METR 104: Our Dynamic Weather (w/lab)	**Lab Exploration #4: Solar Radiation & Temperature Part I: A Simple Computer Model**	Dr. Dave Dempsey, Department of Earth & Climate Sciences, SFSU, **Fall 2013**

(5 points)
(Thursday, Oct. 17)

Your Name _____

Learning Objectives. After completing this activity, you should be able to:

- Configure and run experiments with a simple computer model (a STELLA model) that predicts temperature at the earth's surface over a period of several days, driven by absorption of solar radiation and affected by cloud cover (but little or nothing else).
- Evaluate the model based on experience reading meteogram plots of observed temperature patterns and cloud cover over several days at individual locations.
- Begin to describe the role that computer models play in the way that science works in atmospheric science.

Materials Needed. To complete this activity, you will need:

- A computer in TH 604 or 607 with:
  - STELLA modeling software installed on it, and either
  - a version of a STELLA model of the daily temperature cycle ("DailyTempCycle.I.STMX")
    or
  - an internet connection with a Web browser, to access the Web-based version of the model at:
    http://forio.com/simulate/dempsey2/dailytempcycle-i/simulation/

- A graph of sun angle (in degrees) vs. time (in hours) at the latitude of Hanford, CA (36.3°N) starting on May 22 (Julian day 142)

- A meteogram showing a typical daily temperature cycle under cloud-free conditions at Hanford, CA (KHJO):
  - Ending at 09Z May 24, 1999

I. Introduction. As noted in Lab #2, Part II and Lab #3, forecasting temperature is one of the most common and useful aspects of weather forecasting. Modern professional weather forecasters typically do it by starting with current and recent observations of weather conditions and applying their understanding of the underlying physical causes of temperature change, in a largely quantitative way, to estimate near-future changes in temperature from current conditions.

One of the most important tools that forecasters and atmospheric scientists use is the *computer model*. One type of computer weather forecast and research models are based on the known physical relationships between meteorological quantities (temperature, pressure, wind speed, wind direction, humidity, etc.) and external factors that can affect them (solar radiation, topography, land vs. water surface, etc.). These relationships can be expressed mathematically and solved quantitatively using a computer, providing a forecast or scenario of the future state of the atmosphere, given a starting state.

In this lab you'll configure a very simple computer model, run experiments with it, and evaluate it based on your experience reading surface weather observations displayed on meteograms.

II. A Simple Computer Model of Temperature Driven by Solar Heating

Our intuition is that the sun plays a central (though not necessarily the only) role in causing daily temperature variations, as we began to explore in Lab #2, Parts I and II, and Lab #3. We discovered in those labs that the intensity of solar radiation depends strongly on the angle of the sun above the horizon (*sun angle*), which varies with time of day and time of year at any particular location, and cloud cover also affects insolation at the earth's surface.

To test the extent to which the sun (affected by variations in sun angle and cloud cover) controls the earth's surface temperature, we can build a simple computer model based on a well-established, empirical physical law called the *Law of Conservation of Energy*. (An *empirical physical law* is based on many and repeated observations of the way the physical world behaves in many, many situations.)

One version of the Law of Conservation of Energy describes how objects gain or lose heat and how the temperature of the object responds as a result. It can be written very generally like this:

The **rate** at which an object's **temperature changes**

is proportional to

The **rate** at which an object's **heat content changes** = All of the rates at which the object ***gains*** heat by various mechanisms, *added together* − All of the rates at which the object ***loses*** heat by various mechanisms, *added together*

We could apply this law to the earth's surface. Moreover, if we suppose that the surface *gains* heat only by absorbing solar radiation, and it doesn't *lose* heat by *any* mechanism, then the Law of Conservation of Energy applied to the earth's surface would be simply:

The **rate** at which the earth's surface **temperature changes**

is proportional to

The **rate** at which the **heat content** of a layer of the earth's surface **changes** = The **rate** at which the **surface absorbs solar radiation**

Using this relationship, if we know how fast the surface absorbs solar radiation, then we can calculate how fast the surface temperature changes. From that, we can estimate what the temperatures will be in the near future (if they are driven only by absorption of solar radiation).

We can run this simple model, compare the results to observed daily temperature cycles, and see how well the model performs. That is, we can *evaluate* the model's performance.

If the model does well, it could be useful for helping us understand better how the atmosphere works and perhaps even for making temperature forecasts. (To be sure, we would need more experience and further evaluation of the model.)

If the model doesn't do well, we could question whether the Law Conservation of Energy applies to the earth's surface or, more likely, whether we have represented the absorption of solar radiation in the model correctly, or more likely still, whether or not we have included in the model all of the physical mechanisms by which the earth's surface gains and loses heat.

II. Instructions

- Respond in writing to questions posed in boxes below.
- Print a hard copy of the plot that you create in section D.
- Label the plot clearly with the details of the model run (in particular, the latitude, time of year, cloud cover, nature of the earth's surface).
- Turn in your written responses and plot at the end of the lab session.

