1991 CEDAR Workshop Tutorial
NIST Auditorium, Boulder, CO
Tuesday, June 18, 1991

Research Challenges in Observational Atmospheric Dynamics: Opportunities and Important Studies

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RESEARCH CHALLENGES IN OBSERVATIONAL ATMOSPHERIC DYNAMICS: OPPORTUNITIES AND IMPORTANT STUDIES

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WHAT HAVE WE LEARNED SO FAR?

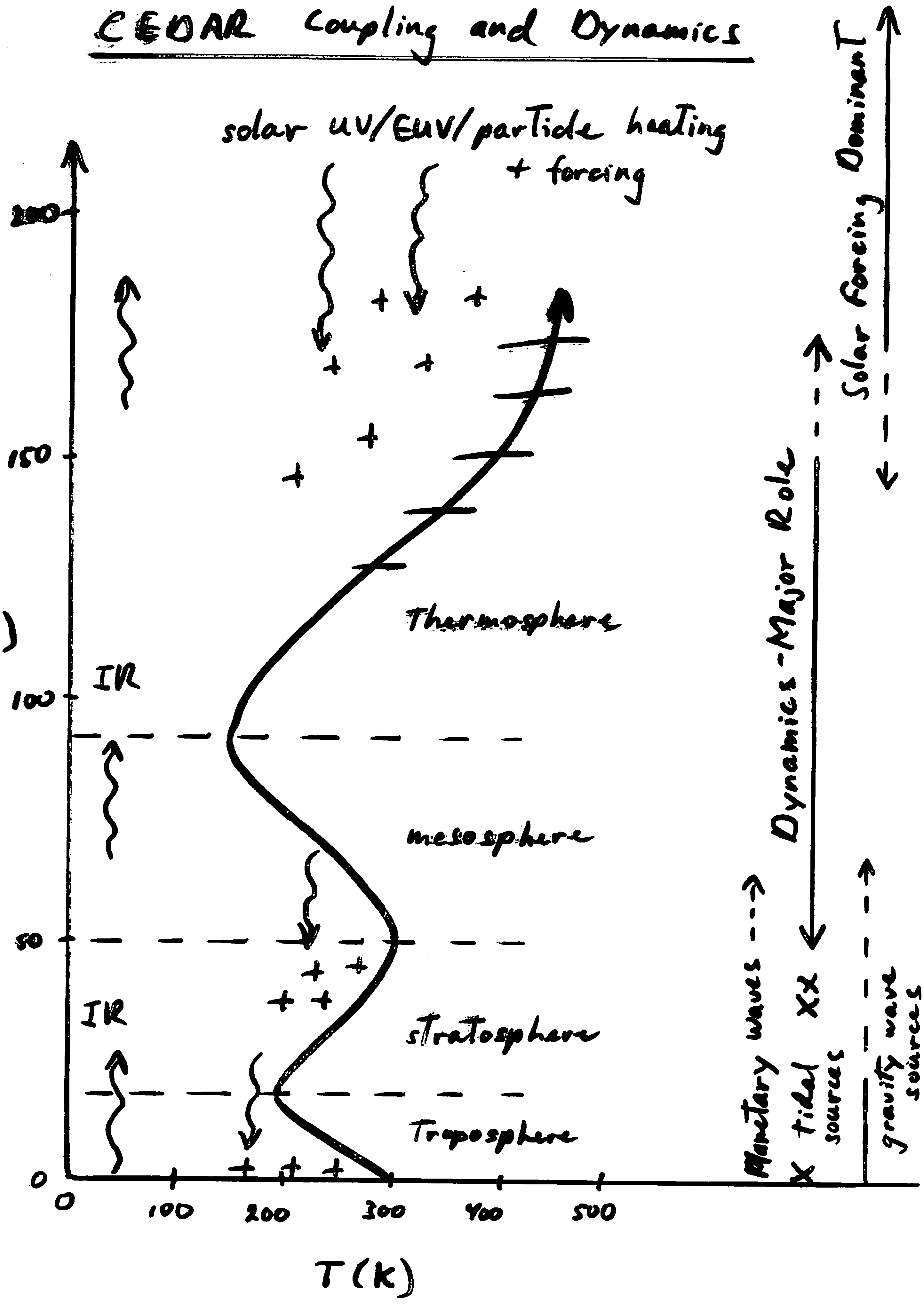
- MEAN STRUCTURE AND CIRCULATION
- CHARACTER AND VARIABILITY OF ATMOSPHERIC MOTIONS
- INSIGHTS INTO IMPORTANT PROCESSES, THEORETICAL UNDERSTANDING

WHERE SHOULD WE GO FROM HERE?

- MAJOR SCIENCE ISSUES
- OBSERVATIONAL PRIORITIES
- OPPORTUNITIES PRESENTED BY NEW INSTRUMENT CAPABILITIES

(THE MAJOR CHALLENGES LIE AHEAD!) !

CEDAR Coupling and Dynamics



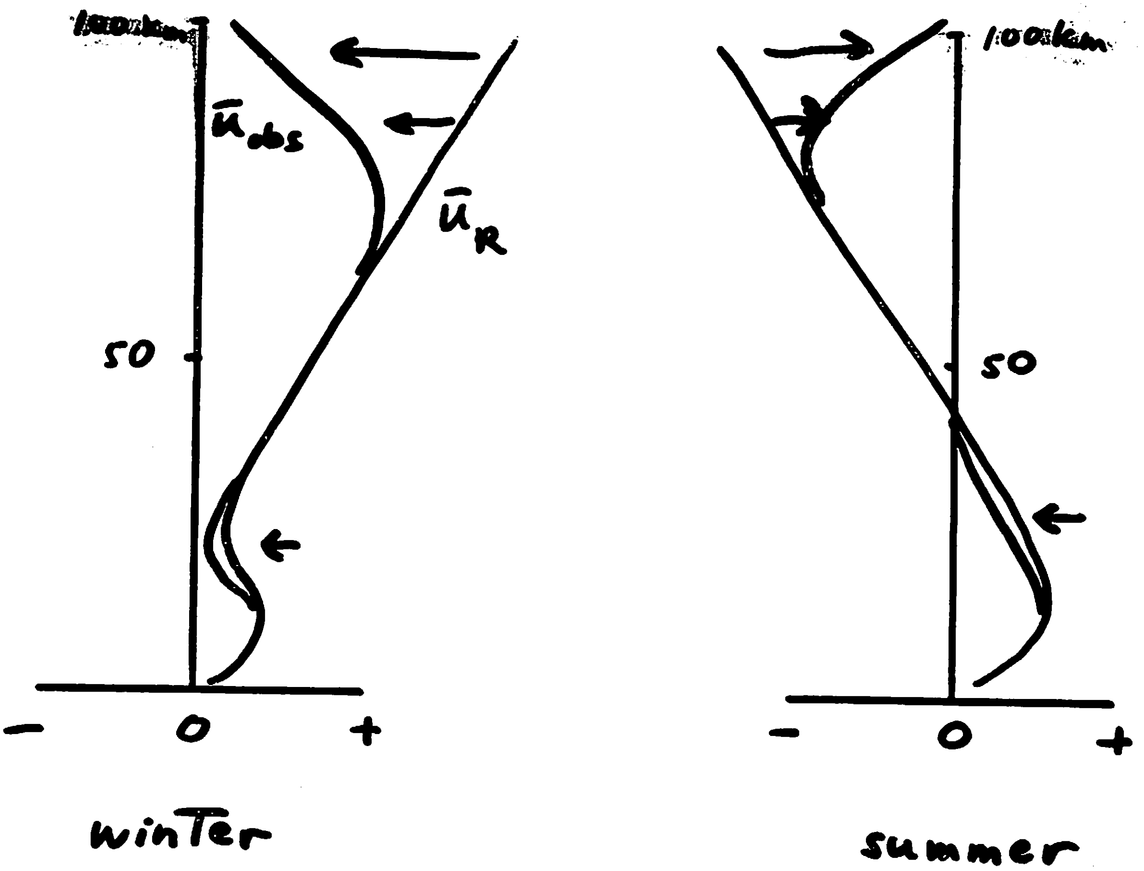
What Have We Learned So Far?

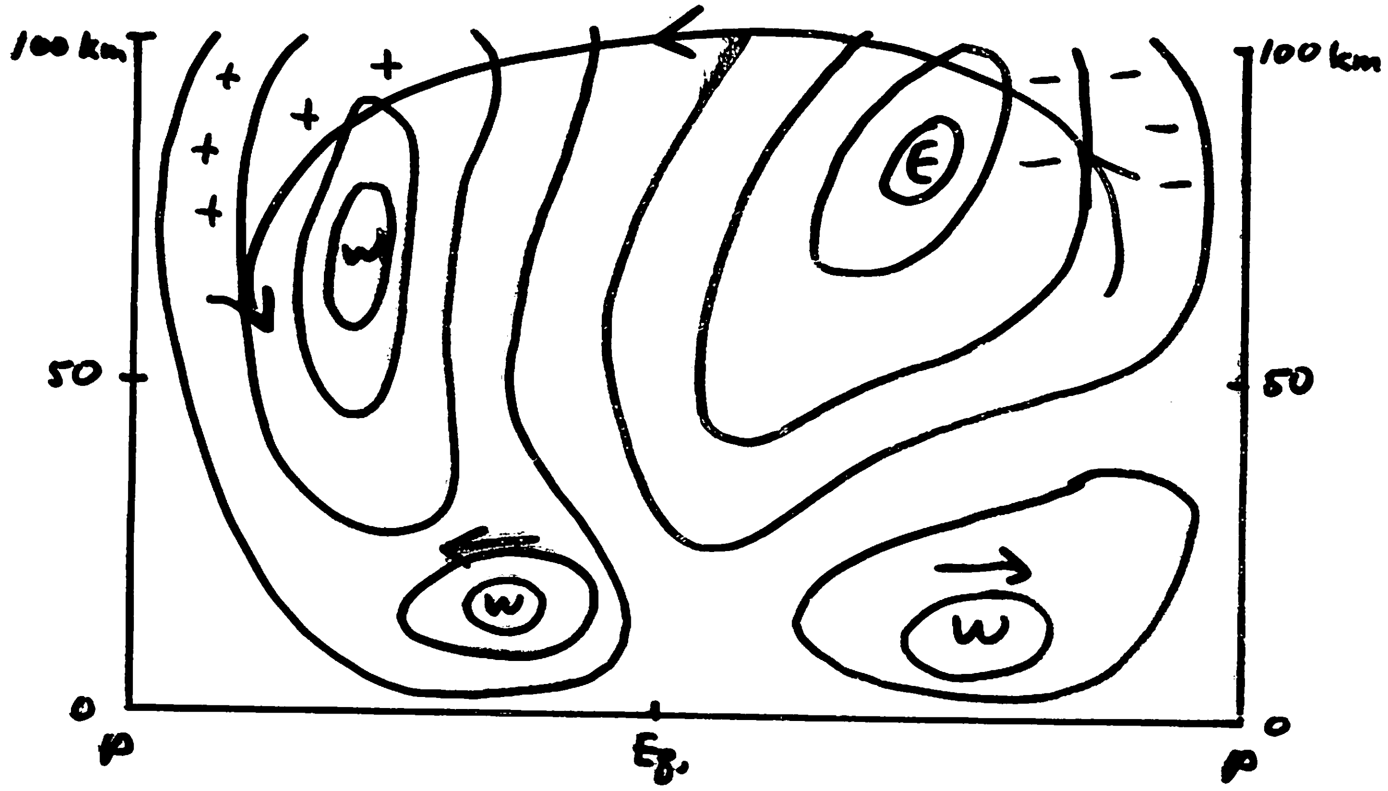
1. mean structure + circulation
    - mean $T(y,z)$ due to radiation, particle fluxes, and <u>dynamics</u>
    - mid-high latitude jets
        - strongly modulated in winter
        - jet closure ⇒

          strong body forces

          $\bar{v}$ and $\bar{w}$ strong

          $\partial T/\partial y$ reversal near mesopause
    - equatorial SAO driven by range of wave motions and merid. transports
        - mean westward motion at $z \gtrsim 70\,km$ due to tidal forcing


