Drought characterization using the University of Washington Surface Water Monitor (SWM)

Shraddhanand Shukla and Dennis P. Lettenmaier
(Department of Civil and Environmental Engineering, University of Washington, Seattle – WA)

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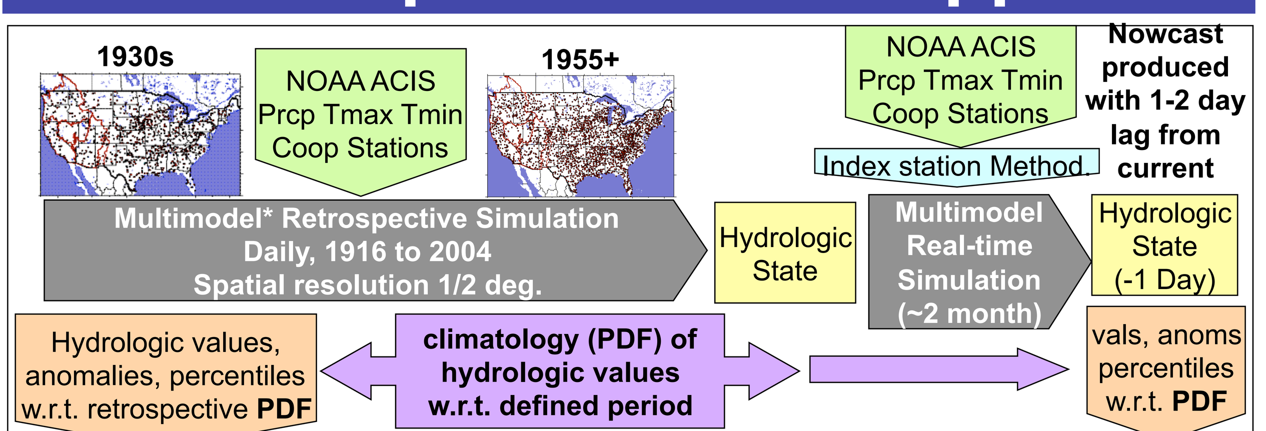
1 Overview

Drought has natural and social dimensions; both of which play a role in its characterization. Therefore the framework for a drought monitoring system should be robust with respect to both hydroclimatological regions (natural dimension) and stakeholders (social dimension). The University of Washington Surface Water Monitor (SWM http://www.hydro.washington.edu/forecast/monitor/) is an experimental drought monitoring system, which combines an array of drought indicators based on a suite of hydrologic variables (e.g. Precipitation, Soil Moisture, Runoff) averaged over time periods from one month to ~ 4 years. It provides daily updates of current drought condition status across the Continental United States (CONUS) and Mexico. We describe the implementation of SWM and its features, along with the findings of a recent study that evaluated the ability of an SWM-like approach to reconstruct the onset, severity, spatial extent; and recovery of droughts in the state of Washington. Our results suggest that this framework can provide a scientific foundation to characterization and prediction of drought events, and support of drought management decisions.

