E. Spatial Coordination of the Fluxes

Two component models interacting through one of the interfaces will generally not have the same horizontal resolution or identical grid layout. The system is designed such that the interfaces are usually defined using the finer of the two component model's resolution, though this needn't always be the case. Thus, output state variables required for flux computations on the interface and output fluxes from the coarser component model will need to be interpolated onto the interface grid.

Different interpolation schemes can be used for different variables. At present only bi-linear interpolation is available. This allows the user to select an interpolation method that maintains certain desirable physical properties of the particular field being interpolated. For example, it may be important to maintain continuity of derivatives in interpolation of the surface wind field in order to produce a smooth wind stress curl distribution to force the ocean model with. On the other hand it is desirable to maintain exact conservation of energy in interpolation of downward radiative fluxes. Which scheme to use is specified on a field by field and interface by interface basis. In the following sections, an output state variable or flux that has been interpolated onto an interface grid is denoted with braces, *e.g.*, $\{G\}_{IJ}^{m}$ indicates that output flux G has been interpolated from the component model grid to interface $m = 1,\ 5$, see Fig. 1.

Two phases called averaging and merging, are distinguished both conceptually and computationally. The first is spatial averaging between the interface resolutions and the component model grid resolutions. The second is merging across the collection of interfaces contributing to the total flux entering a component model. This provides for a simple and flexible treatment of both disparate component model resolutions and subgrid scale heterogeneity on the fine or coarse grids.

Consider first averaging between grid resolutions. In the following, variables subscripted by upper case letters refer to quantities on the component model grid (which will be the same resolution as or coarser than the interface grid), and variables subscripted by lower case letters refer to quantities on the interface (fine) grid. For each interface type m contributing to the total input flux into a component model grid cell I, J (see Figure 2), the flux on the interface grid G_{ij}^{m} is averaged over the area of that interface within the component model cell,

$$[G]_{IJ}^{m} = \frac{\sum_{i\in I}\sum_{j\in J} G_{ij}^{m}\, c_{ij}^{m} dx'_i\, dy'_j}{\sum_{i\in I}\sum_{j\in J} c_{ij}^{m}\, dx'_i\, dy'_j}$$

or

$$[G]_{ij}^{m} = \frac{1}{dA_{ij}^{m}} \sum_{i\in I}\sum_{j\in J} G_{ij}^{m}\, c_{ij}^{m}\, dx'_i\, dy'_j$$

where

$$dA_{IJ}^{m} = \sum_{i\in I}\sum_{j\in J} c_{ij}^{m}\, dx'_i\, dy'_j$$

is the surface area within the component model cell occupied by the interface of type m. The quantity c_{ij}^m is the areal fraction of each *interface (fine) grid* cell under consideration occupied by interface type m. For example, this could represent sea ice concentration or be used to mask out land areas on an ocean model grid. The notation $i \in I$ indicates that an interface grid cell at index i is at least partially contained within a component model grid cell of index I, and similarly with j and J. The interface grid cells can span the boundaries of component model grid cells. The notation indicates the fraction in the x-direction of interface grid cell i contained within component model grid cell I. Referring to Figure 2

$$dx_i' = \min\ (X_{I+1}, x_{i+1}) - \max\ (X_I, x_i)$$

and similarly for dy_j'. In the case of spherical coordinates, the y-dependent weights are given by

$$dy_j = \sin\,(\phi_{j+1}) - \sin\,(\phi_j) \simeq \cos\,\left(\phi_{j+1/2}\right) d\phi_j$$

In the second phase called merging, the set of M spatially averaged fluxes $[G]_{IJ}^m$ on the component model grid are combined, or merged, into the total flux to be passed to the model.

$$G_{IJ} = \sum_{m=1}^{M} f_{IJ}^m\, G_{IJ}^m$$

where f_{IJ}^m is the *fractional* area of component model grid cell I, J occupied by surface interface type m:

$$f_{IJ}^m = \frac{dA_{IJ}^m}{dA_{IJ}}$$

and by definition

$$\sum_{m=1}^{M} f_{IJ}^m = 1.$$

If the component model domains partially overlap, then this last relation can be used to define one of the weights in terms of the others and force the correct normalization. For example, if the land surface model and ocean model do not use precisely the same land-ocean distribution, the weight for the land contribution to the flux can be based on the ocean model land-distribution, or *vice versa.*

