Testing Theories of Gravity Wave Transports and Their Effects on Wind Temperature and Composition

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Topics

Waves

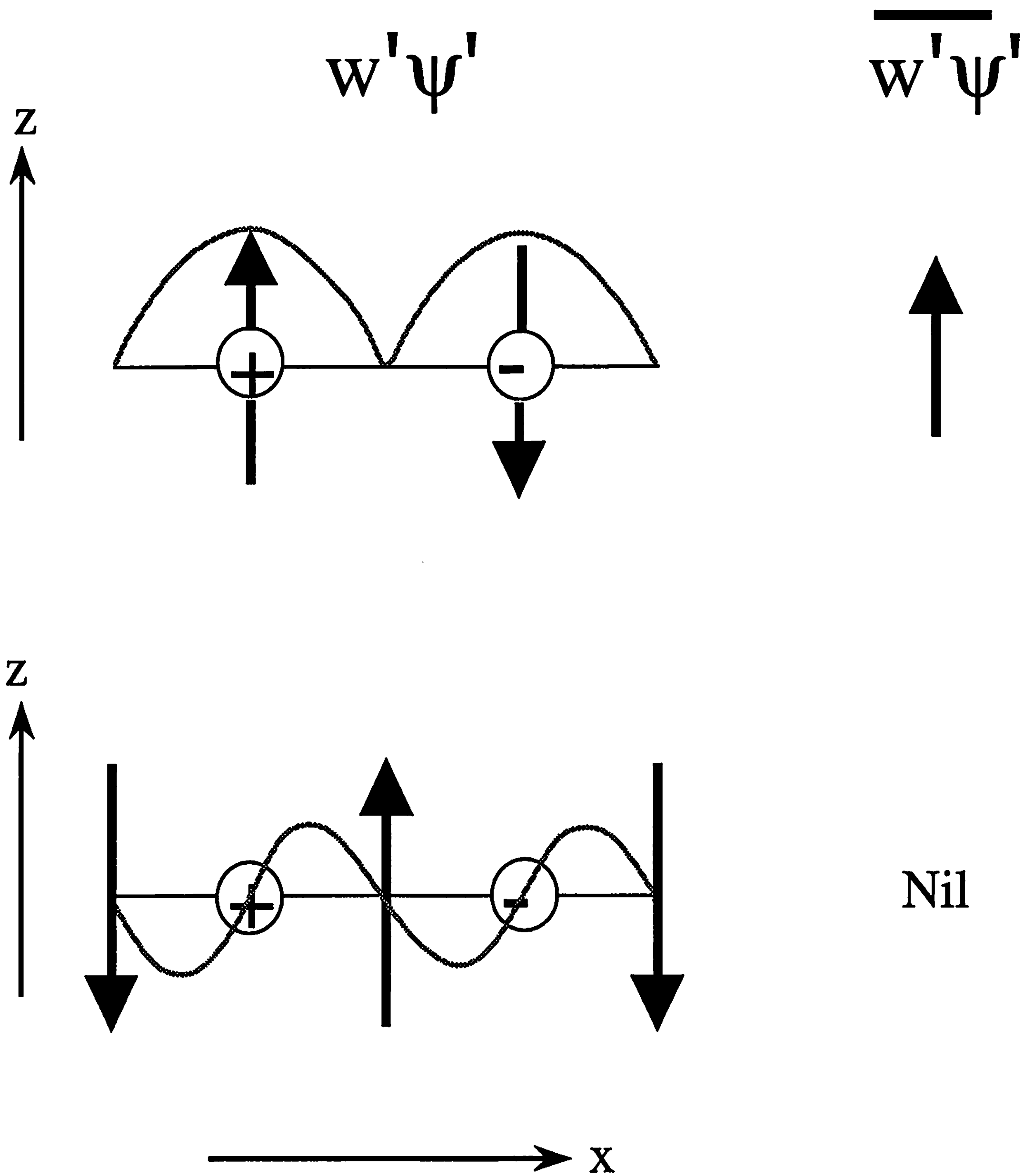
Wave-mean-state interactions

Observable phenomena

Diagnostics

Examples

Vertical Wave Fluxes



Wave Mean State Interactions

Wave Forcing of the Mean State

- Driven by wave fluxes
- Nonacceleration theorem
- Chemically induced forcing

WMSI Phenomena in the Stratosphere and Lower Mesosphere

- Equatorial QBO and SAO
- Sudden Stratospheric Warmings

WMSI Phenomena in the Upper Mesosphere and Lower Thermosphere

- Cold summer mesopause
- Pseudotides
- Wind, temperature and composition disturbances

Wave Fluxes

Mean state changes induced by wave fluxes

$$\frac{\partial \overline{\psi}}{\partial t} = \ldots - \frac{1}{\overline{\rho}} \frac{\partial F_z(\psi)}{\partial z}$$

