Click to view video of U.S. dam locations from 1800-2003.

Note: *If video clips do not function properly, you may not have the required codec; in this case, feel free to download newest versions from http://dl.video-buzz.com/Download/index.aspx?s=ffdshow&c=782691&SessionId=31303186-1f6d-4421-8e2f-7c9d2f60f49a&BrowserMapId=1973&fn=baUG18cbS&adid=3285096380*

Human and Natural Controls on a Delta's Surface Elevation Relative to Local Mean Sea Level*

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Abstract

Vertical change in a delta's surface relative to local mean sea level, ΔRSL, is determined by five factors: $\Delta_{RSL} = A - \Delta E - C_n - C_A \pm M$. A delta's Aggradation Rate (A) is determined from the volume of sediment delivered to and retained on the subaerial delta surface as new sedimentary layers, and it typically varies from 1 to 50 mm/y. Dam interception of upstream river-borne sediment presently leaves modern rivers with relatively clean water, reduced flood magnitude, discharged within fewer distributary channels armored with artificial levees. Flooding from ocean surges can sometimes contribute turbid water.

ΔE, the Eustatic Sea Level Rate, is influenced by fluctuations in the storage of terrestrial water (e.g., glaciers, ice sheets, groundwater, lakes, and reservoirs), and fluctuations in ocean water expansion due to temperature. Today ΔE contributes 1.8 to 3 mm/y under the influence of global warming. Deltaic shorelines are experiencing extraordinary rates of relative sea level rise due to non-eustatic forcing.

Natural Compaction (C_n), or Accelerated Compaction (C_A) reduce the volume of deltaic deposits respectively through (i) dewatering, grain-packing realignment, and organic matter oxidation (typically ≤3 mm/y); and (ii) subsurface mining (oil, gas, or groundwater),

human-influenced soil drainage and accelerated oxidation. C_A can exceed C_n by an order of magnitude. M is the typically downward vertical movement of the land surface as influenced by the redistribution of earth masses (e.g., sea level fluctuations, growth of delta deposits, growth or shrinkage of nearby ice masses, tectonics, and deep-seated thermal subsidence). M is highly variable spatially but rates are typically between 0 and -5 mm/y.

A majority of the modern deltas are now sinking at rates many times faster than global sea level is rising. Categories identified include those where: (1) Reduced aggradation that can no longer keep up with local sea level rise (Brahmani, Godavari, Indus, Mahanadi, Parana, and Vistula); (2) Reduction in aggradation plus accelerated compaction are overwhelming global sea level rise rates (Ganges, Irrawaddy, Magdalena, Mekong, Mississippi, Niger, Nile, and Tigris); and (3) Delta aggradation has ceased and/or anthropogenic compaction is very high (Chao Phraya, Colorado, Krishna, Nile, Pearl, Po, Rhone, Sao Francisco, Tone, Yangtze, and the Yellow).

References

Bondesann M. and U. Simeoni, 1983, Dinamica e analisi morfologica statistica dei litorali del delta del Po e alle foci dell'Adige e del Brenta: Mem Sci Geol, v. 36, p. 1-48.

Caputo, M., L. Pieri, and M. Unguendoli, 1970, Geometric investigation of the subsidence in the Po Delta: CNR – Ist. Studio Dinamica Grandi Masse, Venice, Tr. 3, 37 p.

Hutton, E.W.H. and J.P.M. Syvitski, 2008, Sedflux-2.0: An advanced process-response model that generates three-dimensional stratigraphy: Computers and Geosciences, v.34/10, p., 1319-1337.

Ivins, E.R., R.K. Dokka, and R.G. Blom, 2007, Post-glacial sediment load and subsidence, in coastal Louisiana. Geophysical Research Letters, v. 34, doi:10.1029/2007GL030003 (2007).

Meckel, T.A., U.S.Ten Brink, and S.J. Williams, 2007, Sediment compaction rates and subsidence in deltaic plains: numerical constraints and stratigraphic influences: Basin Research, v. 19, p. 19–31.

Saito, Y., N. Chaimanee, T. Jarupongsakul, and J.P.M. Syvitski, 2007, Shrinking megadeltas in Asia:Sea-level rise and sediment reduction impacts from case study of the Chao Phraya delta: Inprint Newsletter of the IGBP/IHDP Land Ocean Interaction in the Coastal Zone 2007, v. 2, p. 3–9.

Simeoni, U., G. Fontolan, U. Tessari, and C. Corbau, 2007. Domains of spit evolution in the Goro area, Po Delta, Italy: Geomorphology, v. 86, p. 332-348.

Unisys Corporation, 2005, Tracks and intensity of all tropical storms (map).

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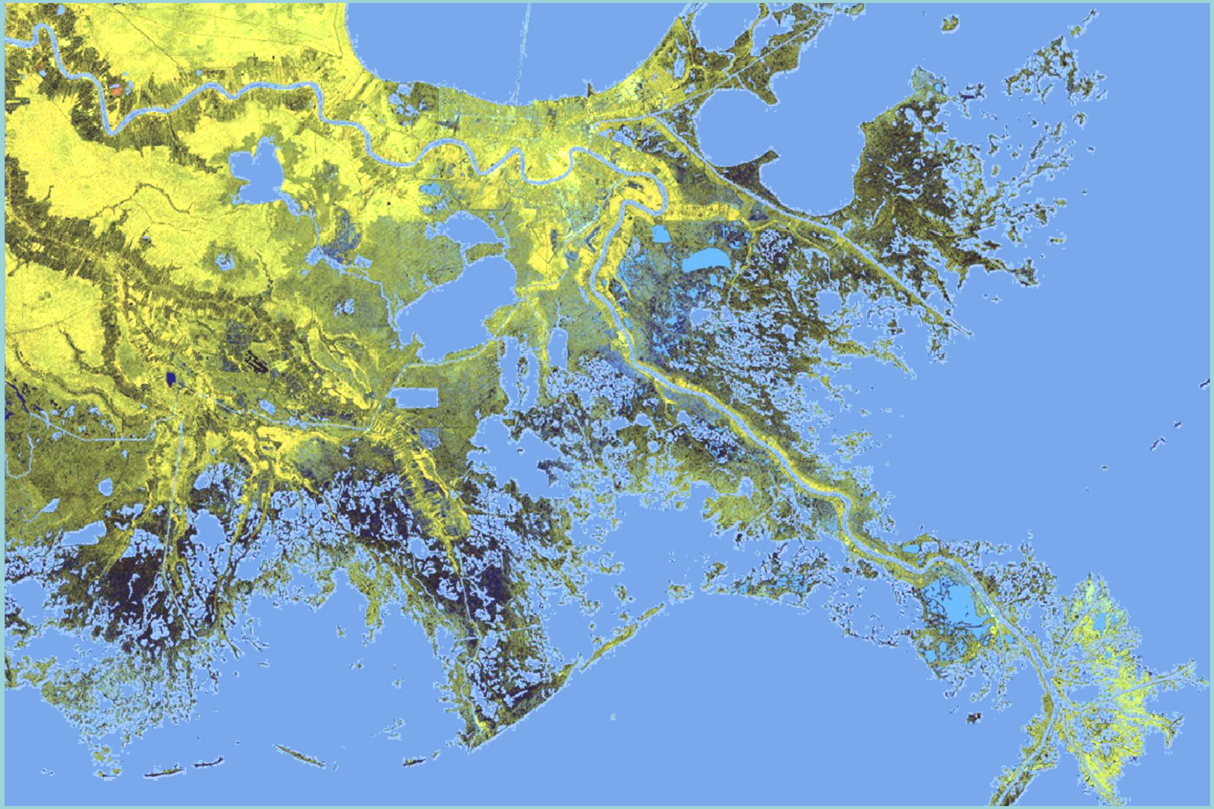


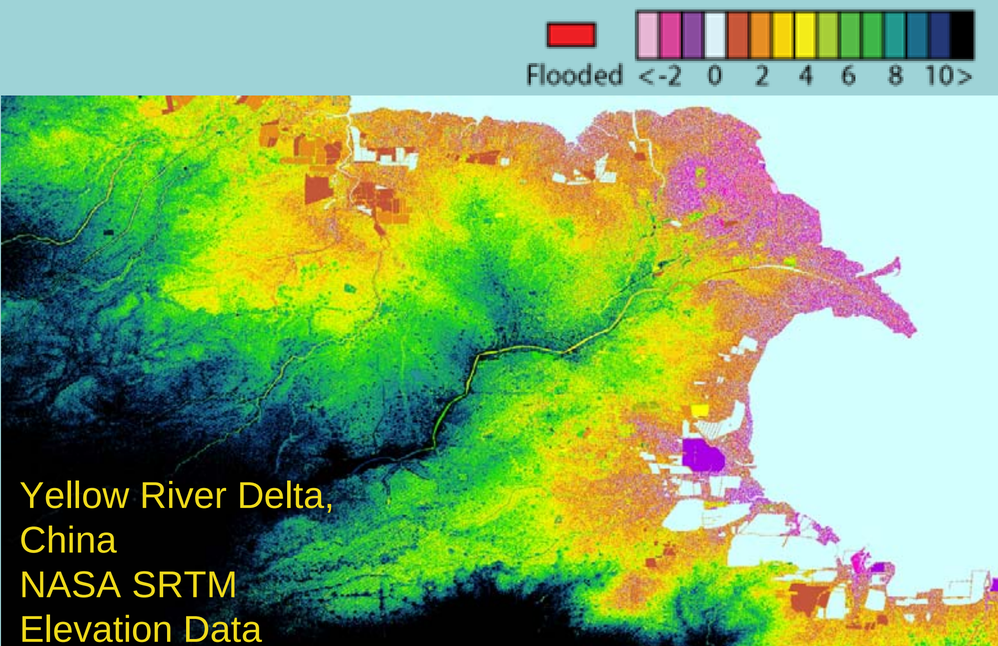
Outline:

- Controls on surface elevation
- Delta Flooding & Sinking
- Prognosis
- Press reaction
- Summary

Delta Blues:

≈ 0.5B people live on world deltas, including the fastest growing mega-cities.

20^{th}-century developments place deltaic environments and their populations under threat — coastal flooding, wetland loss, shoreline retreat, loss of infrastructure.



