Cheapaml

WK Dewar

May 2, 2006

Cheapaml – a package to compute heat, momentum and fresh water fluxes for the ocean module of the MITgcm through interaction of an atmospheric boundary layer model and oceanic sea surface temperature. The design of the atmospheric mixed layer is similar to the development in Seager, et al., (1995)[1].

Equations Solved

The primary subroutine of the Cheapaml package computes the solution of the equations

$$\frac{\partial}{\partial t}T_a + \vec{u_a} \cdot \nabla T_a = K_a \nabla^2 T_a - \frac{\delta F}{\rho_a C_{pa} h_{aml}} \tag{1}$$

$$\frac{\partial}{\partial t}q_a + \vec{u_a} \cdot \nabla q_a = K_a \nabla^2 q_a - \frac{e-p}{\rho_a h_{aml}} \tag{2}$$

where T_a denotes atmospheric temperature, q_a atmospheric specific humidity, $\vec{u}_a$ atmospheric mixed layer velocity, K_a atmospheric lateral diffusivity, e evaporation, p precipitation and δF represents the net energy flux into the atmospheric mixed layer. The two quantities atmospheric sea level density, ρ_a, and atmospheric heat capacity, C_{pa} convert the energy fluxes to heat fluxes. Division by the atmospheric mixed layer height, h_{aml}, produces the required heat and moisture flux divergences. Generally, $\delta F = F_u - F_l$, where F_u is heat flux out of the mixed layer top and F_l the heat flux into the mixed layer base at the ocean-atmosphere interface. Certain applications may not require explicit freshwater flux, e.g. if the fluid is stratified in heat only. In

---

[1] Seager, R., M. Blumenthal and Y. Kushnir, 1995: An Advective Atmospheric Mixed Layer Model for Ocean Modeling Purposes: Global Simulation of Surface Heat Fluxes, *J. Clim.*, 1951-1964.

this case, Cheapaml may be used in a heat forcing only manner where (2) is not solved.

The MITgcm ocean module receives atmospheric heat and water fluxes at its surface. Both, as generally computed, are functions of atmospheric and oceanic interface temperatures, and the objective of Cheapaml is to provide evolving atmospheric temperature and specific humidity fields leading to dynamically computed oceanic heat and water fluxes. In contrast, Cheapaml assumes the two-dimensional velocity field of the atmospheric mixed layer, denoted in (2) as $\vec{u_a}$, is provided as input to the model.

The formula used for δF depends upon where the flux is computed. It is assumed that atmospheric temperature evolution over land is not of primary interest, and therefore T_a at such points is relaxed towards a specified temperature profile, i.e. $\frac{\delta F}{\rho_a C_{pa} h_{ml}} = -\gamma(T_a - T_{spec})$, where T_{spec} is the specified profile and γ is the relaxation timescale. This relaxation is performed implicitly.

Over the ocean, F_l is composed of several parts, i.e. sensible flux, latent flux, upwelled longwave radiation, downwelled longwave radiation and downwelled shortwave radiation nominally of solar origin. The shortwave profile, F_s, is assumed to be given to the model and provided in units of W/m^2 ($W = Watts$). Calling sea surface temperature T_s, upwelled longwave radiation from the ocean surface is computed according to $F^{\uparrow} = \sigma T_s^4$, where σ is the Stefan-Boltzman constant $\sigma = 5.7x10^{-8} W/(m^2 K^4)$. Downwelling longwave radiative flux from the atmosphere is computed according to

$$F^{\downarrow} = -0.5\sigma T_a^4 \tag{3}$$

where the factor 0.5 is included to model the simultaneous radiation of the atmosphere in both vertical directions. The upwelled longwave radiative contribution from the atmosphere is computed according to

$$F^{\uparrow} = 0.5\sigma T_a^4 = -F^{\downarrow} \tag{4}$$

and aside from the sign is identical to the downwelled longwave flux. Sensible and latent flux is computed according to bulk formula in the same manner as done in the bulk forcing subroutine bulkf_formula_LANL.F. If fresh water flux is desired, precipitation is evaluated according to a model discussed below and full evolution of specific humidity is computed. If Cheapaml is used in a heat flux only mode, atmospheric relative humidity is set to a constant value of 80%. This is used to compute evaporation and thus latent heat flux.

Precipitation is neglected in this setting. Both sensible and latent fluxes are computed in units of W/m^2, whereas evaporation and precipitation are computed in units of m/s.

The quantity F_u consists of upwelled atmospheric long wave radiation (4), downwelled short wave radiation and, most importantly, latent flux. The latter contribution reflects the fact that the Seager model identifies the atmospheric boundary layer with the either the sub-cloud marine layer in the tropics or the dry convective layer in the mid-latitudes. Cloud formation occurs at heights where the gaseous water vapor undergoes phase change and condenses back to liquid form. It is at this height where the latent heat in the vapor is released to the atmosphere and may directly affect temperature. In the subcloud or dry convective layers, the energy flux remains in latent form and does not therefore affect temperature. We adopt this same approach. The formula for F_u also implicitly assumes that all of the upwelled longwave flux from the sea surface is absorbed within the subcloud layer, and is meant as a model of the relative atmospheric opacity to longwave radiation.