Calculating the Atmospheric Inputs

The atmospheric inputs can have contributions from any or all of the ocean, sea ice or land surface interfaces. Let G_A be any of the atmospheric flux inputs $\vec{\tau}_A, E_A, H_A$, or $L\uparrow_A$ of section C. For the basic case being considered, the atmosphere has the coarsest spatial resolution and the fastest time scale. In this situation no temporal averaging is required, but the fluxes from each interface must be averaged spatially and merged. Thus, the atmospheric input is given by

$$G_A = f^1_{IJ}\,[G]^1_{IJ} + f^2_{IJ}\,[G]^2_{IJ} + f^3_{IJ}\,[G]^3_{IJ}$$

When, as in the initial configuration, the atmosphere and land surface process models are on the same grid, no averaging is required on that interface $[G]^2_{IJ} = G^2_{ij}$. Note that the land fraction f^2_{IJ} is time invariant, while the ocean f^3_{IJ} and sea ice f^1_{IJ} fractions will vary in time with the evolution of the sea ice distribution. Also note that the scheme can easily handle sub-grid-scale heterogeneity of land surface types by replacing $f^2_{IJ}\,[G]^2_{IJ}$ with a set of weights and fluxes for each land surface type.

Calculating the Hydrospheric Inputs

Let G_H be any of the hydrospheric inputs $\vec{\tau}_H, S_H, H_H$, or F_H, specified in Section C. With the exception of runoff, hydrospheric fluxes come across the ocean-atmosphere interface (3) or the ocean-ice interface (4). The net flux into the ocean is given by

$$G_H = f^3_{IJ}\,G^3_{IJ} + f^4_{IJ}\,G^4_{IJ}$$

As in the case of sea ice, there are typically multiple contributions to an interface flux (combining operations in Fig. 1), so each flux is written out explicitly.

$$\begin{aligned}
\vec{\tau}_H &= f^3_{IJ}\,[\vec{\tau}]^3_{IJ} + f^4_{IJ}\,[\vec{\tau}]^4_{IJ} \\
S_H &= f^3_{IJ}\,\{S\}^3_{IJ} + f^4_{IJ}\,\{S\}^4_{IJ} \\
H_H &= f^3_{IJ}\left([H]^3_{IJ} + \Lambda_E\,[E]^3_{IJ} + \Lambda^*_F\,[P_S]^3_{IJ} + \{L\}^3_{IJ}\right) + f^4_{IJ}\,[H]^4_{IJ} \\
F_H &= \left(f^3_{IJ} + f^4_{IJ}\right)\{P_S\}^3_{IJ} + f^3_{IJ}\left(\{P\}^3_{IJ} + [E]^3_{IJ}\right) + f^4_{IJ}\,[F]^4_{IJ} + \{F\}^5_{IJ}
\end{aligned}$$

where $\{F\}^5_{IJ}$ is the continental runoff into an ocean model grid cell. Again, in the most common circumstance, the ocean model, sea–ice model and both the atmosphere–ocean and sea ice-ocean flux interface grids will be identical. Under these circumstances, $f^4_{IJ} = c_{ij}$, the sea ice concentration, $f^3_{IJ} = 1 - c_{ij}$, the open water fraction, and no spatial averaging of interface fluxes is required.

Calculating the Cryospheric Inputs

The sea–ice model receives fluxes across interfaces with the ocean and atmosphere. The physical types of the fluxes across the two interfaces are generally of different types however, so they are written out explicitly.

$$
\begin{aligned}
\vec{\tau}_C &= f^1_{IJ}\,[\vec{\tau}]^1_{IJ} + f^4_{IJ}\,[\vec{\tau}]^4_{IJ} \\
S_C &= f^1_{IJ}\,\{S\}^1_{IJ} \\
H_C &= f^1_{IJ}\left([H]^1_{IJ} + \Lambda_S\,[E]^1_{IJ} + \{L\}^1_{IJ}\right) \\
L{\uparrow}_C &= f^1_{IJ}\,[L{\uparrow}]^1_{IJ} \\
F_C &= f^1_{IJ}\left([P_S]^1_{IJ} + [E]^1_{IJ}\right) \\
H'_4 &= f^3_{IJ}\left([H]^3_{IJ} + \Lambda_E\,[E]^3_{IJ} - \Lambda^*_F\,[P_S]^3_{IJ} + \{L\}^3_{IJ} + \{S\}^3_{IJ}\right) \\
Q_C &= [Q_H]_{IJ}
\end{aligned}
$$

In the most common case, the ice model, the ocean model, and the ice–atmosphere interface will be on the same grid. Under these circumstances $f^1_{IJ} = f^2_{IJ} = c_{ij}$, the ice concentration, and $f^3_{IJ} = 1 - c_{ij}$ is the open water fraction. The latent heating of vaporization, sublimation and atmospheric snow or ice formation are $\Lambda_V,\ \Lambda_S,\ \Lambda^*_F$, respectively, see Table 1. The sums on the right sides of these expressions are combining operations indicated by a circumscribed x in Fig. 1.

Calculating the Biospheric Inputs

The inputs to the biosphere specified in Section C are all atmospheric model variables, which are passed by the Flux Coupler to the biosphere.