Integration of Remote Sensing Flood Maps and Measurements

G. Robert Brakenridge

Director, Dartmouth Flood Observatory (DFO)

University of Colorado

For GFP 2017, June 27-29, Tuscaloosa, Alabama, USA

- Bob Adler--Objectives of session
- Rob Blevins--Overview and examples from user perspective
- Emily Niebuhr--User interest from GFP and NOAA perspectives
- Bob Brakenridge--Integration of observations (two slides)
- Lorenzo Alfieri--Integration from forecast modeling perspective

Flood Maps Without Supplemental Information Are Incomplete

- Flood mapping via satellite is a useful tool in flood disaster response, and the mapped record of past floods can assist in flood risk assessment for a rapidly growing global population.

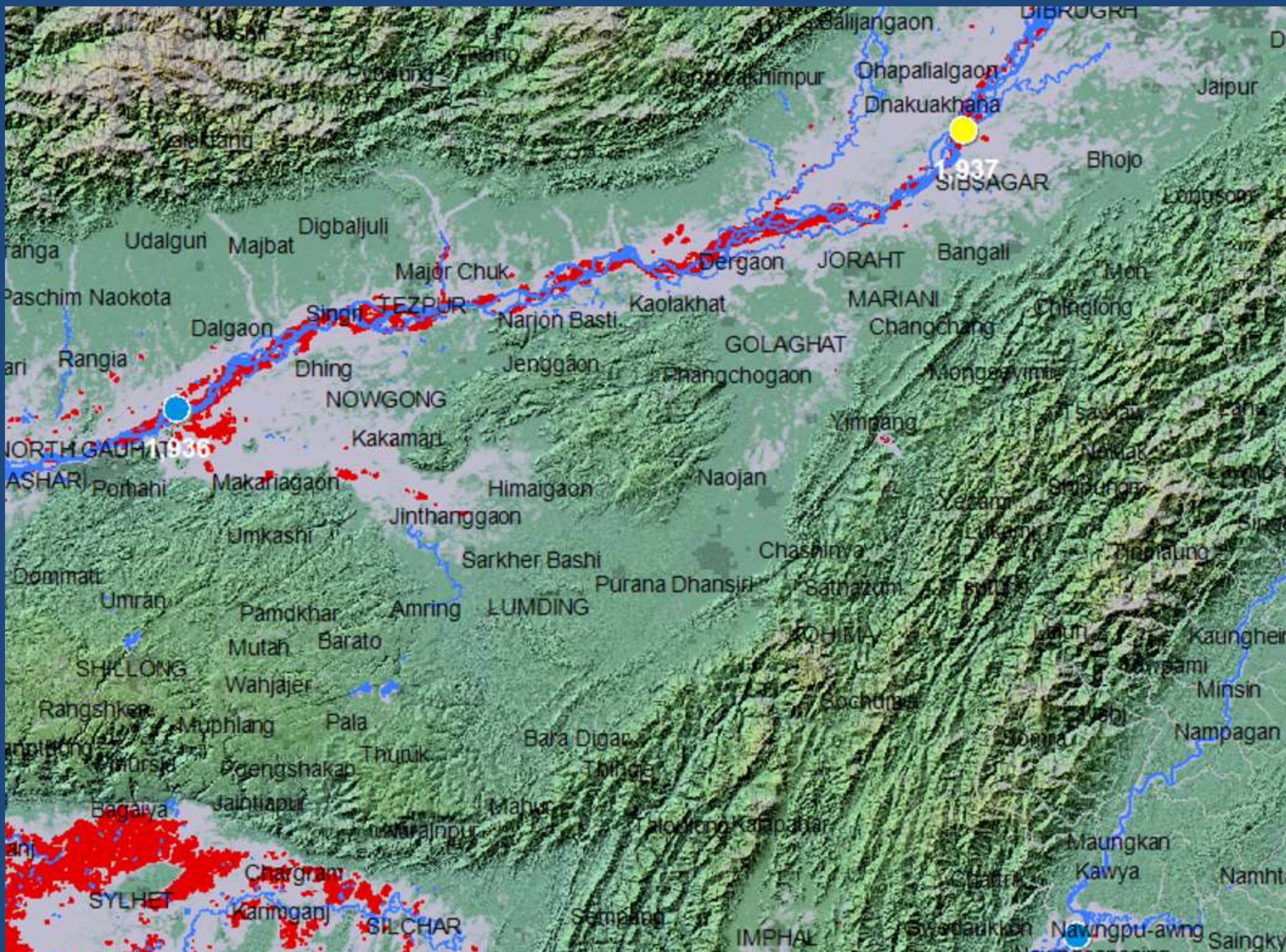
- Flood mapping is incomplete without integration of supporting measurements and maps that allow quantitative assessment concerning the *severity of the flood*.

- In hydrology, *severity* is expressed in terms of "how anomalous" the event is compared to normal surface water variation.

- If integration with such context can be achieved, we can determine how severe the event is, and also create quantitative risk maps for future use.

All previous flooding; June 15-26, 2017, flooding; February 2000.

- http://flooddobservatory.colorado.edu/GlobalFloodplains/090E030NCurrent.html



But wait, not so fast!

Riverine landscape in S Asia experience strong summer monsoon each year.

February reference layer is not appropriate, if goal is to show this year’s unusual, damaging flooding.

Solution: Instead use as reference water a typical annual flood extent (choose appropriate year from our catalog of annual MODIS water extent)

Still, how to quantify flood severity? River Watch sites can be used….

2015-Present *Every flood event mapped, here, can be assigned a recurrence interval*

River Watch Version 3.4

Experimental Satellite-Based River Discharge Measurements using passive microwave radiometry

Signal/Model agreement: **Very Good**

*G. R. Brakenridge**
*T. De Groeve***
*S. Cohen****
*S.V. Nghiem*****
*A. J. Kettner**
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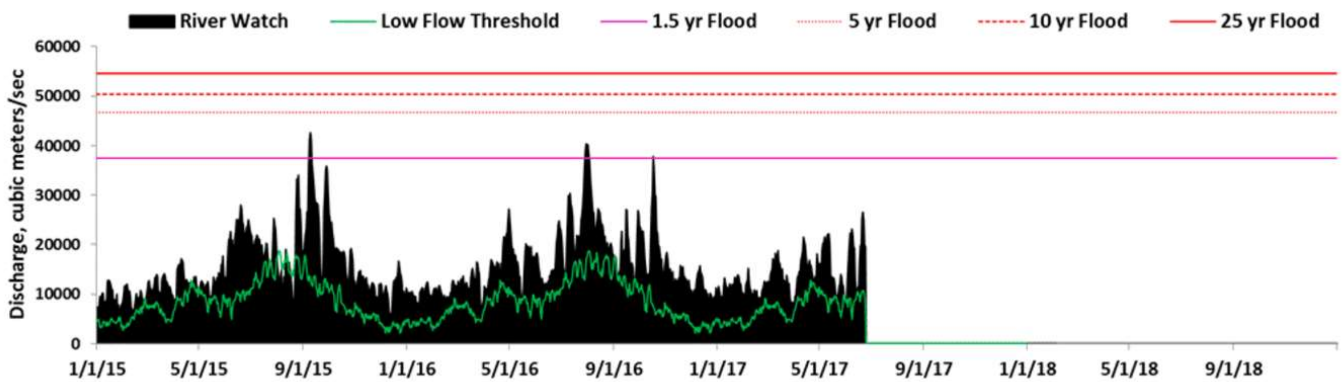
**CSDMS/INSTAAR, University of Colorado*
***Joint Research Centre, Ispra, Italy*
****University of Alabama*
*****Jet Propulsion Laboratory, California*

			Bramaputra	Center:	92.025	Long.	*S/N rating:* **Fair**
GFDS Site Number	1936	Predicted Flooded Area	India	Center:	26.324	Lat.	
GEE Time Lapse			Learn more about this river		**383449**	**sq km**	WBM contributing area
Last measured:	24-Jun-17				Obtain Data		
Discharge:	**19442**	m3/sec	Status:	**2**	(1, low; 2, normal flow; 3, moderate flood, r >1.5 y; 4, major flood, r >5 y)		
7-day Runoff	**35.1**	mm		**150%**	(7-day runoff compared to 10 y average for this date, 2003-2012)		
Flood Magnitude:	**0.0**	Scale of 0-10	Flood Magnitude Defined		Technical Summary		

