Numerical Simulations on the Explosive Cyclogenesis over the Kuroshio Current

Xu Yinlong (许吟隆)

Agrometeorology Institute, Chinese Academy of Agricultural Sciences, Beijing 100081

Zhou Mingyu (周明煜)

National Research Center for Marine Environment Forecast, Beijing 100081

(Received December 2, 1997; revised June 18, 1998)

ABSTRACT

In this paper, the Pennsylvania State University-NCAR Mesoscale Model (MM4) is used to investigate the explosive oceanic cyclone of 14-15 March 1988 over the warm Kuroshio Current. A series of numerical simulations on this cyclogenesis indicates that the favorable weather conditions and strong baroclinity in the low- and middle-level are essential to its explosive development. The explosive cyclogenesis occurred over a wide range of sea surface temperatures (SST's), which was then characterized by strong baroclinity, the low-level jet (LLJ) was initially formed under the favorable atmospheric circulation and then this LLJ advected the moisture and heat northward for the explosive development of the cyclone, the LLJ played an important role in the process of cyclogenesis. Sensitivity experiments show that the latent heating was a key factor to explosive cyclogenesis, the latent heating deepened the short-wave trough, which resulted in the rapid intensification of the cyclone; while in the explosive intensification stage and continuous development stage, there was less contribution of local surface processes for the explosion of the cyclone.

Key words: Kuroshio Current, Explosive cyclogenesis, Numerical simulation

1. Introduction

The Kuroshio Current is the most strong warm western boundary current of the North Pacific, over which explosively deepening extratropical lows frequently occur during wintertime. Sanders and Gyakum (1980) (hereafter referred to as SG) have addressed their statistic analyses on the explosive cyclogenesis in the Northern Hemisphere during the period September 1976–May 1979. These kinds of maritime, cold-season events are usually found that the pronounced frequency maxima occur in the westernmost portions of both the Atlantic and Pacific Oceans, within or just north of the warm waters of the Gulf Stream and the Kuroshio Current, respectively. Detailed study has shown that explosive cyclogenesis occurred over a wide range of SST's, but preferentially near the strongest gradients, which indicates that the explosive cyclogenesis is characterized by baroclinity. Generally speaking, shallow baroclinic low-level convection is formed when cold continental air-mass moving over the warm sea surface, and the explosive cyclogenesis is triggered by the interaction between the shallow baroclinic effects and other mechanisms.

The extratropical surface cyclone where central pressure fall averages at least 1 hPa h^{-1} for 24 h is defined as "bomb" by SG. The central pressure of the "bomb" *QE II* deepened ~ 60 hPa within 24 h, forming the hurricane-like characteristics in wind and cloud field.

These extratropical maritime events often cause great damage of life and property near the coastal region and high seas, for instance, the dragger *Captain Cosmo* was lost and the liner *Oueen Elizabeth II* was damaged in the "bomb" *QE II*. Therefore, it is of great importance to accurately predict the occurrence and evolution of these events.

The explosive cyclogenesis was continuously investigated with statistic approach and numerical simulations since SG. These studies focus on two typical examples: the *QE II*, which battered the liner *Queen Elizabeth II* in 10–11 September 1978, and the Presidents' Day Cyclone of 18–19 February 1979, which produced heavy snow from North Carolina to southeastern New York and extreme southern New England (Foster and Leffler, 1979). Gyakum (1983) revealed that the *QE II* storm originated as a shallow baroclinic disturbance west of Atlantic city, New Jersey, and explosive deepening (~ 60 hPa) commenced once the storm moved offshore, and in association with cumulus convection adjacent to the storm center. Numerical study discussed by Anthes et al. (1983) suggests that baroclinic instability in the weakly stratified lower troposphere is the major mechanism of growth for the *QE II* storm. Furthermore, Uccellini (1986) presents the evidence that the rapid development of the *QE II* storm was marked not only by adiabatic processes, but also by the presence of a deepening short–wave trough / jet streak system. Uccellini et al. (1984) have shown that prior to the Presidents' Day cyclogenesis, the upper troposphere was characterized by an amplifying unbalanced subtropical jet (STJ) streak. Based on the diagnostic analyses of the Presidents' Day Storm, Bosart et al. (1984) found that boundary layer warming and moistening approached 400 and 1,200 W m^{-1}, respectively, in the coastal waters of the pre–cyclogenetic environment. Reed et al. (1986) summarized that both the Presidents' Day Storm and the *QE II* storm formed over warm waters (~ 22℃) and close to the edge of regions of at least moderately strong SST gradients; both were characterized by strong baroclinity, and both were marked by deep convection in the vicinity of the storm center.

