Spatial and time distribution of thunderstorms in SOWMEX-2007

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Abstract

This study diagnoses the movement of thunderstorms associated with the frontal system during Southwest Monsoon Experiment (SOWMEX-2007) around Taiwan. Wind and thermal profiles crossing the stationary front system were collected from dropsondes which were launched on 42000 feet from AIDC-ASTRA jet every morning from June 5 to June 10, 2007. The lightning information came from The Vaisala total lightning detection system (TLDS) of Taiwan Power Company.

During the flights day in SoWMEX-2007, the numerical simulations of Weather Research & Forecasting Model (WRF) revealed a meso-scale vortex genesis above the Middle of Taiwan Strait (called TS) in the early morning and propagated inland to Taiwan. Onshore lightning clusters approached the western coast of Taiwan. The phenomenon could be explained by the warm southwestern low-level jet and the terrain blocked effect which provide the favorite environment for meso-vortex developing accompanying wit the lightning strikes.

The position mapping of intense TLDS lightning on the weather Radar echo had good relationship on the west side of Taiwan, but TLDS has system noise at south corner of Taiwan non-regularly. The third flight of ASTRA on June 7, 2007 was hit by lightning at 20000-feet height during its climb. During its cruise flight on 42000 feet height at the same day, an ice cap plume above the anvil cloud was found from the aircraft. We used WISCDYMM cloud model initiated by a nearby WRF grid profile to simulate this cloud plume. The coming field experiment, SoWMEX/TiMREX-2008, will provide more complete information on these thunderstorm evolution.

1. Introduction

From May to June, the monsoon transition (Wang et al, 2004) causes the peak of precipitation at eastern Asia and Taiwan. Synoptic weather feature favors the frontal systems stationary (Mei-Yu front) in this region. Meso-scale convective cells (MCC) accompany with heavy rainfall and intensive lightning and hit western coast of Taiwan (figure 1). Chen et al. (2007) found the maximum heavy rainfall frequency axis occurs along the windward lower slopes (> 200 m) of Central Mountain Range (MCR). Meanwhile, the occurrence of heavy rainfall events (rain rates > 15 mm/h) have an early morning (~0600 LST) maximum and diminish after sunset. They also found that radar observations frequently show a NE-SW orientated rainband over northern TS at night and in the early morning with only scattered echoes over land during front disturbed days. Active thin convective lines are also frequently observed off the southwestern coast, which perhaps due to the interaction between the shallow land breezes and onshore decelerating flow. The studies in TAMEX (Johnson and Bresch,1991; Li et al.,1998; Yeh and Chen, 2002) suggested that the rainband over northern TS is mainly a result of the localized convergence between the pre-frontal barrier jet along the northwestern coast as a result of island blocking. The rainband frequently results in heavy rainfall over northwestern Taiwan as it moves inland. As the Mei-Yu front moves southerly, convective activities mainly occur over land and windward lower slopes during the day. It is expected that interaction between onshore flow and terrain determines the rainfall distribution over Taiwan, but is not well understood because of the lack of high temporal resolution island-scale data.

From 2006 to 2008, three-year intensive observation plans called Southwest Monsoon Experiment (SoWMEX) were organized in this season to collect detailed weather information and make better short-term prediction on rainfall. This study revised the heavy rainfall events from June 5 to June 8 in 2007 through the added observing sounding data, dropsonde from the ASTRA jet aircraft, and the lightning records surrounding Taiwan in SoWMEX-2007 field experiment to examine the concepts mentioned in the previous papers.

2. Data resources

Six flights of ASTRA jet operated by AIDC (Aerospace Industrial Developing Corp., based on Taichung airport) were arranged in the early morning (0600 LST) of June 5 to 10, 2007. The flight route covered a north-south cross section over TS region, and extended the observing range including Hongkong FIR and Philippines FIR (figure 2). These six flights spent near 3 hours in the air for ~ 15 Vaisala RD93 dropsonde (Hock and Franklin, 1999) to profile the atmosphere. NCAR ASPEN (Atmospheric Sounding Processing Environment) software was used to process these dropsonde original data.

The lightning records, the location of intra-cloud & inter-cloud (ICs) and cloud-to-ground (GC), came from The Vaisala total lightning detection system (TLDS) of Taiwan Power Company (TPC). TLDS has VHF (110-118MHz) interferometric array antenna for lightning location detection with 1 km accuracy, and LF (300 Hz-3 MHz) Discrimination for CG lightning characteristics identification. Seven TLDS stations were built by TPC in 2005 (Wang and Liao,2006; figure 3). Six of TLDS stations spread uniformly at the north and central Taiwan, but only one TLDS station locates at Little Okinawa Island, southwestern Taiwan. TLDS radio signal is jammed occasionally in this area and causes noise.

In addition to observations, the numerical simulation of Weather Research & Forecasting Model (WRF) was used to simulate 24 hourly evolution of air flow over TS and the land in 3-km spatial resolution. The initial condition of WRF comes from NOAA/NCEP re-analysis global 1×1 degree resolution dataset on 1200UTC, June 6 of 2007 was used to execute 24-hour simulation.

The Wisconsin Cloud Dynamical and Microphysical model (WISCDYMM) was used to diagnose the deep convection cell over TS at 2100 UTC, June 6 to 0000UTC, June 7. This cloud model is a kind of three dimensional dynamical & microphysical model. It is a quasi-compressible, time-dependent, non-hydrostatic cloud model. The microphysical processes are parameterized by the bulk method with water substance categorized into six types: water vapor, cloud water, cloud ice, rain drops, snow, graupel & hail. There are 38 microphysical processes (nucleation, condensation, evaporation, freezing, melting, sublimation, deposition, auto-conversion and accretion) included in the model (Wang, 2003).

