LUCCi Land Use and Climate Change Interactions in Central Vietnam

High-resolution climate information of SE Asia: Data for impacts modelers and decision makers

Patrick Laux

Karlsruhe Institute of Technology (KIT)

Institute of Meteorology and Climate Research
Department of Atmospheric Environmental Research (IMK-IFU)

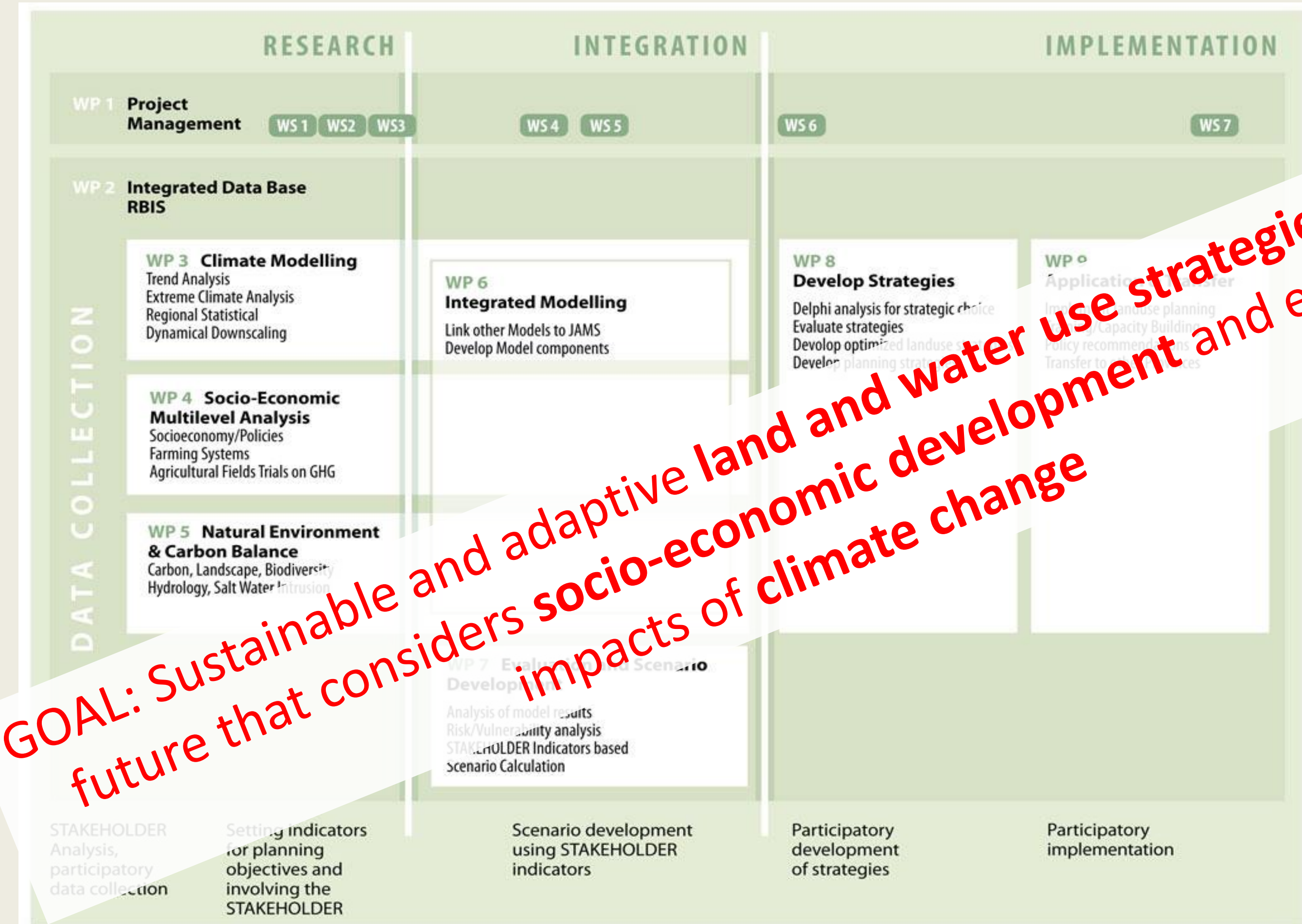



Federal Ministry of Education and Research
FONA Research for Sustainable Development BMBF
SUSTAINABLE LAND MANAGEMENT

Outline

- Background & Motivation
  - LUCCi Project
  - Study Region
  - Dynamical Downscaling
- Regional Climate Simulations
  - WRF Parameterization Experiments
  - Long-term Simulations: Trends and Expected Climate Change
- Summary & Outlook

BMBF Project LUCCi



GOAL: Sustainable and adaptive **land and water use strategies** for the future that considers **socio-economic development** and expected impacts of **climate change**

… more information at: **http://www.lucci-vietnam.info/**

Problem: Data availability

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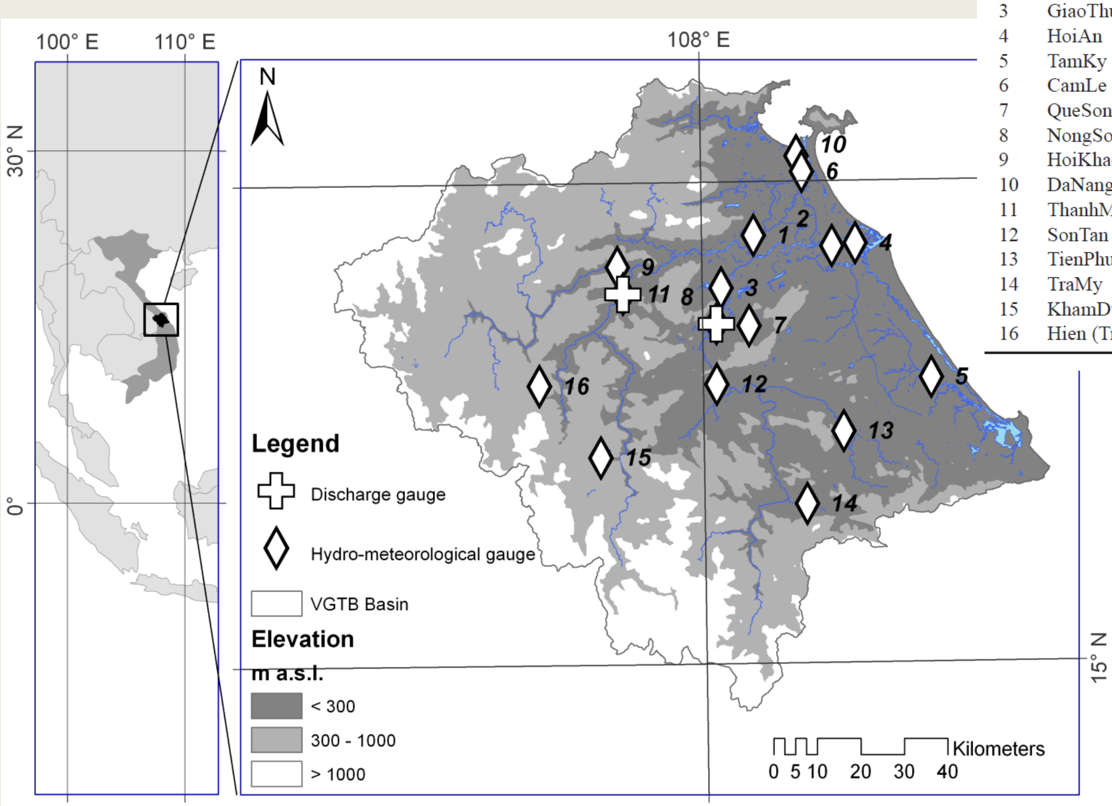
Vu Gia Thu Bon River Basin

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		



Souvignet et al., 2013

Data availability in VGTB basin

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

- Stakeholders demand for **scientific sound CC adaptation strategies**, e.g.:
  - Flood protection measures (adaptation of infrastructure)
  - Future hydropower potential (low flows)
  - Water availability for agriculture

→ High-resolution hydro-meteorological data (past and future) required to feed hydrological and agricultural impact models!

Dynamical Downscaling

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Population Growth, Economic Development & Technological Progress

