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Supplement of

Using MODIS estimates of fractional snow cover area to improve streamflow forecasts in interior Alaska

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1 Supplemental

1.1 MODIS Pre-processing

The MOD10A1 fractional snow covered area (fSCA) data are developed based on the normalized difference snow index (NDSI), which is calculated as a ratio of band 4 and band 6 on the Terra satellite:

$$NDSI=\frac{b_4-b_6}{b_4+b_6} \quad (1\text{-}1)$$

Snow is mapped when NDSI is greater than 0.4 (Hall et al., 2002) and where reflectance in MODIS band 2 is >11% and MODIS band 4 is >10%, although with a number of other spectral tests and screens (Riggs et al., 2006). The fractional product is then calculated developed from binary Landsat Thematic Mapper scenes processed using an empirical algorithm generated from a linear regression and applied to the MODIS NDSI (Salomonson and Appel, 2004).

MODSCAG is a spectral mixing model that utilizes end member analysis to identify the best fit of linear end members that has the strongest relationship to surface spectral reflectance in the Terra MOD09GA product (Painter et al., 2009). Operating under the assumption that spectral reflectance viewed by the MODIS sensor varies based on grain size of the snow, MODSCAG utilizes a radiative transfer model to calculate reflectance across different snow grain sizes. A look up table is used to store and retrieve the spectral reflectance end member formulations. From this look up table, all the end members are permuted to generate multiple models and the algorithm selects the minimized model solution (i.e. low error and minimum number of end members). When a pixel is identified as containing snow, then the fraction of the pixel containing snow is calculated in relation to other end members (soil, rock, ice, vegetation), normalized by the shading geometry (Rittger et al., 2013).

1.2 Community Hydrologic Prediction Framework (CHPS)

The Community Hydrologic Prediction System (CHPS) was implemented at River Forecast Centers across the United States in 2012 and builds on the Delft-Flood Early Warning System (Delft-FEWS) model framework, developed by Deltares. The system allows for integration and ensemble forecasting of multiple models under a single synchronous system. The framework can be run in live mode for forecasting purposes or in an offline standalone mode for testing and development purposes (Werner et al., 2013). The offline model is implemented for this study at the University of Alaska Fairbanks using the calibration capabilities introduced to the NWS with the FEWS 2013.01 build in November, 2013.

The CHPS framework is modified to allow for the ingestion of the MODIS fSCA data to replace the SNOW17 snow cover areal depletion curve, or to update the curve in the case of SCTOL > 0. The MODIS fSCA grids are read in using an import function, and then clipped and averaged over each sub-watershed area using a preprocessing module. The fSCA grids are imported as special forms of ArcInfo ASCII files in a Stereographic projection (this projection, which is generally inappropriate for Alaska, is used due to the limitations of CHPS projection parameters). Calibration modules are configured for peak flow, discharge statistics and water balance for each sub-watershed. We developed a parallel configuration to allow simultaneous display of MODIS and non-MODIS-forced model output. Statistics are generated for calibration, validation, and for the entire time period by altering the initial conditions appropriately for each run using the input MOD10A1 data.

The framework is set up to run on semi-lumped upper and lower sub-basins with additional designations (referred to as units) for north and south facing slopes in the Chena, Chatanika, Salcha, and Goodpaster basins. The model runs at a six-hourly timestep, and is run continuously from 2000 to September 2010, with initial conditions starting in October, 1999. Updates to the model framework included the basin area, and north/south facing slope delineation with new information from the 2012 NED digital elevation model (Gesch et al., 2002). This also formed the basis of updates to the model's area elevation curves and unit hydrographs.

1.3 fSCA in SNOW17

A tolerance parameter is available in the SNOW17 model that can be used to alter the impact of the observed MODIS fSCA data. The tolerance setting for snow cover (SCTOL) can be altered from 0 to 1 to incorporate observed data when there are differences in the simulated versus observed areal extents. When the areal extent of snow cover subtracted from the observed (in absolute terms) is greater than the tolerance multiplied by the observed, the snow cover is updated. Otherwise it is left the same. The effect of this parameter is to rely solely on the observed data value (SCTOL=0), rely partially on observed only when there are large differences (0.1-0.9), or to rely wholly on the simulated data (SCTOL=1).