$$F_z(\psi) = \overline{\rho}\,\overline{w'\psi'}$$

Wave stress

$\psi = u$

Sensible heat flux

$\psi = c_p T$

Species flux

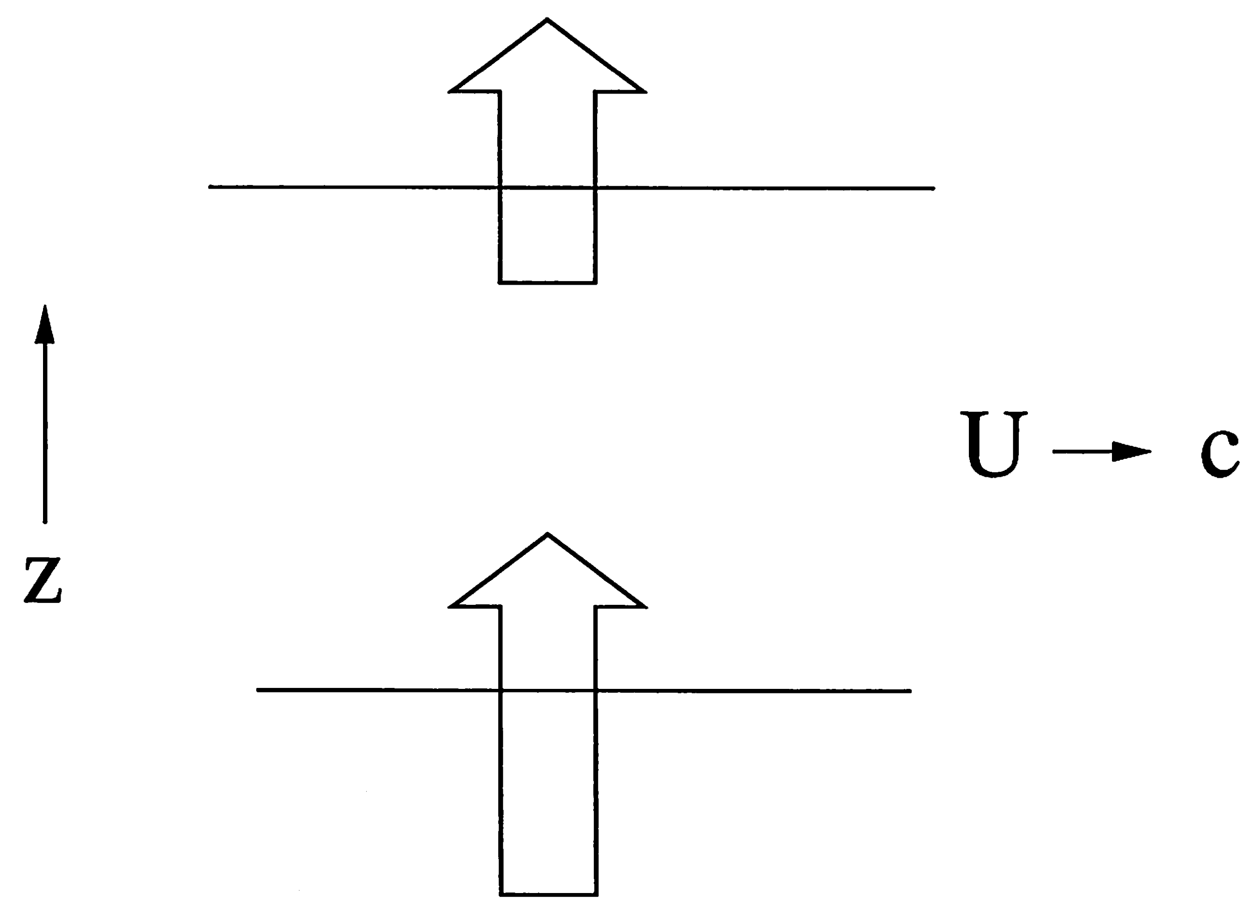
$\psi = r, \ \psi = n$

Nonacceleration Conditions

Waves

- Linear
- Conservative
- Steady
- No critical level ($\bar{u} \neq c$)

Forcing of Mean Wind by Momentum Flux



Critical Levels

Critical level:

$$\overline{u} - c = 0$$

Critical level favored location for wave-mean-state interactions

Strong enhancement of wave dissipation as vertical wavelength and group velocity become small

Orlanski-Bryan condition for wave breakdown satisfied for fairly small-amplitude waves

E-P relation implies sign reversal for vertical momentum flux at critical level

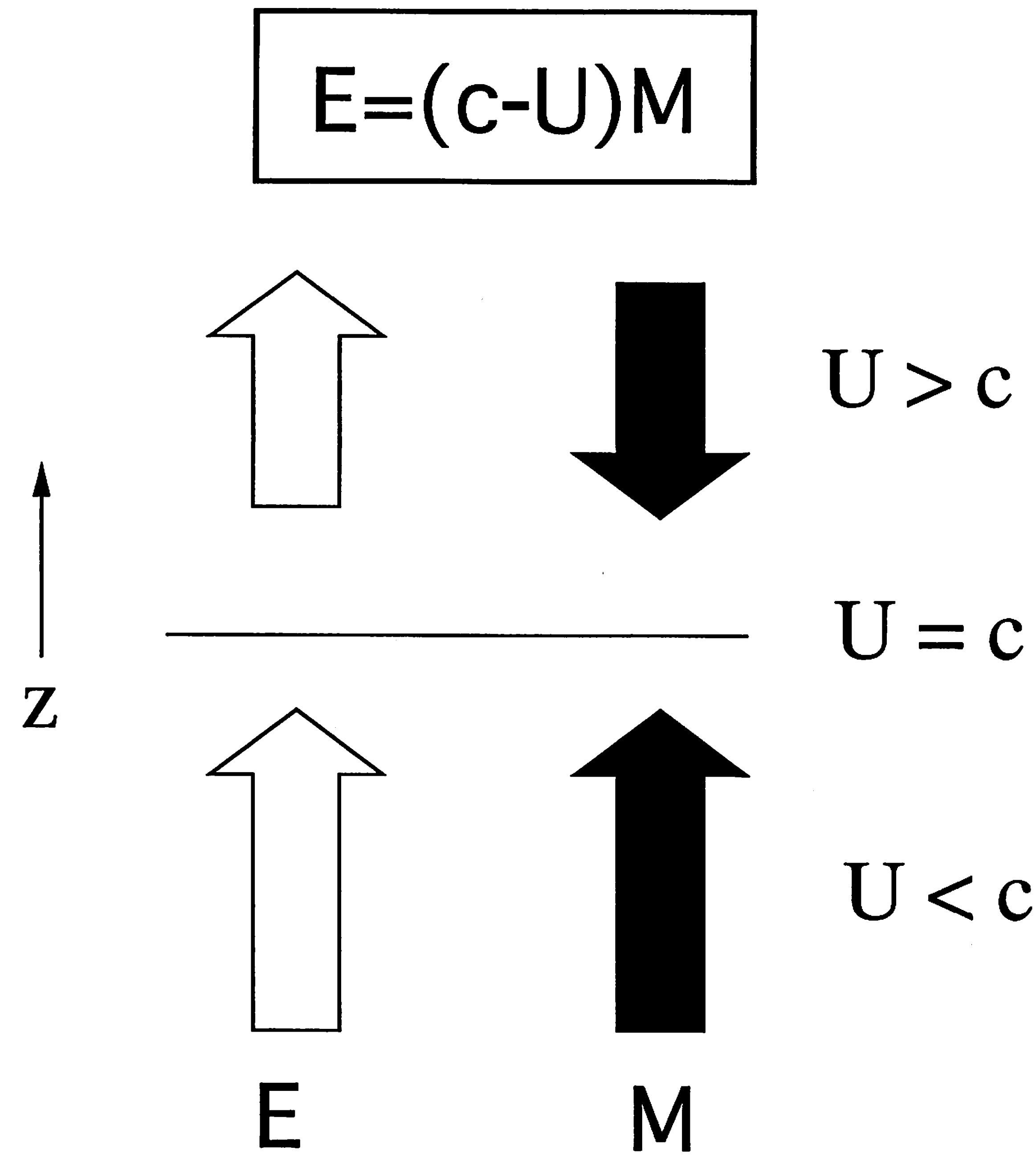
Wave dissipation forces decent of Critical level

Orlanski-Bryan condition for wave breakdown

$$u' \sim c - \overline{u}$$

E-P relation

energy flux $= (c - \overline{u}) \times$ momentum flux



E=(c-U)M
U > c
U = c
U < c
z
E
M

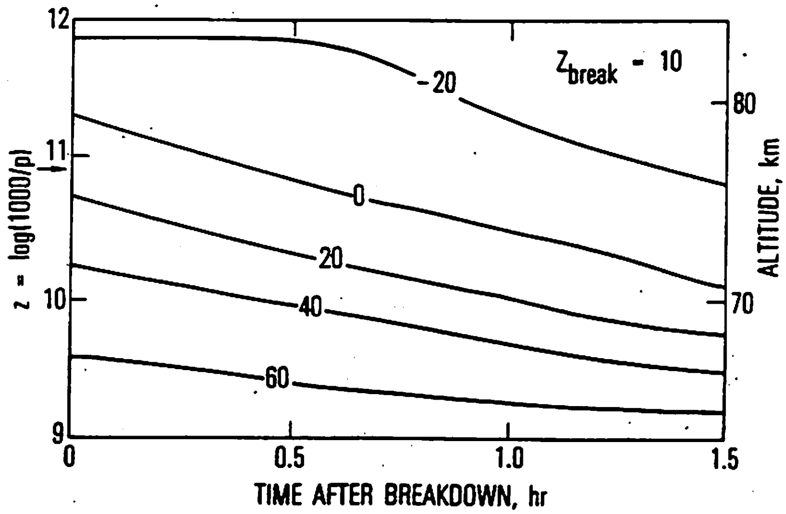


Figure 7. Same as Figure 4 except $Z_{break} = 10$.

