Synthetic Aperture Radar (SAR) Remote Sensing & Hydrological Applications

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Summer School on Water Informatics: Science & Systems
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WIT, SSE, LUMS, Lahore

Introducing GREL

- Geospatial Research & Education Lab (GREL) at Dept. of Space Science, Institute of Space Technology, Islamabad, Pakistan
- Established as a collaboration between Open Source Geospatial Foundation (OSGeo) and International Cartographic Association (ICA)
- First and only ICA-OSGeo affiliated lab in Pakistan: http://www.geoforall.org/locations/

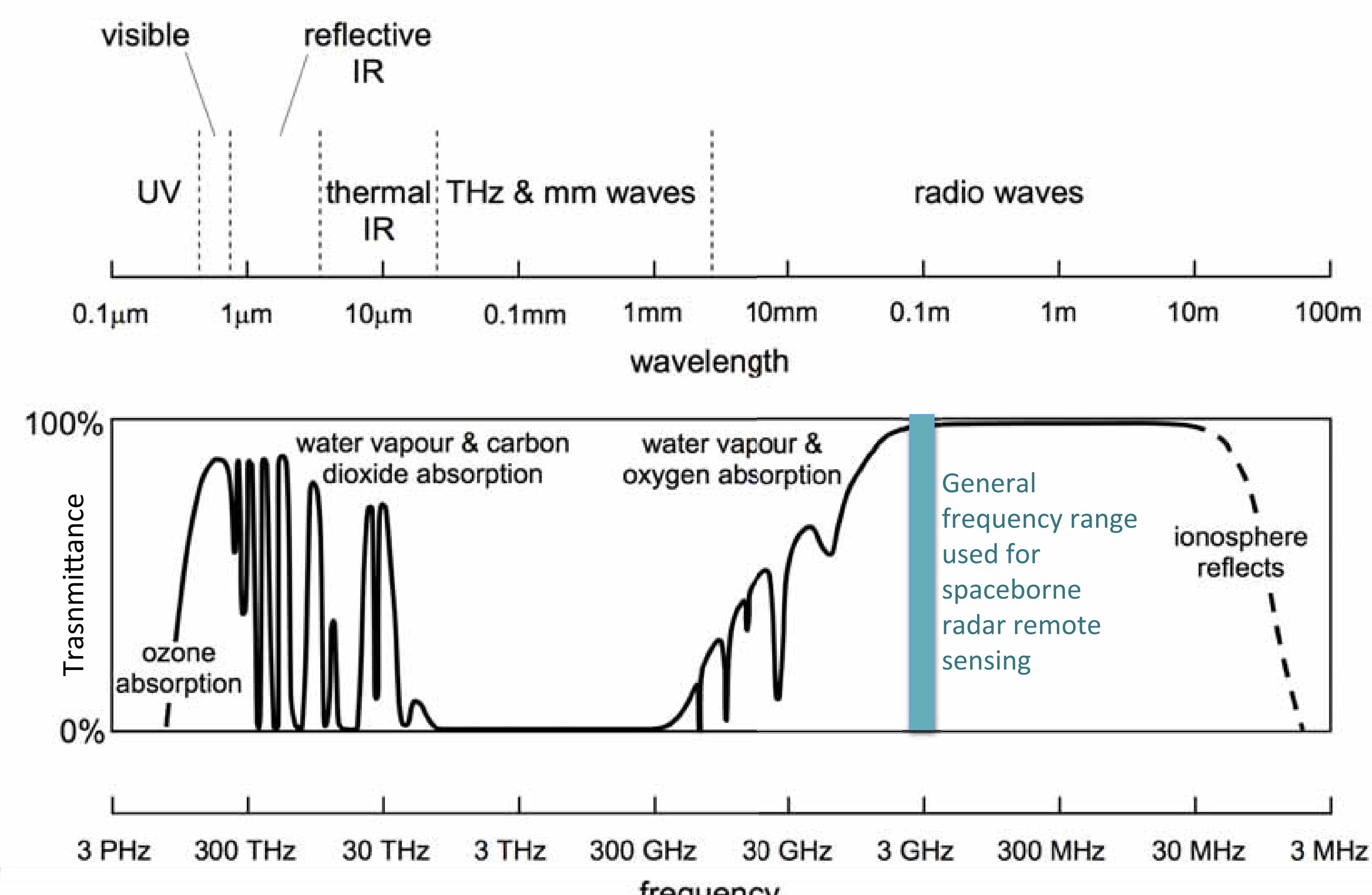
Introducing GREL

- MS Program in *Remote Sensing & Geographic Information Science*
- Research Areas:
  - Remote Sensing
  - Geographic Information Science
  - Atmospheric & Environmental Science

Introducing GREL

- <u>International Collaborations</u>: ICIMOD (International Centre for Integrated Mountain Development), JAXA (Japanese Space Agency), ESA (European Space Agency), IFS (International Foundation for Science), Univ. of Colorado - Boulder, NASA JPL
- <u>National Collaborations</u>: CES & IESE - NUST, NCEG – Univ. of Peshawar, Univ. of Punjab, SUPARCO, NDMA, PCRWR, Planning Commission, Dept. of Forestry – Govt. of Punjab, ITU Lahore, National Institute of Oceanography, **<u>WIT - LUMS</u>**, Dept. of Meteorology − CIIT Islamabad

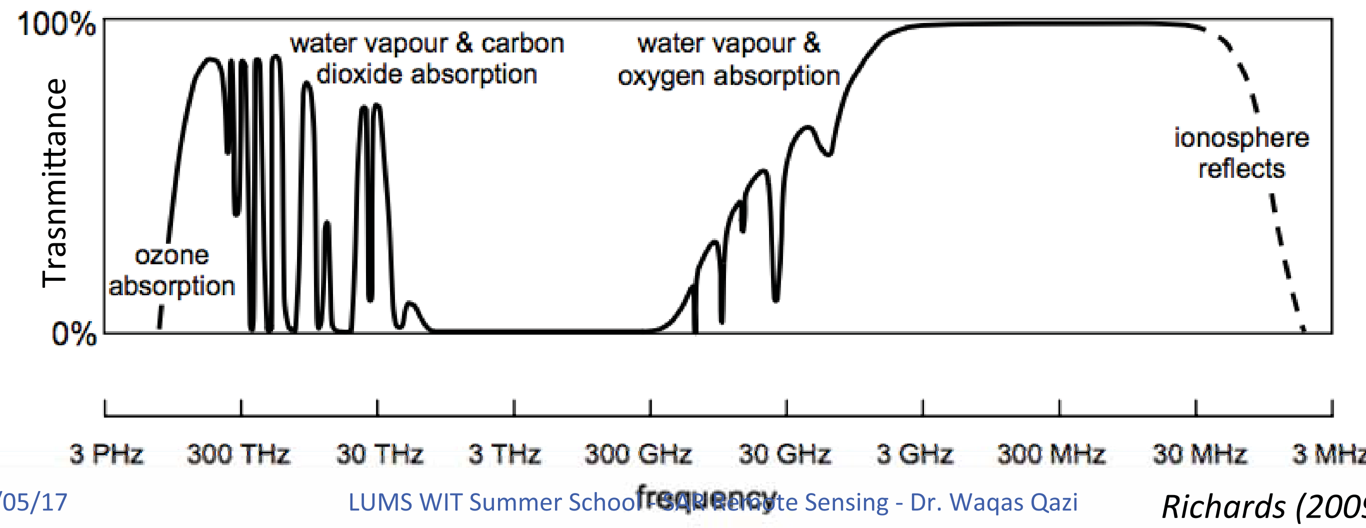
Radar for Earth Remote Sensing



Richards (2009)

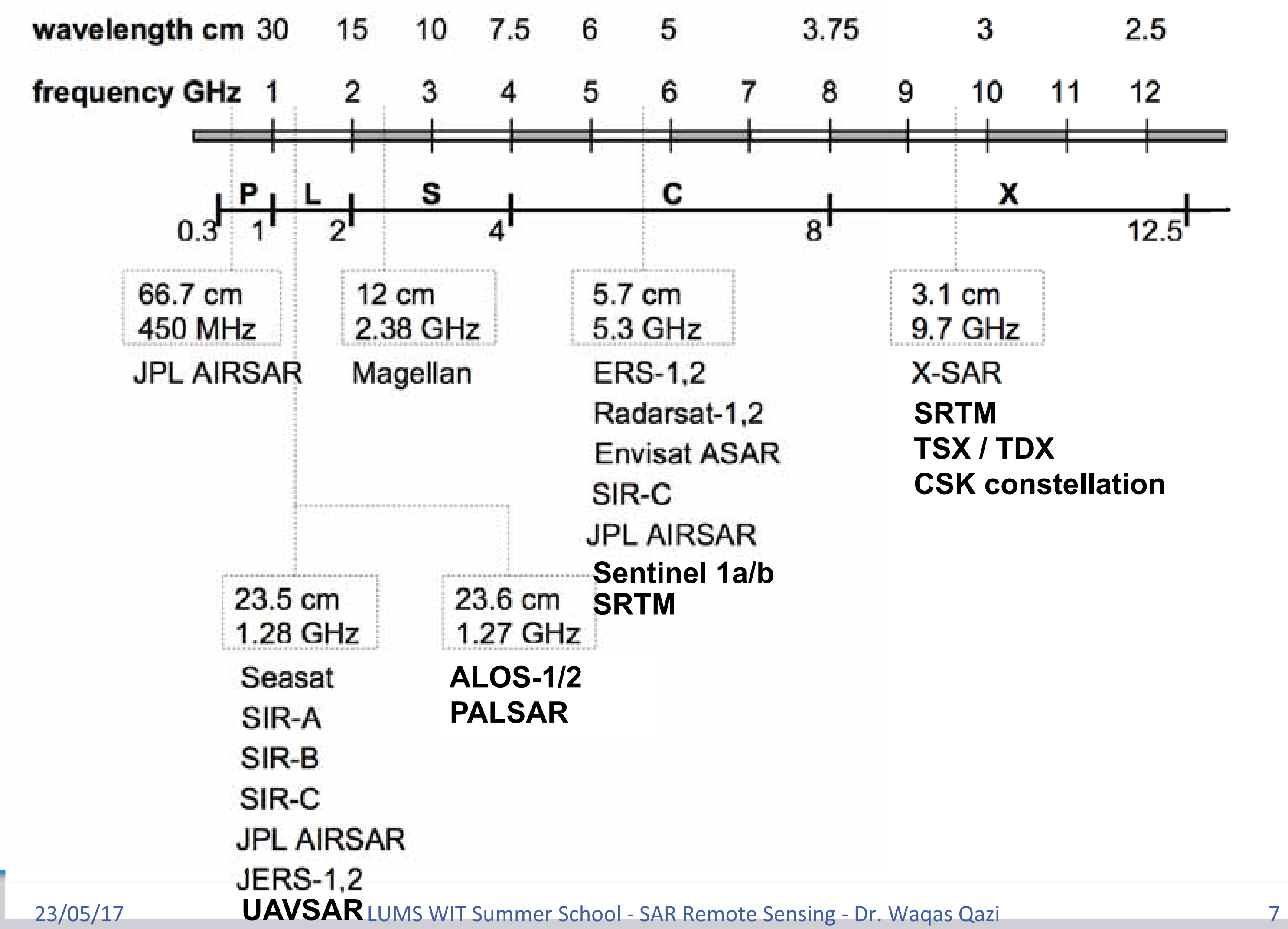
Radar for Earth Remote Sensing

- Atmosphere is generally transparent for microwave frequencies
- Microwaves are cloud-penetrating and are independent of atmospheric conditions like dust and haze.
- Some attenuation windows in 30 MHz - 30 GHz range
- Rainfall attenuation
- Radar remote sensing can function under almost all weather and environmental conditions

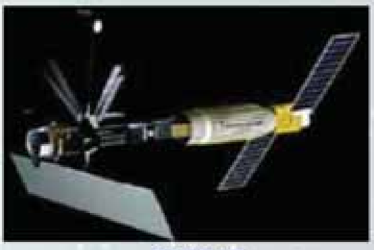


Richards (2009)

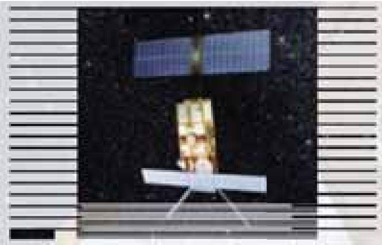
Some Airborne / Spaceborne SAR Imaging Systems



Spaceborne SAR Systems



SEASAT
NASA/JPL (USA)
L-Band, 1978



ERS-1/2
European Space Agency (ESA)
C-Band, 1991-2000/1995-2011

J-ERS-1
Japanese Space Agency (JAXA)
L-Band, 1992-1998

SIR-C/X-SAR
NASA/JPL, L- and C-Band (quad)
DLR / ASI, X-band 1994

RadarSAT-1
Canadian Space Agency (CSA)
C-Band, 1995-2013

Shuttle Radar Topography Mission (SRTM)
NASA/JPL (C-Band), DLR (X-Band)
February 2000

ENVISAT / ASAR
European Space Agency (ESA)
C-Band (dual), 2002-2012

ALOS / PALSAR
Japanese Space Agency (JAXA)
L-Band (quad), Jan. 2006-2011

SAR-Lupe
BWB, Germany
5 satellites, X-Band, 2006/2008

Spaceborne SAR Systems

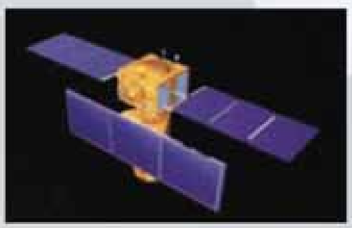
RadarSAT-II
Canadian Space Agency (CSA)
C-Band (quad), 2007

TerraSAR-X/TanDEM-X
DLR /Astrium, Germany
X-Band (quad), 2007/2010

COSMO-SkyMed
ASI, Italy
4 Satellites, X-Band (dual), 2007/2010

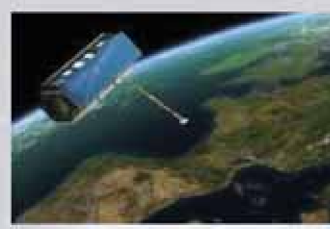
Kompsat-5
KARI, Korea
X-band (dual), 2013

HJ-1C -SAR
CRESDA/CAST/NRSCC, China
S-Band (HH or VV), 2013



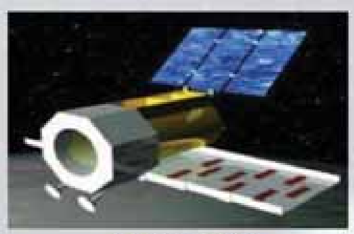
RISAT-1
Indian Space Agency (ISRO), India
C-Band (quad), 2012

SENTINEL-1a/b
ESA, Europe
C-Band (dual), 2014/2015



PAZ
Ministry of Defence, Spain
X-Band (quad), 2014

ALOS-2
Japanese Space Agency (JAXA)
L-Band (quad), 2014



SAOCOM-1/2
CONAE/ASI, Argentina
L-Band (quad), 2016/2018

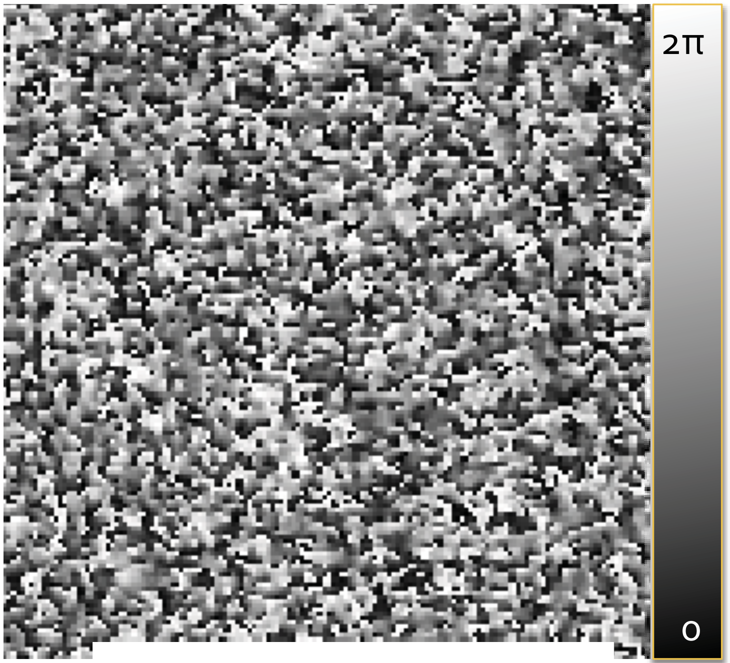
Radarsat Constellation 1-3
CSA/MDA, Canada
C-band (dual), 2018

BIOMASS
ESA, Europe
P-Band (quad), 2020

SAR Image Example

- The basic SAR measurement is a “complex signal”
- Complex signal:
  - “Real part” and “Imaginary part”
  - “Amplitude” and “phase”

