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MEASUREMENT/MODEL INTERFACE RESEARCH
Semiannual Report (Research Inst. of
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Langley Research Center

from

Research Institute of Colorado

Contract #NAG-1-150

"Radiation Budget Measurement/Model Interface Research"

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October, 1981



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FIGURE CAPTIONS

- Fig. 1-1 Global maps (i.e., I.R. emitted flux, net flux, and albedo) of processed NIMBUS-6 data for July, 1977. Units for fluxes (watts/m^2), for albedo (percent).
- Fig. 1-2 Same as 1, except for August, 1977.
- Fig. 1-3 Same as 1, except for September, 1977.
- Fig. 1-4 Same as 1, except for October, 1977.
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- Fig. 1-7 Same as 1, except for January, 1978.
- Fig. 1-8 Same as 1, except for February, 1978.
- Fig. 1-9 Same as 1, except for March, 1978.
- Fig. 1-10 Same as 1, except for April, 1978.
- Fig. 1-11 Same as 1, except for May, 1978.
- Fig. 1-12 Scale and geography for global maps (i.e., Figs 1-11)
- Fig. 1-13 Zonal averages of net radiation flux for April.
- Fig. 1-14 Same as 1-12, except for May.
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- Fig. 2-2 Observed and calculated mean zonal wind 500 mb
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- Fig. 2-5 Observed and calculated pressure velocity ω 500 mb
- Fig. 2-6 Calculated precipitation and mixing ratio day 91-120

SUMMARY

During the first seven months of research on Radiation Budget Measurement/Modeling Interface we have laid plans and completed early work in three areas: (a) Improved Earth Radiation Budget Data Sets, (b) Numerical Model Experiment Definition and (c) Review of Concurrent Research by Other Scientists. All of these areas of work will be reported in detail via special reports now in preparation. Figures included in the following sections of the present report illustrate the work in progress.

1.0 Improved Earth Radiation Budget Data Sets

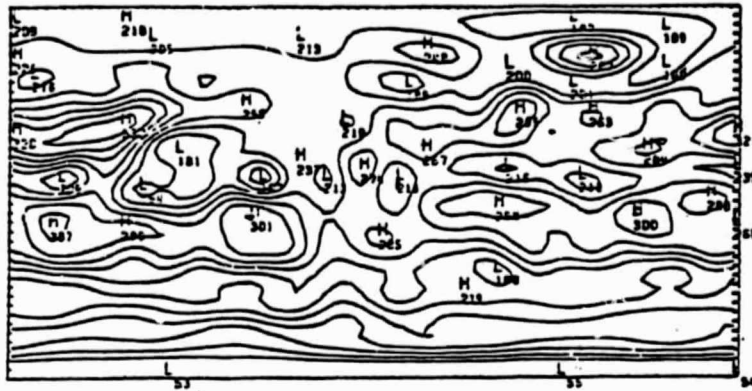
As a guide to selection of climate modeling experiments we are continuing our early work by processing and analyzing the NIMBUS-6 data. The first two years of NIMBUS-6 data as well as earlier data, which have been previously processed, were reported by Stephens *et al.* (1981). In recent months we completed the processing of the third year of NIMBUS-6 data. Unfortunately, the data quality from June, 1978 through October, 1978 was insufficient to provide a meaningful analysis of the earth's radiation budget for this period. Thus, the third year of data extends from July, 1977 to May, 1978. The processed results for the "third year" of the NIMBUS-6 data are shown in Figures 1-1 through 1-11. The scale and geography for these global maps is shown in Figure 12. These data are being combined with earlier data (see Table 1) to form the most up-to-date climatology of the earth's radiation budget from which the model work noted below will be guided. Special attention has been directed to the April - June period, which is hypothesized by the P. I. to be a principal time of potential interannual variability in the radiation budget.

From the processed data generated from the satellites referenced in Table 1, we have computed the zonal averages of net radiation for the three months mentioned above (Figures 1-13 through 1-15). It is still uncertain whether the differences observed in these zonal averages are, in fact, manifestations of an interannual variability within the earth's radiation budget, or if they are merely artifacts of the various satellite sampling systems.

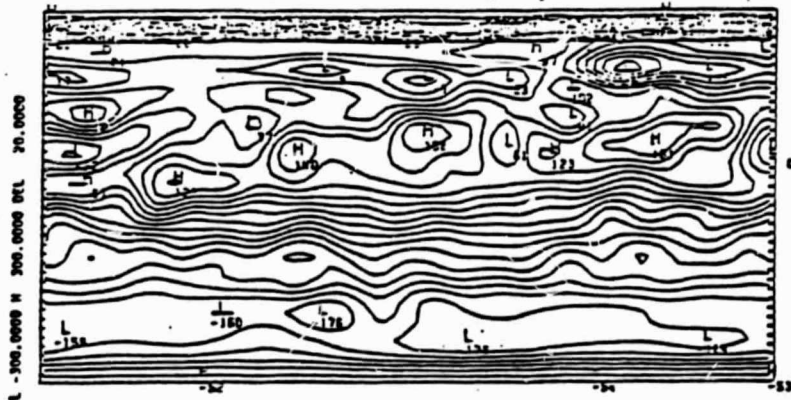
Assuming satellite problems to be minimal, the Northern Hemisphere winters of 1975/76, 1976/77 and now 1977/78 are particularly interesting. In contrast to Campbell (1981) who surmised only minor differences between 75/76 and 76/77, our preliminary results from this research show 75/76 and 77/78 to be strikingly similar in terms of radiation budget - with 76/77, the winter of major North

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MES-236.567-236.567 GLB-235.397-235.397
TR ASSEND INVAS 15 DECON



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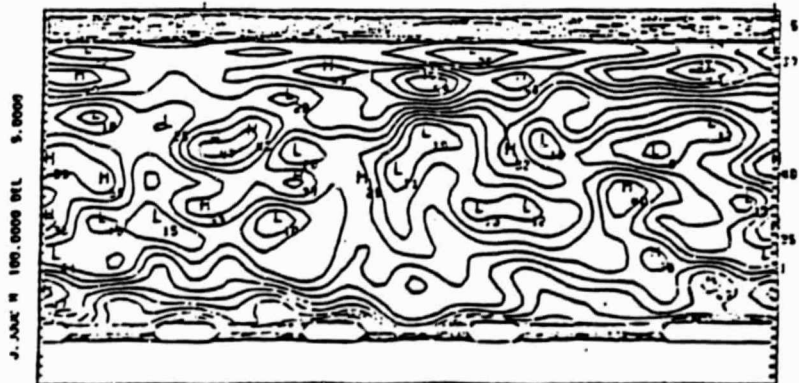
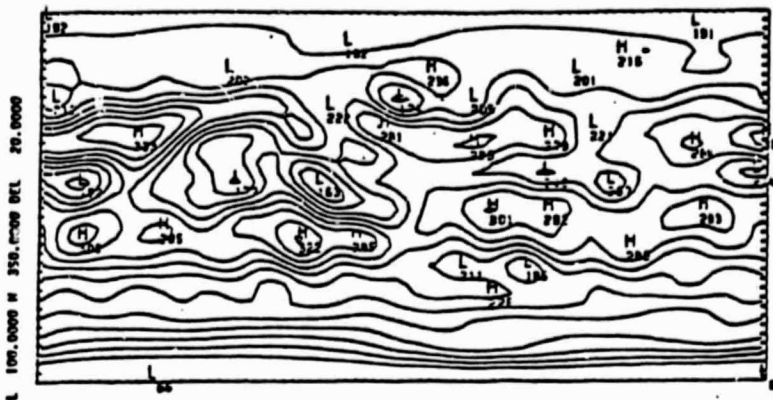


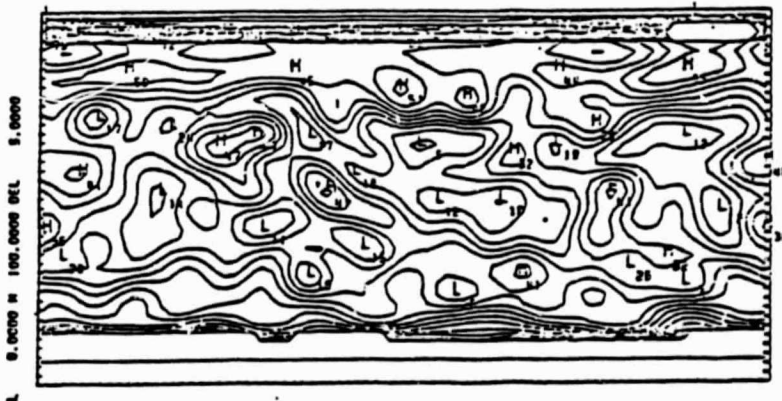
Figure 1-2

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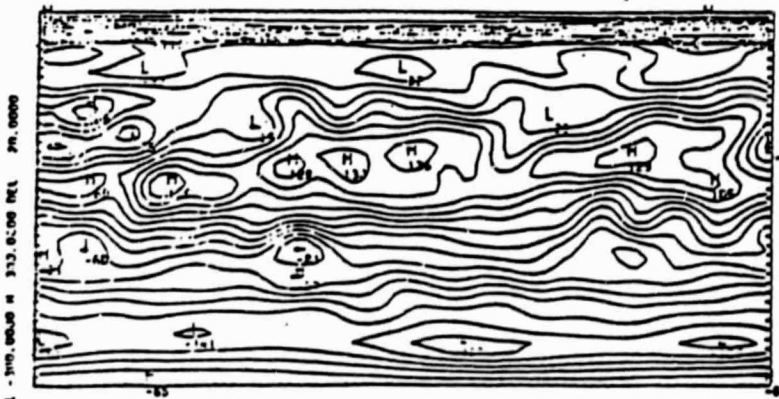
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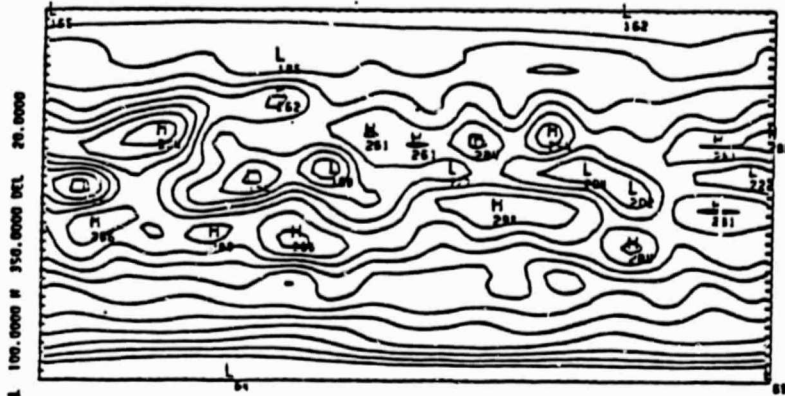


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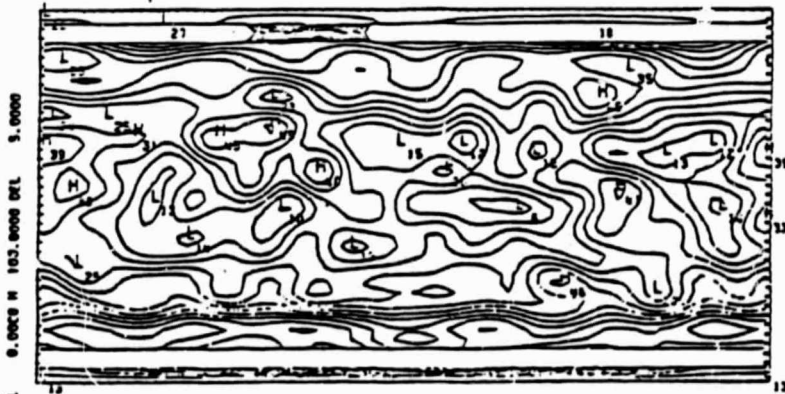


