SIMULATING EFFECTS OF LAND SURFACE CHARACTERS ON TPOPICAL CYCLONE RAINFALL PATTERN USING HURRICANE NATURE RUN (HNR) AND WEATHER RESEARCH FORECASTING (WRF) MODEL

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1. INTRODUCTION

Due to generally unfavorable conditions, Tropical Cyclones (TCs) tend to weaken and decay soon after landfall. The different texture of inland — increased roughness length (friction), moisture loss, and possible reduced latent and sensible heat fluxes — has been proved as the main factors in the landfilling process of TCs.(Tuleya 1994; Tuleya and Kurihara 1978) A following research concluded that land fall process, especially rainfall distribution could also be modified by the surface land conditions(Tuleya et al. 1984). Shen et al. (2002) did a set of experiments to study the effect of surface water over land on the decay of landfalling hurricanes and concluded a layer of half-meter water can noticeably reduce landfall decay due to large entropy flux.

A more detailed study had been launched previously by an idealized experiment launched by Kimball utilizing 7 different land surface properties-different roughness length (RL) and moisture availability (MA) to investigate impact of different land surface characteristics specifically on hurricane rainfall distribution before, during and after landfall. The results showed that the increasing RL has a bigger impact on enhancing storm decay than decreasing MA. However, MA has a greater impact on rainfall amount and distribution. To be more specific, moister case can lead to substantial differences in rainfall accumulations as the storm moves through the area (Kimball 2008), which will also be expected results for this study.

Although idealized study is crucial in understanding the influence of land surface characters on TC rainfall structure, there are a lot of simplifications in idealized studies, such as a fixed land surface temperature (LST), an f plane which means prescribed Coriolis parameters and exclusion of a steering flow. Though Kimball (2008) included a relatively weak steering flow, variable Coriolis parameter and time evolving LST, factors as shape of coastline (Rogers and Davis 1993), various terrain, and non-prescribed sea surface temperature (SST) are not considered in those cases.

A nature run is a component of a Joint Observing System Simulation Experiments Nature Run (JONR) which is a free-running simulation with seasonal forcing and prescribed surface boundary conditions for 13 months over 2005-2006. The nature run is used to generate "simulated observations" that will be fed into forecast models such as HWRF to determine the extent to which these observations can improve forecasts. Nolan and Mattock (2014) simulated a storm that experienced significant land interaction during its development as well as landfall over Florida and the southeast United Stated.

In this study, we use WRF to simulate HNR2's landfall on different types of simplified land surface configurations with state-of-art physical schemes. The purpose is to understand how land surface characters impact a realistic hurricane in a true environment. Currently, this study focused mainly on total rainfall areas and their spatial patterns.

2. CASE SELECTION & MODELING STRATEGY

The path of the HNR2 is shown in Fig. 1. HNR2's intensity is showing Fig. 2 with 5-minute maximum 10m surface wind as well minimum central pressure, the green line indicates the time at landfall. HNR2's track intersects with land for 2 times: first around Siesta Key, Florida at 06Z Aug. 26th and second near Tampa, Florida at 08Z Aug. 26th. Fig. 3 shows the reflectivity image at its landfall time, when the eyewall started to interact with land at 02Z Aug.26th. The eye of HNR2 is relatively large with radius about 45 km but it still lies in the realistic range, compared with results from Kimball and Mulekar (2004). In this paper, the average radius of a TC in North Atlantic Ocean is around 21.7km with a maximum at 50.9 km.

