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Nested Climate Modelling over Southern Africa with a Semi-Lagrangian Limited Area Model

by

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Summary

Atmospheric general circulation model (AGCM) simulations of southern African climate on a regional scale are unsatisfactory. The main reason for this result is that computational requirements determine that AGCMs are run at coarse horizontal resolutions. The impact of local forcing such as complex topography, and important small-scale circulation systems cannot be resolved properly at typical AGCM resolutions. However, mesoscale forcing and circulation systems have an important modifying influence on the southern African climate. The technique of nested climate modelling can be used to obtain detailed climate simulations over limited areas of the earth. Nested climate modelling involves the nesting of a high grid-resolution limited-area model (LAM) within an AGCM (or observational analyses) over an area of interest. The AGCM provides the LAM with boundary conditions during an extended integration period. With a grid resolution of 10-100 km, the LAM model is able to simulate some of the mesoscale features of the circulation.

The limited-area model DARLAM has been developed to meet the requirements of both climate simulation experiments and shorter-term mesoscale studies. The dynamical formulation of DARLAM is characterised by the semi-Lagrangian method used to simulate advection. The essential feature of the scheme is that the total or material derivatives in the equations of motion are treated directly by calculating the departure points of fluid parcels. The semi-Lagrangian approach allows the use of large time steps during the model integration. Numerical experiments performed in the study indicate that the particular semi-Lagrangian method used in DARLAM is highly accurate and has excellent conservation and stability properties.

The results of climate simulations over the SADC region with DARLAM are described. The model is one-way nested within simulations of selected months from a long seasonal varying simulation of the CSIRO9 AGCM. The relatively coarse resolution AGCM is used to provide boundary conditions to DARLAM, which is run at a horizontal grid resolution of 60 km with 18 levels in the vertical. The higher resolution adds significant smaller-scale detail to the coarser simulation of the AGCM. The additional detail provides improved simulation results, when compared to AGCM results over most regions of the LAM domain.

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Genestelde Klimaatmodellering oor Suidelike Afrika met 'n Semi-Lagrange Beperkte-Area-Model

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Samevatting

Atmosferiese algemene sirkulasie model (AASM) simulasies van suider Afrikaanse klimaat op streekskaal is onbevredigend. Die hoofrede hiervoor is dat berekeningsvereistes bepaal dat AASMe geloop word met ruwe horisontale resolusie. Die impak van lokale forsering soos komplekse topografie en kleinskaalse sirkulasiesisteme kan nie vasgevang word met tipiese AASM-resolusie nie. Mesoskaalforsering- en sirkulasiesisteme het egter `n belangrike modifiserende invloed op suider Afrikaanse klimaat. Die tegniek van genestelde klimaatmodellering kan gebruik word om gedetaileerde klimaatsimulasies oor beperkte dele van die aarde te verkry. Die tegniek behels die nes van `n hoë roosterresolusie beperkte- area-model (BAM) binne `n AASM (of waargenome data) oor die area wat van belang is. Die AASM verskaf die BAM met randwaardes gedurende `n verlengde integrasie periode. Met `n roosterresolusie van 10-100 km is kan die BAM sommige mesoskaaleienskappe van die sirkulasie simuleer.

Die beperkte-area-model DARLAM is ontwikkel om te voldoen aan die vereistes van sowel klimaatsimulasie-eksperimente en korter tydskaal mesoskaalstudies. Kenmerkend van die modelformulasie is die semi-Lagrange metode wat gebruik word vir adveksie-simulasie. Die essensiële kenmerk van die skema is dat die totale afgeleides in die bewegingsvergelykings direk hanteer word deurdat vertrekpunte van vloeistofdeeltjies bereken word. Die semi-Lagrange benadering bied die gebruik van groot tydstappe gedurende die modelintegrasie. Numeriese eksperimente uitgevoer dui aan dat die semi-Lagrange metode wat in DARLAM gebruik word hoogs akkuraat is en uitstekende behouds- en stabiliteitseienskappe besit.

Die resultate van klimaatsimulasies oor die SADC gebied met DARLAM word beskryf. Die model is een-rigting genestel binne simulasies van uitgesoektee maande van `n lang, seisonaal variërende simulasie van die CSIRO9 AASM. Die relatief lae resolusie AASM is gebruik om randwaardes aan DARLAM te verskaf, wat geloop is met `n horisontale roosterresolusie van 60 km met 18 vlakke in die vertikaal. Die hoër resolusie voeg betekenisvolle kleiner skaal detail by die ruwer simulasie van die AASM. Die bykomende besonderhede verskaf verbeterde simulasie resultate in vergelyking met die AASM oor die meeste areas binne die BAM gebied.

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TABLE OF CONTENTS

LIST OF SYMBOLS

$\frac{d}{dt}$: Time derivative that follows the motion of a parcel
k : Wave number in the x direction (m^{-1})
l : Wave number in the y direction (m^{-1})
n : number of time steps
u : Velocity component in the x direction (ms^{-1})
v : Velocity component in the y direction (ms^{-1})
t : Time (s)
L_x : Wave length in the x direction (m)
L_y : Wave length in the y direction (m)
R : Relative phase change in time of the numerical solution
$\overline{v}$: Velocity ($ms^{-1)}$
$\hat{v}$: Approximated velocity (ms^{-1})
(x_*, y_*): Departure point of a particle
$\overline{\nabla}$: Spatial gradient operator
ψ : Dependent variable in the advection equation (scalar quantity)
α : Non dimensional advection velocity
α_1 : Non dimensional advection velocity component in the x direction
α_2 : Non dimensional advection velocity component in the y direction
ϕ : Stream function
λ : Amplification factor
λ_{re} : Real component of the amplification factor
λ_{im} : Imaginary component of the amplification factor
θ : Phase change in time of the numerical solution
ω : Phase change in time of the true solution
Λ : x or y amplification factor
Δx : Spatial increment in the x direction (m)
Δt : Time interval (s)
Δy : Spatial increment in the y direction (m)
Ψ : Wave amplitude of scalar quantity
Ω : Angular velocity ($rads^{-1}$)

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

AGCM	Atmospheric general circulation model
BMRC	Bureau of Meteorology Research Centre
CFL	Courant-Friedrichs-Lewy
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DARLAM	Division of Atmospheric Research Limited Area Model
ECMWF	European Centre for Medium-range Weather Forecasting
GFDL	Geophysical Fluid Dynamics Laboratory
LAM	Limited-area model
LBC	Lateral boundary conditions
NCAR	National Centre for Atmospheric Research
NCEP	National Centre for Environmental Prediction
NCM	Nested climate model
RCM	Regional climate model
R21	Rhomboidal truncation at wave number 21
SADC	Southern African Developing Countries
SAWB	South African Weather Bureau
SST	Sea surface temperature
T63	Triangular truncation at wave number 63
UP	University of Pretoria