Sea surface fluxes parameterizations in SURFEX :

Introduction in the externalized surface of the UNITFP and the COARE3.0 parameterizations

1 Introduction

The UNITFP (ex-MEMO) and the COARE 3.0 sea surface fluxes parameterizations are both based on the version 2.5b of the (TOGA-)COARE bulk algorithm (Fairall et al, 1996b, here after FBR96). The COARE 2.5b version includes a correction on the momentum and on the sensible heat flux due to precipitation according to Gosnell et al., 1995 (here after GoF95). The "gustiness" factor *wg* and the Webb correction on the latent heat flux, due to density variation with the evaporation, are also available. The calculation method is not direct any more as in water_flux.f90 (Louis, 1979) but iterative as in mr98.f90 (Mondon and Redelsperger, 1998).

The improvement of the UNIfied Turbulent Fluxes Parameterization is based on new formulations of the neutral coefficients transfer according to the wind speed relative to the sea surface current in neutral conditions at 10 m. These formulations of $C_{D_{10n}}$, $C_{H_{10n}}$, and $C_{E_{10n}}$ are based on a multi-campaigns calibration of the neutral exchange coefficient at 10 m deduced from five experiments dedicated to air-sea fluxes measurements : POMME "Programme Océanique Multidisciplinaire à Moyenne Echelle", FETCH "Flux, Etat de la mer et Télédetection en Condition de Fetch", SEMAPHORE "Structure des Echanges Mer-Atmosphère, Propriétés des Hétérogénéités Océaniques : Recherche Expérimentale", CATCH "Couplage avec l'ATmosphère en Conditions Hivernales" and EQUALANT99. These five experiments dedicated to air-sea fluxes estimation carried out over the Atlantic and the Mediterranean Sea between 1992 and 2001 cover a large range of atmospheric and oceanic conditions (Weill et al., 2003) : light to very strong wind speeds, unstable to extremely stable atmospheric boundary layer. In this calibration, the drag coefficient C_{D_n} is decreased for tropical cyclones wind speed-range ($U_{10n} > 30$ m s^{-1}) as discussed in Powell et al. (2003)'s study and C_{H_n} is saturated in high wind regime (Belamari, 2005). The details of the multi-campaign calibration are shown in section 4.

The COARE 3.0 version of the bulk algorithm (Fairall et al., 2003) is a direct improvement of the COARE algorithm. The transfer coefficients have been obtained by combining COARE data with three other experiments from ETL and also a re-analysis from HEXMAX data (DeCosmo et al. 1996). It permits an extension of the wind range until 20m/s.

More specifically, modifications are the following :

1. Numerical constants for the convective portion in the profile functions have been changed for improved matching to direct profile observations (Grachev et al. 1999).
2. The Kansas stable profile functions (Businger et al 1991) have been replaced by those from Beljars and Holstag (1991) which, based on new profile data taken over the Arctic ice cap (Persson et al 2002), appear to be a better fit at extreme stability.

3. A fixed value of the Charnock parameter ($\alpha = 0.011$) has been replaced by one simple wind-speed dependence above 10m/s (Hare et al. 1999).
4. The scalar roughness parameters(zot,zoq) were previously obtained by the LKB relationships between roughness Reynolds number (for wind) Rr and its scalar analogues (Rt,Rq). They are now calculated directly as $zoq = zot = min(1.15e^{-4}, 5.5e^{-5}/Rr^{0.6})$, which fits the ETL and HEXMAX data sets (see Fairall et al. 2003, fig. 4). The moisture and heat transfer coefficients are now identical and slightly reduced at low winds.
5. The stability iteration loop hes been reduced from 20 to 3 by taking advantages of a bulk Richardson number parameterization for an improved first guess (Grachev and Fairall 1997).
6. The latent heat flux has been reformulated in terms of mixing ratios q instead of water vapor density Q, because q is the quantity that is fundamentally conserved during mixing. This eliminates the need for a Webb correction (Webb et al 1980) ; However the mean Webb vertical velocity is still calculated and may be used for correction of trace gas or particle fluxes measurement.
7. Optional code has been added to account for the effects of surface gravity waves on the velocity roughness, and hence the momentum transfer coefficient. We use either the wave age parameterization of Oost et al., 2002, or the model of Taylor and Yelland, 2001, which parameterizes the surface roughness in terms of the significant wave height and peak wavelength. This feature would allows the algorithm to be applied, for example, in coastal/shallow waters and is partly in response to request from some users

New choices for the CSEA_FLUX variable have been introduced in the namelist NAM_SEAFLUXn.

