On the Structure of Medium-Scale Depressions over the East China Sea during AMTEX '75

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Abstract

From the analysis of three medium-scale depressions which formed over the East China Sea during the AMTEX '75, the following characteristic features were drawn: (1) The medium-scale depression was a shallow disturbance with a warm core below 700 mb. (2) The depression was thought to generate over the East China Sea. The sea-level cyclogenesis, however, commenced when a pre-existing cyclonic vortex at about 850 mb moved over the sea from the continent. (3) The intensification of the system was largest in the lowest layer, and the deepening rapidly decreased with height. (4) The depression formed in the large-scale frontal zone. The above-mentioned features suggested warming in the lowest layer was a primary factor for formation of sea-level medium-scale depression. Heat balances in the three layers between 1000 mb and 500 mb were evaluated by using the equation of thickness tendency. The result of evaluation showed the following three simultaneous dynamical processes were responsible for the formation: (1) warm air advection; (2) upward motion and small adiabatic cooling; (3) apparent heat source in the lowest layer. Sometimes such a shallow system seemed to develop into a strong cyclone. This was attributed to development of a synoptic-scale disturbance rather than to self-development of a medium-scale low.

1. Introduction

Three medium-scale depressions over the East China Sea during AMTEX '75 are discussed in the present paper. As to the definition or nomenclature of small-scale cyclone, there are certain variations. The criteria used in the selection of the three examples was as follows:

(1) A low pressure system characterized on a conventional weather map by at least a closed isobar is selected.

(2) The size of a system is between 500 km and 1,000 km.

(3) A system has a life time of one day or longer.

(4) The vertical extent of a system is more than 1 km.

A detailed introductory review on the studies of medium-scale disturbance has been given by Yoshizumi (1976). The present author would add a short comment. Many Japanese studies of medium-scale disturbance focused attention on convective activity or precipitation associated with the disturbance. Although such weather phenomena are important factors for revealing the character of medium-scale depression, the present...
paper will be particularly concerned with the structure of medium-scale pressure field and its time-variations. This kind of approach was adopted by T. Nitta and Yamamoto (1974) and Nitta, Ts., Nambu and Yoshizaki (1973). The both papers discussed the depressions over the East China Sea where the frequency of cyclogenesis is pronounced in the winter season. AMTEX* special observation was carried out on this particular area during the months of February in 1974 and 1975. The purpose of this paper is to present the structure of the three depressions and to explore factors for the formation of such a disturbance. The two depressions had no significant development and the other one was involved in the development of large-scale disturbance. Therefore a comparative analysis between the developed depression and the non-developed depression was able to be presented. Fig. 1 shows the geographical chart of the East China Sea and the domain of analysis.

2. Synoptic situations

On 27 February, 1975, a medium-scale depression formed in the cold frontal trough approaching the East China Sea (see chart in Fig. 2). This low had no significant development and decayed out off Shikoku island after two days. This low is referred to as ML1 in the following discussion. The chart in Fig. 4 is for the night of 2 March and a medium-scale depression seemed to generate over the AMTEX area. By careful analysis, however, we can trace back its origin over the China continent. We should say the sea-level closed isobar was recognized for the first time over the AMTEX area. The low moved eastwards and gradually decayed. This system will be referred to as ML3. The conventional weather charts for another medium-scale depression are shown in Fig. 3. A wave depression formed to the north east of Taiwan on the night of 13th February. This wave rapidly developed in the next morning (see second chart in Fig. 3). It is doubtful, however, to conclude that the Taiwan low became the developed cyclone. This will be discussed in a later section. The last example will be called ML2 in this text. The 12-hr changes in central pressures of the three depressions are shown in Fig. 5. The ordinate of the graph is the amount of 12-hr change in the height of isobaric surface at the center of system. The development of the depressions ML1 and ML3 was the order of 10 m/12-hr at 1000 mb. On the contrary we found no significant change in

ML1 09 JST 27 FEB. 1975

Fig. 2 Sea-level weather chart for 09JST 27 February, 1975.

