Development of 2D Unstructured Meshes Using a Sizing Function Derived from Euclidean Distances to Coastal Features for the NWM Hydrodynamic Engine (D-Flow FM) Model

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Abstract

Generation of 2D meshes with reduced number of elements while yielding accurate results is a major challenge in coastal numerical models. High-quality 2D unstructured meshes were generated using sizing functions, which were computed from Euclidean distances to coastal features at given spatial locations and assigned element sizes based on calculated distances. The coastal features consist of National Water Model (NWM) streamlines, National Hydrography Dataset (NHD), NOAA Medium Resolution Shoreline and bathymetric features from the United States Army Corps of Engineers (USACE). This approach allows improved integration of the hydrodynamic D-Flow Flexible Mesh (D-Flow FM) model into the hydrological NWM and results in an optimum number of computational points. The method grants the user flexibility to control element sizes and avoids manual iterative procedures by determining an optimal element-sizing function that defines small element scales in regions where geometrical and physical characteristics exist, with larger scales elsewhere. Newly created continental-scale meshes on the Atlantic Ocean, Gulf of Mexico and Pacific Ocean coastlines demonstrate the application of the proposed method for automatic generation of unstructured, high-quality 2D meshes.
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Introduction

• **Goal:** To generate an element sizing function for construction of high-quality 2D unstructured mesh.

• Element sizing function based on proximities of coastal features from
  - National Water Model (NWM) streamlines
  - National Hydrography Dataset (NHD)
  - NOAA Medium Resolution Shoreline and
  - Bathymetric features from the United States Army Corps of Engineers (USACE).

• Finer elements for fine geometric details and coarser elsewhere.

• Input: Complex geometry of coastal features and user assigned element gradation.

• Output: High-quality mesh.
Mesh Generation Method

Euclidean Distance From Boundary Features (DB)

Mean Distance (MD)
MD = 0.5x(DB + DM)

Size Function (SF)
SF = f(MD)

Mesh

Euclidean Distance From Medial Features (DM)

Element Size
SF = ME + G*MD

ME = Minimum element size
G = Gradient

Mean Distance

Quality Assessment

\[ q_{ALS} = \frac{4\sqrt{3}A}{l_1^2 + l_2^2 + l_3^2} \]

Bhatia et al 1990;
Sarrate et al 2003;
Bank et al 1997

# Model Domains (~+10 m, MSL & ~-2 m, MSL)

<table>
<thead>
<tr>
<th></th>
<th>Pacific</th>
<th>Gulf &amp; Atlantic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domain Area (km²)</td>
<td>64,881</td>
<td>329,572</td>
</tr>
<tr>
<td>NWM Reach Length (km)</td>
<td>10,682</td>
<td>105,135</td>
</tr>
<tr>
<td>NHD Waterbody Area (km²)</td>
<td>166</td>
<td>7,010</td>
</tr>
<tr>
<td>USACE Levee Length (km²)</td>
<td>5,603</td>
<td>6,503</td>
</tr>
<tr>
<td>USACE Levee Area (km²)</td>
<td>6,076</td>
<td>23,343</td>
</tr>
<tr>
<td>USACE Navigation Channel Area (km²)</td>
<td>159</td>
<td>1,525</td>
</tr>
<tr>
<td>USACE Navigation Channel Length (km)</td>
<td>4,093</td>
<td>24,691</td>
</tr>
</tbody>
</table>

The National Hydrography Dataset (NHD) is a national-scale dataset that provides a comprehensive view of the nation’s water resources.
Continental Mesh Development

What we want to model

Model Boundary

Features

Medial Axis / Skeleton

Sizing Function

\[ = G*MD+ME \]

MD = Mean Euclidean Distance (All features, Medial features)

Mesh

Continental Mesh

\[ \text{ME} = 100 \text{ m} \]

# of nodes = 8.1 M

# of elements = 16.1 M

~10 m, MSL & ~2 m, MSL

NWM Streamlines
NMD Datasets
NOAA Shoreline
USACE Navigation Channels
USACE Levees

NWM Streamlines
USACE Navigation Channels
USACE Levees
Continental-Scale Mesh (Atlantic & Gulf of Mexico)
Continental-Scale Mesh (Atlantic & Gulf of Mexico)
Mesh Quality Assessment

G=0.1, ME= 2 Units
- # of nodes = 11908
- # of Elements = 22480
- Mean qALS= 0.969

G=0.2, ME= 2 Units
- # of nodes = 6545
- # of Elements = 12011
- Mean qALS= 0.961

G=0.4, ME= 2 Units
- # of nodes = 3180
- # of Elements = 5549
- Mean qALS= 0.956
Mesh Quality

The US Continental Mesh
Mean qALS = 0.96 (High Quality!)

- NWM Streamlines
- NHD Datasets
- NOAA Shoreline
- USACE Navigation Channels
- USACE Levees

Near New Orleans, Louisiana

Near Mississippi River Bird foot Delta, Louisiana
Mesh Quality Cont.

The US Continental Mesh
Mean qALS= 0.96 (High Quality!)

NWM Streamlines
NHD Datasets
NOAA Shoreline
USACE Navigation Channels
USACE Levees

Clearwater
Tampa
Tampa Bay
Near Tampa Bay, Fl

Near Chesapeake Bay

Chesapeake Bay
5 km

2 km
Continental-Scale Mesh (Pacific)

Mesh 1: 50 m resolution, $G = 0.2$, # of nodes: 3.2 M, # of elements: 6.3 M, qALS = 0.963
Continental-Scale Mesh (Pacific)

Mesh 1: 50 m resolution, $G = 0.4$, # of nodes: 1.8 M, # of elements: 3.5 M, $q_{ALS} = 0.957$
Conclusions

• A new method was developed to define small elements in the region where coastal features exist and larger elements elsewhere.
• The method grants the user flexibility to adjust the gradient and avoid manual iterative procedure.
• Quality assessment shows that the new algorithm is capable of producing high quality meshes.
• Newly created continental-scale meshes on the Atlantic Ocean, Gulf of Mexico and Pacific Ocean coastlines demonstrate the application of the proposed method for automatic generation of unstructured, high-quality 2D meshes.
• The method allows improved integration of the hydrodynamic D-Flow Flexible Mesh (D-Flow FM) model into the hydrological NWM and results in an optimum number of computational points.
Thank You!

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