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Activities and first results of WP3 (Climate Research)

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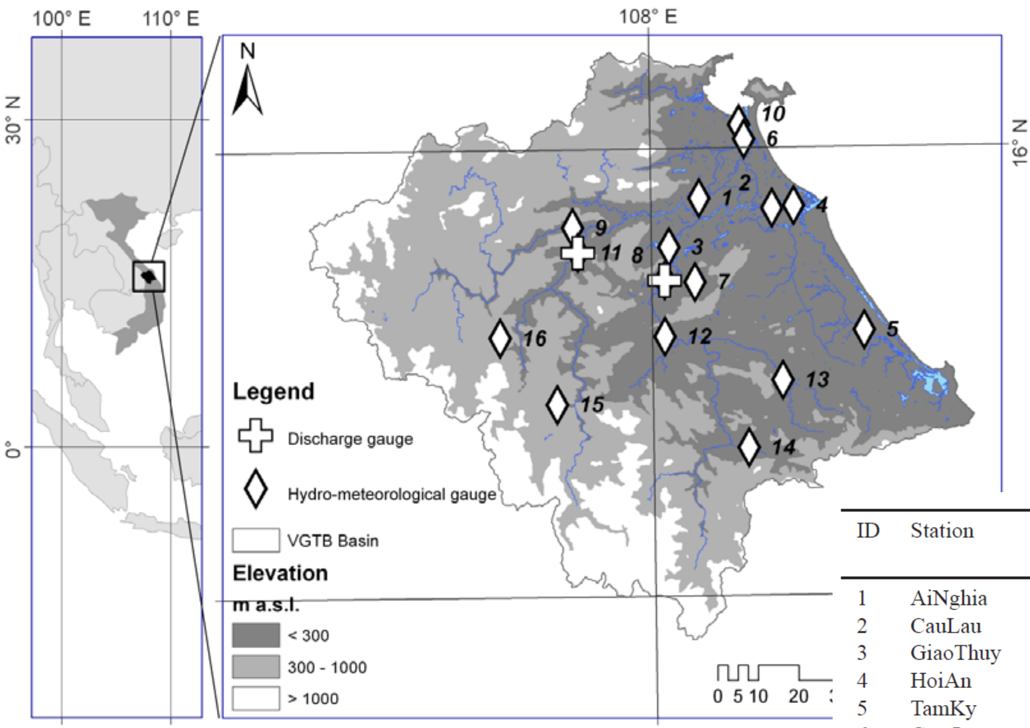
Outline

- **Analysis of observation data**
  - ✓ Availability of data
  - ✓ Historical trend analysis

- **Process-based *Regional Climate Model* simulations**
  - ✓ Motivation: WHY? and HOW?
  - ✓ Introduction to WRF
  - ✓ Preparation transient RCM climate simulations
  - ✓ Work progress

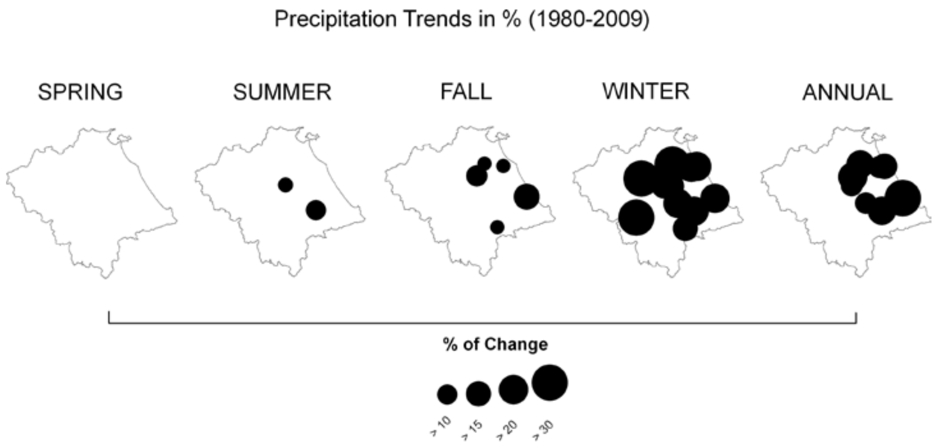
- **Further activities**
  - ✓ Analysis LUC on climate (“what-if” scenarios)
  - ✓ Statistical Downscaling

Availability Observation Data



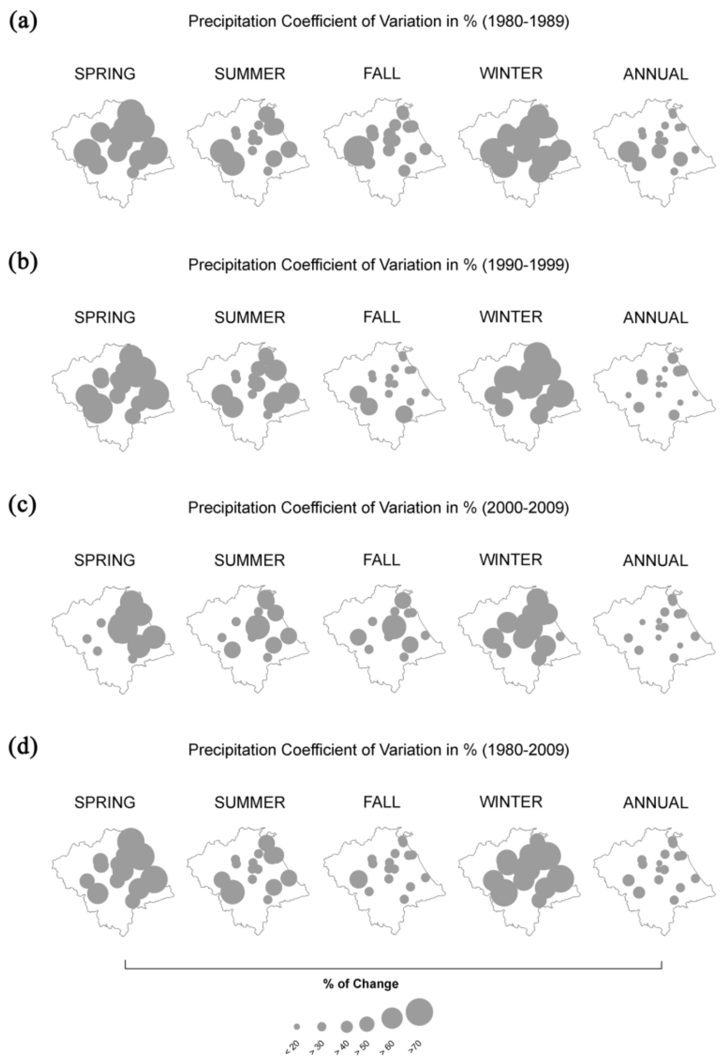
ID	Station	Longitude [°E.]	Latitude [°N.]	Altitude [m a.s.l.]	Data Availability Precipitation	Temperature	Discharge
1	AiNghia	108.12	15.88	6	1976-2009		
2	CauLau	108.28	15.85	5	1976-2009		
3	GiaoThuy	108.13	15.85	5	1976-2009		
4	HoiAn	108.33	15.87	5	1976-2009		
5	TamKy	108.5	15.55	5	1977-2009	1977 - 2009	
6	CamLe	108.2	16.00	6	1976-2009		
7	QueSon	108.1	15.70	7	1977-2006		
8	NongSon	108.03	15.70	9	1976-2009		1976-2009
9	HoiKhach	107.82	15.82	18	1976-2009		
10	DaNang	108.18	16.03	23	1976-2009	1976-2009	
11	ThanhMy	107.83	15.77	24	1976-2009		1976-2009
12	SonTan	108.03	15.57	53	1976-2009		
13	TienPhuoc	108.3	15.48	58	1977-2009		
14	TraMy	108.25	15.33	135	1977-2009	1977-2009	
15	KhamDuc	107.78	15.43	393	1978-2009		
16	Hien (Trao)	107.65	15.59	420	1978-2009		

Historical Trend Analysis (P, T_{min}, T_{max}, R)



ID	Station	Sen's slope [mm/year] 1980-1989	1990-1999	2000-2009
1	AiNghia	-127*	117	116
2	CauLau	-73	64	98
3	GiaoThuy	-103	14	54
4	HoiAn	-59	49	19
5	TamKy	-116	203*	77
6	CamLe	-121+	145	NA
7	QueSon	-115	82*	-219
8	NongSon	-148*	175*	35
9	HoiKhach	-114*	NA	60
10	DaNang	-101	59+	32
11	ThanhMy	-103*	189*	4
12	SonTan	-128+	129+	79
13	TienPhuoc	-69	166*	NA
14	TraMy	-126	112	111
15	KhamDuc	-200	140	190
16	Hien (Trao)	-286**	34	146

Decadal Rainfall Variability



$$C_V = \frac{\sigma}{\mu}$$

Motivation: why do we need process-based RCM simulations?

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- **Sparse observation network of hydrometeorological data**
  - ➢ Few hydrometeorological stations (located in lowlands)
  - ➢ Low sampling rates (daily)

- **Stakeholders demand delineation of climate change adaptation strategies**
  - ➢ Flood protection measures (adaptation of infrastructure)
  - ➢ Future hydropower potential (low flows)
  - ➢ Water availability for agriculture

→ High resolution spatial and temporal distribution of future hydrometeorological variables (P, T, etc.)

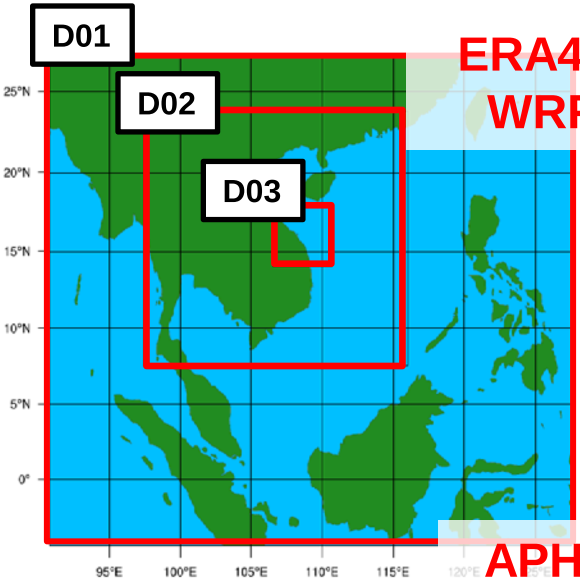
Motivation: why do we need RCM simulations?

