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Drought and water scarcity: monitoring, modelling and forecasting to improve hydro-meteorological risk management
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Space-time variability of soil moisture based drought in the transboundary Koshi River Basin, Central Himalaya

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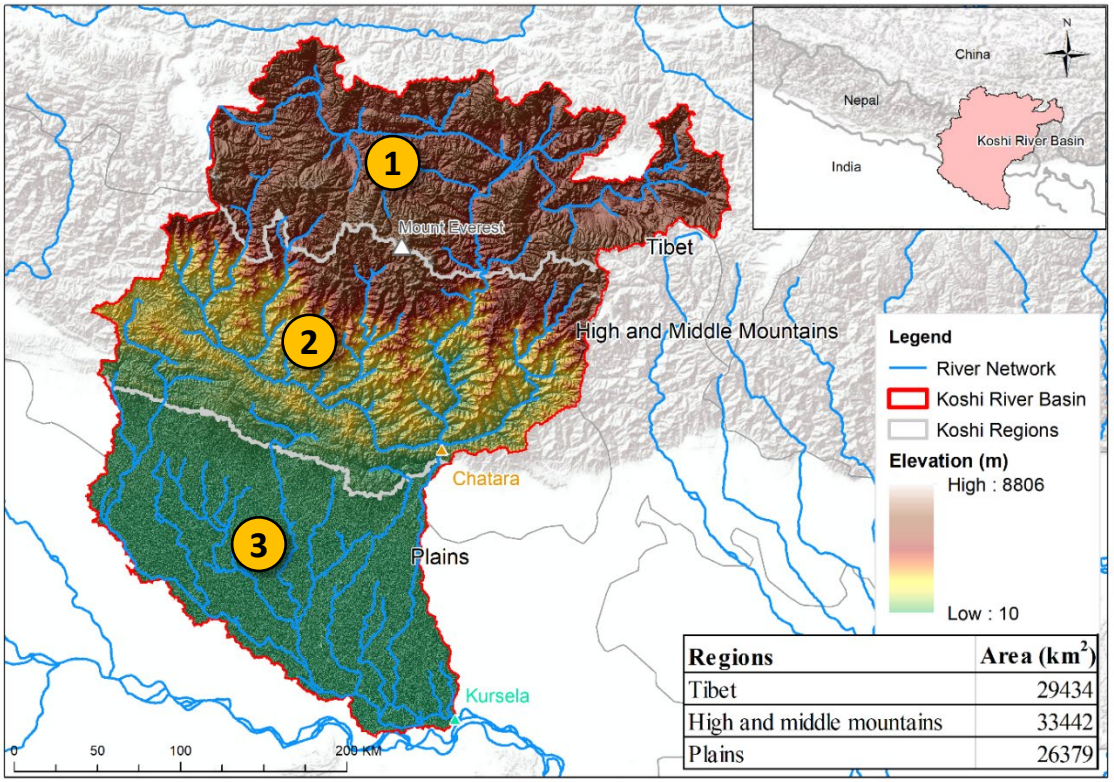
Context

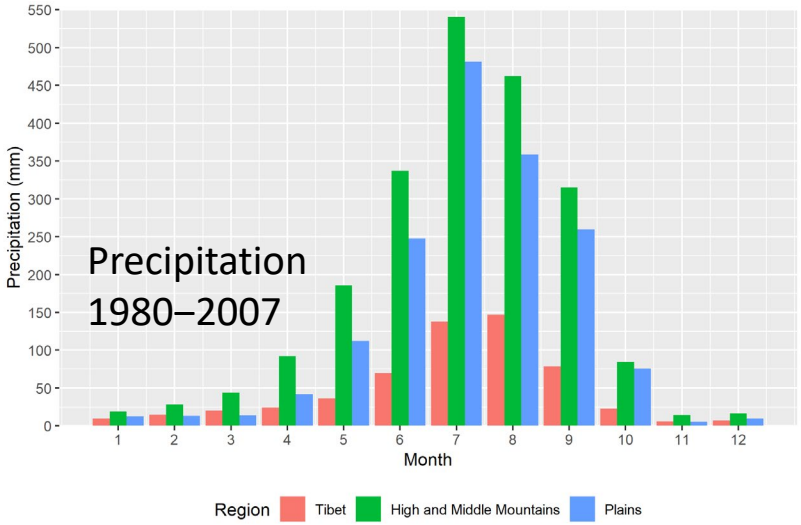
- Droughts compromise sustainable development and are considered one of the major social and economic hazards
- Soil moisture droughts are a major concern as they are directly related to agricultural productivity
- The Koshi River Basin faces both floods and droughts due to its unique climatic system
- To better understand the spatio-temporal pattern of drought occurrence in recent years, this study aims at
  - simulating the basin‘s hydrology and
  - to assess soil moisture drought by means of the Soil Moisture Deficit Index (SMDI)

