Finding the Optimum Resolution, and Microphysics and Cumulus Parameterization Scheme Combinations for Numerical Weather Prediction Models in Northern Thailand:

A First Step towards Aerosol and Chemical Weather Forecasting for Northern Thailand

by
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TNO (Thai National Observatory)
(Chalermprakhiat Astronomical Observatory Commemorating King Bhumibol’s 7th Birthday Anniversary)

Regional Observatories for the Public

In addition to the main National Observatory at Doi Inthanon, NARIT has been committed to establish 5 more regional observatories scattered through the five geographical zones of the country.

TST (Thai Southern Hemisphere Telescope)

In collaboration with the University of North Carolina at Chapel Hill
NARIT High Performance Computer (HPC) cluster

- Installed Feb-Mar 2015
- Testing and commissioning late Mar – April 2015
- Announced to Thai astronomical community during TNAM May 2015
- Open for community use in June/July 2015
Hardware

✧ 1 Management node (12 cores, 2.4 GHz Intel Xeon E5-26xx v3, 32GB RAM)
닺
✧ 5 compute nodes, rack servers
  • Total 80 cores (5 x 16 cores 2.6 GHz Intel Xeon E5-26xx v3)
  • RAM 5 x 64 GB (320GB, 4GB per core) DDR4 RDIMM 2.13 GHz
  • Dual-port 10 Gbps Ethernet, with teaming connections
  • Each rack is compatible with up to 2 GPU cards upgrade
✧ Storage 7.2 TB SAS 10K rpm 6Gbps (RAID5, 2GB cache)
✧ Network Switch 10 Gigabit Ethernet
✧ Expected $R_{\text{max}} = 2.26$ TFLOPS
Software

- OS Rocks 6.1.1 - CentOS Linux 6.5 (RHEL cloned)
- Job scheduling Sun Grid Engine
- Distributed memory processing MPICH2
- Shared memory processing Intel® OpenMP
- Compilers Intel® Fortran, C & C++ compiler for Linux (non-commercial), GNU compilers (gcc, gfortran etc.)
- Numerical Library Intel® Math Kernel Library, GNU Scientific Library (GSL)
- Astronomical Software & Data reduction ESO-Scisoft, Starlink, IDL® & NASA GSFC IDL library
- Interpret languages Python™, IDL®
- Simulation Gadget2, +...
- Cosmology CosmoMC, HEALPix, +...
- Weather Research and Forecasting (WRF)
NARIT has joined The Thai National e-Science Infrastructure Consortium early 2015
NARIT High Performance Computer (HPC) cluster
Phase 2 and the future

New compute nodes
- 16 x Blade Server
- 2 x 14 cores 2.6GHz
- RAM 128GB (8x16GB)
- IB FDR Mezz. Card
- 10GbE Dual port

Infiniband FDR 56Gb (Blade switch, 16 internal & 16 external)

Head Node (existing 2U)
Compute Node (existing 2U), 2 GPUs upgrade
Compute Node (existing 2U)
Compute Node (existing 2U)

Lustre MDS Active (HA)
Lustre MDS Passive (HA)

OSS1/active (existing 2U)
OSS2/active (existing 2U)

OSTs (60 x 2TB NL-SAS)

10/40 GbE Blade Switch

10 GbE network (existing 24-port 10GbE switch)

Login Node + Lustre Router (existing 2U)
NARIT Gateway

Internet

Link aggregation
- 10Gb Ethernet
- 40Gb Ethernet
- IB FDR 56GbE
- SAS 12Gb/s
- 1Gb Ethernet

1GbE Network
12 Gbps SAS
12 Gbps SAS
Using Atmospheric Science in Astronomy

• **Phase 1: Weather/Climate Model Sensitivity Study**
  – Can assist astronomical observations by providing in-house weather forecasts (including astronomical seeing forecasts)
  – Can provide water vapor profiles for radio astronomy

• **Phase 2: Addition of Aerosols**
  – Assist Astronomical Observations / Health

• **Phase 3: Feedback of Space Weather (e.g. solar variability) on Weather/Climate**
  – Fundamental Science
Astronomical Seeing

NARIT Seeing Monitor TNO km44
660 samples as of: 05:30:39 03/16/2559

Raw FWHM, Median of 10 Images/Point
Running Average (10)

