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On the solar stimuli that initiate Makkah Al-Mukaramah, Al-Madinah Al-Munawarah and Jeddah flash floods

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Abstract- Severe solar events manifested as highly energetic X-Ray events accompanied by coronal mass ejections (CMEs) and proton flares caused flash floods in Makkah Al-Mukaramah, Al-Madinah Al-Munawarah and Jeddah. In the case of the 20 January 2005 CME that initiated severe flash on the 22 of January. it is shown that the CME lowered the pressure in the polar region and extended the low-pressure regime to Saudi Arabia passing by the Mediterranean. Such passage accelerated evaporation and caused Cumulonimbus clouds to form and discharge flash floods over Makkah Al-Mukaramah. On the other hand, solar forcing due coronal holes have a different technique in initiating flash floods. The November 25, 2009 and the 13-15 January 2011 Jeddah flash floods are attributed to prompt events due to fast solar streams emanated from two coronal holes that arrived the Earth on 24 November 2009 and 13 January 2011. We present evidences that those streams penetrated the Earth's magnetosphere and hit the troposphere at the western part of the Red Sea, dissipated their energy at 925mb geopotential height and left two hot spots. It follows that the air in the hot spots expanded and developed spots of low-pressure air that spread over the Red Sea to its eastern coast. Accelerated evaporation due to reduced pressure caused quick formation of Cumulonimbus clouds that caused flash floods over Makkah Al-Mukaramah and Jeddah.

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Keywords- Coronal Mass Ejection; Solar wind; Flash Floods; Low-Pressure; Red Sea.

1. INTRODUCTION

Makkah Al-Mukaramah is frequently subjected to flash floods since historical times. The gate of Kabba is highly elevated from the ground as a protection from water inflow into its interior. In 1924 and 1941 flash floods water surrounded Kabba (Fig 1). Makkah Al-Mukaramah's flash floods were studied in an earlier paper [Shahinaz *et. al.* (2006)].

The Earth responds to solar variability through geomagnetic activity, variations of the high atmosphere, and possibly changes of weather, climate and biota [*Mendoza (2011)*].

Table 1 lists the most severe flash floods of Makkah Al-Mukaramah for the period of 1985-2002 with daily precipitation amounts greater than about 15 mm arranged in descending order (Shahinaz, 2006). Makkah Al-Mukaramah's flash floods occurred all the year round with the exception of February, May and June. More frequent flash floods occurred during November, December and January. This increased the hazards during and around the present Hajj years. Of particular interests are the pilgrimage event of January 2005 and Jeddah disasters of November 2009 and 2011.

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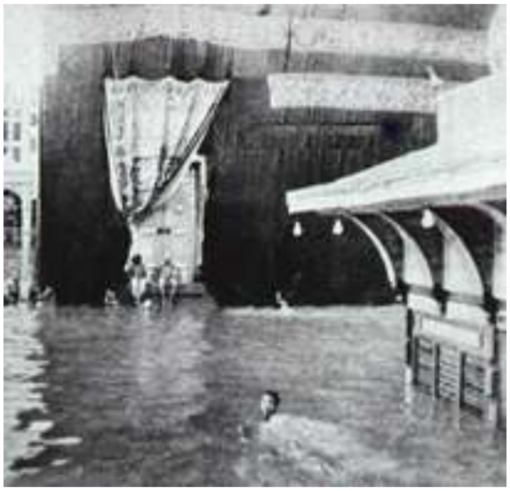

Fig. 1. The Holy Kabba flooded in 1941 and people go around its swimming.

Fig. 2. Frequent flash floods occur in Makkah and Jeddah.

The prime importance of the present paper is to explore solar forcing on flash floods affecting Makkah Al-Mukaramah, Al-Madinah Al-Munawarah and Jeddah.

2. Solar forcing on Makkah Al-Mukaramah, Al-Madinah Al-Munawarah and Jeddah

Flash floods in Makkah Al-Mukaramah, Al-Madinah Al-Munawarah and Jeddah in Saudi Arabia are studied in relation to five severe solar events that were ranked by the university of Maryland team as important solar X-ray events of class M and X (Fig 3). All of the five events were accompanied by halo coronal mass ejections (ejected pieces of the sun that hit the Earth) and proton flares. Details of the solar events are given in Fig 3. Four of those important solar events have caused flash floods in Makkah Al-Mukaramah, Al-Madinah Al Munawarah and Jeddah. The dates of those flash floods and the amount of rain in mm are given in Table 2. Solar forcing might have effects on thunderstorms and hurricanes [Russell and Bergman (2005)].

