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Conversion Characteristics between Barotropic and Baroclinic Circulations of the SAH in Its Seasonal Evolution①

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ABSTRACT

In the context of 1958–1997 NCEP / NCAR re–analyses, the South Asia high (SAH) was divided into two components, barotropic and baroclinic, the former based on mass weighed vertical integration and the latter on the difference between the measured circulation and the barotropic component counterpart, whereupon the barotropic and baroclinic circulation conversion features were addressed of the research SAH during its seasonal variation. Evidence suggests that i) in summer (winter), the SAH is a thermal (dynamical) system, with dominant baroclinicity (barotropicity), either of the components accounting for approximately 70% of the total contribution; ii) as time progresses from winter to summer, accompanied by the barotropic SAH evolving into its baroclinic analog, the SAH is moving under the "thermal guidance" of its baroclinic component circulation, suggesting that the component circulation precedes the system itself in variation; iii) the reversal happens when it goes from summer to winter, with the SAH displacement under the "dynamic steering" of its barotropic component circulation.

Key words: SAH (South Asia high), Barotropic circulation, Baroclinic circulation, Seasonal variation

1. Introduction

The SAH is of such importance in the variation of northern atmospheric circulations as time goes from winter to summer that its arrival at the Tibetan plateau represents one of the marks of the establishment of summer circulation pattern in eastern Asia. Many studies have shown that the summer SAH is a thermal high with rising motion over the mean fields (see, e. g., Yeh et al., 1957; Tao et al., 1964; Flohn, 1968; Yeh, Gao et. al., 1979; Zhang et al., 1988), in whose genesis the plateau heating plays a crucial role, leading to great difference in its structure from the subtropical high. It is well–known that the SAH center shifts noticeably on a seasonal basis (Zhu et al., 1980; Sun, 1984) in such a way that it is to the east of the Philippines in April, travelling westward into the north of the Indo–China peninsula in May, reaching the Tibetan highland in June, and further westward in July. While migrating in this direction, the SAH has its property subjected to change in such a manner that in winter, both the SAH and the western Pacific subtropical high are categorized into a dynamic type over the ocean, and with the march into summer the SAH becomes a thermal type when reaching the plateau. Zhu, Song et al. (1984) asserted that the SAH transformation is the result both of thermal and dynamical effects of the highland.

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Because of data limitation, previous writers generally focused on a case study only for a particular year, leaving details of the SAH seasonal transformation untouched. Additionally, in view of different schemes adopted by different authors in the calculation of dynamical and thermal effects of the plateau, no proportion of dynamic and thermal components of the SAH in the total contribution has been revealed on a seasonal basis.

In terms of 1958–1997 NCEP/ NCAR re–analyses and the method for separating an atmospheric circulation in vertical into a barotropic and a baroclinic component circulation, investigation was made of the SAH barotropic–baroclinic circulation conversion characteristics in its seasonal variation with the percentage of each component presented.

2. Data and method

2.1 *Data*

The data used consist of 1958–1997 NCEP/ NCAR re–analyses of global wind, geopotential height and temperature on a monthly basis (Kalnay et al., 1996) at a 2.5° × 2.5° resolution with such levels in vertical as 1000, 925, 850, 700, 600, 500, 400, 300, 250, 200, 150 and 100 hPa.

2.2 *Method*

In the light of vertical decomposition of an atmospheric circulation (Peixoto and Oort, 1995), the measured 100 hPa wind $\vec{V}$ is divided into $\vec{V}_T$ and $\vec{V}_C$, namely,

$$\vec{V} = \vec{V}_T + \vec{V}_C \ , \tag{1}$$

where

$$\vec{V}_T = (P_S - P_T)^{-1} \int_{P_T}^{P_S} \vec{V} dP \ , \tag{2}$$

and we get

$$\vec{V}_C = \vec{V} - \vec{V}_T \ , \tag{3}$$

in which P_S signifies the surface pressure, P_T the 100 hPa pressure, $\vec{V}_T$ the mass–weighed wind averaged vertically from P_S to P_T to denote the height–invariable part of the realistic wind in the troposphere. We shall refer to $\vec{V}_T$ ($\vec{V}_C$) as a barotropic (baroclinic) component. $\vec{V}_C$ is not only a component of the 100 hPa observed flowfield but the wind vectorial difference between the 100 hPa and mean (barotropic) layer, suggestive of the baroclinicity of the flowfield between the two layers. Then, from the thermal wind relation, the center of 100 hPa baroclinic cyclonic (anticyclonic) circulation corresponds roughly to a cold (warm) center in the upper troposphere.

