Convective-scale NWP for Singapore

Hans Huang and the weather modelling and prediction section
MSS, Singapore

Dale Barker and the SINGV team
Met Office, Exeter, UK

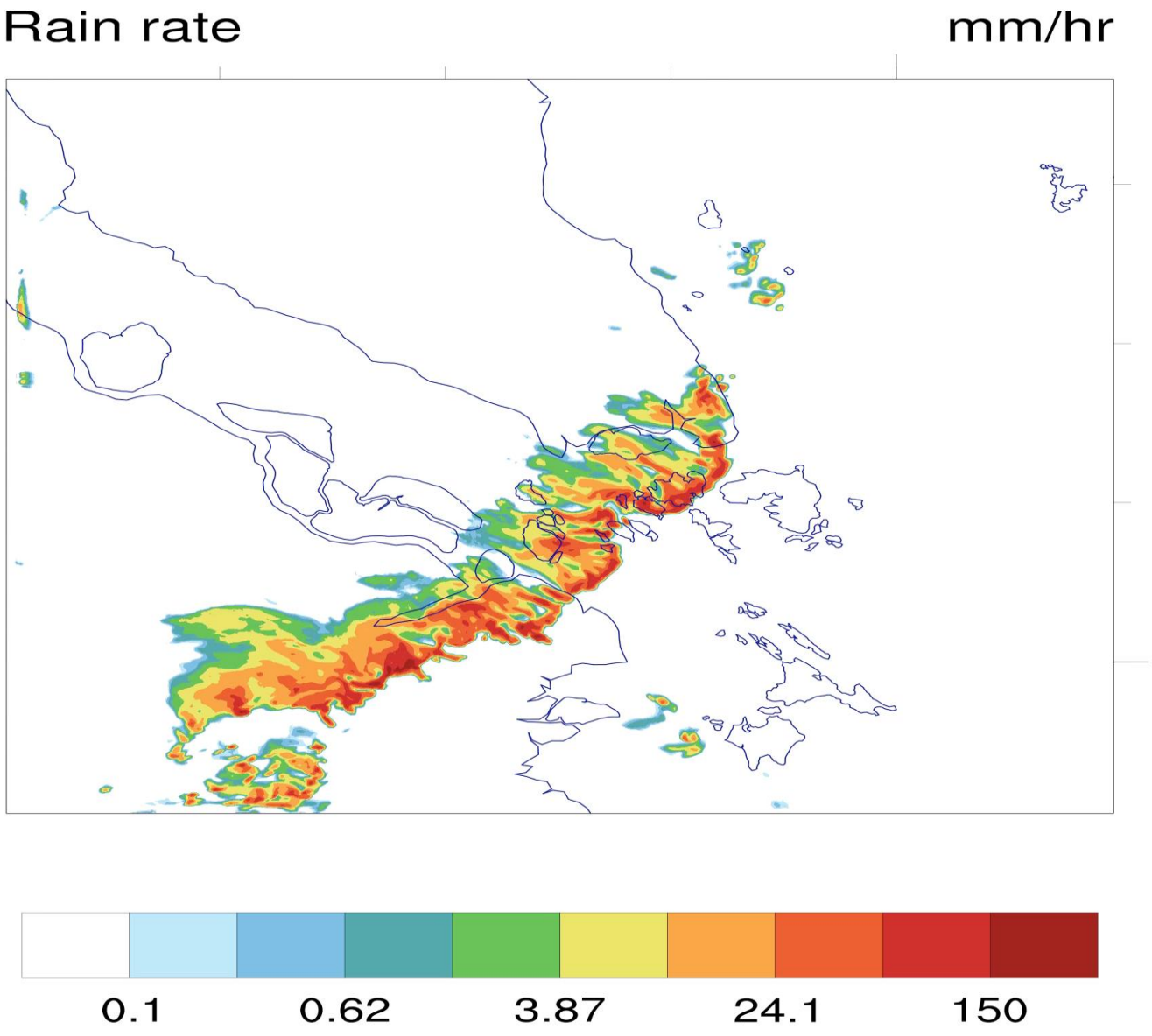
ECMWF Symposium on Dynamical Meteorology and NWP 8 June 2017

Tropical weather systems are complex

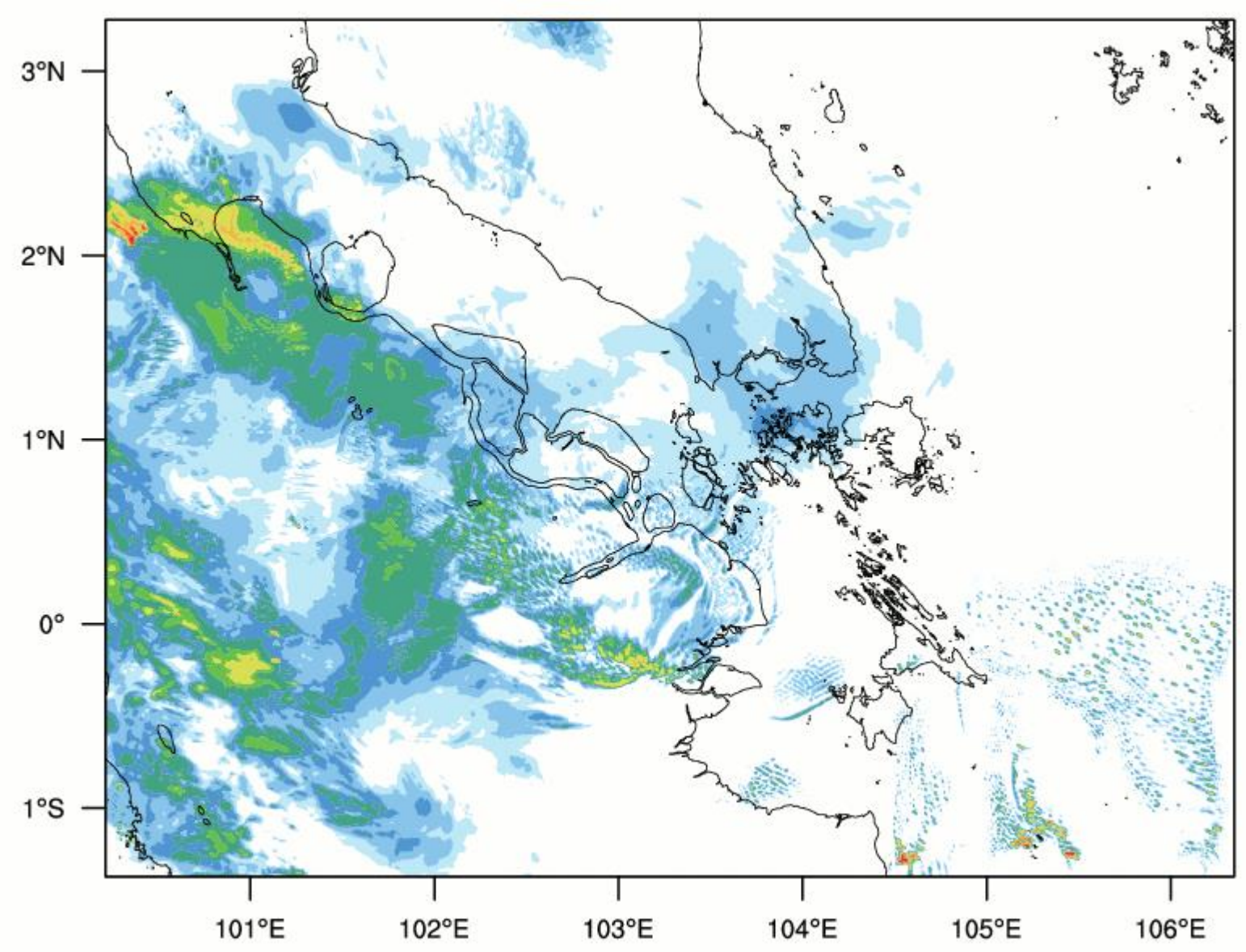
- Convective rain clouds develop rapidly and have short-life span
- Largely driven by winds, which tend to be weaker and more variable in direction in the tropics
- Difficult to give precise forecasts of onset, location and intensity
- “Off-the-shelf” Numerical Weather Prediction (NWP) models - Low skill in predicting convective-scale systems (rain showers, localised thunderstorms)

