CSDMS

Community surface Dynamics Modeling system

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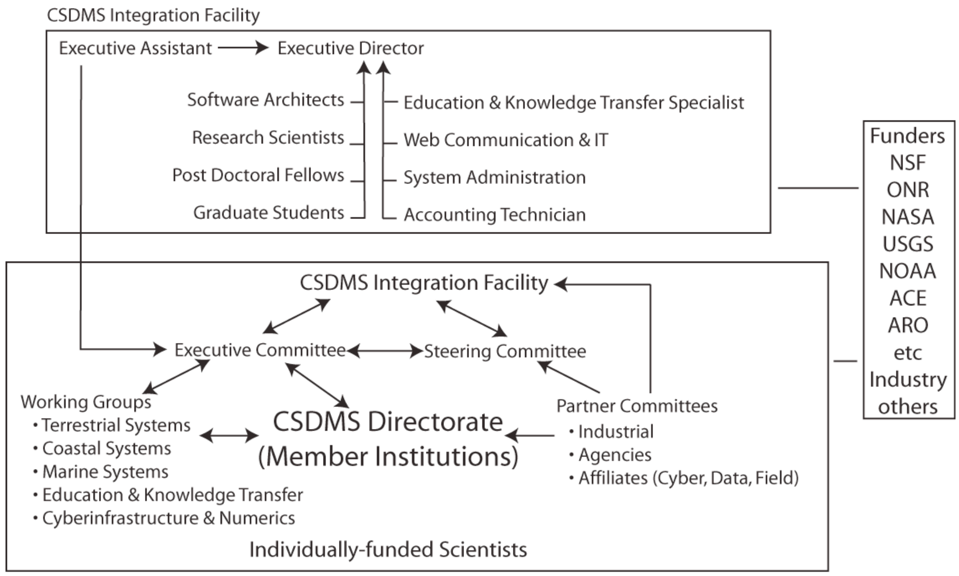
CSDMS Semi-Annual Report, Nov. 2007

CSDMS Mission: The Community Surface Dynamics Modeling System develops, supports, and disseminates integrated software modules that predict the erosion, transport, and deposition of sediment & solutes in landscapes and their sedimentary basins. CSDMS involves the Earth surface — the dynamic interface between lithosphere, atmosphere, cryosphere, and hydrosphere.

CSDMS offers an integrated community of scientific and engineering experts.

- The CSDMS Executive Committtee is in place http://csdms.colorado.edu/organization/excomm.html, comprising of the Chairs of the working groups: 1) Terrestrial Working Group: Greg Tucker, CU; 2) Coastal Working Group: Brad Murray, Duke; 3) Marine Working Group: Pat Wiberg, UVA; 4) Education and Knowledge Transfer Working Group: Lincoln Pratson, Duke; 5) Cyberinformatics and Numerics Working Group: Tao Sun, ExxonMobil. The senior software architect, the CSDMS Ex Director, and the Chair of the CSDMS Steering Committee are ex officio members of the ExCom.
- The CSDMS By-laws http://csdms.colorado.edu/organization/directorate.html were adopted (June 13-14, 2007)
- Protocols for joining the CSDMS governing body the Directorate are established, http://csdms.colorado.edu/directorate.html.
- Protocols for joining the CSDMS working groups are established, http://csdms.colorado.edu/groups.html. As of Nov 2007, 135 participants from more than 75 institutions have joined the program.
- The CSDMS Steering Committtee is in place. http://csdms.colorado.edu/organization/steering.html: comprising of the chair Prof. Rudy Slingerland (Penn State); Dr. Tom Drake (ONR), Dr. Bert Jagers (Delft Hydraulics), Prof. Rick Sarg (Colorado School of Mines), Prof Gary Parker (U. Illinois at Urbana Champaign), Dr. Dan Tetzlaff (Schlumberger-Doll Research), Prof. Dave Furbish (Vanderbilt University), Prof. Tom Dunne (UC-Santa Barbara), and its ex officio members CSDMS Exec. Director Prof James Syvitski (U Colorado), and Dr. Mike Ellis (NSF).
- Industrial Consortium framework is established (see Appendix 1).
- The organizational chart for CSDMS is in place:



• The NSF-supported CSDMS Integration Facility (IF) is established at INSTAAR, University of Colorado-Boulder, Rooms 205 through 221 at 3100 Marine Street, Boulder, with its own Campus Box and zip code http://csdms.colorado.edu/about/contact_us.html. Software Architects Drs. Scott Peckham and Eric Hutton, CSDMS Executive Assistant Mr. Andrew Svec, CSDMS Accounting technician Mary Fentress, and CSDMS Systems Administrator Mr. Chad Stoffel, under the direction of an Executive Director, Prof. James Syvitski, support the CSDMS Integration Facility http://csdms.colorado.edu/organization/personnel.html. The Facility also includes Dr. Irina Overeem (NOPP and ConocoPhilip funds), as its Arctic sedimentary environment specialist, Dr. Albert Kettner (NASA funds), to integrate geochemical modeling of water and sediment fluxes in a spatial framework. Two uate students are supported through various other NSF & ONR funds: Ph.D student Scott Bachman, and graduate student Mark Hannon.
• The Integration Facility (IF) also hosts visiting scientist and to date has hosted 1) Prof. Bjarte Hannisdal (U. Bergen) to work on protocols for adding animal-sediment interactions into a CSDMS framework, 2) Dr. Gywn Lintern (Geological Survey of Canada-Pacific) to work on flocculation dynamics, and 3) Dr. Bert Jagers (Delft Hydraulics), the senior Delft3D software architect, to discuss his company's philosophy and interactions with CSDMS

CSDMS produces protocols for community-generated, continuously evolving, open software.

• CSDMS IF (Integration Facility) employs the version control program Subversion. This free program allows the tracking of changes to any set of files with a complete record of all changes and when they were made. Subversion will play a key role in managing source code submissions to the CSDMS Project.
• CSDMS IF maintains documents on best programming practices, coding standards and software protocols. One of the best is an 81-page document produced by the GNU project called GNU Coding Standards.
• CSDMS IF stays abreast of methods for providing platform-independent graphical user interfaces in support of the CSDMS project. These included Gtk+, FLTK, Gnash (free and similar to Adobe Flash), Java with Swing or SWT, TCL/TK, and others.
• CSDMS IF has installed the complete set of CCA tools using the new (beta version) build system that has been developed by computer scientists Daniel Taylor and Boyana Norris at Argonne National Laboratory. The complete set of CCA tools uses several complete (and constantly changing) applications with complex dependencies that made installation very user-unfriendly with the former build system.

CSDMS enables the rapid development and application of linked dynamical models tailored to specific landscape-basin evolution problems, at specific temporal and spatial scales.

• CSDMS IF has investigated/analyzed a number of model coupling systems, including:

1. Earth System Model Framework (ESMF) www.esmf.ucar.edu,
2. OASIS4 (PRISM), www.prism.enes.org,
3. MCT (Model Coupling Toolkit) www-unix.mcs.anl.gov/mct/,
4. CCA (Common Component Architecture) www.cca-forum.org,
5. OpenMI (http://www.openmi.org).

• CCA includes a compiler called Babel (www.llnl.gov/CASC/components/babel.html) that allows individual components to be written in any of several programming languages, including FORTRAN 90, FORTRAN 77, c, c++, python, and java. (Note that this list includes (a) procedural and object-oriented languages and (b) compiled and interpreted languages.) This language interoperability is achieved without a significant reduction in performance. CCA supports single and multi-processor systems, and is compatible with most major operating systems (Windows, Mac OS X, Linux, other Unix). It also has proven interoperability with ESMF, MCT and OASIS4, and includes a powerful suite of tools (Babel, Chasm, Ccaffeine, BOCCA, etc.). CCA is being used commercially (e.g. Tech-X www.txcorp.com, Fluent www.fluent.com), by academics and government agencies (e.g. DOE). CSDMS IF has successfully linked SedFlux http://code.google.com/p/sedflux/ and HydroTrend http://instaar.colorado.edu/deltaforce/models/hydrotrend.html using CCA.

• OpenMI (http://www.openmi.org) is a standardized interface for programmers that allow them to link together components that conform to the standard. The components should consist Initialize, Run and Finalize modules. OpenMI is entirely based on Microsoft's C# (C-sharp) programming language, which is very similar to the Java language developed by Sun Microsystems. A Java-based version of OpenMI is under development by a company in Italy called HydroloGIS, but is not as far along as the C# version. OpenMI does not appear to provide interoperability with components written in other languages, and OpenMI does not support multiple-processor (distributed or parallel) computing.

• ESMF (http://www.esmf.ucar.edu) is another coupling system that is popular with U.S. climate and ocean modelers and federal agencies. This system uses Fortran 90 as the base language, but support for components written in C is under development. Most ESMF components consist of Initialize, Run and Finalize modules. ESMF also supports multi-processor computing.

• CSDMS IF has written FORTRAN 90 code using ESMF that is able to link two programs. For example SedFlux was broken into three separate functions: an initialize function, a run function, and a finalize function, to link SedFlux to ESMF. Wrappers were written to allow SedFlux's "c" code to communicate with ESMF's FORTAN code.

• CSDMS IF is investigating the open-source modeling environment called GEOFRAME under development by Riccardo Rigon. GEOFRAME proposes to use the following open-source tools:(a) Java as the base language, (b) the Java version of OpenMI as a model coupler, (c) Jgrass and Udig (GIS packages) for GIS and visualization, (d) ESMF as a possible modeling infrastructure, (e) Eclipse as a code development environment, (f) "R" as the main statistical analysis tool, (g) PostgreSQL/PostGIS for database access and (h) the EARTH System Curator for storing the results of simulations.