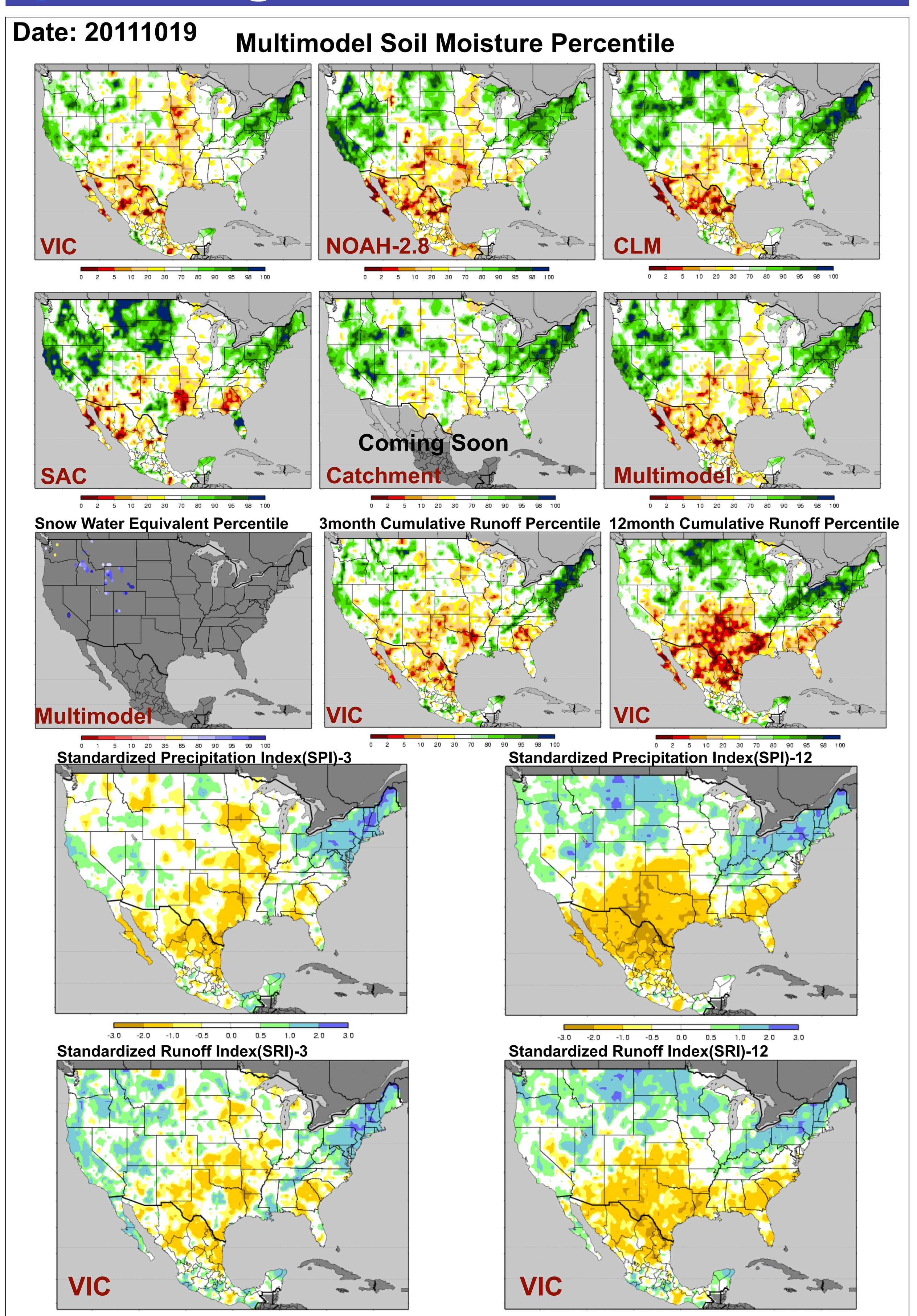
2 SWM Implementation Approach



Note: For the near-real time nowcast over Mexico domain the approach is similar as above however forcings are generated using Servicio Meteorológico Nacional (SMN), México stations data and real-time reanalysis products such as North American Regional Reanalysis (NARR) and the Enhanced Data Acquisition System (EDAS).

*List of Models used in SWM: (1) VIC (Variable Infiltration Capacity) version 4.0.6 (2) Noah(National Centers for Environmental Prediction/Oregon State University/Air Force/Hydrologic Research Lab) version 2.8 (3) SAC (Sacramento/Snow-17) (4) CLM (Community Land Model) version 3.5 (5) Catchment (6) Multimodel (average of the percentiles of VIC, Noah, SAC, CLM and Catchment)

3 Drought Indicators



4 Soil Moisture Drought Severity

Severity–Area–Duration (SAD) algorithm (Andreadis et al., 2005) is used to estimate soil moisture drought severity (currently over CONUS domain only). The algorithm starts by partitioning the domain in drought areas (using a threshold of 20%). The initial drought clusters are formed by grouping drought grid cells that belong in spatially contiguous blocks. After that, drought clusters are merged based on their distance from each other, and their minimum area. A temporal persistence constraint is used to ensure plausible drought recovery; if a grid cell is out of drought at the current time step, its drought status for the previous 3 weeks is examined and if its drought transition probability exceeds 50%, the grid cell is set back in drought. The transition probabilities have been calculated beforehand from grid cell's climatology. A spatial smoothing step that involves examining the neighborhood of each grid cell at a pre-defined radius is applied to produce the final map.

