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KILLER TORNADOES DURING HIGH TIDE PERIOD

1. Solar - lunar gravitational influence produces Ocean tides (spring and neap) during different phases of the Moon. Values of both high tides of the semi- diurnal tides (two high waters and two low waters each day) start decreasing normally from 4^{th} or 5^{th} day, continue decreasing till 8^{th} or 9^{th} day, again start increasing from 10^{th} or 11^{th} or 12^{th} or 13^{th} day and continue increasing till 1^{st} or 2^{nd} or 3^{rd} day of waning and waxing period of the lunar month (15 days each of Krishna paksha and Shukla paksha of Hindu calendar). Ocean tides exhibit the intensity of the gravitational force of the Moon on a particular day. It has been observed that more killer tornadoes (for USA: fatalities 39 or more or massive destruction reported or intensity: EF 3 or more on enhanced Fujita scale; for Asian countries: fatalities 28 or more or massive destruction) develop during high tide period (10^{th} day to 3^{rd} day in both fortnights) than low tide period (4^{th} to 9^{th} day in both fortnights) under favorable synoptic situations.

2. The stretch of the United States, which runs from Kansas through Oklahoma to Missouri, is known as "Tornado Alley": a section in which more tornadoes strike than in any other place in the world. No area is more favorable to their formations than the continental plane of North America (Lynch 2002). Ramasastry (1984) has mentioned that the most preferred regions of their occurrence in India are Assam and adjoining states, West Bengal, Gangetic planes, Punjab and Haryana. He has further mentioned that 72% of the reported tornados have occurred in northeast India. When super cell thunderstorm struck Bihar, West Bengal and Bangladesh on 13^{th} April 2010, it was 14^{th} lunar day of waning period (Krishna paksha Chaturdashi of Hindu calendar). Total fatalities due to these were 120 and severe destructions have been reported (News papers reported tornado) along its path. Longest distance covered by the super cell thunderstorm on 13^{th} April did not suggest a tornado.

3. Year wise tornadoes data for 66 years period (1944-2010) have been collected from Google web site. Shri Venketeshwar Shatabadi Panchangam (hundred years Almanac: 1944 to 2044 AD) has been used to identify lunar day for reported tornadoes. Tide tables for 2009 and 2010 (prepared by Survey of India) have been used.

4. Ramasastry (1984) has mentioned that thunderstorms usually develop in clusters consisting of several thunderstorm cells, each about 4 km across. They tend to move 20° to the right of mid tropospheric direction. During this motion new cells develop to the

right of the decaying ones. The cold down draft of a mature thunderstorm initiates development of a new one by forcing the warm air to rise to fill up the gap created by the down draft. A tornado develops in such secondary thunderstorms. He has further mentioned that strong vertical wind shears in mid tropospheric level with high humidity in the lower levels, favor the formation of tornados. Vertical wind shears in excess of 23 mps 150 hPa are favorable for tornado production, while shears of less than 12 mps are unlikely to produce tornadoes. Lynch (2002) has mentioned about the prevailing synoptic conditions present during the worst tornado outbreak ever recorded in the history of USA or even of the world during 3-4 April 1974: over a period of just 16 hours 148 twisters touched down across 13 states, leaving 315 dead, 5484 injured and entire township obliterated. There were six F5 (Fujita scale: devastating damage) tornados the strongest on the scale and one was 8 kilometers wide. To the southwest of the Great Plains lie the desert regions of the USA. These are at a much higher elevation and warm dry air flows off them and move across Tornado Alley at a height of about 1-2 kilometers (3000-6000 feet) above the ground. This layer of warm dry air is known as a temperature inversion. The warm and moist air from the Gulf of Mexico that is rising below, it is not warm enough to rise any further and is capped. So at first no small thunderstorms are produced. But as more and more warm, moist air flows in and rises up, this inversion layer begins to act like the lid of a pressure cooker, with more energy building up beneath it but nothing allowed to boil over. The cap suppresses storm formation until, by the day after the clear skies have allowed the Sun to heat surface air even more, it is so moist and warm that, when it rises, it is warmer than even the warm air of the cap. Then it breaks through and the resulting thunderstorm grows much, much larger and the warm air rises up to the height of the jet stream itself. This means that more warm air has to be sucked up from below, replenishing and adding to the moisture and doubling intensifying the updraft, setting the stage for final violent phase. These were the conditions that prevailed in April 1974.