Solar forcing of those events can be classified into prompt and delayed events.

Prompt events: like the 20 January 2005 event which caused flash floods on 21-22. Note that from Fig 3 the X-ray flare lasted for more than two days.

Delayed events: like the 14th of July 2000 event which caused mild floods on the 24th only in Makkah Al-Mukaramah and the 28 October 2003 event which caused rain on 10 November. In the case of the 4th of November 2001 event, it is not likely to have caused rain on 22nd of November on Makkah Al-Mukaramah because of the exponential drop of X-ray flux as seen in fig 3. This mild rain might have been caused by another coronal mass ejection which departed the sun on 17 November and arrived Earth on 20 November 0050 UT.

3. Proposed Mechanism to Explain Coronal Mass Ejection Forcing on Flash Floods

When coronal mass ejections CMEs hit the magnetosphere, surround it and get from the night side of the magnetotail, protons and electrons get injected into the Van Allen belt and then into the two polar caps. Their energy gets dissipated into the polar atmospheres expanding the air thus reducing the pressure.

As an example, let us have a look at the CME event of 20 January 2005 which was accompanied by a proton stream accelerated to almost the velocity of light. This event caused serious floods in three destinations, Makkah Al-Mukaramah, Al-Madinah Al-Munawarah and Jeddah. Flash floods in Makkah Al-Mukaramah happened around 14:30 on 22 January.

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Table 1. The highest daily rain amount in Makkah- Al-Mukaramah 1985-2002.

YEAR	MONTH	DAY	PRECIPITATION (mm)
1989	4	9	71.1
1985	12	18	63
2000	11	16	53.7
2002	11	30	50
1992	1	10	49.4
1992	12	14	49.4
1988	12	30	43.8
2001	12	31	42
1993	12	23	40
1998	8	29	35
1997	11	30	34.6
1998	3	6	34.1
1996	11	16	32.2
1996	11	17	31.1
1995	12	30	29.4
2000	11	9	28
1996	11	20	27.1
1989	12	4	26.2
1994	10	22	25.1
1999	1	8	24.7
1995	7	23	24.6
1997	10	22	24.6
1992	8	12	24.4
1986	3	2	24
1991	1	12	22.7
2002	1	6	20.7
1989	12	19	19.4
1993	4	14	19.4
1992	8	15	18.9
1999	9	16	18.7
2001	1	3	18.4
1994	1	15	18.1
1987	3	3	18
1989	12	26	18

The sequence of events that led to these severe flash floods is summarized as follows (consult fig 4):

(1) A CME hit the Northern Polar region on 20 January and lowered the pressure in the hitting spot to about 500mb (compare fig 4a and b).

(2) The low-pressure region extended to lower latitudes passing by the Mediterranean Sea and thus heavy clouds were formed rapidly.

(3) The pressure extension reached Saudi Arabia (Fig 4c).

(4) Flash floods occurred in the three cities starting with Al-Madinah Al Munawarah indicating that the clouds were coming from the Northern direction. (fig. 4d). Note the similarity between the low-pressure zone and rain zone (Figs 4c & d).

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Table 1. Details of flash floods in Makkah El Mukaramah, Jeddah and Al Madinah El Munawarah for the five events given in Fig. 3.

Proton flux	Event	Makkah Day	Rain mm	Jeddah Day	Rain mm	Madinah Day	Rain mm
24000	14 July 2000	24	9		0		0
14800	8 Nov 2000*	9	28				
31,700	Nov 4 2001	22	10.6		0		0
29500	28 Oct 2003	Nov10-12	6m high	Nov10	44.4	Nov10	11.8
5040	20 Jan2005*					21	3.7
		22	65.5	22	32	22	47.3

* prompt events

4. Effect of Coronal Hole Fast Streams on Makkah Al-Mukaramah and Jeddah Flash Floods

4.1 First Case Study: Makkah Al Mukaramah and Jeddah 13-15 January 2011 Flash Floods

Rain started on Makkah Al-Mukaramah late on 13 January then spread to Jeddah the following day. Daily rain fall was between 13 and 29 mm.