Linear interpolation is used to estimate snow cover over periods when no MODIS fSCA data are available. An optional element in CHPS, maxGapLength, can be configured to define the maximum length of gaps that should be filled. Gaps equal to or smaller than maxGapLength will be filled with interpolated values, while gaps larger than maxGapLength will not be filled. This ensures that periods with extensive cloud cover obscuring the MODIS fSCA data are interpolated but long periods with no data, such as the summer period, are not interpolated. A maxGapLength of 11 days was selected after testing revealed that longer and shorter interpolation time steps resulted in lower streamflow simulation skill.

1.4 Calibration of SAC-SMA/SNOW17

The goal of the *physically realistic* calibration was one that focused only on the empirical parameters that have physically-based schemes associated with them. For example, the maximum melt factor for non-rain melt periods (MFMAX, specified for June 21st) represents the melt rate; increasing this parameter is indicative of increasing melt responses towards an earlier date in the season and changing melt timing. The MFMAX value incorporates slope, aspect, forest cover, and meteorological conditions; it is generally considered to be higher for open regions with predominantly deciduous tree covers, higher wind speeds, and mountainous terrain. The TAELEV parameter is used to warm or cool the mean areal temperature (MAT) without recompiling the historical data. The mean elevation of the catchment (ELEV) is the elevation at which the MAT is applied in the snow model. TAELEV is the elevation associated with the historical MAT time series. Using a standard lapse rate of 0.6ºC per km, if ELEV is 1000 m and TAELEV is set to 1200 m, then the MAT that is applied in the SNOW17 model is effectively warmed by 1.2ºC. Since MAT is generated for the entire upper zone, we used TAELEV to "warm" the temps for the southern basin units and "cool" the temps for the northern basin units. Slight adjustments to the NMF parameter were made across all basins and sub-basin units to correct a small over estimate of the values; this was anticipated to have little impact on the overall results but was undertaken to ensure representativeness of the north, south and lower basins.

