ABC vn 2.0: Guide to running Hydro-ABC, the research convective scale modelling system

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1 Introduction

1.1 The ABC model

The Hydro-ABC model (vn 2.0) is a combined 2D (longitude/height) convective-scale toy model, which includes evaporation and condensation processes. The model equations are as follows:

$$\frac{\partial u}{\partial t} + B\mathbf{u} \cdot \nabla u + C\frac{\partial \tilde{\rho}'}{\partial x} - fv = 0 \tag{1a}$$

$$\frac{\partial v}{\partial t} + B\mathbf{u} \cdot \nabla v + fu = 0 \tag{1b}$$

$$\frac{\partial w}{\partial t} + B\mathbf{u} \cdot \nabla w + C\frac{\partial \tilde{\rho}'}{\partial z} - b' = 0 \tag{1c}$$

$$\frac{\partial \tilde{\rho}'}{\partial t} + B\nabla \cdot (\tilde{\rho}\mathbf{u}) = 0 \tag{1d}$$

$$\frac{\partial b'}{\partial t} + B\mathbf{u} \cdot \nabla b' + A^2 w = \mathcal{S}_{b'} \tag{1e}$$

$$p' = C\rho_0\tilde{\rho}' \tag{1f}$$

$$\frac{\partial \tilde{\rho} q}{\partial t} + B\nabla \cdot (\tilde{\rho} q\mathbf{u}) = \tilde{\rho}(Ev - Co) \tag{1g}$$

$$\frac{\partial \tilde{\rho} q_{\mathrm{c}}}{\partial t} + B\nabla \cdot (\tilde{\rho} q_{\mathrm{c}}\mathbf{u}) = -\tilde{\rho}(Ev - Co). \tag{1h}$$

The prognostic variables are as follows:

- u is the zonal wind,
- v is the meridional wind,
- w is the vertical wind,
- $\mathbf{u} = (u, v, w)$ is the wind vector,
- $\tilde{\rho}$ is a density-like variable (where $\tilde{\rho}'$ is the perturbation, $\tilde{\rho} = \tilde{\rho}_0 + \tilde{\rho}'$, where in this model, $\tilde{\rho}_0 = 1$),
- b' is a buoyancy-like variable (for meteorologists, b' is related to potential temperature, θ', by $b' = g\theta'/\theta_{\mathrm{R}}$, where g is the acceleration due to gravity and θ_{R} is the reference potential temperature of 273K),

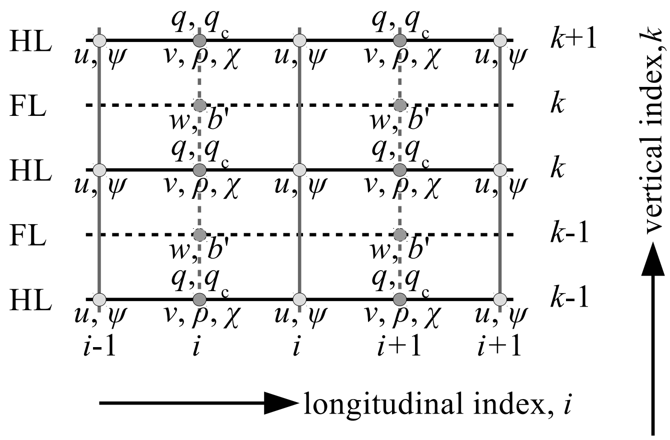

Figure 1: The arrangement of variables on the toy model's grid: an Arakawa-C grid in the horizontal and a Charney-Phillips grid in the vertical. Note the abbreviations: FL=Full Level and HL=Half Level.

- q is the vapour mixing ratio, and
- q_c is the water condensate mixing ratio.

