Where do Hurricanes get their energy?

Fernand Brunschwig (fbrunsch@gmail.com)

Hurricanes get their energy via a fairly straightforward energy transfer from the Sun to thermal energy of the sea water, to phase energy (or "electric field energy") stored in the separation of the water vapor molecules, and finally to thermal energy and kinetic energy of the air. The power output of a typical hurricane is in the range of 10^15 watts, which is about 200 times the total world electrical generating capacity! It's too bad we can't somehow capture all that energy.

There are four diagrams of hurricane energy, as follows:

1. "HURRICANE--SYSTEM SCHEMA.pdf" includes a full set of arrows showing the matter and the energy flow, plus a full set of energy bar graphs.
2. "HURRICANE--SYSTEM SCHEMA-WITHOUT SOME BARS.pdf" includes the arrows and the initial and final energy bar charts but leaves out the bars on the two intermediate energy charts. This can be used as an assignment - You can ask students to put in a set of bars that are consistent with conservation of energy. There are a total of 5 "units" of energy in the first and fourth charts, so the second and third charts should also contain a total of 5 "units" of energy, and the charts should be consistent with the fact that the energy gradually flows from the Sun to the liquid sea water, then to the water vapor, and finally to the thermal and kinetic energy of the air.
3. "HURRICANE--SYSTEM SCHEMA-no bars.pdf" has no bars at all on the four energy charts, so it is somewhat more challenging than the one above with some of the bars. Students would have to make reasonable assumptions about how much energy is originally in the system and about how to apportion it as time goes on.
4. "HURRICANE--SYSTEM SCHEMA-no bars or arrows.pdf" leaves out all the arrows and all the bars on the energy charts. Filling in all the arrows and bars would provide a reasonably challenging assignment for students. They should also, I think, be asked to explain their work, as there are a variety of ways to think about this, and one must make various decisions about what to include and what not to include in the system. An more challenging assignment would be to propose changes to include aspects of the situation that the existing diagram neglects, and an even more challenging assignment would be to create one's own version of the diagram.

The "units" of energy on the diagrams, and the proportions of that energy stored in the four systems shown on the diagrams, are arbitrary and do not reflect actual values from the real world.

If you have a gmail/Google account and would like to get access to the original, editable versions of the diagrams, please send me a request from your gmail account. I "share" the diagrams, you will be able to view them in your Google Docs "shared" folder as well as download them or make copies and then edit and modify the copies.

A more detailed description and explanation of the diagrams and of the hurricane energy flow is below.

==

The energy flows. in somewhat more detail, are as follows:

1. The radiation from the Sun transfers thermal energy to liquid water in the sea, and the temperature of the water and the air above it goes up.

2. The water evaporates and the energy is then stored in the separated water molecules. This can be described as either "phase" energy or as energy of "vaporization" (in the macro or human-scale domain) or as electric field energy (in the micro domain). Basically, in order for the water to evaporate, the water molecules in the liquid water must be pulled apart against the attractive electrical forces between the molecules (the hydrogen bonds), and as part of this process, thermal energy stored in the sea water must be transferred to another form of storage, which is, in fact, in the electric field in the space between the water vapor molecules; this is usually referred to as electric potential energy, but the term "electric field energy" is more specific and does not call forth the misconceptions usually invoked by the term "potential" energy.

3. The water vapor then condenses as liquid water (rain), and the energy is transferred from the electric field between the water vapor molecules (or the phase/vaporization energy of the water vapor) to the thermal and kinetic energy of the air over the sea. As the air over the sea gains thermal and kinetic energy, its temperature and also its speed of motion increase.

4. As the cycle continues, the result can be very high winds, along with rain from the condensing water vapor. The high temperature of the air at the center of the storm means that the air expands and rises, lowering the pressure at the center of the storm. There is also another factor lowering the pressure: the faster a gas is moving, the lower the pressure. (This is the same principle that provides lift on a airplane wing; the cross-sectional profile of the wing is designed so that the air streaming over the top must move further and thus faster than the air under the wing, so the pressure is less above than below, and there is a net force upward. This is known as Bernoulli's Principle, and it is a consequence of conservation of energy.)

As a result, the higher pressure of the atmosphere outside the center of the storm drives air toward the center; this air is saturated with water vapor that has evaporated from the warm sea; the water then condenses as rain and transfers energy to the air, the air temperature and speed rises even more, and the cycle continues. In addition, there is one more very important result, the low pressure of the air at the center of the storm inevitably means an **increase in the water level**: the higher pressure of the atmosphere on the water outside the storm essentially pushes water toward the center of the storm.

The diagrams and steps above do not explain how the actual air flows, but there is a nice diagram of this in Wikipedia:
http://en.wikipedia.org/w/index.php?title=File:Hurricane_profile.svg&page=1

It is also important to remember that as the air flows in toward the center of the storm, the rotation of the earth causes the entire storm to rotate (counter-clockwise in the Northern Hemisphere and clockwise in the Southern Hemisphere). This phenomenon is known as the Coriolis Effect.

