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A linear model study of the mid-tropospheric ridge and its displacement — inclusion of a surface heat sink

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सार — मध्य क्षोभमंडलीय पर्वत शिखर और उसके विस्थापन की औसत स्थिति की देखभाल के अध्ययन के लिए विलंगित ऊष्मा स्रोतों के साथ स्तरित द्रव की स्थायी अवस्था अनुक्रिया वाले एक रैखिक निदर्श का प्रयोग किया गया है । हाल के प्रेक्षणात्मक अध्ययनों से सुस्पष्ट है कि यूरेशिया के ऊपर शीत/बसंत हिम आवरण का 75° पू. पर अप्रैल 500 एच. पी. ए. पर्वत शिखर के साथ नकारात्मक संबंध है । इससे पहले के अध्ययन में मध्य क्षोभमंडलीय पर्वत शिखर के दक्षिणावर्त विस्थापन की एक व्यवहार्य भौतिक क्रिया विधि का प्रस्ताव रखा गया था । इस अध्ययन में यूरेशिया के हिम आवरण के विस्तार से उत्पन्न असंगत शीतलन को उष्ण कटिबंधीय ऊष्मा स्रोतों के लिए उत्तर में (सतह तक फैली हुई) ऊष्मा अपवाहिका के समान माना गया है । इससे इस बात का पता चलता है कि ऊष्मा में ऐसी कमी आने के परिणामस्वरूप मध्य क्षोभमंडलीय पर्वत शिखर में महत्वपूर्ण दक्षिणावर्त विस्थापन हो सकता है।

ABSTRACT. A linear model of the steady response of a stratified fluid to isolated heat sources is used to study the maintainence of the mean position of the mid-tropospheric ridge and its displacement. There is evidence from recent observational studies that the winter/spring snow cover over Eurasia is negatively related to the April 500 hPa ridge position along 75°E. In our earlier study, we proposed a possible physical mechanism of the southward displacement of the mid-tropospheric ridge. In this study the anomalous cooling associated with the increased snow cover in Eurasia is considered as a heat sink (extending to the surface), north of the tropical heat sources. It is demonstrated that such a surface heat sink can also result in significant southward displacement of the mid-tropospheric ridge.

Key words — Mid-tropospheric ridge, Heat sources, Surface heat sink, Southwest monsoon, Normal modes.

1. Introduction

A mid-tropospheric ridge pattern over south India and its seasonal migration is a well known feature of the climatology over the Indian region. The latitudinal position of the 500 hPa ridge along 75°E in April is one of the most important predictors of the summer monsoon rainfall. Banerjee *et al.* (1978) first demonstrated that if the latitudinal position of the 500 hPa ridge during April is much south (north) of its normal position rainfall over India for the subsequent summer monsoon is mostly much below (above) normal. Earlier studies (Blanford 1884, Hahn and Shukla 1976, Bhanukumar 1988) indicate that large and persistent winter snow cover over Eurasia can delay and weaken the spring and summer heating of the land masses, so essential for the establishment of the large scale monsoonal flow.

Mooley *et al.* (1986) argued that the location of the mid-tropospheric ridge along 75°E is a measure of the influence exerted by the troughs in the westerlies on the upper tropospheric thermal conditions over north and central India. Shukla and Mooley (1987) found a correlation coefficient of –0.49 between the April 500 hPa ridge location and December through March

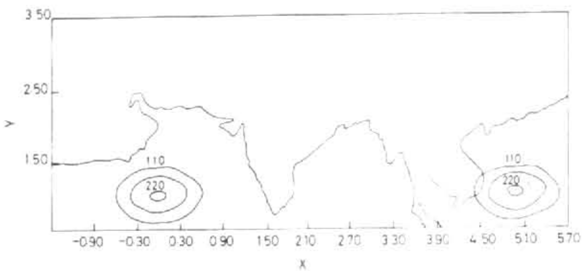

Fig. 1. Contours of geopotential perturbation field (m^2s^{-2}) at a height of 6.5 km for two sources. Highest value of contour is 220 and contour interval is 55

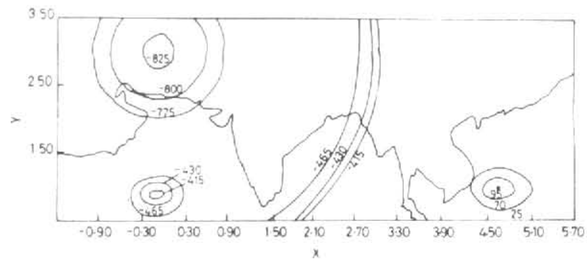

Fig. 2. Contours of geopotential perturbation field (m^2 s^{-2}) at a height of 6.5 km for two sources and one sink

Eurasian snow cover. Chandrasekar and Goswami (1995) proposed a possible physical mechanism of the southward displacement of the mid-tropospheric ridge. The effect of excessive winter and spring snow cover over Eurasia will be that less solar energy will be available to heat the atmosphere due to high albedo of snow. This can lead to a colder than normal conditions upto June thereby adversely affecting the monsoon. Chandrasekar and Goswami (1995) demonstrated that a heat sink (corresponding to the anomalous cooling associated with the increased snow cover over Eurasia) prescribed north of one of the tropical heat sources resulted in significant southward displacement of the mid-tropospheric ridge.