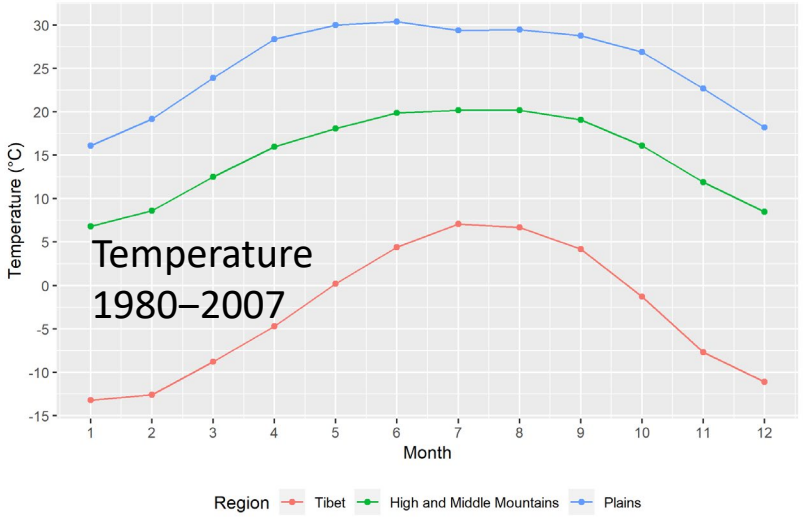
Study Area

- Koshi River Basin (A ~ 88,000km²)
- Three sub-regions
  1. Tibet
  2. High and middle mountains
  3. Plains



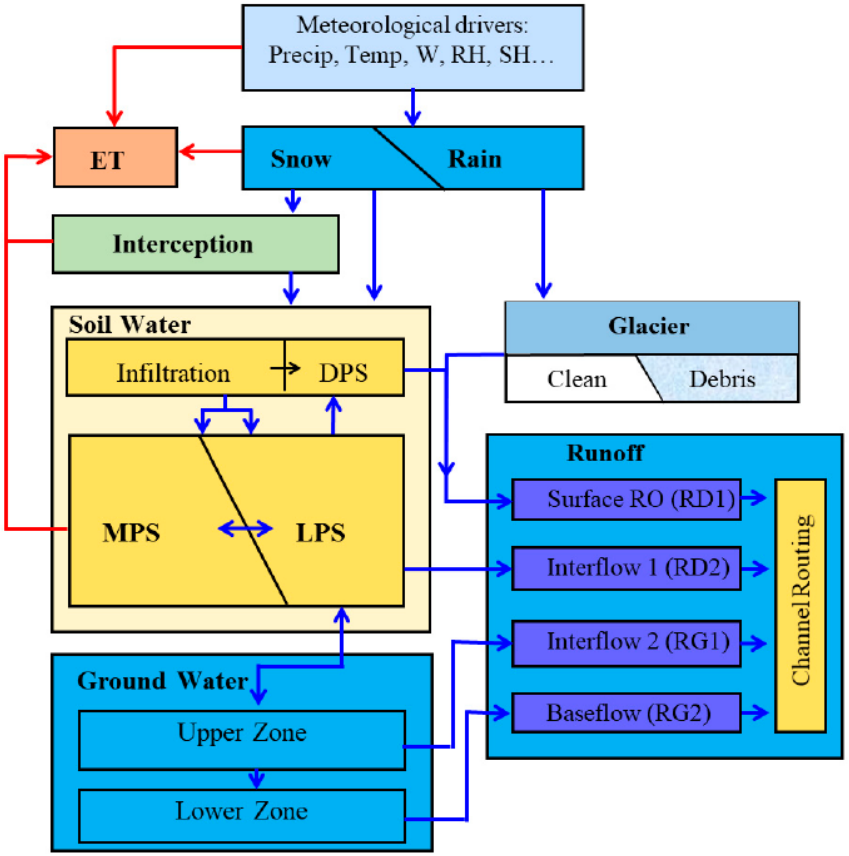
Regions	Area (km²)
Tibet	29434
High and middle mountains	33442
Plains	26379





Methods: Hydrological model JAMS/J2000

- spatially distributed (HRUs) process-oriented
- soil water simulation
  - two water storages (large/middle pores)
  - plant water uptake (ET after Penman-Monteith)
  - percolation
- glacier-extension
- lateral routing (HRUs/reaches)

