Global River Discharge Analyses: Impact of Variable Precipitation in the Context of Different Climate Zones*

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Abstract

Models for fluvial architecture are important for predicting reservoir presence, distribution, quality, and connectivity in continental basins. However, most fluvial models are based on perennial precipitation zone rivers and do not take discharge variability into account; this oversight means many systems preserved in the sedimentary record are modeled inaccurately. Multiple authors (Leier et al., 2005; Fielding et al., 2009; Plink-Bjorklund, 2015) have described a link between seasonal precipitation and variable river discharge in monsoon domain and subtropical rivers, which results in distinct morphodynamic processes and a noticeably different sedimentary record from perennial precipitation zone rivers in tropical rainforest zone and mid-latitudes. These seasonal effects on surface water supply affects river morphodynamics and sedimentation on a wide timeframe, ranging from large single events to an inter-annual or even decadal timeframe. The resulting sedimentary deposits lead to differences in fluvial architecture on a range of depositional scales from sedimentary structures and bedforms to channel complex systems. These differences are important to accurately model for several reasons, ranging from stratigraphic and paleoenvironmental reconstructions to more economic reasons, such as predicting reservoir presence, distribution, and connectivity in continental basins.

This study further develops our understanding of discharge variability using a modern global river database created with data from the Global Runoff Data Centre (GRDC) and the University of Wisconsin's Center for Sustainability and Global Environment (SAGE). We compared river discharge patterns in a variety of climate zones (rainforest, monsoonal, sub-humid subtropics, arid to semi-arid subtropics, mid-latitude, and arctic) to establish the similarities and differences in discharge patterns as well as sediment distribution. A key difference between this study and previous studies is the inclusion of arctic rivers in the dataset. The ultimate objective of this research is to develop differentiated fluvial facies and reservoir models for each of these climate zones.

References Cited


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Introduction
Models for fluvial architecture are important for predicting reservoir presence, distribution, quality, and connectivity in continental basins. However, most fluvial models are based on perennial precipitation zones. The differences in discharge variability expressed in the sedimentary record are mostly caused by different precipitation regimes existing in continental basins. Precipitation differences and the resulting discharge variability result in distinct fluvial architecture and sedimentary structures and help to understand and classify fluvial systems that formed on a worldwide scale. Differences in precipitation patterns affect the discharge variability and thus the transportation of sediments.

Aims
- Further develop understanding of discharge variability using a global river database created with data from the Global Runoff Data Centre (GRDC).
- Examine daily gauging data from 595 river stations worldwide and group them based on the location of the gauging station and group them into seven different climate zones: Arid to semi-arid Subtropics, Cold, Humid Subtropics, Monsoonal, Polar, Rainforest, and Temperate.
- Use the seven climate zones to better understand the nature of discharge variability and thus the nature and size of fluvial systems.
- Develop differentiated fluvial facies and reservoir models for each climate zone.

Methods
Rivers were compared by two main metrics: discharge variability (both monthly and yearly) and climate. The rivers used in this study are from the GRDC pristine river database and were screened to ensure a long enough historical record for analysis of decadal-scale variability. The seven climate zones definitions and boundaries were adapted from the Peel et al., 2007 update of the Köppen-Geiger climate classifications and were combined with the Monsoon Precipitation Domain Index (Wang and King, 2006). Rivers were assigned climate zones based on the location of the gauging stations and their respective drainage basins. Sediment discharge data comes from the USGS Water Data for the Nation database.

1) Monthly Discharge Variability: DVIm
2) Yearly Discharge Variability: DVIy

Discharge Variability Temporal Resolutions
- Variability needs to be considered on different temporal resolutions
- Annual variability > inter-annual variability > discharge variabilityindex

Strength:
- Event-based assessment (such as major flood analysis to understand the nature of flooding)
- Strength allows the range in variability for each river over the years
- Unit-less number for discharge variability
- Strength: able to compare multiple events against each other
- Weakness: DVI compresses variability into one number

Weakness:
- Difficult to compare multiple rivers against each other
- Still difficult to compare multiple rivers against each other

The Global Map of River Gauging Stations coloured by Climate Zone and sized by DVIy

Graphic: Discharge Variability Index
- Unit-less number for discharge variability
- Strength: able to compare it against the entire database
- Weakness: DVI compresses variability into one number

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The Link Between Discharge Variability and Sediment Transport

Water and Sediment Discharge Comparison

Largest Flood Analysis
- Effect of single storm events on seasonal variations
- Arid systems are dominated by punctuated single events
- Monsoonal and Polar systems have strong seasonal controls
- Rainforest systems rarely flood more than their yearly average

Largest Flood for Representative Rivers (Temperate, Humid Subtropics, Polar, and Rainforest Climate Zones)

Representative Rivers Normalized Average Monthly Discharge

Normalized Discharge

Water Discharge, m³/sec

Rainforest - Rio Jurua

Monsoonal - Brahmaputra

Largest Flood Analysis

Clear Fork Brazos Largest Flood - 1957

Largest Flood Analysis

Little River Largest Flood - 1938

Largest Flood Analysis

Elkhorn Largest Flood - 2010

Largest Flood Analysis

Mississippi Largest Flood - 1927

Largest Flood Analysis

Little Beaver Largest Flood - 1986

Largest Flood Analysis

Rio Jurua Largest Flood - 1986

Largest Flood Analysis

Rio Grande Largest Flood - 1944

Clear Fork Brazos Suspended Sediment Discharge (DVIm: 2.41, DVIy: 35.0, Avg Q: 5.7 m³/sec)

Kaskaskia River Suspended Sediment Discharge (DVIm: 1.39, DVIy: 7.01, Avg Q: 109 m³/sec)

Water and Sediment Discharge Comparison

Maximum suspended sediment in one day: 46,200 tons

Maximum suspended sediment in one day: 41,000 tons

Order of magnitude difference in water discharge, yet sediment discharge peaks are on the same order of magnitude

Limited sediment discharge data available for some rivers.
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### Outcrop Scale Fluvial Architecture

- **Channel to Multi-Channel Scale Architecture**
  - Experience frequent avulsions
  - Create highly tabular deposits that range from decimeters to 10’s of meters

- **Inter-Channel Architecture**
  - Sedimentary structures are primarily composed of upper flow regime and high deposition rate structures
  - Sandy channel fill is interbedded with in-channel mud layers

- **Key Takeaways**
  - Variable discharge is a key control on fluvial sedimentation
  - It is necessary to use different temporal resolutions when assessing a river system’s variability
  - Discharge variability is controlled by a number of factors, but can be predicted by climate zone
  - Different climate zones have different temporal controls on discharge and different degrees of predictability
  - The majority of sediment transport occurs during flood stage
  - Rivers with highly variable discharge have different fluvial architecture from rivers with lower discharge variability that is characterized by:
    - Tabular deposits
    - In-channel mud layers
    - Upper flow regime sedimentary structures

### Distribution of Sedimentary Structures

- In-channel mud deposits are characterized by interbedded with sandy channel fill deposits. These events are separated by erosional contacts and deformed tens of meters wide mud horizons.

### References

- Plink-Björklund, Piret. “Morphodynamics of Rivers Strongly Affected by Monsoon Precipitation: Review of part of the channel fill is on decimeter scale, in contrast to the overlying flood units that are 1–2m thick. Each flood deposit is draped by mud, Eocene Green River Fm., Uinta Basin, USA.

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