Data assimilation impacts on coastal heavy rainfall forecast during SoWMEX/TiMREX (2008) IOP#8

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Outline

- Introduction

IVT and rainfall prediction

Terrain effect and rainfall prediction

- Data and Method

- Result

Cycling run including GPSRO data to improve rainfall prediction and large-scale IVT and TPW

Cycling run to improve initial conditions of boundary layer and blocking of airflow over southwestern Taiwan due to antecedent precipitation

- Summary

Introduction

- The vertically integrated horizontal water vapor flux or integrated vapor transport (IVT) is defined as

  , $$IVT = \frac{1}{g}\int q_v V dp$$

- where g (m s^{-2}) is the gravitational acceleration, q_v (kg_{water} kg_{air}^{-1}) is the layer average water vapor mixing ratio between each pressure level, and dp (Pa) is the depth between each pressure level over which q_v is computed, with units of kg m^{-1} s^{-1}.

- Smith et al. (2010) presented a detailed case study of a landfalling atmospheric river, which produced heavy orographic rainfall over Northern California during 29-31 December 2005. They showed that strong water vapor fluxes associated with cross-barrier southwesterly flow and along-barrier flow (up-valley southerly flow) over the Northern California mountain complex contributed to heavy rainfall along the windward coastal ranges, the windward mountain interior (Sierra Nevada Range), and the base of the Siskiyou Range.

- Tu and Chen (2011) found that for the unusual 31 March 2006 heavy rainfall event along the south shore of Oahu, the moisture transport by the southerly wind is important for the development of heavy rainfall. The low-level (850-hPa) southerly winds between a Kona storm (subtropical cyclone) to the west and an anticyclone to the east brought in high TPW (>35 mm) and high θ_e air from the south.

SSM/I TPW

NCEL FNL TPW

NCEL FNL 850hPa θ_e

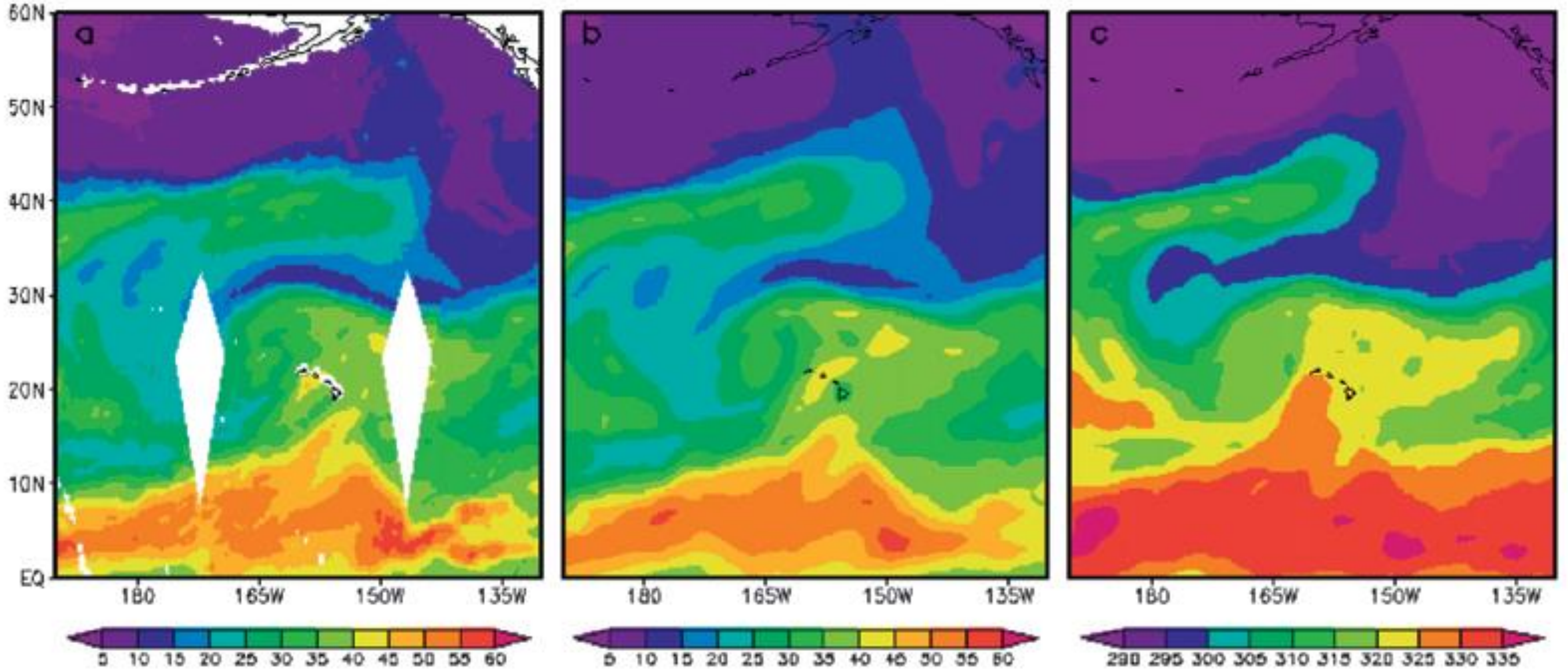


FIG. 12. The daily mean (a) SSM/I and (b) NECP FNL TPW (kg m^{-2}), and (c) NCEP FNL θ_e (K) at 850 hPa on 31 Mar.

- Tu and Chen (2011) also found that for the unusual heavy rainfall case on the south shore of Oahu, the orographic lifting of convective cells as they moved onshore to the Koolau Mountain Rainge resulted in enhancement of convective cells and the development of heavy rainfall.

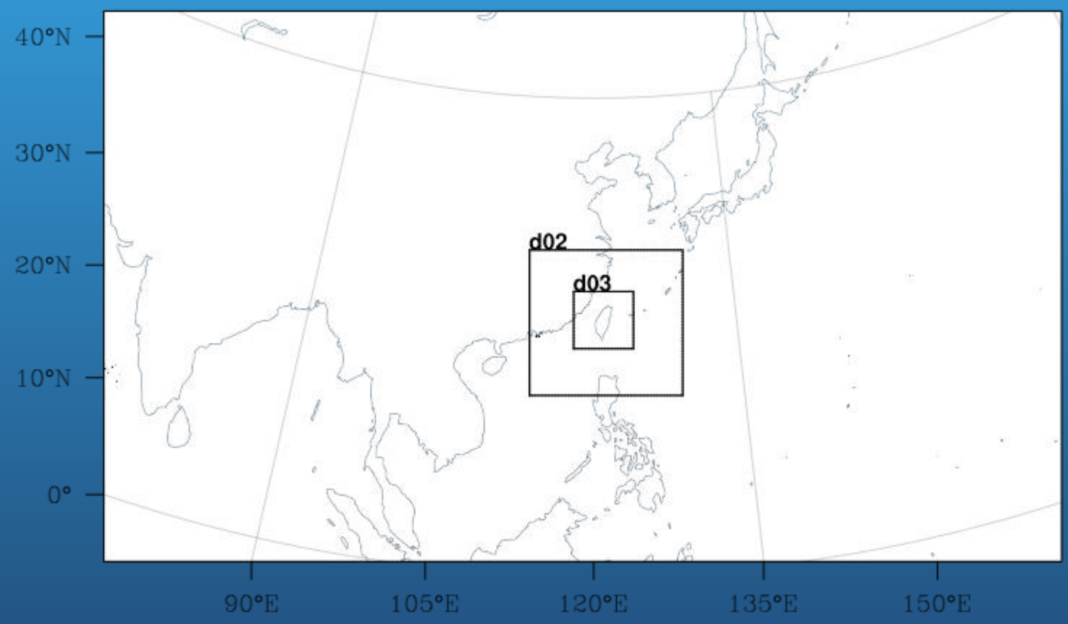
- Tu et al. (2013) found that for the TiMREX IOP#8 over southwestern Taiwan, during daytime of 16 June, pronounced orographic blocking of the warm, moist south/southwesterly flow occurred because of the presence of relatively cold air at low levels with an offshore wind component as a result of rain evaporative cooling from antecedent rainfall there. No sea-breeze/upslope flow developed in the afternoon hours without significant orographic lifting aloft. Thus, rainfall maximum occurred over southwest coast of Taiwan rather than the CMR.

