Multi-scale Simulations of a Mei-Yu Front accompanied by a Drifting Meso-cyclone with a Global Mesoscale Model

B.-W. Shen[1], W.-K. Tao[2], R. Atlas[3], J.-D. Chern[4], S.-J. Lin[5]

1:UMCP/ESSIC; 2:NASA/GSFC; 3:NOAA/AOML; 4:UMBC/GEST; 5: NOAA/GFDL

Introduction:

During early summer when the northwest monsoon transitions to the southwest monsoon, a frontal system commonly occurs that extends from southern Japan to southern China. This quasi-stationary front is known as the Mei-Yu front in Taiwan and China and the Baiu front in Japan. Areas of embedded mesoscale convection within this front can cause long lasting, heavy precipitation. The Mei-Yu front is usually associated with strong low-level wind shear but a weak temperature gradient. Organized meso-α- and/or meso-β-scale convective systems can be embedded within the frontal zone while new convective cells at the meso-γ scale successively form in the upstream direction. These multi-scale weather phenomena (Fig. 1) are a challenge to both global and mesoscale modelers.

Local prediction of the Mei-Yu front in Taiwan and the surrounding area is even more challenging due to the complicated mechanical and thermal effects of surface forcing (e.g., the land-sea contrast of the Taiwan Strait and the high-aspect-ratio Central Mountain Range, which has a length of about 300 km, a width of only 120 km, and an average height of 2 km with a peak value of 3.9 km). Previous studies based mainly on mesoscale models have shown the importance of better representing the terrain and broadening the coverage of the computational domains in improving local weather forecasts. In a recent study with the NCAR MM5 using 6-km horizontal resolution in a nested domain, Zhang et al. (2003) successfully simulated the 36 h evolution of an MCS along a Mei-Yu front accompanied by a mesoscale cyclone.

Traditionally, global circulation models (GCMs) have lacked the resolution and the sophistication in their physical processes to simulate these multi-scale features. Thanks to the recent advancement in high-end computers, researchers at the Japan Earth Simulator Center were able to simulate realistic meso-α phenomena in a Mei-Yu front with the first global mesoscale-resolving GCM (Ohfuchi et al. 2004), even though the meso-β MCS was somewhat distorted. Recently, a global mesoscale model with finite-volume dynamics (also known as the fvGCM) has been deployed on the NASA Columbia Supercomputer. Its performance in simulating mesoscale eddies (e.g., the Catalina Eddy and the Hawaiian wake) and predicting hurricane track and intensity during the 2004 and 2005 Atlantic hurricane seasons has been documented in Atlas et al. (2005) and Shen et al. (2006a-c). In this study, the impact of increasing the resolution and the sensitivities of various cumulus parameterizations will be addressed for a real-case simulation of a Mei-Yu front and accompanying meso-cyclone.

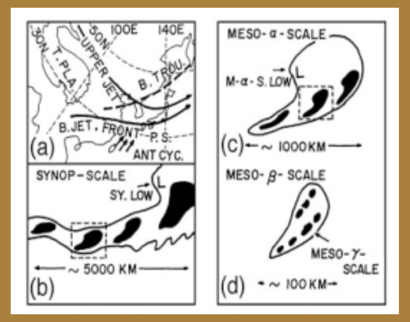
The Model:

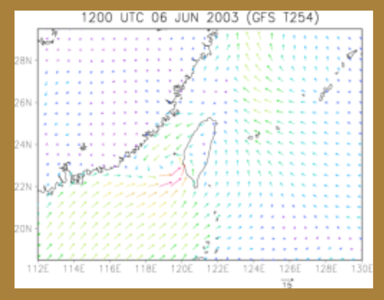
The fvGCM has three major components: 1) finite-volume dynamics (Lin 2004), 2) NCAR physics, and 3) an NCAR land surface model. Initial conditions are obtained from the state-of-the-art data assimilation system at NOAA/NCEP. For moist convective processes, the Zhang and McFarlane(1995, ZM95) and Hack (1994) schemes are applied sequentially for deep and shallow convection, respectively. Recently, the NCEP SAS (simplified Arakawa and Schubert) scheme (Pan and Wu 1995) has been implemented as an alternative deep convective scheme.

Numerical Experiments:

In this study, a series of 48-h simulations of the Me-Yu front initialized at 1200 UTC June 06, 2003 (Fig. 2) are conducted for two deep convection schemes (SAS and ZM95) and at three different resolutions (0.5°, 0.25°, and 0.125°). Results from the SAS parameterization and test runs with ZM95 are discussed first and verified against NCEP GFS analysis data, NASA QuikSCAT 0.5° seawind data, and CWB (Central Weather Bureau in Taiwan) meteorological products .