Fortran name	Fortran type	values	default value
CSEA_FLUX	string of 6 characters	'DIRECT', 'ITERAT', **'UNITFP'**, **'COARE3'**	'DIRECT'
CSEA_ALB	string of 4 characters	'UNIF','TA96'	'TA96'

– "UNITFP" UNITFP parameterization of sea surface fluxes : iterative method proposed by Fairall et al (1996) with multi-campaigns calibration of neutral exchange coefficients (Lebeaupin Brossier et al, 2006). Different options of computation in that case are available : "LPRECIP", "LPWEBB" and "LPWG" must be set to .TRUE. in NAM_SEAFLUXn to take account of respectively, the corrections due to precipitation, the Webb correction and the gustiness effect during the sea surface fluxes computation by the UNITFP parameterization.

– "COARE3" Simplified COARE3.0 bulk algorithm. Different options of computation in that case are available : "LPRECIP" and "LPWG" must be set to .TRUE. in NAM_SEAFLUXn to take account of respectively the corrections due to precipitation and the gustiness effect. The choice of the surface gravity waves scheme is done by affecting value 0, 1 or 2 to "NGRVWAVES" in NAM_SEAFLUXn.

A new namelist NAM_DIAG_SEAFLUXn has been created to add in the future specific diagnostics for the sea surface. Until that day only the logical LCOEF has been created. It must

Fortran name	Fortran type	default value	used in param.
LPWG	logical	.FALSE.	'UNITFP', 'COARE3'
LPRECIP	logical	.FALSE.	'UNITFP', 'COARE3'
LPWEBB	logical	.FALSE.	'UNITFP'
NGRVWAVES	integer	0	'COARE3'

be set to .TRUE. to obtain in diagnostic the three exchange coefficients over the sea (CD for drag, CH for heat and CE for evaporation exchange coefficients).

Fortran name	Fortran type	default value
LCOEF	logical	.FALSE.

2 Flowchart in surfex

```
- - coupling_sean
      |- - coupling_sea_orographyn
            |- - coupling_seafluxn
                  |- - get_luout
                  |- - add_forecast_to_date_surf
                  |- - water_flux
                  |- - mr98
                  |- - coare_seaflux
                        |- - ice_sea_flux
                        |- - unitfp_flux
                        |- - coare30_flux
                  |- - ch_deep_water
                  |- - diag_inline_seaflux
                        |- - param_cls
                        |- - cls_2M
                        |- - cls_wind
                        |- - diag_surf_budget_sea
                        |- - param_cls
```

The routine coare_seaflux.f90 mask the points with ice-sea for the fluxes computation and choose between unitfp or coare30 according to CSEA_FLUX variable.

The routine mode_coare25_psi.f90 and mode_coare30_psi.f90 has been created to include the different psi functions (see Annexe 1). All the routines affected by the change of the namelist NAM_SEAFLUXn and the creation of the namelist NAM_DIAG_SEAFLUXn (default_, alloc_, dealloc_, init_, modd_, pgd_, prep_, read_, write_) have been adapted.

3 Bulk expression of fluxes

In this formulation, the horizontal wind is always minimized by 1 $m.s^{-1}$ in order to avoid computation problems at very weak winds.

By convention, the fluxes are positive if energy is given to the atmosphere.

