Long-term monitoring on debris-flow field at Jiangjia Ravine, China and digital data management

Dongri SONG

Dongchuan Debris Flow Observation and Research Station (DDFORS),

Chinese Academy of Sciences

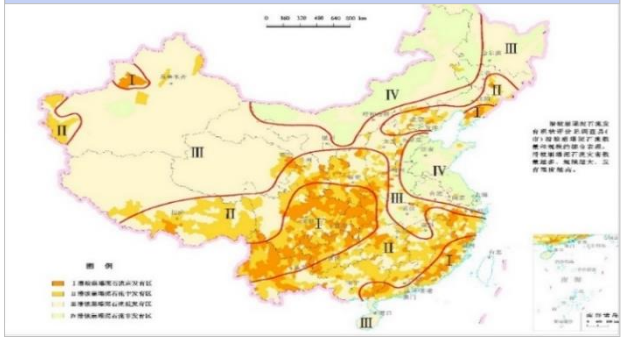
May 30th, 2024

Content

Landslide and debris-flow hazards in China

More than 6.4×10^6 km^2 of the territory consists of complex, tectonically-active terrain with a monsoon climate.
Mountain hazards are widely distributed and threaten the towns, roads, and hydropower engineering.

Distribution of mountain hazards

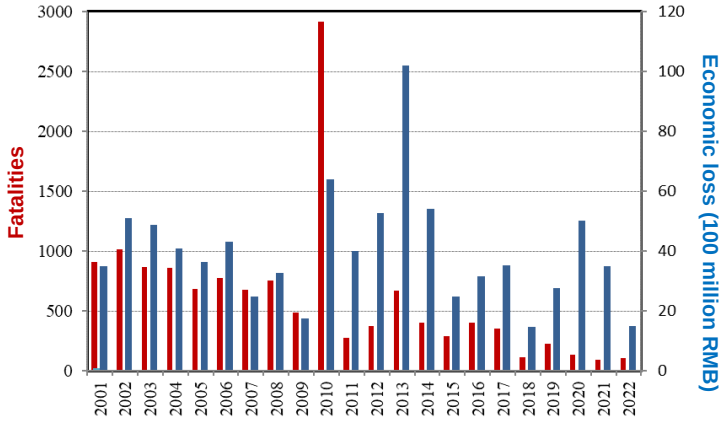


Exposure

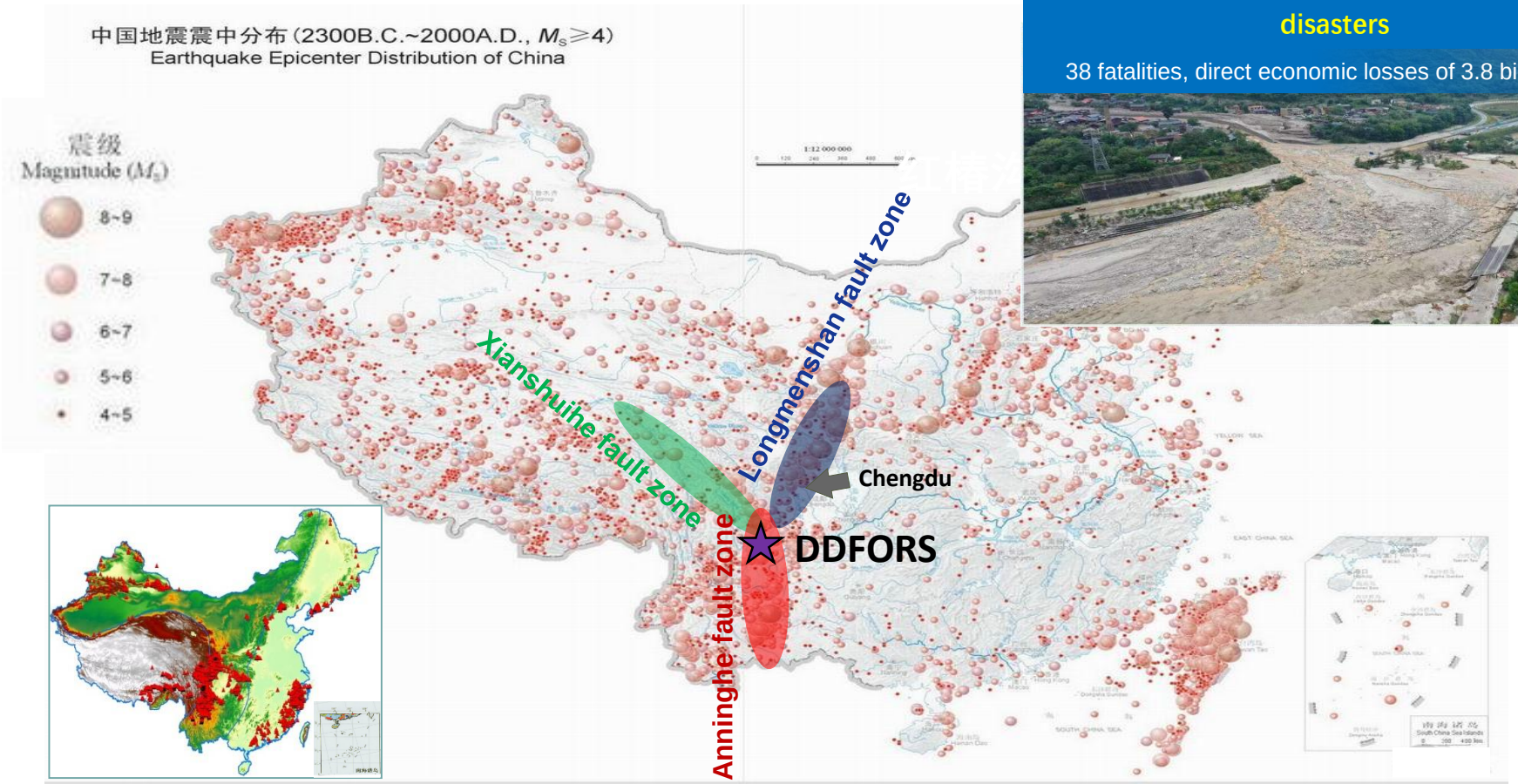
- **90% of hydropower plants**
- **50% of major roads and railways**
- **70% of towns**