Solar coronal holes are dark cold region in the solar corona. They are sources of fast solar wind streams composed of protons, ions and electrons.

We report here in steps the process of formation of the cloud that caused such sudden rain fall in terms of coronal hole forcing (Fig 6):

(1) A fast-solar wind stream consisting of protons, ions and electrons emanated from the coronal stream seen in Fig 5.

(2) This stream reached Earth on 13 January 2011, opened a gate in the Earth's magnetosphere and dissipated its energy in the lower Earth's atmosphere near the western shore of the Red Sea between 0-6h UT at geopotential height 925mb, heating the atmosphere as pointed by the arrow in the temperature map (Fig 6a).

(3) In such a small spot, due to heating, the air expands reducing the pressure between 6-12 h UT as pointed by the arrow in Fig 6b.

(4) The reduced pressure zone expanded easterly over the Red Sea and reached its eastern coast on 14 January between 0-6 h UT (Fig 6c).

(5) Under reduced pressure, water evaporates very quickly. This is the idea, the low-pressure area that is located over the Red Sea, caused heavy clouds to form very rapidly.

(6) Also, the presence of charged particles in the atmosphere owing to solar wind protons, ions and electrons streams as well as their products of interaction with the troposphere enriched this volume with electric charges which act as nuclei for rapid water condensation and enhance rapid cloud cover. Eventually, those clouds get loaded with large amounts of water and caused heavy rain over Makkah Al-Mukaramah and Jeddah on 13-15 January 2011.

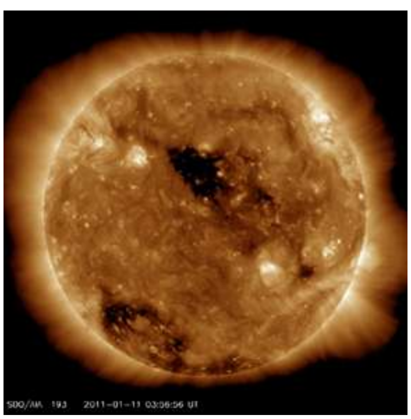

Fig. 5. Coronal Hole on 11 Jan 2011.

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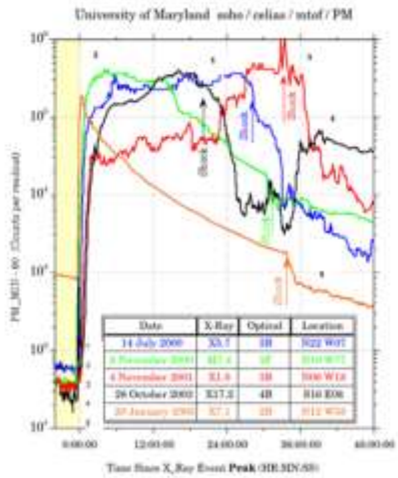

Fig. 3. Five distinguished X-ray flares chosen by SOHO team. X-ray and optical flare importance and locations on the sun are given. The number of event is given on diagram and on left of table.

