# American Geophysical Union

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## San Francisco, California

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Wednesday, 13 December at 17:15 (5:15 p.m.)
Moscone South, Room 310

# Modeling in the Classroom: An Evolving Learning Tool.

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# Abstract

Among the early programs (early 1990s) focused on teaching Earth System Science were the Global Change Instruction Program (GCIP) funded by NSF through UCAR and the Earth System Science Education Program (ESSE) funded by NASA through USRA. These two programs introduced modeling as a learning tool from the beginning, and they provided workshops, demonstrations and lectures for their participating universities. These programs were aimed at university-level education.

Recently, classroom modeling is experiencing a revival of interest. Drs. John Snow and Arthur Few conducted two workshops on modeling at the ESSE21 meeting in Fairbanks, Alaska, in August 2005. The Digital Library for Earth System Education (DLESE) at http://www.dlese.org provides web access to STELLA models and tutorials, and UCAR's Education and Outreach (EO) program holds workshops that include training in modeling.

An important innovation to the STELLA modeling software by isee systems, http://www.iseesystems.com, called "isee Player" is available as a free download.

The Player allows users to view and run STELLA models, change model parameters, share models with colleagues and students, and make working models available on the web. This is important because the expert can create models, and the user can learn how the modeled system works. Another aspect of this innovation is that the educational benefits of modeling concepts can be extended throughout most of the curriculum.

The procedure for building a working computer model of an Earth Science System follows this general format:

(1) carefully define the question(s) for which you seek the answer(s);

(2) identify the interacting system components and inputs contributing to the system’s behavior;

(3) collect the information and data that will be required to complete the conceptual model;

(4) construct a system diagram (graphic) of the system that displays all of system’s central questions, components, relationships and required inputs.

At this stage in the process the conceptual model of the system is compete and a clear understanding of how the system works is achieved.

When appropriate software is available the advanced classes can proceed to

(5) create a computer model of the system and testing the conceptual model.

For classes lacking these advanced capabilities they may view and run models using the free isee Player and shared working models. In any event there is understanding to be gained in every step of the procedure outlined above.

You can view some examples at

http://www.ruf.rice.edu/~few/.

We plan to populate this site with samples of Earth science systems for use in Earth system science education.

# Working through an Example

1. The Questions:
As global warming proceeds does the Earth get wetter or dryer?
What happens to evaporation? Precipitation?
Will it be different over the oceans and the land?

2. The Interacting System Components:
Water is located in the ocean, on land, and in the atmosphere.
Ice exchanges on Greenland and Antarctic are much slower than ocean and land exchanges.
Rivers transport land water to oceans.
Winds transport water through the atmosphere.
Ocean water is much larger than any other reservoir.

# 3. Collect the Information and Data: This is also our conceptual model

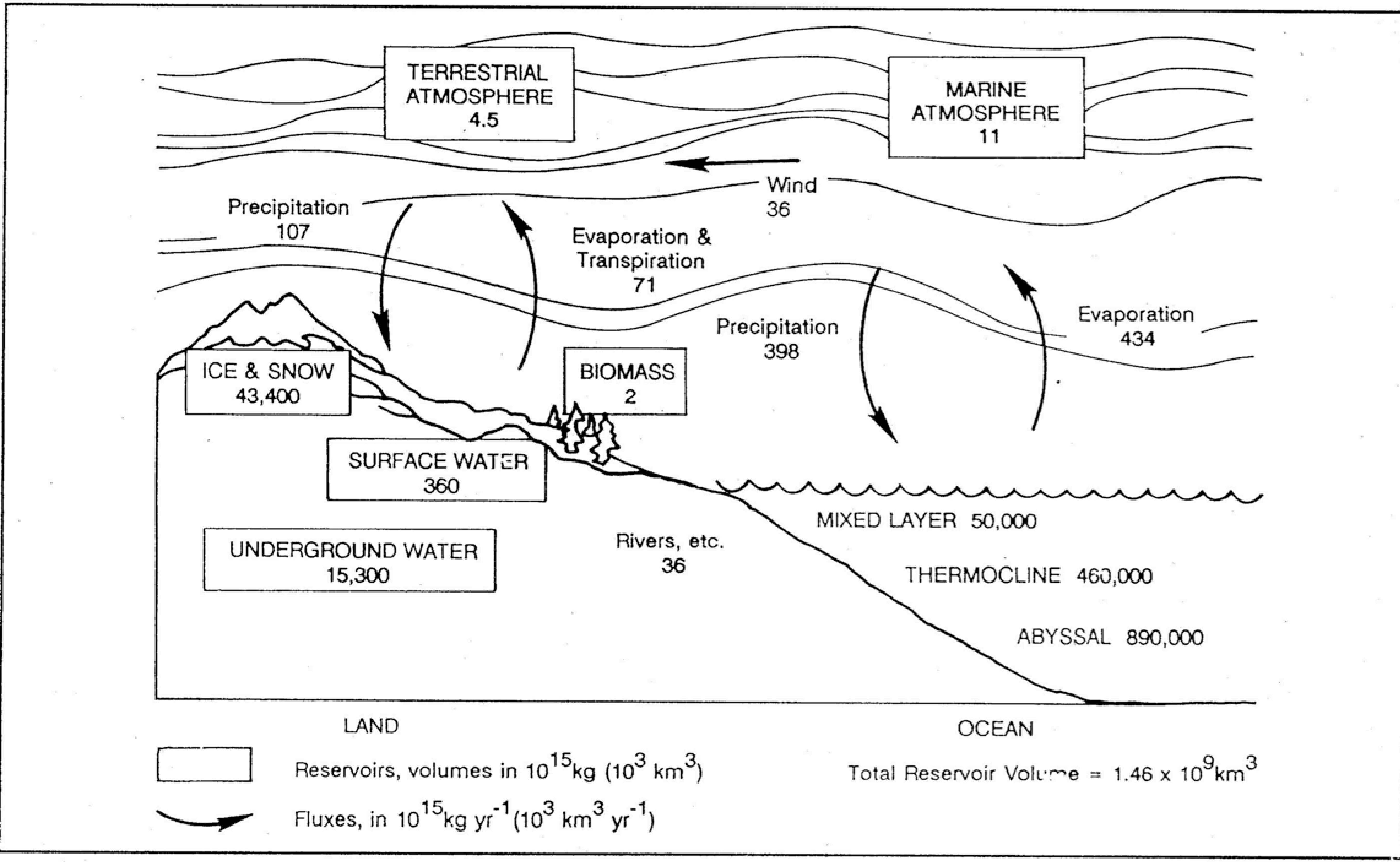



FIG. 4. The climatic hydrologic cycle at global scale (from NRC 1986).

