Growing Typhoon Influence on East Asia

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ABSTRACT

Numerical model studies have suggested that the ongoing global warming will likely affect tropical cyclone activity. But so far little observed evidence has been detected to support the projected future changes. Using satellite-supported best-track data from 1965 to 2003, we show for the first time that over the past four decades the two prevailing typhoon tracks in the western North Pacific (WNP) have shifted westward significantly; the typhoon activity over the South China Sea has considerably decreased; and East Asia has experienced increasing typhoon influence. Our trajectory model simulation indicates that the long-term shifts in the typhoon tracks result primarily from the changes in the mean translation velocity of typhoons or the large-scale steering flow, which is associated with the westward expansion and strengthening of the WNP subtropical high.

1. Introduction

The typhoon movement in 2004 is unusual. Unprecedented number (10) of typhoons hits Japan whereas South China was ravaged by the worst drought since 1951 due to lack of landfall typhoons (NCDC 2004). Does this track shift reflect a long-term change in the typhoon prevailing tracks? So far, many studies, mostly based on numerical model results of global warming experiments, have suggested that ongoing global climate change will likely increase typhoon intensity (Knutson et al. 1998; Knutson and Tuleya 2004), change frequency of occurrence (Bengtsson 1996; Henderson-Sellers 1998), and shift prevailing tracks (Walsh and Katzfey 2000; Wu and Wang 2004). However, little observed evidence has been shown to support these projected changes (Knutson and Tuleya 2004; Chan and Liu 2004).

TC tracks are essentially controlled by large-scale atmospheric circulation patterns. Previous studies have demonstrated that the variability of seasonal typhoon activity is related to the El Nino Southern Oscillation (ENSO) (Chan 1985, 2000; Lander 1994; Chen et al. 1998; Wang and Chan 2002), the quasi-biennial oscillation (Chan 2000) and interdecadal variations (Chan and Shi 1996). The tropical sea surface temperatures (SSTs) have changed abruptly around 1976 (Nitta and Yamada 1989; Kumar et al. 2004), and the atmospheric circulation over the Pacific and the properties of El Nino have also shown concurrent changes in response to the interdecadal SST change (e.g., Trenberth and Hurrell 1994; Wang 1995). Can these changes in large-scale atmospheric circulation lead to changes in the prevailing typhoon tracks? The global temperature has been rapidly increased since late 1970s, which is likely due to anthropogenic influence. The present study is aimed to address a heated issue: Is there any evidence of changes in typhoon activity in the WNP and East Asia?

2. Data

The satellite-supported best track data from the Joint Typhoon Warning Center (JTWC) were used to calculate two critical parameters that measure the seasonal mean TC motion (Wu and Wang 2004). The first, the frequency of TC occurrence, indicates how many TCs enter a specific grid box of 2.5° latitudes by 2.5° longitudes. The higher the frequency in a given box, the more TCs affect it. The other is the mean translation velocity of the TCs. Both of the parameters are calculated annually from 1965 to 2003 for each box. The year of 1965 was chosen as the starting year because the satellite monitoring of weather events first became routine so that no TC would be missed.

The wind data reanalyzed by the National Centers for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) and the European Center for Medium-Range Weather Forecasts (ECMWF) are used to calculate the climatological mean steering flow. The large-scale steering flow is defined in this study as the pressure-weighted mean flow from 850 to 300 hPa (Holland 1993). In order to quantify the changes in the WNP subtropical high, two subtropical-high indices defined by the Chinese National Forecast Center were used in this study. The intensity index is defined as the sum of the grid points of geopotential height covered by contour 5880 m between 110°E and 180°. For each 5°-latitude by 5°-longitude box, the point increases by one from zero when the maximum height in the box increases by each 10 m from 5870 m. For example, the point is 2 if the height is between 5890 to 5899 m. The second index defined by the west-most longitude of the 5880 m contour measures the westward extension of the WNP subtropical high.

3. Shifts in the prevailing tracks

Figure 1a displays the spatial distribution of the 39-year mean frequency of TC occurrence for the typhoon season (June-October). TCs occur most frequently over northern South China Sea (SCS) and an adjacent region to the waters southeast of Taiwan, indicating a prevailing track of the westward-moving typhoons (Track I). The high frequency occurrence also extends from Philippine Sea to Korea and Japan, suggesting another prevailing track that influences the coastal region of East Asia (Track II). In addition, some typhoons tend to recurve northeastward east of 130°E (Track III) often during WNP subtropical ridge splits. As shown in Fig. 1b, the temporal evolution of the seasonal mean frequency of TC occurrence in the activity center (17.5°N, 115°E) is characterized by interannual variations and a significant downward trend, indicating that the TC activity over the central South China Sea has persistently decreased since 1965, in particular in the last seven years.

