ICTP RegCM5

11th Workshop on the Theory and Use of Regional Climate Models
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Reference paper

Giorgi, F. et al. (2023)

The fifth generation regional climate modeling system, RegCM5: Description and illustrative examples at parameterized convection and convection-permitting resolutions.

Journal of Geophysical Research: Atmospheres, 128, e2022JD038199.

https://doi.org/10.1029/2022JD038199

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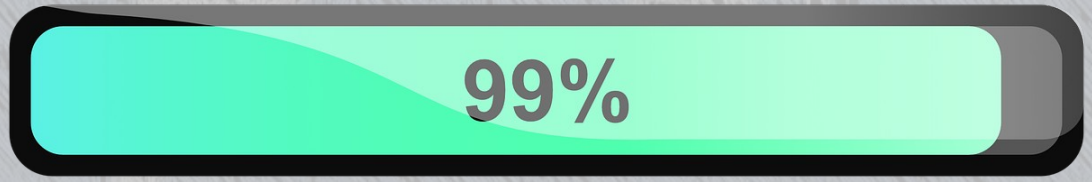
Coming soon ...

Coppola. et al. (2023 ?)

The Fifth Generation Regional Climate Modeling System, RegCM5: the first CP European wide simulation and validation over the CORDEX-CORE domains.



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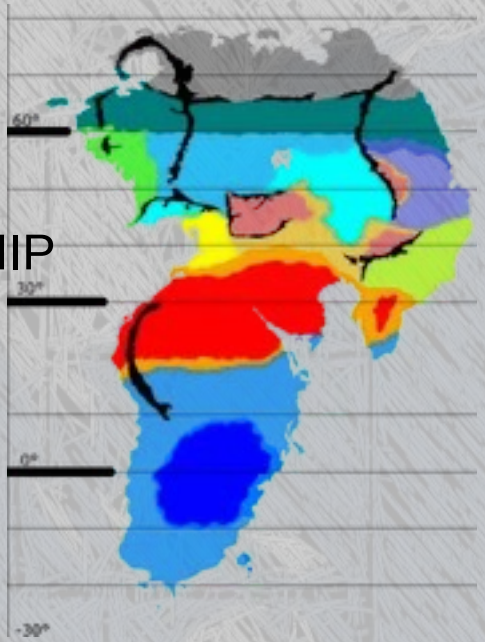
Regional Climate Model



- Limited Area model – Physical Boundary Conditions from a GLOBAL model
- Climate : Radiation Scheme Boundary Conditions following a CMIP protocol
- Model Internal atmospheric (+ land) system status dynamical evolution
  - User defined geolocation and resolution of the computational grid
  - Primitive equations numerically integrated with BC
  - Parameter based packages to describe physical processes that modify status variables by emergent properties coming from the smaller scale phenomena.

Parameterization: The specification of a curve, surface, etc., by means of one or more variables which are allowed to take on values in a given specified range.

Regional Model advantages

- Better description of the surface
  - Topography at a higher resolution
  - Land Model can use regional data providing a better description
  - Extremes, extremes!
- More physics is possible: “better” description
- Tailored schemes for the Region Of Interest
  - Different settings for different domains
  - Multiple physical schemes options: greater parameter space
- Simple model can double up as study and learning tool

Regional Model problems

- Conservation more problematic
  - Local radiative equilibrium: no global system budget possible
  - BC schemes:
- HUGE parameter space. Sometime “good” results clash with physics.
- Does not CORRECT the parent model “BIG” problems
  - Garbage in -> garbage out (double ITCZ? OLR vs. cloud problems? Huge biases?)
    - GCM selection: few GCM “available” as” BC (complete, available, reasonable)
- CORDEX down the line from the global models
  - Always second to the goal: data lags at best 1-2 year behind GCM results
  - Computational and storage effort comparable to GCMs for the CORDEX runs
- CORDEX as the “younger sister” community of CMIP global elders

