AutoFlux - what ARE we doing?

An air-sea interaction experiment

OR

Not just meteorology

OR

Four fluxes.

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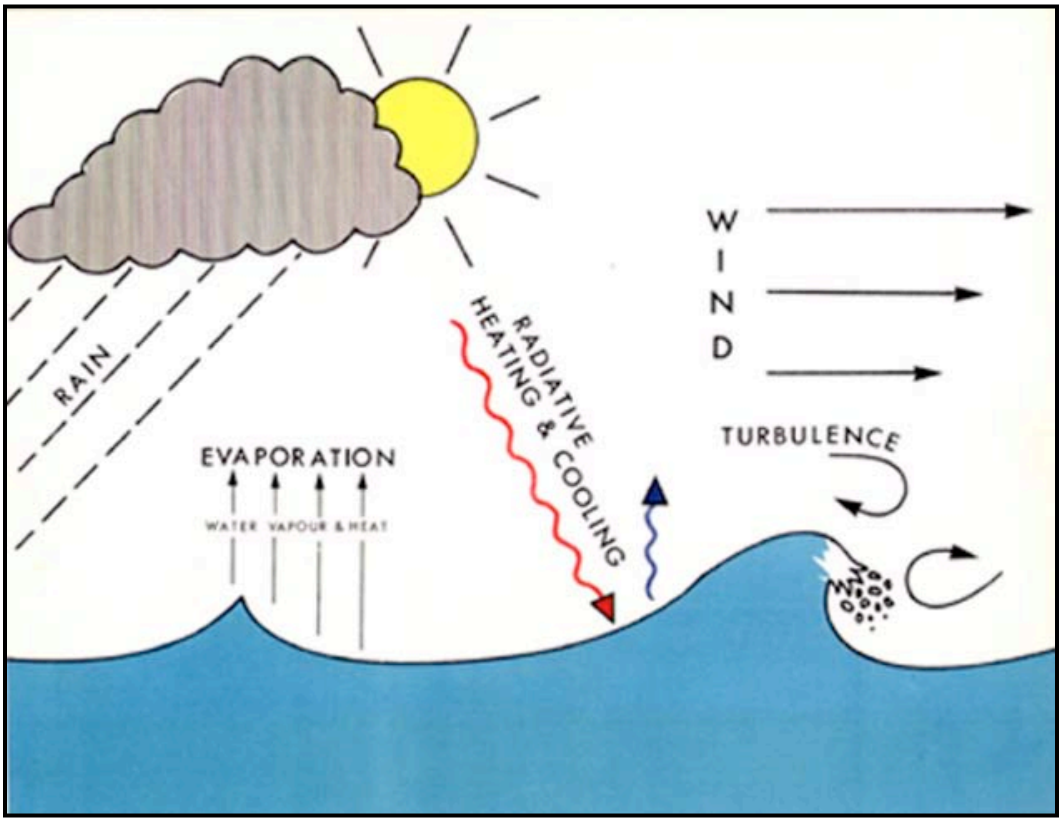
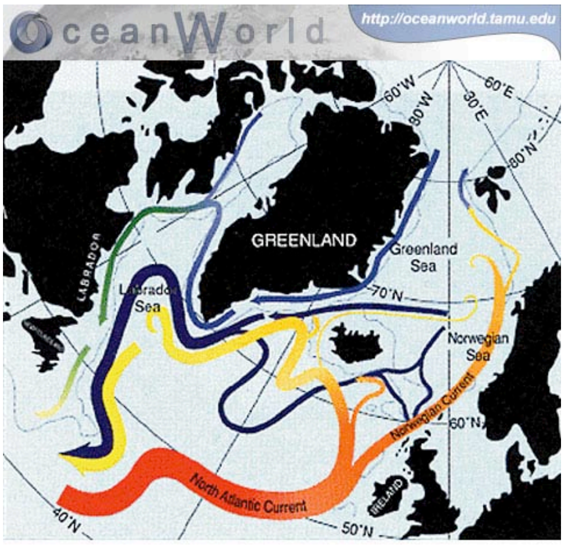


Chapter 1

In which the four fluxes are met for the first time.

