Latitudinal Controls on Siliciclastic Sediment Production and Transport*

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Abstract

How latitude influences climate and the complexities therein, and the production and transport of siliciclastic sediment, will be explored. The primary latitudinal influence is on temperature, precipitation, wind and wave patterns. Surface radiation directly also influences river-water density. At any given latitude, a wide range of precipitation intensities exist, ranging from arid to wet conditions. Precipitation is influenced by the dynamics of atmospheric, but is also strongly modified by land-sea interactions and land surface topography. Global wind patterns are strongly influenced by atmospheric circulation dynamics that form the zonal wind belts. Strong winds include those associated with fronts between air masses and pressure systems and as influenced by topography, short-lived convective winds under thunderstorms, and winds associated with tropical cyclones. Maximum wave power is found on temperate and subarctic western coastlines. Swell-dominated coastlines are located in the tropical western coastlines. Eastern continental coastlines receive lower wave energy. Arctic Ocean waves are fetch-limited. Secondary latitudinal influences include climatic impacts on sediment production. A water temperature increase of 1 °C causes a ~3.1% decrease in the suspended sand transport — suspended sand concentration decreases by ~2%, suspended silt and clay concentration drops off by only 0.35%, flow velocity decreases by ~0.66%, and there is ~2.2% rise in the von Karman parameter. While the abundance of fine sedimentary particles in transport might reflect biochemical weathering of source rocks and soils, intensified downstream fining might also reflect the decreasing transport competency associated with increased water temperature and reduced kinematic viscosity. Scaling models allow for a hypothetical polar river, to be compared to an equally sized river draining similar topography, but as influenced by another climate. Polar climates yield less sediment: 1) melt-induced runoff yield smaller flood waves then surface runoff from falling rain; 2) frozen soils and river beds reduce sediment yield; and 3) summer-time polar rain falls is less intense than from temperate or tropical regions. A basin having similar drainage area and relief, and lithology will have 25 times sediment transport when compared to a tropical basin. Arid basins produce less sediment and more of this sediment is stored between the source area and the coast.

Selected References

Hudson, B., I. Overeem, D. McGrath, J.P.M. Syvitski, A. Mikkelsen, and B. Hasholt, 2014, MODIS observed increase in duration and spatial extent of sediment plumes in Greenland fjords: The Cryosphere, v. 8, p. 1161-1176, doi:10.5194/tc-8-1161-2014, 2014.

Sekine, M., and K. Nishimorie, 2008, Erosion rate of cohesive sediment by running water: Proceedings of the 4th International Conference on Scour and Erosion (ICSE-4 Tokyo), p. 424-429.

Syvitski, J., and J.D. Milliman, 2007, Geology, geography, and humans battle for dominance over the delivery of fluvial sediment to the coastal ocean: The Journal of Geology, v. 115/1, p. 1-19.

Vanmaercke, M., J. Poesen, J. Broeckx, and J. Nyssen, 2014, Sediment yield in Africa: Earth-Science Reviews, v. 136, p. 350–368.

Latitudinal Controls on Siliciclastic Sediment Production & Transport

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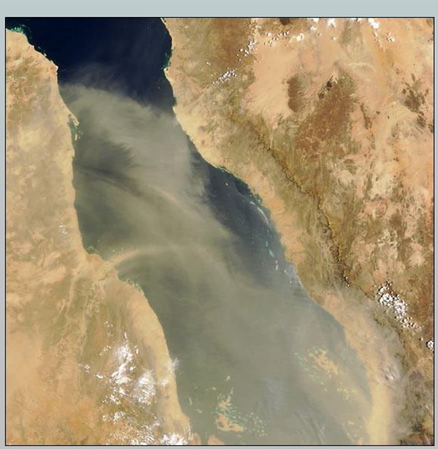
~22 Gt of siliciclastic sediment are delivered to the coastal ocean each year, across latitude-controlled climate zones. Most delivery is by rivers (16 Gt/y: 94% – suspended load, 6% – bedload), ice sheets (4.5+ Gt/y), aeolian transport (1.5 Gt/y), & eroding coasts (0.5 Gt/y).

* **primary latitudinal influences**:
  insolation, temperature, precipitation, and wind patterns.
* **secondary latitudinal influences**:
  physical and biogeochemical weathering, wave action.
* **latitudinal influences on sediment transport**:
  fluvial, aeolian, ice sheet transport;
  river-water temperature & particle settling velocities.



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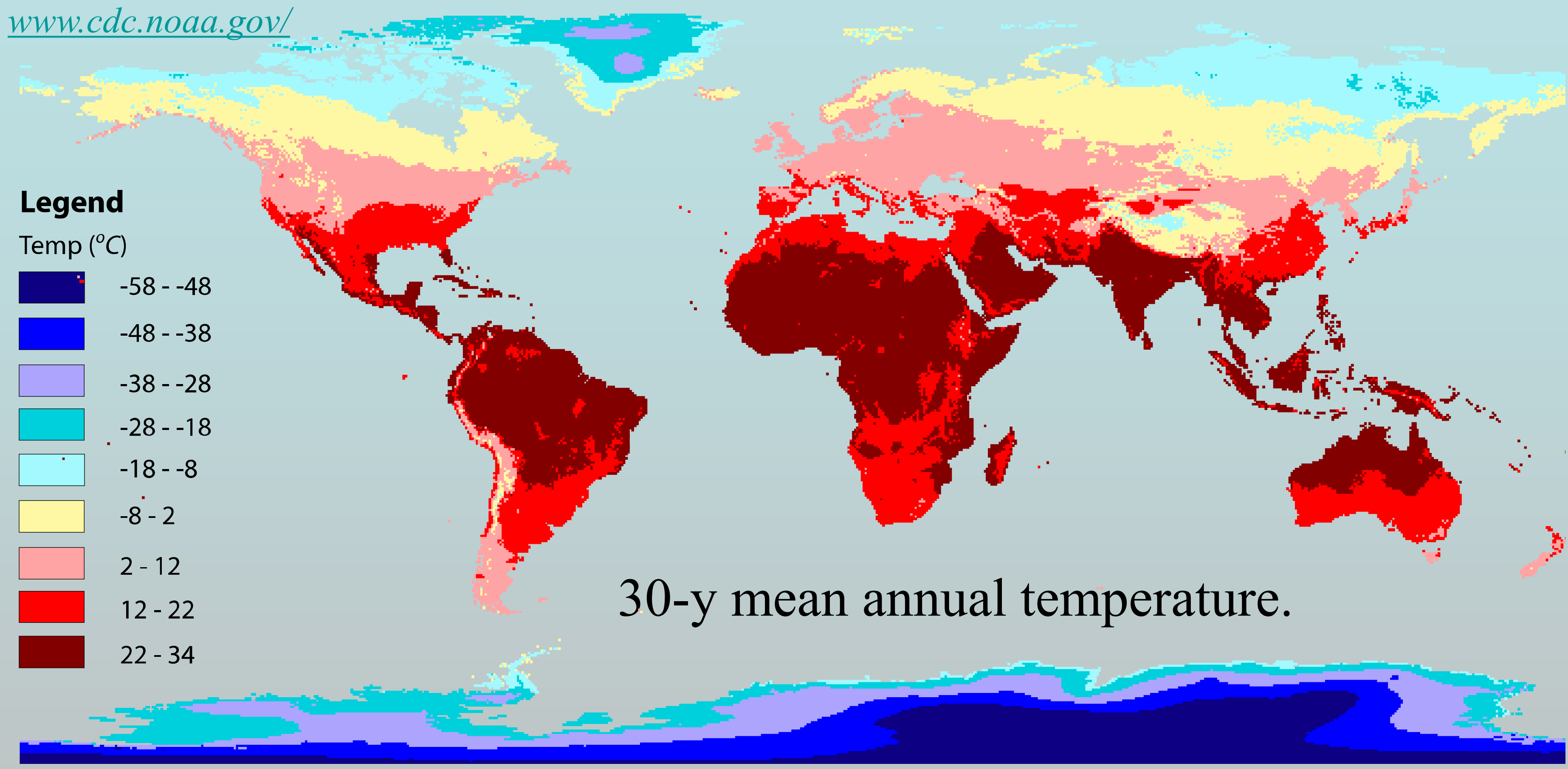
Primary Latitudinal Influences: 1) Terrestrial Temperature



Variances from latitudinal banding reflect the influence of topographic elevation, the "continental" effect, ocean currents, albedo, and cloud distribution.