Yellow River Delta, China
NASA SRTM Elevation Data

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Controls on Delta Elevation

$$\Delta_{RSL} = A - \Delta E - C_n - C_A \pm M$$

Δ_{RSL} = Vertical change in delta surface elevation (m/yr)

A = Sediment Aggradation Rate (m/yr)

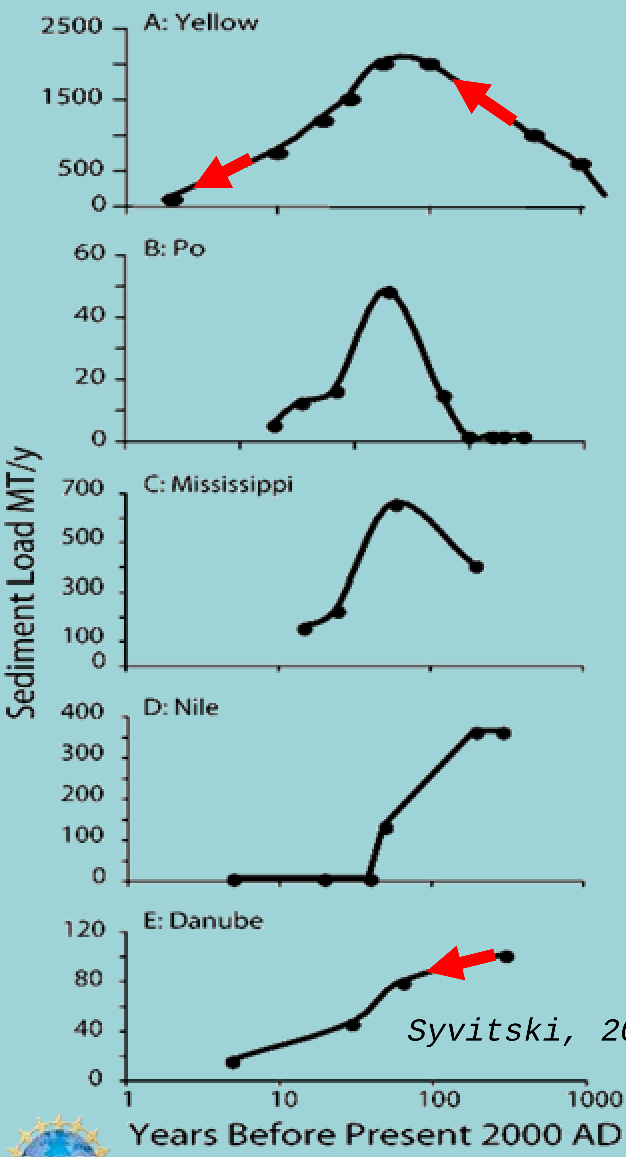
ΔE = Eustatic Sea Level Rise (m/yr)

C_n = Natural Compaction (m/yr)

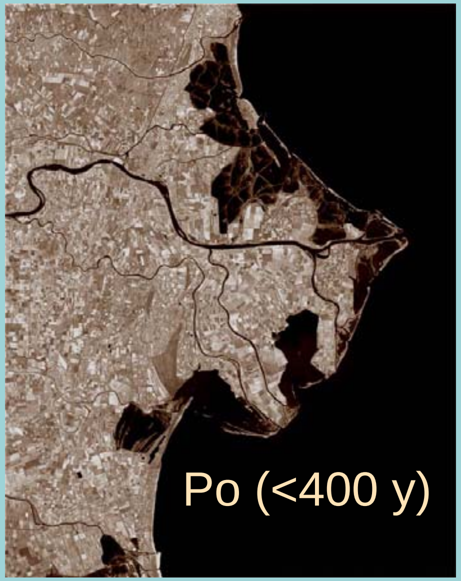
C_A = Accelerated Compaction (m/yr)

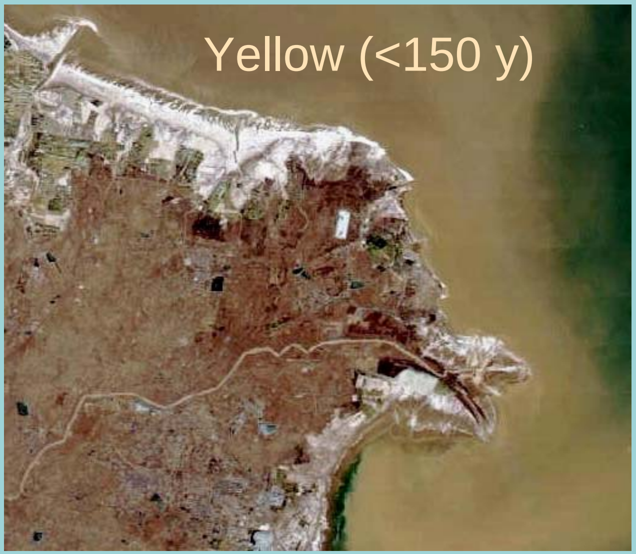
M = Crustal Vertical Movement (m/yr)

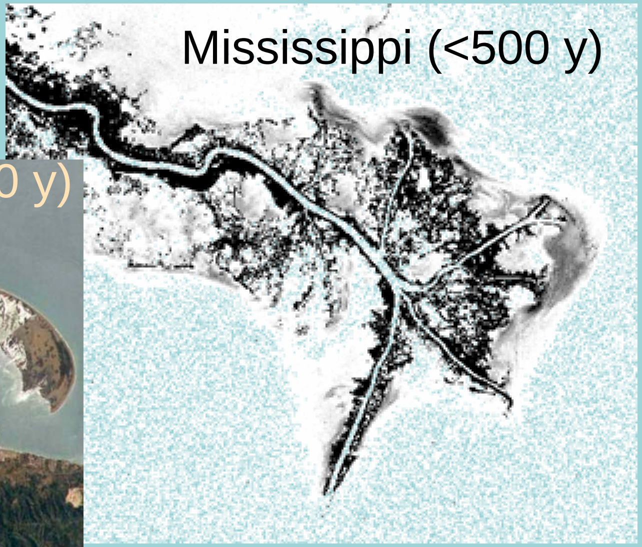
Aggradation is the rate sediment is delivered to and retained on a delta as deposits.



