Developments in Subdomain Modeling

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Subdomain Modeling

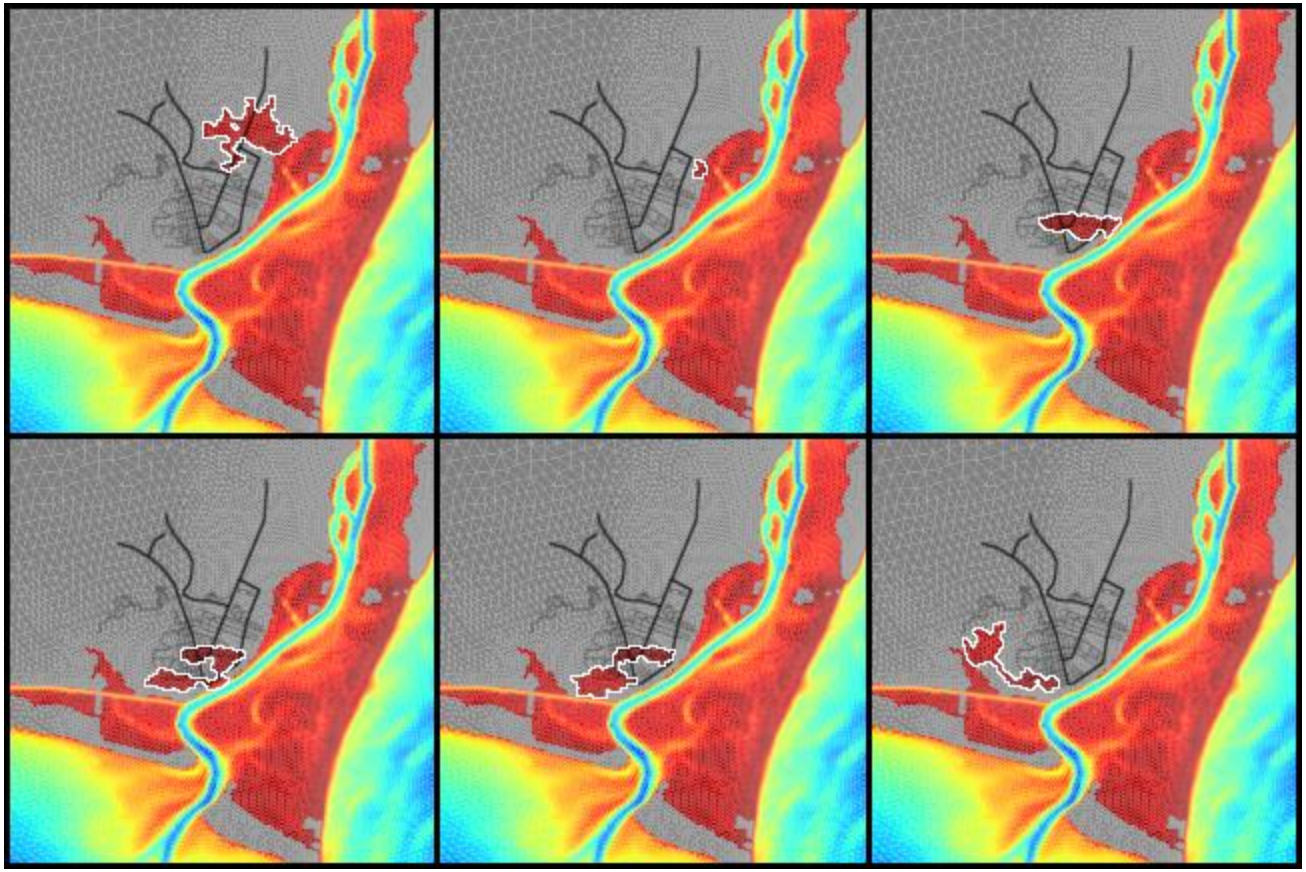
A localized approach for storm surge simulation, subdomain modeling allows modelers to perform repeated simulations with local variations to the original domain, using less computational effort (Altuntas, 2012).

- Hydrodynamic models are used to assess the effects of storm surge in hurricane-prone regions.
- Computational cost may be prohibitive when multiple engineering design and failure scenarios are to be considered.
- The approach is an exact reanalysis technique for assessing multiple scenarios on smaller domains, so long as the subdomain is large enough to fully contain the altered hydrodynamics.

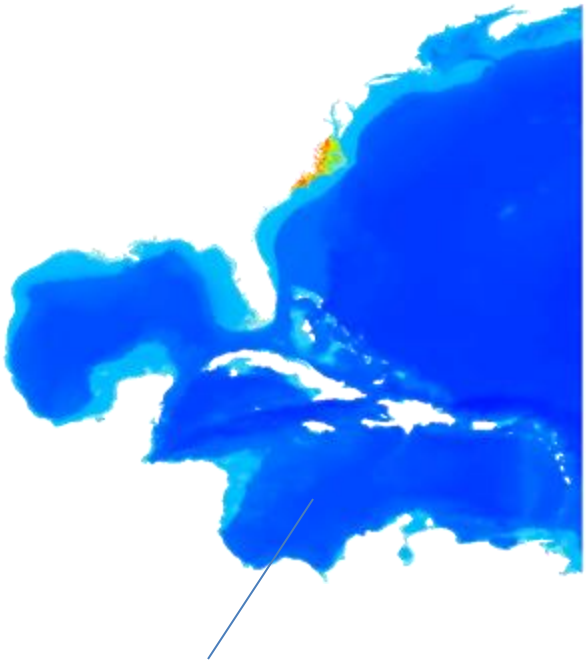
Overview

1. Introduction
2. Workflow of Subdomain Modeling
3. Developments in Subdomain Modeling
4. SMT: A Graphical Interface for Subdomain Modeling
    - An introductory example
5. Adaptive Subdomain Modeling
6. Resources

An array of possible levee failures.



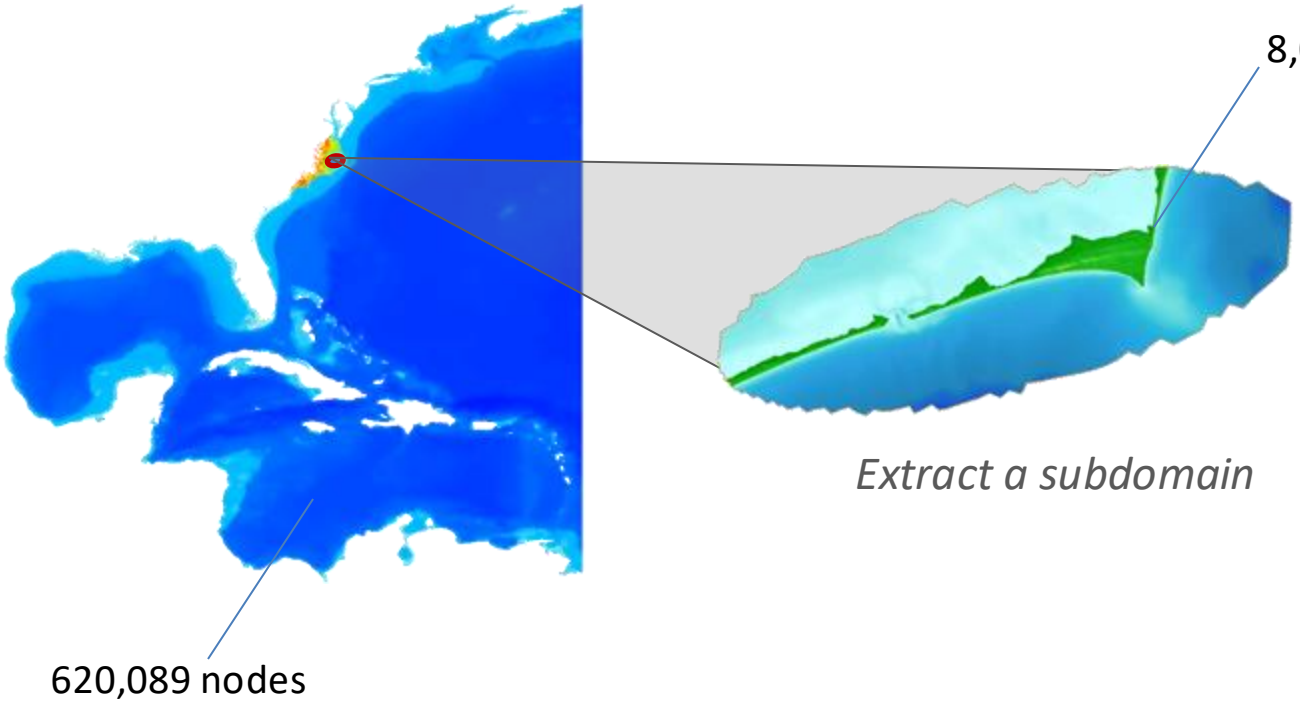
Design process



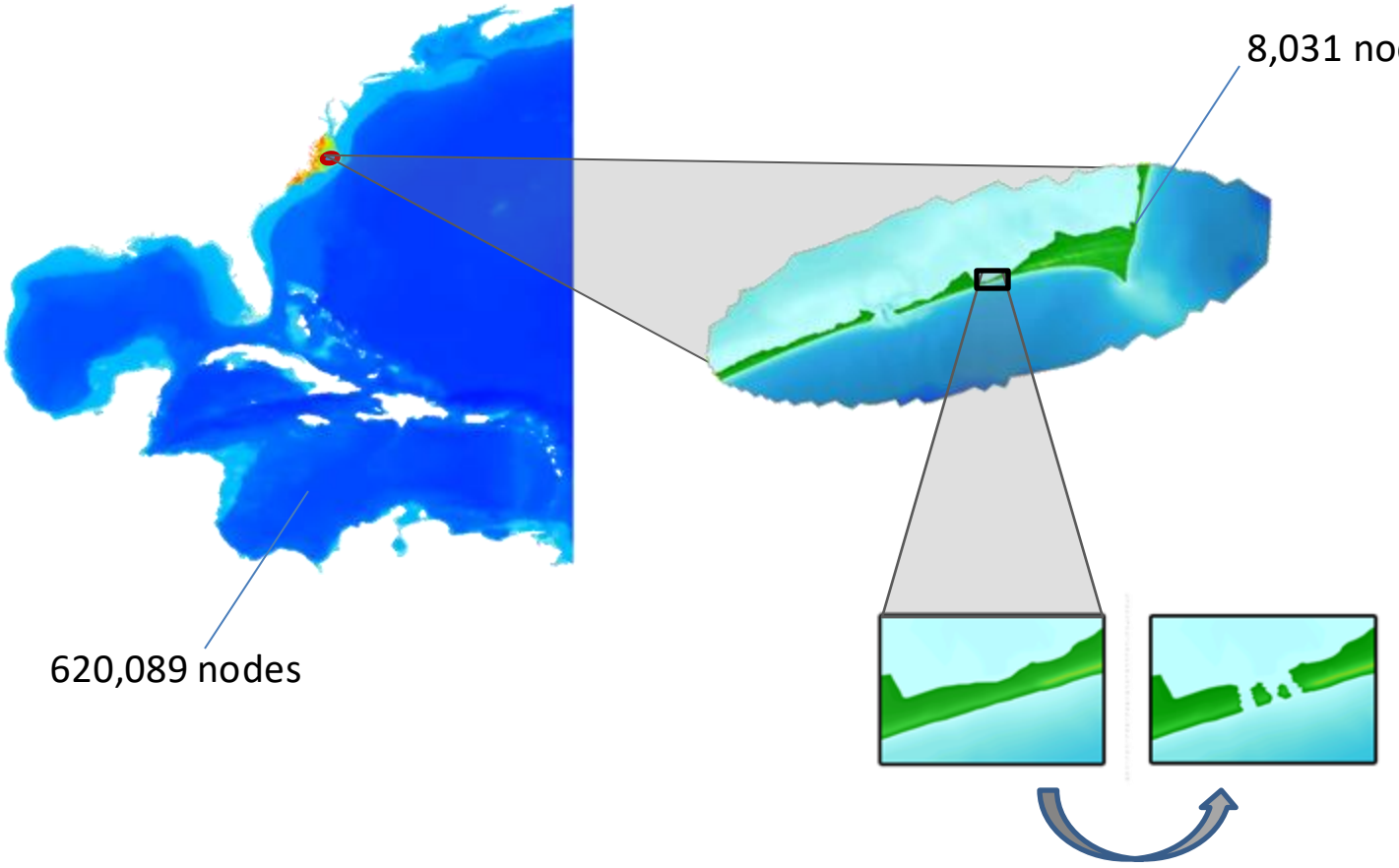
620,089 nodes

Begin with a full domain

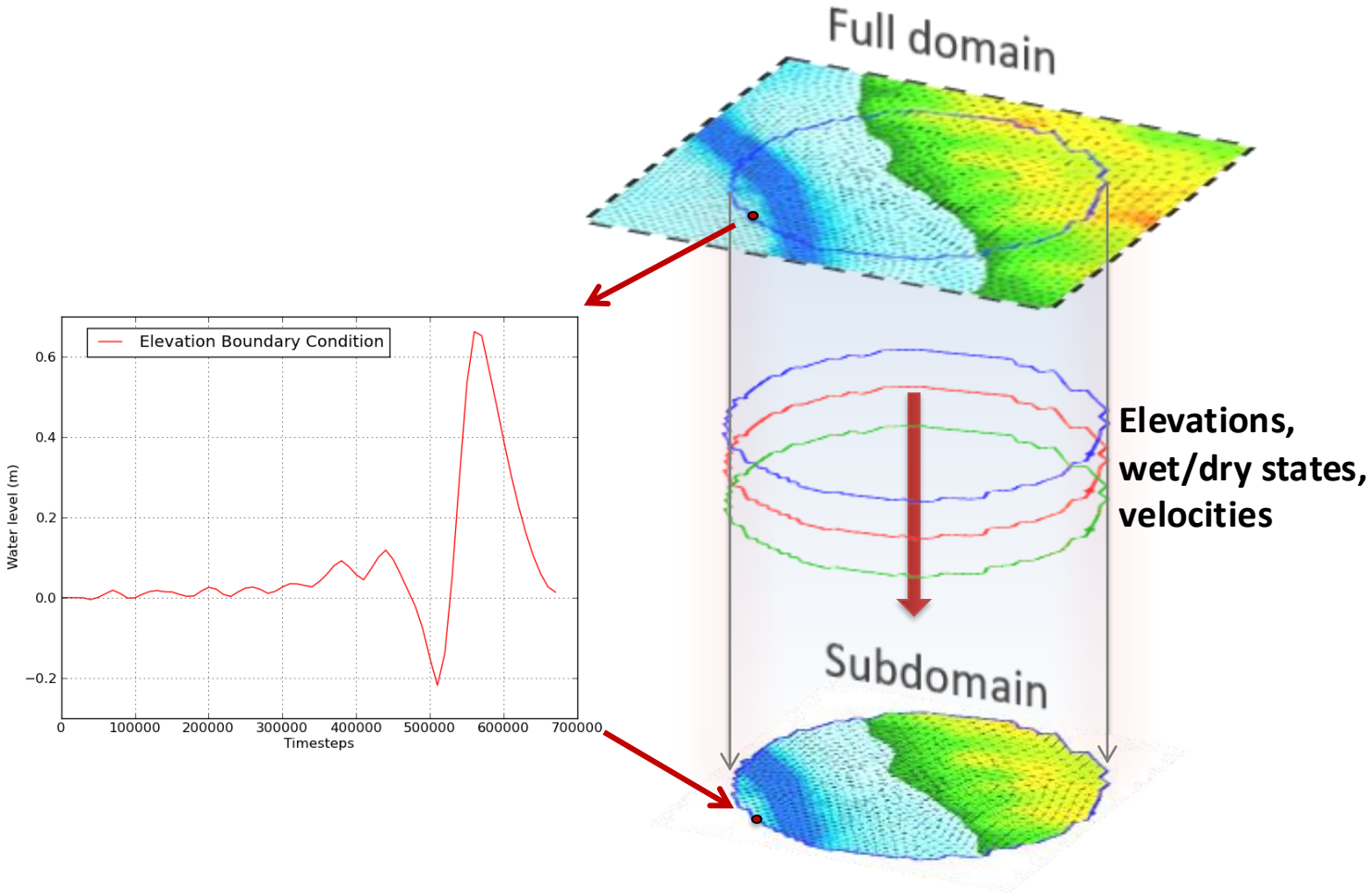
Design process



Design process



Subdomain Modeling: A one-way hand-off of boundary conditions



Overview of the Subdomain Modeling Approach

1. **Construct a subdomain**
   - Locate regions of interest, subdomains, within a sizable original domain, full domain
   - Perform the full domain run to generate boundary conditions
   - Preprocess boundary condition files
   - Perform the subdomain runs
2. **Generate engineering scenarios**
   - Verify the subdomain
   - Apply local alterations
   - Perform the subdomain runs with alterations
   - Verify the alterations

1. Construct a subdomain

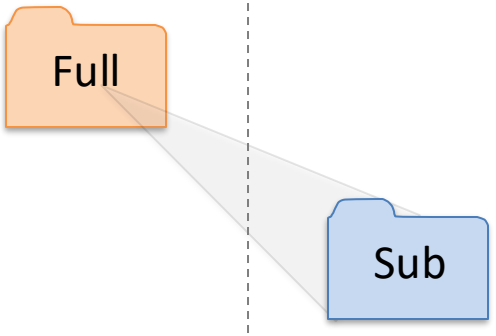
0 Begin with an ADCIRC model

1. Construct a subdomain

0 Begin with an ADCIRC model

↓

1 Generate a subdomain



1. Construct a subdomain

0 Begin with an ADCIRC model

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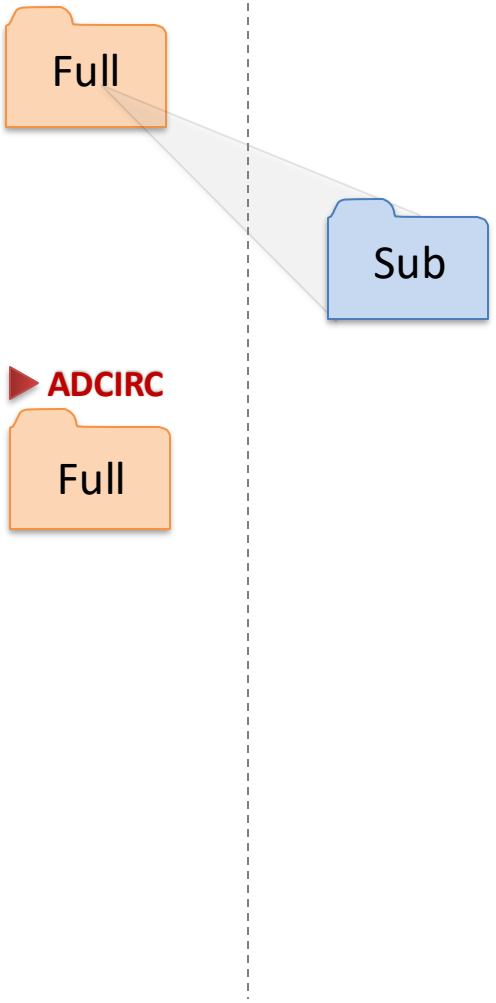
1 Generate a subdomain

