Regional Climate Change Modeling: An Application Over The Caspian Sea Basin

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Outline

I. Background and historical information on the Caspian Sea region

II. Phase I: Simulating and understanding present-day multi-decadal variability in CSL changes

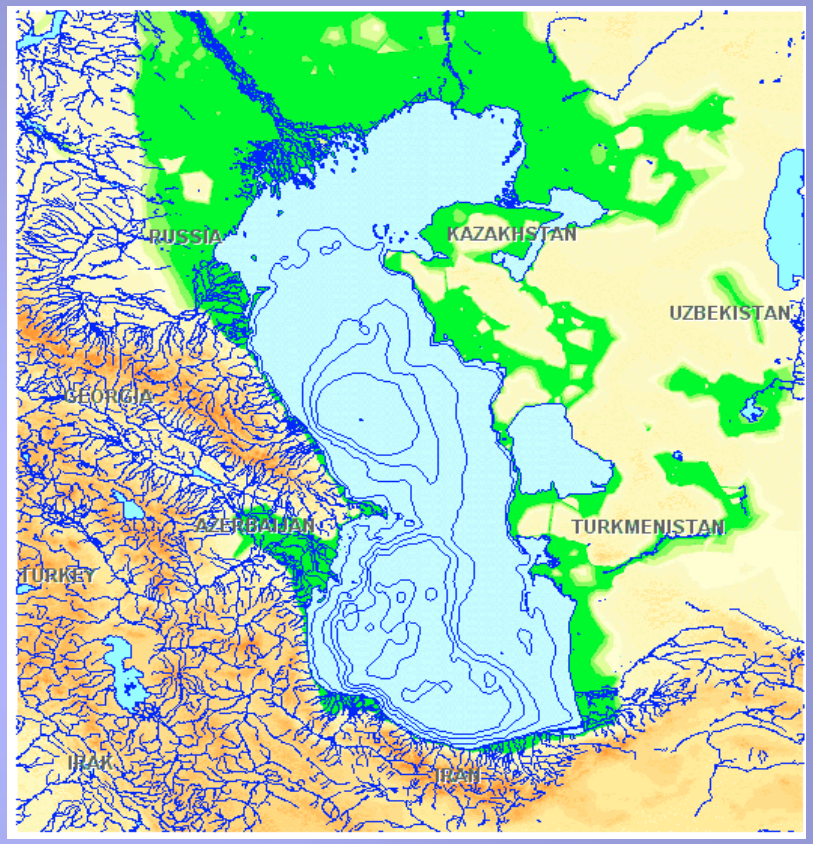
III. Phase II: Simulating future CSL changes in response to climatic changes induced by potential increases in atmospheric GHG concentrations in the 21st century

IV. More projected changes in the CSL for the 21st century based on the latest AOGCMs simulations from the IPCC AR4 project

The Caspian Sea Region

Physical Geography

- Situated between southeastern Europe and Asia.
- The largest enclosed body of water on earth, extends 1200 km N-S and covers ~ 400,000 km^2
- Surrounded by mtns to the south and west, and desert to the east, lowlands to the north
- 130 rivers flow into the sea including the Volga which contributes 80% of total runoff
- Only outflow is into the Kara-Bogaz-Gol Bay to the east



Economics

- Large oil and natural gas reserves
- Large fishing industry (90% of the World's caviar)

Historical Record of Caspian Sea Level (CSL)

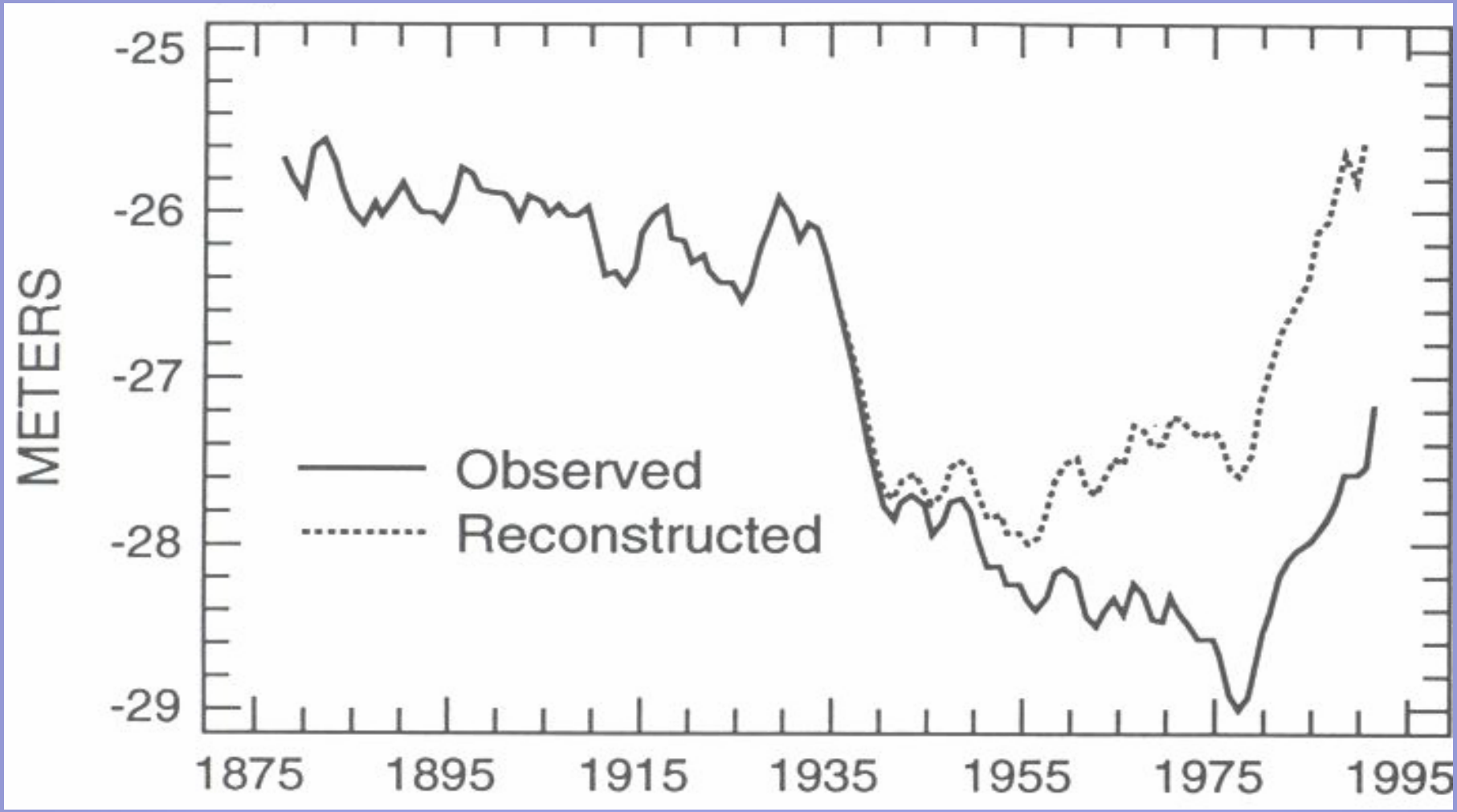


Figure taken from *Global and Regional Climate Interactions: The Caspian Sea Experience*, By **Sergei N. Rodionov**

Previous Work

- **Rodionov, 1994**: comprehensive book addressing the CSL response to climate forcing
- **Panin et al, 1987; Panin et al, 1991:** studied evaporation from Caspian Sea surface, found that a decrease in cyclonic activity reduced wind speeds and thus evaporation over the sea which contributed to the rising Sea level.

Modeling Studies

- **Golitsyn et al, 1995:** evaluated the ability of 13 GCMs to estimate changes in CSL during 1979--88. Found large inter-model variability with high-res. models performing better, however all models tended to significantly overestimate the positive water budget during this period.
- **Arpe, 1999**: Used MPI-ECHAM3 GCM to simulate impacts of increasing GHG on hydrologic cycle over the Caspian basin. Concluded future CSL rise, however, the Caspian Sea was not represented in their model.
- **Mokhov et al, 2003; Mokhov et al, 2005; Meleshko et al, 2003:** Used results of an ensemble of AOGCMs to infer possible changes in the regional hydrological cycle over several basin in Europe and Asia under projected 21st century GHG forcing. Found increase in Volga runoff due to increases in wintertime precipitation.

Goals of Phase I

- Simulate the water balance over the Caspian Sea basin and corresponding changes in the CSL using a regional climate model.

  - perform a 40-year simulation for the period 1950 to 1990
  - validate model performance using observed data
  - develop water balance equation to estimate annual changes in the sea's level

- Evaluate differences in regional climatology before and after 1977 rise to better understand the present day atmospheric processes that affect the CSL
- If successful in present day simulation, continue with Phase II of project to study the impacts of future climate change on the Caspian Sea.