- In this study,

(1) we will study the impact of assimilating GPSRO data and/or TiMREX and GTS data on the flow patterns, IVT and TPW fields in the model.

(2) We will investigate the impacts of terrain and antecedent rain evaporative cooling on flow and rainfall patterns during IOP#8.

Model setup:
GPSGTS (Cycling): every 6 h from 6/14 00Z-6/15 12 Z then forecast till 6/17 00Z
NoGPS (Cycling): Same as GPSGTS run but without GPS RO data.
NoDA: forecast from 6/15 00 Z to 6/17 00Z. The first 12 hour forecast is considered as model spin up.



- The three domains for WRF model simulation with horizontal resolution of 27 km, 9 km, and 3 km, respectively.

Model setup:

- -45 sigma levels from the surface to the 30-hPa level
- -Rapid Radiative Transfer Model (RRTM)
- -Goddard shortwave schemes
- -Yonsei University (YSU) planetary boundary layer scheme
- -Goddard microphysics
- -Kain-Fritsch cumulus parameterization scheme
- -The cumulus parameterization is not applied in the 3 km resolution domain (domain 3).

- Two experiments are set up to investigate the impact of data assimilation of GPS RO soundings of reflectivity and GTS observations: (1) with assimilation of GPS RO soundings, global telecommunications system (GTS) observations, TiMREX sounding, and some available satellite observations (GPSGTS run); and (2) with assimilation of only GTS observations, TiMREX data and some available satellite observations (NoGPS run).
- The GTS and some available satellite observations include SYNOP, METAR, SHIP, BUOY, TEMP, AIREP, PILOT, SATEM, SATOB, and QSCAT. We set up a WRF 3DVAR cycling run for this study. The assimilation experiments are performed with continuous cycling with a ±1.5-h assimilation window.

- GPSGTS and NoGPS cycling run:

- The National Centers for Environmental Prediction Final Analysis (NCEP FNL) data, with an one-degree horizontal resolution, provide the initial and boundary conditions for the cycling run from 6/14 00Z-6/15 12Z.

- GFS data provide the boundary conditions for the forecast from 6/15 12Z-6/17 00Z.

- NoDA run:

- GFS data provide the initial and boundary conditions for the forecast from 6/15 00Z-6/17 00Z.

Data and Method

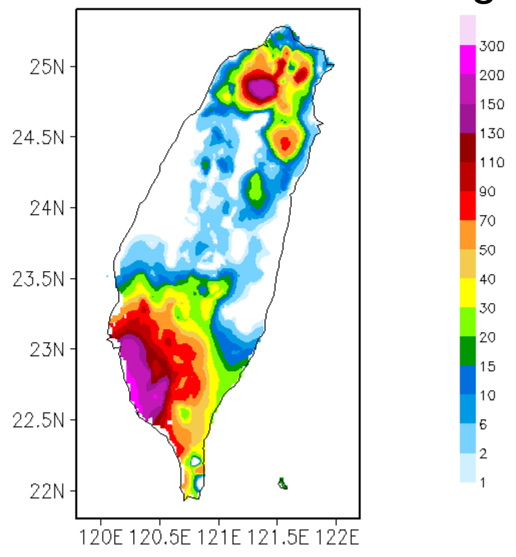
- Rain gauge and CMORPH (0.25 deg resolution) rainfall data
- Model simulated rainfall (3-km resolution) interpolated to 0.25 deg resolution to compare with CMORPH rainfall.
- Model simulated IVT, TPW, rainfall, upper-level geopotential height and flow pattern, boundary layer temperature and winds and reflectivities.

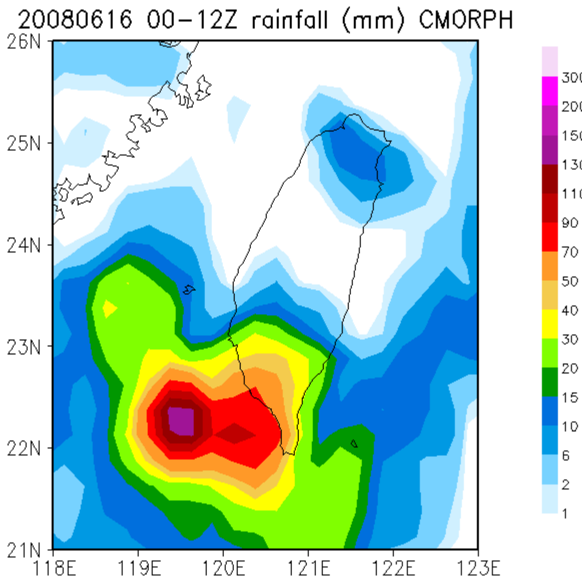
Rainfall Prediction

- GPSGTS forecast with cycling run
- NoGPS forecast with cycling run
- NoDA forecast