↓

Emission Scenarios of GHG Concentrations

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Global Climate Models

↓

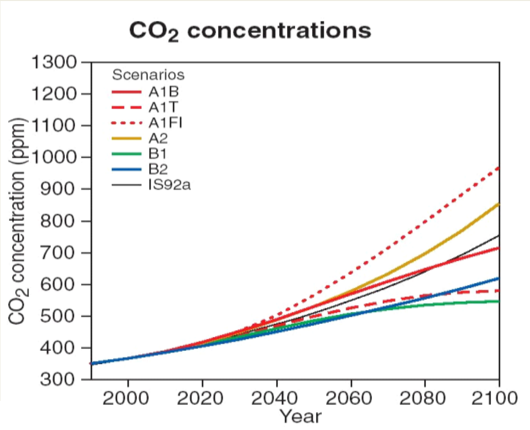
Global Climate Scenarios

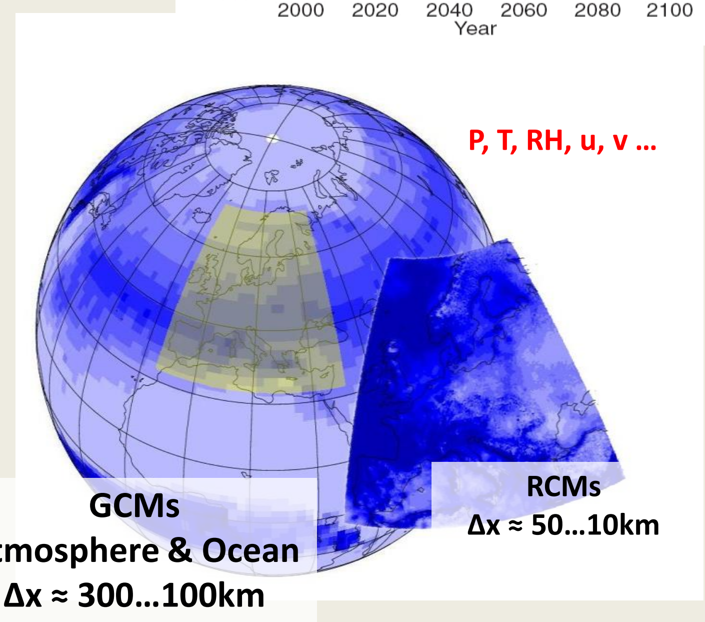
↓

Downscaling Methods

↓

Regional Climate Scenarios



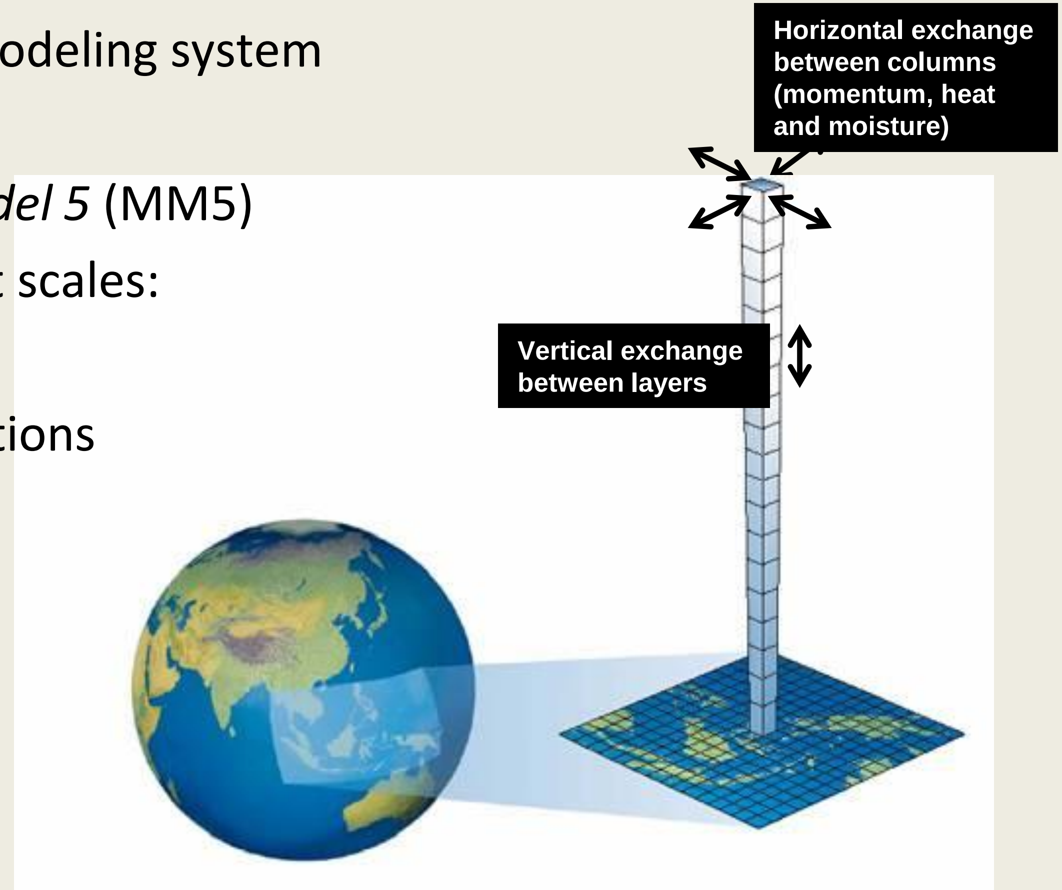


Weather Research and Forecast Model (WRF)

Atmospheric compartment

- Next generation atmospheric modeling system
- Developed at NCAR
- Successor of the *Mesoscale Model 5* (MM5)
- Various applications at different scales:
  - Weather forecasts
  - (Long-term) climate simulations

- Atmospheric and (sub)surface compartments:



Atmosphere – Explicit Calculation of …

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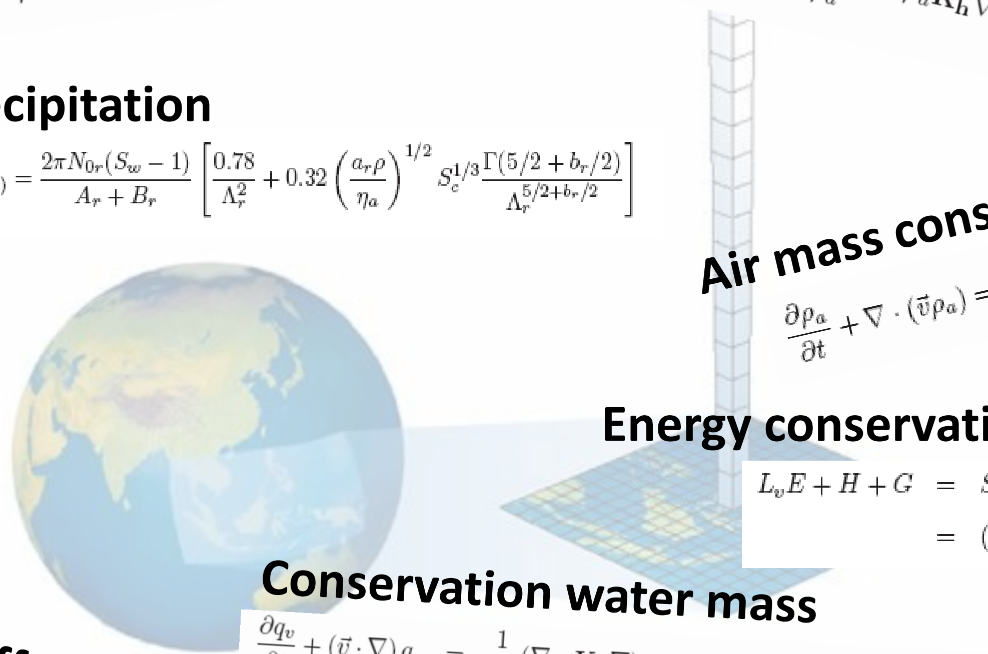

Momentum conservation

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

Energy

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

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

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

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

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

(Sub)surface Compartment

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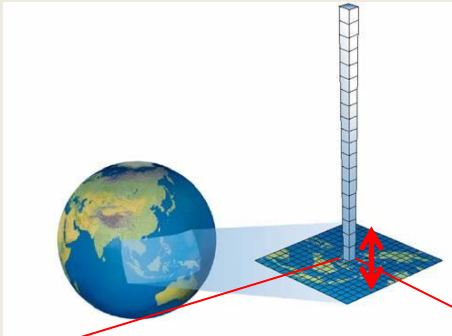
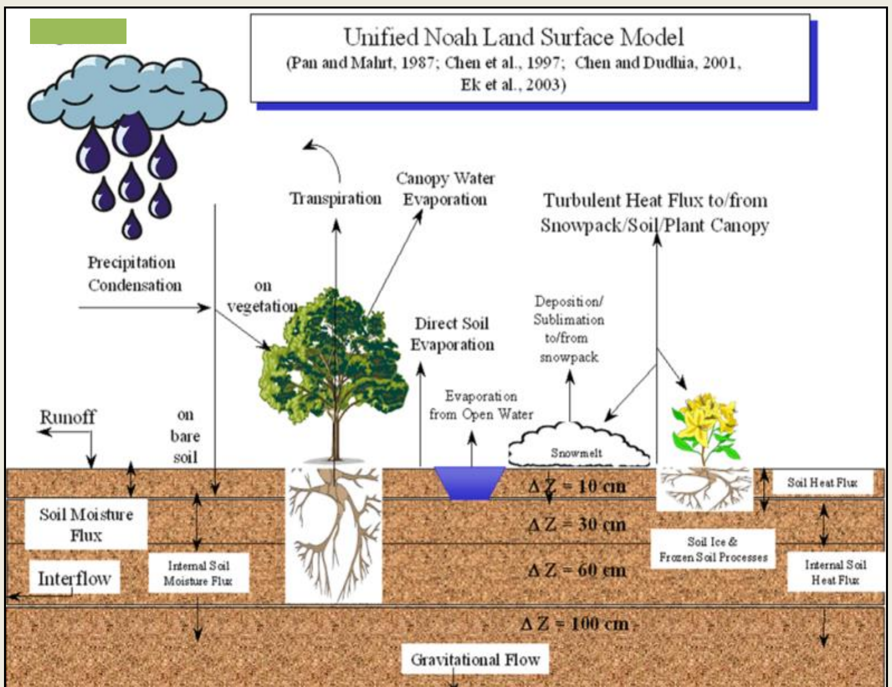
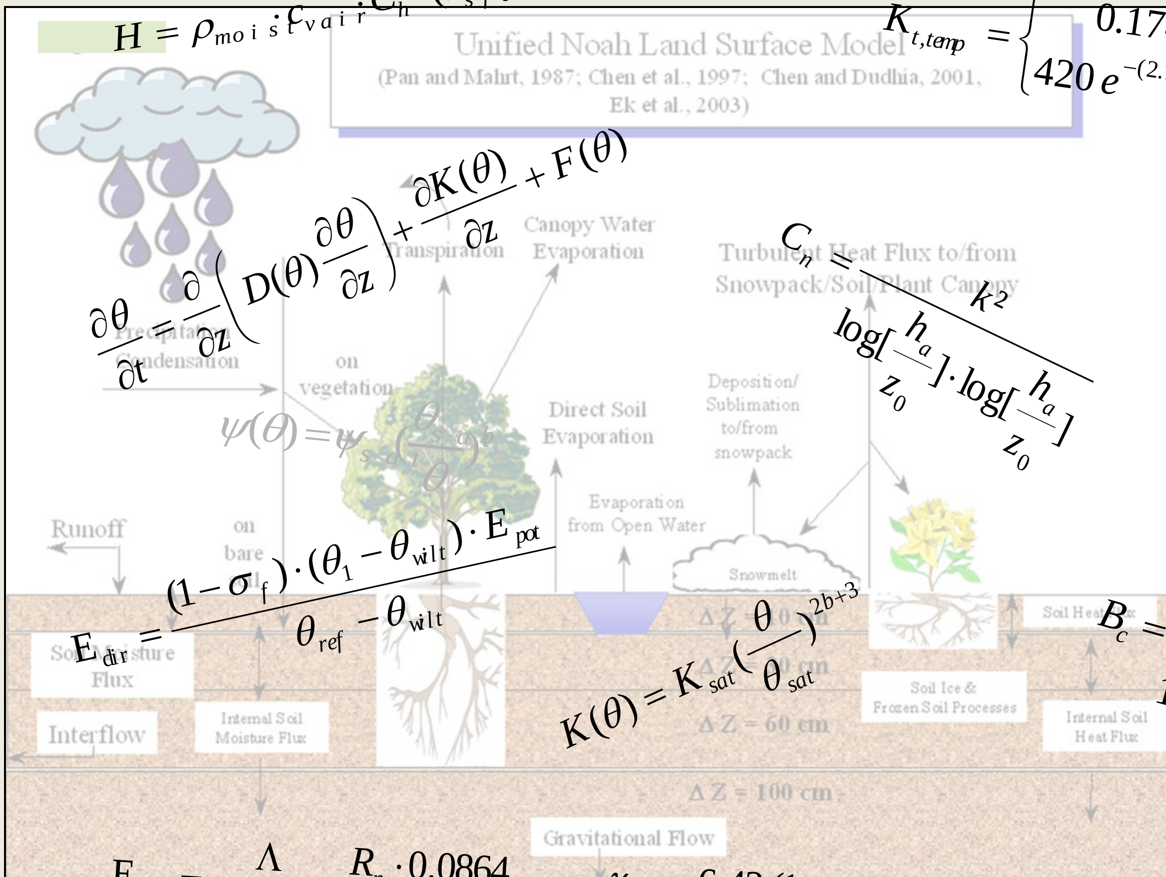


