High-Resolution 8-day Typhoon Ensemble Forecast application for Taiwan by Cloud-Resolving Storm Simulator (CReSS)

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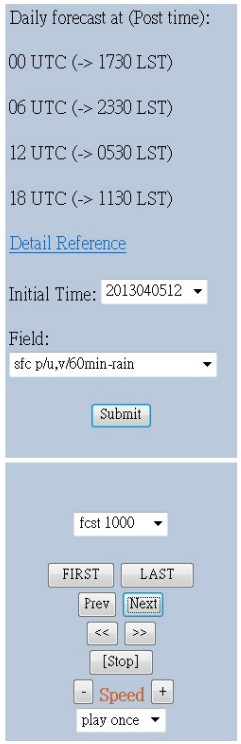
Presentation outline

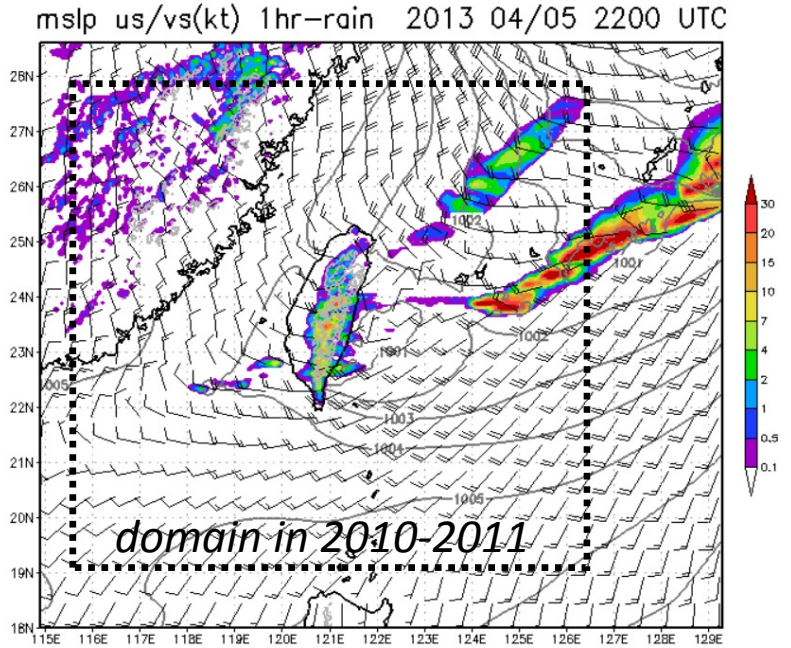
1. ***Brief Introduction of the CReSS Model***
2. ***Time-lagged Ensemble from Deterministic Forecasts***
   - ***2.1 Deterministic versus Ensemble Forecasts***
   - ***2.2 Purpose of Typhoon Forecasts: Rainfall and Hazard Reduction***
   - ***2.3 Strategy with Limited Computational Resources***
3. ***8-Day Experimental Typhoon Forecasts at 2.5 km***
4. ***Conclusion and Summary***

1. Brief Introduction of the CReSS Model

- *Single high-resolution domain without nesting*
- *Make use of and optimized for large-scale parallel computers*
- *Real-time CReSS forecasts for Taiwan in typhoon season (Jul-Oct) since 2007, and non-stop year-round since Apr 2010*
- *Latest (and all past) results available at http://vortex.es.ntnu.edu.tw*
- *Gradual increases in resolution, domain size, and forecast length over time (major ones in 2010 and 2012)*
- *Current forecasts (40L) every 6 h out to 78 h:*
  - *5 km (216 x 180)*
  - *2.5 km (600 x 480)*
- *Routinely provided to TTFRI of Taiwan as the only cloud-resolving member (2.5 km)*



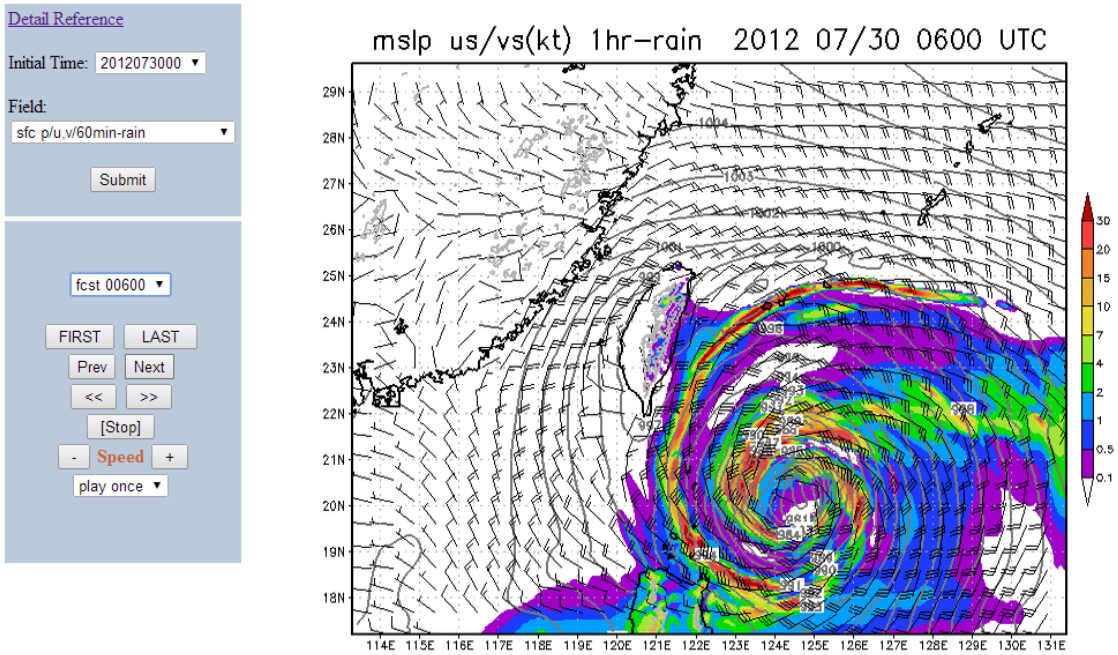
NTNU/Department of Earth Sciences – CReSS 2.5km Realtime Forecast



(Current 2.5-km domain: 1500 km x 1200 km)

- *Single high-resolution domain without nesting*
- *Make use of and optimized for large-scale parallel computers*
- *Real-time CReSS forecasts for Taiwan in typhoon season (Jun-Oct) since 2012, and non-stop year-round since Jan 2014*
- *Latest (and all past) results available at http://vortex.es.ntnu.edu.tw*
- *Current forecasts (40L) every 1 h out to 192 h :*
  - *2.5 km (744 x 544)*

NTNU/Department of Earth Sciences – CReSS 2.5km 8-days Forecast



(Current 2.5-km domain: 1860 km x 1360 km)

2. Time-lagged Ensemble from Deterministic Forecasts

2.1 Deterministic versus Ensemble Forecasts

- *General advantages and shortcomings of deterministic versus ensemble forecasts:*

	Deterministic forecasts (high resolution)	*Ensemble forecasts (low resolution)*
Advantages	■ *Resolve topography and convection better* ■ *More realistic evolution, intensity, and QPFs* ■ *Better predictability of some phenomena*	■ *Quantify uncertainty through probability and measure confidence in forecasts* ■ *Cover possible scenarios through spread*
Shortcomings	■ *No information on probability and forecast uncertainty* ■ *More expensive to run*	■ *Under-predict rainfall intensity and amount due to low resolution*

- *The two approaches are complementary to each other (Roebber et al. 2004)*
- *In reality, compromises are often needed with limited computer resources*

