Method of spatial temperature estimation influences ecohydrologic modeling in the Western Oregon Cascades

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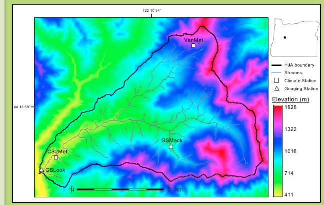
Abstract

Most spatially explicit hydrologic models require estimates of air temperature patterns. For these models, empirical relationships between elevation and air temperature are frequently used to upscale point measurements or downscale regional and global climate model estimates of air temperature. Mountainous environments are particularly sensitive to air temperature estimates as spatial gradients are substantial, and air temperature plays a critical role in snow related processes. We use a distributed, coupled ecohydrologic model to compare estimates of streamflow, snowmelt, transpiration and net primary productivity (NPP) using three temperature interpolation approaches for a forested mountain basin that is dominated by a rain-snow zone in Western Oregon, USA. We compare model estimates using a standard adiabatic lapse rate of -6.5 °C km^{-1}; basin specific lapse rates created using daily point observations at high, middle, and low elevations; and gridded temperature estimates from the Parameter-elevation Regressions on Independent Slopes Model (PRISM) derived at 800 meter and 50 meter resolutions. We show that temperature interpolation strategies influence model calibration. Point-based estimates using a low-elevation station or 800 meter PRISM grids result in significantly fewer parameter sets that model streamflow well, suggesting a bias in parameter selection due to errors in input data. The PRISM 50 meter interpolation slightly improves hydrologic performance, better capturing total flow and timing of snowmelt. The greatest post-calibration impact of temperature lapse rate estimates occurs for model estimates of NPP. The constant temperature lapse rate results in substantially reduced NPP estimates that are more sensitive to inter-annual variation in climate forcing.

Study Site

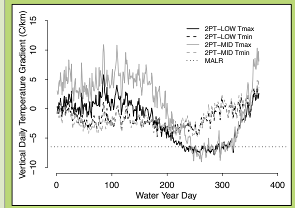


HJ Andrews Experimental Forest (LTER)
- Located on the windward slope of the Western Cascade Range in Oregon, USA
- 410 m to 1630 m elevation range
- Conifer dominated - *Tsuga heterophylla* (Western hemlock) at lower elevations, *Abies amabilis* (Pacific silver fir) at higher elevations, *Pseudotsuga menziessi* (Douglas-fir) throughout
- Mediterranean climate, wet winters/dry summers, approximately 75% of annual precipitation falls from November to April
- Dominated by a rain-snow transition zone
- Prone to cold air drainage/pooling and strong seasonally varying temperature inversions
- Likely to be particularly sensitive to spatial-temporal patterns of air temperature

Temperature Interpolation Methods

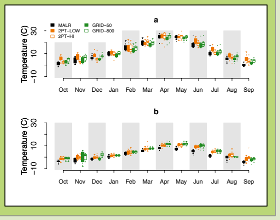
Method	Approach	Data used to derive minimum/maximum temperature lapse rates
MALR	Standard	Mean adiabatic lapse rate; temporally constant mean temperature lapse rate of -6.5 °C km^{-1}
2PT-LOW	Linear Interpolation	daily temperature from local paired point meteorological station measurements: CS2MET (low elevation) and VANMET (high elevation)
2PT-MID	Linear Interpolation	daily temperature from local paired point meteorological station measurements: GSMACK (mid elevation) and VANMET (high elevation)
GRID-50	Non-linear, spatially distributed	Temperature estimated using 50 meter resolution PRISM derived grids
GRID-800	Non-linear, spatially distributed	Temperature estimated using 800 meter resolution PRISM derived grids

We assume here that the GRID-50 scenario is the most physically realistic of the temperature scenarios because it is derived using PRISM at a fine resolution by using more than 30 temperature sensors within the basin



Temperature (T) lapse rate with elevation varies significantly with season. In some cases, winter T actually increases with elevation. Tmax has more seasonal variation than Tmin.

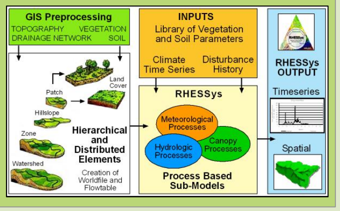
Local effect of T-interpolation method may be more substantial at the watershed scale – the effect of the T-interpolation method is small relative to long-term seasonal patterns.



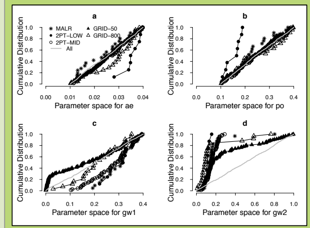
Model: Regional Hydro-Ecological Simulation System (RHESSys)

RHESSys simulates coupled carbon, water and nutrient cycling over spatially heterogeneous terrain. Daily maximum and minimum temperature inputs (for each spatial patch unit) influence:

a) Partitioning of precipitation into either rain or snow
b) Snowmelt
c) Vapor pressure deficit estimation
d) Stomatic conductance
e) Respiration and Photosynthesis



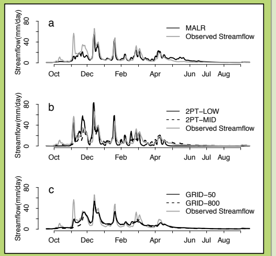
Model Calibration



Daily Streamflow Performance Metrics

T-Scenario	Bias %	NSE	Log(NSE)
MALR	-5.6	0.61	0.82
2PT-LOW	-10.1	0.62	0.83
2PT-MID	-6.3	0.69	0.84
GRID-50	2.6	0.67	0.88
GRID-800	-12.8	0.62	0.84

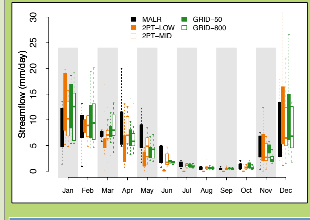
Calibrated soil drainage parameters differ for the different T-interpolation methods; hence, our estimates of soil drainage parameters are BIASed by errors due to the T-interpolation method used.