3. Seasonality of the barotropic changing into/ from the baroclinic component circulation

3.1 *For winter progressing into summer*

A 100 hPa anticyclonic center is located to the east of the Philippines in January to March (figures not shown) and its barotropic circulation shows an anticyclonic closed center

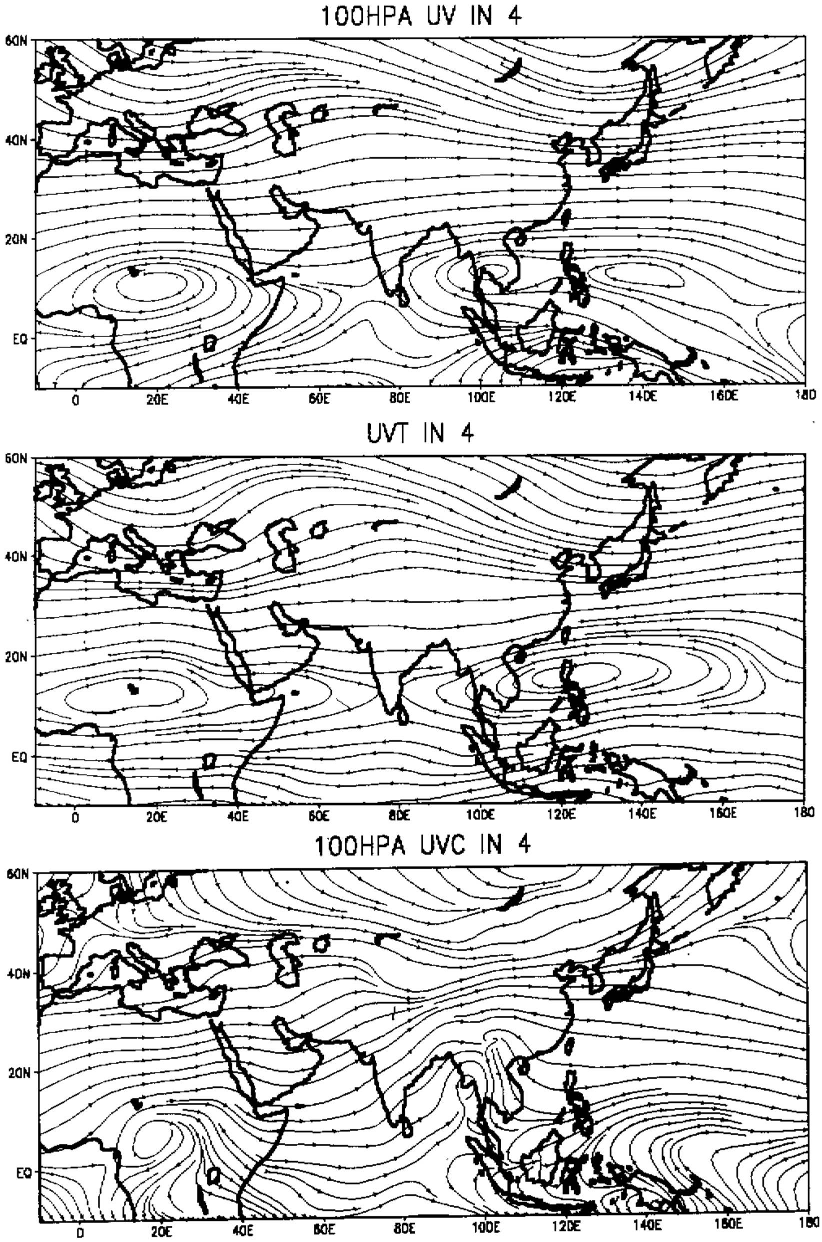

Fig. 1. The measured flowfield (a), barotropic component flowfield, (b) and baroclinic flowfield, (c) at 100 hPa in April.

to the west of the anticyclonic center in the measured flowfield, in contrast to only an anticyclonic circulation with no closed center over the realistic stream field.

