APPENDIX

B

Symbol Definitions

Many symbols are required to represent the quantities used in physical climatology. The letters of the alphabet are less than the number of variables, even if both the English and Greek alphabets are fully utilized. Modern climatology crosses the boundaries between subdisciplines within earth sciences, and the traditional symbol for a quantity in one discipline may be the same as the traditional symbol for some other quantity in another discipline. In developing the symbols used in this book, an attempt was made to balance simplicity and tradition, on one hand, against the clarity of having a unique symbol for every variable, on the other. Some symbols are used to represent more than one variable in order to maintain the traditional usage. It is hoped that the meaning will be obvious from the context. A table containing the symbols used, their meaning, and the equation, section, or figure where they first appear is provided here to assist the student.

ENGLISH SYMBOLS

a	The mean radius of Earth = 6.37×10^6 m	(2.23), (6.4)
a_n	A series of expansion coefficients with index n	(A6)
a_o	Semi-major axis of the Earth's orbit	Fig. 12.8, (13.7)
a_p	Planetary absorptivity = $1 - \alpha_p$	(10.12)
A	Area	Fig. 2.5
A_c	Total fractional area coverage by clouds	(10.43)
A_b	Fractional area coverage by black daisies	(10.45)
A_g	Fractional area coverage by ground in which daisies can grow	(10.48)
A_w	Fractional area coverage by white daisies	(10.44)
A_ν	Absorption of radiation at frequency ν	(3.26)
b_e, b_Φ	Regression coefficients for eccentricity and obliquity	(12.17)

Global Physical Climatology. http://dx.doi.org/10.1016/B978-0-12-328531-7.00015-3

b_n	A series of expansion coefficients with index n	(A6)
B	A coefficient relating OLR to surface temperature	(10.16), (10.21)
B_e	Equilibrium Bowen ratio	(4.34)
$B_\nu(T)$	Planck's black body emission at frequency ν and temperature T	(3.7)
B_o	Bowen ratio = SH/LE	(4.34)
c	Heat capacity per unit area	(13.3)
c^*	Speed of light = 3×10^8 m s^{-1}	(3.1)
c_p	Specific heat of air at constant pressure	(1.15), (3.24)
c_v	Specific heat of air at constant volume	(1.12)
c_s	Specific heat of soil	(4.8)
c_c	Specific heat of organic matter in soil	(4.8)
c_w	Specific heat of water	(4.5)
$\overline{C}_a$	Total effective heat capacity for the atmosphere per unit area	(4.4)
$\overline{C}_o$	Total effective heat capacity for the ocean per unit area	(4.5)
$\overline{C}_{eo}$	Total effective heat capacity for the surface per unit area	(4.3)
C_D	Aerodynamic transfer coefficient for momentum, or drag coefficient	(4.18)
C_{DE}	Aerodynamic transfer coefficient for vapor	(4.27)
C_{DH}	Aerodynamic transfer coefficient for heat	(4.26)
C_s	Volumetric heat capacity of soil	(4.8)
^{14}C	The isotope of carbon with atomic weight of approximately 14	Sec. 13.3
^{13}C	The isotope of carbon with atomic weight of approximately 13	Sec. 13.3
d	Distance of Earth from the Sun	(2.4), (12.7)
d	Total derivative prefix	(3.3), (10.1)
d_a	Earth–Sun distance at aphelion	(12.6)
d_e	A depth scale for baroclinic disturbances	(10.30)
d_n	Day of the year with index n	(A5)
d_p	Earth–Sun distance at perihelion	(12.6)
d_s	An increment of optical path length	(3.12)