Sensors: TRMM, AMSR-E, AMSR-2, GPM

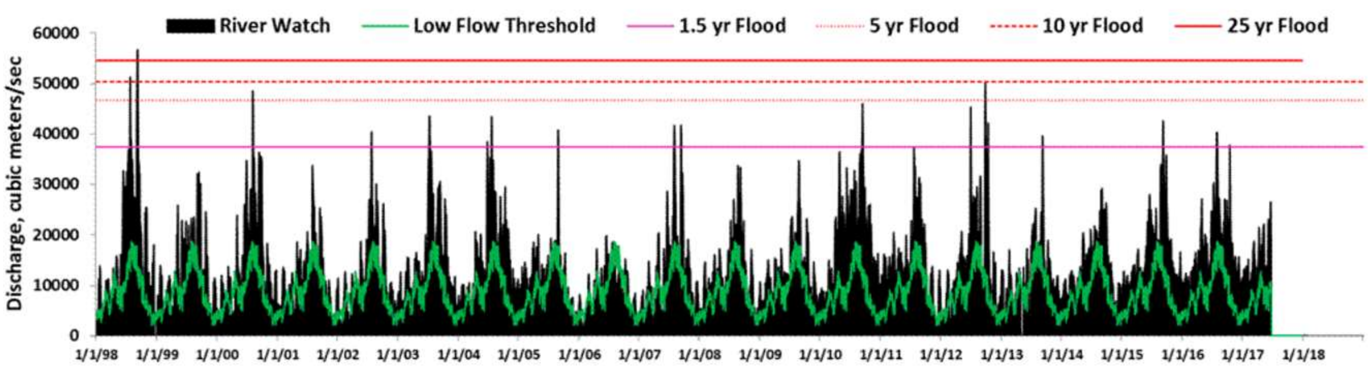


Notes: **4-day** forward moving average is applied.
Low flow threshold is 20th percentile discharge for this day, 2003-2013.

Annual Maximum Discharge

1998	56736	m3/sec
1999	32422	m3/sec
2000	48565	m3/sec
2001	33778	m3/sec
2002	40499	m3/sec
2003	43577	m3/sec
2004	43461	m3/sec
2005	40790	m3/sec
2006	19881	m3/sec
2007	41759	m3/sec
2008	33776	m3/sec
2009	34756	m3/sec
2010	46075	m3/sec
2011	37298	m3/sec
2012	50333	m3/sec
2013	39659	m3/sec
2014	29240	m3/sec
2015	42628	m3/sec

Complete Daily Record, 1998-Present *Are we today mapping a flood similar to 2015, or 1998?*

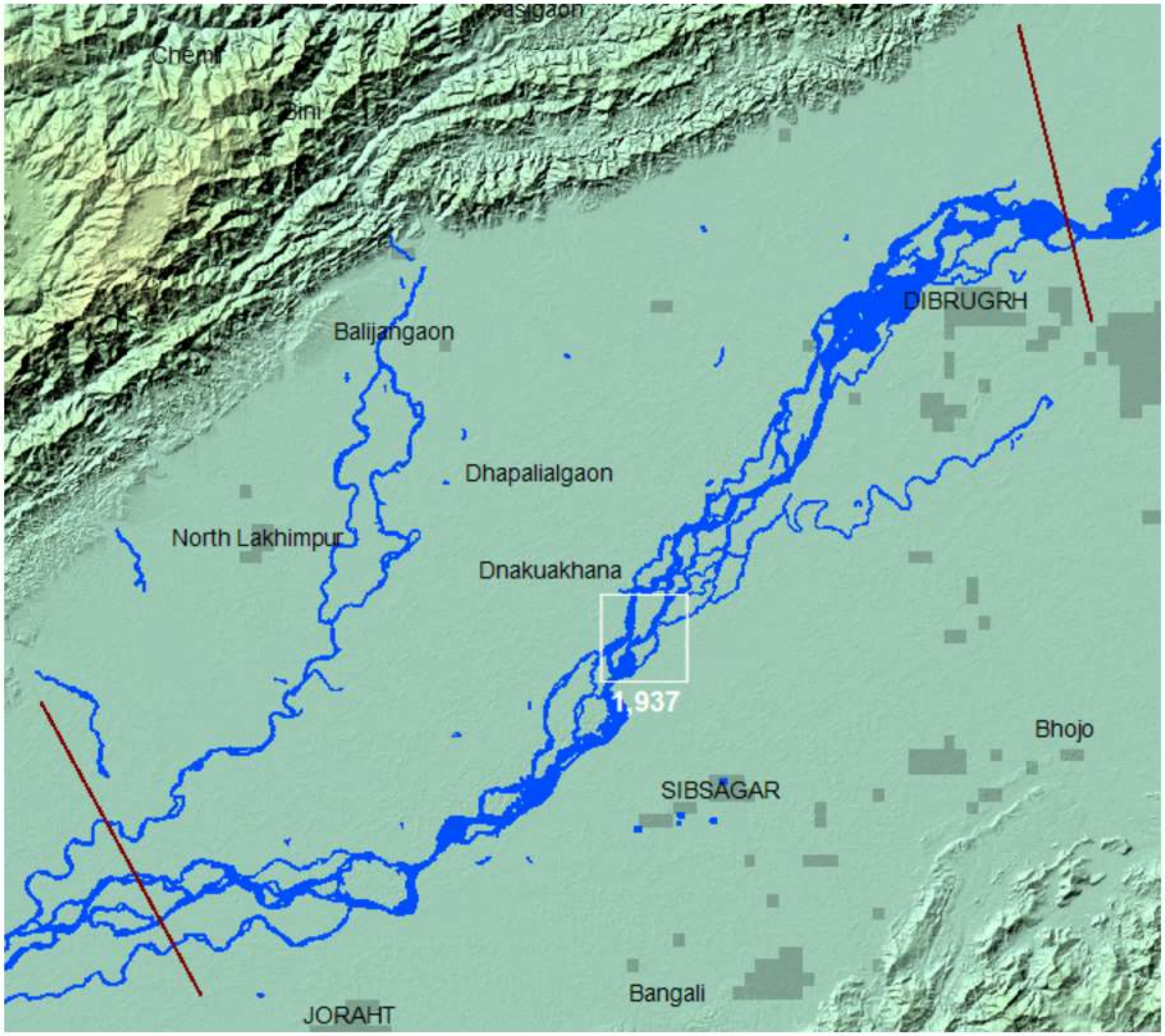


Flood Frequency Analysis, 1998-2015

25 yr*
54641 m3/sec
10 yr*
50340 m3/sec
5 yr (major flood)*
46626 m3/sec
1.5 yr (bankfull flood)*
37427 m3/sec
Mean Discharge
12764 m3/sec
*From Log Pearson III

Low Flow Threshold: 8838 m3/sec
(for today)

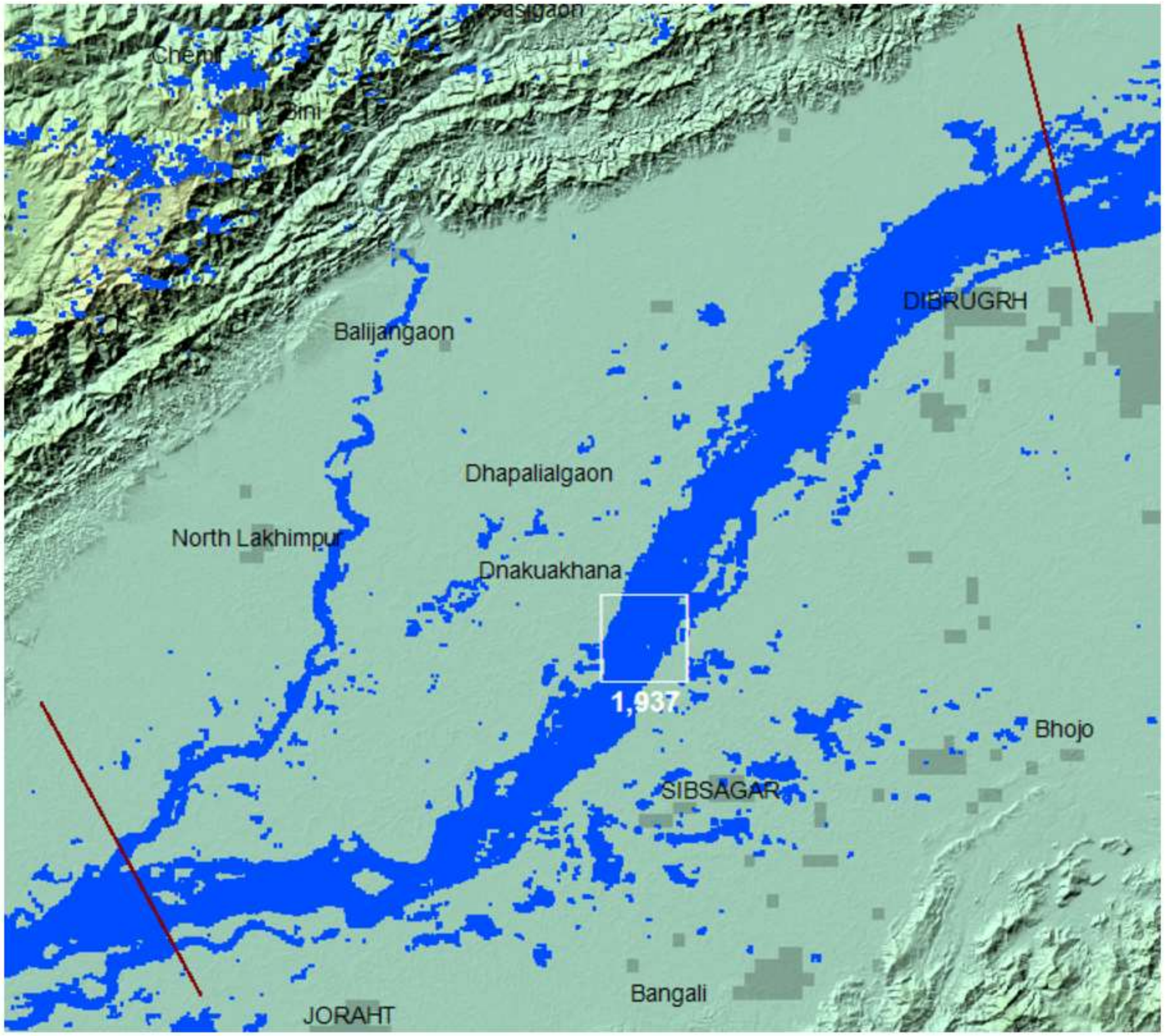
Flooded area for Normal Flow, Winter (~ 240 m3/sec, observed February 11-22, 2000)