Experimental Design – Model Configuration

Regional Climate Model **RegCM**

- BATS land surface model
- Zeng ocean flux parameterization
- Grell cumulus scheme
- SUBEX large-scale precip

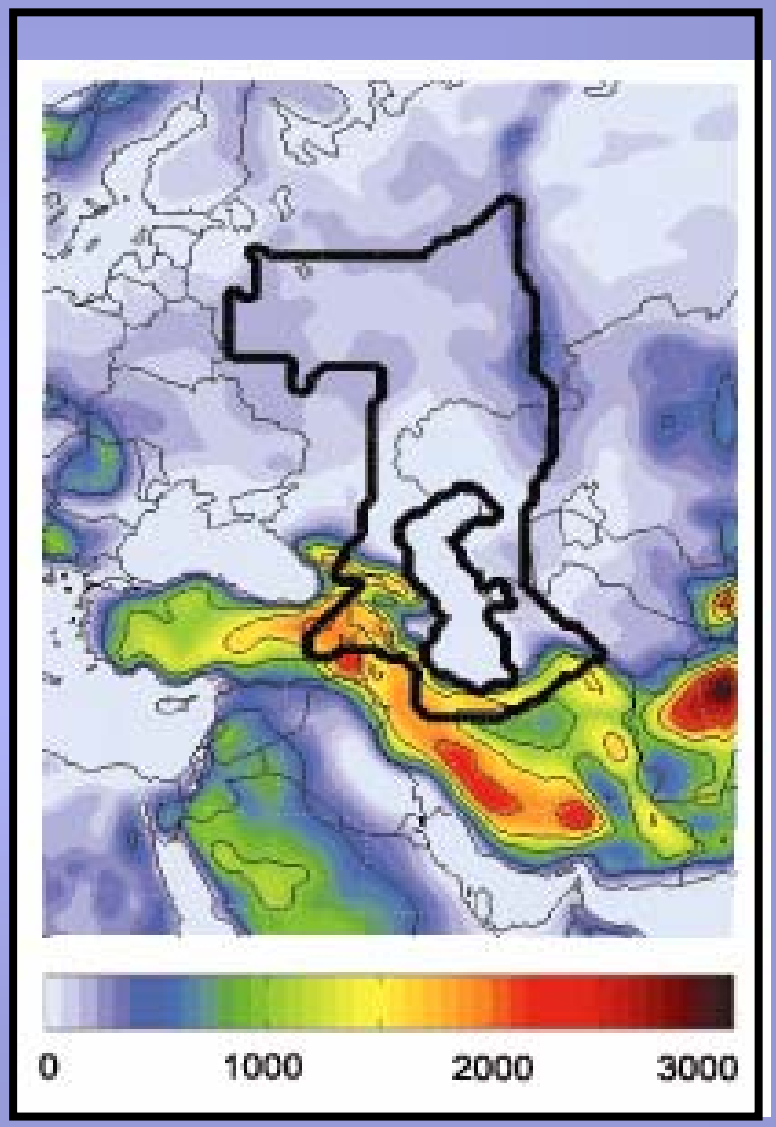
Model Domain

- latitude: ~22°N - 69°N
  longitude: ~7°E – 85°E
- 50 km horizontal grid spacing, 18 vertical levels

42-year simulation: 1948-1990

- Initial and boundary conditions are prescribed by the NCEP Reanalysis datasets. Sea surface temperatures are prescribed by the Hadley Center's GISST monthly dataset

RegCM Domain



Observations used for validating model Temp, Precip and Evap

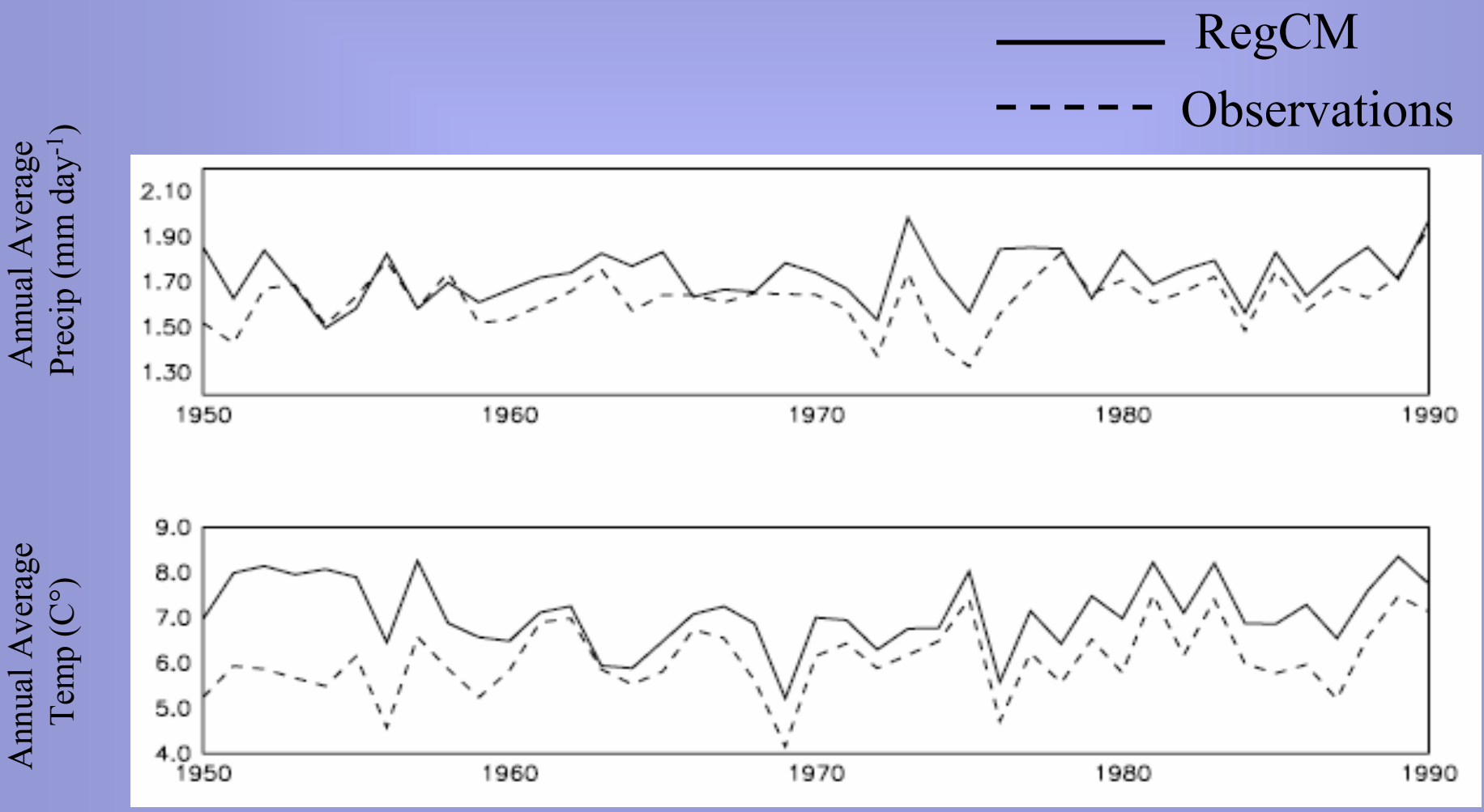
- Global half degree monthly precipitation and surface temperature datasets of Willmott and Matsuura (2001).

  **We apply a rain-gage correction factor to the precipitation dataset as estimated by Legates and Willmott (1990).*

  ***No reliable data over the sea*

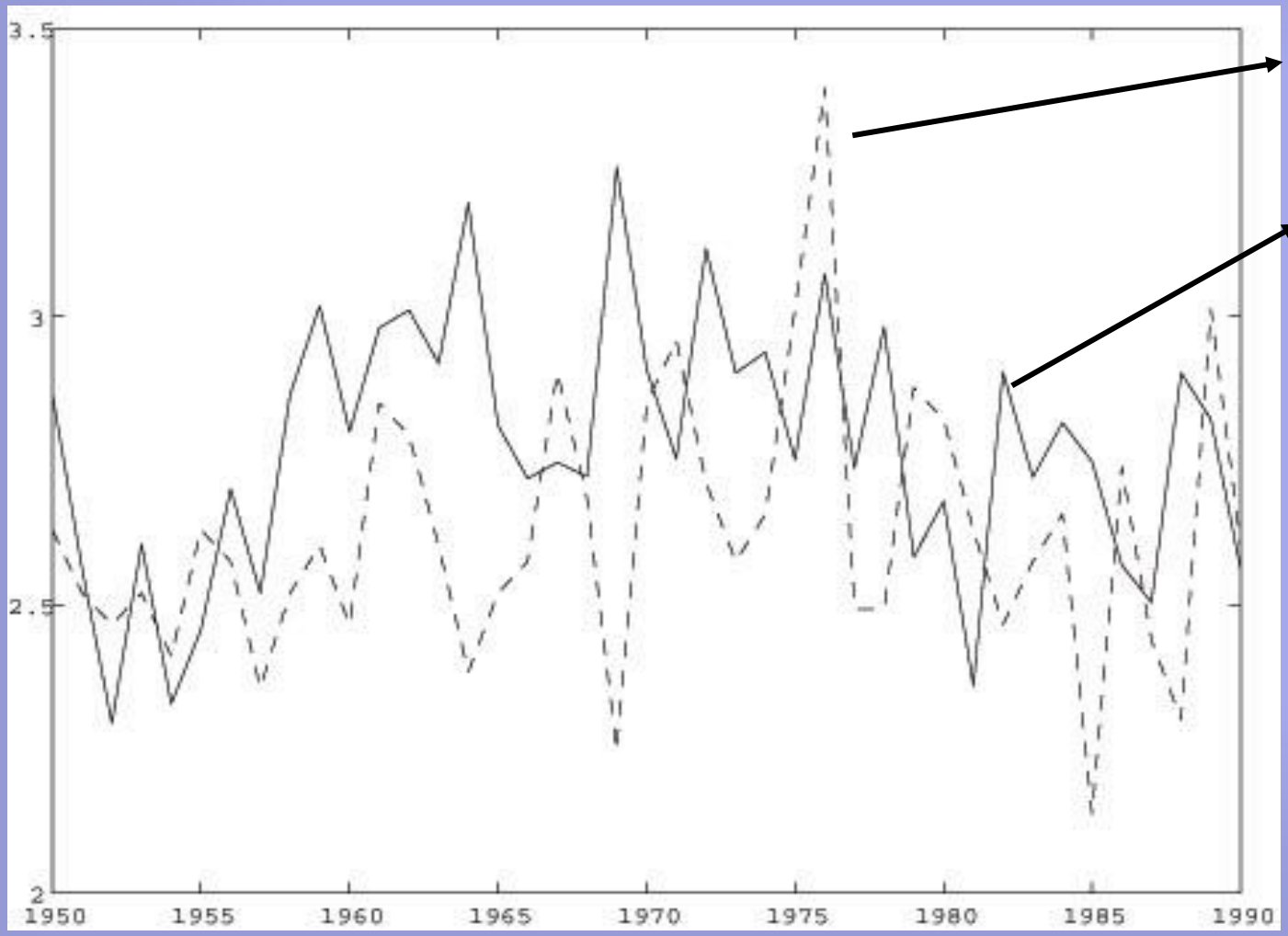
- Rodionov's (1994) estimates of over-sea evaporation calculated as residuals in the Sea's water balance are compared to the model simulated values of evaporation over the Sea.

