A Preliminary Study on the Characteristics of Warm-Season Cloud/Precipitation Episodes over the East Asian Continent under Different Synoptic Weather Regimes

Chung-Chieh Wang[1], George Tai-Jen Chen[2], and Richard E. Carbone[3]

[1]*Department of Atmospheric Sciences, Chinese Culture University, Taipei, Taiwan*
[2]*Department of Atmospheric Sciences, National Taiwan University, Taipei, Taiwan*
[3]*The Institute of Multidisciplinary Earth Studies (TIMES), National Center for Atmospheric Research, Boulder, CO, USA*

Abstract

As reported by Carbone et al. (2002), warm-season precipitation episodes (in Hovmoller space) in the United States exhibit propagating characteristics that suggest an intrinsic predictability at the range of about 6-48 h. Recent studies over other continents, including East Asia, Africa, and Australia also revealed similar findings that some events could travel for long distances, and there is an increasing recognition that skills of warm-season quantitative precipitation forecast (QPF) could be improved. However, before forecasting models can properly resolve mesoscale features that govern the propagation of organized deep convections, it is important to identify synoptic conditions that favor (or suppress) long-lived episodes for a more successful application of the above concept to improve QPF. Therefore, the present study examines the relationship between East Asian warm-season cloud/precipitation episodes during May-July 1997-2002, as identified using GMS IR data and the same method of Wang et al. (2004), and daily synoptic weather regimes over the continent. Four different regimes include those with shallow systems (at low levels) only, with upper-level systems only, with deep systems (at both low and upper levels), and with no systems. Here we report our preliminary findings in relation to the statistical properties of cloud episodes.

When deep synoptic-scale systems were present, conditions were most favorable for large episodes. With only low-level systems, as often occurred near 30°N in June-July, conditions were also suitable for convection initiation and propagation, but the size of episodes tended to be smaller than those with deep systems. Although not as common, when only upper-level systems existed, conditions were also quite favorable for streaks shorter than about 1400 km. These results point to the possibility that both upper-level steering and low-level features are important for large major streaks that propagate across the continent to the lee of the Tibetan Plateau. When no system was present, as expected, conditions were least conducive to large episodes among all four synoptic regimes.

1. Introduction

Based on high-resolution NEXRAD radar data, Carbone et al. (2002) reported that warm-season (May to August) precipitation episodes, defined by coherent sequence of organized convection in Hovmoller (longitude-time) space, in the continental United States (US) exhibit characteristics of propagation at the speed range of 10-25 m s^{-1} (Fig. 1a). The longevity of these episodes in space and time, up to 3000 km and 60 h, suggests the existence of intrinsic predictability and a potential for a significant improvement in warm-season quantitative precipitation forecast (QPF) at ranges of 6-48 h. For the region of East Asia (20°-40°N, 95°-145°E), Wang et al. (2004) used the Japanese GMS-5 infrared (IR) blackbody brightness temperature (T_{BB}) data, and found similar properties in warm-season cloud episodes to the lee of the Tibetan Plateau, with a scale up to more than 2500 km and 40 h (Fig. 1b). This characteristic of eastward propagation was more pronounced and persistent north of 30°N over the continent, while the majority of episodes south of 30°N travel toward the west (in the reversed direction) in mid-summer due to tropical influences (Wang et al. 2005). Other recent studies for the continents of Africa and Australia using satellite data also obtained similar results that precipitation episodes in warm-season exhibit characteristics of propagation, eastward in the subtropics and mid-latitudes and westward in lower latitudes (Laing et al. 2005, Keenan and Carbone 2005). As illustrated by the mean diurnal cycle (Fig. 2), a sizable fraction of these episodes originate at the lee of major mountains (such as the Rockies, the Tibetan Plateau, the Ethiopian Highlands, and the eastern cordillera of Australia) in the afternoon due primarily to thermal forcing over elevated terrain, and significant propagation tends to occur when steering winds are present in middle to upper troposphere (Carbone et al. 2005).

