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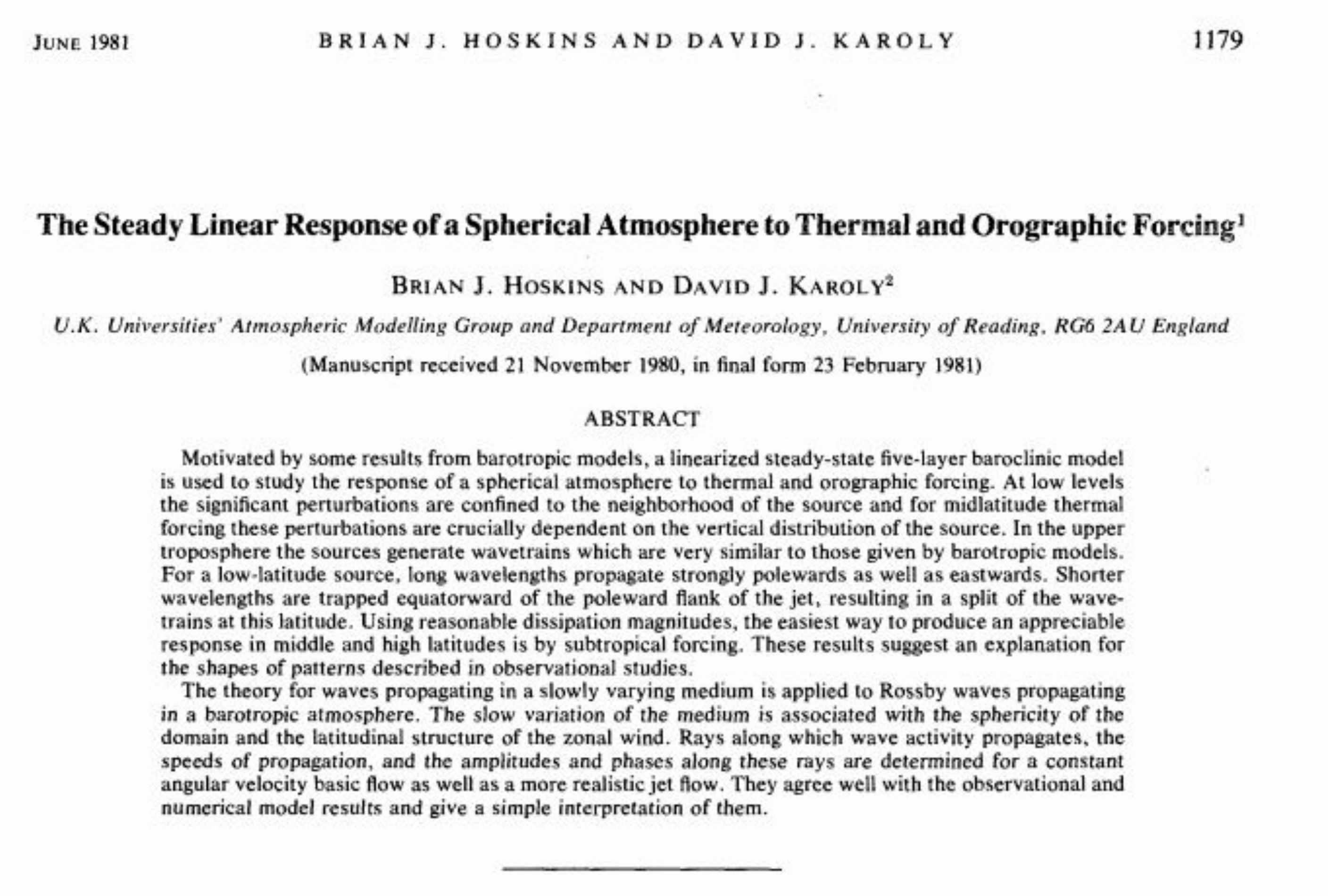