CSDMS provides the cyber-infrastructure to distribute software tools and models.

• CSDMS IF has launched the CSDMS website, including information on the mission, history, CSDMS docs, organization (working groups, directorate, partners, executive committee, steering committee, staff), meetings (upcoming, past, general info), models, tools, and other products. The website uses a tab-based interface, cascading style sheets (CSS) and server-side includes (SSI) to make it easy to maintain and update.

• CSDMS IF has created a web-based database of potential (legacy) CSDMS-candidate models, sorted by their type, author contact information, current URLs, license type, computer language http://csdms.colorado.edu/models/introduction.html.

• CSDMS IF has investigated a number of methods to distribute software to users. As a proof-of-concept various methods were tested out on SedFlux: RPM, Debian, and PackageMaker. Both Debian and RPMs are typical on many Linux operating systems, while PackageMaker produces an installer for OSX. Each distribution contains binaries that have been precompiled for a specific operating system. This is the preferred method of distributing software since a user need not compile anything. The downside for CSDMS is that it will need to compile code on a range of operating systems. For SedFlux, this has been done with Fedora (Linux), Solaris, Windows XP, and OS X. A Python-based program called Contractor can be used to simplify the build process when it is necessary to install a large number of separate packages with complex (e.g. package version) dependencies. For example, it has been used to create an installer program for the complete set of CCA tools.

CSDMS promotes the quantitative modeling of earth-surface processes.

• CSDMS IF provided assistance to UAF users of the TopoFlow hydrologic model. UAF were using the model in a graduate-level course, in which it was compared to two other well-known and well-established models called HBV and HEC-HMS. Students graded the models using various criteria; TopoFlow performed well in comparison to the other models. TopoFlow is a model made available through the CSDMS IF. TopoFlow offers a unique graphical interface that may serve as a prototype for future CSDMS products.
• Graduate student, Scott Bachman, joined the CSDMS Facility (supported through NSF- EAR-0621199) to work on 2D wavelet analysis techniques with application to digital elevation data to extract information on scaling properties and feature orientation. Wavelets and associated source code offer another powerful suite of tools that are expected to be useful in connection with the CSDMS project.
• The first CSDMS special issue in Computers and Geosciences is in press (see Appendix ?. Each of these papers has associated source code that will be made available to users through the journal and as a contribution to the CSDMS repository.

CSDMS addresses the properties of surface-dynamic systems: self-organization, localization, thresholds, system linkages, scale invariance, and interwoven biology & geochemistry.

• CSDMS IF added and recompiled SedFlux 3D with 1) new access to hyperpycnal models (INFLO, SAKURA), and 2) bioturbation module for the mixing of marine sediment. Constructed numerical tests to ensure the new components are running properly.

CSDMS partners with related computational and scientific programs.

* CSDMS Facility has provided support for the following national or international initiatives

- Data Management System for NSF-MARGINS Sedimentological Datasets
- USGGS Mendenhall Postdoctoral Research Fellowship Program
- NSF Surface Process Cyberinfrastructure workshop
- NSF High Performance Computing in the Geosciences & Moving Toward a GeoCollaboratory
- MARGINS Source-to-Sink Theoretical Institute: Teleconnections Between Source and Sink in Sediment Dispersal Systems
- NSF-CMG grant number EAR-0621199: LEM framework advances
- VIMS MRI – Acquisition of a compute cluster for coastal oceanographic research
- Envisioning a National Geoinformatics System for the United States
- NSF/CUASHI Humans Transforming the Water Cycle: Community-Based Activities in Hydrologic Synthesis
- The Science Museum of Minnesota (SMM) WATER PLANET, a 5,000 square-foot traveling exhibition, web site, and associated programs focusing on the new and evolving field of Earth-system science.
- NSF/GEON 2.0: A Geoinformatics Facility to Develop An Open Multidimensional Framework for Integration of Earth Sciences Data Mission Statement

- NSF/IGERT CRCI: Cold Regions Change Initiative Integrating Data and Modeling in the Earth and Environmental Sciences
- NSF/NEON: National Ecological Observing Network
- NSF Boulder Creek Critical Zone Observatory: Weathered profile development in a rocky environment and its influence on watershed hydrology and biogeochemistry
- NOPP Coastal Sediment-Transport Model CSTM http://woodshole.er.usgs.gov/project-pages/sediment-transport/NOPP_Project.htm

* CSDMS Facility has provided support for the following international initiatives
  - ONR Tidal Flats DRI to develop predictive knowledge and computational tools for understanding muddy tidal flat environments
  - New Zealand Margin Source-to-Sink Terrestrial Landscape Change
  - Global Water Systems Project: Dams and Reservoirs Database
  - Scott Polar Research Institute, Cambridge University to develop CSDMS Glacimarine Modules
  - INDO-US Joint Center: 'Large river systems in monsoonal settings: response to climate change'. INSTAAR, VanderBilt Univeristy, University of Technology, Kanpur, India.
  - International Polar Year (IPY) project 'Arctic Circum-Polar Coastal Observatory Network', multi-institutions collaboration led by Alfred Wegener Institute, Germany.

CSDMS supports a strong linkage between predictions and observations in nature or experiments.

- CSDMS IF created a GIS database containing: (a) SRTM data (version 2; 90m² resolution for the world; 30m² resolution for the US), (b) HYDRO1K data of the world, (c) US quads data, (d) Globe; quality-controlled global Digital Elevation Model by NOAA which is a 30 arc-second or 1 km resolution elevation data of the world, (e) the global GEBCO bathymetry data, and (f) HydroSHEDS data of Asia and South America with a resolution of 3 arc-seconds.
- CSDMS IF constructed seamless SRTM mosaics of 13 deltas and their contributed rivers of the world. The elevation is highlighted up to 100m with a cyclic color table that repeats every 10meter (horizontal resolution is 1meter). The data represented in this way clearly shows old abandoned river channels and reservoirs and the changes in channel slope.
- CSDMS IF constructed a tidal database that contains statistical information of over 7,500 tidal stations. The data are available as a kml (Google earth) file. The database is developed through an interface to the UNIX xtide program http://www.flaterco.com/xtide/xtide.html. The database includes tidal characteristics of 7500 stations.

CSDMS supports the imperatives in Earth-science research: 1) discovery, use, and conservation of natural resources; 2) characterization and mitigation of natural hazards; 3) geotechnical support of commercial and infrastructure development; 4) stewardship of the environment; and 5) terrestrial surveillance for global security.

- CSDMS IF hosted and/or organized and/or sponsored three CSDMS related workshops
  - Mechanisms of Sediment Retention in Estuaries Sept. 23-25, 2007, Boulder, CO; http://csdms.colorado.edu/meetings/estuaries_2007.html
  - Deltas at Risk, Sept. 26 to 28, 2007, Boulder, CO; http://csdms.colorado.edu/meetings/deltas_2007.html
  - Arctic Coasts at Risk, Oct. 1 to 3, 2007, Tromsø, Norway; http://csdms.colorado.edu/meetings/arctic_2007.html

  Summaries of these events are included in this report as Appendices to this report.
- CSDMS IF plans for a fourth workshop are underway to develop a Community Sediment Model for Carbonate Systems, Feb. 27-29, 2008, Golden, CO; http://csdms.colorado.edu/meetings/CSM_for_carbonate_systems.html

Appendix 1 : CSDMS Industry Consortiums

An important aim of CSDMS is to provide software products of use to the public, ranging from the educational communities, to those engaged in industrial applications and engineering assessments. Industry partners, along with university faculty and agency professionals, play an important role in contributing to the success of the CSDMS. The goal of the CSDMS Industry Consortiums is to engage industry stakeholders in CSDMS research and to provide them a forum for addressing key issues involved in the development and use of the models and tools produced by CSDMS, its members and partners. Given the nature of the applied problems, ranging from geological time in the case of petroleum or mining companies, to the period associated with human engineering, we have divided the CSDMS Industry partners into 1) a Geological Consortium, and 2) an Engineering and Environmental Consortium.

Benefits of Membership in the CSDMS Industry Consortiums

1) Opportunities to influence the direction of CSDMS research and products

The CSDMS Industry Consortiums provide a significant opportunity for its members to help plan and guide CSDMS research and product development in directions that are relevant to their respective businesses, thus directly benefiting their companies. By identifying needs for information and processes not available elsewhere, providing input to experimental design and product development, and suggesting new research paths, members can help define and focus the direction of research and development in respect to their own short- and long-term needs, while avoiding some of the related costs of in-house research infrastructure, facilities and staff. Additionally, rigorous, objective industry feedback strengthens the resulting research and products, while providing a higher level of overall credibility.

2) Priority access to research activities and product development

CSDMS Industry Consortium members are provided high-level access to current advances in research and products developed through the CSDMS program. Consortium members have ongoing access to CSDMS data, tools, and models as they come on stream, in-depth status reports on progress, and working versions of papers and presentations. Members may provide feedback on draft versions of research, models, tools, and other products. With interest, the CSDMS Integration would organize suggested/targeted short courses for one or more members of the consortium, with instructors chosen from the CSDMS working group membership, that offer expertise in terrestrial dynamics (e.g. flood plain models), coastal dynamics (e.g. delta development), marine dynamics (e.g. turbidity currents), computation and cyber infrastructure (e.g. coupling frameworks for linking models across time and space). Consortium members are invited to attend CSDMS events, including an annual site visit with a review of research activities and experimental data and demonstrations of products in development. Members also receive a copy of the CSDMS annual report as soon as it is available.