Loss

- **Average fatalities: 608**
- **Percentage of flood deaths: 60%**
- **Annual economic loss: 4 billion RMB**



Frequent earthquakes aggravate mountain hazards



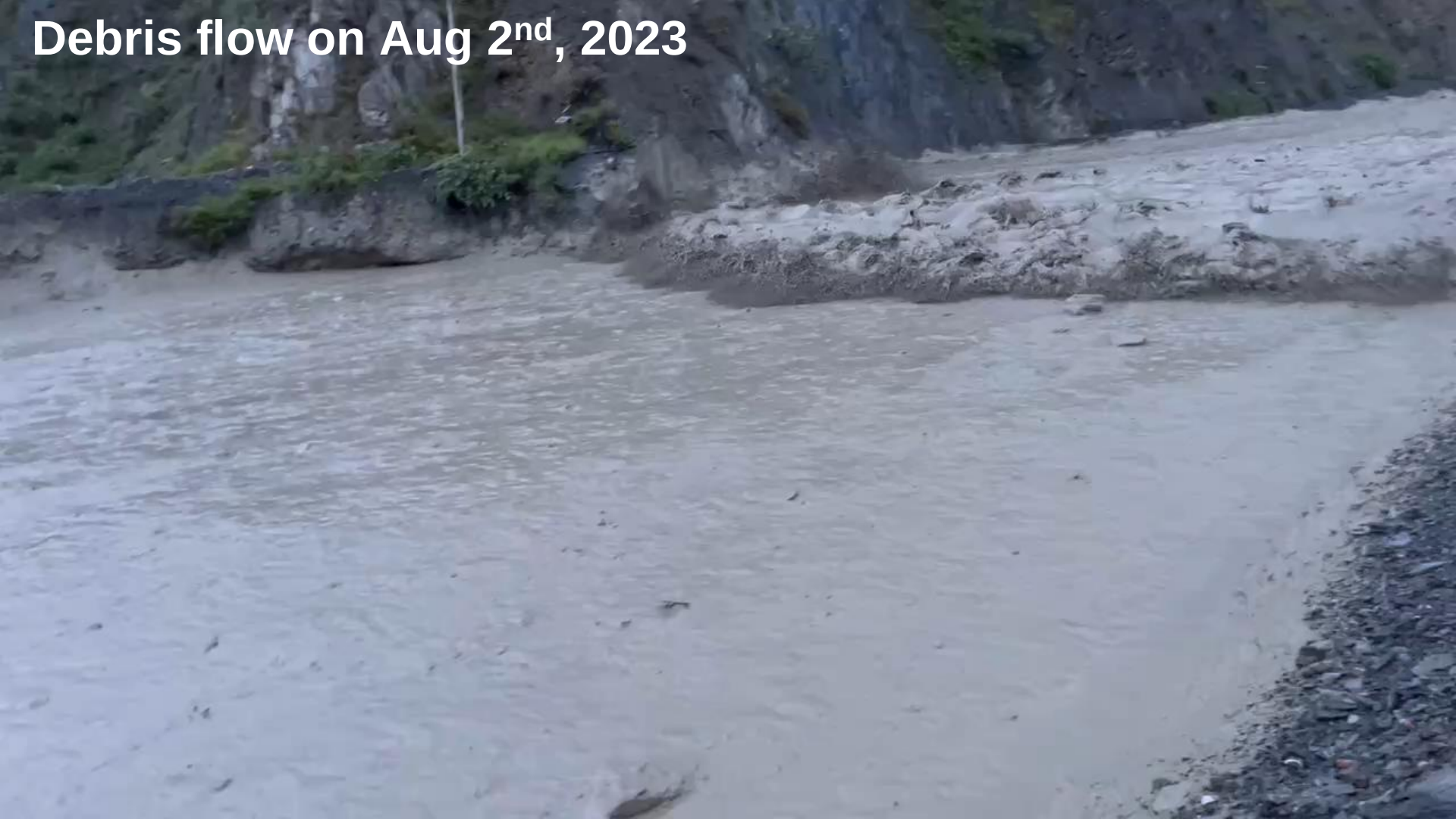
2019 Wenchuan flash flood and debris flow disasters

38 fatalities, direct economic losses of 3.8 billion RMB

Distribution of debris flow-prone watersheds

Location of DDFORS: N26°14', E103°08'

Debris flow on Aug 2nd, 2023



Debris flow on July 23rd, 2019

Gentle slope but high velocity: 3-4°, ~10 m/s
High discharge: 500 m^3/s
Residual layer: >1 m


Debris flow blocking the river channel (around 2000)

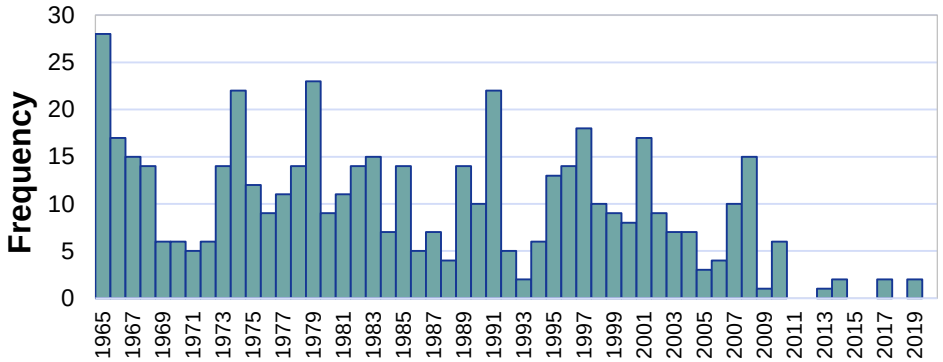
Dongchuan Debris Flow Observation and Research Station (DDFORS)
Long-term debris-flow observation since 1961