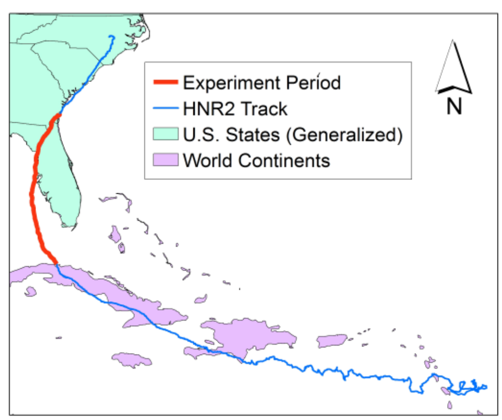

Fig 1 HNR2 track (blue line) and experiment period (red line). The experiment period is 8 days, from 12Z Aug. 20th to 12Z Aug 28th

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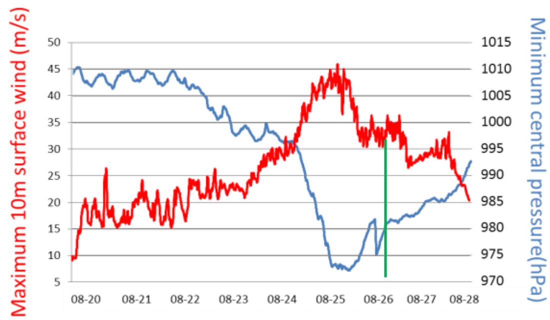


Fig 2 Storm properties showing 5-min maximum 10m surface wind (red line) and minimum sea-level pressure (blue line) with the green line indicating the time at landfall

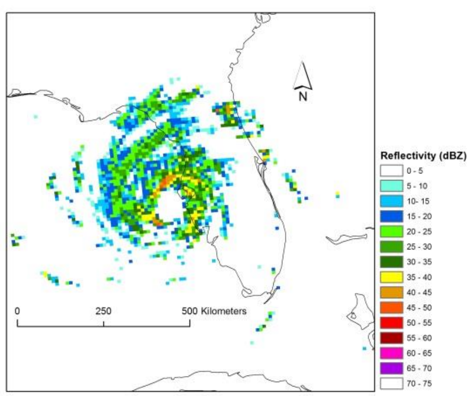


Fig 3 Reflectivity of HNR2 at 3km at the time of landfall (02Z Aug. 26th)

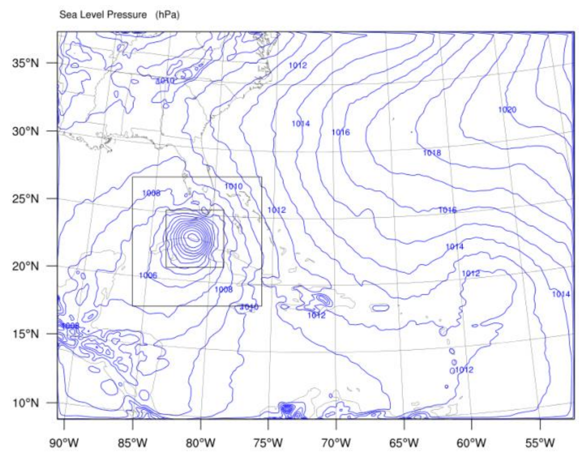
WRF 3.4.1 was used with identical resolutions and physics as used in the original HNR2. Detailed schema is shown in Table 1.Surface layer drag coefficient formula changed back to WRF 3.1.1, because of a better representation of pressure-wind relationship.

Name	Schema
Version	WRF-ARWH 3.4.1
Domains	3-moving-nested
Domain Resolution	9/3/1 km
Land Use Classes	USGS 33-classes
Vertical Levels	60 levels to 50hPa
Microphysics	WDM6
Shortwave/longwave	RRTM-G
Nudging	24h relaxation