Observed and modeled annual basin-wide averaged precipitation and temperature (1950—1990)



Elguindi and Giorgi, 2006: Climate Dynamics, 26:167-181

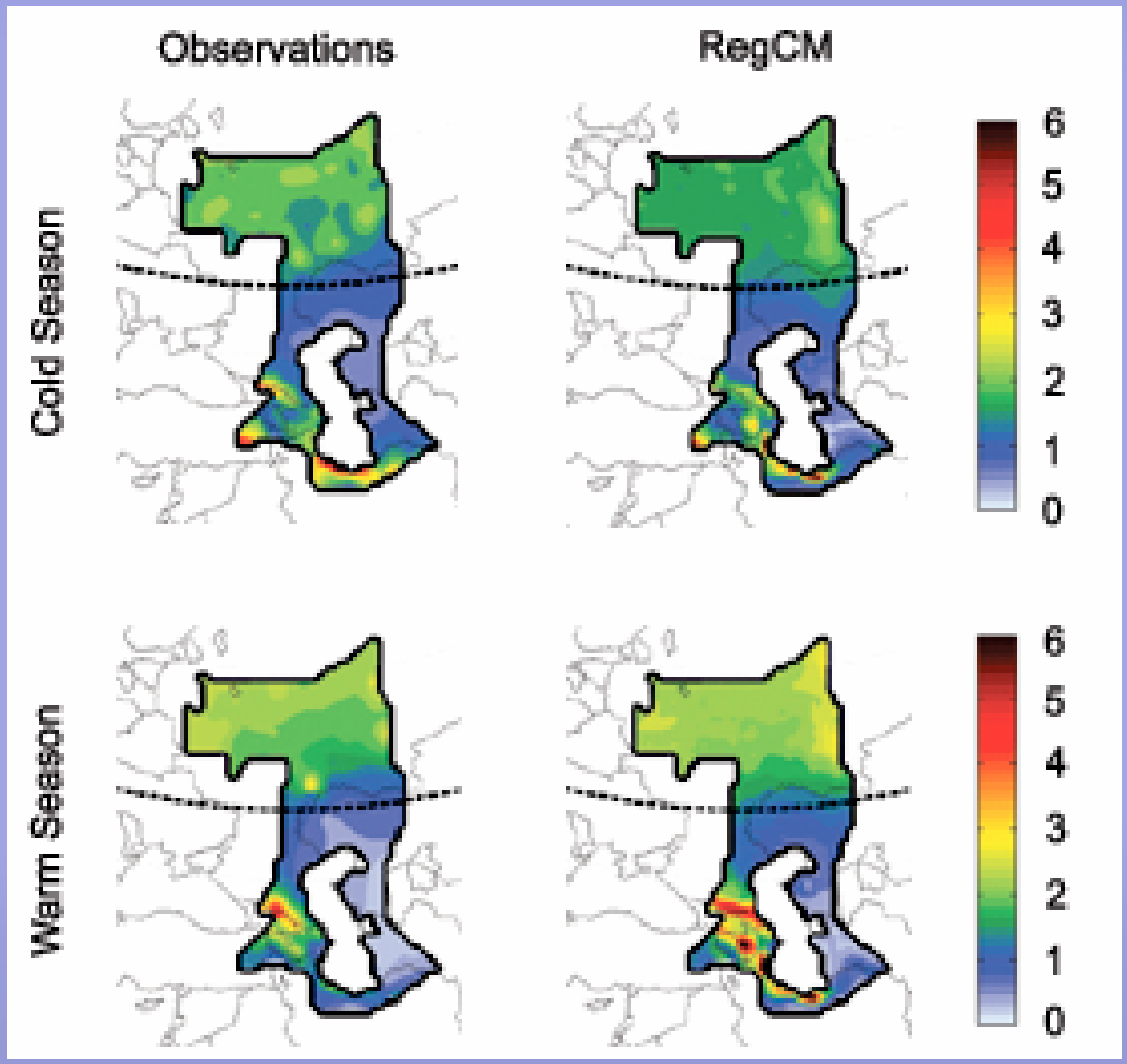
Evaporation over the Sea



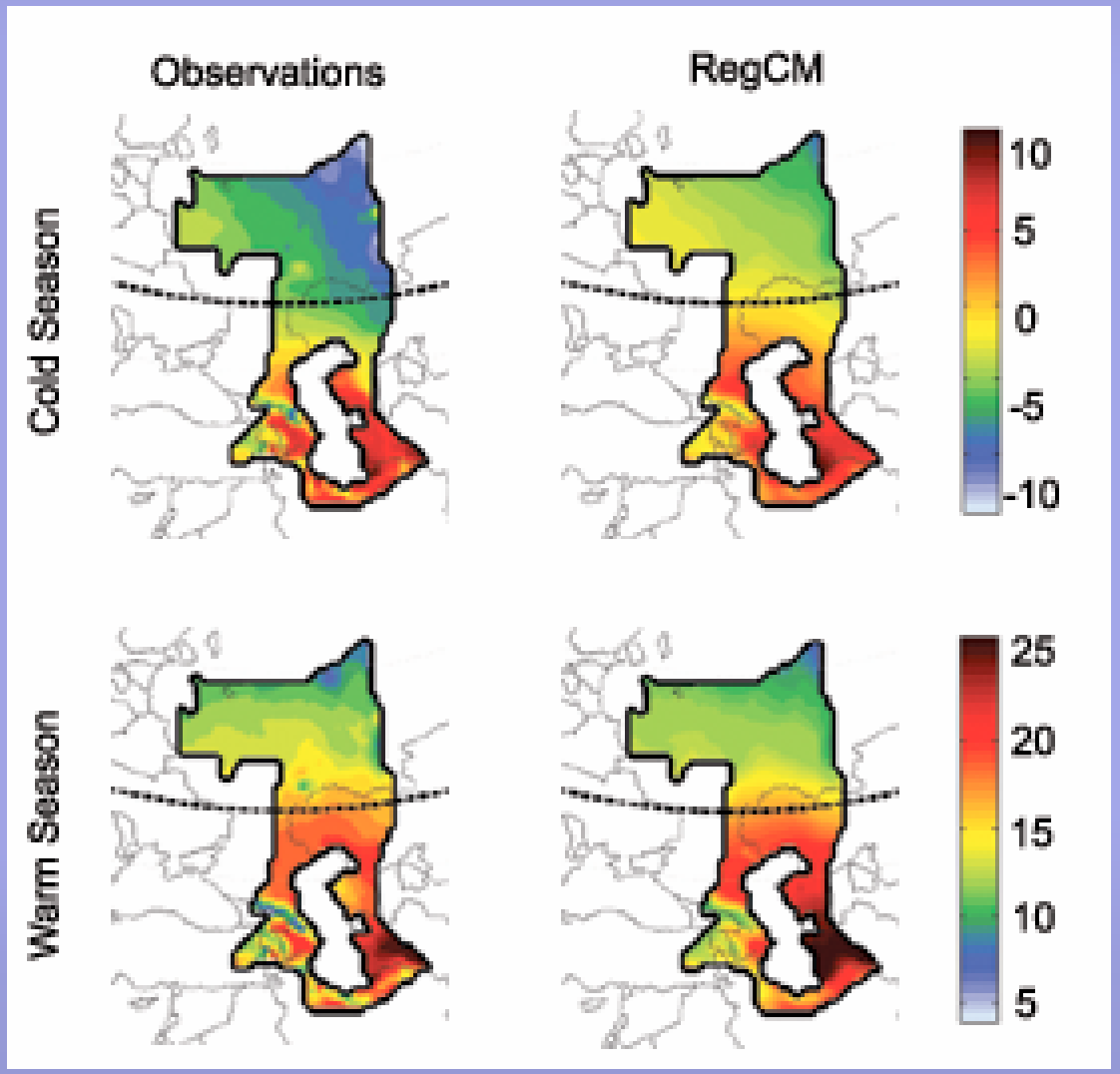
Estimates calculate
As residuals of water
balance (provided
by Rodionov)