3.1 Sensible heat flux

We named s the mean relative wind module that we minimized at 1m s^{-1}. The sensible heat flux is given in equations 1. and 2.a of FBR96 :

$$\begin{cases} HF = \rho_a c_{p_a} u_* T_* \\ HF = \rho_a c_{p_a} C_H s(T_s - T) \end{cases} \tag{1}$$

$$\Rightarrow C_H = \frac{u_* T_*}{s(T_s - T)} \tag{2}$$

with T is the atmospheric potential temperature and T_s is the potential temperature at the sea surface.

3.2 Latent heat flux

The latent heat flux is given by equations 1. and 2.b in FBR96 :

$$\begin{cases} EF = \rho_a \mathcal{L}_e u_* q_* \\ EF = \rho_a \mathcal{L}_e C_E s(q_s - q) \end{cases} \tag{3}$$

$$\Rightarrow C_E = \frac{u_* q_*}{s(q_s - q)} \tag{4}$$

with q the air humidity et q_s the saturated specific humidity at the surface.

3.3 Stress

The stress or the momentum flux is given by equations 1. and 2.c in FBR96 :

$$\begin{cases} |\vec{\tau}| = -\rho_a u_*^2 \\ \tau_i = -\rho_a C_D s(u_{si} - u_i) \end{cases} \tag{5}$$

$$\Rightarrow C_D = (\frac{u_*}{s})^2 \tag{6}$$

4 The Unitfp iterative computation

Here are described the computation step in the routine *unitfp_flux.f90*.

4.1 Initialisation

First the convergence thresholds are fixed : $u_{*th} \quad T_{*th} \quad et \quad q_{*th}$. The initial value of w_g is also fixed and the computation of wind taking into account gustiness effect is made $|\vec{v}_{gust}|_0 = (|\vec{v}|^2 + w_{g_0}^2)^{0.5}$. The Obukhovs stability parameters $(z/L)_0$ are nulls initially. Then the differences of potential temperature and of specific humidity are computed.

$$\delta T = T + 0.0098 Z_{ref} - T_s$$

$$\delta q = q - q_s$$

et

$$\begin{cases} \Delta u_{10n_0} = |\vec{v}_{gust}|_0 \\ \Delta T_{10n_0} = \delta T \\ \Delta q_{10n_0} = \delta q \end{cases}$$

$$\begin{cases} u_{*0} = 0.04 \times \Delta u_{10n_0} \\ T_{*0} = 0.04 \times \Delta T_{10n_0} \\ q_{*0} = 0.04 \times \Delta q_{10n_0} \end{cases}$$

4.2 Richardson number

routine surface_ri.f90
The Richardson number Ri is computed only if the gustiness factor is introduced, according to the equation :

$$Ri = \frac{gZU_{ref}(\delta T + (\frac{R_v}{R_a} - 1)T\delta q)}{T \times MAX(|\vec{v}_{gust}|, 1e-9)^2}$$

The default value of Ri is 0.25 if there is no convergence of the iterative computation.

Then only begins the iterative computation in *unitfp_flux.f90*.

4.3 Stability

First the *Obukhovs'* stability parameters z/L for u,T,q are calculated.

$$\zeta^i = \zeta(T, q, u_*^{i-1}, T_*^{i-1}, q_*^{i-1}, ZU_{ref})$$

The ζ function is defined in annexe 1.

$$ZT_{ref} = Zq_{ref} = Z_{ref}$$

$$(z/L)_u^i = \zeta^i \qquad (z/L)_T^i = (z/L)_u^i \frac{Z_{ref}}{ZU_{ref}} \qquad (z/L)_q^i = (z/L)_u^i \frac{Z_{ref}}{ZU_{ref}}$$

Then stability functions are computed :

$$\psi_u^i = \psi(1, (z/L)_u^i) \quad \psi_T^i = \psi(2, (z/L)_T^i) \quad \psi_q^i = \psi(2, (z/L)_q^i)$$

The ψ function is defined in annexe 1.