The Steady Linear Response of a Spherical Atmosphere to Thermal and Orographic Forcing[1]

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ABSTRACT

Motivated by some results from barotropic models, a linearized steady-state five-layer baroclinic model is used to study the response of a spherical atmosphere to thermal and orographic forcing. At low levels the significant perturbations are confined to the neighborhood of the source and for midlatitude thermal forcing these perturbations are crucially dependent on the vertical distribution of the source. In the upper troposphere the sources generate wavetrains which are very similar to those given by barotropic models. For a low-latitude source, long wavelengths propagate strongly polewards as well as eastwards. Shorter wavelengths are trapped equatorward of the poleward flank of the jet, resulting in a split of the wavetrains at this latitude. Using reasonable dissipation magnitudes, the easiest way to produce an appreciable response in middle and high latitudes is by subtropical forcing. These results suggest an explanation for the shapes of patterns described in observational studies.

The theory for waves propagating in a slowly varying medium is applied to Rossby waves propagating in a barotropic atmosphere. The slow variation of the medium is associated with the sphericity of the domain and the latitudinal structure of the zonal wind. Rays along which wave activity propagates, the speeds of propagation, and the amplitudes and phases along these rays are determined for a constant angular velocity basic flow as well as a more realistic jet flow. They agree well with the observational and numerical model results and give a simple interpretation of them.

Divisão

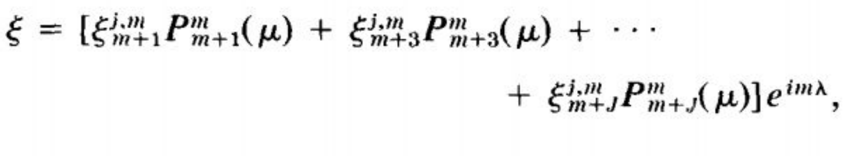
1. INTRODUÇÃO
2. DETALHES DO MODELO E MÉTODOS DE SOLUÇÃO
3. FORÇANTE TÉRMICA
4. FORÇANTE OROGRÁFICA
5. RAIOS DAS ONDAS DE ROSSBY
6. DISCUSSÃO

1. INTRODUÇÃO

- Estudos anteriores
- Objetivo: encontrar padrões em um modelo hemisférico baroclínico
  - Linearizado
  - Estado básico
    - Fluxo zonal de inverno no HN
  - 5 camadas verticais

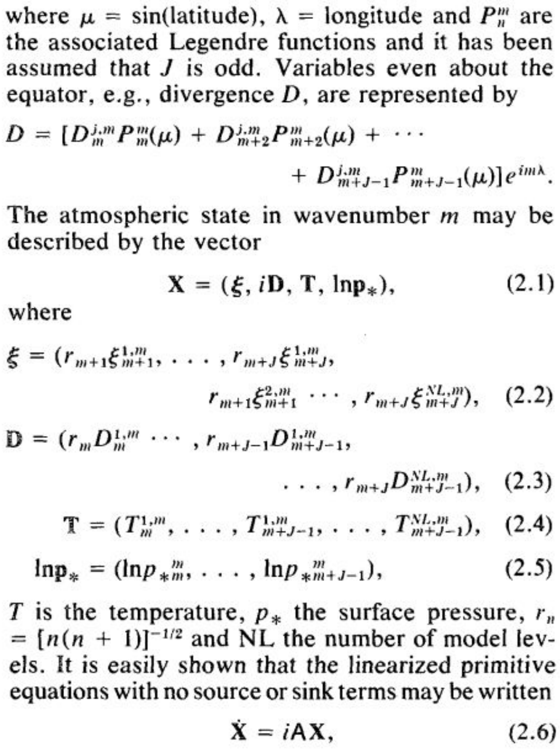
2. DETALHES DO MODELO E MÉTODOS DE SOLUÇÃO

- Modelo numérico:
  - Equações primitivas linearizadas
  - Coordenada σ
  - Técnicas de transformação espectral na horizontal
  - Diferenças finitas de segunda ordem na vertical



$$\xi = [\xi^{j,m}_{m+1} P^m_{m+1}(\mu) + \xi^{j,m}_{m+3} P^m_{m+3}(\mu) + \cdots + \xi^{j,m}_{m+J} P^m_{m+J}(\mu)] e^{im\lambda},$$