JAN 1960

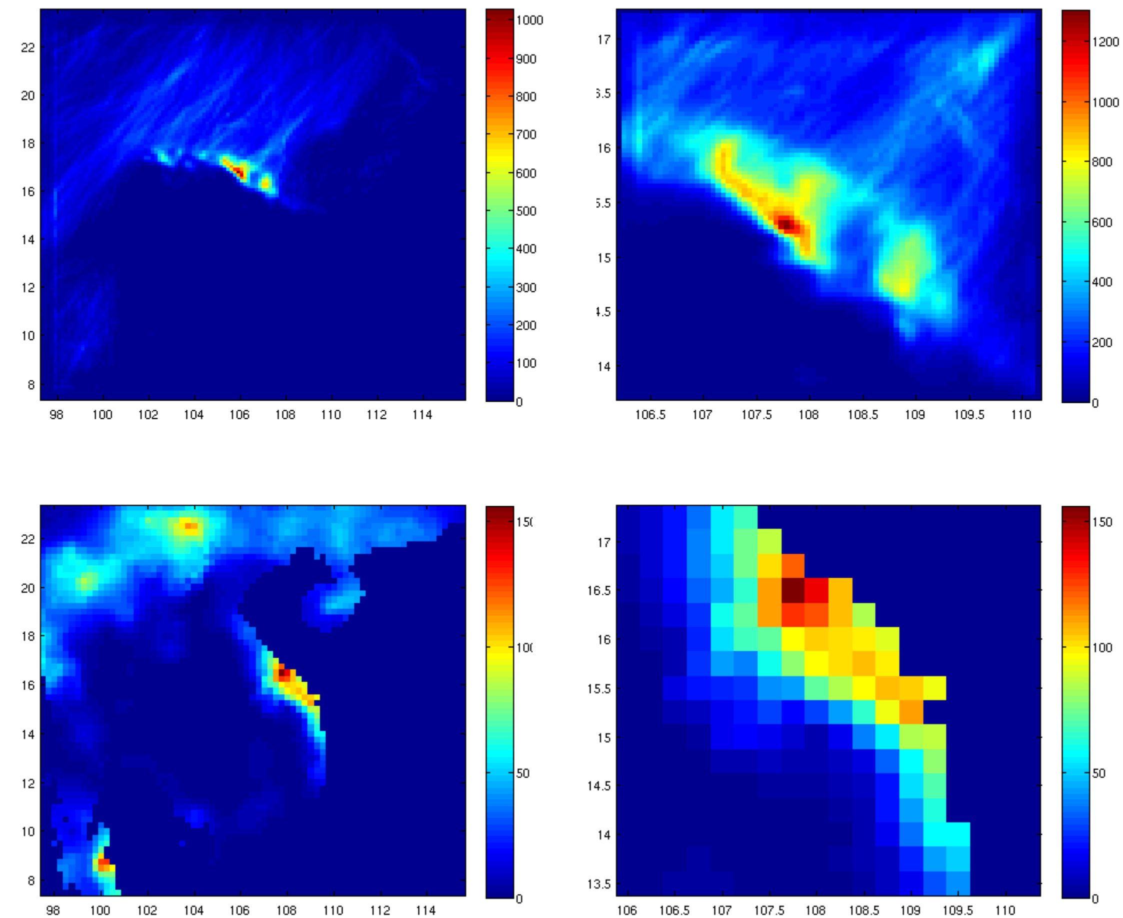
D02

D03

ERA40-WRF



APH



How to derive Regional Climate Projections?

Population Growth Economic Development
Technological Progress

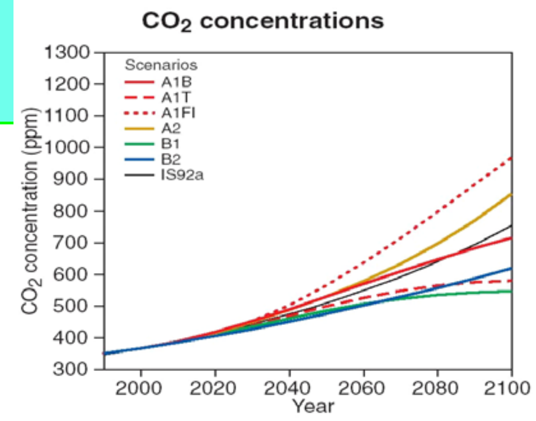
Emission Scenarios
Greenhouse Gas Concentrations

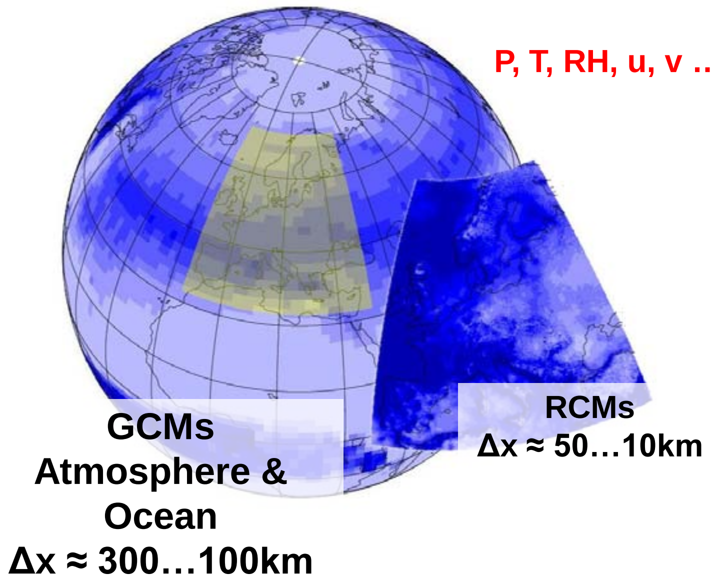
Global Climate Models

Global Climate Scenarios

Downscaling Methods

Regional Climate Scenarios

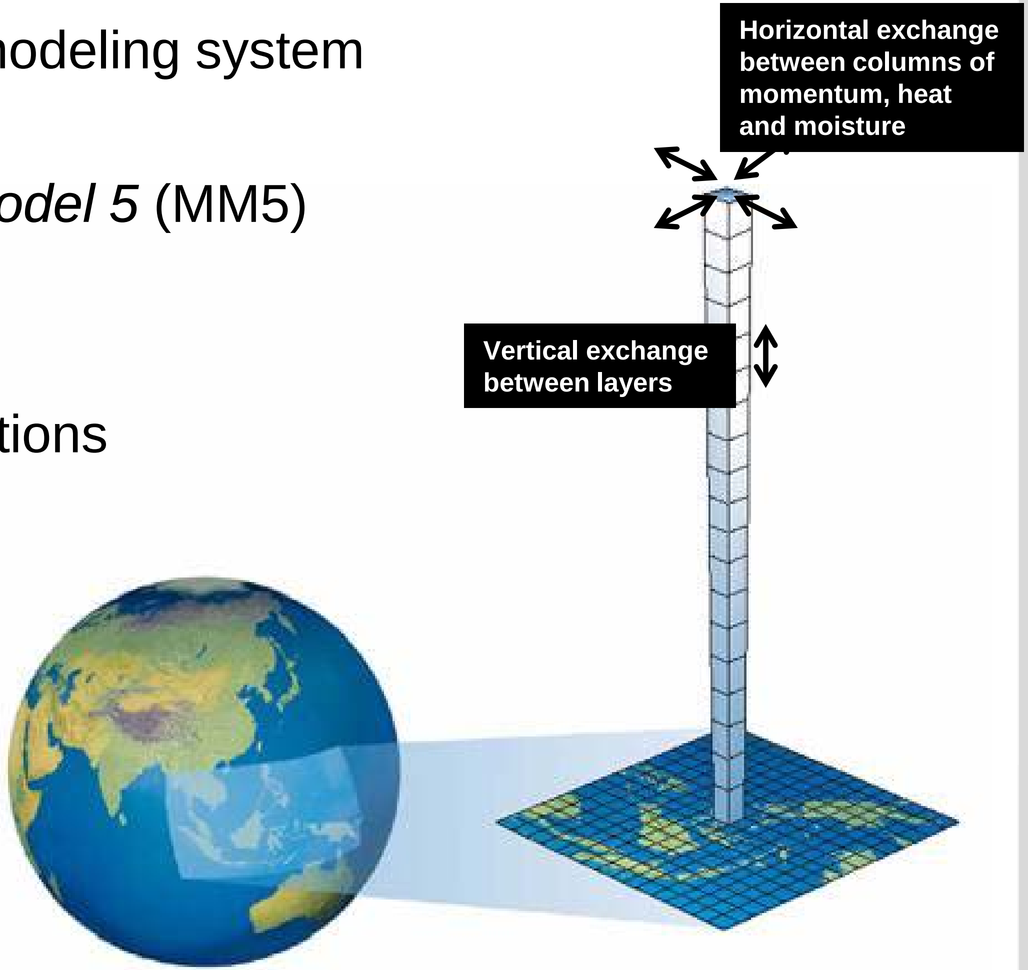




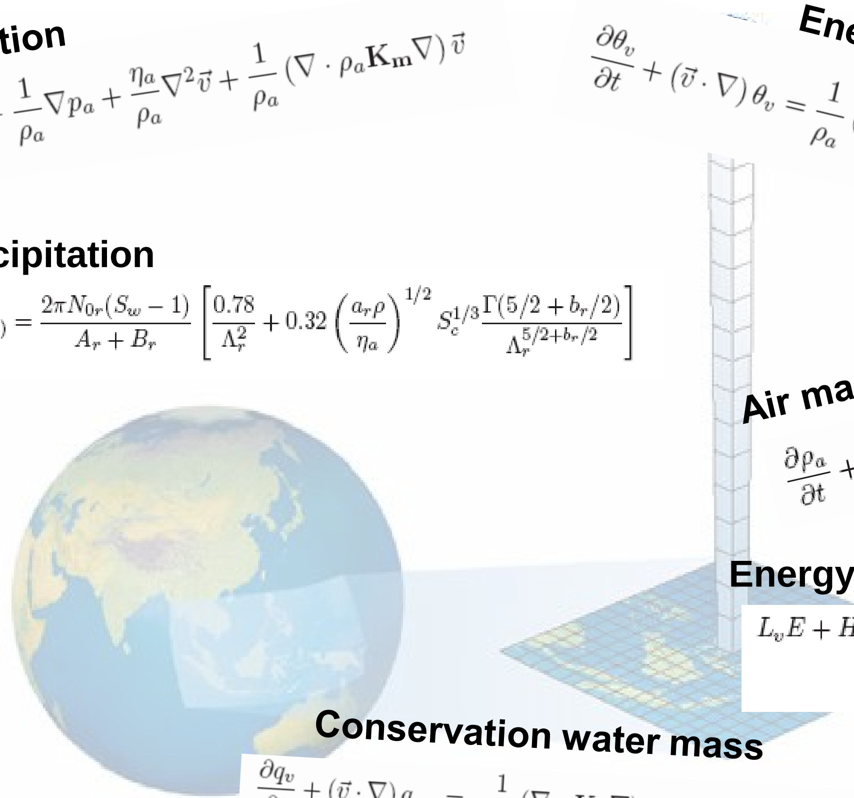
WRF (*<u>W</u>eather <u>R</u>esearch and <u>F</u>orecast Model*)

