

Modeling the Hydro-Climatic Effects of Land Use and Land Cover Changes in the Euphrates & Tigris Basin Under a Changing Climate



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Informatics Institute

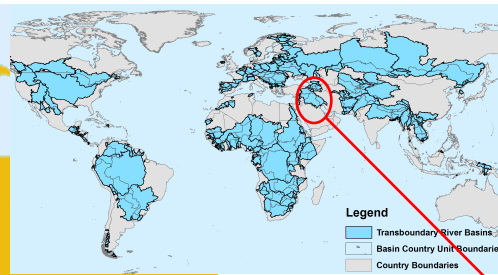
*yelizyilmaz@itu.edu.tr

Harran Plain, Turkey

Image source : Sentinel-2 - 2016



image source: Dowling, Mike.

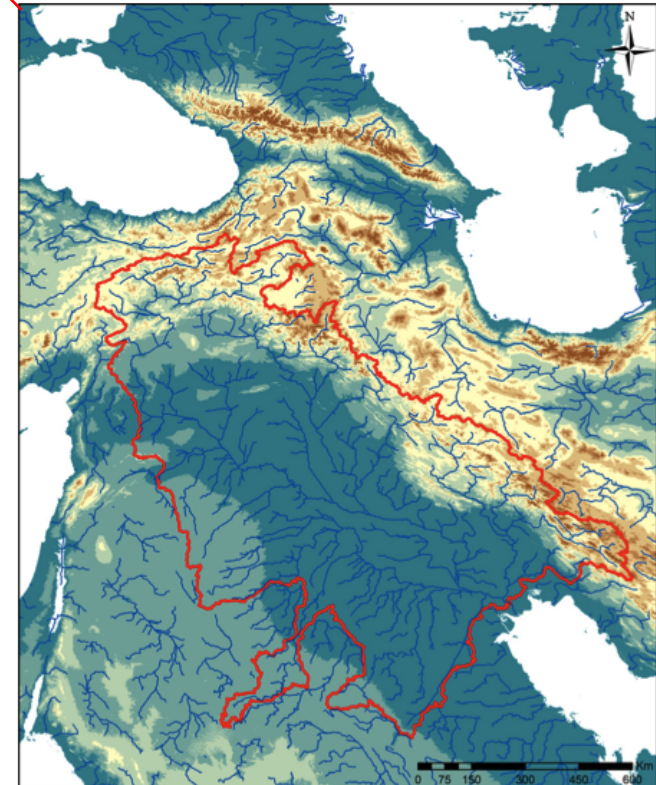


UNEP (2016), TWAP RB
Technical Assessment Report

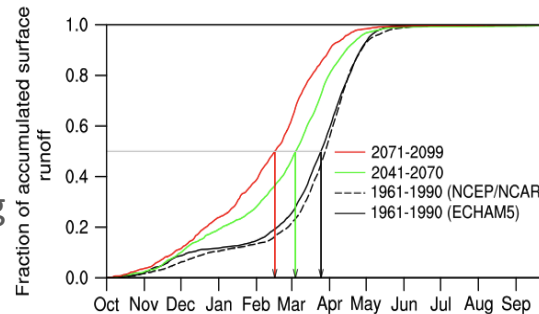
Motivation

Euphrates & Tigris Basin (ETB)

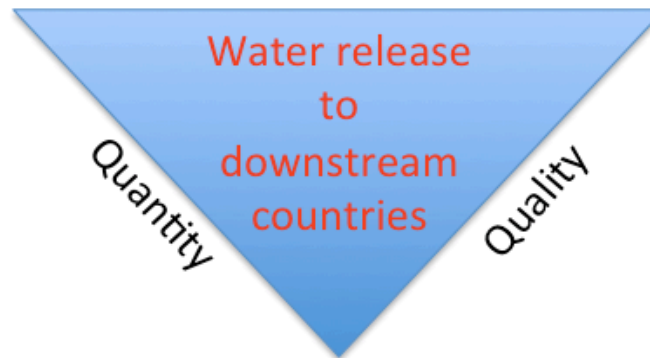
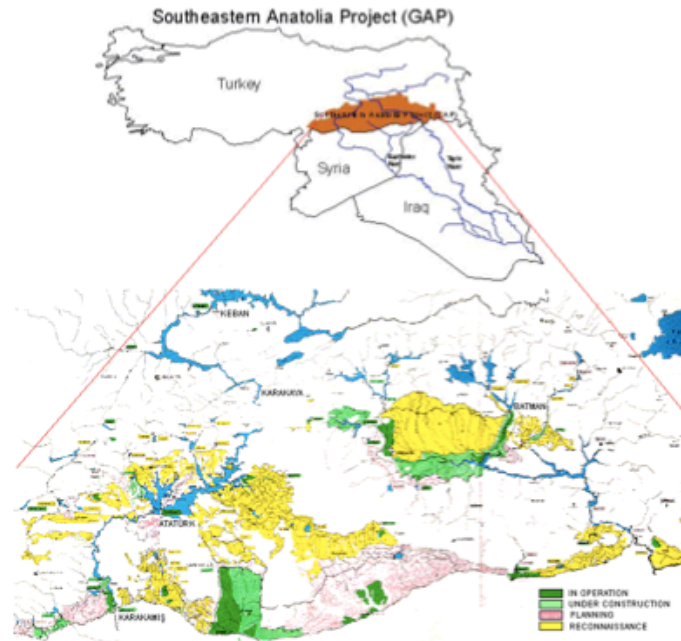
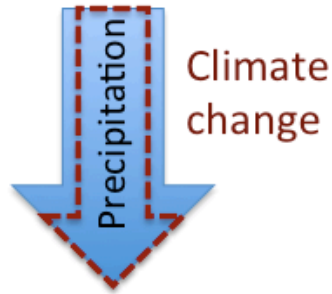
Bozkurt and Sen, J. of Hydrol., 2013



- Snow-fed river basin
- Future simulations
 - Precipitation decrease in headwaters region
 - Streamflow timings are shifting to earlier days
- Southeastern Anatolia Project
 - Irrigated cultivation



Southeastern Anatolia Project (GAP)

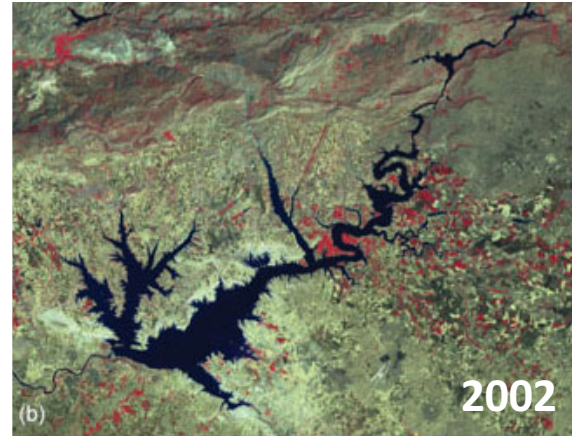
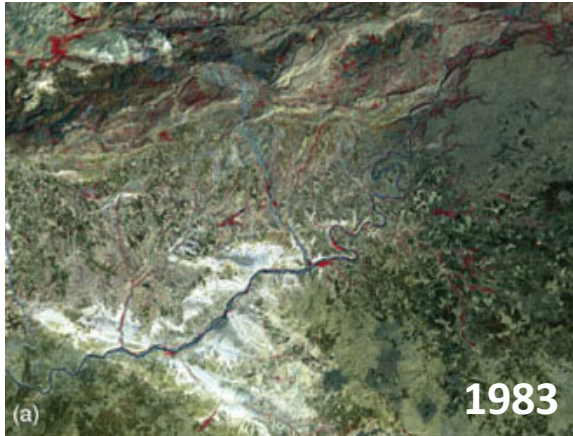


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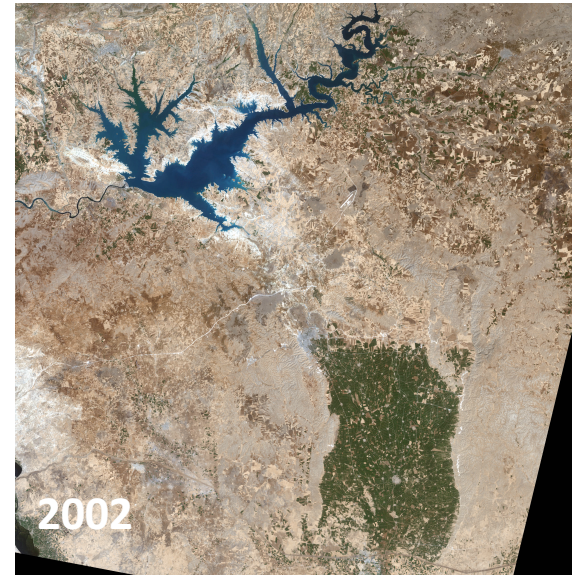
Potential for conflict

Southeastern Anatolia Project (GAP)



Landsat images show the area before (a) and after (b) the Ataturk Dam was built.

<https://visibleearth.nasa.gov/view.php?id=3796>



Extension of the irrigated areas in the Harran Plains.

<https://earthobservatory.nasa.gov/Features/HarranPlains/>

■ Irrigated Area

■ 2016

502,154 ha



■ **Future**

1.8 million ha

22 dams

19 HPP

Objectives

- To reveal the **effect of LCLU changes** on the climate and water resources of the region
- To calculate the **water loss** via evapotranspiration due to the extension of irrigated cultivation
- To evaluate how LCLU changes affect the **regional water budget** under a changing climate

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Method

- Dynamical downscaling
(regional climate model)
 - **RegCM4** (revision 4283)

