INTRASEASONAL OSCILLATIONS IN THE MID-LATITUDES: OBSERVATIONS, THEORY, AND GCMS

M. Ghil

Atmospheric Sciences Dept. & IGPP, UCLA, and
Dpt. Terre–Atmosphère–Océan & LMD, ENS, Paris

Motivation

1. Excellent match between AAM & LOD.
2. Tropical MJ oscillation does not explain all aspects of NH midlatitude oscillation.
3. No satisfactory explanation for MJ oscillation.
4. Promise for extended-range forecasting.

Joint work with: C.Baroud, P. Bernardet, P. Billant, J. Dickey, K. Ide, F.-f. Jin, C. L. Keppenne, D. Kondrashov, F. Lott, S. L. Marcus, K.-C. Mo, M. C. Penland, A. W. Roberston, C. M. Strong, H. Swinney, Y. Tian, J. J. Tribbia, J. Urbach, E. Weeks, & K. Weickmann.

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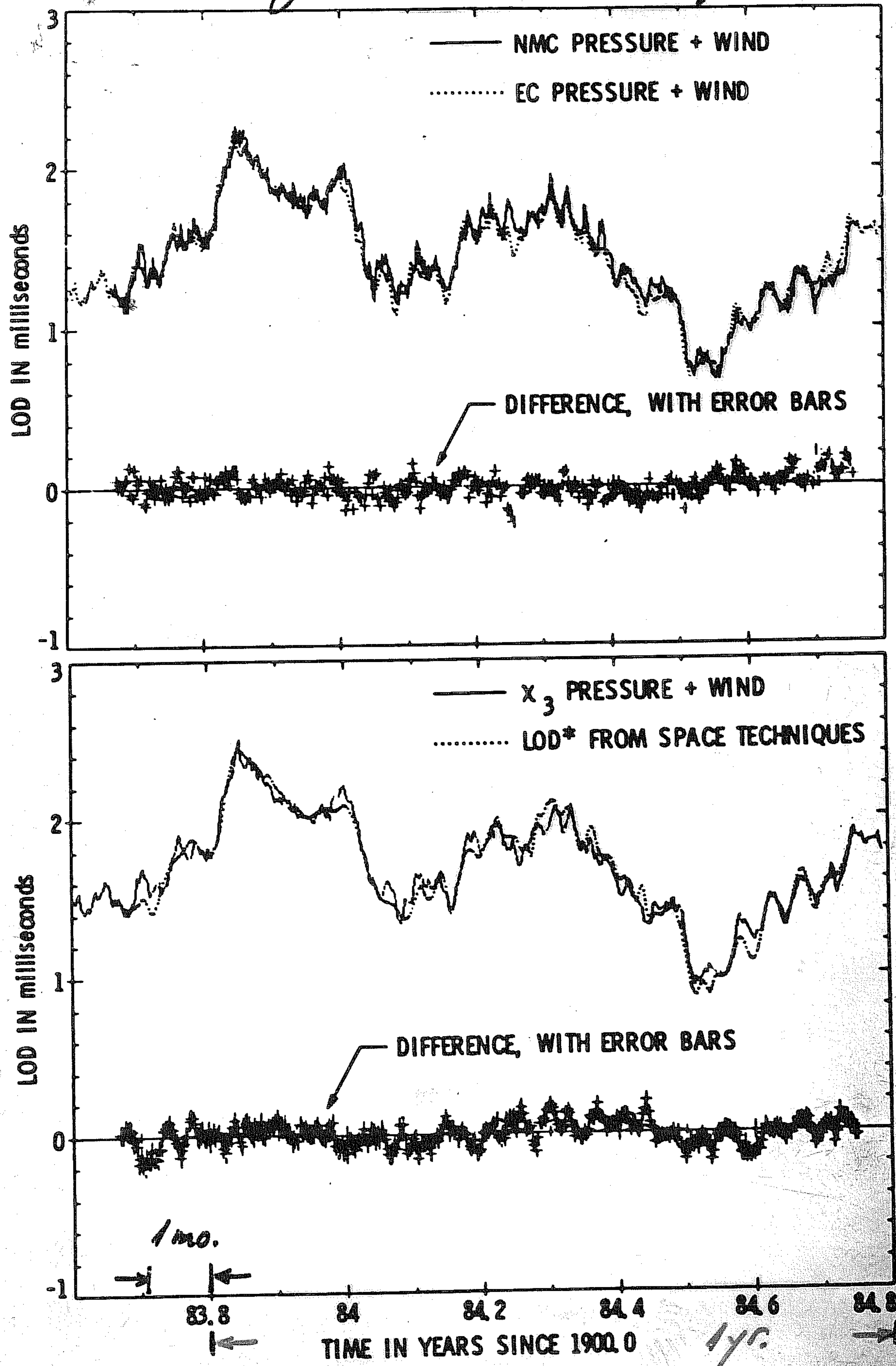

Dickey, Eubanks & Steppe, 1986, JPL TM #144; JGR, '85, 90B

Outline

1. *AAM and LOD*.

2. *Extratropical* LF oscillations: neutral Rossby waves (16–17days), Branstator–Kushnir traveling wave (25–27 days), standing wavenumber-2 (40 days)

3. *Topographic instability:*

   a) Saddle-node bifurcation;

   b) Hopf bifurcation.

4. *Some observations:* AAM data by latitude bands.

5. *UCLA GCM* results.

6. More observations: Torques from reanalysis.

7. *Intermediate model:* Markov chain & oscillations.

7. Concluding remarks.

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3) J. G. Charney & J. G. DeVore (1979):

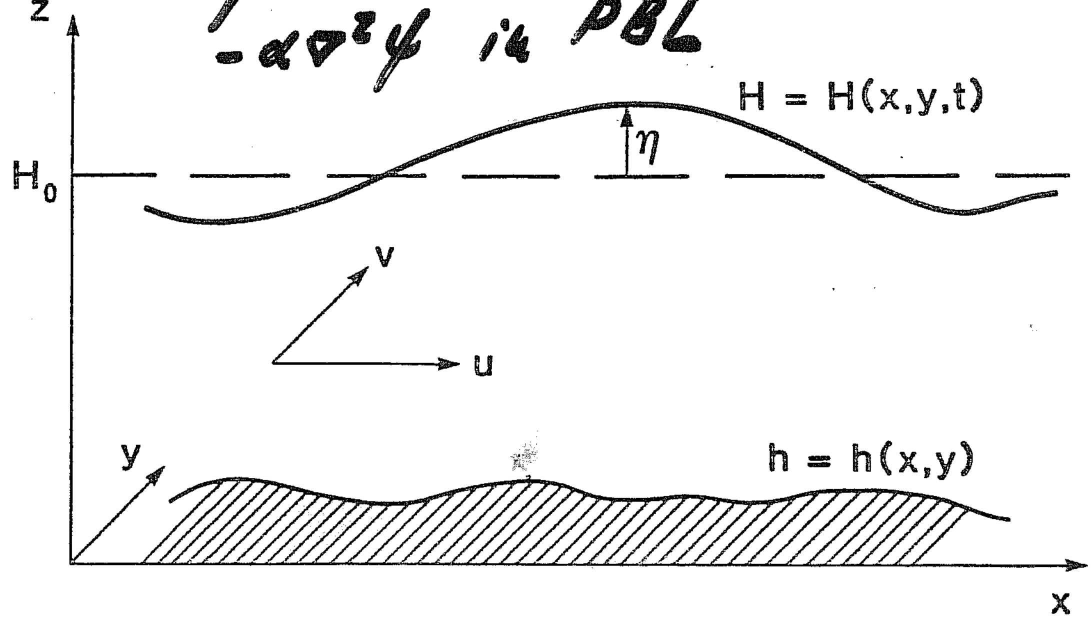
Multiple flow equilibria in the atmosphere & blocking. *J. Atmos. Sci.*, **36**, 1205–1216

$$\partial_t (\nabla^2 - L_R^{-2})\psi + J\{\psi, (\nabla^2 - L_R^{-2})\psi + f_0 h/H_0 + \beta y\}$$

Forcing by zonal jet ψ^* $\quad = \alpha \nabla^2 (\psi^* - \psi)$

Ekman dissipation

$-\alpha \nabla^2 \psi$ **in PBL**



$(u, v) = (-\psi_y, \psi_x)$, $\quad L_R = (g H_0)^{1/2}/f_0$ **- Rossby radius of deform'n**