* Air-Mass Transformation Experiment, a GARP sub-programme.
the height of 850 mb at the center of system. The development of ML2 was the largest, and at 850 mb, the development slowed down to more than half of the one at 1000 mb. The three systems developed mainly in the lowest layer. This seems to be one of characteristic features of the medium-scale lows. This magnitude of development in the three cases is the almost same order
3. Structure of ML1

A time-height section at Naha during the passage of the low ML1 showed warm air and low static stability in the lower layer around 15JST 27 February (Fig. 6). The winds in the section represent winds relative to the moving velocity of the system. Therefore, the minimum wind level around the 700 mb level was a steering level. Above the steering level, the steady westerlies and high static stability persisted. The horizontal configuration of ML1 is shown in Figs. 7(a) and 7(b). The heights and air-temperatures in Fig. 7 represent abnormal values from the areal averages over the AMTEX area. The air temperatures in the low pressure area at lower levels were apparently warmer. At the higher levels, the height contours changed into zonal, and the amplitude of temperature wave also became small. The system ML1 was a shallow warm type disturbance below 700 mb. The air-temperatures and heights in Figs. 6 and 7 were corrected for diurnal variations by using the AMTEX special observation data in the two years.
Fig. 6  Time-height section of thermal stratification and wind at Naha. Thick solid lines are isopleths of potential temperature at 2°K interval. Dashed lines are isopleths of static stability in units of 10^{-2} \text{ m}^2 \text{ sec}^{-2} \text{ mb}^{-2}. Wind symbol represents wind relative to the system, a full barb corresponding to 5 m/s. Here speed of system is 12 m/s.

Fig. 7(a)  Isobaric charts in the lower atmosphere for 09JST, 27 February, 1975. Full lines and dashed lines are height contours (meters) and isotherms (°C) respectively. The values of height and temperature are anomalies from the mean values averaged over the AMTEX area.
4. Structure of ML2 and ML3

For ML2 and ML3, only the 12-hourly routine aerological data are available. In order to get smaller-scale features, analyzed height field was decomposed into medium-scale and synoptic-scale components through spatial smoothing. Fig. 8 shows the response function of the two-dimensional filtering operator used in separating the original field into the two parts. The smoothed field was assumed to represent the synoptic-scale field. The medium-scale field was obtained by subtracting the smoothed field from the original field. In this paper the smaller-scale field was used to represent the features of medium-scale disturbances. The sequence of medium-scale height fields at 1000 mb and 850 mb is shown in Figs. 9 and 10. The charts in Fig. 9 show the pressure fields before appearance of a sea-level depression over the East China Sea. On 1 March, a low pressure area already appeared in the central part of China and moved eastwards. In conventional analysis this medium-scale system over the continent was masked by synoptic-scale pressure gradient. The structure and vertical extent of the pressure systems was presented by making the vertical sections through the southern AMTEX region as shown in the right hand side of Fig. 9. The sections show that the disturbances were confined to below 700 mb, and the air temperatures in the low-level depression were warmer and the ones in the low-level high pressure, cold. There were some medium-scale disturbances at higher levels. However, they had no direct connection with the disturbances at lower levels. The medium-scale pressure fields for 00GMT and 12GMT, 2 March are shown in Fig. 10. The low-pressure at 850 mb moved to the AMTEX area without significant changes in intensity and extent. On the other hand, the low-pressure at 1000 mb slightly changed and finally intensified over the AMTEX area at 12GMT 2 March. The section for 12GMT shows the intensified depression hav-
Fig. 9  Left: height patterns representing the medium-scale disturbances at 1000 mb surface (full lines) and 850 mb surface (dashed lines). Units are meters. Areas of negative deviation at 1000 mb are stippled. Upper chart is for 00GMT 1 May, 1975 and lower chart for 12GMT 1 May, 1975. Right: vertical cross-section through the southern part of the AMTEX area. Full lines are profiles of medium-scale height disturbance (in units of meter) and dashed lines are profiles of medium-scale temperature disturbance (°C). Upper section is for 00GMT 1 May, 1975 and lower section for 12GMT 1 May. Areas of positive temperature are stippled.

