Remote Sensing Essential
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Application of Remote Sensing In Earthquake Studies-II
Lecture - 54

Hello everyone and welcome to a new discussion say part 2 basically of discussion which we had about remote sensing applications in earthquake studies of this course. So, in the part one we have discussed how remote sensing can be applied in earthquake induced landslides and also how remote sensing datasets pre earthquake post earthquake can be applied in earthquake induced liquefaction related studies.

It is very much possible to map in earthquake induced landslides and also liquefaction very accurately implying remote sensing data.

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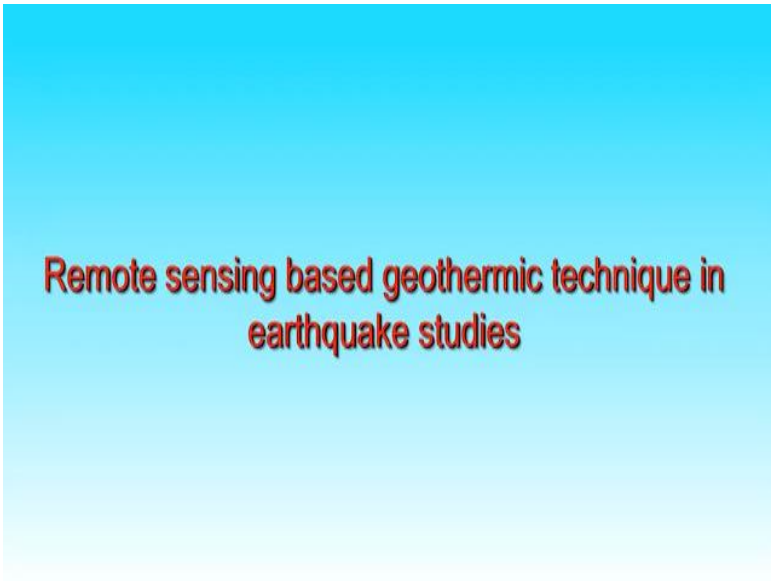

Third and last application related with this earthquake, which we are going to discuss is game implying remote sensing techniques, but this time in most of the examples, I am going to show you the usage of thermal images. So, far examples in earlier examples what we have seen and mainly visible or infrared bands are applications of those bands in earthquake related studies. Now, we are going to discuss about how thermal remote sensing data can be implied in earthquake related studies.

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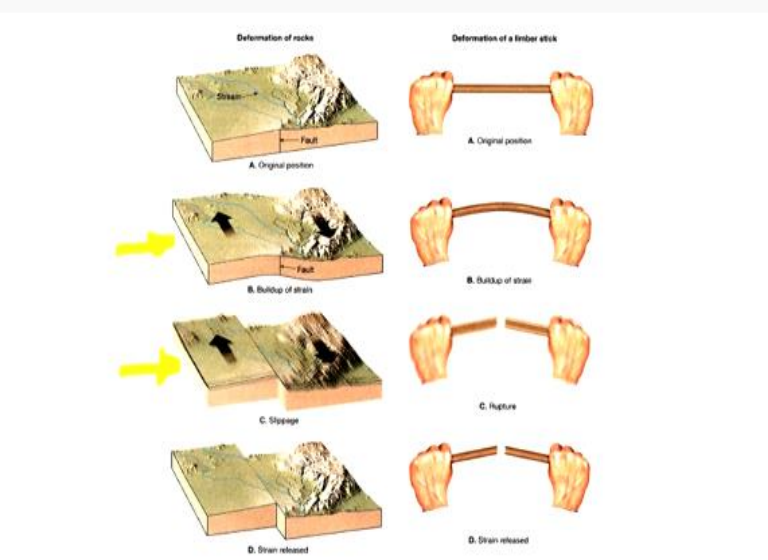

As you know that when earthquake occurs and generally they occurs along the fault line and but before that a lot of stresses are developed because of movement of these plates, crystal plates like Indian plate is going below the Eurasian plate and so on, so forth. So, if we put this analogy, this is what we find that one right hand side that if you bend a you know a sticker or put rod then you keep bending and there will be a stage when it will break and there be exactly in case of earthquakes there what earthquake occurred.

So, here the bending is going on, but there is no break and here that and the bending has reached across the threshold and therefore, the movement has occurred. Similarly, this is what you are seeing here. So, these the rupture will occur once it reached the threshold value across that set threshold volume. So, during that time, there must be a you know, there must be some changes in temperature resume of the surface of the earth.

And this is what we can further understand and these changes in thermal resume by you know, recalling our high school physics, they and we were taught that if you put a heavy coin on the seat of ice like here.

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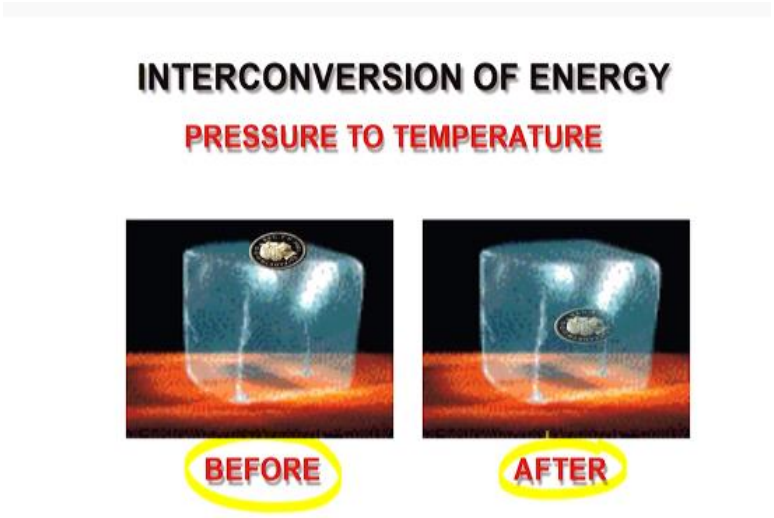

Then after some time what you find that coin goes inside the ice because the coin exerts pressure on the seat of ice and that pressure creates the little high temperature that melts the water or melts the ice and slowly, slowly coin moves inside ice. So, this is what is happened. So, that means there is a basically simple inter conversion of energy from pressure to temperature, whether this thing also happens in case of earthquakes or related with earth.

This is what we are going to see there are some other you know, reasons can which can also bring higher temperatures near the surface during an earthquake event or before an earthquake event so, 2 more processes, which supports this increase in temperature

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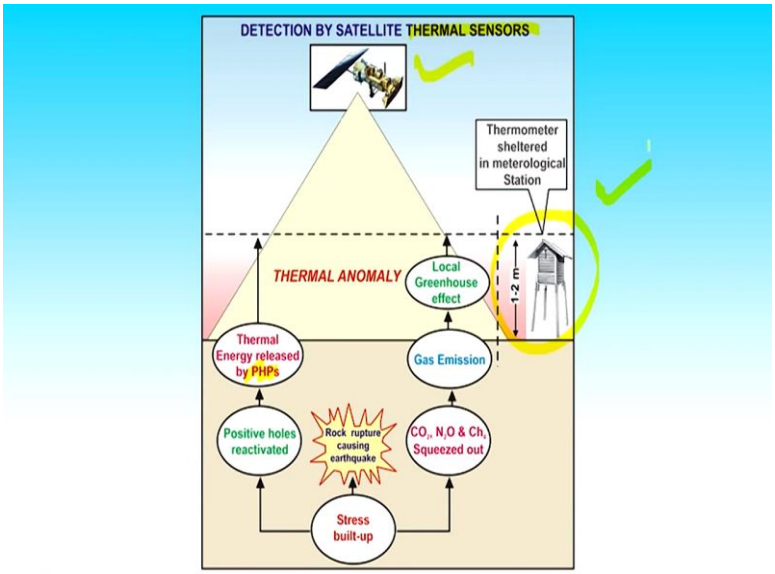

One is this pear holder, this positive hole pears and this can create you know we during the reactivation or during the rupture, these positive holes pear and they can come on the surface and can increase the temperature. Also, there are a lot of greenhouse gases which are entrapped in the puree spaces over rocks so, just before the rupture because of intense pressure or stresses. These gases can also come out.

And they can create a greenhouse effect and that greenhouse effect means rise in temperature. So, this all these things are contributing towards the rise of temperature. Now, it is sometimes very difficult to tell that which has as soon as major effect on rising temperature, but the combined effect which we can detect, implying the remote sensing data especially I am talking about the thermal remote sensing also.

As we know that when these temperatures are measured on the ground, they are generally measured about 1.2 meter above the ground in a wooden ventilated box and this has been the convince and now, we are having digital techniques because, why I am mentioned this because this data we will be using to compare our land surface temperature maps derived from remote sensing data and AI temperature, this we call as this kind of measurement is called AI temperature.

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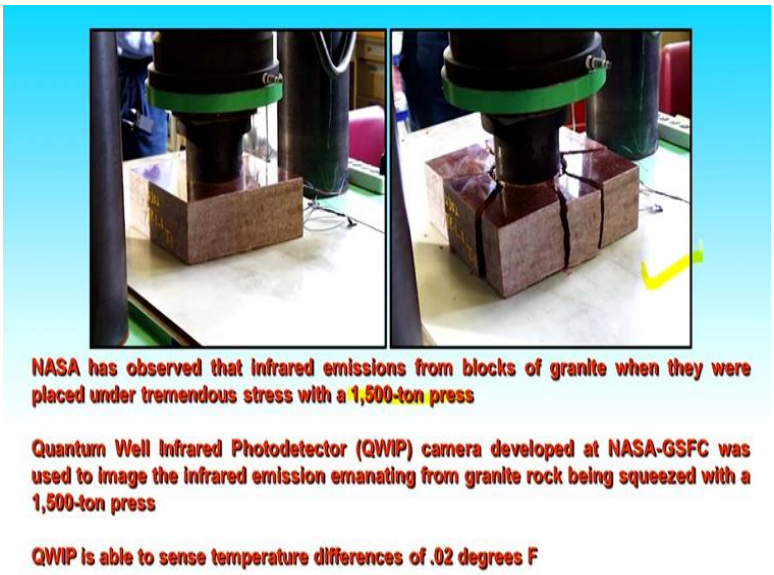

Further, you know people have, like organization like NASA what they have done they put a heavy pressure of 1500 ton press on a block of granite and while doing this experiment the thermal images we are recorded. So, continuously we are recorded and what it has been observed that before this rupture, which you are seeing on the right side image, they will rise in temperature and then of course, the rupture has occurred.

