

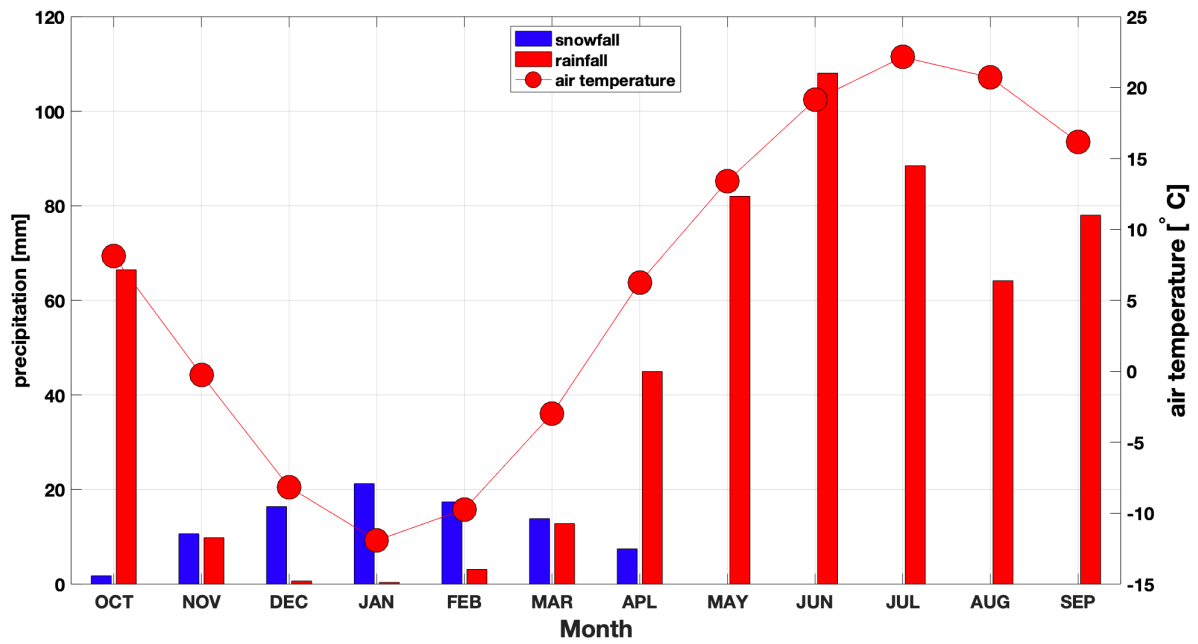


Figure S1. Climatology of the Red River Basin to show monthly snowfall, rainfall, and air temperature, averaged over 1995 to 2013.