SINGV, 500m

07H45M 19 Aug 2016



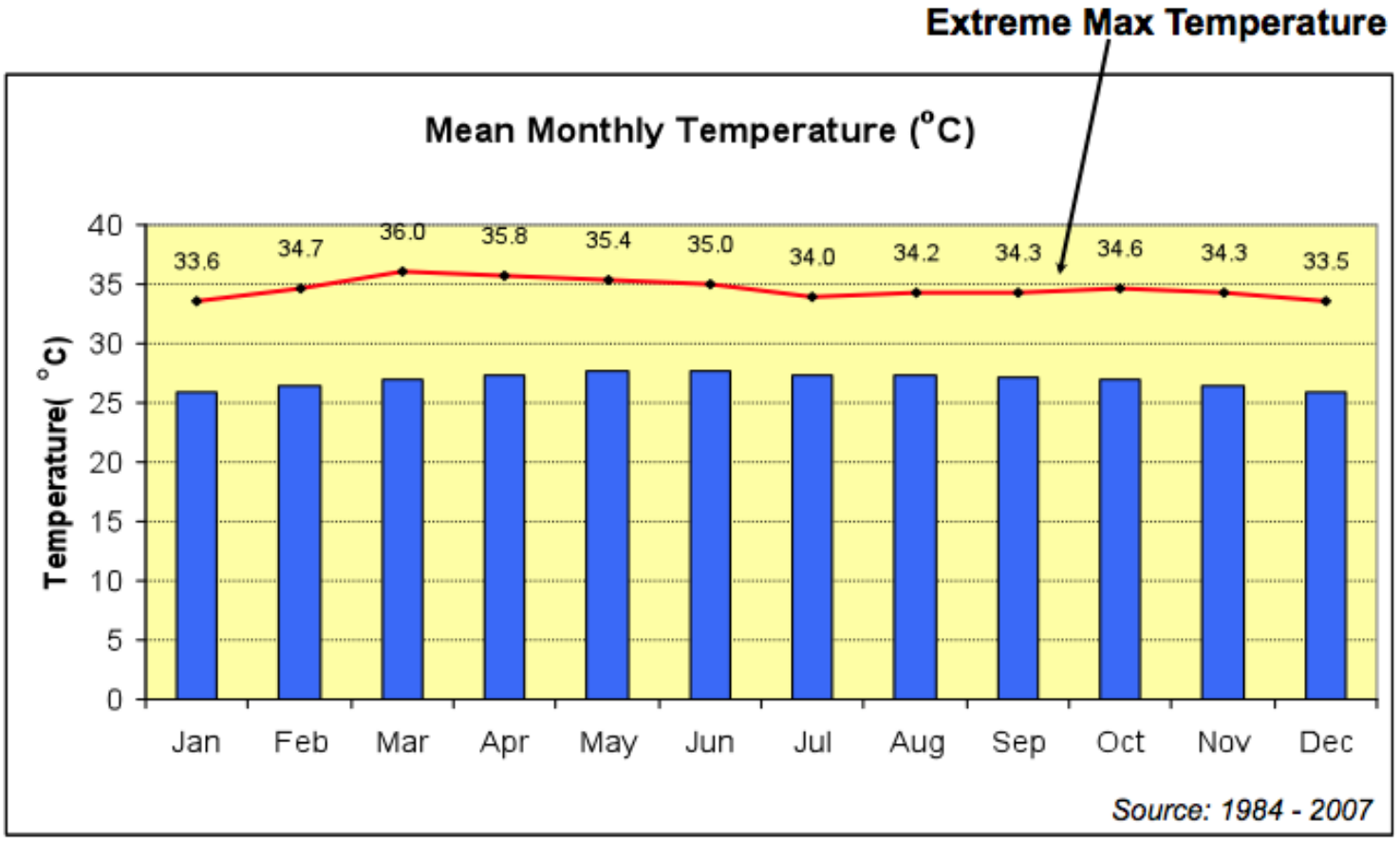
WRF, 500m



Singapore Weather: Surface Temperature

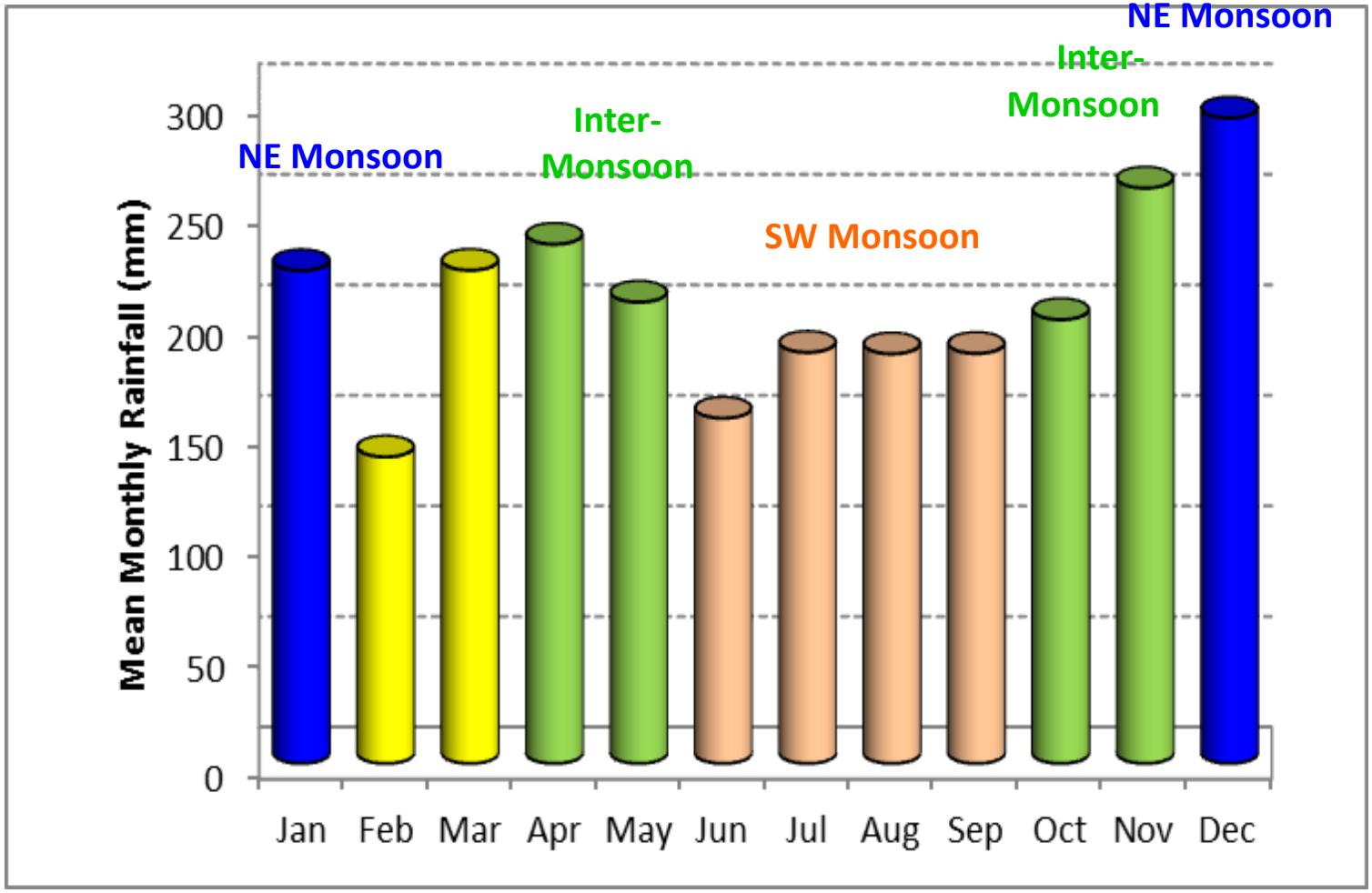
Raizan, MSS

- Little variability through year….

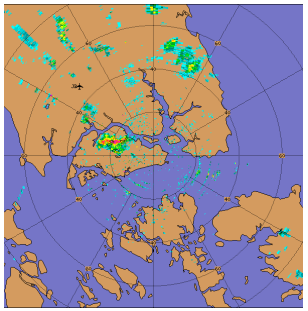


Monsoon Seasons in Singapore

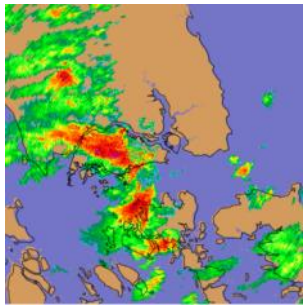
Cheong Wee Kiong, MSS



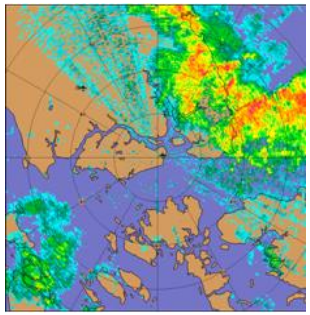
Main weather systems which bring heavy rainfall:



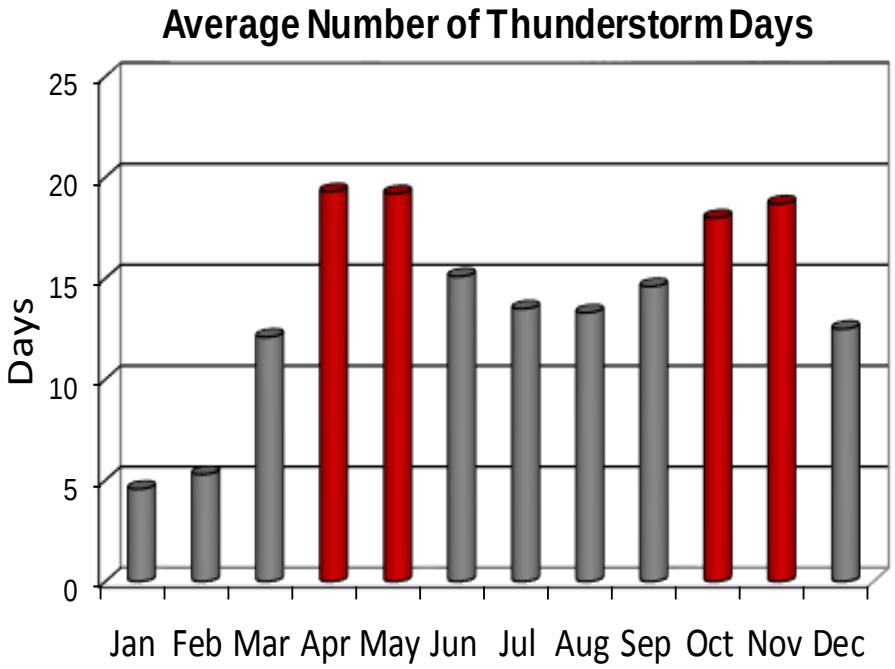
Localized convective thunderstorms

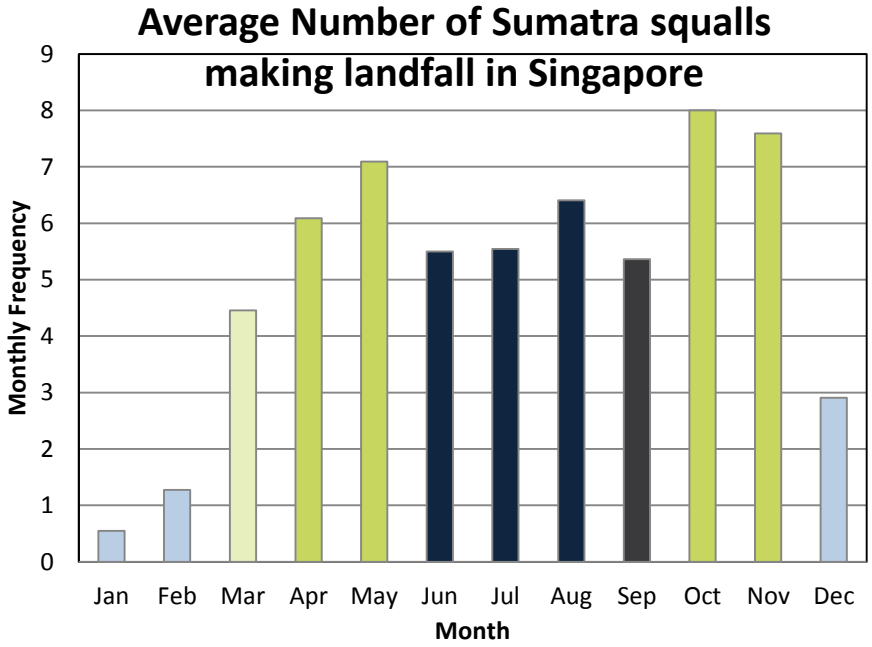


“Sumatra” squalls



Monsoon surges



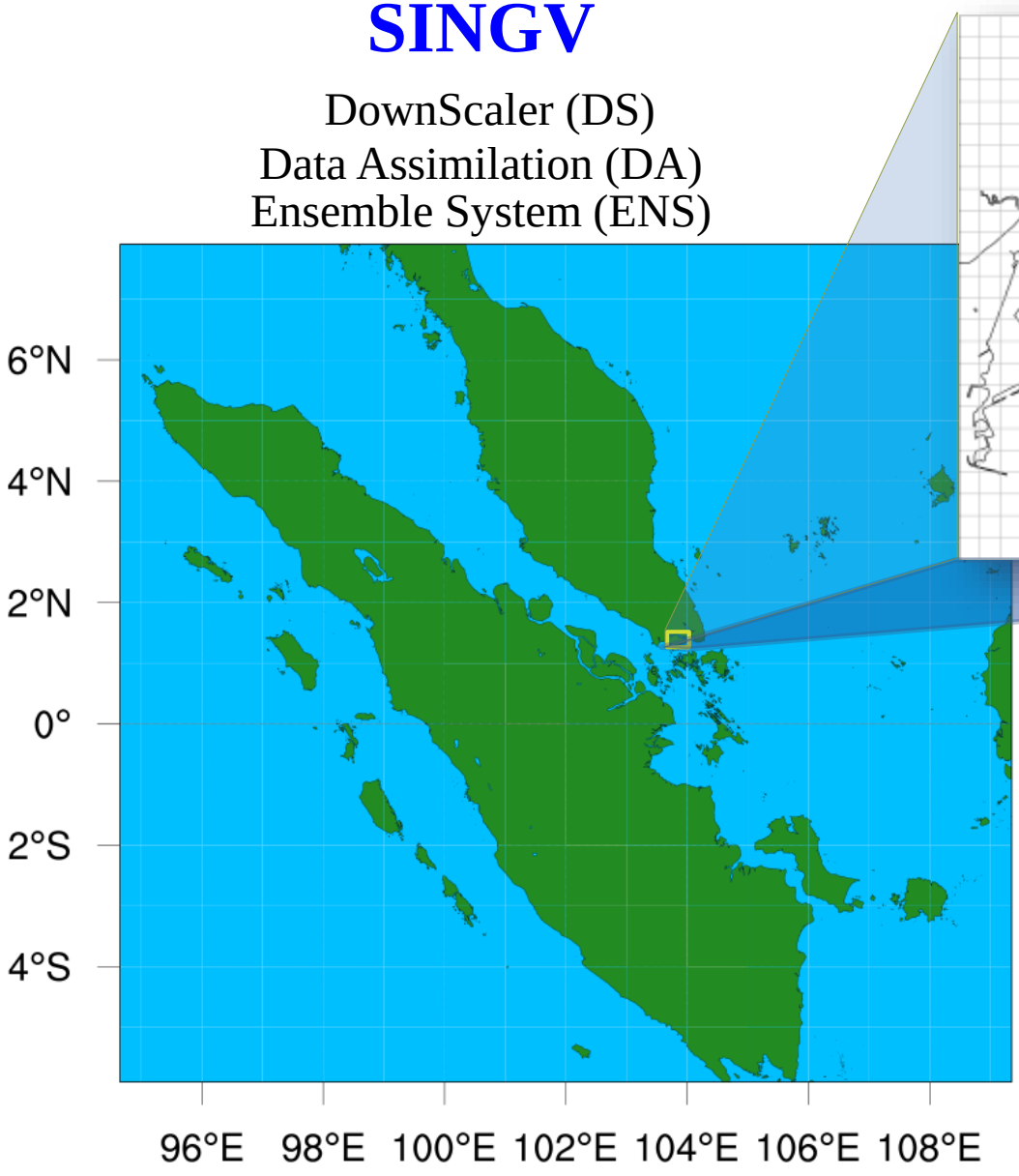


SINGV
– the convective-scale NWP system for Meteorological Service Singapore

- Collaboration: Met Office and Meteorological Service Singapore.
- ~4FTE/yr from each partner.
- Tropical, km-scale NWP R&D plus operational implementation target.
- Core Model R&D -> Evaluation -> DA -> Ensemble + Tech Infrastructure

SINGV

DownScaler (DS)
Data Assimilation (DA)
Ensemble System (ENS)



- Downscaler uses a 1.5 km mesh, runs 2 times per day and produces 36h forecasts.
- Data assimilation system uses a 4.5 mesh, runs in full cycling with 3h assimilation windows and produces 12h forecasts from each analysis.
- Ensemble system uses 12 4.5km DS members, runs 4 times a day and produces 36h forecasts.

SINGV (DownScaler) started in real time at MSS in Feb 2015!