Geotif version

Google Earth kmz version

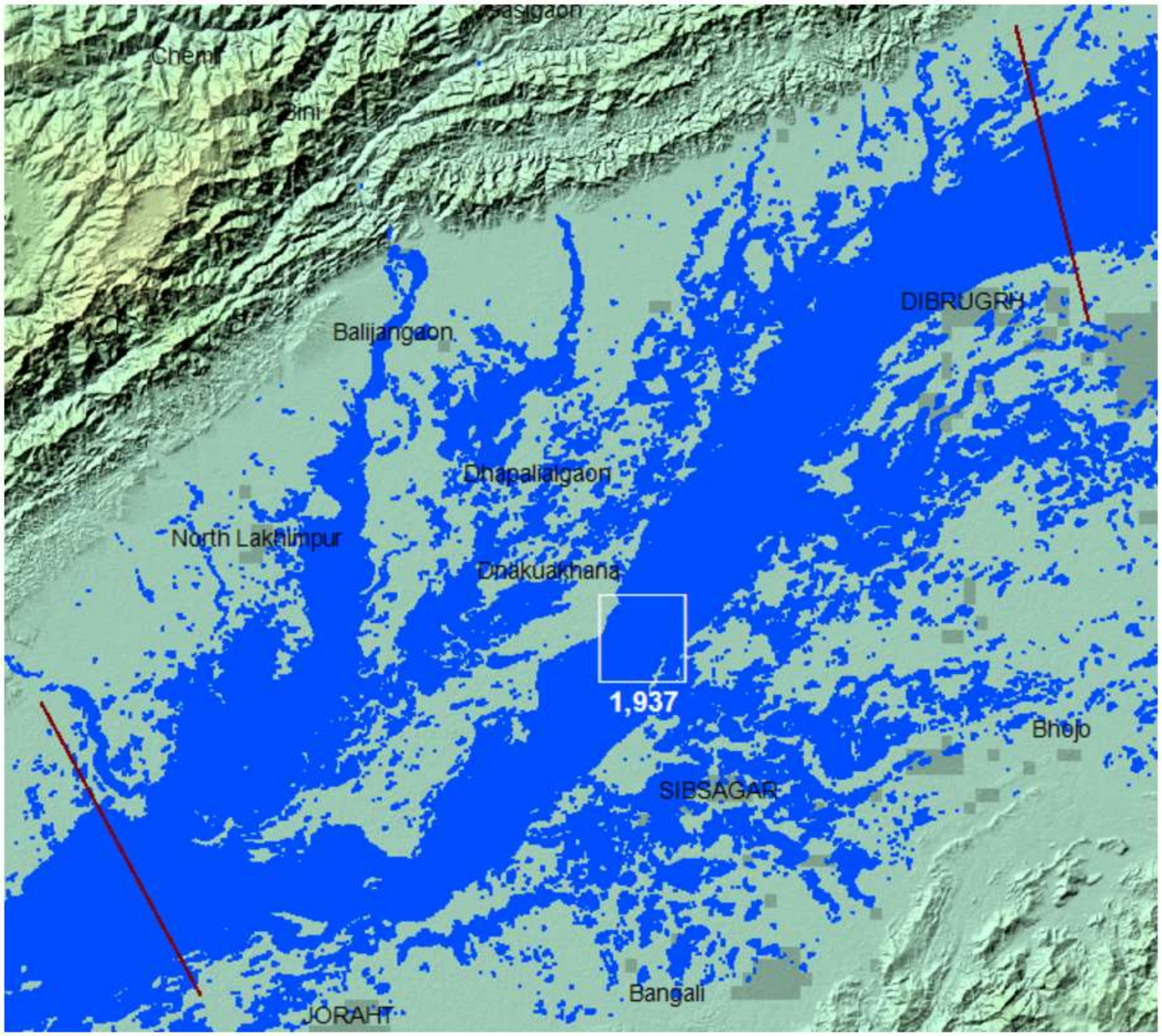
Flooded area for Normal Flow, r = 1.3 yr (observed summer, 2013)



[Geotif version]

[Google Earth kmz version]

Flooded area for Major Flooding, r = 9 yr (observed summer, 2007)



Now we can:

Place recurrence intervals on any flood mapped along this reach;

Predict inundation extent from the microwave values being reported;

Map flood hazard in quantitative terms.

Summary

- In monsoonal areas, in high latitudes where rivers experience a normal "spring flood", mapping of the damaging floods **requires** comparison to mapping of the normal high water (the normal annual "flood").

- Floods of a calculated recurrence interval of 1.5 year (assuming a sufficient period of record) can serve as the "baseline" inundation extent: the needed water "mask".

- Passive microwave radiometry using satellites such as GPM and GCOM-W can provide consistent measurements of flooding extending back to 1998; thus allowing severity estimates for flood maps of today. In the U.S. and other nations, also, combining gauging station records with flood mapping also allows severity of mapped flooding to be evaluated.

- A "flood map" without integration of such information provides potentially very inaccurate situational awareness for flood responders..