Figure 1 depicts the meso-cyclone that appeared southwest of Taiwan near (23°N, 119°E). South of the cyclone, a short frontal line with an east-west orientation was identified by a wind shift line. The cyclone moved northeastward over Taiwan, passing over the CMR before propagating further downstream. While an eastern branch of the front formed and trailed behind the vortex, the western branch of the front remained quasi-stationary south of Taiwan for more than 36 h (Fig. 2). For this particular case, QuikSCAT data captured the locations of the meso-cyclone quite well as the vortex moved away from Taiwan but did not resolve the front. In comparison, the 48 h 1/8° run gives remarkable positional predictions of the drifting vortex and realistically simulates the quasi-stationary nature of the Mei-Yu front, although the western branch of the front is shifted slightly southward because of strong channeling effects. The simulations run at coarser resolutions are less accurate in terms of the narrow frontal zone and the vortex locations.





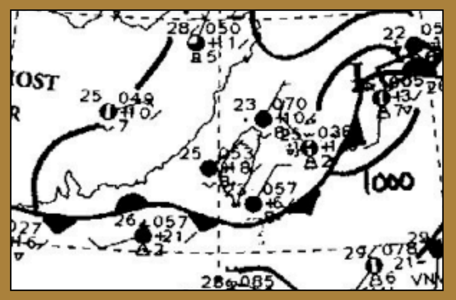


Figure 1 (left): Schematic illustrations of the multi-scale structures of the Mei-Yu frontal zone (from Ohfuchi et al. 2004). Figure 2 (middle): Initial surface winds at 12Z 6 June, 2003. Figure 3 (right): Surface analysis valid at 12Z 8 June, 2003