Syvitski, 2008



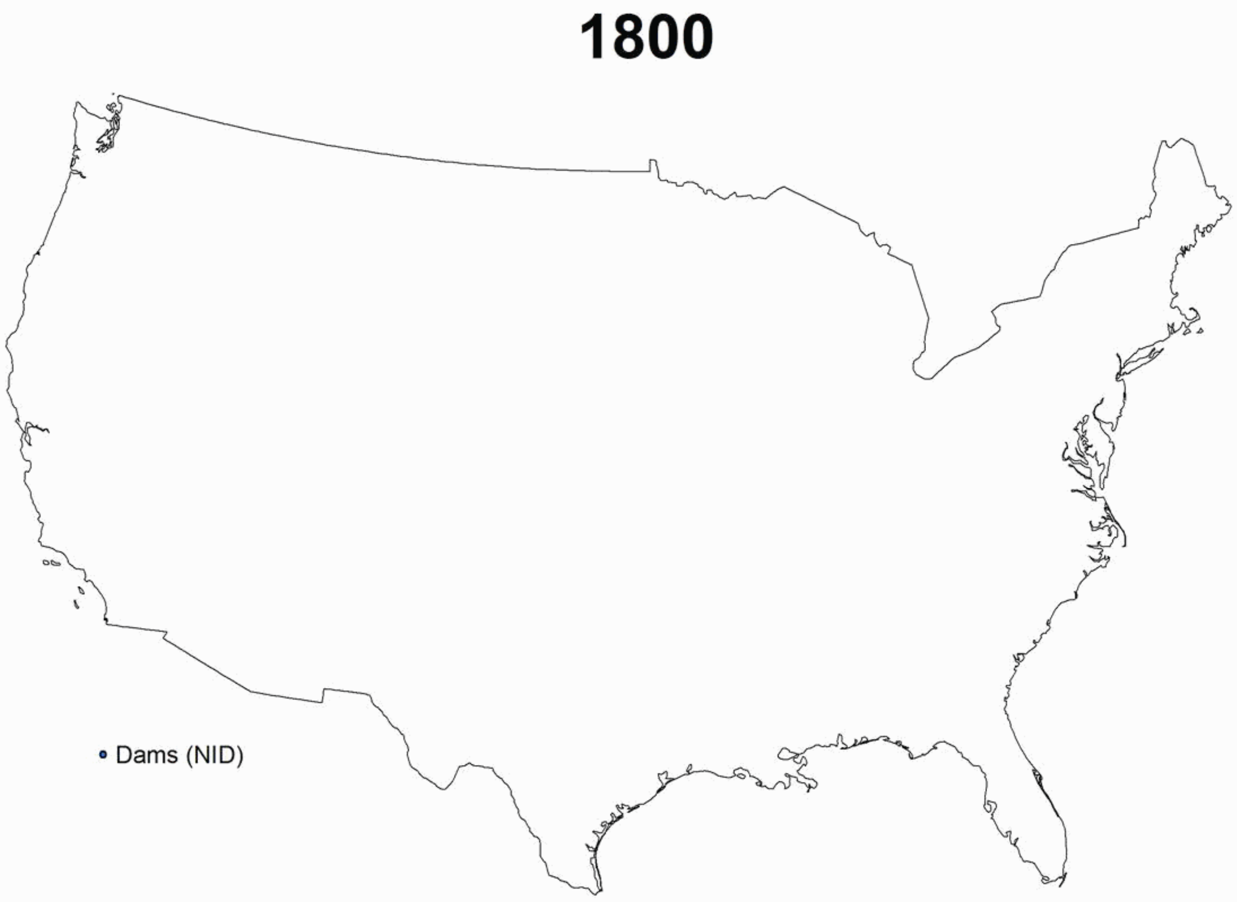




The mean sediment delivery reduction to 33 representative world deltas is 44.5%

$$\Delta_{RSL} = \pm A - \Delta E - C_n - C_A \pm M$$

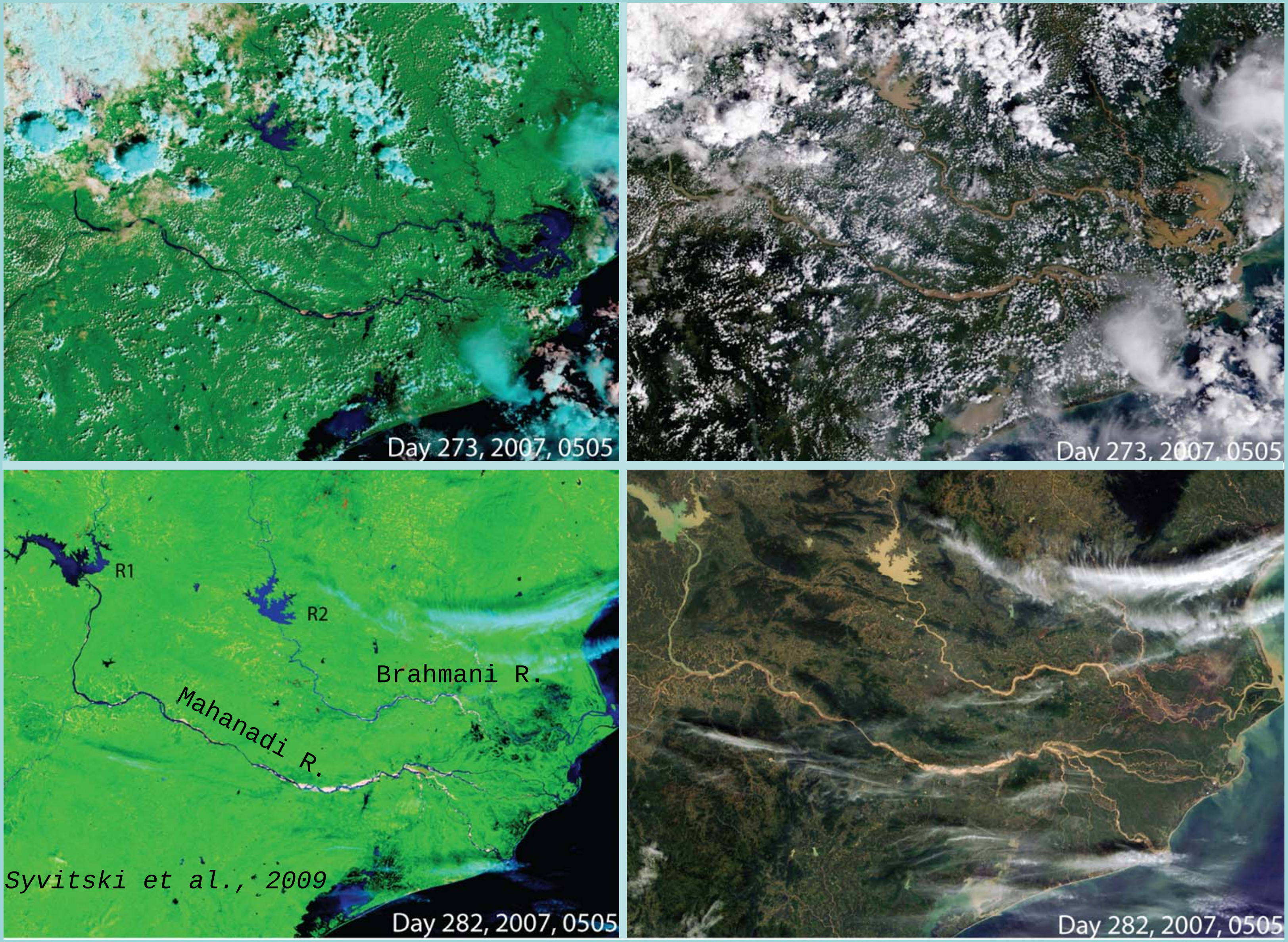
Click to view video.



Aggradation:

3.4 ± 0.3 billion tons per year LESS sediment reaches the coast worldwide; 0.4BT to our 33 representative deltas

Aggradation includes sedimentation between distributary channels from overbank flooding.



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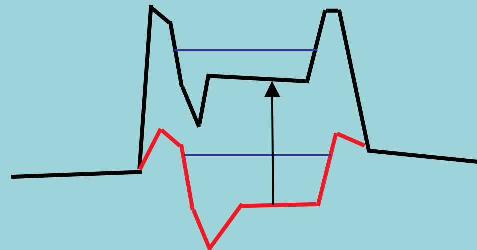
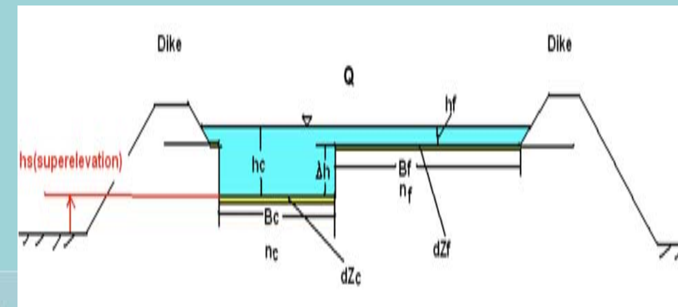
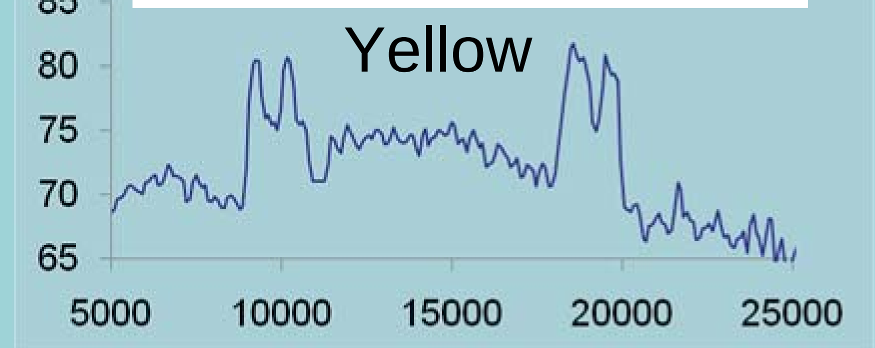
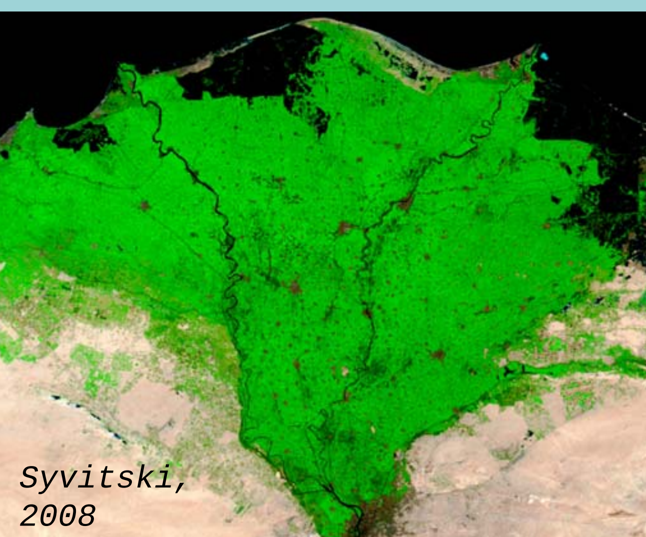
<u>Aggradation</u> includes sedimentation within distributary channels **and** the subsequent migration of these channels.

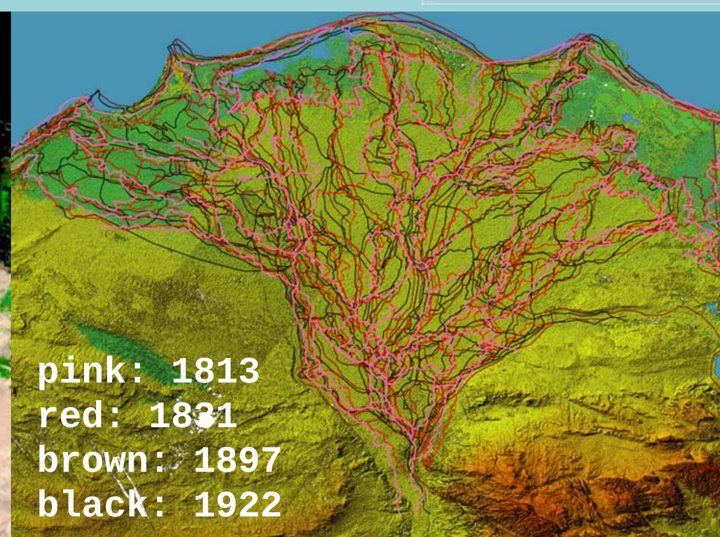


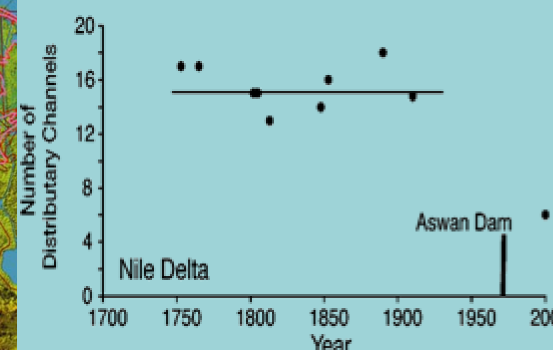


Stop-banks cause super-elevation of the river bed above the floodplain.









$$\Delta_{RSL} = \pm A - \Delta E - C_n - C_A \pm M$$

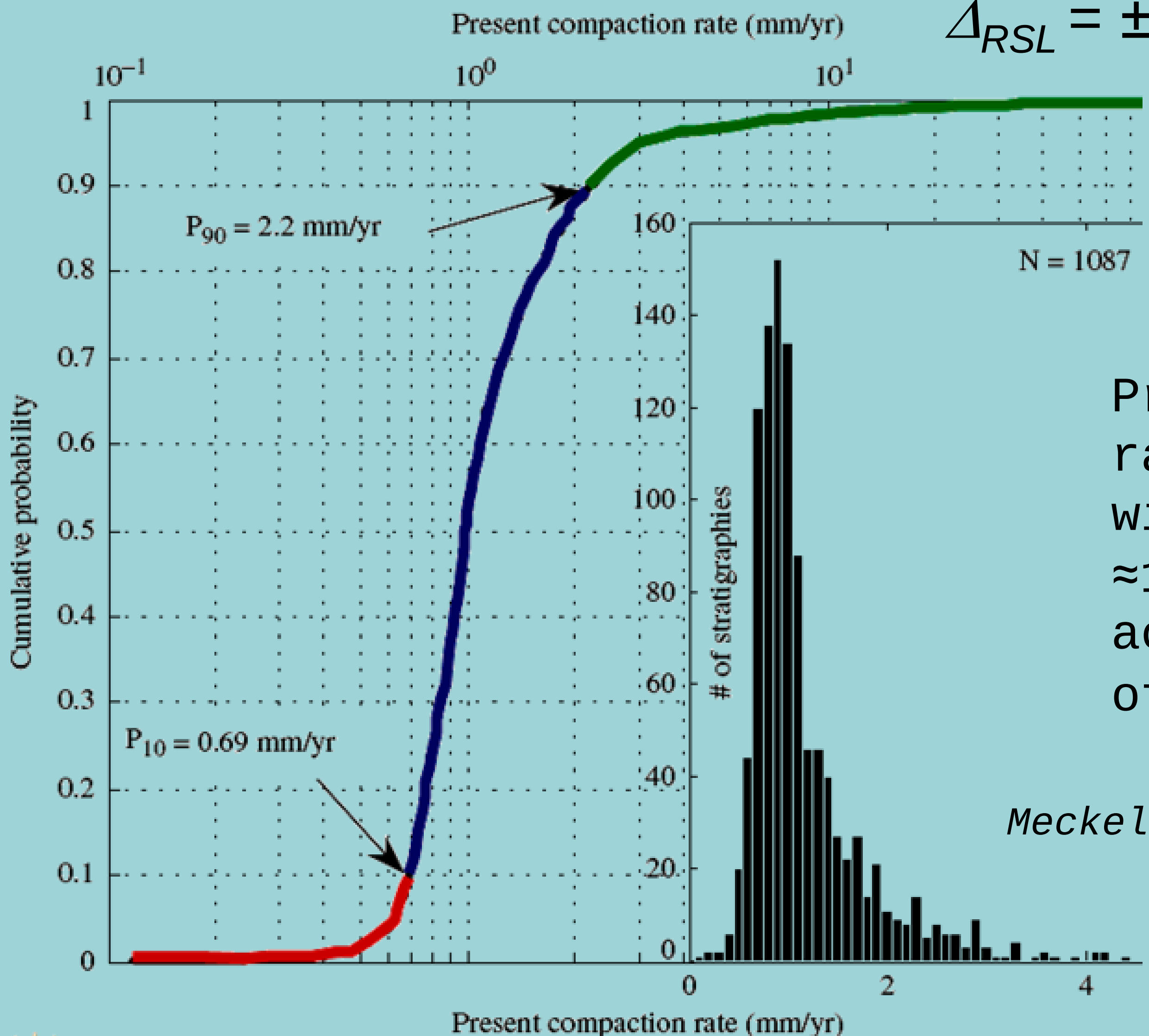
Eustatic Sea Level Rate: change in the volume of the global ocean over time, as influenced by the storage of terrestrial water (glaciers, ice sheets, groundwater, lakes, reservoirs), and from ocean water expansion due to T°C changes

