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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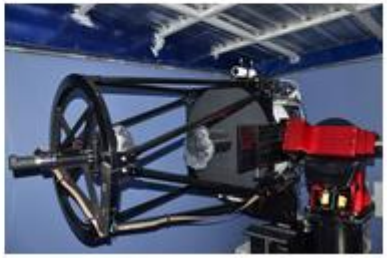
TNO (Thai National Observatory)

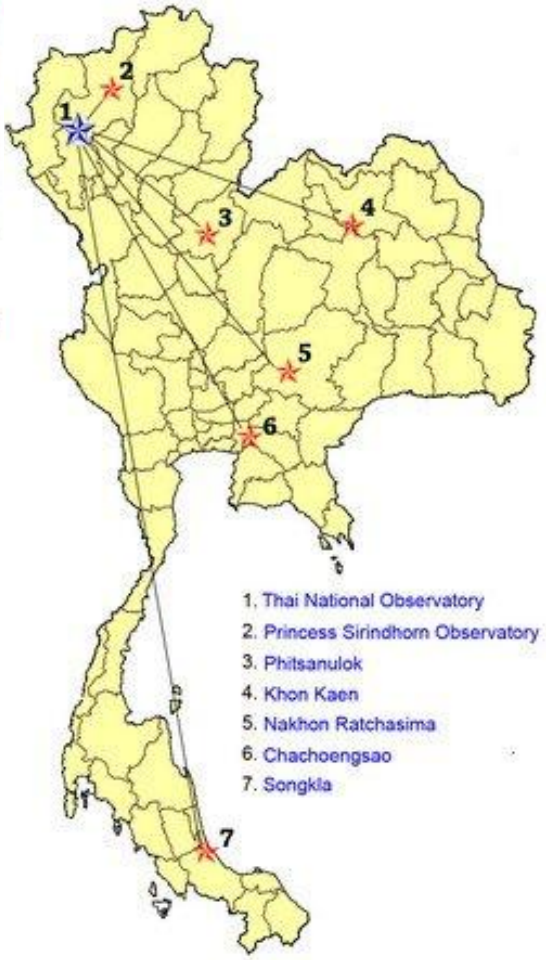
(Chalermprakhiat Astronomical Observatory Commemorating King Bhumibhol's 7th Birthday Anniversary)



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.

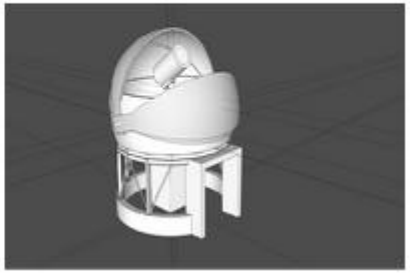





TST (Thai Southern Hemisphere Telescope)

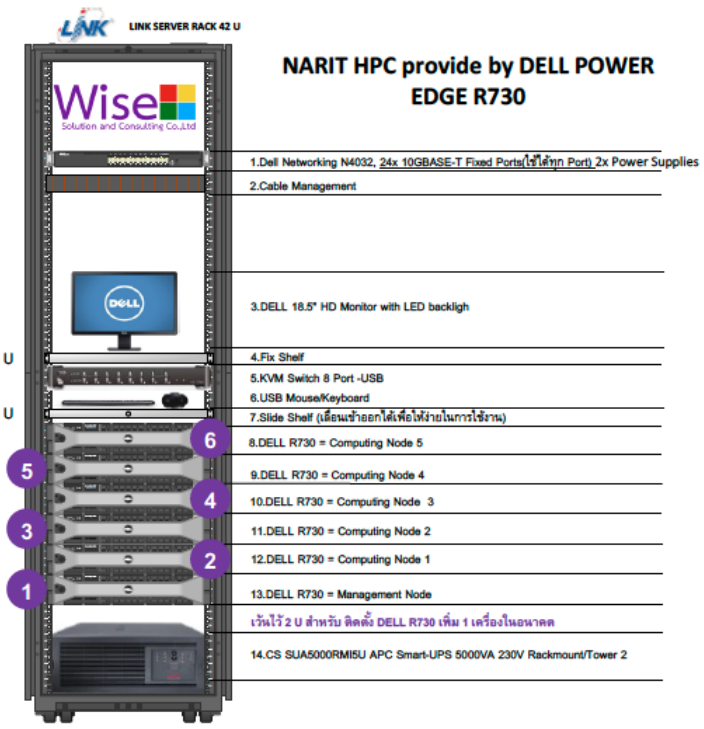
In collaboration with the University of North Carolina at Chapel Hill

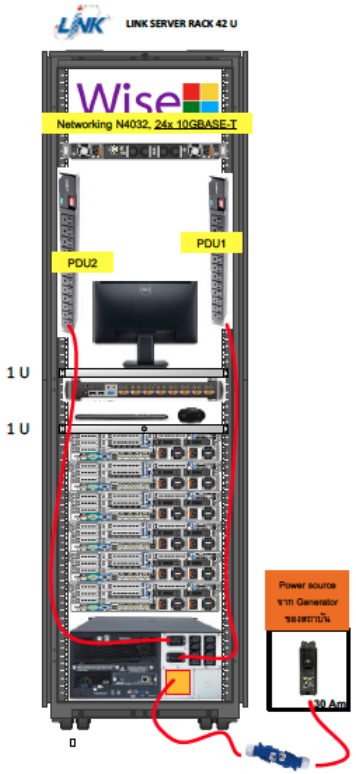




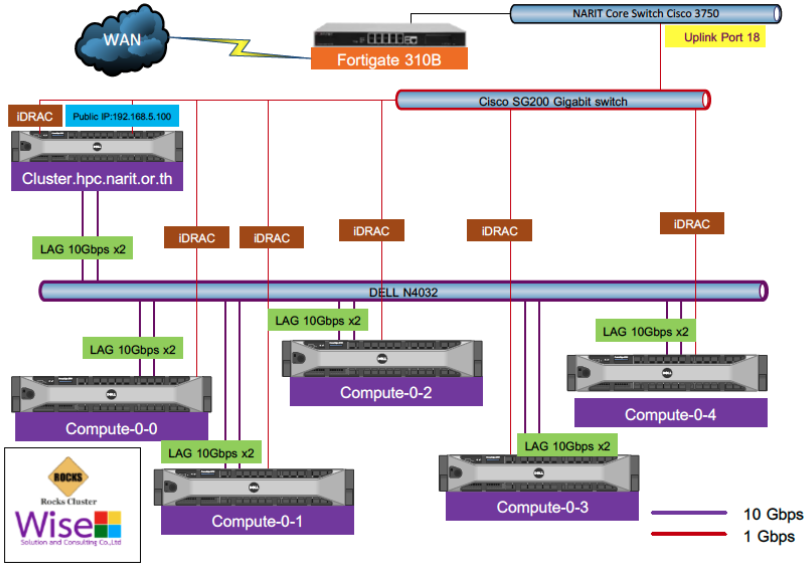
NARIT High Performance Computer (HPC) cluster

CASTOR 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)
- ✧ **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_{max}= 2.26 TFLOPS

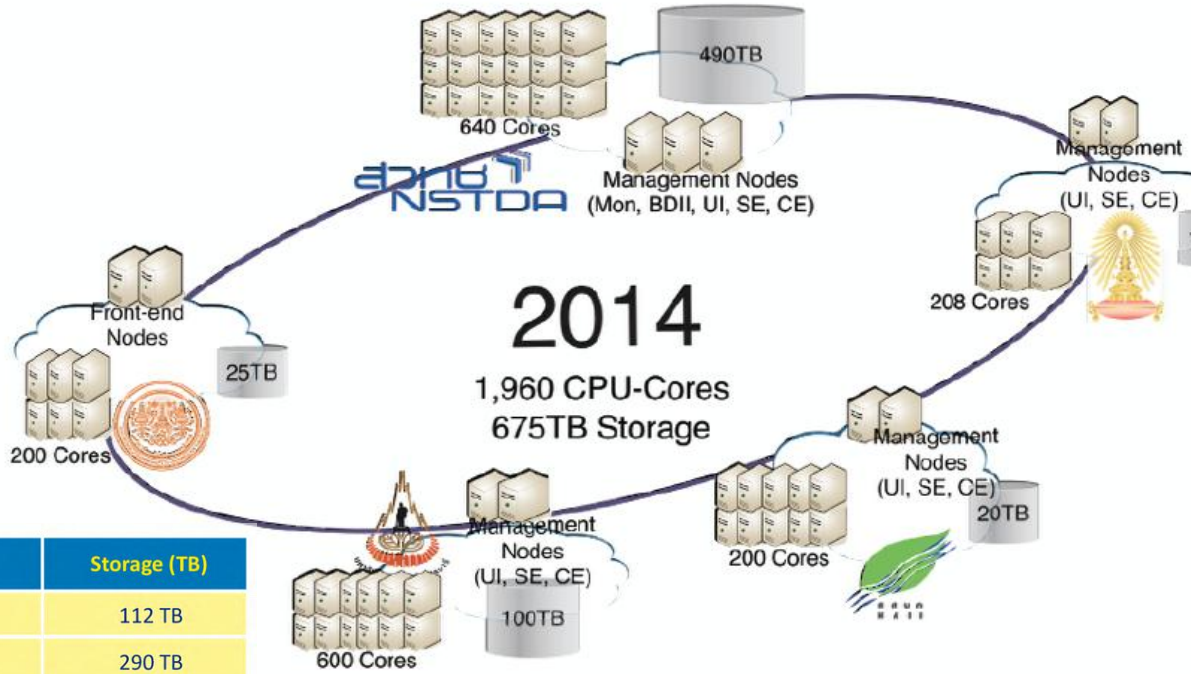
Software

- 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)

NATIONAL E-SCIENCE INFRASTRUCTURE CONSORTIUM

Consortium: Roadmap

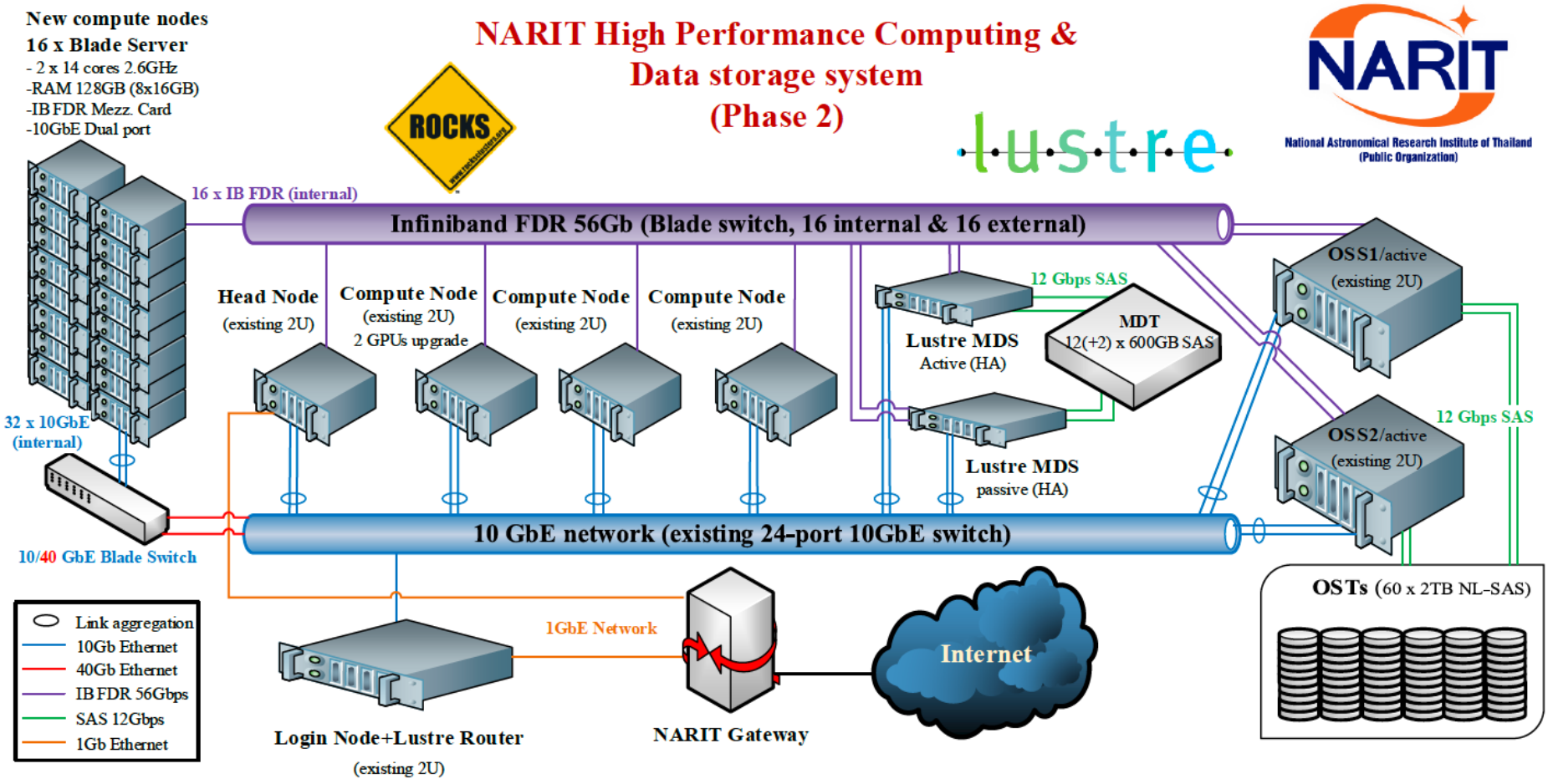
NARIT has joined The Thai National e-Science Infrastructure Consortium) early 2015



Site	CPU (Cores)	Storage (TB)
HAII	896 Cores	112 TB
NSTDA	688 Cores	290 TB
SUT	656 Cores	150 TB
CU	208 Cores	10 TB
KMUTT	224 Cores	25 TB
Total	2,672 Cores	597 TB

NARIT High Performance Computer (HPC) cluster

Phase 2 and the future



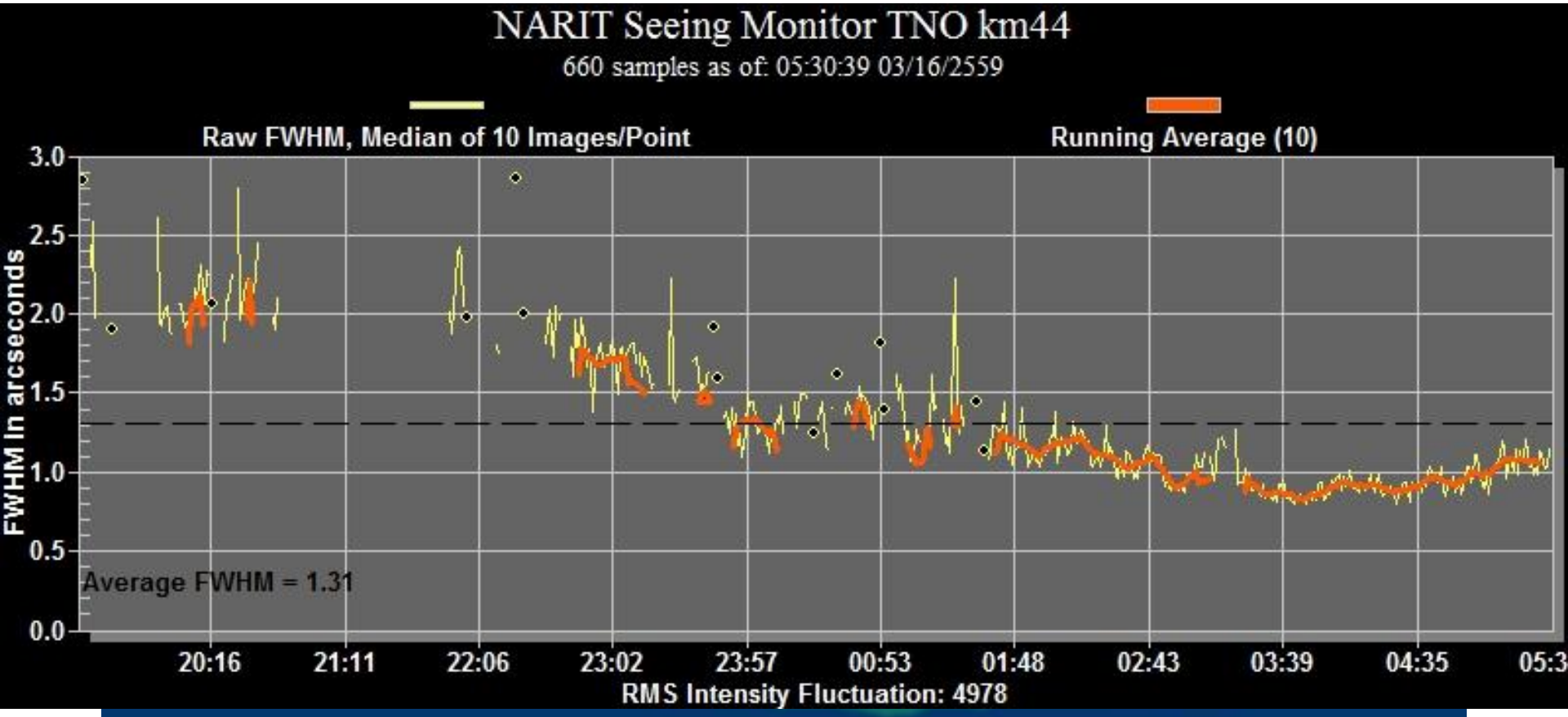
Using Atmospheric Science in Astronomy

- **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



Numerical Weather Prediction (NWP)

ΔA = 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

Δt equals the change in time

$$A^{forecast} = A^{initial} + F(A)\,\Delta t$$

Primitive Equations

Wind Forecast Equations

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

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

Continuity Equation

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

Temperature Forecast Equation

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

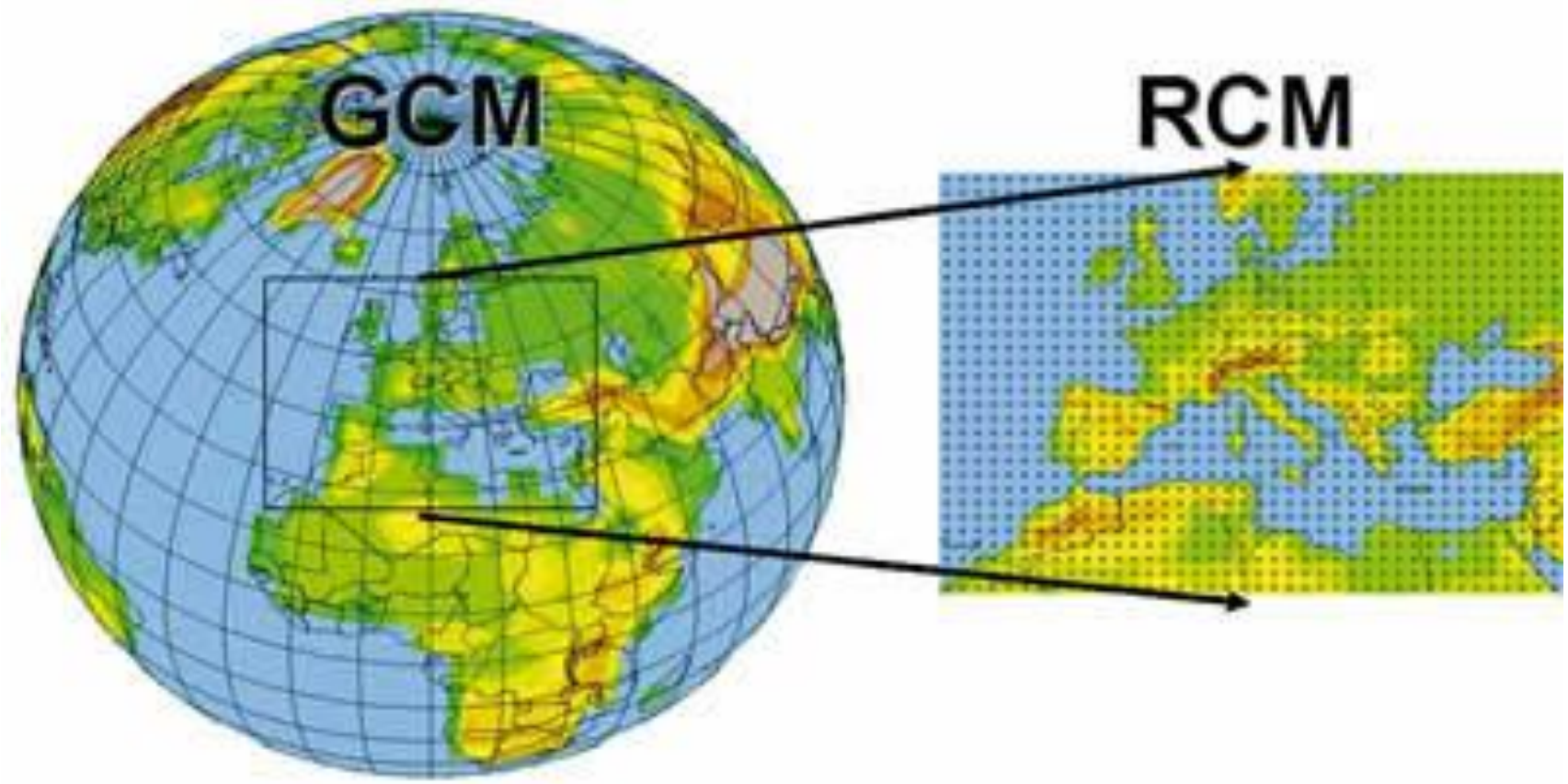
Moisture Forecast Equation

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

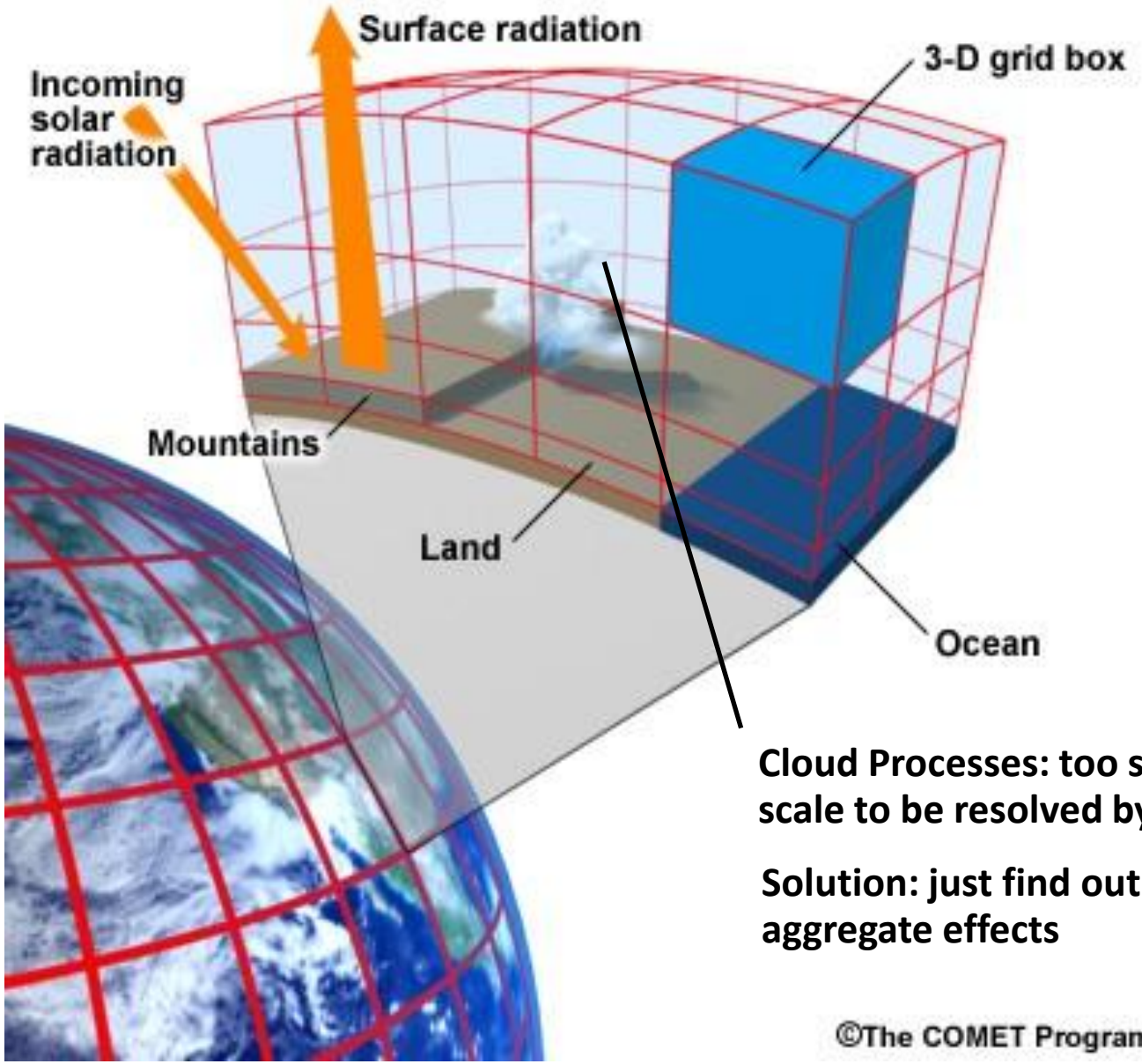
Hydrostatic Equation

5. $$\frac{\partial z}{\partial p} = -\frac{RT}{pg}$$

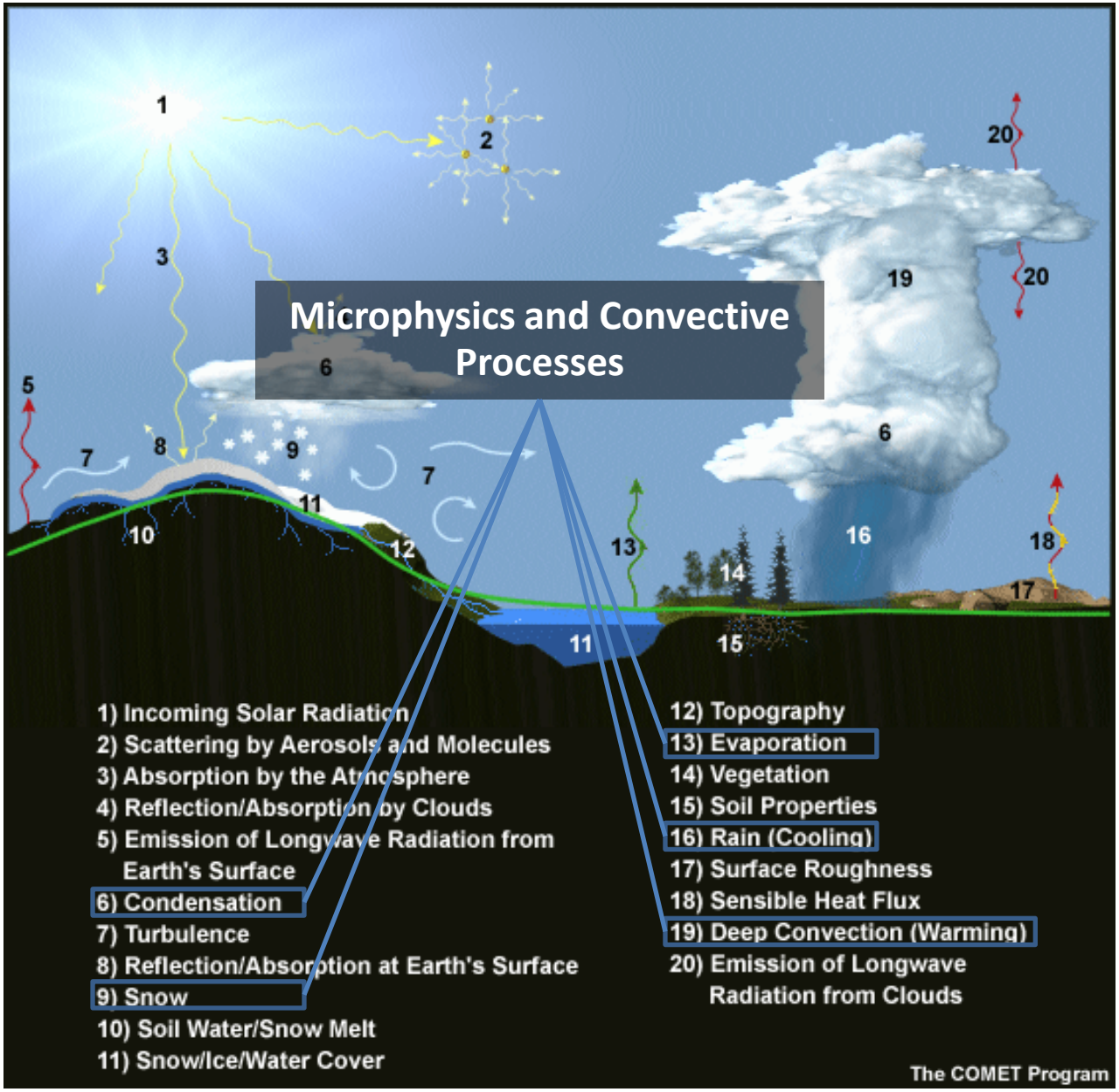
Model Grids, Resolution and Dynamical Downscaling



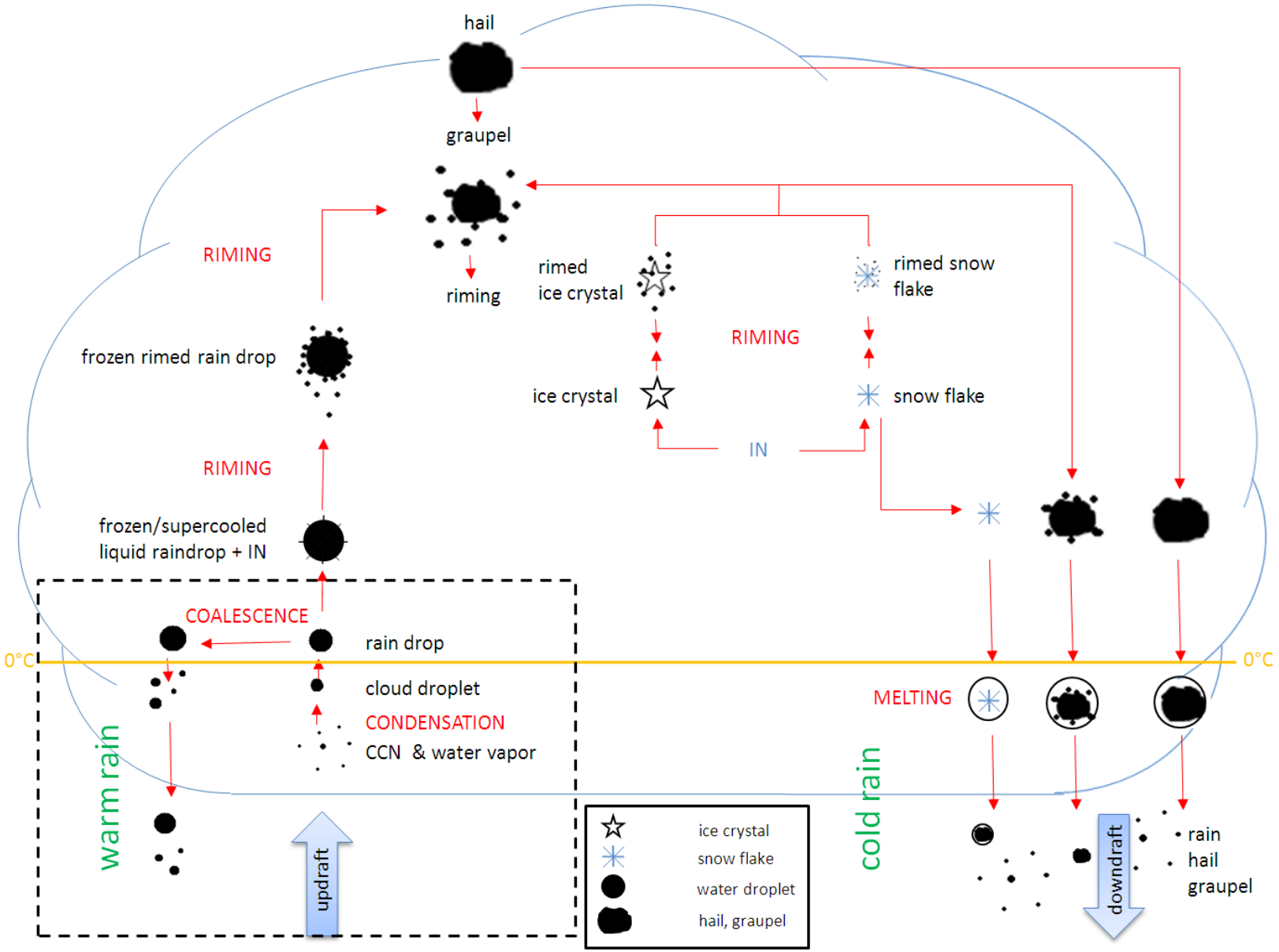
Parameterization



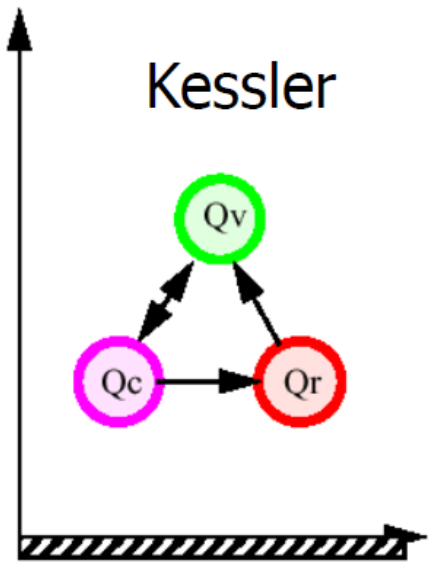
Processes that are Usually Parameterized