The dimension variables are as follows: x is longitudinal distance, z is vertical distance, and t is time. Constant parameters to be chosen by the user are as follows: A (units s^{-1}) is the static stability (equivalent to the pure gravity wave frequency), B (dimensionless) multiplies the advection and divergence terms, and C (units m^2s^{-2}) relates density perturbations to pressure perturbations, $p' = C\rho_0\tilde{\rho}'$, where ρ_0 is a reference density. The value of $\sqrt{BC}$ is the pure acoustic wave speed). These parameters give the model its "ABC" name. The constant f is the Coriolis parameter. $\mathcal{S}_{b'}$ is the buoyancy source term (related to latent heat exchange, which is activated when there is a change in water phase), Ev is the evaporation rate, and Co is the condensation rate. The key differences between Hydro-ABC the dry ABC system are $\mathcal{S}_{b'}$ in (1e), and the additional equations (1g) and (1h). How $\mathcal{S}_{b'}$ and $Ev - Co$ are parametrised in Hydro-ABC is described in the main paper (submitted to Geo-scientific Model Development, December 2022). There is also a tracer transport equation, which advects a tracer, q_{tr}, with the wind vector $\mathbf{u}$, and not by the modified winds, $B\mathbf{u}$:

$$\frac{\partial q_{\mathrm{tr}}}{\partial t} + \mathbf{u} \cdot \nabla q_{\mathrm{tr}} = 0. \tag{2}$$

The model is run in a 2D slice (longitude/height) geometry. All variables are considered constant in the meridional direction. The model grid is an Arakawa-C grid in the horizontal and a Charney-Phillips grid in the vertical (Fig. 1). The default grid has a size of 1.5km in the horizontal, with 360 grid-points, and 60 vertical levels. The scientific rational for this model is given in [1].

The code is set-up as a number of master subroutines, each designed to do a particular job (such as running the model from specified initial conditions). This guide comprises the following sections, in Sect. 2 we give the full list of master routines; in Sect. 3 we describe how the software is downloaded and installed (also stating which software libraries are required), and in Sect. 4 (which makes up the bulk of this documentation) we describe how each master routine is used.

2 List of master routines

The code is written in Fortran-90, and the master routines are run inside bash script wrappers. The recommended operating system to run the code is Linux. Scientific documentation is provided on the model [1] and on the data assimilation (in preparation). Each of these master routines is associated with a top-level Fortran 90 subroutine (*.f90*), and for some a top-level python routine (*.py*) for plotting the results. There are also examples (labelled with the respective master routine name) available.

Master routine	**Purpose**
Master_prepareABC_InitState (Sect. 4.1)	Inputs a UM dump and generates a single 2D longitude/height slice set of fields that is suitable as a set of initial initialised initial conditions for the ABC model.
Master_RunNLModel (Sect. 4.2)	Makes a single run of the ABC model from a specified set of initial conditions.
Master_Linear_Analysis (Sect. 4.3)	Analyses the linear modes of the dry parts of the ABC model.

3 Downloading and installing the software

3.1 Required libraries on host system

This software requires the following free software and libraries to be installed on the host system.

- Fortran compiler (f95). This is needed to compile the Fortran-90 code into executable files.
  - Net CDF library. This is needed to handle the input and output of fields.
  - FFTpack. This is needed to perform the fast Fourier transforms.
  - LApack.
  - tmglib.
  - refblas.

3.2 Contents of ABC download

The following sets of files are included with this software in the respective directories.

- ABCvn1.4/src
  - Readme.txt
  - Fortran-90 source code (multiple .f90 files).
  - Interface files for subroutines that have optional arguments (multiple .interface files).
  - makefile (to manage the compilation of the software, depending upon the master routine to be run).
- ABCvn1.4/docs
  - Documentation of the system.

3.3 Compiling the code

Once the *src* directory is downloaded, go into this directory and type

```
make all
```

to compile all programs. Alternatively to compile just one master program (e.g. Master_RunNLModel), type

```
make Master_RunNLModel.out
```

Further guidance is given below.

4 Using the master routines

Each master routine is described in this section. This includes how to compile the master routine and dependent code, and how to run it. The namelist variables are defined, plus the required input and output files.

4.1 Master_PrepareABC_InitState

Inputs a UM dump and generates a single 2D longitude/height slice set of fields that is suitable as a set of initial initialised initial conditions for the ABC model.