Until now, few case studies have been done for the explosive cyclogenesis over the Northwest Pacific. In this paper, we present a numerical investigation on an explosive cyclogenesis of 14–15 March 1988 over the warm Kuroshio Current, our primary objective is to understand the mechanisms of the explosive deepening cyclone over the Northwest Pacific.

2. A brief description to the explosive cyclogenesis of 14–15 march 1988

Wei et. al. (1992) have given a detailed synoptic overview and analyses on the dynamic and thermodynamic structures of this explosive cyclogenesis, hence, in this section it is just given a brief description of the analyzed results for this explosive cyclone done by Wei et. al. (1992).

A depression circulation at the center (30°N, 120°E) with a central pressure 1000 hPa at 00 GMT 14 March 1988 was observed from the surface map, accompanying with a cloud system northwestward. This depression moved through the East China Sea to (32.5°N, 132.5°E) sea area near the Shikoku of Japan at 12 GMT 14 March, when it had developed to be an extratropical cyclone with the central pressure of 998 hPa. It can be seen a strong warm tongue extended to the central cyclone from southwest to northeast (consistent with the direction of the Kuroshio Current). Hereafter the cyclone explosively developed. At 00 GMT 15 March, the cyclone moved eastward to (36.5°N, 144.0°E), and the central pressure fell to 988 hPa. According to the criterion for the explosive intensification of a cyclone at latitude Φ:

$$24\ \text{hPa} / 24\ \text{h} \cdot \frac{\sin\varphi}{\sin 60^\circ}$$

defined by SG, the central pressure of this cyclone exceeded the critical pressure drop at this latitude by 2 hPa / 12 h. Meanwhile, a mesoscale convection complex was formed southeastward at the central surface cyclone. Following the appearance and development of the convective cloud system, this cyclone was further intensified. At 12 GMT 15 March, the central surface pressure of the cyclone fell to 976.2 hPa at the rate of 11.8 hPa / 12 h. The observed maximum surface wind speed was 26 m s^{-1} and the calculated precipitation rate was 43.4 mm / 6 h. That is to say, the cyclone had developed to be a strong extratropical storm. As a result, the central surface pressure of the cyclone fell by 21.8 hPa from 12 GMT 14 March to 12 GMT 15 March, exceeding the critical pressure-drop value (16.9 hPa / 24 h) by 4.9 hPa.

This explosive cyclogenesis was divided into three development stages: energy storage stage, explosive intensification stage and continuous development stage. In the first stage (00 GMT-12 GMT 14 March), the cyclone was formed in the mainland of China and moved eastward to the East China Sea across the oceanic frontal zone to the main Kuroshio Current area with the SST difference of 10-12℃, which got a lot of heat and water vapor from the warm Kuroshio Current. Within this stage, the cyclonic vorticity advection is favorable to the intensification of the cyclone but so weak for its explosive development. In the second stage (12 GMT 14 March-00 GMT 15 March), the cyclone reached the main sea area of the Kuroshio Current, which continuously supplied heat and water vapor to the cyclone to increase its potential energy. The potential energy was released due to the upward motion, and which eventually strengthened the upward motion. As a result, the release of the baroclinic energy led to explosive intensification, then the cyclone shifted to the continuous development stage.

3. Initial conditions and model design

For this study, the model simulations were started at 12 GMT 14 March 1988, when the cyclone began to explosively develop. The initial upper-level data for model simulations were obtained from the seven-level (1000 hPa, 850 hPa, 700 hPa, 500 hPa, 300 hPa, 200 hPa, 100 hPa) data objectively analyzed by ECMWF; and the surface data were taken from the history synoptic charts. The initial sea surface pressure is given in Fig. 1a, it can be seen that a cyclone of central pressure 998 hPa is situated in the south of Japan. Ten-day mean SST on 10-20 March over the Kuroshio Current is presented in Fig. 1b, which is obtained from the ten-day marine report of Japan Meteorological Agency and taken as the SST input for the model simulations. Fig. 2 illustrates the initial 850 hPa- and 500 hPa-level synoptic maps. It can be seen from 850 hPa map that there is a short wave trough over the west sea of Japan consistent with the sea surface low, which is characterized with intensive isotherm and strong baroclinity. It can be seen from the 500 hPa map that there is a long-wave trough which extends from East Asia to Bering Strait with the maximum wind speed of 50.3 m s^{-1}. Accompanying with the processes of the explosive cyclogenesis, there is a strong supergeostrophic upper-level jet, which effect is also an important factor to the explosive cyclogenesis.

