

Mathematical Notations

Symbol	Description		
a	wave amplitude		1.6.2
a_i	weights corresponding to the spectrally distributed absorption coefficients α_i	(1.62)	1.4.6
a_0	dimensionless constant in microlayer parameterization	(2.47)	2.3.2
A	albedo	(1.54)	1.4.5
A_d	parameter determining free-rising profiler dynamics	(3.10)	3.2.4
A_w	wave age		1.6.6
A_0	dimensionless coefficient in parameterization for gas transfer	(2.41)	2.3.2
b	turbulent kinetic energy (TKE)	(1.24)	1.2.4
b_w	surface wave kinetic energy	(3.57)	3.3.3
B	dimensionless constant in Craig and Banner (1994) model	(3.32)	3.3.2
B_0	vertical flux of buoyancy just below the sea surface	(2.120)	2.5.4
c	phase speed of wave	(1.105)	1.6.2
c	bubble-free sound speed	(7.8)	7.4.3
c_p	phase speed at the spectral peak of wind waves		1.6.6
c_p	specific heat capacity of water at constant pressure	(1.10)	1.2.2
c_{pr}	specific heat of rain water	(1.80)	1.5.4
c_{pa}	specific heat capacity of air at constant pressure	(1.35)	1.3.2
C	conductivity of seawater		2.2.1
C	volume concentration of bubbles	(6.10)	6.1.4
C_i	concentration of tracer	(1.12)	1.2.2
C_w	concentration of tracer in the bulk of water		2.3.2
C_0	surface concentration of tracer		2.3.2
C_D	drag coefficient	(1.34)	1.3.2
C_E	bulk transfer coefficient for latent heat	(1.36)	1.3.2
C_T	bulk transfer coefficient for sensible heat	(1.35)	1.3.2
C_u	drag coefficient in the near-surface layer of the ocean	(4.2)	4.2.1
D_r	diameters of dry particles		6.2.4
$e(k)$	wavenumber spectrum of kinetic energy	(5.2)	5.2
E	evaporation rate	(1.27)	1.3.1

E	vertical flux of the kinetic energy	(4.43)	4.5.1
E_B	one-dimensional (horizontal) wavenumber spectrum of buoyancy	(5.13)	5.3.5
E_ρ	one-dimensional (horizontal) wavenumber spectrum of density	(5.14)	5.3.5
$E_u(k_x)$	one-dimensional wavenumber spectrum of turbulence	(3.8)	3.2.3
f	Coriolis parameter	(1.1)	1.2.1
f	frequency in Hz	(3.8)	3.2.3
f_y	horizontal component of the Coriolis parameter	(1.1)	1.2.1
f_V	source function for penetrating rain	(1.78)	1.5.3
$f_R(z)$	function characterizing the absorption of solar radiation with depth	(1.61)	1.4.6
F_k	flux of kinetic energy carried by rain droplets	(2.126)	2.5.6
F_0	flux of kinetic energy to waves from wind	(1.127)	1.6.6
g	acceleration due to gravity	(1.3)	1.2.1
G_i	flux of i -th component of tracer admixture	(1.12)	1.2.2
G_{Vi}	volume source of i -th tracer	(1.12)	1.2.2
G_0	net air-sea flux of gas	(1.44)	1.3.2
h	layer depth, mixed layer depth, turbulent boundary layer depth		
h_c	penetration depth of convection	(4.45)	4.5.1
h_r	rain-formed mixed layer depth		4.1.4
h_D	diurnal mixed layer depth		4.1.1
h_E	Ekman layer depth	(1.141)	1.7.1
h_{TD}	turbulent diffusion layer depth		3.1.4
h_{w-s}	wave-stirred layer depth		3.1.4
h_0	depth of the near-surface density anomaly		5.4.1
H	depth of nearly isothermal thermal		5.4.1
H	helicity		5.1
H_D	depth of the bottom boundary of diurnal thermocline		4.1.1
ΔH_D	thickness of the diurnal thermocline		4.2.2
H_r	depth of the bottom boundary of rain-formed halocline		4.1.4
H_s	significant wave height	(1.117)	1.6.5
I_L	net longwave irradiance	(1.46)	1.3.3
I_R	volume source of heat due to absorption of solar radiation	(1.10)	1.2.2
I_Σ	insolation (surface solar irradiance)		1.4.2
I_0	solar constant		1.4.2

