WIND ANALYSIS DOWNSCALING

COASTAL-Act Project

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&
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The Consumer Option for an Alternative System to Allocate Losses (COASTAL) Act 11

(COASTAL) Act requires a wind analysis and to estimate the strength and timing of damaging winds at a given, “parcel-scale (10-30 meters)” over-land location in the area impacted by the tropical cyclone and to drive surge and wave models for estimating the water damage. And this can be done using LES.

What is LES mode?

Running the WRF at high resolutions with the PBL scheme turned off and full diffusion turned on. The effects of sub-grid scale turbulence on the state variables is no longer parameterized.

Why Run in LES mode?

1. Capture a very turbulent or small scale phenomena
2. Capture all scales of turbulence >= model grid and their effects implicitly instead of parameterizing them with a PBL scheme
3. Run a high resolution run (<500m)
4. Loss of faith in the current WRF PBL parameterizations

Resolved winds at 10 to 30 meters spatial scale and at higher temporal resolution

Resolve parcel-scale (~10 meters) features & Model Selection?

Why WRF-LES is better choice than any mesoscale model?

WRF-LES model - In the Large Eddy Simulation (LES) subgrid-scale parameterization, the diffusion coefficient is also proportional to Δ; reducing Δ permits a larger range of eddies to be computed and correspondingly less of arrange to be parameterized. Therefore, in an LES model, reducing the grid size allows more of the three-dimensional turbulence to be explicitly computed.

Any mesoscale (HWRF/WRF etc) operational models - In a mesoscale model, reducing the grid size simply reduces the horizontal diffusion coefficient. The parameterization of horizontal diffusion in most mesoscale models is such that the horizontal diffusion coefficient is proportional to Δ (Wyngaard 2004; Rotunno 2009)

Important notes from past research

- *The detailed structure and change of surface winds during landfall, which is controlled by the multi-scale interactions among the storm-scale circulation, meso-vortices, turbulence-scale eddies, and the underlying surface, cannot be obtained from operational numerical simulations* (Ping Zhu 2008)
- Advantages of using fine-resolution WRF/ARW-LES are noted at nighttime (under stable conditions) and over heterogeneous surfaces when local properties are required or when resolving small-scale surface features is desirable (Talbot, 2012)
- WRFARW/LES capable of resolving vertical turbulent transport of momentum, heat, and moisture by the HBL turbulent eddies, their up-scale impact on the development of hurricanes, and the issues regarding the improvement of parameterizing the HBL turbulence. WRF-LES provides an excellent framework for investigating the down-scale impact of the HBL organized wind structures on coastal wind damage.

WRF Physics (Turbulence/Diffusion (diff_opt, km_opt))

High-resolution real-data cases (~100 m grid or less)

- No PBL
- diff_opt=2; km_opt=2,3 (tke or Smagorinsky scheme)
- diff_opt=2 Horizontal diffusion acts along model levels Numerical method includes vertical correction term using more grid points

km_opt selects method to compute K (km_opt=2)

1: constant (khdif and kvdif used)

2: 1.5-order TKE prediction

3: Smagorinsky (deformation/stability based K)

4: 2D Smagorinsky (deformation based onhorizontal wind for horizontal diffusion only)

Explicit large-eddy simulation (LES) PBL in real-data cases (V3)or idealized cases

- bl_pbl_physics = 0"
  - isfflx = 0 (idealized drag and heat flux from namelist)"
  - isfflx = 1 (drag and heat flux from physics)
    - sf_sfclay_physics=1
    - sf_surface_physics=2 (choose non-zero option)”
  - isfflx = 2 (drag from physics, heat flux from tke_heat_flux)
    - sf_sfclay_physics=1

Important considerations

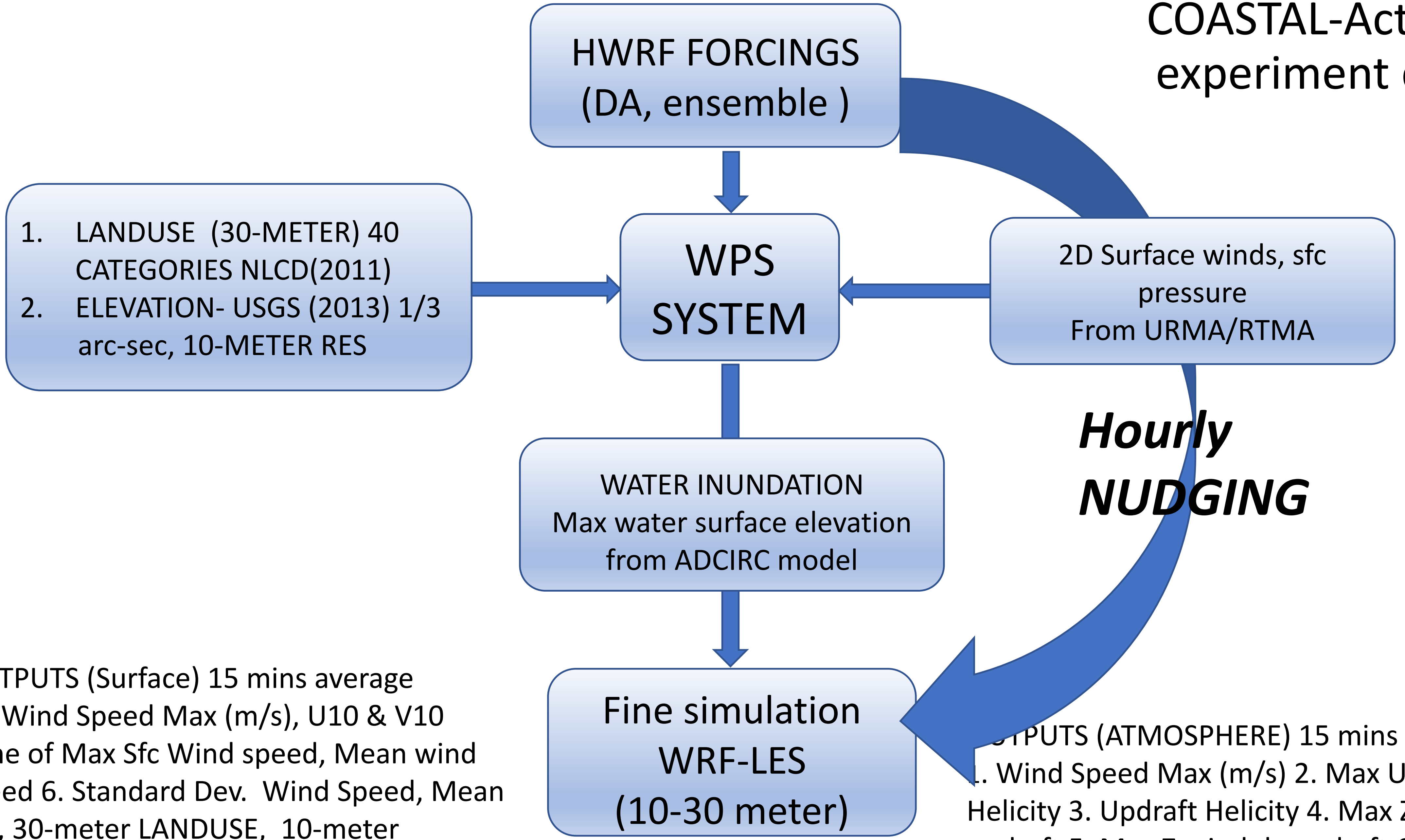
1. There are some namelist.input variables that will help and/or are necessary

```
&domains
 time_step                    = 2

&physics
 sf_sfclay_physics            = 1,
 sf_surface_physics           = 2,
 bl_pbl_physics               = 0,

&dynamics
 w_damping                    = 1,
 diff_opt                     = 2,
 km_opt                       = 2,
 diff_6th_opt                 = 2,
 diff_6th_factor              = 0.3,
 mix_isotrop                  = 1,
 mix_upper_bound              = 0.1,
 time_step_sound              = 8,
 mix_full_fields              = .true.,
```

COASTAL-Act Model experiment design

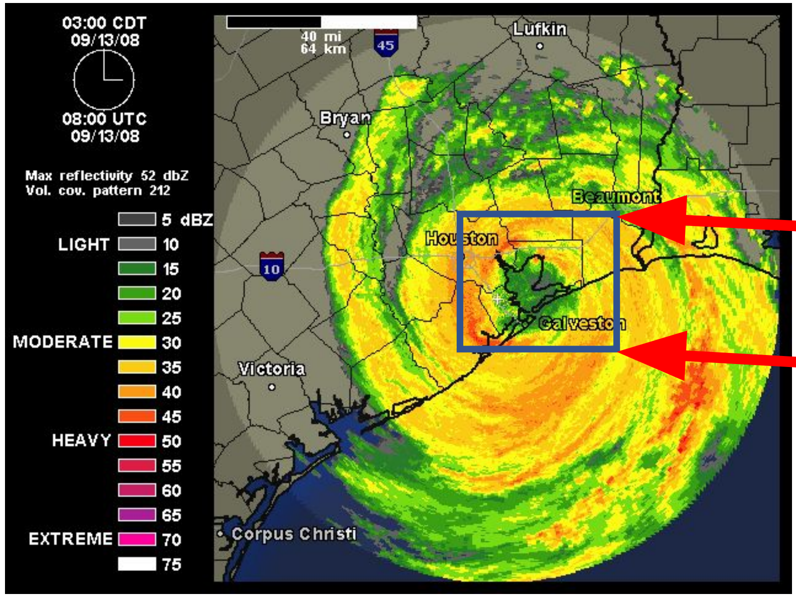


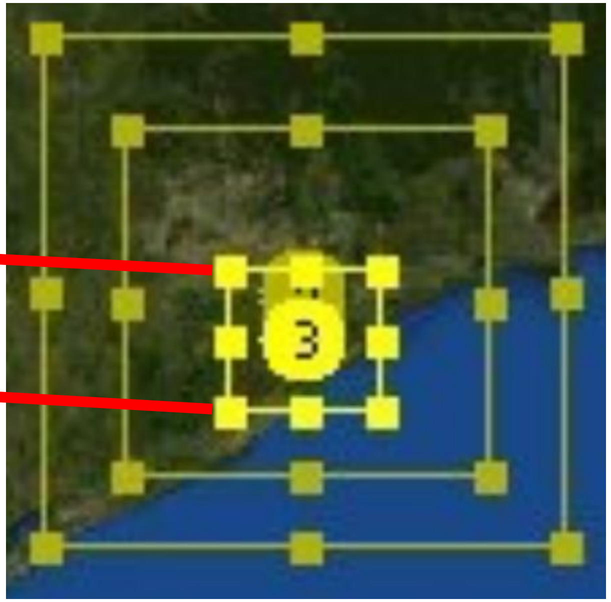
OUTPUTS (Surface) 15 mins average
Sfc Wind Speed Max (m/s), U10 & V10 Time of Max Sfc Wind speed, Mean wind speed 6. Standard Dev. Wind Speed, Mean SLP, 30-meter LANDUSE, 10-meter ELEVATION TERRAIN, Water Inundation mark

OUTPUTS (ATMOSPHERE) 15 mins average
1. Wind Speed Max (m/s) 2. Max Updraft Helicity 3. Updraft Helicity 4. Max Z-wind updraft 5. Max Z-wind downdraft 6. Mean Z-wind 7. Max col integrated Graupel

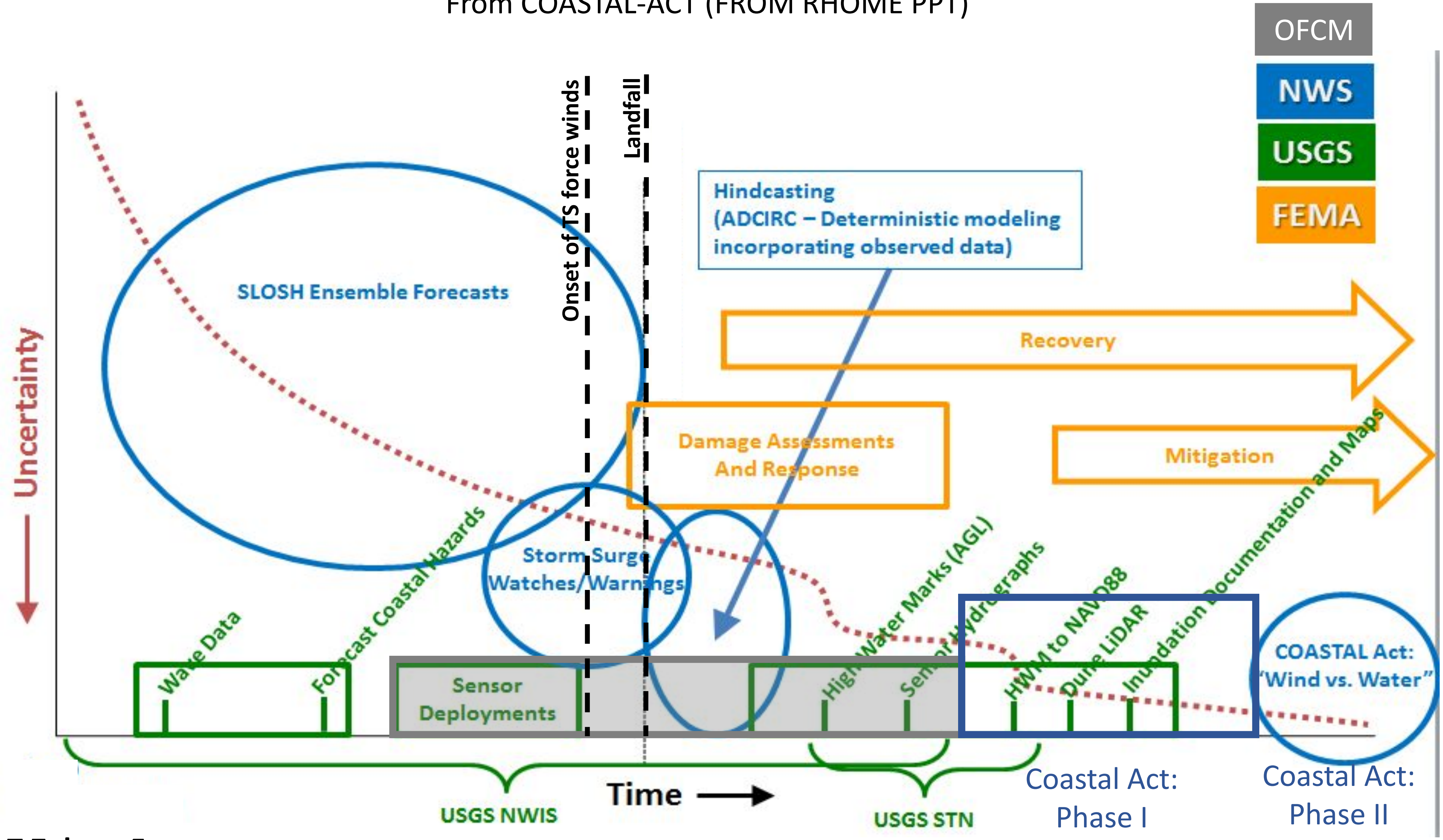
Fine simulation WRF-LES (10-30 meter) For Hurricane Ike 2008

Simulation type	PBL treatment	dx, dy (meters)	Grid Points	
D1-mesoscale	YSU	500	500 x 400	
D2- microscale	LES	100	1000 x 900	
D3-microscale	LES	33	1500 x 1200	
D4-microscale	LES	10	1500 x 1000	





From COASTAL-ACT (FROM RHOME PPT)