The atmosphere and the ocean are very closely linked to each other. A large fraction of the energy from the sun passes straight through the atmosphere and is absorbed by the ocean surface which becomes warmer as a result. Over the open ocean the surface water is usually warmer than the air above it and so heat is transferred from the surface water to the atmosphere, just as a cooker heats a saucepan from beneath.

A dramatic example of how the ocean heats the atmosphere is the Gulf Stream, sometimes called the North Atlantic Current (part of the "Conveyor Belt"). This is a huge surface current of warm water which travels east across the Atlantic from the Caribbean to northern Europe - the massive amount of heat transferred from the water to the atmosphere makes the climate of western Europe much warmer than it would be without this heat exchange (think of icy winters St Petersburg - on the same latitude as the Shetland Islands, which are only wet and windy). Heat is transferred from the ocean to the air directly and by evaporation of water. The direct exchange of heat is called the "sensible heat flux" and the evaporation exchange is called the "latent heat flux".



North Atlantic part of the Conveyor Belt (courtesy of Woods Hole Oceanographic Institution). Warm surface currents are in red/yellow. Cool deep currents are in blue.

The oceans currents change and move over tens or hundreds of years, so if we want to predict the worlds climate we first have to be able to predict what will happen to the oceans currents. We also need to understand the physics of how the oceans and the atmosphere interact. For example - how fast is the heat exchanged between the atmosphere and the ocean? Does the exchange depend on wind speed? Or on sea state?

As well as heat exchange, the atmosphere and ocean interact in other ways. An obvious example is that the wind blowing over the water makes waves and currents, i.e. the wind transfers momentum and kinetic energy to the water. However, the waves can also affect the wind. A perfectly smooth flat surface will have very little effect on the wind above it and very little energy will be transferred between the two. In contrast, a hilly rough surface will slow the wind down by friction and by "drag", and there will be a large exchange of energy. This exchange of energy is called the "momentum flux".

Climate change is a hot topic. One cause of climate change is the increased amount of carbon dioxide being pumped into the atmosphere, largely by the burning of fossil fuels. We do not know exactly what happens to this carbon dioxide. How much CO2 just builds up in the atmosphere? How much is absorbed on land by growing plants? How much is absorbed by the oceans? One estimate is that about one third of the extra CO_2 in the atmosphere is absorbed by the ocean. Some of this will be locked away for good (or at least a few hundred years). For example, some types of plankton use dissolved CO_2 to make their calcium-carbonate bodies - when these plankton die many of them sink to the bottom of the ocean where they, and the carbon they contain, will remain indefinitely.

When the concentration of CO_2 is the same in both the surface water and the air above it, the two are in equilibrium and there is no exchange of CO_2 from one to the other. However, when they are not in equilibrium they will exchange CO_2 - if the air has a higher concentration of CO_2 than the water, CO_2 will be transferred from the atmosphere in to the ocean. As for the other fluxes, we do not know exactly what affects this exchange or flux of CO_2. For example, we know that the flux of CO_2 is larger under strong winds than light winds, but not by how much.

Chapter 2

In which our pitiful lack of knowledge is exposed.

The ocean and atmosphere are linked by four fluxes:

sensible heat - the direct transfer of heat
latent heat - the evaporation of water
momentum - the energy transferred to/from wind and waves
CO_2 - carbon dioxide (actually just one of the many gases and particles which are exchanged)

If we want more accurate weather forecasts, and better predictions of climate change, we need a good understanding of how these fluxes behave in different weather conditions. At this time, there is a lot we don't know about the fluxes. The momentum flux is the best-understood and we know that the exchange of momentum between the wind and the waves increases as the wind speed increases, but we do not know what part the waves themselves play. Some scientists think that "young" waves (newly created wind waves) increase the flux, and others think not. Similarly, some think that if a swell is moving in the same direction as the wind then the flux is decreased, but others disagree. The state of the sea may also affect the transfer of heat. If the sea is calm and smooth then a cool "skin" may form - this can act as a barrier to the transfer of heat. For the CO_2 flux things become really complicated and there are many theories which say that the CO_2 flux depends on;

wind speed
sea state
wave breaking
rain
whitecaps and sea spray
the surface "skin"
the other three fluxes!