$C_{d_{10n}} \times 1000$	$1.3013 - 0.12719\ U_{10n} + 0.013067\ U_{10n}^2 - 2.2261 \times 10^{-4}\ U_{10n}^3$	for $U_{10n} \leq 16.8$
	$1.3633 - 0.13056\ U_{10n} + 1.6212 \times 10^{-2}\ U_{10n}^2 - 4.8208 \times 10^{-4}\ U_{10n}^3$ $+4.2684 \times 10^{-6}\ U_{10n}^4$	for $16.8 < U_{10n} \leq 50.$
	1.7828	for $U_{10n} > 50.$
$C_{h_{10n}} \times 1000$	$1.2536 - 0.12455\ U_{10n} + 0.016038\ U_{10n}^2 - 4.3701 \times 10^{-3}\ U_{10n}^3$ $+3.4517 \times 10^{-6}\ U_{10n}^4 + 3.5763 \times 10^{-9}\ U_{10n}^5$	for $U_{10n} \leq 33.$
	3.1374	for $U_{10n} > 33.$
$C_{e_{10n}} \times 1000$	$1.2687 - 1.1384\ U_{10n} + 1.1467 \times 10^{-2}\ U_{10n}^2 - 3.9144 \times 10^{-4}\ U_{10n}^3$ $+5.0864 \times 10^{-6}\ U_{10n}^4$	for $U_{10n} \leq 29.$
	$-1.3526 + 1.8229 \times 10^{-1}\ U_{10n} - 2.6995 \times 10^{-3}\ U_{10n}^2$	for $29. < U_{10n} \leq 33.$
	1.7232	for $U_{10n} > 33.$

TAB. 1 – Multi-campaigns calibration numerical formulations for the momentum $C_{d_{10n}}$, the sensible heat $C_{h_{10n}}$ and the latent heat $C_{e_{10n}}$ neutral transfer coefficients at 10 m ; U_{10n} in $m.s^{-1}$

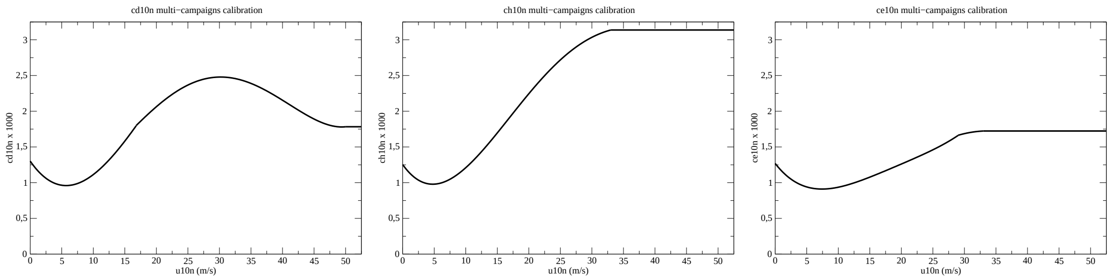

FIG. 1 – The multi-campaign calibration of the neutral exchange coefficients at 10 m function of the neutral relative wind module at 10 m.

4.4 Neutral transfer coefficients calibration

The numerical formulations introduced here come from the multi-campaigns calibration (POMME, CATCH, FETCH, SEMAPHORE et EQUALANT99).

4.5 Computation of u_*^i, T_*^i et q_*^i

If ($C_{Dn} > 0$),

$$\begin{cases} u_*^i = \frac{C_{Dn}^i}{\sqrt{Max(C_{Dn}^i, 1e{-}9)}} \Delta u_{10n}^{i-1} \\ T_*^i = \frac{C_{Hn}^i}{\sqrt{Max(C_{Dn}^i, 1e{-}9)}} \Delta T_{10n}^{i-1} \\ q_*^i = \frac{C_{En}^i}{\sqrt{Max(C_{Dn}^i, 1e{-}9)}} \Delta q_{10n}^{i-1} \end{cases}$$

else there is no convergence (type (b) of no convergence). Note : if ($u_*^i = 0$), no convergence (type (a) of no convergence)

4.6 “Gustiness effect”