Although the phenomena described above is evident, increasingly organized regimes, in which precipitation episodes are longer-lived and propagate for greater distances. This is important not only for a better

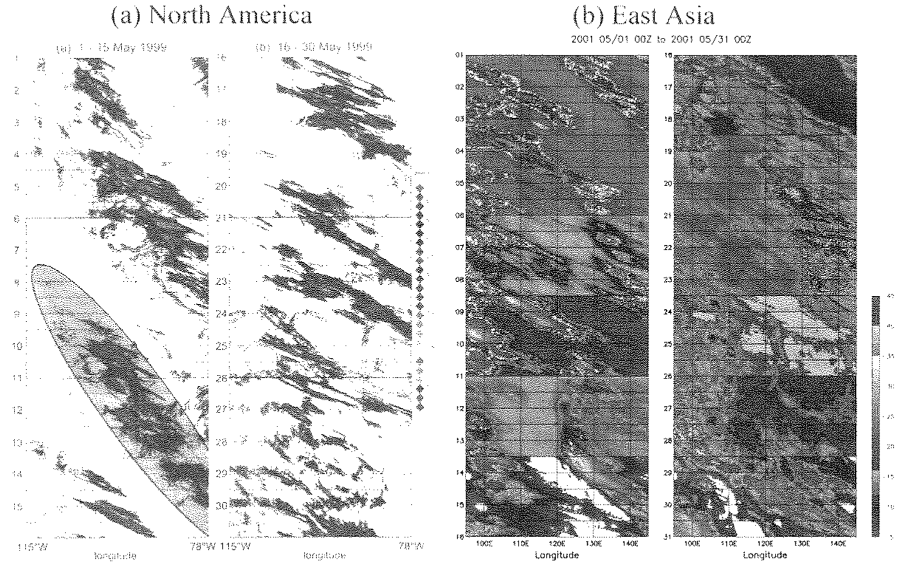

Figure 1. Examples of precipitation/cloud episodes in May over (a) North America (adopted from Carbone et al. 2002), and (b) East Asia (adopted from Wang et al. 2004).

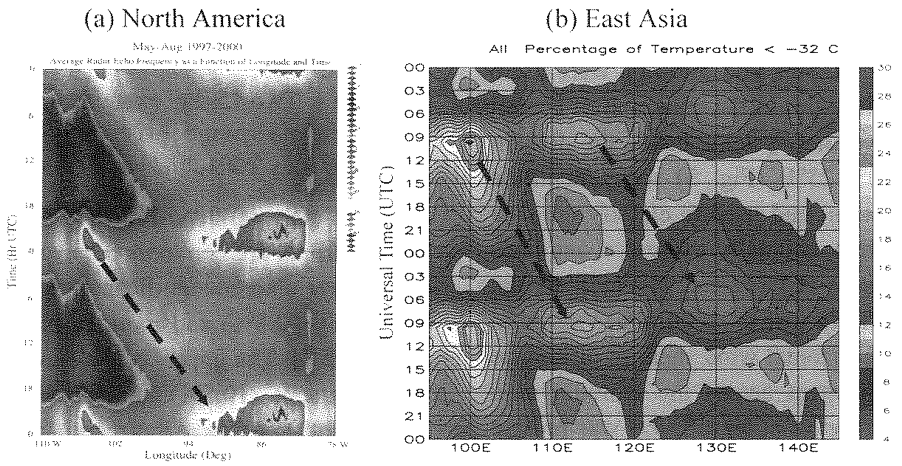

Figure 2. Mean diurnal cycle in the Hovmoller space of (a) radar-echo frequency in the US (adopted from Carbone et al. 2002), and (b) cold-cloud (< −32°C) percentage in East Asia (adopted from Wang et al. 2004), both averaged over 4 warm seasons.

such a phase-lock between thermal and topographic forcing, as well as the subsequent delayed-phase shift of convective precipitation over the downstream areas due to the propagation, are poorly captured by operational numerical models at the present time, and the correct long-term natural space-time distribution of precipitation cannot be reproduced (Davis et al. 2003). This deficiency is recently identified to arise from the convective parameterization, which cannot properly resolve the mesoscale structure of clouds in the presence of vertical wind shear (Davis et al. 2003), and it will be some time before the explicit approach becomes practicable for operational, long-range, and climate models especially (Moncrieff and Liu 2005).

