5. Characteristics of a BGM perturbation

In this section, we examine the characteristics of the perturbation of the MRI-EPS created through the newly developed BGM system described in the previous sections. We also use the MRI-EPS to examine the predictability of the stratospheric sudden warming (SSW) that occurred in the winter of 2001 and compare the results with those obtained with the operational JMA-EPS.

By using the BGM system, we have already calculated and stored NH and SH perturbations up to 25 modes and TR perturbations up to 2 modes from October 2001 to March 2013. These perturbations can be used to immediately start ensemble forecast experiments. In this section, we show the result of an ensemble forecast experiment with the six leading NH bred modes. These bred modes were used to generate 13 initial perturbations by taking into account the polarities of six bred modes and the unperturbed control forecast. This configuration of the ensemble forecast is the same as the configuration of the operational JMA 1-month ensemble forecast for the winter of 2001. We conducted ensemble forecasts starting every day during the period from 28 November through 20 December of 2001, during which a SSW event was observed.

5.1 Spatial structure of bred mode

First, we examine the spatial structure of the obtained NH bred mode. Figure 8 shows a latitude-height cross section of the zonal-mean amplitude of the bred modes averaged over the 23-day experimental period. A common meridional distribution of the amplitude is apparent in the six bred vectors. In fact, the amplitude has two peaks: one is around 300 hPa at 40–50°N, and the other is around 300 hPa at 80°N. The peak at 40–50°N corresponds well with the latitude of the maximum amplitude of climatological synoptic waves (not shown) and also with the region of the maximum baroclinicity of the climatological zonal mean flow.

Figure 9 shows the horizontal structures of the 500-hPa geopotential heights for obtained bred modes on 13 December 2001; all ensemble forecasts starting from this date succeeded in forecasting the occurrence of the SSW (see Section 7.1). On this date, a very prominent blocking high was observed over England (not shown). Associated with this blocking, most bred modes had large perturbation amplitudes around the polar region. These large-amplitude perturbations correspond to the dominant peaks in the amplitudes of the bred modes shown in Figure 8. The observed flow might be highly unstable with respect to the bred mode, because the bred mode will grow due to the dynamical instability of the observed flow.