Vorticidade



where $\mu = \sin(\text{latitude})$, λ = longitude and P^m_n are the associated Legendre functions and it has been assumed that J is odd. Variables even about the equator, e.g., divergence D, are represented by

$$D = [D^{j,m}_m P^m_m(\mu) + D^{j,m}_{m+2} P^m_{m+2}(\mu) + \cdots + D^{j,m}_{m+J-1} P^m_{m+J-1}(\mu)] e^{im\lambda}.$$

Divergência

The atmospheric state in wavenumber m may be described by the vector

$$\mathbf{X} = (\boldsymbol{\xi}, i\mathbf{D}, \mathbf{T}, \ln\mathbf{p}_*), \tag{2.1}$$

where

$$\boldsymbol{\xi} = (r_{m+1}\xi^{1,m}_{m+1}, \ldots, r_{m+J}\xi^{1,m}_{m+J}, r_{m+1}\xi^{2,m}_{m+1} \cdots, r_{m+J}\xi^{NL,m}_{m+J}), \tag{2.2}$$

$$\mathbf{D} = (r_m D^{1,m}_m \cdots, r_{m+J-1} D^{1,m}_{m+J-1}, \ldots, r_{m+J} D^{NL,m}_{m+J-1}), \tag{2.3}$$

$$\mathbf{T} = (T^{1,m}_m, \ldots, T^{1,m}_{m+J-1}, \ldots, T^{NL,m}_{m+J-1}), \tag{2.4}$$

$$\ln\mathbf{p}_* = (\ln p_{*}{}^m_m, \ldots, \ln p_{*}{}^m_{m+J-1}), \tag{2.5}$$

T is the temperature, p_* the surface pressure, $r_n = [n(n+1)]^{-1/2}$ and NL the number of model levels. It is easily shown that the linearized primitive equations with no source or sink terms may be written

$$\dot{\mathbf{X}} = i\mathsf{A}\mathbf{X}, \tag{2.6}$$

3. Forçante Térmica

a) Introdução
b) Forçante subtropical
c) Forçantes de latitudes médias
d) Outros casos

a) Introdução

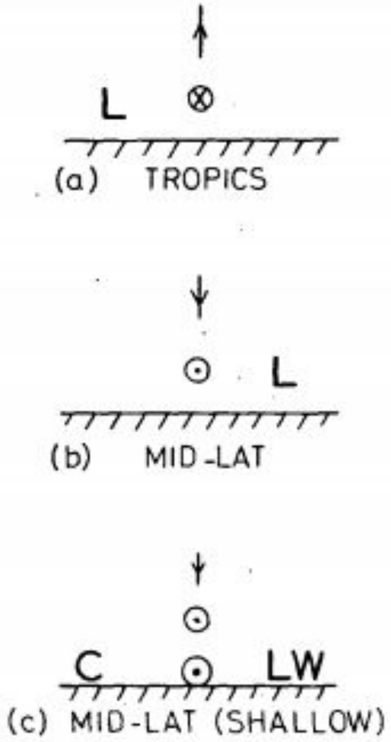


FIG. 2. Longitude-height sections showing the differing responses to thermal forcing in (a) tropics, (b) midlatitudes, and (c) mid-latitudes for shallow forcing. The arrow depicts vertical motion, circled crosses and dots motion into and out of the section, respectively, L the pressure trough, and C and W cold and warm air, respectively.

b) Forçante subtropical

=> Forçante térmica isolada nos subtrópicos (distribuição horizontal de cos²)

