Setting up Regional Climate Simulations for Southeast Asia

Patrick Laux, Van Tan Phan, Christof Lorenz, Tran Thuc, Lars Ribbe, Harald Kunstmann

Abstract Climate change and climate variability are main drivers for land–use, especially for regions dominated by agriculture. Within the framework of the project *Land–Use and Climate Change Interactions in Central Vietnam* (LUCCi) regional climate simulations are performed for Southeast Asia in order to estimate future agricultural productivity and to derive adaptive land–use strategies for the future. Focal research area is the Vu Gia-Thu Bon (VGTB) river basin of Central Vietnam. To achieve the goals of this project reliable high resolution climate information for the region is required. Therefore, the regional non-hydrostatic *Weather Research and Forecasting* (WRF) model is used to dynamically downscale large-scale

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coupled atmosphere–ocean general circulation model (AOGCM) information. WRF will be driven by the ECHAM5-GCM data and the business-as-usual scenario A1B for the period 1960-2050. The focus of this paper is on the setup of WRF for East Asia. Prior to running the long-term climate simulation in operational mode, experimental simulations using different physical parameterizations have been conducted and analyzed. Different datasets have been used to drive the WRF model and to validate the model results. For the evaluation of the parameterization combination special emphasis is given to the representation of the spatial patterns of rainfall and temperature. In total, around 1.7 Mio CPUh are required to perform the climate simulations. The required computing resources have been approved from the Steinbuch Centre for Computing (KIT, SCC).

1 Introduction

Climate change and climate variability are of major concern for Central Vietnam's environment and people's well-being. Increasing frequency and severities of extreme events like floods, droughts, hurricanes but also increasing temperatures, sea level rise and salt water intrusion in the coastal areas are expected to have dramatic consequences for agricultural productivity and thus food security in the VGTB basin. These challenges demand for informed stakeholders and a land management strategies to increase the resilience of the ecosystems.

Vietnams lowlands and midlands are predominantly characterized by rice landscapes. Rice is the pillar of food security for many million households. Rice production is complexly linked with land management, water and environment. Judicious management of rice ecosystems is seen today - in a post–green revolution age - as a major strategy for raising rice productivity, protect the environment and achieve long term food security for rural and urban populations in Vietnam and all over rice producing Asia. Many problems related to rice production and climate change/climate variability in Vietnam became obvious during the last decades. Temperature stress, especially during sensitive rice development stages, negatively affects crops development and yields. Sea level rise and salt water intrusion in lowland coastal areas are affecting rice cropping, while the magnitude of effects depend on the complex interactions between the cropping calendar and the hydrological situation. Although rice is a very salt resistant crop, salinity levels beyond threshold levels will eventually decrease yields. Excessively high water level and prolonged inundation periods can severely affect yields.

The major goals of the LUCCi project is to provide a sound future land use management framework that considers socio-economic development, population growth and expected impacts of climate change on land and water resources. This framework links climate change mitigation – through the reduction of GHC emissions – with adaptation strategies to secure food supply in a changing environment. As a basis, present and past land use practices and the use of water resources in the VGTB basin are analyzed with special emphasis on possible climate change impacts. This in-depth analysis will allow deriving carbon-optimized land and water use strategies for the VGTB basin as well as for the larger region of Central Vietnam.

The *Dynamical Downscaling* (DDS), which is performed by KIT, IMK-IFU will contribute to assess future land–use and quantify agricultural productivity in the VGTB basin of Central Vietnam. This requires reliable and high resolution information about the climatology for the present and past, but also future regional climate projections. It is widely accepted that present-day General Circulation Models (GCMs) are able to simulate the large-scale state of the atmosphere in a realistic manner, and predict large-scale climate change based on assumptions about future greenhouse gas emissions (AR4, IPCC). Their implications on regional and local scales, however, are inadequate mainly due to the limited representation of mesoscale atmospheric processes, topography, and land-sea distribution in GCMs (e.g. Cohen, 1990; von Storch et al., 1993). A direct application of GCM output for regional and local impact studies would lead to inconsistencies in frequency statistics, such as the occurrence probabilities of rainfall events (e.g. Mearns et al., 1997, Smiatek et al. 2009). Within the LUCCi framework, both *Dynamical* as well as *Statistical Downscaling* (SDS) approaches will be followed and combined in that way, that the advantages of each approach are capitalized: The scarcity of observed climate data in this region, and the most probably non-stationary climatic processes for the future period of interest (2010-2050) demand for a DDS approach. Therefore, the regional non-hydrostatic *Weather Research and Forecasting* (WRF) model will be driven in three nesting steps with resolutions of 45 km, 15 km, and 5 km to obtain transient and consistent climate simulations for the period 1960-2050. Due to the high computational demands, WRF will solely be driven by the coupled atmosphereocean general circulation model ECHAM5 and the business-as-usual A1B scenario. The underlying assumptions for the chosen scenario are a future world of very rapid economic growth, low population growth and rapid introduction of new and more efficient technology. In addition to the dynamical downscaling approach, a multimodel and multiscenario ensemblebased SDS technique will be developed which allows for quantifying uncertainties inherent to the downscaling approaches, the GCMs and the chosen scenarios.