↓

2 Run ADCIRC on full domain



1. Construct a subdomain

0 Begin with an ADCIRC model

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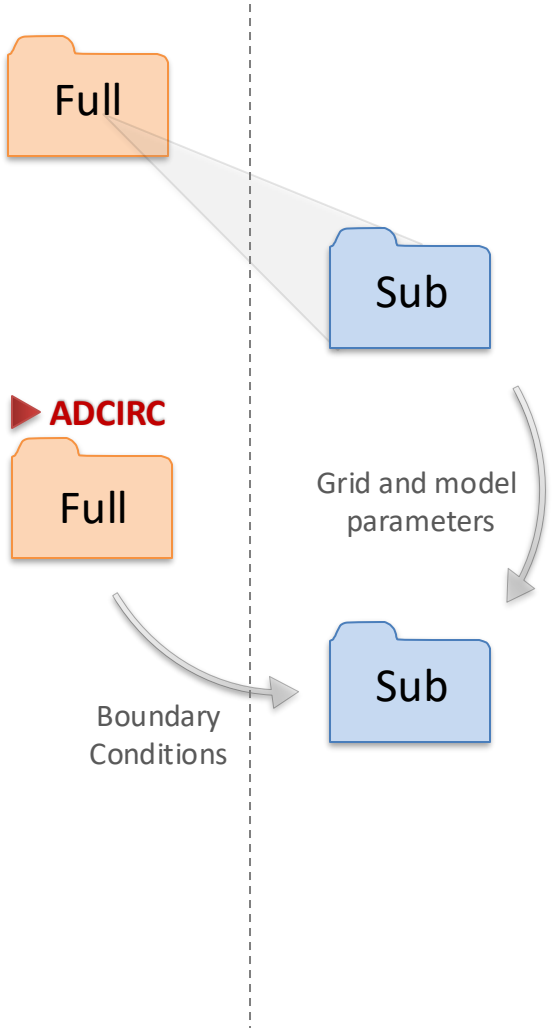
1 Generate a subdomain

↓

2 Run ADCIRC on full domain

↓

3 Extract boundary conditions



1. Construct a subdomain

0 Begin with an ADCIRC model

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1 Generate a subdomain

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2 Run ADCIRC on full domain

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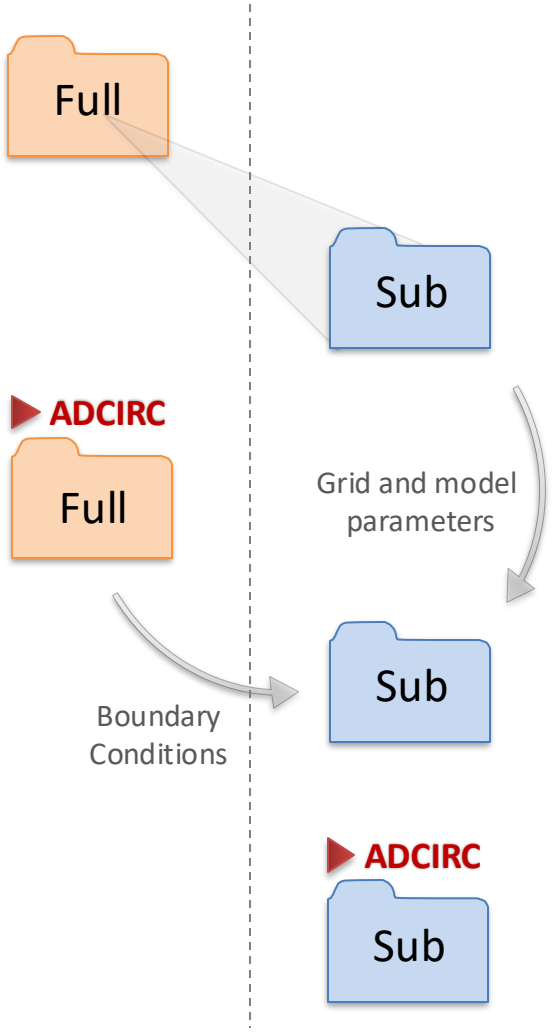
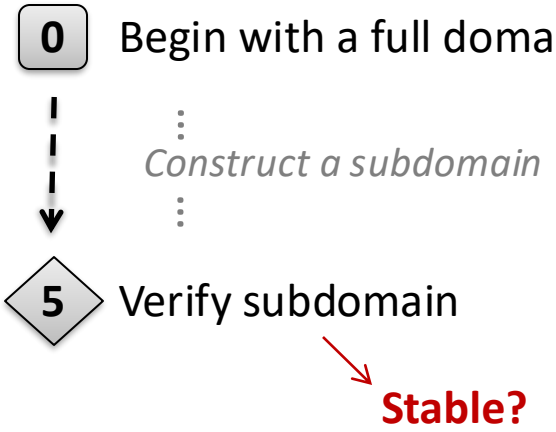
3 Extract boundary conditions

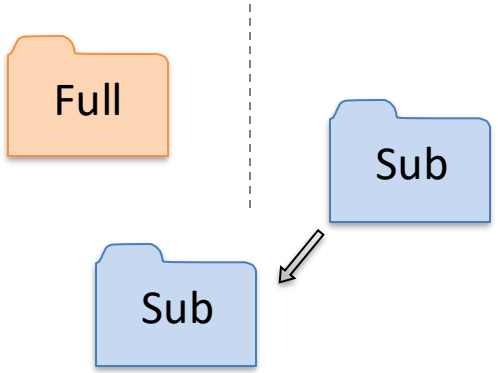
↓

4 Run ADCIRC on subdomain

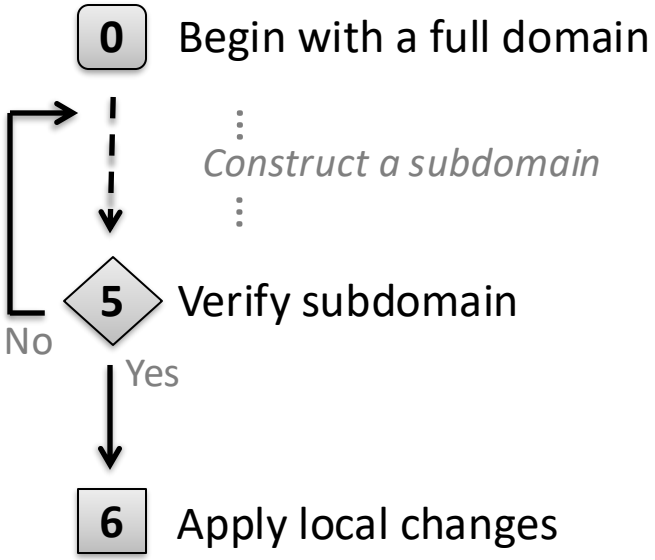


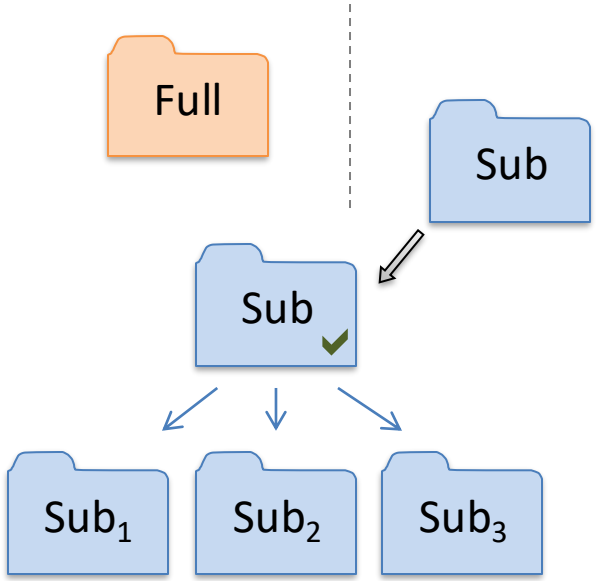
2. Generate engineering scenarios



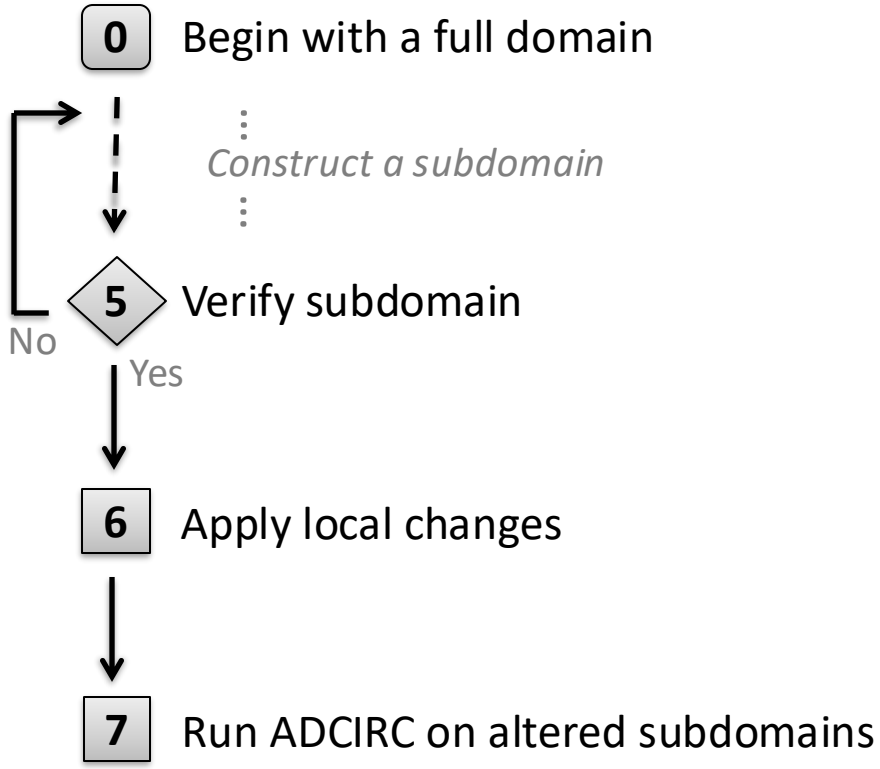


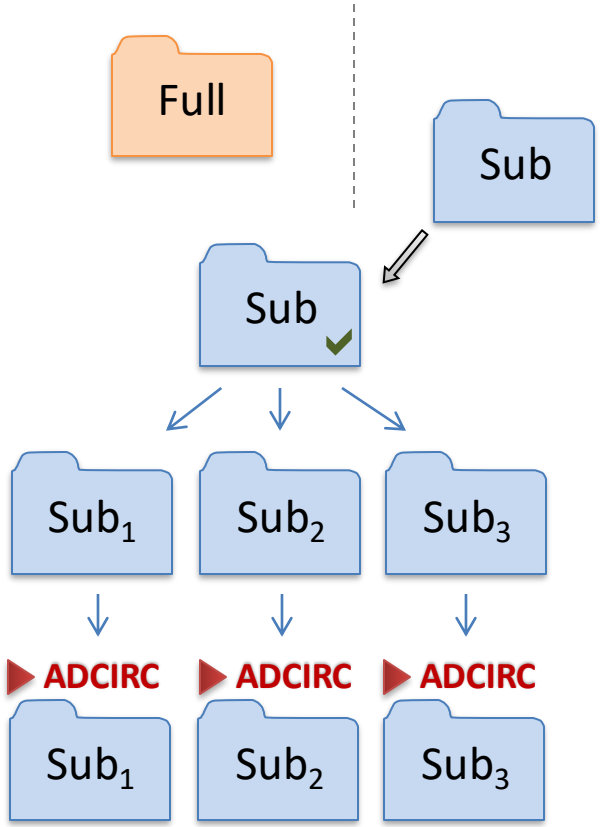
2. Generate engineering scenarios





2. Generate engineering scenarios





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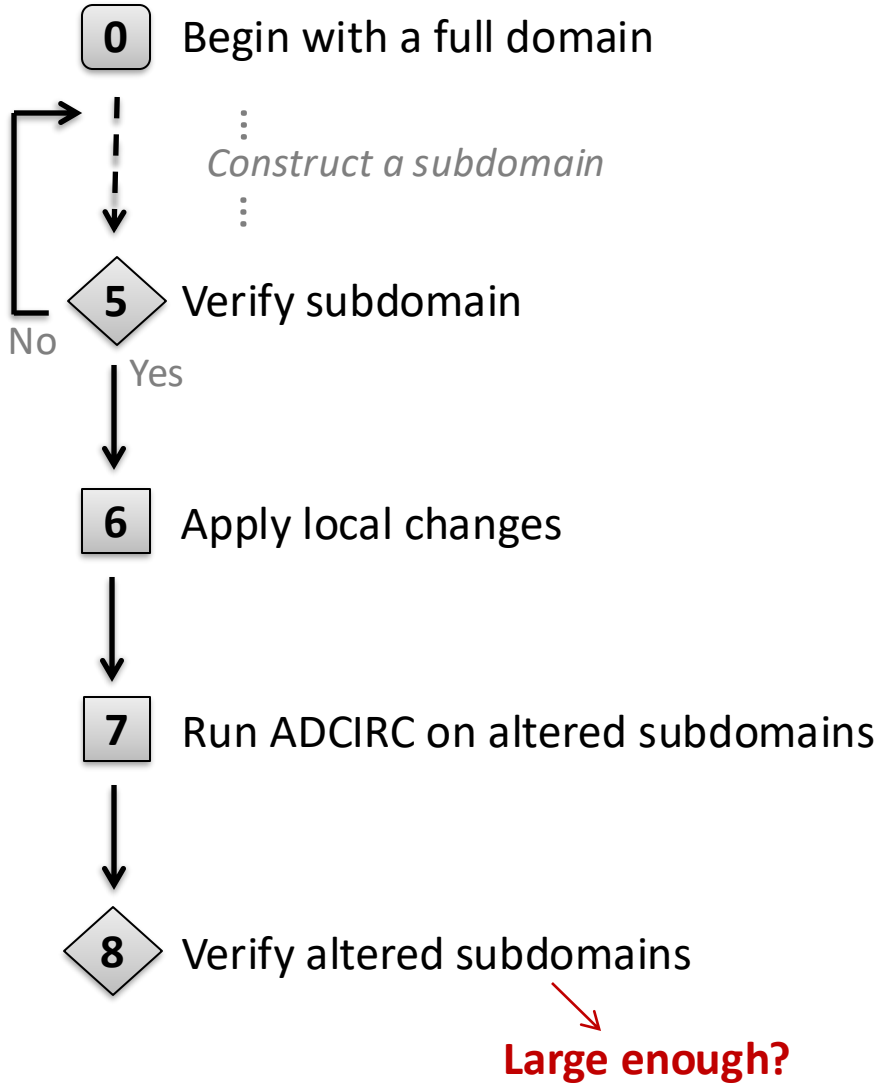

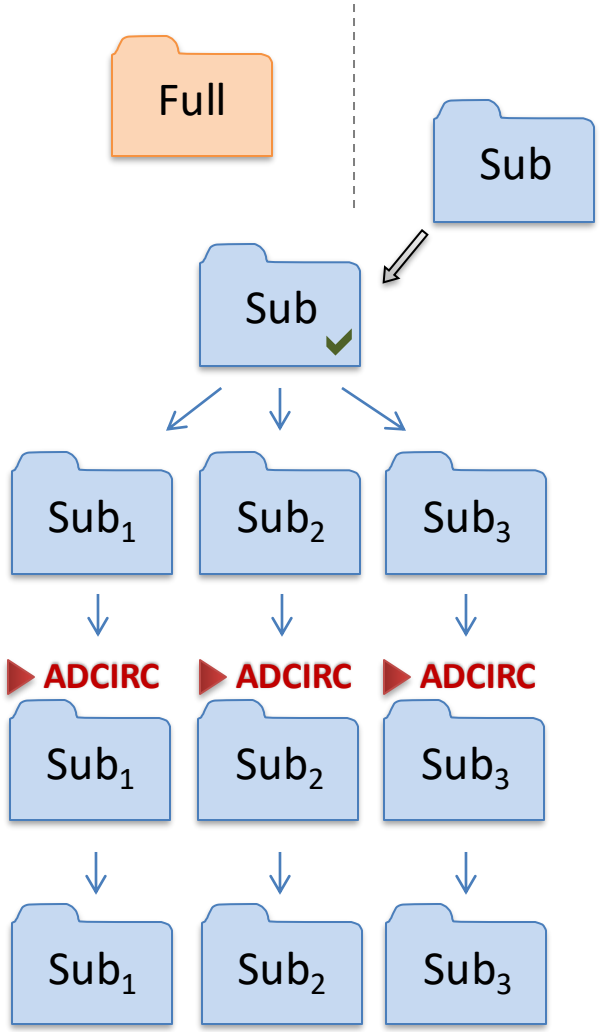

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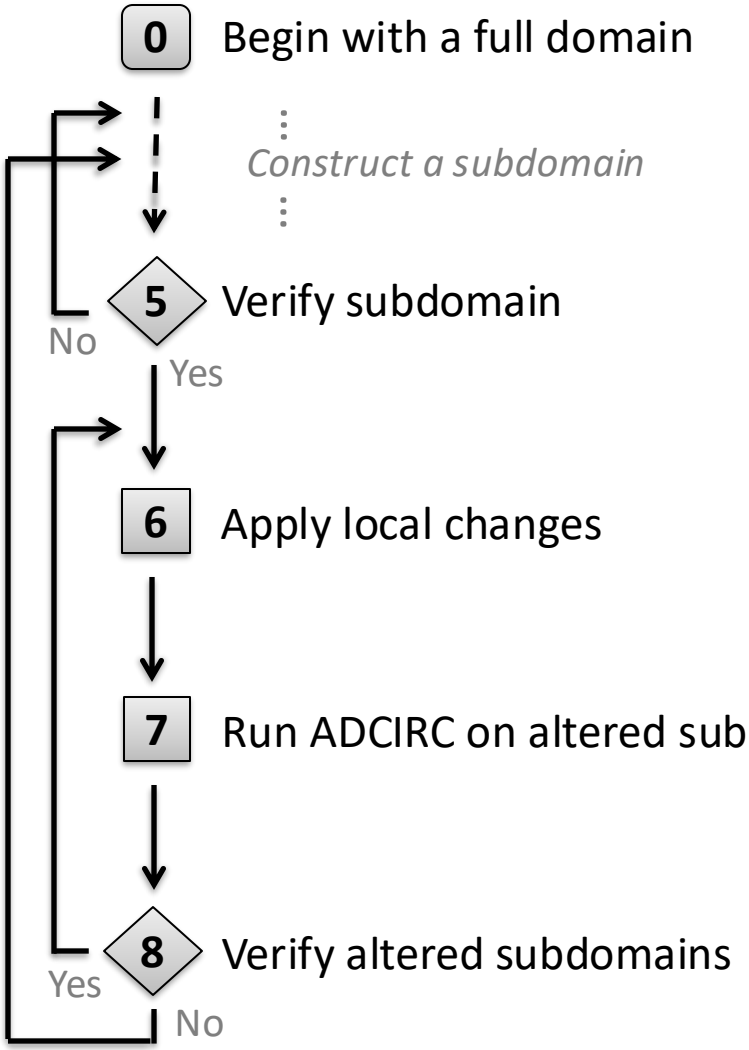
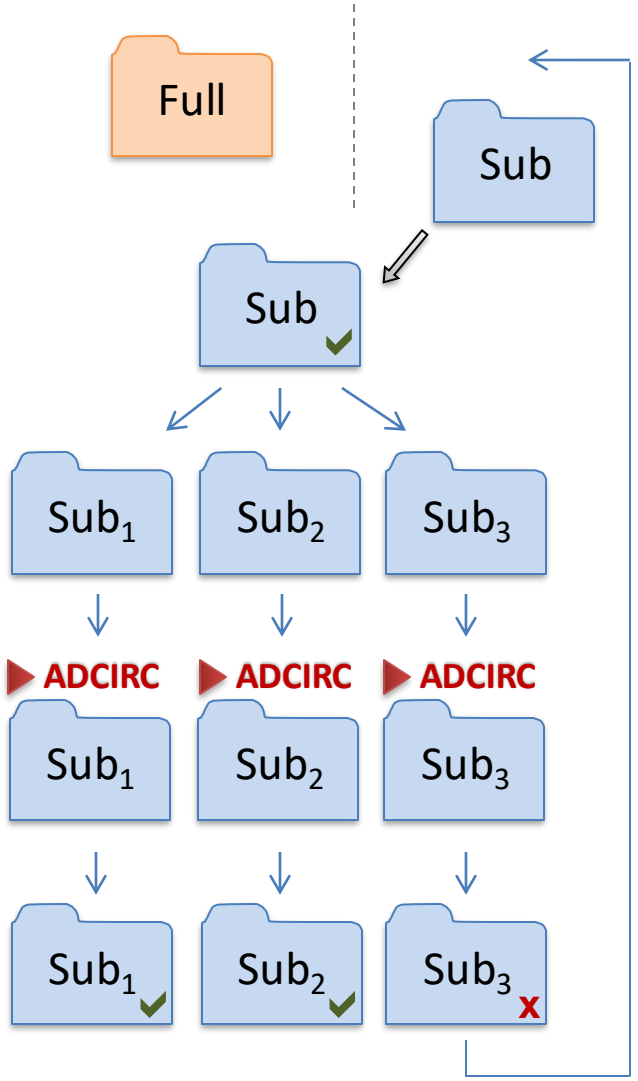




Additional files for ADCIRC Subdomain Modeling

1. **fort.015** – *Subdomain modeling control file*
   - Configuration file for both full domain and subdomain runs.
   - Contains parameters controlling the subdomain modeling approach and options for additional output files.