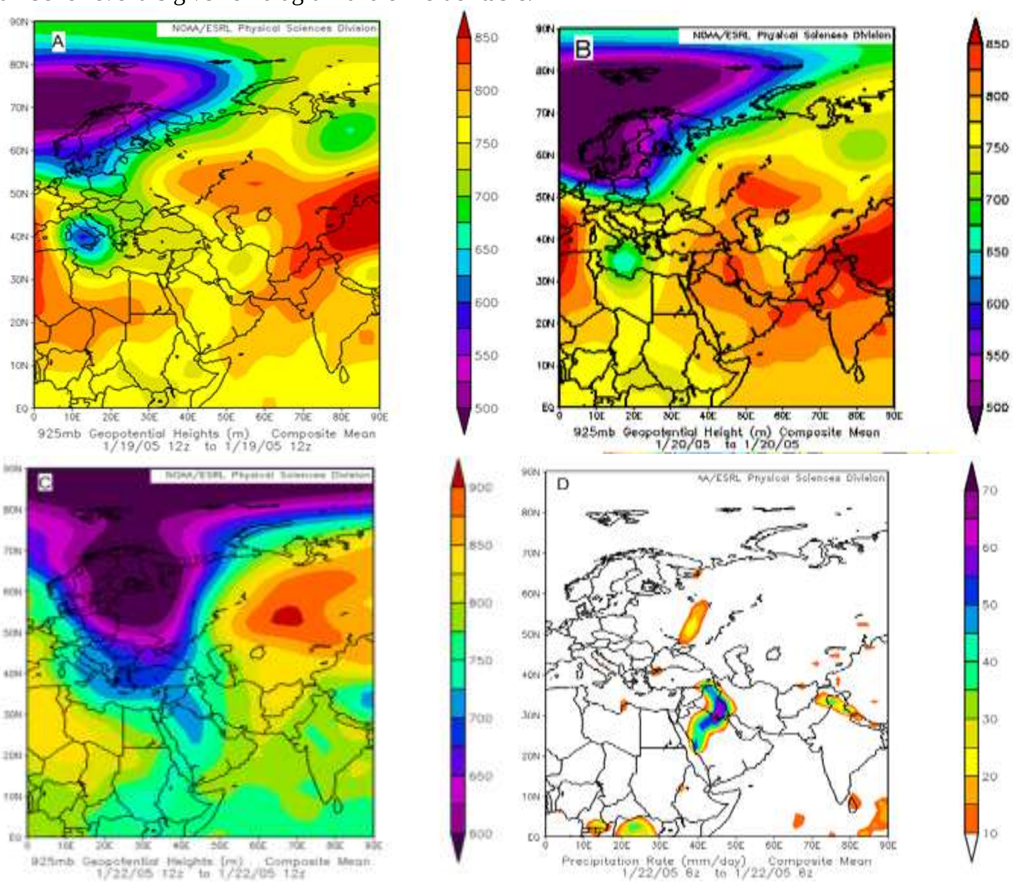

Fig. 4. 925 mb Geopotential height for the event of 22 January 2005 flash floods. A) 19 Jan 2005 map before CME hit the polar cap. B) 20 Jan map showing the position of CME hit of the polar atmosphere. C) 22 Jan at 12 UT map clearly indicates the extension of the low-pressure region southward to Saudi Arabia passing by the Mediterranean Sea where the clouds were loaded with water. D) Precipitation rate map on 22 Jan 6h UT indicating excessive flash floods passing over Makkah Al-Mukaramah, Al-Madinah Al-Munawarah and Jeddah.

