A brief manual for the DRY Princenton AGCM model

σ -Coordinate: $\sigma = \frac{P}{P_s}$ P_s : Surface pressure (1)

Basic equations:

(a) Momentum equation:

$$\frac{d\vec{V}}{dt} = -f\vec{k} \times \vec{V} - \nabla\phi - RT \cdot \nabla \ln P_s - \varepsilon_1 \vec{V} - \nu_1 \nabla^4 \vec{V} \tag{2}$$

(b) Continuity equation:

$$\frac{\partial \ln P_s}{\partial t} + D + \vec{V} \cdot \nabla \ln P_s + \frac{\partial \dot{\sigma}}{\partial \sigma} = 0 \tag{3}$$

(c) Thermal dynamic equation:

$$\frac{dT}{dt} - \frac{1}{\rho C_p} \frac{dP}{dt} = \frac{\dot{Q}}{C_p} - \varepsilon_2 T \tag{4}$$

(d) Hydrostatic equation:

$$\frac{\partial \phi}{\partial \sigma} = -\frac{RT}{\sigma} \tag{5}$$

$$\frac{d}{dt} = \frac{\partial}{\partial t} + \vec{V} \cdot \nabla + \dot{\sigma} \frac{\partial}{\partial \sigma}$$

By the vertical integration of (3), we obtain,

$$\frac{\partial \ln P_s}{\partial t} = -\overline{D} - \overline{\vec{V}} \cdot \nabla \ln P_s \tag{6}$$

$$\overline{D} = \sum_{k=1}^{KX} D \cdot \Delta\sigma_k$$

where the bar represents the vertical mean.

$$\dot{\sigma} = -\int_0^\sigma \{(D - \overline{D}) + (\vec{V} - \overline{\vec{V}}) \nabla \ln P_s\} d\sigma = \dot{\sigma}_D + \dot{\sigma}_A \tag{7}$$

$$\dot{\sigma}_D = -\int_0^\sigma (D - \overline{D}) d\sigma \tag{8}$$

$$\dot{\sigma}_A = -\int_0^\sigma (\vec{V} - \overline{\vec{V}}) \nabla \ln P_s d\sigma \tag{9}$$

Transformation of the equations in the model:

(a) Momentum equation:

$$\frac{\partial \vec{V}}{\partial t} + (f + \varsigma)\vec{k} \times \vec{V} + \dot{\sigma}\frac{\partial \vec{V}}{\partial \sigma} = -\nabla(\phi + E) - RT \cdot \nabla \ln P_s - \varepsilon_1 \vec{V} - \nu_1 \nabla^4 \vec{V} \tag{10}$$

ς : vorticity and $E = \frac{1}{2}(u^2 + v^2)$ for the kinetic energy.

By inducing a reference temperature $\overline{T}_{s0}(z)$, it can be further rewritten,

$$\frac{\partial \vec{V}}{\partial t} = -\nabla\phi - R\overline{T}_{s0}\nabla \ln P_s + \vec{G}_m \tag{11}$$

$$\vec{G}_m = -(\zeta + f)\hat{k} \times \vec{V} - \dot{\sigma}\frac{\partial \vec{V}}{\partial \sigma} - \nabla E + R(T - \overline{T}_{s0})\nabla \ln P_s - \varepsilon_1 \vec{V} - \nu_1 \nabla^4 \vec{V} \tag{12}$$

Eq. (12) is transformed into the form of vorticity and divergence equations.

$$\frac{\partial D}{\partial t} = -\nabla^2\phi - R\overline{T}_{s0}\nabla^2 \ln P_s + \nabla \cdot \vec{G}_m \tag{13}$$

$$\frac{\partial \varsigma}{\partial t} = \vec{k} \cdot (\nabla \times \vec{G}_m) \tag{14}$$

(b) Thermal dynamic equation:

$$\frac{1}{\rho C_p}\frac{dP}{dt} = \frac{RT}{PC_p}\left(\frac{\partial P}{\partial t} + \vec{V} \cdot \nabla P + \dot{\sigma}\frac{\partial P}{\partial \sigma}\right) = \kappa T\left(\frac{\partial \ln P_s}{\partial t} + \vec{V} \cdot \nabla \ln P_s + \frac{\dot{\sigma}}{\sigma}\right) \tag{15}$$

where $\kappa = R / C_p$.