3) Access to professional staff, tools, and research facilities

Consortium fees would principally fund the liaison between members of the CSDMS Industry Consortium and the CSDMS Integration Office. The level of liaison would depend on the income stream from the consortiums. In order of priority this would include: 1) salary support for an advanced Post-Doctoral Fellow; 2) graduate student(s); and 3) salary support for CSDMS Integration personnel, only if required to work on consortium activities. The Post-Doctoral Fellow would ensure that models developed met the prioritized needs of the industrial partners, facilitate the linkage of CSDMS developed models with current industry geological modeling software, and conduct numerical experiments suggested by consortium members. For the Geological Consortium this might involve experiments, for example, to 1) track porosity fields in simulated continental margins, 2) examine the role of climate on sediment production in hinterlands during previous geological periods, and 3) incorporate process model simulations in the data bases used to building reservoir models. The Fellow would provide more personal access to CSDMS Integration software architect for questions about immediate problems that consortium members may need to deal with. The Fellow would ensure members also have immediate access to products and tools developed by CSDMS. For an additional fee, arrangements may be made to provide access to CSDMS labs and facilities, including separate meetings with staff and other partners to discuss current research, tools and projects in greater detail.

4) Association with a diverse group of scientists, universities, agencies, and industries

CSDMS actively works with international university researchers and scientists, representatives of governmental and environmental agencies, and industry partners. The resulting open exchange of information improves all partners' problem solving abilities and decision-making processes, to allow them to be more effective in the application CSDMS research and products. CSDMS involves top global specialists working on surface dynamic problems and models. Membership in the CSDMS Industry Consortium also offers numerous opportunities to develop connections within this diverse group of participants. The insight gained through interacting with this community is an important draw to consortium membership. Additionally, the CSDMS-NSF connections, and support of other government agencies, give CSDMS products an immediate level of professional credibility, increasing their impact, acceptance and application in practice. Industry Consortium members would benefit by being associated with this research and these entities. For example the Geological Consortium may gain new knowledge of direct application to subsurface stratigraphy and sedimentology, and to reservoir prediction.

5) Corporate responsibility and community relations

In addition to hard products, code use, access to programmers, new insights into earth-surface dynamics, and a place at the table to influence research direction and priorities, members in the CSDMS Industry Consortiums demonstrate a commitment to improving quality of life and promoting optimal natural resource management through more accurate modeling of earth surface processes. CSDMS Industry Consortiums support the imperatives in Earth-science research: 1) discovery, use, and conservation of natural resources; 2) characterization and mitigation of natural hazards; 3) geotechnical support of commercial and infrastructure development; 4) stewardship of the environment; and 5) terrestrial surveillance for global security. Consortium member companies are recognized for their commitment and support within CSDMS publications, promotional materials, presentations, and on our website.

Membership Fee

Membership fees from the CSDMS Industry Consortium supplement the funding of the CSDMS program, enabling Consortium members to support and participate in the research and development efforts of CSDMS and contribute to its overall strategic agenda. Fees also support designated staff efforts to make practical, applied connections between the models developed by CSDMS and those used by participating industry members. For more information see the CSDMS Executive Assistant Andrew.swec@colorado.edu.

Appendix 2: Arctic Coastal Zone at Risk: Prognosis and Modeling

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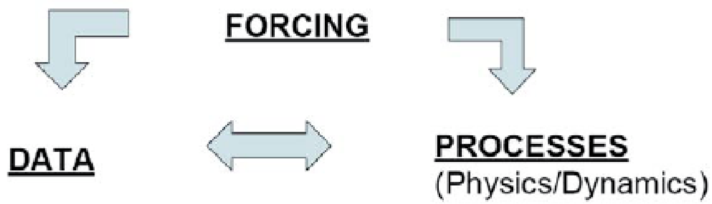
Preamble
The general overarching goal of modeling efforts is to help understand the dynamics and complex interactions of natural, coupled air-sea-land systems, and to get a handle (or put bounds) on the uncertainties of model output. With appropriate validation in the field, modeling tests our understanding of the processes. In the event that models achieve a certain level of accurate, verified quantification, then they can be used to create scenarios for future system states, and thus be used to make a prognosis for the system. As modeling and prognosis are broad terms (with application in a number of research fields), it is appropriate to first define these terms. We begin the discussion below at this point, with focus on the modeling and prognosis of Arctic Coastal Zone (ACZ) processes, and use this to lead into classification of models, scenarios and risk assessment, and modeling and prognosis needs, value, and concerns.

Prognosis: A forecast of the likely outcome of a scenario or situation. The word prognosis has secondary meanings dealing with implications of projected outcomes. Often a prognosis is defined in qualitative terms. In dealing with the ACZ, prognosis refers to defining plausible futures (e.g. sea level change, sea-ice free Arctic Ocean, melting of the coastal permafrost, intensified rainfall, increased complexity in coastal ecosystems, changes in ecosystems).

Model: A simplified description (often mathematical) of a system to assist in quantitative calculations or predictions. Often models are used in quantifying a prognosis or scenario.
Because of the mathematical framework models are used to help understand the sensitivity of a process or system to changing boundary conditions. Advanced models are used to deal with non-linear behavior of systems, including situational thresholds.

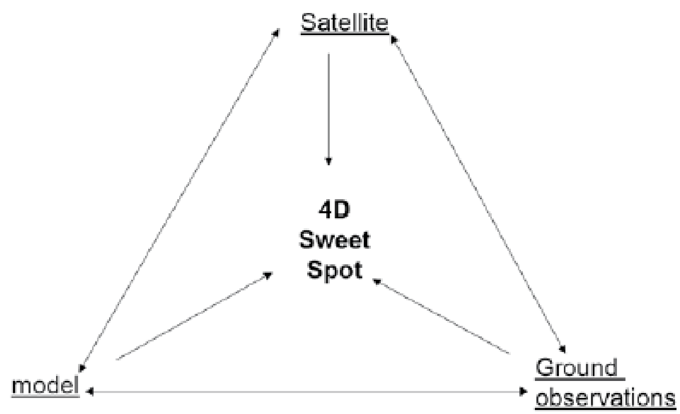
Prognosis and Modeling applied to the ACZ
Prognosis and modeling are important requirements in working in data poor regions as they can be used to test our understanding of the processes through validation experiments and to help understand uncertainties in complex systems. The Arctic tends to be data poor due to issues of accessibility, sampling density, limited long time series, and representation. In addition not all of the forcing functions that drive systems (human, physical, and biological drivers; e.g. discharge) are well constrained. Arctic processes often remain not fully understood, either we are missing information or an understanding of the physical, ecological and socio-economic processes. Additionally we do not fully understand all the various nonlinearities in the system.



We recognize three types of models of importance to studies of the Arctic Coastal Zone (ACZ) based on the nature of the problem or process. The first are the **physical models**. These models are often targeted to specific components of the overall physical system such as ocean circulation, meteorology, climate dynamics and climate forecasting, hydrology, sediment transport, morphodynamics, wave dynamics, tidal modeling, storm surge dynamics, permafrost dynamics, sea-ice and iceberg drift, and tidewater glacier dynamics. The second are **coastal ecosystems models**. These are largely driven by the physical and biological environment and dynamics. They represent various levels of sophistication and dynamics, from simple box models to those that integrate more fully include all the dynamics that define the system. These models include those related to productivity, nutrient dynamics, light, water and temperature regime, snow cover, sea ice movement and trophic dynamics and interspecific competition. The third are socio-**economic models, which** include those related to resources, fisheries, oil and gas production, mineral mining, aquaculture, tourism, coastal infrastructure and pollution.
There are intimate linkages between each of the types of models.

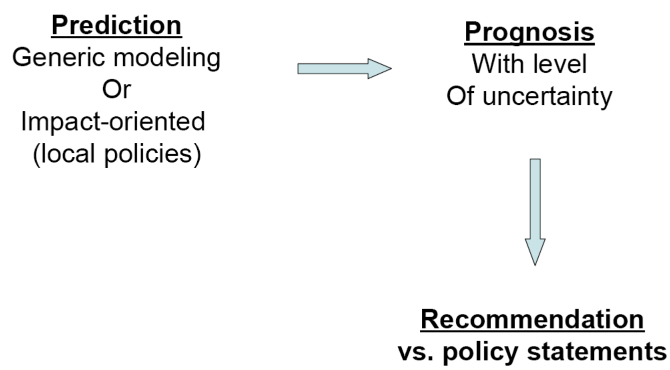
Model scenarios for the ACZ involve analysis of expected changes in 1) climate, 2) social and economic conditions, 3) the physical world, 4) ecosystems, and 5) governance. Scientists often worry about being alarmists and thus have a historical tendency toward consideration of more conservative scenarios. ACZ changes have been more severe than scenarios have considered (sea ice melt for example). Forecasting the impact of severe short-term weather events is a notable exception, where warnings of immediate danger are conveyed for obvious reasons of safety.

Risk assessment is predicated on the notion of humans being risk averse. Thus scientists must better understand the uncertainties associated with models (in data, forcing, physics, and representation). Model validation is imperative for proper risk assessment. Models can be validated with field data in using a hindcast methodology with re-analysis, but the short record lengths often associated with Arctic systems remains a systemic problem for validating arctic models. Many ACZ models are on the scale of human engineering, in other words on the time scales of days to years. These models differ from longer-term morphodynamic models that track changes in topography and bathymetry through decades and in some cases centuries. A worry in employing morphodynamic models is whether the science is in place to discern processes that operate with Gradualism, versus those that employ different dynamics on either side of some well understood threshold condition. Four dimensional (4D) data assimilation schemes offer methods (inversion algorithms, conditional simulations) to improve our ability to incorporate large-scale observations with limited ground observations and model simulations.



