河南大學

The WRF simulation of the impact of land use and land cover change on regional climate in China

Youmin Chen

Henan University, Kaifeng
(youmin.chen@henu.edu.cn)

Outline

1. Domain, model and data
2. Climate downscaling in East Asia（CORDEX）
3. The LULC and MODIS data
4. The impact of LULC change on precipitation
5. The impact of LULC change on temperature
6. Conclusion and discussion

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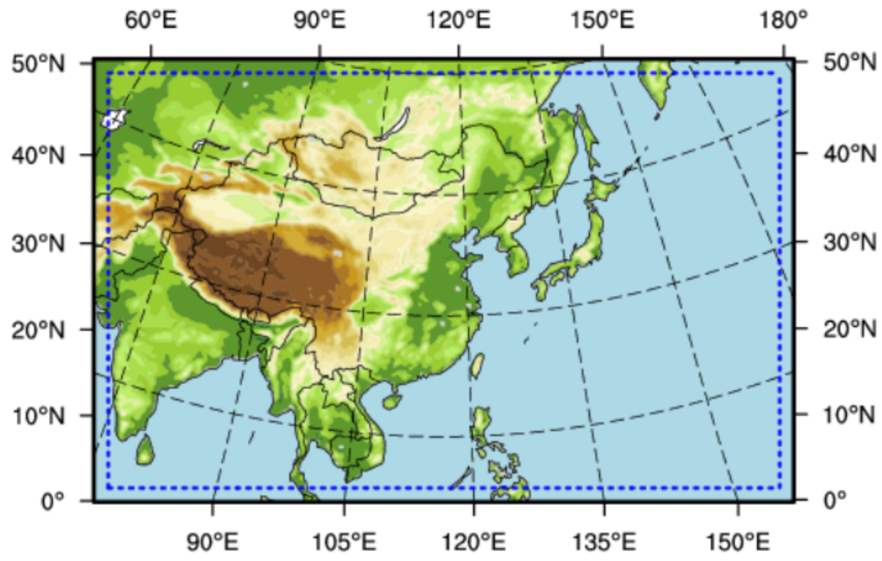
1. The domain, model and data

Model
➢ WRF (weather research and forecast)

Input data
- MODIS （LULC）
- ECMWF-ERA40
- ECMWF-ERAI
- NorESM-RCP45
- NorESM-RCP85
- NorESM-historical

Simulation result
- CORDEX-ERA40
- CORDEX-ERAI
- CORDEX-NorESM

Validation data
- CRU-TS323
- GPCP
- ECMWF-ERAI



Model equations

Fundamental Physical Quantities & Equations

At every grid cell GCMs calculate:

- Temperature (T)
- Pressure (P)
- Winds (U, V)
- Humidity (Q)

- Conservation of momentum

  $\frac{\partial \vec{V}}{\partial t} = -(\vec{V} \cdot \nabla)\vec{V} - \frac{1}{\rho}\nabla p - \vec{g} - 2\vec{\Omega} \times \vec{V} + \nabla \cdot (k_m \nabla \vec{V}) - \vec{F}_d$
- Conservation of energy

  $\rho c_{\vec{v}} \frac{\partial T}{\partial t} = -\rho c_{\vec{v}} (\vec{V} \cdot \nabla) T - \nabla \cdot \vec{R} + \nabla \cdot (k_T \nabla T) + C + S$
- Conservation of mass

  $\frac{\partial \rho}{\partial t} = -(\vec{V} \cdot \nabla)\rho - \rho(\nabla \cdot \vec{V})$
- Conservation of H_2O (vapor, liquid, solid)

  $\frac{\partial q}{\partial t} = -(\vec{V} \cdot \nabla) q + \nabla \cdot (k_q \nabla q) + S_q + E$
- Equation of state

  $p = \rho R_d T$

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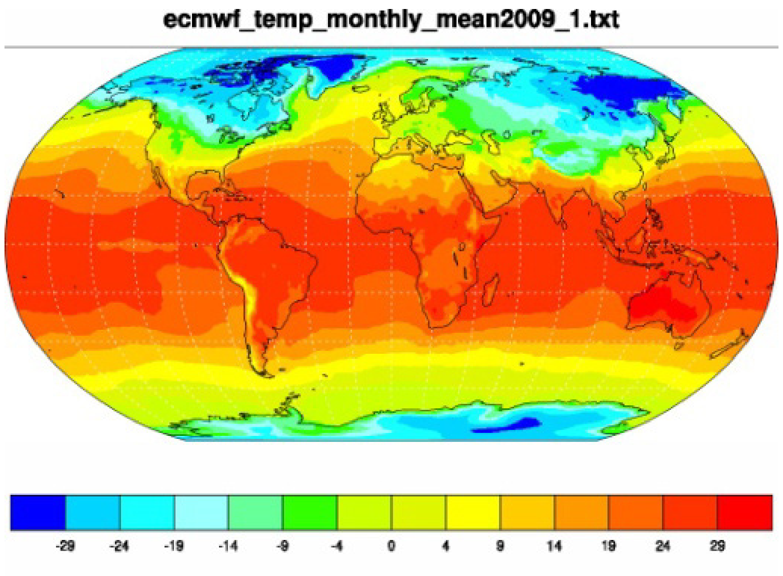
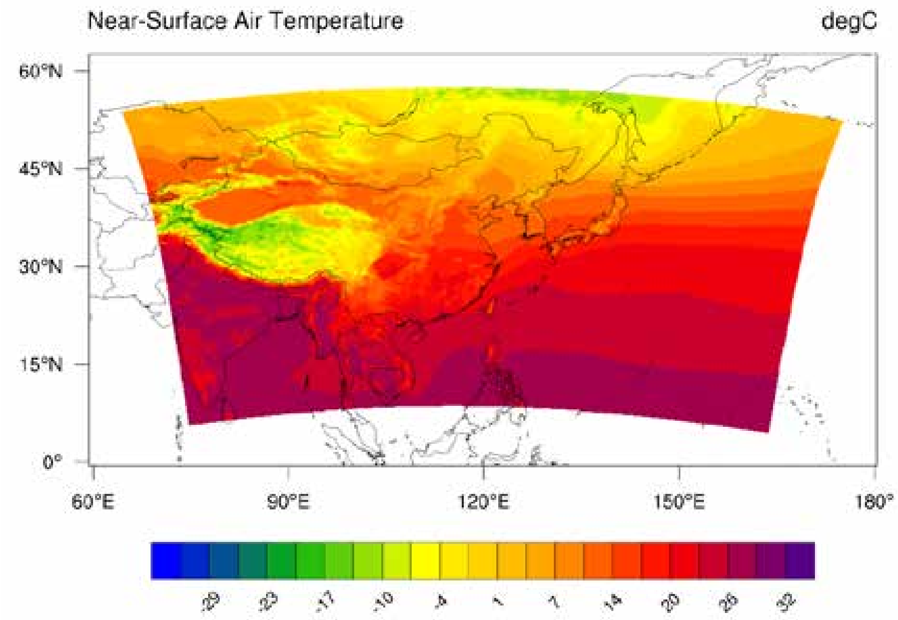
2. Climate Downscaling in East Asia



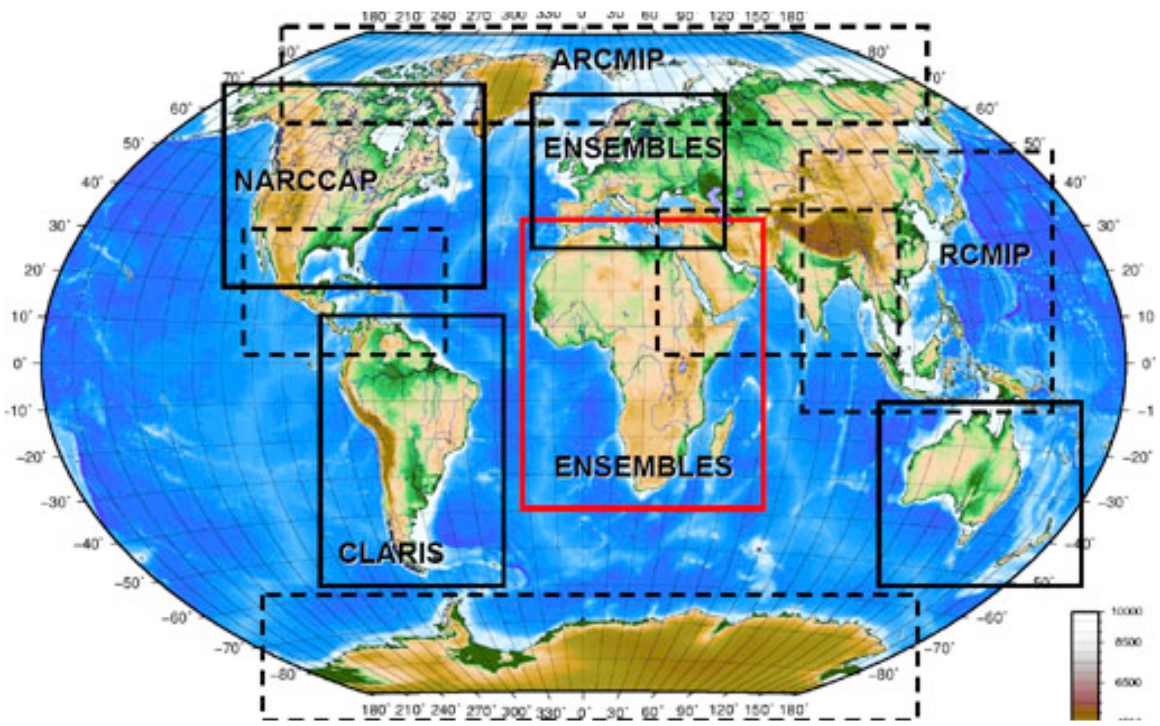


Spatially from 1-2 degree to 0.25 degree

CORDEX: Coordinated Regional climate Downscaling Experiment

CORDEX domains:

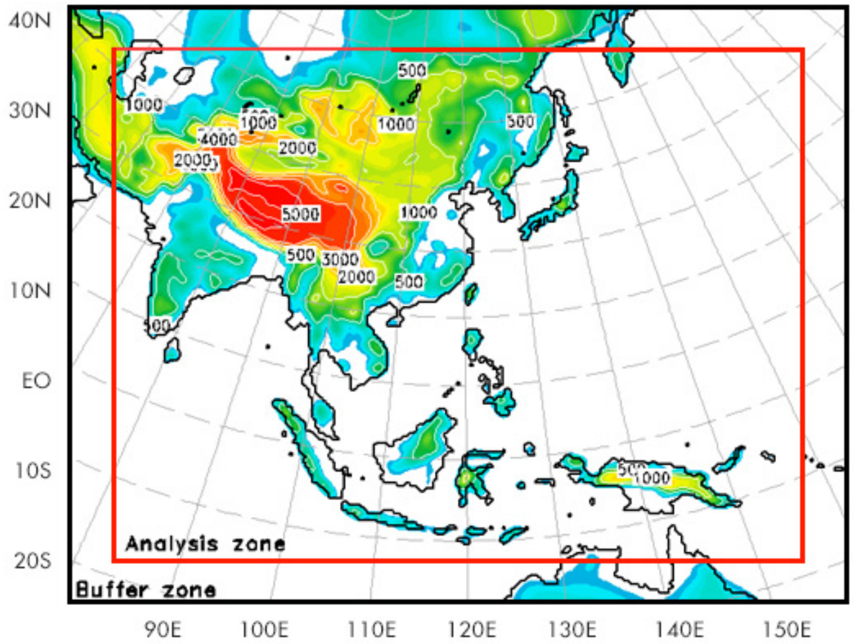
1. SAM (South America)
2. CAM (Central America)
3. NAM (North America)
4. EUS (Europe)
5. AFR (Africa)
6. WAS (West Asia)
7. **EAS (East Asia)**
8. CAS (Central Asia)
9. AUS (Australia)
10. ANT (Antarctica)
11. ARC (Arctic)
12. MED (Mediterranean)



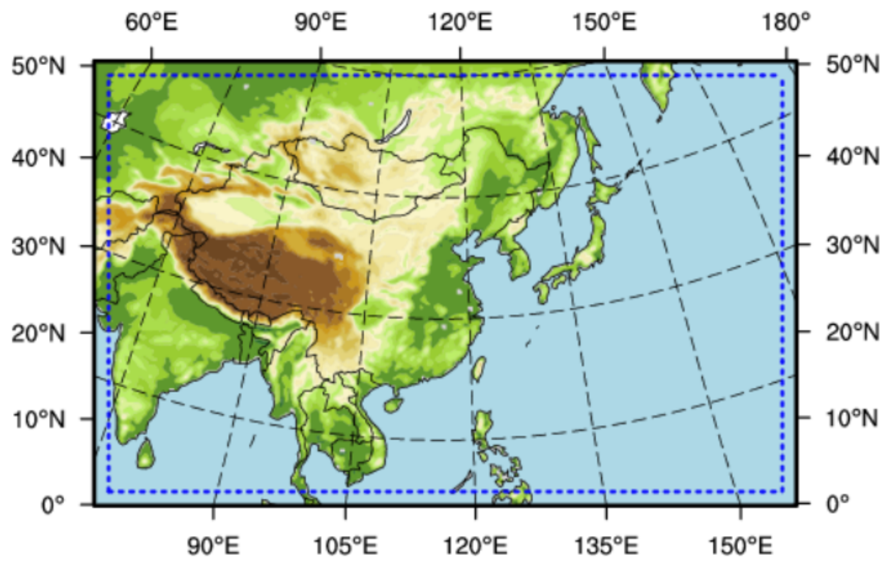
Copied from CORDEX website

Domain of the East Asia

Standard domain



Our modification



The time periods of the input data

- ECMWF-ERA40 (1958-2001)
- ECMWF-ERAI (1979-2014)
- NorESM-historical (1950-2005)
- NorESM-RCP45 (2006-2100)
- NorESM-RCP85 (2006-2100)
- MODIS （2001）

58 daily variables: day

clh	clivi	cll	clm	clt	clwvi	evspsbl	hfls	hfss	hus850
huss	mrfso	mrro	mrros	mrso	pr	prc	prhmax	prsn	prw
ps	psl	rlds	rlus	rlut	rsds	rsdt	rsus	rsut	sfcWind
sfcWindmax	sic	snc	snd	snm	snw	sund	ta200	ta500	ta850
tas	tasmax	tasmin	tauu	tauv	ts	ua200	ua500	ua850	uas
va200	va500	va850	vas	wsgsmax	zg200	zg500	zmla		

tas_EAS-25_ECMWF-ERAINT_evaluation_r1i1p1_HENU-WRF331_v1_day_19790101-19801231.nc
tas_EAS-25_ECMWF-ERAINT_evaluation_r1i1p1_HENU-WRF331_v1_day_19810101-19851231.nc
tas_EAS-25_ECMWF-ERAINT_evaluation_r1i1p1_HENU-WRF331_v1_day_19860101-19901231.nc
tas_EAS-25_ECMWF-ERAINT_evaluation_r1i1p1_HENU-WRF331_v1_day_19910101-19951231.nc
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tas_EAS-25_ECMWF-ERAINT_evaluation_r1i1p1_HENU-WRF331_v1_day_20060101-20101231.nc
tas_EAS-25_ECMWF-ERAINT_evaluation_r1i1p1_HENU-WRF331_v1_day_20110101-20141231.nc