T-7 days: Forecast initiated

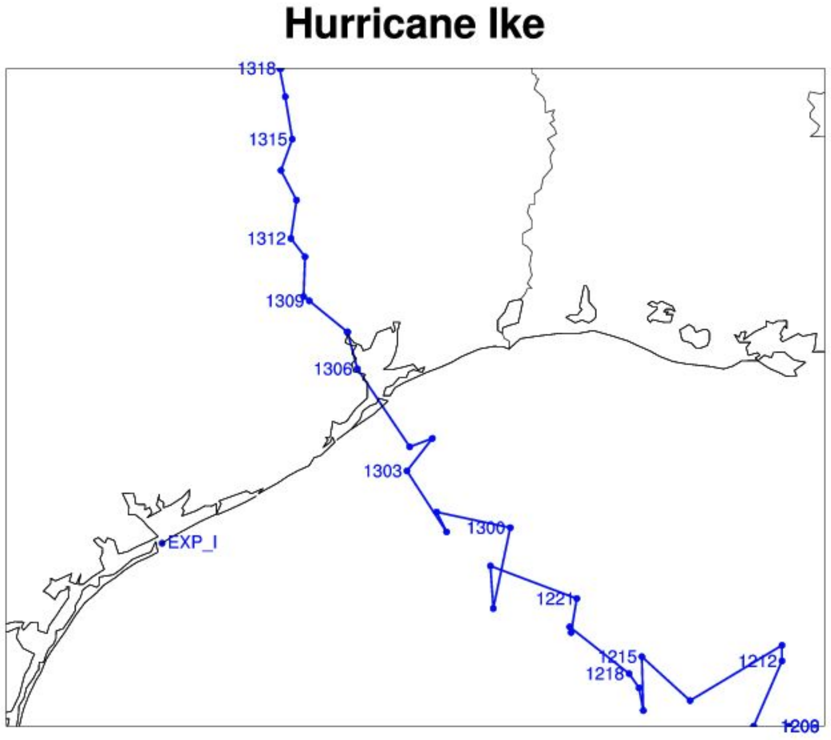
T0: Landfall

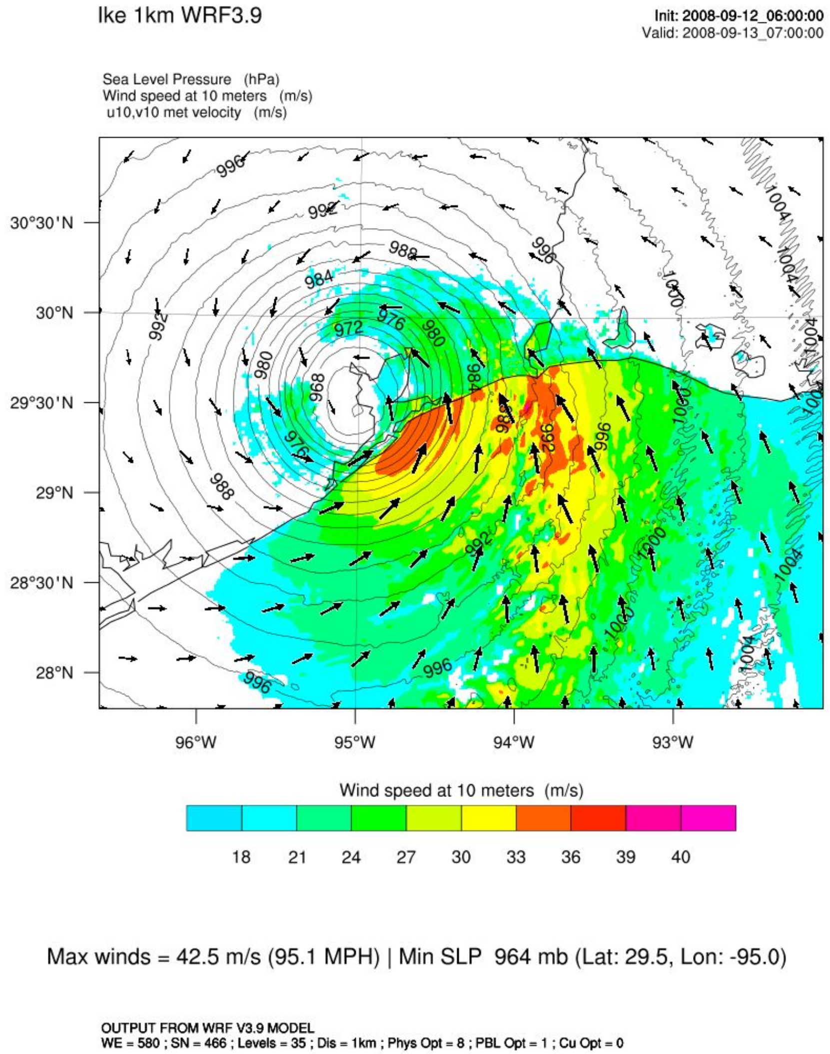
T + 30 days

T + 120 days

NUDGING and NO-NUDGING MODEL EXPERIMENTS

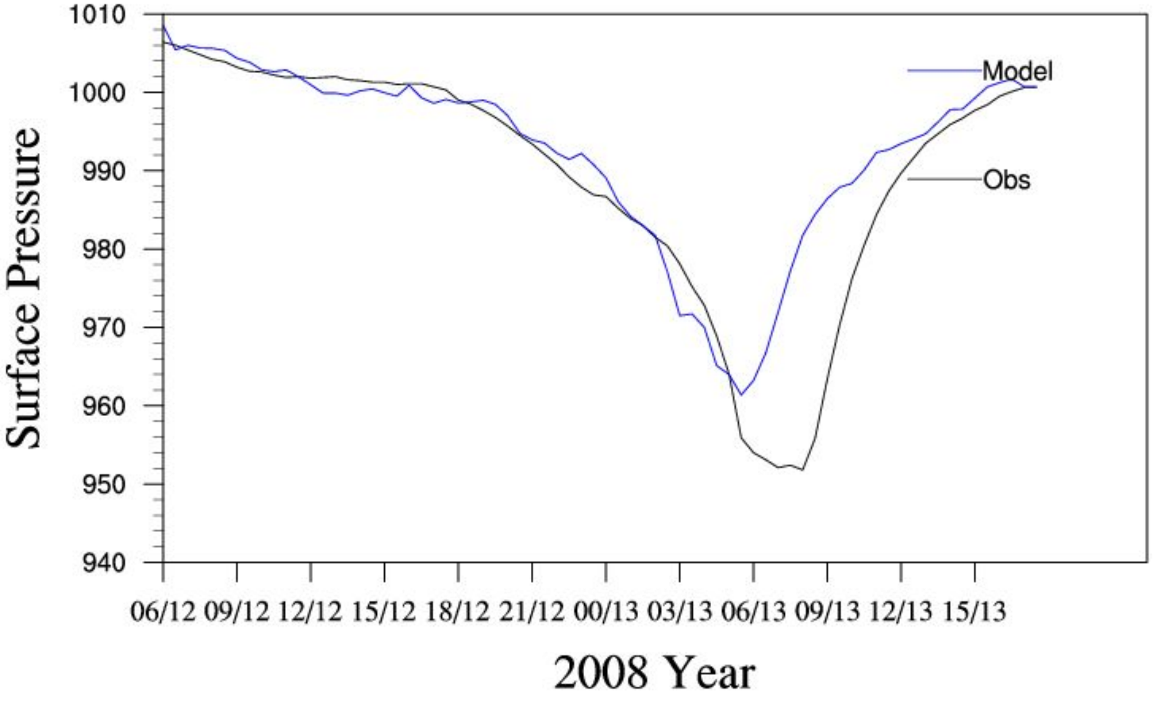
NO NUDGNG EXPERIMENT

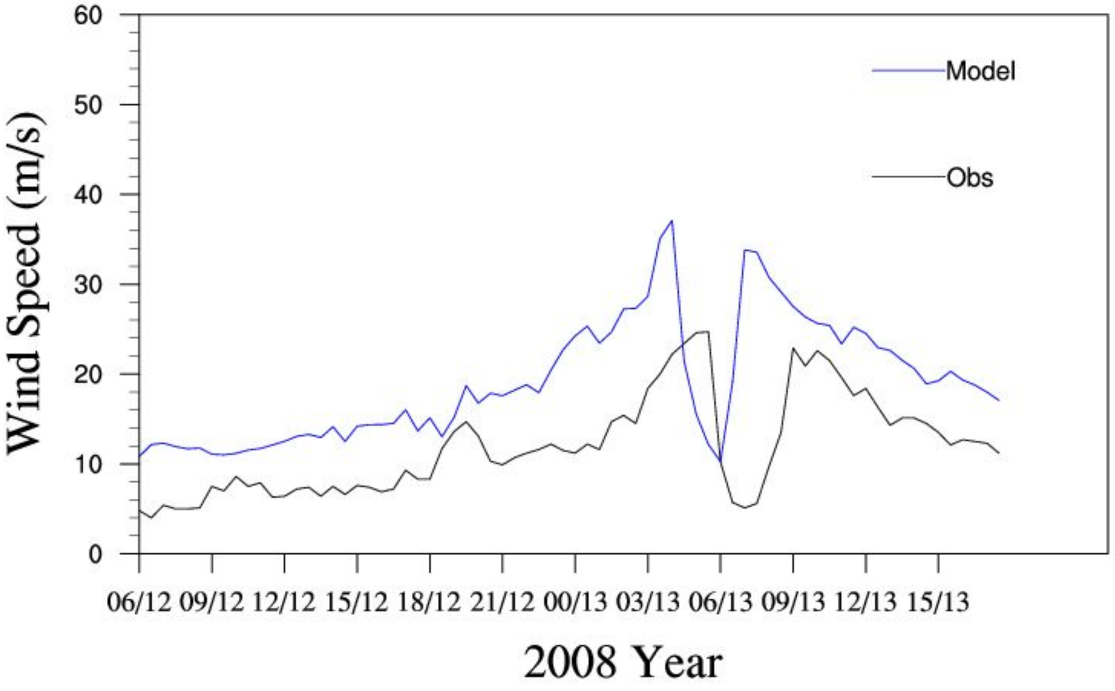




1. Track looks very good as compare with observed track. Model track i almost touching Galveston Bay.
2. But problem is the landfall timing. Model landfall happened close to UTC 13 Sep where as observed data shows 07 UTC 13 Sep.
3. Wind speed seems to be much higher in model simulation and that i our main concern with this simulation.
4. The impact of winds and wave surge is quietly well resolved.

Threshold Wind Speed – 18 m/s or 34 knots





Wind speed are much higher in model simulation

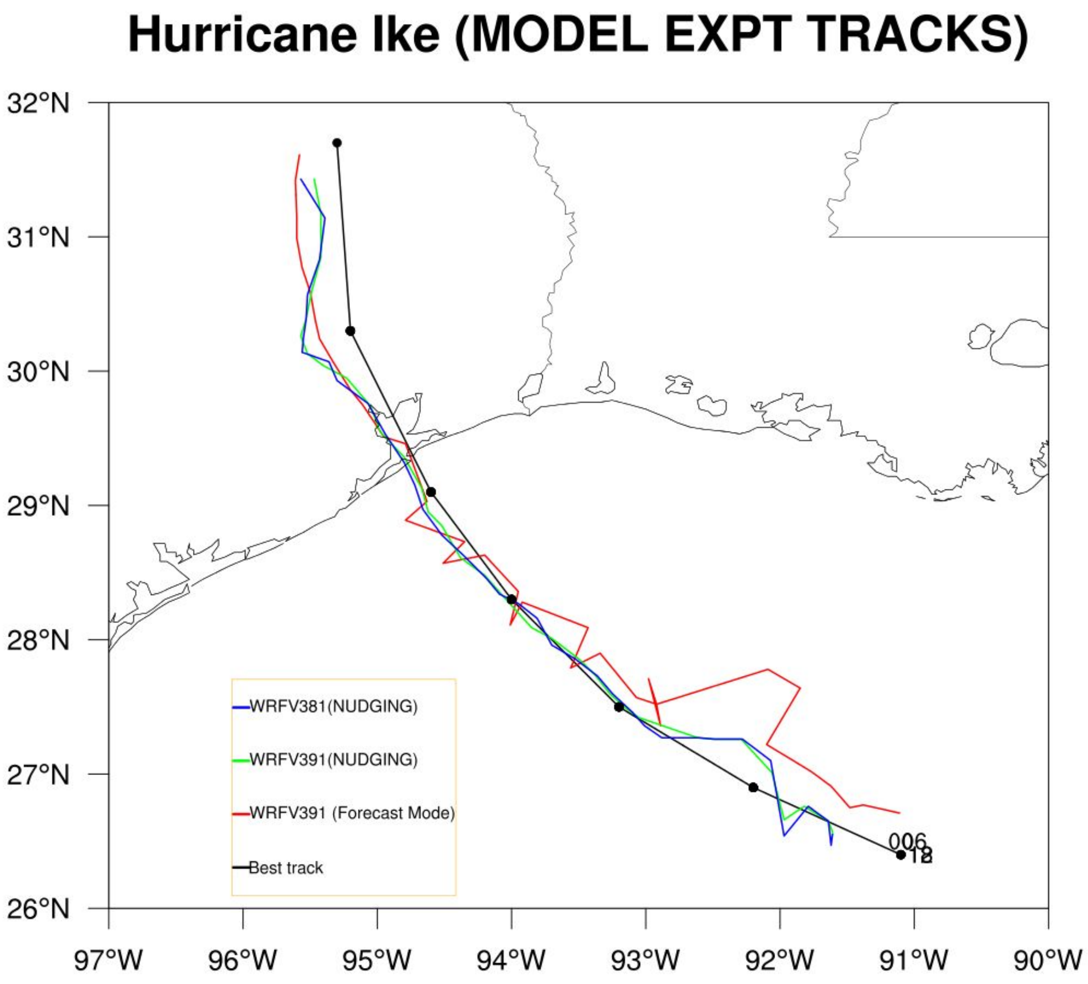
Landfall timing difference is 3 hours between model and observation

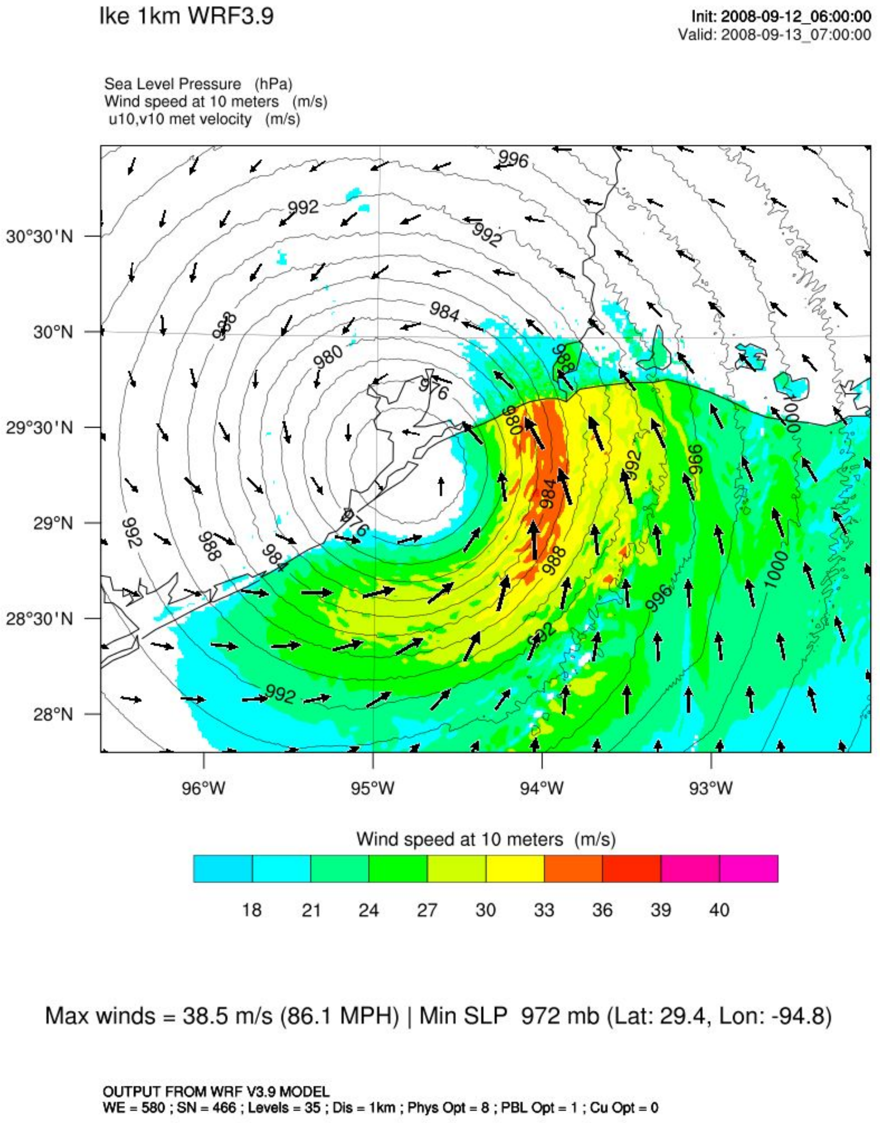
NUDGING EXPERIMENT –WRF/ARW Capability

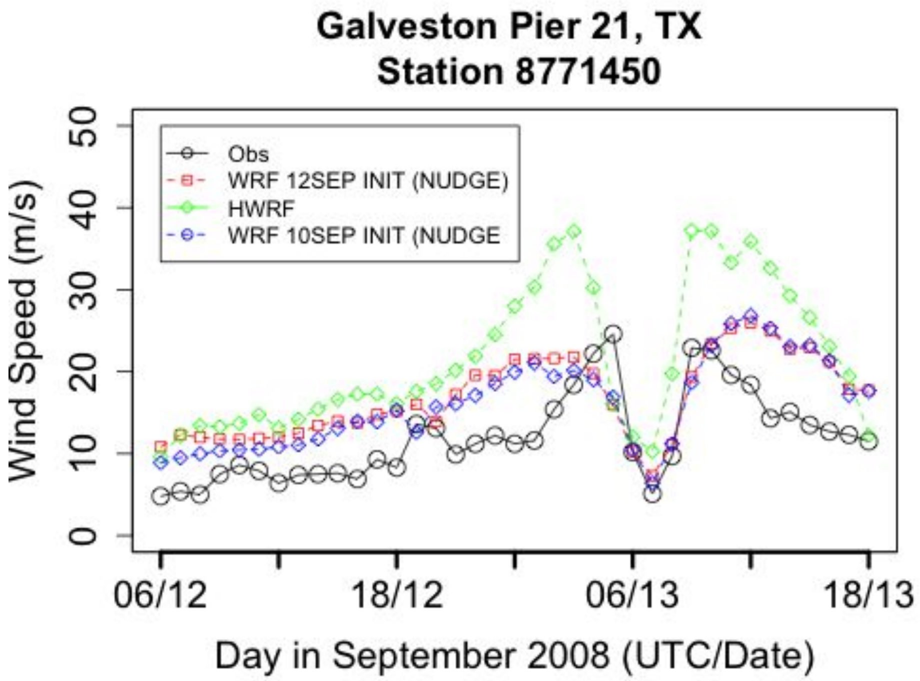
```
&fdda
grid_fdda                 =  1,   1,   1,
gfdda_inname              = "wrffdda_d<domain>",
gfdda_end_h               = 36,  36,  36,
gfdda_interval_m          = 180, 180, 180,
fgdt                      =  0,   0,   0,
if_no_pbl_nudging_uv      =  0,   0,   0,
if_no_pbl_nudging_t       =  0,   0,   0,
if_no_pbl_nudging_q       =  0,   0,   0,
if_zfac_uv                =  0,   0,   0,
 k_zfac_uv                = 10,  10,  10,
if_zfac_t                 =  0,   0,   0,
 k_zfac_t                 = 10,  10,  10,
if_zfac_q                 =  0,   0,   0,
 k_zfac_q                 = 10,  10,  10,
guv                       = 0.0001, 0.0001, 0.0001,
gt                        = 0.0001, 0.0001, 0.0001,
gq                        = 0.0001, 0.0001, 0.0001,
if_ramping                = 0,
dtramp_min                = 60.0,
io_form_gfdda             = 2,
```

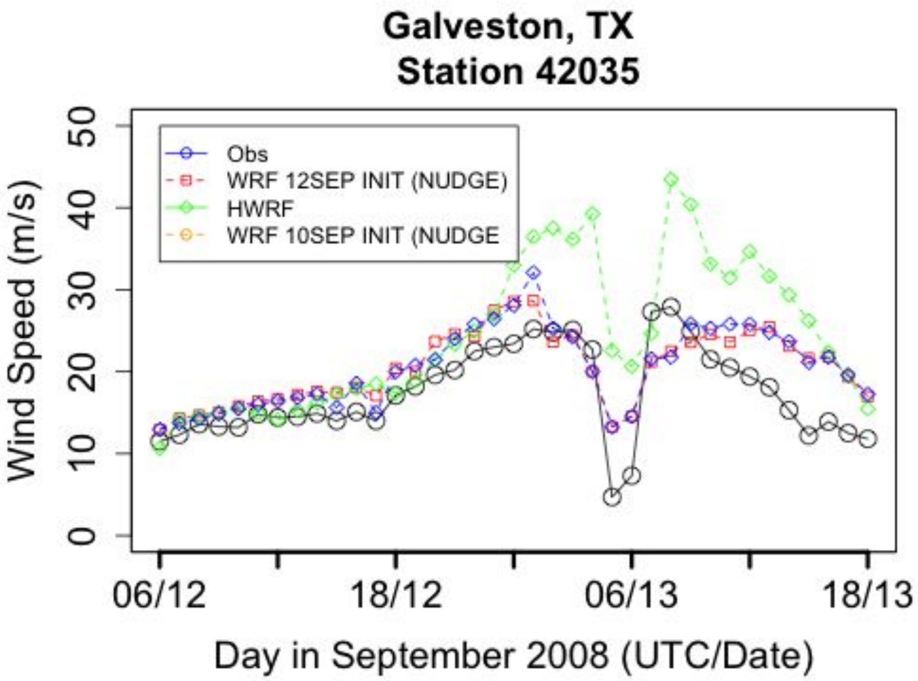
Wind, temperature and moisture are corrected every 1-hourly interval to keep model track and intensity

