

'Jednostavni' modeli u službi klimatologije



Ivana Herceg Bulić
Geofizički zavod PMF-a

Zatvoreni sustav jednažbi

Zatvoreni sustav jednažbi

$$\frac{Du}{Dt} - \frac{uv \tan(\phi)}{a} + \frac{uw}{a} = -\frac{1}{\rho} \frac{\partial p}{\partial x} + 2\Omega v \sin(\phi) - 2\Omega w \cos(\phi) + \nu \nabla^2(u)$$

$$\frac{Dv}{Dt} + \frac{u^2 \tan(\phi)}{a} + \frac{vw}{a} = -\frac{1}{\rho} \frac{\partial p}{\partial y} - 2\Omega u \sin(\phi) + \nu \nabla^2(v)$$

$$\frac{Dw}{Dt} - \frac{u^2 + v^2}{a} = -\frac{1}{\rho} \frac{\partial p}{\partial z} - g + 2\Omega u \cos(\phi) + \nu \nabla^2(w)$$

$$\frac{D\rho}{Dt} = -\rho \nabla \cdot \mathbf{u}$$

$$c_v \frac{DT}{Dt} + p \frac{D}{Dt} \left(\frac{1}{\rho} \right) = J$$

$$p = \rho RT; \quad \alpha = \frac{1}{\rho}$$

Zatvoreni sustav jednađbi

$$\frac{Du}{Dt} - \frac{uv \tan(\phi)}{a} + \frac{uw}{a} = -\frac{1}{\rho} \frac{\partial p}{\partial x} + 2\Omega v \sin(\phi) - 2\Omega w \cos(\phi) + \nu \nabla^2(u)$$

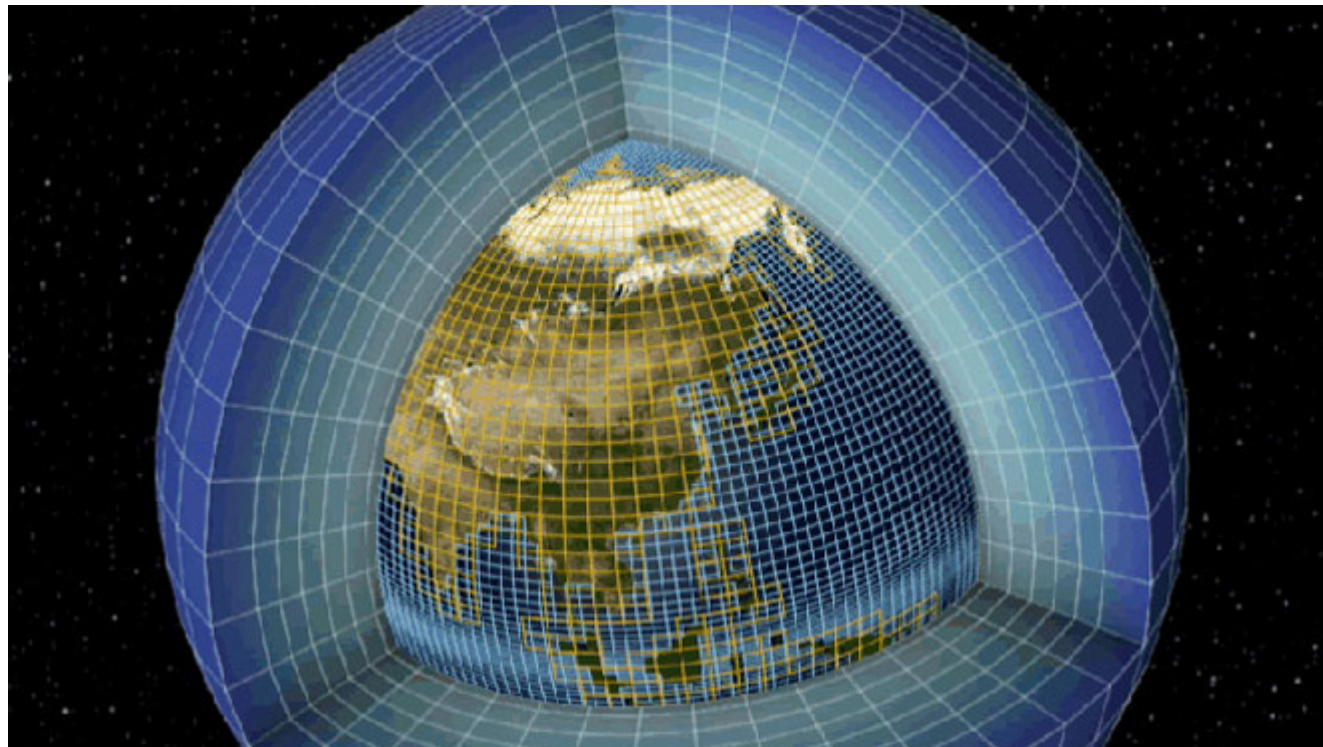
$$\frac{Dv}{Dt} + \frac{u^2 \tan(\phi)}{a} + \frac{vw}{a} = -\frac{1}{\rho} \frac{\partial p}{\partial y} - 2\Omega u \sin(\phi) + \nu \nabla^2(v)$$

$$\frac{Dw}{Dt} - \frac{u^2 + v^2}{a} = -\frac{1}{\rho} \frac{\partial p}{\partial z} - g + 2\Omega u \cos(\phi) + \nu \nabla^2(w)$$