5. It is well known that as the earth rotates only once every 24 hrs, the Coriolis force is quite small, and its effect generally becomes noticeable only for motions occurring over large distances and long periods of time, such as large scale movement of air in the atmosphere or water in the Ocean. Such motions are constrained by the 2-dimensional surface of the earth, so only the horizontal component of the Coriolis force is generally important. James (2004) has mentioned that tornados have high Rossby numbers, so, while tornado- associated centrifugal forces are quite substantial, Coriolis forces associated with tornados are for practical purposes negligible. Grazulis (1993) has mentioned that the most extreme tornado in recorded history was the Tri-State Tornado, which roared through parts of Missouri, Illinois, and Indiana on March 18, 1925 (9^{th} - 10^{th} day of waning period). It holds records for longest path length (219 miles, 352 km), longest duration (about 3.5 hours), and fasted forward speed for a significant tornado (73 mph, 117 km/ h) anywhere on earth. Martinelli (2007) has mentioned that super cell thunderstorm tracked 790 miles (1271 km) across 6 states in 17.5 hours on March 12, 2006, which was probably the longest track covered by a super cell thunderstorm. It began in Noble County, Oklahoma and ended in Jackson County, Michigan, producing many tornados in Missouri and Illinois.

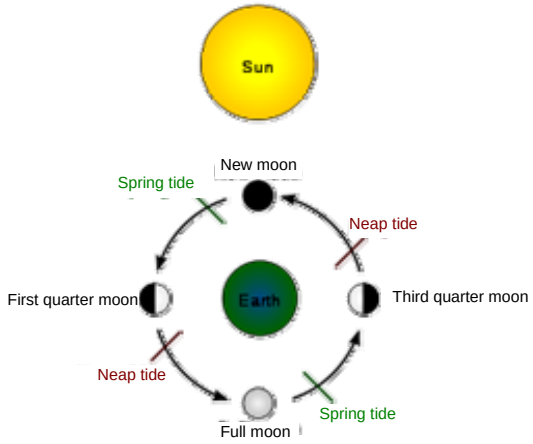

Fig. 1. The types of tides

It is well known that a complete cycle of phases of the Moon from New Moon, first quarter, Full Moon; last quarter and back to New Moon takes approximately 29.53 days, which is known as Synodic month (Burnham *et al.* 2003). Approximately the Moon's eastward progress averages 12° per day during the Synodic month. Kolvankar (2011) has said that earthquakes are triggered by the Earth tides (bulging in earth surface) caused by the positions of the Sun and the Moon and this process seems to be the primary triggering mechanism for all worldwide earthquakes. Maximum of 12 inch bulging, twice a day, in earth surface (earth tides) has been observed because of solar-lunar gravitational force (Google search earthquake http : // www.contentwriter.in/articles/others/earthquake. htm). This is the reason for occurrence of two high and two low tides in Oceans Lambeck (1977) has mentioned that the tides on the Earth are mostly generated by the gradient in intensity of the Moon's gravitational pull from one side of the Earth to the other, the tidal forces. This forms two tidal bulges on the earth, which are mostly clearly seen in elevated sea level as Ocean tides. He has further mentioned that the gravitational attraction of the