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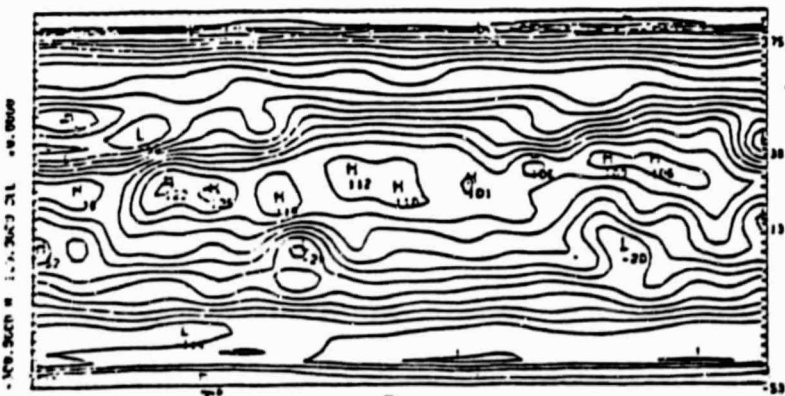
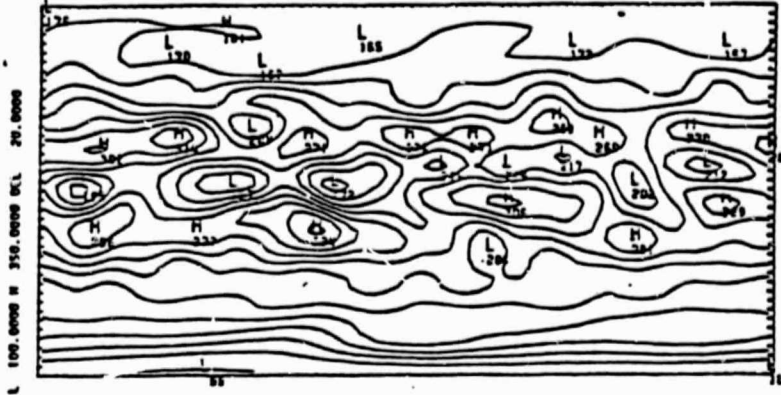


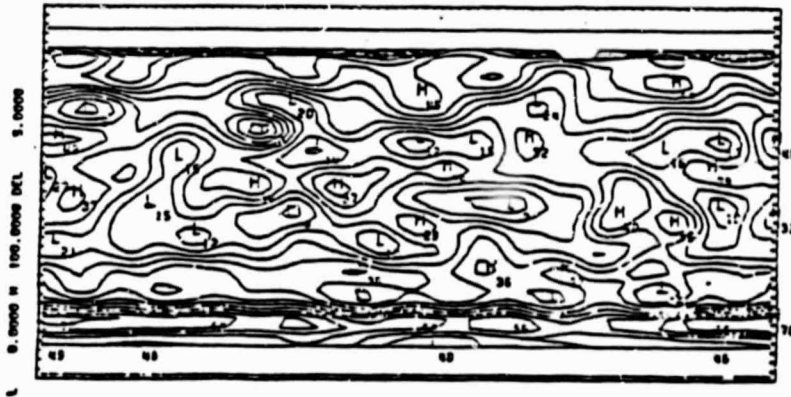
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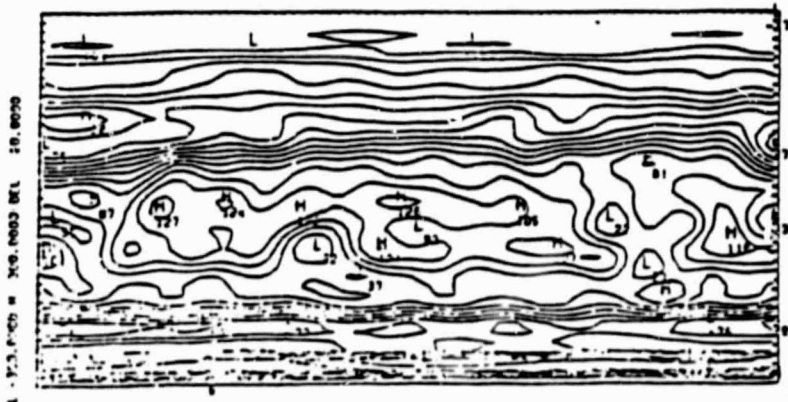
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DAILY AVERREF ASSENDLANDMD SAT



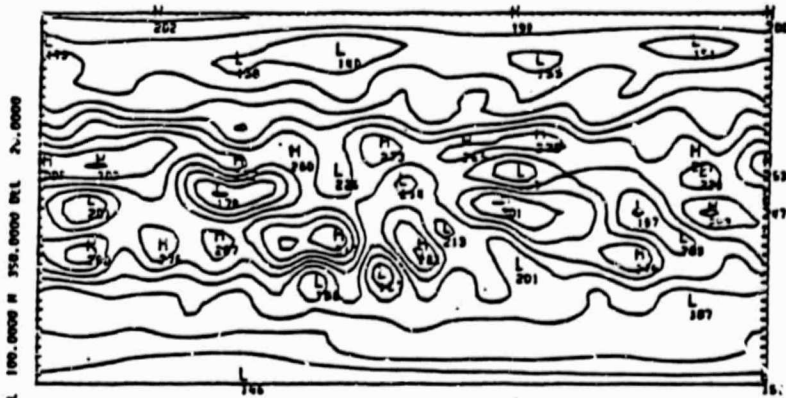
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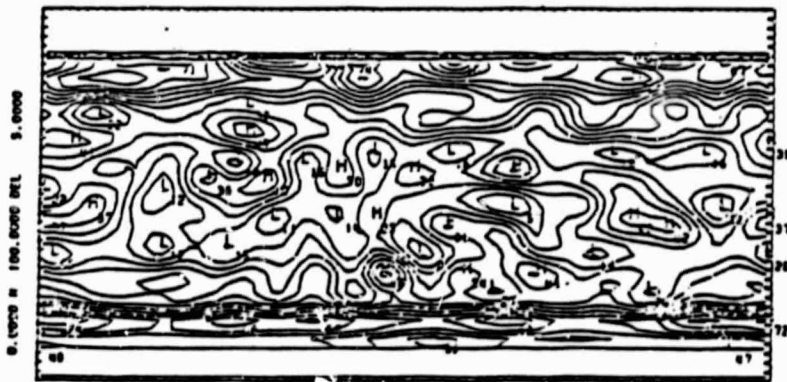
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Figure 1-5

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IR ASSEND INVR5 15 DECON



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DAILY AVERREF ASSENDLANDMD SAT



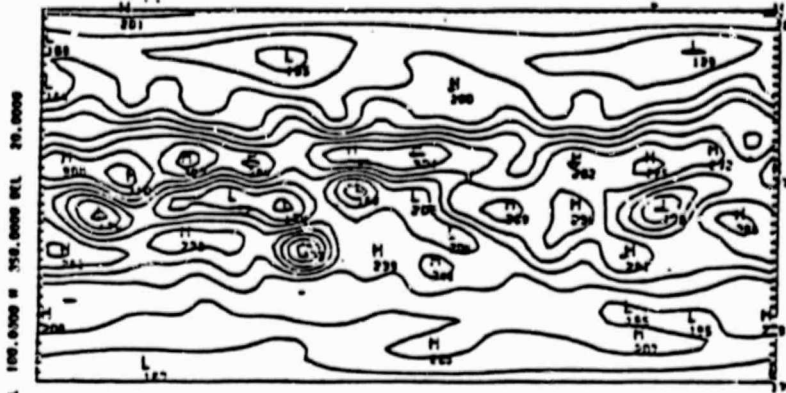
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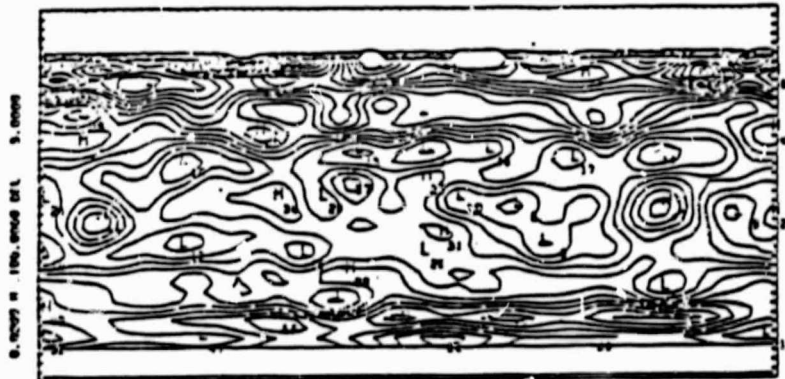
Figure 1-7

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MAX 350.00 INC 20.000 W/M² FLUX 1
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IR ASSEND INVR 15 DECON



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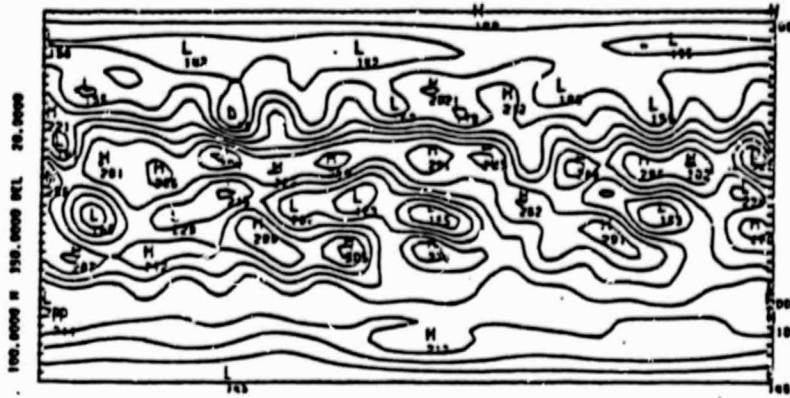
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NET FROM EM DEC 15 ALLDEC 15



Figure 1-8

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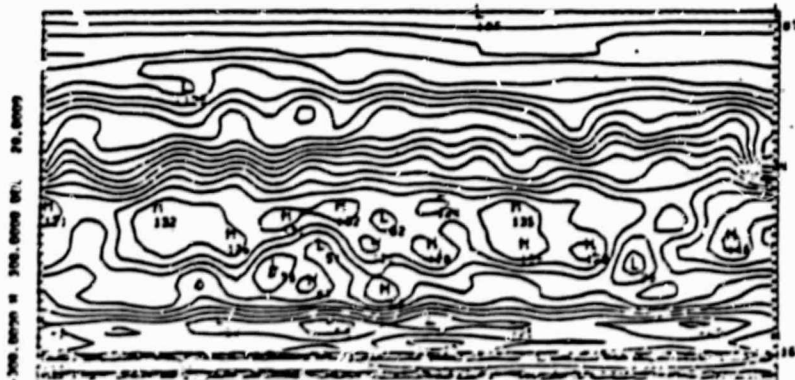
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IR ASSEND INVAR 15 DECON



MAX 100.00 INC 5.0000 W/M² FLUX 4
MES .301 106.718 GLB .305 107.233
DAILY AVERREF ASSENDLANDMD SAT



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NET FROM EM DEC 15 ALLDEC 15