The primary way Cheapaml differs from the Seager model is in calculation of precipitation. Specifically, it is assumed the atmospheric boundary layer is well mixed in all quantities, in particular in water vapor density, m_w measured in kgH_2O/m^3. Thus, the total water content in the atmospheric column evolves according to

$$h_{aml}(\frac{\partial}{\partial t}m_w + \vec{u_a} \cdot \nabla m_w) = -(f_{wu} - f_{wl}) + K_a \nabla^2 m_w \tag{5}$$

where f_{wu} is the water flux through the top of the boundary layer and f_{wl} is the water flux at the air-sea interface. Converting m_w to specific humidity involves division by atmospheric density; here the conversion is achieved by dividing by atmospheric density at sea level, ρ_a.

The bulk formula employed in Cheapaml yield evaporation at the interface in units of m/s, using saturation specific humidity as computed by the Clausius-Clapeyron equation and q_a. The saturation specific humidity of the atmosphere at the top of the boundary layer is computed also using the Clausius-Clapeyron, but now evaluated at the upper boundary layer pressure (estimated based on the supplied value of h_{aml}) and the in-situ atmospheric temperature, itself computed from the local atmospheric potential temperature. If the specific humidity exceeds the upper level saturation specific humidity, the moisture content of the column is reduced to the upper saturation specific humidity. The moisture content loss implied by this specific humidity reduction is considered to be the precipitation from the atmosphere. The total water flux at the lower boundary is the difference of the evaporation and the precipitation, $f_{wl} = e - p$. The model implicitly assumes that the condensation occurs at the top of the atmospheric boundary layer, so that the latent heat release does not affect T_a. Commensurate with this, the upper boundary water flux, F_{wu}, vanishes; thus yielding the specific humidity formula in (2).

Compiling and executing with Cheapaml

To use Cheapaml, it is necessary to include the entry “Cheapaml” in the file packages.conf and to set “useCheapaml” to true in data.pkg, as shown below:

Contents of packages.conf: (packages debug, gneric_advdiff, mnc and Cheapaml are turned on, package bulk_force is turned off.)

```
#
# $Name: $
#
debug
generic_advdiff
mnc
# bulk_force
Cheapaml
```

Contents of data.pkg: (the only package turned on is Cheapaml)

```
# Packages
&PACKAGES
useCheapaml=.TRUE.
&
```

Cheapaml Impact on MITgcm Execution

When the package Cheapaml is invoked and the model executed, the first impact on MITgcm execution is in the subroutine PACKAGES_READPARMS.F. The model is directed to open the required data file “data.Cheapaml” in order to resolve the values of the parameters employed by Cheapaml:

Cheapaml_ntim, Cheapaml_h, Cheapaml_kdiff, Cheapaml_taurelax2, cdrag_1, cdrag_2, cdrag_3, rhoa, cpair, stefan, useFreshwaterFlux.

The definitions of these parameters are:

Cheapaml_ntim (integer) (default value 5)
the number of atmospheric timesteps taken during an oceanic timestep. As atmospheric velocities are typically much larger than ocean velocities, a time step reduction is required to insure maintenance of a CFL condition.

Cheapaml_h (real*8) (default value 1000.d0)
atmospheric boundary layer depth in meters

Cheapaml_kdiff (real*8) (default value 1.d4)
atmospheric horizontal temperature diffusion in m^2/s.

Cheapaml_taurelax2 (real*8) (default value 0.3d0)
expressed in days, controls the relaxation time scale of atmospheric temperature and humidity while over land points.

cdrag_1, cdrag_2, cdrag_3 (all real*8) (defaults cdrag_1=0.0027d0, cdrag_2=0.00142d0, cdrag_3=0.0000764d0)
constants employed in the computation of wind stress from wind speed. The default values are identical to those employed in the subroutine BULKCND.F.

rhoa (real*8) (default value1.3d0)
atmospheric sea level density in kg/m^3

cpair (real*8) (default value 1004.d0)
atmospheric heat capacity in units of $Joules/kg/^\circ K$.

stefan (real*8) (default value $5.67d - 8$)
the Stefan-Boltzmann constant, needed to compute longwave radiation, in units of $Watts/m^2/^\circ K^4$.

useFreshwaterFlux (logical) (default value .FALSE.)
the logical parameter that turns on or off the explicit calculation of specific humidity, and hence the computation of water flux to the ocean.

