Letters to the Editor

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EFFECT OF PALGHAT GAP ON THE RAINFALL PATTERN TO THE NORTH & SOUTH OF ITS AXIS

1.   Climatological normal rainfall pattern of Southwest Monsoon Seasons (SWMS) over south peninsular India shows an area of rainfall gap near Palghat. Divergence caused due to Bernoulli's effect is attributed to this effect.

Here an attempt has been made to explain the divergence using a dynamical model of airflow across a three dimensional mesoscale elliptical barrier. Using Santacruz (SCZ) RS/RW data, of a strong monsoon day, the model has been run to compute the perturbation vertical velocity (w') at the exit (eastern end) of the gap. Vertical profiles of w' at different points in the down stream direction show that it decreases with height at, ensuring divergence. This divergence may cause cyclonic turning of stream lines to the north and anti-cyclonic turning of stream lines to the south of the gap axis, which may be attributed to the observed difference in rainfall to the south and north of Palghat gap at its exit.

2.   Gap winds are low elevation winds associated with gaps or low elevation areas in mountainous terrain, including flow through valleys & canyons & among peaks. These wind fields arise in terrain gaps ranging from hundreds of meters to a few hundreds of kilometers wide & produce local increase in wind speed & often large changes in wind direction that more or less parallel to the gap axis. Gap winds typically blow over shallow depths that do not exceed a kilometer & are often only a few hundreds meters deep. Gap winds are strongest when a large pressure gradient exists across the gap, although same gap winds do not depend on the large-scale pressure gradient but on the wind entering the gap.

Palghat gap is such a gap in the Western Ghats (WG). Western ghats extends from the southern portion of the Tapi river valley along the Malabar coast to Cape Comorin. The range is divided by Palghat gap (About 40 km wide & 80 km long); the section north of the division is about 1290 km long & that to south of the gap is about 320 km. The average elevation of the western ghats is about 900-1100 m.

Ramachandran (1972) studied the rainfall distribution along the Palghat gap. The study showed that the rainfall decreases gradually & continuously from the
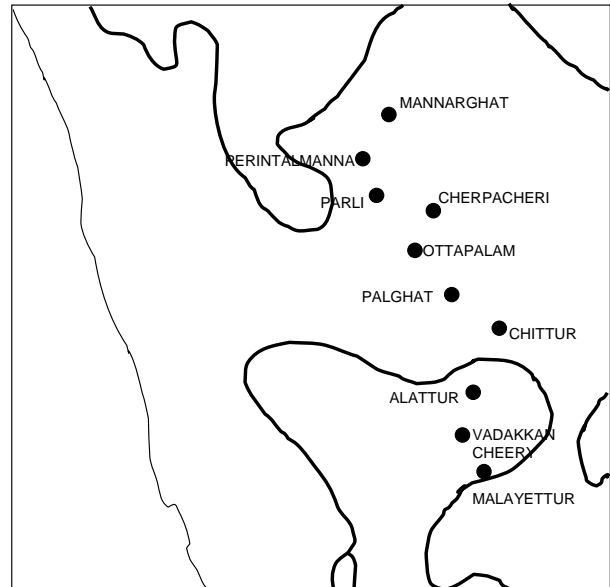

Fig. 1. Different stations north & south of Palghat Gap

coast against the gap cross-section. The study also showed that, along the sections, north & south of the gap, the rainfall increases upto a certain height from the coast in the windward side & decreases gradually in the lee side, which are mainly due to orographic effects shown earlier by Sarker (1966, 1967).

Ramachandran *et al.* (1980) made an observational study at selected sites in and around the Palghat gap to understand the downwind increase of winds transiting the gap. The computations made in the above study indicated a divergence in the lower levels at the gap exit. The study also suggested a dynamical study, using a dynamical model, to confirm their ideas.

Asnani (1993) explained the above divergence using the familiar analogy of the venturi effect.

But venturi effect is not always the correct explanation for gap winds. Because, unlike the tube or nozzle of engineer's venturi, the mountain gap is not a fully enclosed space but a channel with an open top, that is, no rigid upper lid restricts the flow to three-dimensions.