# 3. Collect the Information and Data:

## Residence Time for the Global Hydrological Reservoirs from *Atmospheric Science* 2nd Edition by Wallace & Hobbs

| **Reservoirs of Water** | **Residence Time** |
|---|---|
| Atmosphere | Days |
| Surface | Days to Years |
| Underground | Hundreds of Years |
| Alpine Glaciers | Hundreds of Years |
| Greenland Ice Sheet | 10,000 years |
| Antarctic Ice Sheet | 100,000 years |
| Oceans | ~ Age of the Earth |
| Crust and Mantle | ~ Age of the Earth |

# 3. Collect the Information and Data:

The Clausius-Clapeyron equation allows us to compute the vapor pressure over a wet surface as a function of the surface temperature. This is an exponential function! When T increases ($T>T_0$) the exponent becomes positive and the vapor pressure increases; this increases the evaporation rate relative to $T_0$.

$e$ is the exponential function

$e_s$ is the saturation vapor pressure at temperature T

$e_{s0}$ is the saturation vapor pressure at temperature $T_0$

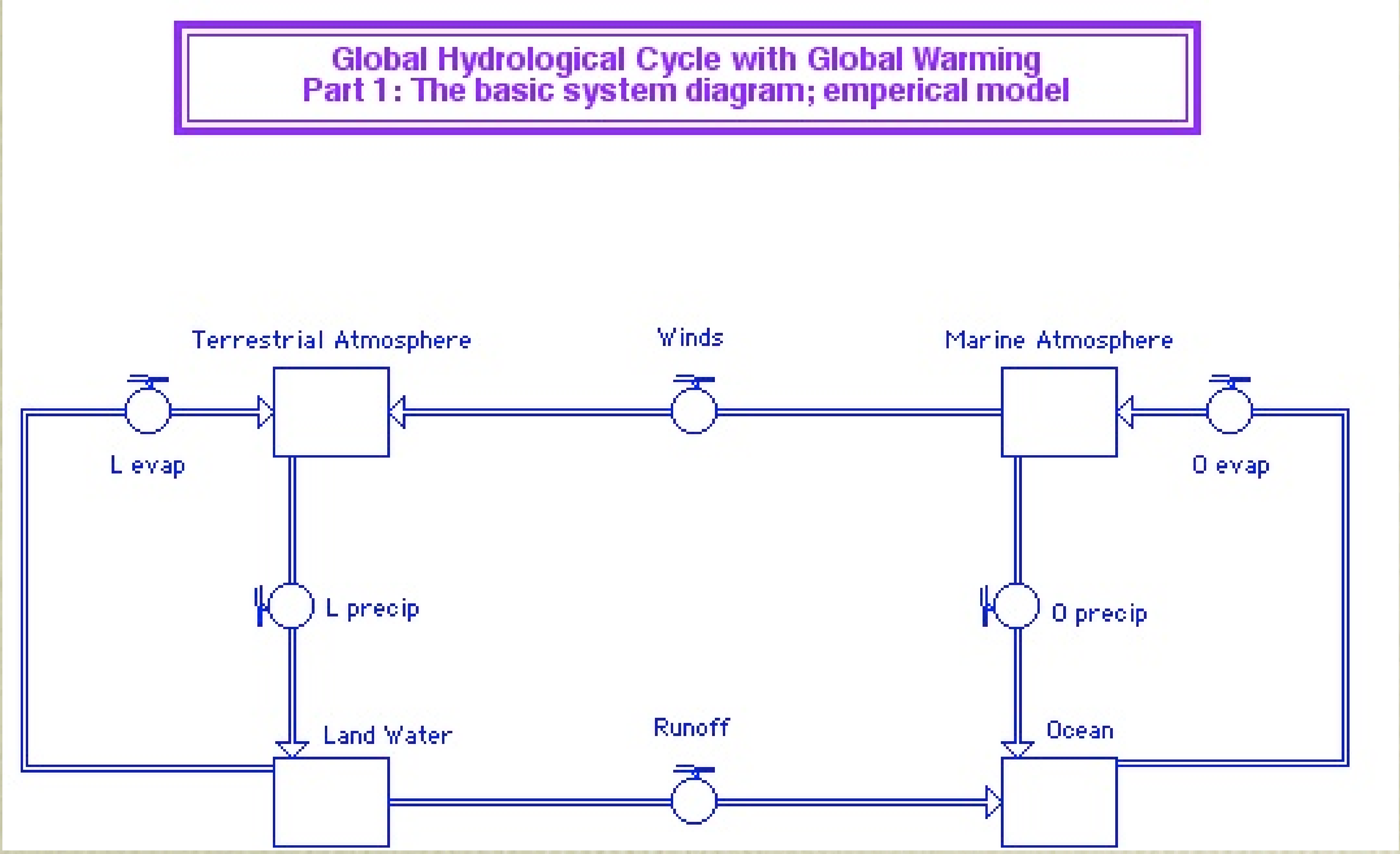
$L = 2.5 \times 10^6 \{\mathrm{J / kg}\}$ is the latent heat of vaporization