1.5 Year-to-year Variability in Discharge for Sub-basins

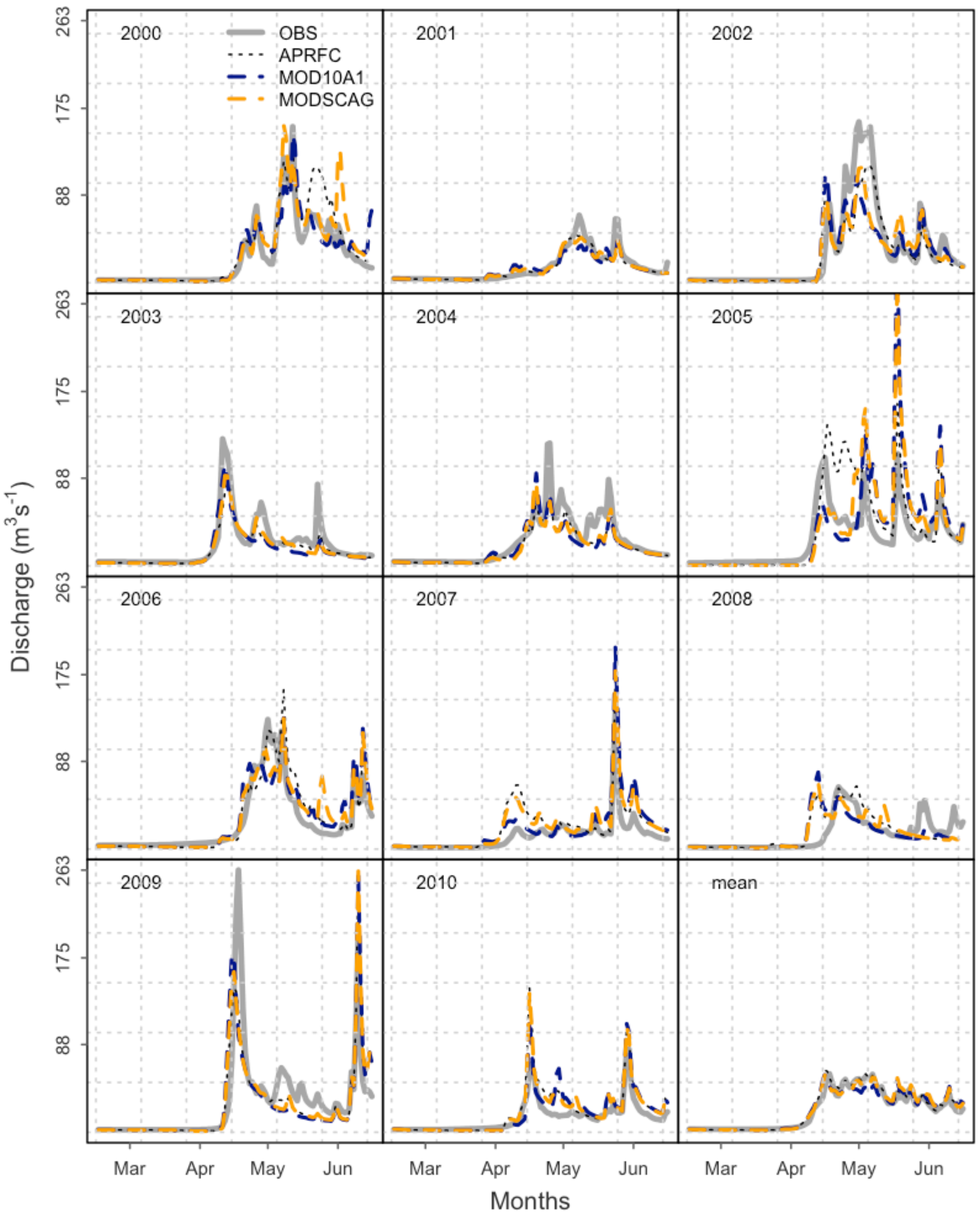