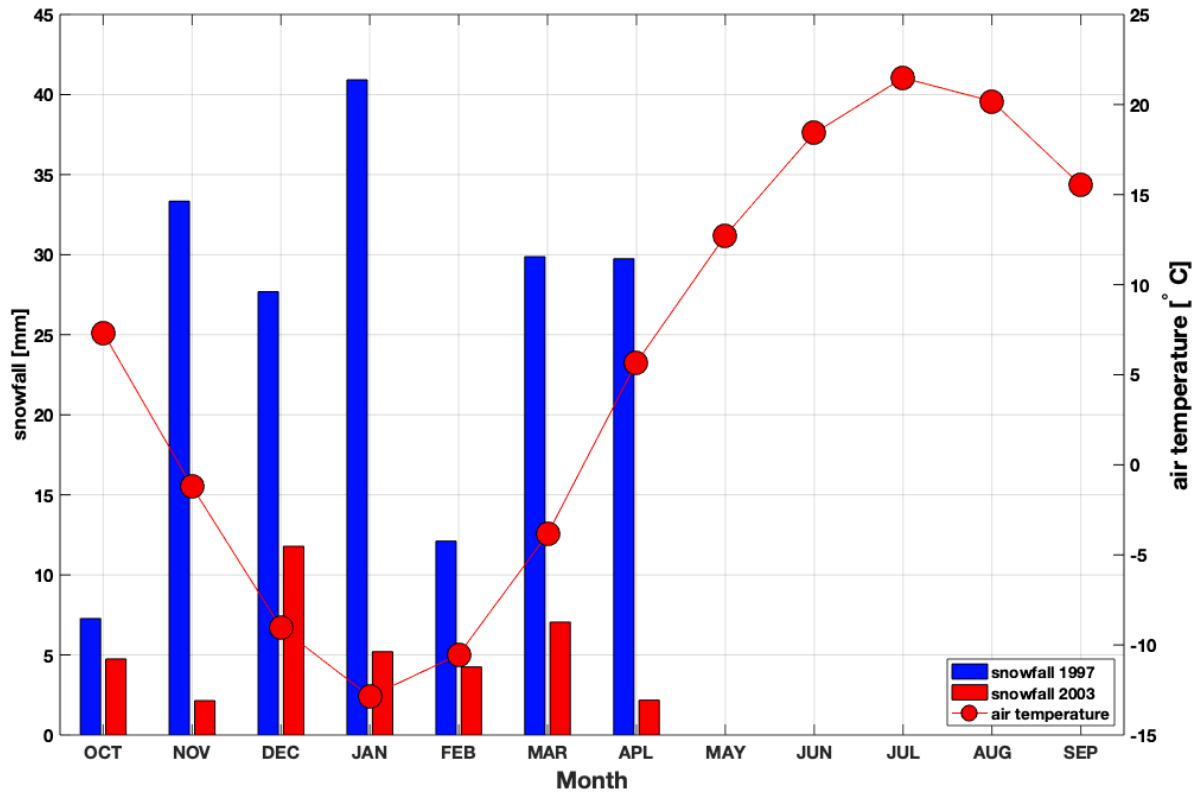


Figure S2. A comparison of snowfall in 1997 and 2003 in the headwaters of Red River Basin along with monthly air temperature. Snowfall forcing dataset is based on non-adjusted one with M_{factor} .

