Spring 2020

A Study on Track Deflection Associated with the Landfall of Tropical Cyclone Sidr (2007) over the Bay of Bengal and Bangladesh

Shak Md Shajedul Karim

North Carolina Agricultural and Technical State University

A Study on Track Deflection Associated with the Landfall of Tropical Cyclone Sidr (2007) over the Bay of Bengal and Bangladesh

Shak Md Shajedul Karim[1] and Yuh-Lang Lin[1,2]

[1]Applied Science & Technology PhD Program and [2]Department of Physics

North Carolina A & T State University, Greensboro, NC

Advisor: Dr. Yuh-Lang Lin

INTRODUCTION

➢Within 47 years of Independence, Bangladesh has been suffered by 33 either severe or less severe tropical cyclones.

➢Tropical Cyclone (TC) Sidr, developed in the north Indian Ocean and made landfall over the coast of Bangladesh on 16 UTC, 15th November 2007, which caused 3,406 death and the total estimated damage of $1.7 billion (GoB, 2008)

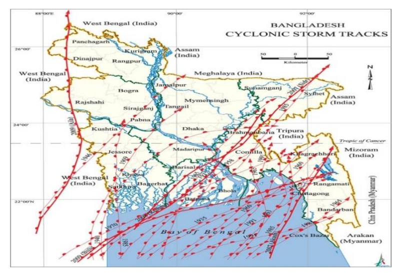


Figure : Tracks of major Cyclones that crossed Bangladesh till 2014. (http://en.banglapedia.org/index.php?title=File:Cyclone.jpg

Figure : Path of TC Sidr (2007) and affected area adopted from Hussain (2013).

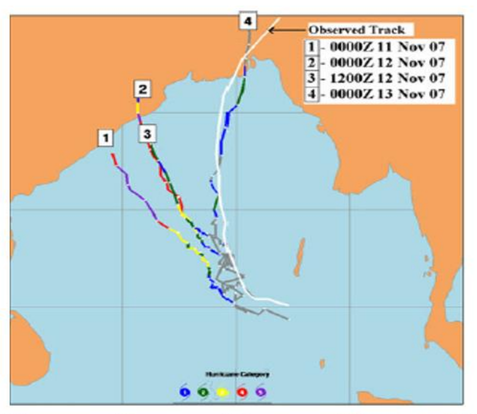


Figure: Simulated track from different model initialization time and observed track (white line) [adapted from Fig. 3 of Kumar et al. (2011)].

➢ Track prediction required a significant improvement due to the lack of numerical simulation studies by researchers on track analysis (Mohapatra et al. 2015)

➢ Of our interest (a) increasing leading time of forecasting remains a top priority in TC track prediction (b) understanding the impacts of environments, including the Himalayas and landmass, physical parameterization schemes, and numerical sensitivity of the model on track deflection.

Research Objective

1. In this study, we will investigate the dynamics of of track deflection associated with the landfall of simulated TC Sidr.
2. Will increase the leading time of TC forecasting.
3. Investigate the upstream influence of the Himalaya Mountains on tropical depressions or cyclones originated from the Bay of Bengal.

Experimental Design and Sensitivity Test Cases

Model: ARW-WRF Version 3.6.1

Initialization: NCEP GFS/FNL $1^o \times 1^o$ data from 11/11/00Z to 11/16/12Z, 2007

Grid Resolution: 27 km.

Grid Dimension: 134 × 120 in the *x-y* directions with 50 vertical levels extending up to 10 hPa.