FWHM in arcseconds

Average FWHM = 1.31

RMS Intensity Fluctuation: 4978
Numerical Weather Prediction (NWP)

$$\Delta A = \text{the change in a forecast variable at a particular point in space}$$

$$\frac{\Delta A}{\Delta t} = F(A)$$

$F(A)$ describes the physical processes that can cause changes in the value of $A$

$\Delta t$ equals the change in time

$$A_{\text{forecast}} = A_{\text{initial}} + F(A) \Delta t$$
**Primitive Equations**

**Wind Forecast Equations**

1a. \[ \frac{\partial u}{\partial t} = -u \frac{\partial u}{\partial x} - v \frac{\partial u}{\partial y} - \omega \frac{\partial u}{\partial p} + f v - g \frac{\partial z}{\partial x} + F_x \]

1b. \[ \frac{\partial v}{\partial t} = -u \frac{\partial v}{\partial x} - v \frac{\partial v}{\partial y} - \omega \frac{\partial v}{\partial p} - f u - g \frac{\partial z}{\partial y} + F_y \]

**Continuity Equation**

2. \[ \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial \omega}{\partial p} = 0 \]

**Temperature Forecast Equation**

3. \[ \frac{\partial T}{\partial t} = -u \frac{\partial T}{\partial x} - v \frac{\partial T}{\partial y} - \omega \left( \frac{\partial T}{\partial p} - \frac{RT}{c_p p} \right) + \frac{H}{c_p} \]

**Moisture Forecast Equation**

4. \[ \frac{\partial q}{\partial t} = -u \frac{\partial q}{\partial x} - v \frac{\partial q}{\partial y} - \omega \frac{\partial q}{\partial p} + E - P \]

**Hydrostatic Equation**

5. \[ \frac{\partial z}{\partial p} = \frac{RT}{pg} \]
Model Grids, Resolution and Dynamical Downscaling
Parameterization

Cloud Processes: too small-scale to be resolved by models

Solution: just find out the aggregate effects
Processes that are Usually Parameterized

Microphysics and Convective Processes

1) Incoming Solar Radiation
2) Scattering by Aerosols and Molecules
3) Absorption by the Atmosphere
4) Reflection/Absorption by Clouds
5) Emission of Longwave Radiation from Earth’s Surface
6) Condensation
7) Turbulence
8) Reflection/Absorption at Earth’s Surface
9) Snow
10) Soil Water/Snow Melt
11) Snow/Ice/Water Cover
12) Topography
13) Evaporation
14) Vegetation
15) Soil Properties
16) Rain (Cooling)
17) Surface Roughness
18) Sensible Heat Flux
19) Deep Convection (Warming)
20) Emission of Longwave Radiation from Clouds
Microphysics Parameterizations

Kessler

WSM3

WSM5

Lin et al./WSM6
Convective Processes

- Updraft
- Detrainment
- Downdraft
- Entrainment
- Compensating subsidence
- Boundary layer
Cumulus/Convective Parameterization

Betts-Miller-Janjic
Cumulus/Convective Parameterization

Kain-Fritsch
Visualization and Analysis Platform for Ocean, Atmosphere, and Solar Researchers (VAPOR) for VR?

https://www.vapor.ucar.edu
Model Domain, Spatial and Temporal Resolution and Coverage

50 km (3-hourly)

2 km (hourly)

10 km (hourly)

1 deg (6-hourly)

No cumulus / convective parameterization

Cool Dry Season
December 1-15, 2014

Hot Dry Season
May 1-12, 2015

Wet Season
August 1-7, 2015
## Parameterizations Used

<table>
<thead>
<tr>
<th>Cumulus</th>
<th>Microphysics</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cumulus</strong></td>
<td>WRF Single-Moment 3-class, WSM3 (mp3)</td>
</tr>
<tr>
<td></td>
<td>WRF Single-Moment 5-class, WSM5 (mp4)</td>
</tr>
<tr>
<td></td>
<td>Lin et al. (Purdue) (mp2)</td>
</tr>
<tr>
<td></td>
<td>WRF Single-Moment 6-class, WSM6 (mp6)</td>
</tr>
<tr>
<td></td>
<td>WRF Double-Moment 6-class, WDM6 (mp16)</td>
</tr>
<tr>
<td>Betts-Miller-Janjic, BMJ (cu2)</td>
<td>X</td>
</tr>
<tr>
<td>Kain-Fritsch, KF (cu1)</td>
<td>X</td>
</tr>
<tr>
<td>Grell-Freitas, GF (cu3)</td>
<td>X</td>
</tr>
<tr>
<td>Grell-3D, G3 (cu5)</td>
<td>X</td>
</tr>
</tbody>
</table>
Validation Sites