The “gustiness” w_g^i factor is calculated by : (T in K)

$$T_{v_*}^i = T_*^i(1+q(\frac{R_v}{R_a}-1)) + (\frac{R_v}{R_a}-1)T\ q_*^i$$

$$bf^i = MAX(0, \frac{-gu_*^i T_{v_*}^i}{T})$$

$$w_g^i = \beta_{gust}(bf^i\ zi)^{\frac{1}{3}}$$

$$|\vec{v}_{gust}|^i = (|\vec{v}|^2 + w_g^{i^2})^{0.5}$$

4.7 Recalibration

The differences with the previous time step are re-computed

$$\begin{cases} \Delta u_{10n}^i = |\vec{v}_{gust}|^i - \frac{u_*^i(ln(\frac{ZU_{ref}}{10})-\psi_u^i)}{\kappa} \\ \Delta T_{10n}^i = \delta TT^i - \frac{T_*^i(ln(\frac{Z_{ref}}{10})-\psi_T^i)}{\kappa} \\ \Delta q_{10n}^i = \delta qq^i - \frac{q_*^i(ln(\frac{Z_{ref}}{10})-\psi_q^i)}{\kappa} \end{cases}$$

4.8 Convergence test

If the convergence is obtained for $i = fin$ iterations, that means :

$$|u_*^i - u_*^{i-1}| < u_{*th}\ \ et\ \ |T_*^i - T_*^{i-1}| < T_{*th}\ \ et\ \ |q_*^i - q_*^{i-1}| < q_{*th}$$

then the cycle stops and the final parameters are computed :

$$|\vec{v}^{fin}| = (|\vec{v}|^2 + w_g^{fin^2})^{0.5}$$

$$C_D = \left(\frac{u_*^{fin}}{|\vec{v}^{fin}|}\right)^2$$

$$C_H = \frac{u_*^{fin} T_*^{fin}}{|\vec{v}^{fin}| MAX(\delta TT^{fin}, 1e-9)} \quad if\ \ \delta TT^{fin} > 0$$

$$C_H = \frac{u_*^{fin} T_*^{fin}}{|\vec{v}^{fin}| MIN(\delta TT^{fin}, -1e-9)} \quad if\ \ \delta TT^{fin} < 0$$

else $C_H = 0$.

$$C_E = \frac{u_*^{fin} q_*^{fin}}{|\vec{v}^{fin}| MAX(\delta qq^{fin}, 1e-9)} \quad if\ \ \delta qq^{fin} > 0$$

$$C_E = \frac{u_*^{fin} q_*^{fin}}{|\vec{v}^{fin}| MIN(\delta qq^{fin}, -1e-9)} \quad if \;\; \delta qq^{fin} < 0$$

else $C_E = 0$.

Note that a number of maximum iteration (i_{max}) is fixed in unitfp_flux.f90. If after i_{max} there is no convergence, the iterative process is stopped and the fluxes are compute as $i_{max} = fin$. This type of no convergence is note (c).

5 The simplified COARE 3.0 bulk algorithm introduced in SURFEX

The COARE 3.0 algorithm for air-sea interface fluxes has been recoded and introduced in SURFEX with some simplifications.

- As for the UNITFP, the "warm layer /cool skin" effects have been deleted compared to the original parameterization, we supposed a “true” SST of the model.
- The specific humidity and the gravity constant computations are those from SURFEX. Corrections due to gustiness and precipitations are still possibles.
- A security for the convergence has been added with a maximal value (very large) of $\mathrm{CD10n}_{max} = 0.1$ to not exceed.

In the COARE bulk algorithm, an iterative loop allows to determine the scale parameters u_*, θ_* and q_* from the flux-profile relationships between the roughness length z_0 and the height z_r of lowest model level :

$$u_* = \frac{\kappa u(z_r)}{ln(\frac{z_r}{z_0}) - \psi_m(\frac{z_r}{L}) + \psi_m(\frac{z_0}{L})} \tag{7}$$

$$\theta_* = \frac{\kappa(\theta(z_r) - \theta_0)}{ln(\frac{z_r}{z_0}) - \psi_h(\frac{z_r}{L}) + \psi_h(\frac{z_0}{L})} \tag{8}$$

$$q_* = \frac{\kappa(q(z_r) - q_0)}{ln(\frac{z_r}{z_0}) - \psi_h(\frac{z_r}{L}) + \psi_h(\frac{z_0}{L})} \tag{9}$$

$L = \frac{u_*^2 \bar{\theta}}{\kappa g \theta_*}$ is the Monin-Obukhov scale height and ψ_m and ψ_h Businger’s functions (see Appendix 1 for the detail of ψ_m and ψ_h) ; and also the roughness lengths z_0, z_{0t} and z_{0q} from the following equations.