$\psi = g\eta / f_0$ $\quad B = \pi L = 5000$ km

$\alpha = 0 \Rightarrow \quad d_t Q = 0$,

$d_t (K + P) = 0$

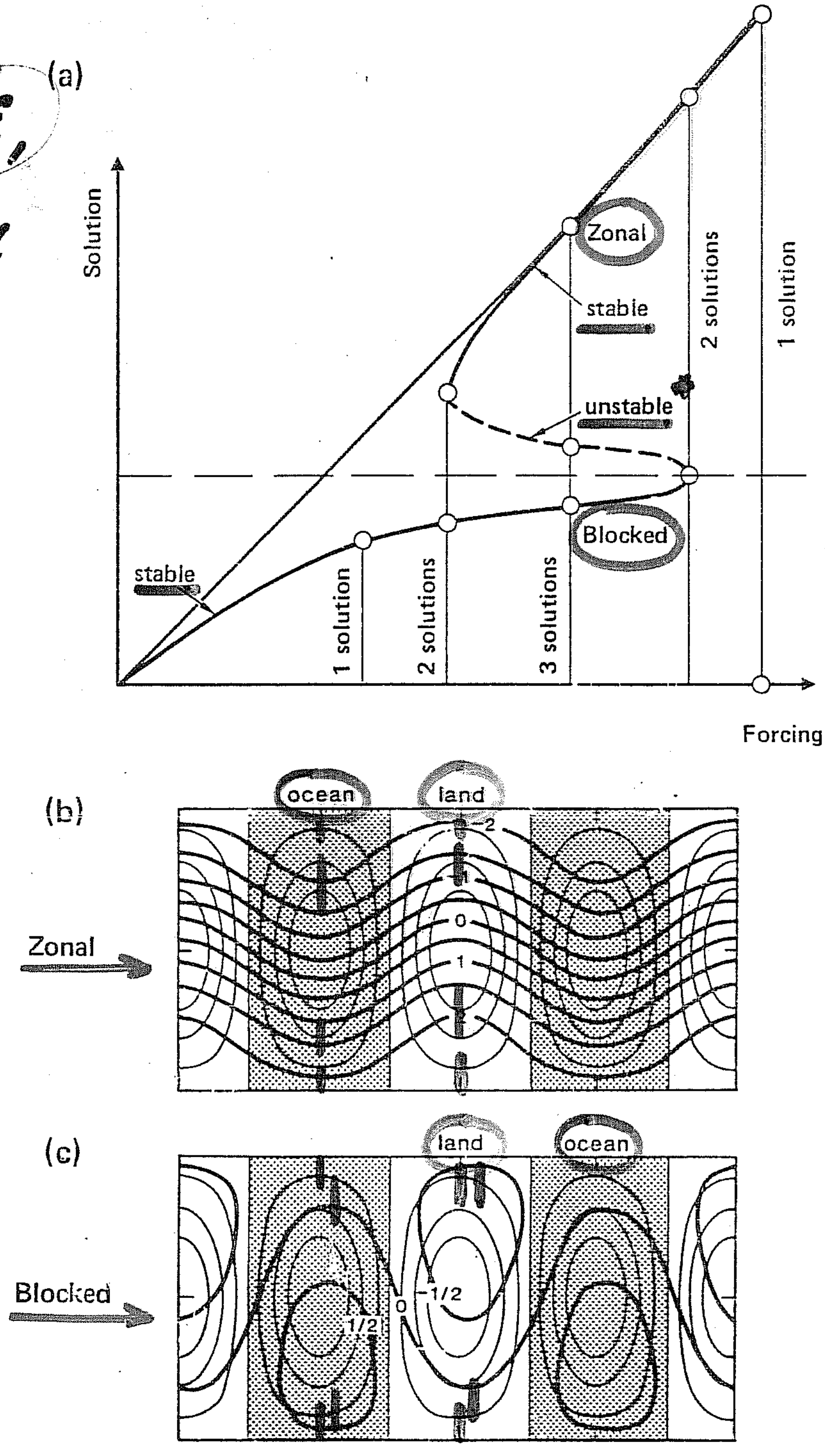
$k = (H-h)(u^2+v^2)/2$, $p = g\eta^2/2$

Mtn. only catalizes exchange of energy & momentum between waves & "mean flow" Fig. 6.4

Charney & DeVore (1979)

multiple equilibria

model:
barotr. PVE,
w/forcing &
dissipation,
3 modes



Topographic instability

Dynamical Extended Range Forecasting (DERF) at the National Meteorological Center

M. STEVEN TRACTON, KINGTSE MO AND WILBUR CHEN

Climate Analysis Center, National Meteorological Center, NWS/NOAA, Washington, D.C.

EUGENIA KALNAY, ROBERT KISTLER AND GLENN WHITE

Development Division, National Meteorological Center, NWS/NOAA, Washington, D.C.

(Manuscript received 11 October 1988, in final form 21 February 1989)

ABSTRACT

Early results are presented of an experimental program in Dynamical Extended Range Forecasting at the National Meteorological Center. The primary objective of this program is to assess the feasibility of extending operational numerical weather prediction beyond the medium range to the monthly outlook problem. Additionally, the extended integrations provide greater insight into systematic errors and climate drift and thereby feedback to model development. In this paper the principal focus is upon assessment of a contiguous set of 108 thirty-day integrations generated with the then operational Medium Range Forecast model from initial conditions 24 hours apart between 14 December 1986 and 31 March 1987.

Recovery of skill in persistence fast at ≥ 20 days

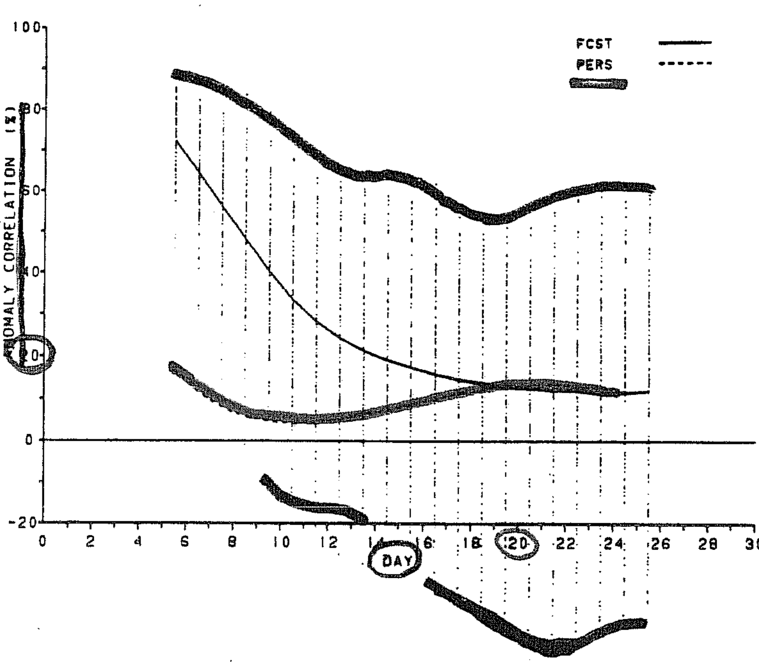


FIG. 7. AC (108-case average) of NH 500 mb height DERF and Persistence forecasts vs. lead time for overlapping 10-day means (1–10 plotted at 5.5 days, 2–11 at 6.5 days, etc.). The distribution of the 108 scores at each time range indicated by a dot for each case.

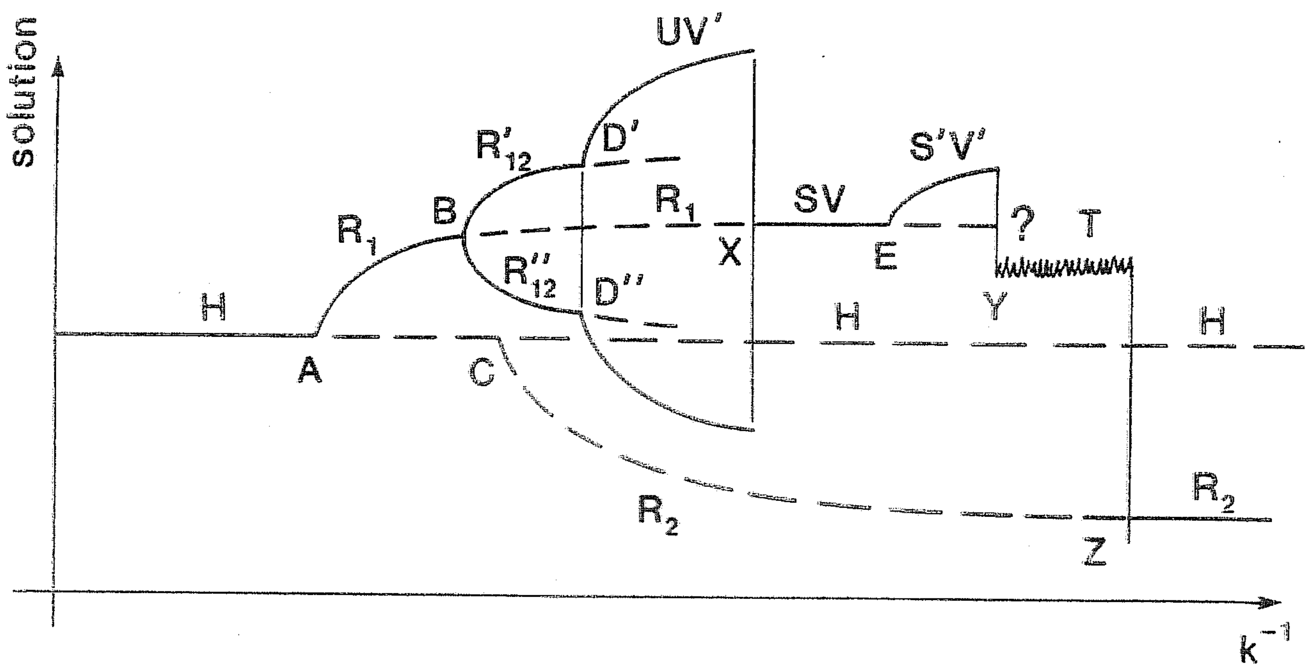
Bifurcation diagram

General situation

$u_t = N(u;\mu)$

$N(u_o;\mu_o) = 0.$

1) **If $L_o = \partial N/\partial u$ at $(u_o;\mu_o)$ is nonsingular, then a unique branch of solutions $u = u(\mu)$ through it exists and is given by $u \cong u_o + (\partial u/\partial\mu)\big|_{\substack{u=u_o \\ \mu=\mu_o}}$.**



2) **The points at which *det* $L_o = 0$ (i.e., where the Implicit Function Theorem fails) are called bifurcation points, and they are in general isolated. Near such points, the behavior of (2 or more) solutions is parabolic:**

