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SCHOOL ON PHYSICAL METHODS FOR THE STUDY OF THE UPPER AND LOWER ATMOSPHERE SYSTEM

26 October - 6 November 1992
Miramare - Trieste, Italy

National Meteorological Center (NMC) daily operational analyses 1000-1 mb (0-50km)

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National Meteorological Center (NMC)
daily operational analyses
1000-1 mb (0-50 km)

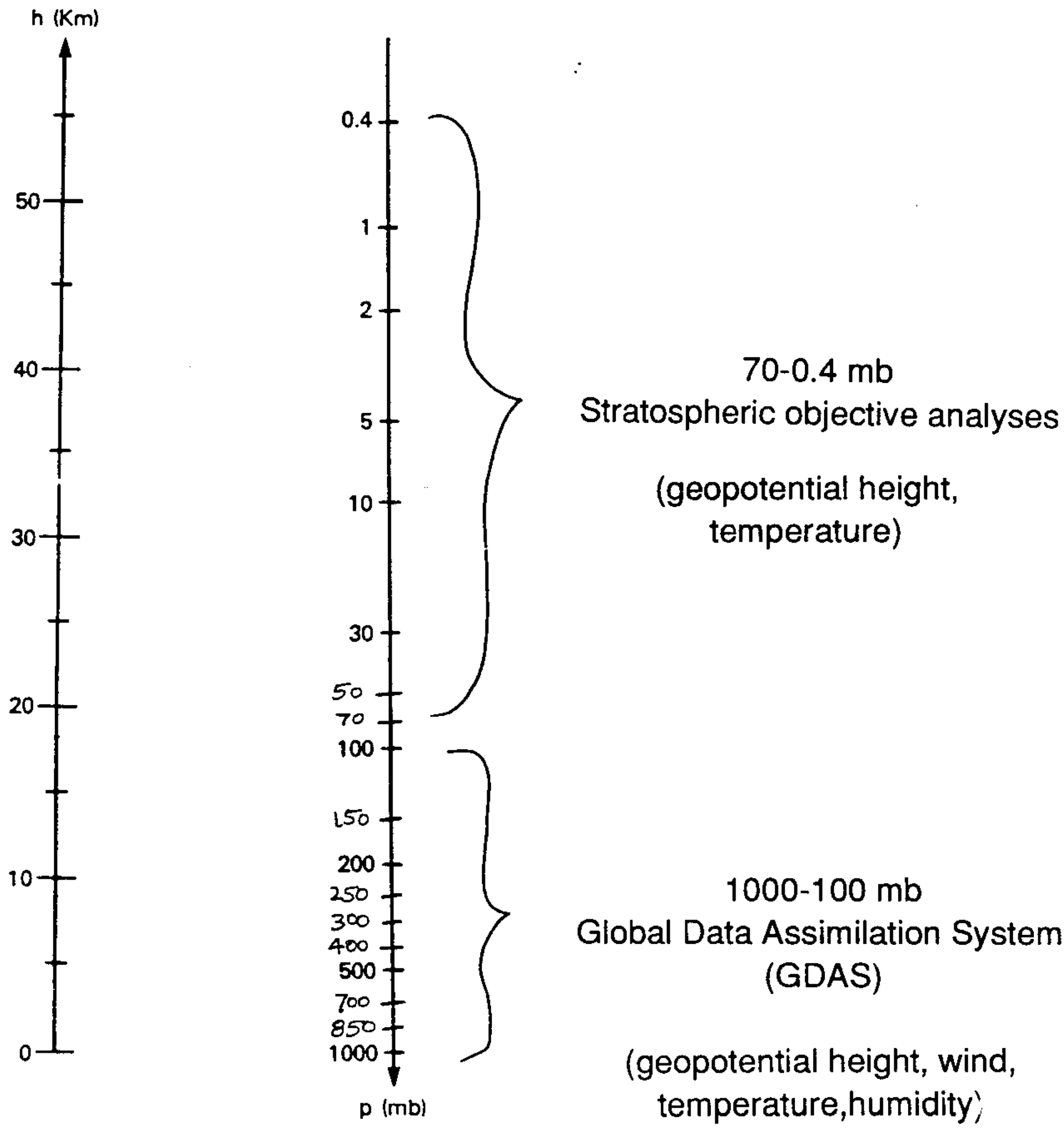
- combination of NMC Global Data Assimilation System tropospheric analyses (1000-100 mb) and NMC operational stratospheric analyses (70-1 mb)

- data origin, characteristics, biases and changes with time

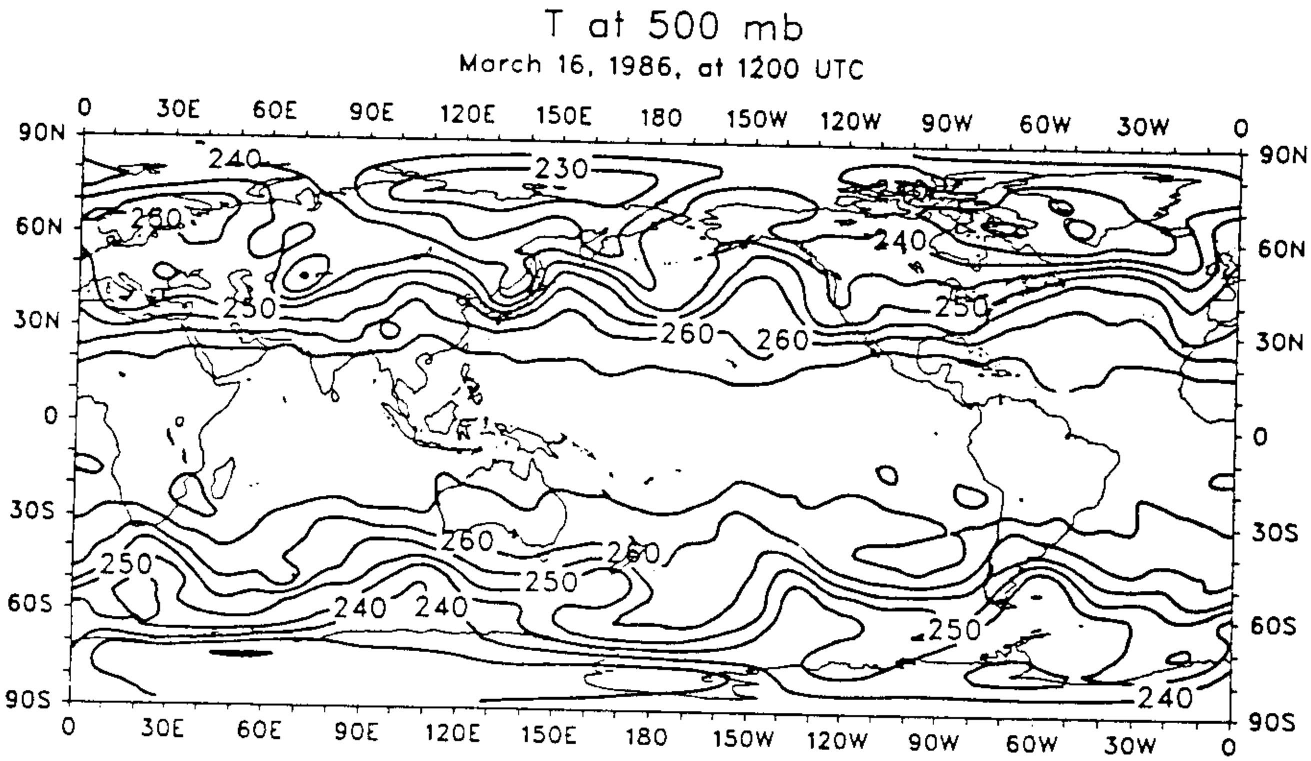
- example of calculations with geopotential height data:

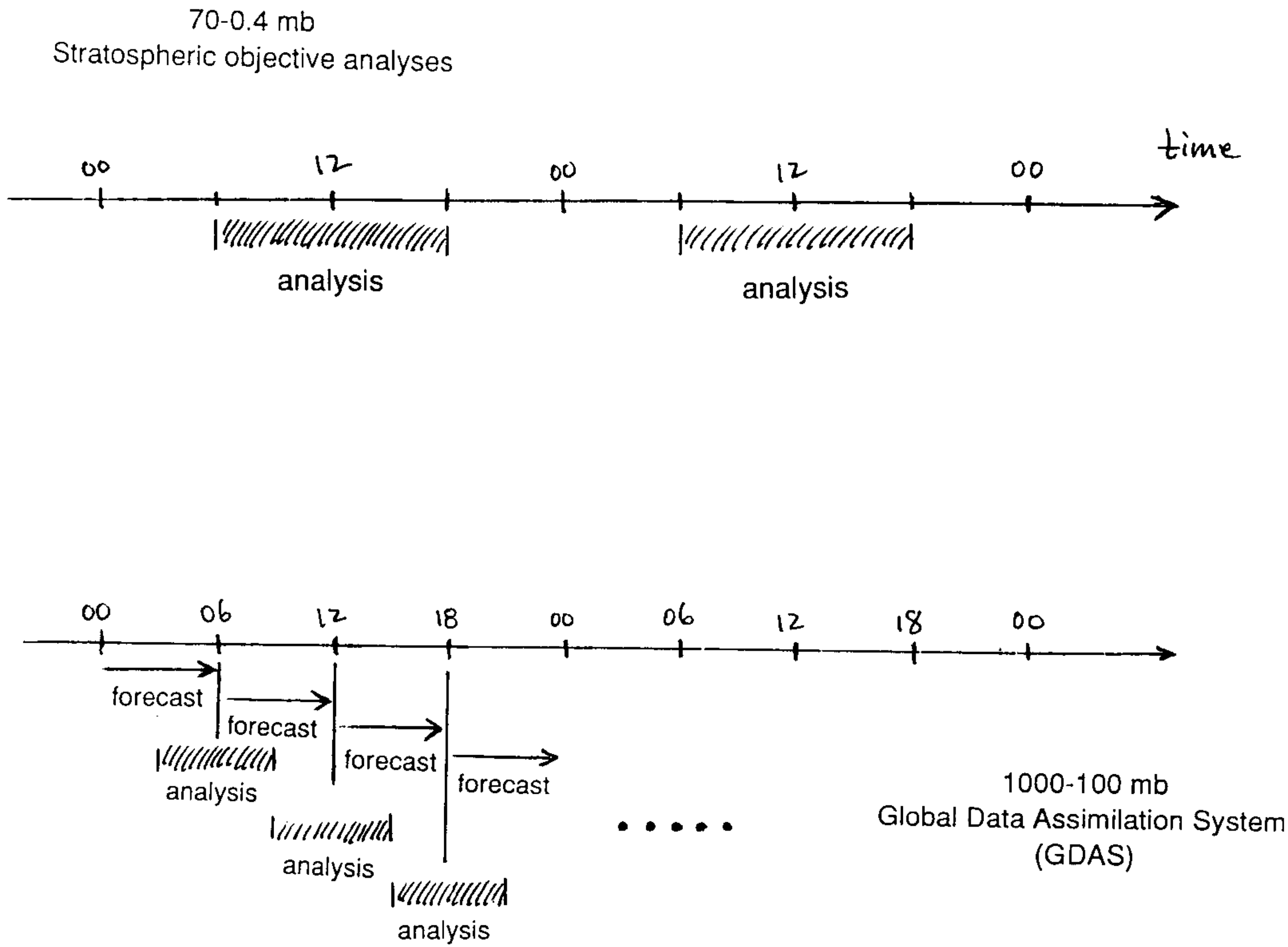
    temperatures
    winds
    eddy flux quantities
    vertical propagation of planetary waves

National Meteorological Center (NMC) daily operational analyses



Example: global temperature analysis at 500 mb




70-0.4 mb
Stratospheric objective analyses
time
00
12
00
12
00
analysis
analysis
00
06
12
18
00
06
12
18
00
forecast
forecast
forecast
forecast
analysis
analysis
analysis
1000-100 mb
Global Data Assimilation System
(GDAS)

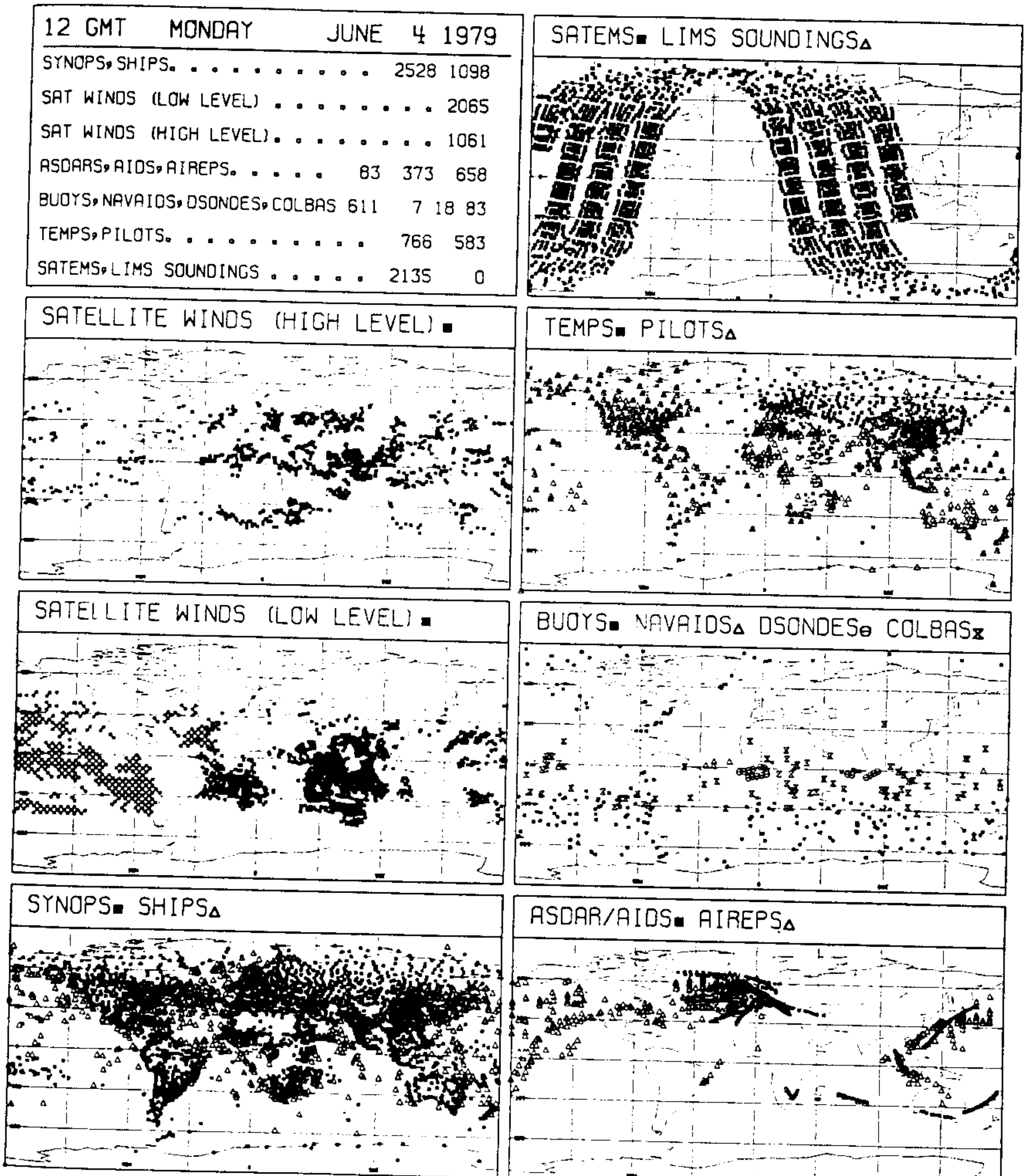


FIG. 4. FGGE level II-b data distribution. 4 June 1979 12 GMT ±3 h.

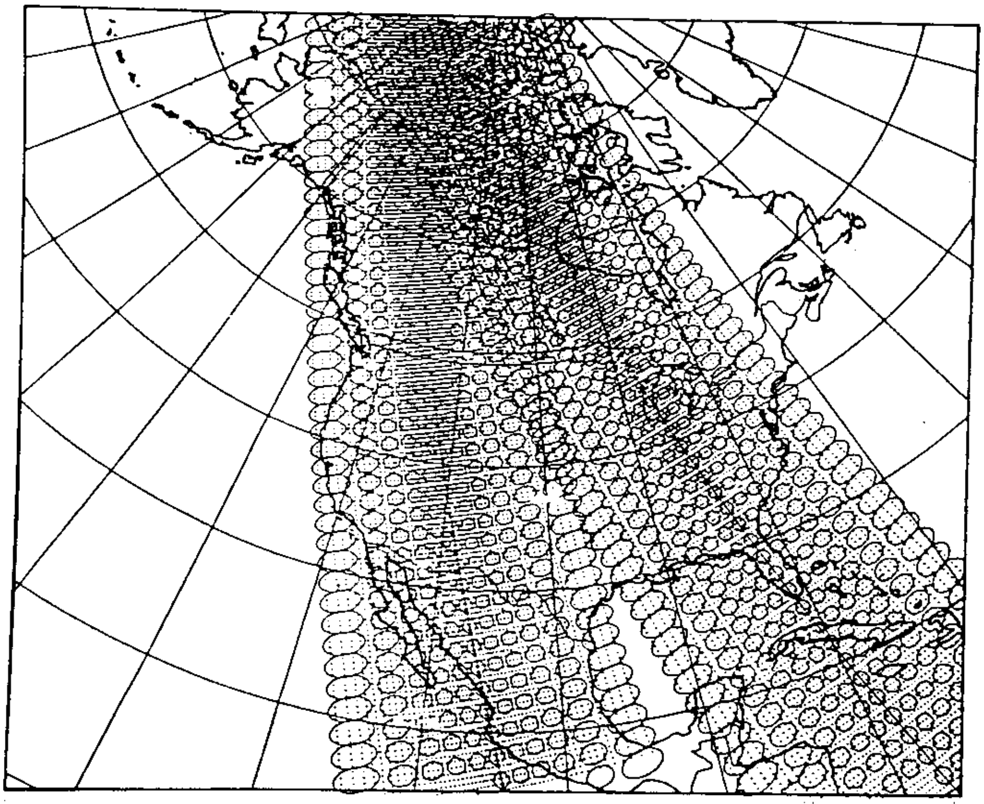


Fig. 2. HIRS and MSU scan patterns for two consecutive orbits.