Soil Moisture Drought Severity
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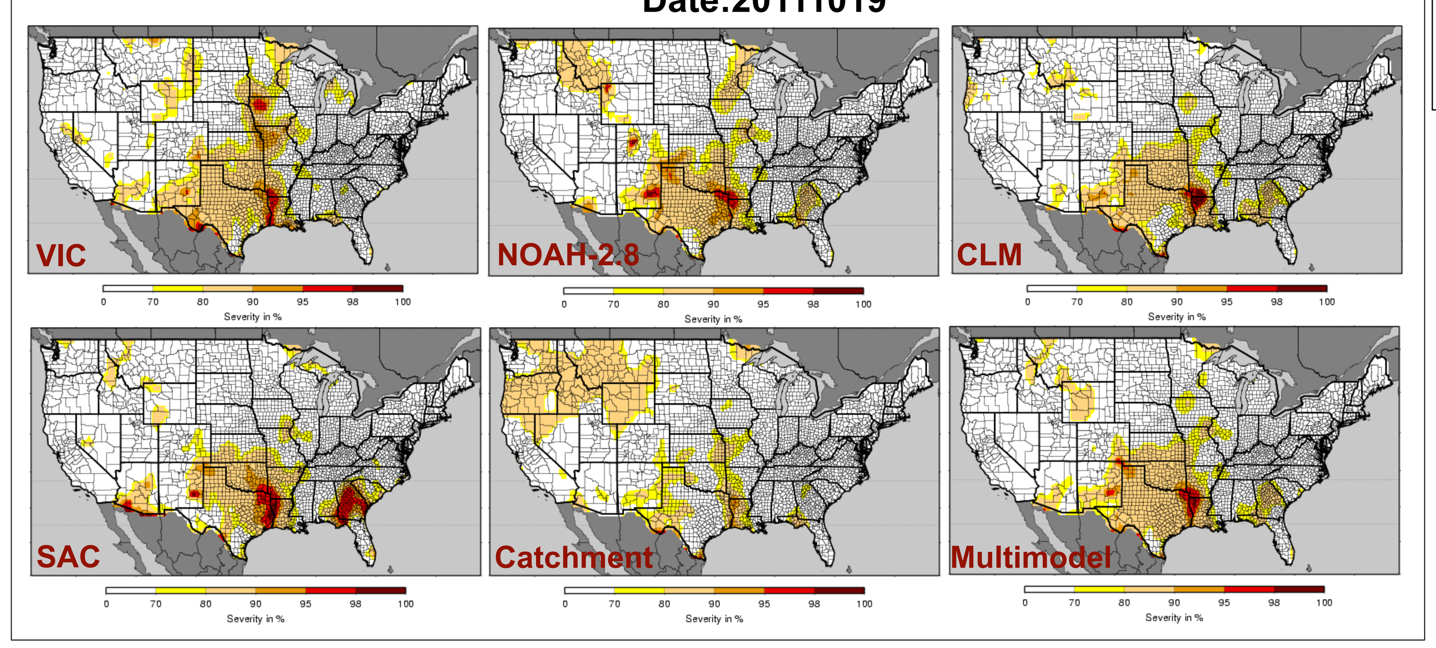

Case Study- Drought Monitoring for Washington State: Indicators and Applications (*Shukla et al., 2011*)

5 Data and study domain

Simulated Soil Moisture and Runoff data (Elsner et al., 2010)
Hydrologic model: Variable Capacity Infiltration model (VIC: Liang, 1994)
Spatial resolution: 1/16th degree (~6 km);
Time-step: Daily;
Simulation Period: 1916-2006;
Domain: Washington State (62 Water Resource Inventory Areas, WRIAs);

