Development and Implementation of a Global-to-Urban Climate Model Suite

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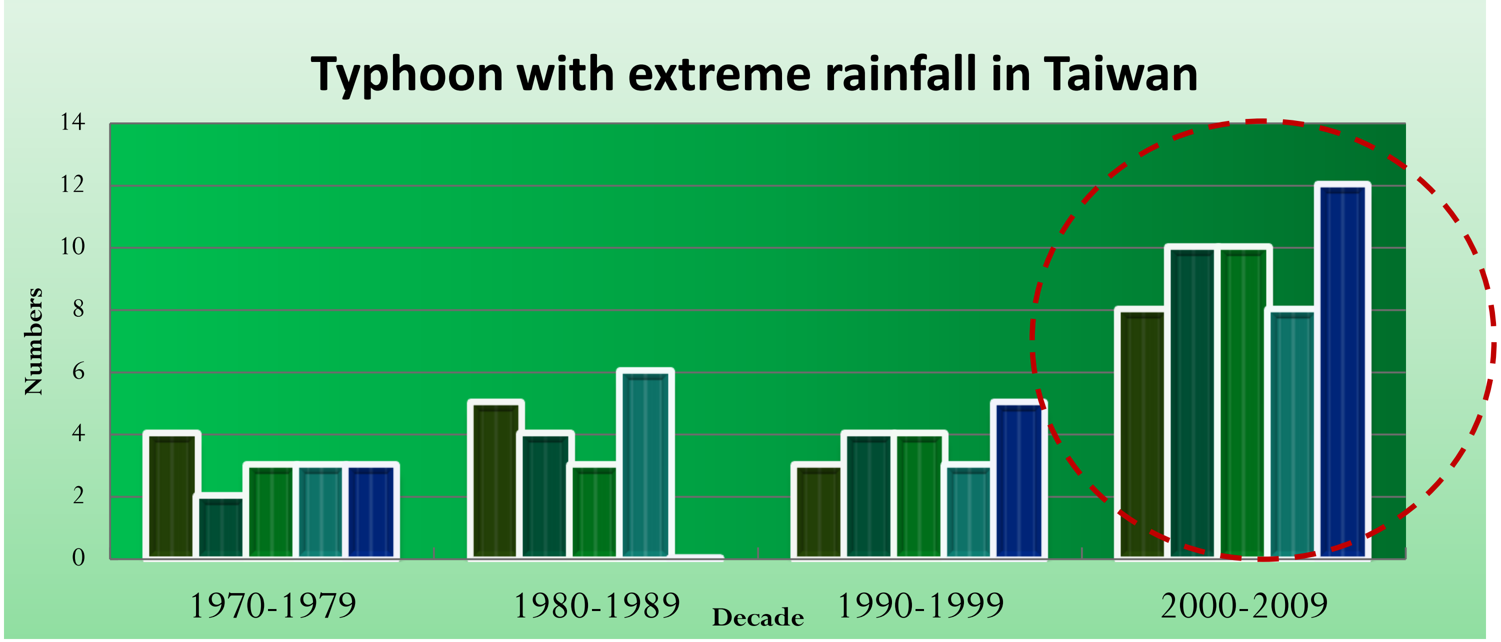
Research Center for Environmental Changes
Academia Sinica

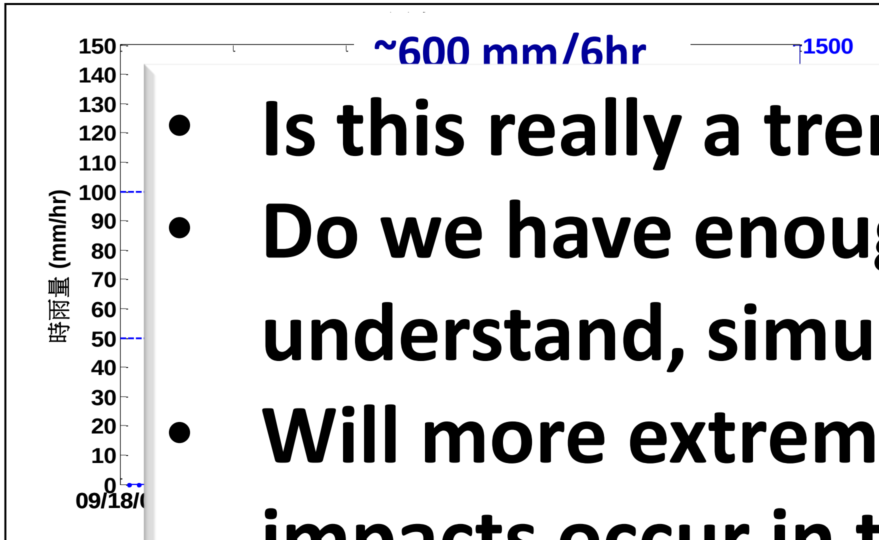
Typhoon with extreme rainfall

- **Increase in extreme events** in recent decade

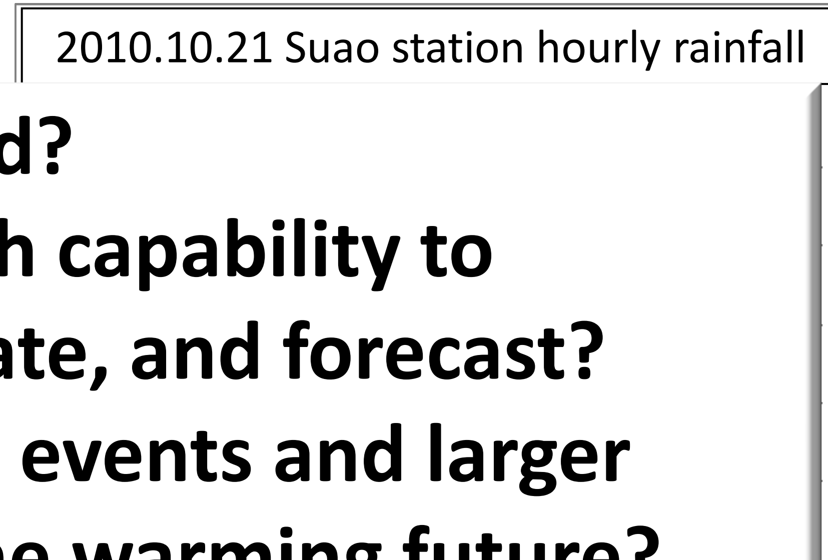


Impacts of Heavy Rainfall (Duration, Intensity)

Typhoon Fanapi (2010)



Typhoon Megi (2010)



- **Is this really a trend?**
- **Do we have enough capability to understand, simulate, and forecast?**
- **Will more extreme events and larger impacts occur in the warming future?**

Consortium for Climate Change Study (CCliCS/MOST)

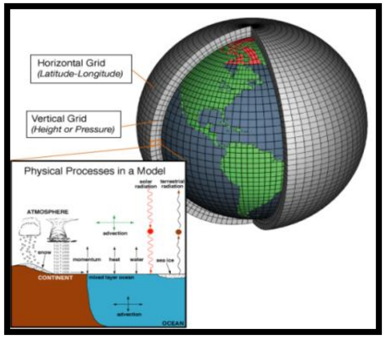
Climate Modeling - Global	Period: 2011/2012-2015/2016

Taiwan Climate Change Information and Projection Platform (TCCIP/MOST)

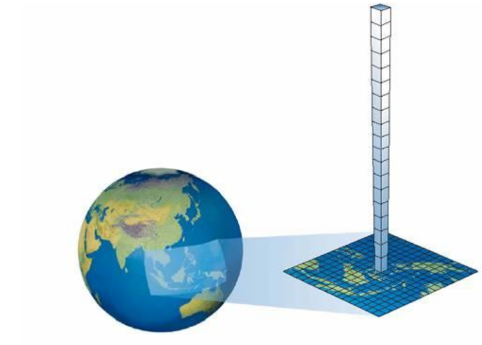
Dynamical Downscaling - Regional	Period: 2010-2012, 2013-2016

Study on Climate Change and Urbanization/Land Use (SCUD/Academia Sinica)

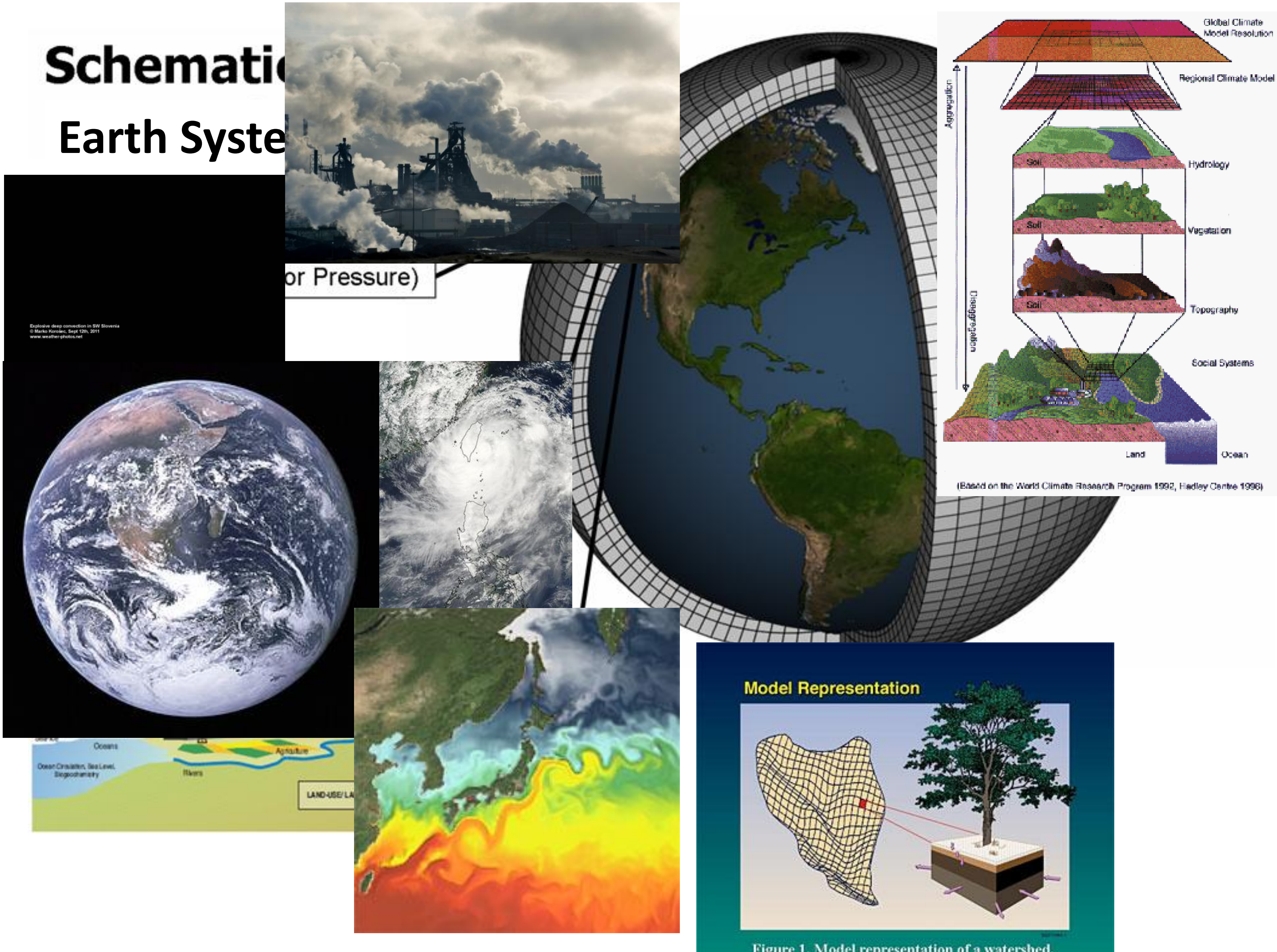
Dynamical Downscaling - Urban	Period: 2013-2015



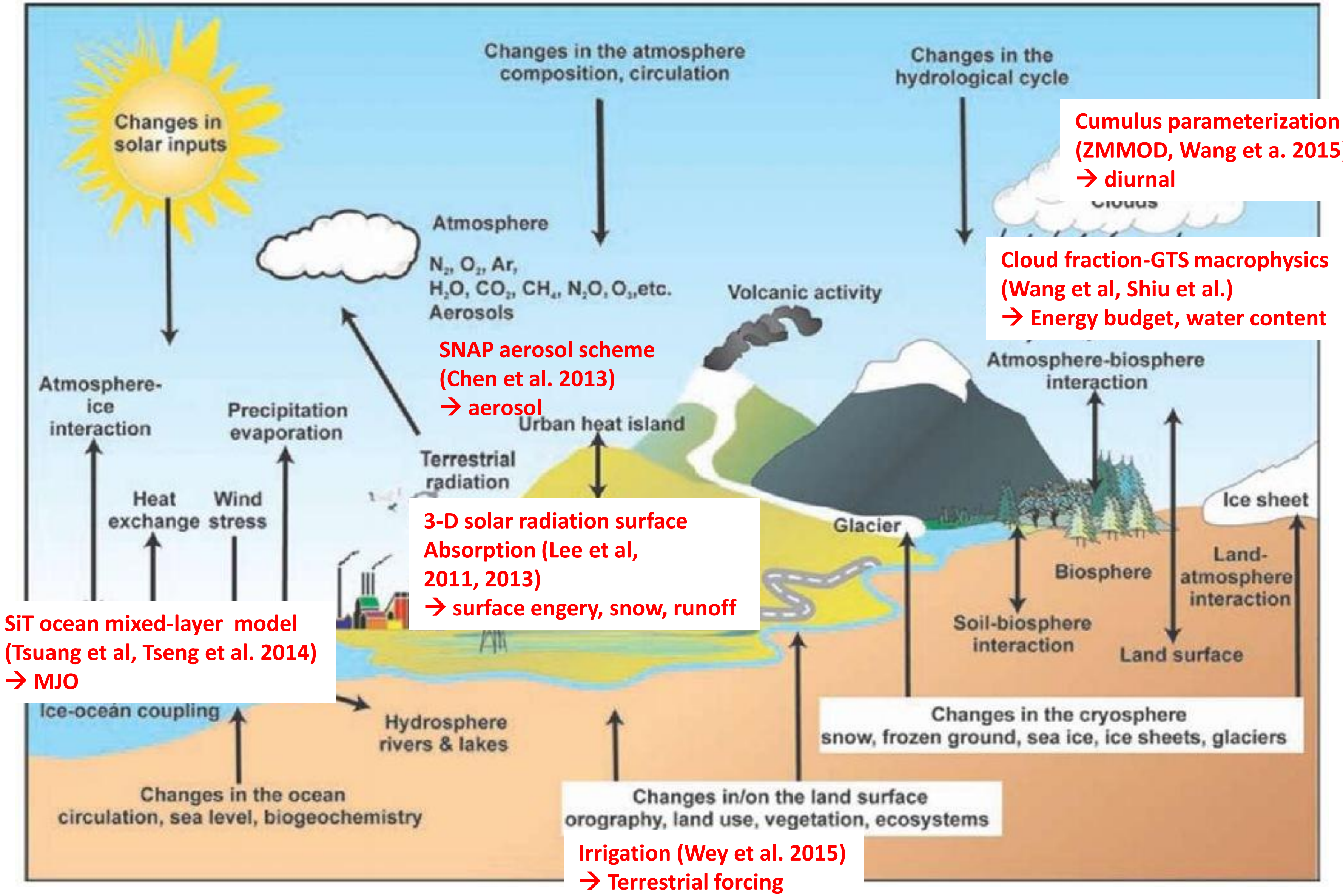
From Global to Urban



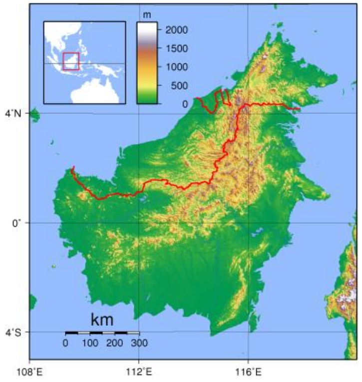
- ➢ **Earth System Model CESM1/NCAR → TaiESM**
  - ■ “Complete” Earth System, coarser resolution: 100-200km
- ➢ **High-res. Atmospheric General Cir. Model HiRAM/GFDL**
  - ■ Ability to resolve extreme weather events, 23km, atmosphere only
- ➢ **Regional Model WRF/NCAR**
  - ■ Regional downscaling to 5-10km
- ➢ **Urban Canopy Model UCM/Tsukuba U.**
  - ■ Urban downscaling: 0.5-1km