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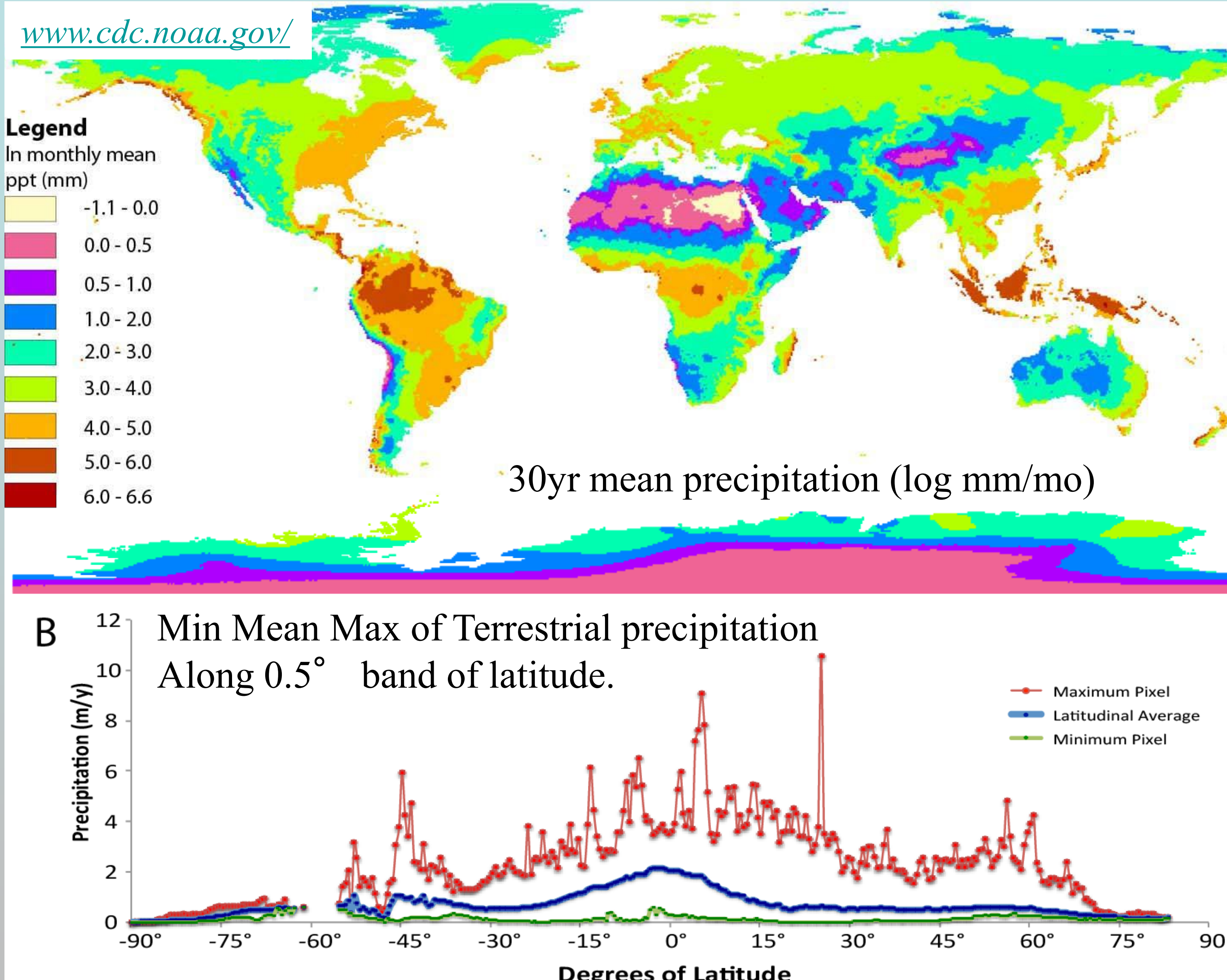
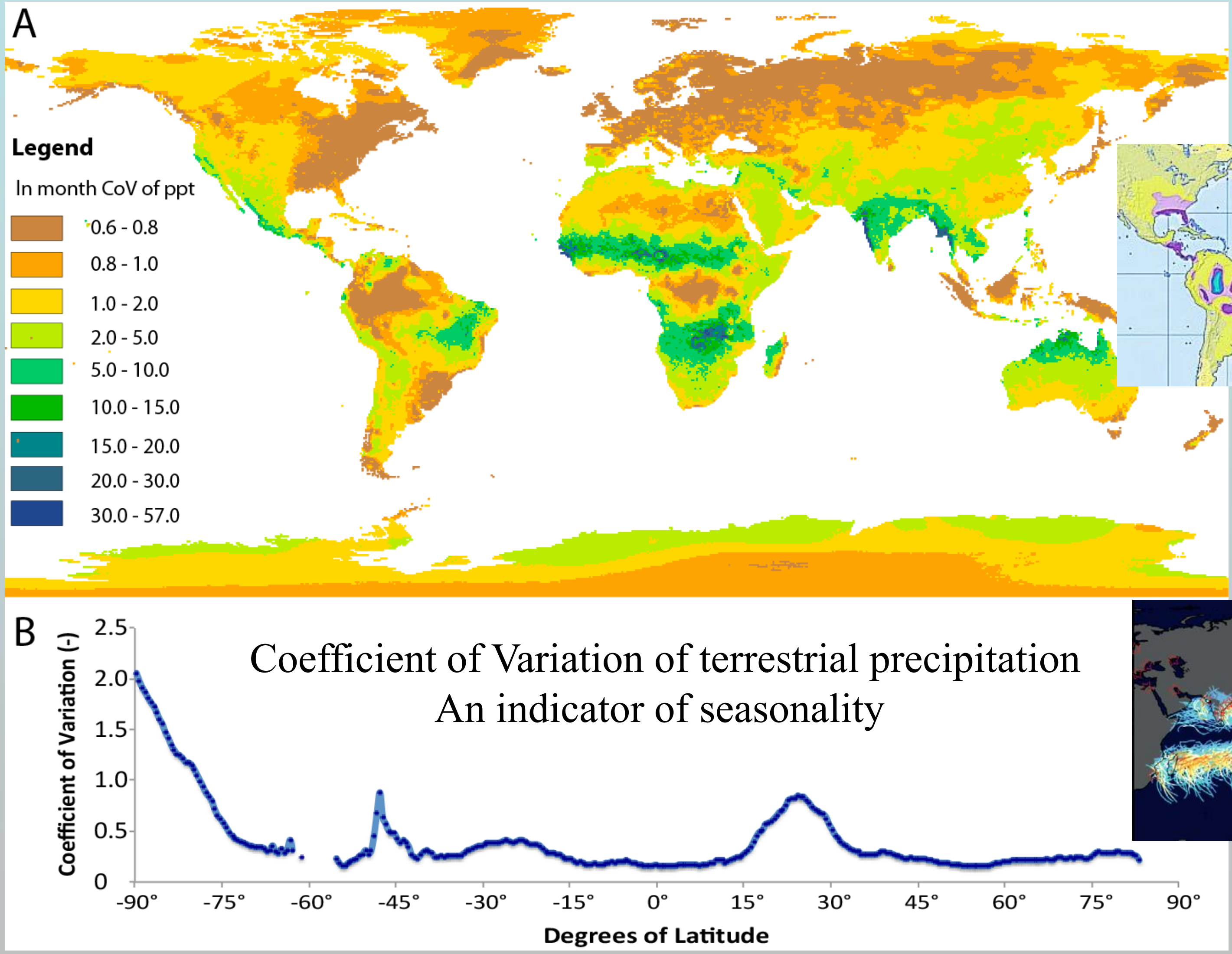
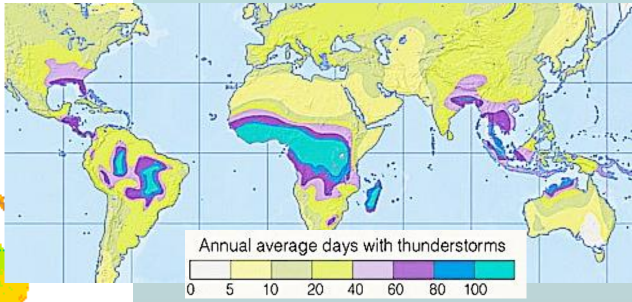
Primary Latitudinal Influences: 2) Terrestrial Precipitation



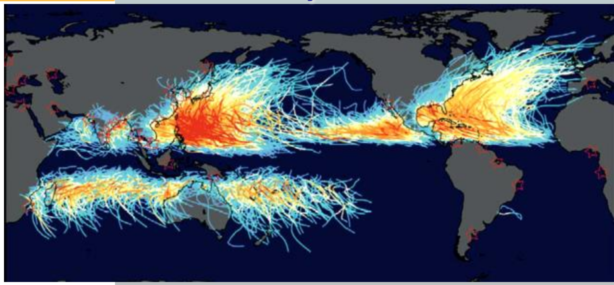
Primary Latitudinal Influences: 2) Terrestrial Precipitation