TABLE 1

Days of killer Tornados over USA and Asia

S. No.	Date	Area	Fatalities	Lunar day	Remarks if any
1	22 Jun 1944	Great lakes- Mid- Atlantic	163**	S-2	
2	23. Jun 1944		**	S-3	
3	12 Apr 1945	Not available	128	S-1	
4	09 Apr 1947	Southern Great Plains	181**	S-5	
5	10 Apr 1947		**	S-6	
6	03 Jan 1949	South Central USA	60	S-6	
7	09 May 1953	Southern Central Great Plains/ Upper Mississippi Valley	144***	K-12	Deadliest in Texas history, 33 tornados
8	10 May 1953		***	K-13	
9	11 May 1953		***	K-14	
10	07 Jun 1953	Central Great Plains-Great Lakes-New England	247***	K-12	48 tornados
11	08 Jun 1953		***	K-13	
12	09 Jun 1953		***	K-14	
13	25 May 1955	Great Plains-Mid west-Mississippi Valley	102**	S-5	47 tornados
14	26 May 1955		**	S-6	
15	11 Apr 1965	Central United States	256**	S-11	51 tornados
16	12 Apr 1965		**	S-12	
17	03 Mar 1966	Mississippi Alabama	58	S-12	202.5 mile path, F5
18	21 Apr 1967	Midwest	58	S-12	45 tornados
19	15 May 1968	Mississippi Valley	74**	K-4	Two F5 in 46 tornados
20	16 May 1968		**	K-5	
21	21 Feb 1971	Southern Mississippi Valley	119	K-11	14 tornados
22	31 Mar 1973	George South Carolina	10	K-13	Extremely destructive tornados and costliest natural disaster in Georgia history
23	03 Apr 1974	Eastern United States-Ontario	315**	S-12	Largest and most intense recorded outbreak, 148 tornadoes, 6 F5
24	04 Apr 1974		**	S-13	
25	04 Apr 1981	Wisconsin	3	K-15	One of the strongest anticyclonic tornadoes on record, F4
26	28 Mar 1984	Carolinas	57	K-12	F3/F4, 24 tornados
27	31 May 1985	US-Canadian Eastern Great Lakes	88	S-13	
28	27 Mar 1994	South Eastern US	40	K-1	27 tornados
29	08 Apr 1998	Metropolitan area of Birmingham, Alabama, Georgia, Louisiana, Tennessee	39	S-13	11 tornadoes
30	31 May 1998	New York tornado outbreak	1	S-7	35 tornadoes, $ 83 million in damage
31	02 Jun 1998	New York to SC	2	S-9	49 tornadoes, $ 43 million in damage
32	23 Aug 1998	Wisconsin, Michigan		S-2	8th costliest in Wisconsin history
33	03 May 1999	Southern Great Plains	46	K-3	66 tornadoes, first tornado to incur $ 1 billion in damages

TABLE 1 (*Contd.*)