Atmospheric compartment

- Next generation atmospheric modeling system
- Developed at NCAR
- Successor of the *Mesoscale Model 5* (MM5)
- Various applications:
  - ✓ Weather forecasts
  - ✓ (Long-term) climate simulations
  - ✓ Different scales
- Atmospheric and (sub)surface compartments:



Atmosphere – explicit calculation of



Momentum conservation

$$\frac{\partial \vec{v}}{\partial t} + (\vec{v} \cdot \nabla)\,\vec{v} = -f\vec{k} \times \vec{v} - \nabla\Phi - \frac{1}{\rho_a}\nabla p_a + \frac{\eta_a}{\rho_a}\nabla^2 \vec{v} + \frac{1}{\rho_a}(\nabla \cdot \rho_a \mathbf{K_m} \nabla)\,\vec{v}$$

Energy conservation

$$\frac{\partial \theta_v}{\partial t} + (\vec{v} \cdot \nabla)\,\theta_v = \frac{1}{\rho_a}(\nabla \cdot \rho_a \mathbf{K_h} \nabla)\,\theta_v + \frac{\theta_v}{c_{p,d} T_v}\sum_{n=1}^{N} \frac{dQ_n}{dt}$$

Precipitation

$$R_{evap\ (rain)} = \frac{2\pi N_{0r}(S_w - 1)}{A_r + B_r}\left[\frac{0.78}{\Lambda_r^2} + 0.32\left(\frac{a_r \rho}{\eta_a}\right)^{1/2} S_c^{1/3} \frac{\Gamma(5/2 + b_r/2)}{\Lambda_r^{5/2+b_r/2}}\right]$$

Air mass conservation

$$\frac{\partial \rho_a}{\partial t} + \nabla \cdot (\vec{v}\rho_a) = 0$$

Gas law

$$p = \frac{nR^*T}{V}$$

Energy conservation at land surface

$$\begin{aligned} L_v E + H + G &= SW_{net} + LW_{net} \\ &= (1-\alpha) SW\downarrow + LW\downarrow - \epsilon\, \sigma_B\, T_{surf}^4 \end{aligned}$$

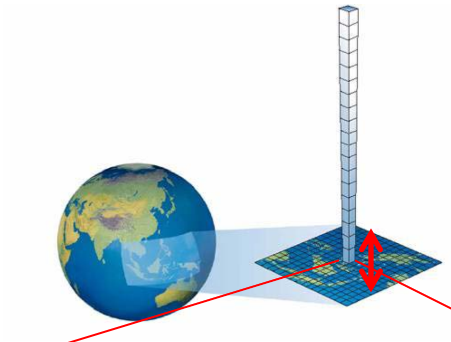
Soil temperature diffusion

$$C_v(\Theta)\frac{\partial T_s}{\partial t} = \frac{\partial}{\partial z}\left[K_t(\Theta)\frac{\partial T_s}{\partial z}\right]$$

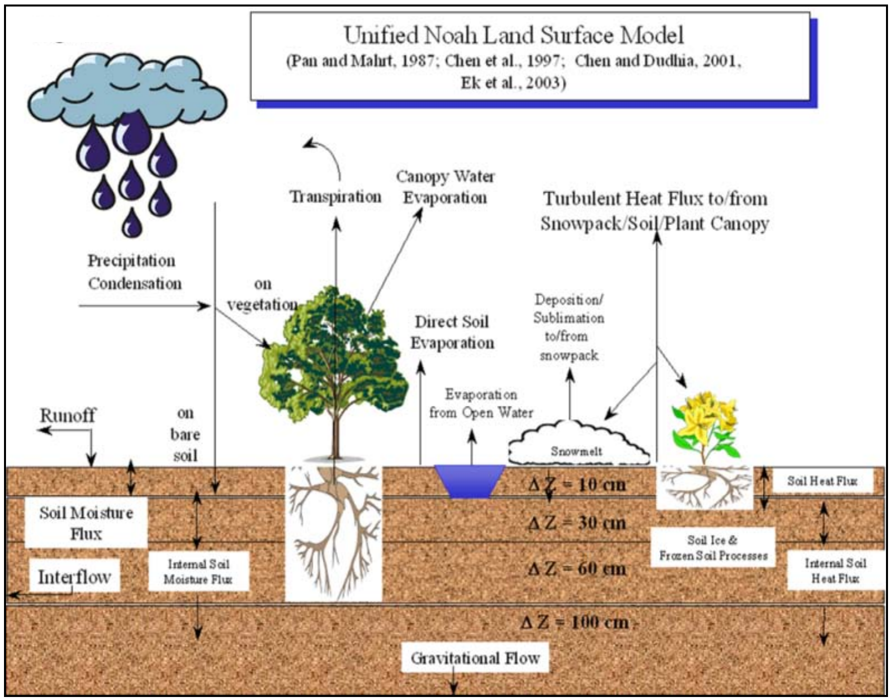
Conservation water mass

$$\begin{aligned} \frac{\partial q_v}{\partial t} + (\vec{v} \cdot \nabla)\,q_v &= \frac{1}{\rho_a}(\nabla \rho_a \mathbf{K_h} \nabla)\,q_v + R_{evap} - R_{cond} - R_{iini} - R_{idep/sub} \\ \frac{\partial q_c}{\partial t} + (\vec{v} \cdot \nabla)\,q_c &= \frac{1}{\rho_a}(\nabla \rho_a \mathbf{K_h} \nabla)\,q_c + R_{cond} + R_{iini} + R_{idep/sub} - R_{aconv} - R_{accr} \\ \frac{\partial q_r}{\partial t} + (\vec{v} \cdot \nabla)\,q_r &= \frac{1}{\rho_a}(\nabla \rho_a \mathbf{K_h} \nabla)\,q_r - R_{evap} + R_{aconv} + R_{accr} - \frac{\partial V_f \rho_a g q_r}{\partial z} \qquad (2.32) \end{aligned}$$

WRF – (sub)surface compartment



Surface and subsurface compartment



- Lower boundary: SVAT-model for surface and subsurface water budgets
- **Joint atmospheric-terrestrial water budget calculations**

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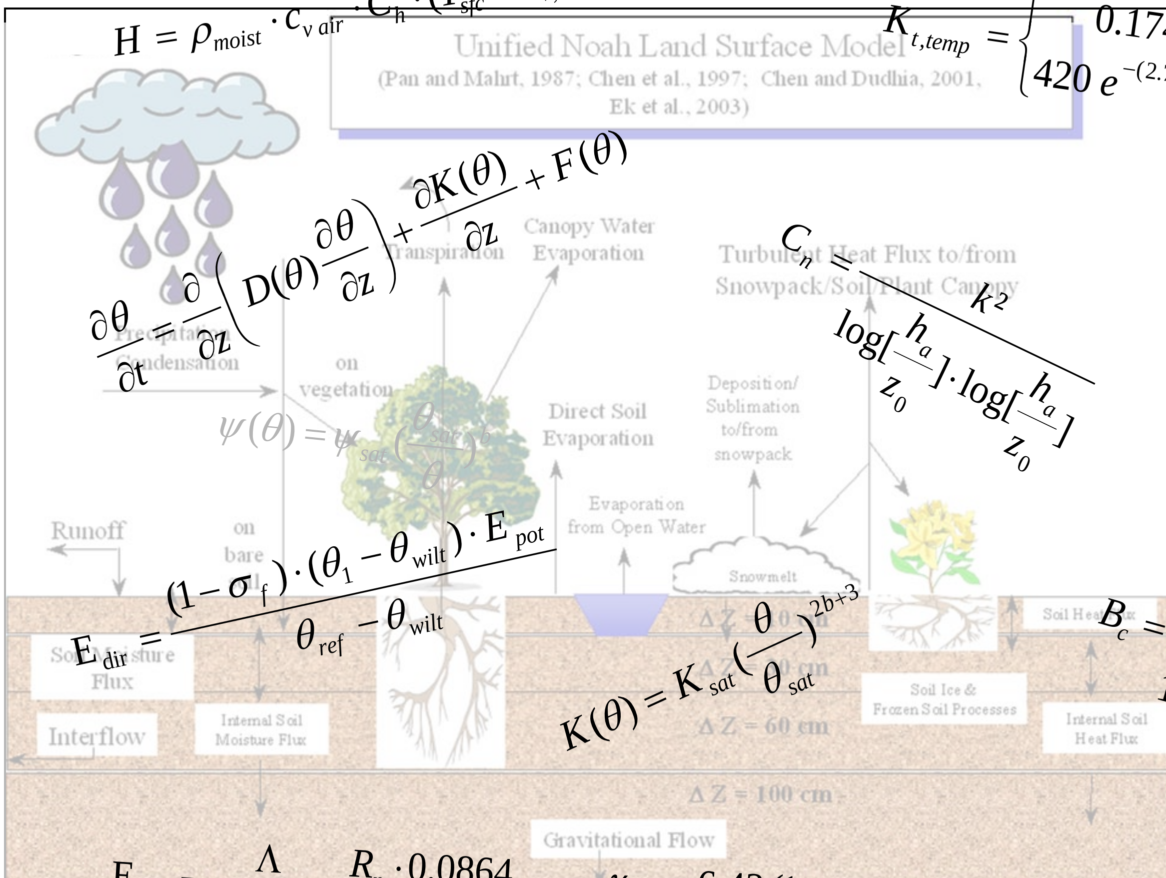
Model Equations NOAH LSM



$$H = \rho_{moist} \cdot c_{v\,air} \cdot C_h \cdot (T_{sfc} - T_{v,a})$$

$$K_{t,temp} = \begin{cases} 0.174 & If[P_f > 5.1 \; or \; P_f < 0] \\ 420\, e^{-(2.7+P_f)} & else \end{cases}$$

$$\frac{\partial\theta}{\partial t} = \frac{\partial}{\partial z}\left(D(\theta)\frac{\partial\theta}{\partial z}\right) + \frac{\partial K(\theta)}{\partial z} + F(\theta)$$

$$C_h = \frac{k^2}{\log[\frac{h_a}{z_0}] \cdot \log[\frac{h_a}{z_0}]}$$

$$\psi(\theta) = \psi_{sat}\left(\frac{\theta_{sat}}{\theta}\right)^b$$

$$D(\theta) = K(\theta)\frac{\partial\psi}{\partial\theta}$$

$$E_{dir} = \frac{(1-\sigma_f)\cdot(\theta_1 - \theta_{wilt})\cdot E_{pot}}{\theta_{ref} - \theta_{wilt}}$$

$$K(\theta) = K_{sat}\left(\frac{\theta}{\theta_{sat}}\right)^{2b+3}$$

$$B_c = \frac{1 + \frac{\Lambda_{q_{sat}}}{R_r}}{1 + R_c \cdot C_h + \frac{\Lambda_{q_{sat}}}{R_r}}$$

$$E_{pot} = \frac{\Lambda}{(\Lambda+\gamma)} \cdot \frac{R_n \cdot 0.0864}{\lambda} + \frac{\gamma}{(\Lambda+\gamma)} \cdot \frac{6.43\,(1+0.536\,v_a)}{\lambda}(e_{sat} - e)$$

$$C_v(\theta)\frac{\partial T}{\partial t} = \frac{\partial}{\partial z}\left[K_i(\theta)\frac{\partial T}{\partial z}\right]$$

