Coast Tools 2017 Summer School worksheet
http://www.cima.ualg.pt/CoastTools/Coast_tools_Aboutus.html

This worksheet was developed for use at Coast Tools 2017 and was designed to be used with CDM v.2

Background on Model

The Coastal Dune Model (CDM) was developed from a desert dune model with a long history — key papers for CDM and the previous dune models are listed at the end of this worksheet. Durán et al (2010) is a review of the model up to 2010.

For this assignment, there are two key papers that we will be working from, and it will be helpful for you to have access to the papers and the figures through your modeling work. First, the paper of Durán and Moore (2013) discusses how the distance from the shoreline that plants can grow sets the maximum height of coastal. Second, Moore et al (2016) discusses the role of shoreline progradation rate in controlling the presence/absence of multiple dune ridges.

The CDM has also been 'published' — an online description of CDM exists at the Community Surface Dynamics Modeling System (CSDMS) website:

http://csdms.colorado.edu/wiki/Model:Coastal_Dune_Model

Quick intro to the mechanics of CDM

CDM operates by modifying two state variables, the topographic domain and the vegetation field. These two states are operated upon by five operations:

1) Compute the shear stress field. The shear stress field is computed by using the u* (shear velocity) of the wind defined for each time iteration and the surface topography. The surface topography sets the shear stress through a analytical formulation utilizing a fourier transform (Weng et al. 1991). The topographic surface is modified by the existence of a separation bubble when there is a dune brink. The shear stress is also modified by the presence of vegetation.
2) A sand flux field is computed from the shear stress field. Flux in the separation zone is set to 0.
3) The flux convergence/divergence is computed for a given time interval (using the forward Euler method) and this sets the change in topography at each grid cell.
4) The new topographic field is polled for slopes greater than the angle of repose (34 degrees). For slopes greater than this, avalanches occur down the steepest descent gradient.
5) The vegetation field is modified based on growth equations, which are determined by the local accretion/erosion rate of the sand surface, growth rules, and nearby vegetation.

The model then goes back to step '1' and repeats for all time steps of the model.

Install and compiling the model

Someone from the school will help you download and install the model in the appropriate directories. Aside from a compiler, CDM requires one external piece of code, the fourier transform library 'fftw' (http://www.fftw.org)

Someone from the school will help you compile the model on your machine.

The parameter file:

Please open up the parameter file ('param.par') and look through to find these relevant parameters that we will be adjusting today.

Saving

- *save.dir* —the name of the directory where the output files are stored. You must make the directory/folder before the model run.

Space and time steps

- *NX* — Number of columns in the model domain (in the wind direction). Better to have NX >= 100 (for dx = 1m).
- *NY* — Number of grid rows in the model domain (perpendicular to the wind). This must be a power of 2 for the wind solver. NY=4 is good for 2D simulations. NY=64 is good for 3D simulations.
- *dx* — absolute grid cell size, in meters, in the NX and NY direction. so dx=1 is a 1m x1m cell size.
- *dt_max* — time step in seconds (now in the bottom of the parameter file)

Wind speed

- *constwind.u* — This is the shear velocity (m/s). For the grain size in the default model, keep in mind that the transport threshold is ~0.2 and relatively strong winds are ~0.5.
- *wind.fraction* — This is a scaling term, and is the fraction of the year wind is above threshold.

Vegetation

- *veget.type* — Defines the vegetation type, where "0" is for a simple logistic growth rate independent on the sand accretion rate and without lateral propagation (typical for mature ecosystems?), and "1" is for a logistic growth rate proportional to the accretion rate and including lateral propagation (typical for dune buildings plants). Vegetation type 0 is modified from Duran and Moore (2013), and type 1 is the model used to study dune formation in prograding shoreline (Moore et al. (2016)).

General for all vegetation types:

- *veget.xmin* — This is the seaward limit of vegetation in meters (referred to as L_{veg} in Durán and Moore (2013) and subsequent papers).
- *veget.zmin* — This is the minimum elevation (m) relative to MSL for plants to growth, assuming lower elevations are more frequently inundated leading to plant death (described in Duran and Moore (2015)).
- *veget.erosion.sensitivity* — The plant sensitivity to erosion (m^-1). Interpreted as the inverse ratio of the root system volume to cover area. Larger *values* means that plants are **more** sensitive to burial. 1.0 is the default value.

For vegetation type 0:
- *veget.Tveg* — the vegetation growth rate or 'characteristic time scale for growth (in days). How fast the vegetation grows (small number, faster growth). Default is 10.
- *veget.0.init* — the initial value of the cover fraction needed to initiate vegetation growth in the logistic model (in the range 1e-5 to 1e-1). Interpreted as cover fraction for initial colonization not included explicitely in the model. Low values means a more difficult/longer colonization. Default value is 1e-2.

For vegetation type 1:
- *veget.Hveg* — Characteristic maximum vegetation height (m) (interpreted as total final standing biomass divided by cover fraction). It controls the vertical growth rate. Larger values means faster growth. Default value 0.25.
- *veget.Vlateral.factor* — The sensitivity of lateral propagation of vegetation to burial rate (dimensionless). A larger value results in faster lateral plant propagation. Default value 100.
- *veget.max.slope* — Maximum slope (degrees) for lateral propagation to be possible. Default is 15^o. Range 0-60
- *veget.1.init* — as veget.0.init but for vegetation type "1" . Low values means a more difficult/longer colonization. Default value is 1e-5.

