NOTES AND CORRESPONDENCE

Medium-Scale Travelling Waves over the North Atlantic

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Abstract

An analysis is made, with the aid of ECMWF operational data, of medium-scale, eastward-traveling waves in the mid-latitude upper troposphere over the north Atlantic area as a counterpart of the similar analysis of Sato *et al.* (1993) for the medium-scale waves over Japan.

It is shown that the waves dominate in wintertime (January and February of 1990) over the north Atlantic centered around 50°N, with the typical wavelength of 2400 km, a period of 33 hours, and hence an eastward phase velocity of about 20 m s⁻¹.

In view of their vertical structure and relationship to the background zonal flow, it is concluded that the wave character obtained in this analysis is the same in essence as that shown by Sato *et al.* (1993).

1. Introduction

In our previous study (Sato, Eito and Hirota, 1993: hereafter referred to as SEH), we found distinct medium-scale, eastward-traveling waves in the mid-latitude upper troposphere, by using both MU radar wind data and the Japan Spectral Model (JSM) data. The waves appear in a latitude band of 30°–40°N in the eastern Asia and western Pacific region in springtime, with a zonal wavelength and wave period of about 2100 km and 26 h, respectively. The zonal phase velocity of 22 m s⁻¹ is about twice as large as that of ordinary long waves which have a typical wavelength and period of 4000–5000 km and 4–5 days, so that the medium-scale waves are not considered to be due to the higher harmonics of the long waves.

There have been some observational and statistical studies on synoptic-scale disturbances in the extratropical tropospheric circulation, ranging from the order of 10 days down to a few days (*e.g.*, Hartmann, 1974; Blackmon, 1976; Nakamura, 1992). Among them, in his Fig. 7, Blackmon (1976) showed the northern hemispheric distribution of high-pass-filtered waves, but he did not distinguish medium-scale waves from long waves in their dynamical characteristics such as the wave structure and phase velocities. In this sense, SEH is the first work that showed clear evidence for the distinction between the two types of waves.

SEH suggested that the appearance of the medium-scale wave is strongly connected with the subtropical jet stream, by showing that the maximum of geopotential height wave amplitude at about 10 km corresponds to the peak of the jet and that the temporal variation of dominant latitudes of the waves is also well correlated with the north-south shift of the jet axis. It is therefore expected to find similar waves in other seasons and regions when and where the mid-latitude westerlies are intense.

The purpose of the present study is to prove that the existence of the medium-scale wave is ubiquitous, by making the same analysis as SEH for the north Atlantic region.

2. Data and method of analysis

Used in this study were ECMWF operational data (ECMWF/TOGA upper-air analysis uninitial-ized data with time intervals of 6 hours, *i.e.* 00Z, 06Z, 12Z, and 18Z). The data are distributed on a 2.5° × 2.5° horizontal mesh and vertically at pressure levels of 1000, 850, 700, 500, 400, 300, 250, 200, 150, 100, 70, 50, 30, and 10 hPa. The time interval of 6 hours may be rather coarse for the detailed analysis of medium-scale waves having a period of about 30 hours. However, we can overcome the restriction by using the statistical method of a lag-correlation analysis, because the horizontal resolution of the data is good for resolving medium-scale waves having zonal wavelengths of 2000–3000 km. Tidal components were removed by processing with

Horizontal wind 300hPa

Fig. 1. A polar stereographic chart of horizontal wind at the 300 hPa level averaged for January and February 1990. The contour intervals are 10 m s^{-1} .

a high-pass filter with a cut-off period of 450 h separately for each time series including data at each time of 00Z, 06Z, 12Z, and 18Z.

Since the purpose of this paper is to compare disturbances over the north Atlantic area with those over Japan reported by SEH, we used time filters with almost the same response functions, *i.e.* a high-pass filter with a cut-off period of 42 h and a band-pass filter with cut-off periods of 48 and 200 h to extract medium-scale and long waves, respectively.