Figure 1. Upper Chena River basin.

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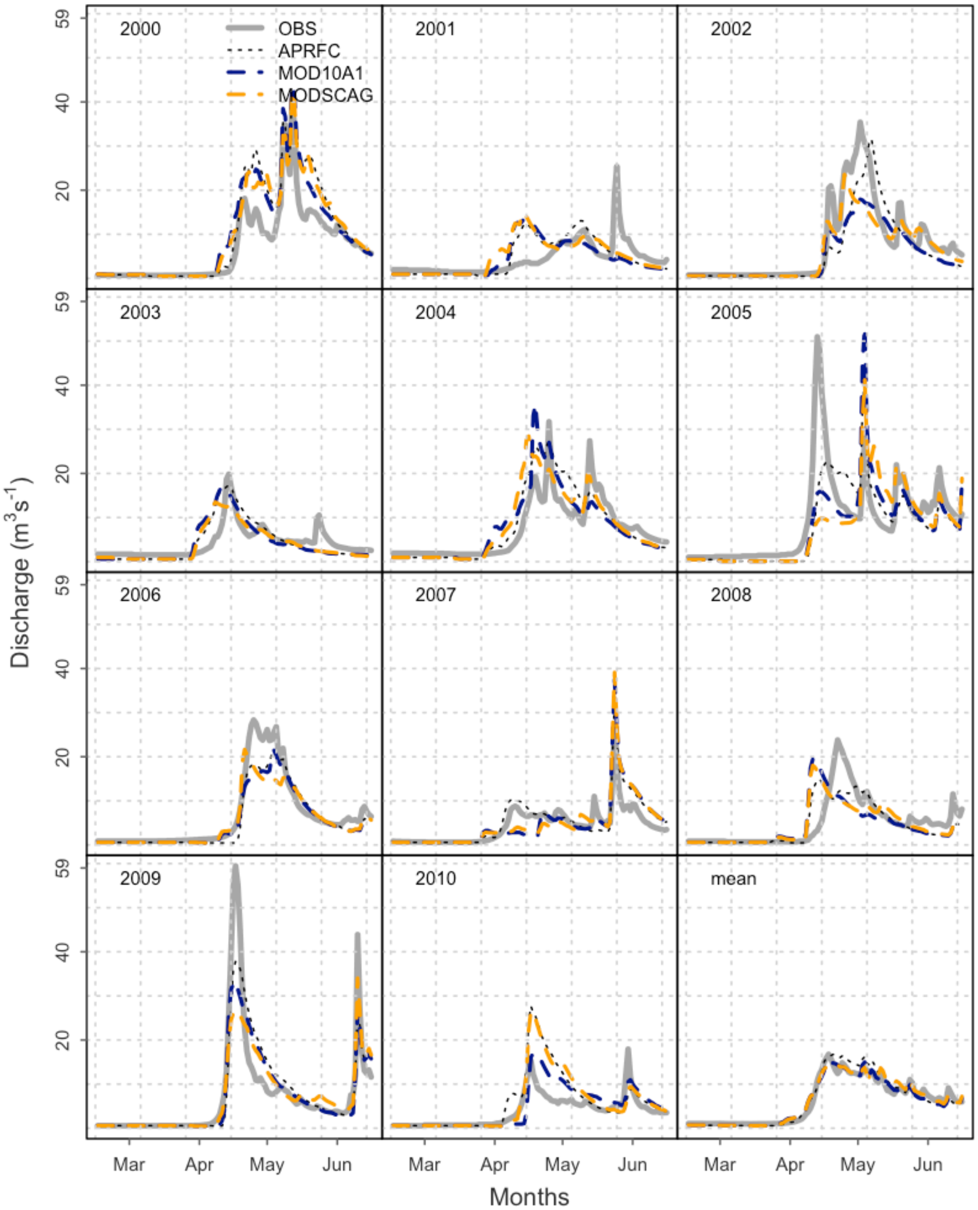