The energy source is the Sun which warms the sea water; that water is continuously evaporating and then condensing as rain, and that is what drives the storm and keeps it going. The hurricane is in fact a giant "heat engine" - transferring energy from thermal form to motion of the wind, just as a car's engine transfers energy from the hot gas produced by burning gasoline into motion of the cylinders and the car itself. Without a source of energy, the storm will gradually die out, which is what happens when it leaves the sea and goes onto land. As you would expect, the storm does the most damage when it first hits land; as has been well reported, Sandy first hit the New Jersey shore not too far south of NY City.
=
The flooding is, of course, closely related to the amount that the sea level rises during the storm, which is connected with the low pressure at the center of the storm. But the tides are also very important: the sea rises and falls twice a day and the times when this occurs, as well as the amount of rise and fall are related to the moon's (and the sun's) gravitational pull on the water of the sea. There are two high tides every day throughout the world, and the time of high tide gets later every day by about 50 minutes. (Since the moon takes 28 days to go completely around the earth, each day it moves (1/28)th of a complete rotation, so we would expect that it would rise about (1/28)th of a day later every day, that is (24/28) hours or ((24*60)/28) = 51.4 minutes.)

If it happens to be high tide just at the time when the hurricane comes onto land, the sea will rise higher than it would without the high tide, and the flooding will be worse, and this is what happened with Sandy. Finally, if the moon and the sun are acting together, the high tide will be especially high; this happens whenever the sun, the moon and the earth are aligned in close to a straight line, and this happens twice a month, at full moon and at new moon. Unfortunately, this was what happened with hurricane Sandy - the moon was full on Oct 29.

One can analyze this further as well - if the Moon, the Sun and the Earth are especially close to being in a straight line, the tides will be higher, and this was indeed the case on Oct 29 (because it wasn't too far away from the Fall Equinox). In addition, if the Moon is at a point in its orbit when it is closer to the earth, the tides will be higher, and this also happened on Oct 29! Fortunately, however, the Earth wasn't at the point in its oribit when it was closest to the sun; that occurs at the Winter Solstice (Dec 21), which would have meant that the tide due to the sun's gravity was highest.

A further question is why the tide occurs twice a day - but I'll leave that for another occasion.

ENERGY FLOW IN A HURRICANE

1. The Sun transfers energy to liquid water in the sea.

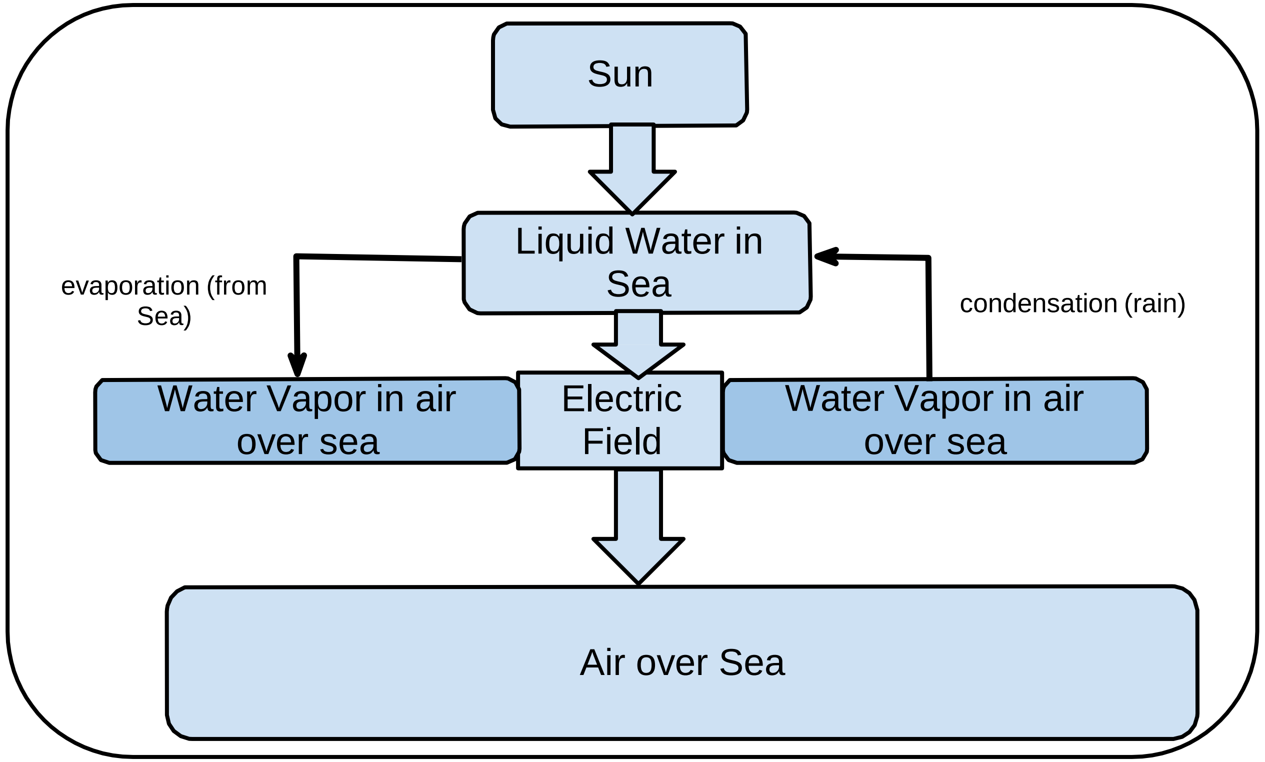
2. The water evaporates and the energy is stored in the electric field between the separated water molecules.

