.,
 DENS= 0.50, 1.00, 0.50,
 RC= 10.0, 10.0, 10.0,
 C1= 6.0, 6.0, 6.0,
 C2= 0.5, 0.5, 0.5,
   ICOMP=1,1,1,  SIGD=.5,  OCCUR=.080
 $END
        3           22-2       STRATOCUMULUS 2000-4000 FT
 $DATA    NLAYER=1,
 ZBASE=660., ZTOP=1320., DENS=0.25, RC=10., C1=6.0, C2=0.5,
 ICOMP=1, SIGD=.5, OCCUR=.192
 $END
        3           20-2       LOW-LYING STRATUS 1500-3000 FT
 $DATA    NLAYER=1,
 ZBASE=500., ZTOP=1000., DENS=0.25, RC=10., C1=6.0, C2=1.0,
 ICOMP=1, SIGD=.5, OCCUR=.087
 $END
        3           10-1       ALTOCUMULUS 8000-9650 FT
 $DATA    NLAYER=1,
 ZBASE=2400., ZTOP=2900., DENS=0.15, RC=10., C1=6.0, C2=0.5,
 ICOMP=1, SIGD=.5, OCCUR=.113
 $END
        3           14-1       ALTOSTRATUS 8000-9650 FT
 $DATA    NLAYER=1,
 ZBASE=2400., ZTOP=2900., DENS=0.15, RC=10.0, C1=6.0, C2=1.0,
 ICOMP=1, SIGD=.5, OCCUR=.023
 $END
        3           1 - T - 1 CIRROSTRATUS TROPICAL, 18-24 KFT
 &DATA    NLAYER=1,
 ZBASE=6000.,
 ZTOP=8000.,
 DENS=0.10,
 RC=40.0,
 C1=6.0,
 C2=0.5,
   ICOMP=3,SIGD=.5,OCCUR=.242,
 &END
        3           21-2       STEADY RAIN, 15 MM/HR
 &DATA    NLAYER=4,
 ZBASE=0.0,150.,500.,1000.,ZTOP=150.,500.,1000.,1500.,DENS=.2,1.,2.,1.
 RC=200.,10.,10.,C1=5.,6.,6.,6.,C2=.5,.5,.5,.5,
   ICOMP=2,1,1,1,SIGD=.5,OCCUR=.141,
 &END
        3           26-1       CUMULONIMBUS W. RAIN 150 MM/HR
 $DATA    NLAYER=6,
 ZBASE=      0.,   300.,  1000.,  4000.,  6000.,  8000.,
 ZTOP=  300.,  1000.,  4000.,  6000.,  8000.,10000.,
 DENS=  6.30,   7.00,   8.00,   4.00,   3.00,   0.20,
 RC= 400.0,   20.0,   10.0,   10.0,   10.0,   40.0,
 C1=    5.0,    6.0,    6.0,    6.0,    6.0,    6.0,
 C2=    0.2,    0.2,    0.2,    0.2,    0.2,    0.5,
```

Sample Data Cards for Program NWRST

```
 ICOMP=2,1,1,1,1,3, SIGD=.5, OCCUR=.014
 $END
99999
SURFACE
    0 1   1 297.         2.00       5.8        3.0        0.66       0.0
99999
STATION
 $DATA
  ISTAT=72211,NAME='TAMPA','FLA.',
 $END
NWRC
         1  140
99999
ENDJOB
/*
```

Sample Data Cards for Program NWRST (cont'd.)

```
BEGIN NWRC STATISTICS PROGRAM                         VERSION   3.0 LEVEL 721023 RUN   3007
TABLE COUNT= 16

PARAMETERS           GULF OF MEXICO - TAMPA, FLORIDA


                                          PARAMETERS SELECTED FOR THIS RUN
                                           RANDOM NUMBER SEED =    62598
                                                   TEST= F
                                                   PRINT= T
                                                   PUNCH=  F
                                                   TAB = T
```

NWRST Sample Output

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****

CLOUD CLOUD COVER CONDITIONS FOR THE GULF OF MEXICO

NUMBER	NAME	PROB	SIGD	BASE	TOP	DENSITY	RADIUS	C1	C2	COMP
1	1-T-1	.242	0.50	6000.	8000.	0.100	40.00	6.0	0.5	3
2	10-1	.113	0.50	2400.	2900.	0.150	10.00	6.0	0.5	1
3	14-1	.023	0.50	2400.	2900.	0.150	10.00	6.0	1.0	1
4	20-2	.087	0.50	500.	1000.	0.250	10.00	6.0	1.0	1
5	21-2	.141	0.50	0.	150.	0.200	200.00	5.0	0.5	2
				150.	500.	1.000	10.00	6.0	0.5	1
				500.	1000.	2.000	10.00	6.0	0.5	1
				1000.	1500.	1.000	10.00	6.0	0.5	1
6	22-2	.192	0.50	660.	1320.	0.250	10.00	6.0	0.5	1
7	25-1	.080	0.50	500.	1000.	0.500	10.00	6.0	0.5	1
				1000.	1500.	1.000	10.00	6.0	0.5	1
				1500.	2000.	0.500	10.00	6.0	0.5	1
8	26-1	.014	0.50	0.	300.	6.300	400.00	5.0	0.2	2
				300.	1000.	7.000	20.00	6.0	0.2	1
				1000.	4000.	8.000	10.00	6.0	0.2	1
				4000.	6000.	4.000	10.00	6.0	0.2	1
				6000.	8000.	3.000	10.00	6.0	0.2	1
				8000.	10000.	0.200	40.00	6.0	0.5	3

SURFACE GULF OF MEXICO - WITH VARIABILITIES

SURFACE PROPERTIES FOR GIVEN CLOUD-COVER MODELS...SURFACE=OCEAN

CLOUD MODEL	<TEMP>	SIGM	<VAR1>	SIGM	<VAR2>	SIGM
CLEAR	297.00	2.00	5.80	3.00	0.66	0.0
10-1	297.00	2.00	5.80	3.00	0.66	0.0
14-1	297.00	2.00	5.80	3.00	0.66	0.0
20-2	297.00	2.00	5.80	3.00	0.66	0.0
21-2	297.00	2.00	5.80	3.00	0.66	0.0
22-2	297.00	2.00	5.80	3.00	0.66	0.0
25-1	297.00	2.00	5.80	3.00	0.66	0.0
26-1	297.00	2.00	5.80	3.00	0.66	0.0
	297.00	2.00	5.80	3.00	0.66	0.0

STATION TAMPA, FLA.'S VITAL STATISTICS

NWRC TAMPA, FLA. STATION 72211

NWRST Sample Output (cont'd.)

****

ID NUMBER 1 STATION 72211 TAMPA FLA. ELEVATION 3.0 METERS
RECORD 1 DATE 3/ 1/59 HOUR 0

Z	T	P	RHO	RHO-PC
0.0	290.00	1011.00	1.361E 01	95.000
101.0	289.70	1000.00	1.238E 01	88.000
530.0	287.80	950.00	1.003E 01	80.000
992.0	285.30	900.00	9.026E 00	84.000
1471.0	282.70	850.00	8.117E 00	89.000
1976.0	282.70	800.00	8.756E 00	96.000
2510.0	280.50	750.00	7.759E 00	98.000
3081.0	277.80	700.00	6.500E 00	98.000
3680.0	274.60	650.00	5.241E 00	98.000
4328.0	272.50	600.00	4.536E 00	98.000
5010.0	268.80	550.00	3.138E 00	88.000
5768.0	263.70	500.00	1.792E 00	73.000
6580.0	258.00	450.00	1.046E 00	66.000
7458.0	251.80	400.00	5.083E-01	53.000
8426.0	243.80	350.00	2.546E-01	53.000
9506.0	234.80	300.00	9.093E-02	44.000
10730.0	224.00	250.00	0.0	0.0
12155.0	213.80	200.00	0.0	0.0
12991.2	212.63	175.00	0.0	0.0
13947.0	211.30	150.00	0.0	0.0
15075.4	207.76	125.00	0.0	0.0
16403.0	203.60	100.00	0.0	0.0
17733.7	203.35	80.00	0.0	0.0
18529.2	203.20	70.00	0.0	0.0
19446.6	206.47	60.00	0.0	0.0
20547.0	210.40	50.00	0.0	0.0

NO CLOUDS OR HAZE FOR THIS CASE

SURFACE PROPERTIES SELECTED FOR THIS CASE

TSUR=294.21 V1= 2.45 V2= 0.66

AVERAGE VALUES FOR ATMOSPHERE

SCALE FACTORS... WATER VAPOR= 1.000E 00,CLOUD DENSITY= 0.0 CLOUD HUMIDITY=100.00

ZBAR	TBAR	PBAR	RHOBAR	CLBAR	RCBAR	C1BAR	C2BAR	ICOMP
50.5	289.85	1005.52	1.299E 01					
315.5	288.75	974.79	1.121E 01					
761.0	286.55	924.78	9.528E 00					
1231.5	284.00	874.77	8.571E 00					
1723.5	282.70	824.75	8.437E 00					
2243.0	281.60	774.73	8.258E 00					
2795.5	279.15	724.72	7.129E 00					
3380.5	276.20	674.70	5.870E 00					
4004.0	273.55	624.67	4.889E 00					
4669.0	270.65	574.64	3.837E 00					
5389.0	266.25	524.61	2.465E 00					
6174.0	260.85	474.56	1.419E 00					
7019.0	254.90	424.51	7.771E-01					
7942.0	247.80	374.45	3.814E-01					
8966.0	239.30	324.36	1.727E-01					
10118.0	229.40	274.24	4.546E-02					
11442.5	218.90	224.07	0.0					
12573.1	213.22	187.22	0.0					
13469.1	211.97	162.18	0.0					
14511.2	209.53	137.12	0.0					
15739.2	205.68	112.04	0.0					
17068.3	203.47	89.63	0.0					
18131.4	203.27	74.89	0.0					

NWRST Sample Output (cont'd.)

8 3007 NWRC STATISTICS PROGRAM VERSION 3.0 (721023) 31 OCT 1972 PAGE 3

****

ZBAR	TBAR	PBAR	RHOBAR	CLBAR	RCBAR	C1BAR	C2BAR	ICOMP
18987.9	204.84	64.87	0.0					
19996.8	208.44	54.85	0.0					
20547.0	0.0	0.0	0.0					

TOTAL WATER CONTENT... VAPOR= 4.098E 00 GM/CM2, CLOUDS= 0.0 GM/CM2

NWRST Sample Output (cont'd.)

5.3 PROGRAM RAPID GABTAWF

All of the computations of microwave attenuation and the resulting brightness temperatures are performed in this program; it thus forms the basis of the microwave analyses. GABTAWF (Generalized Attenuation, Brightness Temperatures, and Weighting Function), computes and outputs all the parameters mentioned in its name for sample atmospheres. RAPID GABTAWF, the program used here, performs the same computations for the atmospheres generated by NWRST but outputs only the brightness temperatures and total attenuation. Despite the name and the abbreviated printout, the complexity of the computations of radiative transfer, and the sophistication of the models used, make this the most time-consuming of all the programs in the system.

The program begins by specifying general parameters such as the radiometer height (RADHT), the background sky temperature (TSKY), the source of the reflectivity for land or ice surfaces (ISRFRD) and scaling factors for moisture (see Keyword PARAMETERS). It then determines which microwave channels are to be analyzed (Keyword CHANNELS), first by specifying the total channel configuration applicable to an entire experiment, and then by indicating the specific channels to be analyzed in a given run. Each channel is defined by a frequency (FREQ), a look angle (ANG), and a polarization (POL); other information may be given about these channels although it is not used in the computations.

Having specified the various radiometric parameters, RAPID then inputs an atmosphere from the magnetic tape generated by NWRST (Keyword NWRC) and proceeds to compute brightness temperatures and attenuation due to water vapor, oxygen, and clouds (liquid water) for each atmospheric layer generated by NWRST. The contributions of the surface and the reflected sky radiation are also computed, either using a sea surface model incorporating the effects of roughness and foam, or assuming a fixed reflectivity in the land areas. The resulting brightness temperatures and attenuations for each of these components, and the total brightness temperature and absorbtivity, are then printed for each of the microwave channels requested. The record identifiers and the total brightness temperature for each channel are output to magnetic tape. This process is repeated for all atmospheres selected from the NWRST data set.

The variables printed by this program are as follows:

Variable	Units		Description
FREQ	GHz	-	The frequency of the microwave channel
OBS-MODE	meters	-	The observing mode Altitude - look direction: UP or DOWN
ANG	degrees	-	The look angle of the microwave channel
POL	degrees	-	The polarization of the microwave channel 0° = vertical, 90° = horizontal
REF		-	The reflectivity of the surface
TBW	°K	-	The brightness temperature due to water vapor
TBO	°K	-	The brightness temperature due to oxygen
TBC	°K	-	The brightness temperature due to clouds (liquid water)
TBS	°K	-	The brightness temperature due to the surface
TBSA	°K	-	The brightness temperature due to reflected sky radiation
TBTOT	°K	-	The total brightness temperature
TAUW		-	The attenuation coefficient τ_W due to water vapor
TAUO		-	The attenuation coefficient τ_O due to oxygen
TAUC		-	The attenuation coefficient τ_C due to clouds (liquid water)
TAU		-	The total attenuation coefficient τ
FACT	%	-	The amount of radiation not absorbed by the atmosphere

6489

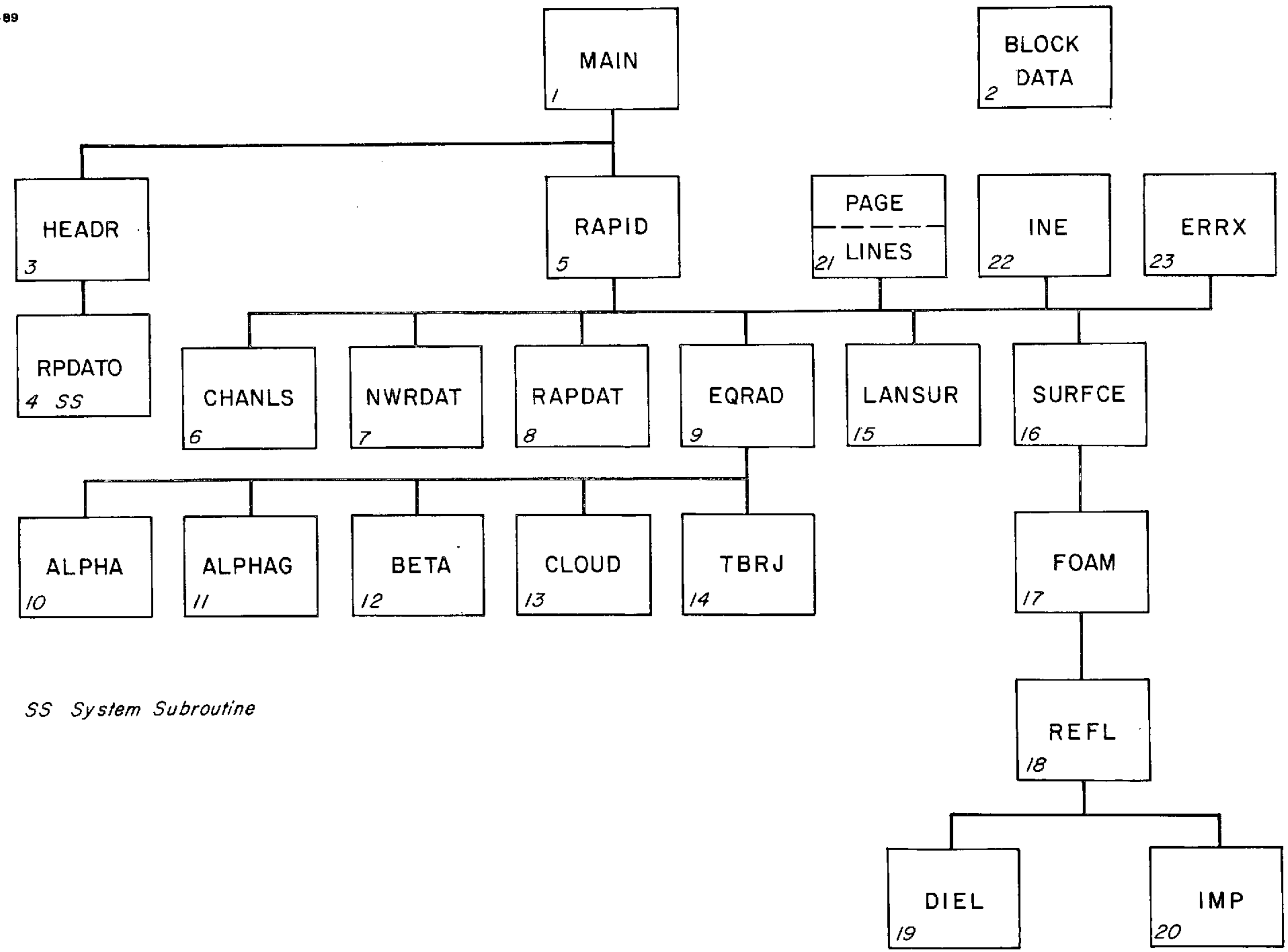

Figure 5-5 Interdependence of Program Elements for RAPID

