K. Values of Physical Constants

Conservation of momentum, heat and freshwater between CSM component models requires that certain physical quantities be kept constant in time and space throughout all the component models and the Flux Coupler. To illustrate, suppose a model is integrated by a first order time scheme over two time steps from $n-1$ to $n+1$, with an incoming flux F between $n-1$ and n and an equal but opposite outgoing flux $-F$ between n and $n+1$. In the absence of all other transports, a prognostic variable, X, will change according to

$$X_{n+1} = X_{n-1} + \frac{F\ \Delta t}{\Delta z}(C_{n-1} - C_n)$$

where C is the coefficient that transforms the flux into a kinematic flux of property X. Conservation, i.e. $X_{n+1} = X_{n-1}$, is satisfied if and only if $C_n = C_{n-1}$. For X being potential temperature, $C = (\varrho C_p)^{-1}$ is the reciprocal of density times heat capacity. Although these are not in general constant, the conserved quantity is $\varrho\, C_p\, \theta$, and when θ is made the prognostic variable, $\varrho\, C_p$ is implicitly assumed constant, taken outside both time and space derivatives and divided out of all equation terms except the flux term shown above. For X being salinity in the ocean and F the flux of water of salinity S_b, C becomes $(S_o - S_b)\varrho_f^{-1}$, where conservation is satisfied for a constant ocean salinity, S_o, freshwater density ϱ_f and S_b. Thus, water fluxes of different salinities, S_b, must first be converted into an equivalent freshwater flux by multiplying by a factor $(S_o - S_b)S_o^{-1}$, before being combined into a single freshwater flux.

Similar arguments concerning heat and water fluxes back and forth across an interface with intervening lateral transport, show that the constants should also be spatially invariant. The latent heat of vaporization is another physical parameter that must remain spatially and temporally invariant. Then all heat lost from the ocean via evaporation appears at the point of condensation in the atmosphere.

The important constants in the CSM model are listed below in Table 1 along with their numerical values, which are set in the Flux Coupler. The last coefficient, C_w, is a special case because it is also used in the ice model, and must have the same value there for consistency. This constant occurs in both the Flux Coupler and sea–ice models because the determination of the ice–ocean stress is a special case in the present CSM setup, see Section G.

Table 1. Constants Set in the CSM Flux Coupler and Their Values

ϱ_a - air density	1.2 kg/m^3
C_{pa} - heat capacity of air	1005 $J/kg/K$
$(\varrho\ C_p)_a$ - air density $\times$ heat capacity	1206 $J/m^3/K$
C_{pv} - heat capacity of water vapor	1810 $J/kg/K$
C_{vir} - $(C_{pv}/C_{pa} - 1)$	0.80
Z_{vir} - $R_v/R_a - 1$	0.606
Λ_V - latent heat of vaporization	2500000 J/kg
Λ_F - latent heat of fusion	334000 J/kg
Λ_S - latent heat of sublimation	2834000 J/kg
ϱ_f - density of freshwater	1000 kg/m^3
ϱ_o - density of ocean water	1026 kg/m^3
C_{po} - heat capacity of ocean water	3996 $J/kg/K$
$(\varrho\ C_p)_o$ - water density $\times$ heat capacity	4.1×10^6 $J/m^3/K$
T_f - freezing point of ocean water	-1.8 C
S_o - salinity of ocean water	34.7 ppt
ϱ_i - density of sea-ice	905 kg/m^3
C_{pi} - heat capacity of sea-ice	2100 $J/kg/K$
$(\varrho\ C_p)_i$ - ice density $\times$ heat capacity	1.9×10^6 $J/m^3/K$
T_m - melting point of sea-ice	0 C = 273.16 K
S_i - salinity of sea-ice	4 ppt
ϱ_s - density of snow	330 kg/m^3
C_{ps} - heat capacity of snow	2090 $J/kg/K$
$(\varrho\ C_p)_s$ - snow density $\times$ heat capacity	690000 $J/m^3/K$
g - gravitational acceleration	9.80616 m/s^2
κ - von Karman constant	0.40
σ - Stefan-Boltzmann constant	5.67×10^{-8} $W/m^2/K^4$
Ω - rotation rate of the earth	$2\pi/86164$ $/s$
C_w - coefficient in ice-ocean stress	0.6524 $kg/m^2/s$