3. Results

3.1 flight weather and logs

During SoWMEX-2007 intensive observation period, the shallow frontal system moved southerly and slowly over TS with non-organized convective cloud system embedded along the wind-shear line. The 24~48 hour weather forecast gave faster speed for this front movement and significant land rainfall on southern Taiwan. The expected weather scenario with heavy rainfall didn't happen at southern Taiwan, but a lot of thunderstorms hit northern Taiwan with local flood events which made forecasters surprised. Figure 4 shows the location of weather factors on June 10, 2007. The intensity of low-level jet was not strong enough to push MCC inland in this week. Table 1 gives summaries for the six flight logs during SoWMEX-2007. For ASTRA jet takeoff at 0600 LST, thunderstorms surrounded the airport from June 5 to June 9, and they caused the temporal close for airport operation on June 5, 7 and 10 during ASTRA jet landing. The third flight (June 7) was also struck by lightning during its climb stage on 20000 feet height. We found the nose dome of jet aircraft was also hut by hail after landing.

3.2 observations

For diagnosing the structure of slow moving front system, we used potential virtual temperature θe and the wind field from dropsonde profile #1 to dropsonde profile #5 to present the daily evolution on the north-south cross segment of front system (Figure 5). It shows that the unstable layer ($\Delta\theta e/\Delta z < 0$) was limited below the middle atmosphere at north of the front. The wind shear line over TS was shallow (below 900 hPa), and the pre-front environment at south was stable through this intensive observation week.

The hourly location of ICs and CG lightning were mapped with the radar echo images for tracking storms moving in this study. During the morning of June 5 to June 8, several significant the lightning clusters moving onshore are found at western coast of Taiwan. The peak value of hourly lightning number in the mornings was 3293 (0700 LST, June 5), 2088 (0600 LST, June 6), 1500 (0500 LST, June 7) and 660 (0800 LST, June 8). Figure 6 shows their spatial distribution with Radar echo at 0600 and 0900 LST each day. In addition to the mesoscale vortex (called M-vortex) related to the frontal shear-line, it seems another vortex (called N-vortex later) existed over north Taiwan to induce the onshore thunderstorms. When the Sun rose, N-vortex deceased its intensity and M-vortex moved southerly to induce another thunderstorm cluster inland southern Taiwan. Figure 7 gives the time evolution of lightning number during this week. The lightning strikes arrive maximum in the morning and decay soon when the storms on land. The M-vortex and N-vortex could be explained by the cited papers in section 1.But the lightning distribution with these vortexes is never discussed before.

3.3 model simulation

(a) WRF mesoscale model

In order to check the evolution of N-vortex and M-vortex mentioned above, we used Weather Research & Forecasting Model (WRF) version 2 to trace the hourly evolution of jet flow on 850 hPa and vertical motion field from 1200UTC June 6 to 1200UTC June 7, 2007. The NCEP Reanalysis 1*1 degree global dataset was used as the initial condition for WRF to run 3-km spatial resolution and 24-hour simulation around Taiwan. The model reveals the barrier effect of MCR on the pre-frontal southwestern jet on 850hPa. A significant mesoscale low system (M-vortex) was induced along the shear-line over TS and propagated easterly. Onshore air flow blew northerly and grew into a short-life wave vortex (N-vortex) at the north end of MCR (Figure 8). When the shear-line moved southerly, the M-vortex kept bringing convective flow into the southwestern Taiwan and the N-vortex became weak and disappeared soon.

(b) WISCDYMM cloud model

The grid profile of WRF at 24.01N, 118.89E on 2100UTC June 6, 2007, was used as the initial profile for WISCDYMM model. From the mixing ratio of bulk cloud water (q_c) and bulk cloud ice (q_i) from 3600 seconds to 5400 seconds of

WISCDYMM output, we found the convection in M-vortex could arrive 17 km height with maximum vertical velocity 30 ms^{-1} at 12 km, but the over-shooting ice cap above the anvil cloud was not simulated well (figure 9) compared to the photo image in figure 10.

4. Summaries

Five dropsondes' profile consisted of a north-south 2D section on the frontal system over TS during SoWMEX-2007. The potential virtual temperature and wind field showed that the shear-line was shallow with not well-organized convective cells along and beyond the front, but the thunderstorms accompanied with two meso-vortexes brought heavy rainfall on the coast cities of Taiwan every morning. WRF model also simulated this mesoscale weather pattern well for the morning of June 7. WISCDYMM cloud model was used to simulate the deep convective cell well, but the small-scale ice cap above the anvil cloud was not simulated.

Hourly lightning data is the specific data source to trace the evolution of inland meso-vortexes during SoWMEX-2007. The spatial location between lightning and Radar echo at middle and northern Taiwan is reasonable, but the situation was fragmental at southern Taiwan. The radio interference not only happens in TLDS lightning signal detection, but also in the weather radar images at Central Weather Bureau Chigu Radar station at southwestern coast corner of Taiwan.

The SoWMEX/TiMREX in 2008 (May 15 to June 30, 2008) will add two polarized Radar systems on the southern Taiwan region to monitor onshore MCC. These Radar systems (NCAR S-POL and National Sicence Council TEAM C-band Radar) will address the cloud physical parameters and the precipitation intensity retrieval for weather forecasting improvement (Jou, 2007). Intense radiosonde network, including balloon, aircraft and ship platforms, will proceed 3-hour to 6-hour interval every day to answer the following questions:

(1) How does air flow along the southwestern coast of Taiwan in the early morning? Does the land surface heating cause weaker barrier jet after sunrise?