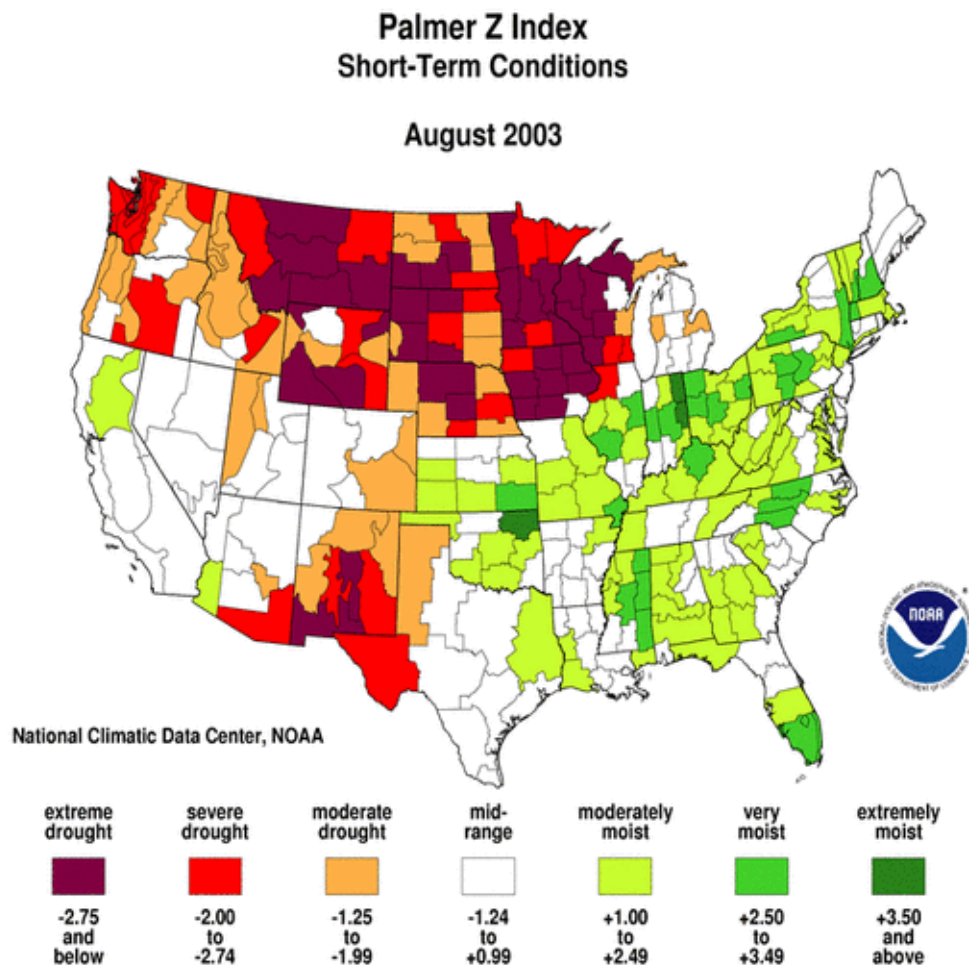


Figure S3. Drought Monitoring Map, NOAA Drought Monitoring System in August 2003. Reproduced from NOAA (2003). Image stated to be in the public domain.

NOAA 2003, Palmer Z Index for 2003, U.S. Drought Highlights, Climate Prediction Center, NOAA, MD, USA, accessed 25 January 2021, <<https://www.ncdc.noaa.gov/sotc/drought/200308>>.

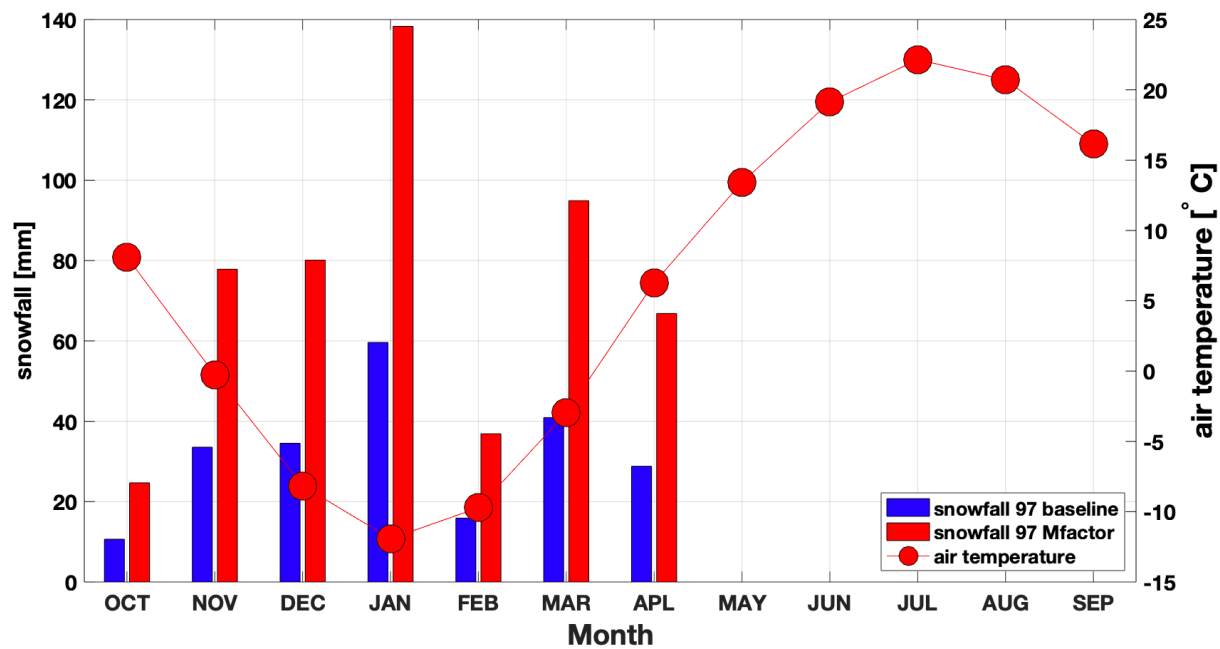


Figure S4. Baseline and M_{factor} Snowfall in Water year 1997 along with monthly air temperature.