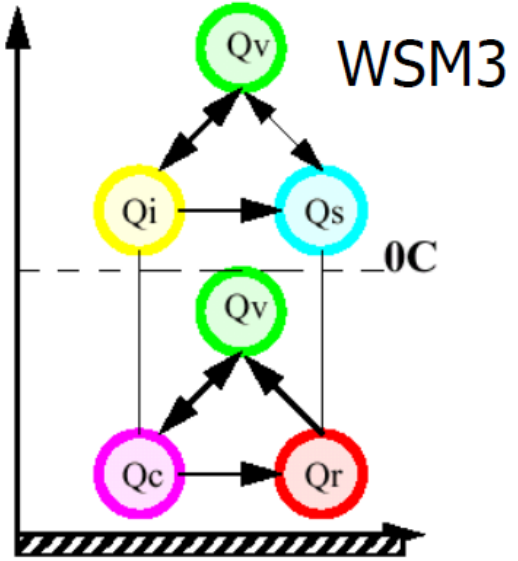


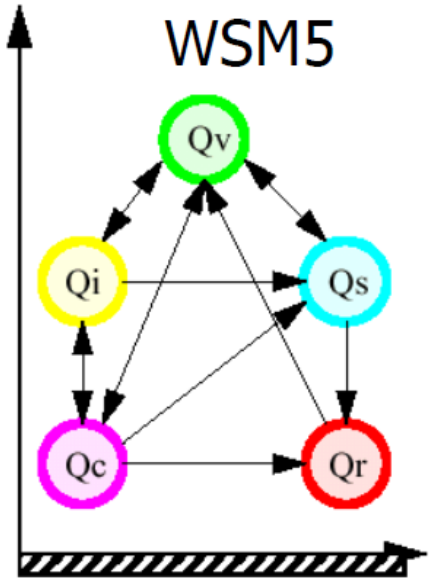
Microphysics Processes

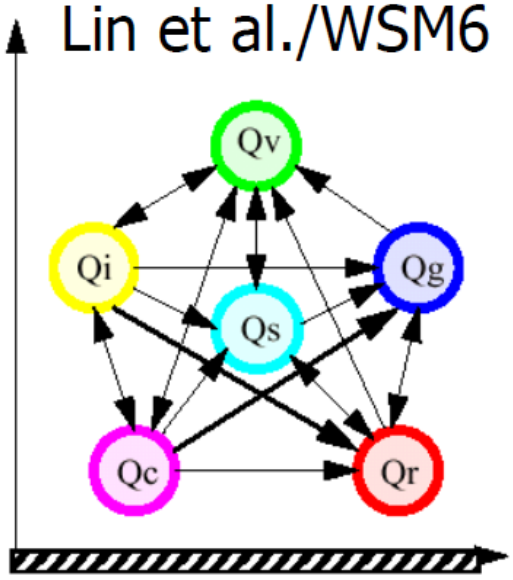


Microphysics Parameterizations

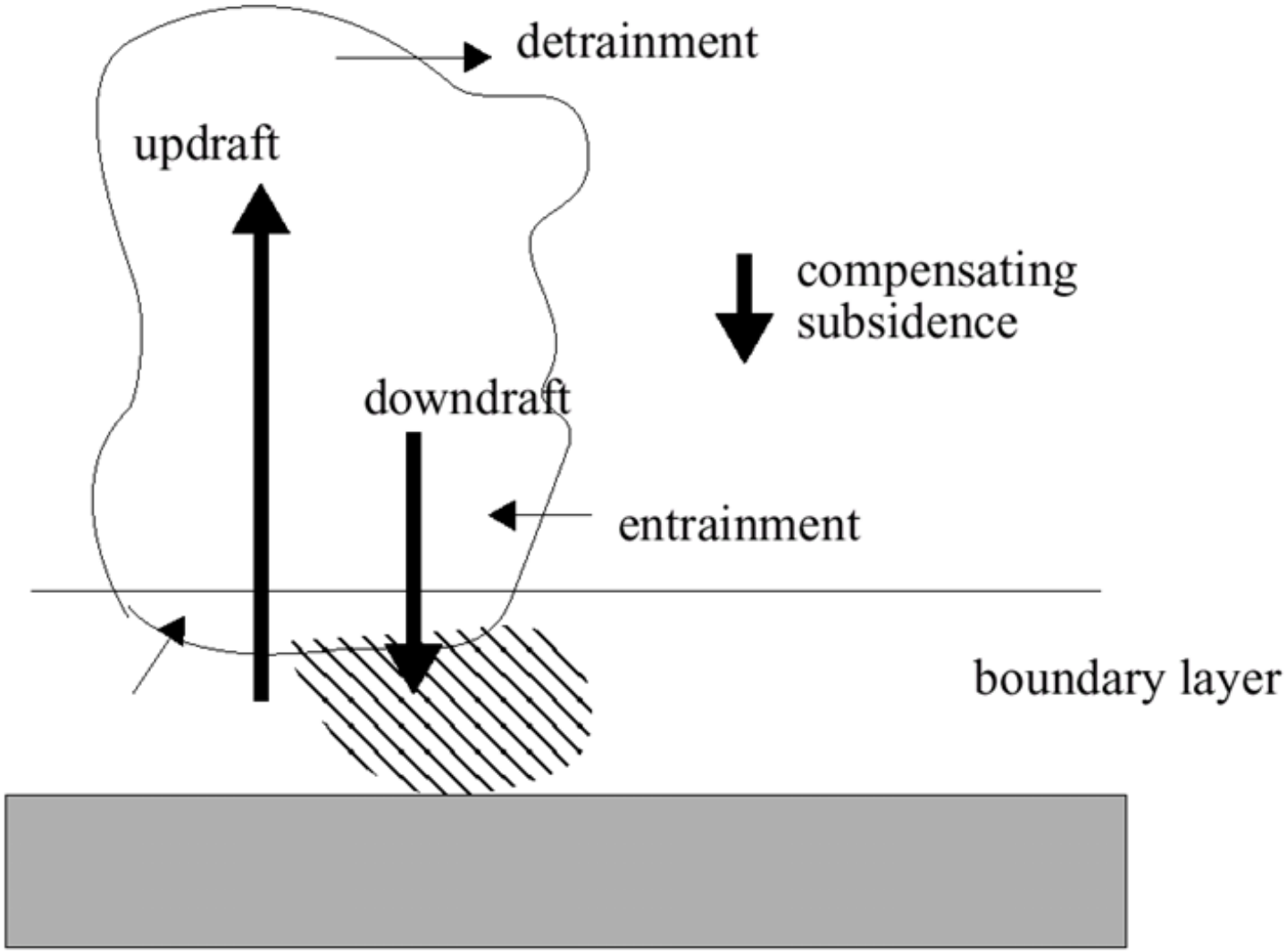






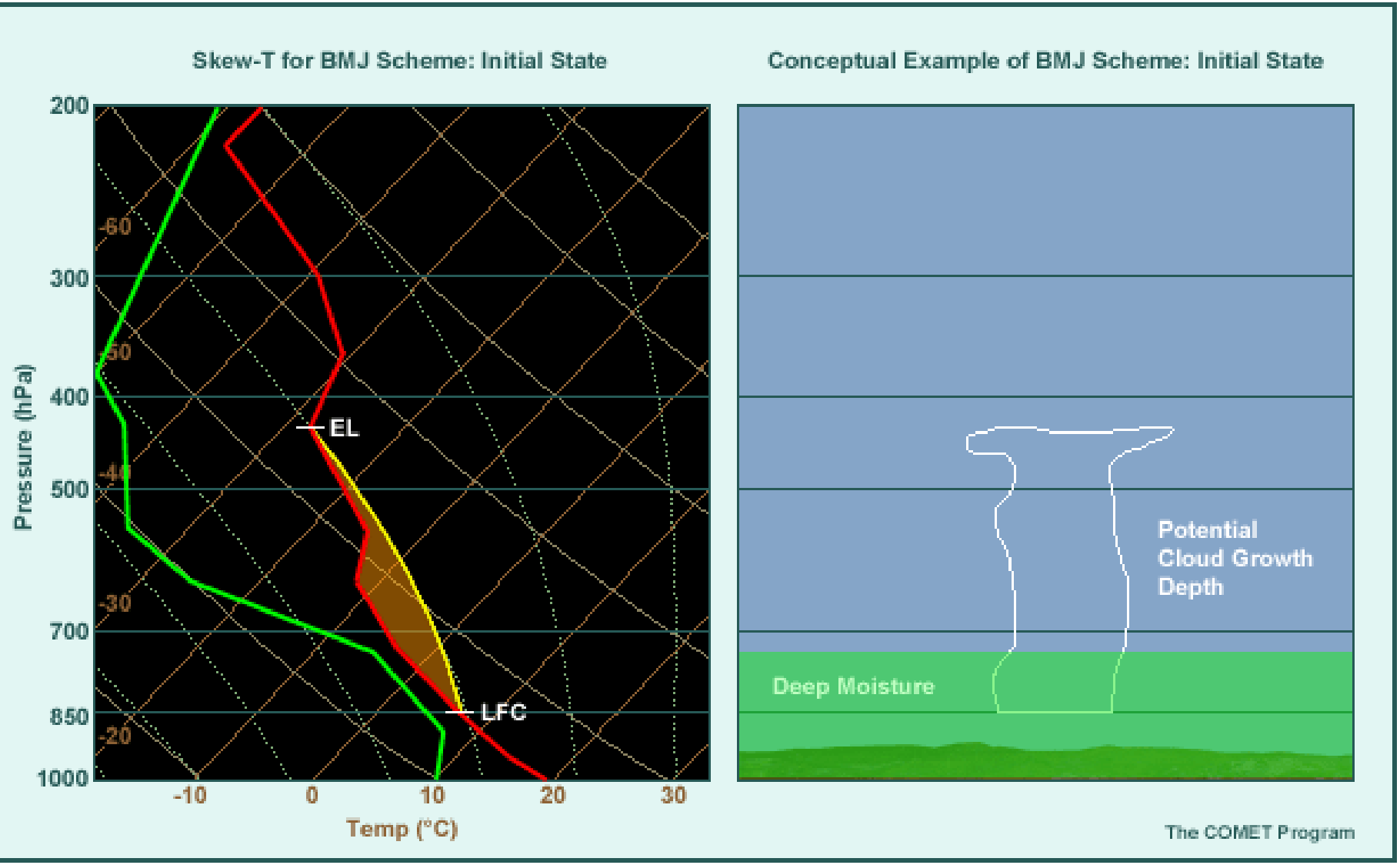


Convective Processes



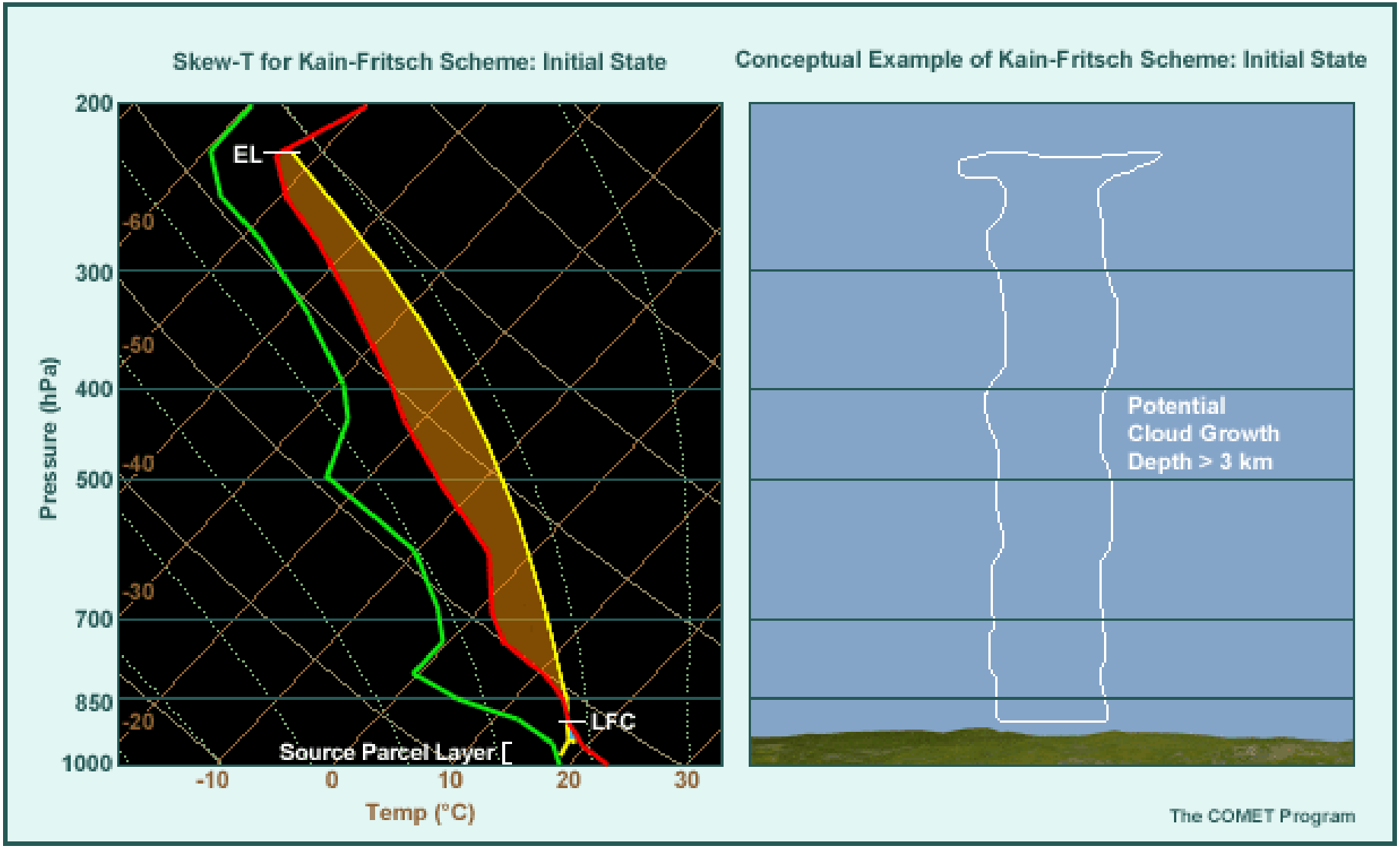
Cumulus/Convective Parameterization

Betts-Miller-Janjic

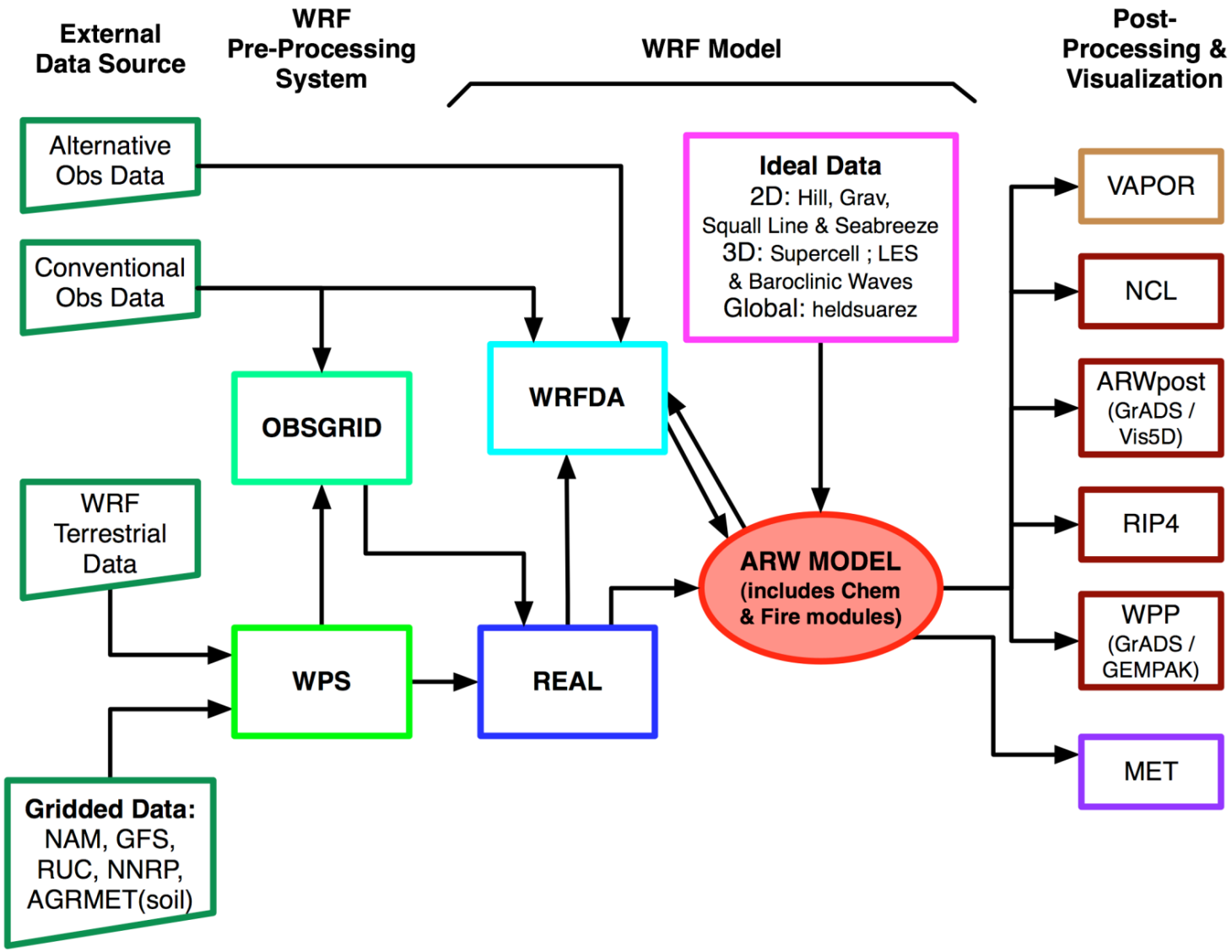


Cumulus/Convective Parameterization

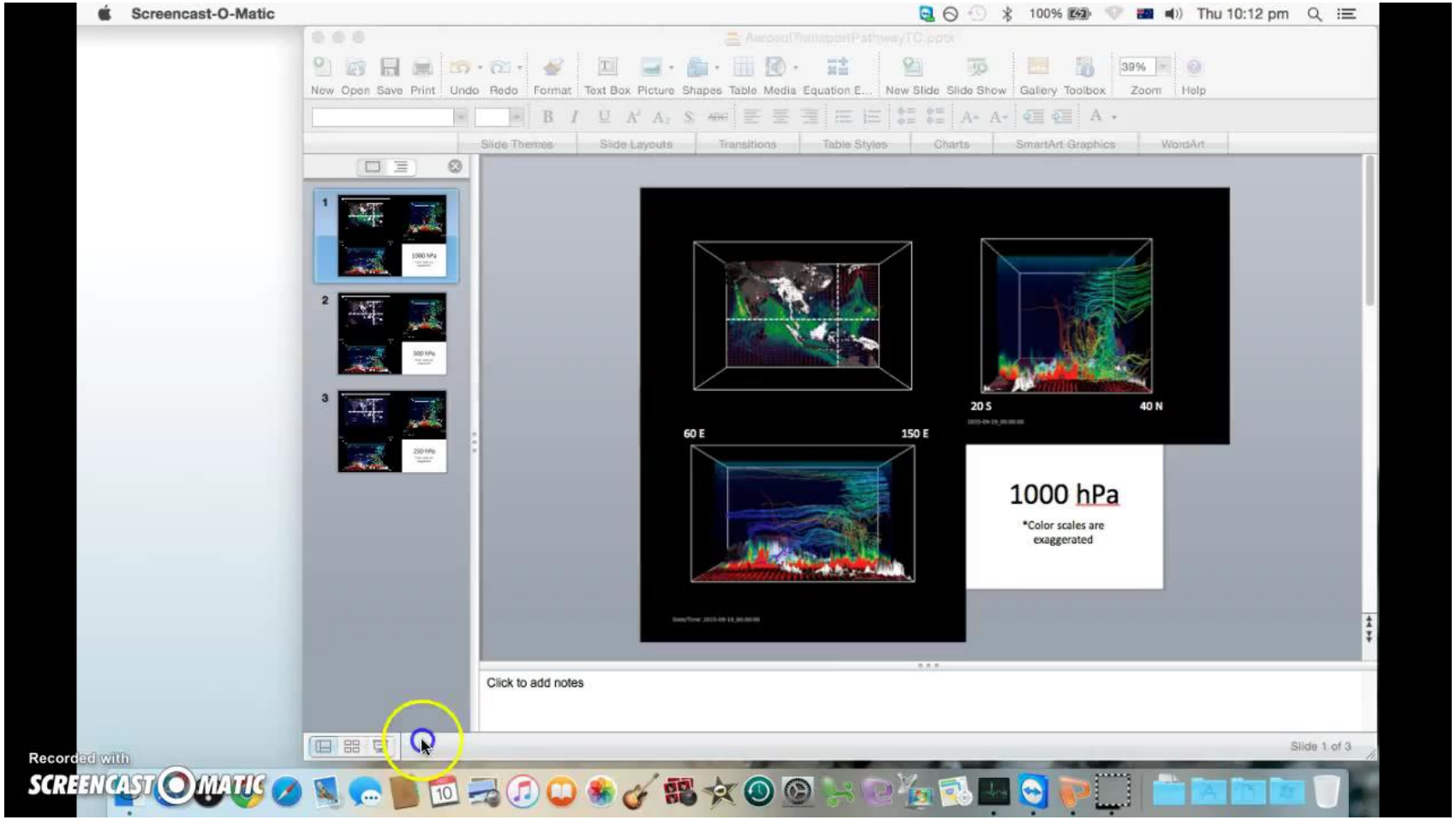
Kain-Fritsch



Weather Research and Forecasting (WRF) Model

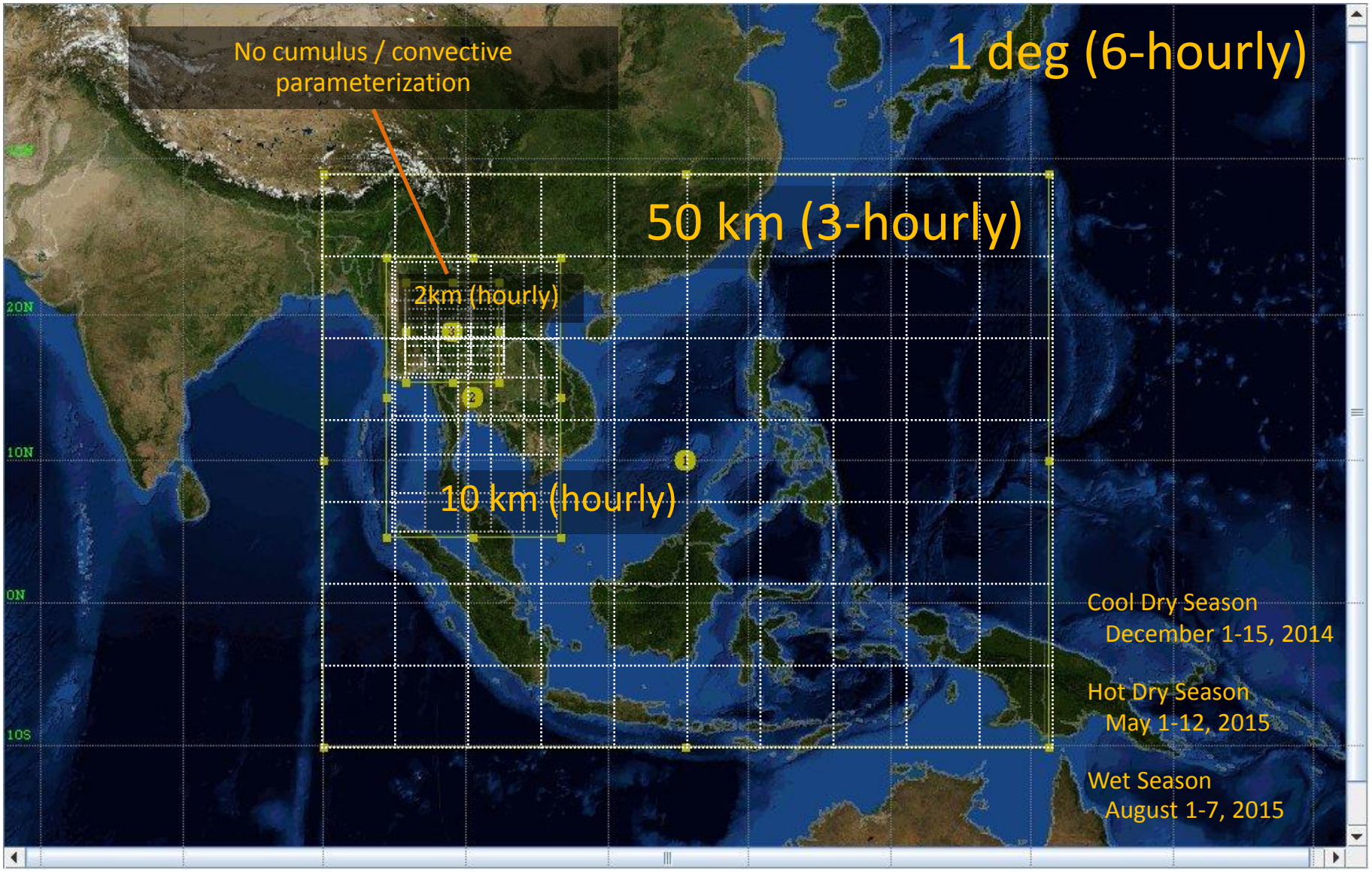


Visualization and Analysis Platform for Ocean, Atmosphere, and Solar Researchers (VAPOR) for VR?



https://www.vapor.ucar.edu

Model Domain, Spatial and Temporal Resolution and Coverage



Parameterizations Used

	Microphysics				
Cumulus	WRF Single-Moment 3-class, WSM3 (mp3)	WRF Single-Moment 5-class, WSM5 (mp4)	Lin et al. (Purdue) (mp2)	WRF Single-Moment 6-class, WSM6 (mp6)	WRF Double-Moment 6-class, WDM6 (mp16)
Betts-Miller-Janjic, BMJ (cu2)			X		
Kain-Fritsch, KF (cu1)	X	X	X	X	X
Grell-Freitas, GF (cu3)		X	X	X	X
Grell-3D, G3 (cu5)		X	X	X	X

Validation Sites

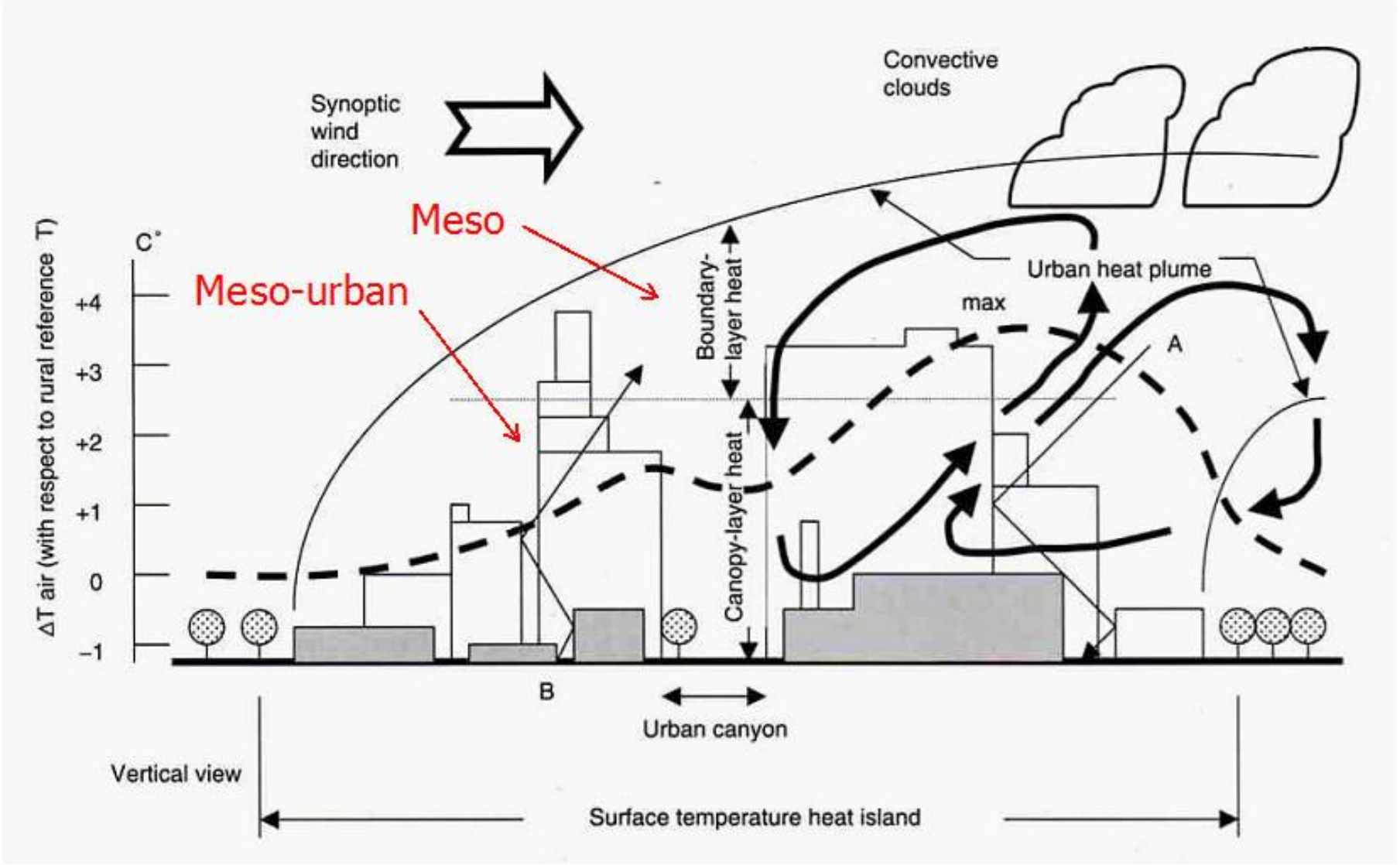
Resolution / Parameterization Performance Metrics

Metric	Equation	Meteorological Parameter Used, y (y_o = observed; y_m = modeled)
Bias	$\frac{\sum(y_m - y_o)}{N}$	temperature, pressure, humidity, rain (only during wet season)
Mean Absolute Error, MAE	$\frac{\sum\lvert y_m - y_o\rvert}{N}$	
Root-Mean-Square Error, RMS	$\sqrt{\frac{\sum(y_m - y_o)^2}{N}}$	
Correlation Coefficient, R	Pearson product-moment	

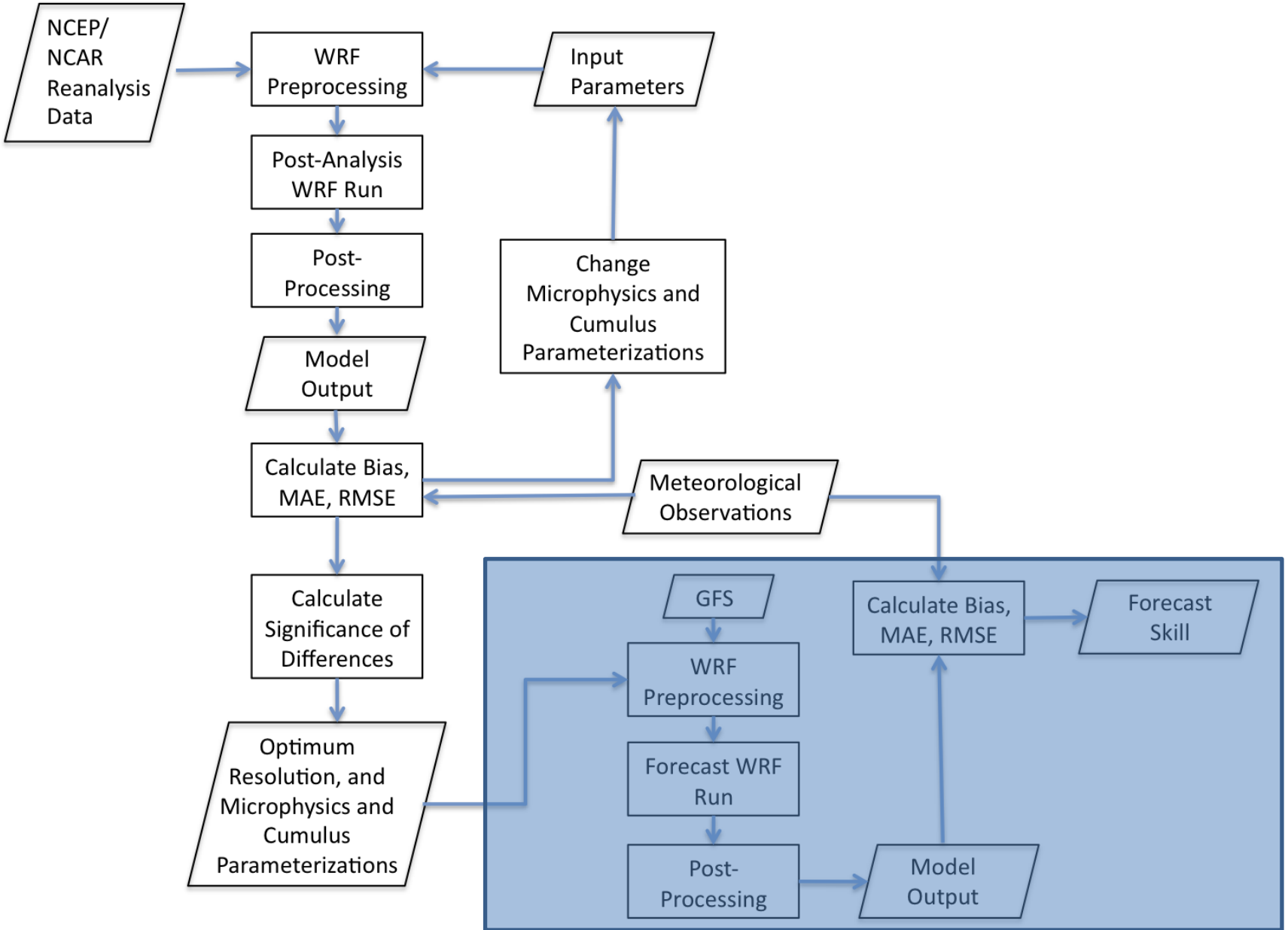
Resolution / Parameterization Performance Metrics