WRF Modeling System

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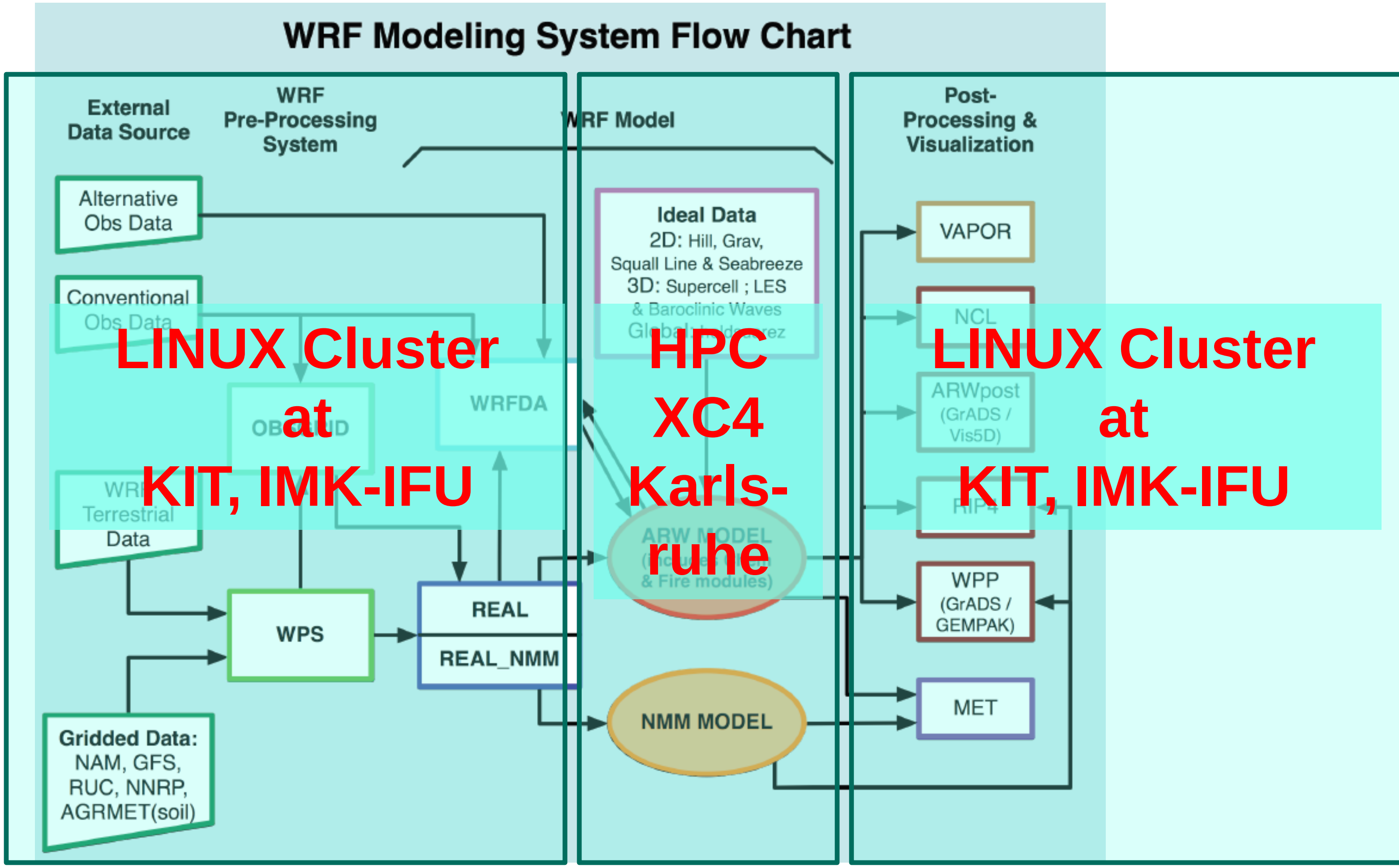

Preparation RCM Simulations: HPC Environment

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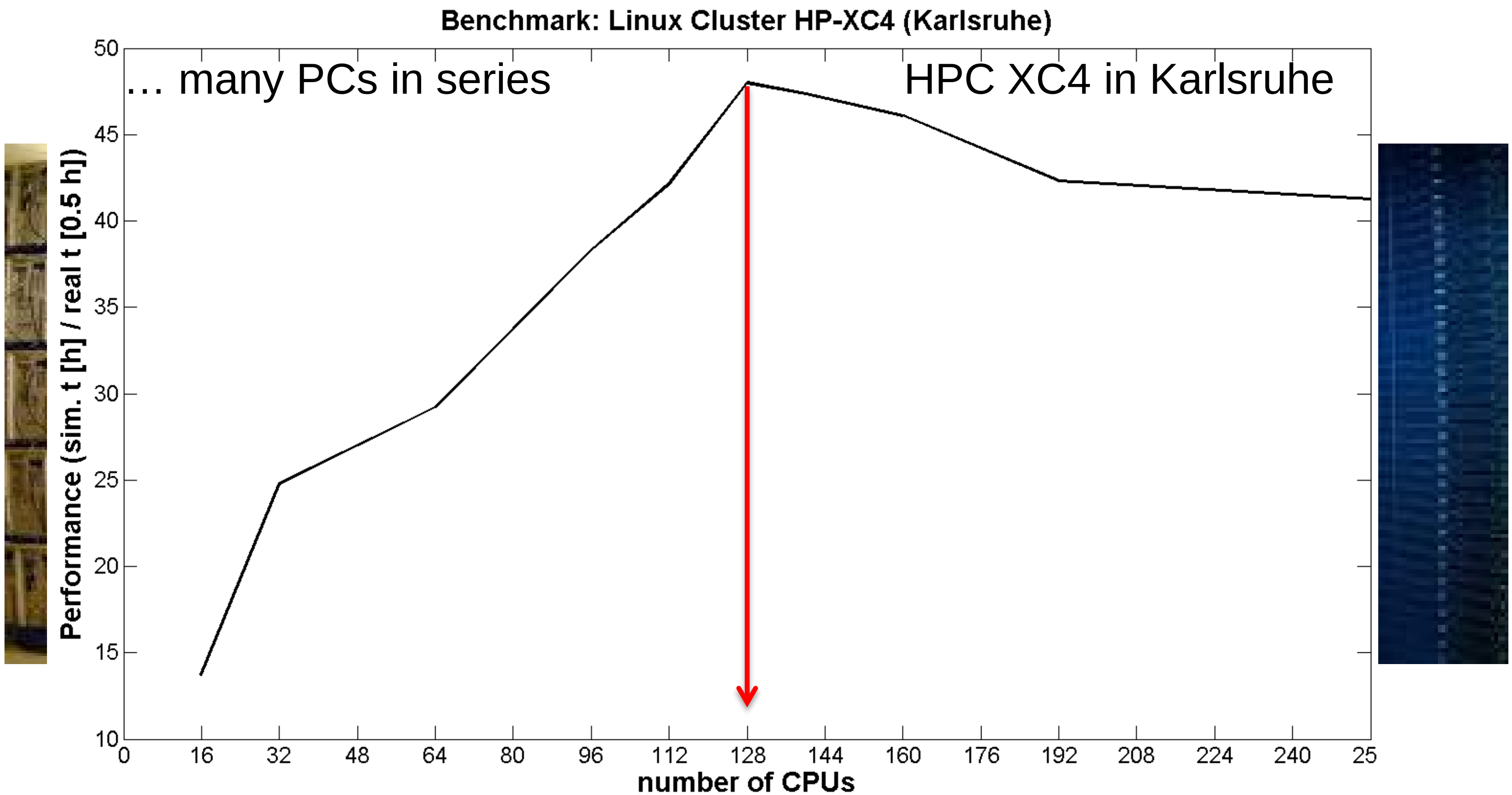
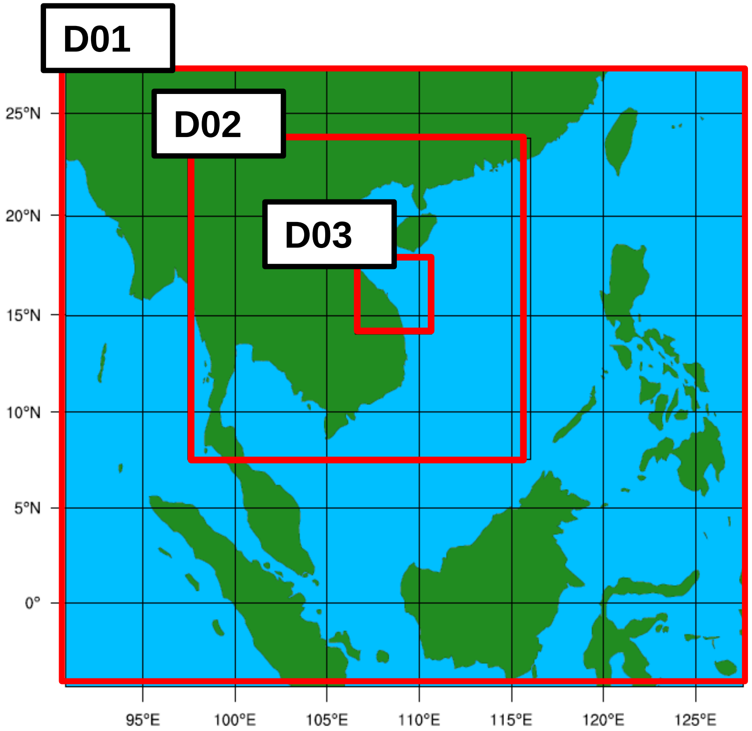


- **Peak performance using 128 CPUs**
- **Depends on CPUs, Compiler (options), but also WRF setup**

