C. <u>List of the Information Exchanged</u>

To function properly the Flux Coupler must provide the inputs required by each component model, based on outputs from all the component models. The inputs are primarily fluxes which force the models and in some cases a state variable input array, $\vec{V}$. The outputs are primarily state variable arrays, $\vec{W}$. Some fluxes are computed by the component models themselves and output to the flux coupler for dissemination to other component models. The purpose of this section is to specify the inputs and outputs exchanged between the coupler and the component models. The flux calculations and exchanges are complicated, as illustrated by the schematic, Fig. 1. In this flux flow diagram, outputs are shown as arrows away from the component models or interfaces, diamond symbols denote partitioning of the fluxes among component models, flux computations by the coupler are represented by circles and encircled crosses indicate that fluxes are combined. The formulae used to compute the fluxes in the coupler are given in Section F. The exchange of state variables is not shown in Fig. 1.

For the present only four component models are to be coupled and these are denoted (*e.g.*, Fig. 1) as follows:

$$\begin{aligned} &\mathrm{A - Atmosphere\ (a)} \\ &\mathrm{C - Cryosphere\ (Sea - Ice,\ i)} \\ &\mathrm{B - Biosphere\ (Land,\ l)} \\ &\mathrm{H - Hydrosphere\ (Ocean,\ o)} \end{aligned}$$

At present the biosphere component is imbedded within the atmospheric model. In this configuration the latter acts as a passive conduit for information exchange between the coupler and the biosphere.

We first specify the inputs to each component model (Subsections *I, II, III* and *IV*), then give the outputs required from each component (Subsections *V, VI, VII* and *VIII*). With no biosphere–cryosphere exchanges, contributions to these inputs and outputs come across the following five interfaces (Fig. 1) :

$$\begin{aligned} &1\ -\ \mathrm{Atmosphere - Cryosphere} \\ &2\ -\ \mathrm{Atmosphere - Biosphere} \\ &3\ -\ \mathrm{Atmosphere - Hydrosphere} \\ &4\ -\ \mathrm{Cryosphere - Hydrosphere} \\ &5\ -\ \mathrm{Biosphere - Hydrosphere}\ . \end{aligned}$$

In order to be consistent with the convention that incident solar radiation is positive, all fluxes will be defined as positive downwards. That is, a positive flux of any quantity across an interface acts to increase the value of that quantity in the layer below that interface. For example, the freshwater flux components, precipitation, P, and evaporation, E, are positive and negative, respectively and the wind stress, $\vec{\tau}$, is positive over both ocean and land.

I. Inputs to the Atmosphere

I.a Fluxes (upward arrows into A, Fig. 1)

Flux inputs to the atmosphere have contributions from the three surfaces (1, 2 and 3) below it. Flux coupler calculations of these fluxes are represented by the four circles below A in Fig. 1.

$\vec{\tau}_A$, > 0, the surface drag on the bottom of the atmosphere. Given as zonal, τ_A^λ, and meridional, τ_A^φ, components.

H_A, the sensible heat flux.

$L\uparrow_A$, < 0, the emitted upward longwave radiation.

E_A, < 0, the evaporative water flux, proportional to the latent heat flux.

LH_A, < 0, the latent heat flux, proportional to E_A, and therefore not shown in Fig. 1.

I.b The input state variable array $\vec{V}_A$

$\vec{\alpha}_A$, a four element array containing the effective surface albedos for visible direct, α_V (dir), and diffuse, α_V (dif), radiation, and for near-infrared direct, α_I (dir), and diffuse, α_I (dif), radiation.

T_A, surface temperature, averaged over the underlying interfaces. Note, T_A, should not be necessary as an atmospheric input and should be removed from the fields to be passed in the future.

I.c Future Atmosphere Inputs

$\vec{\tau}_G$, the gravity wave momentum flux due to sub–gridscale orographic variance.