Fig. 10  Same as Fig. 9 except for 00GMT 2 March, 1975 and 12GMT 2 March, 1975.
ing a warm core below 700 mb. From this analysis, it is inferred that the intensification of depression at sea-level was related to warming in the lowest layer.

Next we examine the case of ML2. In this case also the medium-scale pressure field revealed moving low-pressure systems over the continent before the sea-level cyclogenesis commenced on the East China Sea (see Fig. 11). At 12GMT on the 13th two medium-scale low-pressures were located—one on the lower Yangtze valley and another near Taiwan (see lower chart in Fig. 11). The system near Taiwan was warm and confined to below 850 mb, and the other was deep, and air

![Fig. 11 Same as Fig. 9 except for 00GMT 13 February, 1975 and 12GMT 13 February.](image1)

![Fig. 12 Same as Fig. 9 except for 00GMT 14 February, 1975 and 12GMT 14 February.](image2)
temperatures in the lower half part were colder (see lower cross-section in Fig. 11).

In the conventional weather chart for 15 GMT 13 February, the Taiwan low was analyzed, and another low-pressure area was located on the lower Yangtze valley. Low cloud coverage and precipitation extended from the Yangtze valley to the East China Sea. The DMSP IR picture at 1631 GMT 13 February revealed the wide extension of low-temperature cloud shield from the Yangtze valley to the AMTEX area and high-temperature cloud coverage over Taiwan and the adjacent seas. The two different cloud systems support our analysis shown in the cross-section in Fig. 11. The chart for 00 GMT 14 February shows the medium-scale disturbances in the developing cyclone. The cross-section clearly shows the complex; it consists of a warm type trough and a cold type trough (Fig. 12).

5. Barometric tendencies in synoptic-scale and meso-scale fields

In the previous sections we examined the barometric and thermal structures of medium-scale depressions. ML1 and ML3 intensified as shown in Fig. 5. Their sizes, however, had no significant changes. On the other hand, ML2 seemed to develop into a severe cyclone. Is the severe cyclone on 14 February a result of self-development of the Taiwan wave low or a manifestation of developing of synoptic-scale pressure system? The sequence of medium-scale pressure fields showed that ML2 and ML3 were intensified particularly in the lowest level after their movement to the East China Sea from the China continent. Is this initiation of intensification connected with the change in synoptic-scale field?

To make a synoptic investigation into these problems, barometric tendencies in medium-scale and synoptic-scale fields were analyzed. Vertical distributions of the pressure tendencies will be helpful to considering mutual relations between the pressure changes at higher levels and the sea-level pressure change. Although an individual change of each pressure system is not represented by the barometric tendency field which is a pattern of local height change during 12-hr period, yet the evolution of system may be approximately followed by the sequence of pressure tendencies.

(a) ML3

Fig. 13 shows the chart of the 12-hr height tendencies of four isobaric surfaces during the period from 00 GMT to 12 GMT on 2 March. At the 1000 mb surface, the negative area associated with ML3 was inbedded in a synoptic-scale pressure falling area. The pressure falling areas in the
both components were narrow and rapidly decreased with height. The synoptic-scale tendency turned into a wide pressure rising area at 500 mb. Except the 500 mb level, the differences between the pressure-height tendencies of the both scales were hardly significant. It may be concluded that the intensification of ML3 was confined to the lower layer, and there was no synoptic-scale disturbance which had remarkable influences on ML3 until 12GMT 2 March.

(b) ML2
During the period from 00GMT to 12GMT
on 13 February a medium-scale negative tendency area at 1000 mb extended from the lower Yangtze to Taiwan (Fig. 14). This disturbance was enclosed in a wide and intense synoptic-scale pressure falling area. The latter extended to 500 mb with westward tilting. This pressure fall suggests approach of a large-scale developing trough. Another noteworthy feature was the rapid decrease of the medium-scale negative area over Taiwan with height; the wave cyclone was a shallow and warm type disturbance. On the contrary, the medium-scale pressure falling area over the lower Yangtze extended to 700 mb. The differences in structure and cloud system between the two disturbances were mentioned in Section 4.

