AGU PUBLICATIONS

Water Resources Research

Supporting Information for

Precipitation-Snowmelt Timing and Snowmelt Augmentation of Large Peak Flow Events, Western Cascades, Oregon

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Contents of this file

Additional Supporting Information (Files uploaded separately)

[none]

Introduction

Supporting information includes details of the storm events in the study (Table S1), a description of energy budget modeling and the resulting figure (Text S1 and Figure S1), and hourly measurements of temperature for all the storm events (Figure S2). Data are from http://andrewsforest.oregonstate.edu/.

Text S1.

Energy budget calculations for six persistent melt peak discharge events. We ran a simplified point energy balance model at an hourly time step for six of the persistent melt events based on the equations presented in *Brutsaert* (1975), *Marks et al*. [1998], and *DeWalle and Rango* [2008]. Incoming solar radiation was measured at the nearby CENMET station, snow surface albedo was estimated using a Monte Carlo parameterization scheme, incoming and outgoing longwave radiation were estimated using the Stefan-Boltzmann equation based on air temperature and humidity (incoming) and assuming the snowpack surface temperature was 0°C (outgoing), turbulent fluxes (latent and sensible heat) were calculated using the bulk transfer method with meteorological inputs from H15MET, and the advected heat of precipitation was calculated based on incoming precipitation and air temperature. In addition, a precipitation intensity scaling parameter was developed in order to better match peaks in meltwater output at the hourly scale. The 10 most efficient model runs (out of 1000

Monte Carlo simulations performed to estimate unknown parameters) were chosen for each event based on their Nash-Sutcliffe efficiency values for observed versus modeled snowmelt. We found net radiation and advected heat of precipitation to be important drivers of positive energy fluxes to the snowpack during periods of snowmelt (Figure S1), with turbulent fluxes playing less of a role. For the six modeled events, net radiation (S_n + L_n) contributed, on average, 34 to 49% of positive energy fluxes, followed by the advected heat of precipitation (Q_r, 29 to 44%) and the turbulent fluxes (Q_h and Q_{le}, 8 to 27%). This is consistent with the findings of *Marks et al.* [1998], who found the turbulent fluxes to be less important at their forested study site (H15MET is a narrow forest clearing and experiences low average wind speeds).

Brutsaert, W. (1975), A theory for local evaporation (or heat transfer) from rough and smooth surfaces at ground level, Water Resources Research 11, 543-550.

DeWalle, D. R. and A. Rango (2008), Principles of snow hydrology, Cambridge University Press.

Marks, D., J. Kimball, D. Tingey, and T. Link (1998), The sensitivity of snowmelt processes to climate conditions and forest cover during rain-on-snow: A case study of the 1996 Pacific Northwest flood. Hydrol. Proc., 12(10-11), 1569-1587. doi:10.1002/(SICI)1099- 1085(199808/09)12:10/11<1569::AID-HYP682>3.0.CO;2-L.

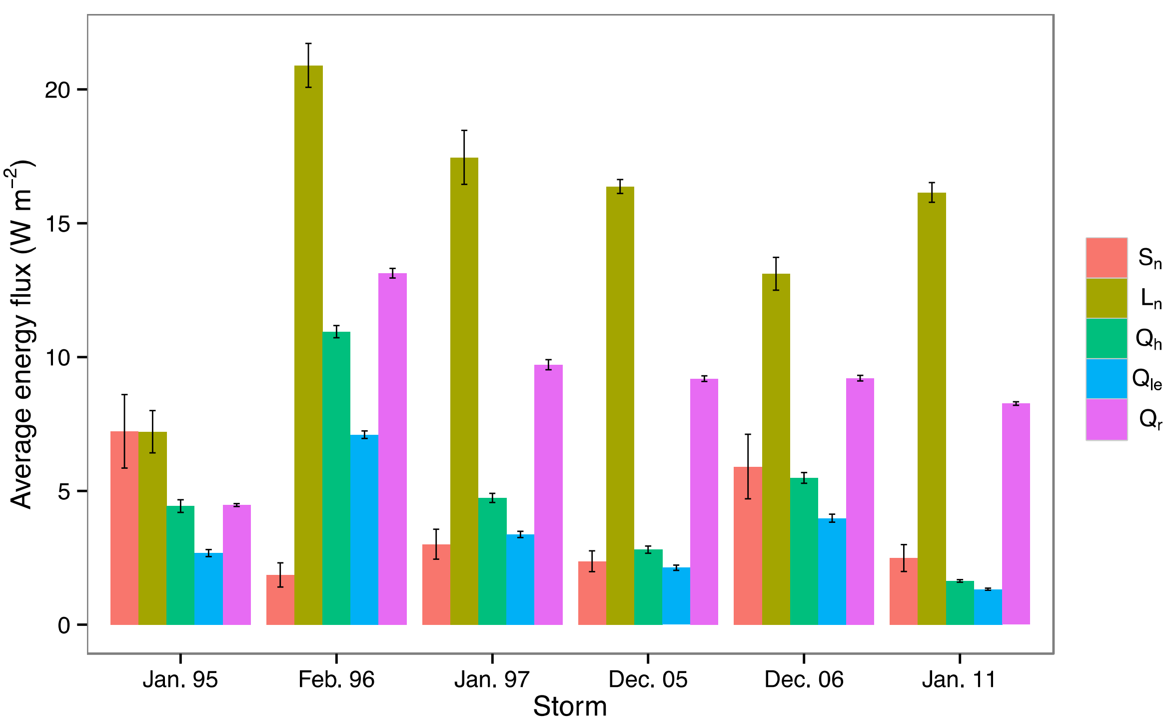

Figure S1. Average energy fluxes (colored bars) and standard errors (error bars) during periods of melt (net snowmelt > 0 mm h^{-1}) for the top 10 best-performing model runs from six of the persistent melt events as determined by the Nash-Sutcliffe efficiency of observed versus modeled snowmelt (S_n = net solar radiation; L_n = net longwave radiation; Q_h = sensible heat; Q_{le} = latent heat; Q_r = advected heat of precipitation).

Figure S2. Temperature observations from four H.J. Andrews meteorological stations (representing a range of elevations in the forest: Pri = 430 m; H15 = 922 m; Van = 1273 m; Upl = 1294 m) during the 26 selected events.

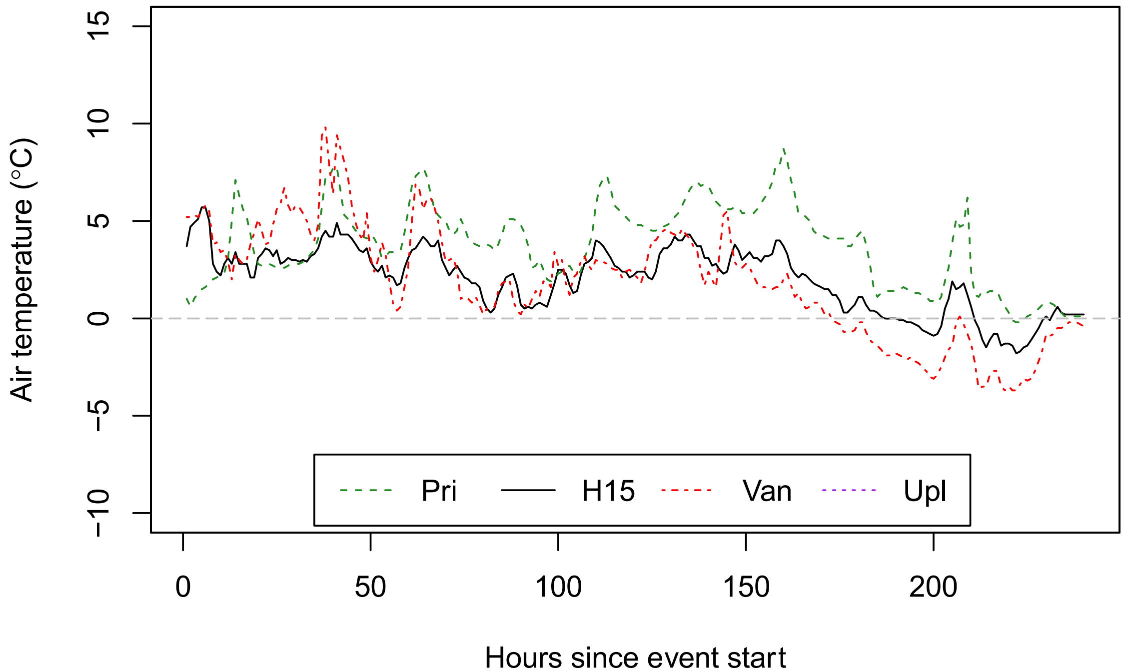

Figure S-2-1. Temperature data from reporting HJA meteorological stations for the 1995-01-08 event. (UplMet missing data for entire event).