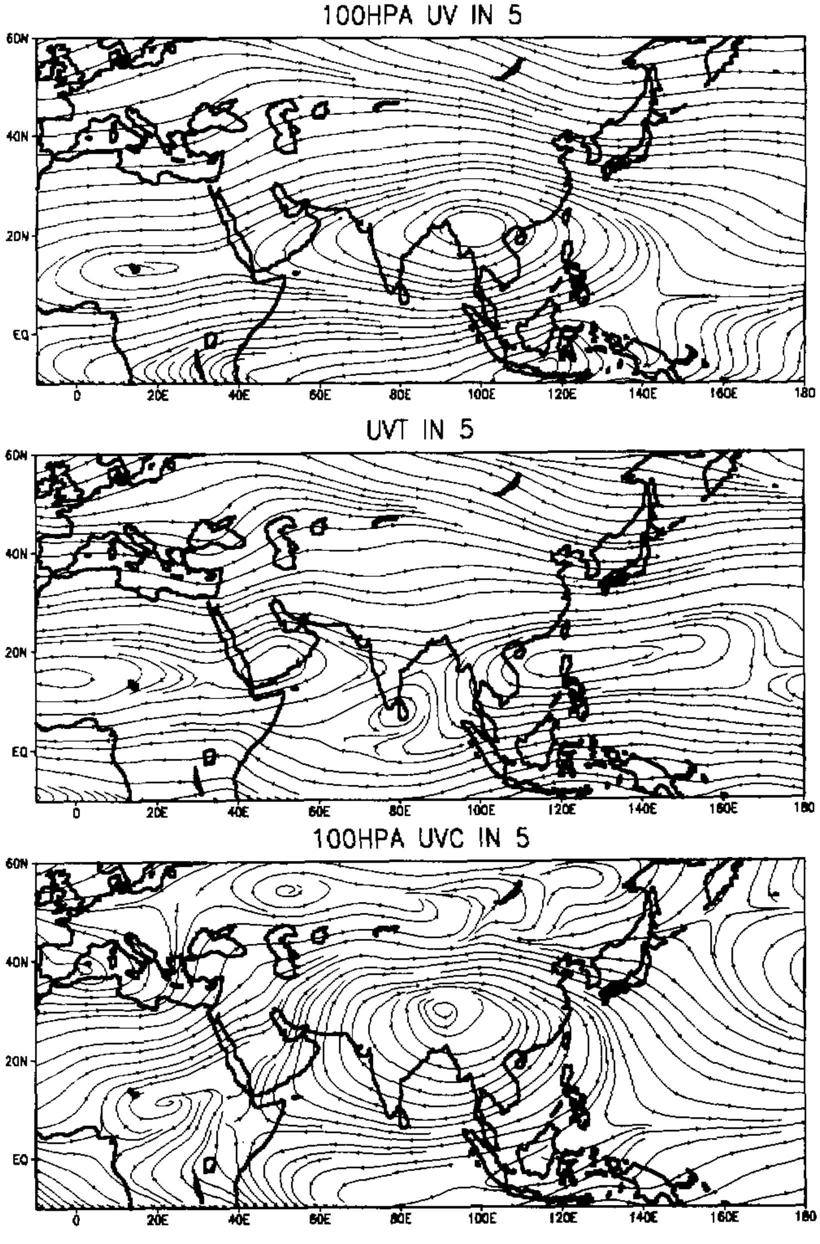

Fig. 2. As in Fig. 1 except for May.

Fig. 1 depicts the observed wind, plots of barotropic / baroclinic flowfields in April. One sees from Fig. 1a that the SAH is separated into two closed centers, one remaining to the east of the Philippines but with a little westward displacement compared to its position in March and the other situated in the south of the Indo–China peninsula. This situation differs more or less from those offered by previous authors who held that the SAH gets to the peninsula in May, which is likely to relate to the utilization of different data. Needless to say, our present data are superior to those adopted previously as regards record length, resolution and quality (See, again, Kalnay et al., 1996) so that our conclusion on the time the SAH arrives in the Indo–China is quite believable.