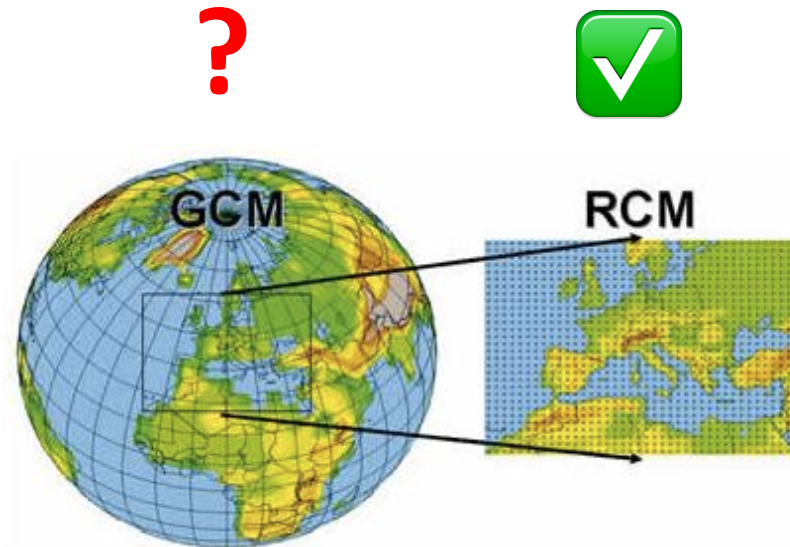


image source : F. Giorgi, WMO Bulletin 57(2), 2008

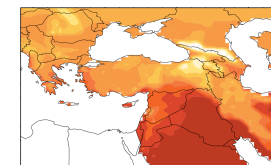
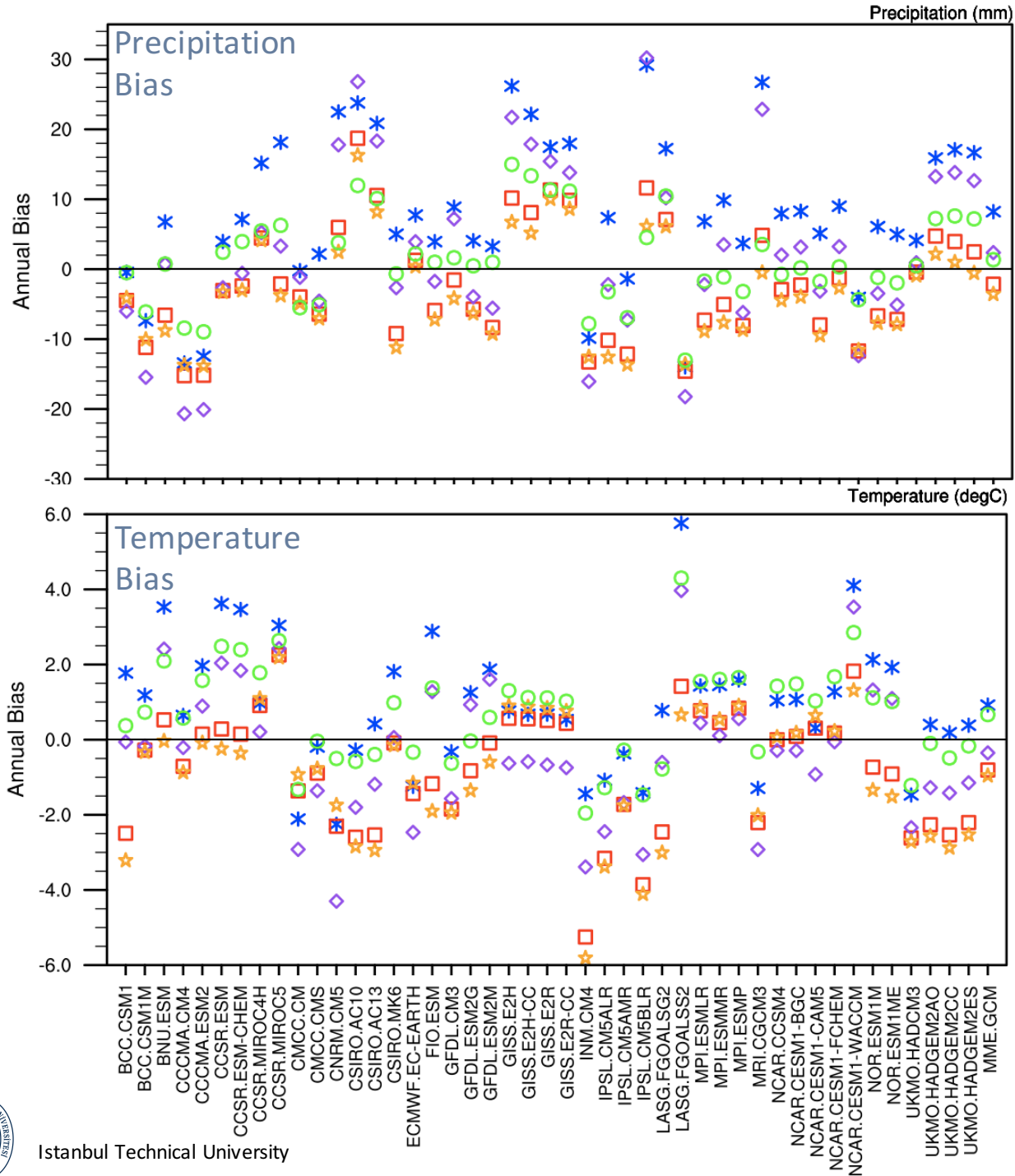
GCM	Model Name	Modeling Center (or Group)	Resolution (lat, lon)
1	BCC CSM1	Beijing Climate Center, China	2.8x2.8
2	BCC CSM 1M	Meteorological Administration	1.1x1.1
3	BNU ESM	College of Global Change and Earth System Science, Beijing Normal University	2.8x2.8
4	CCCMA CM4	Canadian Centre for Climate	2.8x2.8
5	CCCMA ESM2	Modelling and Analysis	2.8x2.8
6	CCSR ESM	Atmosphere and Ocean Research Institute (The University of Tokyo),	2.8x2.8
7	CCSR ESM CHEM	National Institute for	2.8x2.8
8	CCSR MIROC4H	Environmental Studies, and Japan Agency for Marine-Earth Science and Technology	0.56x0.56
9	CCSR MIROC5		1.4x1.4
10	CMCC CM	Centro Euro-Mediterraneo per I Cambiamenti Climatici	0.75x0.75
11	CMCC CMS		1.8x1.8
12	CNRM CM5	Centre National de Recherches Météorologiques / Centre Européen de Recherche et Formation Avancée en Calcul Scientifique	1.4x1.4
13	CSIRO AC10	Commonwealth Scientific and Industrial Research Organization in collaboration with Queensland Climate Change Centre of Excellence	1.25x1.8
14	CSIRO AC13		1.25x1.8
15	CSIRO MK6		1.8x1.8
16	ECMWF EC EARTH	EC-EARTH consortium	1.1x1.1
17	FIO ESM	The First Institute of Oceanography, SOA, China	2.8x2.8
18	GFDL CM3	NOAA Geophysical Fluid Dynamics Laboratory	2x2.5
19	GFDL ESM2G		2x2.5
20	GFDL ESM2M		2x2.5
21	GISS E2H	NASA Goddard Institute for Space Studies	2x2.5
22	GISS E2H-CC		2x2.5
23	GISS E2R		2x2.5
24	GISS E2R-CC		2x2.5

GCM	Model Name	Modeling Center (or Group)	Resolution (lat, lon)
25	INM CM4	Institute for Numerical Mathematics	1.5x2
26	IPSL CM5ALR	Institut Pierre-Simon Laplace	1.9x3.75
27	IPSL CM5AMR		1.25x2.5
28	IPSL CM5BLR		1.9x3.75
29	LASG FGOALSG2	LASG, Institute of Atmospheric Physics, Chinese Academy of Sciences and CESS, Tsinghua	2.8x2.8
30	LASG FGOALSS2	LASG, Institute of Atmospheric Physics, Chinese Academy of Sciences	1.6x2.8
31	MPI ESM LR	Max-Planck-Institut für Meteorologie (Max Planck Institute for Meteorology)	1.9x1.9
32	MPI ESM MR		1.9x1.9
33	MPI ESM P		1.9x1.9
34	MRI CGCM3	Meteorological Research Institute	1.1x1.1
35	NCAR CCSM4	National Center for Atmospheric Research	0.9x1.25
36	NCAR CESM1-BGC		0.9x1.25
37	NCAR CESM1-CAM5		0.9x1.25
38	NCAR CESM1-FCHEM	Community Earth System Model Contributors	0.9x1.25
39	NCAR CESM1-WACCM		1.9x2.5
40	NOR ESM1M	Norwegian Climate Centre	1.9x2.5
41	NOR ESM1ME		1.9x2.5
42	UKMO HADCM3	Met Office Hadley Centre	2.5x3.75
43	UKMO HADGEM2AO	(additional HadGEM2-ES realizations contributed by	1.25x1.875
44	UKMO HADGEM2CC	Instituto Nacional de Pesquisas Espaciais)	1.25x1.875
45	UKMO HADGEM2ES		1.25x1.875
46	MME GCM	Multi Model Ensemble	0.5x0.5

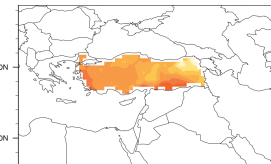
Observation :

CRU (Climate Research Unit) TS v 4.01 (0.5°x0.5°)

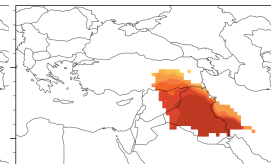
<http://www.cru.uea.ac.uk/cru/data/hrg/>