Avoidance of Flood Disasters and the Benefits of International Cooperation

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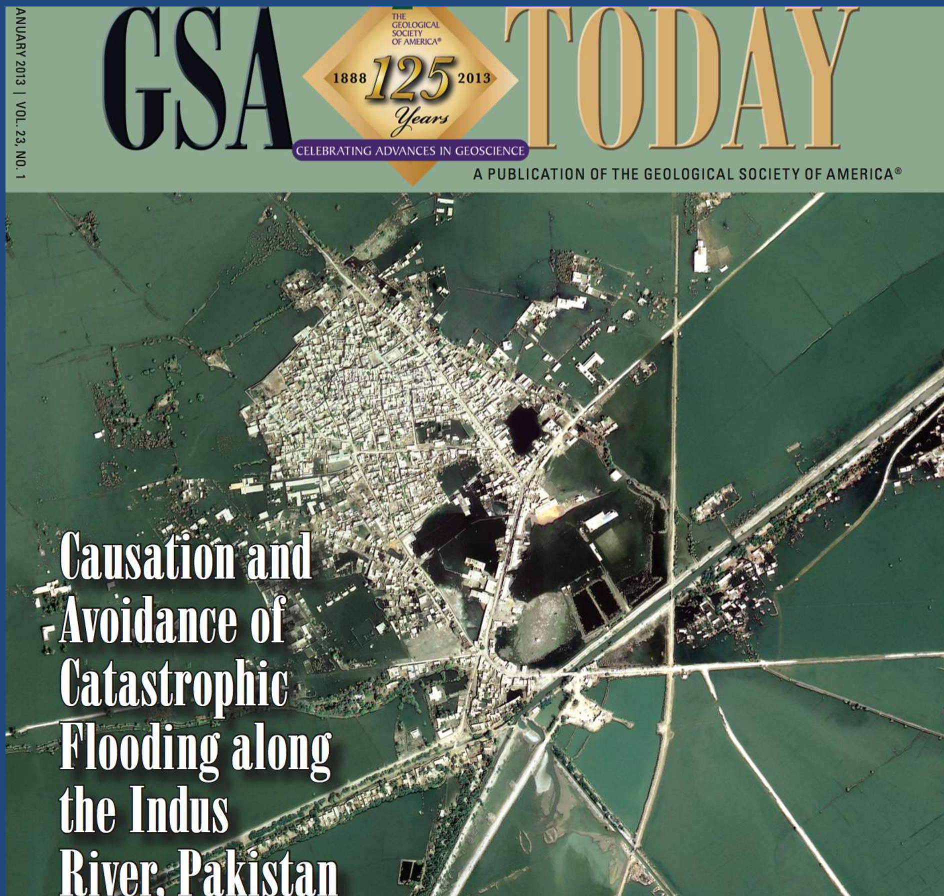
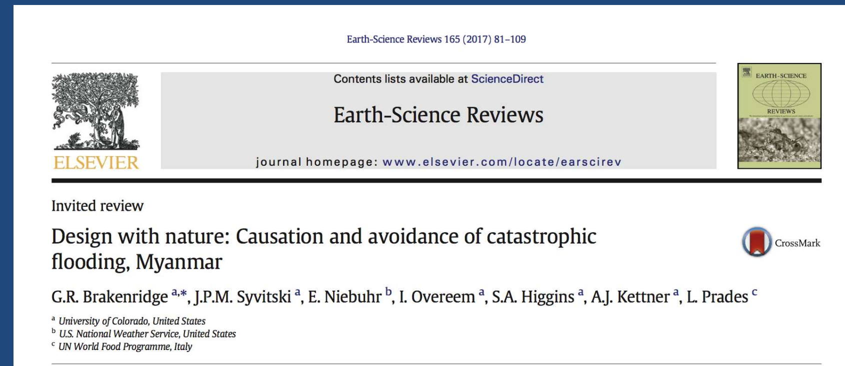
University of Colorado

For GFP 2017, June 27-29, Tuscaloosa, Alabama, USA

Photo: IFRC / Sudanese Red Crescent, Kassala, Sudan. August 2014. “Gash River flooding has affected over 21,000 people in the Aroma locality alone, destroying houses, roads and bridges.”

James P.M. Syvitski *and* ***G. Robert Brakenridge****, University of Colorado, Boulder, Colorado*





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Invited review

Design with nature: Causation and avoidance of catastrophic flooding, Myanmar

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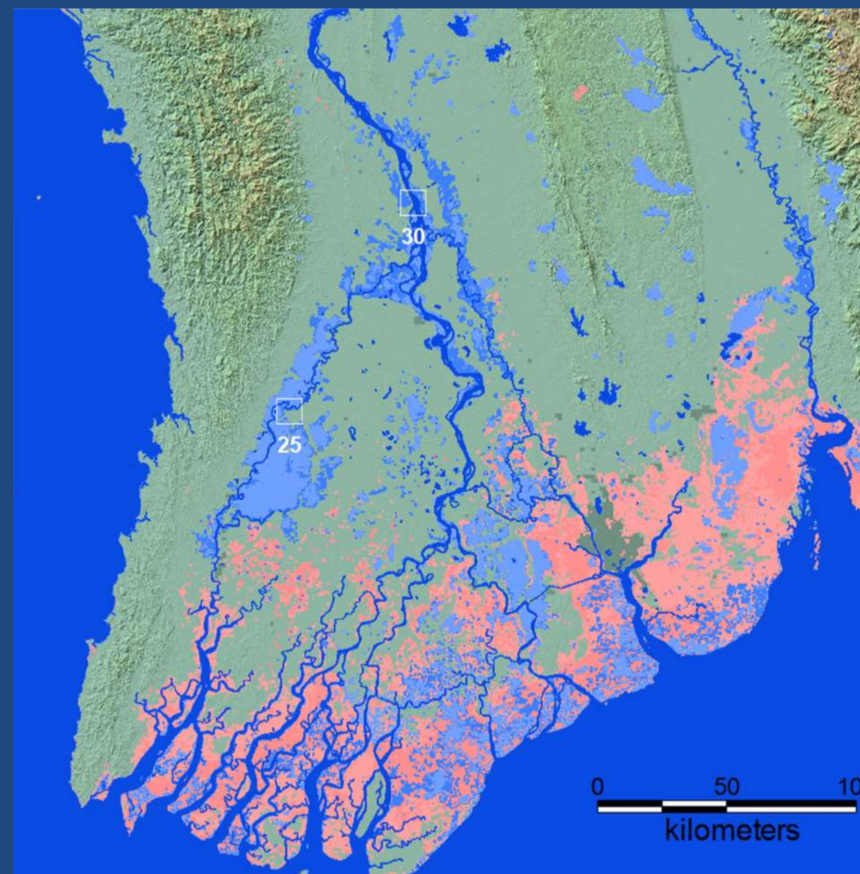
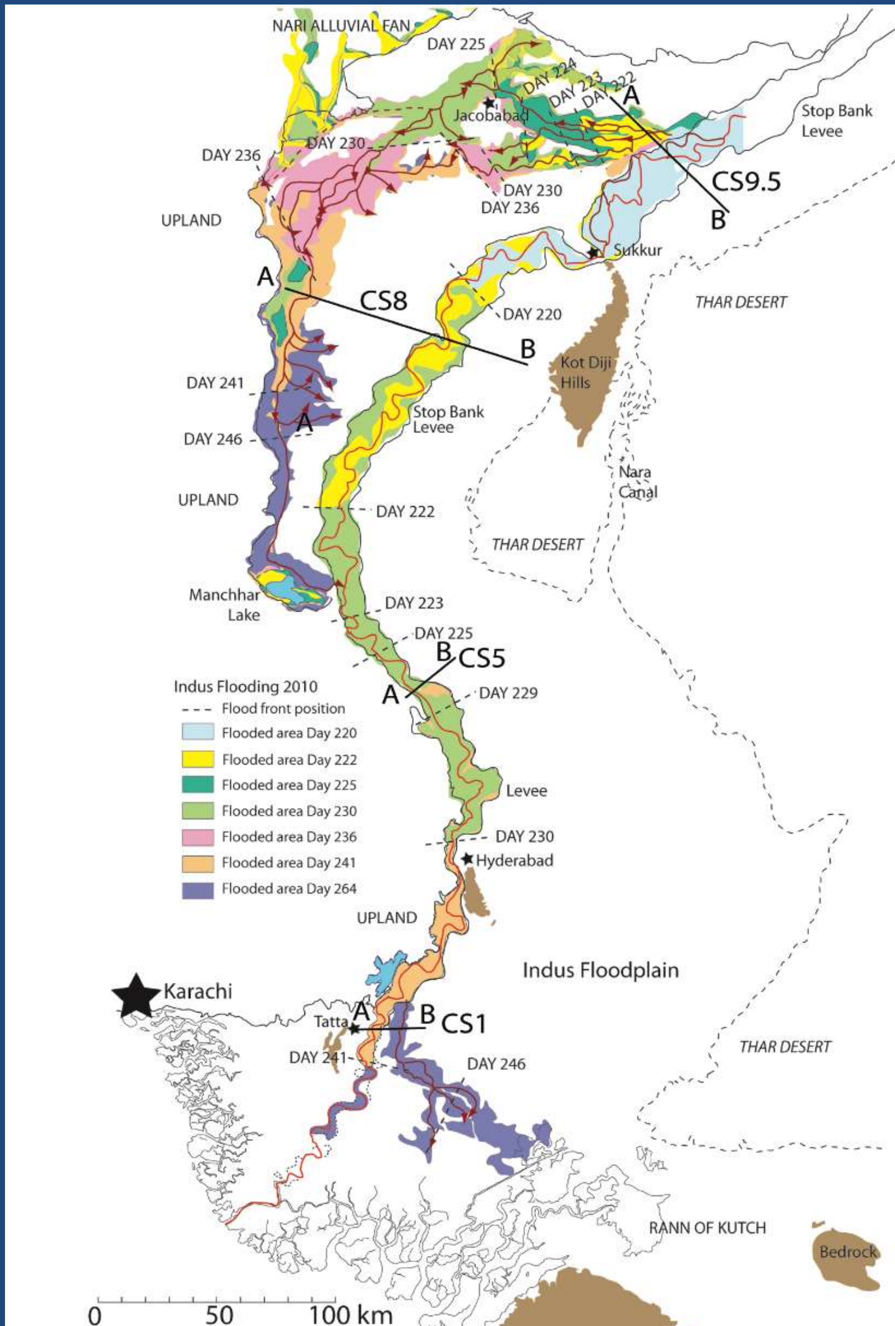
2010, 2000 fatalities, 2,000,000 displaced