d_w	A depth of water	(4.5)
D	Surface condensation (dewfall plus frost)	(5.1)
D_o	Depth of ocean	(7.15)
DJF	December, January and February	
D_T	Thermal diffusivity	(4.9)
$\frac{D}{Dt}$	Material derivative following motion	(6.4), (11.2)
e	Eccentricity of an orbit	(12.6)
e_s	Saturation partial pressure of water vapor	(1.9), (10.8)
e^x	2.71828 raised to the power x	(1.6), (3.17), (7.4)
E	Evapotranspiration or evaporation	(5.1)
E_a	Energy content of the atmosphere per unit area	(6.1)
E_{ao}	Energy content of the atmosphere-ocean climate system	(2.19)
E_{air}	Component of evaporation associated with dryness of air	(5.13)
E_{BB}	Radiative energy emission from a black body	(2.5)
E_{en}	Component of evaporation associated with energy supply to the surface	(5.10)
E_R	Radiative energy emission	(2.6)
E_s	Energy content of the surface	(4.1)
E_{sub}	Mass rate of sublimation of snow	(5.15)
E_ν	Emission of radiation at frequency ν	(3.26)
f	Coriolis parameter = $2\Omega \sin\phi$	(7.1)
F	Energy flux	(3.12)
$F^\uparrow(z)$	Upward longwave flux at altitude z	(3.33), (4.11)
$F^\downarrow(z)$	Downward longwave flux at altitude z	(3.34), (4.11)
$F^\downarrow_{net}(z)$	$F^\downarrow(z) - F^\uparrow(z)$ net downward longwave flux at altitude z	(10.35)
$\vec{F}_a$	The vector of horizontal of energy flux in the atmosphere	(6.1)
$\vec{F}_{ao}$	Horizontal energy flux in the atmosphere plus ocean	(2.19), (7.14)
F_{eo}	Horizontal energy flux below the surface in earth or ocean	(4.1)
F_I	Vertical flux of heat at the base of sea ice	(11.2)

$\vec{F}_o$	The horizontal flux of energy in the ocean	(7.15)
FRH	A subscript indicating a process that takes place with fixed relative humidity	(10.10)
F_s	The vertical flux of energy through soil or snow	(4.6), (11.3)
F_ν	Energy flux in some infinitesimal range of frequency centered on ν	(3.3)
F_ϕ	Meridional flux of energy in the atmosphere–ocean	(2.23)
F_∞	Downward radiation flux at the top of the atmosphere	(3.17)
g	Acceleration of gravity, 9.81 m s^{-2}	(1.2)
g_w	Storage of water at and below the surface	(5.1)
g_{wa}	Storage of water in the atmosphere	(5.3)
G	Energy storage in the surface	(4.1)
h	Hour angle	(2.15), (A1)
h	Planck's constant = 6.625×10^{-34} J s	(3.2)
h_c	Water equivalent depth of soil water capacity	(5.14)
h_I	Depth of sea ice	(11.3)
h_o	Hour angle at sunset and sunrise ($-h_o$)	(2.16)
h_s	Water equivalent depth of snow	(5.19)
h_T	Penetration depth of temperature perturbations in soil	(4.10)
h_v	Water equivalent depth of soil moisture below which plants transpire at less than the potential rate	(5.22)
h_w	Equivalent depth of soil moisture	(5.18)
H	Scale height = RT/g	(1.5), (3.18)
$\vec{i}$	Unit vector in eastward direction	(7.11)
I	OLR scaled by global insolation	(10.22)
I	Global ice volume	(12.18)
I_ν	Intensity of radiation at frequency ν	(3.3), (3.26)
ITCZ	Intertropical Convergence Zone	
$\vec{j}$	Unit vector in northward direction	(7.11)
JJA	June, July, and August	
k	Boltzmann's constant = 1.37×10^{-23} J K^{-1}	(3.7)
$\vec{k}$	Vertical unit vector	(7.11), (10.2)
k_{abs}	Absorption cross-section	(3.12), (12.1)