2. **fort.019** – *Boundary conditions file*
   - Contains elevations, wet/dry states and velocities for subdomain boundary nodes.
   - Extracted from fort.065 files

3. **fort.065** – *Full domain output files*
   1. Contains elevation, wet/dry state and velocity outputs of specified full domain nodes (corresponding to subdomain boundary nodes)
   2. Used to generate boundary conditions files

4. **py.140, py.141** – *Node and Element mapping from subdomain to full domain, respectively*

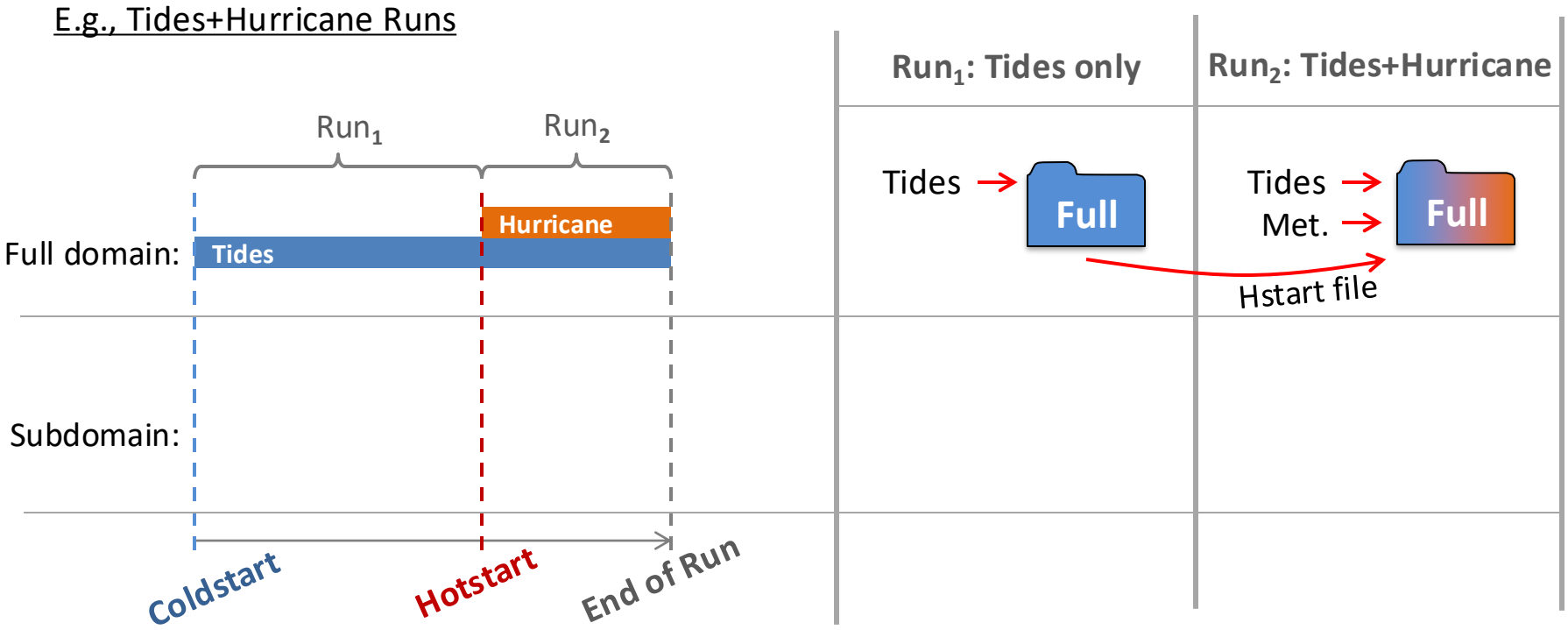
Developments in Subdomain Modeling Approach

- **Hotstarting feature** for subsequent subdomain runs is modified.
- Boundary condition modifications:
  - Performance improvement in the **wetting and drying** component
  - Minor bug fix in the **velocity** component
- Extensive set of **tides+hurricane** test cases performed.
- ADCIRC subdomain branch **merged** into the trunk of ADCIRC repository.

Hotstarting

During the runtime, the hotstarting feature can be used to make changes in the model configuration at a specified timestep. (e.g., adding meteorological forcing)

- Hotstarting scheme of the subdomain modeling is modified to accurately implement this approach for subsequent subdomain runs.



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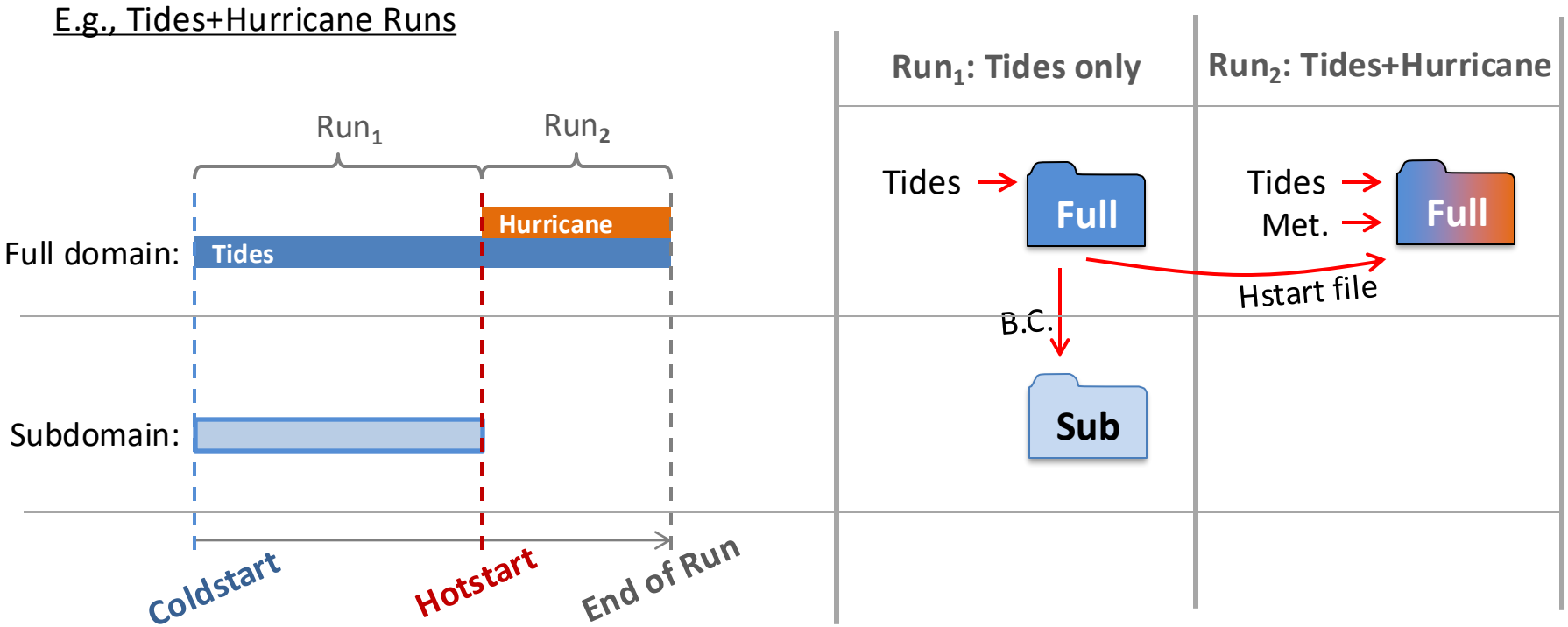

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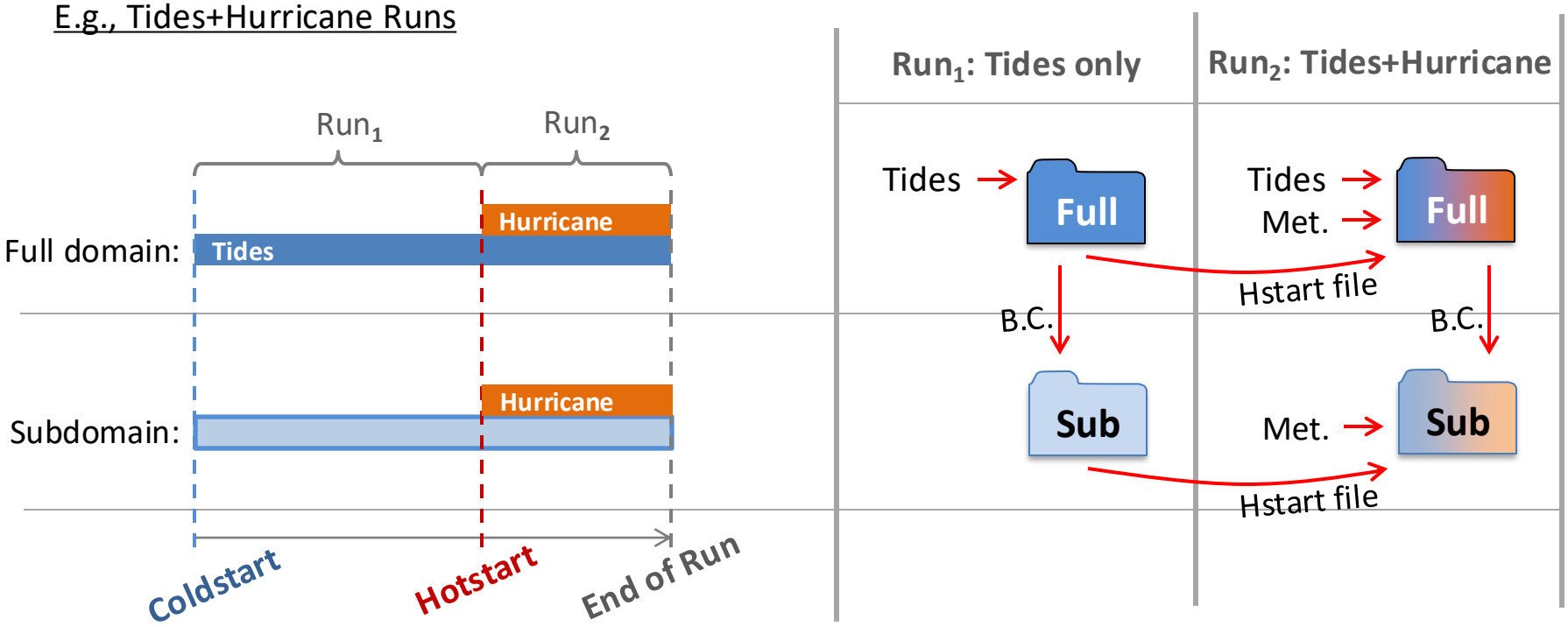
E.g., Tides+Hurricane Runs



Wetting and Drying

Wetting and Drying component of the boundary conditions refined for subdomain runs.

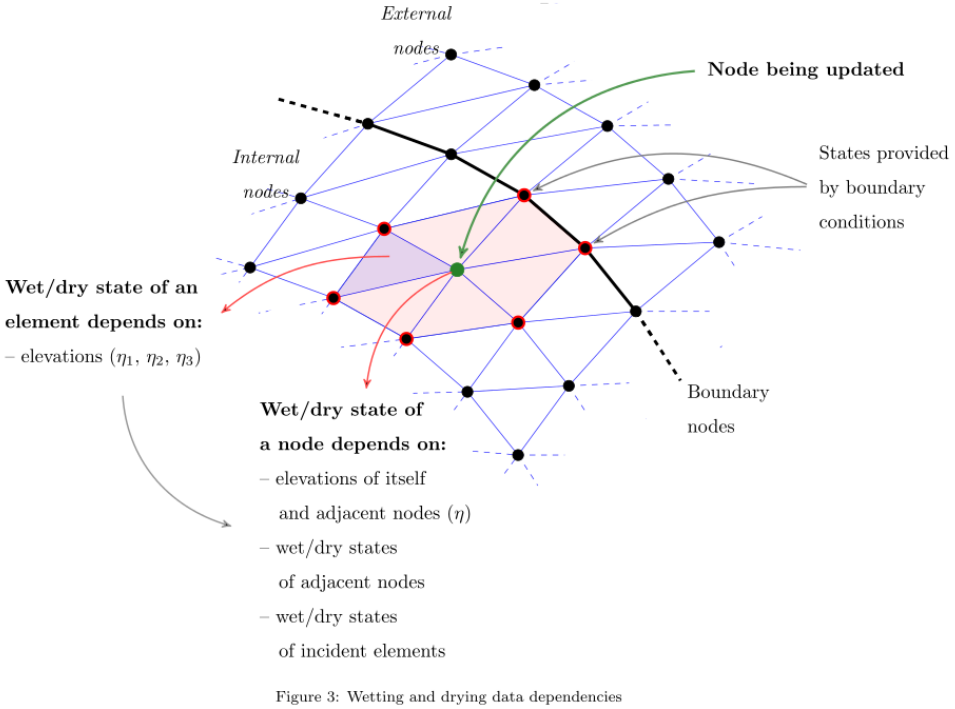
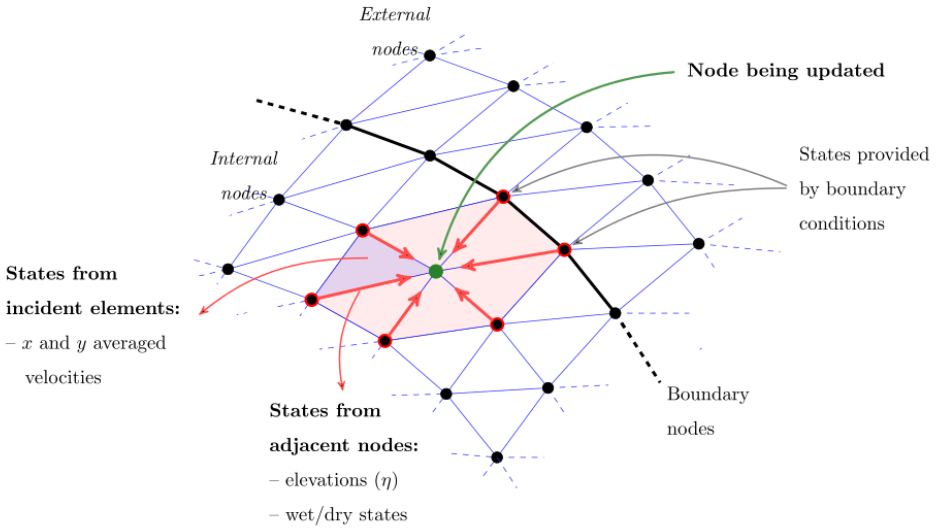


Figure 3: Wetting and drying data dependencies

- Locations in the algorithm at which wet/dry states need to be forced determined.
- Redundant wetting and drying forcings in the algorithm removed.
- Accuracy of the algorithm for subdomain runs verified.

Momentum Equations

Similarly, momentum equation and its domain dependency refined for subdomain nodes at or near the boundaries.

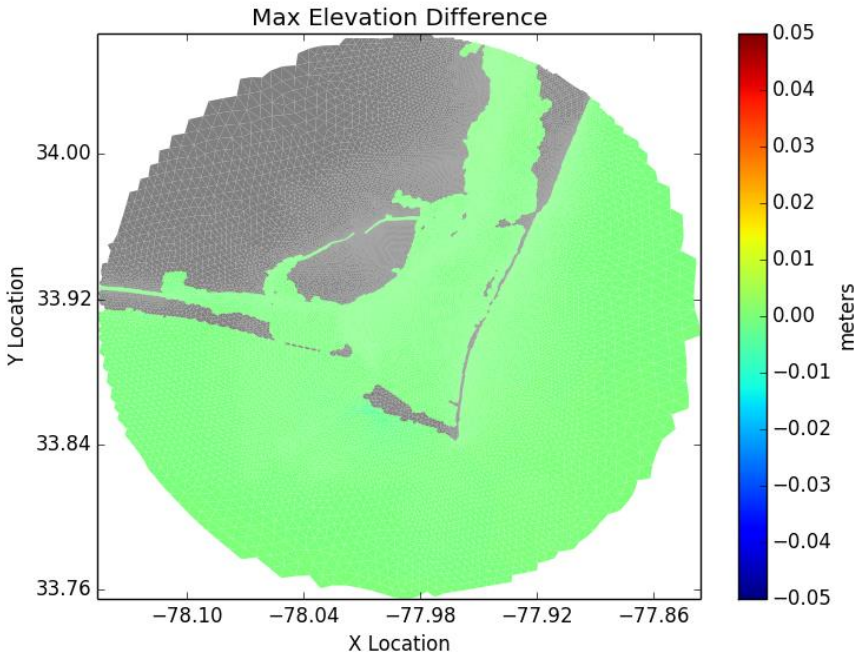


- A bug causing a phase difference between the calculated fluxes of subdomain boundary nodes and corresponding full domain nodes detected and fixed.

Tides+Hurricane Runs

The accuracy of the method confirmed for simulations with combined effects of hurricanes and tidal constituents.

Test Case: Hurricane Irene (2011)

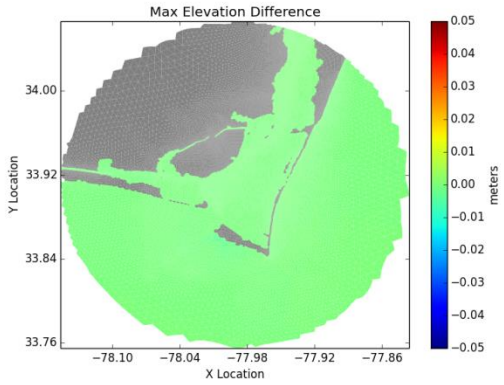


- **Mesh:** NC9
- **Full domain:**
  #Nodes: 622946
  #Elements: 1230430
- **Subdomain:**
  #Nodes: 31500
  #Elements: 62697
- **Tidal Constituents:**
  M2, S2, N2, K2, K1, O1, P1, and Q1

Tides+Hurricane Runs

The accuracy of the method confirmed for simulations with combined effects of hurricanes and tidal constituents.

Test Case: Hurricane Irene (2011)



	FULL	SUB	%
No. of nodes	622946	31500	5.05
Tides+Hurr **Runtime** (CPU-hour)	2090	73	3.49

Merging Subdomain Module

Subdomain branch of ADCIRC merged into the recent ADCIRC release. Several adjustments and modifications made:

- Subdomain modeling files promoted to modules.
- Namelist **`subdomainModeling`** introduced.
- Several bugs caused by the transition to namelist implementation diagnosed and resolved.
- Several bugs regarding the decomposition of the input files for parallel ADCIRC runs diagnosed and resolved.
- Merged ADCIRC code tested, confirming that, when subdomain modeling is active, the merged code works the same as the subdomain branch.

