INTRASEasonal Oscillations in the Mid-Latitudes: Observations, Theory, and GCMS

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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.


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Dickey, Eubanks & Steppe, 1986, JPL TM #144; JGR, 85, 908.
Outline

1. AAM and LOD.

2. Extratropical LF oscillations: neutral Rossby waves (16–17 days), 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.


7. Concluding remarks.

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Multiple flow equilibria in the atmosphere and blocking. J. Atmos. Sci., 35, 1205-1216

\[
\frac{\partial}{\partial t} \left( \nabla^2 - L \nabla^2 \right) \psi + \nabla^2 \left( \nabla^2 - L \nabla^2 \right) \psi + f_0 \psi / H_0 + \beta \psi
\]

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

Ekman dissipation \( -\alpha \nabla^2 \psi \) in PBL

\[(u, v) = (-\psi_y, \psi_x), \quad L = (g H_0)^{1/2} / f_0 \quad \text{Rossby radius of deformation} \]

\[B = \pi L = 5000 \text{ km} \]

\[\alpha = 0 \Rightarrow \frac{\partial}{\partial t} Q = 0, \quad \frac{\partial}{\partial t} (K + P) = 0 \]

\[k = (H - H_0)u^2 + v^2/2, \quad \rho = \rho_0 \]

Mt. only catalyzes exchange of energy & momentum between 2 waves & "mean flow"

Fig. 6.4
model: \( PVE \), multiple equilibria

Forced, dissipation, 3 modes

\( \text{Zonal, stable, 1 solution, 2 solutions, 3 solutions, 1 solution} \)

\( \text{Blocked, unstable, solution} \)

(b) Zonal

(c) Blocked

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

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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

\[ u_t = N(u; \mu) \]
\[ N(u_0; \mu_0) = 0. \]

1) If \( L_0 = \partial N/\partial u \) at \((u_0; \mu_0)\) is nonsingular, then a unique branch of solutions \( u = u(\mu) \) through it exists and is given by \( u \cong u_0 + (\partial u/\partial \mu)|_{u=u_0} \mu = \mu_0 \)

2) The points at which \( \text{det } L_0 = 0 \) (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:

\[ u - u_0 \sim (\mu - \mu_0)^{1/2} \]
Parameter dependence of solutions and their stability

Legras & Ghil (JAS, 1985)

25 spherical harmonics vs. 3 Cartesian waves

Stably solns./1 or more, are stable outside, hatched area

Hopf bif.'s
aper. solns.
2nd Hopf bif.'s, oper. solns.

turning line
(2nd resom.)

--- Hopf bif.'s

--- transition to oper. solns (3 unstable e-values, or more)
TIME SEQUENCE OF PSI(0,1)

POWER SPECTRUM OF PSI(0,1)
M. Kimoto (pers. commun., 1986), based on Legras & Ghil (85) model.
Fig. 2

Dickey et al. (1991), Marcus (1990)
Spectral power for banded RAM data

Fig. 10

Dickey, Whitt & Mears (JGR-Atmos, 1991)
Ghil and Mo (1991, JAS)
Comparison of GCMs (UCLA) with observations & simple models

STAGE III

Atmospheric data

UCLA GCM

Simple model

Filtered AAM

Time (days)
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).
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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: $1 \text{Hd} = 8.64 \times 10^{22} \text{kgm}^2\text{s}^{-1}$. 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
10-30-day band-pass filtering of
NH RAM & Torque
\[ M = T_M + T_F \]

Lott Robertson & Gil (JAS, 2004)
Baroclinic Intermediate Model

4 clusters - AO±, NAO±; 54,000 days

Phase composites of 37-day oscillation

⇒ Markov chain of clusters (NAO⁺ → AO⁺ → NAO⁻ → NAO⁺) is embedded in this oscillation - Kug, Han, et al (2004)
37-day oscillation

Figures 8a–d

- $U_1$
- $U_2$
- $U_3$
- $U_4$

Velocity in subspace $50$ of 3 leading EOFs

Kondrackov, Ide & Glil (JAS 2004)
NH 40–50-day Oscillation

A. What do we know?

1. Standing wave, zonal wavenumber $k = 2$
   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?

2. Are the oscillations but instabilities of particular equilibria?

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;