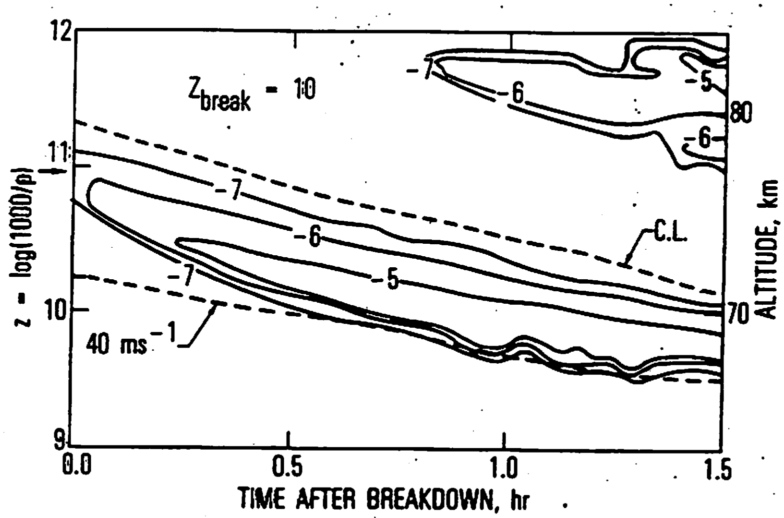


Figure 8. Same as Figure 5 except $Z_{break} = 10$.

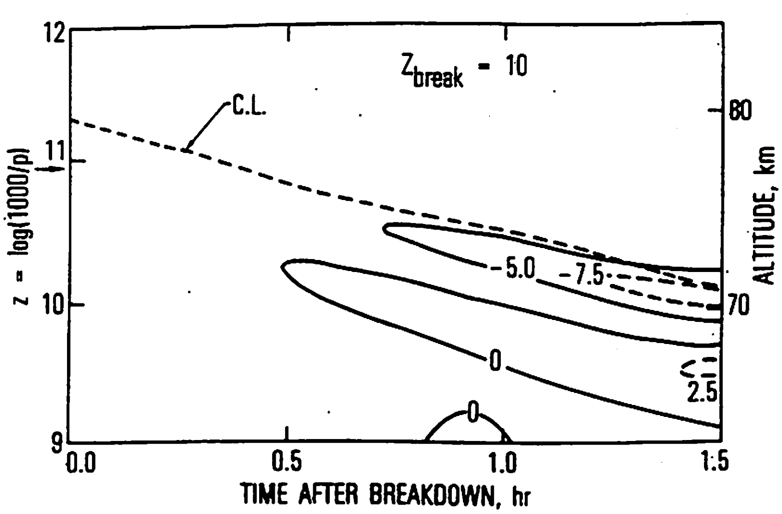


Figure 9. Same as Figure 6 except $Z_{break} = 10$.

Chemical Forcing of Mean-State Minor Constituent Profiles

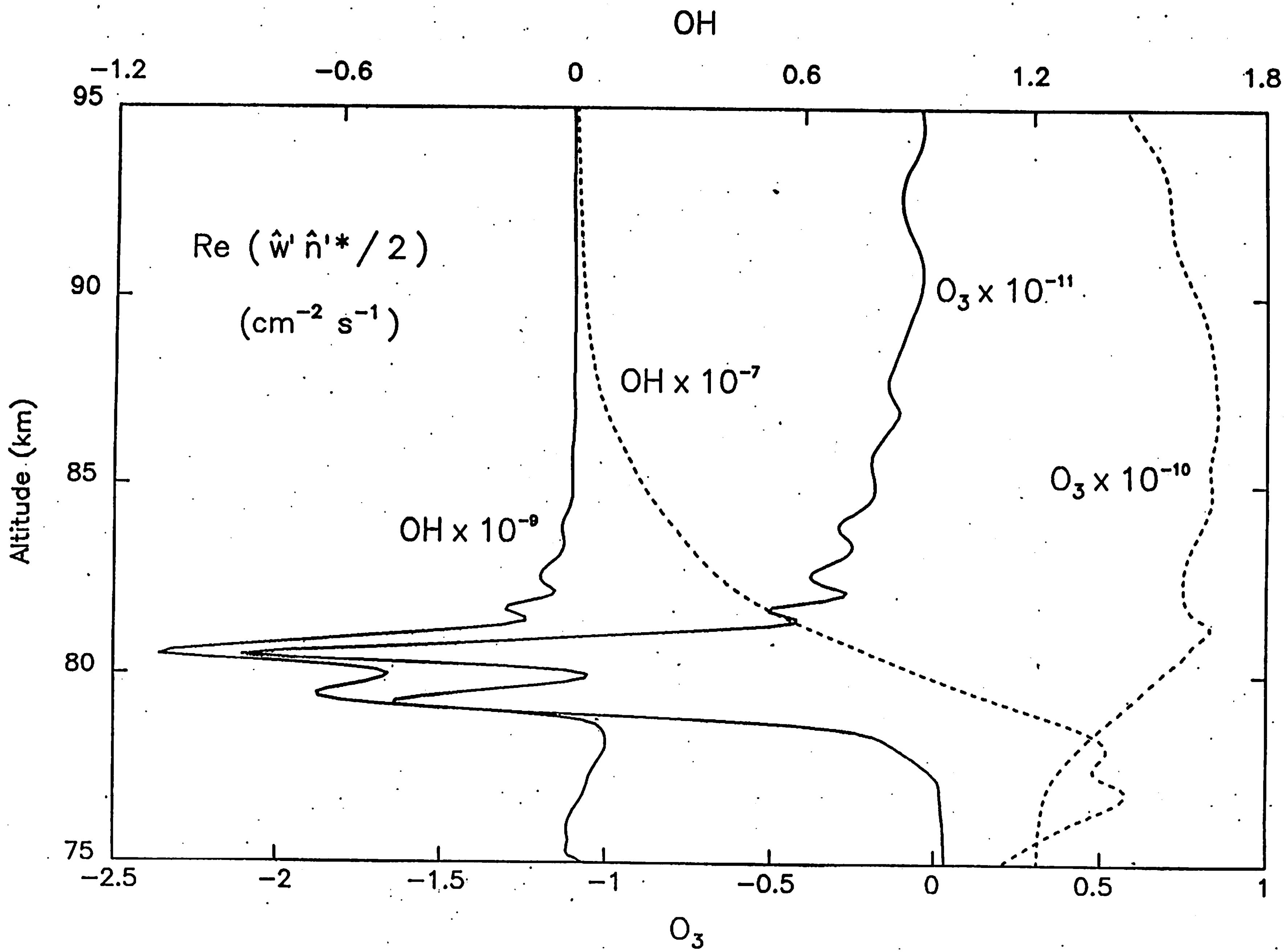
Vertical flux of constituent mixing ratio is zero when nonacceleration conditions apply and chemical production and loss are nil