The model then reads filenames where data on atmospheric temperature, humidity, winds, solar forcing and relaxation temperature profiles are provided. All filenames default to empty, in which case the model uses internally specified fields for these inputs (see below). The list of Cheapaml filenames and the roles played by these fields are

AirTempFile (real*8) initial atmospheric temperature field

AirQFile (real*8) initial atmospheric specific humidity field

UWindFile (real*8) zonal wind field data

VWindFile (real*8) meridional wind field data

SolarFile (real*8) incident solar shortwave forcing field

TrFile (real*8) imposed relaxation profile over the buffer zones

QrFile (real*8) imposed specific humidity profile over land

The contents of a typical data.Cheapaml appear below.

```
# Cheapaml
&Cheapaml_CONST
Cheapaml_ntim = 5
Cheapaml_h = 1000.
Cheapaml_kdiff = 30000.
Cheapaml_taurelax2 = .3d0
&
&Cheapaml_PARM01
UwindFile = uwind.dat
AirTempFile = tairinit.dat
&
```

The next impact on MITgcm is in the subroutine INI_FIELDS.F. Here, the model resolves the initial information needed by MITgcm to integrate the equations of motion. Cheapaml modifies this by resolving the initial atmospheric data needed to integrate (1) and (2). If the current run is an initial value run, the user can direct the model to the data in the files AirTempFile and AirQFile. Alternatively, leaving these filenames empty, the model generates default Tair and qair fields according to

$$Tair = 25.0 - 20.0y/L_y \tag{6}$$

which sets the air temperature to $25°C$ at the southern boundary (y=0) and decreases it linearly in model coordinate y to $5°C$ at the north ($y = L_y$), and

$$qair = 0.8(saturation\ specific\ humidity) \tag{7}$$

where the saturation specific humidity is computed from the Tair profile. If the run is a restart, the model defaults to the values of Tair and qair provided in the restart file.

The model then continues in standard fashion until the subroutine FORWARD_STEP.F. In this subroutine, the first action of Cheapaml is to resolve the external forcing fields, consisting of the winds, shortwave solar and the relaxation profiles. This is done by FORWARD_STEP.F which calls the Cheapaml package subroutine Cheapaml_fields_load. Cheapaml at the present admits two external forcing options, i.e. steady and periodic. The logical parameter periodicExternalForcing determines which of these applies to the current run. If .FALSE., steady forcing is assumed. This is the default, but it may be overridden by including the statement PeriodicExternalForcing = .TRUE. In the file data. In the latter case, it is necessary to define two other parameters, externForcingCycle and externForcingPeriod to define the interval between entries defining the forcing and the period over which the forcing repeats, respectively. The subroutine Cheapaml_fields_load then cycles through the sequence of zonal and meridional winds, solar radiation, temperature relaxation and humidity relaxation, resolving each from storage if a filename has been provided. If no filename has been provided, Cheapaml assumes forcing is steady and defaults to specific fields, viz.

$UwindField = -5.0cos(2\pi y/L_y)$

$VwindField = 0.0$

$SolarFiile = 250.0 - 75.0y/L_y$

$Tr = (2.0 * Solar/stefan)^{(0.25)} - 273.16$

$$Qr = 0.8 * (saturation\ specific\ humidity)$$

where Solar denotes the local value of the shortwave radiation, stefan the Stefan-Boltzmann constant and saturation specific humidity that computed from the Tr profile. Essentially, the specific humidity is relaxed towards a relative humidity of 80% over the buffers. The default zonal wind fields (expressed in m/s) correspond to classical double gyre profiles, with Trades to the south, Westerlies at mid-latitudes and Polar Easterlies at high latitudes. The default meridional winds vanish. The default incident shortwave field corresponds to a net $250W/m^2$ at the south edge of the domain and decreases linearly with meridional coordinate by $75W/m^2$ over the domain. The default relaxation profile (expressed in $^{\circ}C$) is in longwave back radiative balance with the default shortwave radiation.

The model next executes the primary Cheapaml subroutine Cheapaml.F. The first action in this subroutine is the computation of the stress imparted on the ocean from the wind field. This is done in a manner completely like that used in the subroutine BULKCDN.F. The results are stored in the arrays “ustress” and “vstress” and returned to the main MITgcm loop. The other events in this subroutine are the evolution of the atmospheric temperature and specific humidity fields as governed by advection, diffusion and heat flux divergences as described earlier. The new Tair field, qair field and measures of the atmospheric temperature and specific humidity tendencies as needed are returned to MITgcm. Most importantly, the heat fluxes across the ocean interface generated by the sum of incident shortwave, net longwave, sensible and latent heat fluxes are computed and stored in the array “Qnet”. Water flux across the air-sea interface is stored in the array ”EmPmR”. These arrays are returned to the main body of MITgcm and used along with “ustress” and “vstress” later in FORWARD_STEP.F to force the ocean.

The last impact of Cheapaml on MITgcm is in the subroutine WRITE_STATE.F. If Cheapaml is active, the fields Tair, qair, Qnet and EmPmR are written in the standard output files. Options for outputs written according to both the rdmds and mnc conventions are available.