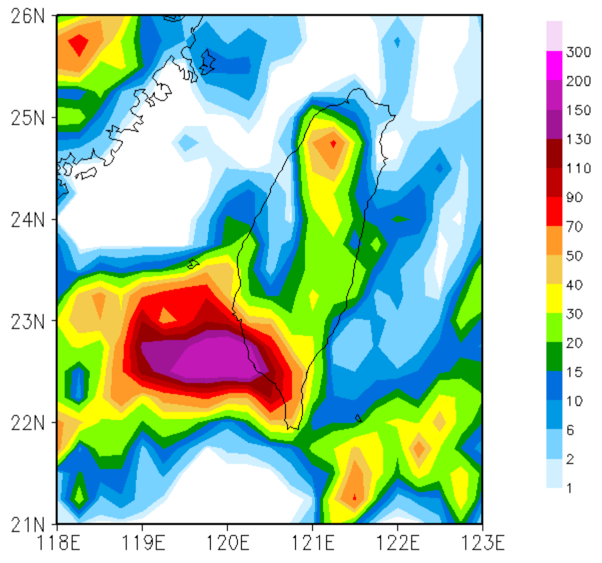
6/16 0000-1200 UTC

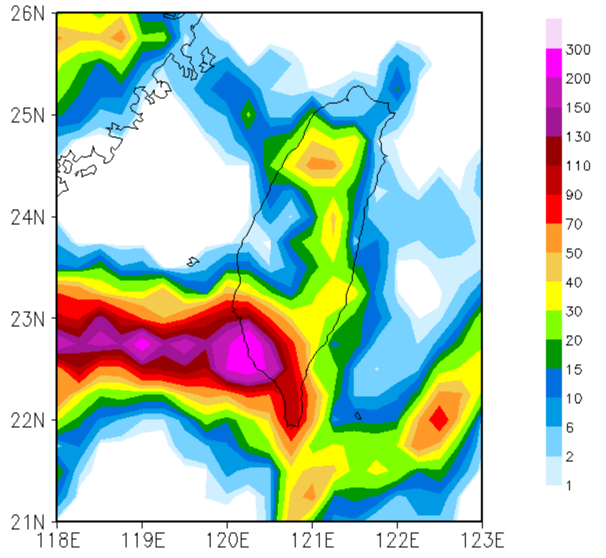
Rainfall observation from rain gauges



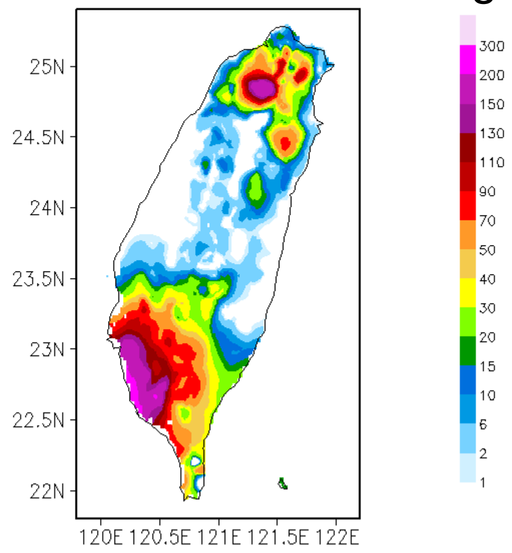


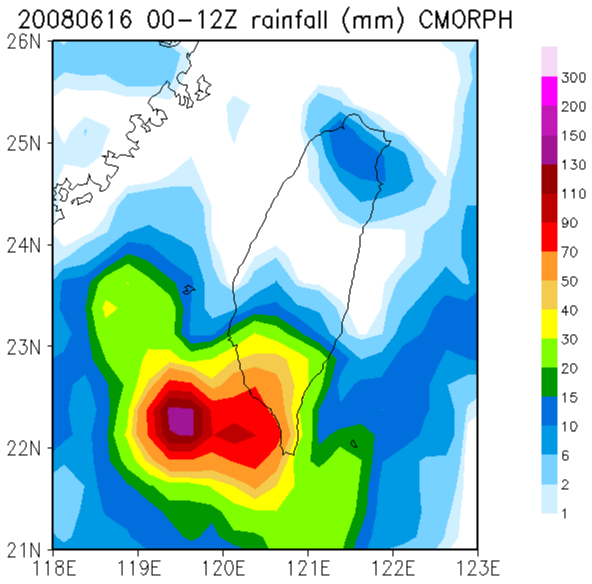
- GPSGTS forecast with cycling run
- NoGPS forecast with cycling run



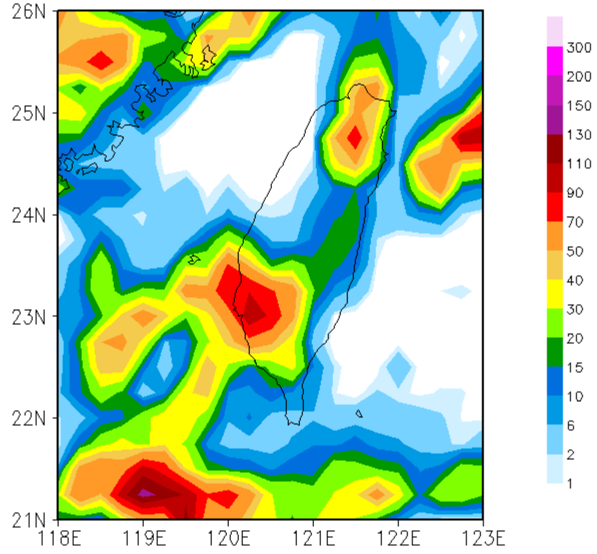


6/16 0000-1200 UTC
Rainfall observation from rain gauges





- NoDA forecast



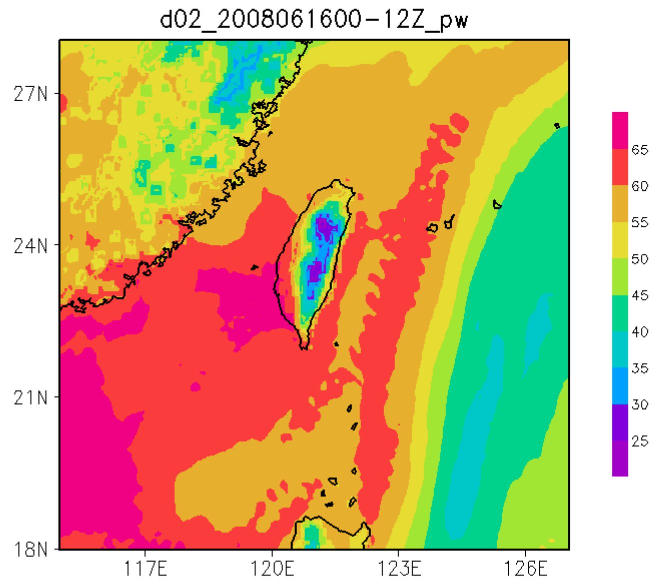
CMORPH rainfall is underestimated over southwest coast of Taiwan compared with rain gauge observation.

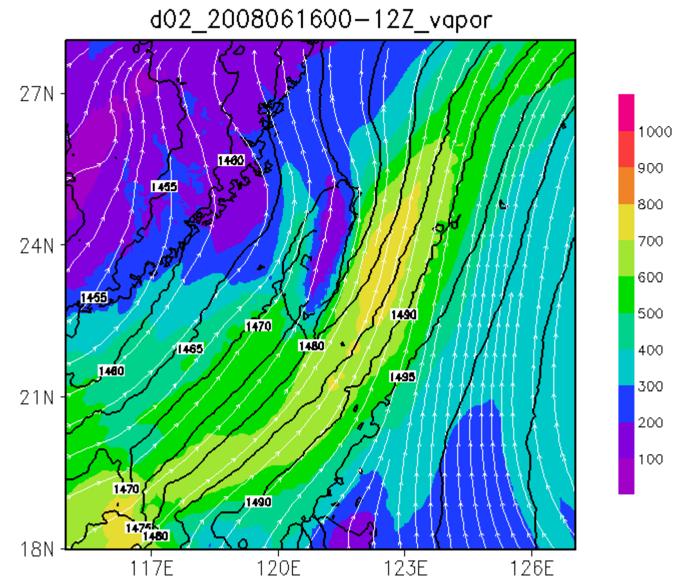
The GPSGTS run provides the best forecast of coastal rainfall.
The E-W oriented MCSs rainfall is too narrow and long in NoGPS run. The coastal MCSs is too weak in NoDA run.