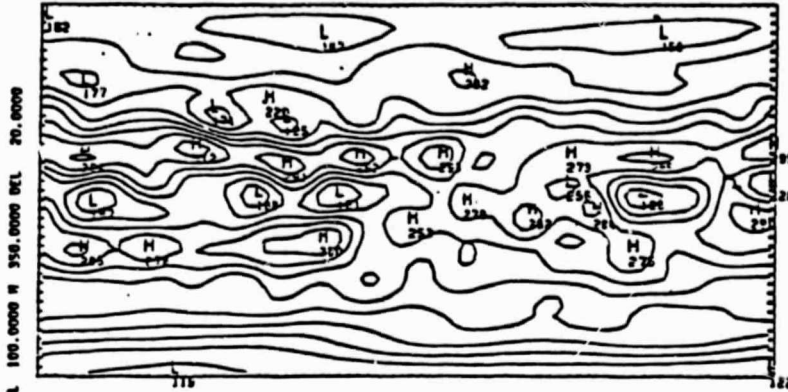
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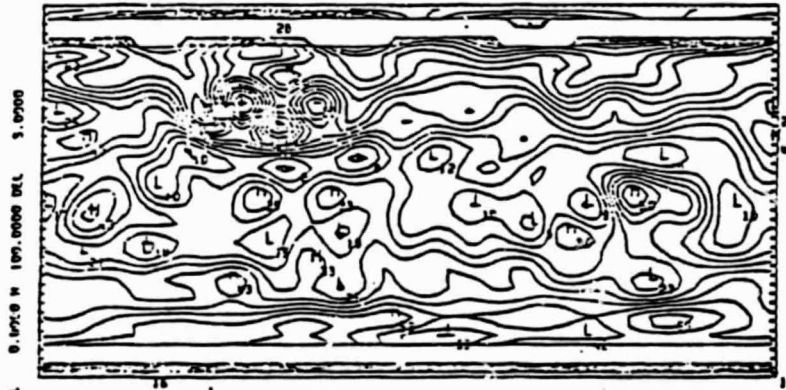
Figure 1-9

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DAILY AVERREF ASSENDLANDMD SAT



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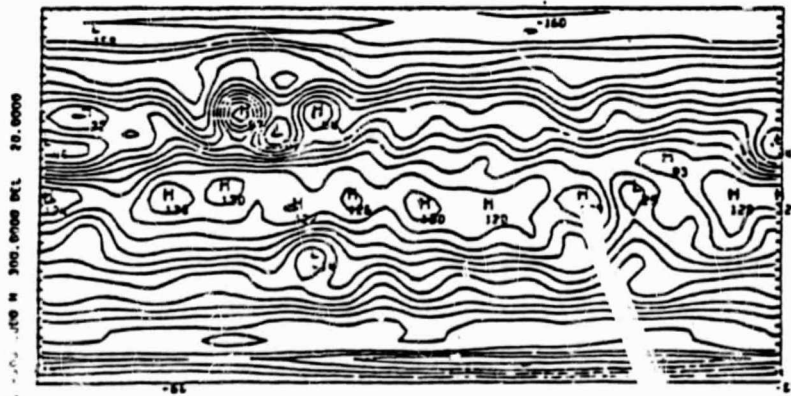
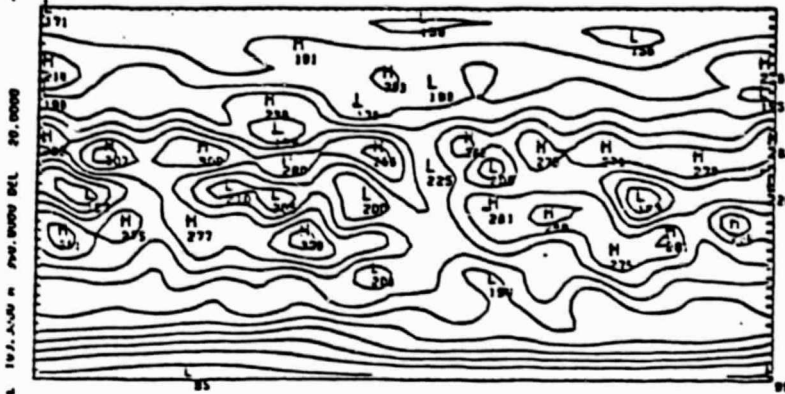


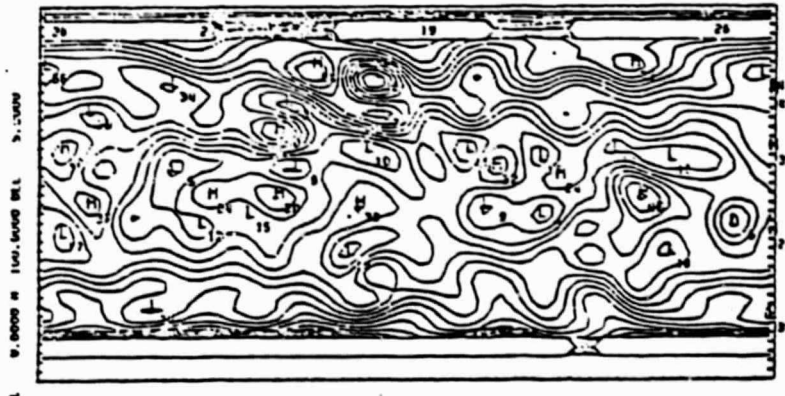
Figure 1-10

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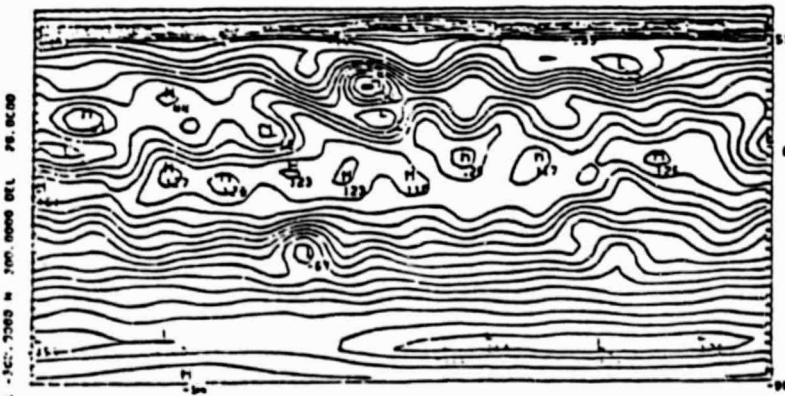
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MES .326 .322 GLB .324 .324
DAILY AVERREF ASSENDLANDMD SAT



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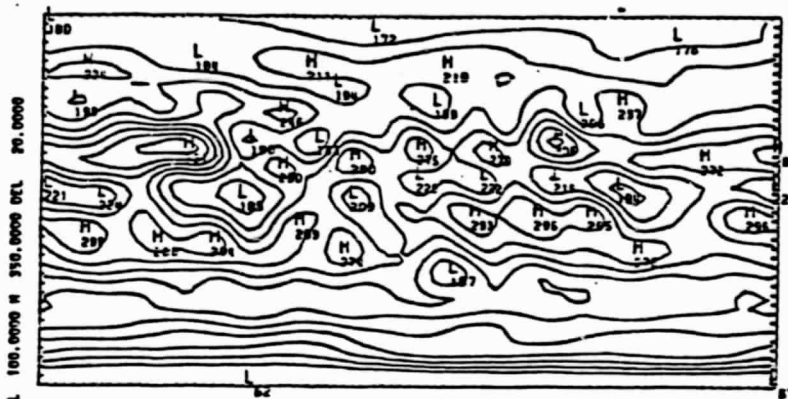


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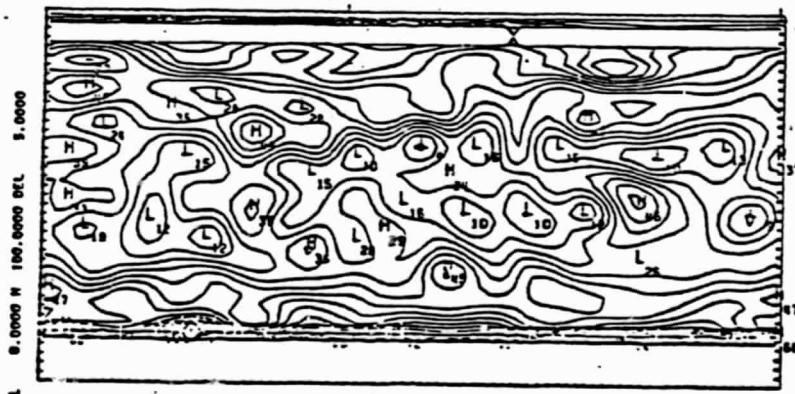
Figure I-11

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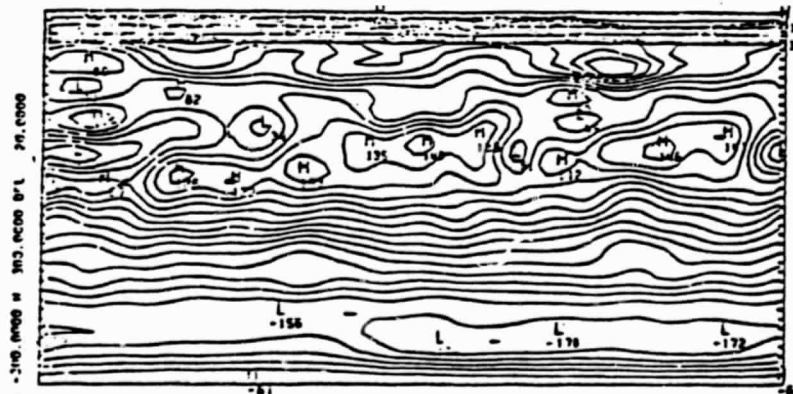
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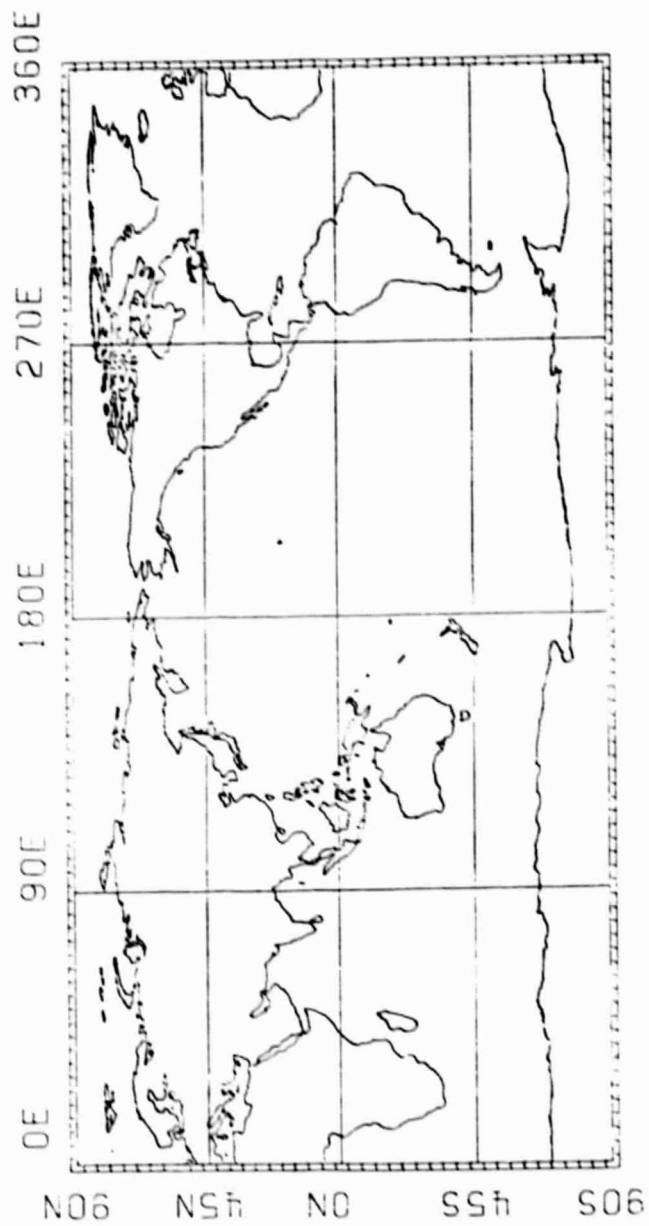


Table 1. Chronological list of earth orbiting satellites from which present radiation measurements were taken. The approximate local time at which each satellite crossed the equator during daylight hours appears in parenthesis. EX - Experimental, N2 - Nimbus 2, N3 - Nimbus 3, N6 - Nimbus 6, E3 - ESSA 3 and E7 - ESSA 7.