Tropical Storm, 2008, 138,000,000 fatalities

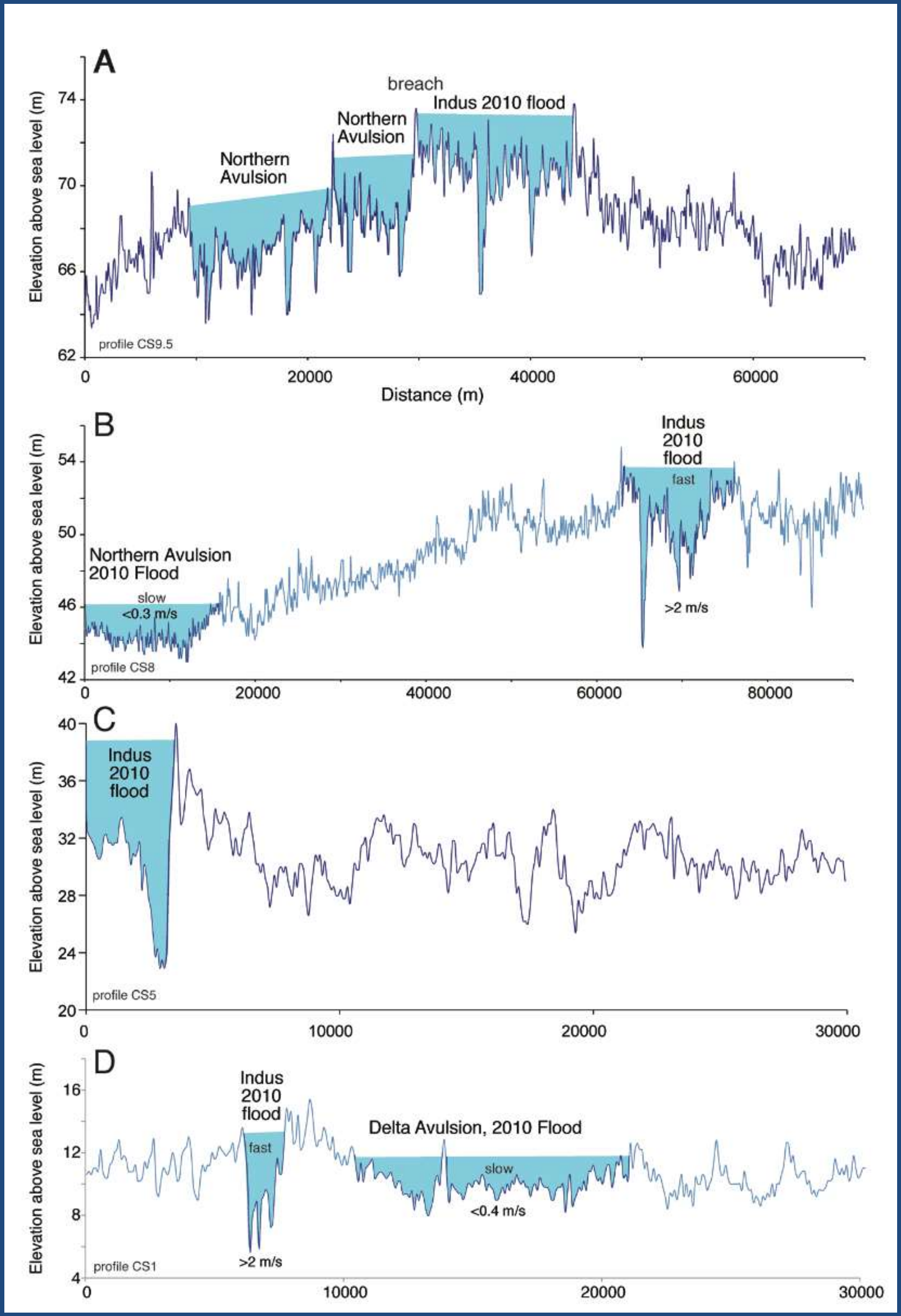
Findings: The these large flood events became catastrophic for humans due to avoidable causes.



Summary map showing the progress of the 2010 Indus flood wave and its two main avulsions. Arrows and colors show the direction and dates of overbank floodwater as determined by progressive inundation from remote sensing.

The flood began in July with unusually intense but not unprecedented rainfall in the upland catchment. Two major river avulsions (sudden changes in flow location) occurred. At the northern avulsion, Indus water flooded ~8,000 km2 of agricultural land to depths of 1–3 m.

It was caused by breaching of the Tori Bund (levee) on 6–7 August, two days before arrival of the first flood crest and long before attainment of peak flow 100 km upstream, on 24 August. The early breach, during the rising stages of the flood, permitted much of the incoming flood wave to feed the avulsion over a sustained period.



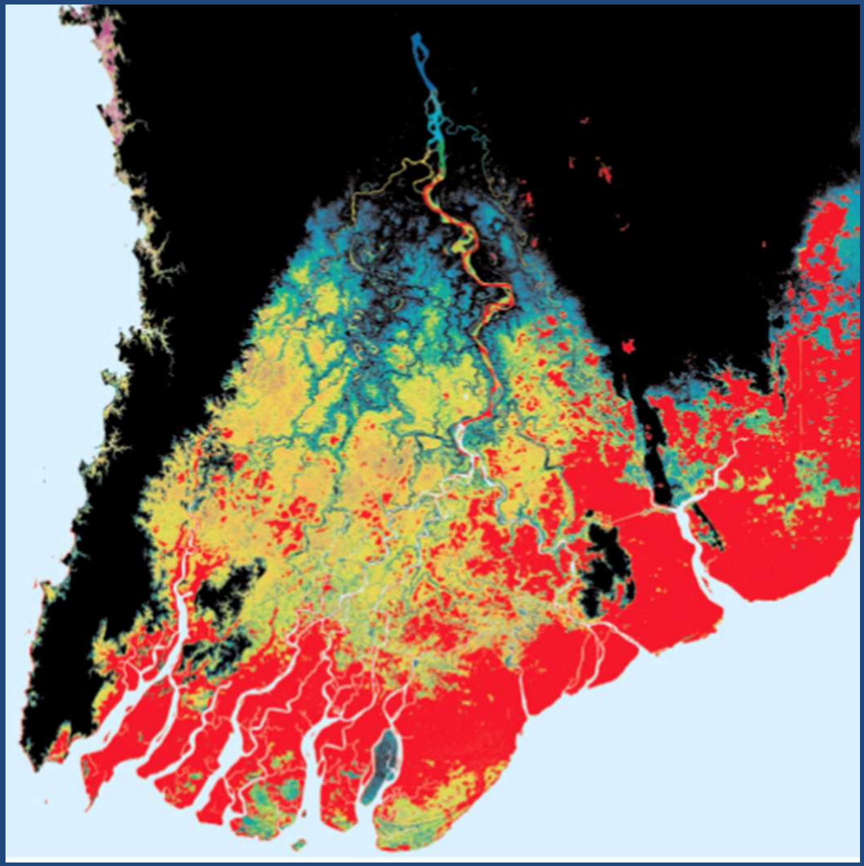
Cross-profiles of the elevated Indus channel and surrounding floodplain lands.