$R_v = 461\{J / kg^\circ K$ is the gas constant for water vapor

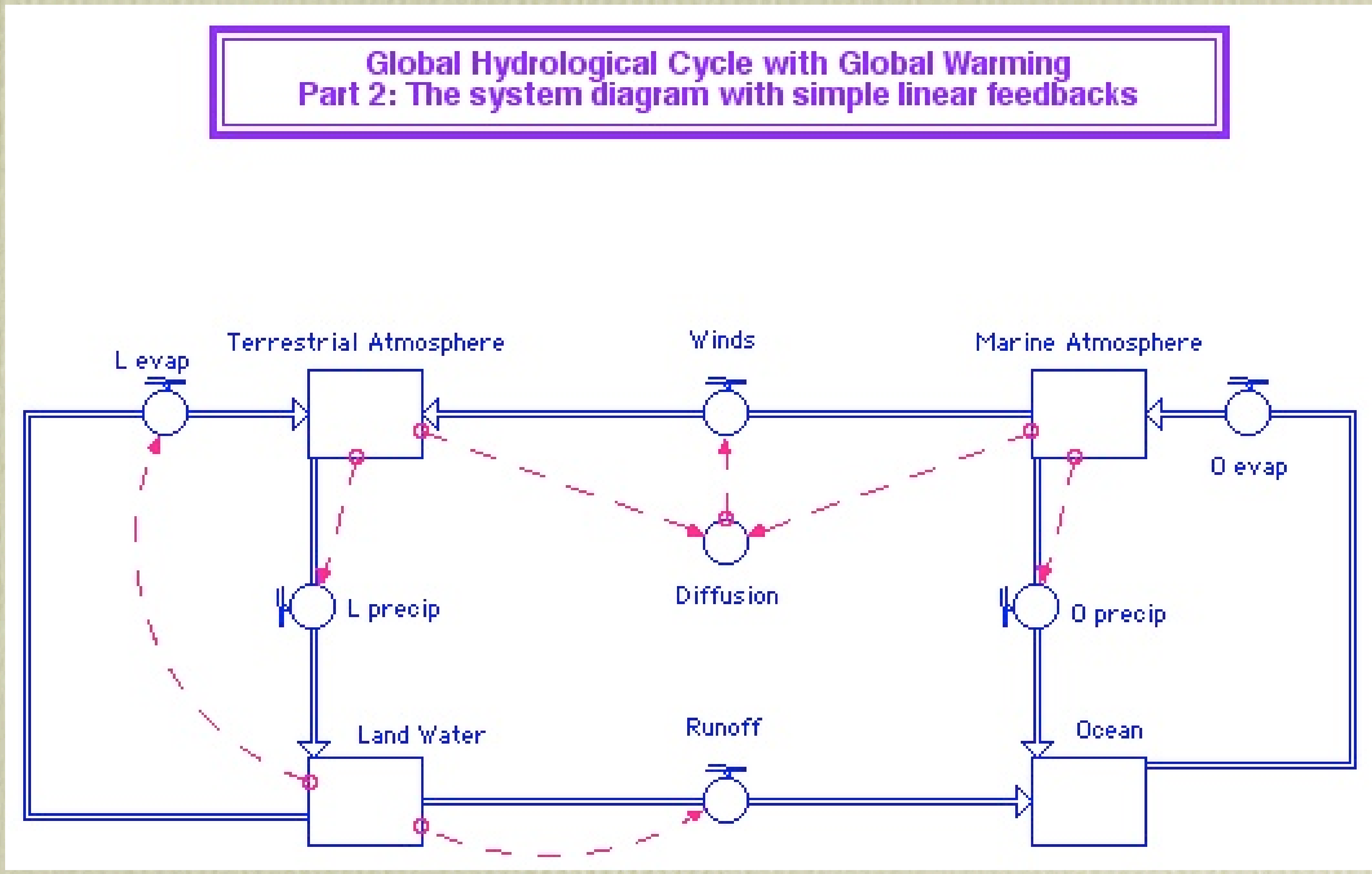
$$\frac{e_s}{e_{s0}} = e^{\frac{L}{Rv}\left(\frac{1}{T_0} - \frac{1}{T}\right)}$$