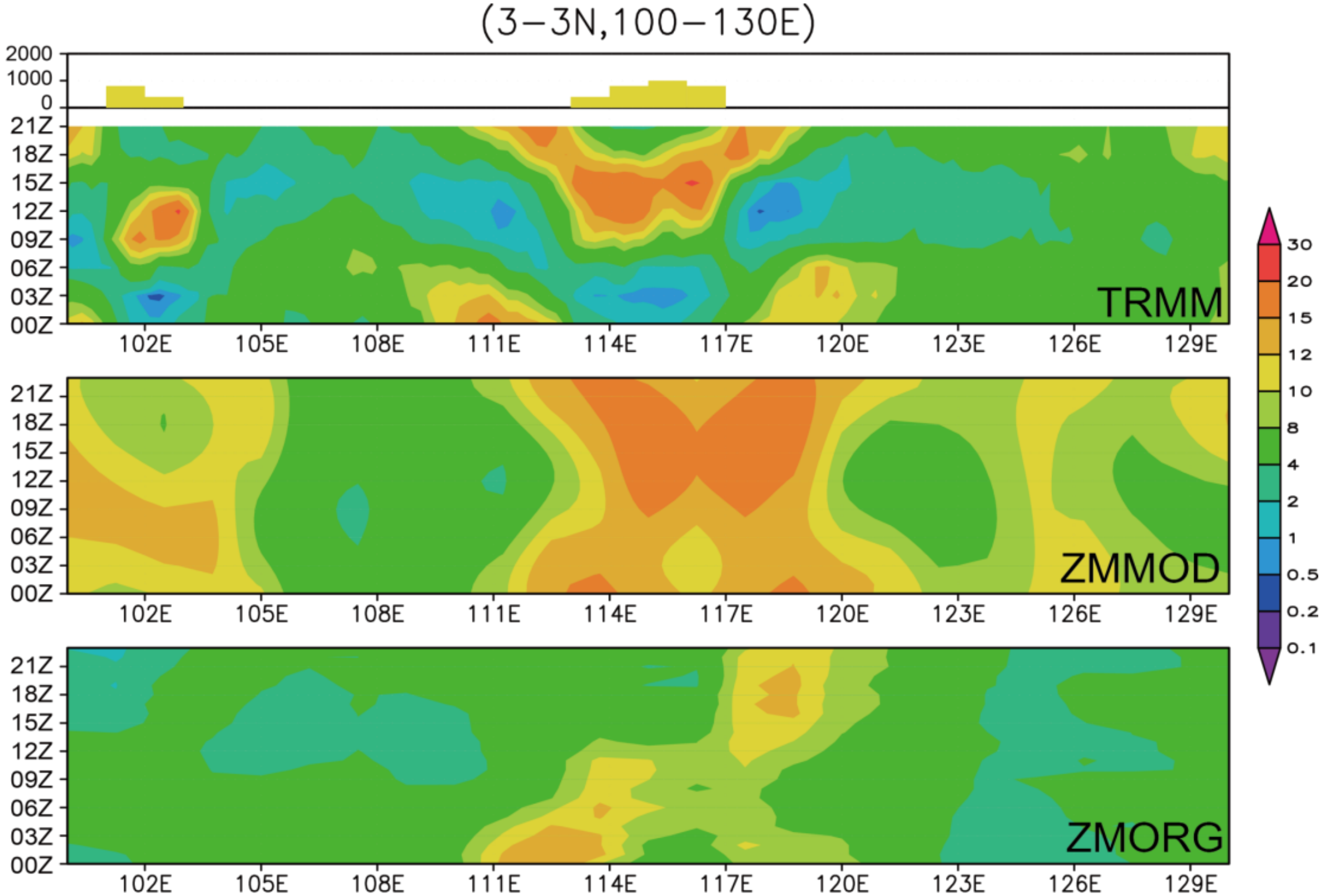

Schemati
Earth Syste
or Pressure)
Global Climate Model Resolution
Regional Climate Model
Hydrology
Soil
Vegetation
Topography
Social Systems
Land
Ocean
Aggregation
Disaggregation
(Based on the World Climate Research Program 1992, Hadley Centre 1996)
Oceans
Rivers
Model Representation
Figure 1. Model representation of a watershed.

CESM1/NCAR → TaiESM v1 (Taiwan Earth System Model)



Improved simulation of diurnal rainfall propagation over the Borneo Island



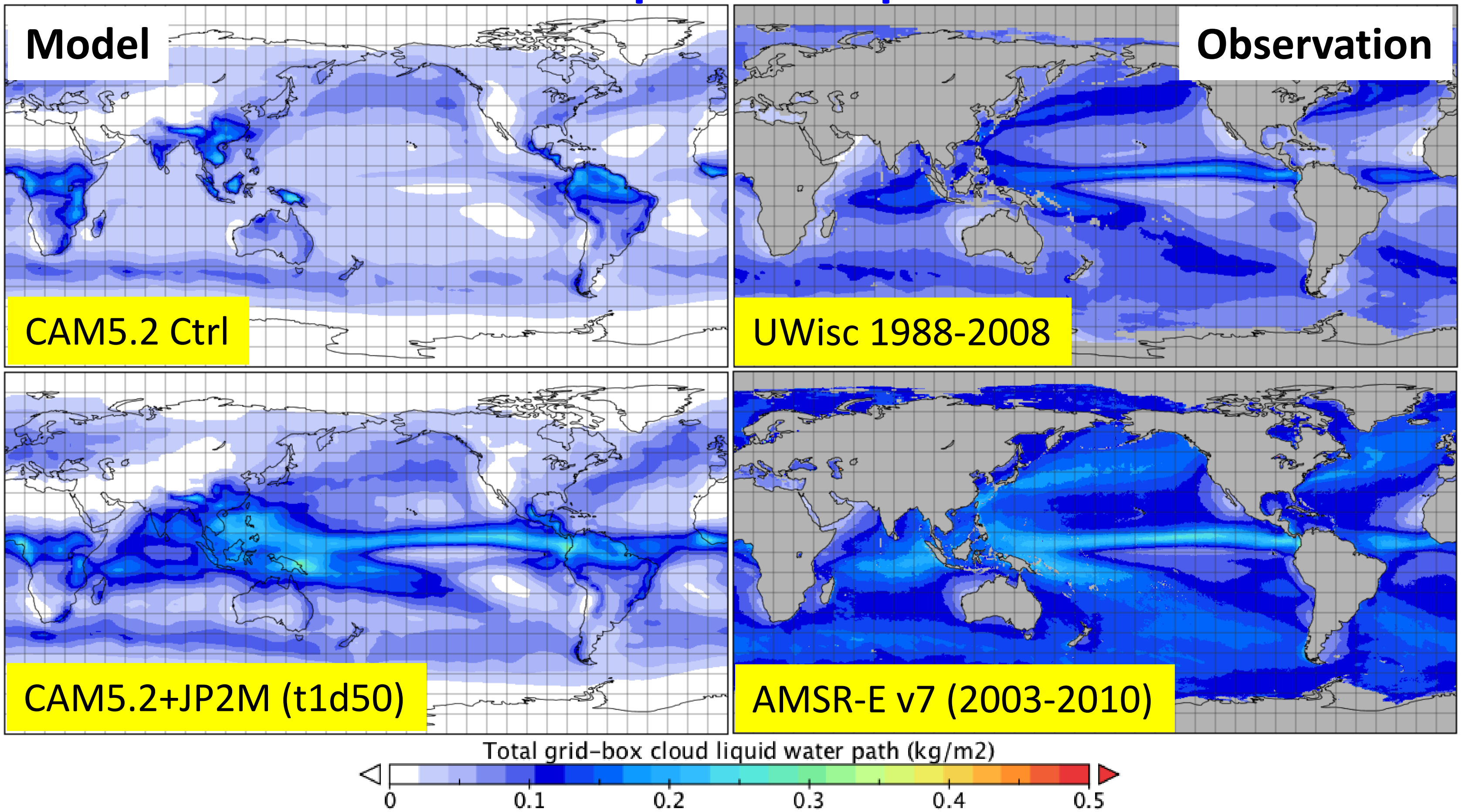


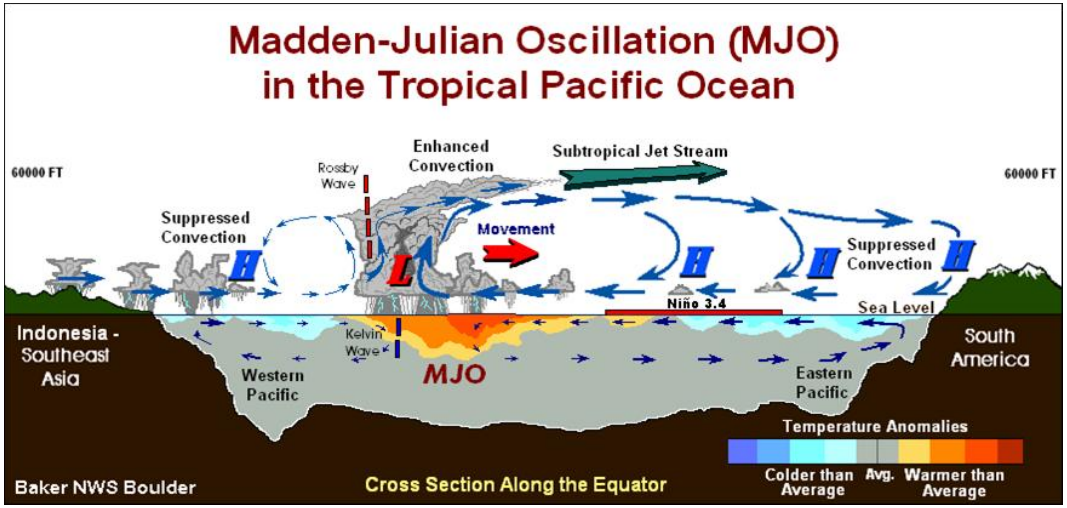
Implementation of warm cloud microphysics to deep convection: Improvement of cloud LWP

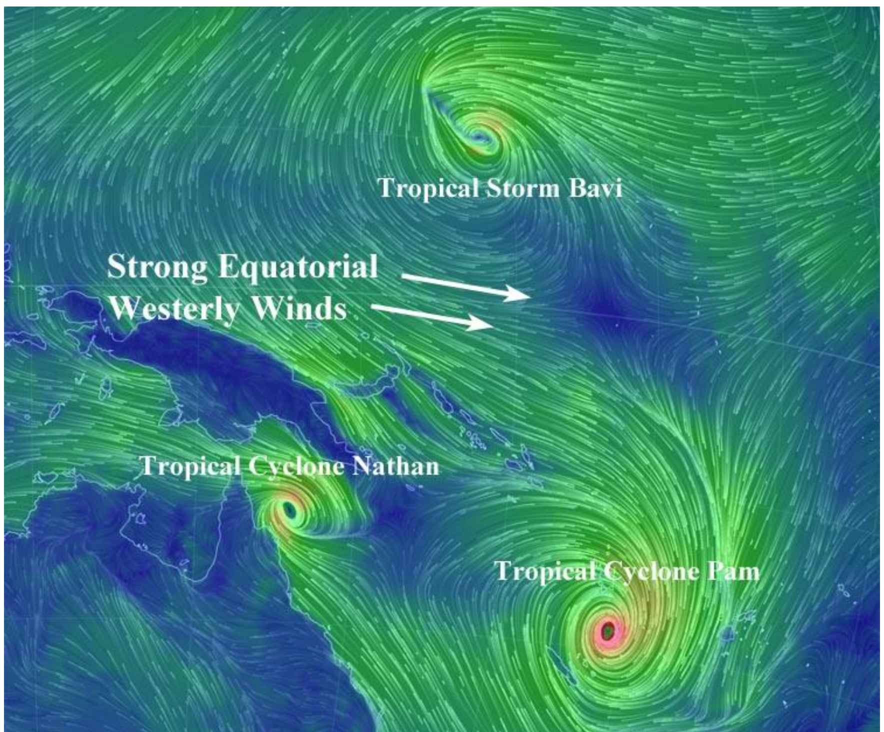
A two-moment warm cloud parameterization (Chen and Liu 2004) is implemented into the deep convection scheme of CAM5 for treatment of conversion of cloud liquid to rain.

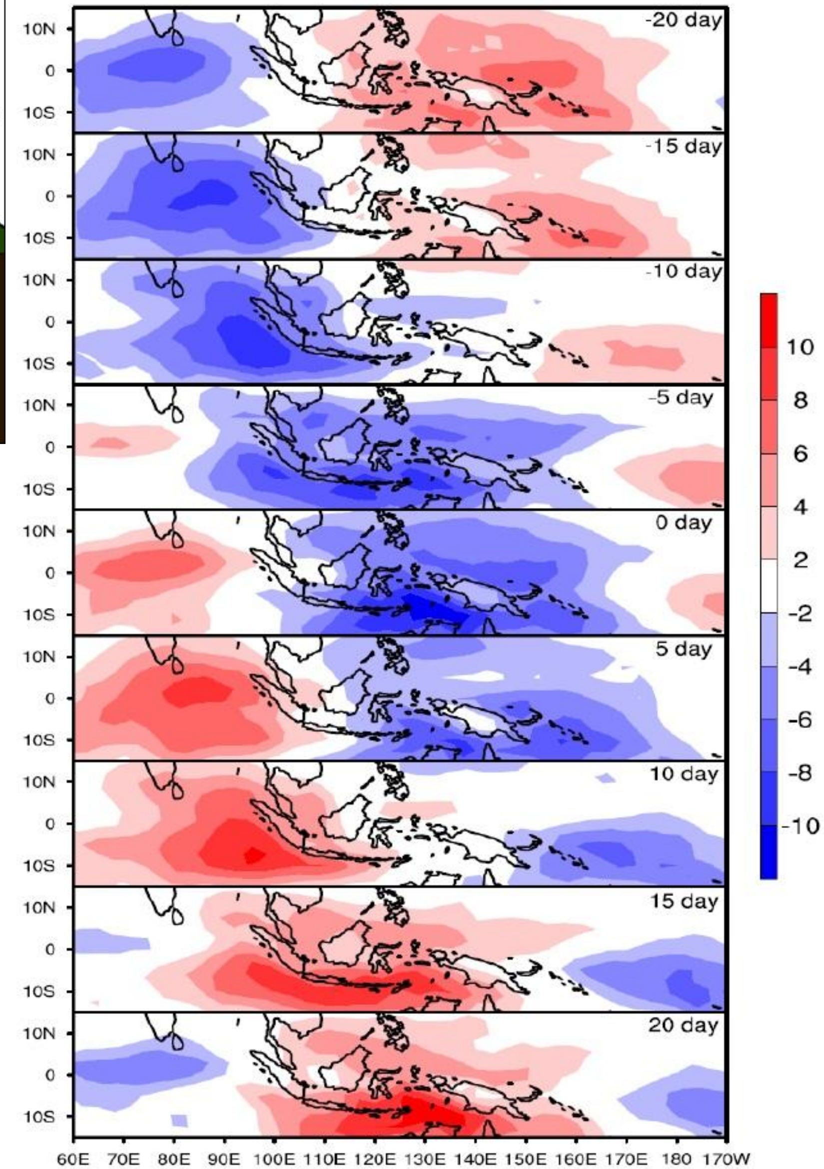
(*Chein-Jung Shiu and Jen-Ping Chen*)