The main goal of this paper is to identify a suitable setup of WRF physical parameterizations for Southeast Asian, which is the prerequisite to conduct long-term climate simulations. Based on the identified setup, the long-term climate simulations are conducted. Albeit few regional climate simulation efforts have been done for Southeast Asia e.g. (Phan et al., 2009), to the best of our knowledge these simulations represent the first efforts i) to identify the best physical parameterization combination in a systematic manner, and ii) to conduct transient long-term climate simulations for the VGTB river basin with this detailed spatio-temporal resolution.

2 The regional climate model simulations

2.1 The regional climate model WRF

WRF is a next-generation mesoscale numerical weather prediction system designed to serve both operational forecasting and atmospheric research needs. The WRF Software Framework (WSF) provides the infrastructure that accommodates the dynamics solvers, physics packages that interface with the solvers, programs for initialization, WRF-Var, and WRF-Chem. There are two dynamics solvers in the WSF. The one applied in this project is the Advanced Research WRF (ARW) solver which was primarily developed at NCAR (National Centre for Atmospheric Research, USA). The ARW dynamics solver integrates the compressible, non-hydrostatic Euler equations. The equations are cast in flux form using variables that have conservation properties. The equations are formulated using a terrain- following mass vertical coordinate. The flux form equations in Cartesian space are extended to include the effects of moisture in the atmosphere and projections to the sphere.
For the temporal model discretization the ARW solver uses a time-split integration scheme. Generally speaking, slow or low-frequency (meteorologically significant) modes are integrated using a third-order Runge-Kutta (RK3) time integration scheme, while the high- frequency acoustic modes are integrated over smaller time steps to maintain numerical stability. The horizontally propagating acoustic modes (including the external mode present in the mass-coordinate equations using a constant-pressure upper boundary condition) and gravity waves are integrated using a forward-backward time integration scheme, and vertically propagating acoustic modes and buoyancy oscillations are integrated using a vertically implicit scheme (using the acoustic time step). The time-split integration for the flux-form equations is described and analyzed in Klemp et al. (2007).
The spatial discretization in the ARW solver uses a C grid staggering for the variables. That is, normal velocities are staggered one-half grid length from the thermodynamic variables. The grid lengths Δx and Δy are constants in the model formulation; changes in the physical grid lengths associated with the various projections to the sphere are accounted for using map factors. The vertical grid length $\Delta 2\eta$ is not a fixed constant; it is specified in the initialization. The user is free to specify the η values of the model levels subject to the constraint that $\eta = 1$ at the surface, $\eta = 0$ at the model top, and η decreases monotonically between the surface and model top.

2.2 WRF domain setup

For the research project LUCCi climate simulations with a target resolution of 5 km for Central Vietnam for 1960 – 2050 shall be performed. For this purpose, WRF is nested in the general circulation model ECHAM5 using the following setup and location of the domains (Figure 1).

1. **Domain1:**
   - horizontal: 99 x 99 grid points with a resolution of 45 km
   - vertical: 50 layers up to 5000 Pa
   - time step: 180 s (adaptive time-step option enabled)
2. **Domain2:**
   - horizontal: 142 x 145 grid points with a resolution of 15 km
   - vertical: 50 layers up to 5000 Pa
   - time step: 180 s (adaptive time-step option enabled)
3. **Domain3:**
   - horizontal: 66 x 75 grid points with a resolution of 5 km
   - vertical: 50 layers up to 5000 Pa
   - time step: 180 s (adaptive time-step option enabled)

2.3 Required HPC ressources

Due to the limitations of the CFL stability condition, the option adaptive time-step has been enabled resulting in an indefinable number of required integration steps. Calculating with the predefined time steps of 180 s, more than 15 Mio integration