Version 2.0:

- Based on PS35 UKV ENDGame
  - No MURK aerosol
  - But L80 rather than L70
- Changes from Version 1
  1. P2A blended BL scheme
  2. Single 1.5 km domain
     - As opposed to version 1 = double nest
     - 1092 x 1026 x L80, dt=50s
     - Fixed not variable resolution
     - ~5 times cost of Version 1 configuration

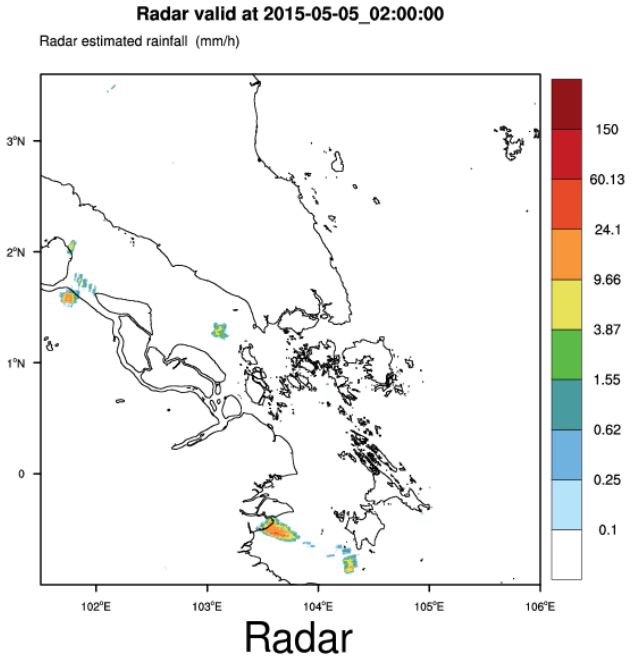
Model (vn 2.0)

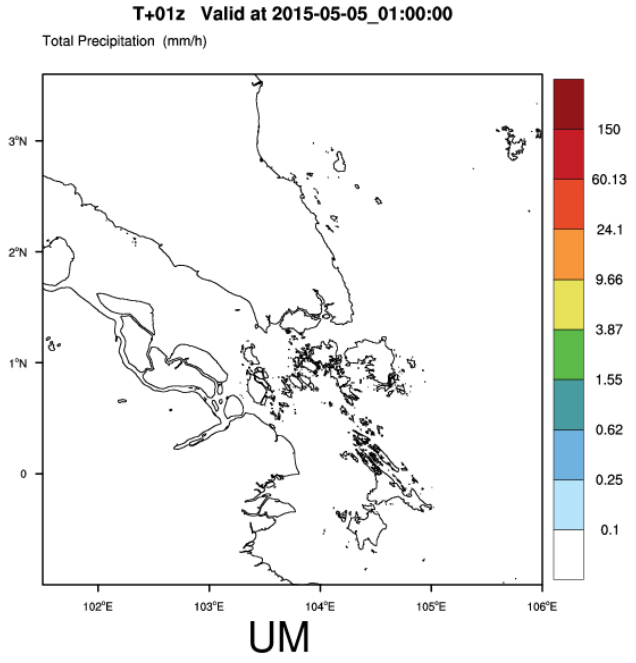
Radar
Estimated Rainfall

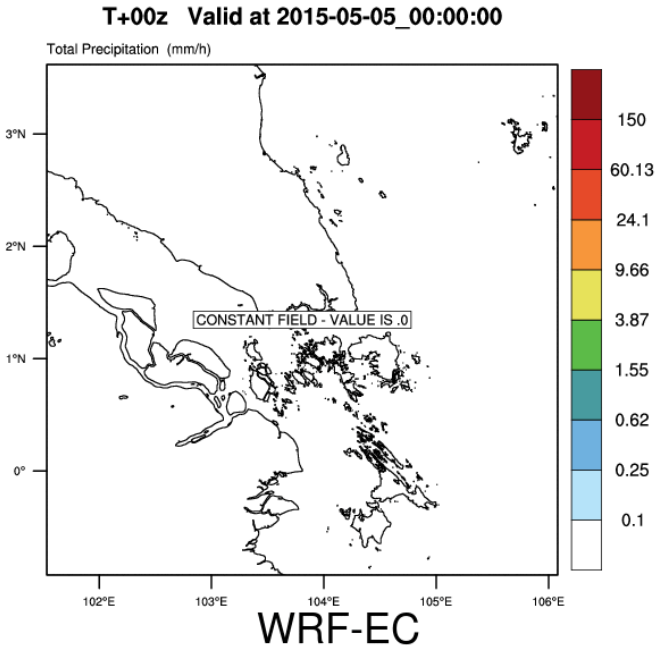
and

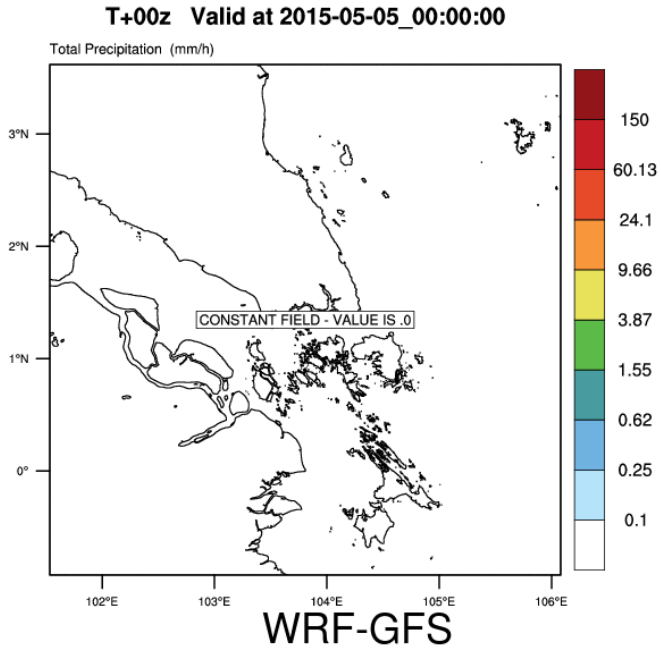
Precipitation Forecasts from SINGV (UM), WRF-GFS, and WRF-ECM

SINGV – clumpiness (blobbiness)









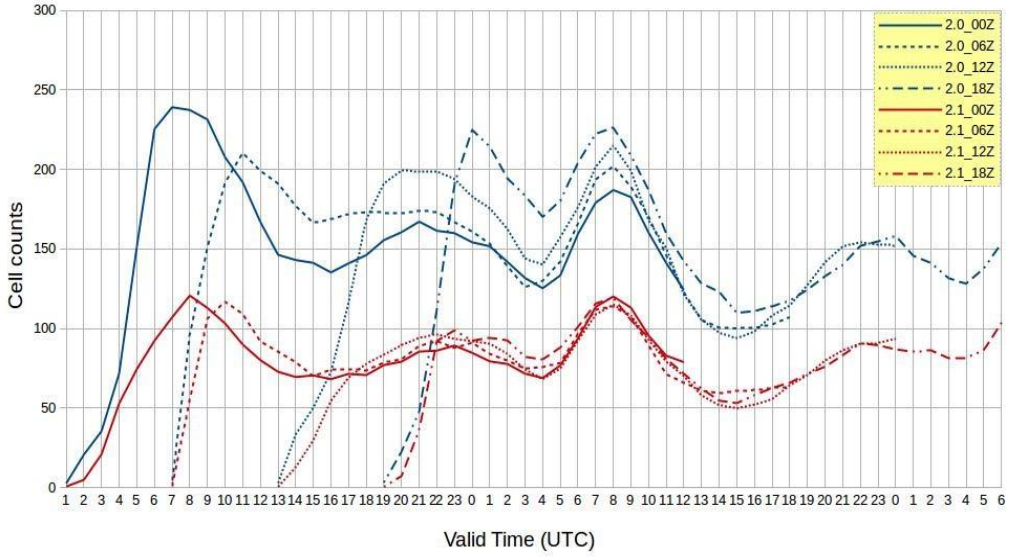
Known Model Issues

- Cloud-scale biases
  - Too much heavy rain and too high peak rainfall rates.
  - Too strong and deep updrafts.
  - Not enough light rain.
  - Too many small cells, too few large if convection is well resolved.
  - Too few cells if under-resolved
- Organisation biases
  - Cells too circular if under-resolved, too elongated if well resolved and orientation tends to be too much along wind.
  - Lack of propagation of squall lines (noted particularly in Singapore).
- Biases in response to large-scale / boundary layer / diurnal forcing
  - Timing of initiation of convection.
  - Other timing issues.
  - Land-sea contrast issues - in particular excessive convective rainfall over land and light rain over the ocean.
- Biases in response to driving model
  - Spin up effects at edge of domain
  - Errors passed from larger scale driving models.

(from convection WG)

SINGV configuration vn2.0 → vn2.1

- Fixed the reconfiguration coding error
- Treatment of the convective boundary layers
  1. Applied the blended boundary layer approach
  2. Introduced stochastic temperature perturbations
- Increase of the mixing length in 3D Smagorinsky scheme
- Switched off the excessive graupel production



Improvements:

- Excessive rainfall reduced;
- Less intensive storm cells;
- Spin-up time reduced.

Counts of Storm Cells

(Storm cells are defined as spanning at least 12 model grid-boxes, with hourly rainfall in excess of 20 mm/hr in every grid-box)

SINGV configuration vn2.1 → vn3.0

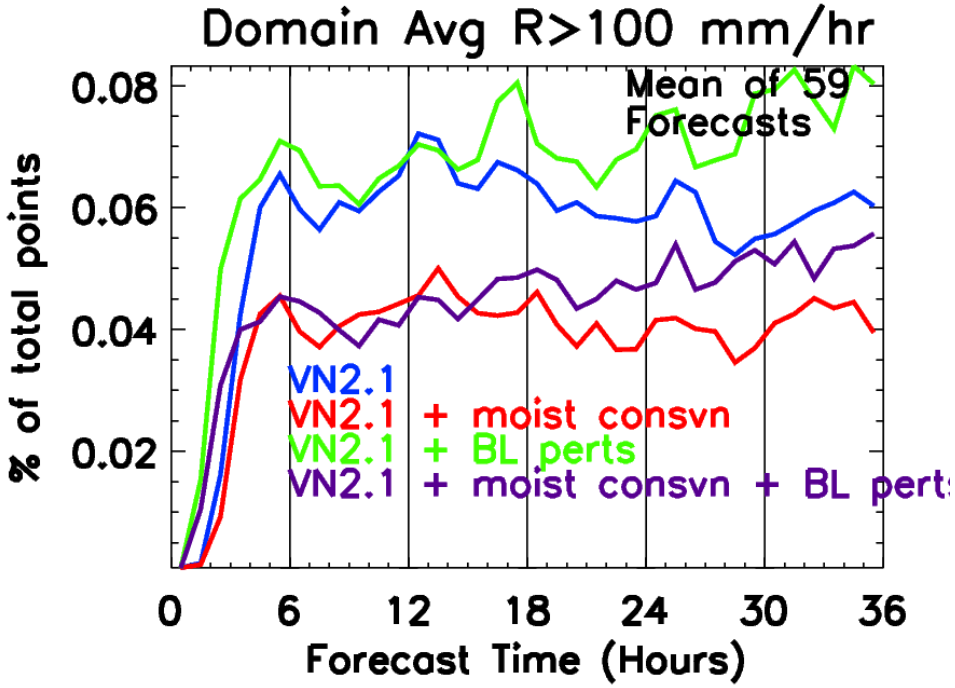
- **The moisture conservation scheme**
- **Temporally correlated stochastic θ perturbations**
- **Stochastic moisture perturbations**

Improvements:

- Areal coverage of rainfall

- Rainfall patterns are more realistic compared with vn2.1;

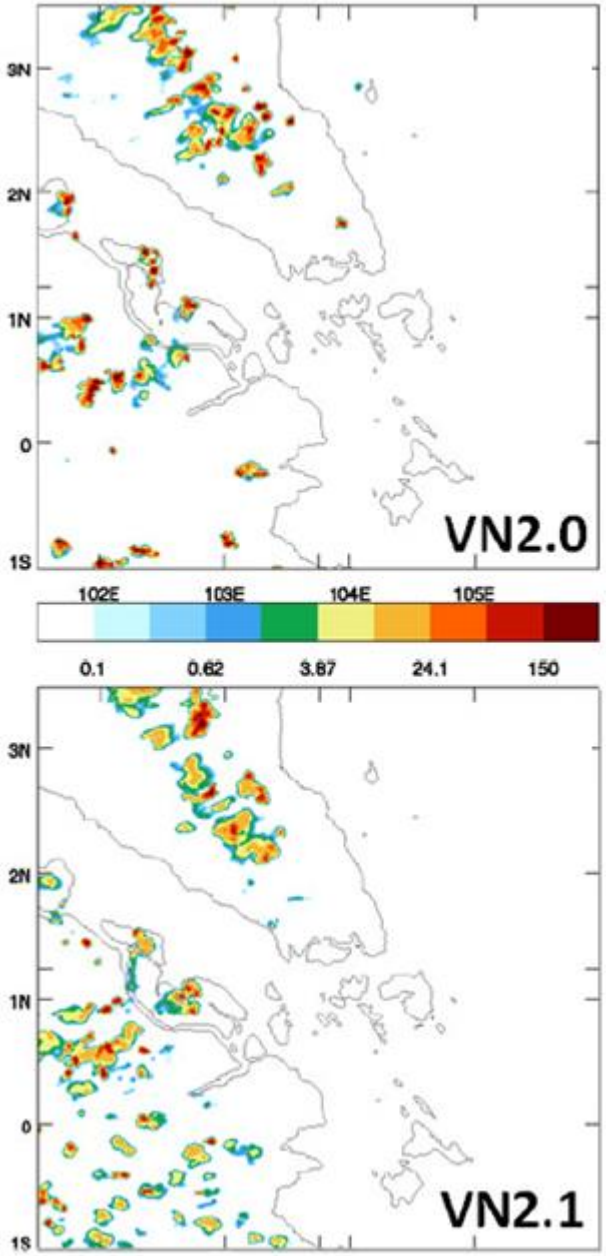
- More rainfall is produced over the sea than vn2.1.