100 km
ū_obs
ū_R
50
−
0
+
winter
100 km
50
−
0
+
summer


100 km
+
+
+
+
+
W
W
E
W
−
−
−
−
−
50
0
p
Eq.
100 km
50
0
p

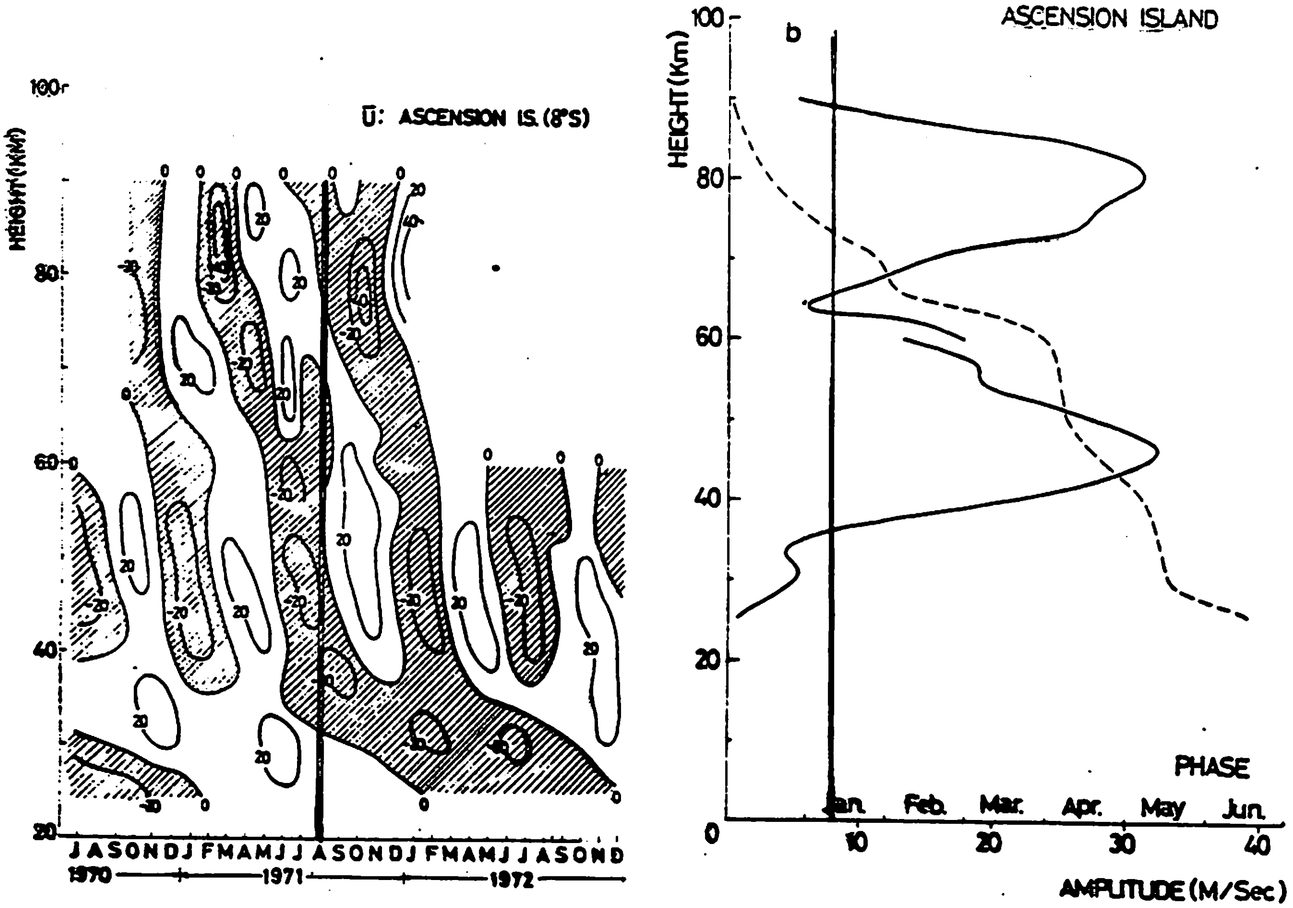


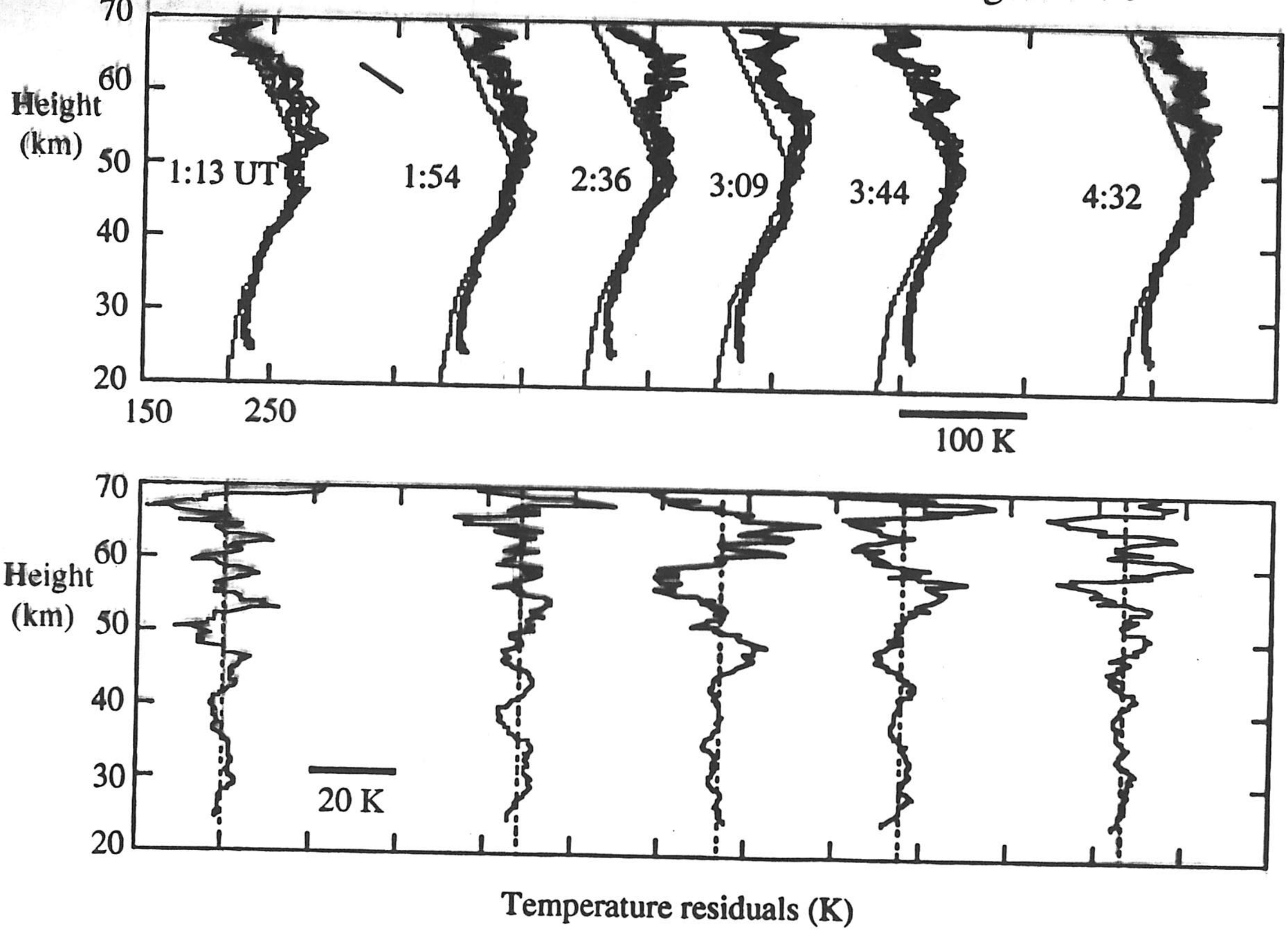
FIG. 1. The semiannual oscillation at Ascension Island (8°S). (a) Oscillation with time-mean and annual cycle removed; (b) amplitude of a sinusoidal fit, and phase of maximum westerlies. From Hirota (1978).

2. atmospheric motions - character, variab., + implications

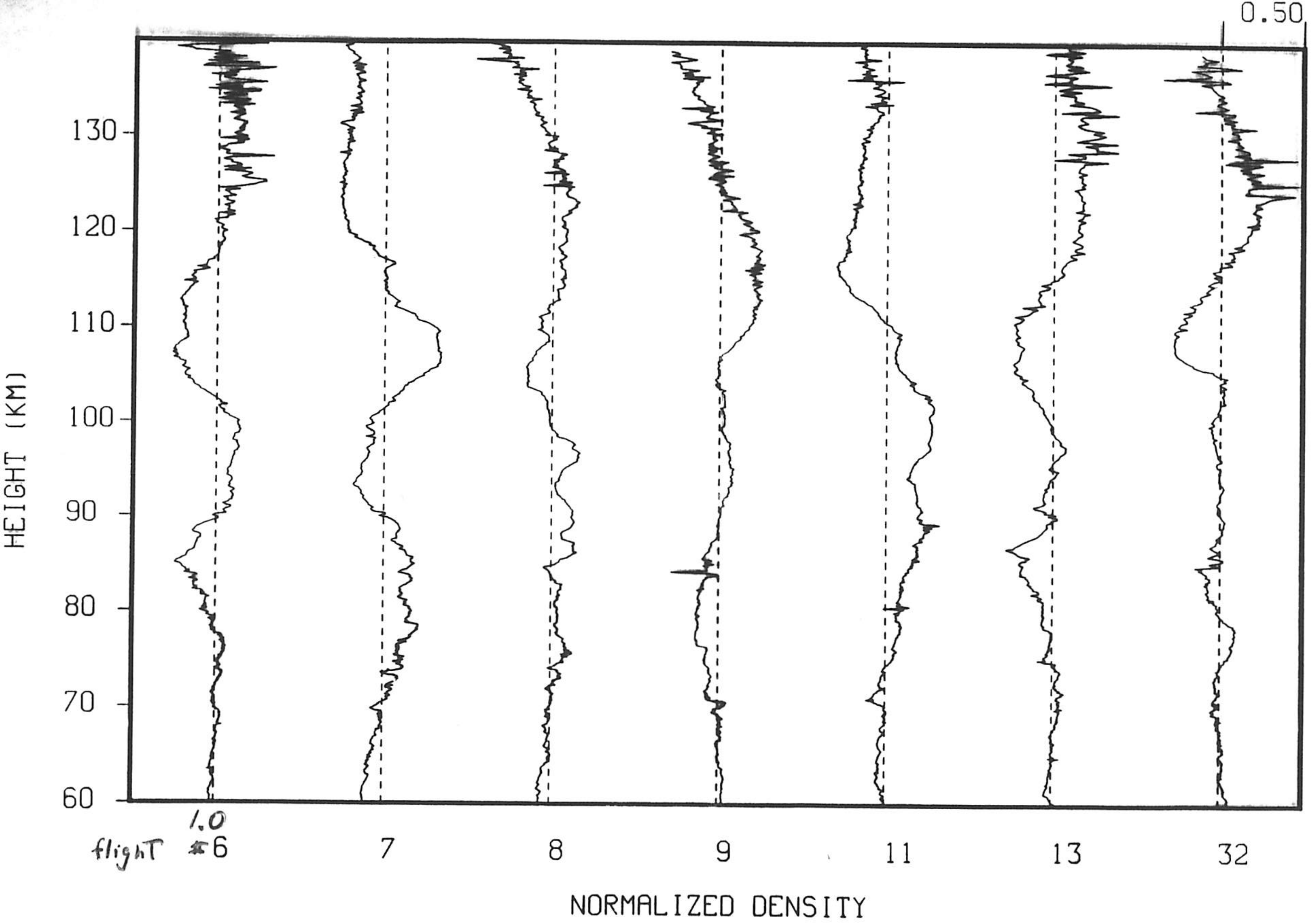
- amplitudes + scales growth with height

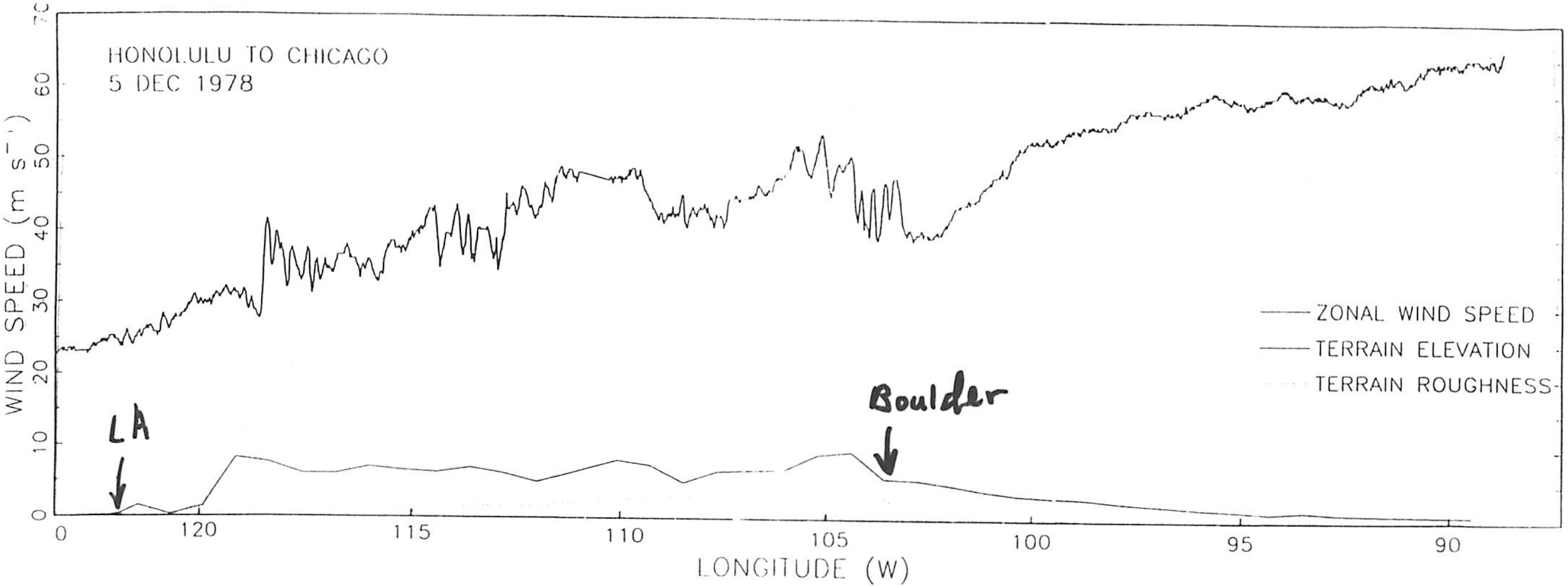
$$E \sim e^{z/H_E}, \quad H_E \sim 12\text{-}15 \text{ km}$$