To compile

Go to directory containing source code ($ABC_SRC), and issue:

```
make Master_PrepareABC_InitState.out
```

To run

Prepare namelist file UserOptions.nl, go to directory containing this file, and issue:

```
$ABC_SRC/Master_PrepareABC_InitState.out < namelist_file
```

Namelist variables

The namelist variables are described in UserOptions.nl, and should be placed in the directory where the above run command is issued. The variables are described in the following table, where blue entries describe the input directories/files, red entries describe the output directories/files, and purple entries describe the input/output directories/files. An example namelist is given in the file ABCvn1.4/examples/Master_PrepareABC_InitialState/UserOptions.nl.

Variable	Type	Description	Default	Notes
nlongs	integer	No. of longitude points	360	
nlevs	integer	No. of levels	60	
dx	double precision	Length of gridbox	1500.0	
Init_ABC_opt	integer	How to create ABC initial conditions.	No default	1=slice of UM; 2=zero apart from pres pert bubble; 3=sum of 1,2; 4=zero apart from buoy pert bubble; 5=sum of 1,4; 6=sum of 2,4; 7=sum of 1,2,4. 8=add 3 $\lvert b'_{\mathrm{neg}}\rvert$ to b' (b'_{neg} is most neg value of b' pre modification)
datadirUM	string	Directory containing UM data.	No default	Needed for all options (e.g. for dimension data).
init_um_file	string	UM data filename (expected in above directory).	No default	Needed for all options (e.g. for dimension data).

latitude	integer	Index of single latitude to extract from UM file.	144	Init_ABC_opt=1,3, 5, 6, 7
Regular_vert_grid	logical	Used to set a regularly-spaced vertical grid.	.TRUE.	
A	double precision	Model parameter (pure gravity wave frequency).	0.02	s^{-1}
B	double precision	Model parameter (modulation of the divergent and advection terms).	0.01	
C	double precision	Model parameter (proportionality constant for the equation of state).	100000.0	$\mathrm{m}^2\mathrm{s}^{-2}$
f	double precision	Model parameter (Coriolis parameter).	0.0001	s^{-1}
source_x	integer	To specify horizontal grid box of centre of press/buoy pert./most bubble	180	Init_ABC_opt=2,3,4,5
source_z	integer	To specify vertical grid box of centre of press/buoy pert./most bubble	30	Init_ABC_opt=2,3,4,5
press_amp	double precision	Amplitude of pressure perturbation	0.01	Init_ABC_opt=2,3
buoy_amp	double precision	Amplitude of buoyancy perturbation	0.1	Init_ABC_opt=4,5
x_scale	integer	No. of horizontal grids to describe size of press/buoy pert.	80	Init_ABC_opt=2,3,4,5
z_scale	integer	No. of vertical grids to describe size of press/buoy pert.	3	Init_ABC_opt=2,3,4,5
Adv_tracer	logical	Used to switch on/off tracer advection.	.FALSE.	Sets up a 4×5 grid of point initial tracer positions.
gravity_wave_switch	logical	Used to switch on/off setting of $u = 0$ to simulate gravity waves.	.FALSE.	
BoundSpread	double precision	No. of horizontal grid points to spread boundary discontinuity for periodic boundary conditions.	50.0	
Moist_on	logical	Set to activate moisture initial conditions	.TRUE.	
theta00	double precision	Surface potential temperature	300.0	K
SH	double precision	Scale height	9000.0	m
IQ_option	integer	Options for q initiation	1	1=vapour bubble, 2=vapour stratification, 3=RH stratification
Lv	double precision	Latent heat constant	2500.0	Jg^{-1}
q_amp	double precision	Amplitude for initiation of q	0.0	gkg^{-1} or RH, depending on IQ_option
datadirABC_out	string	Main output directory.		

init_ABC_file	string	Output filename (in above directory).