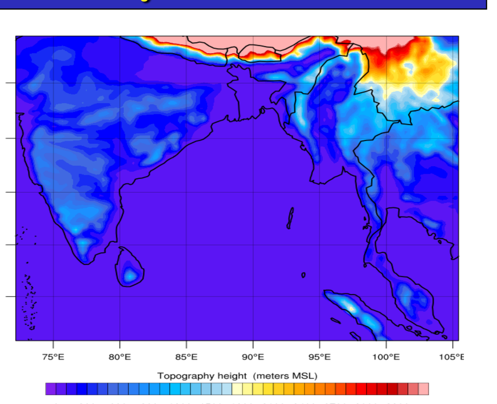


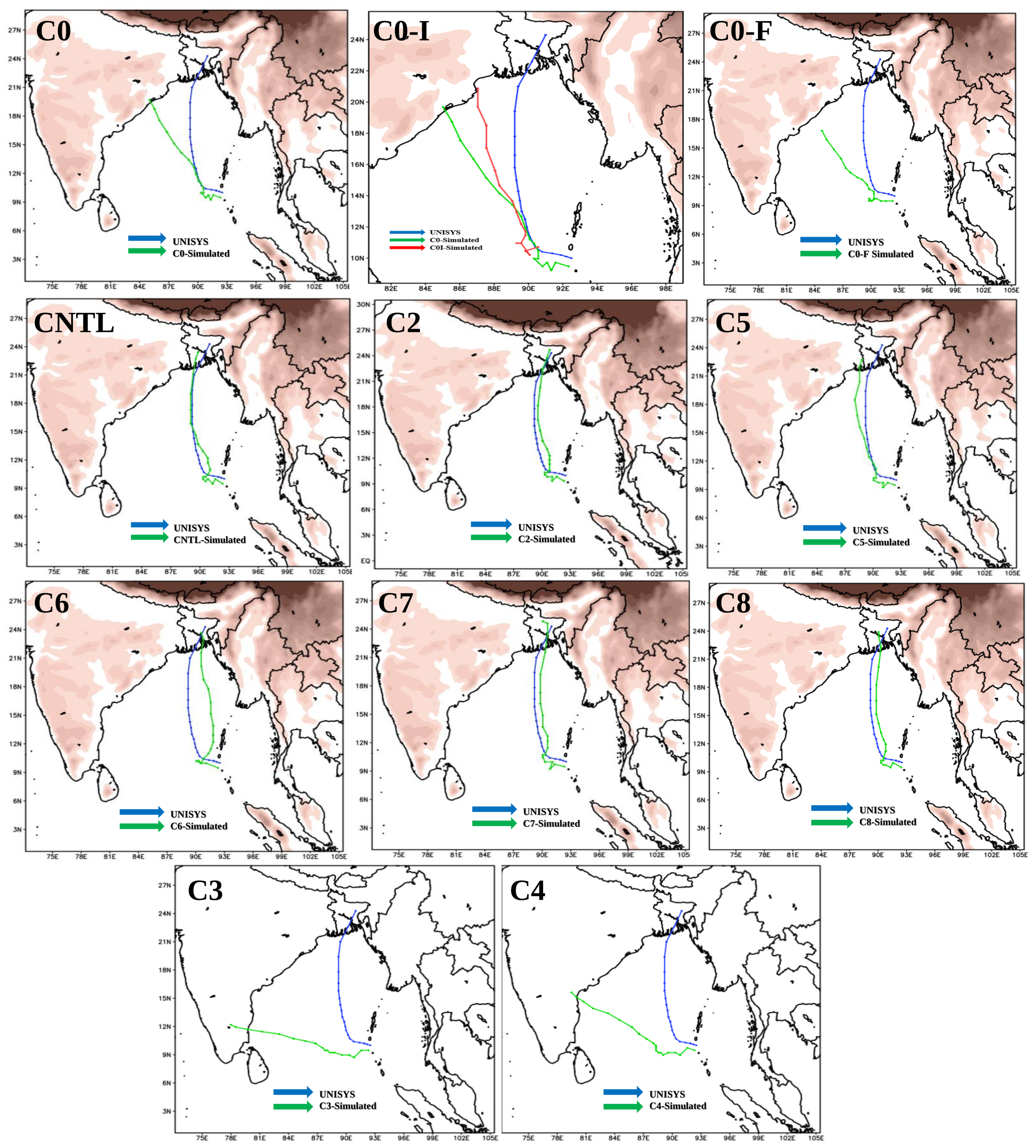
Figure : The model domain and the terrain, which extends from NIO to the Himalayas. The terrain height is in m.