Table S1. Monthly M_{factor} from 1995 to 2013 in the headwaters of the Red River Basin

Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
0.023	0.47	1.27	1.62	4.01	7.69	1.09	0	0	0	0	0

Snow Scheme: how is melting computed in the Variable Infiltration Capacity Model?

Snowmelt is calculated from a modified energy balance, similar to that applied for the ground snowpack, with canopy temperature being computed by solving the intercepted snow energy balance from equation (S-1) [Andreadis et al., 2009].

$\rho_w c_s \frac{dWT_s}{dt} = Q_r + Q_s + Q_e + Q_p + Q_m$	(S-1)
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where c_s is the specific heat of ice, ρ_w is the density of water, W is the water equivalent and T_s is the temperature of the surface layer, Q_r is the net radiation flux, Q_s is the sensible heat flux, Q_e is the latent heat flux, Q_p is the energy flux advected to the snowpack by rain or snow, and Q_m is the energy flux given to the pack because of liquid water refreezing or removed from the pack during melt.

Given the intercepted snow temperature and air temperature, snowmelt is calculated directly from equations (S-2) and (S-3). The total energy available for refreezing liquid water or melting the snowpack over a given time step depends on the net energy exchange at the snow surface

$Q_{net} = (Q_r + Q_s + Q_e + Q_p) \Delta t$	(S-2)
$Q_m \Delta t = \min(-Q_{net}, \rho_w \lambda_f W_{liq}) \quad Q_{net} < 0$ $Q_m \Delta t = -(Q_{net} + c_s W_{ice} T_s^t) \quad Q_{net} \geq 0$	(S-3)

If Q_{net} is negative, then energy is being lost by the pack, and liquid water (if present) is refrozen. If Q_{net} is sufficiently negative to refreeze all liquid water, then the pack may cool. If Q_{net} is positive, then the excess energy available after the cold content has been satisfied, produces snowmelt.

VIC model uses an energy balance approach to represent snow accumulation and ablation on the ground. It assumes that low-lying vegetation is completely covered by snowfall, thus it does not affect the ground snowpack energy balance. The model account for an explicit canopy snow interception scheme that considers sublimation, drip and release of intercepted snow.

Andreadis, K., P. Storck, and D. P. Lettenmaier, (2009): Modeling snow accumulation and ablation processes in forested environments, *Water Resources Research*, **45**, W05429, doi:10.1029/2008WR007042.

VIC snow band

1. The model VIC 4.0.6, which the paper adopts uses **5** snow bands.
2. From the global configure file
 - SNOW_BAND **5** # Number of snow bands; if number of snow bands > 1, we must insert the snow band path/file after the number of bands.
3. Snow Elevation information adopted from NLDAS [Sheffield, Pan, and Wood 2003].
4. $1/8^\circ$ degree $\approx$ 12.5 km x 12.5 km grid cell size.
5. Range of Snow Elevation in RRB (Figure S5)
 - Mean (or median) elevation of elevation band. This is used to compute the change in air temperature from the grid cell mean elevation.
6. Range of Snow Area Fraction in RRB (Figure S6).
 - Fraction of grid cell covered by each elevation band.
 - 75860 ~ 92096 refers to grid cell ID within RRB.
7. Each grid cell has both soil and snow information and parameters.

J. Sheffield, M. Pan, E.F. Wood et al., “Snow process modeling in the North American Land Data Assimilation System (NLDAS): 1. Evaluation of model-simulated snow cover extent,” *Journal of Geophysical Research D: Atmospheres*, **108**, 22, 2003.