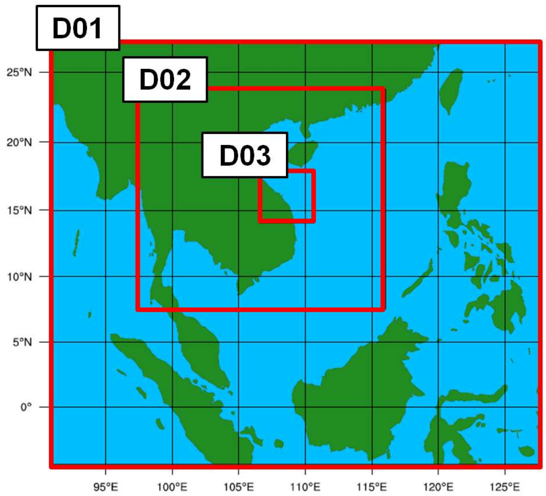

Fig. 1 Domains to be modelled by the regional climate model WRF using nesting strategy.

steps are required respectively on 490050 grid cells for Domain 1, 1029500 grid cells for Domain 2, and 247500 grid cells for Domain 3 with more than 10 degrees of freedom on each grid cell (momentum, mass,pressure and various mixing ratios for moisture like water vapor, cloud water, ice water, rainwater, snow etc.). The resulting size of this task makes it necessary to move to a suitable high performance computing environment.
Software development, testing, benchmarking, and required preprocessing are performed on the KIT, IMK-IFU linux cluster. KIT, IMK-IFU is managing an Infiniband based Linux-Cluster with 116 Opteron, 96 Istan, and 192 Magny processors.
The preprocessing is performed on annual basis. The generated files, which are required to drive WRF, are then transfered to the HPC environement XC4000 via scp. Based on the performed preprocessing WRF is also run in annual time slices, however the WRF restart option enables transient climate simulations, i.e. without initializing WRF every year. WRF and other required software such as netcdf have been successfully installed at the cluster architecture HPC XC4000 using a test account. WRF test runs have been performed using shared memory parallelism (OpenMP).

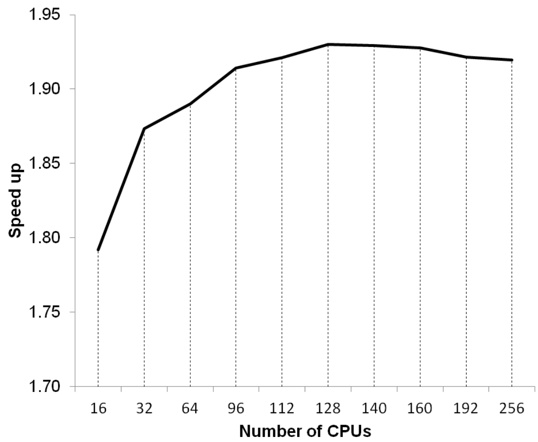

Fig. 2 Performance of WRF on HPC XC4000 in Karlsruhe

It is found that 128 processors (32 CPU cores) show the best performance (see Figure 2). Computing time for the three domains for one month was approximately 8 hours which results in 8 x 128 = 1024 CPUh.

In order to derive the signal expected from future climate change and climate variability, the future climate projection must be compared against the control run. Beside that, a climate simulation driven by ERA40 reanalysis will performed to assess the quality of the control run. The simulation efforts can be subdivided into three blocks of 41 years of simulation time plus 4 years of spin-up time.

1. Climate simulations of the control period (1960–2001)

2. Climate simulations for the future scenario A1B (2001–2050)
3. ERA40 reanalysis simulations of the control period (1960–2001)

This means that for each block of 45 years 45 x 12 x 1024 = 552960 CPUh are required, which we extend to 553000 CPUh to have some additional capacities. For the proposed climate simulations for LUCCi, in total 3 x 553000 = 1659000 CPUh are required for the ERA40 reanalysis and control plus the future climate simulations (A1B). With the proposed 128 CPUs this means approximately 180 days pure computing time per 45 years simulation. Thus, we asses around 8 month total simulation time per block (6 month pure computation time and queue/waiting time), which results in a total time of 2 year for the proposal.

For the intermediate storage of the required input data and the WRF output of a short time period we estimate a storage capacity of 2 TB permanent and 2 TB temporary disc space at HP XC2. The results will be transfered to KIT, IMK-IFU. To permanently archieve the simulation results a storage capacity of about 30 TB is required.

3 Evaluation of different physical parameterization setups

Due to the fact that long-term WRF simulations for Southeast Asia are applied for the first time by KIT, IMK-IFU the performance of climate simulation at a HPC XC4000 requires several preparatory works. These mainly include test simulations with WRF in order to find an optimal setup of the physical parameters, i.e. parameterization for the microphysics, planetary boundary layer, and also cumulus convection. Please note that the cumulus convection scheme is swichted off for the 5 km resolution (here: Domain 3). The different parameter combinations applied for the year 2000 are shown in Table 3.