Ten sensitivity test cases were performed by changing some control parameters:

Cases	Key Changes	Remarks
C0	First experiment: Domain top (Z_T): 50 mb; Number of vertical grid levels (N_Z): 35; Initial time = 11/11/00Z	Track deflected toward northwest, inconsistent with observation (Fig. 3).
C0-I	Same as C0 except initialized after 24h later (11/12/00Z).	Improvement from the C0-simulated track, but still deflected to the west (Fig. 5).
C0-F	Same as C0 except with a finer vertical resolution (N_Z = 50)	Similar to C0, track prediction not improved (i.e. still deflected to the west) (Fig. 6).
C1 (CNTL)	Same as C0 except with Z_T = 10 mb, N_Z = 50, and Δx = Δy = 27 km	Northward track, consistent with observation; Also called C1-27 case (Fig. 7).
C2	Same as C0, but with a larger horizontal domain that includes the Himalayas to the north.	Similar to C1, simulated track is in good agreement with the UNISYS best track as well (Fig. 12).
C3 (C0NM)	Same as C0 but with no mountains.	Track deflected further west compared to C1; Also called C0NM (Fig. 13a).
C4 (C1NM)	Same as CNTL (C1) but with no mountains.	Track deflected further west compared to C1; Also called C1NM (Fig. 13b).
C5	Same as C1 except the MP parameterization scheme changed from Lin to Goddard.	Similar to C1, consistent with the observation (Fig. 14a).
C6	Same as C1 except the CU parameterization scheme changed from Kain-Fritsch to Betts-Miller scheme.	Track slightly deflected to east (Fig. 14b).
C7	Same as C1 except PBL parameterization scheme changes from YSU to ACM2.	Track similar to the observation (Fig. 14c).
C8	Same as C1 except no land (i.e. removing all land parameters).	Consistent with the observation but moved farther northward than C1 (Fig. 15).

RESULTS

Simulated track compared with UNISYS best track



➢The track of Cyclone deflected to the north-westward (C0) while vertical domain and grid levels are lower compared with CNTL (C1) case.

➢Fine vertical resolution case (C0-F) was not also able to produce a better track.

➢Increasing the horizontal domain farther northward (C2), which covers most of the Himalaya Mountains, also produces a better track

➢Changing MP (C5), CP (C6), and PBL (C7) parameterization schemes produced some difference, but it is not significant.

➢Increasing farther horizontal domain (C2) covered to the north; also gave us better track.

➢With mountains removed (C3 & C4), the tracks are significantly deflected to the west for both cases, which indicate that mountains play important roles on the track deflection of TC.

Question: Why simulated track is deflected westward for cases C0, C3, and C4?

Dynamics of Westward Deflection of C0 simulated track

Method A: Steered by Large Scale Deep-Layer Mean Flow

➢ TC Sidr's movement as a point vortex being advected by deep layer environmental steering flow throughout the movement of TC, as that proposed by Neumann (1979).

➢ The storm motion seems to be closely parallel to the environmental flow field at 11/13/00Z (Fig. a). These flow field hence steers the C0-simulated Sidr track to the northwest.