Given the above state of research on the subject, the question arises as to environmental conditions that favor understanding of the behavior of large precipitation episodes (or streaks), but a more successful application of their climatology or statistical properties on QPF also cannot be achieved in the future without such studies. Thus, the present study attempts to differentiate synoptic weather regimes more favorable for long-lived episodes over the East Asian continent, and we report on our preliminary results herein.

2. Data and methodology

The set of cloud episodes (or streaks) was the same as those obtained by Wang et al. (2004), except that the data period was extended to 1997-2002 and all events in August were excluded from our analysis (so the data period was May-July, 1997-2002 here). The original

GMS-5 IR T_{BB} data came at 5-km resolution and 1-h intervals, and values within the computational domain of 20°-40°N, 95°-145°E were averaged using a grid set at 0.1° × 0.1° resolution (Fig. 3). Once the north-south average was performed, Hovmoller diagrams can be obtained using time as the second dimension, and cloud

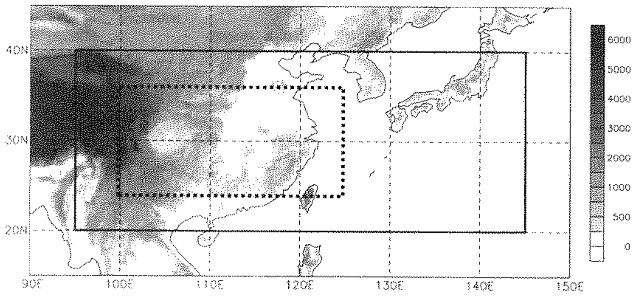

Figure 3. Domains used for Hovmoller calculation (thick solid lines) and weather regime identification (thick dotted lines).

streaks can be identified through the use of a 2-D autocorrelation function, and their statistics can be deduced following the procedure detailed in Wang et al. (2004) or Carbone et al. (2002). For the classification of day-to-day synoptic-scale weather regimes, the Japan Meteorological Agency (JMA) daily weather maps (0000 UTC) at the surface, 850, 500, and 300 hPa were used. Since our interests mainly lies in the continent of central and southern China, weather systems inside the domain of 24°-36°N and 100°-125°E (Fig. 3) were identified (through visual inspection) and used to classify the data period into four different, mutually exclusive, regimes: (1) The *low-level system* (L) regime, where a frontal system and/or a significant low (< 1000 hPa) existed at the surface, or strong horizontal wind shear (a difference of ≥ 25 kts in *u*-component across the latitude) or a southwesterly low-level jet of at least 25 kts was present at 850 hPa; (2) the *upper-level system* (U) regime, where a closed low or a trough with clear meridional flow components existed (for a trough with a smaller amplitude, a corresponding trough must also appear at 300 hPa); (3) the *deep system* (D) regime where both the criteria of low- and upper-level systems were met; and finally (4) the *no system* (N) regime where neither low- nor upper-level system existed. After this classification of weather regimes was completed, each (eastward-moving) cloud streaks, if its center lied to the west of 130°E, were categorized according to the regime at the date of its mid-point through propagation.