So, it appears that there is a need to offer an explanation for the divergence at gap exit, other than venturi effect, using some dynamical model.
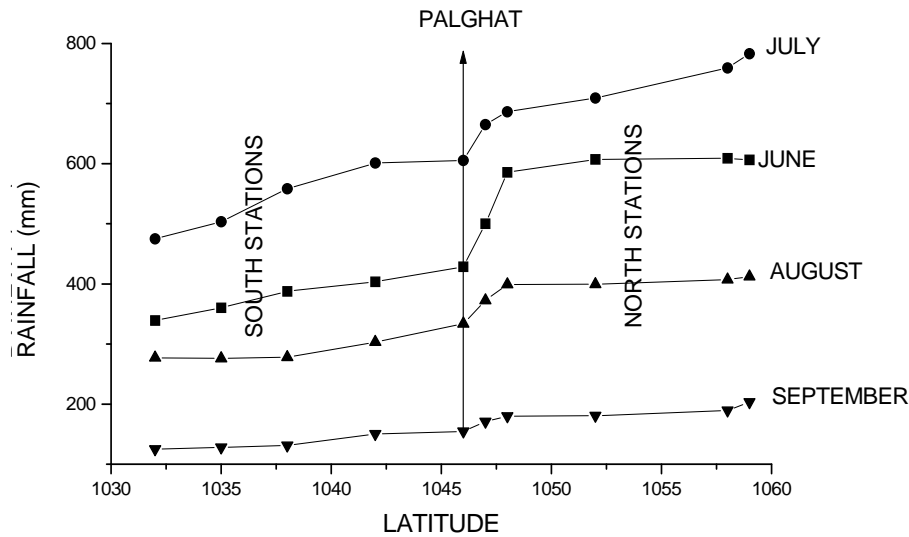
Fig. 2. Variation of rainfall with latitude at different stations during southwest monsoon season
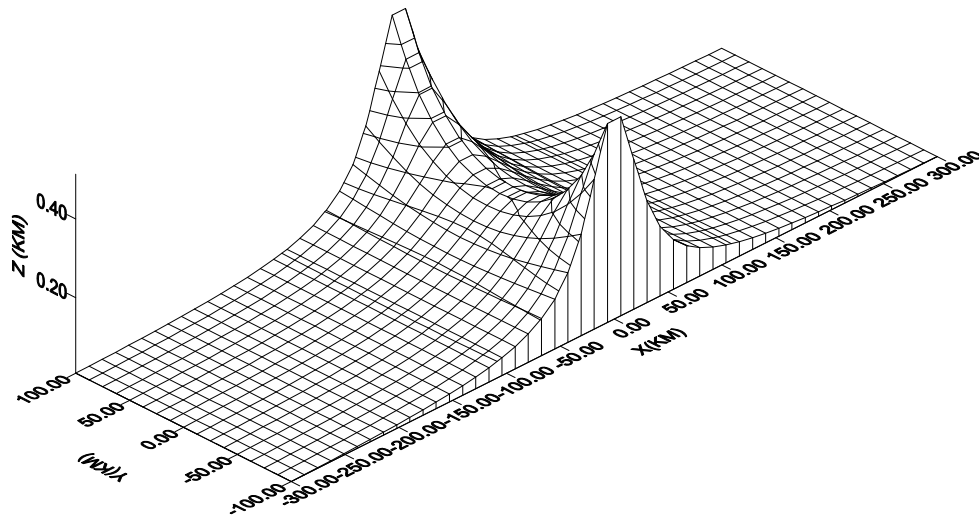

Fig. 3. Schematic representation of a gap between two meso-scale 3 dimensional elliptical barriers

Objective of the present study is to offer an explanation for the divergence at gap exit using a dynamical model for airflow over a terrain.

3. The climatological rainfall data for the months June, July, August & September, based on the period 1901-1950, for those stations, which are within a latitudinal difference of $\pm$ 0.15° & longitudinal difference of 0.2° of Palghat gap, used in the present study. The different stations, which have been considered for the present investigation, are shown in Fig. 1. The different stations with their corresponding latitudinal & longitudinal position & rainfall is given in Table 1 and is also shown in Fig. 2.