Intensity



Phase

Complex Numbers

Define $i = \sqrt{-1}$

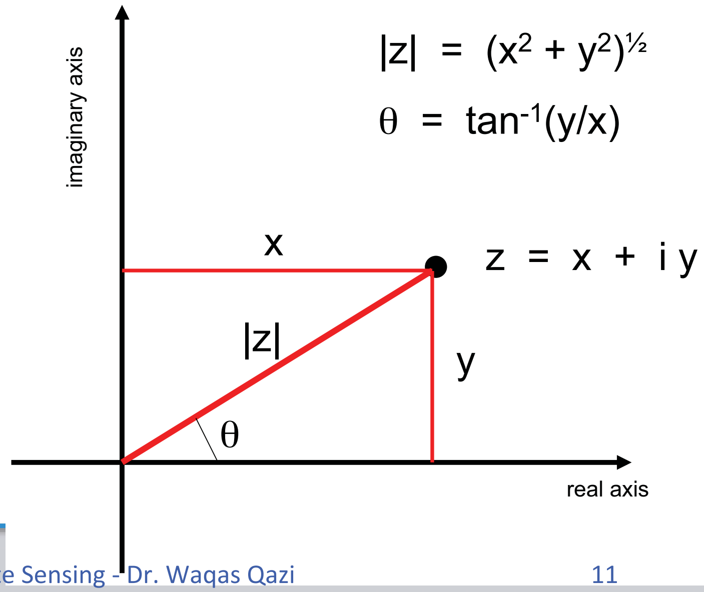
Complex variable : $z = x + iy$

Complex conjugate : $z^* = x - iy$

Squared magnitude of z :

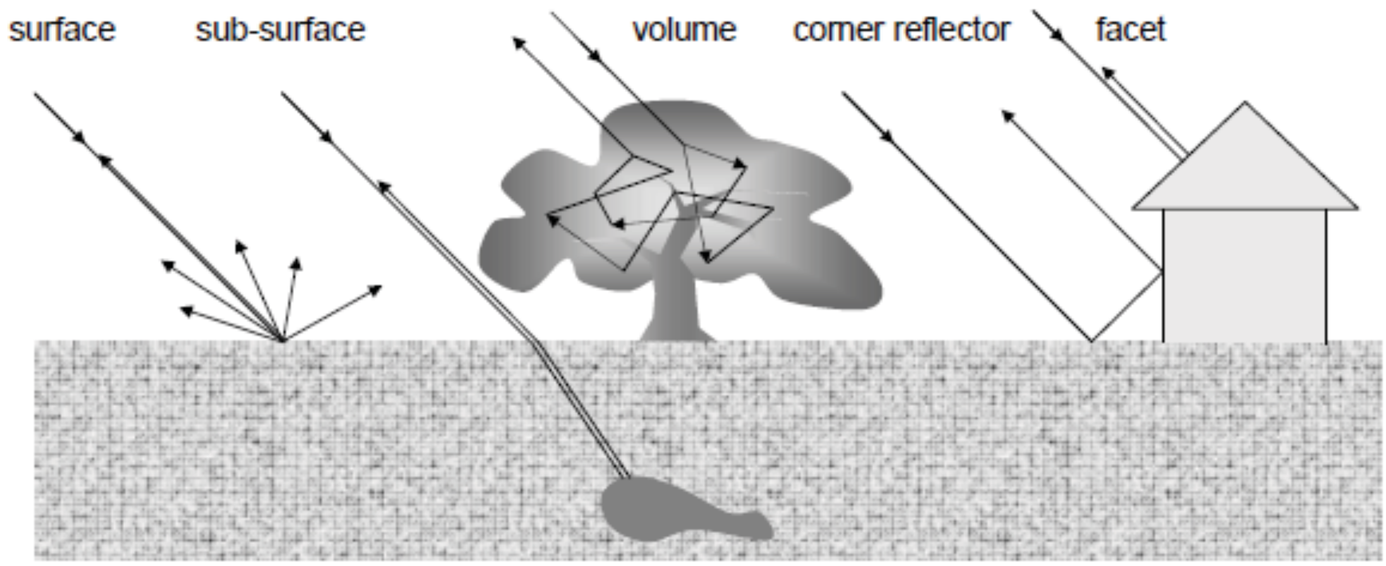
$$|z|^2 = zz^* = (x + iy)(x - iy) = x^2 + y^2$$

Phase of z : $\tan^{-1}(y/x)$



Common Scattering Mechanisms

- Surface scattering
- Volume scattering
- Hard target scattering



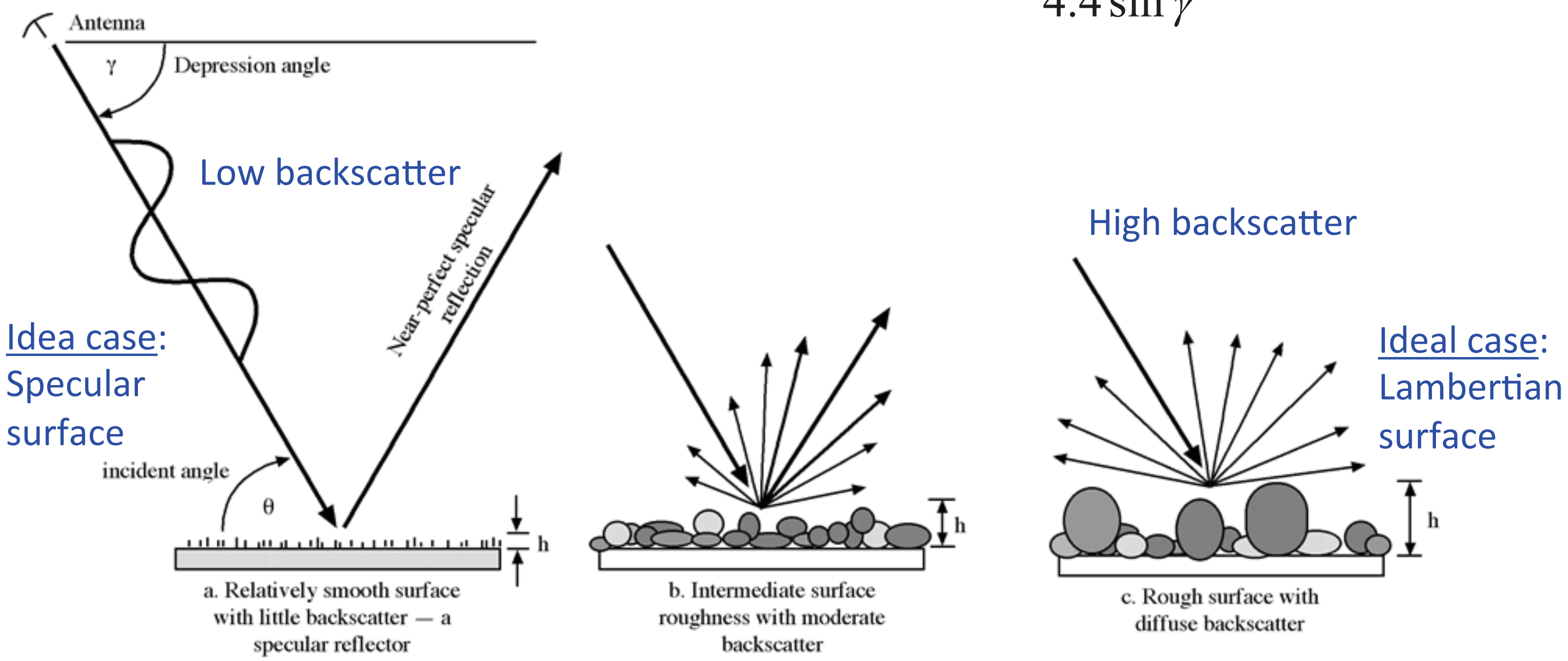
Richards (2009)

Basic SAR Measurement of Surface Scattering: Surface Roughness

Rayleigh roughness criterion::

$$\text{Smooth } h \le \frac{\lambda}{25 \sin \gamma}$$

$$\text{Rough } h \ge \frac{\lambda}{4.4 \sin \gamma}$$



Subsurface Imaging with SAR

Complex Relative Permittivity

- To study the electromagnetic wave interaction with different materials and objects, one parameter that is used is called "relative permittivity" ε_r
- In general, the relative permittivity is a complex number, and is thus also called the "complex relative permittivity":

$$\varepsilon_r = \varepsilon_r^{'} + i\varepsilon_r^{''}$$

- The real part ε', also called "dielectric constant", describes the ability of the medium to store electrical energy or as a measure of reflection / scattering
- The imaginary part ε'', also termed as "loss factor", describes the electromagnetic loss in the medium due to absorption and is used as a measure of "penetration"
- Generally, $\varepsilon_r^{''} << \varepsilon_r^{'}$ for remote sensing targets

Radar Penetration Depth

- The "*penetration depth (δ)*" is defined as the distance at which the power density of the electromagnetic wave drops to *1/e* of its value at the immediate sub-surface:

$$\delta = \frac{\lambda}{2\pi}\frac{\sqrt{\varepsilon_r^{'}}}{\varepsilon_r^{''}}$$

- This equation follows the "small angle approximation" and assumes uniform material properties with depth
- The derivation of penetration depth is mostly covered in any undergrad / grad course on electromagnetic waves. Ask me for relevant references.

Penetration into Surface Materials – Penetration Depth

$$\delta = \frac{\lambda}{2\pi}\frac{\sqrt{\varepsilon_r^{'}}}{\varepsilon_r^{''}}$$

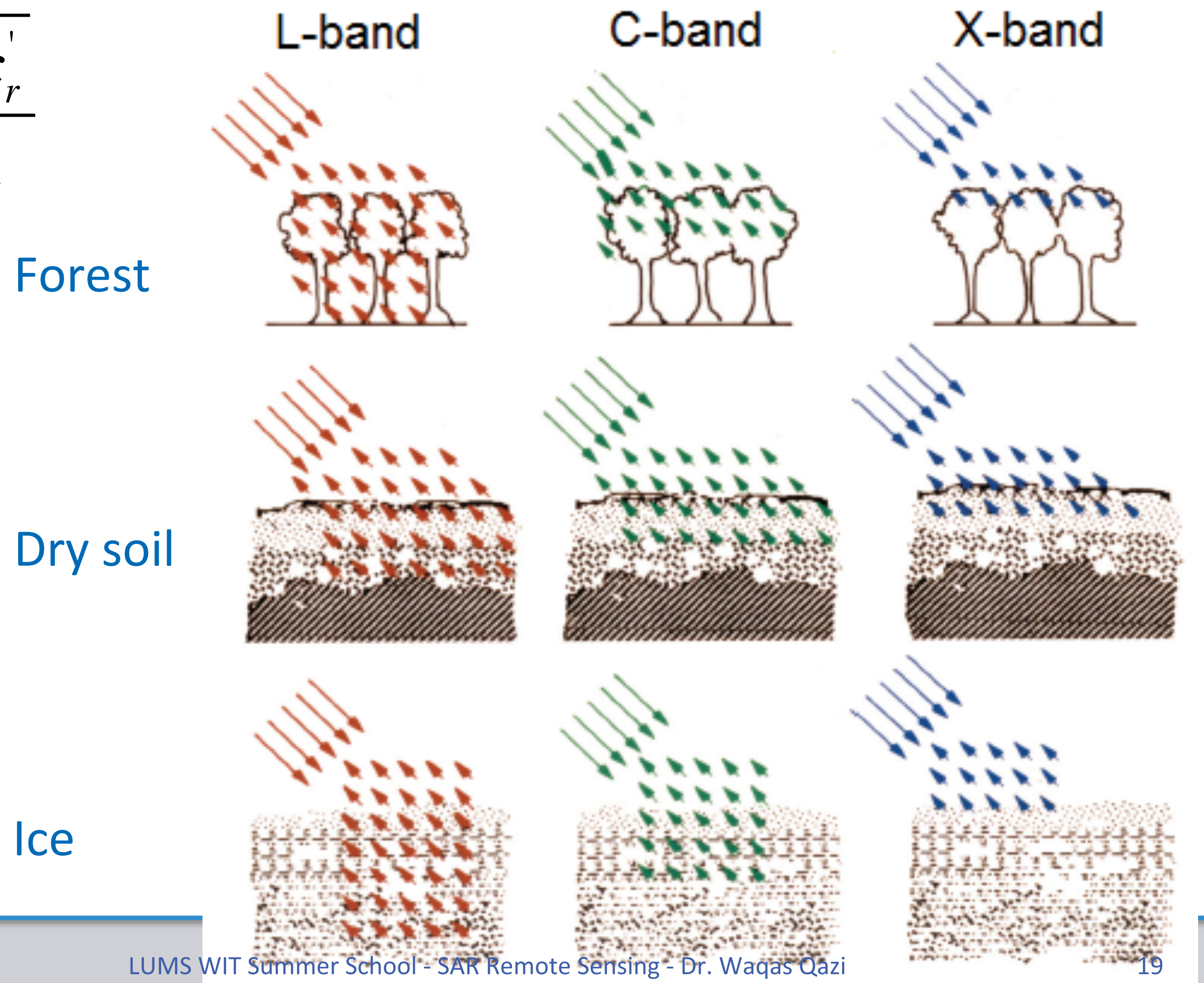
- Larger wavelength (smaller frequency) means more penetration
- Penetration increases as dielectric constant ε_r' increases
- Penetration decreases as loss factor ε_r'' increases

Penetration into Surface Materials – Penetration Depth

- Lower frequencies penetrate more
- Penetration depends upon moisture content; the more the moisture content, the more quickly radar waves get absorbed, i.e. the more the moisture content, the less the radar waves penetrate

Penetration into Surface Materials – Penetration Depth

$$\delta = \frac{\lambda}{2\pi}\frac{\sqrt{\varepsilon_r^{'}}}{\varepsilon_r^{''}}$$

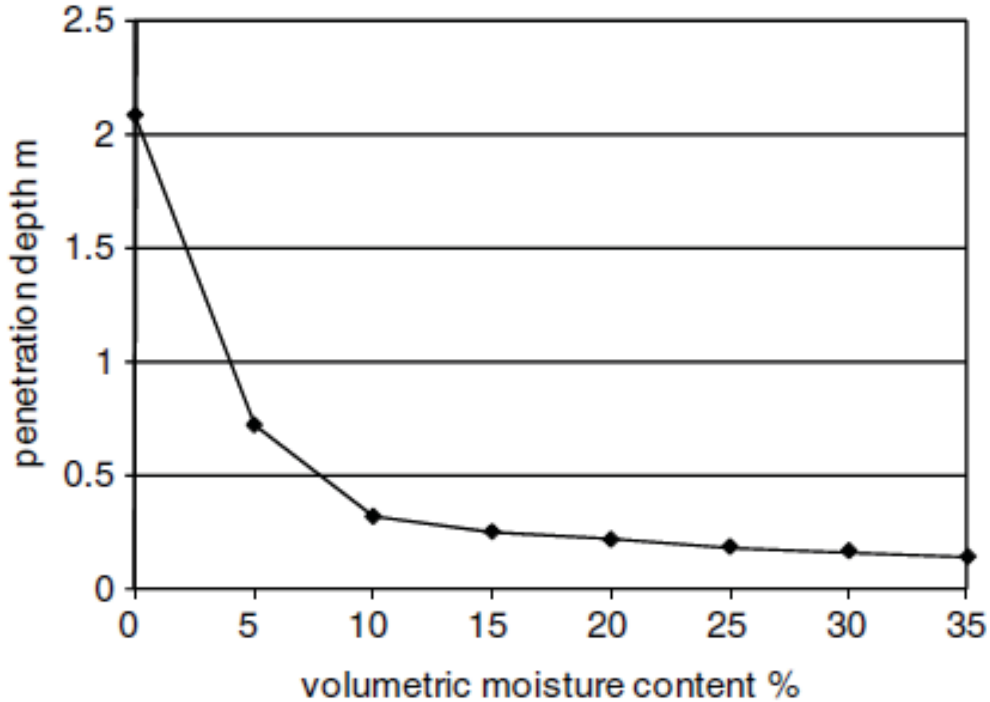


Penetration into Surface Materials – Penetration Depth

$$\delta = \frac{\lambda}{2\pi}\frac{\sqrt{\varepsilon_r^{'}}}{\varepsilon_r^{''}}$$

- Low-frequency SAR / imaging radar signals can penetrate sand up to a few meters only in the case of very dry and arid regions, e.g. Sahara desert

Penetration depth simulation for sand at L-band



Richards (2009)

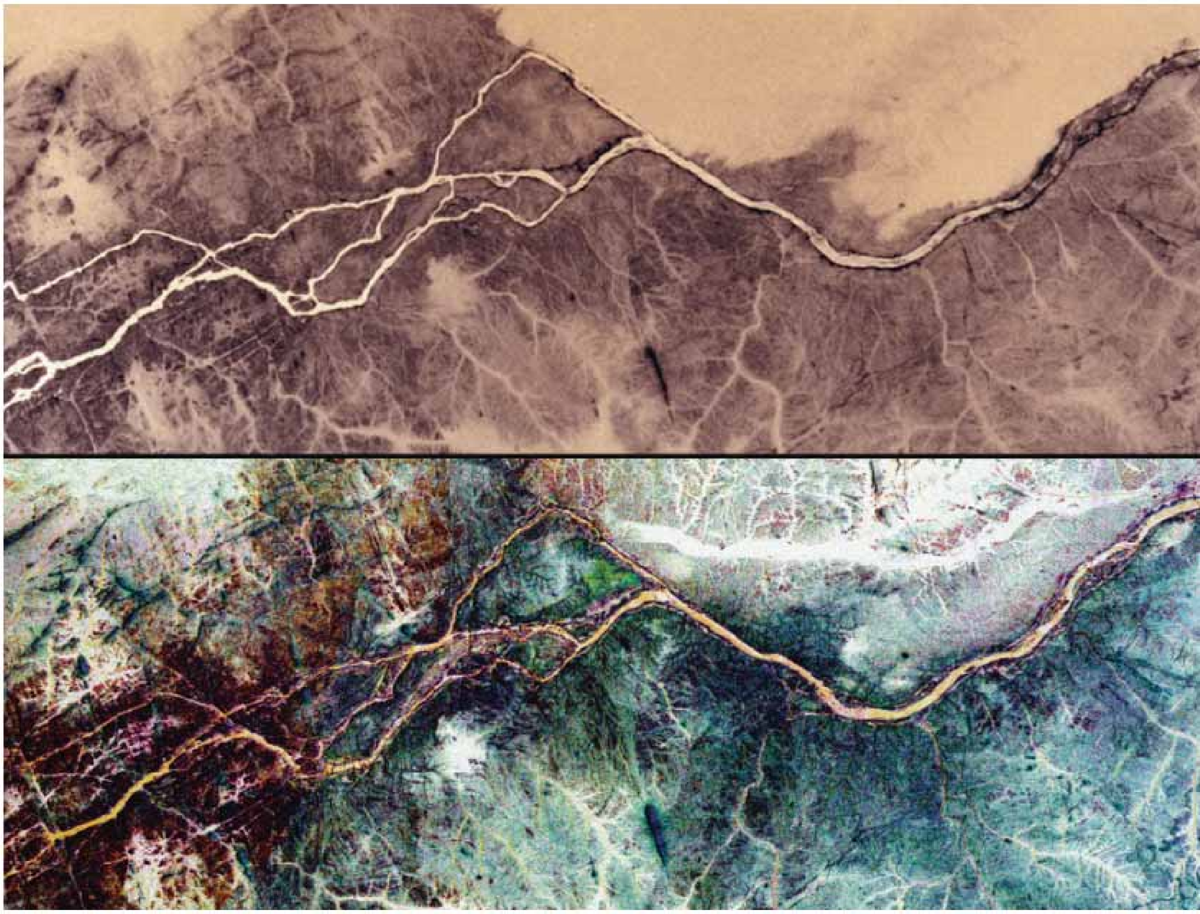
Penetration into Surface Materials – Penetration Depth

- What about penetration into a water body itself, such a lake / ocean?
- Water is a good conductor at microwave frequencies, and the imaginary part of the complex relative permittivity has a significant value for water
- Going through the calculations for water as a conducting medium shows us: The penetration depth of L-band imaging radar in sea water is just 7 mm!