3. The water vapor then condenses as rain, and the energy is transferred from the electric field to the air over the sea. As the air over the sea gains energy, its temperature and speed of motion increase.

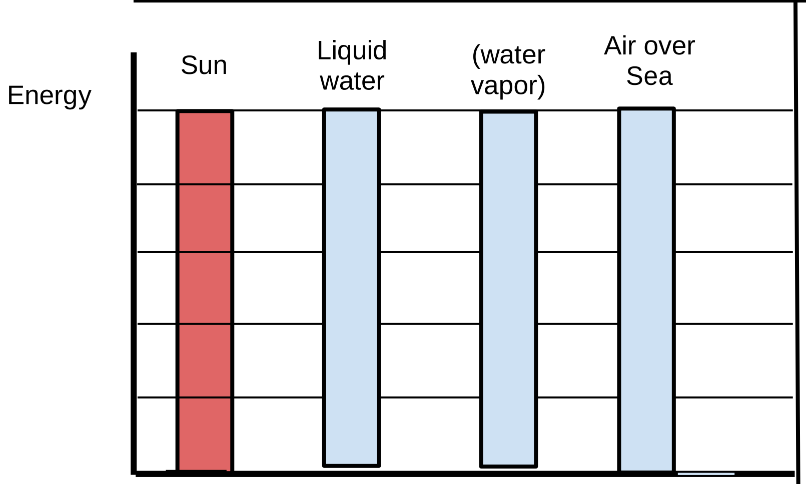
4. As the cycle continues, the result can be very high winds.

Thin black arrows indicate movement of matter.

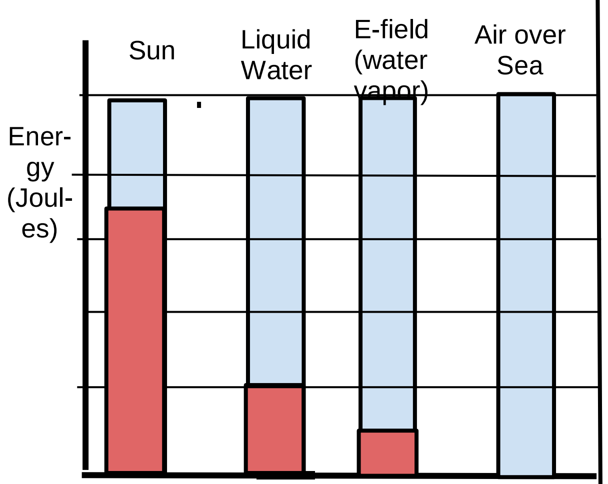
Thick blue arrows indicate transfer of energy.



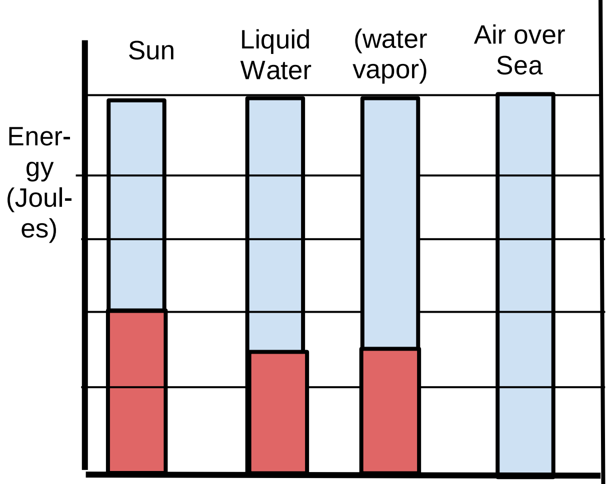
System in initial state (12:00 noon)