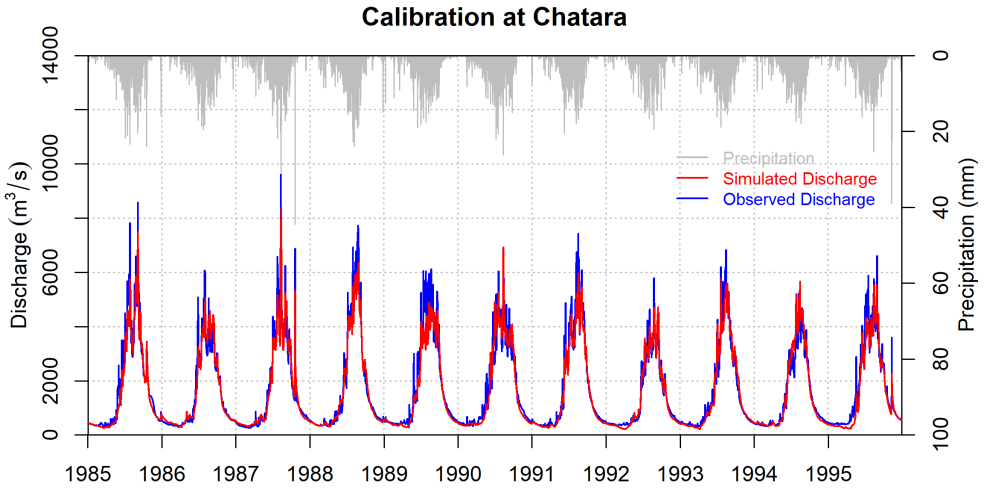


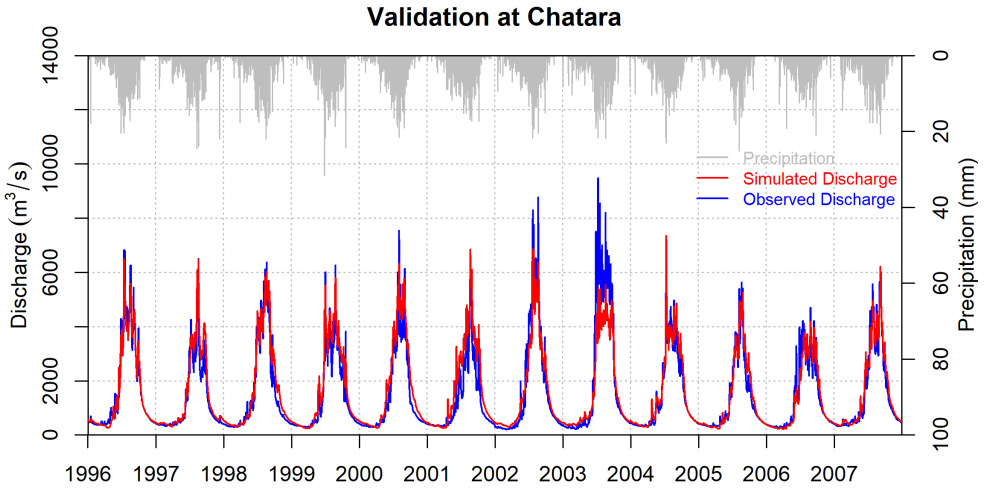
Adapted from Krause (2001) and Nepal *et al.*, (2014)

Methods: Drought Indices

- Soil Moisture Deficit Index (SMDI) (Narasimhan & Srinivasan, 2005)
  - assessment of agricultural droughts
  - characterize variability of soil moisture (Narasimhan and Srinivasan, 2005)
  - calculated based on HRU soil water content in root zone (simulated with JAMS/J2000)
  - weekly temporal resolution, aggregated to seasons
- Standardized Precipitation Index (SPI) (McKee *et al.*, 1993)
  - assessment of meteorological droughts
  - characterize variability of precipitation calculated based on HRU precipitation
  - 3-monthly temporal resolution, aggregated to seasons