Month	Season	1964	1965	1966	1968	1969	1970	1975	1976	1977	1978	Sample Size
Jan	D.J.F.		Ex(10:30)			E7	N3		N6	N6	.	6
Feb			Ex(10:35)			E7			.	N6	.	5
Mar			Ex(10:40)			E7			.	N6	.	5
Apr	M.A.M.					N3(11:30)*			.	N6	.	4
May						N3			.	N6	.	4
Jun				H2(11:30)*		N3			.	N6	.	4
Jul	J.J.A.	Ex(8:30)				N3		N6(11:45)*	.	.	.	5
Aug		Ex(8:55)				N3		N6	.	.	.	5
Sep		Ex(9:15)						N6	.	.	.	4
Oct	S.O.N.	Ex(9:40)		E7(14:30)		N3		N6	.	.	.	6
Nov		Ex(10:05)		E7				N6	.	.	.	5
Dec	D.J.F.	Ex(10:30)		E3(14:40)	E7			N6	.	.	.	6
Annual		6	3	2	3	9	1	6	12	12	5	59

Resolution = Half Power Diameter

Experimental	1280 km, 11.5°
ESSA3	
Nimbus 2	Averaged to 10° grid
ESSA7	2200 km, 20°
Nimbus 3	Averaged to 10° grid
Nimbus 6	1100 km, 10° (analyzed from 16°)

*Albedo corrected for diurnal variation of reflection with directional reflectance model.

Figure 1-13

NET FLUX ZONAL MEANS FOR APR.

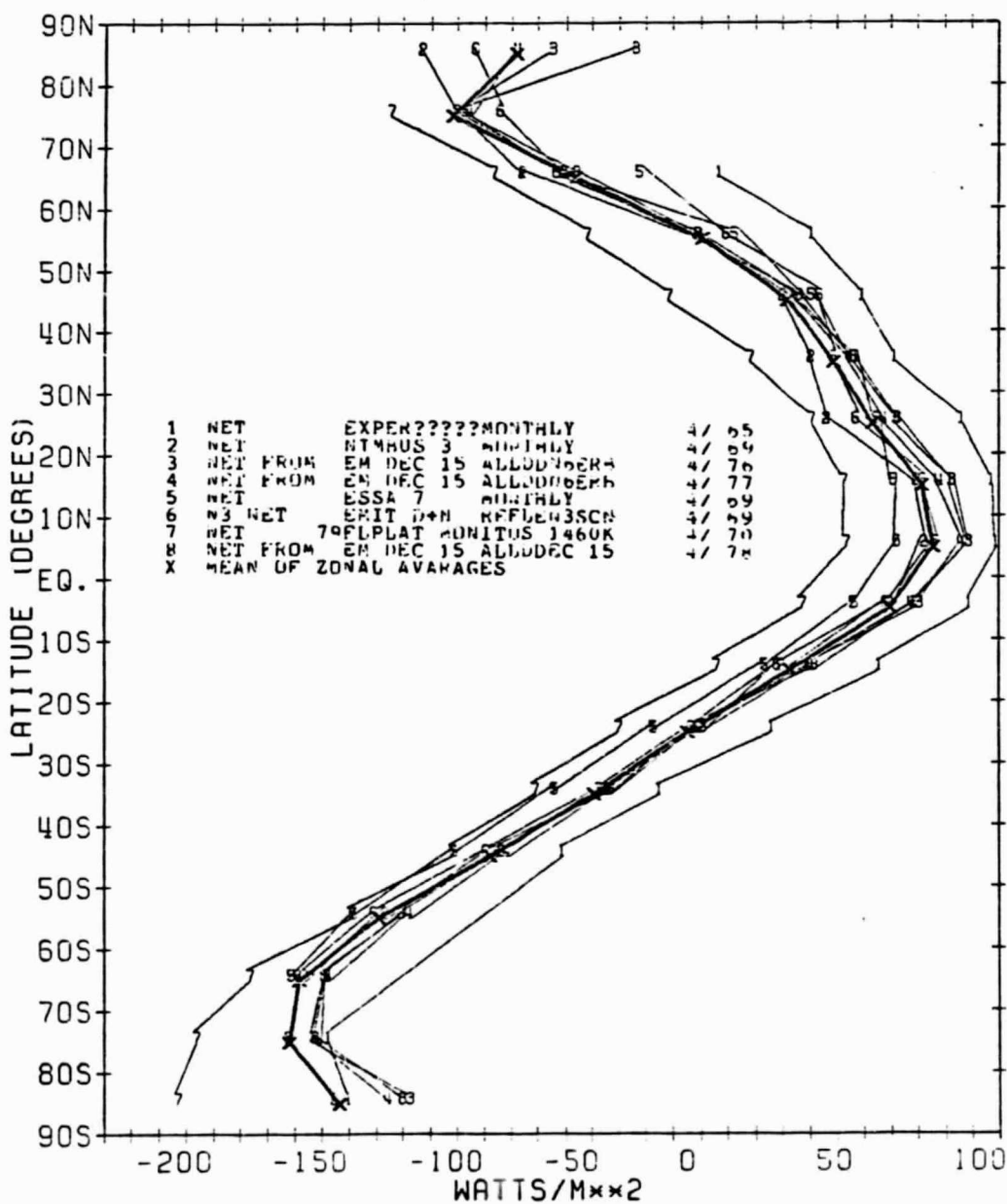


Figure I-14

NET FLUX ZONAL MEANS FOR MAY

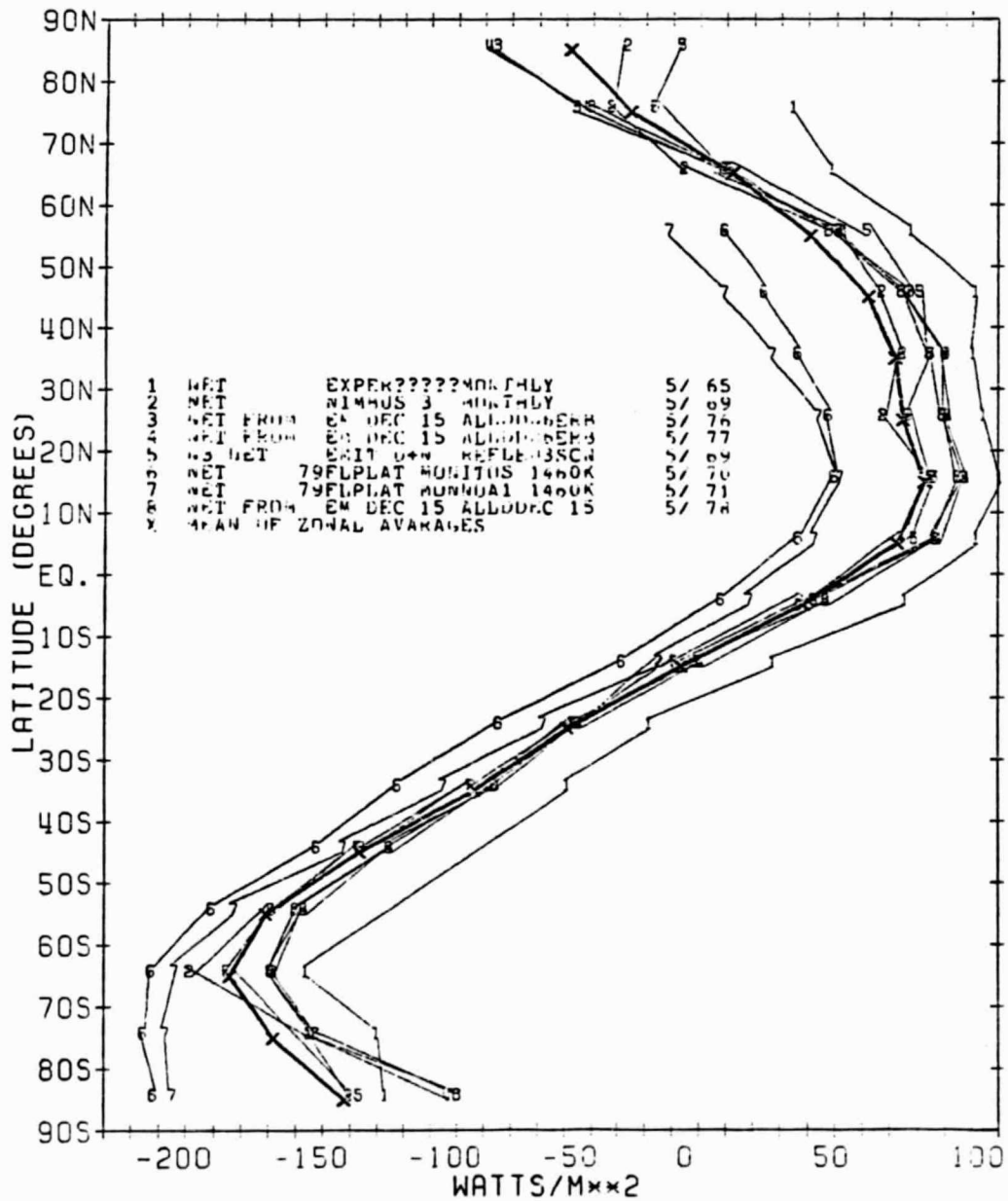
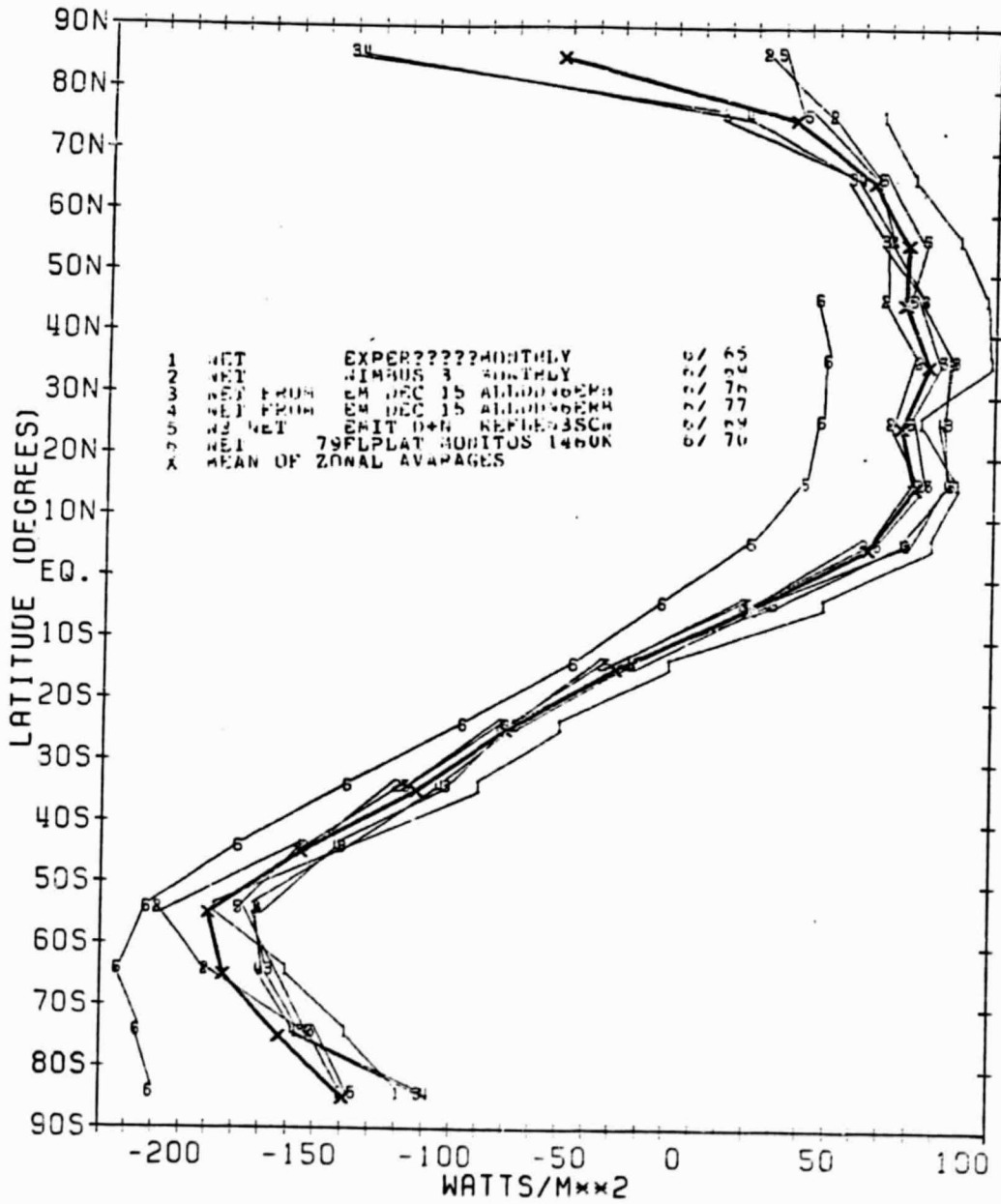