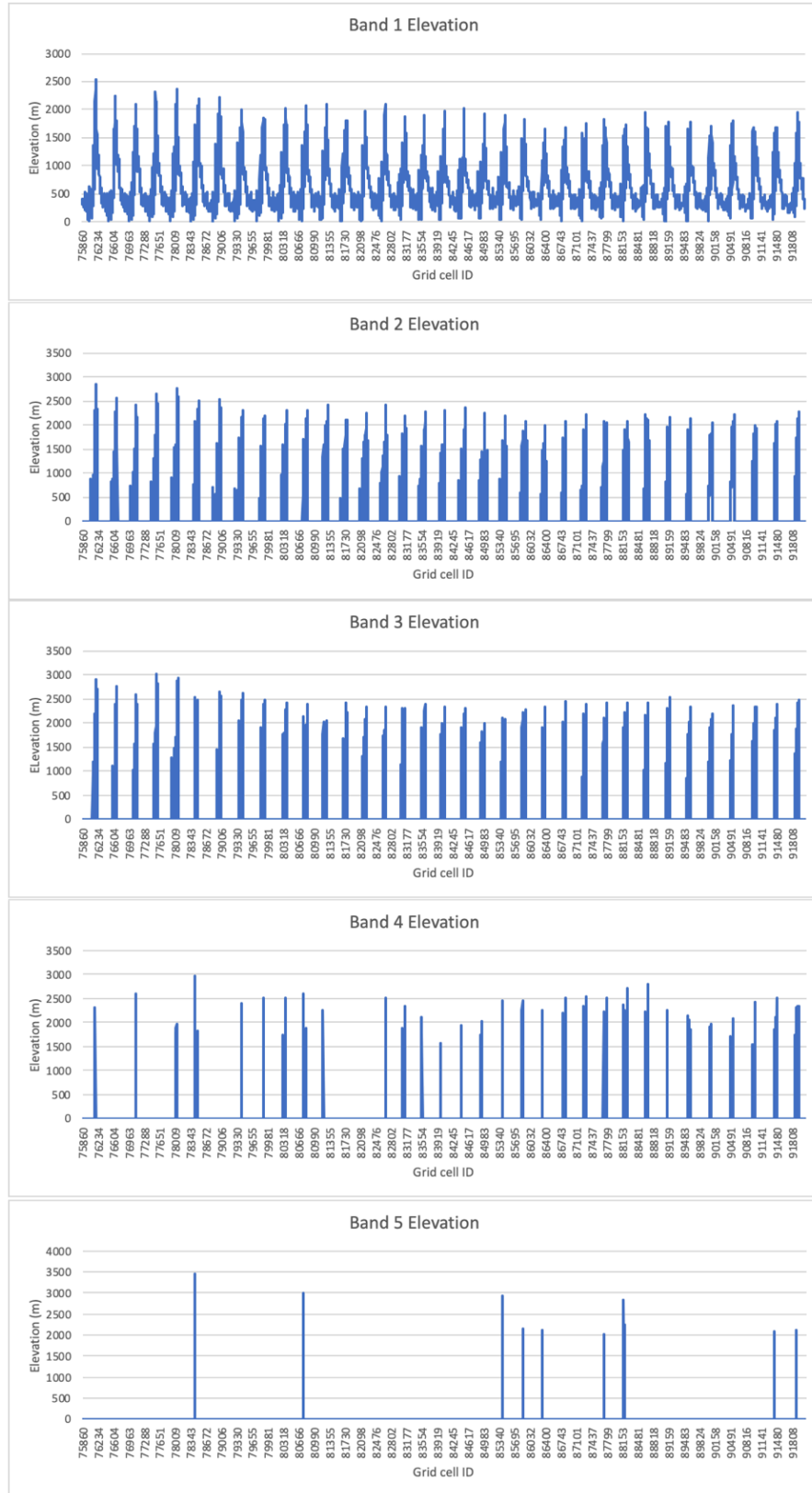


Figure S5. Snow Elevation [m] in the Red River Basin of the North.