Horizontal scan patterns for stratospheric temperature sounders

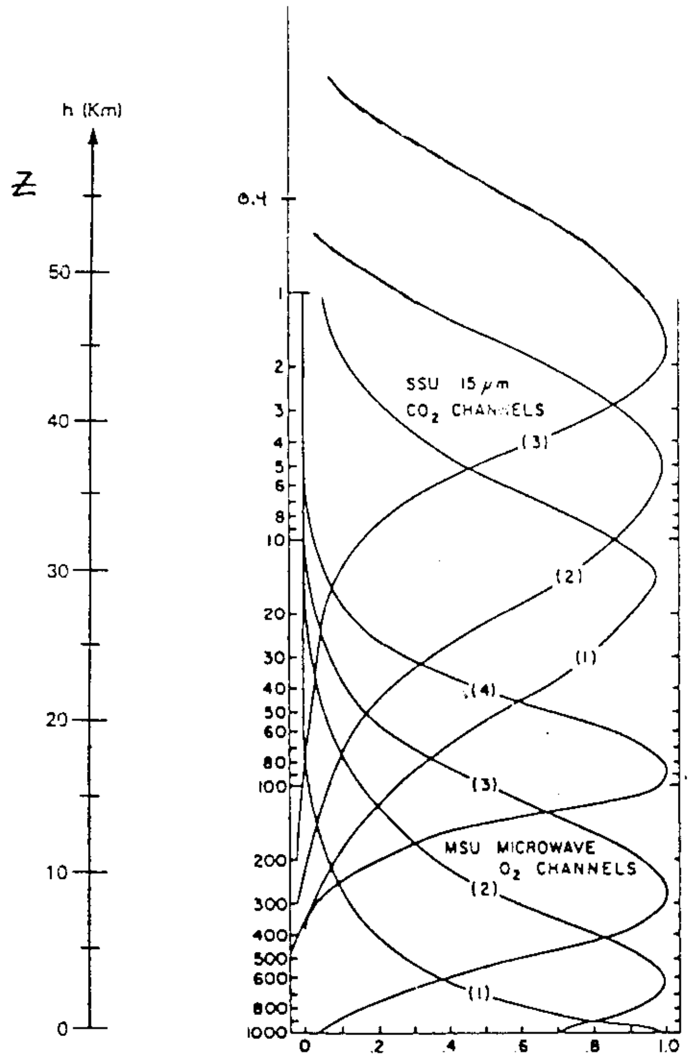
Some cautionary notes regarding use of NMC operational data

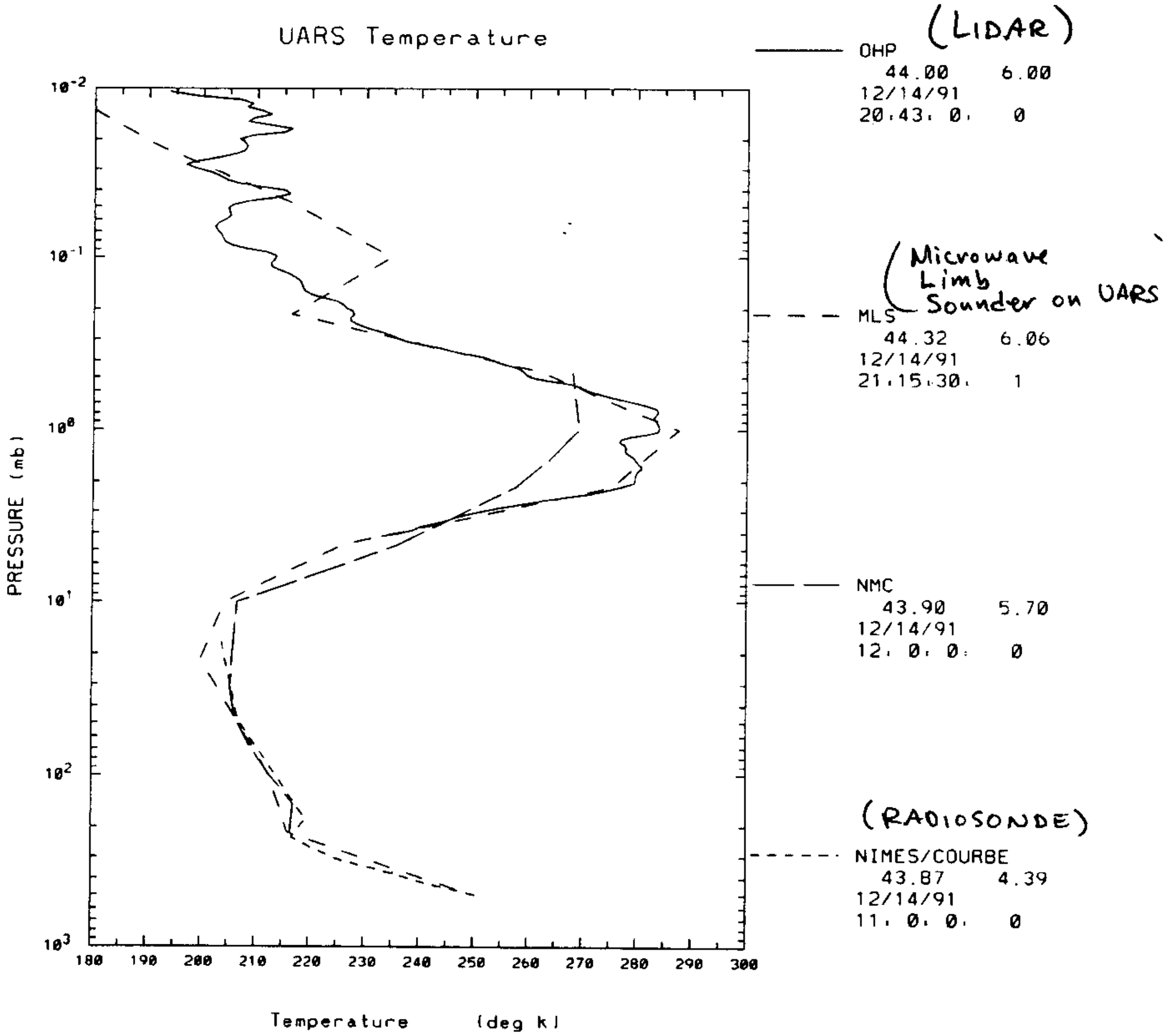
1) stratospheric temperature biases, due to low vertical resolution of satellite measurements

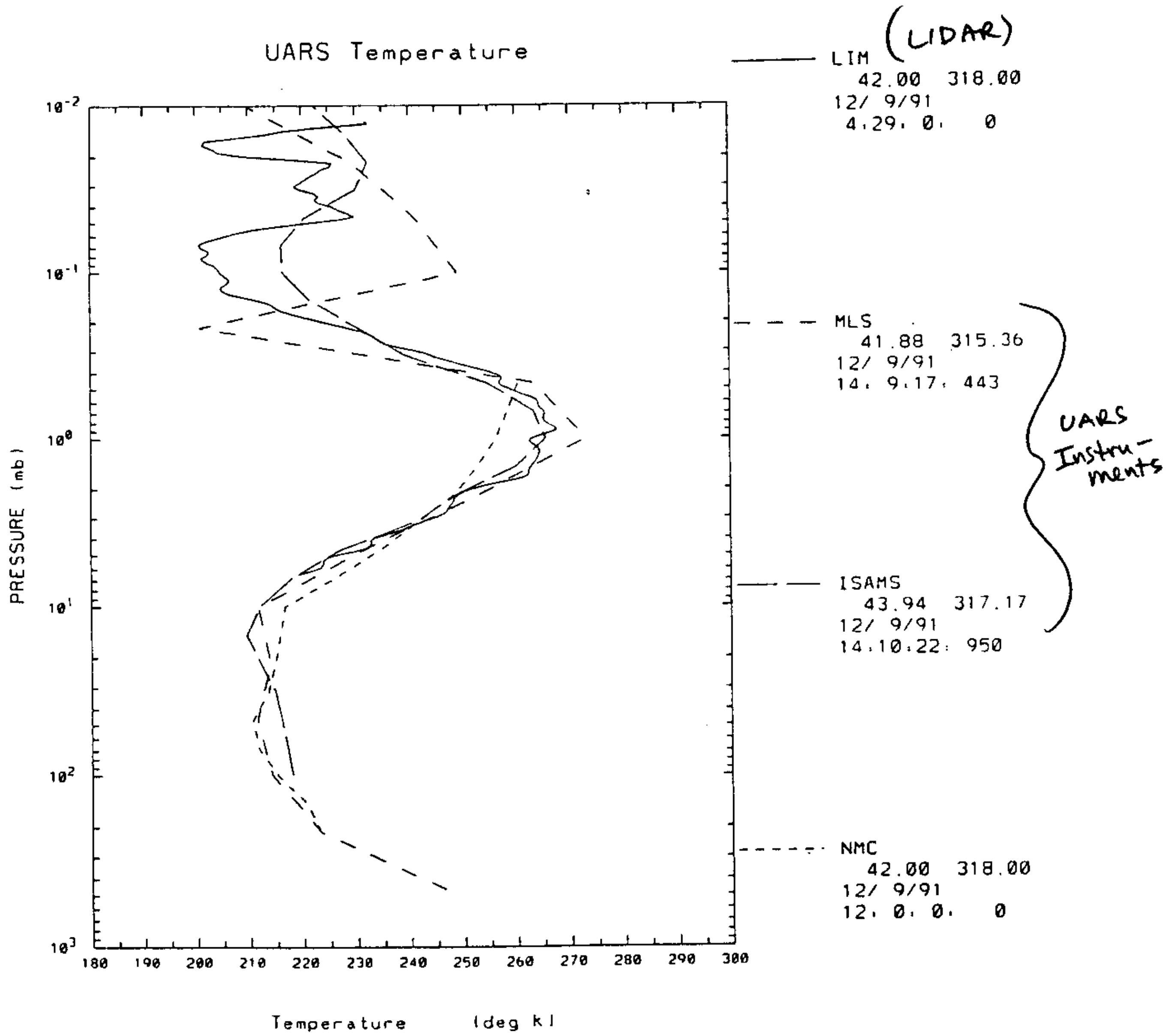
2) changes in products occur when forecast model changes (troposphere) or satellites change (stratosphere)