NUDGING EXPERIMENT



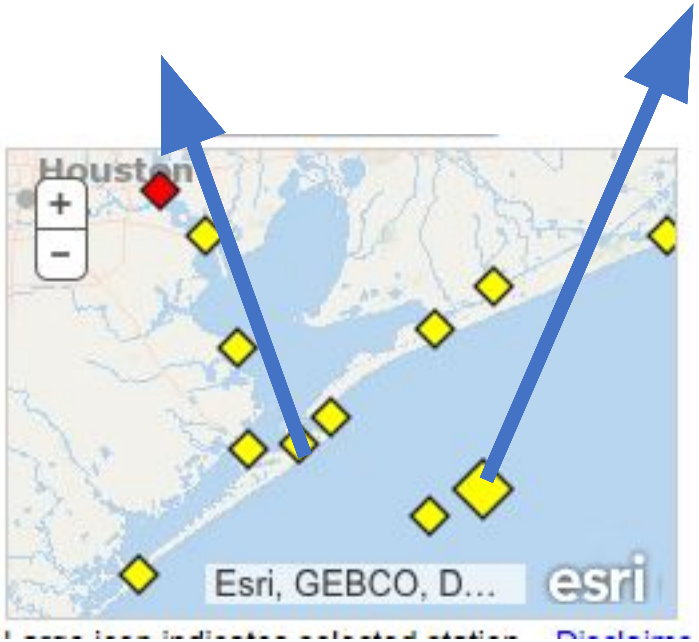






Blue Line - WRF (NUDGE) INITIALIZED
AT 10 Sep 0000 UTC
(90 hours of simulation period)

Red Line - WRF (NUDGE) INITIALIZED
AT 12 Sep 0600 UTC
(36 hours of simulation period)



Implementation of very High-Resolution Landuse and Terrain data

Implementation of High-res Landuse and Terrain data in the LES simulations

Currently available Topography and Landuse in WRF

- LANDUSE : USGS Based 30S (1Km) Data (24-category USGS landuse) & MODIS 30S (21-Category)
- TOPOGRAPHY: GMTED2010 30 arc-second (1-km) topography height (USGS Based)

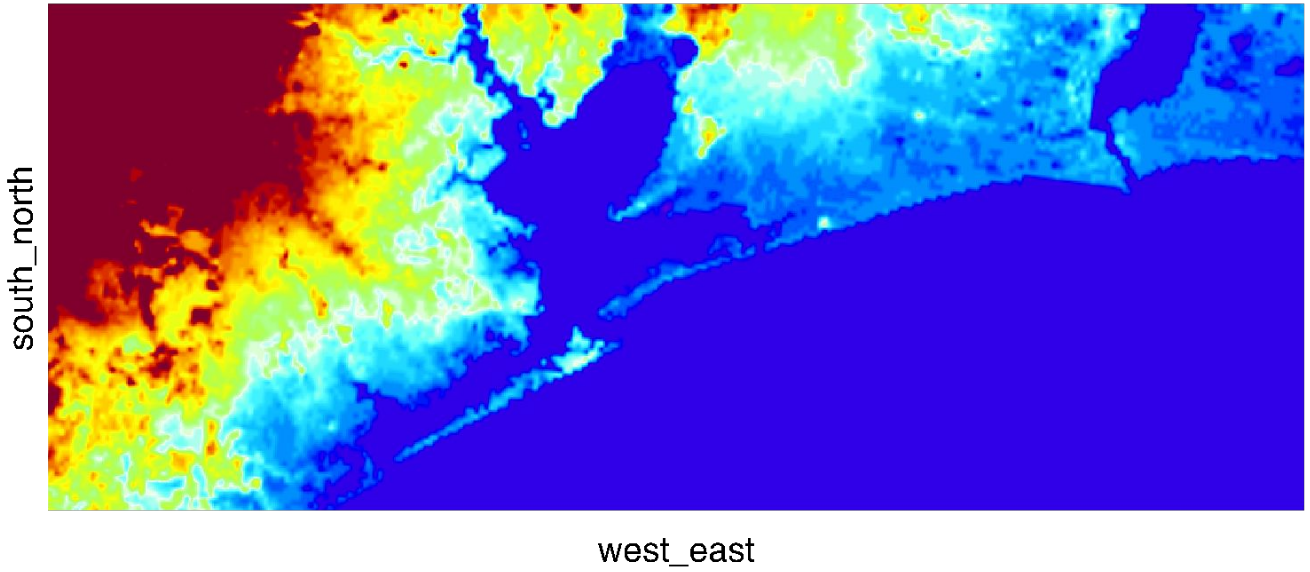
Replace with (For LES domains)

- LANDUSE : NLCD (2011) 1 Arc-second (30-meter) USGS Based (40-category USGS)
- TOPOGRAPHY: USGS (2013) 1/3 Arc-second (10-meters) topography height

LES Domain 1
(Terrain data comparision)

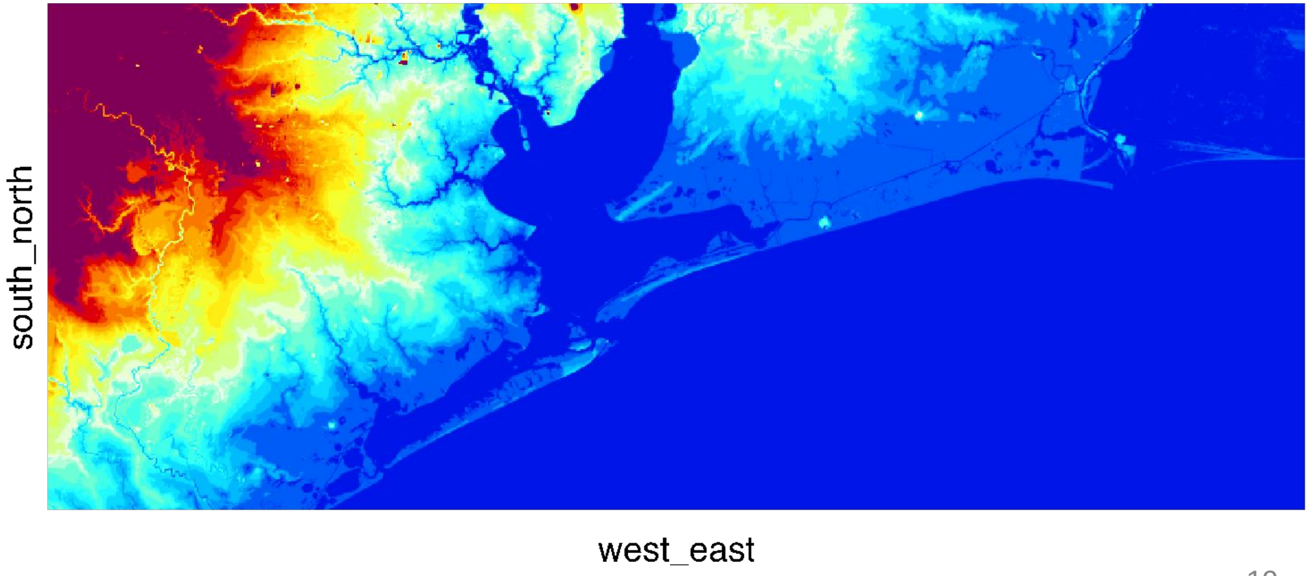
GMTED2010 30-arc-second (1-Km resolution) topography height. The Global Multi-resolution Terrain Elevation Data 2010 (GMTED2010). By USGS and National Geospatial-Intelligence Agency (NGA).

Terrain data: 1-Km Resolution



U.S. Geological Survey (USGS), 2013, USGS National Elevation Data (NED) 1/3 arc-second (10-meter resolution)

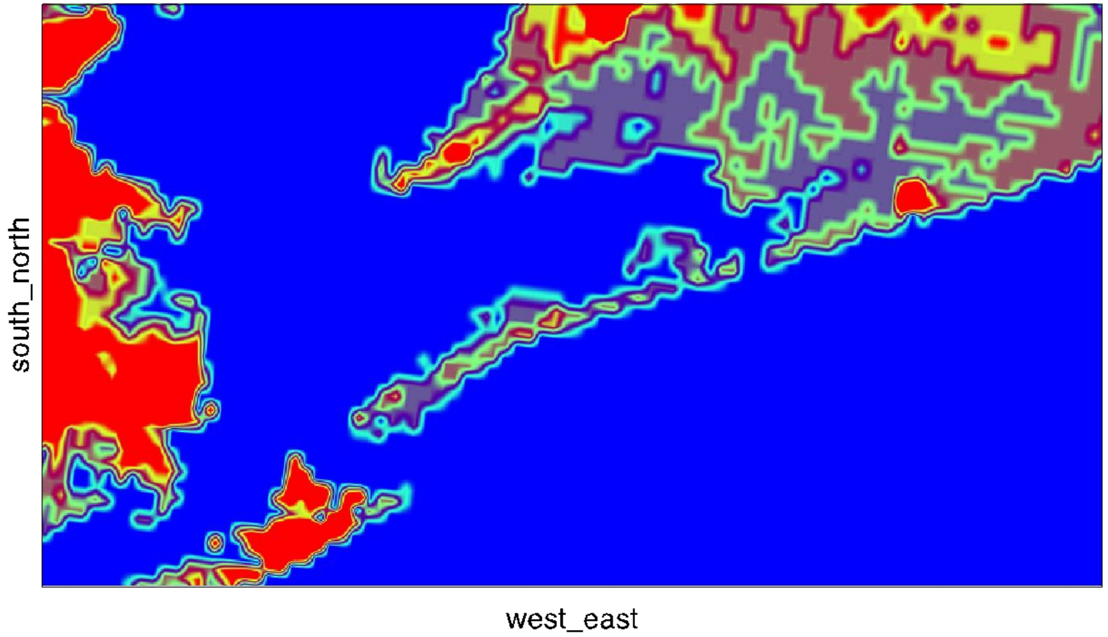
Terrain Data : 10-meter resolution



LES Domain 2 (Terrain data)

GMTED2010 30-arc-second (1-Km resolution) topography height. The Global Multi-resolution Terrain Elevation Data 2010 (GMTED2010). By USGS and National Geospatial-Intelligence Agency (NGA).

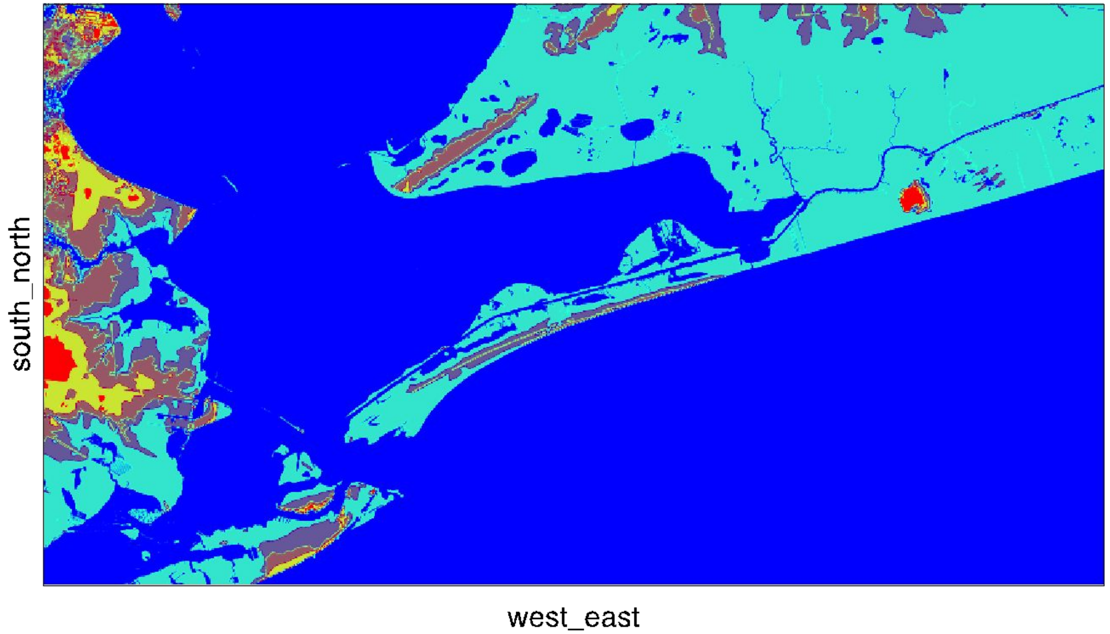
Terrain data: 1-Km Resolution
HGT_M (meters MSL)



U.S. Geological Survey (USGS), 2013, USGS National Elevation Data (NED) 1/3 arc-second (10-meter resolution)

For our LES nested domains over Hurricane Ike landfall location, 10-meters resolution binary files are created & implemented using geogrid process in the WRF Preprocessing System (WPS).

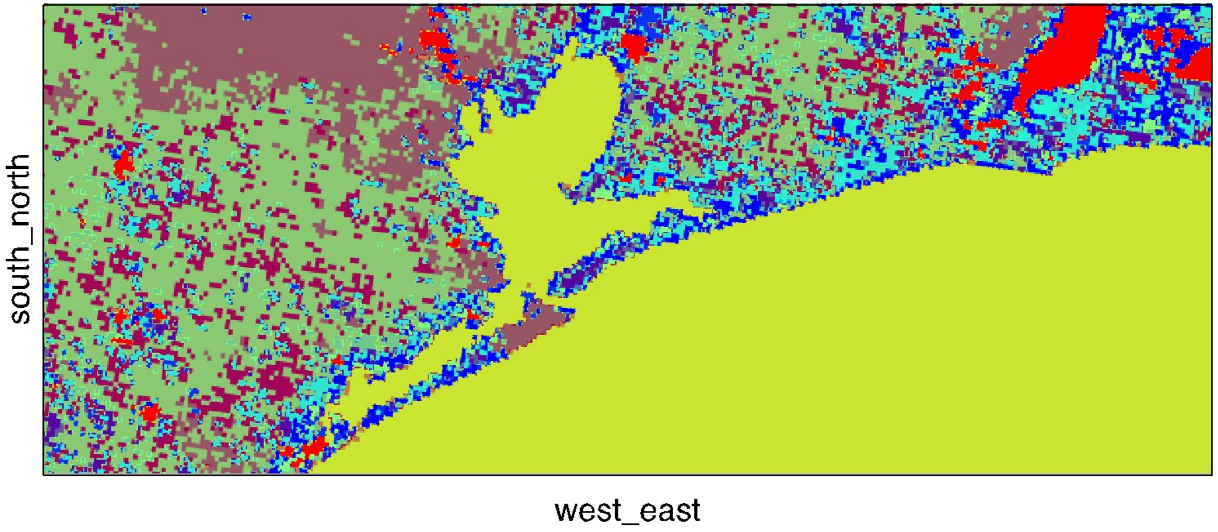
Terrain Data : 10-meter resolution



LES Domain 1
(Landuse Comparison)

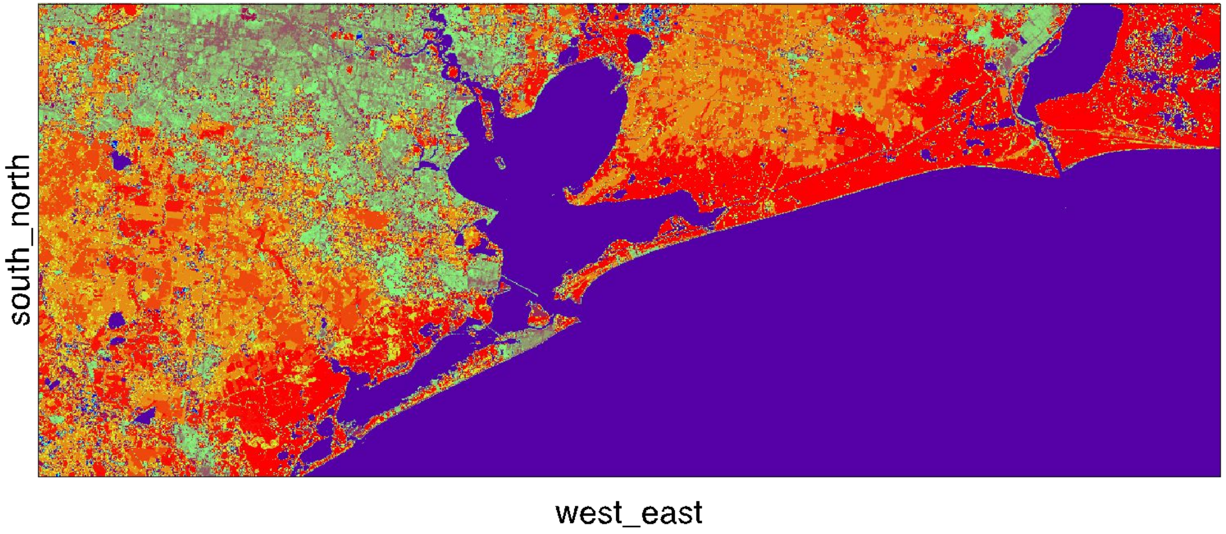
MODIS based (1-Km resolution) Landuse map. 21 landuse categories. Only one class of urban landuse.