A. *Access "Daily Temperature Cycle I", a computer model of the daily temperature cycle written using STELLA modeling software.*

If you are using one of the Mac computers in TH 604 or 607:

1. Make sure that there is a file called "DailyTempCycle.I.STMX" on the Desktop. (If not, alert your instructor.)
2. Locate the STELLA icon on the Dock along the bottom of the screen (a yellow disk with "S" at center). Click on it to start STELLA.
3. Pull down STELLA's "File" menu and select "Open…". (This opens a "Chose a File: STELLA" dialog window.)
4. On the left-hand side of the dialog window, under "FAVORITES", select "Desktop", then select the "DailyTempCycle.II.A.STMX" file.
5. Finally, click on the "Choose" button. You should now see the model interface.

or, almost (but not quite) as good, if you are using a Web browser and have an internet connection, go to:

http://forio.com/simulate/dempsey2/dailytempcycle-i/simulation/

Your instructor will describe the model features and explain how to configure it, run it, and access and read the graphs of model output.

B. *Notice the default model configuration.*

In this version of the daily temperature cycle model, you can control:

- Latitude (in degrees)
- Day of the year (Julian day, a number from 1 to 365)
- "Surface Type" (land or water)
- "Cloud Cover" (as a percentage of the sky covered by clouds)

If necessary, set the items above as follows (but don't run the model yet):

- Latitude: +36° (36°N; negative values are in the S. Hemisphere)
- Day of the year: 142 (Julian day, corresponding to May 22)
- "Surface Type": 1 (1 = land, 2 = sea)
- "Cloud Cover": 0% (no cloud cover at all)

C. *Make your own prediction of the daily temperature pattern, given how the sun angle varies.*

You have been given a plot of sun angle (in degrees) vs. time (in hours) for several days starting on May 22 at the latitude of Hanford, CA. On this plot, identify nighttime vs. daytime periods and the times of sunrise, sunset, and (solar) noon.

Based on the sun angle, sketch the pattern of temperature that you would expect to see. [The actual temperatures aren't important here, just the pattern of temperature—that is, the time(s) when the temperature is lowest and highest and what it does in between—relative to the sun angle pattern.]

D. *Run the model and compare your prediction to the model simulation.*

1. Run the model (using the settings specified in Section B above).

   You should see the same plot of sun angle as in Step C (above) appear on the first graph (which is Page 1 of three pages of graphs).

2. View the second graph (Page 2).

   [Click on the lower left-hand corner of the graph, which looks as if the corner has been bent forward slightly.]

   This graph plots (1) the sun angle (in degrees, the blue line) and (2) temperature (in °F, the red line) simulated by the model.

3. Try the following:

   a. place the cursor on the graph;

   b. click and hold the click, so that a vertical line appears on the graph through the location of the cursor; and

   c. drag the cursor back and forth (which drags the vertical line with it).

   Notice that beneath the "Hours" label along the horizontal axis you'll see the time (in hours) corresponding to the cursor's position, and beneath the "Sun Angle deg" and "Temperature F" labels along the top of the graph you'll see the values of these quantities at that hour. (Note: it works a little differently in the Web-based version.)

   You can use this feature to help answer some of the questions below.

Question #1: Describe any apparent correspondence that you can see between temperature (as calculated by the model) and sun angle.

[For example, how does each behave at night? During daylight hours? When is temperature changing and not changing, relative to what the sun angle is or is not doing?]

Question #2: In what ways is the model simulation of temperature similar to what you sketched in Step C (above)? In what ways is it different?

4. View the third graph (Page 3). It shows:

(1) the rate (in Watts) at which the surface absorbs solar energy (the blue line), and
(2) the temperature (in °F) (the red line).

For **Question #3** below, you should consider surface temperature observations that you've seen plotted on meteograms (for example, on the meteograms accompanying this lab from Hanford, CA, which we first saw in Lab #2, Part II), as well as your own personal experience with the daily temperature cycle.

Question #3: In what ways does the model simulation seem reasonable and in what ways does it not?

Question #4 below asks about the *physical processes* that are represented in the model and that determine the temperatures that the model calculates (*not* about the quality of the graphs that the model produces, which merely show the model output).

Question #4: Do you have any suggestions about what might be done to improve the model?

5. Print a copy of *only* the third graph (Page 3). Label the plot clearly with the details of the model run (in particular, the latitude, time of year, cloud cover, nature of the earth's surface).

   To print the plot (follow these instructions carefully!):

   a. First, pull down STELLA's "File" menu and select "Page Setup", and next to "Orientation", select the landscape mode [the right-hand icon.].
   b. Then click on the printer icon in the lower left-hand corner of the graph. You'll get a "Print" dialog box.
   c. In the "Print" dialog box, make sure that the printer specified is "coriolis". [If coriolis isn't working, use "downpour".]
   d. Also in the “Print” dialog box, pull down the “Pages” menu and select “Single”.
   e. In the text box next to the “Pages” menu, enter “3” (for Page 3).
   f. Click on the “Print” button.
   g. Retrieve your plot from the printer.

E. *Run the model to see if adding cloud cover or changing the nature of the earth's surface improves the simulation.*

1. Specify a cloud cover greater than 50%. *Don't run the model yet.*

Question #5: What do you predict that the temperature pattern will look like?

How does your prediction differ from your first model simulation (without clouds) in Section D above? Why?

2. Run the model, and view the plots on Page 3 of the graphs.

Question #6 below asks you to compare the plots on Page 3 of the graphs to those from your simulation in Section D above (where there was no cloud cover).