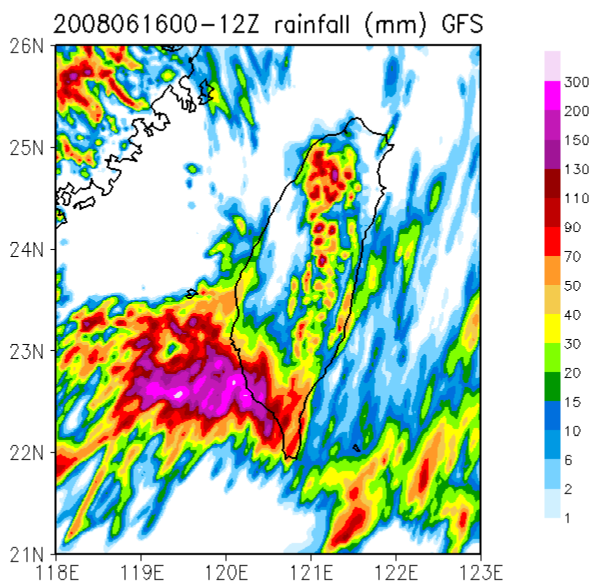
IVT and TPW Prediction

- GPSGTS forecast with cycling run
- NoGPS forecast with cycling run
- NoDA forecast

GPSGTS forecast with cycling run

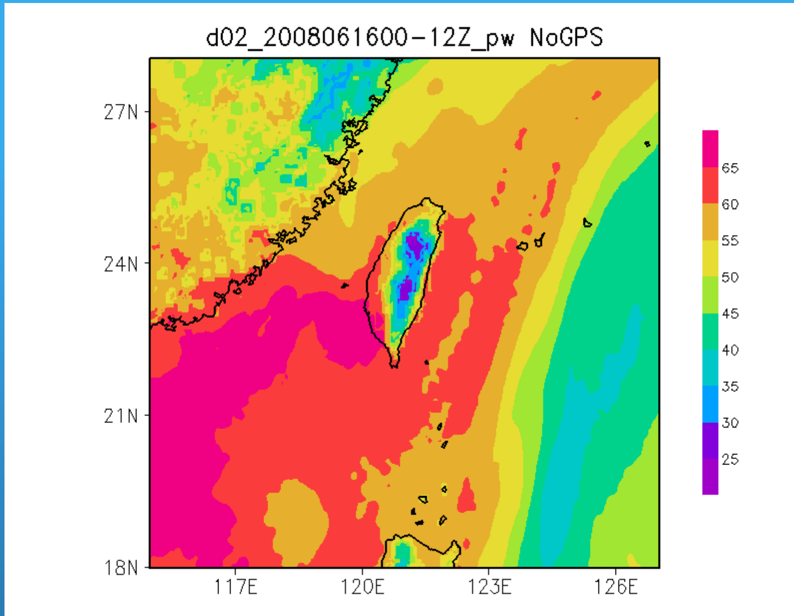


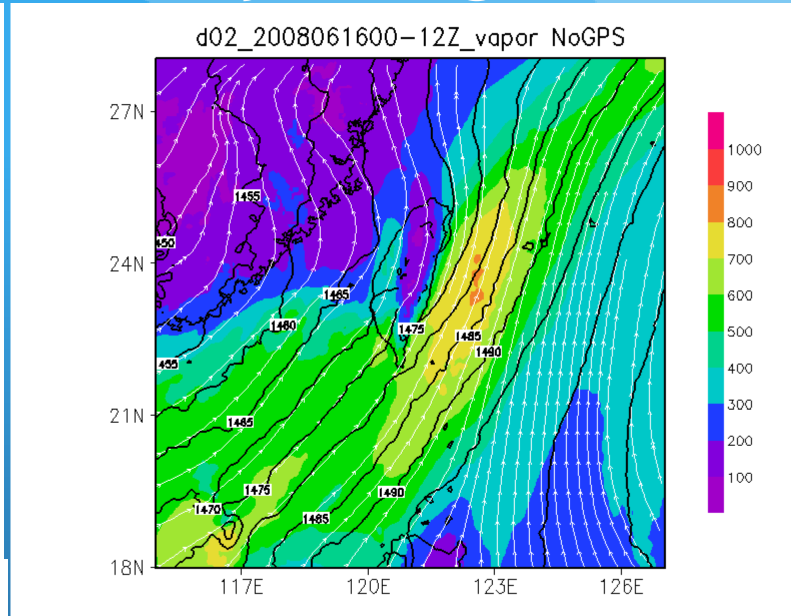


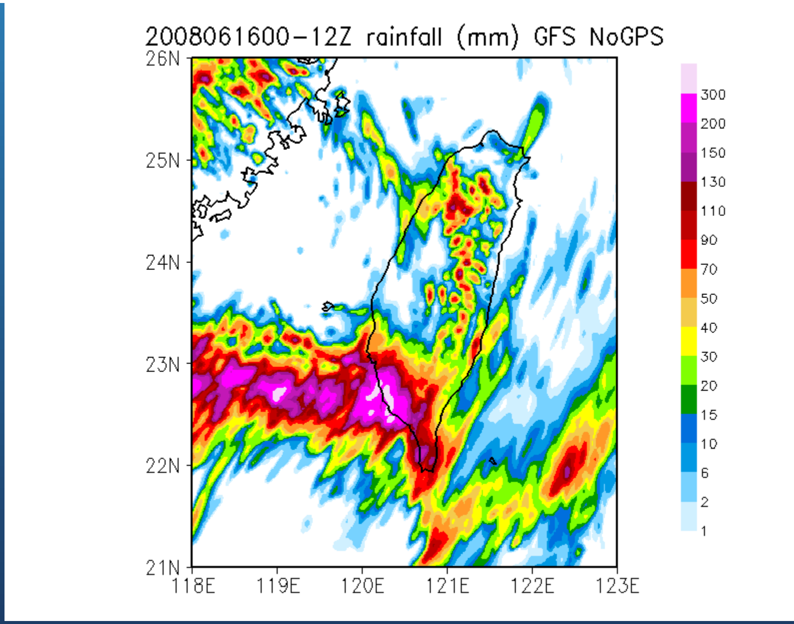


- SW flow upstream of southwestern Taiwan brought in moisture contributing to the coastal rainfall.