Wave parameters of period, zonal wavelength and zonal phase velocity were estimated using data of the meridional wind component as follows: The auto-correlation function was calculated at each longitude for the time series over the 120 h period around a particular time, then the minimum time lag at which the auto-correlation function takes the first minimum was obtained. The wave period at the particular time was determined to be twice the average of the time lags at longitudes of 60°W – 0° , where the medium-scale waves are dominant (as shown later). The zonal wavelength at each time was estimated from auto-correlation function in longitude: The auto-correlation function was calculated at each time for the data with a longitudinal length of 120° around a longitude of 30°W . The wavelength was determined at each time as twice the minimum longitudinal lag at which the auto-correlation function takes the first minimum. The zonal phase velocity at each time was estimated by dividing the zonal wavelength by the wave period.

The characteristics of long waves were similarly obtained, though the used data lengths are 480 h in time and 180° in longitude.

(a) P_S GPH variance 300hPa (b) P_L

Fig. 2. Polar stereographic charts of variance of geopotential height component for (a) P_S and (b) P_L at the 300 hPa level. The contour intervals are 200 m^2 and 2500 m^2 for P_S and P_L , respectively.

3. Results

3.1 Mean wind field

First of all, to see the background field of this analysis, the horizontal wind distribution averaged for the two months of January and February 1990 at the 300 hPa level is illustrated in Fig. 1. It is easily found that the intense westerly jet, the maximum speed of which is larger than 50 m s^{-1} , is located over the north Atlantic in a latitude belt of 40° – 50°N as well as that over Japan, reflecting the dominance of the wintertime steady planetary wave of wavenumber 2.

The mean vertical structure of the background field will be shown later (Fig. 5).

Fig. 3. Hovmöller diagram of the (a) P_S and (b) P_L meridional wind components averaged for latitudes of 45–55°N at the 300 hPa level. The contour intervals for P_S and P_L are 5 m s⁻¹ and 10 m s⁻¹, respectively. Negative values are hatched.

3.2 Wave intensity

As was mentioned in Section 2, wave disturbances were separated into two categories in terms of their time-scales by using two time-filters, *i.e.* the shorter period component P_S ($T \leq 42$ h, T : wave-period) and the longer one P_L ($48 \text{ h} \leq T \leq 200$ h), following SEH.

The variance of geopotential height with respect to time over the two months at the 300 hPa level was estimated for each component and presented in Figs. 2a (P_S) and 2b (P_L). It is of interest to find that the maximum variance appears, for both components P_S and P_L , over the north Atlantic area, while the variance over the Japan area is rather weak even though the jet is intense there. The suppression of mid-winter wave activity in the Pacific has been pointed out by Nakamura (1992).

By assuming that the variance is mostly due to monochromatic migrating waves, we obtained a rough estimate of the height wave amplitude of 50 m for P_S and 150 m for P_L . The validity of the as-

Table 1. Characteristics of medium-scale waves over the north Atlantic. Values in the parentheses are estimations over the north Pacific by SEH.

	horizontal wavelength (km)	period (h)	phase velocity (m s ⁻¹)
P_S	2400±400 (2100±300)	33±5 (26±3)	20±5 (22±2)
P_L	3800±600 (5300±1400)	87±8 (120±30)	12±2 (12±2)

sumption of monochromatic waves will be discussed later (see Section 3.4). It is also noteworthy that the maximum variance of P_S is located at 50°N, a few degrees north of the jet axis ($\approx 45^\circ\text{N}$; Fig. 1), in harmony with the result of SEH. This is the case even if we use the stream function instead of the geopotential height.

Therefore, in what follows, we focus our atten-

Fig. 4. Composite structure of the medium-scale wave in a longitude-height section for (a) the geopotential height, (b) meridional wind, and (c) temperature components. The contour intervals are 10 m for (a), 2.5 m s^{-1} for (b), and 0.5 K for (c). The reference longitude for the composite was taken at 40°W and indicated by +.

tion on the region between 90°W and 0° along the latitude belt centered at 50°N .

3.3 Hovmöller diagram and wave parameters

Following the method of SEH, we made Hovmöller diagrams of the meridional wind component to see the dominant wavelength and period. Figures 3a and 3b show the diagrams for P_S and P_L averaged in a belt of $45^\circ\text{--}55^\circ\text{N}$ at the 300 hPa level, for January 1990. It is clearly seen in both Figs. 3a and 3b that the eastward-migrating wave with almost constant wavelength and phase velocity is dominant throughout the period of analysis.