Table： CORDEX variable list

CORDEX: requested variables

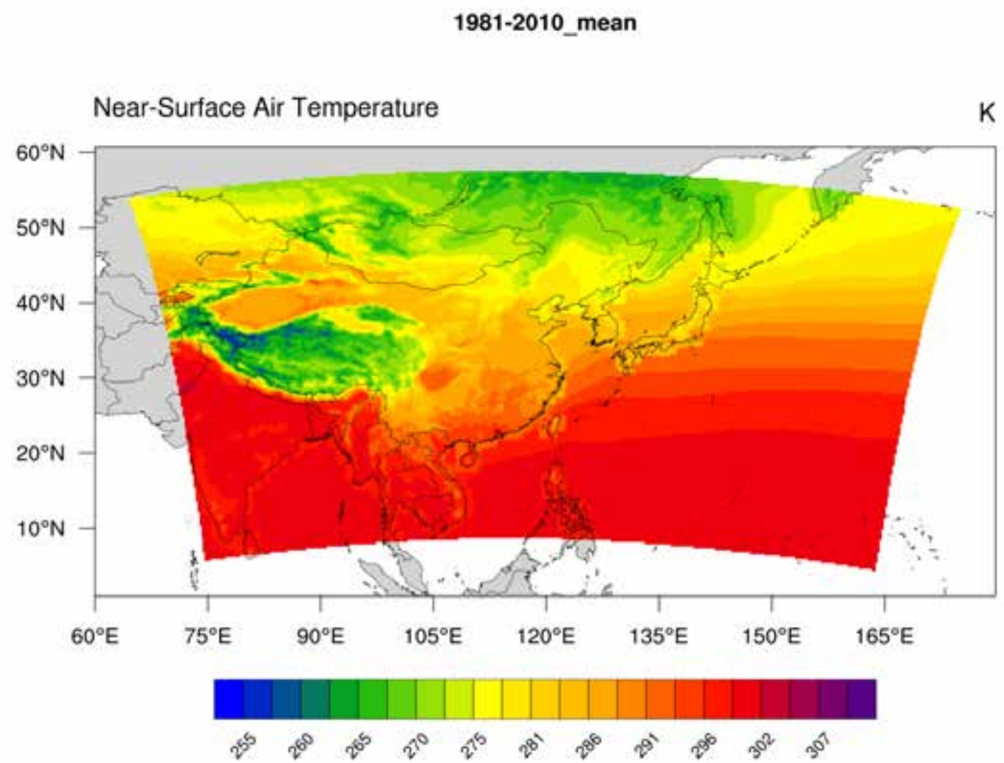
21 Feb 2014 Version 3.1

		Tier 2		Tier 1		Core									
output variable name	units	frq [1/day]	ag	frq [1/day]	ag	frq [1/mon]	ag	frq [1/sem]	ag	fx	long_name	standard_name	direction of positive fluxes[a]	realm (not required, however, if included should have the value as in CMIP5)	cell-method: area (optional)[b]
tas	K	8	i	1	8	1	m*8	1	s*8		Near-Surface Air Temperature	air_temperature		atmos	
tasmax	K			1		1	m	1	s		Daily Maximum Near-Surface Air Temperature	air_temperature		atmos	
tasmin	K			1		1	m	1	s		Daily Minimum Near-Surface Air Temperature	air_temperature		atmos	
pr	kg m-2 s-1	8	a	1		1		1			Precipitation	precipitation_flux		atmos	
ps	Pa	8	i	1	8						Surface Air Pressure	surface_air_pressure		atmos	
psl	Pa	8	i	1	8	1	m*8	1	s*8		Sea Level Pressure	air_pressure_at_sea_level		atmos	
huss	1	8	i	1	8	1	m*8	1	s*8		Near-Surface Specific Humidity	specific_humidity		atmos	
hurs	%	8	i	1	8	1	m*8	1	s*8		Near-Surface Relative Humidity	relative_humidity		atmos	
sfcWind	m s-1	8	i	1	8	1	m*8	1	s*8		Near-Surface Wind Speed	wind_speed		atmos	
sfcWindmax	m s-1			1		1	m	1	s		Daily Maximum Near-Surface Wind Speed	wind_speed		atmos	
clt	%	8	a	1		1		1			Total Cloud Fraction	cloud_area_fraction		atmos	
sund	s	8	a	1		1		1			Duration of Sunshine	duration_of_sunshine		atmos	
rsds	W m-2	8	a	1		1		1			Surface Downwelling Shortwave Radiation	surface_downwelling_shortwave_flux_in_air	down	atmos	
rlds	W m-2	8	a	1		1		1			Surface Downwelling Longwave Radiation	surface_downwelling_longwave_flux_in_air	down	atmos	
hfls	W m-2	8	a	1		1		1			Surface Upward Latent Heat Flux	surface_upward_latent_heat_flux	up	atmos	
hfss	W m-2	8	a	1		1		1			Surface Upward Sensible Heat Flux	surface_upward_sensible_heat_flux	up	atmos	
rsus	W m-2	8	a	1		1		1			Surface Upwelling Shortwave Radiation	surface_upwelling_shortwave_flux_in_air	up	atmos	
rlus	W m-2	8	a	1		1		1			Surface Upwelling Longwave Radiation	surface_upwelling_longwave_flux_in_air	up	atmos	
evspsbl	kg m-2 s-1	4	a	1		1		1			Evaporation	water_evaporation_flux		atmos	
evspsblpot	kg m-2 s-1	4	a	1							Potential Evapotranspiration	water_potential_evaporation_flux		atmos	
mrfso	kg m-2	4	i	1	4	1	m*4	1	s*4		Soil Frozen Water Content	soil_frozen_water_content		land landice	mean where land
mrros	kg m-2 s-1	4	a	1		1		1			Surface Runoff	surface_runoff_flux		land	mean where land
mrro	kg m-2 s-1	4	a	1		1		1			Total Runoff	runoff_flux		land	mean where land
mrso	kg m-2	4	i	1	4	1	m*4	1	s*4		Total Soil Moisture Content	soil_moisture_content		land	mean where land
snw	kg m-2	4	i	1	4	1	m*4	1	s*4		Surface Snow Amount	surface_snow_amount		landice land	mean where land
snm	kg m-2 s-1	4	a	1	4	1		1			Surface Snow Melt	surface_snow_melt_flux		landice land	mean where land
prhmax	kg m-2 s-1			1							Daily Maximum Hourly Precipitation Rate	precipitation_flux		atmos	
prc	kg m-2 s-1	8	a	1							Convective Precipitation	convective_precipitation_flux		atmos	
rlut	W m-2	4	a	1		1		1			TOA Outgoing Longwave Radiation	toa_outgoing_longwave_flux	up	atmos	
rsdt	W m-2	4	a	1		1		1			TOA Incident Shortwave Radiation	toa_incoming_shortwave_flux	down	atmos	
rsut	W m-2	4	a	1		1		1			TOA Outgoing Shortwave Radiation	toa_outgoing_shortwave_flux	up	atmos	
uas	m s-1	4	i	1	4	1	m*4	1	s*4		Eastward Near-Surface Wind	eastward_wind		atmos	
vas	m s-1	4	i	1	4	1	m*4	1	s*4		Northward Near-Surface Wind	northward_wind		atmos	
wsgsmax	m s-1			1							Daily Maximum Near-Surface Wind Speed of Gust	wind_speed_of_gust		atmos	
tauu	Pa	4	a	1							Surface Downward Eastward Wind Stress	surface_downward_eastward_stress	down	atmos	
tauv	Pa	4	a	1							Surface Downward Northward Wind Stress	surface_downward_northward_stress	down	atmos	
ts	K	4	i	1	4						Surface Temperature	surface_temperature		atmos	
zmla	m	4	i	1	4						Height of Boundary Layer	atmosphere_boundary_layer_thickness		atmos	
prw	kg m-2	4	i	1	4						Water Vapor Path	atmosphere_water_vapor_content		atmos	
clwvi	kg m-2	4	i	1	4						Condensed Water Path	atmosphere_cloud_condensed_water_content		atmos	
clivi	kg m-2	4	i	1	4						Ice Water Path	atmosphere_cloud_ice_content		atmos	
ua850	m s-1	4	i	1	4	1	m*4	1	s*4		Eastward Wind	eastward_wind		atmos	
va850	m s-1	4	i	1	4	1	m*4	1	s*4		Northward Wind	northward_wind		atmos	
ta850	K	4	i	1	4	1	m*4	1	s*4		Air Temperature	air_temperature		atmos	
hus850	1	4	i	1	4	1	m*4	1	s*4		Specific Humidity	specific_humidity		atmos	
ua500	m s-1	4	i	1	4	1	m*4	1	s*4		Eastward Wind	eastward_wind		atmos	
va500	m s-1	4	i	1	4	1	m*4	1	s*4		Northward Wind	northward_wind		atmos	
zg500	m	4	i	1	4	1	m*4	1	s*4		Geopotential Height	geopotential_height		atmos	
ta500	K	4	i	1	4	1	m*4	1	s*4		Air Temperature	air_temperature		atmos	
ua200	m s-1	4	i	1	4	1	m*4	1	s*4		Eastward Wind	eastward_wind		atmos	
va200	m s-1	4	i	1	4	1	m*4	1	s*4		Northward Wind	northward_wind		atmos	
ta200	K	4	i	1	4	1	m*4	1	s*4		Air Temperature	air_temperature		atmos	
zg200	m	4	i	1	4	1	m*4	1	s*4		Geopotential Height	geopotential_height		atmos	
clh	%	4	a	1							High Level Cloud Fraction	cloud_area_fraction_in_atmosphere_layer		atmos	
clm	%	4	a	1							Mid Level Cloud Fraction	cloud_area_fraction_in_atmosphere_layer		atmos	
cll	%	4	a	1							Low Level Cloud Fraction	cloud_area_fraction_in_atmosphere_layer		atmos	
snc	%	4	i	1	4	1	m*4	1	s*4		Snow Area Fraction	surface_snow_area_fraction		landice land	
snd	m	4	i	1	4	1	m*4	1	s*4		Snow Depth	surface_snow_thickness		landice land	mean where land
sic	%			1		1	m	1	s		Sea Ice Area Fraction	sea_ice_area_fraction		seaIce ocean	
prsn	kg m-2 s-1			1							Snowfall Flux	snowfall_flux		atmos	
areacella	m2									0	Atmosphere Grid-Cell Area	cell_area		atmos land	
orog	m									0	Surface Altitude	surface_altitude		atmos	
sftlf	%									0	Land Area Fraction	land_area_fraction		atmos	
sftgif	%									0	Fraction of Grid Cell Covered with Glacier	land_ice_area_fraction		land	
mrsofc	kg m-2									0	Capacity of Soil to Store Water	soil_moisture_content_at_field_capacity		land	
rootd	m									0	Maximum Root Depth	root_depth		land	

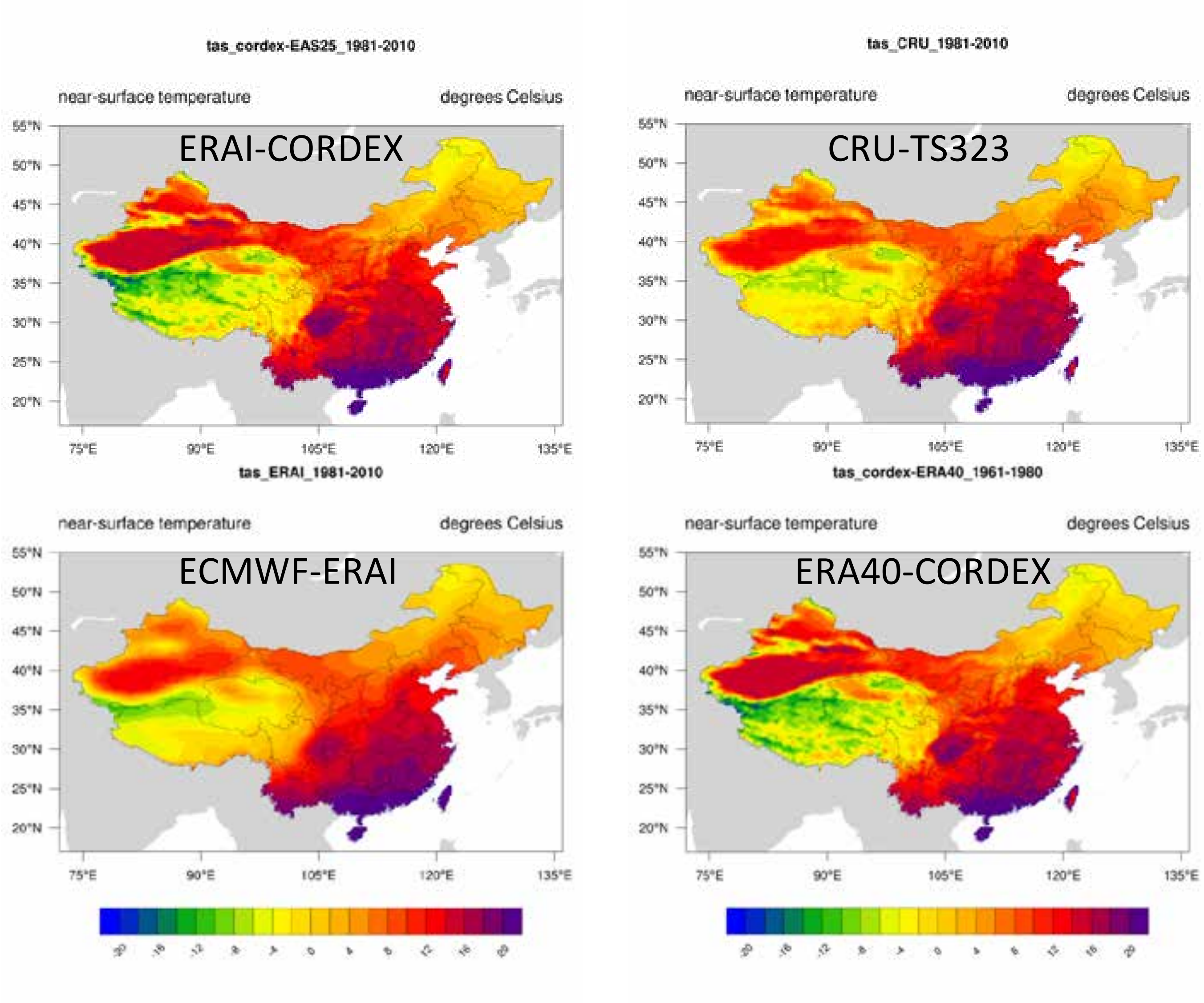
[a] The column specifies the direction of fluxes (redundantly with the standard:name); if given as a NetCDF attribute it must have the value as given here