k_{ext}	Extinction cross-section	(12.1)
k_e	Extinction cross-section	(3.54)
k_I	Thermal conductivity for sea ice	(11.1)
k_s	Thermal conductivity for snow	(11.2)
k_{sca}	Scattering cross-section	(12.1)
k_ν	Absorption cross-section at frequency ν	(3.27)
K_H	A coefficient for horizontal heat transport	(10.19), (10.26)
L_e	A horizontal mixing length scale for atmospheric disturbances	(10.27)
L	Latent heat of vaporization for water = 2.5×10^6 J kg^{-1}	(4.25)
L_o	Luminosity of the Sun	(2.2)
LAI	Leaf area index	Sec. 5.4
LE	Surface cooling by evaporation	(4.1), (6.1)
L_f	Latent heat of fusion for water = 3.34×10^5 J kg^{-1}	(11.5)
L_R	Rossby radius of deformation	(10.28)
LWC	Liquid water content	(3.56)
m_a	Molecular weight of dry air	App. E
m_w	Molecular weight of water	App. E
M	Angular momentum	(6.16)
M_a	Mass mixing ratio of absorber in air	(3.19), (3.25)
M_e	Orbital angular momentum of Earth about the Sun	(12.11)
MAM	March, April, and May	
M_s	Mass rate of snow melting per unit area	(5.19)
N	The buoyancy frequency	(10.28)
N	Total number density of cloud particles	(3.55)
$n(r)$	Number density of cloud particles of radius r	(3.55)
^{18}O	The isotope of oxygen with atomic weight of approximately 18	(9.1)
OLR	Outgoing longwave radiation = $F^{\uparrow}(\infty)$	Sec. 3.11
p	Pressure	(1.2)
p_o	Reference pressure, usually 1000 mb	(1.20)
p_s	Surface pressure	(1.6), (3.19), (10.1)
P	Precipitation by rain and snow	(5.1)

PE	Potential evaporation rate	(5.14)
P_o	Period of Earth's orbit about the Sun	(12.12)
$\hat{P}$	Scattering phase function	(12.4)
P_r	Mass rate of rainfall per unit area	(5.18)
P_s	Mass rate of snowfall per unit area	(5.19)
q	Specific humidity-mass mixing ratio of water vapor in air	(1.10)
q^*	Saturation specific humidity	(4.28)
q_a	Specific humidity at anemometer level	(4.27)
q_s	Specific humidity at the surface	(4.27)
q_s^*	Saturation specific humidity at the surface	(4.32), (10.37)
Q	Heating or energy input	(2.1)
Q_{ABS}	Absorbed solar radiation	(10.11)
Q_{abs}	Absorption coefficient	(12.2)
Q_{ext}	Extinction coefficient	(12.2)
Q_{sca}	Scattering coefficient	(12.2)
r_{eff}	Effective particle radius	Fig. 12.9
r_p	Radius of a planet	(2.7)
r_{photo}	Radius of the photosphere of the Sun	(2.2)
R	Gas constant for air	(1.3)
R^*	Universal gas constant	Appendix D
R_a	Net radiative heating of the atmosphere per unit area	(6.1)
RH	Relative humidity = q/q^*	(4.30)
Ri	Richardson number	(4.20)
R_s	Net radiative energy input at the surface	(4.1), (4.11)
R_{TOA}	Net radiative energy input at the top of the atmosphere	(2.19), (3.59)
R_v	Gas constant for water vapor = 461 J K^{-1} kg^{-1}	(1.10), (10.9)
s	Distribution function for solar radiation	(10.12), (12.10)
$\tilde{s}$	Distribution function for solar radiation for a circular orbit	(12.8)
S_o	Total solar irradiance at the mean Earth–Sun distance (1360.8 ± 0.5 W m^{-2})	(2.7)

S_d	Solar irradiance in W m^{-2} at some distance d from the Sun	(2.4)
SH	Sensible cooling of the surface	(4.1)
SON	September, October, and November	
S_{O_3}	Heating from solar radiation absorption by ozone	(13.1)
SPCZ	South Pacific convergence zone	
$S^{\uparrow}(z)$	Upward solar flux at altitude z	(4.11)
$S^{\downarrow}(z)$	Downward solar flux at altitude z	(4.11)
T	Temperature	(1.1)
T^*	Deviation of temperature from its zonal average	(6.13)
T_A	An atmospheric temperature	(2.11), (3.39)
T_B	Temperature at the bottom of a layer of sea ice	(11.3)
T_a	Temperature of air at anemometer level	(4.26)
T_e	Emission temperature	(2.8), (3.47), (10.7)
T_i	Local emission temperature at point i	(10.46)
T_o	A reference temperature	(4.20)
T_s	Surface temperature	(2.12)
T_{eo}	Effective temperature of the land or ocean surface for heat storage	(4.3)
T_{photo}	Emission temperature of the photosphere of the Sun	(2.2)
T_{SA}	Temperature of the near-surface air	(3.53)
$T_{z_{cb}}$	Temperature of the air at the altitude of cloud base	(3.45)
$T_{Z_{ct}}$	Temperature of the air at the altitude of cloud top	(3.46)
t	Time	(3.24), (13.3)
t_o	Initial time	(10.13)
U	Internal energy	(2.1)
U	Wind speed	(4.16)
U_E	Eastward transport velocity in the oceanic Ekman layer	(7.6)
U_r	A reference wind speed	(4.18)
u	Eastward component of velocity relative to surface	(6.4)
u_E	Eastward component of current velocity in the oceanic Ekman layer	(7.6)