NoGPS forecast with cycling run

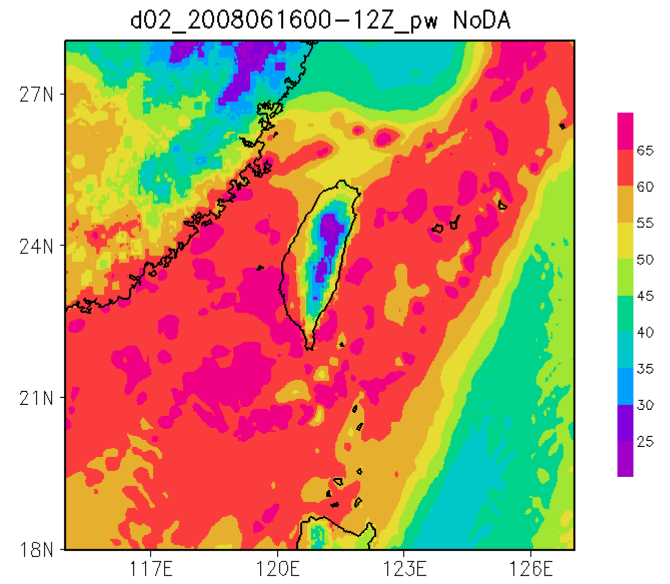


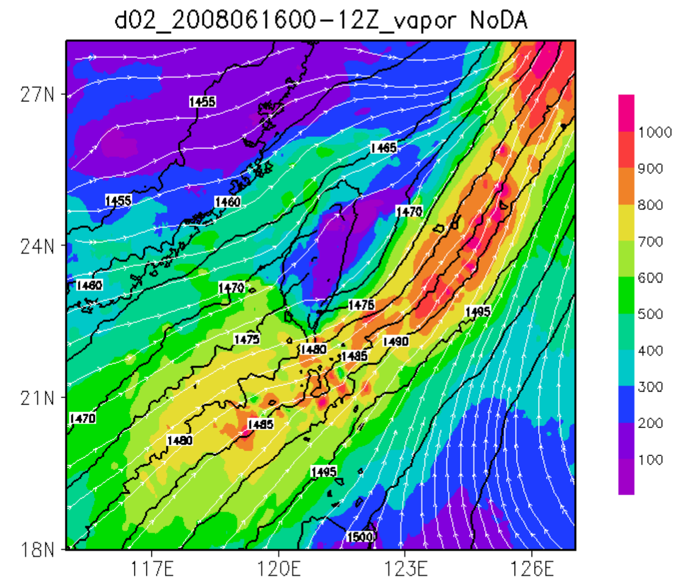


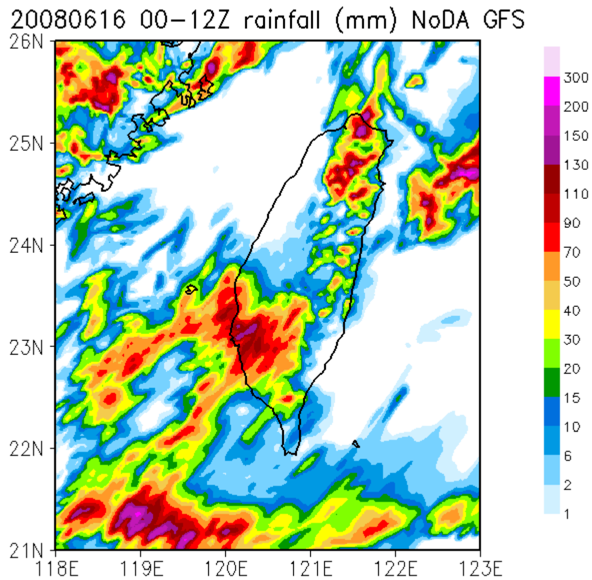


- Too broad moist SW flow upstream of Taiwan corresponds to too long E-W oriented moisture band and MCSs rainfall.