```
//GO.FT03F001 DD DSNAME=K3.S1TCC.S1035.DLOGDATA,DISP=OLD
//GO.FT12F001 DD UNIT=2400-9,LABEL=(,NL),DISP=OLD,
//             DCB=(RECFM=VBS,LRECL=4056,BLKSIZE=4060),
//             VOL=SER=B
//GO.FT13F001 DD UNIT=2400-9,LABEL=(,NL),DISP=NEW,
//             DCB=(RECFM=VBS,LRECL=176,BLKSIZE=1764),
//             VOL=SER=C
//GO.DATA5 DD *
```

(B) ATMOSPHERIC DATA SET

(C) BRIGHTNESS TEMPERATURE DATA SET (OUTPUT)

Data Sets for Program RAPID

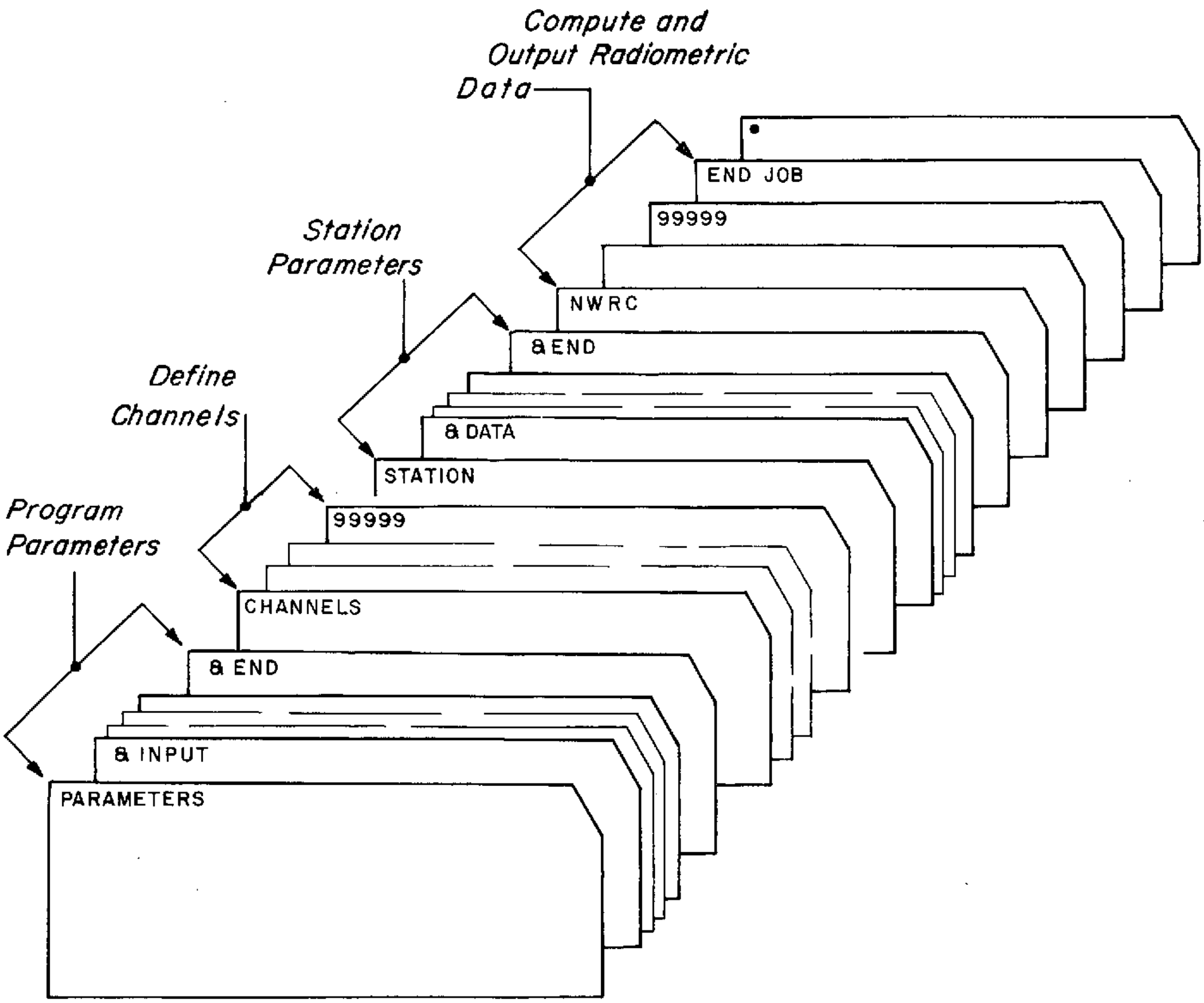

Figure 5-6 Deck Setup for a Typical RAPID Run

6488

'PARAMETERS'

Reads in program parameters via NAMELIST format.

FIRST CARD

Columns	Variable	Format	Meaning
1-8	PARAMETERS		Keyword
21-70	Title	12A4,A2	Title for printing

SECOND CARD

2-7	&INPUT
9-12	NAMELIST assignments (see list of NAMELIST variables)

LAST CARD

2-72	NAMELIST assignments, terminated by &END.

NAMELIST Variables: (Level 730515)

Name	Type	Dimension	Default	Meaning
RADHT	R	10	None	Height of radiometers (meters) 0<down-looking; ≥0. up-looking
TSKY	R	1	3.0	Background radiation temperature of space (°K)
HUMID	R	1	100.0	RH. of the cloud layer
NR1	I	1	1	Starting radiometer height
NR2	I	1	1	Ending radiometer height
REFL	R	(10,10)	100*0.60	Never used
TG	R	1	300.0	Physical surface temperature (°K)
KODE	I	1	None	Not used
TEST	L	1	.FALSE.	.TRUE. print out detailed ocean surface model
PUNCH	L	1	.FALSE.	Never used
ICODE	I	1	None	Never used
SALT	R	1	None	Input from NWRST file
OUTP	L	1	.FALSE.	If .TRUE. write computed brightness temperatures to tape
REFO	R	2	0.5	Reflectivity of the land surface
SYO	R	1	0.0	RMS Cross wind slope (general)
SXO	R	1	0.0	RMS down wind slope (general)
CXO	R	1	0.0	Cox and Munk Coefficients

NAME	TYPE	DIMENSION	DEFAULT	MEANING
CXX	R	1	0.0002	Relating down wind and cross wind to mean square down wind slope
CXY	R	1	0.0	
CYO	R	1	0.0	Cox and Munk coefficient
CYX	R	1	0.0	Relating down wind and cross wind to mean square cross wind slope
CYY	R	1	0.0002	
QF	R	1	.004	Volumemetric mixture ratio of foam
DF	R	1	1.0	Depth of foam (cm)
FW	R	1	0.00025	Dependence of fractional foam coverage on the square of the wind speed
W	R	2	None	Input from NWRST file
RFACT	R	1	1.00	Scales the water vapor
CFACT	R	1	1.00	Scales the liquid water
IPRINT	L	5	T,T,T,T,F	
IPRINT (1)				If .TRUE. Print channels and selected parameters
IPRINT (2)				If .TRUE. Print station information
IPRINT (3)				If .TRUE. Print input NWRST sounding
IPRINT (4)				If .TRUE. Print radiometric values
IPRINT (5)				If .TRUE. Print detailed surface values
MODE	I	1	1	(1) Use subroutine ALPHA (2) Use subroutine ALPHAG (3) Use subroutine ALPHA for frequency less than or equal to 80 GHz, otherwise use ALPHAG Note that if MODE >1 then cards containing water vapor coefficients should be read in.
ISRFRD	I	1	0	(0) Uses REFO from atmosphere or SEASUR (1) Calls LANSUR for REFO (2) Reads REFO as a parameter
FWO	R	1	0.0	Sets fractional foam to desired value (FWO), sets FW to zero

'STATION'

Reads in STATION parameters via NAMELIST formats.

FIRST CARD

Columns	Variable	Format	Meaning
1-7	STATION		Keyword
21-70	Title	12A4,A2	Title for printing

SECOND CARD

2-6	&DATA
9-72	NAMELIST assignments (see list of NAMELIST variables)

LAST CARD

2-72	NAMELIST assignments, terminated by &END.

NAMELIST Variables: (Level 730915)

Name	Type	Dimension	Default	Meaning
ISTAT	I	7	None	Station code number
NAME	I	21	None	Station name
ZSUR	R	7	None	Station elevation (meters)

'CHANNELS'

(see definition of CHANNELS package in Program INVERT)

'NWRC'

Reads control cards, model atmospheres, and computes radiative properties.

FIRST CARD

Columns	Variable	Format	Meaning
1-4	NWRC		Keyword
21-72	Title	15A4	Title for printing

SECOND CARD

Columns	Variable	Format	Meaning
1-5	ID	I5	Delimeter check word
6-10	IR1	I5	First NWRST record number requested
11-15	IR2	I5	Last NWRST record number requested
16-17	JM1	I2	Month of first NWRST record requested
18-19	JD1	I2	Day of first NWRST record requested
20-21	JY1	I2	Year of first NWRST record requested
22-23	JM2	I2	Month of last NWRST record requested
24-25	JD2	I2	Day of last NWRST record requested
26-27	JY2	I2	Year of last NWRST record requested
28-29	JHR	I2	Hour (GMT) of requested soundings
31-25	IOPT(1)	I5	.EQ.1→Rewind File 13;.EQ.2→Start at end of File 13.
36-40	IOPT(2)	I5	File 12 record pointer offset (.EQ.0)
41-45	IOPT(3)	I5	(0) Use normal output heights
41-45	IOPT(3)	I5	(1) Read card specifying output height increments
			(>1) Read specified output heights up to IOPT(3)
46-50	IOPT(4)	I5	Not used

'ADDCHANNELS'

Adds new brightness temperatures for additional channels to existing data set.

FIRST CARD

Columns	Variable	Format	Meaning
1-11	ADDCHANNELS		Keyword
21-70	Title	12A4,A2	Title for printing

SECOND CARD

1-5	INCH	I5	Unit number of the brightness temperature data set. (not equal to 13)

THIRD AND FOLLOWING CARDS

See channels package description.

'COMMENTS'

Reads in COMMENT cards.

FIRST CARD

Columns	Variable	Format	Meaning
1-8	COMMENTS		Keyword
21-70	Title	12A4,A2	Title for printing

SECOND AND FOLLOWING CARDS

See card formats in description of subroutine INE.

Numbered Error Messages

Program RAPID

Routine	Number	Cause
RAPID	200	Down looking sensor path does not intercept earth.
	800	Invalid keyword or control card
	810	Never called
	830	Record number requested >99999
	710	END OF FILE encountered while reading SNDGS
LANSUR	25	Ice reflectivity not properly set
	50	Frequency requested >250 GHz
	150	Surface temperature >320°K
SURFACE	100	IS≠1 for ocean surface

```
PARAMETERS                   GULF OF MEXICO
 &INPUT
 RADHT=-7620.0,
 OUTP=.TRUE.,
 &END
STATION                      TAMPA FLORIDA
 &DATA
 ISTAT=72211,ZSUR=3.0,
 NAME='TAMP','A   ','FLA.',
 &END
NWRC                         GULF OF MEXICO
         1   140
99999
ENDJOB
```

Sample Data Cards for Program RAPID

```
 3  7056     RAPID GABTAWF PROGRAM                              VERSION   7.1  (721101)          20 MAR 1973          PAGE   1
*****************************************************************************************************************************
PARA         GULF OF MEXICO


 3  7056     RAPID GABTAWF PROGRAM                              VERSION   7.1  (721101)          20 MAR 1973          PAGE   2
*****************************************************************************************************************************

                          GULF OF MEXICO


                          RADHT=  -7620.0.

                          TSKY=  3.00 DEG K

                          CLOUD HUMIDITY=100.00 PERCENT

                          TGROUND=300.00 DEG K


 3  7056     RAPID GABTAWF PROGRAM                              VERSION   7.1  (721101)          20 MAR 1973          PAGE   3
*****************************************************************************************************************************
CHAN         GODDARD CHANNELS FOR EOS, ESMR, AND NIMBUS
```

RAPID Sample Output

CHANNEL	FREQUENCY	ANGLE	POLARIZATION
1	1.420	0.0	H
2	4.990	38.00	V
3	4.990	38.00	H
4	10.690	38.00	V
5	10.690	38.00	H
6	31.400	0.0	V
7	37.000	38.00	V
8	37.000	38.00	H
9	19.350	0.0	H
10	19.350	2.30	H
11	19.350	4.60	H
12	19.350	6.90	H
13	19.350	9.20	H
14	19.350	11.50	H
15	19.350	13.80	H
16	19.350	16.20	H
17	19.350	18.60	H
18	19.350	21.00	H
19	19.350	23.50	H
20	19.350	26.00	H
21	19.350	28.60	H
22	19.350	31.20	H
23	19.350	33.90	H
24	19.350	36.70	H
25	19.350	39.60	H
26	19.350	42.70	H
27	19.350	45.90	H
28	19.350	49.30	H
29	22.230	0.0	V
30	53.650	0.0	V
31	54.900	0.0	V
32	58.800	0.0	V
33	0.0	0.0	V
34	0.0	0.0	V
35	0.0	0.0	V
36	0.0	0.0	V

RAPID Sample Output (cont'd.)

I	CHANNEL	FREQUENCY	LOOK ANGLE	POLAR	BEAM WIDTH	NOISE	SCALE	ZERO	CHANNEL NAME
1	1	1.420	0.0	90.000	0.0	0.500	0.0	0.0	EOS CHANNEL 1
2	2	4.990	38.000	0.0	0.0	0.500	0.0	0.0	EOS CHANNEL 2
3	3	4.990	38.000	90.000	0.0	0.500	0.0	0.0	EOS CHANNEL 3
4	4	10.690	38.000	0.0	0.0	0.500	0.0	0.0	EOS CHANNEL 4
5	5	10.690	38.000	90.000	0.0	0.500	0.0	0.0	EOS CHANNEL 5
6	7	37.000	38.000	0.0	0.0	0.500	0.0	0.0	EOS CHANNEL 7
7	8	37.000	38.000	90.000	0.0	0.500	0.0	0.0	EOS CHANNEL 8
8	29	22.230	0.0	0.0	0.0	0.500	0.0	0.0	NIMBUS CHANNEL 1
9	6	31.400	0.0	0.0	0.0	0.500	0.0	0.0	NIMBUS CHANNEL 2
10	30	53.650	0.0	0.0	0.0	0.500	0.0	0.0	NIMBUS CHANNEL 3
11	31	54.900	0.0	0.0	0.0	0.500	0.0	0.0	NIMBUS CHANNEL 4
12	32	58.800	0.0	0.0	0.0	0.500	0.0	0.0	NIMBUS CHANNEL 5
13	9	19.350	0.0	90.000	0.0	0.500	0.0	0.0	ESMR CHANNELS 1-7
14	10	19.350	2.300	90.000	0.0	0.500	0.0	0.0	ESMR CHANNELS 1-7
15	11	19.350	4.600	90.000	0.0	0.500	0.0	0.0	ESMR CHANNELS 1-7
16	12	19.350	6.900	90.000	0.0	0.500	0.0	0.0	ESMR CHANNELS 1-7
17	13	19.350	9.200	90.000	0.0	0.500	0.0	0.0	ESMR CHANNELS 1-7
18	14	19.350	11.500	90.000	0.0	0.500	0.0	0.0	ESMR CHANNELS 1-7
19	15	19.350	13.800	90.000	0.0	0.500	0.0	0.0	ESMR CHANNELS 1-7
20	16	19.350	16.200	90.000	0.0	0.500	0.0	0.0	ESMR CHANNELS 8-10
21	17	19.350	18.600	90.000	0.0	0.500	0.0	0.0	ESMR CHANNELS 8-10
22	18	19.350	21.000	90.000	0.0	0.500	0.0	0.0	ESMR CHANNELS 8-10
23	19	19.350	23.500	90.000	0.0	0.500	0.0	0.0	ESMR CHANNELS 11-12
24	20	19.350	26.000	90.000	0.0	0.500	0.0	0.0	ESMR CHANNELS 11-12
25	21	19.350	28.600	90.000	0.0	0.500	0.0	0.0	ESMR CHANNELS 13-14
26	22	19.350	31.200	90.000	0.0	0.500	0.0	0.0	ESMR CHANNELS 13-14
27	23	19.350	33.900	90.000	0.0	0.500	0.0	0.0	ESMR CHANNELS 15-16
28	24	19.350	36.700	90.000	0.0	0.500	0.0	0.0	ESMR CHANNELS 15-16
29	25	19.350	39.600	90.000	0.0	0.500	0.0	0.0	ESMR CHANNELS 17-18
30	26	19.350	42.700	90.000	0.0	0.500	0.0	0.0	ESMR CHANNELS 17-18
31	27	19.350	45.900	90.000	0.0	0.500	0.0	0.0	ESMR CHANNELS 19-20
32	28	19.350	49.300	90.000	0.0	0.500	0.0	0.0	ESMR CHANNELS 19-20

RAPID Sample Output (cont'd.)

```
 3  7056     RAPID GABTAWF PROGRAM                                   VERSION   7.1  (721101)        20 MAR 1973           PAGE  6
**************************************************************************************************************************************
STAT         TAMPA FLORIDA




 3  7056     RAPID GABTAWF PROGRAM                                   VERSION   7.1  (721101)        20 MAR 1973           PAGE  7
**************************************************************************************************************************************