Surface and subsurface compartment



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

Land (sub)surface – Model Equations



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

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

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

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

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

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

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

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

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

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

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

WRF Setup

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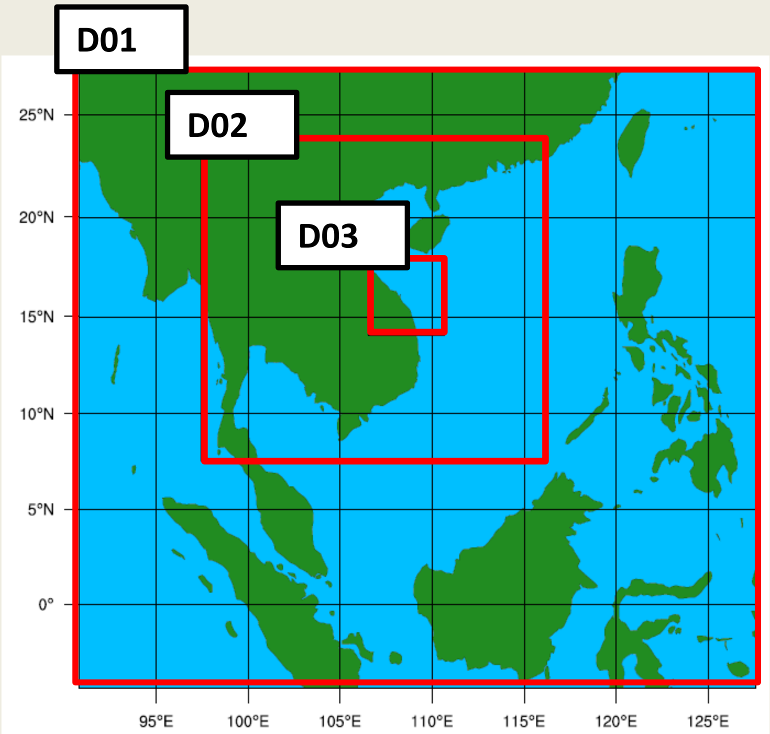

- **Domain D01**
  - horizontal: 99 x 99 grid points with a resolution of **45 km**
  - vertical: 50 layers up to 50 hPa
  - time step: 180 s
- **Domain D02**
  - horizontal: 142 x 145 grid points with a resolution of **15 km**
  - vertical: 50 layers up to 50 hPa
  - time step: 120 s
- **Domain D03**
  - horizontal: 66 x 75 grid points with a resolution of **5 km**
  - vertical: 50 layers up to 5000 Pa
  - time step: 30 s

→ GOAL: Transient WRF simulation from 1960 - 2050

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Parameterization Experiments

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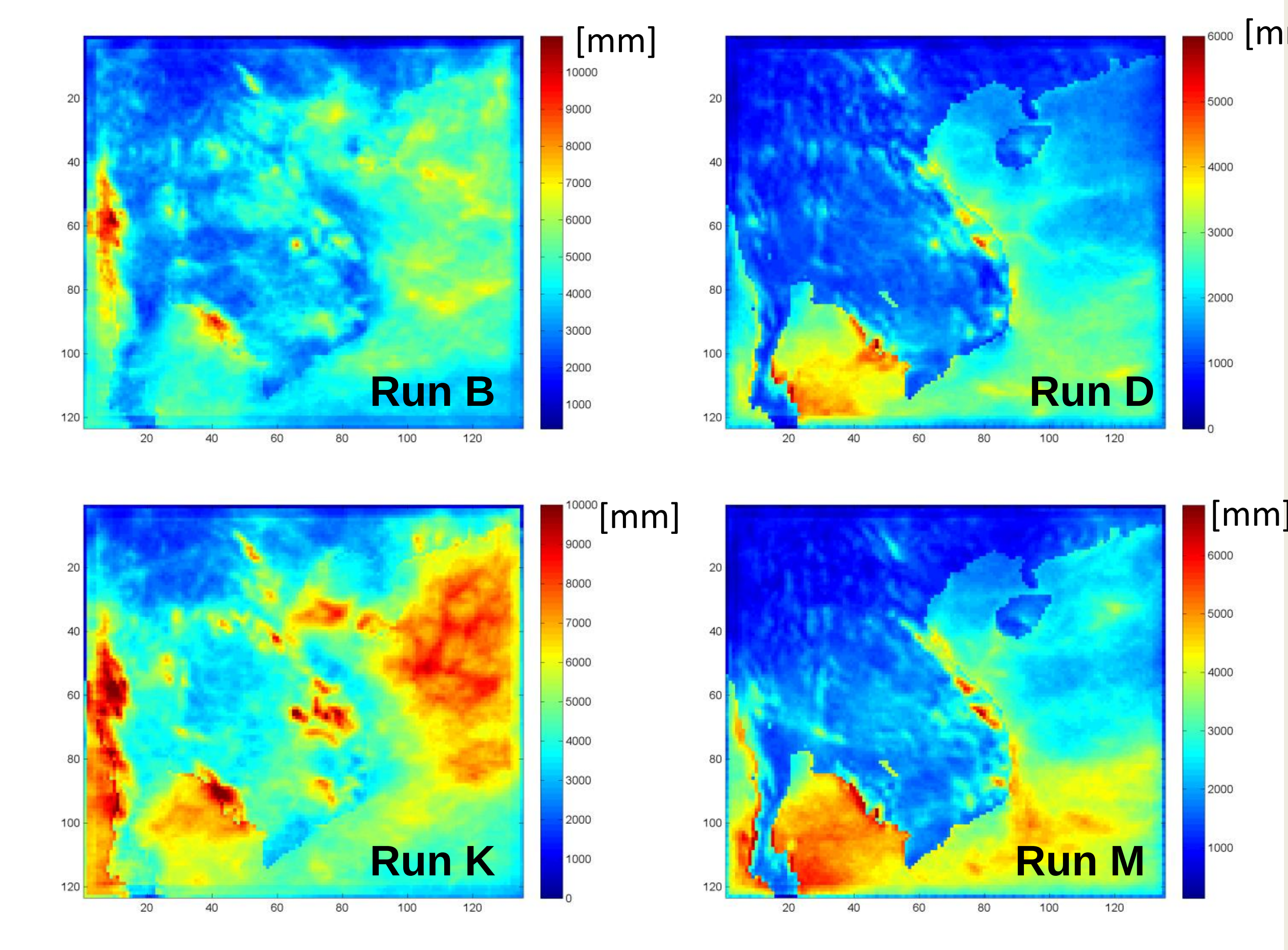
- 12 Combinations using 3 MP, 2 PBL and 2 CU schemes
- 2 Combinations using NCEP & ERA40 Reanalyses

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

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

WRF Parameterization Experiments:



Simulated annual precipitation for 2000

Validation **ERA40**-WRF: **Daily Precipitation**

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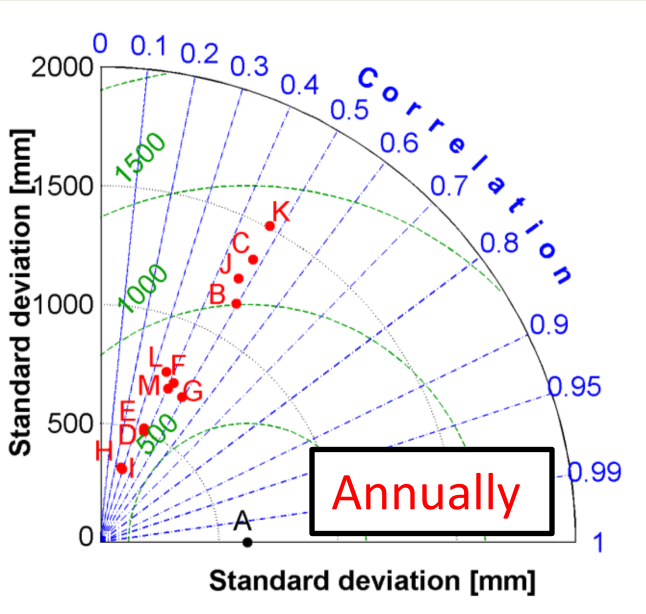
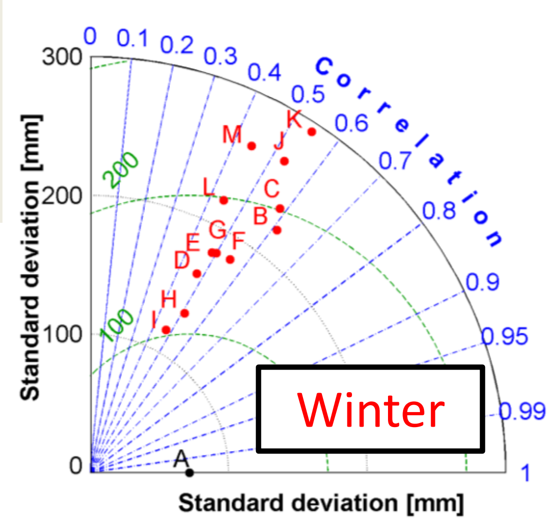
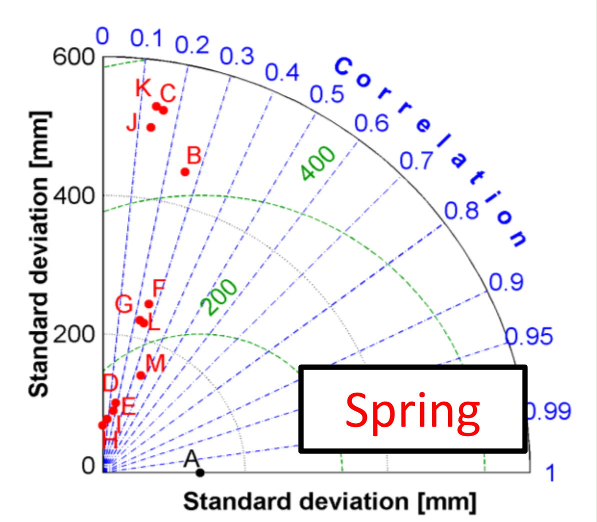
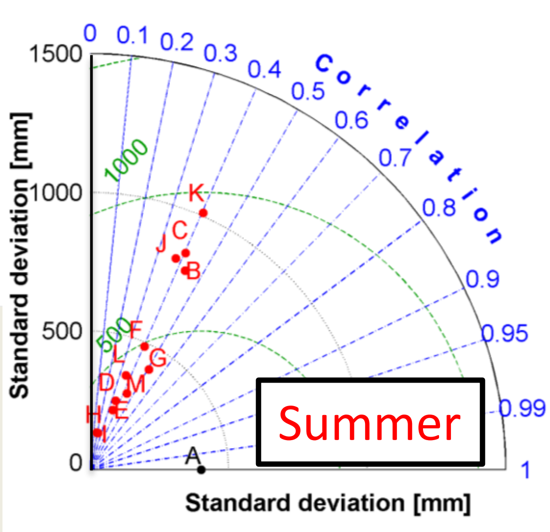
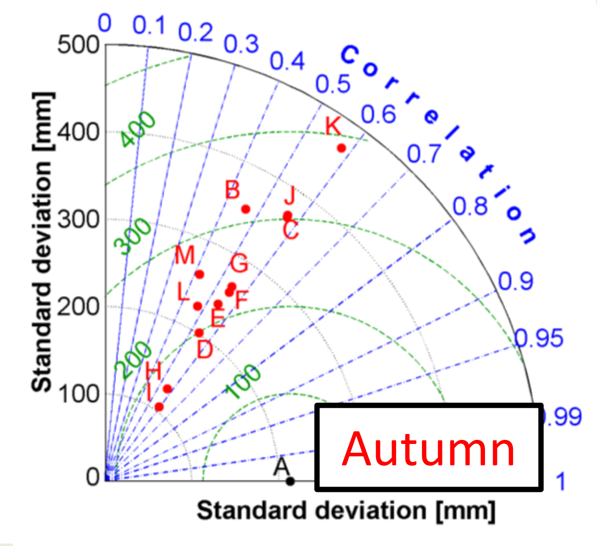
A: APHRODITE data = Reference