Two approaches were used to detect the trends in the frequency of TC occurrence and the mean translation velocity. First, we fit the frequency and mean velocity on each grid box by linear regression: $f_i=a_i+b_it$, where t is time and f_i is the frequency or velocity components on the i^{th} grid. The first term (a_i) represents the base state at $t=0$ (1965) and the second term (b_it) represents the changes associated with linear trends. The significance of the linear trend on each grid box was tested with the Mann-Kendall method (Kundzewicz and Robson 2000). Second, we simply divide the 39-year data into two epochs (1965-1983 and 1984-2003) and contrast their means. The significance of the epoch mean differences was tested with the Student t-test.

The patterns of significant linear trend and epochal change detected by the above two approaches resemble each other in both of the TC occurrence frequency and the mean translation velocity (Figs. 2a and b). The robust spatial consistency among individual grids adds confidence to the results. Figure 2a and b indicate systematic shifts in the prevailing tracks during the past 39 years. The negative anomalies over the central South China Sea mean a sharp decrease in the number of the TCs that follow track I, while the positive anomalies extending from Philippine Sea to the eastern coast of China and in the eastern part of the basin indicate westward shifts of prevailing tracks II and III, respectively.

The shifts in the prevailing tracks can be seen clearly by comparing linear components of the frequency of TC occurrence in the beginning (1965) and the end (2003) of the period examined (Fig. 3). In 1965 three TC active centers between 110-120°E (South China Sea), between 120-130°E (east of Taiwan), and between 140-145°E can be identified. By 2003 the most active region over the SCS shifted northeastward and merged with the center to the east of Taiwan. The resulting new center is located to the north of Philippines. Meanwhile, the third active center shifted westward by about 10 degrees of longitude. As a result, East Asia tends to experience growing typhoon influence.

4. Cause of the prevailing track shift

For a given TC, its track depends on its formation location and subsequent movement. The TC movement is primarily determined by large-scale steering plus a minor propagation (beta-drift) component. The steering component is advection of TC potential vorticity by large-scale environmental flows. The propagation component arises from nonlinear interactions among the environmental flow, planetary vorticity gradient, and TC circulation (Holland 1983; Carr and Elsberry 1990; Wang and Li 1992). Recently Wu and Wang (2004) put forward a trajectory model with which the spatial distribution of TC occurrence frequency can be determined given the TC formation locations and the climatological mean TC translation velocity at each grid box. The latter is also composed of the mean large-scale environmental steering and beta drift.

It is hypothesized that the track changes are mainly due to changes in the large-scale mean flow field whereas the beta drift does not change. Two numerical simulations using the trajectory model were performed, in which all TCs that formed during the period of June-October are assumed to move with the mean translation velocity fields deduced from the epoch means of 1965-1983 and 1984-2003, respectively. The trajectory model simulations capture faithfully the observed frequency changes west of 140°E (Fig. 4), suggesting that the changes in the mean steering flows (translation velocity) are a dominant factor responsible for the prevailing track shift. We also evaluated the influence of the changes in the formation locations on the prevailing track shift. Using the same mean TC translation velocity averaged over the period of 1965-2003 the trajectory model is run with the formation location data over the periods of 1965-1983 and 1984-2003, respectively. We find that the changes in the formation locations play a minor role in terms of the magnitudes.

The changes in the mean TC translation velocity are closely associated with the large-scale steering flow. The mean large-scale steering flows computed by using NCEP/NCAR and ECMWF reanalysis data show very similar patterns of the large-scale steering flow changes between the periods of 1965-1983 and 1984-2003, especially to the west of 130°E. Here we only show that derived from the NCEP/NCAR data (Fig. 4a). The change in large-scale steering flows is characterized by a cyclonic circulation centered over the eastern China. The changes in the large-scale steering flows can well explain the changes in the mean translation velocity of TCs (Fig. 2). Further examination reveals that the enhanced cyclonic steering flow in the last two decades results mainly from the upper-level circulation change (500 hPa and above).