Richards (2009)

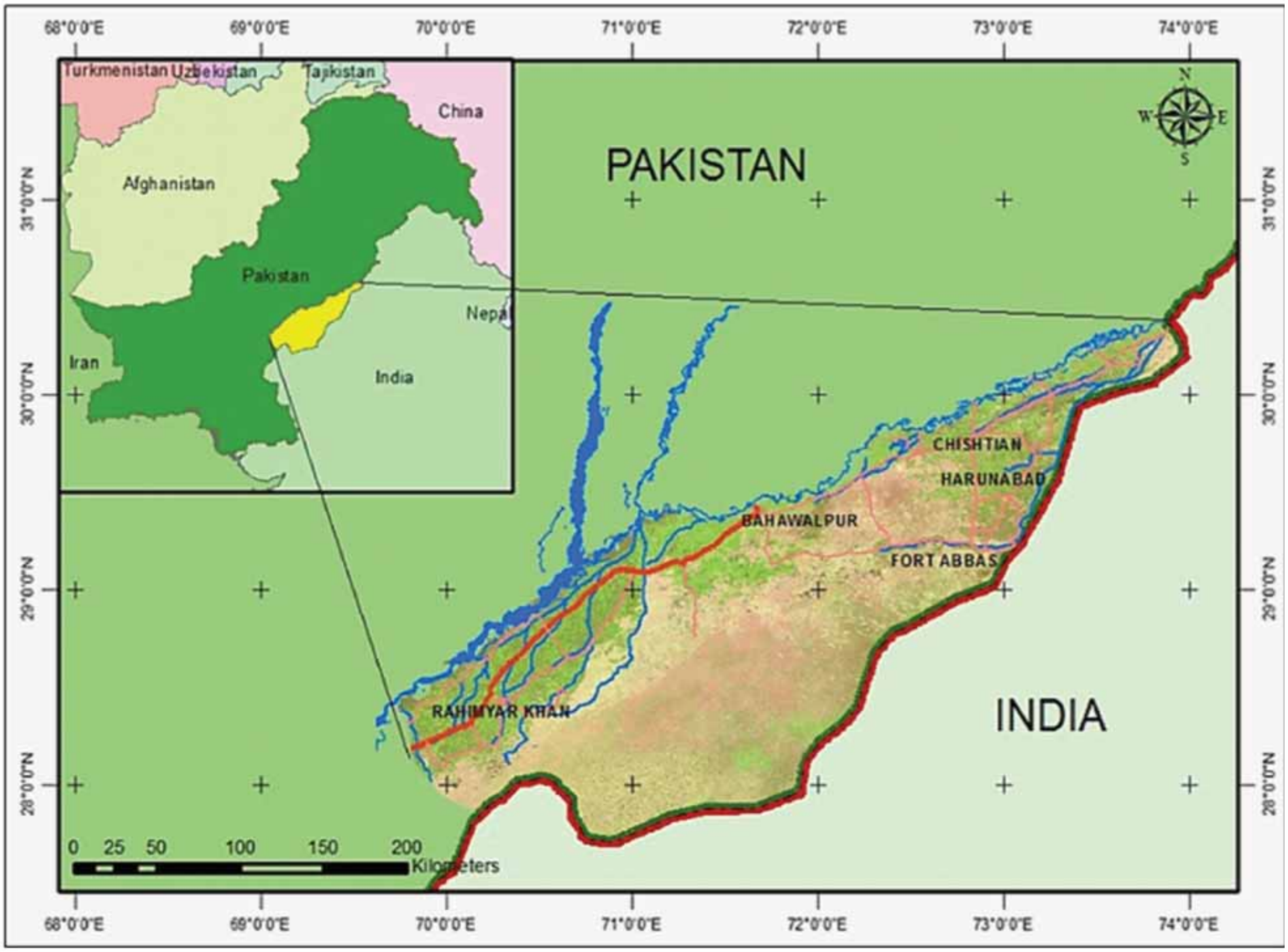
Penetration into Surface Materials – Penetration Depth

Top image is color infrared photo, and bottom image is SIR-C radar image, recorded in 1995 over Sahara Desert in Sudan. The radar color image is created using cross-pol and co-pol composites of L-band and C-band radar images.



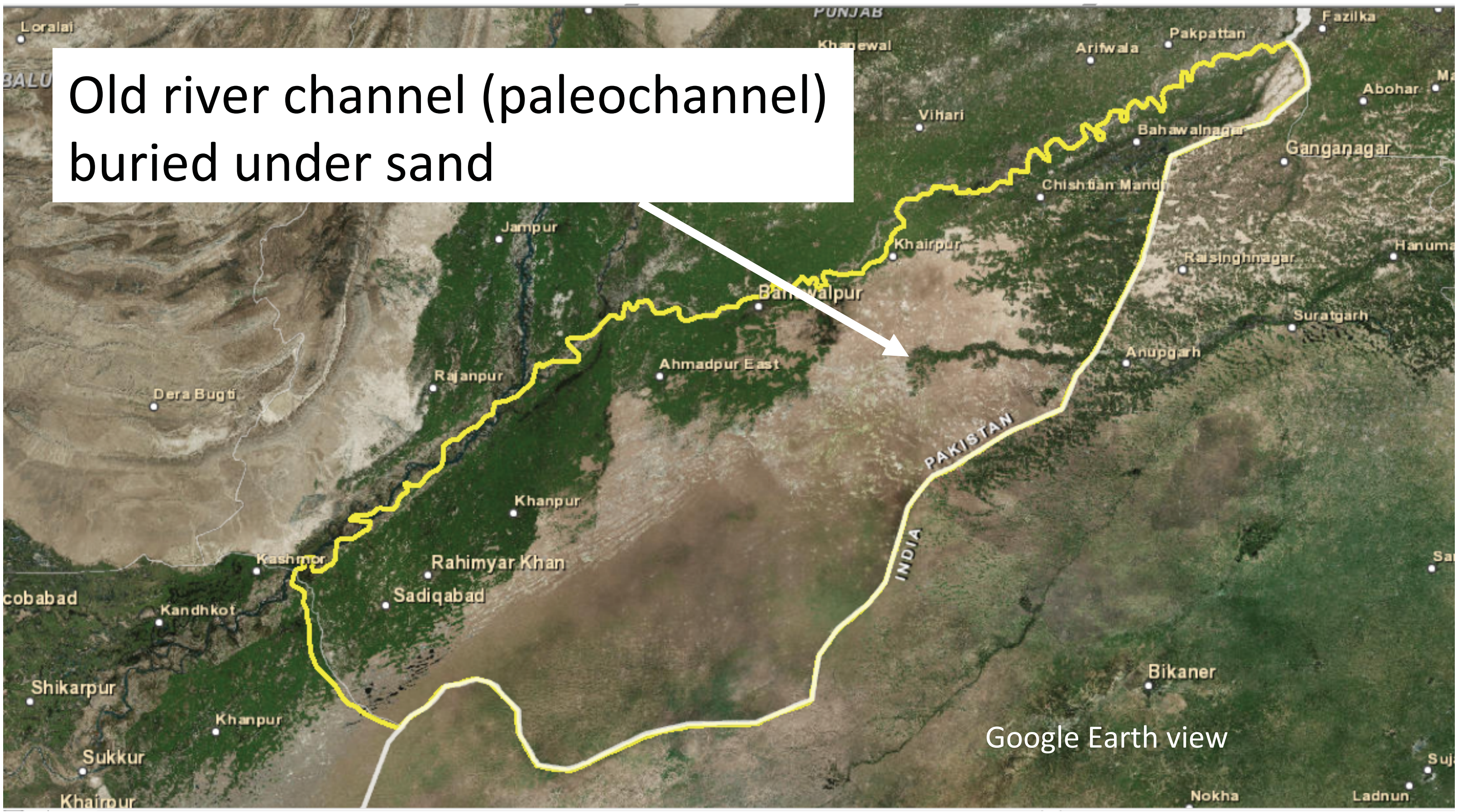
Richards (2009) – Fig. 5.14

Identification of Hakra River Paleochannel



Islam, Z., Iqbal, J., Khan, J. & **Qazi, W.** (2016). Paleochannel delineation using Landsat 8 OLI and Envisat ASAR image fusion techniques in Cholistan desert, Pakistan. *Journal of Applied Remote Sensing*, *10*(4), 46001.

Identification of Hakra River Paleochannel



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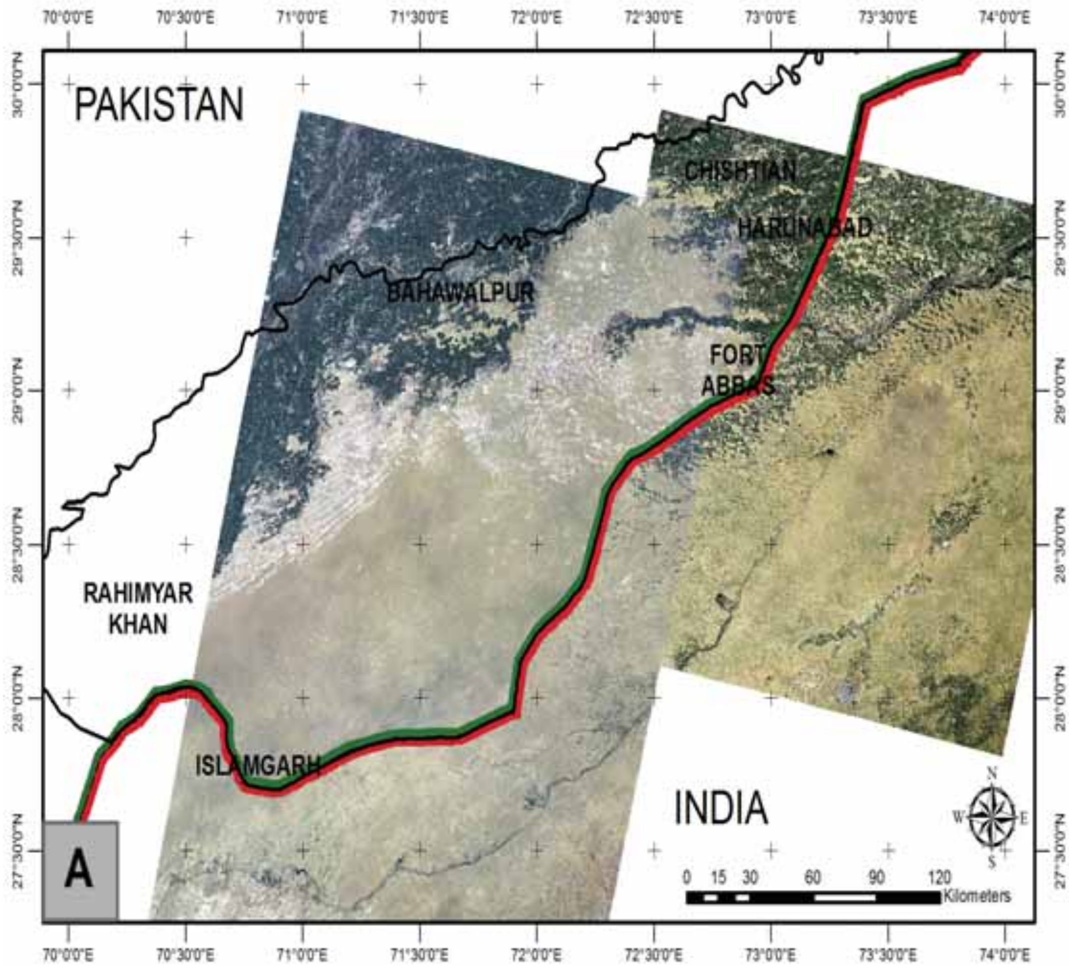
Identification of Hakra River Paleochannel

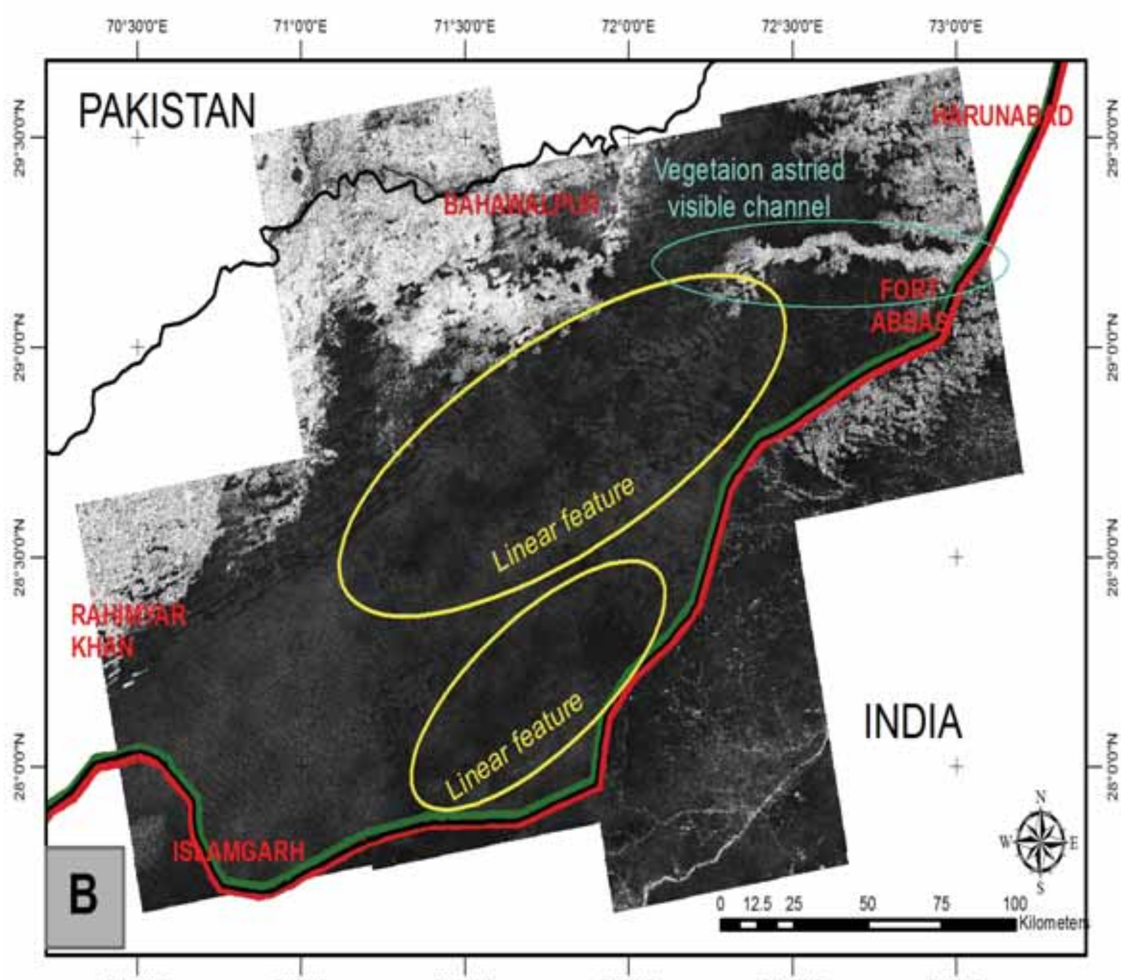
<u>Landsat 8</u>
Atmospheric-corrected and calibrated mosaic
Data acquired from USGS



Islam, Z., Iqbal, J., Khan, J. & **Qazi, W.** (2016). Paleochannel delineation using Landsat 8 OLI and Envisat ASAR image fusion techniques in Cholistan desert, Pakistan. *Journal of Applied Remote Sensing*, *10*(4), 46001.