Metric	Equation	Meteorological Parameter Used, y (y_o = observed; y_m = modeled)
%Bias	$\frac{\sum(y_m - y_o)}{\sum y_o}$	temperature, pressure, humidity, rain (only during wet season)
Mean Absolute Error, %MAE	$\frac{\sum\lvert y_m - y_o\rvert}{\sum y_o}$	
Root-Mean-Square Error, %RMS	$\frac{\sqrt{\frac{\sum(y_m - y_o)^2}{N}}}{\sum y_o}$	
Correlation Coefficient, R	Pearson product-moment	

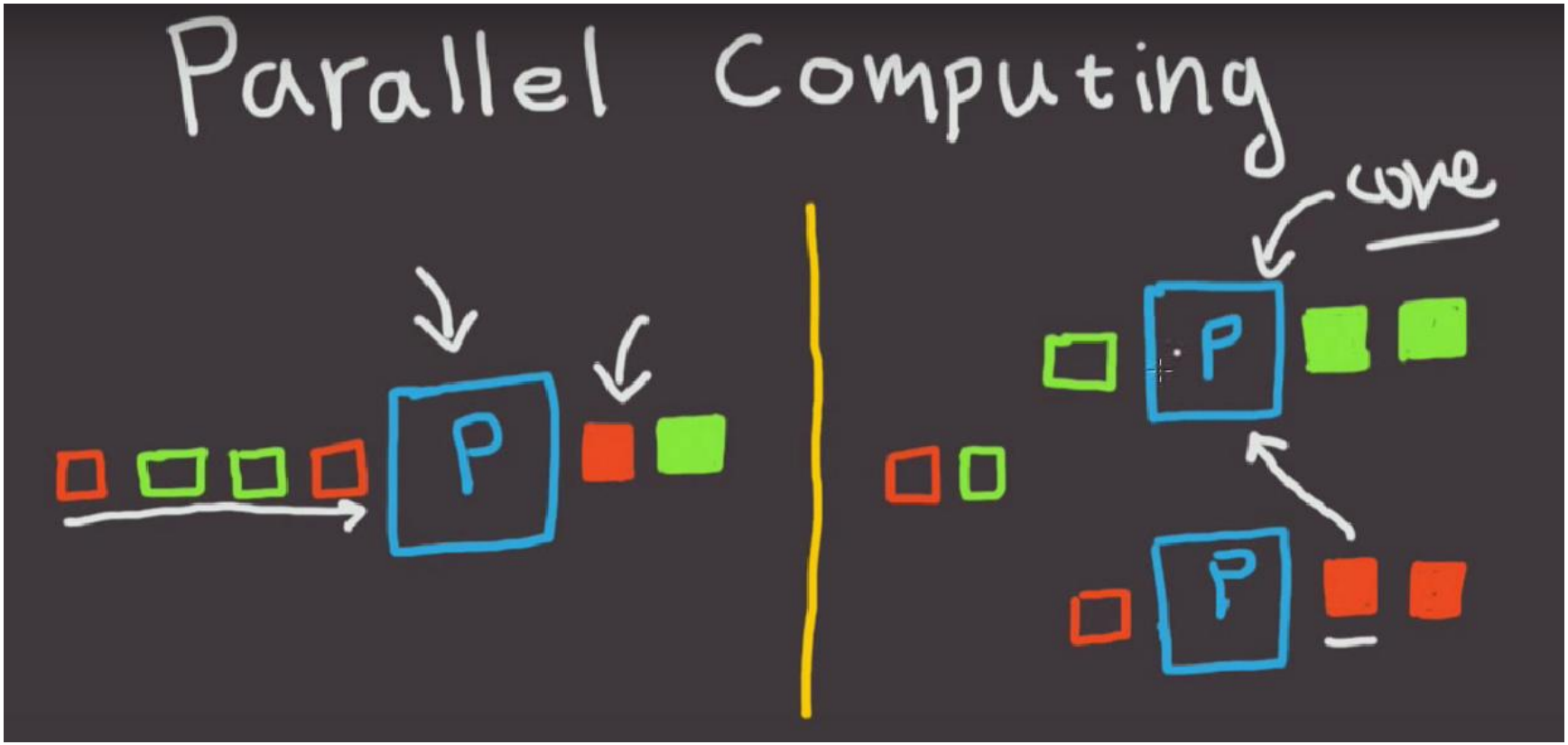
Why wind is not included in the metrics?



Analysis Framework



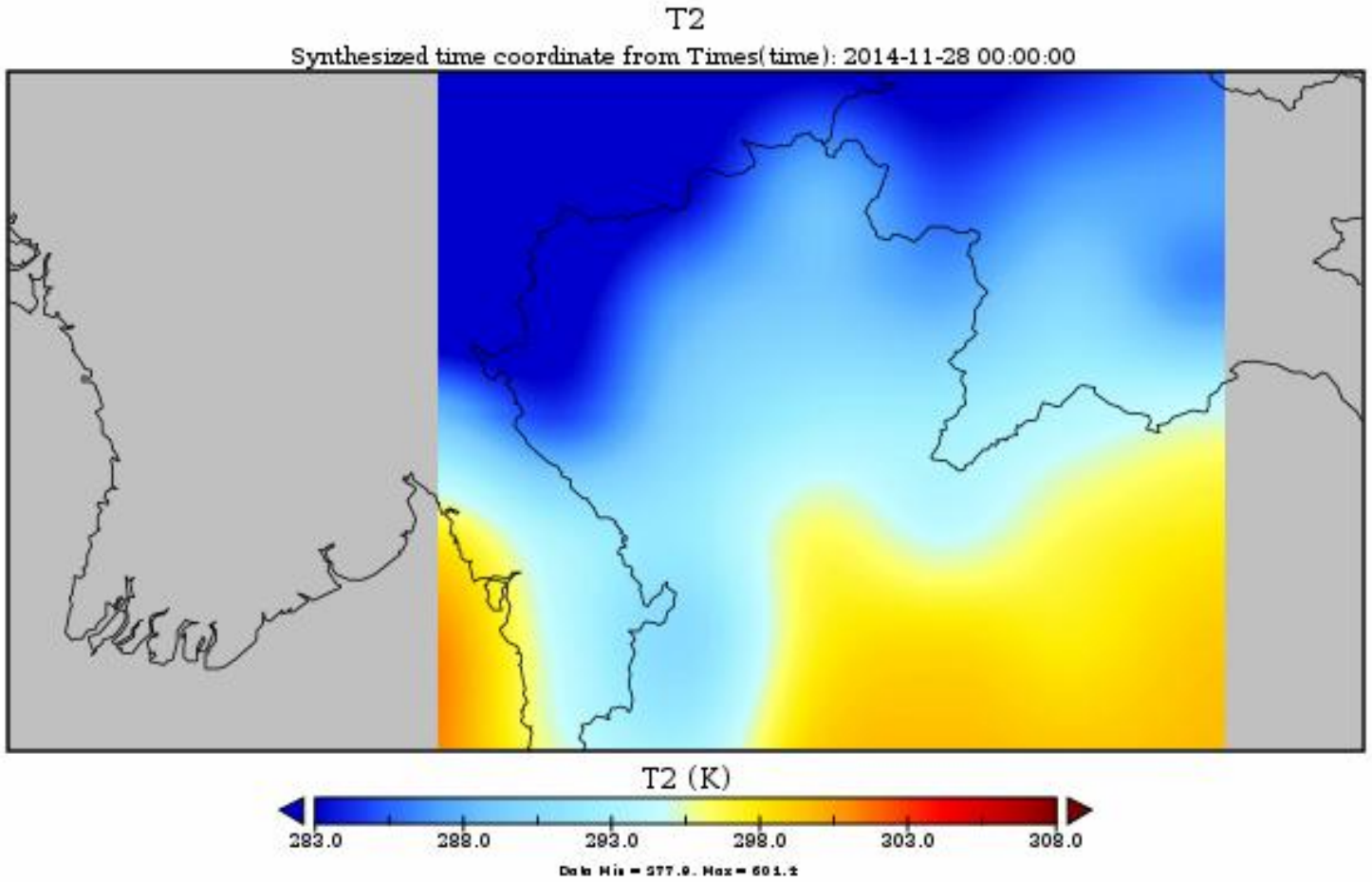
Message Passing Interface (MPI)



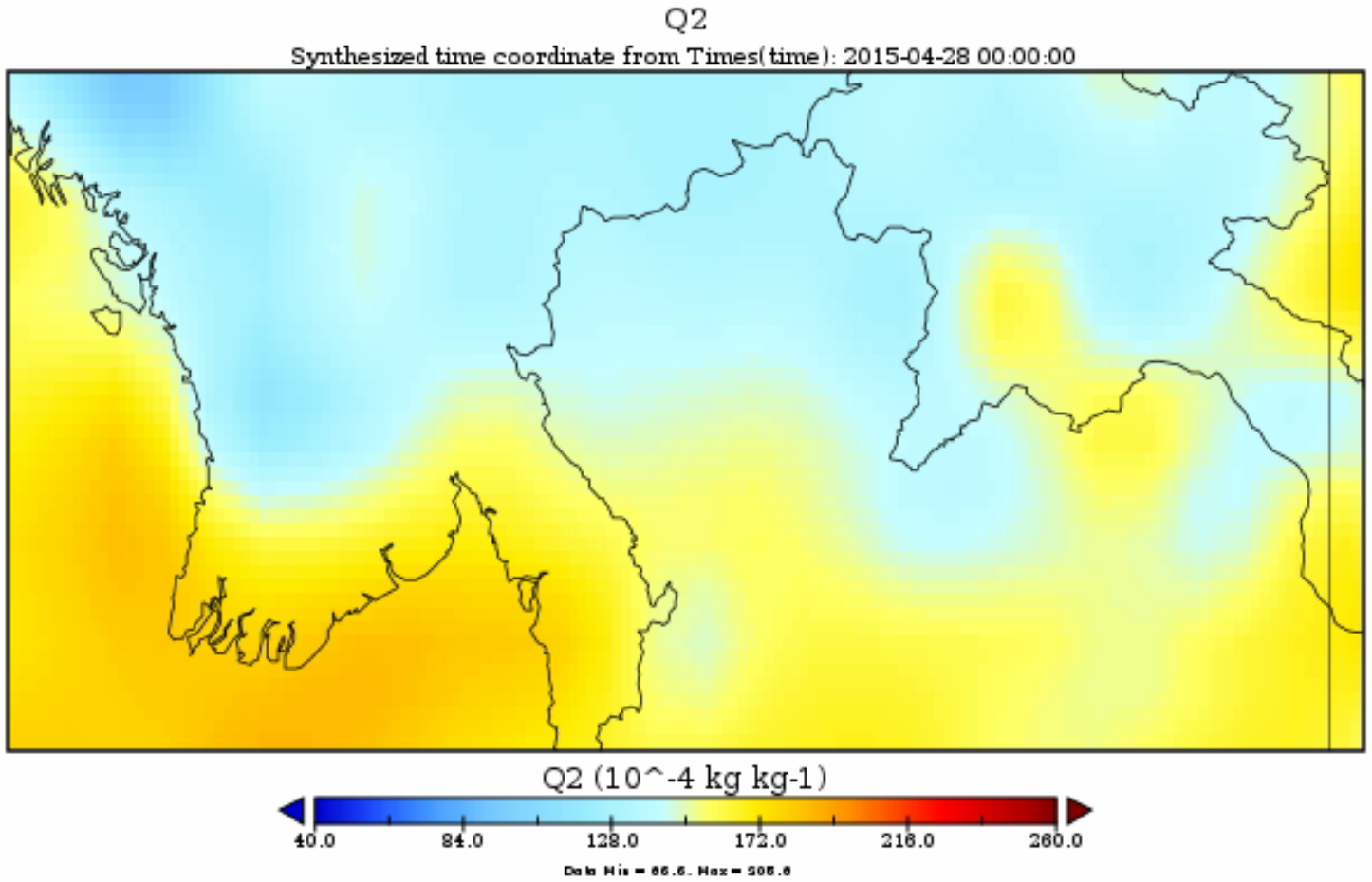
More cores DOES NOT necessarily mean faster

Optimum no. of cores: 8

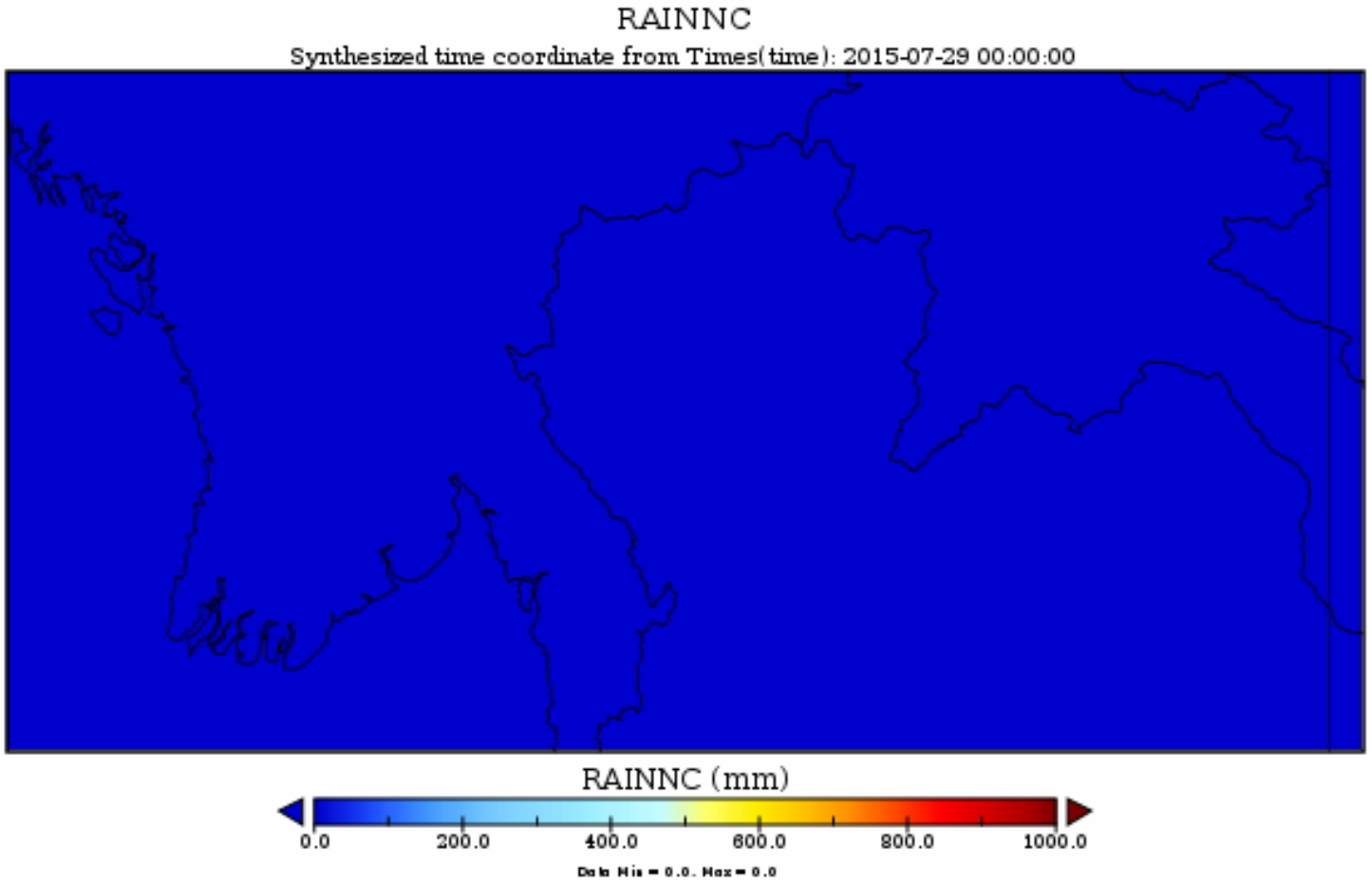
Surface Temperature at during the Cool Dry Season (mp3cu1 – 2 km)



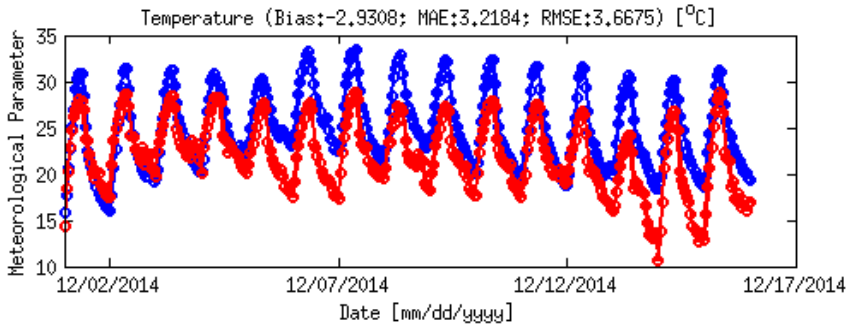
Water Vapor Mixing Ratio during the Hot Dry Season (mp2cu2 – 50 km)

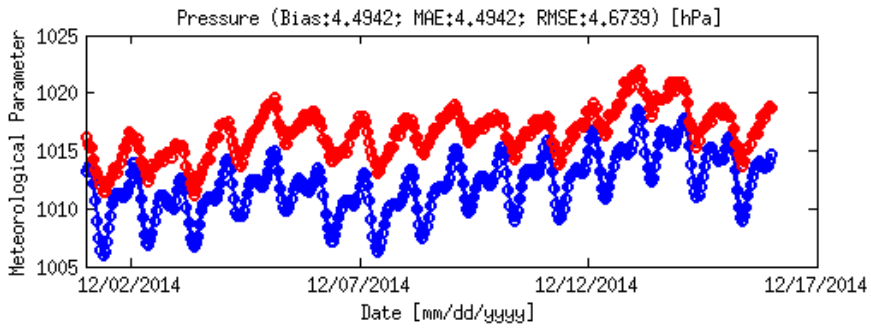


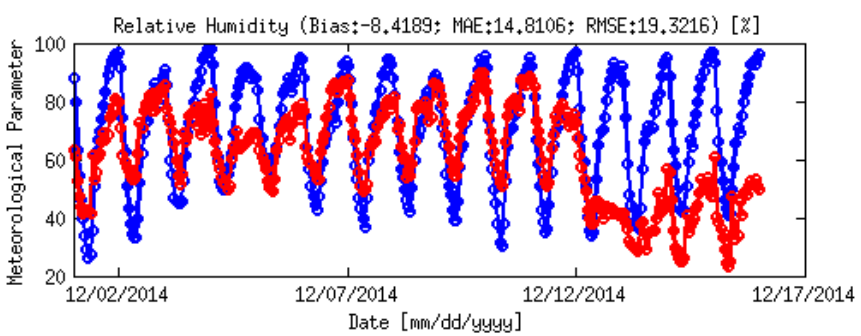
Accumulated Non-Convective Rain during Wet Season (mp16cu5 – 50 km)

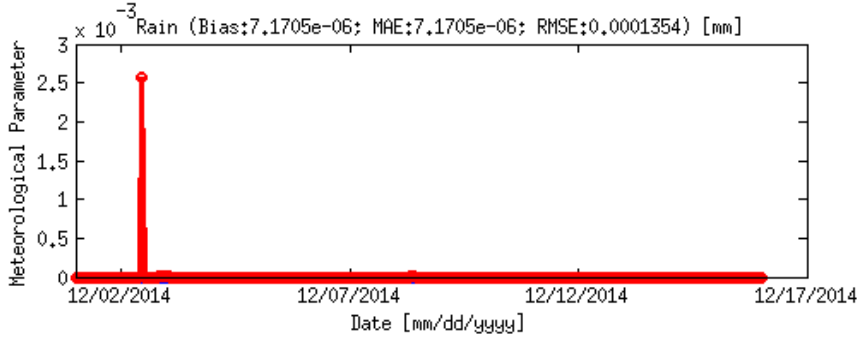


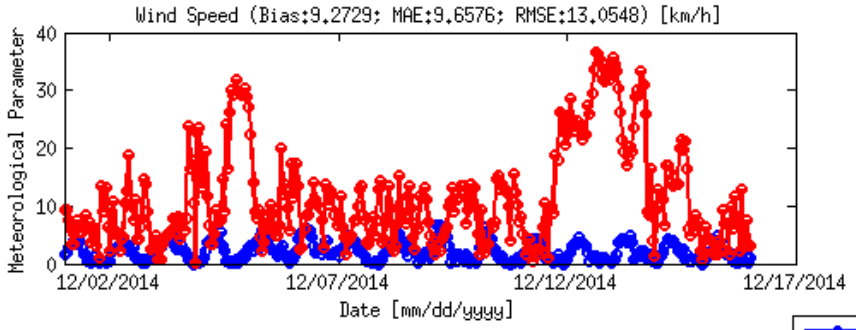
Chiang Mai Airport TMD Station
Cool Dry Season (mp3cu1 – 2 km)

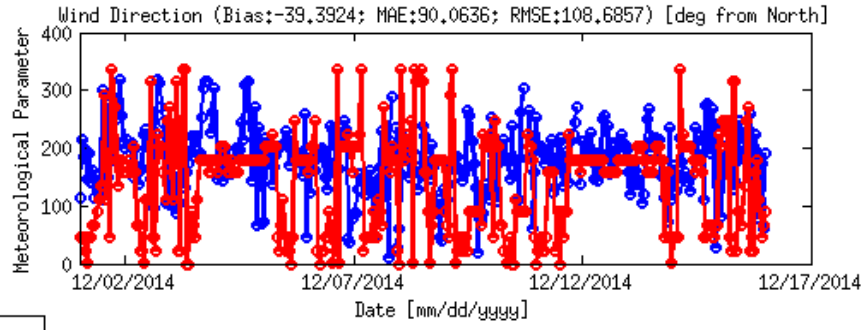


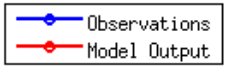




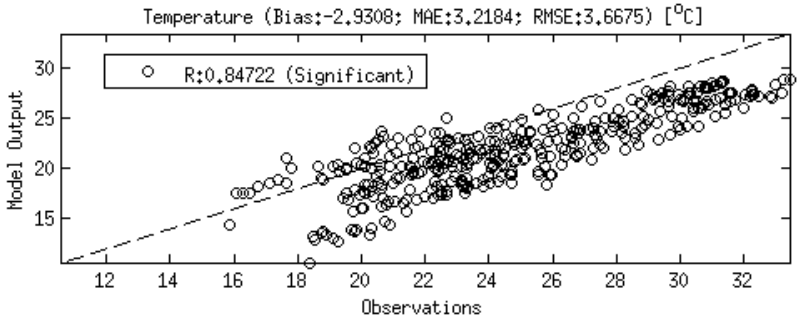


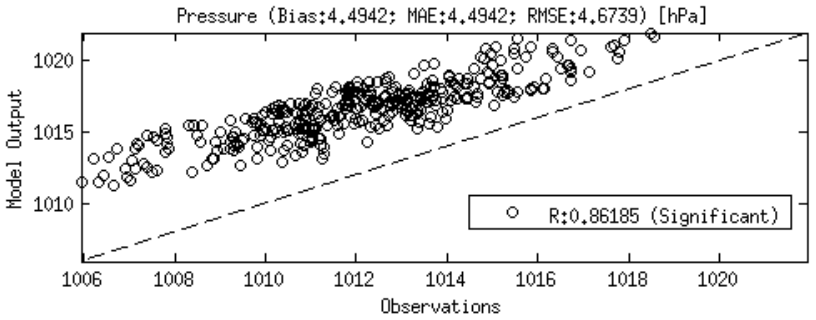


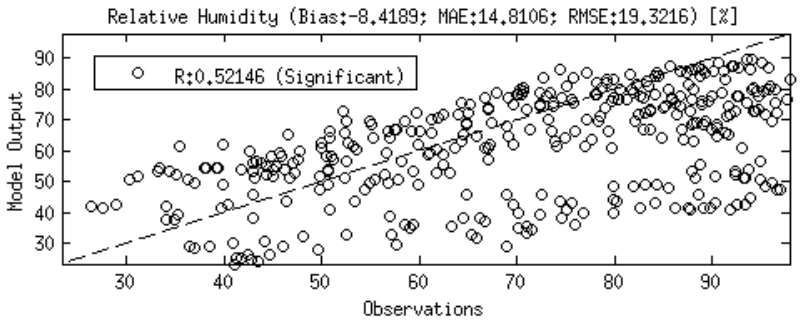


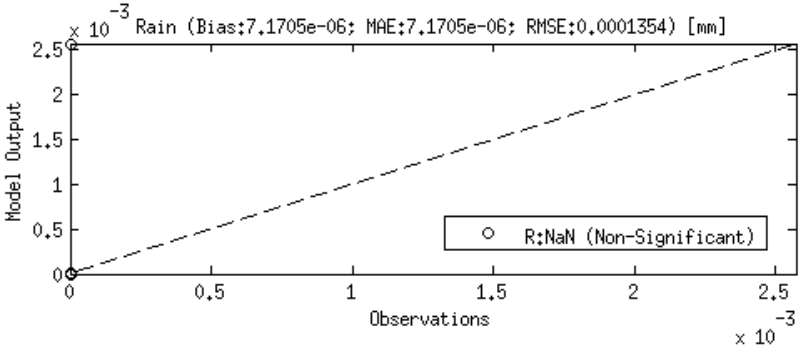


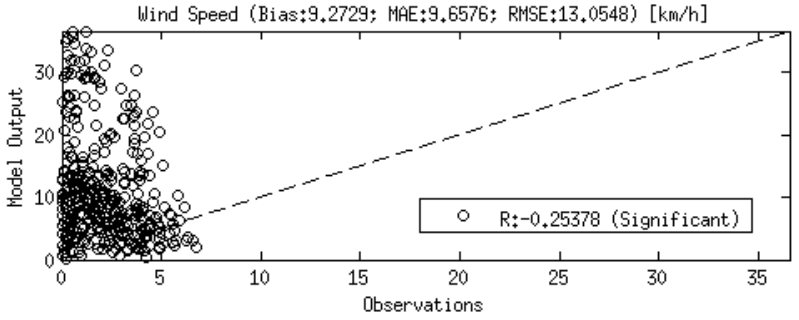
Chiang Mai Airport TMD Station
Cool Dry Season (mp3cu1 – 2 km)

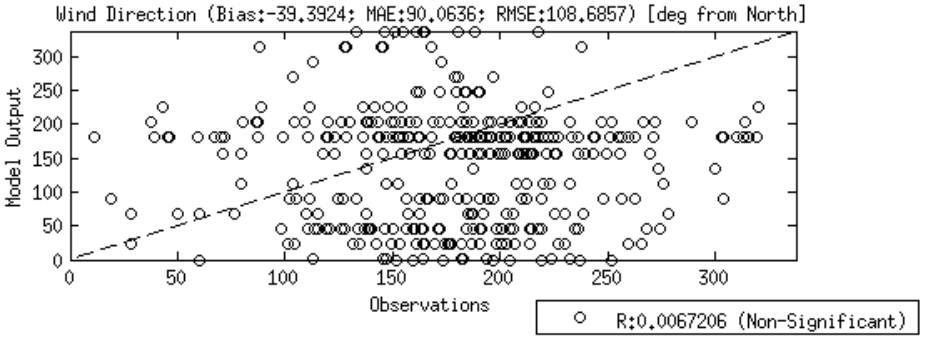




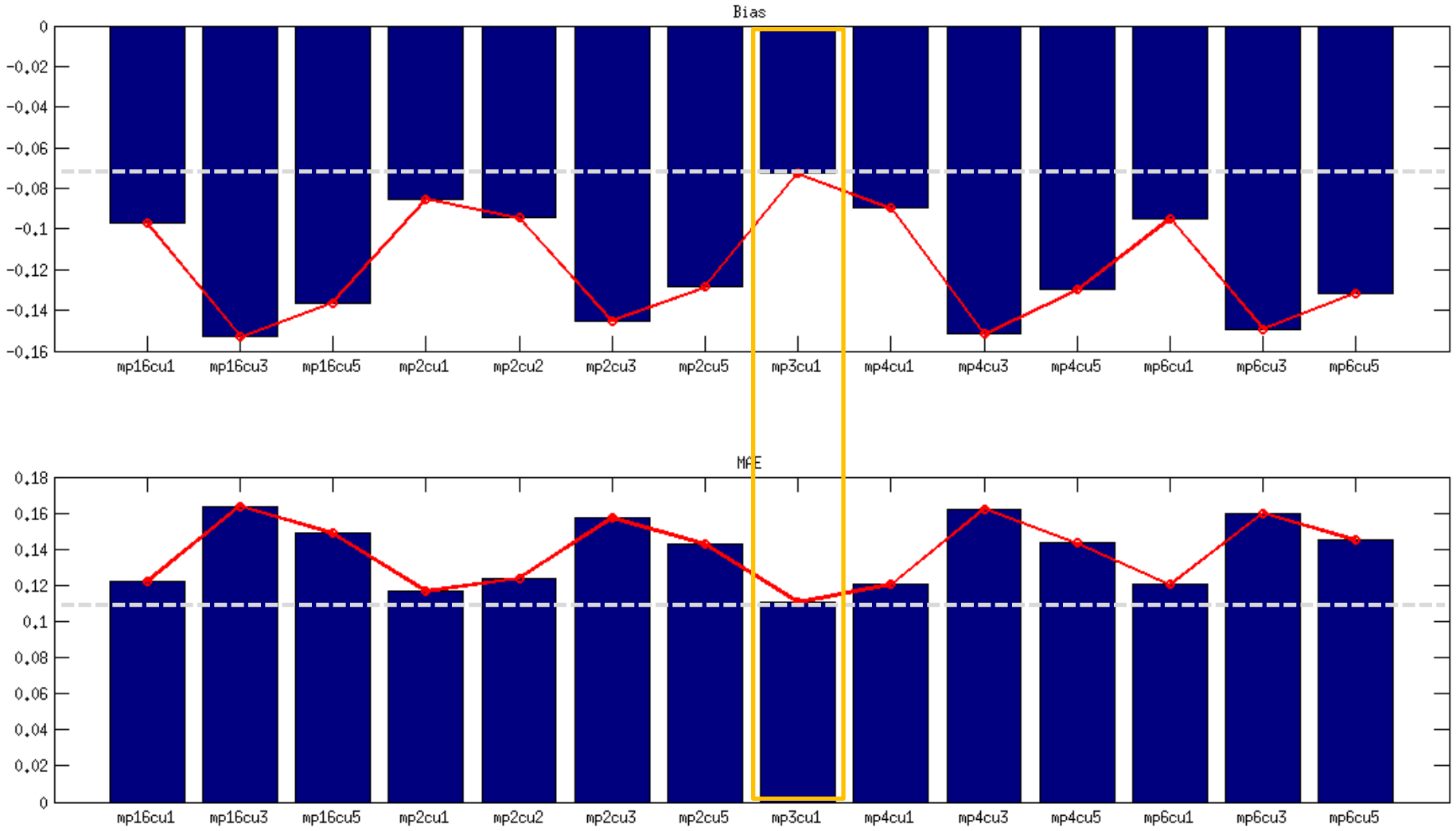




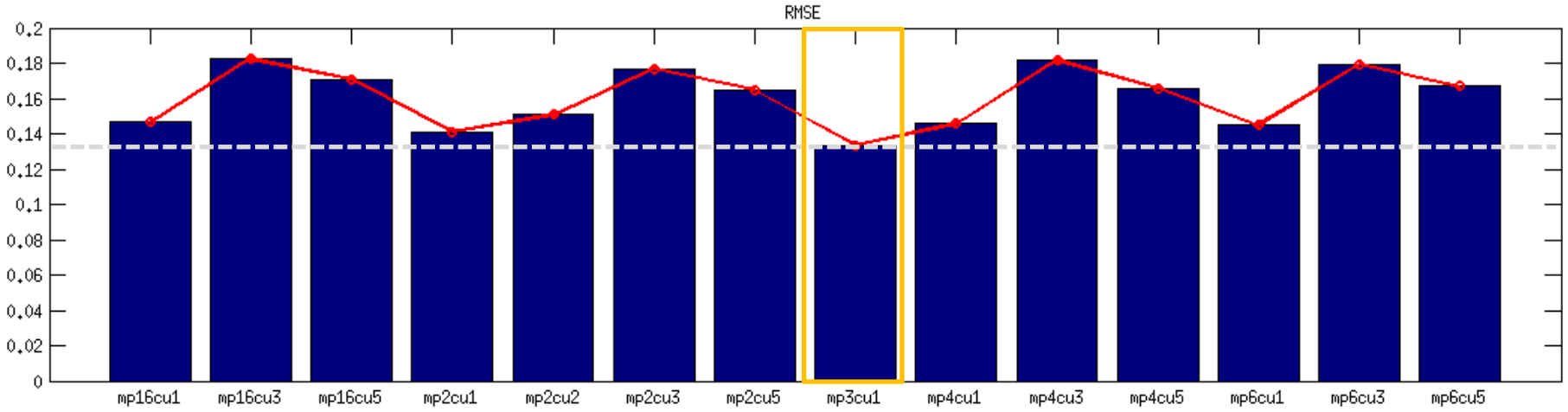


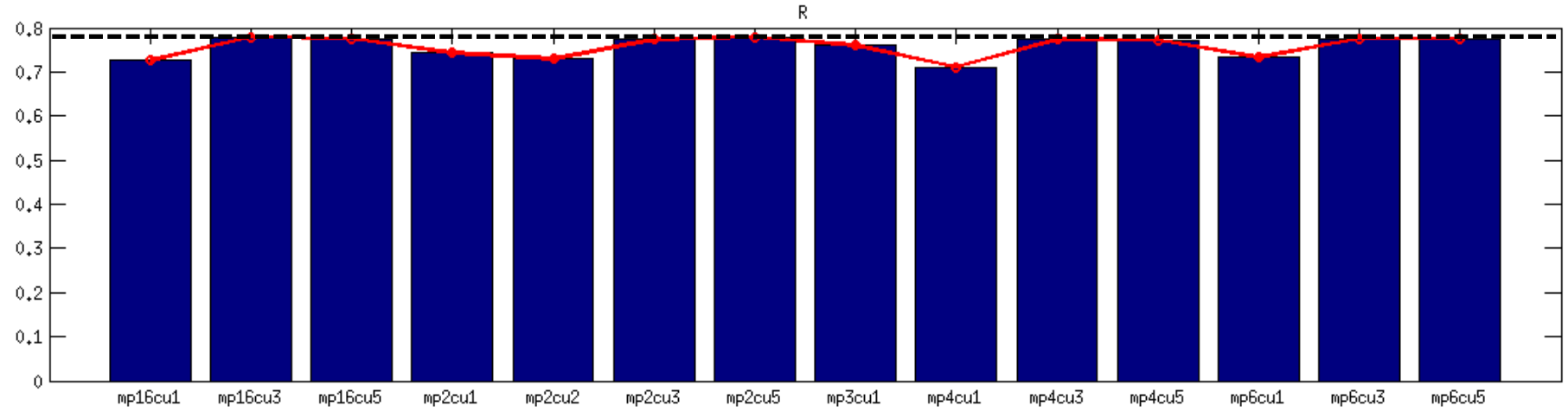


Parameterization Performance Metrics (Cool Dry Season)