WRF Setup



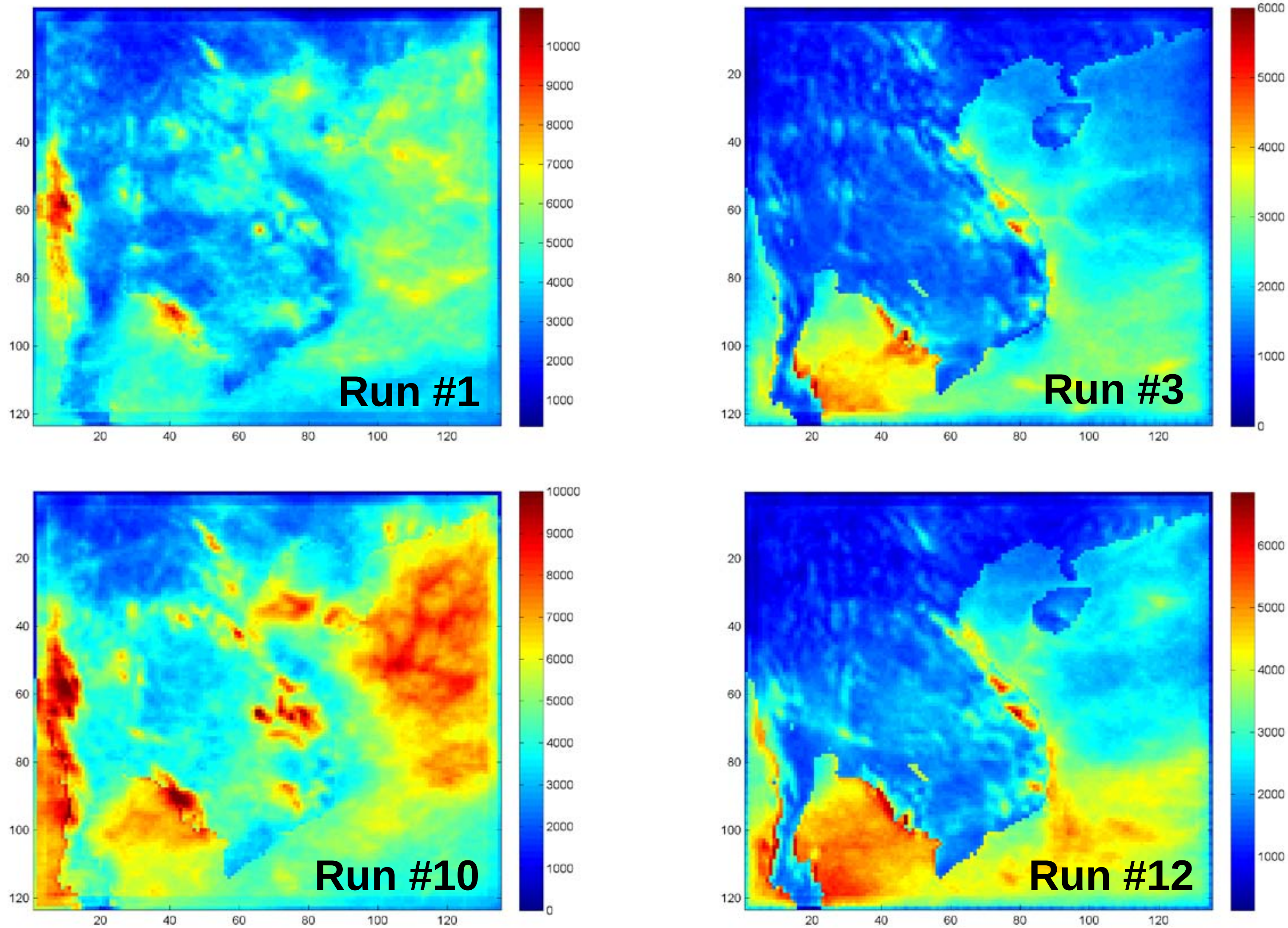
Domain1:
- horizontal: 99 x 99 grid points with a resolution of **45 km**
- vertical: 50 layers up to 5000 Pa
- time step: 180 s

Domain2:
- horizontal: 142 x 145 grid points with a resolution of **15 km**
- vertical: 50 layers up to 5000 Pa
- time step: 120 s

Domain3:
- horizontal: 66 x 75 grid points with a resolution of **5 km**
- vertical: 50 layers up to 5000 Pa
- time step: 40 s

WRF results strongly depend on subgridscale parameterizations

Comparison Parameterization Runs: P



Systematic WRF Experiments: Focus on P

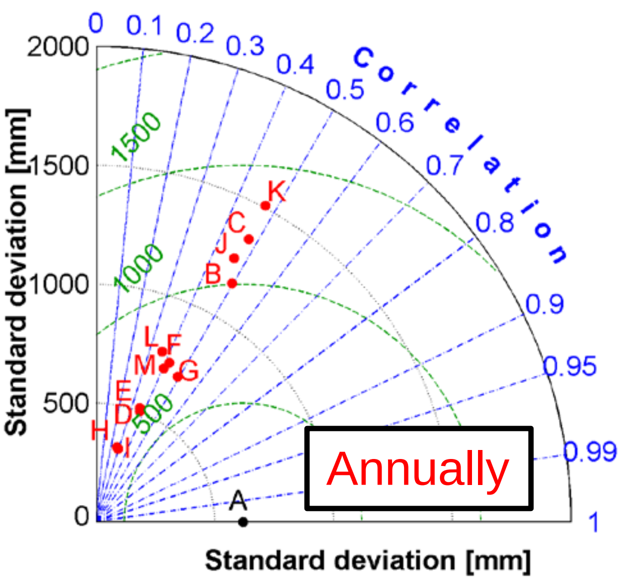
- 12 Combinations using 3 MP, 2 PBL and 2 CU schemes
- 2 Combinations using NCEP & ERA40 Reanalyses

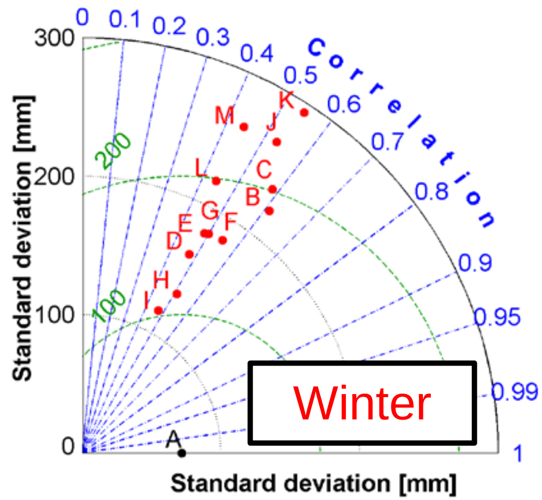
→ 2 x 12 = **24 WRF simulation for 2000**

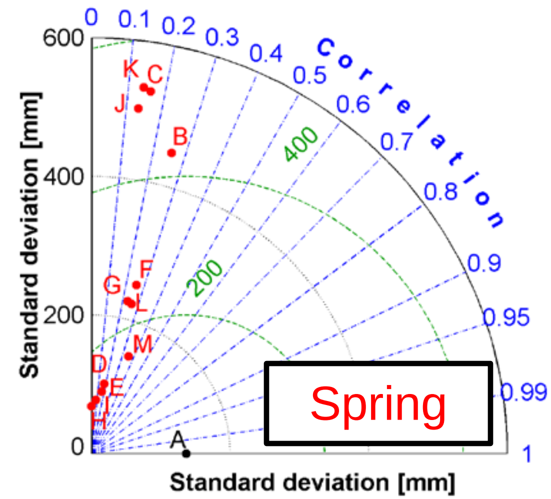
Run	Microphysic schemes	PBL physic schemes	Cumulus physic schemes
B	Lin et al.	Hong et al.	Betts-Miller-Janjic
C	Lin et al.	Nakanishi and Niino	Betts-Miller-Janjic
D	Lin et al.	Nakanishi and Niino	New SAS
E	Lin et al.	Hong et al.	New SAS
F	WRF Single-Moment 3-class	Hong et al.	Betts-Miller-Janjic
G	WRF Single-Moment 3-class	Nakanishi and Niino	Betts-Miller-Janjic
H	WRF Single-Moment 3-class	Hong et al.	New SAS
I	WRF Single-Moment 3-class	Nakanishi and Niino	New SAS
J	WRF Double-Moment 6-class	Hong et al.	Betts-Miller-Janjic
K	WRF Double-Moment 6-class	Nakanishi and Niino	Betts-Miller-Janjic
L	WRF Double-Moment 6-class	Nakanishi and Niino	New SAS
M	WRF Double-Moment 6-class	Hong et al.	New SAS

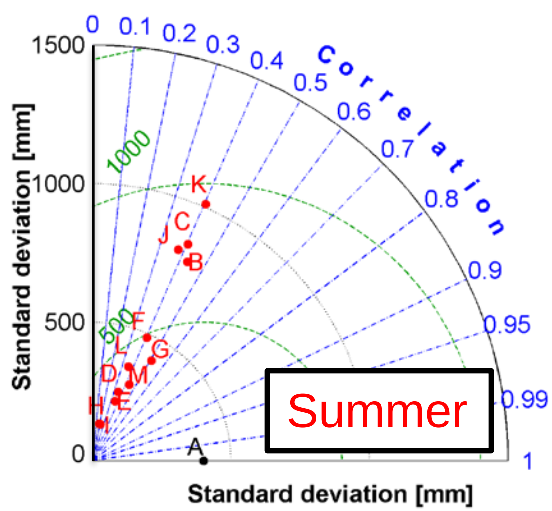
Validation ERA40-WRF 2000 Experiments: P