5. Discussion

The 39-year typhoon data are relatively short for full determination of the climatic trend in typhoon tracks. However, the identified prevailing track shift shows physically meaningful consistency between the changes in the mean translation velocity and the changes in the large-scale circulation. That is, the prevailing typhoon track shift occurred over the past four decades is a primary result of changes in the large-scale steering flow. Since the track shift is intermingled with strong interannual variations, one feels more evident track shift in some extreme years like

2004. Regardless of whether it is a consequence of anthropogenic impacts or is due to a long-term natural variability, the demonstrated shift in the prevailing typhoon tracks may have a profound influence on the countries of East Asia. The increasing trend in the typhoon affecting East Asia appears to be concurrent with the on-going global warming trend.

What causes the enhanced cyclonic steering flows in the East Asia during the last two decades (Fig. 4a) is an important issue that deserves further investigation. Yu et al (2004) found that in contrast to the global warming trend over the past 50 years, a distinctive tropospheric cooling trend is found in the middle latitude East Asia. Accompanying this cooling, the upper-level westerly jet stream shifts southward. We suggest that this tropospheric cooling in the last two decades may be responsible for the large-scale circulation change shown by Fig. 4a. The East Asian tropospheric cooling is expected to generate a cyclonic circulation anomaly that increases with height, resulting in a vertically averaged cyclonic steering flow anomaly due primarily to the lowering of the upper tropospheric geopotential height. On the other hand, this tropospheric cooling induces an anomalous surface anticyclone, which is associated with the westward expansion of the strengthening subtropical high over the WNP (Figs. 4b and c), resisting the northward advance of the southwest monsoon. Consequently, the Yangtze River Valley tends to have more frequent flooding (Gong and Ho 2002, Yu et al. 2004), whereas the northern SCS tends to be drier and less tropical cyclone activity due to large-scale subsidence induced by enhanced western Pacific subtropical High (Figs. 4b and c).

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Figure Captions

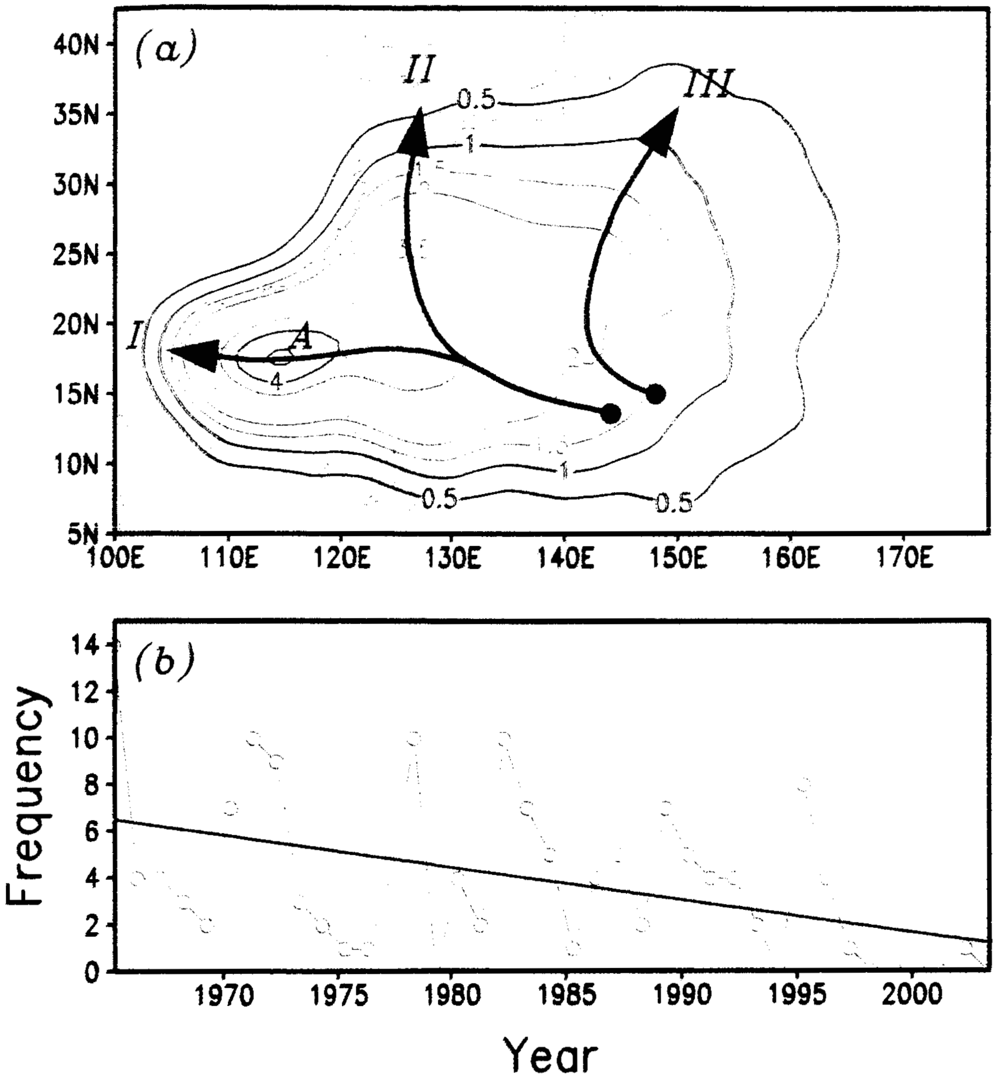
Figure 1: (a) June-October mean frequency of TC occurrence (unit per year^{-1}) derived from the JTWC best-track data from 1965 to 2003 and (b) the time series of the seasonal mean frequency of TC occurrence at the most active center A (17.5°N, 115°E) with a linear fit indicated by the straight line. The thick solid lines with arrows highlight schematically three prevailing typhoon tracks.