Whether such things are also happening in case of real earthquakes that has to be also seen and understood. So, for that purpose we would like to what we look for thermal remote sensing data, there are few satellites and when we discuss different platforms and satellites and senses we discussed about those but just to remind one of the satellites which is having thermal channels and provides the data and cover a very large part of the earth.

Or entire global of earth because of relatively low spatial resolution, a swath width is very high and that is the NOAA data NOAA AVHRR, AVHRR is the sensor.

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1.2m parabolic disk antenna and rotator of NOAA-HRPT system.

And so, what we ourselves are having this kind of setup or earth station which is capable of acquiring NOAA, AVHRR data and this earth station is operational since October 2002 is still it is continuing and we are continuously acquiring in automatic phezzan our remote sensing data from NOAA, AVHRR series.

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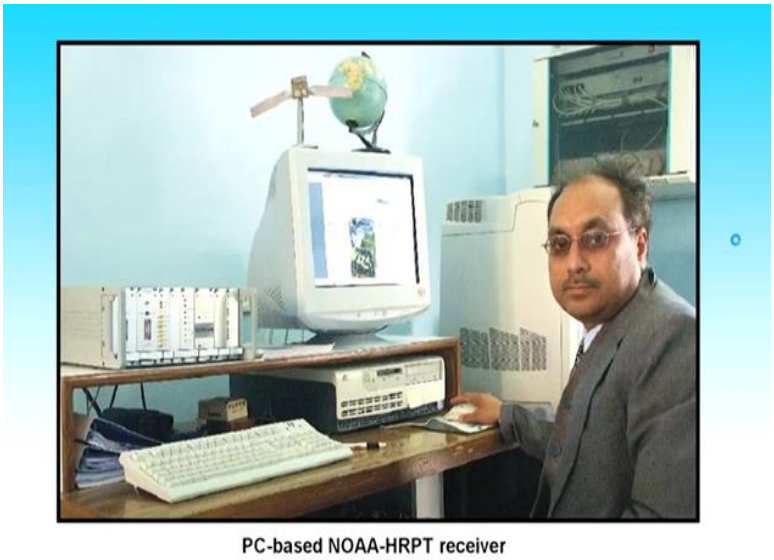

PC-based NOAA-HRPT receiver

These are the different components of this earth station, this is the receiver and this is a simple PC based system and say automatic system, so whenever there are overpasses of new series of satellites, the system will automatically acquire the data.

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Area of coverage IITR-Satellite Earth Station (IITR-SES)

Now because of relatively having low spatial resolution, it covers a very large area and as you can see that our antenna that is our earth station which is marked here is IITR-SES that is a satellite earth station stands for, so that they can cover a about 3000 kilometers radius area that means, anywhere in this circle in space if satellite is there, our earth station is capable of requiring data from that satellite.

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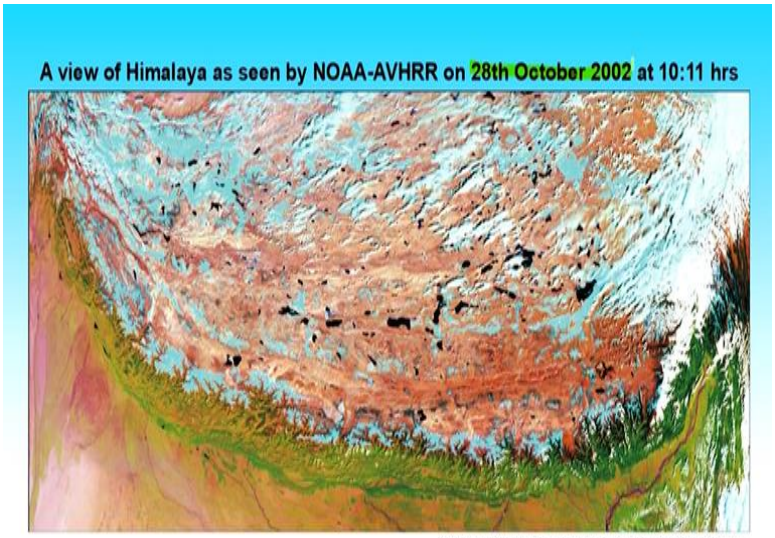

This is one of the examples of image which was acquired by our own and satellite which is our own earth station of NOAA AVHRR data of 28th October 2002 and no one, this is not a mosaic. This is simple one swath image or one image and which has covered almost 95 or 98% of

Himalaya in just one go. So, there is the advantage and this is multispectral sensor that means there are 2 thermal channels also visible channel, infrared channel and 2 thermal channels.

And another advantage because having thermal channel this sensor can also record images in night time, especially in 3 channels one is infrared and 2 thermal channels. So, there are only few satellites which can give you the data of even night time. We will be also seeing those examples, how in earthquake studies especially in pre earthquake thermal anomaly detection, how we can imply daytime data, thermal data and nighttime data and see the what are the advantages and disadvantages. Now, what we see here, the first example I am going to take is again bhuj earthquake January 2001.

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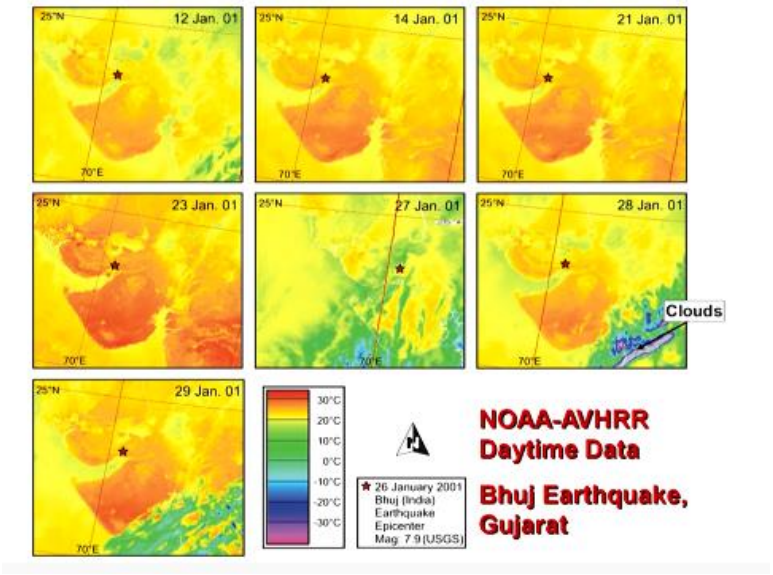

And this data is offcourse, not from our satellite earth station this data was acquired from NIO Goa and do they we are not recording regularly and so, whatever the data, which we got the time series data what we find and that they slowly the temperature was rising before the earthquake as it reached to the maximum 120 on 23rd January and somehow we did not have that in between images and 120 on 7th of January things started becoming normal.

So, this was the first observation, which you may be made using thermal remote sensing data and later when we got our own datasets for the same dates and that is identical processing, when we

performed we found there, that normally the temperature does not, you know, changes so frequently and so rapidly, as has happened in the year 2001.

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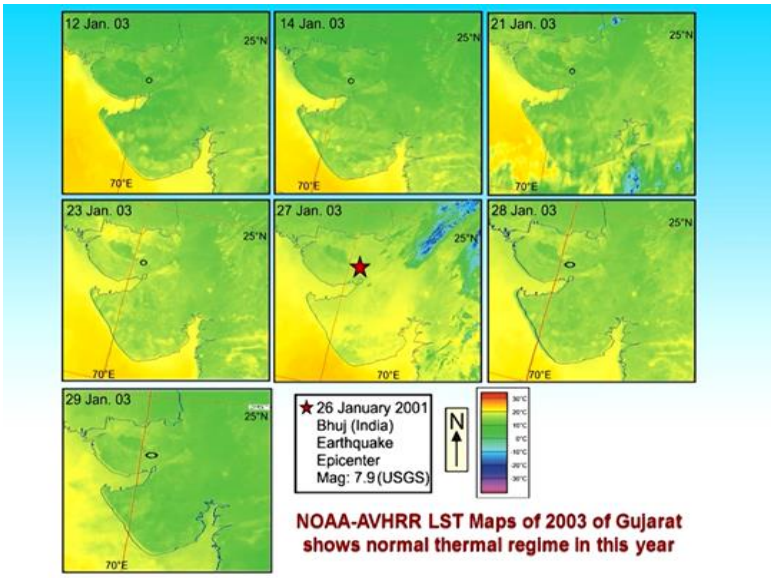

NOAA-AVHRR LST Maps of 2003 of Gujarat shows normal thermal regime in this year

As you can see here, that hardly there are changes in these images. So these are the same dates images, the only difference is the year they are in this image. They are all 2001 here, corresponding dates, but the year is 2003.

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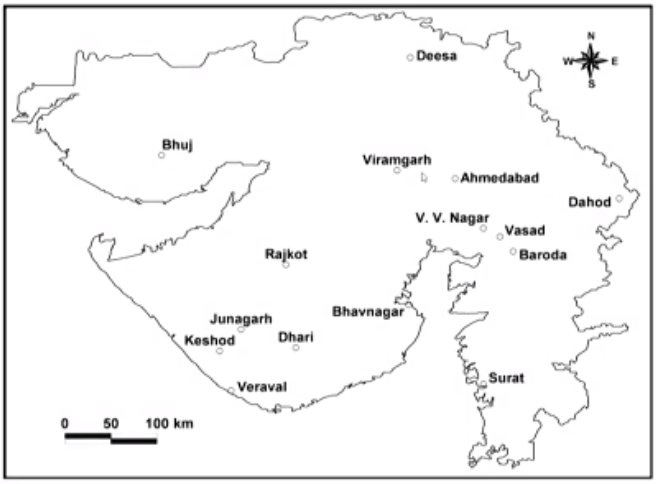

Meteorological Station Location in Gujarat, India

So one observation, second is about the as I mentioned earlier the year temperature. So, we also compared the year temperature data.