MODIS based Landuse: 1-Km Resolution



USGS NLCD 1 arc-second (30-meter resolution)
40 landuse categories
It has urban classifications
Developed Open space (23)
Developed Low Intensity (24)
Developed Medium Intensity (25)
Developed High Intensity (26)

NLCD : 30-meter resolution



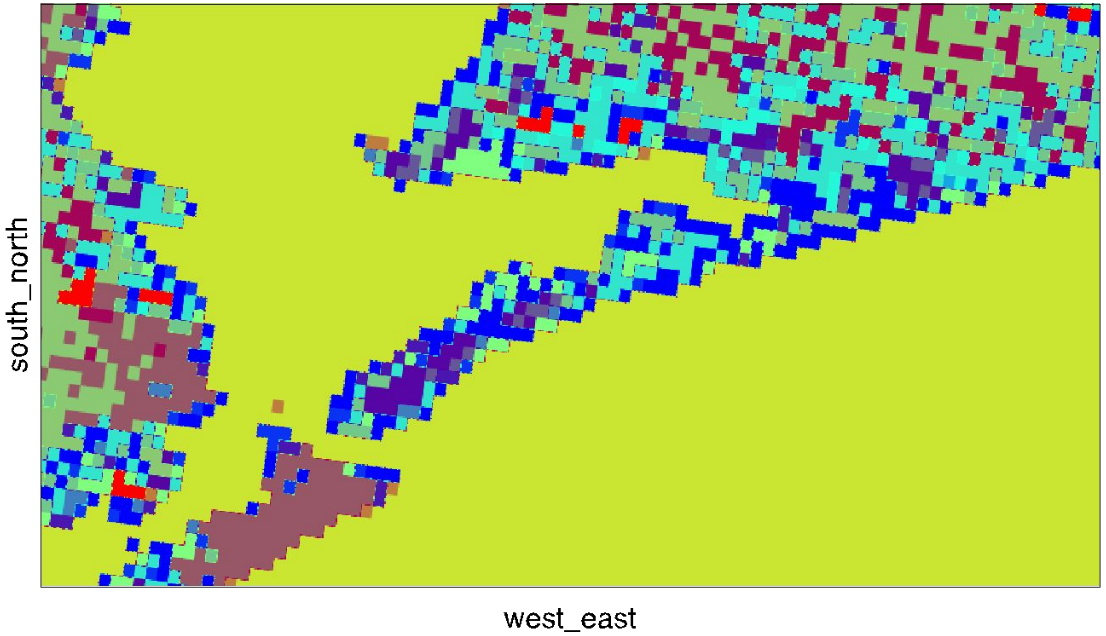
LES Domain 2

MODIS based (1-Km resolution) Landuse map.
21 landuse categories. Only one class of urban landuse.

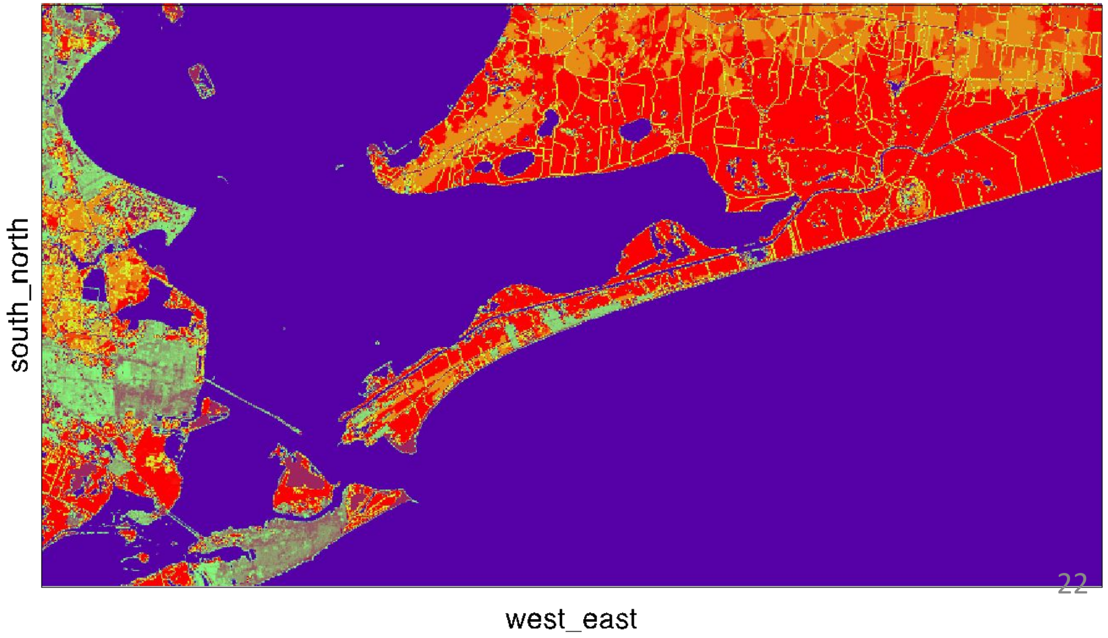
USGS NLCD   1 arc-second (30-meter resolution)
40 landuse categories
It has urban classifications
Developed Open space (23)
Developed Low Intensity (24)
Developed Medium Intensity (25)
Developed High Intensity (26)

For our LES domain selected region-
Hurricane Ike landfall location,
10-meters binary files created &
implemented using geogrid process in
WPS.

Landuse: 1-Km Resolution

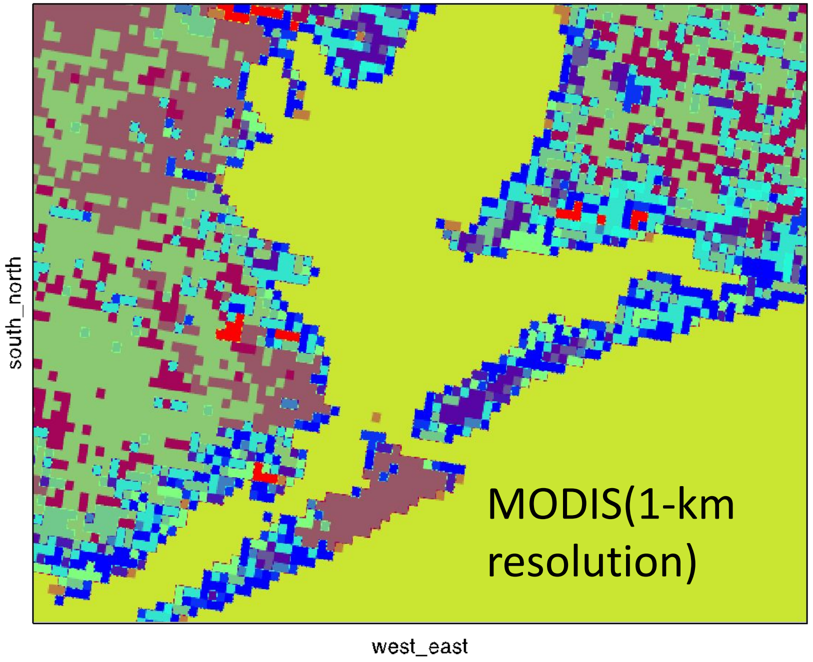


Landuse : 30-meter resolution

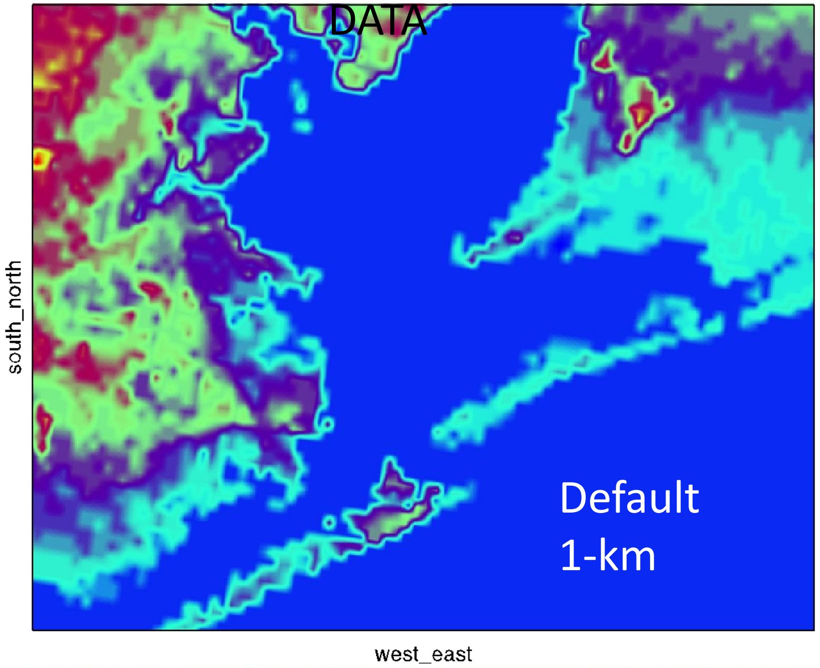


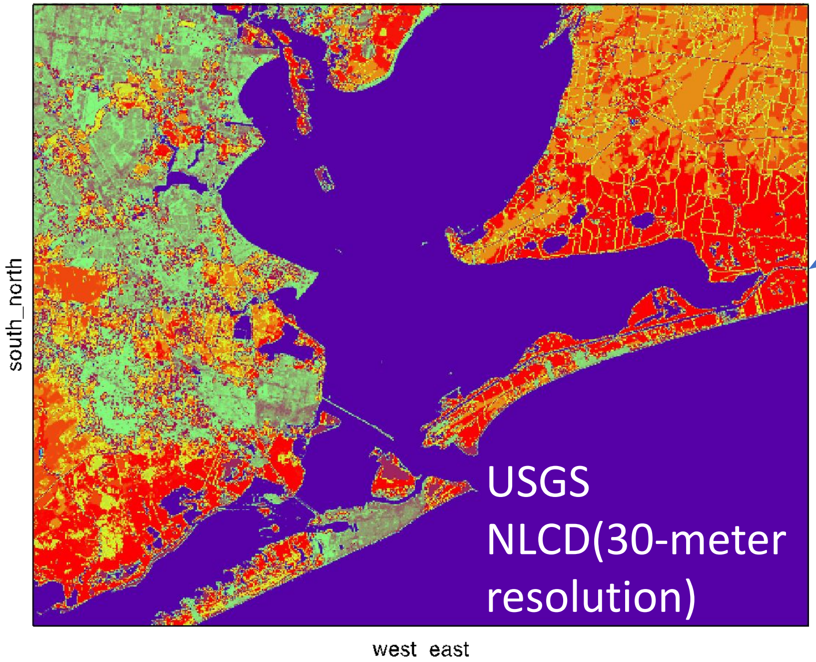
LANDUSE MAP

TERRAIN DATA

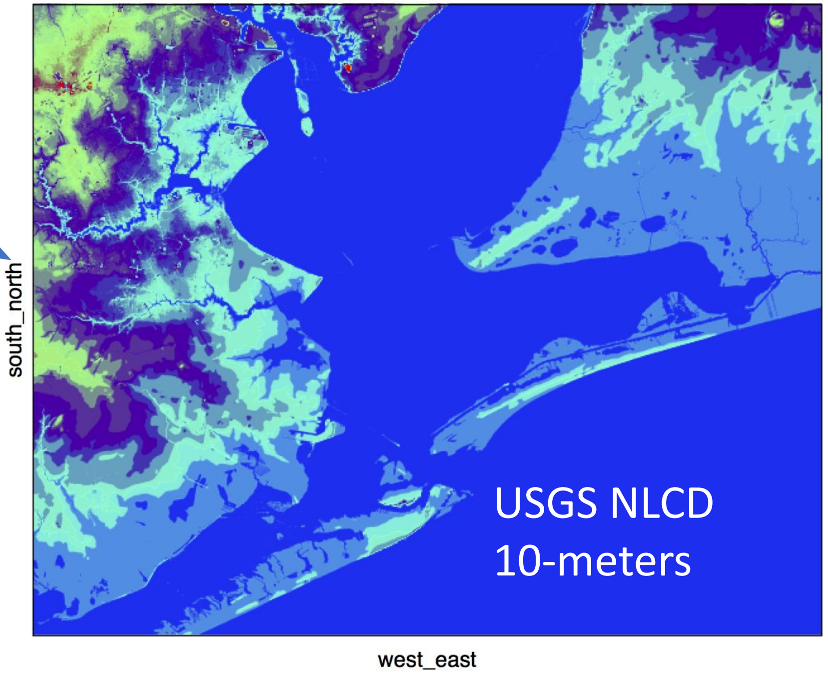


COARSER DATASETS





FOR LES SIMULATIONS



Implementation of Water Inundation (High Water Mark) in the LES simulations

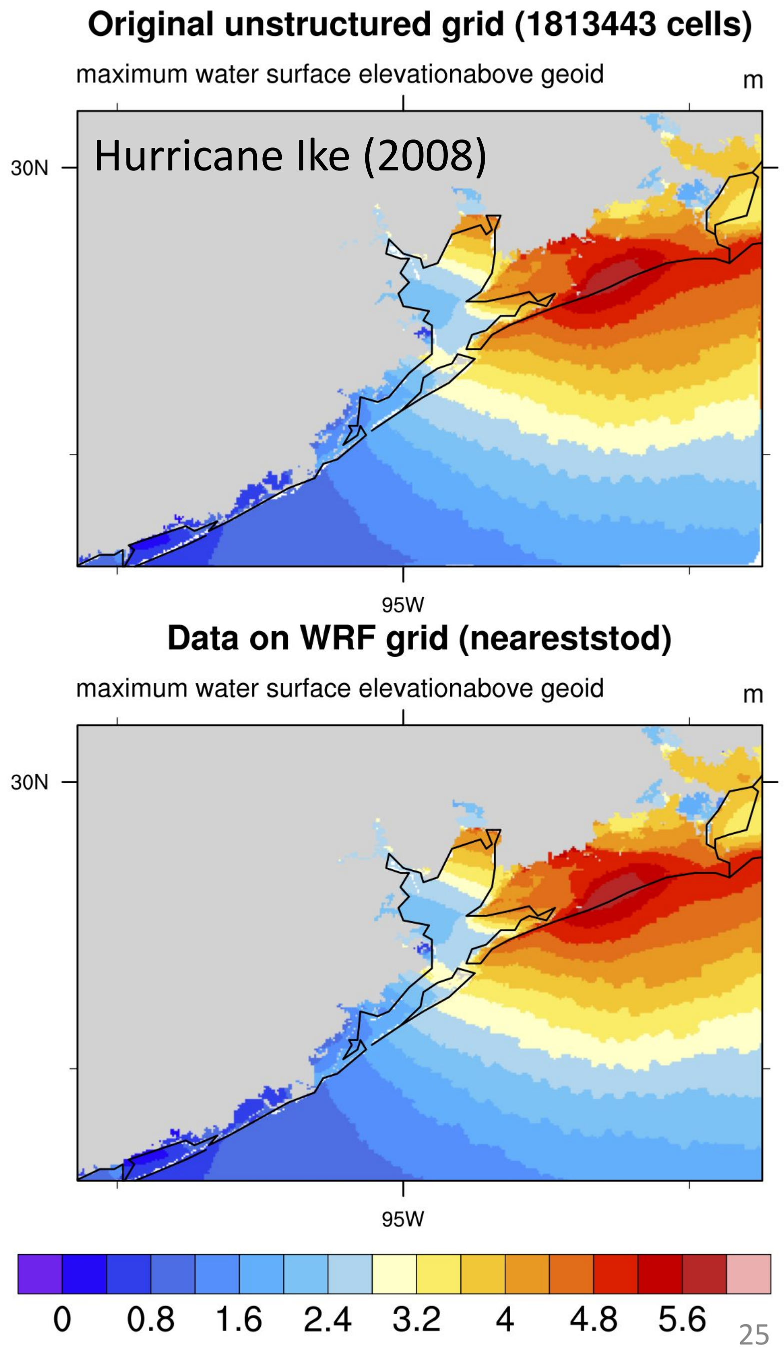
Implementation of Max Water surface elevation in the WPS –WRF System for LES (Hurricane Ike-2008)

1. Maximum water surface elevation(zeta_max) data is available in unstructured grid format from ADCIRC model.
2. First step is to regrid zeta_max variable on WRF grid.
3. ESMF_regrid is used to transform data from unstructured to WRF grid, using ESMF software. ESMF_regrid is part of as suite of regridding routines based on the Earth System Modeling Framework (ESMF) software.

This function is an "all-in-one" function that performs all of these steps:
1. Writes the description of the source grid to a SCRIP or ESMF description NetCDF file.
2. Writes the description of the destination grid to a SCRIP or ESMF description NetCDF file.
3. Generates the weights and writes them to a NetCDF file.
4. Regrids the data by applying the weights.
5. Copies metadata (attributes and coordinate arrays) where possible.

Interpolation Method: nearest neighbor method

We have done this using NCL V6.4.0 (or higher)

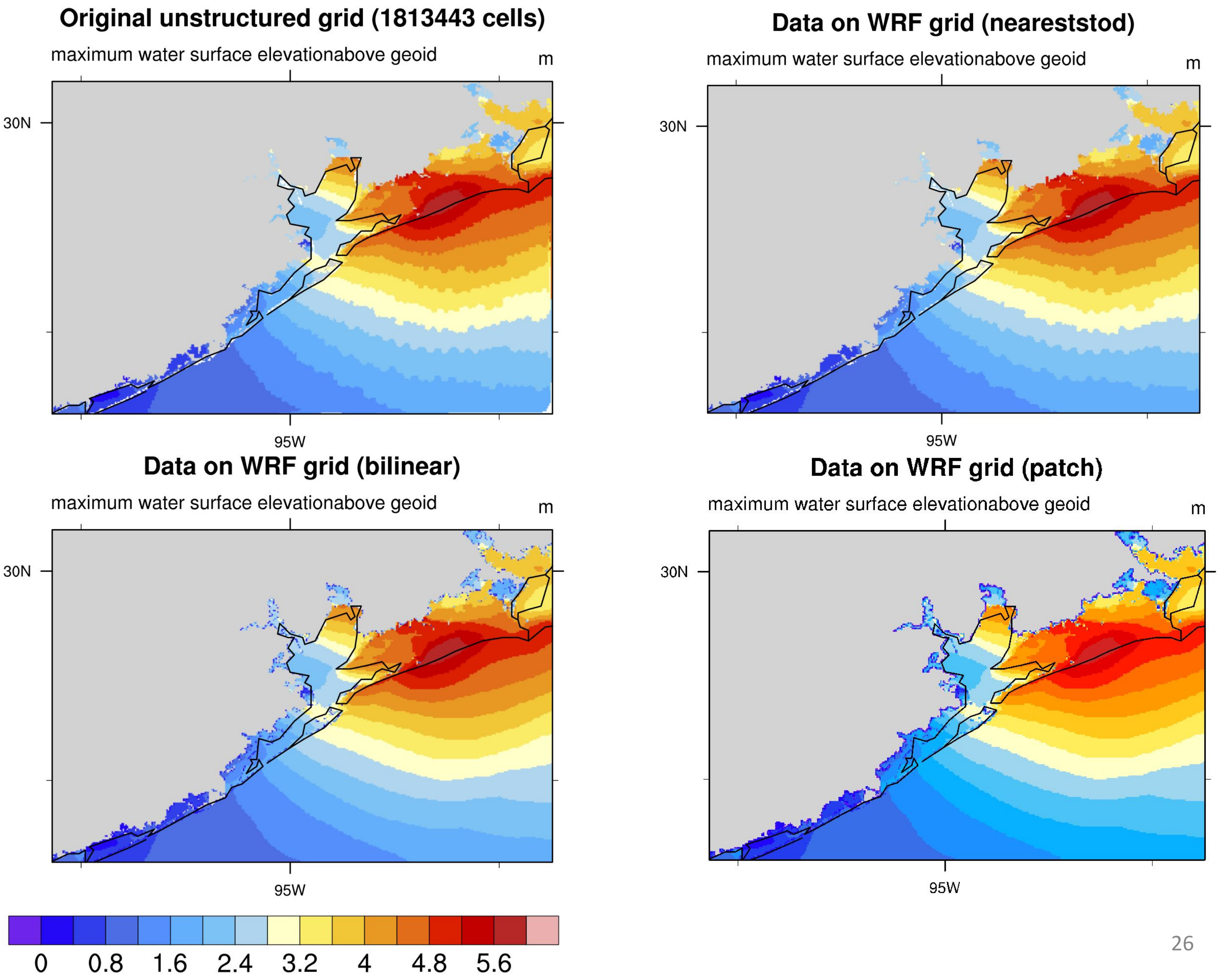


Interpolation Methods

Nearest Point interpolation method looks better than bilinear and patch methods in comparison with original data.