As a plot of the barotropic flowfield for April, Fig. 1b shows that one anticyclonic center is over the Philippines during westward migration but no closed centers appear in the south Indo–China peninsula. Fig. 1c (for the baroclinic flowfield) illustrates that an anticyclonic center is off the western shore of the south Indo–China, corresponding to a warm center in the upper troposphere. As such, the Indo–China center of the SAH in this month is caused mainly by its baroclinic component circulation, i. e., the SAH arrival at the peninsula in April bears a relation to upper tropospheric warming over the region. In their Tbb investigation, Zhu et al. (1996) revealed that the Indo–China convection is initiated as early as April. Hence, *the convection–related warming is most likely to be associated with convection initiation* and thus latent heat release over the peninsula in the month.

Fig. 2 presents that in May, the SAH center is in the north peninsula during which time tropical easterly has been established and the atmospheric circulation pattern at upper levels has turned into a summer type with no substantial alteration of the barotropic component flowfield over East Asia except for a smaller–size closed cyclonic circulation at the tip of the Indian peninsula and an anticyclonic center of the baroclinic circulation resides over the Tibetan highland that covers greater part of South Asia than in April. Obviously, the SAH anticyclonic circulation is caused dominantly by its baroclinic component circulation. It follows that with the SAH evolving into its summer pattern, the effect of its barotropic circulation is becoming successively weak as opposed to that of the baroclinic counterpart.

As shown in Fig. 3 for the situation of June, the SAH center is now over the Tibetan plateau and the anticyclonic circulation covers almost whole South Asia; the barotropic anticyclonic center, originally around the Philippines, makes east– and then northward march, and concurrently, the Indian peninsula as a whole is under the influence of the anticyclonic circulation at which time the baroclinic circulation center makes further northerly shift, expanding its size to such extent that Asia is under the control of the anticyclonic circulation.

Interestingly, the center of the SAH in June well corresponds to that of the baroclinic center in May, i.e., the latter has its change in position ahead of the former; it seems that the SAH moves under the "guidance" of thermal effect of the baroclinic flowfield, and, in other words, the SAH is "thermophilic" in its behaviors.

Fig. 4 depicts that in July the SAH has two centers, the western one being over the Iranian highland and the eastern one located at the baroclinic anticyclonic center of June, displaying again the "thermophilic". On the other hand, from the plot of the barotropic circulation we see two centers that correspond to those of the SAH on one–to–one basis except for greater distance between them. The baroclinic anticyclonic center is between the SAH's ones. It is noted that the baroclinic circulation is vigorous in sharp contrast to the barotropic counterpart. Therefore, the SAH anticyclonic circulation depends predominantly on the baroclinic component. But in August (figure not shown), the two centers of the SAH have merged into one over the Tibetan plateau, other characteristics being much the same as in July.