Identification of Hakra River Paleochannel

<u>Evisat ASAR</u>
Intensity mosaic
Calibrated and Speckle-filtered
Data acquired from ESA



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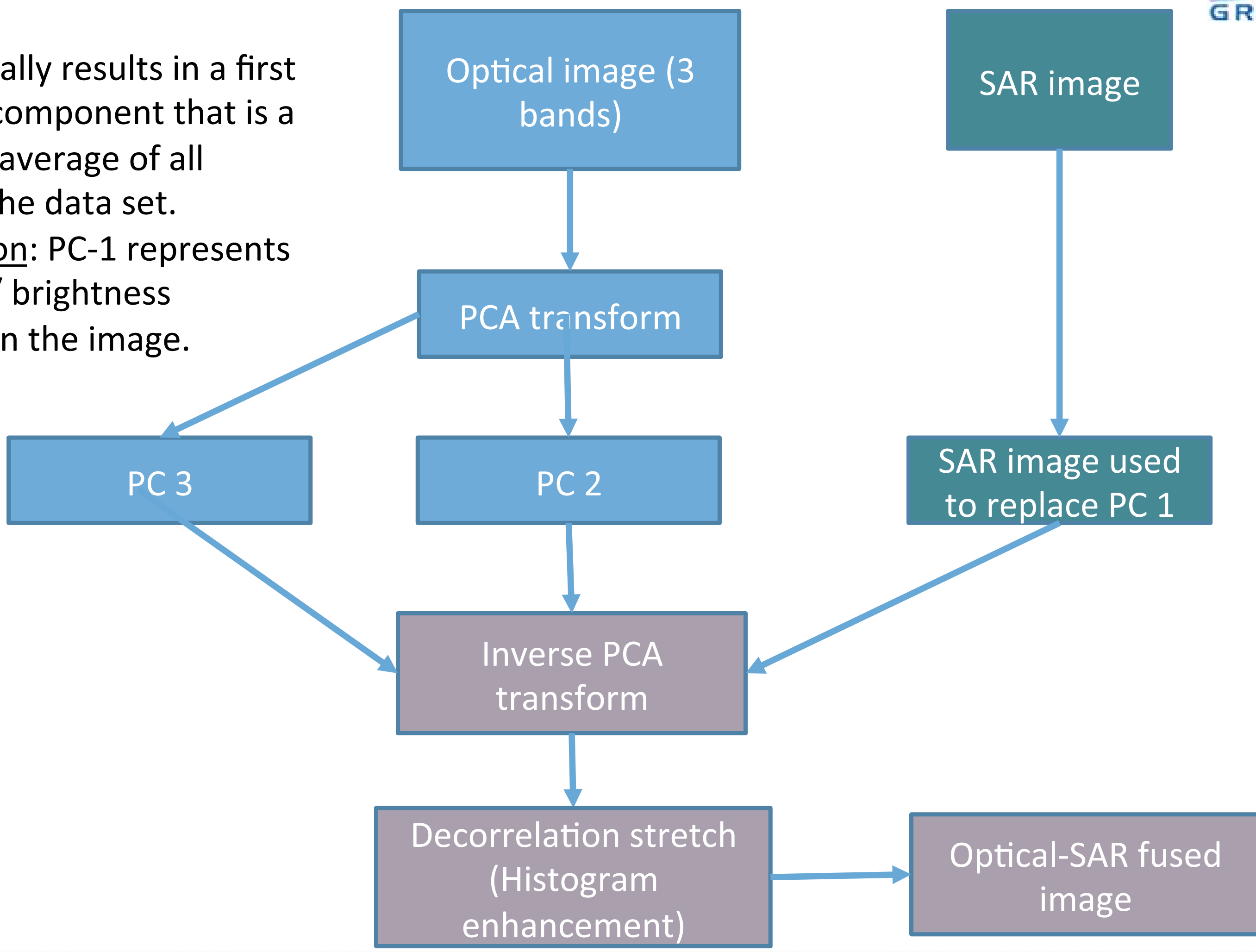
SAR & Optical Data Fusion using PCA

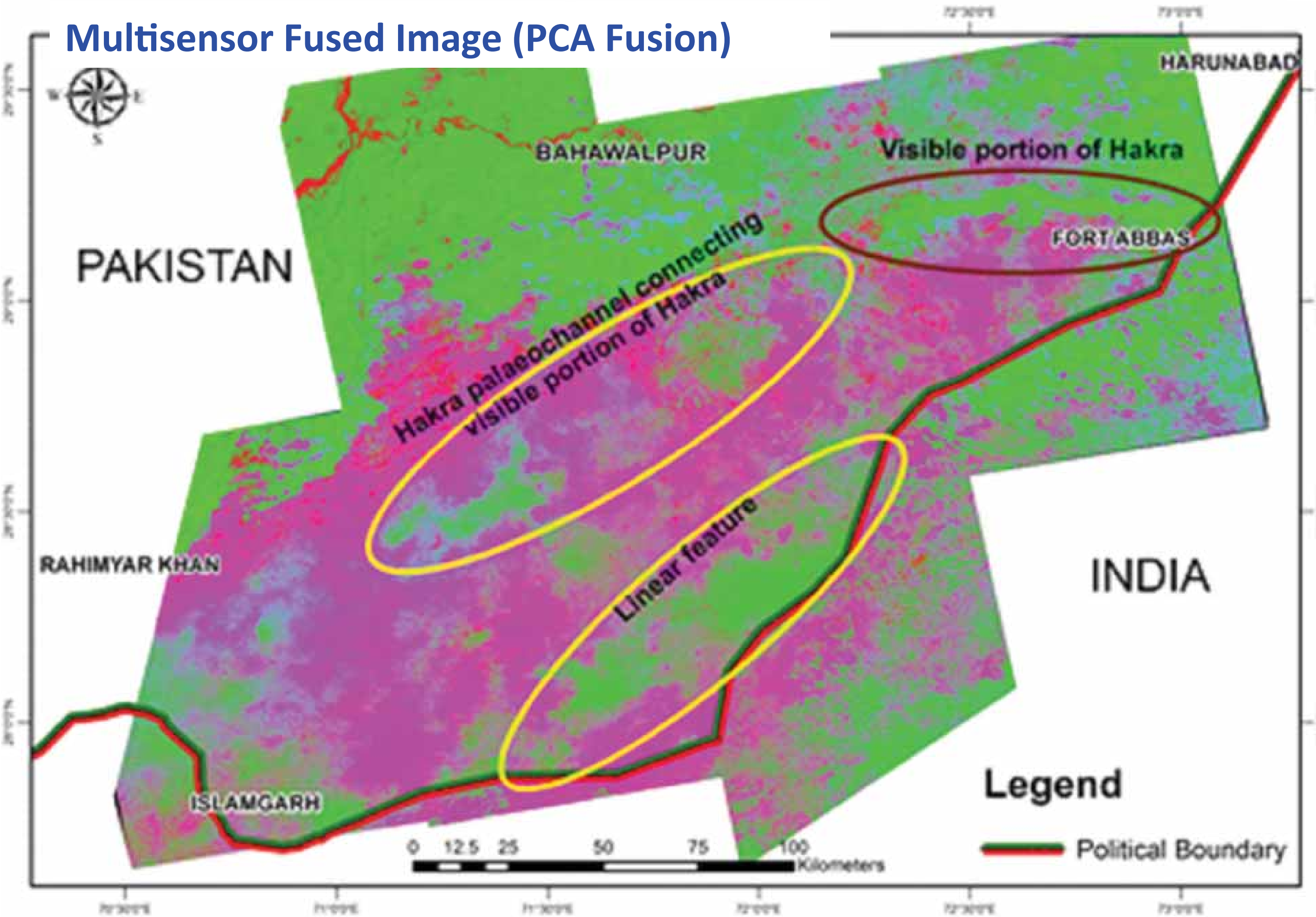
PCA normally results in a first principal component that is a weighted average of all bands in the data set.

<u>Assumption</u>: PC-1 represents intensity / brightness variation in the image.



Identification of Hakra River Paleochannel

Multisensor Fused Image (PCA Fusion)



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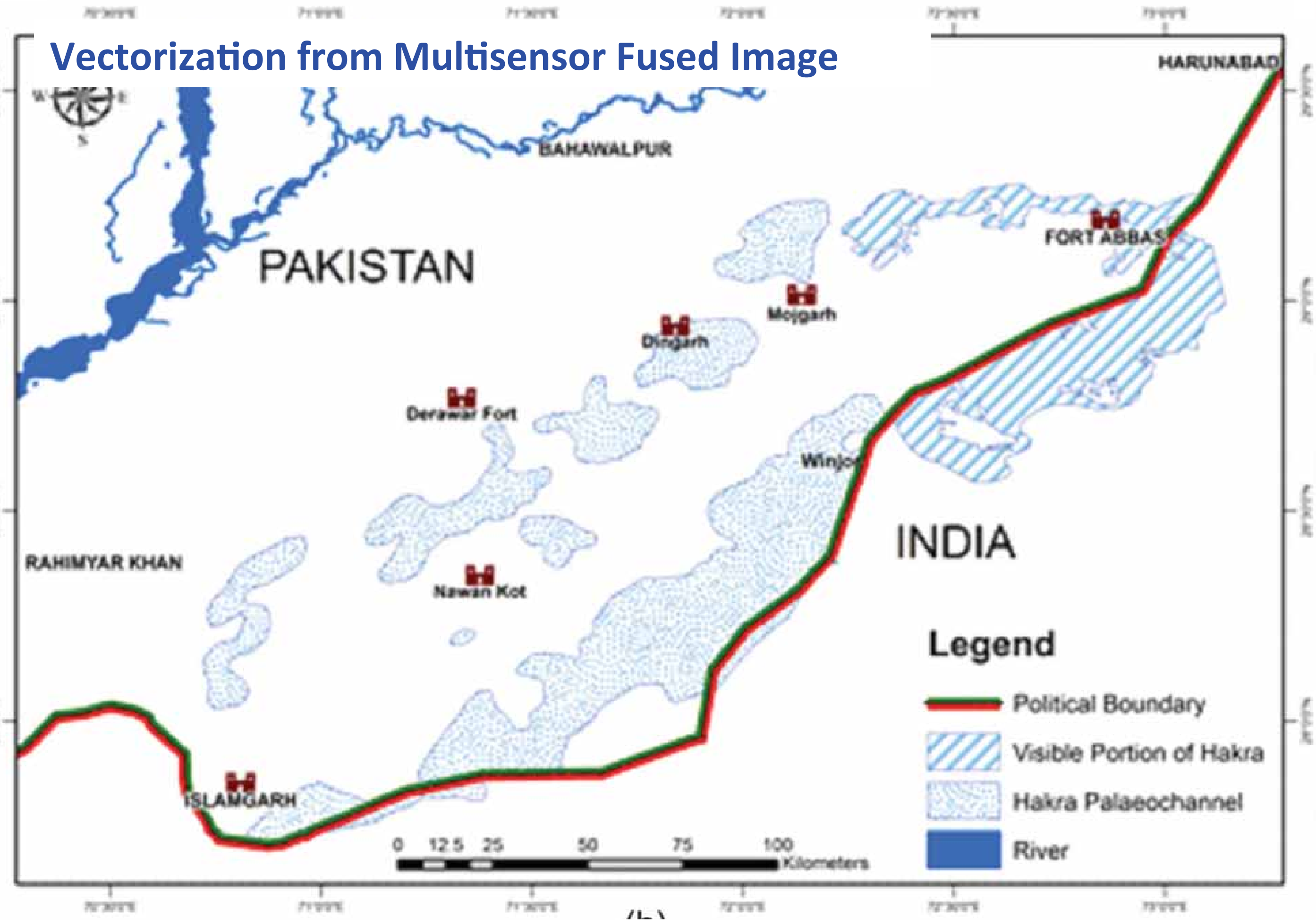
Identification of Hakra River Paleochannel

Vectorization from Multisensor Fused Image



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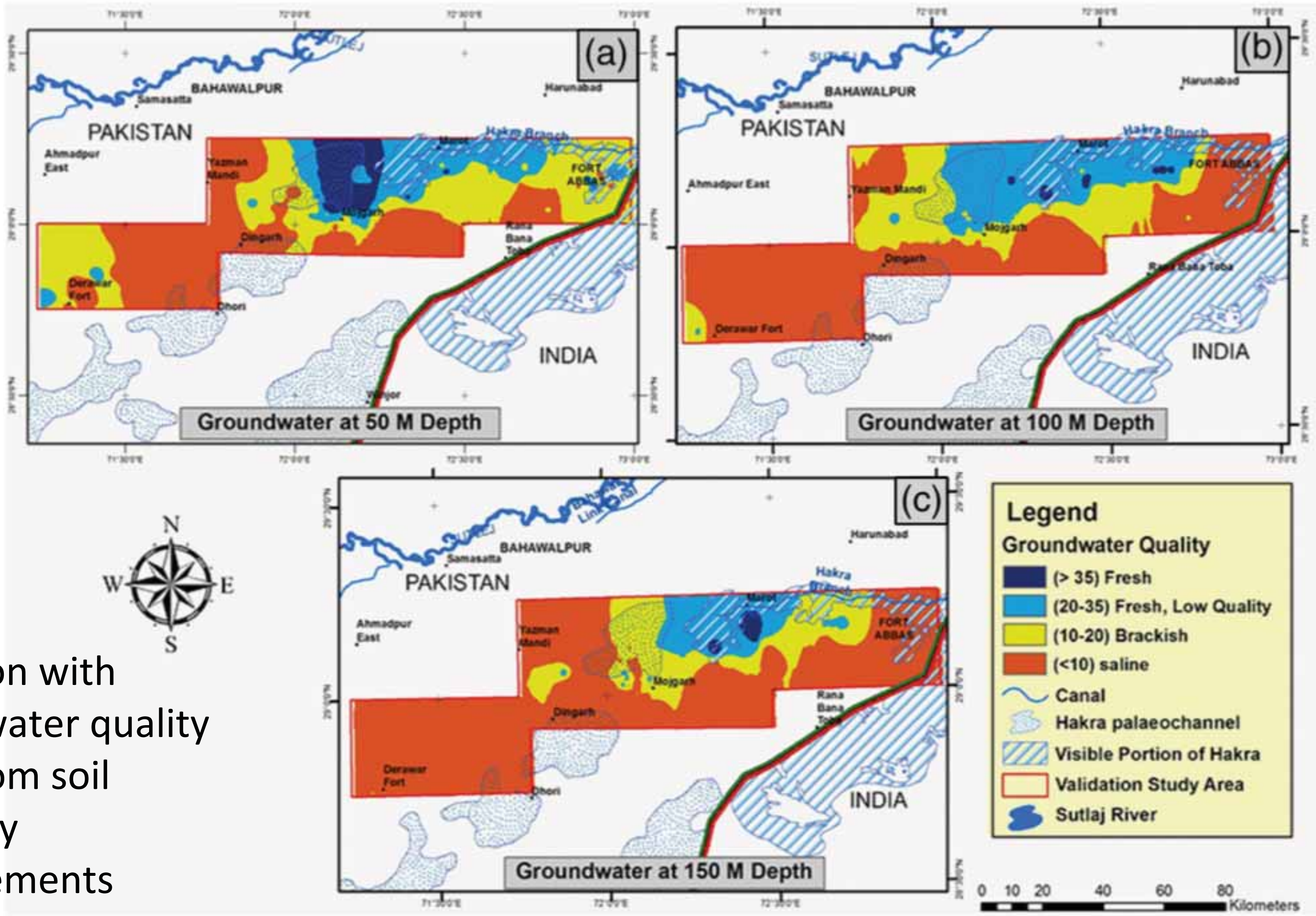
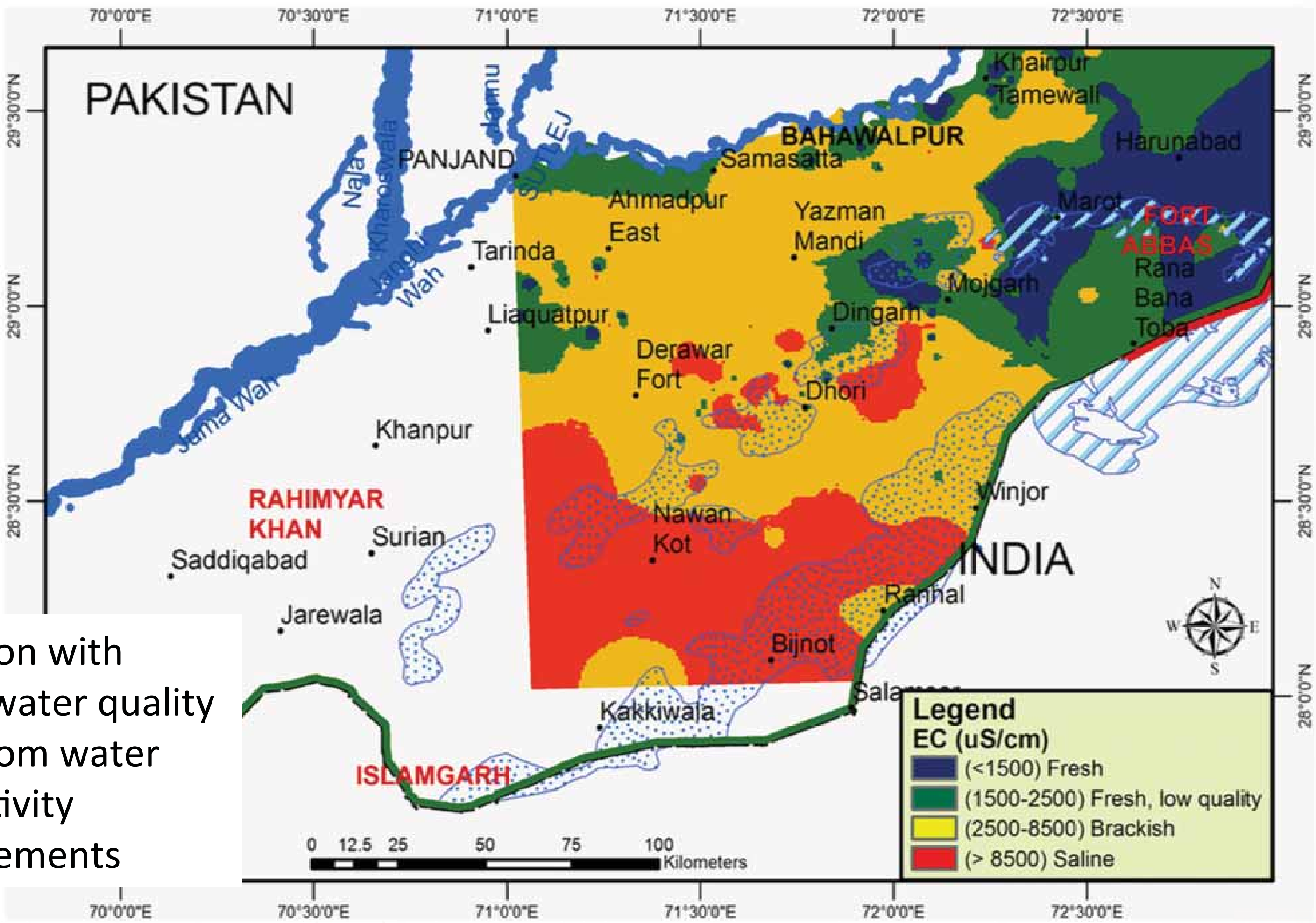
Identification of Hakra River Paleochannel



Validation with groundwater quality maps from soil resistivity measurements

Islam, Z., Iqbal, J., Khan, J. & **Qazi, W.** (2016). Paleochannel delineation using Landsat 8 OLI and Envisat ASAR image fusion techniques in Cholistan desert, Pakistan. *Journal of Applied Remote Sensing*, *10*(4), 46001.