Pearson Correlation Coefficient
Root Mean Squared Error
Standard Deviation

Final Decision (simulated T, P)

ERA40 Reanalysis

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

(Laux et al., 2013)

Run	Microphysic schemes	PBL physic schemes	Cumulus physic schemes
B	Lin et al.	Hong et al.	Betts-Miller-Janjic
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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. Obs (DOM2): P, T2

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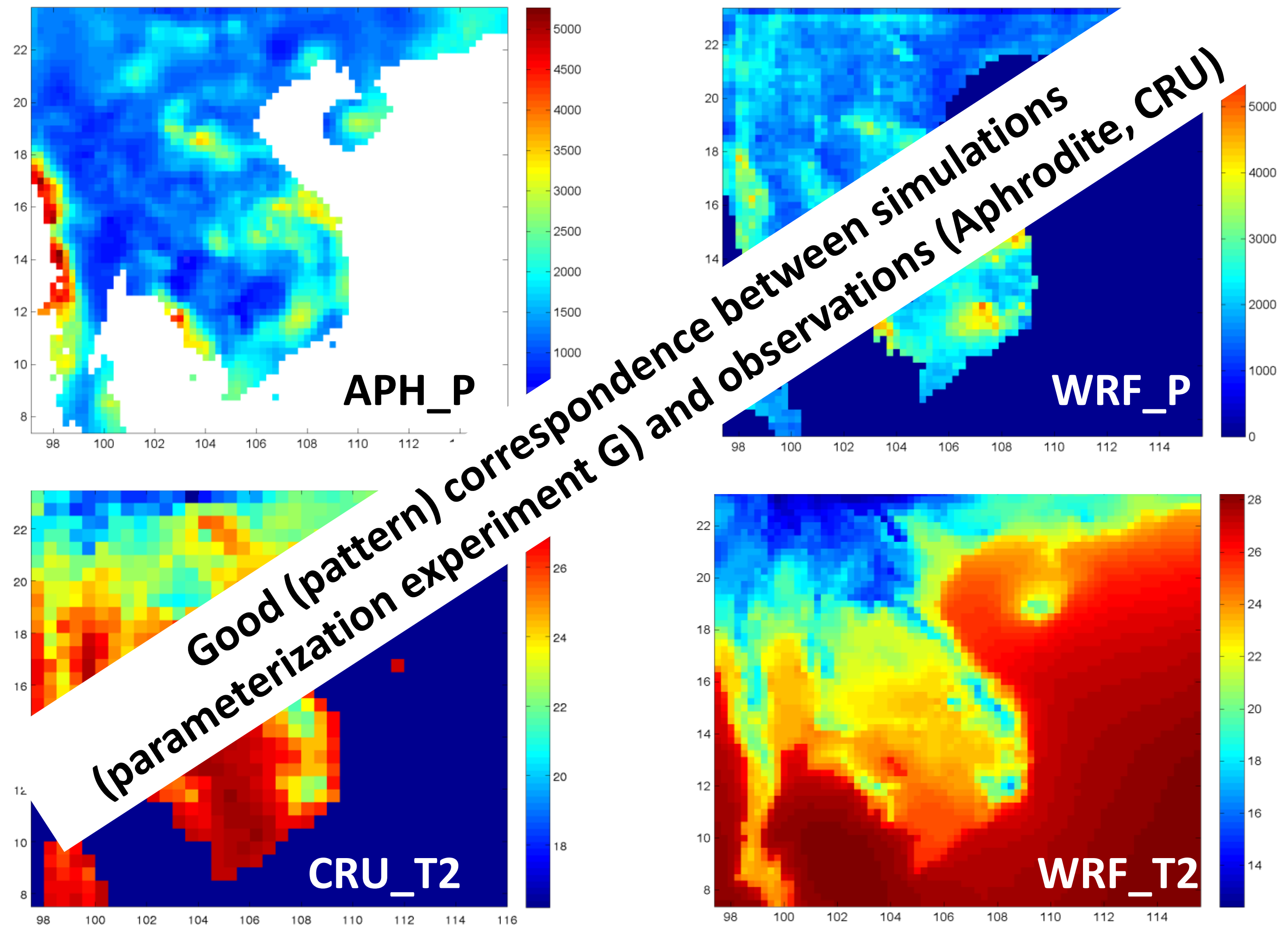

Good (pattern) correspondence between simulations (parameterization experiment G) and observations (Aphrodite, CRU)

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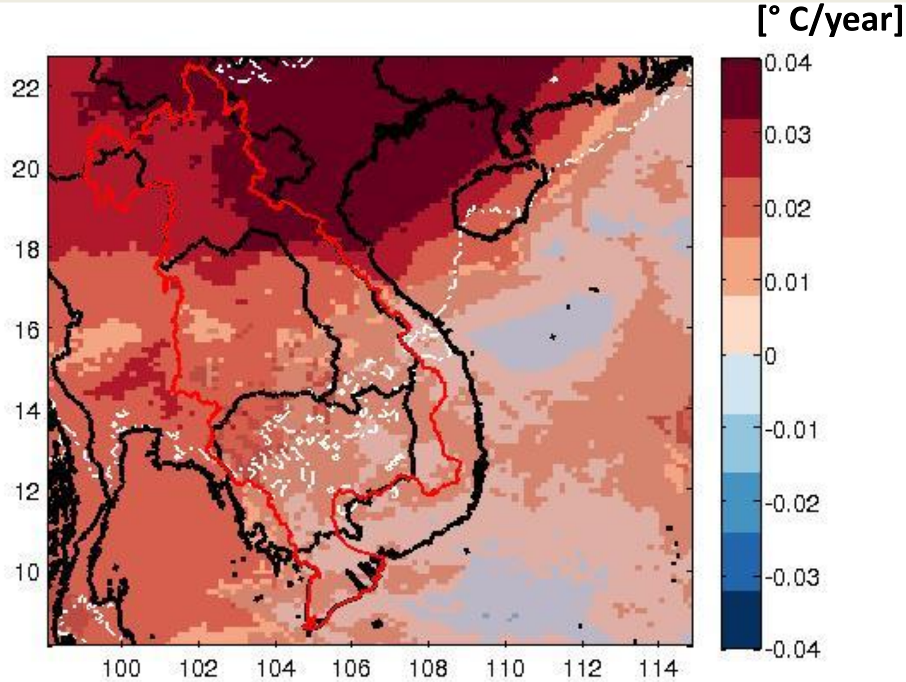
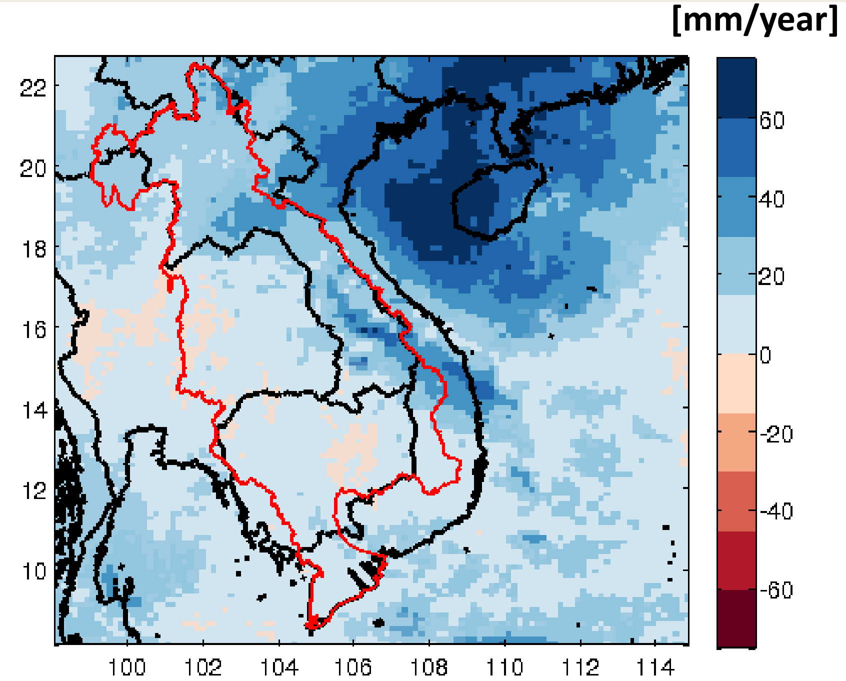
Past Climate: Annual trends WRF-ERA40

T2 (1971-2000)



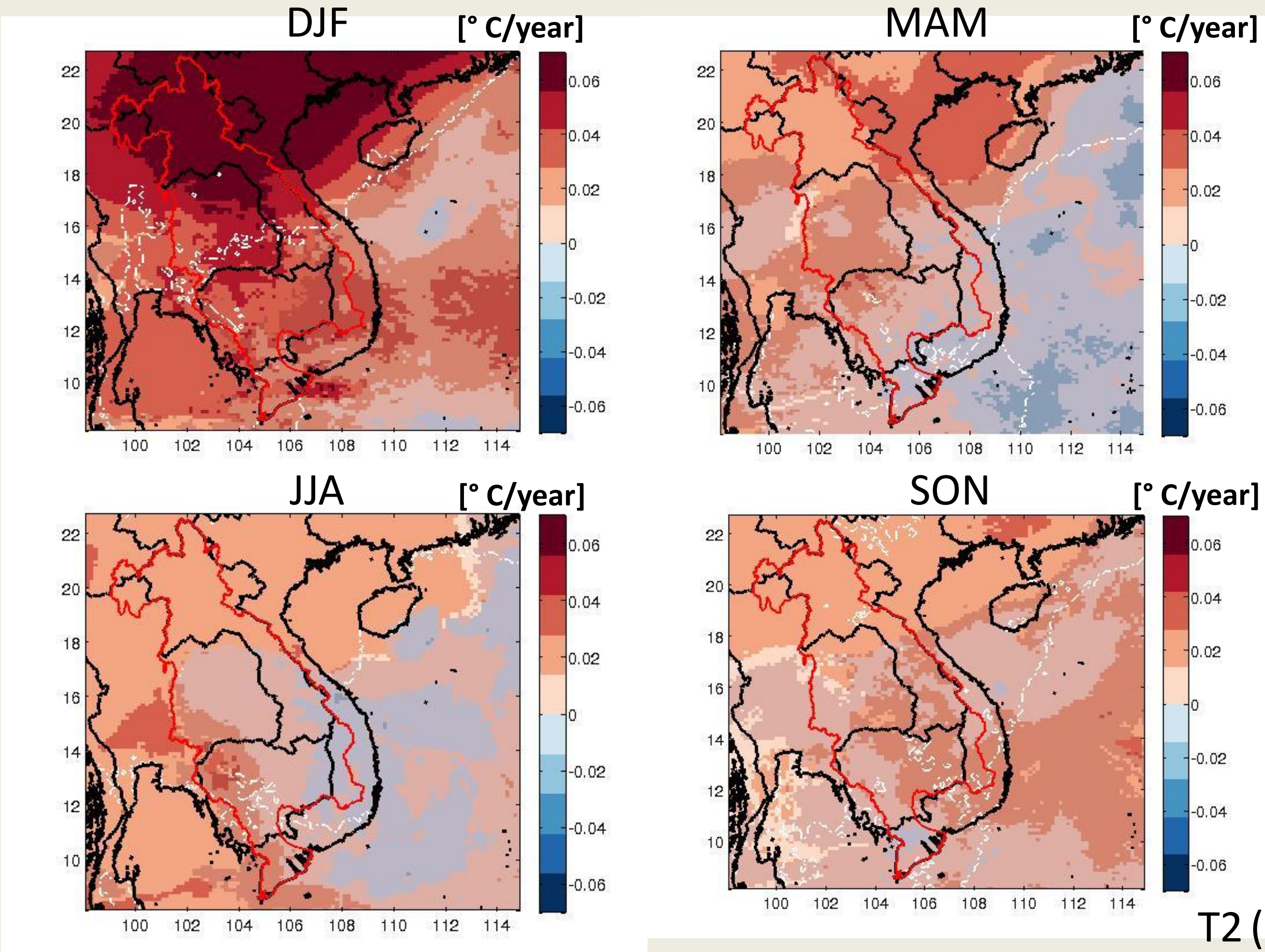
Significant at α=0.05

P (1971-2000)