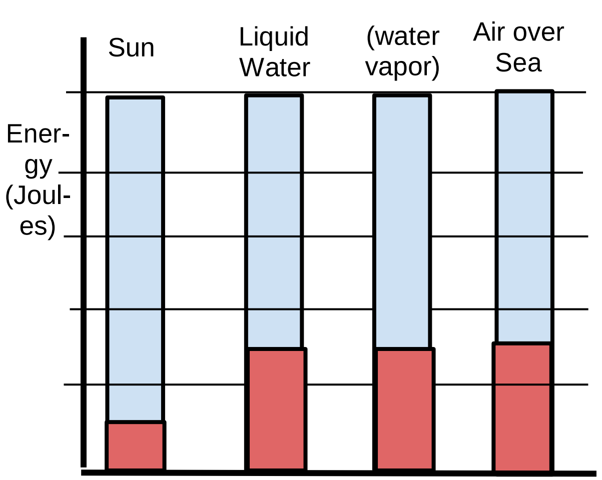
System at later state (12:30 pm)



System at later state (1:00 pm)



System at later state (1:30 pm)



ENERGY FLOW IN A HURRICANE

1. The Sun transfers energy to liquid water in the sea.

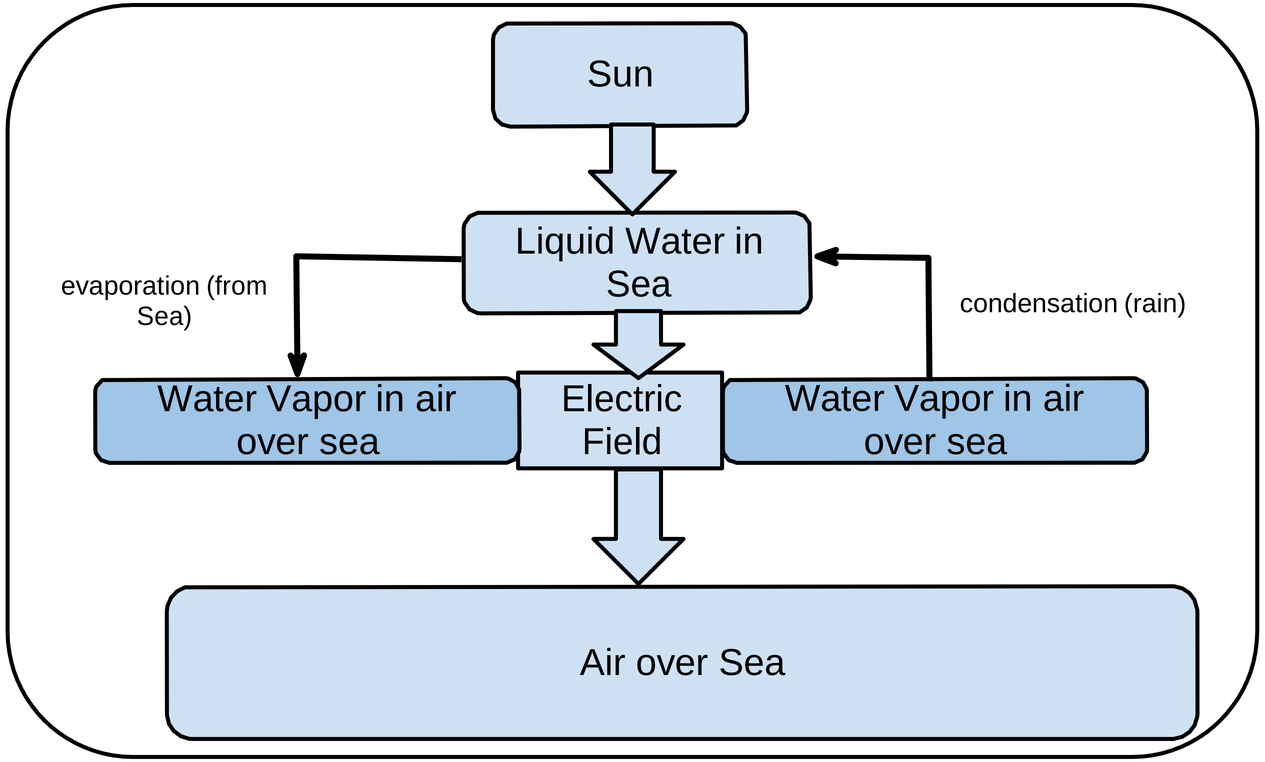
2. The water evaporates and the energy is stored in the electric field between the separated water molecules.

3. The water vapor then condenses as rain, and the energy is transferred from the electric field to the air over the sea. As the air over the sea gains energy, its temperature and speed of motion increase.