RegCM5 NH Atmosphere

- MOLOCH (H coordinate LOCal MOdel)
  - Eulerian time integration
  - Arakawa C grid
  - Hybrid height terrain following coordinate with rigid top
  - No diffusion, only local divergence damping present
  - Weighted Average Flux advection scheme (WAF)
  - Vertical propagation of sound waves implicit equation

Model Grid

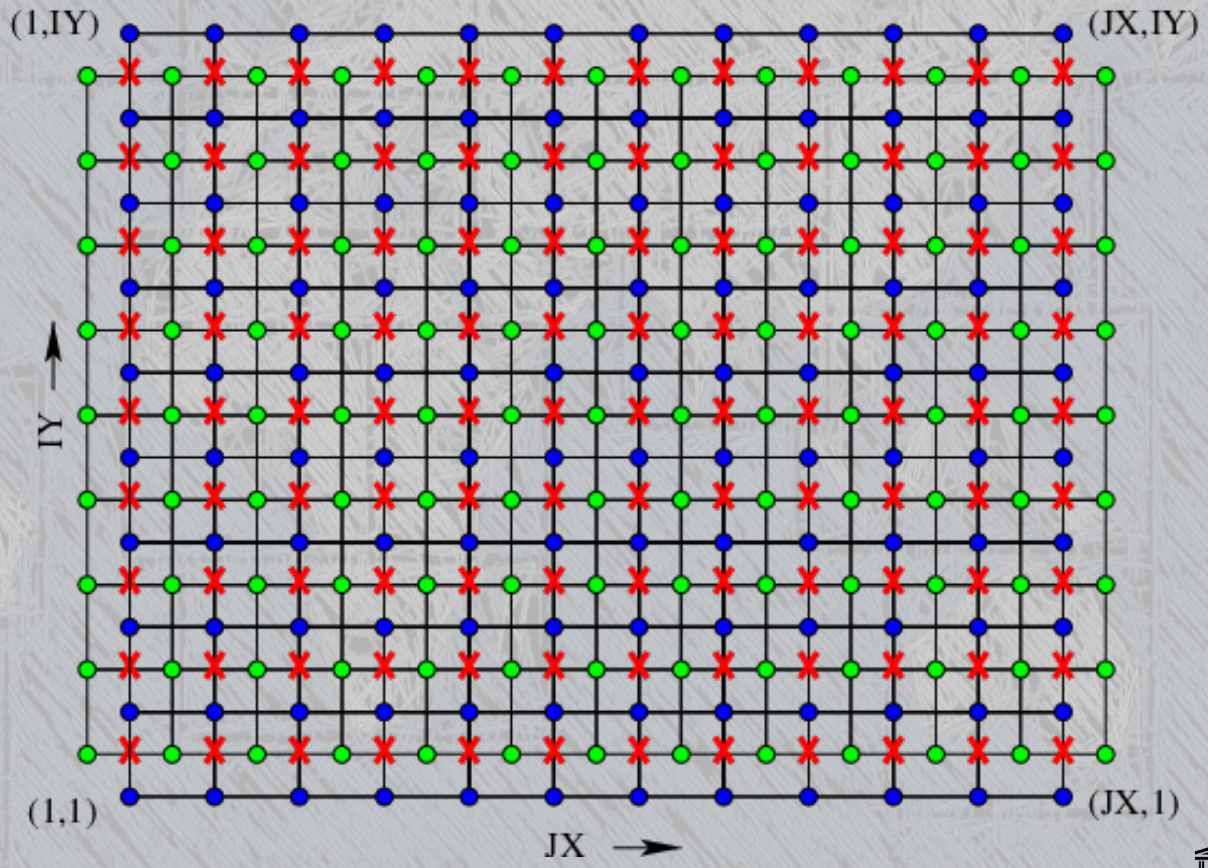
RegCM model grid

```
Staggered U: JX,  IY-1,KZ
Staggered V: JX-1,IY,  KZ
Staggered W: Jx-1,IY-1,KZ+1
Scalar     : Jx-1,IY-1,KZ
```

RegCM output grid

```
Output     : JX-3,IY-3,KZ
```

All variables are interpolated on the scalar grid in output. The output grid doesn't contain though first/last line/column.