To do this, you can address several aspects of the temperature simulations:

(a) the temperature values themselves;
(b) the daily temperature range from minimum to maximum; and
(c) the pattern of temperature, particularly the timing of lows and highs each day and what happens in between.

Question #6: In what way(s) do your two simulations (with and without clouds) differ?

Is the model simulation with clouds any better? (That is, do it's main features resemble the main features of observed daily temperature cycles more closely, such as the one observed at Hanford, CA on May 22, 1999?)

3. Specify (a) no cloud cover, but (b) change the surface type from land to ocean. *Don't run the model yet*.

Question #7: What do you predict the temperature pattern will look like?

How does your prediction differ from your simulation in Section D above, and why?

4. Run the model, and view the plots on Page 3 of the graphs.

Question #8 below asks you to compare the plots on Page 3 of the graphs to those from your simulation in Section D above (where there was also no cloud cover but the earth's surface was land, not ocean).

To do this, you can address several aspects of the temperature simulations:

(a) the temperature values themselves;
(b) the daily temperature range from minimum to maximum; and
(c) the pattern of temperature, particularly the timing of lows and highs each day and what happens in between.

Question #8: In what way(s) are your simulations over land and over ocean (both without clouds) different?

Is the new simulation any better than your first simulation?

5. If you want, try increasing the cloud cover over the ocean surface to see if that helps. Good luck!

6. Turn in this lab with your written responses plus your annotated plot from Section D.

METR 104: Our Dynamic Weather (w/lab)	**Lab Exploration #4: Solar Radiation & Temperature Part II: A More Complex Computer Model**	Dr. Dave Dempsey, Department of Earth & Climate Sciences, SFSU, **Fall 2013**

(5 points)
(Thursday, Oct. 24)

Your Name _____

Learning Objectives. After completing this activity, you should be able to:

- Configure a simple computer model (a STELLA model) and run experiments to calculate temperature at the earth's surface over several days, driven by absorption of solar radiation and radiative cooling.
- Evaluate the model, based on experience reading meteogram plots of observed daily temperature cycles at individual locations.
- Solidify further a description of the role that computer models play in the way that science works in atmospheric science.

Materials Needed. To complete this activity, you will need:

- A computer in TH 604 or 607 with:
  - STELLA modeling software installed on it, and either
  - a version of a STELLA model of the daily temperature cycle ("DailyTempCycle.II.A.STMX")
    or
  - an internet connection with a Web browser, to access the Web-based version of the model at:
    http://forio.com/simulate/dempsey2/dailytempcycle-ii-a/simulation/

- Graphs of sun angle (in degrees) vs. time (in hours) at the latitude of Hanford, CA (36.3°N) starting on May 22 (Julian day 142)

- Two meteograms showing typical daily temperature cycles under cloud-free conditions at Hanford, CA (KHJO):
  - Ending at 07Z December 17, 1998
  - Ending at 09Z May 24, 1999

Prior Knowledge Required:

- Understanding of several forms of energy (especially sensible heat and electromagnetic radiation)
- Understanding of what temperature is, and the difference between temperature and heat
- Understanding of the Principle of Conservation of Energy, expressed in the form of a heat budget equation for an object
  - some ways that the earth's surface can gain and lose heat:
    - absorption of solar radiation
    - emission of longwave infrared radiation
    - (others not yet accounted for)
- Understanding of radiative emission:
  - Emission as a process in which sensible heat in an object is transformed into radiative energy that propagates away (and hence a way for an object to lose heat)
  - How the intensity with which an object emits radiative energy depends on the object's temperature
    - an object emits more radiative energy when it's warmer than when it's cooler (the Stefan-Boltzmann Law)
  - How the wavelengths of radiation that an object emits the most depend on the object's temperature
    - an object emits most of its radiative energy at shorter wavelengths when it's hotter, and at longer wavelengths when it's colder
    - wavelengths of emission by the sun vs. the earth (solar or shortwave radiation vs. terrestrial or longwave radiation)

I. Introduction. This lab activity continues our development of a sense of how we might use (a) experience with observations and (b) basic physical principles, to understand and forecast surface temperature over the course of one to several days. In particular, it continues the development and testing of a computer model of the daily temperature cycle at the earth's surface introduced in Lab #4, Part I.

In this lab you'll configure a more sophisticated version of the computer model, run experiments with it, and evaluate it based on your experience reading surface weather observations displayed on meteograms.