Vertical flux can be induced by chemistry even when nonacceleration conditions apply

Strobel (1981) parameterized effects of chemistry in terms of eddy diffusion coefficient

Schoeberl et al. (1983) modified Strobel's parametization to incorporate turbulent mixing (Lindzen, 1981; Garcia and Solomon, 1985, Bjarnason et al., 1987; LeTexier et al., 1987)

Walterscheid and Schubert (1989) used five-reaction model of wave-perturbed O_3 chemistry near the mesopause to calculate chemically induced wave fluxes of minor constituents


OH
−1.2
−0.6
0
0.6
1.2
1.8
95
90
85
80
75
Altitude (km)
Re (ŵ' n̂'* / 2)
(cm^{-2} s^{-1})
OH x 10^{-7}
OH x 10^{-9}
O$_3$ x 10^{-11}
O$_3$ x 10^{-10}
−2.5
−2
−1.5
−1
−0.5
0
0.5
1
O$_3$

Waves

Obey characteristic dynamical and dispersion relations

Characteristic frequencies, wavelengths (tides, planetary waves)

Vertical phase propagation is opposite to vertical group propagation (except acoustic waves)

Amplitude $\propto \overline{\rho}^{-1/2}$ for steady vertically propagating conservative waves

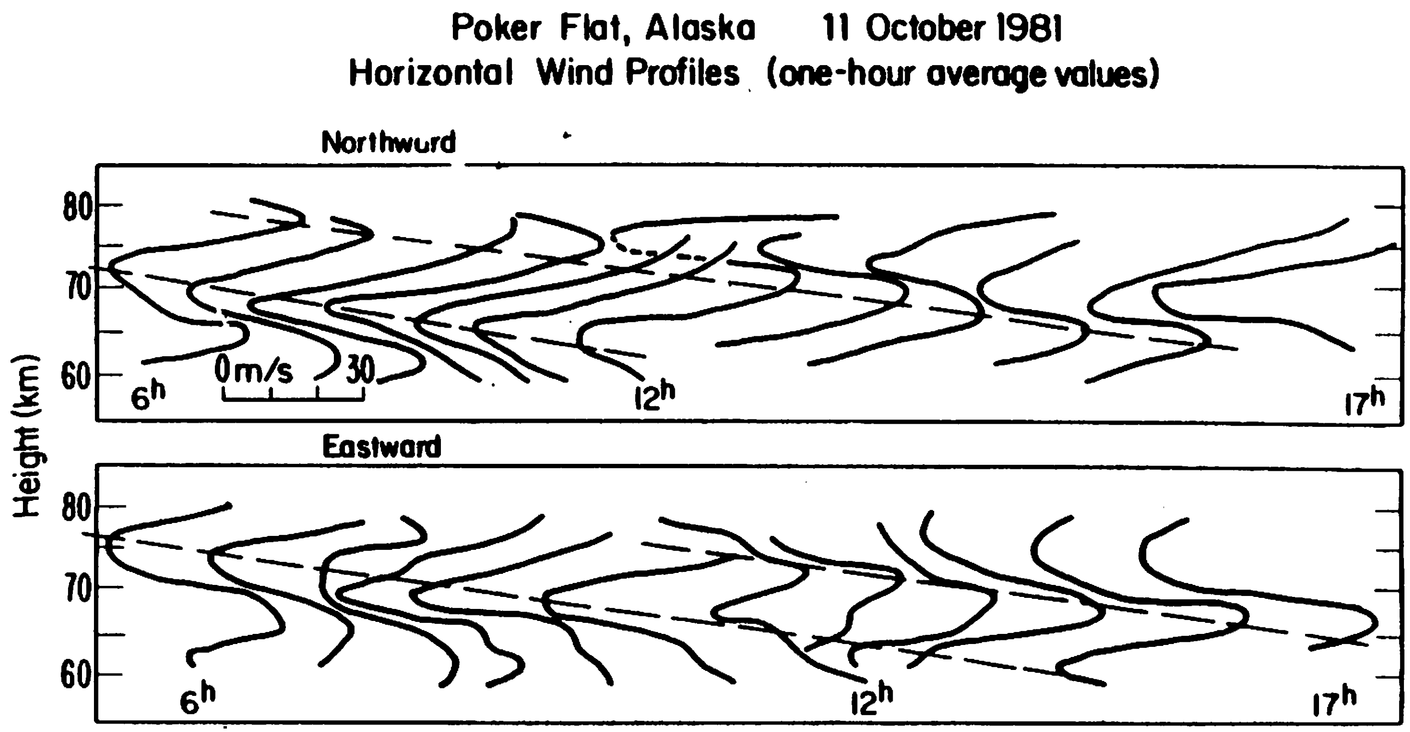


Figure 4. Time sequence of the horizontal velocity profiles shown in Fig. 3. Velocity scale shown in lower left corner of upper panel. Dashed lines indicate approximate height of velocity extreme of the quasi-sinusoidal contours. (Note that left-to-right profile placements are not precisely uniform in time.)

Diagnostics

Wave flux divergence

Nonequilibrium conditions

Anomalous or perturbed conditions

Do not obey wave relations

Examples

Vincent and Reid (1983)

Fritts and Vincent (1987)

Gille and Lyjak (1984)

Czechowsky et al. (1979)

Lieberman and Hays (1994)

Hecht et al. (1995)

