Distributed streamflow predictions based on precipitation data from sparse ground networks and the North American Land Data Assimilation System in Northwest Mexico

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I. Introduction

Arid and semiarid regions of the southwest United States and northwest Mexico are influenced by the behavior of the North American Monsoon (NAM). While we currently have an understanding of the annual streamflow signal within the NAM region, much less is known about the seasonality of runoff generating mechanisms and their relationship to the spatial and temporal variability of rainfall and heterogeneous landscape characteristics (topography, soils, and vegetation). In addition, previous studies that investigated the annual spatial variability of streamflows were conducted at temporal scales that are still too coarse to be able to make streamflow predictions for individual events or for seasonal conditions.

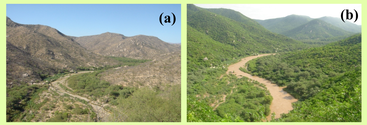

Fig. 1: The Upper Sonora River (a) before the North American Monsoon (June 13th, 2007) (b) during the Monsoon (July 17th, 2007).

In this study, we use a distributed hydrologic model, the Triangulated Irregular Network (TIN)-Based Real-time Integrated Basin Simulator (tRIBS, Ivanov et al., 2004a, 2004b;Vivoni et al., 2007) to explore the spatiotemporal variability of streamflows and runoff generating mechanisms in a large river basin within the NAM. tRIBS was parameterized to estimate streamflow as it relates to rainfall variability and landscape characteristics in the Upper Sonora River Basin (~ 9,500 km^2) that lies within the NAM region in northwest Mexico.

II. Methods

Our distributed approach divided this large watershed into 291 ungauged subbasins (92% of total basin area). For each subbasin, tRIBS was forced using spatiotemporal forcing from: (1) a sparse network of ground-based stations (hourly resolution), (2) raw model products (~12 km pixel, hourly resolution) from the North American Land Data Assimilation System (NLDAS), and (3) the NLDAS product adjusted using available ground data.

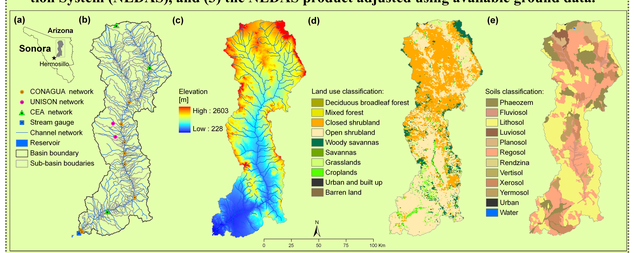

Fig. 2: (a) Upper Sonora River location in Sonora, Mexico. (b) Sub-basin delineation, stream network and observation network. (c) 29 m ASTER DEM. (d) 463 m MODIS-IGBP Land use map. (e) 446 m INEGI-INIFAP-FAO Soil map.

Parameterization of tRIBS was conducted by specifying soil hydraulic and thermal properties, vegetation properties, and channel and hill slope routing parameters.

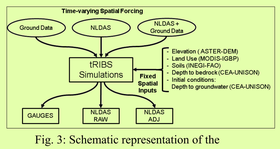

Fig. 3: Schematic representation of the hydrologic simulations.

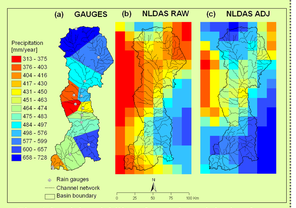

Fig. 4:Spatial variability of annual precipitation for: (a) GAUGES as Thiessen interpolation (542 mm/year). (b) NLDAS RAW (430 mm/year). (c) NLDAS ADJ (518 mm/year).

III. Results

(A) Area weighted basin averaged fluxes:

- **Overestimation of the GAUGES rainfall forcing due to sparse weather/rain gauges in the northern regions of the USRB (Thiessen interpolation).**

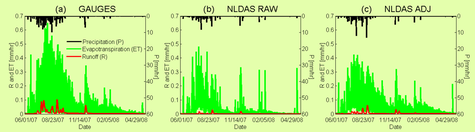

Fig. 5: Simulated basin-averaged precipitation (P in mm/hr), evapotranspiration (ET in mm/hr), runoff (R in mm/hr) for (a) GAUGES. (b) NLDAS RAW. (c) NLDAS ADJ.

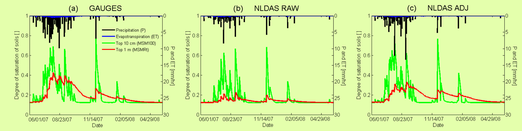

Fig. 6: Simulated basin-averaged degree of saturation in the top 10 cm and top 1 meter for (a) GAUGES. (b) NLDAS RAW. (c) NLDAS ADJ.