$u - u_o \sim (\mu - \mu_o)^{1/2}$

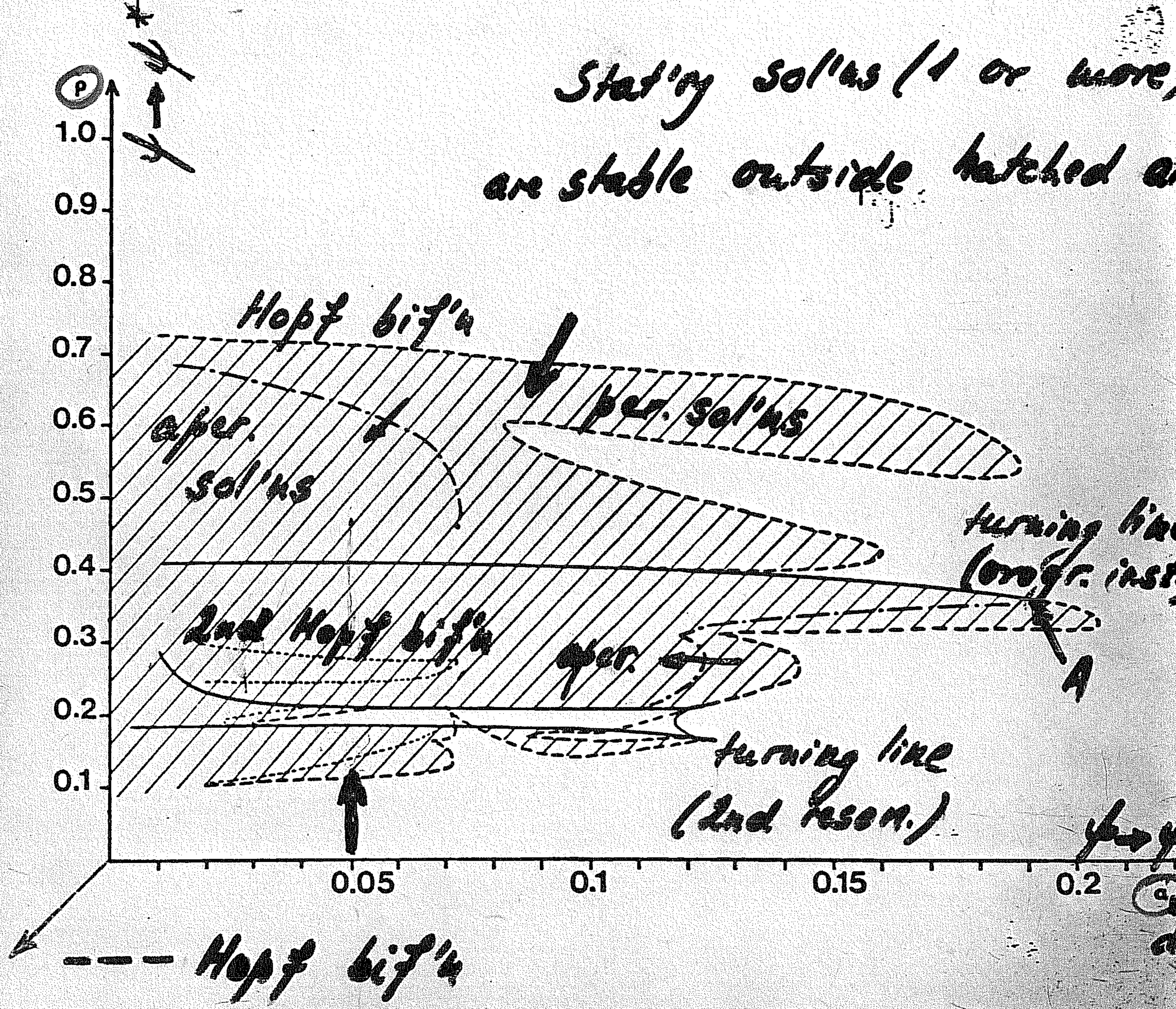
Parameter dependence

of solutions & their stability

Legras & Ghil (JAS, 1985)

25 spherical harmonics vs. 3 cartesian waves

Stat'ry sol'ns (1 or more) are stable outside hatched a[rea]

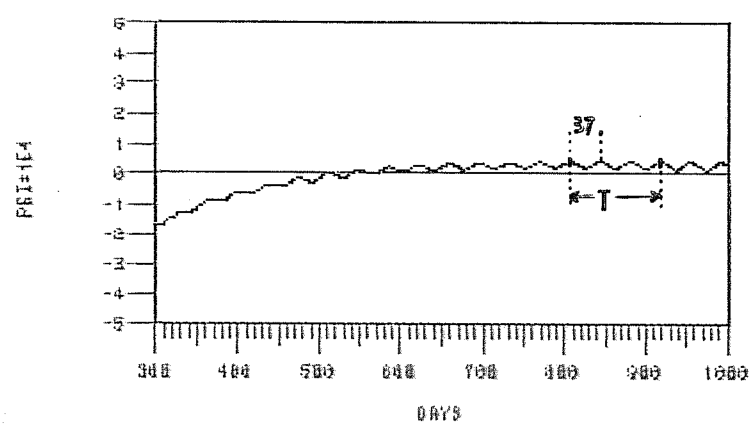


--- Hopf bif'n

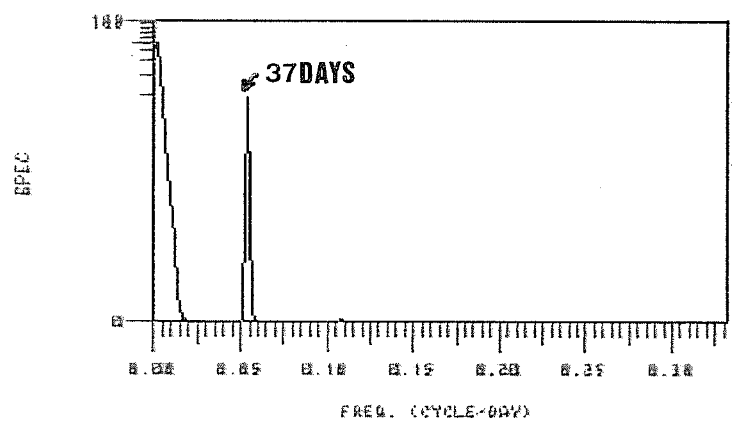
—·—·— transition to aper. sol'ns (3 unstable e-values, or more)

M. Kimoto, pers. Comm., 1986

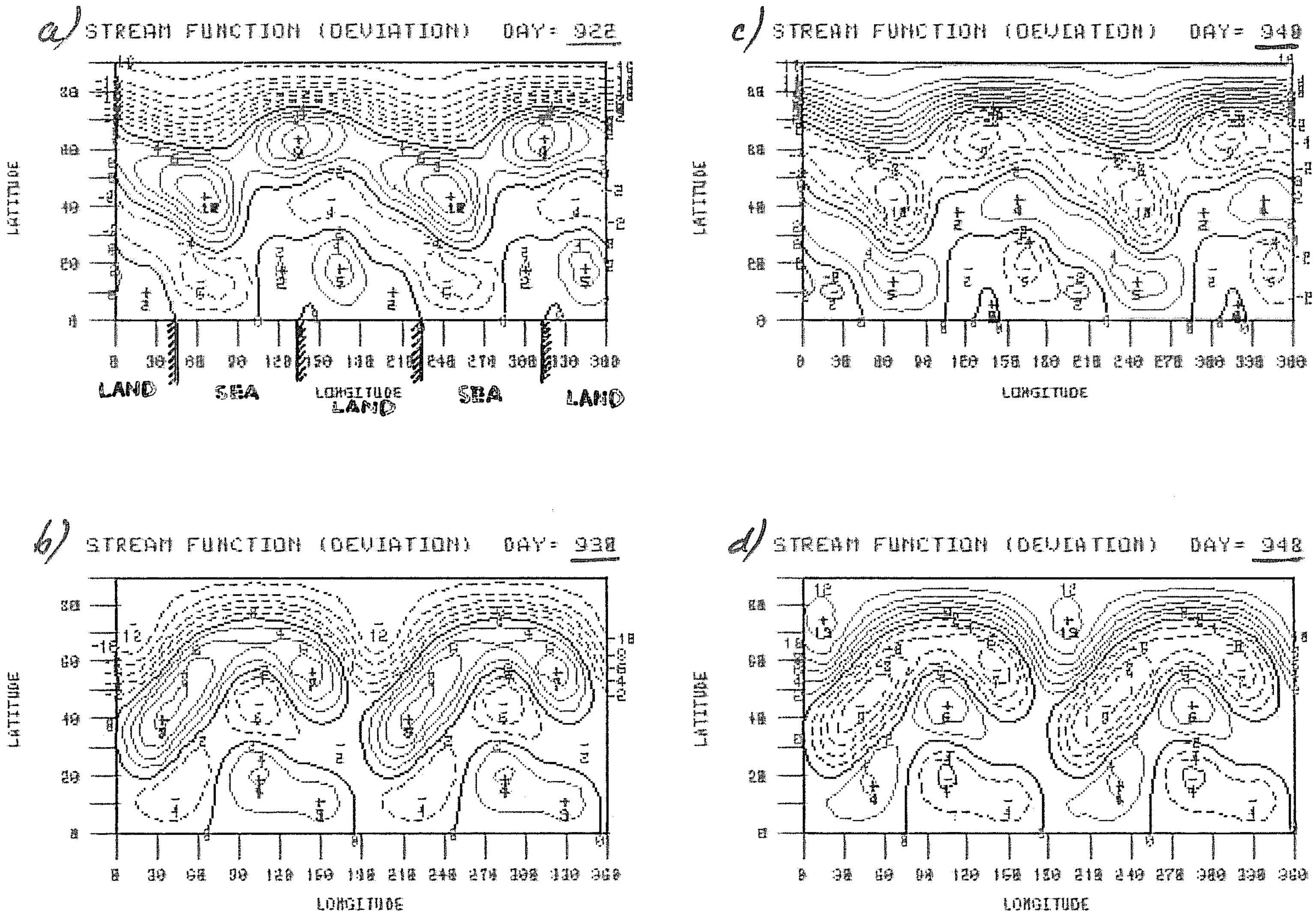
TIME SEQUENCE OF PSI(8,1)