Chiang Rai Agromet Thai Meteorological Department (TMD) Station (401 mASL)

Chiang Mai Airport Thai Meteorological Department (TMD) Station (309.2 mASL)

Lampang Airport Thai Meteorological Department (TMD) Station (248.5 mASL)
## Resolution / Parameterization Performance Metrics

<table>
<thead>
<tr>
<th>Metric</th>
<th>Equation</th>
<th>Meteorological Parameter Used, $y$ ((y_o = \text{observed}; y_m = \text{modeled}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bias</td>
<td>(\frac{\sum (y_m - y_o)}{N})</td>
<td>temperature, pressure, humidity, rain (only during wet season)</td>
</tr>
<tr>
<td>Mean Absolute Error, MAE</td>
<td>(\frac{\sum</td>
<td>y_m - y_o</td>
</tr>
<tr>
<td>Root-Mean-Square Error, RMS</td>
<td>(\sqrt{\frac{\sum (y_m - y_o)^2}{N}})</td>
<td></td>
</tr>
<tr>
<td>Correlation Coefficient, R</td>
<td>Pearson product-moment</td>
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## Resolution / Parameterization Performance Metrics

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<tr>
<td>%Bias</td>
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<td>$\frac{\sum</td>
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<td>$\frac{\sqrt{\frac{\sum (y_m - y_o)^2}{N}}}{\sum y_o}$</td>
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<td>Correlation Coefficient, R</td>
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<td></td>
</tr>
</tbody>
</table>
Why wind is not included in the metrics?
Message Passing Interface (MPI)

More cores DOES NOT necessarily mean faster

Optimum no. of cores: 8
Surface Temperature at during the Cool Dry Season (mp3cu1 – 2 km)
Water Vapor Mixing Ratio during the Hot Dry Season (mp2cu2 – 50 km)
Accumulated Non-Convective Rain during Wet Season (mp16cu5 – 50 km)
Chiang Mai Airport TMD Station
Cool Dry Season (mp3cu1 – 2 km)

Temperature (Bias:-2.9308; MAE:3.2184; RMSE:3.6675) [°C]
Pressure (Bias:4.9492; MAE:4.4942; RMSE:4.6739) [hPa]
Relative Humidity (Bias:-9.4189; MAE:14.8106; RMSE:19.3216) [%]
Rain (Bias:7.1705e-06; MAE:7.1705e-06; RMSE:0.0001354) [mm]
Wind Speed (Bias:3.2725; MAE:9.6576; RMSE:13.0548) [km/h]
Wind Direction (Bias:-39.3924; MAE:90.0636; RMSE:108.6857) [deg from North]
Chiang Mai Airport TMD Station
Cool Dry Season (mp3Cu1 – 2 km)

Temperature (Bias=2.3308; MAE=3.2184; RMSE=3.5275) [°C]

Pressure (Bias=4.4942; MAE=4.4942; RMSE=4.6739) [hPa]

Relative Humidity (Bias=-0.4189; MAE=14.0166; RMSE=19.3216) [%]

Rain (Bias=7.1705e-06; MAE=7.1705e-06; RMSE=0.0001354) [mm]

Wind Speed (Bias=9.2739; MAE=9.6576; RMSE=13.0568) [m/s]

Wind Direction (Bias=-39.3304; MAE=90.6386; RMSE=108.6857) [deg from north]

Model Output vs Observations

R: 0.84722 (Significant)

R: 0.86185 (Significant)

R: 0.52146 (Significant)

R: NaN (Non-Significant)

R: 0.25578 (Significant)

R: 0.0067206 (Non-Significant)
Parameterization Performance Metrics
(Cool Dry Season)
Parameterization Performance Metrics
(Cool Dry Season)

Optimum: mp3cu1 (3 out of 4)
Optimum Microphysics and Cumulus Parameterizations

– mp3cu1 (cool dry season)

– mp2cu2 (hot dry season)

– mp16cu5 (wet season)
Resolution Performance Metrics
(Cool Dry Season)

Optimum: 2 km (4 out of 4)
Chiang Mai Airport TMD Station
Cool Dry Season (mp3cu1 – 2 km)
Chiang Mai Airport TMD Station
Cool Dry Season (mp3cu1 – 50 km)

Temperature (Bias=4.2094; MAE=4.3295; RMSE=4.3649) [°C]