Global Thunderstorms



Global Tropical Cyclones



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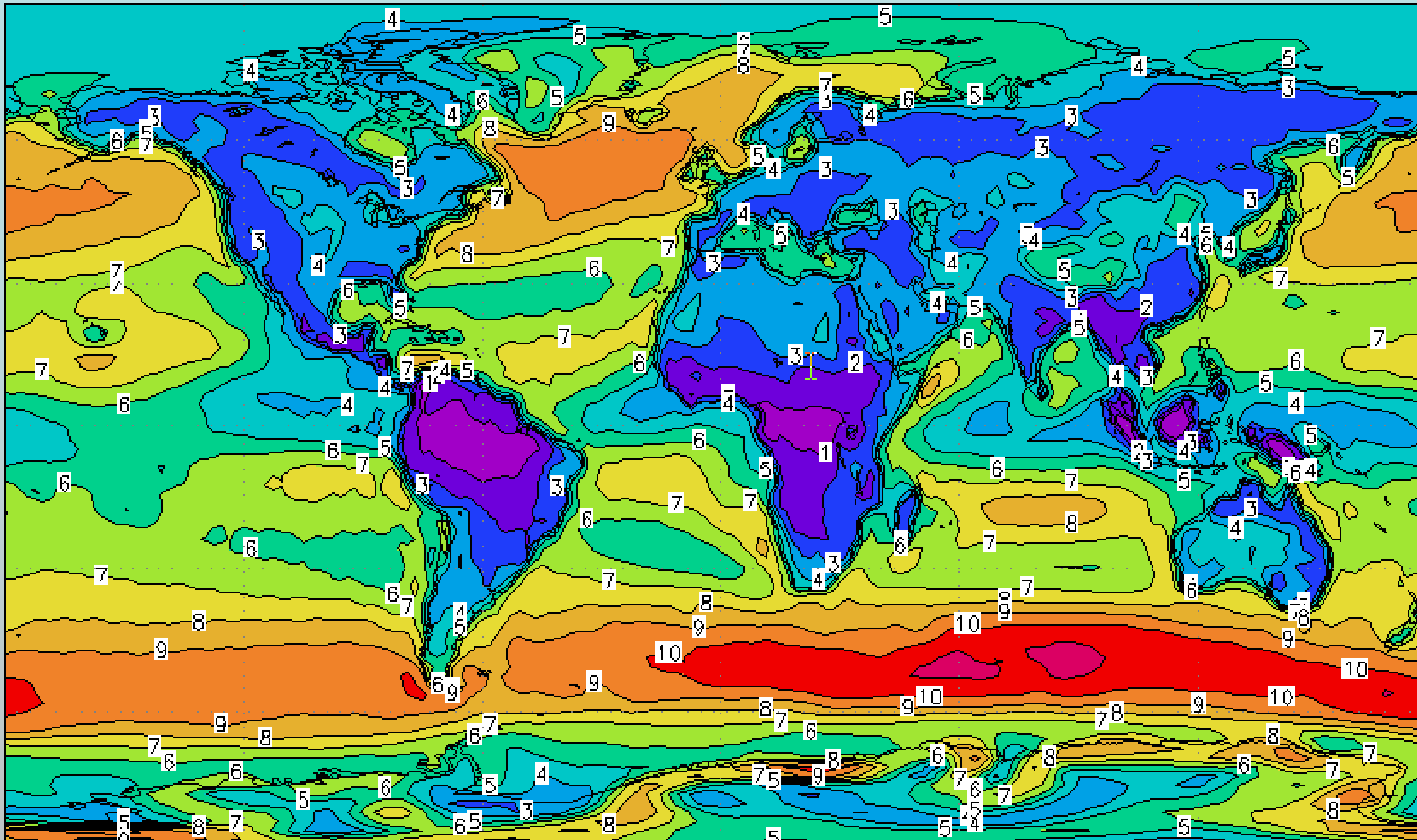
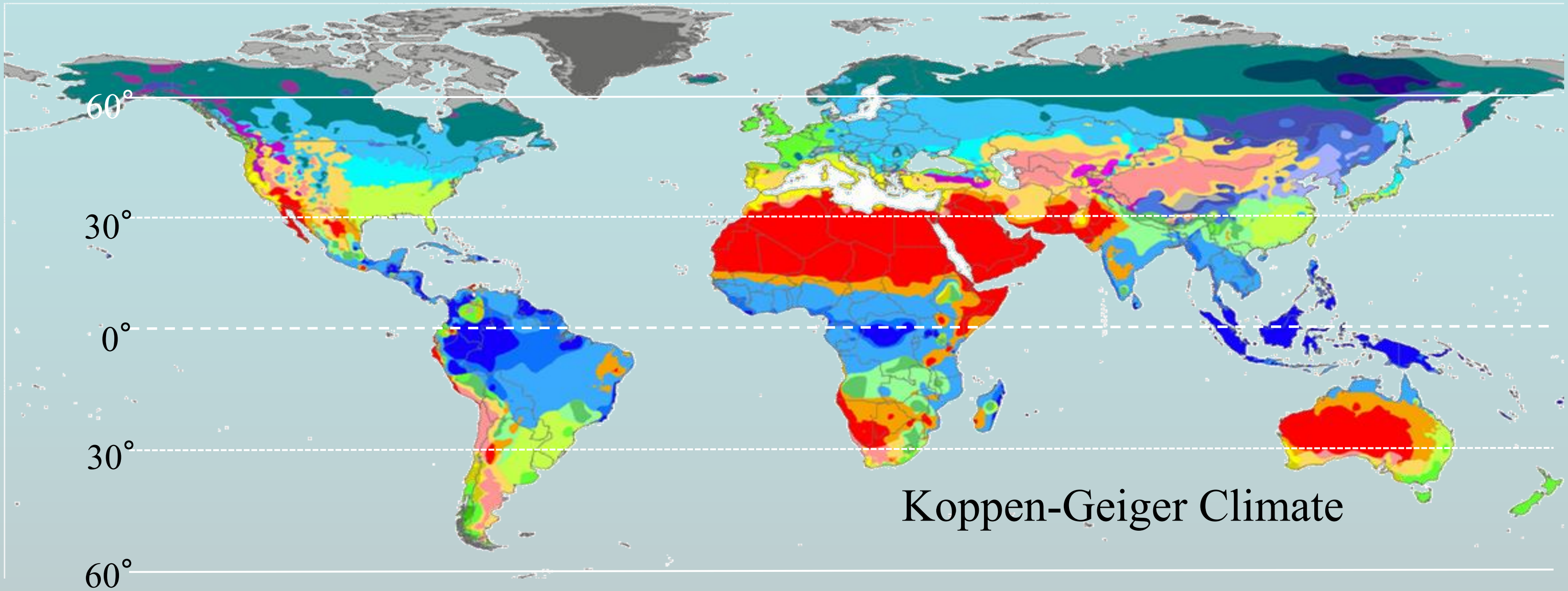
Primary Latitudinal Influences: 3) Wind



mean wind speed m/s @10m a.g.l. (1976-95), NCEP/NCAR reanalysis

Wind over water is ~2 to 3 times higher than wind over land

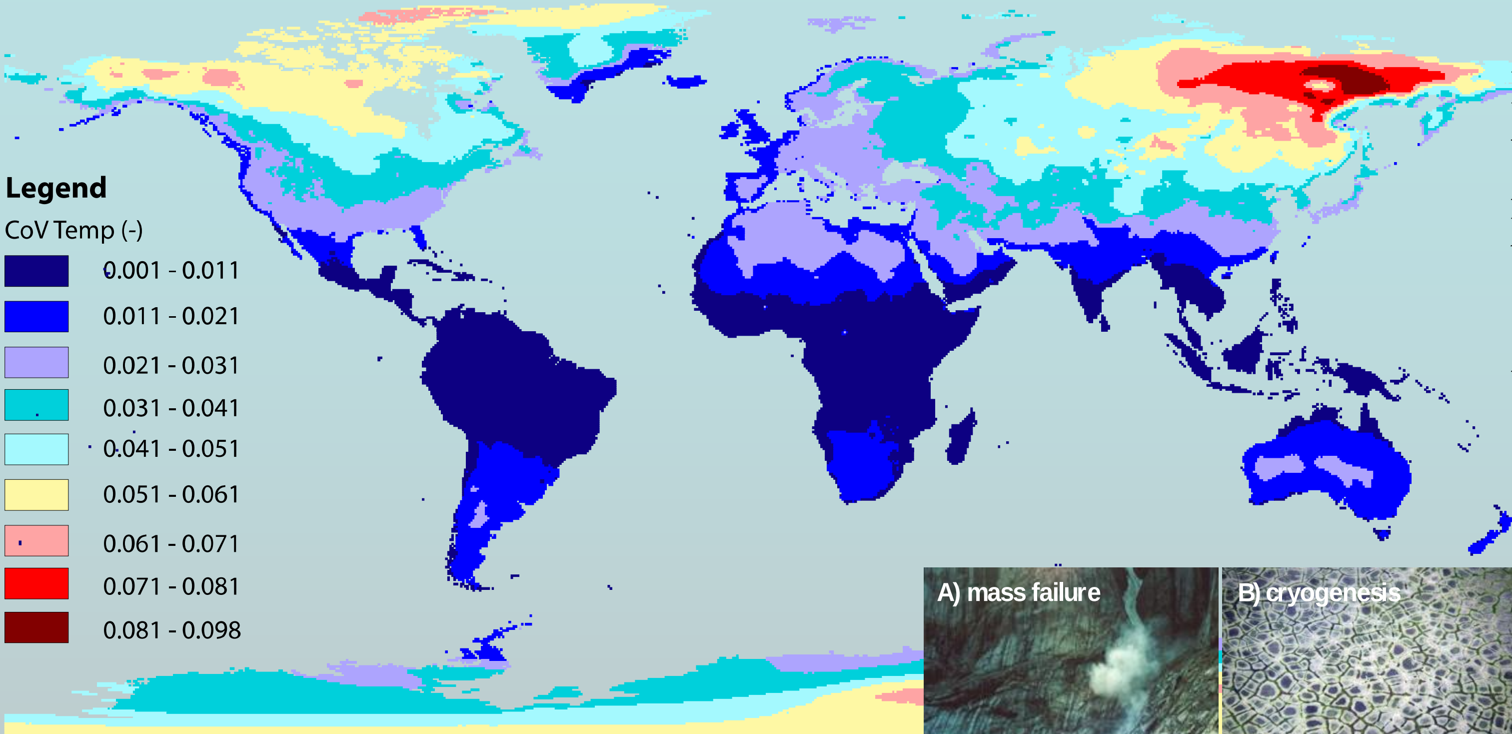
Secondary Latitudinal Influences: 1) Sediment Production



There is an intimate connection between climate and sediment production and transport. Climate zones are based on temperature and precipitation: A) Tropical, B) Dry, C) Temperate, D) Continental, and E) Polar and Alpine regions.

Native vegetation patterns integrate the influences (seasonality, extremes, thresholds) of temperature, precipitation and evapotranspiration.

