GIS-based temperature interpolation for distributed modeling of reference evapotranspiration

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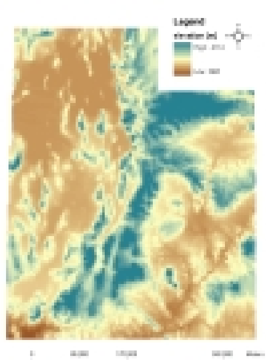
Abstract

Surface air temperature is an important meteorological input in most formulas for point-specific reference evapotranspiration calculation. To model the spatially distributed reference evapotranspiration, interpolation of temperature accounting for topography is necessary. In this paper we evaluated four interpolation schemes using the leave-one-out cross-validation method with the measured temperature data at 139 climate stations in the state of Utah. The interpolation schemes evaluated were respectively (1) inverse distance weighting (IDW) without consideration of elevation effects, (2) ordinary Kriging without consideration of elevation effects, (3) a hybrid scheme that combined a constant lapse rate with ordinary Kriging, (4) an elevationally detrended kriging approach which is a combination of regression against elevation and ordinary Kriging. Cross-validation results show that the 4th scheme has the least root-mean-square error. The steps involved in applying this scheme are: (1) develop a regression relationship between the ground measurements of temperature and site elevations at each calculation step, then (2) interpolate the residual difference between the measured temperature and the temperature obtained from the regression at each station using ordinary Kriging, (3) estimate the temperature at non-station locations by adding the interpolated residuals to the temperature obtained from the regression using elevation from a digital elevation model (DEM). This interpolation scheme was implemented within ArcGIS using the programming capability provided through ArcObjects.

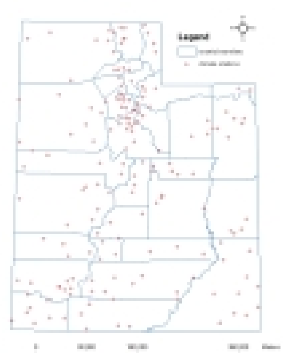
Data used

- 90-meter Digital Elevation Model (DEM) for the state of Utah **ftp://ftp.agrc.state.ut.us/90meter_dem/**
- Air temperature observations at 139 stations within Utah from the National Climatic Data Center database **http://lwf.ncdc.noaa.gov/oa/climate/climatedata.html**

Utah DEM



Utah climate stations



Leave-One-Out Cross Validation method used to compare predicted and observed monthly temperature of each station, using

- the scatter-plots of measured and estimated values
- the distribution of square errors between measured and estimated values
- the Root Mean Square Error (RMSE) of all stations

$$RMSE = \left[\frac{1}{N} \sum_{i=1}^{N} (T_{e,i} - T_{o,i}) \right]^{1/2}$$

Where $T_{e,i}$ is the estimated temperature at i^th gage,

$T_{o,i}$ is the observed temperature at i^th gage,

N is the number of gages in cross-validation process

Background

Accurate estimation of agricultural water use is of importance to regional water resources management. We are working on a regional evapotranspiration (ET) modeling approach that uses ESRI ArcGIS Arcobjects (Zeiler, 2001) modeling environment . Established methods (Jensen et al., 1990) exist to calculate point-specific reference ET from point meteorological data. Here we extend these methods to calculate reference ET field over a region. This approach requires regional meteorological input data such as air temperature and incoming solar radiation. This project focuses on the interpolation of temperature for regional reference ET calculation. ArcGIS provides some two-dimensional spatial interpolation methods, however, these methods may not work well for a spatial variable such as temperature that depends upon topography. The presentation here is therefore focusing on evaluating a set of temperature interpolation schemes(Goovaerts, 1997; Phillips et al., 1992) for use in the GIS–based ET modeling.

Proposed schemes for temperature interpolation

Scheme 1: Apply ArcGIS built-in **Inverse Square Distance (IDW)** method on temperature measurements at all stations without considering topographic effects

Scheme 2: Apply ArcGIS built-in **Ordinary Kriging** method on temperature measurements at all stations without considering topographic effects

Scheme 3: Convert temperature measurements at all stations into temperature values at a reference elevation level based on a **constant lapse rate** (*constant lapse rate: 3.5 °F per 1000 ft*), apply ArcGIS built-in **Ordinary Kriging** for lapsed temperatures , and then convert the temperatures at reference level back to the real level based on the given lapse rate

Scheme 4: Elevationally Detrended Ordinary Kriging

(1) Establish a regional regression relationship between temperature and elevation from temperature observations and station elevations for **each calculation time step**

$$\overline{T} = a_t Z + b_t$$

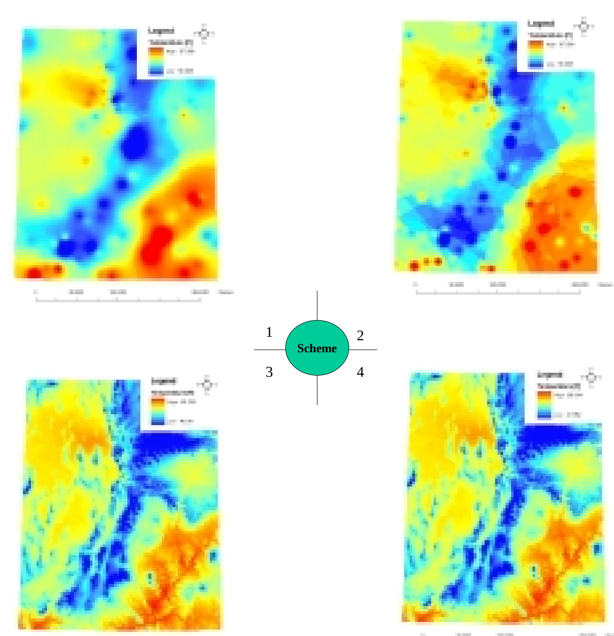
(2) Remove the elevational trend ($\overline{T}_i$)from the measured values based on the above regression and get the residuals at gage locations, $T_i' = T_i - \overline{T}_i$