Satellite weighting functions W(z) used for stratospheric temperature retrievals

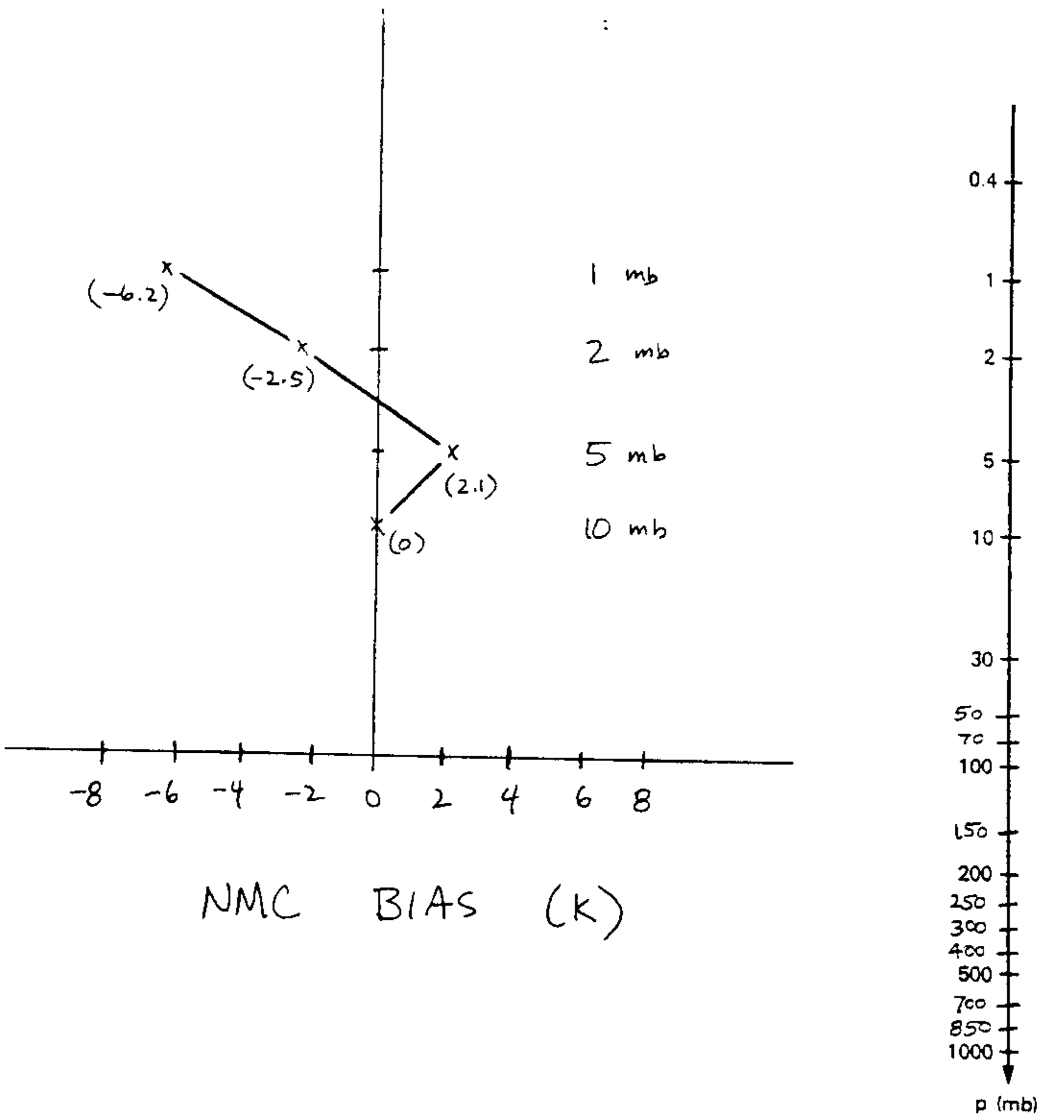
$$\text{SATELLITE MEASURED TEMPERATURE} = \int_0^\infty T(z) \cdot W(z)\, dz$$




UARS Temperature
PRESSURE (mb)
10⁻²
10⁻¹
10⁰
10¹
10²
10³
180
190
200
210
220
230
240
250
260
270
280
290
300
Temperature (deg k)
(LIDAR)
OHP
44.00 6.00
12/14/91
20,43, 0, 0
(Microwave Limb Sounder on UARS
MLS
44.32 6.06
12/14/91
21,15,30, 1
NMC
43.90 5.70
12/14/91
12, 0, 0, 0
(RADIOSONDE)
NIMES/COURBE
43.87 4.39
12/14/91
11, 0, 0, 0


UARS Temperature
PRESSURE (mb)
10⁻²
10⁻¹
10⁰
10¹
10²
10³
180 190 200 210 220 230 240 250 260 270 280 290 300
Temperature (deg K)
LIM (LIDAR)
42.00 318.00
12/ 9/91
4, 29, 0, 0
MLS
41.88 315.36
12/ 9/91
14, 9, 17, 443
ISAMS
43.94 317.17
12/ 9/91
14, 10, 22, 950
NMC
42.00 318.00
12/ 9/91
12, 0, 0, 0
UARS Instruments

NMC stratospheric temperature bias



Example of change in tropospheric analyses resulting from change in forecast model