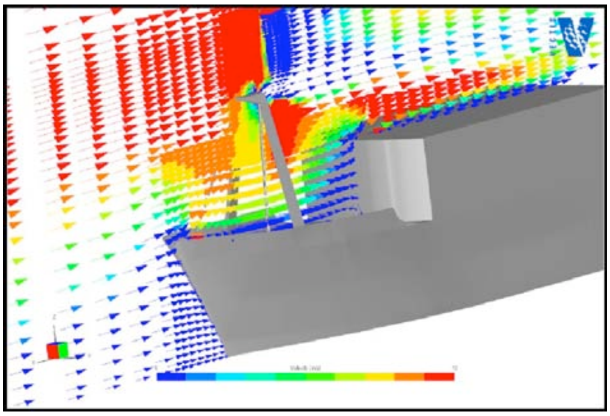
The CO_2 flux is so badly understood that the different theories suggest transfers of CO_2 that differ by 50% for wind speeds of 7 m/s (the average wind speed over the worlds oceans). At higher winds speeds when most of the exchange happens the theories disagree by 100% or more.

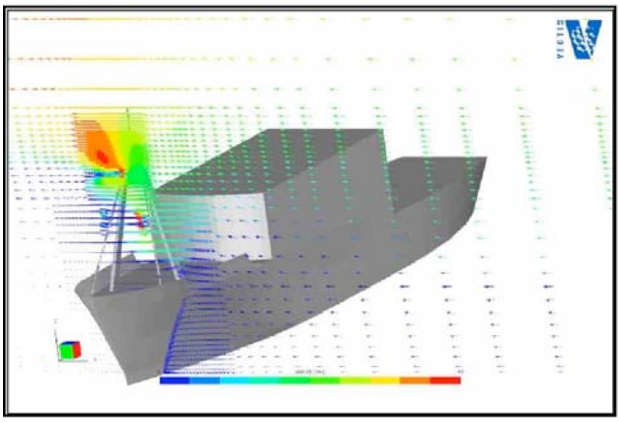
Chapter 3

Air-sea interaction is full of problems.

A major problem is measuring these fluxes. To do this means making very accurate measurements of the wind speed, air temperature, humidity and the atmospheric CO2 concentration. The fluxes depend on the turbulence in the atmosphere so we need to know not just the average value of these measurements, but how they vary in a very short time (less than 0.1 seconds). To get this information all the measurements have to be made 20 times a second and all have to be synchronised together, and all have to made close to each other. One of the most difficult things to measure is how the turbulence makes the wind speed change in the vertical direction. To do this we have to measure the vertical wind speed and the motion of the ship in the vertical direction too, since the motion of the ship moves the anemometer itself up and down.

Making these measurements in the open ocean means we have to use a ship, but the ship causes problems. The ship affects the flow of air to the instruments, no matter where the instruments are put. The flow of air changes speed as it flows over the ship, and is also pushed upwards and sideways. We can correct for this by making computer models of the wind flowing around the ship. The pictures below show a very simple model of the air flow around the *Polarfront* (now that we have plans of the ship we will make much more detailed models). The effect of the ship on the measurements changes with the wind direction. For an anemometer on the starboard side of the foremast platform, the results from the simple model say that the measured wind speed will be wrong by 1% if the wind is blowing directly on to the bow. If the wind is blowing from the starboard beam the measured wind speed will be 3% too high, and if the wind is blowing from the port side it will be 10% too high. These errors may not sound very large, but if the wind speed is wrong by 10% then our measured fluxes will be wrong by about 40%. This is very wrong indeed...





Computer models of the air flow over a simple version of the Polarfront. On the left the wind is blowing on to the bow. On the right the wind is blowing on to the port beam. The colours represent different wind speeds in the two pictures - on the left the red means the wind is too high by 1% and on the right the red means the wind speed is too high by 10%.