$$\frac{D\rho}{Dt} = -\rho \nabla \cdot \mathbf{u}$$

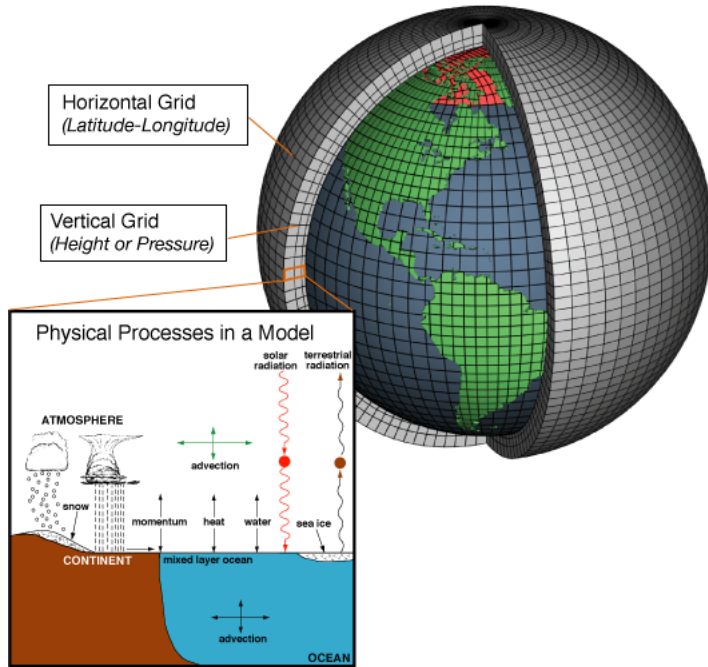
$$c_v \frac{DT}{Dt} + p \frac{D}{Dt} \left(\frac{1}{\rho} \right) = J$$

$$p = \rho RT; \quad \alpha = \frac{1}{\rho}$$

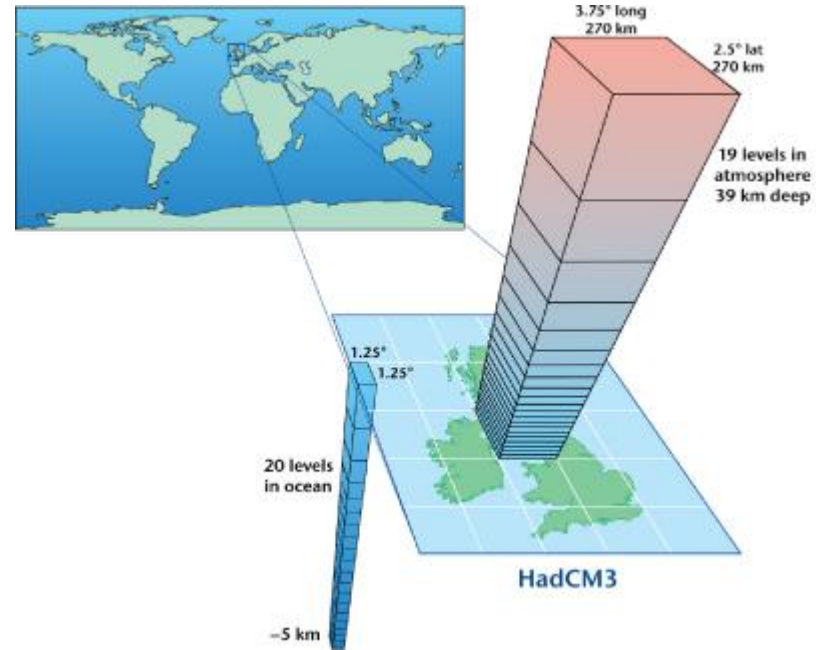


Klimatski modeli

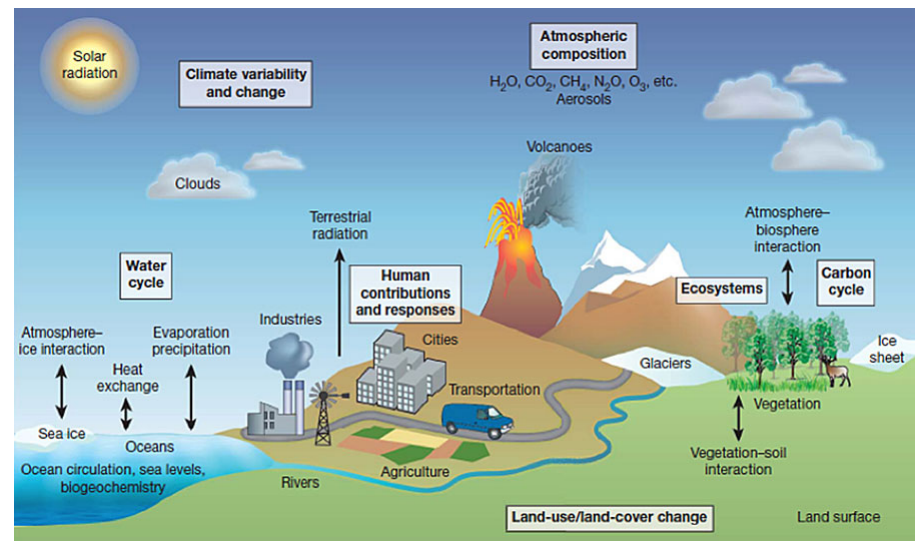
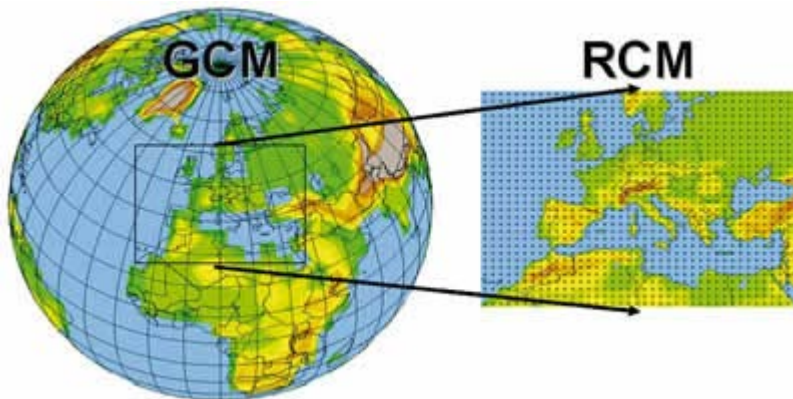
Globalni atmosferski modeli

