The Vernal Window Flow Path: a Cascade of Ecological Transitions Delineated at Scales from Points to Pixels

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Introduction: the vernal window is the transitional period between winter and spring (Figure 1). Climate change may alter the sequence, timing, and / or duration of transitions within the vernal window, with unclear ecosystem implications.

Objectives: determine sequence of transitions, dates at which they occur, and lags that separate them to understand climate change impacts during the vernal window period and the rest of the year.

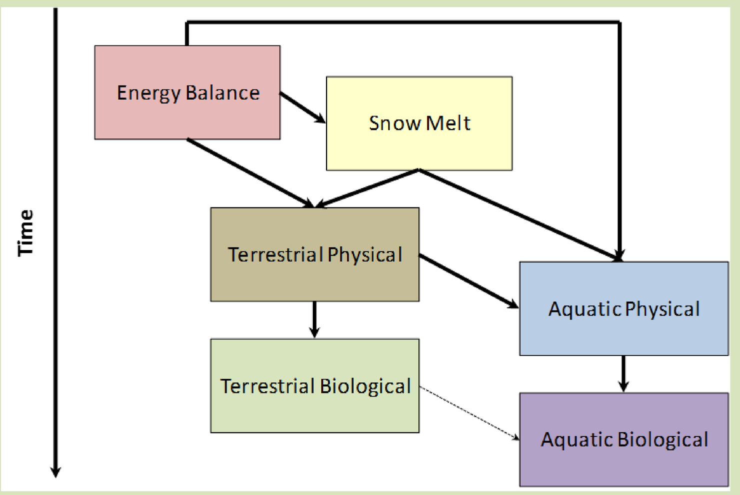

Figure 1. Conceptual model of the vernal window which opens with a change in the ecosystem energy balance and closes with changes in terrestrial and aquatic biological phenomena. Each transition along the vernal window flow path lags behind the one that preceded it. The timing, magnitude, and duration of each transition can impact the one that follows it. The dotted line from terrestrial biological to aquatic biological systems indicates the relationship between forest canopy green-up and in-stream productivity.

Data Sources were citizen science networks, terrestrial and aquatic sensor networks, remote sensing products, and meteorological models throughout New Hampshire, USA (Table 1). Data were assigned to site or statewide analysis based on breadth and depth of observations (Figure 2).

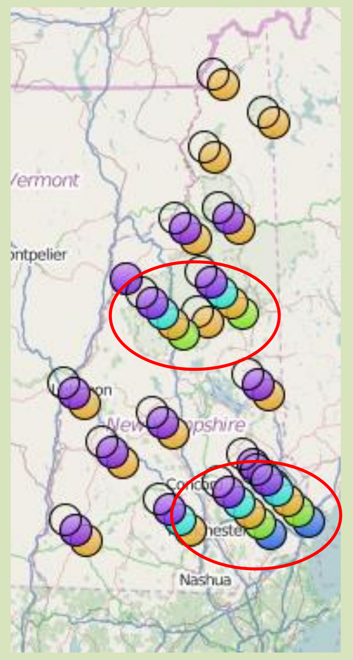

Figure 2. Location of point data throughout NH. Red circles indicate where site level analyses occurred.

Table 1. Data sources, spatial coverage, type (point or grid), frequency, and variables used in analysis

Data Source	Coverage	Type	Years	Frequency	Variables
Aquatic Intensive Network	Site	Point	2014	Subhourly	Stream T, Stage, Q, SC, DO, fDOM, NO3
Terrestrial Intensive Network	Site	Point	2014	Hourly	Air T, Soil T, VWC, SC
Lotic Volunteer network for sensing Temperature, Electrical Conductivity, and Stage (LoVoTECS)	Statewide	Point	2013-2014	Hourly	Stream T, SC
Community Collaborative Rain, Hail and Snow and Albedo Network (CoCoRaHS Albedo)	Statewide	Point	2012-2014	Daily	Air T, albedo, snow depth, SWE
United States Geological Survey (USGS)	Statewide	Point	2012-2014	Daily	Q
National Operational Hydrologic Remote Sensing Center (NOHRSC))	Statewide	Grid	2012-2014	Daily	Snow depth, SWE
National Center for Environmental Protection North American Model (NCEP-NAM)	Statewide	Grid	2012-2014	Daily	Air T, Soil T
Moderate Resolution Imaging Spectroradiometer (MODIS)	Statewide	Grid	2012-2014	Weekly	LAI

Delineating Transitions and Lags (Figure 3)