Cloud liquid water path




Madden-Julian Oscillation (MJO)
in the Tropical Pacific Ocean
60000 FT
60000 FT
Rossby Wave
Enhanced Convection
Subtropical Jet Stream
Suppressed Convection
Movement
Suppressed Convection
Niño 3.4
Sea Level
Indonesia - Southeast Asia
Kelvin Wave
Western Pacific
MJO
Eastern Pacific
South America
Temperature Anomalies
Colder than Average
Avg.
Warmer than Average
Baker NWS Boulder
Cross Section Along the Equator

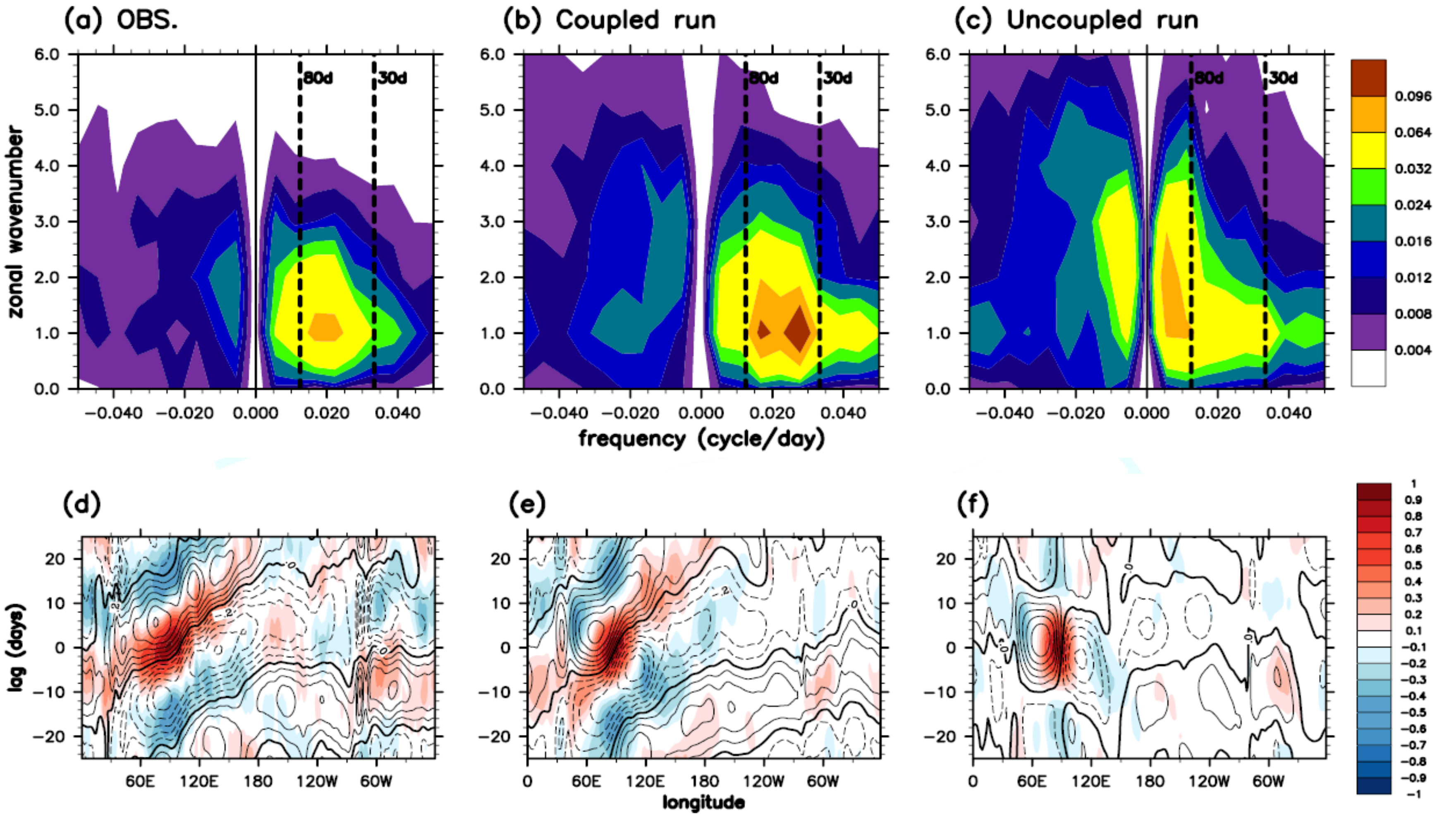

Tropical Storm Bavi
Strong Equatorial Westerly Winds
Tropical Cyclone Nathan
Tropical Cyclone Pam


-20 day
-15 day
-10 day
-5 day
0 day
5 day
10 day
15 day
20 day
10N
0
10S
60E 70E 80E 90E 100E 110E 120E 130E 140E 150E 160E 170E 180 170W
10
8
6
4
2
-2
-4
-6
-8
-10

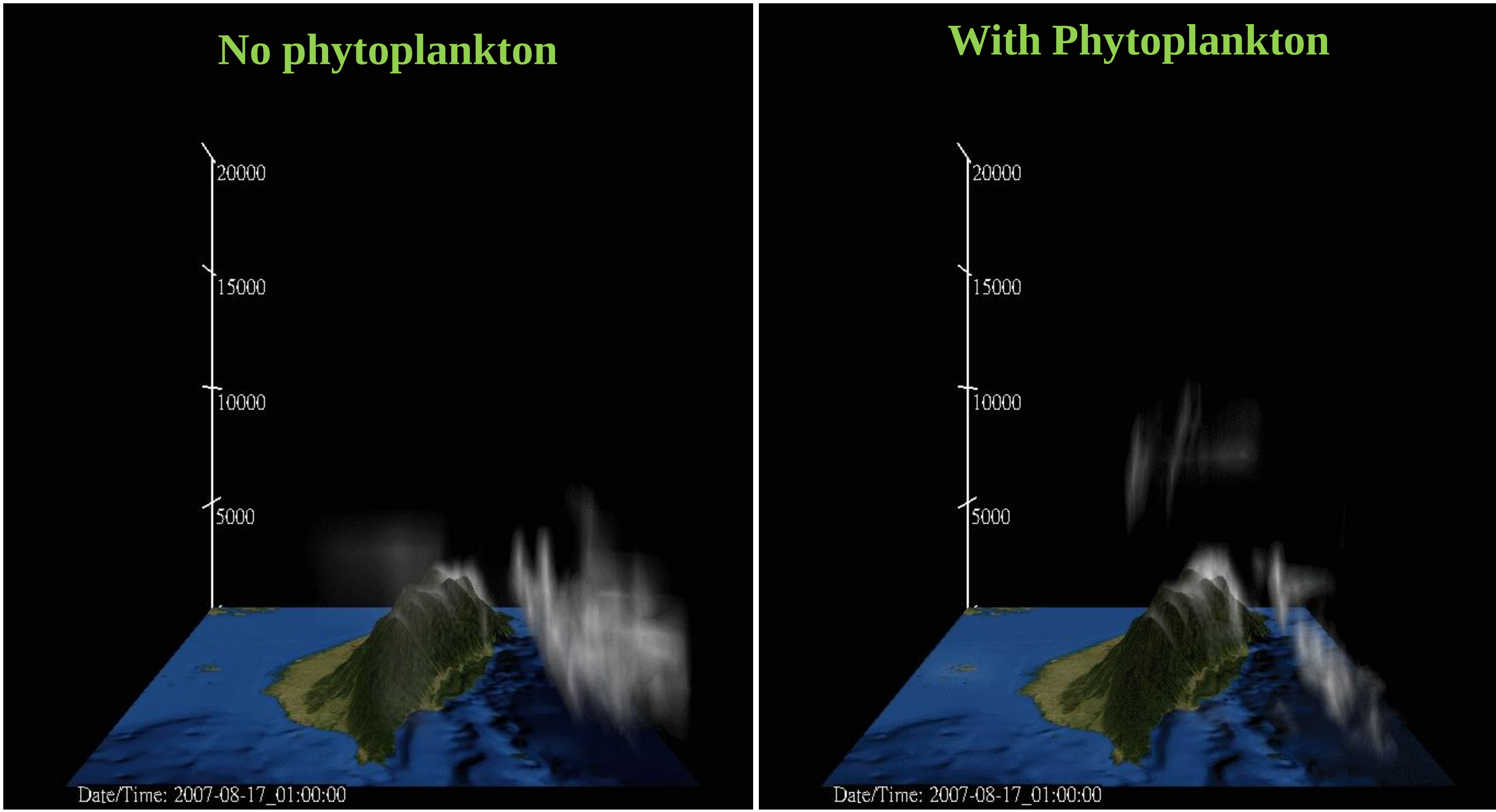
Coupling 1-D (TKE) ocean mixed layer model (SIT) to ECHAM5 →Significant improvement in MJO simulation

(joint effort with Noel Keenlyside, B.J. Tsuang)

Similar improvements seen in two different models.