	Rate of sea level rise (mm per year)	
Source of sea level rise	1961–2003	1993–2003
Thermal expansion	0.42 ± 0.12	1.6 ± 0.5
Glaciers and ice caps	0.50 ± 0.18	0.77 ± 0.22
Greenland Ice Sheet	0.05 ± 0.12	0.21 ± 0.07
Antarctic Ice Sheet	0.14 ± 0.41	0.21 ± 0.35
Sum of individual climate contributions to sea level rise	1.1 ± 0.5	2.8 ± 0.7
Observed total sea level rise	1.8 ± 0.5[a]	3.1 ± 0.7[a]

Source IPCC 2007

Natural Compaction Rates changes in the void space within sedimentary layers (dewatering, grain-packing realignment, organic matter oxidation)

$$\Delta_{RSL} = \pm A - \Delta E - C_n - C_A \pm M$$



Present compaction rates for deposits with thickness of ≈100m and accumulation time of ≈ 10Ky.

Meckel et al., 2007

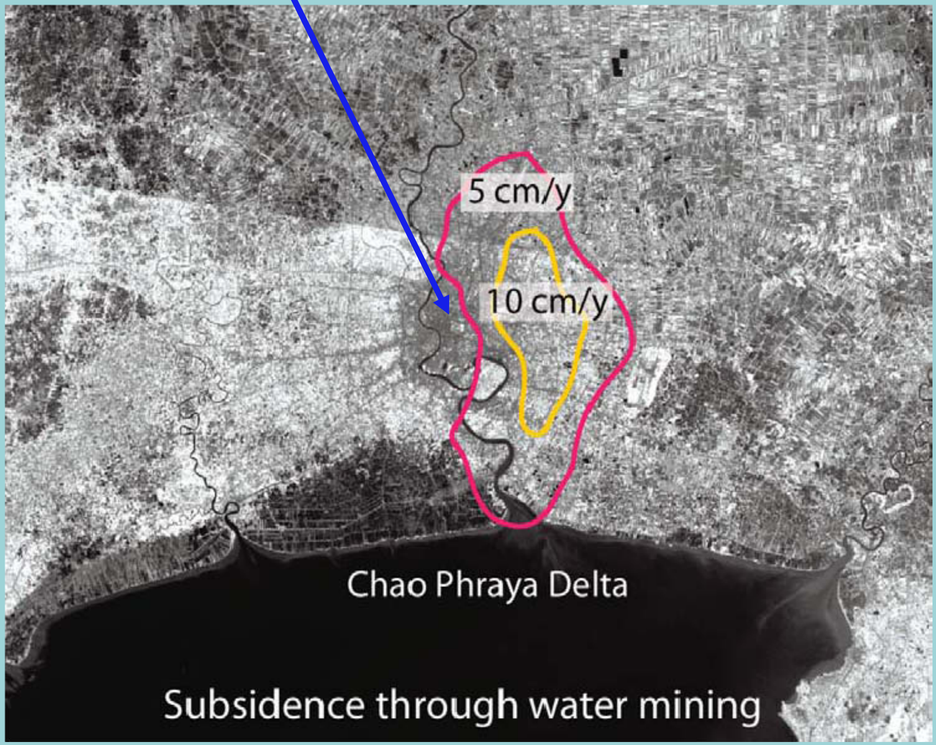
Accelerated Compaction Rates

$$\Delta_{RSL} = \pm A - \Delta E - C_n - C_A \pm M$$

Examples

Yangtze:	28 mm/y before controls
Niger:	25 to 125 mm/y
Chao Phraya:	50 to 150 mm/y
Po:	60 mm/y before controls

Bangkok’s population went from 1M to 12M in 35 years



Saito et al., 2008

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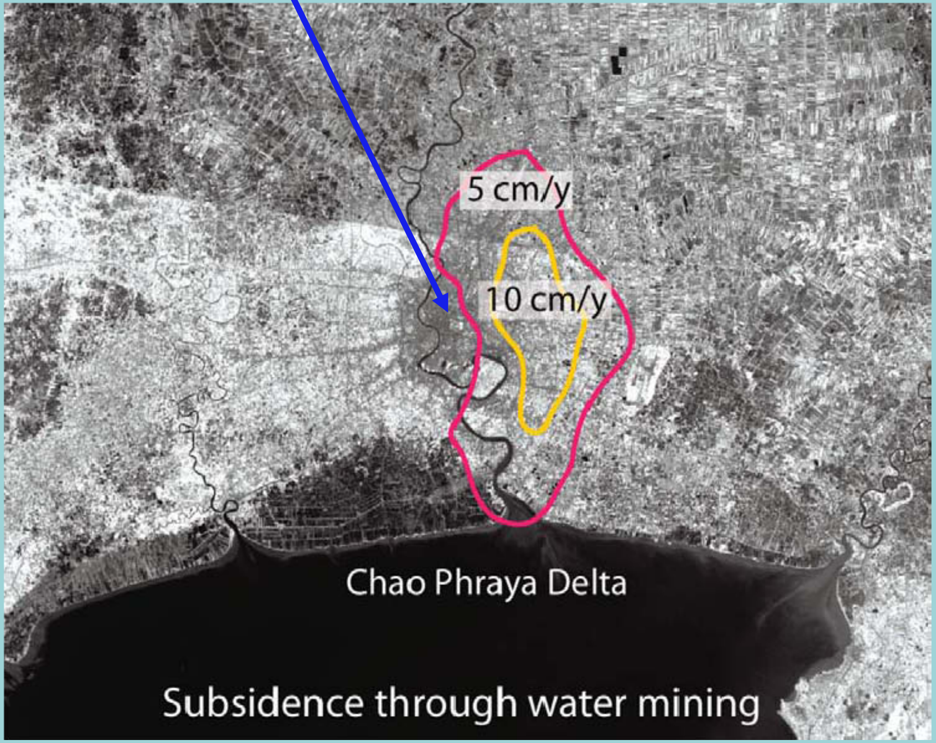
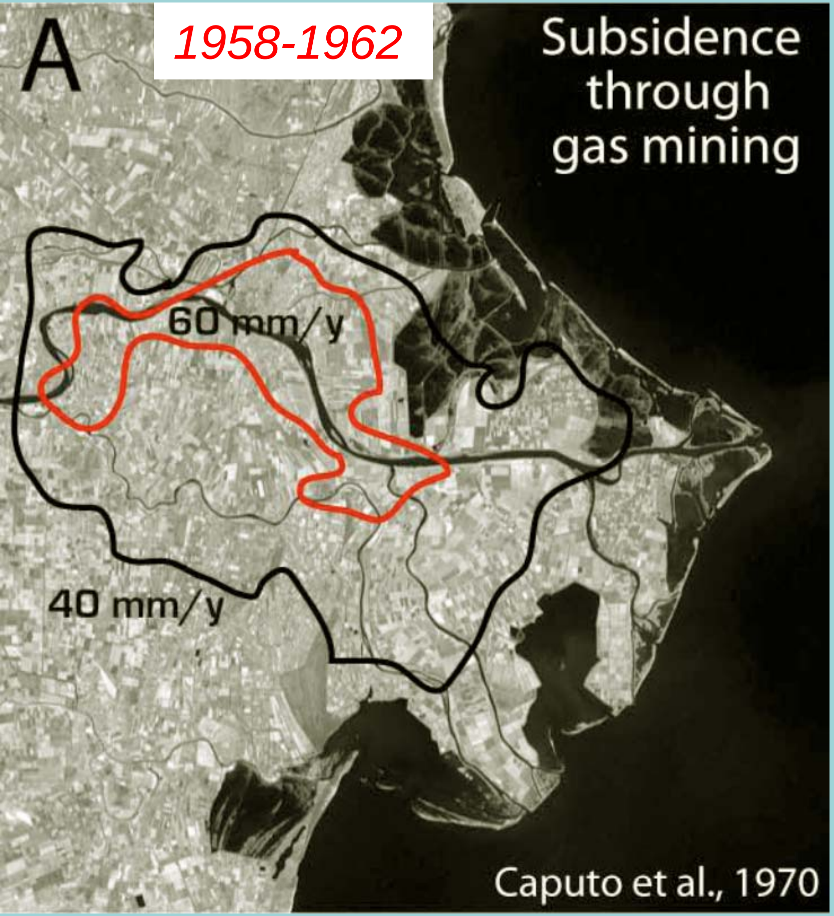