Substitute (6) to (15), we can obtain

$$\frac{1}{\rho C_p}\frac{dP}{dt} = \kappa T\left((\vec{V} - \overline{\overline{\vec{V}}}) \cdot \nabla \ln P_s - \overline{D} + \frac{\dot{\sigma}}{\sigma}\right) \tag{16}$$

Further substitute (16) into (4), after transformation, it arrives,

$$\frac{\partial T}{\partial t} = \frac{\kappa \overline{T}_{s0}}{\sigma}\dot{\sigma}_D - \kappa \overline{T}_{s0}\overline{D} + G_T \tag{17}$$

$$\begin{aligned} G_T = & -\vec{V} \cdot \nabla T - \dot{\sigma}\frac{\partial T}{\partial \sigma} + \frac{\kappa \overline{T}_{s0}}{\sigma}\dot{\sigma}_A + \kappa T(\vec{V} - \overline{\overline{\vec{V}}}) \cdot \nabla \ln P_s) \\ & + \frac{\kappa(T - \overline{T}_{s0})}{\sigma}\dot{\sigma} - \kappa(T - \overline{T}_{s0})\overline{D} + \frac{\dot{Q}}{C_p} - \varepsilon_2 T \end{aligned} \tag{18}$$

(c) Continuity equation:

$$\frac{\partial \ln P_s}{\partial t} = -\overline{D} + G_c \tag{19}$$

$$G_c = -\overline{\vec{V}} \cdot \nabla \ln P_s \tag{20}$$

Model variables: $D, \varsigma, T, \ln(P_S)$. Diagnostic variables: $\dot{\sigma}, \dot{\sigma}_A, \dot{\sigma}_D$ and ϕ .

G_m, G_T, G_c are the nonlinear terms and calculated on the Gaussian grids. After the calculation, these terms are to be transferred to the spectral coefficients. Other terms in each equation are directly calculated by the spectral method.

In this model, ε_1 is taken as the decaying scale of 1 day on the level $\sigma = 0.9$. Newtonian damping ε_2 with an e-folding scale of 10-day for all the model levels. Coefficient of the diffusion term ν_1 is taken to be a decaying scale of 10 days.

Structure of the model

$\dot{\sigma}_1 = 0$ ———————— $\sigma = 0$

ϕ_1, T_1, u_1, v_1

$\dot{\sigma}_2$ ———————— $\sigma = 0.2$

ϕ_2, T_2, u_2, v_2

$\dot{\sigma}_3$ ———————— $\sigma = 0.4$

ϕ_3, T_3, u_3, v_3

$\dot{\sigma}_4$ ———————— $\sigma = 0.6$

ϕ_4, T_4, u_4, v_4

$\dot{\sigma}_5$ ———————— $\sigma = 0.8$

ϕ_5, T_5, u_5, v_5

$\dot{\sigma}_6 = 0$ ———————— $\sigma = 1.0$

$\ln P_s$

Semi-implicit integration scheme for the gravity wave

$$\frac{\partial D}{\partial t}=-\nabla^2(\phi+R\overline{T}_{s0}\ln P_s)+\nabla\cdot\vec{G}_m$$

$$\frac{\partial T}{\partial t}=\frac{\kappa\overline{T}_{s0}}{\sigma}\sum_{k=1}^{kx}(D-\overline{D})\Delta\sigma_k-\kappa\overline{T}_{s0}\sum_{k=1}^{kx}D\cdot\Delta\sigma_k+G_T$$