1. Develop algorithms that delineate transitions

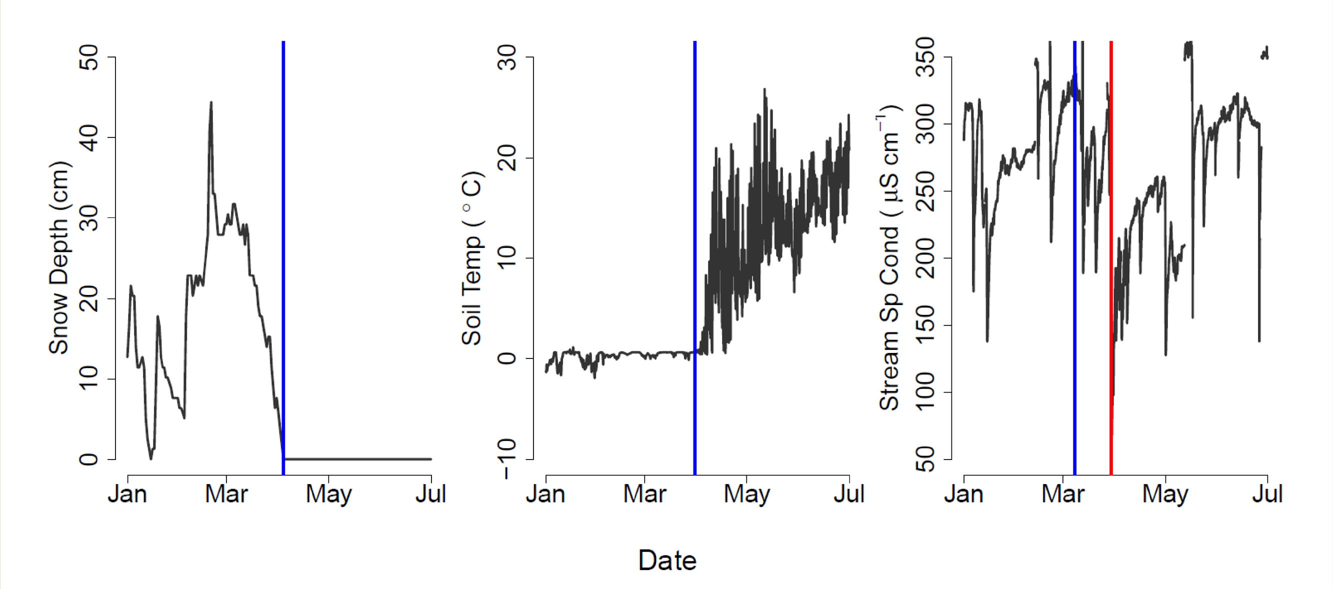

Figure 3. Examples of time series data from one of our research sites. Algorithms were developed from these data to detect transition dates when the system switched from winter to spring. Transition dates are delineated by blue lines, or by blue and red lines where there are two transition dates for the same variable.

1. Monte Carlo Approach Varying Two Factors:
   a. Smoothing: can range from 5-120 days
   b. Analysis Window: ±15 days from 2/15 to 5/15
3. Run 1,000 iterations
4. Transition date is mode of 1,000 iterations
5. Lag = number days between paired thresholds

H1: Transitions within the vernal window follow a predictable sequence

The NH EPSCoR Sensor Team ranked variables to predict transition sequence, but data did not support prediction (Figures 4-5).

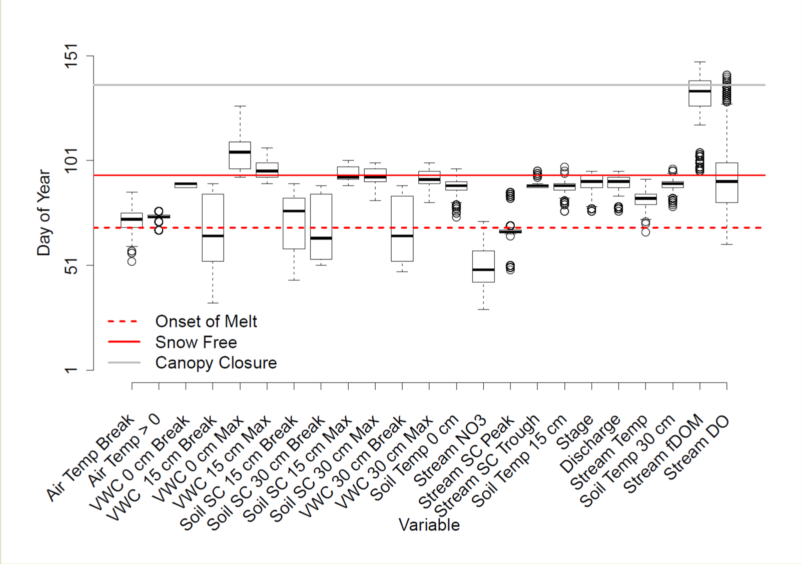

Figure 4. Days of year at which system variables transitioned from winter to spring at one of our intensive sites. Data are 1,000 estimated transition dates and are ordered by hypothesized rank.