3. Weather regime classification

Following the methods described in the previous section, daily weather regime sequence that corresponds to the Hovmoller diagram was produced (Fig. 4). The four regimes, following the order of N, L, U, and D) during the data period occurred roughly 26%, 36%, 11%, and 26% of the time, while the remaining 1% accounts for missing IR data (Fig. 5a). Deep systems (D) appeared almost twice as frequently in May-June (31.1%) than in July (15.6%), while days with only shallow systems confined in the lower troposphere (L) were fewer in May

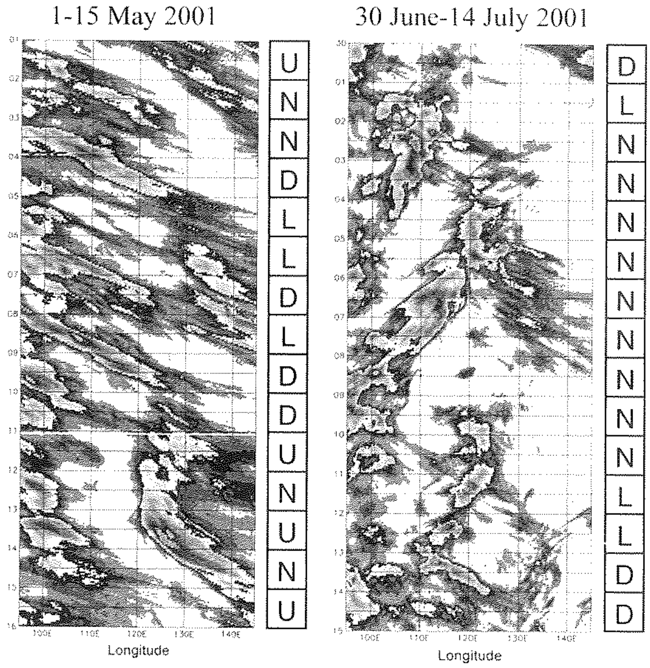

Figure 4. Two 15-day examples of paired Hovmoller diagram and synoptic weather regime sequences. (a) 1-15 May 2001, and (b) 30 June-14 July 2001.

(27.4%) than in June-July (41.0%) when stationary Mei-yu fronts are common occurrences near 30°N. As a result, days with no significant system were the fewest in June (only 12.8%) and more in both May (25.3%) and July (39.2%). The upper-level system regime (U) was the least frequent (10.5%) among all regimes, while the majority of such days occurred in May (Fig. 5a).

Among a total of 2505 qualified (eastward-moving) cloud streaks, by numbers only, the largest fraction of events occurred in regime L, followed by regime D, N, and finally U (Fig. 5b). These numbers were roughly proportional to the number of days of each regime, except in July where relatively few streaks formed under regime N, without any significant synoptic-scale weather system.

4. Statistical property of cloud streaks

The total number of eastward-moving cloud streaks was reduced to 1794, if only those lasting for 3 h or more were taken into account. For zonal span and duration of streaks, the mean values of all cases and of the larger half, as well as the cut-off values (thresholds) at various recurrence frequencies, were all largest under regime D when deep systems were present, except for span at the frequency of 1 per 2 days (Table 1, left). On the contrary, cloud streaks under regime N (no system) tended to be the shortest in zonal span and duration at all recurrence frequencies, since no favorable synoptic conditions existed to help organize the convection into larger episodes after initiation. Regime L (low-level system only) contained the most number of days (201) and the most number of streaks (711), and the cut-off values at