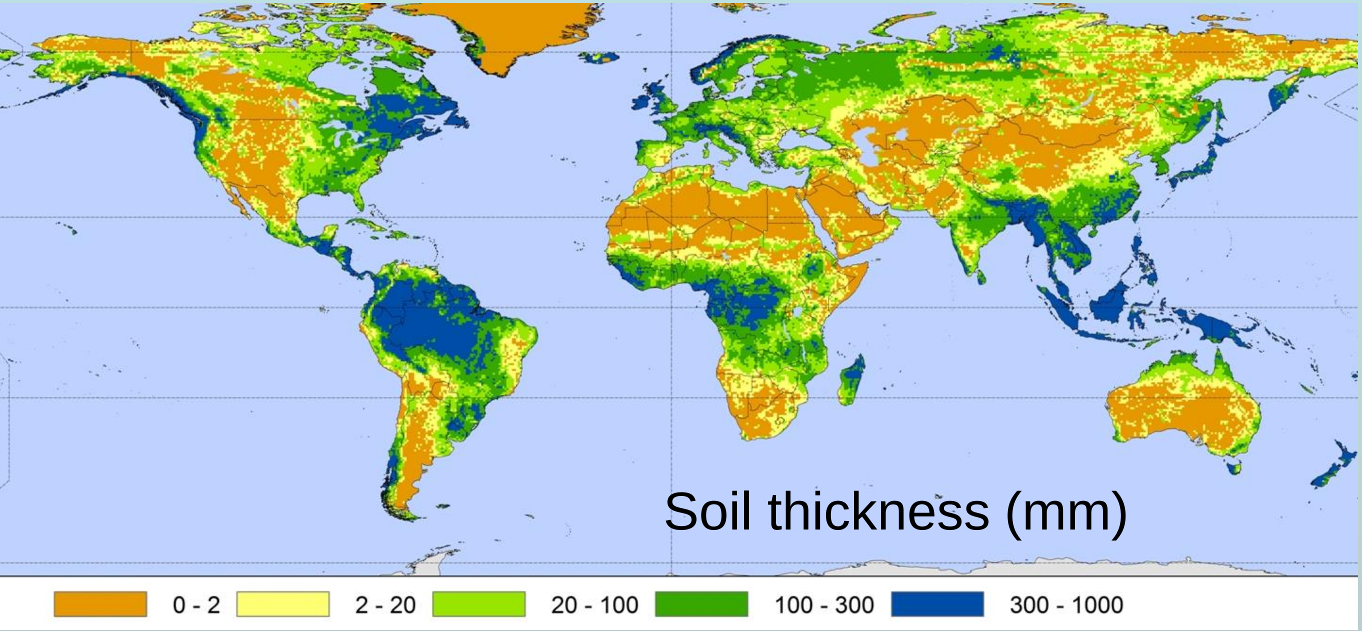
Secondary Latitudinal Influences: 1) Sediment Production

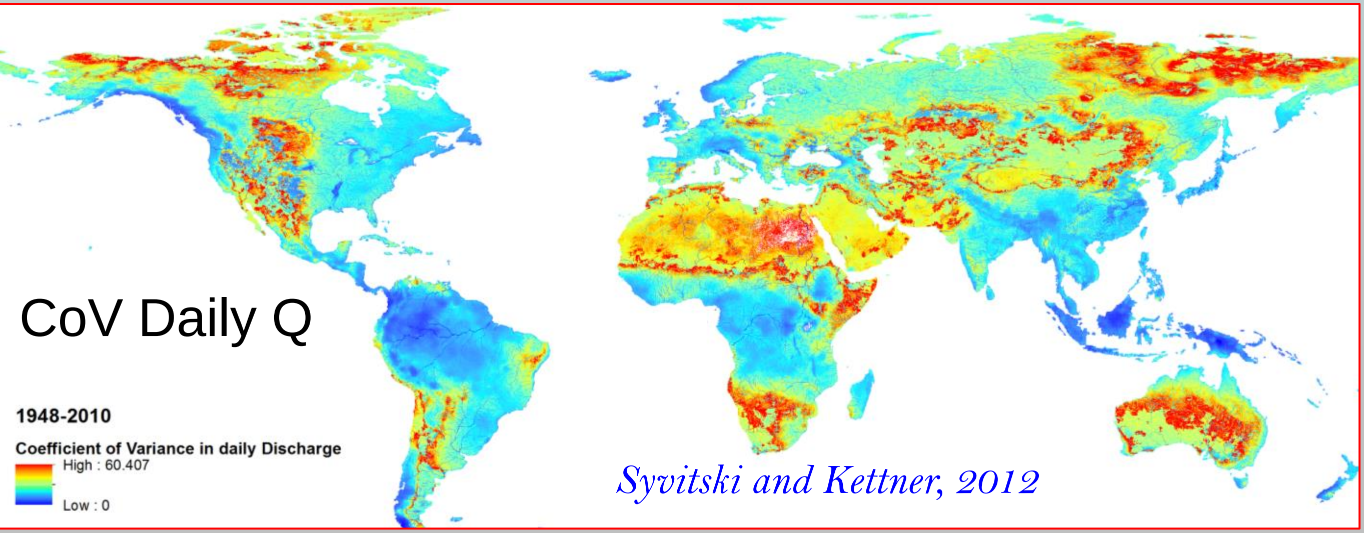


Biogeochemical weathering and rainfall intensity both increase with ground temperatures & strongly influence sediment yield.

Physical weathering is the fracturing of rock and rock material, including the breakdown of sediment particles moving downstream or downwind, without changing the chemical composition of the original material.

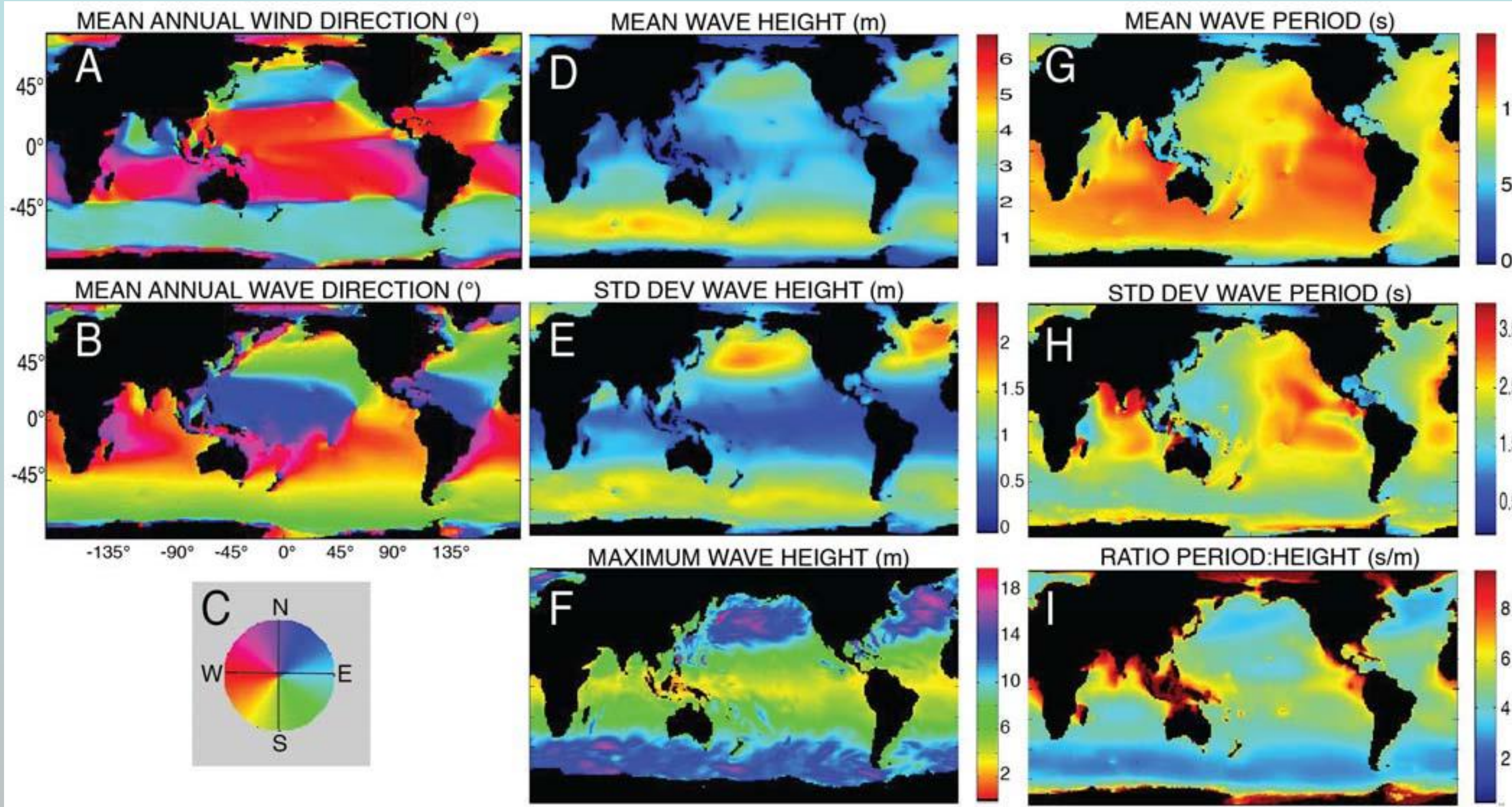
Secondary latitudinal influences: 1) Sediment Production