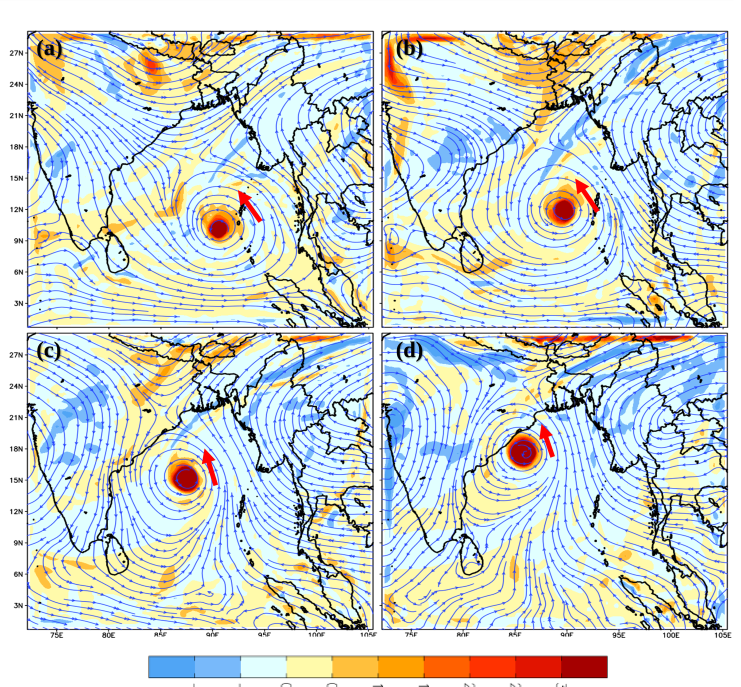


Figure: The streamlines (blue contour) and isotach (shaded) of the deep layer mean (850 mb – 300 mb) wind for the C0 case valid at (a) 11/13/00Z, (b) 11/14/00Z, (c) 11/15/00Z, and (d) 11/15/12Z, 2007.The direction of steering flow shown by the red thick arrow.

Method B: Advection Mechanism Proposed by *Lin et al. (2016)*

➢ The high associated with the Himalayas for C0 is 1026 hpa (Fig. left), which is 3 hpa higher than that of C1 (1023 hpa) (Fig. right) at 11/13/12Z, 2007

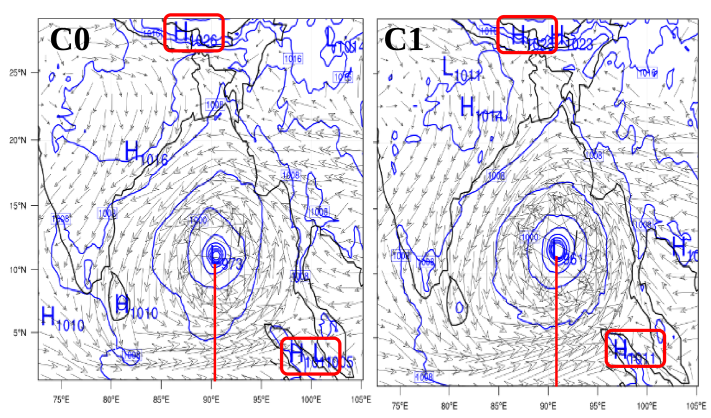


Figure: MSLP and 850 hpa vector field analysis of C0 (left) and CNTL (right) valid at 11/13/12Z, 2007.

Hypothesis: *Higher high pressure could imbalance the geostrophic wind as the northward wind is reduced (i.e., subgeostrophic flow) by the upstream orographic influence, which would advect the numerically generated TC in C0 to the west.*

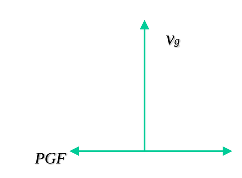
The basic wind flow of C0 (v_0) is smaller compared to the CNTL case (v_1) flow (i.e., $v_0 < v_1$) can be proved by the horizontal momentum equation.

For Case C0: $\frac{Du_0}{Dt} - fv_0 = -\frac{1}{\rho}\frac{\partial p_0}{\partial X}$ .... (a)

For Case C1: $\frac{Du_1}{Dt} - fv_1 = -\frac{1}{\rho}\frac{\partial p_1}{\partial X}$ .... (b)

Subtracting equation (b) from the equation (a),

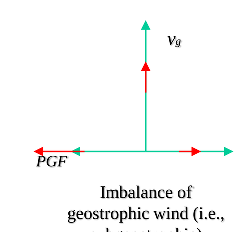
$$\frac{Du_0}{Dt} - \frac{Du_1}{Dt} - f(v_0 - v_1) = -\frac{1}{\rho}\left(\frac{\partial p_0}{\partial X} - \frac{\partial p_1}{\partial X}\right) \text{....... (c)}$$



Geostrophic Balance

Since there is no deflection in our CNTL (C1) case, ($\frac{Du_1}{Dt}$) ~ 0. Also, there is no pressure gradient force difference in x-direction.