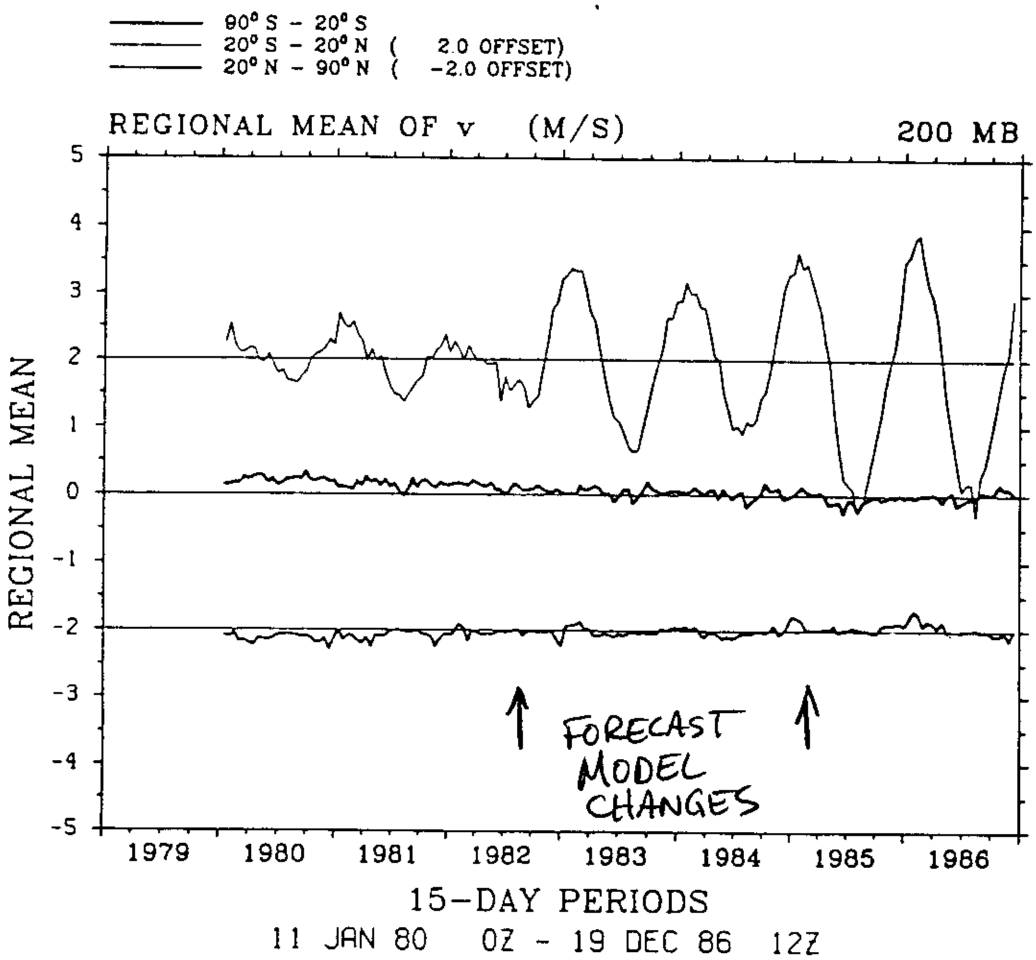
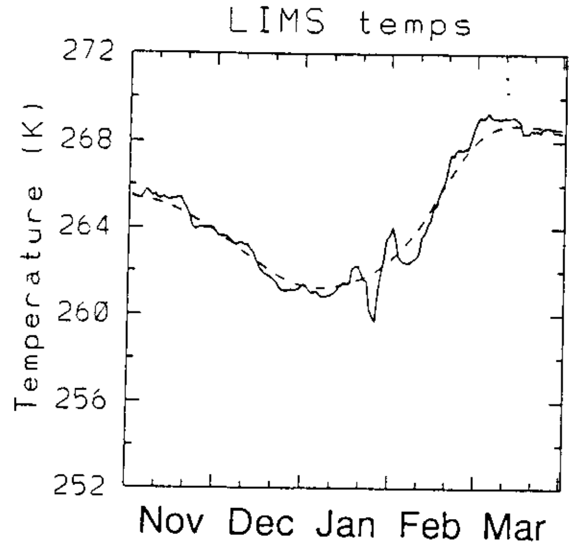


Fig. 14. 15-day averages of areal averages of v at 200 mb, in m s^{-1}.

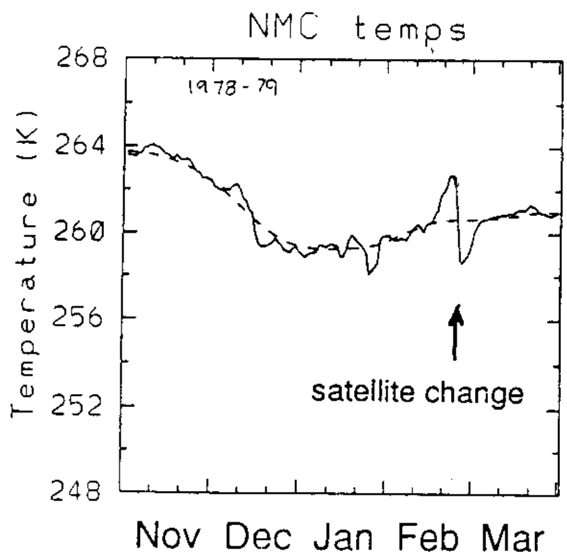
- note change in wind velocity coincident with changes in forecast model.

from Trenberth (1992)

Discontinuities introduced by satellite changes



Limb Infrared Monitor of the Stratosphere data



NMC data

CHANGES DETERMINED BY STATISTICAL EVALUATION

Another method of determining these changes is by statistical evaluation. Determinations based on this approach for 2 mb are also shown in Figure 1 (denoted by Step Regression). An equation of the form

$$T = X + Wt + b_1 d_1 + \ldots b_8 d_8$$

was fit to the monthly mean temperatures (T) for a particular latitude and level. The period of record is defined for each of the eight periods. An offset or step function (d) is then determined for each of the 8 periods in the whole data set. The X is a relative bias for the whole data set (reference is arbitrary) and Wt is the slope (W) with time (t) for the 91 months of record, from October 1978 to April 1986.

The relative pattern of agreement among the different methods depicted in Figure 1 is reasonably good. However, differences of 2 to 4 C degrees are common so that uncertainty in adjustments of this magnitude should be expected.

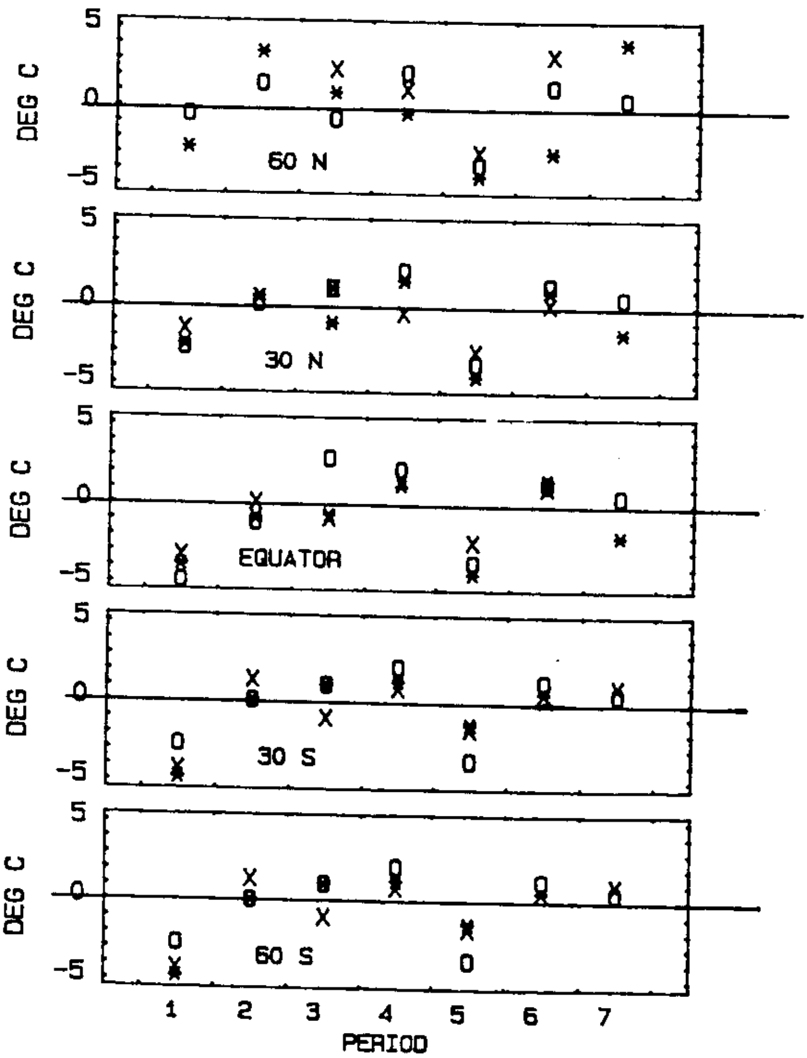
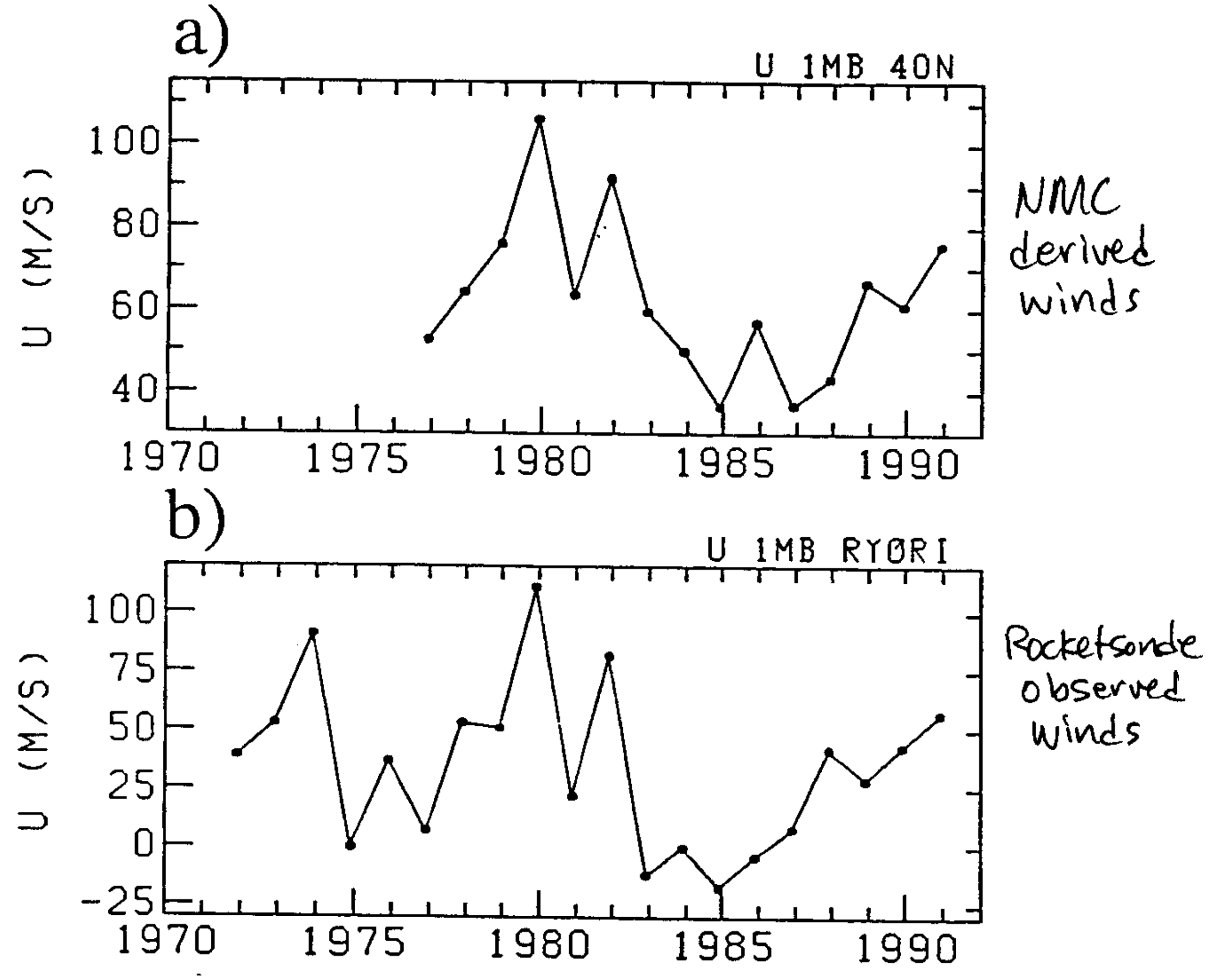


