5.7.3 Overland flow module [addendum]

Surface Water Raster Flux Module Description

ELM v2.5 Documentation Report (July 2006). p. 5-90. Starting with paragraph #2 of section:

[paragraph #2] The flow between two adjacent cells is determined from a simplification of the well-known open channel, diffusion flow model in an explicit, finite-difference framework. Omitting any inertial or acceleration terms, the continuity equation is simply a two-dimensional flux driven by differences in slope of the water surfaces. The flux between a pair of grid cells in the model domain's array is described by the empirical Manning's equation for overland flow:

$$Q = \frac{D^{\frac{5}{3}} L^{\frac{1}{2}} \Delta h^{\frac{1}{2}}}{n} \qquad \text{Eqn 1}$$

where Q is the volumetric flow velocity ($m^3\ d^{-1}$), D is the water depth (= hydraulic radius, m) above ground elevation, L is the length of a grid cell (m), Δh is the difference (m) in water stage between the source and destination cells, and n is the empirically-derived Manning's roughness coefficient. Using an explicit numerical method, the solution is iterated in both the row-wise and the column-wise directions during each time step, the direction alternates (east-west and west-east, north-south and south-north) after each time step. This Alternating Direction Explicit solution minimizes the directional bias that is associated with a uniform- direction solution. Constraints for stability and mass balance are imposed on the calculated flux during each time step, preventing head reversals or flows greater than the volume available in the donor grid cell. The mass of constituents (nutrients, salt/tracer) is passed along in a mass-balance calculation based upon the water volume flux between cells.

[Dispersion: new text starts below]

Calculations of dispersive flux of constituents takes advantage of the properties of the numerical dispersion that is a known property of finite difference solutions. The approach is analogous to that described for the WASP water quality model (Wool et al. in press), in which the advection term of the water flows is adjusted to decrease or increase the dispersive flux of constituents, for a resultant combined advective and dispersive mass transfer among grid cells.

The (horizontal) flow velocity u ($m\ d^{-1}$) of water among grid cells is determined by:

$$u = \frac{Q}{L \cdot D} \qquad \text{Eqn 2}$$

where Q, L, and D are given previously (and L · D is the interfacial area of flow).

Numerical dispersion associated with the solution method (reference in Wool et al. in press) is calculated by:

$$disp_{num} = 0.5 \cdot u \cdot \left(L - u \cdot sfstep\right) \qquad \text{Eqn 3}$$

where *sfstep* is the horizontal solution's time step (days). Numerical dispersion is a non-linear function of velocity, and increases with increasing grid size, while decreasing with

longer time steps. Using this equation, numerical guidelines for selection of the *sfstep* in the expected velocity regimes of the Everglades[1] were demonstrated in Figure 7.5.1 of the ELM v2.5 documentation: the *sfstep* is chosen for each scale of application to maintain a similar trade-off between decreased numerical dispersion and increased Courant λ (with theoretical instabilities in the solution when λ > 1.0) for the Everglades applications.

The estimate of numerical dispersion is then used to adjust the velocity term. In this step, the numerical dispersion component of potential constituent flux is removed by:

$$u_{adj} = \frac{\left(u \cdot L - disp_{num}\right)}{L} \qquad \text{Eqn 4}$$

such that u_{adj} is the velocity (m d^{-1}) adjusted to represent that associated with potential advection of constituents, without the influence of potential numerical dispersion. (Note that the transfer of water volume/mass is not affected by any part of these dispersive flux calculations).

The u_{adj} is then put into the form of a water volume potential:

$$Flux_{adj} = Parm_{agg} \cdot u_{adj} \cdot D \cdot L \qquad \text{Eqn 5}$$

where $Flux_{adj}$ is the volume (m^3 d^{-1}) of potential water flow that is specific to advective transfer of constituents, and $Parm_{agg}$ is a positive or negative, dimensionless parameter that includes the dispersion number, and a grid scale conversion[2]. This parameter is calculated by:

$$Parm_{agg} = \left(1 - \frac{l_{disp}}{L}\right) dispParm \qquad \text{Eqn 6}$$

where l_{disp} is the dispersion mixing length (m), and *dispParm* is a calibration parameter (set to 1.0 in ELM v2.5).

