Diffusive Fluxes

Sensible heat flux

The density of sensible energy is

$$\rho_{ES} = \rho c_p T \cong \rho c_p \theta$$

We have to be a bit careful in the vertical because of compressional effects that are not relevant to vertical energy exchange. Note that for adiabatic processes, θ is conserved and no heat is exchanged. So we need to think in terms of the vertical gradient of θ rather than T to understand the vertical flux of sensible heat.

Downgradient diffusion representation

We can write the vertical flux as a downgradient diffusion process representation

$$F_{SH} = -K_H \rho_a c_P \frac{\partial \bar{\theta}}{\partial z}$$

where $\bar{\theta}$ is the average of potential temperature and K_H is the eddy diffusivity or eddy diffusion coefficient for heat transfer. Note that this diffusivity is NOT the molecular diffusivity we derived in the previous lecture. This is the diffusivity associated with the eddies in the atmosphere. It is still defined analogous to the molecular diffusivity as a length times a velocity but in this case it is a length associated with a relevant scale of the eddies and a velocity associated with the eddies as we will see below.

Bulk aerodynamic or drag coefficient representation

$$F_{SH} = -\rho_a c_p C_H |U| \left[\theta(z) - \theta(0)\right]$$

where C_H is the coefficient of drag for sensible heat transfer.
We can see that

$$C_H |U| \left[\theta(z) - \theta(0)\right] = K_H \frac{\partial \bar{\theta}}{\partial z} = K_H \frac{\left[\theta(z) - \theta(0)\right]}{z}$$

$$C_H |U| = \frac{K_H}{z}$$

$$K_H = z|U|C_H$$

One can think of $z\,|U|$ being the maximum possible eddy diffusivity for the given wind speed and C_H is an efficiency factor ≤ 1 likely indicating the size of the eddies relative to the height, z.

Eddy correlation approach

Any variable can be decomposed into its mean and the variations about the mean. This can be written in the following way

$$\theta = \bar{\theta} + \theta'$$

where $\bar{\theta}$ is the mean and θ' are the variations about the mean. Turbulent fluxes involve the variations in both the quantity and the wind.

$\rho c_p \theta u = \rho c_p (\theta u)$

$$F_{SH} = \rho_a C_P \overline{w'\theta'} \cong \rho_a C_P \overline{w'T'}$$

units: kg m^{-3} J kg^{-1} K^{-1} m s^{-1} K = J m^{-2}s^{-1}.

So

$$F_{SH} = \rho_a C_P \overline{w'\theta'} = -K_H \rho_a c_P \frac{\partial \overline{\theta}}{\partial z}$$

$$\overline{w'\theta'} = -K_H \frac{\partial \overline{\theta}}{\partial z} = -z|U|C_H \frac{\partial \overline{\theta}}{\partial z}$$

Surface Moisture flux and latent heat flux

Evaporation, E, can be treated similarly. Again we want to use a variable that is conserved unless there are sources or sinks. In the case of water vapor, suych a variable is the specific humidity, q. The eddy correlation method yields

$$E = \rho_a \overline{w'q'}$$

The gradient flux form is

$$E = -K_W \rho_a \frac{\partial \overline{q}}{\partial z}$$

The bulk aerodynamic form is

$$E = -\rho_a C_W |U| \left[q(z) - q(0) \right]$$

These can easily be converted to latent heat fluxes as well by simply multiplying the evaporative flux equations by L_v.

$$F_{LH} = \rho_a L_v \overline{w'q'}$$

$$F_{LH} = -K_W \rho_a L_v \frac{\partial \overline{q}}{\partial z}$$

$$F_{LH} = \rho_a L_v C_W U (q_s - q_a)$$

where F is the flux of water vapor from (or onto) the surface, ρ_a is the density of air, U is the near surface wind speed, q_s is the surface mixing ratio and the mixing ratio of the air near the surface and C_W is the turbulent exchange coefficient of latent heat.

