ICTP-IITM-COLA Targeted Training Activity (TTA): "Towards Improved Monsoon Simulations"

Moist processes during breaks of the South Asian summer monsoon in the atmospheric regional climate model HIRHAM5

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Interactions between Tectonics, Climate and the Biosphere in the African-Asian Monsoonal Region
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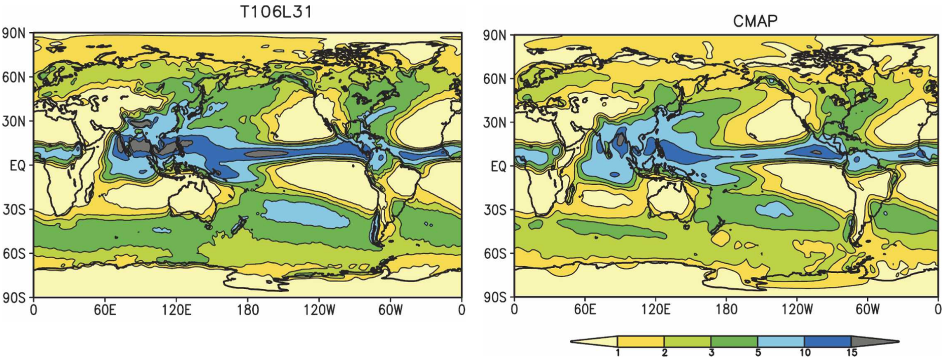
ECHAM5 and CMAP Precipitation in the boreal summer (JJA) for 1979-1998 [mm day^{-1}]



ECHAM5 results – too intense rainfall over the oceans (Bay of Bengal) and along steep mountain slopes (Himalaya, western Ghats)

Hagemann, Arpe and Roeckner (2006, J.Climate - Special Edition)

Dynamically downscaling a reanalysis improves the simulation of the spatial distribution of precipitation over South Asia by better resolving regional forcings, which **helps to represent realistically the moist dynamical processes during breaks** of the South Asian Summer Monsoon.

driven by ERA-Interim

↓

atmospheric Regional Climate Model (RCM)

→

Simulation of the South Asian Summer Monsoon climate with **focus** on **extended breaks** over India

Performance of the RCM ?

→ focus on moist physics and large-scale circulation

Studying dynamics in the deep tropics requires the consideration of physical processes influencing moisture and temperature

→ both become linked by the **Moist Static Energy (MSE), h**

$$MSE \; : \; h = c_p T + gz + Lq$$

c_p specific heat of dry air

T temperature

g acceleration due to gravity

z geopotential height

L latent heat of condensation

q specific humidity

→ **MSE anomalies nearly equivalent to humidity anomalies** in the deep tropics (weak horizontal temperature gradient)

$$MSE \; : \; h = c_p T + gz + Lq$$

c_p specific heat of dry air

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Vertically Integrated MSE Budget

$$\langle \omega \partial_p h \rangle = -\langle \mathbf{v}_h \cdot \nabla T \rangle - \langle \mathbf{v}_h \cdot \nabla q \rangle + \left(\frac{g}{p_T} \right) (F_{rad} + H + E)$$

vertical MSE advection	hor. temperature advection	hor. moisture advection	net radiative flux	sensible heat flux	latent heat flux

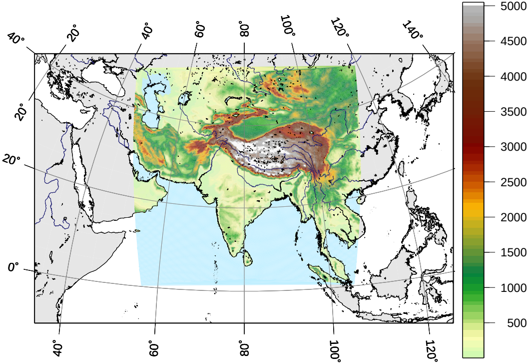
⇒ MSE budget is a powerfull approach to **identify leading moist and radiative processes responsible for rainfall anomalies**

⇒ **useful tool to analyze performance of climate models !**

HIRHAM5 = hydrostatic atmospheric regional climate model

dynamical core:	physical parameterisations:
limited-area weather forecast model **HIRLAM7** *Undén et al. (2002)*	atmospheric general circulation model **ECHAM5** *Roeckner et al. (2003)*

- initial and boundary conditions: **ERA Interim reanalysis**
  Dee et al. (2011, Q.J.R. Meteorol. Soc.)
- horizontal resolution of **25 km**
- vertical resolution of **40 level** (from surface up to 10 hPa)
- time step: $\Delta t = \mathbf{120\,s}$
- **simulation period: 1979-2012**