NoDA forecast

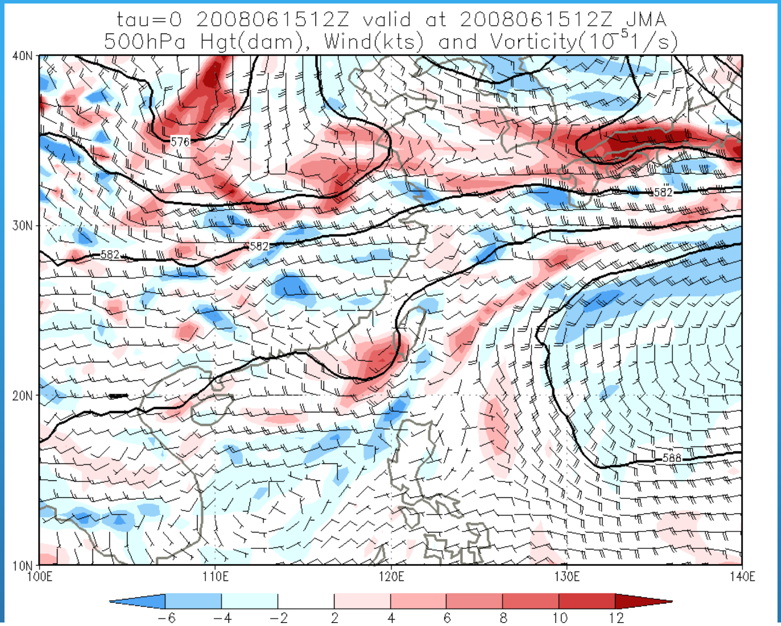


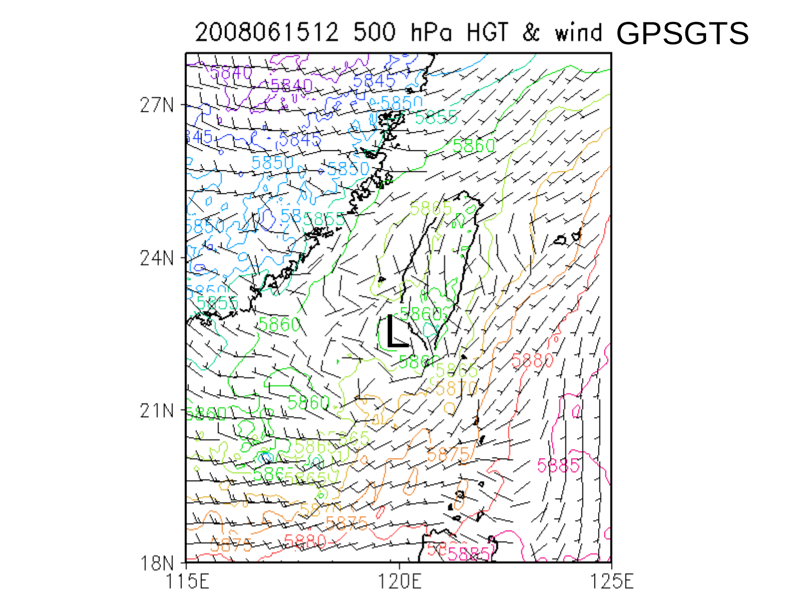


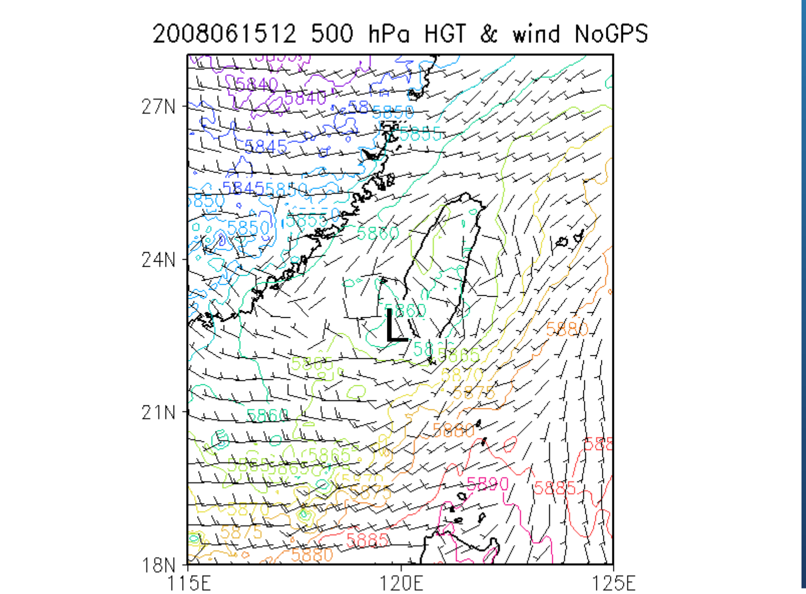


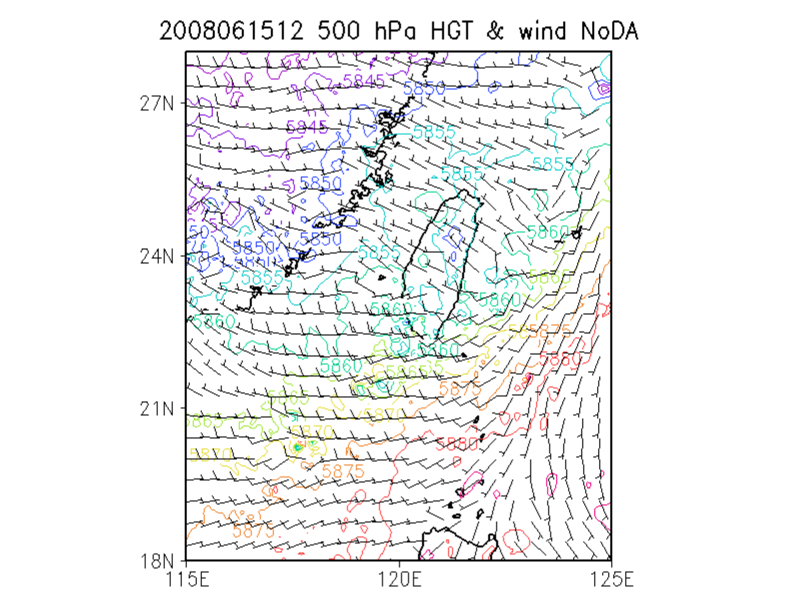
- Large westerly component of SW flow with less blocking and turning of airflow corresponds to rainfall over southwestern Taiwan and CMR without a well defined coastal rainfall maximum over southwestern Taiwan.

DA strengthens the upper-level cyclone intensity

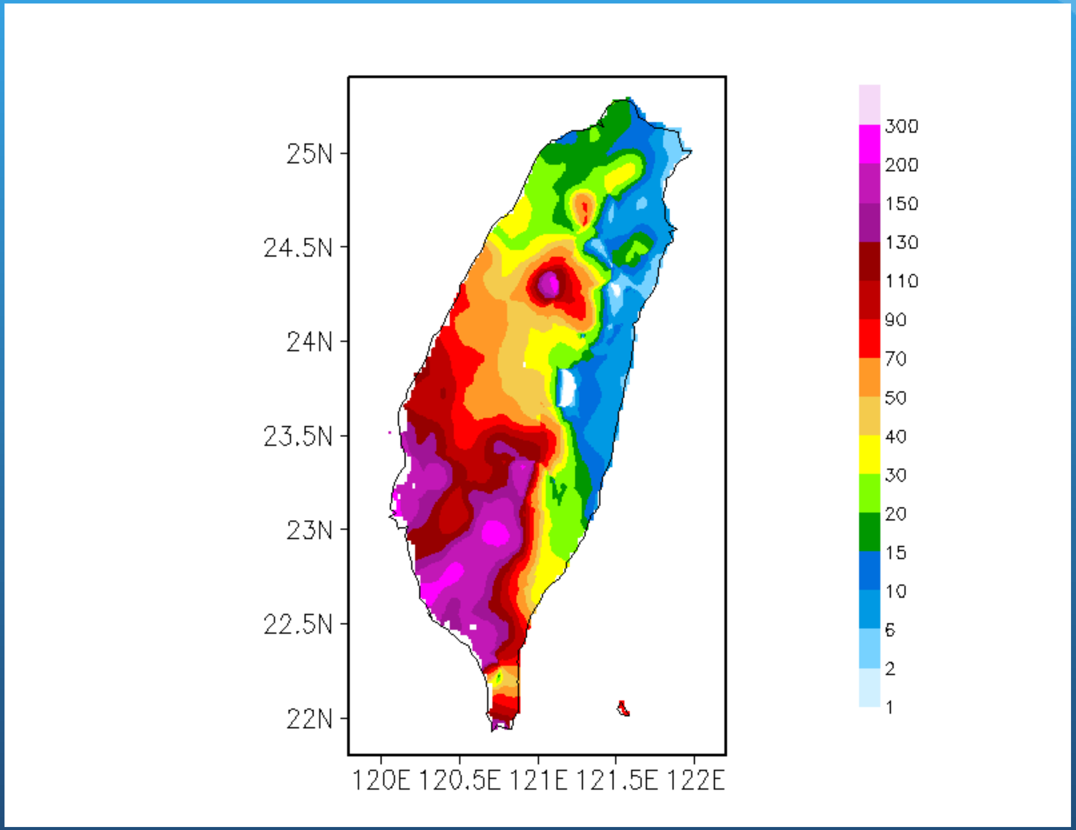






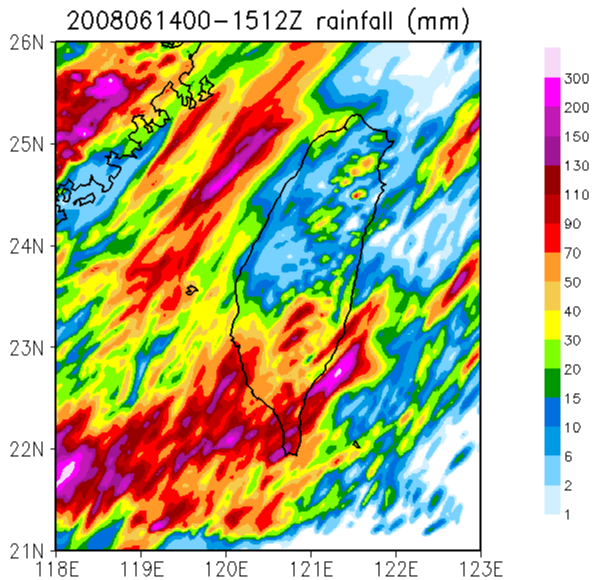


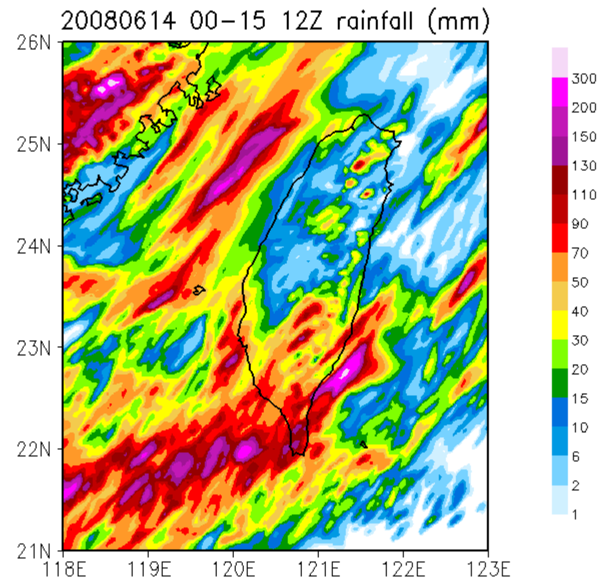
6/14 00Z – 6/15 12Z rainfall observation from rain gauges