Input and output files

- Inputs
  - Suitable Unified Model (UM) dump for the Southern UK region (datadirUM/init_um_file). This is a netcdf file of fields of 360 longitudes, 287/288 latitudes, and 70/71 vertical levels. The file contains the following: u (zonal wind), v (meridional wind), dz_dt (vertical wind, w), $unspecified$ (density, ρr_{E}^2, where r_{E} is the Earth's radius), $theta$ (potential temperature, θ), $field7$ (exner pressure, Π), and ht (2D orographic height field). The dimension names are x (longitude axis for u), x_1 (longitude axis for v, w, ρr_{E}^2, θ, Π, and ht), y (latitude axis for u, θ), y_1 (latitude axis for v, w, ρr_{E}^2, θ, Π, and ht), $hybrid\_ht$ (vertical axis for u, v, and ρr_{E}^2), $hybrid\_ht\_1$ (vertical axis for θ), $hthybrid\_ht\_2$ (vertical axis for w), $hybrid\_ht\_3$ (vertical axis for Π), and $surface$ (vertical axis for ht). The complete filename is datadirUM/init_um_file.
- Outputs
  - Initial dump for the ABC model. This is a netcdf file of fields of 360 longitudes and 60 vertical levels (datadirABC_out/init_ABC_file). The file contains the following: u, v, w, ρ', b', $\rho = 1 + \rho'$, b_{eff}, $tracer$, geo_imbal (geostrophic imbalance), $hydro\_imbal$ (hydrostatic imbalance), $wmom\_source$ (vertical momentum source), $horiz\_div$ (horizontal divergence), $horiz\_vort$ (horizontal vorticity), E_{k} (total kinetic energy), E_{b} (total buoyant energy), E_{e} (elastic energy), E (total energy, $E = E_{\mathrm{k}} + E_{\mathrm{b}} + E_{\mathrm{e}} + E_{\mathrm{l}}$), q, q_{c}, and RH. The dimension names are $longs\_u$ (horizontal axis for u), $longs\_v$ (horizontal axis for other fields), $half\_level$ (vertical axis for u, v, ρ', ρ, $tracer$, geo_imbal, $horiz\_div$, $horiz\_vort$, q, q_{c}, and RH), $full\_level$ (vertical axis for w, b', b_{eff}, $hydro\_imbal$, and $wmom\_source$.

The meanings of the symbols in the output file are described in [1] and the hydro-ABC paper (submitted to Geo-scientific Model Development, December 2022).

4.2 Master_RunNLModel

Makes a single run of the ABC model from a specified set of initial conditions. The model equations are given as Eqs. (1) above. The dry scheme is described by [1] and the moisture-related additions are described in a new manuscript (submitted to Geo-scientific Model Development, December 2022).

To compile

Go to directory containing source code ($ABC_SRC), and issue:

```
make Master_RunNLModel.out
```

To run

Prepare namelist file UserOptions.nl, go to directory containing this file, and issue:

```
$ABC_SRC/Master_RunNLModel.out < namelist_file
```

Namelist variables

The namelist variables are described in UserOptions.nl, and should be placed in the directory where the above run command is issued. The variables are described in the following table, where blue entries describe the input directories/files, red entries describe the output directories/files, and purple entries describe the input/output directories/files. An example namelist is given in the file ABCvn1.4/examples/Master_RunNLModel/UserOptions.nl.

Variable	Type	Description	Default	Notes
nlongs	integer	No. of longitude points	360	
nlevs	integer	No. of levels	60	
dx	double precision	Length of gridbox	1500.0	
datadirABC_in	string	Input directory.		
init_ABC_file	string	Input filename (in above directory).		
A	double precision	Model parameter (pure gravity wave frequency).	0.02	s^{-1}
B	double precision	Model parameter (modulation of the divergent and advection terms).	0.005	
C	double precision	Model parameter (proportionality constant for the equation of state).	100000.0	$\mathrm{m}^2\mathrm{s}^{-2}$
f	double precision	Model parameter (Coriolis parameter).	0.0001	s^{-1}
dt	double precision	Model time step size.	4.0	s
runlength	double precision	Length of integration.	60.0	s
ndumps	integer	The number of times to dump the model state throughout runlength.	10	
Adv_tracer	logical	Used to switch on/off tracer advection.	.FALSE.	