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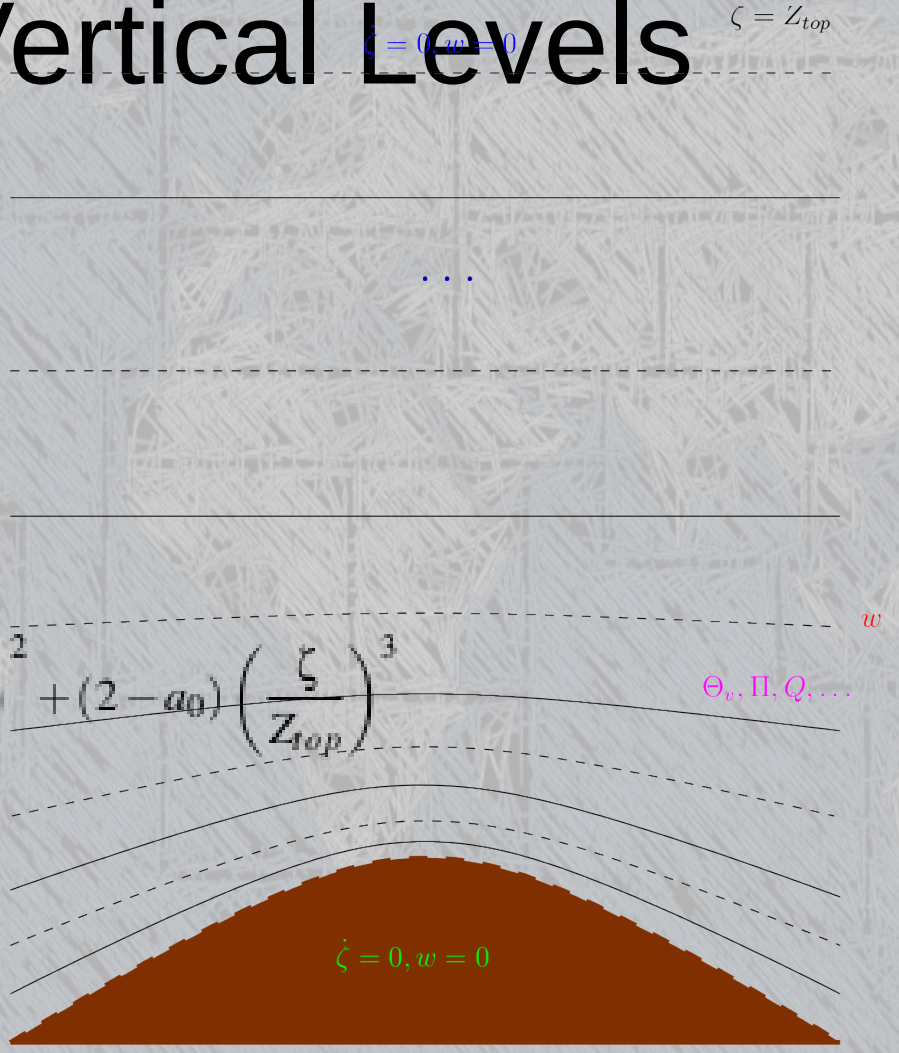
Vertical Levels