*Atmospheric Science, 2nd Edition* by Wallace & Hobbs, 2006

# 4. Construct the System Diagram: Step 1 - Basic System Diagram - Empirical Model



# 4. Construct the System Diagram:
# Step 2 - System Diagram with Linear Feedbacks

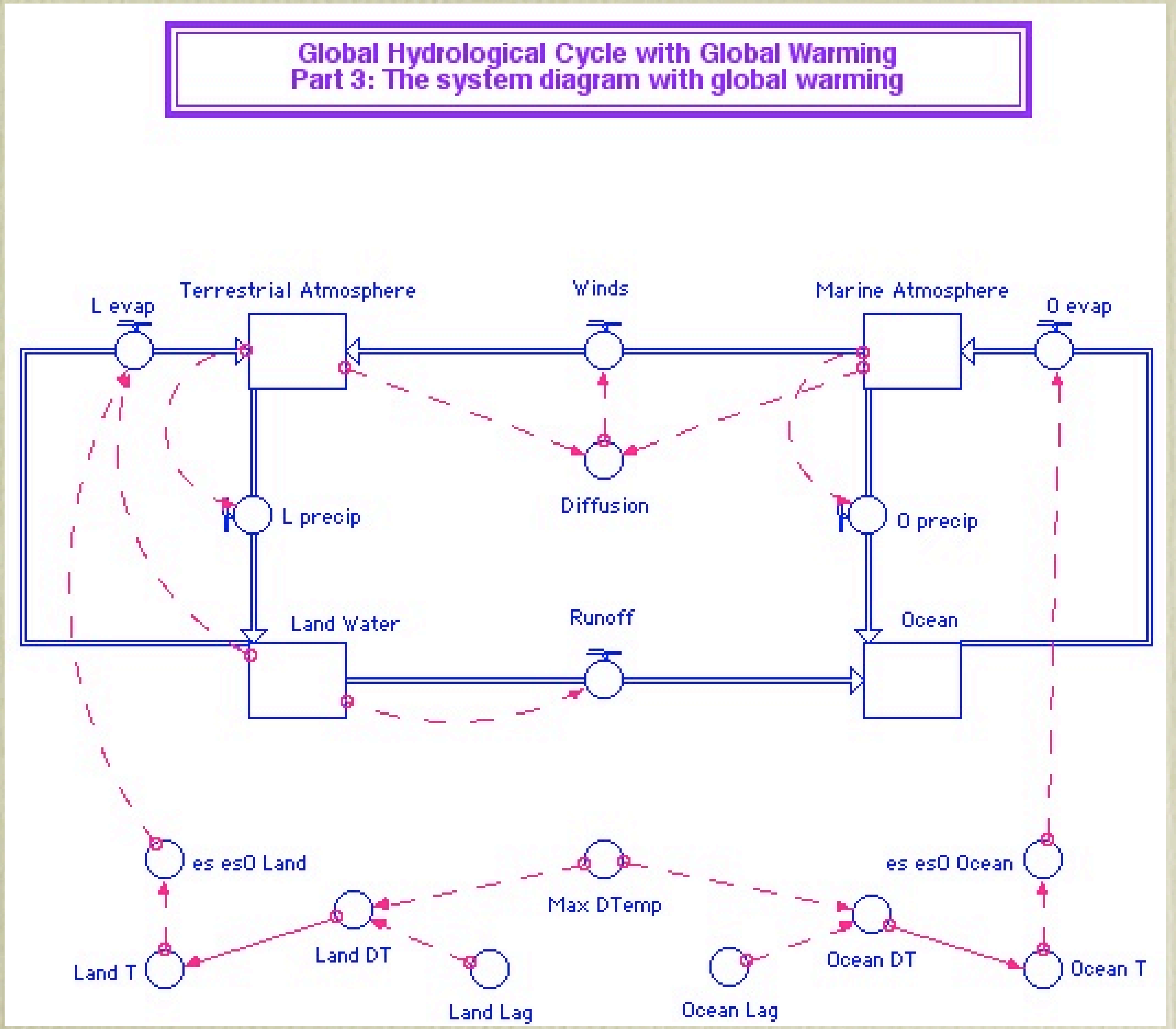



## Examples of Feedbacks

L_precip = 107e15 {kg/yr} *(Terrestrial_Atmosphere/4.5e15)