In this paper, the Penn State / National Center for Atmospheric Research (PSU / NCAR) (Anthes, et al., 1987) mesoscale model, MM4, is employed to investigate the physical mechanisms of the explosive cyclone of 14-15 March 1988 over the Kuroshio sea

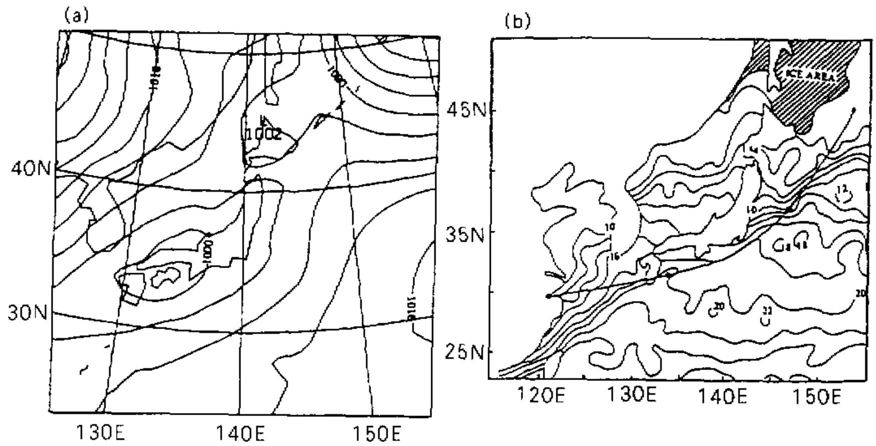

Fig. 1. Initial surface conditions for model simulation at 12 GMT 14 March 1988. (a) sea-surface pressure (contour interval: 4 hPa). (b) SST (contour interval: 2℃). '•' indicates the track of the surface cyclone center for every 12 hours from 00 GMT 14 March to 12 GMT 15 March.

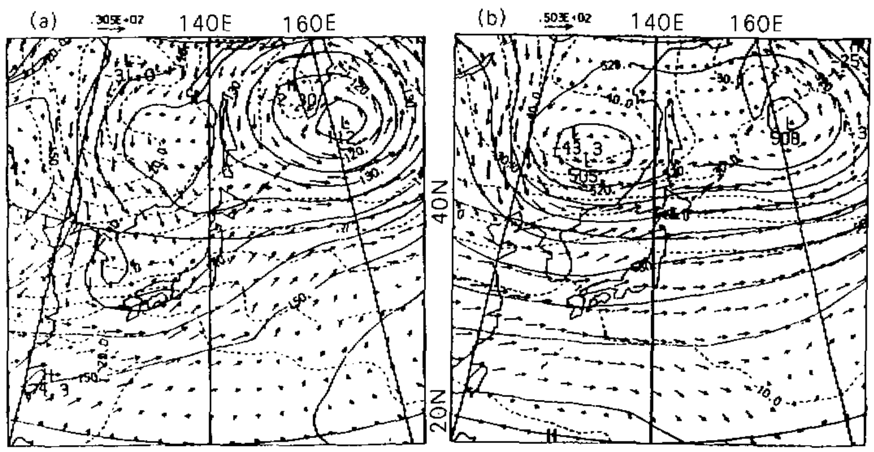

Fig. 2. Initial conditions at 12 GMT 14 March for (a) 850 hPa and (b) 500 hPa geopotential height (solid line, contour interval: 50 gpm for 850 hPa and 100 gpm for 500 hPa) and temperature (dashed line, contour interval: 5℃).

area. We take (38.5°N, 140.0°E) as the center of the computational domain, which contains an array of 73 grid points of 45 km resolution. The vertical coordinate is $\sigma = (p - p_t) / (p_s - p_t)$, where p is pressure, p_s is surface pressure, and p_t is the constant pressure at the top of the model (100 hPa in this application). For all experiments in this paper, the number of σ levels is 16 (0.00, 0.10, 0.20, 0.30, 0.40, 0.50, 0.60, 0.70, 0.78, 0.84, 0.89, 0.93, 0.96, 0.98, 0.99, 1.00). Planetary boundary-layer (PBL) fluxes are computed using the high-resolution model developed by Blachadar, and described by Zhang and Anther (1982). Precipitation from stable ascent and convective processes are parameterized, with the later parameterization based on Kuo's (1974) schemes as modified by Anthes (1977). Sponge lateral boundary condition is used as described by Anthes et al. (1987).

Four numerical experiments—one control experiment and three sensitivity experiments—were performed to investigate the relative importance of the various physical processes in the explosive cyclogenesis. The experiment designs are summarized in Table 1.