Merging Subdomain Module

Namelist **`subdomainModeling`** introduced. The variable **`subdomainOn`** is required to be set to `True` to activate subdomain modeling features.

Quarter Annular Problem – fort.15:

aaltunt@takanami:~/research/subdomain/runs/testTrunk/qa

```
3                                   ! TOTAL NUMBER OF ELEVATION RECORDING STATIONS
  80668.4   12256.0                 ! COORD. OF ELEVATION STATION
 126205.2   10686.9
  51131.1   88884.3
1 0.0 5.0  3                        ! NOUTV,TOUTSV,TOUTFV,NSPOOLV
3                                   ! TOTAL NUMBER OF VELOCITY RECORDING STATIONS
  80668.4   12256.0                 ! COORD. OF VELOCITY STATION
 126205.2   10686.9
  51131.1   88884.3
1 0.0 5.0 3                         ! NOUTGE,TOUTSGE,TOUTFGE,NSPOOLGE
1 0.0 5.0 3                         ! NOUTGV,TOUTSGV,TOUTFGV,NSPOOLGV
1                                   ! NHARFR
M2                                  ! HAFNAM(I)
0.0001405257 1.0 0.0                ! HAFREQ(I=1),HAFF(I=1),HAFACE(I=1)
4.00  5.00  1  0.0                  ! THAS,THAF,NHAINC,FMV
1 1 1 1                             ! NHASE,NHASV,NHAGE,NHAGV
1 512                               ! NHSTAR,NHSINC
1  0  1.E-5  25                     ! ITITER, ISLDIA, CONVCR, ITMAX -
&subdomainModeling subdomainOn=1 /
                                                              65,34         Bot
```

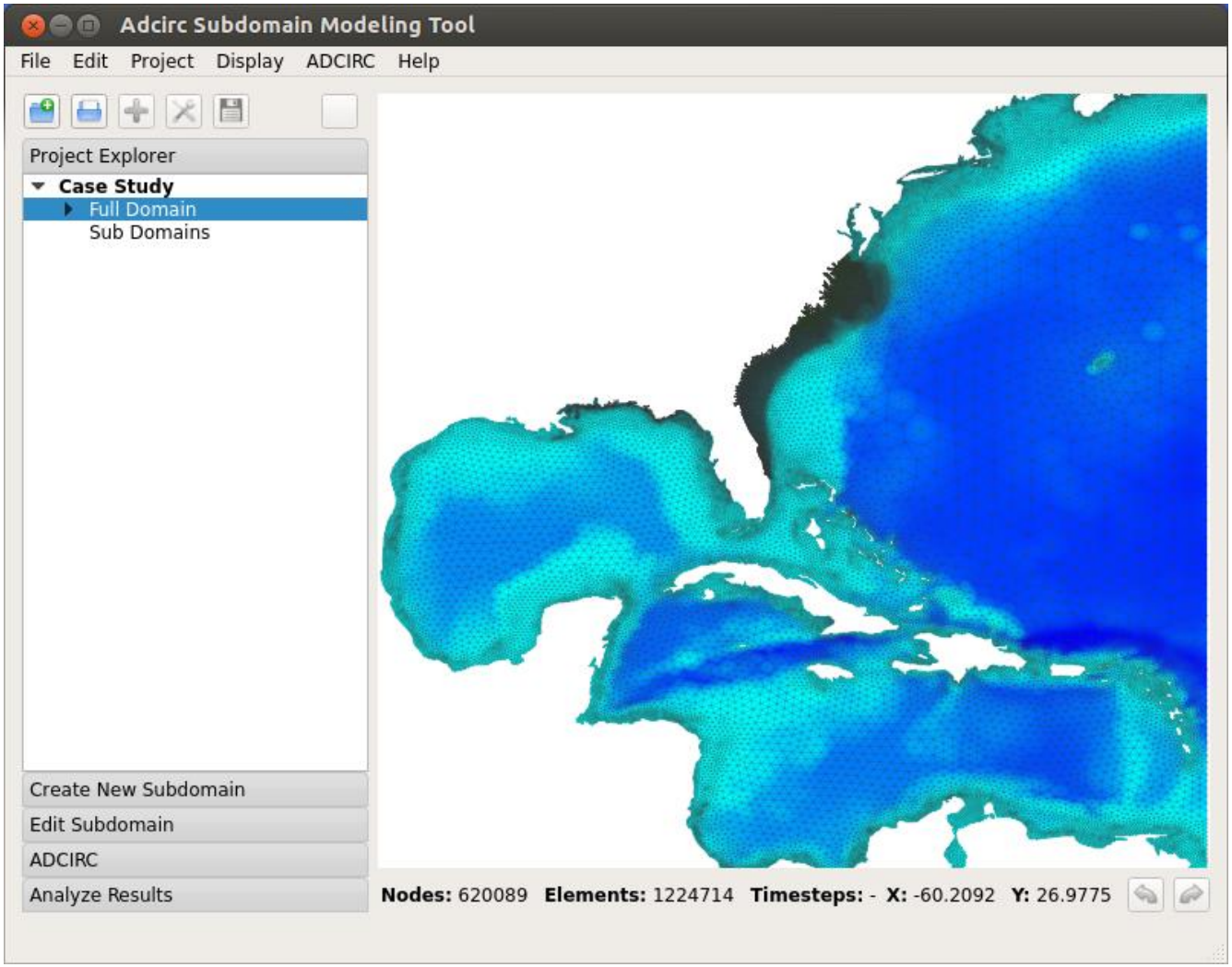
SMT: A graphical interface for ADCIRC Subdomain Modeling

SMT streamlines the pre- and post-processing requirements of the subdomain modeling technique (Dyer, 2013).

The tool automates the workflow of constructing subdomains and visualizing ADCIRC meshes.

Its project manager tool allows modelers to create and run a large number of subdomains from a single full domain.

SMT: A graphical interface for ADCIRC Subdomain Modeling



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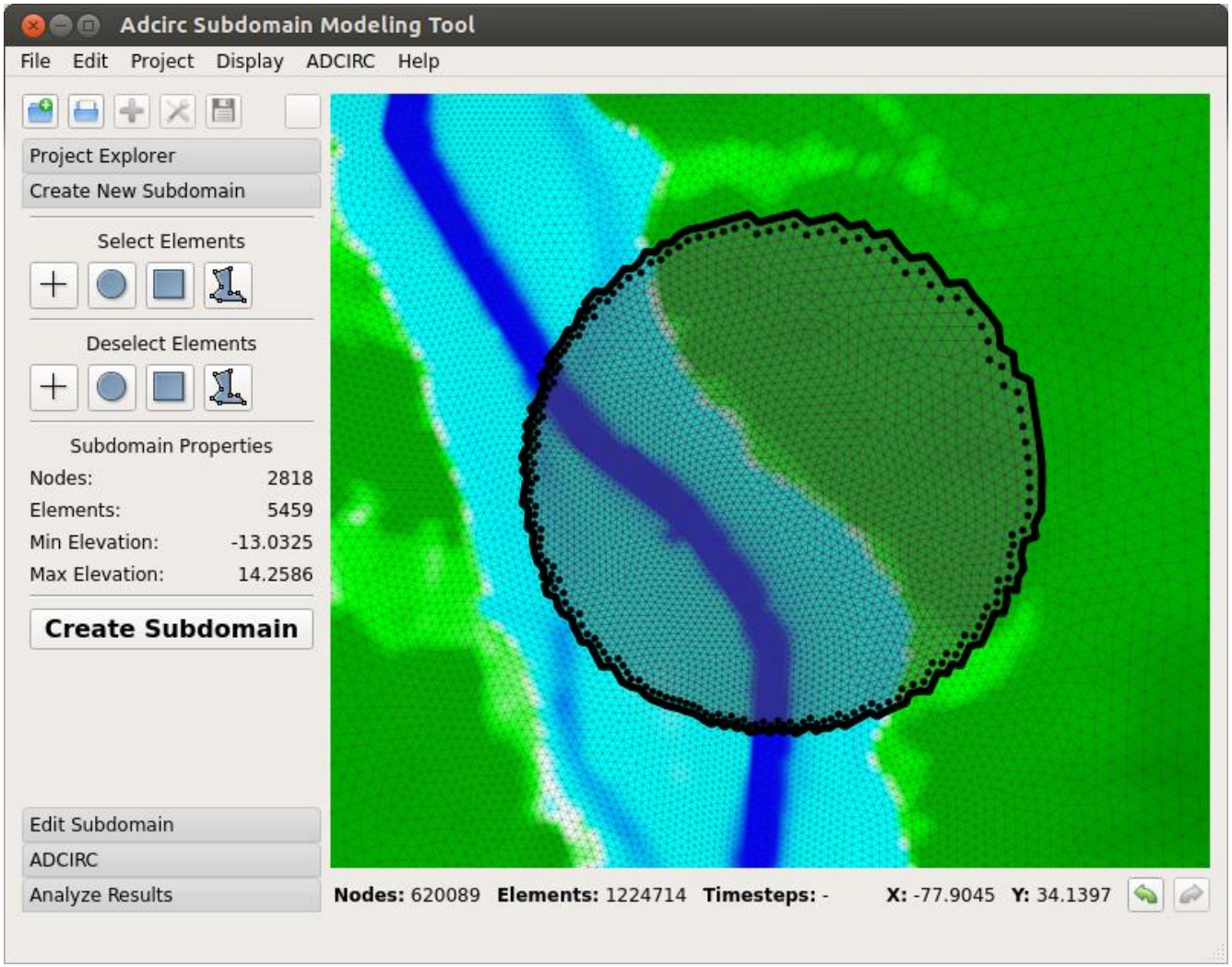

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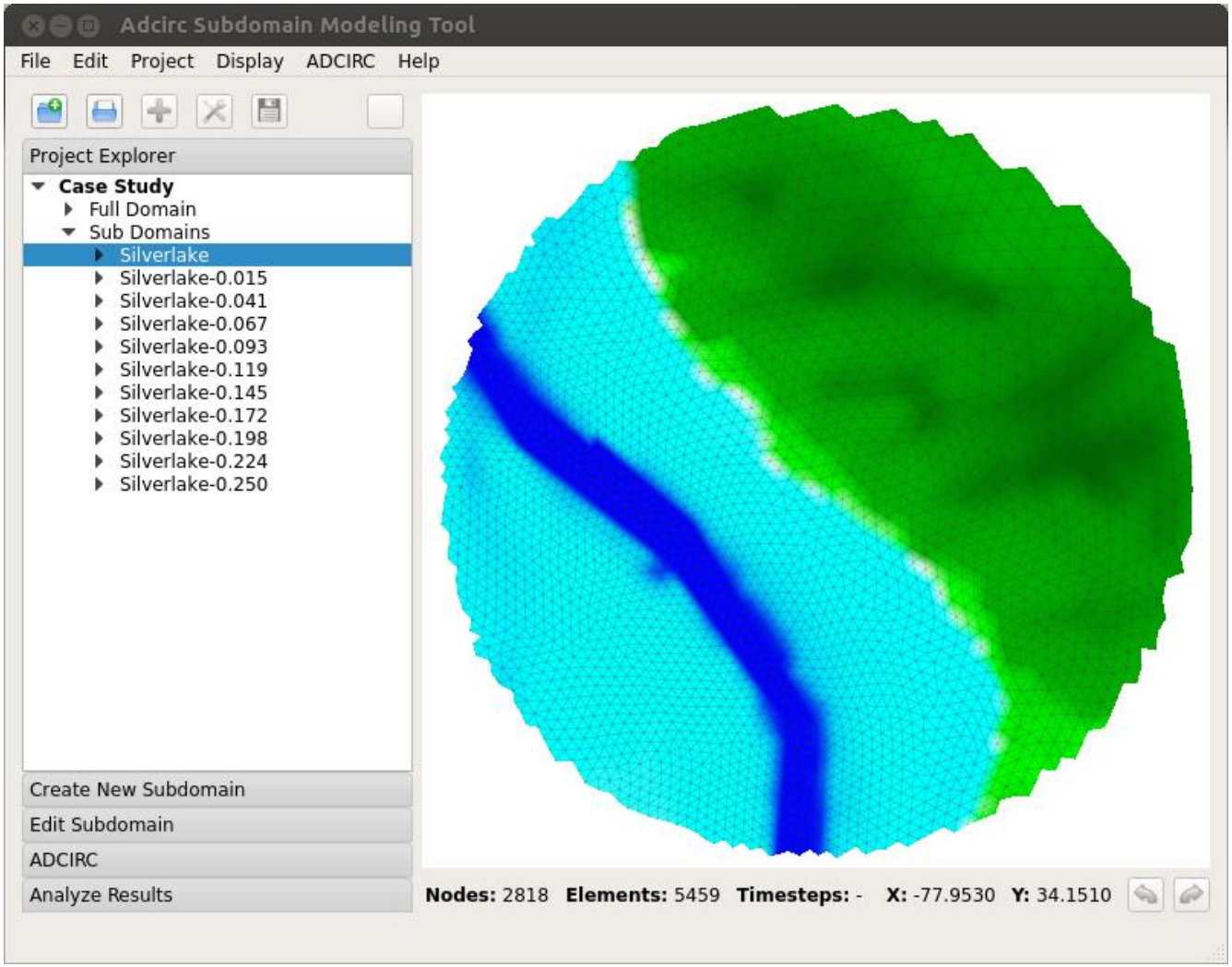

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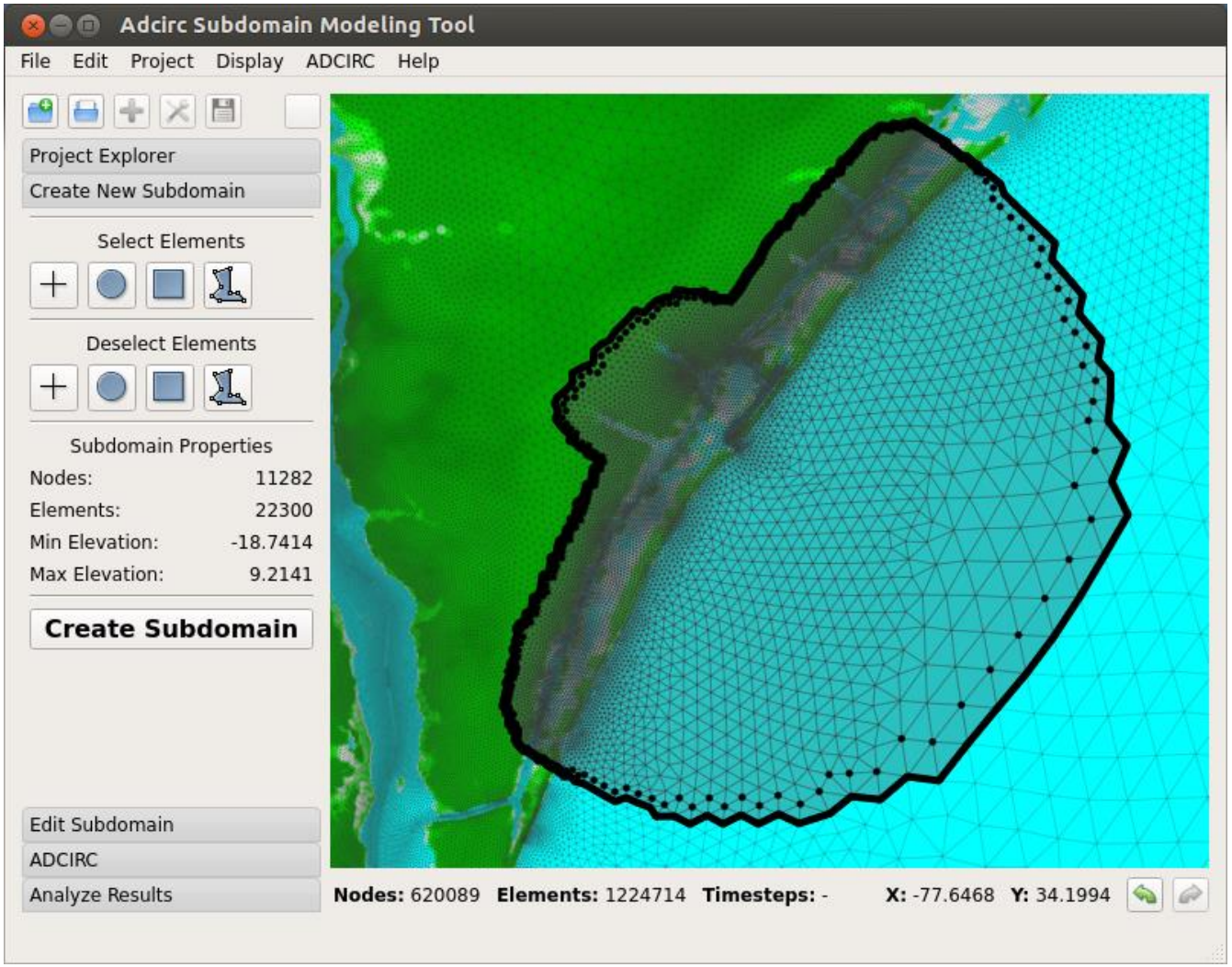