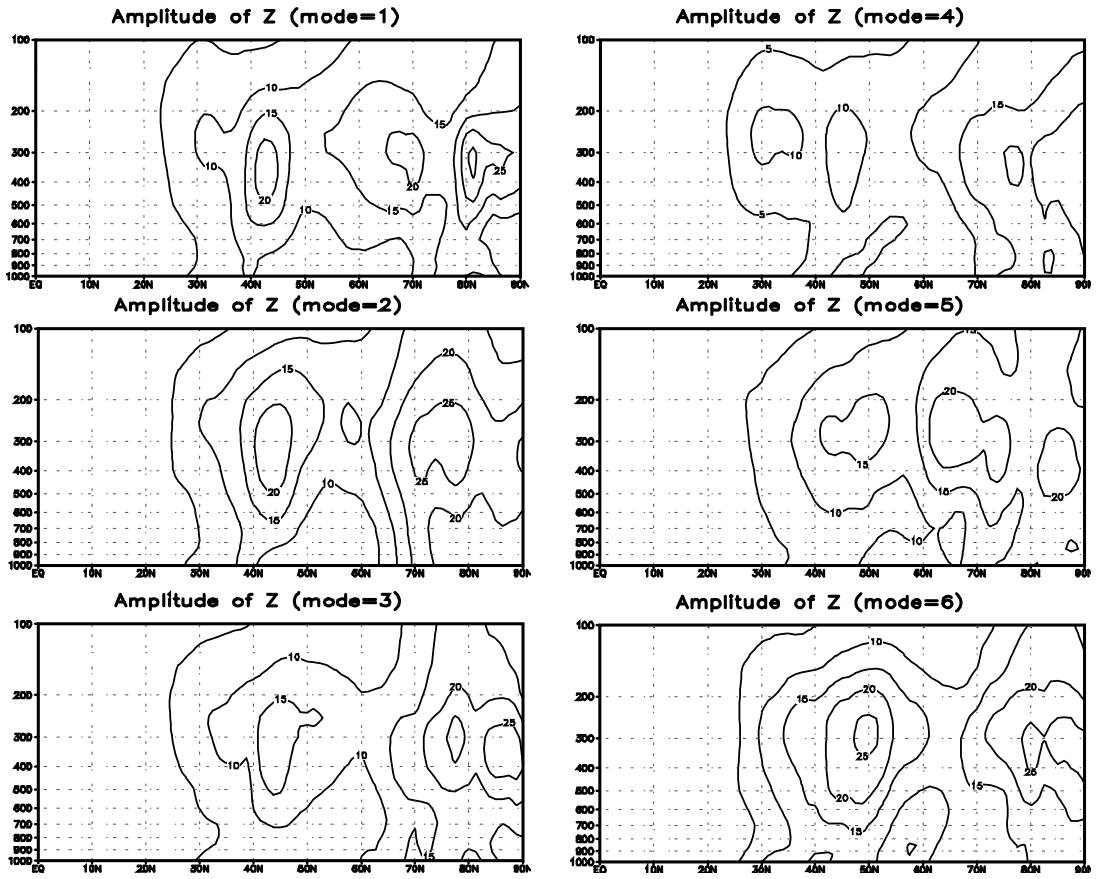

Figure 8: Zonally averaged amplitude of the geopotential height associated with the obtained bred modes. The amplitude was averaged over a period of 23 days from 28 Nov. to 20 Dec. 2001. Contour interval is 5 m.

We also examined the zonal wavenumber spectrum of the geopotential height amplitude of the bred mode. Figure 10 shows the geopotential height amplitude of the bred mode at 300 hPa averaged over 40–50°N as a function of zonal wavenumber. The spectrum was obtained from the average over 23 days of the experimental period. It is apparent that all bred modes have a peak around zonal wavenumber 5 and 6, except for the third mode, in which the highest peak in the spectrum occurs at zonal wavenumber 3. This result also suggests that the obtained bred modes grow through the baroclinic instability of the observed flow.

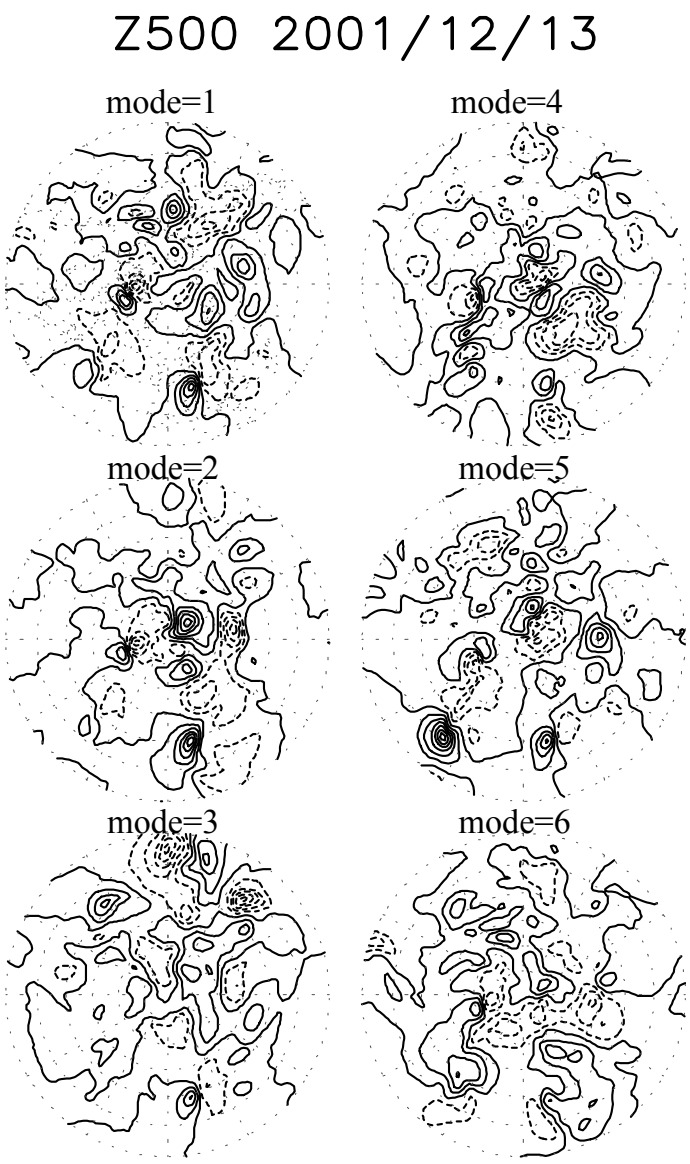

Figure 9: Horizontal distribution of the geopotential height of the obtained bred mode at 500hPa on 13 Dec. 2001 in a polar stereographic map north of 30°N. Top of each panel corresponds to the date line. Contour interval is 20 m. Dashed lines indicate negative values.