POWER SPECTRUM OF PSI(8,1)



Barotropic QG model



M. Kimoto (pers. Commun., 1986) based on Legras & Ghil ('85) model

AAM data

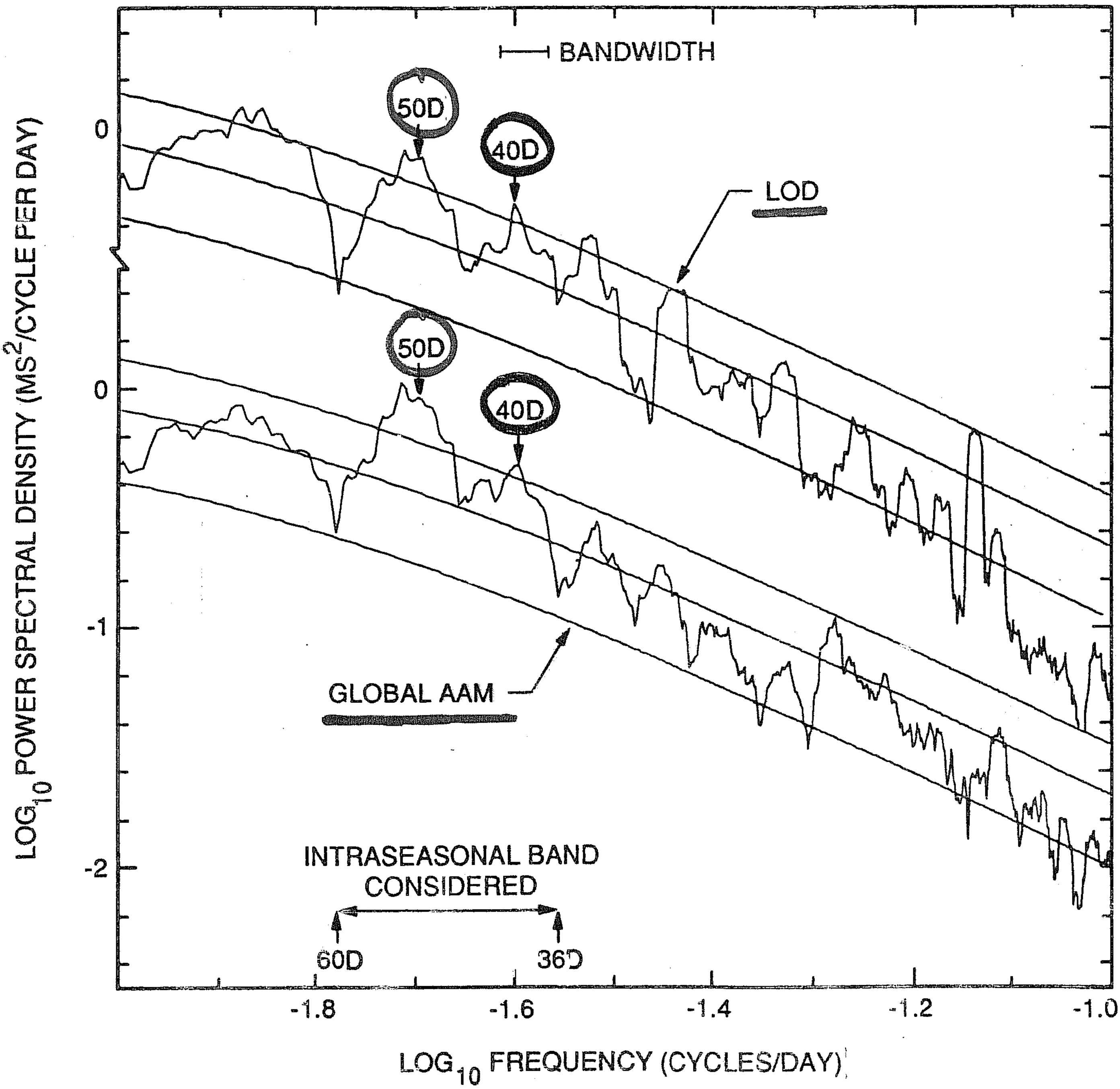


Fig. 2

Dickey et al. (1991), Marcus (1990)

Spectral power for banded AAM data

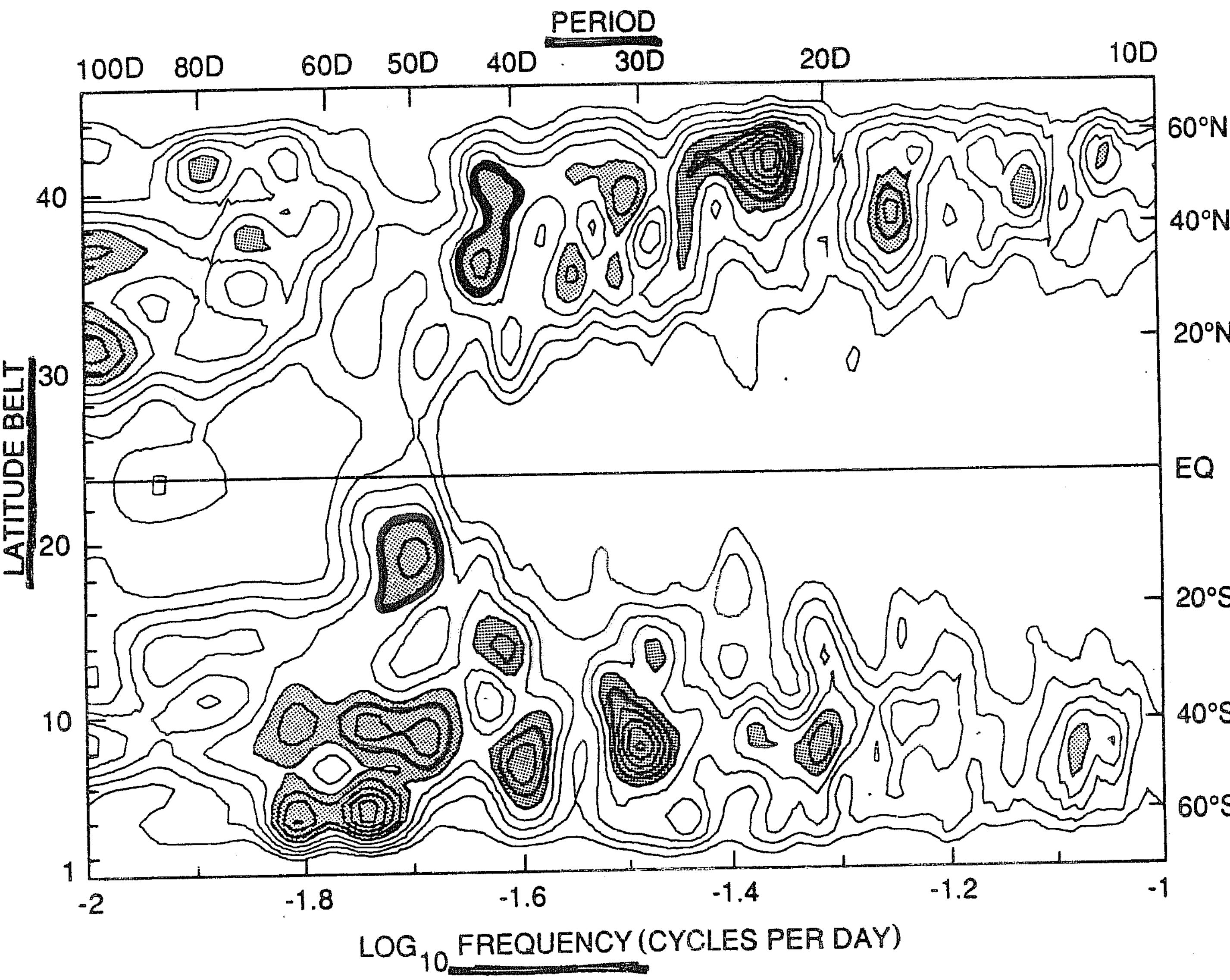
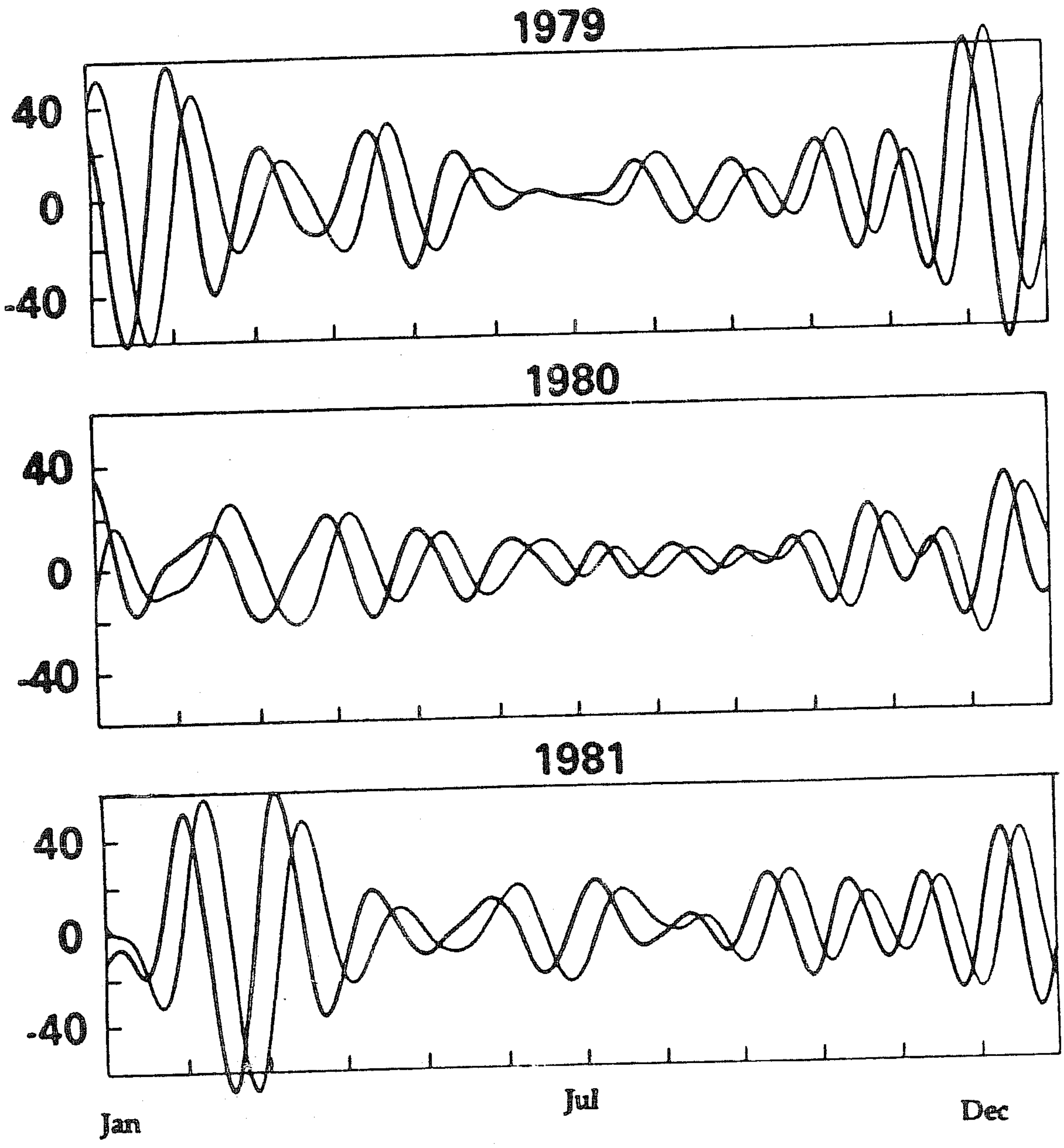