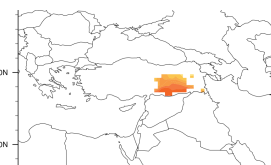
Whole Domain



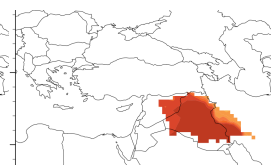
Turkey



Tigris-Euphrates



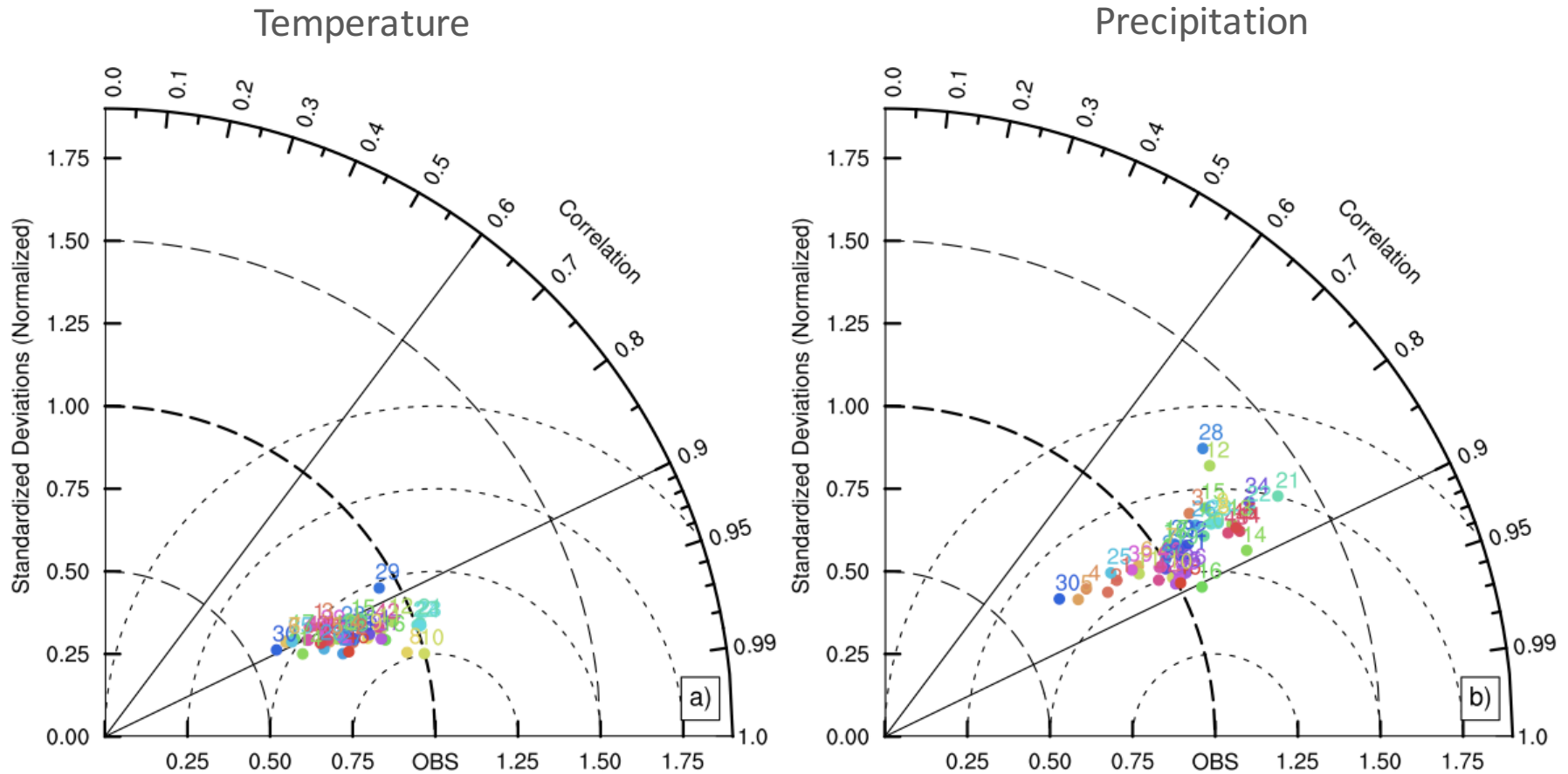
ET-TRin



ET-TRout

Rank	Precipitation	Temperature
1	NCAR.CESM1-BGC	GFDL.ESM2G
2	NCAR.CESM1-FCHEM	CMCC.CMS
3	GFDL.ESM2G	UKMO.HADGEM2AO
4	UKMO.HADCM3	UKMO.HADGEM2ES
5	BCC.CSM1	IPSL.CM5AMR

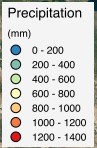
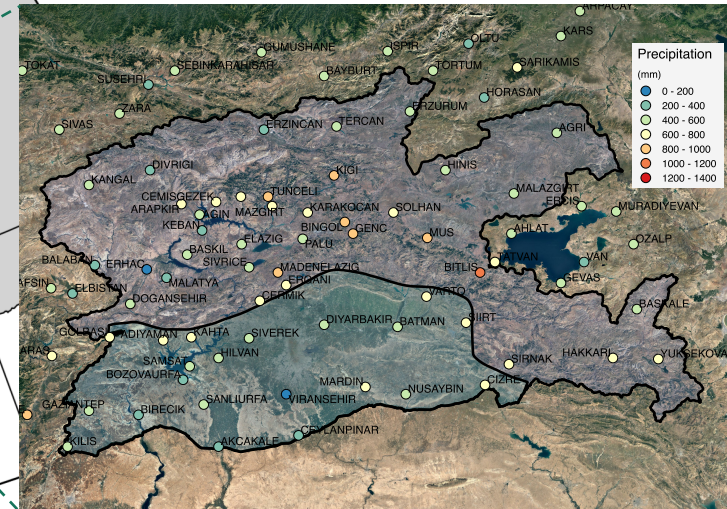
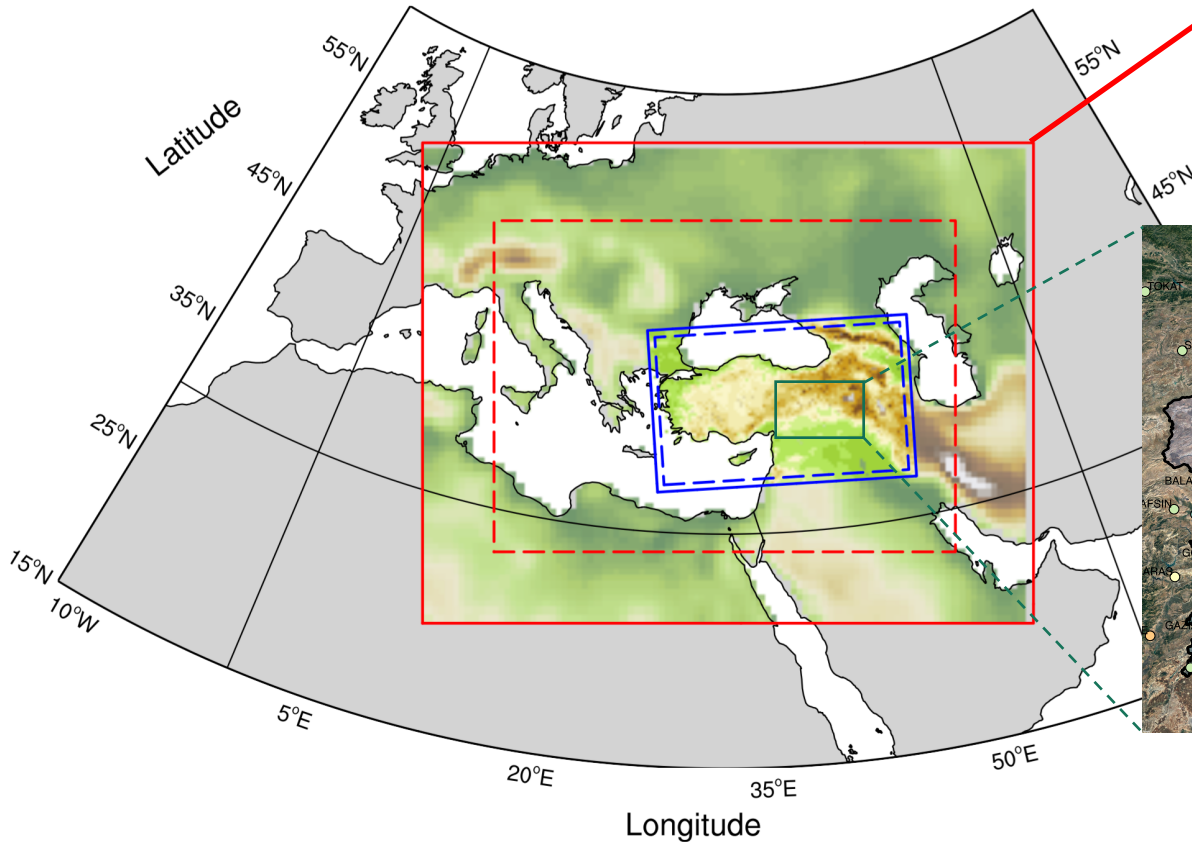
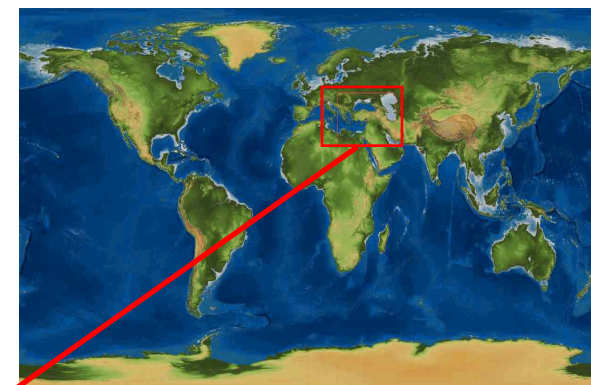
Taylor Diagrams (whole domain - annual)



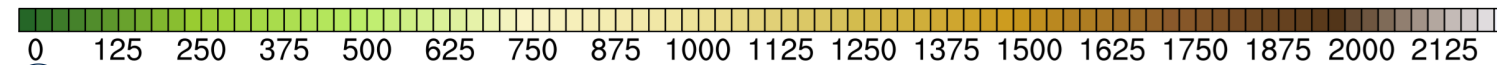
- | | | | | | |
|-------------------|---------------------|------------------|--------------------|-----------------------|---------------------|
| 1 - bcc.csm1 | 9 - ccsr.miroc5 | 17 - fio.esm | 25 - inm.cm4 | 33 - mpi.esmP | 41 - nor.esm1me |
| 2 - bcc.csm1m | 10 - cmcc.cm | 18 - gfdl.cm3 | 26 - ipsl.cm5aLR | 34 - mri.cgcm3 | 42 - ukmo.hadcm3 |
| 3 - bnu.esm | 11 - cmcc.cms | 19 - gfdl.esm2g | 27 - ipsl.cm5aMR | 35 - ncar.cesm4 | 43 - ukmo.hadgem2ao |
| 4 - cccma.cm4 | 12 - cnrm.cm5 | 20 - gfdl.esm2m | 28 - ipsl.cm5bLR | 36 - ncar.cesm1-bgc | 44 - ukmo.hadgem2cc |
| 5 - cccma.esm2 | 13 - csiro.ac10 | 21 - giss.e2h | 29 - lasg.fgoalsG2 | 37 - ncar.cesm1-cam5 | 45 - ukmo.hadgem2es |
| 6 - ccsr.esm | 14 - csiro.ac13 | 22 - giss.e2h-cc | 30 - lasg.fgoalsS2 | 38 - ncar.cesm1-fchem | 46 - mme.gcm |
| 7 - ccsr.esm-chem | 15 - csiro.mk6 | 23 - giss.e2r | 31 - mpi.esmLR | 39 - ncar.cesm1-waccm | |
| 8 - ccsr.miroc4h | 16 - ecmwf.ec-earth | 24 - giss.e2r-cc | 32 - mpi.esmMR | 40 - nor.esm1m | |

Study Domain

- Eastern Mediterranean and Black Sea (OD-48 km)
- Turkey (TR-12 km //with subgrid-3km)
- Euphrates & Tigris Basin



meter



Model Configuration

Domain name	OD48 (48 km)	TR12 (12 km)
Grid number (y,x), Vertical Resolution	75x95, 18 level	100x160, 23 level
Center (latitude, longitude)	40, 32	38.7, 37
Initial and Boundary Conditions (atmosphere, sst)	• NNRP, OI_WK • EC-EARTH	• OD48 outputs
Boundary Condition Parameters (nspgx, nspgd)	12,12	18,18
Boundary Layer Model	Holtslag PBL	Holtslag PBL
Cumulus Convection Scheme	Grell	Grell
Cumulus Closure Scheme	Fritsch & Chappell	Fritsch & Chappell
Moisture Scheme	SUBEX	SUBEX
Ocean Flux Scheme	Zeng	Zeng
Radiation Model	CCSM	CCSM

Land surface processes in RegCM4

- **BATS** (Biosphere-Atmosphere Transfer Scheme)
 - ✓ Subgridding
(3 km resolution)
- **CLM** (Community Land Model)