Simulated

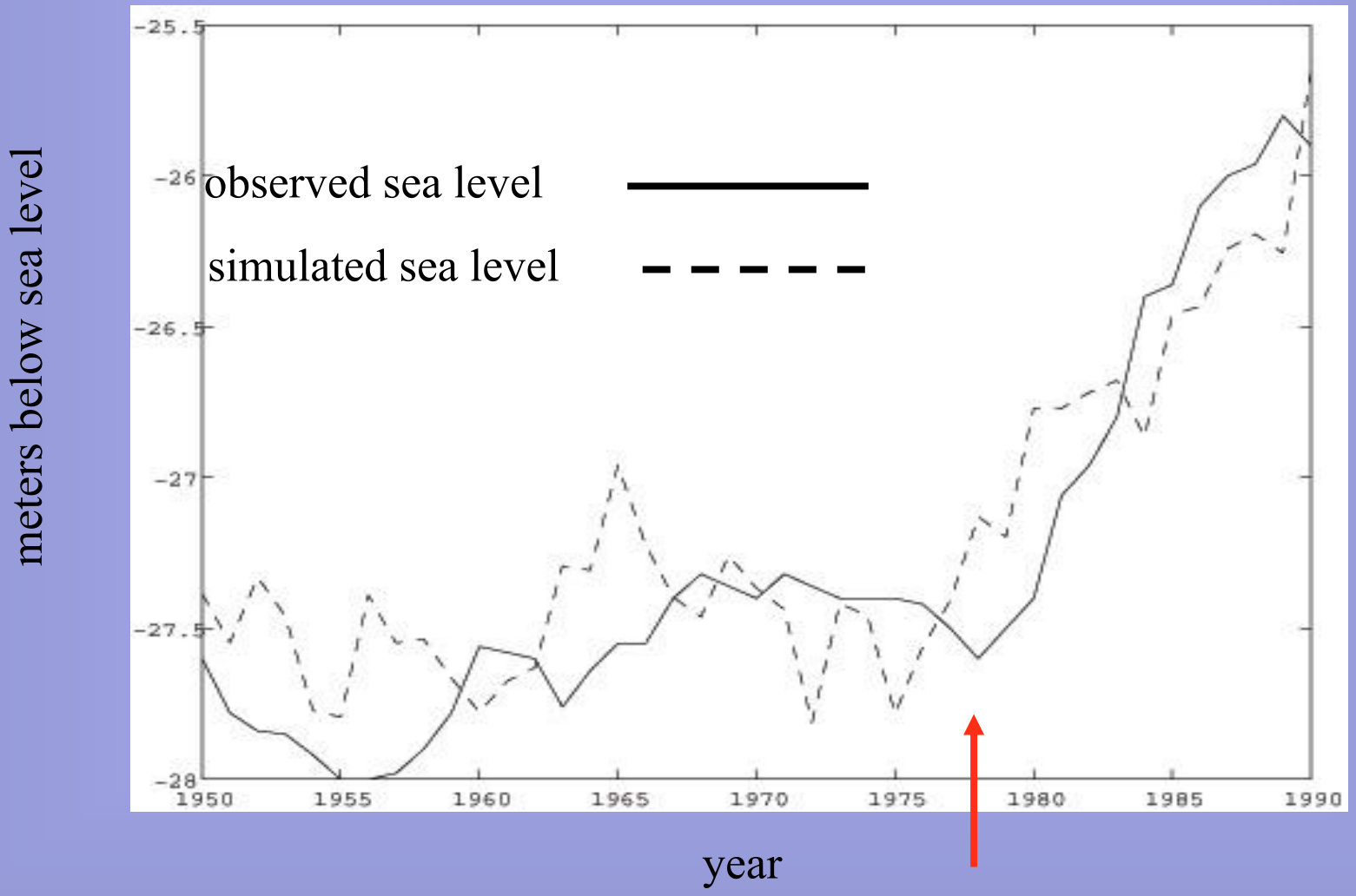
Precipitation (mm day^{-1})
1950—1990 Climatology



Surface Temperature (°C)
1950—1990 Climatology

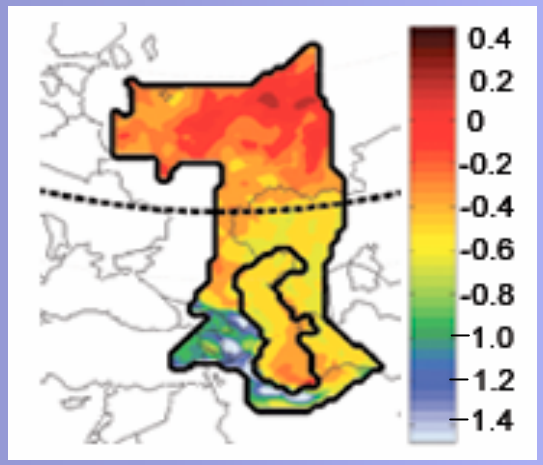


Simulated and Observed CSL annual variability

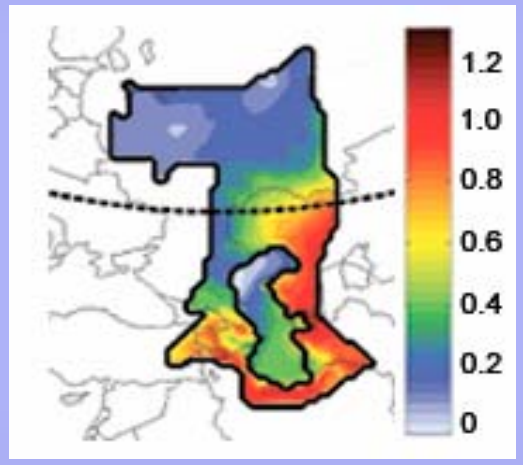


Post-1977 rise climatology **minus** Pre-1977 rise climatology (annual averages)

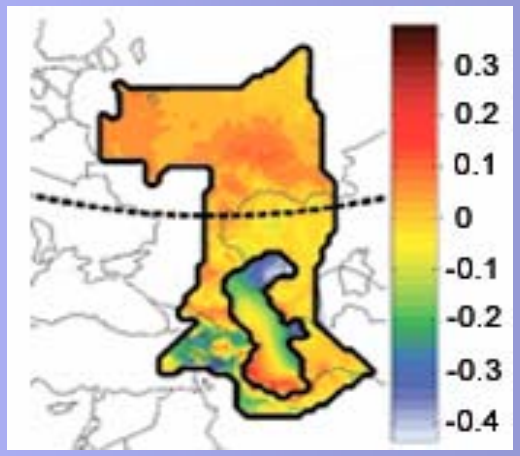
Precipitation (mm day^{-1})



Temperature (^{o}C)



Evaporation (mm day^{-1})



* Dashed line represents 50^{o} N latitude

Post-rise Climatology minus Pre-rise Climatology

Differences between climatologies before and after the 1977 rise of water budget components from northern basin (NL), southern basin (SL), and sea expressed as contributions to annual **ΔCSL** in centimeters.

P = precipitation; E = evapotranspiration

	P_{NL}	P_{SL}	P_{Sea}	E_{NL}	E_{SL}	E_{Sea}	$P\text{-}E_{NL}$	$P\text{-}E_{SL}$	$P\text{-}E_{Sea}$
Cold	2.8	3.8	2.9	0.3	2.2	7.7	2.5	1.6	-4.8
Warm	35.6	-20.2	-1.5	10.4	-9.9	-15.6	25.2	-10.3	14.1
Year	19.2	-8.2	0.7	5.3	-3.9	-4.0	13.8	-4.4	4.7

Phase I Summary

- RegCM can be used to simulate the hydrologic balance of the Caspian Sea basin. We are currently performing some future scenario simulations over the Caspian Sea basin.
- Our results support the argument that the flucuations in the CSL are in response to changes in the regional climate of the basin (at least with regard to the post-1977 rise).
- The CSL rise after 1977 was due to changes in the climate during the warm season which led to increases in precip in the northern basin and decreases in evaporation over the sea, resulting in an increase in the overall surplus in the basin's water budget.

Phase II

Using a Regional Climate Model to predict what will happen to the Caspian Sea level (CSL) in the next 100 years under projected greenhouse gas (GHG) and aerosol forcings….

Experimental Design

- Perform two 30-year RegCM simulations over the Caspian Sea basin; one for the present day (1961—1990) and one for future climatic conditions (2071—2100) under specified GHG forcing (A2 scenario).
- Boundary conditions are provided by corresponding time slice experiments carried out with the NASA/NCAR global atmospheric model, FVGCM/CCM 3 (Coppola and Giorgi, 2005).
- Analyze differences between the two simulations to determine how possible changes in the regional climatology of the Caspian Sea basin affect the basin's hydrologic balance and corresponding changes in the CSL.