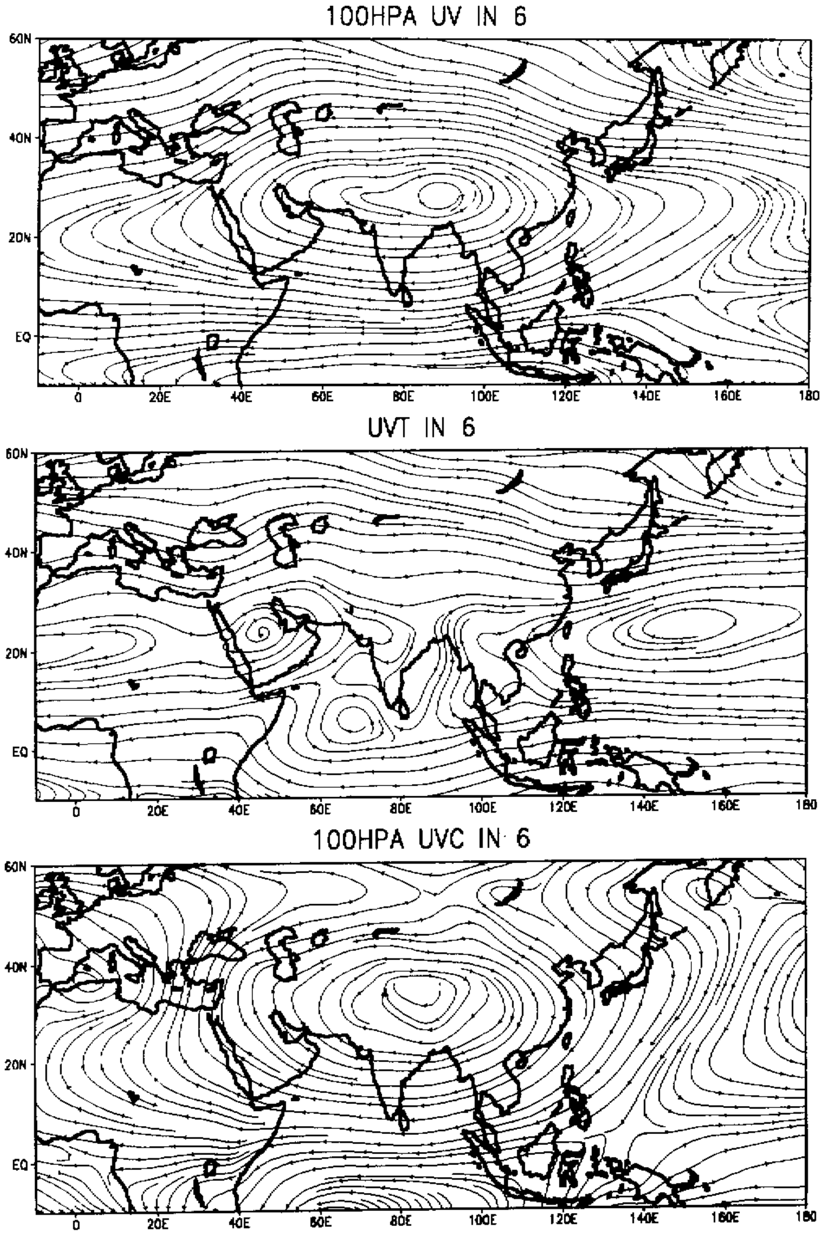

Fig. 3. The same as in Fig. 1 but for June.

3.2 *For summer to winter*

The SAH starts in September its change in character from summer to winter. As we see