How should the Arctic Coastal Community proceed with respect to Prognosis and Modeling at the village scale?

Often coastal zone models are used to understand the generic state of the Arctic; they do not necessarily address the needs of the Indigenous peoples, nor are they able to easily incorporate their historical or oral-based knowledge (e.g. Traditional Knowledge or TK). Coastal management models at the scale of village communities can be applied on a case-by-case basis with good two-way communication, education and outreach.



Prognosis and Modeling Needs:

1. A summary of past modeling efforts from ACIA & IPCC reports related to the ACZ.
2. An inventory of models applied to the ACZ, documenting their success. In addition there is a need for a survey of what models could be applied but have not, as well as what models have yet to be developed --- what pieces are missing? The inventory should include a listing of operational models ((i.e. with real time data) vs. predictive vs. hindcast models.
3. An analysis of modeling opportunities with ongoing or new field programs.
4. An ACZ modeling team should be formulized to have strong interactions with other ACZ working groups.
5. The ACZ modeling team should develop model-nesting experiments.
6. The ACZ modeling team should work with other international efforts of generic model coupling approaches, such as those being used by the Community Surface Dynamic Modeling System (http://csdms.colorado.edu/), including the Common Component Architecture, and the Earth System Model Framework.
7. A workshop should be organized to bring together "social & economic" modelers with "bio & physical" modelers, along with representatives from the monitoring and observational fields.

Value added from Prognosis and Modeling

1. Models are required to address changing states; the simple application of statistics is likely not valid during changes of biophysical states.
2. Models can address/assess ACZ vulnerability, including resilience, adaptability, and sensitivity.
3. Models can often identify gaps in either understanding or observational data.
4. Modeling allows an ability to interpolate between periods or locations of observation, a fact often used in times of reduced research/monitoring budgets.

Prognosis and Modeling Concerns

1. We cannot address the model gaps until an **ACZ model survey** is completed.
2. The ACZ provides an opportunity given the comparatively trophic-level simplification and minimum level of direct human impact, yet the simplification points to the limited level of data to adequately validate ecosystem models.
3. No long-term coastal morphodynamic model is identified suitable to the ACZ, e.g. one that takes into account permafrost or other ice-sediment interactions.
4. A modeling framework system for the ACZ is not yet implemented. Model integration is thus at the earliest stages for the ACZ.
5. More effort is required on error propagation analysis, and an understanding of model uncertainty.
6. A surface heat budget is not in place throughout the arctic. This is important for most ocean-climate modeling efforts as well as for many ecosystem dynamic models.
7. Relative sea level predictions remain poor for the ACZ, although effort has taken place in the Arctic.
8. Very limited long-term (and even medium-term) data are available for many of the physical models validation. Since the Arctic is entering a new state with limited summer sea ice, wave measurements of the past are of limited use for the validation of wave forecast efforts.
9. The present limited observation stations are not adequate for data assimilation schemes.

Summary

Significant, directed research effort is required to attain a level of sophistication and computational efficiency necessary to address complex anthro-bio-geo-physical interactions inherent in modern Arctic Coast Zone models. Because of high socio-economic impacts associated with projected Arctic climate change, particular importance should be placed on understanding model uncertainty, limitations, and quantifying outcomes. In addition to known processes (such as those associated with permafrost, sea ice, and surface waves), such error propagation considerations should become part of the model framework development.

Appendix 3: **Mechanisms of Sediment Retention in Estuaries**

Introduction

The last meeting of WG 122 was held 23-25 September 2008 at the Institute of Arctic and Alpine Research (INSTAAR), University of Colorado at Boulder. Prof. James Syvitski and his staff from the Community Surface Dynamics Modeling System (CSDMS) hosted the meeting by providing all logistic features. Working Group 122 is sponsored by the Scientific Committee for Ocean Research (SCOR), the Land-Ocean Interaction In The Coastal Zone (LOICZ), and the International Association For The Physical Sciences Of The Oceans (IAPSO)

The main objective of the meeting was to integrate the findings made by the WG along its constitution period and to define the integrated output of the WG to the scientific community as well as the larger community of estuarine stakeholders and decision makers.

Participants

WG Full Members

Dr Carl L. Amos - Southampton Oceanographic Center - UK
Dr Pedro Depetris - Universidad de Cordoba - Argentina
Dr Morten Pejrup - University of Copenhagen - Denmark
Dr Gerardo M. E. Perillo - Instituto Argentino de Oceanografía - Argentina
Dr Yoshiki Saito - Geological Survey of Japan - Japan
Prof James P.M. Syvitski - CSDMS - USA
Dr Maria Snoussi - Université Mohamed V - Morocco
Dr Eric Wolanski - Australian Institute of Marine Sciences - Australia

WG Corresponding Members

Prof. John Milliman - Virginia Institute of Marine Sciences - USA
Dr Robert Stallard - Institute of Arctic and Alpine Research - USA
Dr Marek Zajaczkowski - Institute of Oceanology - Poland

Other Local Participants

Dr Eric Hutton - CSDMS - USA
Dr Albert Kettner - CSDMS - USA
Dr Robert Meade – USGS - USA
Dr Irina Overeem - CSDMS - USA
Dr Scott Peckham - CSDMS - USA

Agenda

The agenda for the meeting was structured along the main topics the WG have considered to be the essential issues associated to the WG theme and terms of reference

Sunday Sept 23
09:00 - 09:15 Welcome, CSDMS, meeting logistics & workshop introduction: James Syvitski
09:15 - 09:45 WG 122 Overview: Gerardo Perillo

Key Issue: Sediment Input to Estuaries under human influence

09:45 - 10:15 Geology, Geography, and Humans Battle for Dominance over the Delivery of Fluvial Sediment to the Coastal Ocean: James Syvitski
10:30 – 11:45 Group discussion: Facilitator John Milliman
11:45 - 12:00 Discussion Summary: Rapporteur Maria Snoussi

Key Issue: Morphodynamics and Evolution of Estuaries
13:00 – 13:30 Morphodynamics and evolution of estuaries in response to climatic and Anthropogenic change. Yoshiki Saito
13:30 - 14:00 Sediment processes in tidal river basins and wetlands under human alteration: Pedro Depetris
14:00 - 15:00 Group discussion: Facilitator Eric Wolanski
15:15 - 15:30 Discussion Summary: Rapporteur Marek Zajaczkowski

Key Issue: Sediment-biological interactions
15:30 - 16:00 Biological factors responsible for sediment trapping in estuaries: Morten Pejrup
16:00 - 17:15 Group discussion: Facilitator Bob Stallard
17:15 – 1730 Discussion Summary

Monday Sept 24
Key Issue: Estuarine Hydraulics
09:00 - 09:30 The impact of tidal pumping, turbidity maxima, & density gradients on sediment retention in estuaries Gerardo Perillo
09:30 - 10:00 Group discussion: Facilitator Morten Pejrup
10:15 - 11:15 Group discussion: (cont.)
11:15 - 11:30 Discussion Summary: Rapporteur Eric Wolanski

Keynote Talk
12:00 - 13:00 Climate impacts on discharge: An overview: John Milliman

Key Issue: Relative Sea Level Change
13:15 - 14:30 Brief presentation and general discussion on the role of near term sea level change on sediment retention Facilitator: James Syvitski
14:30 – 14: 45 Rapporteur: Yoshiki Saito
14: 45 – 15:00 Break

Key Issue: The Physics & Models of Sediment Budgets in Estuaries
15:00 – 15:30 Capabilities of models in assessing sediment accumulation, transport, and erosion in estuaries on different time and space: Carl Amos
15:30 - 17:15 Group discussion: Facilitator: Carl Amos
17:15 – 17:30 Discussion Summary: Rapporteur: Scott Peckham

Tuesday Sept. 25
Key Issues: Socioeconomic Impact of changes in Estuarine Sedimentation
09:00 - 09:30 socioeconomic impact of anthropogenic change in estuarine sedimentation: Eric Wolanski
09:30 – 10:30 Group discussion: Facilitator: Carl Amos
10:30 – 10:45 Break
10:45 – 11:00 Group report: Depetris
11:00 - 12:00 Final details and report assignments: Perillo & Syvitski
13:00 Workshop complete

Main Results from the Group Discussions

The workshop was organized around a key issue with a keynote speaker that provide a state-or-the-art situation of the corresponding issue followed by a group discussion that, as the workshop progressed integrated the some outcomes from previous discussions. The main conclusions resulting of this discussion are given below

Key Issue: Sediment Input to Estuaries under human influence

- In most of the rivers, the decrease of sediment load has been greater than the decrease of the water discharge
- It is very difficult to estimate the bed load/suspended load ratio based on present day technology. Grain size is an important parameter that seldom is monitored.
- Dams affect not only the amount of discharges but also its timing. As such flood control has had a major effect on discharge/sediment input into estuaries.
- Given the decrease of sediment inputs to estuaries, have estuaries shifted from retention basins to bypassing systems?
- There are no rules for sediment retention in estuaries. Each system operates differently in response to both inputs and its physical and biological regimes
- The amount of sediment retained in estuaries is in general lower than under pre human impact conditions, except in arctic basins.
- In many, perhaps most small and medium size rivers, most of the sediment load is delivered during episodic events.

Key Issue: Morphodynamics and Evolution of Estuaries

- Sediment transport in the estuary concerns resuspension and mixing processes that ultimately affect sediment accumulation in the system.
- What are the importance of deltas and fjords in the global balance of estuarine retention?
- Locally, bores can be important in stirring sediment, transport and redeposition in an estuary.
- Sea level variation and long-term rise can steer sediment accumulation in the estuary.
- Estuarine equilibrium depends on the age of estuary.
- Harbor dredging influences circulation and sediment regime in estuaries
- Evolution of estuarine morphology was discussed with regard to the various processes that occur within the system but mostly associated to the variability and long-term changes in sediment input.