The experimental climate simulations are performed for the year 2000 and validated using gridded observation data for rainfall and temperature. The validation of simulated precipitation fields has been performed using *Asian Precipitation – Highly-Resolved Observational Data Integration Towards Evaluation of the Water Resources* (Yatagei et al., 2009), hereinafter referred to as Aphrodite data, and for temperature, CRU TS 2.1 data (Mitchell and Jones, 2005), referred to as CRU data, have been used. As boundary conditions for the RCM, both NCEP/NCAR (Kalnay et al., 1996; Kistler et al., 2001) as well as ERA40 (Uppala et al., 2005) reanalysis data have been applied. As the first directive of the regional climate simulations is to match the spatial patterns of precipitation and temperature, the results of the climate simulations of Domain 2 are validated, because they match best with the resolution of the gridded observations. Nevertheless, the climate simulation outputs are regridded to the resolution of gridded observations, i.e. 0.25° and 0.5° for Aphrodite and CRU, respectively. In the following two subsections the climate simulation results of Domain 2 driven by the NCEP/NCAR and ERA40 reanalysis data are validated against the gridded observation data for the year 2000. The results for precipitation

Table 1 Physical parameterization combinations of the different WRF experimental runs. **Microphysics**: 2 - Lin, 3 - WRF Single-Moment-3-class, 13 - Ston Brook University; **Planetary Boundary Layer (PBL)**: 1 - Yonsei University, 5 - Mello-Yamada Nakanishi and Nino Level 2.5 PBL; **Cumulus**: 2 - Betts-Miller-Janjic, 8 - New Simplified Arakawa-Schubert.

	Microphysics D1-D3	PBL D1-D3	Cumulus D1-D2
B	2	1	2
C	2	5	2
D	2	5	14
E	2	1	14
F	3	1	2
G	3	5	2
H	3	1	14
I	3	5	14
J	13	1	2
K	13	5	2
L	13	5	14
M	13	1	14

and temperature are presented in the sequel. The Taylor diagrams provide a visual framework to compare the simulated (WRF) results against a reference (here: the gridded precipitation product *Aphrodite*).

3.1 Validation results of WRF-NCEP/NCAR reanalysis data

Figure 3.1 shows the Taylor diagrams for precipitation (WRF-NCEP/NCAR compared to Aphrodite) obtained for the different physical parametrization setups. Partly high differences between the different setup can be found for precipitation. The spatial correlation patterns strongly depend on the season: the correlation is higher for winter (DJF) and fall (SON), the periods in which most of the rain falls in Southeast Asia. The correlation coefficient is lowest for summer (JJA), the season in which convective rainfall dominates. This season the standard deviation as well as the RMS differences are greatest.

In general, the spatial correlations for temperatures between NCEP/NCAR reanalysis driven WRF simulations and observations (CRU) are high. They are in the order of 0.8, and the different physical parameterizations are not very sensitive for temperature (not shown here).