Parameterization Performance Metrics (Cool Dry Season)



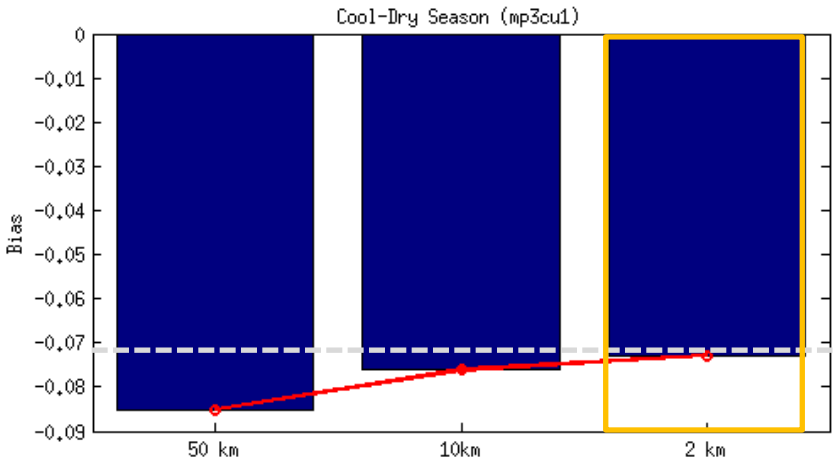


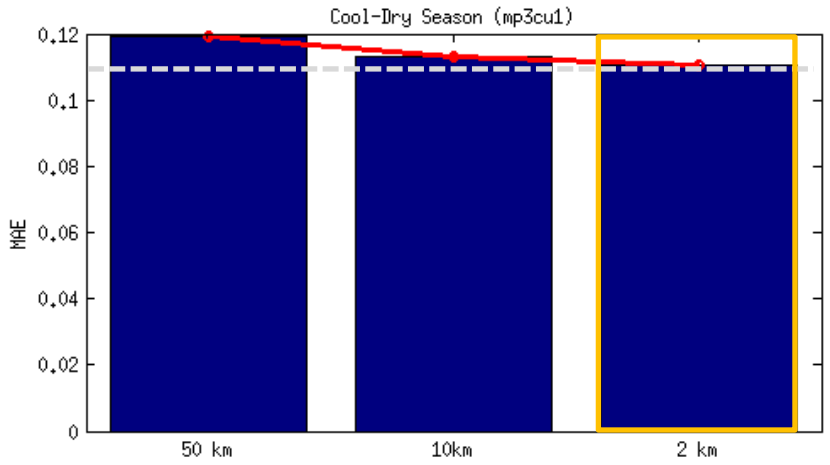
Optimum: mp3cu1 (3 out of 4)

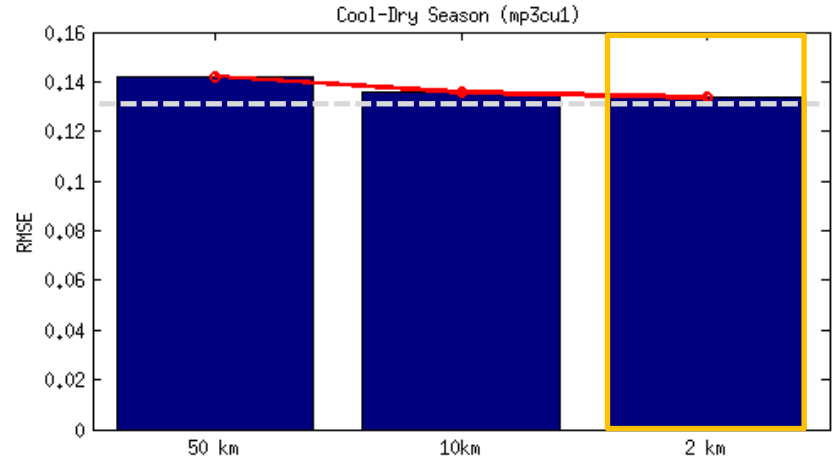
Optimum Microphysics and Cumulus Parameterizations

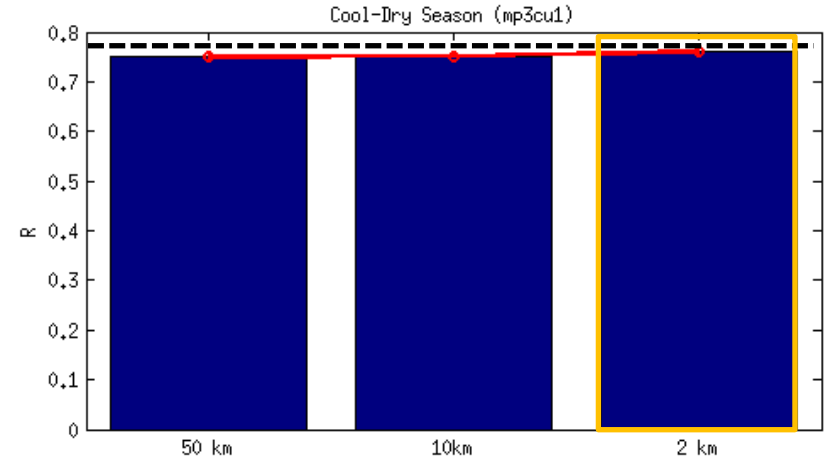
- mp3cu1 (cool dry season)
- mp2cu2 (hot dry season)
- mp16cu5 (wet season)

Resolution Performance Metrics (Cool Dry Season)



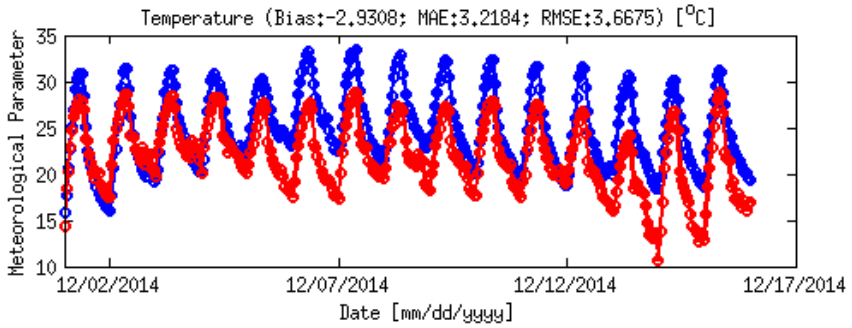


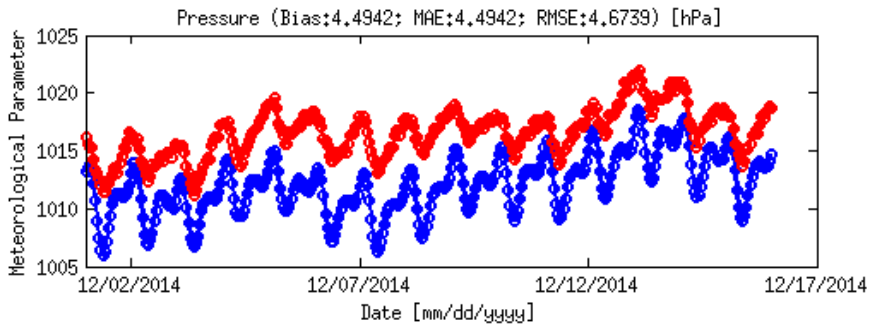


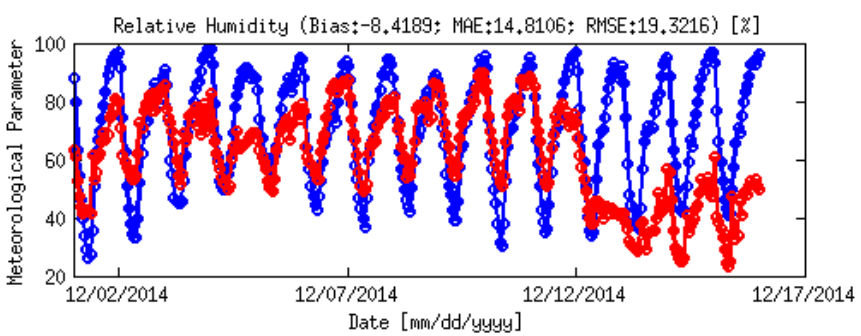


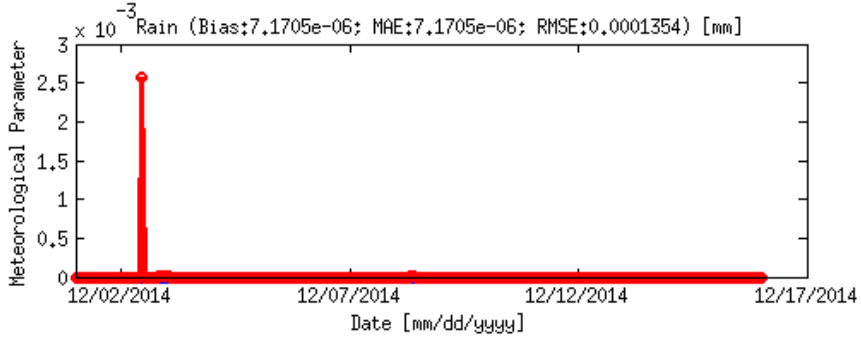
Optimum: 2 km (4 out of 4)

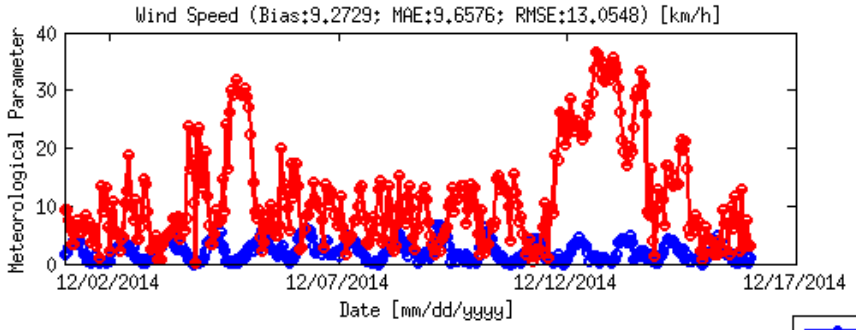
Chiang Mai Airport TMD Station
Cool Dry Season (mp3cu1 – 2 km)

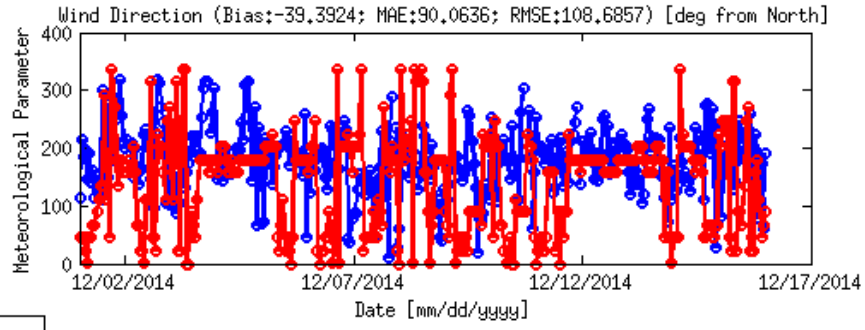


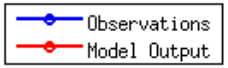




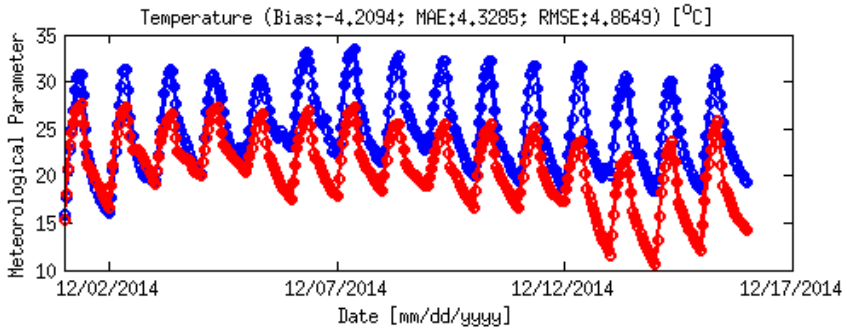


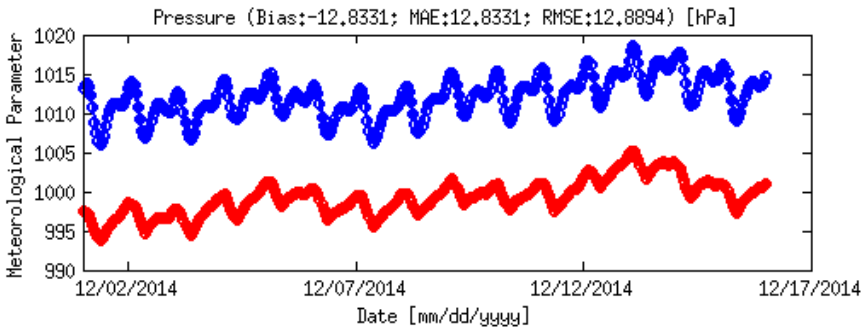


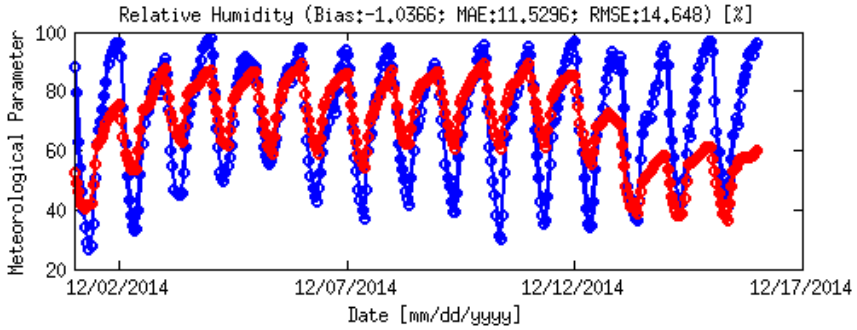


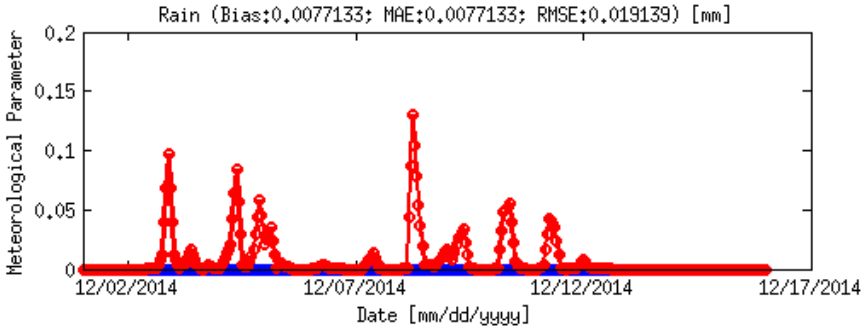


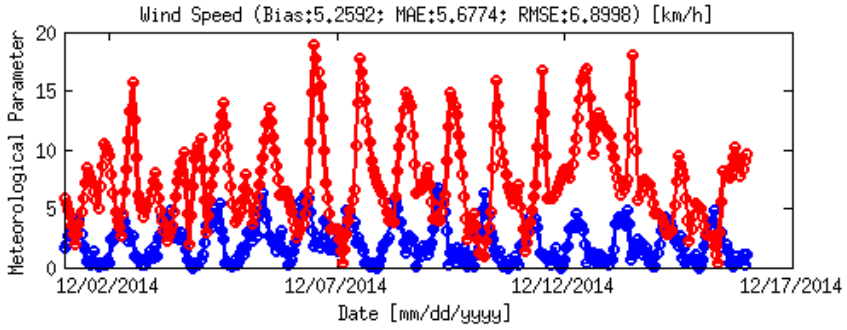
Chiang Mai Airport TMD Station
Cool Dry Season (mp3cu1 – 50 km)

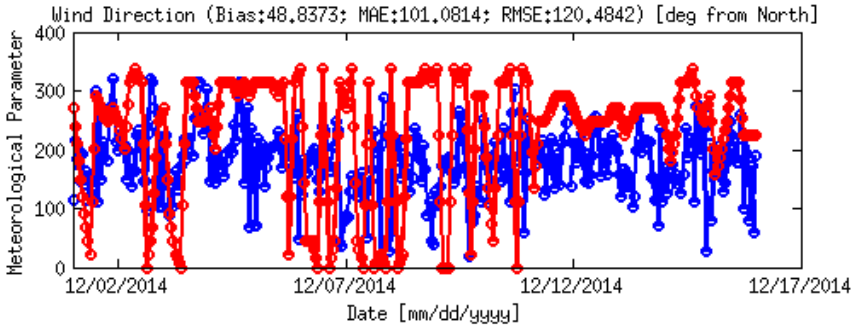


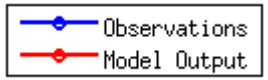




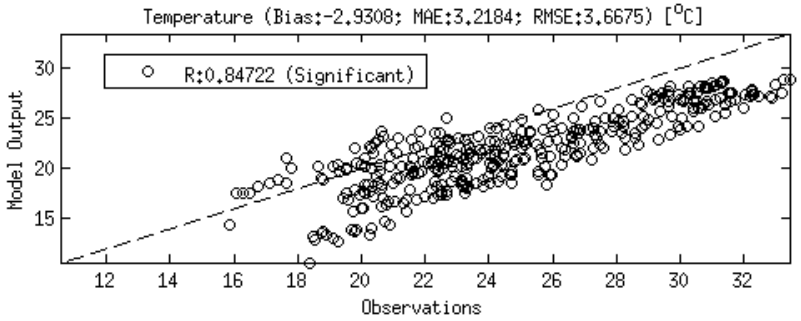


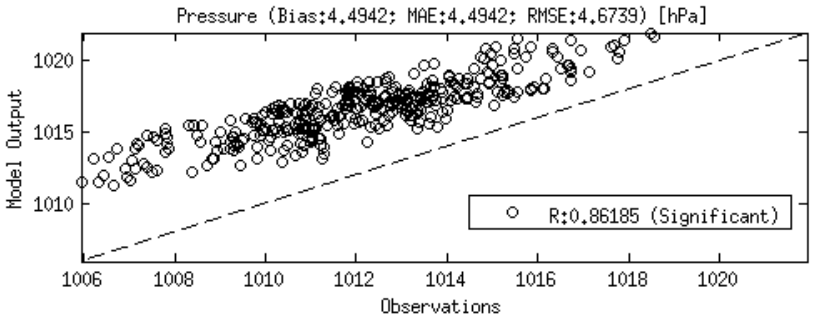


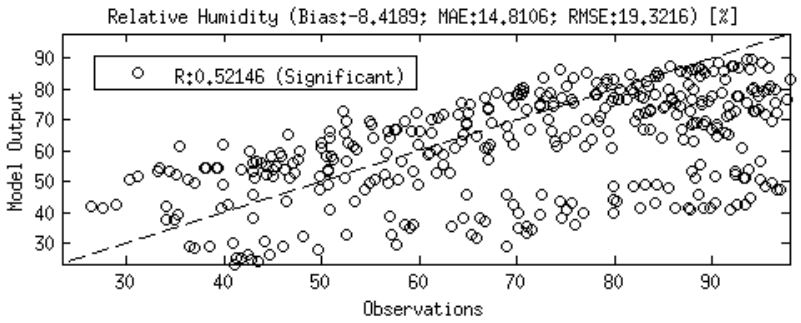


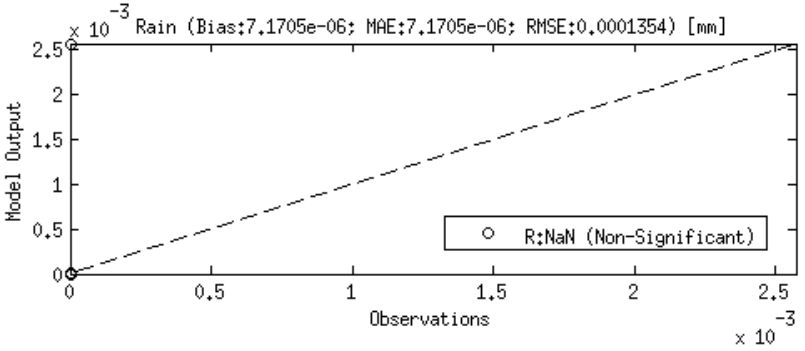


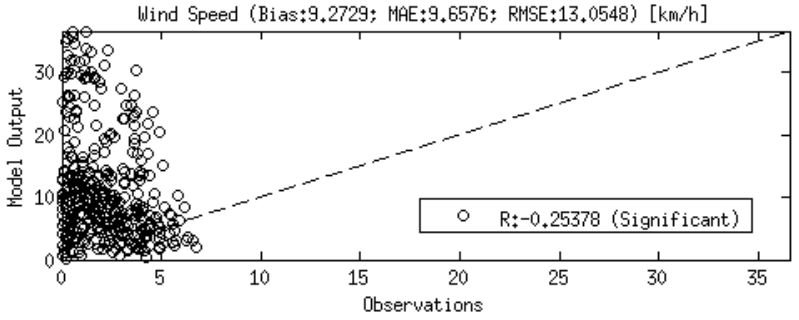
Chiang Mai Airport TMD Station
Cool Dry Season (mp3cu1 – 2 km)

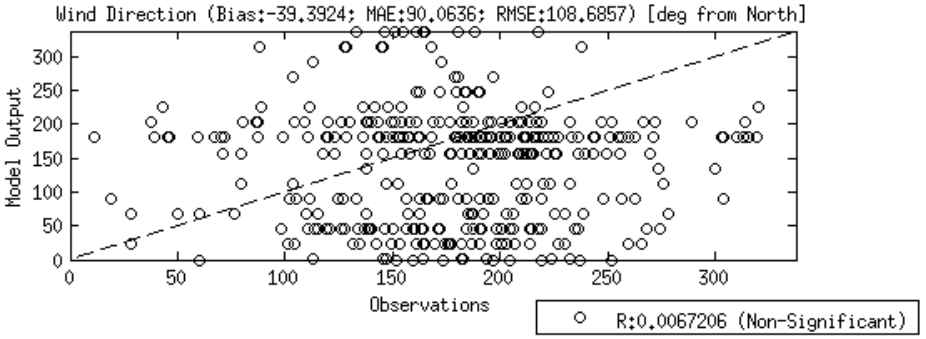




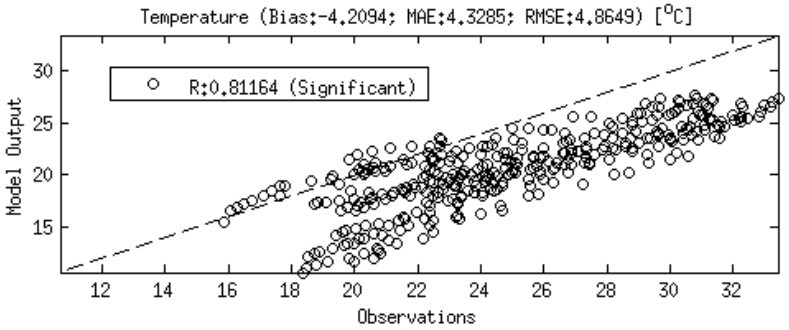


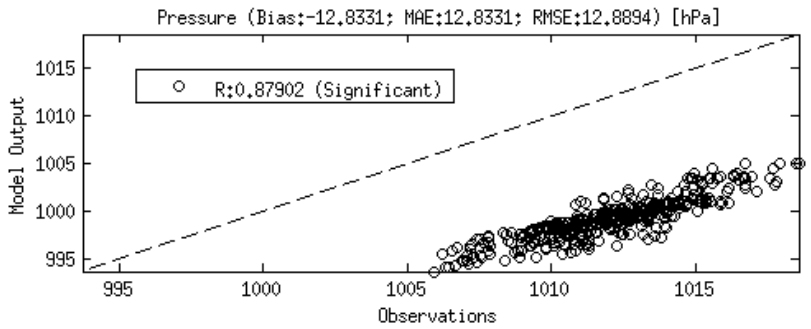


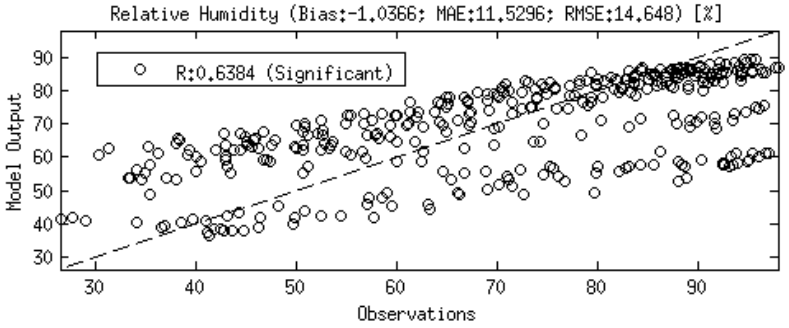


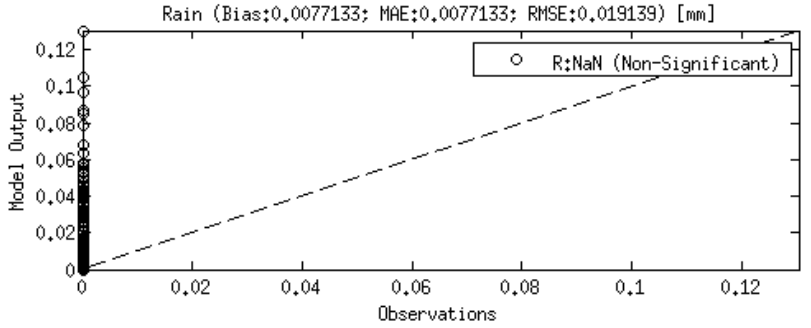


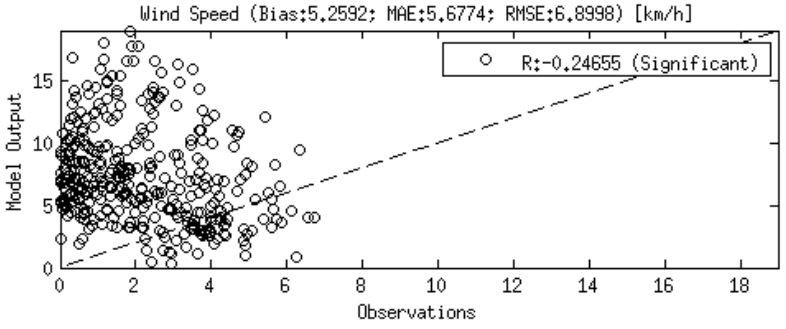
Chiang Mai Airport TMD Station
Cool Dry Season (mp3cu1 – 50 km)

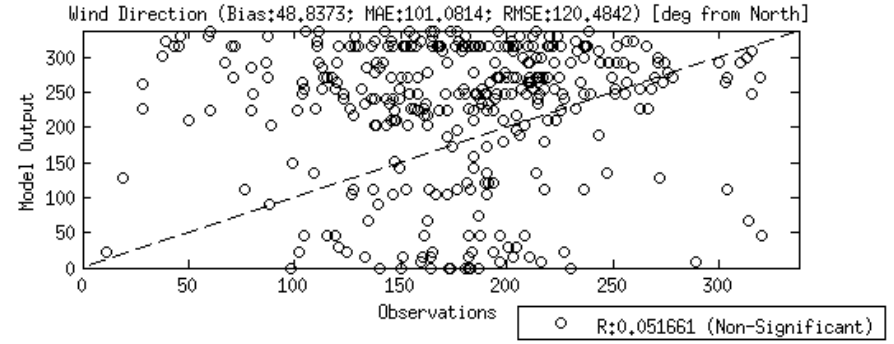




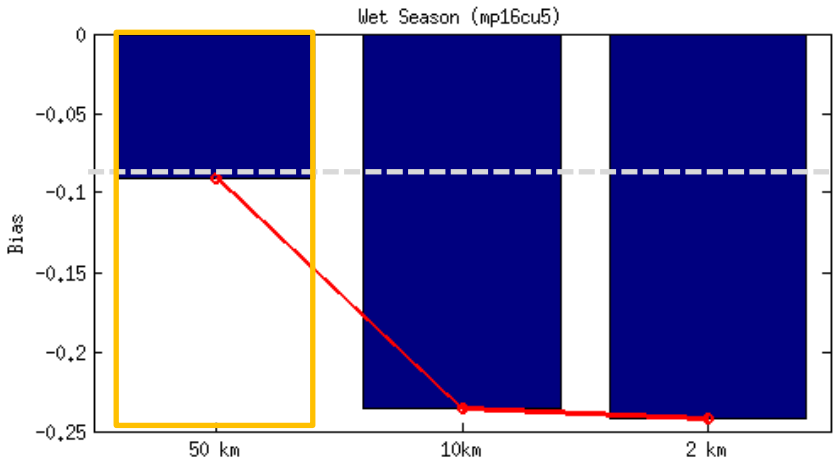


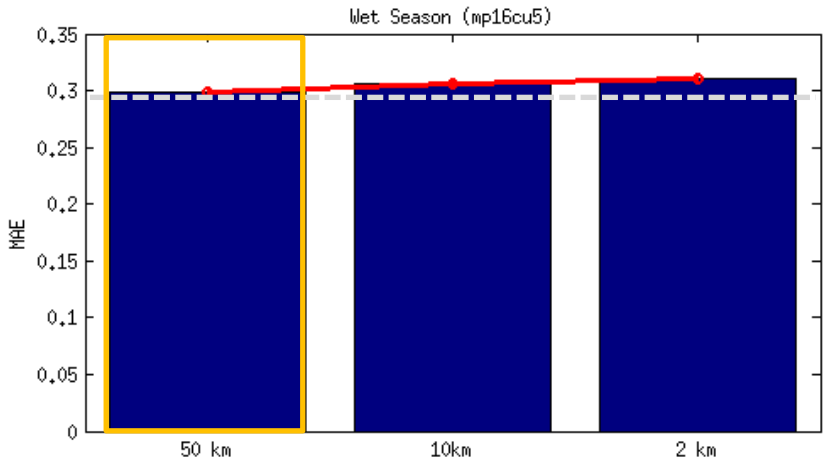


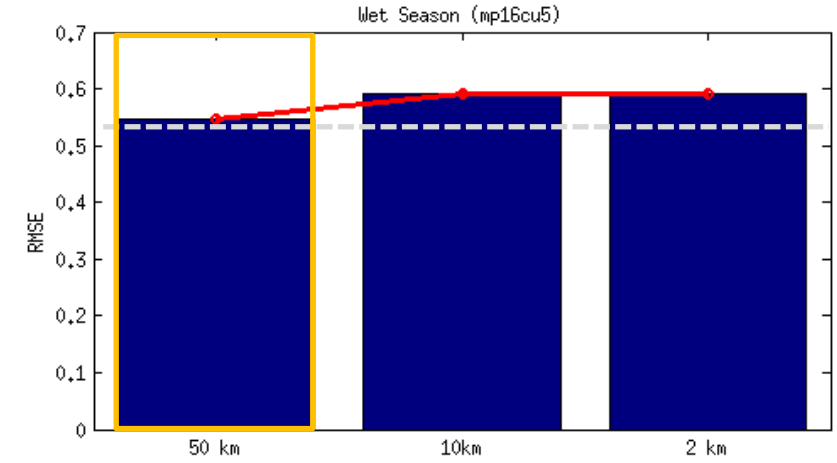


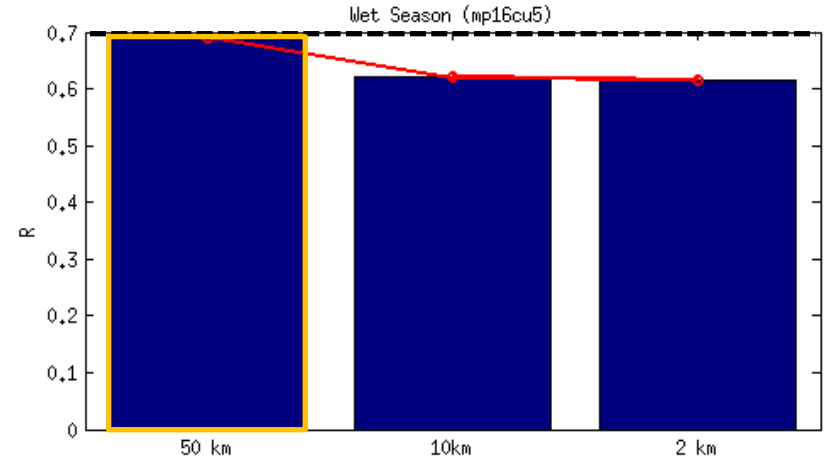


Resolution Performance Metrics (Wet Season)