Key Issue: Sediment-biological interactions

- Biological agents both stabilize and destabilize sediments, thereby also producing geomorphic changes.
- In temperate systems (i.e., Wadden Sea) algae blooms affect erodibility seasonally. Korean and Argentine tidal flats show similar erosion and sedimentation variability as the Wadden Sea system in that algae mats and cyanobacteria influence erosion on seasonal timescales.
- Short-term accumulation rates are affected by biology. However, short-term net accumulation is order of magnitude higher than millennium scale accumulation.
- Uncertain whether biological factors are of importance over longer time scales? It is a problem on that time scale we may not have sufficient data to disentangle sediment budget and causality.
- Tropical systems such as those in southern Asia and Oceania may account for a disproportionately large flux of fine sediment to world's oceans.
    - Mangroves retain sediment. These influence the system over decadal time scale.
    - Mangroves forests may consist of only 2 % in area, but trap 30% of sediment.
    - Human impact on vegetation-biological factors: Introduction of exogenous species both at the estuaries and in the watershed change how sediment is delivered to the estuary as well as the sediment dynamic equilibrium within the system. Examples include beaver-dams, tamarisk in rivers, mangrove removal and shrimp farming.

Key Issue: Estuarine Hydraulics

- Several long standing concepts such as tidal pumping, lag and scour lags have been overextended

- Particle aggregation is a key issue, whether it is biological, physical or chemically induced
- Lack of adequate analysis of net retention by not considering the whole estuary may give misleading results as sediment may be redistributed from one reach to another providing false appreciations of the behavior of the whole system.
- Geomorphology: does it determine sediment transport, or vice-versa? To what extend does that question neglect the history of filling?
- Interaction between the various hydraulic and climatic factors and the geomorphology drives sediment transport, which changes the geomorphology, and thus the hydrodynamics.
- Residual fluxes change the geomorphology. The important point is the cycling. Sediment transport drives the evolution of the estuary.
- Events of short-term deposition of mud are important for net budgets
- Tidal pumping: why not call it residual flux? Since it pushes sediment up gradient and increases the gradient in SSC. The residual movement is not just the tidal current asymmetry
- Qualitatively, just tidal asymmetry is enough for the net result
- Analysis of synchronicity in estuaries has not been considered sufficiently as estuaries may have either hypo (tidal range diminishes headward) or hypersynchronic (tidal range diminishes landward) conditions resulting in different ways to trap/export sediments.
- Settling and scour lags: are they necessary?
  Turbidity maximum can be produced not just by lag effects but also by differential settling
  Lateral variation can produce tidal pumping.
  Shear diffusion also redistributes the sediment.

Key Issue: Relative Sea Level Change

- Present relative sea-level changes at estuarine/deltaic coasts are a combination of eustasy, hydro, sediment and glacial isostasy, and compaction,
- Often overlooked is the relaxation times and influence of isostatic forces that are not adequately considered by IPCC reports.
- Use of satellite data and past sea level geological records is recommended for model validation.
- Rising sea level will impact on inundation, tidal ranges, mean sea level, and hydrodynamics.

Key Issue: The Physics and Models of Sediment Budgets in Estuaries

- A discussion about models vs. time and space scales associated with bottom-up and top-down models. A hybrid model may facilitate a better solution to the sediment transport problem.
- Models require direct measurements + numerical/physical simulation + local "experience" to identify if the model is actually predicting the real conditions.
- Boundary conditions are the biggest problem in modeling, whereas calibration and verification require detailed synoptic-scale data.
- Can we accurately predict the transport pathways? The open-boundary problem means we cannot even determine filtering efficiency.
- An important result from Venice Lagoon modeling is that residence time or filtering efficiency is not constant in time or space.
- Bedform predictions are very difficult or impossible, as the processes are not well understood. It can be done on very small and idealized cases, but it cannot be upscaled.
- The future is to use "coupling systems" like CCA and ESMF, with models like ROMS, ADCIRC, etc.
- Important concept is the fact that estuaries to change from exporter to importer of sediment.

Key Issues: Socioeconomic Impact of changes in Estuarine Sedimentation

- Discussion was concentrated in experiences from relatively small systems, mostly in Australia (~40 km^2) to the Mekong

- Examined systems were macrotidal and muddy, receiving sediments from both, land and marine sources
- The ratio of the estuarine volume to the sediment infilling gives an idea of the time-scale regulating the system. Such systems have a life, where the degree of disturbance seems to follow an inverse relationship with age, i.e., more evolved (i.e., older) systems appear to be less subject to disturbance than systems considered to be young.
- Several important questions were asked: Is the filling up of an estuary a harmonic phenomenon? What is the role of significant events, perhaps connected with a changing climate scenario? What is the relationship existing between the sediment residence time and human impact?
- Perturbation of estuarine systems may be inversely and non-linearly related with the system's size/infilling rate.

Main Conclusions

- Estuaries are being seriously affected by climatic and human impacts, as manifested by changes in the level of sediment input from the land and sometimes from the sea, and through sediment redistribution within the estuary.
- Some estuaries are starved of riverine sediment due to dams; others are enriched in sediment input such as through land clearing; others are sinking due to excess groundwater extraction.
- There are various scales from seasonal to millennia that are superimposed in the evolution of the mechanisms of sediment retention in estuaries, impacting the way the evolution of an estuaries geomorphology.
- The role of relative sea level has not been adequately addressed in our interpretation of an estuaries vulnerability.
- Increased storminess and a rise in sea level from climate change, partially or wholly man-made, may further destabilize an estuary.
- Some mature estuaries may have natural cycles, possibly tens to hundred of years in duration, with alternate periods of prevailing deposition and erosion for the whole system. Such estuaries are thus periodically rejuvenated by climatic events.
- Some estuaries are changing from exporter to importer and vice-versa due to human impacts.
- Present numerical models are capable of predicting estuarine evolution over long periods (hundreds to thousands of years), as there remain many problems in defining and quantifying the conditions at the open boundaries. The future may be to advance toward coupling models operating across different spatial and temporal scales. Behind each model lies commonly used concepts like tidal pumping and scour and settling lags that require further improvements.
- The use of sediment core dating for estimating estuarine sediment accumulation rates and their temporal and spatial changes is important for the proper assessment of the sedimentological and morphological state of estuaries. Such accumulation estimates will also be useful in the process of assessing the results from numerical models being used to monitor changes.
- Other aspect like analyzing the estuaries in reaches rather as a whole system has not been properly considered given our partial understanding of the various processes occurring in them.
- Although there has been significant progress, there is still considerable lack of integrated, multidisciplinary studies considering the biological-physical interaction in estuaries in general, and in wetlands in particular, with the sediment transport processes and modifications in the geomorphology and, as a result, the evolution of habitats.

Appendix 4: **Predictive Modeling in Sediment Transport and Stratigraphy**
Special issue of Computers & Geosciences: Guest Editorial

James P. M. Syvitski
Executive Director, Community Surface Dynamic Modeling System

For over 40 years, scientists have been developing numerical models to help understand and constrain how sedimentary systems are formed (Bonham-Carter and Sutherland, 1967; Briggs and Pollack, 1967). The International Associations of Mathematical Geologists (IAMG), through its journal Computers & Geosciences, has played a strong role in supporting this active area of research (e.g. Bitzer and Harbaugh, 1987; Martinez, 1987, Syvitski and Daughney, 1992; Syvitski and Alcott, 1995; Skene et al., 1997), culminating in a C&G special issue in 2001 edited by Syvitski and Bahr (2001) that focused on the formation of stratigraphy on continental margins. A recent publication provides readers with a generalized summary along with hundreds of references through this interesting period of computational advances (Syvitski et al., 2007). This C&G special issue is firstly a contribution to the EuroSTRATAFORM project (Syvitski et al., 2004; Trincardi and Syvitski 2005; Weaver et al., 2006; Milligan and Cattaneo, 2007), and secondly a formal contribution to the new international effort to develop a Community Surface Dynamic Modeling System (http://csdms.colorado.edu/; Anderson et al., 2004; Syvitski et al., 2004a,b).

The contributing authors include civil engineers, earth scientists, oceanographers, hydrologists, and geophysicists. Their contributions are substantial and state-of-the-art; we thank contributors and their dedicated reviewers. The volume begins with three papers on the fluvial and coastal environment (Table 1): the first provides a climate-driven hydrological water balance and transport model that simulates the flux of sediment to the coastal ocean through distributary channels; the second provides a GIS method for locating small upstream reservoirs from limited data; and the third provides an analytical solution to the solution of the suspended sediment concentration in river plumes, with application to satellite imagery. The next five papers deal with sediment transport in the marine environment (Table 1): a 1D vertical sediment transport model able to predict the flux of both cohesive and non-cohesive sediment; a model to calculate bottom orbital velocities directly from surface water parameters; 1D transport model for integrating the impact of sediment transport, bioturbation, consolidation and armoring; a 3D regional coupled wave-current and sediment transport model; and 2D transport model for depositional particulate density currents. The final six papers illustrate morphodynamic and stratigraphic models and their complexities (Table 1): an advanced modular process-response model to generate 3D stratigraphy in marine basins; a method to determine the various influences on shelf stratigraphy due to loading and subsidence; an analytical solution for the determination of shelf-slope profiles based on the Laplace transform; a method of sub-grid parameterization used in stratigraphic simulations; a river-network model that simulates fluvial incision of continental shelves during sea level fluctuations; and a rule-based simulator of continental-shelf stratigraphy.