2.2 Purpose of Typhoon QPFs: Hazard Reduction

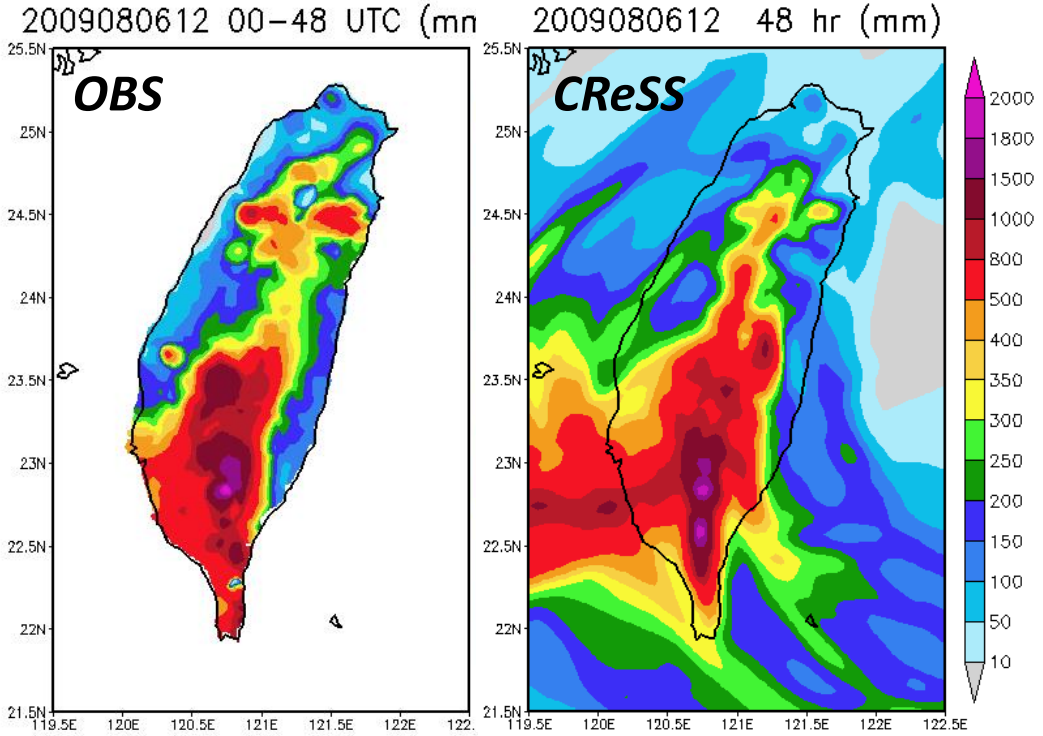
- *Rule of thumb: Make a high-quality forecast as early as possible*
- *Main purpose of typhoon forecasts: Hazard reduction*
  - *Realistic rainfall amount and distribution (scenarios), as hazards are mostly caused by heavy rainfall in Taiwan*
  - *Worse case and its likehood, apart from the most/more likely scenarios (conventional wisdom: hope for the best, but prepare for the worst)*
  - *Lead time is crucial for better preparation of emergency action*

	Low-resolution ensemble models	High-resolution deterministic models
Track	Good	Good
Intensity	Poor	Good
Rainfall	Poor	**Very good**
Striking probability	Good	**N/A**
Lead time	Good	Poor

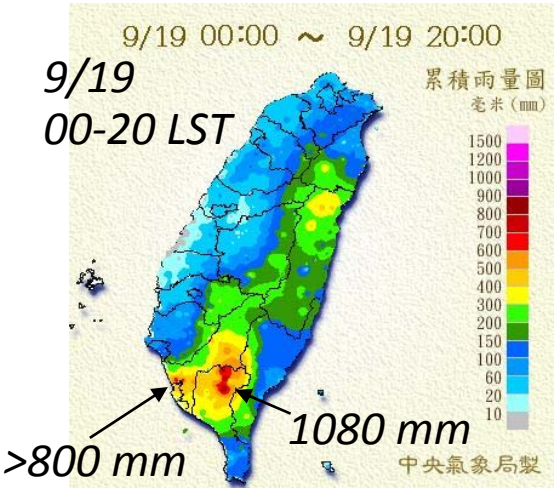
→ Major drawbacks

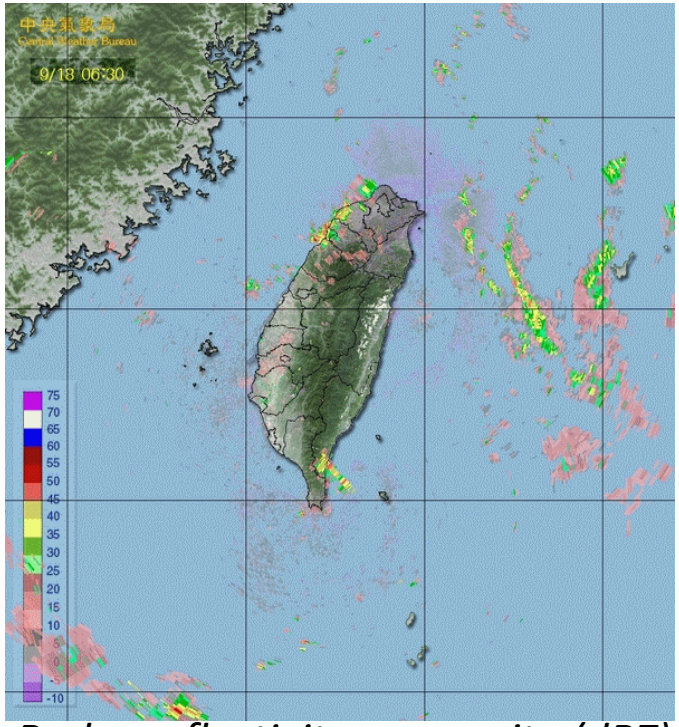
2.3 Strategy with Limited Computational Resources

- *Some examples of high-resolution deterministic forecasts by CReSS:*
- *Morakot (2009): Most devastating typhoon, extreme rainfall up to 2855 mm*
  - *Real-time twice daily 4-km CReSS forecasts (for 48 h) in 2009*
  - *Total 48-h rainfall (mm) from the run starting at 12 UTC 6 Aug 2009:*



(Wang et al. 2013: J. Hydro.)