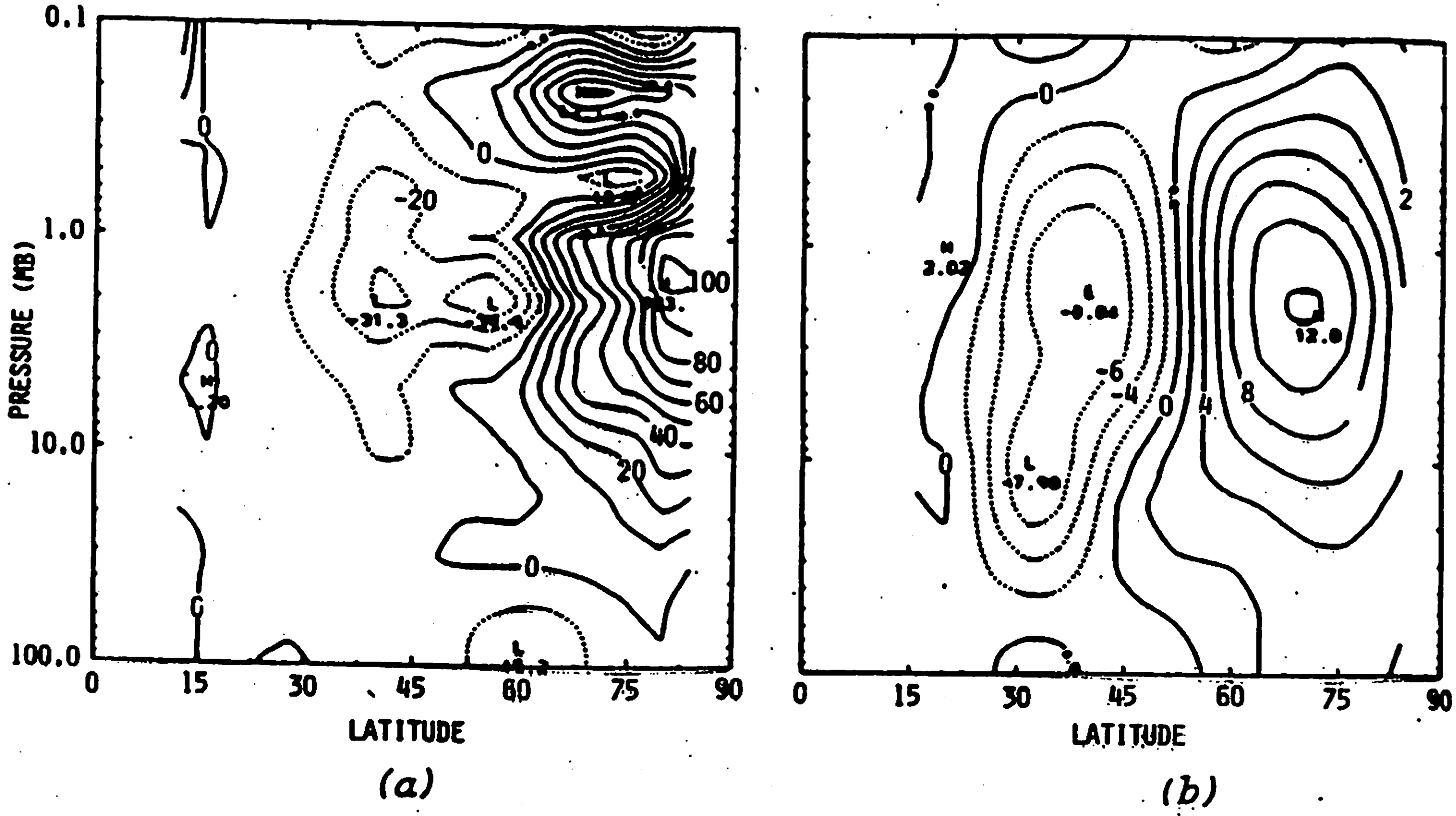


Fig. 11 (a) Wave flux divergence (m s^{-1} day^{-1}), for 29 January 1979.
(b) Acceleration of zonal mean wind speed (m/s day), for 29 January 1979.

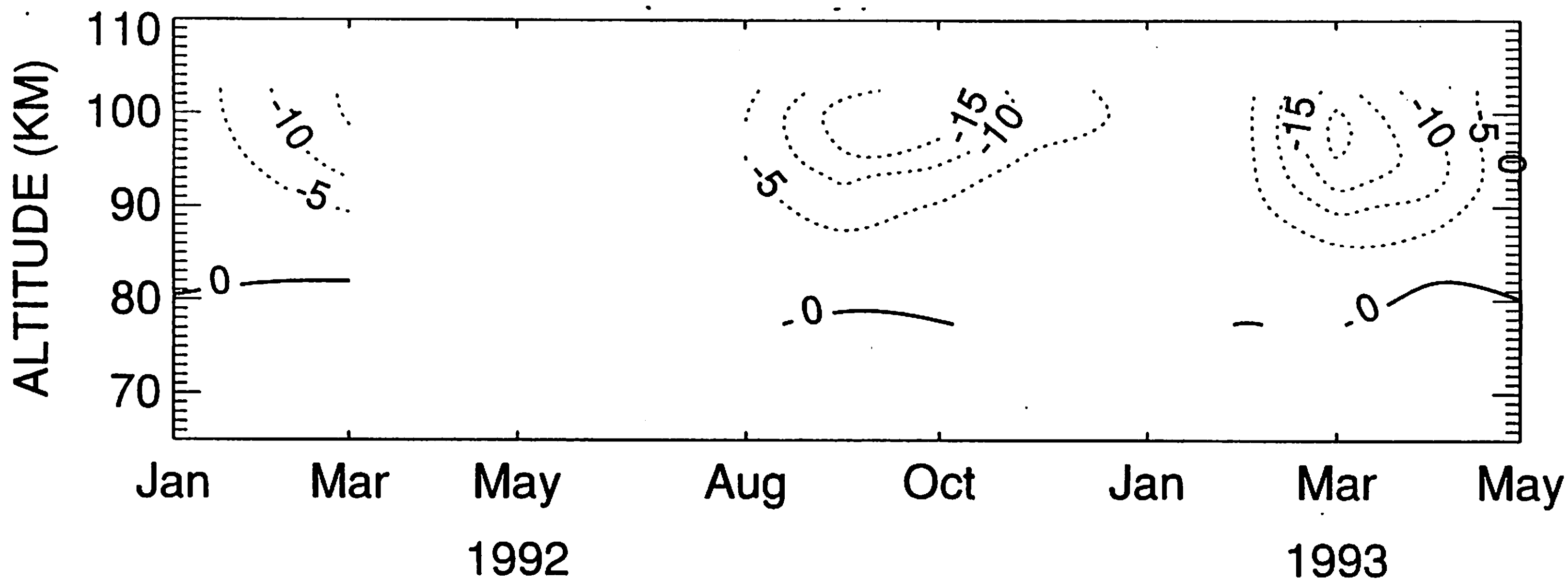
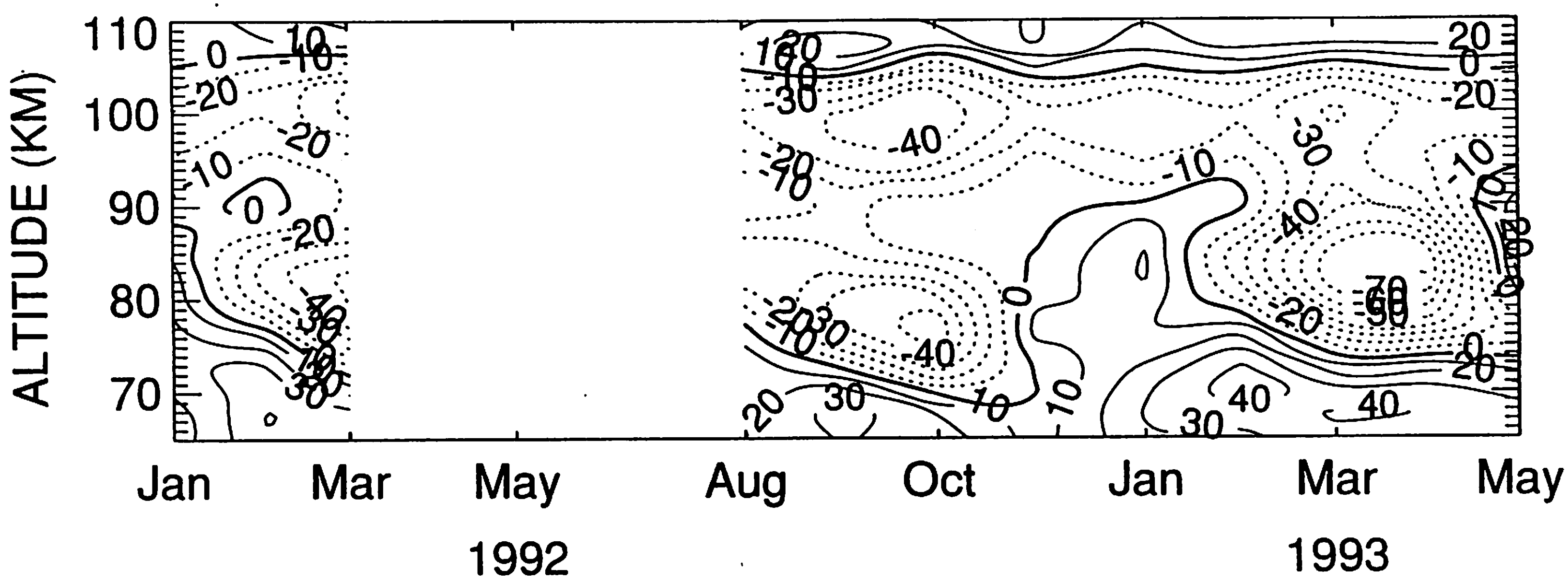