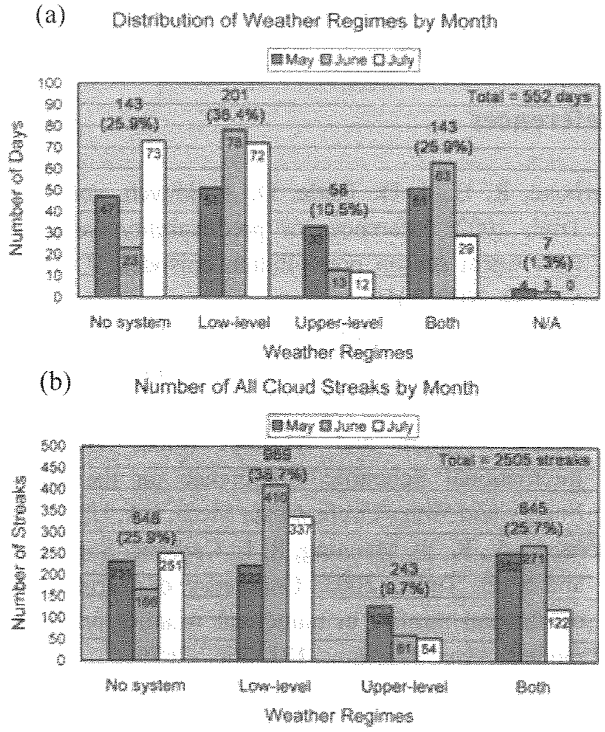

Figure 5. (a) Numbers of days and (b) numbers of eastward-moving cloud streaks under each weather regime (category "Both" corresponds to D regime).

frequencies of 1 per day and 1 per 2 days were quite comparable to those found in regime D. For those larger and less frequent episodes, however, threshold values of span and duration under regime L became increasingly smaller than those under regime D, suggesting that deep baroclinic systems with stronger steering flow aloft are likely indeed helpful for the propagation of precipitati

on systems. For events on the order of several hundred to about 1400 km, regime U (upper-level system only), although the least frequent in numbers of days and streaks (58 and 188, respectively), also produced conditions quite favorable to cloud episodes, with cut-off values only second to those in regime D at many instances (Table 1, left). However, for streaks larger than about 1500 km, apparently low-level conditions were important since values under regime L were generally greater than those under regime U at the same recurrence frequencies. This is consistent with recent findings through an examination on several cases of precipitation episodes over the continental US (Trier et al., personal communications). The mean propagation speed, as computed by dividing span by duration threshold values, at various frequencies showed comparable speed range of 15 to 20 m s^{-1} among all regimes, with a tendency for larger events to propagate faster (Table 1, right).

The scatter plots of zonal span versus duration for all cloud streaks (including those with a lifetime shorter than 3 h) under each regime, consistent with earlier discussion, also indicated that there were more large events under synoptic-scale weather regimes D and L, and these streaks tended to travel at a higher speed of about 17-20 m s^{-1}, which were higher than both the mean (13-14 m s^{-1}) and median speed (about 12.5 m s^{-1}) of all events sampled in each regime (Fig. 6). The N and U regimes, on the other hand, contained relatively fewer large streaks. However, a small fraction of cloud streaks in both categories could still reach the size of at least 2500 km and 36 h. Whether these events indeed occurred during time periods that entirely lacked favorable synoptic-scale weather features, or suitable conditions just disappeared (or weakened to beyond identification by us) temporarily near the mid-point of these events in

Tabel 1. Zonal span and duration (km and h, left half) and mean propagation speed (m s^{-1}, right half) of all eastward-moving cloud streaks of at least 3 h, and under different weather regime (N, L, U, and D) in this study. For all and top half cases, mean values were listed, while at various recurrence frequencies (bottom six rows), cut-off threshold values were given.

Recurrence frequency	All (1794)	N (410)	L (711)	U (188)	D (485)	All (1794)	N (410)	L (711)	U (188)	D (485)
All events (mean)	489 9.2	425 8.2	483 9.3	513 9.5	541 9.8	13.6	13.7	13.1	13.9	14.2
Top half (mean)	828 13.6	719 11.6	814 13.7	877 14.2	918 14.8	19.4	20.1	18.3	20.3	20.1
1 per day	501 9.5	404 8.0	525 10.0	525 10.0	539 10.0	14.5	14.0	14.6	14.6	15.0
1 per 2 days	876 15.5	665 12.0	925 16.0	1011 16.0	997 16.0	15.7	15.4	16.0	17.6	17.3
2 per week	1262 20.0	1045 17.0	1329 21.0	1368 20.0	1449 22.5	17.5	17.1	17.6	19.0	17.9
1 per week	1714 27.5	1392 22.0	1767 27.5	1647 28.0	1974 31.5	17.3	17.6	17.8	16.3	17.4
2 per month	2398 36.0	1767 28.0	2436 34.0	2172 37.0	2663 39.0	18.5	17.5	19.9	16.3	19.0
1 per month	2831 41.0	2383 32.5	2855 41.0	2528 39.5	3390 47.5	19.2	20.4	19.3	17.8	19.8