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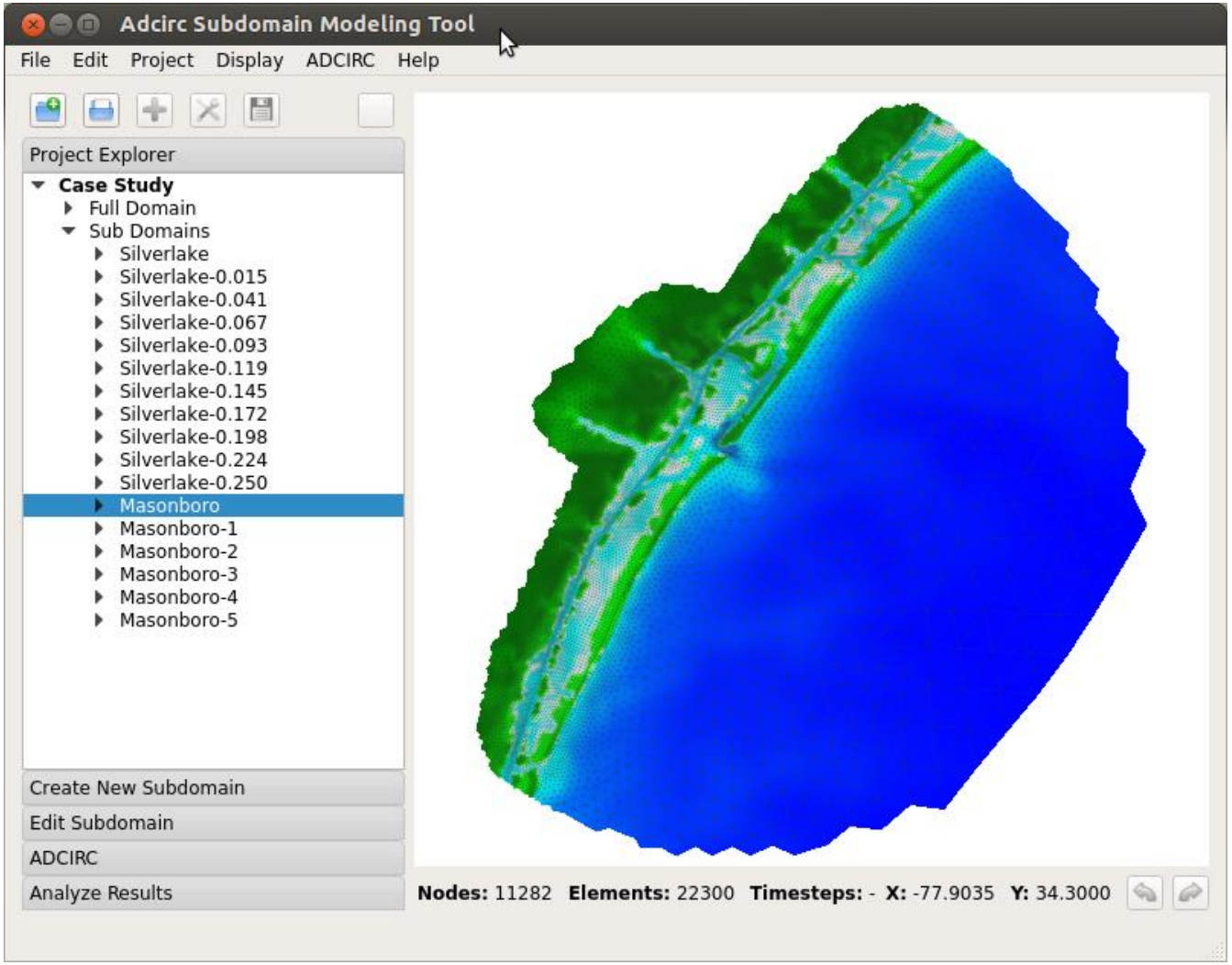
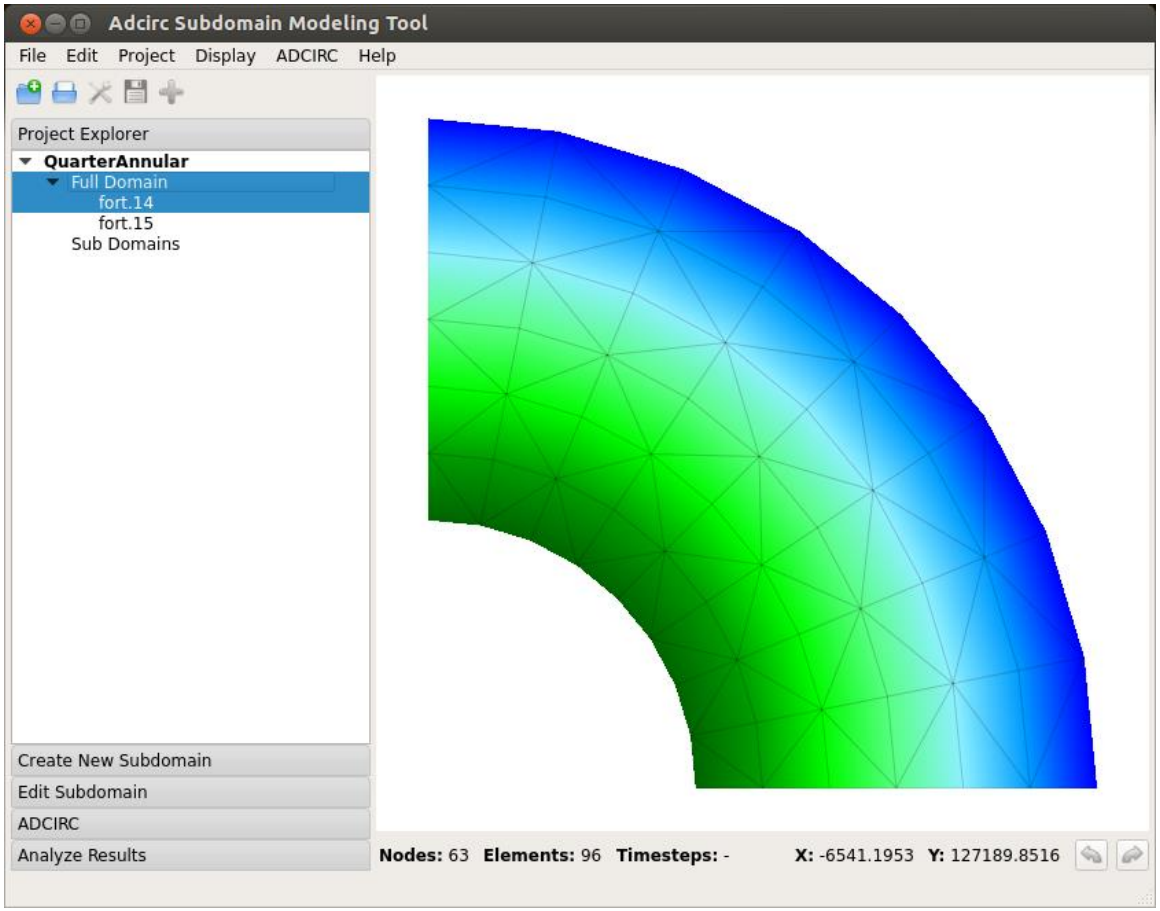