110
100
90
80
70
ALTITUDE (KM)
-10
-5
0
-5
-15
-10
-5
0
-15
-10
-5
0
-0
Jan
Mar
May
Aug
Oct
Jan
Mar
May
1992
1993

Figure 11



ALTITUDE (KM)
110
100
90
80
70
Jan
Mar
May
Aug
Oct
Jan
Mar
May
1992
1993

Figure 12

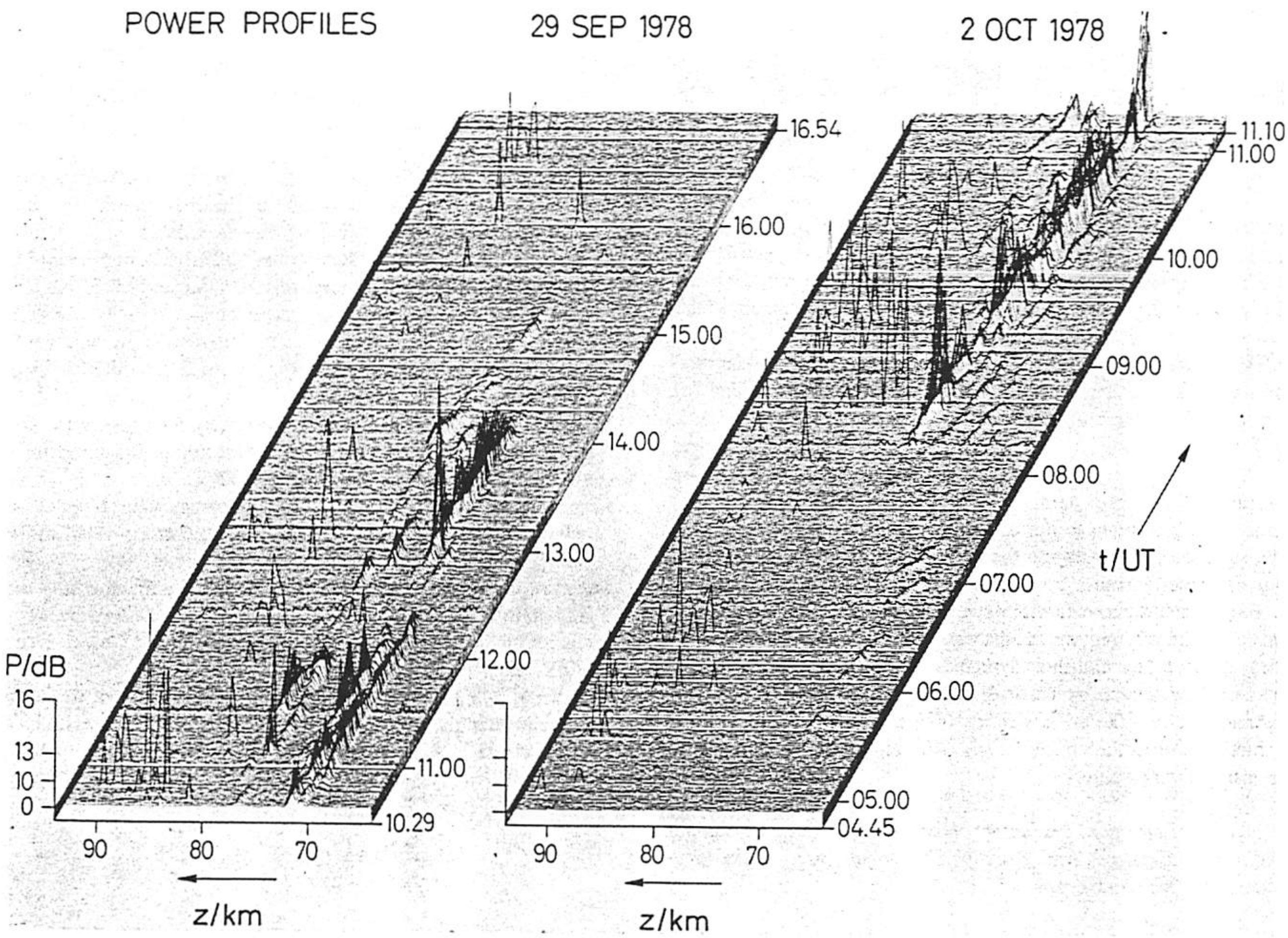


Fig. 3. Three-dimensional graph of the mesospheric echo power as a function of height and time for autumn.