Results: Runoff

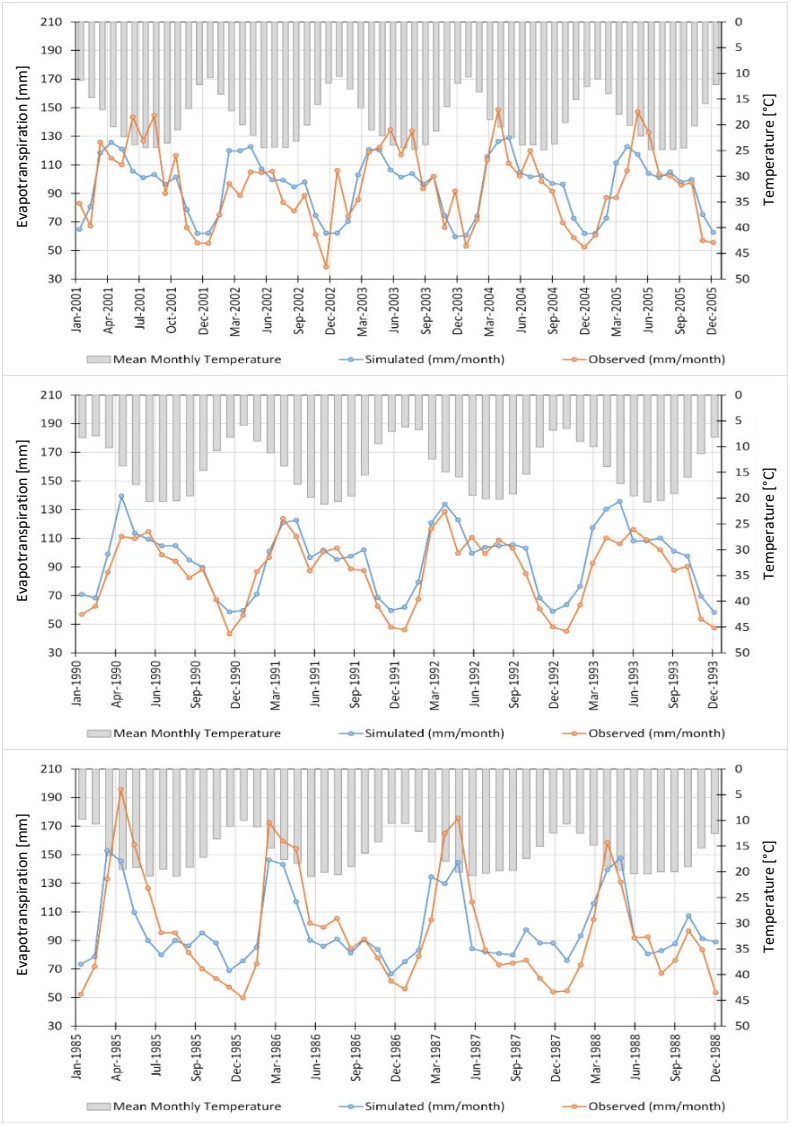




- Model units:
  - number: 18,557
  - avg. area: 4.7km²
- Good performance at Chatara discharge station

	Calibration (1985–1995)	Validation (1996–2007)
KGE	0.93	0.91
NSE	0.95	0.91
R^2	0.95	0.92
PBIAS	–4.6	6.5