 3  7056     RAPID GABTAWF PROGRAM                                   VERSION   7.1  (721101)        20 MAR 1973           PAGE  8
**************************************************************************************************************************************
NWRC         GULF OF MEXICO
```

RAPID Sample Output (cont'd.)

FILE 12 RAPID DATA SET

ID NUMBER 1 STATION 72211 TAMPA FLA. ELEVATION 3.0 METERS
RECORD 1 DATE 3/ 1/59 HOUR 0

CLOUD MODEL=CLEAR

SURFACE MODEL= 1 TSUR= 294.2 VAR1= 2.45 VAR2= 0.66

Z	ZBAR	TBAR	PBAR	RHOBAR	CBAR	RCBAR	C1BAR	C2BAR	IXBAR
0.0	50.5	289.85	1005.52	1.299E 01	0.0	0.0	0.0	0.0	0
101.0	315.5	288.75	974.79	1.121E 01	0.0	0.0	0.0	0.0	0
530.0	761.0	286.55	924.78	9.528E 00	0.0	0.0	0.0	0.0	0
992.0	1231.5	284.00	874.77	8.571E 00	0.0	0.0	0.0	0.0	0
1471.0	1723.5	282.70	824.75	8.437E 00	0.0	0.0	0.0	0.0	0
1976.0	2243.0	281.60	774.73	8.258E 00	0.0	0.0	0.0	0.0	0
2510.0	2795.5	279.15	724.72	7.129E 00	0.0	0.0	0.0	0.0	0
3081.0	3380.5	276.20	674.70	5.870E 00	0.0	0.0	0.0	0.0	0
3680.0	4004.0	273.55	624.67	4.889E 00	0.0	0.0	0.0	0.0	0
4328.0	4669.0	270.65	574.64	3.837E 00	0.0	0.0	0.0	0.0	0
5010.0	5389.0	266.25	524.61	2.465E 00	0.0	0.0	0.0	0.0	0
5768.0	6174.0	260.85	474.56	1.419E 00	0.0	0.0	0.0	0.0	0
6580.0	7019.9	254.90	424.51	7.771E-01	0.0	0.0	0.0	0.0	0
7458.0	7942.0	247.80	374.45	3.814E-01	0.0	0.0	0.0	0.0	0
8426.0	8966.0	239.30	324.36	1.727E-01	0.0	0.0	0.0	0.0	0
9506.0	10118.0	229.40	274.24	4.546E-02	0.0	0.0	0.0	0.0	0
10730.0	11442.5	218.90	224.07	0.0	0.0	0.0	0.0	0.0	0
12155.0	12573.1	213.22	187.72	0.0	0.0	0.0	0.0	0.0	0
12991.2	13469.1	211.97	162.18	0.0	0.0	0.0	0.0	0.0	0
13947.0	14511.2	209.53	137.12	0.0	0.0	0.0	0.0	0.0	0
15075.4	15739.2	205.68	112.04	0.0	0.0	0.0	0.0	0.0	0
16403.0	17068.3	203.47	89.63	0.0	0.0	0.0	0.0	0.0	0
17733.7	18131.4	203.27	74.89	0.0	0.0	0.0	0.0	0.0	0
18529.2	18987.9	204.84	64.87	0.0	0.0	0.0	0.0	0.0	0
19446.6	19996.8	208.44	54.85	0.0	0.0	0.0	0.0	0.0	0
20547.0	20547.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0

RAPID Sample Output (cont'd.)

COMPUTED BRIGHTNESS TEMPERATURES (DEG K)

FREQ	OBS-MODE	ANG	POL	REF	TBW	TBO	TBC	TBS	TBSA	TBTOT	TAUW	TAUO	TAUC	TAU	FACT
1.42	7458.0-DN	0.0	90.0	0.686	0.1	2.8	0.0	93.6	2.3	98.8	1.19E-04	6.08E-03	0.0	6.20E-03	0.994
4.99	7458.0-DN	38.0	0.0	0.566	0.8	3.7	0.0	128.8	2.0	135.3	1.91E-03	8.59E-03	0.0	1.05E-02	0.990
4.99	7458.0-DN	38.0	90.0	0.700	0.9	4.0	0.0	89.1	2.5	96.5	1.91E-03	8.59E-03	0.0	1.05E-02	0.990
10.69	7458.0-DN	38.0	0.0	0.550	4.3	3.9	0.0	132.5	1.9	142.6	9.97E-03	9.10E-03	0.0	1.91E-02	0.981
10.69	7458.0-DN	38.0	90.0	0.687	4.6	4.2	0.0	92.1	2.4	103.4	9.97E-03	9.10E-03	0.0	1.91E-02	0.981
37.00	7458.0-DN	38.0	0.0	0.465	38.8	11.5	0.0	140.0	1.9	192.2	1.05E-01	3.15E-02	0.0	1.37E-01	0.872
37.00	7458.0-DN	38.0	90.0	0.619	42.5	12.6	0.0	99.8	2.5	157.4	1.05E-01	3.15E-02	0.0	1.37E-01	0.872
22.23	7458.0-DN	0.0	0.0	0.590	95.7	3.3	0.0	92.6	1.8	193.5	2.74E-01	9.43E-03	0.0	2.83E-01	0.753
31.40	7458.0-DN	0.0	0.0	0.562	30.9	6.2	0.0	119.8	2.0	158.8	7.60E-02	1.54E-02	0.0	9.14E-02	0.913
53.65	7458.0-DN	0.0	0.0	0.499	18.3	226.3	0.0	26.8	1.5	272.9	1.49E-01	1.57E 00	0.0	1.72E 00	0.179
54.90	7458.0-DN	0.0	0.0	0.496	5.7	258.6	0.0	2.4	0.0	266.8	1.56E-01	3.97E 00	0.0	4.13E 00	0.016
58.80	7458.0-DN	0.0	0.0	0.486	0.5	256.3	0.0	0.0	0.0	256.8	1.77E-01	1.69E 01	0.0	1.70E 01	0.000
19.35	7458.0-DN	0.0	90.0	0.599	35.4	3.5	0.0	109.5	1.9	150.3	8.57E-02	8.57E-03	0.0	9.42E-02	0.910
19.35	7458.0-DN	2.3	90.0	0.600	35.4	3.5	0.0	109.3	1.9	150.1	8.57E-02	8.57E-03	0.0	9.42E-02	0.910
19.35	7458.0-DN	4.6	90.0	0.601	35.4	3.5	0.0	109.0	1.9	149.8	8.57E-02	8.57E-03	0.0	9.42E-02	0.910
19.35	7458.0-DN	6.9	90.0	0.600	35.6	3.5	0.0	109.0	1.9	150.1	8.62E-02	8.63E-03	0.0	9.48E-02	0.910
19.35	7458.0-DN	9.2	90.0	0.603	35.9	3.6	0.0	108.3	1.9	149.6	8.67E-02	8.67E-03	0.0	9.54E-02	0.909
19.35	7458.0-DN	11.5	90.0	0.605	36.2	3.6	0.0	107.8	1.9	149.4	8.73E-02	8.74E-03	0.0	9.61E-02	0.908
19.35	7458.0-DN	13.8	90.0	0.608	36.5	3.6	0.0	106.8	1.9	148.9	8.81E-02	8.82E-03	0.0	9.69E-02	0.908
19.35	7458.0-DN	16.2	90.0	0.610	36.9	3.7	0.0	106.2	1.9	148.7	8.91E-02	8.92E-03	0.0	9.80E-02	0.907
19.35	7458.0-DN	18.6	90.0	0.615	37.5	3.7	0.0	104.6	1.9	147.7	9.03E-02	9.03E-03	0.0	9.93E-02	0.905
19.35	7458.0-DN	21.0	90.0	0.618	38.1	3.8	0.0	103.6	1.9	147.4	9.17E-02	9.17E-03	0.0	1.01E-01	0.904
19.35	7458.0-DN	23.5	90.0	0.623	38.8	3.9	0.0	102.0	2.0	146.7	9.33E-02	9.34E-03	0.0	1.03E-01	0.902
19.35	7458.0-DN	26.0	90.0	0.628	39.7	3.9	0.0	100.4	2.0	146.0	9.52E-02	9.53E-03	0.0	1.05E-01	0.901
19.35	7458.0-DN	28.6	90.0	0.637	40.7	4.0	0.0	97.9	2.0	144.7	9.75E-02	9.75E-03	0.0	1.07E-01	0.898
19.35	7458.0-DN	31.2	90.0	0.641	41.8	4.2	0.0	96.4	2.0	144.4	1.00E-01	1.00E-02	0.0	1.10E-01	0.896
19.35	7458.0-DN	33.9	90.0	0.650	43.2	4.3	0.0	93.7	2.0	143.3	1.03E-01	1.03E-02	0.0	1.13E-01	0.893
19.35	7458.0-DN	36.7	90.0	0.660	44.8	4.4	0.0	90.6	2.1	141.9	1.07E-01	1.07E-02	0.0	1.17E-01	0.889
19.35	7458.0-DN	39.6	90.0	0.670	46.7	4.6	0.0	87.5	2.1	141.0	1.11E-01	1.11E-02	0.0	1.22E-01	0.885
19.35	7458.0-DN	42.7	90.0	0.679	48.9	4.9	0.0	84.8	2.1	140.7	1.16E-01	1.17E-02	0.0	1.28E-01	0.880
19.35	7458.0-DN	45.9	90.0	0.694	51.8	5.1	0.0	80.2	2.2	139.3	1.23E-01	1.23E-02	0.0	1.35E-01	0.873
19.35	7458.0-DN	49.3	90.0	0.711	55.3	5.5	0.0	75.1	2.2	138.2	1.31E-01	1.31E-02	0.0	1.44E-01	0.865

RAPID Sample Output (cont'd.)

5.4 PROGRAM INVERT

Program INVERT, together with the data sets created by NWRST, RAPID and MATCH, generates, evaluates, and uses the D-matrix with real data to predict atmospheric parameters.

The logical structure of the program provides for Keyword package input format. Each package is initiated by a keyword which directs control to an appropriate routine. The first keyword package expected by the program is keyword package 'CHANNELS'. This package contains the information on cards that determines which microwave channels are to be analyzed first by specifying the total channel configuration applicable to an entire experiment, and then by indicating the specific channels to be analyzed. Each channel for the total configuration is defined by frequency (GFREQ), a look angle (GANG), and a polarization (GPOLR). Each channel selected for an invert run is defined by frequency (F), an initial view angle (ANG1), polarization (P), a final view angle (ANG2), increment in view angle (ANG3), beam width (Beam), an RMS noise value (if any), a scaling multiplier, and an offset temperature for scaling the brightness temperatures when desired.

The next keyword package is the parameters package 'PARAMETERS'. This package contains parameters that control input and output options and array size parameters. For each INVERT run the number of observations (NOBS) of atmospheric data and radiometric data from the NWRST - RAPID data sets should be specified for generating the D-matrix. The number of channels requested (ND), the number of atmospheric parameters to invert for (NP,NPB) and the number of data base functions (NDB) which is always ND + 1, should also be specified. A random number generator seed can be set (if desired) that is used by the program to derive random noise values that can be added to the computed brightness temperatures. The parameters ND, NP and the average data base functions computed from the data used to generate the D-matrix together with the D-matrix can be saved on magnetic tape by setting the parameters OUTD and IND equal to · TRUE ·.

The statistics package ('STATISTICS') controls the input and stores the data from the NWRST and RAPID data sets. Two additional keywords are inserted in this package. One is called P-VECTOR (Parameter Vector) and the other D-VECTOR (Data Vector). Keyword P-VECTOR causes the program to read in and store NOBS of atmospheric parameters from the NWRST data set and keyword D-VECTOR reads in and stores NOBS of computed brightness temperatures from the RAPID data set. It is in this mode that random noise values (if any) are added to the computed brightness temperatures. Between the two keyword parameters is a card that contains the height of the aircraft (meters), and four heights (meters) defining the tops of four layers of the atmosphere for computing mean water vapor density.

The evaluation package, keyword 'EVALUATION' is used to evaluate the resulting D-matrix. Again, keywords P-VECTOR and D-VECTOR are used here to read in remaining NOBS of atmospheric and brightness temperature from the NWRST and RAPID data sets. The radiometric observations are used to simulate real data that the D-matrix works on to invert for the predicted parameters. Here the predicted parameters can be used in comparison with the input atmospheric parameters to obtain the inversion errors. At the completion of the simulated inversion an overall summary of the inversion results is computed and output.

Keyword 'INVERT' will cause the program to read in NOBS of real data from the Convair 990 MATCH data set. The brightness temperatures in this data set are scaled (if desired) and corrected for offset and multiplied by the D-matrix for output of predicted atmospheric parameters.

The keyword package concept used in Program INVERT provides the user with several options. For example, if an ENDJOB card is placed after the 99999-card terminating the package for generating the D-matrix, the evaluation and inversion of the real data is supressed. Leaving out keyword INVERT will cause the program to generate the D-matrix, and evaluate the results only.

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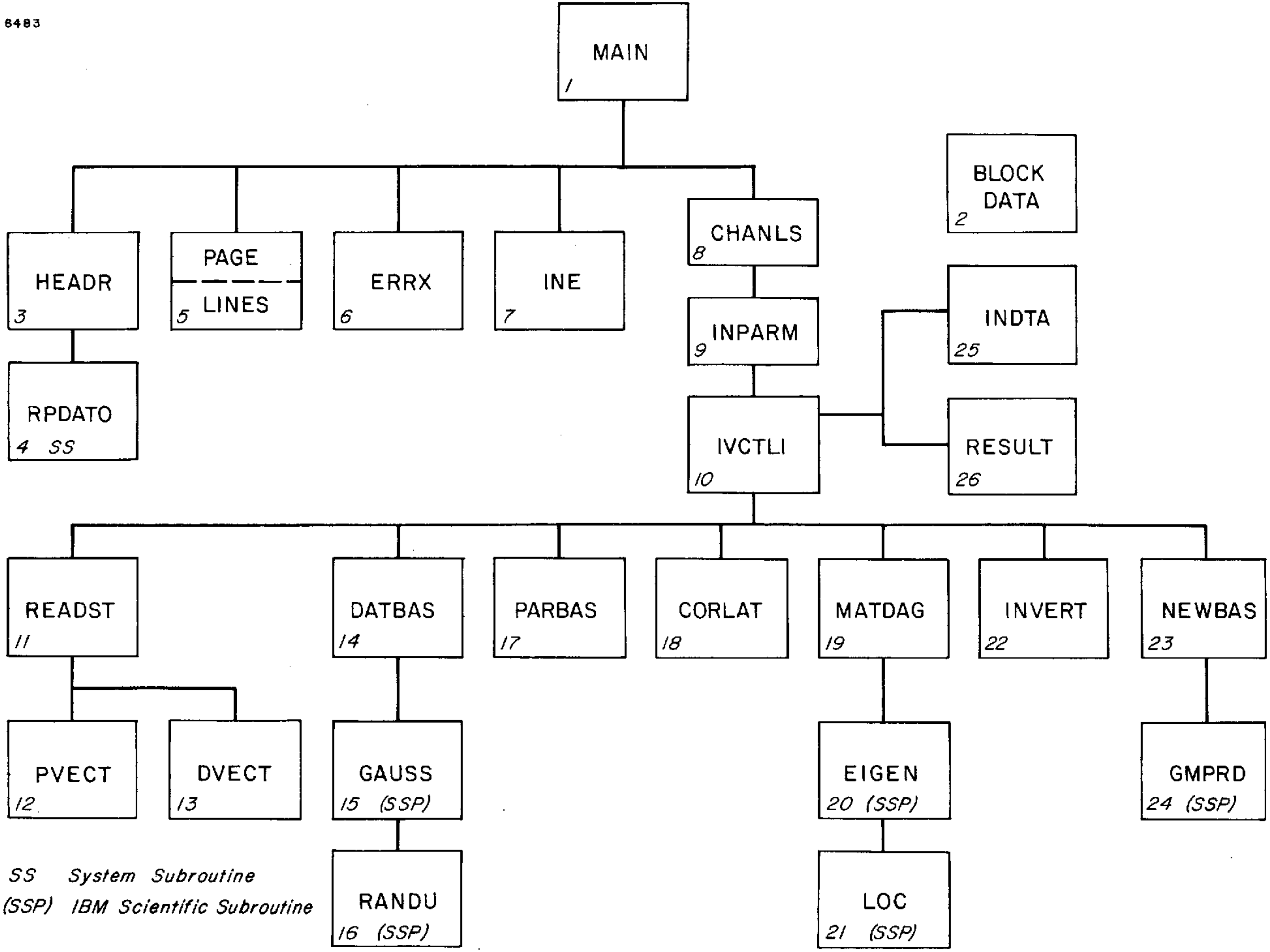

Figure 5-7 Interdependence of Program Elements for INVERT

```
//GO.FT09F001 DD DSNAME=K3.S1TCC.S1035.DLOGDATA,DISP=OLD
//GO.FT12F001 DD UNIT=2400-9,LABEL=(,NL),DISP=OLD,
//             DCB=(RECFM=VBS,LRECL=4056,BLKSIZE=4060),
//             VOL=SER=B
//GO.FT13F001 DD UNIT=2400-9,LABEL=(,NL),DISP=OLD,
//             DCB=(RECFM=VBS,LRECL=176,BLKSIZE=1764),
//             VOL=SER=C
//GO.FT14F001 DD UNIT=2400-9,LABEL=(,NL),DISP=NEW,
//             DCB=(RECFM=VBS)
//             VOL=SER=D-MATRIX
//GO.FT17F001 DD UNIT=2400-9,LABEL=(,NL),DISP=OLD,
//             DCB=(RECFM=VBS,LRECL=160,BLKSIZE=7204),
//             VOL=SER=D
//GO.DATA5 DD *
```

(B) ATMOSPHERIC DATA SET

(C) BRIGHTNESS TEMPERATURE DATA SET

(D) CV990 DATA SET

(D-MATRIX) D-MATRIX SAVE DATA SET

Data Sets for Program INVERT

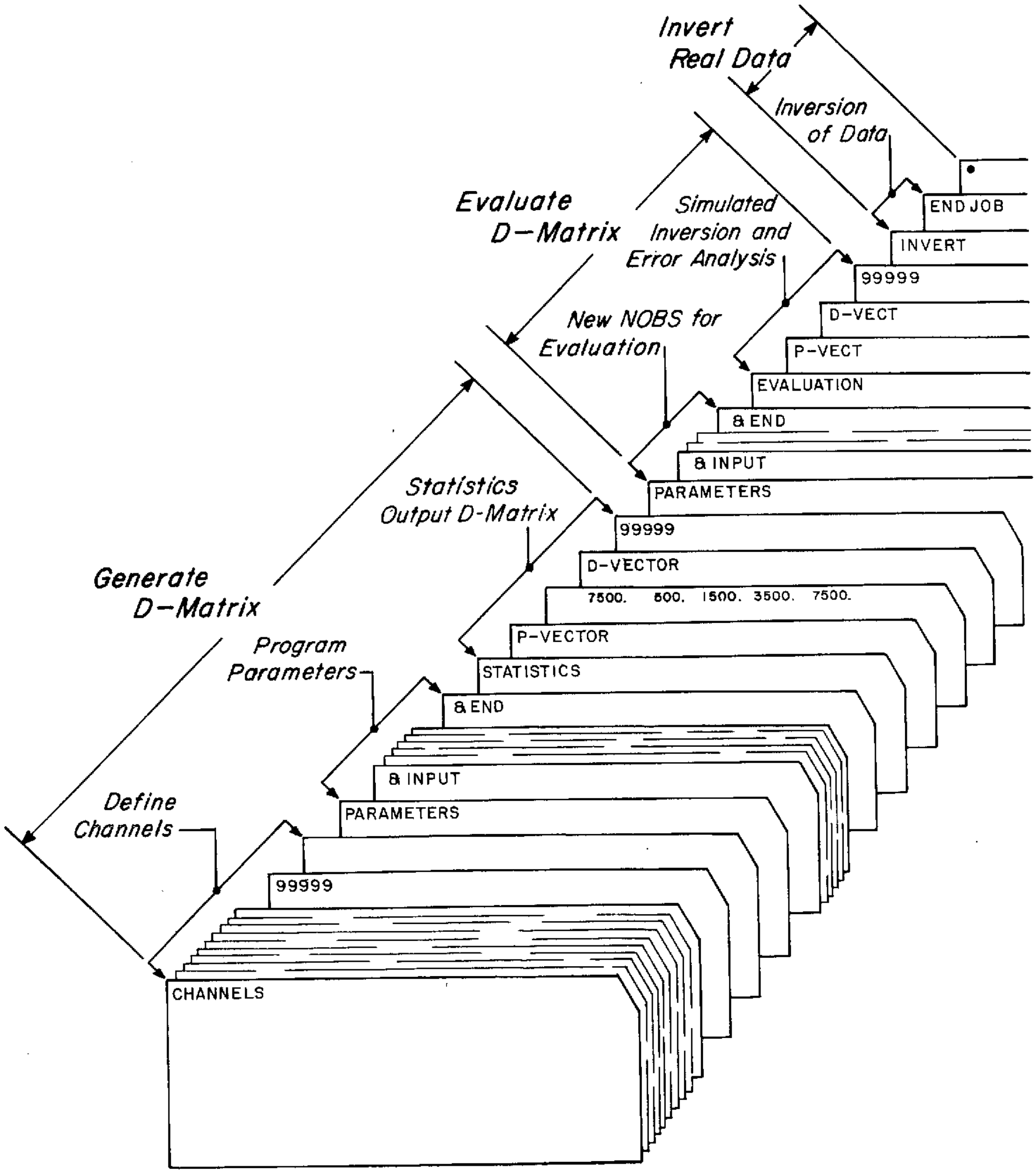

Figure 5-8 Deck Setup for a Typical INVERT Run

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Card Format for Program INVERT

'CHANNELS'

Reads in cards defining the NASA/Goddard channel frequencies, view angles, and polarizations for selected channels that pertain to the ADDAS, ESMR and NEMS experiment.

FIRST CARD

Columns	Variable	Format	Meaning
1-8	CHANNELS		Keyword
21-70	Title	12A4,A2	Title for printing

SECOND, THIRD, FOURTH AND FIFTH CARDS

Columns	Variable	Format	Meaning
1-72	GFREQ	4(9F8.3)	The frequencies of the Goddard channels: 1.42, 4.99, 4.99, 10.69, 10.69,31.4, 37.0,37.0, 19.35/9(19.35)/9(19.35)/19.35,22.23,53.65, 54.90,58.8,0.0,0.0,0.0,0.0.

SIXTH, SEVENTH AND EIGHTH CARDS

Columns	Variable	Format	Meaning
1-72	GANG	2(14F5.2) (8F5.2)	The view angles (degrees) corresponding to each of the channels listed above: 0.0,38.0, 38.0,38.0,38.0,0.0,38.0,38.0,0.0,2.3,4.6, 6.9,9.2,11.5/13.8,16.2,18.6,21.0,23.5,26.0, 28.6,31.2,33.9,36.7,39.6,42.7,45.9,49.3/0.0, 0.0,0.0,0.0,0.0,0.0,0.0,0.0

NINTH CARD

Columns	Variable	Format	Meaning
1-72	GPOLR	36(1X,A1)	The polarization of each of the channels listed above: H,V,H,V,H,V,V,21H,8V (Horizontal (H), Vertical (V))

TENTH AND FOLLOWING CARDS (Channel definition cards: one card per channel)

Columns	Variable	Format	Meaning
1-5	IXD	I5	Delimeter check word
6-12	F	F7.3	Frequency number
15	P	A1	Polarization (H or V)
16-20	ANG1	F5.2	Initial view angle (degrees)
21-25	ANG2	F5.2	Final view angle (degrees)
26-30	ANG3	F5.2	Increment in view angle (degrees)
31-35	BEAM	F5.1	Beam width (degrees)
36-40	RNOISE	F5.1	RMS noise to be added randomly to the computed brightness temperatures (°K)
41-45	SCALE	F5.2	Constant multiplier for scaling the observed brightness temperatures.
46-50	ZERO	F5.2	Offset temperature (°K) to be added to the observed brightness temperatures.

Columns	Variable	Format	Meaning
51-70	CHNAME	5A4	Title defining the channel of interest

- If RNOISE is greater than 0.0 the program will use the variable to represent the standard deviation of a zero-mean normal distribution of random numbers which are added to the computed brightness temperatures.

- All observed brightness temperatures (T) are computed as follows:

  T = T*SCALE+ZERO

  Therefore, the observed brightness temperatures may be scaled if necessary by setting the variables SCALE and ZERO to predetermined values. If SCALE is 0.0, SCALE is set equal to 1.0 by the program.

LAST TWO CARDS

Columns	Variable	Format	Meaning
1-5	'99999'		Denotes end of package.
LAST CARD			
1-64	LCHNUM	36I2	The values on this card are subscripts that are used by the program to line up channels on the matched data set with those on the brightness temperature data set. Specifically these values are: 03,04,05,08,07,33,11,10,12,13,14,15, 16,17,18,19,20,21,22,23,24,25,26,27, 28,29,30,31,32,34,35,36.

'PARAMETERS'

Reads in program parameters via NAMELIST format.

FIRST CARD

Columns	Variable	Format	Meaning
1-10	PARAMETERS	3A4	Keyword
21-70	Title	12A4,A2	Title for printing

SECOND CARD

2-7	'&INPUT		
9-72	NAMELIST assignments (see list of NAMELIST variables)		

LAST CARD

2-72	NAMELIST assignments, terminated by &END.		

NAMELIST VARIABLES: (Level 733001)

Name	Type	Dimension	Default	Meaning
NOBS	I	1	100	Number of observations
NDB	I	1	21	Number of data base functions (ND+1)
ND	I	1	20	Number of channels requested (≤32)
NP	I	1	10	Number of atmospheric parameters
NPB	I	1	10	Number of parameter base functions (=NP)
IX	I	1	3	Random number generator seed (odd integer)
UNIT	I	6	-12,-13, -14,-15, -16 -17	Data set unit numbers, - indicates that the data set is rewound before using.
OUTD	L	1	.FALSE.	If .TRUE. output the D-matrix
IND	L	1	.FALSE.	If .TRUE. input the D-matrix
DV	I	32	01 thru 32	Not used
PV	I	32	None	Not used
PNOISE	R	1	0.0	

'STATISTICS'

Reads in and stores NOBS 'days' of atmospheric data from the atmospheric data set generated by NWRST and reads in and stores NOBS 'days' of corresponding computed brightness temperatures generated from program RAPID.

Columns	Variable	Format	Meaning
FIRST CARD			
1-10	STATISTICS		Keyword
21-70	Title	12A4,A2	Title for printing
SECOND CARD			
1-8	P-VECTOR		Keyword for reading in atmospheric parameter vector
THIRD CARD			
11-20	ZRAD	F10.5	Height of aircraft (meters)
21-30	WVH(1)	F10.5	Maximum height of first layer of mean water vapor density (meters)
31-40	WVH(2)	F10.5	Maximum height of second layer of mean water vapor density (meters)
41-50	WVH(3)	F10.5	Maximum height of third layer of mean water vapor density (meters)
51-60	WVH(4)	F10.5	Maximum height of fourth layer of mean water vapor density (meters)
FOURTH CARD			
1-8	D-VECTOR		Keyword for reading in computed brightness temperature data vector
FIFTH CARD			
1-5	99999		Denotes end of package

'EVALUATION'

Remaining atmospheric and brightness temperatures not used in generating the D-MATRIX are read in. The D-MATRIX operates on this data to perform an inversion and does an error analysis on the final results.

FIRST CARD

Columns	Variable	Format	Meaning
1-10	EVALUATION		Keyword
21-70	Title	12A4,A2	Title for printing
SECOND CARD			
1-8	P-VECTOR		Keyword for reading in atmospheric parameter vector
THIRD CARD			
1-8	D-VECTOR		Keyword for reading in brightness temperature data vector
FOURTH CARD			
1-5	99999		Denotes end of package.

'INVERT'

Reads in the matched ADDAS, ESMR and NEMS data vector. The vector is then multiplied by the D-MATRIX to give predicted atmospheric parameters.

FIRST CARD

Columns	Variable	Format	Meaning
1-5	INVERT		Keyword
21-70	Title	12A4,A2	Title for printing

'ENDJOB'

Terminates job execution.

FIRST CARD

Columns	Variable	Format	Meaning
1-6	ENDJOB		Keyword terminates job execution.

'COMMENTS'

Reads and prints comments cards.

FIRST CARD

Columns	Variable	Format	Meaning
1-8	COMMENTS		Keyword
21-70	Title	12A4,A2	Title for printing

SECOND AND FOLLOWING CARDS

Columns	Variable	Format	Meaning
15	IFORM	A1	' ', print comment on same page, no blank line '0', print comment on same page, with initial blank line '1', print comment on next page
21-70	COM	12A4,A2	Comment to be printed
71-72	JF	A2	If blank, terminate and return to calling program, otherwise read and print next card.

Numbered Error Messages

PROGRAM INVERT

Routine	Number	Cause
MAIN	40	Unidentified keyword card
	900	END OF FILE when reading keyword card
INPARM	15	ND>32, or NP>10 or NDB>41
	20	NOBS > 100
	22	Invalid D-MATRIX output unit specification
	900	END FILE while reading NAMELIST cards
READST	80	END FILE when reading keyword card
	800	END FILE when reading keyword card
	2900	END FILE when reading keyword card
PVECT	30	Number of radiosonde levels is > 100
	300	END FILE while reading atmosphere data set
DVECT	8	Invalid unit specification
	800	END FILE when reading brightness temperature data
INDTA	8	Invalid unit specification
	800	END FILE when reading CV990 data set
CHANNELS	25	More than 32 channels have been defined
	32	Polarization is not equal to V,P,H,N,L, R,C, or U
	100	The number of channels stored in a record containing the computed brightness temperatures is less than the number requested.
	110	Channel numbers on file do not agree with requested channels
	210	Number of channels is greater than 32.