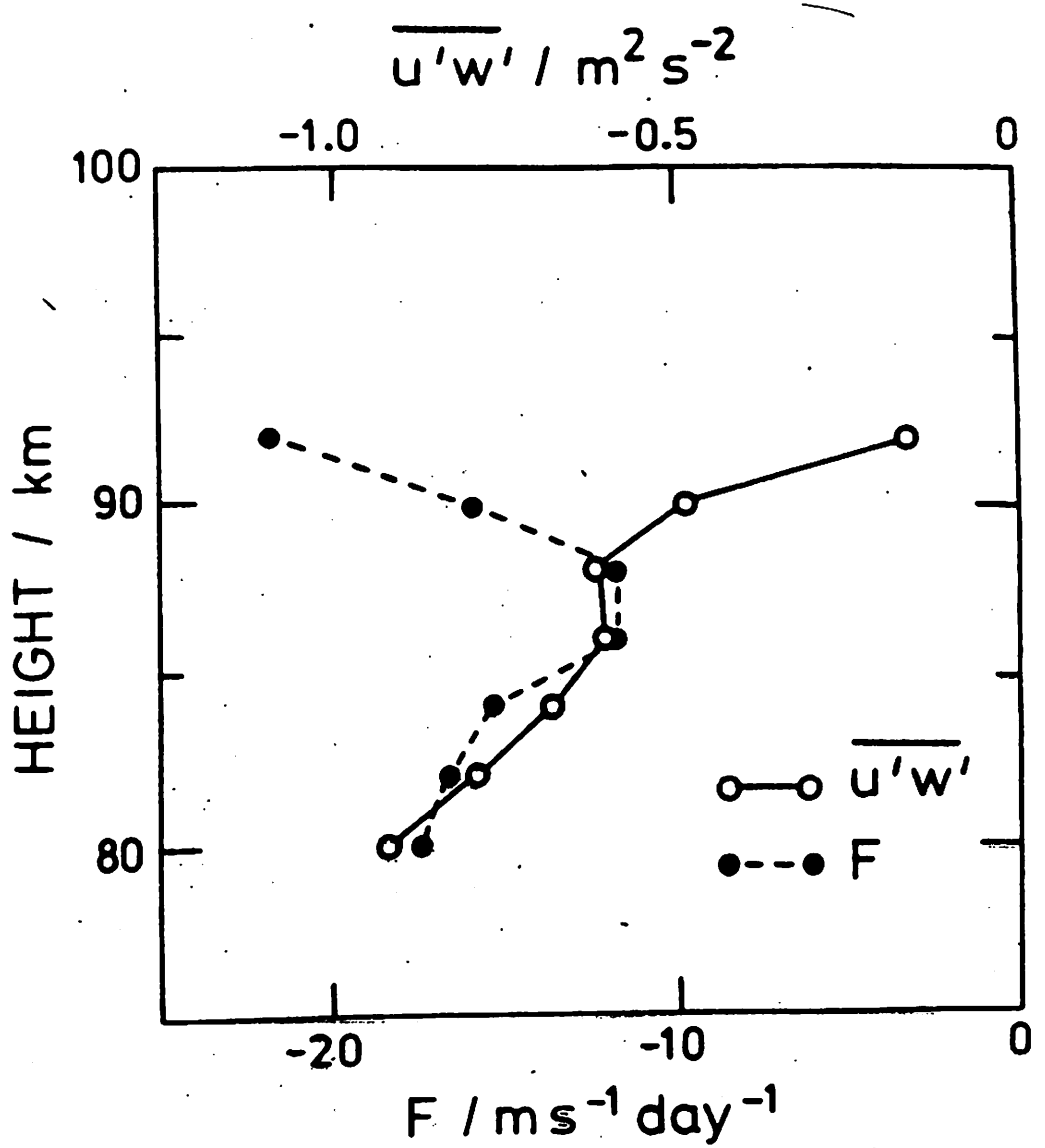
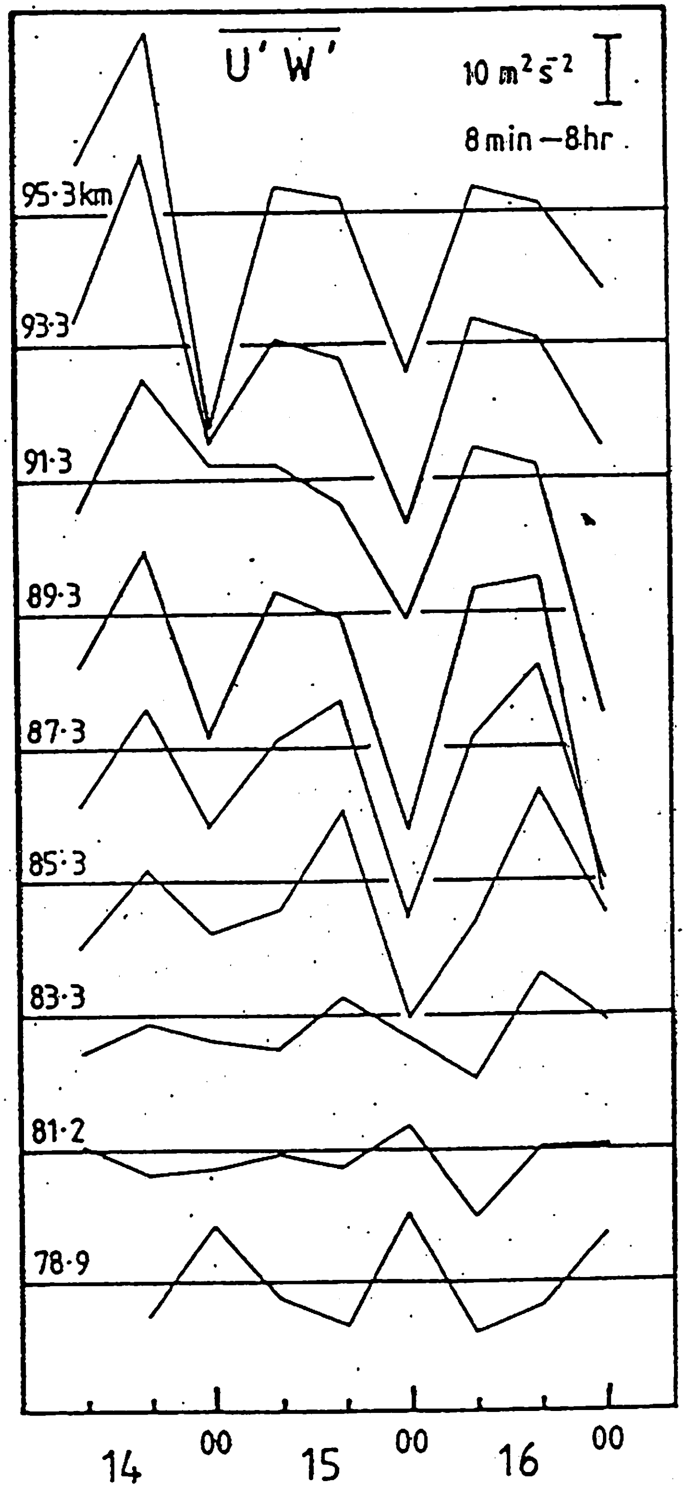
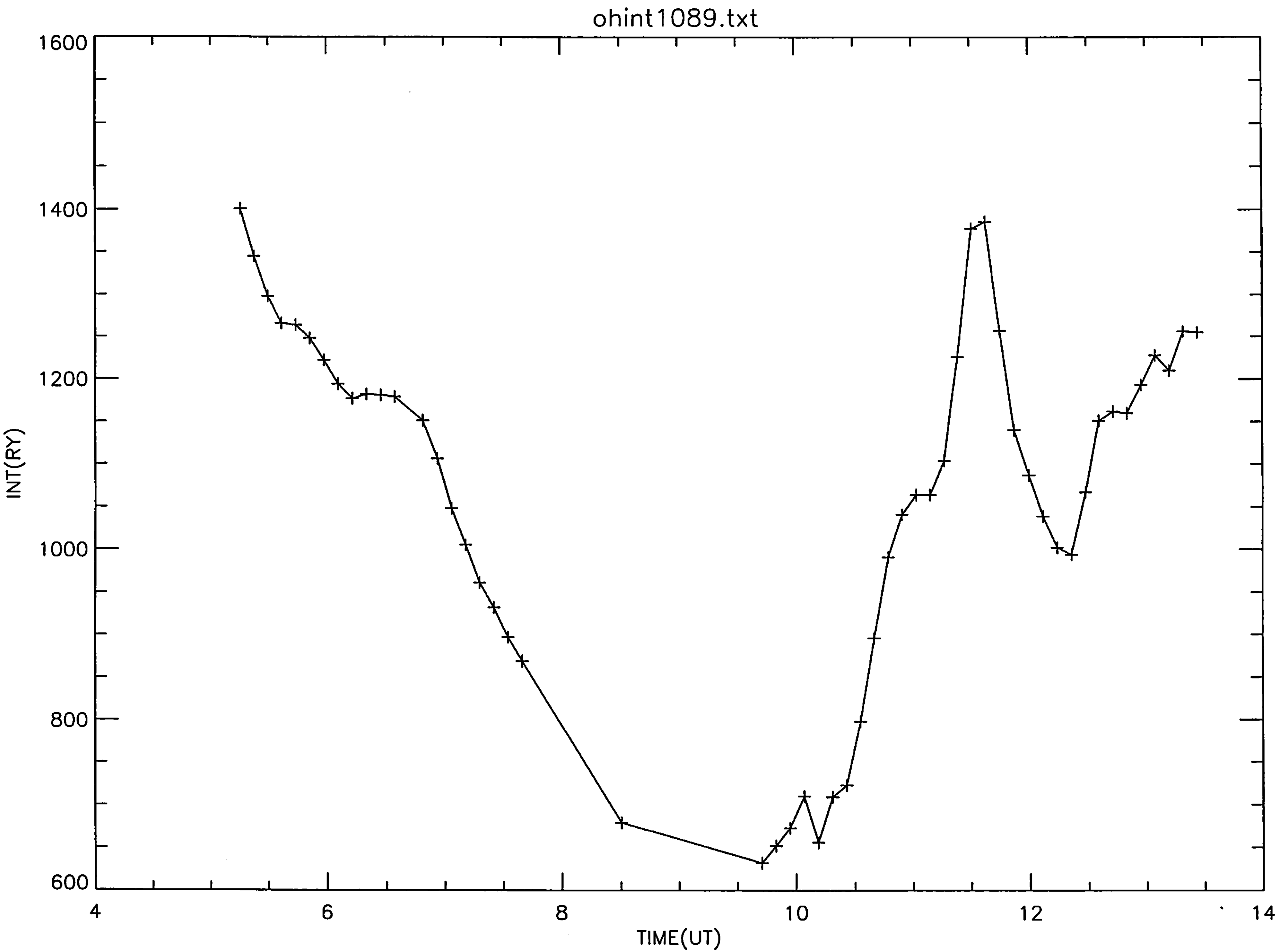