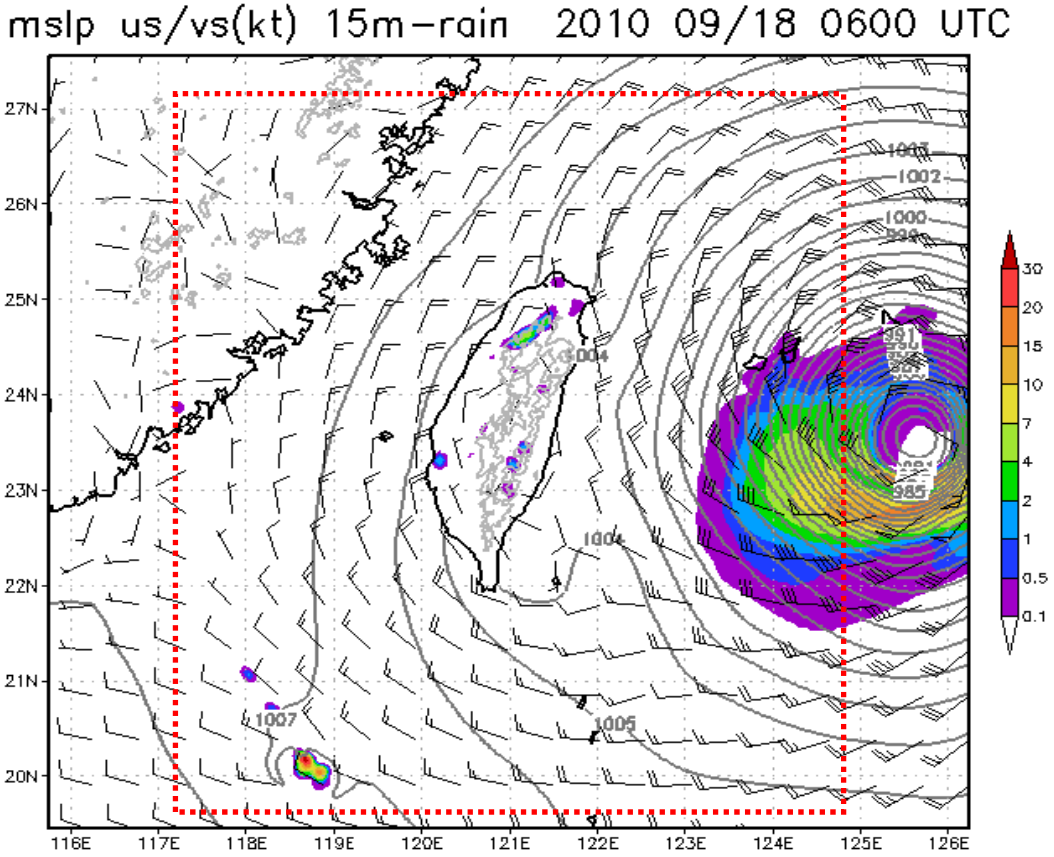




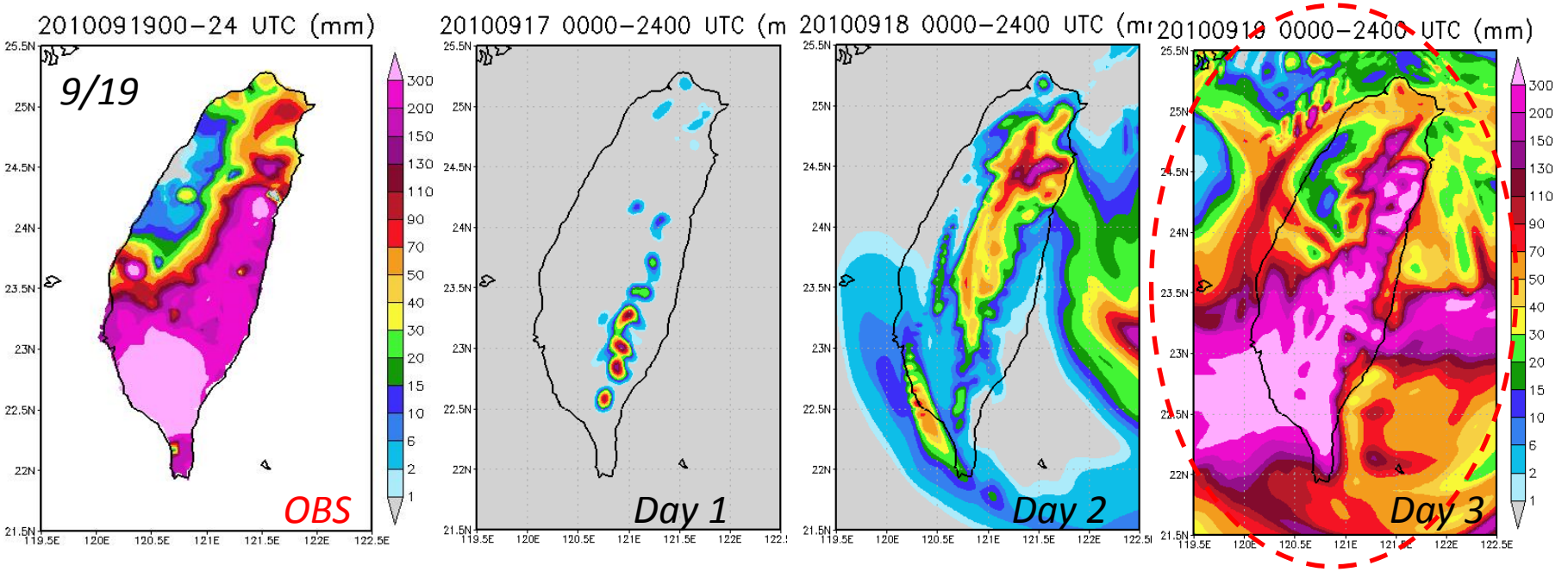
Radar reflectivity composite (dBZ)

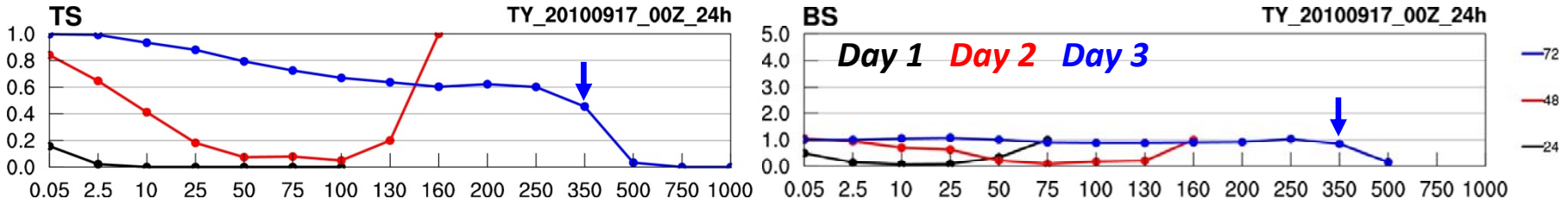
- *Real-time 2.5-km CReSS forecasts made at 9/17 00 UTC, for Typhoon Fanapi (2010), from 9/18 06 UTC to 9/20 00 UTC:*

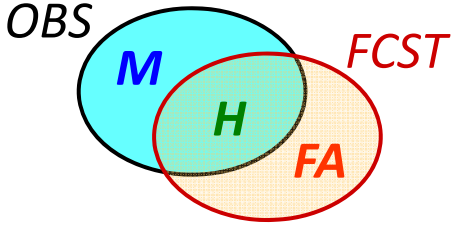
Model forecasts (made at 00 UTC 17 Sep) of MSLP, sfc winds, and 15-min rainfall (mm)



- *Real-time 2.5-km forecasts made at 9/17 00 UTC, for Fanapi (2010):*







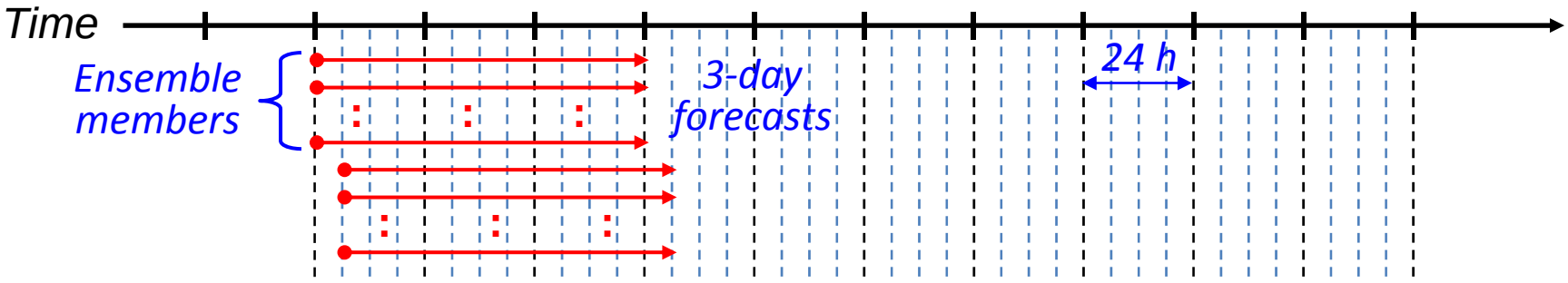
$TS = H / (M + H + FA)$

$BS = (H + FA) / (H + M)$

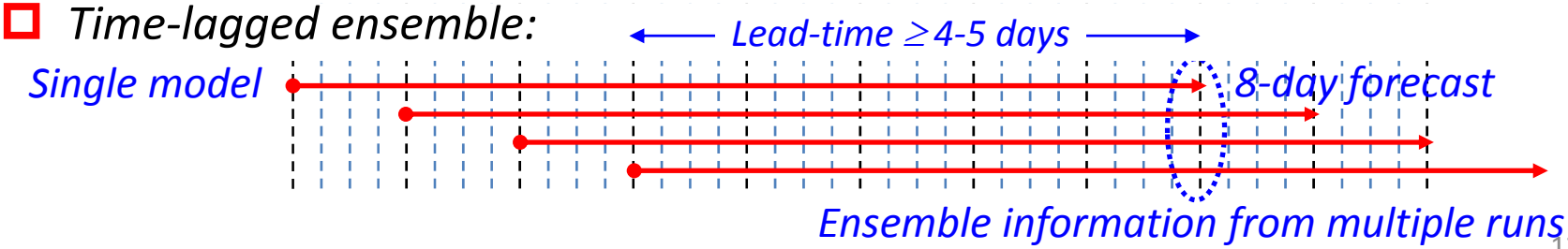
	Low-resolution ensemble models	High-resolution deterministic models
Track	Good	Good
Intensity	Poor	Good
Rainfall	Poor	**Very good**
Striking probability	Good	**N/A**
Lead time	Good	Poor

How to improve?