$$\frac{\partial\ln P_s}{\partial t}=-\sum_{k=1}^{kx}D\Delta\sigma_k+G_c$$

$$\left[\frac{\partial D}{\partial t}\right]=-\nabla^2(\phi^{t+1}+R\overline{T}_{s0}\ln P_s^{t+1}-\phi^{t-1}-R\overline{T}_{s0}\ln P_s^{t-1})-\nabla^2(\phi^{t-1}+R\overline{T}_{s0}\ln P_s^{t-1})+\nabla\cdot\vec{G}_m$$

$$=-(2\Delta t)\nabla^2\left\{\left[\frac{\partial\phi}{\partial t}\right]+R\overline{T}_{s0}\left[\frac{\partial\ln P_s}{\partial t}\right]\right\}-\nabla^2(\phi^{t-1}+R\overline{T}_{s0}\ln P_s^{t-1})+\nabla\cdot\vec{G}_m \quad (21)$$

$$\left[\frac{\partial T}{\partial t}\right]=\frac{\kappa\overline{T}_{s0}}{\sigma}\sum_{k=1}^{kx}(D-\sum_{k'=1}^{kx}D\cdot\Delta\sigma_{k'})\Delta\sigma_k-\kappa\overline{T}_{s0}\sum_{k=1}^{kx}D\cdot\Delta\sigma_k+G_T$$

$$=\frac{\kappa\overline{T}_{s0}}{\sigma}[X_B][D]-\kappa\overline{T}_{s0}[D][\Delta\sigma]+G_T$$

$$=\left[\frac{\kappa\overline{T}_{s0}}{\sigma}[X_B]-\kappa\overline{T}_{s0}[\Delta\sigma]\right][D]^{t+1}+G_T$$

$$=(2\cdot\Delta t)\left[\frac{\kappa\overline{T}_{s0}}{\sigma}[X_B]-\kappa\overline{T}_{s0}[\Delta\sigma]\right]\left[\frac{\partial D}{\partial t}\right]+\left[\frac{\kappa\overline{T}_{s0}}{\sigma}[X_B]-\kappa\overline{T}_{s0}[\Delta\sigma]\right]\left[D^{t-1}\right]+G_T \quad (22)$$

$$\left[\frac{\partial\ln P_s}{\partial t}\right]=-[D][\Delta\sigma]+G_c$$

$$=-(2\cdot\Delta t)\left[\frac{\partial D}{\partial t}\right][\Delta\sigma]-\left[D^{t-1}\right][\Delta\sigma]+G_c \quad (23)$$

$$\left[\frac{\partial\phi}{\partial t}\right]=[X_D]\left[\frac{\partial T}{\partial t}\right]$$

$$\left[\frac{\partial D}{\partial t}\right]=-(2\Delta t)\nabla^2\left\{[X_D]\left[\frac{\partial T}{\partial t}\right]+R\overline{T}_{s0}\left[\frac{\partial\ln P_s}{\partial t}\right]\right\}-\nabla^2(\phi^{t-1}+R\overline{T}_{s0}\ln P_s^{t-1})+\nabla\cdot\vec{G}_m \quad (24)$$

$$[\Delta\sigma]=\begin{pmatrix}\Delta\sigma_1 & \Delta\sigma_2 & .... & \Delta\sigma_{KX}\end{pmatrix} \qquad [D]=\begin{pmatrix}D_1\\ D_2\\ \ldots\\ D_{KX}\end{pmatrix}$$

Anomaly model:

$$\frac{\partial \vec{V}'}{\partial t} = -\nabla\phi' - R\overline{T}_{s0}\nabla(\ln P_s)' + \vec{G}_m - \overline{\vec{G}_m} \tag{25}$$

$$\frac{\partial T'}{\partial t} = \frac{\kappa\overline{T}_{s0}}{\sigma}\dot{\sigma}'_D - \kappa\overline{T}_{s0}\overline{D'} + G_T - \overline{G_T} \tag{26}$$

$$\frac{\partial(\ln P_s)'}{\partial t} = -\overline{D'} + G_c - \overline{G_c} \tag{27}$$