The next 12-hr height tendencies showed the intense development of the synoptic-scale deep trough (Fig. 15). This large and extensive pressure fall was a great difference from the case of ML3. The intensification of ML2 was attributed to the development of large-scale pressure disturbance rather than the self-development of the Taiwan low. The medium-scale depressions near Taiwan and over the lower Yangtze were involved into the evolution of a large-scale pressure system.

6. Baroclinicity

The thermal field of ML1 showed a typical frontal wave-pattern as presented in Fig. 7. ML2 at the initial state (i.e., the Taiwan low) and ML3 were shallow warm core disturbances. The latter two depressions also formed not in a warmer air-mass but in a frontal zone as shown in the following. Fig. 16 shows horizontal gradients of synoptic-scale temperature fields in the lower layers. On 2 March, the concentration of baroclinicity decayed with height. On the other hand, the frontal zone on 13 February was distinct up to 700 mb. Since the synoptic-scale frontal zones were found at the map-times previous to the formation of the medium-scale depressions, it is clear that ML2 and ML3 formed in a synoptic-scale frontal zone. Consequently the three medium-scale depressions were frontal waves. Although the development of ML1 and ML3 were weak, according to the category presented by Petterssen and Smeybe (1971), the three depressions may be classified into Type A. At its developing stage only ML2 has a characteristics of Type B, because the development commenced when a pre-existing upper trough spreaded over the low-level system as discussed in Section 5. Therefore ML2 is a case of mixed Type. Results of static stability analysis showed that low static stability area was confined to the lower layer below 700 mb in the cases of ML3 and ML1, whereas in the central

Fig. 16 Distribution of horizontal temperature gradients in the two layers (1000 mb-850 mb) and (850 mb-700 mb), in units of °C/111 km. Full lines are for the lower layer and dashed lines, for the upper layer.
part of ML2 at developing stage, the region of low static stability extended from the surface up to 500 mb.

7. Characteristic features of the medium-scale depressions over the East China Sea

From the results of analysis presented in the foregoing sections, the common features of the medium-scale depressions may be summarized into the following four points:

(1) The medium-scale depression was a shallow disturbance with a warm core below 700 mb.

(2) The depression was generally thought to generate over the East China Sea. The sea-level cyclogenesis, however, commenced when a pre-existing cyclonic vortex at low level (around 850 mb) moved over the sea. In other words the lowest part of a shallow cyclonic system was intensified over the sea. In the continent, sometimes, the system was masked by the synoptic-scale pressure gradient.

(3) The intensification of the system was largest in the lowest layer, and the deepening rapidly decreased with height. The influence of large-scale vorticity advection was hardly found at the incipient stage of the system.

(4) The medium-scale depression formed in the large-scale frontal zone. The frontal baroclinicity, was confined to the lower layer.

8. Analysis of depressions from the viewpoint of heat balance

The characteristic features of medium-scale depressions mentioned in Section 7 suggest that warming in the lowest layer is a primary factor for the formation of the sea-level low pressure. Then the heat budgets in the three thickness layers between the 1000 mb and 500 mb levels were evaluated. An equation used for the evaluation was the equation of thickness tendency, and the computation was done by using a grid system. The spacing of the grid point is 2°-latitude in the south-north and 2°-longitude in the west-east, and vertical levels are the 500, 700, 850 and 1000 mb levels. The equation may be written as

$$\Delta h = AV + AD + AH,$$

where

$$AV = -\frac{1}{2} (\mathbf{v} \cdot \nabla h_t + \mathbf{v} \cdot \nabla h_{t+\Delta t}),$$