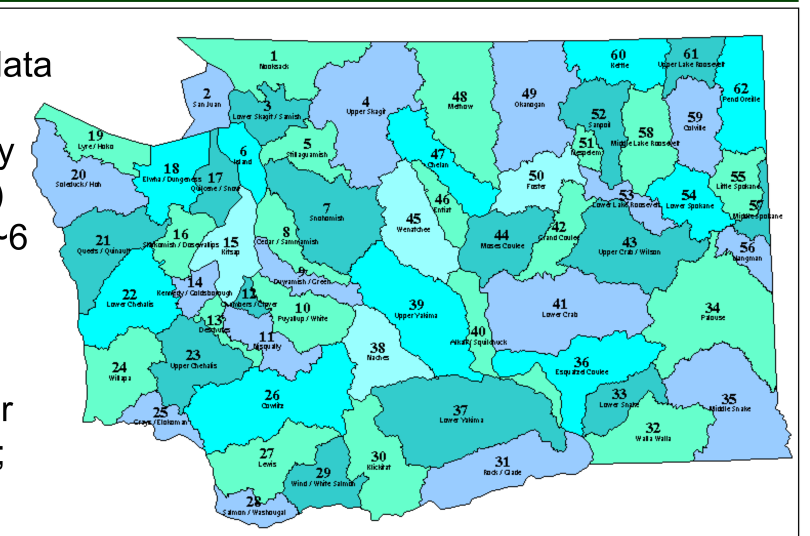

Fig. 1: Map of 62 Water Resource Inventory Areas (WRIAs).

6 Model based drought indicators and drought severity classification

Standardized Precipitation Index (SPI): (McKee et al., 1993) We used monthly gridded precipitation data to compute SPI for each grid cell. To estimate an n-month SPI (where n was 1, 3, 6, 12, 24, and 36), precipitation was averaged over the n-months and a Gamma distribution was fit to the time series.

Standardized Runoff Index (SRI): (Shukla and Wood, 2008) We followed the same method as in SPI and used n-months averaged surface runoff + base flow, to estimate SRI.

Soil Moisture Percentile (SMP): (Sheffield et al., 2004) We used total column soil moisture (SM) (i.e. sum of the three model layers) averaged by month. The 91 years of monthly values formed the climatology for each grid cell and month. We converted the SM into percentiles using the Weibull probability distribution

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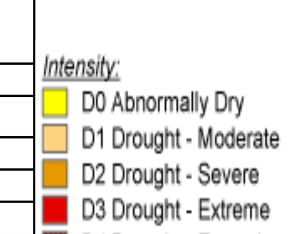
Table 1: Drought severity classifications, according to percentiles.

Standardized Precipitation Index (SPI)	Standardized Runoff Index (SRI)	Soil Moisture Percentile (SMP)	Drought Severity Class
0.50 to 1.0	0.50 to 1.0	0.50 to 1.0	1
0.35 to 0.50	0.35 to 0.50	0.35 to 0.50	2
0.20 to 0.35	0.20 to 0.35	0.20 to 0.35	3
0.10 to 0.20	0.10 to 0.20	0.10 to 0.20	4
0.05 to 0.10	0.05 to 0.10	0.05 to 0.10	5
0 to 0.05	0 to 0.05	0 to 0.05	6



7 Assessment of drought onset and recovery*

(*Approach adapted from Steinemann and Cavalcanti, 2006.)

50% or more of the WRIAs have a drought severity of class 3 or higher for three consecutive months.

Month 1	>=50%
Month 2	>=50%
Month 3	*>=50%*

Drought Onset

Fewer than 50% of the WRIAs have a drought severity of class 3 or higher for four consecutive months.

Month 1	<50%
Month 2	<50%
Month 3	<50%
Month 4	<50%

Drought Recovery

8 Analysis of indicators and droughts

Table 2: Number of WRIAs in class 3 or more severe drought according to indicators during the (a)1976-1977 (b) 2000-2001 (c) 2004-2005 drought.

Drought onset | Drought recovery

(a)