Fig. 10

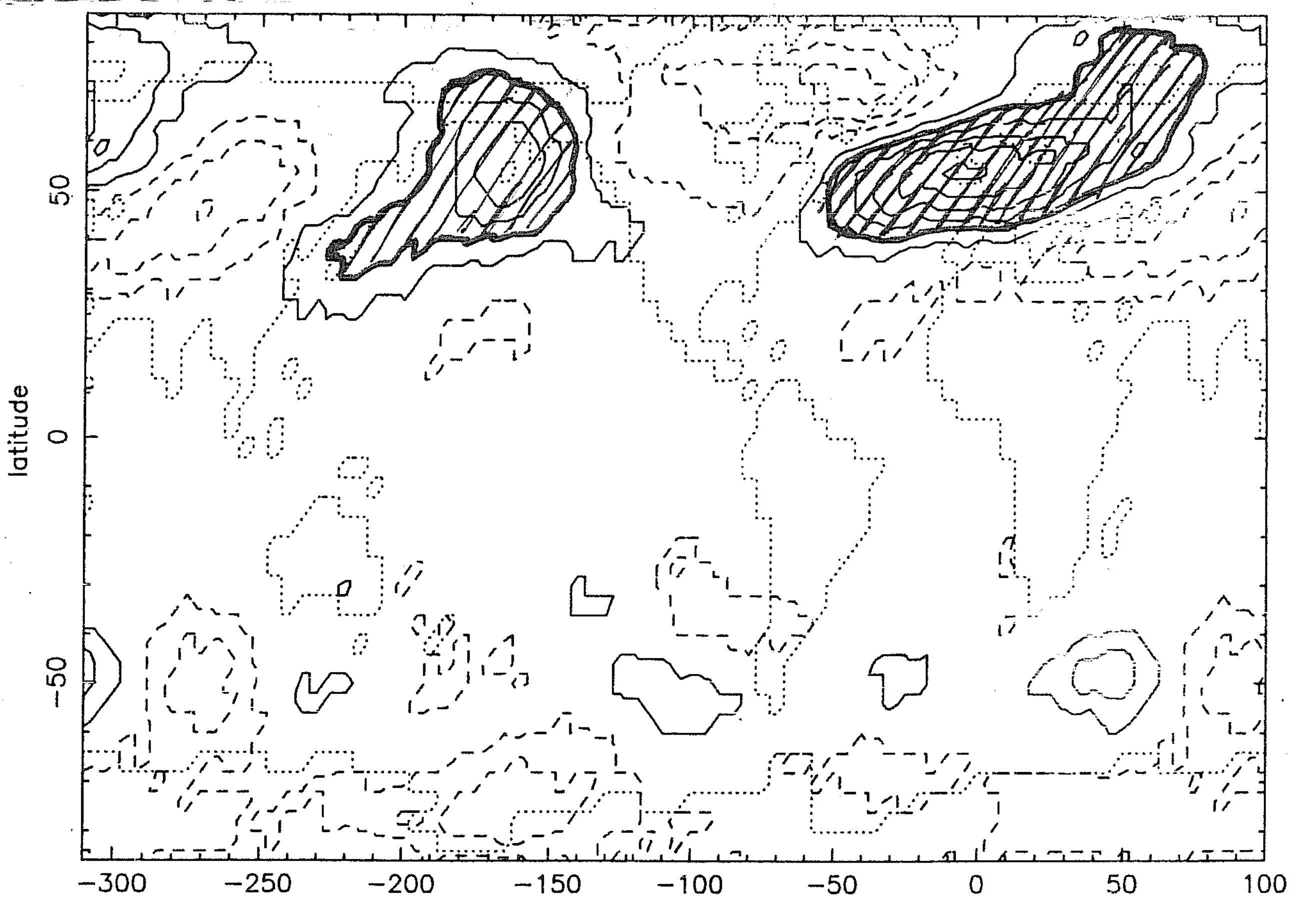
Dickey, Ghil & Marcus (JGR-Atmos., 1991)



Ghil and Mo (1991, JAS)

