

Heat Exchange routine in SELFE (sflux_subs.F90): a theory manual

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Based on slides from Dr. Mike Zulauf

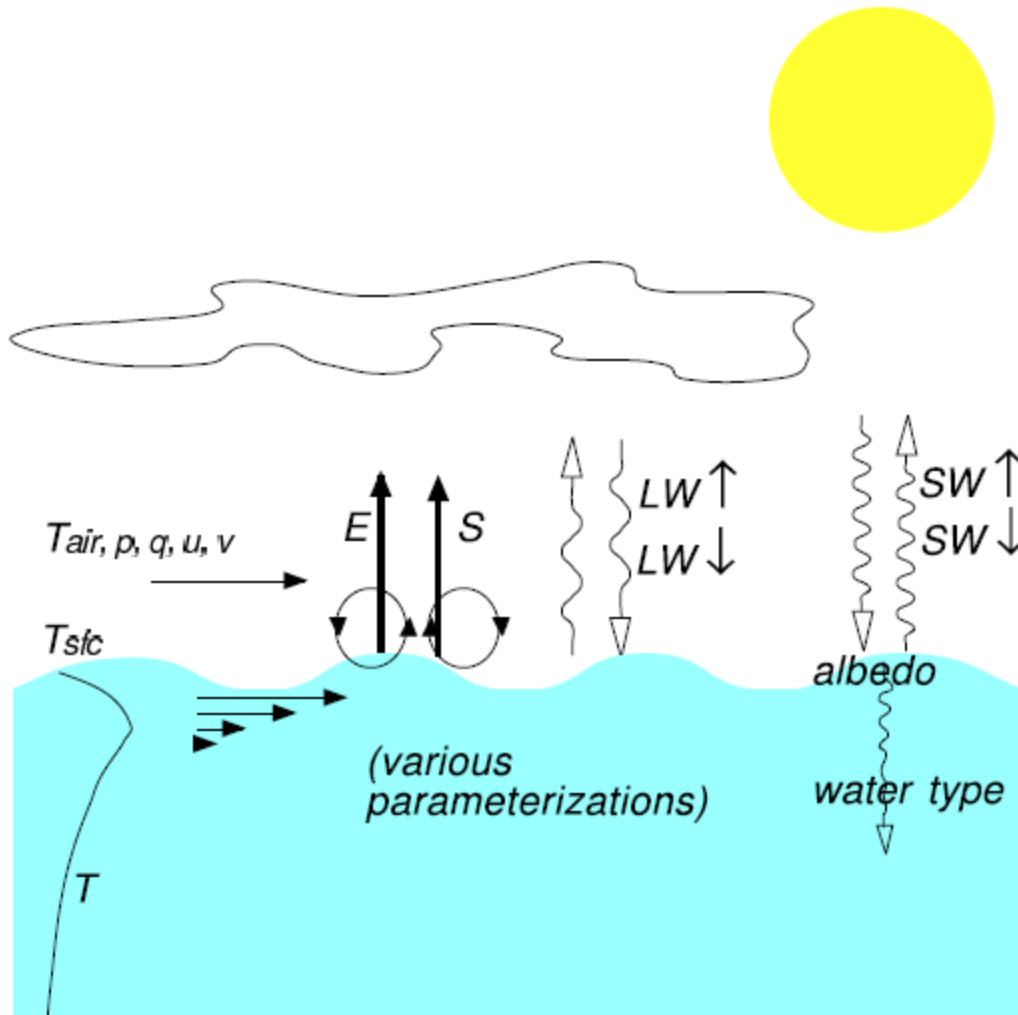


Fig 1: Illustration of variables

1. Atmospheric Forcing

- 1) *free surface height*: variations in atmospheric pressure over the domain have a direct impact upon free surface height; set up due to wind stresses
- 2) *momentum*: near-surface winds apply wind-stress on surface (influences advection, location of density fronts)
- 3) *heat*: various components of heat fluxes (dependent upon many variables) determine surface heat budget

- shortwave radiation (solar) - penetrative
 - longwave radiation (infrared)
 - sensible heat flux (direct transfer of heat)
 - latent heat flux (heating/cooling associated with condensation/evaporation)
- 4) *water*: evaporation, condensation, precipitation act as sources/sinks of fresh water

2. Total Heat Balance at the Air-Water Interface

$$H_{tot} \downarrow = (SW \downarrow - SW \uparrow) + (IR \downarrow - IR \uparrow) - S - E$$

where:

$H_{tot} \downarrow$ is the net downwards heat flux at the air-water interface

$SW \downarrow$ and $SW \uparrow$ are down/upwelling solar (short-wave) radiation at surface

$IR \downarrow$ and $IR \uparrow$ are down/upwelling infrared (long-wave) radiation at surface

S is the turbulent flux of sensible heat (upwelling)

E is the turbulent flux of latent heat (upwelling)

Note the infrared and turbulent fluxes essentially act at the surface of the water, and can be applied as a boundary condition for the internal heat equation; the solar radiation is penetrative - attenuation (which depends upon turbidity) acts as a heat source within the water.