1. Based on the observed mean state of $\overline{u}, \overline{v}, \overline{T}, \overline{P_s}$, obtain the tendency of the nonlinear terms in each equation by the mean state.
2. Include heating term in the thermal equation, integrate the model and reach a new steady state.
3. The anomalous circulation is obtained by the deviation between the new state and mean state. And the anomalous tendency terms can also be obtained by the difference between the total tendency and the one by mean state only.

Attention: This anomalous model is mainly employed for the study on the tropical region. A strong Newtonian cooling rate of 1 K/day is applied for the off-tropical region beyond 40^{o}N and 40^{o}S. If you intend to check the tropical-midlatitude interaction, you should modify this Newtonian cooling rate.

See "./gcm/main.F "

```
c for T42
        rtautnl0=1./(86400.*1.)
        do j=22,43
        rtautnl(j)=rtautnl0*(exp(-(j-22.)/2.)+exp(-(43-j)/2.))
        enddo
        do j=1,21
        rtautnl(j)=rtautnl0
        enddo
        do j=44,IL
        rtautnl(j)=rtautnl0
        enddo
```

Model codes can be downloaded from the following website:

http://www.soest.hawaii.edu/~jiang/agcm.tar.gz

To unpack the file, enter "tar –zxvf agcm.tar.gz" under the UNIX prompt.

Note: Should be careful that a directory "agcm" will be created under the current directory after execute this command.

Any problems when downloading the codes, please contatct Xianan Jiang: xianan@hawaii.edu.

Structure of the model codes

agcm :: **gcm** (source codes of the model)

ncep (mean state for each month by the NCEP reanalysis)

post (some script files (.ctl, .gs) for post-processing)

rundeck (the script file to execute this model)

transforms (codes for the spectral transforms, no need to be modified.)

How To run the model?

(a) Modify the "modeldir" in the file "./rundeck/run" with your current directory for the model after unpacked.

(b) Excute "./run&" under the directory "./rundeck". An intergration for 60 days of the model (by default in the model) is expected to last about 20-30 minutes on Sun workstation.

Attention: By default, the model output will be stored in the directory "./tmp". If this directory doesn't exist, it will be created. In case this directory exists before you run the model, all the files under this directory will be deleted! Therefore, if you want to keep these results from the previous run, you'd better change "FTMPDIR" in the file "./rundeck/run".

Appendix: file "run" under ./rundeck

```
#! /bin/csh
#
#
###limit cputime 600


set modeldir = your_home_directory/agcm      <= Your directory
FTMPDIR = $modeldir/tmp    <= working directory for the output


if (-d $FTMPDIR) then
  /bin/rm -r $FTMPDIR
endif
mkdir $FTMPDIR

""cd $FTMPDIR



set speclib = $modeldir/transforms
set prog    = $modeldir/gcm
set fft     = $speclib/fftnew.F
set pst     = $modeldir/post


date >! printout
date >! job.log

echo '                                            ' >> job.log
echo '********************************************' >> job.log
echo '                                            ' >> job.log
#date >> job.log


set bomb = 0


set tnl = anomalymodel
set res = t42

set comp = not_ymp
set pol = pol1
#set pol = pol2
set trunc = triang
set ntrace=0

set xtrace = trace
if ($ntrace == 0) then
  set xtrace = notrace
endif


set vec = lat

/bin/cp $prog/*.[Ffh] .
#/bin/cp $prog/grtend.$vec grtend.F

/bin/cp $speclib/*.[h] .
/bin/cp $speclib/spectral.F .

if($comp != ymp) then
/bin/cp $fft fftnew.f
endif


# for restart only
```

```
#/bin/cp fort.40 fort.30


f90 -D$comp -D$res -D$pol -D$trunc -D$vec -D$xtrace -D$tnl -O -o gcm *.[fF] >> printout
|| set bomb = 1

if ($bomb > 0) then
  echo "Problems in compile"
  exit
endif


gcm >> printout || set bomb = 1

if ($bomb > 0) then
  echo "Problems in run"
  exit
endif



echo 'IDEAL GCM ' >> job.log
date >> job.log
time >> job.log
echo '                                            ' >> job.log
echo '********************************************' >> job.log
echo '                                            ' >> job.log



#clean up tmp
/bin/rm *.[Ffho]


/bin/cp $pst/ *.ctl .
```