4. Results of the numerical experiments

4.1 *Control experiment*

Fig. 3 illustrates the surface results at simulation time of 12 h and 24 h, respectively. It can be seen that the simulated cyclone center is (37.2°N, 143.4°E), in the eastern sea of Japan, the simulated central pressure dropped to 987.7 hPa, which is consistent with the observed value of 988 hPa, and the simulated cyclone center is near to the observed position (36.5°N, 144.0°E). It is indicated from the wind vector that the typical cyclonic wind field was formed around the central cyclone, the maximum wind speed is 23.8 m s^{-1} at the head of the front. At 12 GMT 15 March, the cyclone center moved to (42.3°N, 155.5°E), the simulated central pressure fell to 978.3 hPa (a drop of 9.4 hPa within 12 hours, difference of 2.1 hPa compared with the observed value of 976.2 hPa), strong wind field appeared at the head of the front, maximum wind speed reached 25.5 m s^{-1}, in accordance with the observed maximum wind speed 26 m s^{-1} (note that the wind field given here is the value at the lowest level of the model atmosphere, where σ is equal to 0.995, which approximates to 45 m height, but the surface wind was observed at 10 m height).

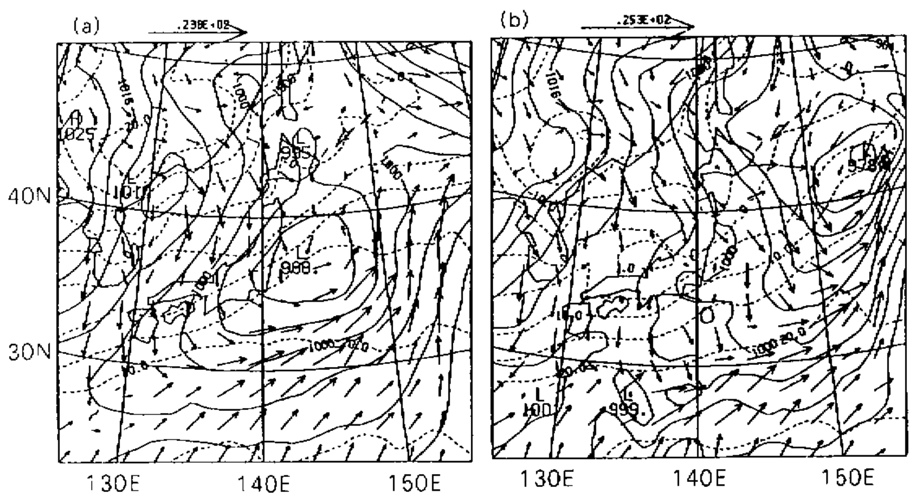

Fig. 3. Sea level pressure (solid line: contour interval : 4 hPa) and temperature (dashed line: contour interval : 5°C) after (a) 12 h and (b) 24 h of the CTRL experiment.

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Table 1. Name and functions of numerical experiments, the simulated central pressure, position and maximum relative vorticity at 850 hPa-level

No.	Name	Local Surface Physical Process		Latent-heat release	12 h		24 h		maximum relative vorticity in the central cyclone at 850 hPa-level (1×10^{-5} s^{-1})	
		sensible heat flux	moisture flux		central pressure (hPa)	position	central pressure (hPa)	position	12 h	24 h
Expt 1	CTRL	on	on	on	987.7	(37.2°N, 143.4°E)	978.3	(42.3°N, 155.5°E)	22.0	19.6
Expt 2	NLH	on	on	off	990.8	(36.4°N, 142.3°E)	985.0	(41.2°N, 152.0°E)	13.8	15.6
Expt 3	NSH	off	on	on	987.7	(36.8°N, 143.4°E)	976.3	(42.3°N, 155.5°E)	20.3	16.3
Expt 4	ADB	off	off	off	990.7	(36.5°N, 141.8°E)	984.3	(41.2°N, 152.0°E)	13.3	14.3
* comparison to observed values					988.0	(36.5°N, 144.0°E)	976.2	(44.0°N, 152.0°E)	-	-

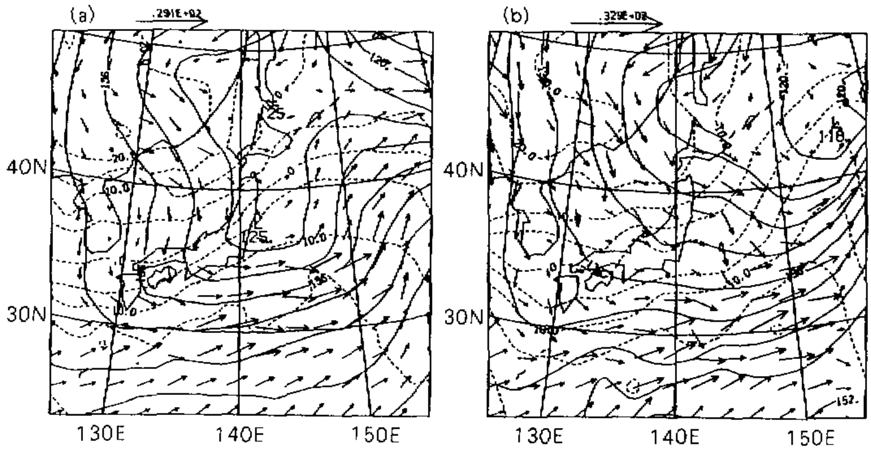

Fig. 4. 850 hPa-level geopotential height (solid line, contour interval: 40 gpm) and temperature (dashed line, contour interval: 5℃) after (a) 12 h and (b) 24 h of the CTRL simulation.