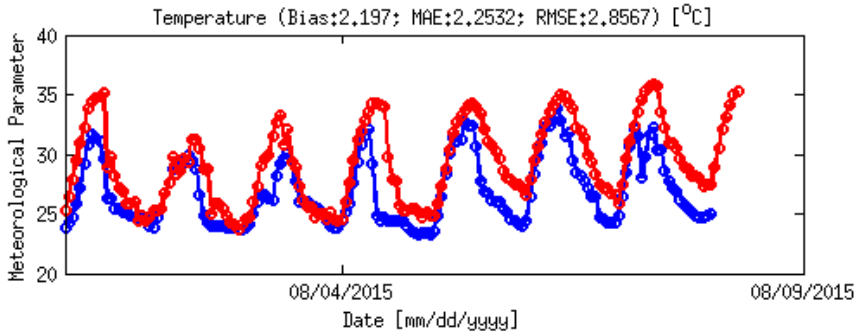


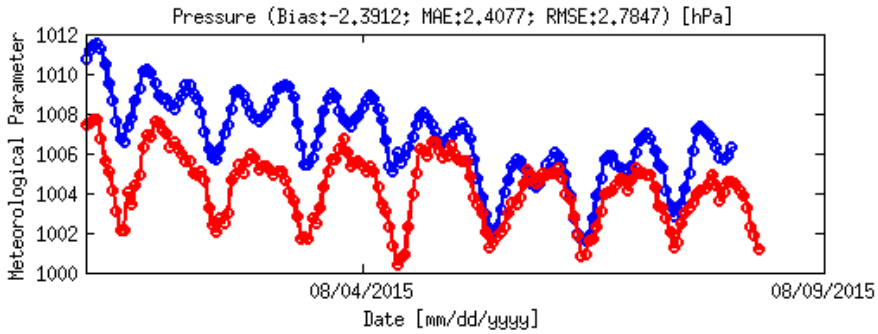


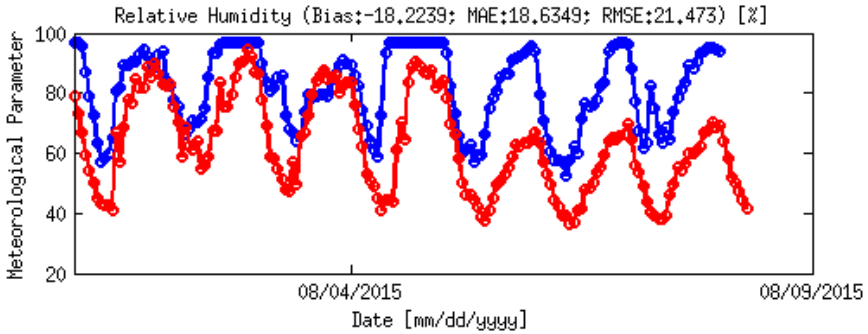


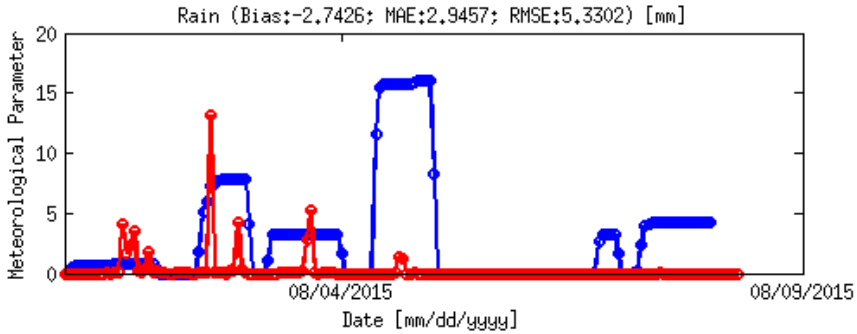
Optimum: 50 km (4 out of 4)

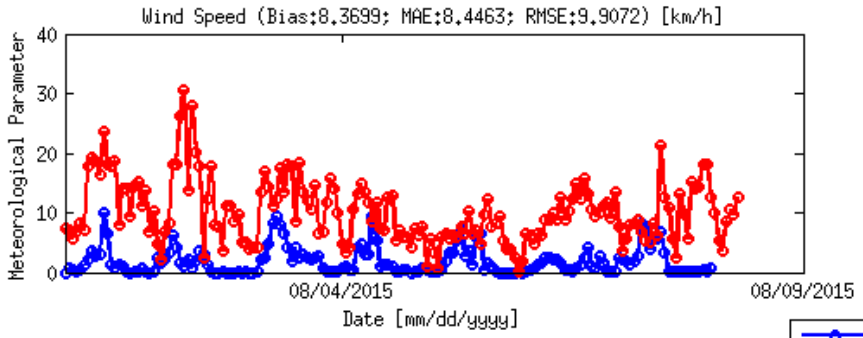
Lampang Airport TMD Station
Wet Season (mp16cu5 – 2 km)

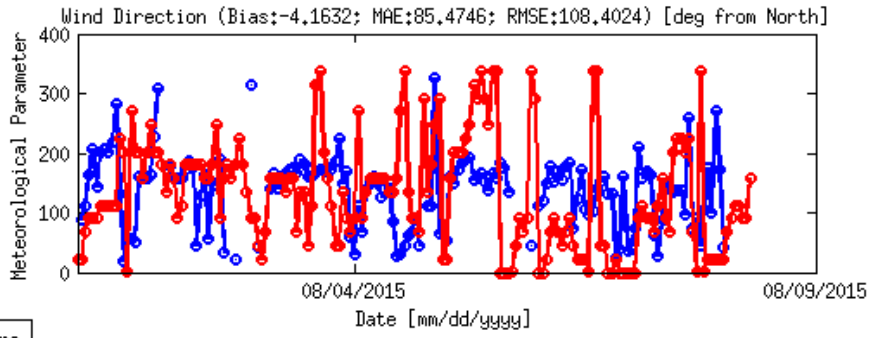


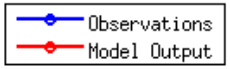




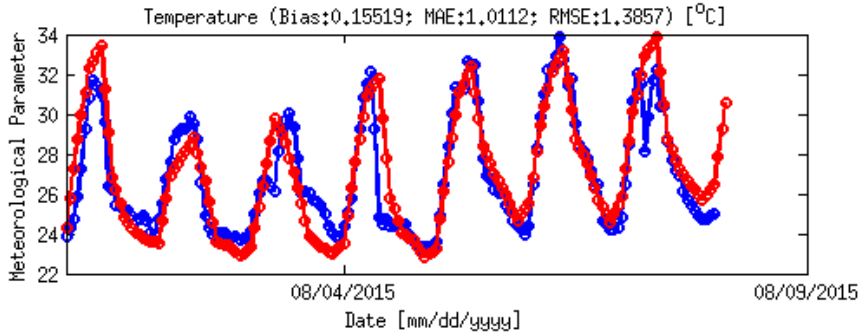


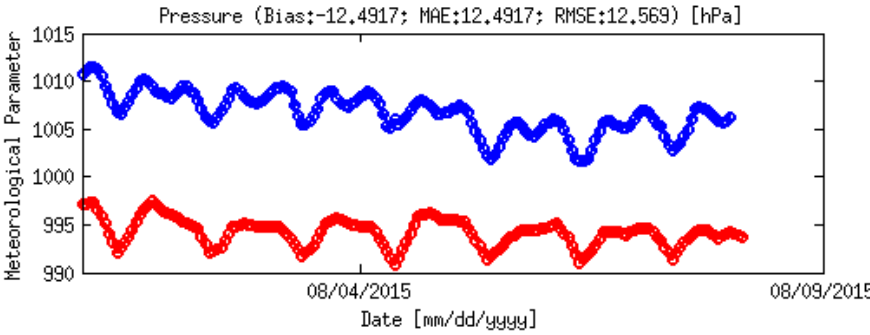


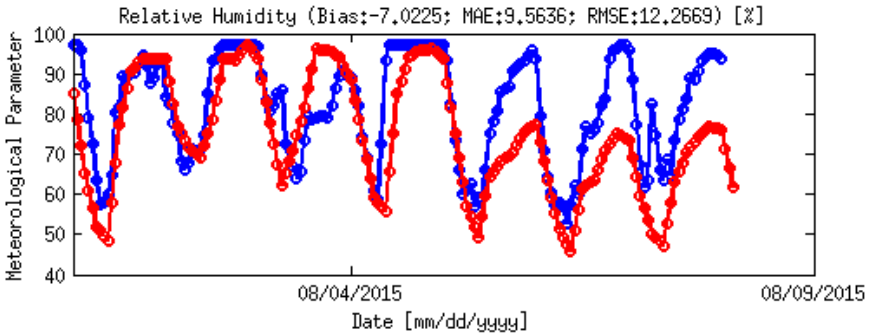


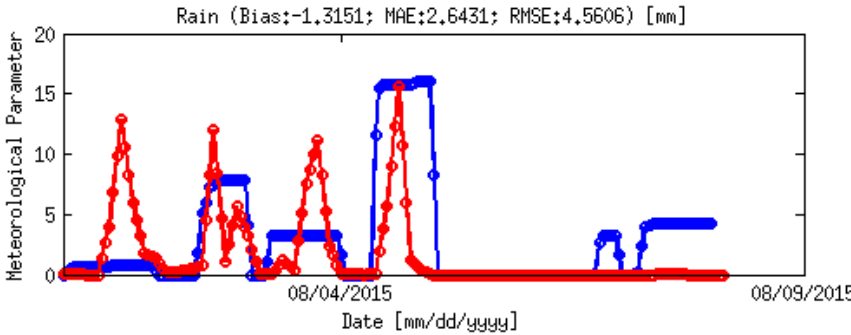


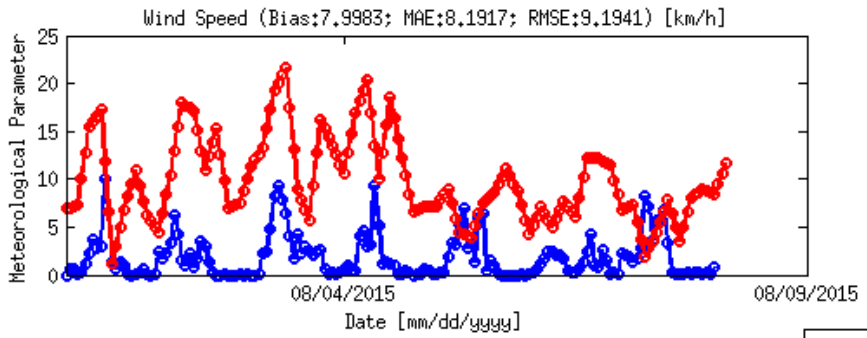
Lampang Airport TMD Station
Wet Season (mp16cu5 – 50 km)

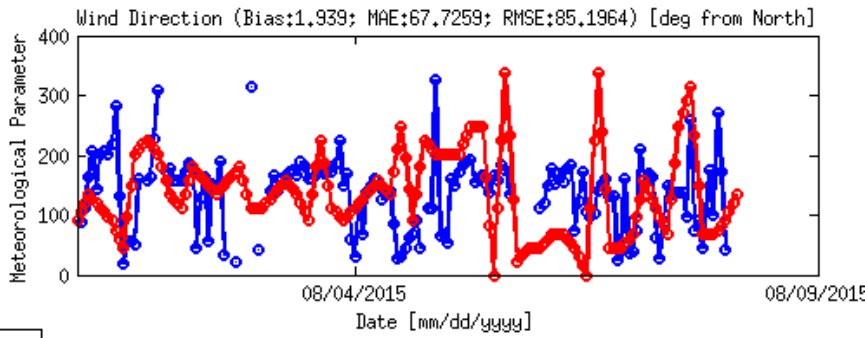


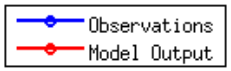




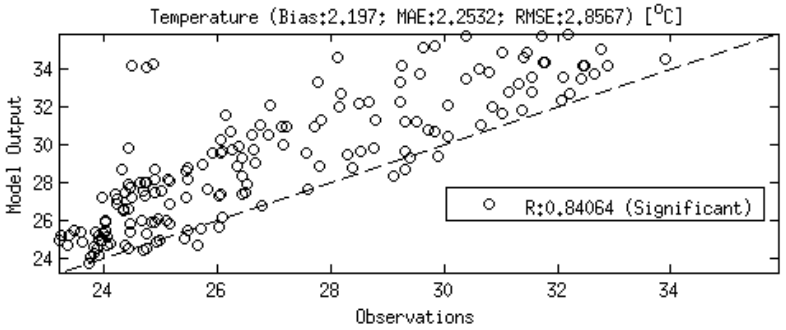


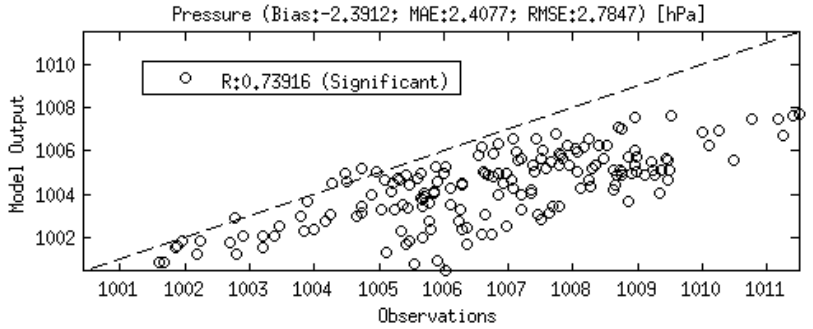


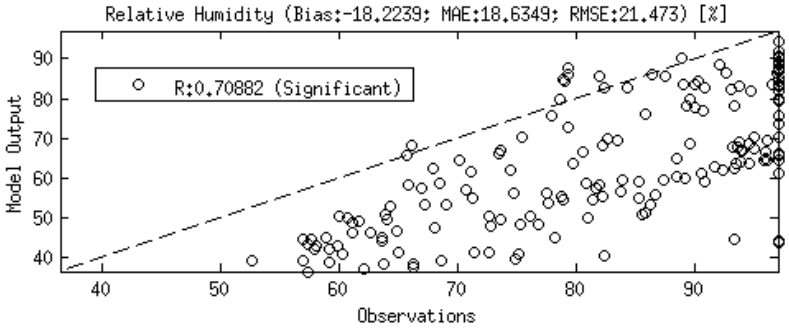


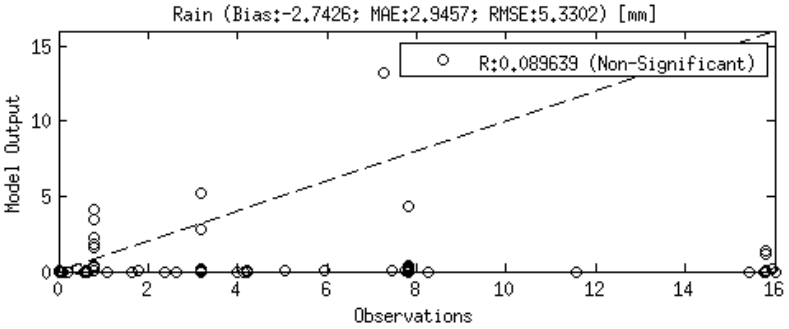


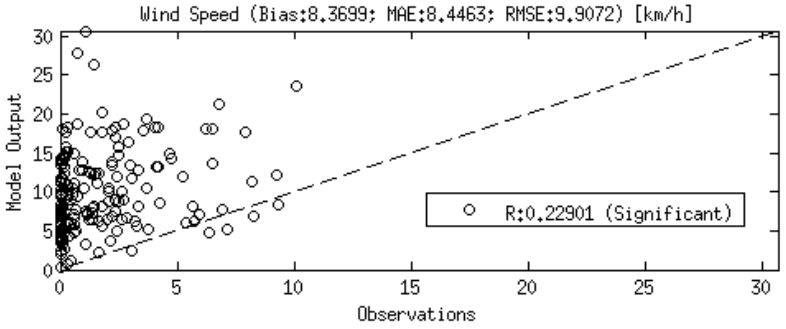
Lampang Airport TMD Station
Wet Season (mp16cu5 – 2 km)

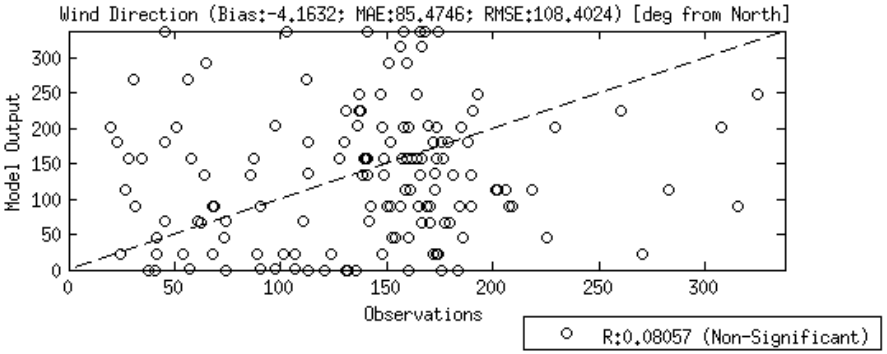




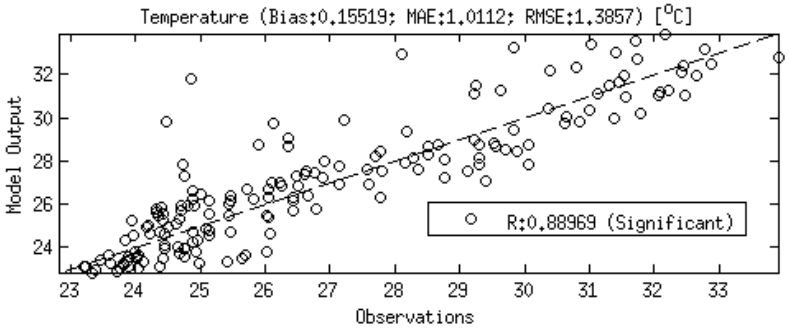


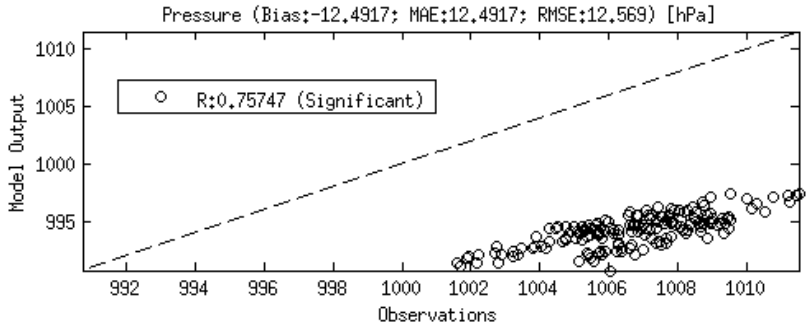


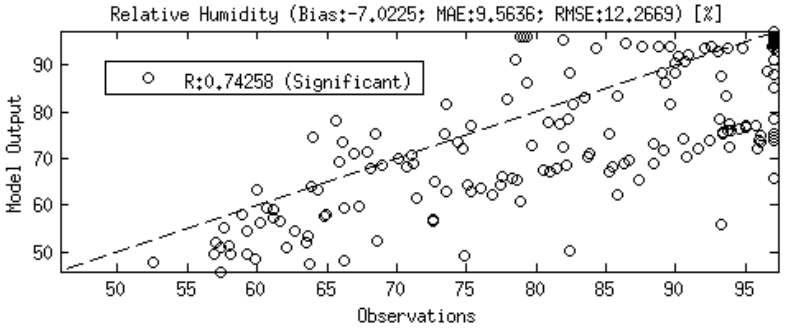


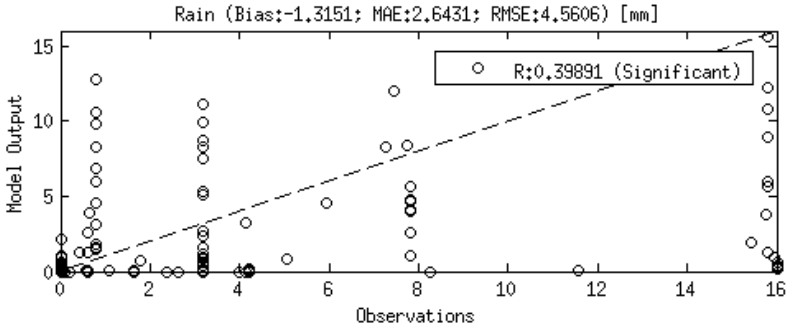


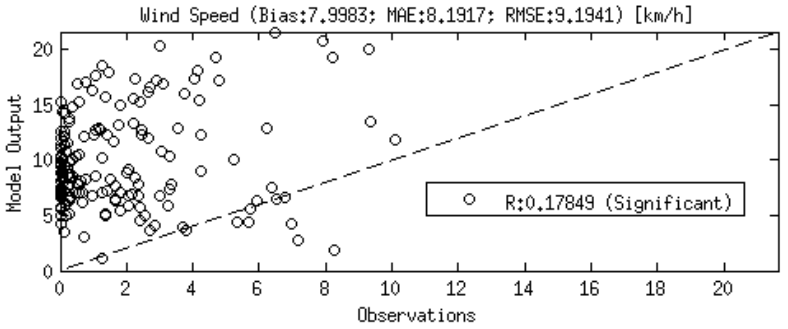
Lampang Airport TMD Station
Wet Season (mp16cu5 – 50 km)

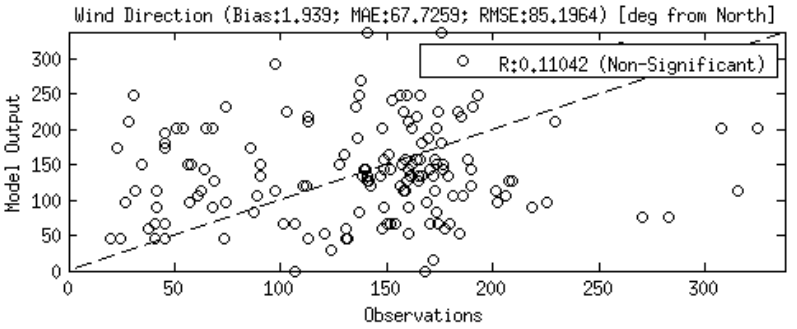












Optimum Resolutions

- 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

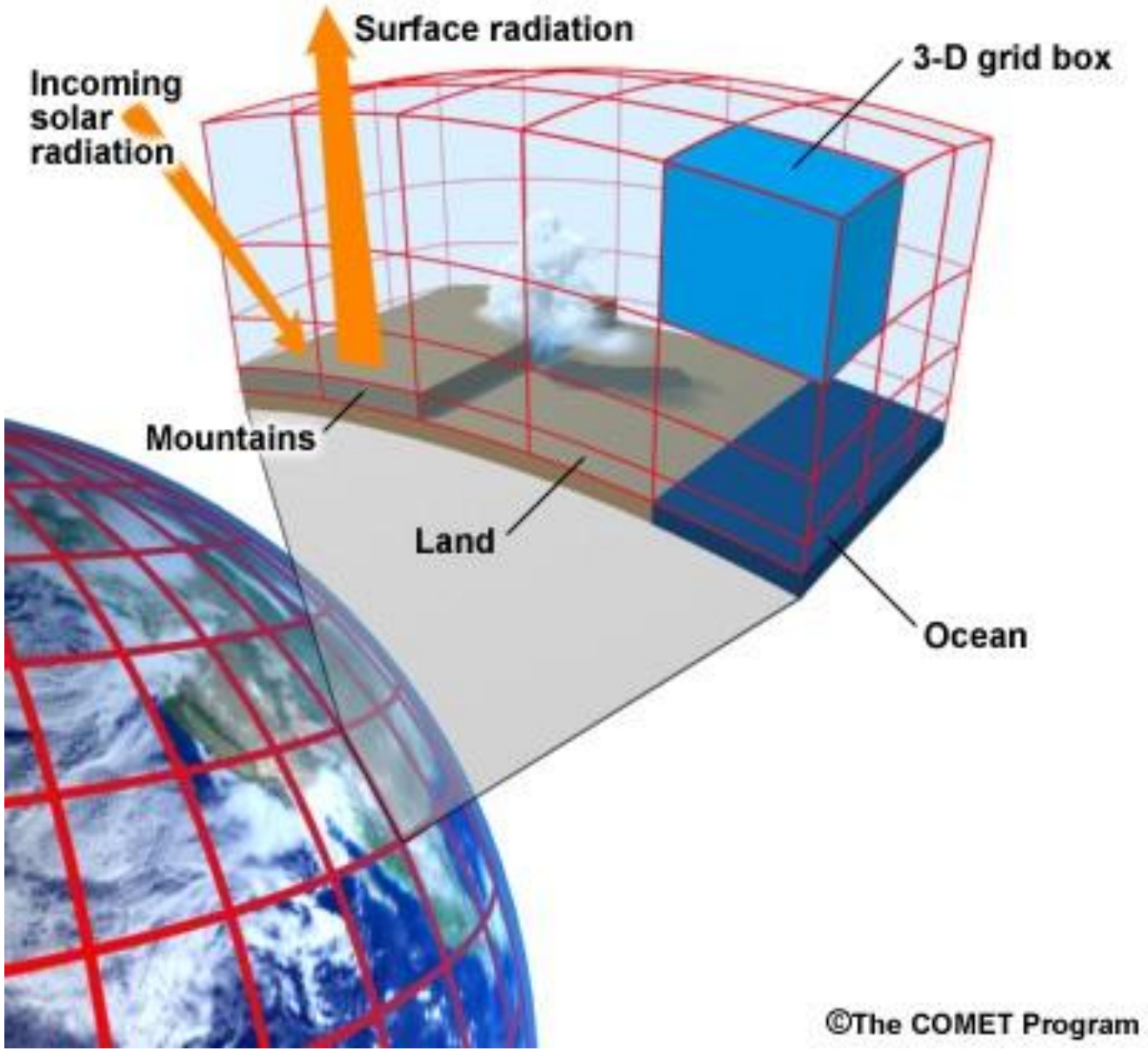
The End

Thanks to

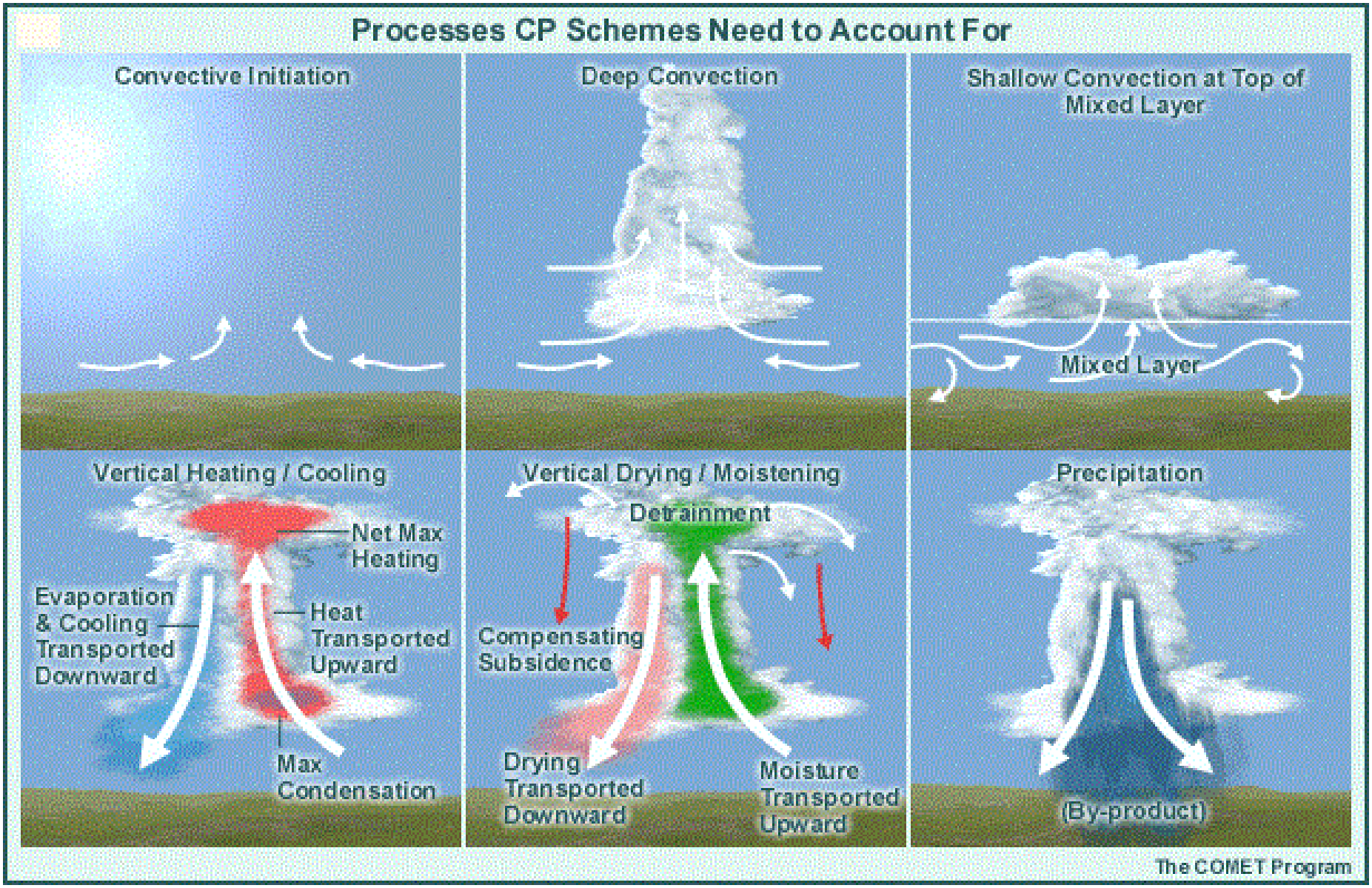
Utane Sawangwit
Saijai Cumwan
Wannisa Kanta
Suparerk Aukkaravittayapun
Saran Poshyachinda
Boonrucksar Soonthornthum
Nirun Hirunsook
Kanlaya Thapiang