Figure I-15

NET FLUX ZONAL MEANS FOR JUNE

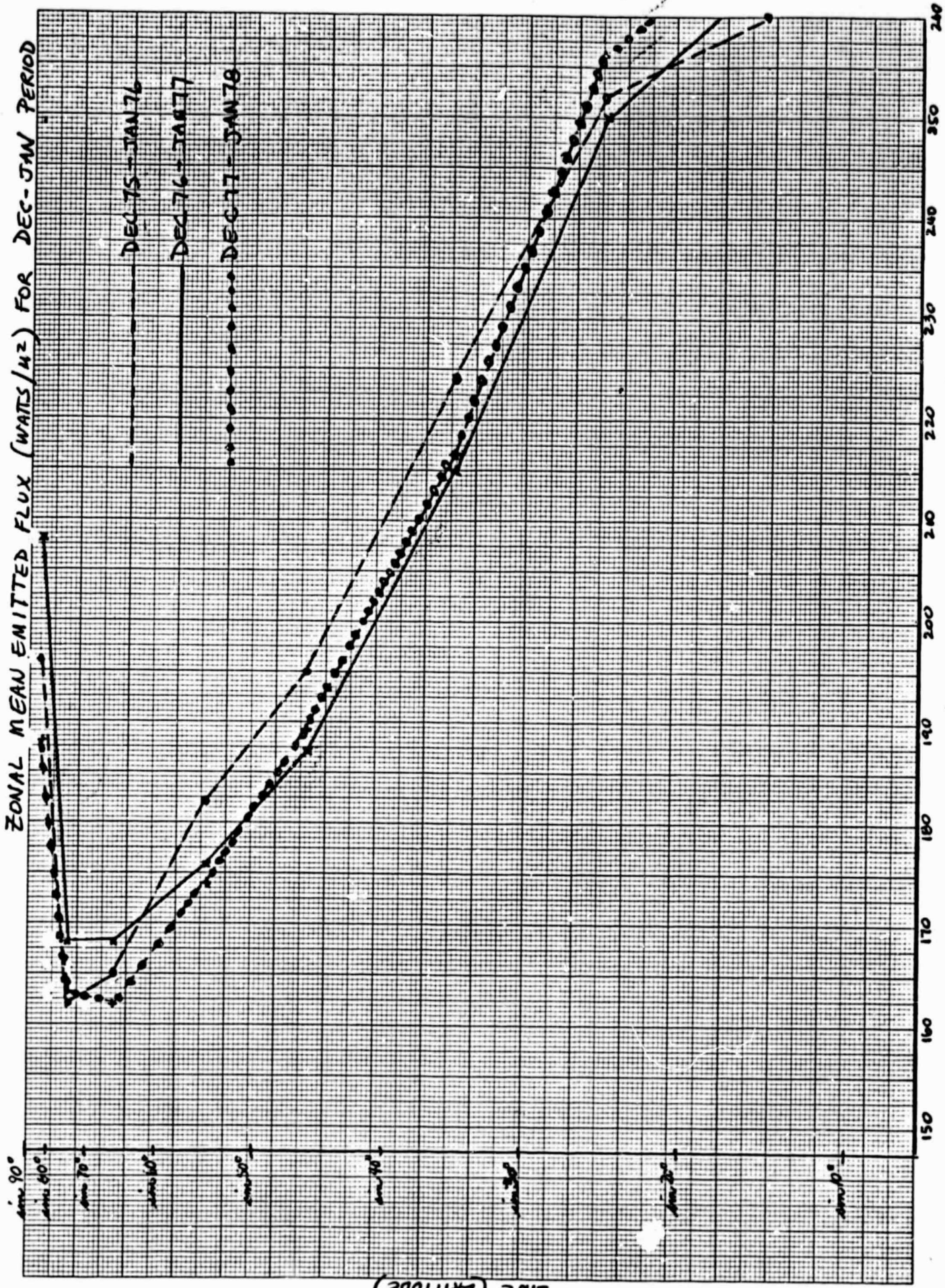


American weather anomalies, distinctly different from the preceding and following years. Differences can be noted in the December-January zonal means for emitted and net fluxes for these years (Figures 1-16 and 17, respectively). The fact that the emitted flux (Figure 1-16) in Dec. 76 - Jan. 77 was larger at higher latitudes ($60^{\circ}\text{N} - 90^{\circ}\text{N}$) and lower at mid-latitudes ($30^{\circ}\text{N} - 90^{\circ}\text{N}$) in comparison to the other years may be indicative of the strong and persistent atmospheric "blocking" patterns which characterized this period in the Northern Hemisphere. For under such blocking conditions, the increased meridional circulation would allow anomalous amounts of warm air to be advected into higher latitudes which, in turn, would result in increased longwave emission. Conversely, at mid-latitudes, the increase in cold air advection associated with the blocking flow would result in decreased longwave emission. Since the NCAR Community Climate Model (CCM) has recently replicated the blocking situation found over North America during the 1976/77 winter (Blackman, 1981), our model experiments planned for the remaining portion of the research period of this contract have additional impetus potential.

A more complete documentation of the new NIMBUS-6 results, as well as preliminary discussion, is in preparation (Ciesielski, Campbell, and Vonder Haar, 1981). This special report under the present contract will be patterned after Ellis and Vonder Haar (1976) and Campbell and Vonder Haar (1980).

2.0 Numerical Model Experiment Definition and Tests

Two complementary models are presently under development. The first is a statistical-dynamical model patterned after the recent work of Ashe (1979). It contains very crude vertical resolution (only two levels; but in principle, more can be added) and an arbitrary horizontal resolution. The horizontal dependence is represented by spectral components, which have recently been

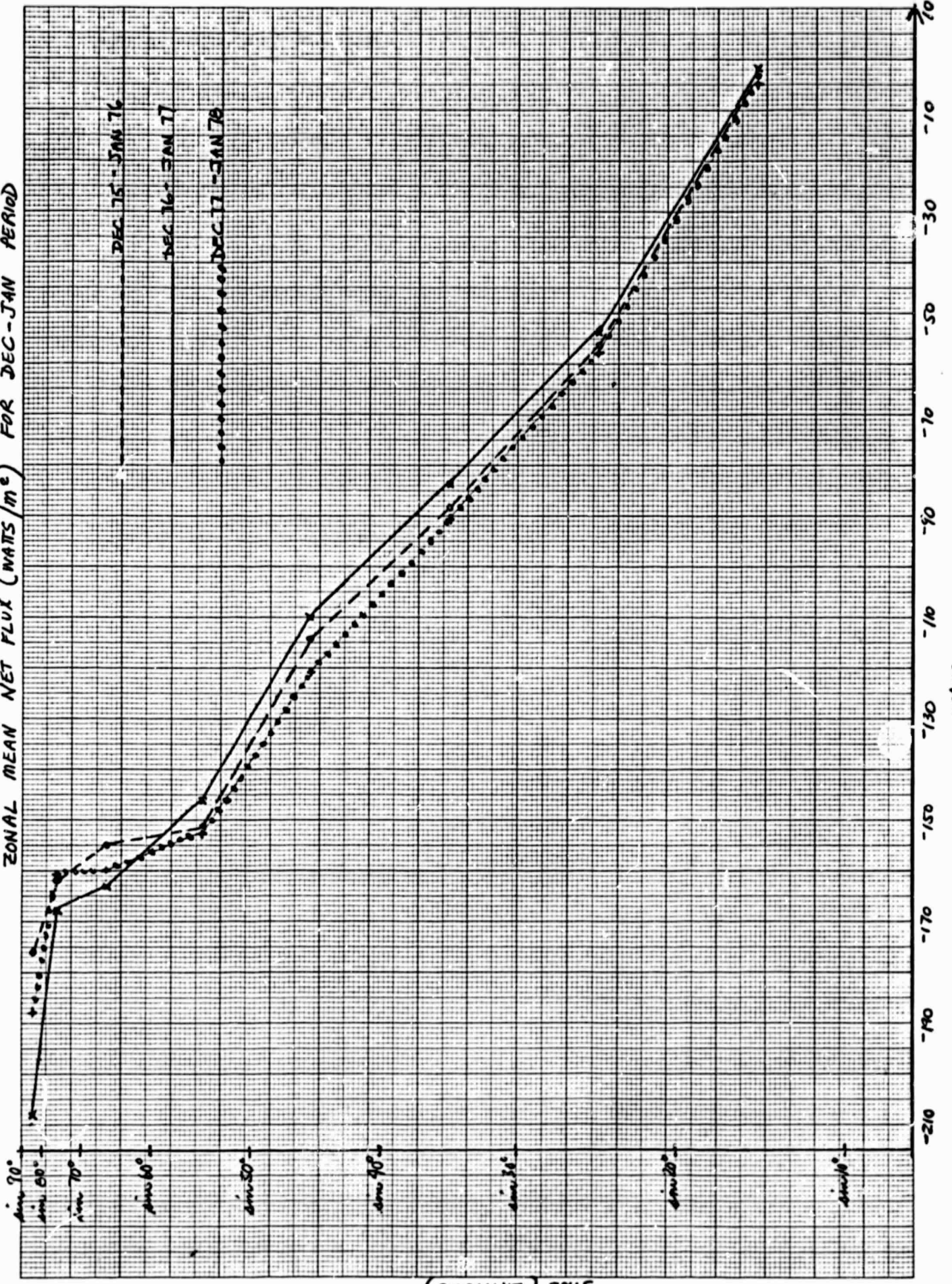


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10 0 TH TIME 18 X 2 KEUFFEL & ESSER CO MADE IN U.S.A.

Figure I-17

ZONAL MEAN NET FLUX (WATS/m²) FOR DEC-JAN PERIOD



40 JULIO

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SINE (LATITUDE)

demonstrated superior to a finite difference grid. Because the dissipation is often modeled by horizontal diffusion, it is useful to use spherical harmonics as the spectral basis functions.

In this first model approach, the diabatic forcing is assumed temporally constant (e.g., a seasonal average) and we solve for the steady circulation as a response. Transient motions (i.e., weather) are parameterized as dissipative to the steady circulation. To make the model tractable, the results understandable, and the energetics simple, a dynamical approximation to the primitive equations is assumed. At present the "linear balance" system is being used because it is the simplest quasi-geostrophic-type system which is valid globally. Despite the "linear balance" label, the vorticity and thermodynamic budgets are fully non-linear. This is the chief distinction from the generation of linear models (e.g., Sankar-Rao and Saltzman) used in the 1960's; in those earlier studies, the mean zonal flow was specified a priori independent of the standing eddies. Hence, a large part of the general circulation was assumed, and not necessarily consistent relative to the eddies. Here we take the much more satisfying approach of finding both the mean flow and the standing eddies which result from a prescribed stationary forcing, consisting primarily of radiative heating/cooling, latent heat release, and sensible/latent heat flux from the surface.