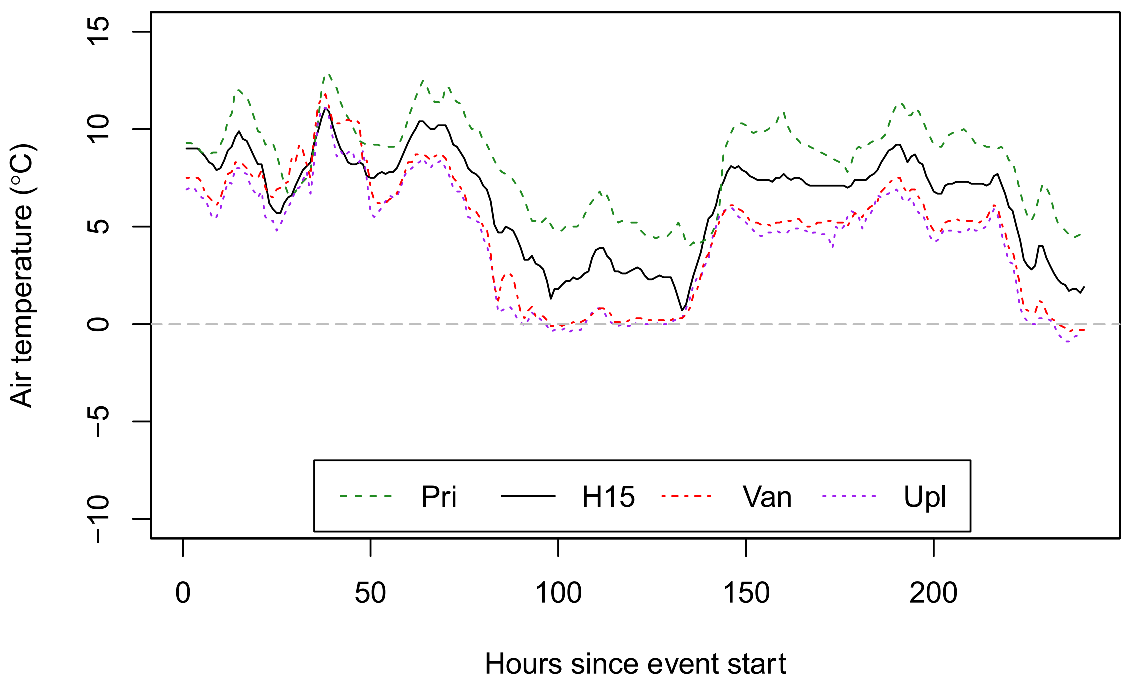

Figure S-2-2. Temperature data from reporting HJA meteorological stations for the 1995-11-22 event.

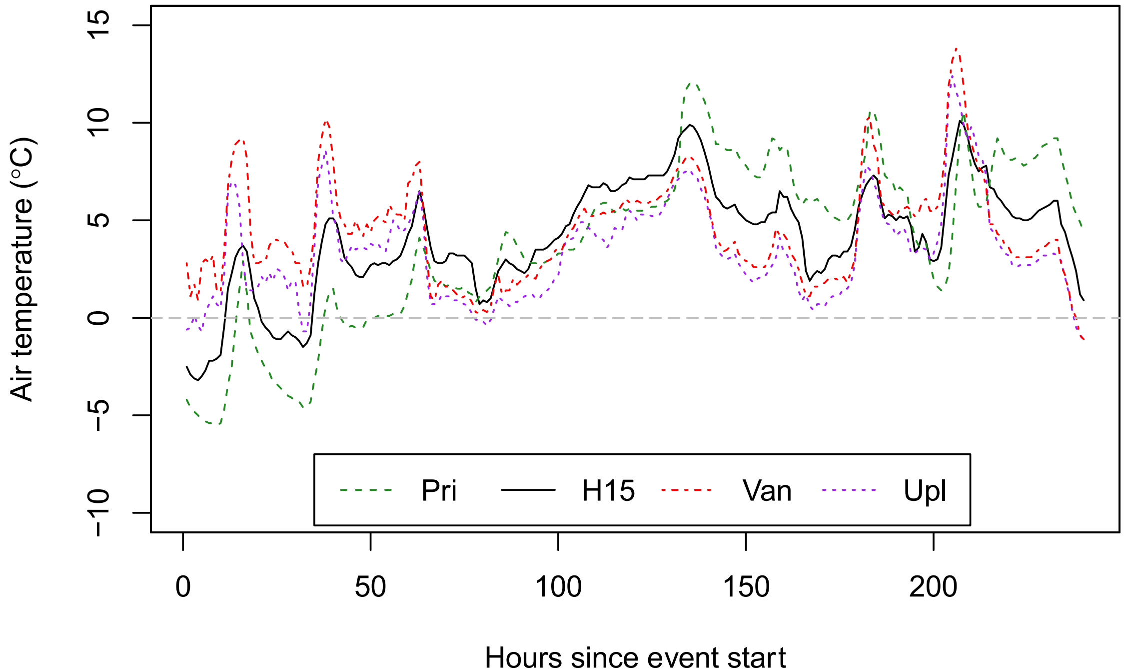

Figure S-2-3. Temperature data from reporting HJA meteorological stations for the 1995-12-25 event.

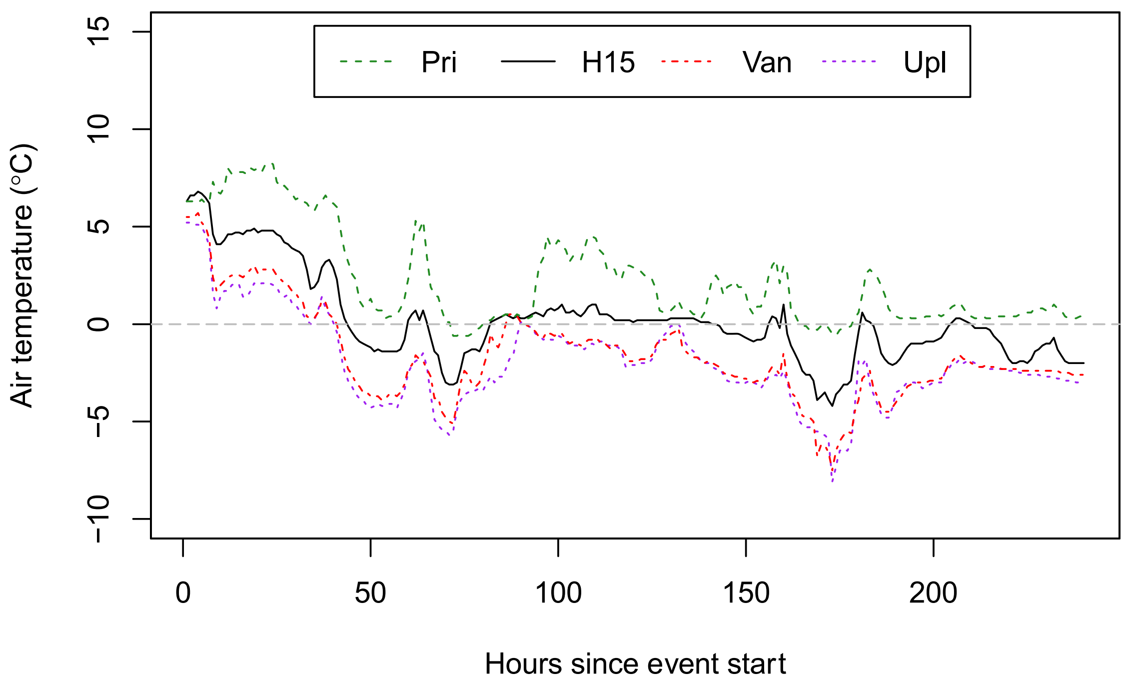

Figure S-2-4. Temperature data from reporting HJA meteorological stations for the 1996-01-15 event.

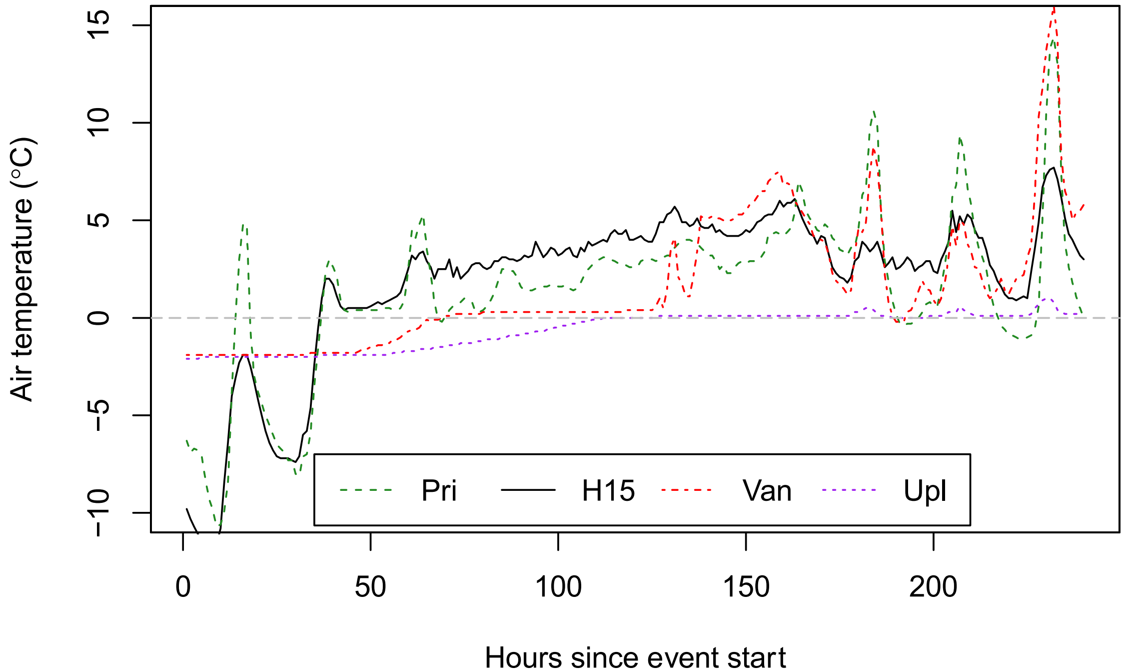

Figure S-2-5. Temperature data from reporting HJA meteorological stations for the 1996-02-02 event.