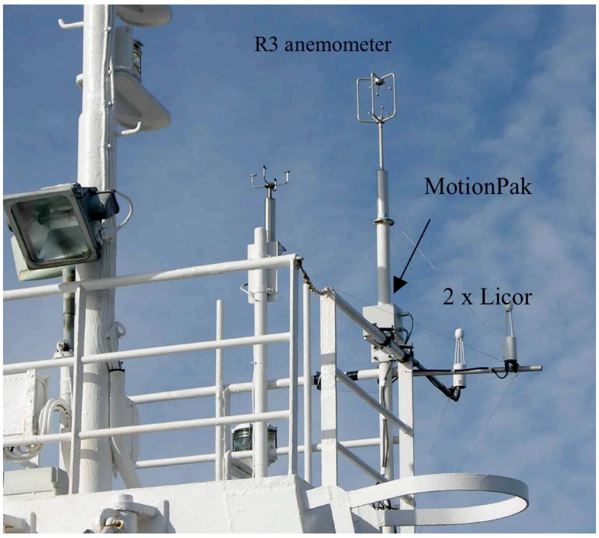
Chapter 4

In which the mysterious objects on the foremast are identified.

To make the flux measurements, we have a group of sensors which measure at 20 to 100 Hz. They are all mounted close together on the starboard side of the foremast platform. The sensors are;

- an R3 sonic anemometer - this measures all three components of the wind speed and also air temperature
- two Licor H2O/CO2 sensors. - these measure atmospheric humidity and CO2
- a MotionPak - for accurate ship motion measurements

The R3 anemometer data, combined with the motion data, eventually provide us with the momentum and sensible heat fluxes and the Licor instruments provide the latent heat flux and the CO2 flux.



Left: the flux sensors on the foremast. Right: a Licor with the shroud in place. Table Mountain is in the background.

The R3 anemometer is a well-tested instrument which we have used to measure the momentum flux for nearly 20 years. The Licors are quite new instruments and are very good at measuring the latent heat flux. One problem with the Licors is that the head of the sensor is not completely rigid and tends to bend very slightly as the sensor is waved about by the ship motion. This causes errors in the CO2 flux measurements. To check that we have removed these errors correctly we need to cover one sensor at a time using a shroud which sits over the head. When the shroud is on the flux measurements should be zero. We need to do this on a regular basis to make sure that the errors have not changed. For future cruises one Licor at a time will be shrouded, with the shroud swapped from on to the other when the ship visits port once per month.

Chapter 5

A cast of thousands.

The *Polarfront* is an almost perfect ship for this experiment since it is dedicated to meteorological observations, unlike any other ship in the world. It occupies a station where high wind speeds (and therefore large fluxes) occur and where the ocean and atmosphere are often not in equilibrium for CO2. The foremast platform is very well exposed for all wind directions except those from aft, and the ship spends the majority of the time with the wind on the beam or bow.

Once we have measured the fluxes we have to explain their behaviour in terms of the conditions at the time. For this we also need measurements of;

true wind speed and direction
air temperature and humidity
atmospheric pressure
sea temperature
"skin temperature" of the sea surface
sea state
wave breaking and whitecapping
rain
CO2 concentration of the water
CO2 concentration in the atmosphere

We will get some of these (e.g. sea temperature and air pressure) from the existing ship's equipment provided by DNMI, and the data on CO2 concentration are being obtained by the group from Bergen University. Information on wave breaking and whitecapping will be provided by the two digital cameras on the bridge. The temperature of the surface "skin" of the water will be recorded by two Tasco infra-red sensors mounted on the bridge top. The ship's SYNOP hourly meteorological observations will be the source of information about rain events.

Information on sea state will be obtained from both the ship borne wave recorder (SBWR) and the Wavex wave radar. The SBWR does not provide any information about the direction of the waves, but measures the significant wave height (Hs) quite well. In contrast, the Wavex does provide data about the wave direction but the quality of the wave height information from this system is not known. The combined data from both together will provide excellent information about the sea state.

To understand the relationship between the fluxes and all the other variables requires a very large amount of data, obtained under a wide range of conditions. In particular we need data in high winds speeds, i.e. average wind speeds of more than 20 m/s. To obtain enough data means having all of our instruments operating continually. We will leave all the instruments operating on the *Polarfront* for at least three years as part of "HiWASE" (High Wind Air-Sea Exchanges) which is a project funded by the U.K. Natural Environment Research Council program "SOLAS" (Surface Ocean Lower Atmosphere Study). Towards the end of the three years we will try to secure further funding to keep the installation operating semi-permanently.