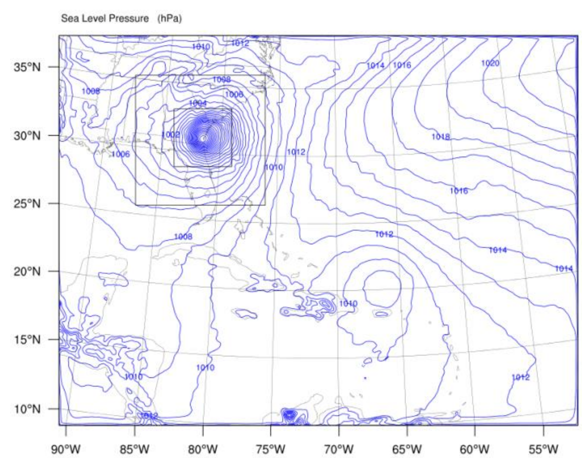
Table 1 Namelist configuration for HNR2 runs (Further detail could be found in Nolan and Mattock (2014))

3. EXPERIMENTAL DESIGN

Since we only focus on interactive process of land surface and rainfall procedure after landfall, to save time and computing resource, we designed a 2-day restart run initiated at 00Z Aug. 25th, when the cyclone's center leaves Cuba, and ended at 00Z August 27. The total run includes 48 hours with approximate 24 hours before landfall and 24 hours after landfall. Fig. 4 shows the positions of the start and end time of HNR2 as well as boundaries for domain 2 and domain 3.



(a)



(b)

Fig 4 Sea level pressure contours with domain boundaries at 00Z Aug. 25th (a) and 00Z Aug. 27th (b).

The the land use types of the input file had been modified into a unified land use type for four different land use types as listed in Table 1, for all the land area North of 24°N. Then the restart runs were launched five times with different input files. The land use changing is showing in Fig. 5 and Table 1 showing the predefined RL and MA for each land use type that is used in Fig. 5.

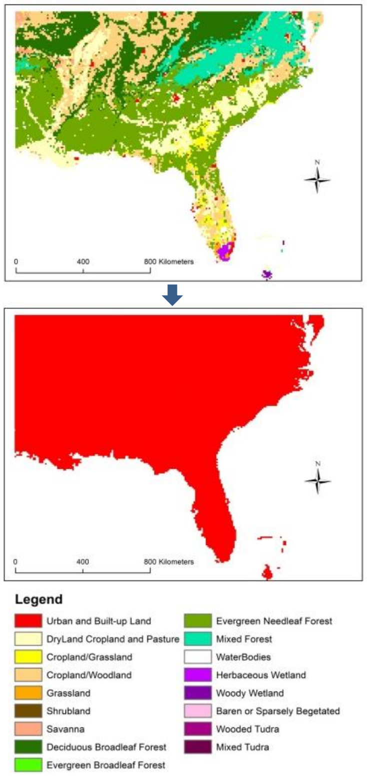


Fig 5 Illustration of land use modification in experiments (example of changing all land use type to "urban")

	Rough length (cm)	Soil Moisture Availability (%)
Open Water	0.01	100
Herbaceous wetland	20	60
Savanna	15	15
Urban	80	10

Table 2 Prescribed RL and MA parameters for land use types

4. **TRACK AND INTENSITY**

All tracks (shown in Fig 6) from experimental cases are close to the track in original case. This result is expected, indicates that boundary condition is quite steady. This is also good for future analysis in comparison of rainfall patterns on each side of the track. Fig 7 shows the intensity comparison for each case. Comparing with original case, storms in the cases of Open water, Savanna and Urban experienced a more rapid intensification around 18Z Aug 25th. Case Wetland experienced an earlier intensification around 12Z Aug. 25th along with an earlier weakening before landfall, which could be caused by possible unstable condition in WRF.

Further investigation is needed to explain this result. Except the wetland case, all other cases reached a lower minimum central pressure at 10Z Aug. 25th after landfall, this could be caused by the fact that HNR2 is moving along the coastline for a while before moved more inland, the landfilling process did not start right after landfall.