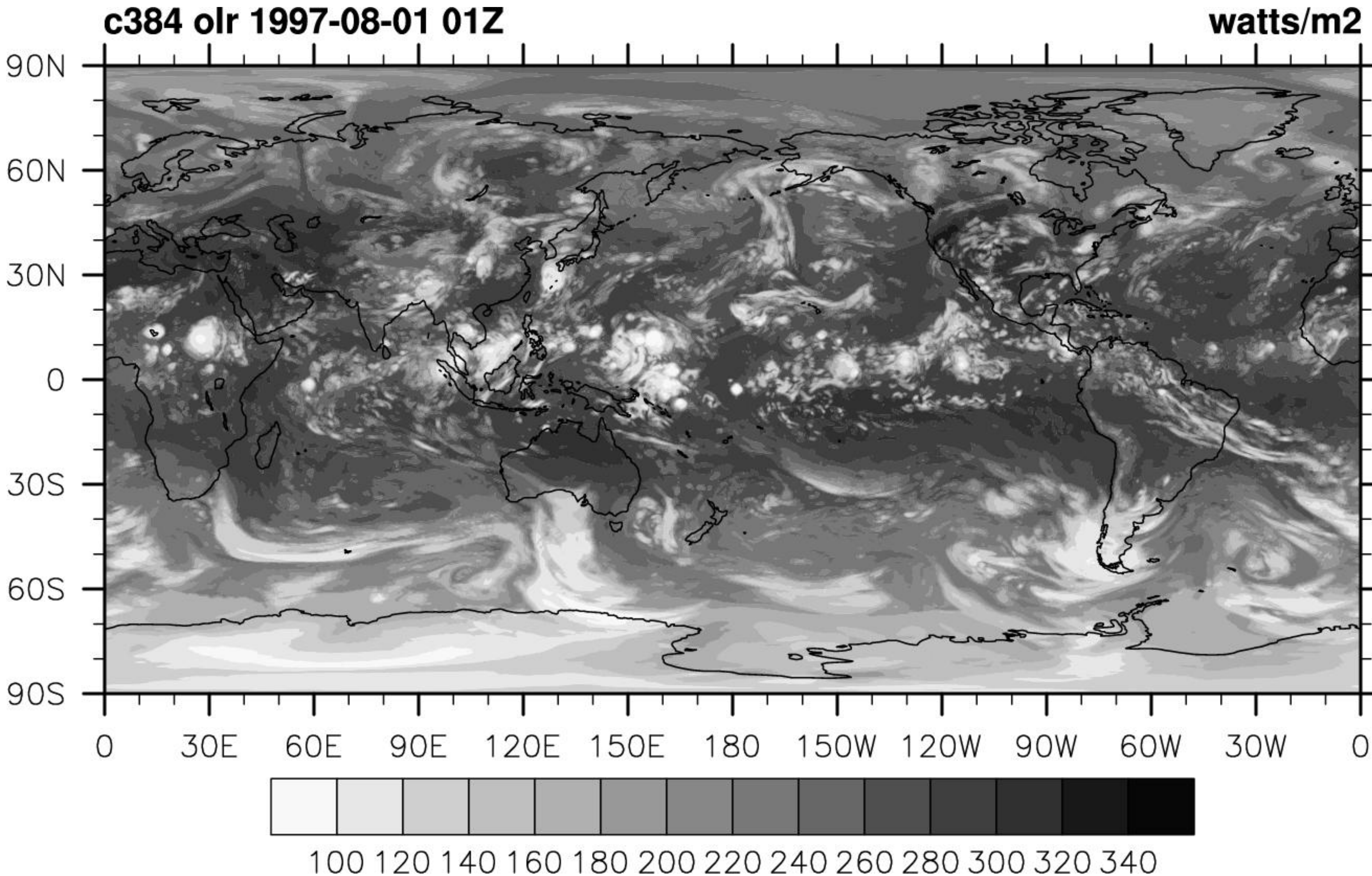


Phytoplankton enhances convection in typhoon

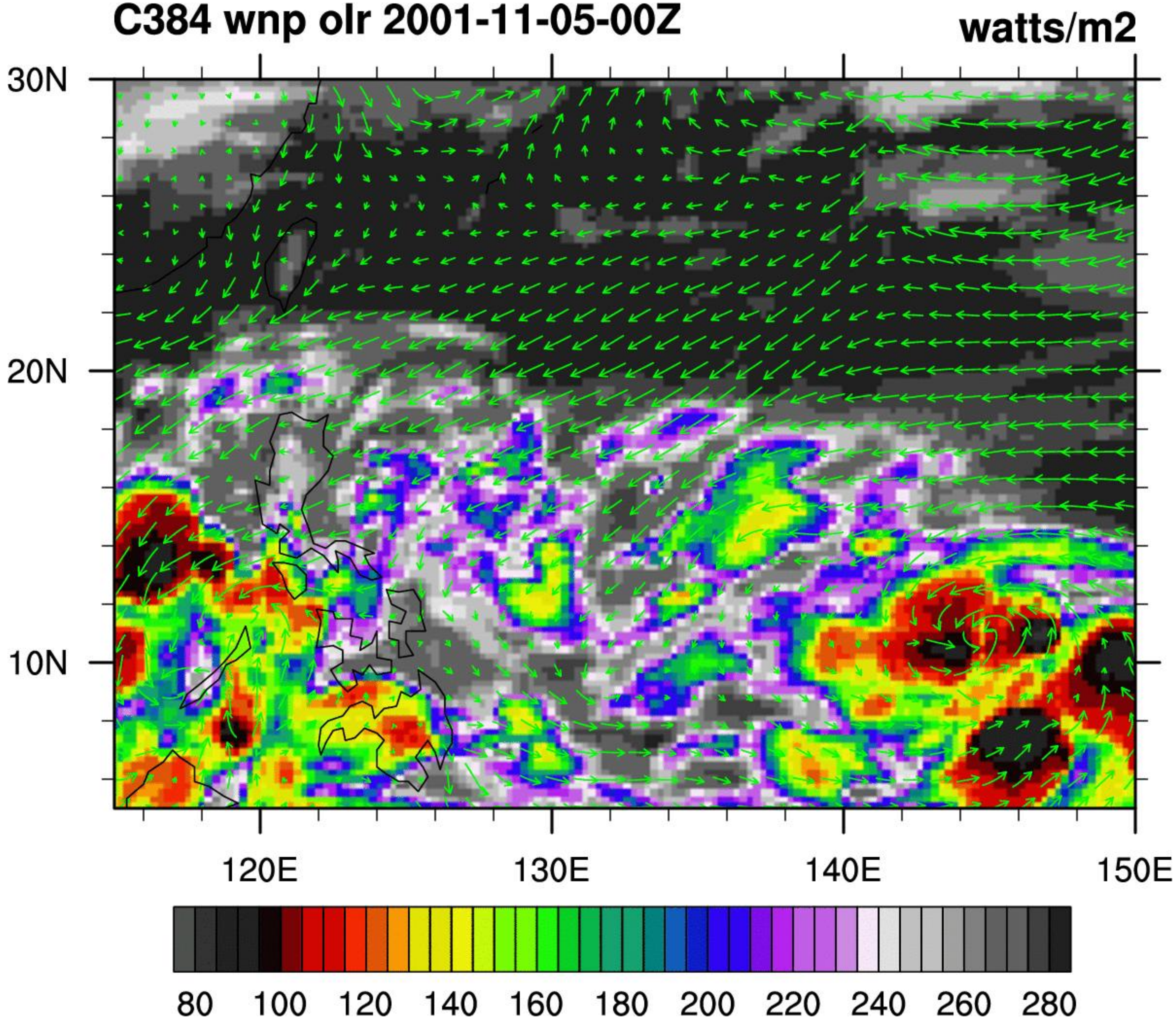


droplet Ice snow grauple rain

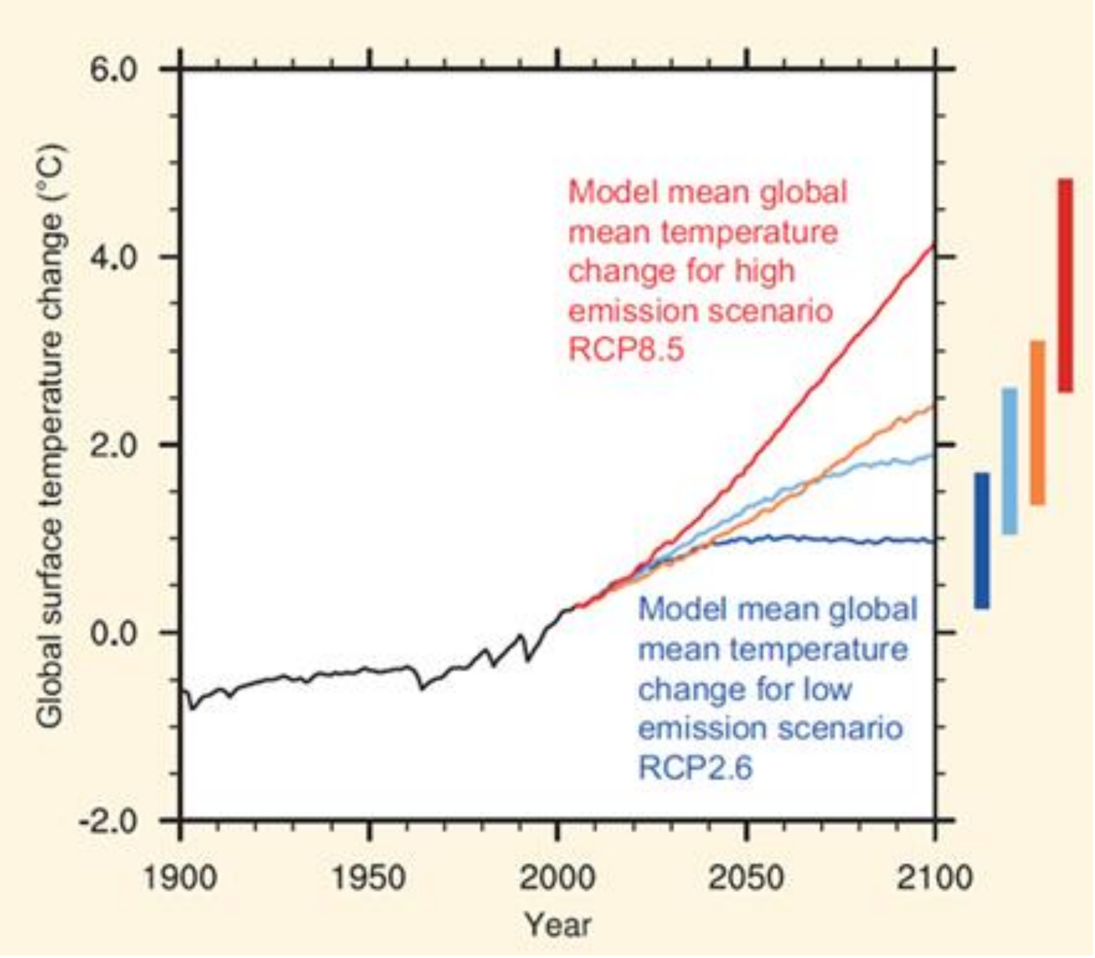
Earth System Model (100-200km) → High-resolution Global Atmospheric Model (HiRAM, GFDL/NOAA, 23km)



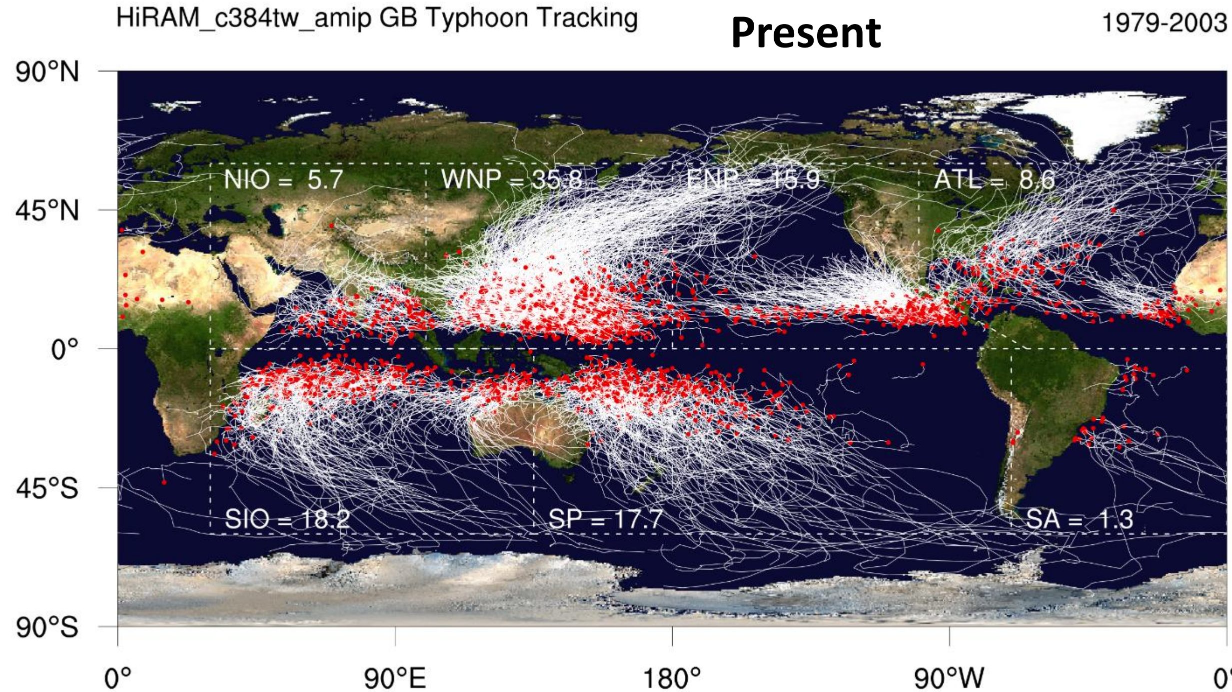
A "TC" in HiRAM

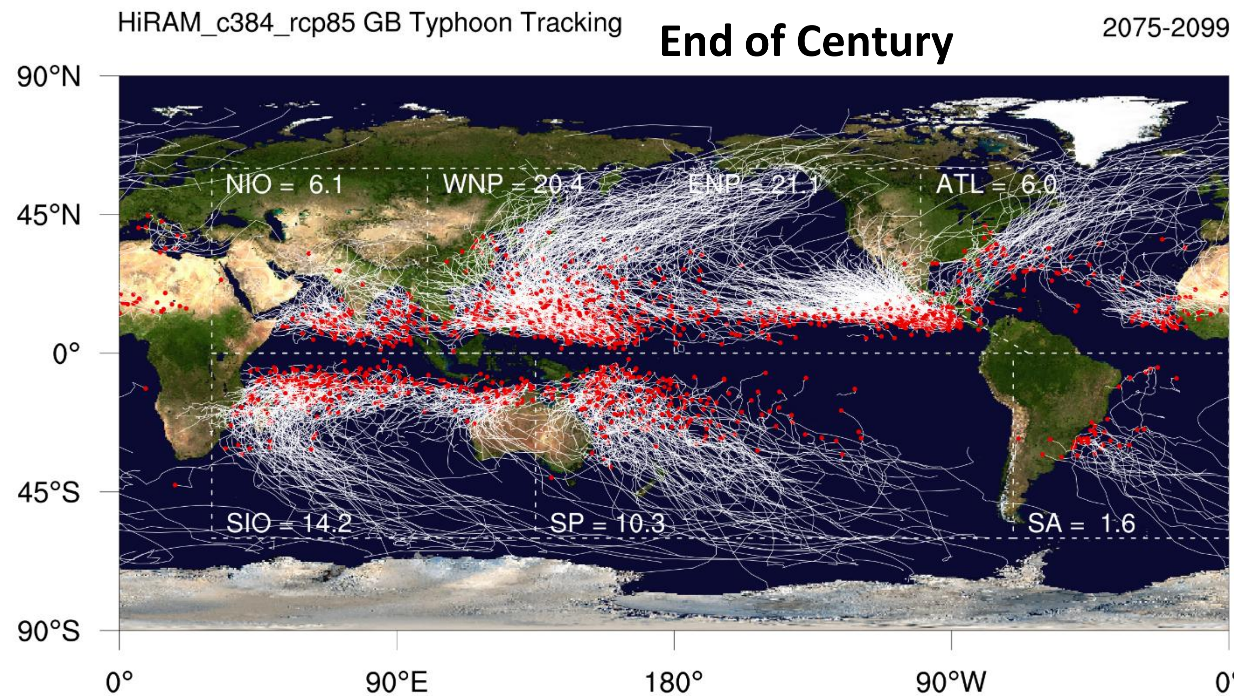

C384 wnp olr 2001-11-05-00Z
watts/m2
30N
20N
10N
120E
130E
140E
150E
80
100
120
140
160
180
200
220
240
260
280

High-res. Simulation and Projection of Climate Change
HiRAM: 1979-2008, 2075-2100 (RCP8.5)
(C.-Y. Tu, P.-J. Chiu, Lex Chang, S.-J. Lin)



C.-Y. Tu



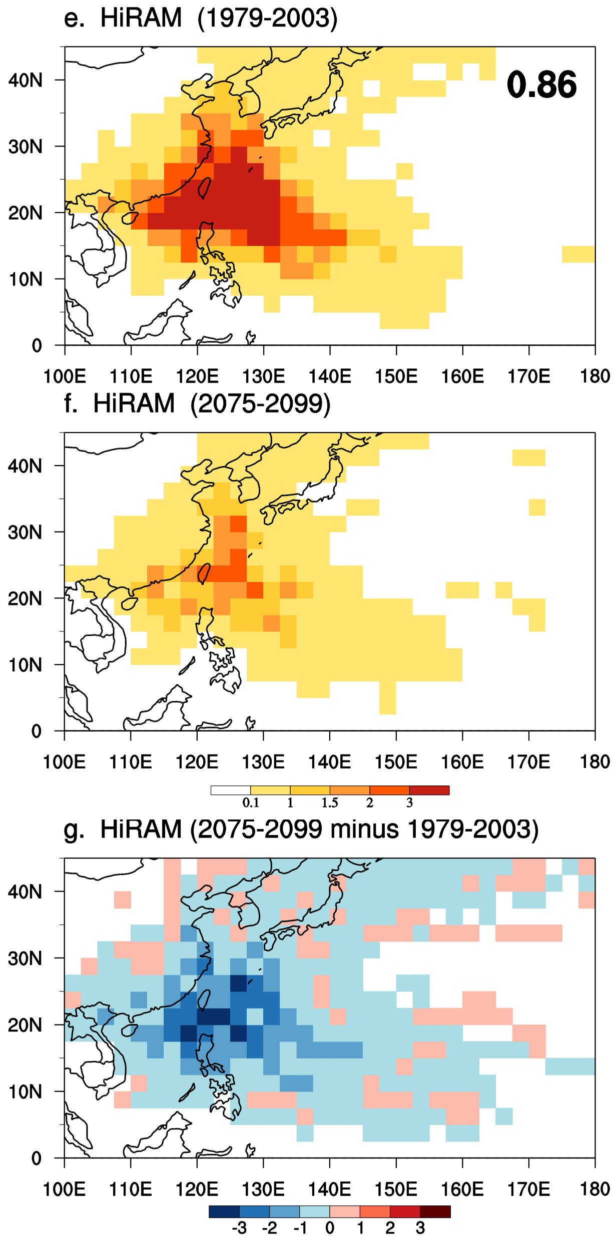


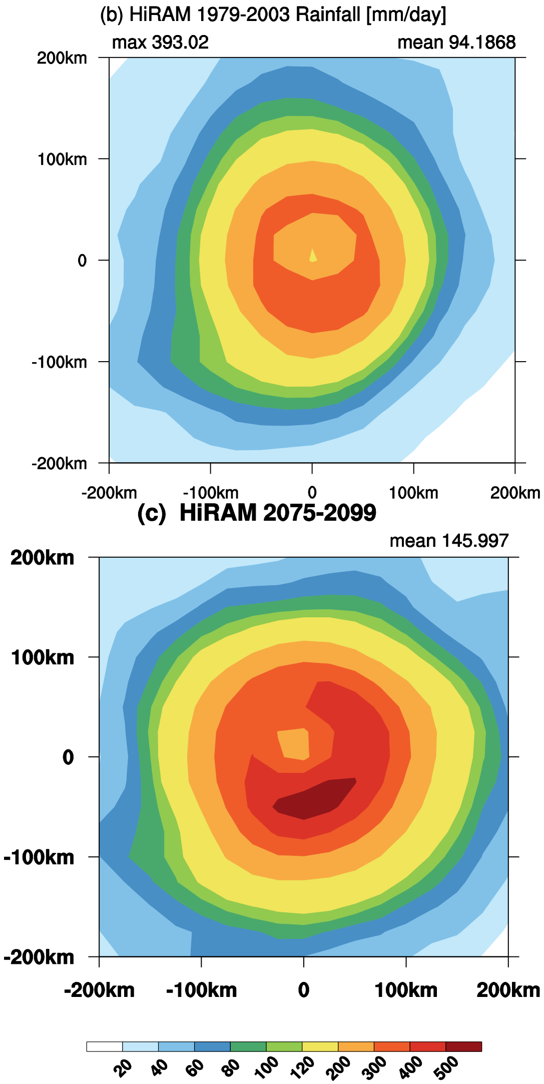
HiRAM C384

similar in C192

TC Counts	AMIP	RCP8.5
NIO	5.7	6.1
WNP	35.8	20.4
ENP	15.9	21.1
ATL	8.6	6.0
SIO	18.2	14.2
SP	17.7	10.3
SA	1.3	1.6

Changes in typhoon frequency and strength





- Significantly reduced in number but strengthened
- Rainfall within 200 and 100 km radius increased by 44 and 20 %

FIG. Distribution of TWCN TS track frequency (shaded, unit: numbers per 2.5º longitude/latitude per season period) in JUN.-NOV.