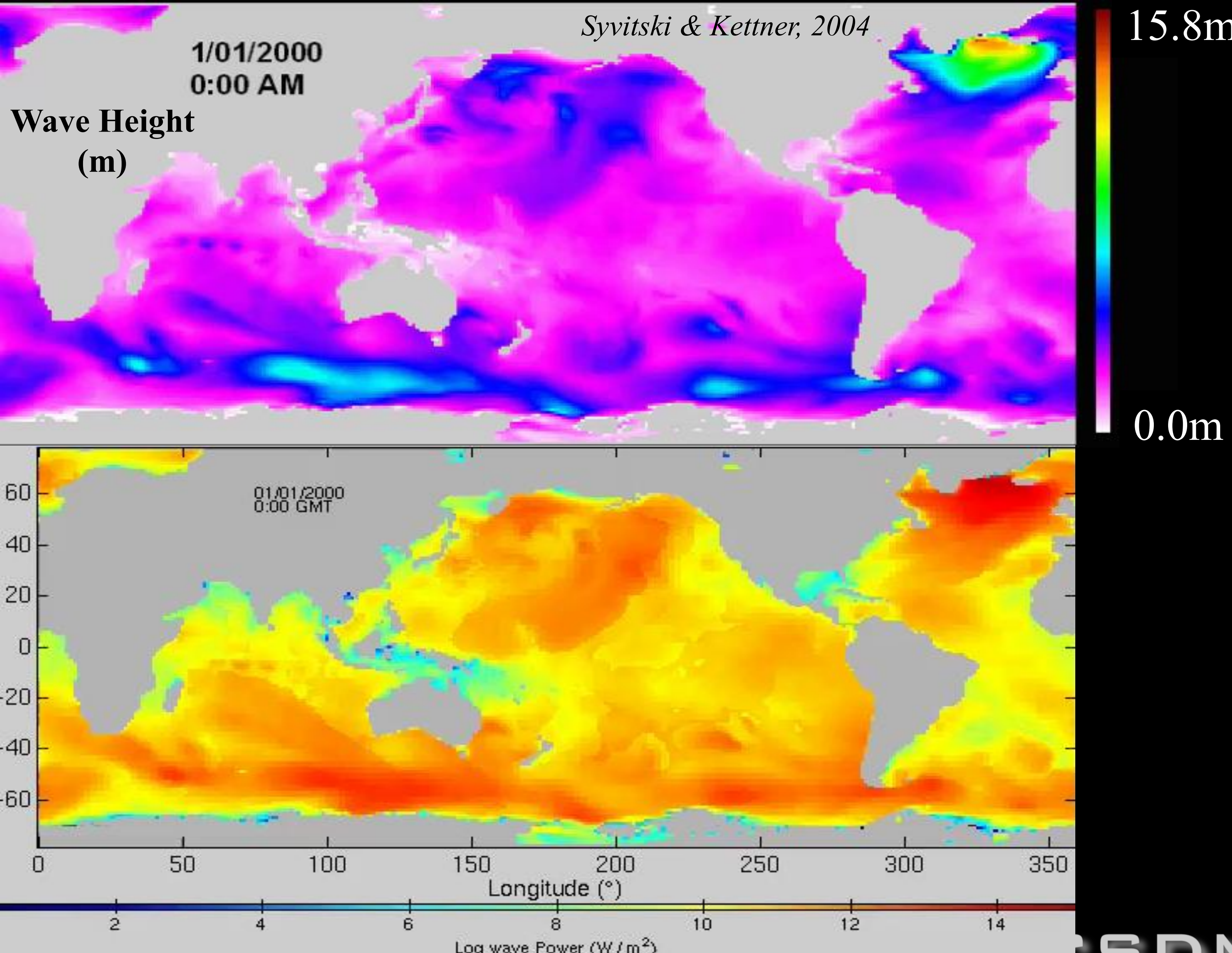


Soil formation reflects latitudinal influences through integrating precipitation variability and temperature, BUT also wetland distribution and thus both mechanical and chemical weathering.

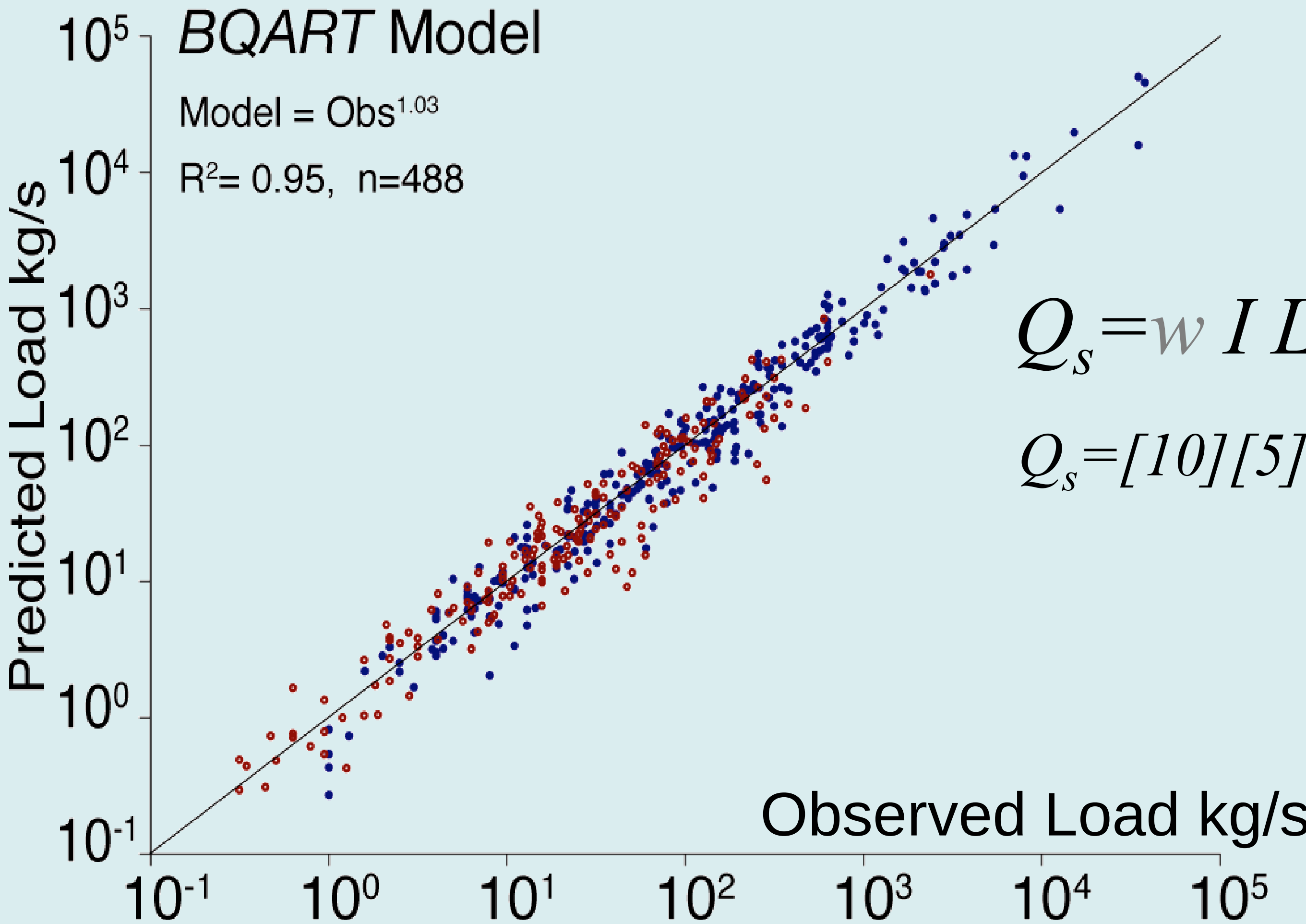
Secondary Latitudinal Influences: 2) Wave Action



Ocean storm waves reflect the size of the windstorm, the fetch, and the windstorm duration. Over the deep ocean, winds reflect distinct wind belts at different latitudes. Continents act as wind barriers and partially redirect winds. Outside of a fetch zone, ocean swells develop and travel long distances no longer influenced by wind.


Syvitski & Kettner, 2004
1/01/2000
0:00 AM
Wave Height
(m)
15.8m
0.0m
01/01/2000
0:00 GMT
60
40
20
0
-20
-40
-60
0
50
100
150
200
250
300
350
Longitude (°)
2
4
6
8
10
12
14
Log wave Power (W / m²)

Latitudinal influences on Sediment Transport: 1) Fluvial Transport



$$Q_s = w\, I\, L\, Q^{0.31} A^{0.5} R\, T$$

$$Q_s = [10][5][10][10^2][10^3][10]$$

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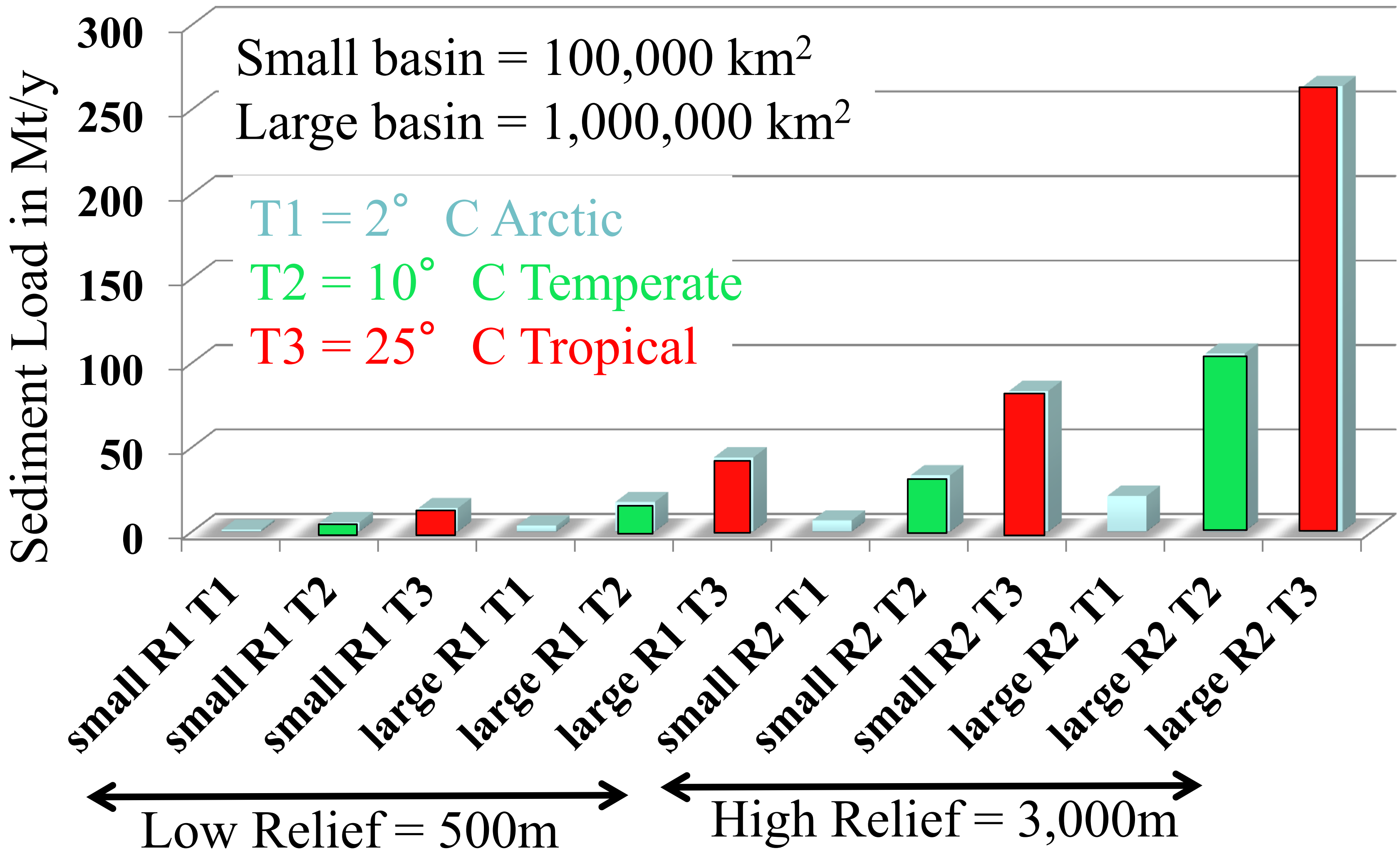