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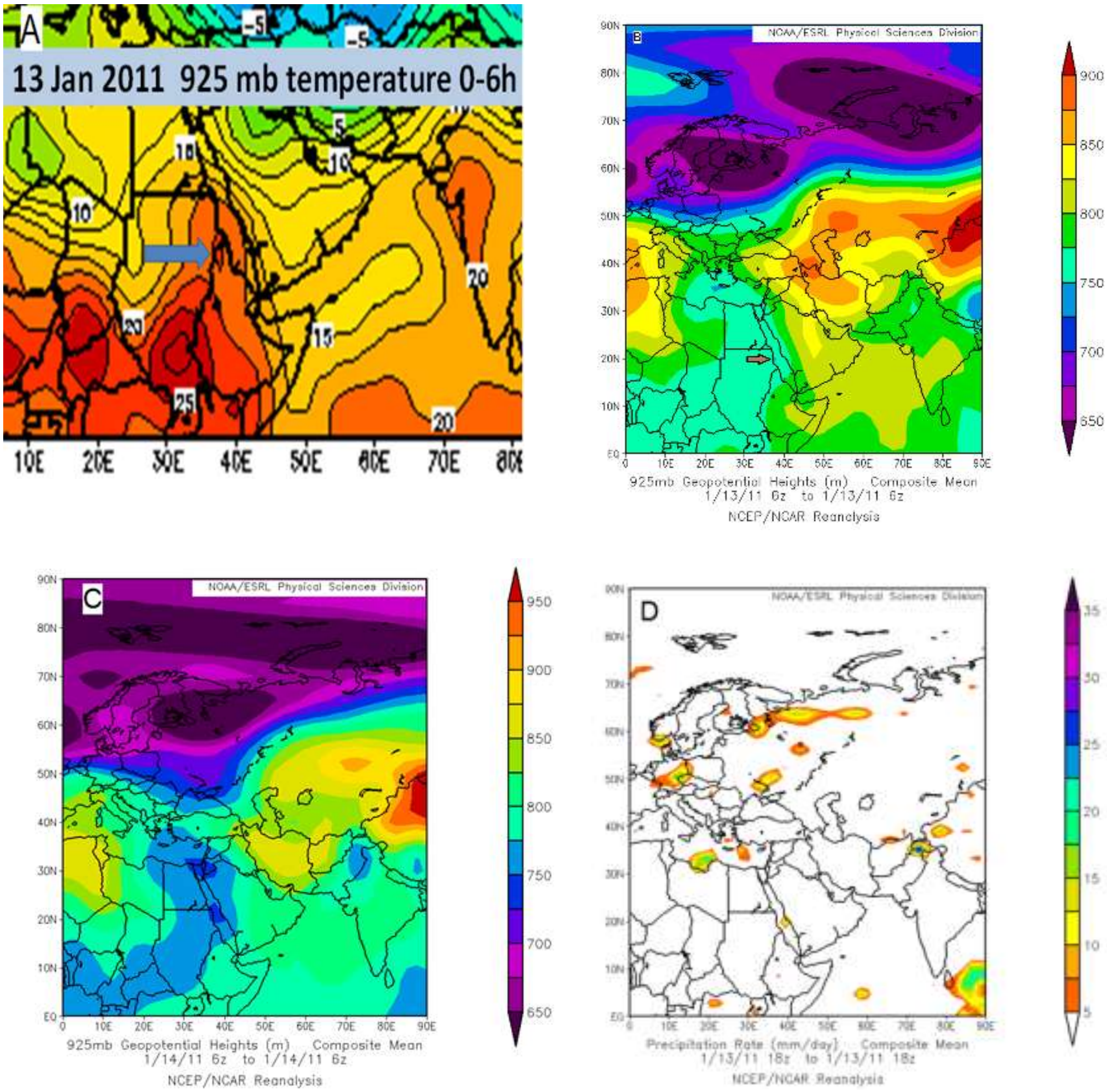

Fig. 6. A) Air temperature at sea level on 13Jan 2011 0h UT, arrow indicates the hot spot where the coronal hole stream heats the atmosphere. B) 925mb geopotential height map on 13 Jan 2011 at 6h UT, arrow indicates the low-pressure spot. C) 925mb geopotential height map on 14 Jan 6h UT showing the expansion of the low-pressure spot to the eastern side of Red Sea. D) Precipitation on 13 Jan 18h UT showing rain on the coast of Jeddah.

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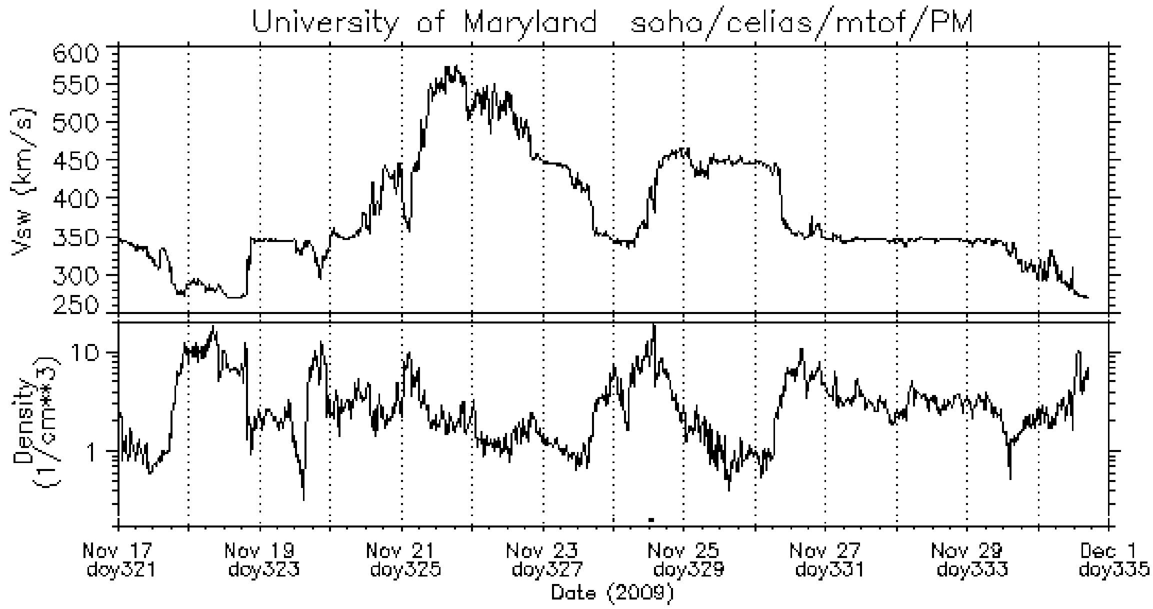