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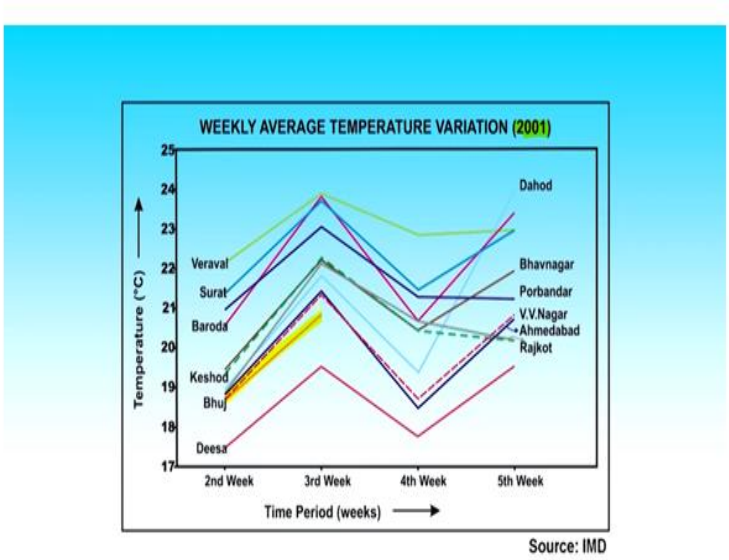

This is 30 years of weekly average data of a few mythological stations which are shown in this map and these stations in a weekly every data all in the third week, the week in which the 2001 26th January earthquake occurred that for week and generally they were showing all low temperature,

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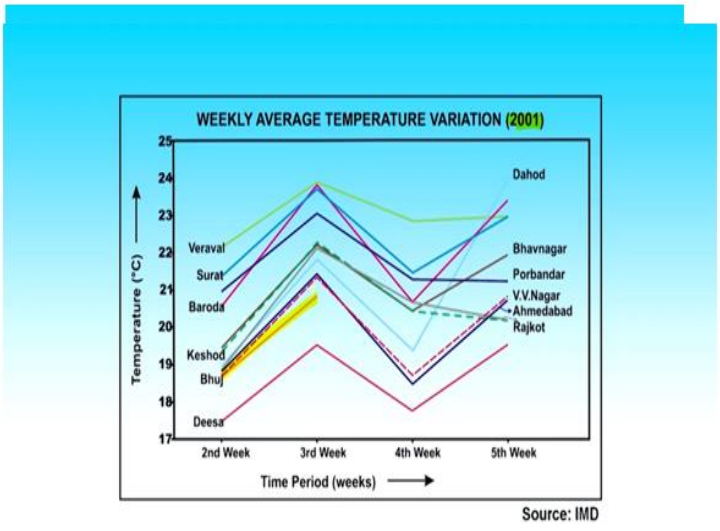

But they in the year 2001 all these new stations few more which we are not available and between those 51 to 80 and they also have shown very high temperature for all these stations and especially as you can see that the Bhuj station stopped working got damage due to earthquake event. So, as you can see that air temperature we are also showing high values in that week or in that week corresponding compared to the 30 years weekly average data.

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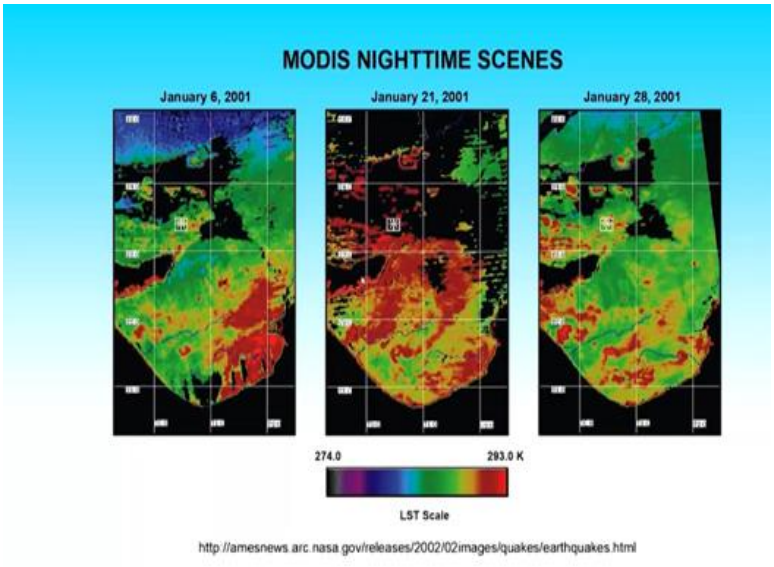

Implying other sensor that is MODIS another very popular and more sensor which is on 2 satellite Terra and Aqua, this MODIS sensor is also having 2 thermal channels almost identical to the NOAA AVHRR channels that NOAA, AVHRR which are our channels about 1.1 kilometer or 2 spatial resolution. MODIS thermal channels are 1 kilometer resolution and the 2 acquired data in daytime and nighttime.

So after our studies also, the other people have also studied and though they did not have the full time series data, the reason that MODIS was being tested during that time, the MODIS really declared operational only in 2002. So whatever that tested images were there as you can also observe that on 21st of January 2001, 5 days before that earthquake they were rise in temperature or land surface temperature as you can see here. So, it basically matches with our interpretations our analysis of thermal data of earthquake.

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Some earthquakes of different parts of the world studied through NOAA-AVHRR & MODIS data sets

S. N.	Earthquake	Origin		Location (in DD)		Magnitude (M_w) (USGS)	Focal Depth (km)
		Date	Time (UTC)	Lat (N)	Long (E)		
1	Bhuj, India	26.01.01	03:16	23.41	70.23	7.7	16
2	Bam, Iran	26.12.03	01:57	29.00	58.34	6.6	10
3	Zarand, Iran	22.02.05	02:25	30.74	56.90	6.4	14
4	Darb-e-Astaneh, Iran	31.03.06	01:17	33.58	48.79	6.1	07
5	Boumerdes, Algeria	21.05.03	18:44	36.90	03.71	6.8	10
6	Banda-Aceh, Sumatra	26.12.04	00:58	3.31	95.95	9.3	30
7	POK, Pakistan	08.10.05	03:51	34.43	73.53	7.6	10

So, after getting encouragement from such kind of his studies is basically on bhuj be started looking other earthquakes not only are part of India, but other parts and in the surrounding region because as you know, that earth station can acquire data of not only India, but a large part of neighboring countries, including, you know, like Iran does not directly and directly neighbor country, but because of large, you know, capability of acquiring data.

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Some earthquakes of different parts of the world studied through NOAA-AVHRR data sets

S. N.	Earthquake	Origin		Location(in DD)		Magnitude (M_w) (USGS)	Focal Depth (km)
		Date	Time (UTC)	Lat (N)	Long (E)		
8	Changoreh-Avaj, Iran	22.06.02	02:58	35.67	48.93	6.5	10
9	Jahron, Iran	10.07.03	17:40	28.35	54.17	5.8	10
10	Kerman, Iran	21.08.03	04:02	29.50	59.77	5.9	20
11	Firozabad- Kajoor, Iran	28.05.04	12:38	36.29	51.61	6.3	29
12	Qeshm, Iran	27.11.05	10:22	26.77	55.86	6.0	10
13	Faryab, Iran	28.02.06	07:31	28.12	56.87	6.0	18
14	Fin, Iran	25.03.06	07:28	27:57	55.69	5.9	14
15	Persian-Gulf, Iran	28.06.06	21:02	26.82	55.90	5.8	10

We could analyze many earthquakes of Iran and several earthquakes from different parts of the world. So, far we have analyzed more than 28 earthquakes of different parts of the world.

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Some earthquakes of different parts of the world studied through NOAA-AVHRR data sets

S. N.	Earthquake	Origin		Location (in DD)		Magnitude (M_w) (USGS)	Focal Depth (km)
		Date	Time (UTC)	Lat (N)	Long (E)		
16	Jabalpur, India	22.06.1997	04:21 (IST)	23.08	80.06	6.0	35
17	Vrancea, Romania	27.10.2004	20:34	45.78	26.62	5.9	96
18	Yamnotri, India	22.07.2007	23:02	30.93	78.27	5.0	35
19	Ravar, Iran	14.10.2004	06:00	31.71	57.18	5.1	18
20	Baluchistan, Pakistan	29.10.2008	11:32	30.56	67.48	6.4	14
21	Aiqule, Bolivia	22.05.1998	04:48	-17.73	-65.43	6.6	24
22	Gorkha, Nepal	25.04.2015	06:26	28.15	84.71	7.8	15

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Earthquakes of different parts of the world studied through DMSP-SSM/I data

S. N.	Earthquake	Origin		Location (in DD)		Magnitude (M_w) (USGS)	Focal Depth (km)
		Date	Time (UTC)	Lat (N)	Long (E)		
22	Kalat, Pakistan	04.03.90	19:46:19	28.92	66.33	6.1	10
23	Zhangbei, China	10.01.98	03:50:41	41.08	114.50	6.2	30
24	Izmit, Turkey	17.08.99	00:01:39	40.74	29.86	7.6	17
*	Bhuj, India	26.01.01	03:16:41	23.41	70.23	7.7	16
25	Double Earthquakes of Hindukush, Afghanistan	03.03.02	12:08:06	36.44	70.45	6.2	195
		03.03.02	12.08.22	36.54	70.42	7.4	256
26	Hindukush, Afghanistan	25.03.02	14:56:37	35.97	69.18	6.1	33
27	Southern Xinjiang, China	24.02.03	02:03:41	39.61	77.24	6.4	11

* Already counted

Implying either data which was acquired by our own earth station or data acquired by others stations, which have been shared with us.