- Extend forecast range to 8 days, enlarge domain size to 1860 x 1360 km
- Extract ensemble information from multiple forecasts over a period of time
- Typical ensemble forecast:

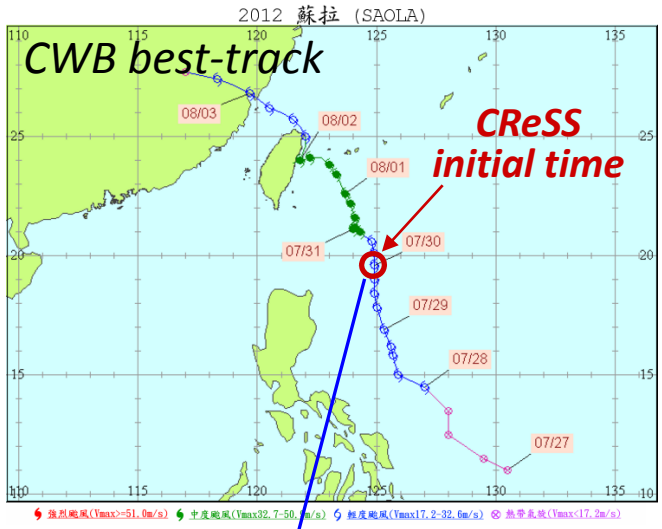


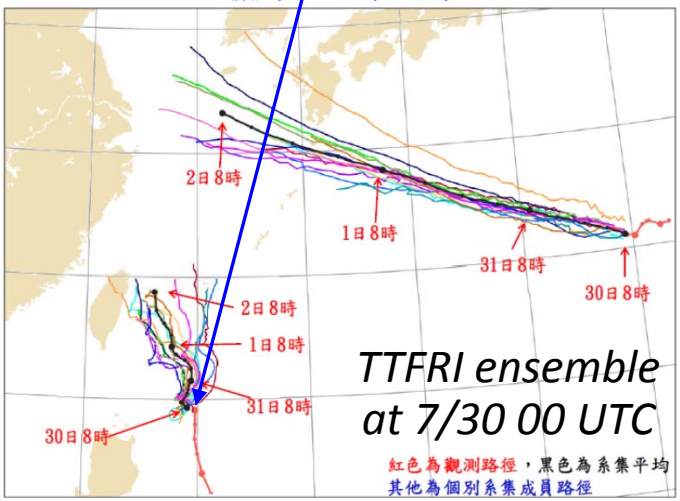
- Time-lagged ensemble:



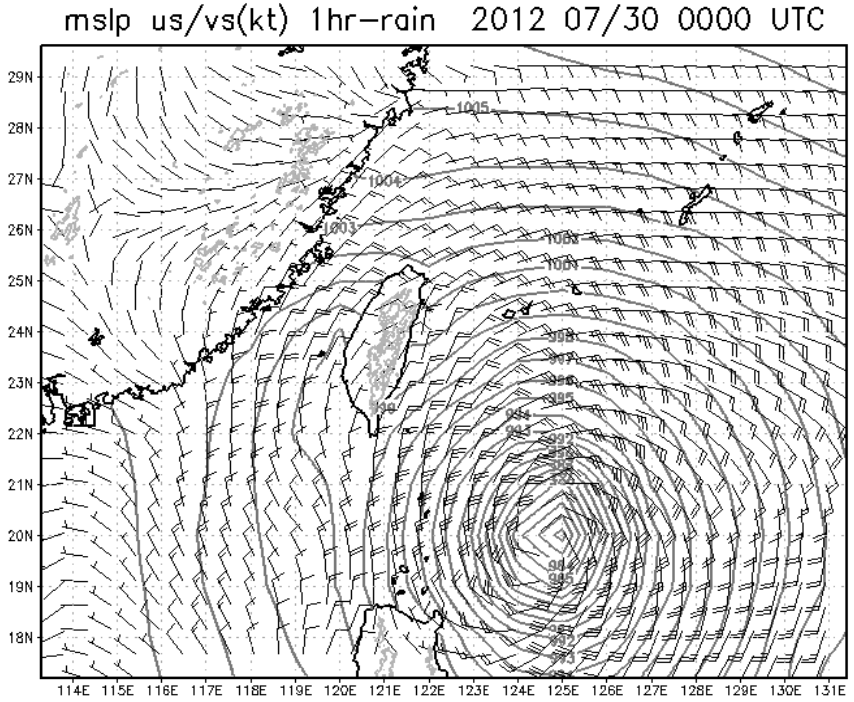
3. 8-Day Experimental Typhoon Forecasts at 2.5 km

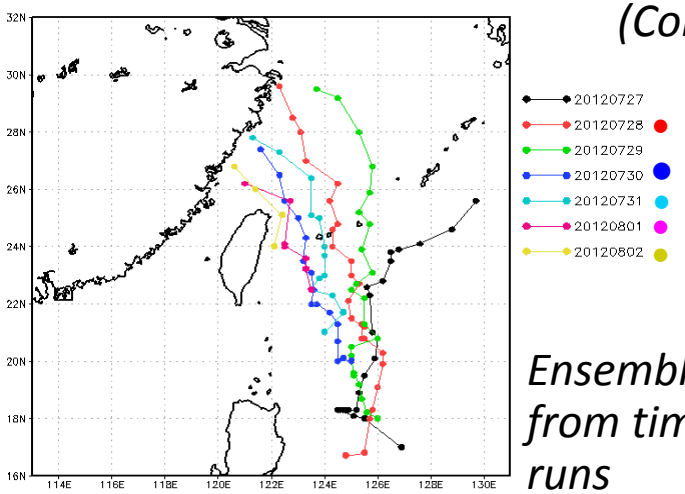
- *Forecast for Typhoon Saola, starting at 00 UTC 30 Jul 2012*





(~24 members)



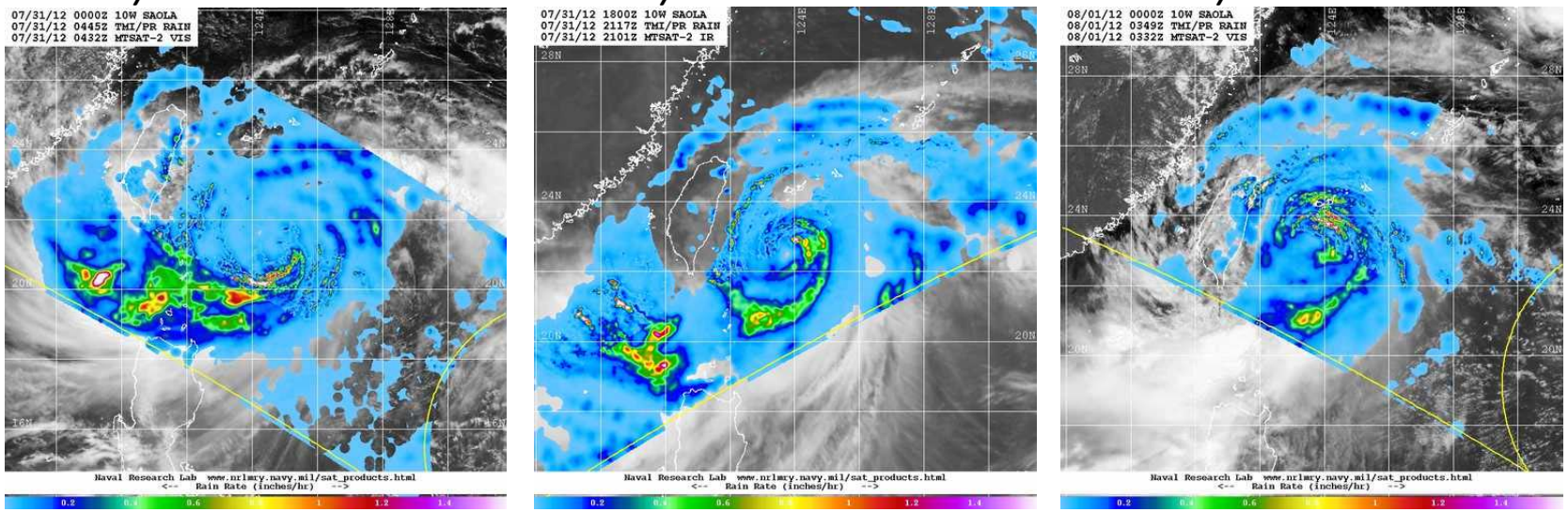


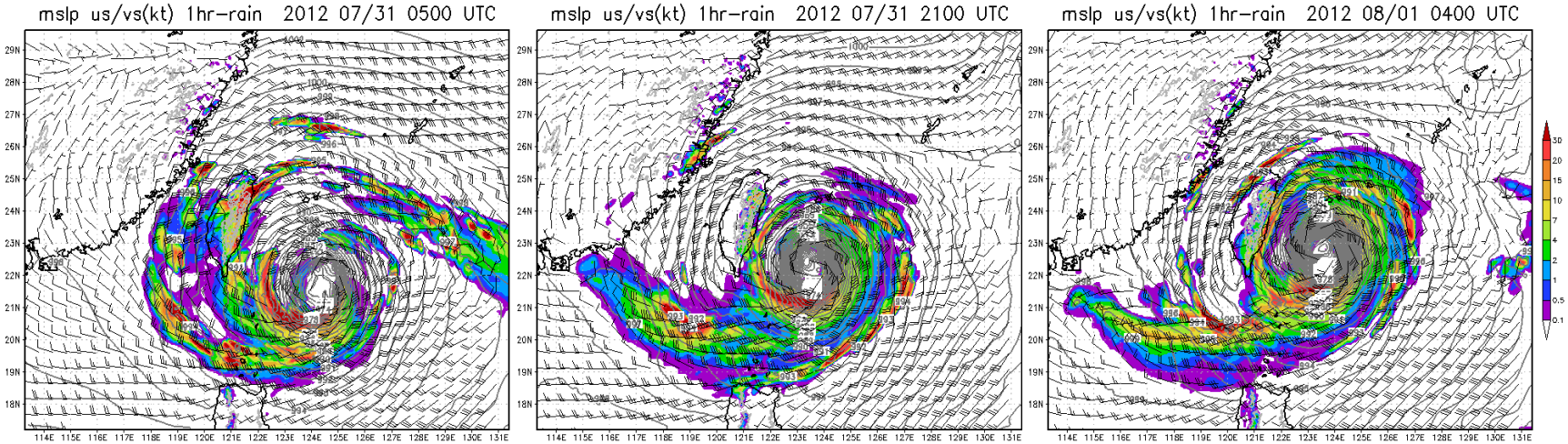
(Computational demand: ~5 TTFRI-WRF members)