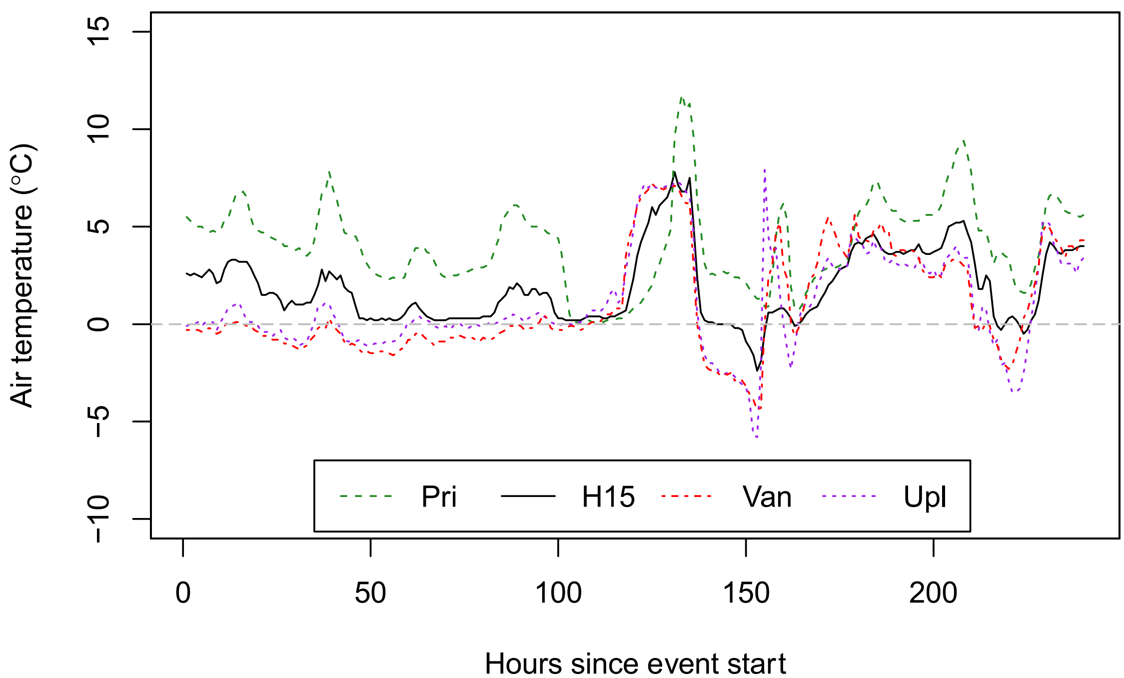

Figure S-2-6. Temperature data from reporting HJA meteorological stations for the 1996-11-14 event.

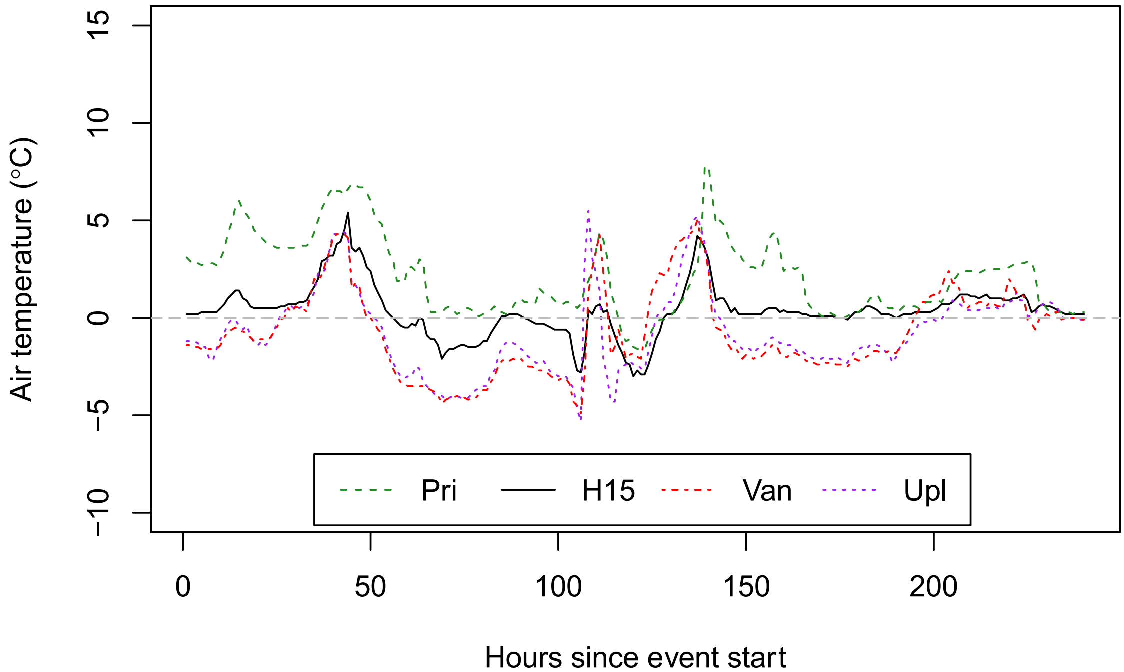

Figure S-2-7. Temperature data from reporting HJA meteorological stations for the 1996-11-29 event.

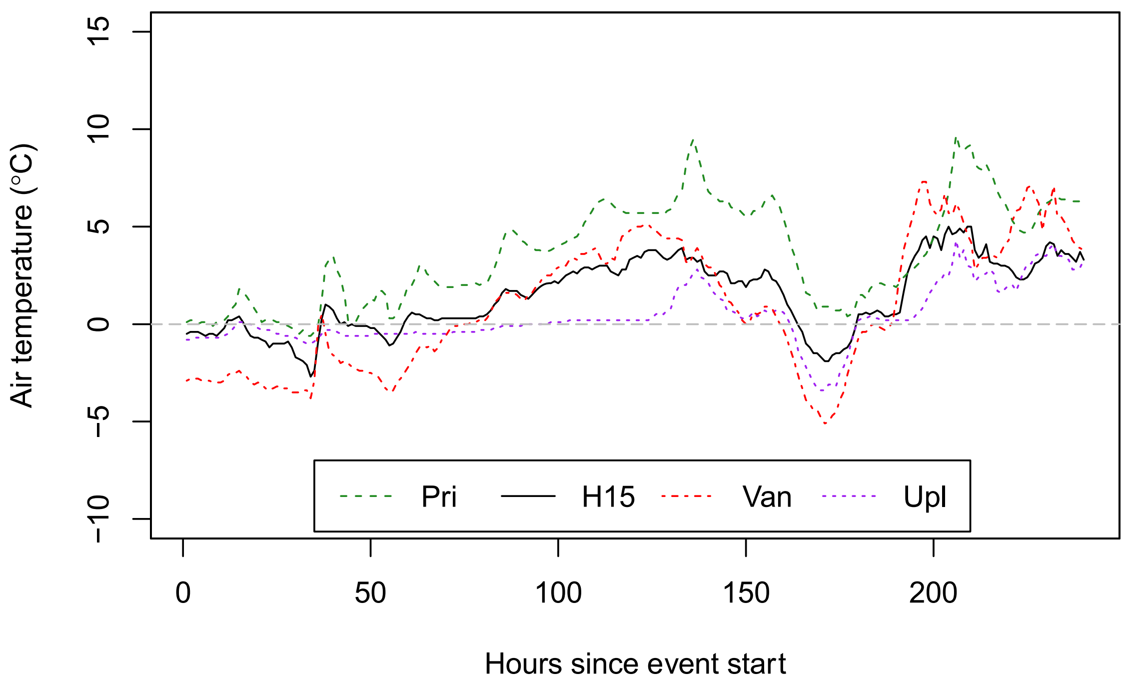

Figure S-2-8. Temperature data from reporting HJA meteorological stations for the 1996-12-21 event.

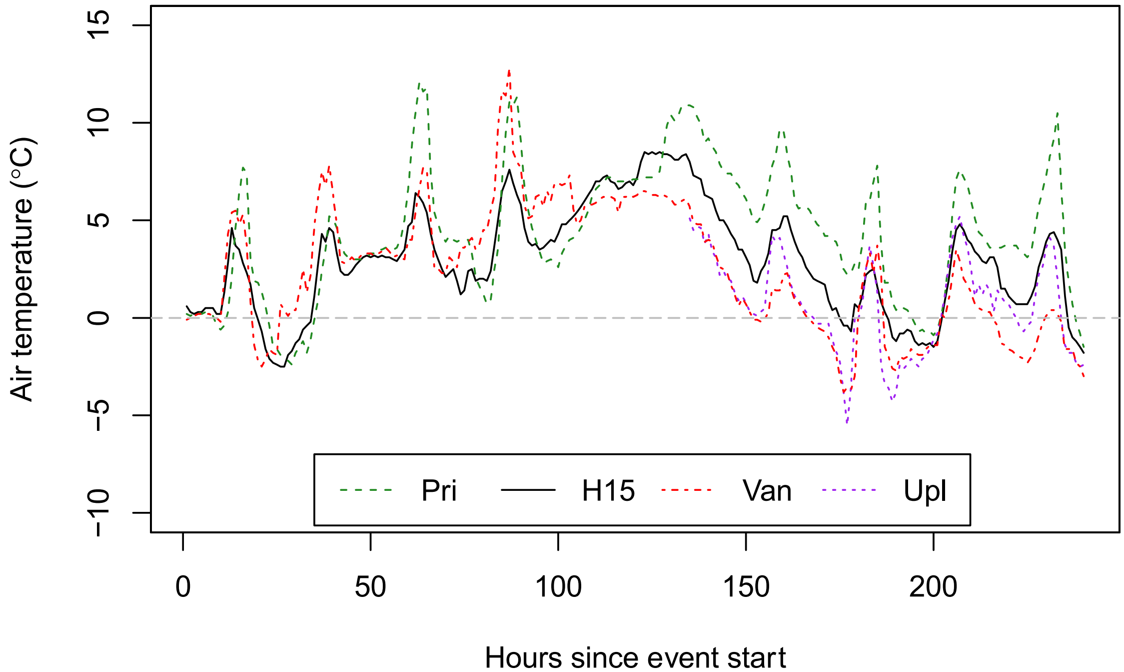

Figure S-2-9. Temperature data from reporting HJA meteorological stations for the 1997-01-26 event.