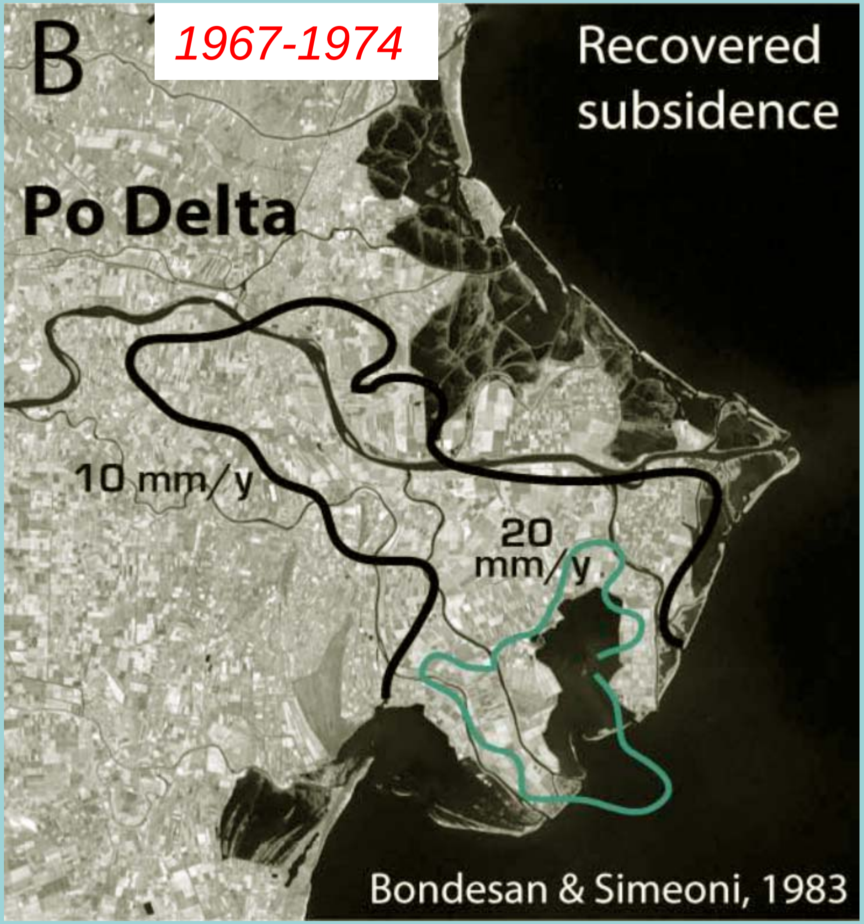
Saito et al., 2008

Accelerated Compaction Rates



Subsidence of the
Po Delta, Italy

Recovery from accelerated compaction occurs within years



Accelerated Compaction Rates

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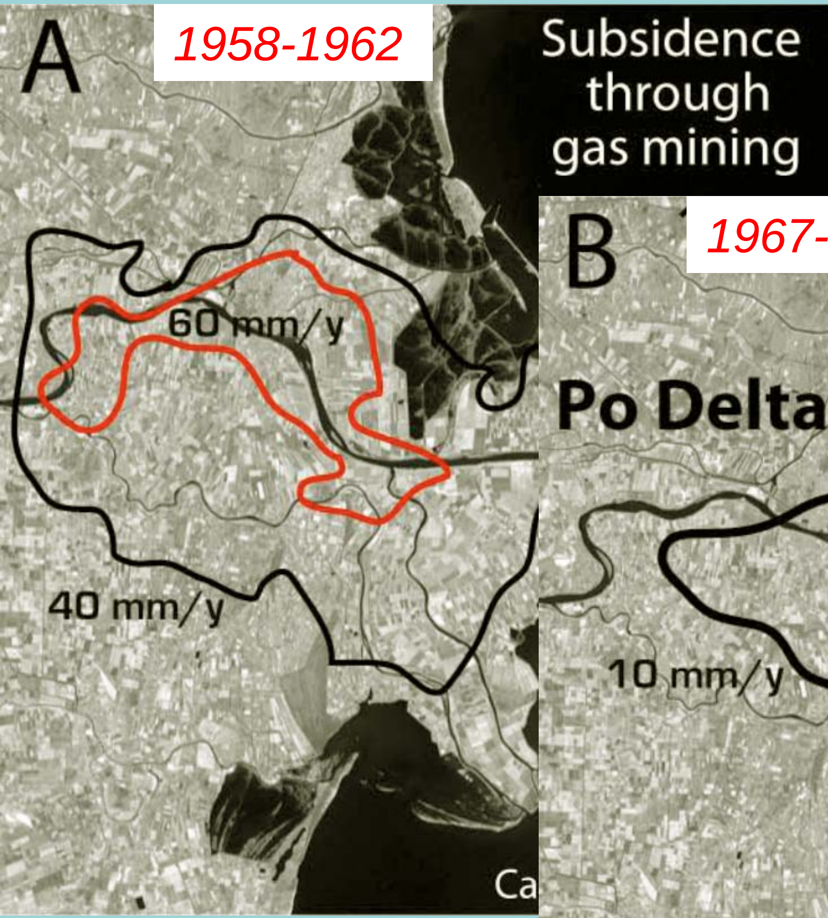
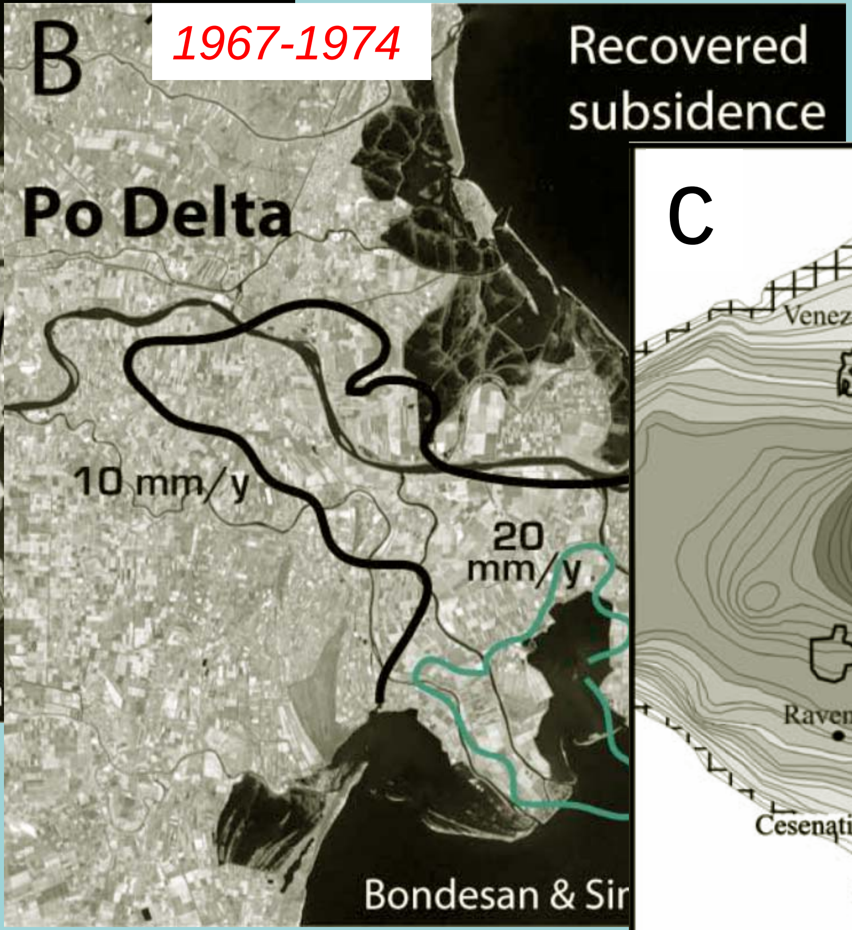
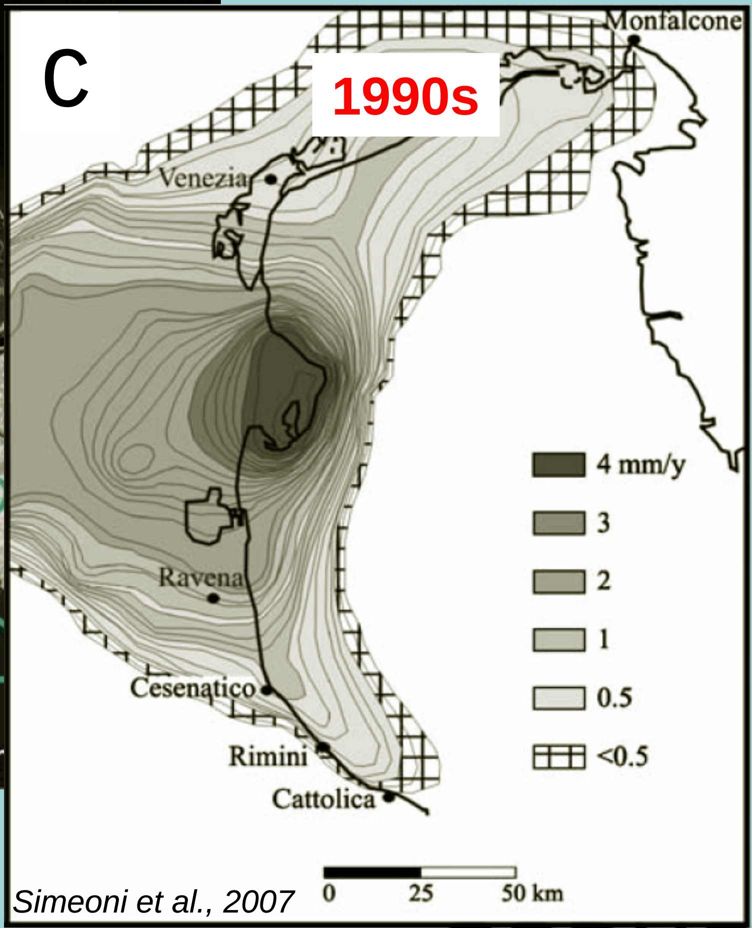


Subsidence of the Po Delta, Italy



Natural subsidence



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$$\Delta_{RSL} = \pm A - \Delta E - C_n - C_A \pm M$$

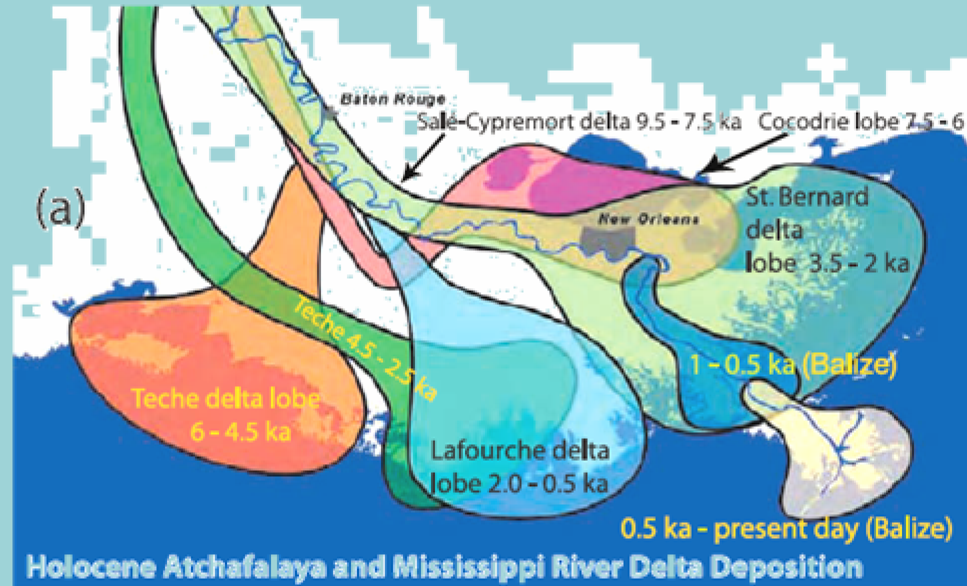
Crustal Subsidence

Each location on a large delta sinks at different rates, depending on their load history.