TABLE 1

Rainfall (mm) at stations north & south of Palghat gap (1901-1950)

Station name	Latitude	Longitude	Rainfall (mm)			
			June	July	August	September
Mannar-ghat	$10^0\ 59'$	$76^0\ 28'$	606.3	783.1	412.2	203.2
Perintal-manna	$10^0\ 58'$	$76^0\ 18'$	609.1	759.2	407.1	189.5
Cherpa-cheri	$10^0\ 52'$	$76^0\ 19'$	607.3	709.4	399.4	180.6
Parli	$10^0\ 48'$	$76^0\ 33'$	585.7	686.6	399	179.9
Ottapa-lam	$10^0\ 47'$	$76^0\ 23'$	500.4	675.1	372.6	170.9
↑ northward stations ↑						
Palghat	$10^0\ 46'$	$76^0\ 39'$	428.5	605.3	333.8	154.7
↓ southward stations ↓						
Chittur	$10^0\ 42'$	$76^0\ 44'$	403.5	601.1	303.1	150.2
Alattur	$10^0\ 38'$	$76^0\ 33'$	387.8	558.3	278	131.3
Vadakkan-cherry	$10^0\ 35'$	$76^0\ 26'$	360.3	503.4	276.1	128
Malaye-ttur	$10^0\ 32'$	$76^0\ 31'$	339.2	475.1	277.1	125.1

4. In the present study the mountain gap is represented by two-mesoscale three-dimensional elliptical barriers and is shown schematically in Fig. 3. It is analytically expressed as

$$h(x, y) = H\left[\frac{1}{1+(x^2/a^2)+[(y+d/2)^2/b^2]} + \frac{1}{1+(x^2/a^2)+[(y-d/2)^2/b^2]} - 1\right]$$

(1)

where,

a = Half width along W-E section = 20 km

b = Half width along N-S section = $2.5 \times a$ = 50 km

H = Maximum height of the mountain = 1 km

d = Distance between the centers of two mountains = $6.0 \times b$ = 300.0 km.

To compute the perturbation vertical velocity (w') across the above gap, we use a linear dynamical model of airflow over a mesoscale 3-D elliptical barrier (Dutta 2003, 2004). This model considers a steady state, adiabatic, Boussinesq, non rotational & laminar flow over a mesoscale 3-D elliptical barrier. For simplicity the basic flow has been assumed solely normal to the major ridge of the barrier.

Under the above assumptions the linearized governing equations, used in the model are :

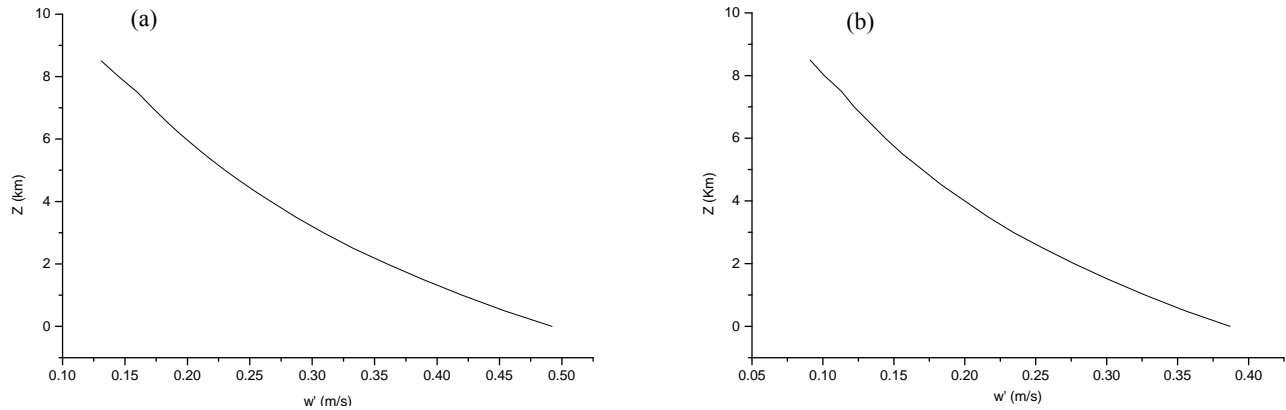$$U\ (\partial u'/\partial x) + w'\ (dU/dz) = -\ (1/\rho_o)\ (\partial p'/\partial x) \qquad (2)$$

$$U\ (\partial v'/\partial x)\ = -\ (1/\rho_0)\ (\partial p'/\partial y) \qquad (3)$$

$$U\ (\partial w'/\partial x)\ = -\ (1/\rho_0)\ (\partial p'/\partial z) + g\ (\theta'/\theta) \qquad (4)$$

$$(\partial u'/\partial x)\ + (\partial v'/\partial y) + (\partial w'/\partial z) = 0 \qquad (5)$$

$$U(\partial\theta'/\partial x)\ + w'\ (d\theta_o/dz) = 0 \qquad (6)$$

Here, $[U(z),0,0]$ is the basic flow wind, (u',v',w') is the perturbation wind, ρ_0,θ_0 are basic state density and potential temperature respectively and p',θ' are respectively the perturbation pressure and potential temperature.