Modeled streamflow for water year 2000, a year of average annual precipitation (over record from 1957-2005) illustrates differences in seasonal timing using the five T-interpolation methods.

Post-calibration streamflow estimates are relatively similar across the different T-interpolation methods – and all achieve acceptable performance based on commonly applied metrics used to evaluate hydrologic models.

Thus "general" streamflow performance may not be sensitive to the T-interpolation method used.



Average monthly streamflow for water years 1991-2000 for all temperature interpolation scenarios.

Metrics that specifically examine snowmelt periods and interannual variation in minimum flows, however, do show sensitivity to T-interpolation approach even after calibration.

Table lists seasonal (Spring/Fall) streamflow performance metrics of each temperature scenario for water years 1991-2000.

	Spring, March-April-May			Fall, 7-day Low Flow	
Scenario	RMSE (mm)	Bias (%)	Average # Days removed from observed DofCM	RMSE (mm)	Bias (%)
MALR	16.8	18.3	20 later	11.9	-21.6
2PT-LOW	16.7	-1.0	10 earlier	8.4	-1.3
2PT-MID	8.8	0.9	12 later	8.0	6.5
GRID-50	7.3	-3.7	3 later	7.3	5.6
GRID-800	11.3	-7.8	9 later	7.9	-4.5

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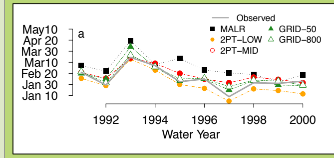
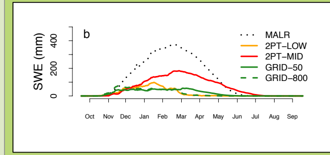
Model Performance: Streamflow and Snow

Timing of snowmelt, reflected here as streamflow's day of center of mass (DofCM) where points modeled above the grey line (observed) indicate delay in melt



- The standard temperature lapse rate scenario (MALR) produces substantially more snow and later melt than the other scenarios.
- Substantial differences between SWE estimates based on different point measurements (LOW vs. MID) demonstrates the effect of location of paired met stations.



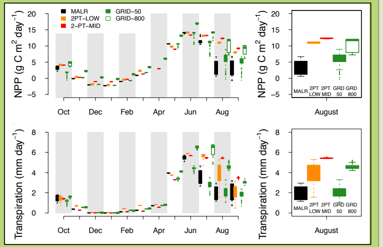
- Gridded approaches (and 2PT-LOW) produce lower peak SWE and earlier melt. Coarser resolution gridded temperature inputs (GRID-800), however, tend to have faster melt and lower, earlier peaks relative to finer resolution gridded temperature inputs (GRID-50).

Magnitude of snow accumulation, shown as the 10-year average snow water equivalent (SWE)

Ecological Modelling: Transpiration and Carbon Cycling

T-interpolation method effect on modeled ecological processes:

- Mean annual model estimates of NPP and transpiration fall within a range of measured values for Pacific Northwest Douglas-fir for all T-interpolation approaches
- Estimation of both means and inter-annual variation (climate sensitivity) of ecohydrologic variables are significantly different across T-interpolation approaches.
- The mechanisms behind these differences are complex and reflect the influence of temperature on the combination of interacting controls on growing season water use and NPP – including available water late in the summer, mid-late summer VPD and respiration.



- *Snow accumulation/melt influence timing and magnitude of growing season water availability, but surprisingly larger snowpack (MALR) did not result in greater NPP*
- *The fine resolution temperature scenario (GRID-50) estimates substantially reduces later summer NPP and transpiration relative to the linear interpolation scenarios We note that although GRID-800 produces streamflow statistics relatively close to those obtained using GRID-50, the NPP estimates from GRID-800 are substantially larger than all other scenarios.*
- *Similar winter/spring NPP and transpiration fluxes suggest spring T estimates are not a critical control.*

T-Scenario	Mean Annual NPP (g C m^{-2})	Std Dev of Annual NPP (g C m^{-2})	Mean Annual Transpiration (mm yr^{-1})	Std Dev of Annual Transpiration (mm yr^{-1})
MALR	450	230	580	80
2PT-LOW	930	80	730	30
2PT-MID	900	120	760	80
GRID-50	520	130	500	40
GRID-800	1440	80	790	50

Conclusion

Given calibration, all temperature interpolation methods yield acceptable estimates of daily streamflow. However - The temperature interpolation strategy used influences soil parameter calibration, suggesting that "Good" streamflow performance can be misleading….

Seasonally specific streamflow metrics, such as the timing of center of mass of streamflow and basin-averaged SWE estimates, are more sensitive to T-interpolation approaches. Model estimates of means and inter-annual variation (climate sensitivity) of eco-hydrologic fluxes (NPP and transpiration) show *substantial* variation across T-approaches

This sensitivity of NPP estimates to the temperature interpolation approach used (including which "type" of method is used, station locations and resolution in the gridded case) has implications for climate change model predictions of forests as carbon sinks, and forest vulnerability to drought and other climate related stressors.