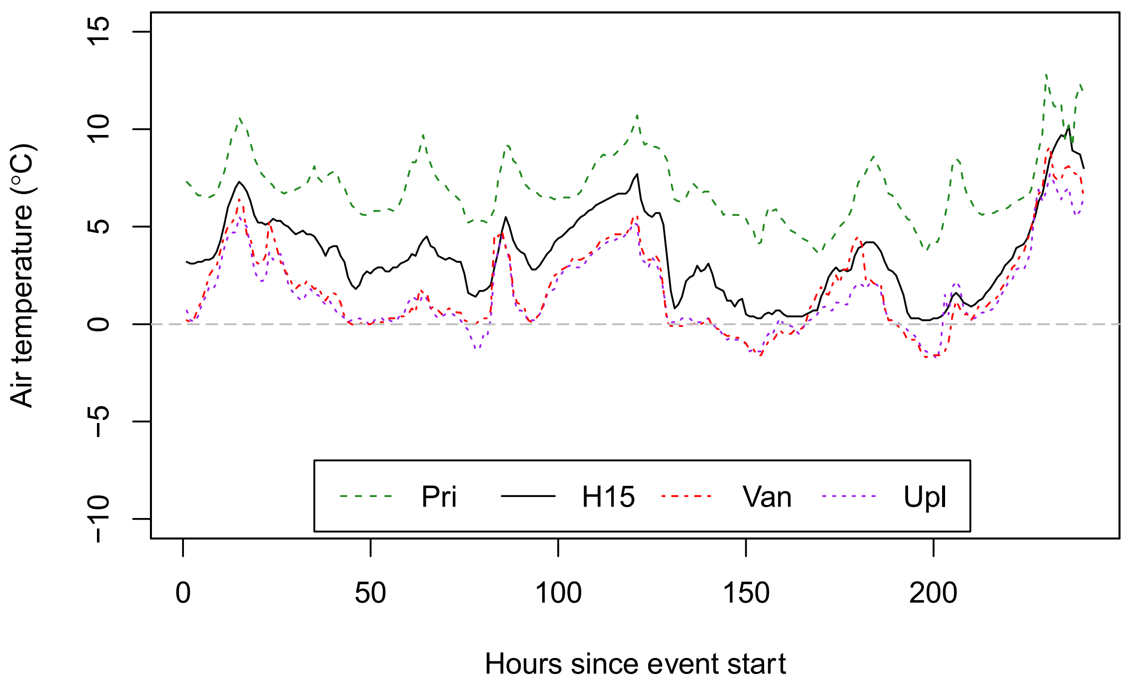

Figure S-2-10. Temperature data from reporting HJA meteorological stations for the 1998-11-16 event.

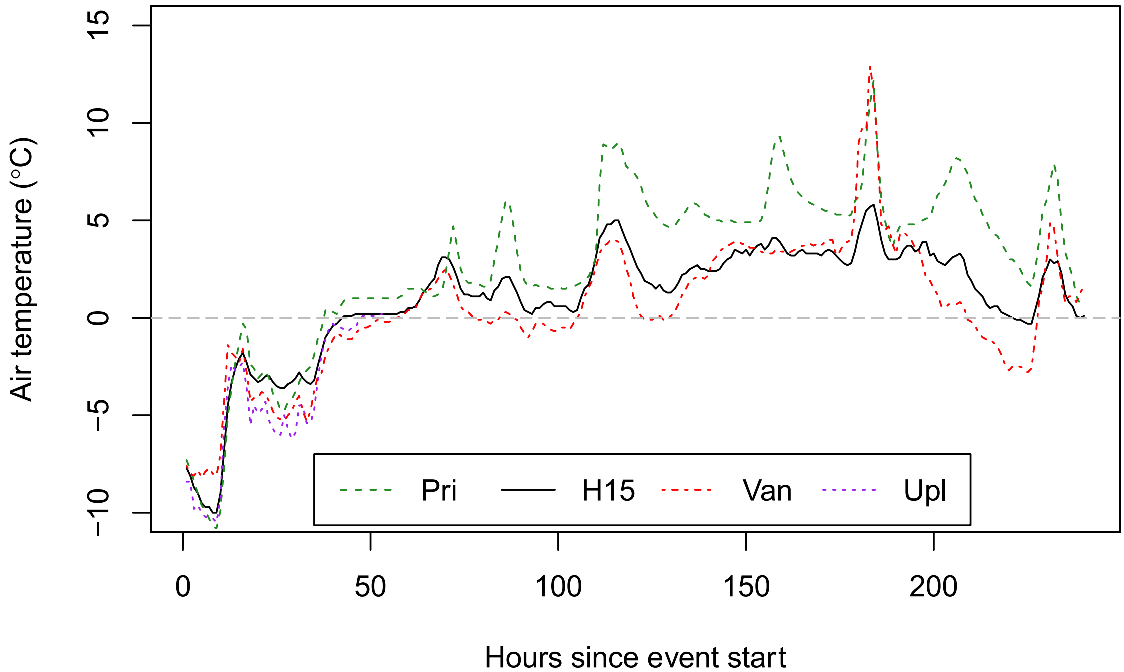

Figure S-2-11. Temperature data from reporting HJA meteorological stations for the 1998-12-23 event (UplMet missing data after 1998-12-25 at 4:00 AM).

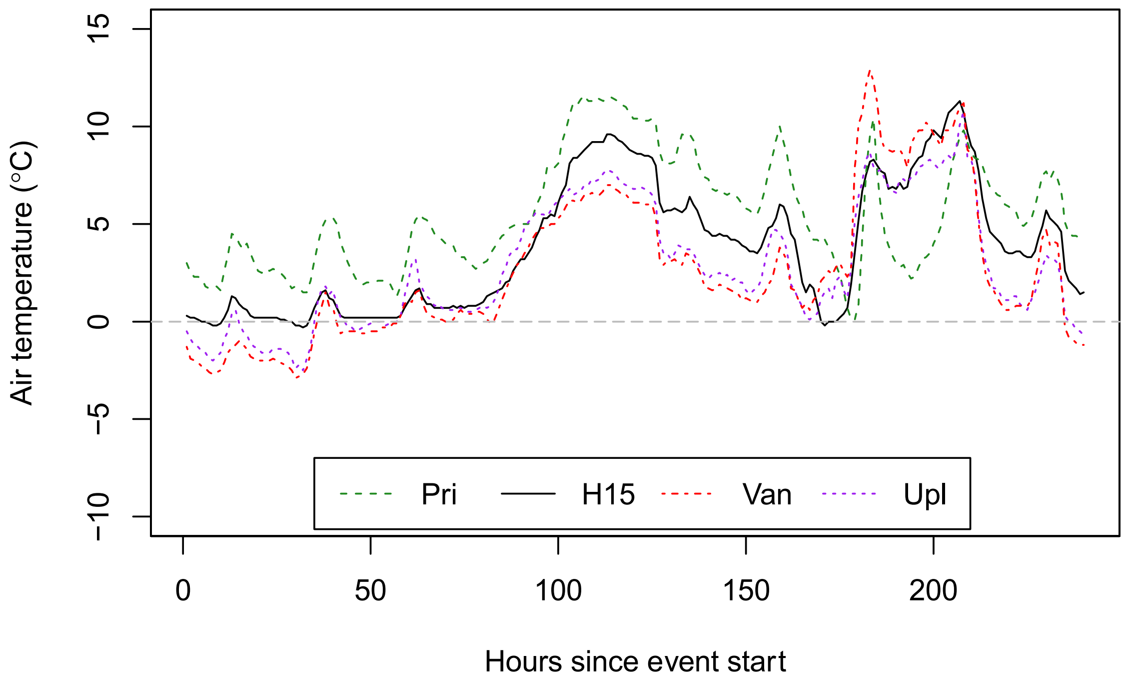

Figure S-2-12. Temperature data from reporting HJA meteorological stations for the 1999-11-21 event.

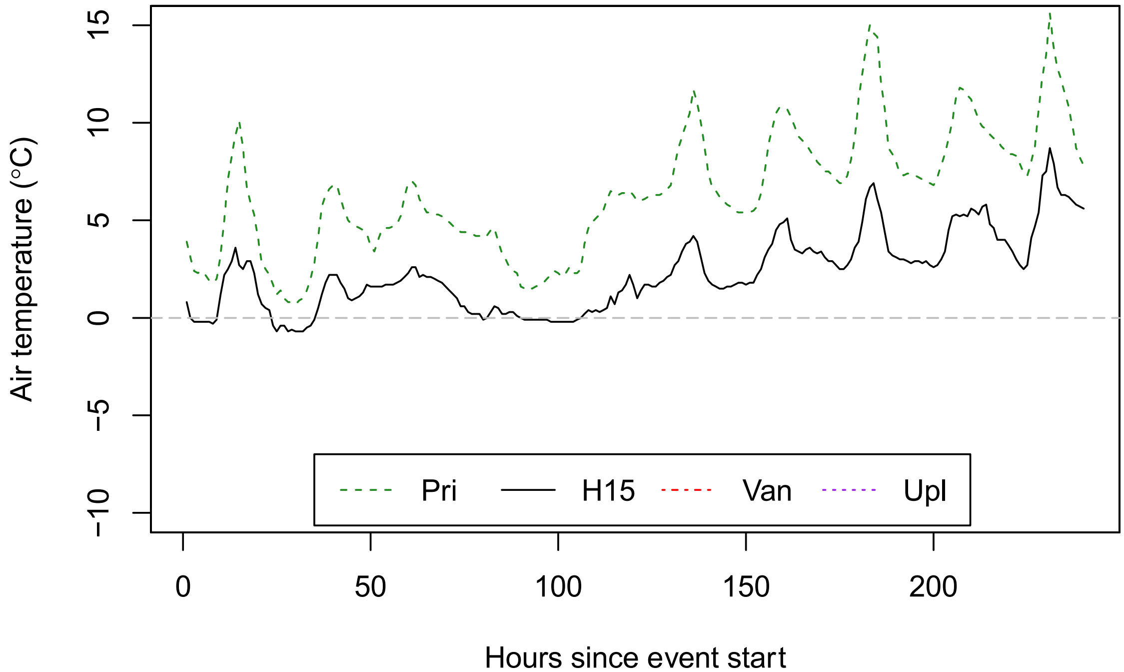

Figure S-2-13. Temperature data from reporting HJA meteorological stations for the 2003-03-03 event (VanMet and UplMet missing data for entire event).