Distributions of surface heat and moisture fluxes

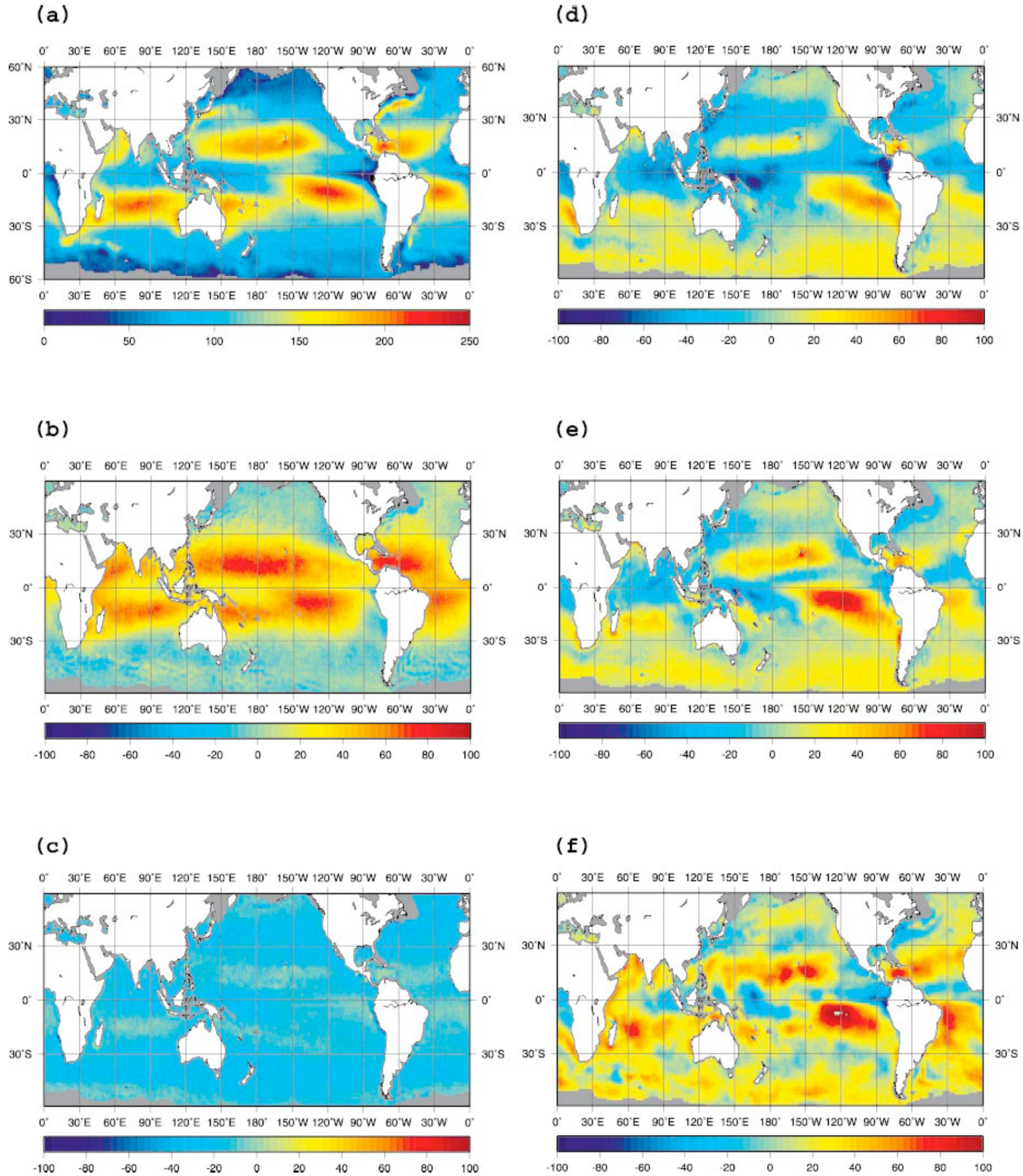

FIG. 1. (a) J-OFURO mean latent heat flux in W m^{-2} for the period Jan 1992–Dec 1994 and the average difference field between J-OFURO and (b) HOAPS, (c) GSSTF, (d) ECMWF, (e) NCEP1, and (f) da Silva. The period for the da Silva data is from Jan 1992 to Dec 1993.

Comparison of latent heat flux field estimates from The Japanese Ocean Flux Data Sets with use of Remote Sensing Observations (J-OFURO) with the Hamburg Ocean–Atmosphere Parameters and Fluxes from Satellite Data (HOAPS), the Goddard Satellite-Based Surface Turbulent Fluxes (GSSTF), ECMWF, NCEP–NCAR reanalysis (NCEP1), and da Silva et al.'s fields.