Unfortunately, this important aspect of reality also makes the problem much more difficult to solve, because a non-linear system of equations must be solved. There is no universally applicable method for finding the non-linear solution; indeed, there is not even a guarantee of a unique solution or of any solution at all. Because of Ashe's results, we are confident that a solution can be obtained. At present, we are attempting three methods of solution:

- (1) Iterate in time from a simple initial condition to the asymptotic steady state.
- (2) Use a standard IMSL non-linear equation solver. (Unfortunately, this method depends crucially on initial conditions, which may not be sufficiently precise.)
- (3) First calculate a linear response and then use this solution as the initial guess in the iterative methods (1) and/or (2).

We still have a significant amount of work to do in this area in order to obtain the non-linear solution. Because of the notorious difficulties with non-linear systems of equations, there is no guarantee of success.

The second model approach makes similar dynamic approximations, but explicitly calculates the time evolution of the flow. Thus, time-dependent radiation can be taken from observations (including the seasonal cycle and the interannual variation), applied as a forcing, and the response of the atmosphere computed. The individual "synoptic" flows can then be averaged to obtain monthly means, seasonal means, and interannual variations. Thus, we will be able to find whether or not the atmospheric circulation is sensitive to externally specified changes in radiative forcing. In turn, this will guide our understanding and interpretation of the present and future radiation budget measurements from satellites.

The preliminary development of the latter model is being done by Adel Hanna, a Ph. D. student, under the auspices of other funding sources. Duane Stevens is advising him in this research effort. As this model is in an early development stage, results are of a very preliminary nature. Further "tuning" of the physical parameterization will probably be required in order to attain an approximately veritable simulation of the annual average and seasonally-varying circulation. The following represents some of these preliminary results.

The second model under discussion is a two-level global "linear balance" model. In the horizontal domain a rhomboidal spectral truncation is assumed (presently, we truncate at zonal wave no. 9). In this section the results of time integration of the model up to 120 days, to simulate the January circulation, are discussed.

The model was initiated assuming an atmosphere at rest and with constant moist adiabatic lapse rate ($6.5^{\circ}/\text{km}$). Assuming a perpetual January forcing, the solar inclination is fixed to that of the first of January. Figure 2-1 shows the net solar radiation at the top of the model's atmosphere and the net solar radiation absorbed by the earth's surface at different latitudes in the model. Except the Arctic Ocean, sea surface temperature were prescribed as the January climatological values. Orographic effects are parameterized through the vertical motion at the 1000-mb level.

The winter observational estimations for different variables were taken from Newell *et al.* (1971). Data for the average January were taken from Oort and Rasmusson (1971).

a) The Average Zonal Wind

The zonal wind component at different grid points was averaged in latitude and time (30 days). In the northern hemisphere (winter hemisphere) the average 500-mb zonal wind compared well with the observed pattern (Figure 2-2). The same for the 250-mb distribution (Figure 2-3). The observations show a westerly jet at 30°N (20 m sec^{-1} at 500 mb and 38 m sec^{-1} at 250 mb). The calculated values place the maximum zonal wind at 23°N with maxima of 15 m sec^{-1} and 25 m sec^{-1} for the 500-mb and 250-mb cases, respectively. It can also be noticed that the calculated averages for the period 61-90 days show nearly the same values as the averages for the periods 91-120 days in the case of 500 mb, also the same agreement between the 31-60 days average and 91-120 days in

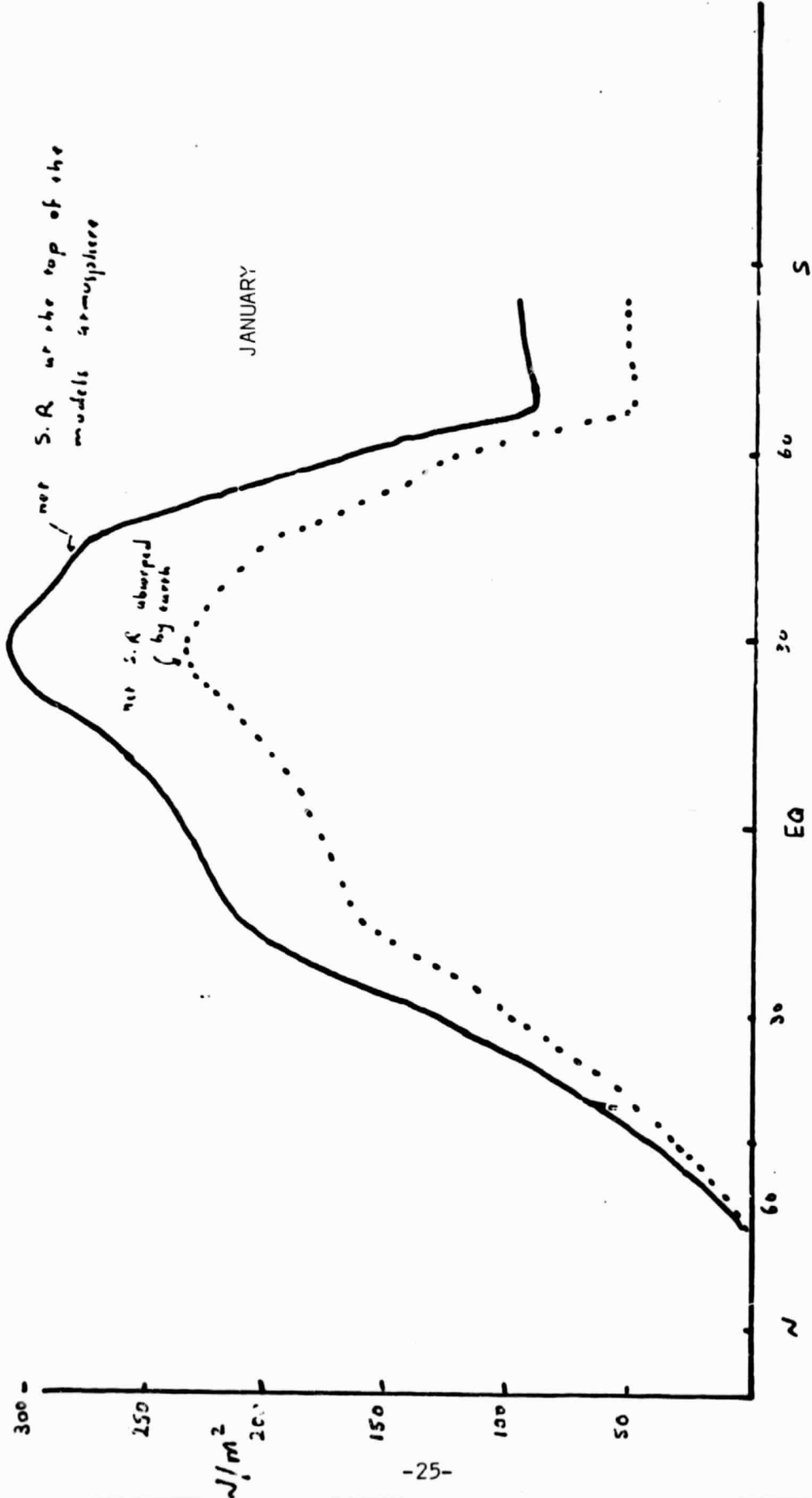


Fig. 2-1 Net Solar radiation at the surface and top of the model's atmosphere for January

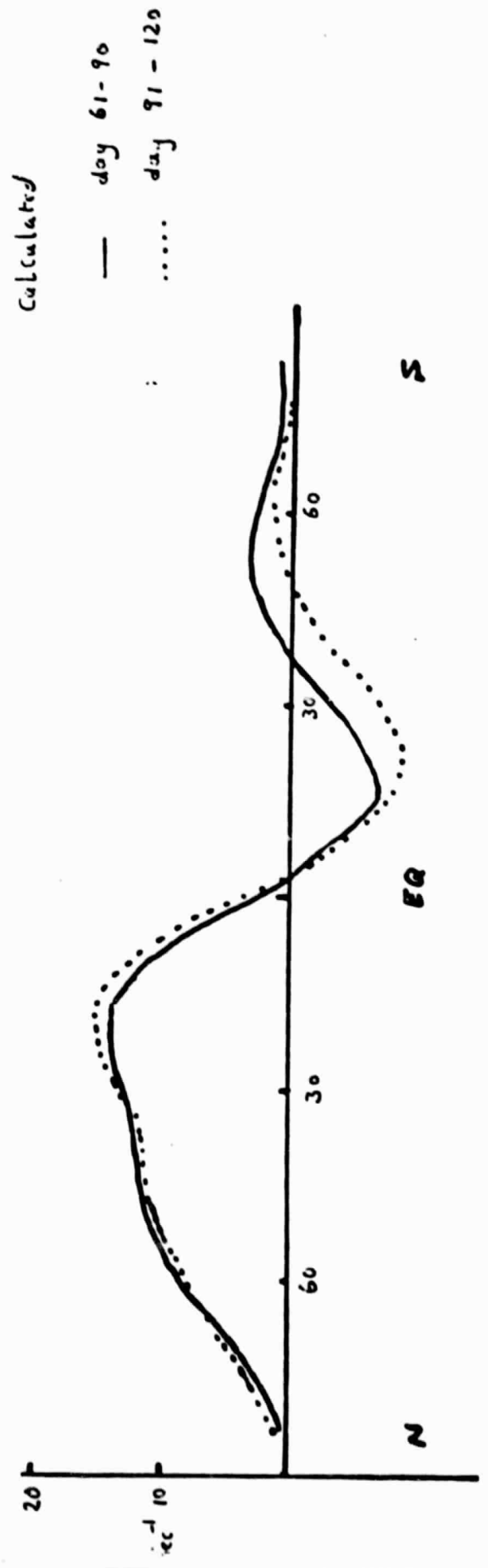
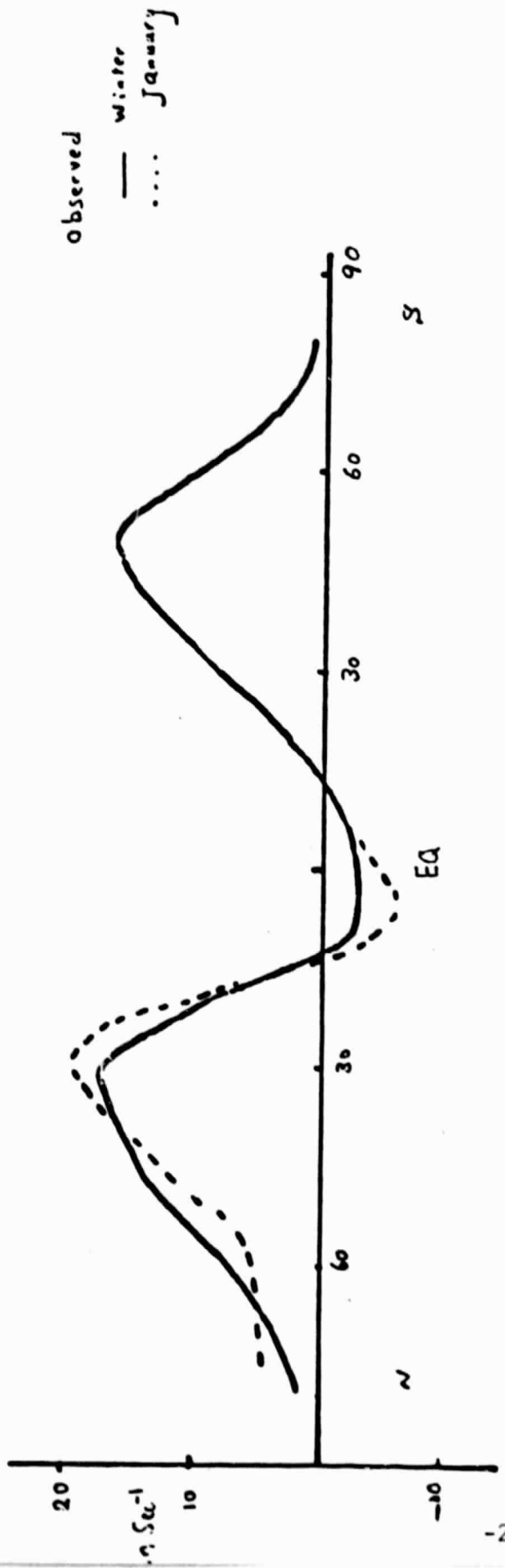
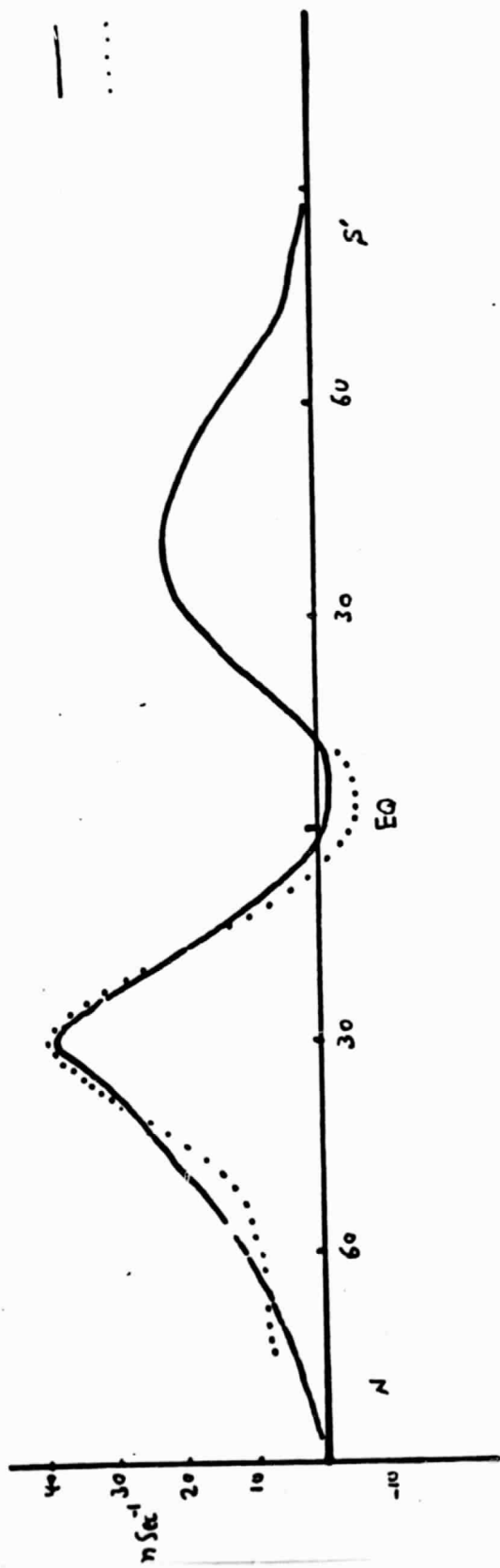