C.-H. Tsou and P.-Y. Huang
(TCCIP，NTNU)

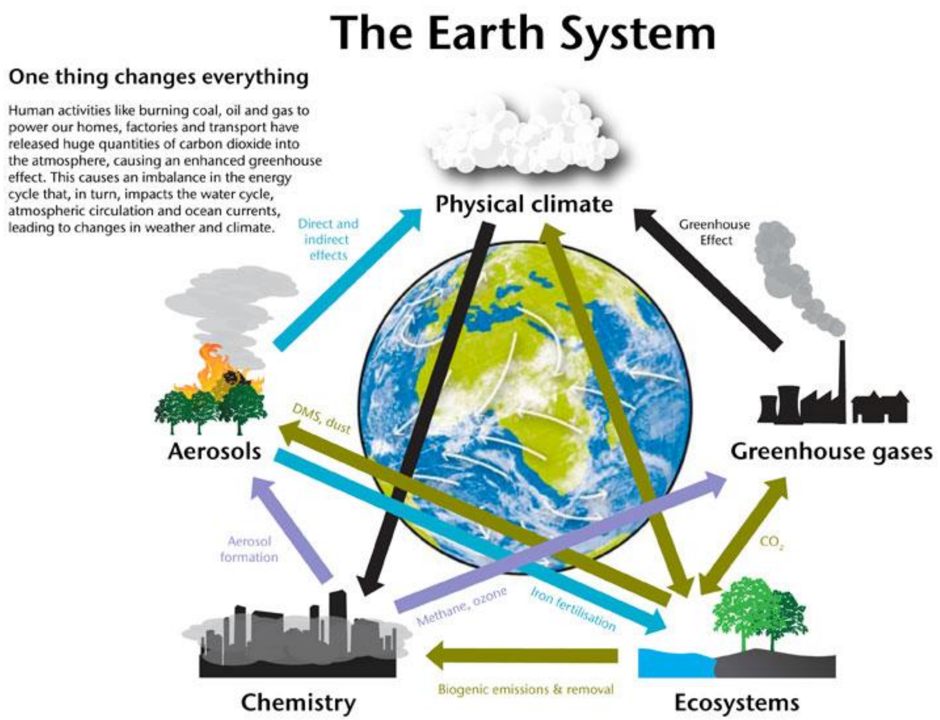
WCRP CMIP6

World Climate Research Programme

for IPCC AR6

AR5-COP21 scientific basis

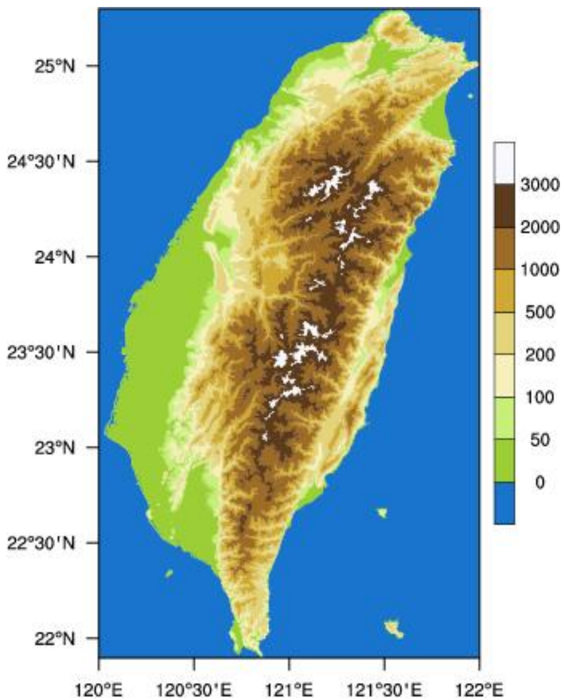
CMIP: Understanding past, present and future climate



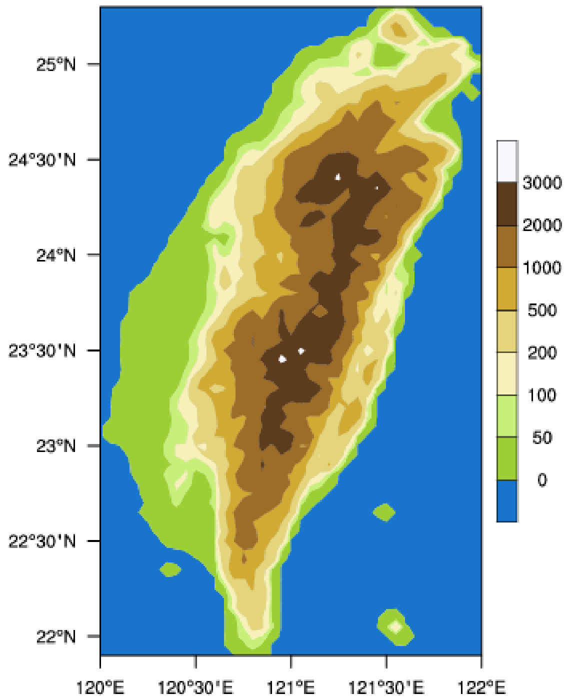
Bird view of Taiwan in different scales

不同空間解析度鳥瞰台灣

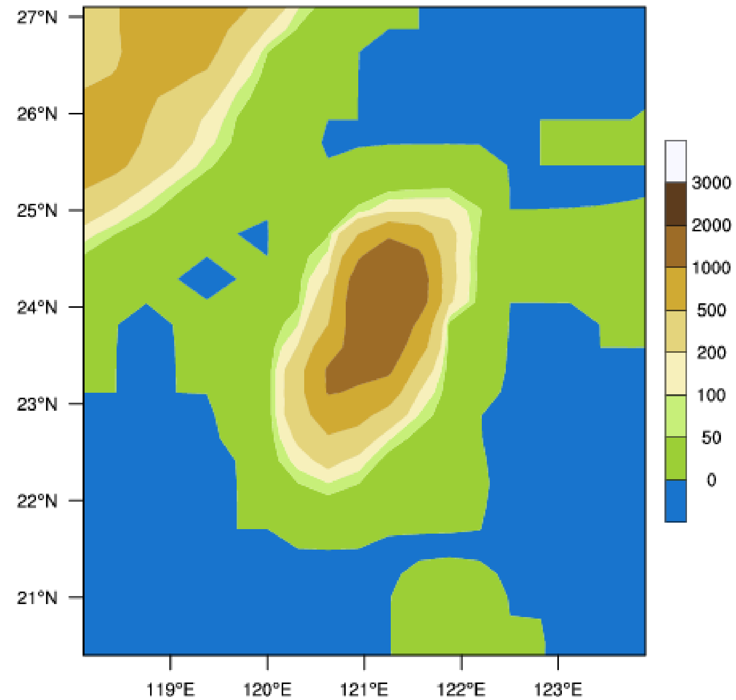
30 m



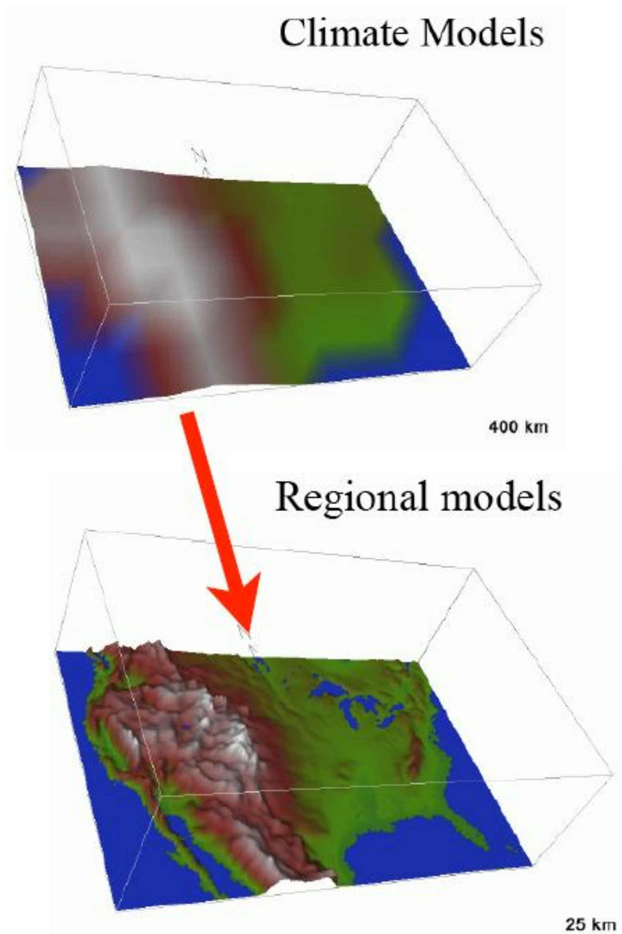
5 km

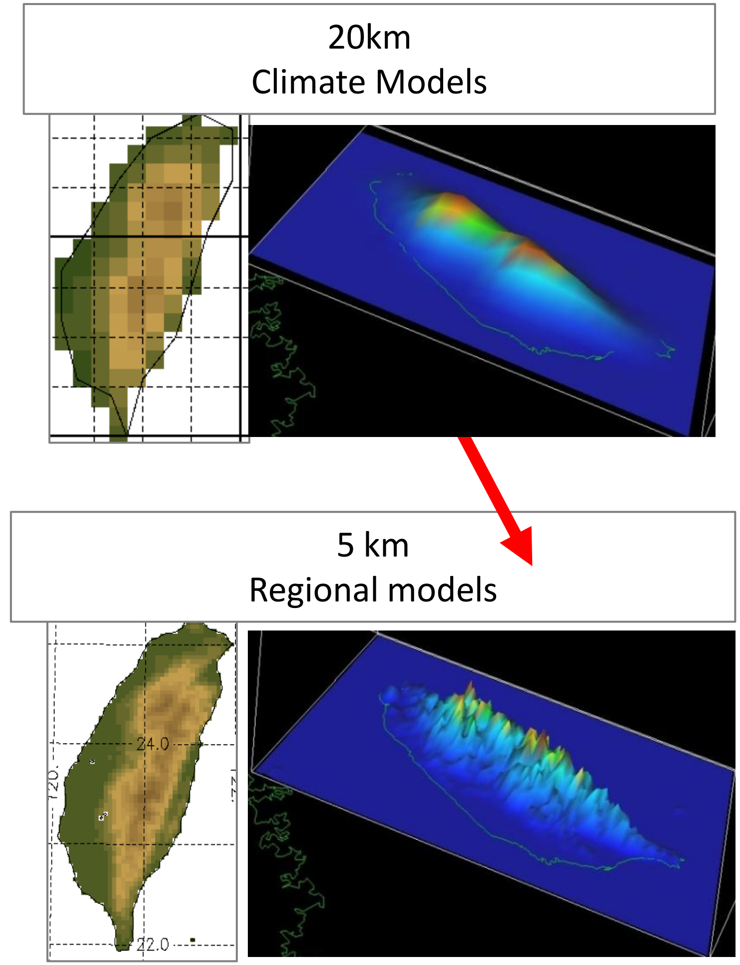


25 km



Purpose: To increase spatial resolution

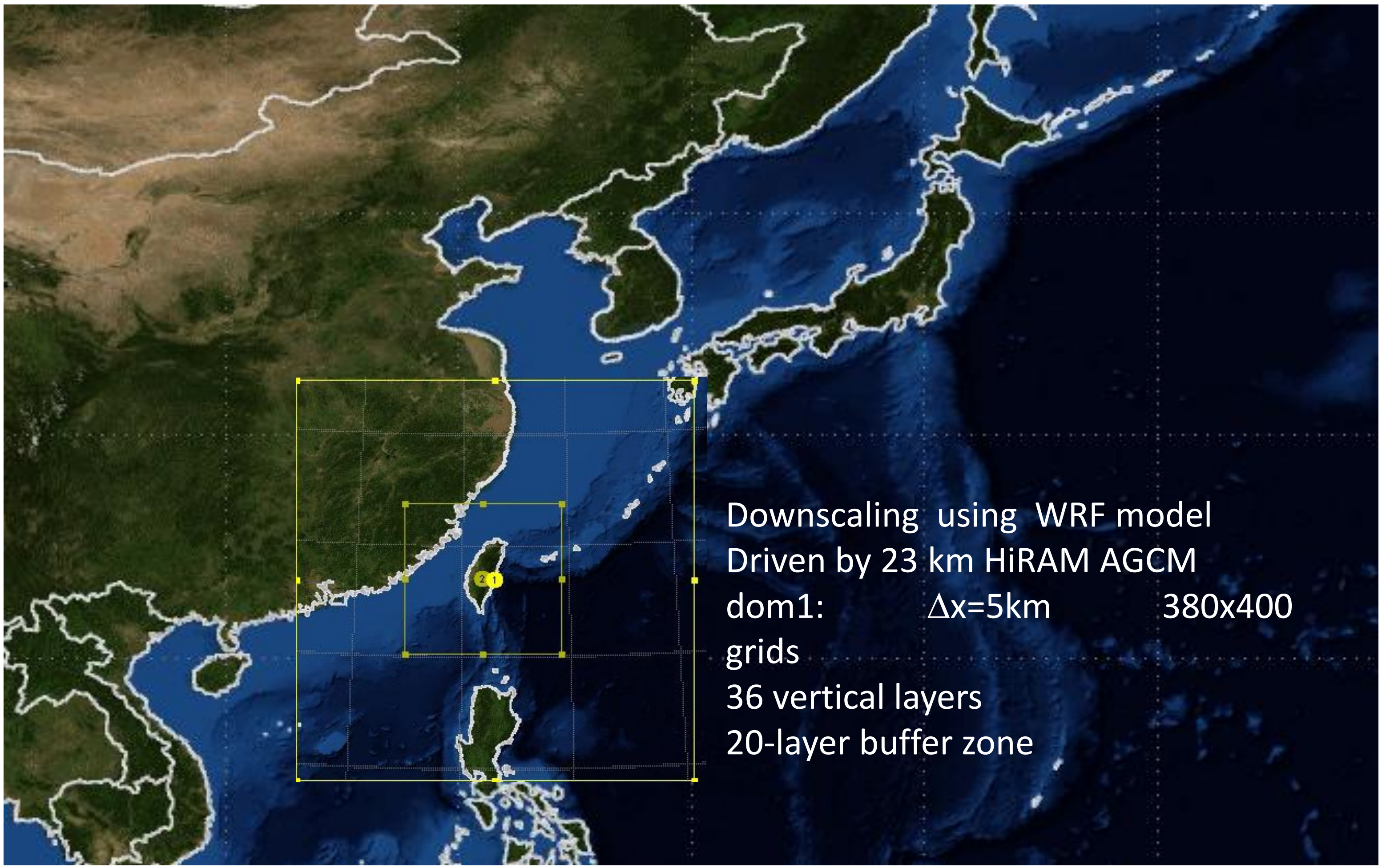




For US, downscaling to few tens of km may be enough.

For Taiwan, we need to downscale to few km or even finer scale.