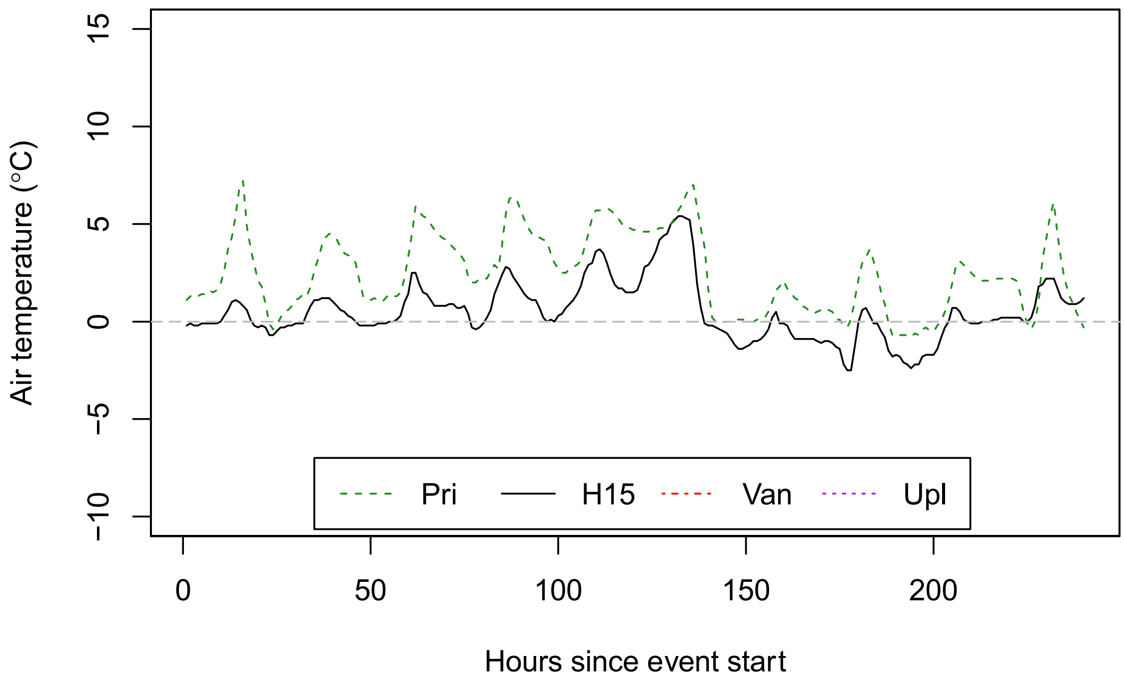

Figure S-2-14. Temperature data from reporting HJA meteorological stations for the 2003-12-08 event (VanMet and UplMet missing data for entire event).

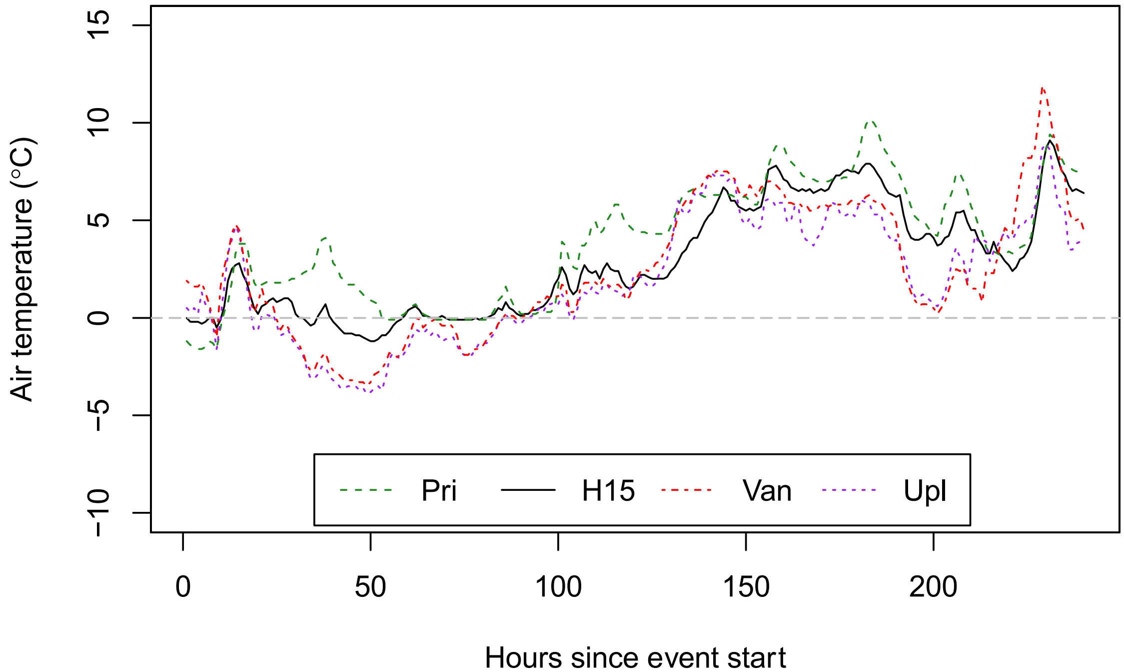

Figure S-2-15. Temperature data from reporting HJA meteorological stations for the 2004-12-04 event.

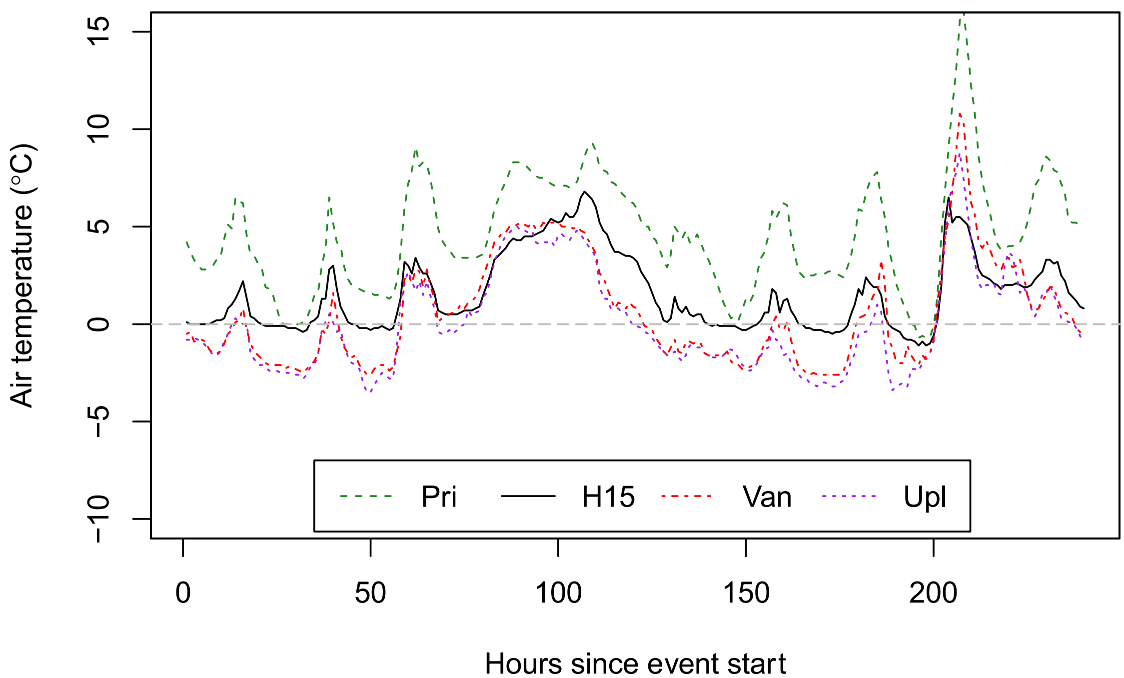

Figure S-2-16. Temperature data from reporting HJA meteorological stations for the 2005-03-23 event.

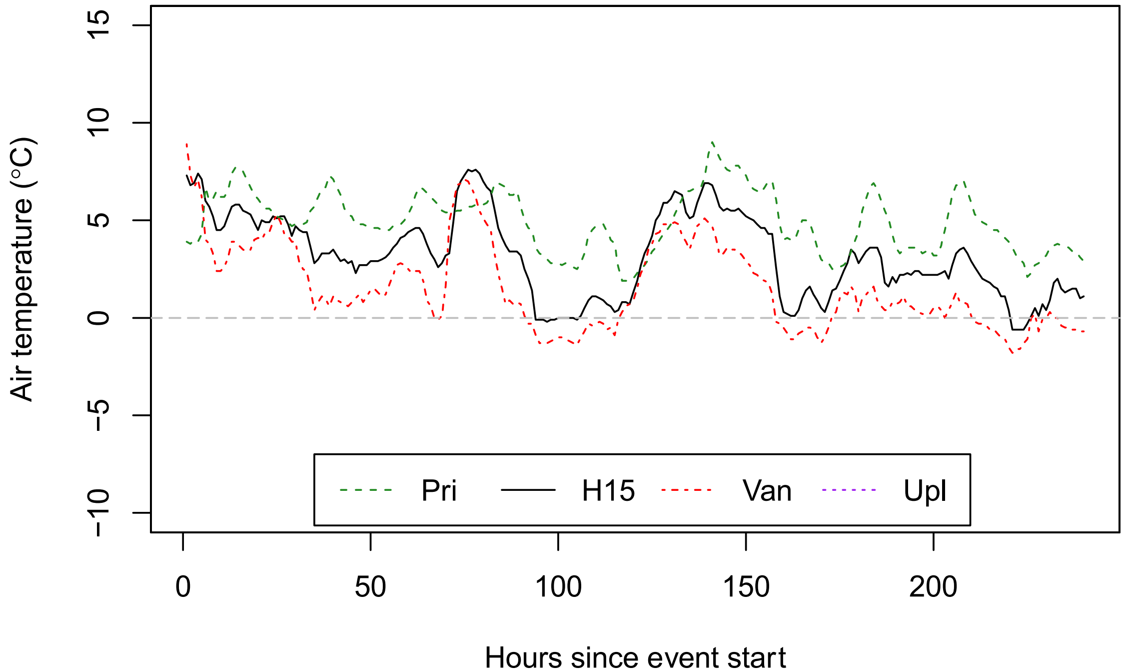

Figure S-2-17. Temperature data from reporting HJA meteorological stations for the 2005-12-25 event (UplMet missing data for entire event).