$S_u = \sqrt{u^2 + v^2 + w_g^2} = \sqrt{S^2 + w_g^2}$ is the scalar wind speed including the convective gustiness, defined as

$$w_g = \beta w_*,$$

where $\beta = 1.2$ is a coefficient and w_* is the convective velocity scale or the Deardoff velocity,

$$w_* = \left(-\frac{g}{\theta_v} \theta_{v_*} u_* z_i \right)^{\frac{1}{3}}$$

α is the Charnock parameter (Charnock, 1955) which varies with the wind speed S such that

$$\alpha = \begin{cases} 0.011 & for\ S_u \leq 10\ m\ s^{-1} \\ 0.011 + \frac{0.007}{8}(S - 10) & for\ 10 \leq S_u \leq 18\ m\ s^{-1} \\ 0.018 & for\ S_u \geq 18\ m\ s^{-1} \end{cases} \tag{10}$$

z_0 could then be compute with three different schemes that take into account the waves effects in different ways :

$$z_0 = \begin{cases} \alpha \frac{u_*^2}{g} + 0.11 \frac{\nu}{u_*} & \textit{Smith } 1988 \\ \frac{50}{2\pi} L_{wv} \left(\frac{u_*}{C_{wv}} \right)^{4.5} + 0.11 \frac{\nu}{u_*} & \textit{Oost et al. } 2002 \\ 1200 H_{wv} \left(\frac{H_{wv}}{L_{wv}} \right)^{4.5} + 0.11 \frac{\nu}{u_*} & \textit{Taylor and Yelland } 2001 \end{cases} \tag{11}$$

H_{wv}, C_{wv}, L_{wv} values are given in the following section.

The roughness lengths for heat and moisture are

$$z_{0t} = z_{0q} = MIN(1.1 \times 10^{-5}, 5.5 \times 10^{-5} Re_*^{-0.6}),$$

where Re_* is the Reynolds number defined as $z_0 u_*/\nu$; ν is the kinematic viscosity of dry air.

Then, the neutral drag transfer coefficients $C_{D_{10n}}, C_{H_{10n}}$ and $C_{E_{10n}}$ are estimated with equations

$$C_{D10n} = \left[\frac{\kappa}{ln(10/z_0)} \right]^2 \tag{12}$$

$$C_{H10n} = \left[\frac{\kappa}{ln(10/z_0)} \right] \left[\frac{\kappa}{ln(10/z_{0t})} \right] \tag{13}$$

$$C_{E_{10n}} = \left[\frac{\kappa}{ln(10/z_0)} \right] \left[\frac{\kappa}{ln(10/z_{0q})} \right] \tag{14}$$

. Then the frictional velocity, temperature and humidity scaling factors u_*, θ_* and q_* are determined from the neutral transfer coefficient at 10 m ($C_{D_{10n}}, C_{H_{10n}}$ and $C_{E_{10n}}$) and from the atmospheric gradients S_u, $\Delta\theta$ and Δq, respectively. The fluxes are then deduced from u_*, θ_* and q_* according to the first members of the bulk equations.