In determining the actual mass of constituent to flux from cell to cell, the total Flux volume is compared to that representing advective transfer of constituents:

$$P = \frac{\left(Q - Flux_{adj}\right)}{D \cdot L \cdot L} \cdot sfstep \qquad \text{Eqn 7}$$

where *P* (dimensionless) is the proportion of the total available (donor) water volume that will be associated with constituent flux. The available (donor) constituent mass is multiplied by that proportion for cell-cell flux, thus completing the constituent mass

[1] Generally << 5 cm sec^{-1}, as discussed in the ELM v2.5 Documentation Report, Uncertainty Chapter 7.

[2] A bug was found in the implementation of this aggregated parameter in ELM v2.5, resulting in the definition of the use of the l_{disp} (GP_dispLenRef) parameter in the GlobalParms database to be incorrect. The aggregated parameter does not "auto-scale" the dispersion among different grid applications, which was the original intent. The actual implementation of this parameter in ELM v2.5 leads the model to scale the amount of dispersion as the ratio of the GP_dispLenRef length to the grid cell length, as described in this section. The amount of dispersion in the regional (1km grid length) ELM v2.5 (Model Performance Chapter 6) was of the intended magnitude, reducing the potential numerical dispersion in the 1km grid. This bug was found during the quality-control tests of the multi-grid scale implementations of the century-scale perturbation experiments, during the 2006 ELM Peer Review.

advection and dispersion flux for a time step. Note that if the $Parm_{agg}$ is equal to 0.0, no correction to numerical dispersion occurs; a negative $Parm_{agg}$ increases the simulated dispersion, while a positive parameter value decreases simulated dispersion.

To demonstrate the use of the parameters to scale the magnitude of actual dispersion in ELM applications, we used a simple subregional domain for a 250 m and a 1 km grid application[3]. A series of Indicator Regions (Figure 1a) were established along a gradient of decreasing elevation (NorthNW to SouthSE), in order to monitor the mass of a conservative tracer along the primary flow path of the simulated system(s). (The mass of the tracer was summed within the multiple grid cells of each Indicator Region). In both applications, the system was inoculated with an initial tracer concentration in the surface water of a 1 km^2 region near the high-elevation (northern) boundary (Figure 1b). With no (northern) water inflows to the domains, the systems had significant water outflows in the downslope, SouthSE section of the domain, inducing the landscape flows. Flows of the tracer mass were monitored on a daily basis as they transited through the Indicator Regions and exited the model domain.

The l_{disp} was set to ½ of the grid cell length in both applications (500 and 125 m for the 1 km and 250 m applications, respectively), to match the dispersion length used in the regional (1 km grid) ELM v2.5 application. (Note that, as explained above, the parameter definition incorrectly implies a dispersion mixing length; to strive for consistency/clarity, we maintained the terminology as defined in the ELM v2.5 documentation). The simulation was run for three months. At the end of the simulation, 41.1% of the original mass of tracer remained in the 250 m grid domain, while 47.9% remained in the 1 km grid domain. Given that the fine scale application was 16x finer resolution relative to the 1 km application, this difference of approximately 7% was indicative of effective control of numerical dispersion that will be present to some degree in any "large" grid. In the 1 km grid application, no adjustment for numerical dispersion (l_{disp} = grid width) resulted in 22.1% of the original mass remaining (or approximately half that under the lower dispersion implementation).

For the finer-scale, 250 m application, we performed a series of model experiments in which we modified the l_{disp} parameter to double- and half- that of the 250 m grid length (and width), in order to demonstrate the effect of altering the simulated dispersive flux. Water velocity varied in time and space in the model, but was on the order of 0.5-1.0 cm/sec, representing moderately high velocities for the present day Everglades landscape. In comparing the model experiments, the time at which the maximum tracer mass was found in each Indicator region was used as a quantitative indicator of the difference in dispersion under each parameter set (Figure 2). The time for the maximum mass to be attained in Indicator Region 16 was 17 d, 25 d, and 34 d for the l_{disp}= 500, 250, and 125 m, respectively. Thus, if the magnitude of actual dispersion becomes better understood (quantified) in these vegetated wetlands (see Uncertainty Chapter 11), the dispersion fluxes in ELM can be further refined through appropriate parameter adjustments.

[3] Further information on the data behind this subregional application is provided in the Perturbation Experiments Chapter 11 (November 2006 addendum to July 2006 ELM Documentation Report).

Literature cited

[includes only the references used in this Addendum]

Wool, T. A., R. B. Ambrose, J. L. Martin, and E. A. Comer. *in press*. Water Quality Analysis Simulation Program (WASP) Version 6.0 Draft: User's Manual. US Environmental Protection Agency - Region 4, Atlanta, GA

Figures

Two figures follow.