The 850 hPa simulation results are illustrated in Fig. 4. It is shown that the low-level trough propagated following the surface cyclone center, the maximum geopotential height dropped to 1,250 gpm at 00 GMT and 1,180 gpm at 12 GMT 15 March, respectively. From the relationship between the isoline of the geopotential height and the wind vector, we can find that the progress of the explosive intensification of the cyclone accompanied with the existence of LLJ. Because of the frontal warm advection and the latent heat release of precipitation, the frontal isotherms obviously deflected northward (Fig. 4a); it can be seen a warm tongue extended to the cyclone center at 12 GMT 15 March (Fig. 4b).

The 500 hPa-level simulation results illustrated in Fig. 5 present that the maximum wind speed increased up to 53.8 m s^{-1} at 00 GMT and 60.1 m s^{-1} at 12 GMT 15 March, respectively, and a warm tongue extended to the cyclone center, which coincides with the results analyzed by Wei et al. (1992). The simulated distribution of the accumulated precipitation of 6 h time interval is shown that the precipitation concentrated at the central cyclone within fore-12 simulation hours, the maximum of the accumulated precipitation exceeded 15 mm within time interval between 12 GMT—18 GMT 14 March, and 20 mm between 18 GMT 14 March—00GMT 15 March. Within the later-12 h simulation period, precipitation obviously decreased, and there was only scattered showers near the central cyclone within the last 6-h interval. It can be inferred from the spatial and temporal distribution of precipitation that the latent heating is a main factor to the explosive intensification within the pre-period of the cyclogenesis, and the continuous explosive development of the cyclone is attributed to the upper motion due to the latent heat release and the supergeostrophic current.

Uceellini et al. (1984) emphasize the important role of the upper STJ and LLJ prior to the development of the Presidents' Day Cyclone. The ageostrophic wind in the entrance region of an anticyclonically curved STJ streak could induce a transverse indirect vertical circulations and strengthen the LLJ, which would then advect moisture and heat northward contributing to the explosive development of the cyclone. Similar features can be found in this case study. We find that the cyclogenesis accompanied with the existence of a streak in Fig. 5

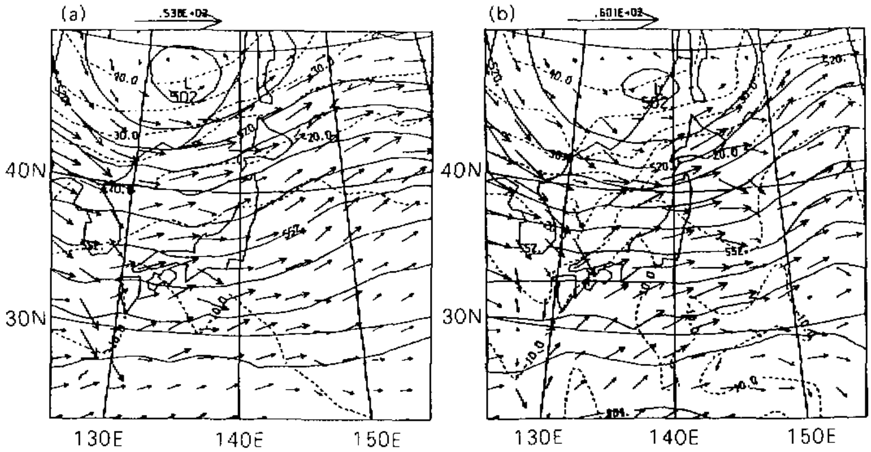

Fig. 5. 500 hPa-level geopotential height (solid line, contour interval: 80 gpm) and temperature (dashed line, contour interval: 5℃) after (a) 12 h and (b) 24 h of the CTRL simulation.

and the precipitation concentrated in the central and eastern region of the cyclone, exit region of the streak.