Identification of Hakra River Paleochannel

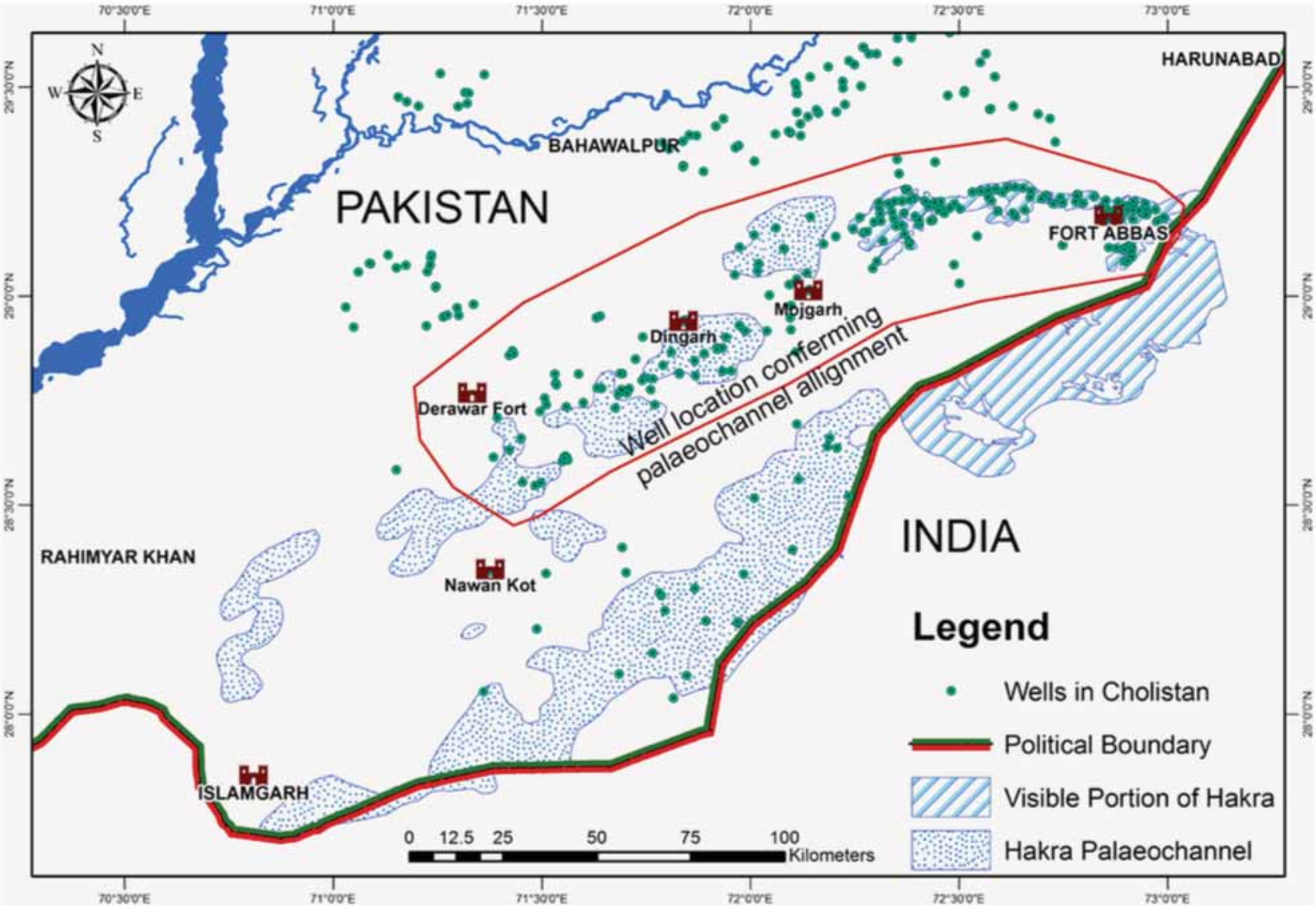


Validation with groundwater quality maps from water conductivity measurements

Islam, Z., Iqbal, J., Khan, J. & **Qazi, W.** (2016). Paleochannel delineation using Landsat 8 OLI and Envisat ASAR image fusion techniques in Cholistan desert, Pakistan. *Journal of Applied Remote Sensing*, *10*(4), 46001.

Identification of Hakra River Paleochannel

Validation with forts and water sources locations



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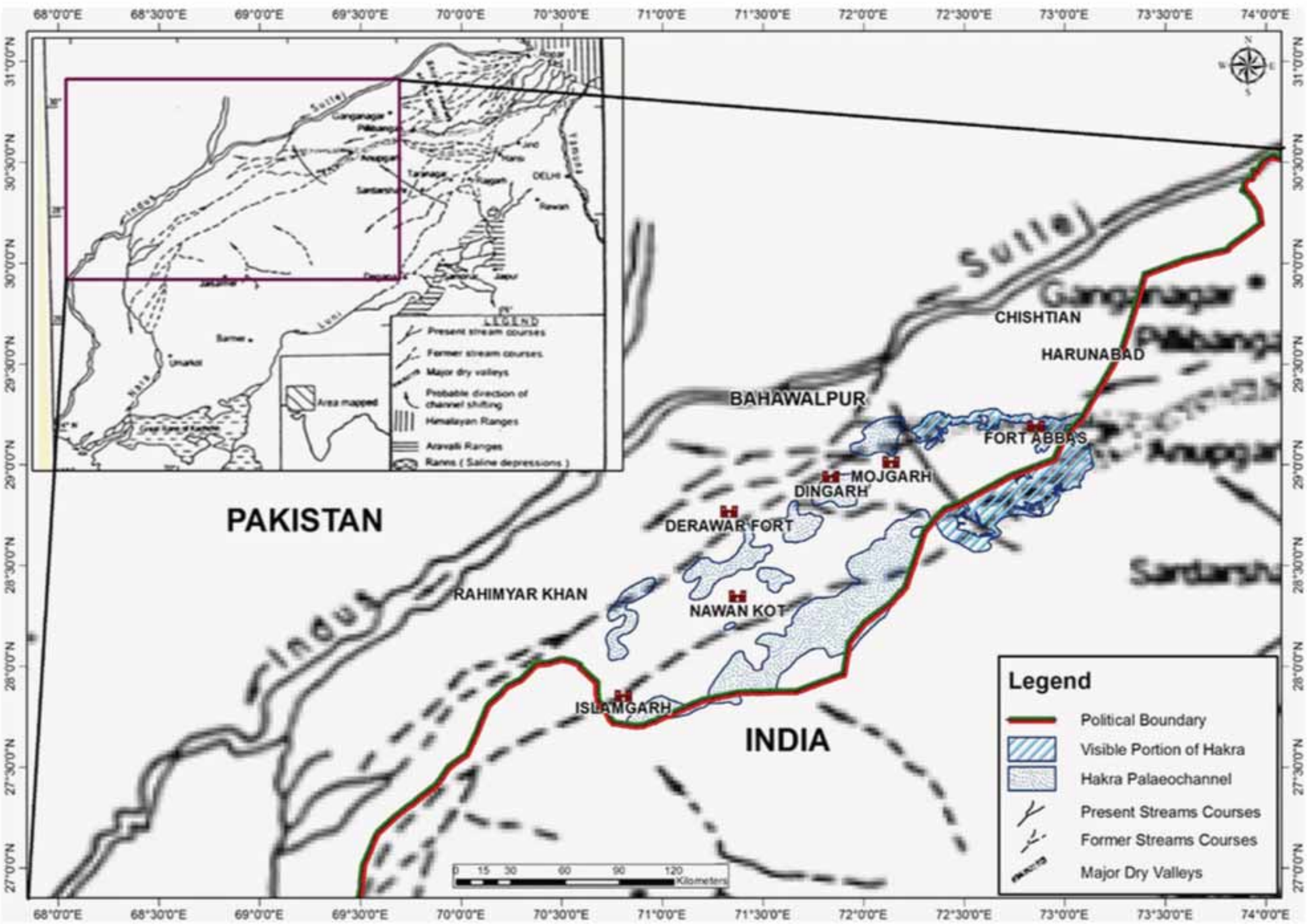
Identification of Hakra River Paleochannel

Validation with paleochannels reported by Sinha (2006)



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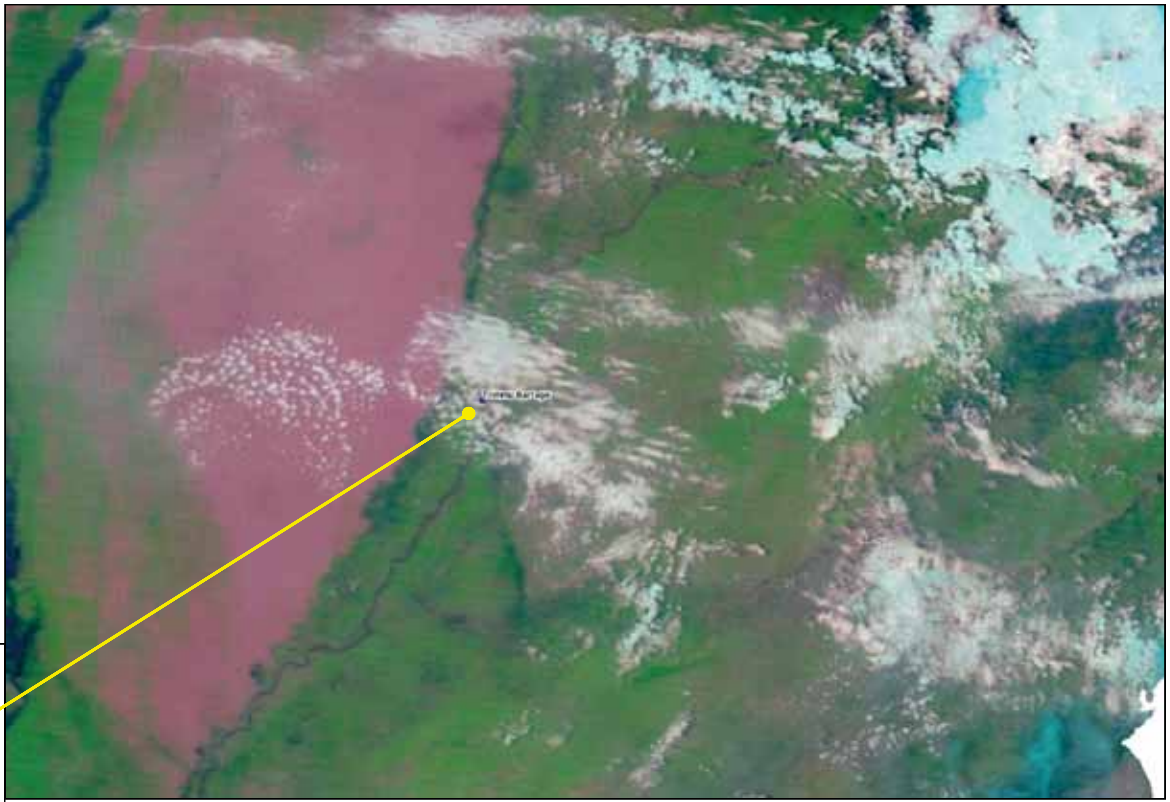
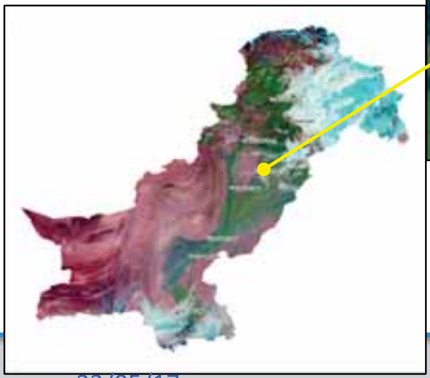
Flood Inundation Mapping