Pressure (Bias=12.8331; MAE=12.8331; RMSE=12.8384) [hPa]

Relative Humidity (Bias=-1.0566; MAE=11.5296; RMSE=14.648) [%]

Rain (Bias=0.0077135; MAE=0.0077135; RMSE=0.019133) [mm]

Wind Speed (Bias=5.2592; MAE=5.6774; RMSE=6.8998) [km/h]

Wind Direction (Bias=48.0375; MAE=101.0814; RMSE=120.4842) [deg From North]

Model Output vs Observations
Resolution Performance Metrics
(Wet Season)

Optimum: 50 km (4 out of 4)
Lampang Airport TMD Station
Wet Season (mp16cu5 – 2 km)

Temperature (Bias=2.137; MAE=2.2532; RMSE=2.6567) [°C]

Pressure (Bias=-2.3912; MAE=2.4077; RMSE=2.7847) [hPa]

Relative Humidity (Bias=-18.2259; MAE=18.6349; RMSE=21.473) [%]

Rain (Bias=-2.7426; MAE=2.9457; RMSE=5.3302) [mm]

Wind Speed (Bias=8.5693; MAE=8.4453; RMSE=9.9072) [km/h]

Wind Direction (Bias=-4.1632; MAE=85.4746; RMSE=108.4024) [deg from North]
Lampang Airport TMD Station
Wet Season (mp16cu5 – 50 km)

Temperature (Bias:0.15518; MAE:1.0112; RMSE:1.3357) [°C]

Pressure (Bias:-12.4917; MAE:12.4917; RMSE:12.569) [hPa]

Relative Humidity (Bias:-7.0225; MAE:9.5636; RMSE:12.2669) [%]

Rain (Bias:-1.3151; MAE:2.6431; RMSE:4.5606) [mm]

Wind Speed (Bias:7.9903; MAE:9.1917; RMSE:9.1941) [km/h]

Wind Direction (Bias:1.689; MAE:67.7259; RMSE:85.1964) [deg from North]
Lampang Airport TMD Station
Wet Season (mp16cu5 – 2 km)
Lampang Airport TMD Station
Wet Season (mp16cu5 – 50 km)
Optimum Resolutions

– 2 km (cool dry season)

– 50 km (hot dry season)

– 50 km (wet season)
Summary

- Seasonal dependence of optimum resolution, microphysics and cumulus parameterization (seasonal presence of hydrometeor types – microphysics; seasonal convective processes)
  - mp3cu1, 2 km (cool dry season)
  - mp2cu2, 50 km (hot dry season)
  - mp16cu5, 50 km (wet season)

- 2 km simulates temperature and pressure better (cool dry season) – rain not included in metrics

- 50 km simulates temperature and humidity better (hot dry season) – rain not included in metrics

- 50 km simulates temperature, humidity and rain better (wet season)
Next Steps...

• Apply to forecasts (forecast skill)

• Find out the reasons why these resolution and parameterization combinations were close to observations
  – Compare with observed profiles (wind)
  – Investigate hydrometeor profiles and convective processes

• Apply to Astronomical Seeing
Recommendations for Re-Analysis/Forecasting (Phase 1)

• Use higher resolution boundary conditions

• Increase the number of validation sites

• Utilize a longer temporal period

• Use a higher resolution land use data (MODIS)

• Include urban surface physics parameterization (surface wind)

• Perform spectral and observational nudging
The End

Thanks to

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Kanlaya Thapiang
APPENDIX
Model Grid and Resolution
Convective Processes

Processes CP Schemes Need to Account For

Convective Initiation
Deep Convection
Shallow Convection at Top of Mixed Layer

Vertical Heating / Cooling
Vertical Drying / Moistening
Precipitation

Evaporation & Cooling
Transported Downward
Net Max Heating

Heat Transported Upward
Max Condensation

Drying Transported Downward
Compensating Subsidence
Moisture Transported Upward

Detrainment
(By-product)
Parameterization Performance Metrics
(Hot Dry Season)
Parameterization Performance Metrics
(Hot Dry Season)

Optimum: mp2cu2 (4 out of 4)
Parameterization Performance Metrics (Wet Season)

Optimum: mp16cu5 (3 out of 4)
Resolution Performance Metrics (Hot Dry Season)

Optimum: 50 km (3 out of 4)
Chiang Mai Airport TMD Station
Hot Dry Season (mp2cu2 – 2 km)