- highly variable amplitudes + scales
  - variable wave sources
  - wave interactions + filtering



Sondrestrom PL lidar observations: 15/16 August 1990


0.50
130
120
110
100
90
80
70
60
HEIGHT (KM)
1.0
flighT #6
7
8
9
11
13
32
NORMALIZED DENSITY


HONOLULU TO CHICAGO
5 DEC 1978
WIND SPEED (m s⁻¹)
0
10
20
30
40
50
60
70
ZONAL WIND SPEED
TERRAIN ELEVATION
TERRAIN ROUGHNESS
LA
Boulder
0
120
115
110
105
100
95
90
LONGITUDE (W)

8-hour

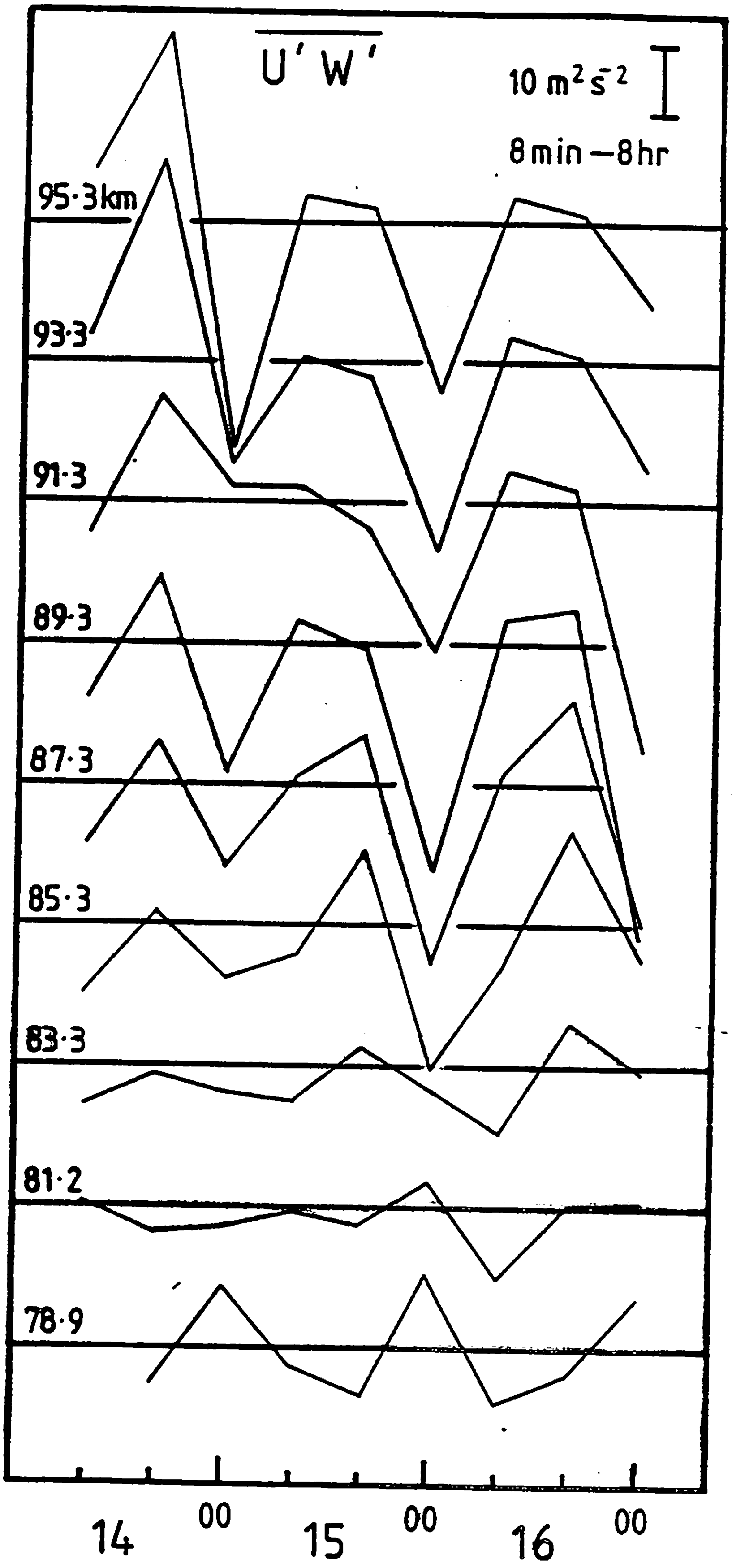
zonal momentum fluxes

during large diurnal tidal motion

⇒

$\Delta \overline{u'w'}$

$\gg (\overline{u'w'})_{mean}$



Fritts + Vincent ('87)

3. wave spectra + implications

- ω spectra
  - ~ uniform with height
  - Tidal peaks
    - ⇒ Tides have major roles (wave filtering, chemistry)
  - GW spectra

    $E_h(\omega) \sim \omega^{-5/3}$

    - insensitive to Doppler shifting
    - GW fluxes <u>most</u> important

    $E_v(\omega)$

    - <u>sensitive</u> to Doppler shifting

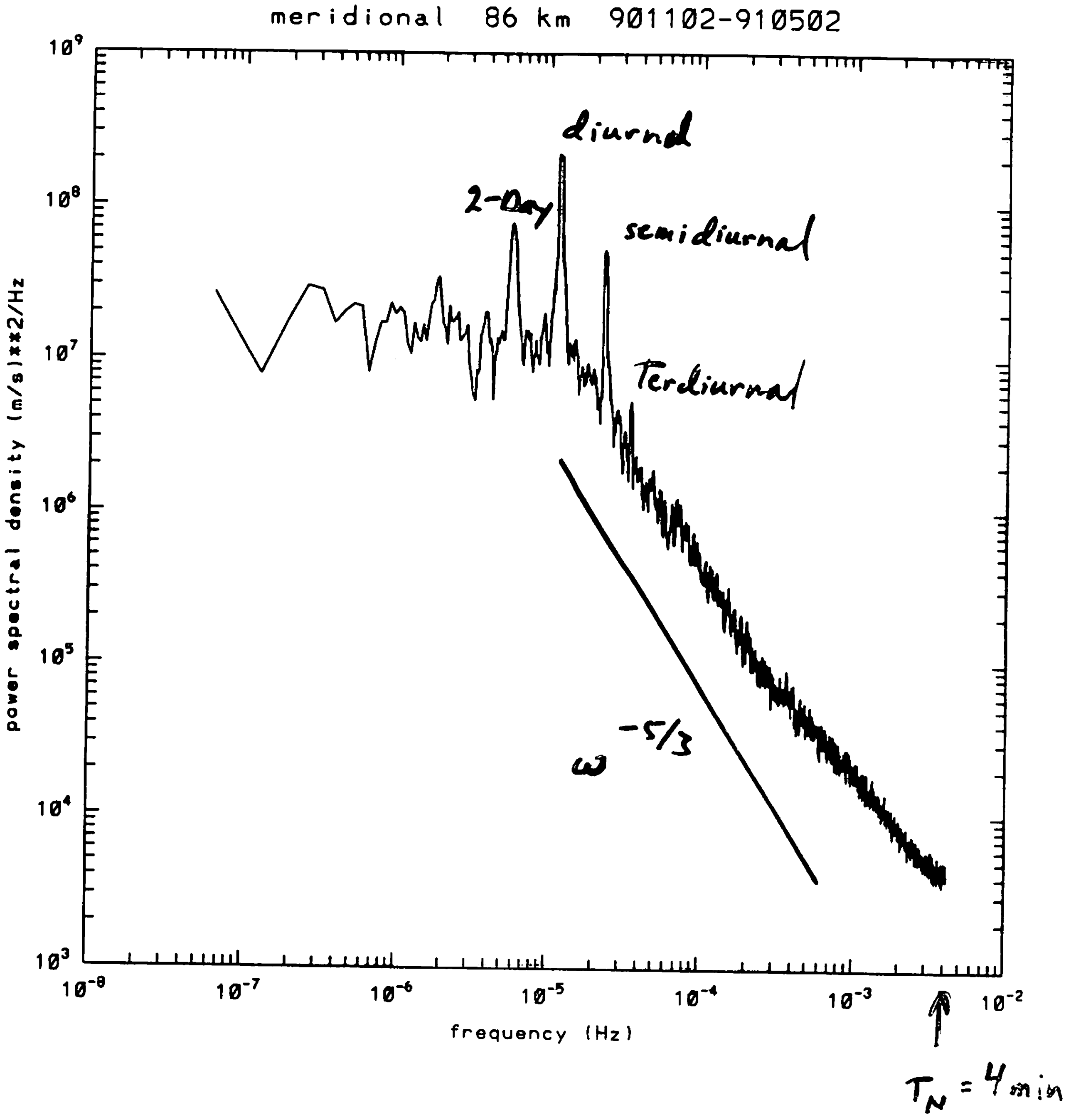
    ⇒

    - strong anisotropy
    - spectral character (m)