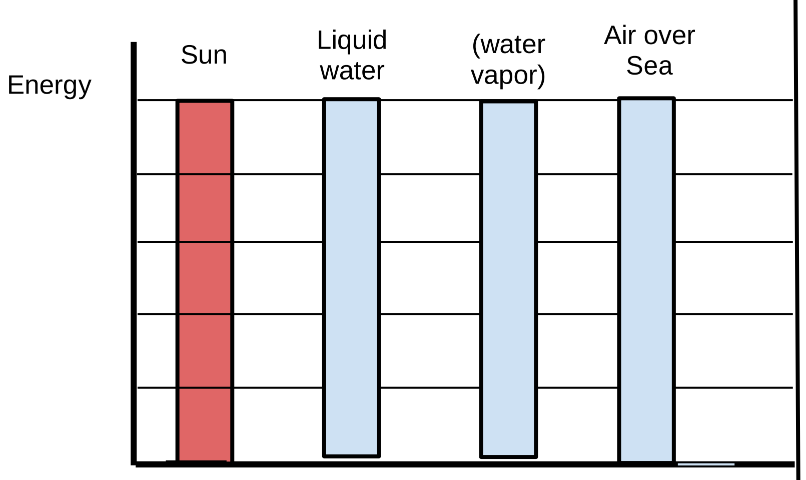
4. As the cycle continues, the result can be very high winds.

Thin black arrows indicate movement of matter.

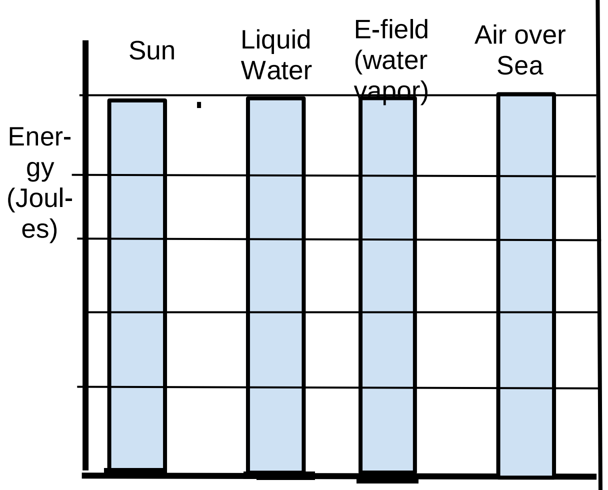
Thick blue arrows indicate transfer of energy.



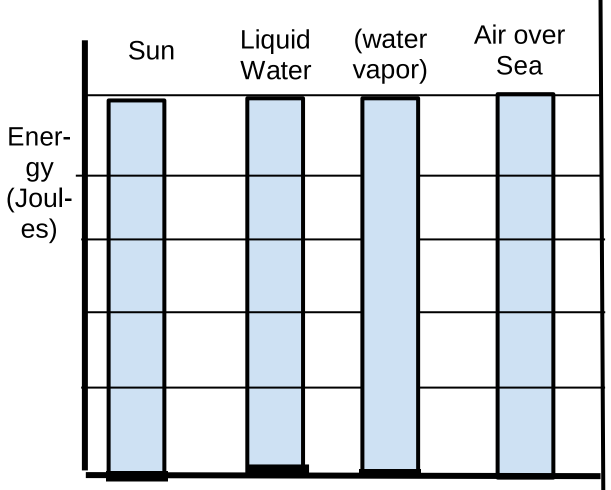
System in initial state (12:00 noon)



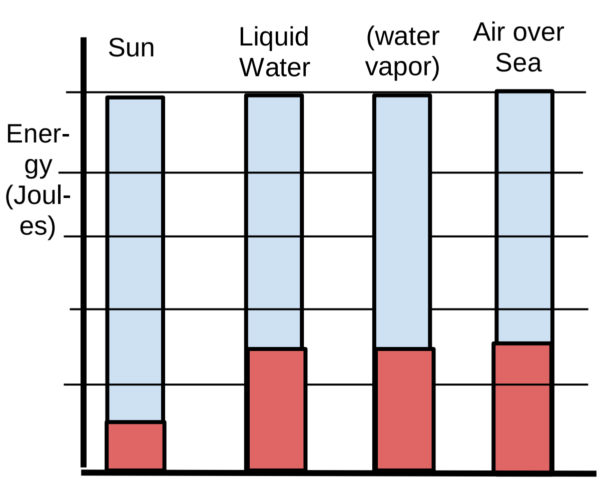
System at later state (12:30 pm)



System at later state (1:00 pm)



System at later state (1:30 pm)



