QA/QC and Calibration of Standardized, Long-term, and Basin-wide Reference ET Datasets

or:

For River Basins (starting with Arkansas Basin):
1) Automated QA/QC of climate dataset for ASCE Std ET
2) Comparison of ET calibration methods
3) Automated generation of long-term reference ET datasets for climate stations and user defined locations

Kelley Thompson; Modeling and DSS Team, CDWR

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References

ASCE-EWRI. (2005). The ASCE Standardized Reference Evapotranspiration Equation Edited by Richard G. Allen; Ivan A. Walter; Ronald L. Elliott; Terry A. Howell; Daniel Itenfisu; Marvin E. Jensen; Richard L. Snyder

ASCE Manual 70. (2015). Evaporation, Evapotranspiration, and Irrigation Water Requirements. Second Edition. Edited by Marvin E. Jensen and Richard G. Allen.

FAO-56. (1998). "Crop evapotranspiration: Guidelines for computing crop water requirements . Richard G. Allen, L.S. Pereira, D. Raes, and M. Smith. United Nations Food and Agriculture Organization, Rome.

Ley, T., Allen, R., and Jensen, M. (2013). "Translating Wind-Speed Measurements over Alfalfa Having Varying Height for Use in the ASCE Standardized Reference ET Equation." J. Irrig. Drain Eng., 139(6), 463–475.

Hill, R.W., and Ley, T.W. (2002). "Crop Water Use Estimates for the Arkansas River Basin in Southeastern Colorado". Kansas v. Colorado Expert report prepared for the CO State Eng.

Allen, Allen et. al. ……..

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More General Purpose of presentation

- **Discuss QA/QC and calibration techniques that YOU could also apply for HCU analysis.** Most from literature (ie ASCE/EWRI 2005, Manual 70, FAO-Allen et. al.); but a few methods are new, or applied in new ways.
- **Introduce basin-wide datasets and tools that we are developing in case they could be of use to you.**
- **Hoping for peer review that we are doing things right to develop accepted and standardized datasets.**
  - *Please tell us if we might be doing something wrong*
- **Wanting to know if this could be of use to you and if we should continue for this in other basins**

WHY are we doing this?

<u>For the Arkansas River Basin</u>:

A) ArkDSS – Arkansas Decision Support System

- Use methods that are equal to (or better than) the HI model used for Compact Administration
  - *Other DSS projects have so far used MBC with one or two calibrated crop coefficient sets*
  - *The HI model uses ASCE Std ET Equation*
- Need long-term Etrs / ETc datasets for locations throughout the Arkansas basin

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Why (continued)?

B) ATM legislation (HB13-1248 - Lease Fallow Pilot Projects) and other upcoming legislation

- DWR SEO needs simplified, streamlined, standardized, and accepted data and tools to estimate HCU.
  - *Stated goal of HB1248 was to develop streamlined methods to evaluate ATM projects*
  - *Criteria and Guidelines were developed to simplify and standardize HCU evaluation*
  - *LFT (lease fallow tool) developed with standard and accepted data for "1-minute" HCU analysis*

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Why (continued)?

C) For in-house evaluations for SWSPs or when there are compact compliance issues etc., CDWR/SEO also needs simplified, streamlined, standardized, and accepted data/tools to estimate HCU and/or water requirements

D) Accepted/standardized ET datasets or tool applications could be used by YOU for HCU Analysis where appropriate. CDWR might be less concerned when an accepted set is used.

- ***But CDWR is not declaring, or mandating use of, an approved dataset or tool***

CoAgMet System Climate Stations

- Colorado Agricultural Meteorological Network maintained by Colorado Climate Center at CSU:
  - Nolan Doesken, Zach Schwalbe, Lane Simmons
- Some support from CWCB, CDWR, UAWCD*, etc
- CoAgMet stations have sensors(temp, RH, solar, wind) to enable use of ASCE Standardized ET Equation
- Lane Simmons maintains Arkansas Basin systems
  - anemometer bearings replaced annually
  - temp/RH probe and pyranometer recalibrated two years
  - sensors periodically checked and cleaned
  - Vegetation periodically trimmed.
- CoAgMet Data Quality has improved significantly in recent years particularly over data from the 1990s