(2) How do the thunderstorms develop with the meso-vortexes? How to identify lightning characteristics from polarized Radar products?

(3) How do the variations in upstream conditions (stability, moisture, thermodynamic properties and winds) affect the onshore flow intensity, and how different on the timing and locations of heavy rainfall occurrences?

Following the lightning modeling research works (Helsdon et al.,1992；MacGorman and Rust,1998), we also plan to develop the off-line lightning module with WISCDYMM cloud model, and use TLDS observation to verify the model simulation.

5. References

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Table 1: the six flight logs of ASTRA jet during SoWMEX-2007.

Mission	Date	Operation time (LST)	Dropsonde numbers	Note
1	2007/06/05	05:59~10:27 11;31~11:56 (4 hr ,53 min)	15	CCK airport closed when ASTRA ready to landing
2	2007/06/06	06:05~09:55 (4 hr ,18 min)	13	Medium turbulence Raining during landing
3	2007/06/07	06:14~09:21 (3hr ,20 min)	8	Lightning strike during climb Dome nose hit by hail
4	2007/06/08	05:59~08:25 (2 hr ,45 min)	8	Thunderstorms on the takeoff path Airport flood
5	2007/06/09	05:55~10:10 (4 hr ,15 min)	14	Raining and medium turbulence over ocean
6	2007/06/10	05:50~07:27 (2 hr ,37 min)	8	Fuel indicator failed Abort mission for entering HK FIR Heavy rain at CCK airport after landing
total		22hr 08 min	66	

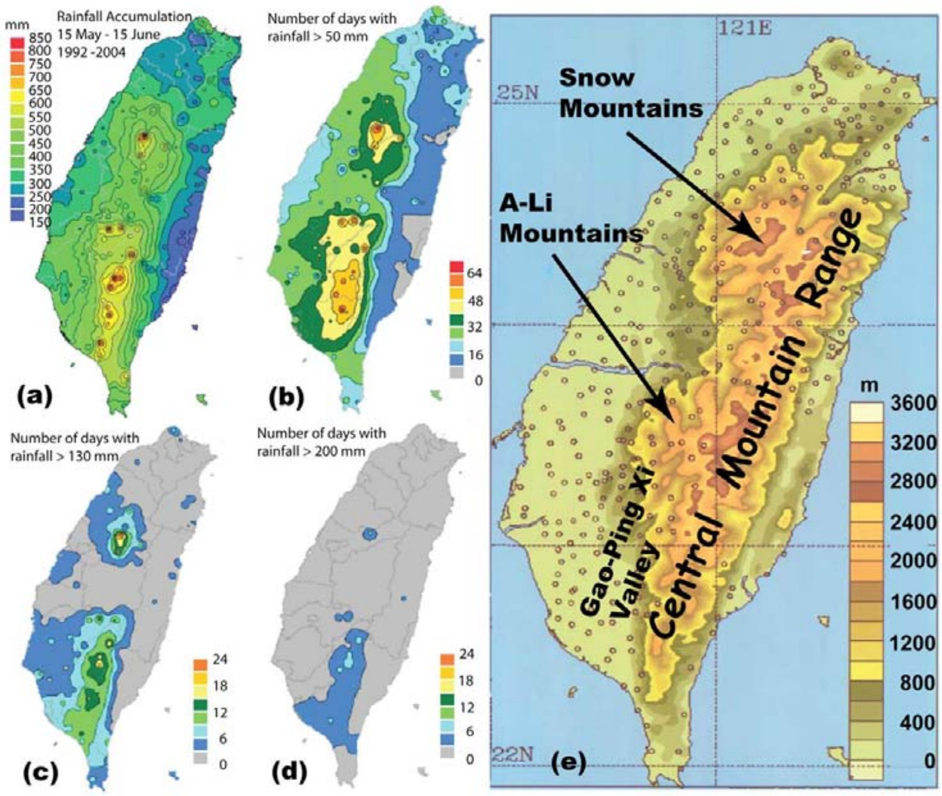

Figure 1: The statistics of heavy rainfall occurrences in Taiwan (1992~2004) and Taiwan island terrain (from Central Weather Bureau).

