Description for MIROC6

平成 33 年 1 月 27 日

1 1 Sea Surface Conditions

Sea surface processes provide the boundary conditions at the lower end of the atmosphere through the exchange of momentum, heat, and water fluxes between the atmosphere and the surface. Until CCSR/NIES AGCM, both land surface and sea surface were treated as one of the atmospheric physical processes, but after MIROC3 (Hasumi and Emori, 2004), land surface processes became independent as MATSIRO. However, since MIROC3 (Hasumi and Emori, 2004), land surface processes have been separated into MATSIRO. This chapter describes sea surface processes, which are still treated within the framework of atmospheric physical processes (MIROC6). For the land surface processes, please refer to Description of ILS.

1.1 1.1 Overview [済 1 月]

In `MODULE: [PGSFC]`, `[OCNFLX]` (`MODULE: [POCEN]`) is called for the sea surface, and `[LNDFLX]` of MATSIRO model is called for the land surface. In `[OCNFLX]`, the following procedure is used to deal with sea surface processes.

1. prepare variables for sea ice extent and no ice extent, respectively, using sea ice concentration. 2. Determine the surface boundary conditions. 3. Calculate the flux balance. 4. Calculate the radiation budget at the sea surface. 5.

(3) Calculate the deposition by CHASER.

6. solve the heat balance at the sea surface and update the surface temperature and each flux value.

The four modules discussed in this chapter are as follows.

module name	file name	contents
MODULE:[PGSFC]	./physics/pgsfc.F	surface driver
MODULE:[PSFCL]	./physics/psfcl.F	surface bulk transfer coefficient
MODULE:[PSFCM]	./physics/psfcm.F	surface fluxes
MODULE:[PGOCN]	./physics/pgocn.F	mixed layer/fixed SST ocean

1.2 1.2 Passing variables between AGCM and land/sea level schemes [PGSFC] [not yet done, work to be done in January].

Calling OCNFLX (MODULE: [POCEN]) for sea level and LNDFLX of the MATSIRO model for land level, respectively.
カップラーのセクションと merge 予定。

1.3 1.3 Setting Sea Surface Conditions [済 1 月]

1.3.1 1.3.1 Input variables from the atmosphere

variable	meaning
GAUA	u-wind
GAVA	v-wind
GATA	temperature T
GAQA	humidity q
GAPA	pressure P
GAPS	surface pressure Ps
GAZS	surface height
RSFCD	surface radiation fluxes
RCOSZ	cos(solar angle)

If use CHASER, variables below are also needed.

variable	meaning
EH	Henry const
PFLXC	precipitation flux (cumulus convection scheme)
PFLXL	precipitation flux (large scale condensation scheme)
LLAT	latitude

Practically, precipitation flux from 2 schemes are treated together.

$$Pr = Pr_c + Pr_l \tag{1}$$

In the sea ice area ($L = 1$), the surface temperature T_s is the sea ice surface temperature T_{ice}. However, if T_{ice} is higher than $T_{melt} = 0$, then T_{melt} is used.

$$.T_s = min(T_{ice}, T_{melt}) \tag{2}$$

.

The sea ice bottom temperature T_b is assumed to be the ocean surface temperature $T_{o(1)}$.

$$.T_b = T_{o(1)} \tag{3}$$

.

The amount of sea ice W_{ice} and the amount of snow on it W_{snow} are converted per unit area by considering R_{ice} and used in the calculation. However, a limiter ϵ is provided to prevent the values from becoming too small.

$$R_{ice} = \max(R_{ice,orginal}, \epsilon) \tag{4}$$

In the ice-free region ($L = 2$), the surface temperature T_s and sea ice bottom temperature T_b are assumed to be the ocean surface temperature $T_{o(1)}$.

$$.T_s = T_b = T_{o(1)} \tag{5}$$

.

The evaporation coefficient is assumed to be $GRBET = 1$ for both $L = 1and2$.

If the sea ice concentration R_{ice} is not given, it can be diagnosed simply from the sea ice volume W_{ice}.

$$.R_{ice} = \min\left(\sqrt{\frac{\max(W_{ice}, 0)}{W_{ice,c}}}, 1.0\right) \tag{6}$$

.