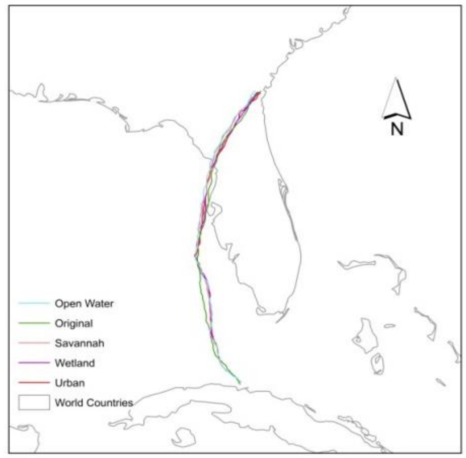


Fig 6 Tracks for all cases

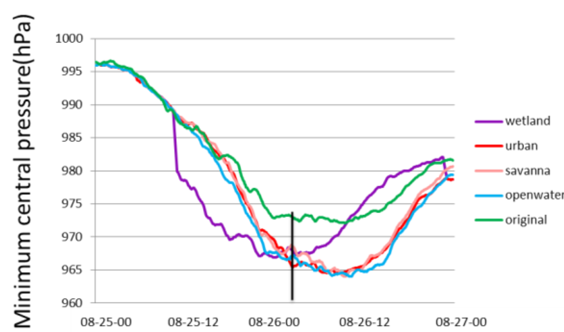


Fig 7 Intensity comparison between cases. The black line indicates the time of landfall.

5. **TOTAL PRECIPITATION**

Fig. 8 shows the two-day accumulated total precipitation within 500 km distance from the TCs' center for each case. Comparing with the original case, all unified land use cases showed more asymmetric total precipitation. To better interpret the result, the total region had been divided into 3 zones showing in Fig. 8 (a). In Zone 1, all unified cases showed more precipitation on the right side of the track, indicating more asymmetric spatial patterns. Among these unified land cover type cases, Open water showed the most symmetric structure with less precipitation on the right side of the track before landfall, which could also be explained by the less dramatic change between open water and ocean compared with other cases, this could also explain the more asymmetric in case Savanna and Urban. In Zone 2, the highest precipitation region shifted to the left side of the track which is consistent with previous studies mainly due to the increased inward wind because of frictions. This asymmetric is again the least obvious in the original case. Among the modified cases, Open water seems had a more extent to the right side of the track which will talk about more in detail in the net section. In Zone 3 the original case showed the most asymmetric to the left side of the track among all cases. Since for all modified cases, there were more dramatic changes for the two side of the coastline. The wetland case showed the highest asymmetric in Zone 3, this could be caused by the increased MA. However, we did not find a high level of asymmetry in case open water with high MA, which could be caused by low RL, which slows down the inward velocity which could enhance asymmetry.