The objective of this study is to extend the earlier work of Chandrasekar and Goswami (1995) by including a more realistic heat sink extending right up to surface. In the earlier study, the prescribed heat sink had maximum cooling in the lower troposphere and vanished at the surface. The present heat sink included in this study has maximum cooling at the surface and the introduction of the same results in significant southward displacement of the mid-tropospheric ridge.

2. Model and heat sources

The model used in this study is identical to the model used by Chandrasekar and Goswami (1995) and hence the details of the same are not reproduced here. In order to simulate the mid- tropospheric anticyclone (Fig. 2 of Shukla and Mooley 1987), we prescribed two non-circular heat sources. The heat sources were identical to the one used in the earlier study. The heating is symmetric in the vertical and the vertically averaged heating corresponds to 3°C/day.

3. Inclusion of a surface heat sink

In this study we have extended the earlier work of Chandrasekar and Goswami (1995) by including a more realistic heat sink. In the earlier study the prescribed heat sink had maximum cooling in the lower troposphere and vanished at the surface. However, the present heat sink included in this study is more realistic in the sense that it extends right upto the surface and has maximum cooling at the surface. Inclusion of surface heat sink, as in the case here, results in the boundary condition of a non-zero surface temperature, $T_0 = Q(x, y, 0) / (\alpha c_p)$.

In order to obtain boundary condition at the surface independent of our surface heat sink, the usual approach is to follow the Green's function technique (Morse and Feshback 1953) and replace this with a boundary condition of $T_0 = 0$, adding a sheet sink of forcing at the surface. The surface sheet sink essentially provides for a jump in the temperature from zero surface temperature to a temperature of T_0 just above the surface. An equivalent approach (as discussed in Sashegyi and Geisler 1987) is to provide for a jump in the cooling at the surface from zero below the surface to its interior value just above the surface. This is very simply achieved by multiplying the low level heating function corresponding to the heat sink by a unit step function. Integrating the linear thermodynamic heat balance equation in a thin surface layer now yields a zero surface temperature and the same temperature T_0 just above the surface. The horizontal dependence of the heat sink is the same as in the earlier study of Chandrasekar and Goswami (1995) while the vertical dependence B (z) of the heat sink is given by,

$$B(z) = L(z)\ I(z) \qquad (1)$$

where,

$$L(z) = (Q_{90}/2) \quad [1 - \tanh \{(z - z_0)/z_w\}] \qquad (2)$$

where, z_0 = 3 km is the centre of the tanh function, z_w = 2.5 km the half width, $I(z)$ the Heaviside unit step function defined by,

$$I(z) = \begin{cases} 1 & z > 0 \\ 0 & z = 0 \end{cases} \qquad (3)$$

Q_{90}, the maximum cooling rate, is so chosen that $B(z)/c_p$ vertically averaged upto a height of 13 km corresponds to a cooling of 2°C/day.

The unit step function ensures that the heating is zero at the surface so that the forcings can be expanded by the set of vertical normal modes with the homogeneous boundary condition of zero temperature perturbation at the surface. The effect of the step function is essentially to move the non-zero surface temperature (due to surface layer cooling) to just above the surface. With the above prescription of the heat sink we see that most of the cooling is confined to heights below 6 km. The contribution of the sensible heat sink given by Eqns. (1) & (2) to the forcing function defined by,

$$F = -\exp(-z/2H) \left\{ (Q/c_p) - H\,(Q/c_p)_z \right\} \qquad (4)$$

and given by,

$$F_s(z) = I(z)\, F_L(z) + H\, L(z)\, \delta(z) \exp(-z/2H) \qquad (5)$$

where, H is the scale height, Q is the heating function, c_p is the specific heat at constant pressure and the subscript z indicates partial derivative with respect to z.

$F_L(z)$ in Eqn. (5) is given by,

$$F_L(z) = -\exp(-z/2H) \left\{ (L/c_p) - H\,(L/c_p)_z \right\} \qquad (6)$$

and $\delta(z)$ is the Dirac delta function. The first term on the right hand side of Eqn. (5) describes the forcing due to the low level cooling $L(z)$ alone, while the second term describes the sink at the surface of magnitude $H\,Q_{90}\,\delta(z)$, which provides the needed temperature jump just above the surface. The amplitude of the coefficient $\hat{F}_n$ defined as follows:

$$\hat{F}_n = \frac{\int_0^D F(x, y, z)\, G_n(z)\, dz}{\int_0^D G_n(z)\, G_n(z)\, dz} \qquad (7)$$

for the sensible heat sink function F_s can, then, be written as a sum of two contributions