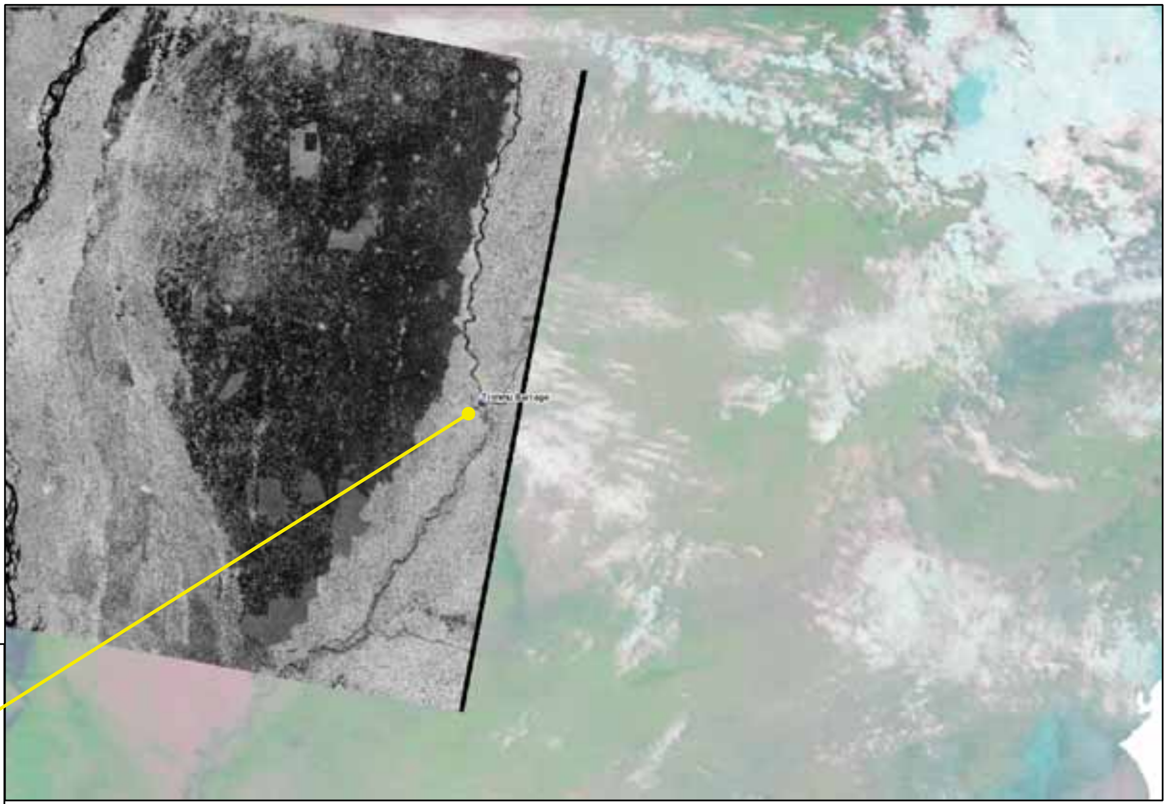
Flood Inundation Mapping

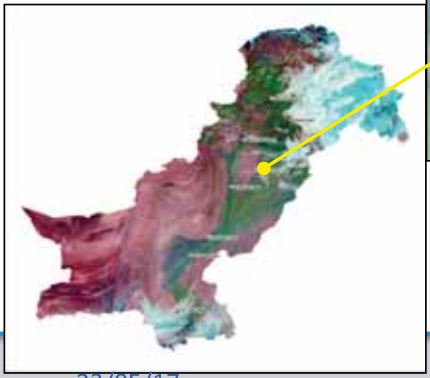




Courtesy: SACRED-SUPARCO

Flood Inundation Mapping

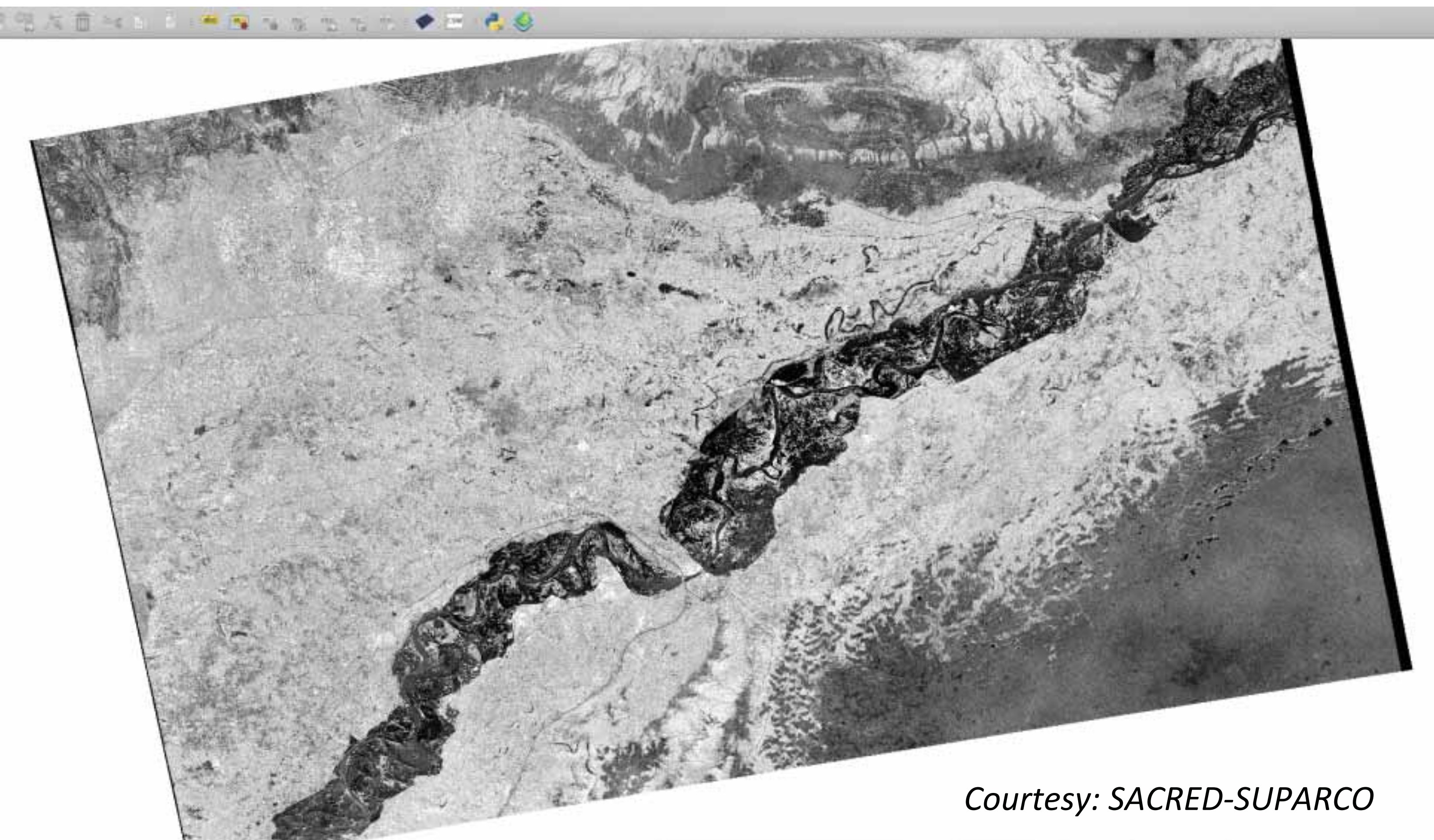




Courtesy: SACRED-SUPARCO

Flood Inundation Mapping

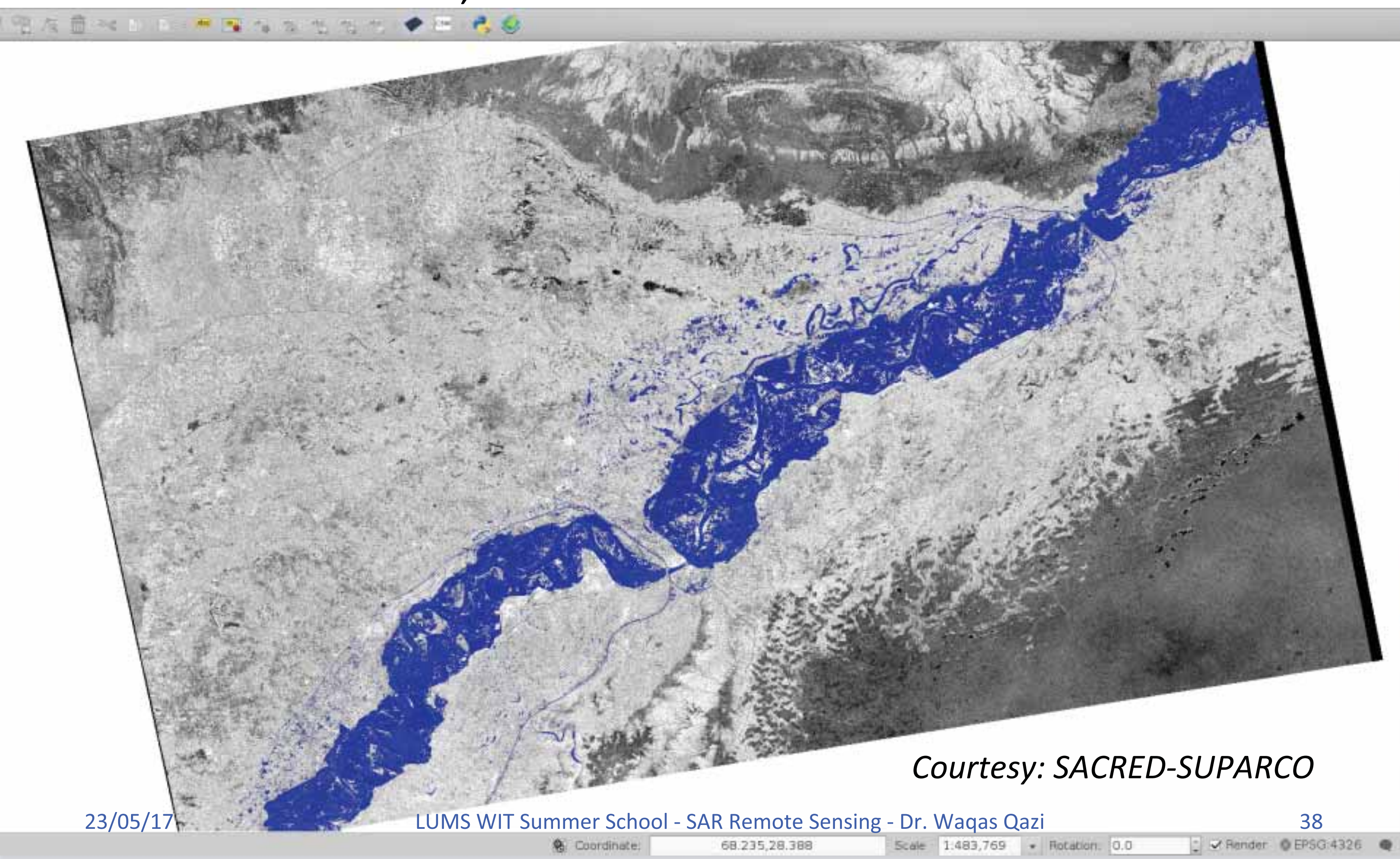
Sentinel-1 SAR data, Pakistan floods 2015



Courtesy: SACRED-SUPARCO

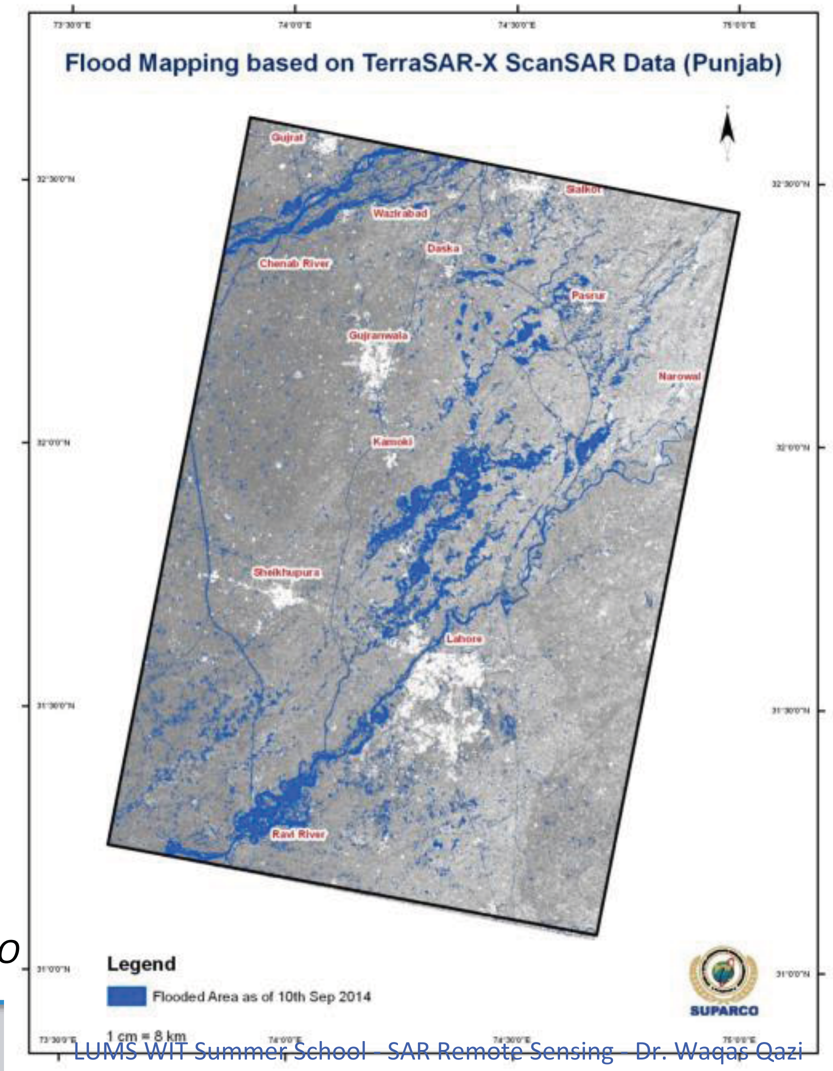
Flood Inundation Mapping

Flood inundation mapped by SACRED-SUPARCO on Sentinel-1 SAR data, Pakistan floods 2015



Courtesy: SACRED-SUPARCO

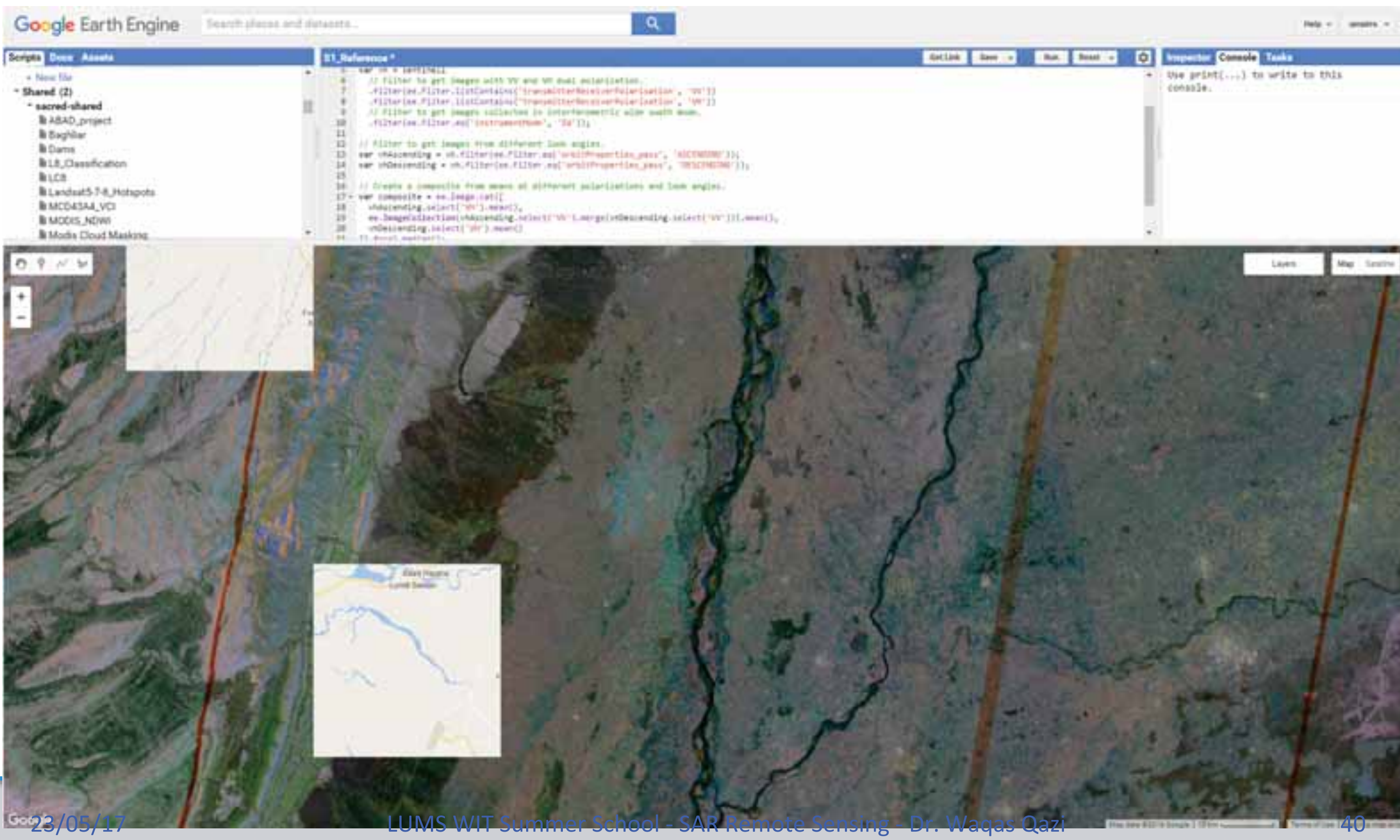
Flood Inundation Mapping



Courtesy: SACRED-SUPARCO

Flood Inundation Mapping – Cloud- based Large-Scale Analysis over Sentinel-1

https://earthenable.wordpress.com/2015/09/01/processing-terabytes-of-satellite-imagery-in-google-earth-engine-crisis-response-for-2015-flood-season-in-pakistan/



SSOR-FIM: Satellite SAR and Optical Rapid Flood Inundation Mapping

- Undergrad FYP, just being finished at IST, Islamabad.
- We have used a combination of different software tools (*ENVI MCTK, IDL, MATLAB, ESA SNAP*) and operate them using *Windows command-line* to generate a semi-automated tool for flood inundation mapping using both optical and SAR imagery

SSOR-FIM: Satellite SAR and Optical Rapid Flood Inundation Mapping

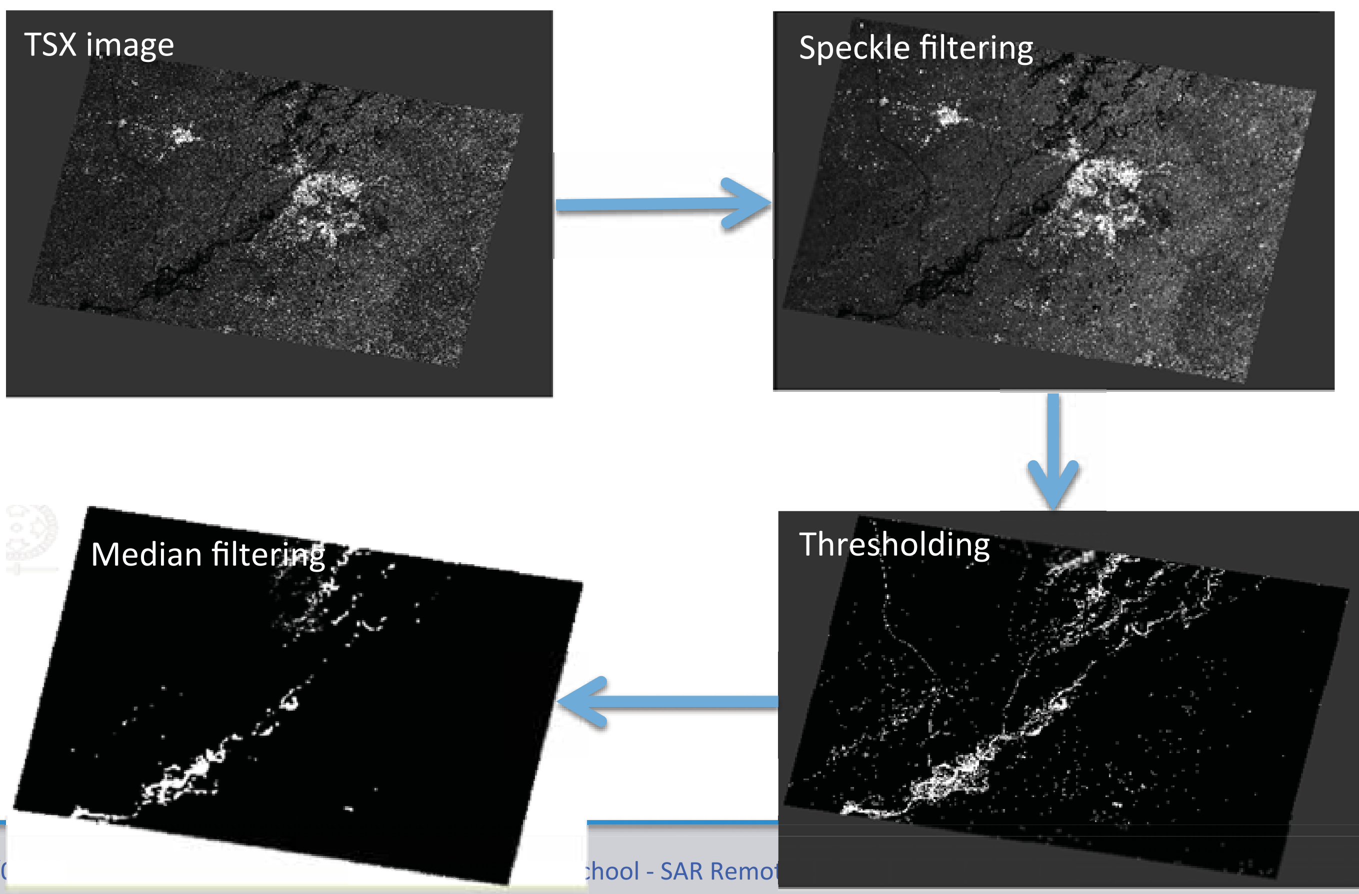
Running using Windows Command Line (.bat file)