```
CHANNELS               GODDARD CHANNELS FOR EOS, ESMR, AND NIMBUS
   1.42     4.99     4.99    10.69    10.69    31.4     37.0     37.0     19.35
  19.35    19.35    19.35    19.35    19.35    19.35    19.35    19.35    19.35
  19.35    19.35    19.35    19.35    19.35    19.35    19.35    19.35    19.35
  19.35    22.23    53.65    54.9     58.8      0.0      0.0      0.0      0.0
 0.0 38.0 38.0 38.0 38.0  0.0 38.0 38.0  0.0  2.3  4.6  6.9  9.2 11.5
13.6 16.2 18.6 21.0 23.5 26.0 28.6 31.2 33.9 36.7 39.6 42.7 45.9 49.3
 0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
 H V H V H V V H H H H H H H H H H H H H H H H H H H H H V V V V V V V V
       1.420  H 0.0                        2.00  0.0-36.0   EOS CHANNEL 1
       4.990  V38.0                        1.00  0.0 10.0   EOS CHANNEL 2
       4.990  H38.0                        1.00  0.0 21.0   EOS CHANNEL 3
      10.690  V38.0                        0.50  0.0-25.0   EOS CHANNEL 4
      10.690  H38.0                        0.50  0.0-19.0   EOS CHANNEL 5
      19.350  H 0.0                        1.00  0.0-12.0   ESMR CHANNEL 1
      22.230  V 0.0                        0.50  0.0  0.0   NIMBUS CHANNEL 1
      31.400  V 0.0                        1.00  0.0 -2.0   NIMBUS CHANNEL 2
      37.000  V38.0                        1.00  0.0 -1.0   EOS CHANNEL 7
      37.000  H38.0                        1.00  0.0 -3.0   EOS CHANNEL 8
99999
0304050607331110121314151617181920212223242526272829303132343536
PARAMETERS
 &INPUT
 IX=68523,
 OUTD=.TRUE.,
 IND=.TRUE.,
 NOBS=52,ND=10,NDB=11,NP=9,NPB=9,
 &END
STATISTICS
P-VECTOR
             7620.0     500.0     1500.0     3500.0      7620.0
D-VECTOR
99999
PARAMETERS
 &INPUT
 NOBS=43,ND=10,NDB=11,NP=9,NPB=9,
 &END
EVALUATION
P-VECT
D-VECT
99999
INVERT
ENDJOB
```

Sample Data Cards for Program INVERT

****

CHANNELS GODDARD CHANNELS FOR EOS, ESMR, AND NIMBUS

CHANNEL	FREQUENCY	ANGLE	POLARIZATION
1	1,420	0,0	H
2	4,990	38,00	V
3	4,990	38,00	H
4	10,690	38,00	V
5	10,690	38,00	H
6	31,400	0,0	V
7	37,000	38,00	V
8	37,000	38,00	H
9	19,350	0,0	H
10	19,350	2,30	H
11	19,350	4,60	H
12	19,350	6,90	H
13	19,350	9,20	H
14	19,350	11,50	H
15	19,350	13,80	H
16	19,350	16,20	H
17	19,350	18,60	H
18	19,350	21,00	H
19	19,350	23,50	H
20	19,350	26,00	H
21	19,350	28,60	H
22	19,350	31,20	H
23	19,350	33,90	H
24	19,350	36,70	H
25	19,350	39,60	H
26	19,350	42,70	H
27	19,350	45,90	H
28	19,350	49,30	H
29	22,230	0,0	V
30	53,650	0,0	V
31	54,900	0,0	V
32	58,800	0,0	V
33	0,0	0,0	V
34	0,0	0,0	V
35	0,0	0,0	V
36	0,0	0,0	V

Sample Output from Program INVERT

```
13  3310     GENERALIZED DATA INVERSION PROGRAM            VERSION   3.3  (733001)            12 JUL 1973               PAGE   2
*************************************************************************************************************************************
```

I	CHANNEL	FREQUENCY	LOOK ANGLE	POLAR	BEAM WIDTH	NOISE	SCALE	ZERO	CHANNEL NAME
1	1	1.420	0.0	90.000	0.0	2.000	0.0	-36.000	EOS CHANNEL 1
2	2	4.990	38.000	0.0	0.0	1.000	0.0	10.000	EOS CHANNEL 2
3	3	4.990	38.000	90.000	0.0	1.000	0.0	21.000	EOS CHANNEL 3
4	4	10.690	38.000	0.0	0.0	0.500	0.0	-25.000	EOS CHANNEL 4
5	5	10.690	38.000	90.000	0.0	0.500	0.0	-19.000	EOS CHANNEL 5
6	9	19.350	0.0	90.000	0.0	1.000	0.0	-12.000	ESMR CHANNEL 1
7	29	22.230	0.0	0.0	0.0	0.500	0.0	0.0	NIMBUS CHANNEL 1
8	6	31.400	0.0	0.0	0.0	1.000	0.0	-2.000	NIMBUS CHANNEL 2
9	7	37.000	38.000	0.0	0.0	1.000	0.0	-1.000	EOS CHANNEL 7
10	8	37.000	38.000	90.000	0.0	1.000	0.0	-3.000	EOS CHANNEL 8

Sample Output from Program INVERT (cont'd.)

```
********************************************************************************************************************************