The clumpiness was still an issue

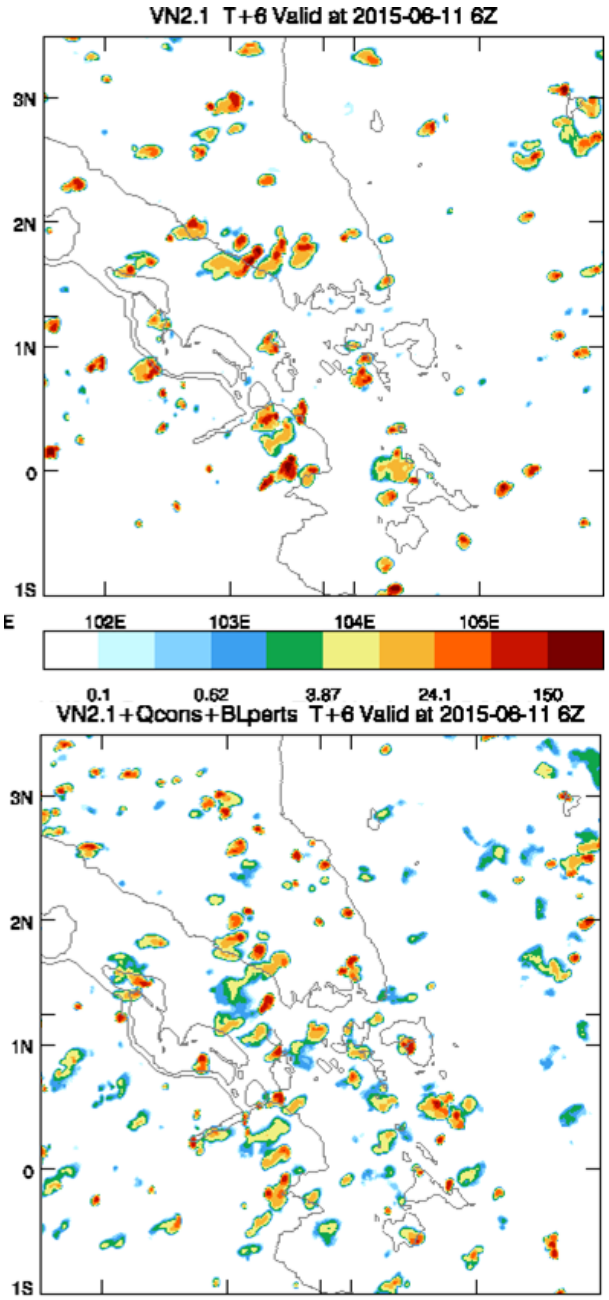
vn2.0

vn2.1



vn2.1

vn3.0



SINGV configuration vn3.1 → vn4.0

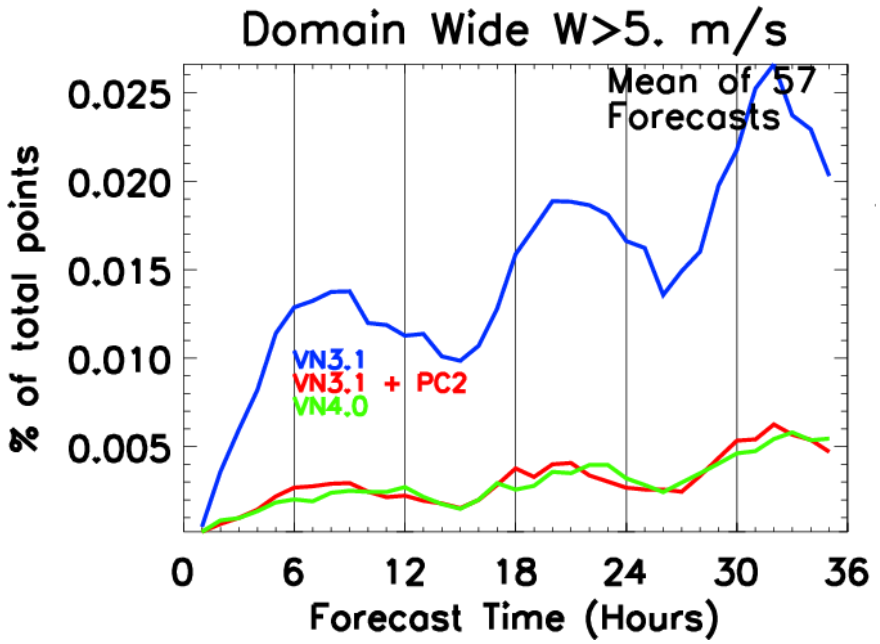
- Use of prognostic cloud cover scheme (PC2) instead of Smith's scheme.
- Revised stochastic boundary layer perturbations
- Revised moisture conservation

Remarks

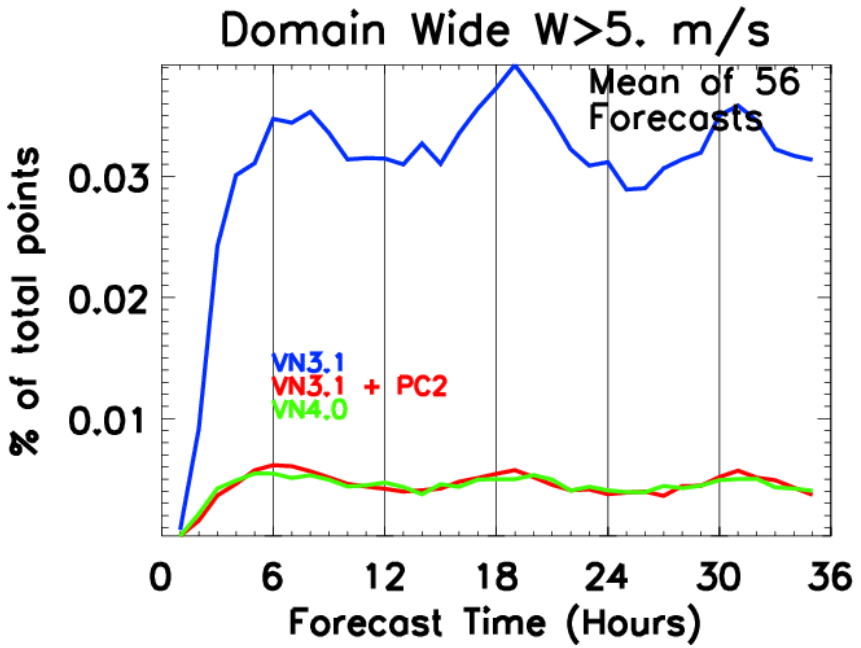
- Cloud cover is too variable over tropics.
- Switch to the prognostic cloud cover scheme (PC2) from Smith's scheme made significant impact. Reason not fully understood yet!