Figure 2. Little Chena River basin.

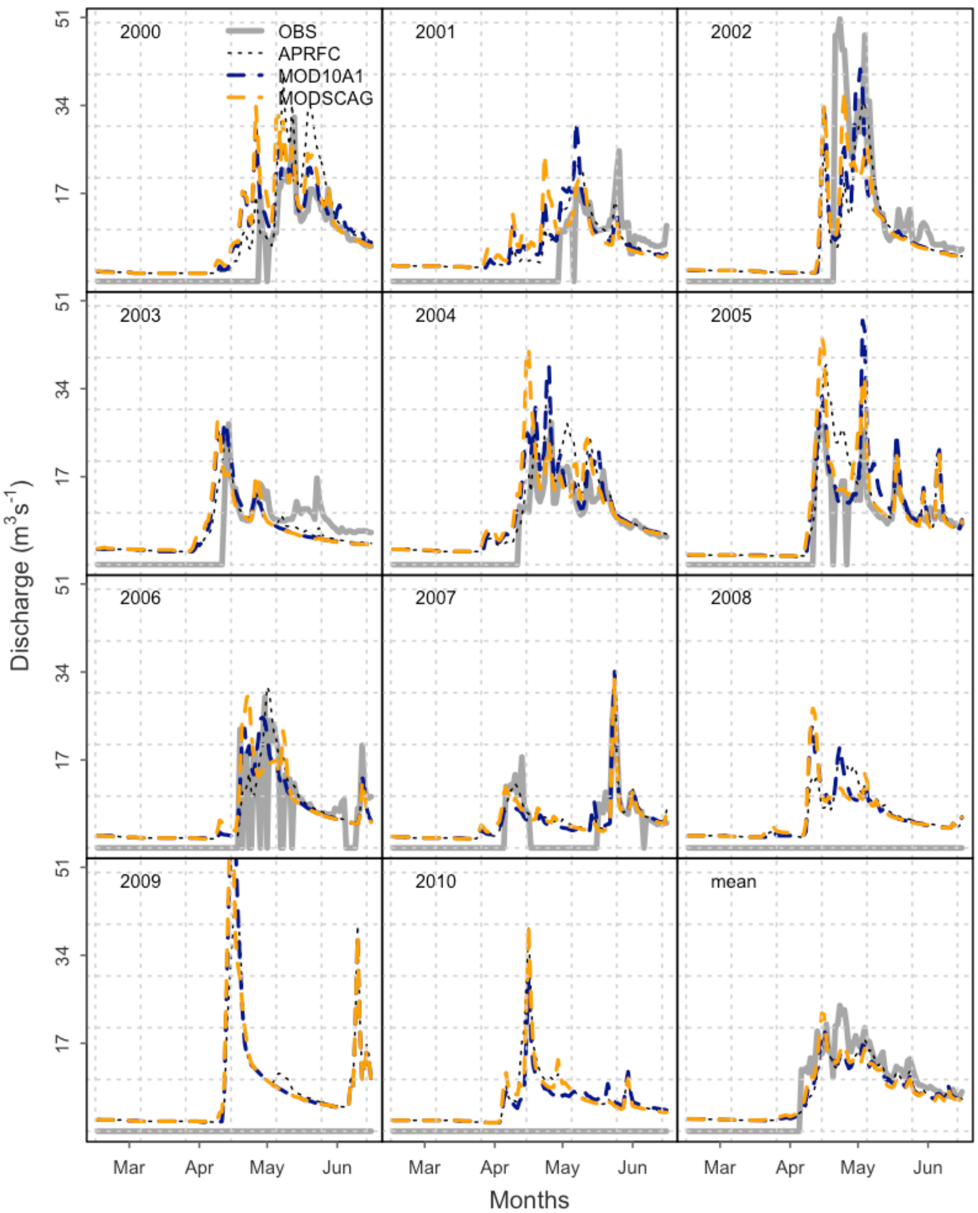

Figure 3. Chatanika River basin.