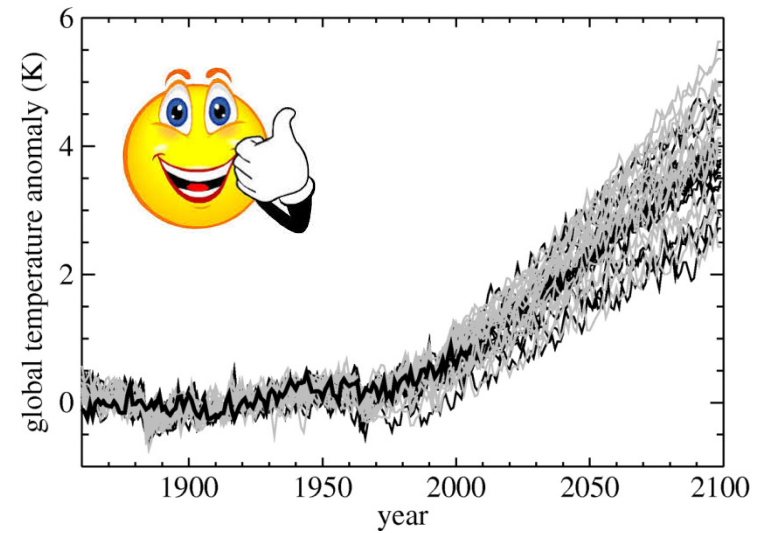
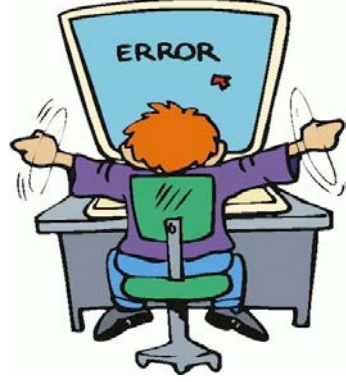
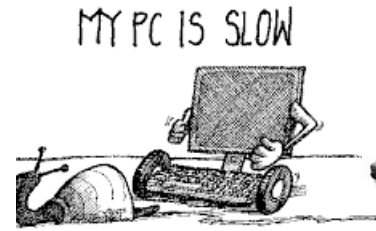
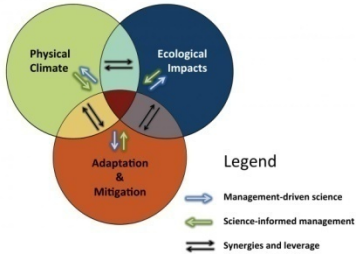


Združeni atmosfersko-oceanski modeli



Regionalni modeli





ICTP AGCM Speedy

ICTP AGCM Speedy

- **SPEEDY** (eng. *Simplified Parametrizations primitive-Equation DYNamics*), razvijen u Međunarodnom centru za teorijsku fiziku Abdus Salam - ICTP, Trst, Italija.
- Relativno jednostavan model (eng. *model of intermediate complexity*).
- 8 vertikalnih slojeva atmosfere (od 925 hPa do 30 hPa); razlučivost T30L8.
- Mreža modela sastavljena od 96×48 točaka; 3.75° (~400 km).
- Hidrostatički model, koristi σ -koordinatu.
- Računalno vrlo učinkovit (1 godina → 6 min → 25.4 MB).
- Mogućnost združivanja:
 - plitki oceanski sloj,
 - model vlage u tlu,
 - interaktivni model vegetacije.
- Fleksibilan – moguće su jednostavne modifikacije s ciljem specifičnih istraživanja; testovi osjetljivosti.
- Široka primjena u znanstvenim istraživanjima dinamičke klimatologije.

Neki primjeri primjene modela SPEEDY i postavke eksperimenata

Neki primjeri primjene modela SPEEDY i postavke eksperimenata

Prinudno djelovanje tropskog Pacifika na Europu

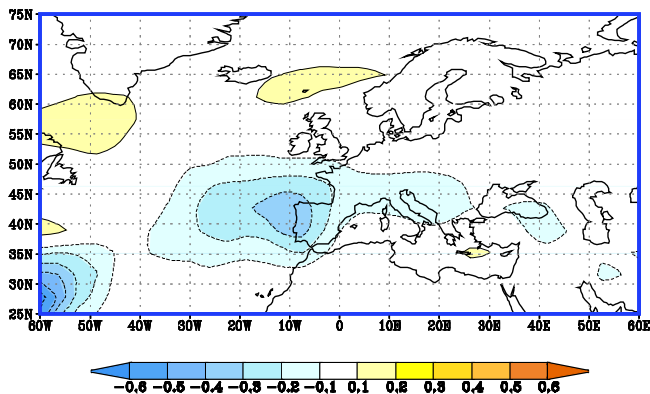
Herceg Bulić and Branković: ENSO forcing of the Northern Hemisphere climate in a large ensemble of model simulations based on a very long SST record. ClimDyn 2007.

Utjecaj pojave ENSO na područje Europe:

- Ansambl od 35 simulacija; 1854.-2002.
- Osmotrene površinske temperature mora SST (NOAA_ERSST_V2).