Reduction in intense convection

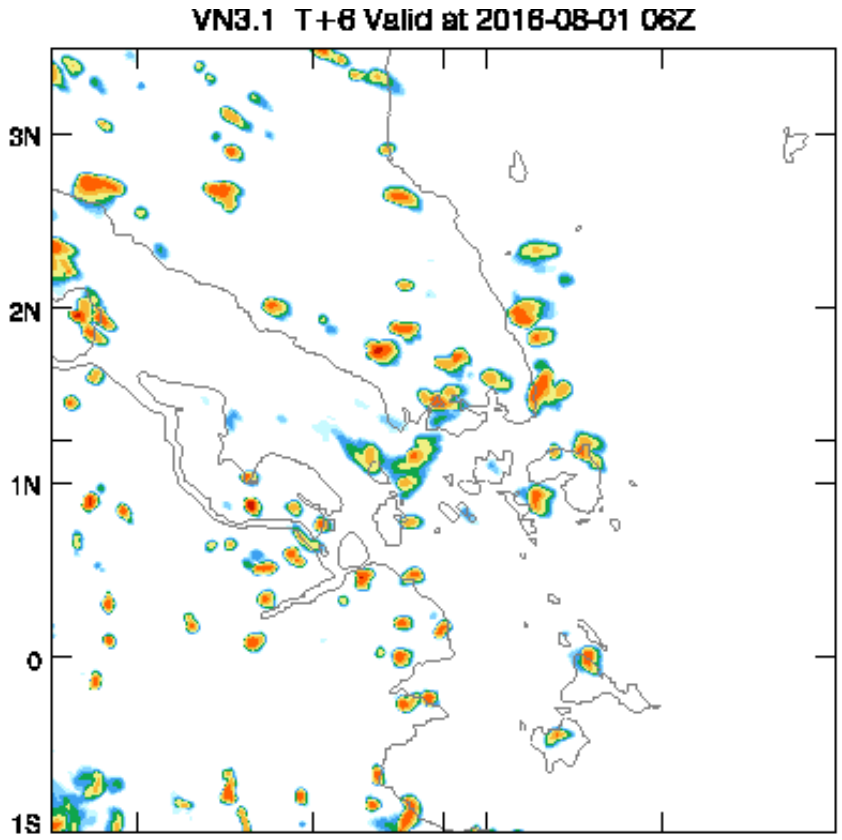
August

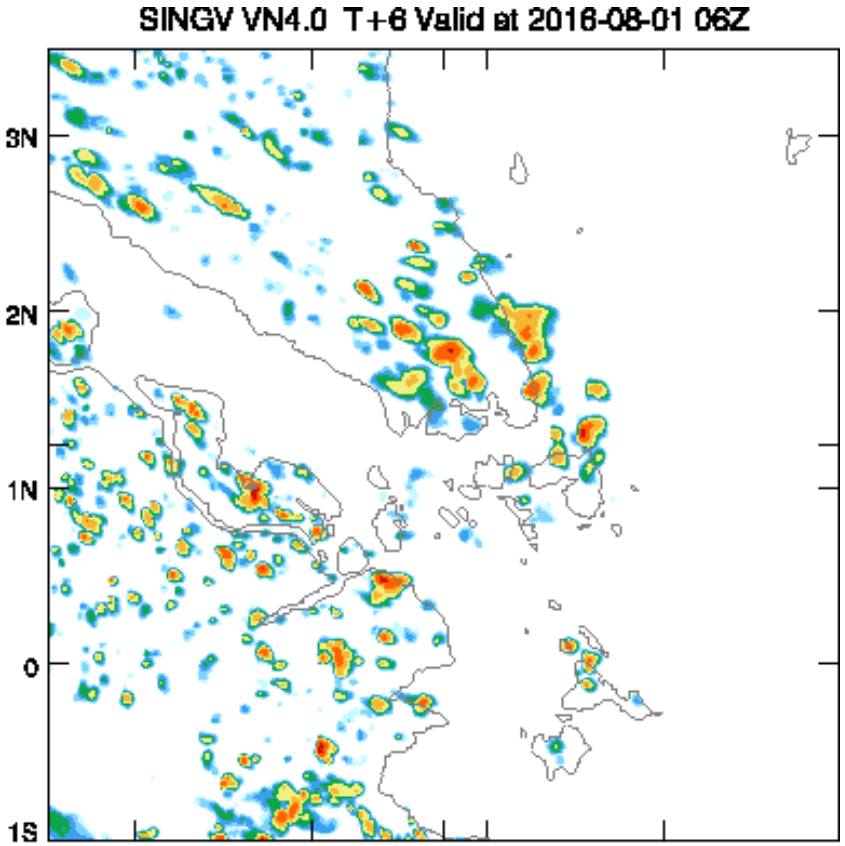


November



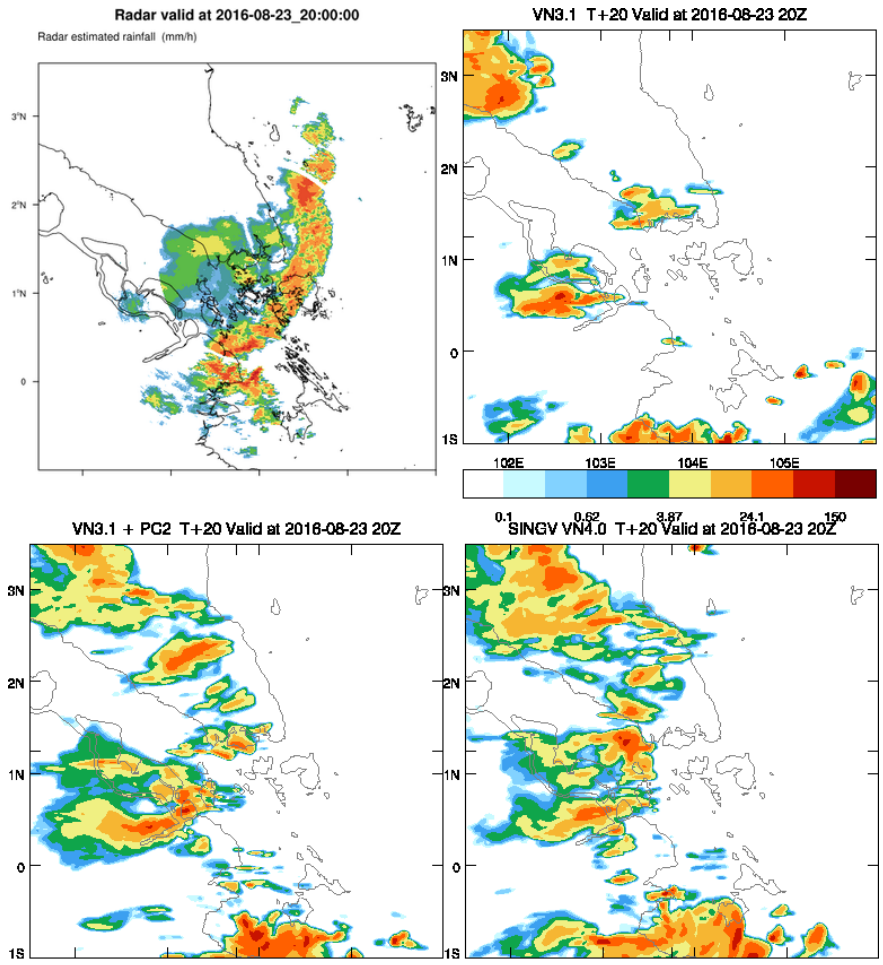
Reduced clumpiness

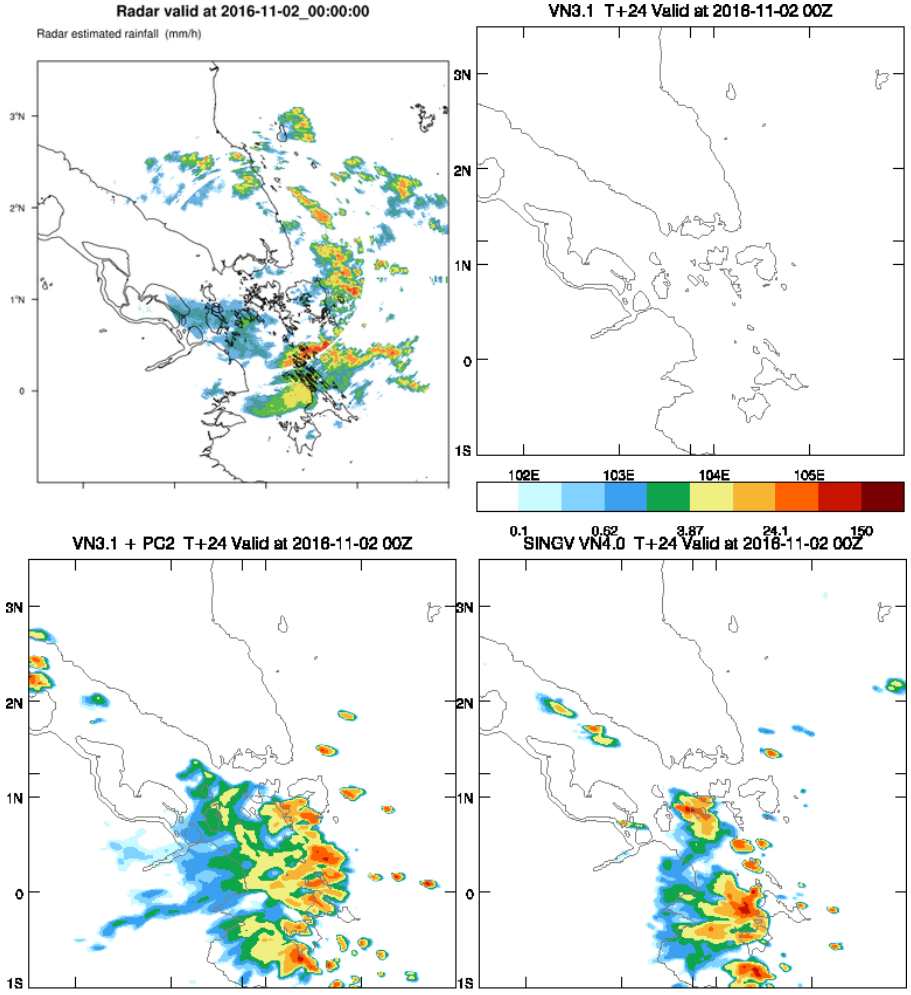




Increase in light rainfall and reduction in high rainfall intensity gives the impression of reduced clumpiness

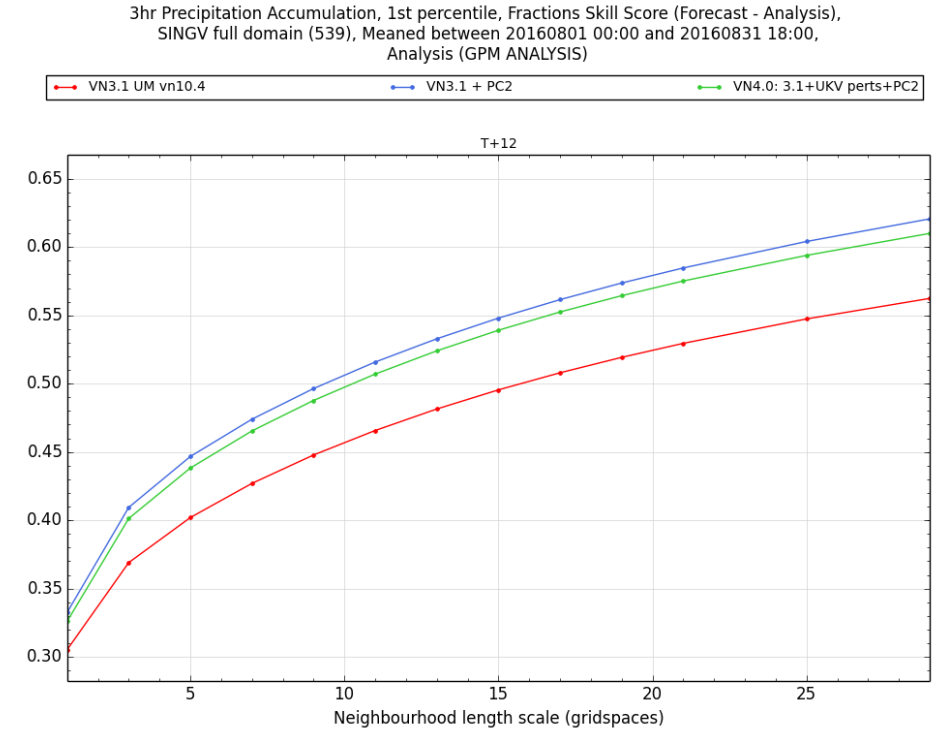
Improved squall lines





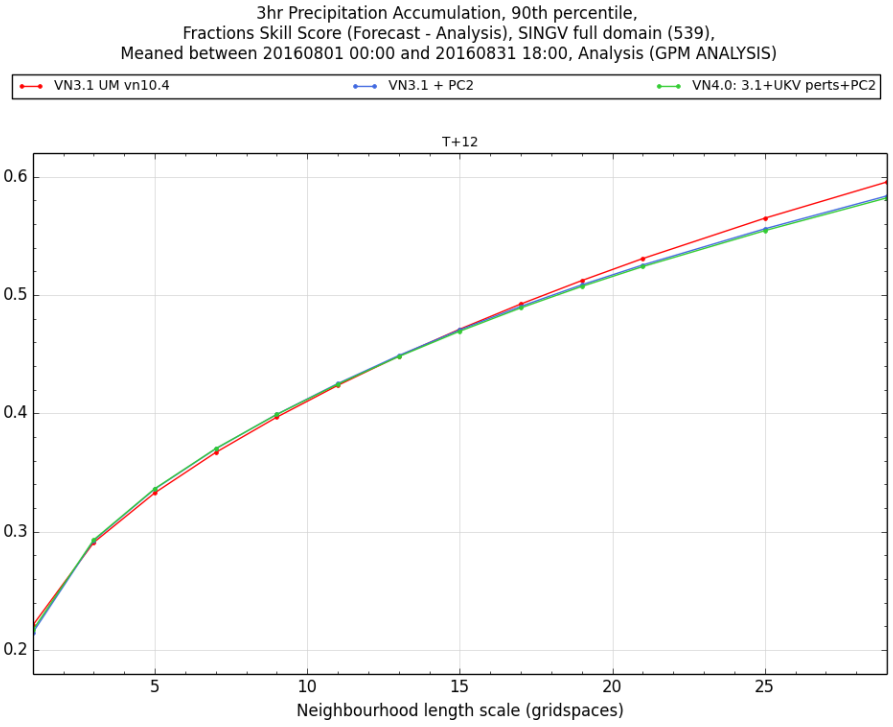
FSS score August, full SINGV domain

Light Rain



vn4.0 is more skilful than vn3.1

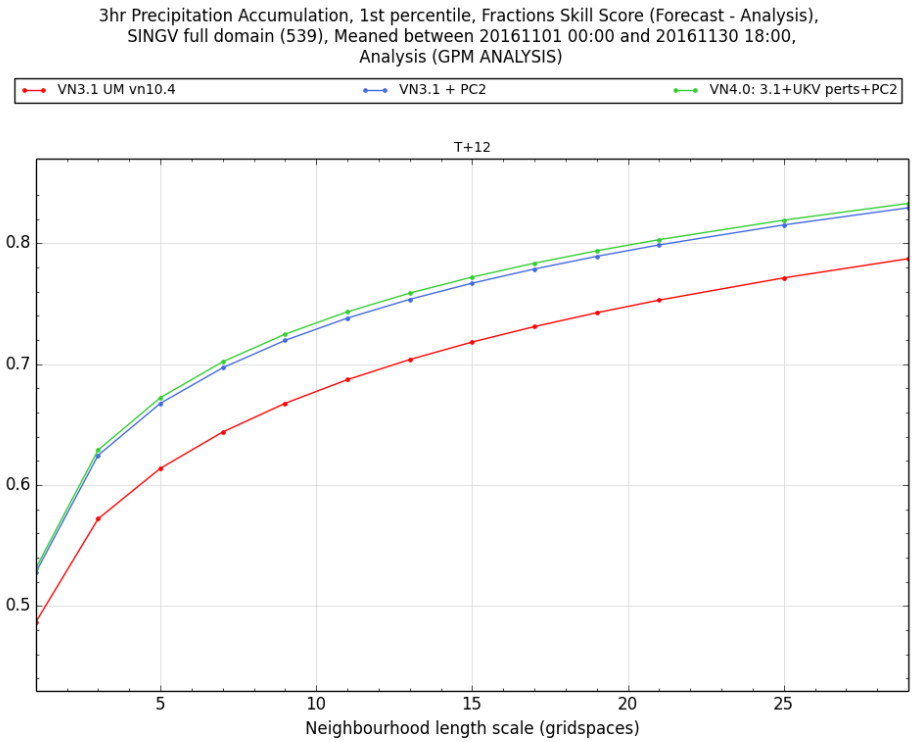
Heavy Rain



vn4.0 is of comparable skill

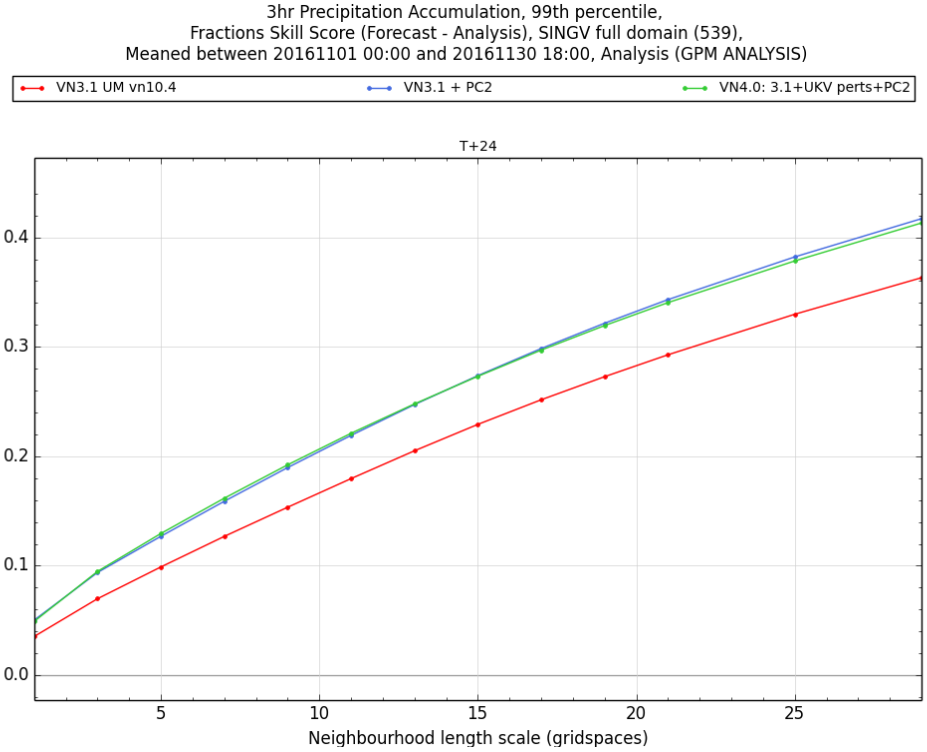
FSS score for November, full SINGV domain

Light Rain



vn4.0 is more skilful than vn3.1

Heavy Rain



vn4.0 is more skilful than v3.1

SINGV Data Assimilation

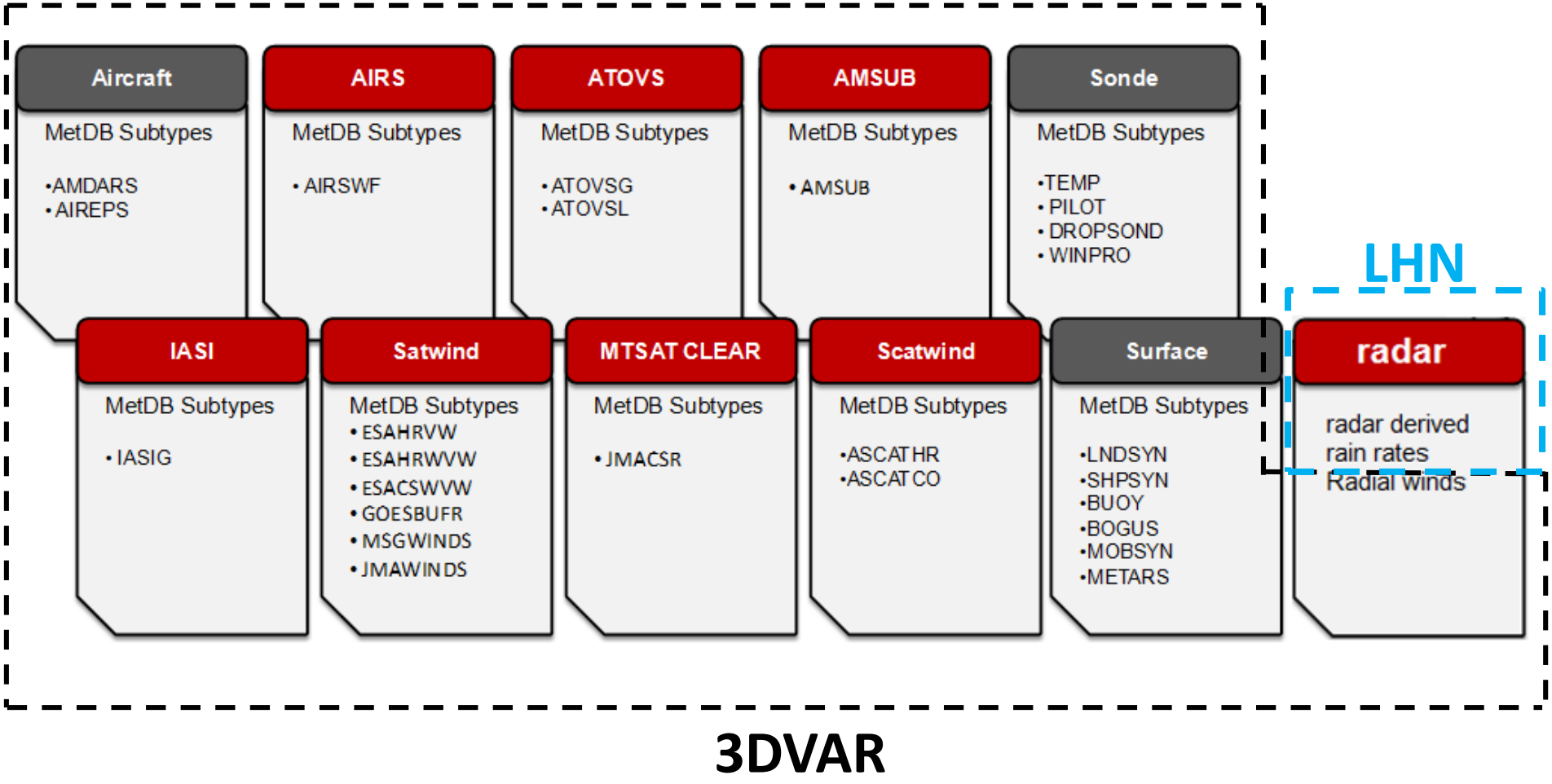
- Initial technique: 3D-Var cycling every 3hr
- **Real time implementation: April 2016**