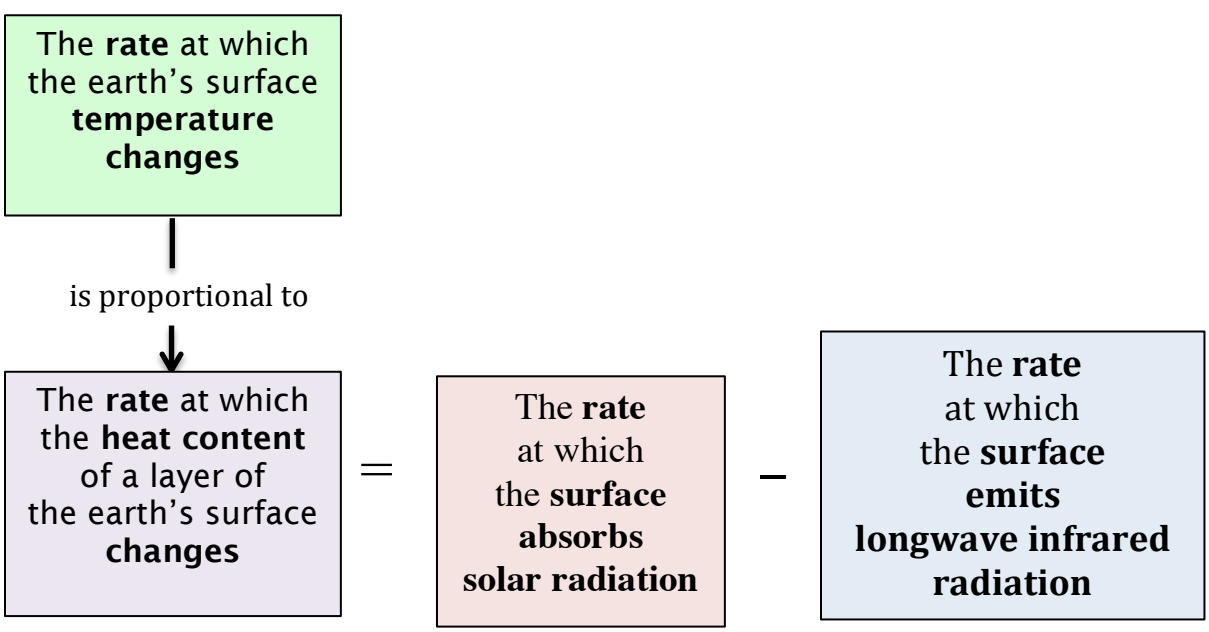
II. A Somewhat More Sophisticated Computer Model of Temperature Driven by Solar Heating

The sun certainly plays a central (though not necessarily the only) role in controlling daily temperature variations, and clouds modify (in particular, reduce) the effect that solar radiation has on temperature during the daytime. However, we discovered in Lab #4, Part I that solar radiation alone doesn't account for some aspects of the daily temperature cycle. In particular, by accounting only for solar radiation absorption (even when modified by clouds), the temperature never falls (at night or any other time), and the temperature rises all day to a maximum at about sunset (where it stays all night), not to a maximum time in the afternoon between noon and sunset.

In retrospect, the fact that the temperature never falls in that model should make sense. For an object to cool, it must lose heat. The mere absence of solar heating does not by itself give the earth's surface any way to lose heat and cool off—it merely means that it's not gaining any heat and so the temperature doesn't change, as the model predicted.

To overcome this shortcoming, we'll try adding emission of radiative energy to the model, a mechanism by which the earth's surface can lose heat.

With this new physical processes included, the Law of Conservation of Energy applied to the earth's surface and written in a form that describes how the surface gains and loses heat and how its temperature responds as a result, can be written like this:



Using this relationship, we can calculate how fast the surface temperature changes and from that we can estimate what the temperatures will be in the near future (if they are driven by absorption of solar radiation and emission of radiative energy).

We can run this somewhat more sophisticated model, compare the results to observed daily temperature cycles, and see how well the model performs. That is, we can evaluate or validate the model.

If the model does well, it could be useful for helping us understand better how the atmosphere works and for making temperature forecasts. (To be sure, further experience and evaluation of the model would be necessary.)

If the model doesn't do well, we have to question any assumptions that underlie the physical relationship as we've applied it (above), or perhaps take into account physical processes that are important but that we neglected.

II. Instructions

- Read and follow these instructions carefully.
- Respond in writing to questions posed in boxes below.
- Print a hard copy of the plot that you create in section E.
- Turn in your written responses and plot at the end of the lab session.

A. *Access "Daily Temperature Cycle II.A", a computer model of the daily temperature cycle written using STELLA modeling software.*

If you are using one of the Mac computers in TH 604 or 607:

1. Make sure that there is a file called "DailyTempCycle.II.A.STMX" on the Desktop. (If not, alert your instructor.)
2. Locate the STELLA icon on the Dock along the bottom of the screen (a yellow disk with "S" at center). Click on it to start STELLA.
3. Pull down STELLA's "File" menu and select "Open…". (This opens a "Chose a File: STELLA" dialog window.)
4. On the left-hand side of the dialog window, under "FAVORITES", select "Desktop", then select the "DailyTempCycle.II.A.STMX" file.
5. Finally, click on the "Choose" button. You should now see the model interface.

or, almost (but not quite) as good, if you are using a Web browser and have an internet connection, go to:

http://forio.com/simulate/dempsey2/dailytempcycle-ii-a/simulation/

Your instructor will describe the model features and explain how to configure it, run it, and access and read the graphs of model output. Note the ways in which this model differs from the version in Lab #4, Part I.

B. *Notice the default model configuration.*

In this version of the daily temperature cycle model, the latitude is set to 36°N (the latitude of Hanford, CA). However, you can specify:

- Either of two days of the year (May 22 or December 16)
- Whether or not the surface emits longwave infrared radiative energy
- "Surface Type" (land or water)

If necessary, set the items above as follows (but don't run the model yet):

- Day of the year: May 22
- Emission of longwave infrared radiation: Turned off
- "Surface Type": 1 (1 = land, 2 = sea)

C. *Make your own prediction of the daily temperature pattern, given how the sun angle varies.*

You have been given a plot of sun angle (in degrees) vs. time (in hours) for several days starting on May 22 at the latitude of Hanford, CA. On this plot, identify nighttime vs. daytime periods and the times of sunrise, sunset, and (solar) noon.