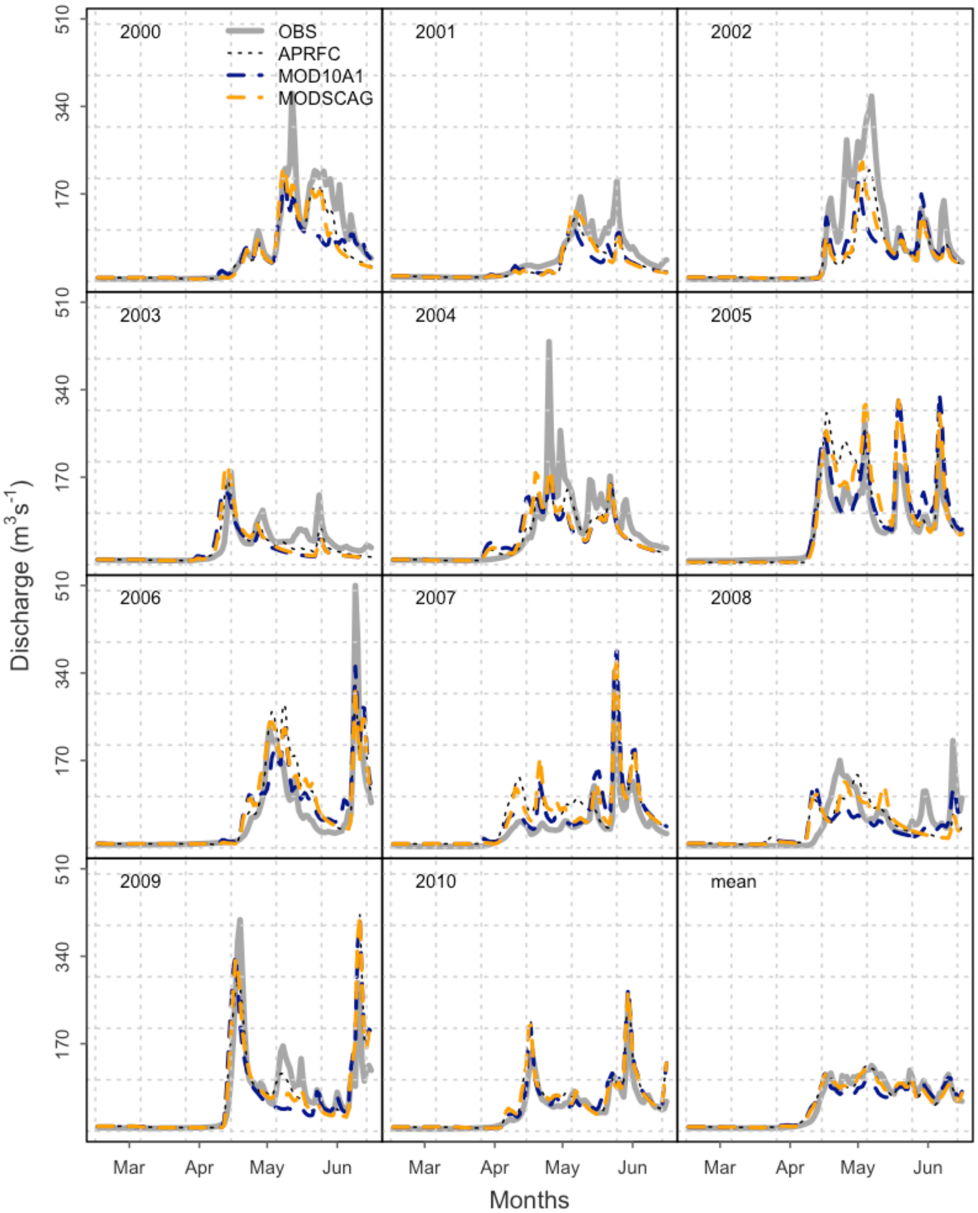

Figure 4. Salcha River basin.