Founded in 1961

Became one of the five open field observation stations of CAS in 1988

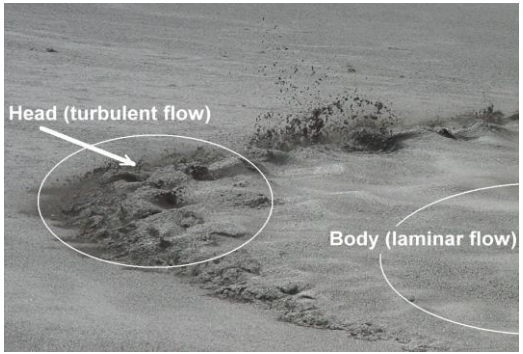
Upgraded to State Key Field Observation Station in 2000

Frequent debris-flow events



- **Jiangjia Ravine – debris flow triggered by rainstorm**
- **Mount St. Helens, Mount Yakedake -volcanic debris flows**
- **Alps (Illgraben) - debris flow triggered by snow melting**

"Debris-flow museum" in China and supplies advantageous research conditions



➢ **Diverse debris-flow regimes and kinematic processes**

Academic contributions to international debris-flow research

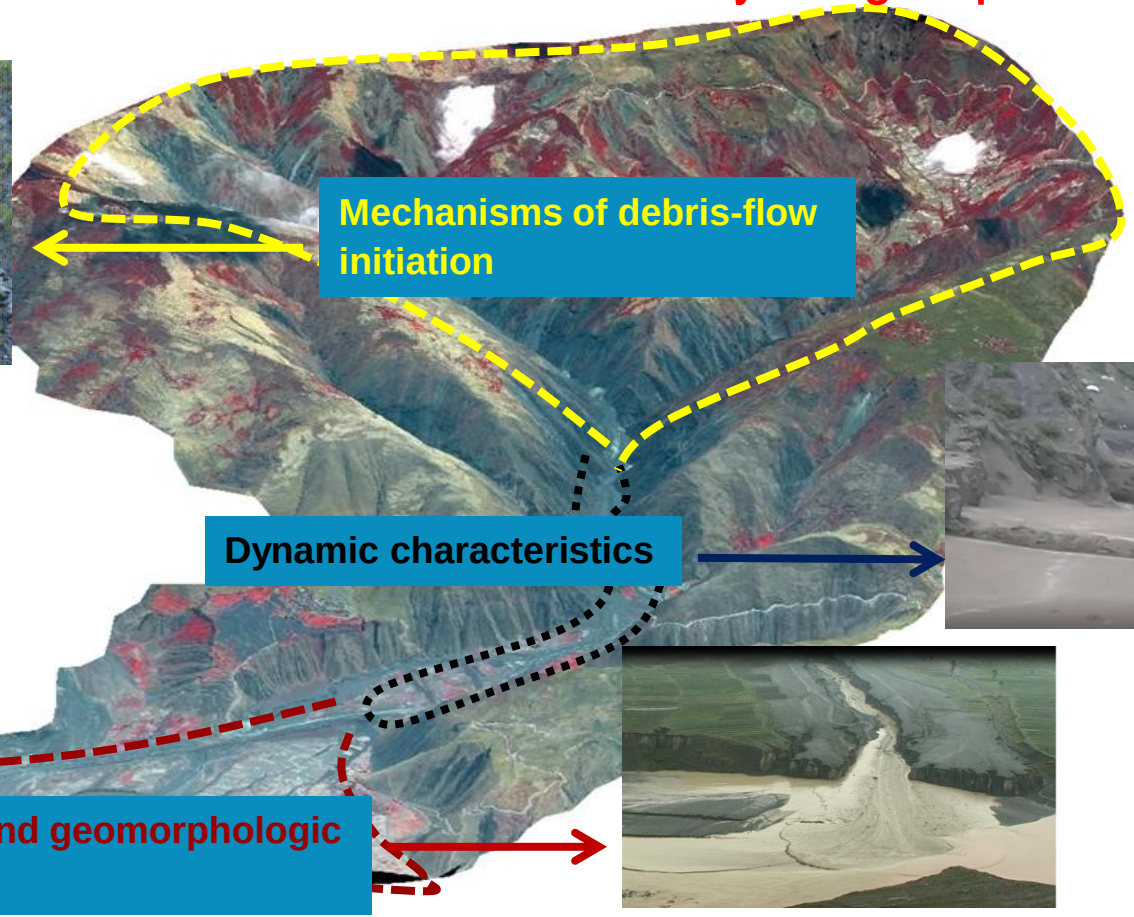
Ideal research site for debris-flow observation and prototype validation

- Validation of debris-flow dynamics models (Iverson 1997, 2003, 2013; Takahashi, 2007)
- Prototype and validation of the roll-wave theory (Zanuttigh and Lamberti 2007; Arai et al. 2013)
- Prototype and validation of the debris-flow particle segregation theory (Major 1997)
- Important supplementary data for international sediment research