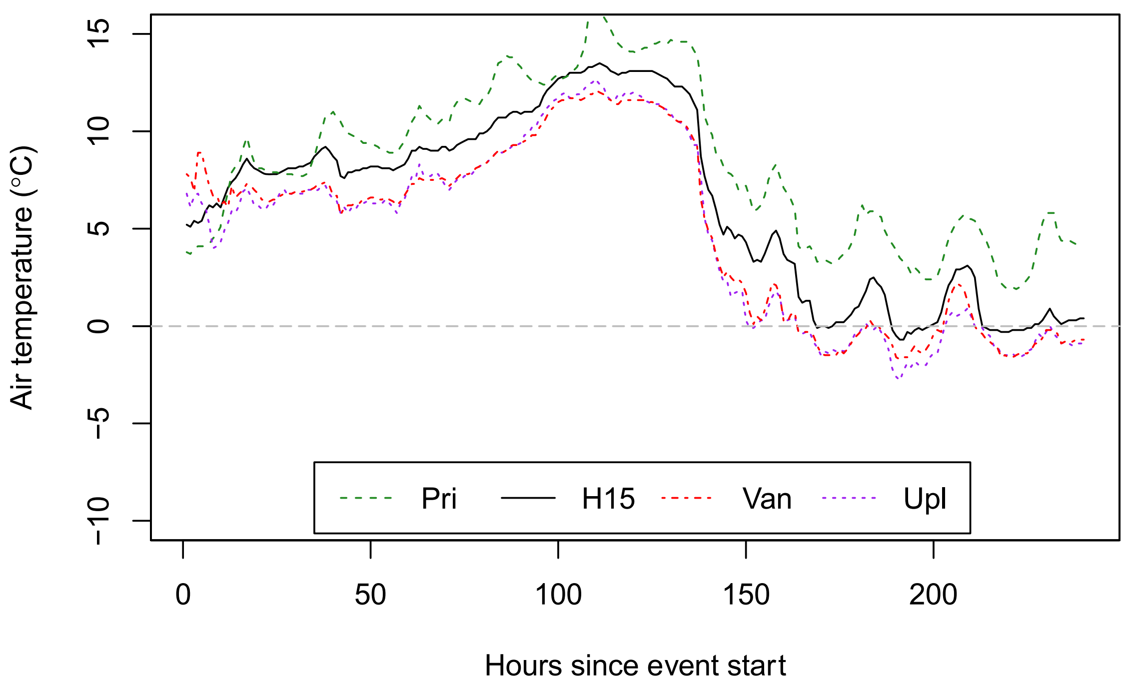

Figure S-2-18. Temperature data from reporting HJA meteorological stations for the 2006-11-02 event.

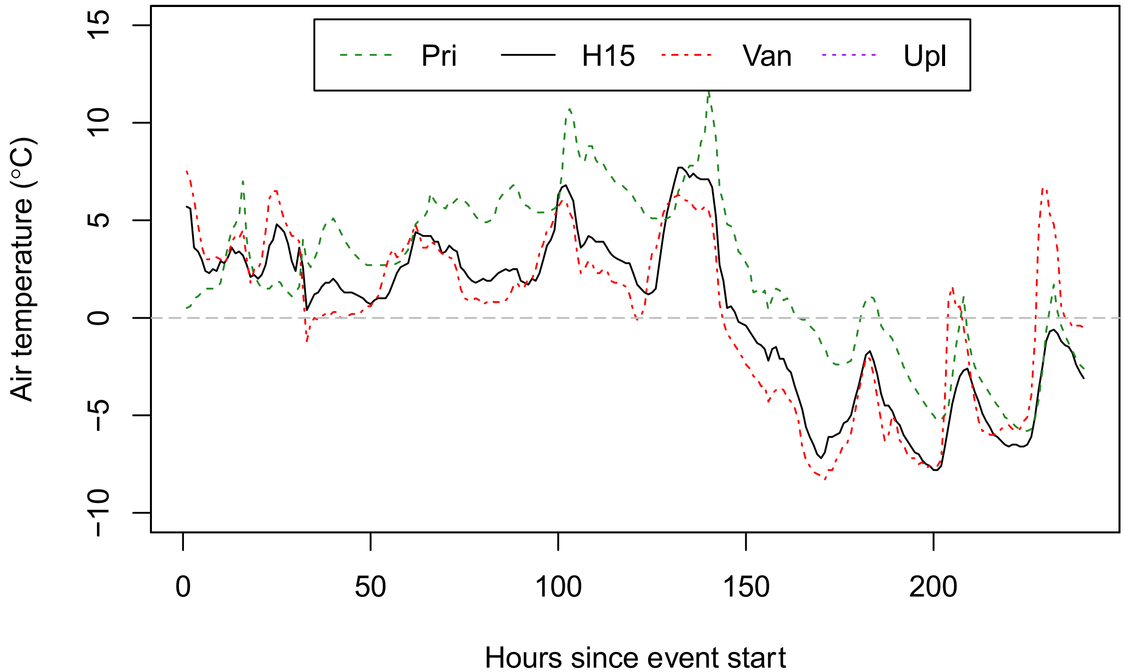

Figure S-2-19. Temperature data from reporting HJA meteorological stations for the 2006-12-09 event (UplMet missing data for entire event).

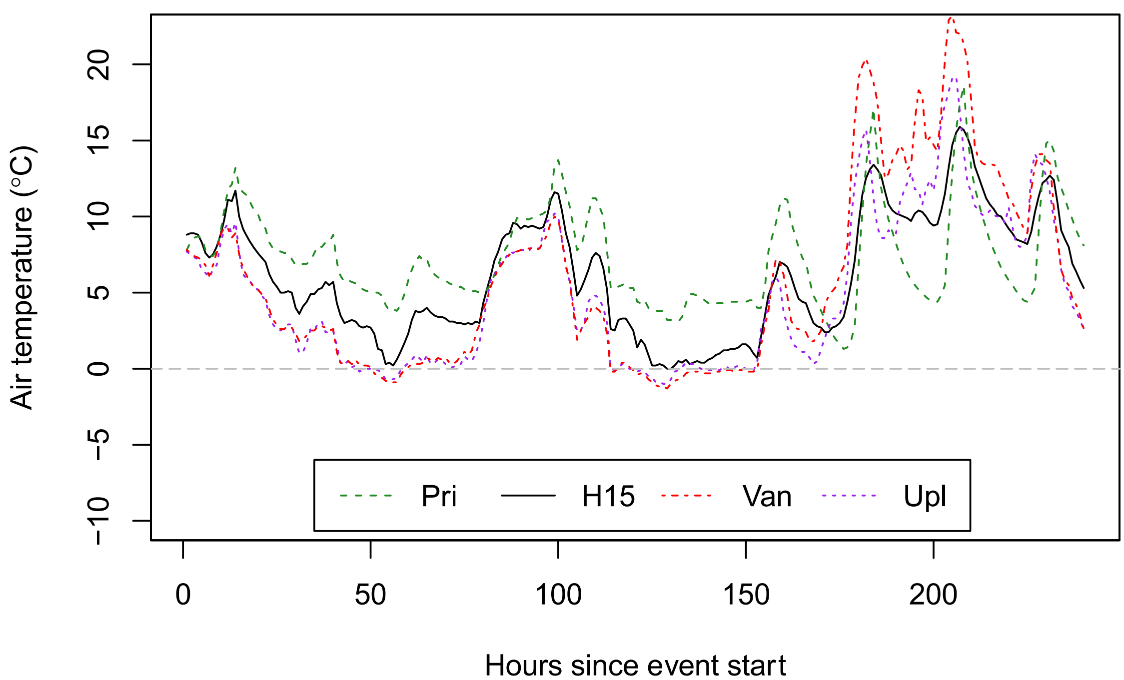

Figure S-2-20. Temperature data from reporting HJA meteorological stations for the 2007-10-15 event.