"patch" - this method is the ESMF version of a technique called "patch recovery" commonly used in finite element modeling. It typically results in better approximations to values and derivatives when compared to bilinear interpolation.

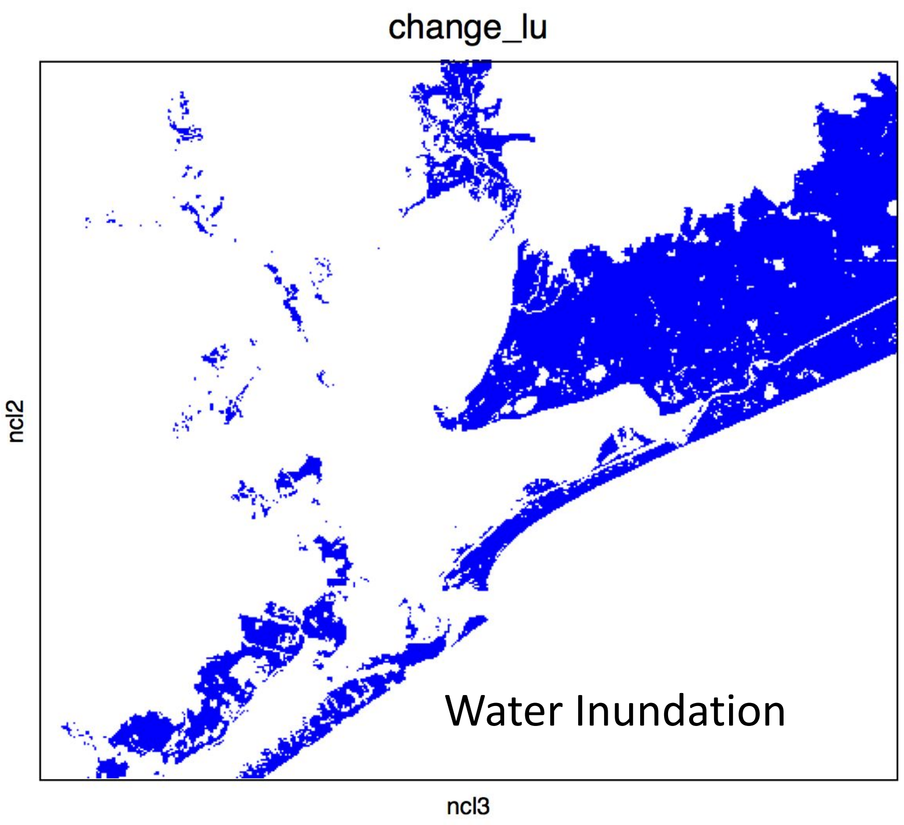
Using nearest point method
In our analysis.



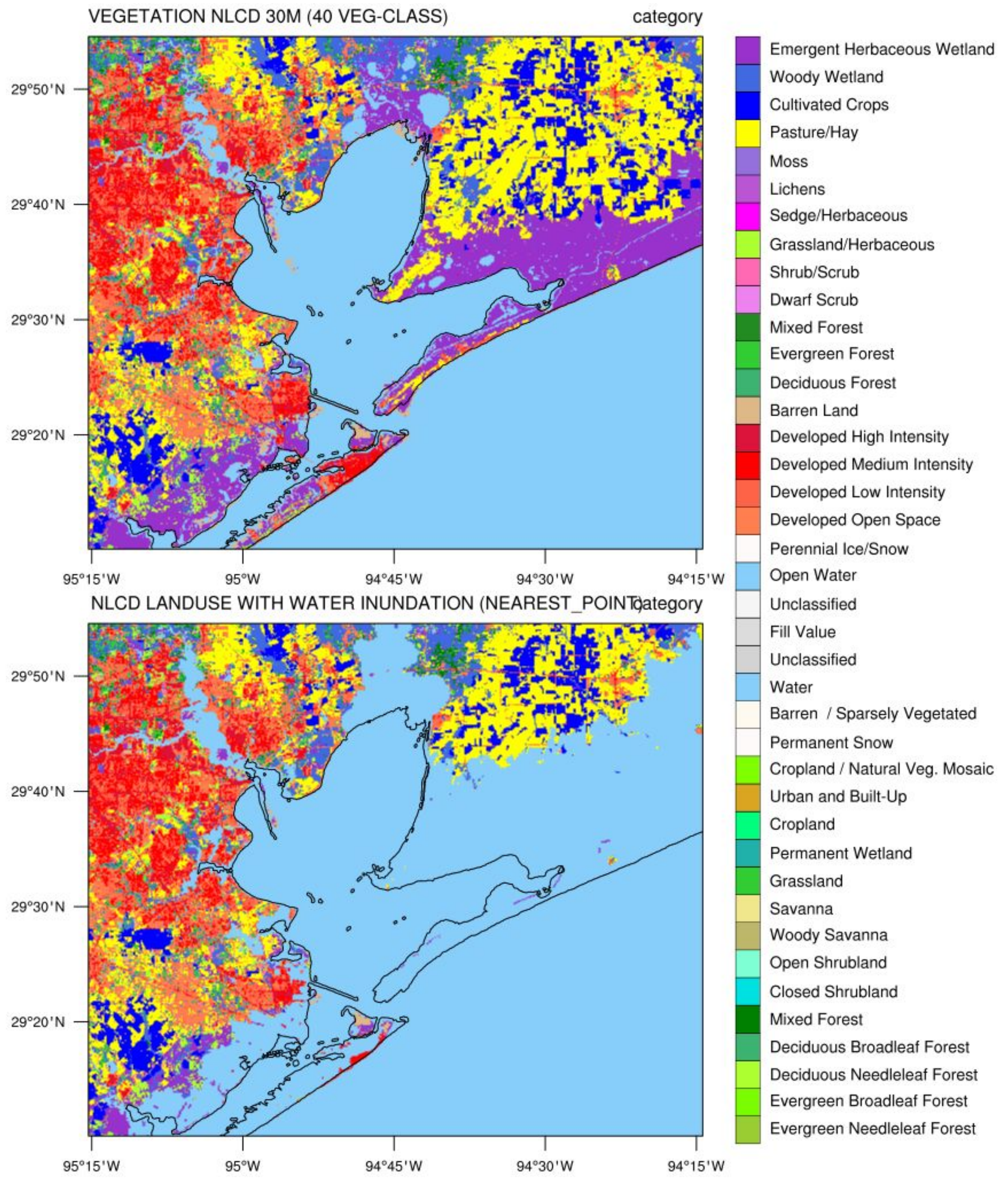
Water Inundation – Summary Points

- 1. mapping the high water level [aka inundation] data from is unstructured grid to the WRF-ARW grid
- 2. where Maximum water surface greater than the model's terrain, we set landuse to open water.
- 3. not changing the land-sea mask nor the terrain height or sfc-pressure in the model.

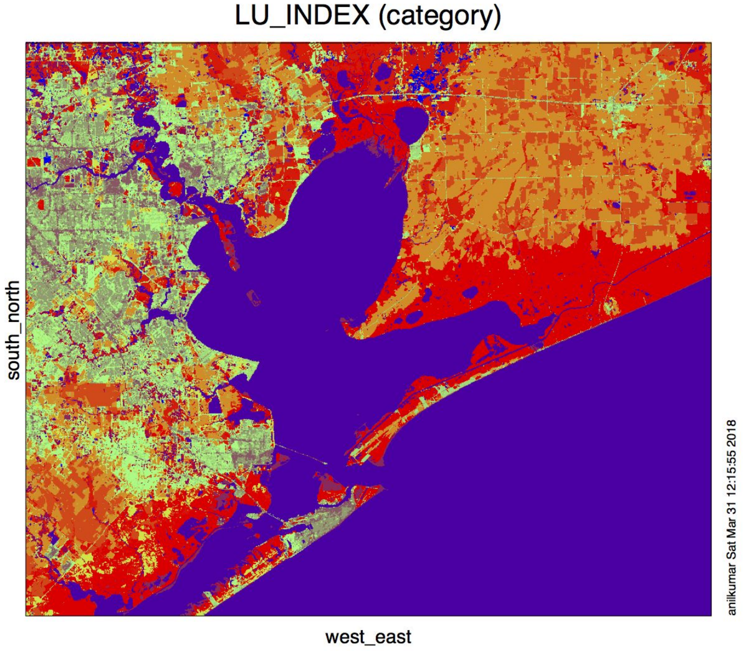
Domain 2 (Outer Domain 90 meter)

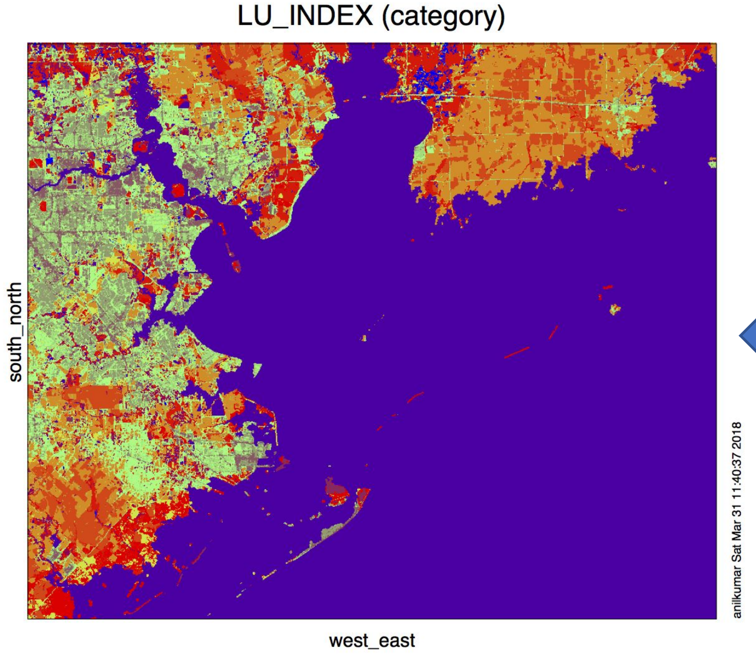


Update the Landuse (LU_INDEX geo_em.d02.nc) in WPS



Domain-2
90-m resolution

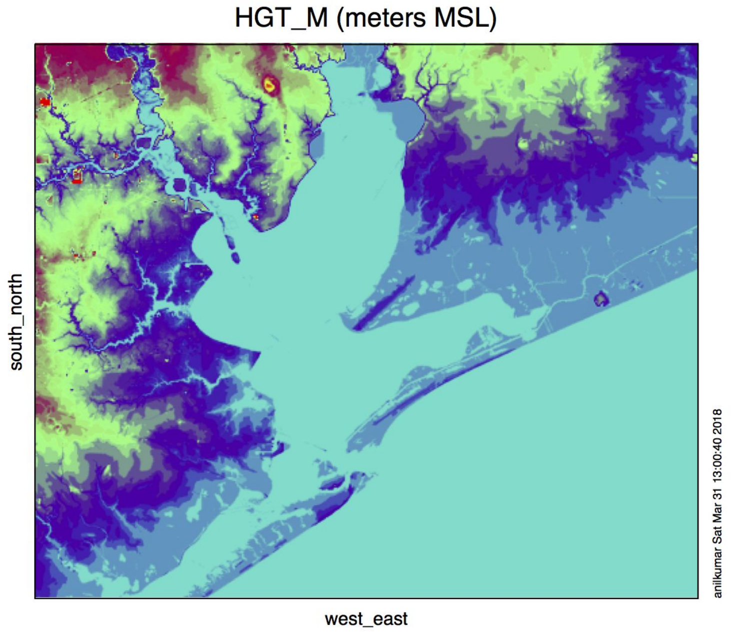


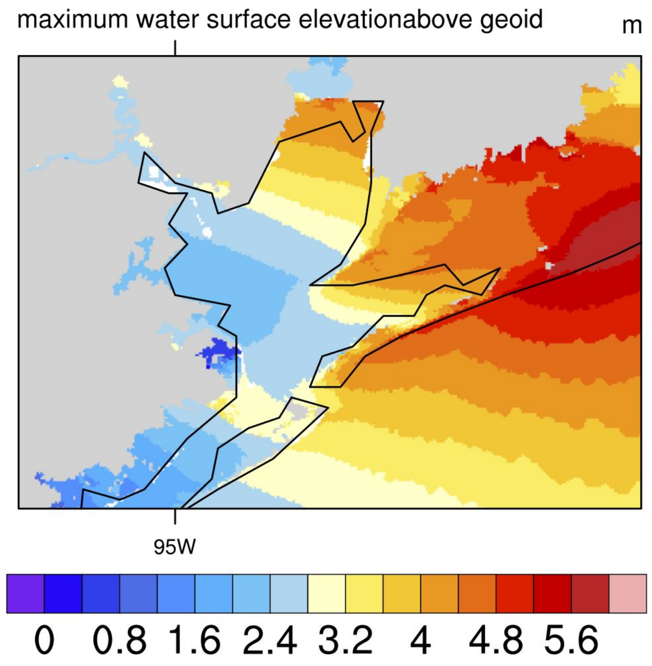


Snapshot from WPS
geogrid file
(from ncview)