(3) Interpolate the residuals (T_i') with ArcGIS built-in ordinary Kriging to get the horizontal residual (T') of temperature at all other locations

(4) Use DEM and the regional regression relationship between temperature and elevation to get the vertical trend ($\overline{T}$) at all other locations

(5) Obtain the estimation of temperature (T) at any location by adding the above two terms,

$$T = \overline{T} + T'$$

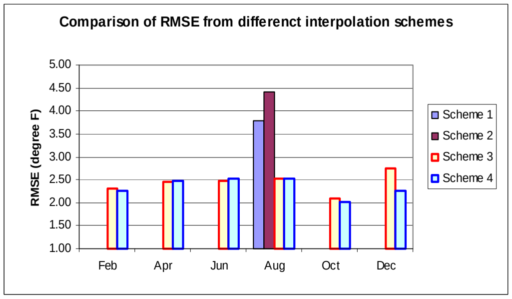


Spatial patterns of temperature from different interpolation schemes in August, 2000

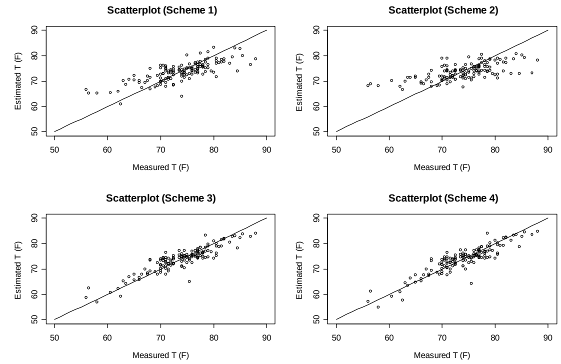
Cross-Validation Results

RMSE (^{o} F) from different interpolation schemes for mean temperature

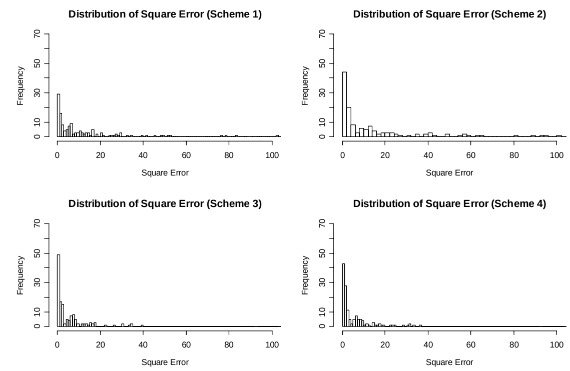
Interpolation Schemes	Feb	Apr	Jun	Aug	Oct	Dec	Average
Scheme 1				3.78			
Scheme 2				4.43			
Scheme 3	2.32	2.46	2.48	2.52	2.09	2.74	2.435
Scheme 4	2.25	2.48	2.53	2.53	2.01	2.25	2.342



The first two schemes that do not consider the topographic effects result in larger errors in August and are therefore inferior. While the performance of the last two schemes are similar, the 4th scheme has a slightly smaller average of root mean square error throughout the validation period.



Scatter-plots for validation in August, 2000

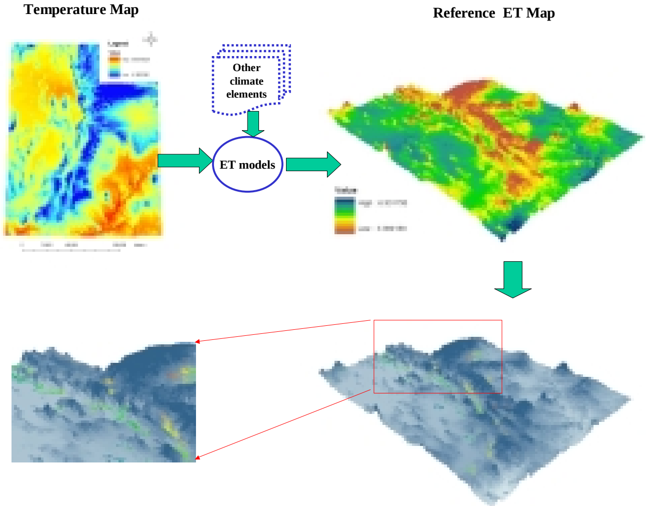


Histograms for validation in August, 2000

Implementation of the optimal scheme for distributed ET modeling

The interpolated regional temperature together with other interpolated meteorological variables and particular standard reference ET calculation methods are used to obtain spatially distributed reference ET information. This can then be combined with crop coefficients based on land use/cover data to obtain potential ET and potential crop water use over the region of interest.

Temperature Map **Reference ET Map**



Spatial distribution of crop evapotranspiration

Summary

- The dependence of temperature on elevation needs to be recognized and incorporated into temperature interpolation methods.
- The lapse rate value used in fixed lapse-rate method (3rd scheme) is subjective.
- The 4th scheme is more objective since the relationship between temperature and elevation is established through ground measurements at each calculation time step.
- The above comparison shows that the 4th interpolation scheme is preferable.
- The selected scheme can be easily programmed into any specific hydrological models within GIS environment.

References

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