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Now I am going to take example of bam earthquake and which occurred on 26 December 2003, magnitude was 6.6.

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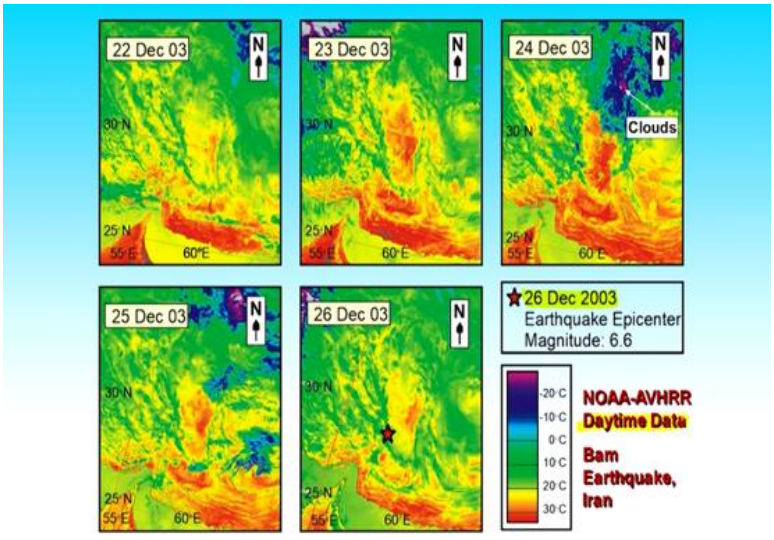

The data was acquired by our own earth station that is IITR-SES, so, now, we are having full control on time series and when we analyze the data, we are putting here only those images which are most relevant here. So what do we remember that earthquake occurred on 26 December 2003 and temperature is started rising from 22nd december onward, and on 24th of december, it has reached to the maximum as you can see here, of course, there are some clouds also we have detected now.

Nonetheless and things started becoming normal on 25th they are going basically in the background 26 is almost from temperature point of views the same image as all most of 22nd December, but in between on that the earthquake has occurred. So, what we are seeing, So, far in these 2 examples, that there is a rise in temperature and the peak is reached before the earthquake occurs and then earthquake occurred and things becomes normal.

One important point which I want to mention, that, we are not in prediction mode, we are still trying to understand this whole phenomenon through different examples, whether in each and every earthquakes of large magnitude and such pre earthquake anomalies are occurring, if they are occurring, then when, how early they are occurring and what happens just after that earthquake so, this is all in hindsight, these are all postmodern studies developing knowledge.

About pre earthquake thermal anomaly, which are transient an anomaly and of course, later once a confidence is there along with some other precursors let it be earthquake, some forecast or prediction might be possible in long term or in future, but just based on one precursor light pre earthquake thermal anomaly, nobody should think to forecast anything about this complex phenomena. So, all these results which we are I am showing here are all done after the earthquake has occurred so, we knew where earthquake has occurred.

This point you must note, nonetheless, what do you see a very important observation is that there is a rise systematic rise in temperature which reaches to the peak before the earthquake, 2 days, 3 days in different cases and then things started becoming normal an earthquake occurs. So, this is one example this was a if you notice that this was the daytime data from our own satellite earth station and for the same earthquake,

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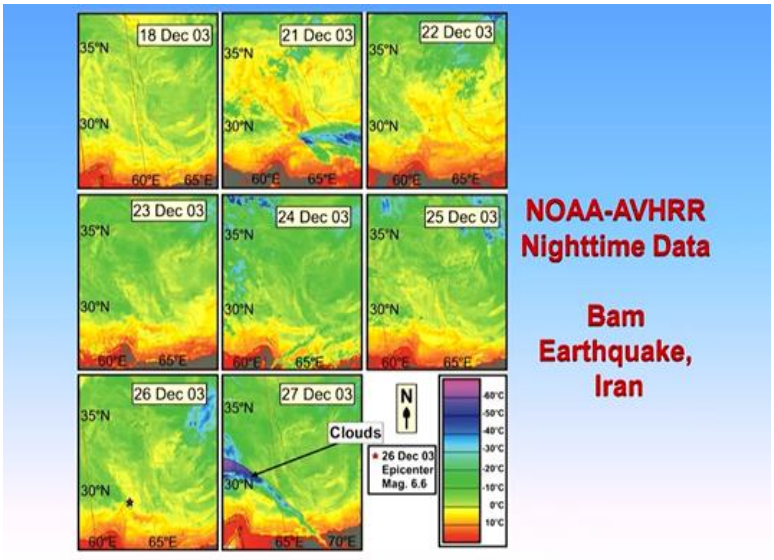

We also imply the nighttime data. So, what we observed that on this 21st December, that means, roughly about 5 days before the earthquake event, we saw a normally the peak we saw in daytime they normally was seen just 2 days before in nighttime, it was 5 days before. The reason is that in nighttime data, you do not have the differential solar heating and many times the meteorological differences local meteorological disturbances are also and generally less as compared to daytime.

So, that is why it was very much possible to detect this pre earthquake thermal anomaly 5 days before of course, in the post earthquake analysis that means in hindsight after that quake has occurred, so, that that, but this definitely tells us that the nighttime data can be much more reliable than daytime data especially in hilly reasons. So, this is a not as rugged as like Himalaya and this part of Iran, but nonetheless, it is also a reason now, where we have detected. This is another point and which should be noticed here that the area which we have seen and normally.

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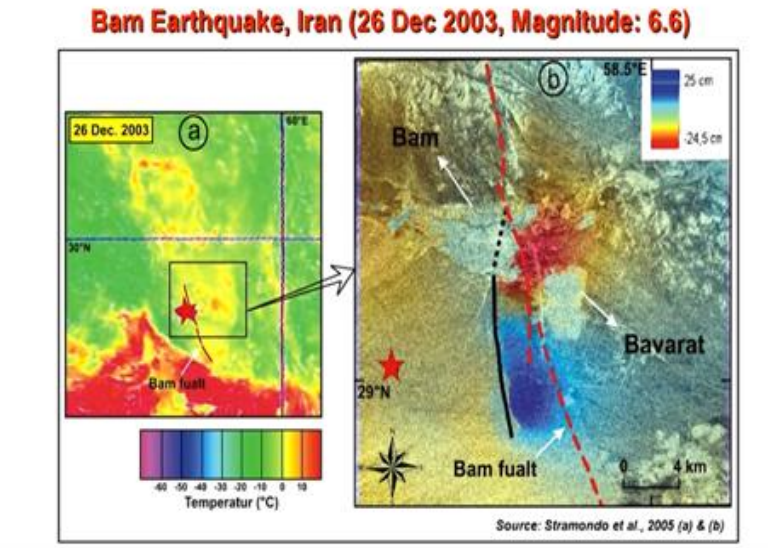

The same area, head also CO seismic deformations that means a lot of changes in the ground has happened during that earthquake event on 26 December 2003. And these were mapped implying the SAR interferometer technique again remote sensing technique, of course be personally did not do this analysis this is this was done by instrumental at all in 2005. Later on we also had our own datasets, which we got from the European Space Agency.

And we analyzed what we see that where we have notice the pre earthquake anomaly 2 days before or 5 days before in nighttime data, the same area got involved in CO seismic deformation. Because otherwise some people might be thinking that this thermal anomalies atmospheric phenomena rather than ground phenomena, so this basically, you know, and this, this tells us that this is not an atmospheric phenomena, this is truly a land surface temperature phenomena or ground liquid phenomena.

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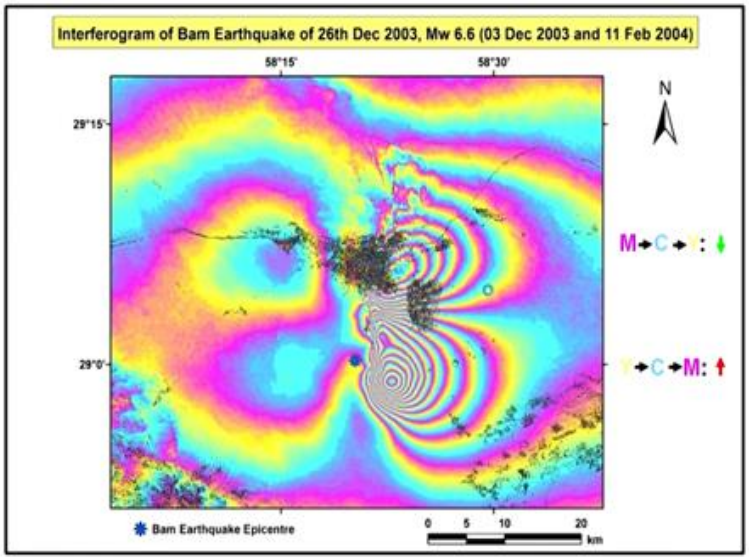

Now, when we analyze the data using this Envisat data of the 26 December 2003 earthquake this is the interferogram.

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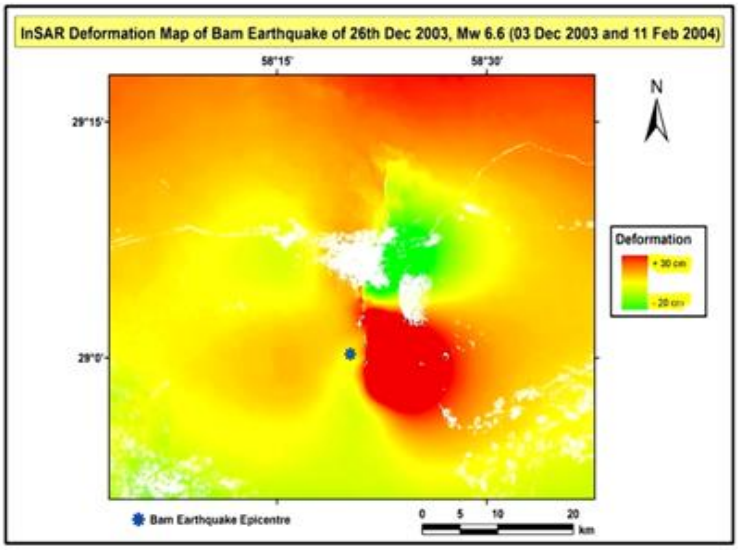

And this what the ground information map, this is very ideal data was available and as you can see that there were rise in some areas, the lower part the red part has shown 30 centimeter up and the green part has shown minus 20 centimeter down and that is in the line of sight, because it is you know, that in our radar remote sensing data, the data is not taking in other view it is taken in oblique direction.