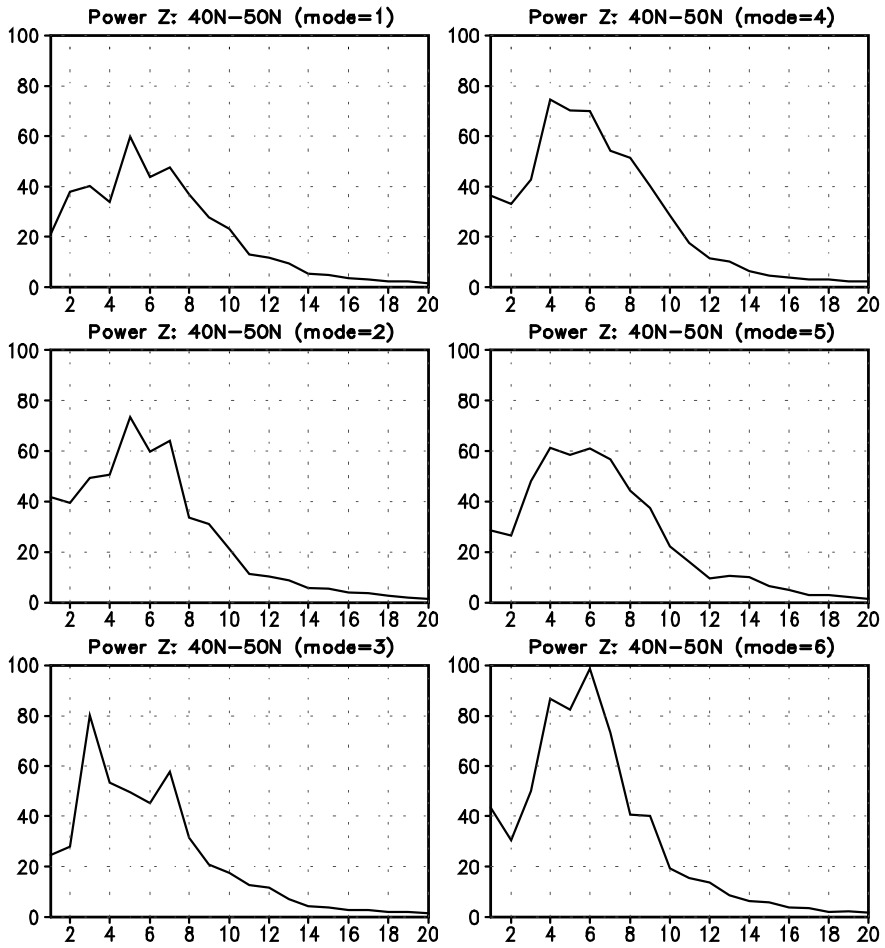

Figure 10: Zonal wavenumber spectrum of the amplitude of geopotential height at 300 hPa of the bred mode averaged over 40–50°N and a period of 23 days from 28 Nov. to 20 Dec. 2001. The abscissa is the wave number. Units of the ordinate are square meters.

5.2 Temporal evolution of bred modes

In this subsection, we examine the temporal evolution of the obtained NH bred mode. As described in Section 2.1, the amplitude of each NH bred mode at the initial time of forecast is specified such that the variance of the 500-hPa geopotential height of the mode, averaged north of 20°N, is 14.5% of the climatological variance.

Figure 11b shows the temporal variation of the amplification of each mode during initial one-day temporal integration starting every day. The magnitude of the amplification is assessed by the increment of the amplitude over one day. The same NWP model (GSM) used in the BGM cycle of the MRI-EPS was used to evaluate the temporal evolution of the bred mode. The operational NWP model used in Mukougawa *et al.* (2005) is referred to as the GSM0103. Note that the initial amplitude of each bred mode is about 15 m. Figure 11b shows that the average amplitude increment is about 6 m. The NH bred mode thus increases its amplitude by about 40% during the first day. However, it should be noted that the day-to-day variation of the amplification is very large. Moreover, the rate of amplification is almost the same among the bred modes: the amplitude increments, averaged over the experimental period, are 5.9, 6.3, 5.9, 6.3, 6.1, and 6.0 m for bred modes 1–6, respectively. We also confirmed that, as of 2001, the bred modes of the operational 1-month ensemble forecast of the JMA (GSM0103) evolve over time in a similar way (Figure 11a): the amplitude increments for each mode are 6.5, 5.8, 6.1, 6.2, 5.5, and 6.0 m, respectively.