=> Máxima taxa média de aquecimento vertical (2.5 K/dia ⇔ 10mm)

c) Forçantes de latitudes médias

=> Fonte centrada em 45ºN

=> Distribuição horizontal circular

d) Outros casos

=> Fontes em diferentes latitudes

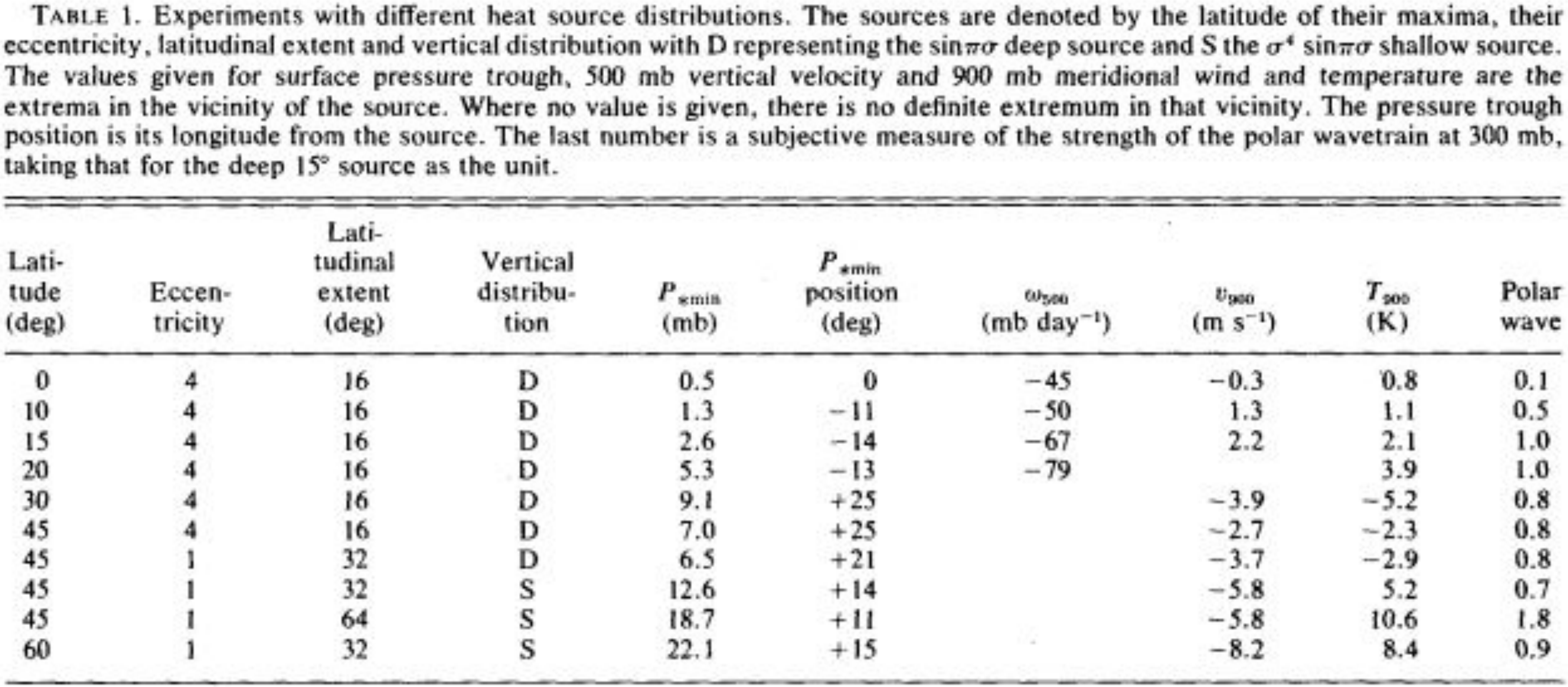


TABLE 1. Experiments with different heat source distributions. The sources are denoted by the latitude of their maxima, their eccentricity, latitudinal extent and vertical distribution with D representing the $\sin \pi\sigma$ deep source and S the $\sigma^4 \sin \pi\sigma$ shallow source. The values given for surface pressure trough, 500 mb vertical velocity and 900 mb meridional wind and temperature are the extrema in the vicinity of the source. Where no value is given, there is no definite extremum in that vicinity. The pressure trough position is its longitude from the source. The last number is a subjective measure of the strength of the polar wavetrain at 300 mb, taking that for the deep 15° source as the unit.