Tropical river basins can produce and transport 2.5 times more sediment than a similar scale basin located in a temperate region and 12 times more sediment than a similar scale Arctic basin

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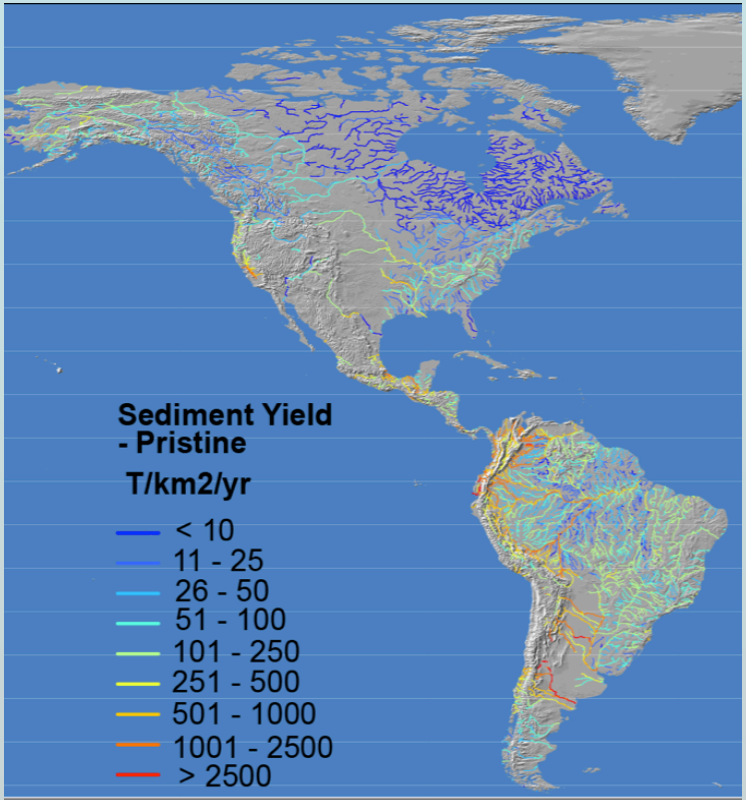
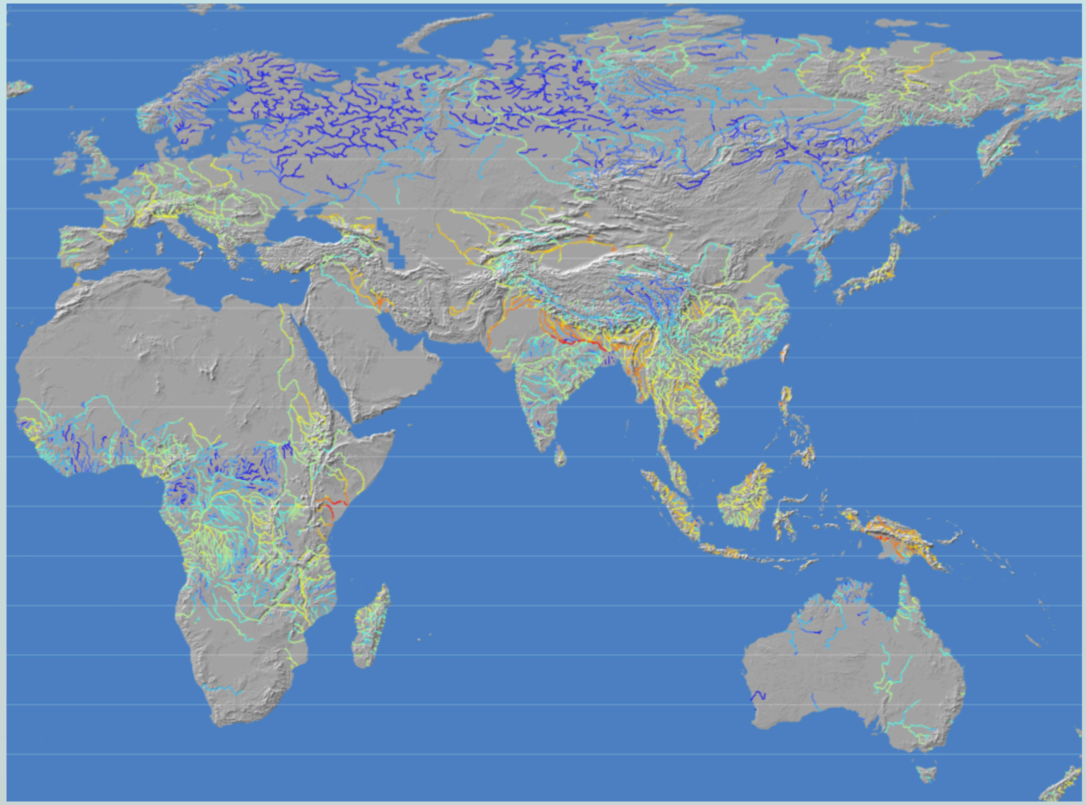
Latitudinal influences on Sediment Transport: 1) Fluvial Transport

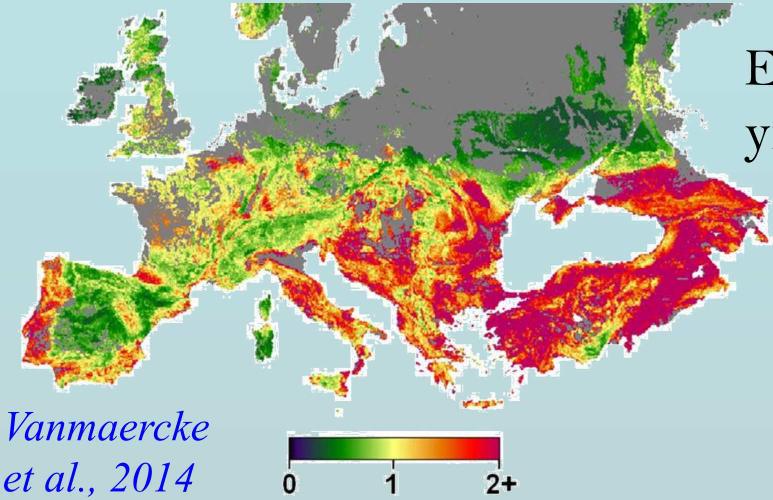




$$Q_s / A = Y_s = \omega \cdot B \cdot Q^{0.31} A^{-0.5} R \cdot T$$

Globally-averaged fluvial sediment yield is 154 T/km^2/y, but values >2000 T/km^2/y are found along tectonically active mountain chains. Sub-polar & polar regions offer large areas of very low sediment yield (<20 T/km^2/y), as these northern continental shield areas have relatively low relief, temperatures are cold, lithology is hard, and precipitation is low to moderate.