[b] If given as a NetCDF attribute it must have the value as given here

From East Asia to China for validation

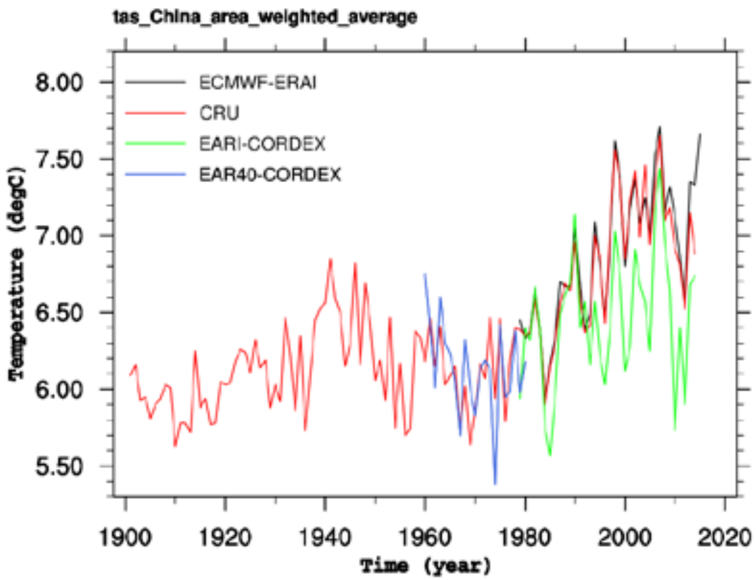


The 30-year mean temperature (deg C)