So, it is the change in the line of sight not directly vertical but it can be converted and you can get more accurate values like this. So, you can you can know exactly where which area got uplifted and which area has got subsided induced by that earthquake event.

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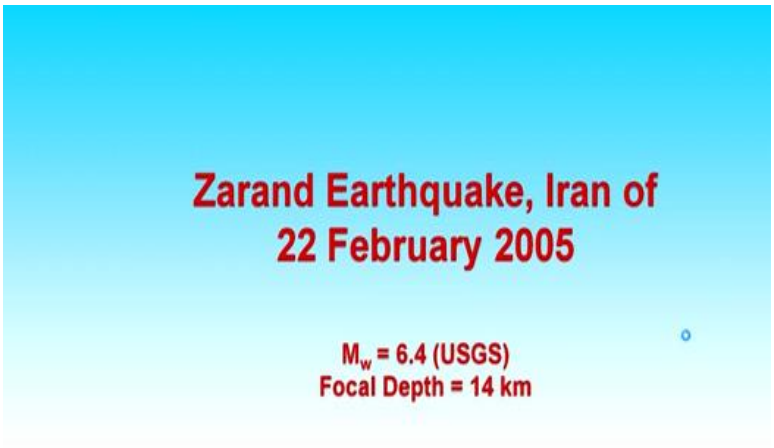

We will take another example of pre earthquake thermal anomalies which we detected very clearly in the in our own datasets, which we acquired from NOAA, AVHRR and satellite, and this earthquake of which we which is known as zarand earthquake of Iran occurred on 22nd February 2005.

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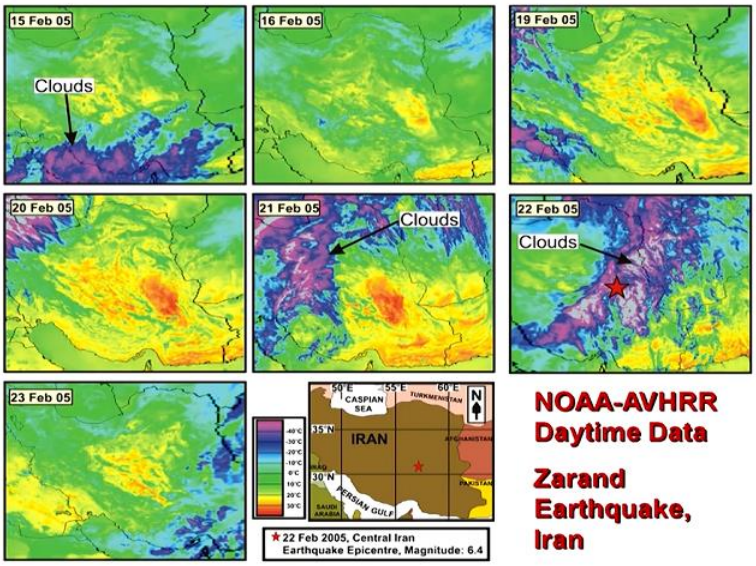

And again in time series data what we see here that the there were a buildup of anomaly, it reached to the maximum on 21st Feb. 2005. And unfortunately on 22nd, the day when earthquake has occurred, they were and linear clouds, things is started becoming normal, but indeed been earthquake has occurred. So, and what we are seeing here in this example, that about one day, or 24 hours or maybe 36 hours before they were high the peak has reached to the maximum.

But this is all in hindsight, if, if I am working in the real time for forecasting then say on 21st I do not know how whether it will go further higher or I have reached the maximum that I do not know. So, only when we are you know doing a postmortem, we are telling that the maximum has reached on 21st February. So, these are the things which have to be considered, and when to declare that maximum has reached if we are working in forecasting mode.

Which we have not working yet, that day is quite far, we have to develop that kind of understanding to imply this kind of technique towards the earthquake forecasting or prediction.

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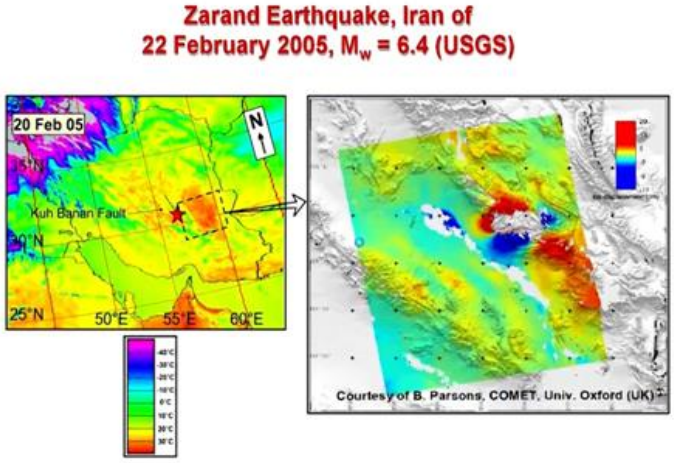

But nonetheless, whatever is there it is still allowing us to develop a knowledge or understanding about this phenomena. Now, in a zarand earthquake also that also witnessed the Co seismic deformation and of course, this is why be parson and this analysis was done. See media was involved in CO seismic deformations.

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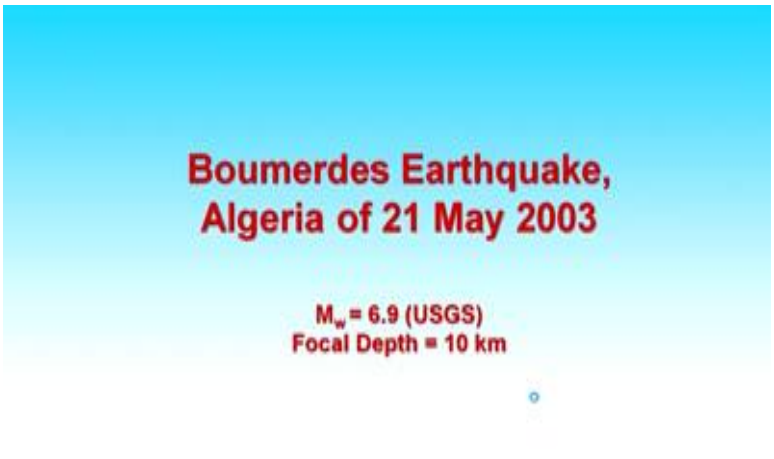

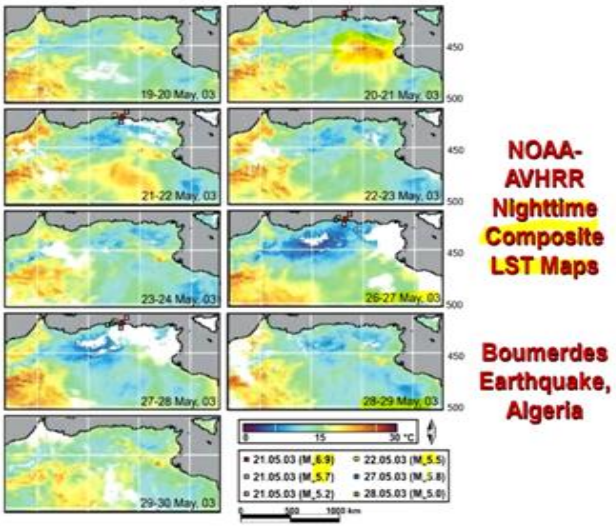

So we are going to take another example of Boumerdes earthquake of Algeria of 21st may 2003. Of course, this is a different dataset different datasets means it is an average daily average, one day average of this dataset. This is the night time composite images of land surface temperature maps and as you can see that they were rising temperature. In this part, this was very interesting and then, things became normal earthquakes above called earthquakes. I am using plural word because many earthquakes have occurred of after the 6.9 magnitude 5.7, 5.5, 5.8 lot of earthquakes have occurred.

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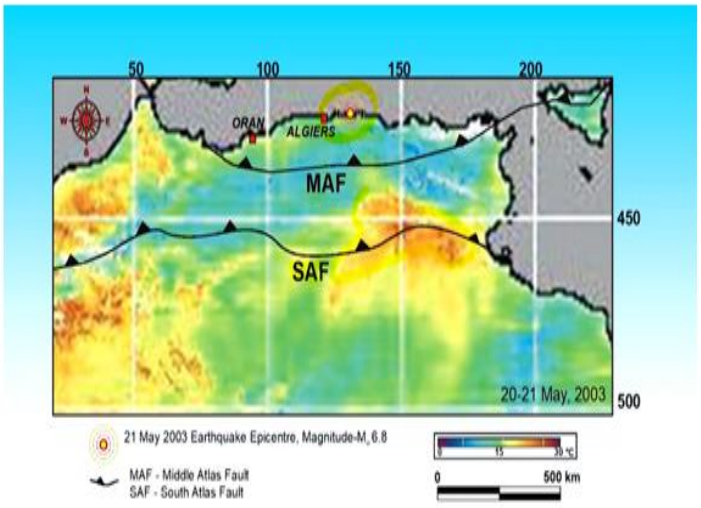

If I see the blow up of that particular image where it normally was maximum in this part, we are at the epicenter was here. So, this brings another better understanding about this phenomena. That it is not necessary that where we are observing in a epicenter, the same area will have the anomalous reason or anomaly, because it basically depends on the fault which is responsible for that, or those earthquakes or that particular event.

So, in this case in boumerdes earthquake of Algeria, the South Atlas fault, which is marked here as SAF, while responsible, and this can be explained here.