Latitudinal influences on Sediment Transport: 1) Fluvial Transport



Vanmaercke et al., 2014

Earthquake shaking can increase sediment yields by a factor of 2

Lithology can impact sediment yields by a factor of 3

Syvitski & Milliman, 2007

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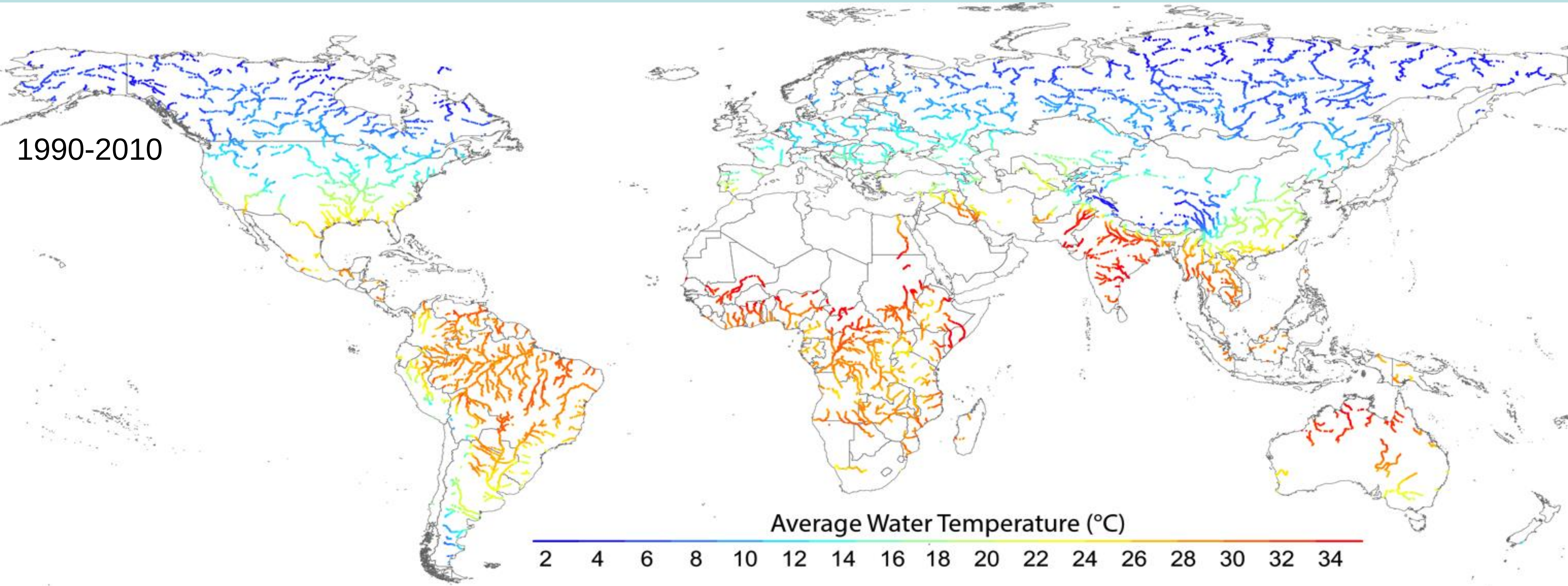
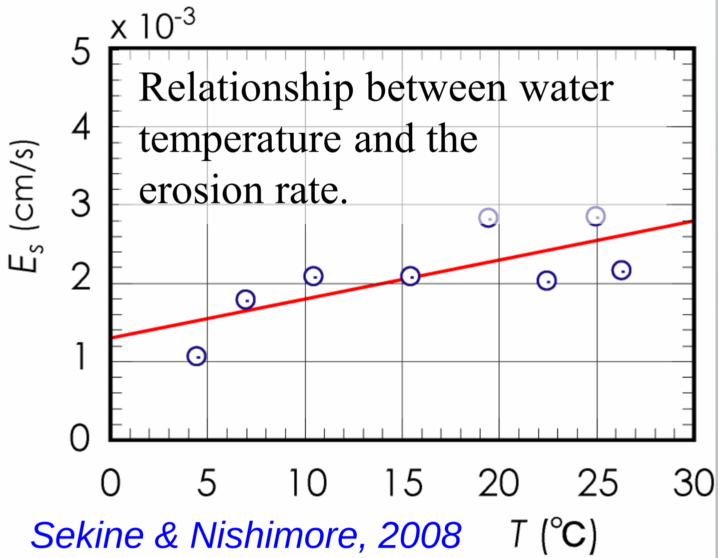
Latitudinal influences on Sediment Transport: 1) Fluvial Transport





Sekine & Nishimore, 2008

Particle settling increases linearly with water temperature. A water temperature increase of 1° C causes a ~3.1% decrease in the suspended sand transport. When suspended sand concentration decreased by 2%, suspended silt and clay concentration drops off by only 0.35%, flow velocity decreases by ~0.66%, and there is ~2.2% rise in the von Karman parameter. *Syvitski et al., 2014*

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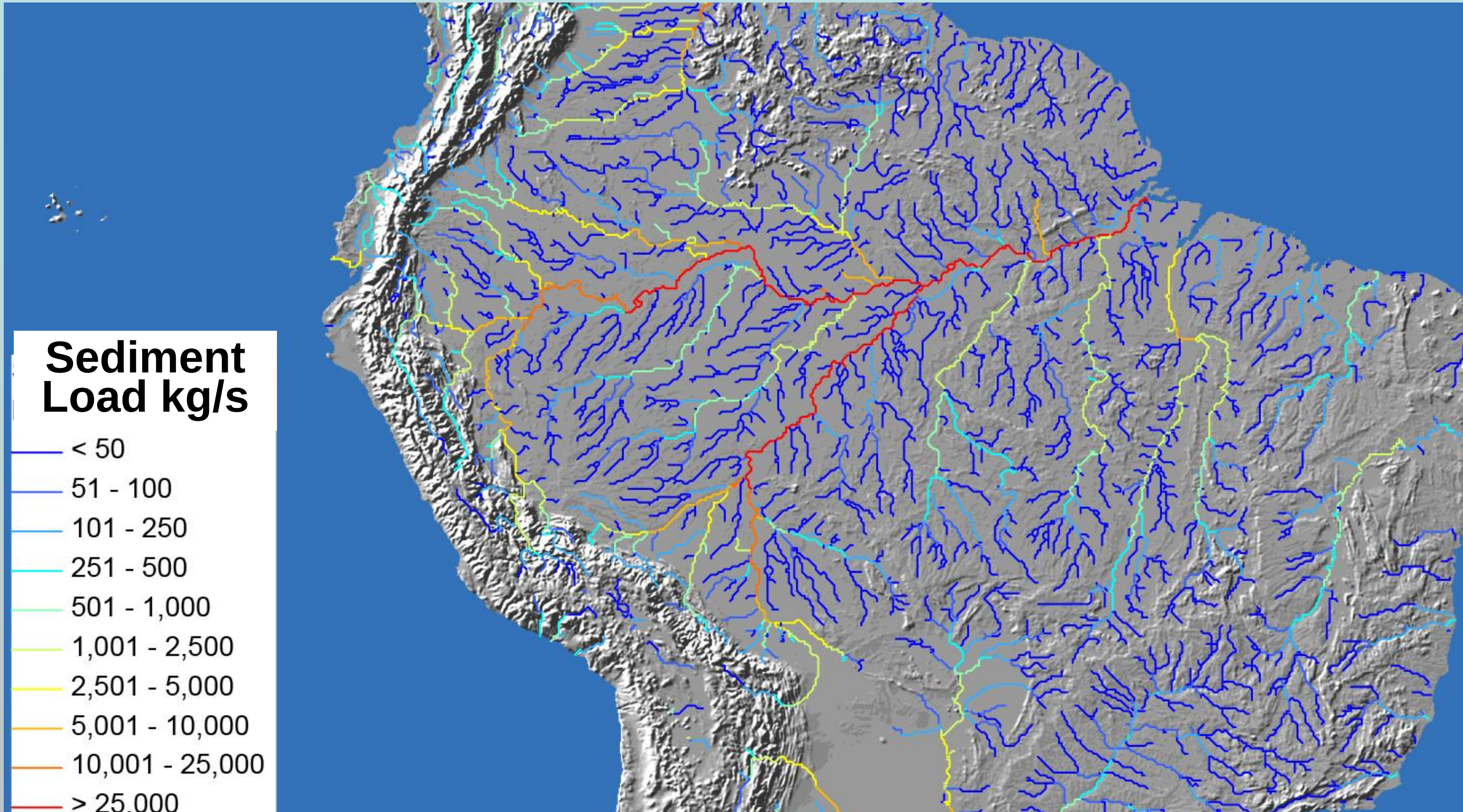
Latitudinal influences on Sediment Transport: 1) Fluvial Transport



The abundance of fines in tropical transport might reflect both the accelerated biochemical weathering of source rocks and soils, and intensified downstream fining from the decreasing transport competency associated with increased water temperature and reduced kinematic viscosity. .

AAPG/SEPM, Calgary, Syvitski

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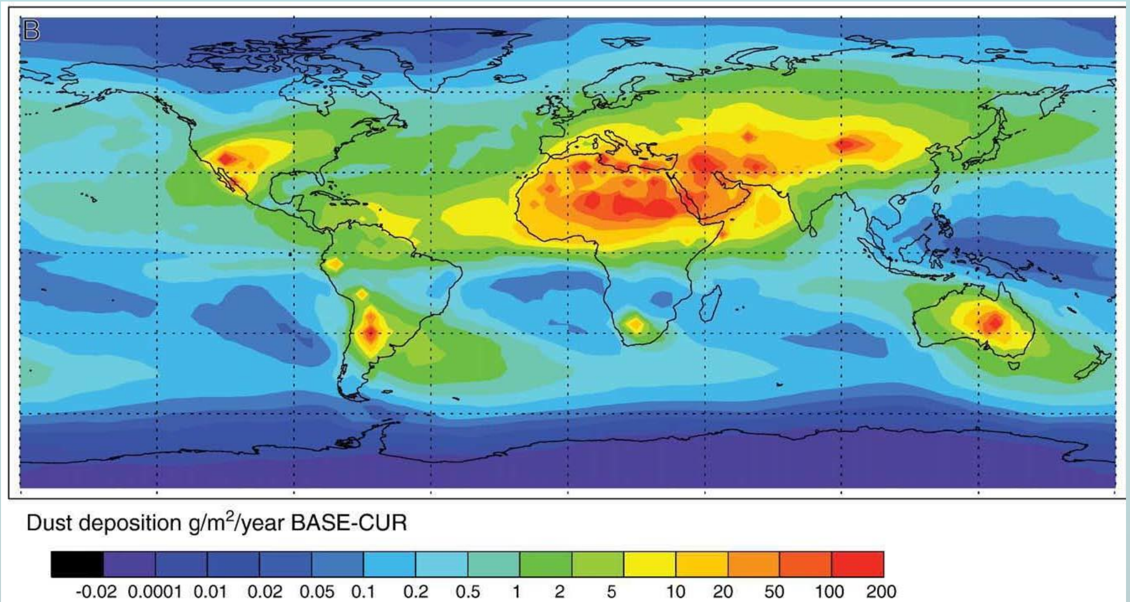
Latitudinal influences on Sediment Transport: 2) Aeolian Transport



Sediment transport by wind occurs where: 1) there is a suitable sediment source, and 2) winds are of sufficient strength to move the available sediment. North Africa accounts for 67% of the global dust flux, followed by Arabia (16%), Australia (6%), central Asia (5%), East Asia (3%), South America (2%), and North America and Southern Africa (1% each) (Tanaka and Chiba 2006).