3. Solar Radiation

Downwelling $SW \downarrow$ at the surface is forecast in NWP models - a function of time of year, time of day, weather conditions, latitude, etc.

Upwelling $SW \uparrow$ is a simple function of downwelling $SW \downarrow$

$$SW \uparrow = a SW \downarrow$$

where: a is the albedo - typically depends on solar zenith angle and sea state.

Net downwelling SW at the surface is therefore:

$$SW_{net} \downarrow = (1 - a) SW \downarrow$$

Attenuation of SW radiation in the water column is a function of turbidity and depth d (see Jerlov, 1968, 1976; Paulson and Clayson, 1977):

$$SW(d) = SW_{net} \downarrow [Re^{-d/d_1} + (1 - R)e^{-d/d_2}]$$

Finally, the divergence of the downwelling SW radiation acts as a heat source within the water column:

$$\frac{\partial T}{\partial t} = \dots \frac{1}{\rho C_p} \frac{\partial SW}{\partial z}$$

4. Infrared Radiation

Downwelling *IR* at the surface is forecast in NWP models - a function of air temperature, cloud cover, humidity, etc.

Upwelling *IR* is can be approximated as either a broadband measurement solely within the *IR* wavelengths (i.e., 4{50 μ m), or more commonly the blackbody radiative flux:

$$IR\uparrow = \varepsilon \sigma T_{sfc}^4$$

where:

ε is the emissivity, 1

σ is the Stefan-Boltzmann constant

T_{sfc} is the surface temperature

Net downwelling *IR* is therefore:

$$IR_{net}\downarrow = IR\downarrow - \varepsilon \sigma T_{sfc}^4$$

$IR_{net}\downarrow$ can simply be applied as a boundary condition for the internal heat equation.

In SELFIE, $SW\downarrow$ and $IR\downarrow$ are inputs read in from sflux_rad*.nc; these are usually available from atmospheric models.

5. Turbulent Fluxes of Sensible and Latent Heat

In general, turbulent fluxes are a function of:

- T_{sfc} (surface water temperature) and T_{air}
- near-surface wind speed
- surface atmospheric pressure
- near-surface humidity

Scales of motion responsible for these heat fluxes are *much* smaller than can be resolved by any operational model - they must be parameterized (i.e., bulk aerodynamic formulation):

$$\begin{aligned} S &= -\rho_a c_{pa} \overline{w'T'} = -\rho_a c_{pa} u_* T_* \\ E &= -\rho_a L_e \overline{w'q'} = -\rho_a L_e u_* q_* \end{aligned}$$

where:

u_* is the friction scaling velocity

T_* is the temperature scaling parameter

q_* is the specific humidity scaling parameter

ρ_a is the surface air density

c_{pa} is the specific heat of air

L_e is the latent heat of vaporization

The scaling parameters are defined using Monin-Obukhov similarity theory, and must be solved for iteratively (i.e., Zeng et al., 1998), as follows:

At each time step:

- i. begin with initial (approximate) values for z , z_0 , u_* , T_* , q_* , etc
- ii. enter iterative loop
- iii. calculate u_* from Eq (7-10) in Zeng et al.
- iv. calculate z_0 and z_{0t} from Eq (24-26)
- v. calculate T_* and q_* from Eq (11-14)
- vi. calculate L and z from Eq (4)
- vii. iterate if necessary; assume convergence after 10 iterations or extreme stability ($z \geq 2.5$)

6. Wind Shear Stress: Turbulent Flux of Momentum

Calculation of shear stress follows naturally from calculation of turbulent heat fluxes.

Total shear stress of atmosphere upon surface:

$$\tau = \rho_a u_*^2$$

x-component:

$$\tau_{xz} = \rho_a \overline{u'w'} = \tau \frac{u}{\sqrt{u^2 + v^2}}$$

y-component:

$$\tau_{yz} = \rho_a \overline{v'w'} = \tau \frac{v}{\sqrt{u^2 + v^2}}$$

An alternative formulation for shear stress (Pond & Pickard 1998) doesn't account for surface layer stability, free convection, etc:

$$\begin{aligned}\tau_{xz} &= \rho_a C_{DS} u \sqrt{u^2 + v^2} \\ \tau_{yz} &= \rho_a C_{DS} v \sqrt{u^2 + v^2}\end{aligned}$$

where C_{DS} is purely a function of wind speed.

References

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- Paulson, C. A. and J. J. Simpson (1977). "Irradiance measurements in the upper ocean." J. Phys. Oceanogr 7: 952-956.
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Zeng, X., M. Zhao and R. E. Dickinson (1998). "Intercomparison of bulk aerodynamic algorithms for the computation of sea surface fluxes using TOGA COARE and TAO data." J. Clim. 11: 2628-2644.