Water Balance Equation

$$\Delta CSL = (A_L/A_S)\,[\,(P_L(1-fl) - E_L)] + (P_S - E_S - D)$$

ΔCSL = annual change in lake level

(A_L/A_S) = ratio of basin land area to lake area = 6.35

P_L = precip over land in the basin

E_L = evapotranspiration over land in basin

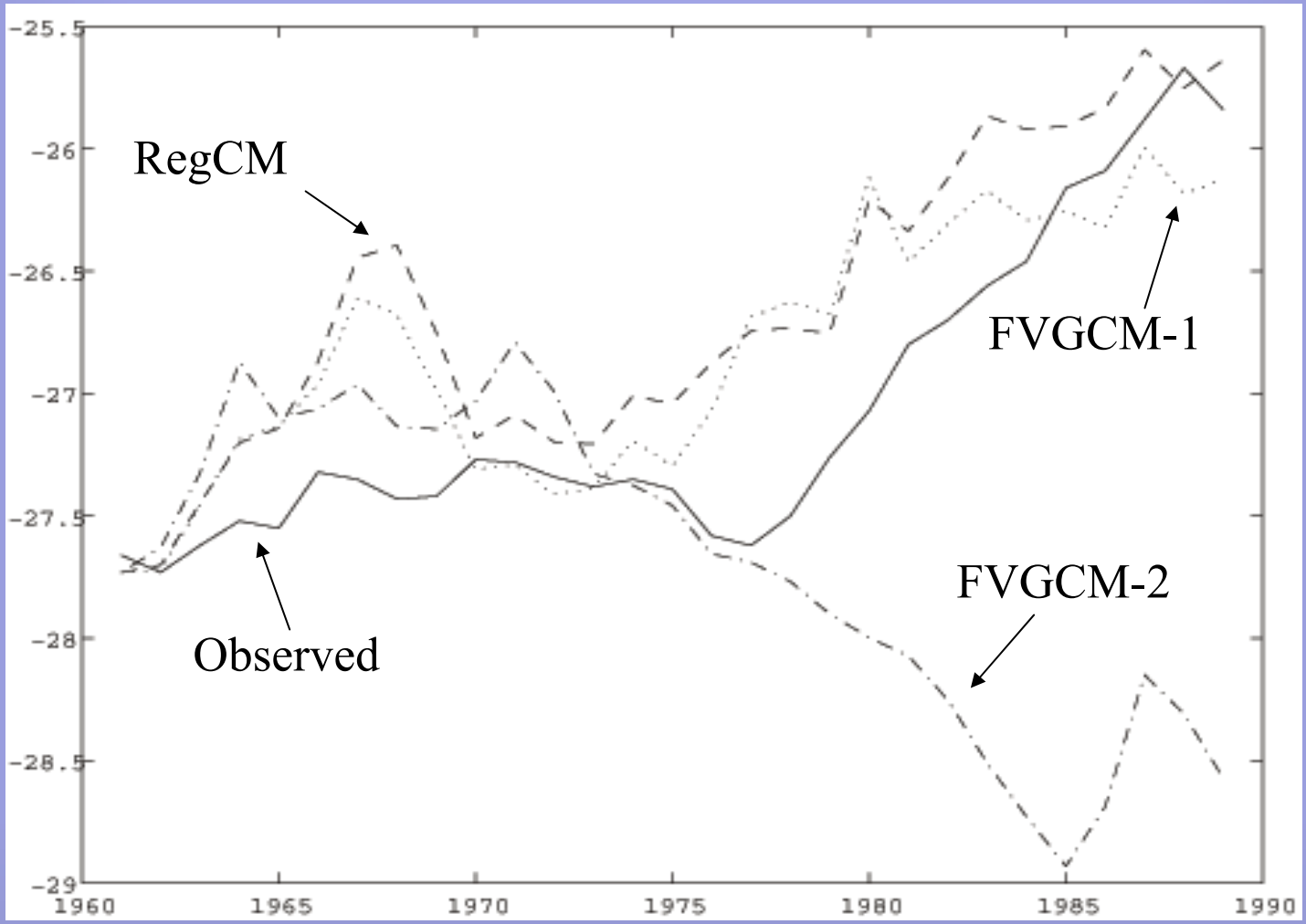
P_S = precip over sea

E_S = precip over sea

D = discharge out of sea (Kara-Bogaz-Gol) = 3 cm yr^{-1} of sea's layer except in 1980's

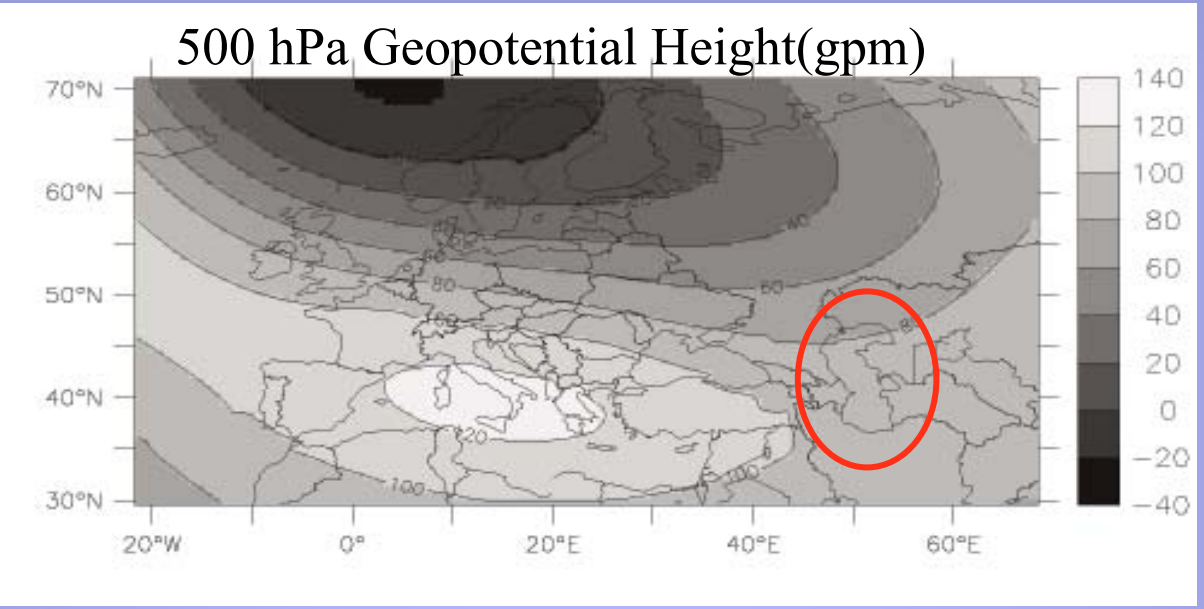
fl = fraction of ''lost'' over land precipitation due to actual evaporation from rivers, the Volga delta, and ephemeral reserviors of water or groundwater storage, ect.
We estimate this fraction to be about 10% which is consistent with the literature.

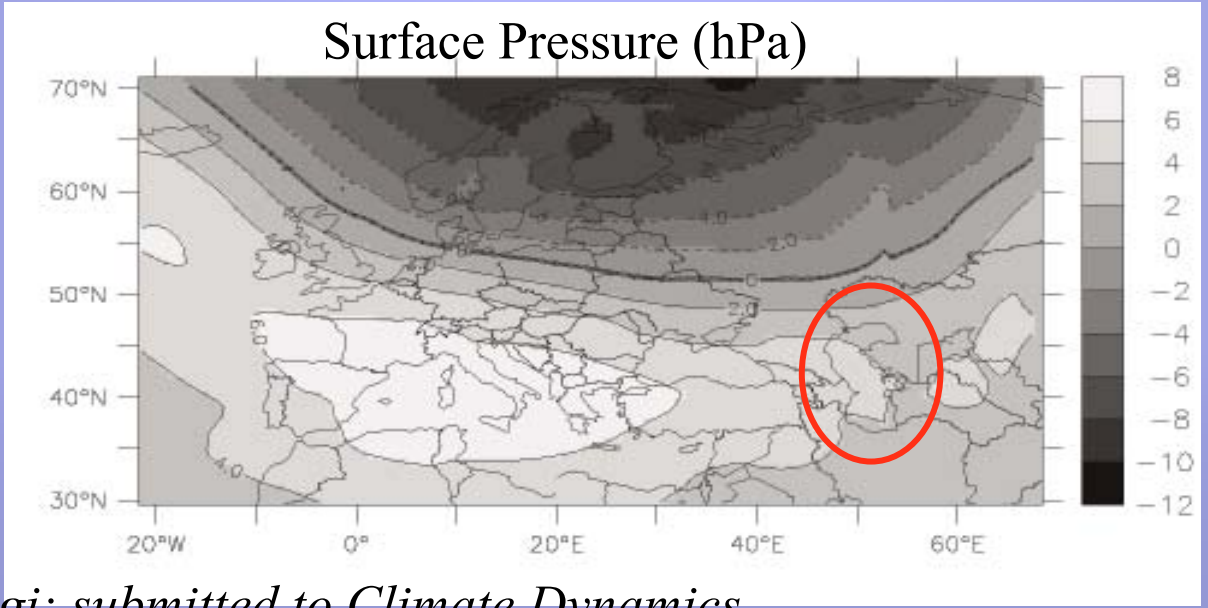
Simulated and Observed CSL annual variability for present day (1961—1990)



So how does the future climate compare with the present-day climate? .....

Future Climate (2071—2100) **minus** Present Climate (1961—1990)
(Dec-Jan-Feb averages)