The standard gives the amount of sea ice per area as $W_{ice,c} = 300[\mathrm{kg/m^2}]$.

1.3.2 1.3.2 Ocean Surface Conditions `[OCNBCS]`

- Output variables

variable	Presentation	Meaning
GRALB	α	surface albedo
GRZ0	–	surface roughness
GFLUXS	G	heat flux
DGFDS	$\frac{\partial G}{\partial T_s}$	dG/dTs

- Input variables

Variable	Presentation	Meaning
GRTS	T_s	skin temperature
GRTB	$T_{b,ice}$	ice base temp.
GRICE	–	sea ice
GRSNW	–	snow smount
GRICR	R_{ice}	ice fraction
GDUA	U_0	u sfc wind
GDVA	V_0	v sfc wind
RCOSZ	–	cos(sol.zenith)

1.3.2.1 Albedo In this module, surface albedo and roughness are calculated. They are calculated supposing ice-free conditions, then modified.

First, let us consider the sea albedo. The sea level $\alpha_{(d,b)}$, $b = 1, 2, 3$ represent the visible, near-infrared, and infrared wavelength bands, respectively. Also, $d = 1, 2$ represents direct and scattered light, respectively.

1. Sea Surface Albedo for Visible `[SEAALB]`

- Internal parameters

Meaning	Presentation	Variable	unit	value
–	C_1, C_2, C_3	CC	[-]	$-0.7479, -4.677039, 1.583171$

For sea surface level albedo $\alpha_{L(d)}$, $d = 1, 2$ represents direct and scattered light, respectively. Using the solar zenith angle at latitude θ, the albedo for direct light is presented by

$$\alpha_{L(1)} = e^{(C_3 A^* + C_2) A^* + C_1} \tag{7}$$

where

$$A = \min(\max(\cos(\theta), 0.03459), 0.961) \tag{8}$$

On the other hand, the albedo for scattered light is uniformly set to a constant parameter.

$$\alpha_{L(2)} = 0.06 \tag{9}$$

2. Sea Surface Albedo for Near-Infrared and Infrared

The albedo for near-infrared is set to same as the visible one.

$$\alpha_{1,2} = \alpha_{1,1} \tag{10}$$

$$\alpha_{2,2} = \alpha_{2,1} \tag{11}$$

The albedo for infrared is uniformly set to a constant value.

3. Albedo modification by ice

The grid-averaged albedo, taking into account the sea ice concentration R_{ice}, is

$$\alpha = \alpha - R_{ice}\alpha_{ice} \tag{12}$$

α_{ice} is given by the standard as $\alpha_{ice,1} = 0.5, \alpha_{ice,2} = 0.5, \alpha_{ice,3} = 0.05$. 4.

4. albedo modification by snow

In addition, we want to consider the effect of snow cover. Here, we consider the albedo modification by temperature. The standard threshold values for snow temperature are $T_{al,2} = 258.15$[K] and $T_{al,1} = 273.15$[K]. The snow albedo changes linearly with temperature change from $\alpha_{snow,1} = 0.75$ to $\alpha_{snow,2}$. Let the coefficient τ_{snow}, which is $0 \leq \tau \leq 1$.

$$\tau_{snow} = \frac{T_s - T_{al,1}}{T_{al,2} - T_{al,1}} \tag{13}$$

Update the snow albedo α_{snow} as

$$\alpha_{snow} = \alpha_{snow,0} + \tau_{snow}(\alpha_{snow,2} - \alpha_{snow,1}) \tag{14}$$

1.3.2.2 Roughness

1. Sea Surface Roughness `[SEAZOF]`

The roughness variation of the sea surface is determined by the friction velocity $u^\star$

$$u^\star = \sqrt{C_{M_0}({U_0}^2 + {V_0}^2)} \tag{15}$$

We perform successive approximation calculation of C_{M_0}, because F_u, F_v, F_θ, F_q are required.