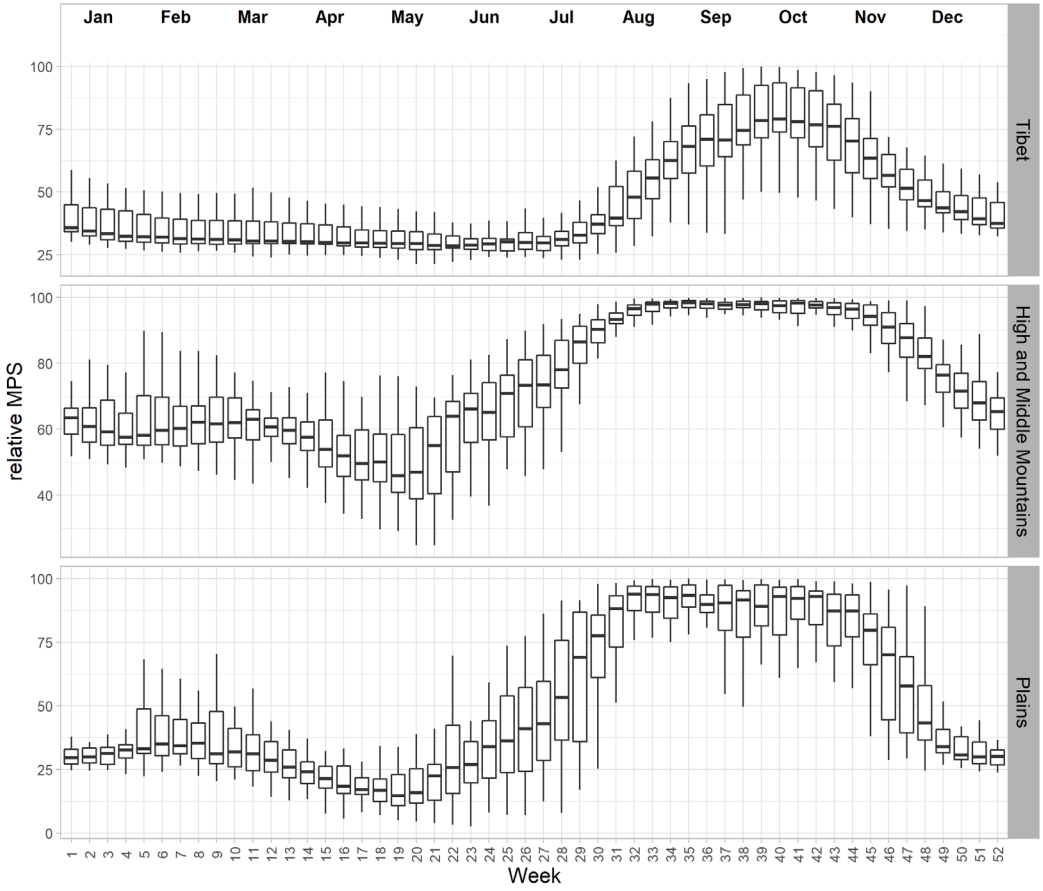
Results: Pot. Evapotranspiration



- Class-A pan PET measurements at Kathmandu, Okhaldhunga, and Jiri in Nepal
- Elevations: 1,300–2,000 m asl
- Validation of simulated PET (Penman-Monteith) showed satisfying results

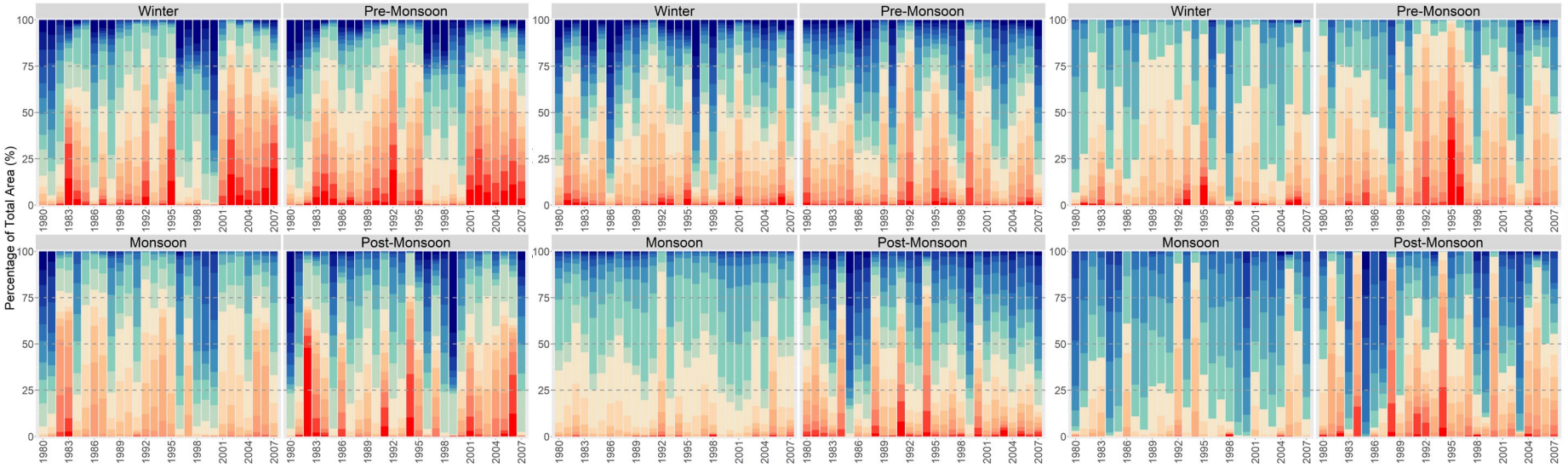
Station	R^2	PBIAS	Missing values (observed)
Kathmandu	0.56	–0.05%	25%
Jiri	0.84	9.4%	15%
Okhaldhunga	0.71	1.1%	3%

Results: Soil Moisture



- Aggregation of long-term weekly relative soil moisture (MPS) for sub-regions
- Low average soil water saturation in Tibet suggests high drought vulnerability