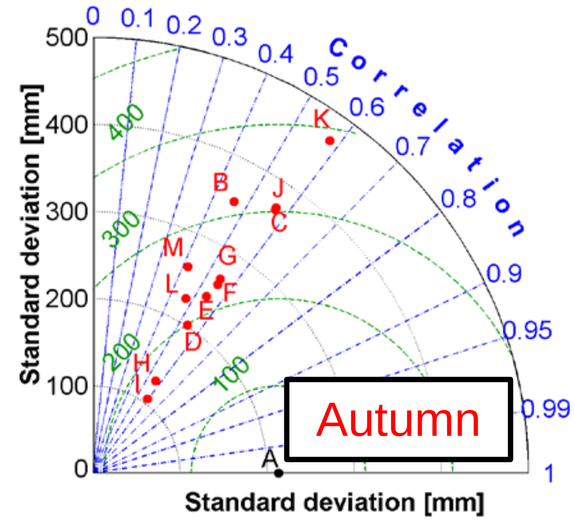
A: APHRODITE data







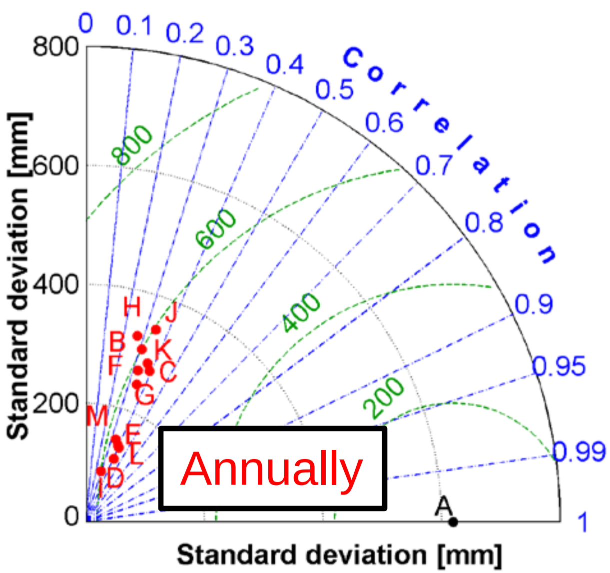


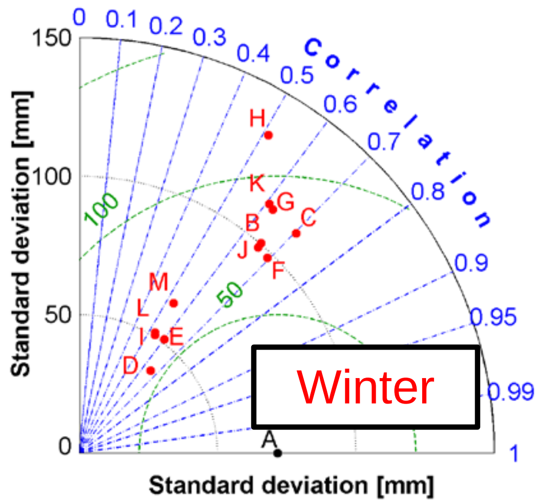


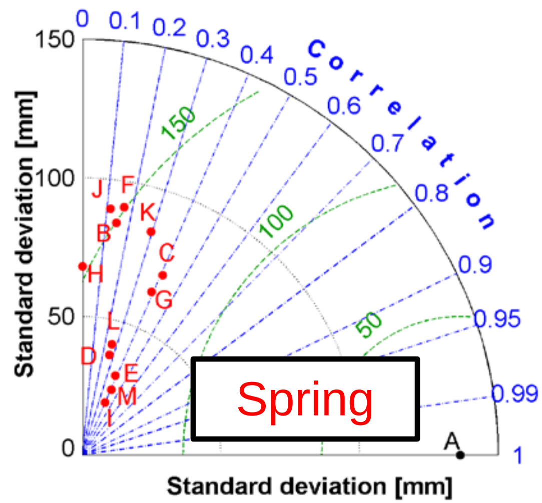
Pearson Correlation Coefficient
Root Mean Squared Error
Standard Deviation

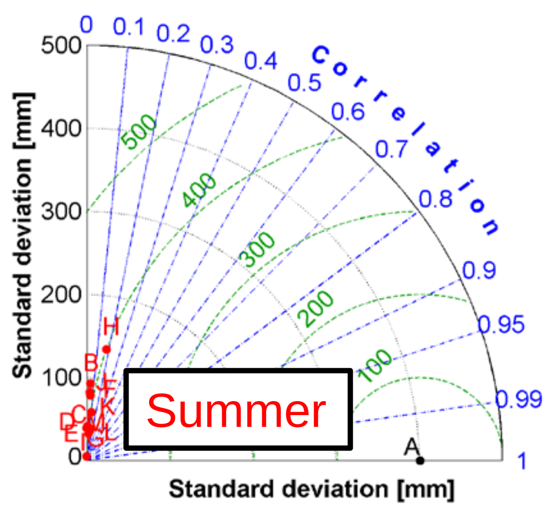
Validation NCEP-WRF 2000 Experiments: P

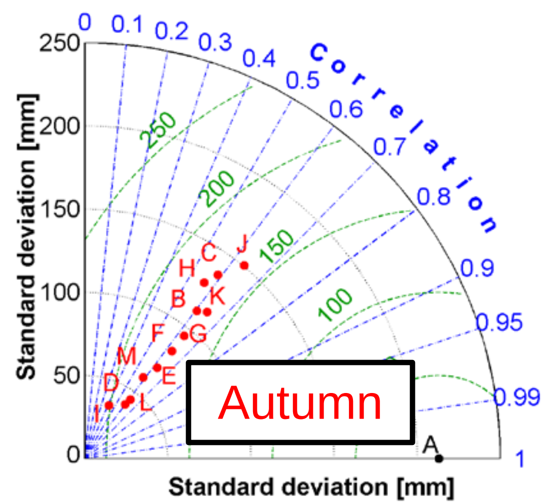
A: APHRODITE data







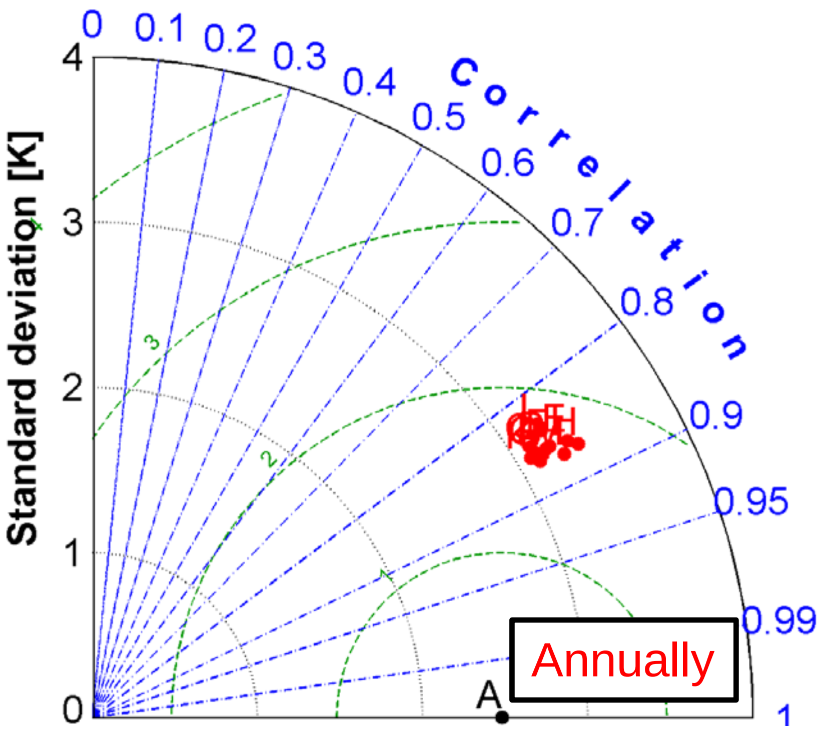




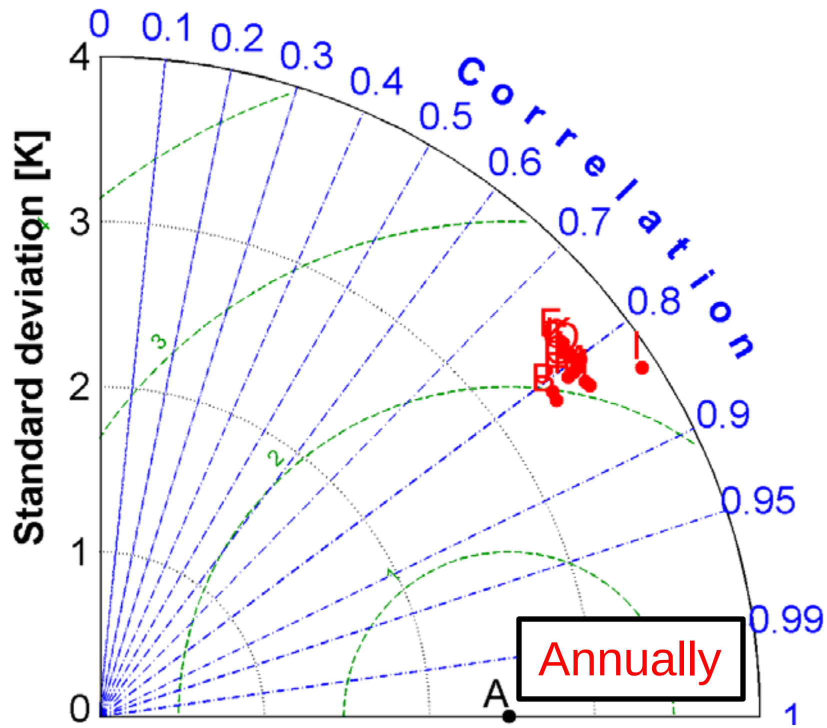
Pearson Correlation Coefficient
Root Mean Squared Error
Standard Deviation

Validation WRF 2000 Experiments: T2

A: CRU data



ERA40



NCEP

Final Decision (based on simulated T, P)

- **ERA40 Reanalysis**
  - Lower bias in T
  - Higher pattern correlation of P (summer)

Run	Microphysic schemes	PBL physic schemes	Cumulus physic schemes
B	Lin et al.	Hong et al.	Betts-Miller-Janjic
C	Lin et al.	Nakanishi and Niino	Betts-Miller-Janjic
D	Lin et al.	Nakanishi and Niino	New SAS
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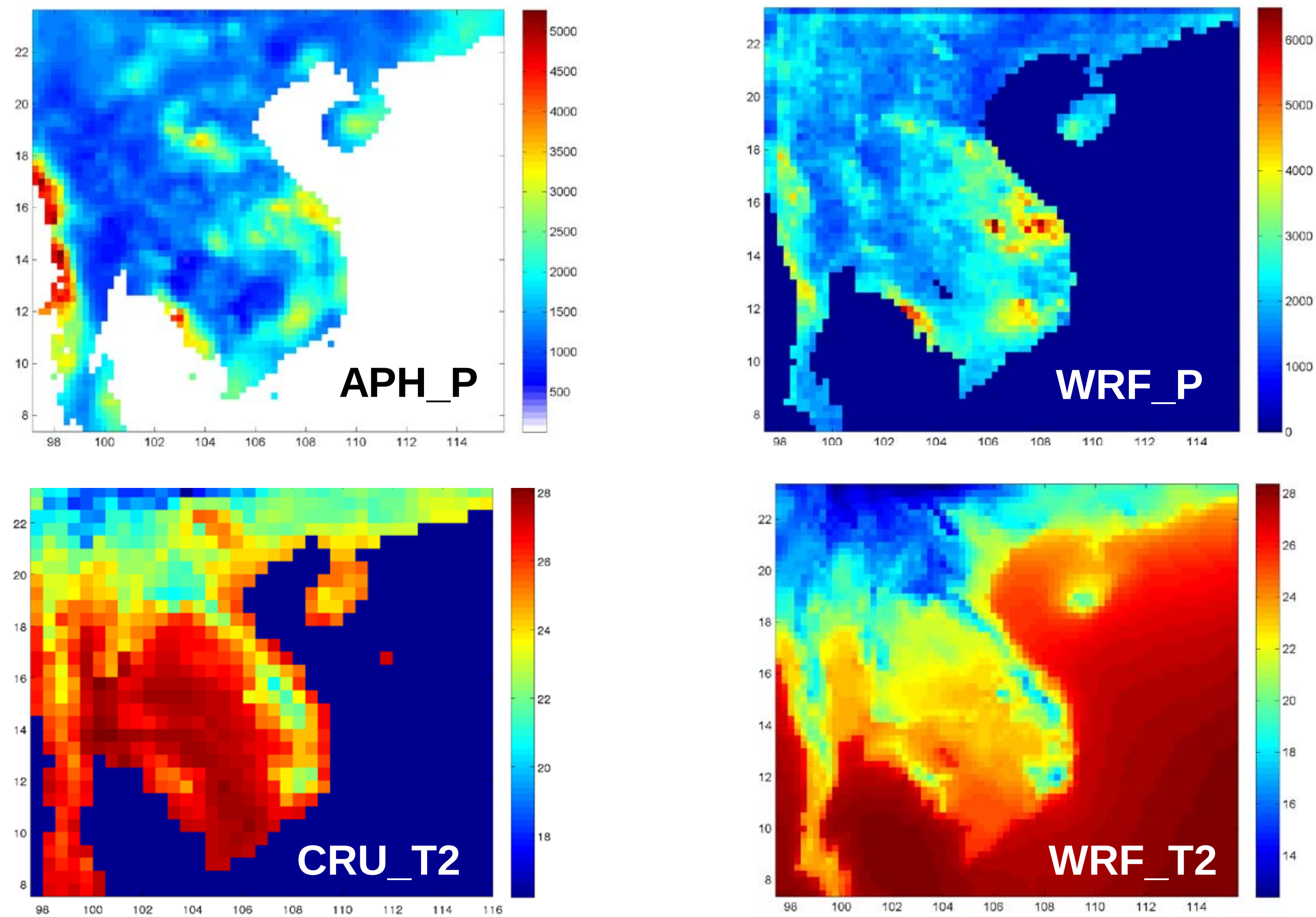
L	WRF Double-Moment 6-class	Nakanishi and Niino	New SAS
M	WRF Double-Moment 6-class	Hong et al.	New SAS