Month	SMP	SPI-3	SRI-3	SPI-6	SRI-6	SPI-12	SRI-12	SPI-24	SRI-24	SPI-36	SRI-36
Jan-76	0	1	0	0	0	0	0	0	0	0	0
Feb-76	0	0	0	0	0	0	0	0	0	0	0
Mar-76	1	0	1	0	0	0	0	0	0	0	0
Apr-76	0	0	3	0	0	0	0	0	0	0	0
May-76	4	25	4	0	0	0	0	0	0	0	0
Jun-76	0	37	4	3	0	0	0	0	0	0	0
Jul-76	0	3	3	2	0	0	0	0	0	0	0
Aug-76	0	0	0	0	3	0	0	0	0	0	0
Sep-76	0	0	0	3	0	0	0	0	0	0	0
Oct-76	11	8	7	13	3	3	0	0	0	0	0
Nov-76	52	61	55	58	30	10	0	0	0	0	0
Dec-76	61	61	61	59	41	59	17	0	0	1	0
Jan-77	*61*	*61*	*61*	*61*	53	61	38	30	1	13	0
Feb-77	61	61	61	61	*61*	*61*	41	50	3	20	0
Mar-77	57	61	61	61	61	61	*49*	50	10	24	3
Apr-77	61	61	61	61	61	61	54	*53*	18	44	12
May-77	55	19	60	61	61	61	58	45	22	38	15
Jun-77	53	50	61	61	61	61	61	52	26	*39*	19
Jul-77	56	4	55	56	61	61	61	49	31	54	23
Aug-77	53	0	52	8	59	61	61	49	34	33	22
Sep-77	22	0	34	2	57	61	61	30	*34*	19	23
Oct-77	22	0	28	1	50	61	61	58	44	16	20
Nov-77	23	0	21	1	39	61	61	60	53	13	21
Dec-77	2	0	1	0	18	9	56	61	56	5	17
Jan-78	8	0	1	0	6	2	50	61	60	14	18
Feb-78	8	5	2	1	1	0	44	61	61	20	15
Mar-78	21	55	23	9	1	2	42	61	59	32	17
Apr-78	8	37	29	2	2	0	29	61	60	18	15
May-78	0	5	31	5	4	2	19	61	61	12	19
Jun-78	6	0	22	41	28	1	11	61	61	17	20

(b)

Month	SMP	SPI-3	SRI-3	SPI-6	SRI-6	SPI-12	SRI-12	SPI-24	SRI-24	SPI-36	SRI-36
Jan-00	0	0	0	0	0	0	0	0	0	0	0
Feb-00	7	0	0	0	0	7	0	0	0	0	0
Mar-00	1	9	11	0	0	0	0	0	0	0	0
Apr-00	11	12	9	0	0	0	0	0	0	0	0
May-00	0	5	10	0	0	0	0	0	0	0	0
Jun-00	0	0	3	2	6	0	0	0	0	0	0
Jul-00	2	1	2	6	9	0	0	0	0	0	0
Aug-00	17	30	4	7	8	0	0	0	0	0	0
Sep-00	18	29	14	1	6	0	0	0	0	0	0
Oct-00	13	16	28	5	3	0	0	0	0	0	0
Nov-00	48	46	53	54	36	31	7	0	0	0	0
Dec-00	58	61	61	60	59	43	30	0	0	0	0
Jan-01	*61*	*61*	*61*	*61*	*61*	*53*	35	31	1	2	0
Feb-01	61	61	61	61	61	59	44	55	21	10	0
Mar-01	61	61	61	61	61	61	*57*	*55*	27	10	0
Apr-01	61	44	61	61	61	59	60	50	33	2	0
May-01	52	7	56	61	61	61	61	51	38	10	2
Jun-01	47	0	52	59	61	61	61	49	*45*	4	3
Jul-01	44	0	50	25	61	61	61	49	49	3	3
Aug-01	34	0	48	0	57	61	61	54	50	1	3
Sep-01	36	38	52	0	54	61	61	54	50	3	4
Oct-01	43	0	37	0	46	61	61	47	50	0	4
Nov-01	20	0	15	0	36	58	61	48	53	3	5
Dec-01	9	0	12	0	27	30	59	47	53	14	14
Jan-02	7	0	7	0	13	0	45	48	54	14	20
Feb-02	13	2	8	0	12	0	33	53	55	51	36
Mar-02	14	4	3	0	8	0	31	54	57	48	43
Apr-02	1	16	9	1	4	1	30	54	57	*41*	*41*
May-02	16	3	8	4	5	2	23	57	57	38	43
Jun-02	22	1	12	6	5	0	15	57	58	44	43

(c)