Fig. 2-2 Observed and calculated mean zonal wind 500 mb.

observed

— winter
..... January



calculated

— 91-120 day
..... 31-60 day

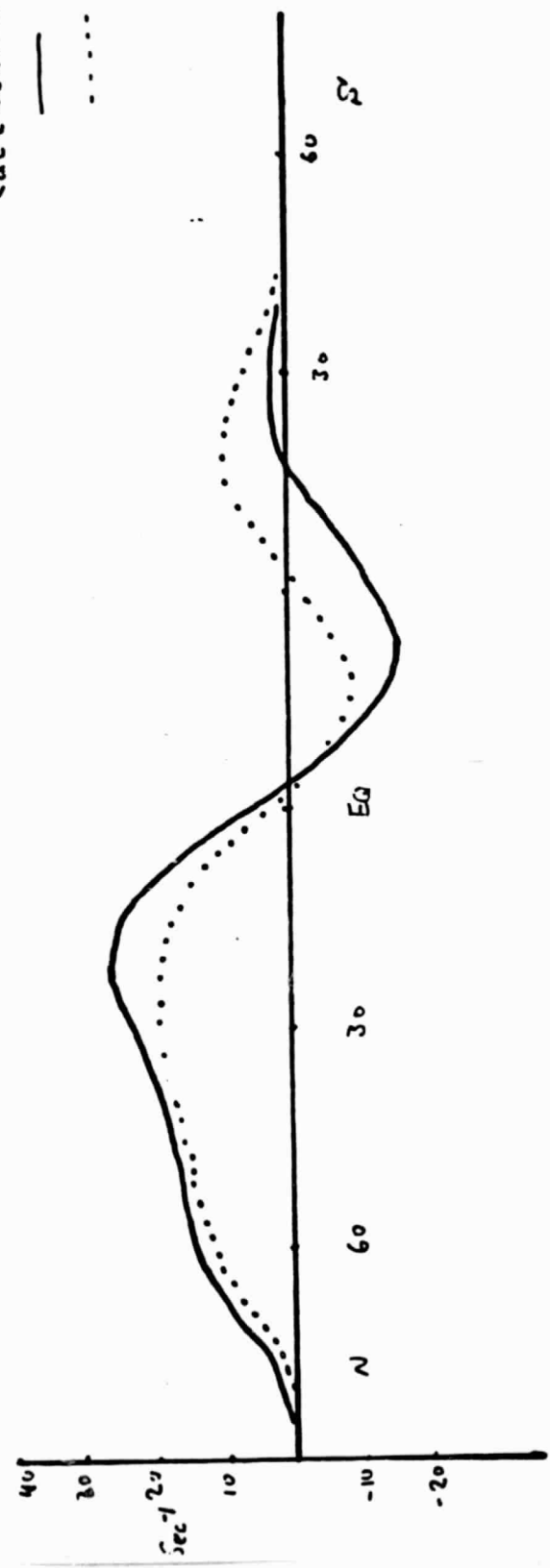


Fig. 2-3 Observed (200 mb) and calculated (250 mb) mean zonal wind.

the case of the 250 mb. This indicates that the zonal momentum is reaching a statistical steady state.

In the southern hemisphere (summer hemisphere) the calculated values have less agreement with observations than the northern hemisphere case. In both the calculated 500-mb and 250-mb cases, the westerly jet in the extratropical southern hemisphere is much damped and shifted. On the contrary, the equatorial easterlies are amplified and broadened to reach the southern hemisphere mid-latitudes. The variability between different time averages for both 500 mb and 250 mb may suggest that values at this region need a longer simulation than already have been done.

b) Meridional Wind Component

The zonally averaged meridional wind component is being calculated from the zonally-averaged velocity potential. The latter is at least one order of magnitude smaller than the velocity stream function (in middle and high latitudes). Even observational estimates show a large variability between winter and January cases (Figure 2-4). In the northern hemisphere the calculated averaged meridional velocity at 750 mb changes its sign corresponding to the vertical mass flux at 500 mb (Figure 2-4), validating the mass continuity. In the southern hemisphere the areas of equatorward flux (positive v) are not simulated since the vertical mass flux is mainly upward (negative w).

c) Vertical Velocity

The observed and calculated 500 mb vertical velocity field (units 10^{-4} mb sec^{-1} , 10^{-5} mb sec^{-1} , respectively) is shown in Figure 2-5. Again in the northern hemisphere the calculated values resemble the observed phase but with smaller amplitudes. The midlatitude ascending motions and the subtropical subsidence are well fitted with the observations. The calculated subtropical subsidence occurs in a rather broad latitude band in comparison to that which is observed. This feature may account for the same mass flux to counter the

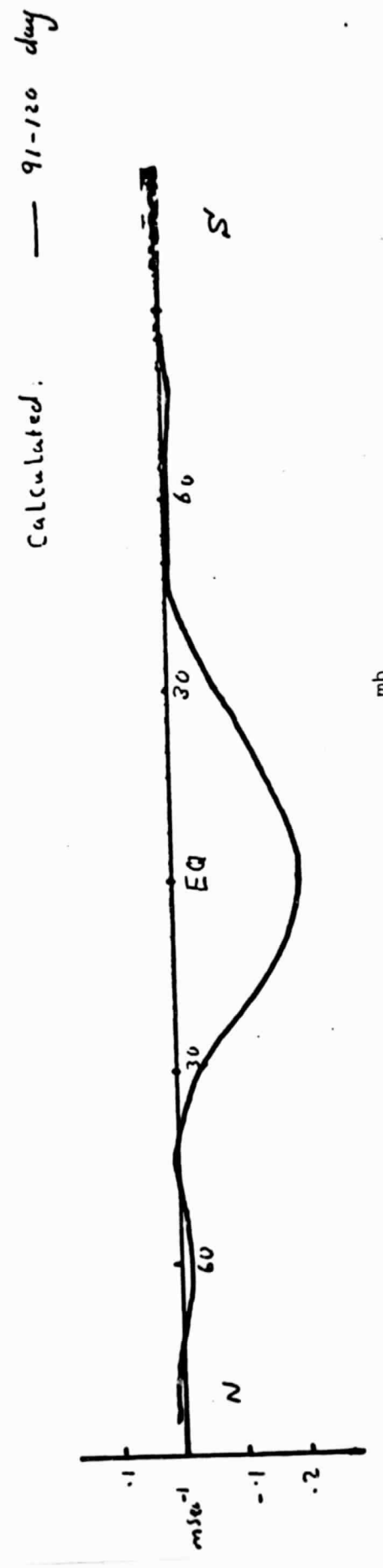
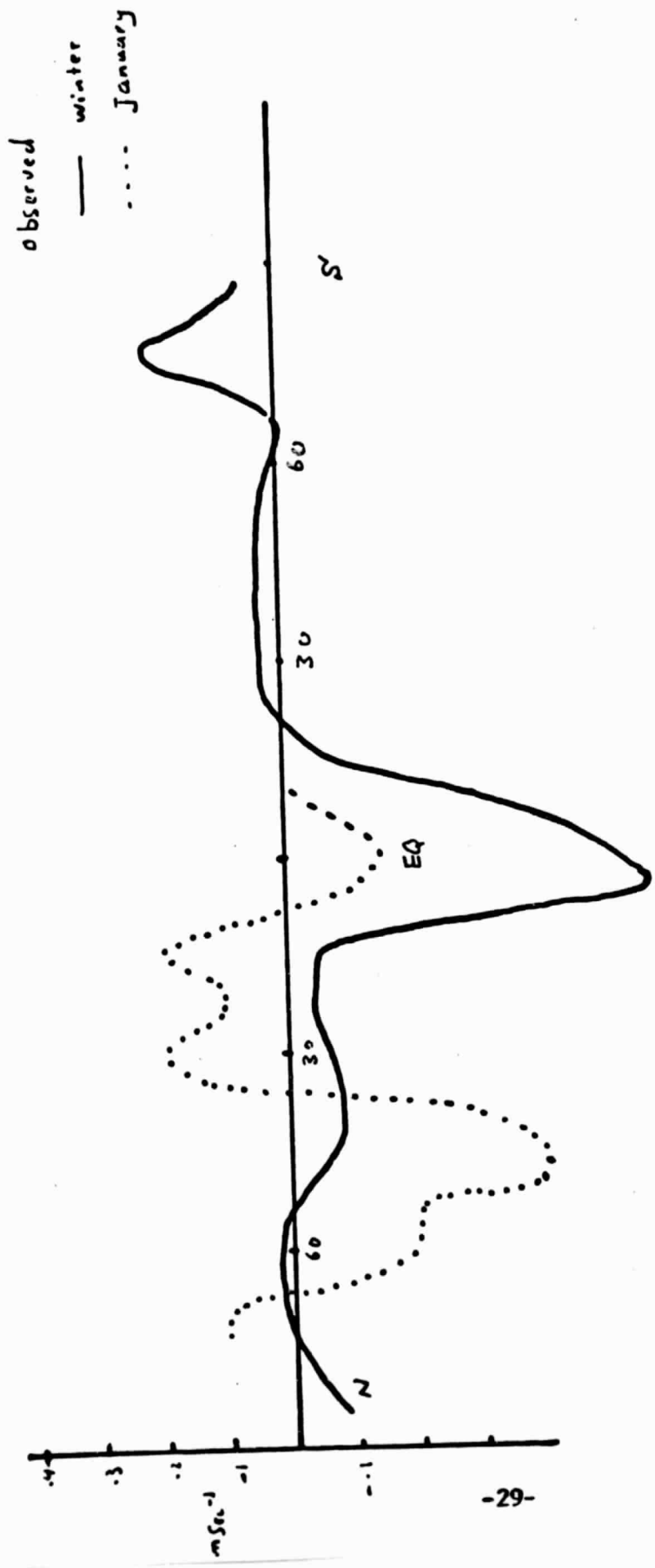
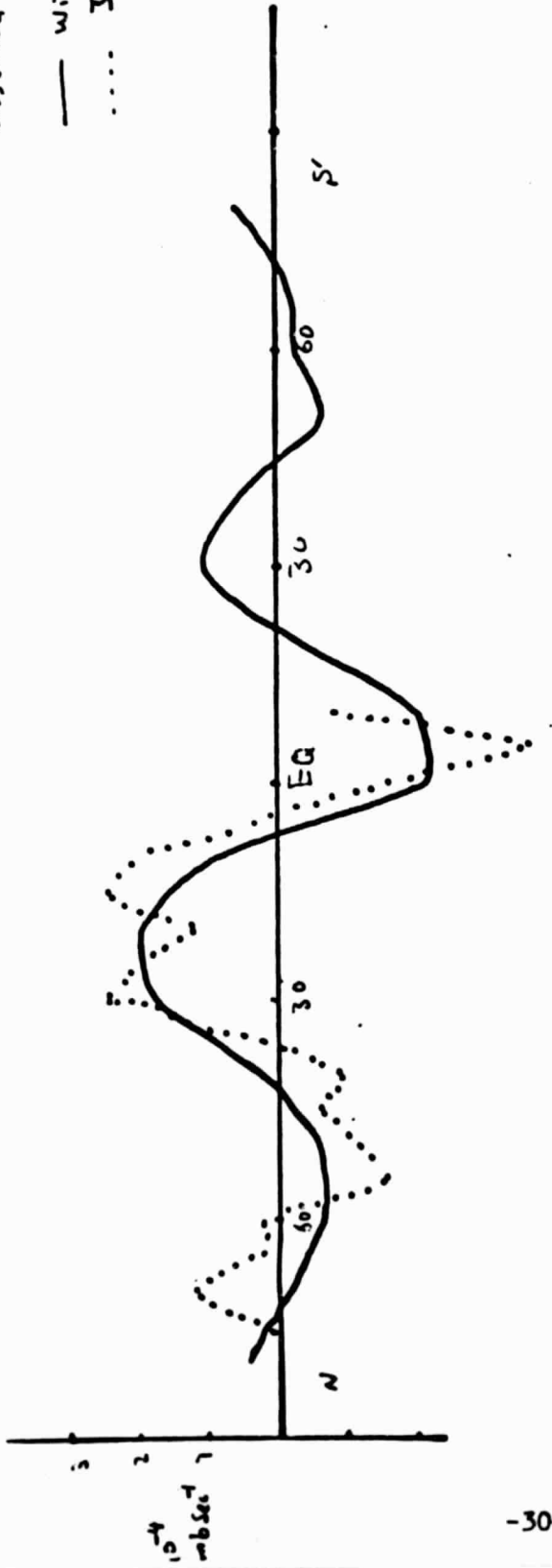