Landuse Maps

1993 period

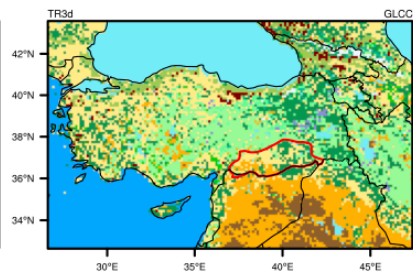
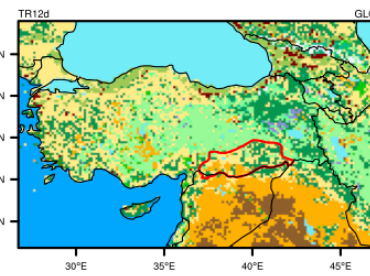
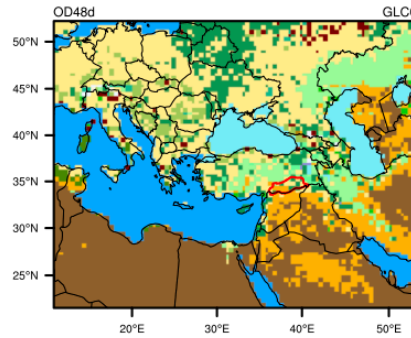
Pre-GAP

- GLCC (USGS)
- Non-irrigated

48 km

12 km

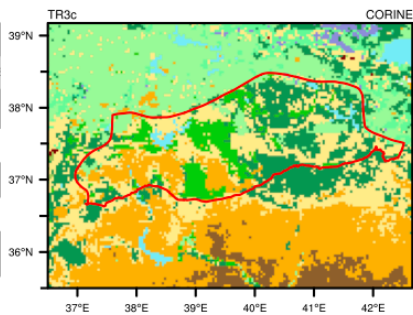
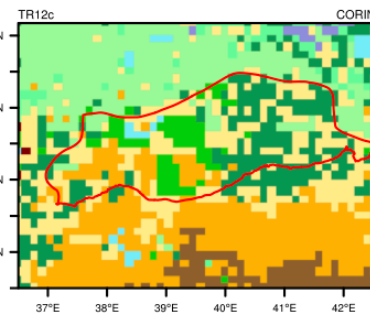
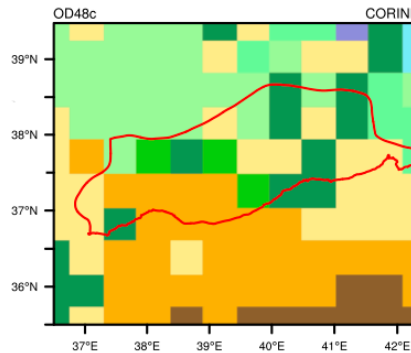
3 km



2000 period

Current GAP (25%)

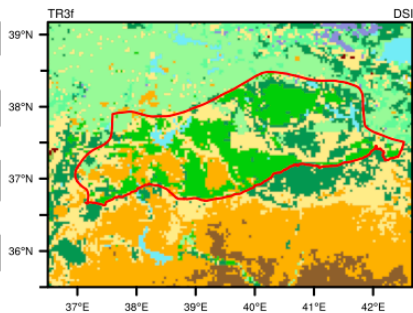
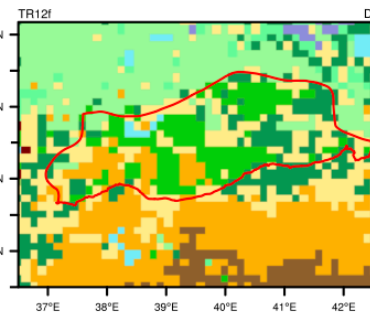
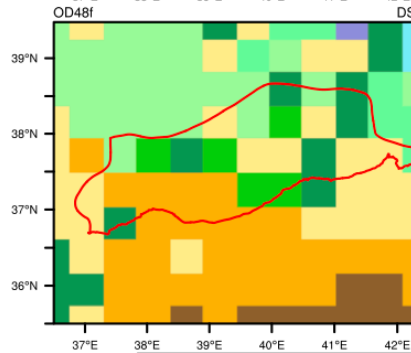
- CORINE (EEA)
- Partly irrigated



Future period

Future GAP (%100)

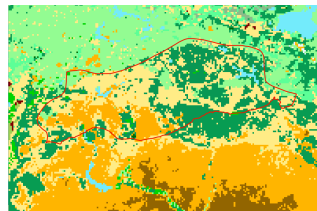
- DSI (Turkish State Hydraulic Work)
- Fully irrigated



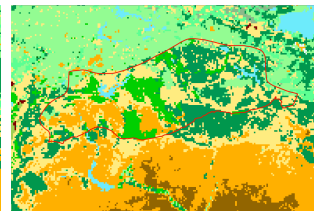
- | | | | | | |
|-----------------------------|----------------------------|--------------------|--------------------|---------------------------|--------------|
| 1 Crop/mixed farming | 5 Deciduous broadleaf tree | 9 Tundra | 13 Bog or marsh | 17 Deciduous shrub | 21 Urban |
| 2 Short grass | 6 Evergreen broadleaf tree | 10 Irrigated Crop | 14 Inland water | 18 Mixed Woodland | 22 Sub-Urban |
| 3 Evergreen needleleaf tree | 7 Tall grass | 11 Semi-desert | 15 Ocean | 19 Forest/Field mosaic | |
| 4 Deciduous needleleaf tree | 8 Desert | 12 Ice cap/glacier | 16 Evergreen shrub | 20 Water and Land mixture | |

Experimental Design

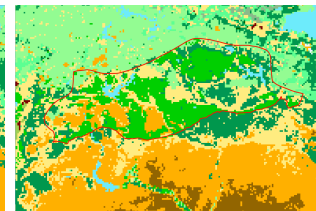
No	Forcing Data	Land Use Map	Simulation Period
1	NCEP/NCAR Reanalysis	Non-irrigated	1991-2010
2	NCEP/NCAR Reanalysis	Partly irrigated	1991-2010
3	NCEP/NCAR Reanalysis	Fully irrigated	1991-2010
4	EC-EARTH	Non-irrigated	1986-2008
5	EC-EARTH / RCP 4.5	Non-irrigated	2046-2065
6	EC-EARTH / RCP 8.5	Non-irrigated	2046-2065
7	EC-EARTH / RCP 4.5	Fully irrigated	2046-2065
8	EC-EARTH / RCP 8.5	Fully irrigated	2046-2065
9	EC-EARTH / RCP 4.5	Fully irrigated	2081-2100
10	EC-EARTH / RCP 8.5	Fully irrigated	2081-2100



(Non-irrigated)



(Partly irrigated)



(Fully irrigated)

Model Evaluation

48 km (1991-2008)

No	Forcing Data	Land Use Map	Simulation Period
1	NCEP/NCAR Reanalysis	Non-irrigated	1991-2010
4	EC-EARTH	Non-irrigated	1986-2008

Temperature

OBS

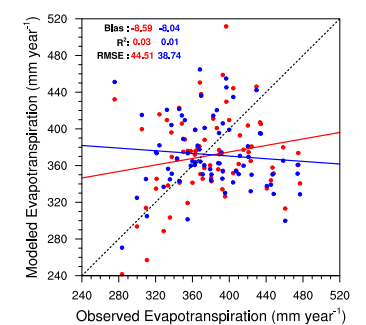
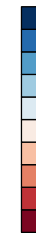
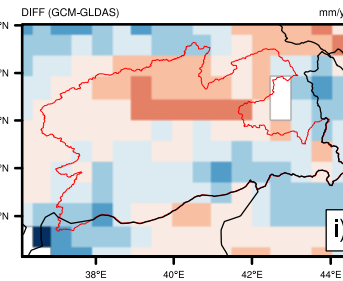
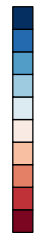
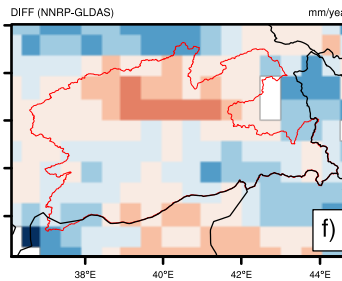
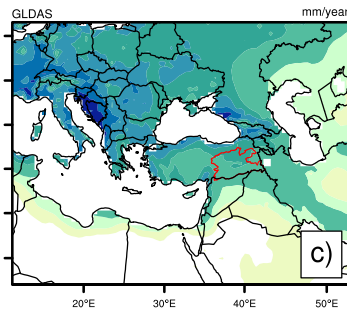
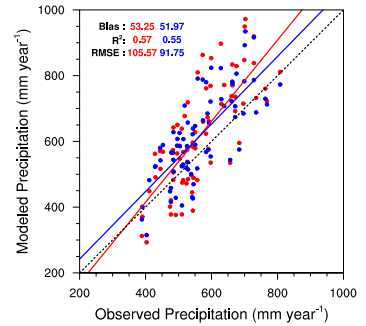
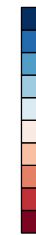
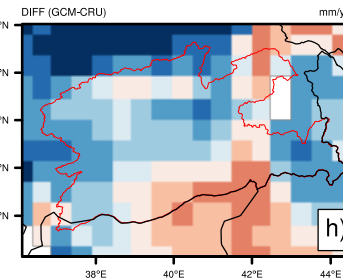
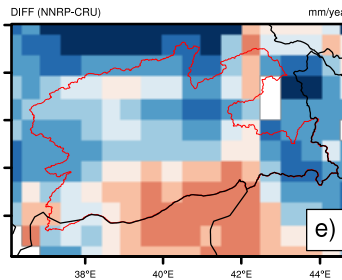
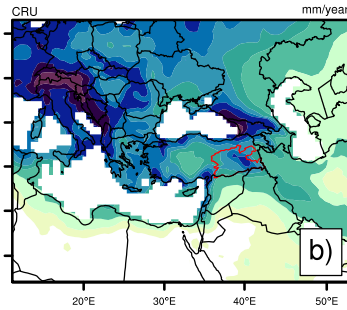
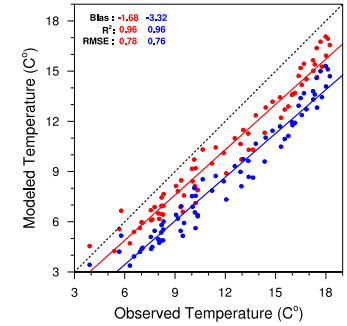
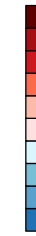
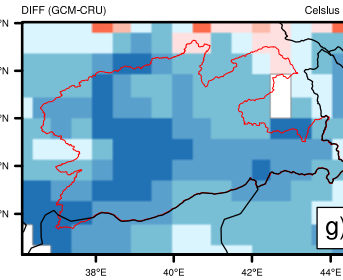
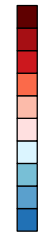
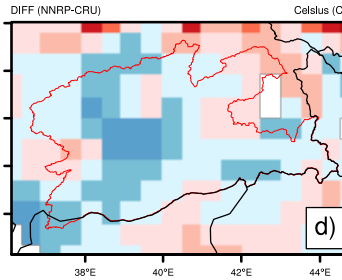
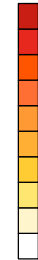
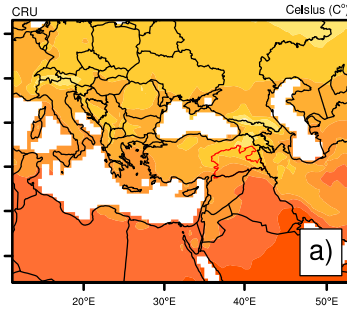
NNRP-OBS