Not significant at α=0.05

Past Climate: Seasonal trends WRF-ERA40



T2 (1971-2000)

Expected Climate Change: WRF-ECHAM5

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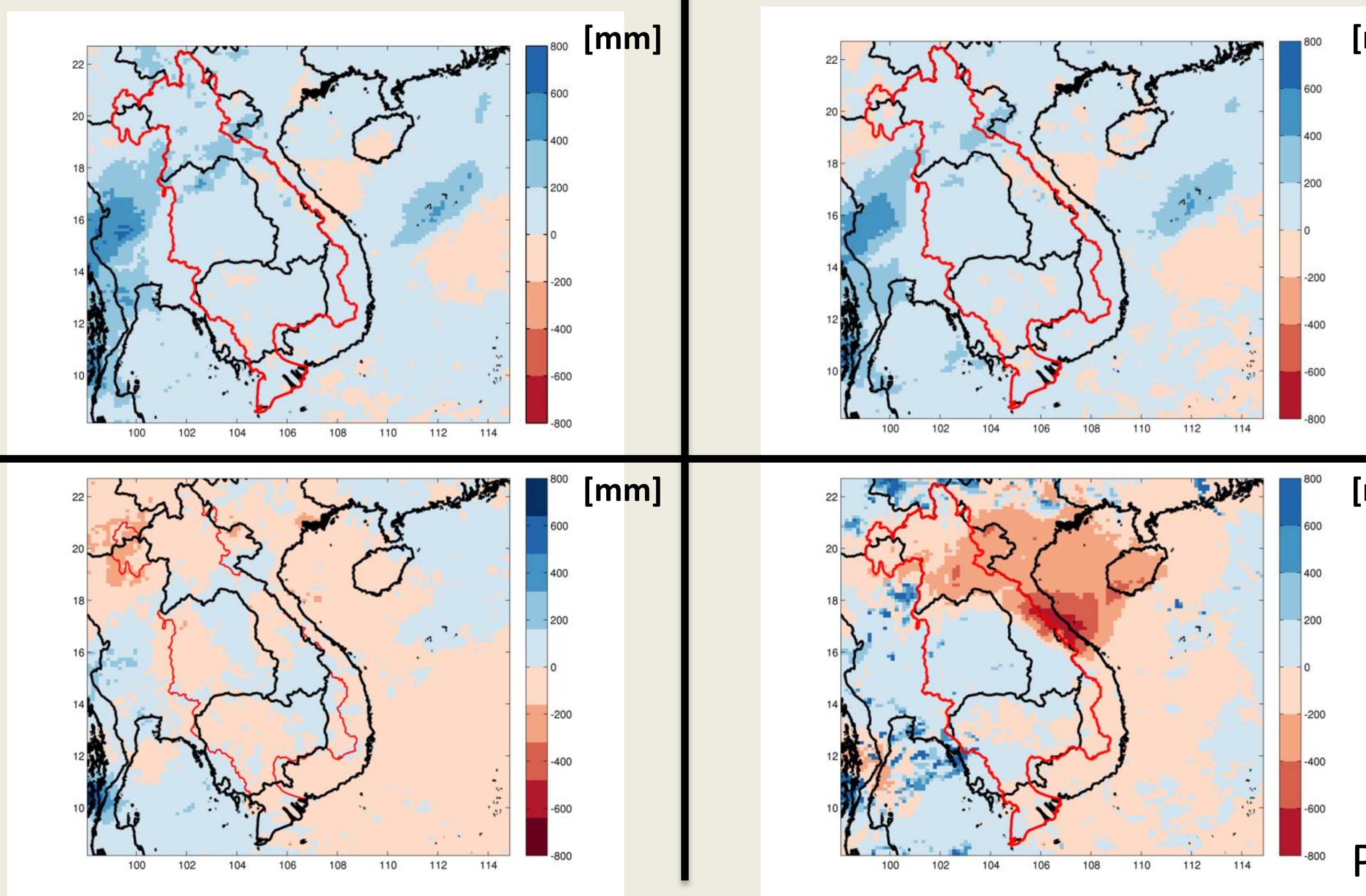
(2001-2030) *minus* (1971-2000) | **(2021-2050) *minus* (1971-2000)**

B1

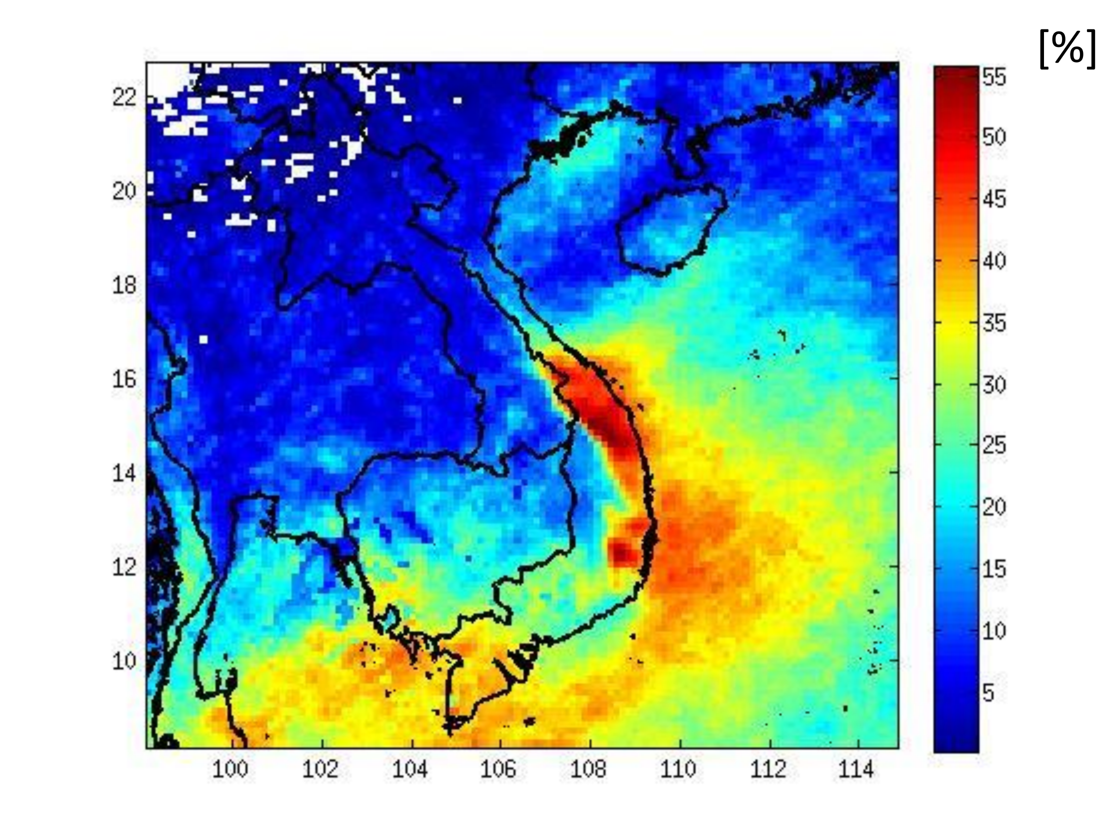
A1B



Precipitation

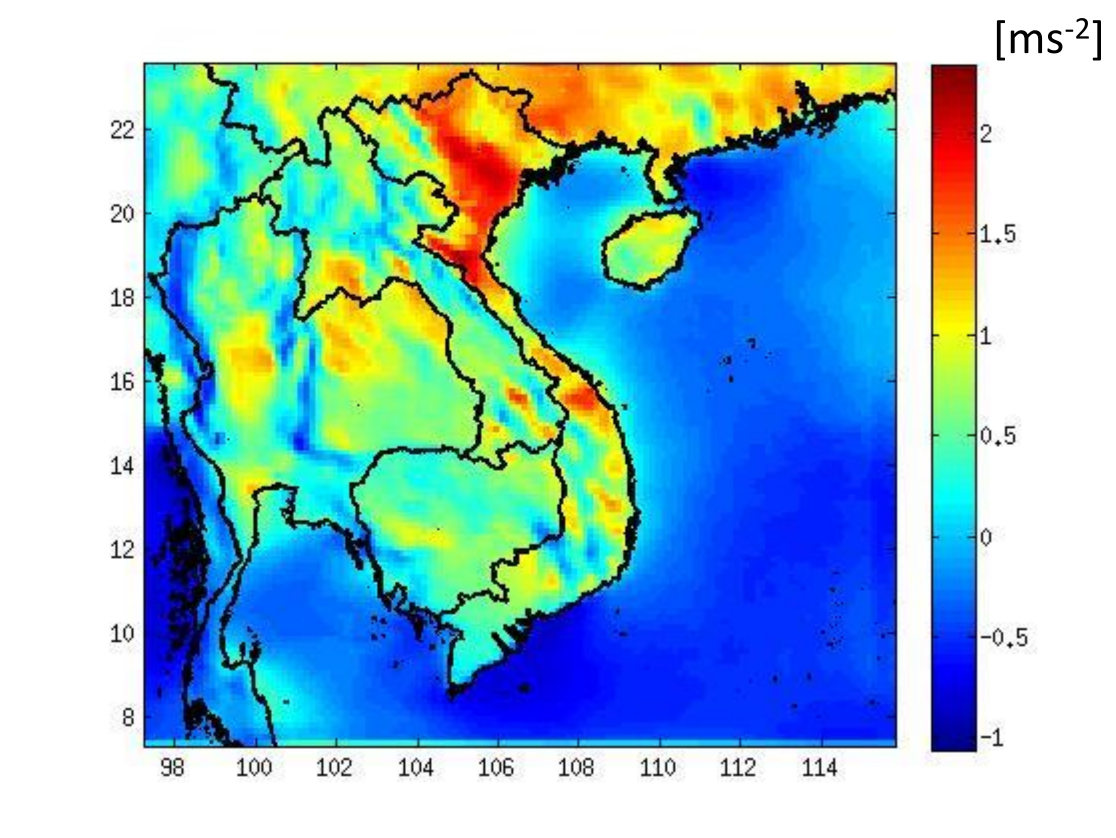
Tailor-made Information for Stakeholders