$$r_{0,M} = z_{0,M_0} + z_{0,M_R} + \frac{z_{0,M_R} u^{\star 2}}{g} + \frac{z_{0,M_S} \nu}{u^\star} \tag{16}$$

$$r_{0,H} = z_{0,H_0} + z_{0,H_R} + \frac{z_{0,H_R} u^{\star 2}}{g} + \frac{z_{0,H_S} \nu}{u^\star} \tag{17}$$

$$r_{0,E} = z_{0,E_0} + z_{0,E_R} + \frac{z_{0,E_R} u^{\star 2}}{g} + \frac{z_{0,E_S} \nu}{u^\star} \tag{18}$$

Here, $\nu = 1.5 \times 10^{-5}$[m^2/s] is the kinetic viscosity of the atmosphere. $z_{0,M}, z_{0,H}$ and $z_{0,E}$ are surface roughness for momentum, heat, and vapor, respectively. z_{0,M_0}, z_{0,H_0} and z_{0,E_0} are base, and rough factor (z_{0,M_R}, z_{0,M_R} and z_{0,E_R}) and smooth factor (z_{0,M_S}, z_{0,M_S} and z_{0,E_S}) are taken into account.

2. Roughness modification by ice

When the sea ice exists ($L = 1$),

$$z_{0,M} = z_{0,M} + (z_{0,ice,M} - z_{0,M})\alpha_{ice} \tag{19}$$

$$z_{0,H} = z_{0,H} + (z_{0,ice,H} - z_{0,H})\alpha_{ice} \tag{20}$$

$$z_{0,E} = z_{0,E} + (z_{0,ice,E} - z_{0,E})\alpha_{ice} \tag{21}$$

Here, $r_{0,ice,*}$ is roughness of sea ice, α_{ice} is the sea ice concentration.

3. Roughness modification by snow

When the snow even exists,

$$z_{0,M} = z_{0,M} + (z_{0,snow,M} - z_{0,M})\alpha_{snow} \tag{22}$$

$$z_{0,H} = z_{0,H} + (z_{0,snow,H} - z_{0,H})\alpha_{snow} \tag{23}$$

$$z_{0,E} = z_{0,E} + (z_{0,snow,E} - z_{0,E})\alpha_{snow} \tag{24}$$

Here, $r_{0,snow,*}$ is roughness of sea ice, α_{snow} is the sea ice concentration.

1.3.2.3 Sea Surface heat flux

1. Conductivity of ice

When sea ice exists ($L = 1$), the thermal conductivity $k^{\star}_{ice}$ of sea ice is obtained by using $D_{f,ice}$ (thermal diffusivity of sea ice) and sea ice density σ_{ice}.

$$k^{\star}_{ice} = \frac{D_{f,ice}}{\max(R_{ice}/\sigma_{ice}, \epsilon)} \tag{25}$$

2. conductivity modification by snow

The calculated thermal conductivity is modified to k_{ice} to take into account that it varies with snow cover.

$$h_{snow} = \min(\max(R_{snow}/\sigma_{snow}), \epsilon), h_{snow,max}) \tag{26}$$

$$k_{ice} = k^{\star}_{ice}(1 - R_{ice}) + \frac{D_{ice}}{1 + \|D_{ice}/D_{snow} \cdot h_{snow}\|} R_{ice} \tag{27}$$

where h_{snow} is the snow depth, R_{snow} is the snow area fraction, σ_{snow} is the snow density, $h_{snow,max}$ is the maximum snow depth, and D_{snow} is the thermal diffusivity of snow. 3.

3. calculate flux and its derivative

Therefore, the heat conduction flux and its derivative are

$$G = k_{ice}(T_b - T_s) \tag{28}$$

$$\frac{\partial G}{\partial T} = k_{ice} \tag{29}$$

.

Note that in the ice-free region ($L = 2$)

$$G = k_{ocn} \tag{30}$$

where k_{ocn} is the heat flux in the ocean surface layer. Here, k_{ocn} is the heat flux in the ocean surface layer.

1.4 1.4 Surface Flux [済 1 月]

1.4.1 1.4.1 Overview

The surface flux scheme evaluates the physical quantity fluxes between the atmospheric surfaces due to turbulent transport in the boundary layer. The main input | are wind speed (u, v), temperature (T), and specific humidity (q), and the output | are the vertical fluxes and the differential values (for obtaining implicit solutions) of momentum, heat, and water vapor.