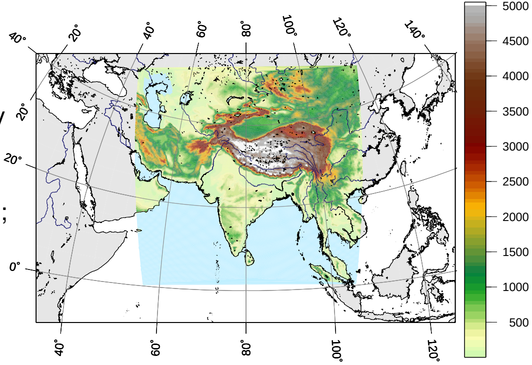
HIRHAM5 model domain and model orography [m]

Model HIRHAM5 and Simulation Set-Up

HIRHAM5 = hydrostatic atmospheric regional climate model

dynamical core:	physical parameterisations:
limited-area weather forecast model **HIRLAM7** *Undén et al. (2002)*	atmospheric general circulation model **ECHAM5** *Roeckner et al. (2003)*

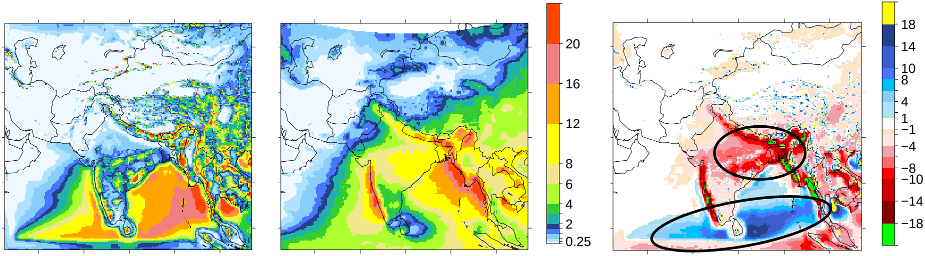
- cumulus convection: **Tiedtke mass flux scheme**; deep convection: convective activity expessed in terms of CAPE
- implemented boundary relaxation scheme of *Davies (1976 Q.J.R. Meteorol. Soc.)*; buffer zone size = 10 grid points
- 1 % nudging according to the dynamical relaxation technique *Davies and Turner (1977 Q.J.R. Meteorol. Soc.)* at all levels in inner model domain



HIRHAM5 model domain and model orography [m]

Total Precipitation [mm day^{-1}]

June-September (JJAS)



HIRHAM5
1979-2012

TRMM Product 3B42
1999-2012

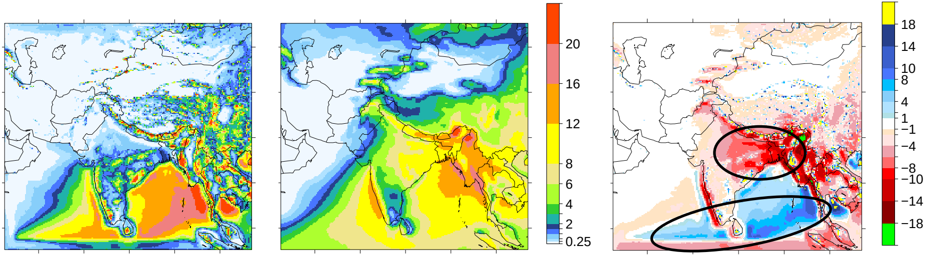
HIRHAM5 - TRMM
1999-2012

→ underestimation of rainfall over the Northern Indo-Gangetic Plain and central India

→ overestimation of rainfall over warm Indian Ocean

Total Precipitation [mm day^{-1}]

June-September (JJAS)



HIRHAM5 1979-2012

ERA-Interim 1979-2012

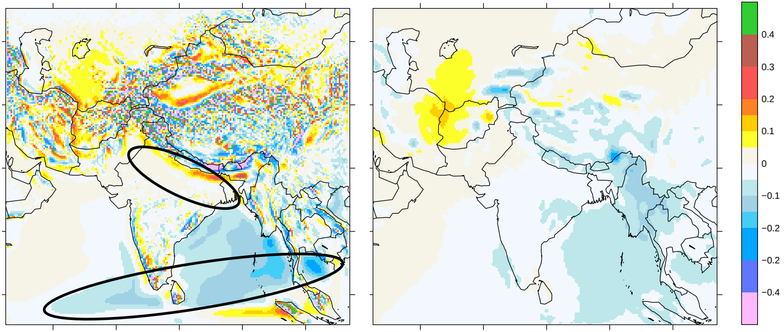
HIRHAM5 - ERA-Interim 1979-2012

→ underestimation of rainfall over the Northern Indo-Gangetic Plain and central India

→ overestimation of rainfall over warm Indian Ocean

Omega at 500hPa [Pa s^{-1}]