II. Inputs to the Hydrosphere

II.a Fluxes (downward arrows into H, Fig.1)

$\vec{\tau}_H$, the surface stress on the top of the ocean due to both the wind and relative sea-ice movement, given as zonal, τ_H^λ, and meridional, τ_H^φ, components. It is the vector sum of two flux coupler calculations: the atmospheric stress across interface (3) and the ice-ocean stress across interface (4). In Fig. 1, such summations are represented by encircled crosses.

S_H, the net (after reflection) solar radiation directly from the atmosphere plus any solar radiation penetrating through the sea-ice interface (4).

H_H, the net non-solar surface heat flux exchanged with the atmosphere and the cryosphere. It has many contributors, as illustrated by the 3 summations below interface 3 in Fig.1. These are the sensible and latent heat fluxes across interface 3, the net longwave radiation ($L\uparrow_3 + L\downarrow_3$) across interface 3, and the net heat flux across interface 4, H_4, which includes the cooling due to snow and ice melt, but not due to the freezing of sea water, which is an output, Q_4, of the hydrosphere (see Section F and Section H of the Technical Note on the CSM ocean model).

F_H, the net surface flux of freshwater. Its components are the evaporation, E_3, the total of convective and large scale rainfall and snowfall, P_3, and the melting of cryosphere ice and snow, F_4, plus runoff from the biosphere, F_5. As for H_H above, it does not include the freshwater flux due to ocean water freezing (see Section F and Section H of the Technical Note on the CSM ocean model).

III. Inputs to the Cryosphere

III.a Fluxes (arrows pointing towards C, Fig. 1)

$\vec{\tau}_C$, $= \vec{\tau}_1$ - $\vec{\tau}_4$, the vector difference between the wind stress on the ice minus the stress of the ice on the underlying water, as represented by the encircled cross inside of area C in Fig. 1. Also see Section G.

S_1, > 0, the net (after reflection) solar radiation penetrating the snow/ice surface.

H_1, the sum of the latent and sensible heat fluxes and the downward long-wave radiation exchanged with the atmosphere.

$L\uparrow_1$, < 0, the upward long-wave radiation emitted to the atmosphere. The surface energy balance calculation of surface ice temperature in many ice models requires that this flux remain separate from H_1.

Q_H, $= Q_4$, the net heat exchange (and implied water flux) between the ice and ocean due to ocean freezing (> 0), or the potential heat available in the upper ocean to melt sea-ice (< 0) (see Section F below and Section H of the Technical Note on the CSM ocean model).

F_1, the snowfall (presently all convective and large scale precipitation) onto the ice/snow surface, plus the evaporation of snow and ice.

H_4', $= H_3 + S_3$, the total surface heat flux through the atmosphere–hydrosphere interface (3). This flux is needed by some ice models to control the rate of lateral ice growth into leads.

III.b The input state variable array $\vec{V}_C$

$\vec{\nabla}\eta$, the sea-surface slope.

dH_1, the derivative of H_1 with respect to T_1. Used in energy balance determination of T_1.

IV. Inputs to the Biosphere

All inputs are for the future as the land model is presently part of the atmospheric model and has access to all atmospheric fields.

IV.a Fluxes (downward arrows at interface 2, Fig. 1)

S_B, the net (after reflection) solar radiation across interface 2.

$\vec{I}_B$, a four element array containing the four components of incident (before reflection) downward solar radiation (direct and diffuse visible, and direct and diffuse near-infrared).

$L\downarrow_B$, the net downward longwave radiative flux across interface 2.

$\vec{P}_B$, the precipitation onto the biosphere in two components: Pc_B, the convective precipitation, and Pl_B, the large scale precipitation.

IV.b The input state variable array $\vec{V}_B$

This array contains complete information on the state of the atmosphere needed for the computation of atmosphere-biosphere fluxes, such as $\vec{\tau}_2, H_2, E_2$ and the runoff, F_5, within the biosphere component model. It is comprised of the complete atmospheric output state variable array $\vec{W}_A$ listed below in subsection V, with the exception of air density.

V. Atmospheric Model Outputs

V.a The output state variable array $\vec{W}_A$

Z_A, the height of the first atmospheric level.

$\vec{U}_A$, the wind velocity at the first atmospheric level.