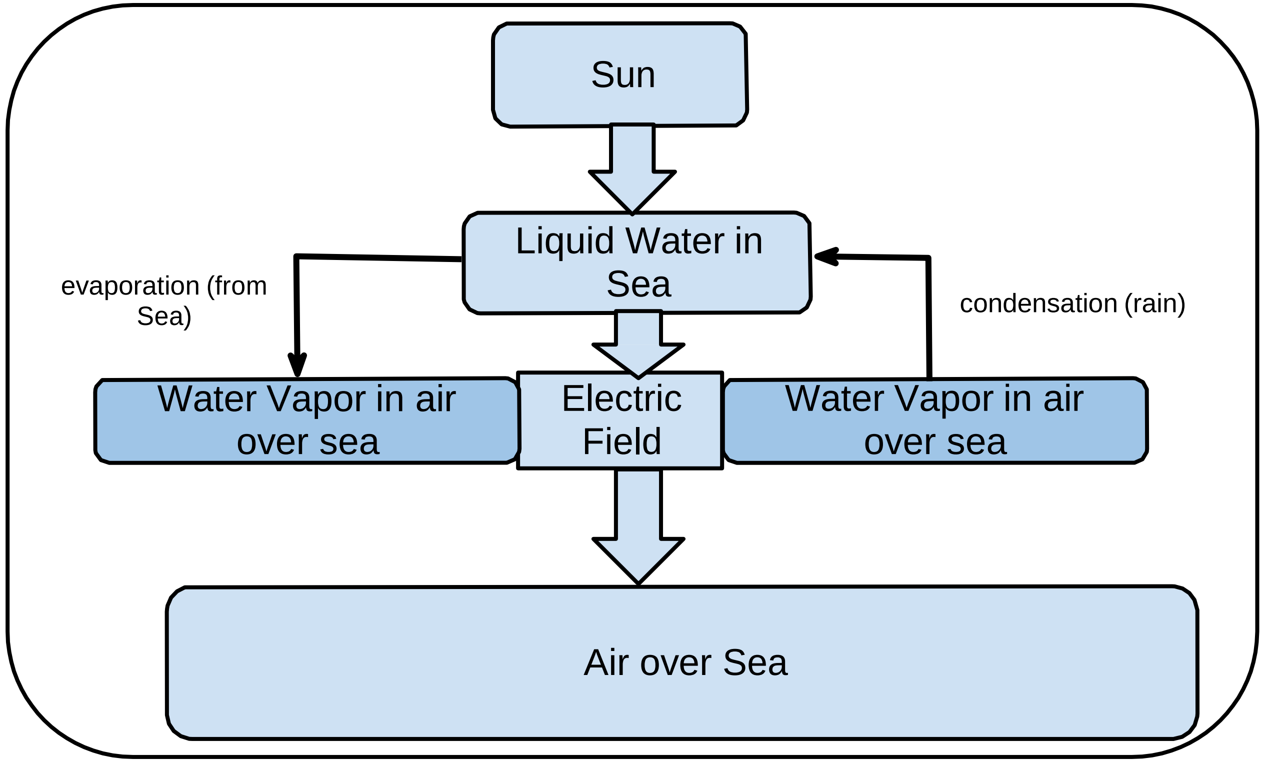
ENERGY FLOW IN A HURRICANE

1. The Sun transfers energy to liquid water in the sea.

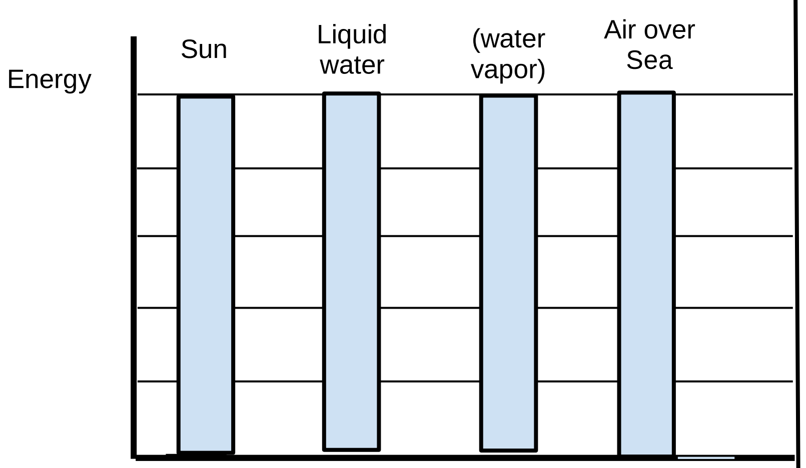
2. The water evaporates and the energy is stored in the electric field between the separated water molecules.

3. The water vapor then condenses as rain, and the energy is transferred from the electric field to the air over the sea. As the air over the sea gains energy, its temperature and speed of motion increase.