The bulk coefficients are obtained according to Louis (1979) and Louis *et al.*(1982), except for the correction for the difference in roughness between momentum and heat. However, corrections are made to take into account the difference between momentum and heat roughness.

The outline of the calculation procedure is as follows.

1. Calculate the roughness including modifications by ice and snow. `MODULE:[SEAZOF]`
2. Calculate the Richardson number as the stability of the atmosphere. `MODULE:[PSFCL]`
3. Calculate the bulk coefficient from Richardson number. `MODULE:[PSFCL]`
4. Calculate the flux and its derivative from the bulk coefficient. `MODULE:[PSFCM]`
5. If necessary, the calculated fluxes are re-calculated after taking into account the roughness effect, the free flow effect, and the wind speed correction.

1.4.2 Basic Formula for Flux Calculations Surface fluxes $(F_u, F_v, F_\theta, F_q)$ are expressed using the bulk coefficients (C_M, C_H, C_E) as follows

$$F_u = -\rho C_M |\mathbf{v}| u \tag{31}$$

$$F_v = -\rho C_M |\mathbf{v}| v \tag{32}$$

$$F_\theta = \rho c_p C_H |\mathbf{v}| (\theta_g - \theta) \tag{33}$$

$$F_q^P = \rho C_E |\mathbf{v}| (q_g - q) \tag{34}$$

Note that F_q^P is the possible evaporation flux.

1.4.2 1.4.2 Roughness `[SEAOF]`

1.4.2.1 variables

- Output Variables

Variable	Presentation	Meaning
GRZ0M	$r_{0,M}$	surface roughness (V)
GRZ0H	$r_{0,H}$	surface roughness (T)
GRZ0E	$r_{0,E}$	surface roughness (q)

- Input variables

Variable	Presentation	Meaning
USFC	U_0	u sfc wind speed
VSFC	V_0	v sfc wind speed

- Internal variables

Variable	Presentation	Meaning
USTAR	$u^\star$	friction velocity

- Internal parameters

Variable	Presentation	Meaning	Values
Z0M0	r_{0,M_0}	base	0
Z0MR	r_{0,M_R}	rough factor	0.18
Z0MS	r_{0,M_S}	smooth factor	0.11
Z0H0	r_{0,H_0}	base	$1.4\hat{} - 5$
Z0HR	r_{0,H_R}	rough factor	0.0
Z0HS	r_{0,H_S}	smooth factor	0.4
Z0E0	r_{0,E_0}	base	$1.3\hat{} - 4$
Z0ER	r_{0,E_R}	rough factor	0.0
Z0ES	r_{0,E_S}	smooth factor	0.62
VISAIR	ν	kinematic viscosity	$1.5\hat{} - 5$
CM0	C_{M_0}	bulk coef for $u^\star$	$1.0\hat{} - 3$

Variable	Presentation	Meaning	Values
USTRMN	–	$\min(u^\star)$	$1.0\hat{} - 3$
Z0MMIN	–	minimum	$3.0\hat{} - 5$
Z0HMIN	–	minimum	$3.0\hat{} - 5$
Z0EMIN	–	minimum	$3.0\hat{} - 5$

1.4.3 1.4.3 Richardson Number [PSFCL]

The bulk Richardson number (R_{iB}), which is used as a benchmark for the stability between the atmospheric surfaces, is

$$R_{iB} = \frac{\frac{g}{\theta_s}(\theta_1 - \theta(z_0))/z_1}{(u_1/z_1)^2} = \frac{g}{\theta_s}\frac{T_1(p_s/p_1)^\kappa - T_0}{u_1^2/z_1} f_T \tag{35}$$

Here, g is the gravitational acceleration, θ_s (Θ_0 in MATSIRO description) is the basic potential temperature, T_1 is the atmospheric temperature of the 1st layer, T_0 is the surface skin temperature, p_s is the surface pressure, p_1 is the pressure of the 1st layer, κ is the Karman constant, and

$$f_T = (\theta_1 - \theta(z_0))/(\theta_1 - \theta_0) \tag{36}$$

is a correction factor, which is approximated from the uncorrected bulk Richardson number, but we abbreviate the calculation here.