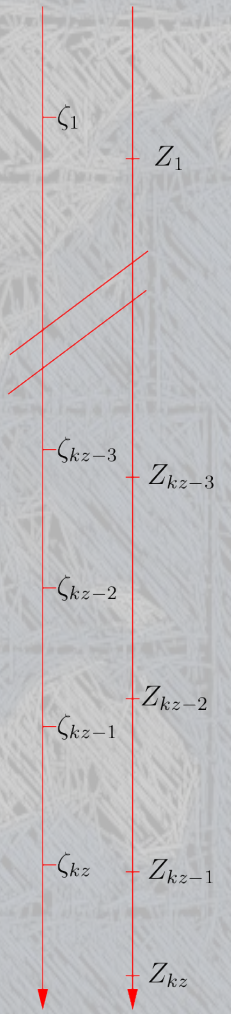
$$\Delta\zeta = \frac{Z_{top}}{kz}$$

$$Z_f = \frac{Z_{top}}{e^{\frac{Z_{top}}{H}}-1}$$

$$Z = h(x,y)G(\zeta) + Z_f e^{\frac{\zeta}{H}-1}$$

$$G(\zeta) = 1 - a_0\frac{\zeta}{Z_{top}} - (3-2a_0)\left(\frac{\zeta}{Z_{top}}\right)^2 + (2-a_0)\left(\frac{\zeta}{Z_{top}}\right)^3$$





Equations

$$\Pi = \left(\frac{P}{P_0}\right)^{\frac{R_d}{c_{p_d}}}$$

$$\Theta_v = \frac{T_v}{\Pi}$$

$$T_v \approx T(1+ew)$$

$$\sigma = 1 - \frac{\zeta}{Z_{top}}$$

$$Z_f = \frac{Z_{top}}{e^{\frac{Z_{top}}{H}} - 1}$$

$$F_z = \frac{\partial \zeta}{\partial z} = \frac{1}{G(\zeta)h(x,y) + \frac{1}{H} Z_f e^{\frac{\zeta}{H}}}$$

$$\dot{\zeta} = s = F_z \left[w - \left(u\frac{\partial h}{\partial x} + v\frac{\partial h}{\partial y} \right) G \right]$$

$$\frac{du}{dt} = mc_{p_d}\Theta_v \frac{\partial \Pi}{\partial x} - mG(\zeta)\frac{\partial h}{\partial x}\left(g + \frac{dw}{dt}\right) + fv + K_u$$

$$\frac{dv}{dt} = mc_{p_d}\Theta_v \frac{\partial \Pi}{\partial y} - mG(\zeta)\frac{\partial h}{\partial y}\left(g + \frac{dw}{dt}\right) - fu + K_v$$

$$\frac{dw}{dt} = -F_z c_{p_d}\Theta_v \frac{\partial \Pi}{\partial z} - g + K_w$$

$$\frac{d\Theta_v}{dt} \approx K_{\Theta_v}$$

$$\frac{d\Pi}{dt} \approx -\Pi \frac{R_d}{c_{v_d}} \nabla \vec{V}$$

$$\nabla \vec{V} = F_z \left\{ m^2 \left[\frac{\partial\left(\frac{u}{mF_z}\right)}{\partial x} + \frac{\partial\left(\frac{v}{mF_z}\right)}{\partial y} \right] + \frac{\partial\left(\frac{s}{F_z}\right)}{\partial \zeta} \right\}$$

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```
dtadv = dt / nadv
dtsound = dtadv / nsound