Latitude (deg)	Eccentricity	Latitudinal extent (deg)	Vertical distribution	$P_{*\min}$ (mb)	$P_{*\min}$ position (deg)	ω_{500} (mb day^{-1})	v_{900} (m s^{-1})	T_{900} (K)	Polar wave
0	4	16	D	0.5	0	−45	−0.3	0.8	0.1
10	4	16	D	1.3	−11	−50	1.3	1.1	0.5
15	4	16	D	2.6	−14	−67	2.2	2.1	1.0
20	4	16	D	5.3	−13	−79		3.9	1.0
30	4	16	D	9.1	+25		−3.9	−5.2	0.8
45	4	16	D	7.0	+25		−2.7	−2.3	0.8
45	1	32	D	6.5	+21		−3.7	−2.9	0.8
45	1	32	S	12.6	+14		−5.8	5.2	0.7
45	1	64	S	18.7	+11		−5.8	10.6	1.8
60	1	32	S	22.1	+15		−8.2	8.4	0.9

4. Forçante Orográfica

a) Introdução
b) Montanha circular em 30°N
c) Outros casos simples de montanhas
d) Orografia da terra

a) Introdução

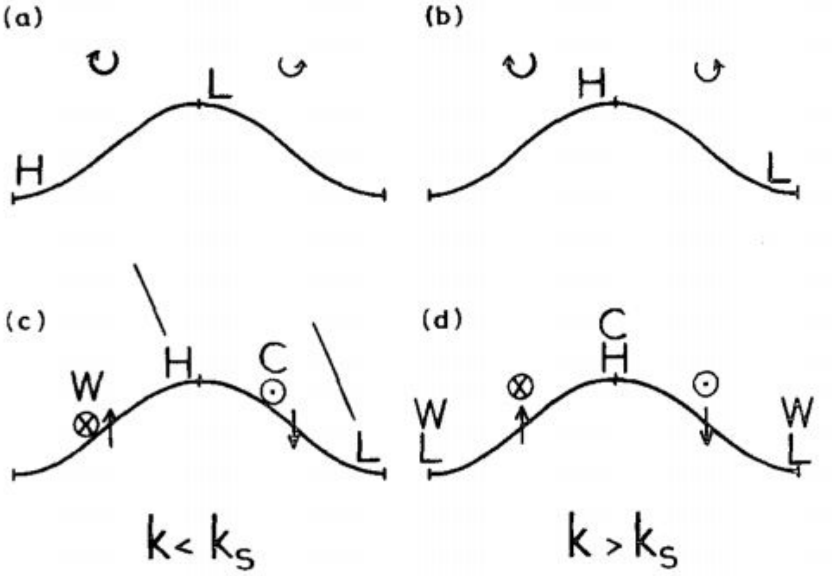


FIG. 7. Vertical sections showing the response to westerly flow over topography as described in the text. (a) and (b) are barotropic atmospheres with clockwise and counterclockwise arrows signifying the generation of anticyclonic and cyclonic vorticity, and H and L the pressure ridge and trough. (c) and (d) are baroclinic atmospheres with circled crosses and dots signifying poleward and equatorward flow, W and C the warmest and coldest air, H and L the mean sea-level pressure ridge and trough, and lines from them showing the vertical tilt of the pressure wave.