Ensemble tracks from time-lagged runs

- *Comparison with TRMM-PR rain-rates for realistic scenarios:*
  - *Same forecast starting at 00 UTC 30 Jul 2012*

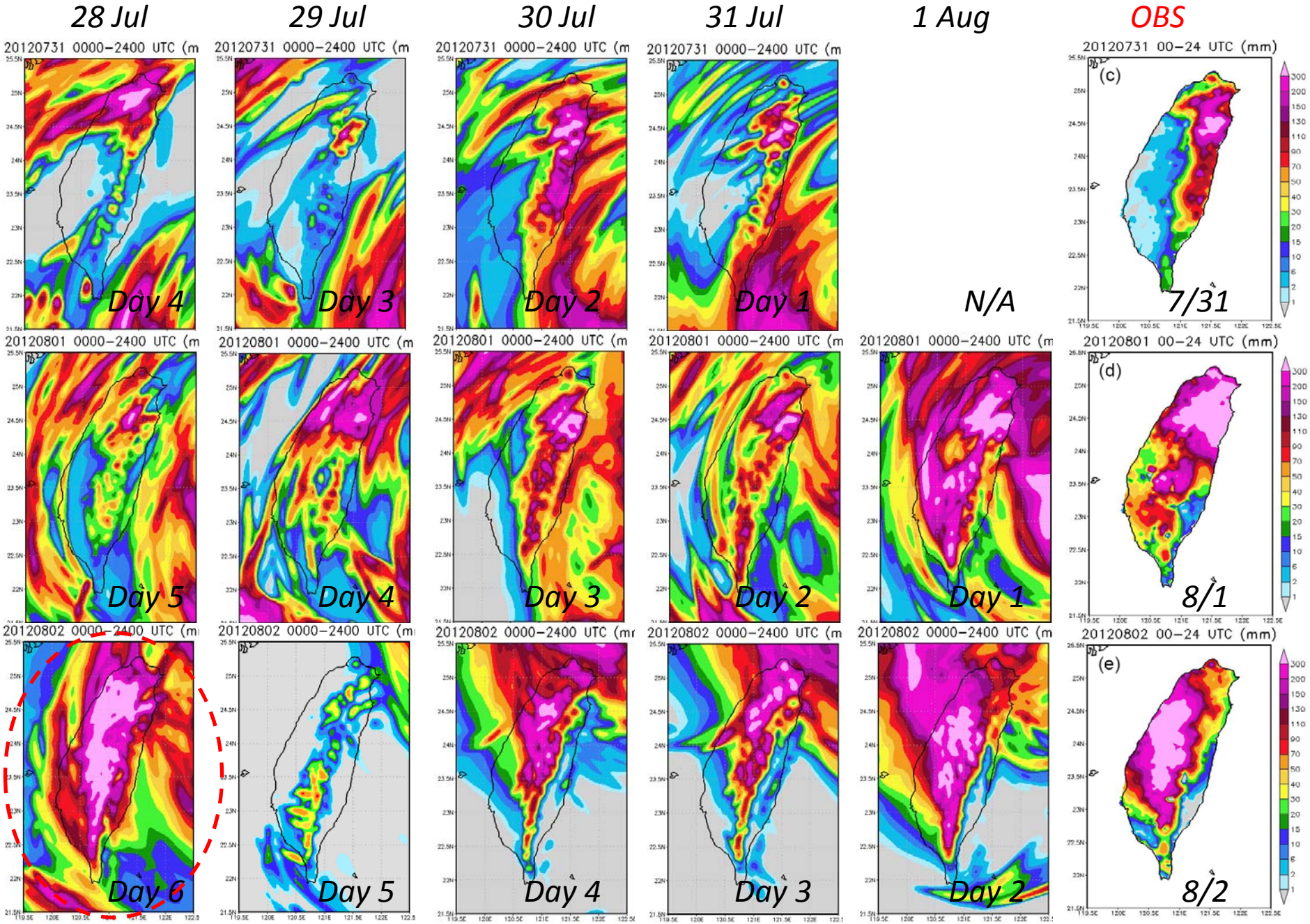
7/31 0445 UTC *7/31 2117 UTC* *8/1 0349 UTC*



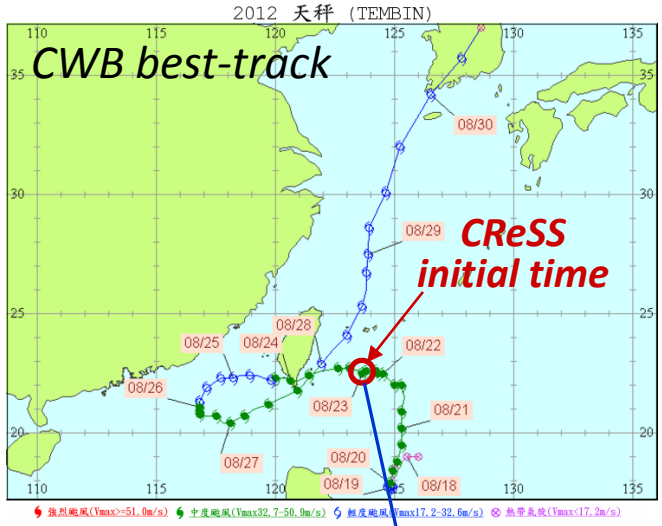


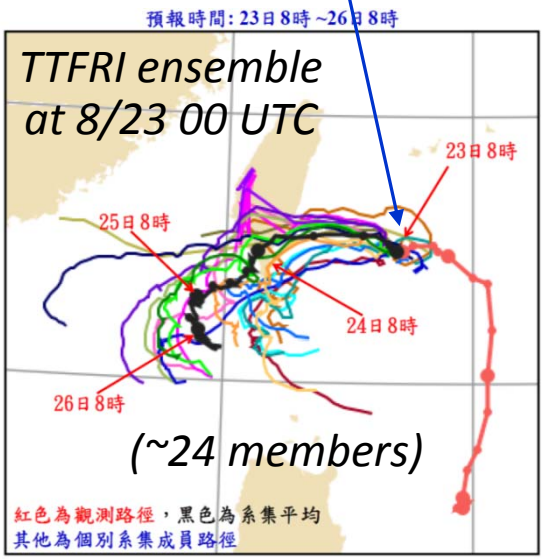
7/31 0500 UTC *7/31 2100 UTC* *8/1 0400 UTC*

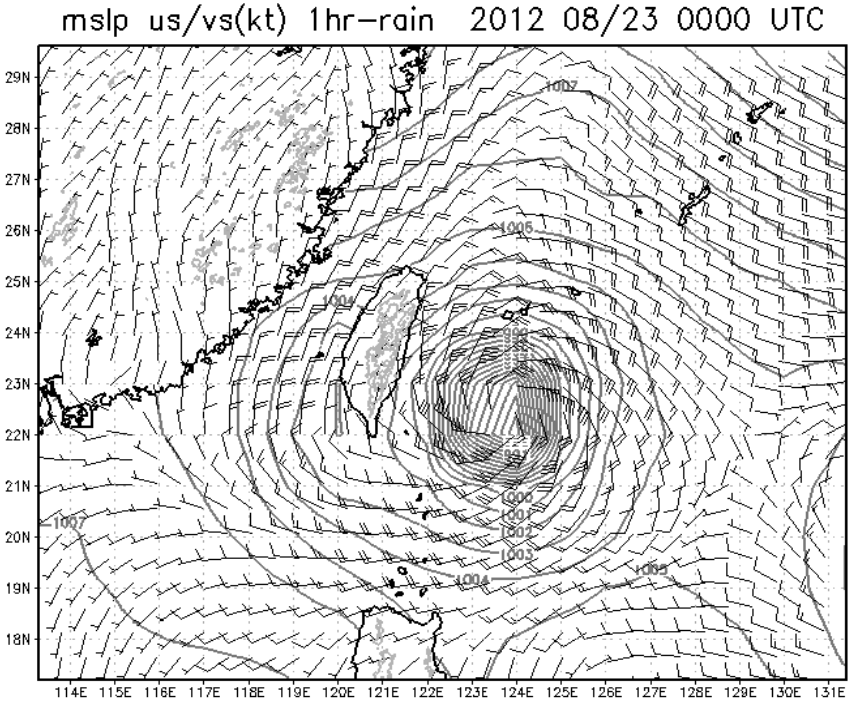
- *Daily rainfall forecasts for TY Saola, starting at 00 UTC, 28 Jul-1 Aug:*