Diffusion = (Marine_Atmosphere-Terrestrial_Atmosphere)/6.5e15

# 4. Construct the System Diagram:
# Step 3 - System Diagram with Global Warming

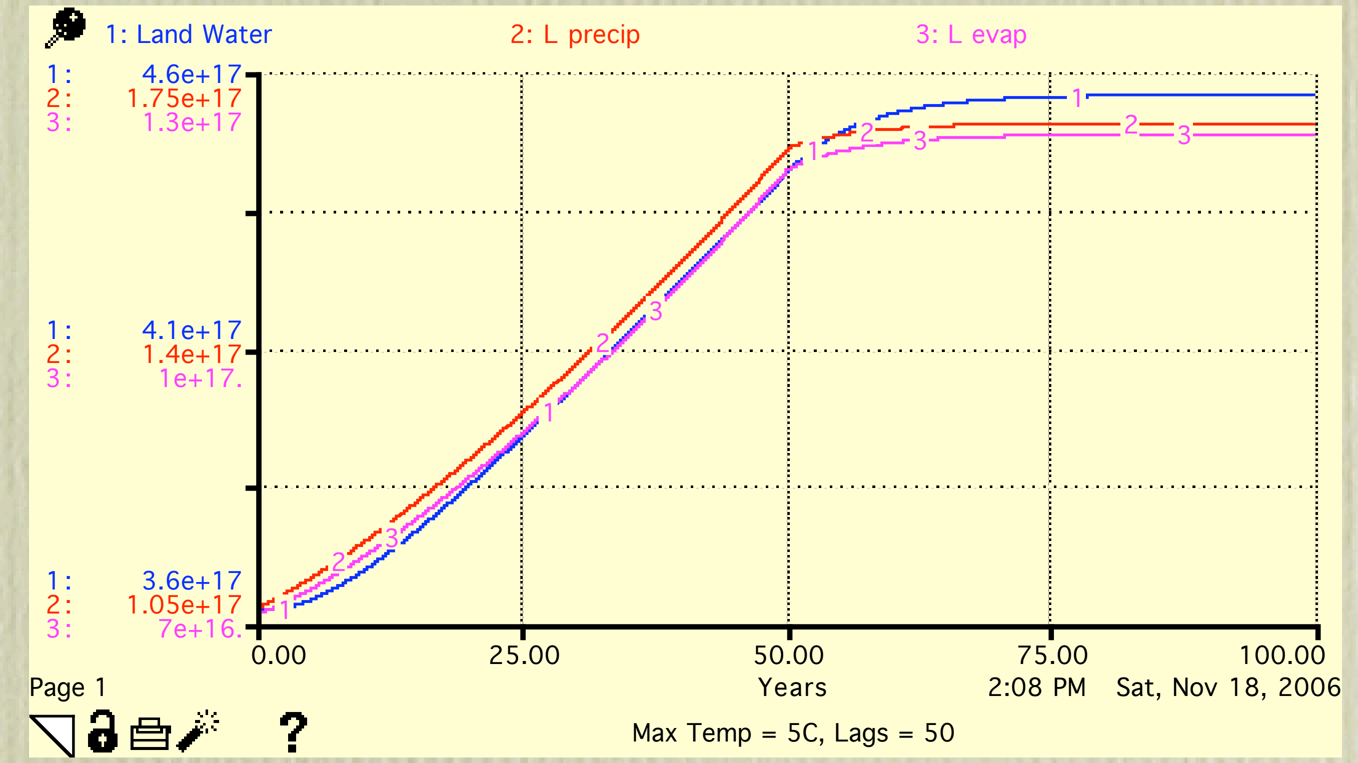


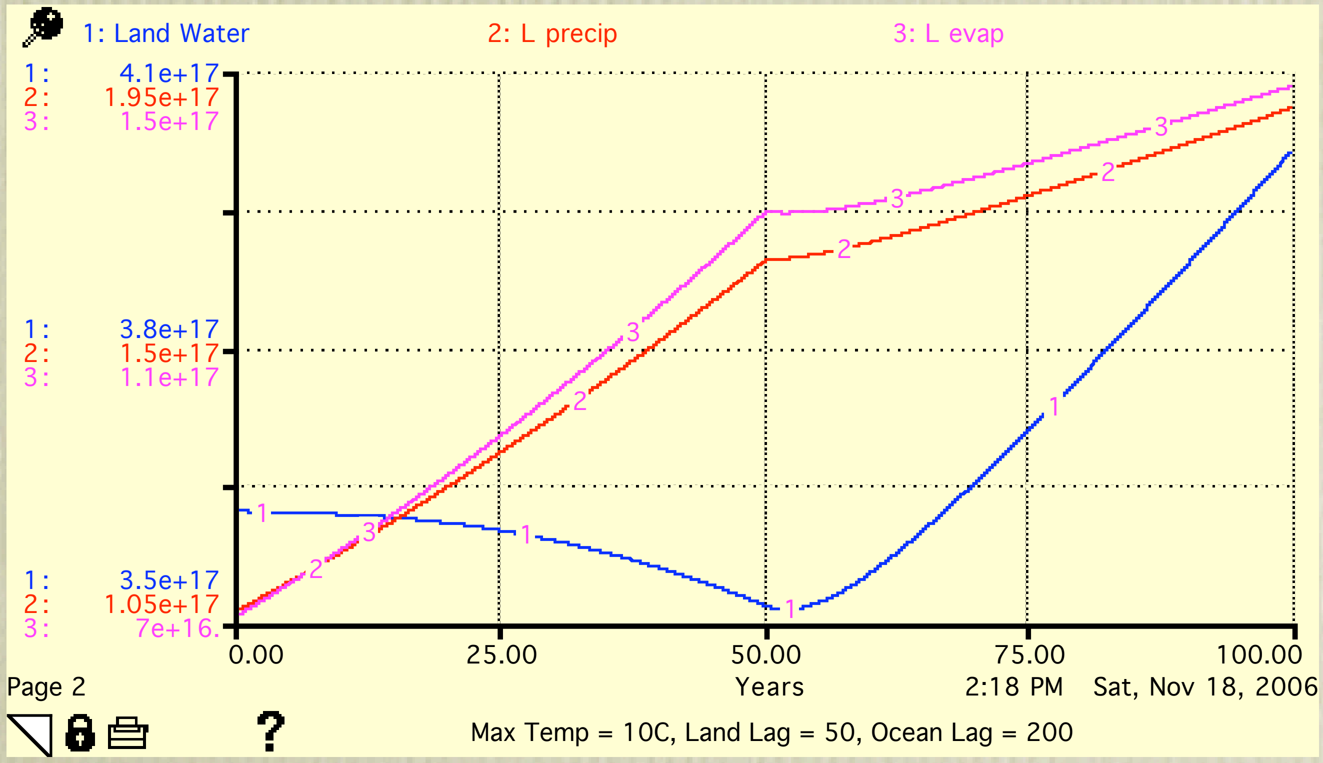
# 5. Create and Test the Computer Model:

Land_DT = IF(TIME<Land_Lag) THEN(TIME*(Max_DTemp/Land_Lag)) ELSE(Max_DTemp)

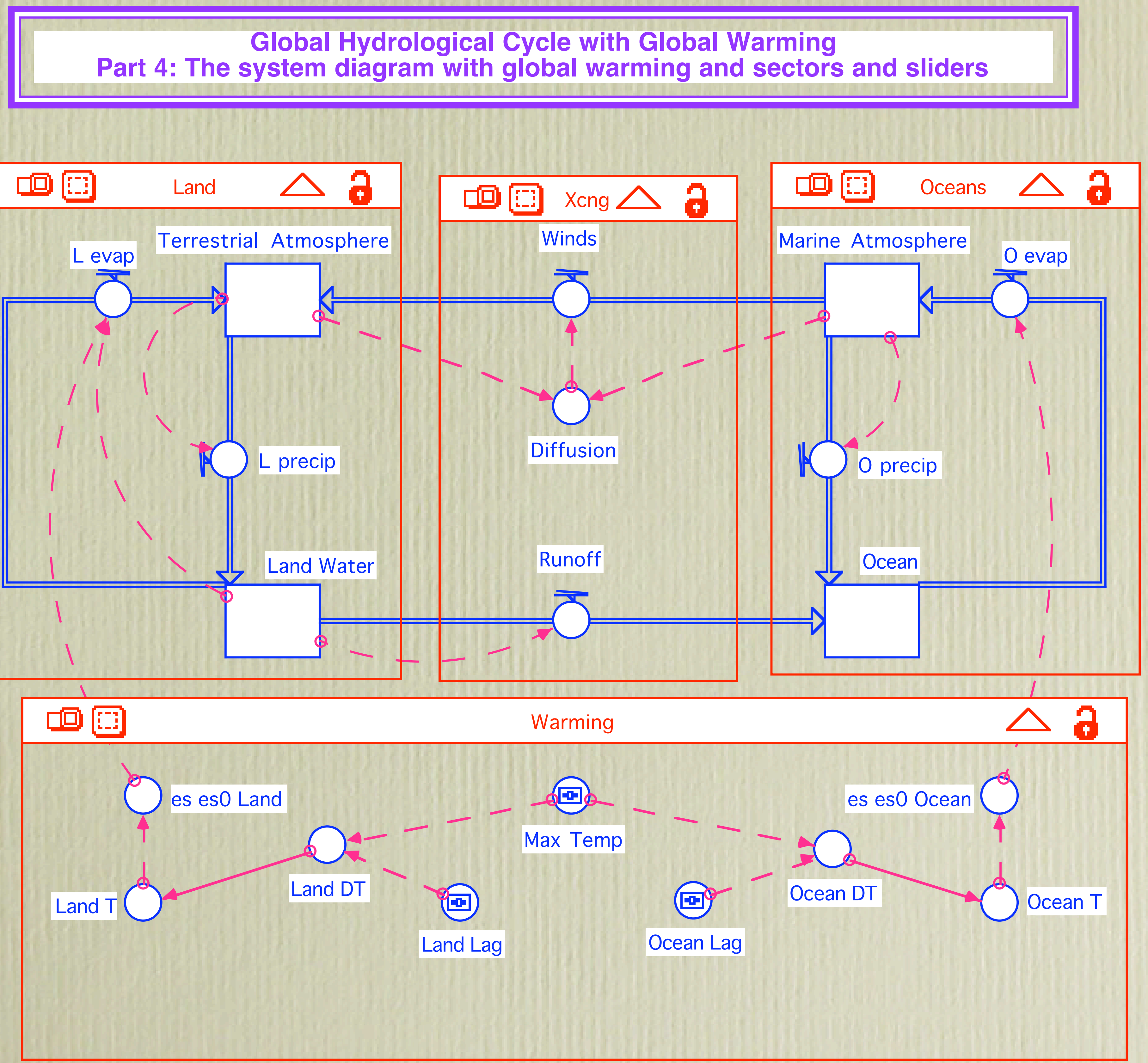
Land_T = 288 + Land_DT

es_es0_Land = EXP(5.42e3 *((1/288)-(1/Land T)))