EC-EARTH-OBS

NNRP Driven Simulation
EC-EARTH Driven Simulation

Precipitation

Evapotranspiration



Effects of LCLU change

No	Forcing Data	Land Use Map	Simulation Period
1	NCEP/NCAR Reanalysis	Non-irrigated	1991-2010
2	NCEP/NCAR Reanalysis	Partly irrigated	1991-2010
3	NCEP/NCAR Reanalysis	Fully irrigated	1991-2010

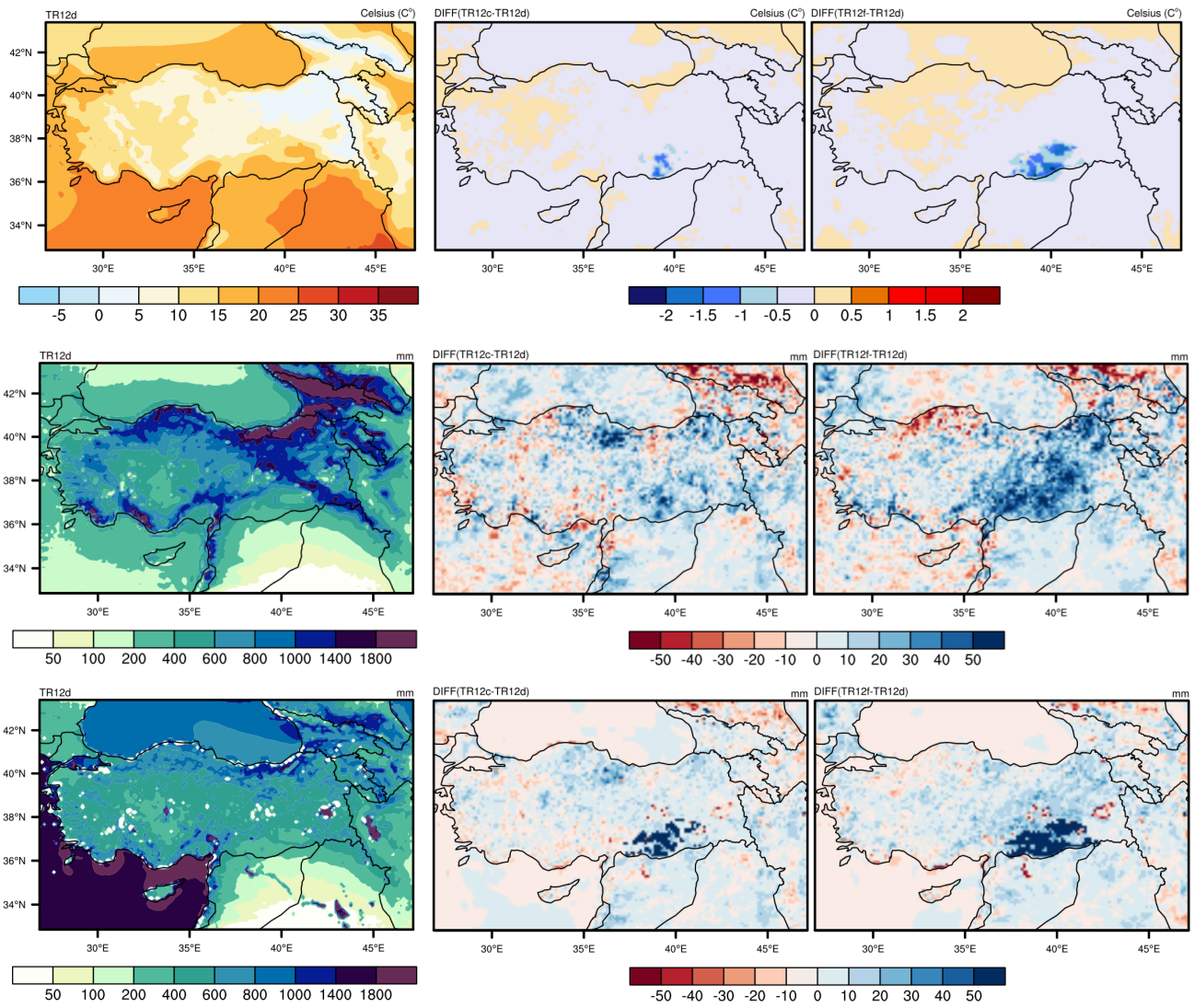
NNRP driven 12 km simulations
 1991-2010

Temperature

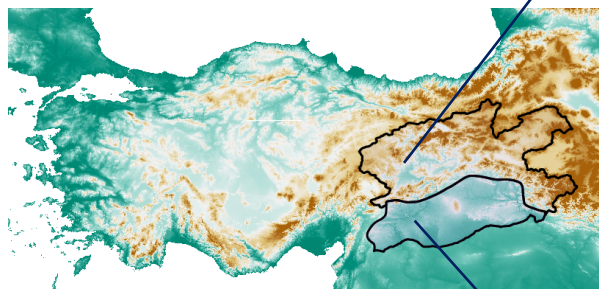
Precipitation

Evapotranspiration

Non-irrigated
Partly irrigated
Fully irrigated



Effects of LCLU changes on the water budget

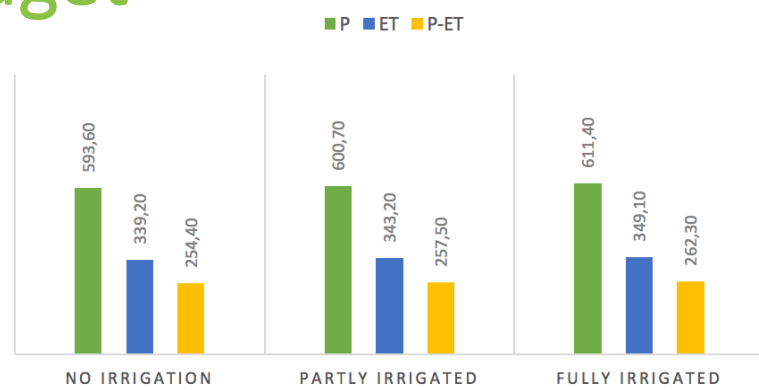


1991-2010

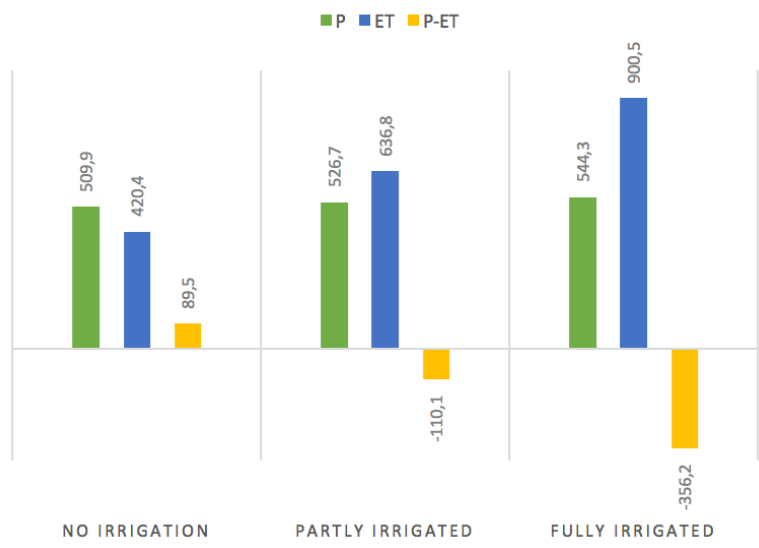
increase of evapotranspiration in GAP

- ▲ 51% with partly irrigated map
- ▲ 114% with fully irrigated map

UPPER E&T BASIN

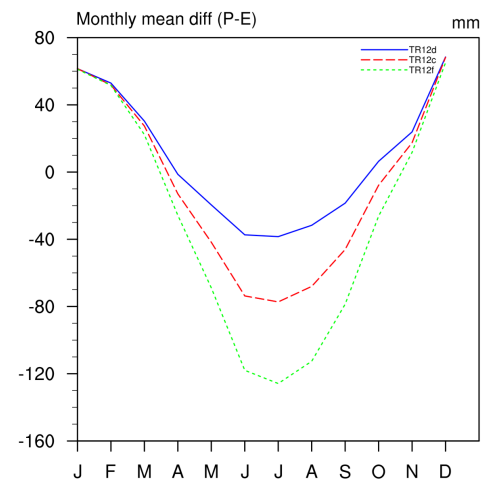
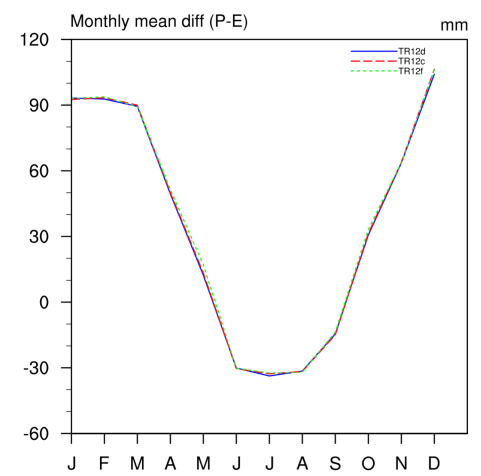


GAP REGION



P : Precipitation
ET : Evapotranspiration

*unit (mm/year)



— Non-irrigated
- - Partly irrigated
... Fully irrigated



What happens if we ONLY change the LCLU?

- Land use and land cover changes cause
 - annual surface **temperature decrease** by about 0.4 °C and 0.8 °C (irrigation's cooling effect)
 - **precipitation increase** 3% and 7%, mostly in spring.
(soil moisture ↑ >> latent heat flux ↑ >> convective precipitation ↑)
 - **increase in evapotranspiration** amounts by 51% and 114% compared to the pre-GAP conditions, which means significant water loss from the region.
- The increasing **water demand** of the irrigated region (GAP) is currently **barely compensated** by the headwaters of the Euphrates & Tigris basin.

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Let's add the effects of increasing greenhouse gas emissions!