S. No.	Date	Area	Fatalities	Lunar day	Remarks if any
34	24 Jun 2003	South Dakota	0	K-11	63 tornadoes, Tied U.S. record for most tornadoes in one state during 24 hour period
35	05 Feb 2008	Tennessee, Kentucky Arkansas, Mississippi, Alabama, Indiana, Texas	59**	K-14	Deadliest U.S. outbreak since 1985 U.S.- Canadian tornado outbreak on 31 May 1985
36	06 Feb 2008		**	K-15	
37	27 Apr 2011	Alabama, Arkansas, Georgia, Mississipi, Tennessee and Virginia etc.	324	K-10/ S.I.	205 tornadoes, with four EF5 (enhanced intensity), 4th deadliest (srh.noaa.gov) and costliest in USA history. Total damages of nearly $11 billion (2011 USD)
38	22 May 2011	Jasper and Newton counties in Missouri	158	K-6	48 tornadoes with one EF5 (enhanced intensity). Total damages of nearly $2.8 billion (2011 USD)
39	19 Apr 1963	Assam, India	139	K-10	
40	11 Apr 1964	Khulna Division, Bangladesh	500	K-14	
41	14 Apr 1969	Bangladesh	923	K-13	More than 2 tornadoes
42	17 Apr 1973	Dhaka Division, Bangladesh	681	S-15	
43	01 Apr 1977	Dhaka Division, Bangladesh	500	S-12	
44	17 Mar 1978	New Delhi, India	28	S-8	
45	10 Apr 1978	Orissa, India	150	S-3	
46	09 Jun 1984	Western Russia	400	S-11	
47	26 Apr 1989	Barisal Division Bangladesh	1300	K-5	One and half mile wide tornado, deadliest tornado in world history
48	14 Jun 1990	Southern Philippines	30	K-6	
49	19 Apr 1995	Guangzhou Province, China	37	K-5	
50	13 May 1996	Dhaka Division Bangladesh	700	K-11	
51	24 Mar 1998	West Bengal-Orissa, India	160	K-10	
52	18 Sep 2006	Nobeoka, Miazaki Prefecture, Japan	3	K-11	2nd deadliest in recent Japan history
53	07 Nov 2007	Saroma, Hokkaido, Japan	9	K-3	Deadliest tornado in recent Japan history
54	13 Apr 2010	Bihar, West Bengal, Bangladesh	120	K-14	Super cell

** Combined fatalities for two days.
*** Combined fatalities for three days.

Sun on the Earth's Oceans is almost half that of the Moon and their gravitational interplay is responsible for spring (maximum tidal range) and neap (minimum tidal range) tides. Fredrick and Becker (1976) have mentioned that spring tide occurs when the Moon is New or Full. Because the Moon and Sun are then attracting from the same or opposite directions, lunar and solar tides reinforce each other. The neap tide occurs when the moon is at either quarter phase; then the Moon and Sun are at 90° apart in the sky, so that one set of tides is partly neutralized by the other. When the Moon is New or Full also in perigee (nearest point), the difference in level between low and high tides is especially great (Fig. 1). When the Moon is at apogee (farthest point) the tidal range shrinks.

6. Tornado has been identified as killer on a day when the fatalities have been reported as 39 or more or massive destruction reported or enhanced intensity on Fujita Scale is observed as 3 or more (≥ EF3). In Asian countries, tornadoes have been reported in less numbers. Thus for Asian countries, tornado has been identified as killer, when the fatalities have been reported as 28 or more or massive destruction reported. Out of 54 days, these killer tornados have been observed over USA on 38 days

and over Asian region on 16 days (one day super cell thunderstorm). Appropriate lunar day has been marked on all these days (Table 1). The alphabet 'K' and 'S' denote waning and waxing period respectively (Krishna and Shukla Paksha). First day of the waning period has been marked as K-1. An appropriate lunar day has been marked on all day of respective months of the Tide Table. Normally semi-diurnal tides (two high waters and two low waters each day) were forecast for the all months. In every month, 3 tides a day were forecast for three to five days, when two tides were separated by more than 6 hours. On 20th March only two tides were forecast. Normally both values of high tides start decreasing from 3rdor 4th or 5th day of waning and waxing period and continue decreasing till 8th or 9th day of both fortnights. Again, normally, both values of high tides start increasing from 10th or 11th, or 12th or 13th and continue increasing till 1st or 2nd or 3rd during waning and waxing period. High tide and low tide periods have been considered from 10th to 3rd and 4th to 9th during each waning and waxing period of the Moon respectively. It has been observed that most destructive tornadoes had developed during 40 days (including one super cell) of high tide period and on 14 days during low tide period (25.9%). It has been also verified, whether more evaporation takes place during high tide period by examining the apparent evaporation for Colaba (43057), Mormugoa (43196) and Panjim (43192) observatories under Regional Meteorological Center, Mumbai, for the month of April 2010. No significant increase was noticed.