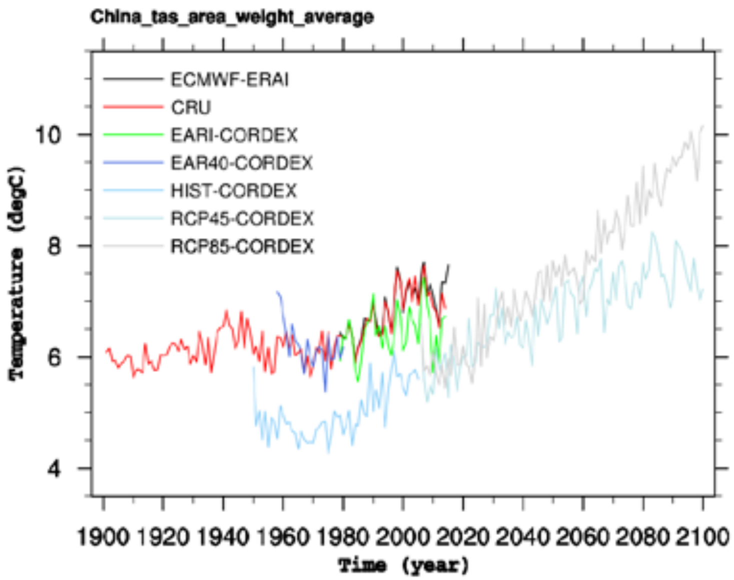


Result comparison of temperature

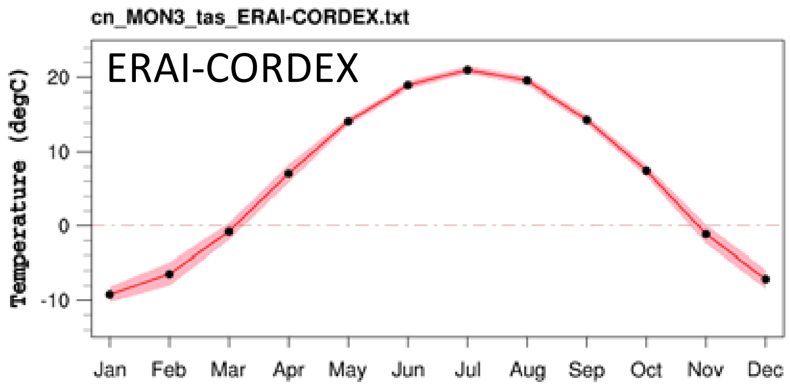
Vs. observation

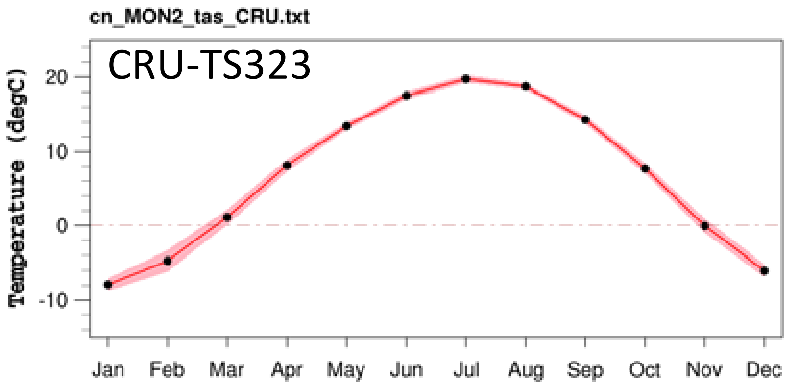


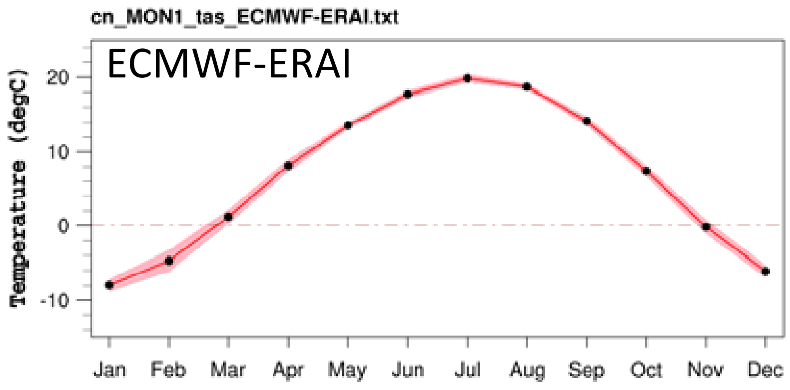
Vs. climate future projection



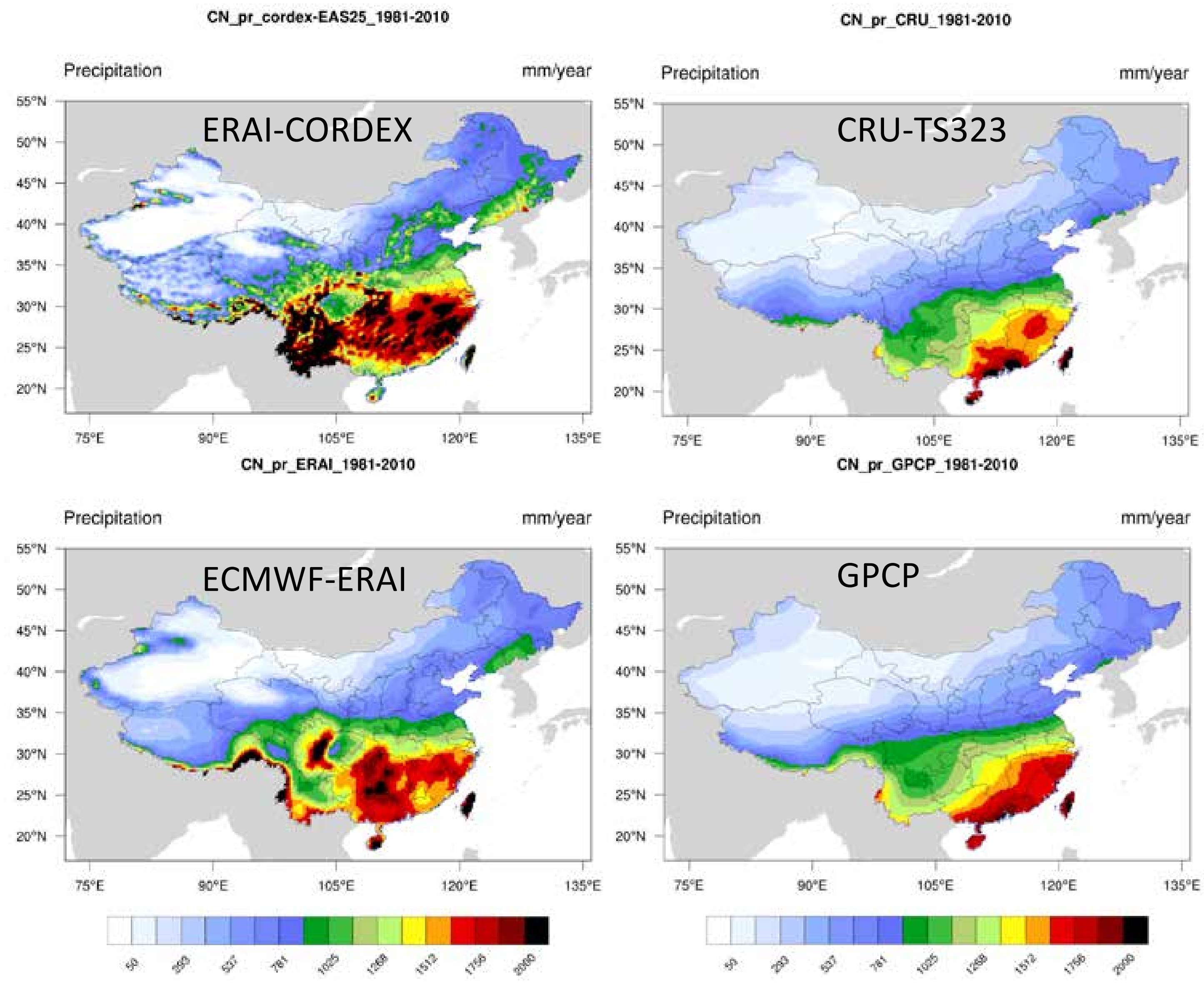
Result comparison with seasonal cycle





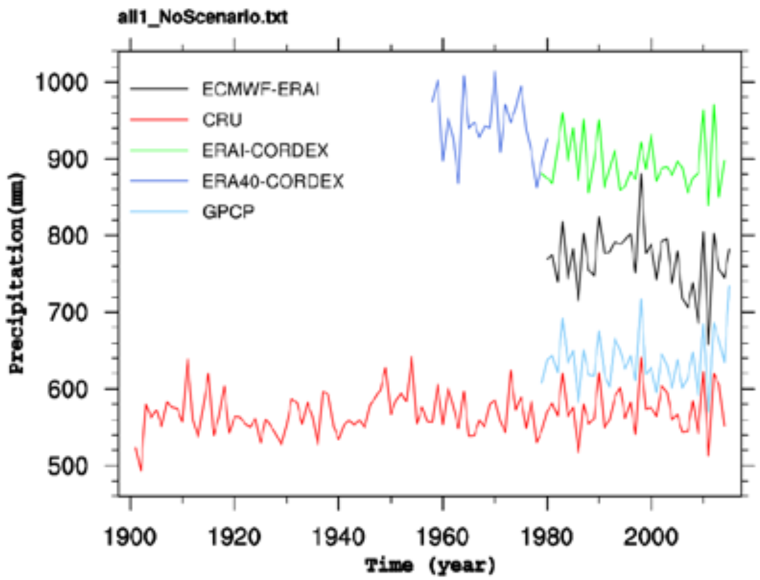


The 30-year mean precipitation

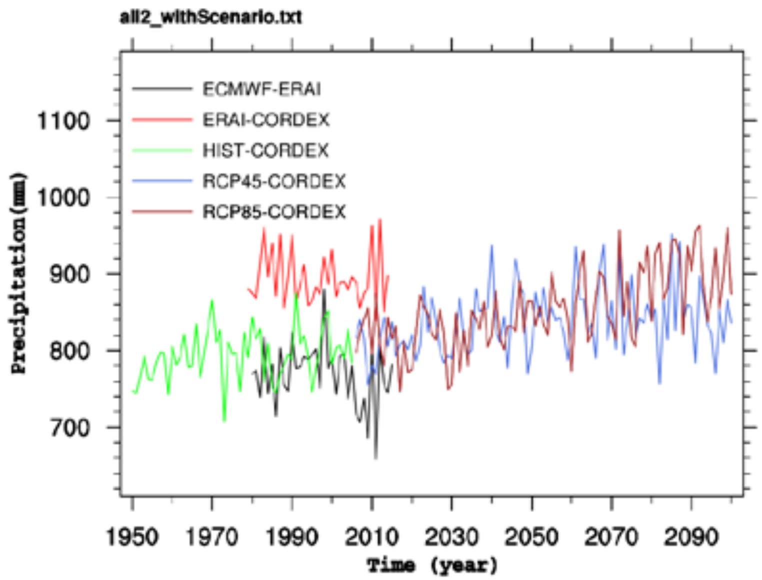


Result comparison of precipitation

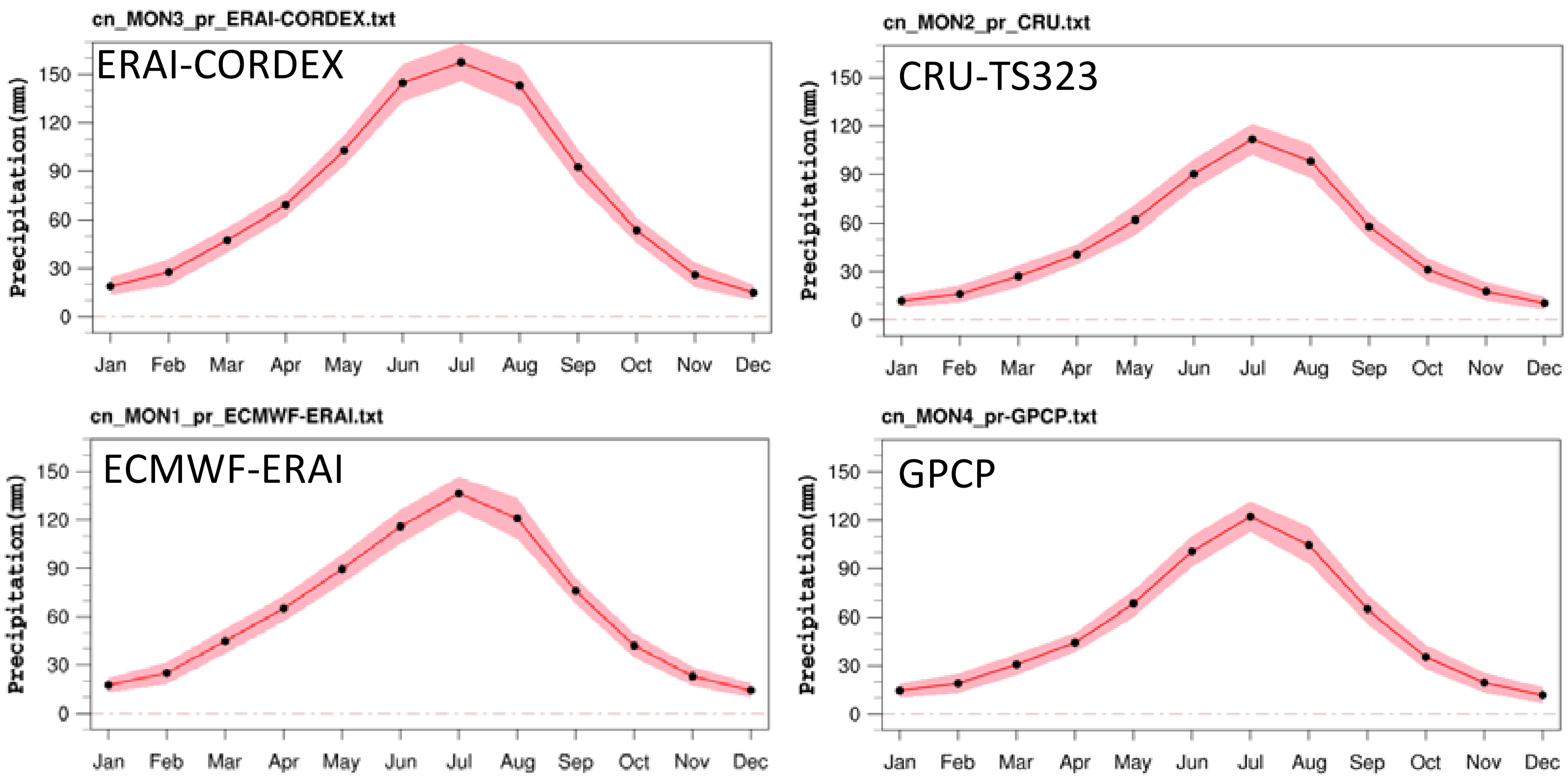
Vs. observation



Vs. climate future projection



Result comparison with seasonal cycle



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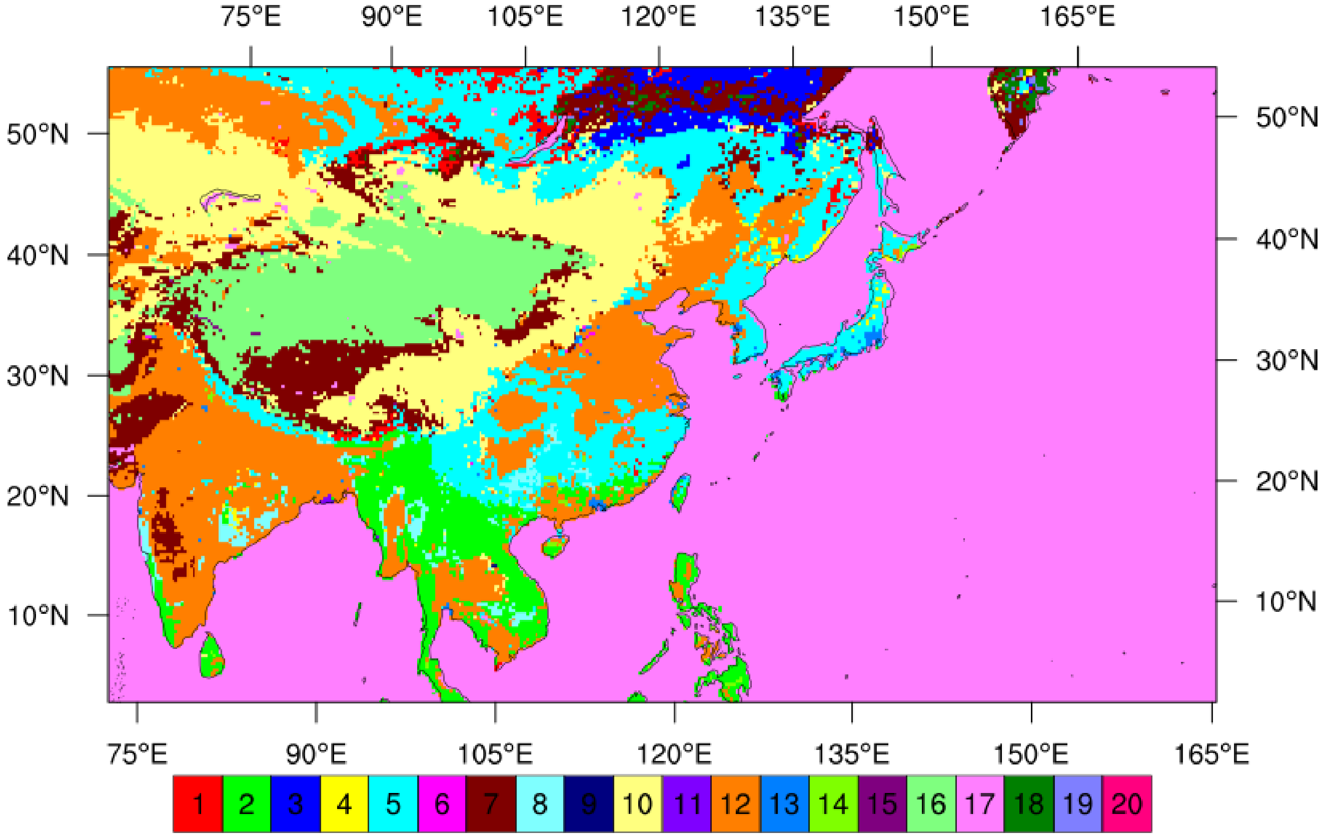
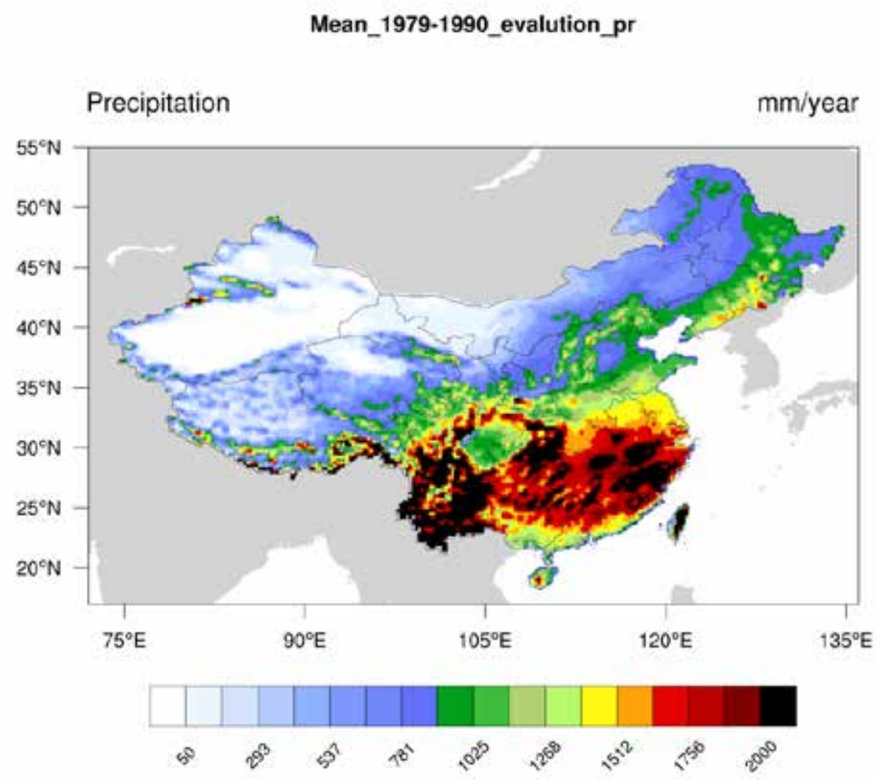
3. MODIS data of LULC (2001)



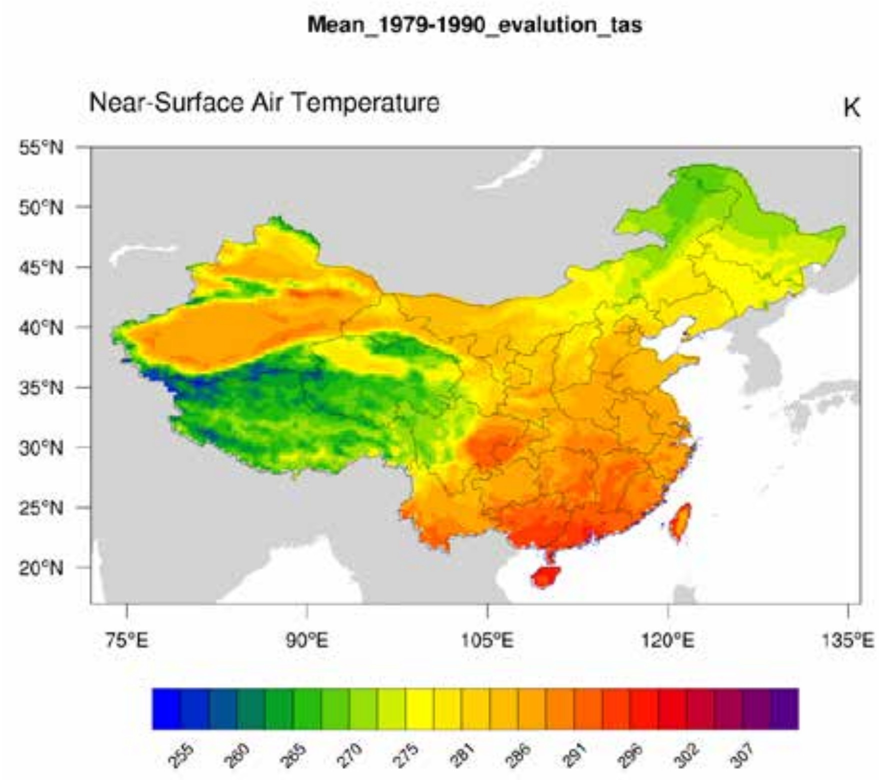
1 Evergreen Needleleaf
2 Evergreen Broadleaf
3 Deciduous Needleleaf
4 Deciduous Broadleaf
5 Mixed Forest
6 Closed Shrublands
7 Open Shrublands
8 Woody Savannas
9 Savannas
10 Grasslands
11 Permanent Wetlands
12 Croplands
13 Urban and Built-up
14 Cropland Mosaics
15 Snow and Ice
16 Bare Soil and Rocks
17 Water Bodies
18 Wooded Tundra
19 Mixed Tundra
20 Barren Tundra