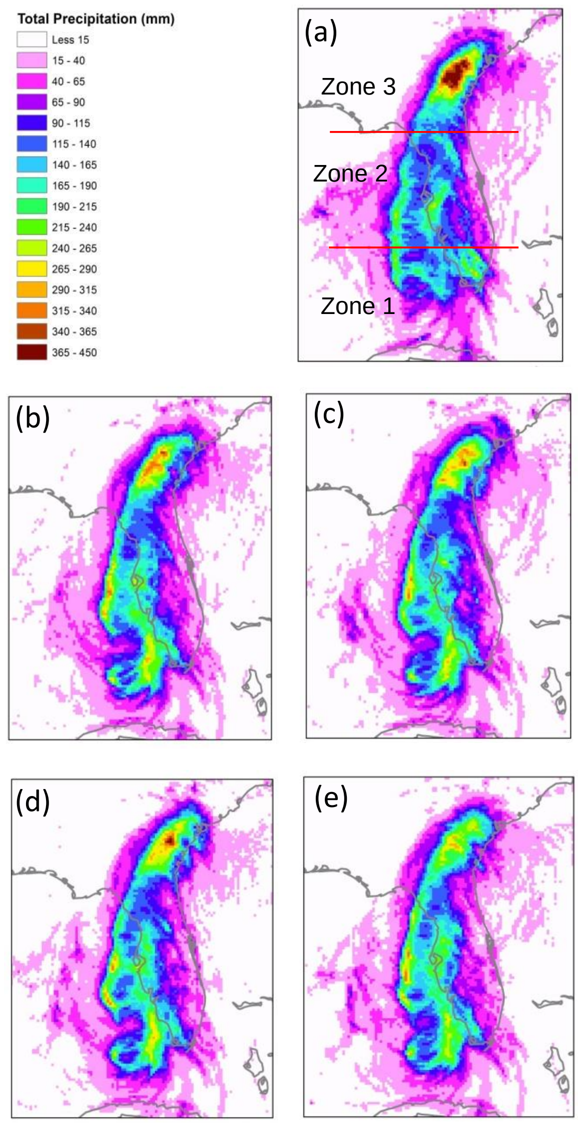


Fig 8 Two-day accumulated total precipitation within 500 km distance from the TCs' center (a) Original (red line representing different zones for analysis); (b) savannah; (c) urban; (d) herbaceous wetland; (e) open water.

The next step we calculate frequency of each total precipitation interval for each case, the result is showing in Fig. 9. The most significance shows at the flowing 3 intervals, 90 mm to 190 mm, 190 mm to 340 mm and above 340 mm. The original case showed the highest frequency in the interval of 90 - 190mm and above 340 mm, and showed the lowest frequency in the interval of 190-340mm. The area of each three intervals had been illustrated in Fig. 10. As in Fig. 10, the original case showed the widest width for the precipitation total ranged from 90mm to 190mm, the open water case showed the smallest width among modified cases, which is consistent with the graph in Fig. 9. These results also reflected that original case showed the least asymmetric pattern in Zone 1 and Zone 2 (showed in Fig. 8). For the total precipitation more than 340mm, Fig 10 also showed clearly that the original case has the largest extent of interval – above 340mm – in Zone 3.

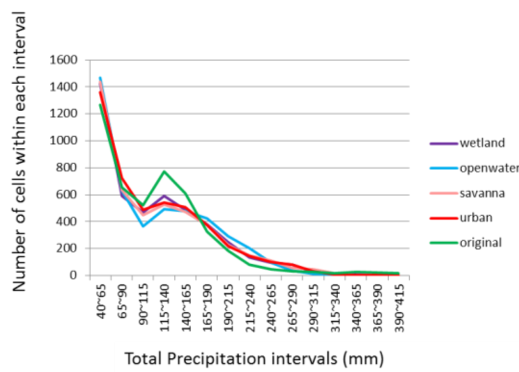


Fig 9 Frequencies of total precipitation for each interval in Fig 8

Among the 3 intervals mentioned before, the range between 190mm to 340mm shows the most significant differences between cases, especially in the area in the green cycle in Fig. 10. Case savanna illustrated a separation of two areas. One region more to the north and on shore around the Tampa area, the other one more the south and off shore. Case urban showed a sparser pattern where the mainly on shore area is to the north of Tampa, and several small area to the south and off shore area. As for the same region for wetland case, the total area is larger than case original, savanna and urban, which could be explained by the high MA, the middle area in this case showed the largest extent around Tampa area. Open water showed the largest extent in this cycled area, especially on shore along the coastline. To qualify the level of fragmentation in this region, Perimeter/Area ratio (P/A), which is calculated by the sum of perimeter for each patches and divided by the area of the patches, is used to examine which case has the most fragmentation structure in this region. The results shows that urban > wetland > open water > savanna > original. Case urban shows the highest value for this ratio indicating the sparsest structure, which is consistence with previous results analysis.