Figure 1. The model experiments were conducted in a 10x10 km subregion (in common with the Chapter 11 Model Perturbation experiments). The Indicator regions (a) used to monitor the tracer mass followed the downslope elevation gradient. A 1 km^2 area (b) was inoculated with an initial concentration (green-yellow) of conservative tracer in the ponded surface water. A snapshot of the (yellow) surface water tracer concentration (c) in the 250 m and 1 km grid applications after 25 days of simulation provides a visualization of the relative differences in dispersal at the two grid scales.

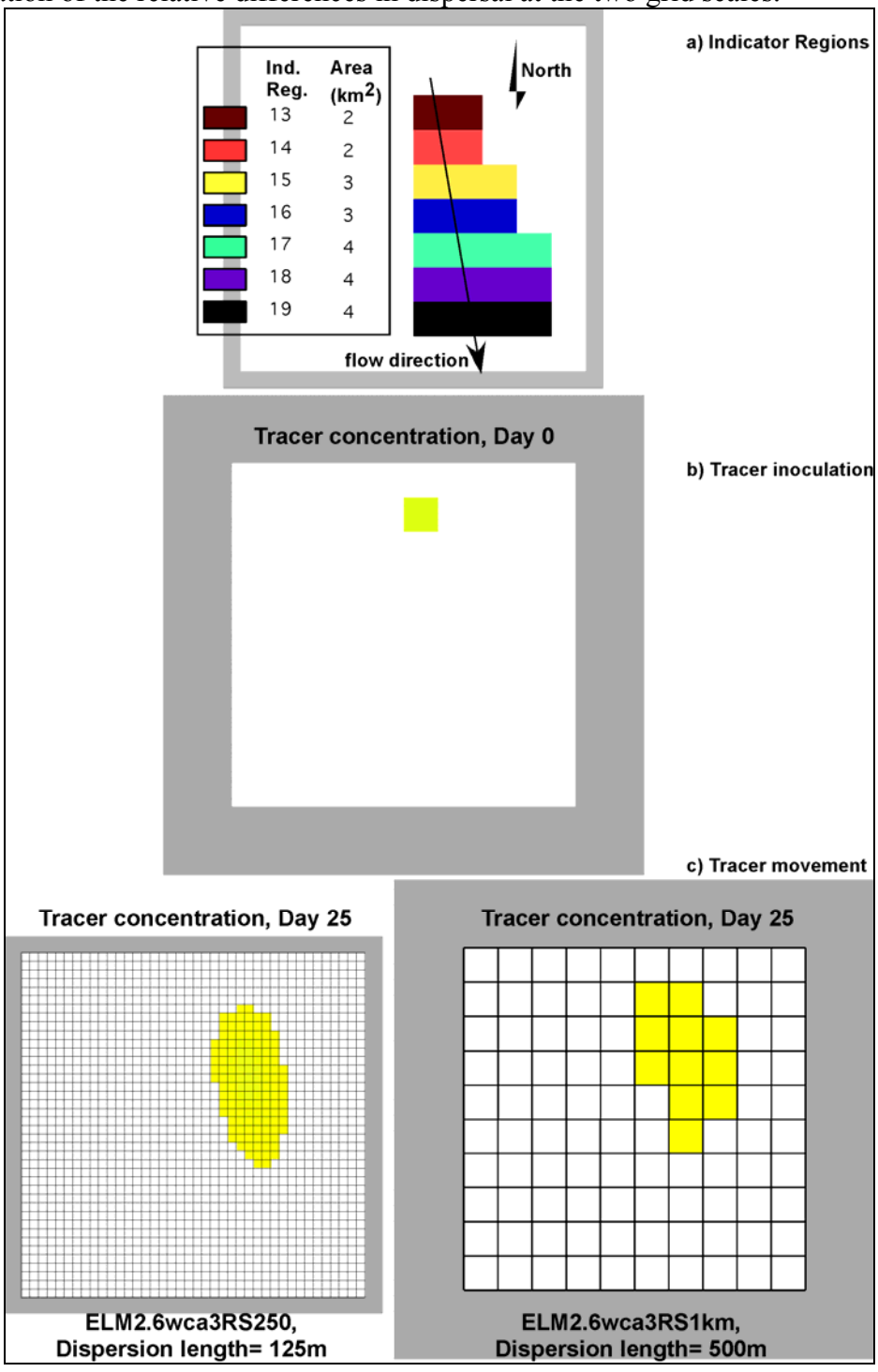
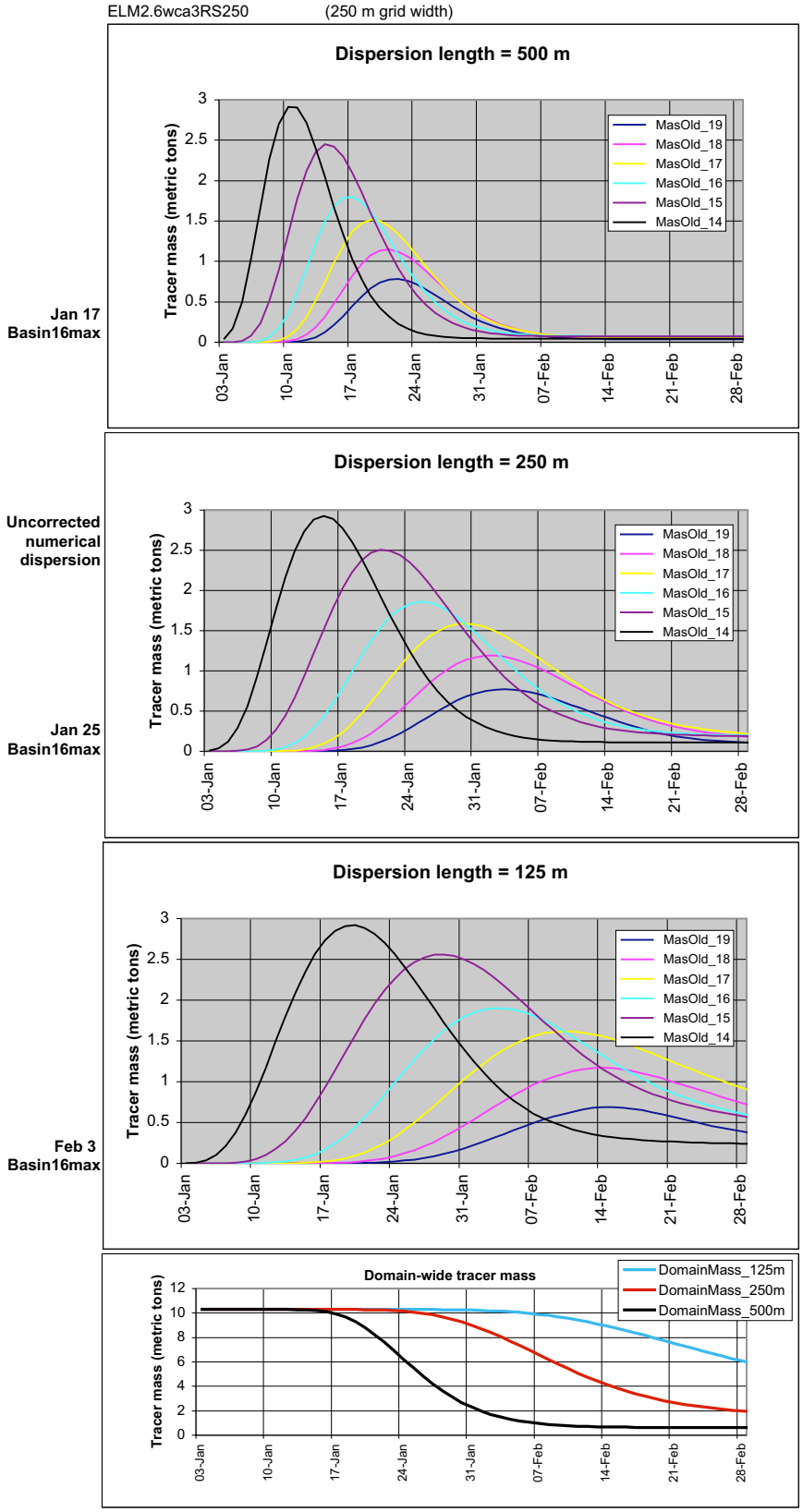


Figure 2. Time series plots of tracer mass in each Indicator Region, for three different values of the "dispersion length" parameter in the 250 m grid application, simulated from Jan 1 - Mar 31.
See the text and Figure 1 for details.



Note that the Indicator Regions are large enough that they encompass most of the mass of the tracer that advects and disperses downstream, regardless of the parameter chosen for scenario.

Mass balance error:
0.0 nanograms/m^2 cumulative error in each Indicator Region, & entire doman