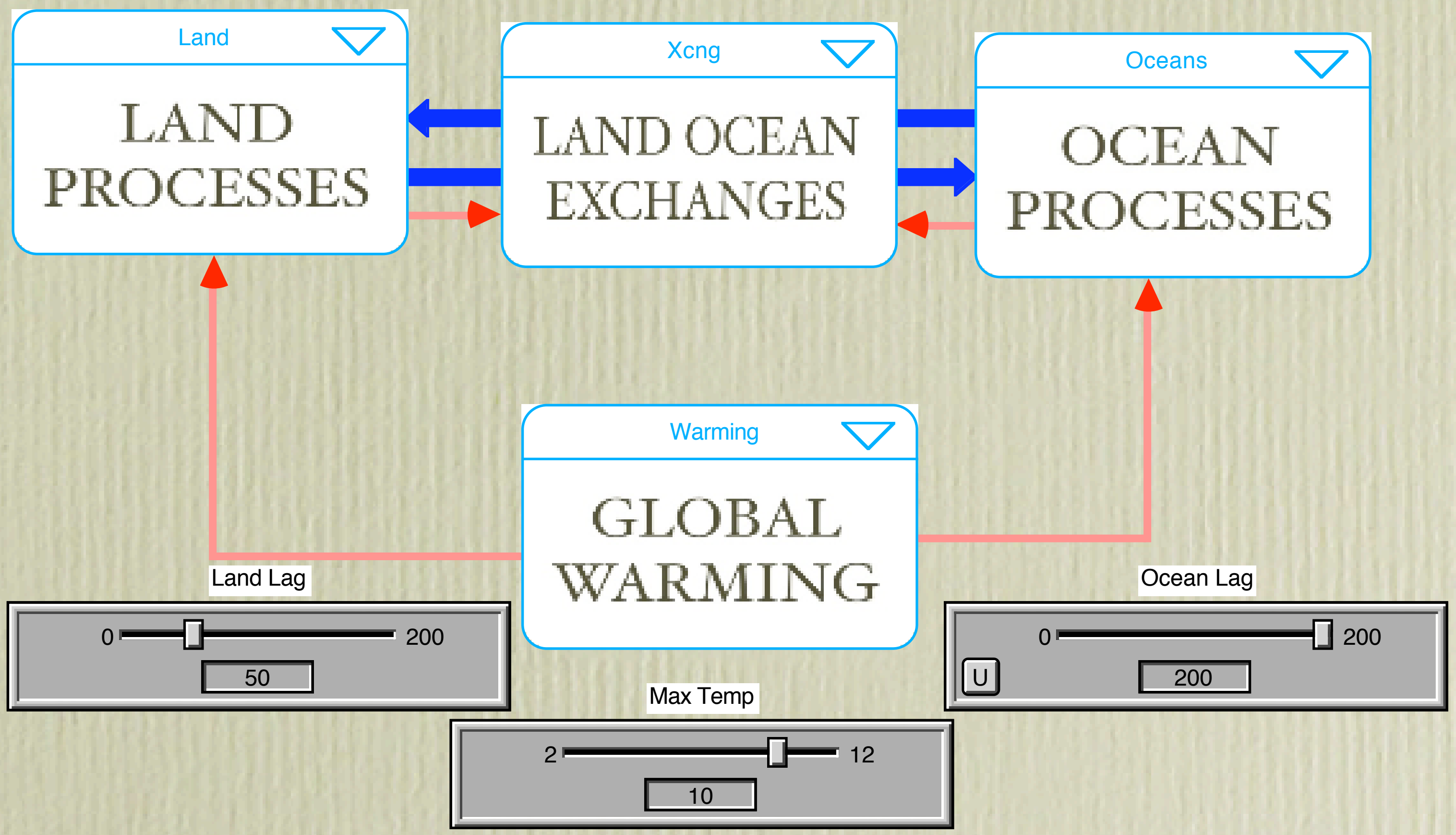


We will now create an exportable version of the model that can be used on the isee Player (free software). The red boxes are "sectors" and the icons in Max Temp, Land Lag, and Ocean Lag are "sliders."