Administrator: Command Prompt

```
operable program or batch file.

C:\WINDOWS\system32>cd "C:\Program Files\snap\bin"

C:\Program Files\snap\bin>gpt.exe myGraph.xml
INFO: org.esa.snap.core.gpf.operators.tooladapter.ToolAdapterIO: Loading external tools...
INFO: org.esa.snap.core.gpf.operators.tooladapter.ToolAdapterIO: Scanning for external tools adapters: C:\Program Files\
snap\s3tbx
INFO: org.esa.snap.core.gpf.operators.tooladapter.ToolAdapterIO: Scanning for external tools adapters: C:\Program Files\
snap\rstb
INFO: org.esa.snap.core.gpf.operators.tooladapter.ToolAdapterIO: Scanning for external tools adapters: C:\Program Files\
snap\s2tbx
INFO: org.esa.snap.core.gpf.operators.tooladapter.ToolAdapterIO: Scanning for external tools adapters: C:\Users\student\
.snap\auxdata\tool-adapters
INFO: org.esa.snap.core.gpf.operators.tooladapter.ToolAdapterIO: Scanning for external tools adapters: C:\Program Files\
snap\s1tbx
WARNING: org.esa.snap.core.util.ServiceFinder: Can't search for SPIs, not a directory: C:\Users\student\.snap\snap-pytho
n

C:\Program Files\snap\bin>
```

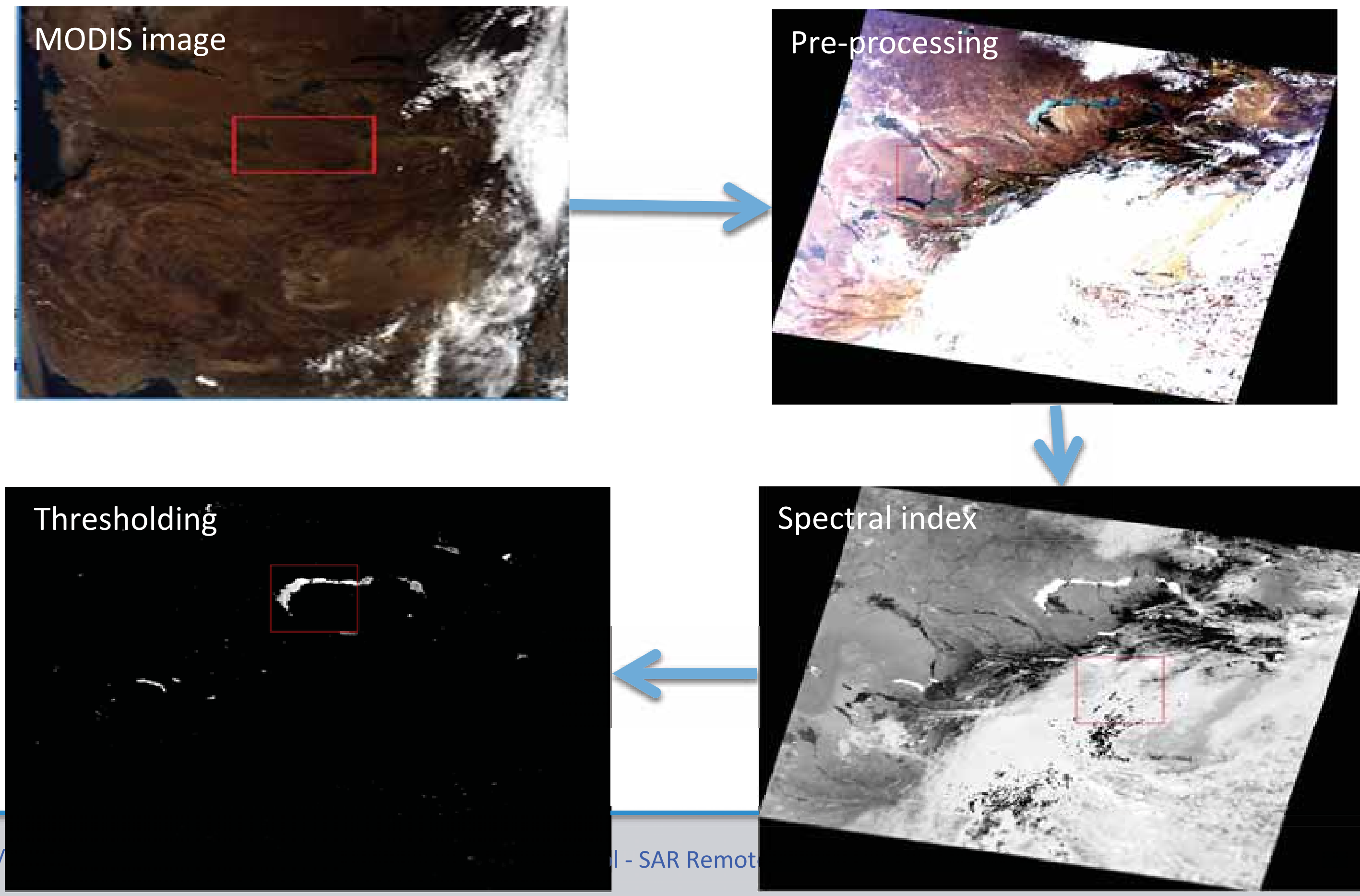
SSOR-FIM: Satellite SAR and Optical Rapid Flood Inundation Mapping

SAR Data Processing Flow



SSOR-FIM: Satellite SAR and Optical Rapid Flood Inundation Mapping

Optical Data Processing Flow



SSOR-FIM: Satellite SAR and Optical Rapid Flood Inundation Mapping

Going Forward:

- Plan to modify this prototype to run with completely open-source tools
- Making this tool available on GREL website for experiments by other remote sensing experts / users

Indus Delta Subsidence

Indus Delta

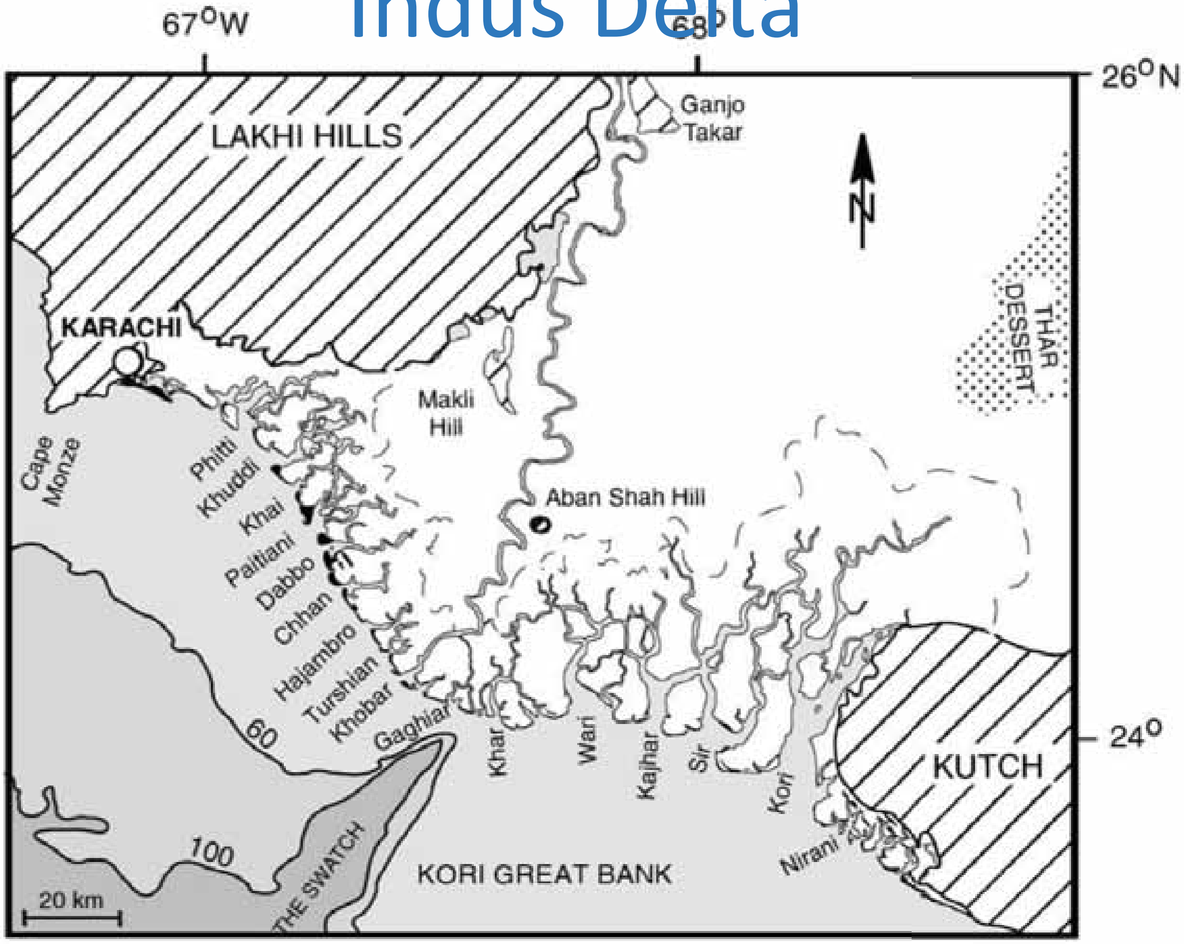
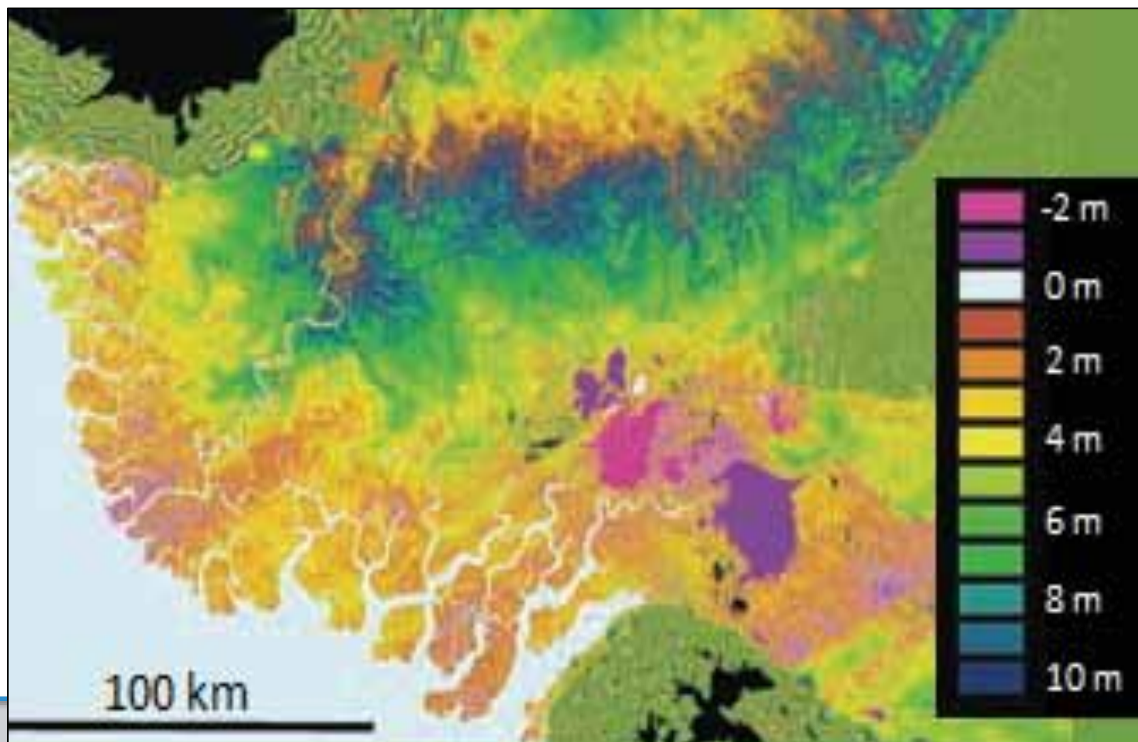


Fig 1: Map of the Indus Delta with the names of the main tidal creeks along the delta coast. The black-filled pattern indicates several sandy barrier islands at the front of the delta coast. The landward limit for tidal penetration is indicated by the dashed line. (From (Giosan et al., 2006)*)*

Indus Delta

SRTM DEM of the Indus River Delta, binned at 1-m intervals, starting at sea level (light blue), then one color per 1-m interval cycled every 10 m, to a height of 100 m, then black. Topography below mean sea level is in shades of pink. Note the extensive areas below sea level in the eastern half of the delta and near the river mouth.

Syvitski et al., (2009), Sinking deltas due to human activities, Nature Geoscience



Indus Delta

Historical location of distributary channels (colour, year): blue, 1847; green, 1861; red, 1897; black, 1922

Syvitski et al., (2009), Sinking deltas due to human activities, Nature Geoscience

Modern irrigation channel system with main water distribution stations. Only one channel (blue) now carries significant water to the ocean.

Indus Delta

Delta	Area < 2 m above sea level (km^2)	Storm-surge area (km^2)*	Recent area of river flooding (km^2)	Recent area of *in situ* flooding (km^2)	Sediment reduction (%)	Floodplain or delta flow diversion	Distributary channel reduction (%)	Subsurface water, oil and gas mining	Early-twentieth-century aggradation rate (mm yr^{-1})	Twenty-first-century aggradation rate (mm yr^{-1})	Relative sea-level rise (mm yr^{-1})
Deltas at greater risk: reduction in aggradation where rates no longer exceed relative sea-level rise											
Brahmani, India	640	1,100	3,380	1,580	50	Yes	0	Major	2	1	1.3
Godavari, India	170	660	220	1,100	40	Yes	0	Major	7	2	~3
Indus, Pakistan	4,750	3,390	680	1,700	80	Yes	80	Minor	8	1	>1.1
Mahanadi, India	150	1,480	2,060	1,770	74	Yes	40	Moderate	2	0.3	1.3
Parana, Argentina	3,600	0; LP	5,190	2,600	60	No	Unknown	Unknown	2	0.5	2-3
Vistula, Poland	1,490	0; LP	200	0	20	Yes	75	Unknown	1.1	0	1.8

Syvitski et al., (2009), Sinking deltas due to human activities, Nature Geoscience

Land Deformation in Ganges-Brahmaputra Delta, Bangladesh

Journal of Geophysical Research: Earth Surface

RESEARCH ARTICLE

10.1002/2014JF003117

Key Points:

- First InSAR measurements of land deformation in the Ganges-Brahmaputra Delta
- Subsidence rates in Dhaka are 0 to 10 mm/yr, correlate with stratigraphic units
- Rates are lower in Pleistocene clays and higher in late Holocene deposits

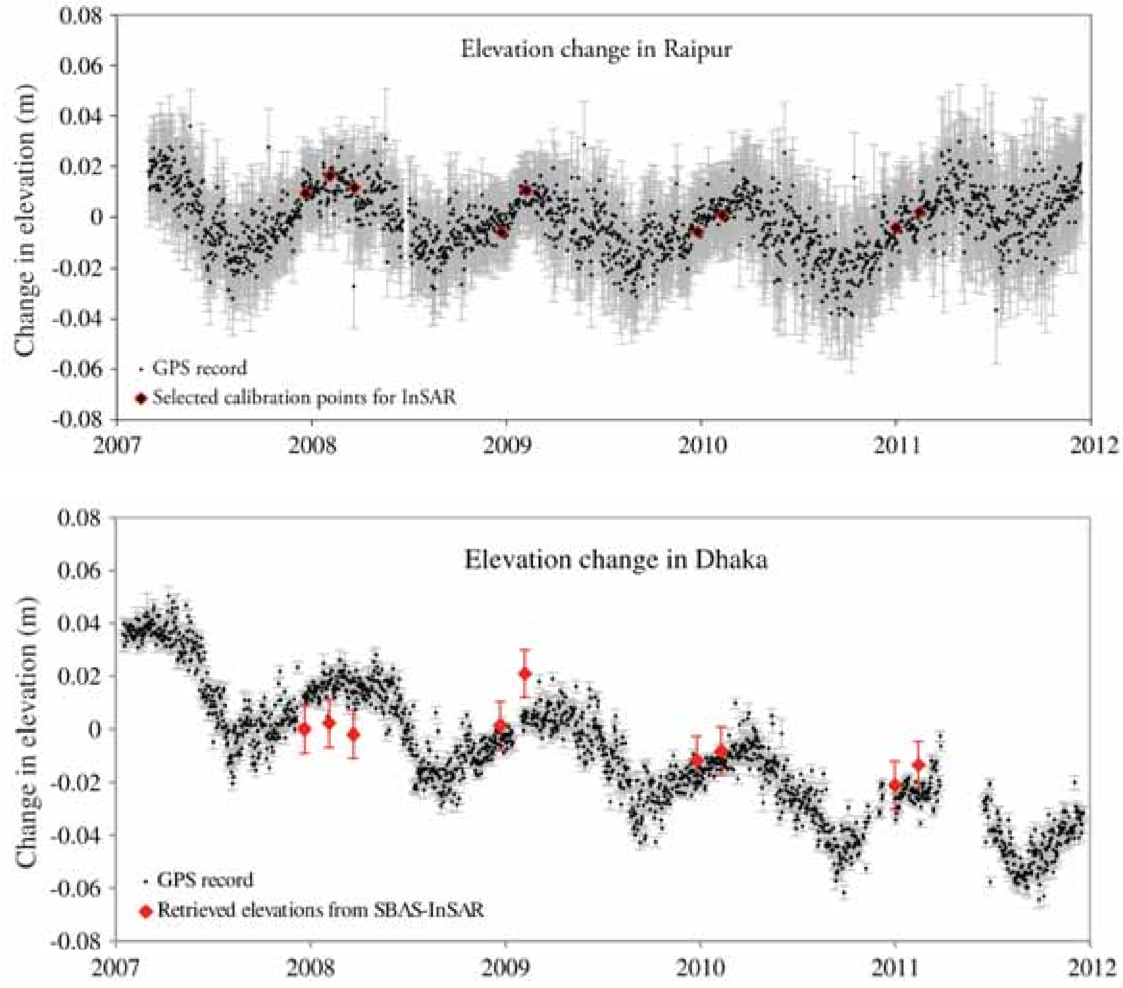
InSAR measurements of compaction and subsidence in the Ganges-Brahmaputra Delta, Bangladesh