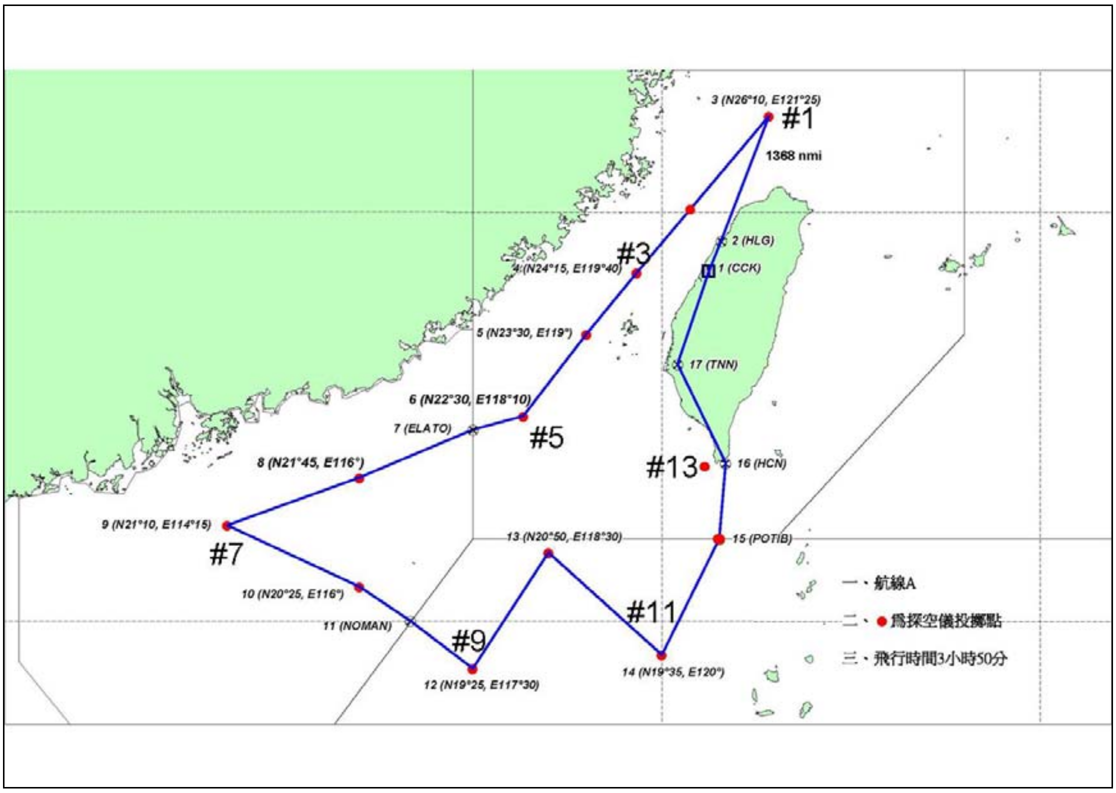

Figure 2: ASTRA jet route in SoWMEX-2007. Red points with the number mean the dropsonde launch location. The square mark (CCK) is the jet base and the flight route is clockwise.

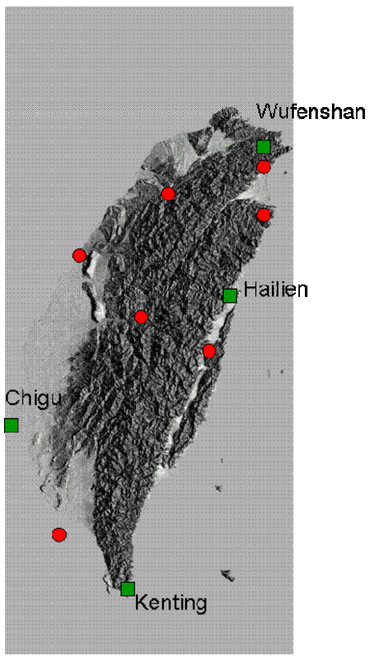

Figure 3: Total Light Detection System (TLDS) stations (solid red circle) and Central Weather Bureau weather Radar stations (solid green box) in Taiwan.

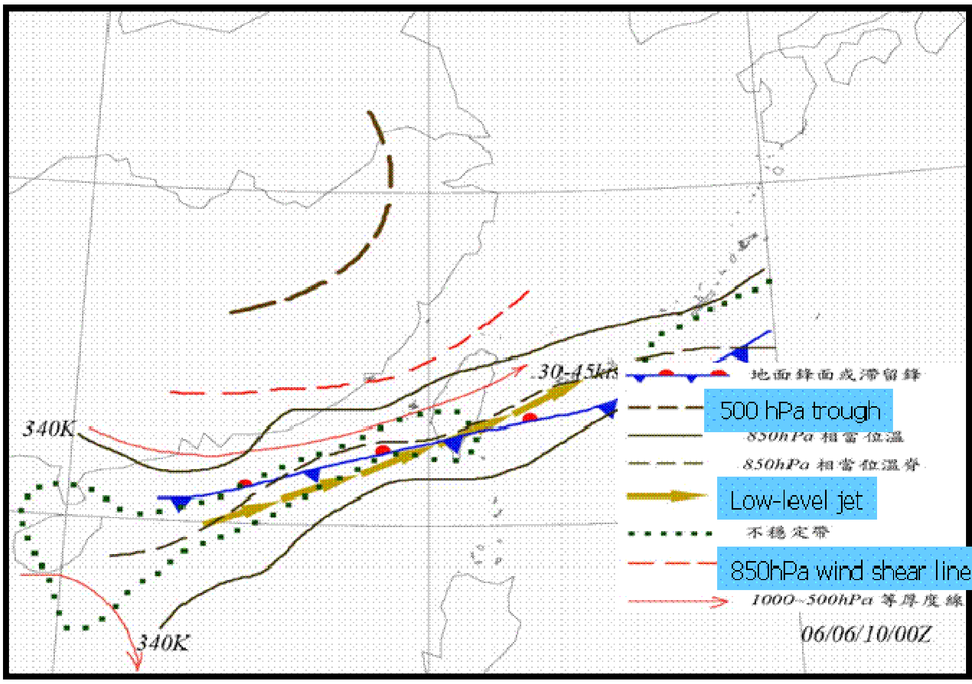

Figure 4: The significant weather factors on 0000UTC, June 10, 2007 (produced by Central Weather Bureau).