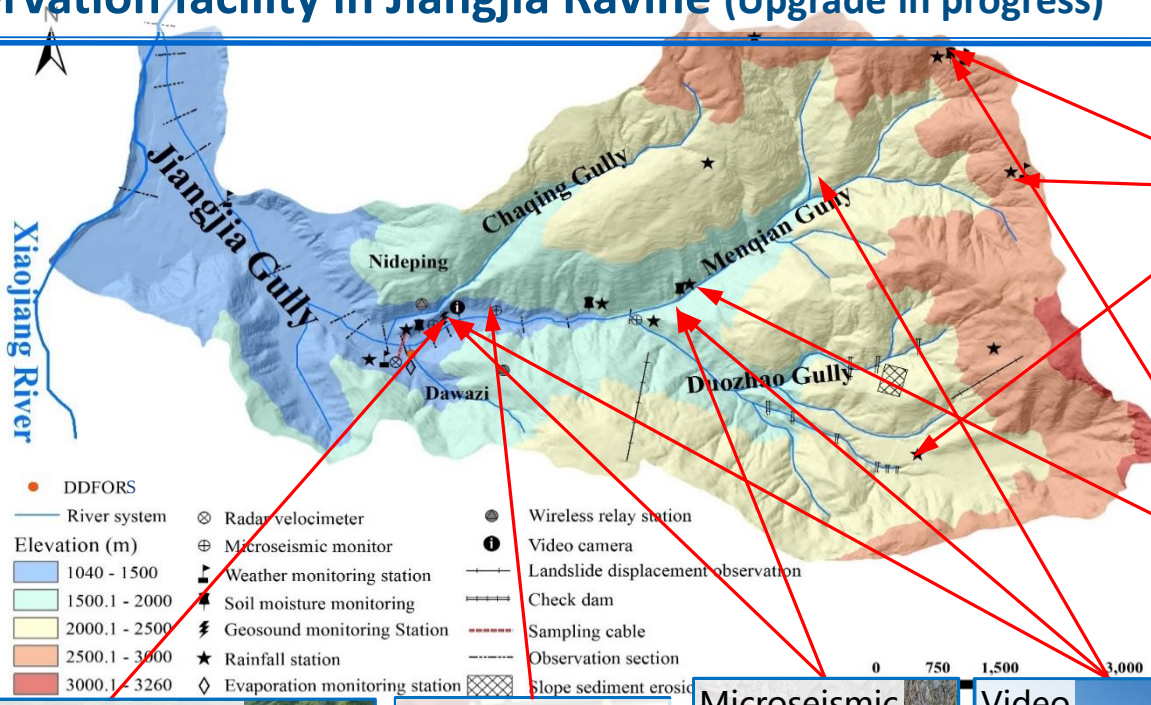
Content

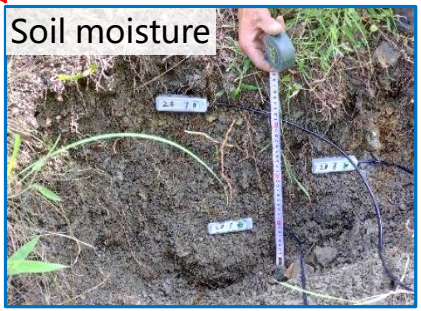
Observation of the whole debris-flow process

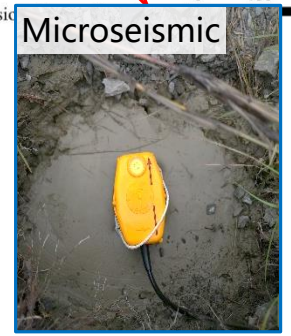
Unlike slope failure, debris flow is a catchment-scale hydrological process

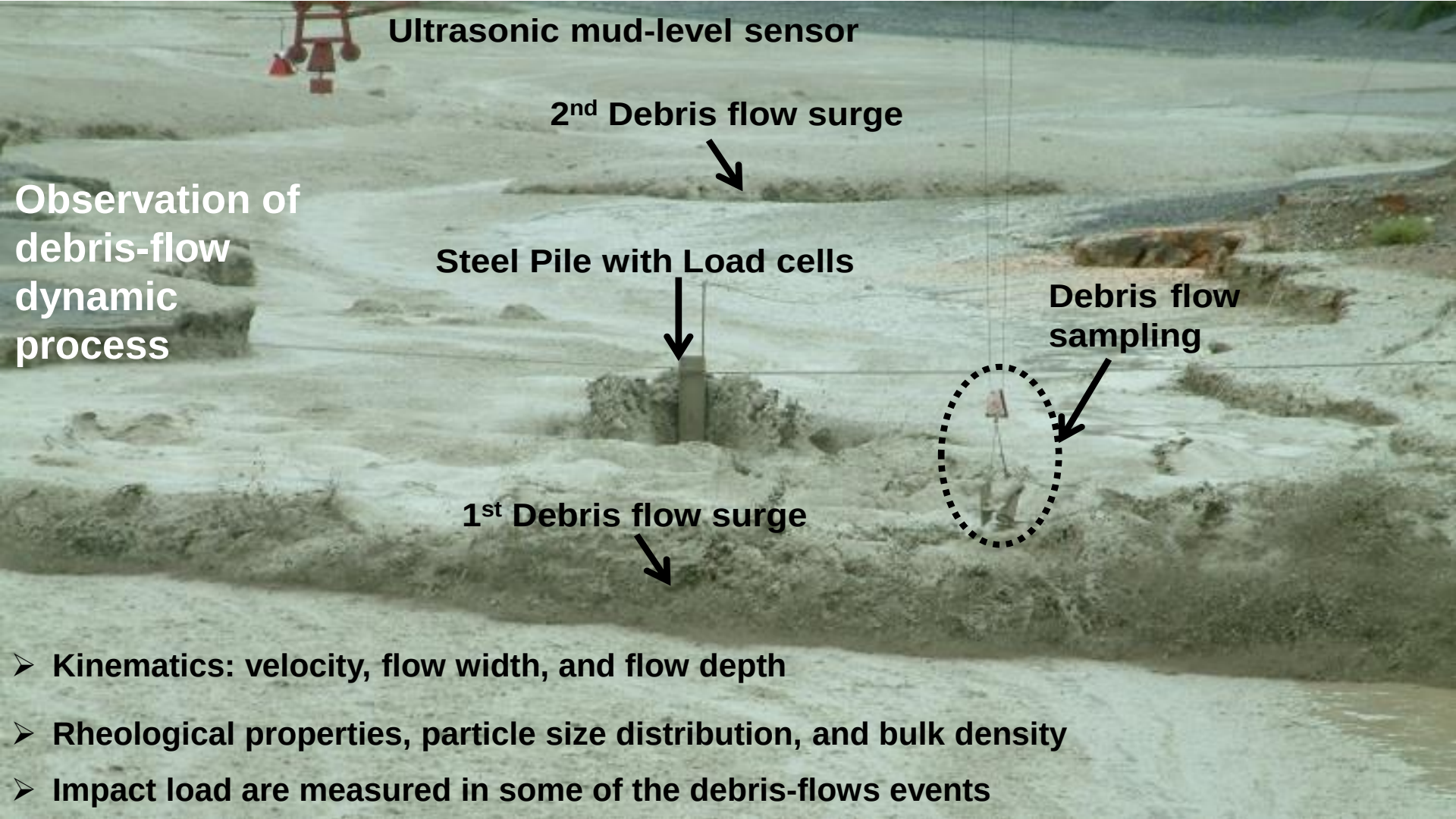


Observation facility in Jiangjia Ravine (Upgrade in progress)