Based on the sun angle, sketch the pattern of temperature that you would expect to see (assuming no clouds). [The actual temperatures aren't important here, just the pattern of temperature—that is, the time(s) when the temperature is lowest and highest and what it does in between—relative to the sun angle pattern.]

D. *Run the model and compare your prediction to the model simulation.*

1. Run the model (using the settings specified in Section B above).
   You should see the same plot of sun angle as in Step C (above) appear on the first graph (which is Page 1 of three pages of graphs).

2. View the second graph (Page 2 of the graphs).
   This graph plots (1) the sun angle (in degrees, the blue line) and (2) temperature (in °F, the red line) simulated by the model.

3. Try the following:

    a. place the cursor on the graph;
    b. click and hold the click, so that a vertical line appears on the graph through the location of the cursor; and
    c. drag the cursor back and forth (which drags the vertical line with it).

    Notice that beneath the "Hours" label along the horizontal axis you'll see the time (in hours) corresponding to the cursor's position, and beneath the "Sun Angle deg" and "Temperature F" labels along the top of the graph you'll see the values of these quantities at that hour. (Note: it works a little differently in the Web-based version.)

4. Rerun the model for December 16, view the second graph (Page 2 of the graphs), and notice of any differences from May 22.

E. *Reconfigure the model to run with radiative emission turned on, predict the results, run the model, and compare your prediction to the model simulation.*

1. Turn on IR Emission and set the day of the year to May 22.

2. You have been given a second plot of sun angle (in degrees) vs. time (in hours) for 2.5 days (60 hours) starting on May 22 at the latitude of Hanford, CA.

    Based on the sun angle, sketch the pattern of temperature that you would expect to see with radiative emission turned on (again assuming no clouds).

3. Run the model and view the second graph (Page 2 of the graphs).

As before, this graph plots (1) the sun angle (in degrees, the blue line) and (2) temperature (in °F, the red line) simulated by the model.

Question #1: Describe any apparent correspondence that you can see between temperature (as calculated by the model) and sun angle.

[For example, how does each behave at night? During daylight hours? When is temperature changing (and how fast), or not changing, relative to what the sun angle is or is not doing?

(Use the cursor to help pinpoint specific temperatures and sun angles at specific times on the plot.)]

4. View the third graph (Page 3 of the graphs). It shows:

(1) Blue line: The rate (in Watts) at which the surface absorbs solar energy; and

(2) Red line: The temperature (in °F).

For **Question #2** below, you should consider surface temperature observations that you've seen plotted on meteograms (for example, on the meteograms accompanying this lab from Hanford, CA, which we first saw in Lab #2, Part II), as well as your own personal experience with the daily temperature cycle.

Question #2: In what ways does the model simulation seem reasonable and in what ways does it not?

Question #3: Does the model seem to perform *better* than it did previously, when it calculated the effects of only solar radiation absorption? If so, how?

Question #4: Are there aspects of the model prediction that don't seem to capture reality very well? If so, what?

(You can rerun the model for December 16 and see if any of your observations and conclusions differ.)

5. Print a copy of *only* the third graph (Page 3) for the May 22 model simulation. Put your name on it, along with other information about the model simulation beyond what is already on the plot. To print the plot (follow these instructions carefully!):

    a. First, pull down STELLA's "File" menu and select "Page Setup", and next to "Orientation", select the landscape mode [the right-hand icon.].
    b. Then click on the printer icon in the lower left-hand corner of the graph. (*Don't* select "Print" from the "File" menu.) You should get a "Print" dialog box.
    c. In the "Print" dialog box, make sure that the printer specified is "coriolis". [If coriolis isn't working, use "downpour".]
    d. Also in the "Print" dialog box, pull down the "Pages" menu and select "Single".
    e. In the text box next to the "Pages" menu, enter "3" (for Page 3).
    f. Click on the "Print" button.
    g. Retrieve your plot from the printer.

6. Turn in the plot along with this lab (with your written responses to **Questions #1-4**).

METR 104: Our Dynamic Weather (w/lab)	**Lab Exercise #4: Solar Radiation & Temperature Part III: An Even More Complex Computer Model**	Dr. Dave Dempsey, Department of Earth & Climate Sciences, SFSU, **Fall 2013**

(5 points)
(Thursday, Nov. 7)

Learning Objectives. After completing this activity, you should be able to:

A. Configure and run more experiments with a simple computer model (a STELLA model) of the daily temperature cycle.
B. Evaluate the model based on experience reading meteograms.
C. Solidify further a description of the role that computer models play in the way that science works in atmospheric science.