θ_A, the potential temperature at the first atmospheric level.

q_A, the specific humidity at the first atmospheric level.

ρ_A, the air density at the first atmospheric level.

B_A, the barometric pressure at the first atmospheric level.

B_S, the surface barometric pressure.

V.b Flux outputs from the atmosphere (downward arrows from A, Fig.1)

S_A, the net (after reflection) solar radiation at the bottom of the atmosphere.

$\vec{I}_A$, four components of incident downward solar radiation: direct and diffuse visible, and direct and diffuse near-infrared.

$L\downarrow_A$, the downward longwave radiation at the bottom of the atmosphere.

$\vec{P}_A$, a two component precipitation array consisting of Pc_A, the convective precipitation at the bottom of the atmosphere, and Pl_A, the large scale precipitation at the bottom of the atmosphere.

V.c Future outputs from the atmosphere

P_S, the precipitation falling as snow (may not include snowfall explicitly, in which case the Flux Coupler may compute snowfall over ice from Pc_A, Pl_A, and θ_A).

$\alpha_a(dif)$, the albedo of the atmosphere as seen by upwards diffuse shortwave radiation.

VI. Hydrospheric Outputs

VI.a The output state variable array $\vec{W}_H$

T_H, the sea surface temperature.

$\vec{U}_H$, the zonal and meridional components of the first layer water velocity.

$\vec{\nabla}\eta$, the sea-surface slope.

VI.b Fluxes (upward arrow out of H, Fig. 1)

Q_H, $= Q_4$ the cumulative heat of fusion (and implied water flux) if any sea-ice is formed (> 0) or the potential to melt sea-ice if ice is present (< 0) (see Section F and Section H of the Technical Note on the CSM ocean model).

VI.c Future outputs from the hydrosphere

$\vec{\alpha}_H$, the ocean albedos for direct, α_H(dir) and diffuse, α_H(dif) solar radiation, respectively. Both albedos have two components: for visible and near–infrared wavelengths. These values are presently constants and set in the Flux Coupler.

VII. Cryospheric Outputs

VII.a The output state variable array $\vec{W}_C$

$\vec{U}_C$, the two components of ice velocity.

T_C, the ice surface temperature.

f_C, the ice concentration as a fraction.

$\vec{\alpha}_C$, the sea-ice albedos for direct α_C (dir) and diffuse, α_H (dif) solar radiation, respectively. Both albedos have two components: for visible and near-infrared wavelengths.

d_C, the snow depth (or flag) which can be used to compute the final albedos.

VII.b Fluxes (downward arrows at interface 4, Fig. 1)

S_4, > 0, the solar radiation passing through the ice and into the hydrosphere below.

H_4, < 0, the heat flux into the hydrosphere due to snow/ice melt in response to upper layer ocean temperatures above freezing as communicated by $Q_H = Q_4 < 0$. Note, unless all the ice and snow melts, $H_4 = Q_4$.

F_4, > 0, the water flux into the hydrosphere due to snow/ice melt associated both with H_4 above and with atmospheric heating and rainfall. The H_4 contribution becomes $B_4 = B_H$, the net flux of brackish water with the salinity of sea–ice $= S_I$, for $S_I \neq 0$.

VIII. Biospheric Outputs

All outputs are for the future, as the land model is presently part of the atmospheric model and has access to all atmospheric fields.

VIII.a The output state variable array $\vec{W}_B$

T_B, the surface temperature.

$\vec{\alpha}_B$, the terrestrial albedos for direct α_B (dir) and diffuse, α_B (dif) solar radiation, respectively. Both albedos have two components: for visible and near-infrared wavelengths.

d_B, snow depth over land.

VIII.b Flux outputs from the biosphere

$\vec{\tau}_B$, the surface drag of the biosphere on the atmosphere. Given as zonal, τ_B^λ, and meridional, τ_B^φ, components.

H_B, the sensible heat flux.

LH_B, the latent heat flux.

E_B, the evaporative water flux, proportional to the latent heat flux.

$L \uparrow_B$, the emitted upward longwave radiation (not shown in Fig. 1).