- Consider 4D-Var: 2016
- Adding ensemble to DA:2017

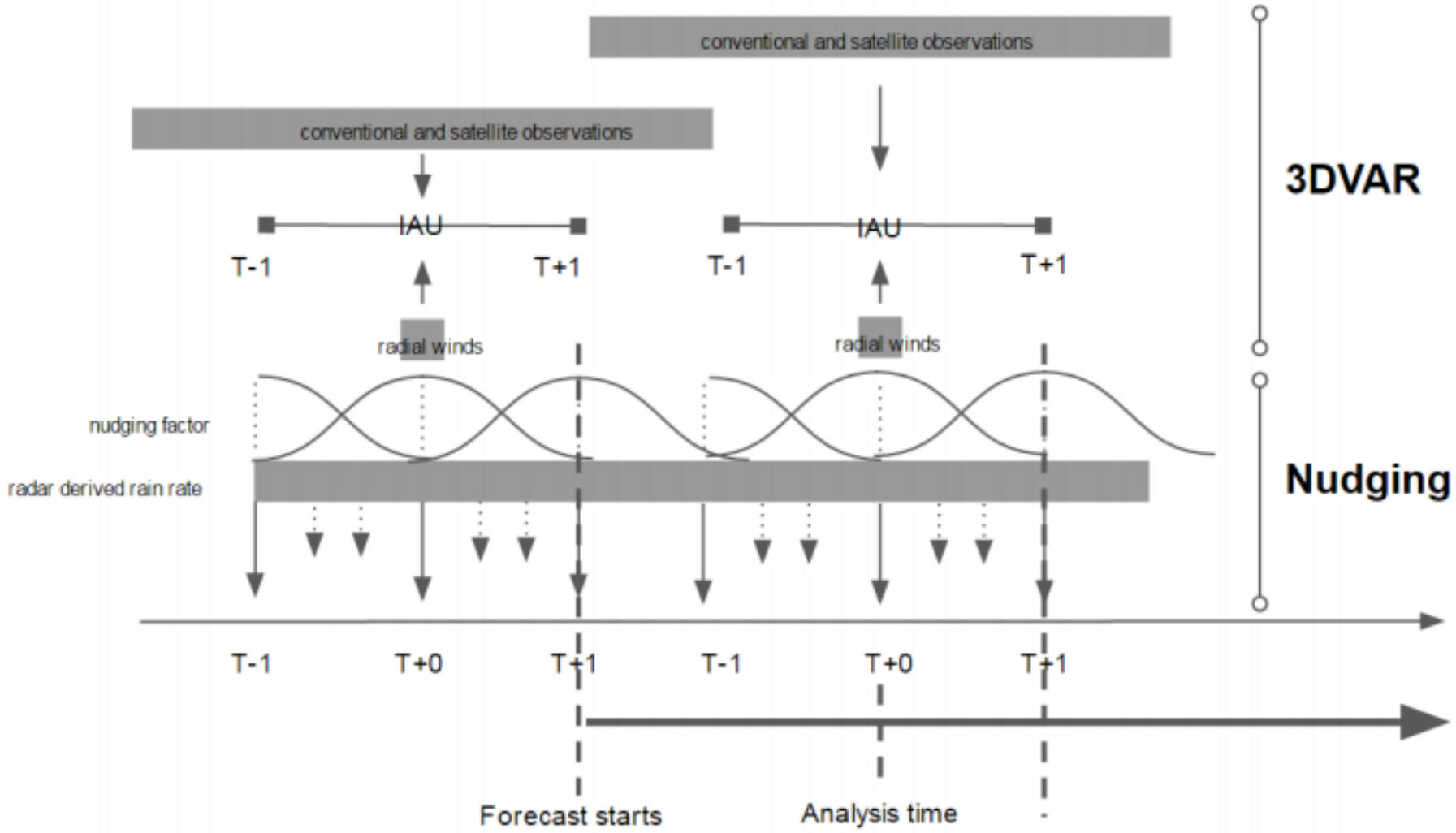
SINGV DA Version 1: conventional observations + amsub + iasi + satwind + mtsatclear (with global bias configuration)

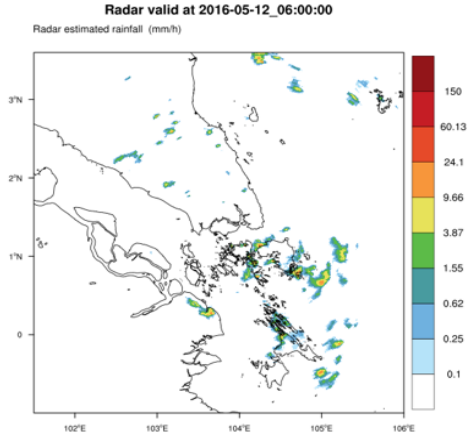
SINGV DA Version 2: conventional observations + amsub + iasi + satwind + scatwind + airs + saphir (with SINGV specific configuration) + **Singapore radar**

Observation for SINGV

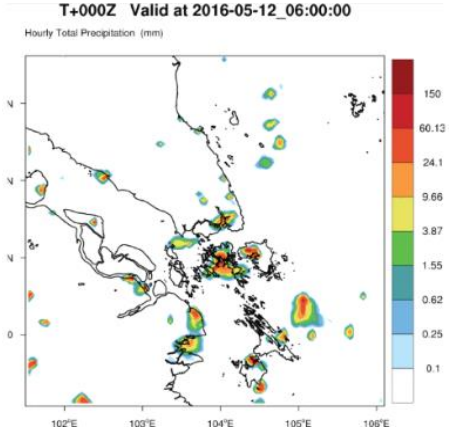


SINGV Data Assimilation System



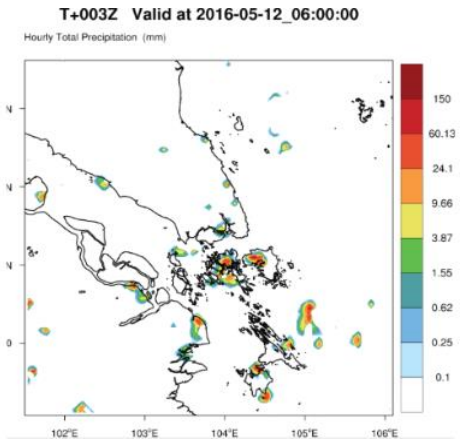


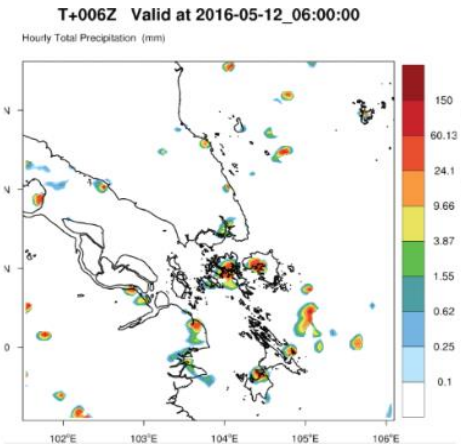
Radar

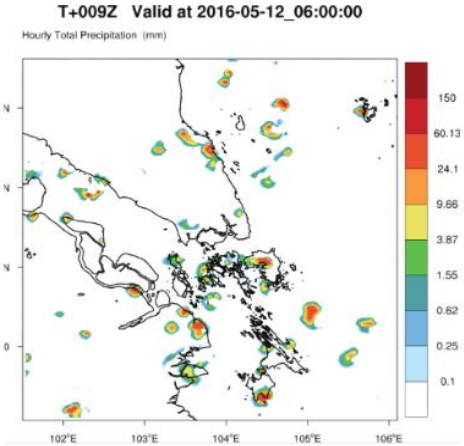


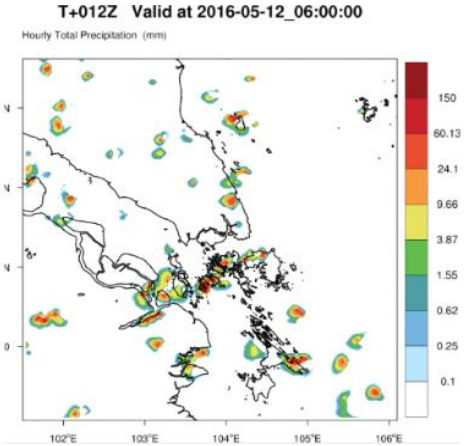
Analysis

Cycling DA produces more forecasts at one valid time, with reasonable consistency







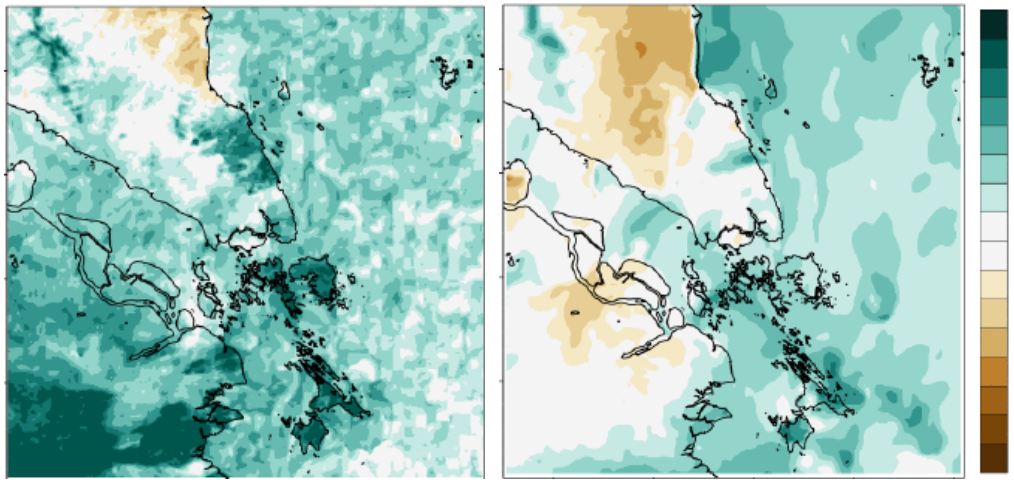


Forecasts at the same valid time (left->right: T+3h, T+6h, T+9h and T+12h)

“Dryness” issue in the DA cycling system

DA is too dry.

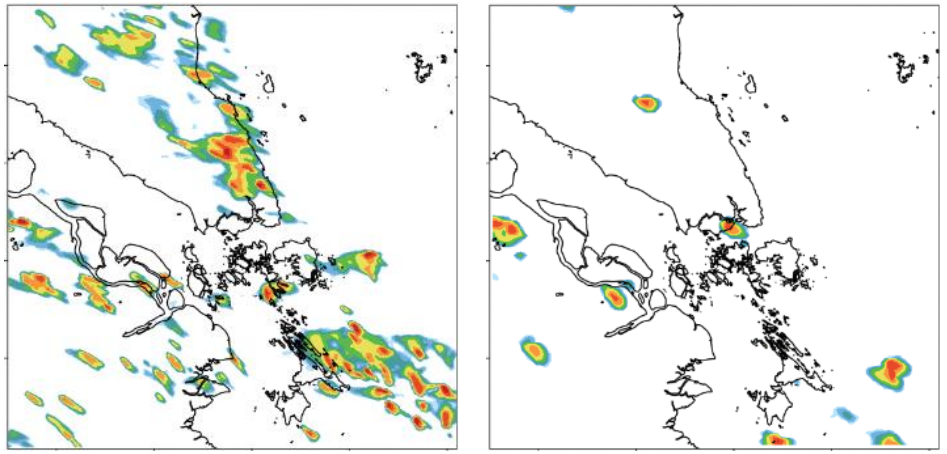
Relative humidity at surface for
(left) DS (T+3h)
(right) DA (T+3h)
2016-05-24 03:00:00



DS (downscaler) DA (data assimilation)

DA produces much less rain.