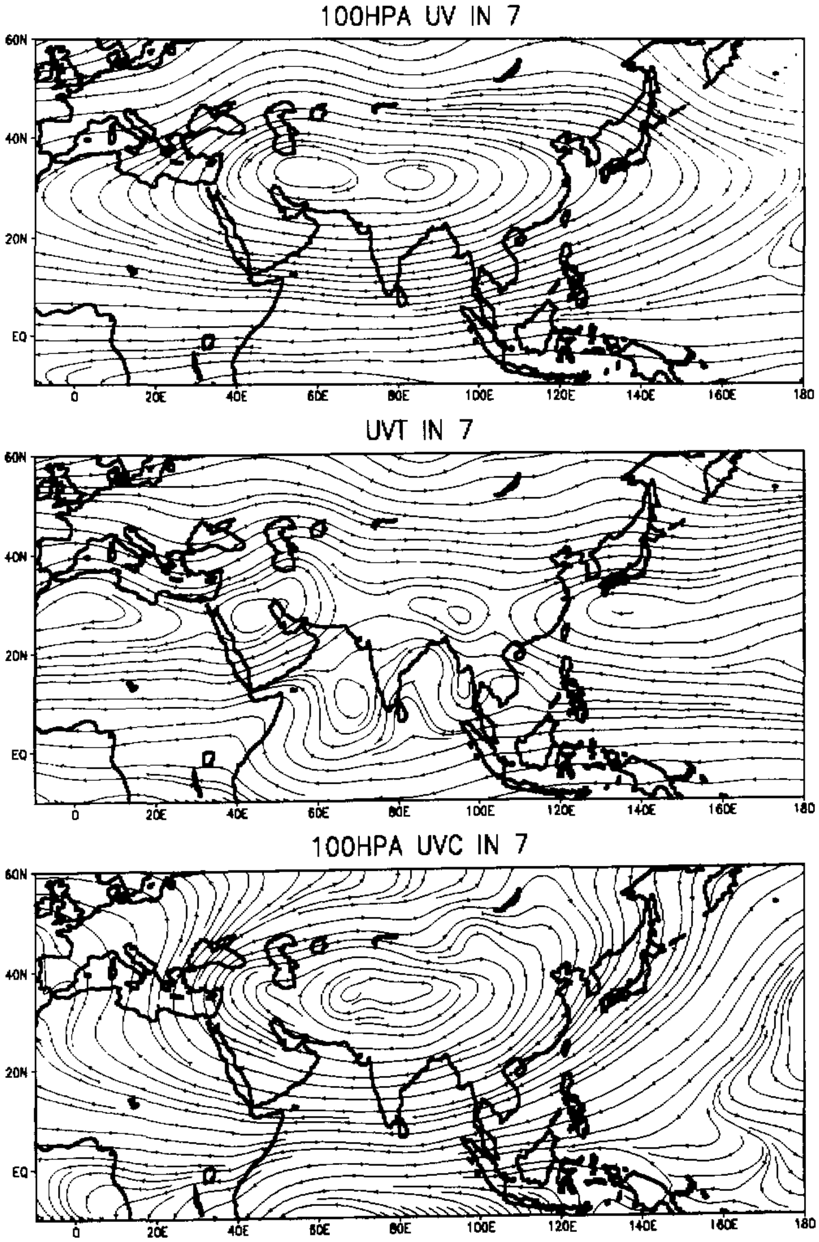

Fig. 4. As in Fig. 1 but for July.

from Fig. 5, 1) the SAH has its center retreating southward as far as to the south of the Tibetan plateau and north of the Bay of Bengal where the barotropic anticyclonic center is located in August, suggesting that the barotropic flowfield experiences change ahead and the

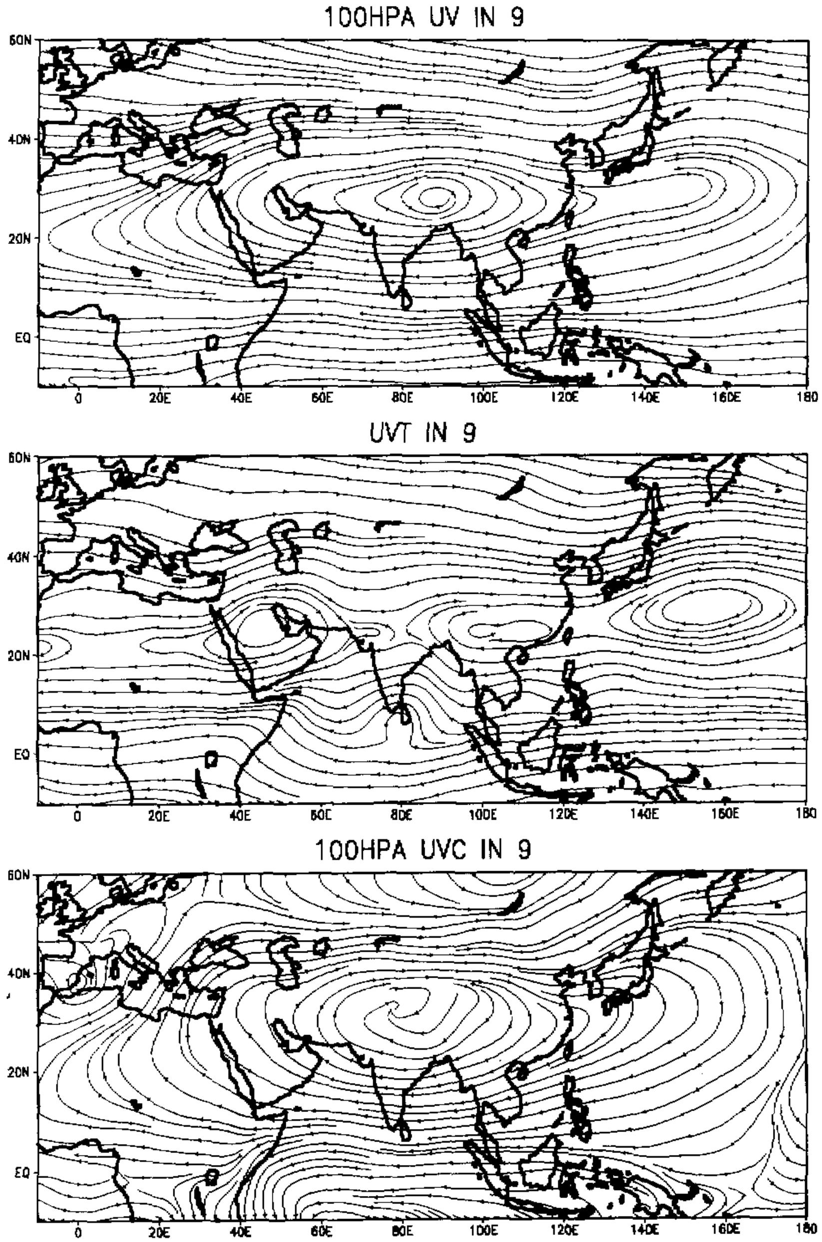

Fig. 5. As in Fig. 1 except for September.