The initial maximum wind speed of the LLJ is 23.4 m s^{-1} (Table 2), this LLJ is situated in the southern edge of the cyclone (bottom of the low level trough), and the advection effect of this LLJ over the warm Kuroshio Current prepared efficient energy and moisture for the explosive development of the cyclone. By 18 GMT 14 March, the LLJ was located in the southeast of Honshu, Japan, the maximum wind speed increased from 23.4 m s^{-1} to

Table 2. Maximum wind speed of the LLJ in the CTRL and NLH experiments (unit: m s^{-1})

Experiment	initial	06 h	12 h	18 h	24 h
CTRL	23.4	33.3	32.3	31.0	32.6
NLH	23.4	26.0	29.6	29.5	31.0

33.3 m s^{-1} (increased by ~ 10 m s^{-1}, and there was an intensive precipitation center in the southeastern Honshu corresponding to the existence of the LLJ). From 18 GMT 14 March to 12 GMT 15 March, the LLJ moved northeastward and the maximum LLJ wind speed maintained at more than 31 m s^{-1}. In the process of the explosive cyclogenesis, the LLJ provided sufficient water vapor for the explosion of the cyclone and the latent heating maintained and strengthened the LLJ. The LLJ played an important role in the explosion of the cyclone.

4.2 *Sensitivity experiments*

The sensitivity experiments and the considered physical processes are summarized in Table 1. Sensitivity experiment NLH examines the role of the latent heating played in the explosive cyclogenesis; NSH experiment tests the influence of the surface sensible heat flux to the cyclogenesis; and ADB experiment isolates the adiabatic process contributing to the development of the cyclone from other numerical experiments.

It is presented in Table 1 that the central sea–surface pressure of the cyclone dropped to 990.8 hPa at 00 GMT 15 March in the NLH experiment, 3.1 hPa less than the drop value in the CTRL experiment. By 12 GMT 15 March, the central pressure in the NLH experiment dropped to 985.0 hPa, that is to say, within the 24–h simulation period, the drop value of central pressure in non–latent–heating case is 6.7 hPa less than that in the CTRL experiment. According to the definition by SG, the critical value for the explosion of the cyclone should be 16.9 hPa / 24 h, i.e., the central pressure should drop to 981.1 hPa. The simulated central pressure in the NLH experiment is 985.0 hPa, 3.9 hPa different from the critical value for the explosion.

Here we notice the interesting simulation results in the NSH experiment. Within the fore–12 h of the NSH experiment, the central pressure dropped to 987.7 hPa, positioned at (37.2°N, 143.4°E), well consistent with the CTRL experiment; but at the end time of 24 h simulation, the central pressure dropped to 976.3 hPa, 2.0 hPa deeper than the value of 978.3 hPa in the CTRL experiment. The NSH results indicate that the surface sensible heat flux had little effects on the explosion of the cyclone within the explosive intensification stage, and weakened the extend of the cyclogenesis in the later–12 h continuous development stage.

It can be clearly seen from Table 1 that the results of the NSH experiment are close to those of the CTRL experiment, and the results of the ADB experiment are close to those of the NLH experiment, so hereafter we will focus our analyses on the results of the CTRL and NLH experiments.

The simulation results of the NLH experiment at 850 hPa–level are drawn in Figs. 6a and b. It is indicated that the short wave trough became shallow in the non–latent–heating case. At 00 GMT 15 March, there is no minimum geopotential height presented near the central cyclone (in the CTRL experiment, the minimum geopotential height at the central cyclone is 1,210 gpm). At 12 GMT 15 March, the minimum geopotential height at the central cyclone is 1,210 gpm (while 1,180 gpm in the CTRL experiment). Thus we can infer that the latent–heating deepened the short–wave trough, which resulted in the rapid intensification of the cyclone.

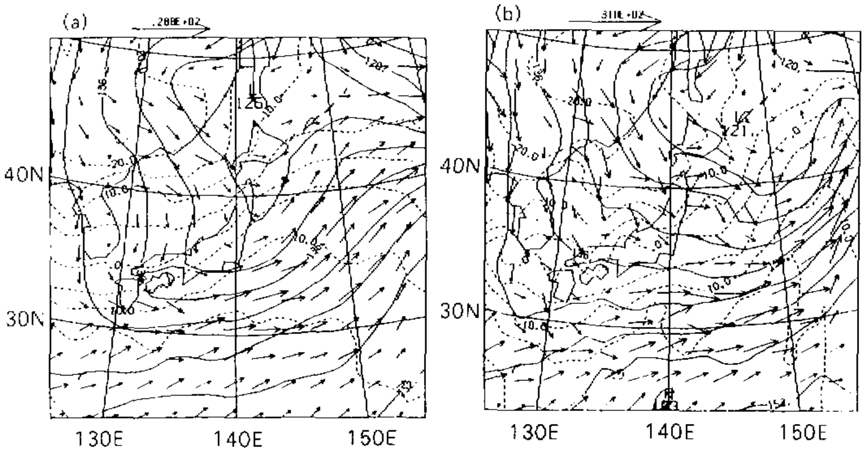

Fig. 6. 850 hPa level geopotential height (solid line, contour interval: 40 gpm) and temperature (dashed line, contour interval: 5℃) after (a) 12 h and (b) 24 h of the NLH simulation.