PARAMETERS

            NUMBER OF OBSERVATIONS=   52

            NUMBER OF PARAMETERS=    9

            NUMBER OF P-BASIS FCNS=    9

            NUMBER OF DATA ELEMENTS=   10

            NUMBER OF D-BASIS FCNS=   11

            EXPECTED NOISE (PARAMETERS)=   0.0

            IX=      68523

            PARAMETER DATA SET=-12

            INVERSION DATA SET= 13


            D-MATRIX INPUT FROM UNIT 14

            D-MATRIX OUTPUT TO UNIT 14
```

Sample Output from Program INVERT (cont'd.)

STATISTICS

P-VECTOR SELECTED HEIGHTS(M)= 500.00 1500.00 3500.00 7620.00
AIRCRAFT ALTITUDE = 7620.00 METERS

ATMOSPHERIC DATA FROM WEATHER BUREAU STATION 72211

OBS	MM	DD	YY	HH	1	2	3	4	5	6	7	8	9
					SURF TEMP (K)	WIND SPEED METERS/SEC	INTEGRATED WATER VAPOR (G/CM**2)	INTEGRATED LIQUID WATER (G/CM**2)	CLOUD DROP MOD RADIUS	MEAN WATER VAPOR DENSITY (G/M**3)			
1	3	1	59	0	2.942E 02	2.450E 00	4.043E 00	0.0	0.0	1.157E 01	9.088E 00	7.478E 00	2.574E 00
2	3	2	59	0	2.933E 02	9.455E 00	2.391E 00	6.857E-02	1.000E 01	1.065E 01	8.229E 00	3.932E 00	6.045E-01
3	3	3	59	0	2.982E 02	1.214E-01	8.318E-01	0.0	0.0	5.908E 00	2.178E 00	9.781E-01	2.985E-01
4	3	4	59	0	2.985E 02	7.436E-01	2.043E 00	2.274E-03	1.092E 01	1.338E 01	1.035E 01	1.175E 00	2.519E-01
5	3	5	59	0	2.964E 02	3.864E 00	2.133E 00	2.367E-02	1.000E 01	9.747E 00	1.079E 01	1.782E 00	5.110E-01
6	3	6	59	0	2.967E 02	3.943E 00	4.860E 00	2.328E-01	1.086E 01	2.117E 01	1.586E 01	7.508E 00	1.733E 00
7	3	7	59	0	2.971E 02	8.442E-01	1.710E 00	3.262E-03	4.000E 01	7.729E 00	3.281E 00	2.653E 00	1.129E 00
8	3	8	59	0	2.996E 02	1.037E 01	2.696E 00	2.563E-02	1.000E 01	5.361E 00	8.363E 00	4.300E 00	1.775E 00
9	3	9	59	0	2.949E 02	7.213E 00	2.199E 00	1.050E-02	1.000E 01	6.299E 00	6.212E 00	4.627E 00	8.179E-01
10	3	10	59	0	2.965E 02	5.452E 00	1.391E 00	0.0	0.0	4.628E 00	3.840E 00	2.671E 00	5.859E-01
11	3	11	59	0	2.985E 02	6.077E 00	1.371E 00	0.0	0.0	8.417E 00	5.675E 00	9.222E-01	4.820E-01
12	3	12	59	0	3.003E 02	7.499E 00	3.840E 00	2.929E-01	1.089E 01	1.827E 01	1.329E 01	5.036E 00	1.435E 00
13	3	13	59	0	2.973E 02	3.554E 00	1.210E 00	2.334E-02	4.000E 01	5.355E 00	3.466E 00	9.310E-01	9.939E-01
14	3	14	59	0	2.964E 02	4.654E-01	1.233E 00	2.261E-02	1.000E 01	3.811E 00	6.703E 00	9.648E-01	4.347E-01
15	3	15	59	0	2.967E 02	7.843E 00	3.134E 00	6.725E-02	1.000E 01	1.079E 01	1.223E 01	4.025E 00	1.375E 00
16	3	16	59	0	2.997E 02	7.056E 00	4.151E 00	0.0	0.0	1.336E 01	1.279E 01	7.882E 00	1.523E 00
17	3	17	59	0	2.959E 02	2.946E 00	3.616E 00	3.045E-01	1.090E 01	1.269E 01	1.326E 01	6.635E 00	7.967E-01
18	3	18	59	0	2.943E 02	3.195E 00	3.889E 00	3.544E-02	1.092E 01	9.626E 00	1.067E 01	8.052E 00	1.839E 00
19	3	19	59	0	2.956E 02	9.166E 00	2.895E 00	3.289E-02	1.000E 01	8.641E 00	8.513E 00	4.360E 00	1.796E 00
20	3	20	59	0	2.948E 02	7.455E 00	3.439E 00	2.233E-02	1.000E 01	1.079E 01	9.717E 00	6.797E 00	1.380E 00

Sample Output from Program INVERT (cont'd.)

49	2	23	61	0	2,977E 02	7,032E 00	2,848E 00	1,959E-02	4,000E 01	1,543E 01	1,012E 01	3,246E 00	1,009E 00
50	2	24	61	0	3,007E 02	4,683E 00	3,418E 00	3,094E-02	4,000E 01	1,516E 01	1,054E 01	4,937E 00	1,502E 00
51	2	25	61	0	2,975E 02	5,159E 00	2,889E 00	8,007E-03	4,000E 01	1,571E 01	1,518E 01	1,948E 00	4,757E-01
52	2	26	61	0	2,937E 02	1,049E 01	2,267E 00	1,155E-01	4,000E 01	8,376E 00	9,695E 00	3,286E 00	5,379E-01

D-VECTOR

COMPUTED BRIGHTNESS TEMPERATURES

OBS	MM	DD	YY	HH	1	2	3	4	5	6	7	8	9	10
1	3	1	59	0	9,878E 01	1,353E 02	9,650E 01	1,426E 02	1,034E 02	1,503E 02	1,935E 02	1,588E 02	1,922E 02	1,574E 02
2	3	2	59	0	9,947E 01	1,355E 02	9,949E 01	1,461E 02	1,106E 02	1,540E 02	1,814E 02	1,795E 02	2,171E 02	1,934E 02
3	3	3	59	0	9,738E 01	1,351E 02	9,669E 01	1,403E 02	1,011E 02	1,306E 02	1,430E 02	1,419E 02	1,736E 02	1,339E 02
4	3	4	59	0	9,727E 01	1,357E 02	9,688E 01	1,419E 02	1,025E 02	1,396E 02	1,619E 02	1,505E 02	1,834E 02	1,464E 02
5	3	5	59	0	9,804E 01	1,357E 02	9,718E 01	1,430E 02	1,042E 02	1,434E 02	1,684E 02	1,588E 02	1,942E 02	1,607E 02
6	3	6	59	0	9,814E 01	1,385E 02	1,006E 02	1,550E 02	1,192E 02	1,814E 02	2,220E 02	2,173E 02	2,552E 02	2,422E 02
7	3	7	59	0	9,779E 01	1,354E 02	9,660E 01	1,415E 02	1,021E 02	1,371E 02	1,620E 02	1,492E 02	1,825E 02	1,450E 02
8	3	8	59	0	9,753E 01	1,362E 02	1,000E 02	1,444E 02	1,082E 02	1,481E 02	1,805E 02	1,628E 02	1,968E 02	1,670E 02
9	3	9	59	0	9,880E 01	1,350E 02	9,790E 01	1,421E 02	1,046E 02	1,425E 02	1,704E 02	1,556E 02	1,890E 02	1,550E 02
10	3	10	59	0	9,812E 01	1,352E 02	9,718E 01	1,410E 02	1,023E 02	1,350E 02	1,550E 02	1,459E 02	1,779E 02	1,395E 02
11	3	11	59	0	9,747E 01	1,355E 02	9,772E 01	1,414E 02	1,030E 02	1,352E 02	1,538E 02	1,461E 02	1,778E 02	1,400E 02
12	3	12	59	0	9,726E 01	1,397E 02	1,033E 02	1,585E 02	1,248E 02	1,846E 02	2,195E 02	2,268E 02	2,623E 02	2,529E 02
13	3	13	59	0	9,772E 01	1,361E 02	9,747E 01	1,439E 02	1,051E 02	1,406E 02	1,609E 02	1,618E 02	1,986E 02	1,676E 02
14	3	14	59	0	9,806E 01	1,352E 02	9,694E 01	1,419E 02	1,032E 02	1,373E 02	1,549E 02	1,540E 02	1,892E 02	1,544E 02

Sample Output from Program INVERT (cont'd.)

DATA BASIS FUNCTION CORRELATION MATRIX

MATRIX BEFORE DIAGONALIZATION

1,0000E 00	3,4186E-04	9,9857E-04	5,5665E-04	8,8002E-04	6,4967E-04	9,0144E-04	1,2104E-03	1,0693E-03	9,7011E-04	1,2770E-03
3,4186E-04	5,0991E 00	2,1195E-01	4,2044E-01	1,9875E 00	2,5571E 00	5,9598E 00	6,0360E 00	1,0967E 01	1,1794E 01	1,5670E 01
9,9857E-04	2,1195E-01	1,7929E 00	1,6557E 00	3,8318E 00	4,9109E 00	1,1188E 01	1,5078E 01	1,9274E 01	2,1058E 01	2,8100E 01
5,5665E-04	4,2044E-01	1,6557E 00	4,0021E 00	5,3078E 00	7,6729E 00	1,5613E 01	2,0644E 01	2,6524E 01	2,8246E 01	3,8926E 01
8,8002E-04	1,9875E 00	3,8318E 00	5,3078E 00	1,5177E 01	1,8968E 01	4,4935E 01	6,1057E 01	7,5699E 01	8,0920E 01	1,0837E 02
6,4967E-04	2,5571E 00	4,9109E 00	7,6729E 00	1,8968E 01	2,5316E 01	5,7244E 01	7,7259E 01	9,6540E 01	1,0311E 02	1,3888E 02
9,0144E-04	5,9598E 00	1,1188E 01	1,5613E 01	4,4935E 01	5,7244E 01	1,4504E 02	2,1086E 02	2,2933E 02	2,4570E 02	3,2968E 02
1,2104E-03	6,0360E 00	1,5078E 01	2,0644E 01	6,1057E 01	7,7259E 01	2,1086E 02	3,3500E 02	3,1215E 02	3,3587E 02	4,5246E 02
1,0693E-03	1,0967E 01	1,9274E 01	2,6524E 01	7,5699E 01	9,6540E 01	2,2933E 02	3,1215E 02	3,9175E 02	4,1983E 02	5,6090E 02
9,7011E-04	1,1794E 01	2,1058E 01	2,8246E 01	8,0920E 01	1,0311E 02	2,4570E 02	3,3587E 02	4,1983E 02	4,5515E 02	6,0610E 02
1,2770E-03	1,5670E 01	2,8100E 01	3,8926E 01	1,0837E 02	1,3888E 02	3,2968E 02	4,5246E 02	5,6090E 02	6,0610E 02	8,1117E 02

MATRIX AFTER DIAGONALIZATION

2,0965E 03	3,4495E-06	-5,6705E-07	2,7854E-09	-8,0311E-07	3,6324E-08	2,1402E-08	8,6684E-08	4,2660E-06	1,5649E-06	6,7399E-10
3,4495E-06	7,7141E 01	1,3645E-06	9,1582E-10	-5,9479E-09	5,2021E-05	-6,0642E-06	5,4158E-05	7,8815E-07	1,8978E-08	5,1526E-12
-5,6705E-07	1,3645E-06	4,8859E 00	-3,3344E-06	2,2062E-08	1,6479E-08	1,4552E-10	-2,2311E-07	-6,2422E-07	-1,1118E-05	1,4676E-05
2,7854E-09	9,1582E-10	-3,3344E-06	4,1774E 00	-5,0988E-06	-7,6950E-06	-1,5619E-06	1,3704E-11	3,1646E-10	-1,1450E-07	1,6264E-08
-8,0311E-07	-5,9479E-09	2,2062E-08	-5,0988E-06	3,1075E 00	6,0822E-06	3,9878E-07	2,3286E-10	-3,9723E-10	-1,4462E-07	7,1358E-05
3,6324E-08	5,2021E-05	1,6479E-08	-7,6950E-06	6,0822E-06	1,1600E 00	-3,6038E-05	2,7291E-05	-2,3466E-10	-3,3142E-11	4,4318E-07
2,1402E-08	-6,0642E-06	1,4552E-10	-1,5619E-06	3,9878E-07	-3,6038E-05	1,0000E 00	-9,5731E-06	1,7096E-05	-2,3512E-05	-1,4807E-06
8,6684E-08	5,4158E-05	-2,2311E-07	1,3704E-11	2,3286E-10	2,7291E-05	-9,5731E-06	9,5257E-01	8,1346E-09	2,3246E-10	5,7342E-09
4,2660E-06	7,8815E-07	-6,2422E-07	3,1646E-10	-3,9723E-10	-2,3466E-10	1,7096E-05	8,1346E-09	6,9007E-01	-2,7538E-09	-1,7789E-13
1,5649E-06	1,8978E-08	-1,1118E-05	-1,1450E-07	-1,4462E-07	-3,3142E-11	-2,3512E-05	2,3246E-10	-2,7538E-09	4,9295E-01	-1,4552E-11
6,7399E-10	5,1526E-12	1,4676E-05	1,6264E-08	7,1358E-05	4,4318E-07	-1,4807E-06	5,7342E-09	-1,7789E-13	-1,4552E-11	3,7044E-01

MATRIX OF EIGENVECTORS, EIGENVECTORS STORED COLUMNWISE IN ORDER OF DECREASING EIGENVALUES.
EIGENVALUES ARE GIVEN IN PRECEDING DIAGONALIZED MATRIX.

Sample Output from Program INVERT (cont'd.)

1,2189E-06	-4,8760E-06	3,8808E-05	2,1993E-04	1,9654E-04	2,7828E-03	9,9993E-01	1,1238E-02	-2,5560E-03	-3,8855E-04	-5,5233E-04
1,1502E-02	4,0036E-02	9,5998E-01	-3,7824E-02	2,3576E-01	-3,1720E-02	1,4558E-03	-1,1323E-01	5,3217E-02	4,6964E-02	2,8476E-02
2,1327E-02	1,6857E-02	-1,0510E-01	1,6408E-02	1,1021E-01	2,6618E-01	5,5071E-03	-3,7741E-01	8,3682E-01	5,7283E-02	-2,4275E-01
2,9336E-02	2,3390E-02	-1,6571E-01	3,6063E-01	5,9425E-01	-1,5506E-02	4,9332E-03	-5,2309E-01	-2,8300E-01	-3,4958E-01	1,0842E-01
8,3164E-02	2,9203E-02	-5,8720E-03	2,2192E-01	-7,0177E-02	1,4708E-01	-2,1694E-04	8,4972E-02	2,5435E-01	6,6045E-02	9,1657E-01
1,0618E-01	4,7311E-02	-5,8660E-02	4,5775E-01	2,8375E-01	1,1043E-01	-2,4269E-03	1,6775E-01	-1,1633E-01	7,8366E-01	-1,5808E-01
2,5798E-01	-2,2627E-01	1,4672E-01	4,3530E-01	-1,5384E-01	5,7630E-01	-5,6527E-03	3,1900E-01	-4,5016E-02	-4,0796E-01	-2,1260E-01
3,6246E-01	-8,7743E-01	-1,7521E-02	-1,4938E-01	5,3181E-02	-1,7872E-01	2,1311E-03	-1,3404E-01	7,6841E-03	1,3852E-01	6,4188E-02
4,2938E-01	2,0561E-01	8,1523E-02	4,1797E-01	-5,3105E-01	-4,4084E-01	4,9142E-03	-3,2649E-01	2,3039E-02	4,8560E-04	-9,2266E-02
4,6299E-01	2,3871E-01	-2,1813E-02	-4,3499E-01	-1,1810E-01	5,1652E-01	1,9275E-03	-3,4936E-01	-3,1012E-01	1,8786E-01	6,8551E-02
6,1944E-01	2,7226E-01	-8,6573E-02	-1,8369E-01	4,1380E-01	-2,6244E-01	-3,7469E-03	4,3272E-01	1,9947E-01	-1,8139E-01	-2,9561E-02

INVERSE OF EIGENVECTOR MATRIX

1,2189E-06	1,1502E-02	2,1327E-02	2,9336E-02	8,3164E-02	1,0618E-01	2,5798E-01	3,6246E-01	4,2938E-01	4,6299E-01	6,1944E-01
-4,8760E-06	4,0036E-02	1,6857E-02	2,3390E-02	2,9203E-02	4,7311E-02	-2,2627E-01	-8,7743E-01	2,0561E-01	2,3871E-01	2,7226E-01
3,8808E-05	9,5998E-01	-1,0510E-01	-1,6571E-01	-5,8720E-03	-5,8660E-02	1,4672E-01	-1,7521E-02	8,1523E-02	-2,1813E-02	-8,6573E-02
2,1993E-04	-3,7824E-02	1,6408E-02	3,6063E-01	2,2192E-01	4,5775E-01	4,3530E-01	-1,4938E-01	4,1797E-01	-4,3499E-01	-1,8369E-01
1,9654E-04	2,3576E-01	1,1021E-01	5,9425E-01	-7,0177E-02	2,8375E-01	-1,5384E-01	5,3181E-02	-5,3105E-01	-1,1810E-01	4,1380E-01
2,7828E-03	-3,1720E-02	2,6618E-01	-1,5506E-02	1,4708E-01	1,1043E-01	5,7630E-01	-1,7872E-01	-4,4084E-01	5,1652E-01	-2,6244E-01
9,9993E-01	1,4558E-03	5,5071E-03	4,9332E-03	-2,1694E-04	-2,4269E-03	-5,6527E-03	2,1311E-03	4,9142E-03	1,9275E-03	-3,7469E-03
1,1238E-02	-1,1323E-01	-3,7741E-01	-5,2309E-01	8,4972E-02	1,6775E-01	3,1900E-01	-1,3404E-01	-3,2649E-01	-3,4936E-01	4,3272E-01
-2,5560E-03	5,3217E-02	8,3682E-01	-2,8300E-01	2,5435E-01	-1,1633E-01	-4,5016E-02	7,6841E-03	2,3039E-02	-3,1012E-01	1,9947E-01
-3,8855E-04	4,6964E-02	5,7283E-02	-3,4958E-01	6,6045E-02	7,8366E-01	-4,0796E-01	1,3852E-01	4,8560E-04	1,8786E-01	-1,8139E-01
-5,5233E-04	2,8476E-02	-2,4275E-01	1,0842E-01	9,1657E-01	-1,5808E-01	-2,1260E-01	6,4188E-02	-9,2266E-02	6,8551E-02	-2,9561E-02

Sample Output from Program INVERT (cont'd.)

DATA BASIS FUNCTION CORRELATION MATRIX

2.0965E 03	-2.9719E-03	8.5537E-04	2.5462E-03	-1.0857E-05	1.9487E-03	-3.2278E-05	3.2636E-04	-7.8009E-04	-1.9660E-04	-4.1081E-04
-2.9719E-03	7.7141E 01	-6.1164E-05	3.2249E-04	2.5588E-04	-1.9103E-04	4.2182E-07	1.9563E-04	7.9302E-05	6.0485E-04	1.6961E-04
8.5537E-04	-6.1164E-05	4.8859E 00	-7.5414E-05	-5.7459E-05	3.4257E-05	3.5511E-06	-5.2571E-05	-4.0967E-05	-3.6354E-05	-6.1604E-05
2.5462E-03	3.2249E-04	-7.5414E-05	4.1769E 00	2.9261E-04	9.2616E-05	-2.2191E-06	1.0964E-04	-6.0851E-05	-1.5357E-04	-5.7349E-05
-1.0857E-05	2.5588E-04	-5.7459E-05	2.9261E-04	3.1076E 00	-2.6180E-04	3.6680E-07	2.4092E-04	1.8344E-04	1.1611E-04	2.2710E-04
1.9487E-03	-1.9103E-04	3.4257E-05	9.2616E-05	-2.6180E-04	1.1595E 00	1.2276E-06	-1.4059E-04	1.1289E-04	-3.1543E-04	-9.0379E-05
-3.2278E-05	4.2182E-07	3.5511E-06	-2.2191E-06	3.6680E-07	1.2276E-06	1.0000E 00	-1.3262E-06	-2.9745E-06	1.0832E-06	-2.3475E-06
3.2636E-04	1.9563E-04	-5.2571E-05	1.0964E-04	2.4092E-04	-1.4059E-04	-1.3262E-06	9.5292E-01	2.0583E-04	6.4334E-06	2.6661E-04
-7.8009E-04	7.9302E-05	-4.0967E-05	-6.0851E-05	1.8344E-04	1.1289E-04	-2.9745E-06	2.0583E-04	6.9010E-01	5.4529E-05	9.1824E-05
-1.9660E-04	6.0485E-04	-3.6354E-05	-1.5357E-04	1.1611E-04	-3.1543E-04	1.0832E-06	6.4334E-06	5.4529E-05	4.9291E-01	2.5864E-05
-4.1081E-04	1.6961E-04	-6.1604E-05	-5.7349E-05	2.2710E-04	-9.0379E-05	-2.3475E-06	2.6661E-04	9.1824E-05	2.5864E-05	3.7049E-01

PARAMETER-DATA CORRELATION MATRIX

7.5781E-01	2.0190E 01	3.1322E 01	2.8575E 00	6.6511E 01	1.1906E 02	1.1058E 02	4.7491E 01	9.5681E 00
-1.0365E 00	-5.2540E 00	-5.8107E 00	1.5865E-01	4.0086E 00	-1.3764E 01	-1.2990E 01	-1.2641E 01	-3.2934E 00
-5.9693E-01	-1.2816E 00	1.1607E-01	8.1035E-03	-4.5311E 00	1.4628E 00	2.8229E-01	4.8010E-01	-1.2733E-01
1.7953E 00	2.4270E 00	-1.0014E-01	2.4386E-02	-7.3924E 00	1.5018E-01	-2.3790E-01	2.5879E-01	-1.6879E-01
4.8887E-01	4.1434E 00	-7.7679E-02	-1.7624E-02	-1.7786E-01	4.0139E-01	-5.1870E-01	-5.9637E-01	1.4296E-02
1.3755E 00	-3.2350E-01	1.8936E-04	2.1739E-03	-8.9051E-01	-4.2264E-01	4.1655E-04	9.9207E-02	-2.5073E-02
2.9723E 02	6.1384E 00	2.5548E 00	3.9592E-02	1.4615E 01	1.0957E 01	8.9323E 00	3.7328E 00	9.4349E-01
3.3327E 00	8.1454E-02	3.8266E-02	-8.6655E-04	-2.2331E 00	7.5801E-02	2.4463E-01	3.2140E-01	-7.3497E-02
-2.8893E-01	-2.6292E-01	-1.6278E-02	-6.6460E-04	1.2985E 00	1.2367E-01	8.7776E-02	-1.0285E-01	-1.3911E-02
-1.3035E-01	3.0166E-01	-3.1060E-02	7.0176E-04	2.5360E 00	-5.3870E-01	-4.2981E-01	1.8753E-03	7.9199E-02
1.6333E-01	-4.7865E-01	2.6439E-03	1.8762E-03	1.2269E 00	2.3147E-01	-1.3949E-01	-1.7638E-01	2.0878E-02

Sample Output from Program INVERT (cont'd.)

```
****************************************************************************************************************

D-MATRIX FOR STATISTICALLY ORTHOGONAL DATA BASIS FUNCTIONS

        3.6147E-04 -1.3437E-02 -1.2217E-01  4.2981E-01  1.5731E-01  1.1863E 00  2.9723E 02  3.4974E 00 -4.1868E-01 -2.6446E-01
        4.4086E-01
        9.6303E-03 -6.8110E-02 -2.6231E-01  5.8105E-01  1.3333E 00 -2.7901E-01  6.1384E 00  8.5479E-02 -3.8098E-01  6.1200E-01
       -1.2919E 00
        1.4940E-02 -7.5327E-02  2.3756E-02 -2.3975E-02 -2.4997E-02  1.6331E-04  2.5548E 00  4.0157E-02 -2.3588E-02 -6.3014E-02
        7.1362E-03
        1.3630E-03  2.0567E-03  1.6586E-03  5.8382E-03 -5.6713E-03  1.8749E-03  3.9592E-02 -9.0936E-04 -9.6305E-04  1.4237E-03
        5.0639E-03
        3.1725E-02  5.1965E-02 -9.2738E-01 -1.7698E 00 -5.7233E-02 -7.6802E-01  1.4615E 01 -2.3434E 00  1.8816E 00  5.1449E 00
        3.3115E 00
        5.6790E-02 -1.7843E-01  2.9938E-01  3.5955E-02  1.2916E-01 -3.6450E-01  1.0957E 01  7.9547E-02  1.7920E-01 -1.0929E 00
        6.2477E-01
        5.2748E-02 -1.6839E-01  5.7776E-02 -5.6955E-02 -1.6691E-01  3.5926E-04  8.9323E 00  2.5672E-01  1.2719E-01 -8.7199E-01
       -3.7650E-01
        2.2653E-02 -1.6386E-01  9.8262E-02  6.1957E-02 -1.9191E-01  8.5561E-02  3.7328E 00  3.3728E-01 -1.4904E-01  3.8046E-03
       -4.7608E-01
        4.5639E-03 -4.2693E-02 -2.6062E-02 -4.0411E-02  4.6002E-03 -2.1625E-02  9.4349E-01 -7.7129E-02 -2.0157E-02  1.6068E-01
        5.6351E-02


D-MATRIX FOR ORIGINAL DATA BASIS FUNCTIONS
THE FIRST  11 STATISTICALLY ORTHOGONAL BASIS FUNCTIONS WERE USED

        2.9725E 02 -1.2007E-01  1.9715E-01  1.4559E-01  7.7200E-01  1.6057E-02  3.0028E-01 -1.0069E-01 -1.7110E-01 -1.3177E-01
        3.3098E-02
        6.1400E 00  1.7733E-02  1.4024E-01  7.8772E-01 -1.2400E 00  1.3543E 00 -9.8856E-02  1.0237E-01 -2.6048E-01 -4.3387E-01
        3.9352E-01
        2.5552E 00  1.0131E-02 -3.2719E-02 -7.6877E-03 -5.4018E-03 -6.8650E-02  4.1507E-02  6.4926E-02 -5.7425E-03 -1.1256E-02
       -4.9747E-03
        3.9584E-02  3.9323E-04 -1.5331E-03 -4.8569E-04  6.5378E-03  1.5936E-03  2.4961E-03 -2.1273E-03  5.7714E-03  1.4917E-03
       -3.7925E-03
        1.4577E 01 -8.7348E-02  1.8895E 00 -1.1786E 00  3.1592E 00  2.0099E 00 -5.0616E 00  1.6657E 00  1.5518E-01  1.8842E 00
       -1.1076E 00
        1.0955E 01  3.0451E-01 -1.4945E-01  4.5477E-01  4.9349E-01 -9.9643E-01  1.5307E-01  1.4132E-01  9.3051E-02 -4.6673E-01
        3.1207E-01
        8.9348E 00 -4.8850E-02  7.3164E-02  6.0944E-03 -3.5219E-01 -6.9639E-01  5.2273E-01  6.0770E-03  5.4736E-02 -2.7390E-01
        1.9542E-01
        3.7372E 00 -1.6338E-02 -1.2563E-01 -2.8126E-01 -4.0985E-01  1.1534E-01  3.5600E-01  4.7087E-02  2.2855E-02 -8.7204E-02
       -3.6719E-02
        9.4245E-01 -5.1920E-03  9.1666E-03 -7.4057E-03  3.7191E-02  8.4537E-02 -1.3031E-01  8.7785E-02  5.4893E-03  6.7419E-02
       -6.3281E-02
```

Sample Output from Program INVERT (cont'd.)

```
13  3310      GENERALIZED DATA INVERSION PROGRAM              VERSION   3.3  (733001)           12 JUL 1973            PAGE  13
*****************************************************************************************************************************

    AVERAGE VALUE OF ORIGINAL DATA BASIS FUNCTIONS


          1     1.00000E 00
          2     9.77642E 01
          3     1.35598E 02
          4     9.86055E 01
          5     1.44532E 02
          6     1.07064E 02
          7     1.48569E 02
          8     1.77068E 02
          9     1.65419E 02
         10     2.00092E 02
         11     1.70020E 02

    D-MATRIX OUTPUT TO LOGICAL UNIT 14
```

Sample Output from Program INVERT (cont'd.)

