GEOS/ATMO 573   Term Project

Developing a Global Energy-Moisture Balance Climate Model

Through this project, you will learn the typical procedure for building models for climate studies. You will develop, test run, validate and document a global energy-moisture balance model based on the paper by Fanning and Weaver (1996) (F&W hereinafter).

Fanning, A. F., and A. J. Weaver (1996), An atmospheric energy moisture-balance model: climatology, interpentadal climate change and coupling to an OGCM. J. Geophys. Res., ***101****, 15111-15128.*

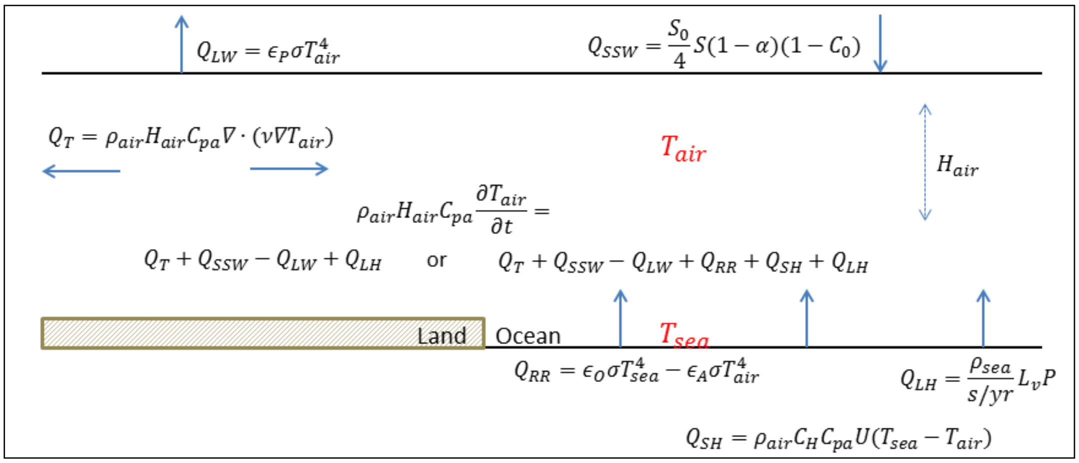

Figure 1. Schematic illustration of the model

I. Development of model codes

(1) You can choose your preferred programming language and plotting software (e.g., Fortran, Matlab, Python, Ferret, etc.)

(2) At the beginning of your codes, document your model codes briefly, including the name of model developer, the reference paper, numerical schemes, and previous modifications/corrections made to the model codes.

(3) You should use modular design when coding the model, separating the functionality of a program into independent, interchangeable modules (e.g., call separate subroutines for model initialization, integration and output).

(4) To increase the readability of your codes, you should add comments within your codes and use easily recognized variable names (e.g., `T` for temperature, `Q` for specific humidity, `PRECIP` for precipitation, `SST` for sea surface temperature, etc.)

(5) The model should have a global domain and a 5° × 4° (longitude by latitude) resolution.
Longitude (-180°, -175°, -170°, …, 170°, 175°)   Latitude (-90°, -86°, -82°, …, 86°, 90°)
`PARAMETER(IQ=72,JQ=46)` !Number of grid points in zonal and meridional direction
`REAL T(IQ,JQ,3), Q(IQ,JQ,3)`

(6) Heat (ν) and moisture (κ) diffusion coefficient (m^2/s; Fig. 1 in F&W) as a function of latitude (ϕ) can be calculated as

$$\nu(\phi) = 3\times 10^6 \times (0.81 - 1.08\sin^2\phi + 0.74\sin^4\phi)$$
$$\kappa(\phi) = 1.7\times 10^6 \times (1.9823 - 17.3501|\sin\phi| + 117.2489|\sin\phi|^2 - 274.1129|\sin\phi|^3 + 258.2244|\sin\phi|^4 - 85.7967|\sin\phi|^5$$

(7) Atmospheric (ϵ_A) and planetary (ϵ_P) emissivity (Fig. 2 in F&W) can be calculated as

$$\epsilon_A(\phi) = 0.8666 + 0.0408\sin\phi - 0.2553\sin^2\phi - 0.4660\sin^3\phi + 0.9877\sin^4\phi + 2.0257\sin^5\phi - 2.3374\sin^6\phi - 3.1990\sin^7\phi + 2.8581\sin^8\phi + 1.6070\sin^9\phi - 1.2685\sin^{10}\phi$$

$$\epsilon_P(\phi) = 0.5531 - 0.1296\sin\phi + 0.6796\sin^2\phi + 0.7116\sin^3\phi - 2.7940\sin^4\phi - 1.3592\sin^5\phi + 3.8831\sin^6\phi + 0.8348\sin^7\phi - 1.9536\sin^8\phi$$