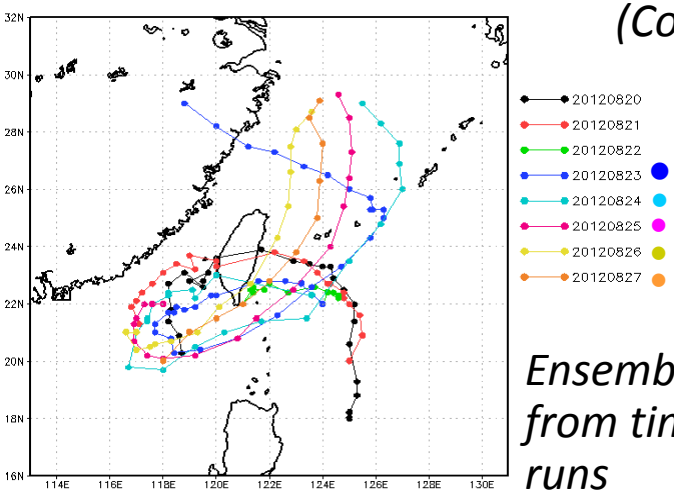


- *Forecast for Typhoon Tembin, starting at 00 UTC 23 Aug 2012*





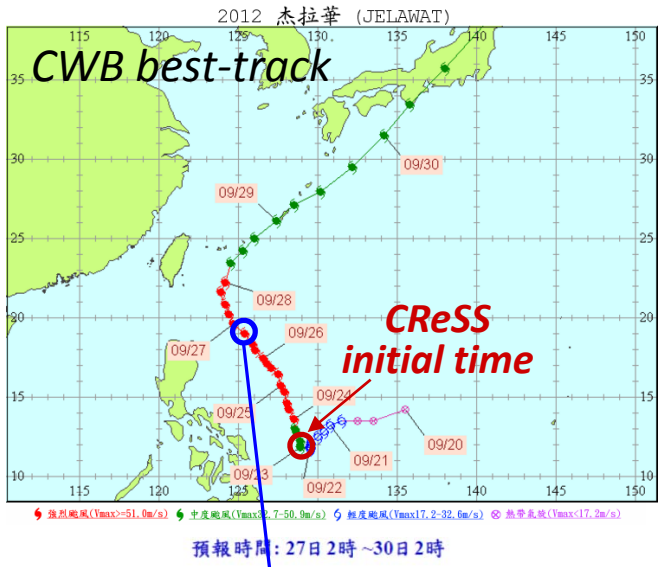


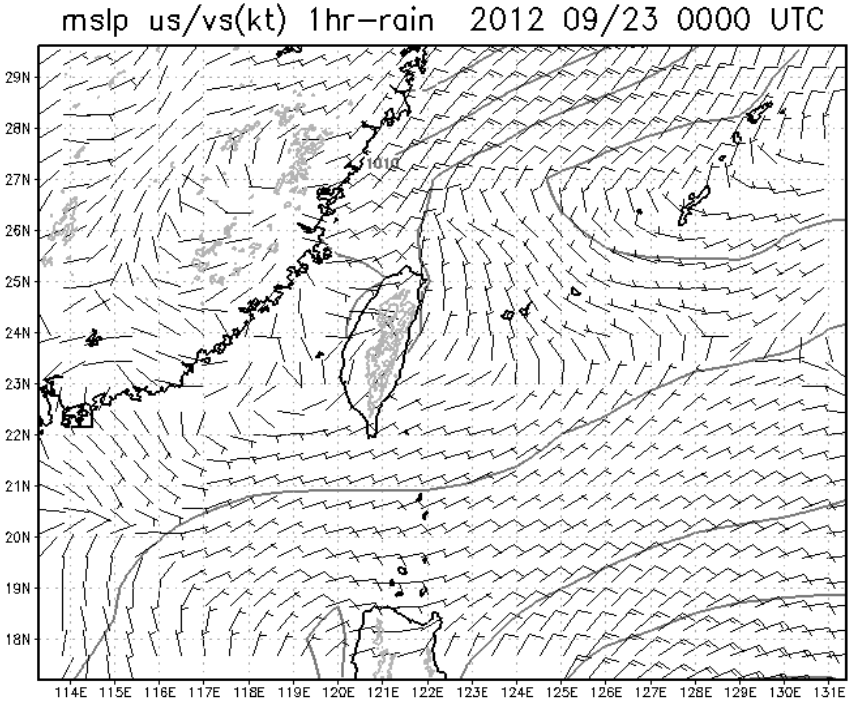


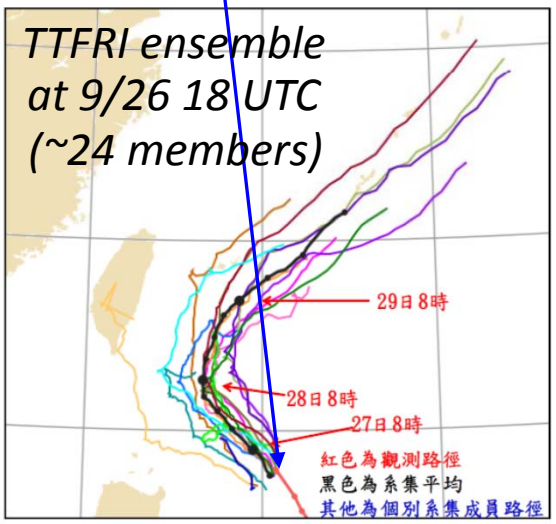
(Computational demand: ~5 TTFRI-WRF members)