duration, remains to be further examined and clarified. If the former was the case and these long-lived streaks occurred apparently without the presence of favorable conditions, then it would be interesting to explore just how convections organized into major precipitation episodes and propagated for long distances under seemingly unfavorable conditions.

5. Concluding remarks

In the present study, warm-season cloud/precipitation episodes over East Asia during the period of May-July 1997-2002 were identified, as previously done using the GMS-5 satellite IR blackbody brightness temperature (T_{BB}) observations and the same strategy of Carbone et al. (2002) and Wang et al. (2004). By using JMA daily weather charts, day-to-day synoptic weather regimes for the domain of 24°-36°N, 100°-125°E during the same period were also identified and classified into four types: The L regime where conditions favorable for convection existed only at low levels; the U regime where systems were only present at upper levels; the D regime where deep system existed (with favorable conditions at both low- and upper-levels); and the N regime where no systems were present. The dependency of cloud episodes (or streaks) on weather regimes was examined and discussed, mainly from a statistical standpoint. In the near future, specific weather patterns that are particularly conducive to long-lived episodes, as well as those suppressing such episodes, will be further investigated.

Major results can be summarized as the following:

1) Conditions were most favorable for larger episodes (in space and time) to occur when significant deep synoptic-scale systems existed at both lower and upper troposphere, i.e., under D regime. This regime occurred more frequently in May and June (~31%).
2) The presence of low-level system, which is a common occurrence during June and July (~41%), also provide suitable conditions for convection initiation and propagation (L regime), but the size of episodes tended to be slightly smaller .without upper-level support.
3) When only upper-level systems were present (U regime, only about 10% of the time, mostly in May), conditions were also quite favorable for streaks on the order of several hundred to about 1400 km. For even larger streaks, it appears that both upper-level steering and low-level features are important.
4) When no system was present (N regime, about 26% of the time, less frequently in June), streaks tended to be smaller in span and duration, and conditions were least favorable among all four regimes.

Acknowledgements. Stimulating discussions with Drs. Stan Trier, John Tuttle, and Mitch Moncrieff during the first and second authors' visit to MMM of NCAR are greatly appreciated. The current study is supported by the National Science Council of Taiwan, under NSC-93-2111-M-002-009, NSC-93-2111-M-002-010, and NSC-94-2111-M-002-015.

References

Carbone, R. E., J. D. Tuttle, D. Ahijevych, and S. B. Trier, 2002: Inferences of predictability associated with warm season precipitation episodes. *J. Atmos. Sci.*, **59**, 2033-2056.

------, A. Laing, T. D. Keenan, C.-C. Wang, and G. T.-J. Chen, 2005: Conditions associated with warm season rainfall over Africa, Australia, China and the United States. Program and Abstract Book, The Fifth International Scientific Conference on the Global Energy and Water Cycle, Costa Mesa, CA, USA, 256.

Davis, C. A., K. W. Manning, R. E. Carbone, S. B. Trier, and S. B. Tuttle, 2003: Coherence of warm-season continental rainfall in numerical weather prediction models. *Mon. Wea. Rev.*, **131**, 2667-2679.

Keenan, T. D., and R. Carbone, 2005: Characteristics of warm season precipitation in the Australian region. Program and Abstract Book, The Fifth International Scientific Conference on the Global Energy and Water Cycle, Costa Mesa, CA, USA, 269.

Laing, A., J. Tuttle, R. Carbone, and V. Levizzani, 2005: Developing a climatology of convective precipitation patterns in Africa. Program and Abstract Book, The Fifth International Scientific Conference on the Global Energy and Water Cycle, Costa Mesa, CA, USA, 273.