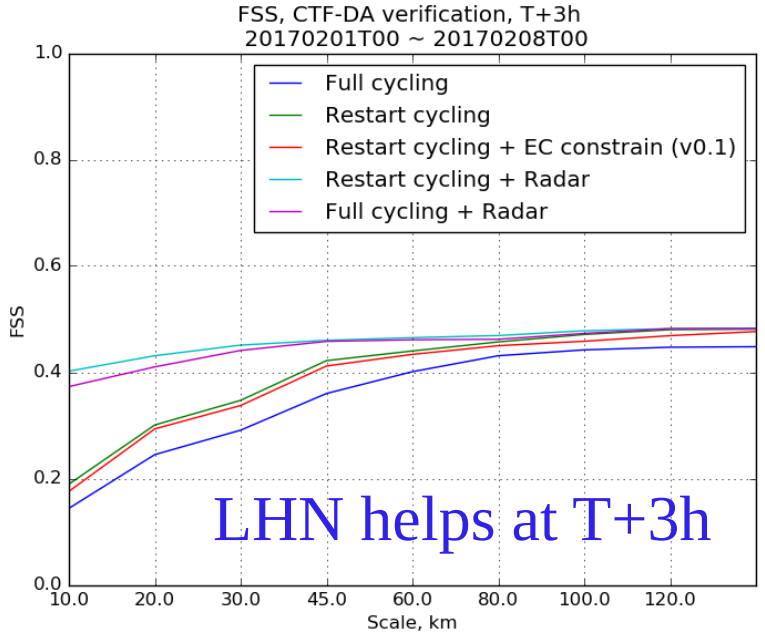
Hourly precipitation for
(left) DS (T+9h)
(right) DA (T+6h)
2016-10-25 09:00:00

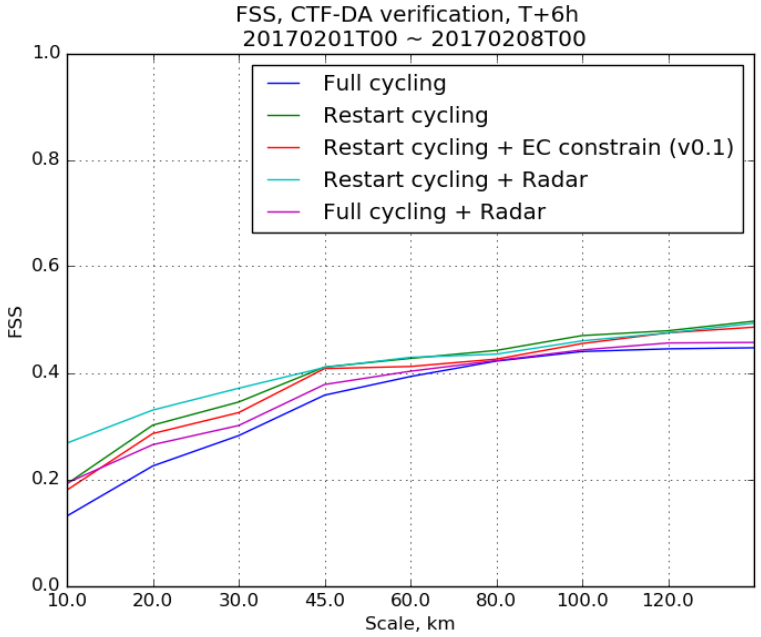


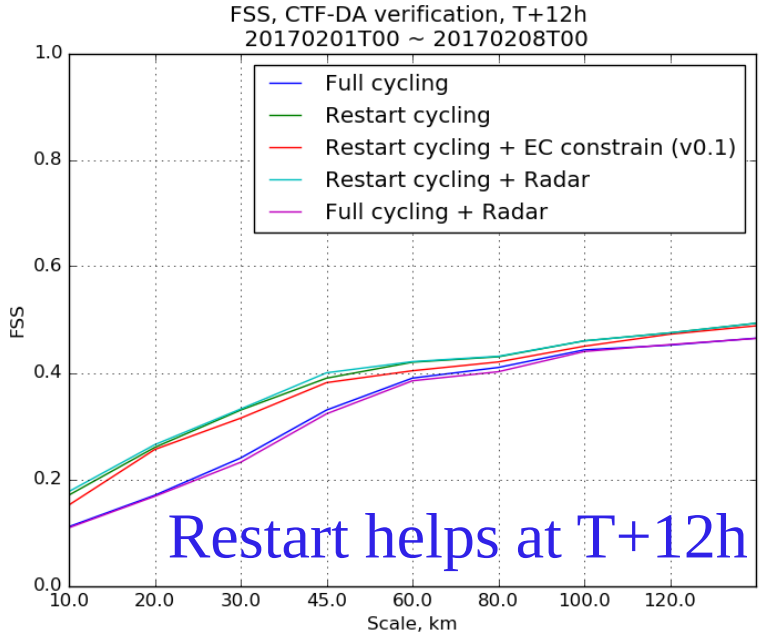
Remarks: not a DA problem ?! May be due to model and lateral boundaries.

Experiments with different DA configurations

Precipitation scores for different forecasting schemes over a week (01-08 Feb 2017)







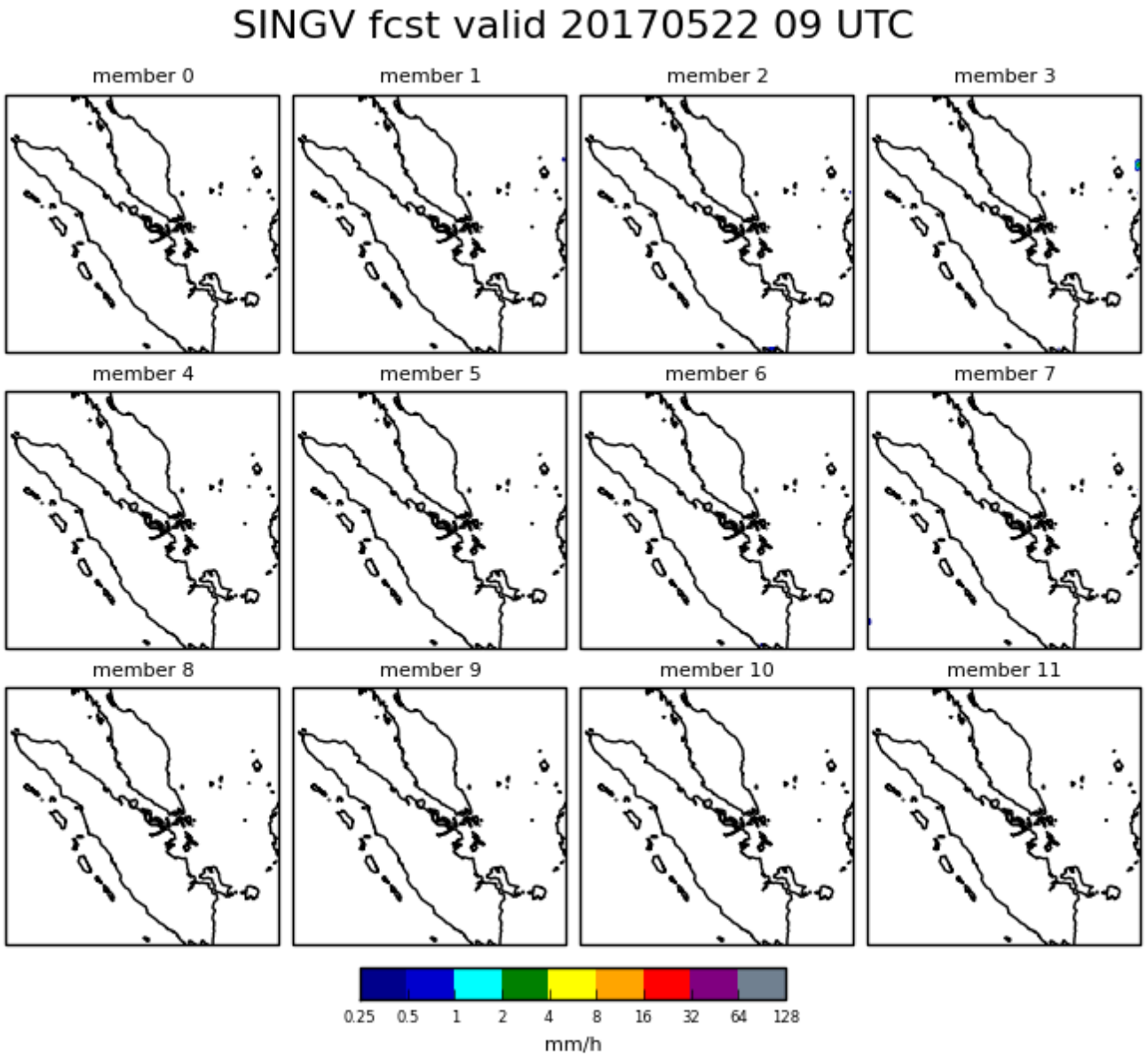
SINGV Ensemble Configuration

- **Model settings**
  - Model: UM 10.6
  - Resolution: 4.5 km
  - Grid: 364x342 grid points
  - Vertical levels: 80 levels (model top 38.5km)
  - Forecast range: T+36
  - Time step: 100 seconds

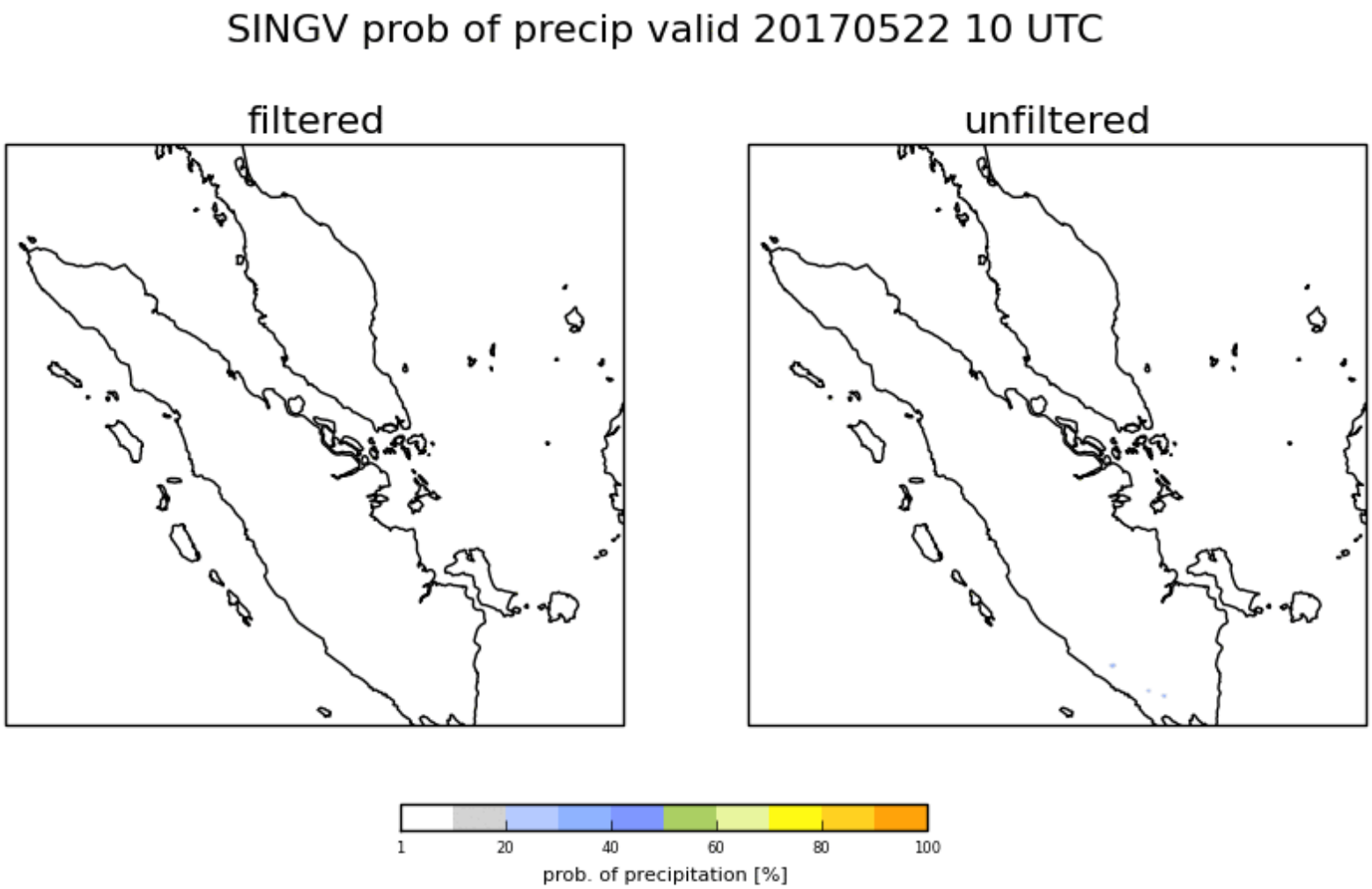
- **Operational details**
  - Real time (planned): **by 31st March 2017**
  - Run 4 cycles per day (3, 9, 15, 21 UTC), the four cycles are driven from the T+3 dumps of 00/06/12/18z Global ensemble MOGREPS-G cycles
  - Forecast length: T+36
  - 12 ensemble members - 1 control run + 11 perturbed members

- **Initial conditions**
  - Initial conditions from global ensemble: MOGREPS-G
  - Perturbations generated by Ensemble Transform Kalman Filter (ETKF).
  - The 03 and 15 UTC cycles receive perturbations from the global ensemble members 1 to 11, whereas the 09 and 21 UTC cycles use perturbed members 12 to 22