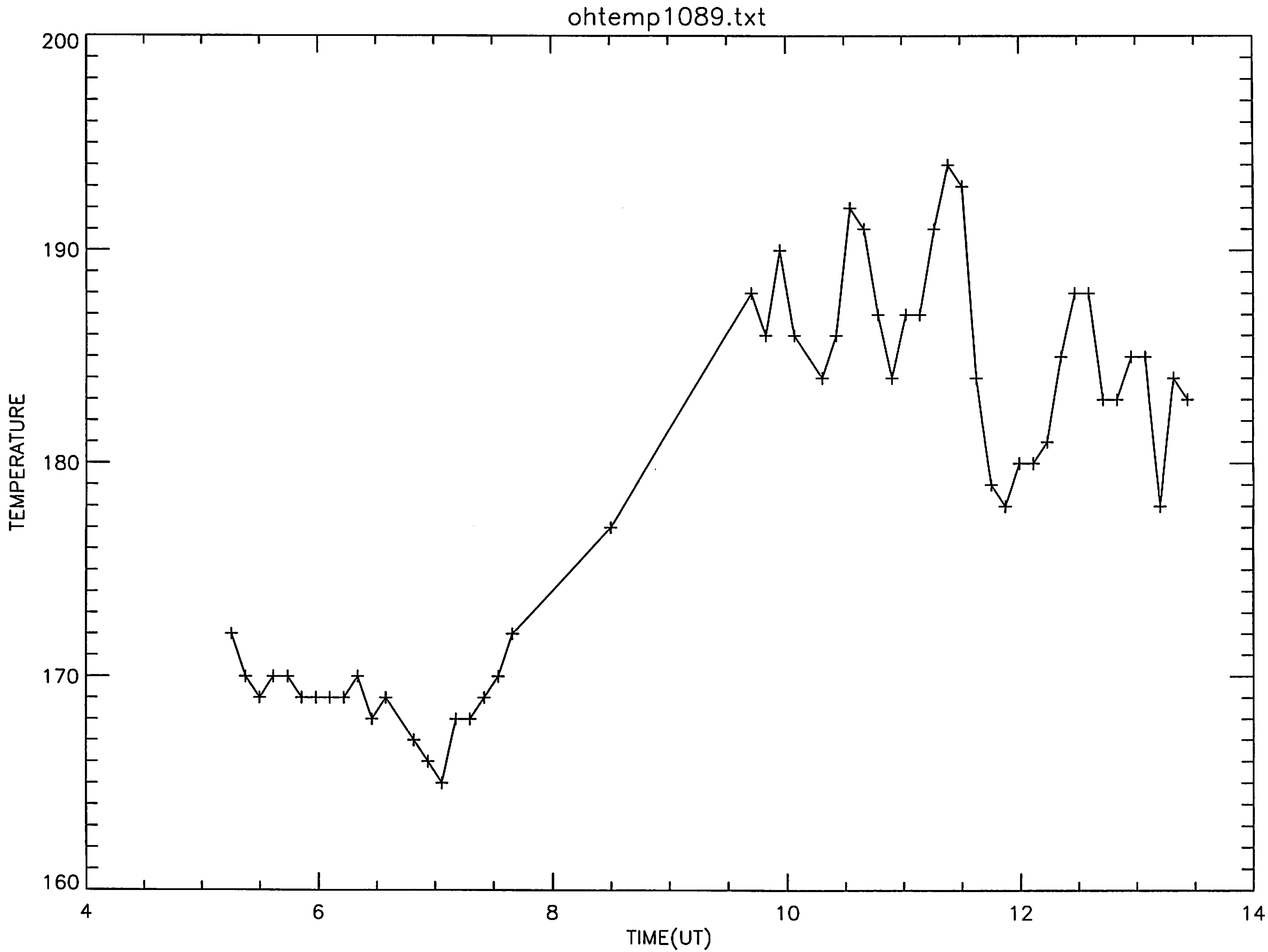
FIG. 6. Height profiles of the upward flux of zonal momentum ($\overline{u'w'}$) for the period 11–14 May 1981 (open circles) and the associated body force F (solid circles).



$\overline{U'W'}$
10 m²s⁻²
8 min – 8hr
95·3km
93·3
91·3
89·3
87·3
85·3
83·3
81·2
78·9
00
00
00
14
15
16



ohint1089.txt
1600
1400
1200
1000
800
600
INT(RY)
4
6
8
10
12
14
TIME(UT)


ohtemp1089.txt
TEMPERATURE
TIME(UT)
200
190
180
170
160
4
6
8
10
12
14

Conclusions

Wave Mean State Interactions driven by wave fluxes

Primary diagnostic is relationship between changes and fluxes

Important to measure time and space variations of different quantities simultaneously