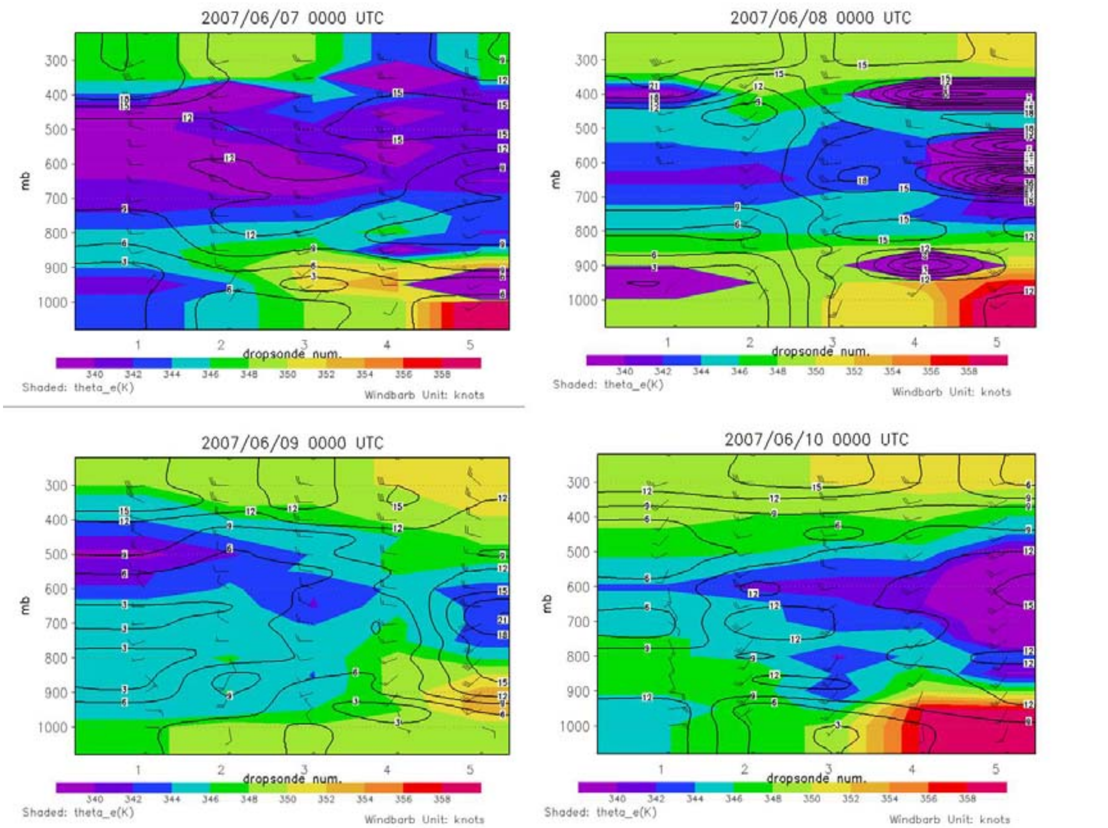

Figure 5: the four-day cross section of virtual potential temperature field (color shaded, unit:°K) and wind field (unit:ms^{-1}) from 5 dropsondeprofiles (#1~#5, left to right) over Taiwan Strait in figure 2.

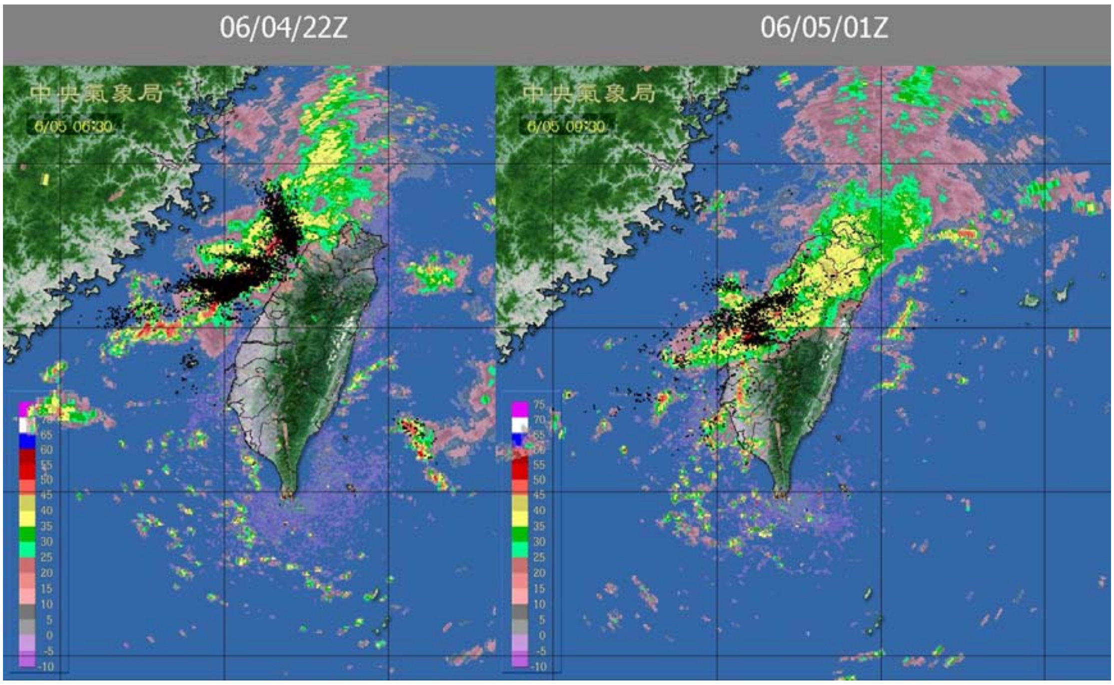

Figure 6 (a): Lighting strikes (black points) on the weather Radar echo in 2200UTC, June 4 (left panel) to 0100UTC, June 5, 2007 (right panel).