SAH moves east– and withdraws southward possibly under the "guidance" of dynamic effect of the barotropic circulation; 2) the barotropic anticyclonic circulation begins intensification, making its center shift east– and retrogresses southward; the anticyclonic center, situated in the north of the Bay of Bengal in August, moves eastward as far as to the northern Indo–China, Southwest and South China; the anticyclonic center, anchored in August to the southeast of Japan, displaces southeast and gets enhanced; 3) the baroclinic anticyclonic circulation commences to reduce in vigor with little migration of its center. It follows that as the SAH changes in character from a summer into a winter type, effect of its barotropic component is growing progressively, as opposed to that of the baroclinic component.

The SAH's main body has returned to the ocean in October (figure omitted) except that a strong anticyclonic circulation remains in the northern Indo–China peninsula without a closed center; the barotropic circulation has two anticyclonic centers, one in the northern peninsula and the other over the sea; the baroclinic circulation is southward of its former position and its coverage has been decreased.

From the foregoing analysis we come to the following: 1) in the seasonal evolution of the SAH, its barotropic and baroclinic circulation components experience the inter–conversion in such a way that as the time goes from winter to summer, dominant barotropicity is yielding its prevalence to baroclinicity for the system, and v.v., thereby forming a seasonal cycle; 2) from winter to summer (summer to winter) the anticyclonic center of its baroclinic (barotropic) component circulation has its change ahead of the SAH's center, meaning its motion under the thermal (dynamic) "steering" of the baroclinicity (barotropicity).

4. Calculation of relative contribution of both component circulations

We have examined qualitatively the conversion features of the barotropic and baroclinic circulations during the SAH evolution on a seasonal basis. Now we proceed to deal with the calculation of respective proportion of both components in total contribution.

The SAH is a planetary–scale anticyclonic circulation system so that we are allowed to define its strength through the agency of vorticity. From (1) we find

$$\zeta = \zeta_T + \zeta_C \ , \tag{4}$$

which is rewritten as

$$(\zeta_T / \zeta) + (\zeta_C / \zeta) = 1 \ , \tag{5}$$

in which ζ stands for the vertical vorticity of a measured windfield, and $\zeta_T(\zeta_C)$ of a barotropic (baroclinic) flowfield.

We have tabulated the coverage of the SAH on a monthly basis by virtue of its center's locality and size (Table 1). The monthly regional mean vorticities ζ and ζ_C are calculated to represent the intensities of the SAH and baroclinic component, respectively. Fig. 6 shows the seasonal variation for the ratio of ζ_C to ζ.

Table 1. Geographic coverage taken for the SAH on a monthly basis in 1958–1997

Jan.	Feb.	Mar.	Apr.	May	Jun.
150°E–180°	160°E–170°W	155°E–175°W	150–180°E	85–115°E	75–105°E
5–25°N	2.5–22.5°N	5–25°N	2.5–22.5°N	10–30°N	17.5–37.5°N
July	Aug.	Sept.	Oct.	Nov.	Dec.
70–100°E	67.5–97.5°E	72.5–102.5°E	87.5–117.5°E	132.5–162.5°E	145–175°E
20–40°N	22.5–42.5°N	17.5–37.5°N	12.5–32.5°N	10–30°N	7.5–27.5°N

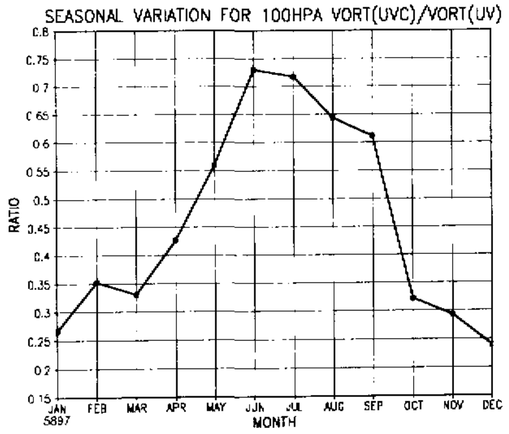

Fig. 6. Seasonal variation in ζ_C / ζ at 100 hPa (refer to text).