- Temperature (Bias=1.0367; MAE=1.703; RMSE=2.0771) [°C]
- Pressure (Bias=2.341; MAE=2.3469; RMSE=2.6417) [hPa]
- Relative Humidity (Bias=-3.8114; MAE=7.3058; RMSE=9.3504) [%]
- Rain (Bias=-0.3331; MAE=0.51257; RMSE=1.7233) [mm]
- Wind Speed (Bias=8.8585; MAE=9.4158; RMSE=12.3641) [km/h]
- Wind Direction (Bias=-12.061; MAE=107.6366; RMSE=121.1821) [deg from North]
Chiang Mai Airport TMD Station
Hot Dry Season (mp2cu2 – 50 km)
Chiang Mai Airport TMD Station
Hot Dry Season (mp2cu2 – 2 km)
Chiang Mai Airport TMD Station
Hot Dry Season (mp2cu2 – 50 km)
Chiang Rai Agromet TMD Station
Hot Dry Season (mp2cu2 – 50 km)
Chiang Rai Agromet TMD Station
Hot Dry Season (mp2cu2 – 2 km)
Chiang Rai Agromet TMD Station
Hot Dry Season (mp2cu2 – 50 km)

Temperature (Bias=1.4259; MAE=2.0478; RMSE=2.4195) [°C]

Relative Humidity (Bias=-56.4938; MAE=-33.4958; RMSE=40.5568) [%]

Wind Speed (Bias=3.4185; MAE=8.4688; RMSE=19.6234) [km/h]

Wind Direction (Bias=-87.2413; MAE=32.8165; RMSE=107.5485) [deg from North]

Pressure (Bias=-30.6589; MAE=30.6589; RMSE=30.6813) [hPa]

Rain (Bias=1.7656; MAE=1.7812; RMSE=5.5523) [mm]
Lampang Airport TMD Station
Hot Dry Season (mp2cu2 – 2 km)

Temperature (Bias:2.7177; MAE:2.9662; RMSE:3.5394) [°C]

Pressure (Bias:2.0652; MAE:2.0907; RMSE:2.3945) [hPa]

Relative Humidity (Bias:-18.568; MAE:18.7399; RMSE:21.281) [%]

Rain (Bias:-1.3873; MAE:1.3875; RMSE:5.6311) [mm]

Wind Speed (Bias:10.5907; MAE:10.6796; RMSE:13.1977) [km/h]

Wind Direction (Bias:-37.1563; MAE:127.076; RMSE:143.2326) [deg from North]

Observations
Model Output
Lampang Airport TMD Station
Hot Dry Season (mp2cu2 – 50 km)

Temperature (Bias: 1.1314; MNE: 2.0231; RMSE: 2.4656) [°C]

Pressure (Bias: -7.822; MNE: 7.922; RMSE: 7.907) [hPa]

Relative Humidity (Bias: -13.7165; MNE: 14.2672; RMSE: 16.9624) [%]

Rain (Bias: -1.3271; MNE: 1.4135; RMSE: 5.6232) [mm]

Wind Speed (Bias: 8.0979; MNE: 8.2261; RMSE: 9.675) [km/h]

Wind Direction (Bias: -82.1767; MNE: 107.2351; RMSE: 123.515) [deg from North]

Legend:
- Observations
- Model Output
Lampang Airport TMD Station
Hot Dry Season (mp2cu2 – 2 km)
Lampang Airport TMD Station
Hot Dry Season (mp2cu2 – 50 km)

Temperature (Bias:1.1314; MAE:2.0231; RMSE:2.4656) [°C]

Pressure (Bias:-7.822; MAE:7.822; RMSE:7.907) [hPa]

Relative Humidity (Bias:-43.7165; MAE:14.2672; RMSE:16.9624) [%]

Rain (Bias:-1.3271; MAE:1.4136; RMSE:5.6232) [mm]

Wind Speed (Bias:-8.0579; MAE:3.2251; RMSE:5.675) [km/h]

Wind Direction (Bias:-82.1767; MAE:107.2321; RMSE:123.515) [deg from North]
Chiang Mai Airport TMD Station
Wet Season (mp16cu5 – 2 km)
Chiang Mai Airport TMD Station
Wet Season (mp16cu5 – 50 km)
Chiang Mai Airport TMD Station
Wet Season (mp16cu5 – 2 km)
Chiang Mai Airport TMD Station Wet Season (mp16cu5 – 50 km)