

Numerics of the African-based Earth System Model and key applications

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Earth System Modelling at the GCI in South Africa



The Uniform Earth System Model: A Wits-GCI-CSIR-CSIRO-UCT-UniVen collaboration

- Development of an African-based ESM at the GCI in collaboration with international and national partners.
- Projecting future climate change to inform CMIP6 and AR6 of the IPCC.
- Modelling paleoclimate: the late Pliocene (3.3-3 Ma), Last Glacial Maximum (21 ka) and more.
- Detailed downscalings of regional climate over southern Africa in support of regional climate services and policy making.
- NWP selected predictability problems.
- New cadre of GCI-based post-graduate and post-doctoral students studying at Wits.
- National Research Foundation (NRF) Earth System Science Research Programme (ESSRP) and ACCESS funding.

Earth System Model development at the Wits GCI and partners

- Numerics of cube-based grids
- Biomass burning aerosols in southern Africa and impacts on Sc and convective clouds
- Cumulus convection parameterisation (African focus)
- DGVMs and the African savannahs
- Benguela Upwelling and Agulhas Current
- Parameterisation of Southern Ocean Mixing
- Antarctic sea-ice modelling
- Urban Heat Island modelling





Quasi-uniform C48 grid with resolution about 210 km

Flexible stretchedgrid capabilities allow for regional Earth System Modelling

Alternative cubed-sphere grids



and Rancic)

All C32

Vertex views of C48 grids



5

Location of variables in grid cells



All variables are located at the centres of quadrilateral grid cells.

In CCAM, during semi-implicit/gravity-wave calculations, u and v are transformed reversibly to the indicated C-grid locations.

Produces same excellent dispersion properties as spectral method (see McGregor, MWR, 2006), but avoids any problems of Gibbs' phenomena.

2-grid waves preserved. Gives relatively lively winds, and good wind spectra.





HPC and codescalability



CCAM-ocean scaling with 35 atmosphere levels and 30 ocean levels, suggesting excellent simulation speed for computing resources (CSIRO cluster)

- Computer clusters available to the project include the CHPC in South Africa
- The cube-based design for both ocean and atmosphere has achieved some comparable resolution and computing times with significantly less cores than required by some more traditional coupling approaches.



Meteosat IR satellite image 2016-05-15 12:00

The coupled climate system of southern Africa and the Atlantic: Benguela upwelling + Sc cloud decks + biomass burning aerosols (~ 20% of global emissions) + tree-grass-fire dynamics in the African savannah + climate change and feedbacks + climate sensitivity + CMIP5 SST biases = CORDEX FLAGSHIP project.

Aerosol scheme in CCAM

- 11 prognostic aerosol species
- **CAM-AERONET** comparison
- CCAM performs well (in line with CMIP5 models), except that it overestimates dust (area of improvement)

mean AOD_{550nr} 0.2 0.4 0.6

2

- 4 -6 8

month



Horowitz et al. ACP, 2017



CCAM-CABLE CORDEX simulations: aerosol direct and indirect effects over Africa



Dynamic circulation studies of aerosol recirculation events underway,

ORACLES, CLARIFY: international opportunities that promote regional climate model development over southern Africa.

1.4e - 09

First verification paper on simulation of aerosol attributes: Horowitz, Garland, Thatcher, Engelbrecht et al. (2017), ACP.

This capability to be applied in WGNE aerosol project

Examining scale sensitivities that couple ocean-atmosphere carbon exchange in the Southern Ocean



160°W 140°W 120°W 100°W 80°W 60°W 40°W 20°W 0° 20°E 40°E 60°E 80°E 120°E 120°E 140°E 160°E



Experimental model platform Coupled Ocean-Ice-Biogeochemistry models (NEMO-PISCES, African ESM-PISCES)

Hierarchy of model configurations global medium-resolution (~200km) to finerscale regional ocean models (10-50km) and at sub-regional ultra-high resolution (1-5km).

The computing cost of these models are a limiting factor the these experiments. Increasing model resolution to include critical small scales adds to the need for large computing requirements.





New NRF ESSRP project to explore machine learning to develop parameterisation of Southern Ocean mixing as induced by submesoscale eddies

Cool colours indicate CO₂ is released from the ocean into the atmosphere



Warm colours indicate CO_2 is taken up by ocean from the atmosphere

High-res Nemo simulations (Nicolette Chang, Pedro Monteiro of CSIR SOCCO) inform parameterisations in ESM, and serves to benchmark ESM

Regional climate modelling over Africa using regional ESM



CCAM stretched-grid over southern Africa

CCAM and UCOM (ocean) applied in stretched-grid mode

Modest stretching provides a resolution of about 8 km over southern Africa

Development of Africa's first ESM is ongoing

Development targets the main unresolved climate change questions for Africa and the SH in support of climate services



Climate simulations inform adaptation opportunities under the Paris agreement

- The Paris Agreement also makes provision for the funding of ambitious climate change adaptation projects in developing countries
- Projections of changing winter rainfall over the southwestern
 Cape for 2070-2099 relative to 1961-1990.
- Engelbrecht et al. (2015). ERL.
- Engelbrecht, Malherbe et al. (2019). In prep.



Mosselbay paleoscape by Maggie Newman



























CCAM simulated July westerly-wind anomalies: LGM vs present-day

Forcing from 8 CMIP5 GCM projections of LGM climate

Significant equatorward displacements of Southern Hemisphere westerlies

Engelbrecht et al. (2019) QSR *In press.*

CHPC XSEDE



CCAM projected change in winter (JJA) average rainfall (mm/day) over southwestern SA for the LGM relative to present-day climate

Consistent with Cowling et al. (1999) and the higher diversity of plants species (both of fynbos and succulent Karoo) in the western compared to the eastern parts of the GCFR of southwestern southern Africa

Engelbrecht et al. QSR (2019). In press.

CHPC XSEDE

Conclusions: ESM development in southern Africa



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- Projecting future climate change globally to inform CMIP6 and AR6 of the IPCC
 - Detailed downscalings of regional climate over southern Africa in support of regional climate services and policy making.
- Palaeo climate modelling is important as tests for ESMs and to support the assessment of climate sensitivity
- Important palaeo climate modelling applications at Wits relate to understanding hominin evolution in the grasslands
- ESM development fosters human capacity building in developing countries and promotes multi-disciplinary research