UCLA GCM

500 MB HTS: 36-60 NH AAM LO-HI



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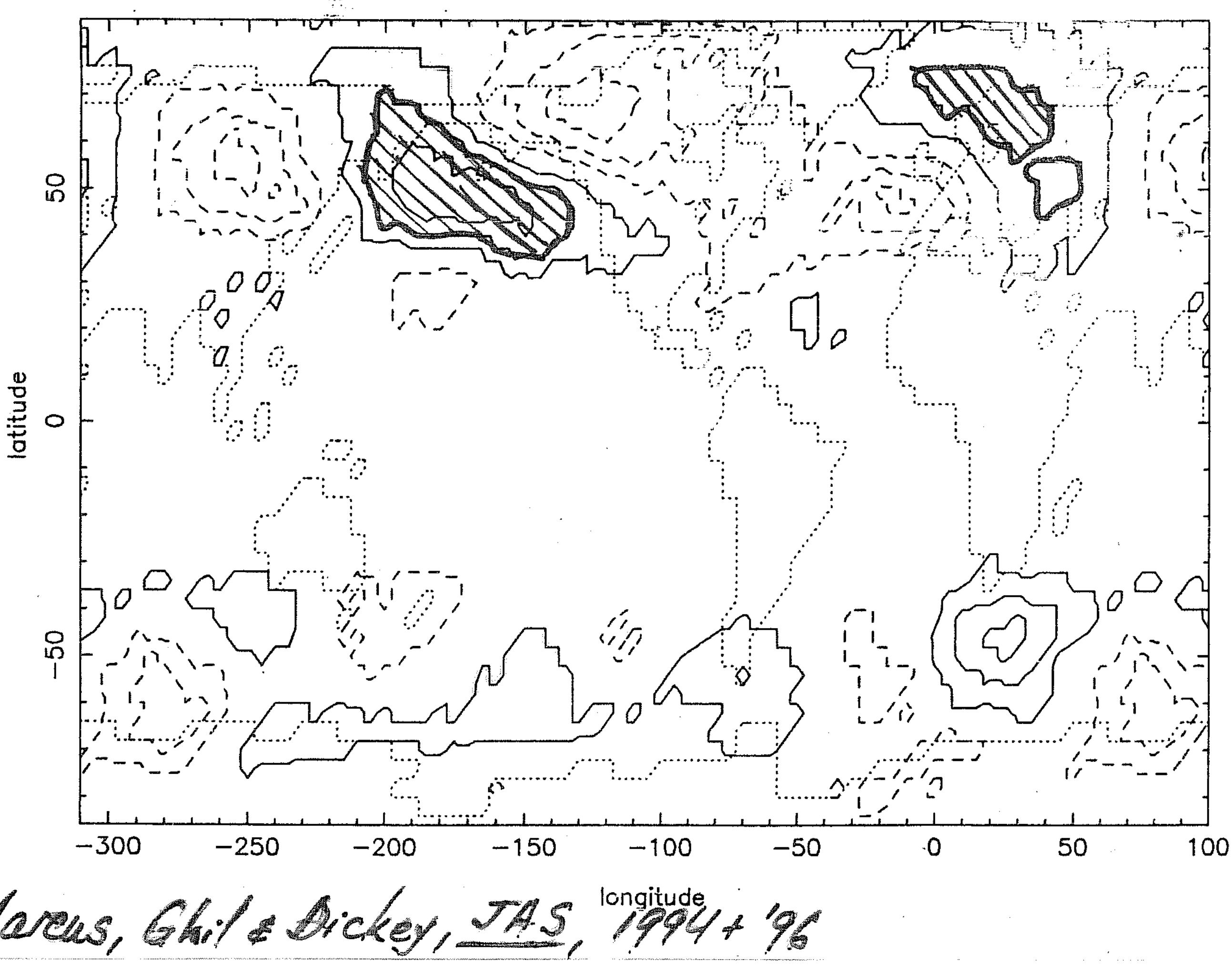
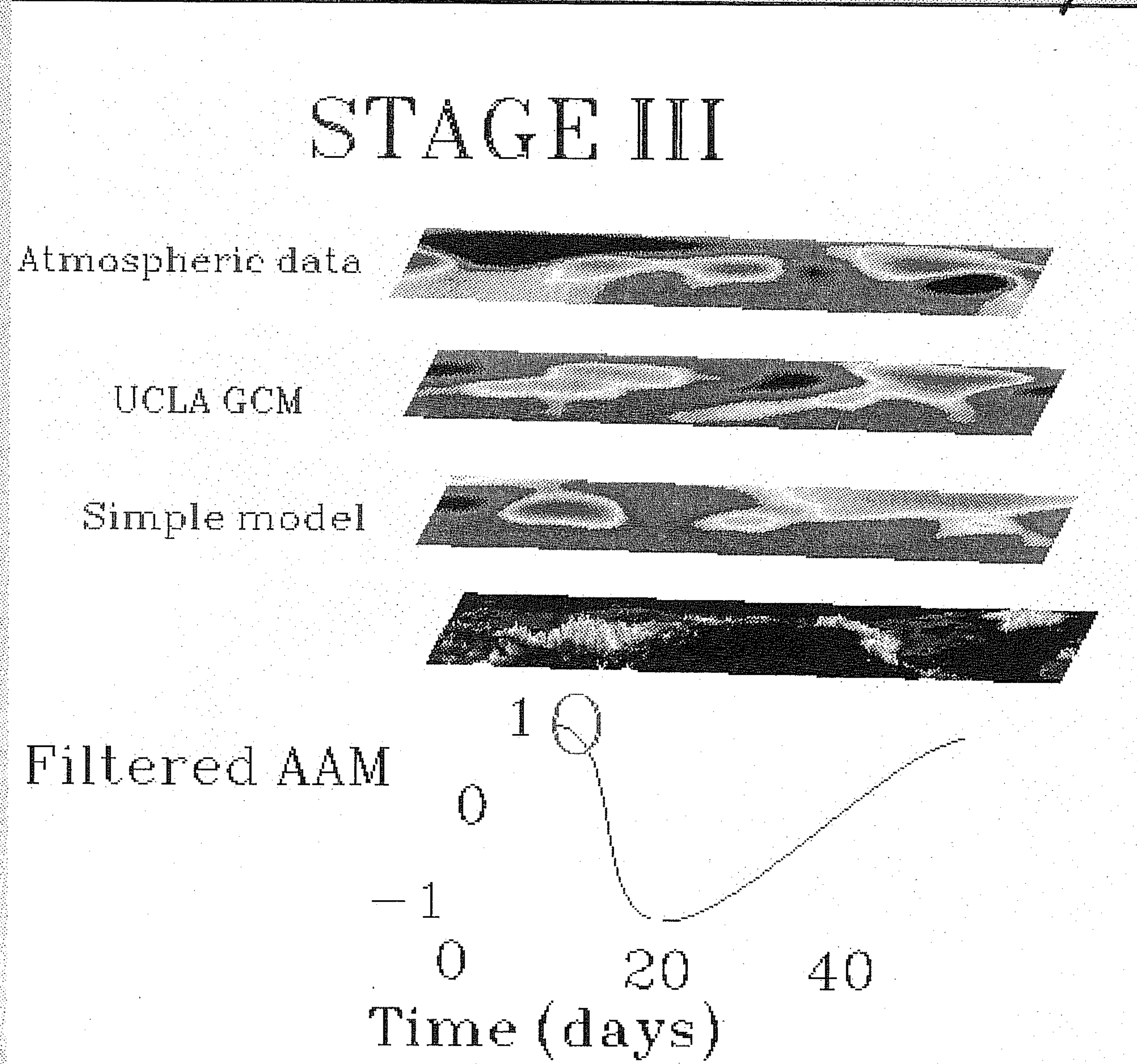
500 MB HTS: 36-60 NH AAM DECR-INCR



Marcus, Ghil & Dickey, JAS, 1994 + '96

Comparison of GCM (UCLA) with observations & simple models



Mtn. torques & NH LFV

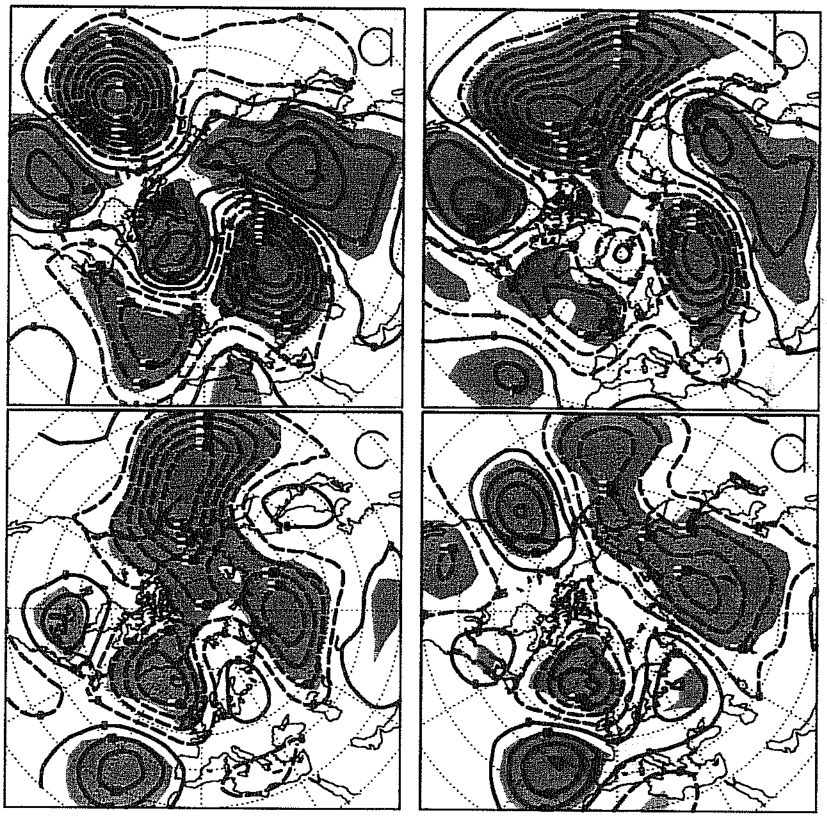
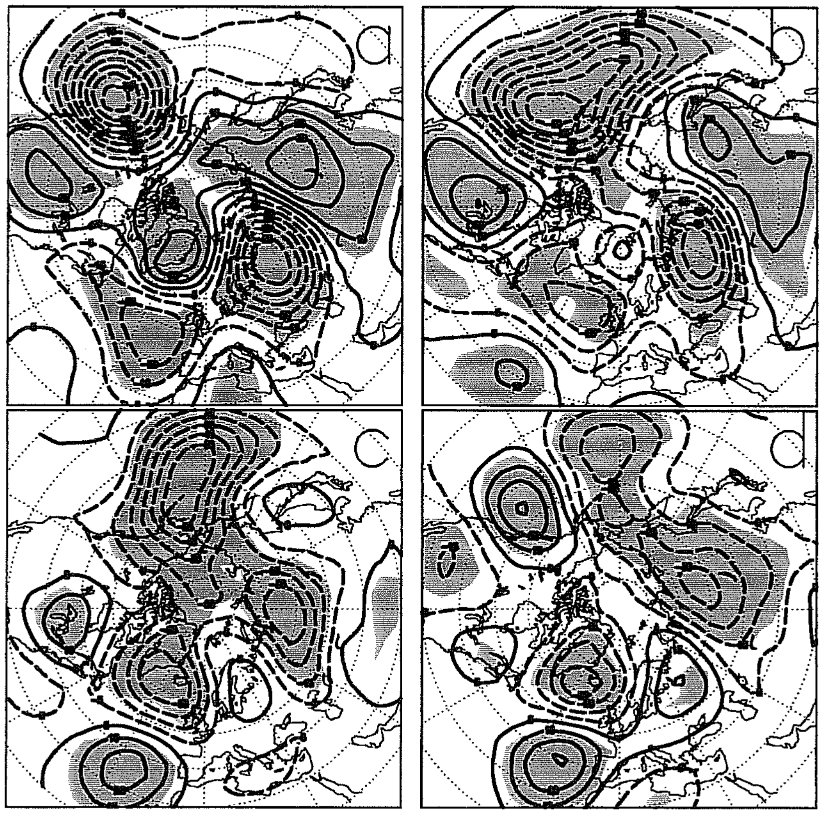


Figure 5: Composite anomalies of Z_{700} maps from the IS time series, keyed to the 20–30-day signal of NH mountain torque. (a) 0-day lag; (b) 3-day lag; (c) 6-day lag; and (d) 9-day lag. Contour interval: 10 m; positive values, heavy solid; negative values, heavy dashed; 95% confidence shaded; continental contours are light solid. The days for each composite cycle are counted from the local extremum of the 20–30-day NH T_M for that cycle (see text for details).

