Appendix B

SSEBop

Upper Colorado River Basin (UCRB) – Monthly and Daily SSEBop Evapotranspiration (ETa) using Remote Sensing, April-October, 2020

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Contents

1. Basin-wide SSEBop ETa Monthly Total (mm) for Apr 01 - Oct 31, 2020, (GeoTIFF, 16-bit Integer)
2. Basin-wide cloud-free pixel count QA layers for each month Apr-Oct, (GeoTIFF, 16-bit Integer)
3. Eddy Covariance Station location SSEBop ETa Daily Total (mm) for Apr 01 - Oct 31, 2020, (GeoTIFF, 32-bit Float)
4. Landsat 2020 Scene Inventory tables for the 4 tower locations (.xlsx file).

Model Data Summary

- Landsat 7 and Landsat 8 scenes were used from Collection-2 Level-2 Tier-1 data with less than 40% cloud cover from path 34 rows 32-35, path 35 rows 31-35, path 36 rows 31-35, path 37 rows 30-35, and path 38 rows 30-34 from April-October for 2020.
    - Included SSEBop data is between April 1st and October 31st. Note: Scenes from March and November were used to complete the interpolation process for April and October imagery.
- Landsat 30-meter imagery was accessed for processing from the Google Earth Engine public data catalog. More information about Landsat Collection 2 imagery can be found here: https://www.usgs.gov/core-science-systems/nli/landsat/landsat-collection-2-level-2-science-products.
- Level-2 Surface Temperature was used as the primary input for SSEBop. More information here: https://www.usgs.gov/core-science-systems/nli/landsat/landsat-collection-2-surface-temperature.
- SSEBop ETa raster products are provided in WGS_1984_UTM_Zone_12N coordinate system.

Model Methods

SSEBop Model Actual ET processing for 2020 growing season in the Upper Colorado River Basin used the following methods and auxiliary data:

- All model data processing was performed using the Google Earth Engine (GEE) cloud computing platform (https://earthengine.google.com/) with the GEE Python API.
- Auxiliary inputs for the model include daily climatology (1981-2010, 1-km) for Daymet maximum air temperature and daily psychrometric constant (1/dT, 1-km) (Senay, et al 2013, 2018).

- Daily 2020 bias-adjusted alfalfa-reference ET rasters generated from Gridmet data supplied by DRI.
- Each scene was parameterized with gridded correction coefficient (*c-factor*, 5-km) model calibration data (Senay et al. 2019; Senay et al. 2017). More information on model parameters can be found in Senay (2018).
- Daily ETa at 4 EC station sites included scenes with <40% Cloud Cover. See inventory table for list of overpass scene IDs used at each site.
- Cloud-masked pixels and Landsat 7 SLC-off data masks identified as cloud and cloud shadow by the QA band were both filled using linear temporal interpolation of ET fraction values from preceding and subsequent image acquisitions, ranging up to 32 days from target date and included all clear pixels from overlapping Landsat paths and rows, where available.
- Monthly and seasonal ET were simply generated by summing the product of ET fractions and reference ET over the given aggregation period. Thus, the final seasonal product ET estimation will depend on the availability of images and the accuracy of the linear interpolation technique to fill missing/gap image pixels.

Auxiliary Data

- Daymet Maximum Air Temperature (Tmax), daily climatology (1981-2010), 1-km, source: https://daymet.ornl.gov/. An Elevation Lapse Rate (ELR) adjustment using USGS SRTM DEM (90-meters) was applied per SSEBop methodology. Generally, irrigated lands are not present in locations of Tmax ELR adjustment. More information can be found below in the section 2020 SSEBop Model Updates.
- Daily psychrometric constant (1/dT, 1-km) created from clear-sky net radiation and Daymet temperature sources.
- Landsat Collection-2 Level-2 LST, USGS EROS, Landsat 7 & 8, GEE catalog source: https://developers.google.com/earth-engine/datasets/catalog/LANDSAT_LC08_C02_T1_L2
- Bias-adjusted daily Reference ET (ETr) from DRI, Daily, 4-km, 2020.
- Cloud masks from Landsat Collection 2 Band_QA band. The SSEBop model used those pixels identified as 'clear' in the image QA band (L7 QA values of 672, 676, 680, or 684 and L8 QA values of 2720, 2724, 2728, and 2732)