Fig. 2-4 Observed (700 mb) and calculated (750 mb) mean meridional wind.

observed
— winter
.... January



60-90 day
91-120 day

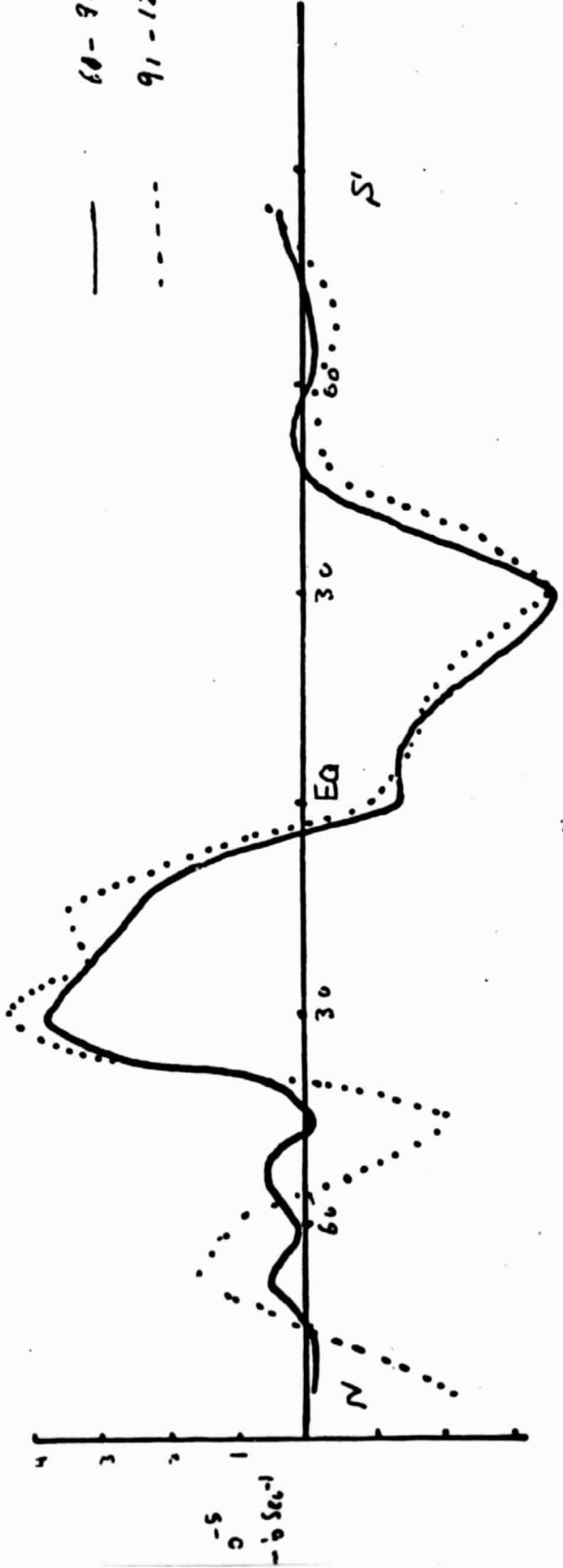


Fig. 2-5 Observed and calculated pressure velocity at 500mb.

decrease of amplitude. In the southern hemisphere maximum shifting with the ITCZ is shifted to 30°S with a very weak subsidence in the extratropical latitudes.

d) Moisture Budget

The model uses a simple moisture budget equation in the lower layer with the assumption that the upper layer is dry. Precipitation occurs with release of latent heat of condensation when the relative humidity of the lower layer exceeds 80%. The model's atmosphere is convectively adjusted if the temperature lapse rate, after the release of latent heat, exceeds the saturated adiabatic lapse rate. Figure 2-6 shows the zonally averaged precipitation and mixing ratio (gm/gm); both have a reasonable distribution except the subtropical maxima at 30°N . This is a result of the critical relative humidity assumed for precipitation (80%). At the subtropical latitudes the relative humidity may exceed 80% without any precipitation.

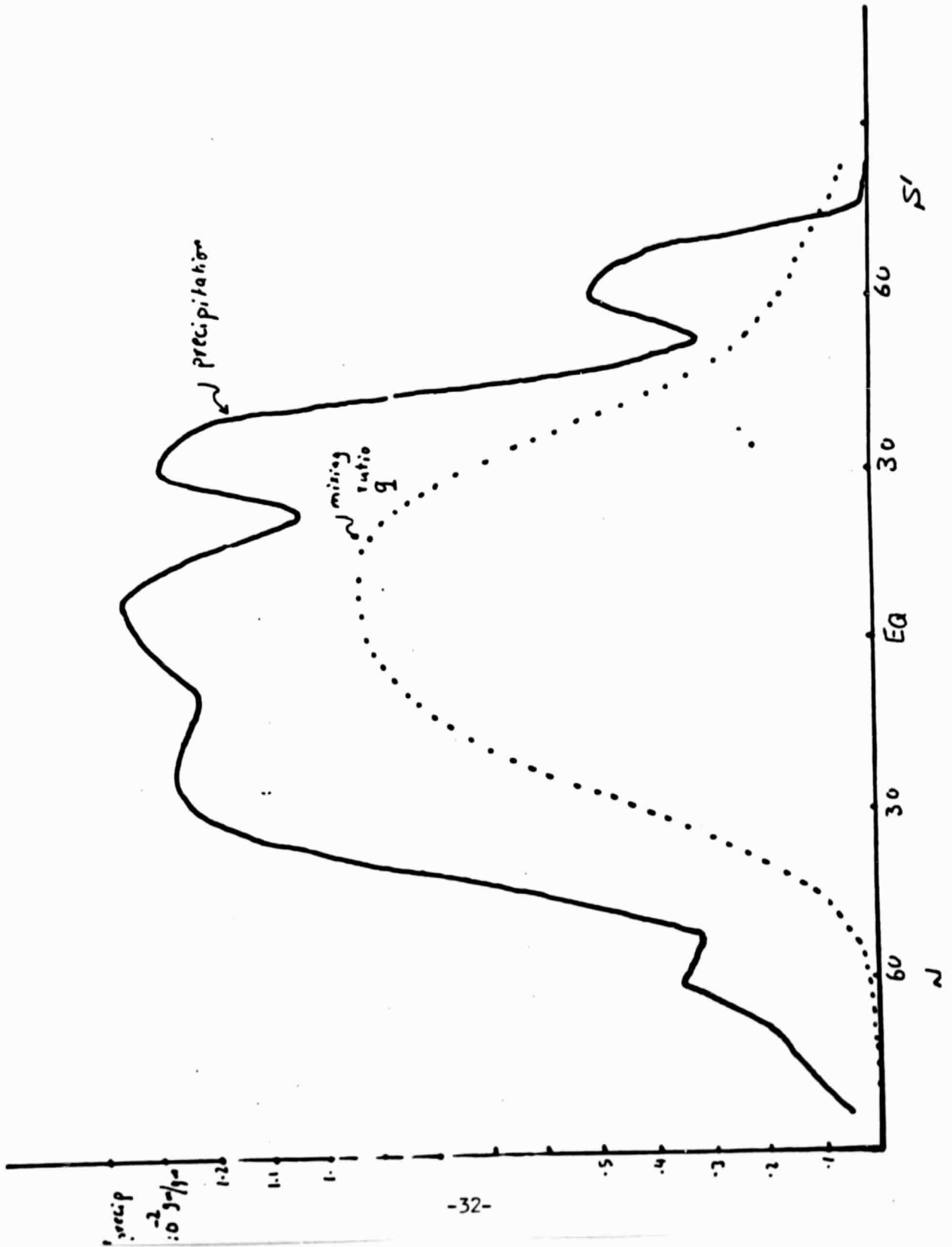


Fig. 2-6 Calculated precipitation and mixing ratio day 91-120.

3.0 Review of Concurrent Radiation Budget Research by Other Scientists

During the last year new papers and reports by Ohring, G. Smith et al., Gruber, Hansen et al., and others have continued the study of earth radiation budget and related modeling. We are reviewing these papers as they relate to our work on this project. They will be referenced in our reports in preparation.

4.0 References

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