40 years of NCEP/NCAR reanalysis (1958–97): daily values of P_s, Z_{700} & u (zonal wind at 19 levels)

Lott Robertson & Ghil (JAS, 2004a,b)



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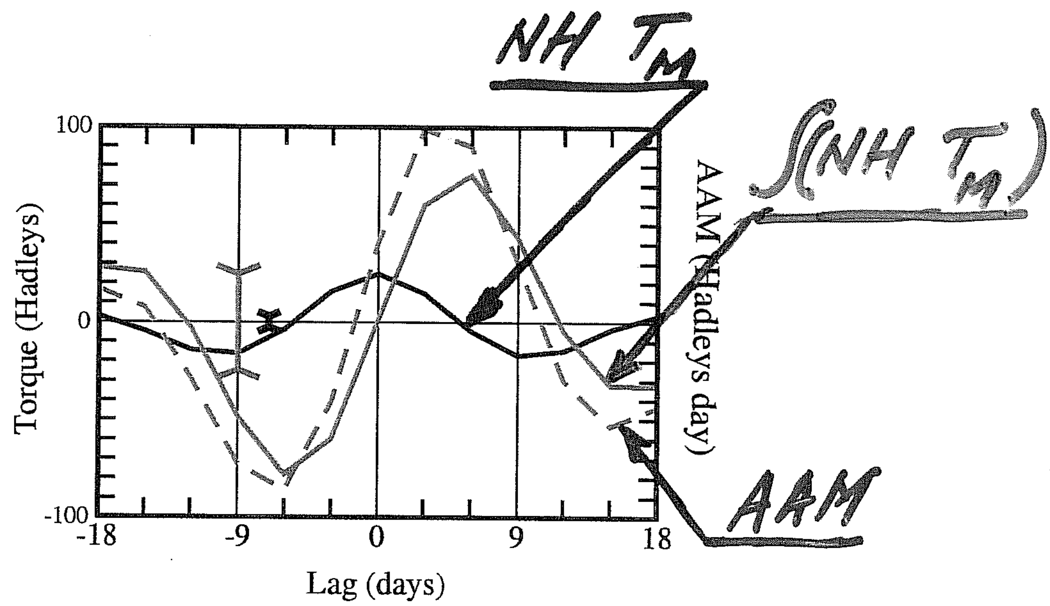
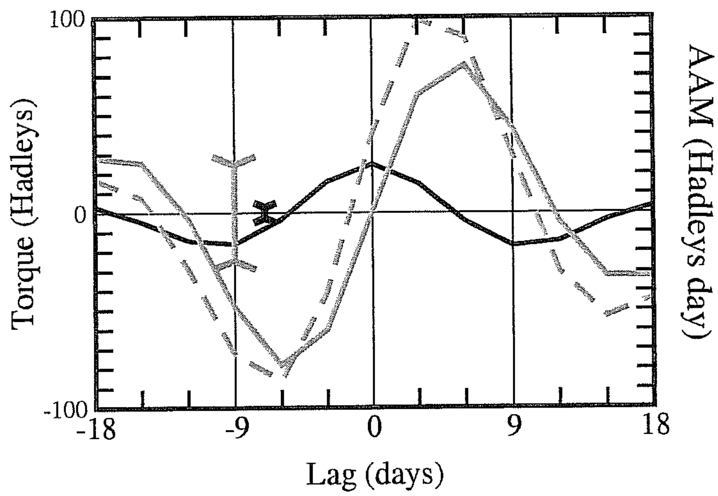


Figure 6: Composites of different terms in the AAM budget during the composite cycle illustrated in Fig. 5: IS NH T_M (black solid); integral of IS NH T_M (grey solid); and global IS-M (grey dashed). Units for the global atmospheric angular momentum, M, are in Hadley-day: 1 Hd = 8.64 10^{22} kgm^{2}s^{-1}. The vertical black bar and the vertical grey bar indicate the 95% confidence interval of a Monte-Carlo test for the torque and for the global AAM, respectively.



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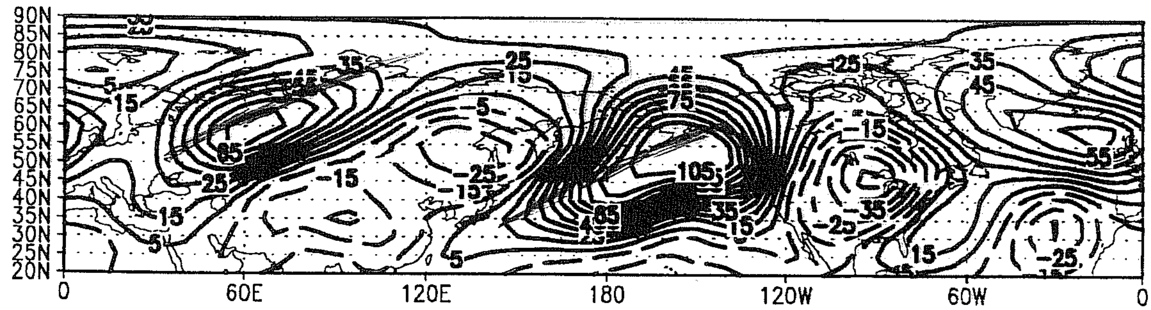
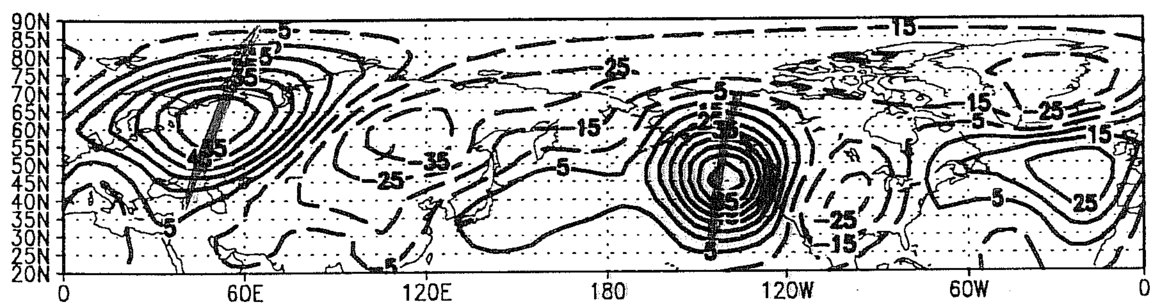
NCEP/NCAR Reanalysis

700-hPa heights, 1958-1997 (40 years)

M (Lo–Hi)



Tm (Lo –Hi)



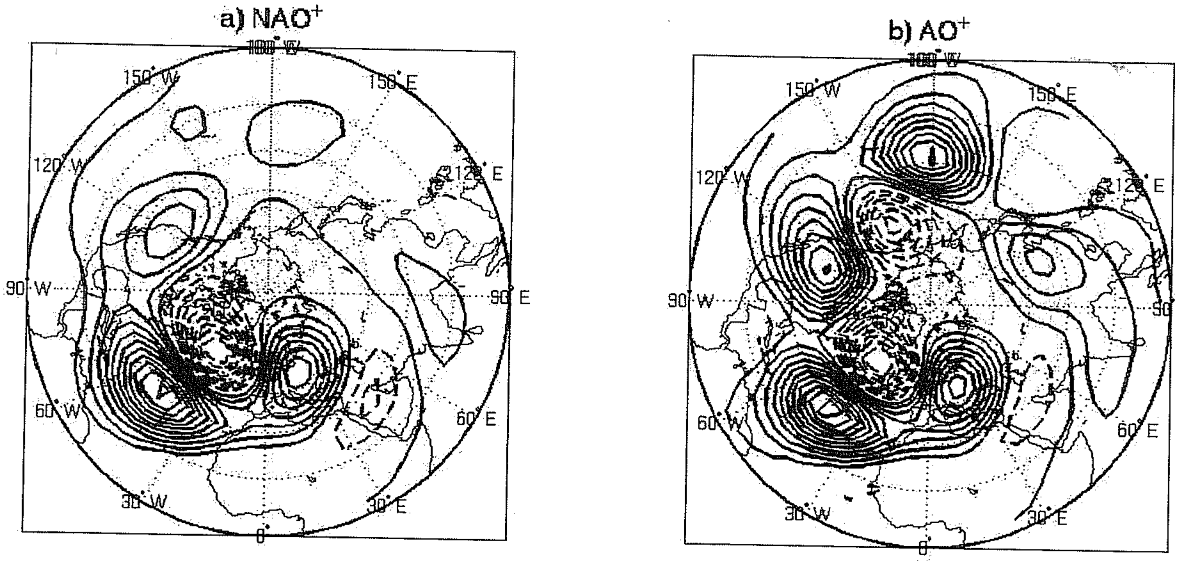
Composites based on
20-30-day band-pass filtering of
NH AAM & Torque

$$\dot{M} = T_M + T_F$$

Lott, Robertson & Ghil (JAS, 2004b)