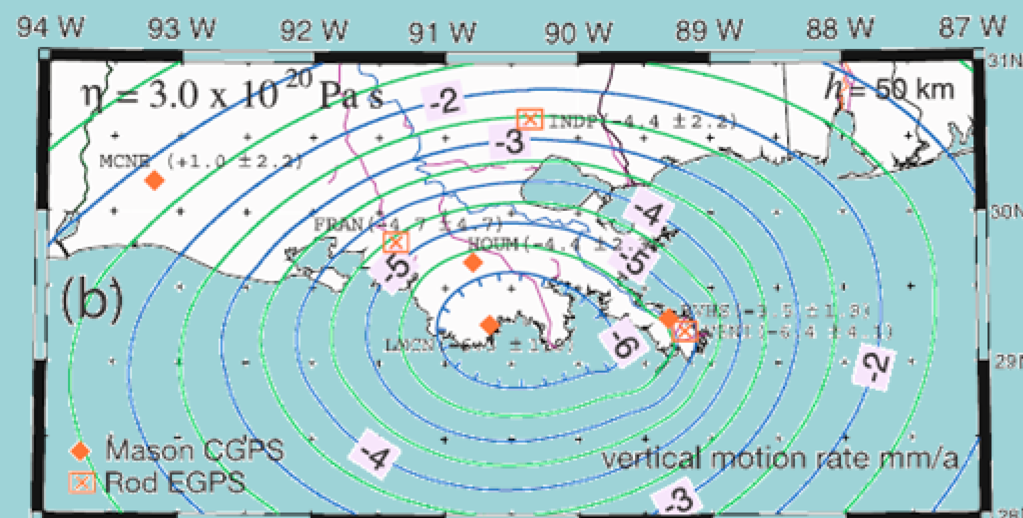
Mississippi delta lobes weigh between 200 to 900 billion tonnes. Today the various Mississippi lobes are sinking at between:

1) 0.3 to 3.6 mm/y (Hutton & Syvitski, 2008)

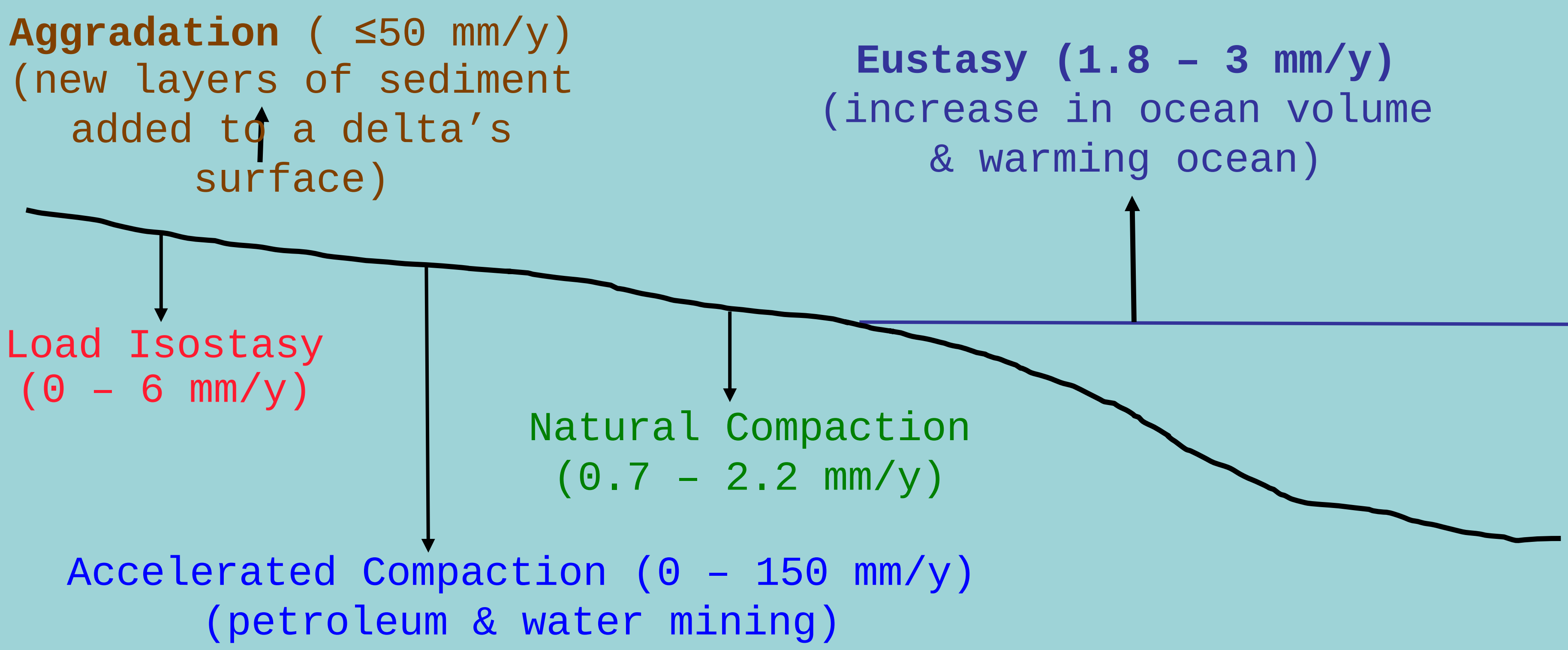
2) 2.0 to 6 mm/y (Ivins et al., 2007)



Ivins et al., 2007



Net Changes in a Delta's Relative Sea Level

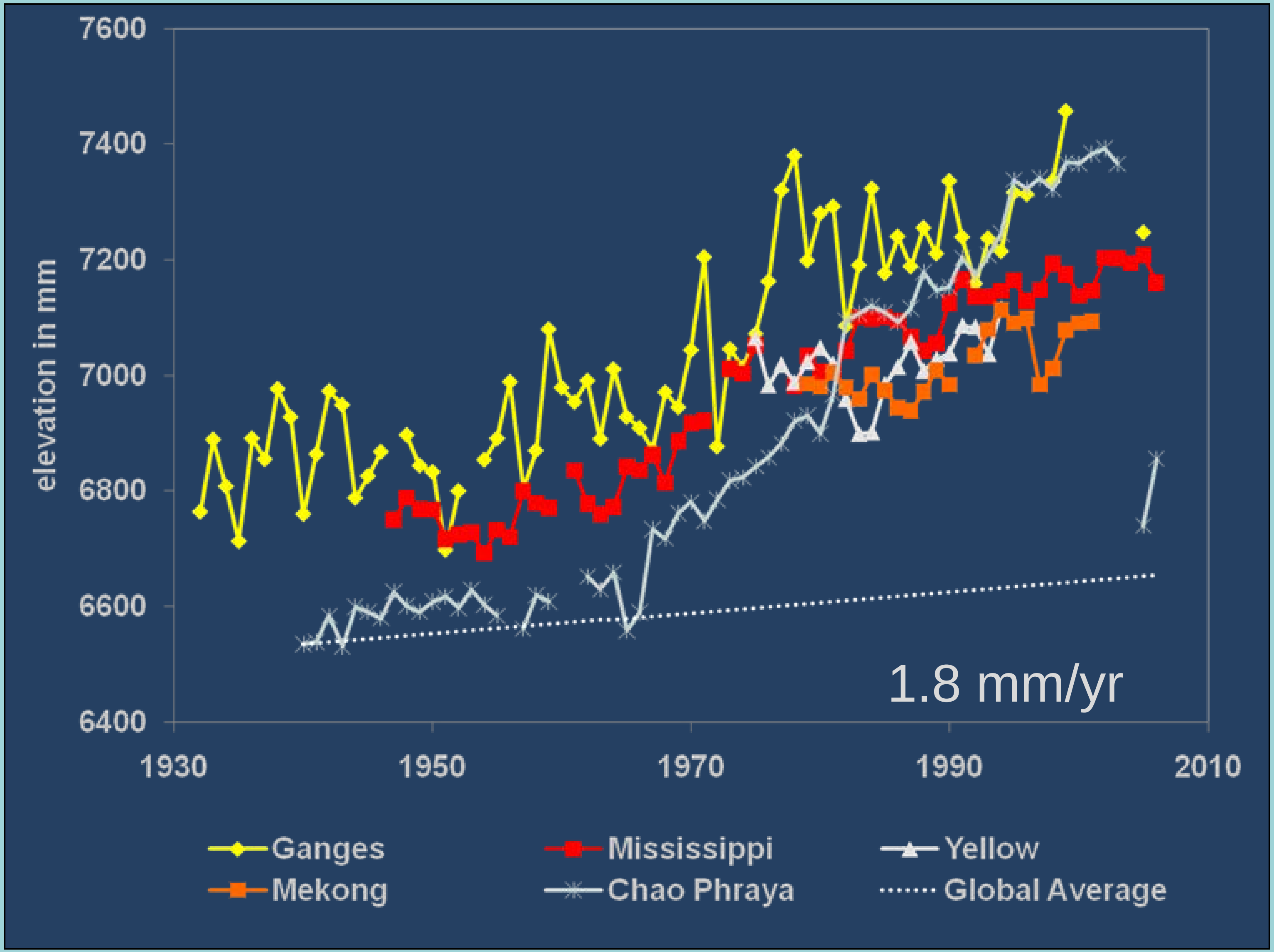


Controls on Delta Surface Elevation $\Delta_{RSL} = A - \Delta E - C_n - C_A - M$

e.g. natural conditions 10-1-2-0-2 = + 5 mm/y

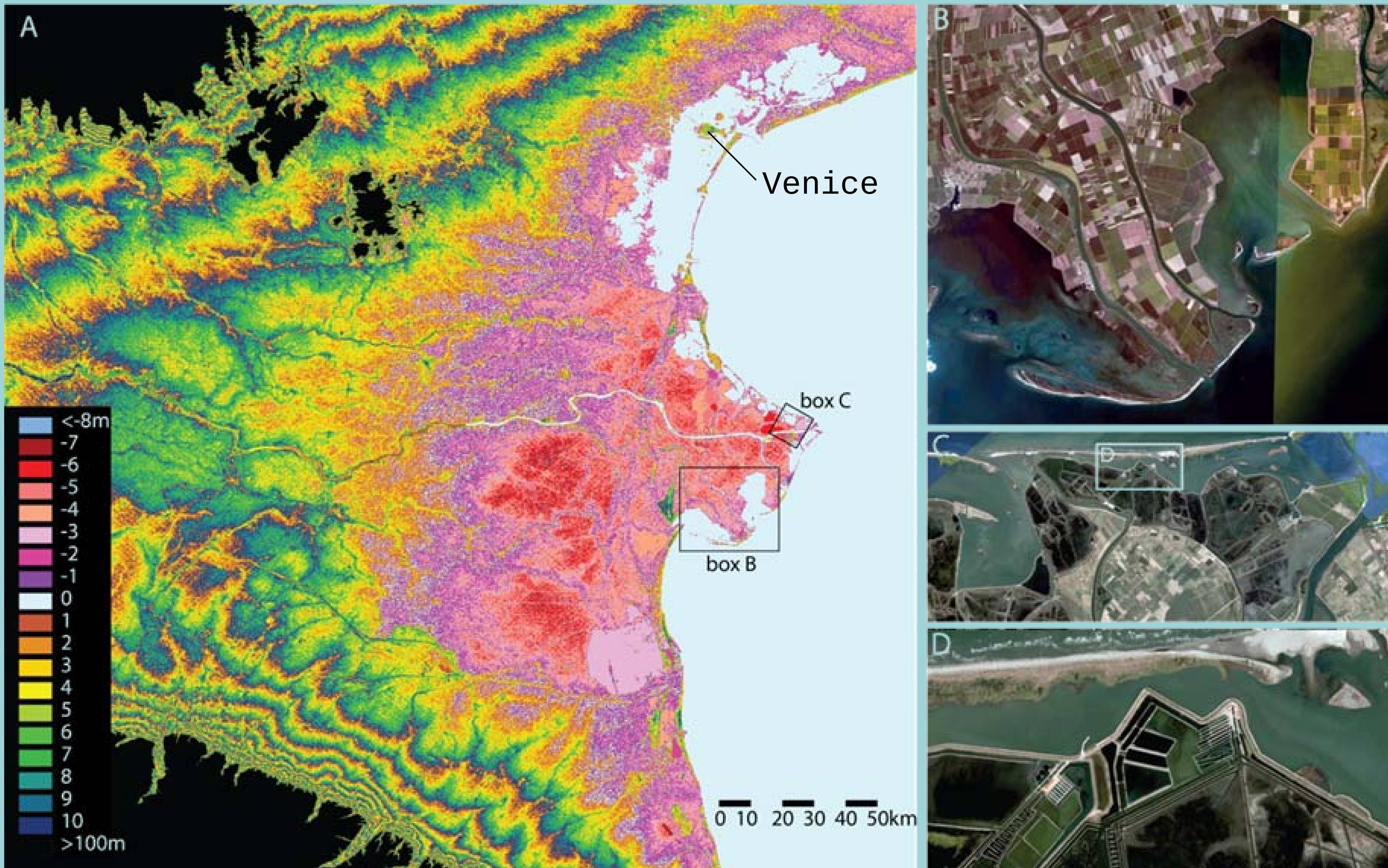
e.g. anthropogenic forcing 5-3-2-13-2 = - 15 mm/y