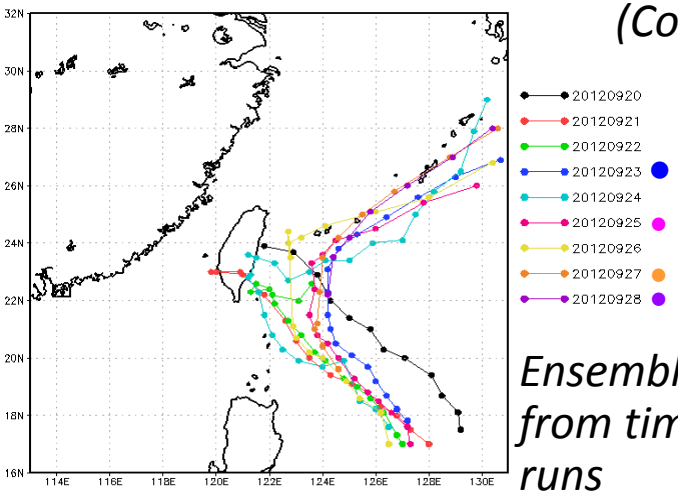
Ensemble tracks from time-lagged runs

- *Forecast for Typhoon Jelawat, starting at 00 UTC 23 Sep 2012*







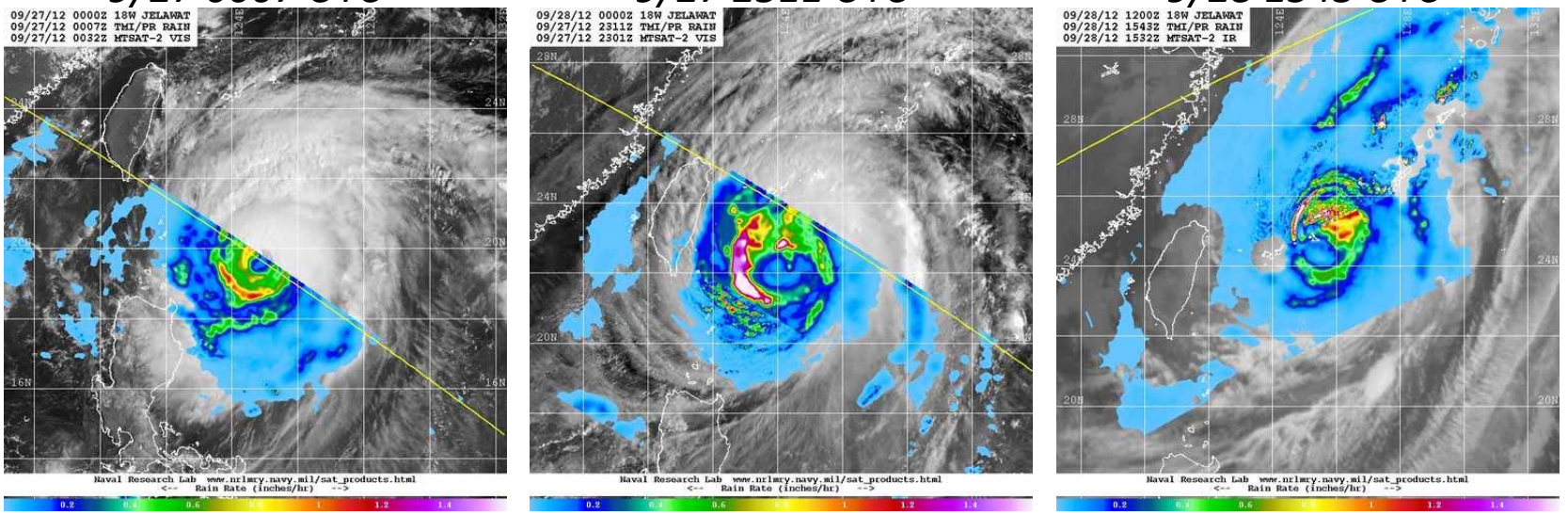


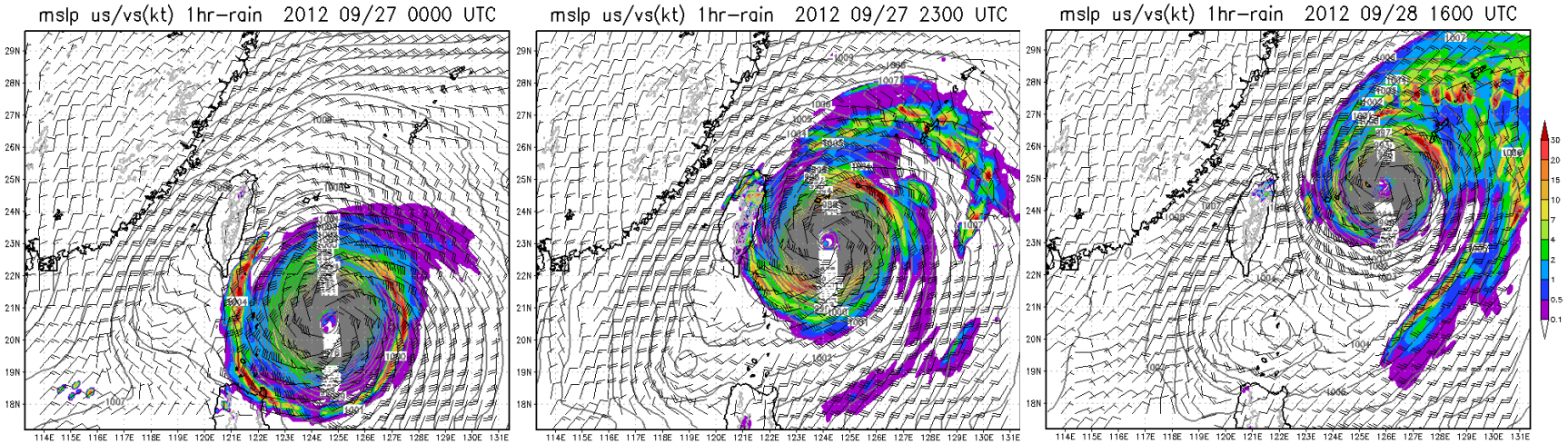
(Computational demand: 5 TTFRI-WRF members)

Ensemble tracks from time-lagged runs

- *Comparison with TRMM-PR rain-rates for realistic scenarios:*
  - *Same forecast starting at 00 UTC 23 Sep 2012*

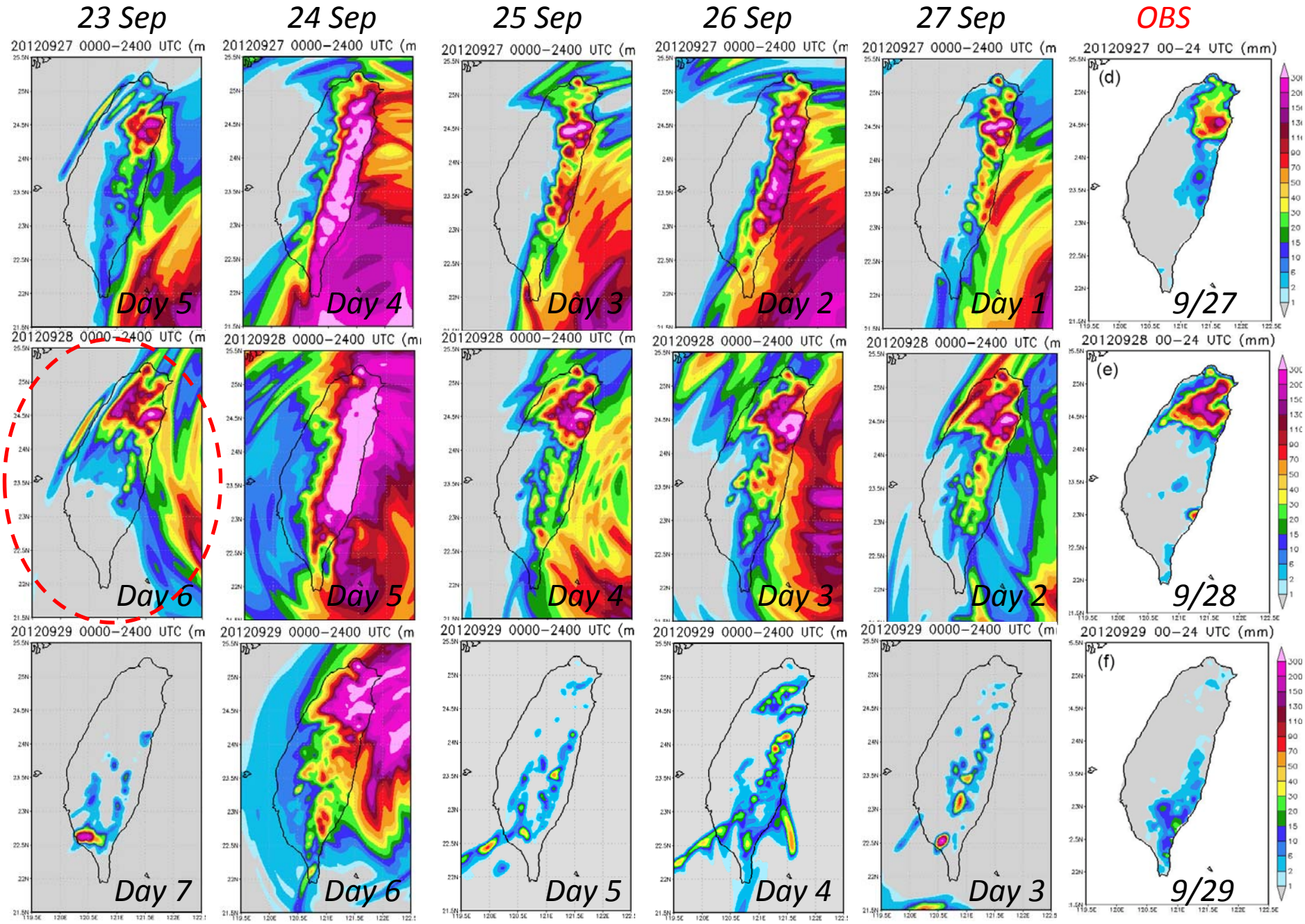
9/27 0007 UTC *9/27 2311 UTC* *9/28 1543 UTC*