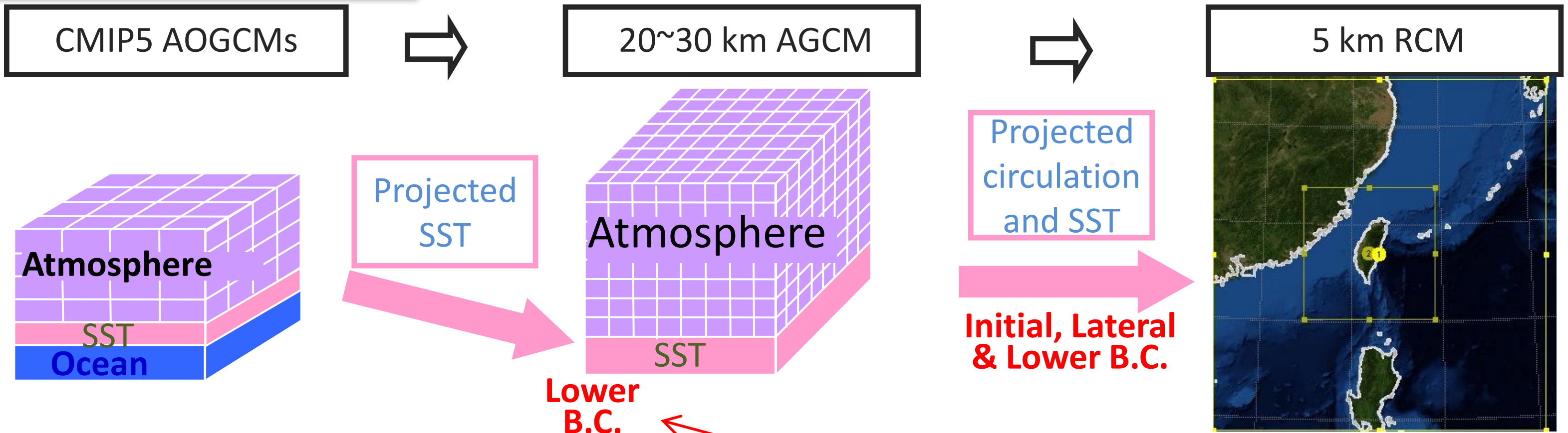
Downscaling using fine-res. dynamical model
Global → Regional (HiRAM-WRF)



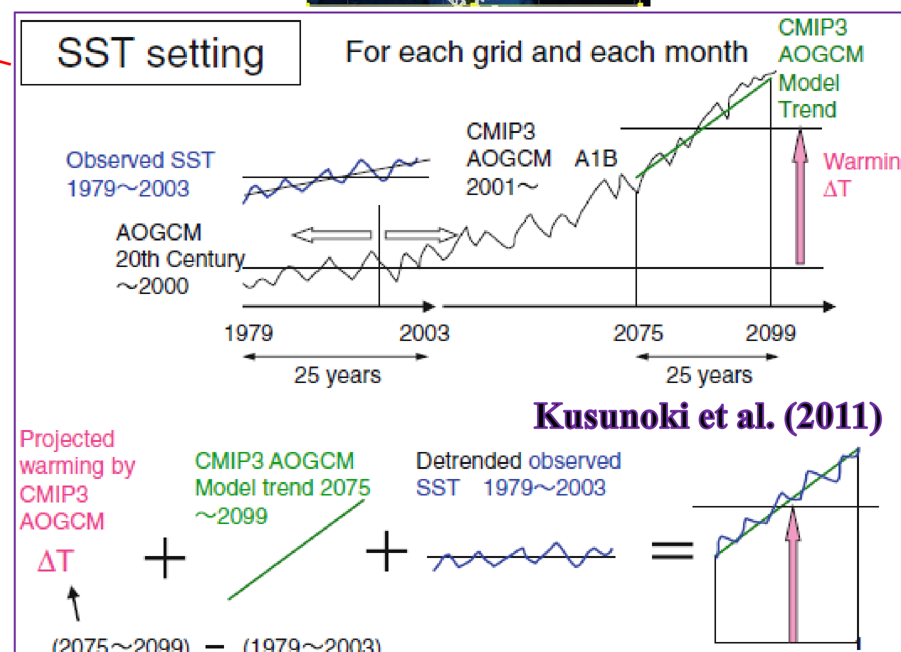
TCCIP1/TCCIP2 Dynamical Downscaling: 25km(AGCM) → 5km(WRF)

Models: MRI-AGCM with 20km resolution
HiRAM with ~25km resolution
CAM5 with ~25km resolution

Time-Slice Experiments



C.-T. Cheng



SST in AGCM

Present (1979-2003)

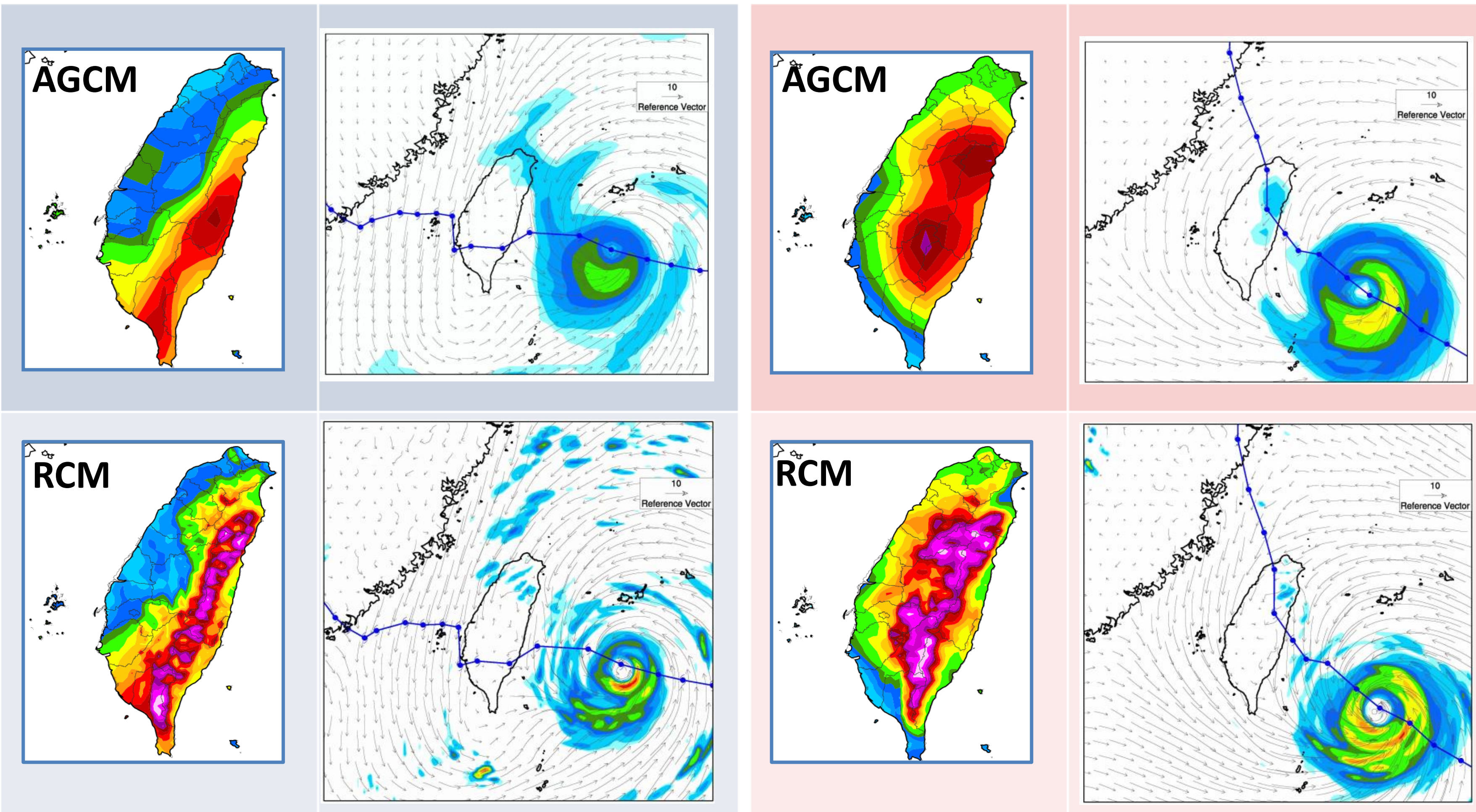
the observed sea surface temperature (SST) and sea-ice concentration

Future (2075-2099)

the SST and sea-ice anomalies of the CMIP5 multi-model ensemble mean are added to the observations, retaining the present interannual variability

Typhoon Precipitation: Effect of downscaling

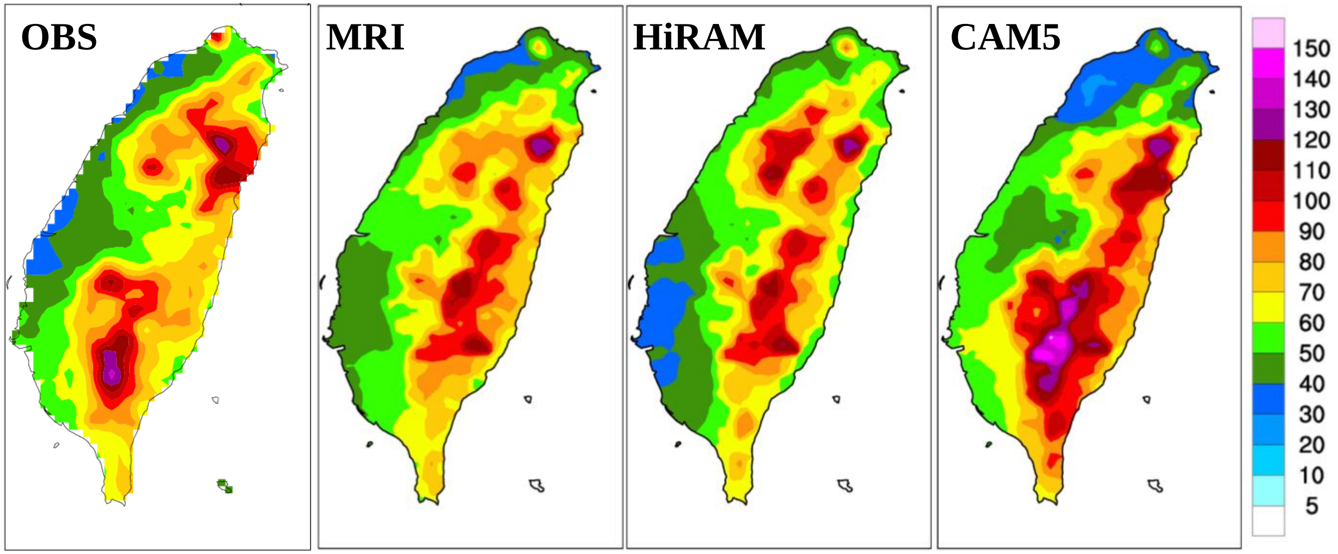
MRI 200505 | **HiRAM 199701**



- TCs were well simulated by super high resolution AGCM.
- RCM can provide more realistic and detailed information.

Typhoon Rainfall simulation

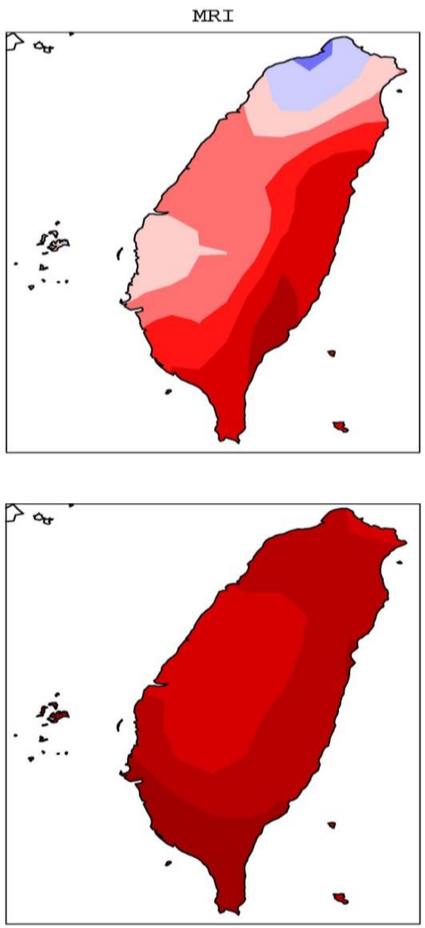
driven by three AGCMs



- Simple Day Intensity Index (SDII, mm/day) of typhoon precipitation is comparable to observation

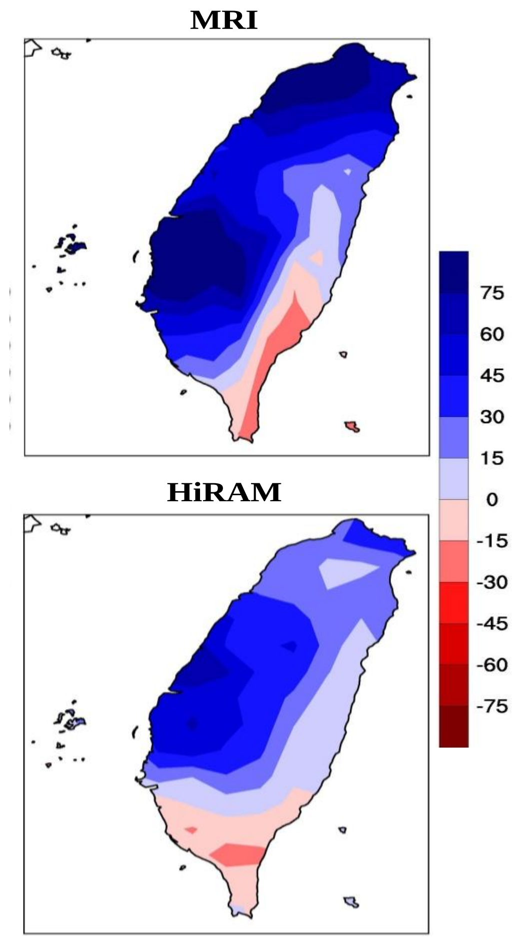
Projected Future Change in Typhoon Rainfall (RCP8.5)

Decreased total rainfall
(fewer typhoons)

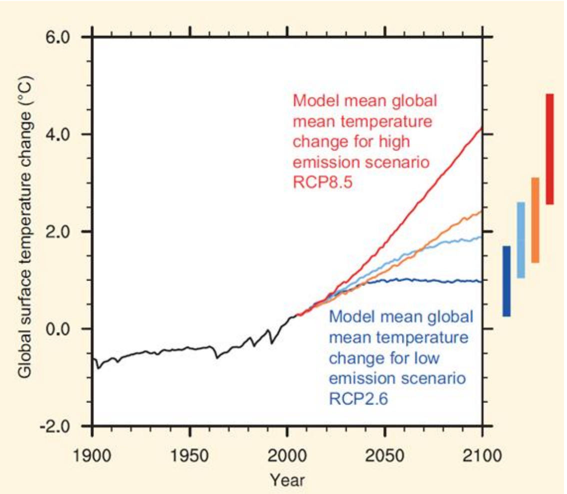


Change rate of
TC rainfall change

Increased rainfall intensity
(Stronger typhoons)