Figure 2: (a) Changes of the June-October mean frequency of TC occurrence and the motion vectors based on the derived linear trend change and (b) the difference in TC occurrence frequency between the periods 1965 – 1983 and 1984 – 2003. The areas with confidence level

exceeding 95% for the identified changes are shaded. The contour interval is 0.3 year^{-1} and the unit of the vectors is ms^{-1}. The thick solid lines with arrows denote the prevailing typhoon tracks.

Figure 3: (a) The June-October mean frequency of TC occurrence in 1965 and (b) the same as in (a) except that a linear trend has been added so that the plot can be viewed as June-October mean frequency of TC occurrence in 2003 obtained by linear regression. The contour intervals are 0.5.

Figure 4: (a) The changes of the June-October mean frequency of TC occurrence resulting from the changes in the mean translation velocity. Superimposed are the climatological prevailing typhoon tracks (thick solid lines with arrows). The vectors are the differences of the large-scale steering flows between the periods of 1965-1983 and 1984-2003 derived from the NCEP/NCAR reanalysis data. The contour intervals are 0.3 year^{-1} and the unit of the vectors is m s^{-1}. (b and c) Time series of the intensity and west-most longitude of the July-September mean WNP subtropical high, respectively.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130E
140E
150E
160E
170E
(b)
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8
6
4
2
0
1970
1975
1980
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1990
1995
2000
Year