Materials Needed. To complete this activity, you will need:

- A computer in TH 604 or 607 with STELLA modeling software installed, plus either:
  - version III of a STELLA model of the daily temperature cycle ("DailyTempCycle.III.STM"), *or*
  - an internet connection with a Web browser, to access the Web-based version of the model at http://forio.com/simulate/dempsey2/dailytempcycle-iii/simulation/
- Two meteograms showing typical daily temperature cycles under cloud-free conditions at Hanford, CA (KHJO):
  - Ending at 09Z May 24, 1999
  - Ending at 07Z December 17, 1998

Prior Knowledge Required:

- Background needed for the previous lab exploration (Lab #4, Part II)
- Understanding of the Principle of Conservation of Energy, expressed in the form of the heat budget equation for an object, including the earth's surface
  - Some ways that the earth's surface can gain and lose heat:
    - absorption of solar radiation
    - emission of longwave infrared radiation
    - absorption of longwave infrared radiation emitted downward by greenhouse gases and clouds
    - conduction of heat from the surface into the atmosphere (or vice versa)
    - evaporation of water from the earth's surface
- Understanding of radiative absorption: when an object absorbs radiation, the energy is transformed into (an equal amount of) sensible heat in the object

II. An Even More Complex Computer Model

We have been conducting a series of lab explorations to investigate ways to explain the commonly observed daily temperature cycle. In Lab #2, Part I we constructed graphs of solar radiation intensity data recorded at Hanford CA on two particular days. In Lab #2, Part II we described features of the solar radiation intensity observed at that location, and began looking for connections between the patterns of temperature and solar radiation observed there over the course of a day. In Lab #3 we looked at the meteograms for two consecutive days at two locations in Colorado and saw examples of how “the weather complicates things”, in particular, how factors such as cloud cover can affect the daily temperature cycle.

In Lab #4, Parts I and II we began using a computer model based on the principle of conservation of energy to try to simulate observed daily temperature cycles, and to evaluate how well the model performed. The model we used in Part I (called "DailyTempCycle.I.STM") assumed that the surface temperature cycle is driven *exclusively* by the rate at which the surface *absorbs* solar radiation. We found that this model did not do a good enough job of explaining the temperature cycle. In Part II we modified the model (calling it "DailyTempCycle.II.A.STM") to take into account the fact that, in addition to absorbing solar radiation, the surface also emits longwave infrared radiation.

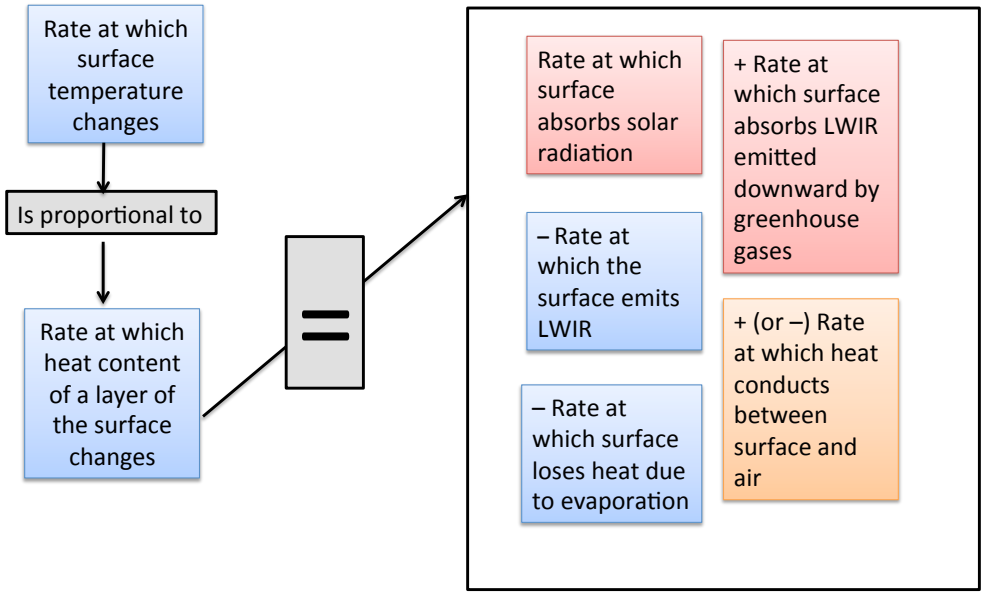
That last model produced a daily temperature pattern that was realistic in some ways but not in others. It produced a temperature maximum in the afternoon and cooling thereafter until near (just after) sunrise, as we commonly see in observations of the real atmosphere. The daily maximum temperature, although a little too high, wasn't too bad, but the minimum temperatures were much colder than we'd expect to see, and so the daily temperature range (the difference between the minimum and maximum temperature) was too large. We concluded that, although that model did much better than its predecessor did in Lab 4, Part I, it is likely missing one or more physical mechanisms not accounted for yet. What might those mechanisms be?

We know that greenhouse gases and clouds absorb longwave infrared radiation emitted by the earth's surface. We also know that greenhouse gases and clouds emit longwave infrared radiation of their own, that they emit part of that radiation downward, and that the surface absorbs it. Hence, we'll include in the model this additional source of heat for the surface.

We also know that when two objects at different temperatures are in direct contact, heat will "flow" from the warmer one to the cooler one (so the warmer one cools off and the cooler one warms up). This is the process of ***conduction*** of heat. In particular, when air in contact with the earth's surface is warmer or colder than the surface, heat will conduct from one to the other, and the surface will gain or lose heat. We'll try to represent this process in the model.