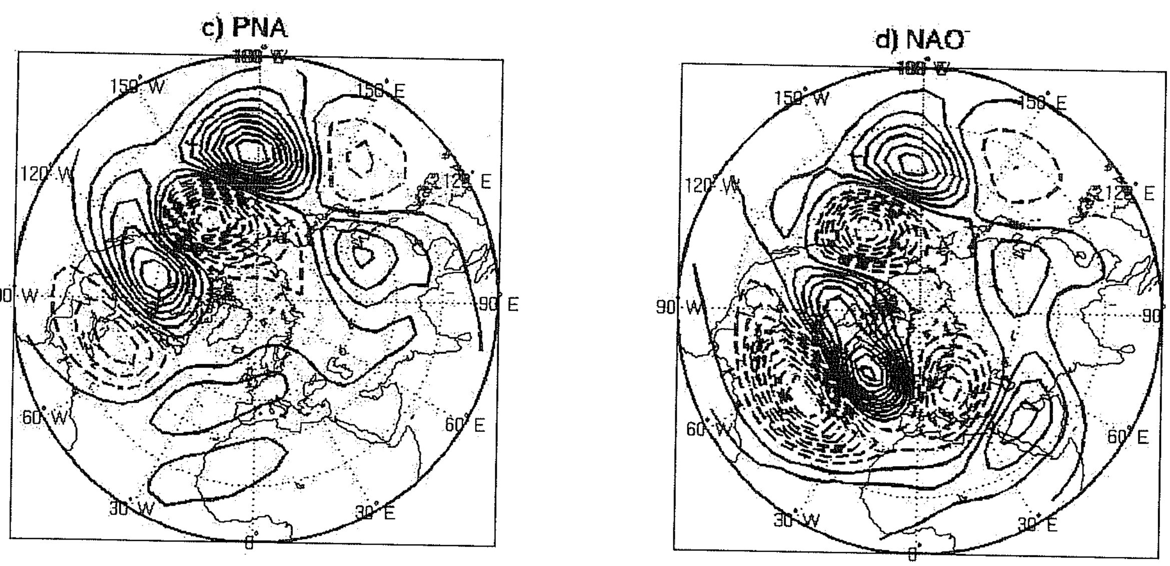
Baroclinic intermediate model

Figure 7



Marshall & Molteni (1993) - QG, 3-L, T21

4 clusters - AO$^\pm$, NAO$^\pm$; 54 000 days

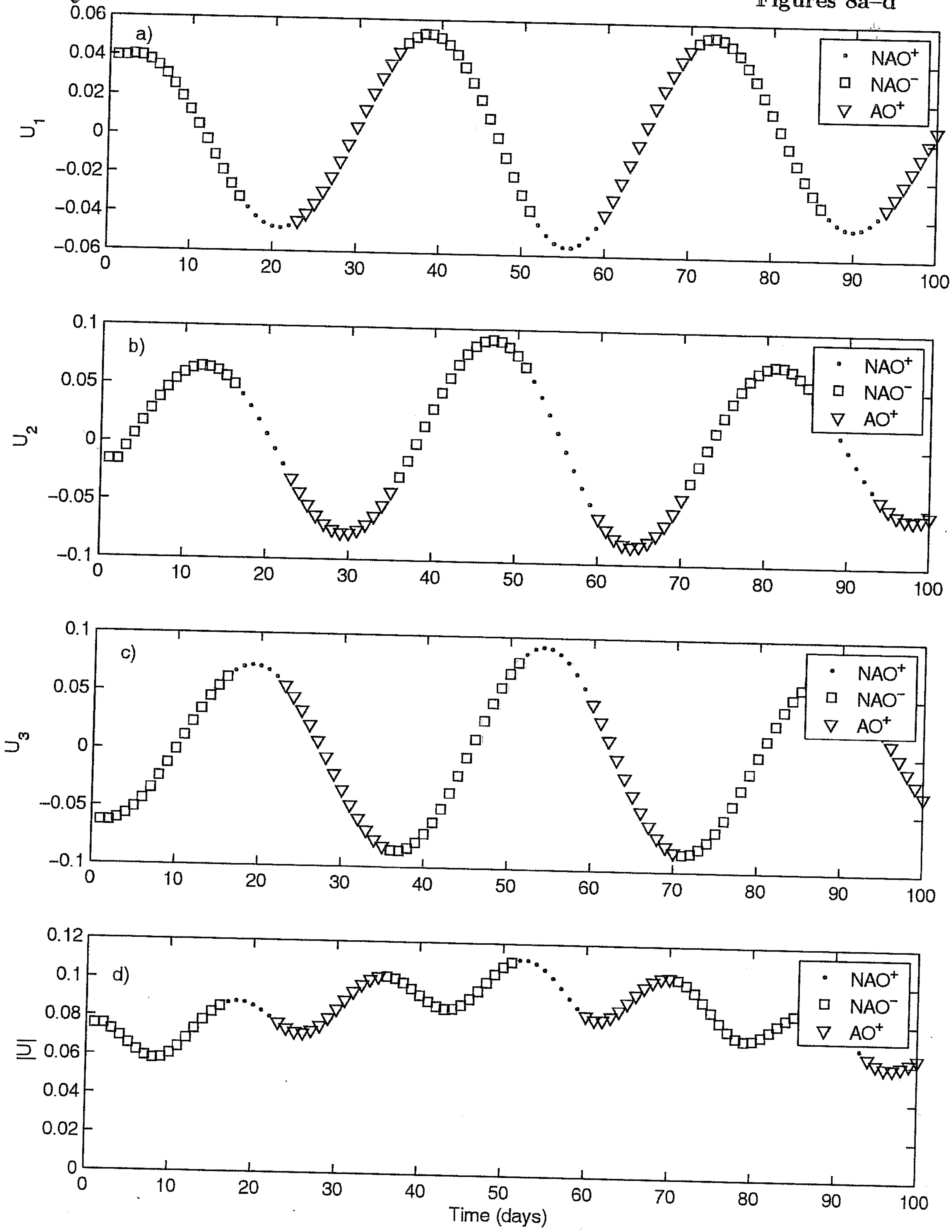


Phase composites of 37-day oscill'n

⇒ Markov chain of clusters (NAO$^+$ → AO$^+$ → NAO$^-$ → NAO$^+$) is embedded in this oscillation. Kondrashov et al (2004)

37-day oscillation

Figures 8a–d



Velocity in subspace of 3 leading EOFs

Kondrashov, Ide & Ghil (JAS, 2004)

NH 40–50-day Oscillation

A. What do we know?

1. *Standing wawe, zonal wavenumber $k = 2$*
   Ghil (1987) – simple model (cf. Legras & Ghil, 1985)
   Ghil & Mo (1991a) – 700 mb observations
   Marcus *et al.* (1994, 1996) – UCLA GCM

2. *Period is distinct from the tropical one* (40d *vs.* 50d)
   Dickey *et al. (1991)* – banded AAM
   Magaña (1993) – banded AAM & tropical convection (OLR)

3. *Topography essential **for instability***
   Jin & Ghil (1990) – simple model
   Marcus *et al.* (1994, 1996) – GCM

4. *Higher meridional modes ($m \geq 2$) are important*
   Jin & Ghil (1990), Tribbia & Ghil (1990)
   – simple & intermediate model

5. *Baroclinic effects are secondary*
   – C. L. Keppenne (1989), Keppenne *et al.* (2000)

6. *Substantial, episodic equatorward propagation*
   Dickey *et al.* (1991) – AAM data
   Marcus *et al. (1994, 1996)* – GCM

7. *Stronger in NH winter*
   Knutson & Weickmann (1987), Ghil & Mo (1991a)
   –observations
   Strong *et al.* (1993, 1995) – intermediate model

8. *Oscillation quite robust*
   – all of the above + barotropic annulus (Weeks *et al., 1997)*

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B. What don't we know?

1. *The exact cause of the NH topographic oscillation*
   Jin & Ghil (1990) — local Hopf bifurcation
   Tribbia & Ghil (1990) — global nonlinear interaction

2. *The exact period*
   All of the above + Kondrashov *et al.* (2003) – 40 days
   Lott *et al.* (2001, 2003a, b) – 20–30 days (reanalysis)

3. *Cause of Branstator-Kushnir (23–25-day) wave*

4. *Cause of Plaut-Vautard (70-day) wave*
   —also related to boundary forcing (Atlantic vs. Pacific)?

5. *Cause of tropical 20–30-day and 40–50-day oscillations*

6. *How do the tropical & midlatitude oscillators interact* —
   Resonance? Energy & AAM fluxes? Synoptic aspects?

7. *More about SH oscillations* (17, 31 and 48 days)

8. *Practical applications to LRF*

   — What is predictable, and how much?

   — How to predict it – dynamically?
   – statistically?
   – hybrid scheme?

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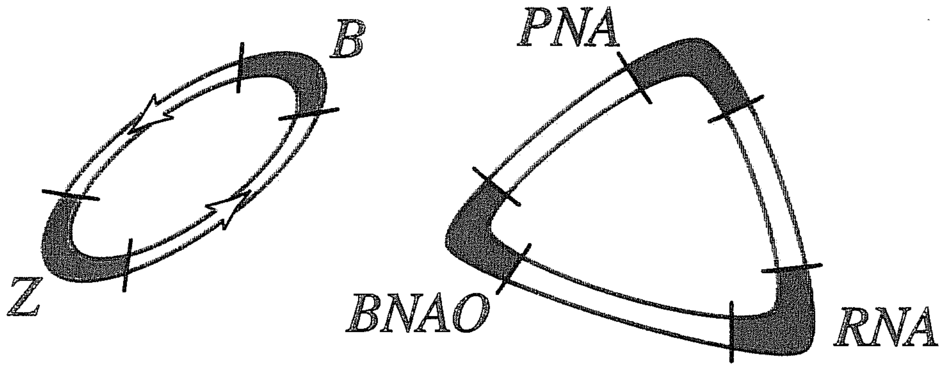
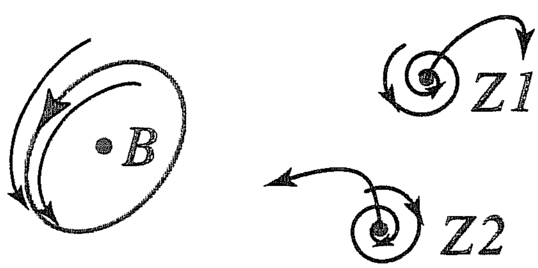
"Waves vs. Particles"
in Atmospheric Low-Frequency Variability

1. Are the regimes but slow phases of the oscillations?



Kimoto & Ghil
(*JAS*, 1993a, b)

2. Are the oscillations but instabilities of particular equilibria?

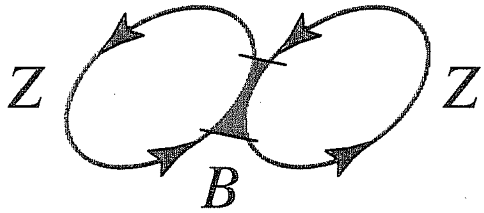


Legras & Ghil
(*JAS*, 1985)

3. How about both: "chaotic itinerancy" (Itoh & Kimoto, *JAS*, 1999)

4. How about neither? Null hypotheses:

a) It's all due to interference of linear waves, *e.g.*, neutrally stable Rossby waves;



Lindzen *et al.*
(*JAS*, 1982)

b) It's all due to red noise — Hasselmann (*Tellus*, 1976), Mitchell (*Quatern. Res.*, 1976), Penland & co. (Magorian, Sardeshmukh, 1990s).