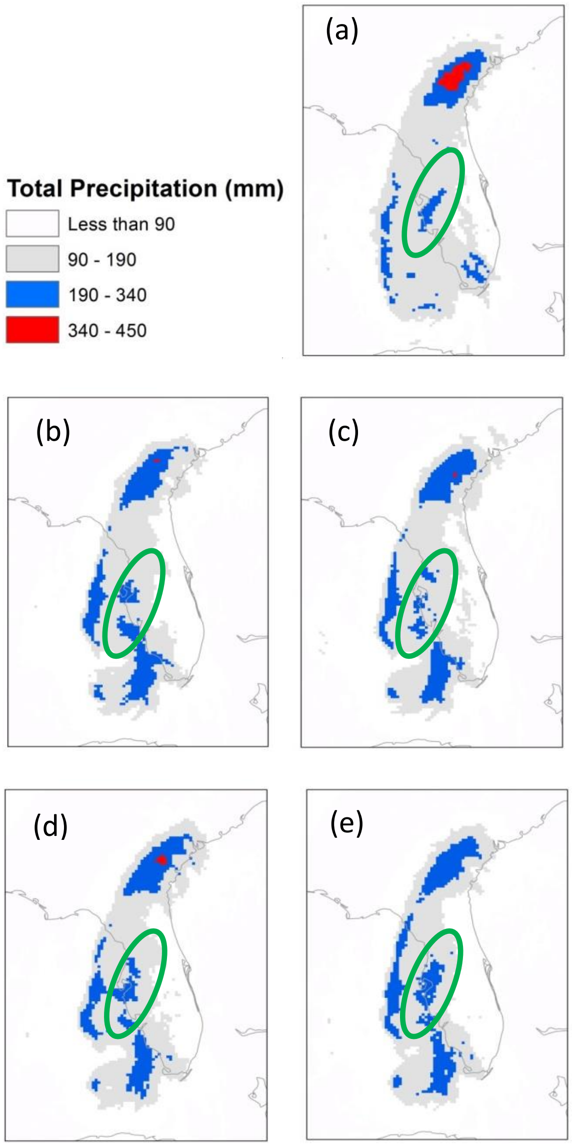


Fig 10 Area of the three different intervals of total precipitation in different cases: (a) original; (b) savannah; (c) urban; (d) herbaceous wetland; (e) open water. Green cycle highlights the area with most significant difference

6. **RAIN FIELD SIZE**

Rainfall produced by TCs had shown complex spatial variability, the swath of TCs could vary greatly between cases (Matyas 2010).Thus we calculated total rain field for all simulated hurricanes. Fig. 11 shows the area comparison of all cases of the largest 25 mm contour. It seems there is no significant on the right side of the track, but more on the left side. The urban case showed the smallest swatch on the left side among case, while original case showed the widest.

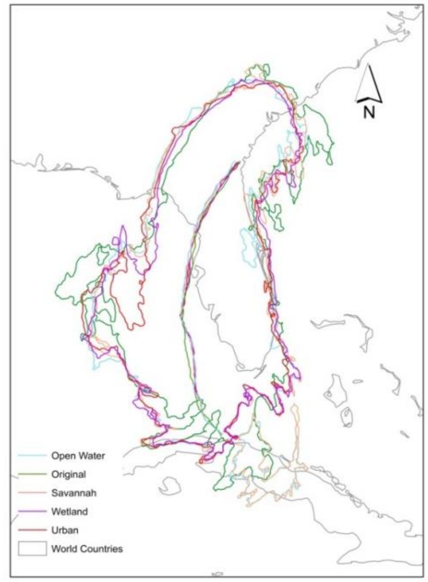


Fig. 11 Outer edge of contours of 25mm total precipitation for all cases

7. **SUMMARY AND FUTURE WORK**

From the results, we can see some changes between different cases with different land surface characters, which can prove land surface characters do have influence on rainfall patterns of a TC. However, some patterns are unexpected, such as with moister case, there is no significant increase in total rainfall. This may be caused by the limited time range of the experiment period. We consider WRF may take up to 2-3 diurnal cycles to pick up the change of land surface. So in future studies, we will which means in following studies, we will move the start time of experimental run 2 days earlier. Moreover, we plan to add perturbation scheme to experiments in order to investigate possible randomness in the model.

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