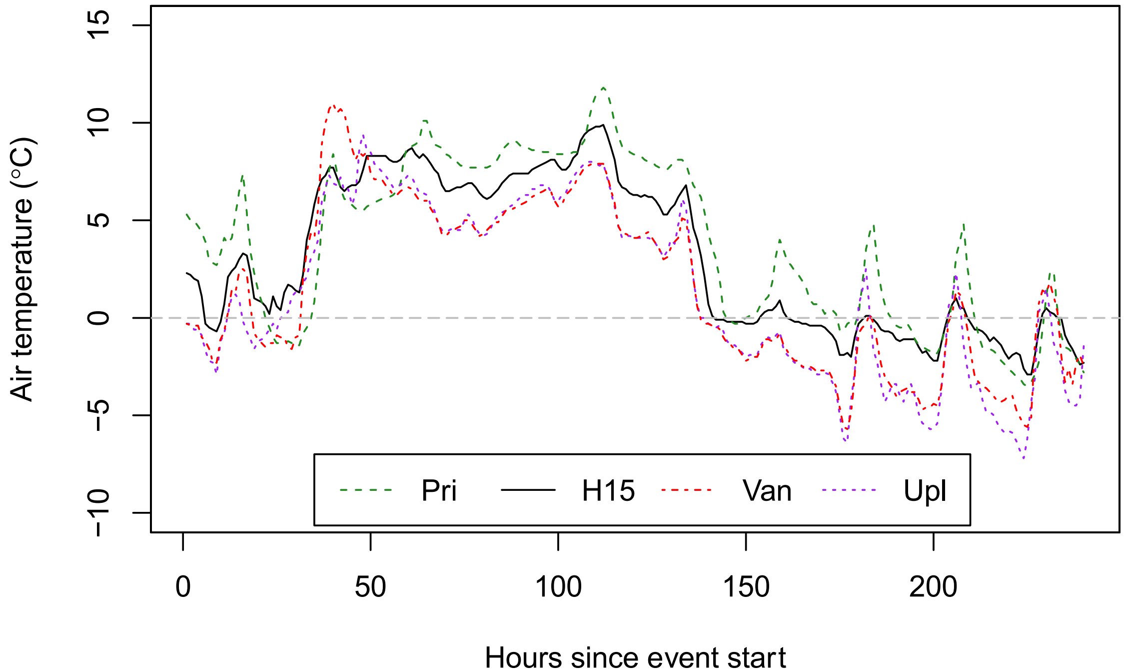

Figure S-2-21. Temperature data from reporting HJA meteorological stations for the 2007-11-13 event.

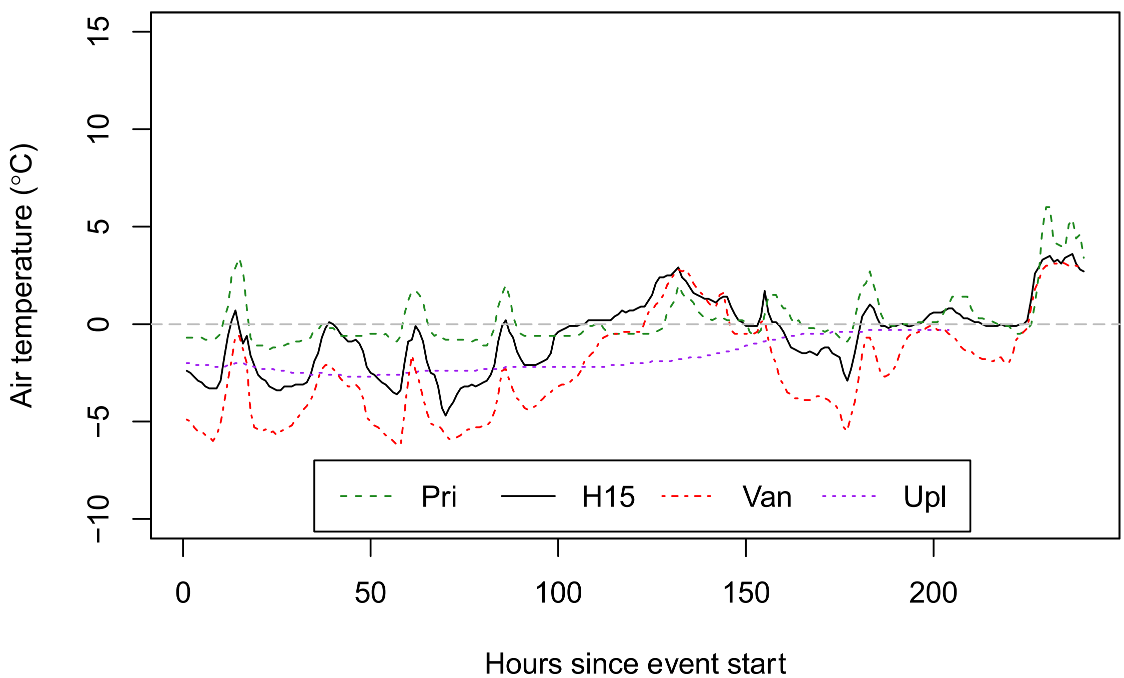

Figure S-2-22. Temperature data from reporting HJA meteorological stations for the 2008-12-23 event.

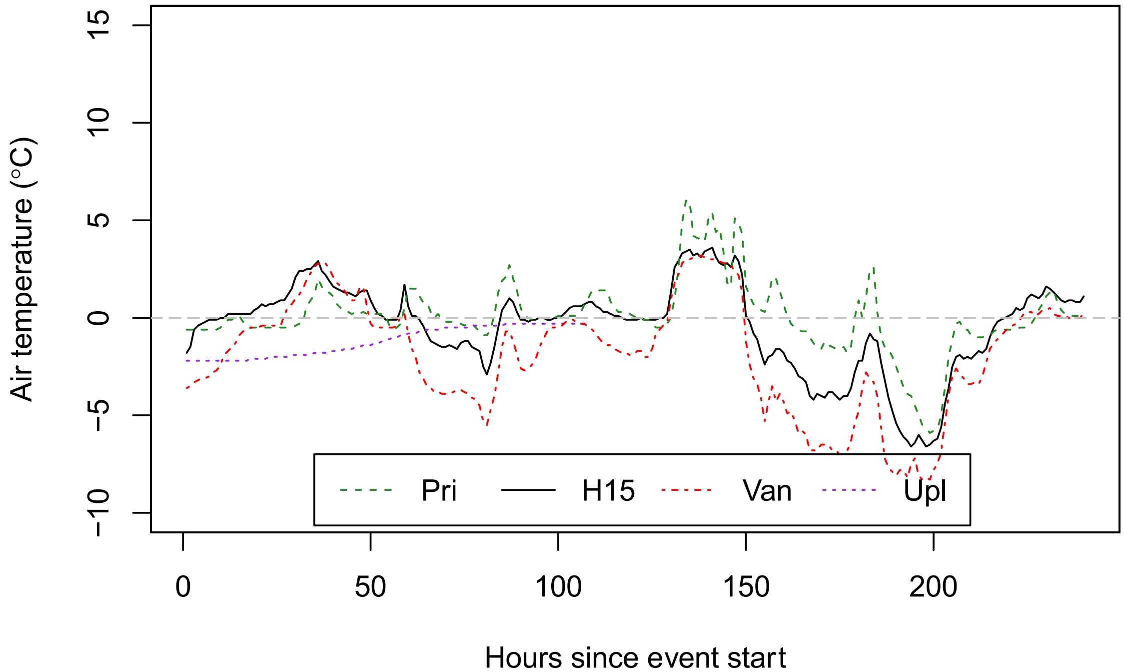

Figure S-2-23. Temperature data from reporting HJA meteorological stations for the 2008-12-27 event (UplMet missing data after 2008-12-31 at 11:00 AM).

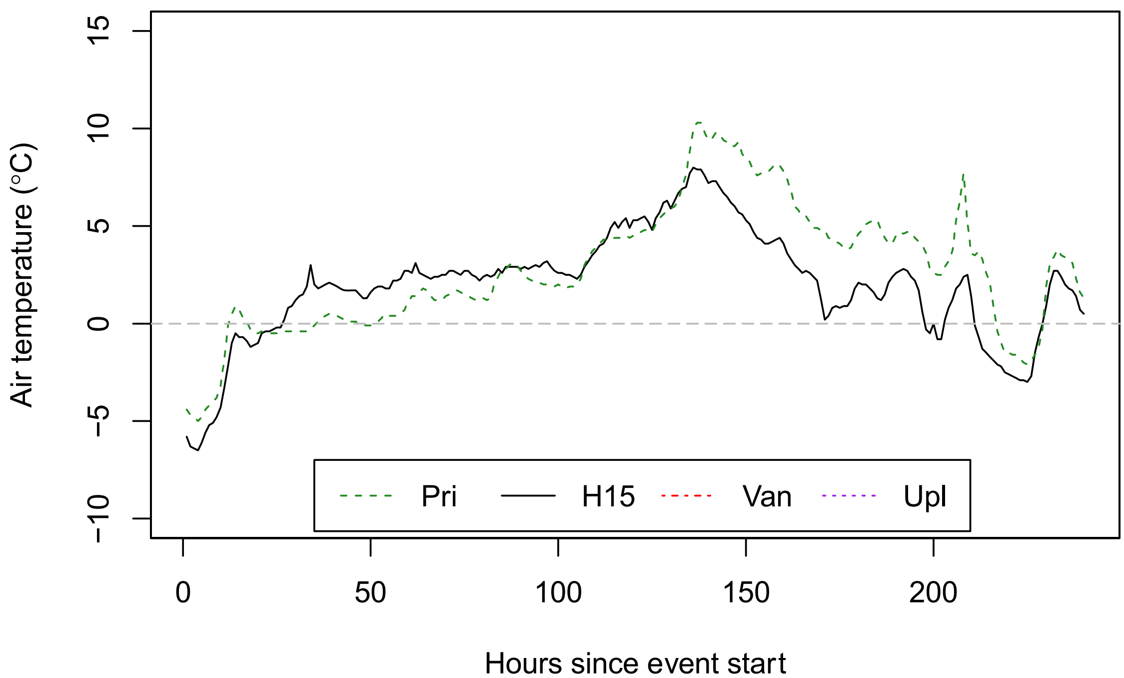

Figure S-2-24. Temperature data from reporting HJA meteorological stations for the 2011-01-11 event (VanMet and UplMet missing data for entire event).