Valid at 00Z June 7 | Valid at 12Z June 7 | Valid at 12Z June 8

GFS

Quik-SCAT

1/8°

1/4°

1/2°

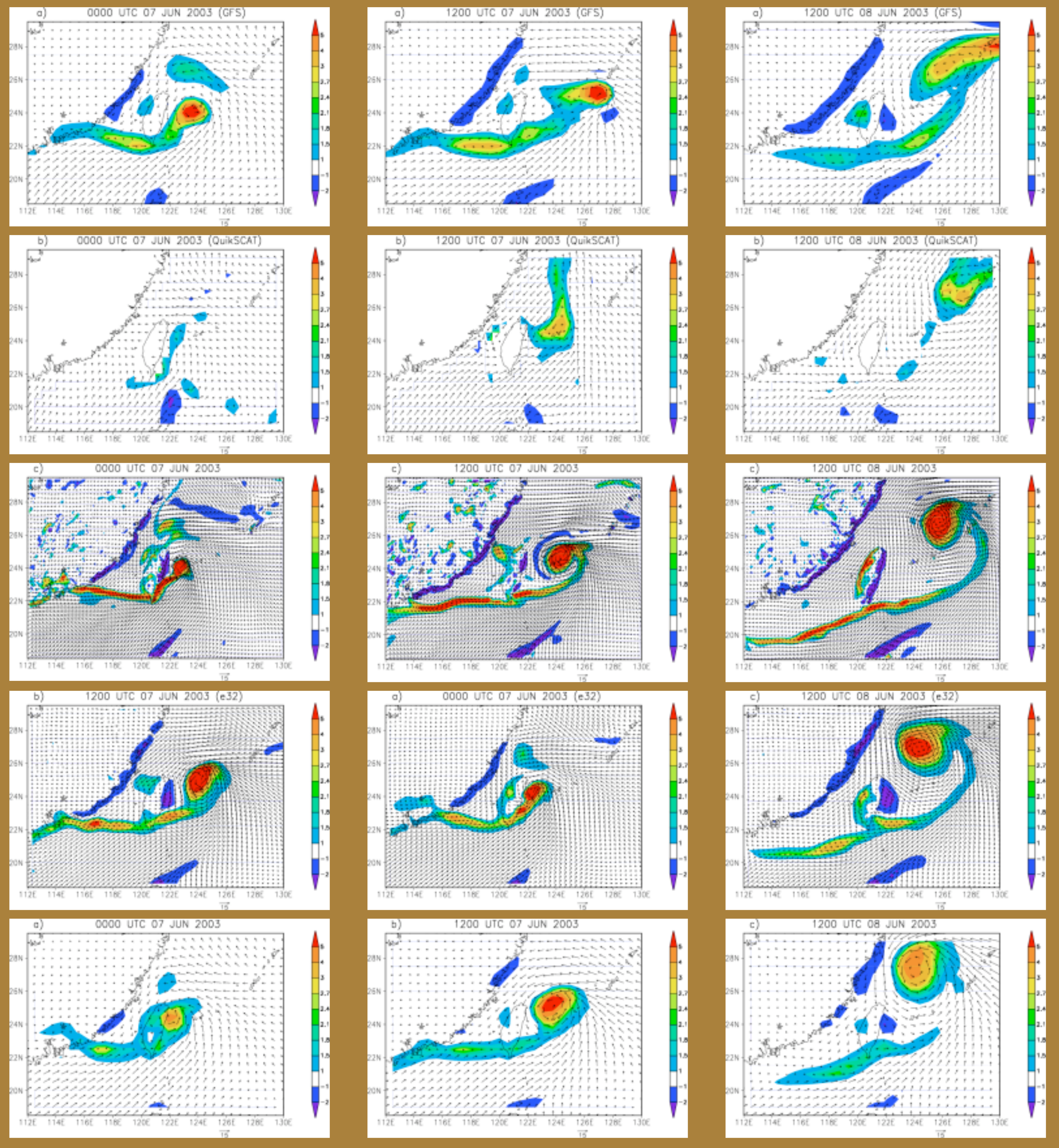


Figure 4: Time evolution of surface wind and vertical vorticity valid at 00 and 12z 7 June and 12z 8 June 2003 from the NCEP GFS analysis, QuickSCAT seawinds, and the 0.125°, 0.25°, and 0.5° runs, respectively from top to bottom.

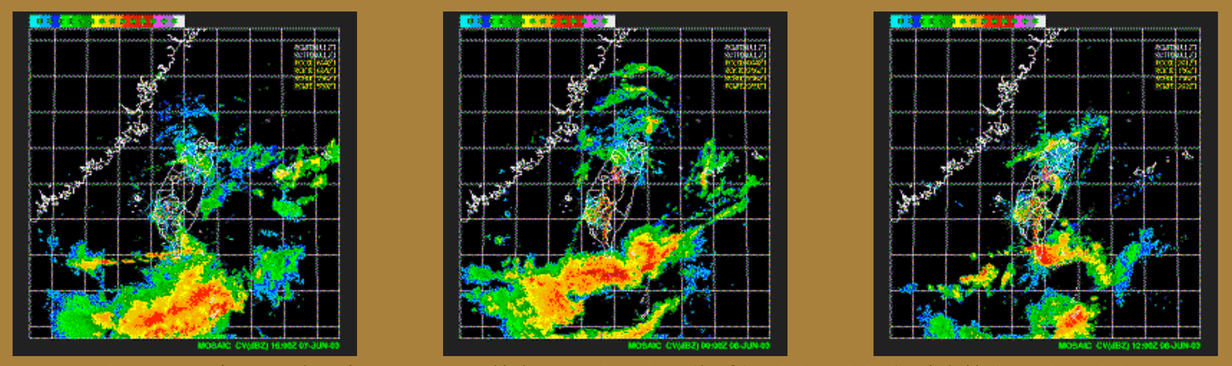
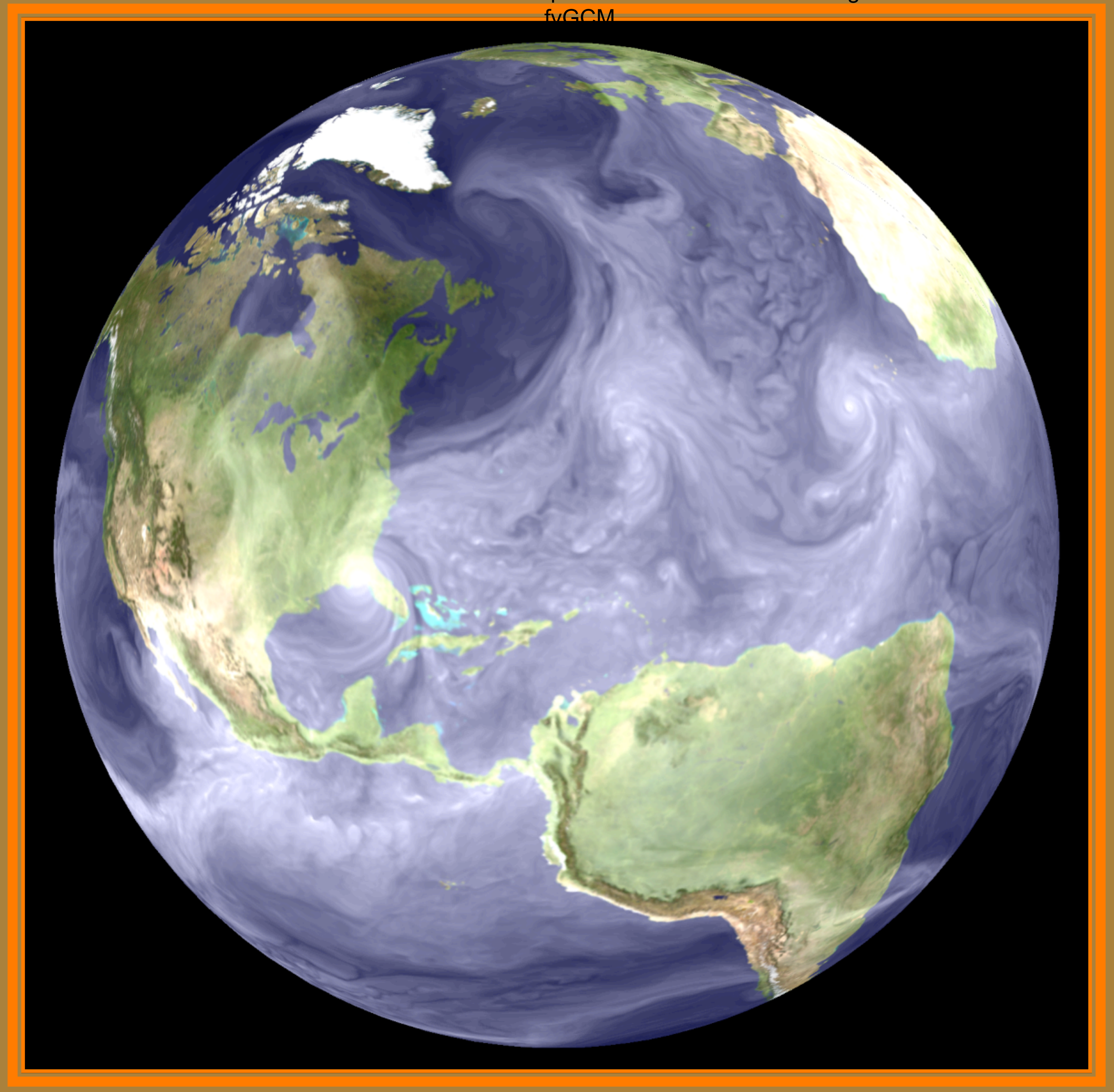