The simulated maximum wind speed of the LLJ in the NLH experiment is given in Table 2. By 18 GMT 14 March, the maximum wind speed of the LLJ increased from initial 23.4 m s^{-1} to 26.0 m s^{-1} (only 2.6 m s^{-1} increase within 6 h simulation period, 7.3 m s^{-1} less than 33.3 m s^{-1} in the CTRL experiment during the same period). From 18 GMT 14 March to 12 GMT 15 March, the maximum wind speed of the LLJ maintained at ~ 30 m s^{-1}. Within the whole 24h simulation period, wind speed in the NLH experiment was less than that in the CTRL experiment. The wind speed in the NLH experiment increased gradually with the development of the cyclogenesis while the wind speed in the CTRL experiment increased rapidly. It is indicated that the LLJ played an important role in the explosive cyclogenesis.

Table 1 presents the maximum 850 hPa-level relative vorticity at the central cyclone for the NLH and CTRL experiments. At 00 GMT and 12 GMT 15 March, the simulated 850 hPa-level maximum relative vorticity at the central cyclone in the CTRL experiment was 22.0×10^{-5} s^{-1}, and 19.6×10^{-5} s^{-1}, respectively. For the NLH experiment, by 00 GMT 15 March, the maximum relative vorticity at 850 hPa-level at the central cyclone increased from initial 9.89×10^{-5} s^{-1} to 13.8×10^{-5} s^{-1} (only 3.91×10^{-5} s^{-1} increment within 12 h interval, while 12.11×10^{-5} s^{-1} increment within the same period for the CTRL experiment); at 12 GMT 15 March, it increased to 15.6×10^{-5} s^{-1}, 4.0×10^{-5} s^{-1} less than the simulated result of 19.6×10^{-5} s^{-1} in the CTRL experiment. It is indicated that in the continuous development stage of explosive cyclogenesis, the relative vorticity at the central cyclone is mainly determined by dynamic characteristics instead of thermodynamic characteristics, which effects decreased because of the decrease of precipitation.

Table 1 also presents the maximum 850 hPa-level relative vorticity at the central cyclone for the NSH and ADB experiments. It can be clearly seen that the smallest relative vorticity appeared in the ADB experiment for four numerical experiments. At 00 GMT and 12 GMT 15 March, the relative vorticity at the central cyclone increased from initial 9.89×10^{-5} s^{-1} to 13.3×10^{-5} s^{-1} (only 3.41×10^{-5} s^{-1} increment within 12 h simulation period), and 14.3×10^{-5} s^{-1} (only 1.0×10^{-5} s^{-1} increment within 12 h period), respectively. It means that the cyclone is hard to explosively develop only by the adiabatic effects.

5. Conclusions and discussion

In this paper, the process of an explosive cyclogenesis of 14–15 March 1988 over the Kuroshio Current was simulated, and three sensitivity experiments were performed to identify the roles the different main physical processes played in the evolution of the cyclone. Several results can be obtained from the above numerical analyses:

(1) The simulation results in this paper are well accorded with the real processes of the explosive development of the cyclone. The cyclone simulated in this paper was initially formed over the warm sea area (SST ~ 20℃) of the Kuroshio Current, and the cyclogenesis extended over a wide range of SST (at the resting place of the cyclone, SST ~ 0℃), which was then characterized by strong baroclinity. The favorable weather conditions and strong baroclinity in the low- and middle-level are essential to the explosive cyclogenesis.

(2) It is indicated from the NLH experiment that the latent-heating due to the precipitation, which contributed to about one-third of the central pressure fall, is a main factor to the explosion of the cyclone.

(3) The LLJ played an important role in the explosive development of the cyclone. The LLJ was initially formed under the favorable atmospheric circulation and then this LLJ advected the moisture and heat northward for the explosive development of the cyclone. The

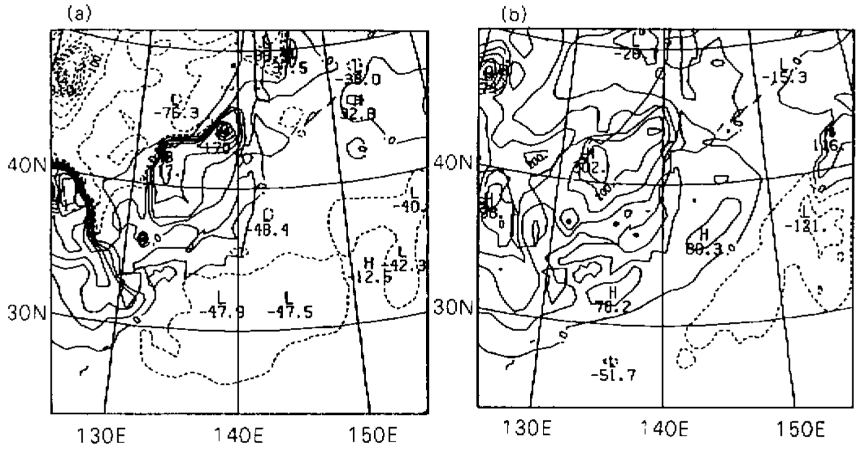

Fig. 7. Surface sensible heat flux of CTRL simulation. (a) fore−12 h average (contour interval: 25 W m^{-2}), (b) later−12h average (contour interval: 50 W m^{-2}).