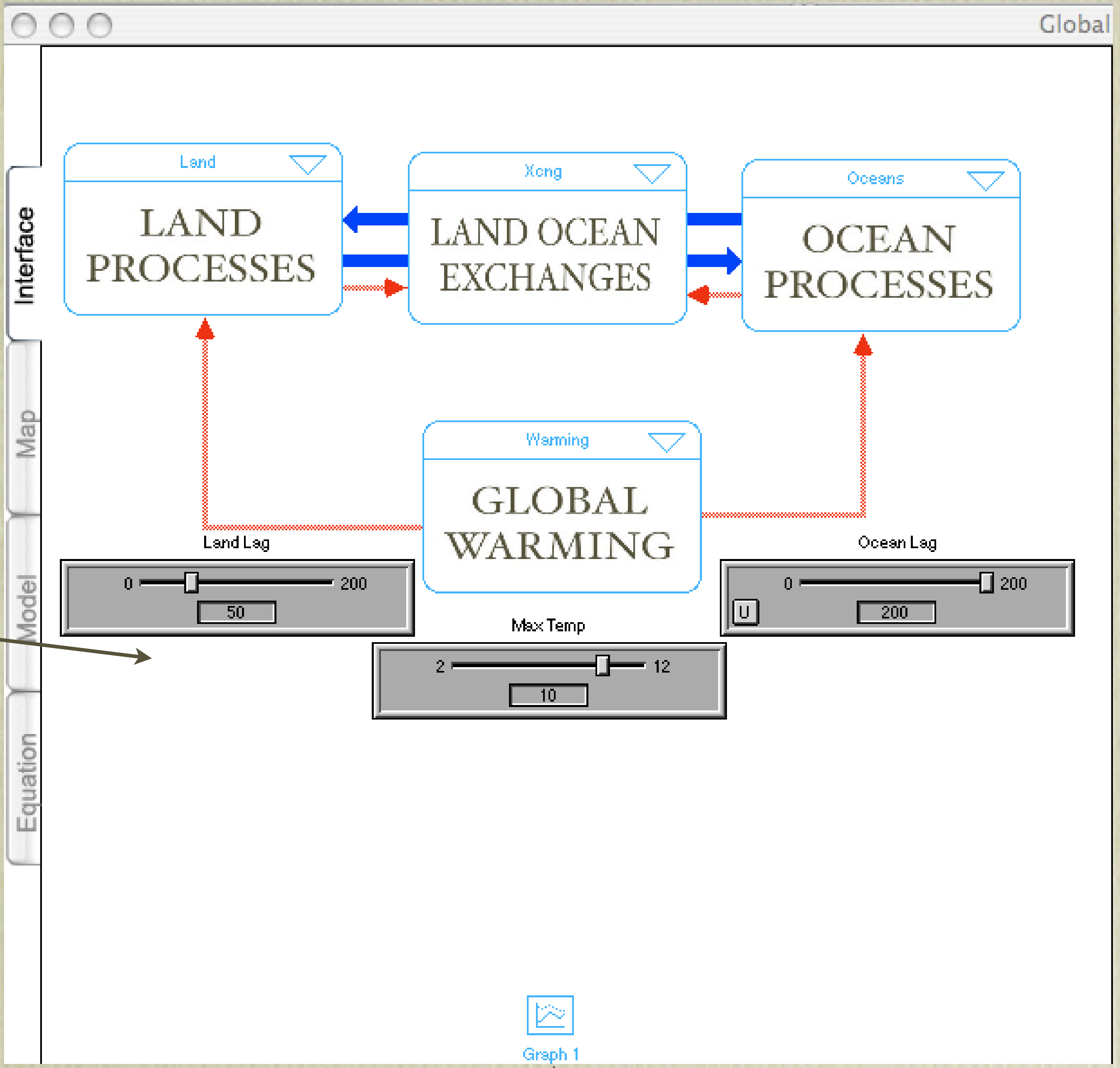


This is how the model first appears in the isee Player; it is the same view that we get in the interface level of STELLA. The sectors are now small blue boxes and the sliders look like electronic amplitude controls. In order to see how the Player can work we need to actually run the player.



# This is what the student/user will see in isee Player

This is the interface level



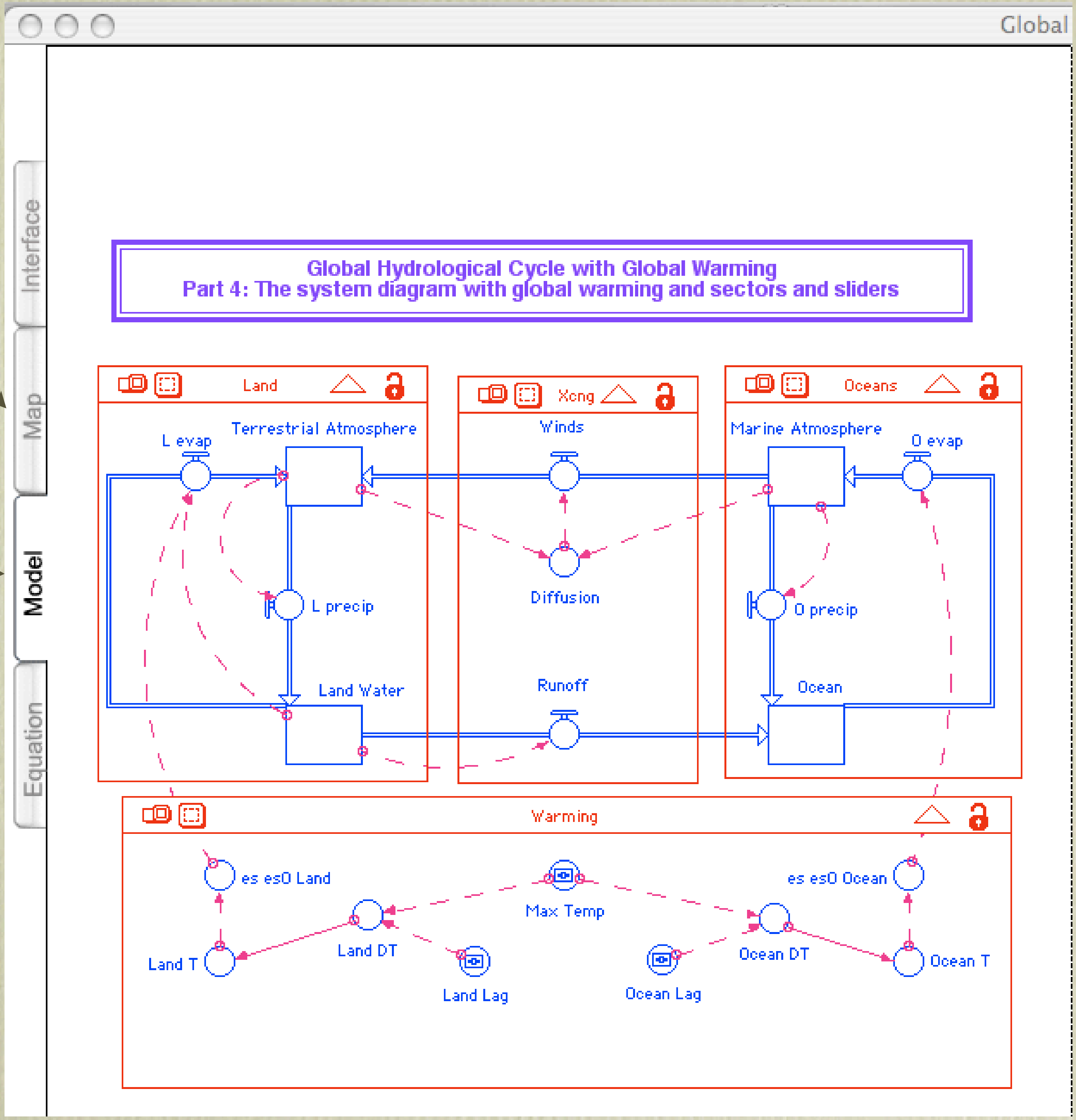

The student/user can change these parameters but cannot otherwise alter the model.

The student/user can open the graph, run the model, and observe the results develop

# This is what the student/user sees in the Model level of isee Player

The map level looks like the Model level but not very useful.

This is the Model level; here the student/user can see the actual system diagram of the model. Modifications by the student/user are not allowed.