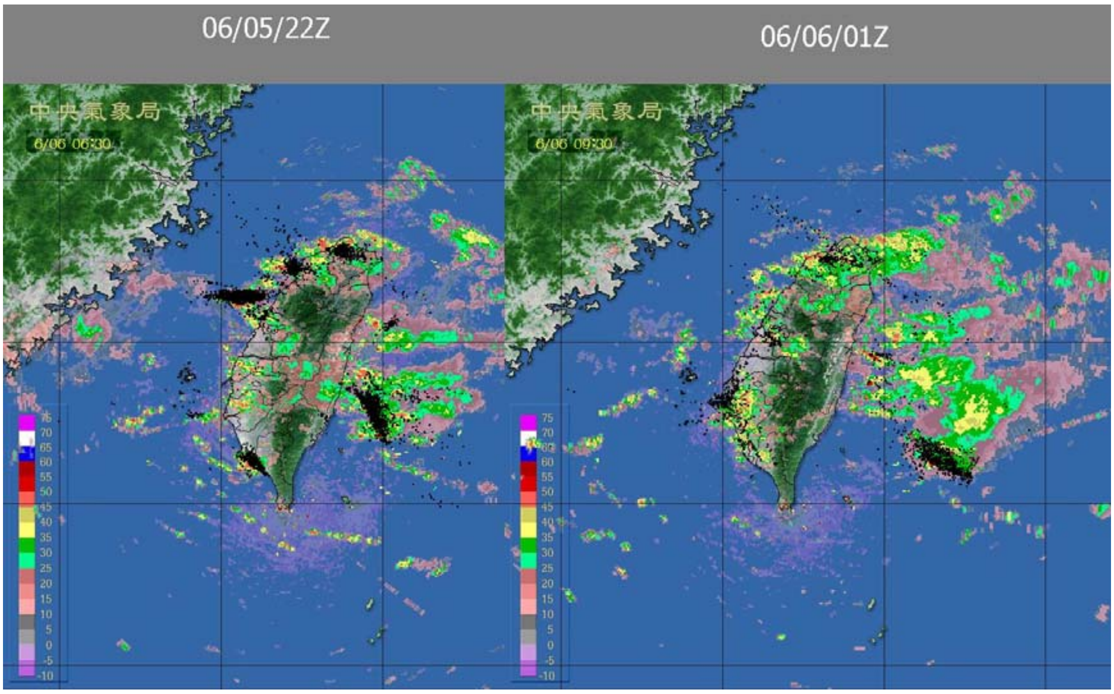

Figure 6 (b): Lighting strikes (black points) on the weather Radar echo in 2200UTC, June 5 (left panel) to 0100UTC, June 6, 2007 (right panel).

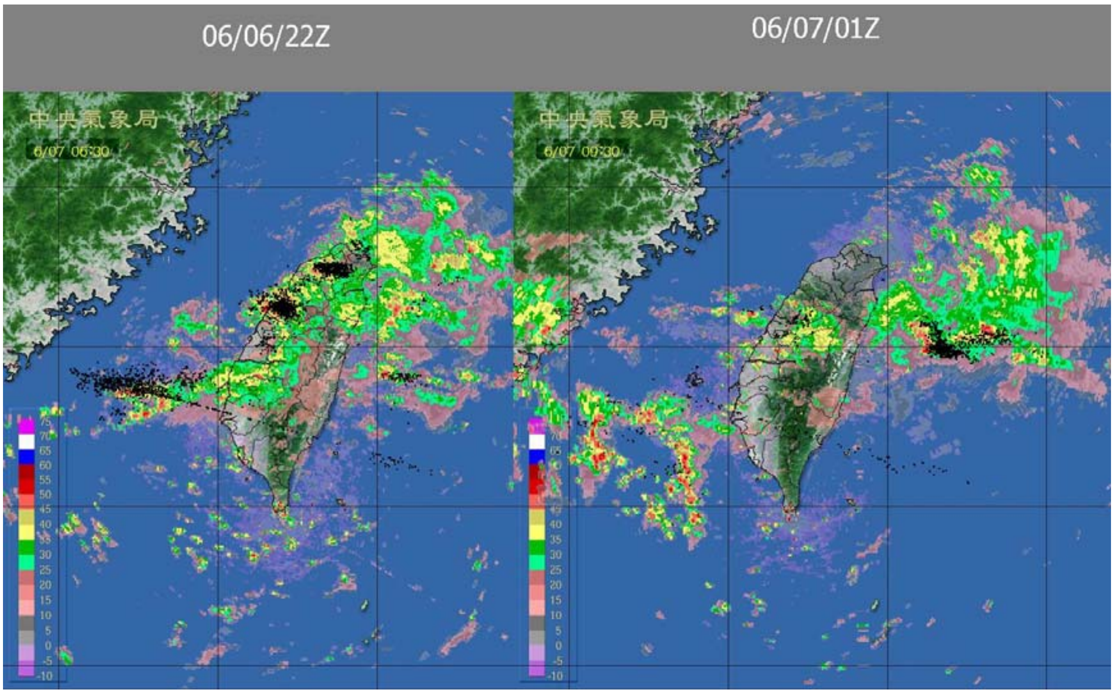

Figure 6 (C): Lighting strikes (black points) on the weather Radar echo in 2200UTC, June 6 (left panel) to 0100UTC, June 7, 2007 (right panel).