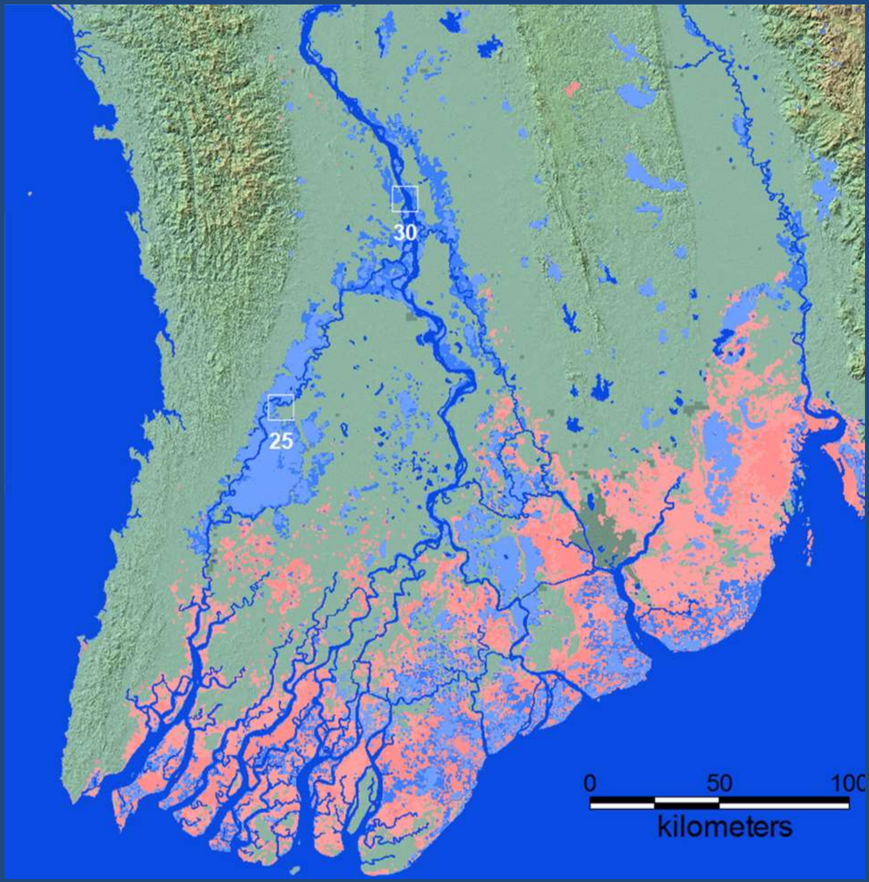
As was the case for the dramatic avulsion of the Kosi River, India, in 2008, the lack of planned accommodation to the river's high sediment load and its super-elevation above the surrounding terrain set the stage for exceptionally dangerous levee failures and channel avulsions.

The numerous levee failures extended from upstream areas, where some record discharges occurred, to downstream and the delta, where peak discharges were not extreme.

The observed dynamics indicate that reinforcing the existing engineering structures is not a sustainable strategy for avoiding future flood catastrophes

Delta topography from the NASA SRTM mission, compared to the remote sensing record of storm surge flooding, Nargis, 2008. All mapped inland flooding is shown in light blue, the 2008 flooding in light red.



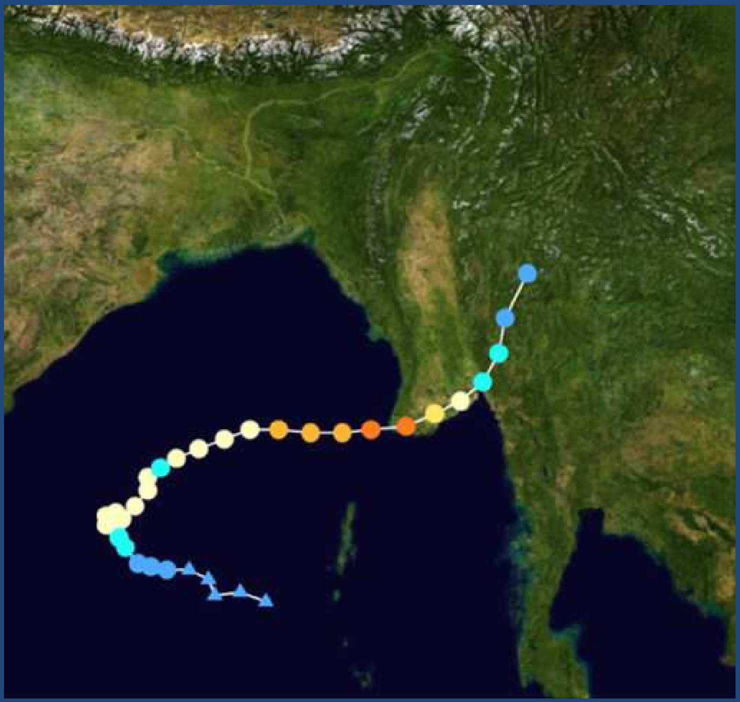


The map is a record of land vulnerable to storm surge. A hazard map, but what is the estimated recurrence interval of this catastrophic storm?

We searched for similar storms…

Left: track of the 1982 Cyclone Gwa. Blue: tropical depression; green: tropical storm; yellow to orange to red: category 1 to category 5 tropical cyclone. Six-hour intervals.

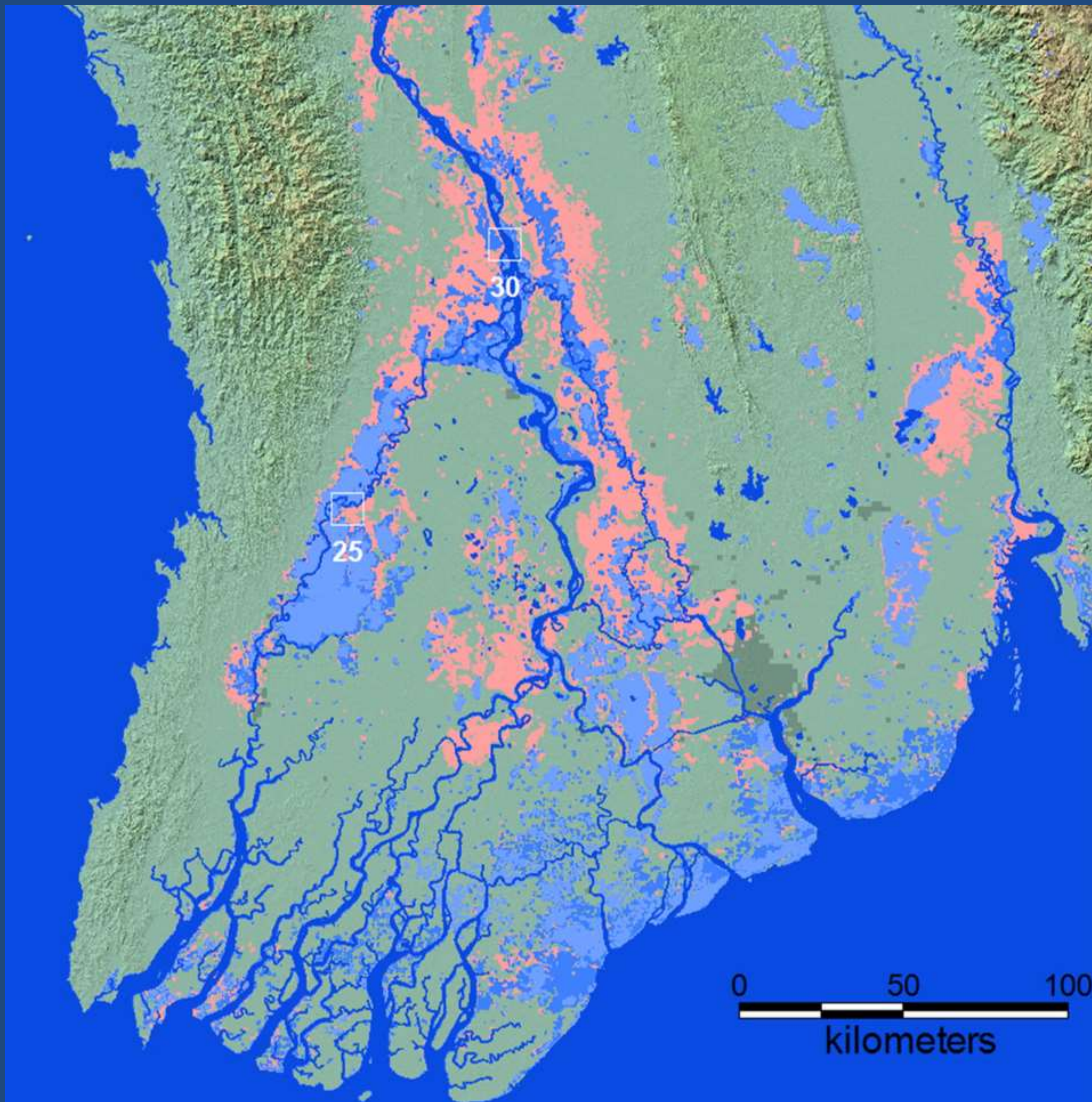
Cyclone Nargis, April 27–May 3, 2008, storm track (right). Nargis, followed an unusual (but not “unprecedented”) storm track. And in the 26 y since the last Nargis-like event (Gwa), both the region's total population and its location had very much changed.



- At the time of Nargis, the overall Myanmar population was much larger and also younger than in previous decades.

- At the 1983 census the nation's population was 35.4 million. The 2014 census show a total population of 51-60 million, +150% in ~30 y. Population estimates for Yangon, upper delta, are: 1980, 2.4 million, and 2010, 4.3 million (a 180% increase).

- Thus: in the 26 y since the last Nargis-like event (Gwa), both the region's total population and its location had very much changed. It was an unprecedented storm, in their experience.