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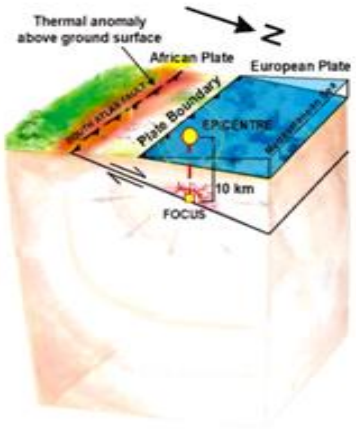

Schematic diagram showing the the Boumerdes epicenter and a subsurface view of the focus and SAF plane.

That epicenter is just vertical projection of focus on surface. So, this epicenter that is here, whereas, that in an anomaly was seen all along this south atlas fault. So, sometimes you may get upside, offset a few kilometers or 10s of even kilometers sometimes you may get because it is not always necessary, that the where the epicenter is there, you will get the number depends all on the faults which are responsible for earthquake event or the moment along the fall which is occurring or the falls which are allowing the heat to escape.

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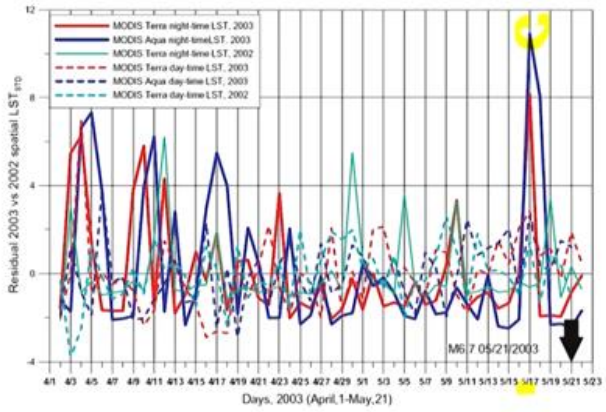

Time series mean MODIS LST night- and day-time from Terra and Aqua (April–May, 2003/2002) in area of 50 × 50 km around the earthquake of Boumerdes, northern Algeria, M6.8, May 21, 2003.

Source: S. A. Pulinets, D. Ouzounov, L. Ciraolo, R. Singh, G. Cervone, A. Leyva, M. Dunajecka, A. V. Karelin, K. A. Boyarchuk, A. Kotsarenko (2006). Thermal, atmospheric and ionospheric anomalies around the time of the Colima M7.8 earthquake of 21 January 2003, Annales Geophysicae (2006) 24: 835 - 849.

And therefore, the anomaly might be between epicenter or an anomalous region there might be sometimes upside our interpretation was further you know supported by a study done by Pulinets at all. And they too use implying MODIS nighttime data, daytime data as you can see here in the index and the peak was reached on 17th April and then on 21st April earthquake has occurred. So, by whether you imply AVHRR data or MODIS data.

Which provides the thermal channel covers a large area, these datasets can be used to study such phenomena which are occurring before an earthquake event now, I will take one more, one or 2 more examples, we are large upsides have been observed and this says one example is from Chamoli earthquake.

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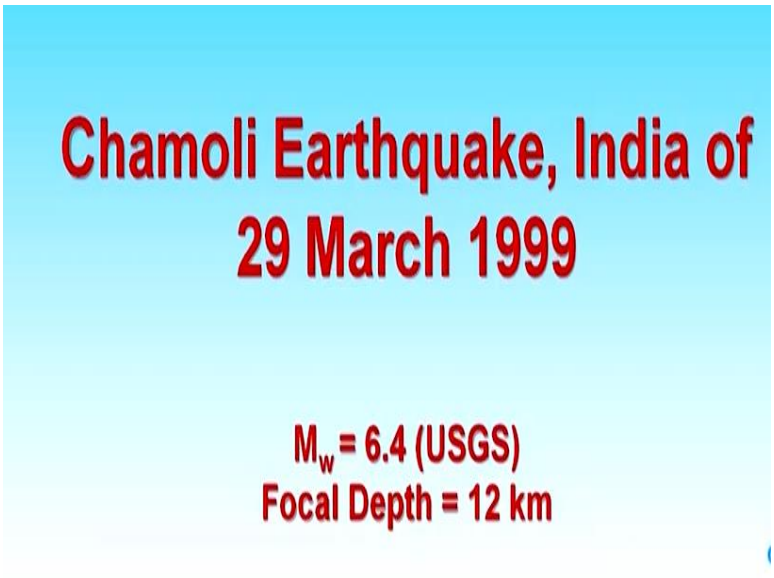

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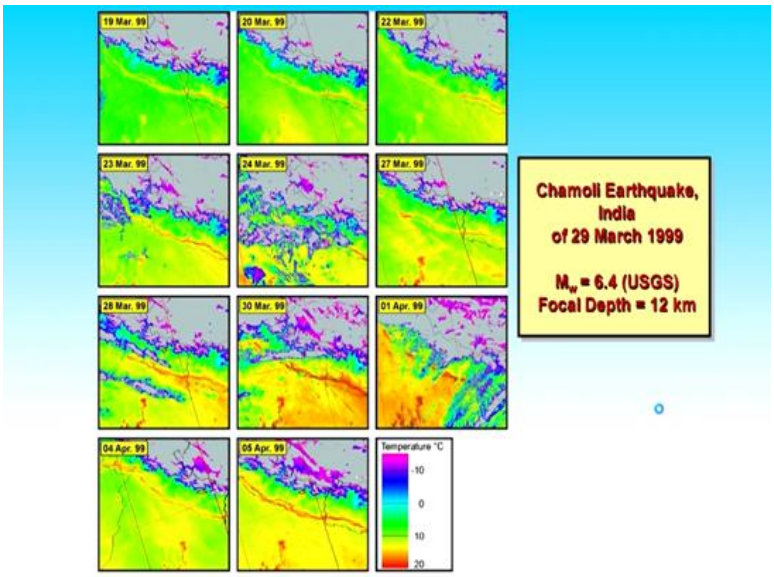

This example we have taken in case of earthquake induce landslides. The same earthquake and when we got this data, of course, this data was not from our own satellite earth station because our earth station if you recall, it is started operating in October 2002. So, this is this earthquake has occurred in 1999. But after a few years, we got access to this data through again and NIO Goa earth station, and what we hear observed and that the earthquake epicenter was here, as you can see a circle.

But the anomaly was seen in form of line and that too quite I know, maybe 60 70 kilometer south of epicenter and that really perturbed us for some time that how it is happening, why it is happening and when we analyze further.

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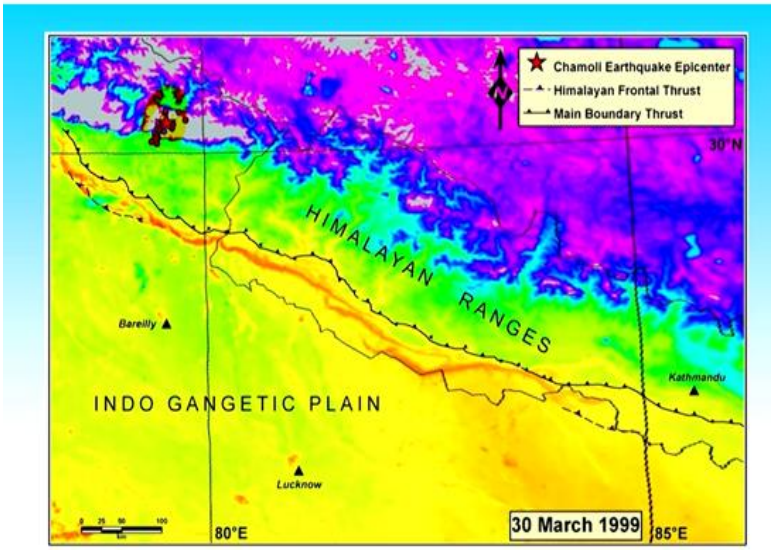

And we found and this is the anomalous region and we found that there this Himalayan frontal thrust and that along which Himalayan frontal thrust, this thermal line or thermal anomaly was observed the earthquake and aftershocks were here. So, you can see about 60, 70 kilometer south of this the anomaly was seen.

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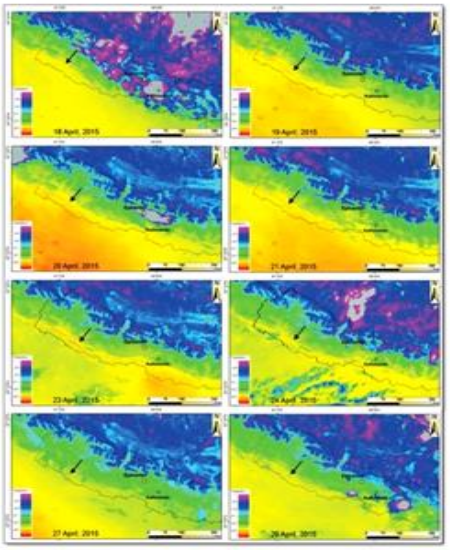

Nighttime NOAA-AVHRR LST time series map of Nepal Earthquake of 25 April, 2015

And now, this is very important, and that, why it is there, that they so much offset and they normally is appearing in a linear form linear form can be explained, because the heat which could get escaped all along this Himalayan frontal thrust So, just to hold for some time about this discuss on that, why there is offset by this thing. Let me take one more example, because when we saw this kind of phenomena.

We could of course, explain that why it has occurred, but, when Nepal earthquake occurred, we wanted to check whether exactly same way in case of Nepal this has happened or not and you know surprising satisfaction to us was it truly It has also happened in case of Nepal earthquake, as you can see of this Nepal earthquake, the first one of 25th April 2015 the anomaly appeared in the almost same way as in case of chamoli earthquake.