$$\hat{F}_n = \hat{F}_{ln} + \hat{F}_{\delta n} \qquad (8)$$

where, $\hat{F}_{ln}$ is the amplitude of the projection of the forcing $F_L(z)$ due to the cooling alone and $\hat{F}_{\delta n}$ is given by

$$\hat{F}_{\delta n} = \left\{ H\, Q_{90}\, G_n(0) \right\} / \int_0^D G_n(z)\, G_n(z)\, dz \qquad (9)$$

is the contribution from the sink at the surface. Here D (22.5 km) is the height at which the rigid lid is kept and $G_n(z)$ is the set of vertical normal modes. Evaluating Eqn. (9) for the internal modes we have,

$$\hat{F}_{\delta n} = (-2\, H\, Q_{90}/D) \left\{ 1 + (D/2n\,\pi\, H)^2 \right\}^{1/2} \qquad (10)$$

while for the external mode (n = 0) we have,

$$\hat{F}_{\delta 0} = Q_{90} \left\{ 1 - \exp(-D/H) \right\}^{-1} \qquad (11)$$

The non-dimensionalised steady state equations are solved for the external and each of the first six internal modes and the solution variables are summed over these modes. The details regarding the solution procedure can be found in Chandrasekar and Goswami (1995). The domain is rectangular having $-2.5 \le x \le 7.5$ and $-2 \le y \le 5$ with $\Delta x = 0.1$ and $\Delta y = 0.05$.

4. Results

Fig. 1 presents the geopotential perturbation field at a height of 6.5 km for the case of two non-circular sources centered at (0, 1) and (5, 1) roughly at 11°N latitude. The figure clearly shows a high situated over each of the heating centres. Since the structure of the two tropical sources are identical with the earlier work, Fig. 1 is virtually identical to Fig. 3 of Chandrasekar and Goswami (1995). Fig. 2 presents the geopotential perturbation field at a height of 6.5 km for the case where a circular heat sink is prescribed north of one of the heat sources. The horizontal structure of the heat sink is the same as in the earlier work $\left(\alpha_1^2 = \alpha_2^2 = 0.25\right)$ and the sink is centered at (0, 3) roughly at 34°N latitude. The vertical structure of the heat sink (as described in section 3) is different from the earlier work and is presently more realistic. Fig. 2 clearly reveals the southward displacement of one of the anticyclones by 123 km (two grid point movement southward).

It is true that Chandrasekar and Goswami (1995) obtained a southward displacement of 123 km of one of the anticyclones as in the present study. However in the earlier work the vertically-averaged cooling rate over the entire atmospheric column (22.5 km) of the heat sink was assigned a value of 2°C/day. In the present study, however, the vertically-averaged cooling rate was confined to a height of 13 km (approximately half the earlier height) and was assigned the same value of 2°C/day. Also a more realistic heat sink has been prescribed in the present study.

5. Conclusions

A simple linear model of the steady response of a stratified fluid to isolated heat sources is used to study the mid-tropospheric ridge. An attempt has been made to demonstrate that increased snow cover over Eurasia results in the southward displacement of the mid-tropospheric anticyclone by prescribing a surface heat sink at 34°N. The surface heat sink is more realistic (as compared with the earlier work) with maximum cooling at the surface and is very extensive in the horizontal. Inclusion of the above results in moderate displacement of the mid-tropospheric anticyclone by 123 km.

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References

Banerjee, A.K., Sen, P.N. and Raman, C. R. V., 1978, "On foreshadowing southwest monsoon rainfall over India with mid-tropospheric circulation anomaly of April", *Indian J. Met. Geophys.*, **29**, pp. 425-431.

Bhanukumar, O.S.R.U., 1988, "Interaction between Eurasian winter snow cover and location of the ridge at the 500 hPa level along 75°E", *J. Met. Soc. Japan*, **66**, pp. 509-514.

Blanford, H.F. , 1884, "On the connection of the Himalayan snow with dry winds and seasons of droughts in India", Proc. Roy. Soc. London, 37, pp. 3-22.

Chandrasekar, A. and Goswami, B.N., 1995, "A linear model study of the mid-tropospheric ridge and its displacement", (communicated to Mausam).

Hahn, D. and Shukla, J., 1976, "An apparent relationship between European snow cover and Indian monsoon rainfall", *J. Atmos. Sci.*, **33**, pp. 2461-2463.

Mooley, D. A., Parthasarathy, B. and Pant, G. B., 1986, "Relationship between Indian summer monsoon rainfall and location of the ridge at the 500 mb level along 75°E", *J. Clim. & Appl. Meteor.*, **25**, pp. 633-640.

Morse, P.M. and Feshbach, H., 1953, "Methods of Theoretical Physics", Part I, McGraw - Hill, pp. 791-811.

Sashegyi, K. D. and Geisler, J.E., 1987, "A linear model study of cross equatorial flow forced by summer monsoon heat sources" *J. Atmos. Sci.*, **44**, pp. 1706-1722.

Shukla, J. and Mooley, D.A., 1987, "Emperical prediction of the summer monsoon rainfall over India", *Mon. Wea. Rev.*, **115**, pp. 695-703.