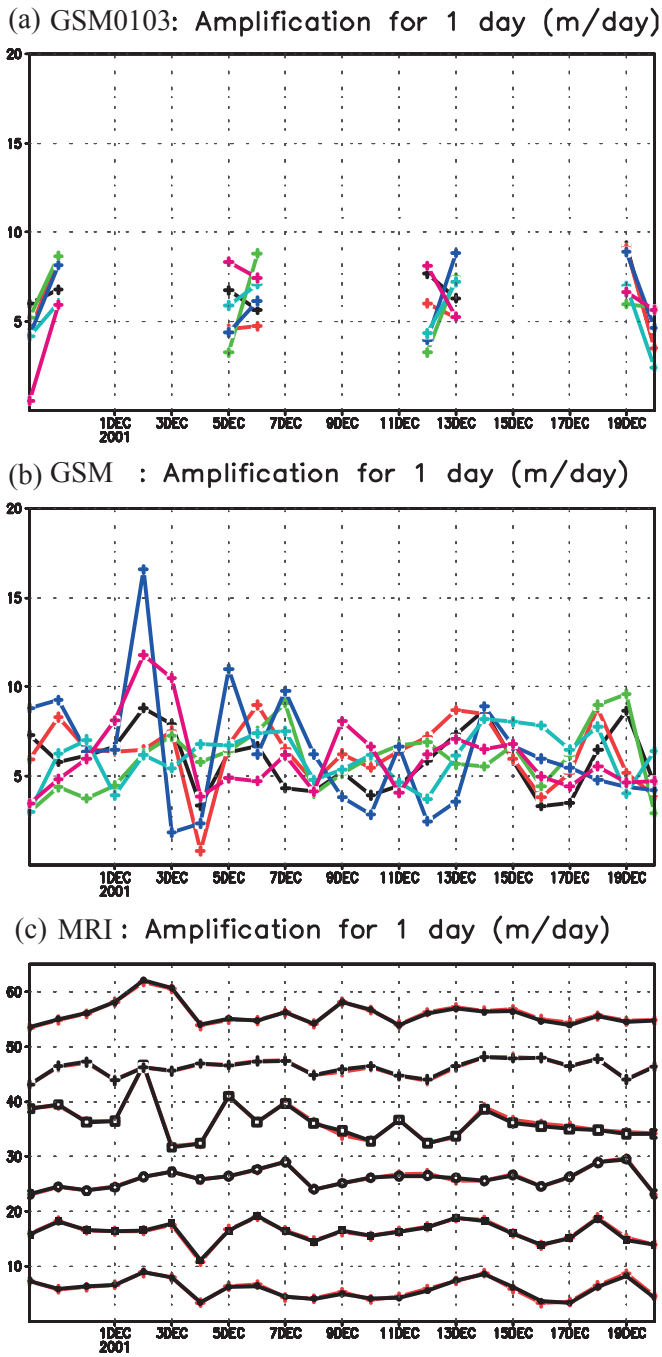

Figure 11: Amplitude increments (m) of each bred mode during the first one day. (a) The operational one-month ensemble forecasts as of 2001 (GSM0103). (b) Numerical forecasts are conducted by the GSM, and these forecasts are also used to obtain the bred mode. The amplitude is evaluated by the root-mean-square of the 500-hPa geopotential height variation poleward of 20°N. Each bred mode is designated by colors in (a) and (b): black for the first mode, orange for the second, yellow-green for the third, blue for the fourth, blue-green for the fifth, and magenta for the sixth. For panel (c), numerical forecasts were conducted by the

MRI-AGCM3.2 (black lines). The values for the GSM are also shown by red lines, which are the same as in panel (b). Note that 10(n – 1) m is added to the amplitude of the n-th bred mode in this panel to easily distinguish the amplitude of each mode.