```
13  3310     GENERALIZED DATA INVERSION PROGRAM                  VERSION   3.3  (733001)          12 JUL 1973          PAGE  14
*****************************************************************************************************************************

PARAMETERS

                  NUMBER OF OBSERVATIONS=   50

                  NUMBER OF PARAMETERS=    9

                  NUMBER OF P-BASIS FCNS=    9

                  NUMBER OF DATA ELEMENTS=   10

                  NUMBER OF D-BASIS FCNS=   11

                  EXPECTED NOISE (PARAMETERS)=   0.0

                  IX=      68525

                  PARAMETER DATA SET= 12

                  INVERSION DATA SET= 13


                  D-MATRIX INPUT FROM UNIT 14

                  D-MATRIX OUTPUT TO UNIT 14
```

Sample Output from Program INVERT (cont'd.)

EVALUATION

P-VECTOR

ATMOSPHERIC DATA FROM WEATHER BUREAU STATION 72211

OBS	MM	DD	YY	HH	1 SURF TEMP (K)	2 WIND SPEED METERS/SEC	3 INTEGRATED WATER VAPOR (G/CM**2)	4 INTEGRATED LIQUID WATER (G/CM**2)	5 CLOUD DROP MOD RADIUS	6 MEAN WATER VAPOR DENSITY (G/M**3)	7	8	9
1	2	27	61	0	2,989E 02	3,358E 00	2,339E 00	2,818E-01	1,092E 01	1,334E 01	1,201E 01	1,544E 00	3,956E-01
2	2	28	61	0	2,982E 02	5,031E 00	3,204E 00	8,285E-02	1,000E 01	1,060E 01	1,312E 01	5,486E 00	6,429E-01
3	3	1	61	0	2,949E 02	1,130E 01	3,428E 00	7,781E-03	1,000E 01	1,478E 01	1,018E 01	6,623E 00	8,393E-01
4	3	2	61	0	2,979E 02	3,713E 00	2,019E 00	0,0	0,0	1,291E 01	7,755E 00	2,071E 00	4,471E-01
5	3	3	61	0	2,939E 02	6,253E 00	3,003E 00	9,445E-03	1,000E 01	1,266E 01	1,035E 01	5,733E 00	4,589E-01
6	3	4	61	0	2,938E 02	1,057E 01	3,208E 00	0,0	0,0	1,433E 01	1,168E 01	4,490E 00	1,033E 00
7	3	5	61	0	2,938E 02	2,435E 00	3,261E 00	6,147E-03	1,000E 01	1,375E 01	1,111E 01	6,286E 00	4,995E-01
8	3	6	61	0	2,998E 02	1,704E 00	3,300E 00	1,142E-02	4,000E 01	1,311E 01	1,039E 01	5,348E 00	1,301E 00
9	3	7	61	0	2,966E 02	3,569E 00	3,864E 00	1,381E-02	1,000E 01	1,406E 01	1,571E 01	6,065E 00	9,138E-01
10	3	8	61	0	2,952E 02	9,752E 00	3,225E 00	2,038E-02	1,000E 01	1,475E 01	1,423E 01	3,440E 00	9,126E-01
11	3	9	61	0	2,973E 02	9,669E 00	4,018E 00	2,288E-02	1,000E 01	1,633E 01	1,453E 01	6,087E 00	1,289E 00
12	3	10	61	0	2,966E 02	7,815E 00	1,467E 00	9,281E-02	1,000E 01	5,800E 00	6,341E 00	1,928E 00	3,808E-01
13	3	11	61	0	2,941E 02	7,206E-01	1,163E 00	1,842E-02	1,000E 01	5,402E 00	5,685E 00	9,558E-01	3,227E-01
14	3	12	61	0	2,934E 02	5,197E 00	1,313E 00	0,0	0,0	7,782E 00	4,841E 00	1,455E 00	3,620E-01
15	3	13	61	0	2,978E 02	4,765E 00	2,632E 00	1,868E-02	1,000E 01	9,793E 00	1,208E 01	3,760E 00	4,436E-01
16	3	14	61	0	2,958E 02	9,966E 00	2,986E 00	6,318E-03	1,000E 01	1,140E 01	8,327E 00	5,547E 00	1,151E 00
17	3	15	61	0	2,951E 02	3,119E 00	2,283E 00	6,579E-03	1,000E 01	1,233E 01	8,073E 00	3,418E 00	4,268E-01
18	3	16	61	0	2,977E 02	4,031E 00	1,784E 00	1,296E-02	1,000E 01	5,816E 00	1,066E 01	1,029E 00	5,372E-01
19	3	17	61	0	2,978E 02	5,300E 00	3,035E 00	0,0	0,0	1,376E 01	1,083E 01	3,506E 00	1,365E 00
20	3	18	61	0	2,990E 02	7,738E 00	4,042E 00	1,820E-01	1,000E 01	1,321E 01	1,485E 01	6,626E 00	1,389E 00
21	3	19	61	0	2,974E 02	9,170E 00	3,454E 00	1,240E-02	1,000E 01	1,108E 01	9,216E 00	6,622E 00	1,588E 00

Sample Output from Program INVERT (cont'd.)

OBSERVATION NO. 1

RESULTS OF INVERSION

ACTUAL PARAMETER NO	VALUE	A PRIORI PARAMETER MEAN	ERROR	INFERRED PARAMETER VALUE	ERROR	FIG-M
1	298.9360	297.2505	-1.6855	299.8044	0.8684	1.941
2	3.3583	6.1402	2.7818	5.0167	1.6584	1.677
3	2.3391	2.5552	0.2161	2.8773	0.5382	0.401
4	0.2818	0.0396	-0.2422	0.2691	-0.0127	19.043
5	10.9198	14.5797	3.6600	11.1285	0.2087	17.537
6	13.3368	10.9556	-2.3812	14.1594	0.8225	2.895
7	12.0051	8.9345	-3.0706	12.7891	0.7840	3.917
8	1.5439	3.7369	2.1930	3.9976	2.4537	0.894
9	0.3956	0.9425	0.5469	0.3666	-0.0290	18.862

OBSERVATION NO. 2

RESULTS OF INVERSION

ACTUAL PARAMETER NO	VALUE	A PRIORI PARAMETER MEAN	ERROR	INFERRED PARAMETER VALUE	ERROR	FIG-M
1	298.1707	297.2505	-0.9202	297.4938	-0.6719	1.370
2	5.0308	6.1402	1.1094	5.3043	0.2735	4.056
3	3.2042	2.5552	-0.6490	3.0841	-0.1201	5.405
4	0.0828	0.0396	-0.0433	0.0655	-0.0174	2.487
5	10.0000	14.5797	4.5797	25.0095	15.0095	0.305
6	10.6028	10.9556	0.3528	12.2284	1.6257	0.217
7	13.1205	8.9345	-4.1860	10.8919	-2.2286	1.878
8	5.4856	3.7369	-1.7488	4.1021	-1.3835	1.264
9	0.6429	0.9425	0.2996	1.2023	0.5594	0.536

Sample Output from Program INVERT (cont'd.)

13 3310 GENERALIZED DATA INVERSION PROGRAM VERSION 3,3 (733001) 12 JUL 1973 PAGE 44

OBSERVATION NO, 49

RESULTS OF INVERSION

ACTUAL PARAMETER NO	ACTUAL PARAMETER VALUE	A PRIORI PARAMETER MEAN	A PRIORI PARAMETER ERROR	INFERRED PARAMETER VALUE	INFERRED PARAMETER ERROR	FIG-M
1	297,5339	297,2505	-0,2834	299,5913	2,0574	0,138
2	7,7932	6,1402	-1,6531	5,7918	-2,0014	0,826
3	0,8134	2,5552	1,7418	0,5949	-0,2185	7,973
4	0,0	0,0396	0,0396	0,0	0,0	
5	0,0	14,5797	14,5797	16,0876	16,0876	0,906
6	4,5307	10,9556	6,4249	4,7274	0,1966	32,673
7	2,7098	8,9345	6,2247	2,6631	-0,0467	133,176
8	0,8052	3,7369	2,9317	0,0028	-0,8024	3,654
9	0,3757	0,9425	0,5668	0,1341	-0,2417	2,345

OBSERVATION NO, 50

RESULTS OF INVERSION

ACTUAL PARAMETER NO	ACTUAL PARAMETER VALUE	A PRIORI PARAMETER MEAN	A PRIORI PARAMETER ERROR	INFERRED PARAMETER VALUE	INFERRED PARAMETER ERROR	FIG-M
1	297,6414	297,2505	-0,3909	297,7124	0,0710	5,502
2	3,3927	6,1402	2,7474	3,5465	0,1538	17,865
3	1,1983	2,5552	1,3569	1,1157	-0,0826	16,427
4	0,0205	0,0396	0,0191	0,0235	0,0029	6,514
5	10,0000	14,5797	4,5797	10,7694	0,7694	5,952
6	5,4718	10,9556	5,4838	7,1661	1,6943	3,237
7	6,4540	8,9345	2,4805	4,7692	-1,6848	1,472
8	0,7897	3,7369	2,9472	0,7935	0,0038	779,515
9	0,2946	0,9425	0,6479	0,1251	-0,1695	3,821

Sample Output from Program INVERT (cont'd.)

OVERALL SUMMARY OF INVERSION RESULTS

INDEX	PARAMETER VALUE MEAN	STD.DEV.	INVERSION ERRORS STD.DEV.	PERCENT	MEAN	PERCENT	FIGURE OF MERIT
1	296.7883	2.0767	14.6105	4.92	2.5023	0.84	0.142
2	5.5296	2.6923	11.5439	208.77	1.4690	26.57	0.233
3	2.6328	1.0008	0.6005	22.81	-0.0438	-1.66	1.667
4	0.1018	0.4114	0.2350	230.88	-0.0321	-31.58	1.750
5	11.9496	10.1620	26.8038	224.31	5.8019	48.55	0.379
6	11.2419	4.0514	2.8803	25.62	-0.1832	-1.63	1.407
7	9.8535	3.6414	2.4988	25.36	-0.7314	-7.42	1.457
8	3.7800	2.1410	1.5547	41.13	0.0655	1.73	1.377
9	0.7994	0.4801	0.7420	92.82	0.2707	33.87	0.647

NOISE ADDED TO DATA= 2.000

NOISE ADDED TO PARAMETERS= 0.0

NOISE ADDED TO DATA= 1.000

NOISE ADDED TO PARAMETERS= 0.0

NOISE ADDED TO DATA= 1.000

NOISE ADDED TO PARAMETERS= 0.0

NOISE ADDED TO DATA= 0.500

NOISE ADDED TO PARAMETERS= 0.0

NOISE ADDED TO DATA= 0.500

NOISE ADDED TO PARAMETERS= 0.0

NOISE ADDED TO DATA= 1.000

NOISE ADDED TO PARAMETERS= 0.0

NOISE ADDED TO DATA= 0.500

NOISE ADDED TO PARAMETERS= 0.0

NOISE ADDED TO DATA= 1.000

NOISE ADDED TO PARAMETERS= 0.0

NOISE ADDED TO DATA= 1.000

NOISE ADDED TO PARAMETERS= 0.0

NOISE ADDED TO DATA= 1.000

NOISE ADDED TO PARAMETERS= 0.0

Sample Output from Program INVERT (cont'd.)

SCALE FACTORS =	1.000E 00	1.000E 00	1.000E 00	1.000E 00	1.000E 00	1.000E 00	1.000E 00	1.000E 00	1.000E 00	1.000E 00
IMPLIED OFFSET=	-3.600E 01	1.000E 01	2.100E 01	-2.500E 01	-1.900E 01	-1.200E 01	0.0	-2.000E 00	-1.000E 00	-3.000E 00

OBSERVED BRIGHTNESS TEMPERATURES

OBS DD HH MM SS	1	2	3	4	5	6	7	8	9	10
1 76 17 37 23	7.794E 01	1.367E 02	1.003E 02	1.438E 02	1.060E 02	1.474E 02	1.810E 02	1.550E 02	1.893E 02	1.535E 02
2 76 17 37 34	8.058E 01	1.357E 02	1.007E 02	1.428E 02	1.054E 02	1.484E 02	1.810E 02	1.550E 02	1.893E 02	1.555E 02
3 76 17 37 43	7.785E 01	1.352E 02	9.970E 01	1.436E 02	1.059E 02	1.474E 02	1.810E 02	1.550E 02	1.871E 02	1.552E 02
4 76 17 37 54	7.634E 01	1.362E 02	9.997E 01	1.437E 02	1.028E 02	1.465E 02	1.810E 02	1.550E 02	1.886E 02	1.536E 02
5 76 17 38 3	7.667E 01	1.354E 02	9.854E 01	1.438E 02	1.052E 02	1.492E 02	1.810E 02	1.550E 02	1.888E 02	1.548E 02
6 76 17 38 14	7.923E 01	1.346E 02	9.957E 01	1.414E 02	1.056E 02	1.467E 02	1.810E 02	1.550E 02	1.892E 02	1.556E 02
7 76 17 38 23	7.893E 01	1.367E 02	9.922E 01	1.423E 02	1.041E 02	1.484E 02	1.810E 02	1.550E 02	1.875E 02	1.555E 02
8 76 17 38 33	8.428E 01	1.363E 02	9.991E 01	1.436E 02	1.047E 02	1.472E 02	1.810E 02	1.556E 02	1.874E 02	1.541E 02
9 76 17 38 44	8.187E 01	1.352E 02	9.909E 01	1.438E 02	1.049E 02	1.483E 02	1.810E 02	1.561E 02	1.881E 02	1.551E 02
10 76 17 38 53	7.560E 01	1.347E 02	9.958E 01	1.429E 02	1.053E 02	1.499E 02	1.810E 02	1.567E 02	1.867E 02	1.534E 02
11 76 17 39 4	7.863E 01	1.354E 02	9.938E 01	1.435E 02	1.046E 02	1.489E 02	1.812E 02	1.569E 02	1.889E 02	1.555E 02
12 76 17 39 13	7.693E 01	1.364E 02	9.807E 01	1.767E 02	1.039E 02	1.475E 02	1.817E 02	1.568E 02	1.873E 02	1.551E 02
13 76 17 39 23	8.589E 01	1.346E 02	9.841E 01	-9.990E 02	-9.990E 02	1.481E 02	1.822E 02	1.566E 02	1.896E 02	1.553E 02
14 76 17 39 34	8.160E 01	1.354E 02	9.844E 01	-9.990E 02	-9.990E 02	1.494E 02	1.827E 02	1.564E 02	1.881E 02	1.556E 02
15 76 17 39 43	7.869E 01	1.346E 02	9.920E 01	1.437E 02	1.067E 02	1.485E 02	1.832E 02	1.563E 02	1.886E 02	1.545E 02
16 76 17 39 54	7.962E 01	1.360E 02	9.974E 01	1.448E 02	1.062E 02	1.477E 02	1.837E 02	1.561E 02	1.878E 02	1.536E 02

Sample Output from Program INVERT (cont'd.)

DERIVED PARAMETERS

OBS DD HH MM SS	1 SURF TEMP (K)	2 WIND SPEED METERS/SEC	3 INTEGRATED WATER VAPOR (G/CM**2)	4 INTEGRATED LIQUID WATER (G/CM**2)	5 CLOUD DROP MOD RADIUS	6 MEAN WATER VAPOR DENSITY (G/M**3)	7	8	9
1	3.014E 02	8.121E 00	2.855E 00	0.0	2.058E 01	5.543E 00	9.582E 00	4.701E 00	1.680E 00
2	3.005E 02	9.584E 00	2.984E 00	0.0	6.532E 00	7.477E 00	1.104E 01	5.306E 00	1.315E 00
3	3.013E 02	9.119E 00	2.930E 00	0.0	1.205E 01	7.045E 00	1.052E 01	5.225E 00	1.408E 00
4	3.011E 02	3.982E 00	3.046E 00	0.0	1.688E 01	8.302E 00	1.160E 01	4.281E 00	1.485E 00
5	3.017E 02	6.011E 00	3.026E 00	0.0	7.240E 00	6.236E 00	1.143E 01	5.930E 00	1.269E 00
6	2.988E 02	1.062E 01	2.942E 00	0.0	1.035E 01	5.761E 00	1.055E 01	5.740E 00	1.490E 00
7	3.006E 02	7.997E 00	3.061E 00	0.0	2.894E 00	8.157E 00	1.278E 01	5.793E 00	1.092E 00
8	3.005E 02	7.239E 00	3.030E 00	0.0	1.381E 01	9.654E 00	1.073E 01	4.743E 00	1.403E 00
9	3.008E 02	6.346E 00	3.061E 00	1.662E-03	8.361E 00	8.756E 00	1.120E 01	5.437E 00	1.271E 00
10	3.013E 02	7.892E 00	3.074E 00	6.071E-03	0.0	6.727E 00	1.241E 01	6.646E 00	1.104E 00
11	3.009E 02	5.952E 00	3.071E 00	2.854E-03	5.718E 00	8.061E 00	1.190E 01	5.599E 00	1.226E 00
12	3.265E 02	0.0	2.892E 00	2.107E-01	1.179E 02	2.424E 01	4.679E-01	0.0	2.572E 00
13	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	3.007E 02	8.667E 00	3.076E 00	2.718E-03	1.471E 01	5.997E 00	9.974E 00	5.975E 00	1.668E 00
16	3.017E 02	7.348E 00	3.077E 00	5.644E-03	2.364E 01	7.468E 00	9.605E 00	4.921E 00	1.818E 00
17	3.027E 02	5.856E 00	3.244E 00	9.477E-03	1.142E 01	8.885E 00	1.109E 01	5.509E 00	1.463E 00

Sample Output from Program INVERT (cont'd.)

```
 13  3310     GENERALIZED DATA INVERSION PROGRAM                    VERSION   3,3  (733001)           12 JUL 1973           PAGE  53
***************************************************************************************************************************************

ENDJOB

END OF PROGRAM,
```


Sample Output from Program INVERT (cont'd.)

5.5 PROGRAM MATCH

Program MATCH was primarily designed to output a single data set consisting of 140 records of combined EOS, ESMR and NEMS data. The data from the ADDAS system is matched up so that the observed brightness temperatures from the back and down viewing sensors correspond geographically with the forward viewing sensor. The aircraft's height, pitch, roll and time of the down viewing observation are used to represent each record of matched data.

The data from the ESMR scanning radiometer system are read in and combined timewise with the matched ADDAS data. Moreover, the left side of the ESMR scan spots are averaged with those observed on the right side. Each resulting record is then averaged over some predetermined time interval (TINT) and stored for further processing.

The data from the NEMS system (punched on cards) is read in and stored in a separate array. The data is combined with the matched ADDAS data by a linear interpolation scheme.

The entire 140 records created and stored on tape from the above process are printed out in the form shown in Table 5-1. As can be seen from this table, each record of matched data is preceded by an average time and average aircraft height, pitch and roll. Any missing data is represented by -999.0.

Figure 3-2 illustrates the radiometer configuration on board the CV990, 1972 Meteorology Expedition.

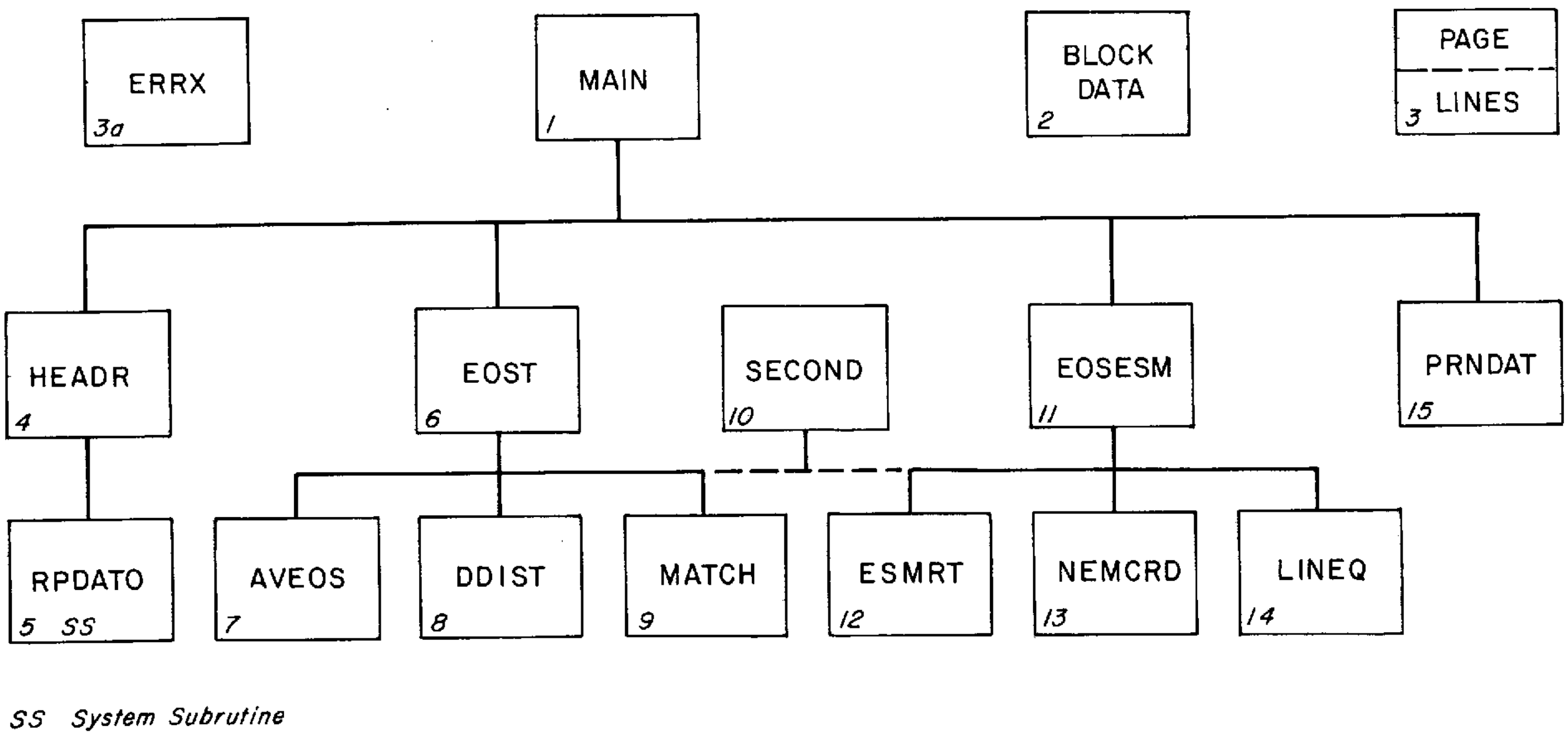


Figure 5-9 Interdependence of Program Elements for Program MATCH