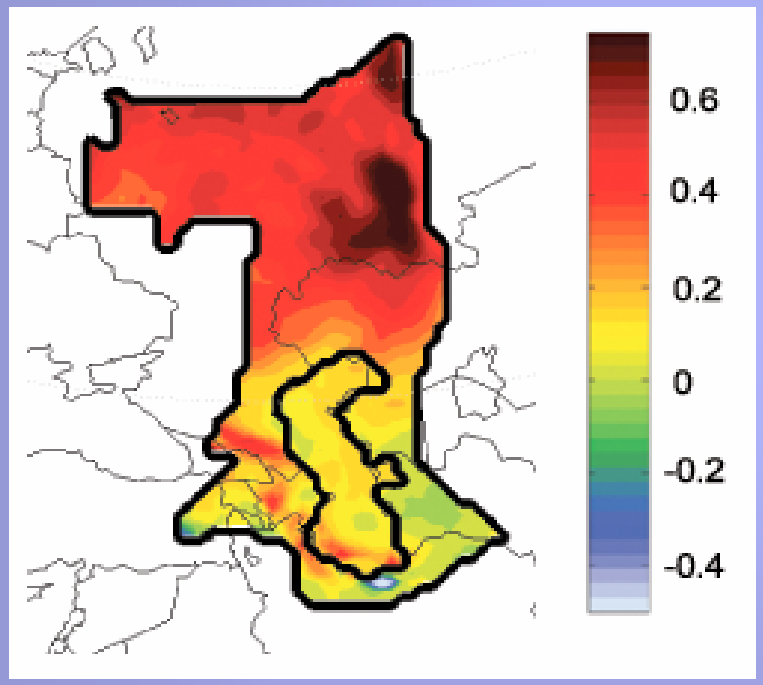


Elguindi and Giorgi: submitted to Climate Dynamics

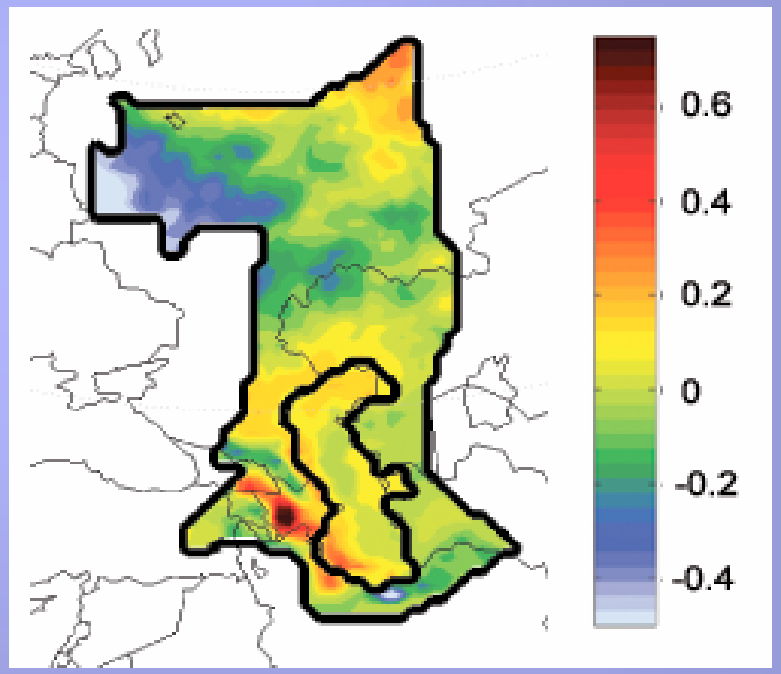
Precipitation (mm day^{-1})

Future Climate (2071—2100) **minus** Present Climate (1961—1990)

Cold Season (Oct-Mar)



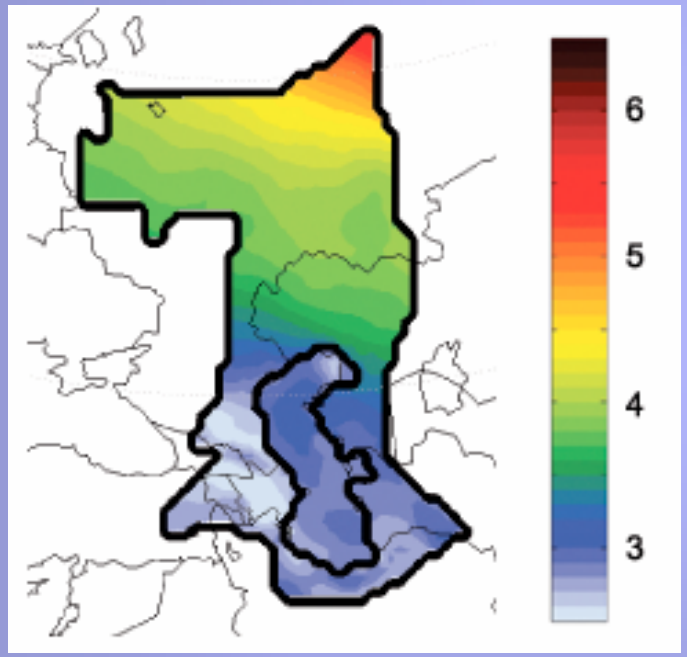
Warm Season (Mar-Sept)



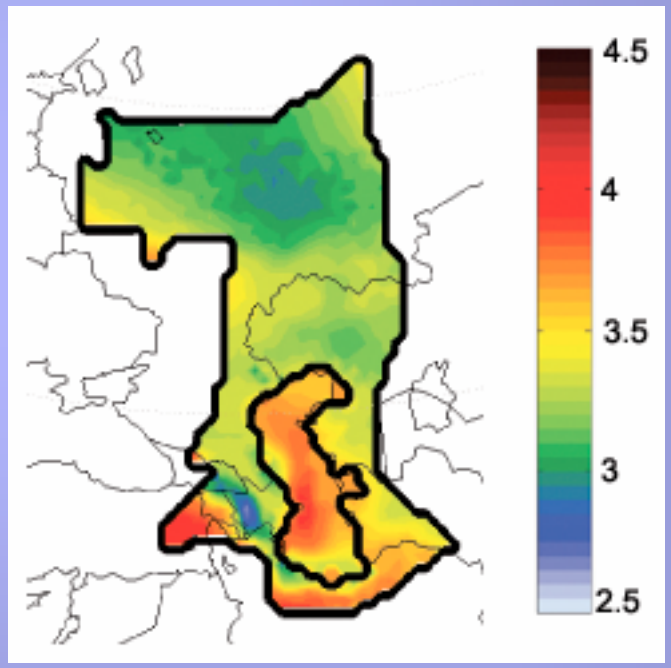
Temperature (°C)

Future Climate (2071—2100) **minus** Present Climate (1961—1990)

Cold Season (Oct-Mar)



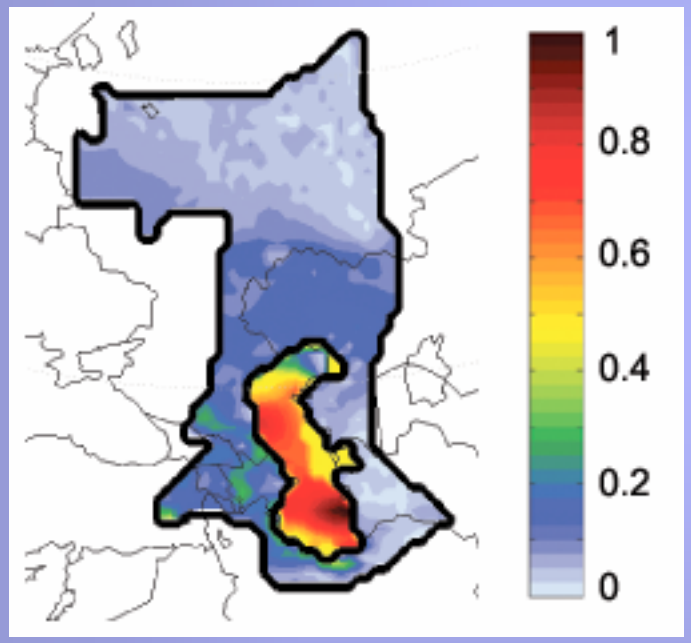
Warm Season (Mar-Sept)



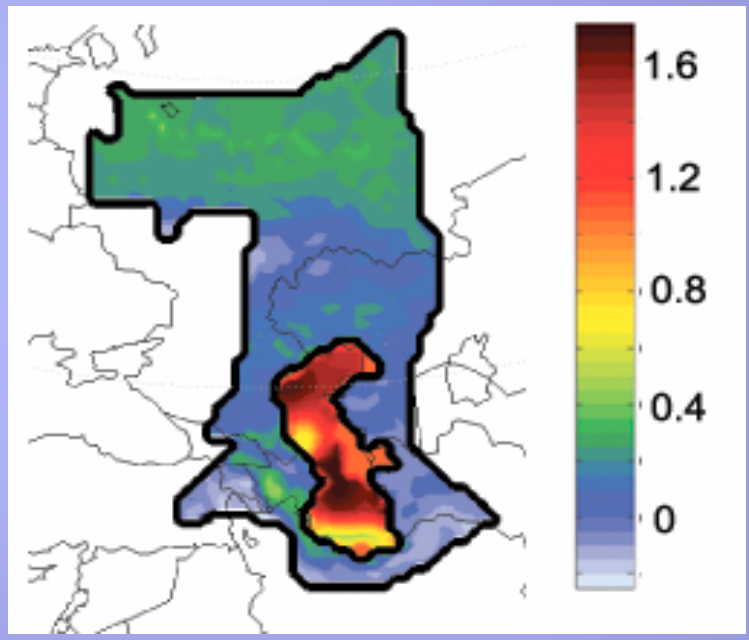
Evapotranspiration (mm day^{-1})

Future Climate (2071—2100) **minus** Present Climate (1961—1990)