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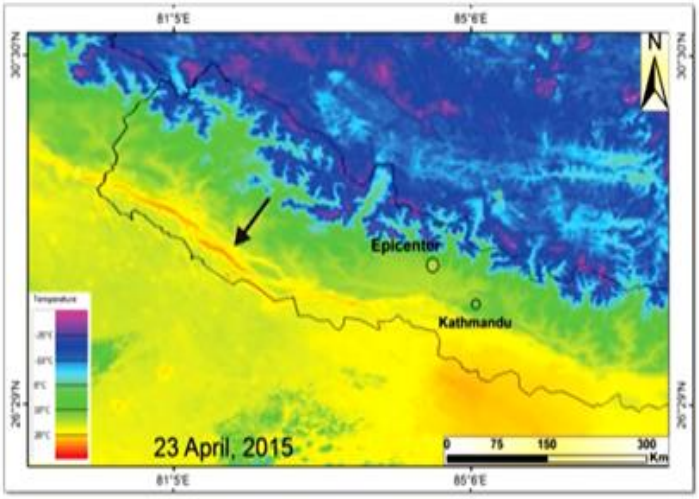

And you can see in those large views that see this, and all along this again, Himalayan frontal thrust, and normally the thermal anomaly appeared. End of game disappeared with earthquake or false some time it remained there and not exactly in typical pre earthquake tunnel anomaly in other cases which we have seen. So, this came why it is happening why so be offset this we could explain, which I am going to narrate here.

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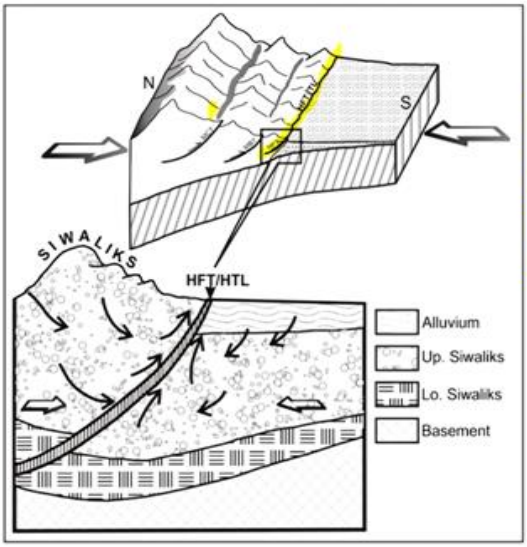

Cross- Sections showing the main thrust and fault systems of Himalayas. (Saraf et al., 2009)

As you see that this is the setup is a schematic is that Himalayan frontal thrust is here. So if earthquake is occurring here, the because this area is having very saturated water conditions, and if earthquake like chamoli earthquake has occurred, just a fog end of the winter month. And as you know, the groundwater temperature is always constant, the temperature of surface water varies with the season, but the groundwater temperature remained the same.

So what we think that because of this movement, during that earthquake and is the water and the underground water came on the surface because this is (())(30:06) from groundwater point to be is called very cielo groundwater conditions. So, the groundwater conditions are cielo when stresses beer build up, and the water which had the higher temperature relatively than the ground temperature came near to the surface and which has brought this thermal line and that 2 alone Himalayan frontal thrust.

So, in both cases, in case of chamoli, as well as in case of this Nepal earthquake, and the thermal anomaly appeared, and of course, later on, they disappear,

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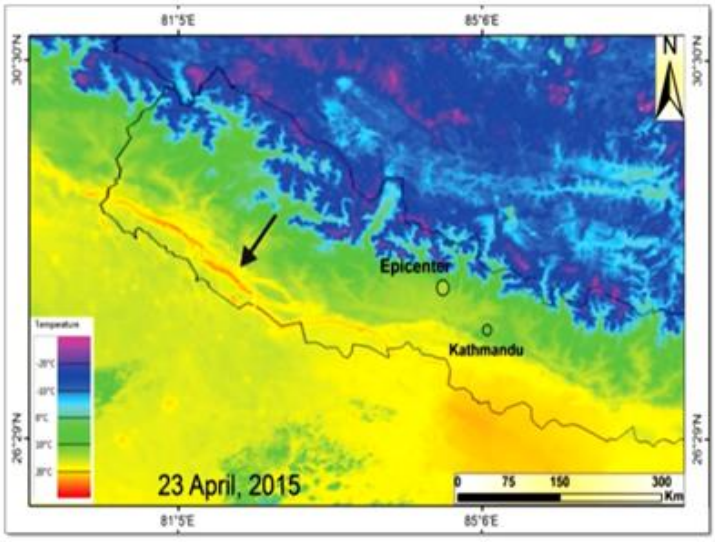

Though a typical pre earthquake thermal anomaly or anomalous regions, which we have seen in case of Bam earthquake and zarand earthquake of Iran and which we did not observe in these 2 Himalayan earthquakes of chamoli Nepal earthquake. However, definitely these 2 earthquakes, we have observed clear appearance of a linear thermal anomaly and about 60 70 80 kilometers south of epicentral reason and the reason I have just explained.

Because of cell groundwater conditions and because of this earthquake and seeking the water which has relatively higher temperature compared to the ground temperature appear, and it created the thermal anomaly. So, a, you know, analyzing remote sensing data is basically the thermal remote sensing data, thermal channels data or these 28 29 earthquakes of different parts of the world.

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SUMMARY

S. N.	Earthquake	Mag. (M_w)	Focal Depth (km)	Pre-earthquake thermal anomaly (before the earthquake)		Intensity of thermal rise	Spatial extent of thermal anomaly (km^2)	Fault Type
				Rise started	Maximum rise observed			
1	Bhuj, India 26 Jan 01	7.7	16	12 days	3 days	5-10° C	179,150	East-West thrusting, no surface rupture
2	Boumerdes, Algeria 21 May 03	6.8	10	7 days	Few hours	5-10° C	91,100	low angle thrust South Atlas fault (SAF)
3	Bam, Iran 26 Dec 03	6.6	10	7 days (nighttime data), 4 days (daytime data)	5 days (nighttime data), 2 days (daytime data)	7-13° C (nighttime) 7-10° C (daytime)	308,000 (nighttime) 328,200 (daytime)	Right-lateral strike-slip motion on the N-S trending Bam fault
4	Dahoeieh-Zarand, Iran 22 Mar 05	6.4	14	5 days	1 day	10-12° C	75,600	Reverse slip on an East-North-East or East-striking fault
5	Darb-e-Astaneh 31 Mar 06	6.1	7	7 days	1 day	5-10° C	290,000	Strike-slip fault (Dorud fault)
6	Banda-Aceh Earthquake, Sumatra 26 Dec 04	9.0	30	>15 days (whole region was very cloudy)	1 day	6-12° C	Could not be calculated due to extensive cloud cover	Subduction in plate boundary (Sunda Trench Thrust)
7	POK 08 Oct 05	7.6	10	8 days	6 days	6-8 ° C	45,000	Thrust fault

What we have observed that a thermal anomaly above earthquake having a magnitude 6 and above and if we are getting completely cloud free images, then thermal anomaly is being observed in almost in all these cases. We have observed there might be some offset which I have just explained, but thermal anomaly has been observed. However, if earthquake is a 4 magnitude or 5 magnitude, then this is not bringing this kind of energy or temperature changes and therefore, we could not detect any such thermal anomaly in earthquakes.

Which are below 6 magnitude and earthquakes whether if they are occurring in thrust fault regime or another fault regime like normal fault or others. They both are showing and this anomalous reason, but especially in the Himalayan region, what we have seen the examples of trust fault regimes of chamoli and Nepal earthquake. So, likewise

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SUMMARY

S. N.	Earthquake	Mag. (M_w)	Focal Depth (km)	Pre-earthquake thermal anomaly (before the earthquake)		Intensity of thermal rise	Spatial extent of thermal anomaly (km^2)	Fault Type
				Rise started	Maximum rise observed			
16	Jabalpur, India 22 May 1997	6.0	35	10 days	7 days	5-10°C	154000	Thrust type fault with left lateral strike slip component
17	Vrancea, Romania 27 Oct 04	5.9	96	7 days	2 days	5-7° C (?)	236000	Strike slip fault
18	Yamnotri, India 22 Jul 2007	5.0	35	6 days	1 day	7-10°C	291458	Thrust type fault
19	Ravar, Iran 14 Oct 2004	5.1	18	8 days	6 days	2-4° C	41368	Strike-slip faulting
20	Baluchistan,Pakistan 29 Oct 2008	6.4	14	7 days	5 days	2-6°C	81579	Zhob thrust; Gwal Bagh and Ghazaband strike slip fault also run in close proximity
21	Aiqule, Bolivia Earthquake	6.6	24	7 days	1 day	7-10°C	840370	N–S oriented fault, with a strike that is oblique to the principal topographic features

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S. N.	Earthquake	Magnitude (M_w)	Focal Depth (km)	Thermal anomaly before the earthquake (weekly SSM/I data used)	Intensity of thermal rise	Spatial Extent of Thermal Anomaly	Fault Type
22	Kalat, Pakistan 04.03.90	6.1	10	2 weeks	2-10° C	Due to relatively poor spatial resolution it is not possible to obtain accurate areal extent of thermal anomaly	Strike slip Chaman fault
23	Zhangbei, China 10.01.98	6.2	30	3 weeks	4-8° C		Thrust, N10-20° E striking fault with right lateral reverse slip
24	Izmit, Turkey 17.08.99	7.6	17	1 week	6-10° C		Right-lateral strike-slip movement on the North Anatolian fault
	Bhuj, India 26.01.01	7.7	16	1 week	4-8° C		East-West thrusting, no surface rupture
25	Double earthquakes in Hindukush, Afghanistan 03.03.02	6.2 and 7.4	195	Few days to a week	4-10° C		Left lateral strike slip Darvaz-Karakul Fault (DKF)
26	Hindukush, Afghanistan 25.03.02	6.1	33	2 weeks	6-10° C		Left lateral strike slip Darvaz-Karakul Fault (DKF)
27	Xinjiang, China 24.02.03	6.4	11	Less than a week	4-6° C		Collision of the Indian and Eurasian plates, which lies 1000 km to South of epicenter Has not been attributed to any particular fault

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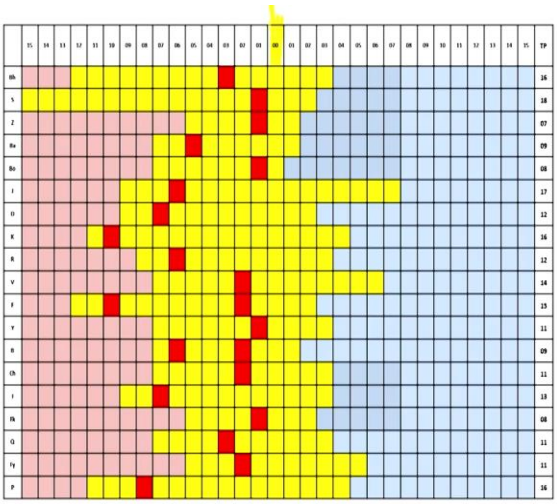

J = Jabalpur eq., D= Dabiran eq., K= Kerman eq., R= Ravar eq., V= Vrancea eq., F= Fin eq., Y= Yamnotri eq., B= Balochistan eq.,
Bh = Bhuj eq., Bo = Boumerdes eq., Ba = Bam eq., S = Sumatra eq., J = Jahron eq., Fk = Firozabad- Kajoor, Fy = Faryab eq.,
P = Persian Gulf eq., and TP= Transient Period (in days).