Hawaii MF radar

$E_v(\omega)$

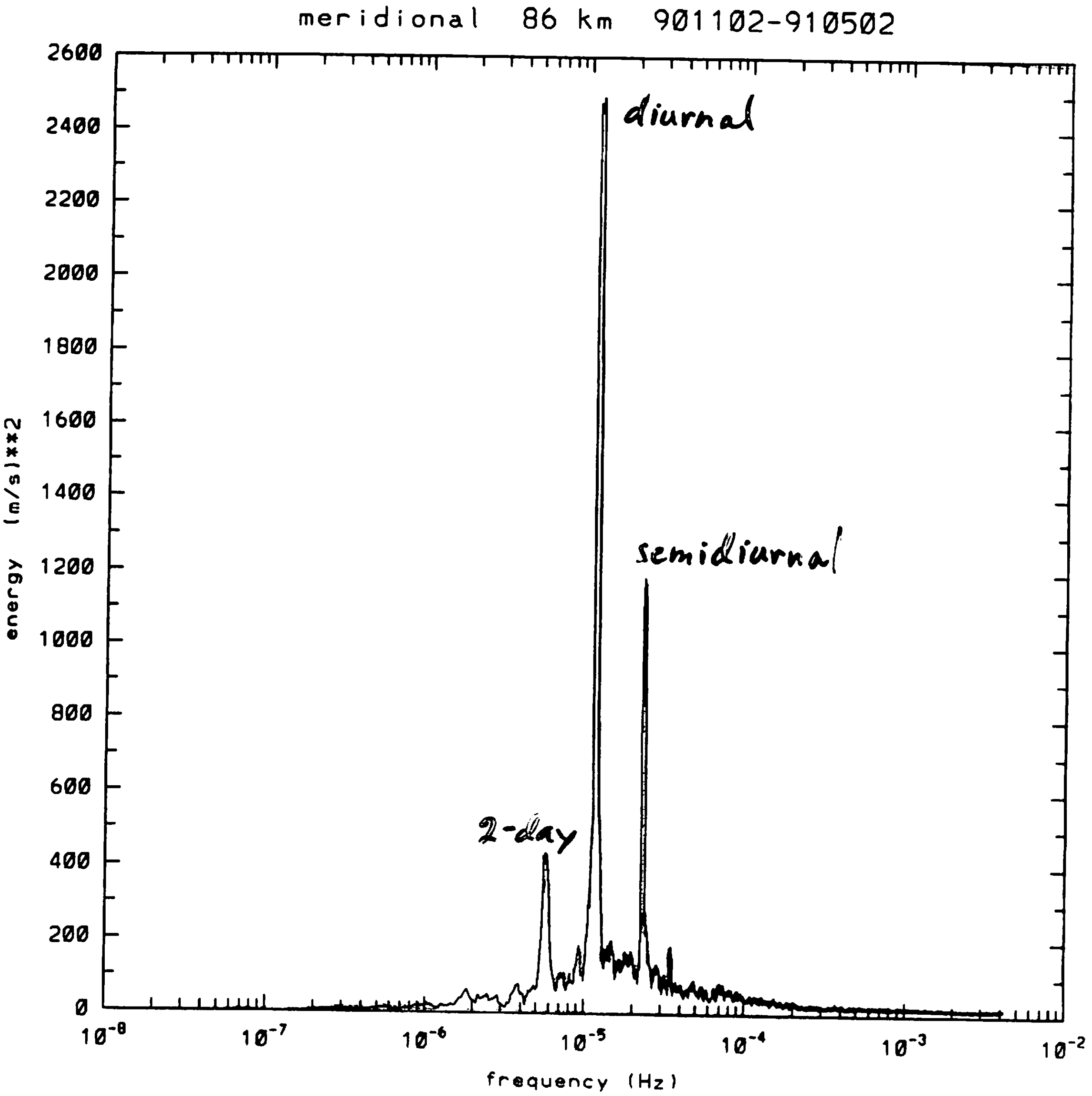
standard form



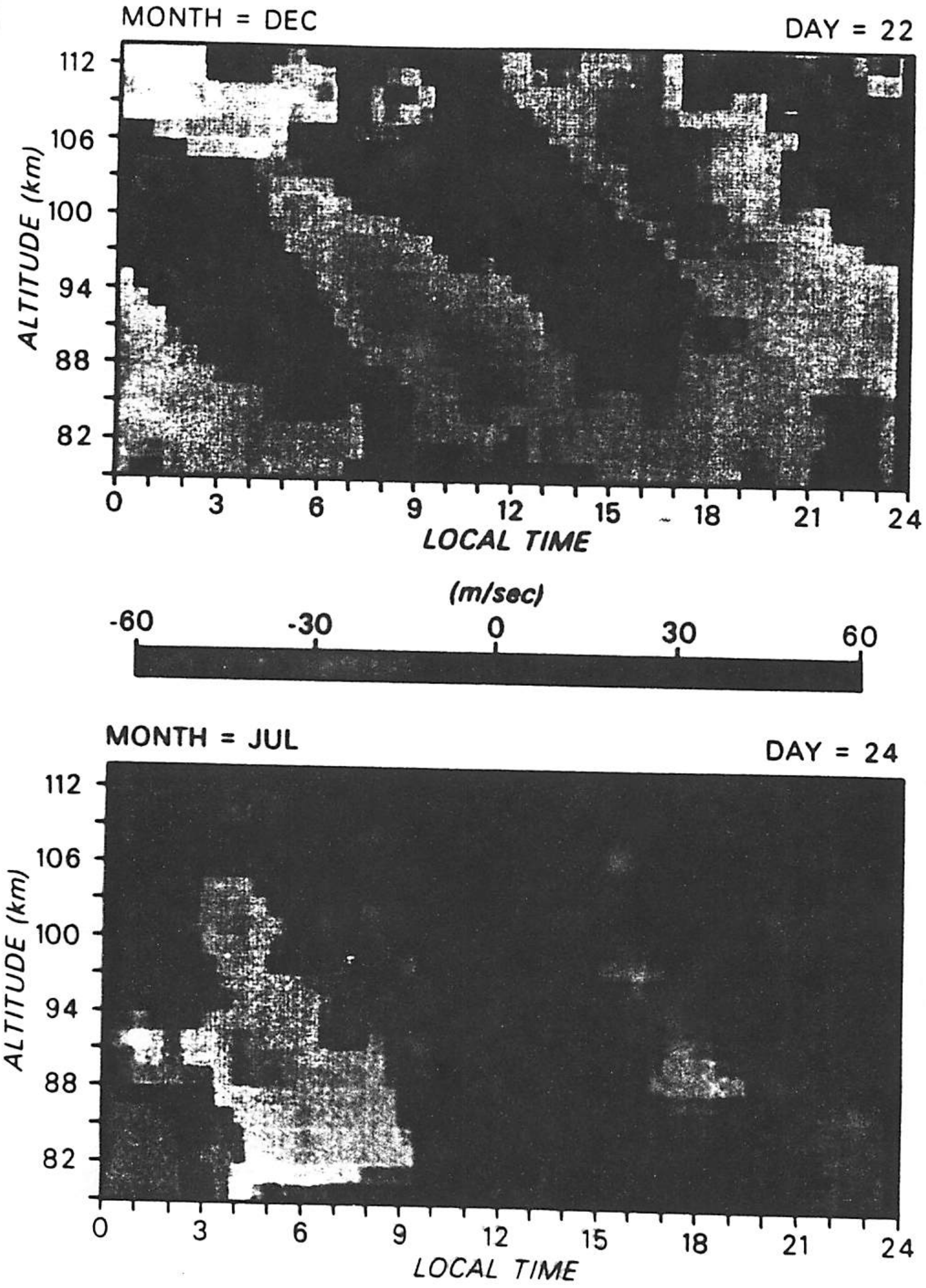
Hawaii MF radar

$\omega E_v(\omega)$ (semilog)

area preserving variance content



Dynamics of the Mesosphere and Lower Thermosphere



Saskatoon, Canada Northward Wind Component

gravity wave fluxes

momentum flux

$$\overline{u'w'} \sim \frac{\omega}{N}\,\overline{u'^2}$$

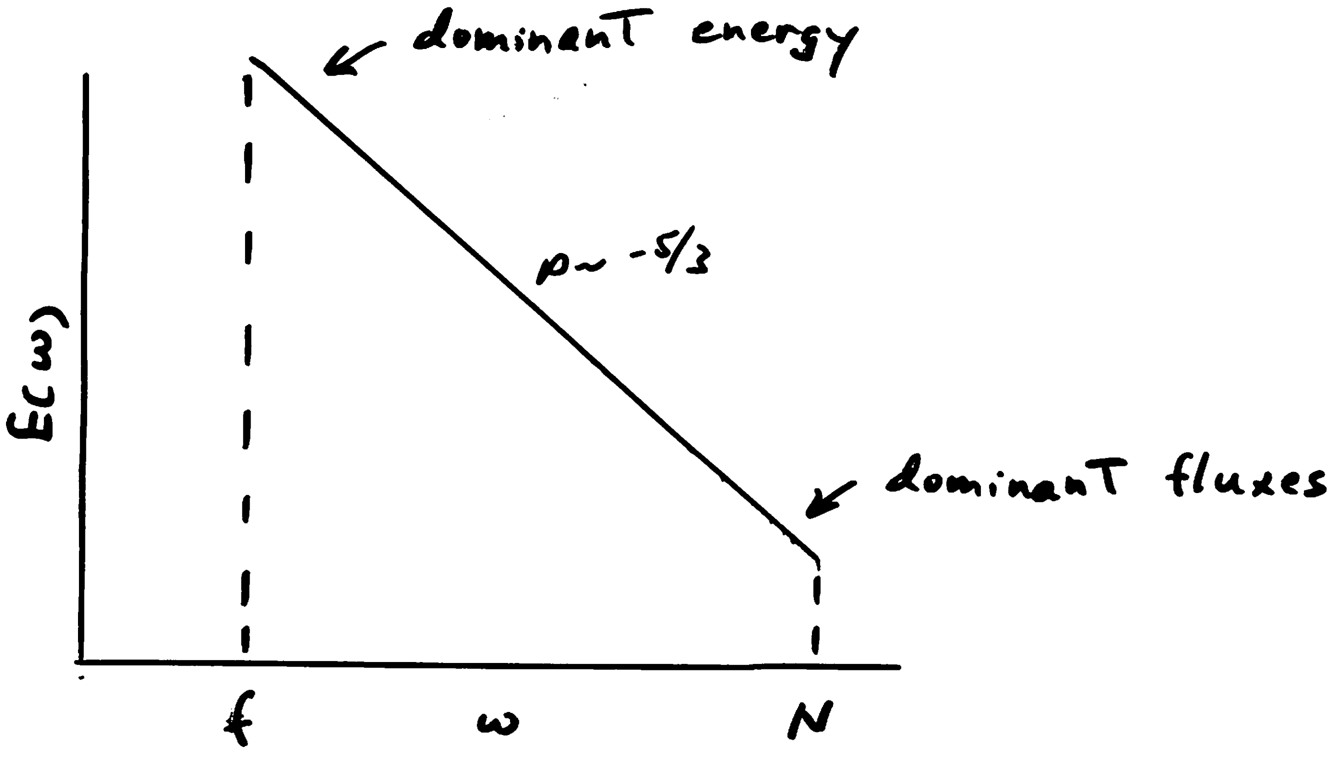
energy flux

$$c_{gz}\,E \sim \frac{\omega}{N}(c-\bar{u})\,\overline{u'^2}$$

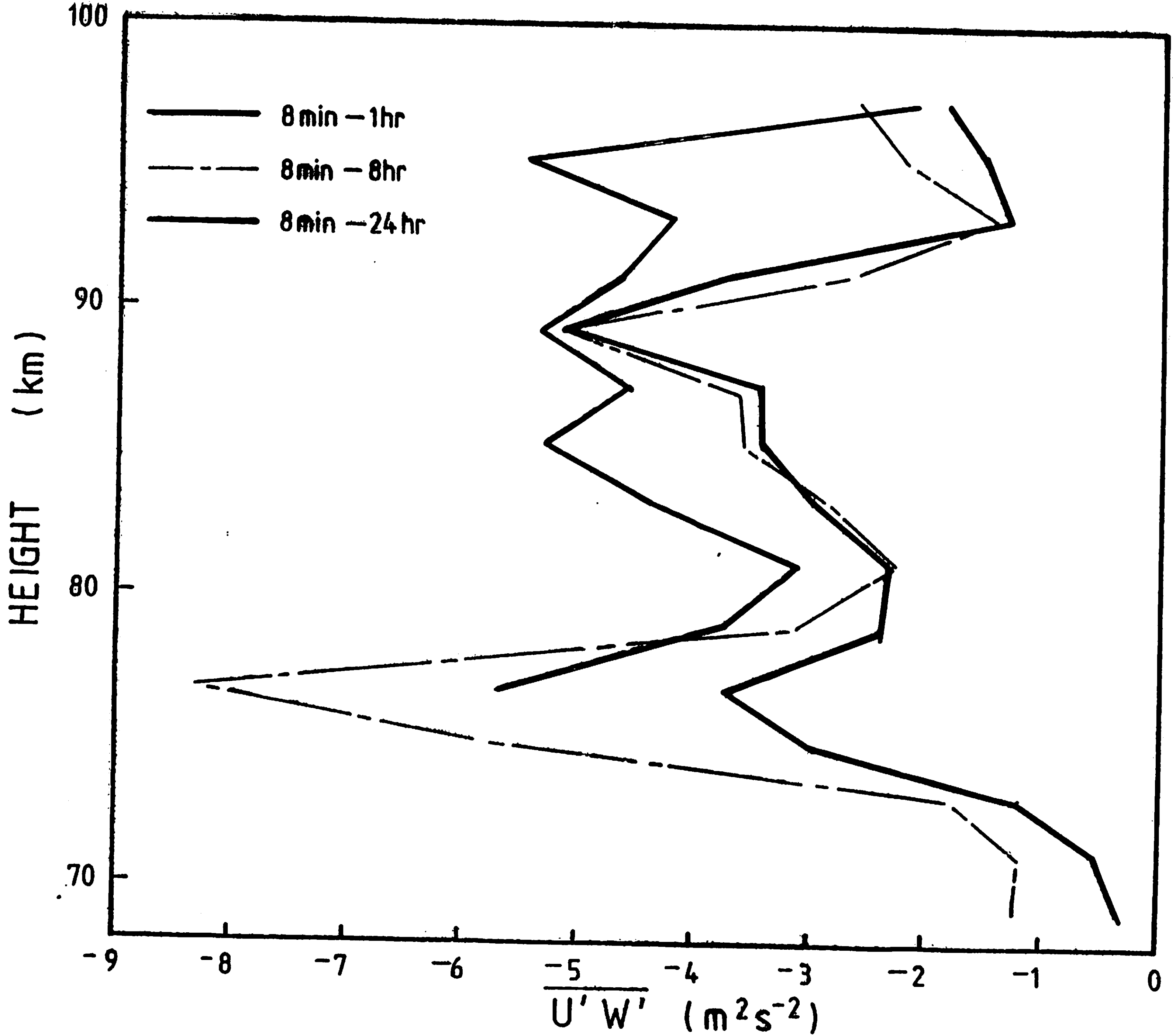
⇒ dominant fluxes by GWs with large

u' or λ_z

ω



ZONAL MOMENTUM FLUXES JUNE 9-17 (35°S)