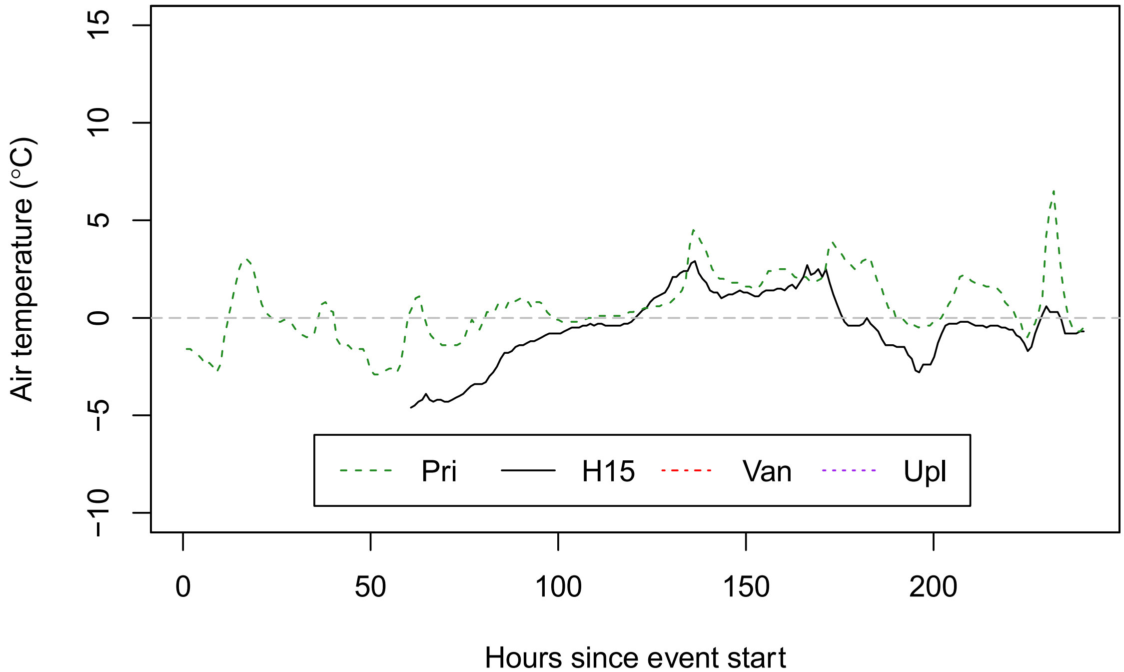

Figure S-2-25. Temperature data from reporting HJA meteorological stations for the 2012-01-14 event (H15Met missing data before 2012-01-16 at 1:00 PM;VanMet and UplMet missing data for entire event).

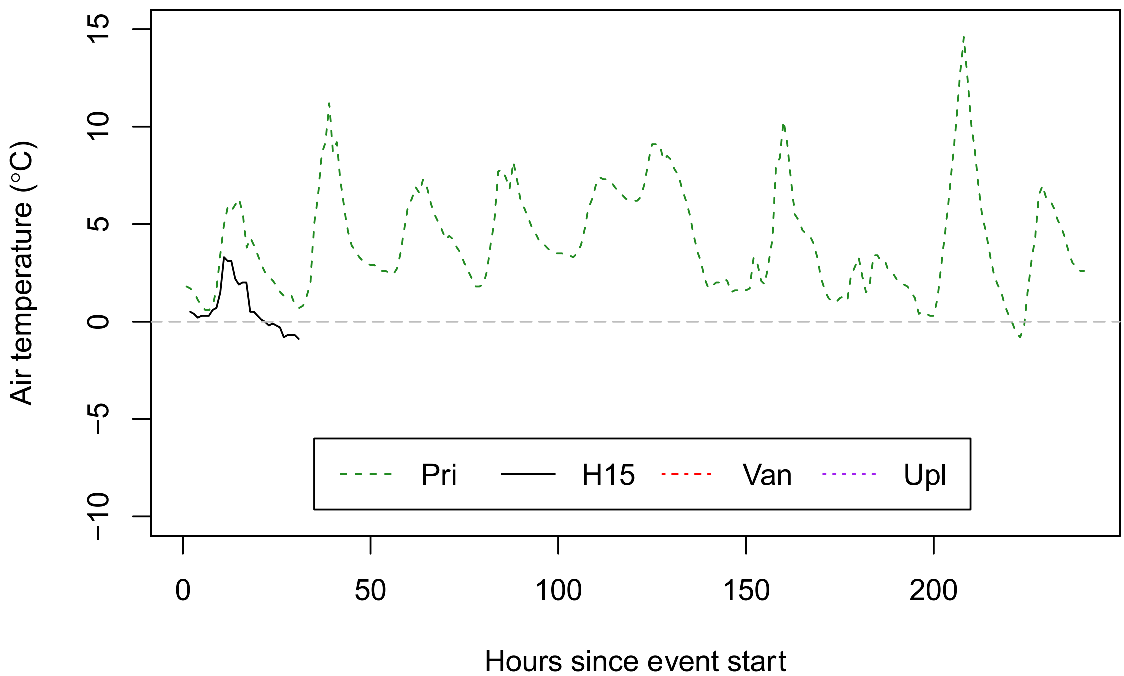

Figure S-2-26. Temperature data from reporting HJA meteorological stations for the 2012-03-25 event (H15Met missing data after 2012-03-26 at 6:00 AM; VanMet and UplMet missing data for entire event).

Table S1.

Category	Start date	Total P (mm)	Rain fraction	Snow fraction	Total N (mm)	Total P+N (mm)	Total P+N:P ratio	Initial SWE (mm)	Final SWE (mm)	Mean dew-point T (°C)	Mean air T (°C)	Mean wind speed ($m\ s^{-1}$)	WS8 peak flow ($mm\ h^{-1}$)	Lookout Creek peak flow ($mm\ h^{-1}$)
(=)	1995-12-25	182	1.0	0.0	11	193	1.1	46	34	3.8	4.7	0.2	1.5	2.0
	1998-11-16	328	1.0	0.0	20	348	1.1	30	127	3.2	3.7	0.2	2.1	3.0
	2007-10-15	202	1.0	0.0	2	204	1.0	0	17	6.0	6.5	0.1	1.1	0.6
	2012-03-25	200	1.0	0.0	-12	188	0.9	820	870	1.1	1.6	0.2	3.1	3.8
(+)	1995-01-08	201	1.0	0.0	123	323	1.6	530	542	1.9	2.4	0.3	2.4	2.9
	1995-11-22	256	1.0	0.0	54	310	1.2	1	16	6.4	6.7	0.2	1.5	1.6
	1996-02-02	310	1.0	0.0	133	443	1.4	504	421	2.4	3.4	0.5	6.6	13.2
	1997-01-26	184	1.0	0.0	68	252	1.4	512	486	3.4	3.8	0.2	2.6	3.6
	2005-12-25	343	1.0	0.0	38	381	1.1	201	216	3.1	3.3	0.2	3.7	5.0
	2006-12-09	237	0.9	0.1	91	328	1.4	250	252	0.8	1.0	0.2	4.0	3.7
	2011-01-11	234	1.0	0.0	103	336	1.4	439	398	2.6	2.6	0.1	3.9	7.5
(-)	1996-01-15	266	0.6	0.4	-176	89	0.3	48	308	0.1	0.5	0.3	0.6	0.7
	1996-11-29	338	0.8	0.2	-110	228	0.7	112	299	0.9	0.9	0.1	2.5	3.3
	2006-11-02	335	1.0	0.0	-273	61	0.2	8	32	6.3	6.4	0.1	1.2	1.9
	2008-12-23	355	0.7	0.3	-95	260	0.7	244	392	-0.6	-0.5	0.1	2.9	3.2
	2008-12-27	386	0.8	0.2	-68	317	0.8	302	448	-0.5	-0.3	0.1	2.9	4.6
	2012-01-14	331	0.6	0.4	-101	230	0.7	146	310	-1.0	-0.7	0.1	2.7	3.5
(-/+)	1996-11-14	314	0.9	0.1	10	324	1.0	40	107	2.1	2.2	0.1	4.4	4.9
	1996-12-21	343	0.9	0.1	-28	315	0.9	451	526	2.1	2.2	0.4	3.3	3.9
	1998-12-23	335	0.9	0.1	35	370	1.1	288	372	1.2	1.6	0.2	3.4	5.6
	1999-11-21	286	1.0	0.0	19	305	1.1	10	15	3.5	4.1	0.2	2.9	5.2
	2003-03-03	196	0.8	0.2	32	228	1.2	169	304	2.2	2.6	0.2	1.0	1.3
	2004-12-04	212	0.9	0.1	20	231	1.1	39	88	2.6	3.0	0.2	1.2	1.9
(+/-)	2003-12-08	193	0.7	0.3	-9	184	1.0	121	211	0.5	0.6	0.1	2.6	3.4
	2005-03-23	214	0.8	0.2	-37	177	0.8	97	192	1.3	1.5	0.1	1.0	1.2
	2007-11-13	198	0.9	0.1	-28	170	0.9	9	24	2.9	3.3	0.1	1.6	1.3

Table S1. Climatic and hydrologic data for the 26 events in this study. P = precipitation, T = temperature, N = net snowpack outflow.

SWE is the average of all reporting snow pillows in the Andrews Forest and nearby SNOTEL sites. Snowpack (snow water equivalent, SWE) data were obtained from CENmet (1028 m), VANmet (1268 m), and UPLmet (1298 m), and three Snowpack Telemetry (SNOTEL) stations within 30 km: Jump Off Joe (1070 m), McKenzie (1450 m), and Roaring River (1510 m) using stainless-steel and hypalon snow pillows with a resolution of 0.1 in. CENmet is nearest to H15met (909 m) and WS 8 (968 to 1182 m), the location of the principal snowmelt lysimeter, precipitation, and streamflow data used in this study, but SWE data from CENmet were available for only 10 of 26 events. SWE data reported here are averages from all reporting SNOTEL sites (n=3) and Andrews Forest snow pillows for each event; these sites are at higher elevation than the H15 snowmelt lysimeter (909 m) used in this study, hence these data are only a general indication of whether snow was on the ground, and they may show increases in SWE during a storm in which SWE decreased at the study site.