```
//GO.FT09F001 DD DSNAME=K3.S1TCC.S1035.DLOGDATA,DISP=OLD
//GO.FT15F001 DD UNIT=2400-9,LABEL=(,NL),DISP=(OLD,DELETE),
//             DCB=(RECFM=VBS,LRECL=1388,BLKSIZE=13884,DEN=3),
//             VOL=SER=ADDAS
//GO.FT16F001 DD UNIT=2400-9,LABEL=(,NL),DISP=(OLD,DELETE),
//             DCB=(RECFM=FB,LRECL=280,BLKSIZE=5600),
//             VOL=SER=ESMR
//GO.FT17F001 DD UNIT=2400-9,LABEL=(,NL),DISP=NEW,
//             DCB=(RECFM=VBS,LRECL=160,BLKSIZE=7204),
//             VOL=SER=D
//GO.DATAS DD *
```

(ADDAS)	ADDAS TAPE
(ESMR)	ESMR TAPE
(D)	ADDAS, ESMR AND NEMS MATCHED DATA SET FOR PROGRAM INVERT (OUTPUT)

Data Sets for Program MATCH

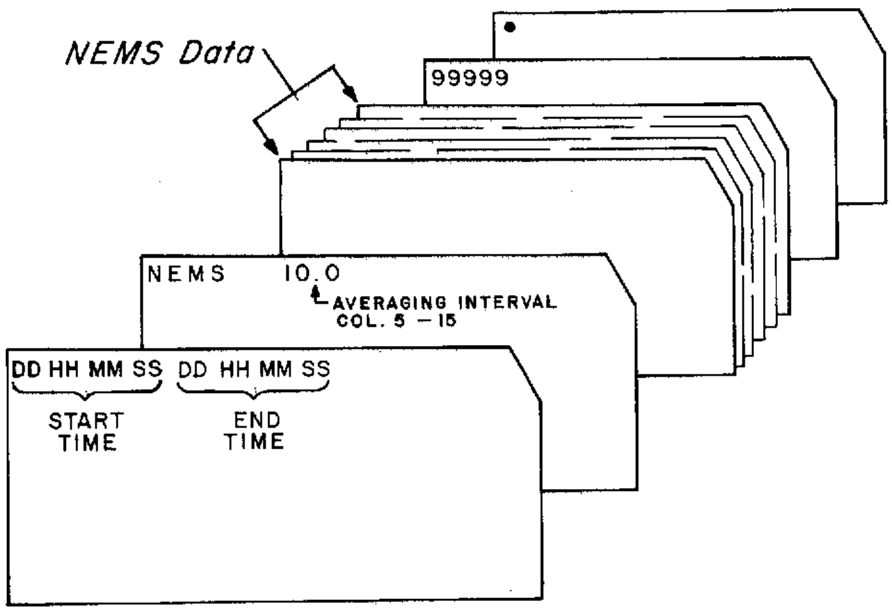


Figure 5-10 Deck Setup for a Typical MATCH Run

6491

Card Formats for Program MATCH

FIRST CARD

Columns	Variable	Format	Meaning
1-3	IDAY	I3	Calendar day of START time
4-6	IHR	I3	Hour of START time (GMT)
7-9	MIN	I3	Minute of START time
10-12	ISEC	I3	Second of START time
13-15	ID2	I3	Calendar day of END time
16-18	IH2	I3	Hour of END time
19-21	IM2	I3	Minute of END time
22-24	IS2	I3	Second of END time

o Maximum period of time requested should not exceed 10 minutes.

SECOND CARD

Columns	Variable	Format	Meaning
1-4	NEMS	A4	Keyword NEMS = NEMS - process NEMS DATA NEMS = BLANK - do not process NEMS DATA
5-14	TINT	F10.5	Time interval in seconds over which the matched data will be averaged

THIRD AND FOLLOWING CARDS (if NEMS DATA is to be processed.

Columns	Variable	Format	Meaning
1-2	IY	I2	Year
3-5	ID	I3	Calendar day of year
6-7	IH	I2	Hour (GMT)
8-9	IM	I2	Minute
10-11	IS	I2	Second
12-20	DN(2)	F9.4	Temperature (°K) for 22.23 GHz
21-30	DN(3)	F10.4	Temperature (°K) for 31.40 GHz
31-40	DN(4)	F10.4	Temperature (°K) for 53.65 GHz
41-50	DN(5)	F10.4	Temperature (°K) for 54.90 GHz
51-60	DN(6)	F10.4	Temperature (°K) for 58.80 GHz
73-78			Card sequence number

LAST CARD

Columns	Variable	Format	Meaning
1 - 5	99999		Denotes end of NEMS DATA set

Numbered Error Messages

PROGRAM MATCH: Level 721212

Routine	Number	Cause
MAIN	101	Time interval on NEMS keyword card is ≤ 0.
EOST	8	Unit number for ADDAS tape is 0
EOSESM	1	Unit number for ESMR tape is 0
	9	END OF FILE sensed on ESMR tape
ESMRT	20	Unit number for ESMR tape is 0

```
 76 17 37 52 76 17 46 37
NEMS       10.0
72076173930     182.8     158.4      0.0      0.0      0.0      1
72076173946     183.9     158.0      0.0      0.0      0.0      2
    .
    .
    .
99999
```

Sample Data Cards for Program MATCH

TABLE 5-1

Sample Output from Program MATCH

DAY	76	76	76	76	76	76	76	76	76	76
HOUR	17	17	17	17	17	17	17	17	17	17
MINUTE	37	37	37	37	38	38	38	38	38	38
SECOND	23	34	43	54	3	14	23	33	44	53
HEIGHT M	10010.3	10030.0	10027.0	10004.5	10014.4	10039.3	10023.1	10022.1	10006.6	10017.4
PITCH	1.7	1.4	1.0	1.1	1.4	1.2	1.1	1.2	1.2	1.5
ROLL	1.2	1.1	-0.3	-0.3	0.7	1.4	0.4	-0.4	-0.2	0.2
EOS CHANNELS										
10-12 U	-999.0	-999.0	-999.0	-999.0	-999.0	-999.0	-999.0	-999.0	-999.0	-999.0
1.42 VER	134.3	136.1	134.8	135.9	135.1	135.4	131.9	141.8	138.4	134.7
1.42 HOR	113.9	116.6	113.9	112.3	112.7	115.2	114.9	120.3	117.9	111.6
4.99 VER	126.7	125.7	125.2	126.2	125.4	124.6	126.7	126.3	125.2	124.7
4.99 HOR	79.3	79.7	78.7	79.0	77.5	78.6	78.2	78.9	78.1	78.6
9.3 UP	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
10.69HOR	125.0	124.4	124.9	121.8	124.2	124.6	123.1	123.7	123.9	124.3
10.69VER	168.8	167.8	168.6	168.7	168.8	166.4	167.3	168.6	168.8	167.9
31.4 UP	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
37.0 HOR	156.5	158.5	158.2	156.6	157.8	158.6	158.5	157.1	158.1	156.4
37.0 VER	190.3	190.3	188.1	189.6	189.8	190.2	188.5	188.4	189.1	187.7
ESMR 19.35 GHZ										
0.0 DEG	159.4	160.4	159.4	158.5	161.2	158.7	160.4	159.2	160.3	161.9
2.3 DEG	158.8	158.6	158.9	159.0	159.2	159.2	159.9	159.6	160.6	160.4
4.6 DEG	158.9	160.0	158.3	159.1	160.3	159.9	159.4	159.5	161.2	161.5
6.9 DEG	159.2	159.2	158.7	158.9	160.8	159.4	159.6	158.6	160.1	161.4
9.2 DEG	159.2	158.6	158.5	157.3	158.6	158.1	158.7	158.4	160.6	160.3
11.5 DEG	159.3	158.4	158.5	158.4	159.6	158.5	158.6	159.1	159.9	161.3
13.8 DEG	158.6	159.1	157.7	158.9	158.3	159.4	158.4	159.5	160.4	160.7
16.2 DEG	157.9	155.6	157.2	158.3	158.3	158.2	158.1	158.4	160.1	161.2
18.6 DEG	156.9	157.0	157.4	156.9	158.3	158.0	158.2	156.8	159.5	159.9
21.0 DEG	156.4	156.8	155.7	158.5	156.6	157.0	159.2	156.8	159.5	159.2
23.5 DEG	155.9	155.6	155.7	157.0	157.1	156.7	156.4	157.9	158.7	158.0
26.0 DEG	156.0	154.1	155.6	156.3	156.1	155.8	155.3	155.9	157.3	158.2
28.6 DEG	154.5	154.4	153.6	155.4	156.0	154.5	155.2	156.1	157.7	157.4
31.2 DEG	154.9	154.4	154.6	154.9	154.5	155.3	155.8	154.8	157.2	158.4
33.9 DEG	154.9	152.8	152.9	154.2	154.0	154.6	153.9	154.6	156.6	156.7
36.7 DEG	153.6	152.7	152.6	152.5	153.7	154.1	155.0	155.3	155.9	158.8
39.6 DEG	151.3	150.1	151.4	151.5	151.5	152.5	152.8	152.6	155.4	157.6
42.7 DEG	150.9	150.0	148.5	148.7	151.2	149.8	149.9	151.0	154.2	157.5
45.9 DEG	150.7	150.2	148.7	149.4	149.4	150.2	150.6	151.3	157.3	166.7
49.3 DEG	146.7	145.3	144.4	146.6	147.2	147.4	147.7	149.8	161.5	177.9
NEMS CHANNELS										
22.23 WV	181.0	181.0	181.0	181.0	181.0	181.0	181.0	181.0	181.0	181.0
31.4 WV	157.0	157.0	157.0	157.0	157.0	157.0	157.0	157.6	158.1	158.7
53.65 O	-999.0	-999.0	-999.0	-999.0	-999.0	-999.0	-999.0	-999.0	-999.0	-999.0
54.9 O	-999.0	-999.0	-999.0	-999.0	-999.0	-999.0	-999.0	-999.0	-999.0	-999.0
58.8 O	-999.0	-999.0	-999.0	-999.0	-999.0	-999.0	-999.0	-999.0	-999.0	-999.0

5.6 PROGRAM FLITE

Program FLITE was designed to process ESMR data for detailed studies of the 19.35 GHz scanning microwave radiometer observations over specified areas.

For each time period requested, the program will read in and print out each scan line encountered (see Figure 5-13). At the completion of each time period requested, the program outputs the mean and standard deviation of each scan spot position and plots these results as shown in Table 5-2 and Figure 5-14.

In Figure 5-14, the mean brightness temperatures from Table 5-2 are plotted as asterisks and the standard deviations about the mean are represented by dashes. It should be noted that the scale on the y axis can vary from case to case.

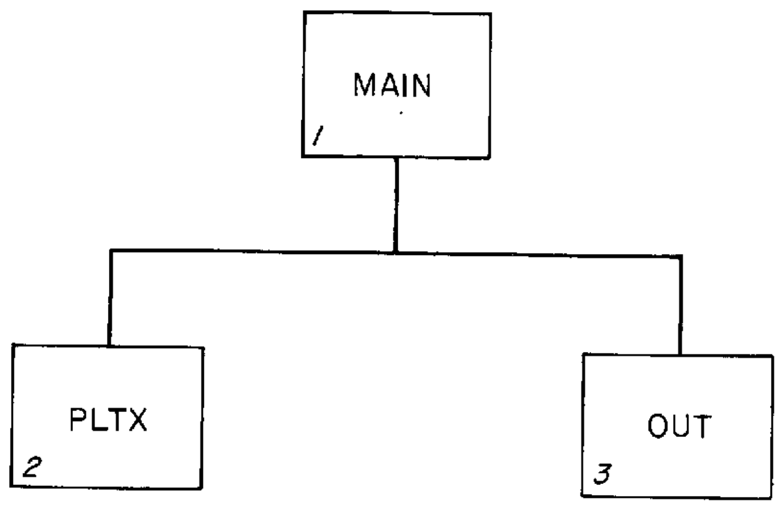


Figure 5-11 Interdependence of Program Elements for Program FLITE

6492