Brief description of the programs (./gcm):

bound.F :: dynamical damping in the boundary layer .

damp.F :: horizontal diffusion coefficients

dinit.F :: calculate the damping coefficients

geop.F :: calculate geopotential height by T and ϕ_s (for anomaly model, ϕ_s =0)

grtend.F :: calculate the tendency of nonlinear terms in each model equation on the Gaussian grid system.

heat.F :: prescribe heating term in the thermal dynamical equation.

hist.F :: Output model results on both the sigma levels and interpolated pressure levels.

impint.F :: Calculate the coefficient matrix for the semi-implicit method

implic.F :: calculate tendency by the semi-implicit part

init.F :: Initialize the model variables and read the initial condition from the restart file if a restart run is specified.

main.F :: Driving part of this model.

rinit.F :: Radiation drag coefficients is prepared.

sptend.F :: calculate the tendency of linear terms in each model equation in the spectral space.

step.F :: To control the integration step.

Main controls:

Anomaly Model or not?

./rundeck/run :: “set tnl = anomalymodel”

The horizontal resolution of the model:

./rundeck/run :: “set res = t42”

The vetical resolution of the model:

./gcm/param1.h :: “kx=5”

Time step:

./gcm/main.F :: “NSTEPS=48” which shows the number of the steps per day, i.e. 30 minutes.

Integration period:

./gcm/main.F :: “JSTEPS=60*nsteps” which means 60 days.

Output frequency:

./gcm/main.F :: “IPRINT=48” which mean 48 steps, i.e., 1day when the NSTEPS is set to be 48.

Topography:

./gcm/main.F :: “ITOP”, value “0” represents without topography ϕ_s, “1” indicates with topography when computing the gepotential height $\phi = \phi_s + \int_1^{\sigma} RT \ln \sigma d\sigma$. For the anomaly model, ITOP should be set to “0”. If ITOP is set to be “1”, the topography profile should be given in the subroutine “TOPOG” (topog.F, ZSTAR).

Advanced controls:

(i) To modify the anomalous heating distribution, both horizontally and vertically, and its intensity.

./gcm/heat.F

(a) Vertical distribution:

```
vvvv(1)=0.2
vvvv(2)=0.8
vvvv(3)=1.0
vvvv(4)=0.5
vvvv(5)=0.1
```

The above setting shows the maximum of the heating center about $\sigma = 0.3 \sim 300hPa$, which is usually observed for the deep convection in tropics. You can modify this setting to fit for your study.

(b) Horizontal distribution:

```
**Equator 120E
      if(i.lt.49.and.i.gt.35.and.j.gt.29.and.j.lt.36)
* hhhh=(cos((i-42.)/7.*pih)**2)*(cos((j-32.5)/3.*pih)**2).
```

You can modify the shape and extension here.

(c) The amplitude of the heating:

```
hting=2.0/86400.*vvvv(k)*hhhh
```

which gives an amplitude of 2K/day.

(ii) To choose different basic state.

./gcm/basic.F

```
open(9,file='../ncep/bu_jun.t42',
```

open(10,file='../ncep/bu_jul.t42',
open(11,file='../ncep/bu_aug.t42',

By default, the summer mean (JJA) is given in this model (basic.F); you can change to any seasonal or month mean by modifying the input file(s). All the basic state files for every month are stored in "./ncep".