Fig. 1. Temperature changes in the 2 mb NMC analyses, as inferred from rocket comparisons (o,Rocket), comparison of analyses around change dates (x,Joint), and regression (*,Step Regression), as explained in text.


a)
U 1MB 40N
100
80
60
40
U (M/S)
1970
1975
1980
1985
1990
NMC derived winds
b)
U 1MB RYORI
100
75
50
25
0
-25
U (M/S)
1970
1975
1980
1985
1990
Rocketsonde observed winds

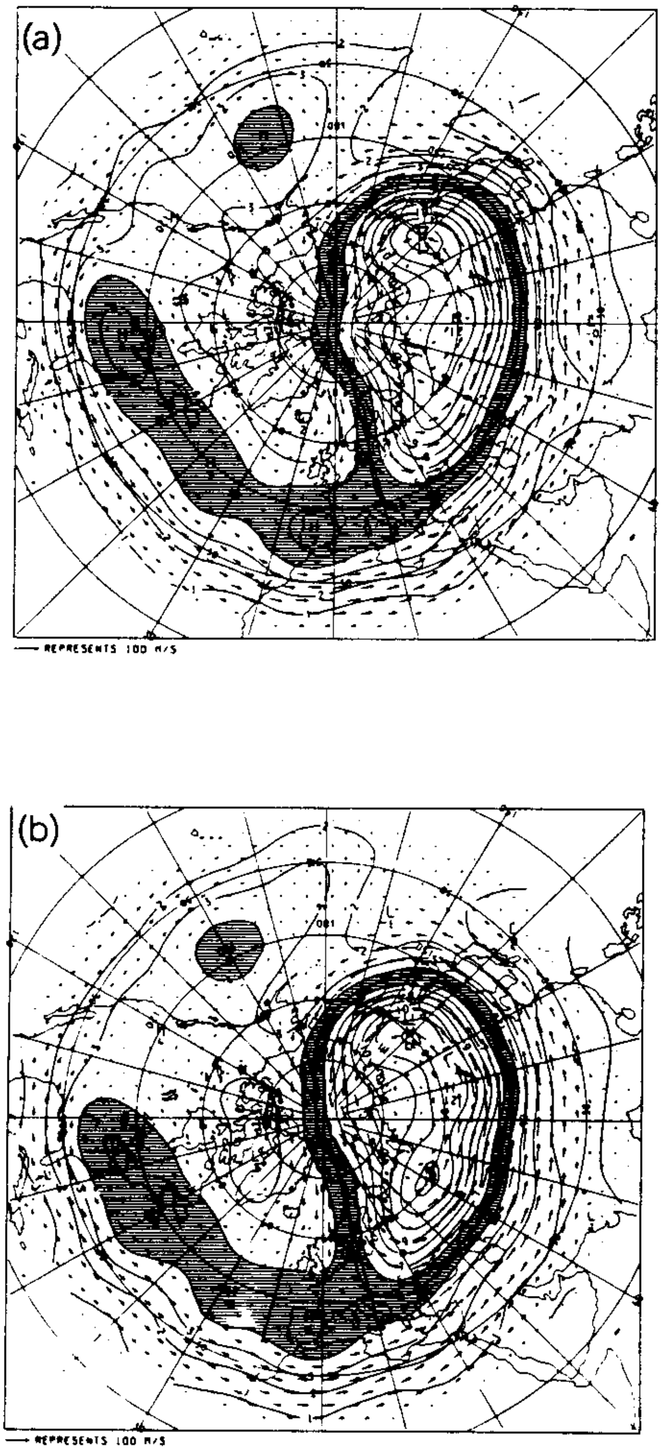


Figure 1. Ertel's potential vorticity, Q, and geostrophic winds evaluated on the 850 K isentropic surface for 7 December 1981. (a) Using data from NOAA-6; (b) using data from NOAA-7. Units: K m^2 kg^{-1} s^{-1} $\times 10^{-4}$. In these units, areas with values of Q between 4 and 6 are shaded.

NMC data available at Trieste

Global analyses of geopotential height
covering 1000-1 mb (17 pressure levels)

Once daily analyses covering 1979-1990

Stored as zonal Fourier coeffecients
(up to wavenumber 8) on a regularly spaced
latitude grid (spacing near 4.4 degrees)

$$Z(\lambda, \phi, p) = \sum_{k=1}^{8} ZS(\phi, p) \cdot \sin(k\lambda) + ZC(\phi, p) \cdot \cos(k\lambda)$$

longitude (λ), latitude (ϕ), pressure (p)

k: zonal wavenumber

TEMPERATURE, WIND AND WAVE FLUX DERIVATIONS

Temperatures are derived grom the geopotential grids via the hydrostatic relation:

$$T = -R \frac{\partial \Phi}{\partial \ln p} \qquad (1)$$

Here Φ is the geopotential height, ln p is the logarithm of pressure, and R the gas constant (287 $m^2\ s^{-2}\ K^{-1}$) Although simply called temperature here, this expression actually results in the virtual temperature (the temperature of dry air having the same density and pressure as the true, moist air).

Zonal mean winds are evaluated from the so-called gradient wind expression:

$$\frac{\overline{u}^2}{a}\tan\phi + 2\Omega\sin\phi \cdot \overline{u} + \frac{1}{a}\frac{\partial\overline{\Phi}}{\partial\phi} = 0 \qquad (2)$$

Values at the equator are evaluated from the curvature expression:

$$\overline{u} + \frac{1}{2\Omega a} \cdot \frac{\partial^2\overline{\Phi}}{\partial\phi^2} = 0 \qquad (3)$$

Fleming and Chandra (1989) have compared equatorial winds derived from these data via Eq. 3 with monthly mean rawinsonde and rocketsonde measurements. They show that the derived winds reproduce the general characteristics of the quasi-biennial oscillation (QBO) and semi-annual oscillation (SAO), although the amplitude of the QBO is substantially underestimated in the derived winds.

Zonal Fourier components of horizontal winds are derived from the zonal and meridional momentum equations linearized about the zonal mean zonal wind $\overline{u}$:

$$\frac{\overline{u}}{a\cos\phi}\frac{\partial u'}{\partial\lambda}+\hat{f}v'+\frac{1}{a\cos\phi}\frac{\partial\Phi'}{\partial\lambda}=0 \tag{4a}$$

$$\frac{\overline{u}}{a\cos\phi}\frac{\partial v'}{\partial\lambda}+\tilde{f}u'+\frac{1}{a}\frac{\partial\Phi'}{\partial\phi}=0 \tag{4b}$$

In Eqns. (2)-(4), λ is longitude, φ latitude, u and v the zonal and meridional velocities, respectively, and a is earth radius (6.37×10^6 m). Overbars denote zonal means and primes deviations therefrom, and

$$\hat{f}=\left[2\Omega\sin\phi-\frac{1}{a\cos\phi}\frac{\partial}{\partial\phi}(\overline{u}\cos\phi)\right] \tag{4c}$$

$$\tilde{f}=\left[2\Omega\sin\phi+\frac{2\overline{u}}{a}\tan\phi\right] \tag{4d}$$

where Ω is earth rotation rate (7.3×10^{-5} sec^{-1}). The coupled equations (4a-b) are solved for each zonal wave number to evaluate the spectral coeffecients of u' and v'; note that these equations become singular for zonal wave k as

$$\delta\equiv\frac{(\overline{u}\cdot k/a\cos\phi)^2}{\hat{f}\tilde{f}}\rightarrow 1 \tag{4e}$$

For the data presented here, geostrophic winds were substituted if $\delta > 0.5$ (the results are not sensitive to this exact value). The use of these balanced winds and their improved treatment of stratospheric data (as compared to geostrophic winds) is discussed extensively in Randel (1987).