J	salinity flux	(1.11)	1.2.2
J_{rV}	volume source of freshwater due to the decay of raindrops	(1.11)	1.2.2
k	wavenumber ($k = 2\pi / \lambda$)	(1.102)	1.6.2
\vec{k}	wavenumber vector with components k_x, k_y	(1.100)	1.6.2
K_b	bubble-mediated transfer velocity	(7.26)	7.5.3
K_B	turbulent diffusion coefficient for bubbles	(6.10)	6.1.4
K_D	turbulent diffusion coefficient for droplets	(6.17)	6.2.2
K_h	horizontal mixing coefficient	(5.16)	5.3.7
K_{int}	interfacial (direct) transfer velocity	(7.23)	7.5.2
K_{Ci}	diffusion coefficient for i -th tracer	(1.15)	1.2.2
Ke	Keulegan number	(2.1)	2.2.3
K_M	kinematic viscosity	(1.5)	1.2.1
K_S	diffusion coefficient for salinity	(1.14)	1.2.2
K_T	thermal diffusion coefficient	(1.13)	1.2.2
K_u	gas transfer (piston) velocity	(1.44)	1.3.2
K_0	mixing coefficient in the logarithmic boundary layer	(3.93)	3.4.2
l	characteristic length scale of turbulence	(3.30)	3.3.2
L	width of frontal interface		5.4.4
L	specific heat of vaporization for water	(1.28)	1.3.1
$L(z, \theta, \phi)$	radiance in the direction defined by the zenith angle θ and azimuth angle ϕ , and z is the depth	(1.47)	1.4.1
L_c	diameter of low-salinity lense		5.3.5
L_E	Ekman length scale	(3.5)	3.1.2
L_f	baroclinic Rossby radius		5.3.5
L_G	Garwood et al. (1985) length scale		3.5.3
L_O	Oboukhov buoyancy length scale	(3.6)	3.1.2
L_p	pressure-gradient length scales		3.5.4
L_B	equatorial baroclinic Rossby radius		5.3.1
m_d	mass of the free-ascending device	(3.9)	3.2.4
M_r	cumulative precipitation	(4.27)	4.2.4
$n(r_0)$	initial drop size distribution (at $z = 0$)	(1.65)	1.5.2
N	Brunt-Vaisala frequency	(3.98)	3.4.3
Nu	Nusselt number	(2.66)	2.3.3
p	pressure	(1.1)	1.2.1
p_a	gas partial pressure in air	(1.45)	1.3.2
p_w	gas partial pressure in water	(1.45)	1.3.2
p_0	atmospheric pressure	(1.93)	1.6.1