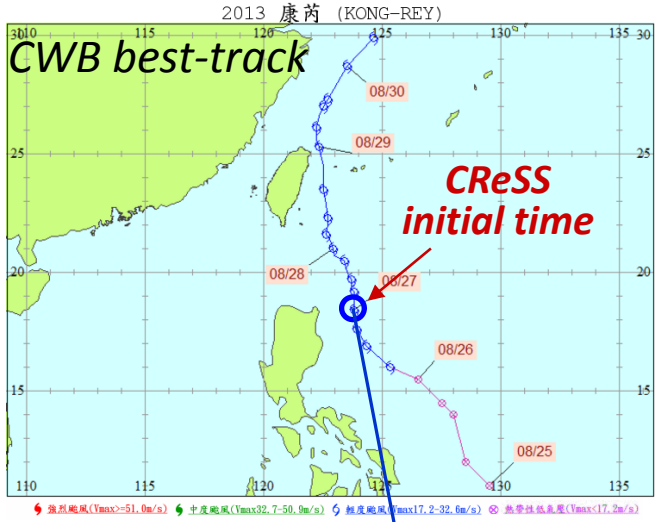


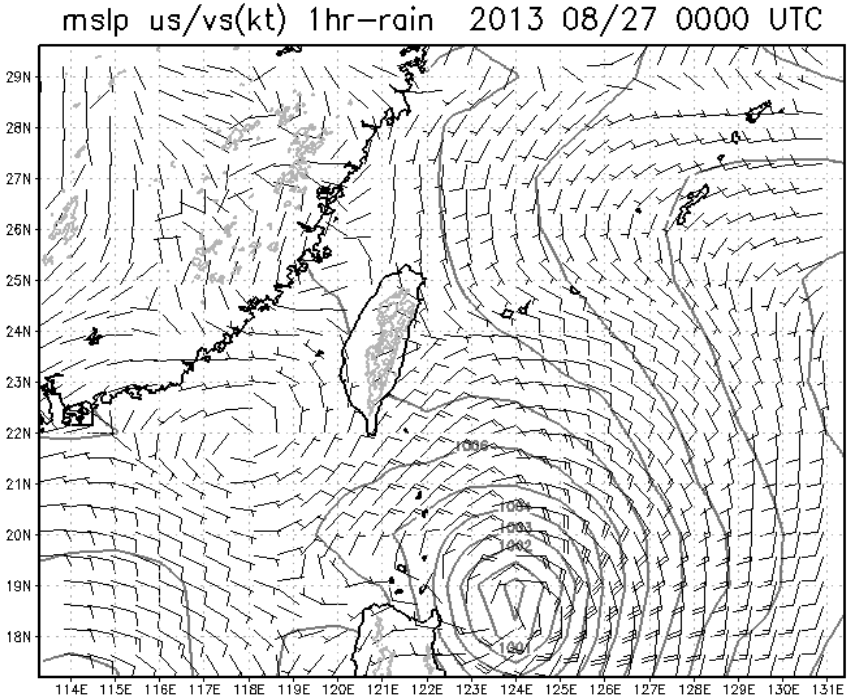
9/27 0000 UTC *9/27 2300 UTC* *9/28 1600 UTC*

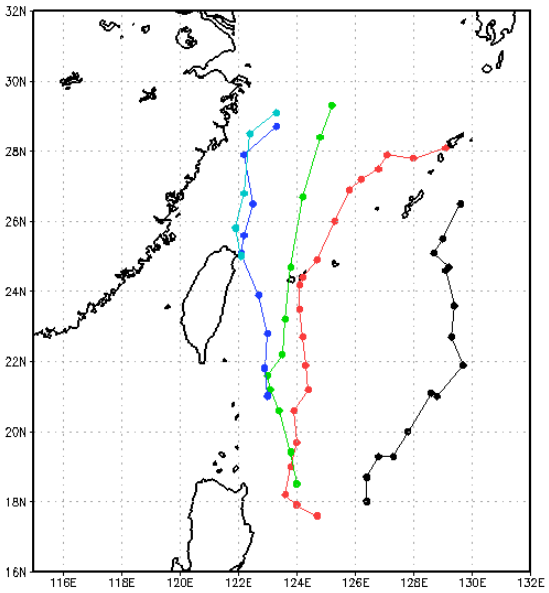
- *Daily rainfall forecasts for TY Jelawat, starting at 0000 UTC, 23-27 Sep:*



- *Forecast for Typhoon Kong-Rey, starting at 00 UTC 27 Aug 2013*





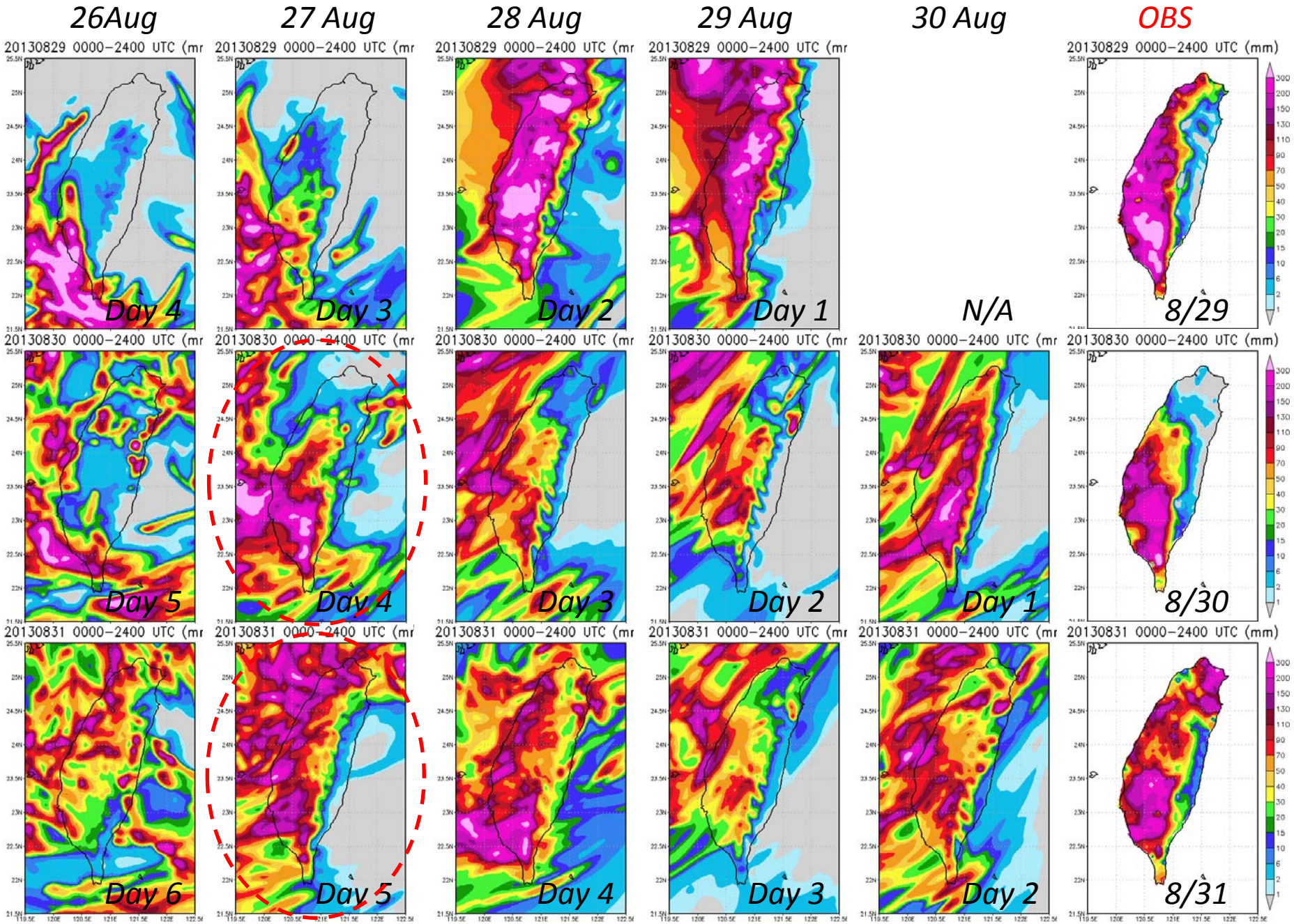


(Computational demand: 5 TTFRI-WRF members)

2013082500
2013082600
2013082700
2013082800
2013082900

Ensemble tracks from time-lagged runs

- *Daily rainfall forecasts for TY Kong-Rey, starting at 0000 UTC, 26-30 Aug:*



4. Conclusion and Summary

- *Advantages of high-resolution forecasts with larger domain/longer range:*
  - *Realistic rainfall scenarios associated with different tracks*
  - *Realize potential lead-time for early warning and better preparation*
  - *Both the above are extremely important for hazard reduction in Taiwan*
  - *Estimates on probabilities still available from time-lagged runs*
  - *Improvement in TC track and intensity (high resolution, large domain)*

	Low-resolution ensemble models	*High-resolution models with increased range and domain*	
Track	*Good*	***Better***	→ *Improved*
Intensity	*Poor*	***Better***	→ *Improved*
Rainfall	*Poor*	***Very good***	→ *Realistic*
Striking probability	*Good*	*Good/**Better***	→ *Available*
Lead time	*Good*	***Very good***	→ *Extended*

  - *Increase chance to make high-quality forecasts as early as possible*
  - *Start preparation for the worse case early and make adjustments later on with real-time verification*
  - *It is feasible even under limited resources (4 times daily/~1600 cores)!*

--- The End ---

Thank you for listening!