Figure 1

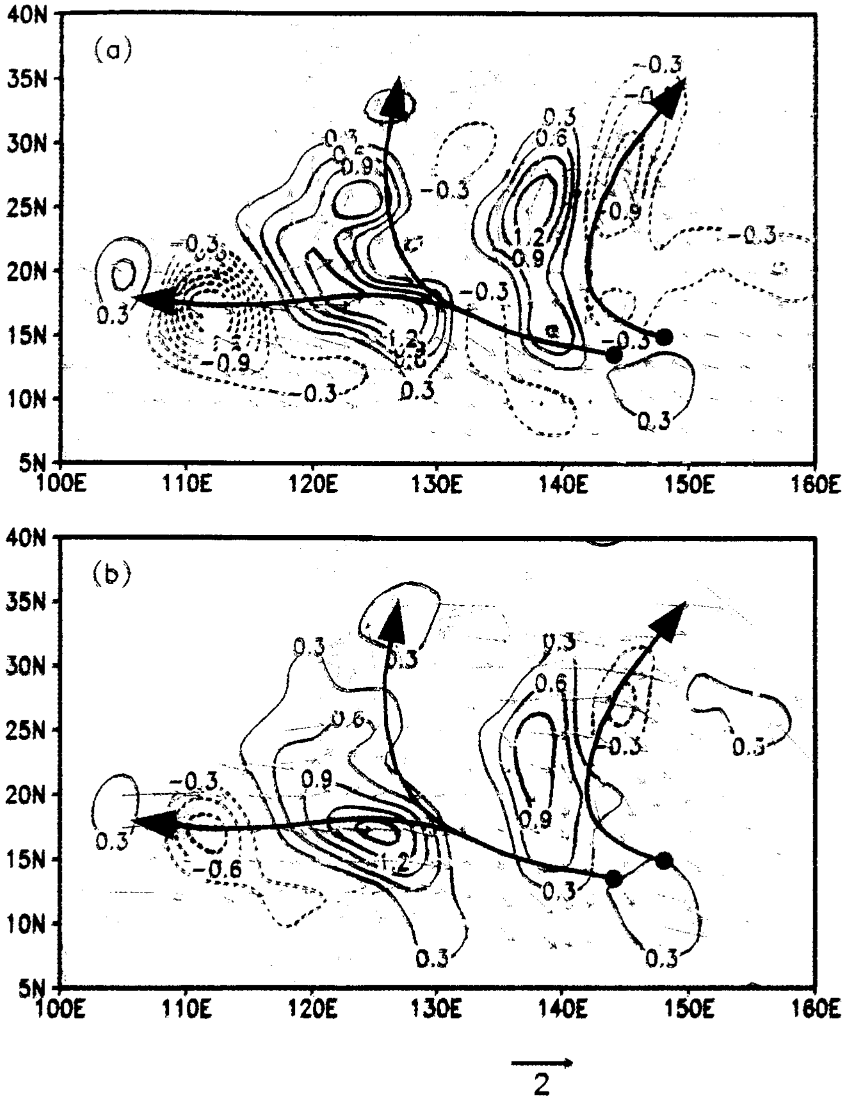
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Figure 2