- Kinematics: velocity, flow width, and flow depth
- Rheological properties, particle size distribution, and bulk density
- Impact load are measured in some of the debris-flows events

Long-term evolution of the debris-flow channel

Soil erosion and hydrographic monitoring

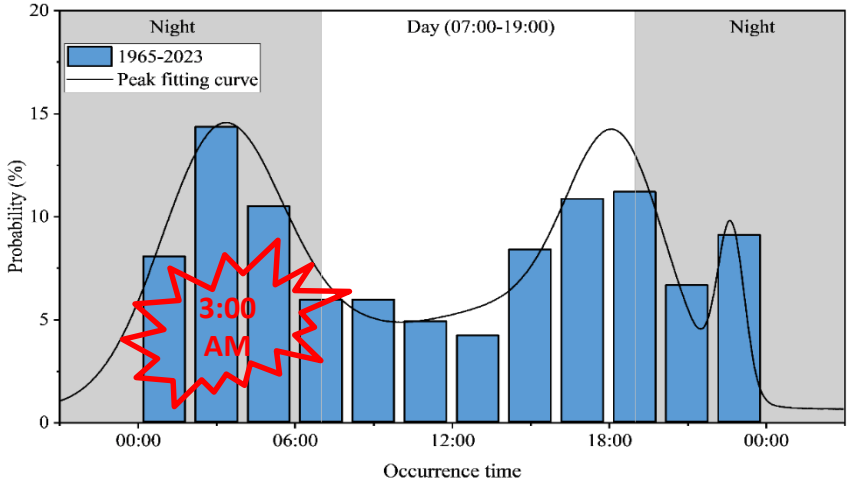
Erosion and deposition monitoring in the channel

Landform changes and river evolution

Content

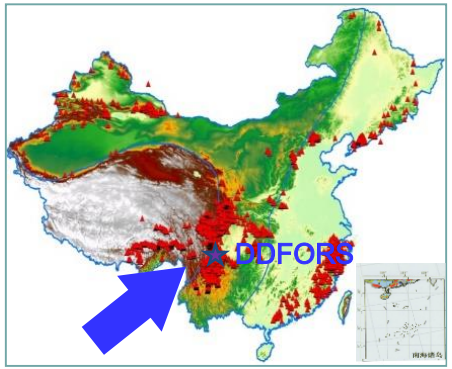
3.1 Debris flows before dawn make nightmares in Southwest China

Embankment landslide (2:10 in 1st May 2024) in Guangdong province (South China)



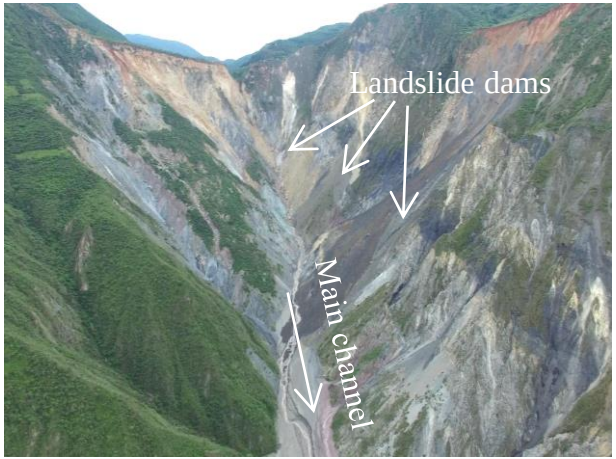
Timing of debris flows in Jiangjia Ravine

- Most deadly debris-flow events occurred in the night? Long-terms statistical data are needed.
- Occurrence of debris flow is related to heavy rainfall in the night.
- Rainfall-based early warning system would be effective!

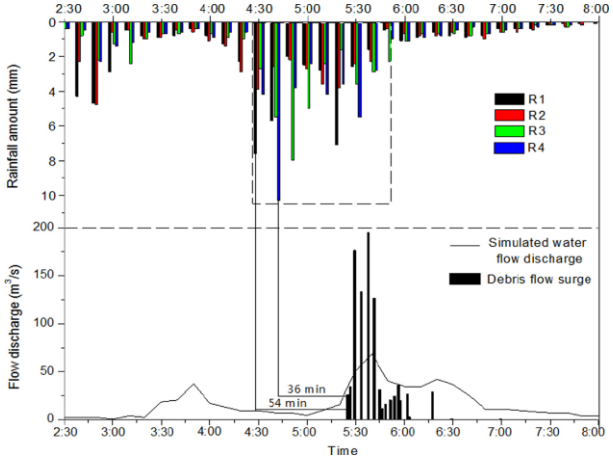


3.2 Temporary damming-breaching of landslides dams magnifies the debris-flow discharge

A debris-flow event is a catchment-scale hydrological process



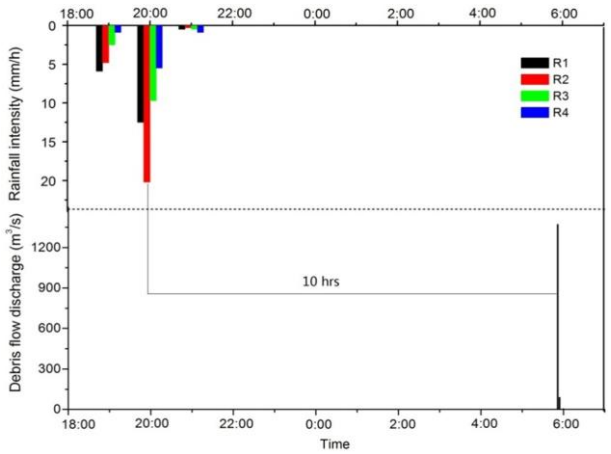
Landslide dams cause temporary blockage of the channel, and magnifies the discharge when breaching