Fig. 7. Time series of Solar wind velocity and density for the period 27th November-1 December 2009. The upper panel shows that there are two successive solar wind streams. The second one starts on the 24 November and is the likely cause of the 25th flash flood.

4.2 Second Case Study: Jeddah 25 November 2009 Flash Flood

Excessive flash floods (70mm) affected Jeddah on Wednesday 25 November 2009 causing severe damages and large death toll [Mashael Al Saud (2011)].

This flash flood may be attributed to fast solar wind stream that is emendated from a coronal hole.

The solar wind velocity exceeded 550 km/s as seen in Fig 7. This fast stream might have caused a delayed flash flood event. There is a second solar wind stream of slower velocity but large density with negative Bz component of interplanetary magnetic polarity which makes it geoeffective with maximum density on 24 November. This second stream is the likely candidate for the production of prompt Jeddah flash floods on the following day. This second choice is most likely as the Presidency of Meteorology & Environmental in Jeddah failed to forecast the November 2009 flash flood while it forecasted successfully the November 2010 event four days ahead. This indicates that the November 2009 event was a prompt event while the November 2010 was a delayed event.

The steps that lead to the Jeddah 25 November 2009 flash floods are summarized as follows (Fig 8):

(1) A fast-solar wind stream composed of protons, ions and electrons emanated from a coronal hole and was directed towards the Earth.
(2) This stream penetrated the Earth's magnetosphere and reached the western coast of the Red Sea on 24 November.
(3) Energy dissipation of the solar stream components happened at geopotential height 925 mb and heated a localized area of the troposphere.
(4) The heating caused air expansion and led to the formation of a low depression as pointed by the arrow in Fig 8a on the 925 mb geopotential height map of 24 November at 6h UT.
(5) The air depression expanded quickly and reached the eastern coast of the Red Sea.
(6) Crossing the Sea enhanced water evaporation and loaded clouds with excessive amount of water in a very short time forming Cumulonimbus clouds. The cloud unloaded.

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5. DISCUSSIONS

All of the five strong solar X-ray events studied in this paper were accompanied by Halo coronal mass ejections directed towards the Earth. Coronal mass ejections have the following effects on Earth [Miyasakaa et. al. (2005)]: They compress the day side of the Earth's Magnetosphere to about half of its normal distance.

The magnetic lines of force open up provided that the interplanetary magnetic field is in the southerly direction, allowing protons to leak inside.

In addition, proton and electron streams surround the Earth, got injected from the night side into the Van Allen belts and dissipate into the two Polar Regions. As they enter the polar atmospheres, their energy gets dissipated there, heating the polar air thus, it expands, and the low-pressure regions will be deepened.

During a highly energetic event, when the magnetic storm is strong, and the aurora extends to lower latitudes indicating that proton and electron streams get dissipated at such lower latitudes, thus the low-pressure zones extend to lower latitudes.

In the case of the 20 January CME which was accompanied by very energetic protons, the low-pressure zone expended from the Polar Regions down to Saudi Arabia and caused excessive flash floods in Makkah Al-Mukaramah on the 22nd day of the month.

Numerous flash floods occurred during the period 1985-2010. The event of the 9th of April 1989 was on the top of the list with precipitation 71mm. Something odd was going on the sun on that date that led to the disappearance of 11 filaments showing blue or red shifts (NOAA). Details of this particular event will be discussed elsewhere.