1.4.4 1.4.4 Bulk factor [BLKCOF]

The bulk coefficients of C_M, C_H, C_E are calculated according to Louis (1979) and Louis *et al.*(1982). However, corrections are made to take into account the difference between momentum and heat roughness. If the roughnesses for momentum, heat, and water vapor are set to $z_{0,M}, z_{0,H}, z_{0,E}$, respectively, the results are generally $z_{0,M} > z_{0,H}, z_{0,E}$, but the bulk coefficients for heat and water vapor for the fluxes from the height of $z_{0,M}$ are also set to $\widetilde{C_H}$, $\widetilde{C_E}$ first, and then corrected.

$$C_M = \begin{cases} C_{0,M}[1 + (b_M/e_M)R_{iB}]^{-e_M} & , R_{iB} \geq 0 \\ C_{0,M}\left[1 - b_M R_{iB}\left(1 + d_M b_M C_{0,M}\sqrt{\frac{z_1}{z_{0,M}}|R_{iB}|}\right)^{-1}\right] & , R_{iB} < 0 \end{cases} \tag{37}$$

$$\widetilde{C_H} = \begin{cases} \widetilde{C_{0,H}}[1 + (b_H/e_H)R_{iB}]^{-e_H} & , R_{iB} \geq 0 \\ \widetilde{C_{0,H}}\left[1 - b_H R_{iB}\left(1 + d_H b_H \widetilde{C_{0,H}}\sqrt{\frac{z_1}{z_{0,M}}|R_{iB}|}\right)^{-1}\right] & , R_{iB} < 0 \end{cases} \tag{38}$$

$$C_H = \widetilde{C_H} f_T \tag{39}$$

$$\widetilde{C_E} = \begin{cases} \widetilde{C_{0,E}} [1 + (b_E/e_E) R_{iB}]^{-e_E} & , R_{iB} \geq 0 \\ \widetilde{C_{0,E}} \left[1 - b_E R_{iB} \left(1 + d_E b_E \widetilde{C_{0,E}} \sqrt{\frac{z_1}{z_{0,M}} |R_{iB}|} \right)^{-1} \right] & , R_{iB} < 0 \end{cases} \tag{40}$$

$$C_E = \widetilde{C_E} f_q \tag{41}$$

$C_{0M}, \widetilde{C_{0H}}, \widetilde{C_{0E}}$ is the bulk coefficient (for fluxes from z_{0M}) at neutral,

$$C_{0M} = \widetilde{C_{0H}} = \widetilde{C_{0E}} = \frac{k^2}{\left[\ln \left(\frac{z_1}{z_{0M}} \right) \right]^2} \tag{42}$$

Correction Factor f_q is ,

$$f_q = (q_1 - q(z_0))/(q_1 - q^*(\theta_0)) \tag{43}$$

but the method of calculation is omitted. The coefficients of Louis factors are $(b_M, d_M, e_M) = (9.4, 7.4, 2.0)$, $(b_H, d_H, e_H) = (b_E, d_E, e_E) = (9.4, 5.3, 2.0)$.

1.4.5 1.4. Calculation of surface turbulent fluxes [PSFCM]

- Modified variables

Variable	Presentation	Meaning
UFLUXS	–	flux of U
VFLUXS	–	flux of V
TFLUXS	–	flux of T
QFLUXS	–	flux of q

- Output variables

variable	Presentation	Meaning
DUFDU	–	-d(tau)/du

variable	Presentation	Meaning
DTFDT	–	-dH/dTa
DQFDQ	–	-dLE/dqa
DTFDS	–	dH/dTs
DQFDS	–	dLE/dTs
CDVE	–	bulk coef.
RM10	–	coef. for 10m u
RH2	–	coef. for 2m T
RE2	–	coef. for 2m q
U10	–	10m u
V10	–	10m v
T2	–	2m T
Q2	–	2m q