Hence, $\frac{1}{\rho}\left(\frac{\partial p_0}{\partial X} - \frac{\partial p_1}{\partial X}\right) \sim 0$



Imbalance of geostrophic wind (i.e., subgeostrophic)

Equation (c) now becomes, $\frac{Du_0}{Dt} = f(v_0 - v_1) < 0$

✓ Due to this weaker basic wind in C0 (v_o), the Coriolis force (fv_o) decreases. Hence, the pressure gradient force is greater than the Coriolis force, which allows the basic wind to advect the TC vortex to the west in C0.

Dynamical & Physical processes of generating stronger high-pressure in C0

Vertical energy flux ($\overline{pw}$) Analysis:

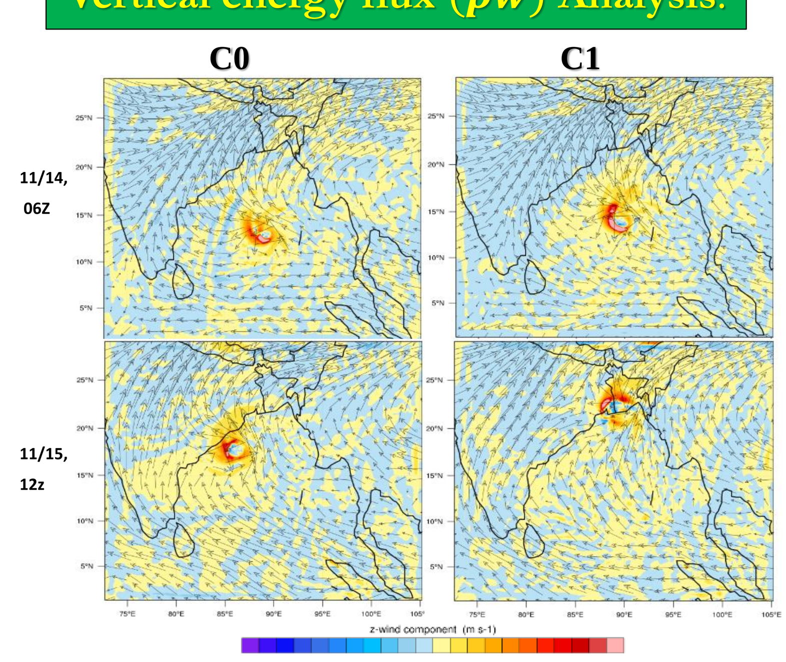


Figure : Vertical energy flux (kgs-3) analysis at 11/14/06Z and 11/15/12z, 2007 for case C0 (a, b) and for control case C1 (c, d).