7. Continuous changes in the values of both high tides during every fortnight have been put under four different categories. Each specific feature is noticed once in each waning and waxing period in every month and 24 times in a year. The details of tides feature which were found in the tide tables for the years 2009 and 2010 are as under :

	Feature	*Lunar days (total number of occurrence)*
1.	Both started decreasing (S.D.)	K-2(3), K-3(4), K-4(10), K-5(6) and K-6 (1): K- (24) S-1(1), S-3(6), S-4(9), S-5(7) and S-6(1): S (24)
2.	Both continued decreasing (C.D.)	K-8(9), K-9(16): K- (25) S-7(1), S-8(11), S-9(11) and S-10 (2): S-(25)
3.	Both started increasing (S.I.)	K-10(8), K-11(5), K-12(8), K-13 (2), K-14(1) and K-15(1): K-(25) S-10(4), S-11(9), S-12(5), S-13(5) and S-15(1): S- (24)
4.	Both continued increasing (C.I)	K-1(5), K-2(5), K-3(8), K-4(1), K-13 (1) and K-15(1): K-(21) S-1(7), S-2(5), S-3(10), S-11(1), S-14(2), S-15 (3): S-(28)

8. It has been observed from tidal features for 2009 and 2010 that both high tides S.D. from 1st or 2nd or 3rd in 14 cases (low tide period has been considered from 4th) and they C.D. up to 8th in 21 cases (low tide period has been considered up to 9th). Thus high and low tide periods are compensated and consideration of high and low tide periods in general for the study from 10th to 3rd and from 4th to 9th are justified in absence of tide tables for different years. Super cell and killer tornado had been reported in Asian countries on 9 days out of 16 days during the month of April. One example each of 'S.I.' and 'C.I.' tidal features (high tide period), which were observed during April 2010, are as under: All timings in the tide tables have been given in IST (Hour Minute: HM). Tide tables for 7th, 8th and 9th are as under:

HM	*Height (M)*	*HM*	*Height (M)*	*HM*	*Height (M)*
0129	2.43	0311	2.26	0351	2.02
0553	2.66 (7th)	0752	2.67 (8th)	0932	2.92 (9th)
1151	1.89	1318	1.93	1439	1.84
1930	3.23	2103	3.32	2143	3.47

Both high tide values S.I. on 8th (K-10).

Tide tables for 13th, 14th and 15thare as under:

0523	0.87	0552	0.65	0010	4.03
1149	4.04	1223	4.24	0618	0.49
1737	1.44 (13th)	1811(14th)	1.44	1257 (15th)	4.39
2344	3.99			1844	1.43

Only three tides were forecast for 14th. New moon (K-15) started at 1141 UTC (1711 hrs IST) on 13th and ended at 14/ 1228 UTC (1758 hrs IST). Super cell thunderstorm which affected Bihar (north), West Bengal and Bangladesh developed on 13th. Both values of high tides continued increasing till 15th (S-2). Both high tides values S.D. on 17th (S-4) and C.D. till 22nd (S-9). During 2011 tornadoes struck USA violently on 27th April (K-10, 205 tornadoes with four EF5 enhanced intensity, 324 fatalities and massive destruction) and 22nd May (K-6, 48 tornadoes with one EF5 enhanced intensity, 158 fatalities and damages nearly $2.8 billion, 2011 USD). Both high tides started increasing on 27th April.

From 2401 local time (after 12 pm night) new English date is considered. Tide Tables for a day have been prepared on the basis of English date (*i.e*., height of Tides has been given from 0001 hrs IST). All four trends (S.D., C.D., S.I. and C.I.) observed for Arabian Sea may differ for other Seas by a day or two but lunar day would remain same for all countries. Solar-lunar eclipses are observed on a fixed date for all countries.

9. *Conclusion* – (*i*) Killer tornadoes develop mostly during high tide period (74.1%) under favorable synoptic situations. (*ii*) April (20 days: 37%) is the most favored month for occurrence of killer tornadoes.

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