Updated Landuse
In WPS

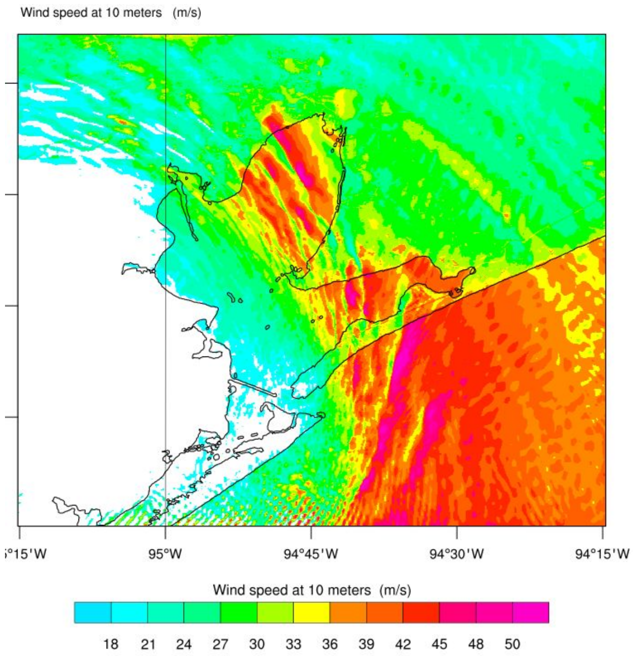
Terrain HGT

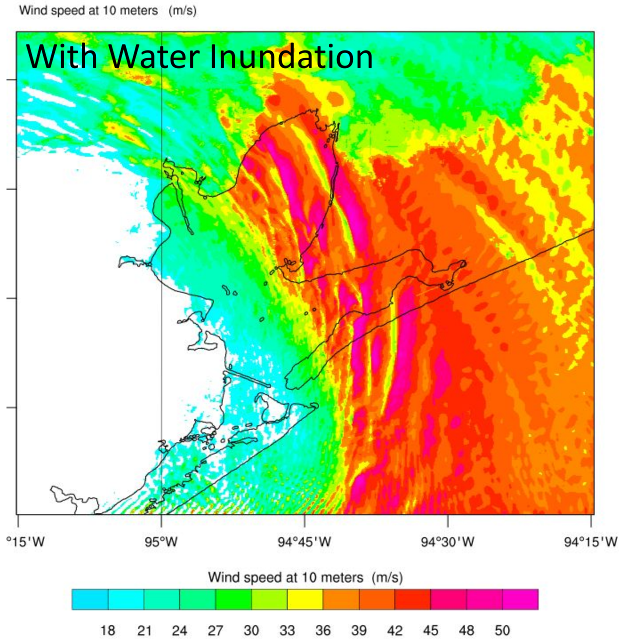


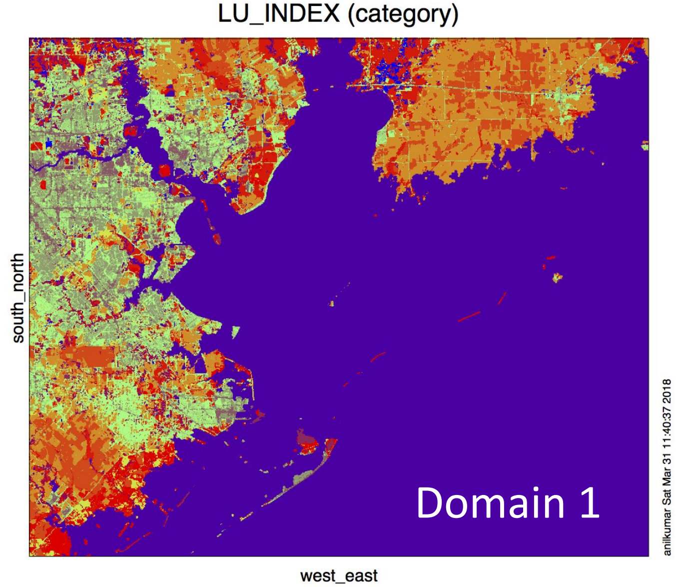


Domain 1 = 90 meter

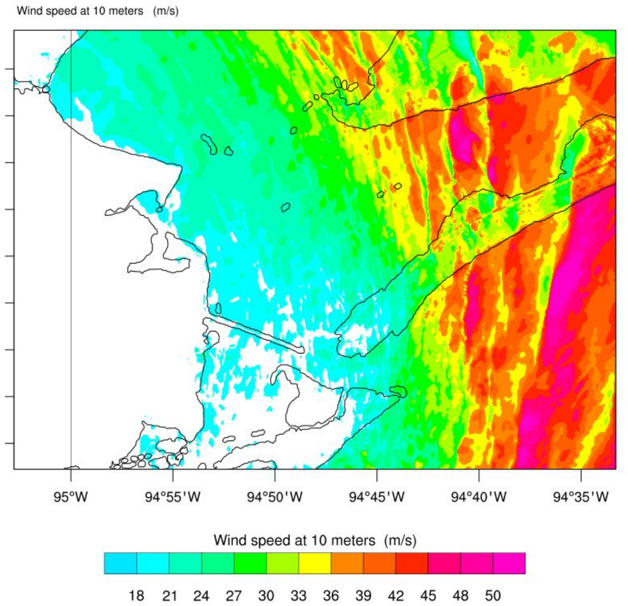
Water Inundation map

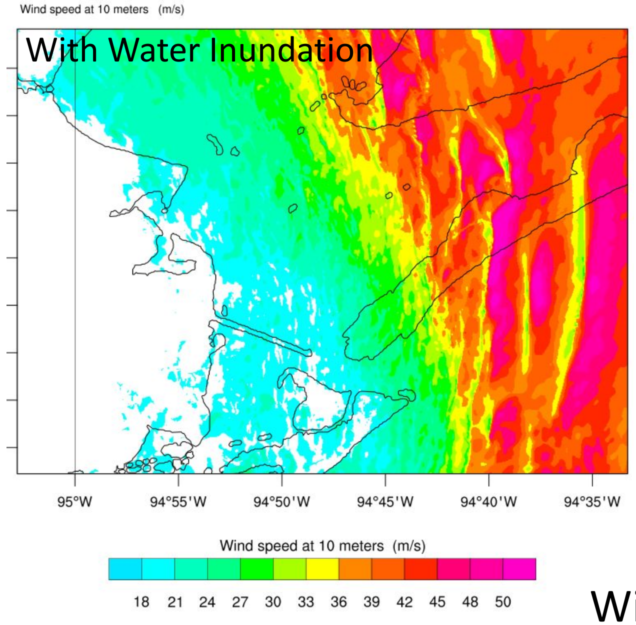


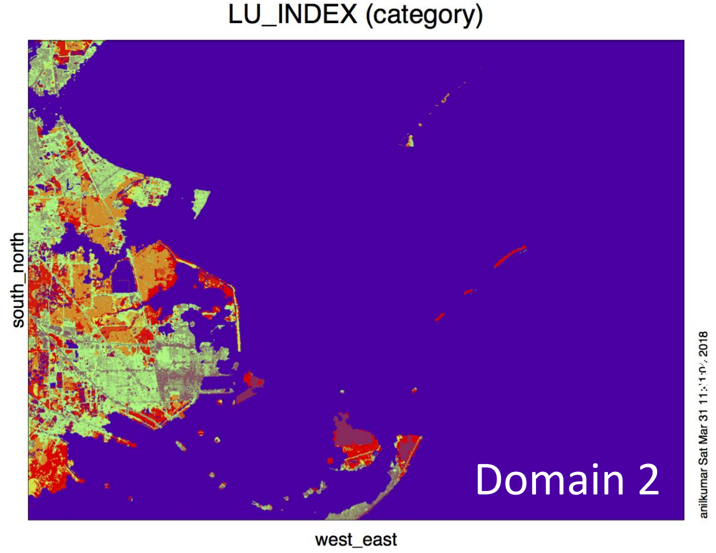




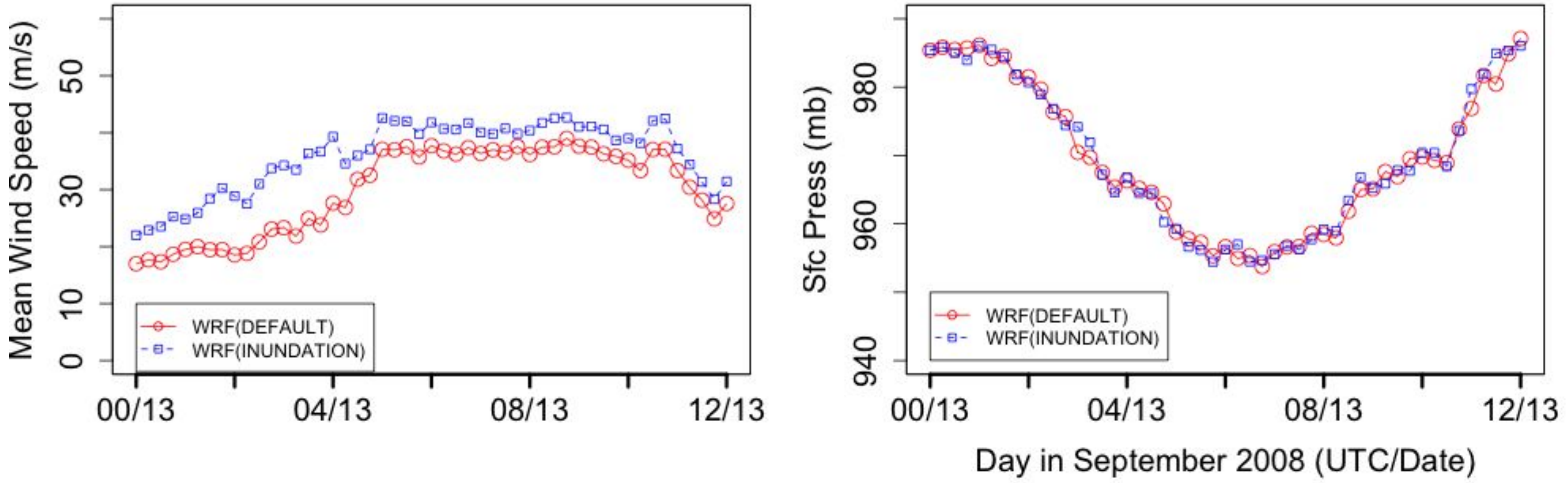
Domain 2 = 30 meter





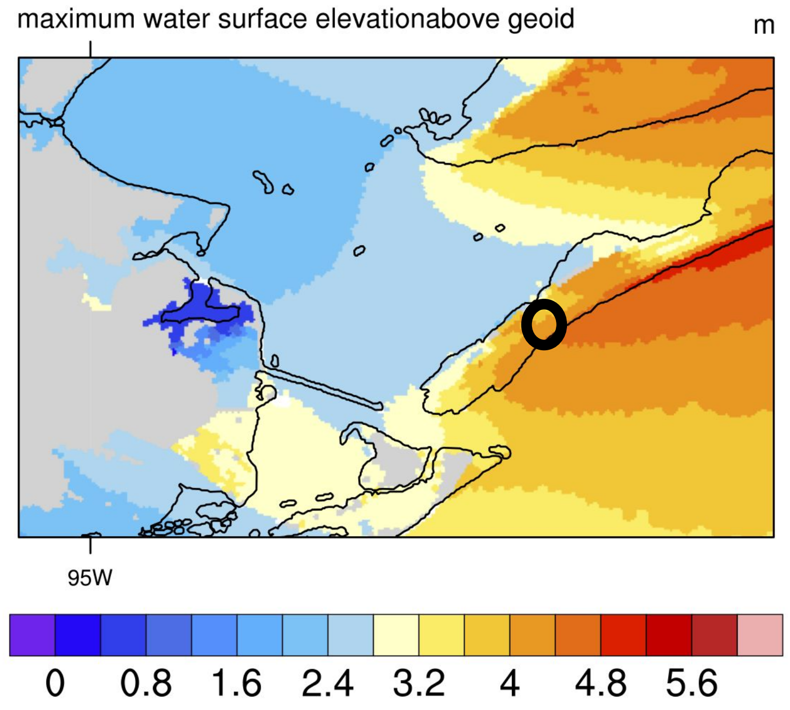


Wind Speed 10-meters (0800 UTC 13 Sep 2008)



No Observation at this location

Time–dependent Inundation will be much more realistic to capture accurate near surface winds?

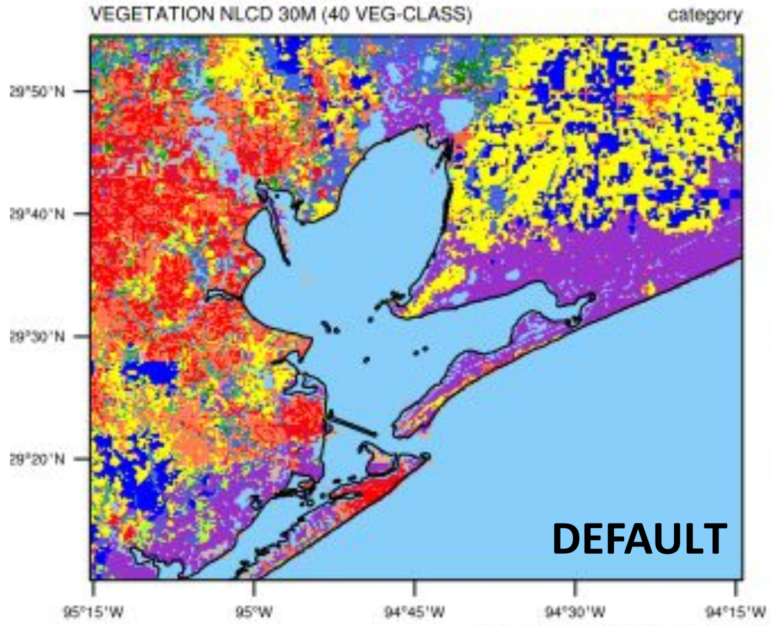


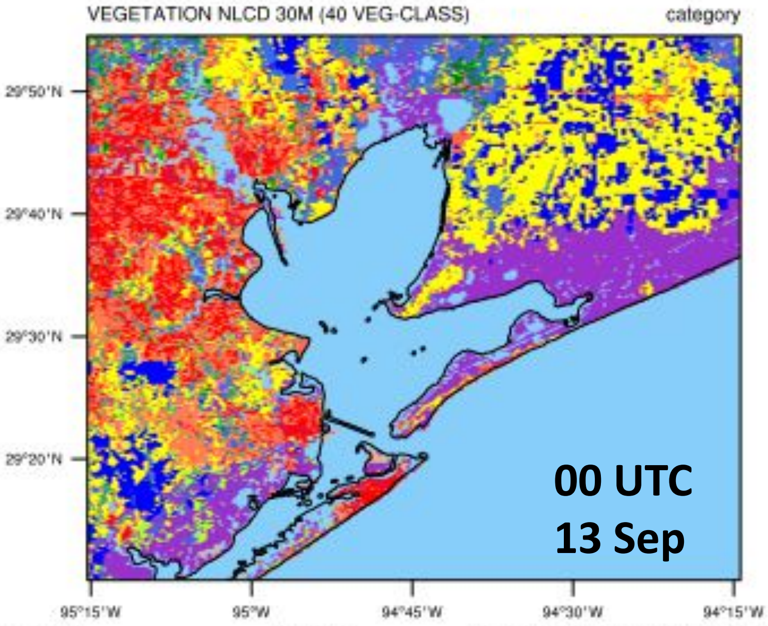
5-10 m/s higher wind speed (at 10-meters) over inundation nearly 3 to 4 meters

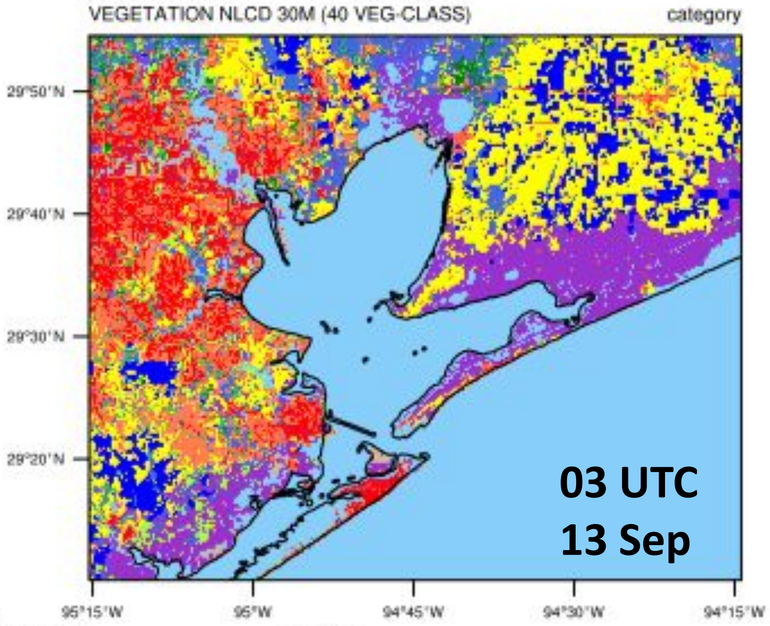
Time-Dependent Inundation

- One hourly Inundation from ADCRIC model
- Uses 3-hourly inundation information for Hurricane Ike case
- Changing landuse (LU_INDEX, vegetation type (IVGTYP) and soil type (ISLTYP))
- All these changes are made in wrfinput files and wrf-restart files.

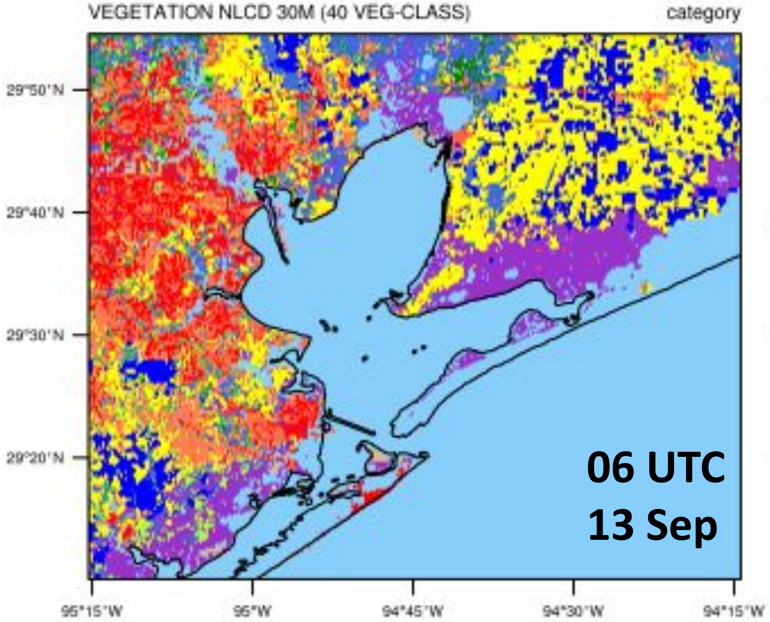
Domain 1 (90-meters)

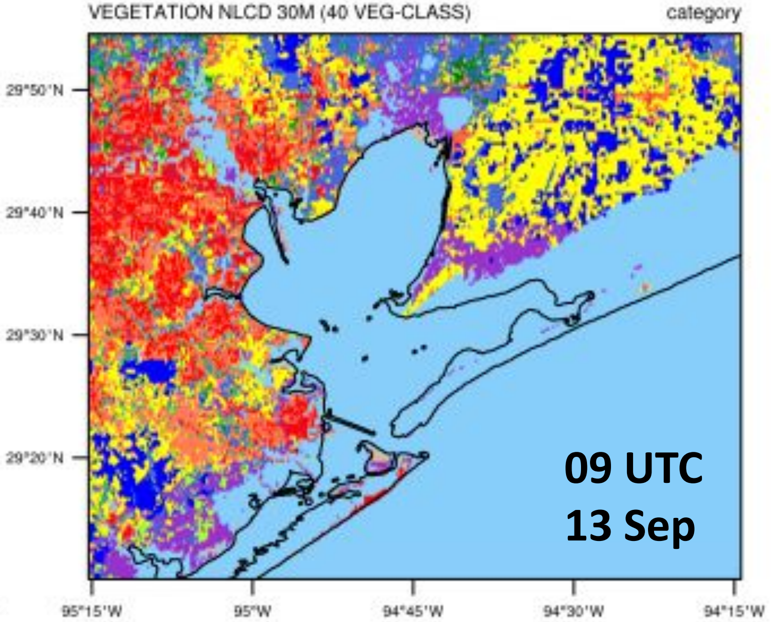




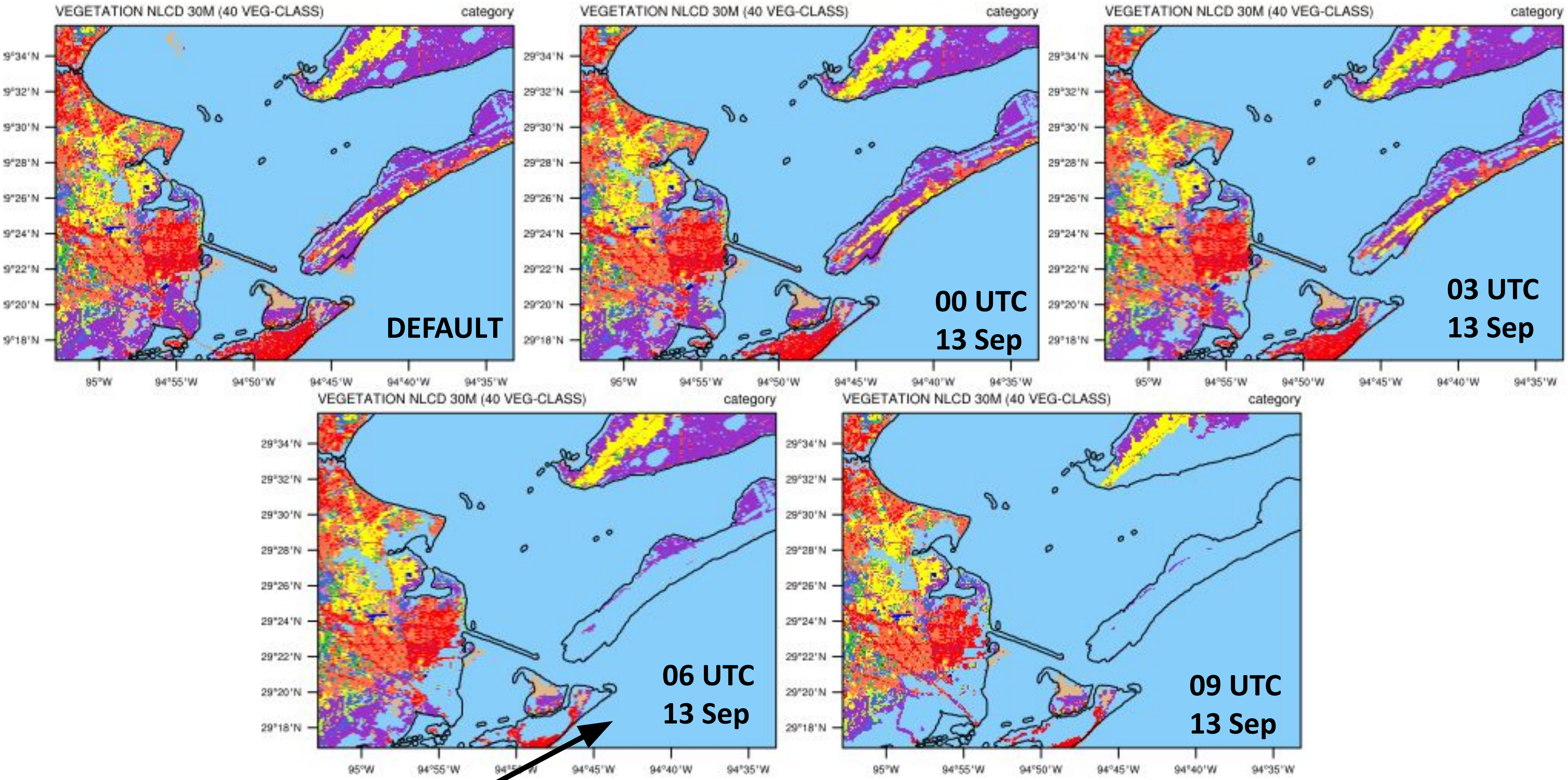


Much Inundation happened after landfall (after 06 UTC).