Many of the models are available either through the lead author or through the *Computers & Geoscience* web site. We are strong proponents of code transparency and code sharing, as the only viable way of advancing the field.

Table 1: *Computers & Geosciences* **Special issue contents**

Fluvial & Coastal Environment

1) HydroTrend3.0: a Climate-Driven Hydrological Transport Model that Simulates Discharge and Sediment Load leaving a River System: A. J. Kettner (Delft U. Technology) and J. P.M. Syvitski (INSTAAR)
2) Geolocation of man-made reservoirs across terrains of varying complexity using GIS. D. M. Mixon (INSTAAR), D.A. Kinner (Western Carolina U.), R.F. Stallard USGS), and J.P.M. Syvitski (INSTAAR)
3) A New Method for Estimating Suspended Sediment Concentrations and Deposition Rates from Satellite Imagery Based on the Physics of Jets and Plumes: S.D. Peckham (INSTAAR)

Marine Environment

4) Sedtrans05: An improved sediment-transport model for continental shelves and coastal waters: U. Neumeier (U. Québec-Rimouski), C. Ferrarin (ISMAR-CNR Venice), C. L. Amos (NOC U.

Southampton), G. Umgiesser (ISMAR-CNR Venice) and M. Z. Li (GSC)
5) Calculating wave-generated bottom orbital velocity from surface wave parameters. P.L. Wiberg (U. Virginia) and C.R. Sherwood (USGS)
6) Modeling a dynamically varying sediment bed with resuspension, deposition, bioturbation, consolidation, and armoring: L. P. Sanford (U. Maryland)
7) Development of a 3D Regional Coupled Wave-current-sediment Transport Model: J.C. Warner, C.R. Sherwood & R.P. Signell (USGS), C.K. Harris (VIMS), H.G. Arango (Rutgers U)
8) Effect of Particle Inertia on the dynamics of depositional turbidity currents: M.I. Cantero & M.H. Garcia (U. Illinois, Urbana-Champaign), and S. Balachandar (U. Florida)

Morphology and Stratigraphy
9) *Sedflux 2.0*: an advanced process-response model that generates three-dimensional stratigraphy: E.W.H. Hutton & J.P.M Syvitski (INSTAAR)
10) Response To Loading And Subsidence Of The Rhône Deltaic Margin During The Last Climatic Cycle (Gulf Of Lions, Nw Mediterranean): G. Jouet (IFREMER), E.W.H. Hutton & J.P.M Syvitski (INSTAAR), S. Berné (IFREMER)
11) Mathematical Methods for Predicting the Form and Stability of Continental Shelf Profiles: S.D. Peckham (INSTAAR)
12) Sub-grid parameterization of fluvio-deltaic basin filling models: R.A.F. Dalman & G. J. Weltje (Delft U. Technology)
13) The Role of Equilibrium Conditions on Fluvial Incision of Continental Shelves During Sea Level Cycles: S. Fagherazzi (Boston U.), A. D. Howard & P. L. Wiberg (U. Virginia)
14) Assessing variability of fluvio-deltaic stratigraphy using process-response modeling: R.M. Hoogendoorn (Delft U. Technology), I. Overeem (INSTAAR) Joep Storms (Delft U. Technology)

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Appendix 5: **Dynamics and Vulnerability of River Delta Systems**

GWSP-LOICZ-CSDMS

26-28 September, 2007, Boulder

Workshop Agenda

Day 1 Setting the Stage: What do we know? (Chair James Syvitski)

09:00 - 09:15	Welcome, CSDMS, meeting logistics & workshop introduction: James Syvitski
09:15 - 09:30	LOICZ & Deltas: Hartwig Kremer
09:30 - 09:45	GWSP & Deltas: Marcel Endejan
09:45 - 10:00	Deltas: environmental perspective: James Syvitski
10:00 - 10:15	Global Change Impacts on Deltas: Charles Vörösmarty
10:45 - 11:00	Deltas: Risk Analysis: Ilan Kelman
11:00 - 11:30	Summary discussion

Case Studies (Chair Juergen Weichselgartner)

11:30 - 12:00	Case study report #1: Danube/Indus: Liviu Giosan
12:00 - 12:30	Case study report #2: Mississippi: Bob Meade
13:30 - 14:00	Case study report #3: Yellow R./Chao Phraya: Yoshiki Saito
14:00 - 14:30	Case study report #4: Nile: John Milliman
14:30 - 15:00	Case study report #5: Magdalena: Juan Restropo
15:15 - 15:45	Case study report #6: Ganges & Volga: Irina Overeem
15:45 - 16:15	Case study report #7: Po: Albert Kettner
16:15 - 17:30	Summary Discussion: Chris Paola

Day 2 Key Issues of Vulnerability and Database Development

Key Issues of Vulnerability (Chair Charles Vörösmarty)

09:00 - 09:15	Welcome & Recap: Christoph Sebald
09:15 - 09:45	Deltas: human perspective (urbanization, agriculture): Alex de Sherbinin
09:45 - 10:15	Deltas: Climate & Hurricane Risks: Greg Holland
10:30 - 10:45	Charge to 3 breakout groups and breakout group discussions: (1) vulnerability questions, (2) key research questions, and (3) assessment questions
10:45 - 12:30	Discussion in breakout group
13:30 - 14:30	Groups report and plenary discussion: Joep Storms

Data Base and Affiliated Model Development Efforts (Chair Scott Peckham)

14:30 - 15:00	Joining History and Space Age Science: James Syvitski
15:15 - 15:45	Introducing the Delta Database: Albert Kettner
15:45 - 16:15	Introducing the Framework for Land-to-Ocean Linkages: Charles Vörösmarty
16:15 - 16:45	Introducing Delta Modeling: Chris Paola
16:00 - 17:30	2 breakout groups (1) data & (2) models: What is there, what is not, how to get it

Day 3 Formulation of Joint Research Agenda and Next Steps (Chair Marcel Endejan)

09:00 - 10:00	2 Breakout groups report and plenary discussion: Julia Ericsson
10:00 - 12:30	3 breakout groups: (1) areas for new disciplinary and interdisciplinary research; (2) database development (3) predictions/scenario development and modeling
13:30 - 14:30	Groups report and plenary discussion: Christoph Sebald
14:30 - 15:30	Plans for further activities & summary of accomplishment: Hartwig Kremer
15:30	Workshop complete

Background Information

Workshop title:

- **Dynamics and Vulnerability of River Delta Systems**

Workshop goals:

1. **Craft a Science & Implementation Plan** for a joint assessment and synthesis research project on the vulnerability of deltas, based on input from representatives of earth system scientists, engineers, physical scientists, ecologists, economists, geographers, demographers, conservation & development NGOs,

representatives of industry and government, and emergency/hazard experts;
2. **Enhance a prototype Global Database of River-Delta Systems** and an allied Global Delta Typology featuring status and scenarios of change and options of adaptation;
3. **Identify key research questions and challenges** of sustainable development to which the integrated Database and subsequent analysis and modeling could be applied by multiple users.

Meeting organizers:
- James Syvitski (CSDMS): james.syvitski@colorado.edu
- Marcel Endejan (GWSP) marcel.endejan@uni-bonn.de
- Juergen Weichselgartner (LOICZ): j.weichselgartner@loicz.org
- Charles Vörösmarty (ISEOS): charles.vorosmarty@unh.edu

Workshop location and participants:
- CSDMS, INSTAAR, Boulder, CO, USA
- Workshop invitation was through the workshop meeting organizers.

1. Marcel Endejan, Global Water System Project
2. Julia Ericsson, ConocoPhilips
3. Liviu Giosan, Woods Hole Oceanographic Institution
4. Greg Holland, University Corporation for Atmospheric Research
5. Greg Hood, Skagit River System Cooperative
6. Eric Hutton, University of Colorado
7. Ilan Kelman, National Center for Atmospheric Research
8. Albert Kettner, University of Colorado
9. Hartwig Kremer, GKSS Research Center
10. Wonsuck Kim, University of Illinois at Urbana-Champaign
11. Bob Meade, U.S. Geological Survey
12. John Milliman, Virginia Institute of Marine Science
13. Irina Overeem, University of Colorado
14. Chris Paola, University of Minnesota
15. Scott Peckham, University of Colorado
16. Juan Dario Restrepo Angel, EAFIT University
17. Yoshi Saito, Geological Survey of Japan
18. Christoph Sebald, GKSS Research Center
19. Alex De Sherbinin, Columbia University
20. Charles Simenstad, University of Washington
21. Joep e.a. Storms, Technical University of Delft
22. Dennis Swaney, Cornell University
23. James Syvitski, University of Colorado
24. Charles Vörösmarty, University of New Hampshire
25. Juergen Weichselgartner, GKSS Research Center

Documentation:
- Presentations are available at http://csdms.colorado.edu/meetings/deltas_2007.html

Workshop Minutes
Day 1: Setting the Stage: What Do We Know?

