Model Name: REALM

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Suite under development:
REALM-2D: hydrodynamics and transport (in testing)
PTM: Particle tracking (in testing)
NCC: Multi-constituents with kinetics (2009)
Oprule: Model steering (2009-2010)
REALM-1D: More efficient 1D channelized regions (2010)
Real-time data assimilation (2010-2011)
Moving embedded boundary capability (2011)
REALM-3D (inferred z-momentum hydrodynamics and transport) (2011)

Purpose:
REALM is a model for simulation of hydrodynamics, transport and particles. Our focus is on water project planning and operation, water quality, South Delta flow/surface regulations, planning and operation of hydraulic structures and impacts on fish. We focus on the multi-scale problems encountered by DWR:

1. Planning over long hydrologic periods.
2. Coarse scale impacts over the full extent of the Bay-Delta.
3. Focal modeling on sub-regions such as intakes or complex mixing zones or a flooded island.
4. "What-if" scenarios, particularly involving climate change, new structures and major flooding events.

The initial REALM release is 2D and uses high performance (parallel), adaptive techniques to negotiate tradeoffs between the above objectives. Future releases will streamline treatment of 1Dchannelized areas and provide 3D in regions of stratification or secondary currents.

Anticipated strengths:
Accuracy: The current solver features accurate propagation speeds of tides and rapid inflow changes, which are hard to model with existing, high-CFL methods.
Geometry: We incorporate LIDAR and bathymetry data at very high resolution compared to the computational grid. Our data set will be released in the latter part of 2009.
Performance: The REALM model is built atop Chombo, a $20M computational infrastructure library tested in parallel applications involving thousands of processors. We do not pay much of the cost of scaling our work. Since the beginning of work, the availability of processors has grown by an order of magnitude -- our anticipated resources have changed from 32 to 256 processors.
Data assimilation: We are collaborating with UCB to incorporating Eulerian sensor and Lagrangian drifter observations into the model while it runs. This capability will provide a model that is "always running" and agrees well with field measurements.
Project connectivity: The Chombo Adapted Mesh infrastructure is under consideration for inclusion to the Earth Sciences Modeling Framework and development of free

visualization tools are supported by a multi-million dollar open source project at Lawrence Livermore National Lab.
Climate change: The embedded boundary grid can move, and is extensible to problems (sea level rise, flooding) involving accurate evolution shape of the boundary.
Flooded Islands (extension): The model has numerous advantages for modeling the initial stages of island flooding. The moving embedded boundaries can track the front of water onto the island and the numerical scheme can more accurately model how the water travels over a dry bed. The transmission of the event downstream (drawing in salt from the Bay) can also be expected to be more accurate.

Weaknesses:
Readiness: Model is in progress and not verified to IEP standards.
Performance: Currently, the time step restriction on small channels limits the 2D solver to small time steps when small channels are resolved.

Graphic interface:
REALM has an ARC-GIS interface that currently has these capabilities:

1. Map visualization and bathymetry database in 2D and 1D
2. Cross-section development in 1D
3. Import and export of bathymetry into model format
4. Limited exchange with HDF5

And our current agreements over the next year will include:

1. Visualization of embedded boundary adaptive mesh data from HDF5.
2. Flow, surface and quality information.
3. Drawing of hydraulic structures and interior boundaries.
4. Visualization of particle travel and summary of fluxes.

Inputs:
Velocity boundary conditions, tidal water surfaces, source/sink flows, initial conditions of all modeled parameters, friction coefficient, dispersion coefficient. We are currently attempting to implement friction and dispersion as non-spatially varying to reduce model parameterization.

Output formats:
Full domain: HDF5 with the Chombo Adaptive Mesh Refinement data over the full domain. Chombo uses IO in HDF5, the most widely used output format in high performance computing. A free tool (VisIt) is available from Lawrence Livermore National Laboratory for animation of results, and we are developing an ARC-GIS interface. Matlab, Tecplot and Python also access HDF5.
Point data: NetCDF-4 (using the parallel HDF5 backend)
Particles: Particle output uses a trace file in HDF5, which can also be animated in VisIt.

Spatial Extent and Resolution:
This is a new model and the spatial extent is expanding rapidly. We have applied it to Bay-Delta domains from several km outside the Golden Gate to just upstream of Frank's Tract. In our prototype application, typical cell sizes range from 800m outside Golden Gate to 4-800m in Bays, 200m near Suisun Bay and confluence and 50m-100m upstream. The model is slower at higher resolutions, motivating methods to do coarse-grain modeling in channelized regions faster.

Platform: Linux, Windows (Cygwin) for solver. ARC-GIS/Windows for interface.

Developers and project scope:
DWR: 1 full time developer (Qiang Shu) plus project design and management (Eli Ateljevich), allocation for 1-2 members of staff for applications and particles.
LBL: 1 full time scientist (Peter Schwartz), 2 part time high performance computational specialists, technical lead (Phillip Colella).
GIS: 2 part time developers (Tom Heinzer and Diane Williams)
DWR: 1 graduate student working on data assimilation.

We welcome participation from universities, especially in the area of validation and extension to applications. Participants contributing code to the project tend to have skills or interests commensurate with professional developers in industry.

Public Use:
Yes. So far we work with academic collaborators and have released code to them. We intend to release the model publically very soon, including training.

Off-the-shelf availability:
Not yet. Requires some expertise to compile and run. We will support installation for agencies.

Documentation, verification, validation and testing:
The Adaptive Mesh Refinement, hyperbolic and diffusion algorithms used in REALM due to Colella and collaborators have been published in the Journal of Computational Physics and cited in numerous related papers on numerical analysis. An article on the shallow water specifics and geometry is in preparation and the design document is available upon request. The REALM test suite includes convergence tests of the model operations on real and contrived geometries, and we are extending these to include verification against analytical test problems. There is one staff person at DWR responsible for validating REALM on Delta data and we intend to extend the validation and verification project to include UC Davis.

Peer review of REALM requires knowledge of Finite Volume Methods. While these are standard techniques and currently occupy an important share of the water literature, they are underrepresented in the Bay-Delta community. We are eager that the algorithm be reviewed external reviewers who have expertise in FVM methods, e.g.:
Randall LeVeque (U. Washington)
Mike Bains (U. Reading, U.K.)
Eleuterio Toro (Spain)
Guus Stelling (Delft Hydraulics)
Brett Sanders (UC Irvine)

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