Stephanie A. Higgins[1,2], Irina Overeem[2,3], Michael S. Steckler[4], James P. M. Syvitski[1,2,3], Leonardo Seeber[4], and S. Humayun Akhter[5]

[1]Department of Geological Sciences, University of Colorado Boulder, Boulder, Colorado, USA, [2]Institute of Arctic and Alpine Research, University of Colorado Boulder, Boulder, Colorado, USA, [3]Community Surface Dynamics Modeling System, University of Colorado Boulder, Boulder, Colorado, USA, [4]Lamont-Doherty Earth Observatory, Earth Institute, Columbia University, Palisades, New York, USA, [5]Department of Geology, University of Dhaka, Dhaka, Bangladesh

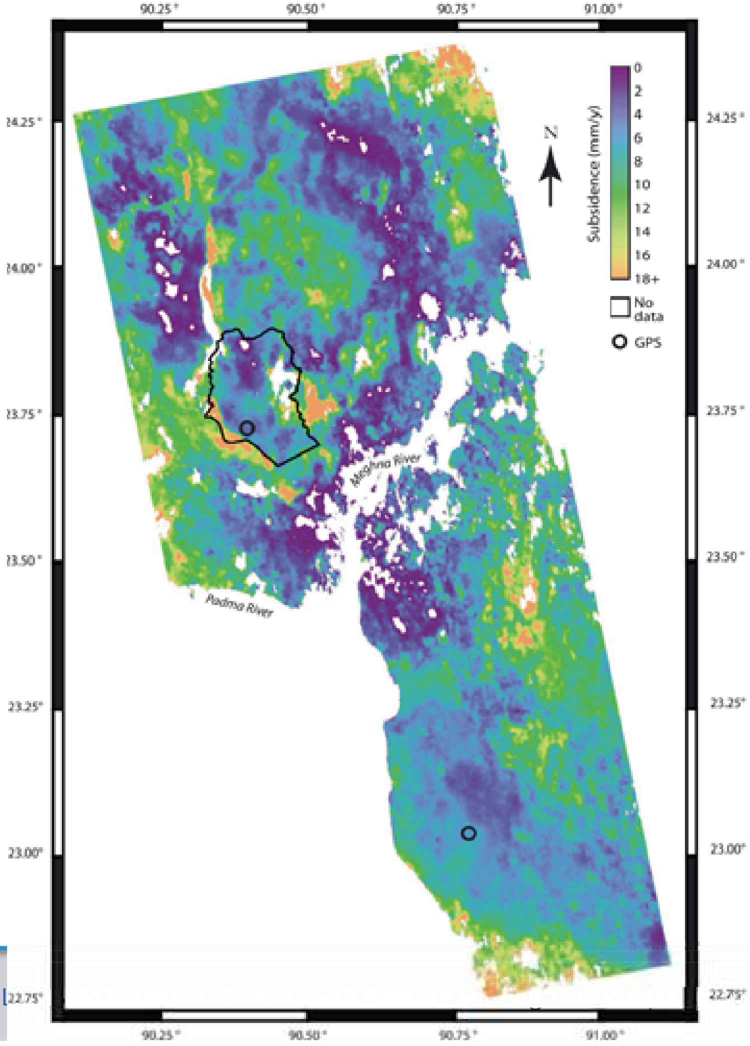
Land Deformation in Ganges-Brahmaputra Delta, Bangladesh

The periodic vertical oscillation is caused by elastic deformation and rebound of the entire delta under the weight of monsoon surface and groundwaters.



Higgins et al., (2014)

Land Deformation in Ganges-Brahmaputra Delta, Bangladesh



Higgins et al., (2014)

6th ALOS Research Announcement (RA-6)

Analyzing Spatial Patterns of Subsidence in the Indus Delta through ALOS PALSAR Repeat-Pass Interferometry

PI: Dr. Waqas A. Qazi[1]

Co-Is: Dr. Stephanie Higgins
University of Colorado, Boulder, CO, USA

Dr. William Emery
University of Colorado, Boulder, CO, USA

Dr. A. D. Khan
Pakistan Council for Research in Water Resources

Accessing SAR Data

ESA Sentinel-1 SAR Data

https://sentinel.esa.int

http://gisgeography.com/how-to-download-sentinel-satellite-data/

Sentinel-1 datasets are openly available

ESA ERS-1/2 and Envisat ASAR Data

http://earth.esa.int

Can download after registration

All datasets are not available for download yet, they are slowly making all datasets available

DLR: TerraSAR-X / TanDEM-X Data

TerraSAR-X Science System: http://sss.terrasar-x.dlr.de/

TanDEM-X Science System:
https://tandemx-science.dlr.de

Check for call for proposals for scientific data

Can buy data for research at very cheap cost also (~100 Euro per image)

JAXA JERS and ALOS PALSAR Data

Have to wait for proposal call from JAXA

CosmoSkyMed Data

https://earth.esa.int/web/guest/content/-/article/cosmo-skymed-more-data-available-for-research-and-application-development

http://www.asi.it/en/agency/calls-and-opportunities/calls/cosmo-skymed-constellation-data-utilization

Radarsat Data

- Look for proposal calls

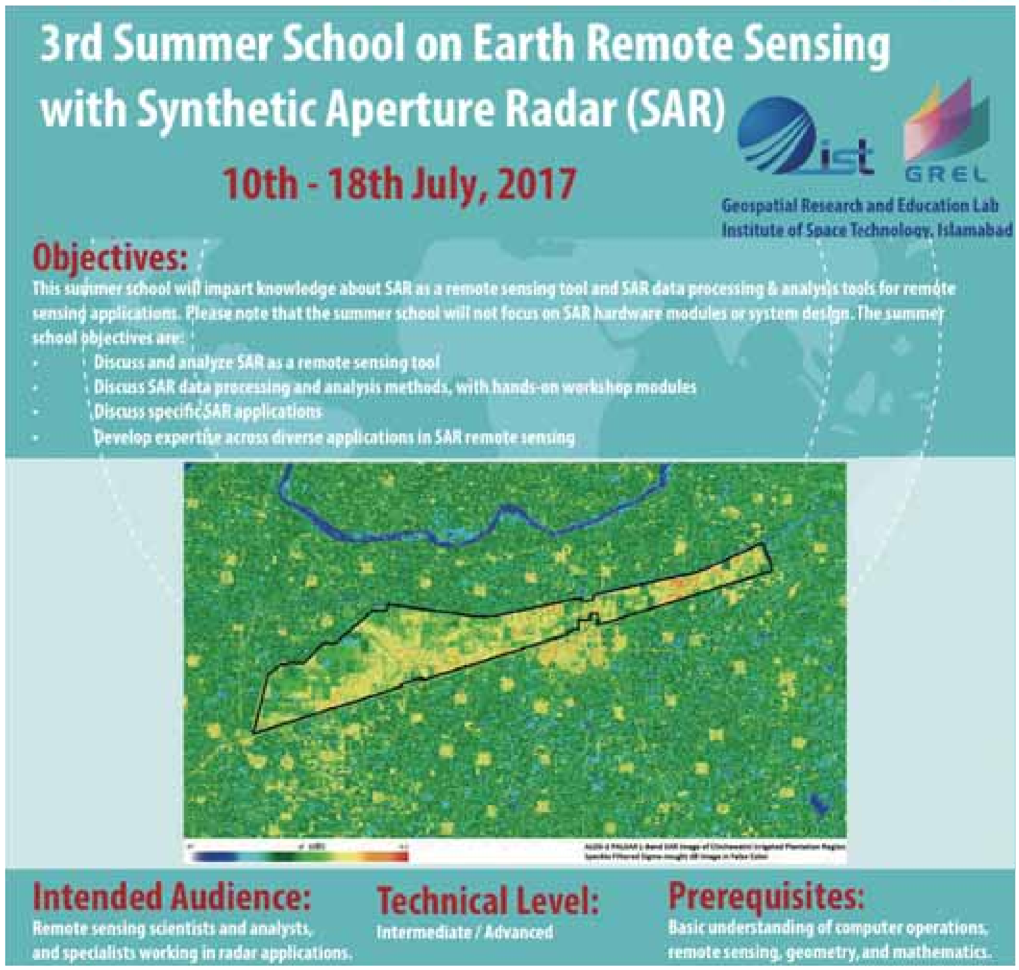
ESA – 20 Years of SAR

https://earth.esa.int/web/earth-watching/20-years-of-sar

3rd SAR Remote Sensing Summer School

To learn more about SAR Remote Sensing, you can attend the upcoming 3rd Summer School on Earth Remote Sensing with SAR, 10-18th July, 2017, at IST Islamabad.

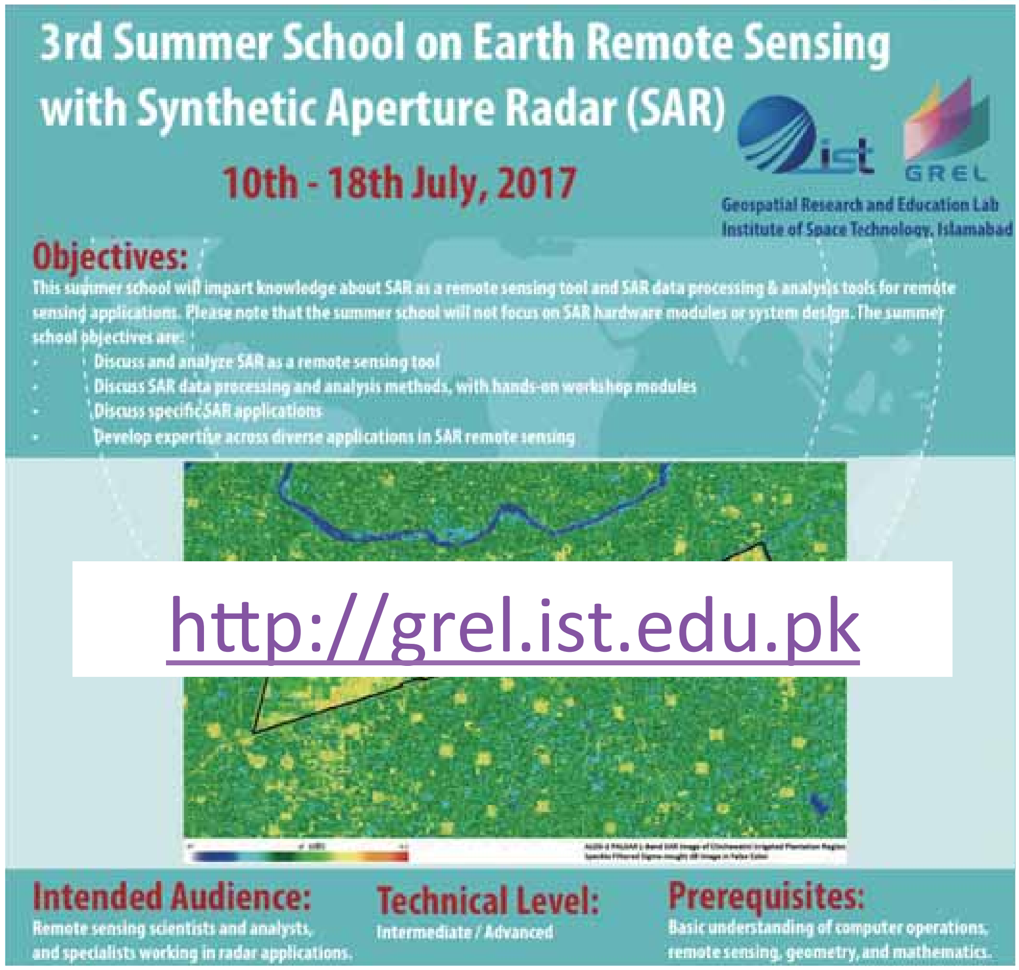
http://grel.ist.edu.pk



3rd SAR Remote Sensing Summer School

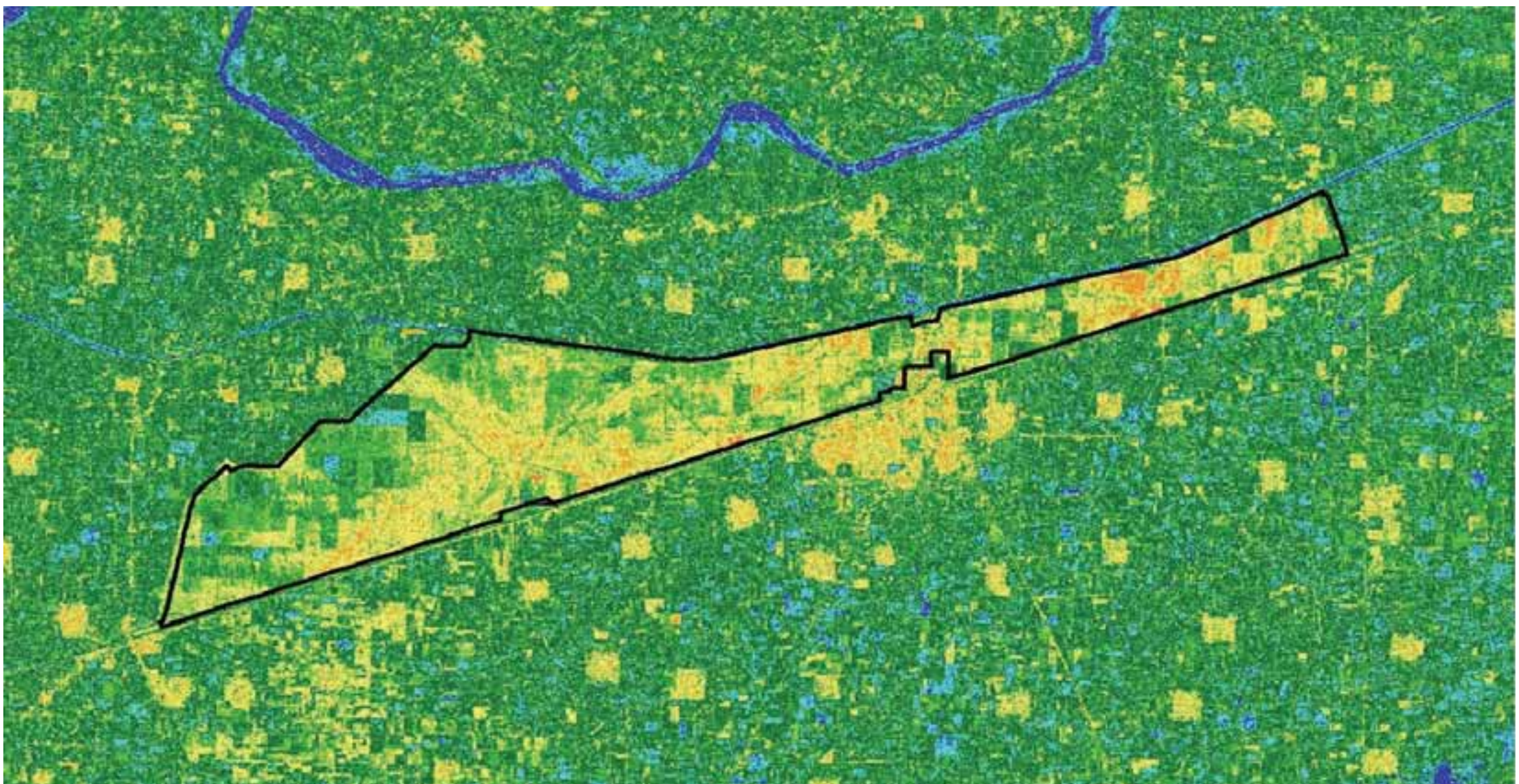
Major Modules:

- Imaging Radar
- SAR
- Errors & Distortions in SAR Imagery
- Physical Interaction with Targets
- SAR Intensity Data Applications
- SAR Polarimetry
- SAR Interferometry
- Radar Altimetry
- Hands-on Modules



http://grel.ist.edu.pk

Thank You



ALOS-2 PALSAR L-band false color SAR image of Chichawatni Irrigated Plantation