An introductory example: Quarter Annular Problem

0 Begin with an ADCIRC model



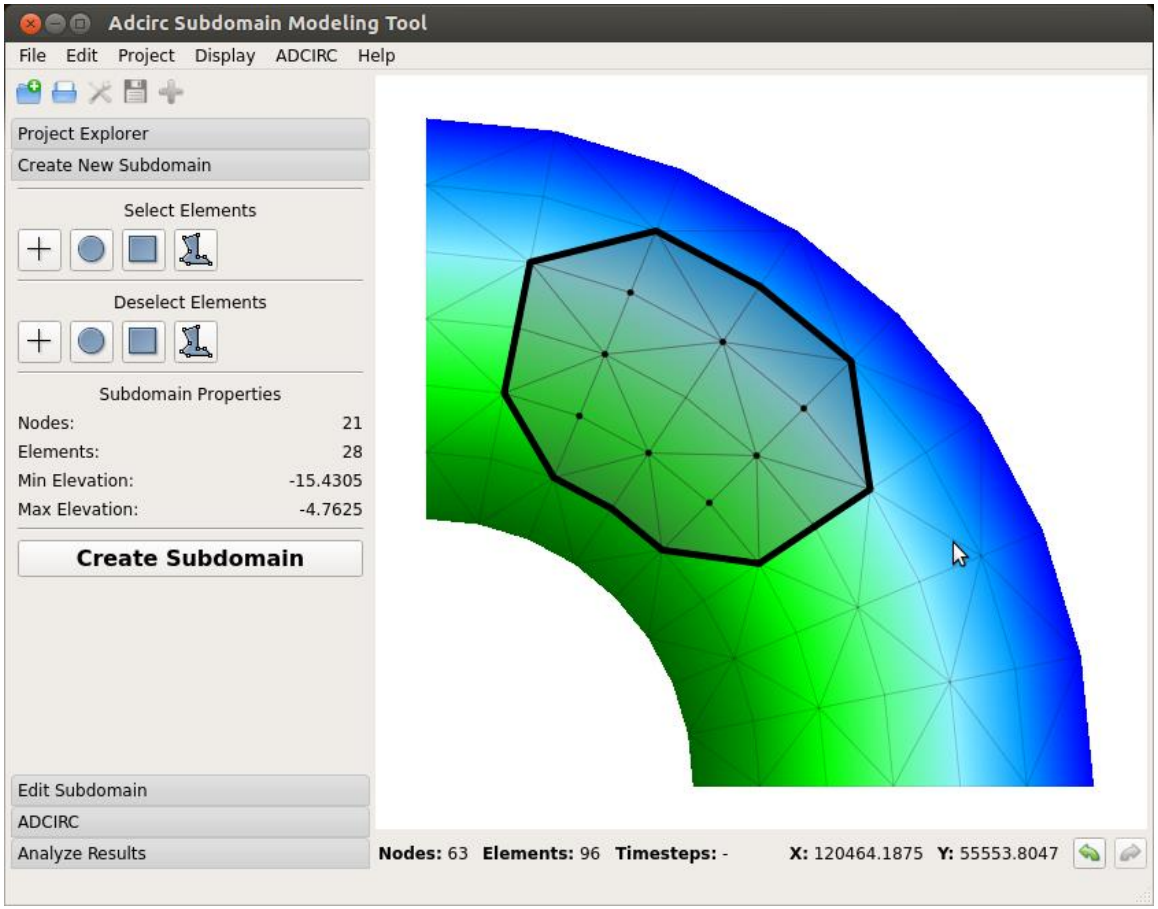
Create a new project

An introductory example: Quarter Annular Problem

0 Begin with an ADCIRC model

↓

1 Generate a subdomain



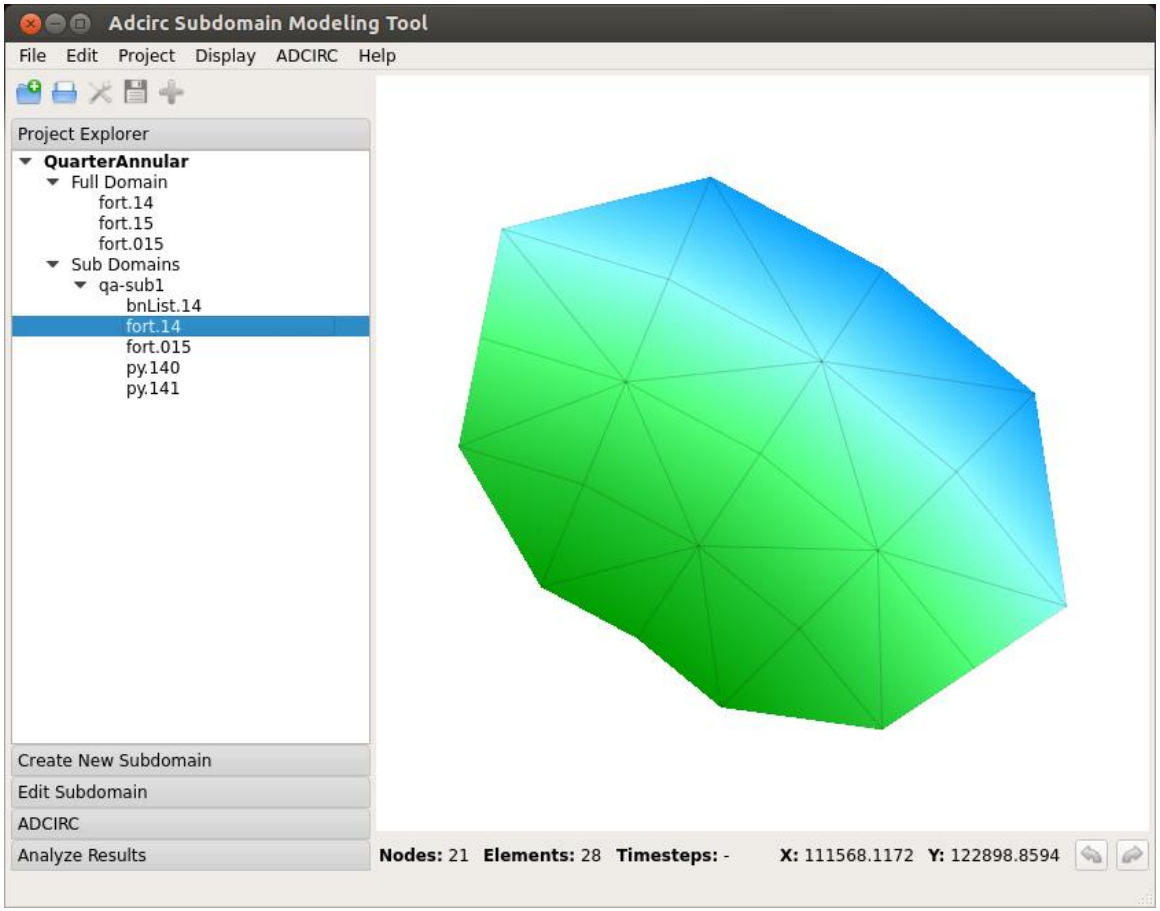
Select the region of interest

An introductory example: Quarter Annular Problem

0 Begin with an ADCIRC model

↓

1 Generate a subdomain



Create the subdomain

An introductory example: Quarter Annular Problem

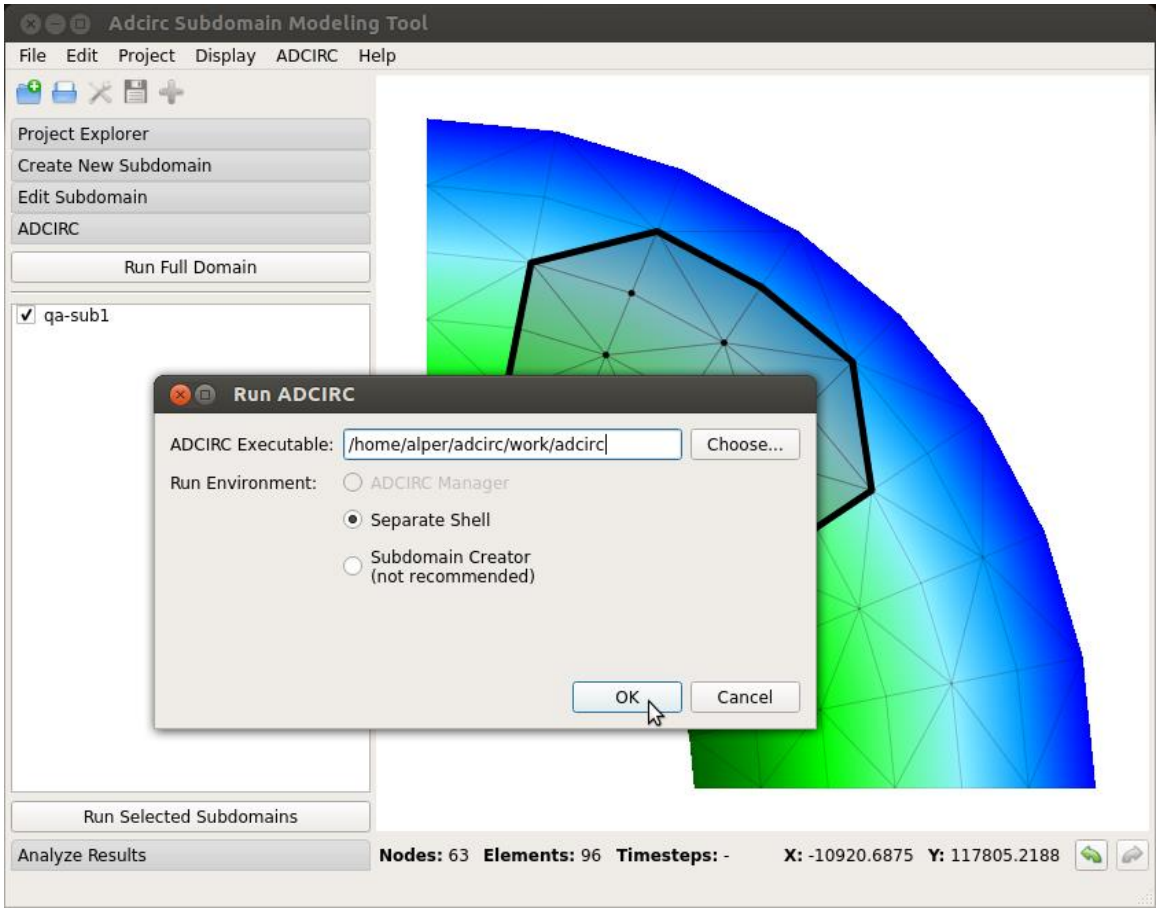
0 Begin with an ADCIRC model

↓

1 Generate a subdomain

↓

2 Run ADCIRC on full domain



Run ADCIRC on full domain

An introductory example: Quarter Annular Problem

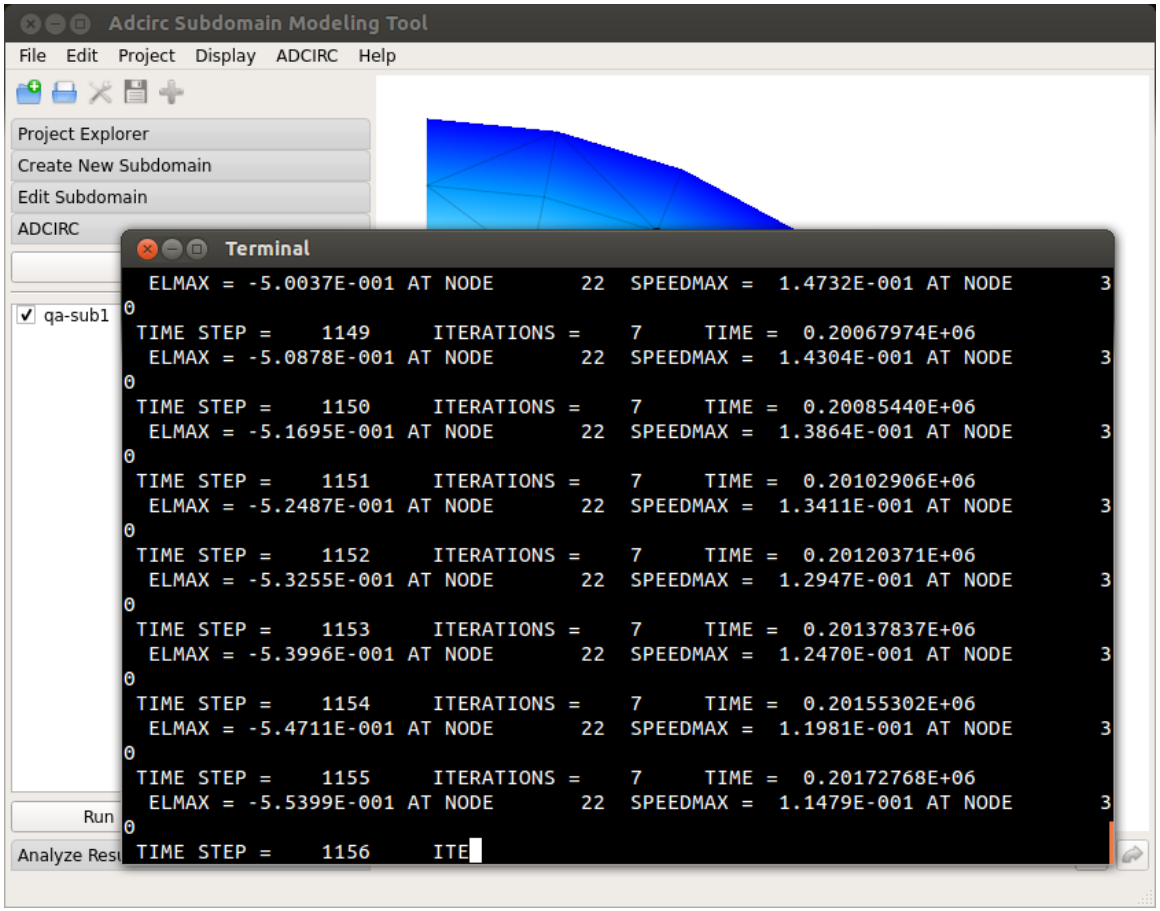
0 Begin with an ADCIRC model

↓

1 Generate a subdomain

↓

2 Run ADCIRC on full domain



Run ADCIRC on full domain

An introductory example: Quarter Annular Problem

0 Begin with an ADCIRC model

↓

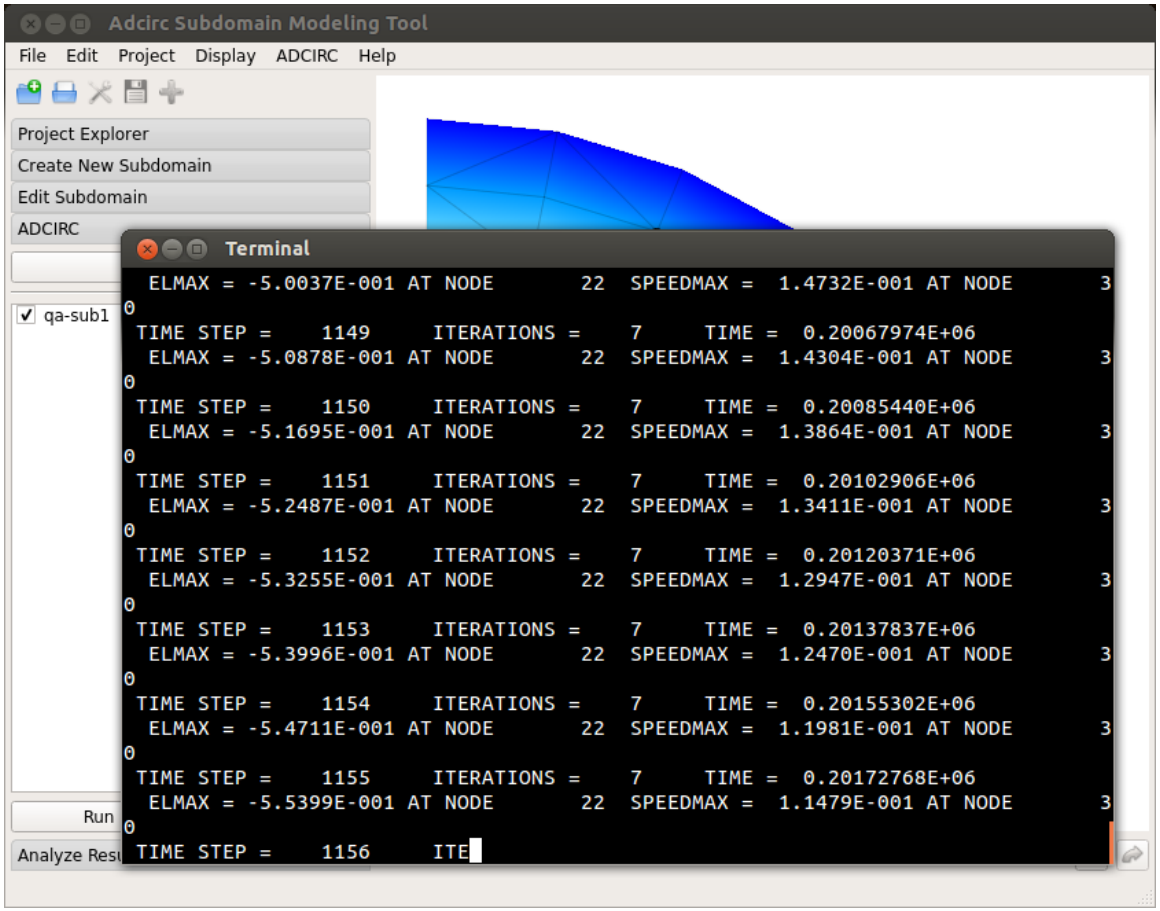
1 Generate a subdomain

↓

2 Run ADCIRC on full domain

↓

3 Extract boundary conditions



Extract boundary conditions

An introductory example: Quarter Annular Problem

0 Begin with an ADCIRC model

↓

1 Generate a subdomain

↓

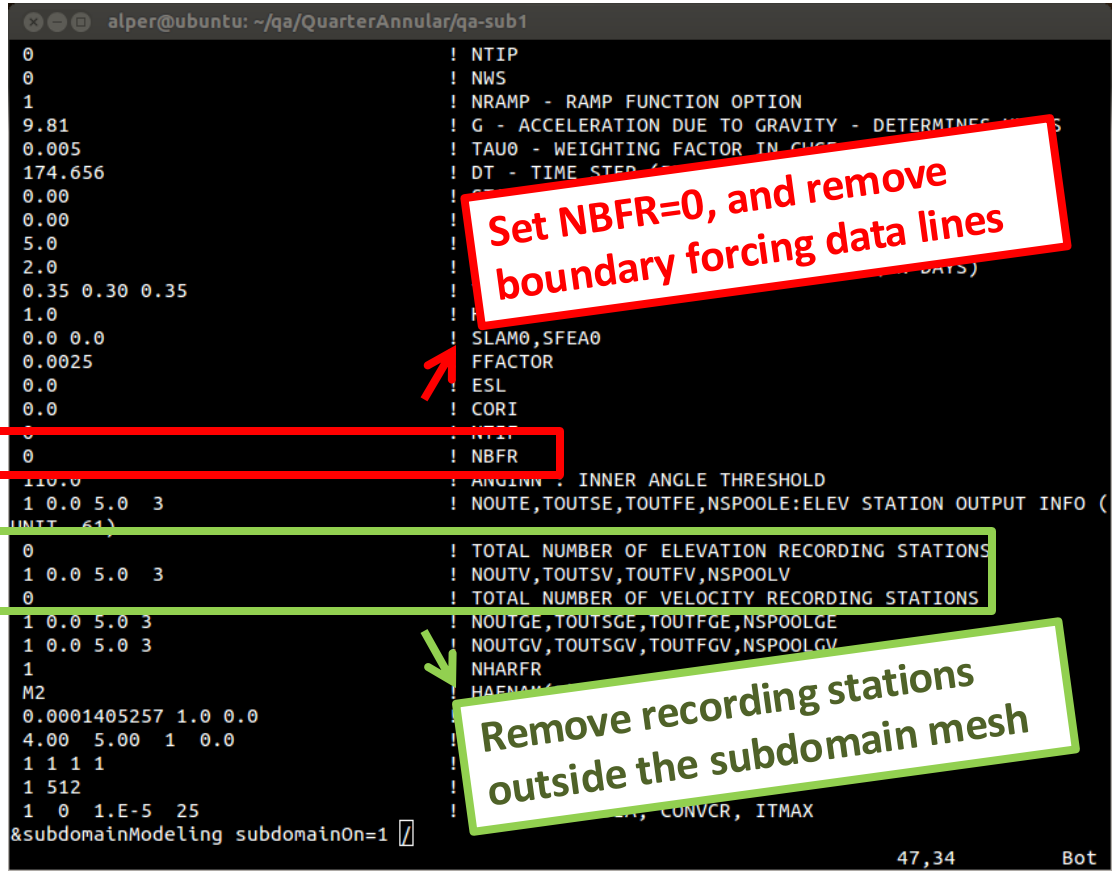
2 Run ADCIRC on full domain

↓

3 Extract boundary conditions

↓

4 Run ADCIRC on subdomain



Edit subdomain fort.15 file manually

An introductory example: Quarter Annular Problem

0 Begin with an ADCIRC model

↓

1 Generate a subdomain

↓

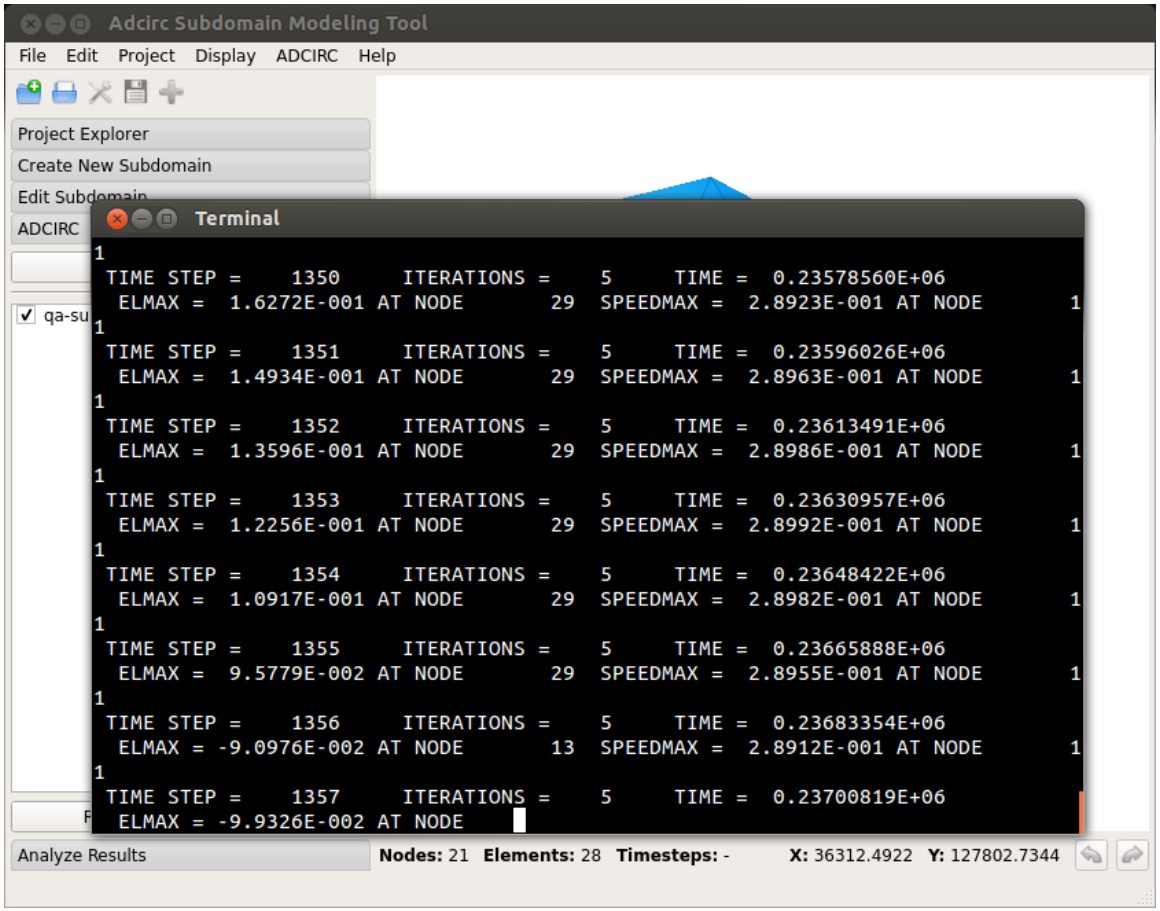
2 Run ADCIRC on full domain

↓

3 Extract boundary conditions

↓

4 Run ADCIRC on subdomain



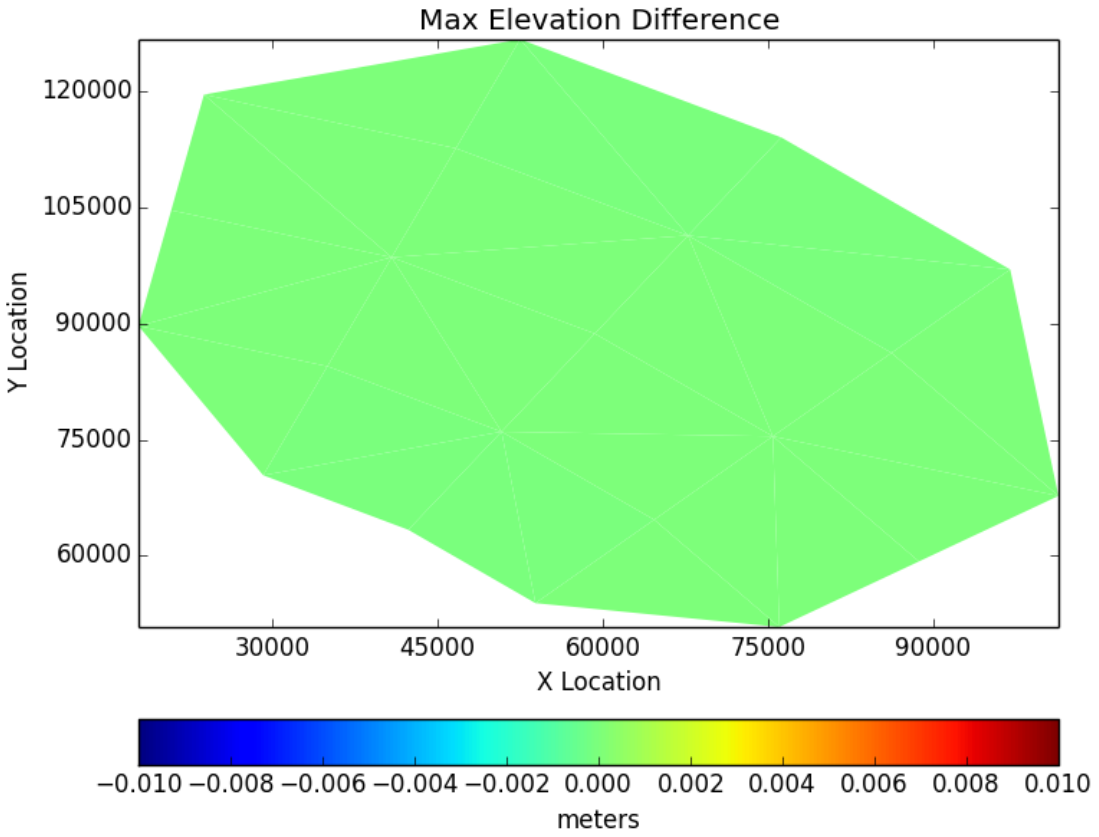
Run ADCIRC on subdomain

An introductory example: Quarter Annular Problem

0 Begin with an ADCIRC model

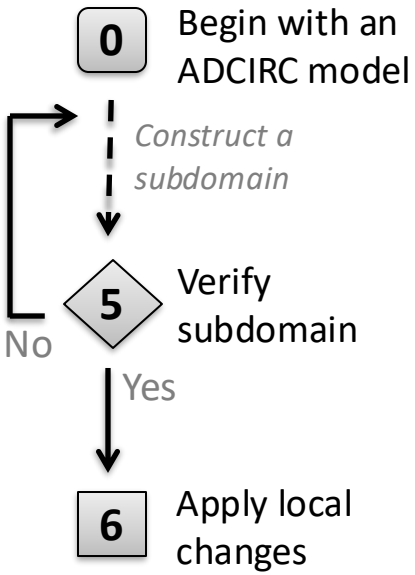
Construct a subdomain

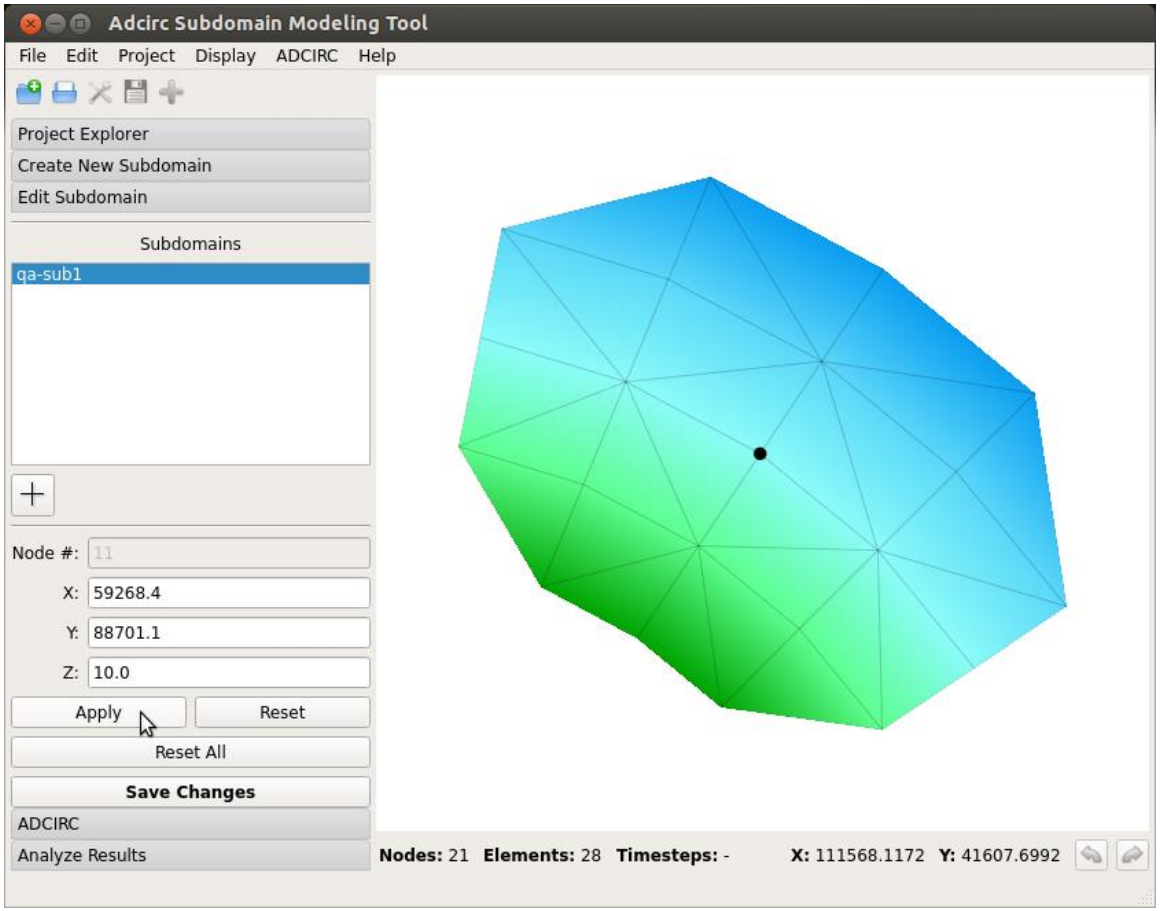
5 Verify subdomain



Check if subdomain is stable

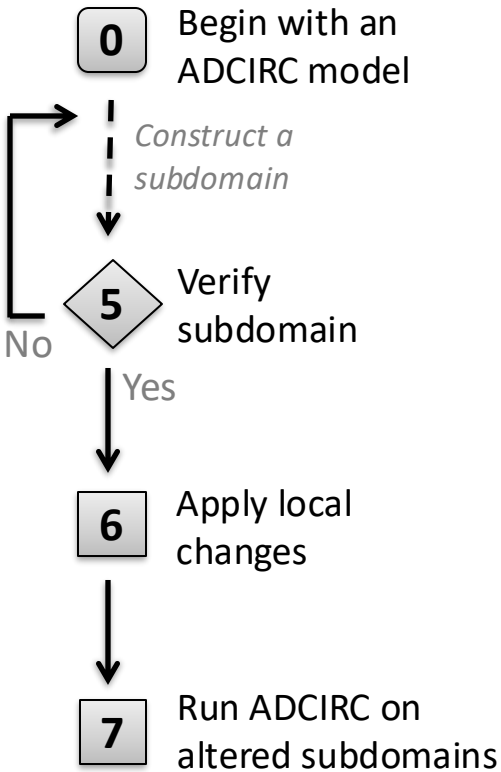
An introductory example: Quarter Annular Problem