- Input variables

Meaning	Presentation	Variable
westerly u	–	GDUA
southern wind v	–	GDVA
temperature T	–	GDTA
humidity q	–	GDQA
pressure (lev=1)	–	GDPA
surface pressure	–	GDPS
surface skin temperature	–	GDTS
surface roughness	–	GRZ0
soil wetness	–	GRBET
ocean u	–	GRUA
ocean v	–	GRVA

The turbulent fluxes at the sea surface are solved by bulk formulae as follows. Then, by solving the surface energy balance, the ground surface temperature (T_s) is updated, and the surface flux values with respect to those values are also updated. The solutions obtained here are temporary values. In order to solve the energy balance by linearizing with respect to T_s, the differential with respect to T_s of each flux is calculated beforehand.

- Momentum flux

$$\tau_x = -\rho C_M |V_a| u_a \tag{44}$$

$$\tau_y = -\rho C_M |V_a| v_a \tag{45}$$

where τ_x and τ_y are the momentum fluxes (surface stress) of the zonal and meridional directions, respectively.

- Sensible heat flux

$$H_s = c_p \rho C_{Hs} |V_a| (T_s - (P_s/P_a)^\kappa T_a) \tag{46}$$

where H_s is the sensible heat flux from the sea surface; $\kappa = R_{air}/c_p$ and $R_{air}$are the gas constants of air; and c_p is the specific heat of air.

- Bare sea surface evaporation flux

$$\hat{F} q^P_{1/2} = \rho_{1/2} C_E |\mathbf{v}_1| \left(q^\star(T_0) - q_1 \right) \tag{47}$$

1.5 1.5 Radiation Flux at Sea Surface [RADSFC] [済 1 月]

For the ground surface albedo $\alpha_{(d,b)}$, $b = 1, 2$ represent the visible and near-infrared wavelength bands, respectively. Also, $d = 1, 2$ are direct and scattered, respectively. For the downward shortwave radiation $SW^\downarrow$ and upward shortwave radiation $SW^\uparrow$ incident on the earth's surface, the direct and scattered light together are

$$SW^\downarrow = SW^\downarrow_{(1,1)} + SW^\downarrow_{(1,2)} + SW^\downarrow_{(2,1)} + SW^\downarrow_{(2,2)} \tag{48}$$

$$SW^\uparrow = SW^\downarrow_{(1,1)} \cdot \alpha_{(1,1)} + SW^\downarrow_{(1,2)} \cdot \alpha_{(1,2)} + SW^\downarrow_{(2,1)} \cdot \alpha_{(2,1)} + SW^\downarrow_{(2,2)} \cdot \alpha_{(2,2)} \tag{49}$$

1.6 1.6 Surface Heat Balance [OCNSLV] [済 1 月]

The comments for some variables say "soil", but this is because the program was adapted from a land surface scheme, and has no particular meaning.

- Outputs

Meaning	Presentation	Variable	dimension	unit
surface water flux	$W_{free/ice}$	WFLUXS	IJLSDM,2	–
upward long wave	$LW^{\uparrow}$	RFLXLU	IJLSDM	–
flux balance	F	SFLXBL	IJLSDM	–

- Inputs variables

Meaning	Presentation	Variable
sensible heat flux coefficent	$\frac{\partial H}{\partial T_s}$	DTFDS
latent heat flux coefficient	$\frac{\partial E}{\partial T_s}$	DQFDS
surface heat flux coefficient	$\frac{\partial G}{\partial T_s}$	DGFDS
downward SW radiation	$SW^{\downarrow}$	RFLXSD
upward SW radiation	$SW^{\uparrow}$	RFLXLU
downward LW radiation	$LW^{\downarrow}$	RFLXLD
sea surface albedo	α	GRALBL
sea ice concentration	R_{ice}	GRICR

- Modified in this subroutine

Meaning	Presentation	Variable	dimension	unit
skin temperature	T_s	GDTS	IJLSDM	–
surface heat flux from `seaBC`	G	GFLUXS	IJLSDM	–
sensible heat flux	H	TFLUXS	IJLSDM	–
latent heat flux	E	QFLUXS	IJLDSM	–