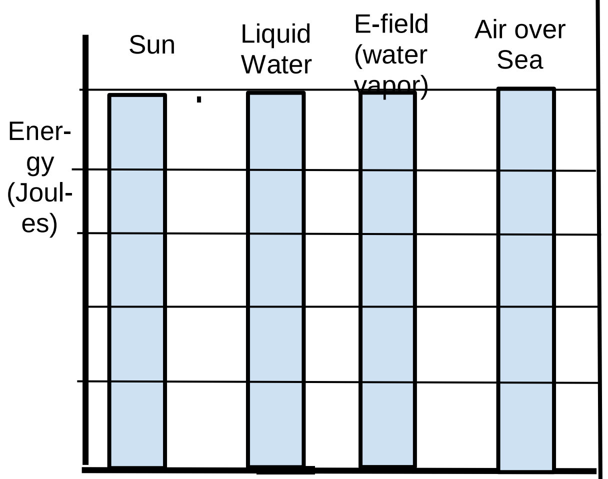
4. As the cycle continues, the result can be very high winds.



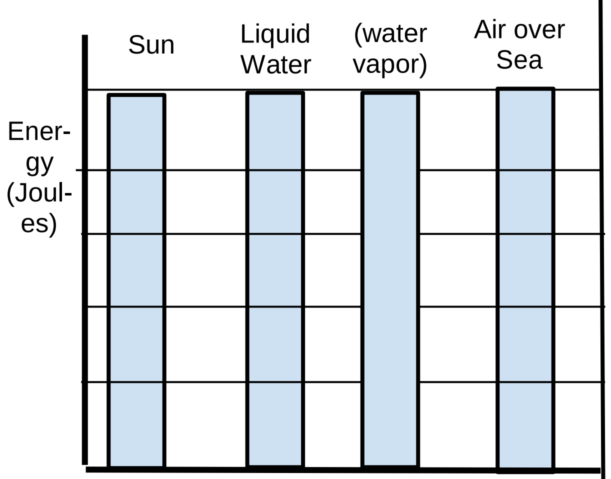
System in initial state (12:00 noon)



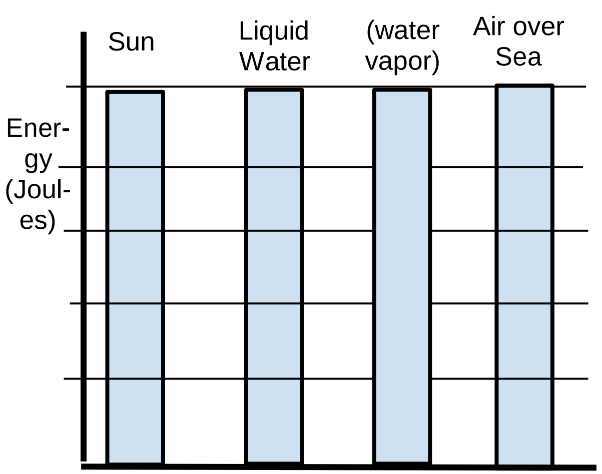
System at later state (12:30 pm)



System at later state (1:00 pm)



System at later state (1:30 pm)