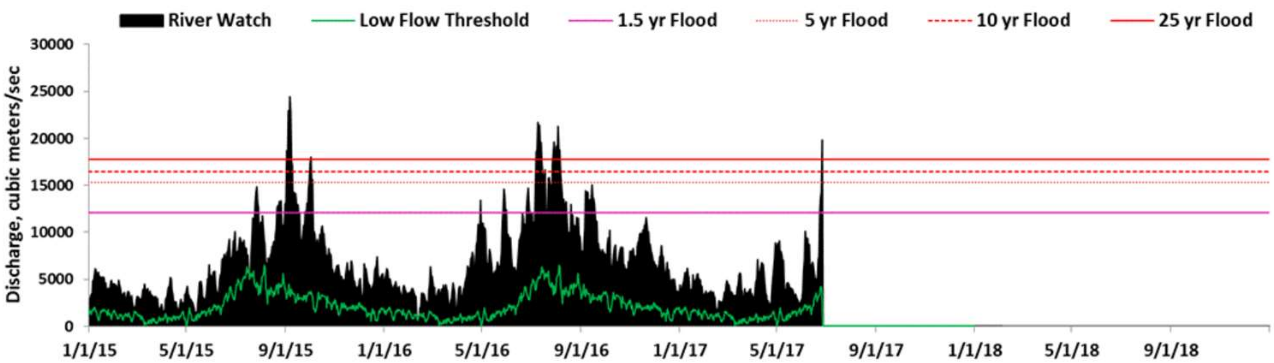
Again, in 2015, unusually heavy monsoonal rains plus a slow-moving tropical storm (Komen) together caused major flooding, ~130 fatalities, and very severe damage and losses.

Again, the event triggered international food, medical, and other assistance, in-cluding efforts to design rebuilding with greater resilience to floods.

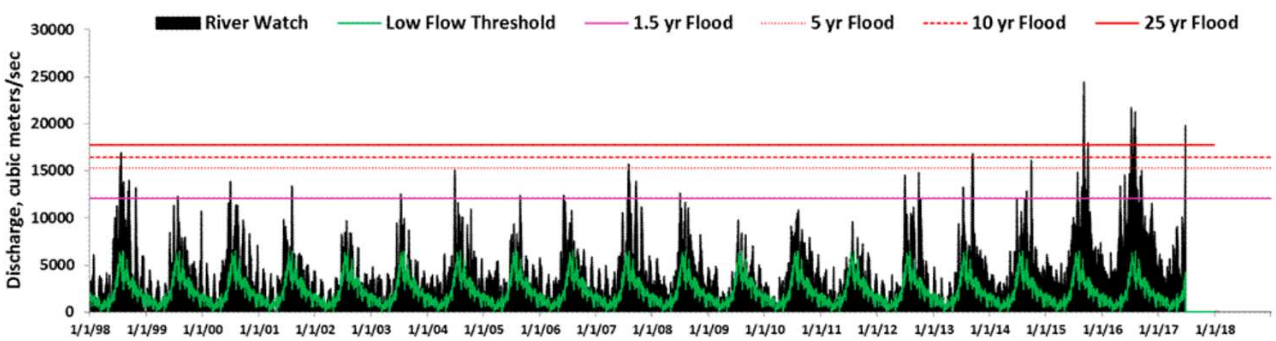
River Watch Version 3.4

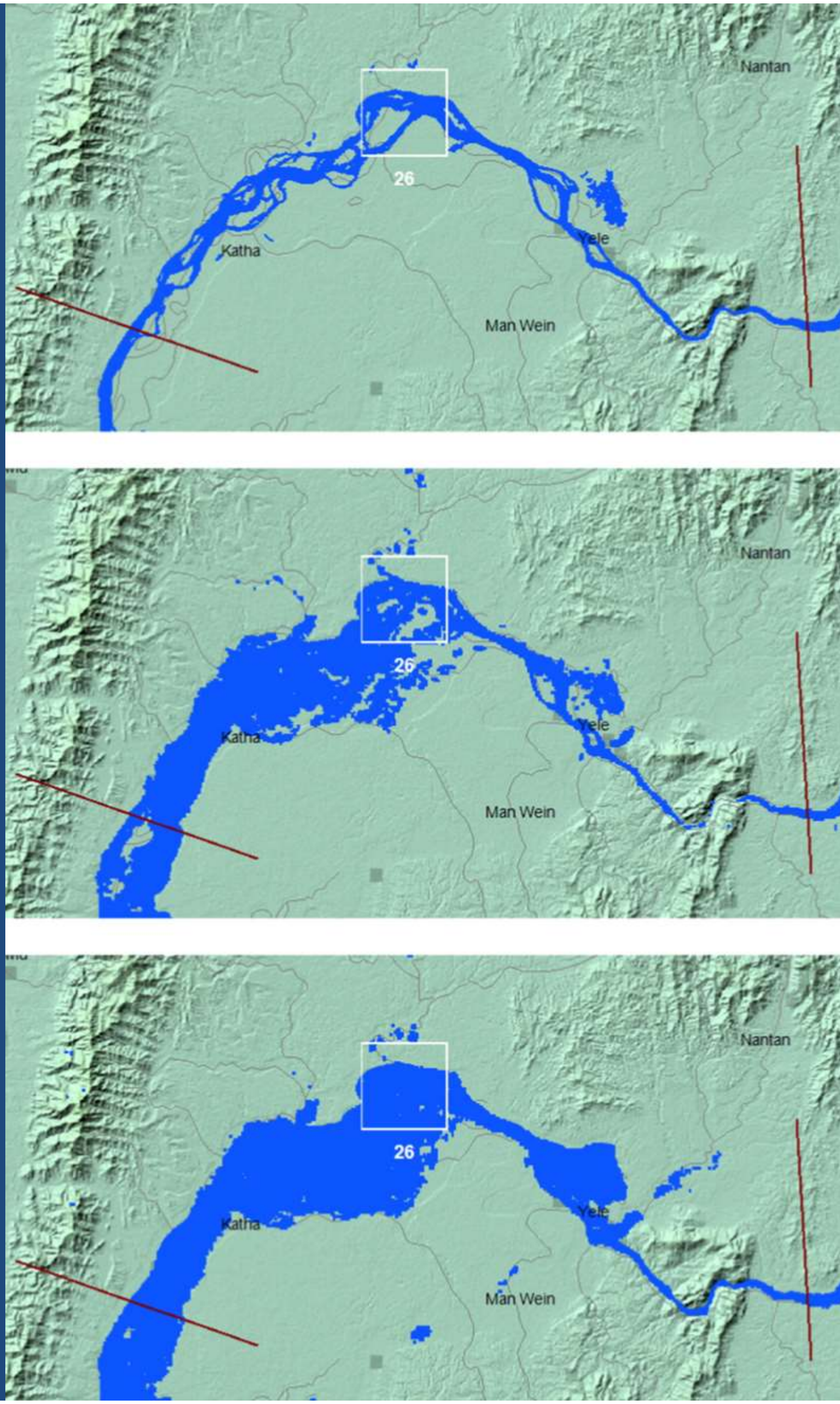
Experimental Satellite-Based River Discharge Measurements using passive microwave radiometry *Signal/Model agreement:* **Very Good**

			Irrawaddy	Center:	96.615	Long.	*S/N rating:*	**Fair**
GFDS Site Number	26	Predicted Flooded Area	Myanmar	Center:	24.344	Lat.		
GEE Time Lapse			Learn more about this river			**74436**	**sq km**	WBM contributing area
Last measured:	26-Jun-17					Obtain Data		
Discharge:	**19831**	m3/sec	Status:	**4**	(1, low; 2, normal flow; 3, moderate flood, r >1.5 y; 4, major flood, r >5 y)			
7-day Runoff	**92.6**	mm		**179%**	(7-day runoff compared to 10 y average for this date, 2003-2012)			
Flood Magnitude:	**0.7**	Scale of 0-10	Flood Magnitude Defined			Technical Summary		



Notes: **4-day** forward moving average is applied.
Low flow threshold is 20th percentile discharge for this day, 2003-2013.





Inundation for (top) a normal winter flow, at ~200 m3/s in February 2000; (middle) normal monsoon season flow, recurrence interval of 1.1 y, ~9000 m3/s, in 2002, and (bottom) during a rare flood, recurrence interval of 21 y, 18,200 m3/s, in 2013. The recurrence interval and peak discharge estimates are from River Watch site 26 (defined by the white 10 km square).

Along this reach of the Ayeyarwady, the inundation difference between annual and unusual flooding reflects a 2× increase in discharge; the normal annual maximum discharge is, however, N10× higher than annual low flow.