Month	SMP	SPI-3	SRI-3	SPI-6	SRI-6	SPI-12	SRI-12	SPI-24	SRI-24	SPI-36	SRI-36
Jan-04	43	0	26	3	26	17	31	50	44	22	54
Feb-04	29	36	39	0	26	12	29	51	48	16	46
Mar-04	44	39	27	16	23	42	46	*59*	*43*	20	*41*
Apr-04	54	*61*	*40*	50	43	59	59	58	48	35	42
May-04	*57*	34	36	39	46	*57*	*56*	49	50	21	40
Jun-04	32	32	49	*37*	*44*	42	55	49	53	32	41
Jul-04	54	0	44	44	46	31	54	47	53	34	40
Aug-04	35	0	31	12	37	0	50	42	51	17	37
Sep-04	0	0	12	2	38	0	47	26	49	6	31
Oct-04	2	0	3	0	24	12	49	12	45	10	32
Nov-04	3	4	13	0	30	29	52	4	40	42	46
Dec-04	22	52	28	7	31	27	50	8	41	48	51
Jan-05	34	56	25	28	23	43	42	48	51	*53*	52
Feb-05	43	*61*	41	56	42	49	44	53	53	58	53
Mar-05	48	61	47	57	45	41	51	*55*	53	55	53
Apr-05	40	57	*51*	*57*	46	35	50	55	55	55	54
May-05	38	0	39	50	51	36	51	52	55	45	54
Jun-05	21	0	31	35	52	30	50	41	55	44	54
Jul-05	19	0	32	13	54	24	49	37	54	44	55
Aug-05	22	3	34	0	39	40	50	34	54	43	55
Sep-05	42	13	36	0	35	43	51	51	54	41	55
Oct-05	22	1	28	0	32	42	52	39	54	40	54
Nov-05	8	0	18	3	35	31	51	39	54	28	52
Dec-05	43	0	15	1	25	25	50	34	53	29	51
Jan-06	0	0	0	0	4	0	21	16	40	4	46
Feb-06	1	0	0	[illegible]	2	0	18	16	36	3	38
Mar-06	8	0	0	[illegible]	2	0	15	11	38	29	50
Apr-06	9	38	15	0	1	0	14	5	32	31	49
May-06	17	26	25	0	0	[illegible]	11	9	32	25	48
Jun-06	0	6	11	0	0	[illegible]	3	6	31	19	43

Official State Declarations

9 Conclusions and implications

The main findings of this study are as follows:
1.For drought onset, drought indicators, *primarily the SPI-3, -6, -12, SRI-3, -6, and monthly SMP,* showed the onset of statewide drought at least 0 to 2 months before the state's official declarations of the 1976-1977, 2000-2001, and 2004-2005 droughts.
2.For drought recovery, drought indicators, primarily the SPI-3 and -6, showed recovery from statewide drought at least 0 to 4 months before the state's official declarations in the 1976-1977, 2000-2001, and 2004-2005 droughts.

The results suggest that model based drought indicators can provide a method for early detection of the onset, duration, severity and recovery from drought and would allow for finer-scale resolution of drought declaration. The approach used in this study also provides a scientific basis for indicators and triggers that can assist in drought management decisions for Washington State and other regions.

10 References

Andreadis, K. M., E. A. Clark, A. W. Wood, A. F. Hamlet, D. P. Lettenmaier, 2005: Twentieth-Century Drought in the Conterminous United States. J. Hydrometeor., 6, 985–1001. doi: 10.1175/JHM450.1.
Elsner, M. M., and Coauthors, 2010: Implications of 21st century climate change for the hydrology of Washington State. Climatic Change, 102, 225–260. doi:10.1007/s10584-010-9855-0.
Liang, X., D. P. Lettenmaier, E. F. Wood, and S. J. Burges, 1994: A simple hydrologically based model of land surface water and energy fluxes for GCMs. J. Geophys. Res., 99, 14415–14428.
McKee, T. B., N. J. Doesken, and J. Kleist, 1993: The relationship of drought frequency and duration to time scales. Proc. Eighth Conf. of Applied Climatology, Anaheim, CA, Amer. Meteor. Soc., 179–184.
Sheffield, J., G. Goteti, F. Wen, and E. F. Wood, 2004: A simulated soil moisture based drought analysis for the United States. J. Geophys. Res., 109, D24108. doi: 10.1029/2004JD005182.
Shukla, S., and A. W. Wood, 2008: Use of a standardized runoff index for characterizing hydrologic drought. Geophys. Res. Lett., 35, L02405. doi:10.1029/2007GL032487.
Shukla, S., A. C. Steinemann, and D. P. Lettenmaier, 2011: Drought Monitoring for Washington State: Indicators and Applications. J. Hydrometeor.,12, 66–83.doi: 10.1175/2010JHM1307.110.1175/2010JHM1307.1.
Steinemann, A., and L. Cavalcanti, 2006: Developing multiple indicators and triggers for drought plans. J. Water Resour. Plann. Manage., 132, 164–174.

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