6 Fluxes corrections

6.1 Corrections due to precipitation

The aim is to evaluate the corrections due to precipitation on the sensible heat flux Q_p and on the momentum flux τ_p

$$HF = Q_s + Q_p \tag{15}$$

$$\tau_p = \frac{\mathcal{R} u}{3600} \tag{16}$$

pp 3752 in FBR96 ; with $\mathcal{R}$ the precipitation rate in $mm.h^{-1}$ and the water density is implicit.

$$Q_p = \mathcal{R} c_{p_r} \Delta T \varepsilon \left(1 + \frac{1}{B} \right) \qquad (Eq.\ 12\ GoF95)$$

$\mathcal{R}$ is always the precipitation rate but this time in $kg.s^{-1}$.

c_{p_r} is the specific heat of rainwater ($= 4186\ J.kg^{-1}.K^{-1}$). $B = \frac{c_p \Delta T}{\mathcal{L} \Delta q}$ is the *Bowen* ratio. The dew point factor ε is :

$$\varepsilon = 1/\left(1 + \frac{R_a}{R_v} \frac{\mathcal{L} d_v}{d_h c_p} \frac{dq_s}{dT} \right) \qquad (Eq.\ 11\ GoF95)$$

$\mathcal{L} = (2.501 - 0.00237T)e6$ is the vaporization latent heat of rainwater. c_p the atmospheric specific heat. $d_v = 2.11e-5\,(\frac{T}{273.16})^2$ et $d_h = \frac{0.02411\,(1+3.309e-3\,T-1.44e-6\,T^2}{\rho_a c_{pa}}$ are respectively the vapor diffusivity ant the heat diffusivity.

q_s is the saturated humidity which depends on the temperature. dq_s/dT is given by the Clausius-Clapeyron's formulation :

$$\frac{dq_s}{dT} = \frac{q\mathcal{L}}{R_a T^2}$$

Note : T in K.

6.2 Webb correction (only for Unitfp latent heat flux)

First, turbulent fluxes are approximated by a linear combination of the "bulk" fluxes :

$$\overline{w'q'} = \frac{EF}{\mathcal{L}_e} \;\; et \;\; \overline{w'T'} = \frac{HF}{c_{p_a}}$$

Then $\overline{w}$ the mean of the vertical speed fluctuations is computed :

$$\overline{w} = 1.61\frac{EF}{\mathcal{L}_e} + (1+1.61q)\frac{\frac{HF}{c_{pa}}}{T}$$

The Webb correction on the latent heat flux is :

$$EF_{Webb} = \rho_a \mathcal{L}_e \overline{w} q \tag{17}$$

This correction is added to the "bulk" latent heat flux to obtain the total latent heat flux over the sea surface.

6.3 Surface gravity waves options in the COARE 3.0 algorithm

The COARE 3.0 bulk algorithm account for the effects of surface gravity waves on the velocity roughness. Three formulae could be used :
- The classic Smith 1988 formula
- The wave age parameterization of Oost et al., 2002
- The model of Taylor and Yelland, 2001, which parameterizes surface roughness in terms of the significant wave height and peak wave length.

The numerical values of the constants H_{wv}, C_{wv}, L_{wv} are :

$$H_{wv} = 0.018 S_u^2 (1 + 0.015 S_u)$$

$$C_{wv} = \frac{9}{2\pi}(0.729 S_u)$$

$$L_{wv} = \frac{9}{2\pi}(0.729 S_u)^2$$

Annexe

Saturated specific humidity computation

The saturated vapor pressure is given by the Clausius-Clapeyron's formulation in *mode_thermos.f90* routine.

$$es = 6.1121 \times (1.0007 + 3.46 \times 10^{-6} P) exp(\frac{17.502T}{240.97 + T})$$

T in Celsius degree, P in mb so es in mb.

The saturated specific humidity is

$$q_{sat} = \frac{r_1 es}{P - r_2 es}$$

q_{sat} in kg/kg with P in mb, $r_1 = R_a/R_v$ and $r_2 = 1 - r_1$.

The salinity of sea water (34 psu on averaged) is taken into account by multiplying by the factor 0.98.

$$q_{sat}^{sea\ surf.} = 0.98 \frac{r_1 es}{P - r_2 es}$$

where P is atmospheric pressure in mb.