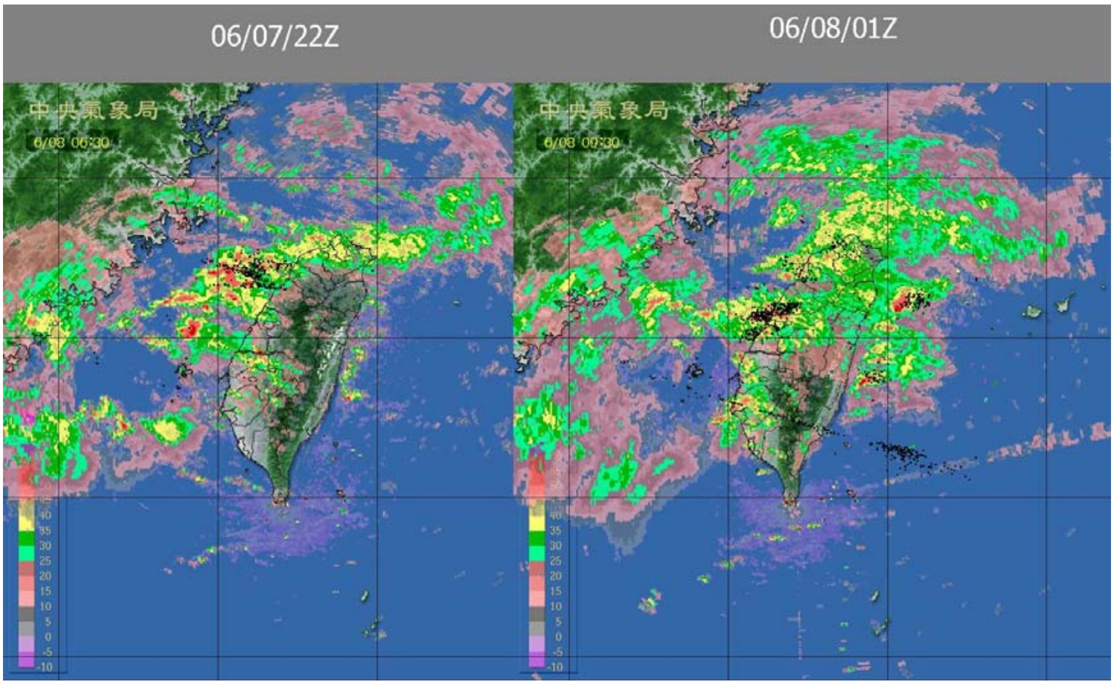

Figure 6 (d): Lighting strikes (black points) on the weather Radar echo in 2200UTC, June 7 (left panel) to 0100UTC, June 8, 2007 (right panel).

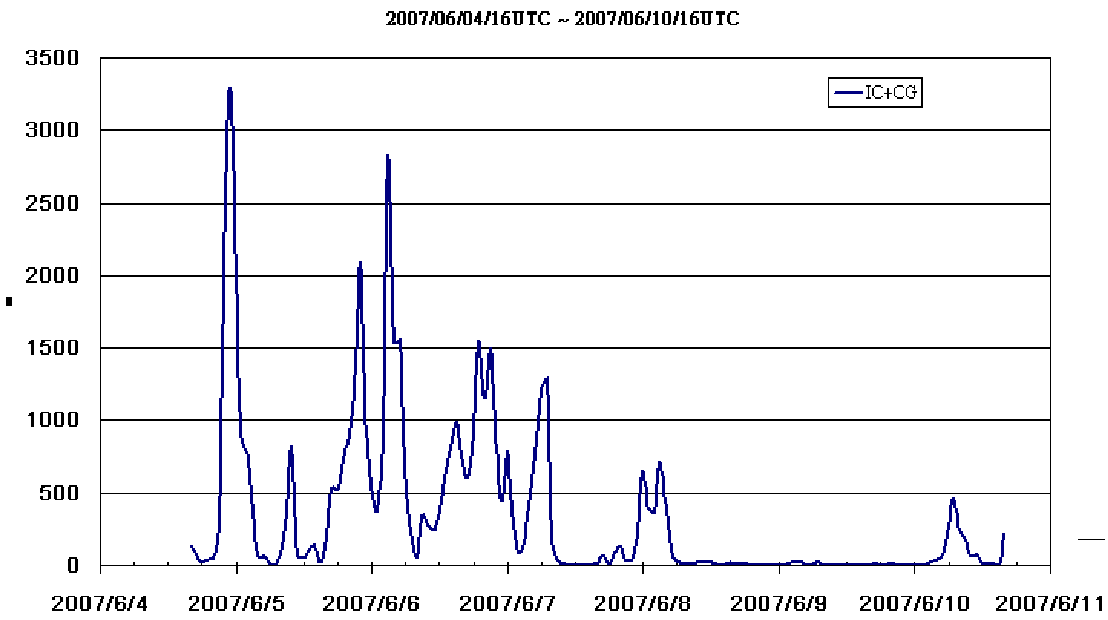

Figure 7: the hourly IC and CG lightning number detected by TLDS around Taiwan from 1600UTC, June 4 to 1600UTC, June 10,2007.