b) Montanha circular em 30°N

=> 2 km

c) Outros casos simples de montanhas

=> Vento zonal mais intenso

=> Redução de $2^{1/2}$ nas dimensões horizontais

d) Orografia da terra

=> Suavização

5. Raio das ondas de Rossby

a) Introdução

=> Aplicação da teoria cinemática de ondas

=> Modelo barotrópico

=>Raio: todo lugar na direção de c_g (energia se propaga ao longo de um raio com velocidade igual a velocidade de grupo)

b) Ondas de Rossby barotrópicas em um meio variando lentamente

=> Soluções da equação da vorticidade linearizada, não-divergente, barotrópica numa esfera

=> Projeção de Mercator

c) Fluxo com velocidade angular constante

d) Fluxos mais realistas
   => (b) aplicado num fluxo zonal realista

Principais resultados:

- Em baixos níveis as perturbações significativas são confinadas nas vizinhanças da fonte
- Para fontes de calor em latitudes médias, as perturbações dependem muito da distribuição vertical da fonte
- Na alta troposfera as fontes geram trens de onda similares aos obtidos com modelos barotrópicos
- Para fontes em pequenas latitudes, comprimentos de onda maiores se propagam mais em direção ao polo e também para leste. As ondas mais curtas ficam aprisionadas no lado equatorial do jato => divisão do trem de ondas

- Uma forçante subtropical é o jeito mais fácil de produzir uma resposta nas latitudes médias e altas (usando magnitudes razoáveis de dissipação)

- Explicação para os padrões descritos nos estudos observacionais

6. Discussão

- Buscar padrões de ondas induzidas por forçantes de larga escala
- Assumir um estado básico linear e estacionário não distorce muito a resposta atmosférica
- Métodos para prever o padrão geral das perturbações induzidas por forçantes de larga escala
- Importância nas médias latitudes de forçantes subtropicais na região dos ventos alísios
- Dissipação fraca possibilita ressonância ⇔ as soluções não são tão sensíveis; grande dissipação faz desaparecer a sensibilidade da estrutura da resposta ⇔ mesmos padrões mas com amplitudes reduzidas

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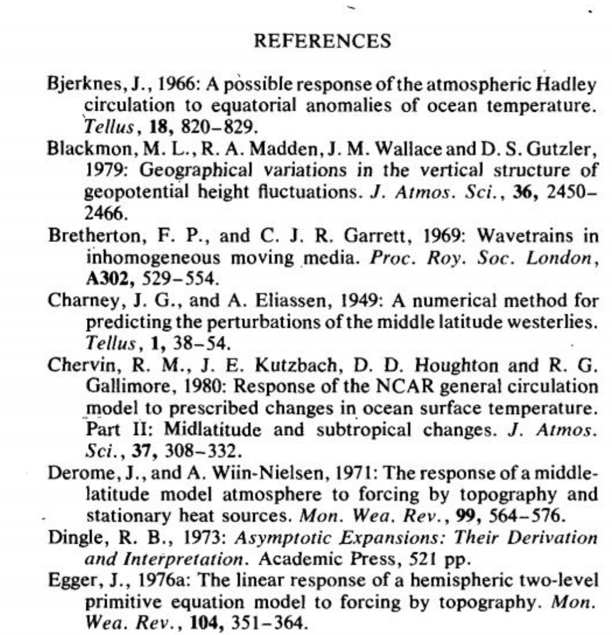