Precipitation and temperature under the original LULC

Precipitation

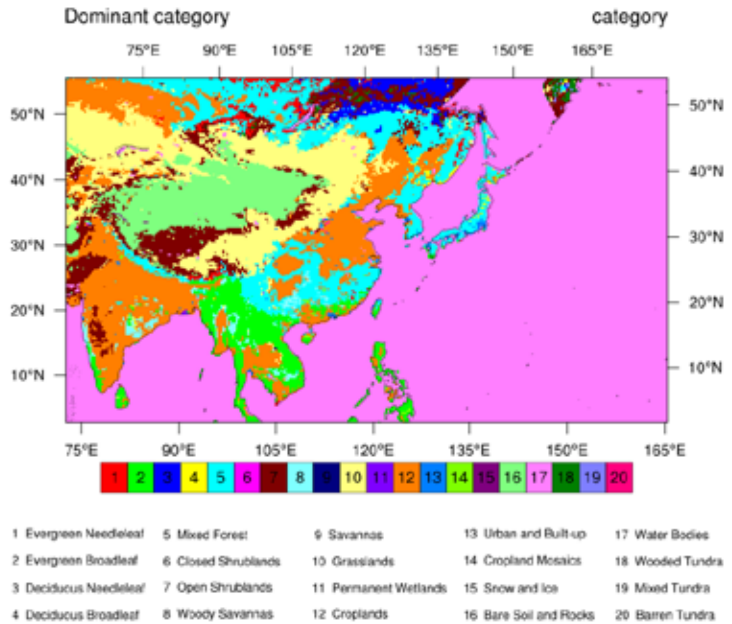


Temperature

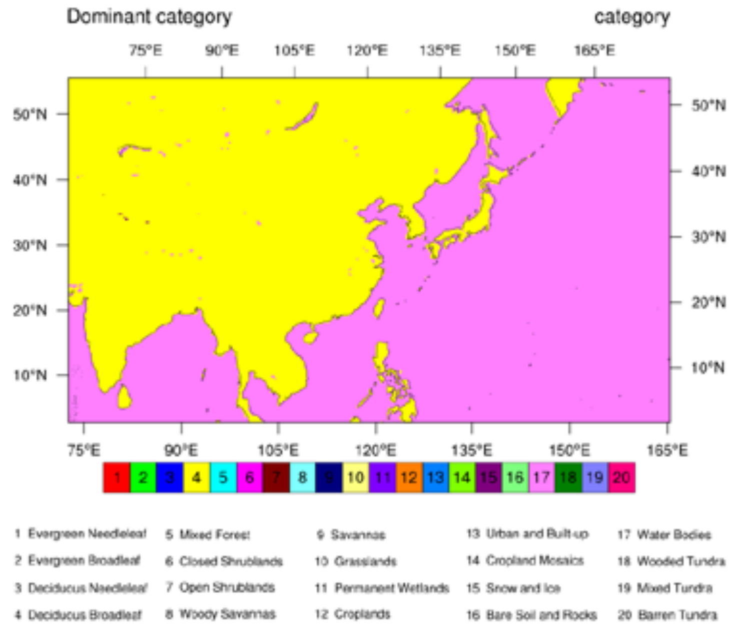


Modifying LULC

Original MODIS LULC

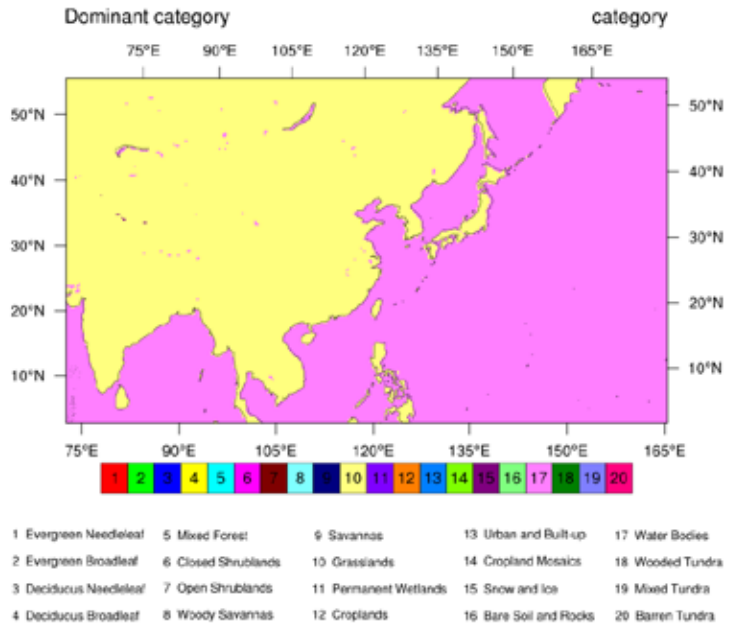


All forest

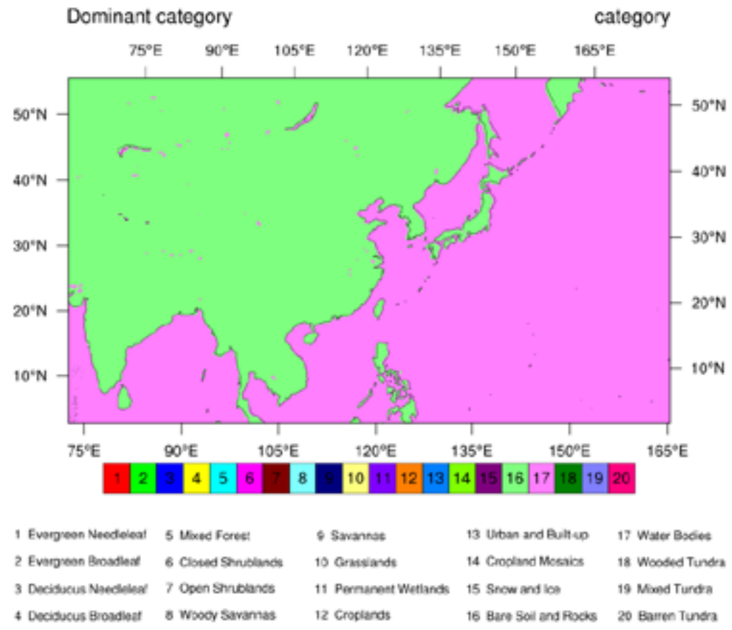


Modifying LULC

Grasslands



Bareland



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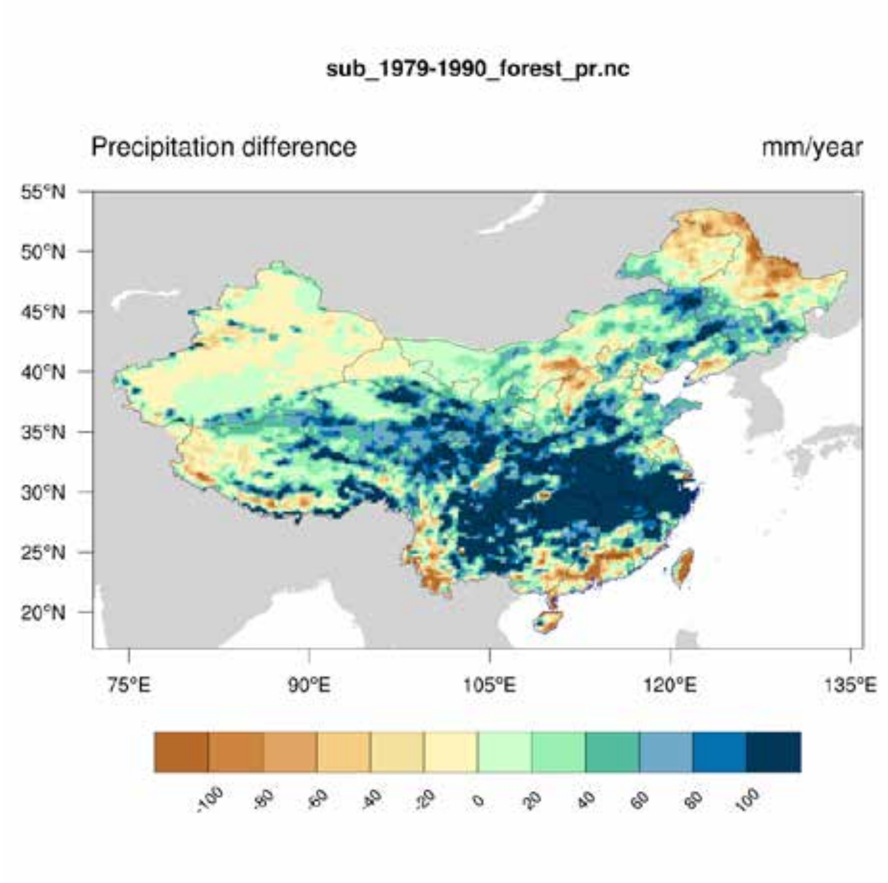
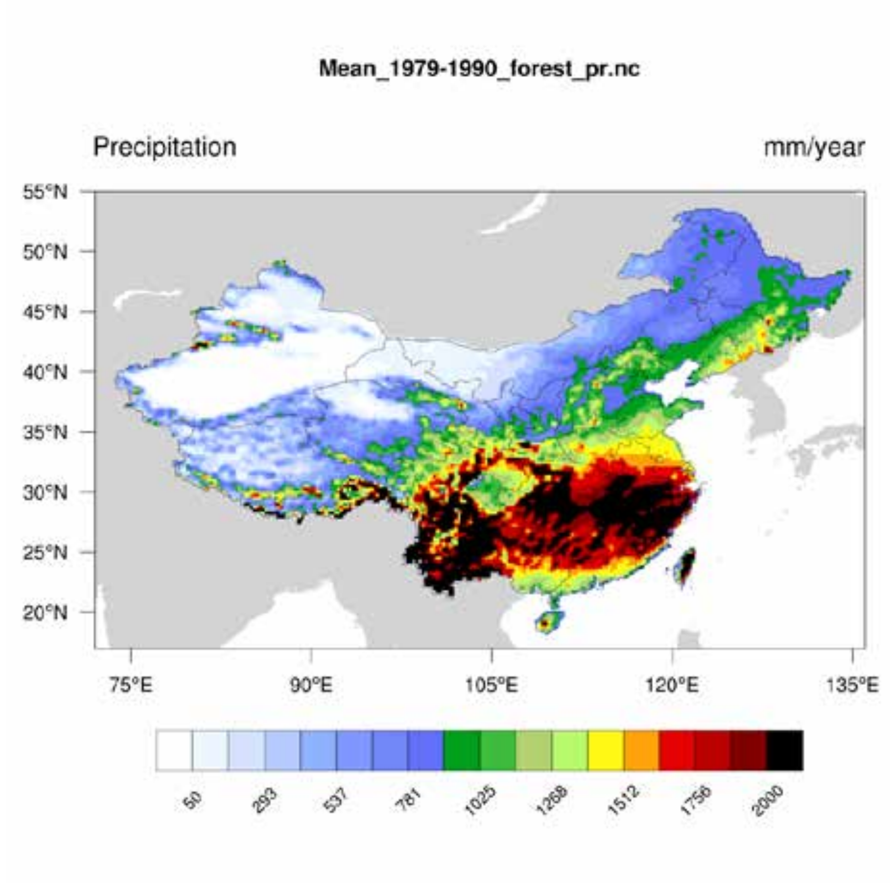
All Forest

Precipitation difference



Precipitation pattern



Formula for t-test (T and V-value)

Definition The two-sample *t*-test for unpaired data is defined as:

H$_0$: $\mu_1 = \mu_2$

H$_a$: $\mu_1 \neq \mu_2$

Test Statistic: $T = \frac{\bar{Y}_1 - \bar{Y}_2}{\sqrt{s_1^2/N_1 + s_2^2/N_2}}$

where N_1 and N_2 are the sample sizes, $\bar{Y}_1$ and $\bar{Y}_2$ are the sample means, and s_1^2 and s_2^2 are the sample variances.

If equal variances are assumed, then the formula reduces to:

$$T = \frac{\bar{Y}_1 - \bar{Y}_2}{s_p \sqrt{1/N_1 + 1/N_2}}$$

where

$$s_p^2 = \frac{(N_1 - 1)s_1^2 + (N_2 - 1)s_2^2}{N_1 + N_2 - 2}$$

Significance Level: α.

Critical Region: Reject the null hypothesis that the two means are equal if

$$|T| > t_{1-\alpha/2,\nu}$$

where $t_{1-\alpha/2,\nu}$ is the critical value of the *t* distribution with ν degrees of freedom where

$$\upsilon = \frac{(s_1^2/N_1 + s_2^2/N_2)^2}{(s_1^2/N_1)^2/(N_1 - 1) + (s_2^2/N_2)^2/(N_2 - 1)}$$

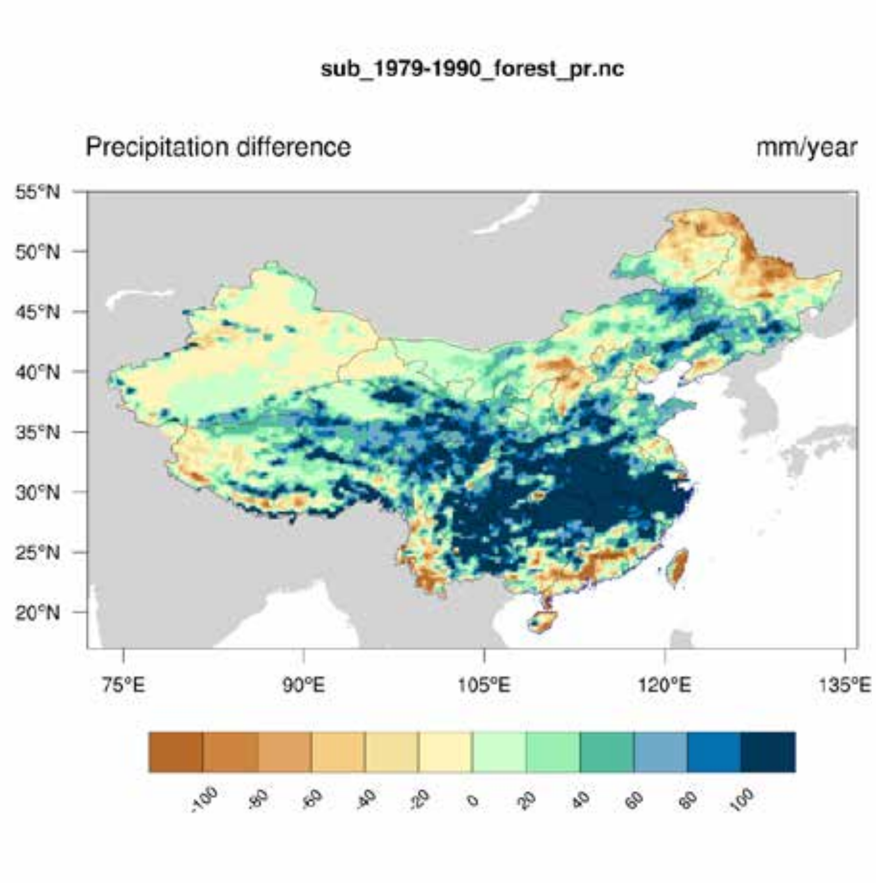
If equal variances are assumed, then $\nu = N_1 + N_2 - 2$

v-value 2.552-2.821 (99%)

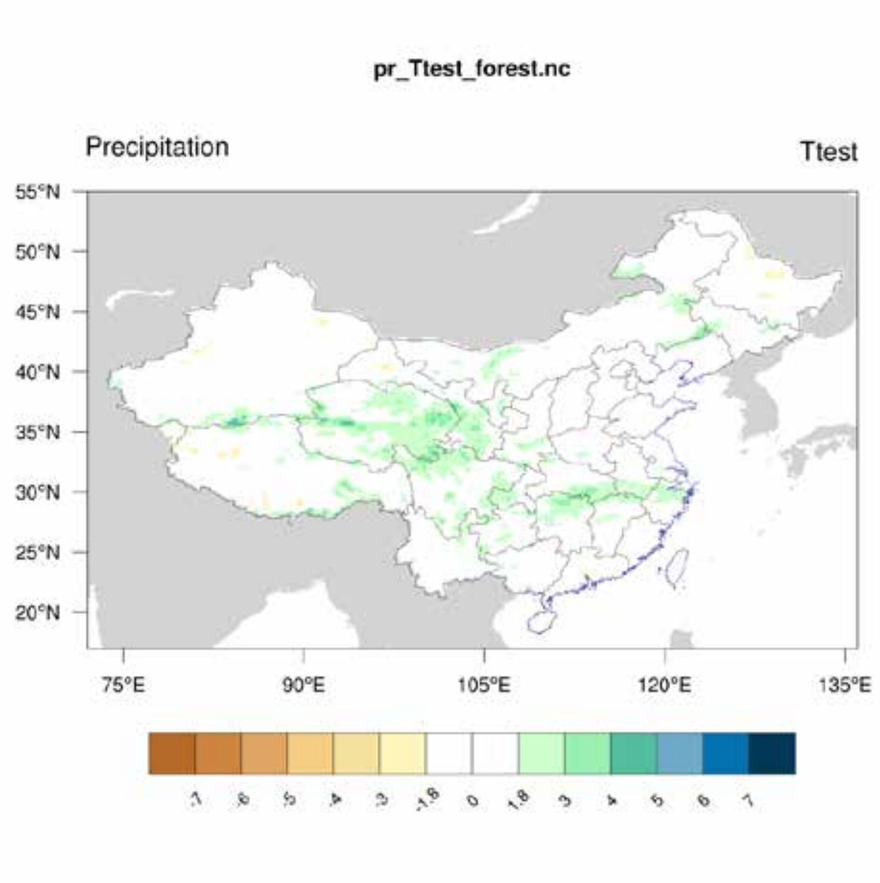
v-value 1.734-1.833 (95%)