(B) Spatial variability of streamflows and runoff generating mechanisms:

- **Higher contribution from subbasins residing on the western side of the watershed.**
- **Dominance of Infiltration excess runoff.**

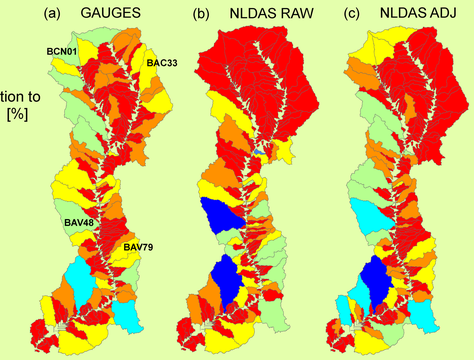

Fig. 7: Spatial variability of simulated percent contribution of each subbasin to the total streamflow in the USRB for: (a) GAUGES (574 Mm^3) (. (b) NLDAS RAW (85 Mm^3). (c) NLDAS ADJ (254 Mm^3).

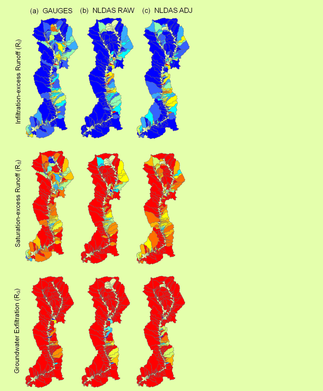

Fig. 8: Spatial variability of simulated runoff generation mechanisms as a percentage of total runoff for (a) GAUGES. (b) NLDAS RAW. (c) NLDAS ADJ. (top row) Infiltration-excess runoff. (middle row) Saturation-excess runoff. (bottom row) Groundwater exfiltration.

(C) Topographic controls on runoff generating mechanisms:

- **High impact of soil spatial heterogeneity on runoff generating mechanisms.**

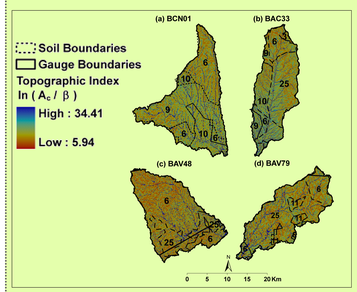

Fig. 9: Topographic index, ln (Ac/ β), distribution in four selected sub-basins: (a) BCN01. (b) BAC33. (c) BAV48. (d) BAV79. Numbers represent the value of saturated hydraulic conductivity (mm/hr).

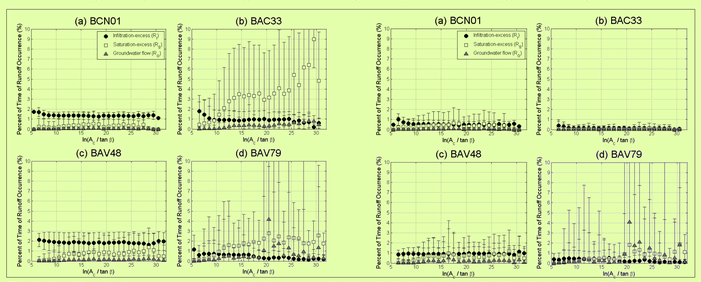

Fig. 10: Runoff mechanism occurrence variation with the topographic index (λ) for four basins: (a) BCN01. (b) BAC33. (c) BAV48. (d) BAV79. Results shown are for the GAUGES and NLDAS ADJ simulations. Vertical bars represent standard deviations of the values computed for the corresponding bins associated with each λ.

(D) Annual Runoff Ratio and Streamflow routing comparisons:

- **Better agreement of NLDAS ADJ with INEGI.**
- **Synthetic streamflows capture two distinct temporal periods.**

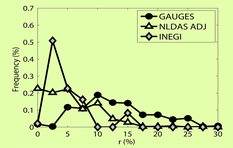

Fig. 11: Frequency distribution of Annual Runoff Ratio, r (%) for GAUGES, NLDAS ADJ and INEGI.

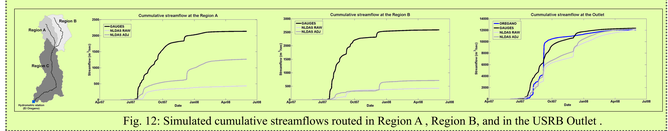

Fig. 12: Simulated cumulative streamflows routed in Region A , Region B, and in the USRB Outlet .

IV. Findings

- **Differences in the rainfall forcing had significant impacts on the predicted streamflows. Large regions where sparse weather/rain gauges were available resulted in overestimations of the predicted streamflows.**
- **The application of the NLDAS RAW forcing product required additional correction, particularly with regards to the precipitation field that underestimates observed rainfall. In this study the regions in the northern part of the USRB had the least number of available gauges for this corrections. In that regard, the use of a combined remote sensing product and the available ground observations may be best to generate accurate streamflows predictions.**
- **We found important spatial variability patterns of the streamflows generating processes. These patterns are in large part caused by the spatial distribution of the soils in this basin, particularly the saturated hydraulic conductivity.**
- **Gochis et al (2006) and Brito-Castillo et al (2003) estimated that streamflows during the core months of the NAM can account to up 85% of the total annual runoff . The synthetic streamflows generated in this study ranged from 51% to 71%.**

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