Change rate of
TC SDII

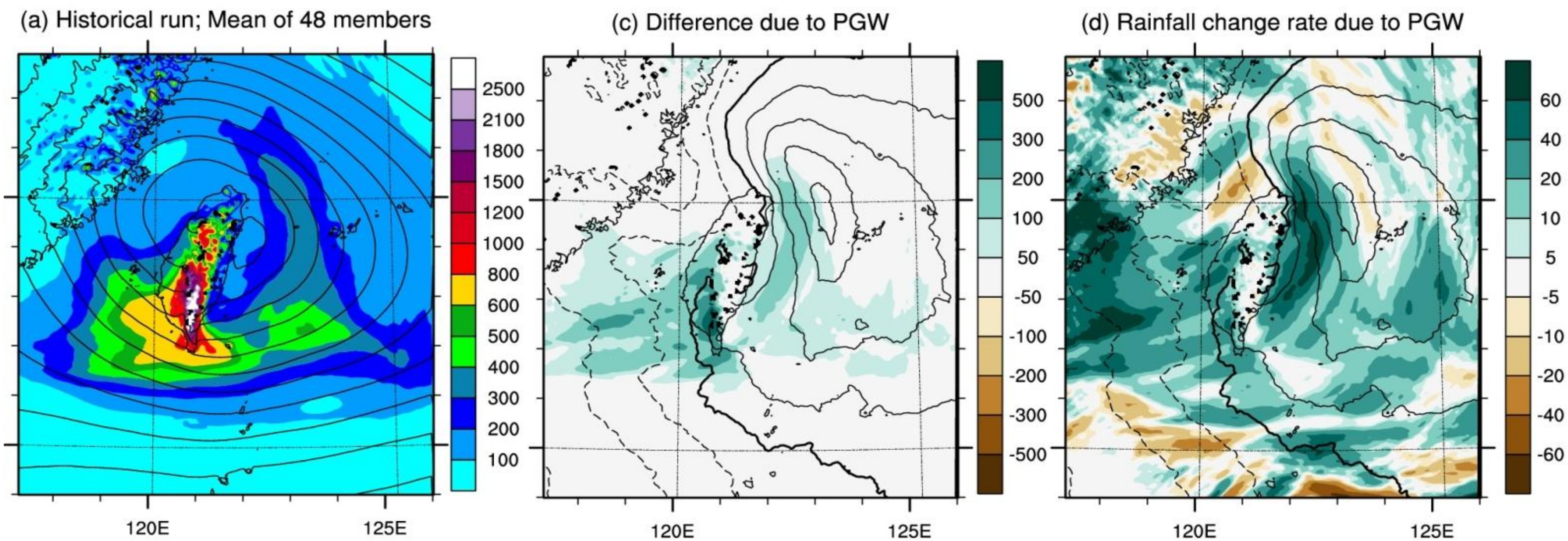


Pseudo Global Warming Experiment for Historical Typhoons
- Typhoon Morakot (2009) in the end of 21st Century

Superposition circulations of future change and historical events

$$C_{PGW} = C_{history} + (\overline{C}_{future} - \overline{C}_{present})$$

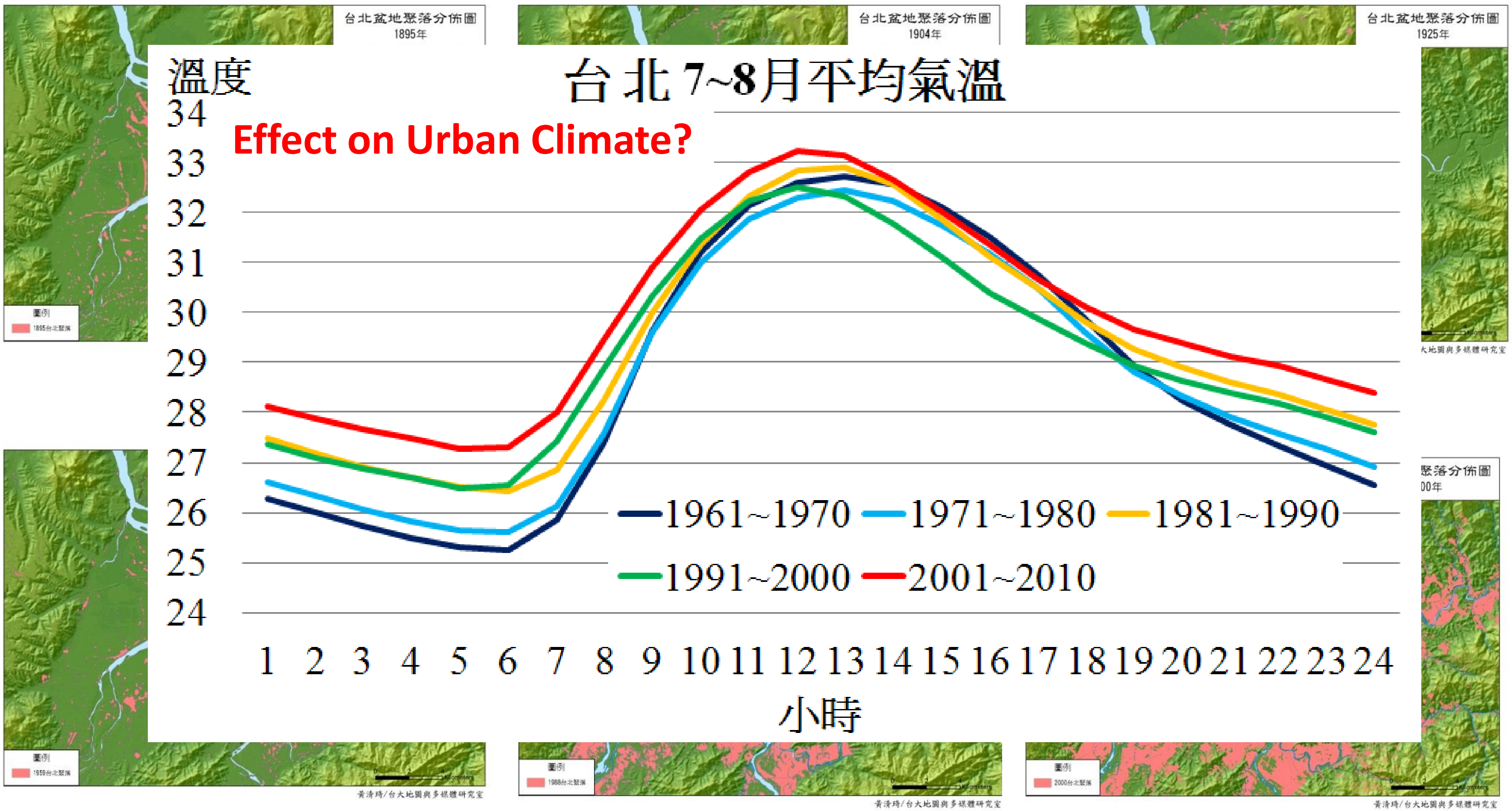
$\overline{C}$: Climatology of 30 day mean; $C = T$、RH、U、V、Φ、SST



- Consider circulation change of MRI-AGCM3.2S in 2075-2099 under A1B scenario and 2009 typhoon Morakot (top rainfall record : 3000 mm in 5 days)
- 48 ensemble runs.
- Precipitation increase rate over southern plain can reach 40% (from 3000 mm to 4200 mm)

Global Warming vs. Historical Land Use Changes

- Taipei as an example

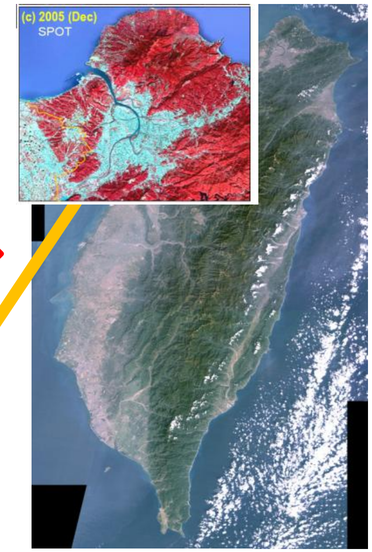


(台大賴進貴教授提供)

Regional to Urban

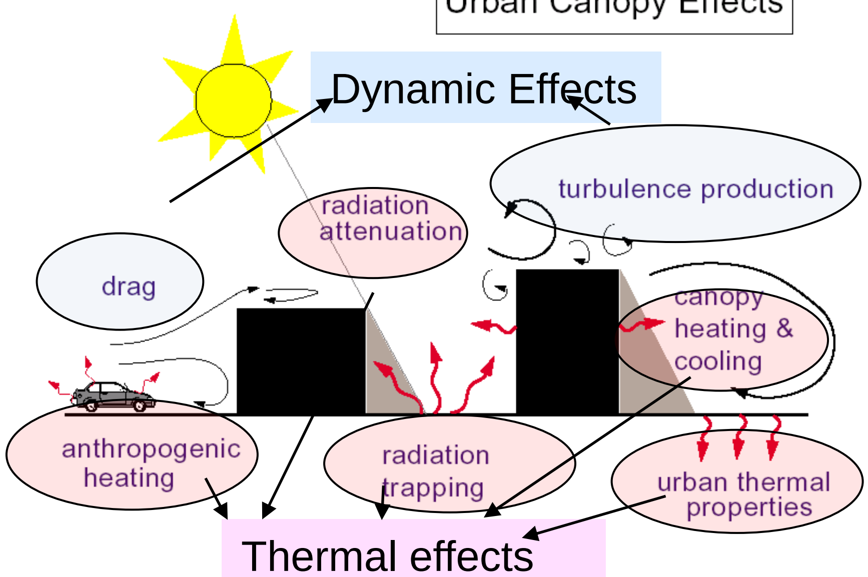
Regional scale

Local scale

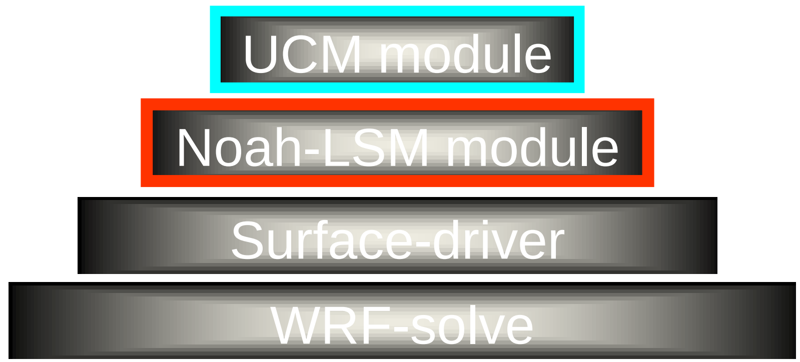


Urban scale

Urban Canopy Effects



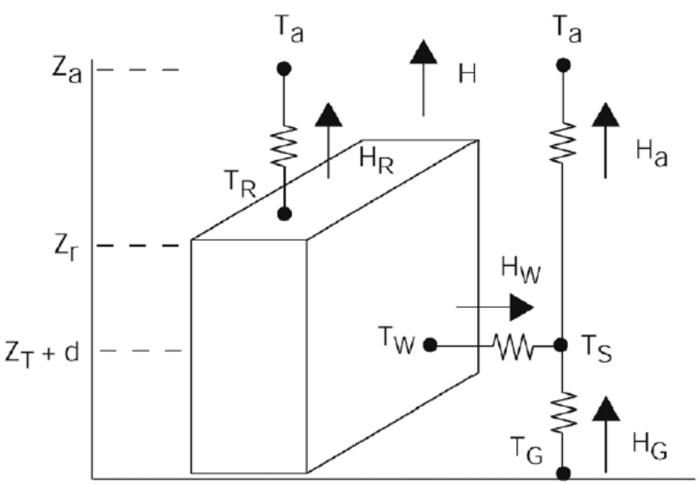
WRF-Noah-UCM modeling system



Chun-Yao Lin

Urban Canopy model (UCM)

(Kusaka et al. 2004)



Ta is the air temperature at reference height z
TR the building roof temperature,
TW the building wall temperature,
TG the road temperature, and
TS the temperature defined at zT +d.
H is the sensible heat exchange at the reference height.
Ha is the sensible heat flux from the canyon space to the atmosphere,
HW is from wall to the canyon space,
HG is from road to the canyon space,
HR is from roof to the atmosphere

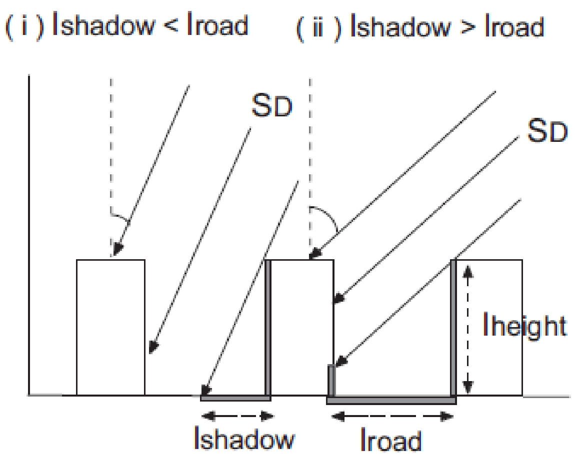
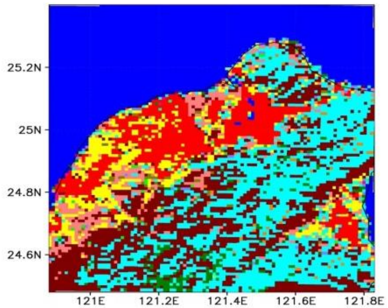


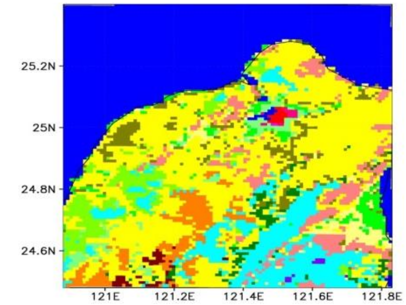
Fig. 2. Radiation of the single-layer urban canopy model. S_D is the direct solar radiation incident on a horizontal surface. l_{road} is the normalized road width and h_c is the normalized building height ($l_{roof} + l_{road} = 1$). l_{shadow} is the normalized shadow length on the road.