(Chair James Syvitski)
- J. Syvitski welcomed participants, introduced workshop settings, and outlined meeting logistics
- Each participant introduced him-/herself
- H. Kremer introduced LOICZ and related activities
- M. Endejan introduced GWSP and related activities
- J. Syvitski presented environmental perspectives of deltas
- C. Vörösmarty presented global change impacts on deltas
- I. Kelman presented the terms vulnerability and resilience
- very short discussion

Case Studies (Chair Juergen Weichselgartner)
The following case studies were presented:
1. Danube / Indus (L. Giosan)
   - Largest wetland in Europe, second largest compact reedbed in the world

- Good to study what are the marine and the human factors
- Global influences on the delta: sea level rise, climate
- Delta developed in stable sea level conditions which is threatened now by sea level rise
- Intense floods are connected to climate
- Regional influences on the delta: water (constant) and sediment discharge (decreasing due to dams), deforestation, dam, irrigation, river mouth morphodynamics, political issues (a channel was build)
- Delta doesn't suffer too much from SLR and sediment shortcut but from micro-scale redistribution of sediments and plans for large transportation channels
- Local influences on the delta: sediment distribution, fishing, transportation,
- Problems: sediment decreased, stable sea level conditions are threatened by sea level rise, regime changed from natural to is engineered,
- Indus: case study for climate change; largely monsoon regime driven system and large system for irrigation; almost no net runoff (250 days after 2000); salinization, desertification, coast evolution influenced by dams

2. Mississippi (B. Meade)
   - Strong fluvial gradient from high rainfall in the East to low rainfall in the West
   - Control structures have been build
   - Four active subdeltas of the modern Mississippi delta
   - Problems: decrease in suspended-sediment discharge, loss of wetlands (i.e., storm surge protection) and vulnerability to hurricanes
3. Asian Deltas (Y. Saito)
   - Yellow River: sediment load to the sea increased from 1000 to 1950 due to deforestation, and since then decreased, since 1996 delta is decreasing due to erosion
   - Yangtze River: delta is shrinking
   - Red River: sediment discharge is decreasing since the 1960s, strong coastal erosion
   - Mekong River: sediment reduction by dams ca. 5%, shoreline changes (deposition, erosion), deforestation of mangroves, shrimp farms
   - Chao Phraya (Bangkok): coastal erosion, many shrimp farms, sediment discharge decreased since 1960s, 60 cm rise in sea level (1960-1990), 20 cm land subsidence (1992-2000),

4. Nile (J. Milliman)
   - Drought decreased river discharge, Egypt probably would not have survived the drought without the Aswan high dam
   - Total offshore fish catch first decreased after the Aswan dam was build (mid 1960s), but increased since mid 1980s because of fertilizer use in Egypt increased ("lots of fish now – but no one wants to eat it") (Scott Nixon – Ambio article a few years ago)
   - Transboundary issue of damming if for instance Ethiopia would start damming the upper stretches of the Nile,
   - Usually change in runoff more or less reflects change in precipitation
   - Some rivers actually have less precipitation now but more discharge (Lena, Bramaputra)
   - Since 1964, erosion has been extremely localized
   - Deficit rivers mainly at the equator
   - We do not only change land use and decrease sediments, but also freshwater
   - Problem: if Ethiopia (or Sudan) starts building dams, this will have impacts on Egypt
5. Magdalena (J. Restropo)
   - Colombia has 6 delta systems, which have not been included in global databases
   - Morphology has been described qualitatively, but there are no quantitative databases of key morphodynamic factors
   - Land cover change: annual deforestation rate of 1.9%, forest cover decrease by 40% in 20-year-period
   - 68% of the drainage basin area show increasing sediment loads
   - High inter-annual variability in sediment fluxes
   - Delta in the top 10 in terms of wave energy, very high marine power index
6. Ganges & Volga (I. Overeem)
   - Relative stable coast 1850-1909, rapid progradation 1909-1927 due to emergence, 1951-1981 lowstand, channel network fills, 1981-1990 coastline is stable despite 1,5m sea level rise
   - Deltas that have high sediment supply rates may be more resilient to sea-level change
   - Interacting forces can be explored with numerical modeling, several processes/modules need further research, notably supply mechanisms, and floodplain sedimentation
   - Caspian has an own regime of sea level change (3 m over last century)

- Volga depends on precipitation; 80% of Caspian influx from Volga
- 1 year flux of Volga is about 60 cm of Caspian Sea Level (Arpe et al. 2000)
- Ganges: Indian Monsoon dominated, thus quite variable; however, in terms of sediment fluxes it would be even prograding in case of a two meter sea level rise
- Recommendation: we need to be clear about which processes we need to look at to properly model Delta Dynamics

7. Po (Albert Kettner)
   - Delta system controlled by sea level rise
   - Subsidence by gas mining; decrease in sediment load by damming; subsidence went as far as 70 km inland
   - With UNH and NASA, model development is planned to look into accretion and erosion in a certain basin at different locations

Summary Discussion (Chair Chris Paola)

- 350 million people worldwide live in deltas
- 10 million people per year get flooded from the sea
- Beside the artic deltas (and the buried ones), most have been influenced by human beings
- Overall, many are back to some sort of pre Anthropocene sediment flux conditions after suffering from heavy erosion (e.g., due to deforestation)
- Take advantage of historic records of pristine deltas
- What's out there in terms of system process functioning, than put into social and political discourse
- Basic science questions: how is the puzzle fitting together? How we deal with vulnerability?
- Putting the human dimension into the science, than take a proactive approach
- 18:30: group dinner at Rincon del Sol

Day 2: Key Issues of Vulnerability and Database Development

Key Issues of Vulnerability (Chair Charles Vörösmarty)

- Short recap by C. Sebald
- A. de Sherbinin outlined human perspective on deltas:
  - Human-environment interactions are complex and require input from multiple social (as well as natural) science disciplines
  - Deltas are a useful focal area in which to view human-environment interactions
  - Vulnerability frameworks may be one way of approaching this work – and there is a rich and growing literature on this
  - Human-related datasets provided/used by CIESIN include: population size (GPW3); population density (GPW3); urban extents (GRUMP); GDP (Sutton & Costanza 2002); poverty (CIESIN infant mortality rates); land cover (GLC2000); % land in crops (Ramankutty et al. forthcoming); Roads (VMAP0); protected areas (WDPA 2007)
  - Roads: VMAP0 will be gridded soon
  - Urban extend: night time lights used to classify urban/rural
  - Infant mortality as indicator for poverty (number of first year deaths per 1000 births; highest in Indus 72, followed by Ganges 55)
  - Protected areas according to WDPA, recent study by Karen Seto on mangroves in Vietnam and RAMSAR sites; result: rate of deforestation same as in non-protected areas
  - 4 example deltas used: Nile, Indus, Ganges, Mekong
  - Population: Ganges highly population 1220 people/16km^2
  - Proportion of land in crops shows the high production in deltas (the reason for living there)
  - Vulnerability framework from Clark University (Turner et al., PNAS 2003). Components: exposure (human, ecosystem, agricultural system), sensitivities to perturbations, resilience – usable as way to understand complex systems – climate related hazards for cities studied; Mumbai: the poor live in lowest areas; chaotic environment but resilience due to self help of slum dwellers – Shanghai: major flood during the last years with 3000 death; top-down decision making effective (planting mangroves; disaster managers; dikes built / effectiveness of governance)
  - Human-environmental interactions are complex and require input from multiple social as well as natural science disciplines; deltas are useful focal areas in which to view human-environment interaction; vulnerability frameworks may be on way of approaching the work

Discussion:

  - Results of the study are published in an article; no information about the use of the results available – the framework is also used to discuss relevant issues with stakeholders
  - Mangroves are used for flood control; vulnerability can be reduced by good land management (vulnerability in context of landscape); Delta-related questions: How are people interacting and shaping factors relevant for waves, floods etc.? How do people manipulate the physical system? (farming, canalizing, water use definitely impact the environment)
  - CIESIN would be interested to spatial modeling (hope is that by identifying areas of higher vulnerability you trigger behavioral change)
  - Question of scale: dataset use depends on aims; benefits of using global datasets: same approach is used to set up the dataset all over the globe
  - Assessments: drivers need to be considered (urbanization, sea level rise etc) as well as their the impacts on the deltas
  - General question for further discussion: Are we already able to assess the vulnerability in delta regions or do we need some more research on, for example, the physical aspect?
- G. Holland talked about climate and hurricane risks, emphasizing North America
  - Past: Anthropogenic Climate Change is substantially influencing the characteristics of North Atlantic tropical cyclones through complex ocean-atmosphere connections and may be influencing other regions.
  - Past Hurricane Climate Changes: Frequency: has increased in North Atlantic, ambiguous elsewhere, with global total roughly constant – Intensity: has not experienced any sustained long-period change, but increased major hurricanes in last few decades – Rainfall: has probably increased, unable to rigorously confirm – Distributions: possible increase in near equatorial (especially for major hurricanes), and subtropical activity
  - Future: Good evidence for increased rainfall, moderate intensity increase, sea-level rise, decreased global frequency; Some evidence for substantial increase in major hurricanes;
    No real idea on distributions
  - Potential Future Hurricane Changes: Frequency: likely global decrease, regional effects poorly known – Intensity: poorly handled by current models; 5-10% increase in maximum for each 1°C SST (sea surface temperatures) increase, possible distribution shift towards more intense systems – Rainfall: Increase of ~7% for each 1°C SST increase, reasonably firm result – Distributions: No idea – Ancillary Impact: Sea Level Rise of >1m
  - Humans will have the big impact in future: How to deal with new threats?
  - Hurricane impacts: winds (storm surge, wave action) and rainfall (freshwater flooding)
  - Storm surges responsible for ~1 million deaths in the last 50 year, mostly in delta regions
  - Length of hurricane season increase (is expanding)
  - Eastward expansion in formation region (the warm pool: 28 deg isotherm)
  - Tide height is important for forming storm surges
- Participants split up into three breakout groups to discuss vulnerability issues, key research questions, and assessment questions
  - Topic 1: Basic science questions / challenges (including social, physical, chemical); interaction with deltas and the effects; how do deltas work?
  - Topic 2: How to handle the vulnerability question? Policy-relevant issue (including GDP, human health, population), examples: protected areas; what are the problems from different angles (insurance, ecologists, economists etc)
  - Topic 3: For Friday: what could we usefully do in terms of fundraising? To be discussed on Friday.
- H. Kremer, J. Ericsson, and C. Sebald presented the group discussion results
  - See detailed breakout group reports in Annex III
  - Focus currently on physical issues
  - Further studies needed, e.g. on floods, land loss
  - A more detailed discussion is on risk and vulnerability (2 different concepts)
  - It might be helpful to talk to insurance and other relevant companies
  - How to integrate all of it?
  - A selection of case-study deltas would be needed (high/low GDP, high/low population etc).
- J. Syvitski talked about joining history and space age science
  - Historical view needed in order to assess the human impacts on deltas
  - Comparison of delta distributaries past/current
  - Humans cut down the number of distributary channels (Nile: from 15 to 4; Indus from 9 to 1)
  - Some deltas distributaries used to switch spatially