```
//GO.FT08F001 DD UNIT=2400-9,LABEL=(,NL),DISP=OLD,
//             DCB=(RECFM=FB ,LRECL=280,BLKSIZE=5600),
//             VOL=SER=ESMR
//GO.DATA5 DD *
```

Data Sets for Program FLITE

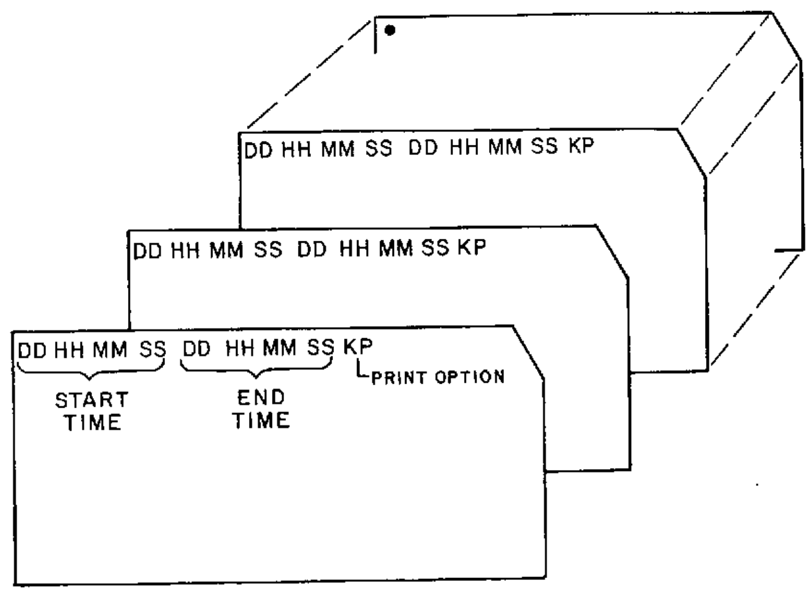


Figure 5-12 Deck Setup for a Typical FLITE Run

6493

Card Formats for Program FLITE

FIRST CARD

Columns	Variable	Format	Meaning
1-3	ID	I3	Calendar day of the year for START
4-6	IH	I3	Hour of START time (GMT)
7-9	IM	I3	Minute of START time
10-12	IS	I3	Second of START time
13-15	ILD	I3	Calendar day of the year for END.
16-18	ILH	I3	Hour of END TIME
19-21	ILM	I3	Minute of END TIME
22-24	ILS	I3	Second of END TIME
25-27	KPRINT	I3	0 suppress scanline printout
			1 print out individual scan lines

SECOND AND FOLLOWING CARDS

Second and following cards are in the exact format shown above. As many time intervals as desired can be processed in one job providing that the cards are arranged in order of increasing time.

LAST CARD

System E.O.F. card

Numbered Error Messages

Program FLITE

Routine	Number	Cause
	None	

FLIGHT 5 03/16/72 19 GHZ 1972 CALIBRATED DATA. RUN DATE 72 176

RESULTS FOR DAY 76 HR 17 MIN 37 SEC 50 THRU DAY 76 HR 17 MIN 39 SEC 50

CODES (- ADD 100) (BLANK ADD 200) (+ ADD 300) (* ADD 0) DEGREES KELVIN

DD	HH	MM	SS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39
76	17	37	51	-44	-50	-46	-52	-54	-57	-57	-55	-59	-54	-56	-55	-55	-54	-57	-57	-56	-58	-57	-59	-57	-57	-60	-55	-56	-56	-58	-58	-56	-52	-53	-55	-52	-53	-51	-49	-49	-45	-47
76	17	37	53	-44	-49	-46	-50	-50	-56	-52	-55	-57	-57	-56	-59	-58	-58	-60	-57	-58	-56	-58	-56	-59	-60	-60	-58	-59	-62	-54	-58	-57	-57	-56	-54	-56	-52	-57	-50	-52	-48	-47
76	17	37	55	-49	-51	-49	-50	-50	-51	-59	-54	-55	-57	-60	-54	-61	-58	-55	-53	-58	-58	-58	-59	-57	-62	-60	-57	-56	-59	-57	-56	-56	-58	-54	-55	-53	-53	-52	-51	-51	-49	-46
76	17	37	57	-45	-50	-50	-55	-50	-57	-57	-57	-58	-58	-59	-57	-58	-62	-57	-57	-57	-57	-62	-58	-57	-63	-58	-58	-58	-59	-58	-54	-57	-57	-55	-56	-50	-52	-48	-49	-46	-46	-45
76	17	37	59	-47	-52	-46	-52	-56	-54	-56	-56	-54	-56	-61	-56	-61	-59	-60	-56	-59	-58	-60	-58	-60	-57	-58	-58	-59	-57	-58	-55	-60	-59	-57	-51	-52	-51	-53	-51	-48	-49	-46
76	17	38	1	-46	-51	-51	-52	-54	-52	-52	-57	-53	-56	-54	-57	-61	-55	-59	-62	-60	-61	-59	-61	-59	-58	-59	-60	-60	-58	-57	-59	-56	-56	-54	-55	-52	-51	-55	-51	-49	-52	-46
76	17	38	3	-48	-53	-49	-55	-54	-54	-56	-54	-54	-55	-58	-58	-58	-60	-60	-58	-61	-57	-58	-61	-58	-60	-61	-57	-61	-57	-55	-57	-56	-61	-59	-55	-52	-56	-51	-50	-50	-46	-47
76	17	38	5	-45	-55	-49	-53	-57	-55	-56	-57	-55	-60	-56	-58	-57	-59	-57	-56	-64	-61	-58	-60	-59	-60	-57	-56	-57	-58	-57	-57	-57	-53	-56	-54	-56	-52	-51	-49	-51	-46	-48
76	17	38	7	-46	-50	-51	-46	-53	-55	-55	-57	-56	-59	-56	-57	-59	-60	-60	-59	-61	-57	-59	-62	-62	-62	-59	-59	-58	-59	-56	-58	-55	-54	-56	-59	-52	-52	-51	-50	-51	-45	-48
76	17	38	9	-47	-49	-52	-52	-55	-55	-56	-54	-56	-56	-54	-59	-60	-55	-59	-58	-58	-60	-57	-60	-60	-62	-62	-57	-59	-56	-58	-57	-57	-56	-55	-54	-52	-54	-51	-51	-52	-43	-47
76	17	38	11	-48	-54	-50	-53	-55	-58	-59	-58	-57	-58	-57	-55	-58	-59	-57	-59	-57	-61	-57	-58	-60	-59	-61	-57	-58	-60	-57	-57	-52	-56	-52	-53	-50	-51	-51	-54	-49	-47	-47
76	17	38	13	-44	-50	-53	-51	-56	-55	-59	-54	-59	-57	-53	-60	-59	-61	-57	-60	-61	-61	-59	-60	-57	-59	-61	-59	-59	-58	-56	-58	-56	-54	-52	-53	-55	-51	-52	-51	-49	-48	-49
76	17	38	15	-46	-51	-48	-51	-57	-53	-54	-57	-58	-55	-61	-59	-59	-60	-58	-60	-59	-59	-59	-55	-61	-61	-60	-58	-59	-57	-59	-58	-56	-57	-56	-51	-52	-56	-54	-48	-49	-50	-46
76	17	38	17	-46	-53	-50	-58	-53	-55	-57	-56	-56	-57	-58	-58	-58	-57	-56	-58	-55	-58	-61	-59	-58	-56	-57	-57	-56	-59	-54	-54	-57	-57	-51	-52	-52	-53	-51	-49	-50	-46	-49
76	17	38	19	-45	-52	-50	-54	-56	-56	-60	-54	-56	-58	-58	-58	-59	-60	-61	-54	-60	-61	-57	-58	-58	-58	-58	-55	-60	-58	-57	-58	-55	-53	-55	-51	-52	-52	-52	-51	-46	-46	-50
76	17	38	21	-48	-52	-50	-49	-56	-54	-58	-56	-56	-60	-59	-59	-56	-60	-57	-55	-56	-59	-62	-61	-59	-58	-59	-60	-59	-56	-61	-55	-58	-54	-53	-52	-57	-49	-52	-56	-49	-47	-46
76	17	38	23	-46	-55	-49	-53	-59	-58	-55	-54	-53	-57	-61	-62	-59	-58	-59	-58	-60	-58	-59	-56	-58	-55	-60	-58	-55	-57	-57	-55	-56	-53	-58	-54	-52	-52	-50	-49	-45	-47	-47
76	17	38	25	-48	-52	-50	-55	-56	-54	-57	-55	-55	-59	-59	-60	-60	-63	-60	-58	-58	-59	-61	-61	-59	-61	-58	-58	-57	-57	-60	-55	-59	-57	-54	-52	-54	-53	-54	-55	-52	-50	-47
76	17	38	27	-46	-49	-49	-51	-57	-53	-57	-57	-52	-55	-61	-59	-55	-56	-60	-56	-60	-60	-59	-58	-58	-57	-61	-59	-58	-58	-55	-57	-59	-53	-56	-53	-54	-52	-52	-53	-49	-46	-49
76	17	38	29	-51	-53	-50	-51	-59	-54	-58	-60	-58	-56	-57	-56	-56	-57	-59	-61	-59	-56	-61	-62	-59	-61	-61	-60	-58	-57	-58	-59	-58	-55	-54	-52	-52	-54	-51	-51	-51	-50	-45
76	17	38	31	-48	-53	-55	-53	-59	-56	-57	-60	-58	-59	-57	-58	-59	-62	-59	-58	-55	-61	-60	-61	-60	-59	-57	-57	-59	-58	-60	-56	-54	-58	-55	-51	-52	-53	-55	-51	-49	-48	-45
76	17	38	33	-48	-53	-49	-55	-56	-57	-57	-54	-55	-59	-55	-57	-58	-57	-57	-57	-62	-59	-57	-60	-60	-60	-62	-57	-57	-61	-59	-57	-55	-57	-55	-54	-52	-51	-51	-50	-49	-47	-46
76	17	38	35	-47	-57	-50	-53	-56	-55	-53	-58	-54	-55	-59	-55	-53	-59	-58	-55	-60	-57	-59	-54	-60	-59	-57	-61	-60	-57	-56	-58	-55	-56	-55	-54	-49	-54	-53	-50	-49	-47	-50
76	17	38	37	-56	-52	-52	-55	-57	-55	-61	-57	-58	-58	-59	-55	-59	-60	-57	-60	-58	-56	-60	-59	-58	-58	-55	-61	-59	-60	-58	-54	-57	-55	-55	-54	-53	-55	-51	-49	-48	-50	-48
76	17	38	39	-57	-55	-53	-54	-58	-53	-57	-59	-59	-59	-54	-57	-57	-58	-61	-57	-57	-61	-61	-59	-57	-59	-57	-56	-58	-57	-58	-56	-57	-58	-50	-55	-52	-50	-52	-51	-51	-48	-48
76	17	38	41	-61	-60	-54	-53	-57	-57	-58	-59	-55	-60	-55	-60	-59	-60	-59	-62	-55	-62	-61	-59	-63	-60	-63	-60	-60	-60	-57	-59	-54	-54	-57	-55	-56	-52	-51	-52	-54	-50	-49
76	17	38	43	-65	-60	-57	-57	-58	-59	-59	-57	-58	-56	-59	-60	-59	-60	-59	-59	-59	-62	-59	-59	-59	-61	-62	-58	-58	-58	-61	-58	-59	-59	-56	-58	-54	-52	-54	-55	-50	-47	-50
76	17	38	45	-74	-65	-56	-57	-59	-60	-58	-58	-62	-60	-62	-60	-61	-60	-59	-62	-59	-60	-63	-62	-60	-63	-58	-60	-59	-62	-63	-59	-58	-57	-56	-58	-54	-51	-51	-55	-50	-49	-46
76	17	38	47	-80	-69	-58	-57	-59	-58	-60	-60	-58	-60	-63	-59	-60	-59	-61	-59	-61	-63	-60	-58	-57	-58	-58	-60	-61	-62	-58	-60	-62	-58	-54	-56	-54	-55	-53	-51	-49	-49	-48
76	17	38	49	-87	-71	-58	-60	-61	-62	-61	-56	-57	-60	-61	-59	-60	-58	-57	-60	-60	-60	-60	-62	-59	-59	-61	-60	-61	-60	-59	-56	-58	-59	-55	-55	-52	-54	-52	-53	-50	-46	-50
76	17	38	51	-96	-75	-58	-59	-62	-61	-60	-56	-60	-60	-62	-60	-64	-60	-61	-59	-65	-59	-59	-61	-60	-61	-60	-58	-60	-60	-62	-57	-58	-59	-58	-54	-57	-53	-54	-51	-53	-50	-49
76	17	38	53	-99	-81	-64	-61	-64	-59	-60	-58	-60	-55	-57	-64	-63	-61	-63	-62	-61	-61	-59	-62	-60	-62	-60	-57	-62	-61	-60	-60	-60	-56	-53	-52	-53	-50	-50	-52	-50	-48	-53
76	17	38	55	6	-83	-67	-62	-61	-61	-65	-61	-56	-64	-59	-62	-59	-62	-60	-57	-62	-60	-57	-61	-62	-62	-57	-60	-62	-58	-60	-59	-58	-54	-57	-58	-57	-53	-54	-52	-47	-48	-47
76	17	38	57	15	-88	-67	-65	-65	-59	-59	-61	-59	-61	-60	-58	-61	-61	-61	-64	-62	-60	-61	-62	-56	-63	-61	-61	-60	-61	-58	-59	-59	-53	-57	-55	-53	-54	-54	-53	-49	-50	-51
76	17	38	59	11	-89	-69	-65	-62	-61	-61	-59	-58	-58	-58	-60	-62	-61	-60	-60	-60	-60	-63	-61	-60	-62	-62	-60	-59	-58	-59	-54	-57	-54	-58	-53	-54	-51	-56	-51	-47	-50	-46
76	17	39	1	16	-94	-75	-69	-64	-61	-61	-57	-61	-58	-59	-62	-60	-62	-61	-61	-58	-62	-60	-59	-59	-61	-62	-61	-54	-57	-56	-58	-60	-58	-55	-56	-51	-54	-51	-51	-49	-48	-48
76	17	39	3	23	2	-83	-71	-65	-60	-59	-60	-57	-59	-59	-57	-61	-59	-61	-63	-59	-59	-61	-60	-57	-64	-59	-56	-59	-57	-60	-55	-58	-58	-57	-56	-50	-50	-51	-51	-49	-48	-51
76	17	39	5	18	6	-83	-71	-65	-63	-60	-58	-61	-60	-59	-64	-60	-61	-58	-59	-61	-60	-61	-61	-61	-61	-64	-63	-59	-62	-60	-55	-58	-55	-52	-57	-55	-53	-53	-53	-50	-46	-45
76	17	39	7	20	2	-81	-67	-66	-60	-62	-55	-59	-57	-57	-60	-58	-62	-61	-60	-59	-63	-58	-59	-61	-59	-59	-60	-59	-59	-60	-59	-56	-59	-56	-54	-52	-54	-53	-50	-49	-48	-52
76	17	39	9	22	5	-85	-72	-68	-60	-62	-57	-57	-58	-57	-60	-62	-59	-59	-59	-55	-55	-59	-62	-57	-63	-57	-61	-60	-59	-63	-55	-60	-55	-53	-53	-55	-56	-51	-50	-51	-48	-50
76	17	39	11	22	10	-92	-74	-67	-66	-61	-57	-56	-58	-56	-58	-61	-63	-60	-59	-57	-63	-60	-61	-61	-60	-63	-60	-58	-58	-61	-58	-55	-56	-57	-53	-51	-52	-53	-50	-50	-50	-48
76	17	39	13	25	14	-96	-81	-69	-70	-60	-57	-56	-58	-61	-58	-61	-60	-60	-60	-59	-59	-60	-60	-62	-61	-62	-58	-57	-59	-59	-55	-58	-53	-54	-56	-57	-48	-53	-52	-53	-47	-45
76	17	39	15	25	15	-94	-87	-75	-65	-64	-56	-60	-60	-59	-59	-58	-63	-61	-60	-61	-60	-59	-62	-62	-57	-60	-62	-59	-59	-57	-59	-55	-55	-55	-54	-57	-52	-54	-52	-51	-50	-48
76	17	39	17	21	12	2	-88	-81	-65	-63	-58	-59	-61	-61	-59	-62	-56	-60	-61	-61	-61	-58	-56	-60	-61	-62	-58	-59	-58	-57	-60	-56	-55	-56	-54	-53	-57	-54	-52	-51	-49	-50
76	17	39	19	18	10	1	-92	-83	-70	-55	-57	-57	-57	-61	-63	-60	-59	-58	-60	-60	-62	-60	-58	-59	-61	-62	-57	-60	-60	-59	-58	-60	-56	-56	-54	-53	-53	-49	-50	-49	-47	-47
76	17	39	21	16	6	-99	-89	-82	-67	-64	-58	-57	-58	-58	-60	-59	-58	-56	-59	-61	-59	-59	-59	-58	-57	-60	-57	-59	-54	-59	-58	-60	-56	-53	-54	-55	-58	-55	-55	-51	-47	-50
76	17	39	23	13	0	-90	-87	-77	-71	-65	-56	-60	-57	-59	-61	-60	-62	-60	-58	-59	-57	-61	-58	-61	-60	-62	-61	-60	-59	-60	-60	-59	-59	-60	-55	-55	-55	-52	-53	-54	-51	-48
76	17	39	25	5	-90	-84	-84	-80	-72	-63	-61	-60	-60	-56	-60	-58	-59	-59	-62	-59	-62	-60	-62	-58	-61	-60	-60	-59	-59	-59	-60	-58	-57	-58	-60	-55	-54	-55	-50	-56	-52	-47
76	17	39	27	-93	-86	-75	-77	-73	-68	-64	-58	-59	-59	-58	-60	-57	-62	-58	-59	-58	-59	-60	-61	-56	-58	-60	-61	-61	-60	-59	-57	-57	-59	-56	-54	-56	-54	-53	-56	-49	-52	-49
76	17	39	29	-83	-78	-72	-70	-69	-64	-61	-58	-59	-59	-60	-57	-58	-56	-63	-63	-60	-61	-58	-58	-58	-59	-62	-57	-61	-58	-60	-60	-55	-57	-57	-56	-59	-56	-55	-50	-55	-53	-49

Figure 5-13 Sample Output from Program FLITE

TABLE 5-2

Sample Output from Program FLITE (cont'd.)

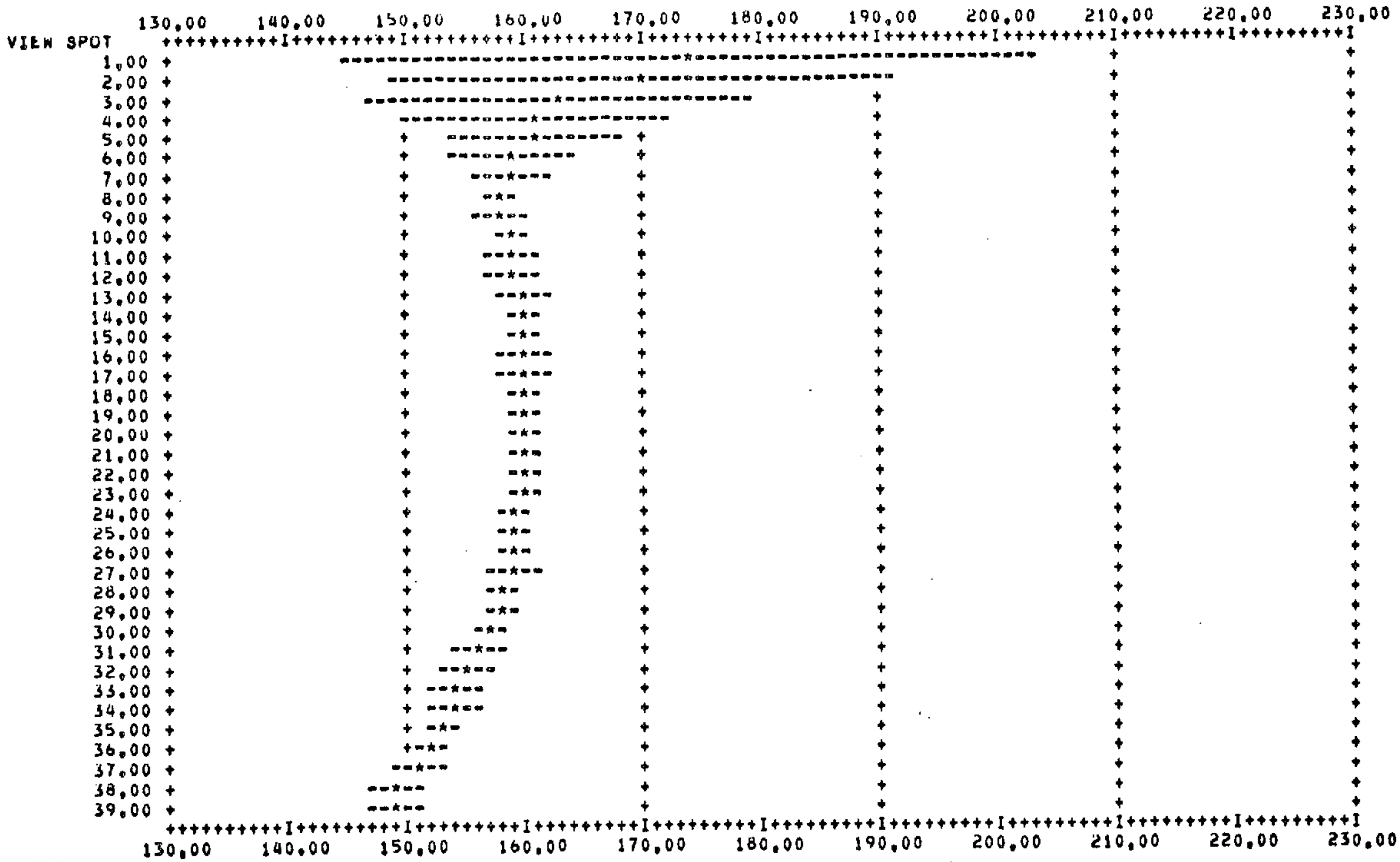
FLIGHT 5 03/16/72 19 GHZ 1972 CALIBRATED DATA, RUN DATE 72 176

RESULTS FOR DAY 76 HR 17 MIN 37 SEC 50 THRU DAY 76 HR 17 MIN 39 SEC 50

SPOT NUMBER	ANGLE	MEAN TEMPERATURE	STANDARD DEVIATION	NUMBER OF OBSERVATIONS
1	49.3	173.65	29.6	60
2	45.9	169.84	21.5	60
3	42.7	162.59	16.2	60
4	39.6	161.32	11.6	60
5	36.7	161.40	7.9	60
6	33.9	159.08	5.0	60
7	31.2	159.21	3.1	60
8	28.6	157.59	1.9	60
9	26.0	157.86	2.3	60
10	23.5	158.75	1.9	60
11	21.0	158.89	2.2	60
12	18.6	159.35	2.1	60
13	16.2	159.56	2.1	60
14	13.8	159.95	2.0	60
15	11.5	159.81	1.9	60
16	9.2	159.57	2.3	60
17	6.9	159.89	2.1	60
18	4.6	160.15	2.0	60
19	2.3	160.07	1.5	60
20	0.0	160.21	1.9	60
21	-2.3	159.75	1.7	60
22	-4.6	160.50	1.9	60
23	-6.9	160.44	1.9	60
24	-9.2	159.32	1.8	60
25	-11.5	159.42	1.6	60
26	-13.8	159.26	1.8	60
27	-16.2	158.97	2.1	60
28	-18.6	158.03	1.8	60
29	-21.0	157.74	1.8	60
30	-23.5	156.78	2.0	60
31	-26.0	156.01	2.1	60
32	-28.6	155.09	2.2	60
33	-31.2	154.14	2.2	60
34	-33.9	153.53	2.1	60
35	-36.7	153.11	1.9	60
36	-39.6	152.08	2.0	60
37	-42.7	150.92	2.3	60
38	-45.9	149.11	2.3	60
39	-49.3	148.81	2.1	60

FLIGHT 5 03/16/72 19 GHZ 1972 CALIBRATED DATA, RUN DATE 72 176 .

RESULTS FOR DAY 76 HR 17 MIN 37 SEC 50 THRU DAY 76 HR 17 MIN 39 SEC 50



JOB END

Figure 5-14 Sample Output from Program FLITE (cont'd.)

5.7 General Subroutines

Subroutines that are utilized by more than one program are stored in a separate library (ERTLIB) on disk and are linked to each program before execution. There are seven of these subroutines which are as follows:

1. HEADR
2. PAGE
3. INE
4. ERRX
5. CHANLS
6. RAPDAT
7. NWRDAT

A brief description of the first four of these subroutines is described in this section.

Subroutine HEADR

Subroutine HEADR, in conjunction with a system subroutine RPDATO, (The Goddard system program which supplies the date), the labeled common/HEAD/, and a private disk data set called DLOGDATA, does run accounting and generates page heading information for most programs described in this system.

Calling Sequence

CALL HEADR (IC, VER, LEV)

IC	INTEGER * 4	This is the user assigned program code number
VER	REAL * 4	Program version number
LEV	INTEGER * 4	Program version date (YY MM DD), year, month and day

The subroutine requires other variables that should be passed through a labeled common block called HEAD. These variables are as follows:

TITLE (6)	REAL * 8	This is the title of the program
ICODE	INTEGER * 4	User program code
VERS	REAL * 4	Program version number
LEVEL	INTEGER * 4	Program DATE (YY MM DD)
DAT (3)	REAL * 4	Space for system generated date
IRUN	INTEGER * 4	Space for run number update
NPAGE	INTEGER * 4	Space for page counting
NLOG	INTEGER * 4	Unit number assigned to DLOGDATA

Comments

In order to perform the run accounting and page header generation (see subroutine PAGE), HEADR should be called only once at the beginning of the program. A BLOCK DATA subprogram can be used for generating COMMON/HEAD/.

Subroutine PAGE

Description

Subroutine PAGE is designed to print a page header at the beginning of each page of output containing the program code number, version number + run number, program name, version number, level number, date and page number, respectively and prints a line of asterisks separating the header from further output.

A second entry to the subroutine (LINES), keeps count of the page number and line numbers. Whenever the line counter equals 61 lines, the page is advanced and the header information mentioned above is printed.

Arguments to be supplied to subroutine PAGE are passed through labeled common/HEAD/. (See description of subroutine HEADR.)

Therefore, subroutine HEADR must be called prior to using subroutine PAGE.

Calling Sequence

CALL PAGE

This call will cause the page to advance and the header information above to be printed at the top of the page.

CALL LINES (N, *)

This call will keep track of the number of lines being printed.

N	INTEGER * 4	This is the number of lines that will be printed on return to the calling program.
*		The statement number in the calling program where return is made if the line counter exceeds 61 lines.

Subroutine INE

Description

Subroutine INE was designed to read and print comment cards.

Calling Sequence

CALL INE (IC,PRINT)

IC INTEGER * 4	Unit number from which cards are to be read.

PRINT LOGICAL	If this is .TRUE., the cards read in will be printed; .FALSE. the cards will not be printed.

Card Format

The comment cards to be read should be in the following format:

Columns	Variable	Format	Meaning
1-14	None	-	Blank
15	IFORM	A1	'', or '0' print on same page; '1' print on next page.
16-20	None	-	Blank
21-70	COM	12A4	Comment
71-72	JF	A2	Card sequence value; if blank return to calling program.

Subroutine ERRX

Description

Subroutine ERRX was designed to assist in the programming of error messages and to reduce the amount of BCD text that error messages often use in programs.

Calling Sequence: (double entry routine)

(Entry 1) CALL ERRX(N,NAME)

N	INTEGER * 4	This is an error number supplied by the programmer that distinguuishes a certain error condition.
NAME	REAL * 8	This is the name of the routine where the error occurred.

This entry will print out the error number and name and terminate execution.

(Entry 2) CALL ERRM (N,NAME,*)

Arguments N and NAME are the same as above.

*	This is a statement number in the calling program where return will be made

This entry will print out the error number and name and return to the calling program for continued execution.

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