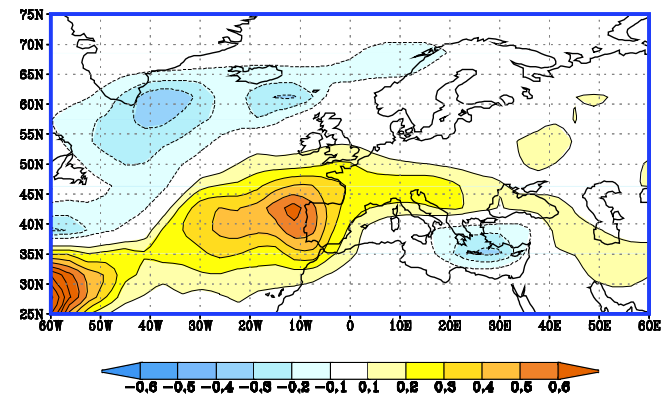
La Niña

(a) Oborina; izrazito hladni skup; int = 0.1mm/dan



El Niño

(b) Oborina; izrazito topli skup; int = 0.1 mm/dan

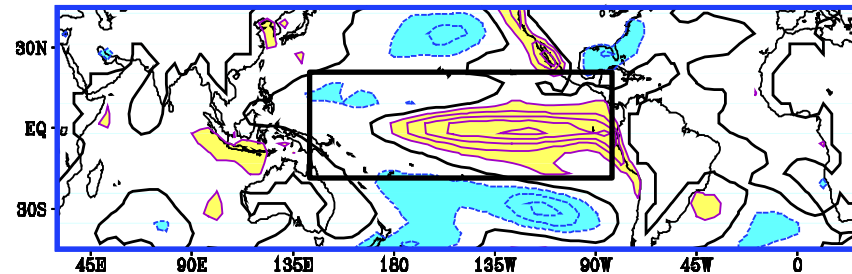


TroPac - eksperiment s prinudnim djelovanjem ograničenim samo na tropski Pacifik

- Da li su dobivene anomalije zaista posljedice prinudnog djelovanja u tropskom Pacifiku?

TroPac - Eksperiment s prinudnim djelovanjem ograničenim samo na tropski Pacifik

- Da li su dobivene anomalije zaista posljedice prinudnog djelovanja u tropskom Pacifiku?



TroPac eksperiment: anomalije SST – u tropskom Pacifiku, a izvan tog područja su klimatološke vrijednosti SST – međugodišnja promjenjivost SST prisutna je samo unutar zadanih granica, dok su SST izvan tih granica konstantne tijekom cijele integracije.

→ Rezultati su potvrdili prinudno djelovanje tropskog Pacifika na Europu.

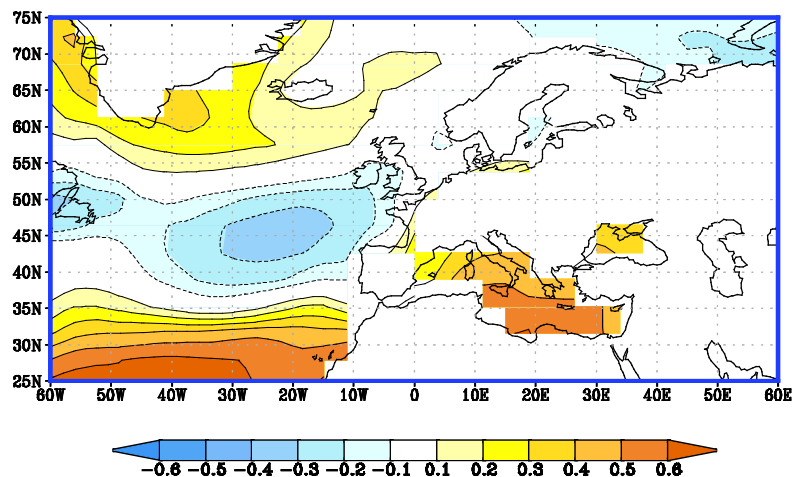
Međudjelovanje more-atmosfera

ENSO i NAO

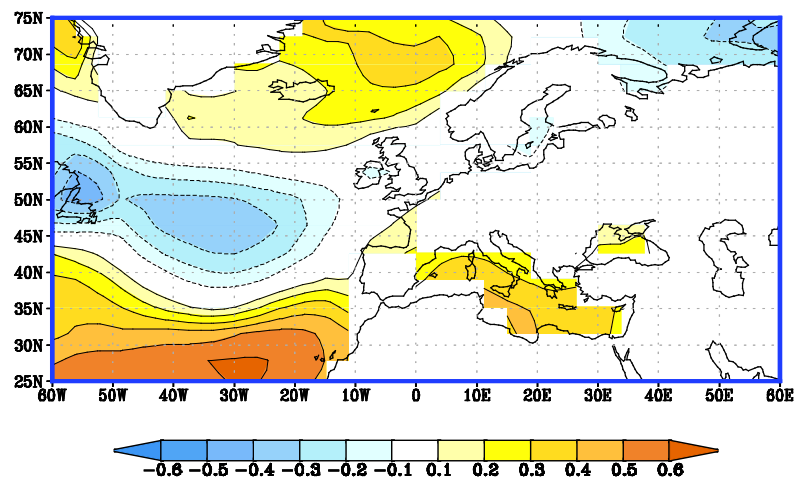
- *Herceg Bulić and Kucharski F: Delayed ENSO impact on spring precipitation over North/Atlantic European region. ClimDyn 2012.*
- *Herceg Bulić and Kucharski : North Atlantic SSTs as a link between wintertime NAO and the following spring climate. JClim 2014.*

Sjeverni Atlantik – važna karika u fizičkom mehanizmu utjecaja zimskog ENSO-a i NAO-a na klimatsku varijabilnost Europe tijekom narednog proljeća.