Figs. 4(a&b). Vertical profile of w' (a) at $X = 35$ km and (b) at $X = 40$ km along gap axis

Then the above equations are subjected to 2-D Fourier transform & after some algebraic simplification we obtain the following vertical structure equation :

$$\frac{\partial^2 \widetilde{w}_1}{\partial z^2} + \left[\frac{N^2(k^2 + l^2)}{(Uk)^2} - \frac{1}{U}\frac{d^2 U}{dz^2} - \frac{1}{\rho_o}\frac{d\rho_o}{dz}\frac{1}{U}\frac{dU}{dz} \right.$$
$$\left. -(k^2 + l^2) + \frac{1}{4\rho_o{}^2}\left(\frac{d\rho_o}{dz}\right)^2 - \frac{1}{2\rho_o}\frac{d^2\rho_o}{dz^2} \right]\widetilde{w}_1 = 0$$

(7)

Where $\quad \widetilde{w}(k,l,z) = \sqrt{\dfrac{\rho_o(0)}{\rho_o(z)}}\,\widetilde{w}_1(k,l,z)$ (8)

and $\widetilde{w}(k,l,z)$ is the 2-D Fourier transform of $w'(x,y,z)$.

Since in south-west monsoon season westerly basic flow is neutral with respect to saturated adiabatic lapse rate (Sarker 1966, 1967), hence, in the present study, the Brunt-Vaisalla frequency is given by, $N^2 = \dfrac{g}{\overline{T}}(\Gamma_s - \Gamma_e) \approx 0$, where, $\overline{T}$ is the basic state temperature, Γ_s is saturated adiabatic lapse rate and Γ_e is the environmental lapse rate.

Eqn. (7) has been solved quasi numerically for $\hat{w}_1$ using following boundary conditions:

(*i*) At the lower boundary *i.e.*, at the surface airflow is tangential to the ground surface. So, at $z = 0$

$$w'(x,y,0) = U(0)\frac{\partial h}{\partial x}$$

Therefore $\hat{w}(k,l,0) = \hat{w}_1(k,l,0) = ikU(0)\hat{h}(k,l)$.

(*ii*) On and above the upper boundary $\widetilde{w}_1$ diminishes exponentially with height for any wave number vector *i.e.*, $\widetilde{w}_1 \propto e^{-\kappa z}$ where $\kappa = \sqrt{(k^2 + l^2)}$.

Eqn. (7) has been solved for $\widetilde{w}_1(k,l,z)$ quasi-numerically following Dutta (2004). Then, using Eqn. (8), $\widetilde{w}(k,l,z)$ is computed at each grid level and for each pair (k,l). Then using numerical 2-D inverse Fourier transformation $w'(x,y,z)$ is computed.

5.   The above methodology is then applied for westerly wind passing through Palghat gap in India during the south west monsoon season to compute $w'(x,y,z)$ at the eastern end of the gap ($x = 20$ km, 30 km) along the gap axis.

From equation (5) it is clear that at any point perturbation horizontal divergence (D$_H$) is given by

$$D_H = (\partial u'/\partial x) + (\partial v'/\partial y) = -\frac{\partial w'}{\partial z}.$$ Thus at any

point there is perturbation horizontal divergence if w' decreases with height.

The vertical profiles of $w'(x,y,z)$, at the eastern end of the gap axis are shown in Figs. 4(a&b).

From the figures it is clear that at x = 35 km and x = 40 km w' decreases with height. Hence there is perturbation horizontal divergence at the eastern end (gap exit). This divergence may cause a cyclonic turning/anti cyclonic turning of the stream lines to the north/ south of the gap axis near its exit.

6. From the foregoing study we come to the following conclusions.

(*i*) The dynamical model shows that perturbation vertical velocity decreases with height at the gap exit.

(*ii*) This in turn causes a perturbation horizontal divergence at the gap exit. This divergence in-turn may cause a cyclonic/anti-cyclonic turning of the streamlines to the north/south of the gap axis at the exit.

(*iii*) The observed difference in the mean seasonal rainfall during SWMS to the north and south of the Palghat gap may be attributed to the above.

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