Finally, we know that when water ***evaporates***, heat in the water transforms into latent heat in the water vapor, reducing the amount of heat in the remaining water. (We experience this directly when we overheat, produce sweat, and feel cooler when the sweat evaporates from our skin.) We'll try to represent evaporative cooling in the model (especially from the oceans, less so from land).

With these three new physical process added, the Law of Conservation of Energy applied to the earth's surface and written in a form that describes how the surface gains and loses heat (that is, a heat budget) and how its temperature responds as a result, can be written like this:



Using this relationship, we can calculate how fast the surface temperature changes and estimate temperature in the near future (at least, if the model is complete and accurate). We can run this more complete model, compare the results to observed daily temperature cycles, and see how well the model performs. That is, we can evaluate, or *validate*, the model.

If the model does well, it could be useful for helping us to understand better how the atmosphere works and for making temperature forecasts. (We'd need further experience and validation of the model to be sure.) If the model doesn't do well, we have to question any assumptions that underlie the physical relationship as we've applied it above, or perhaps take into account physical processes that are important but that we have neglected.

III. Instructions

- Read and follow these instructions carefully.
- Respond in writing to questions posed in boxes below.
- Print a hard copy of the plot that you create in section E.
- Turn in your written responses and plot at the end of the lab session.

A. *Access "Daily Temperature Cycle III", a computer model of the daily temperature cycle written using STELLA modeling software*

If you are using one of the Mac computers in TH 604 or 607:

1. Make sure that there is a file called "DailyTempCycle.III.STMX" on the Desktop. (If not, alert your instructor.)
2. Locate the STELLA icon on the Dock along the bottom of the screen (a yellow disk with "S" at center). Click on it to start STELLA.
3. Pull down STELLA's "File" menu and select "Open…". (This opens a "Chose a File: STELLA" dialog window.)
4. On the left-hand side of the dialog window, under "FAVORITES", select "Desktop", then select the "DailyTempCycle.II.A.STMX" file.
5. Finally, click on the "Choose" button. You should now see the model interface.

or, almost (but not quite) as good, if you are using a Web browser and have an internet connection, go to:

http://forio.com/simulate/dempsey2/dailytempcycle-iii/simulation/

Your instructor will describe the model features and explain how to configure it, run it, and access and read the graphs of model output. Note the ways in which this model differs from the version in Lab #4, Part II.

B. *Notice the default model configuration.*

Don't run the model yet, but note that in this version of the daily temperature cycle model you can specify:

1. *Where and when the model runs*:
   - latitude (in degrees)
     [default: 36°N, the latitude of Hanford, CA]
   - day of the year (Julian day, expressed as a number from 1 to 365)
     [default: day 142, which is May 22]

2. *Whether or not each of the following ways for the surface to gain or lose heat is turned on*:
   - emission of longwave infrared radiative energy [default: turned on]
   - absorption of longwave infrared radiation emitted downward by greenhouse gases and clouds [default: turned off]
   - conduction of heat between the surface and the atmosphere, and evaporation of water from the surface [default: turned off]

3. *Several more model parameters*:
   - "Surface Type" (land or water) [default: land]
   - "Cloud Cover" (% of the sky covered by clouds) [default: 0%]

C. *Repeat a model simulation that you performed in Lab #4, Part II and confirm that is the same*. (No written response required.)

You have been given a plot of sun angle (in degrees) and temperature (in °F) vs. time (in hours) for 2.5 days (60 hours) starting on May 22 at the latitude of Hanford, CA. (You generated this plot in Lab 4, Part II.) *Run* the latest version of the model with the default configuration described above, and *verify* that it reproduces this plot. (The plot is on the second graph, on Page 2 of the five pages of graphs available in this version of the model.

Note one difference: the hours plotted along the bottom axis in this version of the model will be from 360 hours to 420 hours (15.0 to 17.5 days) instead of 0 to 60 hours (0 to 2.5 days). However, both series of times start at midnight and end at noon.

Note the maximum and minimum temperatures achieved over the course of each day, and the time of day when they occur.

D. In this section we will look at the effects of (1) greenhouse gases, and (2) conduction and evaporation, on the daily temperature cycle.

Respond to the questions in writing in the space provided.

Before you run the model again:

Question 1: How do you think that turning on greenhouse (GH) gas heating in the model will affect the temperature pattern?

Turn on GH gas heating and run the model, without changing anything else.

Question 2:

a) Does the pattern of the daily temperature cycle change in any significant way from the previous model simulation? If so, how?

b) Refer to the meteogram for Hanford, CA for the same day of the year. Do the temperatures simulated by the model (for example, the maximum and minimum values) seem more realistic, less so, or no different than, the previous model run?

Now turn on conduction/evaporation, too, and run the model again.

Question 3:

a) Does the pattern of the daily temperature cycle change in any significant way from the previous run? If so, how?

b) Refer to the meteogram for Hanford, CA for the same day of the year. Do the temperatures simulated by the model (for example, the maximum and minimum values) seem more realistic, less so, or no different than, the previous model run?

Print a copy of the graph on Page 2 of your last model run. Remember to specify that only Page 2 should be printed (not all 5 pages!). (See Lab #4, Part I or Part II for instructions about printing graphs in STELLA.) Put your name on it. Turn it in with your written responses to the questions in Sections D (above) and Section E (next page).