APPENDIX

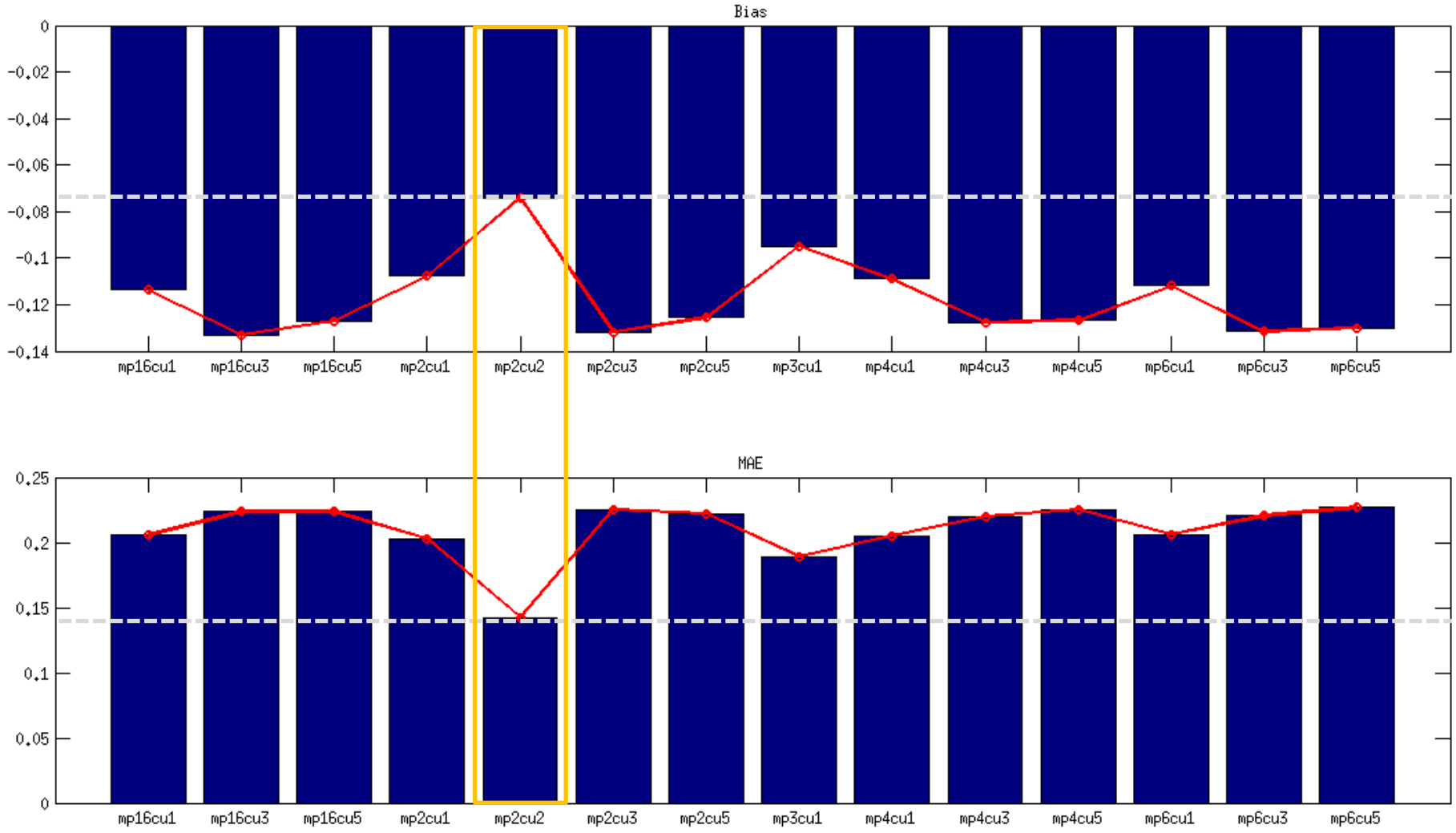
Model Grid and Resolution



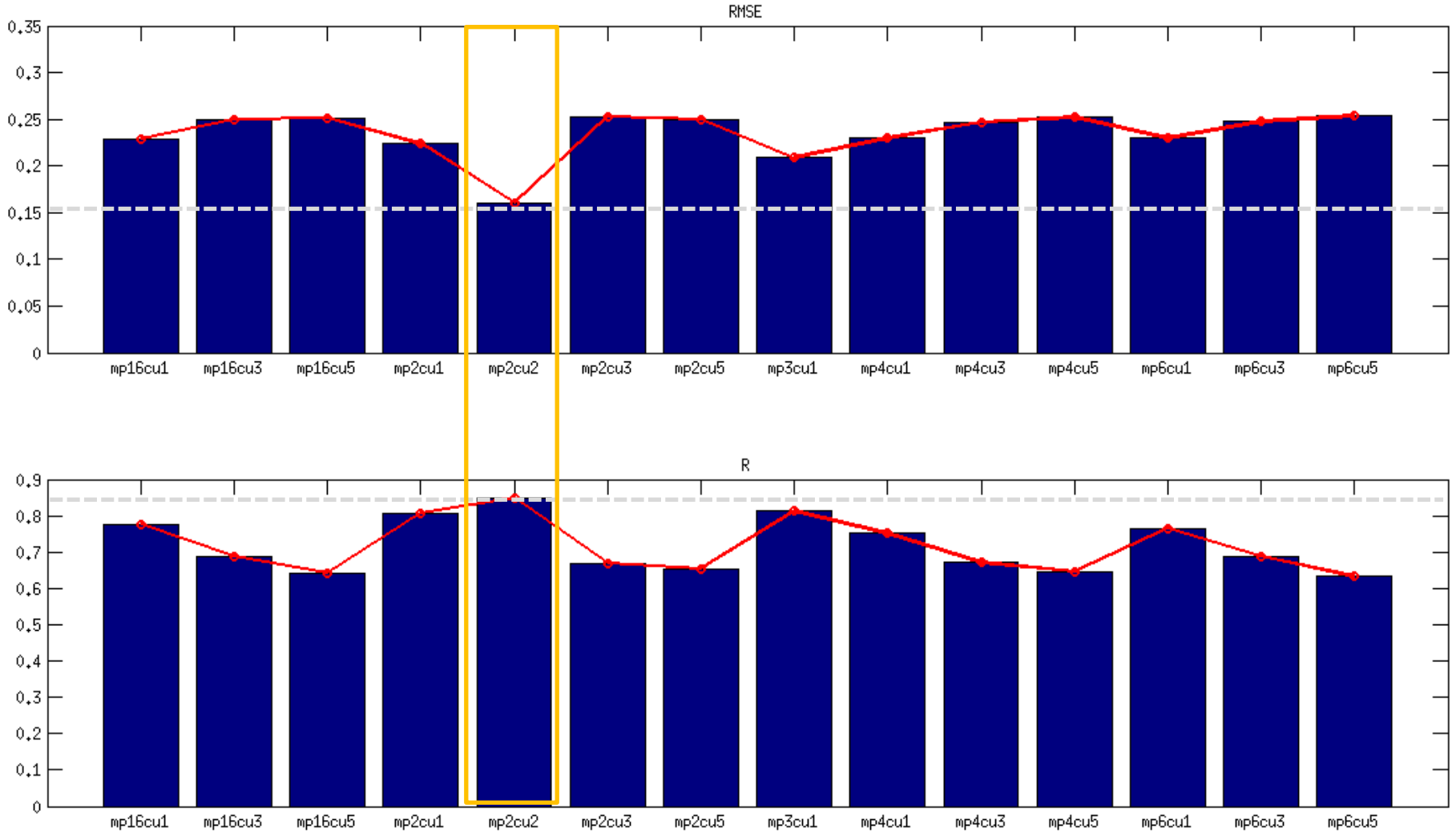
Convective Processes



Parameterization Performance Metrics (Hot Dry Season)

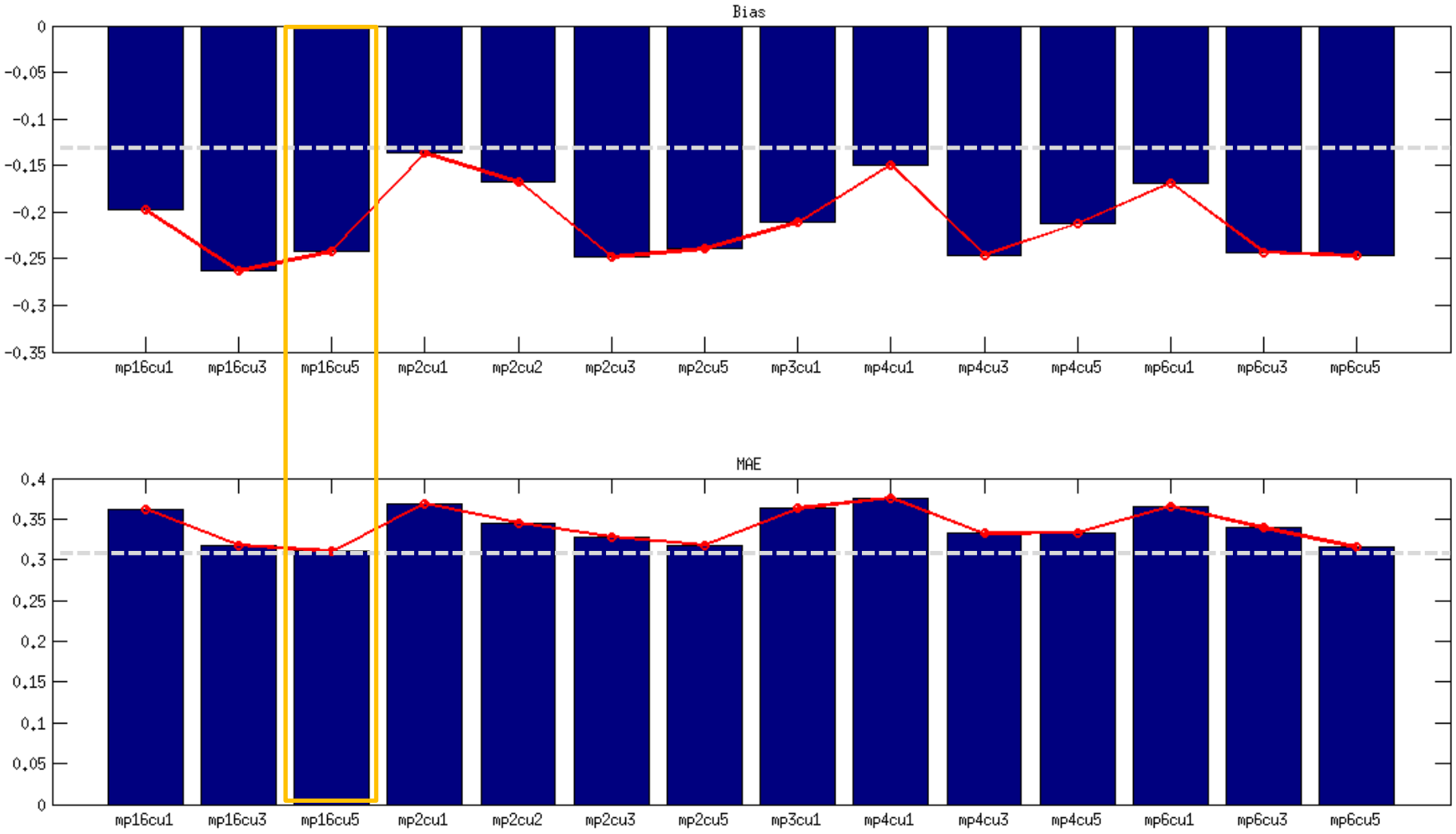


Parameterization Performance Metrics (Hot Dry Season)

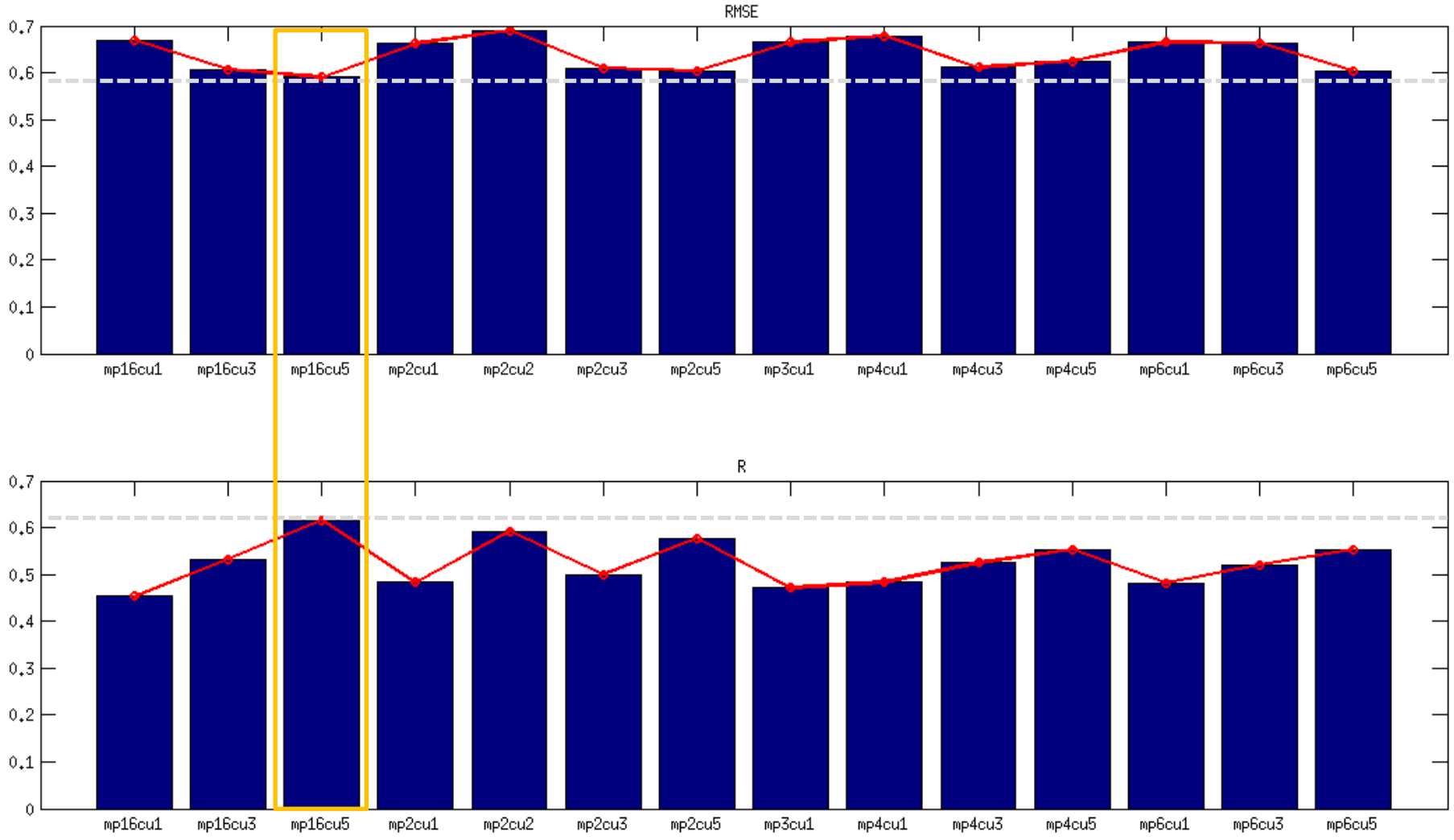


Optimum: mp2cu2 (4 out of 4)

Parameterization Performance Metrics (Wet Season)

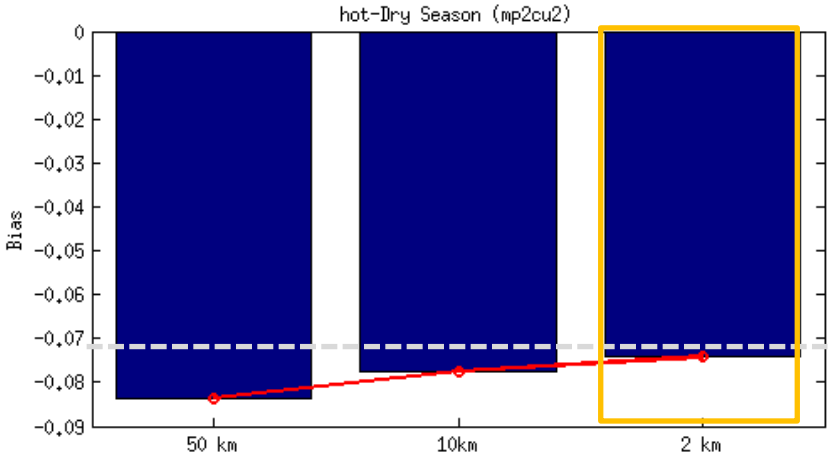


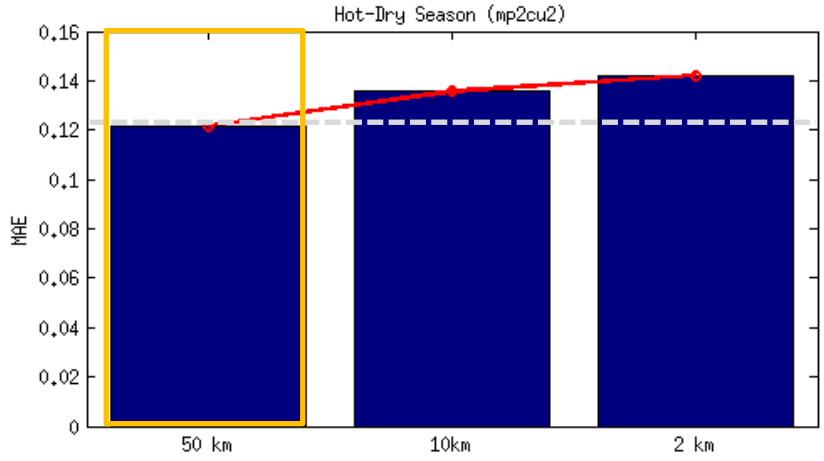
Parameterization Performance Metrics (Wet Season)

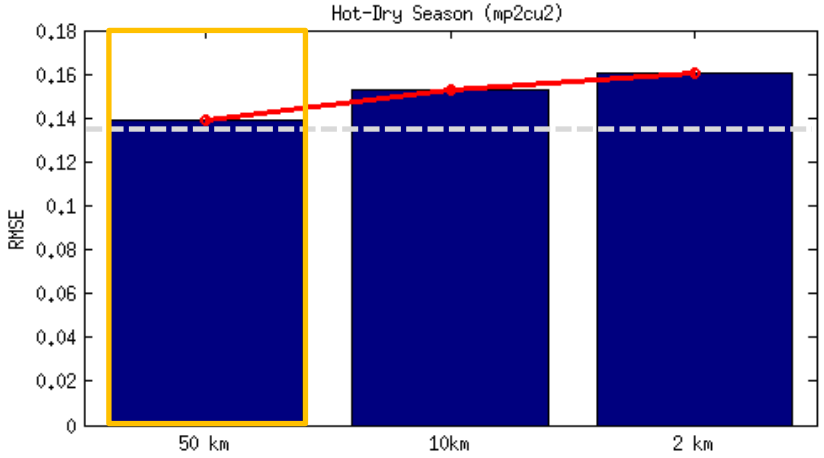


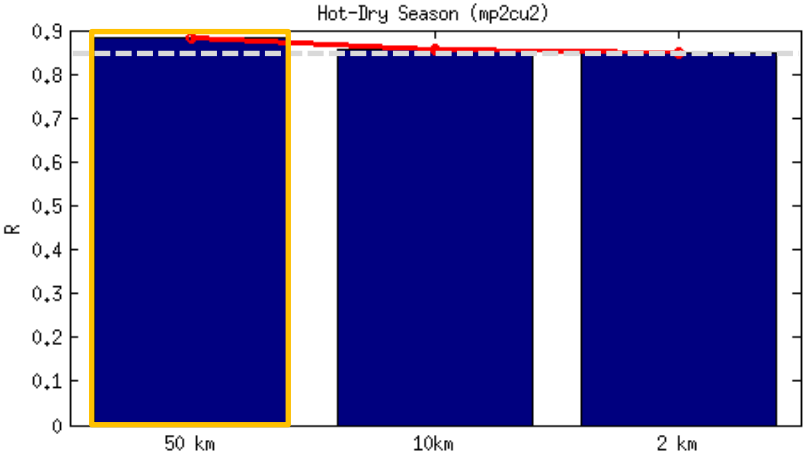
Optimum: mp16cu5 (3 out of 4)

Resolution Performance Metrics (Hot Dry Season)



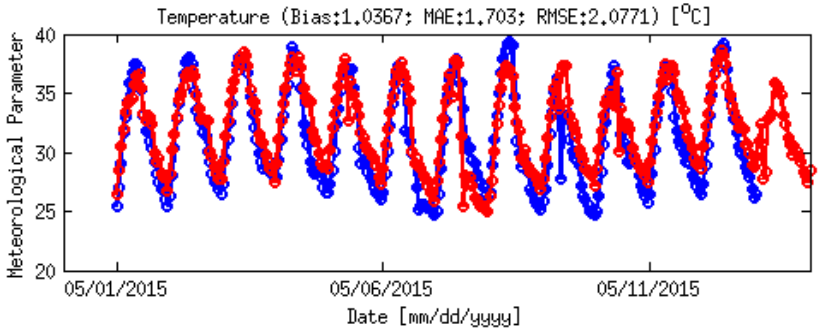


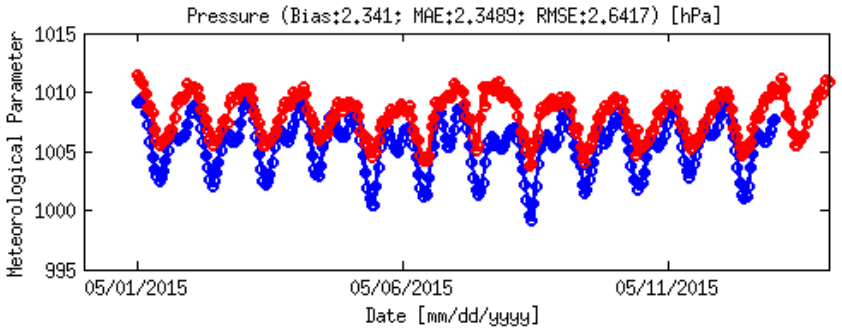


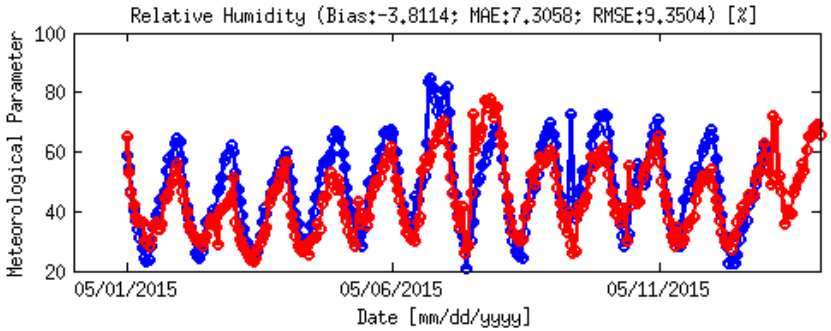


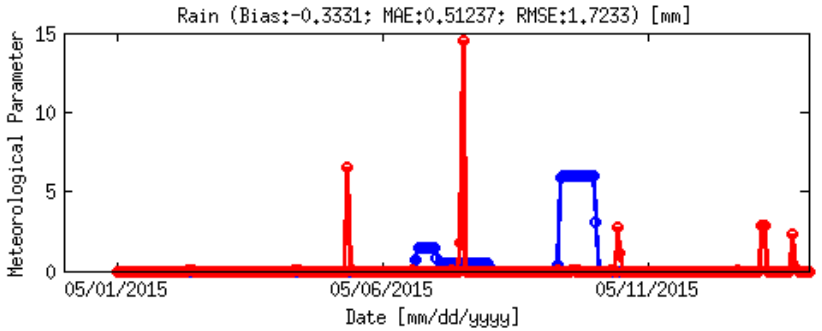
Optimum: 50 km (3 out of 4)

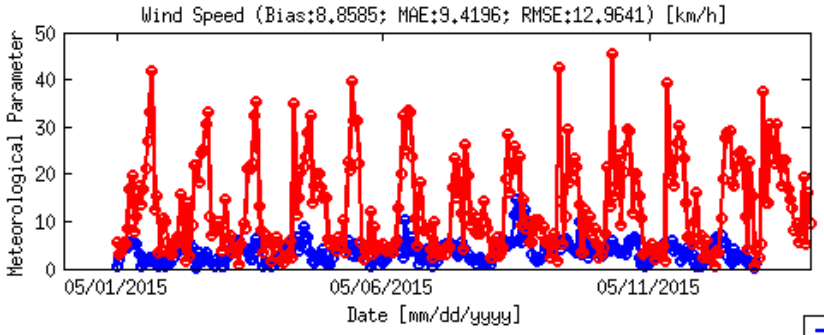
Chiang Mai Airport TMD Station
Hot Dry Season (mp2cu2 – 2 km)

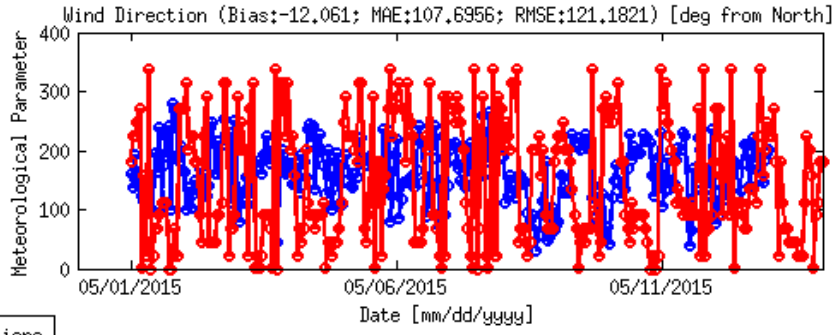


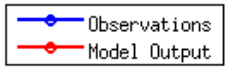




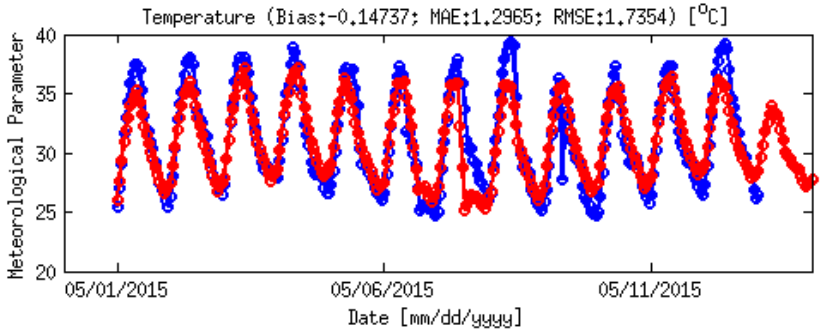


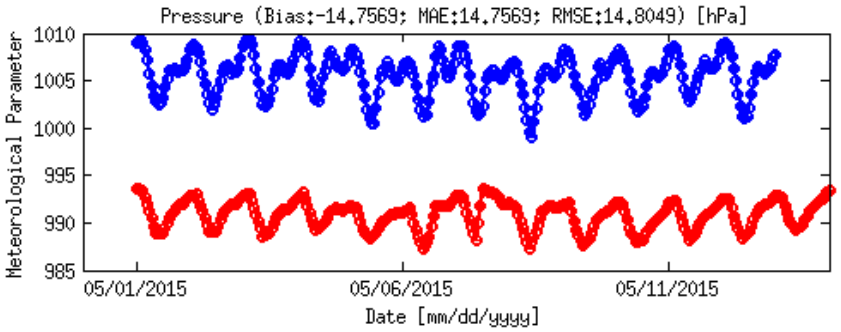


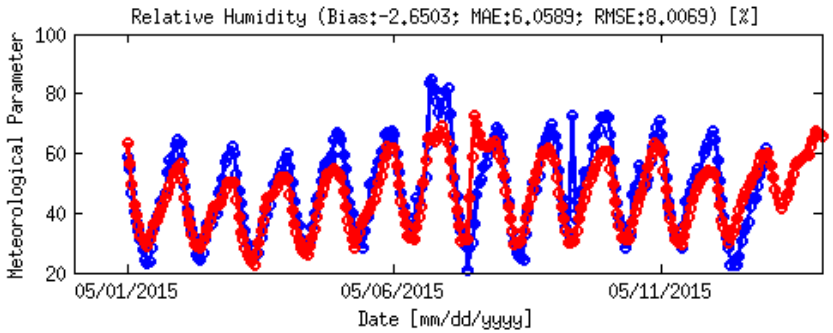


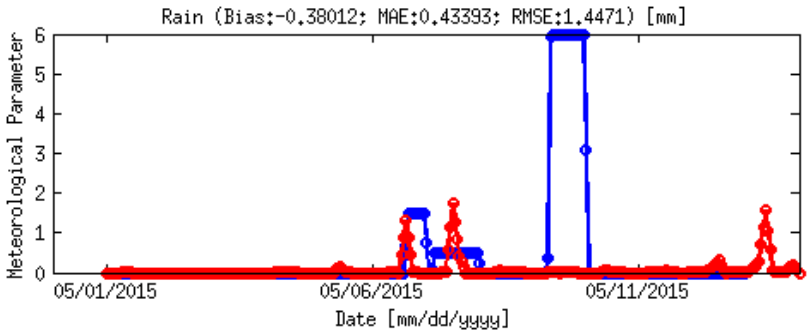


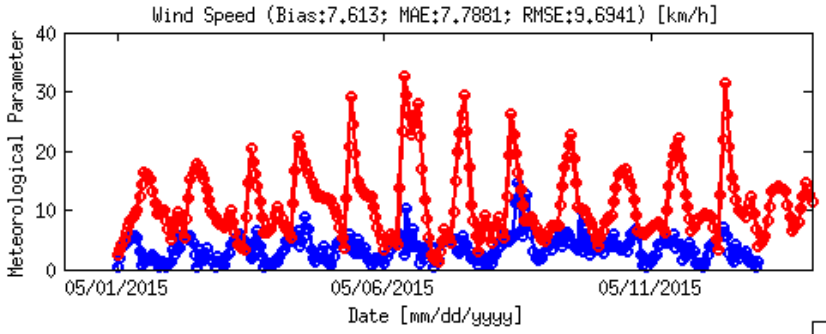
Chiang Mai Airport TMD Station
Hot Dry Season (mp2cu2 – 50 km)

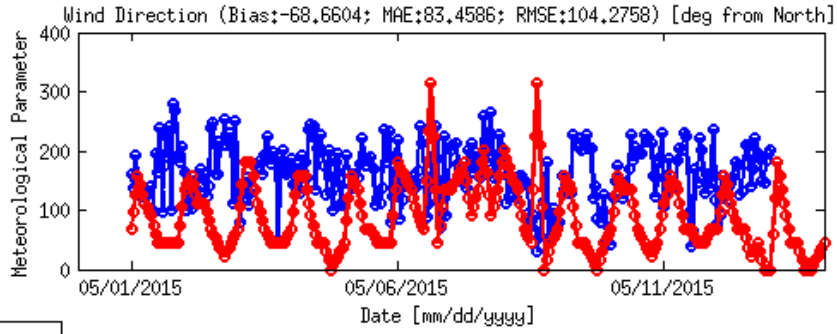


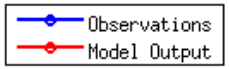




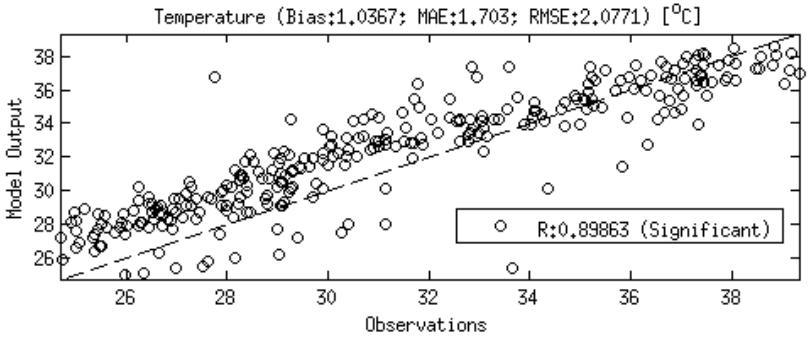


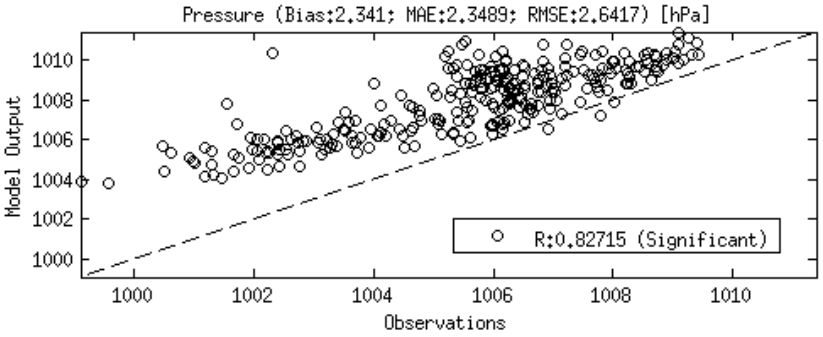


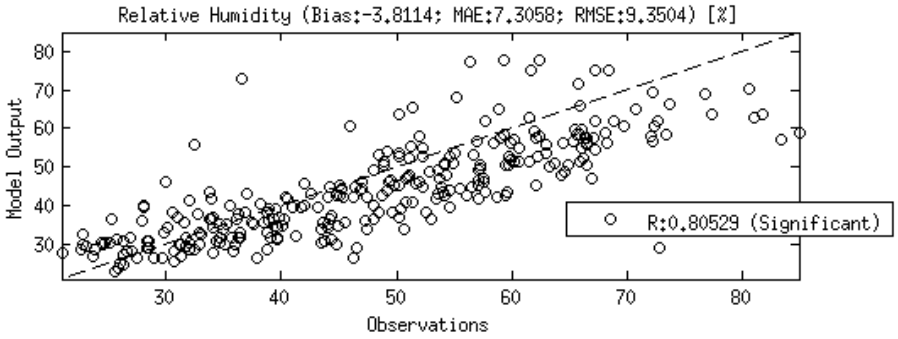


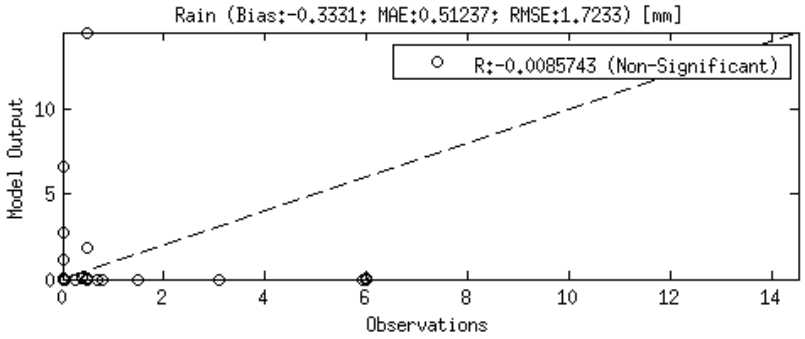


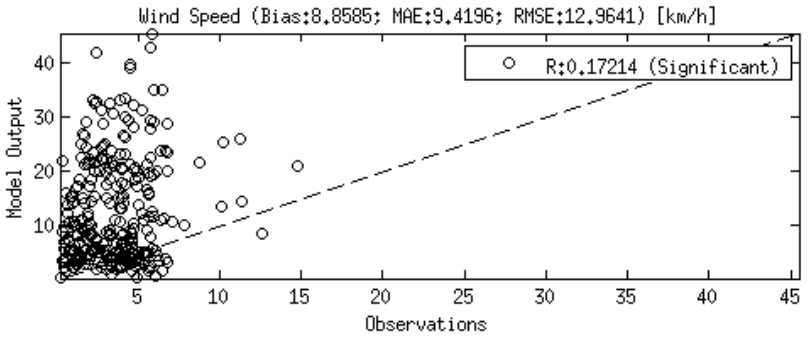
Chiang Mai Airport TMD Station
Hot Dry Season (mp2cu2 – 2 km)