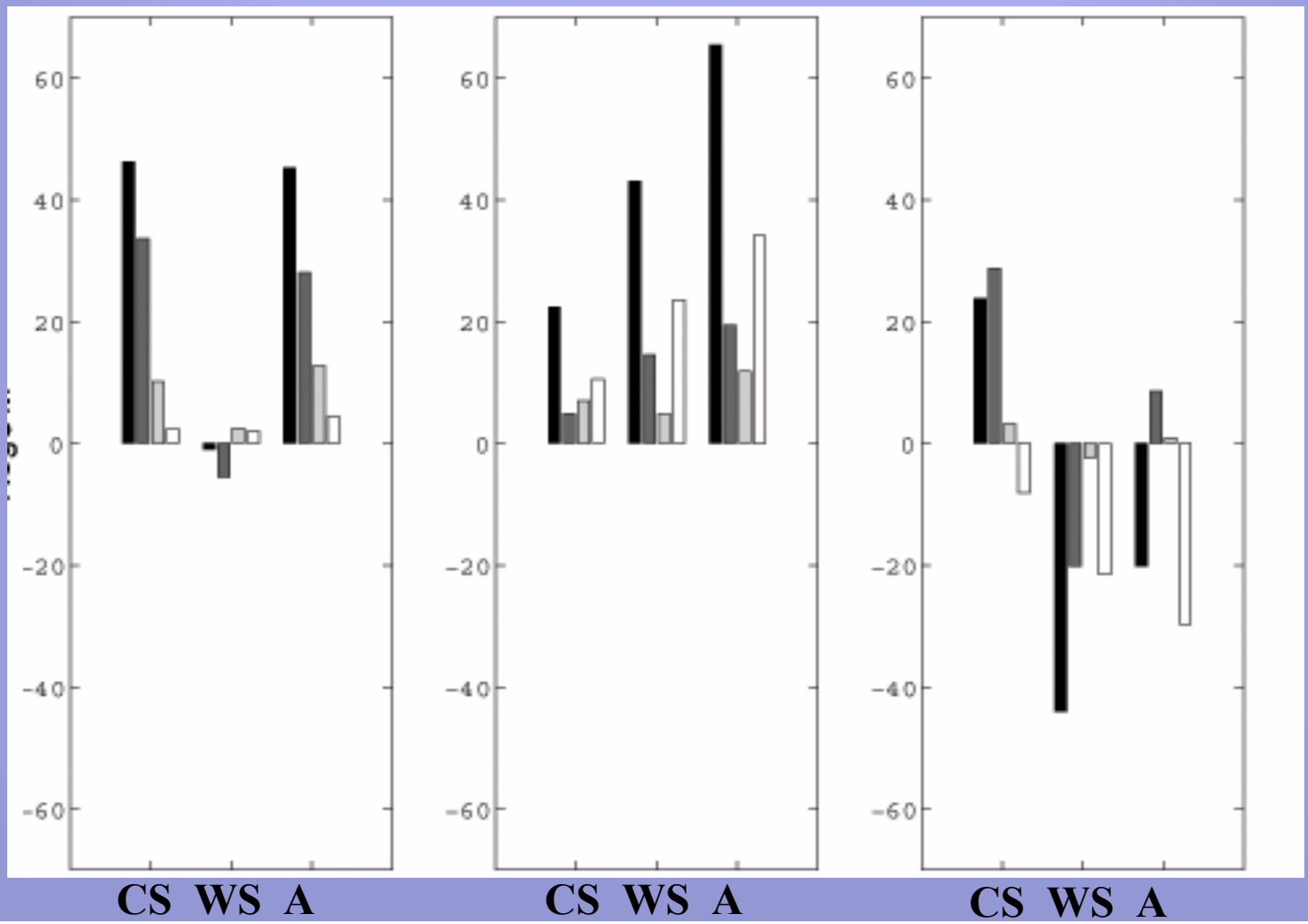
Cold Season (Oct-Mar)



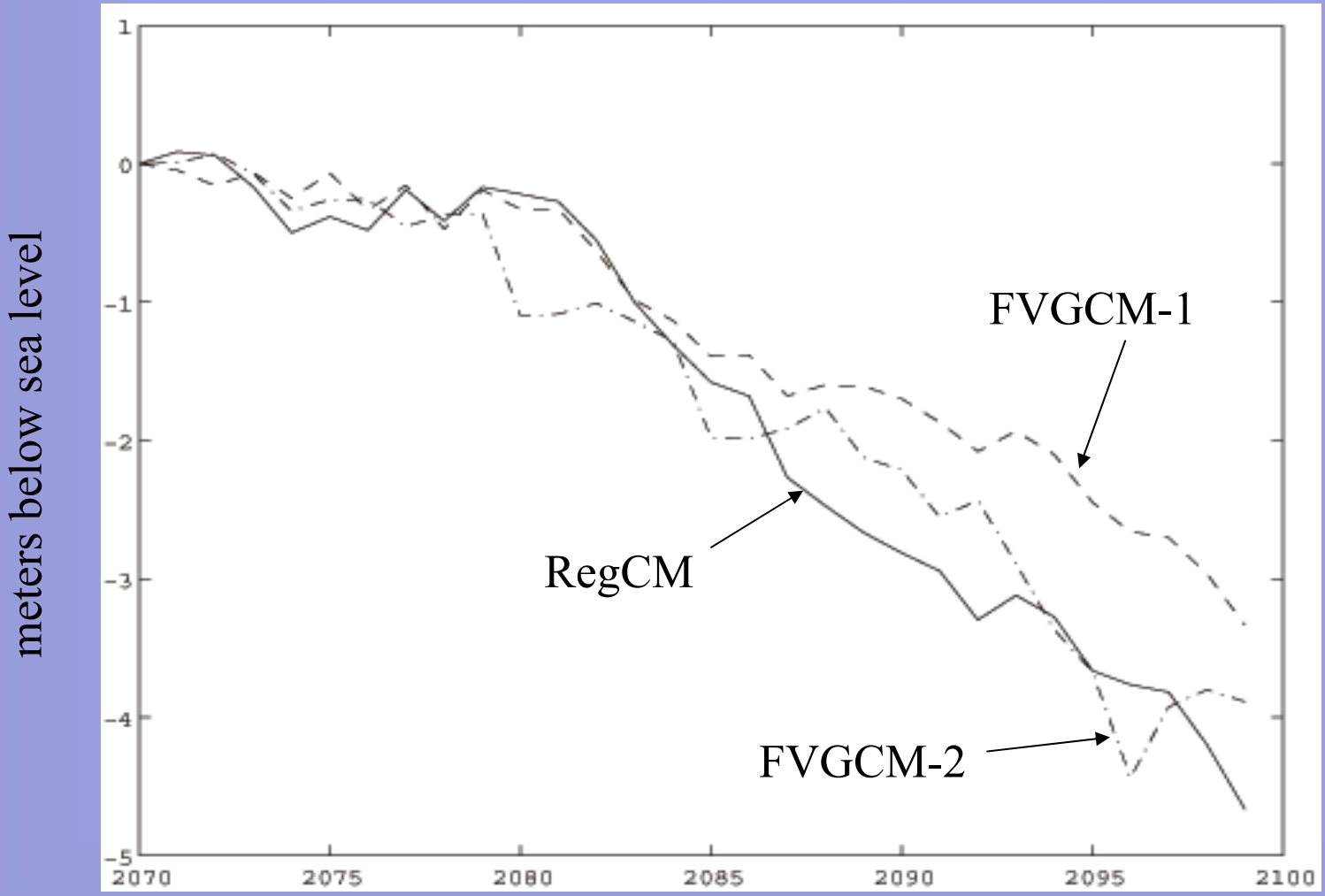
Warm Season (Mar-Sept)



Differences between future and present day climatologies in average water budget components expressed in contribution to sea level change (cm year^{-1}) for the whole basin (black bars), northern basin (dark gray bars), southern basin (light gray bars) and sea (white bars) for the cold season (CS), warm season (WS) and annually (A).



Accumulated changes in CSL (m) calculated from future climate simulations (2070—2100)



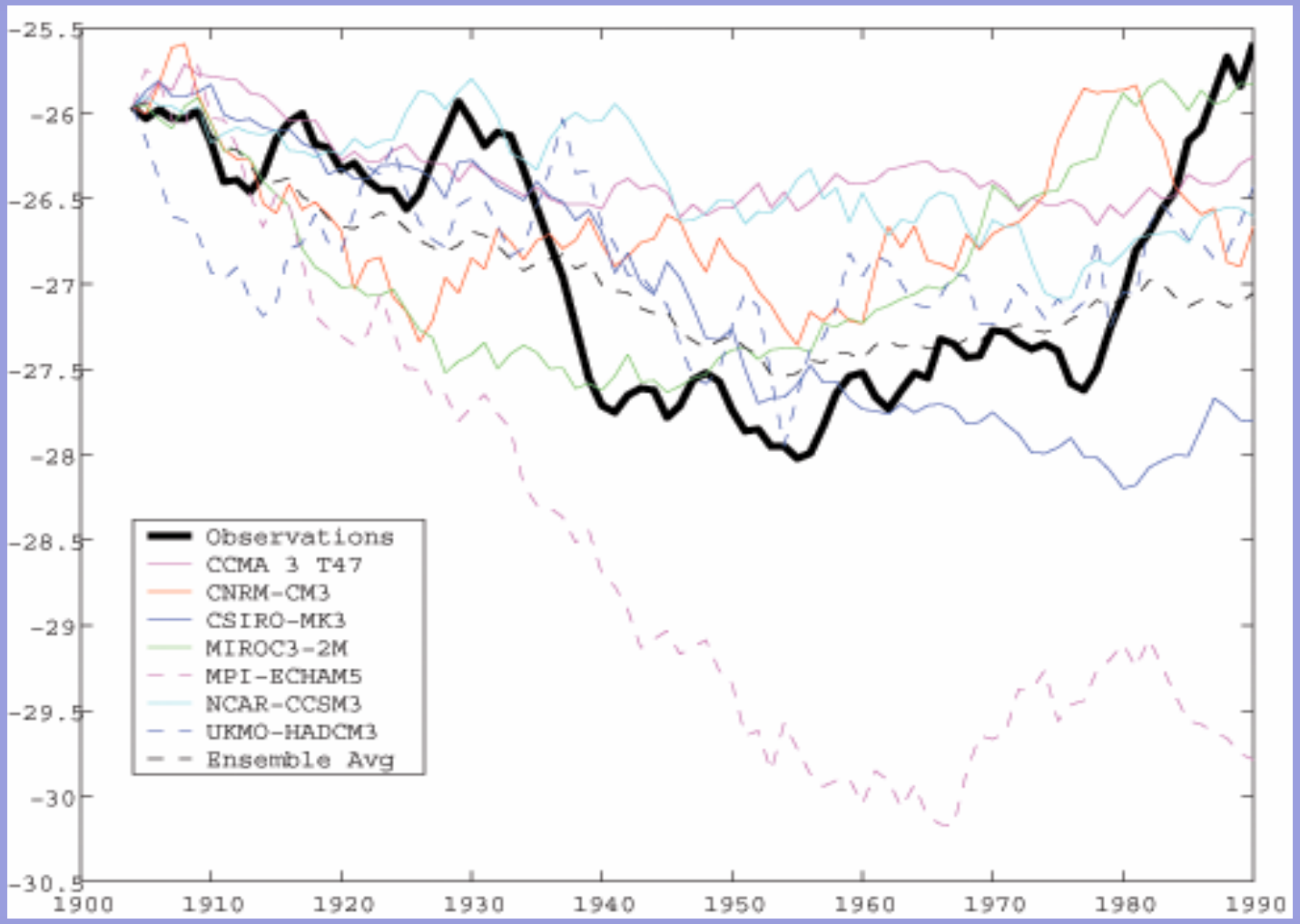
Phase II Summary

- Precipitation increases in the northern basin, especially in the cold season- consistent with other studies-more NAO shift in storm tracks.
- However, there is a substantial decrease in the CSL mainly due to the increase in evaporation over the sea's surface

Uncertainties

- Only single GCM and RCM scenario
- Sea surface temperatures were specified by the driving GCM. A coupled lake model would allow for air-sea interactions and feedbacks which might modify evaporation from the sea and improve simulation.
- The area of the Sea is held constant, however, the actual sea area changes as the sea level changes.