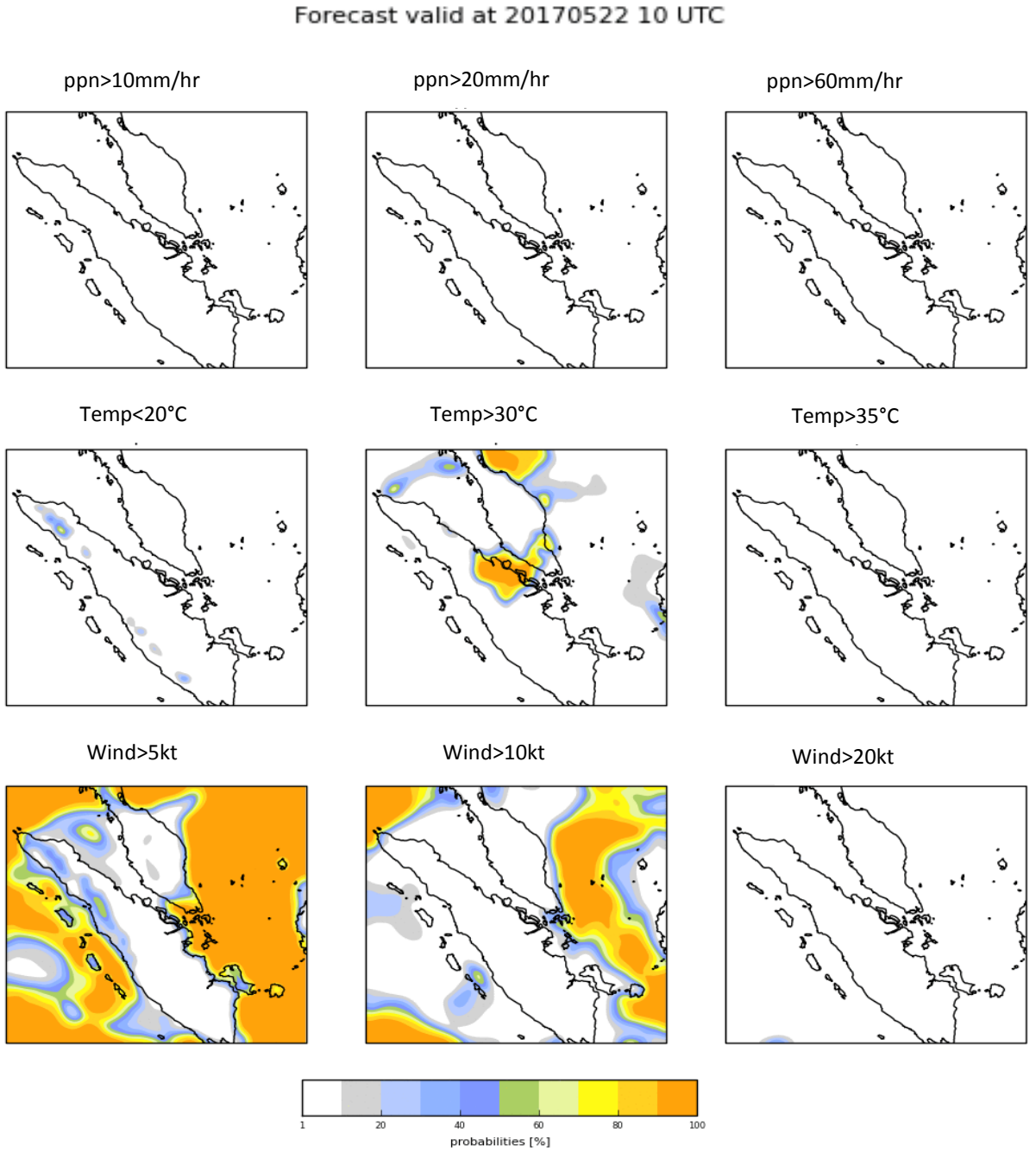
Postage stamp map



Hourly Rainfall Probability



Summary Plot



Forecaster's Evaluation

(MSS-UKMO joint effort)

- Focused on deterministic assessment of the forecasts
- Of course, with only a downscaler, it may not be expected that the model will perform well. We may need to wait for the inclusion of ensembles before the potential can be fully assessed

Assessment Criteria

Skills in rainfall prediction over Singapore and the surrounding region

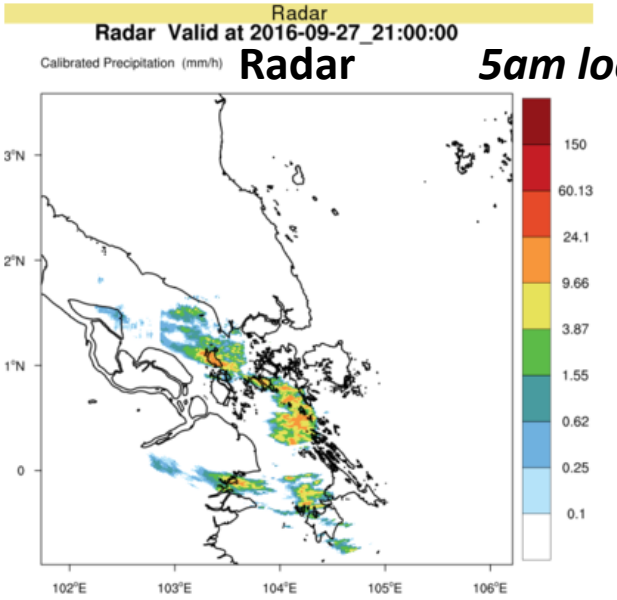
- Spatial coverage of the rainfall;
- Structure and orientation of the rain cluster;
- Rainfall intensity

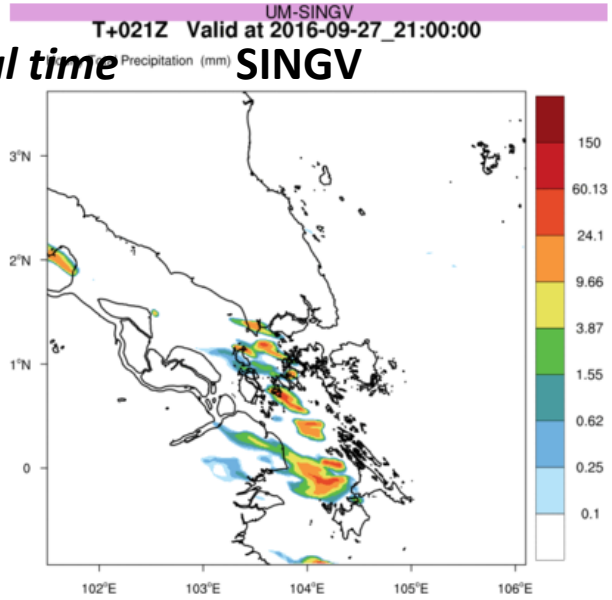
1. Does SINGV or WRF-EC provide value-added guidance in comparison with EC global model?

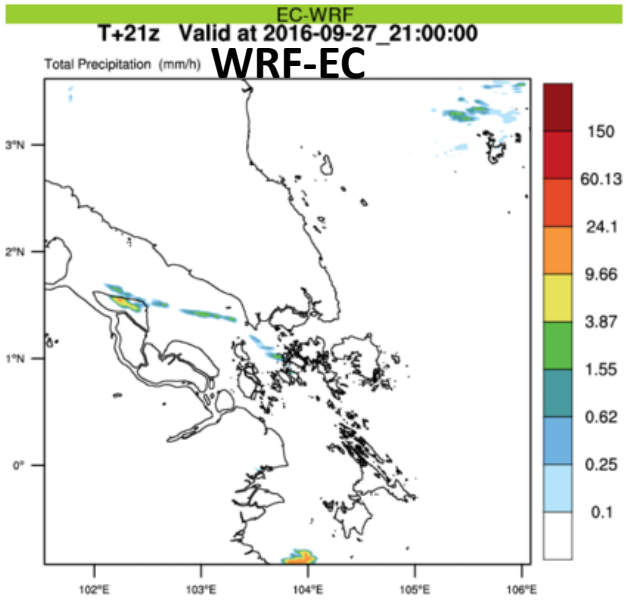
2. Does SINGV offer better guidance than WRF-EC?

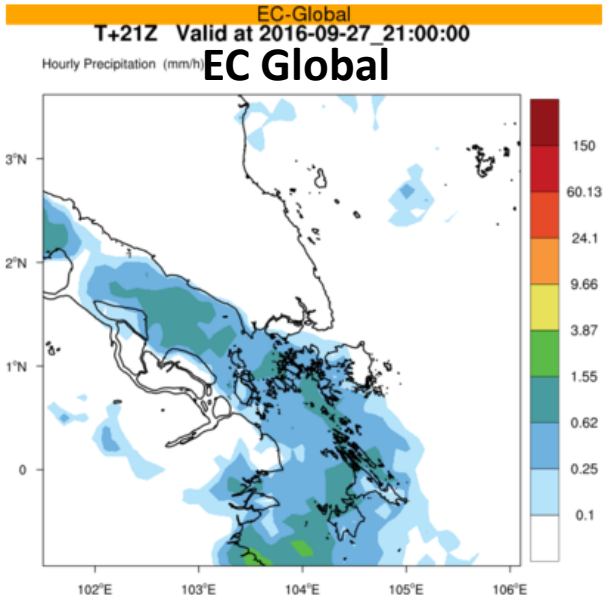
Forecaster Evaluation

SINGV > EC Global > WRF-EC





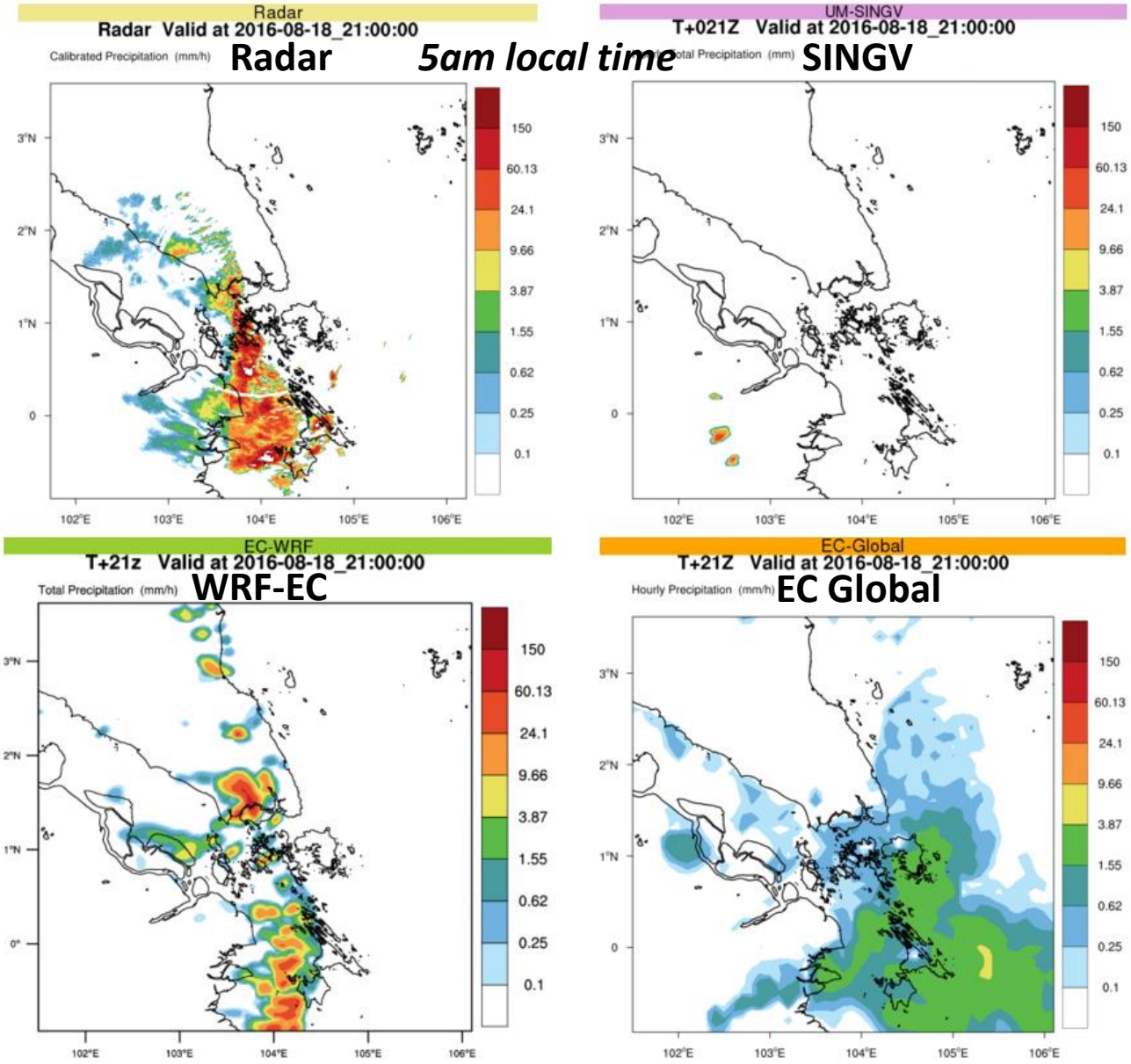




- SINGV had captured this event relatively well
- EC Global had captured this event relatively well but had under-forecast the rainfall intensity
- WRF-EC missed this event.

Forecaster evaluation

WRF-EC > EC Global > SINGV



- WRF-EC had captured this event relatively well
- SINGV missed this event totally
- EC Global missed the rainfall over Singapore and Peninsular Malaysia

Remarks and Ongoing Work

- Convective-scale NWP in tropics, especially for Singapore, is a difficult problem
- SINGV has definitely helped put forward NWP challenges in the deep tropics
- Updates have been made in model physics to tackle some of the known problems and collaborative effort is needed to understand the issues
- Improements are only incremental due to limited resources
- The current focus in model development is to test the grey-zone convection scheme
- SINGV DA will be focussing on LHN and tackling some of the issues
- SINVG EPS will be focussing on putting it to real-time
- In objective verification, we are working on issues on using GPM and Radar as references
- We are also working with forecasters on subjective evaluation, which will assess the usefulness of SINGV in operational applications