- Grain-size of delta sediments and vegetation variations play an important role in channel stabilization
- Old channels may get reoccupied in flood events
- Geological perspective: the present is not always the key to the past; many deltas would not reach their present shape without human engineering
- Human perspective: seaward flooding is replaced by landward flooding
- All maps are uploaded in GoogleEarth
- Announcement: James and Chris organize an Ocean Sciences Conference (Orlando, 03/08); see http://www.aslo.org/orlando2008/ for details

- A. Kettner presented ideas for a delta database
  - There is no database yet
  - Database to determine the vulnerability of deltas (rivers, waves, tides)
  - four physical datasets that might be useful for the database:
    - runoff/discharge and fluvial sediment fluxes (BQART Model) (a global map on fluvial sediment fluxes published by Syvitski at al. Science 2005) – might be used as potential delta map – reservoir trapping not included
    - waves/wind from wave model of NOAA (wave power and wave height); model based on 3h observational data; available for a 10-year period
    - global tides for 9500 tide stations; storm surges not included (based on observations and model simulations); data for 1970-2038 available
    - elevation data: SRTM elevation data; 30US 90, 1m height; vegetation excluded (using an algorithm)
  - quality of data in databases is an issues (about 20% of databases have good quality, 60% bad quality); uncertainty information need to be attached
  - Discussion about 'our' database
  - Datasets of interest: stratigraphy, land-use, land-cover, althematry (over the ocean), Exclusive Economic Zones (EEZ), relative see level (Liviu: such a database does exists for Great Britain), sea level anomalies (from NOAA), see ice, population density, national building databases, national infrastructure databases, datasets from the LOICZ Topology database, Gross Domestic Product (GDP), Human Development Index (HDI), lithology, soils,
  - To be discussed / clarified: What do we need the database for?
- C. Vörösmarty talked about Introducing FrAMES, a Framework for Studying Land-to-Ocean Linkages
  - CSDMS will choose a coupling system to link modules implemented in different programming languages and develop a module-based software architecture to foster community model development and synthesis studies
  - UNH Modeling Framework GHAAS; patterned after Earth System Modeling Framework (ESMF); provides supporting functions, such as domain, variable, and time management (NASA WaterNET and IDS) – four layers: data mining; databases; interface services; clients
  - FrAMES: Framework for Aquatic Models of the Earth System: Multi-constituent Modules (mass balances)
  - Nitrogen mass balance approach (Green at al., 2004): includes natural lands, crop lands, grazing lands, and developed lands
  - Nitrogen transport efficiency; efficiency average is 18% (82% will not reach the oceans)
  - Related questions: What is the role of the land surface in nitrogen transport; where does the watershed N sinks?
  - Integrated approach to global water resource assessment and global change studies: link geophysics of water, governance, vulnerability, supply limitations imposed by pollution and ecosystem flow requirements – idea: integrate external data to GWSP Atlas, use the datasets with frameworks and present results to decision makers/stakeholders; 10kmx10km scale globally, meters resolution for local analysis
  - GWSP indicators development using a mapping and analysis tools
  - HydroSHEDS might not be useful for deltas; work done by Benjamin Halpern might be more suitable
  - Tangible products: 1) curiosity-based science: IT-based frameworks to couple process-based models including physics, humans, biology and 2) service to the policy and management communities: digital map of river-coastal delta complexes, geographies of long-term vulnerability and of upland/ocean events, now-cast/forecast systems and scenarios
- C. Paola, W. Kim, and I. Overeem introduced delta modeling
  - NCED landscape restoration in New Orleans (C. Paola and W. Kim):
  - Delta subsides by compaction and other processes; under natural conditions it is balanced by sedimentation
  - Example for a growing delta: Wax Lake Delta
  - There is enough sediment to maintain the Mississippi delta

- Ecological connection is critical (sediment trapping etc.)
- Cellular modeling used to simulation channel development
- A lot of models used can be run on spreadsheets
- Experimental data (W. Kim) show that the shore line is very variable
- Natural variability of shoreline can be very high
- Three-dimensional numerical modeling of deltas (I. Overeem):
- Numerical modeling allow indirect experimentation on the influence of forcing functions and boundary conditions
- Mix of different grain sizes is modeled for each of the 3-D grid cells
- Rivers build up their own levees; filling up the riverbed can cause changes of the river channel
- Problems: quantitative understanding of different processes in 3-D still missing; models need to be tested better; time-average methodology vs. event-based methodology (latter still needs to be done)
- Some modeling groups also add vegetation into their simulations

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Day 3: Formulation of Joint Research Agenda and Next Steps

(Chair Marcel Endejan)

- Misc.
  - The 'Sea Around Us' project has produced a global estuary database (see http://www.seaaroundus.org/newsletter/Issue15.pdf for details)
  - James Syvitski will compare delta masks based on different delta definitions
- Short report on Data and Models
  - Sources of data & models were suggested by the workshop participants
  - Julia Ericsson presented a first draft list of suggested datasets/models
  - The resulting list is given in the Annex IV
- Split up into three breakout groups
  - (1) areas for new disciplinary and interdisciplinary research
  - (2) database development
  - (3) predictions/scenario development and modeling
- Results of Working Group I (Research Questions)
  - Distinction between natural dynamics (ecological, physical, eco-physical) and human dynamics
  - Developing a framework to 'mesh' social and natural science is a major research question
  - Discussion
    'risk of what? Further discussion needed – example of integrative science: John Robinson, UBC Vancouver (http://www.ires.ubc.ca/people/faculty/profiles/John_Robinson.html)
  - See Annex III for further details
- Results of Working Group II (Database)
  - global maps of wetlands, mangroves, sea grass, coral reefs are available (according to Si Simenstad)
  - Importance of datasets depend on concrete questions
  - Requirements analysis needed (What do we need?)
  - Main aim of the database needs to be discussed further (depends on research questions)
  - New datasets need to be prioritized
  - Delta boundaries are below the sea level (subaquaus delta)
  - Three main determinants of delta dynamics: Sediment supply; sea level; subsidence
  - Technical related issues: interoperability – LOICZ typology used format that can be used for statistical analysis on coastal ecosystems
  - Available datasets/databases need to be organized
  - Global vs. delta coverage datasets (delta: list of deltas/identify deltas)
  - Issues on spatial / temporal resolution and coverage need to be discussed (as well as the need for gridded or polygon data)
  - A possible way to develop a database is to concentrate on deltas (delta areas) and link them with associated basins, countries, etc. (do not cookie-cut datasets!)
  - See csdms website for further details (e.g. about relevant datasets); http://csdms.colorado.edu/meetings/talks/Deltas_2007/database_development.htm
- Results of Working Group III (Modeling and Scenario Development)
  - There is an overlap with the Working Group II on the database development

  - The use of fishery database to assess ecosystem heath was suggested
  - Available scenario datasets, e.g. about sea level, should be used/utilized
  - An eco-tourism region might used as a case study region
  - See Annex III for further details
- Plans for further activities and summary of accomplishment (Hartwig Kremer)
  - How achieve a holistic approach and to integrate LOICZ and GWSP and CSDMS research? LOICZ: links with continental shelves; governmental baseline development; GWSP: dealing with the whole basin; Continue as a joint project between LOICZ and GWSP
  - Group I: Ideas should be sorted out in a white paper (e.g. an EOS publication) in about 6 months; everybody should write a 1 or 2 page description to express own interest in the effort
  - Group II: What kind of vulnerability data is out there (e.g. through IHDP)? Question needs to be answered.
  - Group III: to achieve a holistic approach, we could see what is coming out of the paper and create further activities; keep communicating
  - Suggested early products: white paper; announcement that we have a global problem; indicator building using Charles Vörösmarty's tool with a small group facilitated by GWSP IPO
  - Aim of paper: communicate outside and guide us how to work on the case studies; use white paper to produce something that can be used to make a proper paper and to raise funding

- Further comments and suggestions
  - Human impacts on deltas become very obvious at the meeting
  - We should not try to tackle the whole world with a single database; focus is needed; we should not put together too many variables
  - A lot of good questions were raised and there is room for development and integration
  - Meetings to update on new developments would be very helpful
  - Writing a research agenda, e.g. entitled 'a research agenda for deltas at risk in the context of GEC using three case studies'?, might be helpful to proceed the effort
  - Put together a 200-1000 word article for the Newsletters (GWSP, LOICZ, CSDMS, …); Ilan Kelman volunteer to take the lead
  - There is currently no research foundation and no journals on deltas
  - There are a lot of case studies available that we could bring together for a special issue (Liviu could lead this effort)
  - 1st priority: 200-1000 word article (based on 1 pagers from everybody as supporting documents providing visions, thoughts, ideas), then Science article, then probably a special issues
  - A joint working group with LOICZ/GWSP/CSDMS (NCED as partner) may be establishing