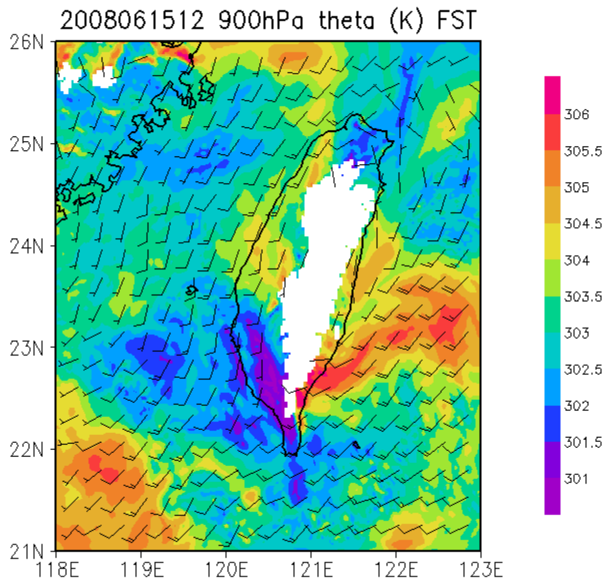


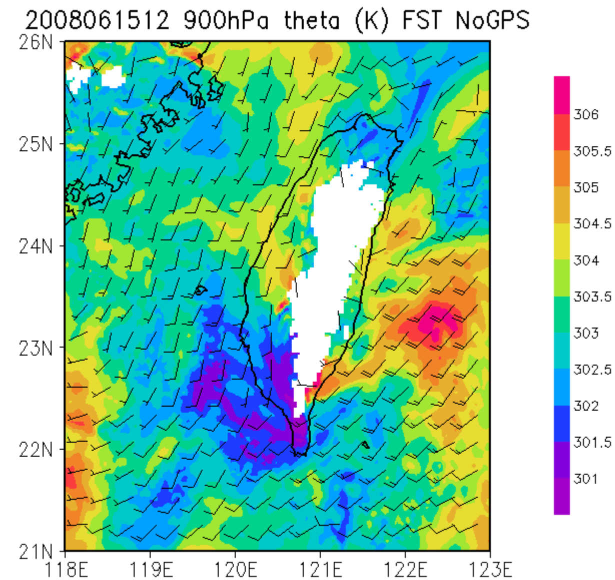
GPSGTS

NoGPS

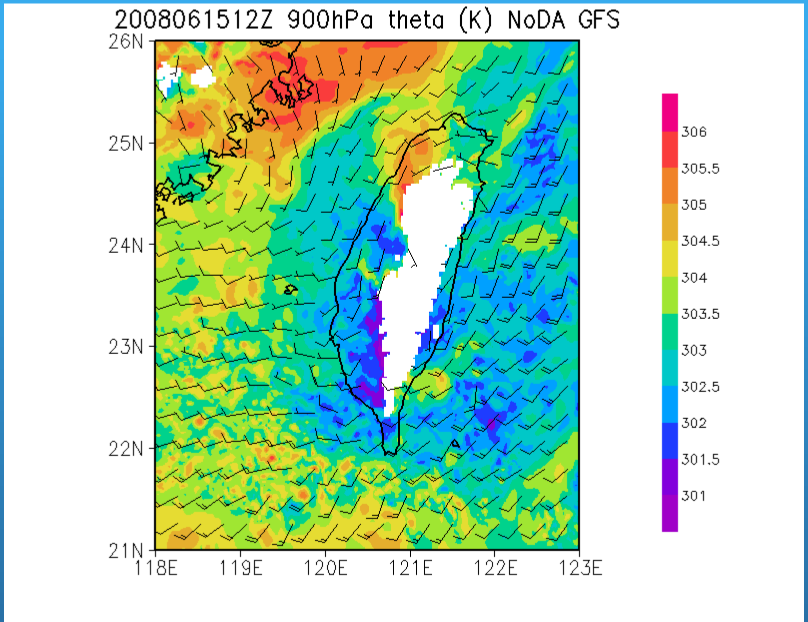




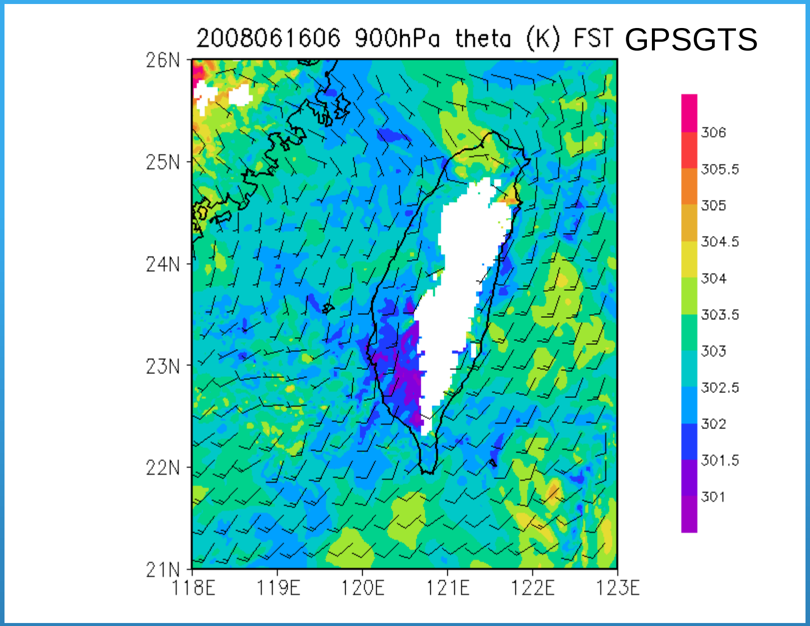


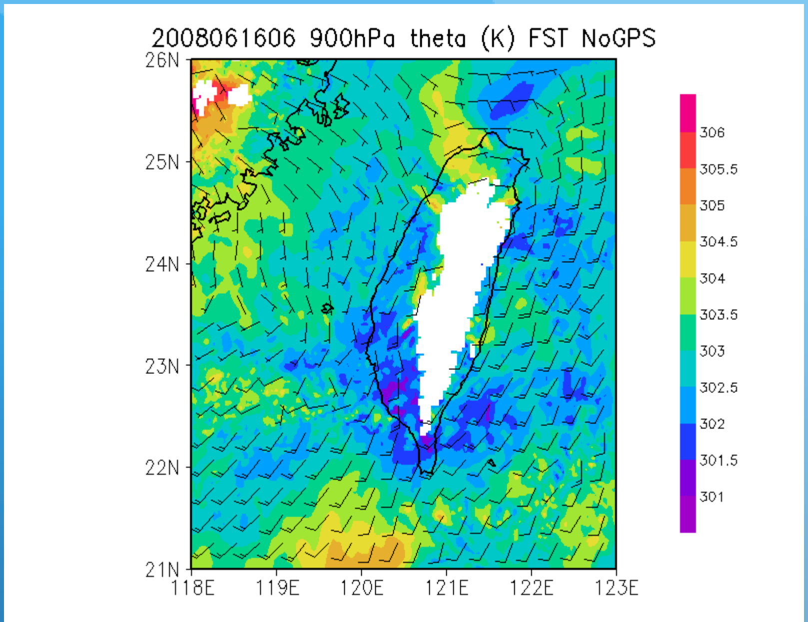


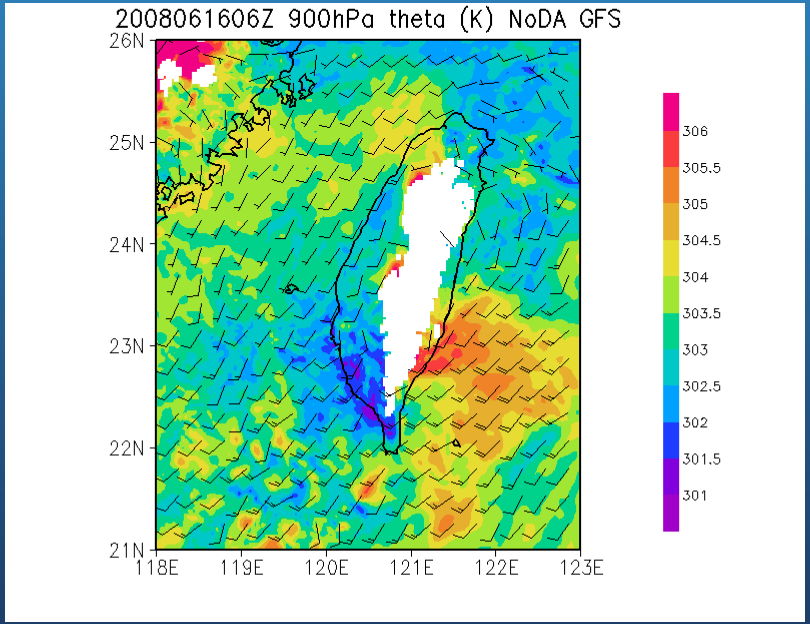
NoDA



- Cycling run provides better initial conditions of cold boundary layer over southwesetern Taiwan which is resulted from rain evaporative cooling from 6/14 to 6/15.
- Blocking and turning of SW flow is better simulated in cycling run.

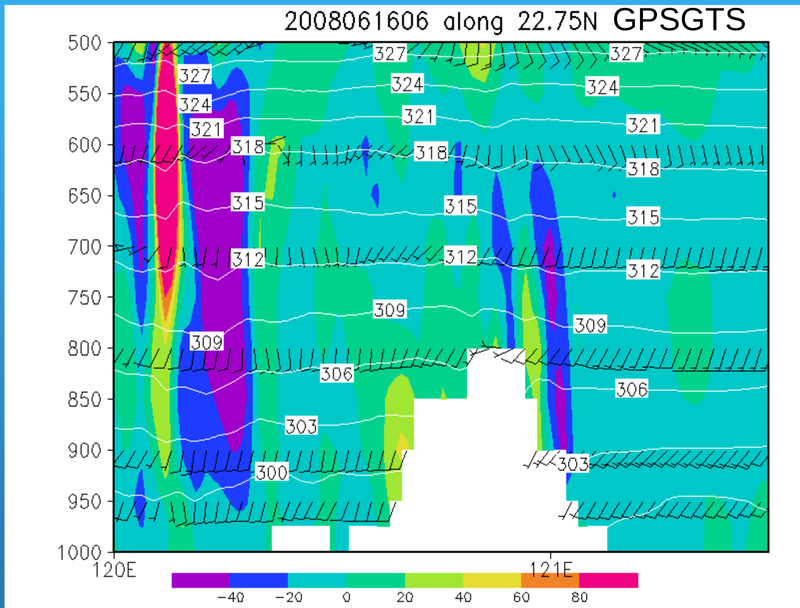


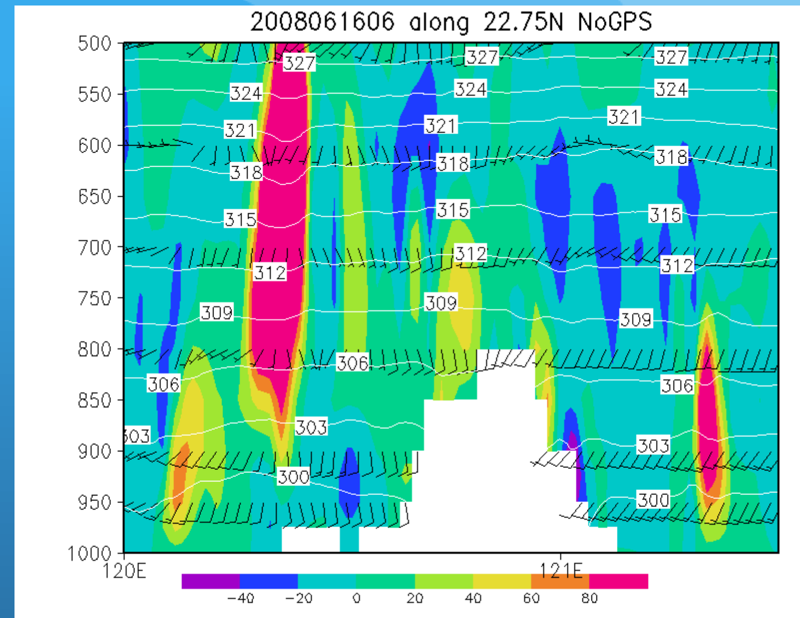


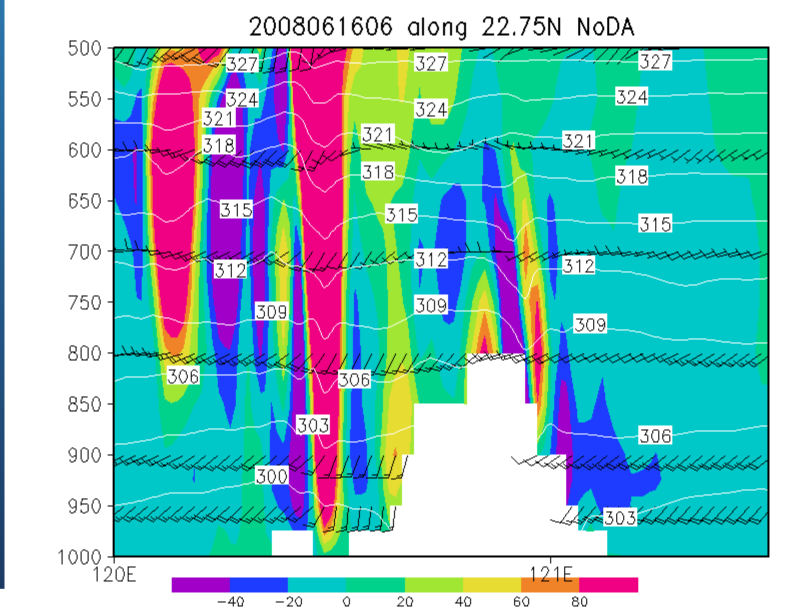


- Blocking of SW flow is more evident in cycling run.

Vertical cross section of winds, theta and w







- Cycling run: SSW flow converged with blocked southerly flow forming coastal convection.
- NoDA run: In addition to coastal convection, the orographic lifting of SW flow over southwestern slope and leeside adiabatic warming are evident.

Summary

- The GPSGTS run provides the best forecast of coastal rainfall. GPS RO data improve large-scale TPW and IVT and rainfall prediction.
- Data assimilation strengthened upper-level cyclone intensity.
- Cycling run improves initial conditions of cold boundary layer and blocking of airflow over southwestern Taiwan due to antecedent precipitation
- The SSW flow over southwestern Taiwan is evident in cycling run. Blocking of SSW flow resulted in coastal convection. For NoDA run, in addition to coastal convection, the orographic lifting of SW flow over southwestern slope and leeside adiabatic warming are evident.