Figure 5: Composite radar images valid at 16Z 07 (left), 00Z 08 (middle), 12Z 08 (right) June 2003.

5-day forecast of total precipitable water

initialized at 0000 UTC 1 September 2004 with the 1/8 degree fvGCM



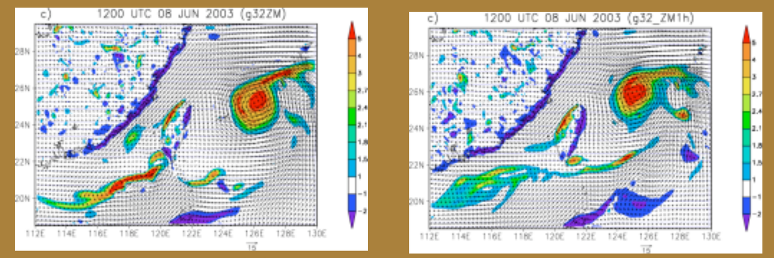


Figure 6: Sensitive tests with ZF95 on the simulation of the Mei-Yu Front. The relaxation time is 3 h and 1 h, respectively.

Concluding Remarks:

In this study, a series of 48-h simulations of a Mei-Yu front accompanied by a drifting meso-cyclone are conducted with a global mesoscale model and then compared to the NCEP GFS T254, NASA QuikSCAT 0.5° seawind data, and CWB weather products. It is shown that: 1) the newly-implemented SAS is more applicable over a wider range of resolutions than the ZM95; 2) the predicted locations of the meso-cyclone with SAS and ZM95 are comparable; 3) the quasi-stationary front is better simulated at 0.125° with SAS than with ZM95; 4) along the frontal zone, the embedded mesoscale wavelike structures in vorticity and convergence are better revealed by the 0.125° run with SAS; 5) the Mei-Yu front simulation with a reduced relaxation time of 1 h in ZM95 better agrees with the GFS analysis data than the control run with a relaxation time of 3 h.

However, it should be noted that further analysis of Figs. 3, 5c and 6a is desired; 6) the performance of CPs on multi-scale simulations depends on grid spacing and the temporal/spatial scales of the individual weather system, which poses a challenge for determining universal parameters for CPs.

References and Notes:

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