(a) corr PC1(JFM_Nino3.4_SST) AMJ_SST_MIX_winter_ENSO
cont=0.1



(b) corr PC1(JFM_Nino3.4_SST) AMJ_SST_MIX
cont=0.1

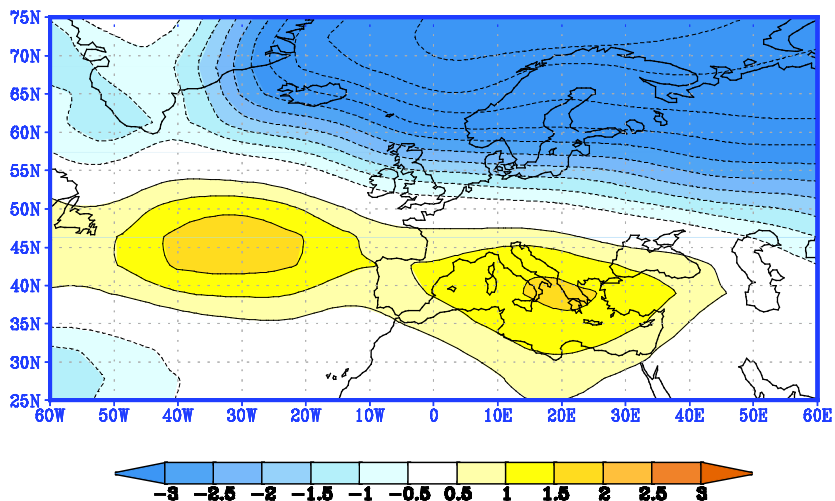


Globalno zatopljenje

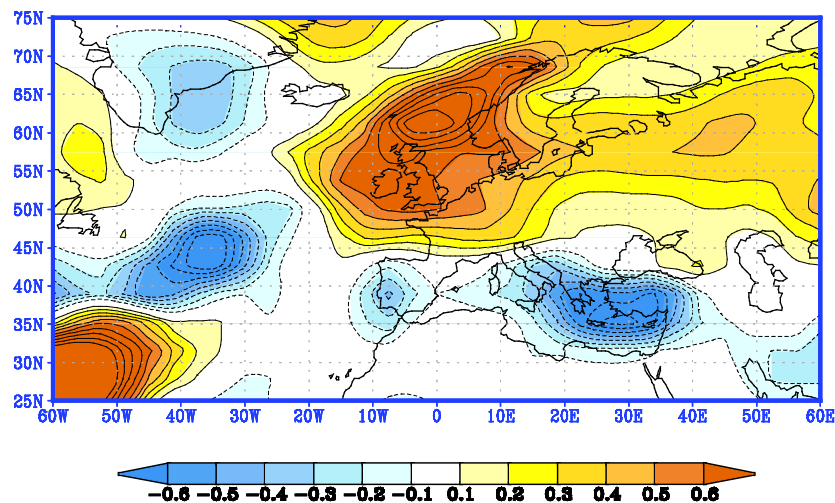
- *Herceg Bulić, Branković and Kucharski: Winter ENSO teleconnections in a warmer climate. ClimDyn 2012.*
- **CTRL** eksperiment - simulacija sadašnje klime:
 - CO₂ – prosječna vrijednost za razdoblje 1961-1990 (**1×CO₂**)
 - SST izmjerene vrijednosti 1855-2002 (NOAA_ERSST_V2 data) + morski led (HadSSTI)
- **2×CO₂** eksperiment – simulacija toplije klime
 - CO₂ – dvostruka vrijednost u odnosu na CTRL (**2×CO₂**)
 - SST klimatologija i morski led – simulirane vrijednosti modelom HadCM3 za dvostruku koncentraciju CO₂
 - SST anomalije – iste kao u CTRL eksperimentu