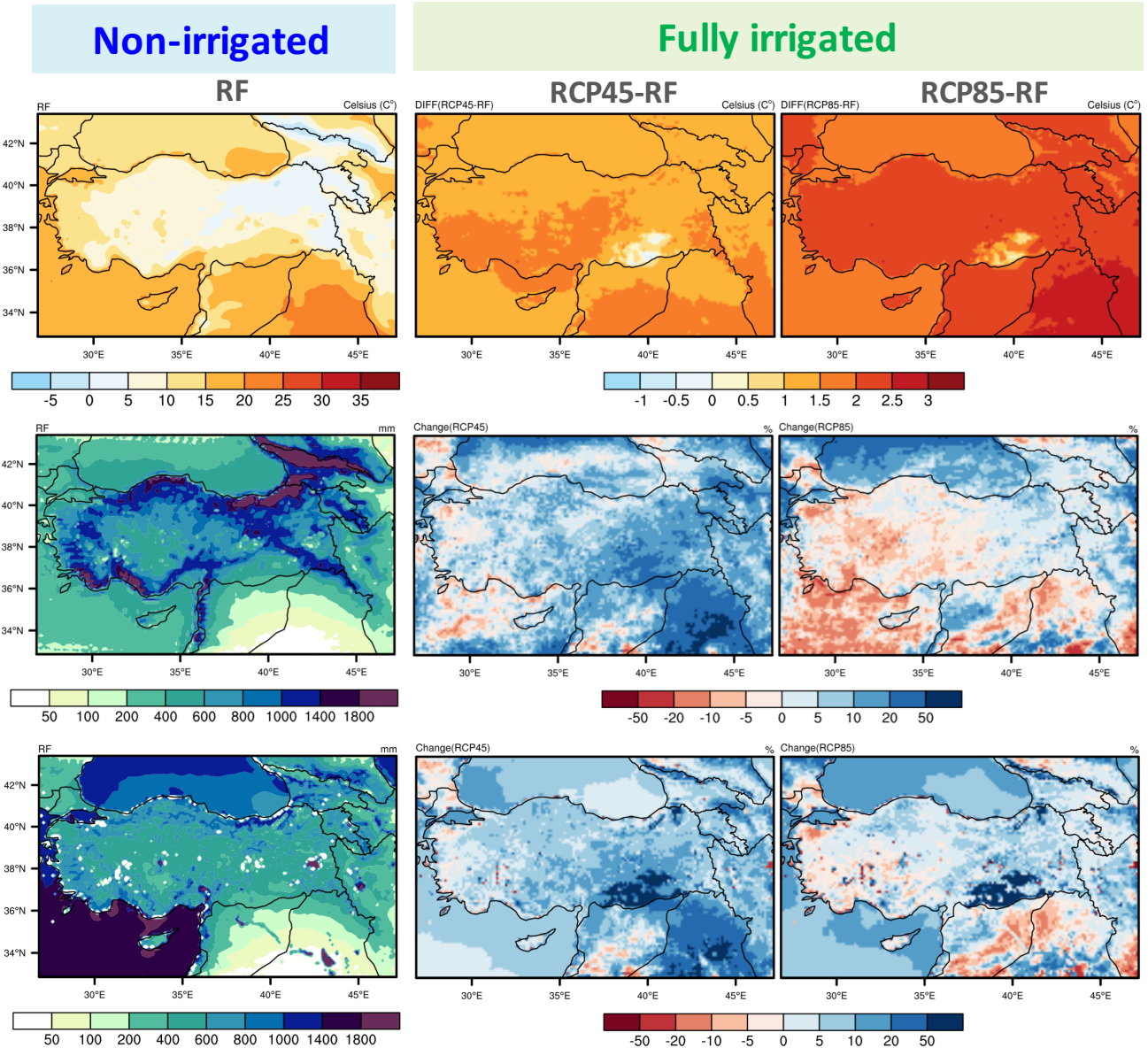
INTEGRATED Effects of LCLU change + RCPs

EC-EARTH driven 12 km simulations
2046-2065

Temperature

Precipitation

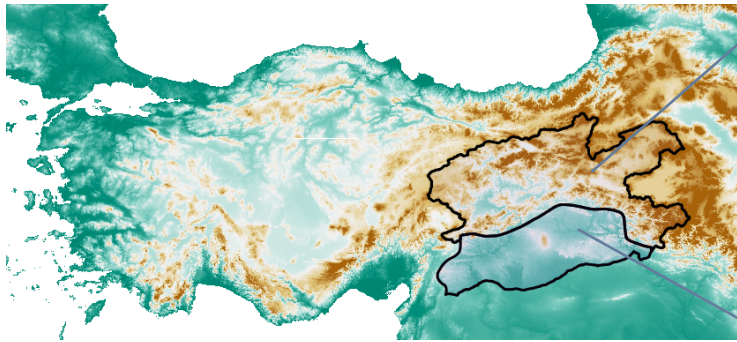
Evapotranspiration



Seasonal Cycle (P-E)

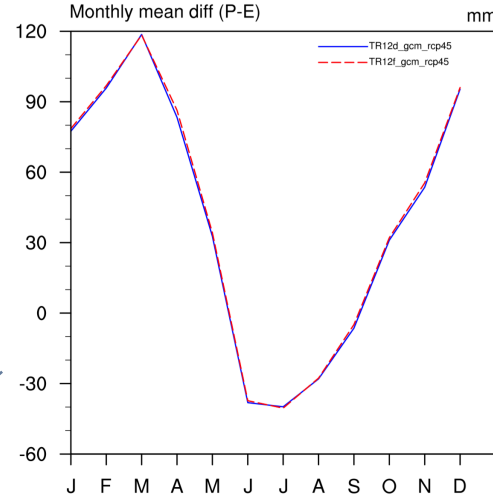
Upper Euphrates
& Tigris Basin
(headwaters region)

2046-2065

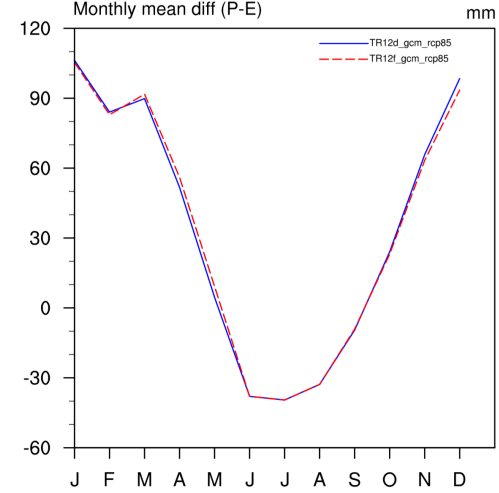


GAP region
(irrigation projects)

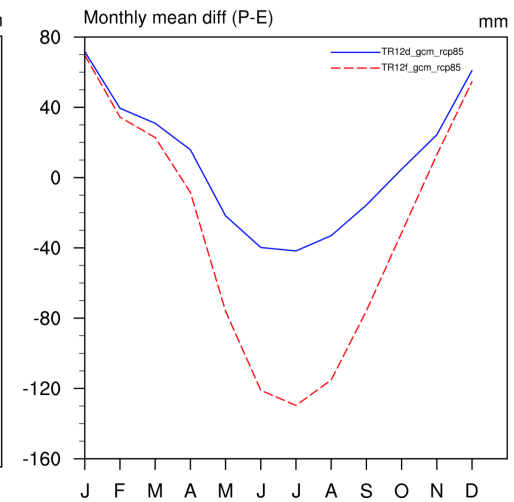
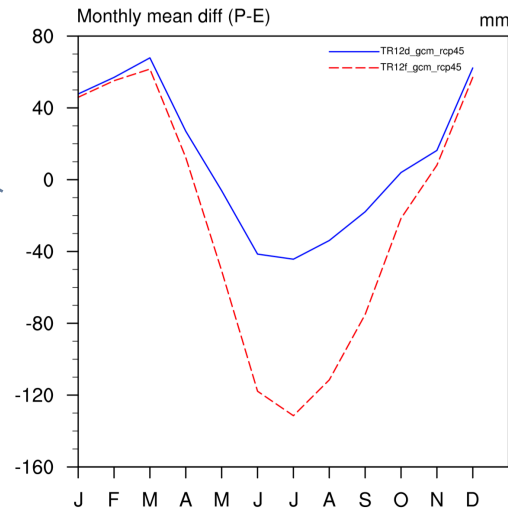
RCP 4.5



RCP 8.5



— Non-irrigated
- - - Fully irrigated

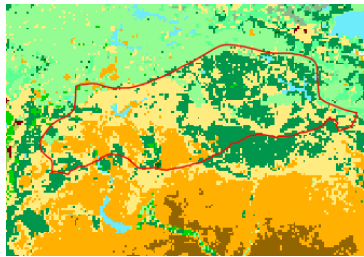
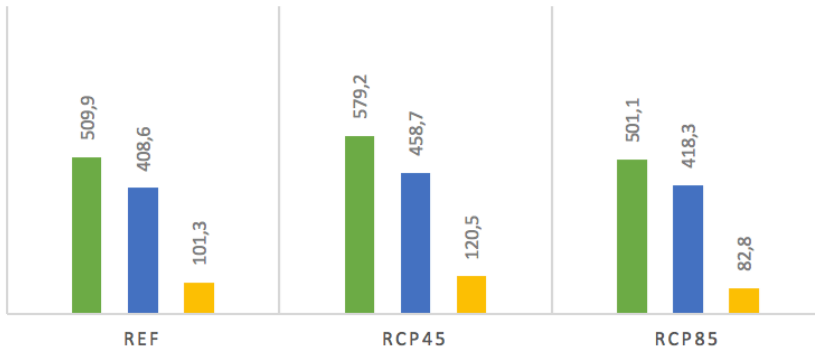


Effects of RCP scenarios

Integrated effects (LCLU + RCPs)

GAP REGION - NO IRRIGATION

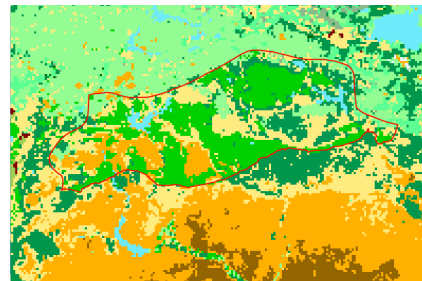
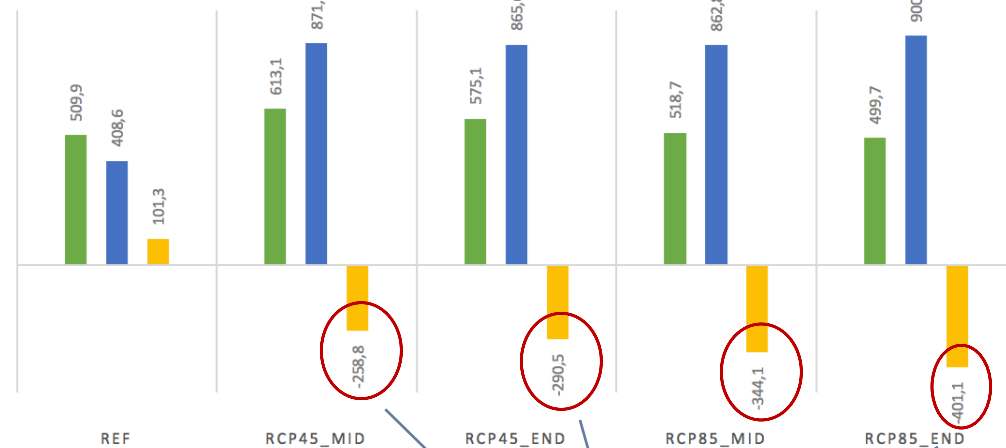
■ P ■ ET ■ P-ET



P : Precipitation
 ET : Evapotranspiration
 *unit (mm/year)

GAP REGION - FULLY IRRIGATED

■ P ■ ET ■ P-ET



water deficit

REF : 1986-2008
 MID : 2046-2065
 END : 2081-2100

Conclusions

- Our experiment reveals that the regional water budget will be adversely affected by the **water loss through the increased evapotranspiration**.
- The increasing **water demand** of the irrigated region (GAP) is currently **barely compensated** by the headwaters of the Euphrates & Tigris basin.
- Temperature decrease caused by increased evapotranspiration will be at the same order of the increase in temperature due to RCP forcing. Hence, the **temperature of the irrigated region** will not be changed significantly in the future.
- The water of the region is primarily partitioned between energy production, irrigation and release for the downstream countries, the dramatic increase in water loss through evapotranspiration has potential to **alter the water management practices and policy measures** in the larger region.