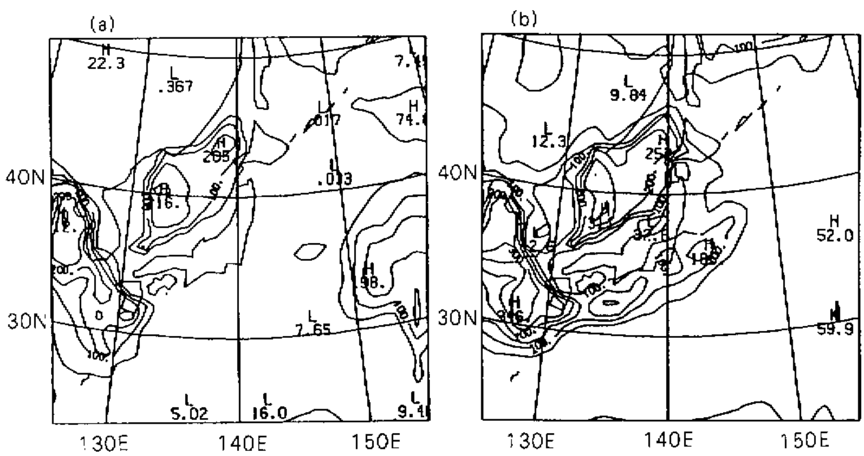

Fig. 8. Surface latent heat flux of CTRL simulation, (a) fore−12 h average (contour interval: 25 W m^{-2}), (b) later−12 h average (contour interval: 50 W m^{-2}).

LLJ was strengthened by the latent heating of the precipitation, which would result in the continuous explosive development of the cyclone.

(4) It is indicated from the NSH and ADB experiments that the surface sensible− and latent− heat fluxes had little effects on the development of the cyclone, i.e., in the stage of the explosive cyclogenesis, the intensification of the central pressure was determined by the local atmospheric circulation and the latent−heating of the precipitation, and the local surface physical processes contributed little to the explosion of the cyclone.

It has been shown that the simulated central pressure in the NSH results absent of surface sensible heat flux deepened 2.0 hPa more than that in the CTRL experiment including all physical processes. Now we have a more detailed discussion about the NSH simulation results. Figs. 7a and b illustrate the contours of the average sensible heat flux within the fore-12h and later-12h simulation period. It can be seen from Fig. 7 that the surface sensible heat flux of the sea area where the cyclone went by was downward ($0 \sim -25$ W m^{-2} within the fore-12 h and up to -121 W m^{-2} within the later-12 h). Within all periods of the cyclogenesis, the cyclone moved from the warm SST (~ 20℃) to relatively colder SST(~ 0℃). As the cyclone moving from the warm sea area of the Kuroshio Current to the colder sea northward, the boundary-layer atmospheric temperature at the central cyclone was relatively higher than the SST below, thus the surface sensible heat was transported downwards. With the cyclone moving northward, the SST approached to zero, and the difference between the boundary-layer atmosphere and the sea surface becomes larger and larger. It can be inferred that the sea-atmosphere heat exchange in this explosive cyclogenesis consumes the cyclonic energy and thus played an obstructive role in the explosive development of the cyclone.

Fig. 8 illustrates the mean average contours of the surface latent heat flux within fore-12h and later-12h period for the CTRL experiment. It is shown that the value of the surface latent heat flux at the sea area where the cyclone went by was small (less than 50 W m^{-2} overall). The distribution of the latent heat flux indicates that when the cyclone moved northward from warmer sea waters to colder sea waters, the boundary-layer atmosphere was saturated or near-saturated, little amount of moisture was transported from sea-surface to atmosphere, therefore the heat and moisture needed for cyclonic explosion came from the initial storage and the LLJ advection.

It is just a preliminary attempt to numerically investigate the explosive cyclogenesis over the Kuroshio Current of the northeastern Pacific. Our analyses on the dynamic and physical mechanisms of this cyclogenesis are greatly limited because of the sparsity of the observed data over the Pacific. There are many aspects, such as the effects of the STJ on the cyclogenesis, synergetic interaction between the LLJ and STJ and the effects of the baroclinic disturbance of the boundary-layer atmosphere over the Kuroshio Current prior to the explosive cyclogenesis, left for more analyses.

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