Moncrieff, M. W., and C. Liu, 2005: Predicting convective precipitation over the continental United States. Program and Abstract Book, The Fifth International Scientific Conference on the Global Energy and Water Cycle, Costa Mesa, CA, USA, 193.

Wang, C.-C., G. T.-J. Chen, and R. E. Carbone, 2004: A climatology of warm-season cloud patterns over East Asia based on GMS infrared brightness temperature observations. *Mon. Wea. Rev.*, **132**, 1606-1629.

------, ------, and ------, 2005: Variability of warm-season cloud episodes over East Asia based on GMS infrared brightness temperature observations. *Mon. Wea. Rev.*, **133**, 1478-1500.

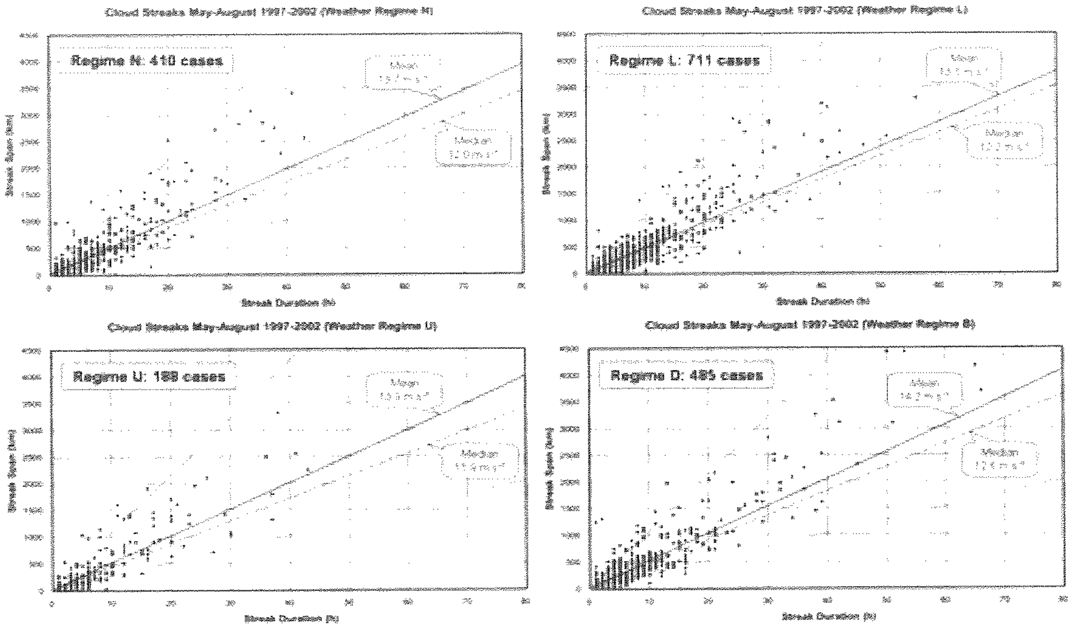

Figure 6. Scatter plots of zonal span versus duration under the four different synoptic-scale weather regimes.

Supertyphoon Boosters in the Northwest Pacific Ocean

I-I Lin, Chun-Chieh Wu, and Iam-Fei Pun

* *Department of Atmospheric Sciences, National Taiwan University, Taiwan*

Most of the world's most powerful typhoons occur in the western North Pacific Ocean. How these category-five "supertyphoons" obtain their extraordinary strength remains a mystery. Although the ensemble of typhoon tracks span over the entire western North Pacific Ocean, they apparently intensify only across a confined zone. Here we use a combination of *in-situ* measurements, remote sensing, and numerical experiments to show that the intensification zone is delimited by an abundance of warm ocean eddies and by the thickest belt of warm subtropical gyre water. We suggest that the robust structure of these warm waters effectively limit typhoon's self-induced cooling that otherwise restrains the intensification of a typhoon.