Statistics of several derived quantities are also presented here. A measure of the zonal mean static stability is given by the Brunt-Vaisala (or bouyancy) frequency squared:

$$N^2=\frac{R}{H}\left(\frac{\partial\overline{T}}{\partial z}+\frac{\kappa\overline{T}}{H}\right) \tag{5}$$

where H is the atmospheric scale height, chosen here to be 7000 m, z = H ℓn (1000 mb/p) is the vertical coordinate, and $\kappa = 2/7$. Relatively large values of N^2 correspond to strong stability with respect to vertical motions. A central quantity in the quasi-geostrophic theory of Rossby wave propagation and stability of the zonal mean flow is the latitudinal gradient of zonal mean potential vorticity:

$$\bar{q}_y = \frac{2\Omega}{a}\cos\phi - \frac{1}{a^2}\frac{\partial}{\partial\phi}\left[\frac{1}{\cos\phi}\frac{\partial}{\partial\phi}(\bar{u}\cos\phi)\right] - (2\Omega\sin\phi)^2 \cdot e^{z/H}\frac{\partial}{\partial z}\left(e^{-z/H}\cdot\frac{1}{N^2}\cdot\frac{\partial\bar{u}}{\partial z}\right) \qquad (6)$$

A zonal cross section of potential temperature (Θ) and Rossby-Ertel potential vorticity (PV) is included for each month. Potential temperature is calculated as:

$$\Theta = T\left(\frac{1000\ mb}{p}\right)^{\kappa} \qquad (7)$$

and potential vorticity from:

$$PV = -g(2\Omega\sin\phi + \zeta)\cdot\frac{\partial\Theta}{\partial p} \qquad (8a)$$

Here ζ is the relative vorticity, and g = 9.81 m $\cdot$ sec^{-2}. For the zonal mean, this reduces to

$$\overline{PV} = -g\left[2\Omega\sin\phi - \frac{1}{a\cos\phi}\frac{\partial}{\partial\phi}(\bar{u}\cos\phi)\right]\cdot\frac{\partial\bar{\Theta}}{\partial p} \qquad (8b)$$

PV is scaled in units of 10^{-6} K m^2 $kg^{-1}s^{-1}$, termed a PV unit. Statistics of the zonally-averaged poleward eddy heat flux ($\overline{v'T'}$) and poleward eddy momentum flux ($\overline{u'v'}$) are calculated and displayed. Also calculated are estimates of the zonal mean Eliassen-Palm (EP) flux vectors and their divergence. The orientation of the EP flux vectors indicates the wave group velocity or direction of wave activity flux (where such quantities are well defined), and the relative importance of heat versus momentum fluxes. The EP flux divergence (also called the wave driving) gives a concice measure of the net effect of wave-induced heat and momentum fluxes in terms of a force per unit mass on the zonal mean flow; it is also equivalent to the poleward flux of quasi-geostrophic potential vorticity. A review of the motivation and theory behind EP flux diagnostics can be found in Edmon *et al.* (1980). Here the EP flux vectors and divergences are estimated using the primitive equation expressions, neglecting terms involving the vertical velocity. The zonal mean wave driving (DF) is given by:

$$\begin{aligned} DF &= \frac{1}{\rho(z)\cdot a\cos\phi}(\nabla\cdot\vec{F}) \\ &= \frac{1}{\rho(z)\cdot a\cos\phi}\left[\frac{1}{a\cos\phi}\frac{\partial}{\partial\phi}\left(F_\phi\cos\phi\right)+\frac{\partial F_z}{\partial z}\right] \end{aligned} \tag{9}$$

with

$$F_\phi = \rho(z)\cdot a\cos\phi\left[-\overline{u'v'}-\frac{R}{H}\cdot\frac{\partial\overline{u}}{\partial z}\cdot\frac{\overline{v'T'}}{N^2}\right] \tag{10a}$$

$$F_z = \rho(z)\cdot a\cos\phi\cdot\left[\hat{f}\cdot\frac{R}{H}\cdot\frac{\overline{v'T'}}{N^2}\right] \tag{10b}$$

Here $\rho(z)$ is the basic state density (proportional to $e^{-z/H}$). EP flux diagrams here follow the convention in Randel *et al.* (1987); notably, the vectors are multiplied by $e^{z/2H}$ so that they are visible throughout the stratosphere. Because the use of balanced winds in the tropics is problematic, wave fluxes and EP diagnostics are displayed only polewards of 20° in each hemisphere.

Vertical derivatives are approximated by finite differences between adjacent pressure levels, followed by linear interpolation in log pressure back to the original pressure levels. Because of the separate analysis schemes at 100 and 70 mb, and the high number of derivatives used, eddy heat fluxes occasionally show discontinuous behavior between the 100 and 70 mb levels. Further vertical differentiation of these fluxes can result in obviously bad EP flux divergence estimates; this problem is alleviated here by smoothing the eddy heat flux values across 100 and 70 mb prior to the EP flux calculations. Meridional derivatives are approximated by centered finite differences on the Gaussian latitude grid, and longitudinal derivatives are calculated spectrally.

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NCAR TECHNICAL NOTE

February 1992

Global Atmospheric Circulation Statistics, 1000-1 mb

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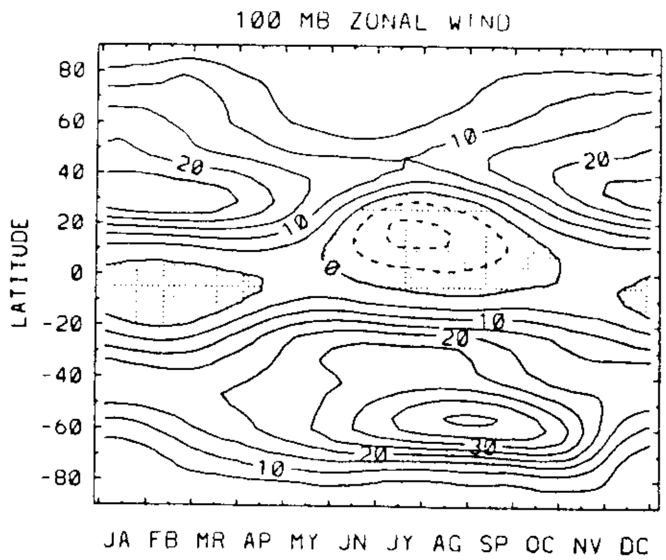