Sadašnja klima - 2×CO₂ klima

(a) MSLP 2×CO₂-CTRL JFM klim
cont 0.5 hPa

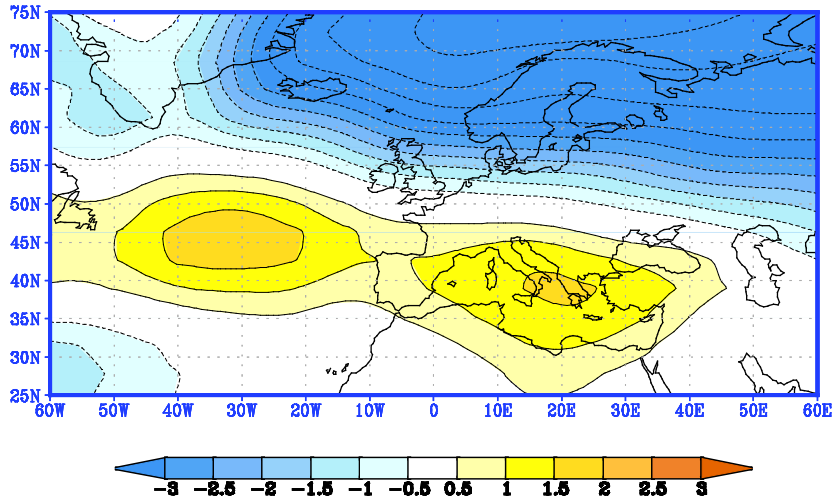


(b) Ukupna oborina 2×CO₂-CTRL JFM klim
cont 0.1 mm/dan

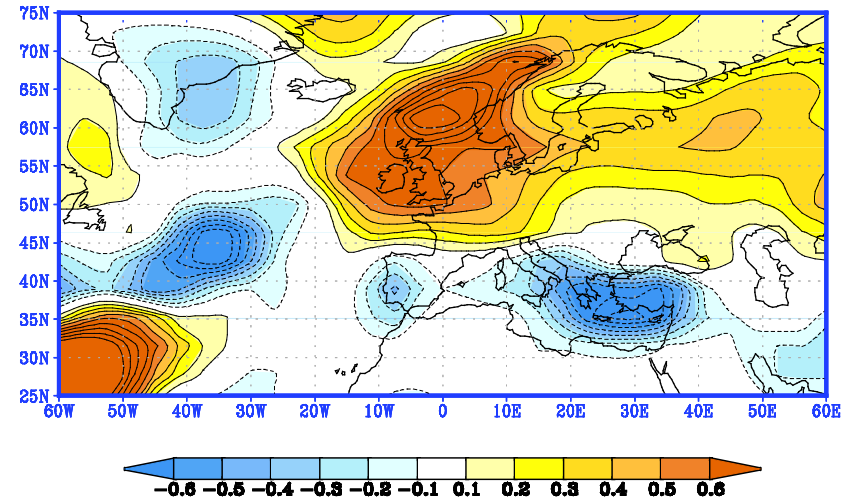


Sadašnja klima - 2×CO₂ klima

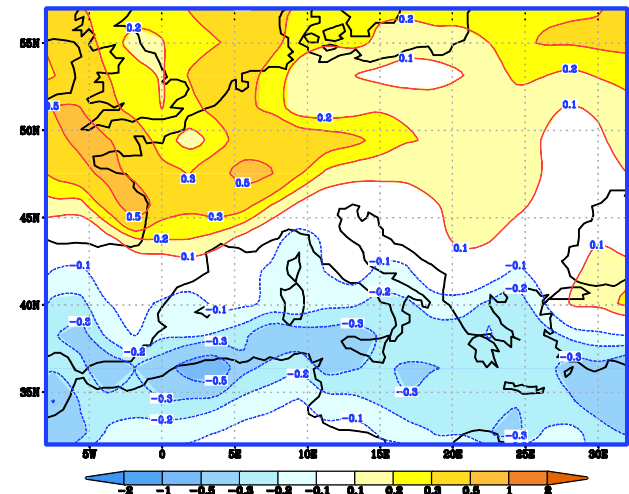
(a) MSLP 2×CO₂-CTRL JFM klim
cont 0.5 hPa



(b) Ukupna oborina 2×CO₂-CTRL JFM klim
cont 0.1 mm/dan



Ukupna oborina DJF; SRESA2-20C3M srednjak ansambla;
cont=0.1 0.2 0.3 0.5 1 2 mm/dan



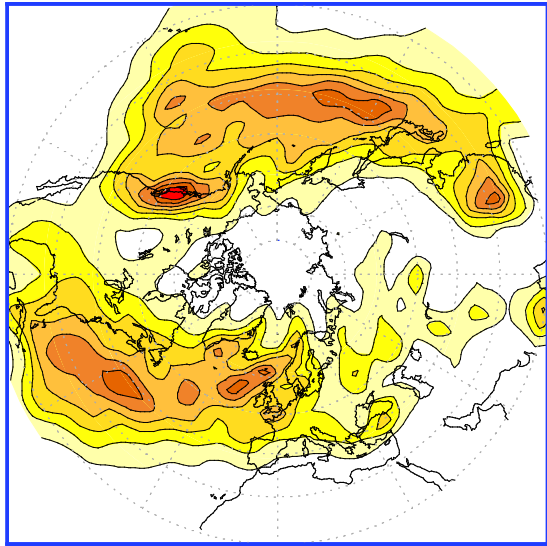
*An assessment of global and regional climate change
based on the EH50M climate model ensemble
(Branković, Srnec i Patarčić, Climatic Change 2010)*

Izravni i neizravni utjecaj CO₂

Izravni utjecaj – povećanje koncentracije CO₂ (apsorpcijsko-radijacijsko procesi DV zračenja)

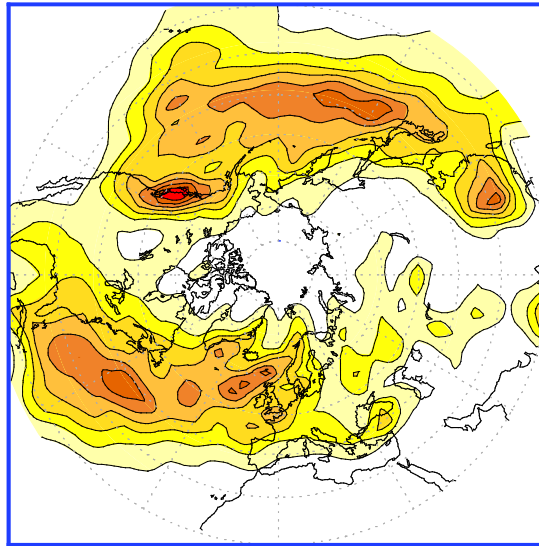
Neizravni utjecaj – promjene na donjoj granici (snijeg, led, morski led...)