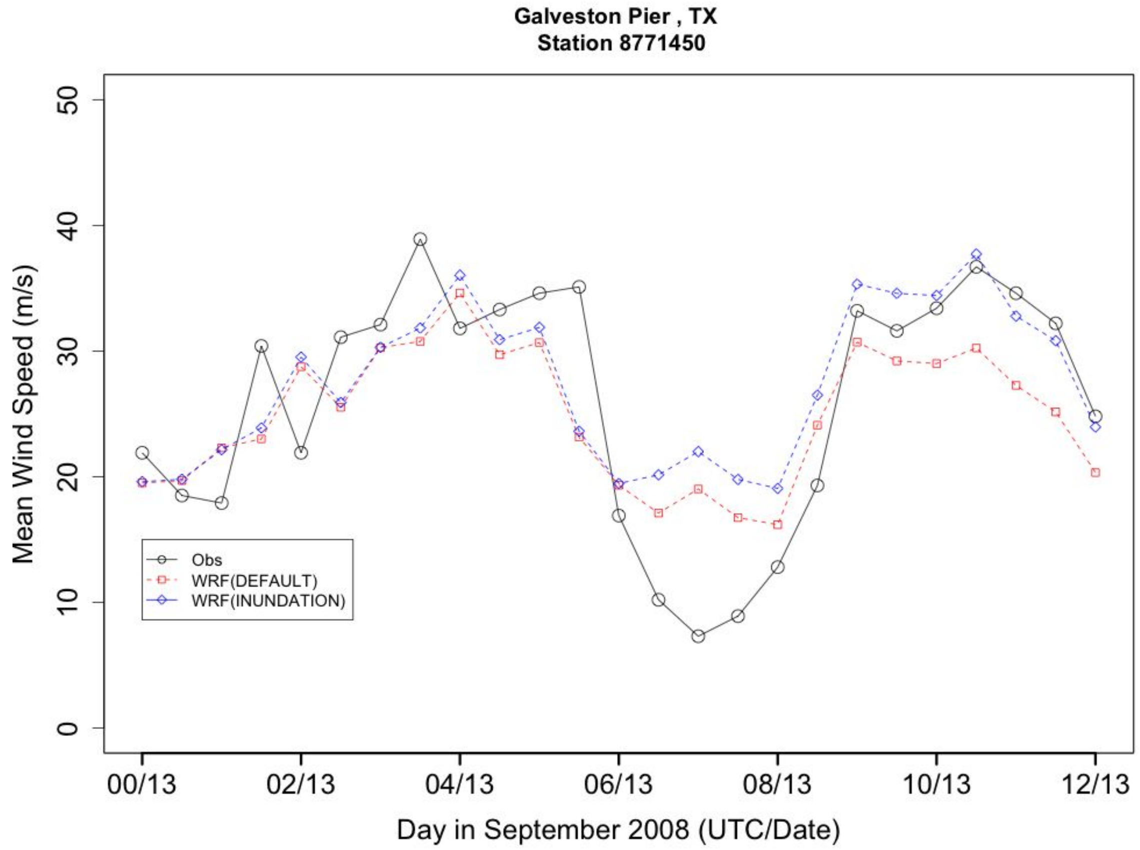


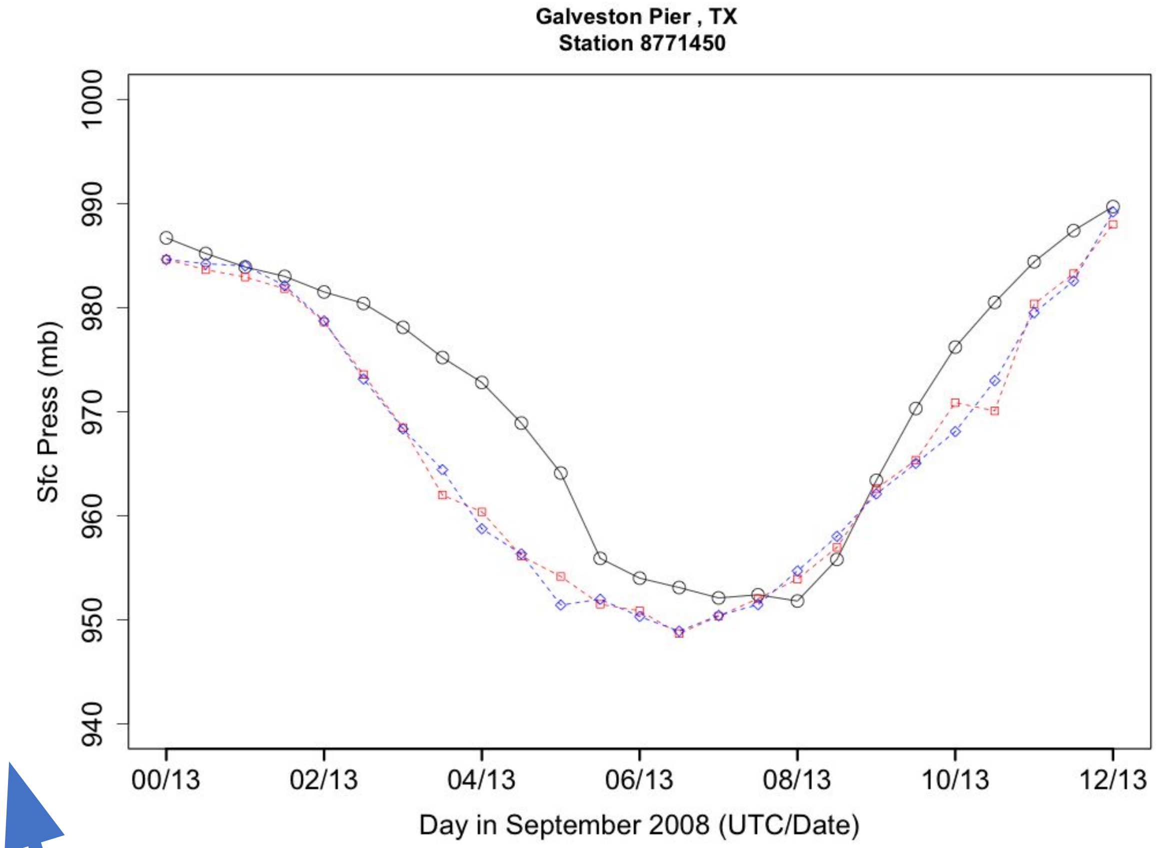


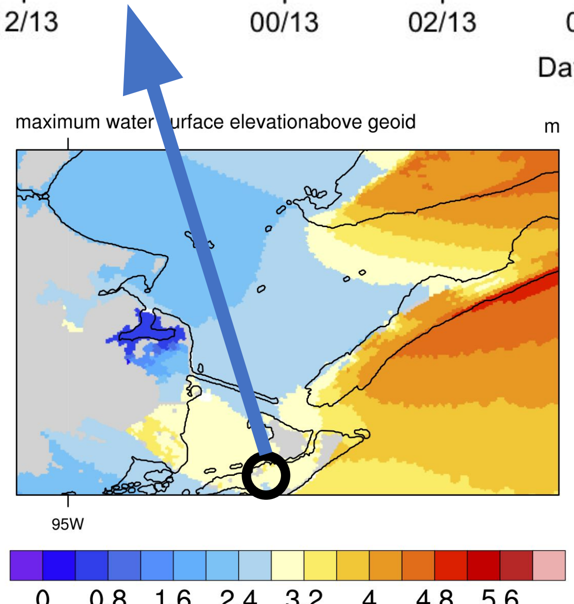
Domain 2 (30-meters)