(8) Annual distribution of shortwave radiation (S in Eq. 4 of F&W)

$$S(\phi) = 1.5(1 - \sin^2\phi)$$

(9) Coalbedo ($1-\alpha$ in Eq. 4 of F&W)

$$(1-\alpha) = 0.7995 - 0.315\sin^2\phi$$

(10) Use 0.65 (over ocean) and 0.3 (over land) for the solar scattering coefficient C_0 in Eq. 4.

(11) Saturation vapor pressure ($e_s;\ millibar$) and saturation specific humidity ($q_s;\ kg/kg$) as a function of temperature ($T;\ Kelvin$) can be calculated as

$$e_s(T) = 6.112\exp\frac{17.67\,(T-273.15)}{(T-273.15)+243.5}$$

$$q_s(T) = 0.622\frac{e_s(T)}{1013.26 - 0.378e_s(T)}$$

(12) For the forcing terms ($Q_{SSW}, Q_{LW}, Q_{RR}, Q_{SH}$), use the leapfrog scheme for time differencing, and occasionally use the Euler forward scheme to suppress the computational mode from leapfrog.

$$\tilde{T}^{n+1} = \tilde{T}^{n-1} + 2\Delta t Q^n \qquad \text{Leapfrog}$$

$$\tilde{T}^{n+1} = \tilde{T}^{n} + \Delta t Q^n \qquad \text{Euler forward}$$

(13) For the diffusion terms (Q_T, M_T), use the Matsuno scheme as follows (recall we learned the Heun scheme).

$$\tilde{T}^* = \tilde{T}^n + \Delta t Q(t^n, \tilde{T}^n)$$

$$\tilde{T}^{n+1} = \tilde{T}^n + \Delta t Q(t^{n+1}, \tilde{T}^*)$$

(14) To better monitor your model run, you should regularly calculate and output integrated statistics such as the global mean temperature and specific humidity.

II. Model run

Starting from a uniform initial condition ($T = 273.15\ K$ and $q = 0\ kg/kg$ everywhere) and under fixed SST and wind speed climatology, integrate your model forward for 5000 time steps with a 1 hour time step (you can try other Δt values). You can find the forcing data on the server in the Climate Modeling Lab. To access the server and data, do the following (notice case sensitive):

`ssh GEOS573@climate.geo.arizona.edu -o ForwardX11=yes`
password: `ClimateModeling`

The data are stored in the `/data` directory.
`sst.dat` - SST climatology (°C) (180°W~175°E, 90°S~90°N)
`wind.dat` - wind speed climatology (m/s) (180°W~175°E, 90°S~90°N)
`mask.dat` - land-sea mask (0 - land ; 1 - ocean)

With Fortran these data can be read in as

```
      READ(11,1000) SST
      READ(12,1000) WIND
1000  FORMAT(72F8.1)
      READ(13,2000) MASK
2000  FORMAT(72I1)
```

You can use the Climate Server to work on the term project. After login, please create a directory using your last name, keep all your work in your own directory and don't mess up with other students'. If you use Fortran programing, use `gfortran` to compile your codes.

```
gfortran yourcodes.f
```

If you use Matlab, use the following to invoke Matlab on the server (notice case sensitive).

```
matlab
```

III. Model validation

Plot the modeled global mean surface air temperature and precipitation as a function of time step (i.e., model spinup). Compare their geographical distribution and zonal mean at the last time step against observations. You can find the observed surface air temperature and precipitation climatology in the `/data` directory.
`sat.nc` - global surface air temperature climatology
`precip.nc` - global precipitation climatology

IV. Documentation of your codes and model performance

Write and turn in a documentation paper on your model. In the paper, you should include: (*a*) the scientific basis of the energy-moisture balance model; (*b*) your model codes; (*c*) description of variables, subroutines and numerical schemes; (*d*) plots and discussion about the global mean surface air temperature and precipitation as a function of time; (*e*) plots and discussion about their geographical distribution and zonal mean compared against observations; and (*f*) a general conclusion about the performance of the simplified energy-moisture balance model.

Due date: Nov 29, 2018