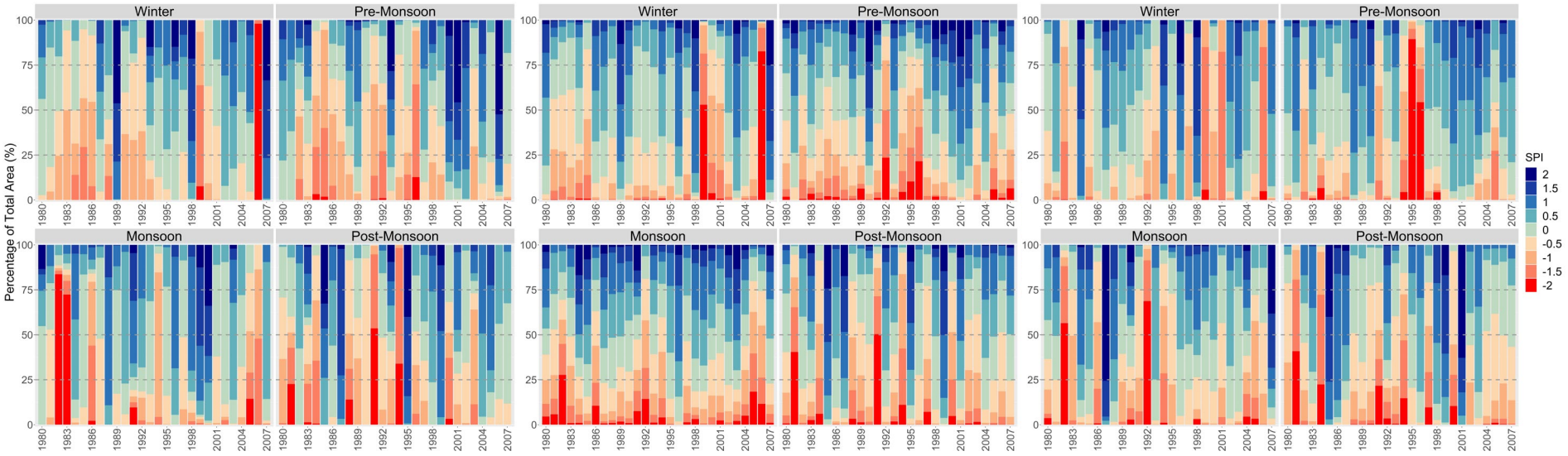
Results: Seasonal SMDI



Tibet **High and middle mountains** **Plains**

- High spatial coverage of low SMDI in Tibet, followed by Plains, especially during Pre-Monsoon
- Monsoon season with higher SMDI in all regions

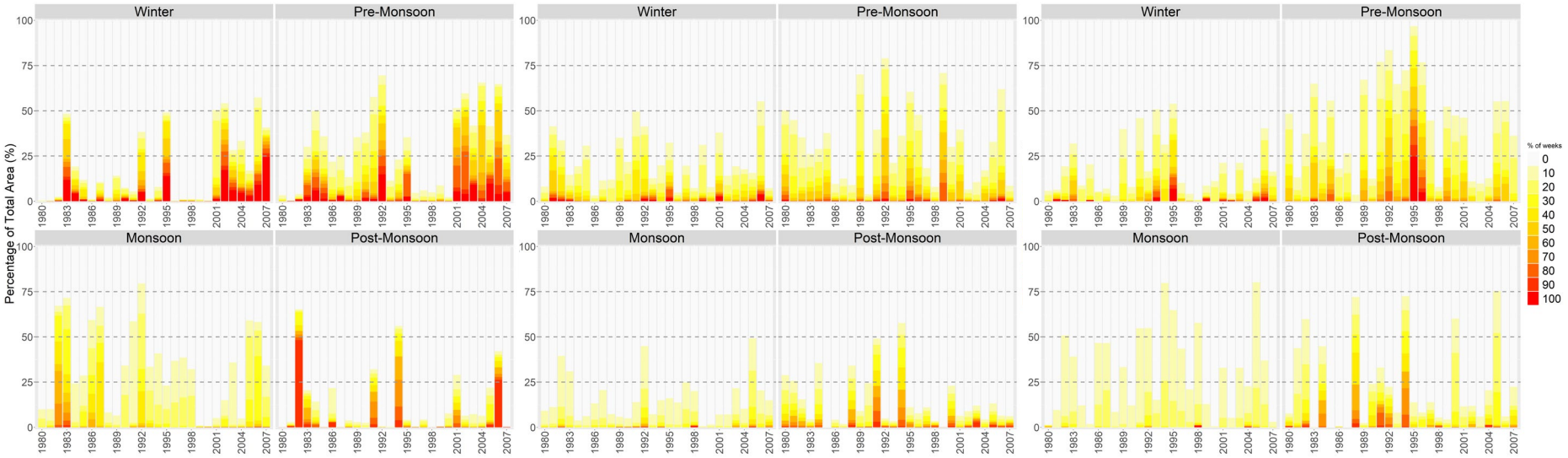
Results: Seasonal SPI



Tibet **High and middle mountains** **Plains**

- SPI reflects precipitation variability, thus more pronounced
  (e.g. Tibet/Winter 2006; Plains/Pre-Monsoon 1995)
- SMDI also accounts for temperature and soil water storage
  (e.g. Tibet/Pre-Monsoon 2001-2007; Plains/Pre-Monsoon 1992)
- Overall more buffered reaction of SMDI on low precipitation periods

Results: Drought Events



Tibet **High and middle mountains** **Plains**

- SMDI < -3.0 considered as drought event
- Visualization of spatial coverage and length of drought events reveals severe conditions in Tibet after 2001 (Winter/Pre-Monsoon)
- Monsoon season less impacted in all regions