u_{earth}	Eastward velocity of the surface associated with Earth's rotation	(6.15)
u_ϕ	Eastward velocity air will have at any altitude ϕ, if it is zero at the equator	(6.17)
u_*	Friction velocity	(4.15)
u^*	The deviation of u from its zonal average	(6.13)
v	Northward component of velocity	(6.4)
v^*	The deviation of v from its zonal average	(6.6)
v_{E}	Northward component of current velocity in the oceanic Ekman layer	(7.5)
V	A horizontal velocity scale	(10.27)
$\vec{V}$	Horizontal velocity vector	(7.10)
V_{eff}	Variance of particle radius	Fig. 12.9
V_{E}	Northward transport velocity in the oceanic Ekman layer	(7.8)
V_{I}	Northward current velocity in the ocean interior	(7.14)
w	Vertical component of velocity	(4.22), (6.5)
w_{E}	Vertical velocity at the base of the Ekman layer	(7.10)
w_{w}	Soil water mass per unit area	(5.18)
w_{s}	Surface snow mass per unit area	(5.19)
W	A vertical velocity scale	(10.33)
W	Work	(2.1)
x	Eastward spatial coordinate and distance	(7.5)
x	Sine of latitude	(10.11)
x	A symbol for an arbitrary variable	(6.12)
x_i	Sine of latitude poleward of which perennial ice cover exists	(10.21)
y	Northward spatial coordinate and distance	(7.5), (10.26)
z	Vertical spatial coordinate and distance	(1.1)
z_{E}	Ekman depth	(7.6)
z_{o}	Roughness height	(4.17)
z_{r}	A reference height	(4.19)
z_{s}	Elevation of the surface, often zero	(3.35)
z_{cb}	Altitude of cloud base	(3.45)
z_{ct}	Altitude of cloud top	(3.46)

GREEK SYMBOLS

α	Specific volume	(1.12)
α_p	Planetary albedo	(2.7)
α_g	Albedo of bare ground	(10.48)
α_w	Albedo of white daisies	(10.48)
α_b	Albedo of black daisies	(10.48)
α_s	Surface albedo	(4.12)
β	Meridional derivative of the Coriolis parameter	(7.13)
β	Birth rate of daisies	(10.44)
β_E	Ratio of evapotranspiration to potential evaporation	(5.21)
∂	Partial differential symbol	(1.1)
δ	Solar declination angle	(2.15), (A1)
δ	γ/B ratio of horizontal transport to longwave cooling coefficients	(10.23)
$\delta^{18}O$	Normalized deviation of $^{18}O/^{16}O$ fraction from normal in ‰	(9.1)
$\vec{\nabla}\bullet$	Divergence of vector operator	(10.19)
Δ	A prefix to signify a difference	(3.58)
Δ	A prefix to signify a divergence operator	(2.21)
Δf	Runoff or divergence of horizontal water flux at and below the surface	(5.1)
Δf_a	Divergence of horizontal water flux in the atmosphere	(5.3)
ΔF_{ao}	The divergence of the horizontal transport of energy by the atmosphere and ocean	(2.21), (10.17)
ΔF_a	Divergence of horizontal heat flux in the atmosphere	(6.1)
ΔF_{eo}	Divergence of the horizontal heat flux below the surface $\approx \Delta F_o$	(4.1)
ΔF_o	Divergence of the horizontal heat flux in the ocean	(4.1)
γ	A heat exchange coefficient	(10.17)
Γ	Lapse rate	(1.1)
Γ_d	Dry adiabatic lapse rate	(1.24)
Γ_s	Saturated adiabatic lapse rate	(1.25)
$\vec{\nabla}$	Vector gradient operator	(7.11), (10.19)