<u>Shoreline dynamics and Sea level rise</u>
- *shore.sealevelrise* — Rate of SLR (m/yr). Will induce a Brum-type shoreline migration (erosion) and a lowering of the subaerial profile. Range 0-0.1
- *shore.alongshore_grad* — Shoreline erosion (>0) and accretion (<0) rate (m/yr).

Running the Model
- Go to your working directory (for example 'SIM'):
  cd SIM
- In your working directory, make a new directory that matches the *save.dir* value in the *parameter.par* file (for example 'DATA'):
  mkdir DATA
- Now run the model, type:
  Dune param.par > output &
- (Note that 'Dune' is the name of the program and 'output' contains some basic information about parameters; nothing important really, mostly for debugging)

Basic Visualizations:
The basic temporal evolutions are in text file in 'DATA' entitled 'time.dat'. The first lines of this file explain data. By column, the data is:

1: iterations
2: time in yr
3: maximum height
4: maximum cover
5: volume of sand
6: shoreline change rate

You can use any language to plot the data, here is an example form Matlab:

- Open Matlab and set "CurrentFolder" to the folder where you saved your Data:
  type: D=load('time.dat');
- to see elevation vs. time, type:
  plot(D(:,2),D(:,3));
- to see vegetation cover vs. time type:
  plot(D(:,2),D(:,4));
- to see volume conservation vs. time:
  plot(D(:,2),D(:,5));

For profile Visualizations, we need to look in the raw topographic and vegetation output files.

- Topographic grids are 'h.xxxxx.dat' (where 'xxxxx' is a number)
- Vegetation grids are 'veget_x.xxxxx.dat' (where 'xxxxx' is a number)
  - there may also be 'veget_y.xxxxx.dat'files, which are a second 'species', but for now the model is set to only use 1 vegetation 'sepcies', so we can ignore the 'veget_y' files

Now, let's plot the dune elevation profile at two different times.

- Navigate to the folder where you saved your data, then type:
  - T=load(' h.00100.dat');
- The columns of T are the width of the model domain (perpendicular to the wind; *NY*), and the rows of T are the length of the model domain (parallel to the wind; *NX*).
- so to get a topo profile, type:
  - plot(T(1:100,2))

  Now find the last topographic grid (the last 'h.xxxxx.dat' file), import the data and plot it to find the final dune profile.

To plot the profile of vegetation cover fraction, repeat the above procedure, just using the 'veget_x.xxxxx.dat' files. Note that raw values will be between 0 (no vegetation) and 1 (100% vegetation).

Note that you could write a script to display movies of the topographic profile evolving with each time step.

Possible tests to reproduce published results and explore Parameter Space:

<u>Change the maximum size of the final dune by varying the seaward limit of vegetation or 'Lveg' (*veget.xmin*)</u>
Now that you know the basics of the model, lets try to reproduce some results, starting with figure 2B from Durán and Moore, (2013).

This is independent of the vegetation type. Set first plant erosion to zero for simplicity (*veget.erosion.sensitivity* = 0)

You should run multiple experiments varying only *veget.xmin*—the seaward limit of vegetation in meters — and *save.dir* — your save directory. Try varying *veget.xmin* from 10-50 m (with 10 m spacing) and use the 'time.dat' file to make a plot similar to Figure 2B from Durán and Moore, (2013).

Transition from a stable foredune to an unstable one, leading to blowouts and parabolic dunes (better for 3D configuration):
This is only possible for vegetation type 0 (for reasons we don't fully understand yet), so set *veget.type* = 0.

Increase plant sensitivity to erosion (*veget.erosion.sensitivity > 1, e.g. 2-3*) and/or the wind velocity (*constwind.u > 0.35*) to get 'blowouts', parabolic dunes and for extreme erosion barchans/transversal dunes — Figure 6 from Durán and Moore, (2013).

The same result can be obtained by decreasing vegetation growth rate (increase *veget.Tveg* to 20-30) for *veget.erosion.sensitivity =1-2.*

Coastal dune response to shoreline erosion and SLR:
This is better to also do it for vegetation type 0 with some sensitivity to erosion (*veget.erosion.sensitivity > 1*).

Increase the rate of shoreline erosion (*shore.alongshore_grad > 0*, example 5m/yr, 10m/yr) to go from a relatively stable single foredune to an unstable foredune increasing in volume.

Increasing the rate of SLR will lead to similar results but now the backbarrier becomes submerged.

Formation of new furedunes/ridges in prograding coasts:
This is only possible for vegetation type 1, so set *veget.type* = 1.

Increase the rate of shoreline accretion (*shore.alongshore_grad < 0*, example -5m/yr, -10m/yr) to go from a closely spaced tall ridges to increasingly separated low ridges.

New ridges won't form if you decrease the limit angle for lateral propagation close to 0 (in the range *veget.max.slope = 0-15*).

Change the lateral propagation speed (*veget.Vlateral.factor*) and initial colonization fraction (*veget.1.init*) to explore the effects on new ridges formation (change ridge separation and elevation).

CDM Model Bibliography:

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