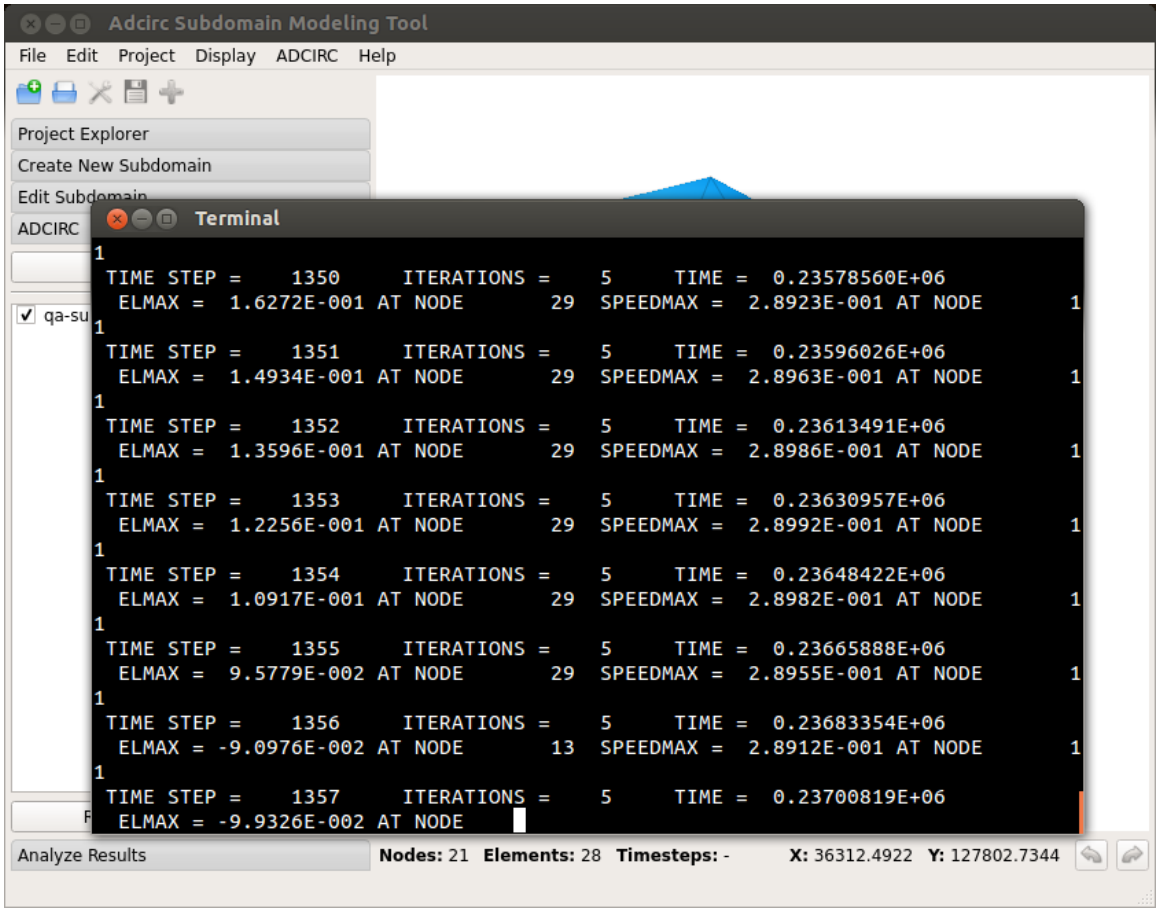




Modify subdomain locally

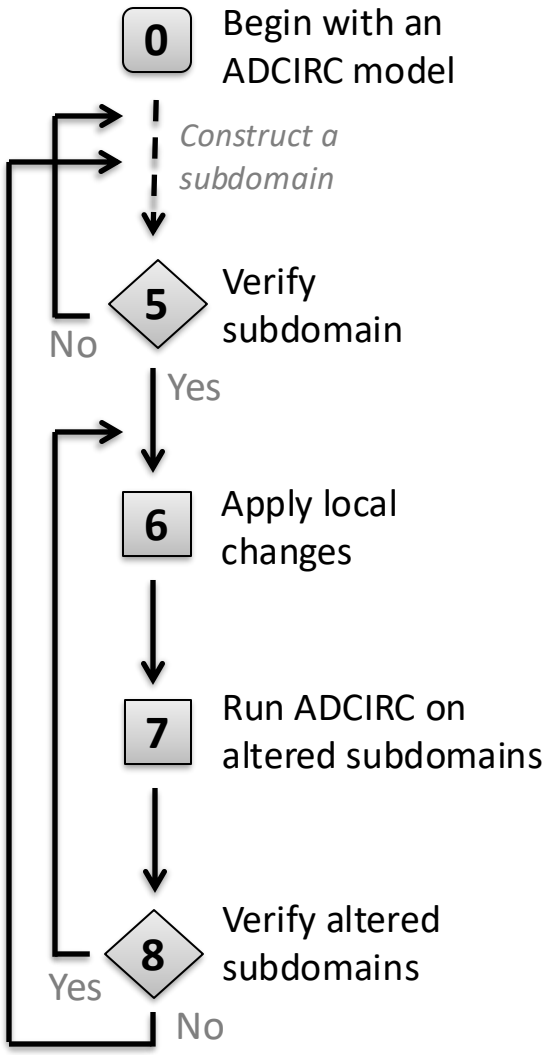
An introductory example: Quarter Annular Problem

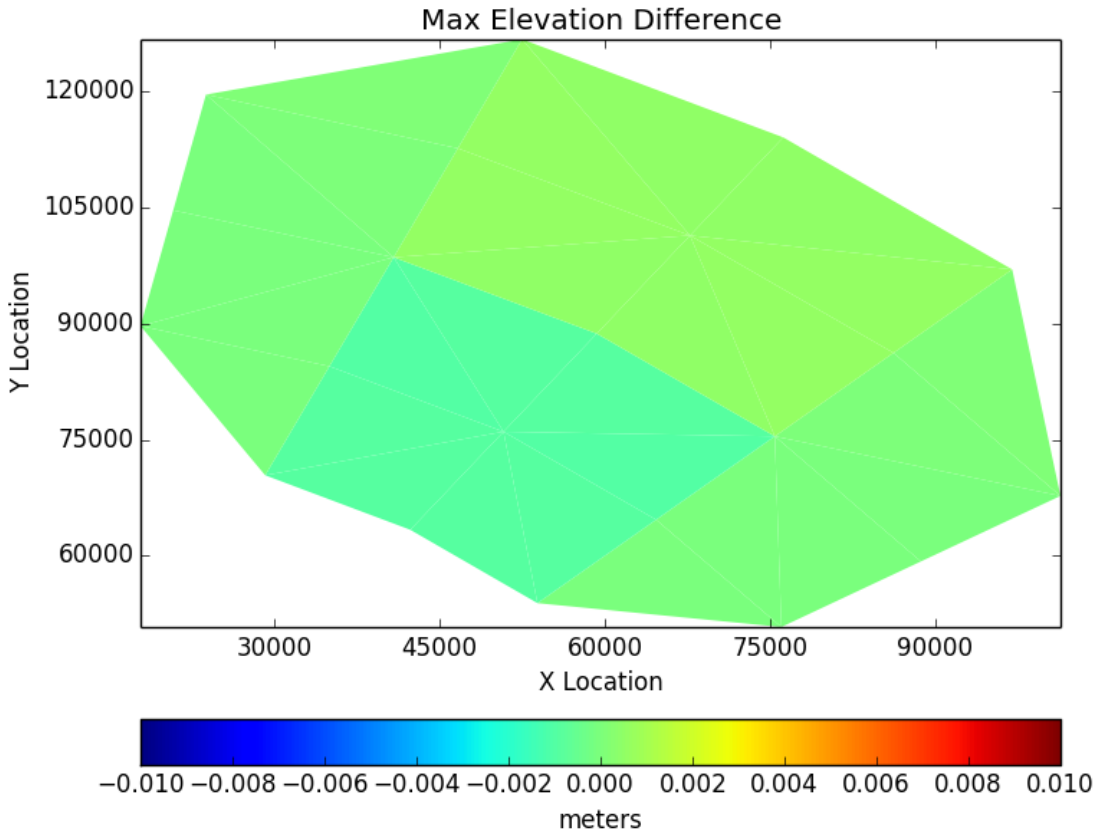




Run ADCIRC on altered subdomain

An introductory example: Quarter Annular Problem





Check if altered hydrodynamics reach to the boundary

Adaptive Subdomain Modeling: A New Approach

The subdomain sizes are determined automatically and the boundaries are moved adaptively depending on the response of the model, thus ensuring that the technique is both efficient and accurate.

- Subdomain meshes are **expanded** if altered hydrodynamics reach to the boundaries, to ensure that the enforced boundary conditions are still valid.
- Subdomain meshes are **contracted** if altered hydrodynamics are far enough from the boundaries, to provide better computational performance.
- Subdomain geometries need not be contiguous.
- Full domain and subdomain runs are performed **concurrently.**
- A new software framework is being designed with the aim of serving as a base for adaptive/dynamic ocean models.

A software framework for adaptive/dynamic ocean models

Contrary to most numerical models using procedural programming languages, our software framework is based on object-oriented programming languages, mainly; **C++** & **Python**.

With the help of recent advances in compilers and optimization tools, efficient models can be constructed using OOP languages.

- **OOP Mechanisms:** encapsulation, polymorphism, abstraction and class inheritance
- **Data Structures:** Efficient and flexible containers and an effective system design
- **GUI & OpenGL Visualization**
- **Various Parallelism strategies**: Message Passing, Multithreading, GPU Programming, Hybrid strategies

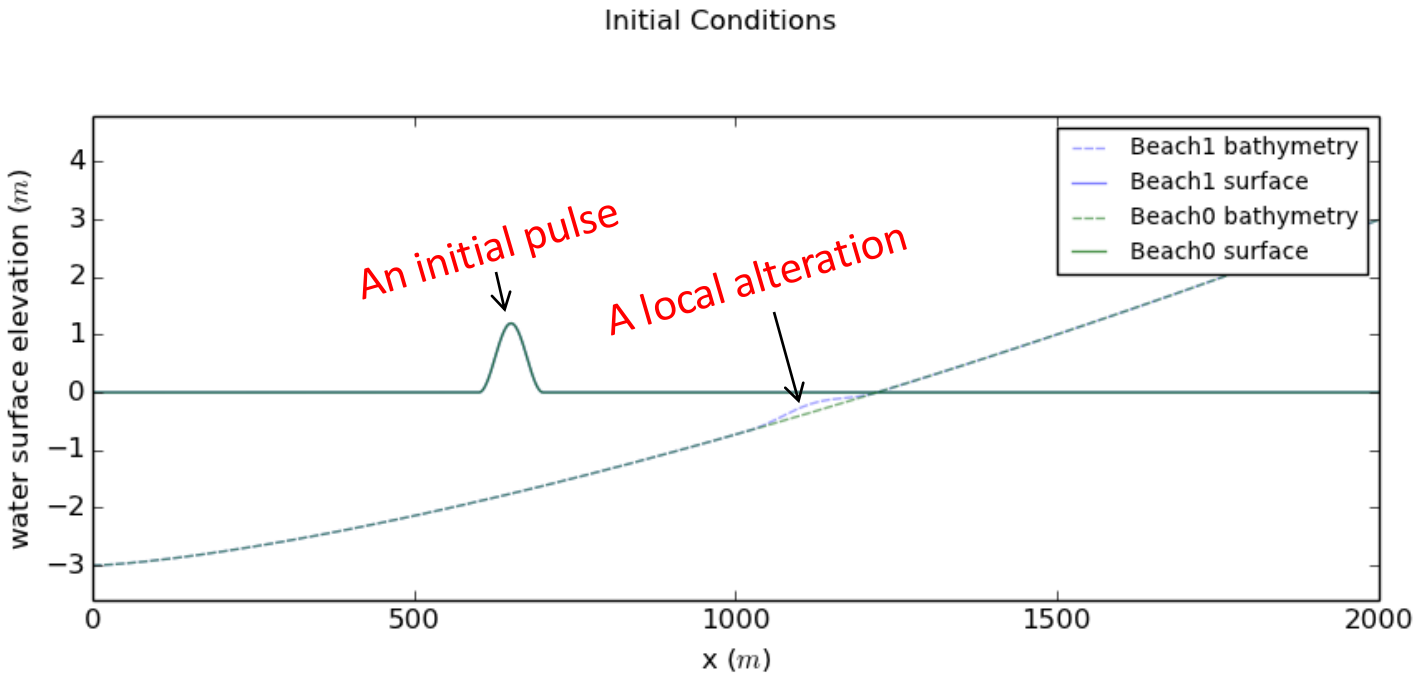
ASMFV: Adaptive Subdomain Modeling – Finite Volume

An experimental finite volume code written in C++, based on our new software framework

- Adaptive Subdomain Modeling feature included
- Original full-domain run and locally-modified subdomain runs performed concurrently
- Solves 1D/2D Shallow Water Equations, using HR-FVM (LeVeque, 2004)
- An embedded GUI created using Qt, and an OpenGL 3D visualization tool