Post-processing:

Output of the model (./tmp):

hiss.dta :: horizontal heating pattern using in this model, using the corresponding Grads file "heat.ctl" to open it.

hist.dta :: output of u, v, T, ϕ on the 5 model-sigma levels, using the corresponding Grads file "hist.ctl" to open it.

hiss.dta :: output of u, v, T, ϕ on the 5 pressure levels, using the corresponding Grads file "hiss.ctl" to open it.

*Note: You can change the output pressure levels, by modifying the PREFK(k) in the subroutine "SIGMATOP" in ./gcm/hist.F.

Fort.40 :: the restart file archived for a new run.

The GRADS files are stored in the ./post directory.

Two examples of the application of this AGCM can be found in the following papers.

Wang, B., R. Wu, T. Li, 2003: Atmosphere-Warm Ocean interaction and its impact on Asian-Australian Monsoon variation. *J. Climate*, 16, 1195-1211

Jiang, X. and T. Li, 2005: Reinitiation of the boreal summer intraseasonal oscillation in the tropical Indian Ocean. *J. Climate*, 18, 3777-3795.

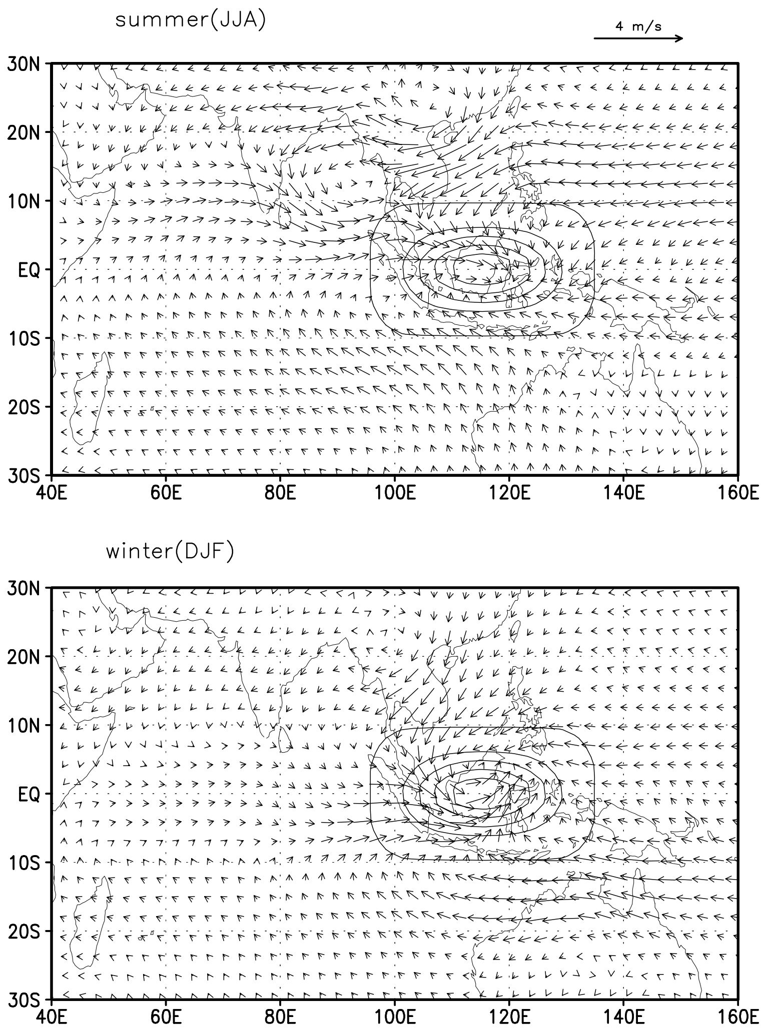

Fig. 1. The low-level wind response to an equatorial symmetric heating simulated by using an anomalous AGCM with specified realistic 3D mean summer (JJA) basic state. The contours represent horizontal distribution of the heating strength at an interval of 0.48^{o}C day^{-1} with maximum amplitude of the heating rate of 2^{o}C day^{-1}, which is located in the mid-troposphere.