ERA40-WRF vs. OBSERVATIONS D1 (P, T2)



Different Reference Datasets: P

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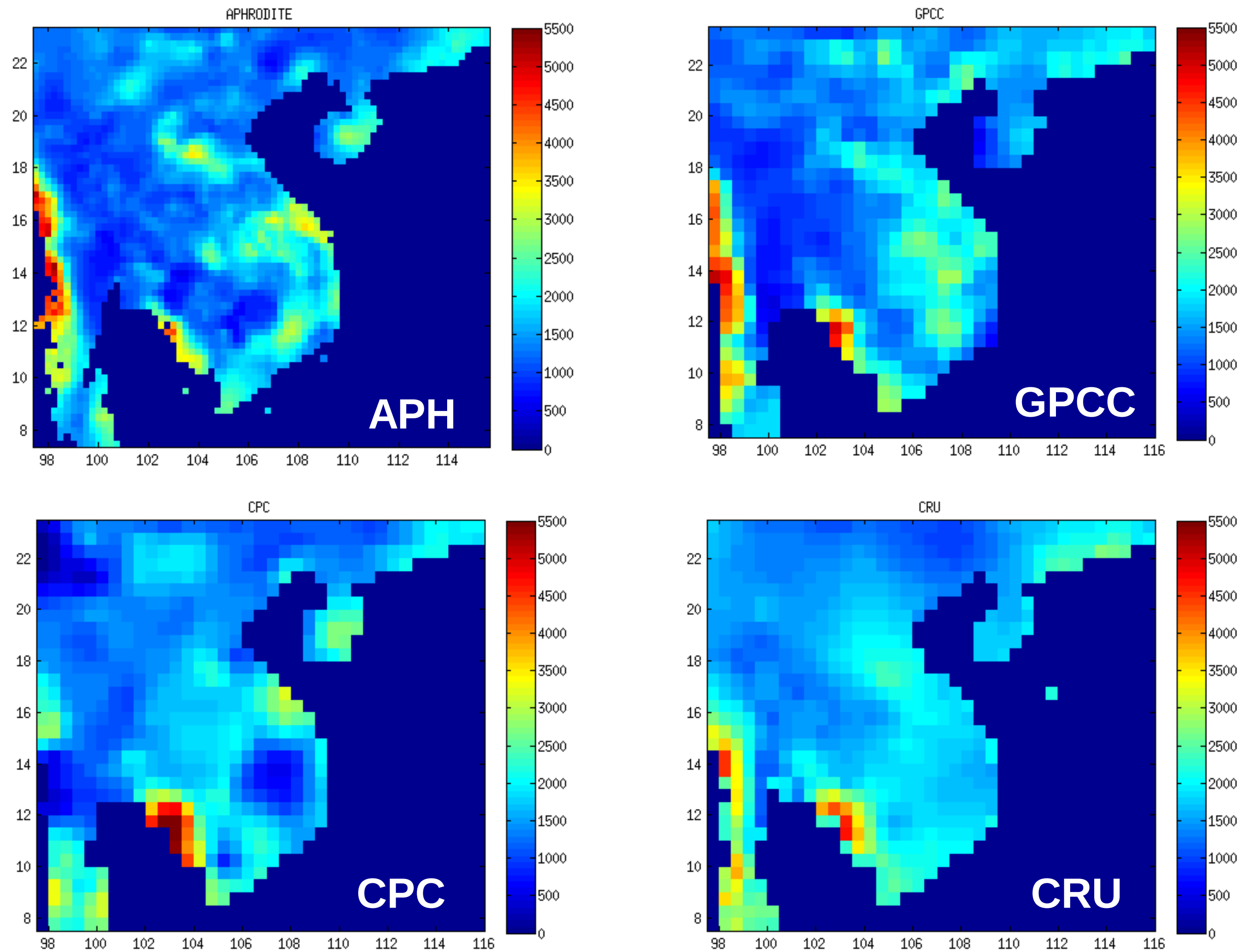
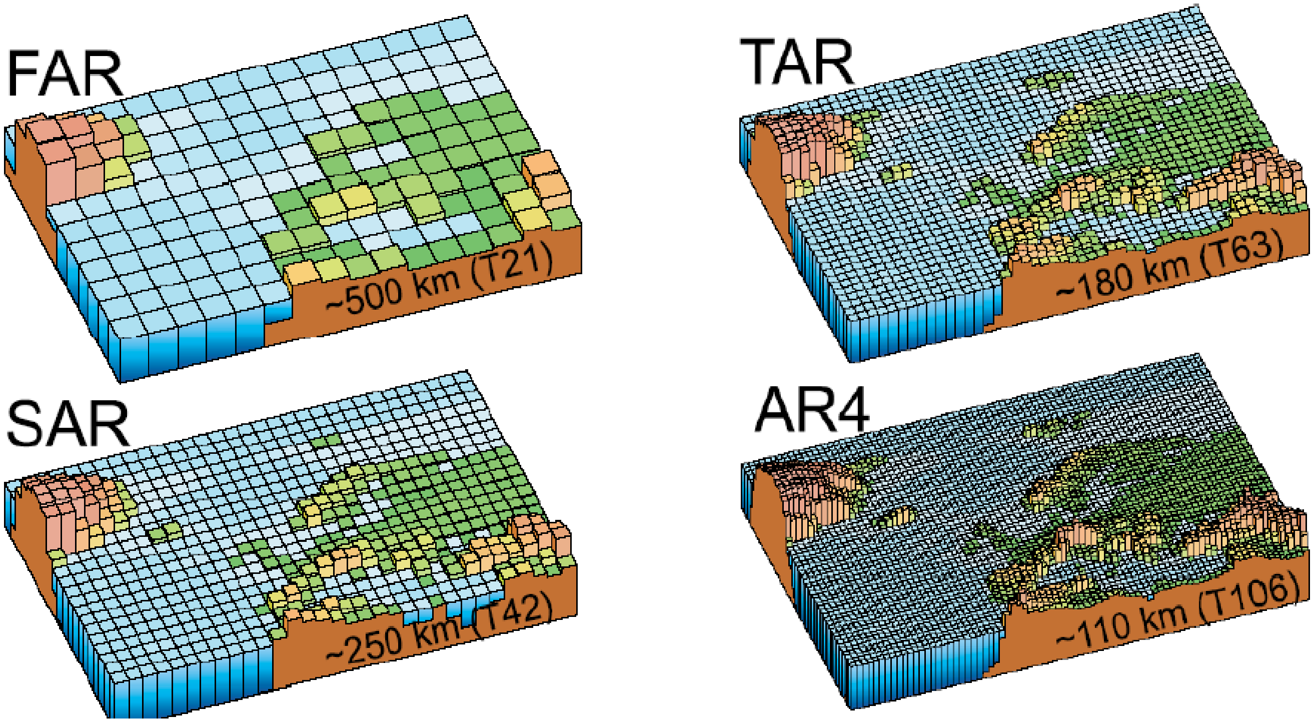