Model Improvement: land use (vegetation)



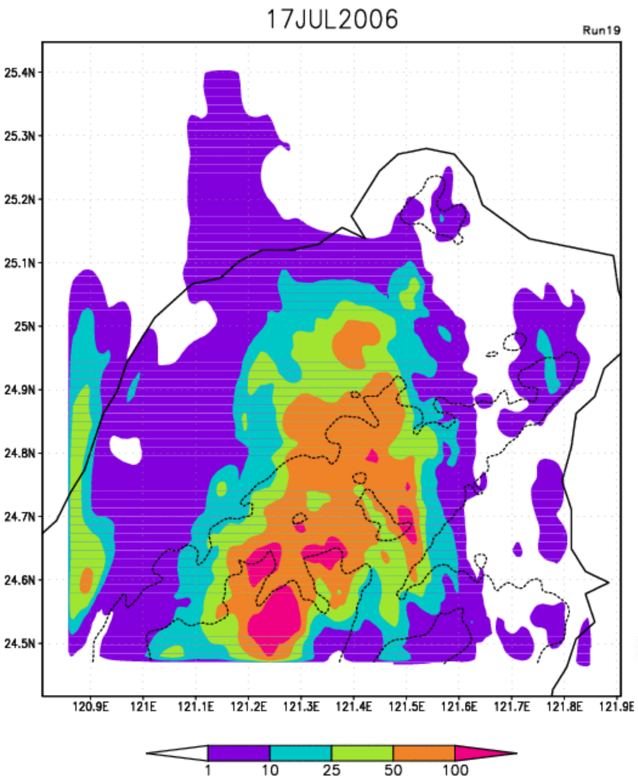
MODIS

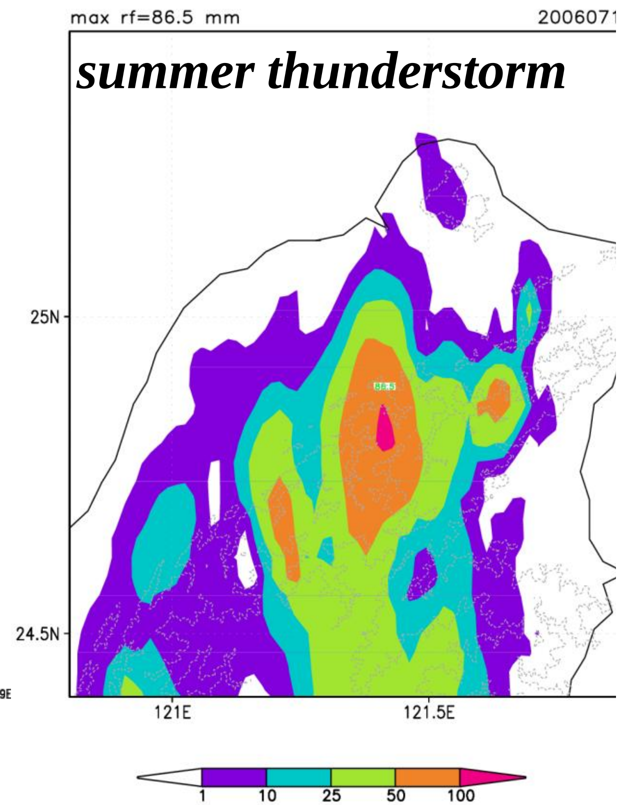
Using realistic land use improves afternoon thunderstorm simulation

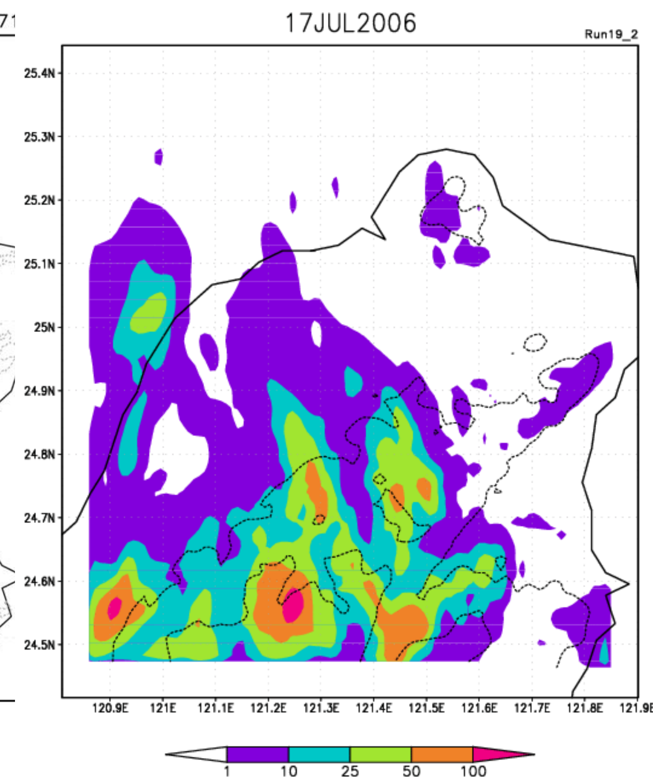


Original
WRF-USGS

Observation

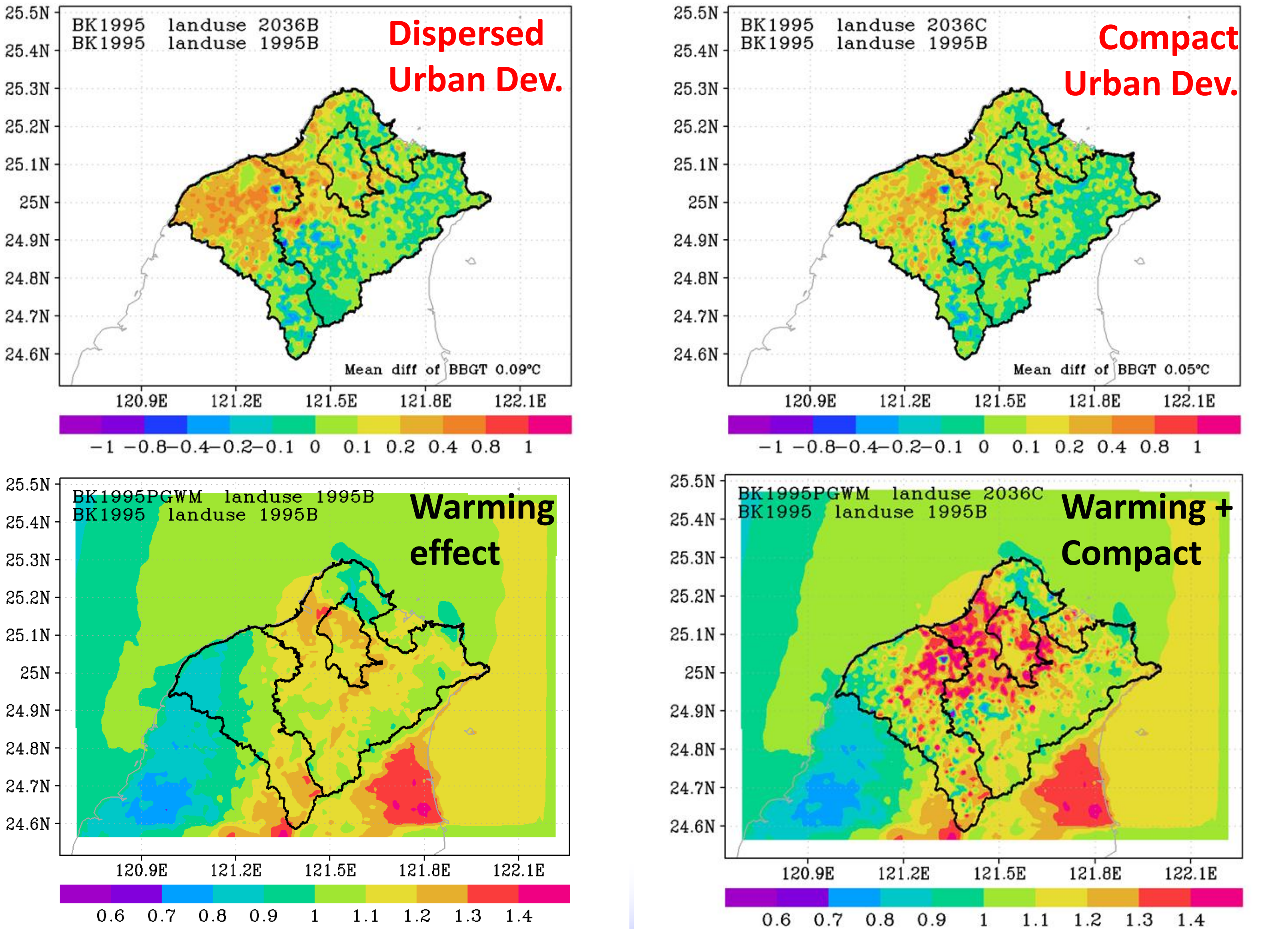






(Lin et al. 2011, JAMC)

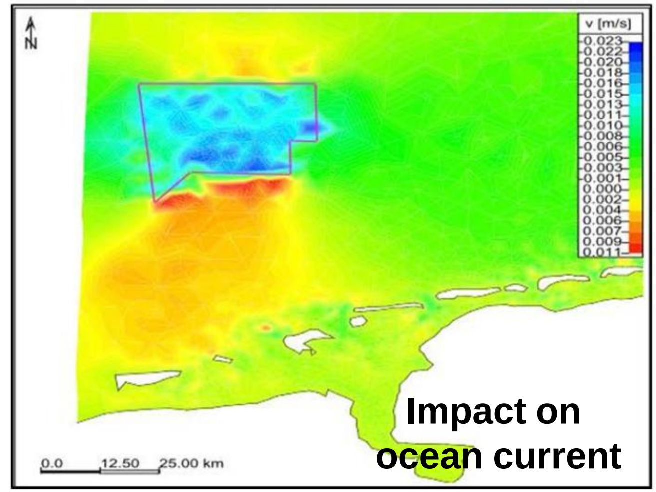
Combined effect of urban development and global warming

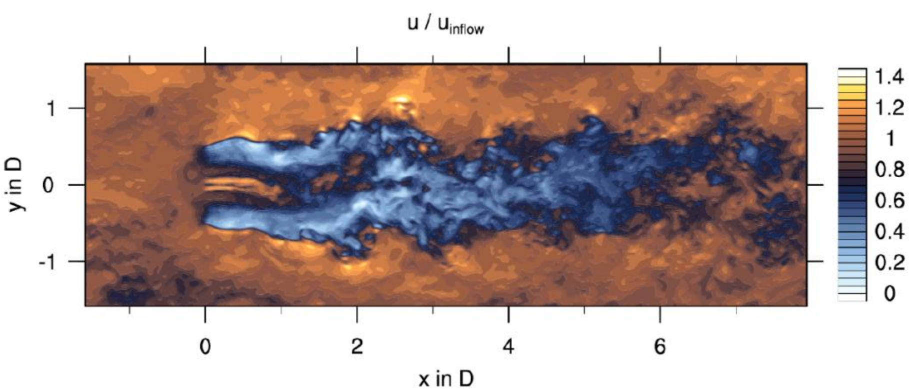


氣候變遷與都市發展/土地利用研究（永續中心計畫）

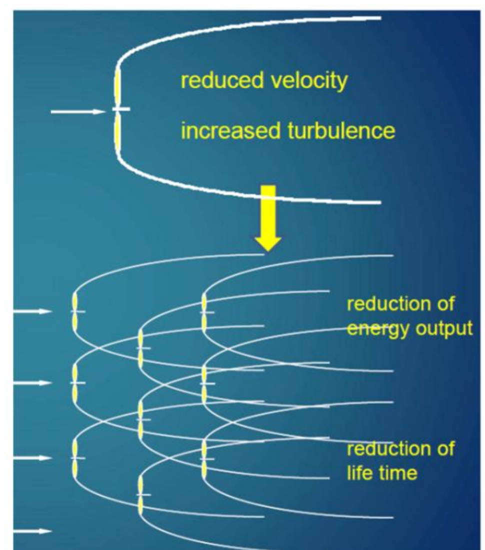
1,000 wind farm to be installed in Taiwan Strait

- Environmental impacts?
- Efficiency and prediction of wind power?



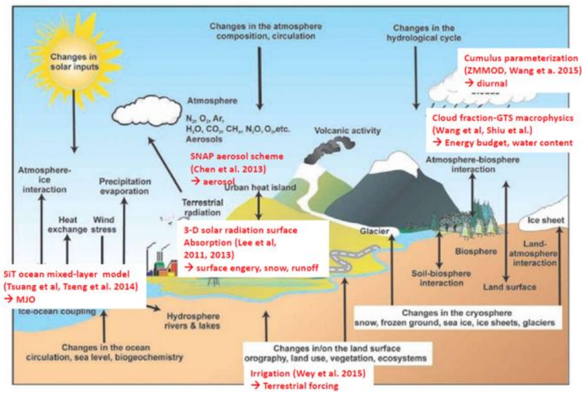


LES enables analysis of wake dynamics



Cross-scale Climate Modeling System

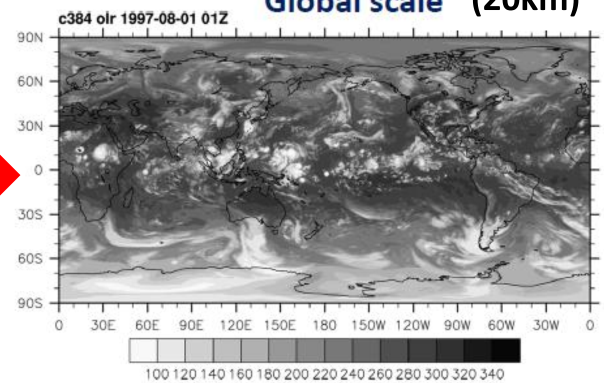
Earth scale – TaiESM
(100-200km)



CCliCS

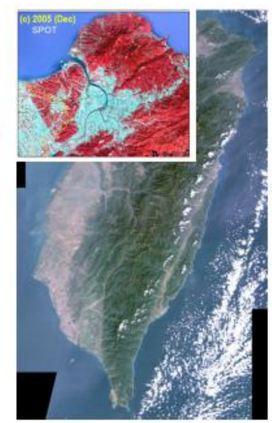
Global-Regional-Urban Climate Modeling

Global scale (20km)



Regional scale (5-10km)

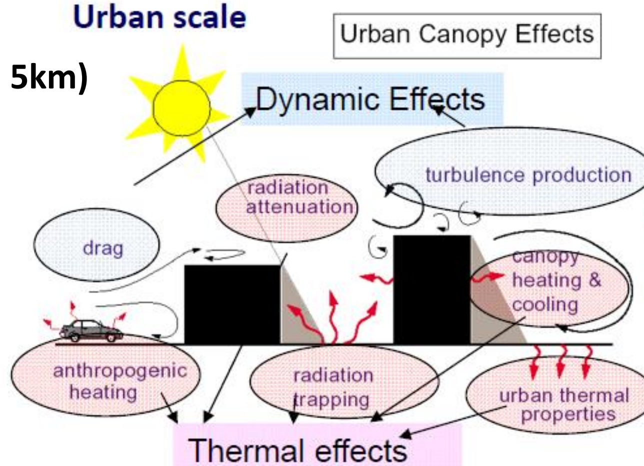
Local scale



TCCIP

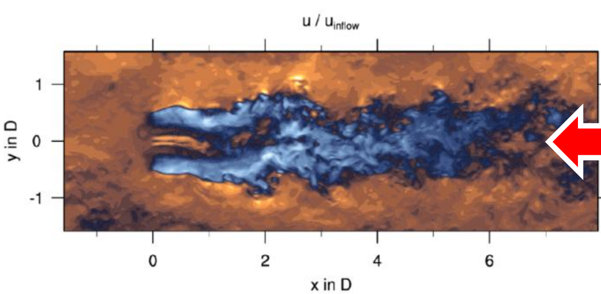
Urban scale

(< 5km)



RCEC/AS

Large eddy scale (< 1km)



LES enables analysis of wake dynamics

Thank you for Your Attention

LABORATORY FOR CLIMATE CHANGE RESEARCH

CCliCS

Computing & Storage Demand (Basic)
(ALPS: 177 T-Flops, 25,600 CPUs, 225M SU/yr)

MIPs	Model	Computing	Storage
CMIP6 (DECK)	TaiESM 1º 991 model years	4.31M SU (8*544 SU/yr)	60TB (60GB/yr)
HighResMIP	HiRAM C192 & C384 66 model years (Tier 1 only, no DECK)	4.84M SU (73,344 SU/yr)	370TB ((4.6+1)TB/yr)
PMIP	TaiESM 1º 200 model years	0.87M SU	12TB
CFMIP	TaiESM 1º 174 model years	0.76M SU	10.4TB
AerChemMIP	TaiESM 1º 600 yrs AMIP+1274 yrs coupled	8.11M SU	112.4TB
GMMIP	TaiESM 1º 144 yrs AMIP	0.63M SU	0.86TB
GMMIP	*HiRAM C192* *80 yrs extra from HighResMIP*	*0.68M SU* *(8,448 SU/yr)*	*80 TB* *(1TB/yr)*
Total	**GMMIP - TaiESM 1º** **(GMMIP - HiRAM C192)**	**19.52M SU** **(19.57M SU)**	**566TB** **(645TB)**