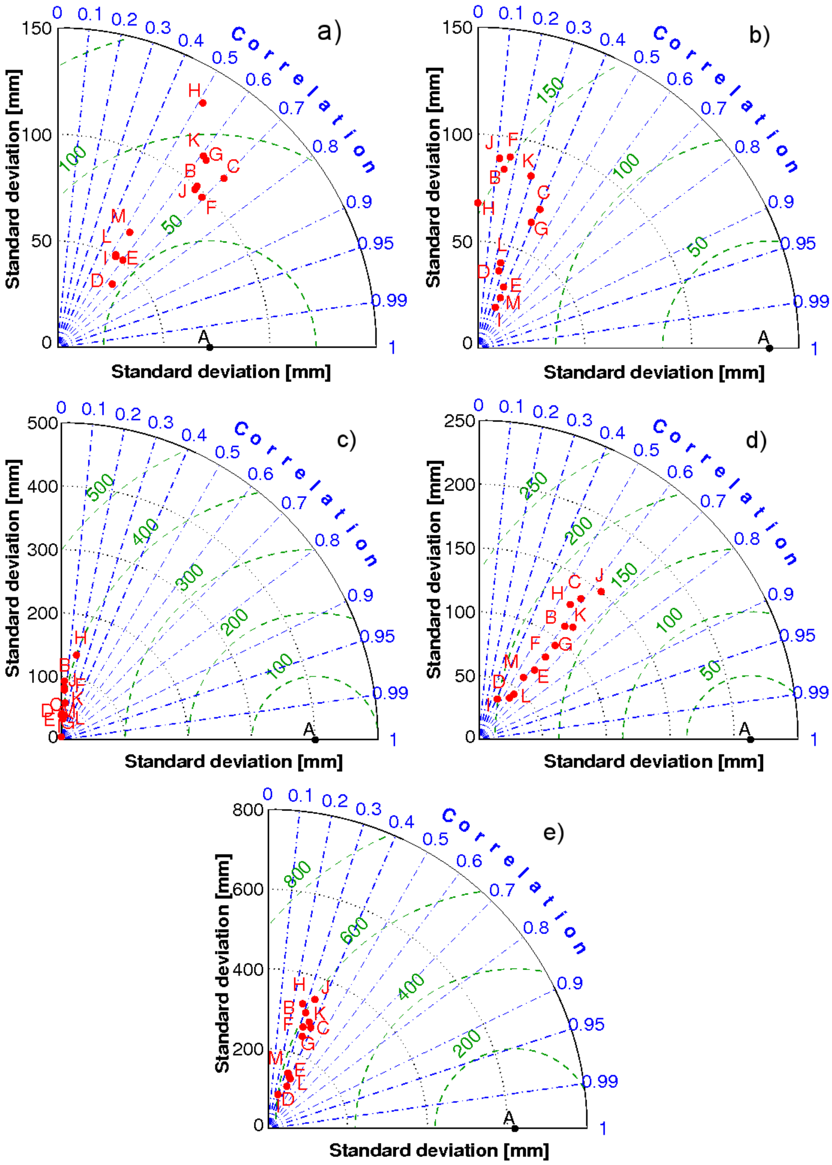

Fig. 3 Taylor diagram of NCEP/NCAR driven WRF simulations and observed (Aphrodite) precipitation amounts for a) winter 2000 (DJF), b) spring 2000 (MAM), c) summer 2000 (JJA), d) fall 2000 (SON), and e) the whole year of 2000. The observation data (here: Aphrodite) is shown as A, the coding for the parameter combinations can be obtained from Table 3. The similarity of two patterns is quantified in terms of their correlation (blue), their root-mean-square (RMS) difference (green), and their standard deviation (black).

Table 2 Bias of mean temperatures between NCEP/NCAR reanalysis driven WRF simulations and gridded observations CRU for winter, spring, summer, and fall of the year 2000 and the whole Domain 2. The observation data (here: CRU) is shown in A, the coding for the parameter combinations can be obtained Table 1.

	winter				sring				summer				fall			
	$\bar{x}$	σ	*RMSc*	*r*	$\bar{x}$	σ	*RMSc*	*r*	$\bar{x}$	σ	*RMSc*	*r*	$\bar{x}$	σ	*RMSc*	*r*
A	28.22	5.19	–	–	25.63	2.82	–	–	26.71	1.87	–	–	24.71	2.24	–	–
B	13.01	6.67	4.33	0.76	22.95	3.10	1.87	0.81	24.99	3.00	1.94	0.78	19.11	3.99	2.38	0.85
C	11.11	7.29	4.77	0.76	22.38	3.05	2.07	0.75	24.66	3.21	2.09	0.79	19.28	3.99	2.39	0.85
D	13.31	6.95	4.22	0.80	22.50	3.16	1.94	0.80	24.76	3.11	2.07	0.76	18.30	4.34	2.83	0.81
E	14.66	6.89	4.01	0.81	20.11	3.16	1.98	0.79	20.91	3.08	2.21	0.70	19.44	3.61	2.05	0.86
F	10.46	7.18	5.11	0.70	22.07	3.12	1.93	0.79	24.78	3.02	1.94	0.78	17.61	4.39	2.89	0.81
G	14.67	6.84	3.93	0.82	22.28	3.21	2.07	0.77	22.56	3.05	2.05	0.75	18.53	4.08	2.52	0.84
H	14.93	6.54	3.69	0.83	20.37	3.21	1.91	0.81	17.81	3.16	2.28	0.70	16.75	3.83	2.38	0.82
I	13.41	6.86	4.14	0.80	19.88	3.33	2.08	0.78	17.79	3.43	2.54	0.69	16.20	4.29	2.66	0.85
J	12.18	6.56	4.33	0.75	22.70	3.13	1.89	0.80	25.69	3.20	2.08	0.79	19.64	3.82	2.22	0.86
K	13.96	7.06	4.47	0.78	22.82	3.07	2.00	0.77	24.04	3.08	2.00	0.78	17.61	4.25	2.77	0.81
L	13.45	6.89	4.20	0.79	22.33	3.18	1.92	0.80	24.44	3.15	2.08	0.77	18.48	4.15	2.63	0.82
M	14.54	6.99	4.13	0.81	20.30	3.31	1.95	0.81	23.60	3.38	2.36	0.74	16.03	4.14	2.67	0.81

3.2 Validation results of ERA40 reanalysis data

Comparing the ERA40 driven simulation results, illustrated in Figure 3.2, with the results obtained using NCEP/NCAR reanalysis data (Figure 4), one can clearly observe a better representation of the spatial correlations for the summer season while the skill of the fall and winter seasons are reduced. The deviations of single WRF experiments compared to the observations, such as B, C, J, and K (see Table 2) illustrated as RMS differences and standard deviations are drastically increased.