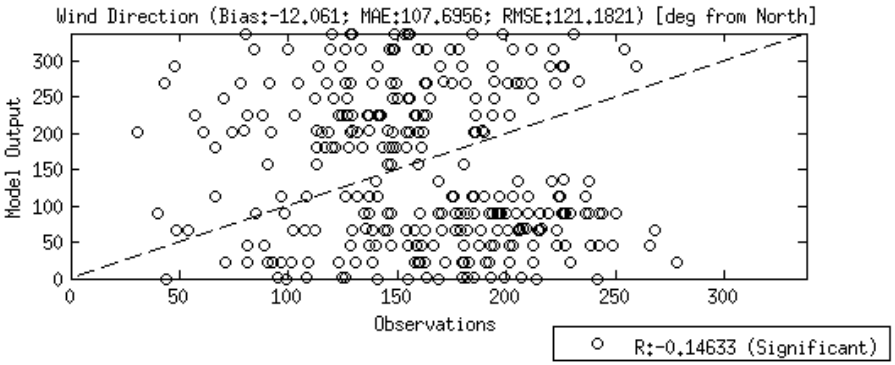




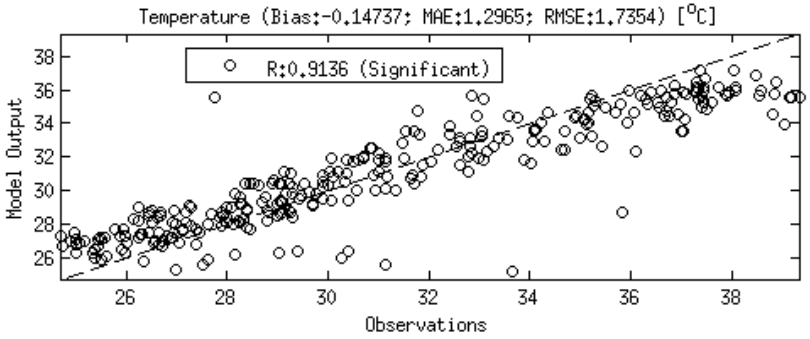


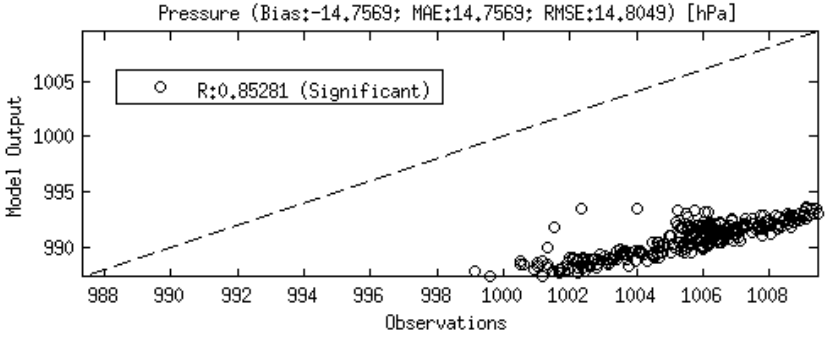


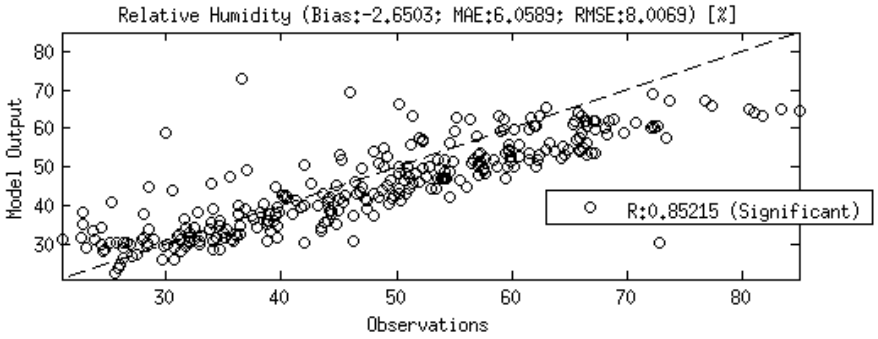


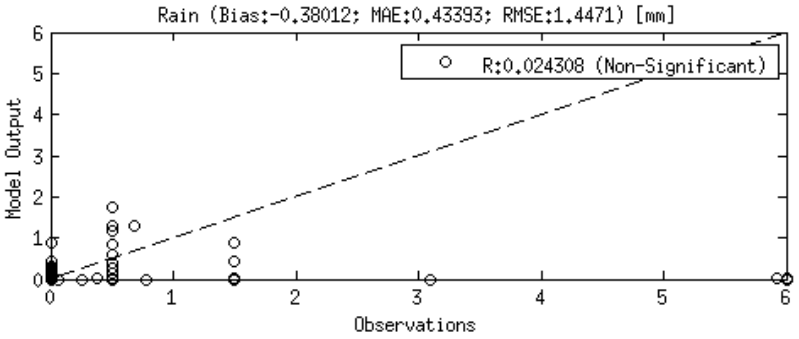


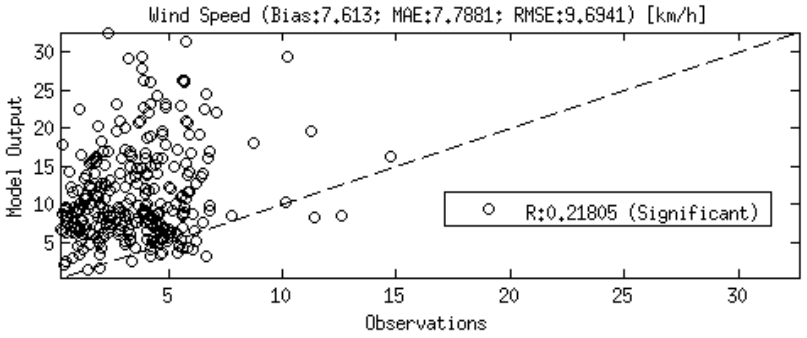
Chiang Mai Airport TMD Station
Hot Dry Season (mp2cu2 – 50 km)

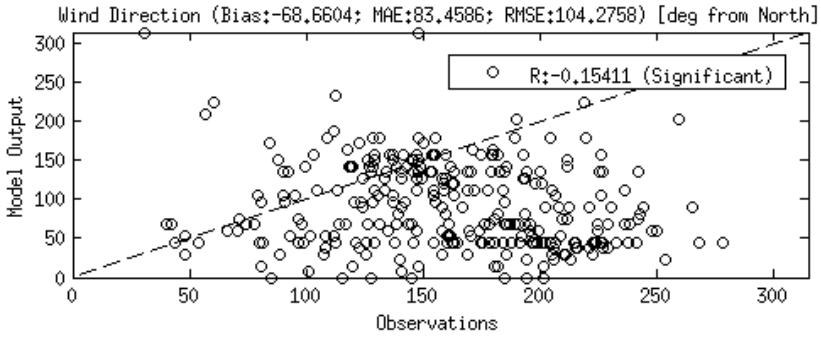




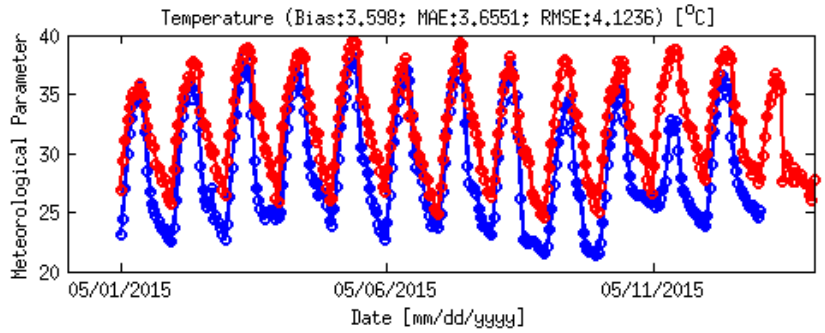


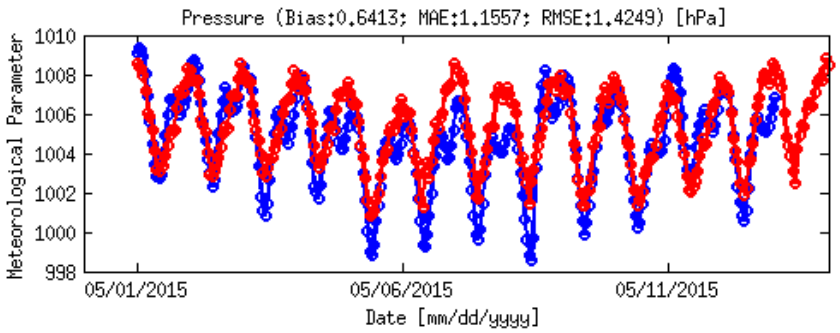


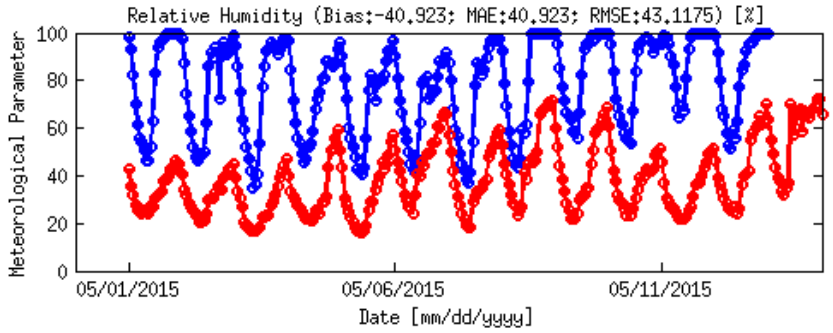


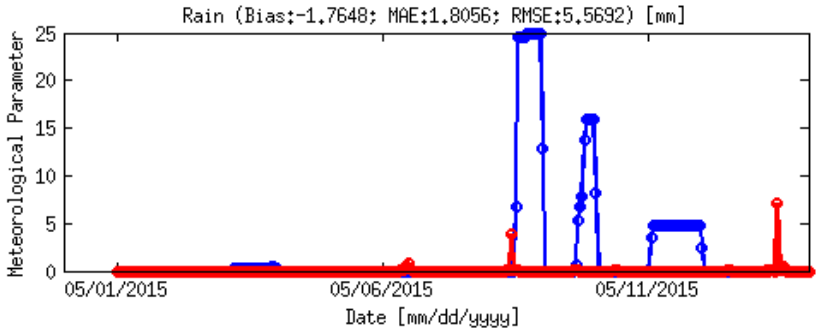


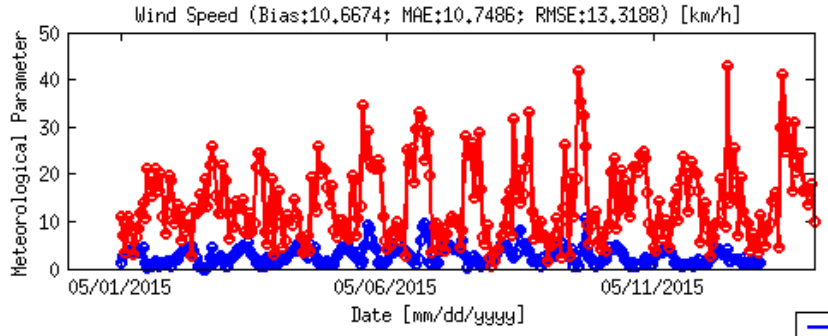
Chiang Rai Agromet TMD Station Hot Dry Season (mp2cu2 – 2 km)

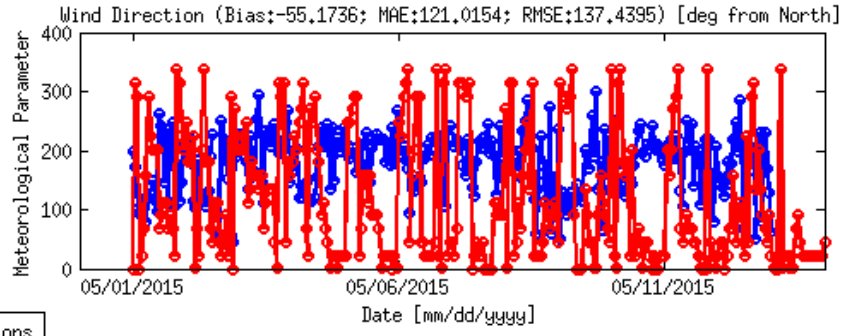


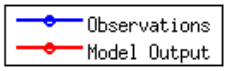




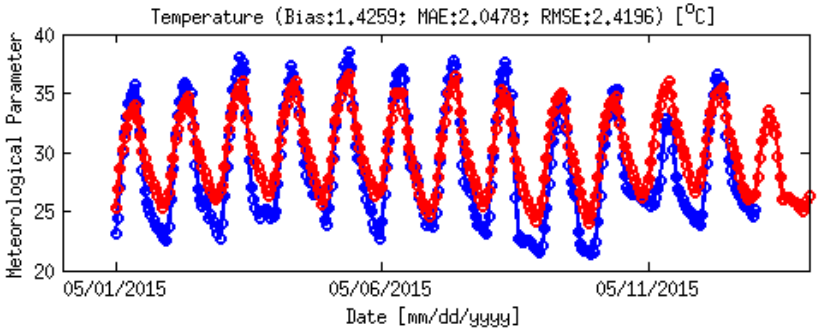


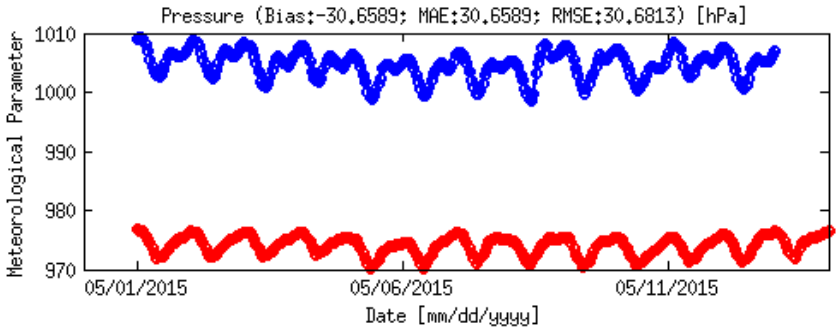


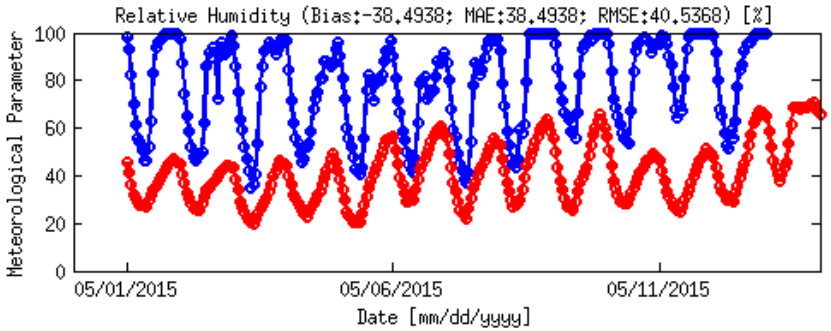


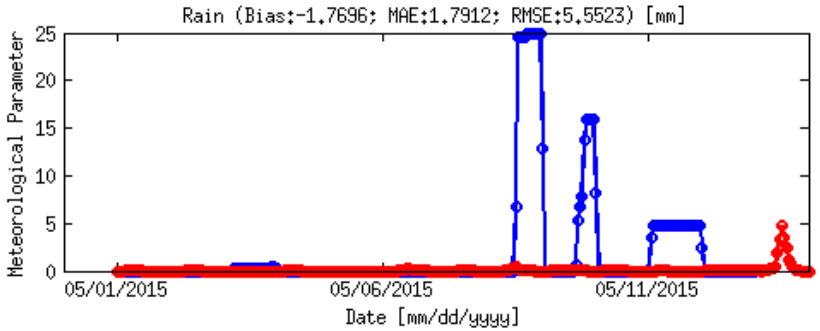


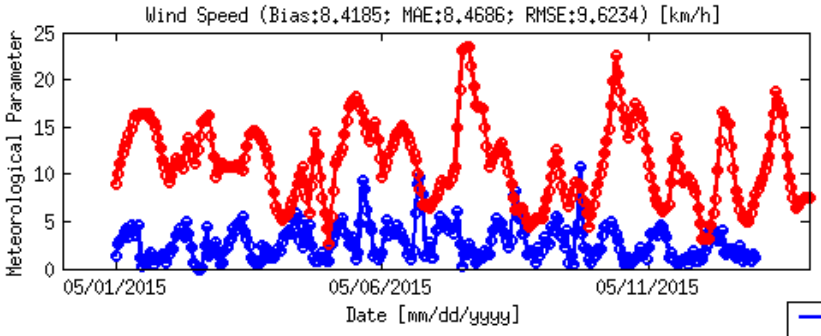
Chiang Rai Agromet TMD Station
Hot Dry Season (mp2cu2 – 50 km)

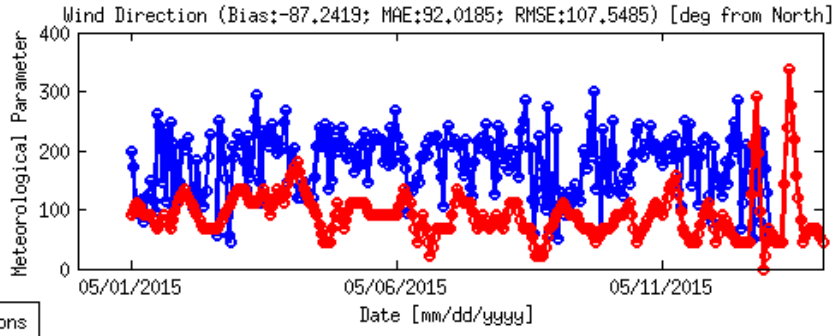


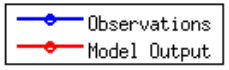




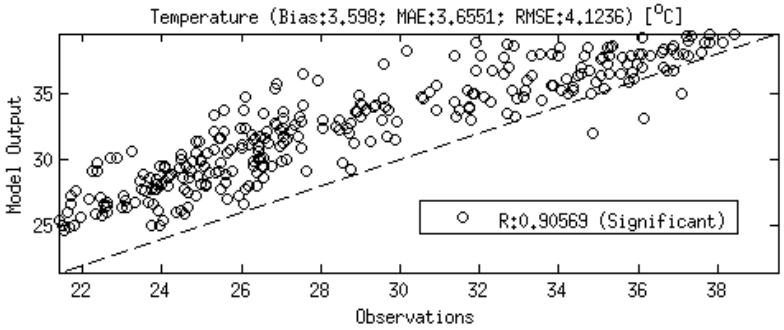


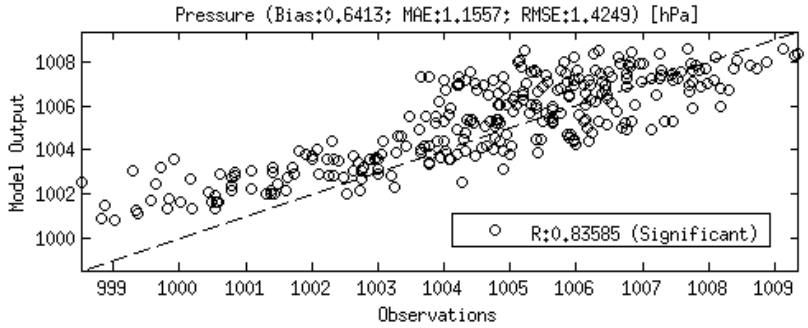


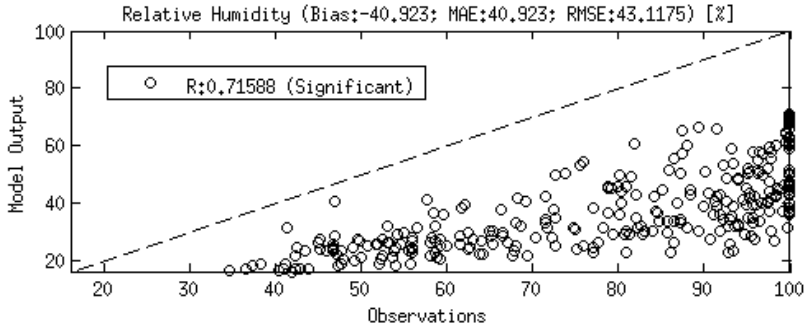


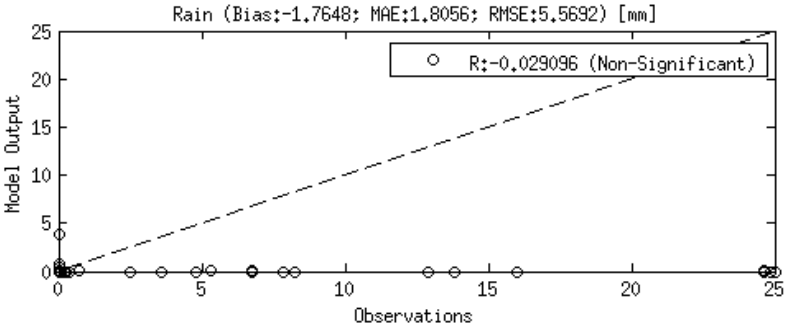


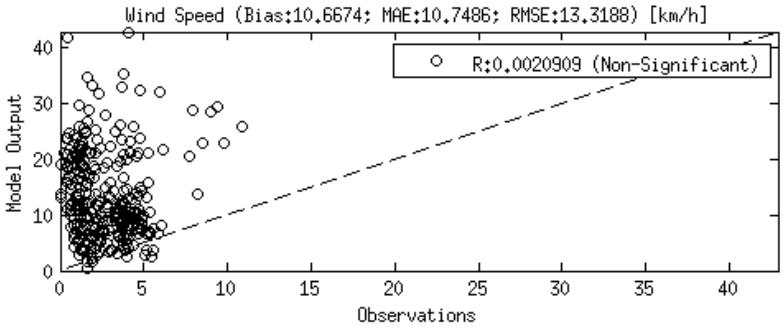
Chiang Rai Agromet TMD Station Hot Dry Season (mp2cu2 – 2 km)

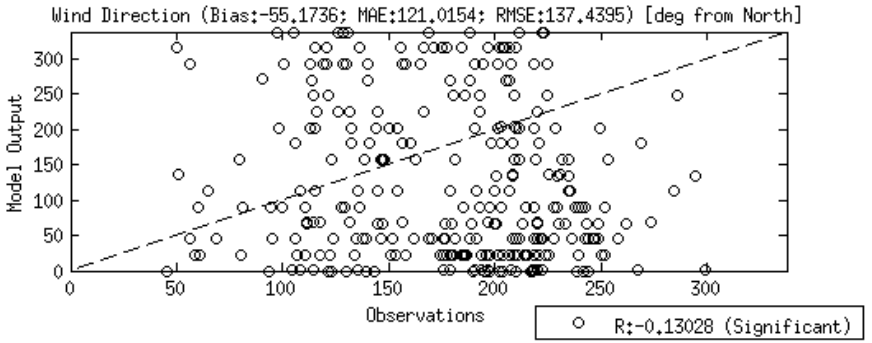




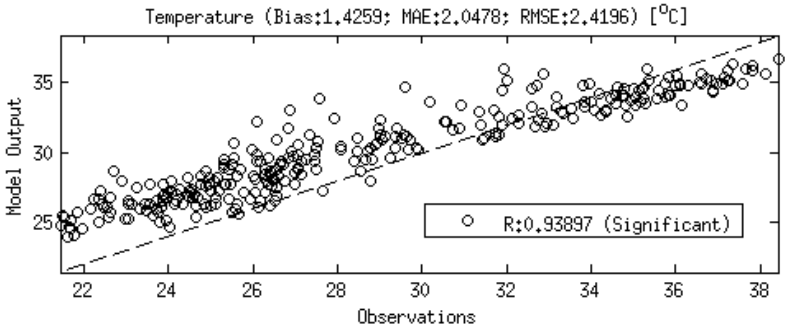


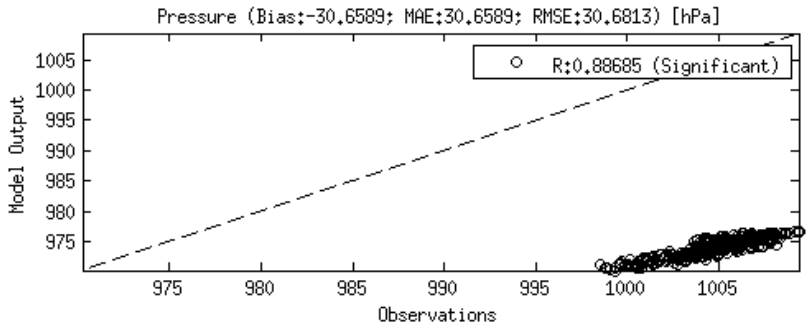


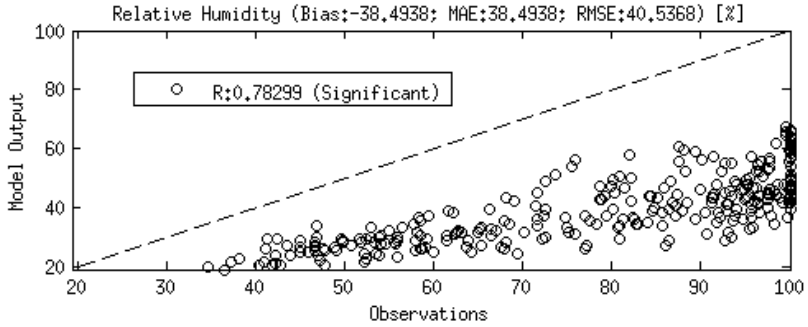


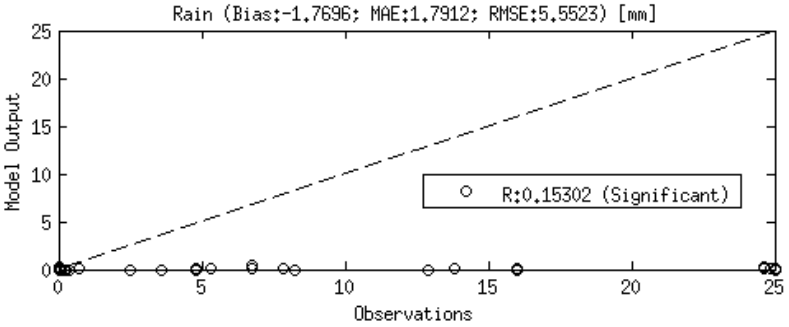


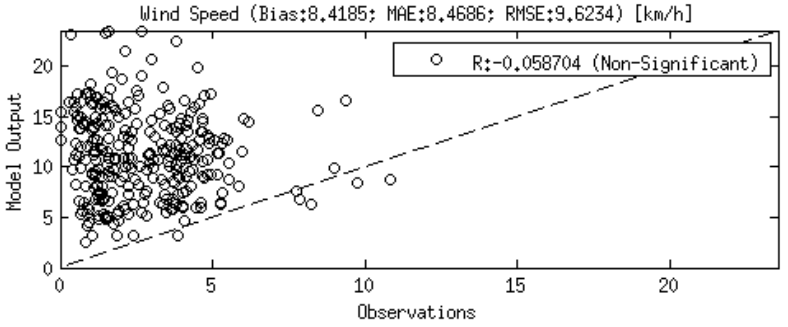
Chiang Rai Agromet TMD Station Hot Dry Season (mp2cu2 – 50 km)

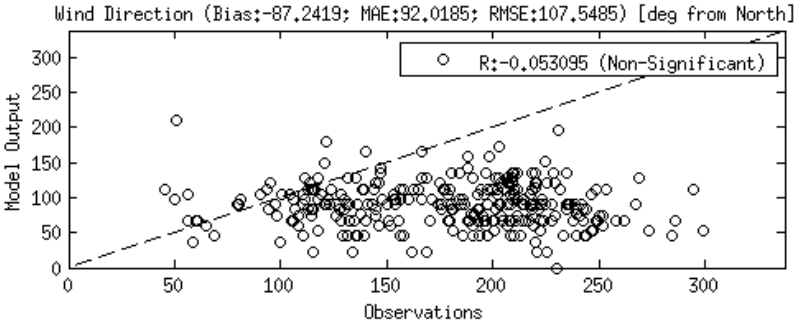




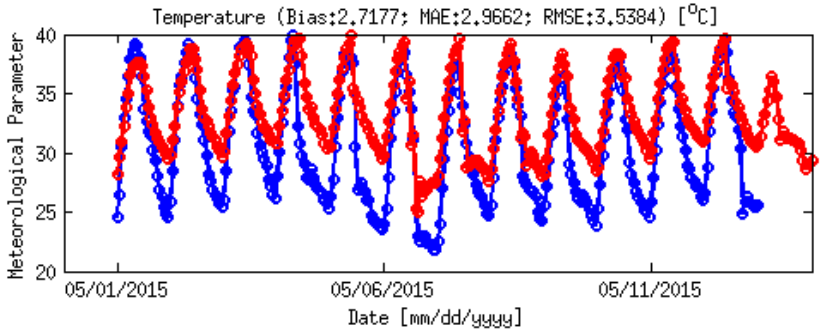


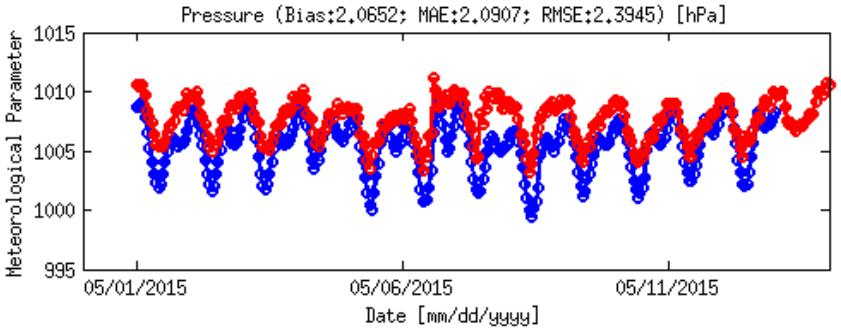


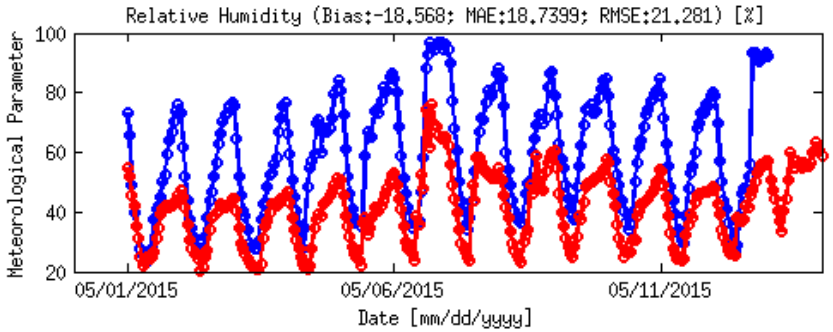


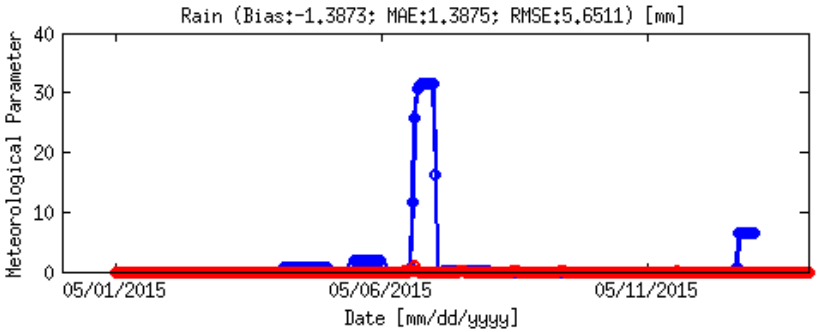


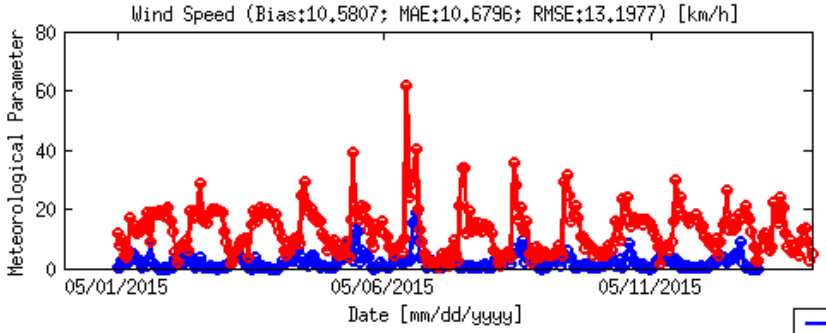
Lampang Airport TMD Station
Hot Dry Season (mp2cu2 – 2 km)