and

$$AD = \frac{1}{2} (S_{ot} + S_{ot+\Delta t}) \frac{\Delta t \Delta p}{g}.$$  

Here $\Delta h$ is the thickness tendency for time-interval $\Delta t= (=12$ hours), $\mathbf{v} \cdot \nabla h_t$ the horizontal advection of thickness at time $t$, $S$ the static stability, $\omega$ the vertical p-velocity, $\Delta p$ the pressure increment for the thickness, $h$, and $g = 9.8 \text{ m/sec}^2$. The term $AH$ is the apparent heat source or sink. $AH$ is interpreted into a sum of non adiabatic processes and divergence of subgrid-scale heat flux. The local time change, $\Delta h$, the horizontal advection, $AV$, and the adiabatic change, $AD$, were computed with the analyzed thickness and wind fields. $\omega$ was computed by the continuity equation with the boundary condition: $\omega$ at 1000 mb = 0. $AH$ was evaluated from the residual. The equation (1) shows $\Delta h$ is composed with the three components. In the present analysis, however, $AH$ is dependent on the other three terms. Therefore possible process of thickness change is specified with one of the following eight combinations.

$$AV$$  
\[\begin{array}{ccc}
\text{upward motion} & \text{increase} & \bullet \\
\text{downward motion} & \text{increase} & \circ \\
\text{upward motion} & \text{decrease} & \times \\
\text{downward motion} & \text{decrease} & \square \\
\end{array}\]

Thus the characteristics of the thickness tendencies are denoted by plotting the above symbol on each grid point according to this classification. Some selected examples will be shown in the following.

(a) $ML3$

The lower part of Fig. 17 is a vertical cross-section through the center of $ML3$. Here the
tion and small adiabatic cooling contributed to the increase of thickness. Apparent heating of $3^\circ \sim 4^\circ/12$-hr, however, was necessary in order to account for the actual increase in thickness. Considering the magnitude of each component the heating in the lowest layer mostly contributed to the genesis of ML3. It was previously mentioned that a pre-existing medium-scale cyclone was detected at 850 mb, but the surface low-pressure associated with the upper disturbance was very weak and masked by the synoptic-scale pressure gradient. The upper part of Fig. 17 shows the heat budget 12-hour before the formation of ML3. Considerable warm air advection was located in the middle layer (700 mb-850 mb), but, in the bottom layer, no systematic upward motion and no heating were accompanied with the advection. The effect of warm air advection in the middle layer was mostly compensated with the adiabatic cooling in the top layer (500 mb-700 mb), and the amount of height fall at 1000 mb was about a half of that for the next 12 hr period (lower cross-section in Fig. 17).

Fig. 17 Cross-section of heat budget. Full lines denote change in mean virtual temperatures of the three layers due to the horizontal advection (in units of $^\circ\text{C}/12$-hr). Vertical lines with arrow heads denote the amounts of the changes due to adiabatic vertical motion. The arrow shows the direction of the vertical motion, and the scale of magnitude is shown at the top of section. Dashed lines denote the amounts of apparent heating or cooling (in units of $^\circ\text{C}/12$-hr), and hatched areas indicate apparent cooling. The broken lines at the bottom of section represents the profile of medium-scale height tendency (m/12-hr). As for symbols at grid points, refer to the text. Upper: section along 28$^\circ$N for the period 12 GMT 1 March to 00 GMT 2 March. Lower: section along 26$^\circ$N for the period 00 GMT to 12 GMT 2 March.

amount of thickness change is converted into the change in virtual temperature. The broken line at the bottom is a profile of medium-scale 1000 mb-height tendency along the section. The profile shows the pressure fall around long. 124$^\circ$E, which suggested the formation of ML3. The thickness of the lowest layer (850-1000 mb) on this region much increased. Warm air advec-

Fig. 18 Same as Fig. 17 except for the period 00 GMT to 12 GMT 13 February. Upper: section along 30$^\circ$N. Lower: section along 26$^\circ$N.
The upper part of Fig. 18 is the section along the latitude circle of 30°N, for the period from 00GMT to 12GMT 13 February. At this time the medium-scale depression was located in the middle layer over the Yangtze, and upward motion extended in a wide area, particularly in the top layer. Warm air advection centered in the middle layer, and apparent heating was small except the eastern border. On the contrary, in the cross-section along the latitude circle of 26°N, for the same period, (lower cross-section in Fig. 18), downward motions were located in the top layer, and the warm air advection in the bottom layer (850-1000 mb) was more remarkable than in the northern region. Furthermore apparent heating was about three times as large as the one on the lower Yangtze. These processes in the bottom layer were responsible for the formation of the Taiwan low.