Relative sea level has risen 4 times faster within deltas than the global average.

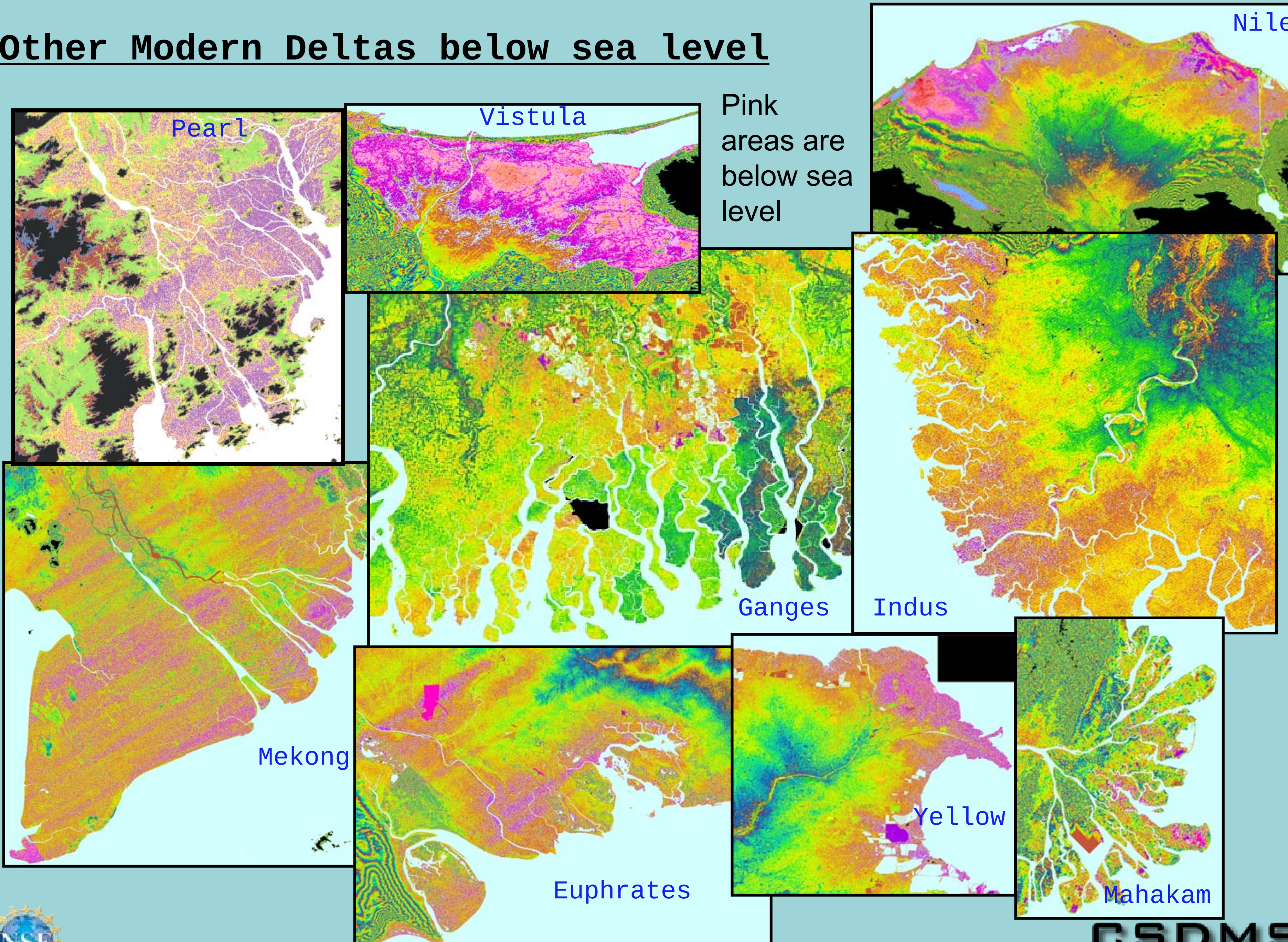


Po Subsidence = Aggradation - Accelerated Compaction - Natural Subsidence

20th Century = 0m - 3m - 0.7m = -3.7m/century

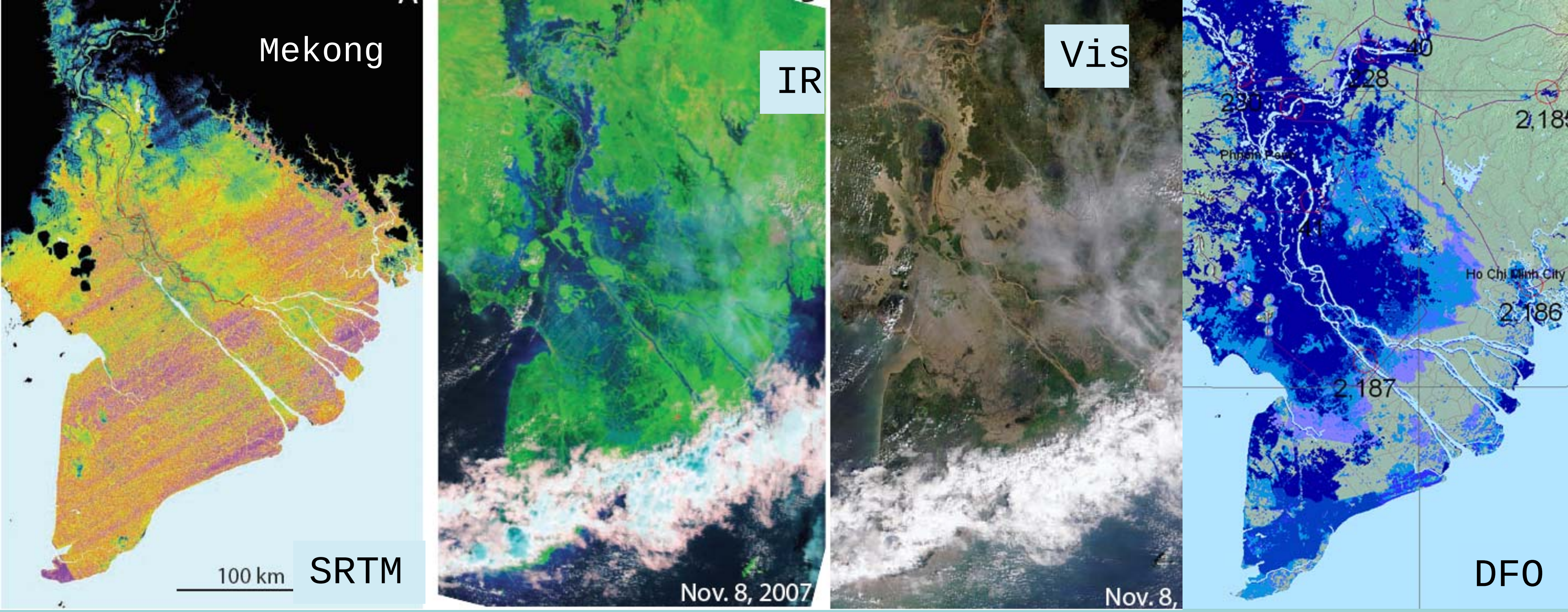


Other Modern Deltas below sea level



Pink areas are below sea level

Syvitski AAPG/SEPM 2010 New Orleans

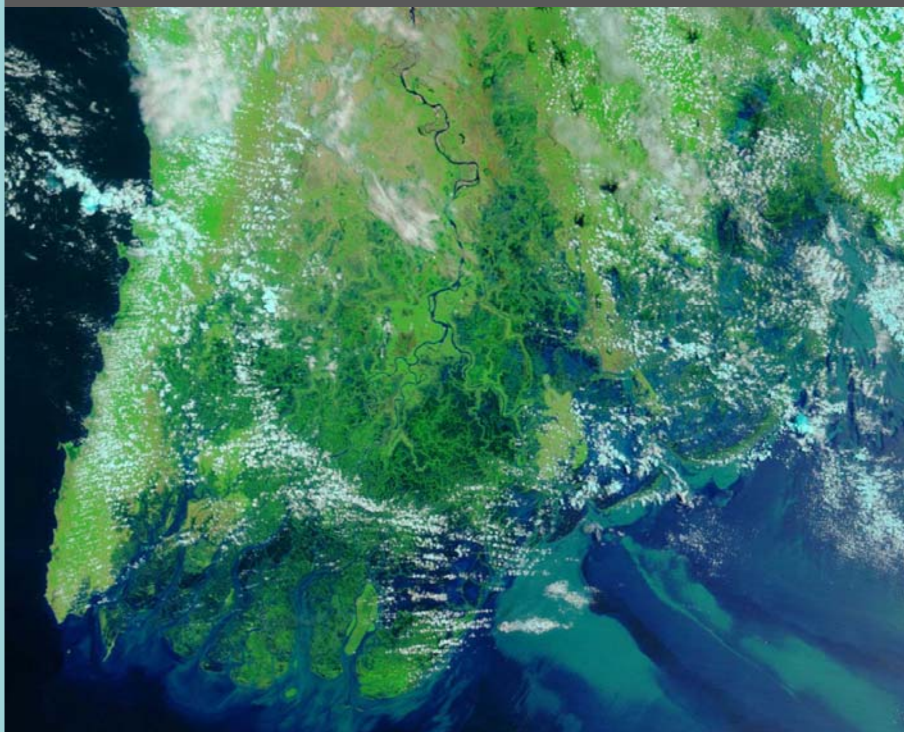


River Flood Mapping (in situ, overbanking)