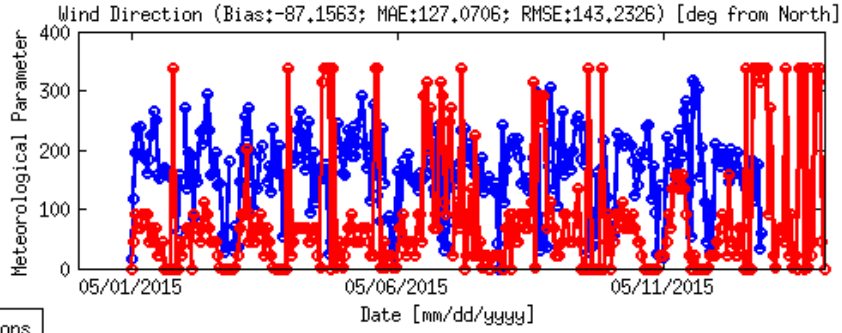


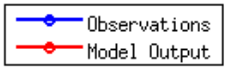




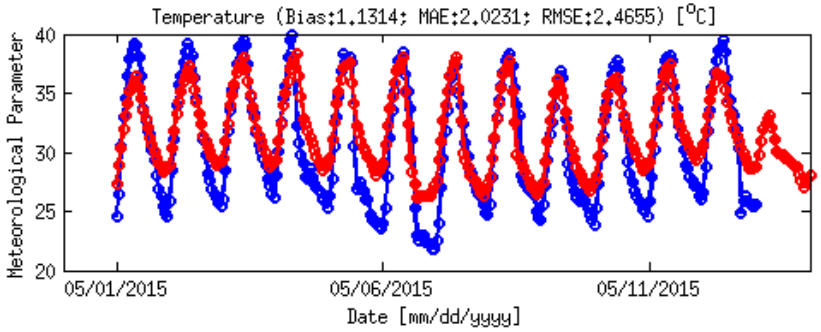


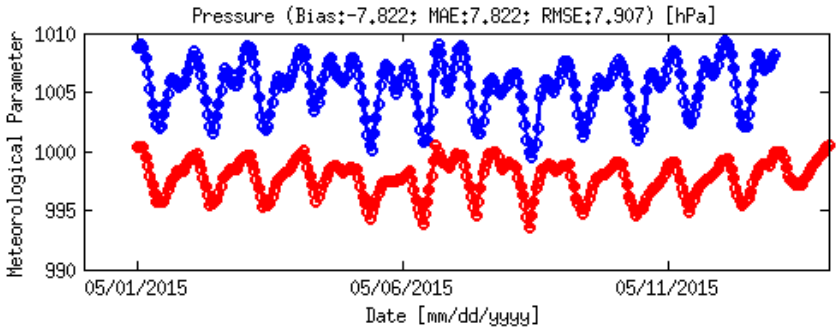


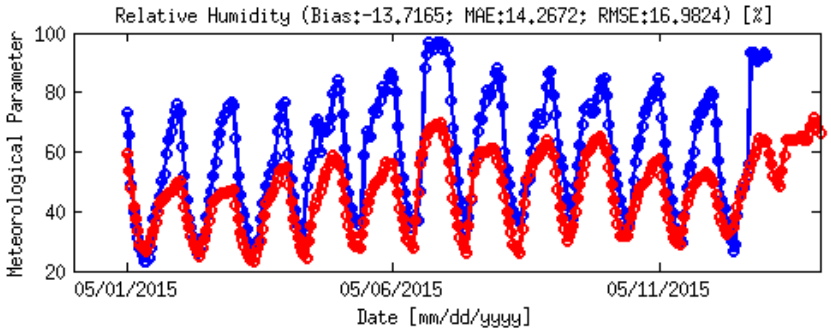


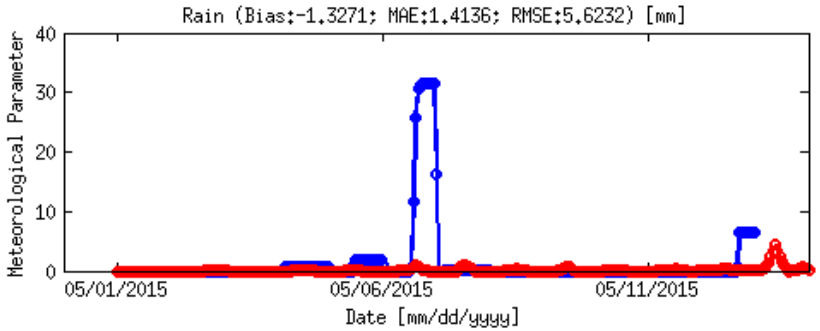


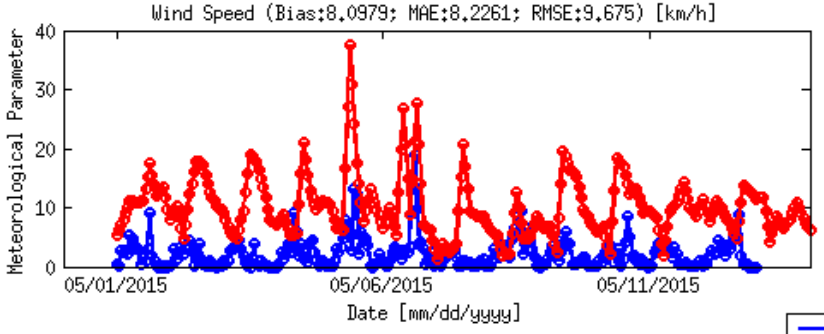
Lampang Airport TMD Station
Hot Dry Season (mp2cu2 – 50 km)

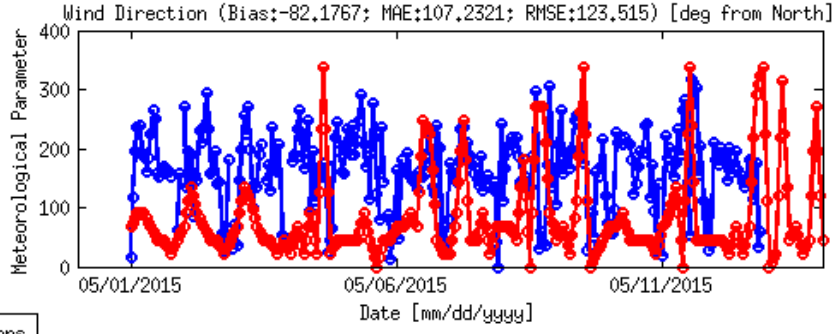


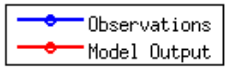




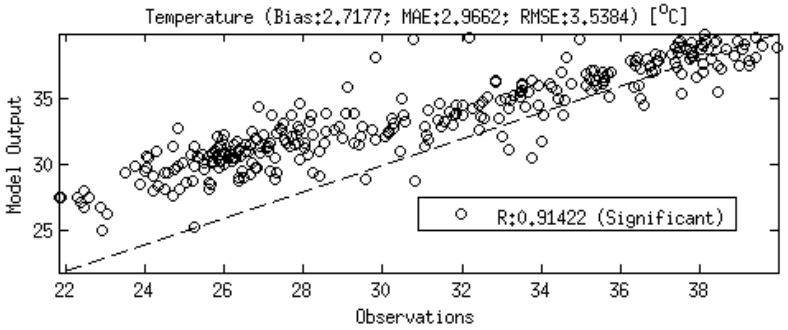


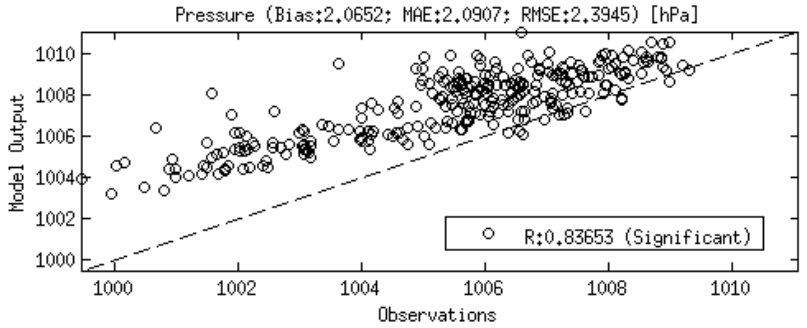


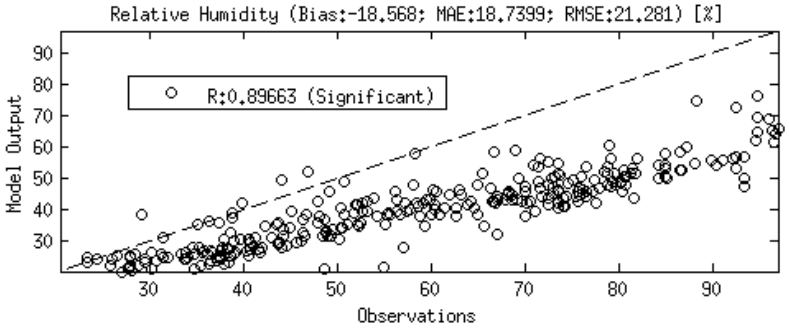


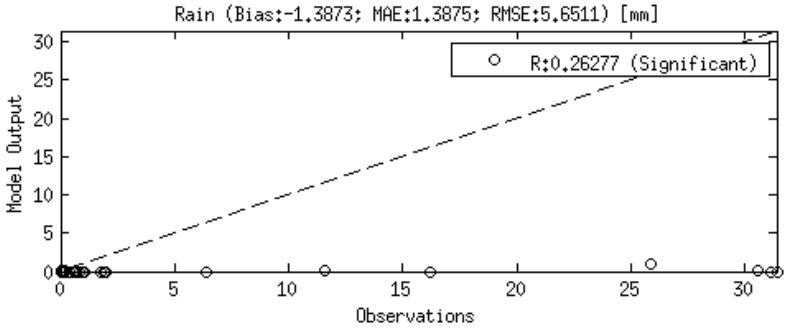


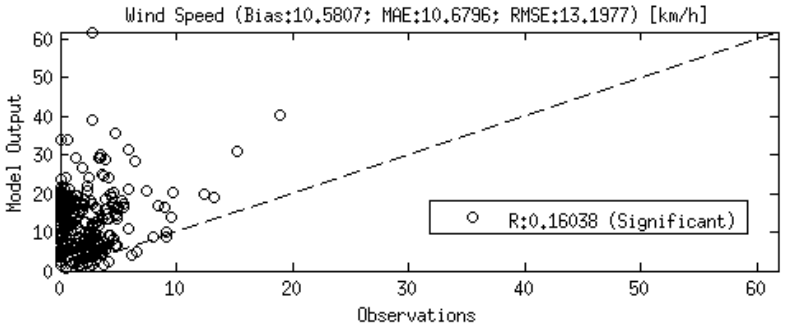
Lampang Airport TMD Station
Hot Dry Season (mp2cu2 – 2 km)

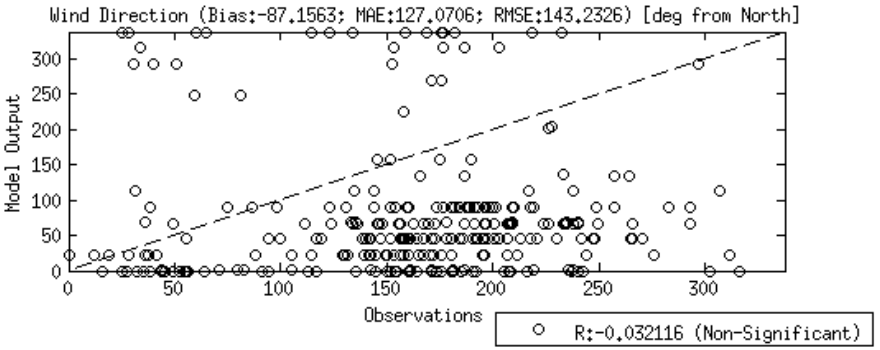




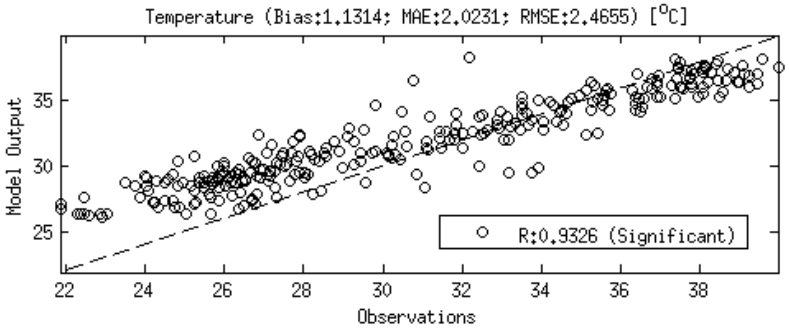


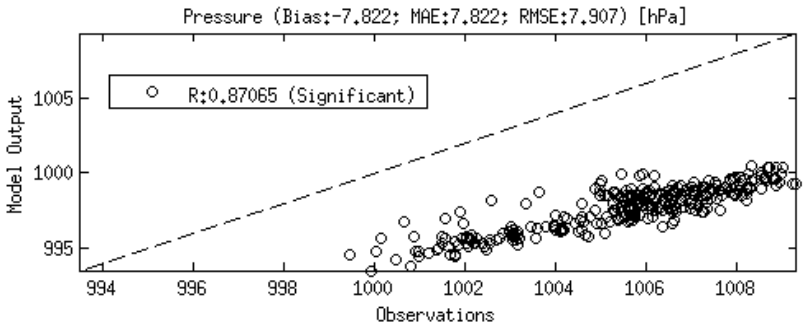


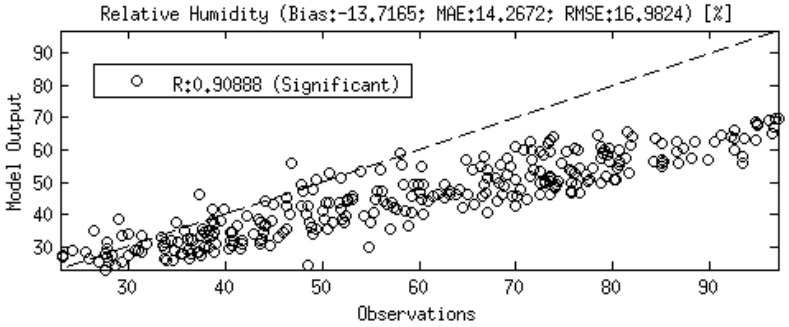


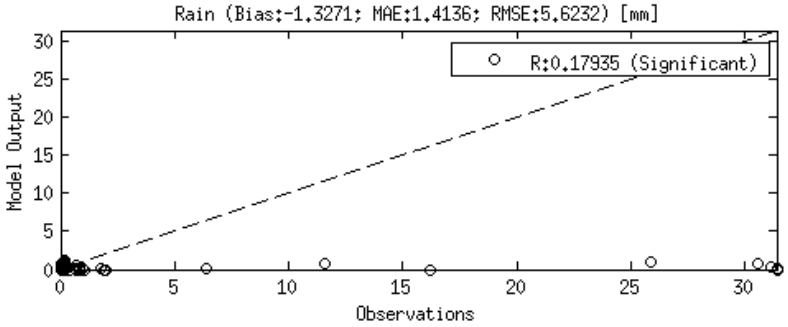


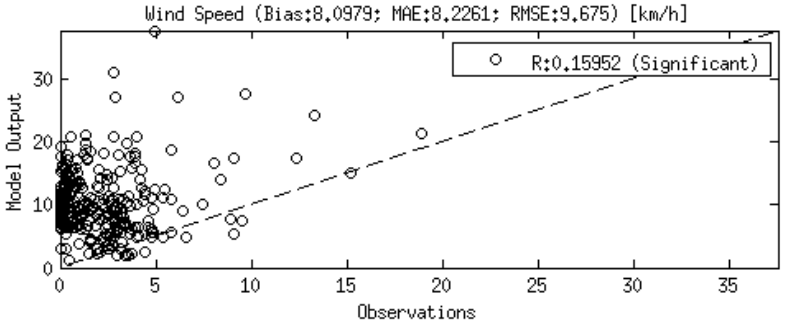
Lampang Airport TMD Station
Hot Dry Season (mp2cu2 – 50 km)

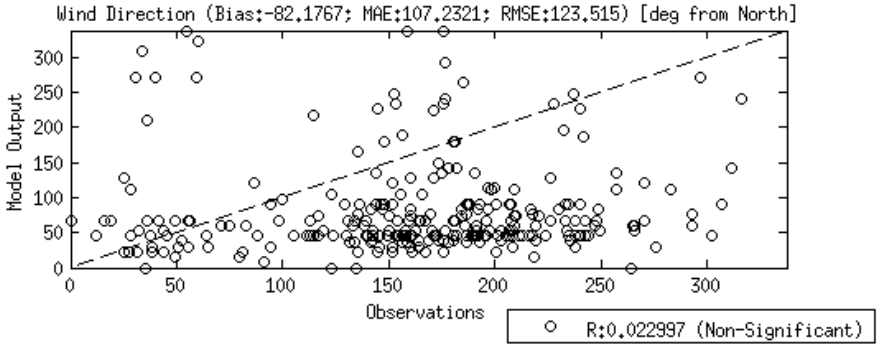




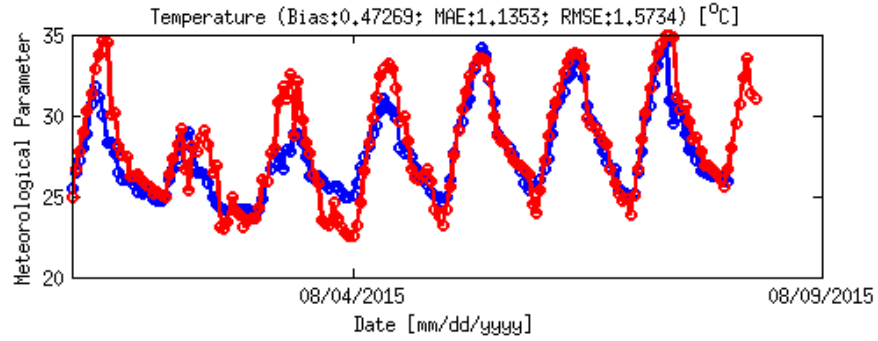


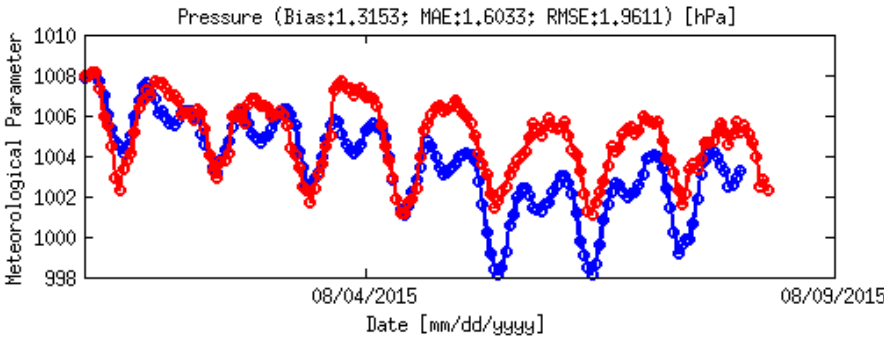


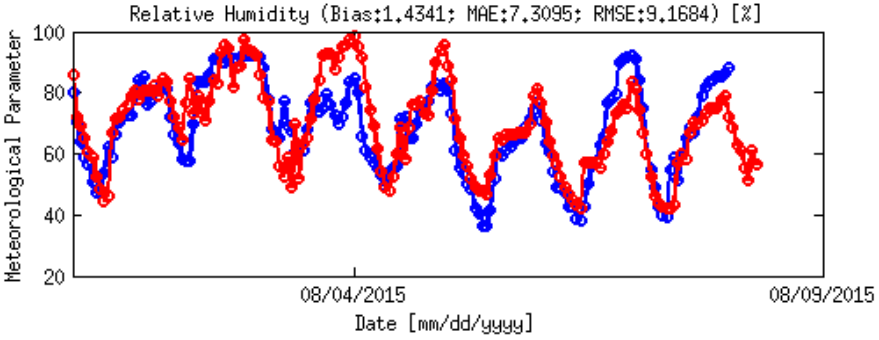


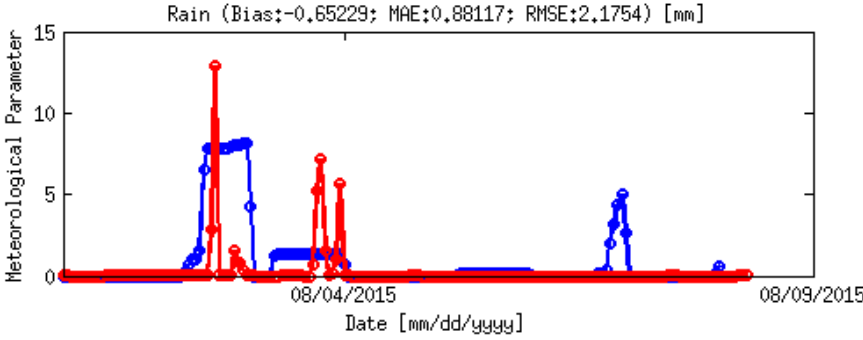


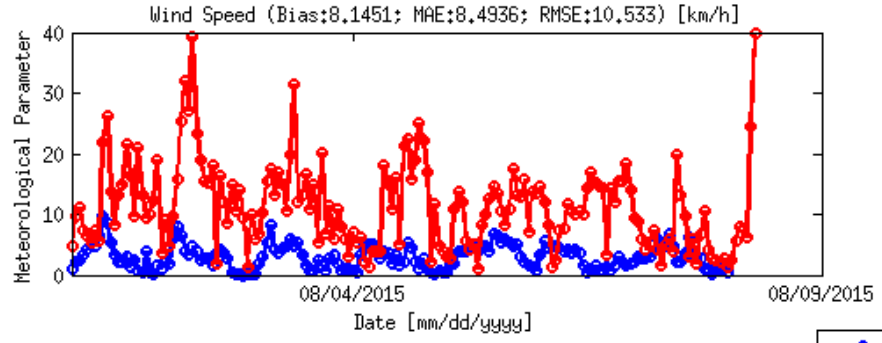
Chiang Mai Airport TMD Station
Wet Season (mp16cu5 – 2 km)

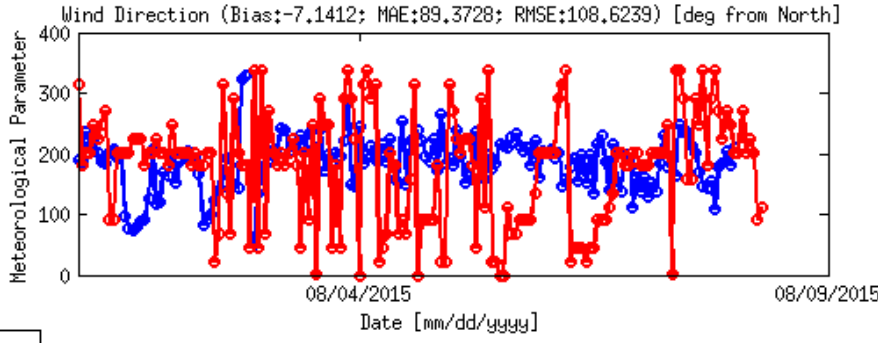


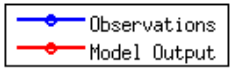




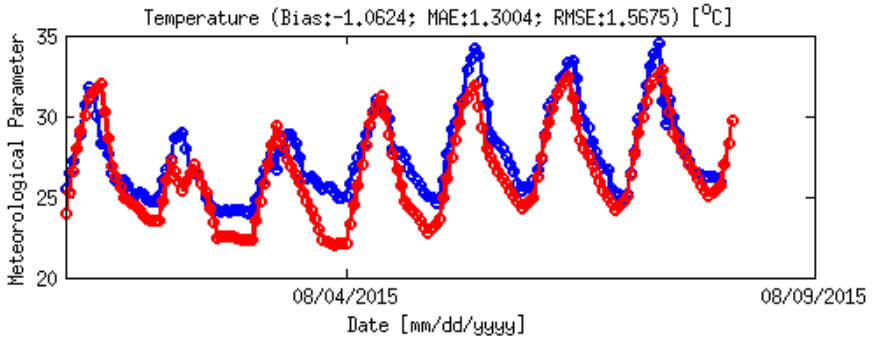


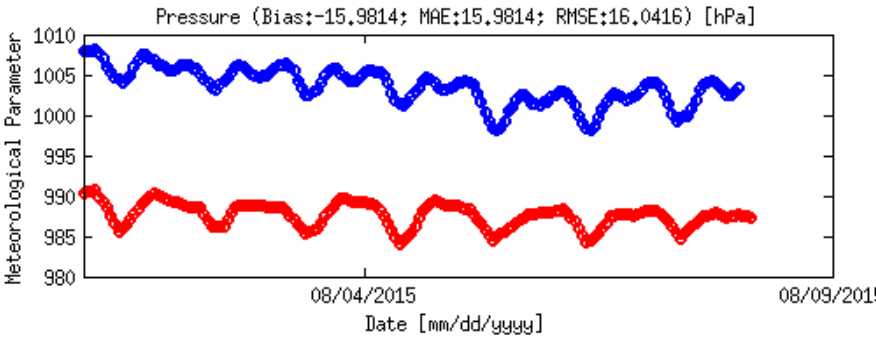


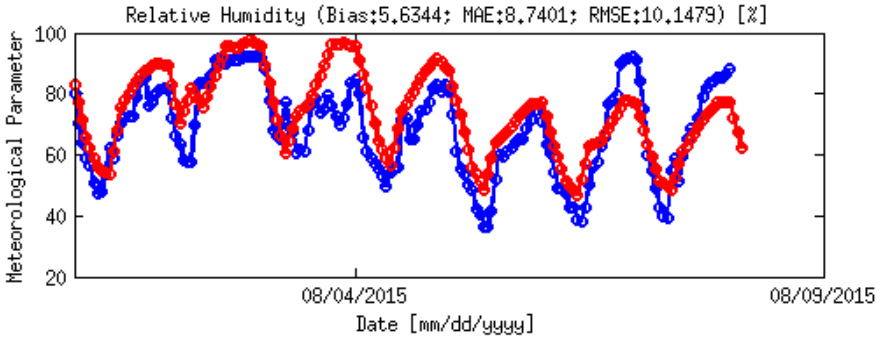


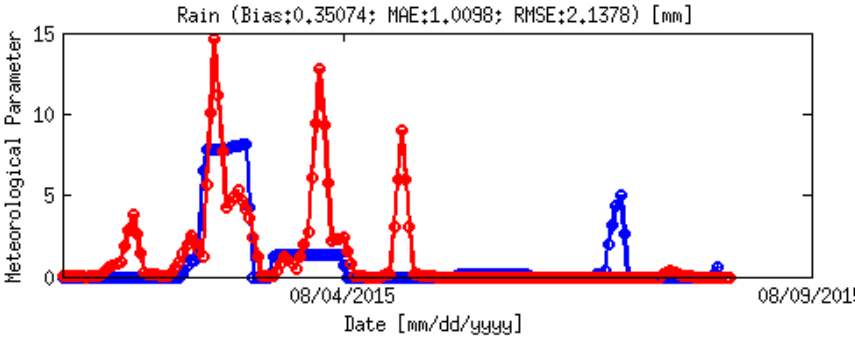


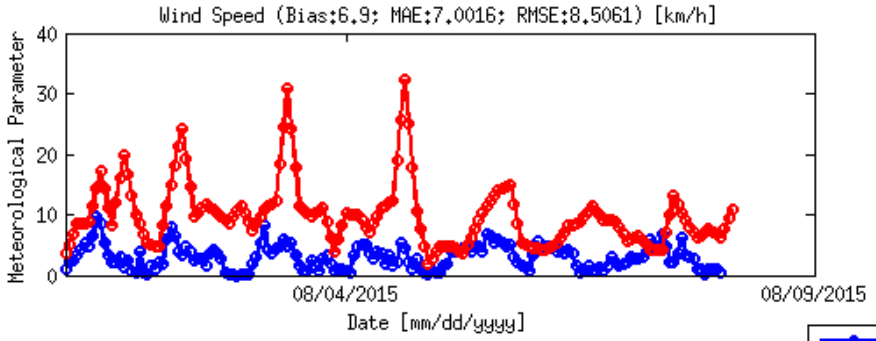
Chiang Mai Airport TMD Station
Wet Season (mp16cu5 – 50 km)

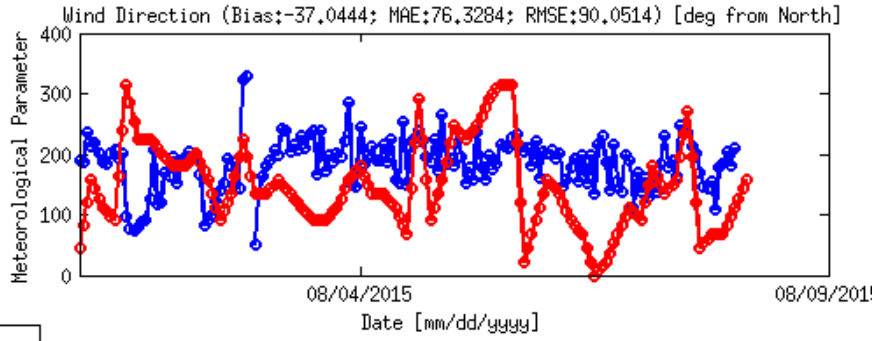


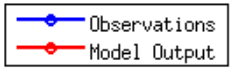




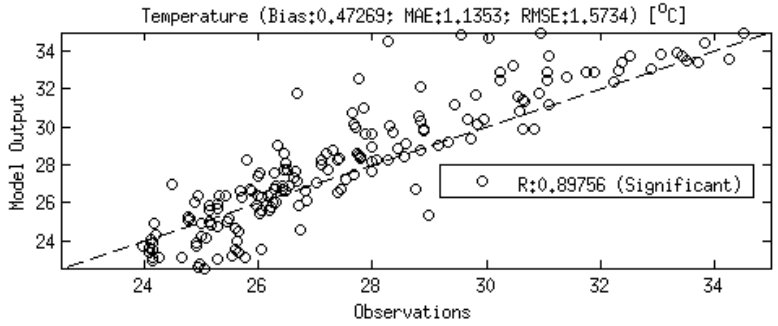


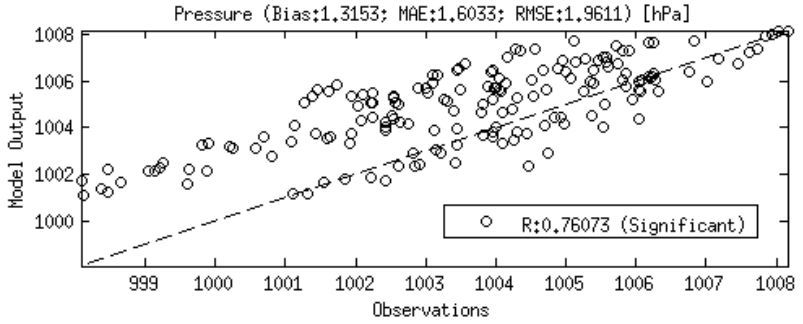


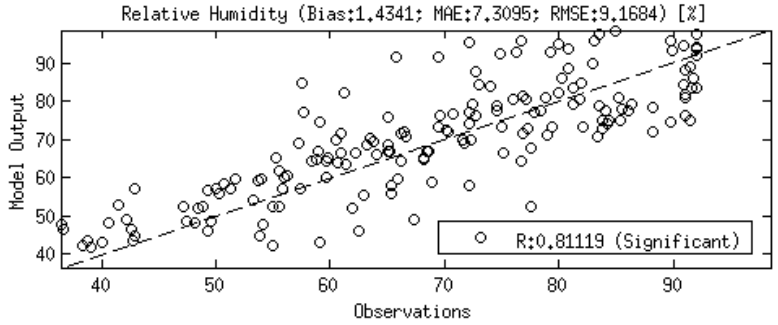


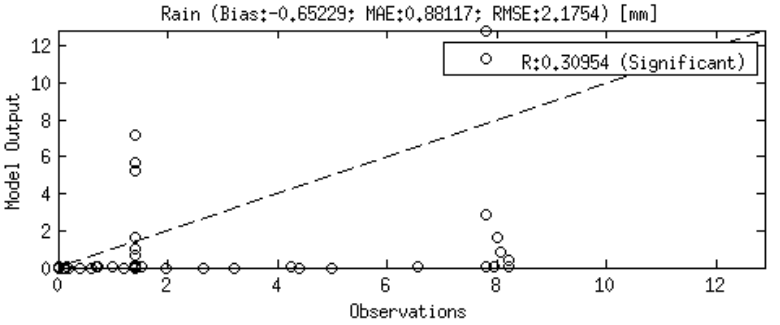


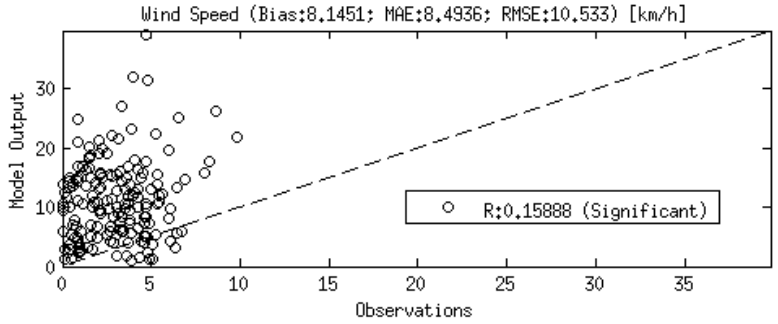
Chiang Mai Airport TMD Station Wet Season (mp16cu5 – 2 km)

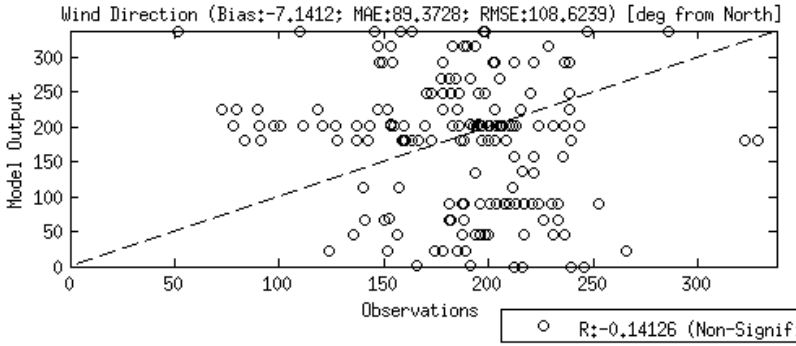












Chiang Mai Airport TMD Station Wet Season (mp16cu5 – 50 km)