Thank you*

yelizyilmaz@itu.edu.tr










* This study was supported by TÜBİTAK (The Scientific and Technological Research Council of Turkey) .

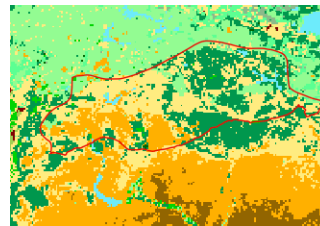
Research Grant Number : 114Y114

* My NCAR visit is currently supported by the TÜBİTAK Doctoral Research Fellowship Programme.

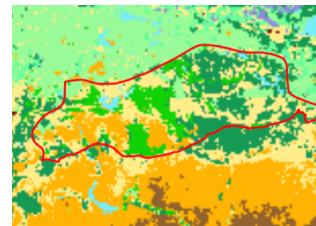


Change of Land Use Types

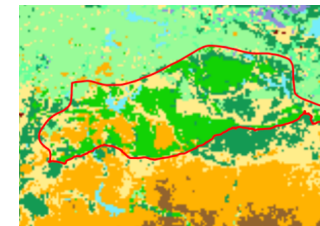
Land cover	Area (%)		
	Non-irrigated	Partly irrigated	Fully irrigated
 1 - Crop/mixed farming	41.3%	32.2%	24.4%
 2 - Short grass	8.4%	8.0%	7.9%
 3 - Evergreen needleleaf tree	0.1%	0.1%	0.1%
 4 - Deciduous needleleaf tree	0.1%	0.0%	0.0%
 7 - Tall grass	0.6%	0.5%	0.5%
 10 - Irrigated Crop	0.7%	17.4%	37.9%
 11 - Semi-desert	14.6%	12.6%	10.6%
 14 - Inland water	1.7%	2.5%	3.0%
 19 - Forest/Field mosaic	32.4%	26.7%	15.6%



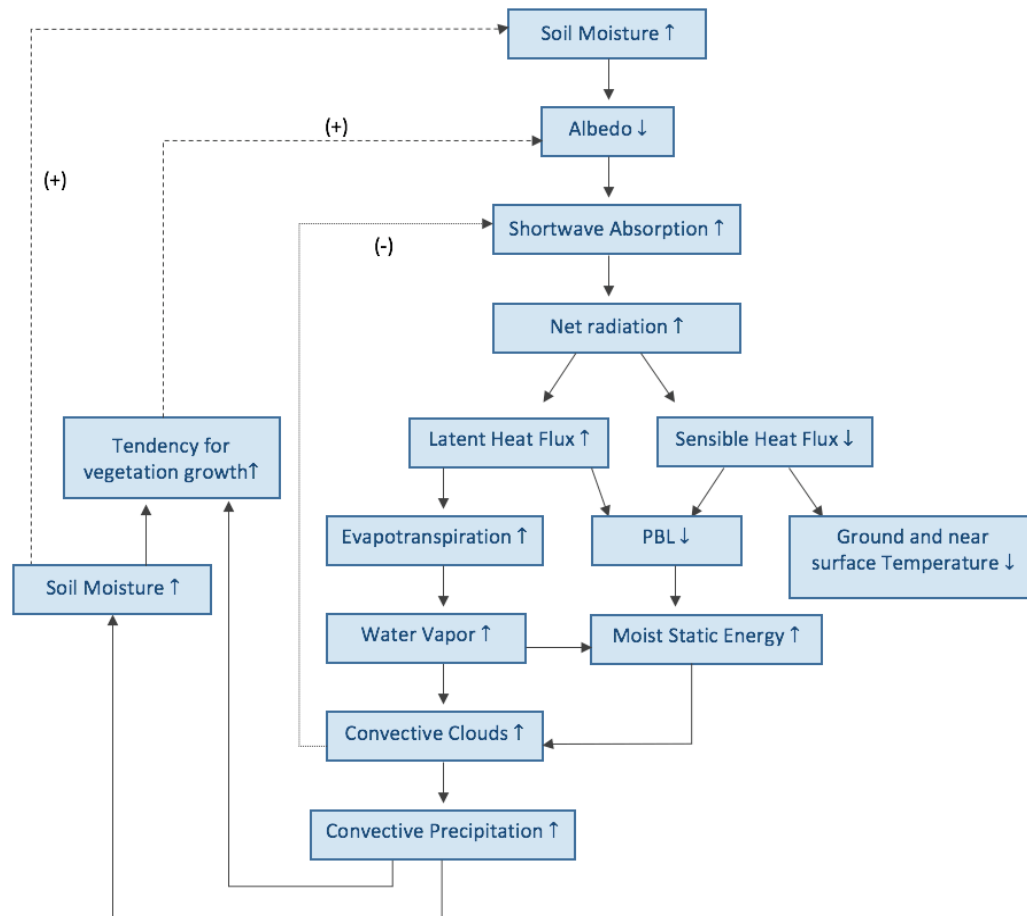
(Non-irrigated)



(Partly irrigated)



(Fully irrigated)

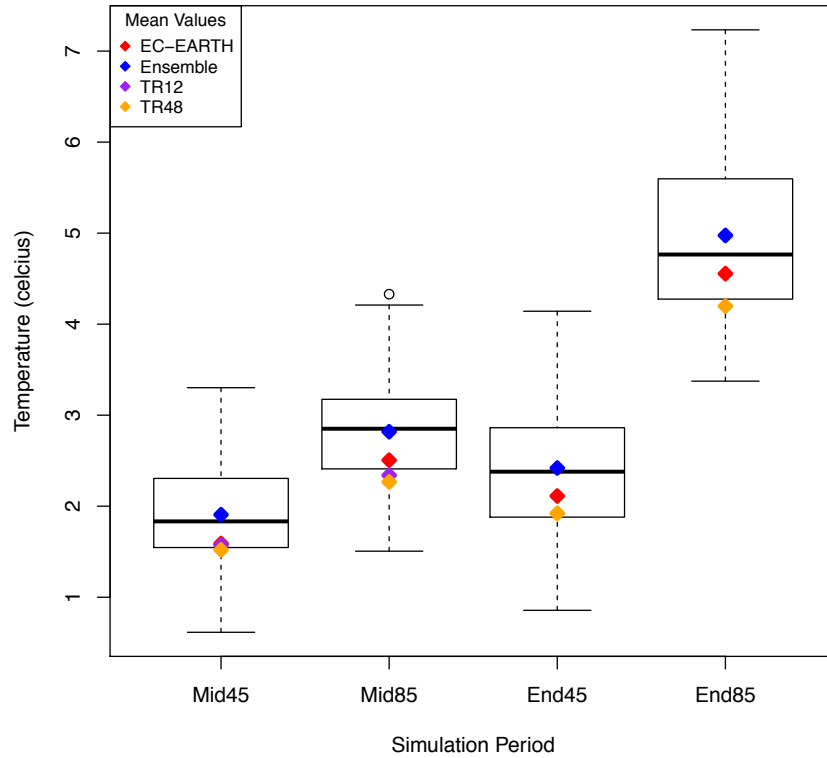


Conceptual diagram of the land-atmosphere interactions due to a change in soil moisture. The dashed lines show a positive feedback, while the dotted line represents a negative feedback. Figure is adopted from the studies of Pitman (2003), Lawrence & Slingo (2005) and Seneviratne et al. (2010).