However, the temperature bias is reduced compared to the NCEP/NCAR driven WRF simulation results.

Amongst all test parameter combinations it is found that combination G (see Table 3), i.e. WRF Single-Moment-3-class, Mello-Yamada Nakanishi and Nino Level 2.5 PBL, and Betts-Miller-Janjic is leading to reasonable results for both precipitation and temperature values. Due to the lower biases in temperature (especially during the winter months) it is decided for the ERA40 reanalysis as driving dataset.

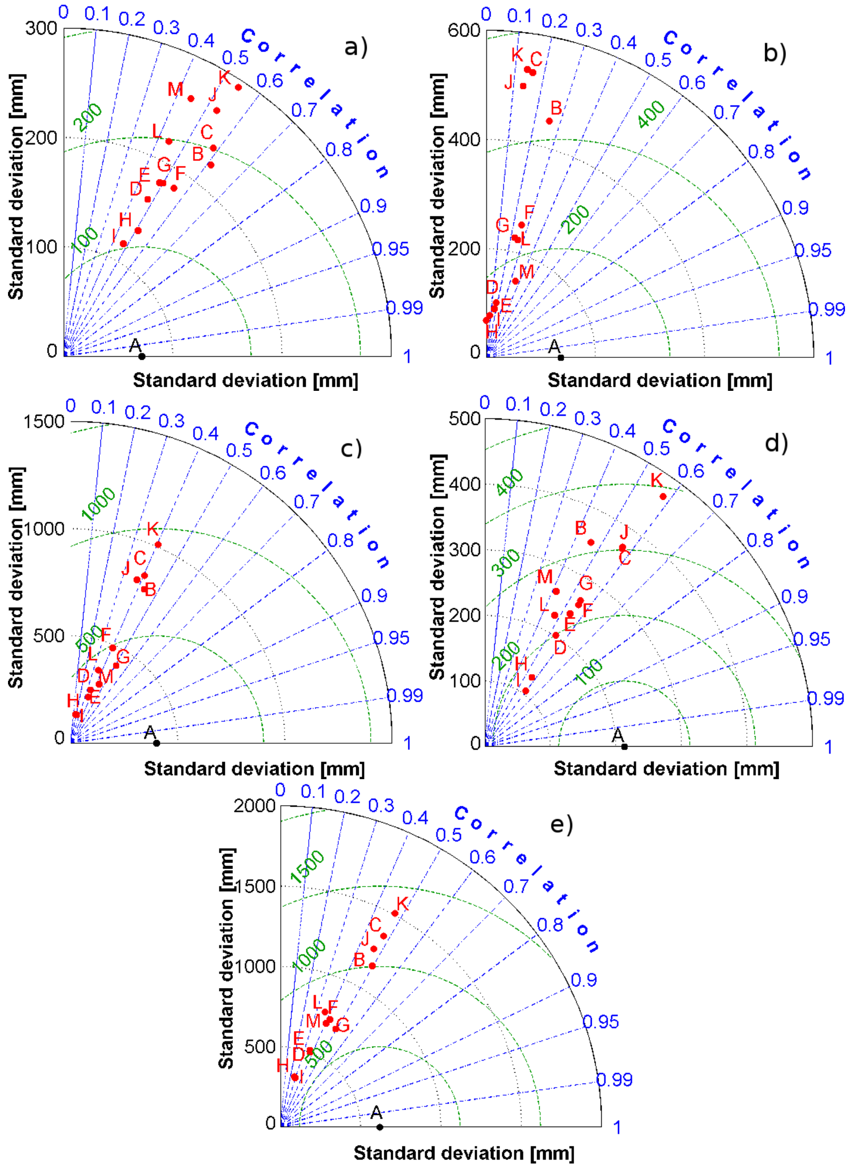

Fig. 4 Taylor diagram of ERA40 driven WRF simulations and observed (Aphrodite) precipitation amounts for a) winter 2000 (DJF), b) spring 2000 (MAM), c) summer 2000 (JJA), d) fall 2000 (SON), and e) the whole year of 2000.