Wang, B., R. Wu, T. Li, 2003: Atmosphere-Warm Ocean interaction and its impact on Asian-Australian Monsoon variation. *J. Climate*, 16, 1195-1211

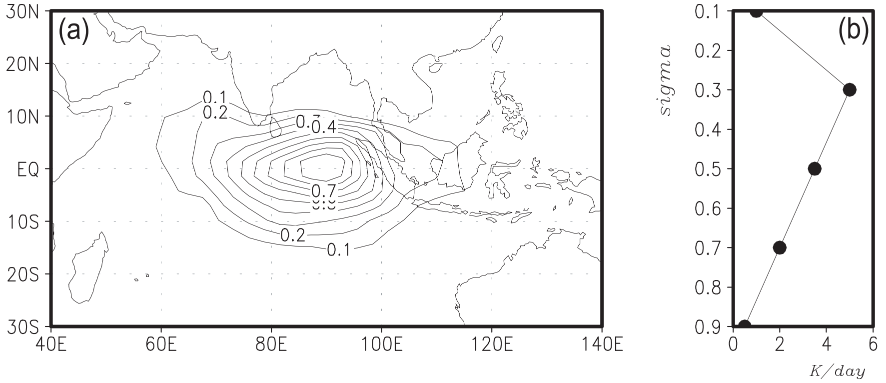

Fig. 2 Horizontal distribution (a) and vertical profile (b) of the diabatic heating ($K \cdot day^{-1}$) prescribed in the AGCM which is adopted from the BSISO OLR pattern at composite day 0. The vertical coordinate in (b) is sigma level.

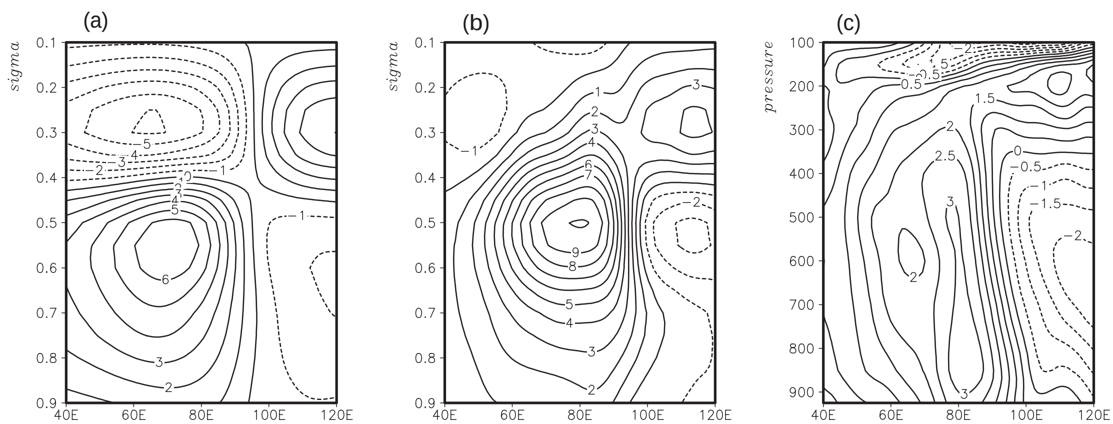

Fig. 3 Longitudinal-vertical profile of wind u-component (m s^{-1}): (a) by AGCM experiment with a resting environmental flow; (b) by the experiment with summer mean flow; (c) by NCEP-NCAR reanalysis at composite day 0. The vertical coordinates for (a) and (b) are the sigma levels in the model, for (c) is pressure (hPa).

Jiang, X. and T. Li, 2005: Reinitiation of the boreal summer intraseasonal oscillation in the tropical Indian Ocean. *J. Climate*, 18, 3777-3795.