It is seen therefrom that the seasonal variation of the ratio is quite obvious in that 1) in winter the baroclinic component forms a smaller proportion on the order of 30% in contrast to some 70% of the barotropic counterpart; 2) in summer, the reversal occurs; 3) in spring the proportion of the baroclinic component grows rapidly from less than 45% in April to more than 55% in May, exceeding the part of the barotropic component; 4) in autumn the proportion of the baroclinicity drops sharply from approximately 60% to 30% in September to October.

Evidently, it is difficult to distinguish the thermal from the dynamic effect of an atmospheric system because both are closely interweaved. As such, the quantitative results presented here are considered only as approximate calculations for the relative contribution of thermal and dynamic effect of the SAH.

5. Concluding remarks

Based on the above discussion we come to the following.

(1) The SAH's barotropicity and baroclinicity are interconverted in its season evolution. In winter, barotropicity-dominanted, the system is dynamical in nature over the ocean. When it gets over the southern Indo-China in April, its baroclinicity begins increase as the barotropicity decreases till summer. Then the SAH grows into a thermal system, dominated by baroclinicity. When autumn sets in, the baroclinicity (barotropicity) is reducing (growing). This constitutes a seasonal cycle.

(2) In the evolution from winter to summer the SAH displays a thermophilic tendency, namely, the baroclinic component circulation experiences alteration ahead of the SAH itself, and the high under research seems to migrate under the thermal "guidance" of the baroclinic circulation whereas it travels under the dynamic "steering" of the barotropic circulation as the season goes from summer to winter.

(3) Calculations show that in winter the SAH barotropicity (baroclinicity) accounts for roughly 70% (30%) and the figures are reversed in summer.

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REFERENCES

Flohn, H., 1968: Atmospheric Scientific Paper, No. 130, Colorado State University, 120.

Kalnay, E. et al., 1996: The NCEP / NCAR 40–year Reanalysis Project, *Bulletin of the American Meteorological Society*, 77(3), 437–471.

Peixoto, J. P., and A. H. Oort., 1995: *Physics of Climate* (its Chinese version translated and corrected by Wu Guoxiong, Liu Hui et al.), 47–50, China Meteorological Press, Beijing (in Chinese).

Sun Guowu et al., 1984: Research of the seasonal variation in South Asian high, in *Symposium on Tibetan Plateau Meteorological Experiment* (2), Science Press, Beijing (in Chinese).

Tao Shiyan, and Zhu Fukang, 1964: Variation in 100 hPa summer flow pattern in South Asia in relation to pro– and retrogress of the western Pacific subtropical high. *Acta Meteorologica Sinica*, **34**, 385–395 (in Chinese).

Yeh Tu–cheng, Luo Siwei, and Zhu Baozhen, 1957: On flow pattern and tropospheric thermal balance over the Tibetan plateau and its vicinity. *Acta Meteorologica Sinica*, **28**, 108–121 (in Chinese).

Yeh Tu–cheng, Gao Youxi et al., 1979: *Tibetan Plateau Meteorology* (see Chapter 10), Science Press, Beijing (in Chinese).

Zhang Jijia, Zhu Baozhen et al., 1988: *Advances in Tibetan Plateau Meteorology* (see Chapter 7), Science Press, Beijing (in Chinese).

Zhu Fukang et al., 1980: *On South Asia High*, Science Press, Beijing (in Chinese).

Zhu Baozhen and Song Zhengshan, 1984: Qinghai–Tibetan high's genesis and its periodic oscillation–analysis of observational facts, in *Symposium on Tibetan Plateau Meteorological Experiment* (*1*), 303–313, Science Press, Beijing (in Chinese).

Zhu Qiangen, He Jinhai, and M. Murakami, 1996: T_{bb} revealed seasonal cycle of Asian–Australian monsoon with interannual anomaly, *J. Appl. Meteor.*, **7**, 129–139 (in Chinese).