SSEBop Model Summary

The SSEBop ET algorithm is an operational parameterization of the Simplified Surface Energy Balance (SSEB) model that computes daily total actual evapotranspiration using a combination of land surface temperature (LST) and reference ET (Equations 1 and 2). The SSEBop model can be described as a partial energy balance model that only solves for the latent heat flux at a daily time scale using a Satellite Psychrometric Approach (SPA) where the difference between the dry-bulb (observed LST) and wet-bulb reference LST are used to determine the ET fraction in combination with a surface psychrometric constant (Senay, 2018). The SPA formulation of SSEBop is defined using two model parameters: (1) the wet-bulb LST equivalent is determined from gridded air temperature (Senay et al., 2013, 2016, 2017), (2) the surface psychrometric constant is determined from surface energy balance calculations over an idealized bare ground (Senay et al., 2013; Senay, 2018).

$$ETf = 1 - \gamma^s(Ts - Tc) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where *ETf* is ET fraction, nominally varying between 0 and 1; γ^s is denoted as a "surface psychrometric" constant (SPC) based on the aerodynamic properties of a dry-bare surface (K^{-1}); *Ts* is satellite-derived land surface temperature (LST, K); and *Tc* is the cold/wet-bulb surface temperature (K) limit, derived from air temperature (Senay et al., 2013, 2016, 2017). The constant 1 represents the value of ET fraction during maximum ET, i.e., *Ts = Tc.*

$$ETa = ETf * ETr \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

where *ETa* is daily total ET (mm/day), *ETf* is ET fraction (-) from Equation 1 and *ETr* is the alfalfa reference ET (mm/day).

A brief model summary is included below. More information about SSEBop can be found at Senay et al., 2013, 2016, 2017 and Senay, 2018.

Basic SSEBop Modeling Steps for UCRB ETa Processing:

- ❑ Pre-define temperature difference (dT) based on "gray-sky" energy balance over bare ground; *dT* is in the inverse of γ^s in Equation 1.
- ❑ Define gridded *Tc* from daily gridded Daymet Tmax data using model correction coefficient: gridded *c* factor
- ❑ Use surface temp (*Ts*) from satellite to estimate ET fraction: $ETf = 1 - \frac{Ts - Tc}{dT}$
- ❑ Use weather data to calculate maximum daily ET based on alfalfa reference: *ETr*
- ❑ Estimate Actual daily ET as: *ETa = ETf * ETr*

The SSEBop model by its nature only creates daily ET. The ET fraction in the equation is assumed to represent a per-pixel daily ET fraction value. Thus, by using a daily total *ETr* in combination with *ETf*, daily total actual ET (*ETa*) is created.

2020 SSEBop model updates

1. Elevation Lapse Rate adjustment to daily maximum air temperature input data, for improved Tmax input data conditioning at locations of dynamic elevation change. Note, previous versions of the SSEBop model used a generalized ELR factor methodology applied at locations greater than 1500m elevation. The following approach for ELR adjustment was used in this study:

   Air temperature adjustment for elevation lapse rate

   For SSEBop model parameterization, when Ts (LST) cools faster than Ta (Tmax) in complex topography and elevation, ETa may tend to be overestimated. Therefore, additional environmental lapse rate (ELR) correction is necessary to adjust for these differences. Daily Ta data is corrected using an ELR constant (0.005 K/m) to adjust for lapse rate differences between air and surface temperature values at high elevations and sharp rises in topography.

ELR_mask = (DEM - (DEM_smooth + 100)) > 0
Ta_adj = Ta - (0.005 * ELR_mask)

Where ***ELR_mask*** is the geographic locations of elevation difference (greater than zero) between the source DEM and DEM_smooth + 100 meters. ***DEM*** is the source digital elevation model data in meters (e.g. SRTM 90-m), ***DEM_smooth*** is a smoothed variant of the DEM first resampled to match Ta pixel resolution (e.g. 1-km when using DAYMET Tmax grid) then applied a median focal statistics operator (e.g. radius = 80-km kernel when used with DAYMET, but varying for other temperature datasets/resolution), and ***Ta_adj*** is the conditioned daily maximum air temperature (Ta) with adjusted pixel values based on the ELR correction. Ta was reduced by a factor of 0.005 K/m, equating to an additional reduction of 5 K for every kilometer rise in locations identified by the ELR_mask. Continued analysis in lapse-rate atmospheric dynamics and conditioning for various Tmax-to-LST relationships will aid in improving the application of SSEBop in complex and high-elevation terrain.

References:

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