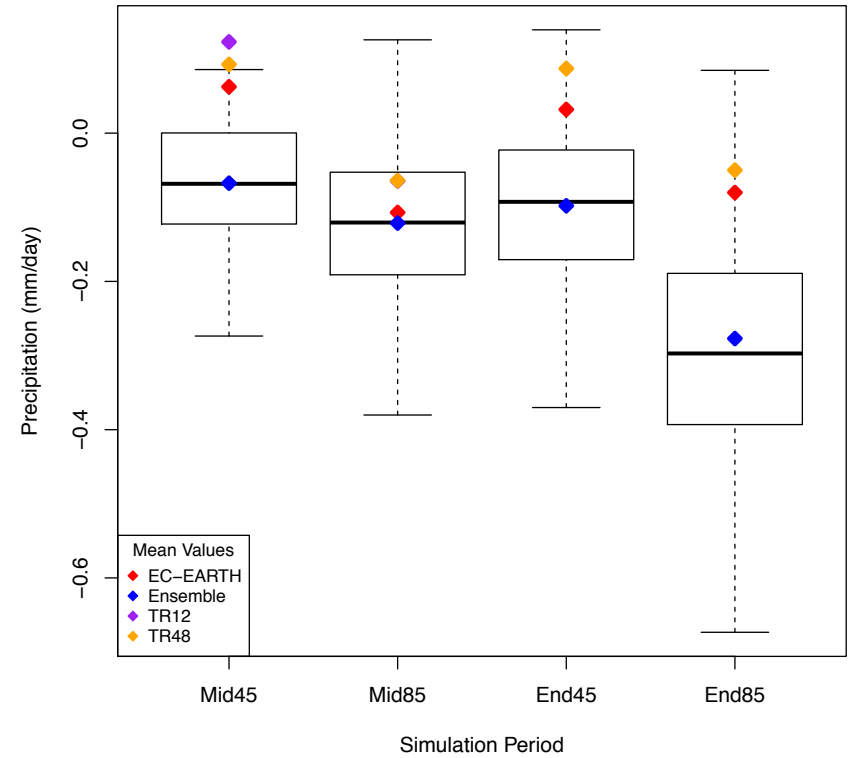
EC-EARTH

Performance Evaluation

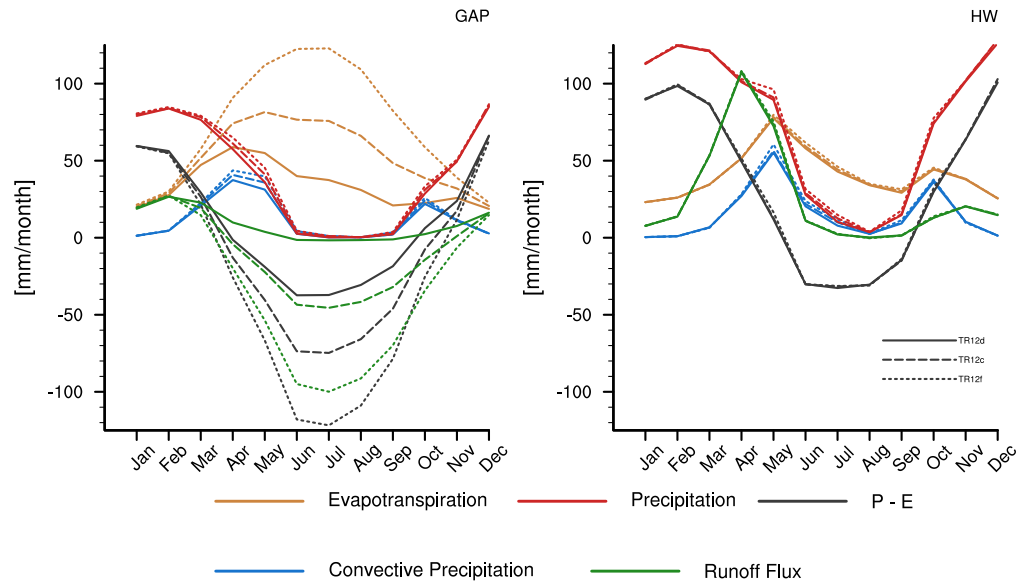
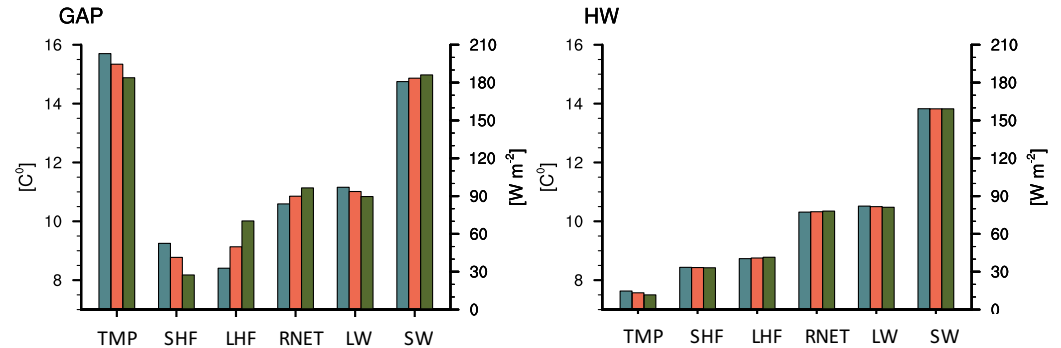
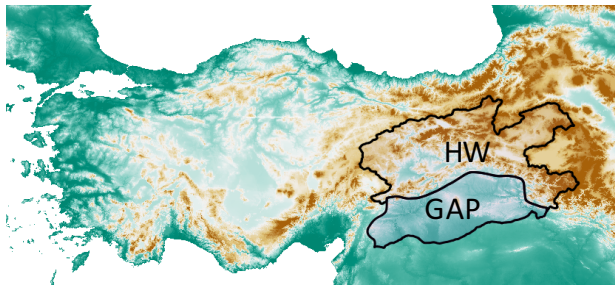
FUTURE-REF (TURKEY)

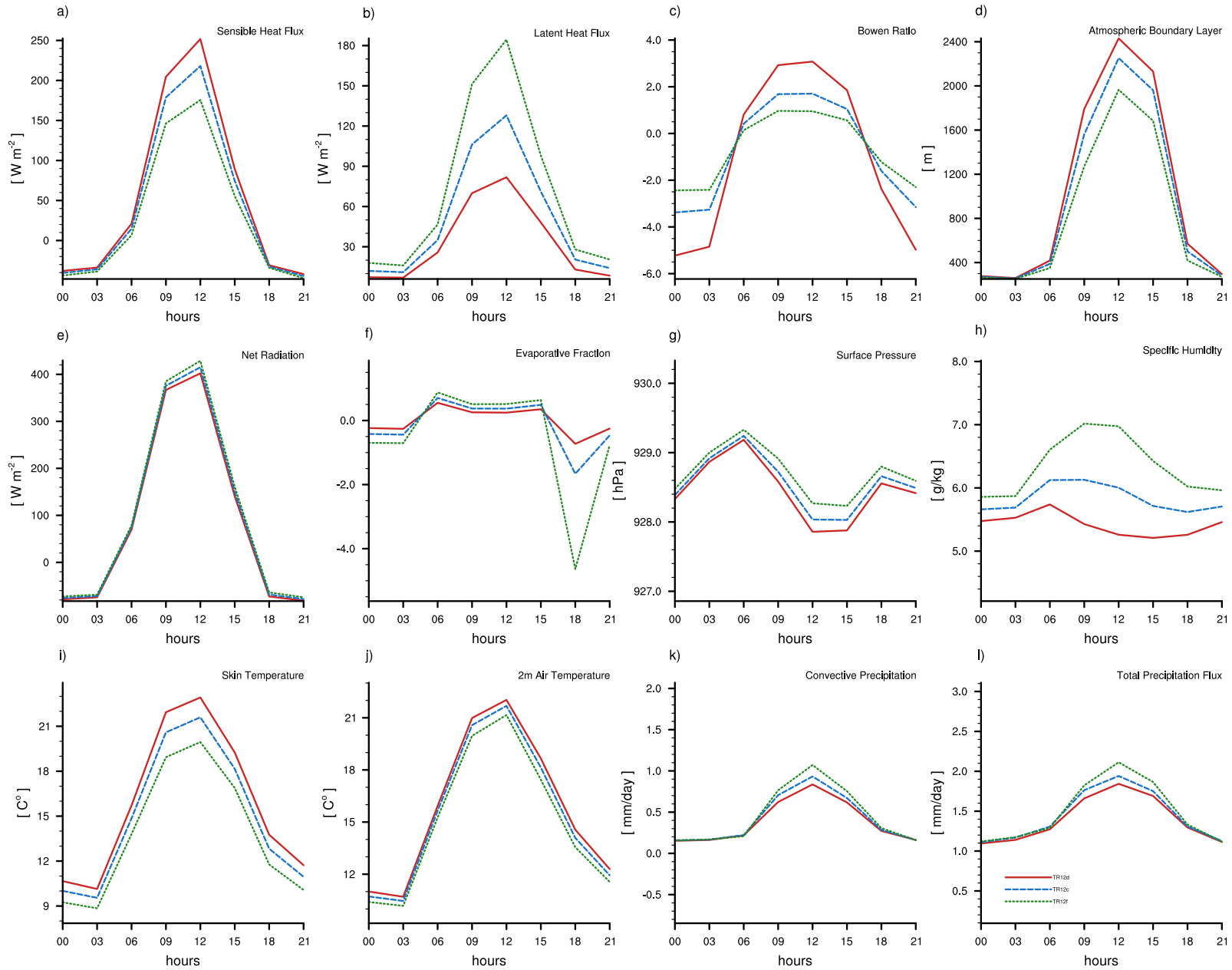


FUTURE-REF (TURKEY)



Effects of LCLU changes on the energy and water budget





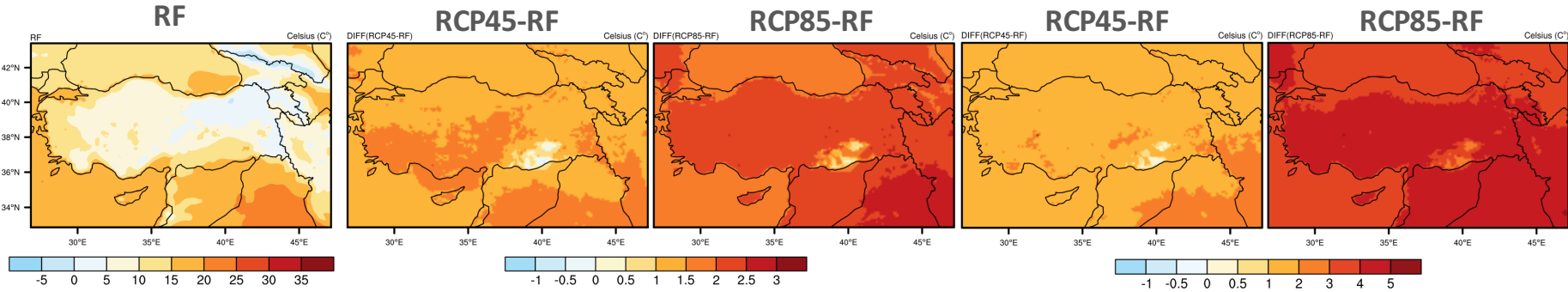
LCLU change + RCPs effect

Non-irrigated

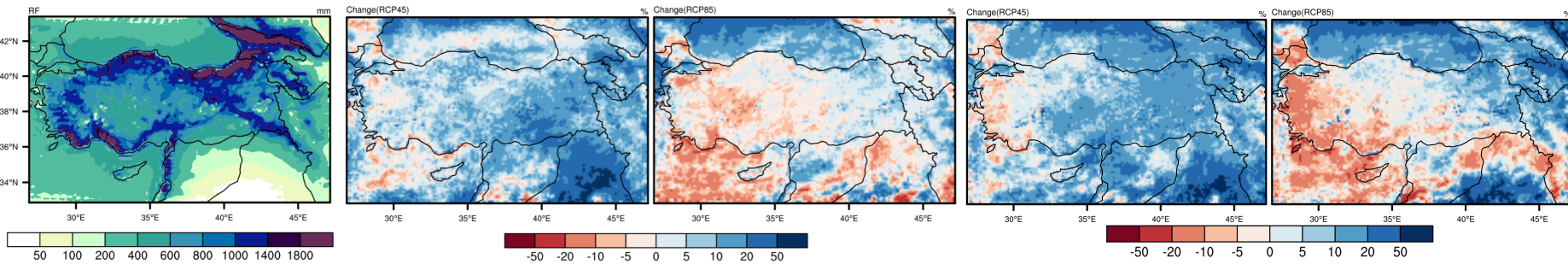
Fully irrigated // Mid-century

Fully irrigated // End-century

Temperature



Precipitation



Evapotranspiration