All Forest

Precipitation difference

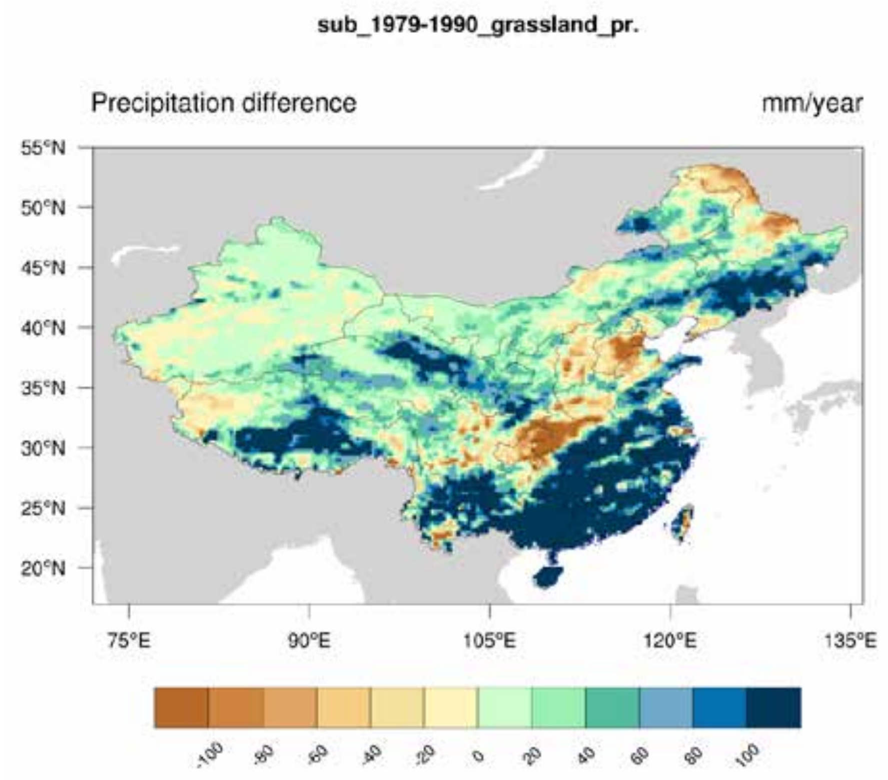


T-test of the difference

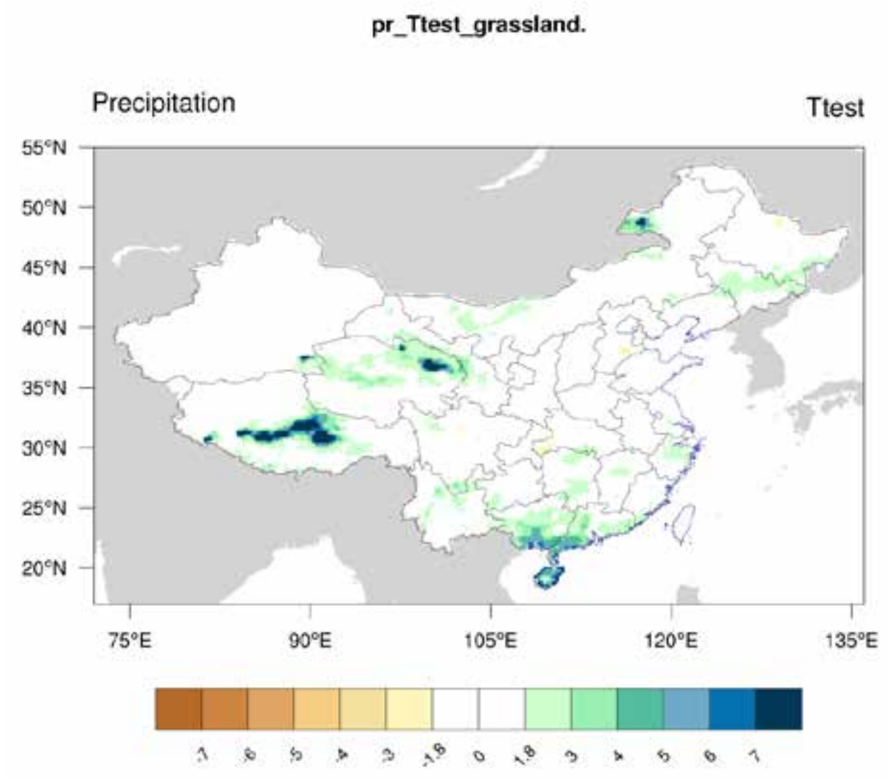


All grasslands

Precipitation difference

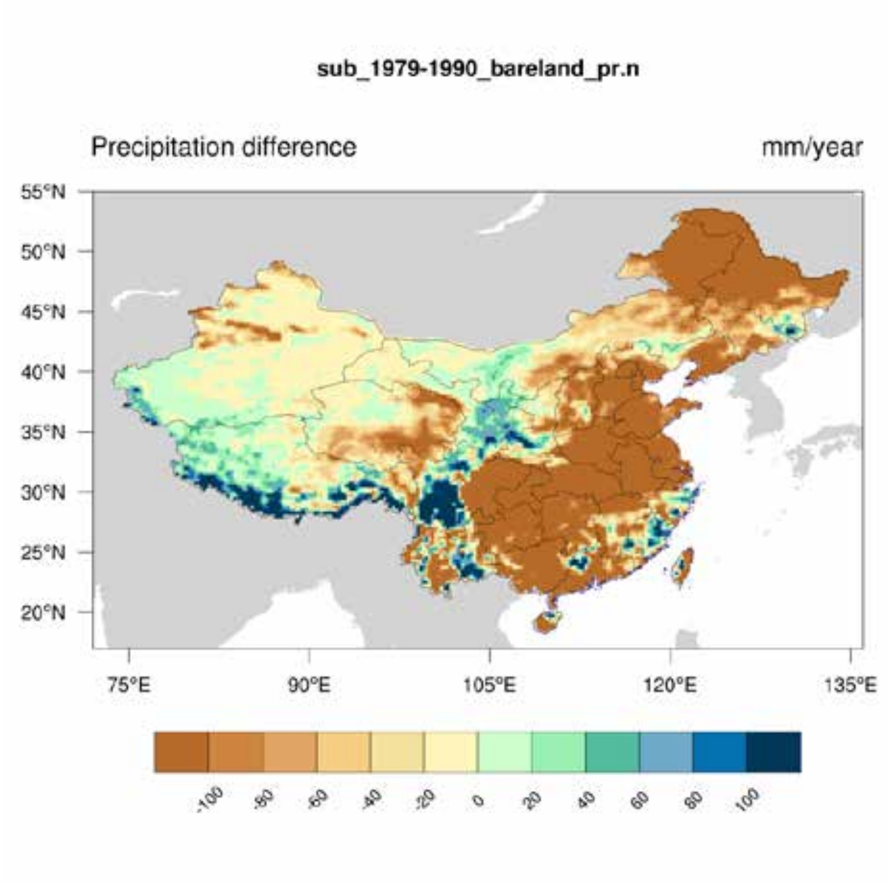


T-test of the difference

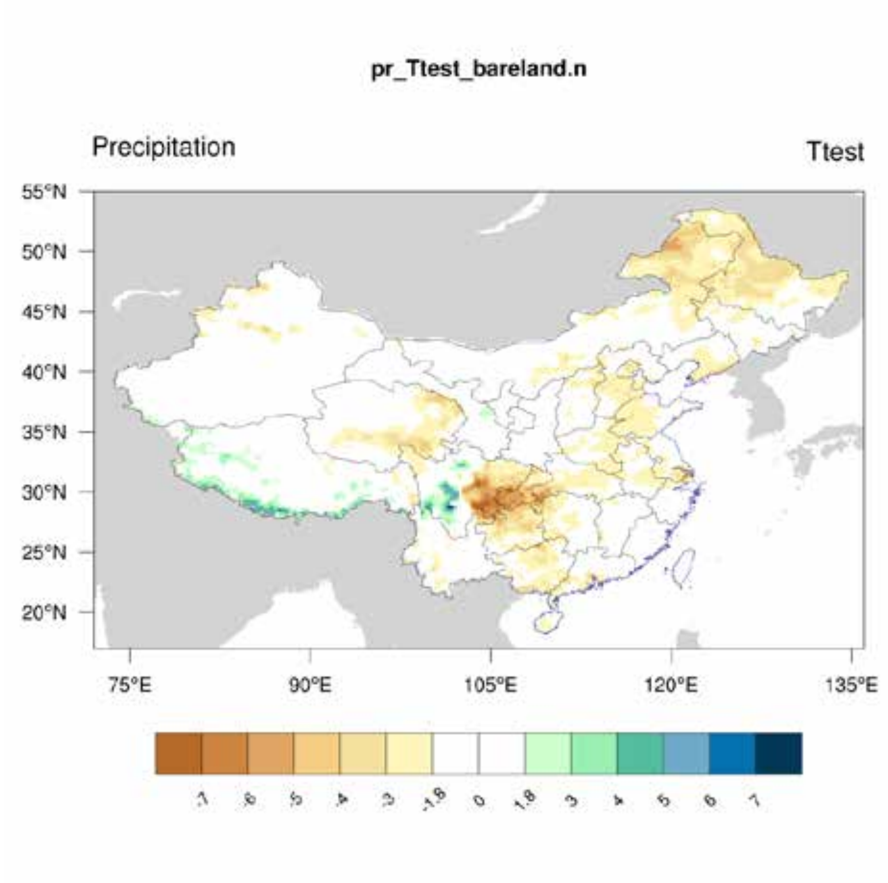


All bareland

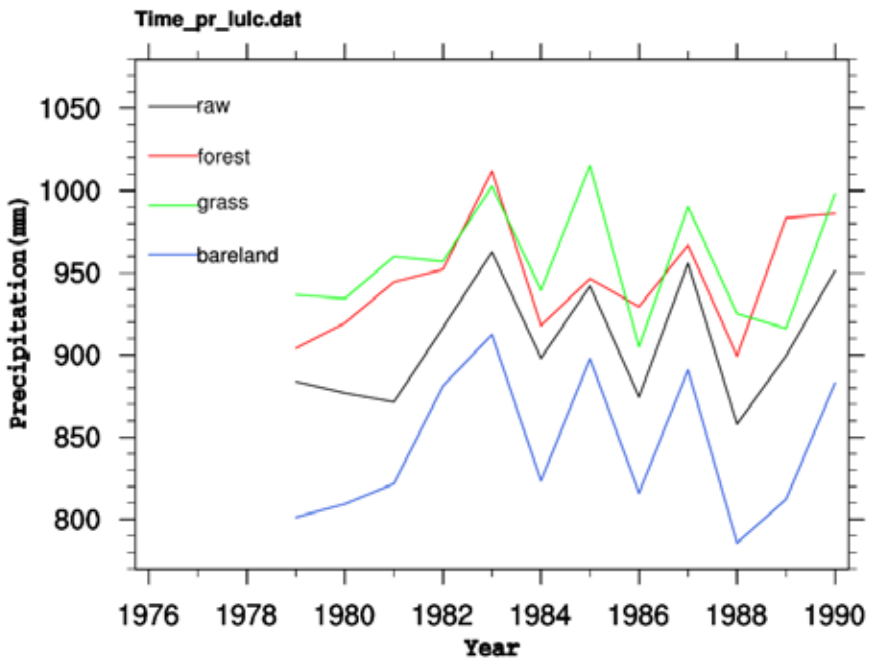
Precipitation difference



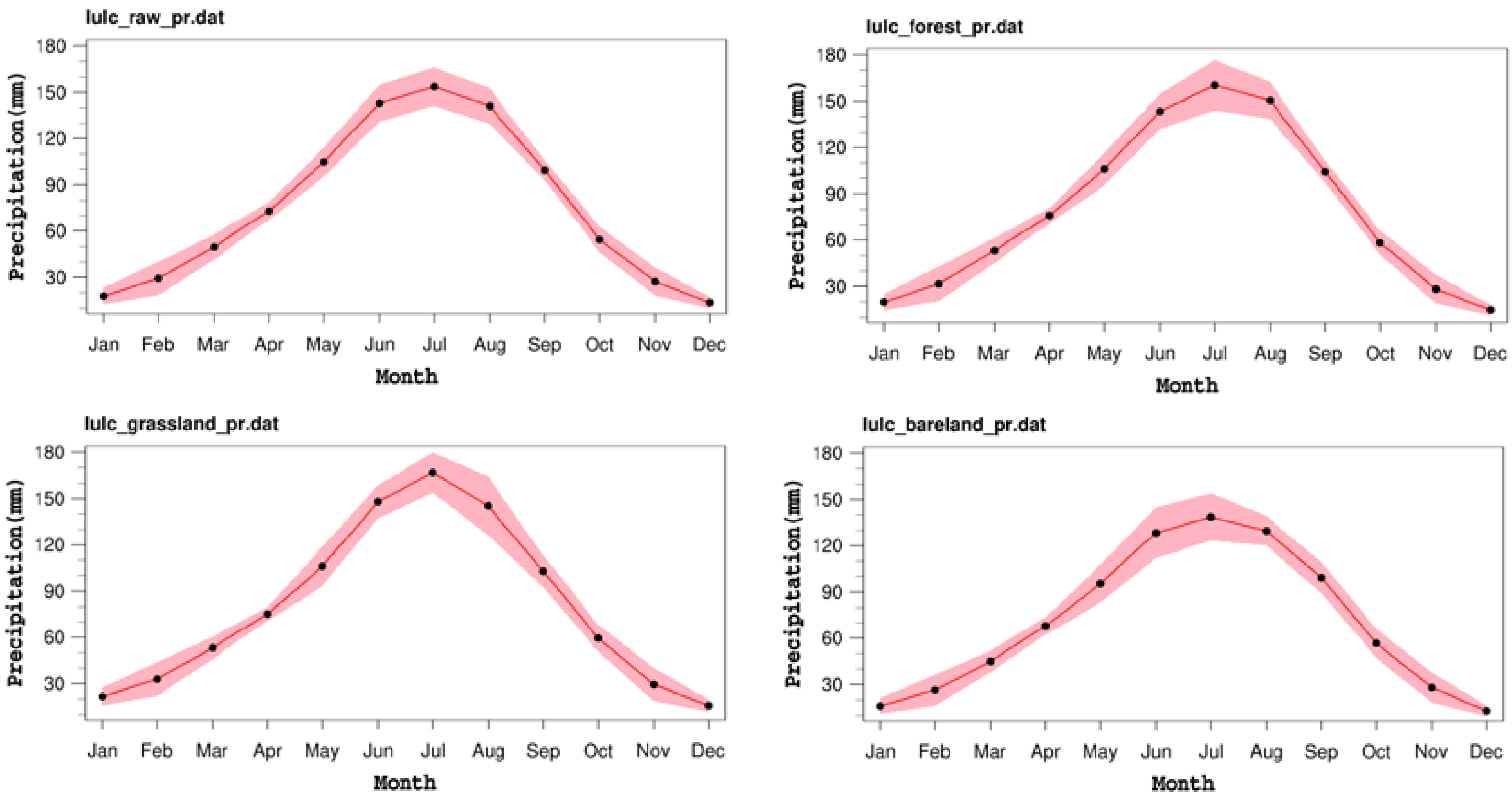
T-test of the difference



The inter-annual variation of precipitation under different LULC



Seasonal variation of precipitation under different LULC

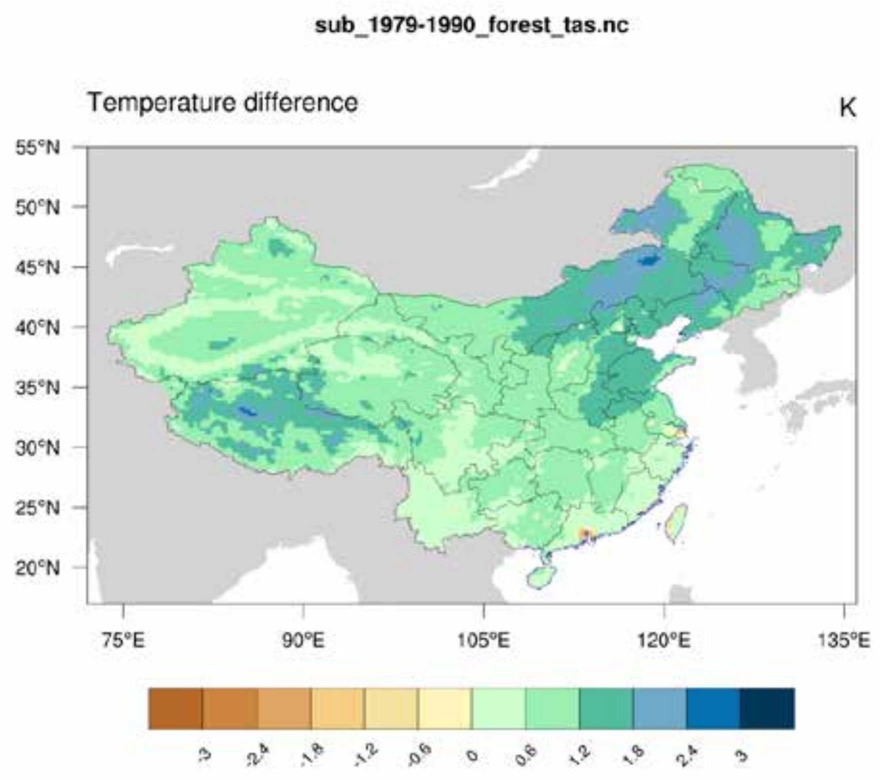


Outline

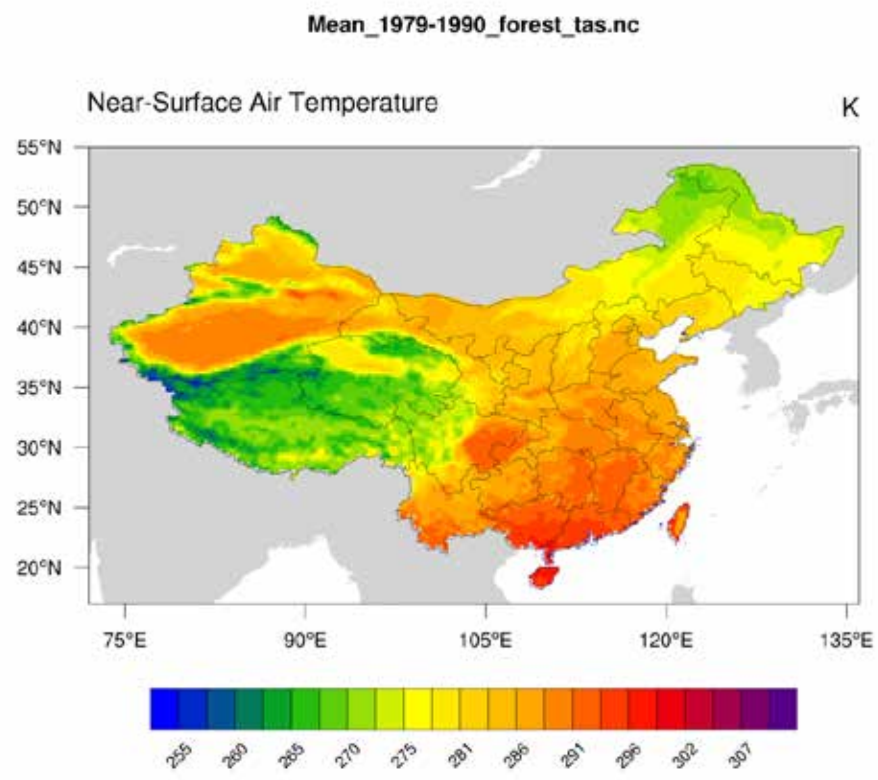
1. Domain, model and data
2. Climate downscaling in East Asia（CORDEX）
3. The LULC and MODIS data
4. The impact of LULC change on precipitation
5. The impact of LULC change on temperature
6. Summary and discussion