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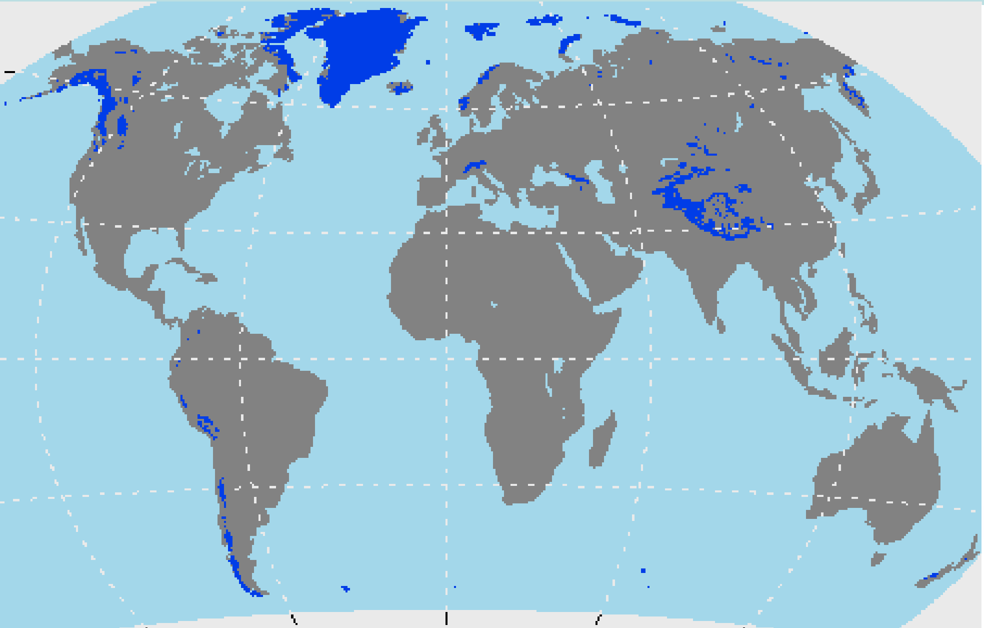
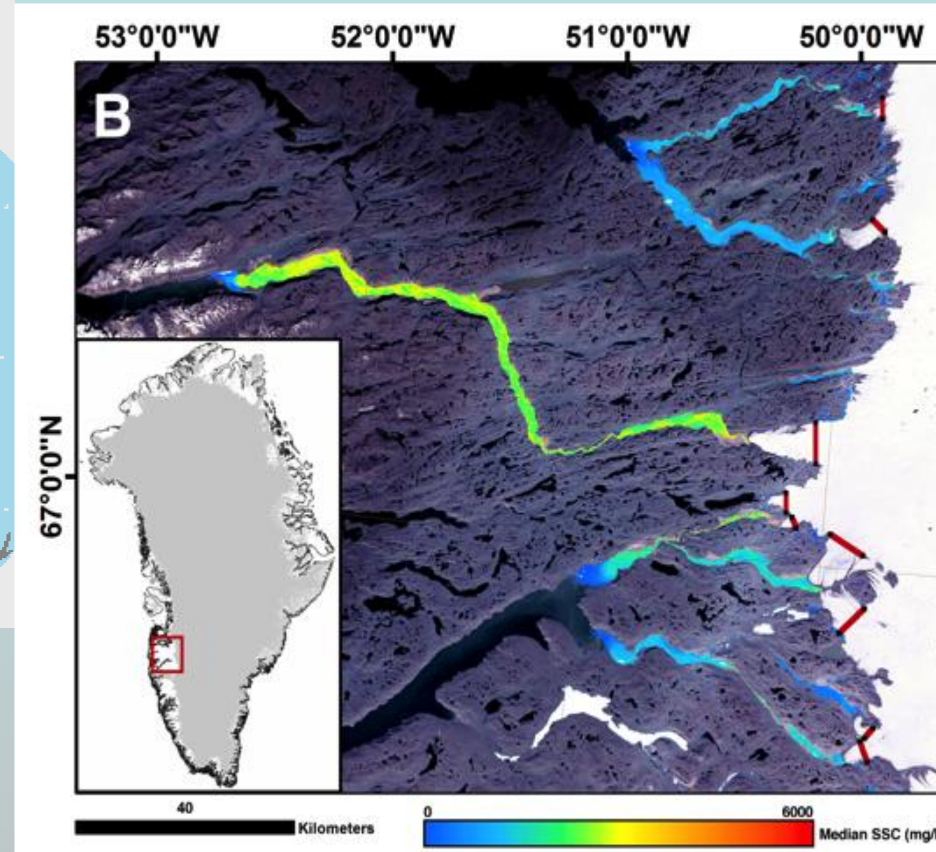
Latitudinal influences on Sediment Transport: 3) Ice Sheet Transport

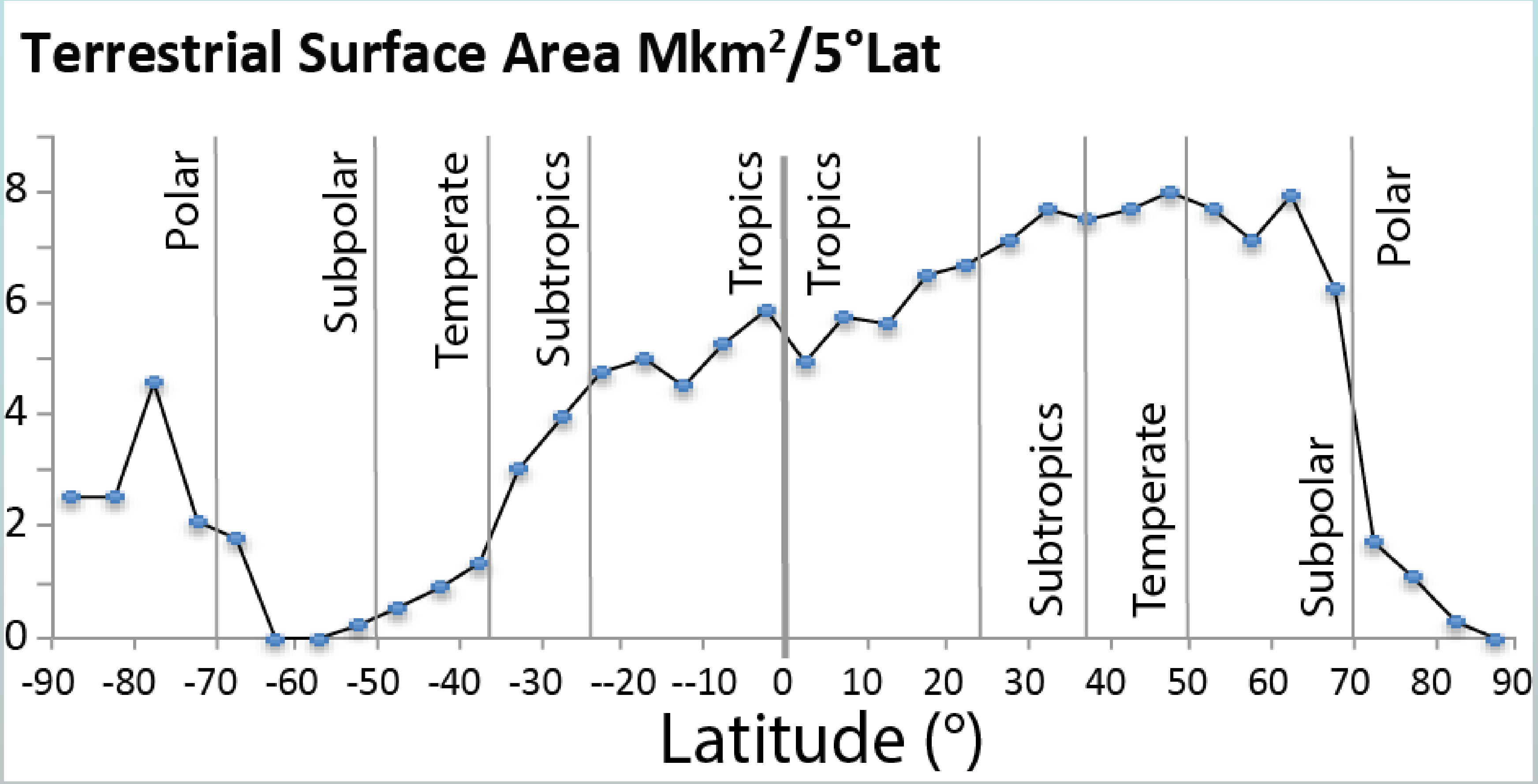




Today the GIS delivers 1.1 Gt/y of sediment in meltwater (0.65 Gt/y in 1999 —1.30 Gt/y in 2012) & icebergs shed from the Greenland Ice Sheet transport <u>another</u> 3.1 Gt/y of sediment. Iceberg rafting was once 5x higher during the ice ages than today. So was the sediment fluxes.

Hudson 2014

Earth Geometry



The distribution of the Earth's terrestrial land surface area binned by 5° of latitude. The Northern Hemisphere has 2/3 of the terrestrial surface area; the Southern Hemisphere has land at its pole, and open water in its Subpolar region. The present-day Terrestrial Earth is dominated by Tropical and Sub-tropical regions (55%).

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Summary

Lat °	Zone	Terrestrial Area Mkm²	Temper.	Precipitation	Wind	Waves	Sediment Production	Grain Settling Velocity	Aeolian Transpor
70 to 90	Polar	3.2	v cold	low	high	ice	v low	v low	v low
50 to 70	Subpolar	29.0	cold	moderate	v high	seas ice	low	low	low
38 to 50	Temperate	19.4	cool	moderate	high	storm	moderate	moderate	moderate
23.5 to 38	Subtropics	18.5	warm	moderate	moderate	mixed	high	high	high
0 to 23.5	Tropics	29.5	hot	high	m low	swells	v high	v high	moderate
0 to -23.5	Tropics	25.4	hot	high	m low	swells	v high	v high	moderate
-23.5 to -38	Subtropics	7.6	warm	moderate	moderate	mixed	high	high	low
-38 to -50	Temperate	2.1	cool	variable	high	storm	moderate	moderate	high
-50 to -70	Subpolar	2.1	cold	moderate	v high	seas ice	low	low	v low
-70 to -90	Polar	11.8	v cold	low	high	land	v low	v low	v low