Change of **Precipitation Extremes** (P95)
A1B: (2021-2050) *minus* (1971-2000)



Tailor-made Information for Stakeholders

Change of mean **Wind Speed**
A1B: (2021-2050) *minus* (1971-2000)



Tailor-made Information for Stakeholders

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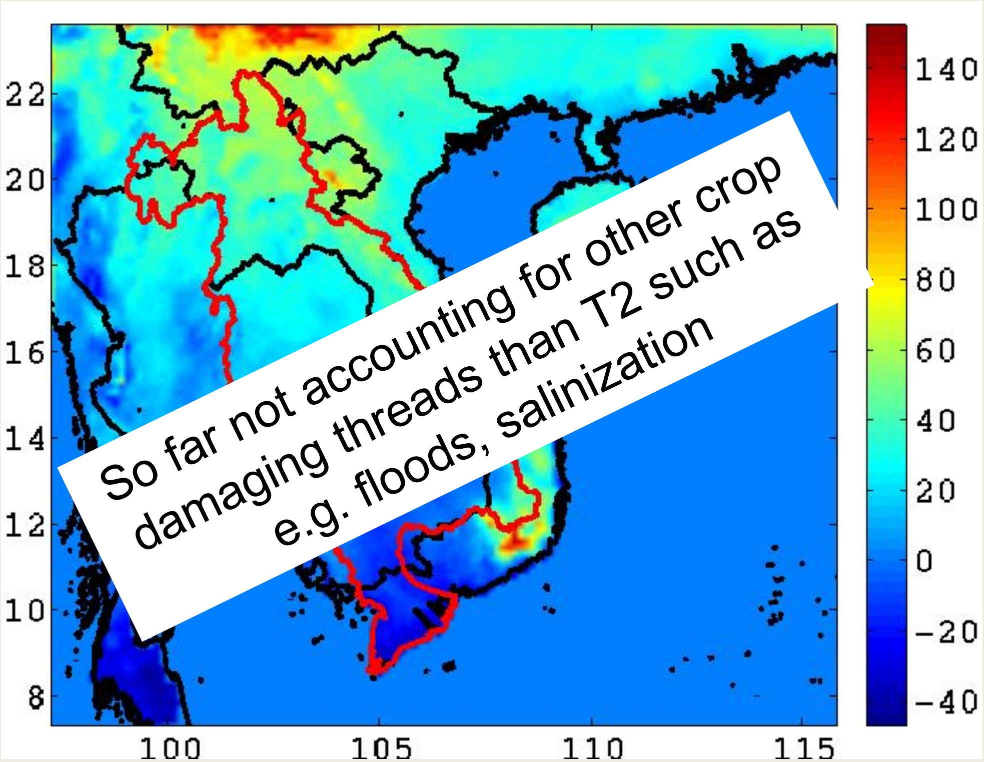
Change of **Growing Days of 2nd cropping cycle (Rice)**
A1B: (2021-2050) *minus* (1971-2000)



Growing days = Number days after 1 July between the first occurrence of > 6 consecutive days with T2 > 20 °C and > 6 consec. days with T2 < 20 °C

Summary & Outlook

LUCCi

- **High-resolution and reliable climate information (~1 Mio CPU hours):** WRF-ECHAM5 (1961-2050) for A1B and B1, WRF-ERA40 (1971-2000)
  - **Past:** T2 increased up ~1.2° C & P increased ~300 mm (1971-2000), **but:** strong spatio-temporal differences
  - **Future:** CC is expected to increase (decrease) water availability for B1 (A1B) scenario, increase of precipitation extremes expected

- Addressing stakeholder's needs and **providing tailor-made information** for different sectors (agriculture, hydrology, energy, etc.) → please contact me

- **Further Research:**
  - Analysis of occurrence probabilities & return intervals of rare events (Extremes Value Theory)
  - Uncertainty estimation coming from forcing GCMs (Statistical Downscaling)

Acknowledgments

Donors of LUCCi Project

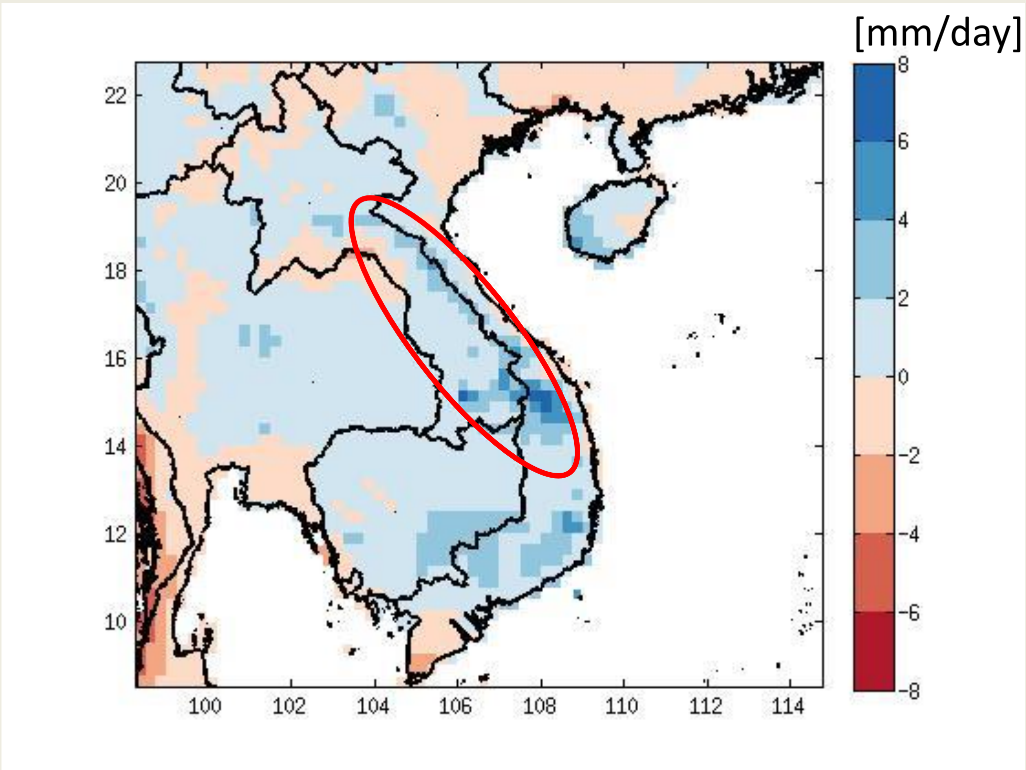
Organization Team

Computing Resources and Support

Contact: patrick.laux@kit.edu

Open question: Bias correction?

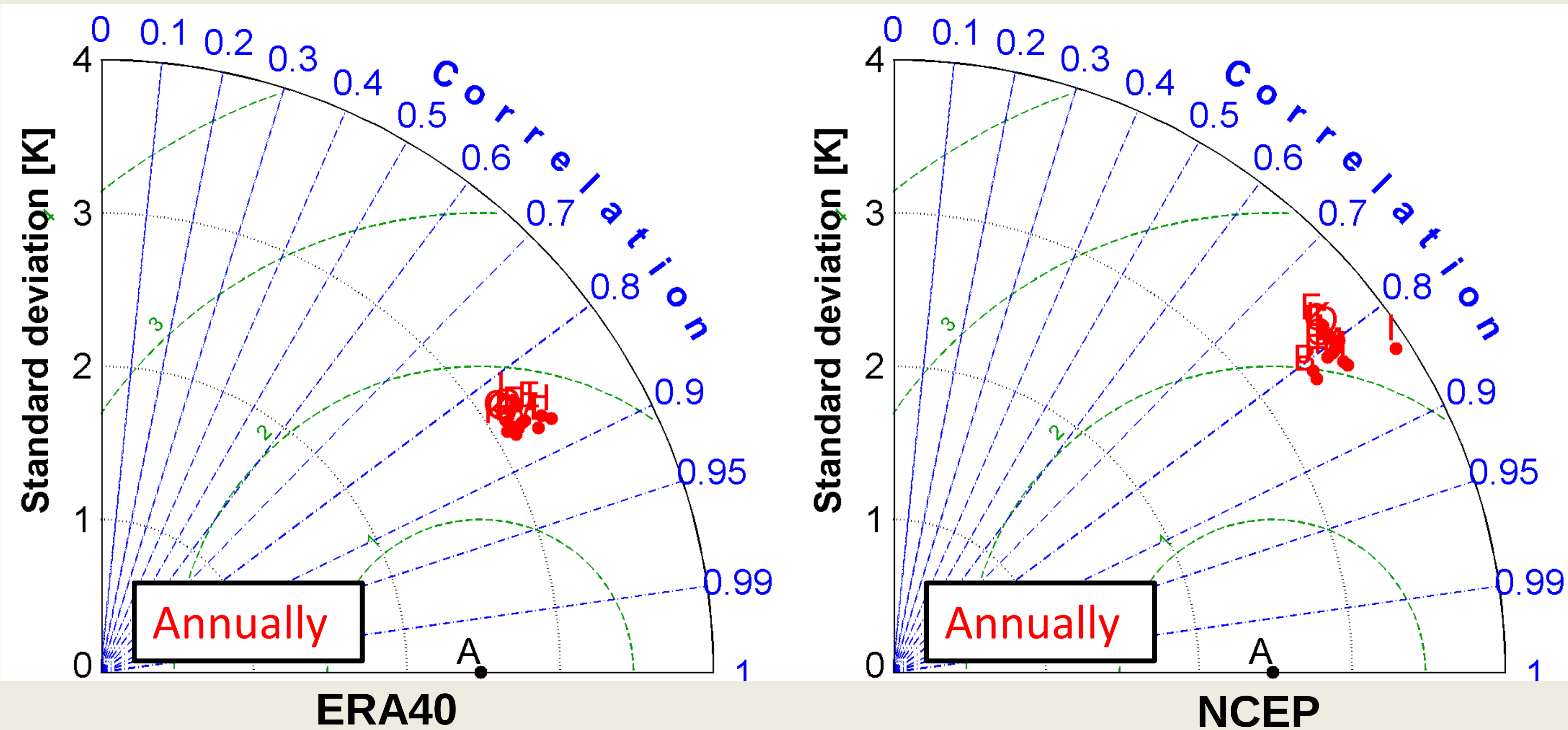
Mean daily precipitation bias WRF-ERA40 (1971-2000)



Real bias of WRF simulations or **artifacts in gridded rainfall products** induced by interpolation of sparse hydro-meteorological observations and lack of data in high elevations?