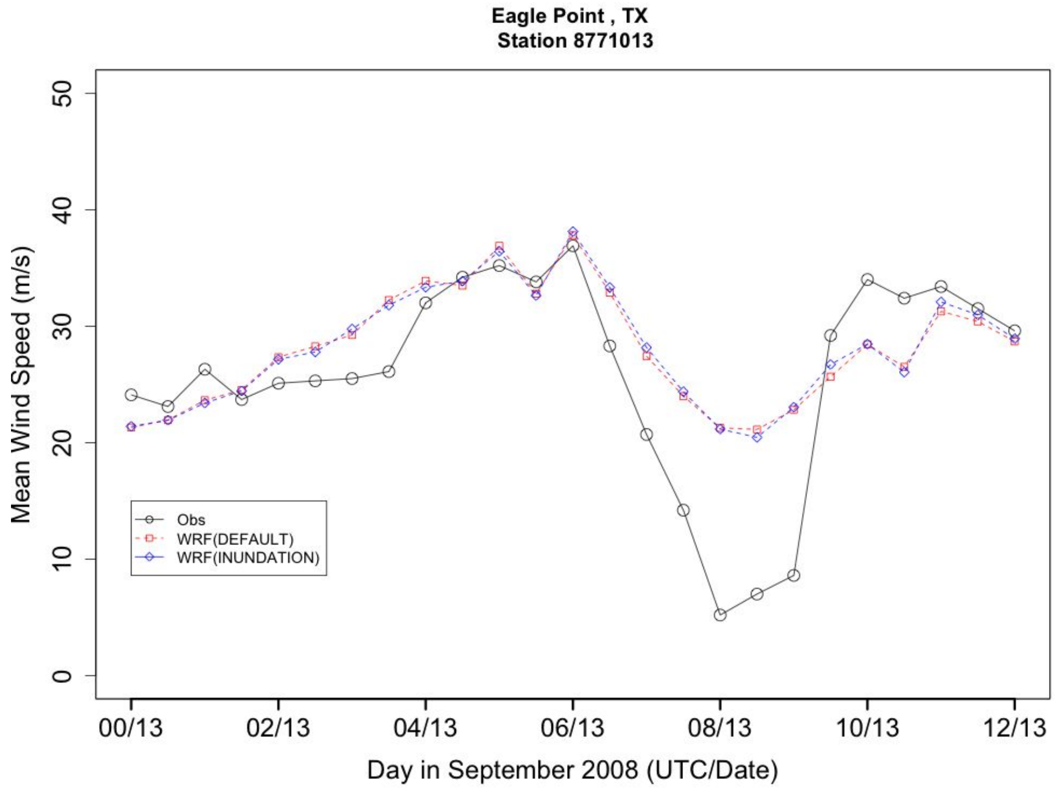
Landfall

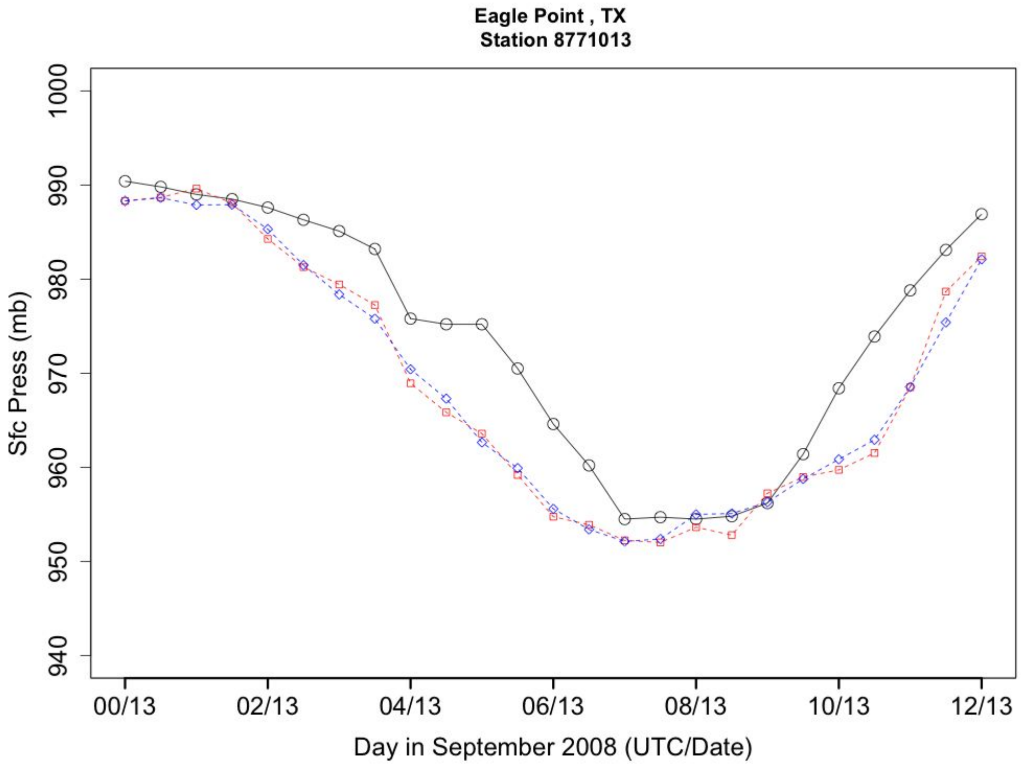


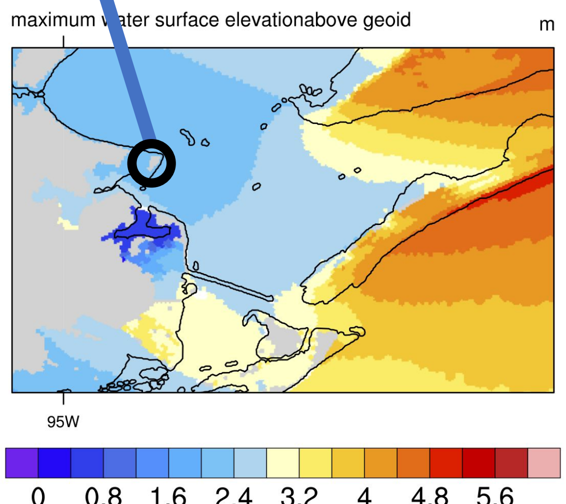




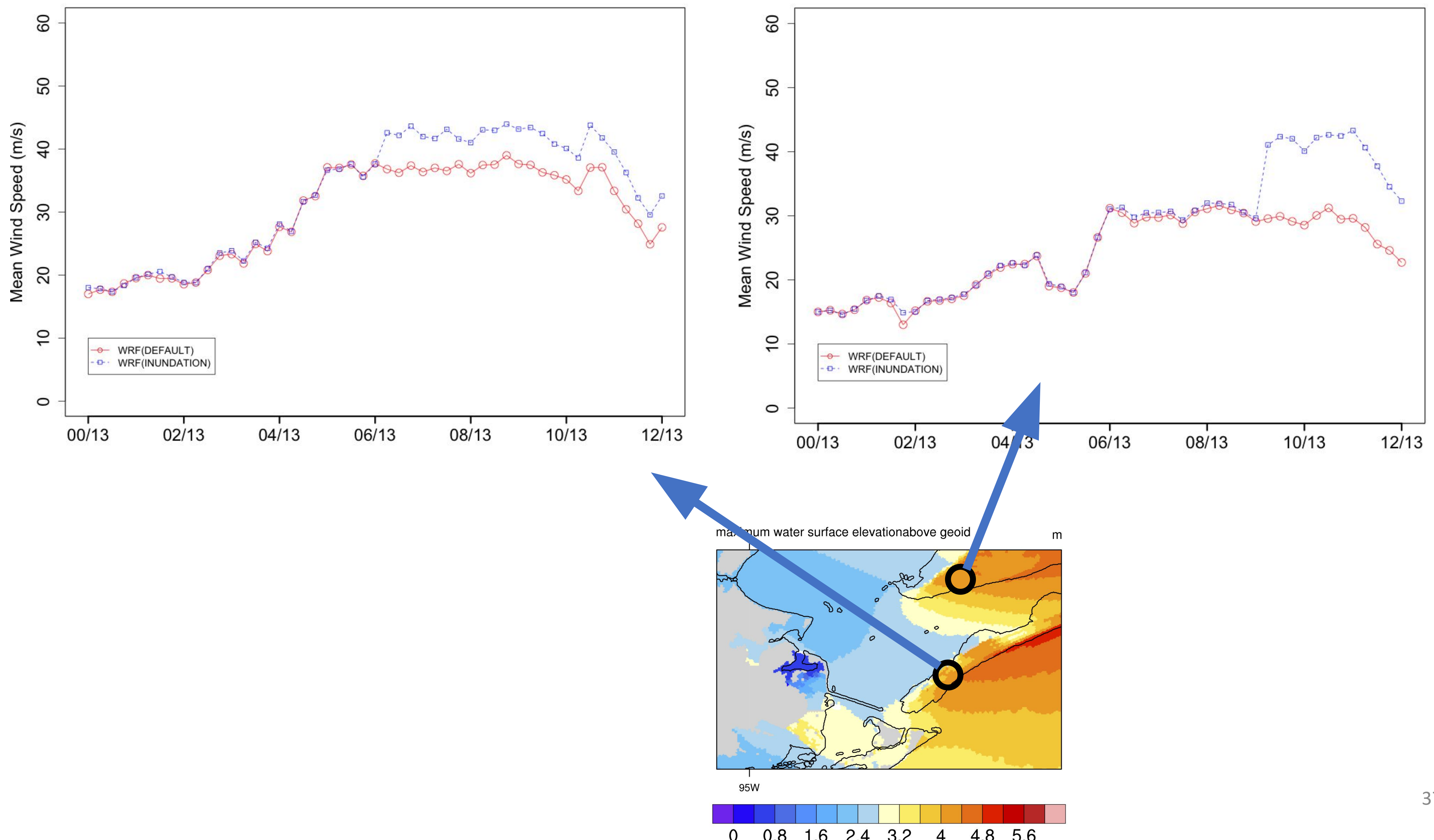
Galveston Pier TX station





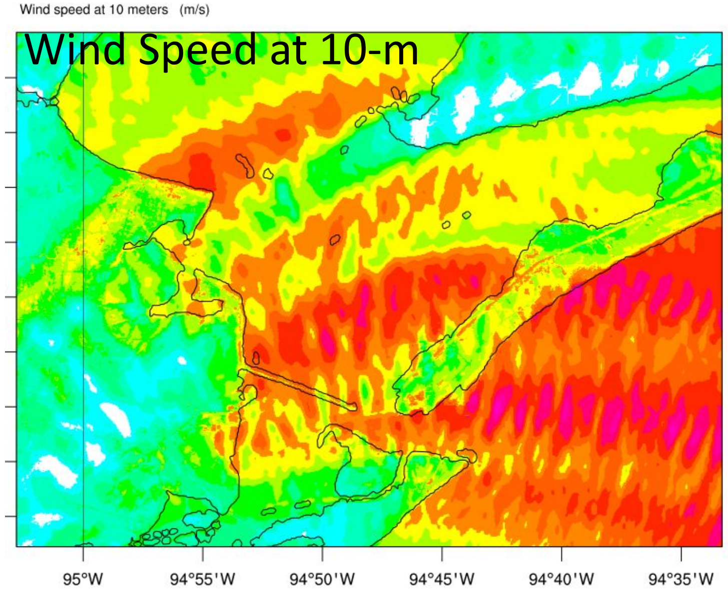


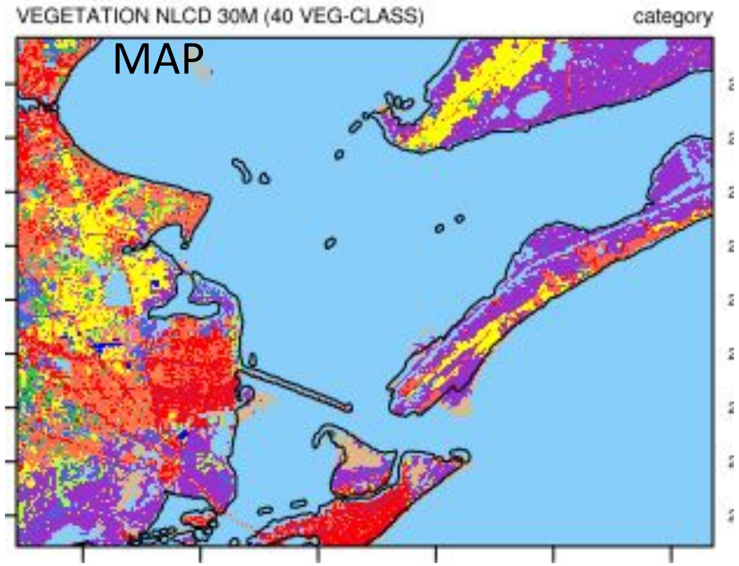
Eagle Point TX station



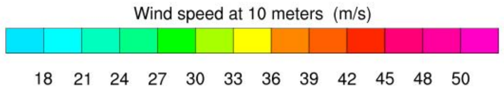
Mean Wind Speed (m/s)
0
10
20
30
40
50
60
00/13
02/13
04/13
06/13
08/13
10/13
12/13
WRF(DEFAULT)
WRF(INUNDATION)
Mean Wind Speed (m/s)
0
10
20
30
40
50
60
00/13
02/13
06/13
08/13
10/13
12/13
WRF(DEFAULT)
WRF(INUNDATION)
mum water surface elevationabove geoid
m
95W
0
0.8
1.6
2.4
3.2
4
4.8
5.6

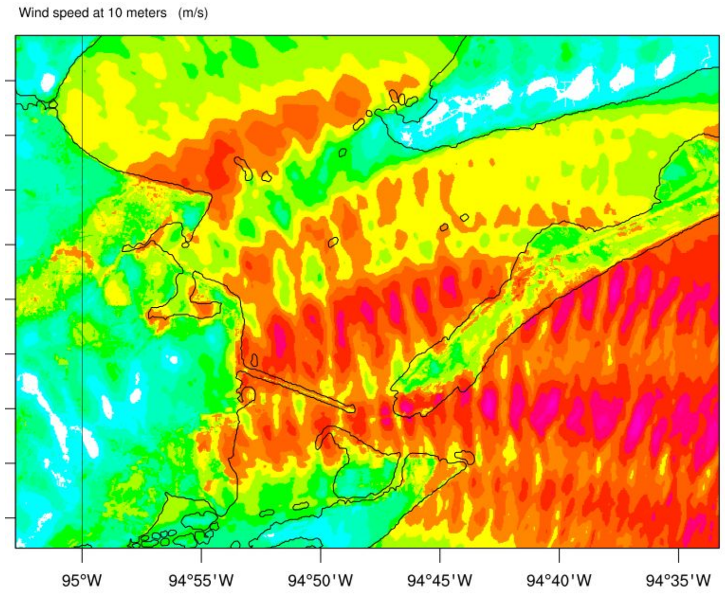
0500 UTC 13 Sep 2008 (Before landfall)

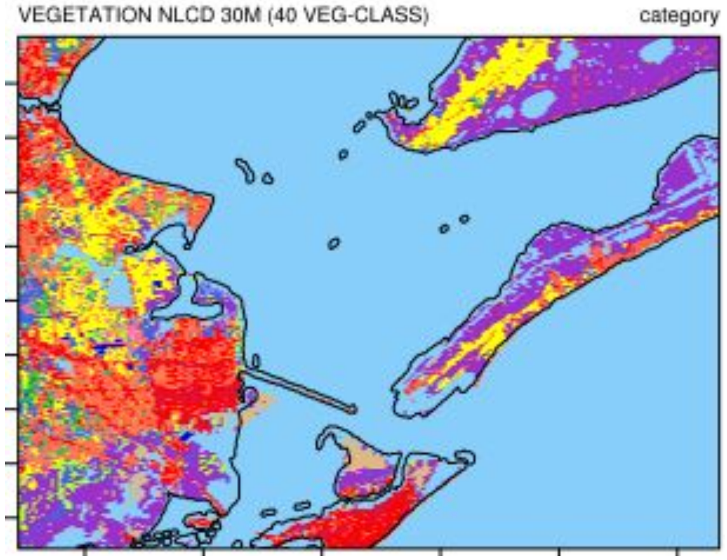




Default expt

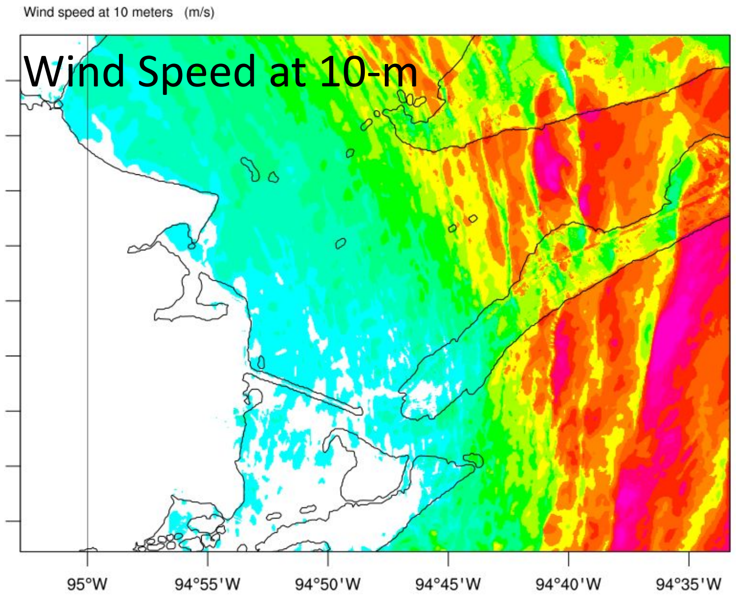


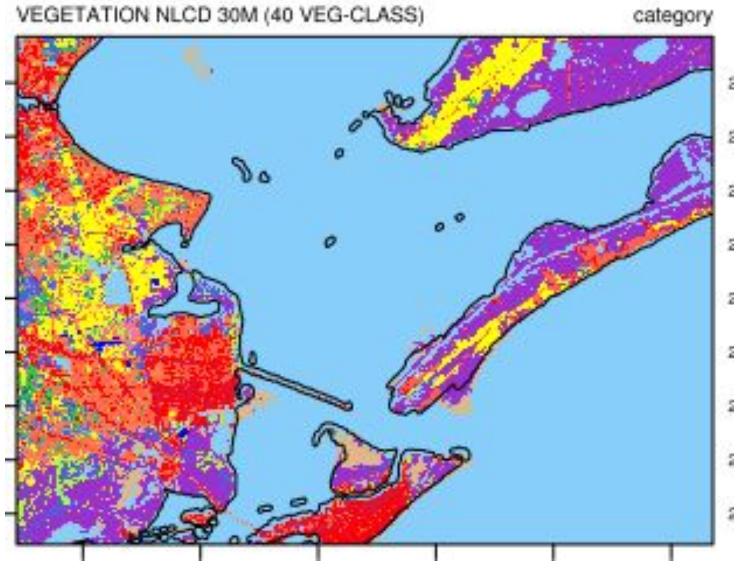




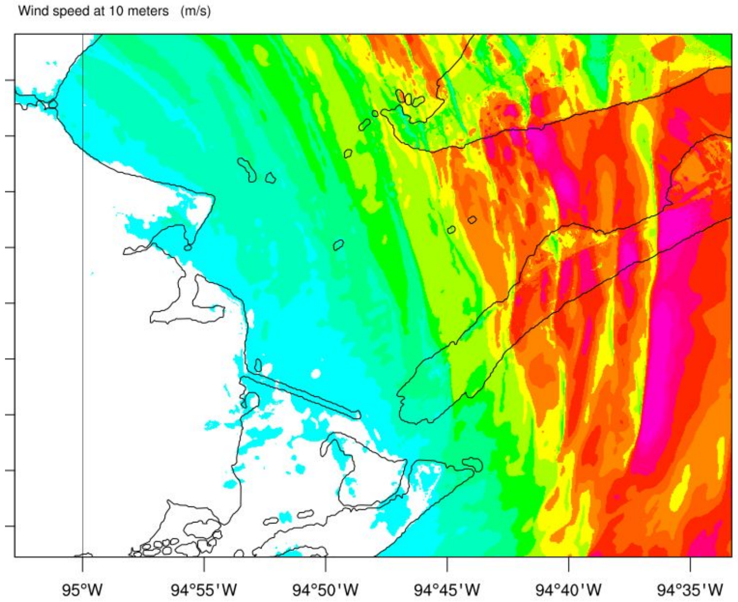
Inundation expt

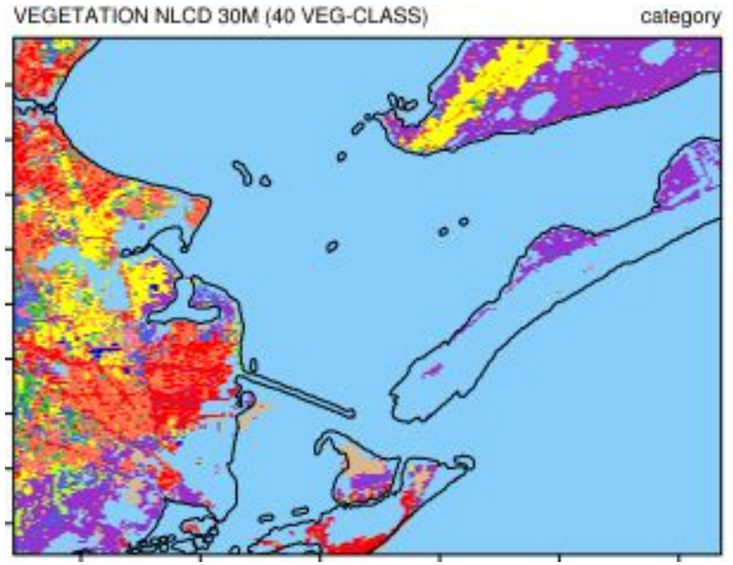
0800 UTC 13 Sep 2008 (at landfall)





Default expt

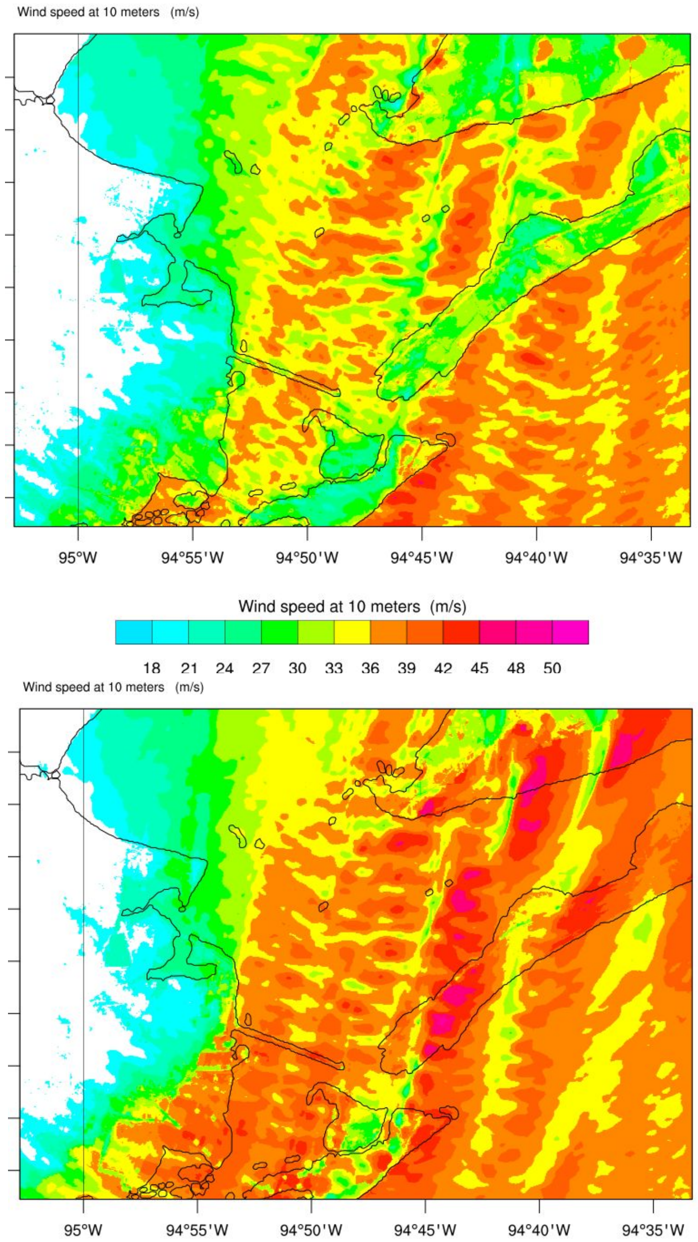


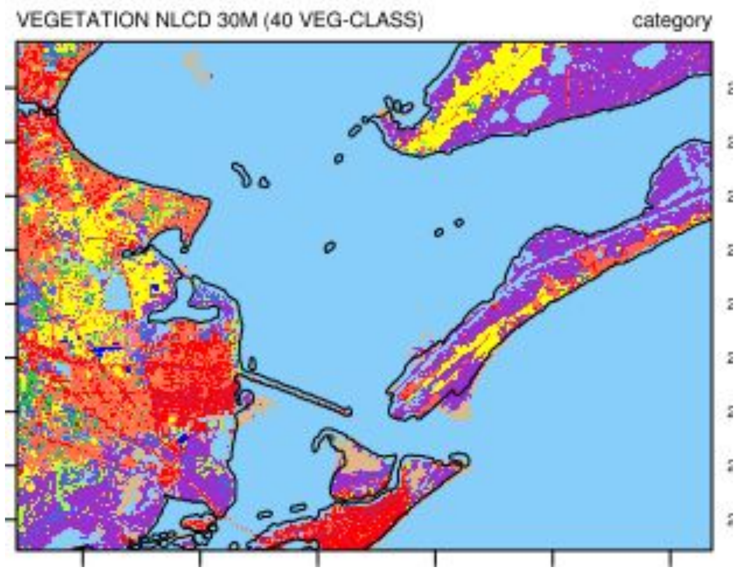


Inundation expt

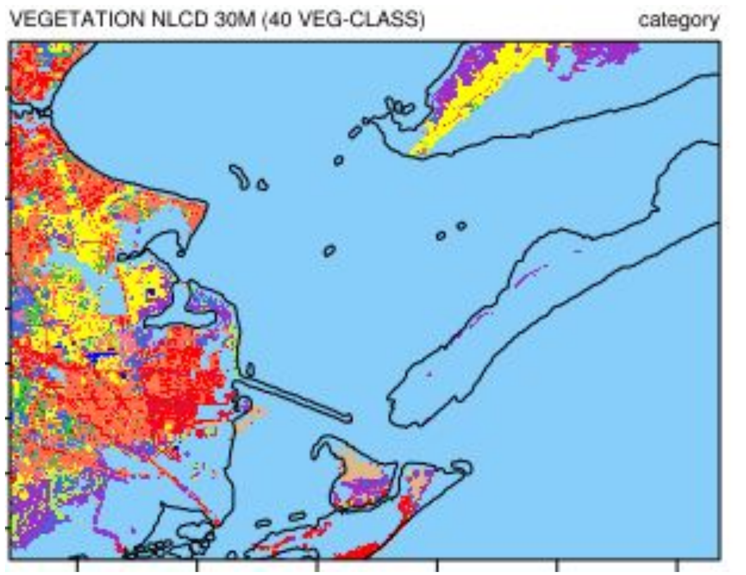
1000 UTC 13 Sep 2008 (after landfall)

Wind Speed at 10-m





Default expt



Inundation expt

FINAL POINTS

Hurricane cases

- Hurricane Ike 2008 –LES parcel scale simulation with HWRF forcing (Completed).
- Wind downscaling for 2018 – Sandy (2012) and possibly Irma(2017) will be investigated
- Wind Downscaling for 2019 – more cases Maria (2017), Matthew (2016) - -If Harvey (2017) is allowed, then we will conduct Harvey instead of Matthew (2016)

- Refine wind downscaling component if needed. (all hurricane cases needs to be completed, 2018-2019 year)
- Future Plans: Integration with national water model. (Contacted Brian Cosgrove). NWM is complex model with lakes and rivers & WRF-LES is fine downscale atmospheric-land model. Timeline and technical details- needs discussion.
- Work flow between WRFLES with Wave/Surge & ADCIRC

(SANDY 2012 case – Domain)