2009.8.4 debris-flow event

τ : 36~54 min
Q_d : 60.6 m³/s
Q_w : 64.3 m³/s
Q_d/Q_w : 1~3

Normal



2010.8.5 debris-flow event

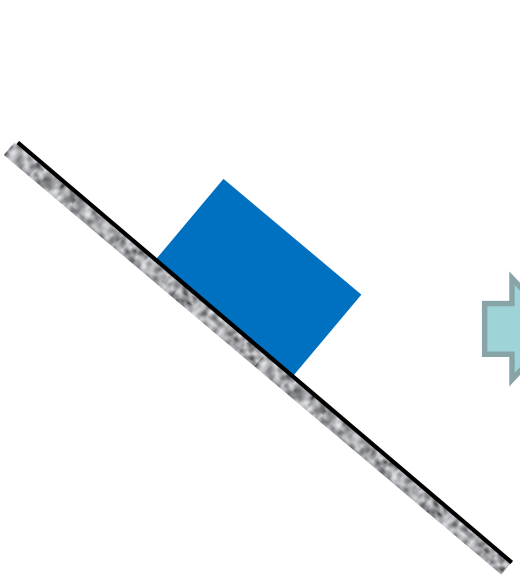
τ : 10 h
Q_d : 1370 m³/s
Q_w : 120 m³/s
Q_d/Q_w : 11.4

Abnormal

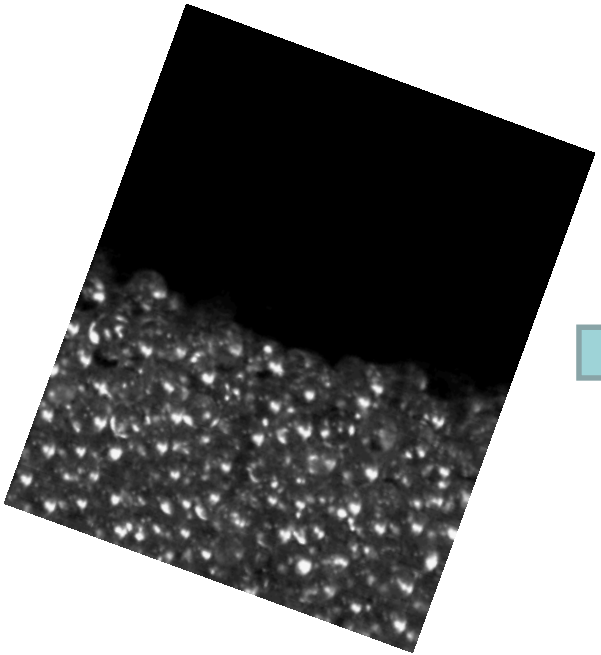
Classification of hydrological processes of surge debris flows:
the time lag τ, the ratio of debris-flow discharge to flood-flow discharge Q_d/Q_w

3.3 Flow resistance dominated by the coupled visco-collisional forces

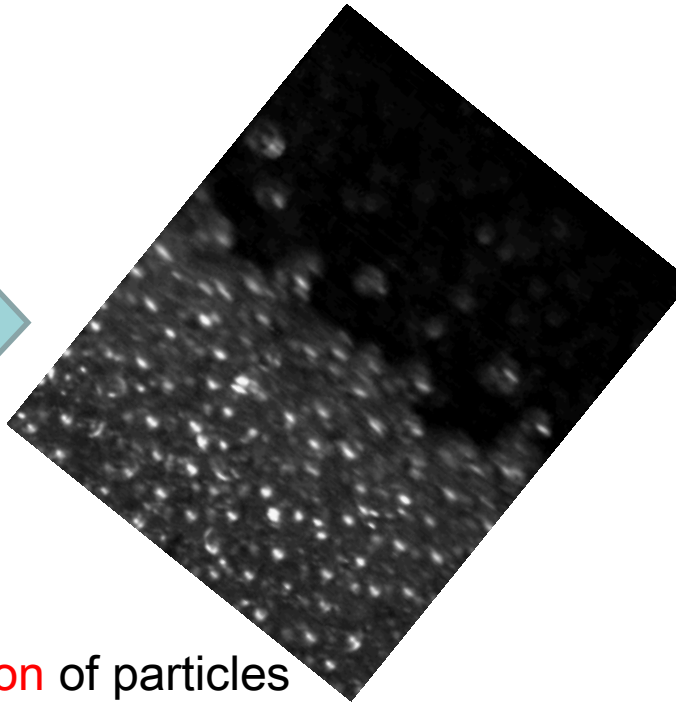
Basic forces in dry granular flows: particle friction+particle collision



Friction of single block



Friction of particles



Collision of particles

Jop, P., Forterre, Y., & Pouliquen, O. (2006). A constitutive law for dense granular flows. Nature, 441(7094), 727-730.

3.3 Flow resistance dominated by the coupled visco-collisional forces

Intuitive flow resistance model considering particle friction and fluid viscous drag

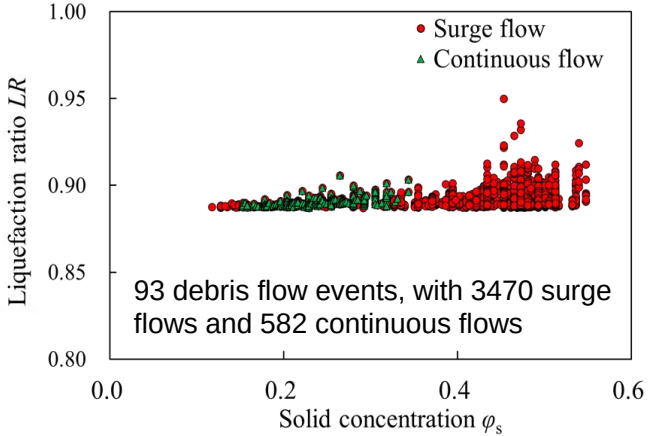
$$\tau = \sigma_s \tan\phi + \dot{\gamma}\eta$$

Steady flow: $\tau = \rho g h \sin\theta$

$\sigma = \rho g h \cos\theta$

Effective stress: $\sigma_s = \sigma - P$

$$LR = \frac{P}{\sigma} = 1 + \frac{\dot{\gamma}\eta}{\sigma \tan\varphi} - \frac{\tan\theta}{\tan\varphi}$$