Table 3 ERA40-CRU (winter, spring, summer, and fall). The observation data (here: CRU) is shown in A, the coding for the parameter combinations can be obtained Table 3.

	winter				sring				summer				fall			
	$\overline{x}$	σ	*RMSc*	*r*	$\overline{x}$	σ	*RMSc*	*r*	$\overline{x}$	σ	*RMSc*	*r*	$\overline{x}$	σ	*RMSc*	*r*
A	28.22	5.19	–	–	25.63	2.82	–	–	26.71	1.87	–	–	24.71	2.24	–	–
B	17.89	6.83	3.37	0.88	23.12	2.95	1.66	0.83	24.76	2.24	1.38	0.79	21.24	3.08	1.60	0.87
C	17.16	6.71	3.41	0.87	23.07	2.90	1.67	0.83	24.67	2.23	1.38	0.79	20.72	3.14	1.67	0.86
D	17.34	6.61	3.27	0.87	22.88	2.95	1.62	0.84	24.16	2.40	1.41	0.81	21.06	3.30	1.73	0.87
E	18.17	6.82	3.29	0.88	22.31	3.12	1.79	0.82	24.96	2.47	1.37	0.84	20.89	3.36	1.81	0.87
F	17.38	6.89	3.59	0.86	23.24	2.96	1.66	0.84	24.81	2.32	1.36	0.81	21.10	3.25	1.73	0.87
G	17.18	6.62	3.31	0.87	22.94	2.94	1.69	0.83	24.80	2.24	1.31	0.81	20.60	3.17	1.70	0.86
H	17.31	6.77	3.52	0.86	23.20	3.05	1.54	0.86	26.99	3.00	1.72	0.85	21.92	3.40	1.76	0.89
I	17.44	6.52	3.16	0.88	24.05	3.18	1.61	0.86	26.02	2.75	1.52	0.85	21.44	3.34	1.73	0.88
J	18.10	6.80	3.31	0.88	23.39	2.96	1.65	0.84	24.88	2.16	1.35	0.78	21.37	3.06	1.57	0.87
K	17.59	6.67	3.28	0.88	23.15	2.87	1.68	0.83	24.73	2.15	1.35	0.78	20.85	3.08	1.61	0.86
L	17.48	6.74	3.40	0.87	23.16	3.12	1.87	0.80	24.38	2.17	1.28	0.81	18.96	3.35	2.06	0.80
M	17.44	6.52	3.16	0.88	24.05	3.18	1.61	0.86	26.02	2.75	1.52	0.85	21.44	3.34	1.73	0.88

4 Analysis of the temperature biases

Albeit the spatial patterns for temperature between observed and simulated temperatures are matched well, the large biases (Table 2) for the winter and fall season require further investigations. As all parameterization combinations are leading to underestimated temperatures of the WRF simulations within Domain 2, it has been speculated that the CRU data might overestimate temperature for this region. Figure 3.2 shows the differences between the gridded observation datasets CRU, DEL, and GLDAS and the ERA Interim Reanalysis for winter of the year 2000. Comparing CRU with alternative gridded observation datasets it is observed that CRU significantly overestimates the temperature during winter. Especially for Vietnam, this overestimation is obvious. Figure 3.2 illustrates the differences of the different datasets averaged over the grid cells corresponding to Vietnam. It is speculated that the overestimated temperatures of the CRU data result from the coarse network of observation stations within this topographically complex region. These observations are interpolated based on the surrounding 8 stations. Fist inspection of the CRU derived interpolated elevation model based on the heights of the 8 surrounding observation stations shows party strong deviations compared to the elevation model as used for the WRF model in Domain 2 (not shown). As a consequence, the temperature estimates of the CRU grid cells can deviate significantly from model results. Comparing CRU with other observation datasets in regions with similar complex terrain and low observation densities could help to judge the qulity of the CRU dataset. However, it remains unclear why this deviation is stronger during winter and fall than during the other seasons. A more detailed analysis is required.