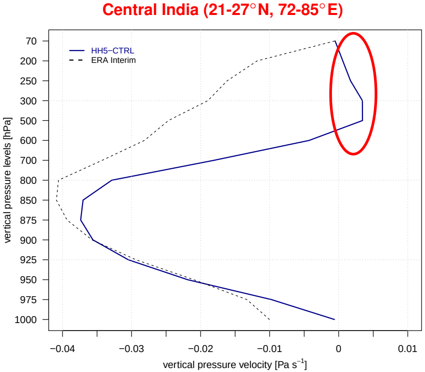
June-September (JJAS)

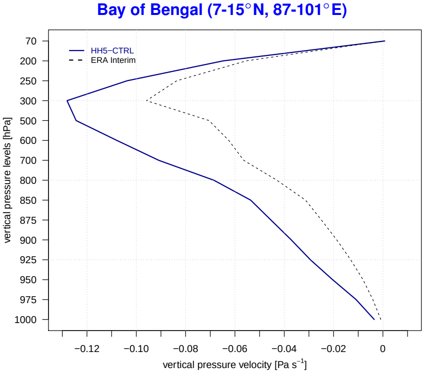


HIRHAM5
1979-2012

ERA-Interim
1979-2012

Omega [Pa s^{-1}]





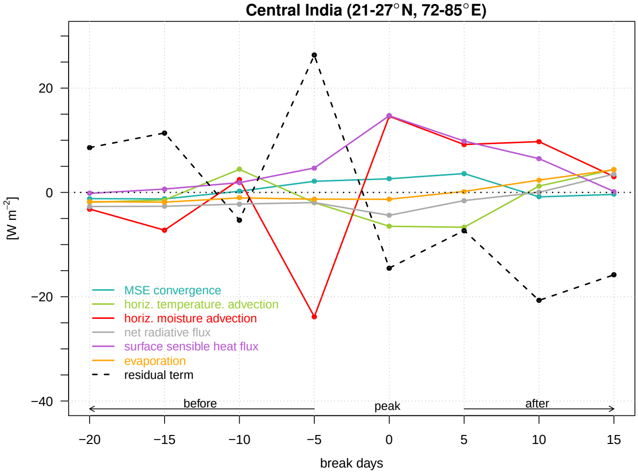
→ positive values above 600hPa !

→ very top-heavy structure !

⇒ **over both regions largest deviations around the freezing level (500hPa)**

MSE Budget during the Evolution of Breaks

$$\widehat{\omega\partial_p h}' = -\widehat{D_T T}' - \widehat{D_q q}' + \left(\frac{g}{p_T}\right)(F'_{\mathrm{rad}} + H' + E')$$



→ underestimated **net radiative cooling** (reduced amplitude by a factor of 10)

↪ **too weak cloud-radiative feedbacks in the HIRHAM5 ?!**

proposed hypothesis:

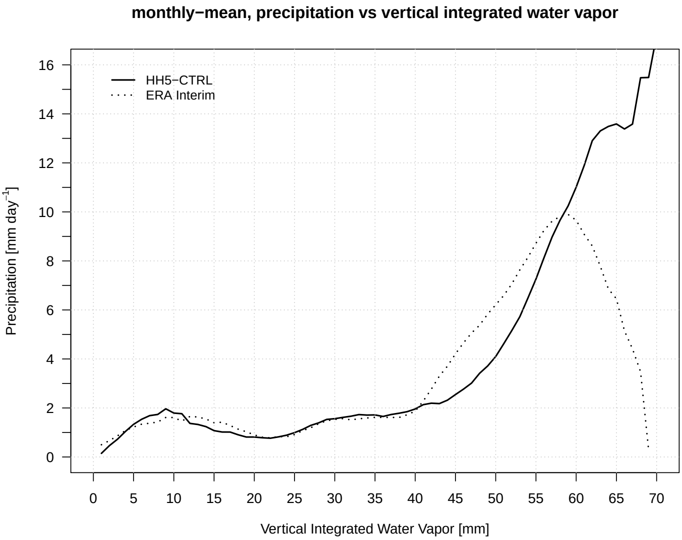
> Dynamically downscaling a reanalysis improves the simulation of the spatial distribution of precipitation over South Asia by better resolving regional forcings, which helps to represent realistically the moist dynamical processes during breaks of the SASM.

$\rightarrow$ **the proposed hypothesis could not be confirmed !**

model deficiencies:

- **dry bias over central India** and **wet bias over warm Indian Ocean**
  $\rightarrow$ similar wet bias found in ECHAM5 !
- ω **bias is largest around freezing level**
  $\rightarrow$ indicates lacks in the specification of cloud downdraft physics
  $\rightarrow$ too weak entrainment/detrainment rates?
- MSE Budget revealed **too weak cloud-radiative feedbacks**
  $\rightarrow$ leading to an earlier return to the normal monsoon state after a break

JJAS Precipitation vs JJAS Water Vapor Path



→ HIRHAM5 is overreacting to a given Water Vapor Path ! → systematic error ?

Thank You for Your Attention!