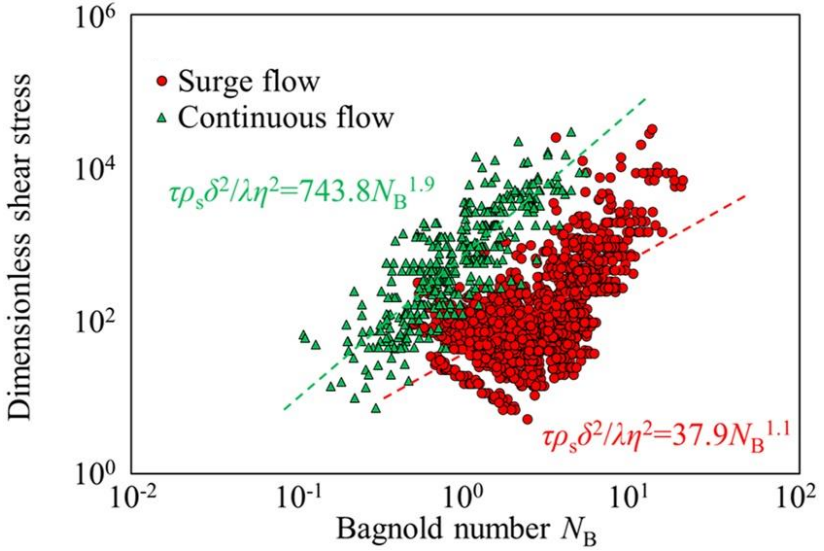
Degree of liquefaction of debris flows

- Degree of liquefaction: 0.89~0.95, close to full liquefaction
- The particle friction provided by the effective stress is not the main source of flow resistance at DDFORS

3.3 Flow resistance dominated by the coupled visco-collisional forces

The contribution of particle collision and fluid viscous drag can be unified by the Bagnold number N_B

$$\tau = a\left(\frac{\lambda\eta^2}{\rho_s\delta^2}\right)N_B^b \rightarrow \tau = a\left(\frac{\lambda^{1+b}\eta^2}{\rho_s\delta^2}\right)\left(\frac{\rho_s\dot{\gamma}\delta^2}{\eta}\right)^b$$



Relationship between dimensionless shear stress and Bagnold number N_B

The index *b* falls in the range of fluid viscous drag (*b*=1) and particle collision (*b*=2), indication the joint contribution of both fluid viscous drag and particle collision

- For surge flows, *b* =1.1, $\tau = a\lambda^2\dot{\gamma}\eta$, flow resistance is mainly contributed by the fluid viscous drag
- For continuous flows, *b* =1.9, $\tau = a\lambda^3\rho_s\dot{\gamma}^2\delta^2$, flow resistance is mainly contributed by particle collision stress

- [INTRODUCTION OF JIANGJIA RAVINE] Cui, P., Chen, X., Wang, Y., Hu, K., & Li, Y. (2005). Jiangjia Ravine debris flows in south-western China. *Debris-flow hazards and related phenomena*, 565-594.

- Chen, Q., Song, D., Chen, X., & Zhong, W. (2023). Visco-Collisional Scaling Law of Flow Resistance and Its Application in Debris-Flow Mobility. *Journal of Geophysical Research: Earth Surface*, 128(2), e2022JF006712

- Du, J., Zhou, G. G. D., Tang, H., Turowski, J. M., & Cui, K. F. E. (2023). Classification of stream,hyperconcentrated, and debris flow using dimensional analysis and machine learning. *Water Resources Research*,59, e2022WR033242.

- Jiang, Y., Hu, X., Liang, H., Ning, P., & Fan, X. (2023). A physically based model for the sequential evolution analysis of rainfall-induced shallow landslides in a catchment. *Water Resources Research*, 59, e2022WR032716.

- Yan, Y., Tang, H., Hu, K., Turowski, J. M., & Wei, F. (2023). Deriving debris-flow dynamics from real-time impact-force measurements. *Journal of Geophysical Research: Earth Surface*, e2022JF006715.

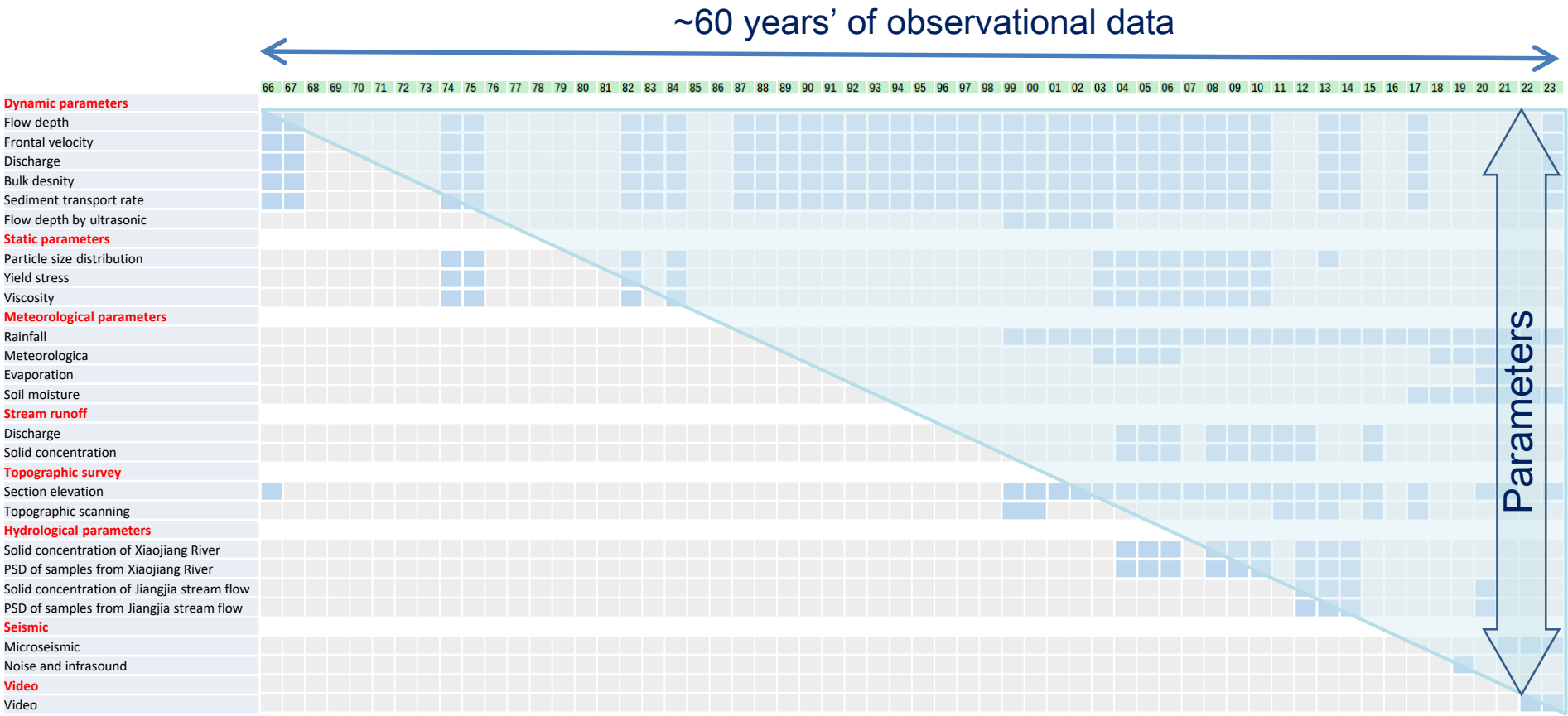
- Yang, H. J., Zhang, S. J., Hu, K. H., Wei, F. Q., Wang, K., & Liu, S. (2022). Field observation of debris-flow activities in the initiation area of the Jiangjia Gully, Yunnan Province, China. *Journal of Mountain Science*, 19(6), 1602-1617.