- Others (appeared in texts)

Meaning	Presentation	Variable	dimension	unit
sea surface albedo for shortwave radiation (ice-free)	α_S	–	[-]	–
the Stefan-Boltzmann constant	σ	STB	–	–

Reference: Hasumi, 2015, Appendices A

Downward radiative fluxes are not directly dependent on the condition of the sea surface, and their observed values are simply specified to drive the model. Shotwave emission from the sea surface is negligible, so the upward part of the shortwave radiative flux is accounted for solely by reflection of the incoming downward flux. Let α_S be the sea surface albedo for shortwave radiation. The upward shortwave radiative flux is represented by

$$SW^{\uparrow} = -\alpha_S SW^{\downarrow} \tag{50}$$

On the other hand, the upward longwave radiative flux has both reflection of the incoming flux and emission from the sea surface. Let α be the sea surface albedo for longwave radiation and ϵ be emissivity of the sea surface relative to the black body radiation. The upward shortwave radiative flux is represented by

$$LW^{\uparrow} = -\alpha LW^{\downarrow} + \epsilon\sigma T_s^4 \tag{51}$$

where σ is the Stefan-Boltzmann constant and T_s is skin temperature. If sea ice exists, snow or sea ice temperature is considered by fractions. When radiative equilibrium is assumed, emissivity becomes identical to co-albedo:

$$\epsilon = 1 - \alpha \tag{52}$$

The net surface flux is presented by

$$F^* = H + (1-\alpha)\sigma T_s^4 + \alpha LW^{\uparrow} - LW^{\downarrow} + SW^{\uparrow} - SW^{\downarrow} \tag{53}$$

The heat flux into the sea surface is presented, with the surface heat flux calculated in `PSFCM`

$$G^* = G - F^* \tag{54}$$

Note that G^* is downward positive.

The temperature derivative term is

$$\frac{\partial G^*}{\partial T_s} = \frac{\partial G}{\partial T_s} + \frac{\partial H}{\partial T_s} + \frac{\partial R}{\partial T_s} \tag{55}$$

When the sea ice exists, the sublimation flux is considered

$$G_{ice} = G^* - l_s E \tag{56}$$

The temperature derivative term is

$$\frac{\partial G_{ice}}{\partial T_s} = \frac{\partial G^*}{\partial T_s} + l_s \frac{\partial E}{\partial T_s} \tag{57}$$

Finally, we can update the surface temperature with the sea ice concentration with $\Delta T_s = G_{ice}(\frac{\partial G_{ice}}{\partial T_s})^{-1}$

$$T_s = T_s + R_{ice}\Delta T_s \tag{58}$$

Then, the sensible and latent heat flux on the sea ice is updated.

$$E_{ice} = E + \frac{\partial E}{\partial T_s}\Delta T_s \tag{59}$$

$$H_{ice} = H + \frac{\partial H}{\partial T_s}\Delta T_s \tag{60}$$

When the sea ice does not existed, otherwise, the evaporation flux is added to the net flux.

$$G_{free} = F^* + l_c E \tag{61}$$

Finally each flux is updated.
For the sensible heat flux, the temperature change on the sea ice is considered.

$$H = H + R_{ice}H_{ice} \tag{62}$$

Then, the heat used for the temperature change is saved.

$$F = R_{ice}H_{ice} \tag{63}$$

For the upward longwave radiative flux, the temperature change on the sea ice is considered.

$$LW^{\uparrow} = LW^{\uparrow} + 4\frac{\sigma}{T_s}R_{ice}\Delta T_s \tag{64}$$

For the surface heat flux, the sea ice concentration is considered.

$$G = (1 - R_{ice})G_{free} + R_{ice}G_{ice} \tag{65}$$

For the latent heat flux, the sea ice concentration is considered.

$$E = (1 - R_{ice})E + R_{ice}E_{ice} \tag{66}$$

Each term above are saved as freshwater flux.

$$W_{free} = (1 - R_{ice})E \tag{67}$$

$$W_{ice} = R_{ice}E_{ice} \tag{68}$$