(a) Total precip; JFM; CO₂x2 IND climatology
cont=1.0 mm/day



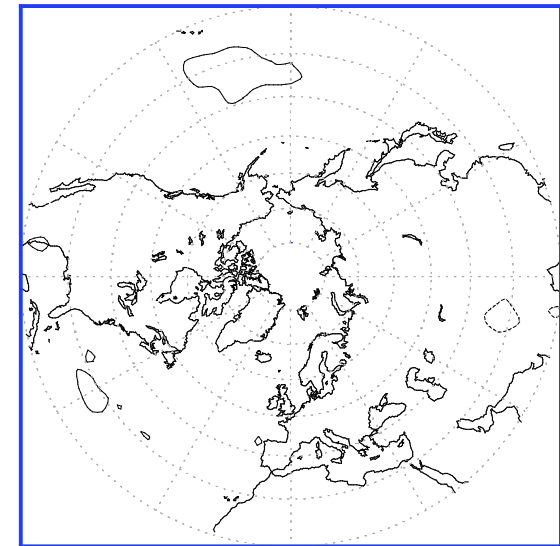
(a) NEIZRAVNI

(b) Total precip; JFM; CO₂x2 IND+DIR climatology
cont=1.0 mm/day



(b) IZRAVNI+NEIZRAVNI

(c) Total precip; JFM; difference (b)-(a)
cont=0.1 mm/day

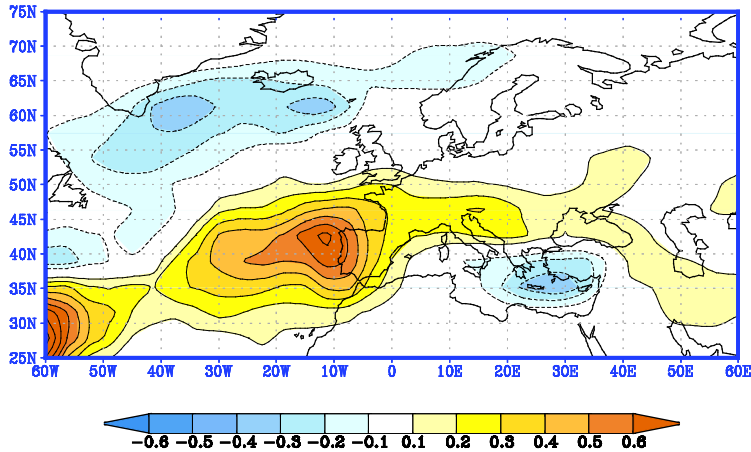


(b) - (a)

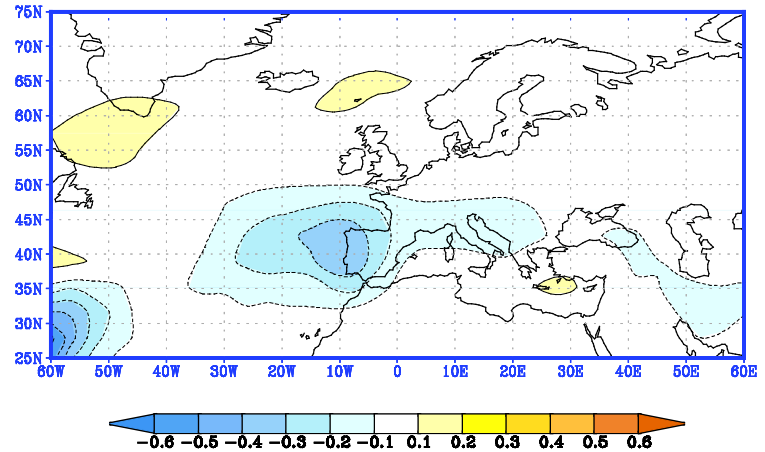
➡ Dominantan utjecaj promjena donjih graničnih uvjeta

Utjecaj ENSO-a u uvjetima toplije klime

(a) Total precip; JFM; CTRL strong warm composite
cont=0.1 mm/day



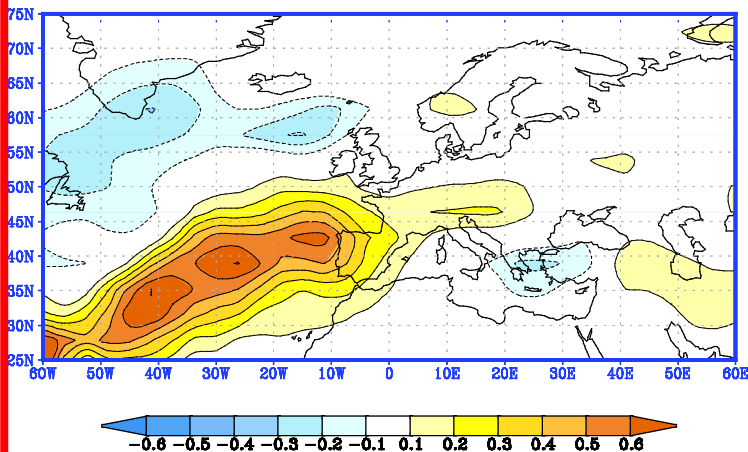
(b) Total precip; JFM; CTRL strong cold composite
cont=0.1 mm/day



CTRL

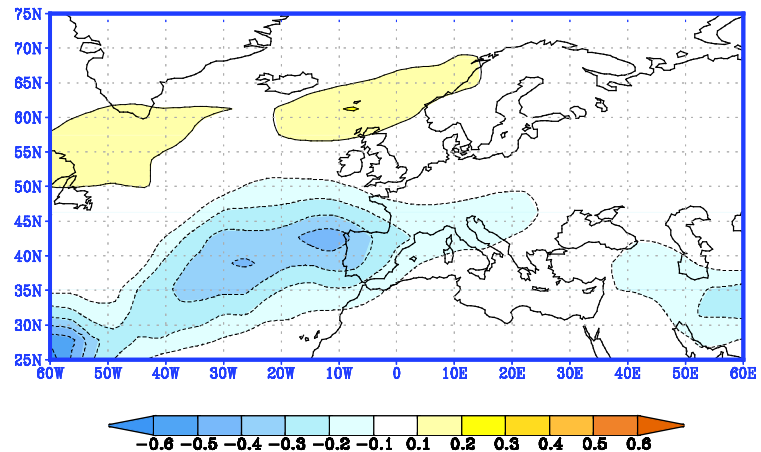
El Niño

(c) Total precip; JFM; CO2x2 strong warm composite
cont=0.1 mm/day



La Niña

(d) Total precip; JFM; CO2x2 strong cold composite
cont=0.1 mm/day



2xCO₂

Polu-empirijske metode

Polu-empirijske metode

Polu-empirijske metode: temelje se na jednostavnom odnosu između promjene srednje globalne morske razine i promjene srednje globalne temperature.