$\overline{P_0W_0} = 55.87 kgs^{-3}$ & $\overline{P_1W_1} = 65.66\ kgs^{-3}$

$Hence, \overline{P_1W_1} > \overline{P_0W_0}$

$\overline{P_0W_0} = 165.51 kgs^{-3}$ & $\overline{P_1W_1} = 203.05\ kgs^{-3}$

$Hence, \overline{P_1W_1} > \overline{P_0W_0}$

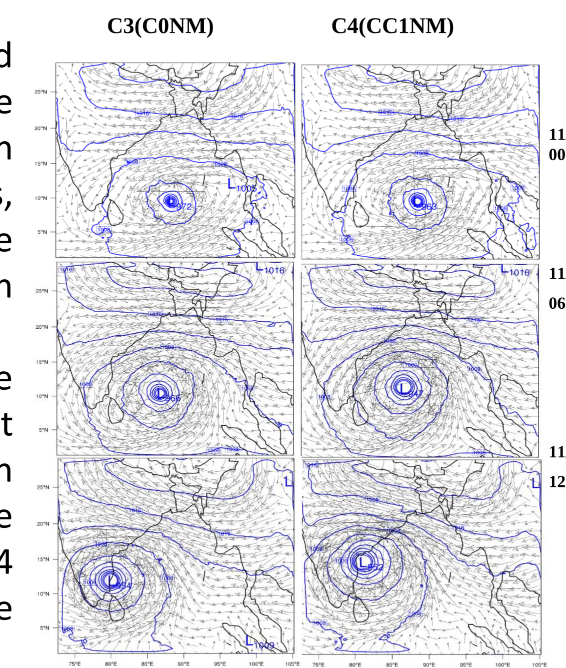
✓ Due to weaker vertical energy flux of C0, part of the energy is reflected back to the physical domain of case C0 inducing the higher pressure, which leads to the westward track deflection, as analyzed above.

Dynamics of no-mountain cases (C3 & C4) track deflection

850 mb vector wind field analysis of C3 & C4

➢ The northeasterly wind speed starts to dominate the northeastern part of the domain from 11/13/00Z for both cases, which is missed in the corresponding full mountain cases.

➢ With mountains removed, the northeasterly flow blows without any blocking of the mountains on the northeastern part of the domain. This deflects C3 and C4 simulated track to the west more significantly.



CONCLUSION

✓ **Extending domain top from 50 hpa to 10 hpa in CNTL (C1) case leading to produce a better track**.

✓ Cases C2, C3, and C4 revealed that the Himalaya Mountains have played a role in affecting the track.

✓ Himalayas mountain produced strong high pressure in C0 than C1, which causes track deflected to the west.

✓ Due to weaker vertical energy flux of case C0, part of the energy was reflected back to the physical domain of case C0 inducing the higher pressure, which led to the westward deflection of the track.

✓ **The model vertical domain height and the Himalayas mountain are the key factors impacting the Cyclone track prediction. So that in forecast models, high enough vertical domain may improve the forecasting of TC track over NIO basins.**

References

1. GoB (2008) Cyclone Sidr in Bangladesh- Damage, Loss and Needs Assessment for Disaster Recovery and Reconstruction. Power 177
2. Kumar A, Done J, Dudhia J, Niyogi D (2011) Simulations of Cyclone Sidr in the Bay of Bengal with a high-resolution model: Sensitivity to large-scale boundary forcing. Meteorol Atmos Phys 114:123–137. https://doi.org/10.1007/s00703-011-0161-9
3. Lin YL, Chen SH, Liu L (2016) Orographic influence on basic flow and cyclone circulation and their impacts on track deflection of an idealized tropical cyclone. J Atmos Sci 73:3951–3974. https://doi.org/10.1175/JAS-D-15-0252.1
4. Mohapatra M, Nayak DP, Sharma M, Sharma RP, Bandyopadhyay BK (2015) Evaluation of official tropical cyclone landfall forecast issued by india meteorological department. J Earth Syst Sci 124:861–874. https://doi.org/10.1007/s12040-015-0581-x
5. Neumann CJ (1979) On the use of deep-layer mean geopotential height fields in statistical prediction of tropical cyclone motion. Sixth Conf. on probability and statistics in Atmospheric Sciences, Banff. American Meteorological Society, 32-38.

Acknowledgements

➢ The NCEP reanalysis data are from the Research Data Archive maintained by the Computational and Information Systems laboratory (CISL) at NCAR.

➢ The authors would like to acknowledge NCAR and CISL for their support of computing time on the Cheyenne supercomputer (**Project No. UNCS0030**).

Contacts: Shak Md Shajedul Karim (skarim@aggies.ncat.edu)
Dr. Yuh-Lang Lin (ylin@ncat.edu)

Spring 2020 N.C. A&T Graduate Research Symposium

Sponsored by the Graduate College and the Graduate Student Advisory Council