$\overline{u'w'}$

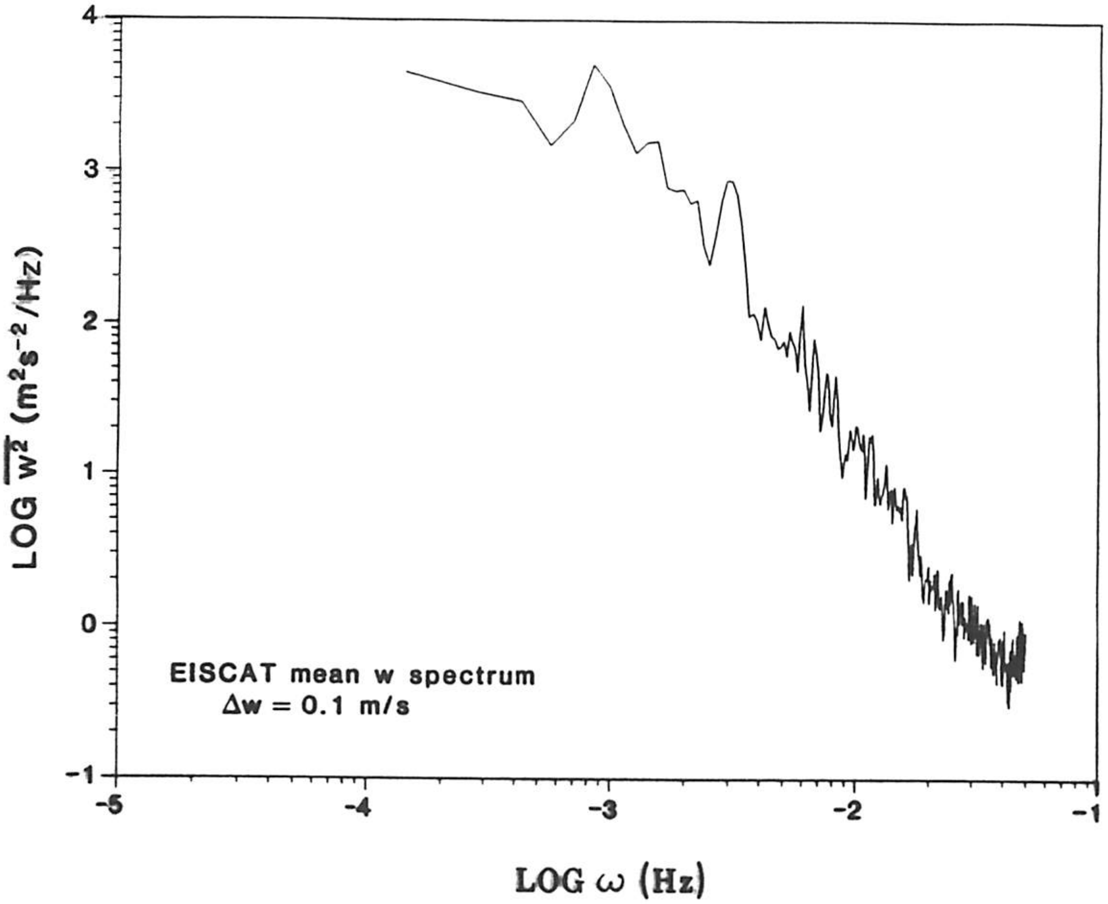
~ - 4-5 [illegible]

$\Rightarrow \frac{\partial \bar{u}}{\partial t}$

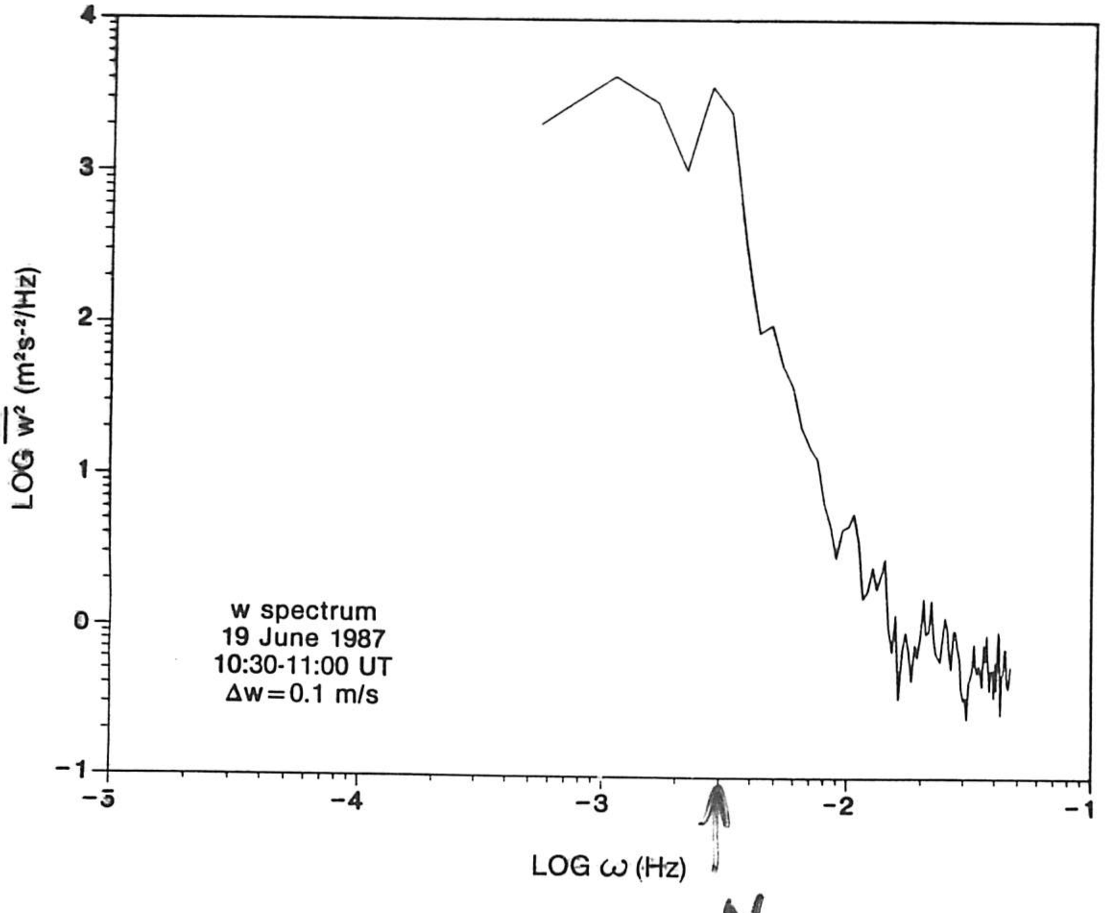
~ -70 m/s/

Fritts + Vincent ('87)

EISCAT VHF - MAC/SINE - 1987



mean spectrum



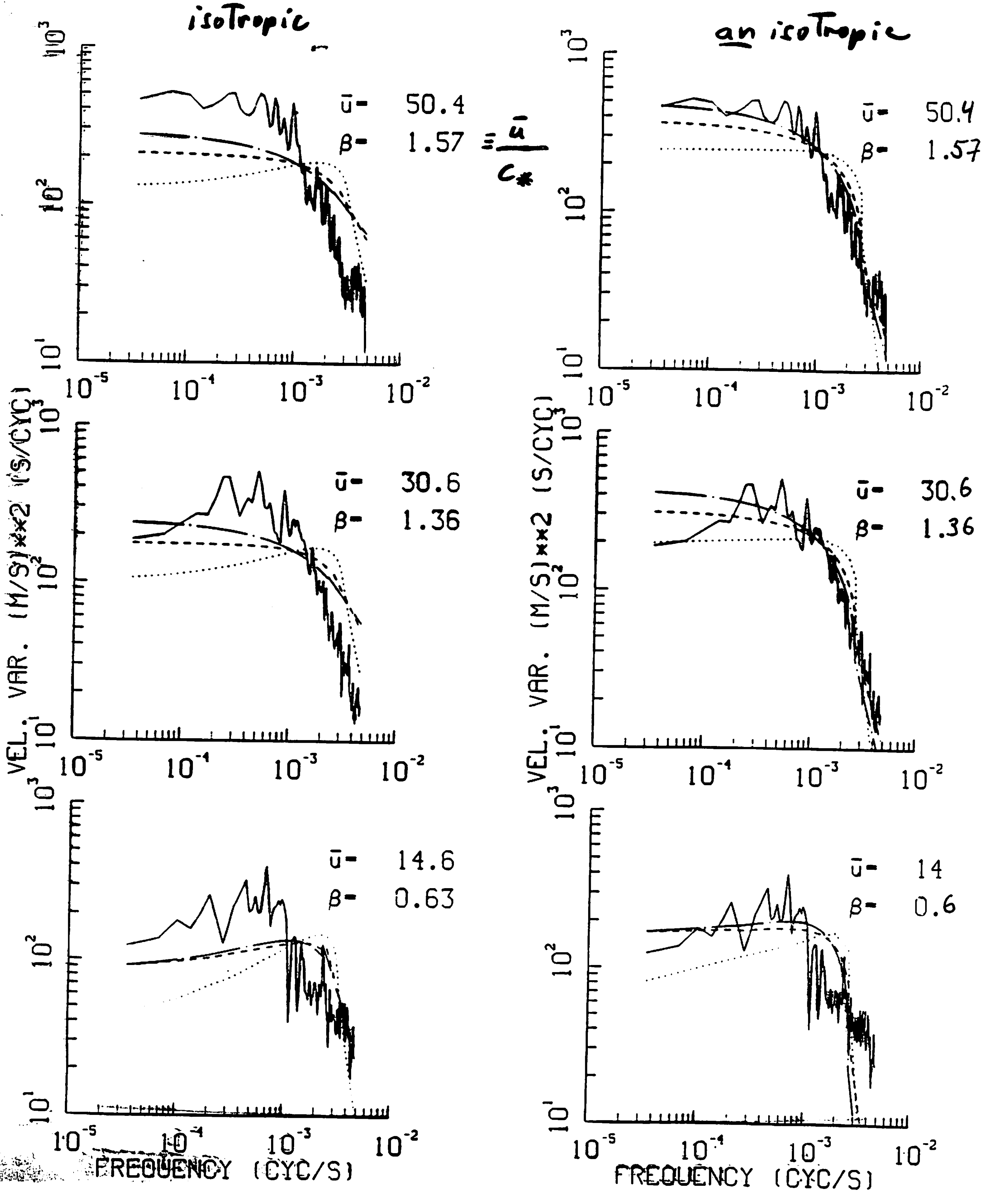
30 min spectrum

N

8-hr spectra Summer Mesopause Poker Flat

WIND(m/s)	NO.	VAR. $m^2 s^{-2}$
14.6	8	0.87
30.6	17	1.11
50.4	13	1.28

Fig. 3



– m spectra

$E(m) \sim m^{-3}$, large m

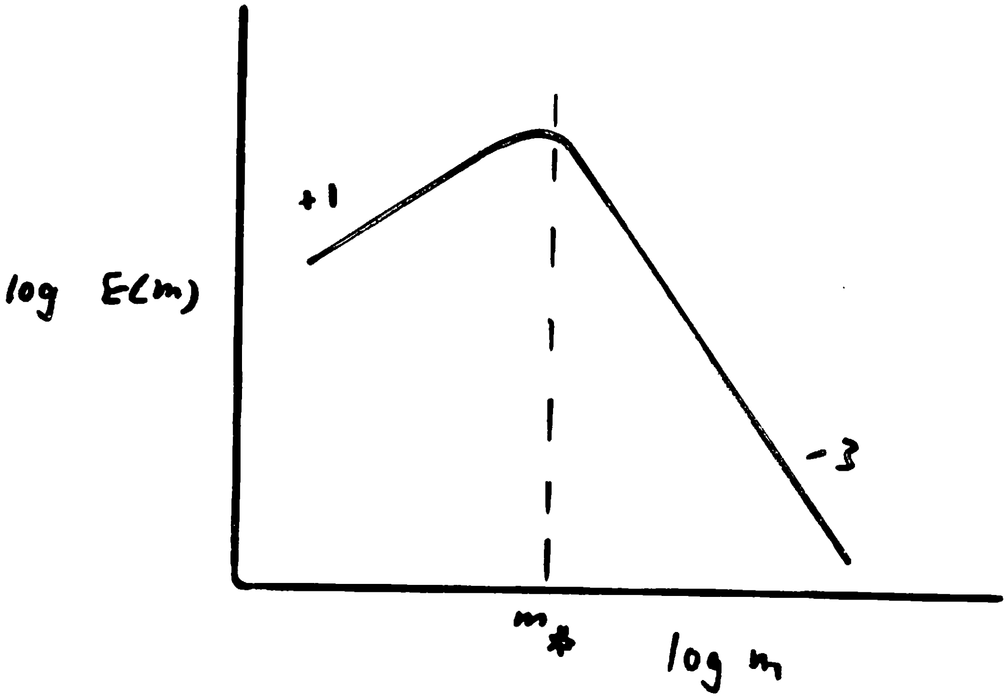
~ limiting spectral amplitude $\sim \frac{N^2}{6m^3}$