Again, remote sensing at various spatial scales can provide much more than "flood mapping".

Left: MODIS band 7,2,1 colour composite (from NASA Worldview), September 11, 2015 (top), and March 13, 2015 (bottom) showing monsoon filling of the same Ayeyarwady river channel during the 2015 flood.

The (low-flow) abandoned meander is re-occupied annually during the monsoon season; it thus provides flood water storage and attenuates downstream-moving flood waves. If flood recover here removes access to the meander during flood (straightens and reinforces the channel), then downstream flooding will be worse.

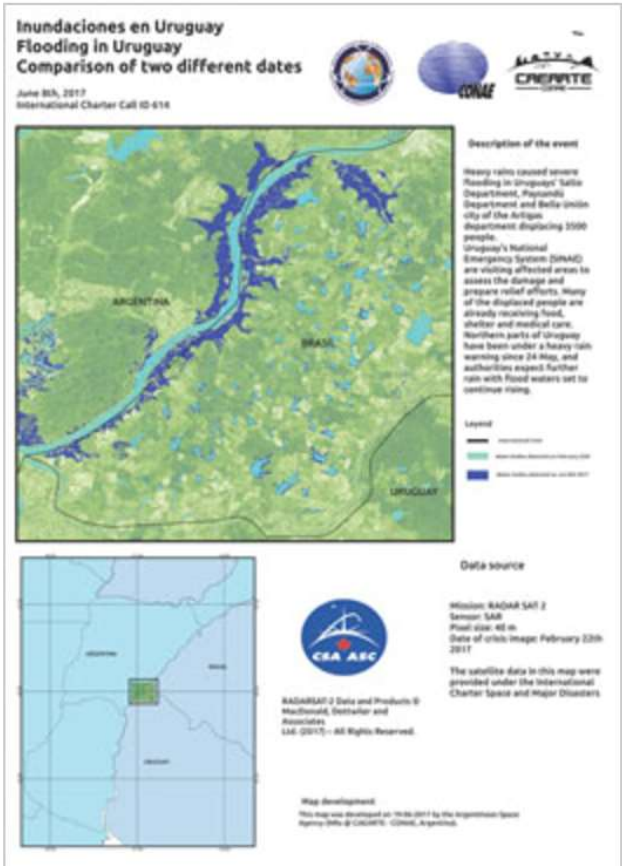
Sittaung River meander migration. The outer channel bank moved 620 m to the southwest between March 21, 2004 and January 20, 2014, for an average rate of 62 m/y. The newly created floodplain land is already being farmed. A village southwest of the river in 2004 was swallowed by the river and no longer exists.

- Myanmar is among 15 nations that account for 80% of global population exposed to flooding.

- Other factors than the storm changed “flood to catastrophe”: high sediment loads carried by Myanmar rivers, locally rapid rates (50–100 m/y) of channel migration, expansion of population into vulnerable locations, and anthropogenic modifications to floodplains, watersheds, and the coastal zone.

- Engineering projects can protect local communities, but flood control structures will fail again unless the environmental changes that increase exposure to flood damage are also mitigated. Long term reduction of societal exposure include floodplain reconnection, levee removal, controlled avulsions, preservation of floodplain storage, and redirecting new settlement onto lands with less severe flood risk.

- Orbital remote sensing can be employed to characterize such damaging flood, quantify future flood risk, and understand flood dynamics. But it must be sustained, not single images of floods.



Comparison of flooding in Uruguay

Source: RADARSAT-2
Acquired: Pre-disaster: 22/02/2017
Post-disaster: 08/06/2017

Map produced by CONAE

Higher resolution version

Flood at Salto

Source: SPOT-6
Acquired: 11/06/2017

Map produced by CONAE

River Watch Version 3.4

Experimental Satellite-Based River Discharge Measurements using passive microwave radiometry *Signal/Model agreement:* **Poor**

Uruguay Center: -58.184 Long. *S/N rating:* **Fair**

GFDS Site Number 792 MODIS History Argentina Center: -32.715 Lat.

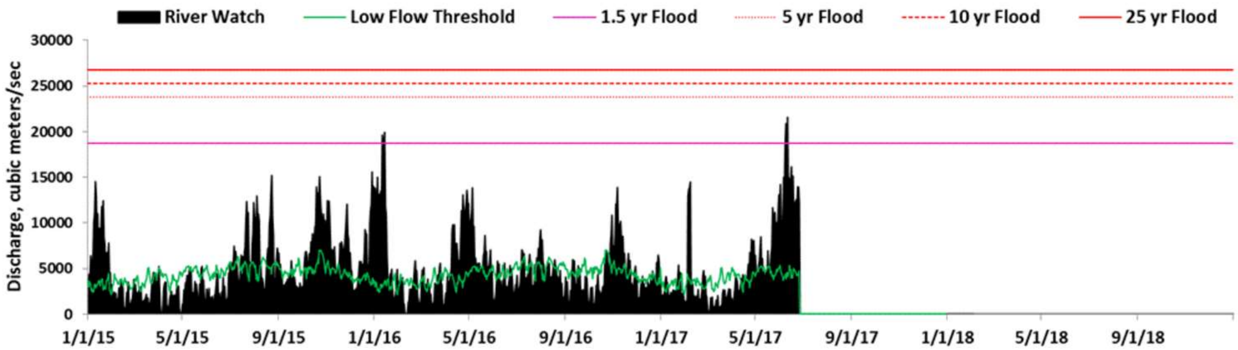
GEE Time Lapse Learn more about this river **263013** **sq km** WBM contributing area

Last measured: 26-Jun-17 Obtain Data

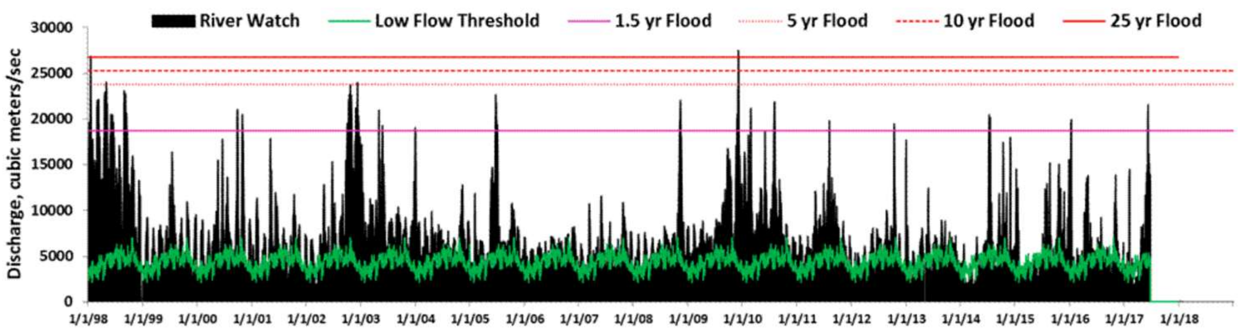
Discharge: **12269** m3/sec Status: **2** (1, low; 2, normal flow; 3, moderate flood, r >1.5 y; 4, major flood, r >5 y)

7-day Runoff **29.0** mm **185%** (7-day runoff compared to 10 y average for this date, 2003-2012)

Flood Magnitude: **0.0** Scale of 0-10 Flood Magnitude Defined Technical Summary



Notes: **4-day** forward moving average is applied.
Low flow threshold is 20th percentile discharge for this day, 2003-2013.



IMPROVING INTERNATIONAL COOPERATION

Example:

CONAE (Argentine Space Agency) responded to Uruguay flooding in June, 2017. Uruguay's National Emergency System (SINAE) were visiting affected areas to assess the damage and prepare relief efforts. The International Charter for Space and Major Disasters was invoked on June 6. So far, so good.

The Project Manager was CONAE. The Charter provided an abundance of images. CONAE produced flood inundation maps using SPOT 6, SPOT 7, CARTOSAT-2, ALOS-2, RADARSAT-2, and TanDEM-X data (next slide). They published these as large format .jpg files.

Uruguay Uruguay's National Emergency System (SINAE) reports that flooding of the Uruguay River has displaced 1,754 in the departments of Salto, Paysandú and Artigas

Summary

Humans, including river engineering , population growth, and land use commonly determine the difference between “major flood event” and “catastrophic flooding”.

What can this (GFP) community do?

- Preserve the Record of what happened, for the insight the insight it provides: into land areas that are hazardous, into the causation of the event, and for the guide it can offer to flood recovery and rebuilding.
- Recognize the power of an full objective record of such major events.
- Move from sharing multiple sensors providing multiple images and maps of flooding, to free sharing and integration of these geospatial data, spatially and temporally, for the rich and important story they tell that can inform flood recovery.