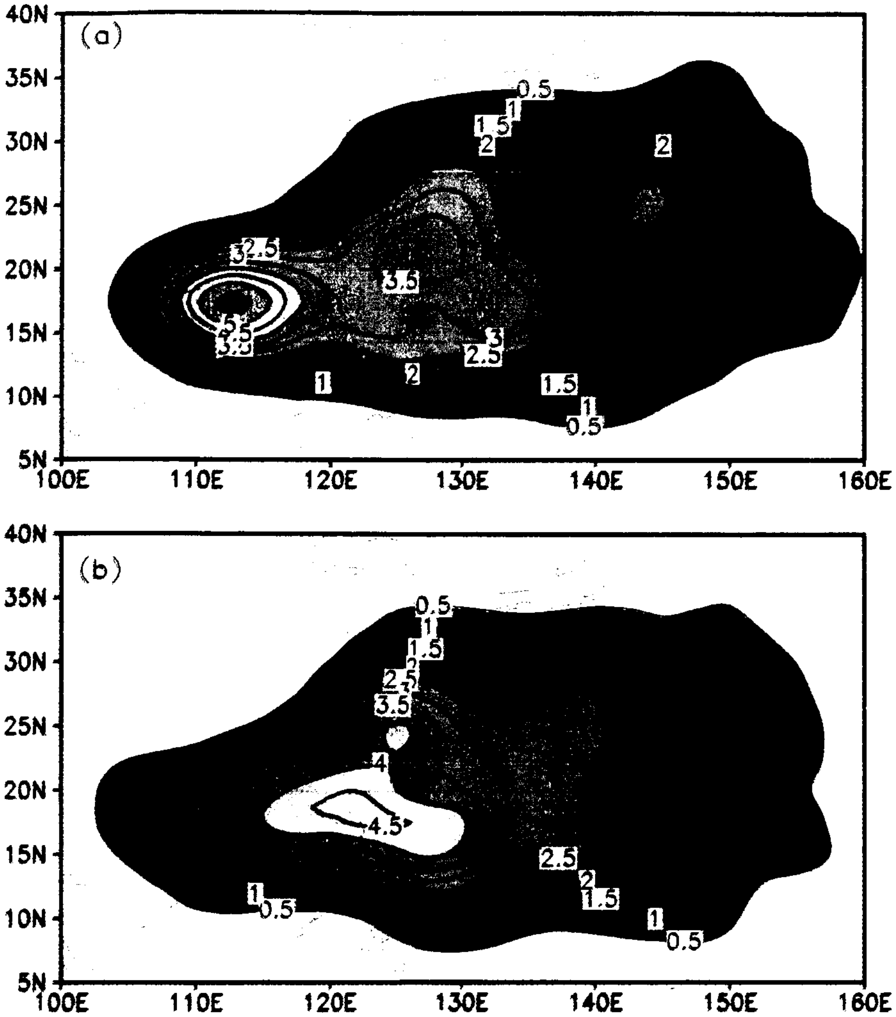
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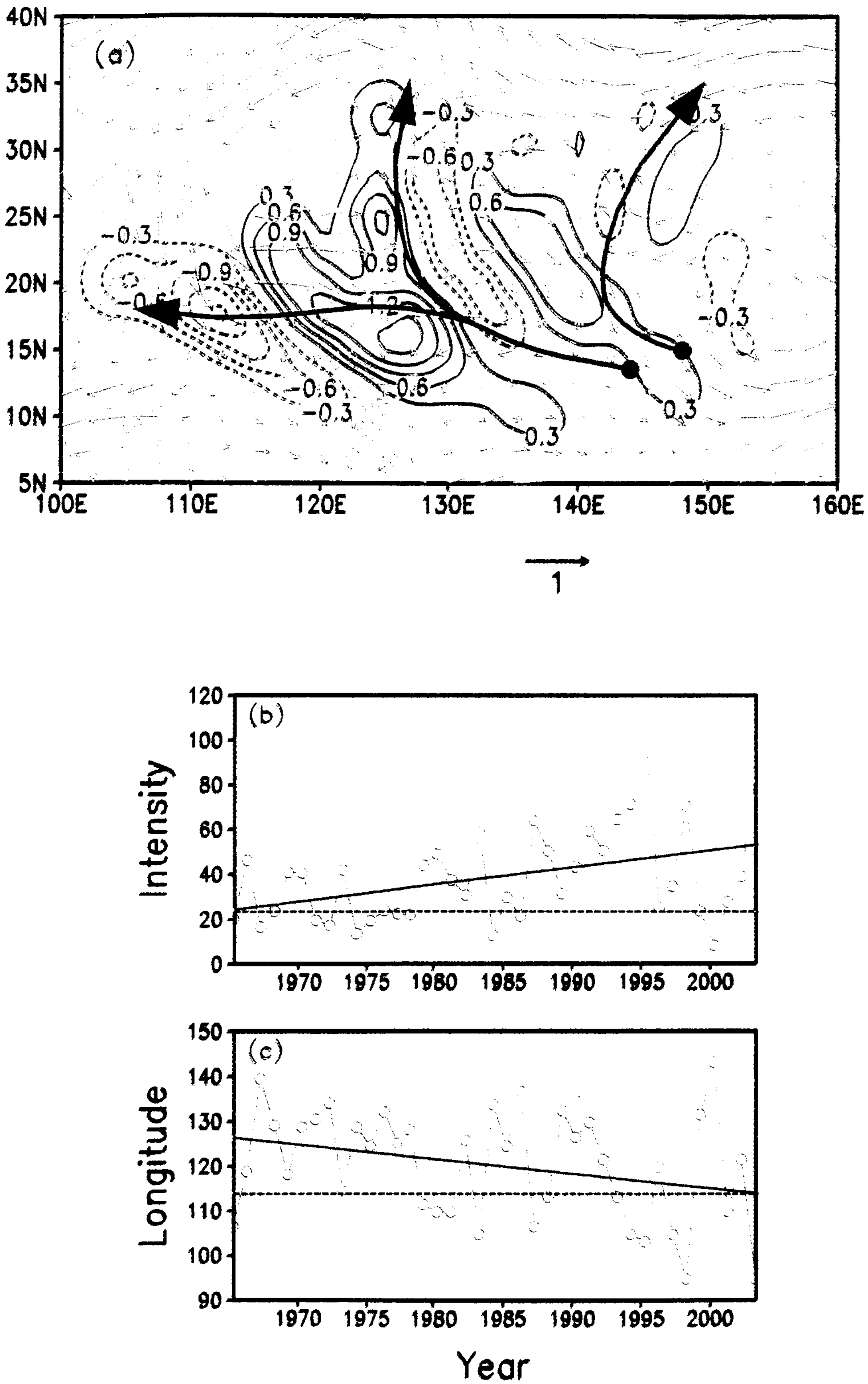
Figure 3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(b)
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1985
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1995
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(c)
Longitude
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100
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Year

Fig. 4