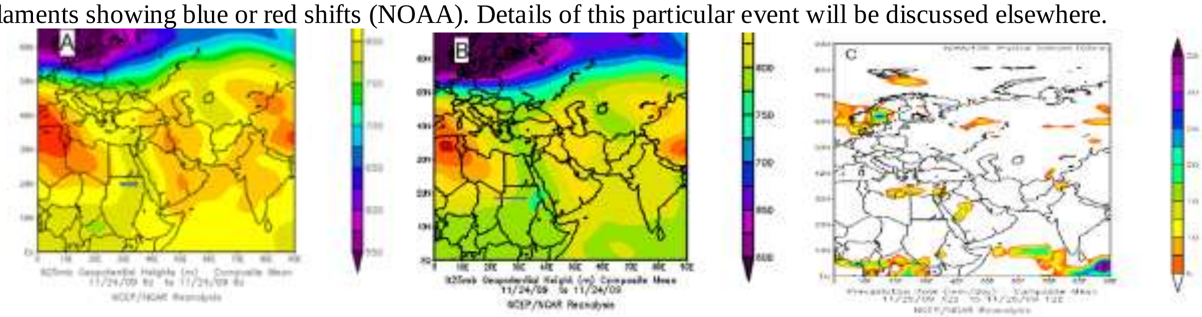

Fig. 8. 925mb geopotential height map, A) on 24 Nov 2009 at 6h UT, arrow indicates low pressure spot where the coronal hole stream interacted with the Earth. B) 24 Nov. map, arrow indicates the extension of the low pressure spot over the Red Sea. C) Precipitation rate map on 25 Nov 12h UT showing rain off the coast of Jaddah

Details of the November 10, 2003 as well as the 20 January 2005 events are given in (Shahinaz et. al., 2006).

In addition, two fast solar streams emanated from two coronal holes and hit the Earth"s troposphere at the west coast of the Red Sea like bullets on 24 November 2009 and 13 January 2011. They both dissipated their energy at 925mb geopotential height causing localized elevation of temperature. With the expansion of the air mass, pressure drop occurred. Low-pressure areas stretch over the Red Sea and thus accelerate evaporation. As a result, Cumulonimbus clouds form quickly and discharge heavy rain over Jeddah`and Mackkah Al- Mukkaramah.

6. CONCLUSIONS

In the present paper, we found that Makkah Al-Mukaramah, Al-Madinah Al-Munawara and Jeddah flash floods can be initiated by two types of solar forcing.

Coronal mass ejections enter the Earth through the Polar Atmosphere. They dissipate their energy there and heat it up. Air thus expands in the location of interaction and the pressure is reduced.

The low-pressure region is pushed southwards toward Saudi Arabia passing by the Mediterranean Sea. There, quick evaporation happen due to the reduced pressure and Cumulonimbus clouds are formed. The clouds are then discharged at the two Holy cities and Jeddah.

The second type of flash floods are initiated by coronal holes where fast ionic, proton and electron streams emendated from such coronal holes when they can make a direct hit to the Earth. The fast stream penetrates the magnetosphere and hit the Western coast of the Red Sea in Sudan facing Jeddah and Makkah Al-Mukaramah. The energy dissipated there heats up the spot which we can call the bullet target. Heat expands the air thus reduce the pressure. This low-pressure region extends to the Saudi Arabian coast by crossing the Red Sea. Over the Red Sea Cumulonimbus clouds form quickly due to the reduced pressure. Within few hours, flash floods occur over Jeddah and Makkah Al-Mukaramah.

Using NOAA weather maps, we can predict flash floods. However, those weather maps are not released except after few days. We thus appeal to NOAA ESRL to make weather maps available on the spot for the purpose of flash floods and Hurricanes prediction anywhere in the world.

We have also discovered the means of hurricanes formation. Improved models of sun-earth connections have to be investigated with the purpose of calculating the exact Earth locations where there would be the arrival of solar wind stream. Solar wind neutron monitors for detections of fast solar wind streams in Sudan at the coast of the Red Sea facing Jeddah are highly recommended.

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