We have analyzed again as I mentioned above 28 earthquakes, this is a sort of summary here. The important point note to here is 00 double 0 column shows the day, when earthquake has occurred, and these are on the on, you can see it the by excess on this table you are seeing a different earthquake which has occurred, they are given in a very abbreviated forms and details are in the bottom and so, like the Bhuj earthquake.

In case of Bhuj earthquake and the anomaly was observed 3 days before in case of this say, the Sumatra earthquake or zarand earthquake that normally was observed one day before. So, likewise what you are observing here that, on the left side, how depending on the dataset, if data is weekly dataset, and then it is a different scenario, but if it is a daily dataset, then you say we are getting anomaly, which are 3 days 4 days before an earthquake event again in daytime data that anomaly seemed quite close to the day of earthquake or quick event.

But in nighttime data as in you have seen in case of Bam it has been noticed 5 days before. So, likewise the analysis have been performed some understanding about this pre earthquake thermal anomaly from different earthquakes of different parts of the world has been developed, but still a lot of work is required to be done before we reach to that milestone when we start using this one as a reliable earthquake precursor. Among one of the precursors among many precursors are they are like for socks they are there, there are changes, a enjoying the radon gas emission.

There are changes in water level conditions and there are other perturbance which occurs or just before the earthquake. So, this is one of the, we can consider is one of the earthquake precursors which is occurring and before an earthquake, if magnitude is 6 and above.

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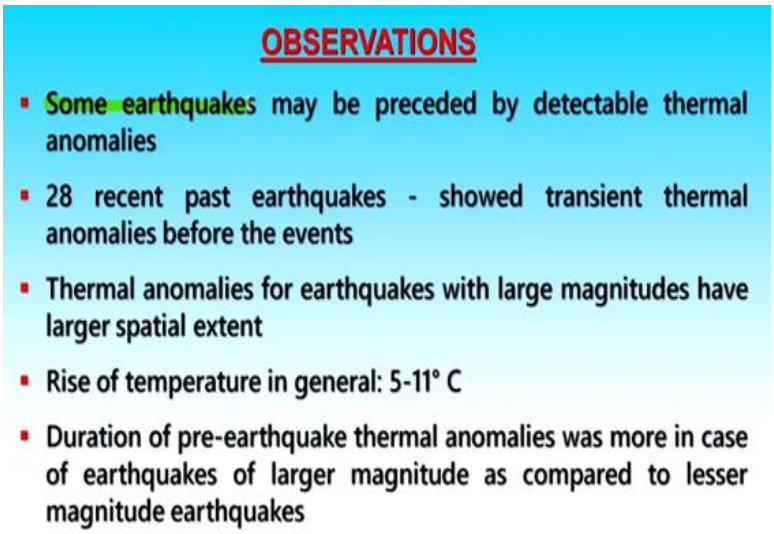

So, some earthquakes very carefully choosing words to summarize all this what we have discussed in this discussion is there some earthquakes not all maybe preceded by detectable thermal anomaly many examples. I have shown of you from different parts of the world 28 recent past earthquake, so transient and thermal anomalies before the events of course, this analysis is all after the earthquake has occurred.

So, it is a hindsight postmortem analysis, thermal anomalies for earthquake with the large magnitudes have larger spatial extent this is very obvious, if earthquake is large, higher magnitude will have a large anomalous reason and if earthquake is quite shallow, it will have a you know a smaller anomaly, but intense anomaly. So, that is also observed and rises temperature LST that is land surface temperature detected.

Or recorded by these thermal channels ranges between 5 to 11 degree centigrade above normal and duration of pre earthquake thermal anomalies was done or more in case of earthquakes of larger magnitude that means, before the earthquake few days before the anomaly seen, but in

case of relatively small earthquake this cannot be there in that case that is the sort of time differences there.

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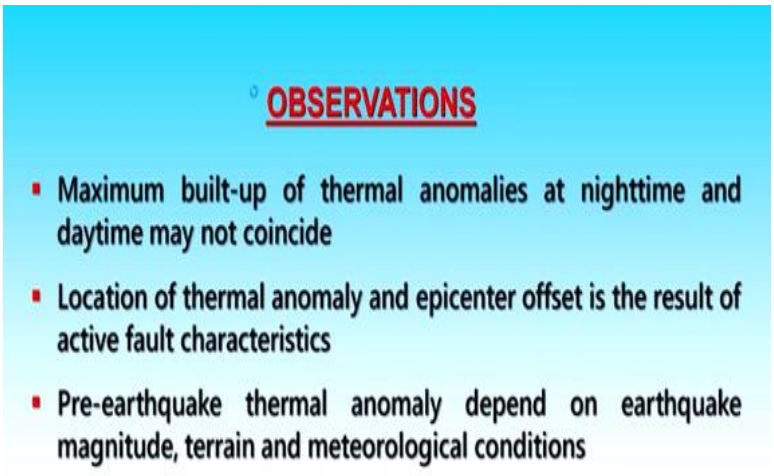

Further in discussion maximum buildup of thermal anomalies at nighttime. As you can see, compared to daytime in case of Bam earthquake and location of thermal anomaly epicenter offset is the result of active fault characteristics I have soon like soon you have the 3 examples one from Bondi algeria earthquake, where observed was there in case of chamoli earthquake and of course in Nepal earthquakes of 2015, pre earthquake thermal anomaly depends on earthquake magnitude, terrain and meteorological conditions.

If the drawback of this technique or the big limitation of this technique is we need to have a completely cloud free time series data. So, we do not have control over mythological condition, but if an area which is having a complete cloud free data, then our interpretation analysis becomes highly reliable level of confidence would be very high. But if we are having intermittent cloud cover, then our level of confidence in the analysis course really low. No some more these remote sensing applications we have seen, but very quickly I will go and that

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We implied this SAR interferometry technique in earthquake of 26 January 2001.

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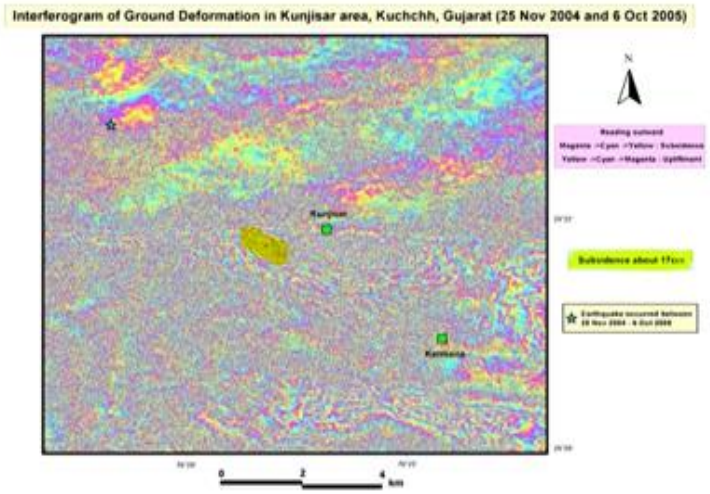

And the important point here it is not these are the image or interferogram which I am showing here are not CO seismic, this is the post seismic and what we have observed in case of this 2001 earthquake, that even in between 2004 and 2005 as you can see here, after 3 years or 4 years of earthquake event ground deformations where is still going on and we could detect and record estimate what kind of ground deformation so, if I blow up as you can see in the kunjisar area you are seeing and these fringes very clearly.

And one more image which you will see here that what you can observed here that the subsidence have about 17 centimeter has been observed in kunjisar area and that too, after roughly 4 or 5 years after the earthquake event, so, this is the first time and the SAR interferometry technique has been implied to even a estimate ground deformations, post to ground post seismic and not CO seismic ground information, but post seismic deformations even after 3 4 years later.

So, this technique if a satellite data such data is available now currently from sentinel, we know where earthquakes occurs and see, if I take the example of India, then we know which are the seismically active region highly seismically active region like June 5 in seismic zoning map of India data is available on regular basis so, if we keep analyzing the data and we will find some ground deformation like here.

These are of course post ground deformation then proudly we can also detect pre seismic ground deformations implying SAR interferometry technique, because now it is possible because a sentinel data is available free of cost on net and only regular analysis of those areas which are seismically active regions of the country. If they are observed monitored regularly analyzed data is analyzed regularly, we can even detect pre seismic ground deformations if there are any.

So, with these words I thank you once again for and this is 2 parts discussion on how remote sensing images datasets whether it is a visible whether it is a infrared and thermal and SAR interferometer radar of microwave data can be implied in earthquake related studies. As said in the beginning of this course, or also in between several times that remote sensing technique is generic technique I showed the examples, in this last 2 lectures.

I have shown the examples of how these techniques or remote sensing technique can be implied in earthquake related studies, but one can use the remote sensing data for water resources or for flood studies or for a drought monitoring for agriculture. So, there are various applications are being developed or have already being developed or can be developed one of the examples as I have said, to detect pre earthquake ground deformations, if there are any. So, with this, and this brings to the end of our discussion. Thank you very much.