Conclusions (1)

- The JAMS/J2000 model is suitable for large-scale soil moisture drought assessment in the Koshi River Basin
- Calibrated and validated using multi-site evapotranspiration and discharge data, the model showed good performance, although flood peaks and overall flooding periods have been simulated with a slightly lower accuracy for some years
- Spatio-temporal analysis of low SMDI revealed severe droughts
  - 1992 throughout the Koshi River Basin
  - 1994 and 2004 in Tibet
  - 1999 and 2006 in the High and middle mountains
  - 1994–1996 in the Plains

Conclusions (2)

- Extreme dry conditions increase in frequency in the later years of the study period and are most evident in the pre-monsoon season
- In Tibet, continuous drought persists after 2000; a similar pattern exists in other regions during winter and pre-monsoon season
- In all regions, Monsoon is less prone to droughts than other seasons
- SMDI considers precipitation, soil, temperature and landuse and thus can represent soil moisture conditions better than SPI

Outlook

- Further validation of model results, e.g. soil moisture
- Spatio-temporal comparison of identified drought events with observed data
- Uncertainty assessment of simulated SMDI
- Trend analysis of drought occurrence in the Koshi River Basin under Climate Change

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Acknowledgements

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- Department of Hydrology and Meteorology (DHM), Government of Nepal