- Guo, X., Li, Y., Cui, P., Yan., H., & Zhuang., J. (2020). Intermittent viscous debris flow formation in Jiangjia Gully from the perspectives of hydrological processes and material supply. *Journal of Hydrology*, 589, 125184.

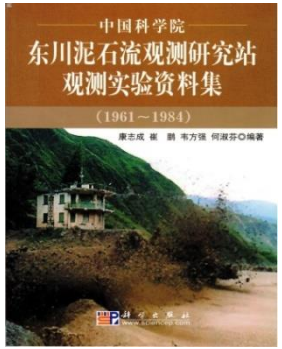
For more information: http://nsl.imde.ac.cn/en/

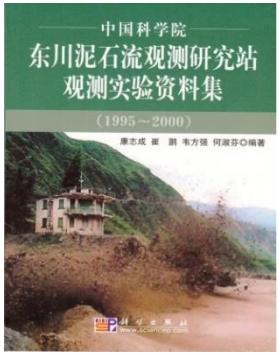
Content

Overview of the observational data

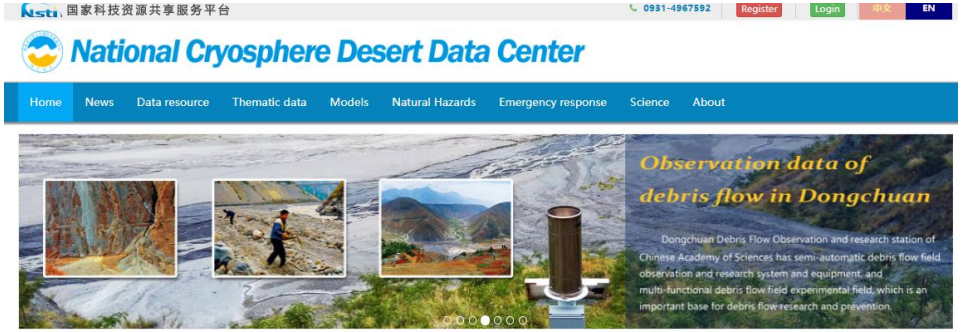


Data availability



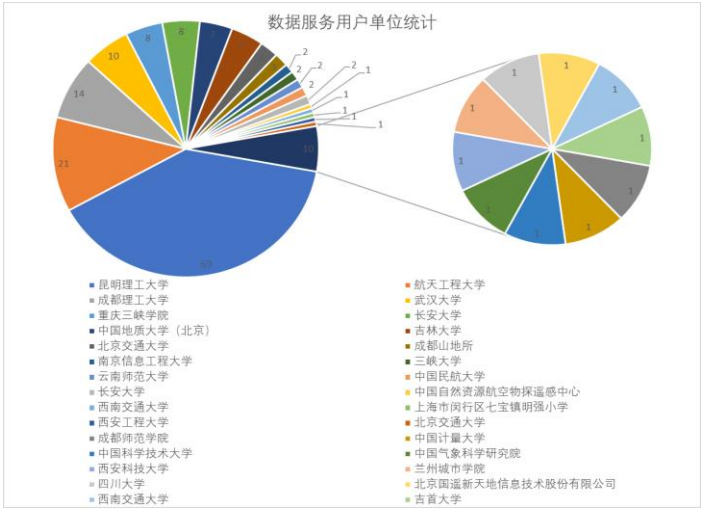


Datasets (before 2000) published in books
(we are now digitalizing them)



Datasets (after 2000) available online:
http://www.ncdc.ac.cn/portal/

User statistics (2022)



- Observation data reaches 300 GB, used by more than 500 researchers in the past five years
- Supporting the construction of national major infrastructure and major scientific research projects

A brief summary

- 60 years' of debris-flow field observation has been carried out at DDFORS.
- Many interesting findings enhance our understanding to debris-flow hazard.
- A new campaign has just launched to further expand the time span and enhance the comprehensiveness of the data.
- The datasets are now available at National Cryosphere Desert Data Center (http://www.ncdc.ac.cn/portal/) and more data will be available within 2024.
- A description of the datasets will be published (target journal Earth System Science Data).


Thank you!
http://nsl.imde.ac.cn/en/
Dongri SONG
drsong@imde.ac.cn