Validation WRF: T2 (Year 2000)

A: CRU data



Pearson Correlation Coefficient
Root Mean Squared Error
Standard Deviation

Validation **NCEP**-WRF: **Daily Precipitation**

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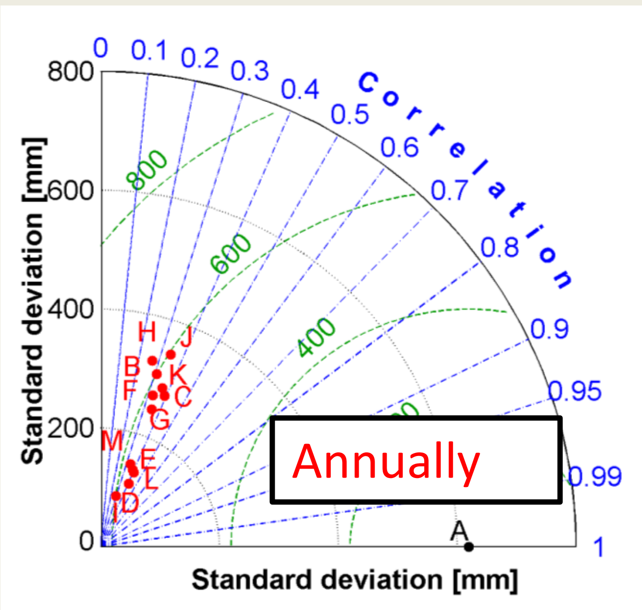
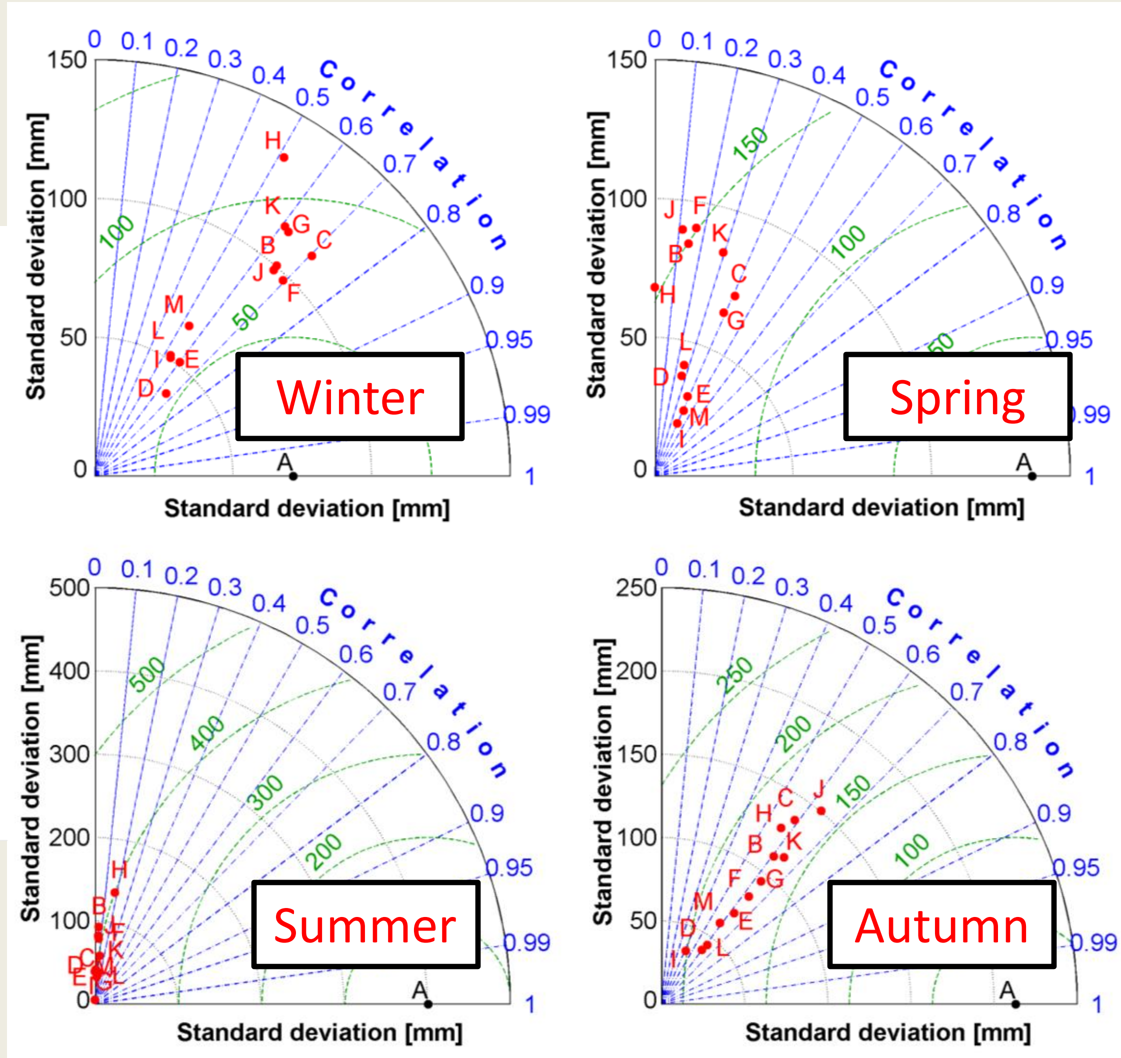
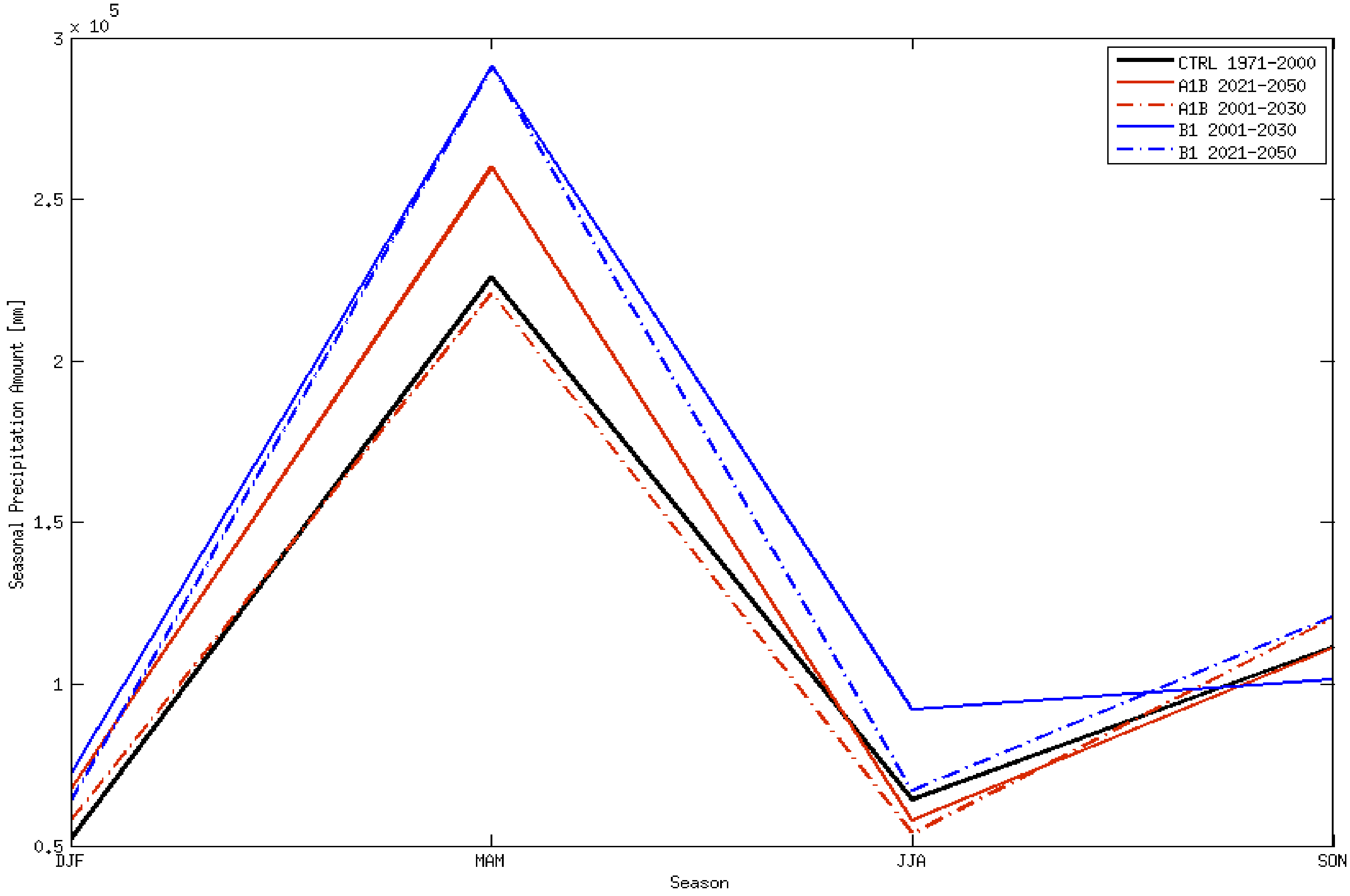
A: APHRODITE data = Reference data



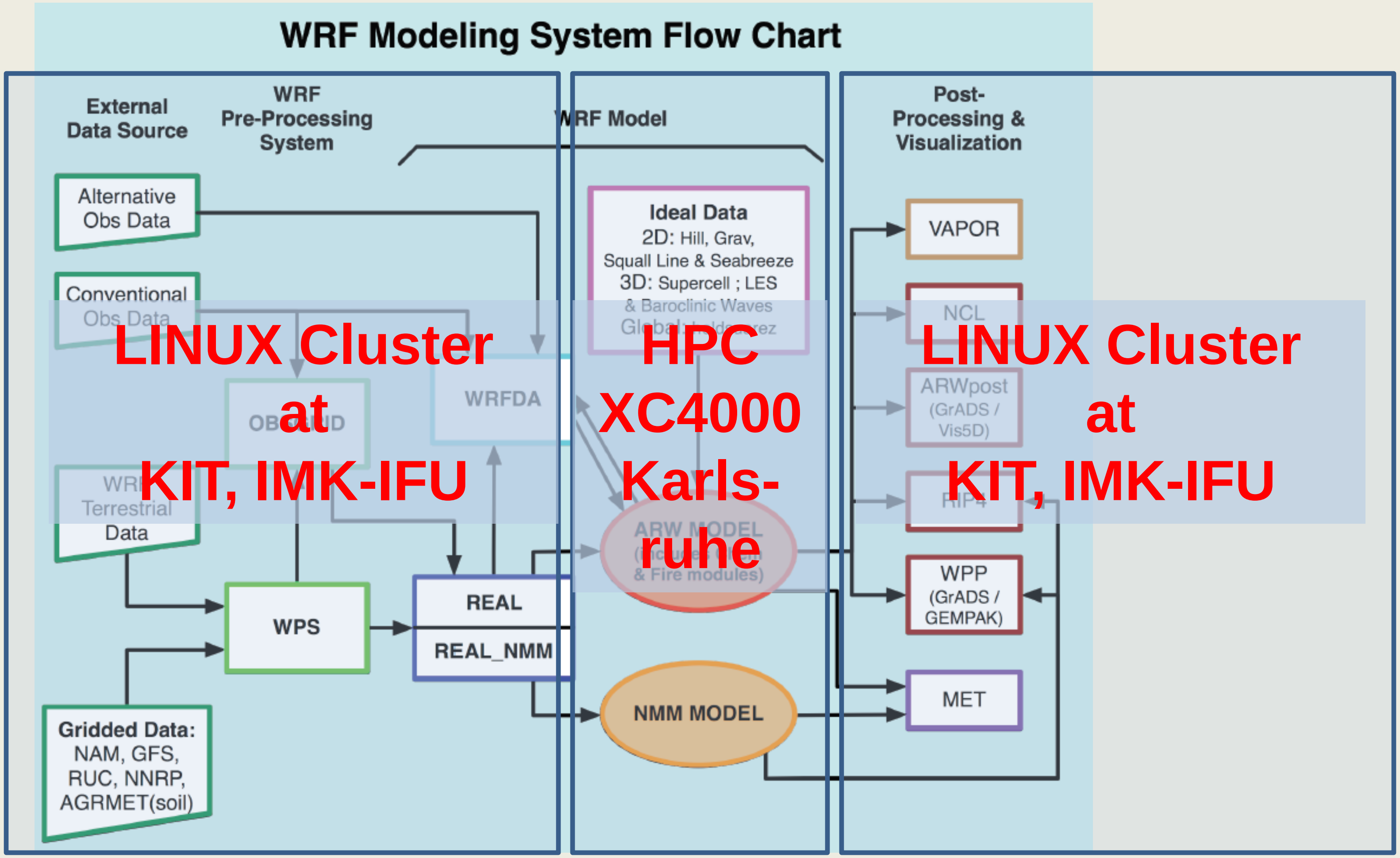


Pearson Correlation Coefficient
Root Mean Squared Error
Standard Deviation

Expected Climate Change: WRF-ECHAM5



WRF Modeling System



Technical details: building and running WRF at XC4000 (KIT, SCC)