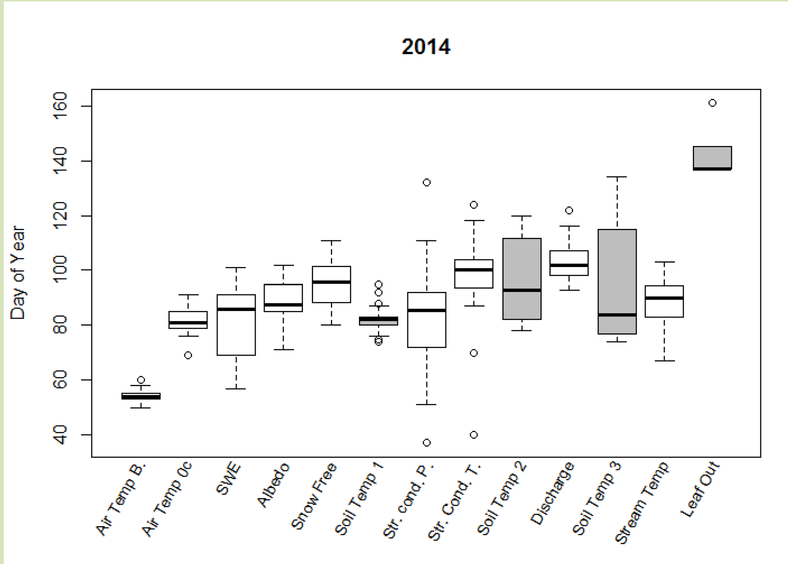

Figure 5. Days of year at which system variables transitioned from winter to spring across the state. Boxes shaded in gray are gridded data while white boxes are point data.

Many transitions occurred simultaneously across the ecosystem in concert with the onset of melt or the disappearance of snow pack.

H2: There are quantifiable lags between transitions

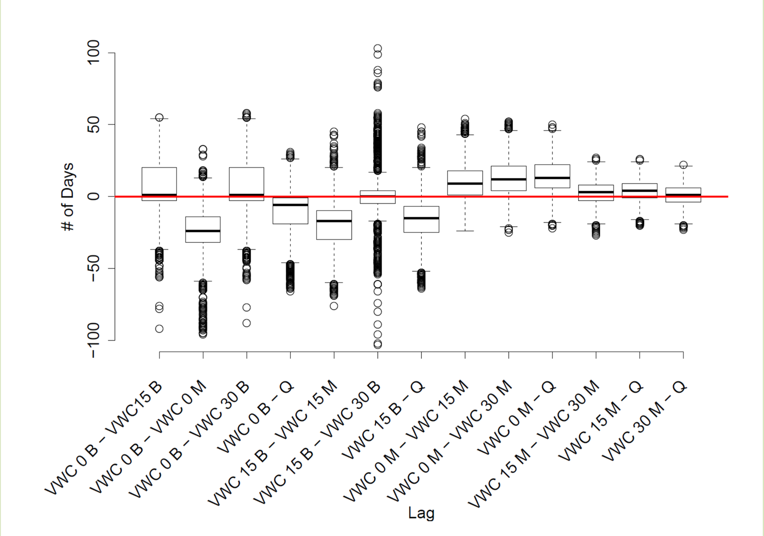

Figure 6. Lags between pairs of soil moisture and stream discharge transition dates at all the intensive terrestrial and aquatic sensor sites. Data are lags calculated from 1,000 estimated transition dates. A negative value indicates that the transition for the first variable occurred prior to the second variable. A positive value means that the transition of the first variable occurred after the second variable.