In this view, Equation, we can see the equations that direct the actions in the system diagram.

Interface | Map | Model | Equation

```
Land
Land_Water(t) = Land_Water(t - dt) + (L_precip - Runoff - L_evap) * dt
INIT Land_Water = 362E+15 {kg, surface + biomass}
INFLOWS:
    L_precip = 107e15 {kg/yr} *(Terrestrial_Atmosphere/4.5e15)
OUTFLOWS:
    Runoff (IN SECTOR: Xcng)
    L_evap = 71e15 {kg/yr} *(Land_Water/362e15) * es_es0_Land
Terrestrial_Atmosphere(t) = Terrestrial_Atmosphere(t - dt) + (L_evap + Winds - L_precip) * dt
INIT Terrestrial_Atmosphere = 4.5e15 {kg}
INFLOWS:
    L_evap = 71e15 {kg/yr} *(Land_Water/362e15) * es_es0_Land
    Winds (IN SECTOR: Xcng)
OUTFLOWS:
    L_precip = 107e15 {kg/yr} *(Terrestrial_Atmosphere/4.5e15)

Oceans
Marine_Atmosphere(t) = Marine_Atmosphere(t - dt) + (O_evap - O_precip - Winds) * dt
INIT Marine_Atmosphere = 11e15 {kg}
INFLOWS:
    O_evap = 434e15 {kg/yr} * es_es0_Ocean
OUTFLOWS:
    O_precip = 398e15 {kg/yr}  *(Marine_Atmosphere/11e15)
    Winds (IN SECTOR: Xcng)
Ocean(t) = Ocean(t - dt) + (Runoff + O_precip - O_evap) * dt
INIT Ocean = 1400E+18 {kg, Mixed_Layer+Thermocline+Abyssal}
INFLOWS:
    Runoff (IN SECTOR: Xcng)
    O_precip = 398e15 {kg/yr}  *(Marine_Atmosphere/11e15)
OUTFLOWS:
    O_evap = 434e15 {kg/yr} * es_es0_Ocean

Warming
es_es0_Land = EXP(5.42e3 *((1/288)-(1/Land_T)))
es_es0_Ocean = EXP(5.42e3*((1/288)-(1/Ocean_T)))
Land_DT = IF(TIME<Land_Lag) THEN(TIME*(Max_Temp/Land_Lag)) ELSE(Max_Temp)
Land_Lag = 50
Land_T = 288 + Land_DT
Max_Temp = 10
Ocean_DT = IF(TIME<Ocean_Lag) THEN(TIME*(Max_Temp/Ocean_Lag)) ELSE(Max_Temp)
Ocean_Lag = 200
Ocean_T = 288 +Ocean_DT

Xcng
Runoff = 36e15 {kg/yr} * (Land_Water/362e15)
OUTFLOW FROM: Land_Water (IN SECTOR: Land)
INFLOW TO: Ocean (IN SECTOR: Oceans)
Winds = 36e15 {kg/yr} * Diffusion
OUTFLOW FROM: Marine_Atmosphere (IN SECTOR: Oceans)
INFLOW TO: Terrestrial_Atmosphere (IN SECTOR: Land)
Diffusion = (Marine_Atmosphere-Terrestrial_Atmosphere)/6.5e15
```

Using isee Player (free ware) the student user has full access to viewing, running, and understanding the inter workings of the model. The instructor can design a wide variety of assignments to direct the students to exploring models and how they are constructed.

# Arthur Few's Web Site

## Arthur's Weather Page CONTENTS

Most Recent Weather Map from Unisys

60-Hour Detailed Forecast for IAH from Unisys

Lewis Thomas Essay,
*The Worlds Biggest Membrane*

Atmospheric Optics

Weather Information at:
Unisys
UCAR/NCAR
NOAA
NCEP

The UCAR Home Page

Rice University Weather Station

Current NWS Radar

Rice U's Flood Alert Site

Long Range Forecasts

Online Meteorology Text

NASA Blue Planet

The forecasts below are from the National Center for Atmospheric Research, NCAR, and are based upon model output from the Global Forecast System, GFS, produced by the National Centers for Environmental Prediction, NCEP.

Forecasts: 12, 18 & 24 hr
MSLP & wind
Temperature

AGU Spring 2006 Poster
Conceptual Modeling as Pedagogy (PDF)
Poster decomposed into a slide presentation (PDF)
Poster decomposed into a slide presentation (Keynote)
Poster decomposed into a slide presentation (PowerPoint)

You will need this free application to run the models.
The isee Player lets you view and share iThink and STELLA models for FREE.
Download your copy today!

The three models shown in the poster can be downloaded below.

Earth Effective Temperature

Greenhouse Earth

Wind Generator

EXTRAS:
Movie of wind generator
Panorama of wind generator farm
Lecture on wind generators (Keynote, PowerPoint, PDF)
General Electric's wind energy web pages.
The wind energy farm near Lamar, Colorado.

AGU fall 2006 Oral Presentation
Modeling in the Classroom:An Evolving Learning Tool.
The slide presentation is available in these formats: Keynote, PowerPoint, PDF

The STELLA Model of the Global Hydrological Cycle with Global Warming can be downloaded here.

## STELLA Models

You will need STELLA software to modify these models. You may view them and run them with isee Player. These files were compressed using Stuffit X (.sitx); they may be downloaded and opened with Stuffit Expander available free from http://www.stuffit.com.

### STELLA Tutorial

The STELLA file below is a short tutorial on STELLA system components, objects, and tools. I use this as an introductional lecture on STELLA Modeling.

STELLA Intro.sitx

### Energy Balance Models for the Earth

These are the instructions for building a series of three energy balance models for the Earth.

Earth Energy Balance Model Part 1. (This is essentially the Earth Effective Temperature used in the AGU Spring 2006 Poster.)

Earth Energy Balance Model Part 2. (This is essentially the Greenhouse Earth used in the AGU Spring 2006 Poster.)

Earth Energy Balance Model Part 3. (In this model we explore the Greenhouse Model when we double the atmospheric carbon dioxide.)

Early Faint Sun Model. Starting with the Energy Balance Model Part 1 above we add the ice-albedo feedback, which alters the albedo as the temperature changes. This model demonstrates very interesting behavior.