Odziv morske razine na temperaturnu promjenu:

$$I \frac{d\eta}{dt} + E\eta = \tau,$$
$$\eta = Z - Z_0, \tau = T - T_0$$

- inercijalni ($I \neq 0, E = 0$)

- ravnotežni ($I = 0, E \neq 0$)

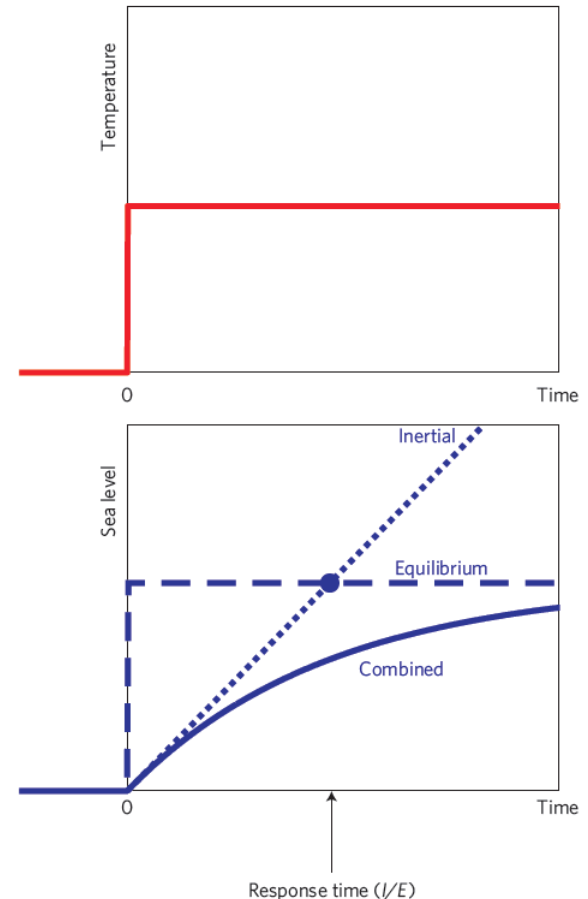
- inercijalni i ravnotežni ($I \neq 0, E \neq 0$)

V. Gornitz et al. (1982)

$$E\eta = \tau$$

S. Rahmstorf (2007)

$$I \frac{d\eta}{dt} = \tau$$



Polu-empirijske metode

Orlić and Pasarić: *Semi-empirical versus process-based sea-level projections for the twenty-first century*, *Nature Climate Change*, 2013.

- Uvažili inercijalni i ravnotežni odziv; izmjereni podaci temperature (uklonjena međugodišnja i dekadna varijabilnost → dobiven je vremenski niz koji sadrži dugoperiodički signal modificiran s multidekadnom oscilacijom)

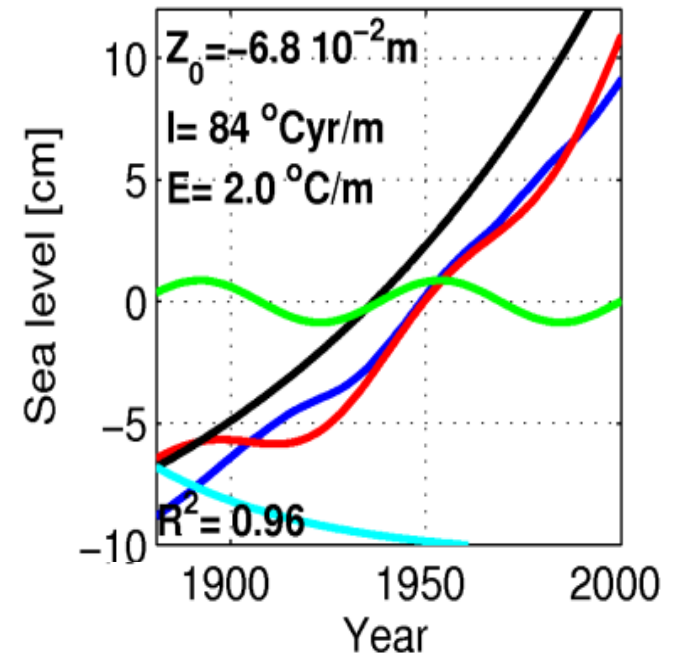
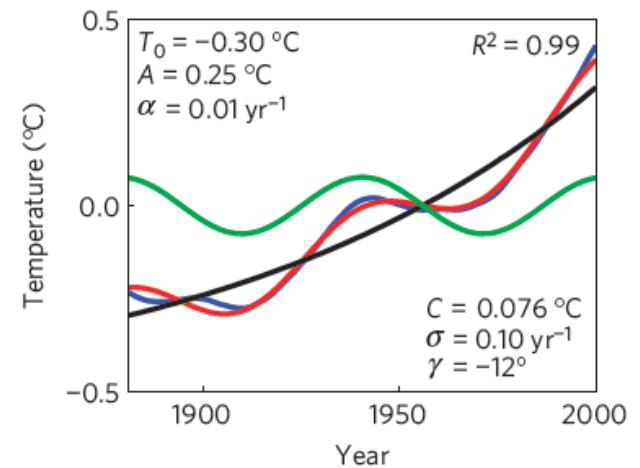
$$\tau = A(e^{\alpha t} - 1) + C \cos(\sigma t - \gamma)$$

$$I \frac{d\eta}{dt} + E\eta = \tau \Rightarrow$$

$$\eta = B\beta(e^{\alpha t} - 1) + B\alpha(e^{-\beta t} - 1) + D \cos(\sigma t - \delta)$$

- primjena na SRES B1 scenarij: prosječni porast srednje morske razine 2000-2100: 74±6 cm (95±5 cm s Chao korekcijom; 62±7 cm s Pokhrel korekcijom)

- projekcije dobivene združenim atmosfersko-oceanskim modelima: 37±9 cm





CARE

(Climate of the Adriatic REgion in its global context)





CARE

(Climate of the Adriatic REgion in its global context)