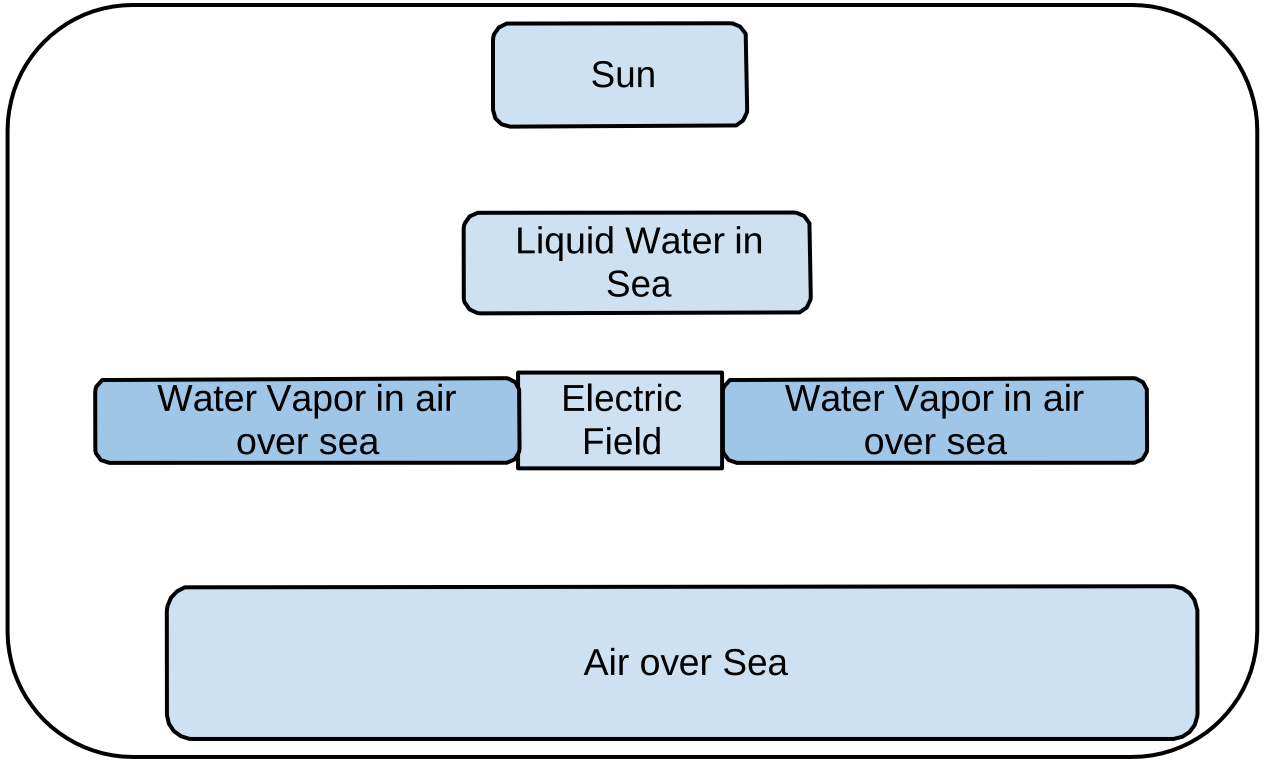
ENERGY FLOW IN A HURRICANE

1. The Sun transfers energy to liquid water in the sea.

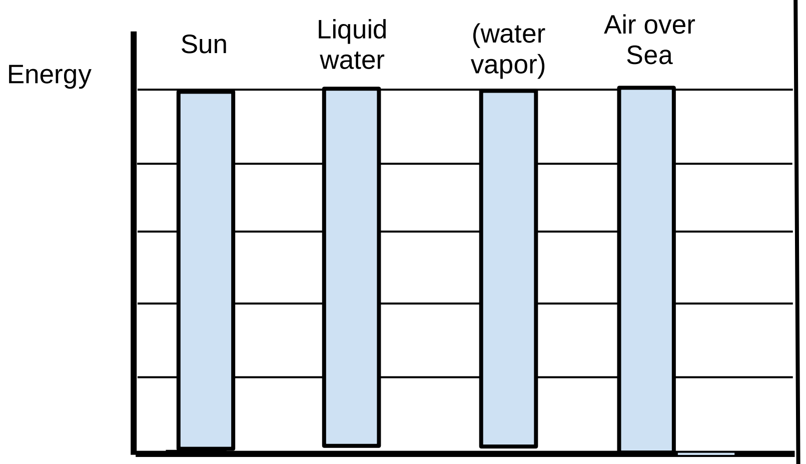
2. The water evaporates and the energy is stored in the electric field between the separated water molecules.

3. The water vapor then condenses as rain, and the energy is transferred from the electric field to the air over the sea. As the air over the sea gains energy, its temperature and speed of motion increase.

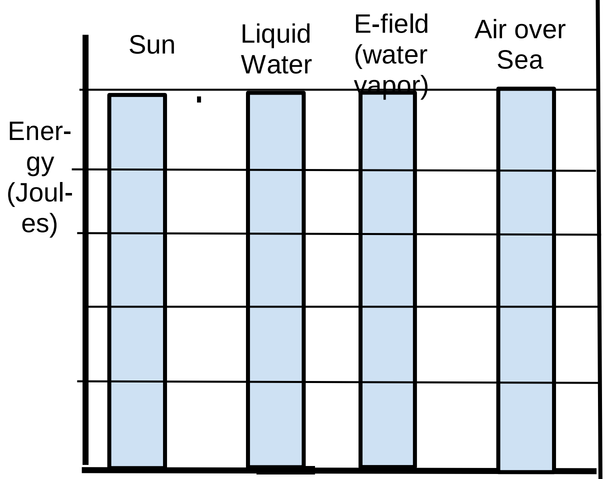
4. As the cycle continues, the result can be very high winds.



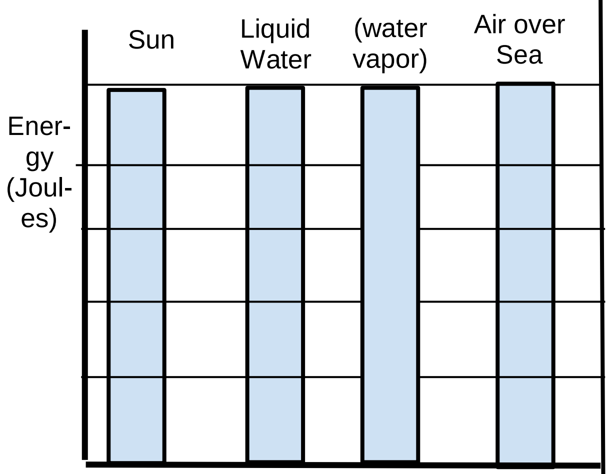
System in initial state (12:00 noon)



System at later state (12:30 pm)



System at later state (1:00 pm)



System at later state (1:30 pm)