Fig. 5. Latitude-height sections of (a) variance of P_S geopotential height component and (b) mean zonal wind at a longitude of 40°W . The contour intervals for (a) and (b) are 150 m^2 and 5 m s^{-1} , respectively. Contours of negative values are dotted. Thick dotted curves denote the tropopause estimated from the temperature field.

The lag-correlation analysis for the whole period of two months gives the wave characteristics shown in Table 1, where the values in parentheses are the estimates given by SEH. It is stressed that the wave parameters of the two analyses are comparable with each other, except that the wavelength and period of P_L are rather shorter than those of SEH.

3.4 Wave structure

Figure 4 shows the longitude-height section of medium-scale waves for geopotential height, meridional wind, and temperature averaged for a band of $45^\circ\text{--}55^\circ\text{N}$, where a composite of 20 days (1–13 January, and 24 January–1 February, 28 cases) was made in a similar manner to SEH. The meridional wind component at 40°W (indicated by +) was taken as the reference of the composite.

The maximum of each of the geopotential height and meridional wind appears at around the 300 hPa

level, and the phase difference between geopotential height and meridional wind ($\approx \pi/2$) is indicative of a quasi-geostrophic balance. The phase is almost vertical, except for the lower troposphere where a weak westward tilt is observed. The characteristic feature of the wave structure is almost the same as that shown by SEH.

It is worth noting that the amplitude of geopotential height (≈ 50 m) estimated from the variance of P_S under the assumption of monochromatic waves (Section 3.2) is close to the maximum value of geopotential height seen in Fig. 4 (≈ 40 m). Therefore it is confirmed that the P_S variance shown in Fig. 2 is mostly contributed to by the medium-scale waves over the north Atlantic.

3.5 Meridional cross section

In order to see the relationship between the wave structure and the background field, the meridional cross section along 40°W of variance of P_S geopotential height and mean zonal wind is presented in Figs. 5a and 5b, where the wave activity is strong.

Inspection of this figure reveals that the medium-scale wave amplitude is confined to the upper troposphere and lower stratosphere with the maximum at about the 300 hPa level, which corresponds to the mid-latitude tropopause height (dashed line in Fig. 5b).

As regards the latitudinal distribution, the wave amplitude is centered at 50°N , a few degrees north of the center of the mean westerly jet at the same height level; as was pointed out in Section 3.2. Another interesting aspect of the amplitude distribution in the meridional plane is that the wave has a rather narrow width in the north-south direction: the half width of variance is only 13 degrees (43° – 56°N), whereas it is 20 degrees (35° – 55°N) for long waves P_L (not shown here).

4. Summary

In this analysis, we have shown the existence of the medium-scale, eastward-travelling wave over the north Atlantic area, the dynamical character of which is almost the same as that obtained by Sato *et al.* (1993). Therefore we can say that the medium-scale wave is not a peculiar phenomenon limited to the east Asia area but a ubiquitous one in the region where the mid-latitude tropospheric jet stream is intense. The medium-scale wave is clearly distinct from the long wave in many aspects of wave character. Although we do not have yet a satisfactory physical explanation for the mechanism of the wave generation, the wave dynamics is no doubt tightly connected with the strong mid-latitude westerlies, as is suggested from Figs. 1, 2 and 5. The expansion of this analysis to the climatological description, such as seasonal variation and regional distribution is quite interesting and is currently being made in our group.

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北大西洋上に卓越する中間規模東進波

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ECMWF 客観解析データを用いて北大西洋中緯度上部対流圏での中間規模東進波について調べた。この解析の目的は、Sato *et al.* (1993) の発見した日本付近に卓越する中間規模東進波が中緯度対流圏ジェットの高い他の地域にも存在する普遍的なものであることを示すことにある。

解析を行なった 1990 年 1 月と 2 月には、 50°N を中心とする北大西洋域で東西波長約 2400 km、周期約 33 時間、東進位相速度 20 m s^{-1} の中間規模波動が卓越していた。さらに波動の鉛直構造、背景風との対応関係も調べてみた結果、この波動の特徴は Sato *et al.* の示したものと本質的に同じものであると結論できた。