P	precipitation rate	(1.27)	1.3.1
Pr	Prandtl number	(2.2)	2
q_a	specific humidity of air	(1.36)	1.3.2
q	turbulent velocity scale	(3.30)	3.3.2
$q_R(z)$	scaled solar irradiance as a function of z	(2.69)	2.4.1
q_{R0}	scaled solar irradiance just below the air-sea interface	(2.79)	2.4.1
q_0	scaled net heat flux at the sea surface	(2.10)	2.3.1
Q	heat flux	(1.10)	1.2.2
Q_E	latent heat flux	(1.28)	1.3.1
Q_{rs}	surface component of rain-induced heat flux	(1.81)	1.5.4
Q_{rv}	volume component of rain-induced heat flux	(1.80)	1.5.4
Q_T	sensible heat flux	(1.26)	1.3.1
Q_v	virtual cooling	(2.60)	2.3.2
Q_0	net surface heat flux	(1.26)	1.3.1
r	drop radius	(1.71)	1.5.3
r	bubble radius		6.1.2
r_0	initial drop radius		1.5.1
R_{rs}	remote sensing reflectance	(7.2)	7.1.6
R_s	surface reflectance (traditional definition)	(1.55)	1.4.5
R_s	surface reflectance (IOCCG, 2000 definition)	(7.1)	7.1.6
Ra	Rayleigh number	(1.20)	1.2.4
Ra_f	flux Rayleigh number		2.2.1
Re	Reynolds number	(1.20)	1.2.6
Rf	flux Richardson number	(2.19)	2.3.1
Rf_0	surface Richardson number		2.3.1
Ri	Richardson number	(3.84)	3.4.1
Ri_{cr}	critical Richardson number	(3.86)	3.4.1
Ro	Rossby number	(1.16)	1.2.3
S	salinity	(1.11)	1.2.2
S_h	shear	(3.98)	3.4.3
S_h	bulk salinity of the mixed layer		4.1.4
S_M, S_q	dimensionless constants in Craig and Banner (1994) model		3.3.2
S_r	bulk salinity of the rain-formed mixed layer		4.1.4
$S_u(f)$	frequency spectrum of turbulence	(3.8)	3.2.3
S_w	bulk salinity	(2.107)	2.5.2
S_μ	gas solubility	(1.45)	1.3.2
S_0	sea surface salinity	(1.27)	1.3.1
Sc	Schmidt number	(2.3)	2

Sc_T	turbulent Schmidt number	(6.17)	6.2.2
t	time, elapsed time		
t_*	renewal time	(2.30)	2.3.2
T	thermodynamic temperature		
T_h	bulk temperature of the upper ocean mixed layer		4.1.1
T_r	raindrop temperature	(1.80)	1.5.4
T_w	bulk water temperature	(1.80)	1.5.4
T_D	bulk temperature of the diurnal mixed layer		4.1.1
T_0	sea surface temperature (SST)	(1.35)	1.3.2
u, v, w	mean velocity components in x, y, z directions, respectively		1.2.1
u_l	typical velocity scale	(1.19)	1.2.4
u_S	stokes surface drift		2.3.2
u_w	current velocity of the bulk of water		
u_{wd}	wind-induced surface drift	(2.62)	2.3.2
u_0	current velocity at the sea surface (relative to the background ocean current)	(2.62)	2.3.2
u_*	friction velocity in the upper ocean boundary layer		1.6.6
u_{*a}	friction velocity in the atmospheric boundary layer		1.3.2
u_{*l}	local friction velocity		3.5.2
u_{*r}	equivalent friction velocity scale induced in the upper ocean corresponding to the flux of kinetic energy carried by the rain	(2.131)	2.5.6
$\overline{\Delta u}$	ensemble averaged velocity difference across the aqueous viscous sublayer		2.3
U_a	mean wind speed relative to the ocean surface	(1.32)	1.3.2
U_0	Relative flow speed (towed or mean flow advection speed)	(3.8)	3.2.3
U_{10}	wind speed at 10 m height		1.3.2
V_x	longitudinal component of the bow velocity signal		3.2.5
w_b	buoyant rise speed of bubbles	(6.1)	6.1.2
w_e	entrainment velocity		4.3
w_i	impact (terminal) velocity of raindrops		1.5.1
w_0	nominal ascending speed of the free-rising profiler in still water	(3.11)	3.2.4
w_*	convective velocity scale	(3.95)	3.4.2
W	total squared vorticity (enstrophy)		5.2