All forest

Temperature difference

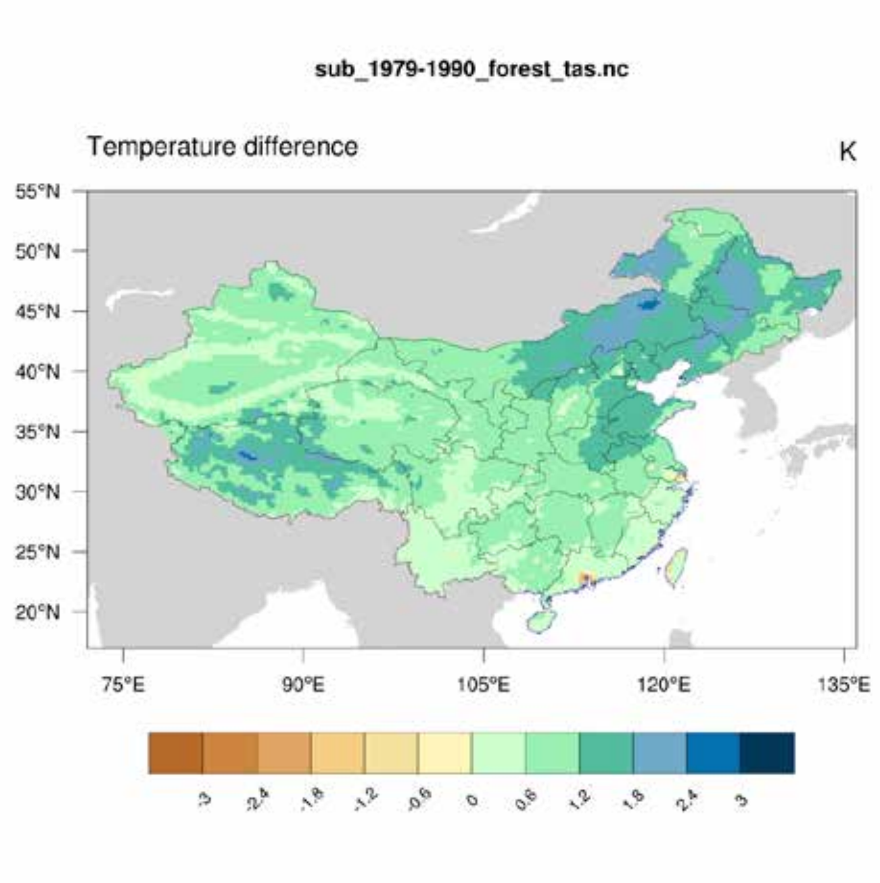


Temperature pattern

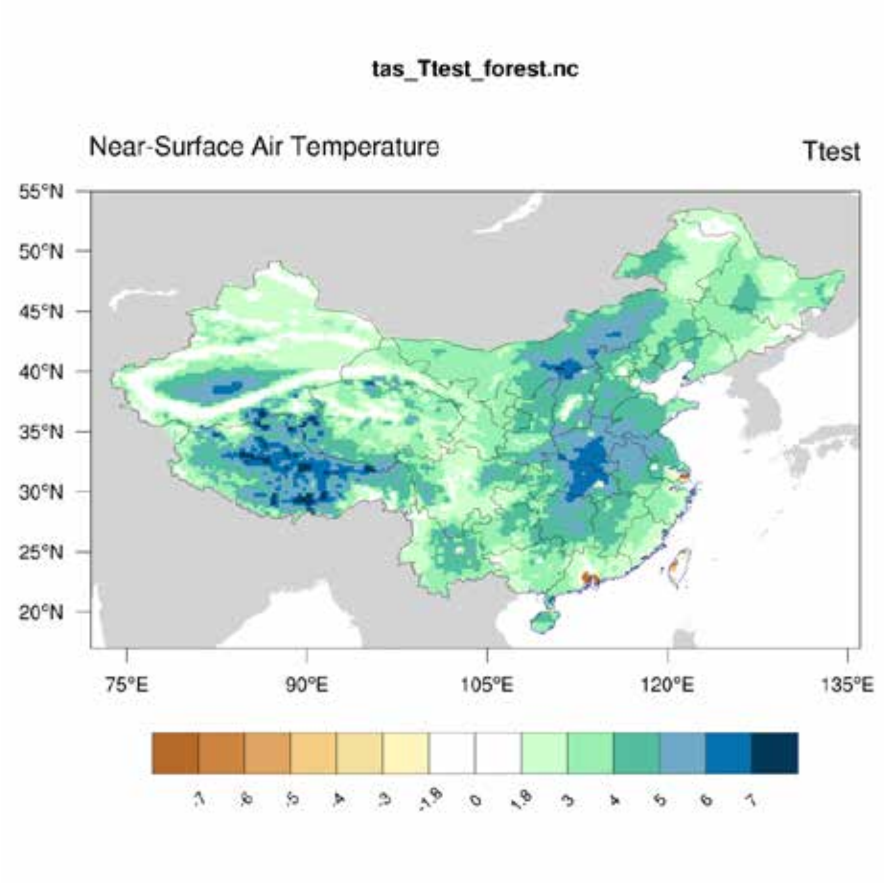


All forest

Temperature difference

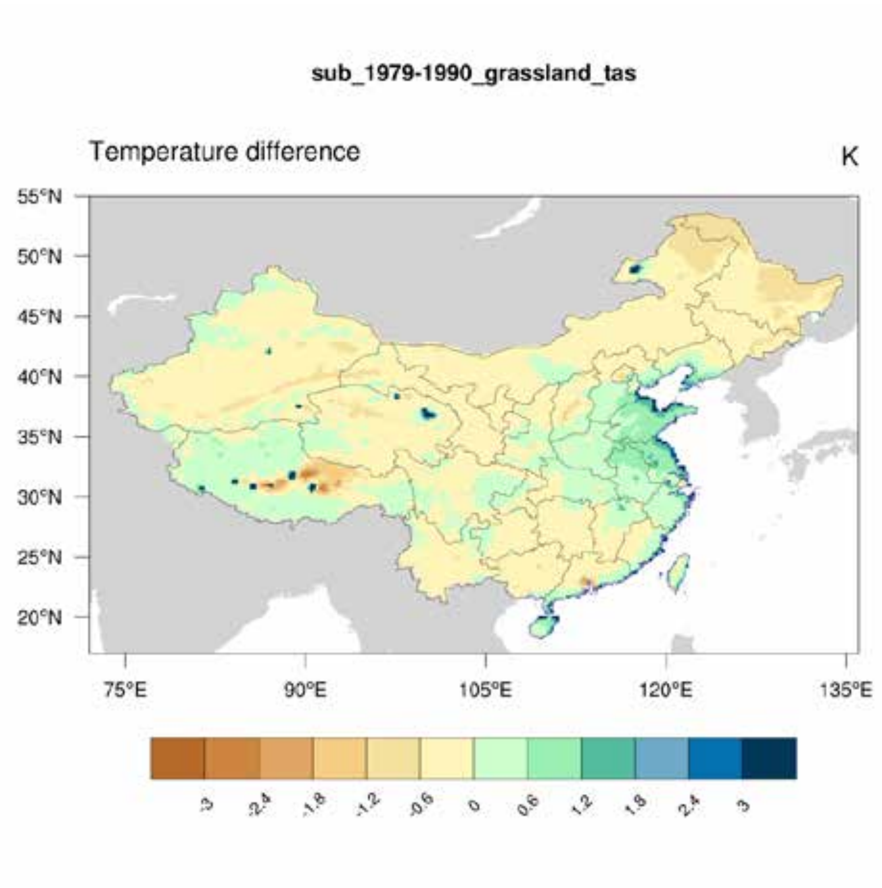


T-test of the difference

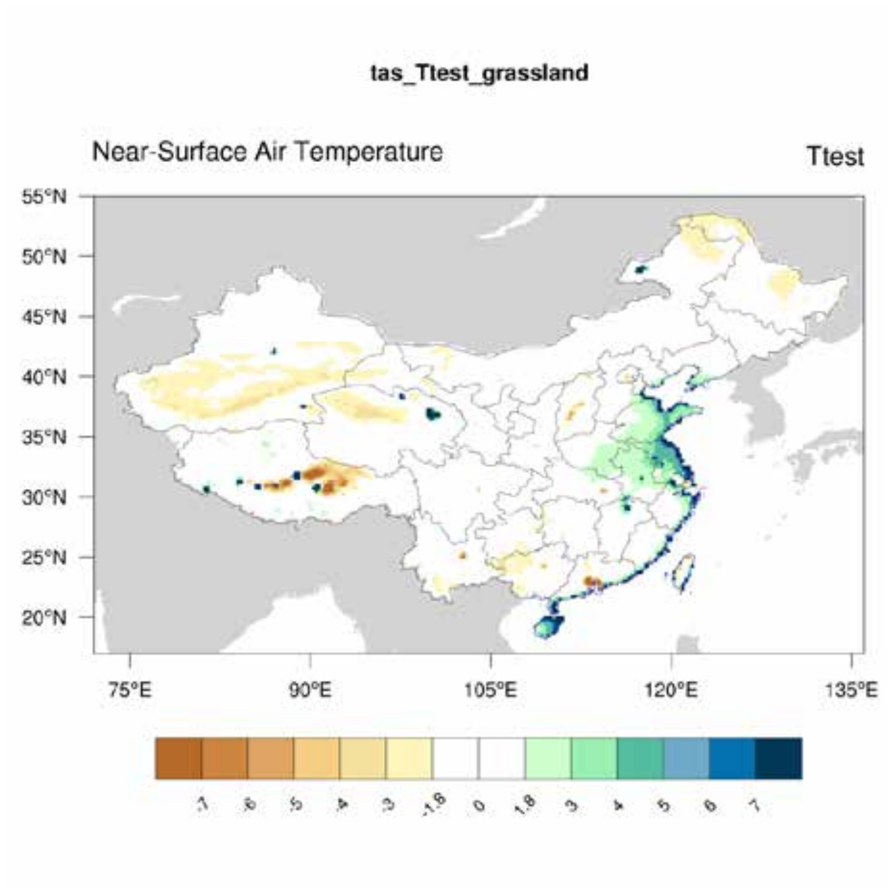


All grasslands

Temperature difference

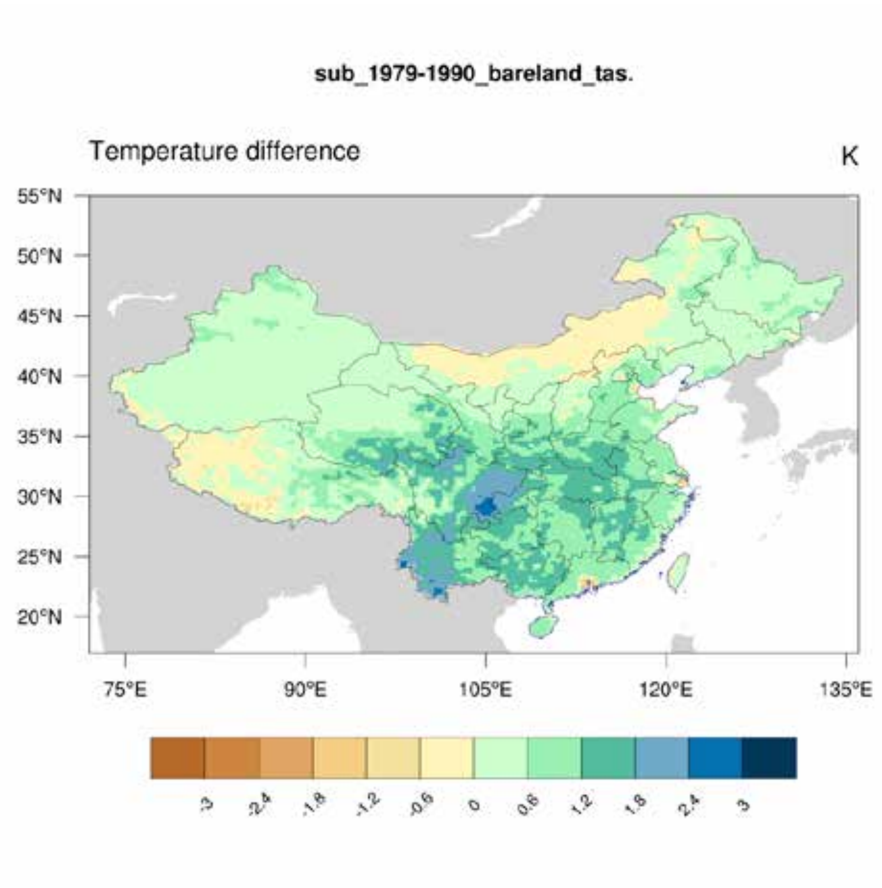


T-test of the difference

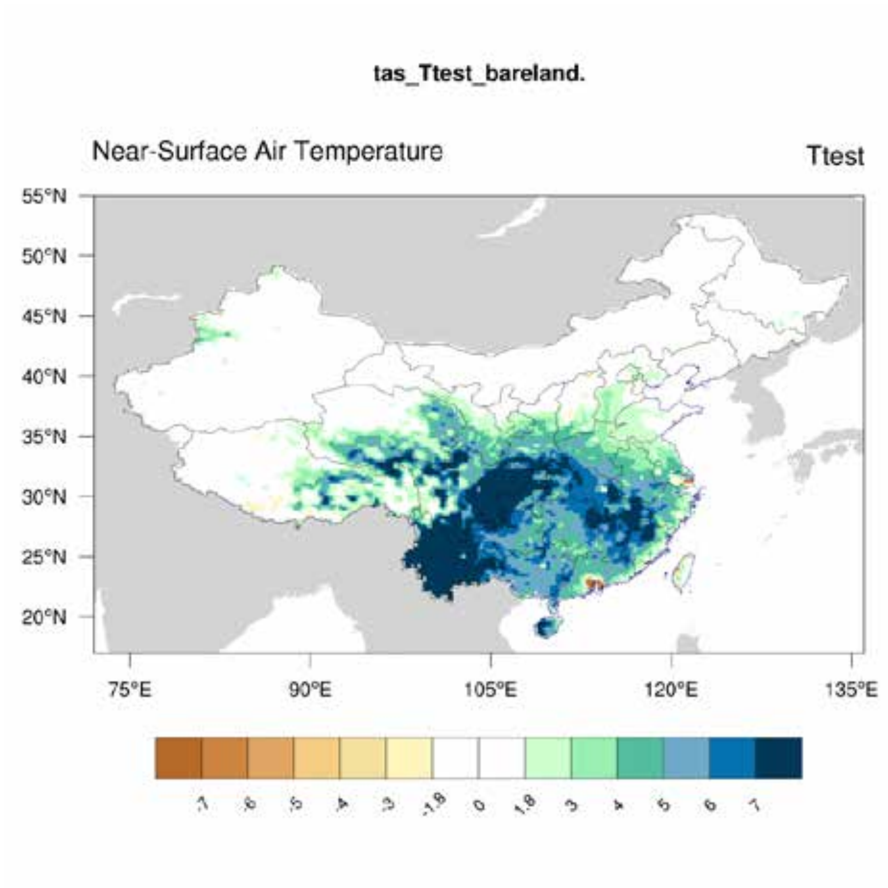


All bareland

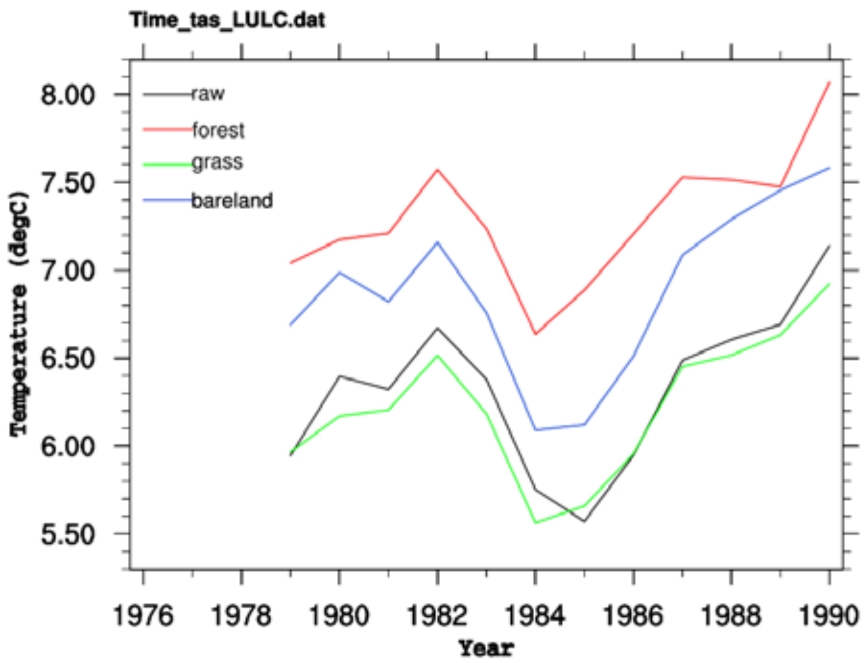
Temperature difference



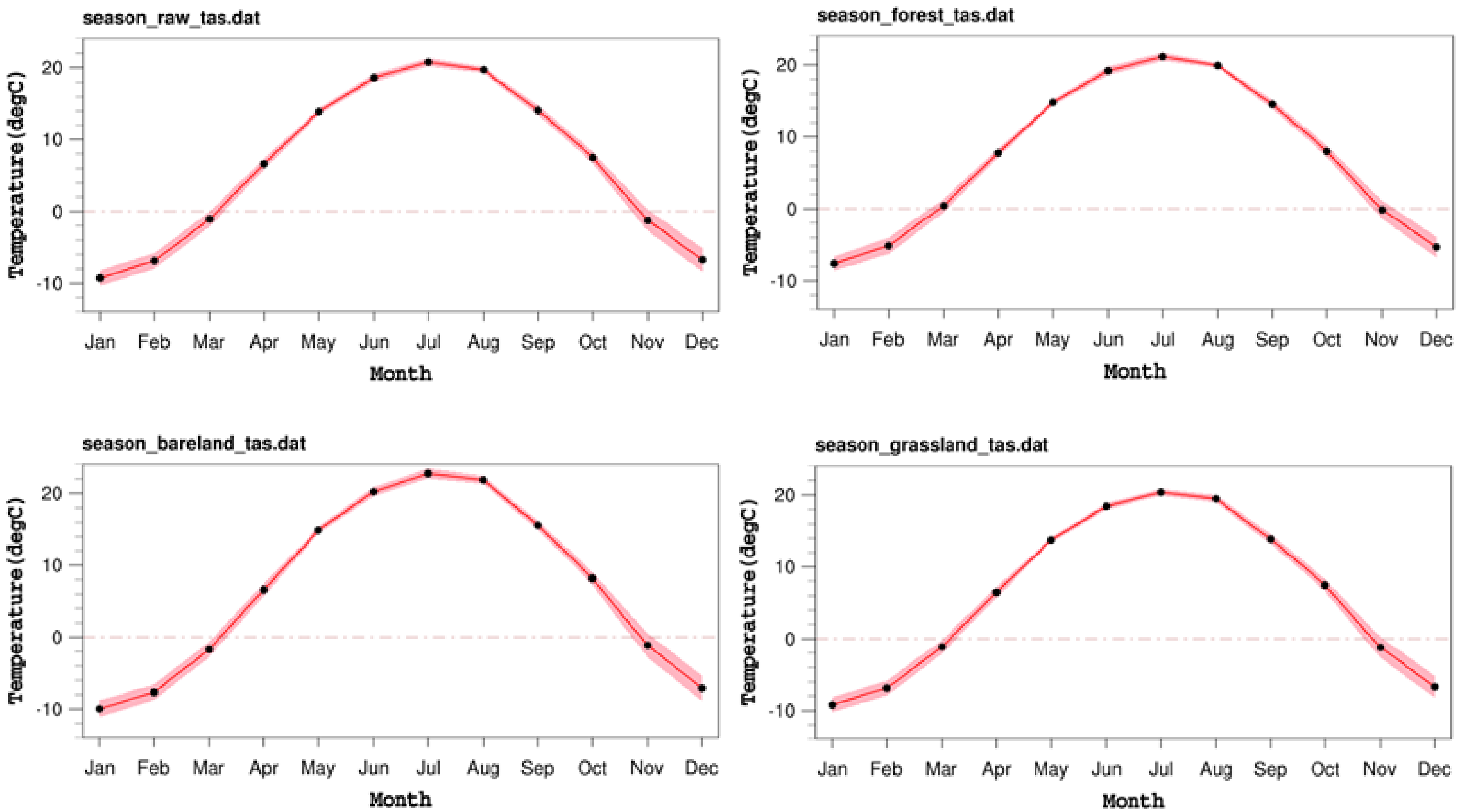
T-test of the difference



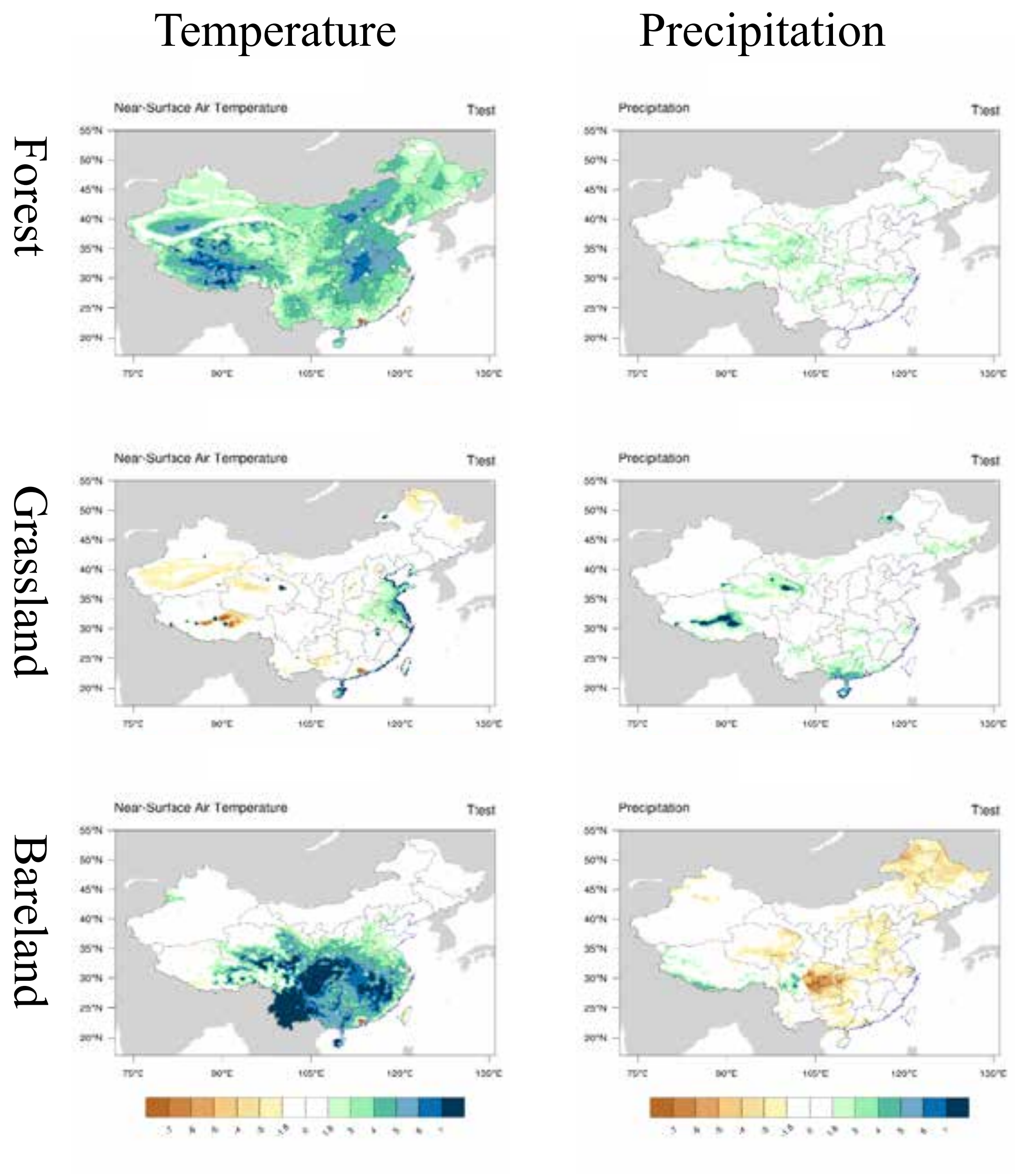
The inter-annual variation of temperature under different LULC



Seasonal variation of precipitation under different LULC



Comparison of t-test for temperature and precipitation

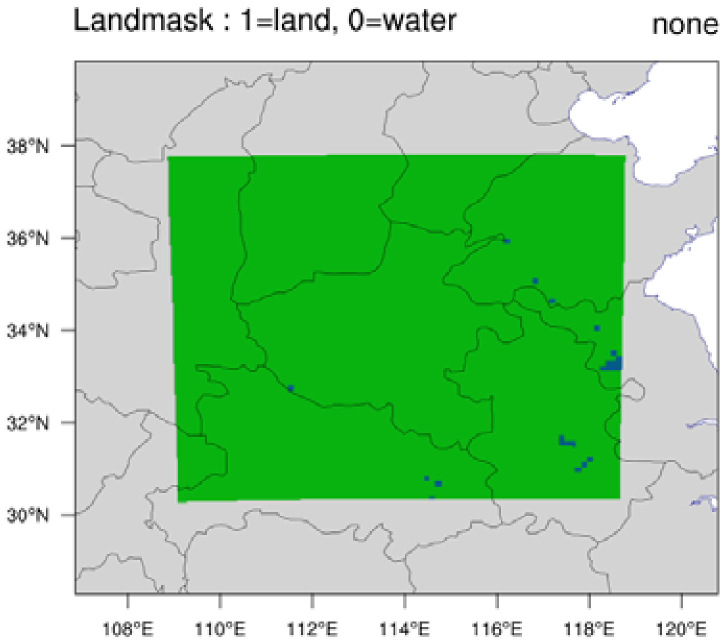


6. Conclusion and discussion

- The regional climate downscaling simulation were well achieved for East Asia with ERA-Interim and NorESM data as climate forcing.
- The artificial LULC modification were carried out, which manifests interesting result for both temperature and precipitation.
- The forest and grassland mainly increase the precipitation, while bareland mainly decrease precipitation.
- The grassland experiment would not impact the temperature significantly, while the forest and bareland would cause warming.
- Forests mainly cause winter warming, while bare land mainly causes summer warming, which results in a smaller annual temperature difference in forests and a larger annual temperature difference in bare land.
- The t-test at 95% confidence shows that the temperature change is more significant (except for grassland) than precipitation change under the LULC modification experiments.

Further work: downscaling simulation at much higher resolution（12km）

Area for Henan Province



Area for Tibet Plateau