do while ( extime >= timestr .and. extime < timeend )
  do jadv = 1 , nadv
    do jsound = 1 , nsound
      !
      ! Implict vertical velocity equation
      !
      call sound(dtsound)
    end do
    !
    ! Advection step, WAF vertical and horizontal both
    !
    call advection(dtadv)
  end do
  !
  ! Physical parametrizations and boundary
  !
  call physical_parametrizations_and_boundary
  extime = extime + dt
end do
```

Physical Parameterization

- Radiation Scheme
  - FORCING for future climate projections
- Boundary Layer Scheme
- Cumulus Scheme
- Cloud Fraction Scheme
- Micro-physics Scheme

Input Layer - Reanalysis

- ERA5 data – 0.25 deg 1940 – today
  - https://tinyurl.com/ECMWFERA5
  - ERAXX : average 1970-2022 of ERA5 for MIV studies
- JMA JRA55 – 1.25 deg 1958 - today
  - https://tinyurl.com/JMAJRA55
- NCEP–DOE Reanalysis II 2.5 deg 1948 - today
  - https://tinyurl.com/NCEPDOE

ECMWF

気象庁
Japan Meteorological Agency

NCEP

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Input Layer GCM

#	Institute	Title	Created	Updated	Closed	Severity	Status
1	NASA-GISS	Pressure level calculation incorrect due to erroneous ...	2023-08-09	2023-08-10	--	High	New
2	NCC	retracting variable od550aer with frequency AERday	2023-07-06	--	--	High	New
3	NCC	retracting and republishing new datasets for ta, ua a ...	2023-02-13	--	--	Medium	New
4	NCC	wrong hus and wap datasets	2022-12-08	--	--	High	New
5	CSIRO	6-hourly tsl in ESM1.5 r6 incorrectly calculated	2022-09-12	2022-09-15	--	Critical	New
6	NCC	Error in fLuc and fHarvest datasets	2022-09-05	--	--	Critical	New
7	NCC	removing most datasets associated with variable sftlf ...	2022-04-05	--	--	Medium	New
8	AWI	sfo3max, AERday incorrect, o3, E3hrPt not required sinc ...	2022-03-25	2022-03-25	--	High	New
9	E3SM-PROJECT	mrro variable appears inconsistent with land-sea mask	2022-03-16	--	--	High	New
10	NCC	Issue with longitude datasets with atoms and aerosol ...	2022-01-14	--	--	High	New
11	CAS	Incorrect unit conversion for hfds data of Omon	2022-01-11	2022-01-11	--	Medium	New
12	CSIRO-ARCCSS	b(lev) values incorrect for all published ACCESS (CM2 ...	2021-10-05	--	--	Medium	New
13	NCC	error with variables msftmrhompa, msftmzmpa and msftm ...	2021-08-24	--	--	High	New
14	NCC	error related to variable sndmasssnf	2021-08-13	--	--	Medium	New
15	NCC	information related to variable areacello, thkcello a ...	2021-08-11	--	--	Low	New
16	NCC	correction for wo data on gr grid	2021-06-28	--	--	High	New
17	NCC	retracting and republishing of datasets for dryss, dr ...	2021-05-26	--	--	High	New
18	NCC	Retracting and republishing few datasets for Scenario ...	2021-05-26	--	--	Critical	New
19	NCC	deleting datasets chlos for Omon frequency	2021-04-15	--	--	High	New
20	NCC	deleting datasets with variable siareas	2021-04-15	--	--	High	New
21	NCC	fNup data are removed as having some unit problem	2021-03-22	--	--	Medium	New
22	NCC	corrupted file or missing data	2021-03-22	--	--	Medium	New
23	CSIRO	Data accidentally multiplied by 10^9	2021-03-16	--	--	Critical	New

- CMIP3
  - ECHAM5
- CMIP5
  - CanESM2, CNRM-CM5, CSIRO-Mk36, EC_EARTH, GFDL-ESM2M, HadGEM2, IPSL-CM5A-LR, MIROC5, MPI-ESM-LR, MPI-ESM-HR, NorESM1-M
- CMIP6 – OpenDAP from ESGF option
  - MPI-ESM1-2-HR, HadGEM3-GC31-MM, NorESM2-MM, CNRM-ESM2-1, CESM2, EC-Earth3-Veg, MIROC6, MIROC-ES2L, CanESM5, CMCC-ESM2