- Building
  - WRF written in Fortran90
  - MPI interface and programs for file parsing written in C
  - WRF build relies on Perl version 5 or later and standard UNIX utilities
  - Modules used
    - intel/12.0.5/default
    - gcc/4.6.0/default
    - hp-mpi/2.3.1/default (distributed memory)
  - External libraries
    - netCDF library

- Running
  - Job chains
    - 1 simulation year per job
    - Restart run performed for each month

Performance of WRF at XC4000 (KIT, SCC)

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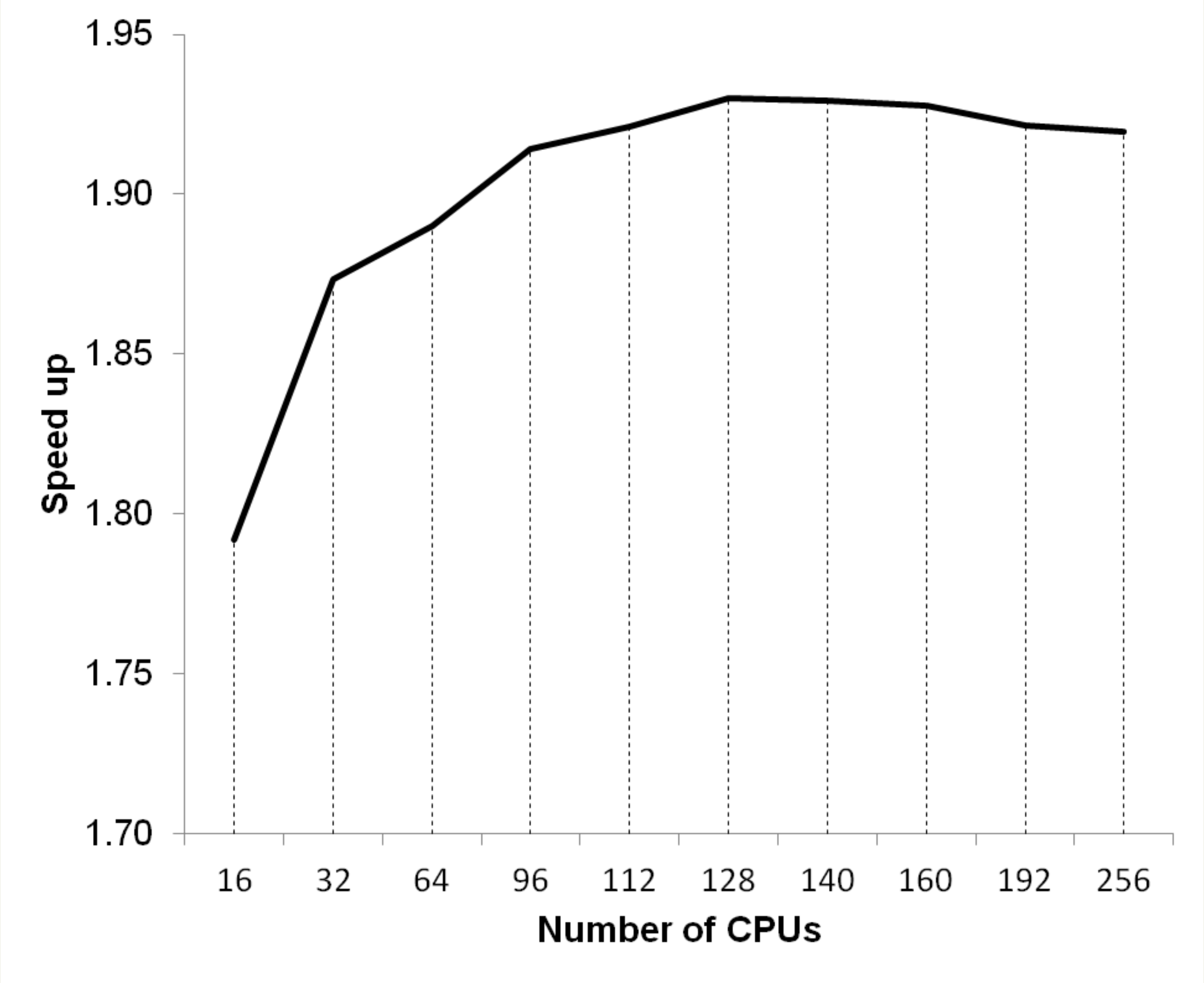
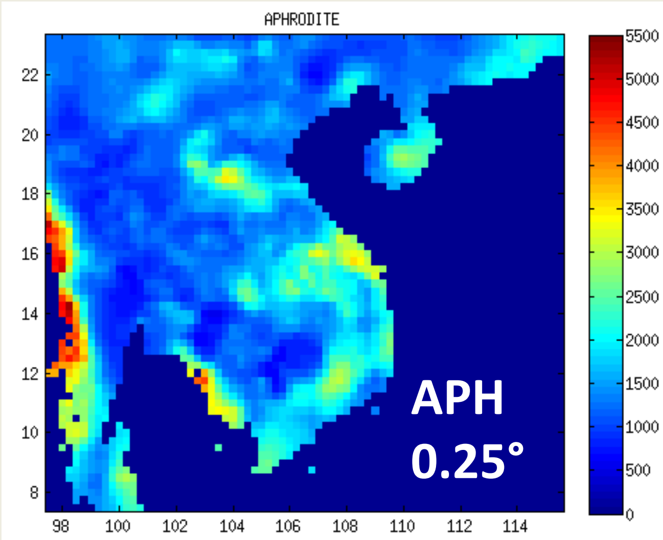


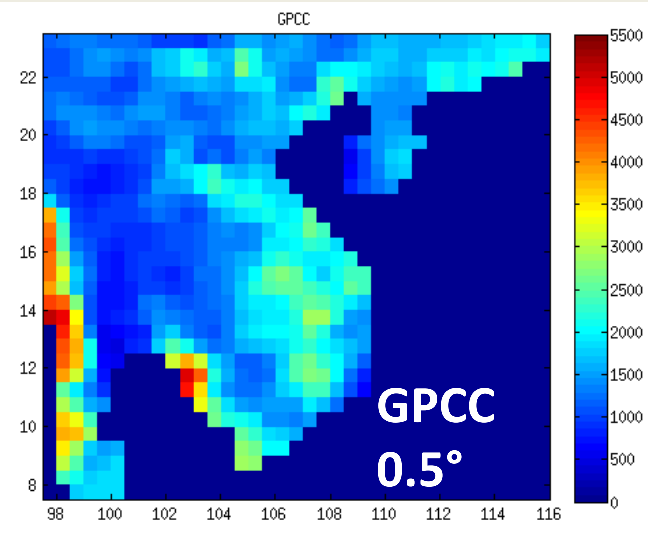
Further technical details:

- CPU resources (for 1 year simulation)
  - Number of CPUs: 128
  - Sum of CPU-time over all processors: 182-16:30:02
  - Elapsed time: 1-11:39:26
  - Maximum virtual memory by any process: 701.62M
  - Maximum number of minor page faults for any process: 40663916
  - Total number of voluntary context switches for all processes: 418026354

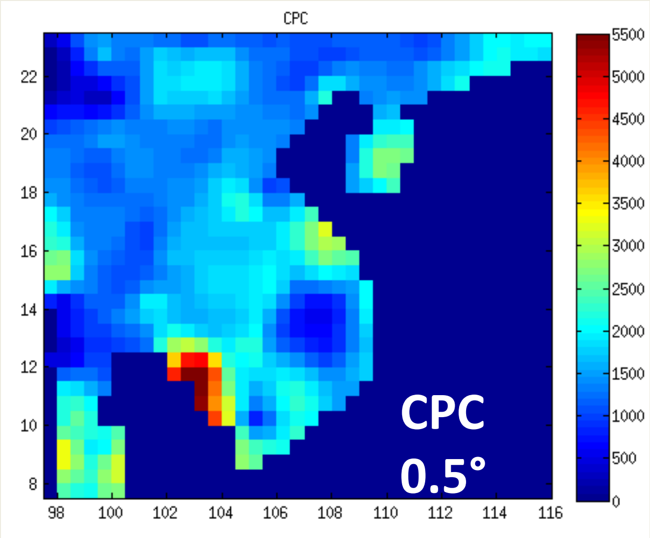
- Approved computation time: 69125d 0h 0m 0s
  - Already used: 28343d 5h 4m 38s (41.00%)

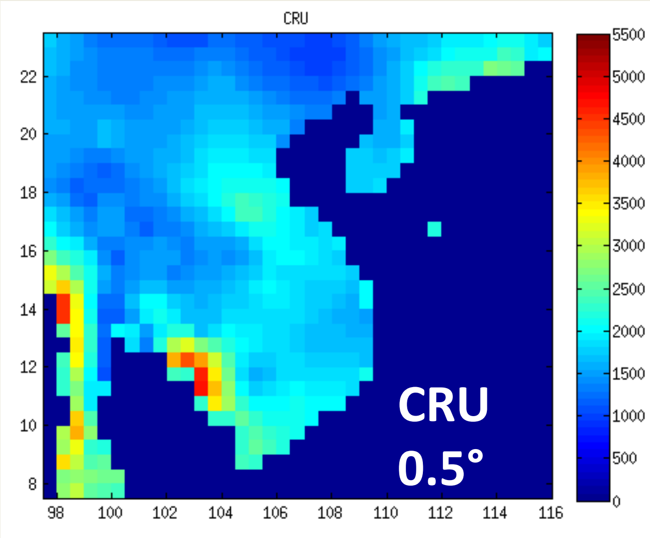
Reference Data





Year 2000





Trends Precip annual ERA40