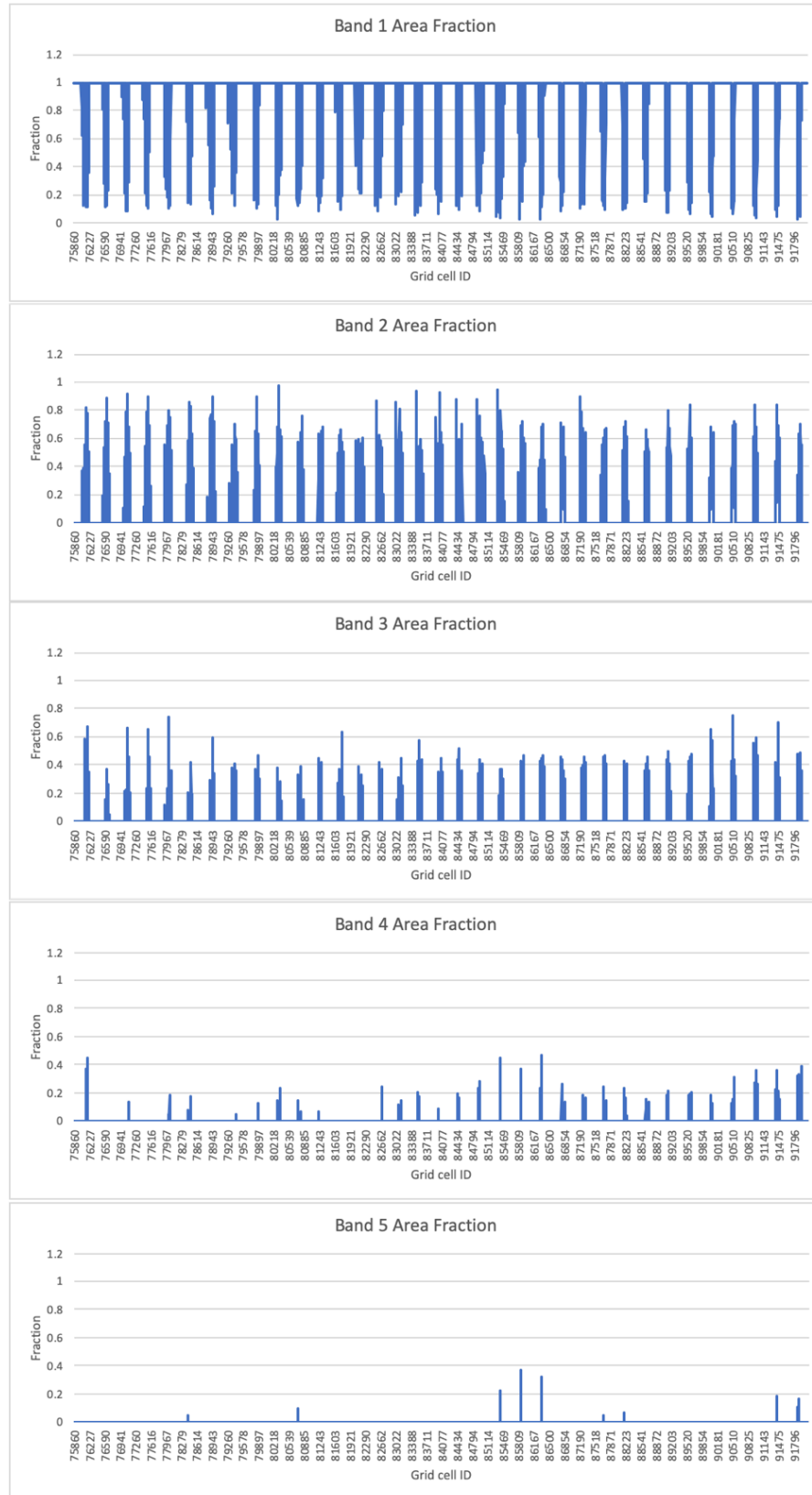


Figure S6. Snow Cover Fraction [m²/m²] in the Red River Basin of the North.