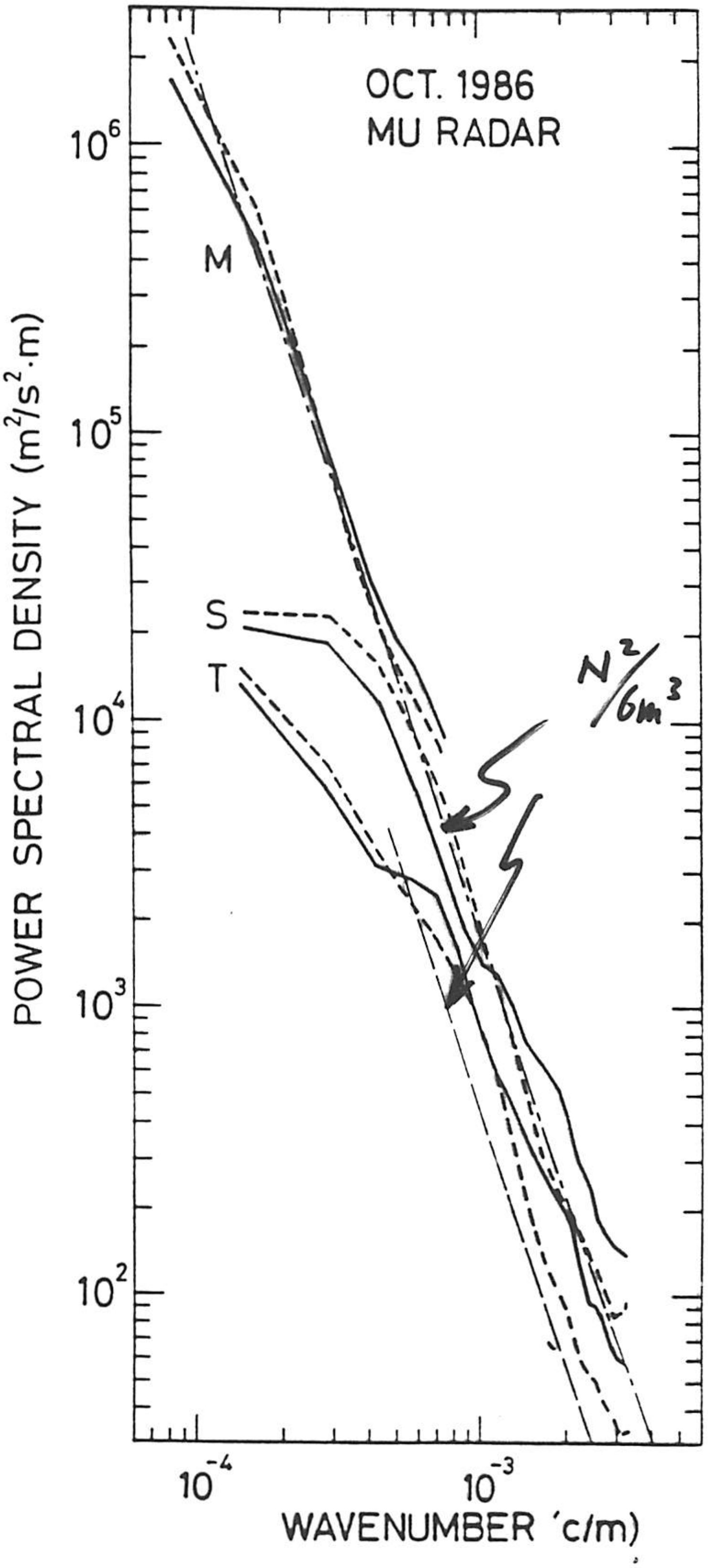
$\Rightarrow$

- wave saturation
- spectral energy transfers
- turbulence + diffusion

best fit to data:

$$E(m) \sim c \, \frac{m/m_*}{1+(m/m_*)^4}$$

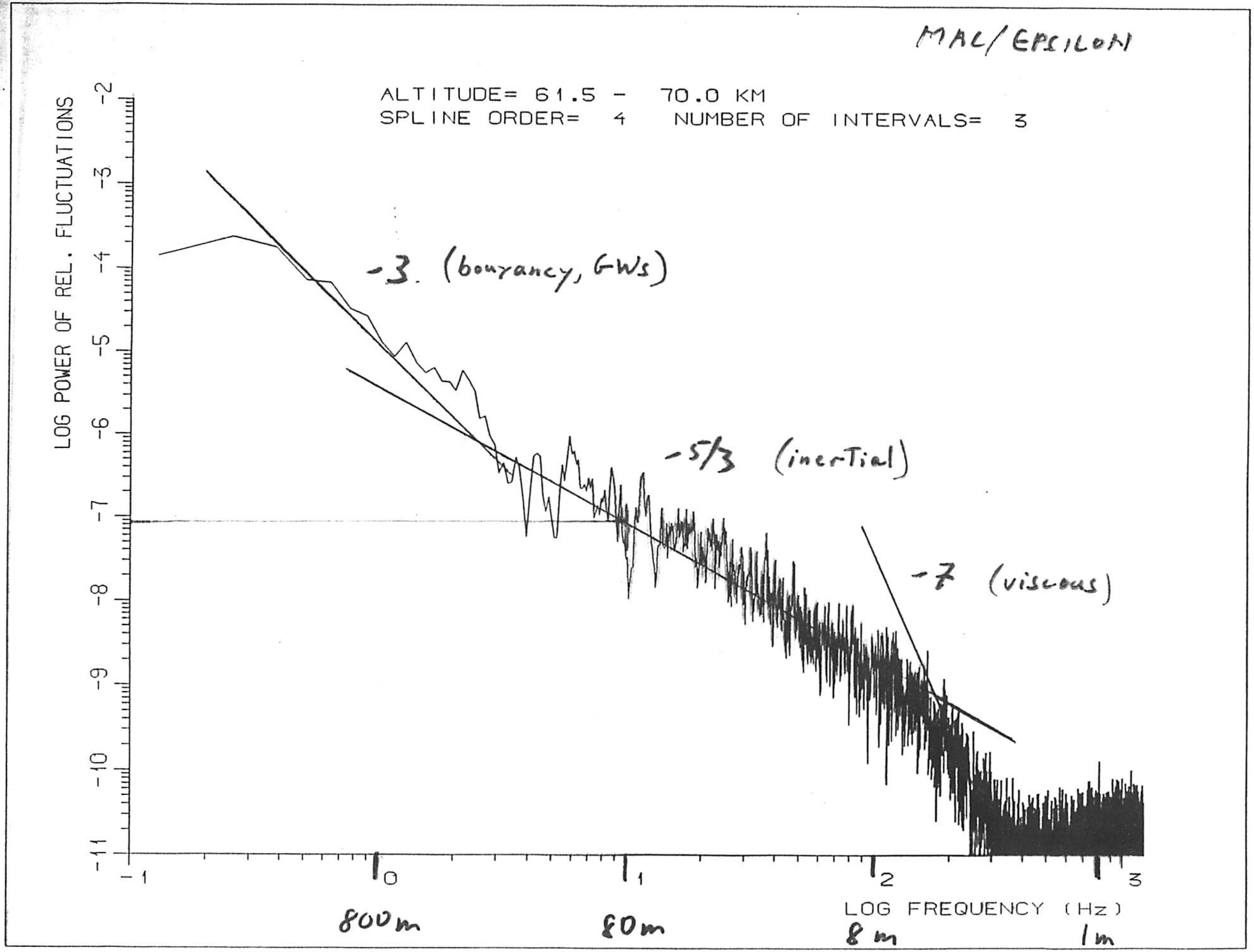




$\rho_T / \rho_m \sim 10^4$

Tsuda et al. ('89)

FIG. 3. Vertical wavenumber spectra in the mesosphere (M), lower stratosphere (S), and troposphere (T) from the MU radar observations in October 1986. The zonal and meridional spectral curves are indicated by (solid) and (dotted) lines, respectively. The model saturated gravity wave spectrum (Smith et al. 1987) is indicated by straight lines, (dashed) for the troposphere and (dot-dashed) for the mesosphere and lower stratosphere.


MAL/EPSILON
ALTITUDE= 61.5 - 70.0 KM
SPLINE ORDER= 4 NUMBER OF INTERVALS= 3
LOG POWER OF REL. FLUCTUATIONS
-2
-3
-4
-5
-6
-7
-8
-9
-10
-11
-1
0
1
2
3
LOG FREQUENCY (Hz)
-3. (bouyancy, GWs)
-5/3 (inertial)
-7 (viscous)
800m
80m
8m
1m

Time Scales for GW Energy Dissipation

mesosphere (~ 60 - 90 km)

$$E_m \sim 10^2 - 10^3 \ m^2/s^2$$

$$\varepsilon = \frac{dE_m}{dt} \sim 10^{-2} - 10^{-1} \ W/kg$$

$$\Rightarrow \ T_m \sim \frac{E_m}{\varepsilon} \sim \underline{\underline{3 \ hr}}$$

lower stratosphere (~ 10 - 20 km)

$$E_s \sim 1 - 10 \ m^2/s^2$$

$$\varepsilon \sim 10^{-6} - 10^{-5} \ W/kg$$

$$\Rightarrow \ T_s \sim \underline{\underline{1 - 10 \ days}}$$

⇒

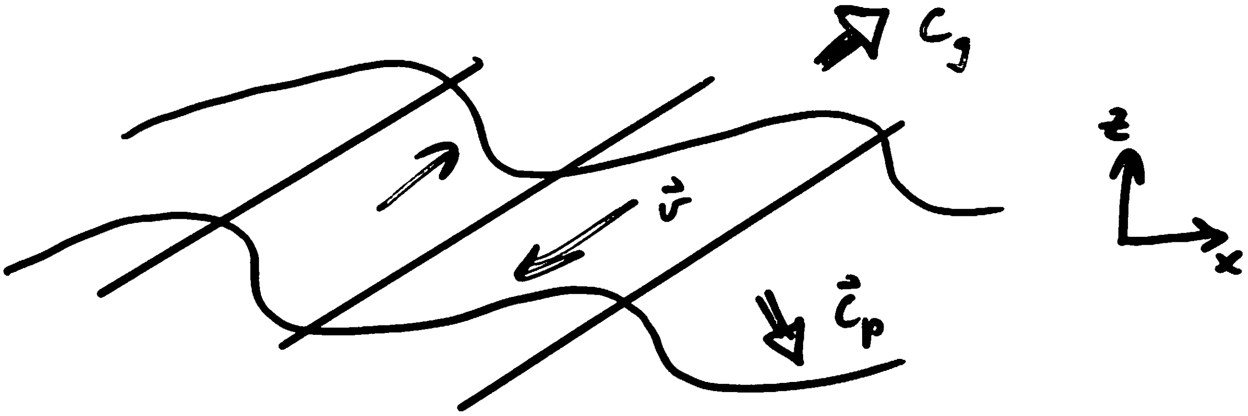
stratosphere may permit

- slow nonlinear energy transfers
- slow "linear" instabilities

mesosphere & lower thermosphere favor

vigorous local instabilities

4. momentum fluxes + implications



$\Rightarrow \rho \overline{u'w'} > 0$

zonal mean momentum equation:

$$\frac{\partial \bar{u}}{\partial t} - f\bar{v} = -\frac{1}{\bar{\rho}}\frac{\partial}{\partial z}\left(\bar{\rho}\,\overline{u'w'}\right) + \cdots$$

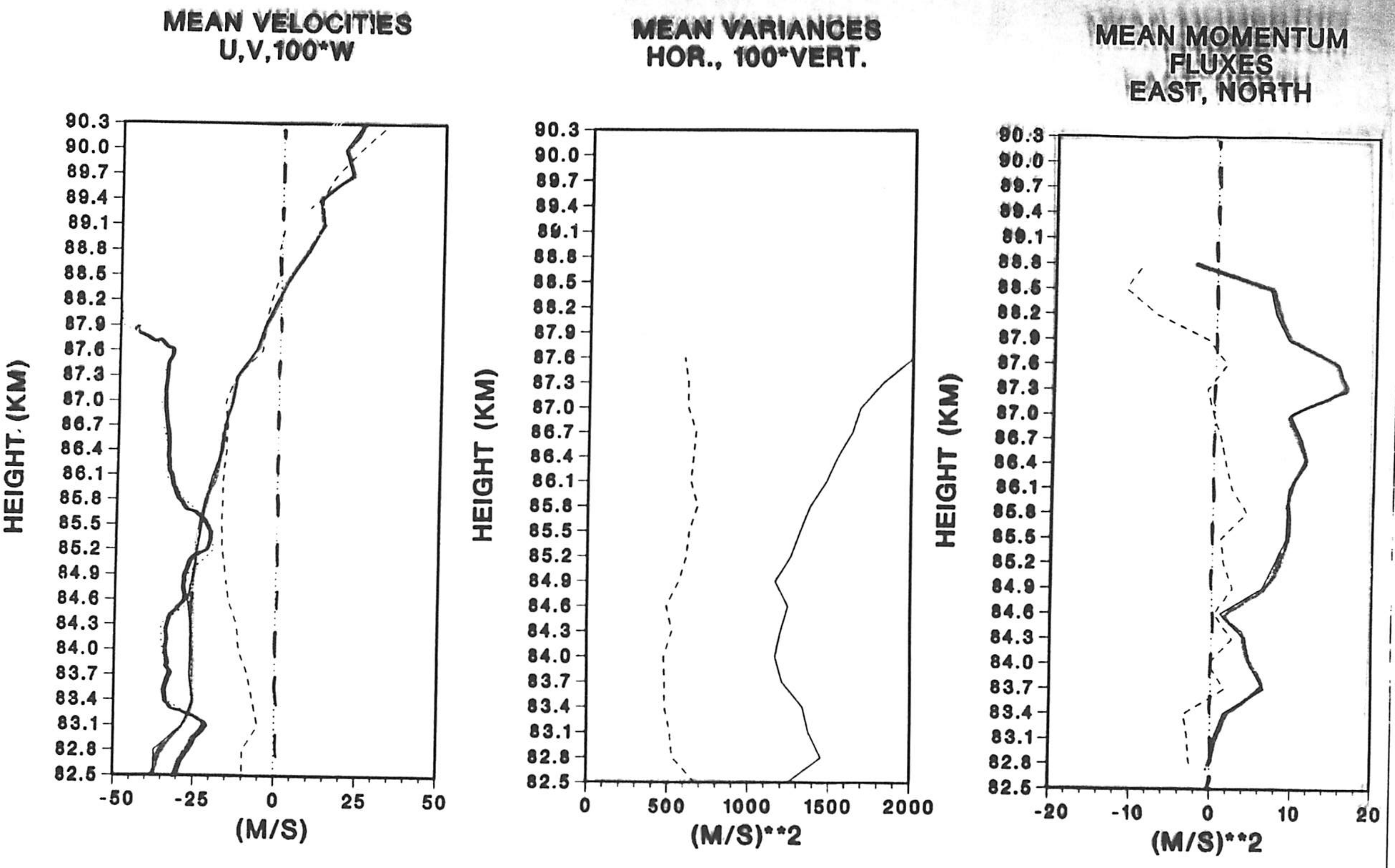
$\Rightarrow$ <u>either</u>

- mean flow accelerations/decels.

or

- $(\bar{v}, \bar{w})$ compensating circulation

<u>and</u> thermal consequences



MEAN VELOCITIES
U,V,100*W

MEAN VARIANCES
HOR., 100*VERT.