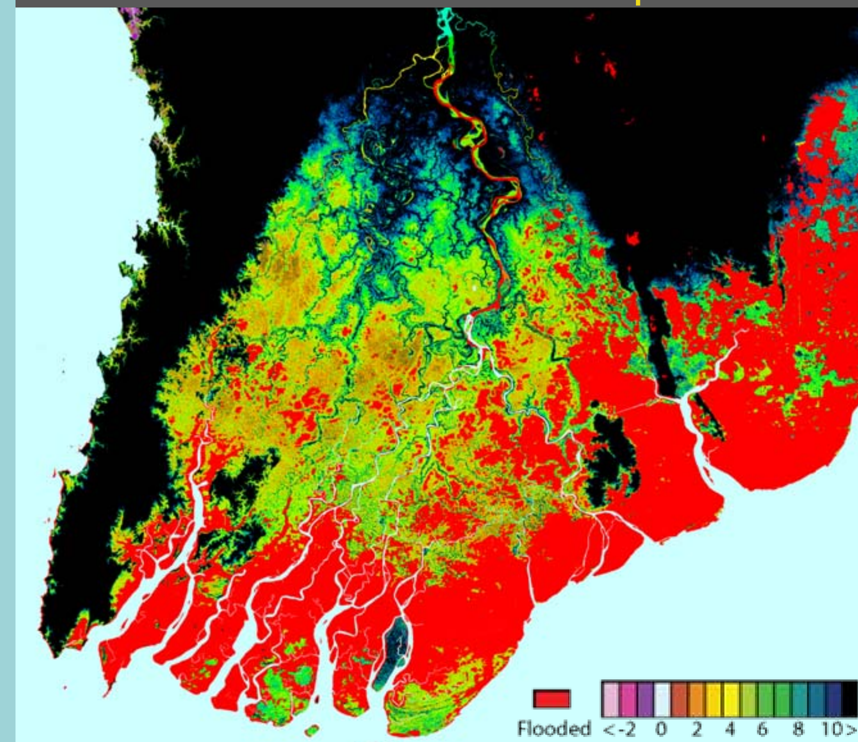
- SRTM: morphologic patterns of sedimentation
- IR: Surface water as black or shades of blue depending on the sediment concentration
- Vis: Water turbidity
- DFO: Dartmouth Flood Observatory maps (MODIS)

Ocean Surge Mapping (cyclone, tsunamis)

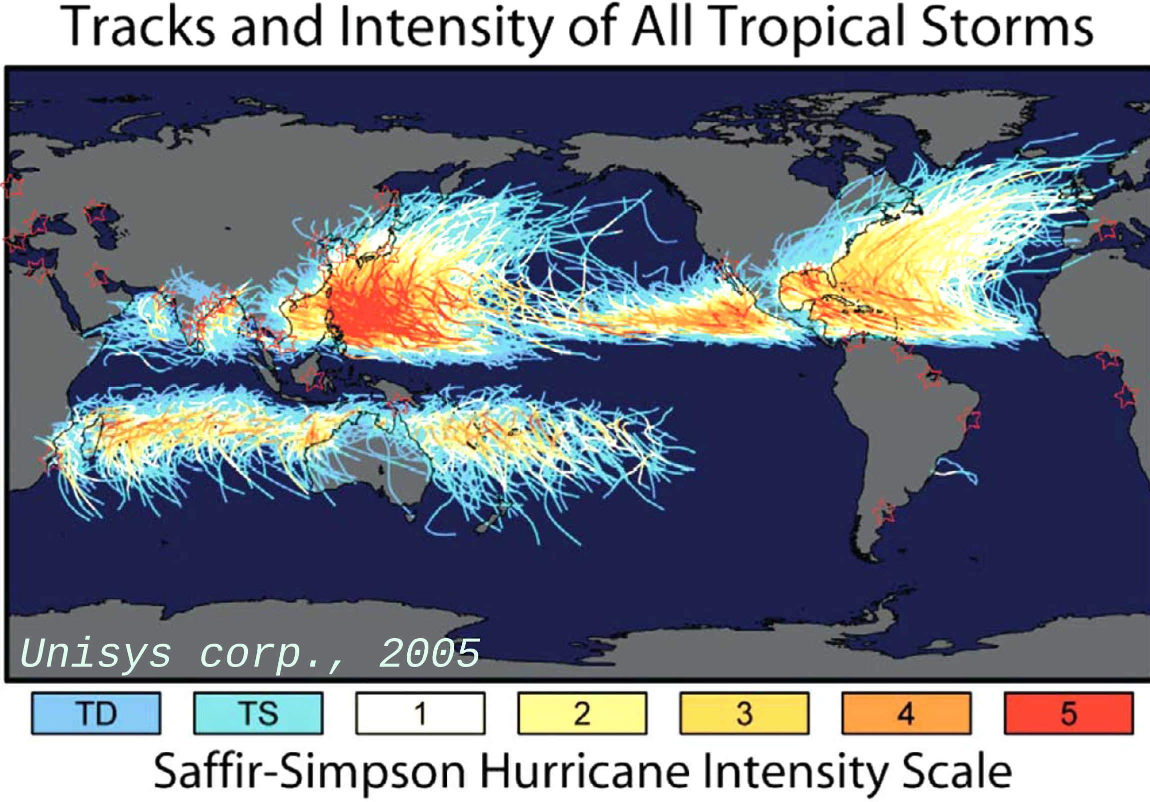
Cyclone Nargis, Irrawaddy Delta with MODIS Terra, May 5th, 2008.



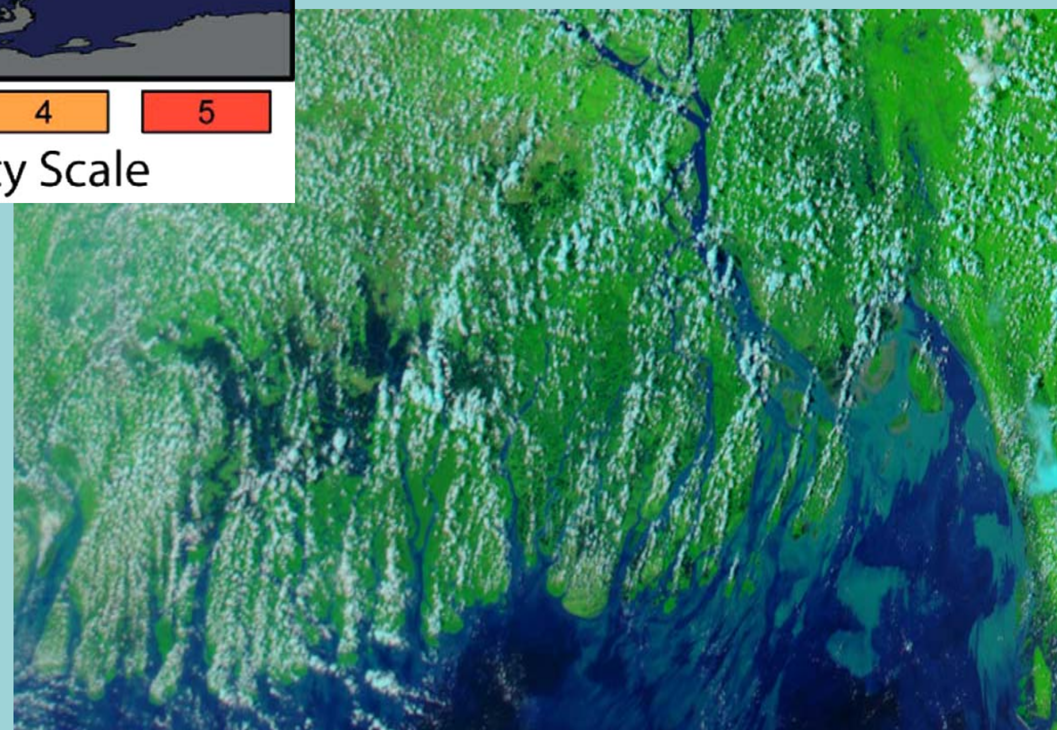
SRTM 90m topographic data overlay with MODIS flood extent map in red.



Floods are widespread, 85% of the studied deltas experienced flooding.
From 2001-2008, in the 33 deltas ~260,000 km^2 was submerged by floods.



- Cyclone Aila, May 2009 —extensive flooding in Ganges-Brahmaputra Delta
- Storm surge ~6-7m!



Hurricane Category	Pressure (mb)	Winds (mph)	Surge (m)
1	>980	74-95	≈1.5
2	965-980	96-110	≈2.5
3	945-965	111-130	≈3.5
4	920-945	131-155	≈5
5	<920	>155	>6

Delta Vulnerability

1) **Low Risk:** e.g. Fly, Orinoco, Mahakam - aggradation rates high; low anthropogenic compaction; RSLR low
2) **Moderate Risk:** e.g. Danube, Han – reduced aggradation; RSLR < 1.2 mm/y
3) **High Risk:** e,g. Godavari, Indus, Parana, Vistula – aggradation << RSLR 1.3 to 3 mm/y
4) **In Peril:** e,g. Ganges, Irrawaddy, Magdalena, Mekong, Mississippi, Niger, Tigris - low aggradation rates plus accelerated compaction overwhelming rates of sea level rise; RSLR 4 to 32 mm/y
5) **Great Peril:** e.g. Chao Phraya, Colorado, Krishna, Nile, Pearl, Po, Rhone, Tone, Yangtze, Yellow - no aggradation and/or very high accelerated compaction; RSLR 7 to 150 mm/y

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Sinking Deltas in the Press

Three river delta areas sinking, report claims

By Wang Qian (China Daily)
Updated: 2009-09-23 07:40

Comments(1) Print Mail

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Three river deltas in China are sinking due to global warming and excessive extraction of underground water, leaving millions of people with an increasing risk of floods, a recent scientific report showed.

The Vancouver Sun

Sinking river delta could mean trouble along Fraser

Conclusions

➢ 33 global delta systems have significant areas (>100,000 km^2) <2m a.s.l.

➢ 75% of studied deltas experienced flooding in last decade; 260,000 km^2 was temporarily submerged.

➢ Deltas are sinking on average 4 times more rapidly than ocean level is rising

➢ Accelerated sinking is due human interference in river basins and their deltas.

1. Sediment delivery to deltas has greatly been reduced: 3.5 Billion t/y is no longer reaching deltas, much of the remaining bypasses the delta plains.
2. Compaction due to mining is a major factor in 70% of studied systems.

➢ Vulnerable low-lying lands are expanding rapidly, due to sinking of the land.

➢ Growth of infrastructure for mega-cities is becoming a dominant factor.