Cảm ơn

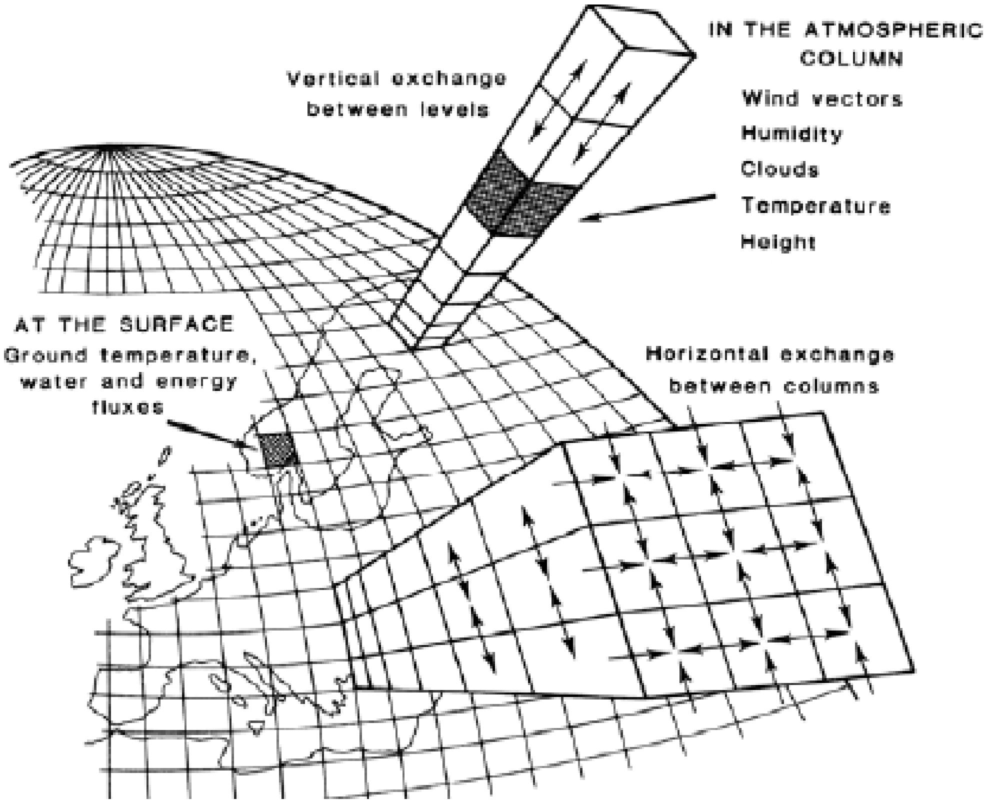
Thank you for your attention

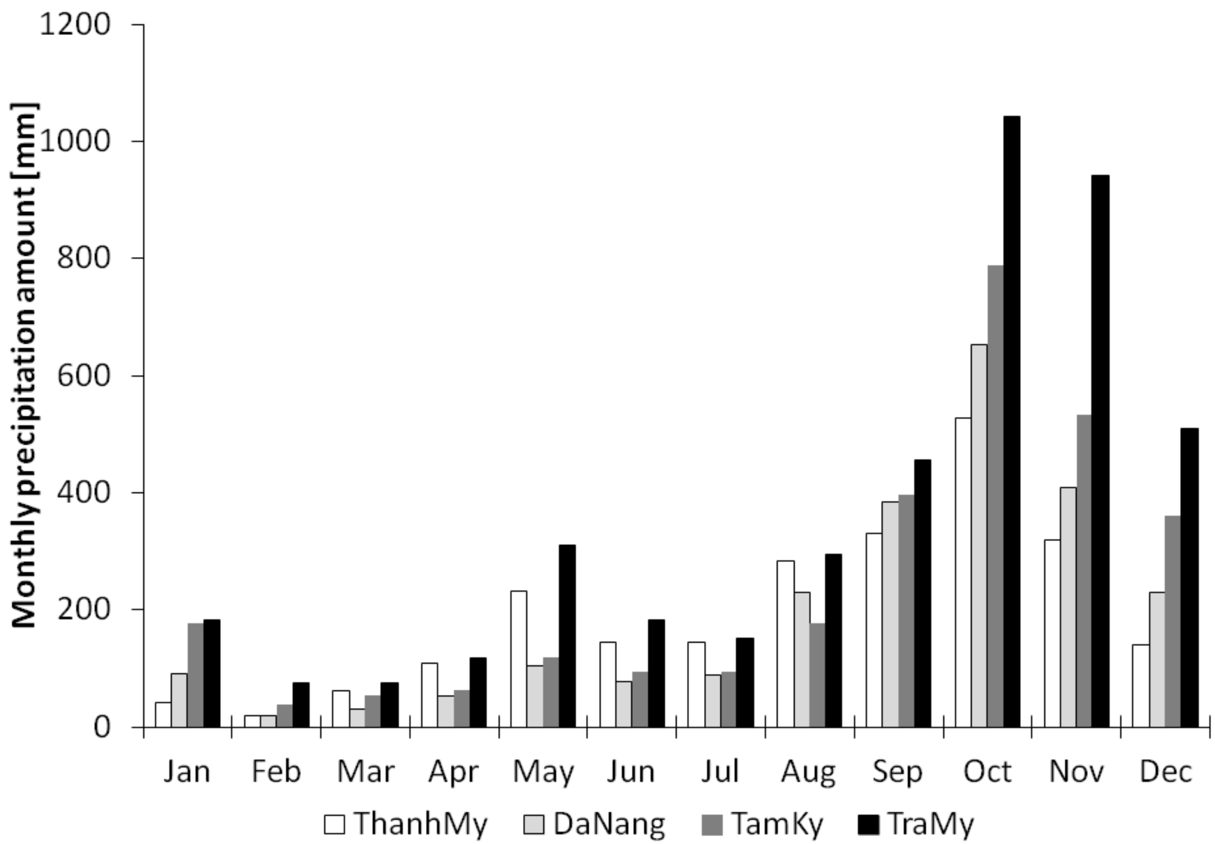
GCMs with Different Resolutions

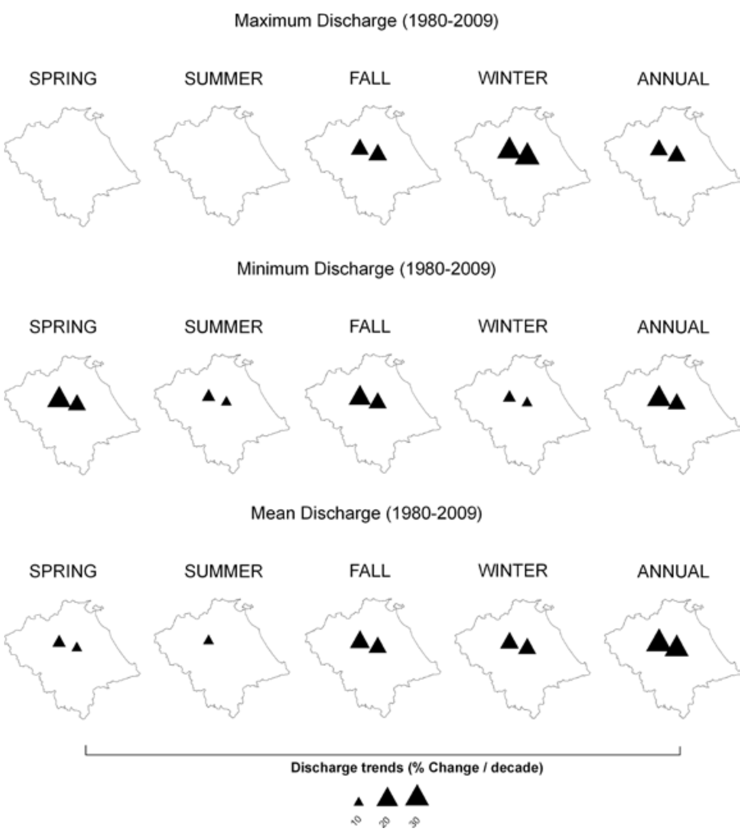


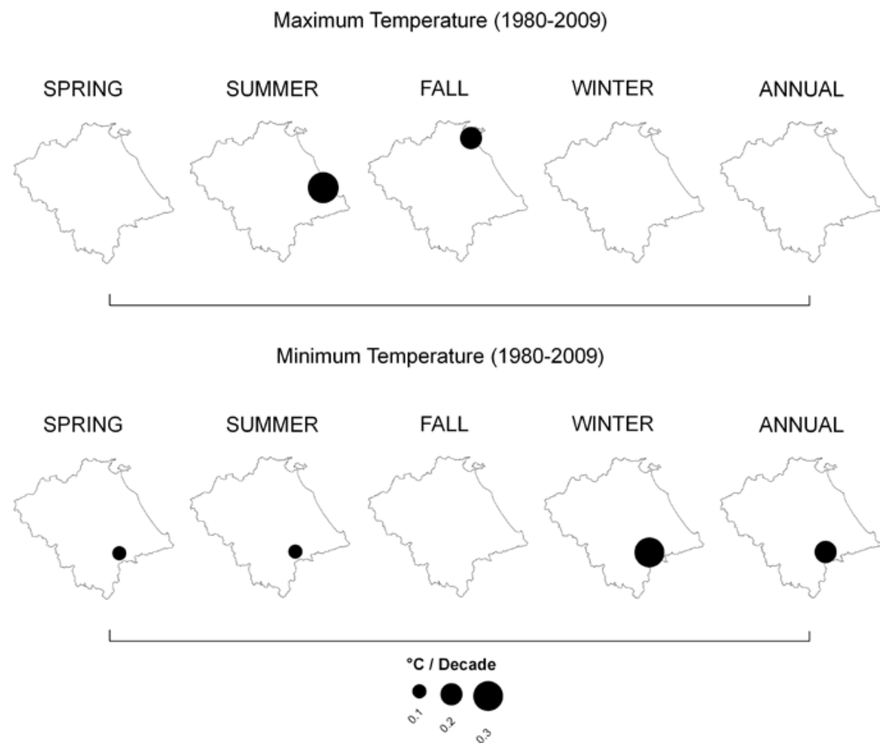
Quelle: IPCC-AR4-WG1 (2007)

Climate Modeling: Looking into the Future…

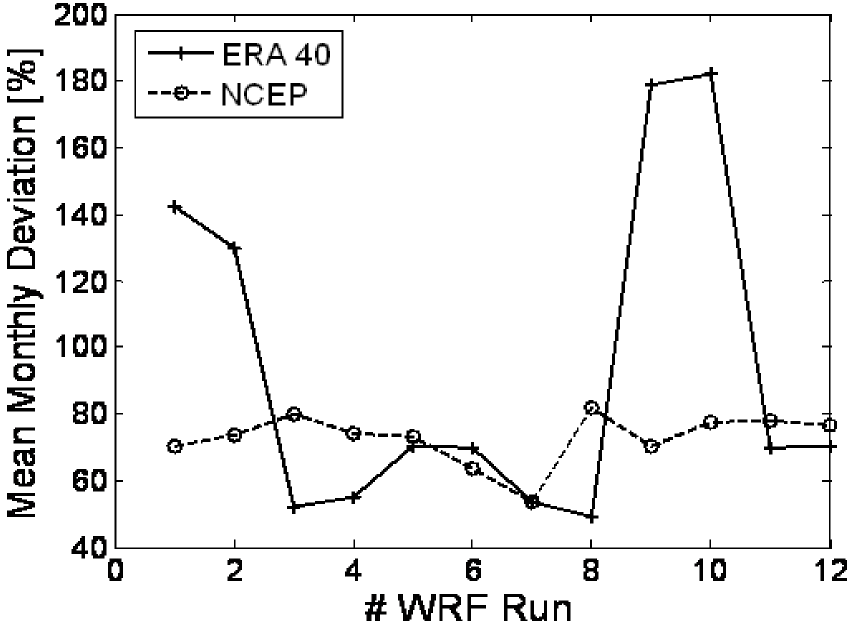



1200
1000
800
600
400
200
0
Monthly precipitation amount [mm]
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
ThanhMy
DaNang
TamKy
TraMy


Maximum Discharge (1980-2009)
SPRING
SUMMER
FALL
WINTER
ANNUAL
Minimum Discharge (1980-2009)
SPRING
SUMMER
FALL
WINTER
ANNUAL
Mean Discharge (1980-2009)
SPRING
SUMMER
FALL
WINTER
ANNUAL
Discharge trends (% Change / decade)
10
20
30


Maximum Temperature (1980-2009)
SPRING
SUMMER
FALL
WINTER
ANNUAL
Minimum Temperature (1980-2009)
SPRING
SUMMER
FALL
WINTER
ANNUAL
°C / Decade
0.1
0.2
0.3

Deviations (absolute values)



A … matlab fig besser

CRU critique