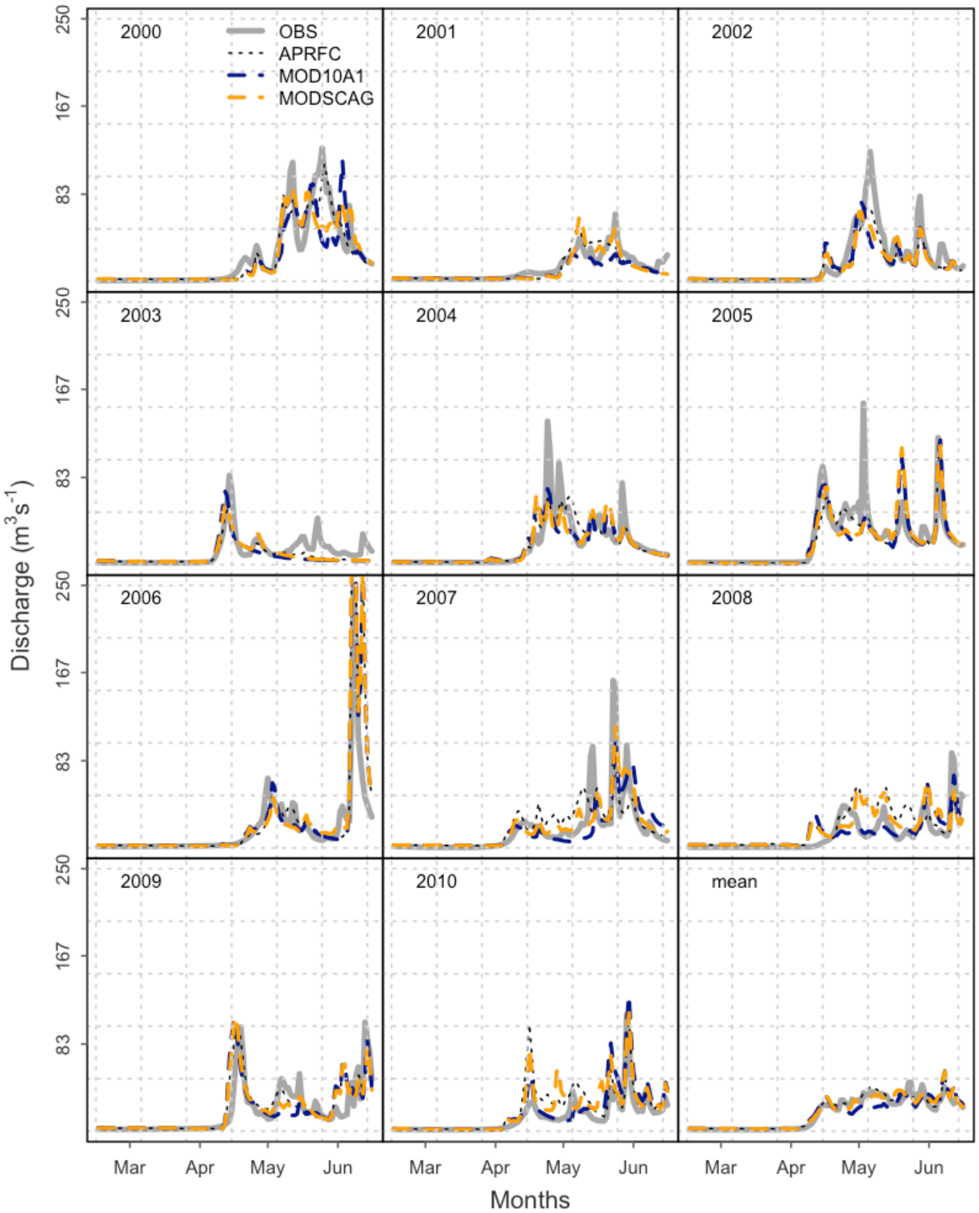

Figure 5. Goodpaster River basin.

2 References

Gesch, D., M. Oimoen, S. Greenlee, C. Nelson, M. Steuck, and D. Tyler (2002), The National Elevation Dataset, Photogramm. Eng. Remote Sens., 68, 5–11.

Hall, D.K., Riggs, G.A., Salomonson, V.V., DiGirolamo, N.E., Bayr, K.J., 2002. MODIS snow-cover products. Remote Sens. Environ., 83 (1): 181-194.

Kane, V.R., Gillespie, A.R., McGaughey, R., Lutz, J.A., Ceder, K., Franklin, J.F., 2008. Interpretation and topographic compensation of conifer canopy self-shadowing. Remote Sens. Environ., 112 (10): 3820-3832.

Liu, J., Melloh, R.A., Woodcock, C.E., Davis, R.E., Ochs, E.S., 2004. The effect of viewing geometry and topography on viewable gap fractions through forest canopies. Hydrol. Process., 18 (18): 3595-3607.

Liu, J., Woodcock, C.E., Melloh, R.A., Davis, R.E., McKenzie, C., Painter, T.H., 2008. Modeling the view angle dependence of gap fractions in forest canopies: Implications for mapping fractional snow cover using optical remote sensing. J. Hydrometeorol., 9 (5): 1005-1019.

Liu, Y., Peters-Lidard, C. D., Kumar, S., Foster, J. L., Shaw, M., Tian, Y., & Fall, G. M. 2013. Assimilating satellite-based snow depth and snow cover products for improving snow predictions in Alaska. Advances in Water Resources. 54: 208-227. doi:http://dx.doi.org/10.1016/j.advwatres.2013.02.005.

Molotch, N.P., Margulis, S.A., 2008. Estimating the distribution of snow water equivalent using remotely sensed snow cover data and a spatially distributed snowmelt model: A multi-resolution, multi-sensor comparison. Advances in Water Resources, 31 (11): 1503-1514.

Painter, T.H., Rittger, K., McKenzie, C., Slaughter, P., Davis, R.E., Dozier, J., 2009. Retrieval of subpixel snow covered area, grain size, and albedo from MODIS. Remote Sens. Environ., 113 (4): 868-879.

Raleigh, M.S., Rittger, K., Moore, C.E., Henn, B., Lutz, J.A., Lundquist, J.D., 2013. Ground-based testing of MODIS fractional snow cover in subalpine meadows and forests of the Sierra Nevada. Remote Sens. Environ., 128 (0): 44-57.

Riggs, G.A., D.K. Hall, V.V. Salomonson., 2006. MODIS Snow Products User Guide to Collection 5 http://modis-snow-ice.gsfc.nasa.gov/?c=userguides.

Rittger, K., Painter, T.H., Dozier, J., 2013. Assessment of methods for mapping snow cover from MODIS. Advances in Water Resources, 51: 367-380.

Salomonson, V., Appel, I., 2004. Estimating fractional snow cover from MODIS using the normalized difference snow index. Remote Sens. Environ., 89 (3): 351-360.

Werner, M., Schellekens, J., Gijsbers, P., Van Dijk, M., Van den Akker, O., Heynert, K., 2013. The Delft-FEWS flow forecasting system. Environ. Model. Software, 40: 65-77.