MEAN MOMENTUM
FLUXES
EAST, NORTH

cm/s

Poker Flat, July '86 (65°N)

Wave Driven Mesopause Circulation and Thermal Structure

mean flow equations:

$$f\bar{v} = \frac{1}{\bar{\rho}}\frac{\partial}{\partial z}\left(\bar{\rho}\,\overline{u'w'}\right)$$

$$\vec{\nabla}\cdot\left(\bar{\rho}\,\bar{\vec{v}}\right) = 0$$

$\Rightarrow$

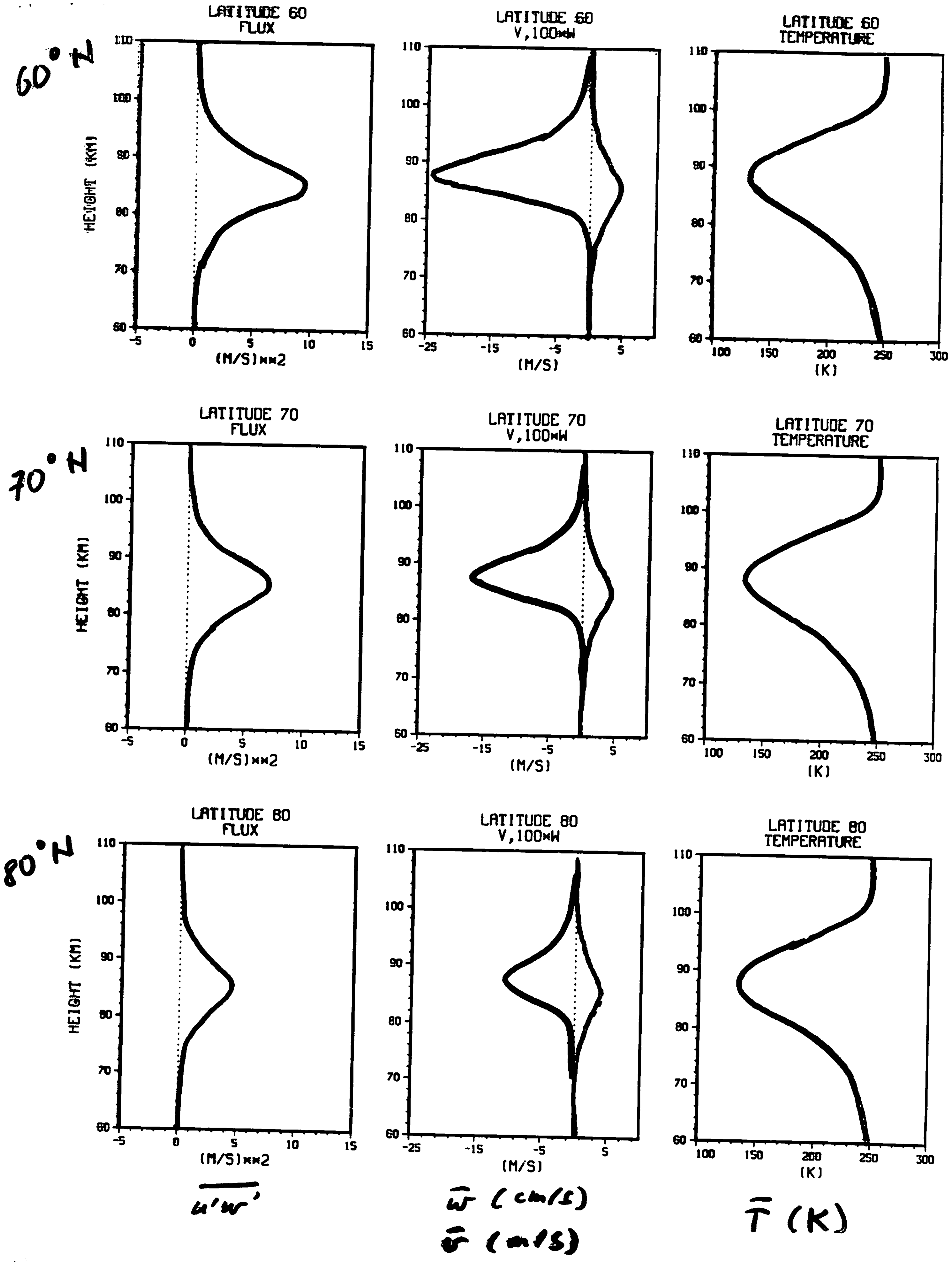
$$\bar{w} \approx -\frac{1}{f}\frac{\partial}{\partial y}\left(\overline{u'w'}\right) \quad \text{near pole}$$

$$\frac{\partial \bar{v}}{\partial y} = -\frac{1}{\bar{\rho}}\frac{\partial}{\partial z}\left(\bar{\rho}\,\bar{w}\right)$$

$\Rightarrow \ (\bar{v}, \bar{w})$

Then radiative forcing + boundary conditions

$\Rightarrow \ \bar{T}(y,z)$


60° N
LATITUDE 60
FLUX
HEIGHT (KM)
(M/S)**2
LATITUDE 60
V,100*W
(M/S)
LATITUDE 60
TEMPERATURE
(K)
70° N
LATITUDE 70
FLUX
HEIGHT (KM)
(M/S)**2
LATITUDE 70
V,100*W
(M/S)
LATITUDE 70
TEMPERATURE
(K)
80° N
LATITUDE 80
FLUX
HEIGHT (KM)
(M/S)**2
LATITUDE 80
V,100*W
(M/S)
LATITUDE 80
TEMPERATURE
(K)
110
100
90
80
70
60
-5
0
5
10
15
-25
-15
-5
5
100
150
200
250
300
$\overline{u'w'}$
$\bar{w}$ (cm/s)
$\bar{v}$ (m/s)
$\bar{T}$ (K)

FUTURE CEDAR RESEARCH PRIORITIES (a personal view!)

MORE COMPLETE VIEW OF ATMOSPHERIC CIRCULATION AND STRUCTURE

* - MEAN WIND (U,$\underline{V}$,$\underline{W}$), THERMAL, AND CONSTITUENT STRUCTURES

- HEMISPHERIC AND REGIONAL ASYMMETRIES

- STATISTICAL FLUCTUATIONS, SPATIAL AND TEMPORAL SCALES

- SECULAR CHANGES, RESPONSES TO CO_2, CFC'S, O_3, ETC.

QUANTIFICATION OF SOLAR INFLUENCES

- FLUXES, HEATING

- MOMENTUM INPUTS

* - VARIABILITY

QUANTIFICATION OF WAVE PROCESSES (GRAVITY, TIDAL, PLANETARY)

* - SOURCE STRENGTH, DISTRIBUTION, AND VARIABILITY (LOWER ATMOSPHERE!)

* - WAVE FILTERING, INTERACTIONS, AND ANISOTROPY

* - COUPLING AND TRANSPORTS, VERTICAL AND HORIZONTAL

* - WAVE DISSIPATION, TURBULENCE, AND DIFFUSION

* - FORCING OF THE MEAN STATE

- COUPLING TO RADIATIVE AND CHEMICAL PROCESSES

- INPUTS TO MODELING AND THEORETICAL EFFORTS vertical velocity variability

Platteville, CO

-correlated w/ planetary wave activity, strong winds

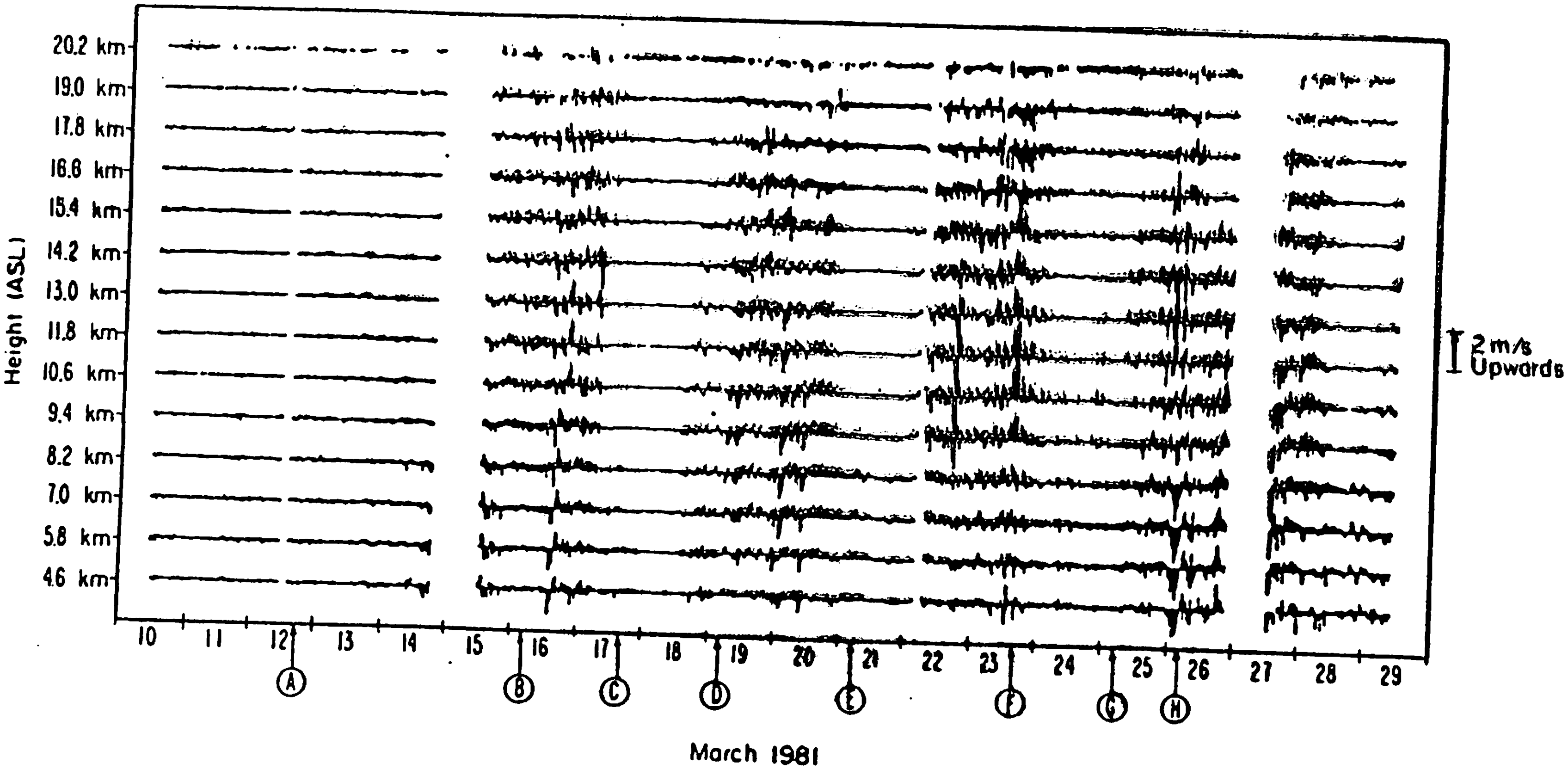
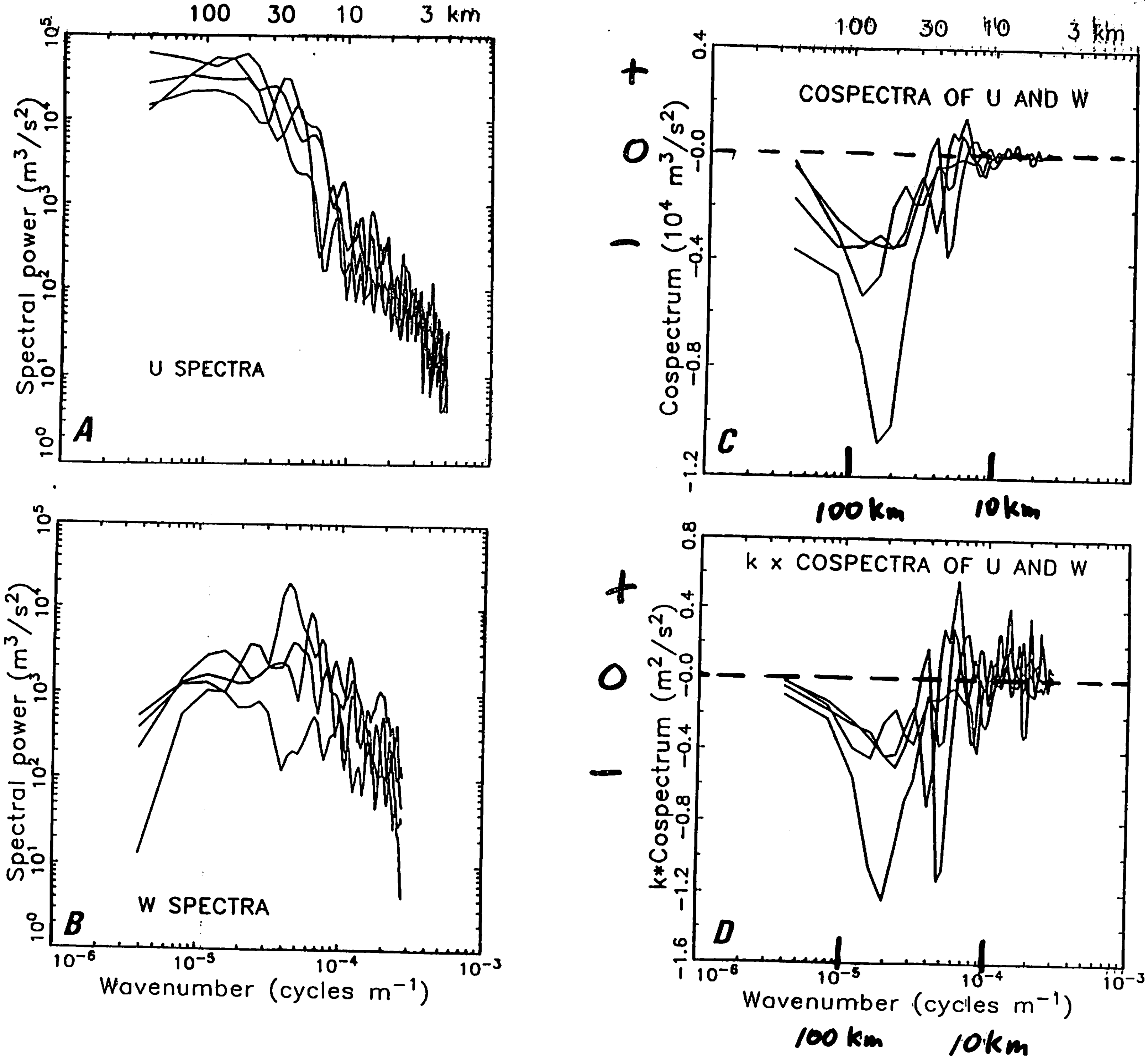