ε	Emissivity	(2.6)
ε_ν	Emissivity at frequency ν	(3.28)
φ_o	A phase angle	(12.17)
φ	An azimuth angle	Fig. 3.2, (3.4)
ϕ	Latitude Earth coordinate	(2.15), Fig. 6.3
Φ	Geopotential height = gz	(10.2)
Φ	Obliquity angle	(12.8), Fig. 12.11
κ	von Kármán constant	(4.16)
η	Horizontal transport efficiency parameter	(10.51)
λ	Wavelength of radiation	(3.1)
λ	Longitude Earth coordinate	(6.4), Fig. 6.3
λ_R	A gross sensitivity parameter for climate	(10.2), (10.6)
Λ	Longitude of perihelion	(12.10), Fig. 12.11
μ	Cosθ	(3.21)
ν	Diffusivity	(7.3)
ν	Frequency of radiation	(3.1)
ν	True anomaly angle of the Earth's orbit	(12.10)
ν	Northward component of velocity on a sphere	(6.4), Fig. 6.3, (7.2)
π	Pi = 3.141592654, ratio of the circumference to diameter of a circle	(2.2)
ρ	Density of air	(1.2)
ρ_a	Density of absorber in air	(3.12)
ρ_{as}	Density of absorber in air at the surface	(3.18)
ρ_c	Density of organic matter in soil	(4.8)
ρ_o	Mean density of seawater	(7.5)
ρ_s	Density of soil material	(4.8)
ρ_I	Density of sea ice	(11.5)
ρ_w	Density of water	(4.5), (5.19)
σ	Stefan–Boltzmann constant, 5.67×10^{-8} W m^{-2} K^{-4}	(2.5)
$\sigma(x)$	The standard deviation of x	(12.17)
ρ_t	Potential density of seawater	Fig. 7.1
θ	A general zenith angle	(3.4), (3.13)
θ_s	Solar zenith angle	(2.15), (Fig. A.1)

Θ	Potential temperature	(1.20)
Θ_e	Equivalent potential temperature	(1.26)
Θ_v	Virtual potential temperature	Fig. 4.6
τ_l	A time scale for global ice volume	(12.19)
τ	Optical depth	(3.15)
τ	A time scale	(4.10)
$\vec{\tau}$	$= \vec{i}\tau_x + \vec{j}\tau_y$, Wind stress vector	(7.14)
τ_o	Surface stress	(4.15)
τ_x	Eastward component of wind stress	(7.5)
τ_y	Northward component of wind stress	(7.5)
τ_ν	Optical depth at a particular frequency ν	(3.31)
τ_R	Response time scale	(13.4)
ϖ	Single scattering albedo	(12.3)
ψ_M	Meridional mass stream function	(6.9)
ω	Angle between the Earth, the Sun and Earth's position at vernal equinox	Fig. 12.11
ω	Rate of change of pressure following an air parcel	(6.5)
ω	Solid angle	(3.4), (12.4)
Ω	The rotation rate of Earth = 7.292×10^{-5} s^{-1}	(6.15), (7.12)
χ	Death rate of daisies	(10.44)
ξ	Azimuth angle between south and the position of the Sun	(A3)
ζ_a	Vertical component of absolute vorticity = $f + \zeta_r$	(7.12)
ζ_r	Vertical component of relative vorticity	(7.12)

MISCELLANEOUS SYMBOLS

$\mathcal{T}\{z, z'\}$	Broadband slab transmissivity between altitudes z and z'	(3.35)
$[x]$	The average of x around a latitude circle, the zonal average of x	(6.7)
$\|x\|$	Absolute value of x	
$\tilde{T}$	The global average of T	(10.18)
$\overline{x}$	The time average of x	(6.8)

$\vec{\nabla} \times \vec{x}$	Vector curl of $\vec{x}$	(7.11)
%	Percent	
‰	Per thousand	
°C	Degrees Celsius temperature unit	
K	Kelvin temperature unit	
°E	Degrees east Earth coordinate	
°F	Degrees Fahrenheit temperature unit	
°N	Degrees north Earth coordinate	
°W	Degrees west Earth coordinate	
°S	Degrees south Earth coordinate	