What do the IPCC AR4 multilple GCM simulations predict? .....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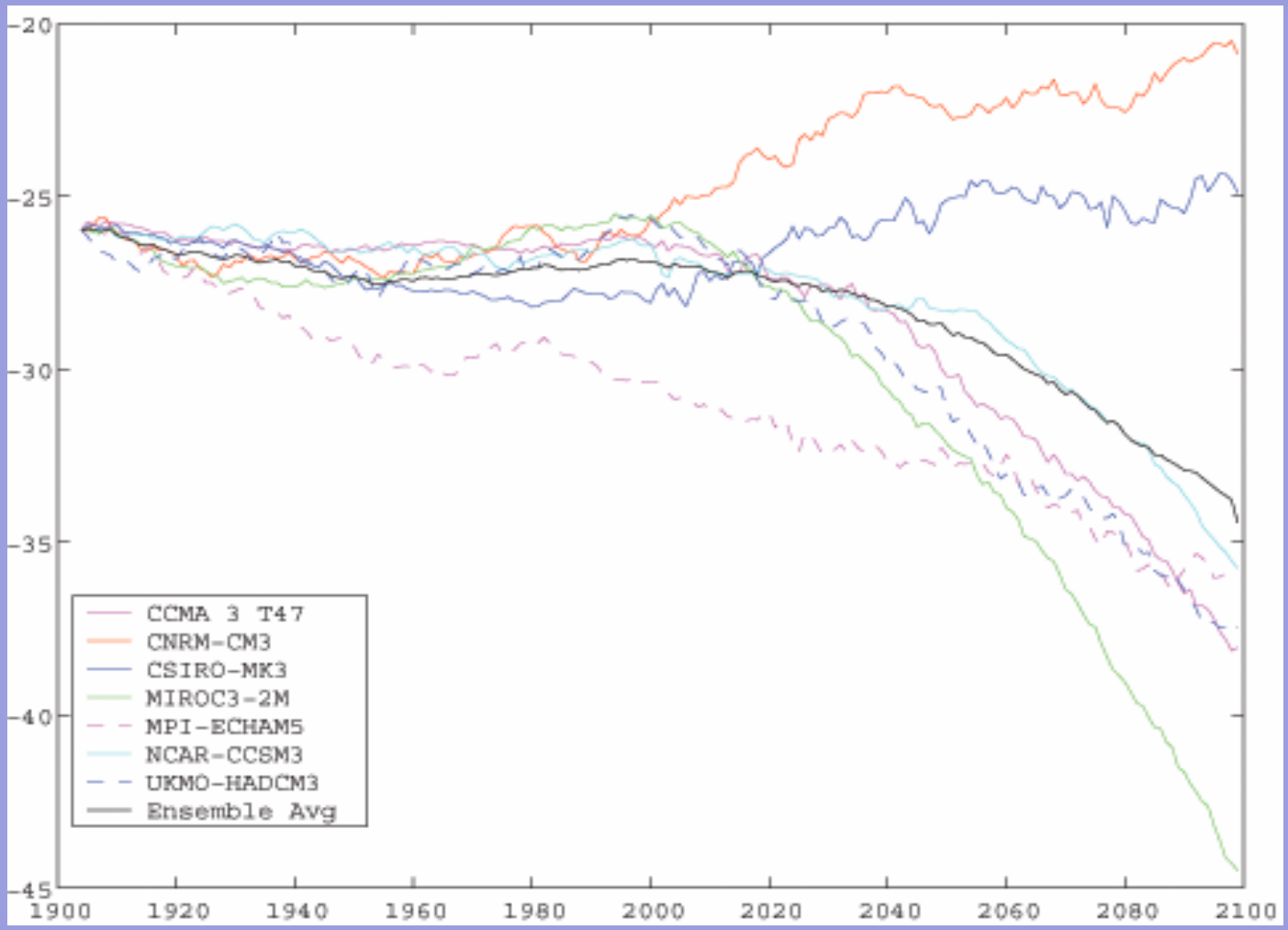
MPI-ECHAM5
NCAR-CCSM3
UKMO-HADCM3
Ensemble Avg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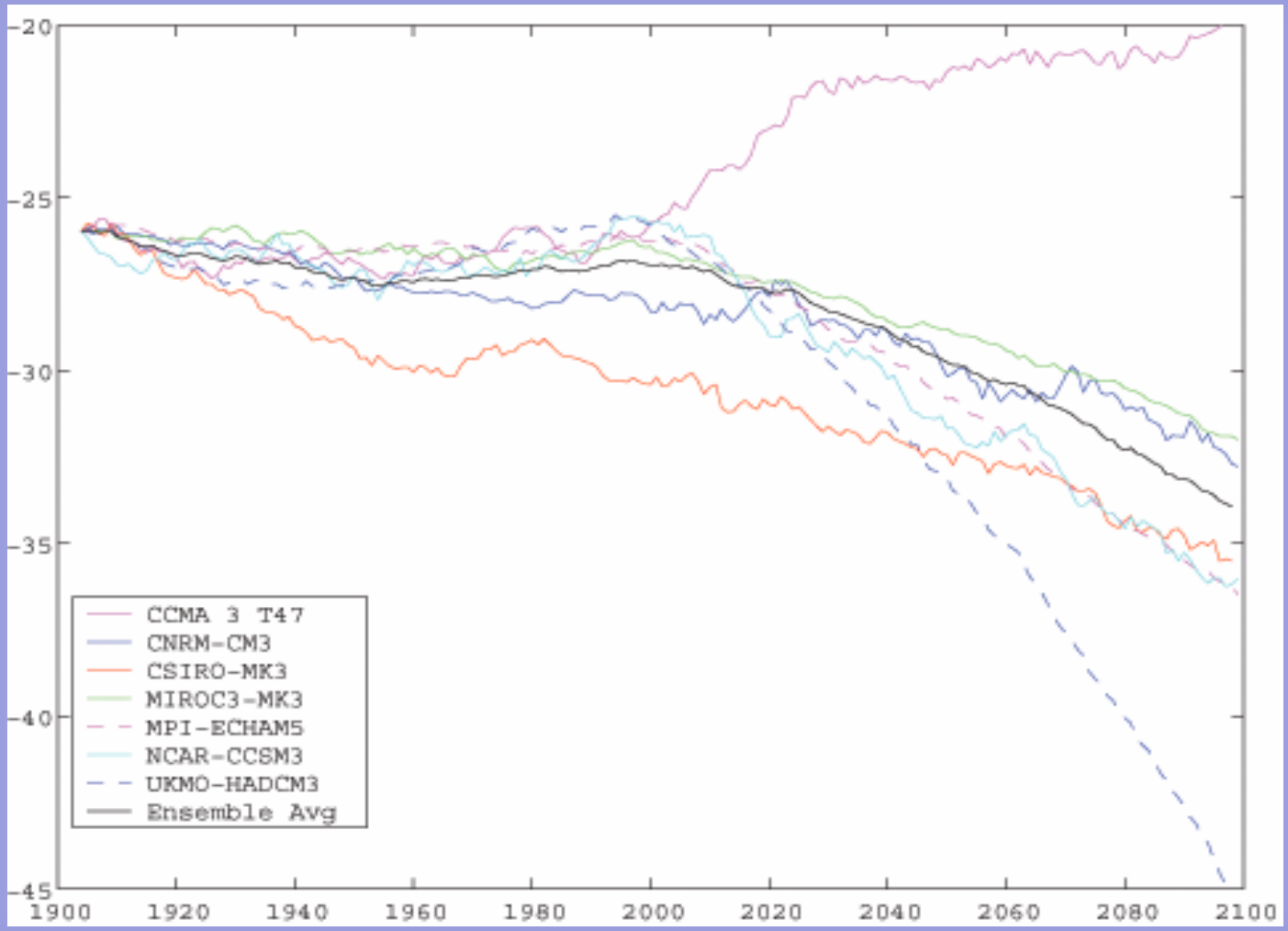
UKMO-HADCM3
Ensemble Avg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MPI-ECHAM5
NCAR-CCSM3
UKMO-HADCM3
Ensemble Avg

Potential impacts due to large decreases in the CSL

- Agriculture, particularly around the Volga delta
- Shipping transport, especially in the shallow northern sea
- Fishing industry
- Biodiversity