FIG. 1. Vertical velocities measured with the Platteville, Colo., 50 MHz radar. The reference scale is shown at the right-hand axis. The time series covers a period of 19 days, and the height resolution is 1.2 km. Alternating quiet and active periods repeat every four to five days.

Ecklund et al. ('81)

GASP momentum flux spectra - $\overline{u'w'}(k)$



8

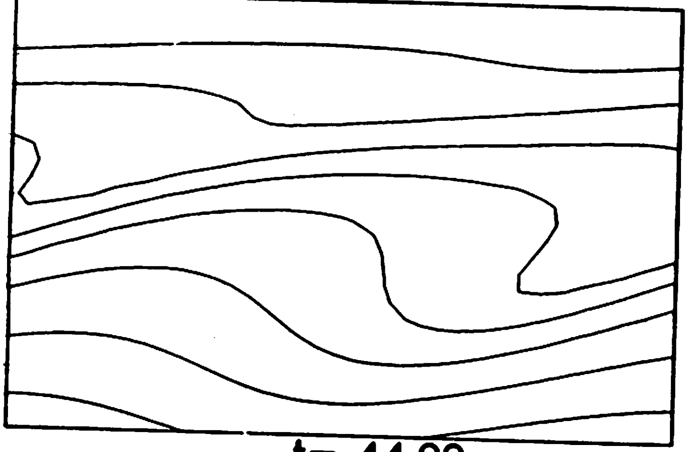
Gravity wave - mean shear interaction

$\lambda_x = 4H \sim 28$ km $\quad z_0 = 1.5H \sim 10$ km

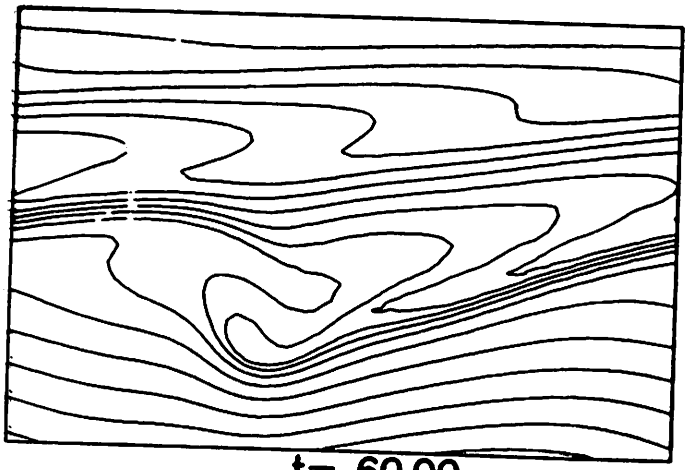
T = 420 sec

2-D, 128 × 65

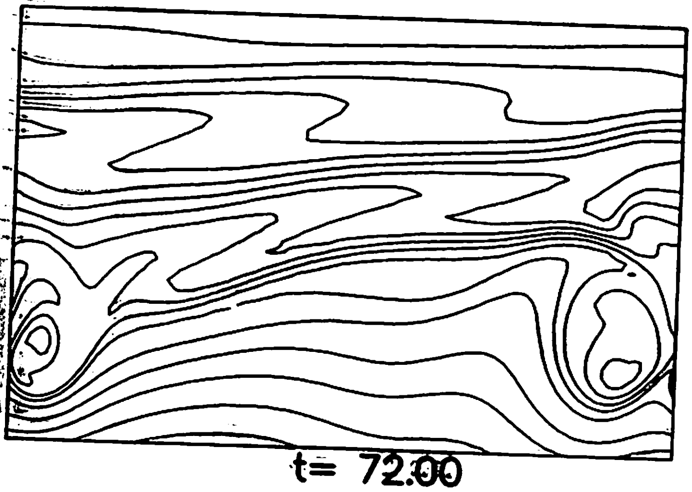
Pot-temp max: 1.33E+00 min:-2.42E-01



t= 44.00



t= 60.00

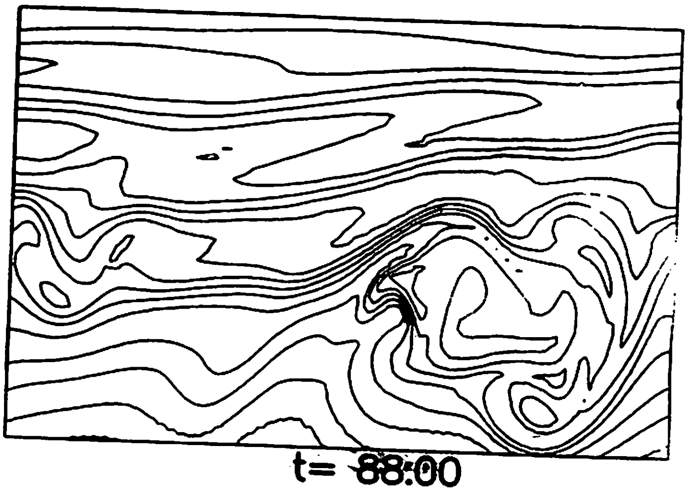


t= 72.00

Pot-temp max: 1.33E+00 min:-2.42E-01

t= 80.00

t= 84.00



t= 88.00

OPPORTUNITIES WITH NEW CEDAR INSTRUMENTATION

NEW CAPABILITIES

- HIGH-RESOLUTION MEASUREMENTS
- SIMULTANEOUS WINDS AND TEMPERATURES
- CONTINUOUS HEIGHT PROFILES, ~ 0 - 100+ KM
- COORDINATED STUDIES OF DYNAMICS, RADIATION, AND CHEMISTRY

MAJOR MEASUREMENT NEEDS

- CONTINUOUS LONG-TERM MEASUREMENTS
- COMPREHENSIVE, MULTI-INSTRUMENT CAMPAIGNS
- ✓ VERTICAL COUPLING STUDIES (WITHOUT RADAR "GAP")
- ✓ RESPONSES TO WAVE SOURCE/FILTERING VARIABILITY
- ✓ SENSITIVITY TO VERTICAL AND MERIDIONAL CIRCULATION
- ✓ FLUX MEASUREMENTS! - MOMENTUM, HEAT, ENERGY

fluctuations ⇒ presence ?

fluxes ⇒ forcing + effects !

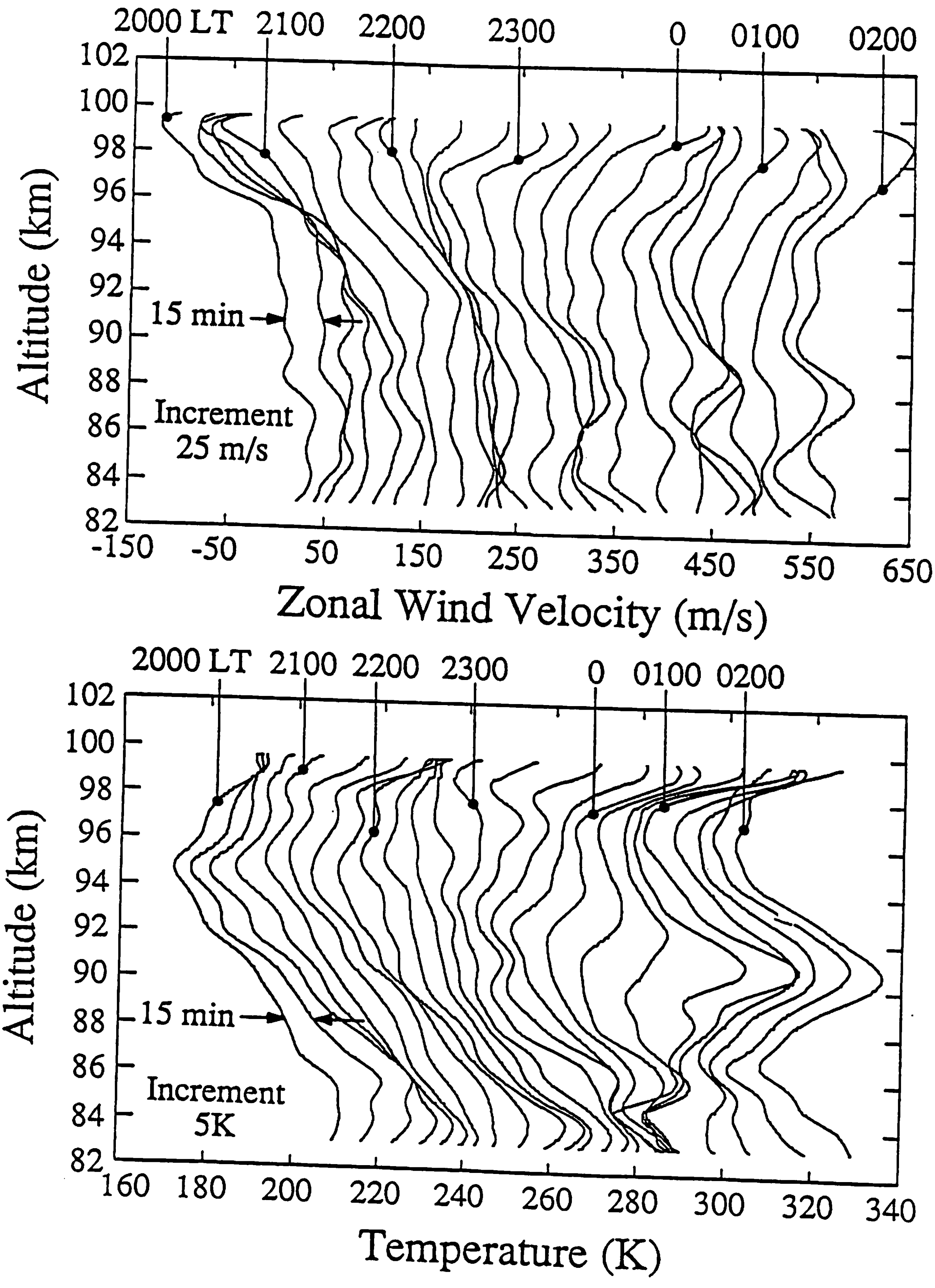


Figure 4. a) Zonal wind profiles spaced 15 min apart and offset by 25 m/s for the 14-15 March 1991 data set. b) Temperature profiles spaced 15 min apart and offset by 5 K. All of the profiles have been smoothed to 1.5 km vertical and 30 min temporal resolution.

CEDAR instrument capabilities (dynamics)