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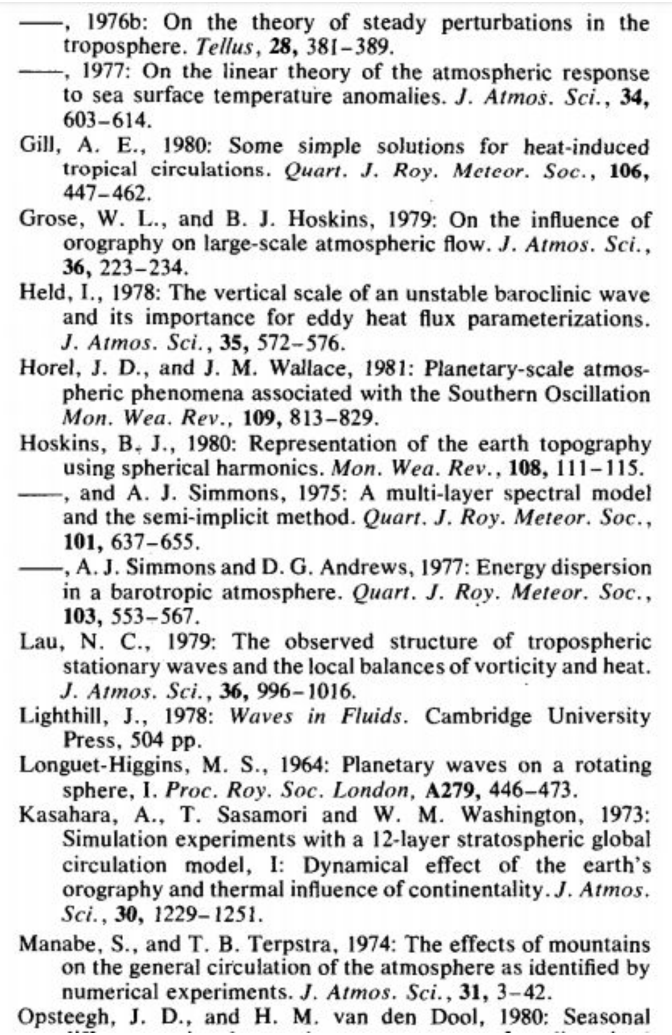

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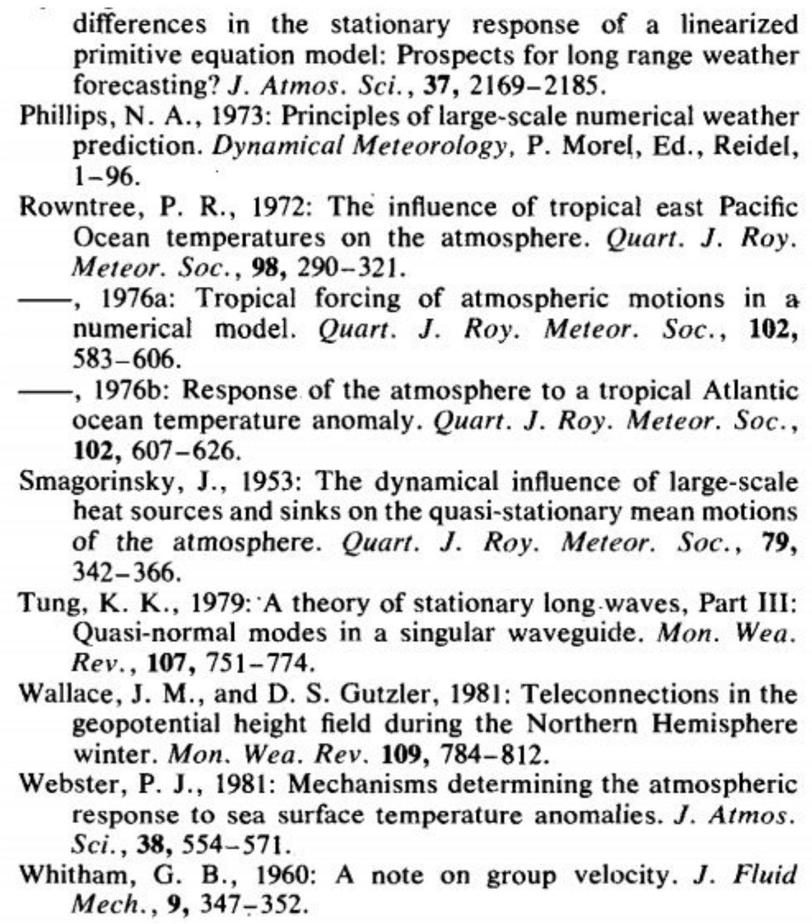

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