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CMIP6 Input4MIPS forcing

- Shared Socio-Economic Pathways Greenhouse gases SSP
  - CO_2 CFC11 CFC12 CH_4 N_2O
    - Sustainability-focused growth and equality (SSP1) 119 126
    - Middle of the Road (SSP2) 245
    - Regional Rivalry (SSP3) 370
    - Inequality (SSP4) 434 460
    - Fossil-fueled Development (SSP5) 534 585
- SOLARIS - HEPPA solar irradiance forcing
- Simple Plume Aerosol model
- Chemistry Climate Model Initiative Ozone data
- NO LUC data

Spatial Interpolation

- Horizontal interpolation
  - K-d tree based nearest neighbor research
  - Spherical Barycentric Coordinate GenLin interpolation
  - ROTLLR projection for MOLOCH dynamical core
- Vertical Interpolation
  - Linear and logarithmic hydrostatic with surface level extrapolation

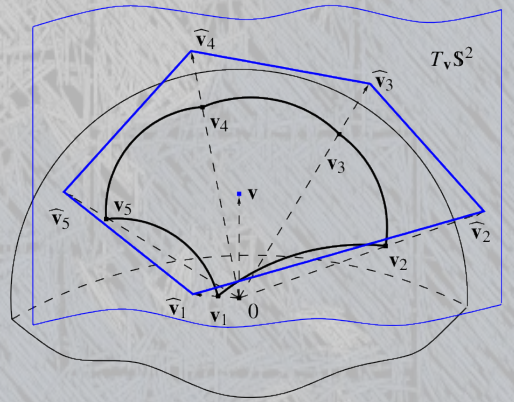

Figure 1: *Construction of spherical barycentric coordinates.*

T. Langer, A. Belyaev, H.-P. Seidel / Spherical Barycentric Coordinate

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RegCM5 Atmosphere-Land

- Dynamical core for time integration
- Integrated Land Model CLM4.5 / CLM3.5 / BATS
- Prescribed SST in the boundary condition
- Input4MIPS forcing

Reanalysis, Scenario runs, What ifs, Paleo

RegCM-ES

- Uses the RegESM (Turunçoğlu) based upon ESMF
  - https://github.com/uturuncoglu/RegESM
- RegCM5 is coupled through RegESM with:
  - MIT GCM c65 (ROMS)
  - CHyM river routing (HD)

11 km MEDCORDEX experiment protocol

Very High Resolution

- Convection permitting CP
  - Deactivate Cumulus clouds evolution parameterization
  - Cumulus evolution explicitly resolved by the micro-physics package

- OPEN PROBLEMS
  - Vertical levels position user defined placement problematic
  - CLOUD MODEL ? What is cloud fraction at HR?
  - Micro-physics in RegCM is still missing graupel / hail
  - High frequency output: data handling is still poor

FPS evolving into longer term simulation

Needs good surface description datasets

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Code NEW! Features

- RRTMG radiation scheme is now working in MOLOCH
- MERRA2 Aerosol optical properties over 5 wavebands can be used for reanalysis run (1980-2020)
- Vertical interpolation target levels in post processing are now configurable in the namelist
- Stochastic parameters possible for MIT scheme
- Implementation of RCEMIP phase 1 protocol settings
- New CMIP6 models (corrected vertical top interpolation).
- Tuning of the NoTo Micro Physics scheme
- Started the implementation of PMIP input layer
- Bug fixes (as always… never ending process).

Near Future

- NEW coupler.
  - Developed for Ocean model SYMPHONIE coupling (LEGOS) using OASIS3-MCT

- CLM5 land model.
  - PhD project ongoing in ICTP
  - LUC in CLM5!!

ICTP Development branch

OpenACC directives partially added to the dynamical core
MPI3 communication

Code Development

https://github.com/ICTP/RegCM

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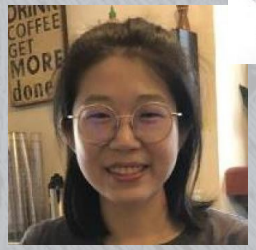
RegCM Tutorial

- Today : new user guided model installation and configuration, first model run
- Tomorrow : use cases, start group work on projects
- How to evaluate the output of a simulation?



- What will not be covered:
  - Operating system installation and use
  - Requisite libraries installation

Questions?