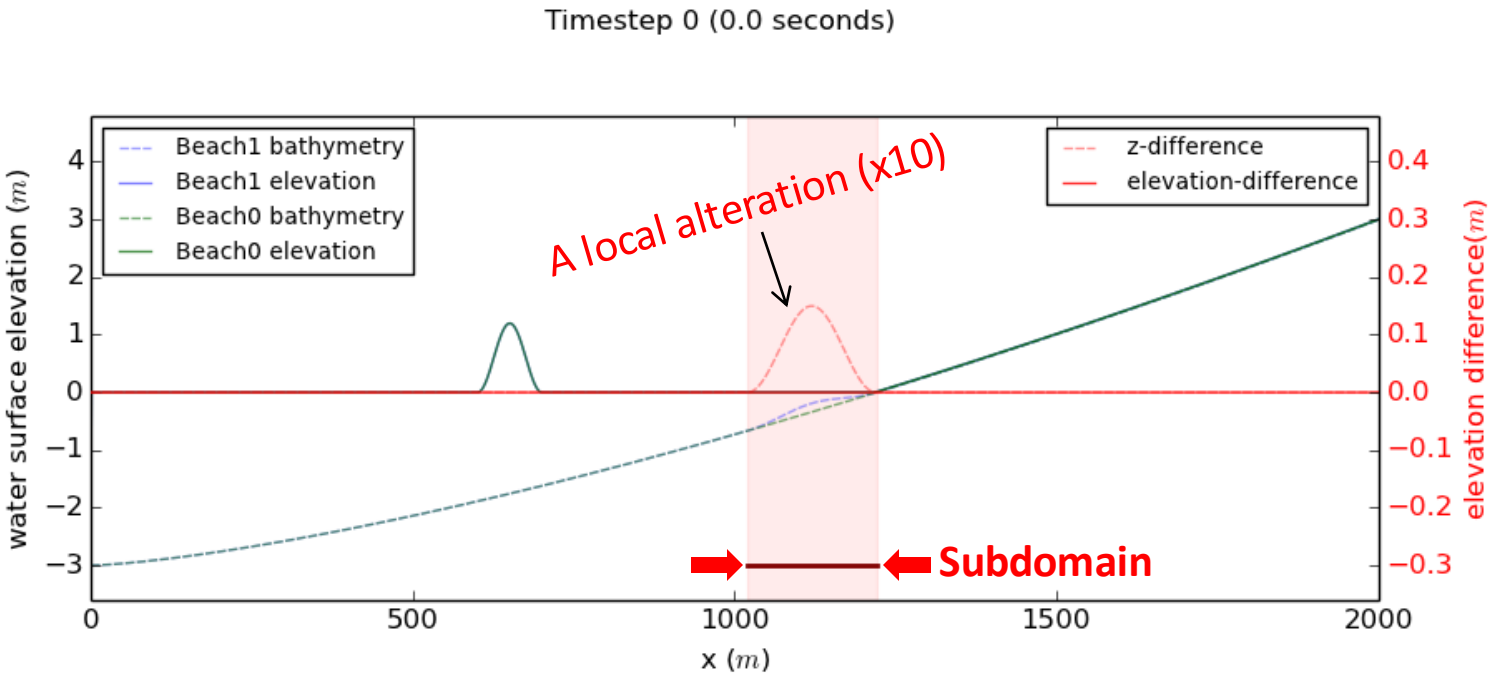
Adaptive Subdomain Modeling

A 1D example: Submerged beach nourishment



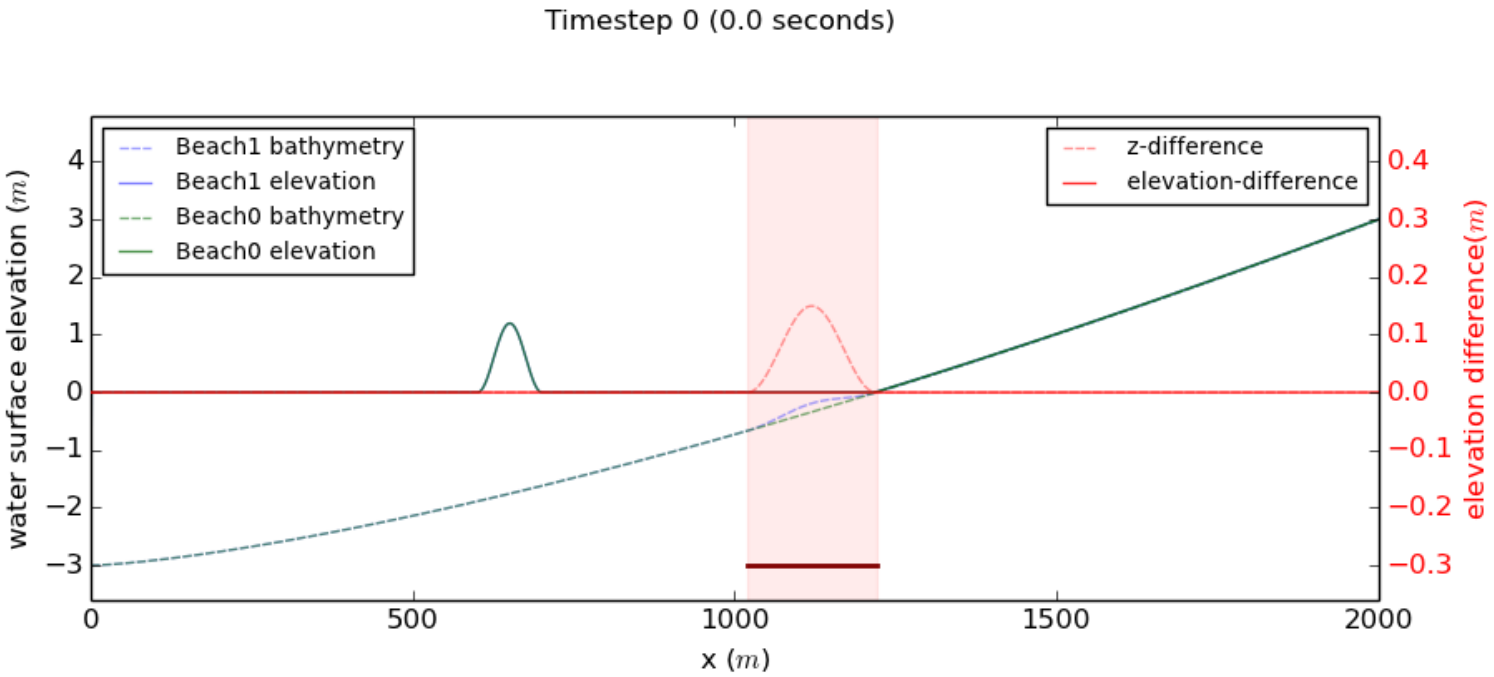
Adaptive Subdomain Modeling

A 1D example: Submerged beach nourishment



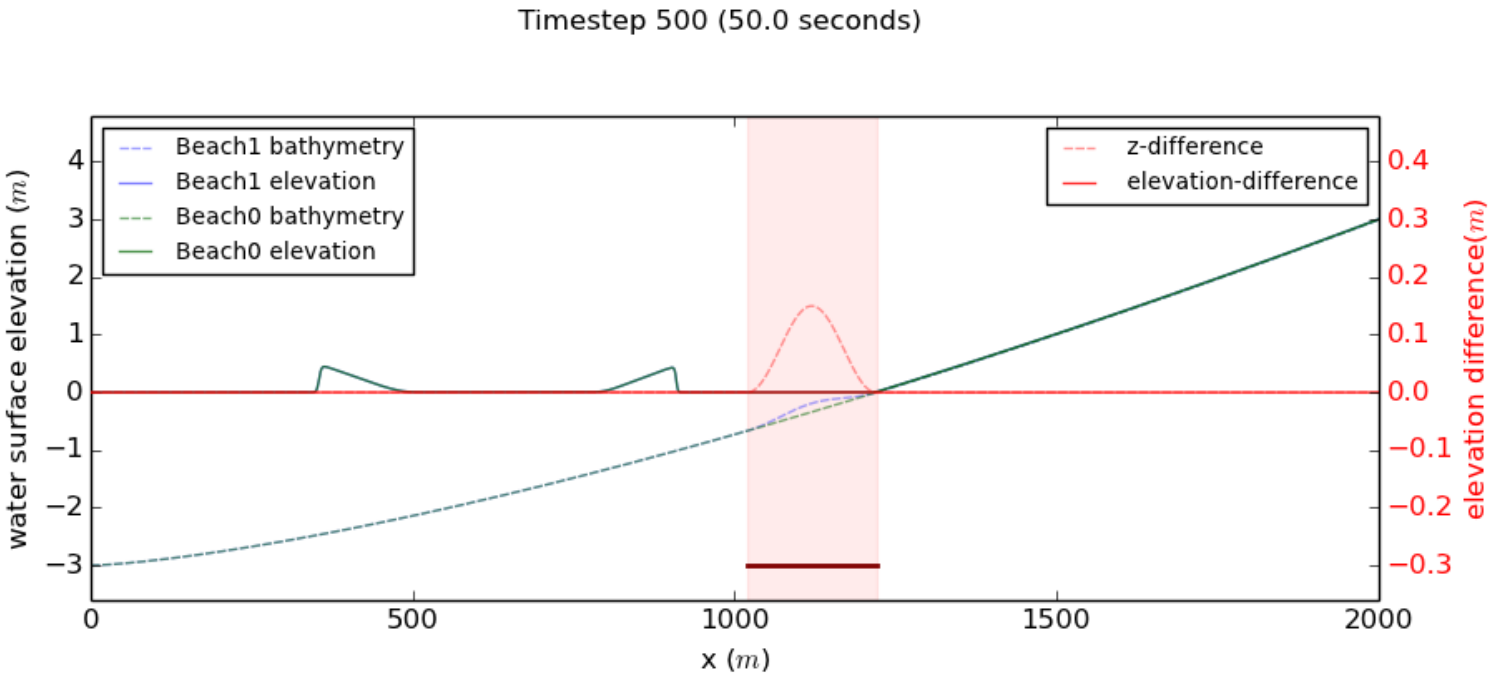
Adaptive Subdomain Modeling

A 1D example: Submerged beach nourishment



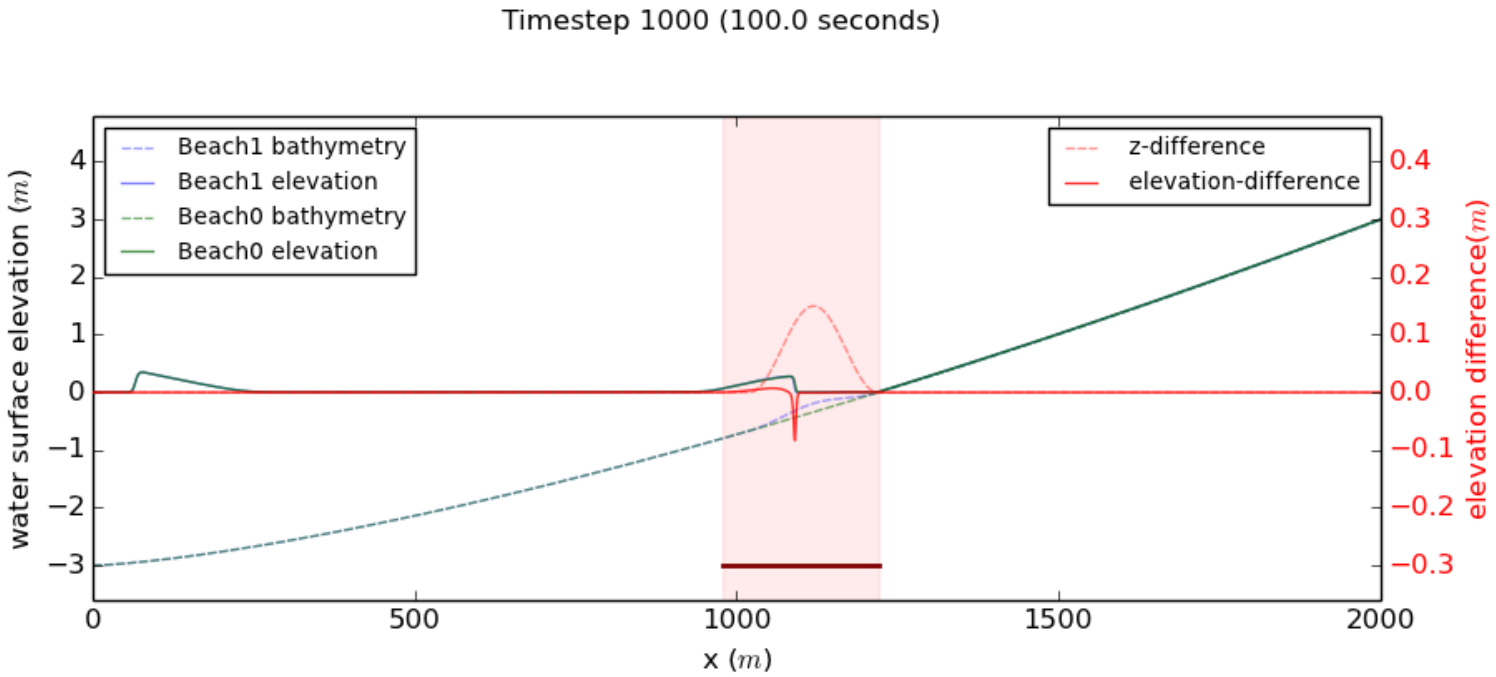
Adaptive Subdomain Modeling

A 1D example: Submerged beach nourishment



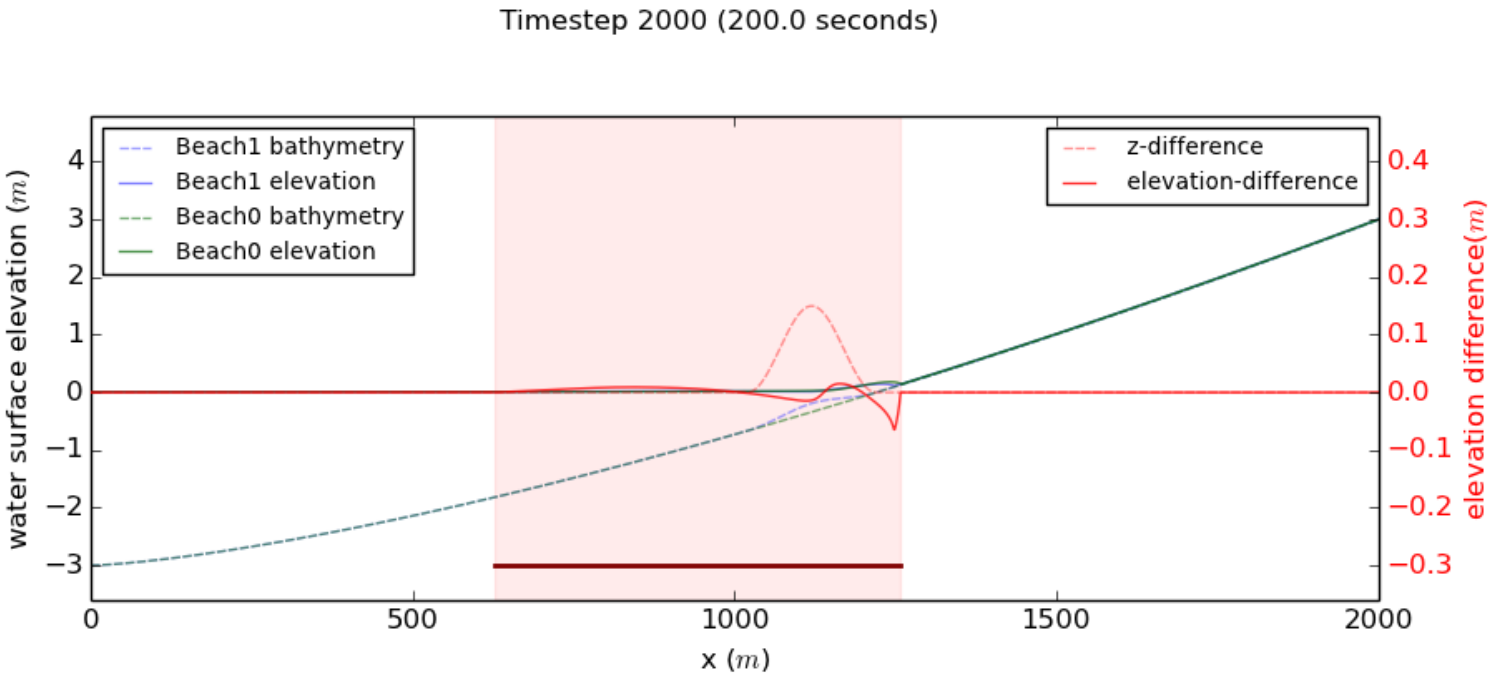
Adaptive Subdomain Modeling

A 1D example: Submerged beach nourishment



Adaptive Subdomain Modeling

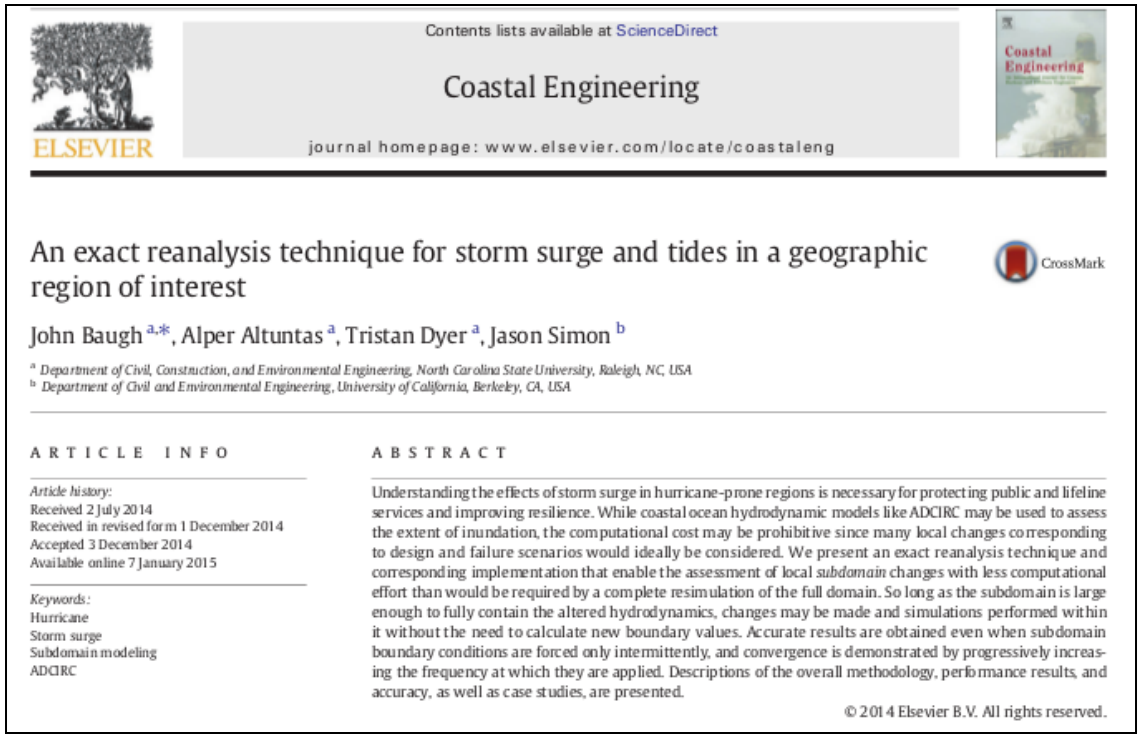
A 1D example: Submerged beach nourishment



Publications

An exact reanalysis technique for storm surge and tides in a geographic region of interest

Baugh et al., March 2015, Coastal Engineering, Vol 97, p.60-77



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Coastal Engineering

journal homepage: www.elsevier.com/locate/coastaleng

An exact reanalysis technique for storm surge and tides in a geographic region of interest

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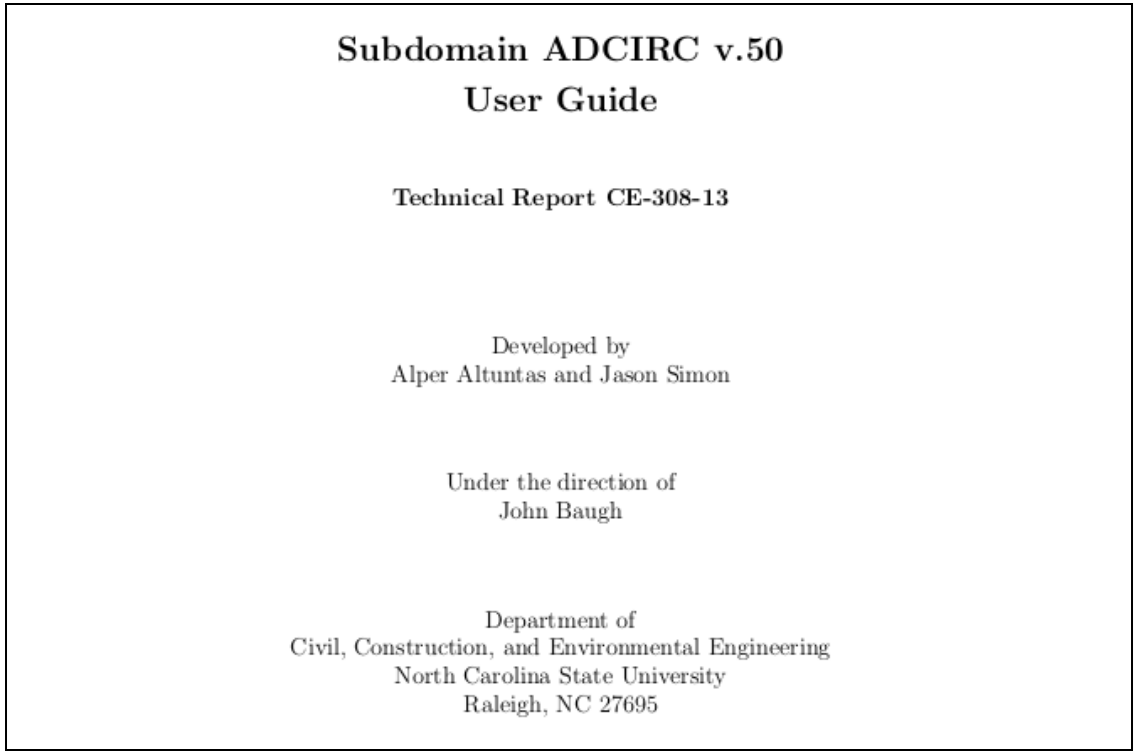
ABSTRACT

Understanding the effects of storm surge in hurricane-prone regions is necessary for protecting public and lifeline services and improving resilience. While coastal ocean hydrodynamic models like ADCIRC may be used to assess the extent of inundation, the computational cost may be prohibitive since many local changes corresponding to design and failure scenarios would ideally be considered. We present an exact reanalysis technique and corresponding implementation that enable the assessment of local *subdomain* changes with less computational effort than would be required by a complete resimulation of the full domain. So long as the subdomain is large enough to fully contain the altered hydrodynamics, changes may be made and simulations performed within it without the need to calculate new boundary values. Accurate results are obtained even when subdomain boundary conditions are forced only intermittently, and convergence is demonstrated by progressively increasing the frequency at which they are applied. Descriptions of the overall methodology, performance results, and accuracy, as well as case studies, are presented.

Publications

Subdomain ADCIRC v.50 User Guide
Technical Report CE-308-13



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User Guide

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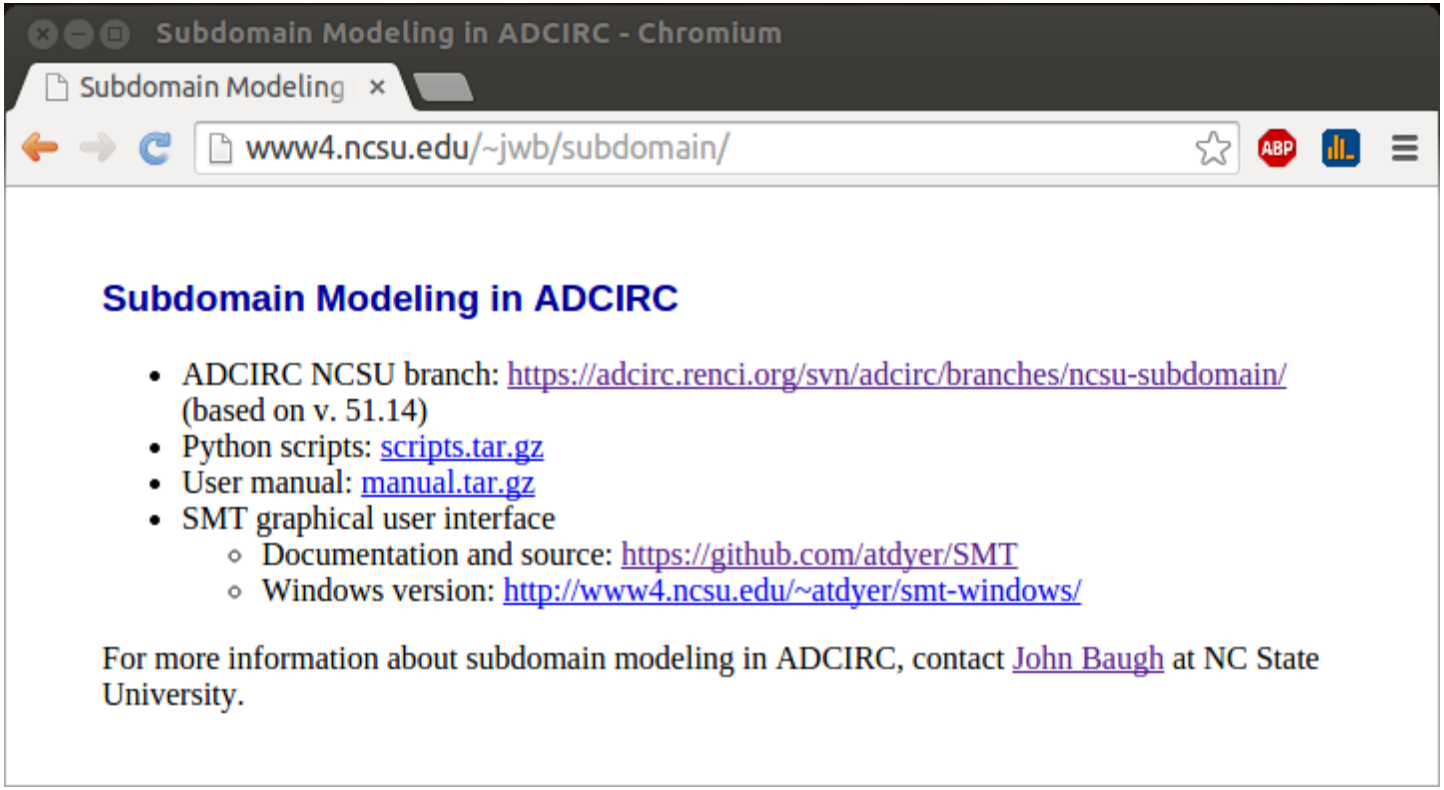
Subdomain Modeling in ADCIRC – Web Page:

www4.ncsu.edu/~jwb/subdomain/



Remarks

- **Subdomain branch merged into ADCIRC trunk**
- **SMT is available online** at https://github.com/atdyer/SMT/
- Hotstarting feature for subsequent subdomain runs refined
- Several adjustments for boundary conditions made
- Extensive set of tides+hurricane test cases performed
- A new technique, called “Adaptive Subdomain Modeling” is being developed.

Thanks…