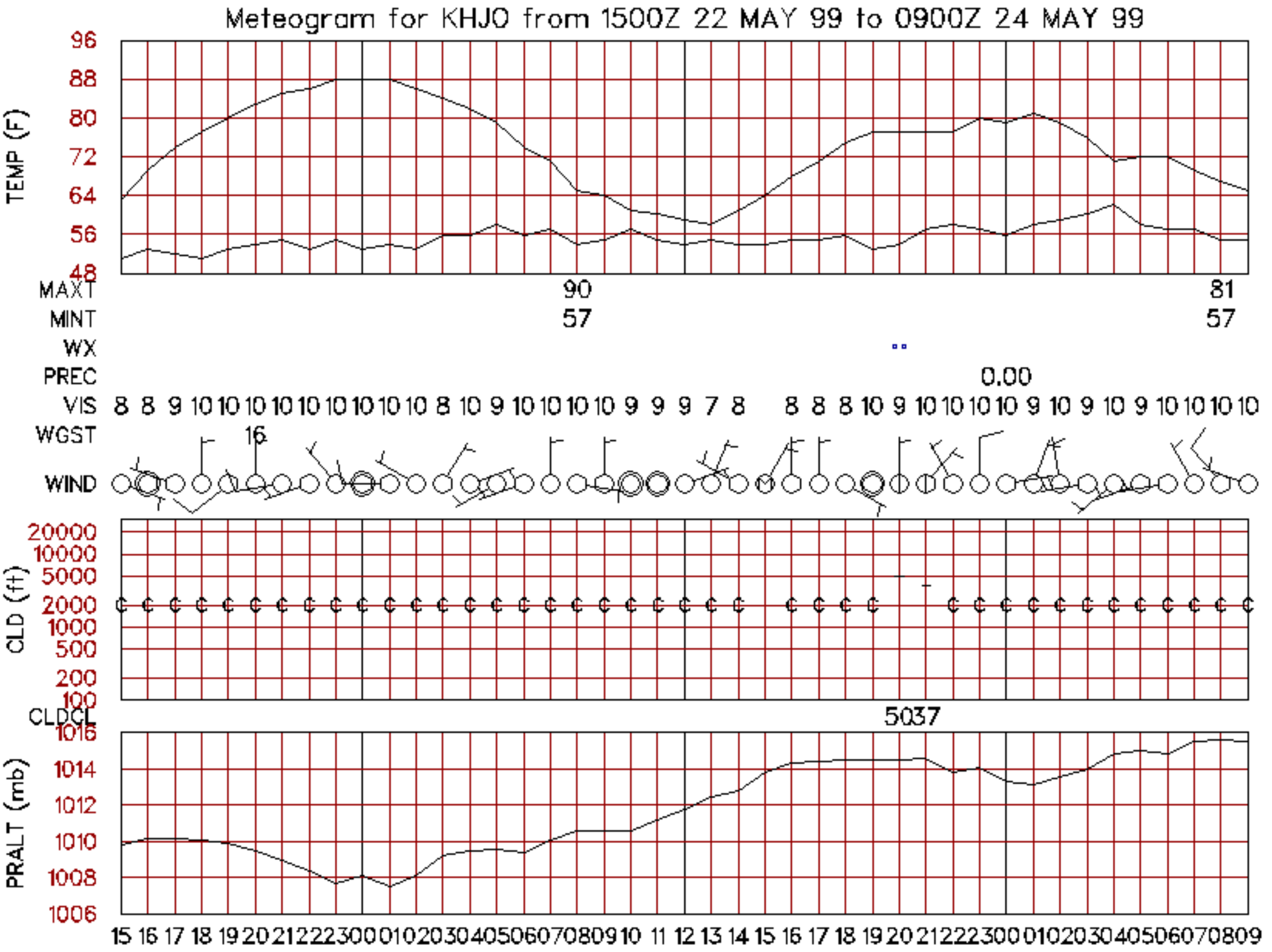
E. In this part you will examine the effects of clouds in the model.

Before your run the model again:

Question 4: If you added a significant percentage of cloud cover to the model, what do you think would happen to the daytime maximum temperature and the nighttime minimum temperature, compared to the previous model run with no cloud cover?

Reconfigure the model to include significant cloud cover. Then run the model and compare the model results to your prediction.

Question 5: What difference do you see in the high and low temperatures simulated by the model with cloud cover? How would you explain these results?


Meteogram for KHJO from 1500Z 22 MAY 99 to 0900Z 24 MAY 99
TEMP (F)
96
88
80
72
64
56
48
MAXT
90
81
MINT
57
57
WX
PREC
0.00
VIS
8 8 9 10 10 10 10 10 10 10 10 10 8 10 9 10 10 10 10 9 9 9 7 8 8 8 8 10 9 10 10 10 10 9 10 9 10 9 10 10 10 10
WGST
16
WIND
CLD (ft)
20000
10000
5000
2000
1000
500
200
100
CLDCL
5037
PRALT (mb)
1016
1014
1012
1010
1008
1006
15 16 17 18 19 20 21 22 23 00 01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 00 01 02 03 04 05 06 07 08 09