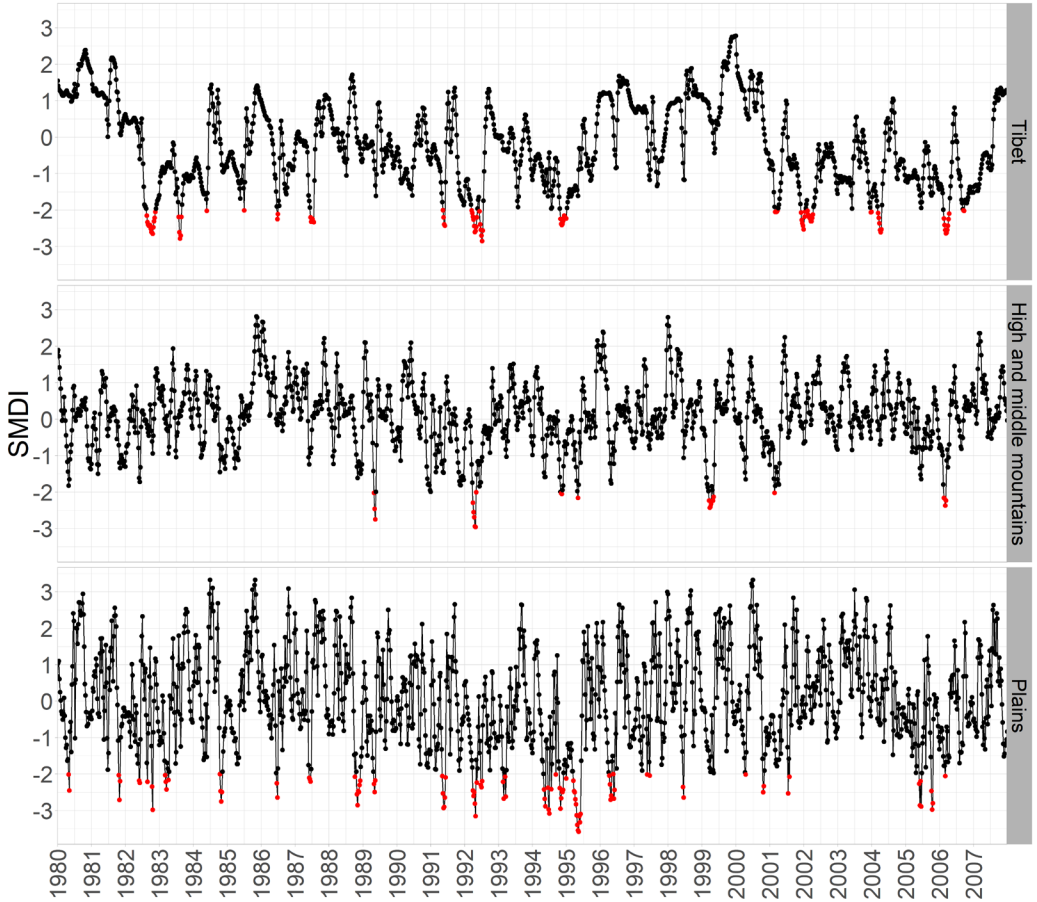
Supplementary Material

Data

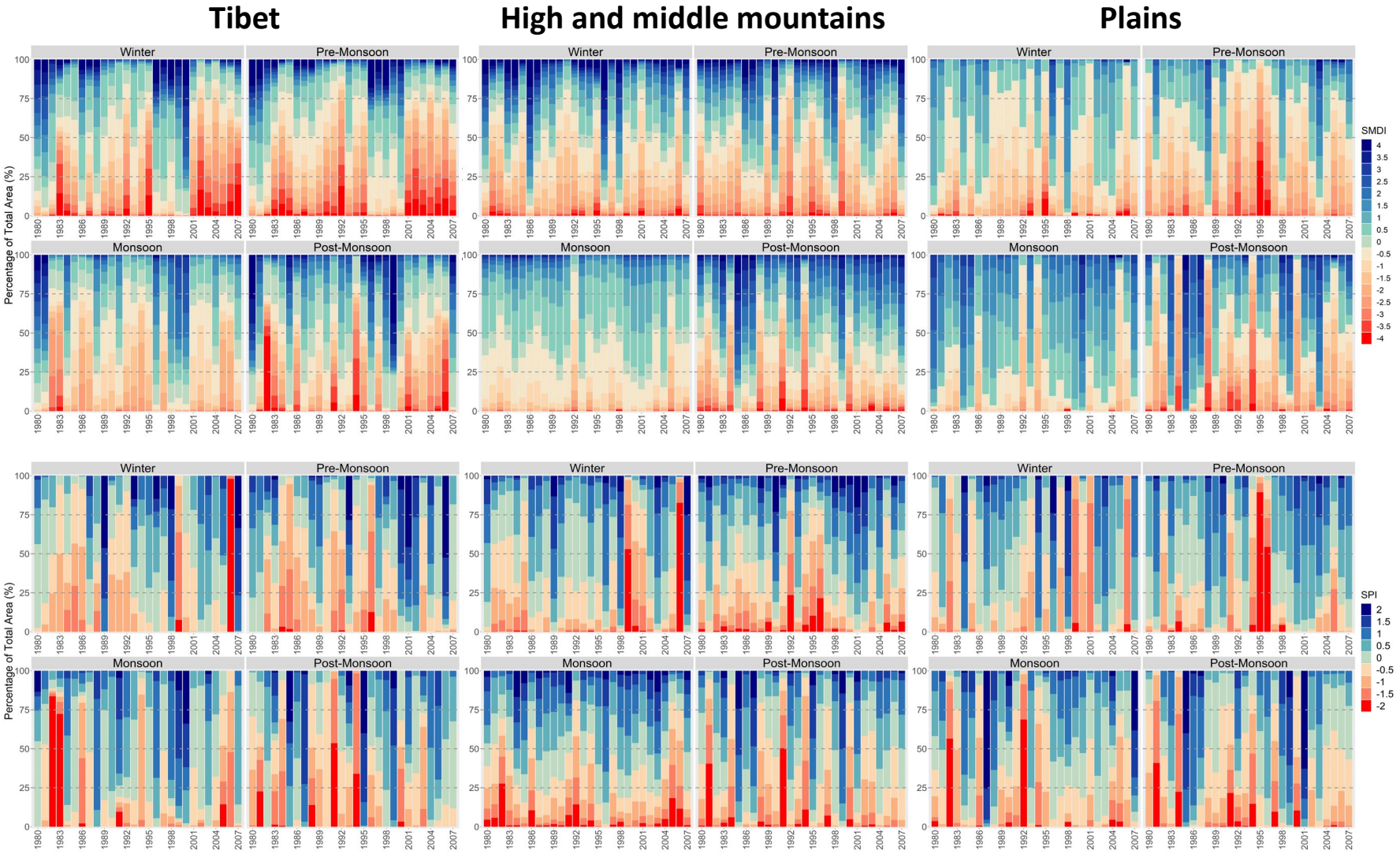
Type	Source		Resolution
Digital Elevation Model (DEM)	ASTER GDEM		30m x 30m
Land use map	Uddin et al. (2016); ICIMOD		30m x 30m
Soil map	SOTER		30m x 30m
Geology map	DMG (1994)		500m x500m
Meteorological data			
a. Precipitation	DHM[a], IMD[b], APHRODITE[c]	(160 stations)	Daily
b. Temperature	DHM, IMD, CFSR[d]	(60 stations)	Daily
c. Relative humidity	DHM, IMD, CFSR	(67 stations)	Daily
d. Wind	DHM, IMD, CFSR	(61 stations)	Daily
e. Sunshine duration	DHM	(4 stations)	Daily

Results: SMDI

- Weekly SMDI aggregated for sub-regions
- Weeks with SMDI < -2.0 considered moderate drought (marked red)
- Moderate drought conditions more often in Tibet and Plains



Results: SMDI vs. SPI



Results: SMDI/SPI Base Data