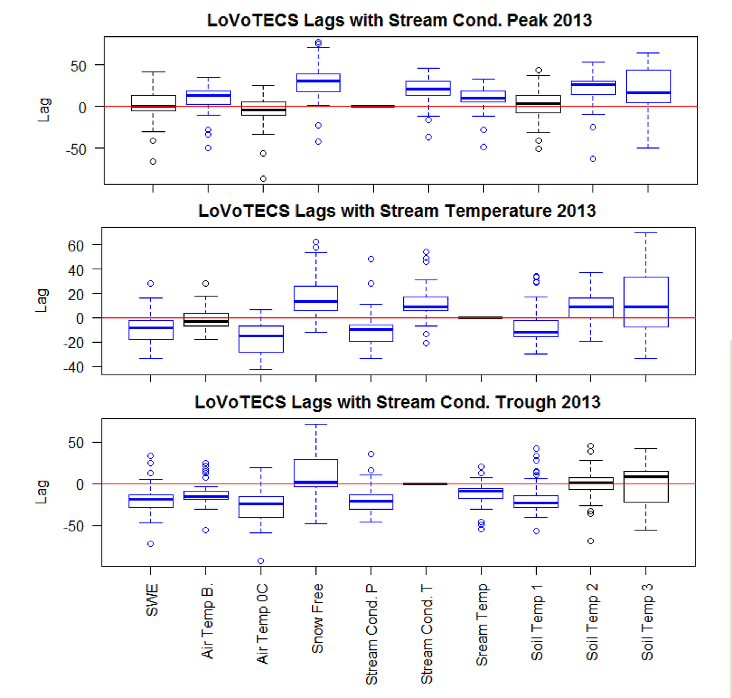

Figure 7. Lags between pairs of transition dates derived from gridded and point data as part of the statewide analysis of the LoVoTECS stream monitoring network. Boxes in blue indicate lags significantly different from zero.

Some lags did not differ from zero. Others were 2-3 weeks long, suggesting longer lags that may be important for ecosystem function (Figures 6 and 7).

H3: Transitions and lags vary with antecedent temperature and snow conditions

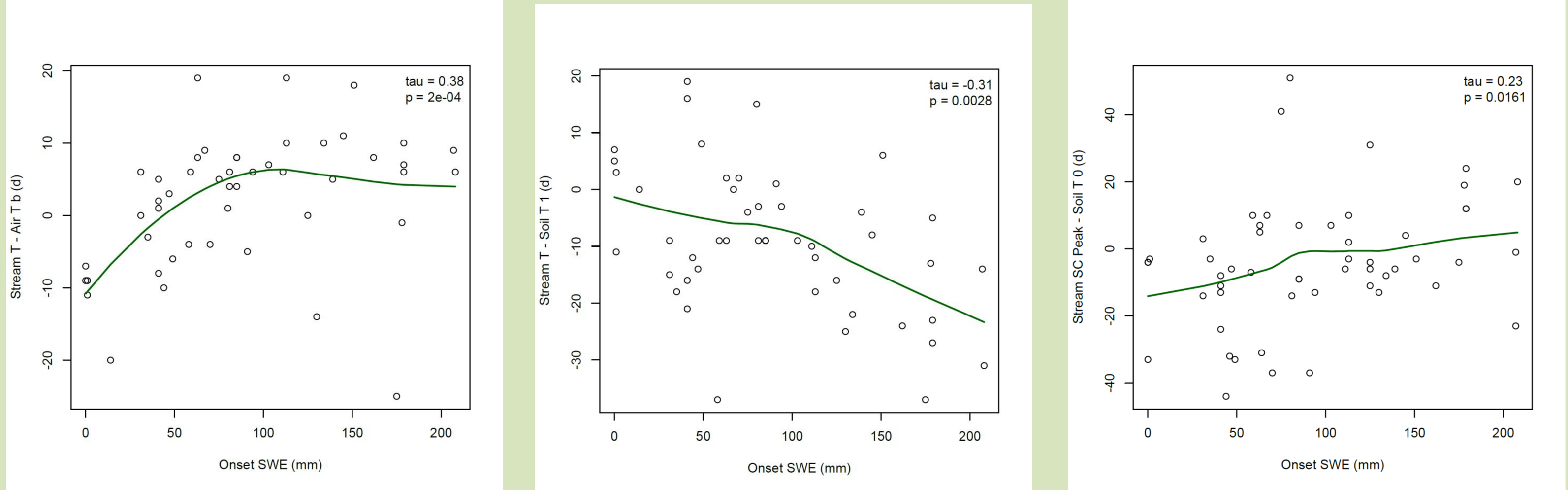

Figure 8. Lags between stream temperature and air temperature, stream temperature and soil temperature, and peak stream conductivity and soil temperature as functions of the amount of snow water equivalent (SWE) present at the onset of melt. The p and tau statistics show the results from Mann-Kendall tests for monotonic trends, while LOWESS produced the smoothed lines.

Lags varied as a function of the amount of snow present at the onset of melt (Figure 8). Reductions in the depth or duration of snowpack with climate change could alter the timing of transitions and lags within the vernal window period, with potential ecosystem consequences.

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