Lengthscale_diagnostics	logical	Used to switch on/off computation of characteristic lengthscales of variables at the final time (and other diagnostics).	.FALSE.	
Moist_on	logical	Set to activate moisture initial conditions	.TRUE.	
tau	double precision	Evaporation timescale	1.0E4	s
theta00	double precision	Surface potential temperature	300.0	K
SH	double precision	Scale height	9000.0	m
Lv	double precision	Latent heat constant	2500.0	Jg^{-1}
Ev_option	integer	Options for evaporation (concerning sign of b')	1	
CO_thresh	double precision	Threshold for condensation	0.0	
datadirABC_out	string	Main output directory.		
output_ABC_file	string	Output file (model trajectory, in above directory).		
diagnostics_file	string	Diagnostics file (in above directory).		

Note that if *runlength*=0.0 and *ndumps*=0, the model is not run, and the output of the code (datadirABC_out/output_ABC_file) is formed from the initial conditions, i.e. the fields that comprise the last time in the input ABC file (datadirABC_in/init_ABC_file).

Input and output files

- Inputs
  - Suitable ABC dump (datadirABC_in/init_ABC_file, e.g. output by Master_PrepareABC_InitState in Sect. 4.1). The latest time present in this file is used as the initial conditions for the model.
- Outputs
  - Time sequence of ABC model trajectory (datadirABC_out/output_ABC_file). This is a netcdf file of fields as the initial dump, but with multiple times.
  - Diagnostics file (datadirABC_out/diagnostics_file). This contains a model-time-step-by-model-time-step output of each component of energy (time, E_k, E_b, E_e, E (where the total energy, E, includes the latent heat contribution)), followed by diagnostics for the last timestep (if Lengthscale_diagnostics is set).

4.3 Master_Linear_Analysis

Analyses the linear modes of the ABC model. A description of the linear analysis is given in Sect. 4 of [1].

To compile

Go to directory containing source code ($ABC_SRC), and issue:

```
make Master_Linear_Analysis.out
```

To run

Prepare namelist file UserOptions.nl, go to directory containing this file, and issue:

```
$ABC_SRC/Master_Linear_Analysis.out < namelist_file
```

Namelist variables

The namelist variables are described in UserOptions.nl, and should be placed in the directory where the above run command is issued. The variables are described in the following table, where blue entries describe the input directories/files, red entries describe the output directories/files, and purple entries describe the input/output directories/files. An example namelist is given in the file ABCvn1.4/examples/Master_Linear_Analysis/UserOptions.nl.

Variable	Type	Description	Default	Notes
A	double precision	Model parameter (pure gravity wave frequency).	0.02	s^{-1}
B	double precision	Model parameter (modulation of the divergent and advection terms).	0.005	
C	double precision	Model parameter (proportionality constant for the equation of state).	100000.0	m^2s^{-2}
f	double precision	Model parameter (Coriolis parameter).	0.0001	s^{-1}
H	double precision	Model domain height.	14862.01	m
datadirLinearAnal	string	Output directory.		

Input and output files

- Inputs
  - No inputs.
- Outputs
  - Gravity wave frequencies file (datadirLinearAnal/grav_frequency.dat). Given as a function of horizontal and vertical wavenumbers.
  - Acoustic wave frequencies file (datadirLinearAnal/acou_frequency.dat). Given as a function of horizontal and vertical wavenumbers.
  - Gravity wave speed (in the horizontal) file (datadirLinearAnal/hori_grav_speed.dat). Given as a function of horizontal and vertical wavenumbers.

- Acoustic wave speed (in the horizontal) file (datadirLinearAnal/hori_acou_speed.dat). Given as a function of horizontal and vertical wavenumbers.
- Gravity wave speed (in the vertical) file (datadirLinearAnal/vert_grav_speed.dat). Given as a function of horizontal and vertical wavenumbers.
- Acoustic wave speed (in the vertical) file (datadirLinearAnal/vert_acou_speed.dat). Given as a function of horizontal and vertical wavenumbers.

Graphics tools

- The python code *PlotWaveSpeeds.py* can be used to plot the wave frequencies and wave group speeds.

References

[1] Ruth Elizabeth Petrie, Ross Noel Bannister, and Michael John Priestley Cullen. The ABC model: a non-hydrostatic toy model for use in convective-scale data assimilation investigations. *Geoscientific Model Development*, 10(12):4419, 2017.