ATMOSPHERIC CHEMISTRY DIVISION

NATIONAL CENTER FOR ATMOSPHERIC RESEARCH
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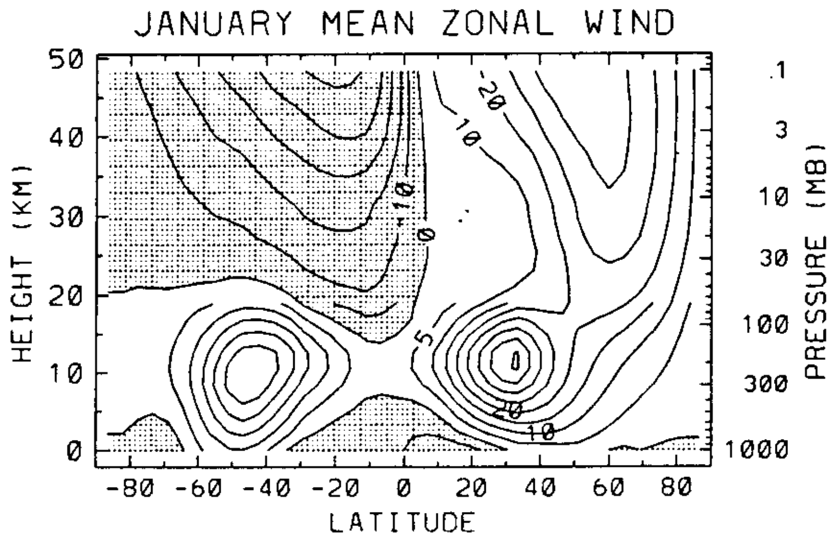
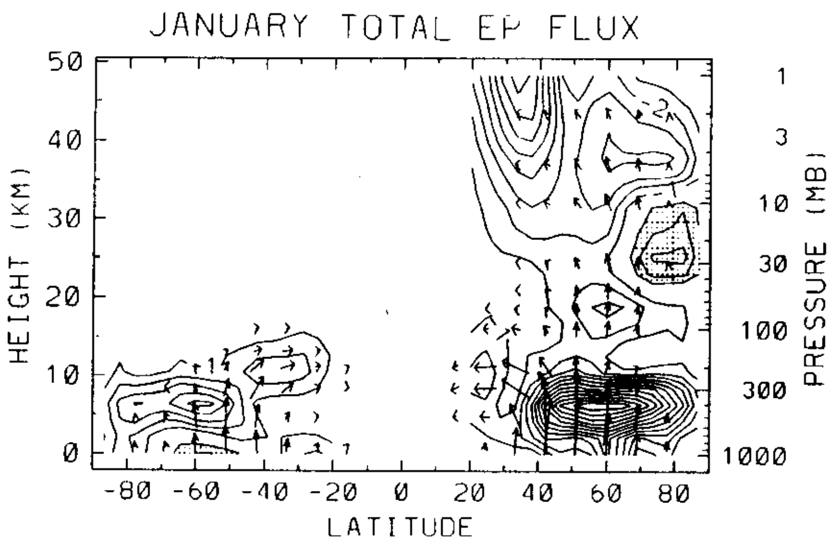
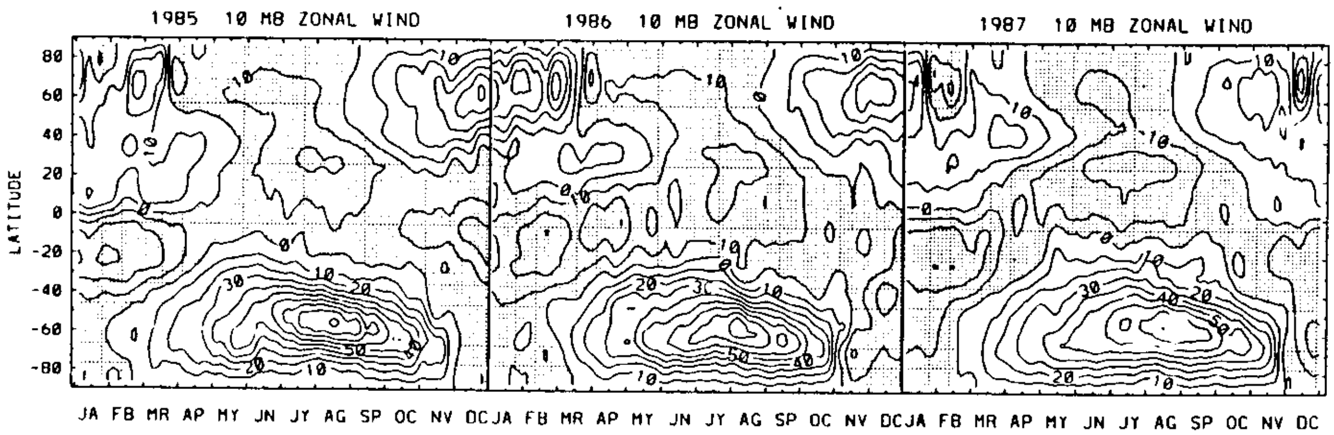
Climatological means

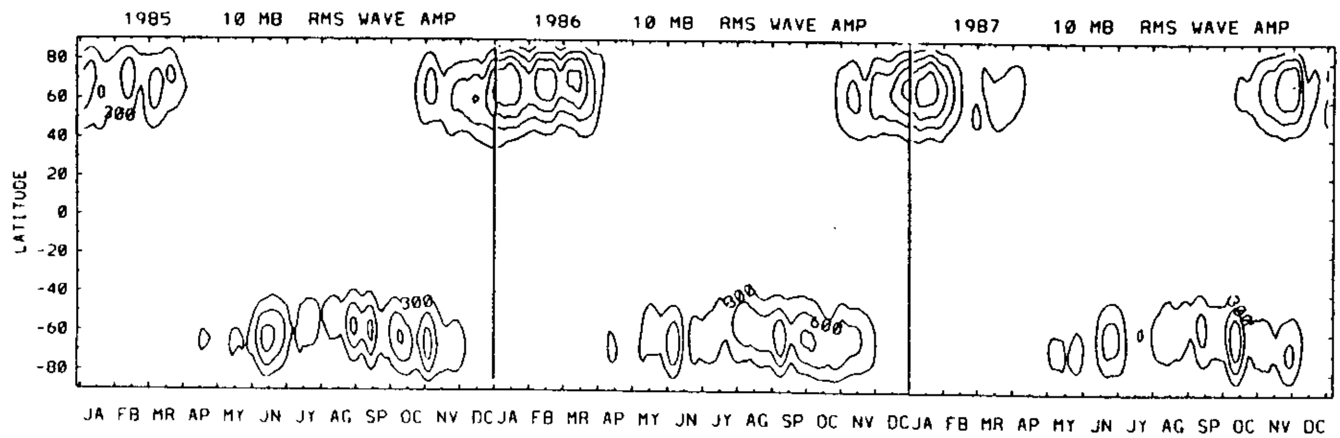




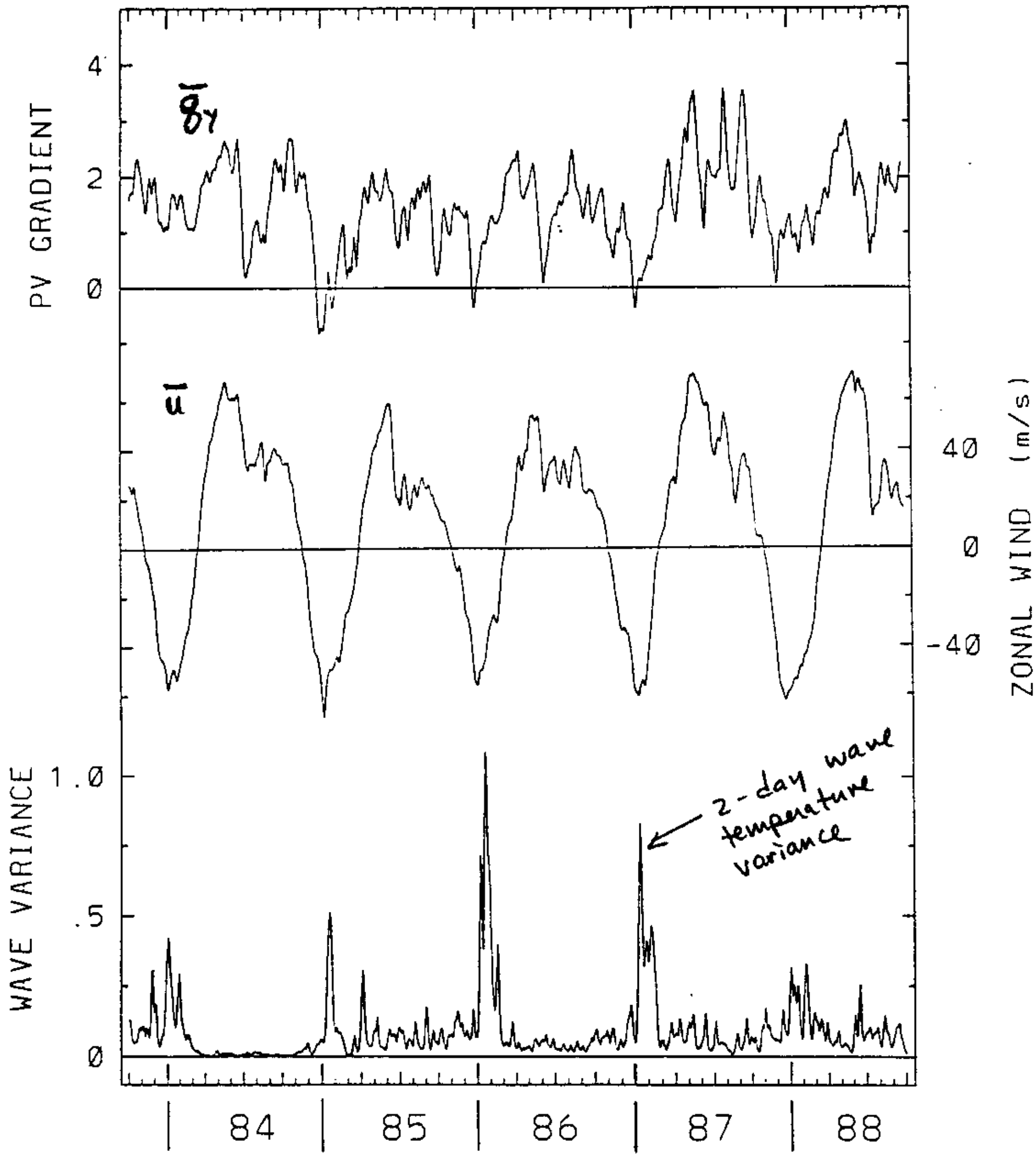
Reference: Randel, 1992: Global Atmospheric Circulation Statistics
NCAR Technical Note #366, 256 pp.

Stratospheric variability





Time series at 1 mb, 20° S



Reference: Randel (1992) in preparation: "The 2-day wave in NMC operational stratospheric analyses"

Fig. 2

Vertically propagating planetary waves

Reference: Randel, 1988, Tellus 40 257-271