ζ function

include in routine unitfp_flux.f90
zl is compute by the equation

$$zl = g\kappa \frac{ZU_{ref}(T_*^{i-1}(1 + r_0 q) + r_0 T q_*^{i-1})}{T(1 + r_0 q) \times MAX(u_*^{i-1}, 1e-9) \times MAX(u_*^{i-1}, 1e-9)}$$

with $r_0 = R_v/R_a - 1$.

$$\zeta = \zeta(T, q, u_*^{i-1}, T_*^{i-1}, q_*^{i-1}, ZU_{ref}) = MIN(zl, 0.25) \quad if \;\; zl \geq 0$$

$$\zeta = \zeta(T, q, u_*^{i-1}, T_*^{i-1}, q_*^{i-1}, ZU_{ref}) = MAX(zl, -200) \quad if \;\; zl < 0$$

ψ, ψ_m and ψ_h functions

routine mode_coare2.5_psi.f90
The aim is to compute $\psi = \psi(id, zl)$.

If $zl = 0$, $\psi = \psi(id, zl) = O$ whatever is id value.
If $zl > 0$, $\psi = \psi(id, zl) = -c_\gamma zl$ whatever is id value, with $c_\gamma = 7$.
If $zl > 0$, $f = 1/(1 + zl^2)$ and $\chi_k = (1 - c_\beta zl)^{0.25}$ are fixed, with $c_\beta = 16$.

– if $id = 1$,

$$\psi_k = 2ln(\frac{1 + \chi_k}{2}) + ln(\frac{1 + \chi_k^2}{2}) - 2arctan(\chi_k) + 2arctan(1)$$

– else

$$\psi_k = 2ln(\frac{1 + \chi_k^2}{2})$$

Finally :

$$\chi_c = (1 - 12.87zl)^{\frac{1}{3}}$$

$$\psi_c = 1.5ln(\frac{\chi_c^2 + \chi_c + 1}{3}) - \sqrt{3}arctan(\frac{2\chi_c + 1}{\sqrt{3}}) + \frac{4}{\sqrt{3}}arctan(1)$$

$$\Longrightarrow \psi = \psi(id, zl) = f \times \psi_k + (1 - f) \times \psi_c$$

routine mode_coare30_psi.f90

The aim is to compute ψ_m and ψ_h.

The Businger's functions used in the COARE 3.0 parameterization are :

	$\psi_m(\frac{z}{L}) =$	$\psi_h(\frac{z}{L}) =$
stable	$-(1 + 1(\frac{z}{L}))^1 - 0.6667\frac{(\frac{z}{L} - 14.28)}{exp(\Gamma)} - 8.525$	$-(1 + \frac{2}{3}(\frac{z}{L}))^{1.5} - 0.6667\frac{(\frac{z}{L} - 14.28)}{exp(\Gamma)} - 8.525$
$(\frac{z}{L} \geq 0)$	$\Gamma = min(50, 0.35\frac{z}{L})$	
unstable :	$(1 - F)\psi_{mK} + F\psi_{mC}$	$(1 - F)\psi_{hK} + F\psi_{hC}$
$(\frac{z}{L} < 0)$	$F = \frac{(\frac{z}{L})^2}{(1.0 + (\frac{z}{L})^2)}$	
$-Kansas$	$\psi_{mK} = 2ln(\frac{1+x}{2}) + ln(\frac{1+x^2}{2}) - 2arctan(x) + \frac{\pi}{2}$	$\psi_{hK} = 2ln(\frac{1+x}{2})$
	$with \quad x = (1 - 15\frac{z}{L})^{\frac{1}{4}}$	$with \quad x = (1 - 15\frac{z}{L})^{\frac{1}{2}}$
$-Convective$	$\psi_{mC} = \frac{3}{2}ln(\frac{y^2+y+1}{3}) - \sqrt{3}arctan(\frac{2y+1}{\sqrt{3}}) + \frac{\pi}{\sqrt{3}}$	$\psi_{hC} = \frac{3}{2}ln(\frac{y^2+y+1}{3}) - \sqrt{3}arctan(\frac{2y+1}{\sqrt{3}}) + \frac{\pi}{\sqrt{3}}$
	$with \quad y = (1 - 10.15\frac{z}{L})^{0.3333}$	$with \quad y = (1 - 34.15\frac{z}{L})^{0.3333}$

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