The cross-section in Fig. 19 shows the heat budget in the central part of the developing cyclone. A deep zone of warm air advection accompanied with upward motion and a deep apparent heat source were characteristic features compared with the situation in the previous stage.

9. Discussion

In the cross-sections shown in Section 7, the domain of warm air advection extended through a wide area, while adiabatic and diabatic processes changed with medium-scale spacing. This medium-scale spatial variation has a close relation to the spatial variation in thickness tendency and consequently to the medium-scale variation in pressure field. The large-scale baroclinic process and the energy transfer due to small-scale motion are not uniform in a system. The active parts of the processes have a tendency to concentrate in medium-scale regions inside a system. This local variation brings about variations of weather and the subsynoptic-scale variations in pressure field. For instance existence of two fronts in a cyclone is a typical example. In general a frontal zone exists a priori, and some times intensification of the front or new frontgenesis is resulted through cyclone development. Even in a front, spatial variation of the activity is recognizable.

From the heat budget analysis it is concluded that the following three simultaneous dynamical processes are basic factors for the formation of sea-level depression: (1) warm air advection, (2) upward air motion and small adiabatic cooling, and (3) apparent heating in the lowest layer. The warm air advection is connected with the southerly flows and with the existence of large-scale frontal zone. The upward motion is related to convergence at low levels, and the convergence has a connection with the frontal circulation. The upward motion, or convergence causes increase of the positive vorticity. The small adiabatic cooling is possible in the region of low static stability. The detailed mechanism of apparent heating is unknown, but it is essential, closely connecting with the low-level convergence, for warming in the lower layer. The apparent heating looks like a heating function in the CISK method of parameterization. The results of budget suggested the convective activity, three-dimensional local circulation and radiation of cloud, all of which are included into the apparent heat source or sink, have considerable effects on a formation of medium-scale disturbance. What is important is the concentration of warming into an area of particular horizontal size. For instance, in the lower cross-section in Fig. 17, the resultant of positive contributions of the three processes mentioned above made up the concentration of increasing of thickness around 124°E.

The present paper discussed a relationship between the spatial variation in thickness-field and the formation of sea-level low-pressure area. Since height of isobaric surface is adopted as a parameter representing disturbance and basic field, the formation of pressure system such as depression is most appropriately described as the time changes in geostrophic vorticity and thermal vorticity fields. As well known, the time tendency of geostrophic vorticity at sea-level is related to the vorticity advection at non-divergence level.
and the tendency of thermal vorticity between the non-divergence and sea levels. Therefore decrease of thermal vorticity is a favorable condition for the formation of sea-level depression. The case study in Section 8 presented an analysis of the thickness tendency which made the favorable condition.

References

**AMTEX’75 期間における東支那海上の中間規模低気圧の構造について**

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**AMTEX’75 期間の三つの地表面の中間規模低気圧は 700 mb 以下の浅い暖気核を有するものので、中心示度の深まりは最下層で最大で、高さと共に深まりは急減する。一般に東シナ海上で発生すると考えられているが、機構乱は中国大陸にまで拡がることが出来て、機構乱の下層部分の深まりが海上でおこる。これら中間規模低気圧はいずれも総観規模の前線帯内に形成された。総観規模の気圧場が発達する時は、あたかも中間規模の機構乱が強い低気圧になった様に見えるが、中間規模機構乱が大きな低気圧になるのではなく、総観規模の場の発達が大きな低気圧を形成する。熱収支の計算結果より、地表面の中間規模低気圧の形成には（1）緩流移流，（2）上昇流，ただしこれに伴う断熱冷却は弱いような鉛直安定度，（3）最下層に見かけの熱源のあること，の三条件が同時にそろうことが必要と結論される。**