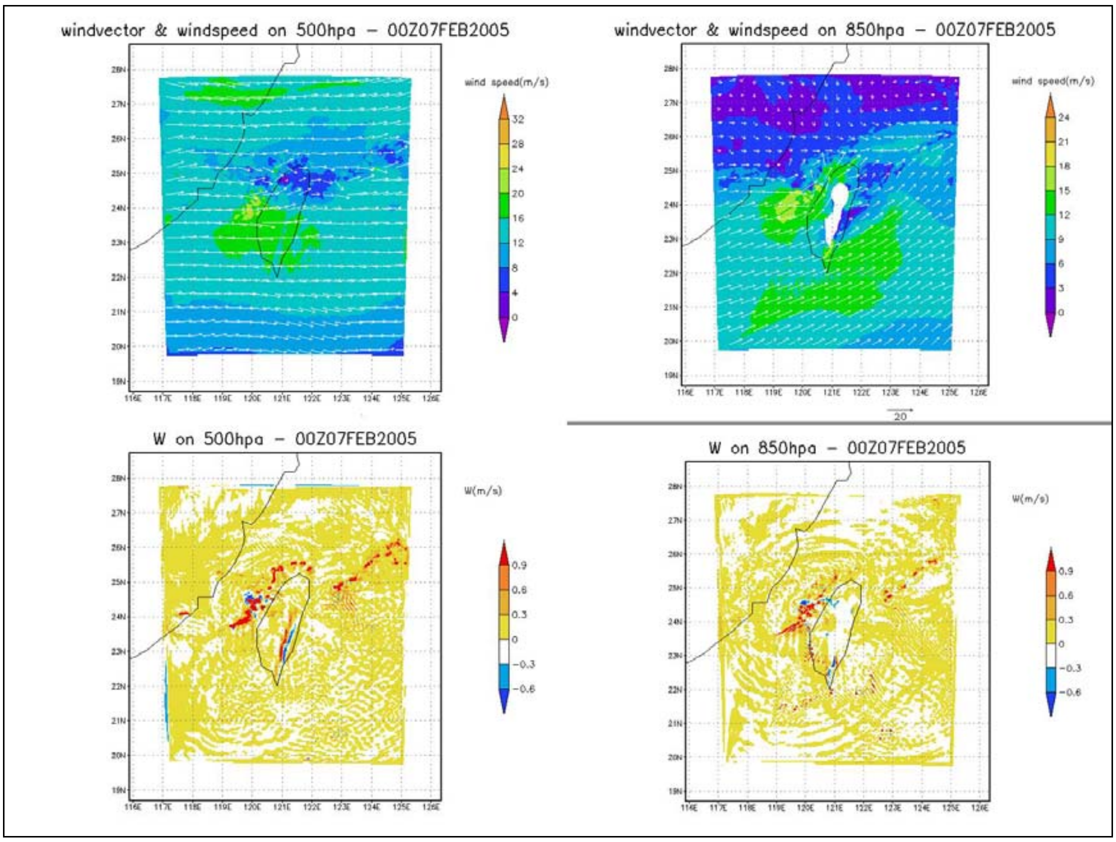

Figure 8: the horizontal wind field and vertical velocity simulation on 0000UTC, June 7,2007 by WRF model (see the content).

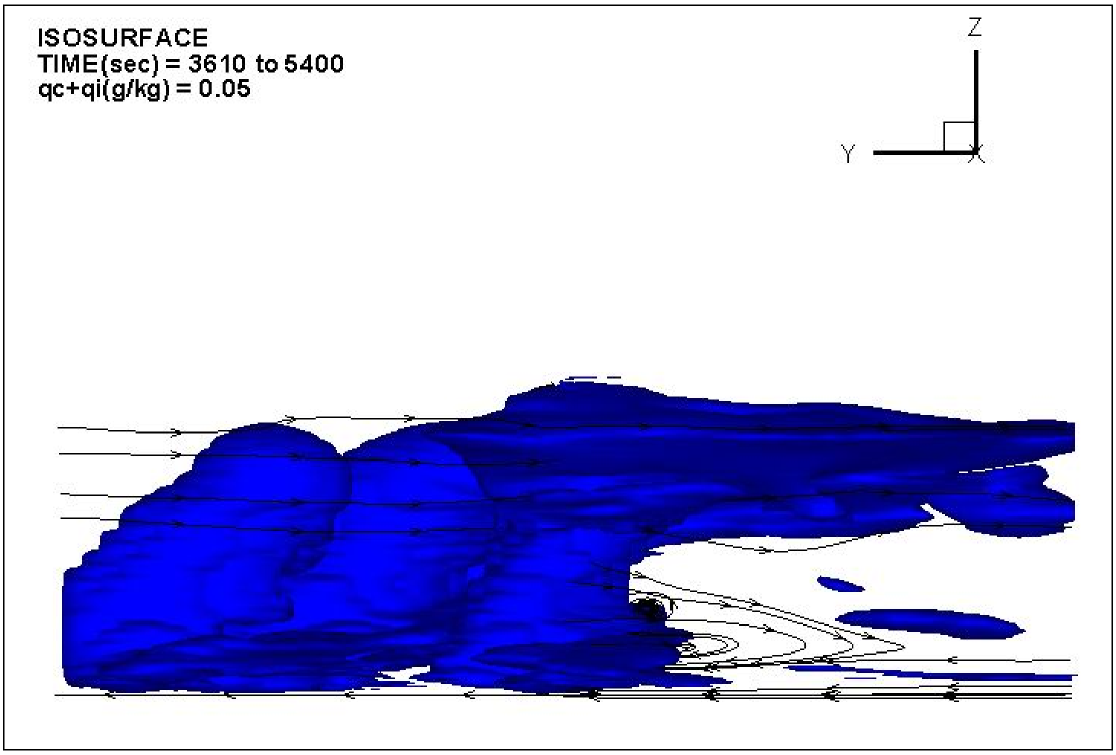

Figure 9: mixing ratio isosurface (0.05 g kg^{-1}) of bulk cloud water (q_c) and bulk cloud ice (q_i) from WISCDYMM (see the content). The left side is north and the east points into the page.

Figure 10: the anvil cloud with the ice cap on 42000 feet cruise layer of ASTRA jet. The geo-location near the dropsonde #4 in figure 2.