W_c	fraction of sea surface covered by oceanic whitecaps	(6.14)	6.1.5
We	Weber number	(1.63)	1.5.1
x, y, z	Cartesian coordinate system with origin at the sea surface (x directed eastward, y directed northward, z directed upward or downward)		1.2.1
z	depth		
z_c	compensation depth		4.5.1
z_0	surface roughness length scale	(3.3)	3.1.2
z_{0a}	surface roughness length scale from the air side of the air-sea interface	(1.42)	1.3.2
α	Ostwald solubility coefficient (dimensionless)	(7.26)	7.5.3
α	polar angle		
α_T	thermal expansion coefficient of seawater		1.2.4
α_i	spectrally distributed absorption coefficients	(1.62)	1.4.6
α_w	proportionality coefficient for kinetic energy flux from wind to waves	(1.128)	1.6.6
β	void fraction of entrained air		
β_S	coefficient of saline contraction		1.2.4
β_w	e -folding scale for the temporal growth of wave energy in the absence of nonlinear interactions and dissipation	(1.126)	1.6.6
γ	dimensional parameter in nonlinear diffusion equation	(5.15)	5.3.6
δ	solar declination angle	(1.53)	1.4.3
δ_v	thickness of the viscous sublayer		2.3.1
δ_μ	thickness of the diffusion sublayer	(2.4)	2.1.3
Δ_e	equilibrium supersaturation	(7.22)	7.5.1
ε	viscous dissipation of the turbulent kinetic energy		1.2.4
ε_0	viscous dissipation of the turbulent kinetic energy in water near the sea surface	(3.61)	3.3.3
ζ	Stability parameter in the Monin-Oboukhov theory	(1.41)	1.3.2
η	surface wave displacement		1.6.1
η_D	internal diffusivity length scale of turbulence	(2.3)	2
η_T	internal thermal length scale of turbulence	(2.2)	2
η_ν	Kolmogorov's internal length scale of turbulence	(2.1)	2
θ	zenith angle	(1.51)	1.4.3
θ	wind direction		3.5.2

Θ	potential temperature	(1.10)	1.2.2
κ	von Karman constant		1.3.2
κ_T	molecular coefficient of thermal diffusivity		1.2.4
λ	wavelength		
λ_{IG}	wavelength of equatorial inertia-gravity wave		5.3.3
λ_S	nondimensional coefficient in cool-skin parameterization		2.1.2
Λ_0	dimensionless constant in microlayer parameterization	(2.39)	2.3.2
μ	molecular coefficient of kinematic tracer diffusivity (for gas, salinity etc.)		
μ	parameter relating to the vertical mixing process and horizontal buoyancy gradients	(5.12)	5.3.5
ν_a	molecular kinematic viscosity of air		
ν_T	eddy viscosity in Benilov and Ly (2003) model	(3.55)	3.3.3
ξ	solar elevation angle		1.4.5
ρ	water density		
ρ_a	air density		
ρ_r	density of rain water	(1.80)	1.5.4
σ_s	surface tension		1.5.1
σ_t	sigma-t density		
σ_*	Bubble decay rate	(6.12)	6.1.4
σ_η^2	variance of surface wave elevation		3.3.2
τ	relaxation time	(4.32)	4.3
τ_{ij}	components of the viscous stress tensor (where i and j can be x , y , or z)	(1.5)	1.2.1
τ_{rs}	surface component of rain-induced stress	(1.85)	1.5.5
τ_{rV}	volume component of rain-induced stress	(1.84)	1.5.5
τ_r	stress due to rain	(1.83)	1.5.5
τ_t	tangential component of air-sea momentum flux	(2.8)	2.2.3
τ_0	magnitude of wind stress	(1.34)	1.3.2
Υ	heat content	(4.23)	4.2.3
φ	geographical latitude		1.2.1
ϕ	potential function	(1.91)	1.6.1
$\Phi_\eta(\vec{k}, \omega)$	surface wave spectrum		3.1.1
$\Phi(\omega)$	frequency spectrum of surface waves	(1.113)	1.6.5
$\Psi(\vec{k})$	wavenumber spectrum of surface wave	(1.122)	1.6.5
ω	frequency ($\omega = 2\pi/f$)		

ω_p	frequency of the wave spectrum peak		
ω_0	lowest eigenfrequency of a single bubble oscillation	(7.7)	7.4.3
Ω	magnitude of the Earth's rotation vector		1.2.1

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