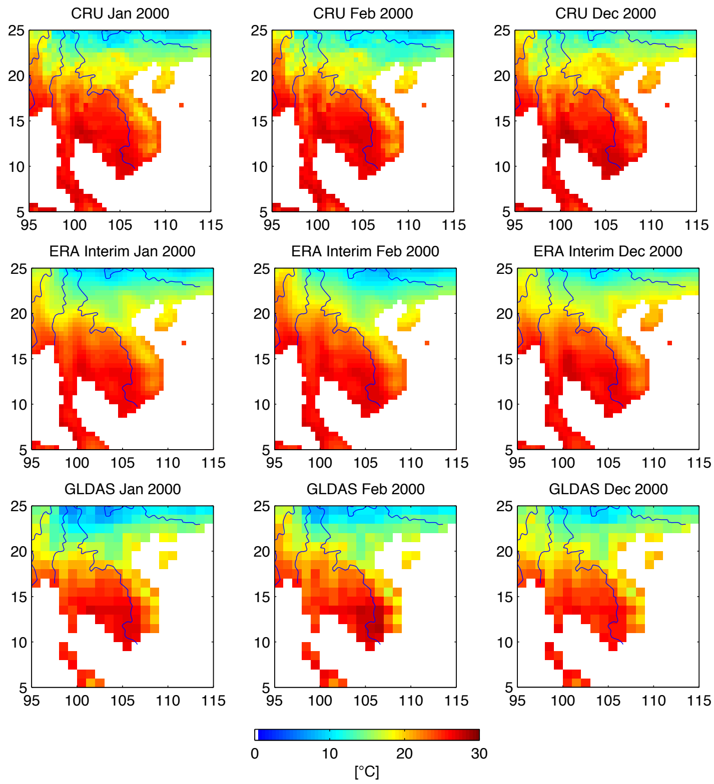

Fig. 5 Mean temperature [° C] for January, February, and December (2000) for the datasets CRU, DEL, ERA Interim, and GLDAS.

5 Ongoing activities and future work

The operational long-term climate simulations are performed on monthly time slices using the restart option of WRF. This means that the results of the last time step of the previous month will be temporarily stored and used as input for the subsequent month. For the continuous performance of the climate simulations batch processing will be applied. The model output will be stored in a 6 hourly resolution. Many surface climate variables are additionally stored in hourly resolution to meet specific requirements of the LUCCi project consortium. Besides the instantaneous variables, retained in a six hourly and hourly resolution, additional meteorological surface variables containing the magnitude and timing of the actual mimimum and maximum values of a day are retained. This will allow for detailed analysis of extreme events lateron.

It is expected that the climate simulation will be finalized by end of 2012. The re-

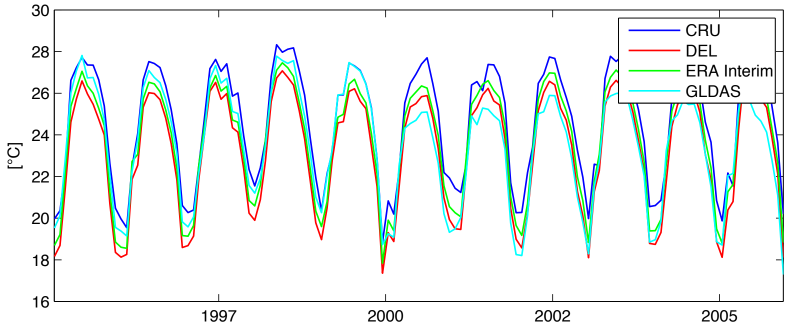

Fig. 6 Time series of monthly temperature for Vietnam (average values for the grid cells corresponding to Vietnam) using the different datasets CRU, DEL, ERA Interim and GLDAS.

sults will be provided to the LUCCi project consortium, but results can be provided on request to the climate change and climate impact community.

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References

1. Cohen SJ (1990) Bringing the global warming issue closer to home: the challenge of regional impact studies. Bulletin of the American Meteorological Society 71:520–526
2. Kalnay et al. (1996) The NCEP/NCAR 40-year reanalysis project, Bull. Amer. Meteor. Soc. 77:437–470
3. Klemp JB., Skamarock WC, Dudhia J (2007) Conservative split-explicit time integration methods for the compressible nonhydrostatic equations. Mon. Wea. Rev.. 135:2897–2913
4. Mearns LO, Rosenzweig C, Goldberg R (1997) Mean and Variance Change in Climate Scenarios: Methods, Agricultural Applications, and Measures of Uncertainty. Climatic Change 35:367–396
5. Mitchell TD, Jones PD (2005) An improved method of constructing a database of monthly climate observations and associated high-resolution grids. International Journal of Climatology 25:693–712
6. Phan VT, Ngo-Duc T, Ho TMH (2009) Seasonal and interannual variations of surface climate elements over Vietnam. Journal of Climate Research 40(1):49–60
7. Smiatek G, Kunstmann H, Knoche R, Marx A (2009) Precipitation and temperature statistics in high- resolution regional climate models: Evaluation for the European Alps. Journal of Geophysical Research, 114:D19107. doi: 10.1029/2008JD011353

8. Von Storch H, Zorita E, Cubasch U (1993) Downscaling of global climate change estimates to regional scales: An application to Iberian rainfall in wintertime, J. Climate, 6:1161–1171