**Upper Arkansas Water Conservancy District*

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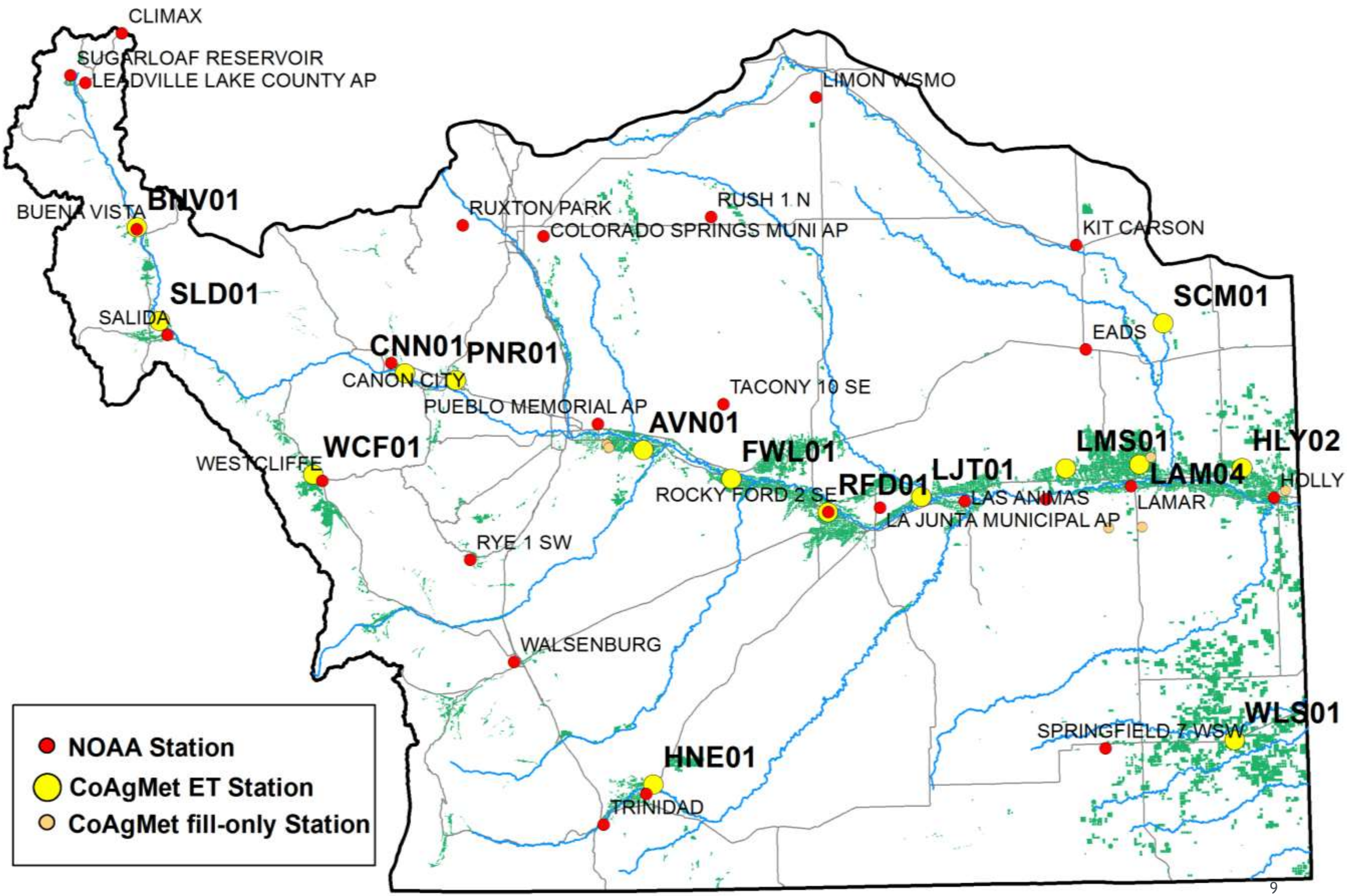
Station Locations - Arkansas River Basin



QA/QC of Climate Data for ASCE Std – Why?

- ET climate stations (ie CoAgMet and NWCD) have numerous sensors (temp, RH, solar, wind) increasing risk of issues or loss of calibration.
- Things happen: ie hail, ice, tornado cells, dirt storms, tumble weeds, birds, cows, people, etc
- Climate Data must be QA/QC-ed before use in ET calculations
  - ASCE-EWRI (2005), manual 70, FAO-56, and many others stress importance of data quality
  - Has been a critical part of HI model datasets

QA/QC of Climate Data for ASCE Std ET

- DWR originally developed QA/QC software for HI model updates; now multiple years/stations
- QA/QC Software:
  - Automatically identifies most bad data
  - Enables manual identification of bad data
  - Automatically fills/replaces missing/bad data
- Software developed for QA/QC, calibration, and dataset production processes are automated and "data" centered so that with additional years of data, datasets can be easily updated.

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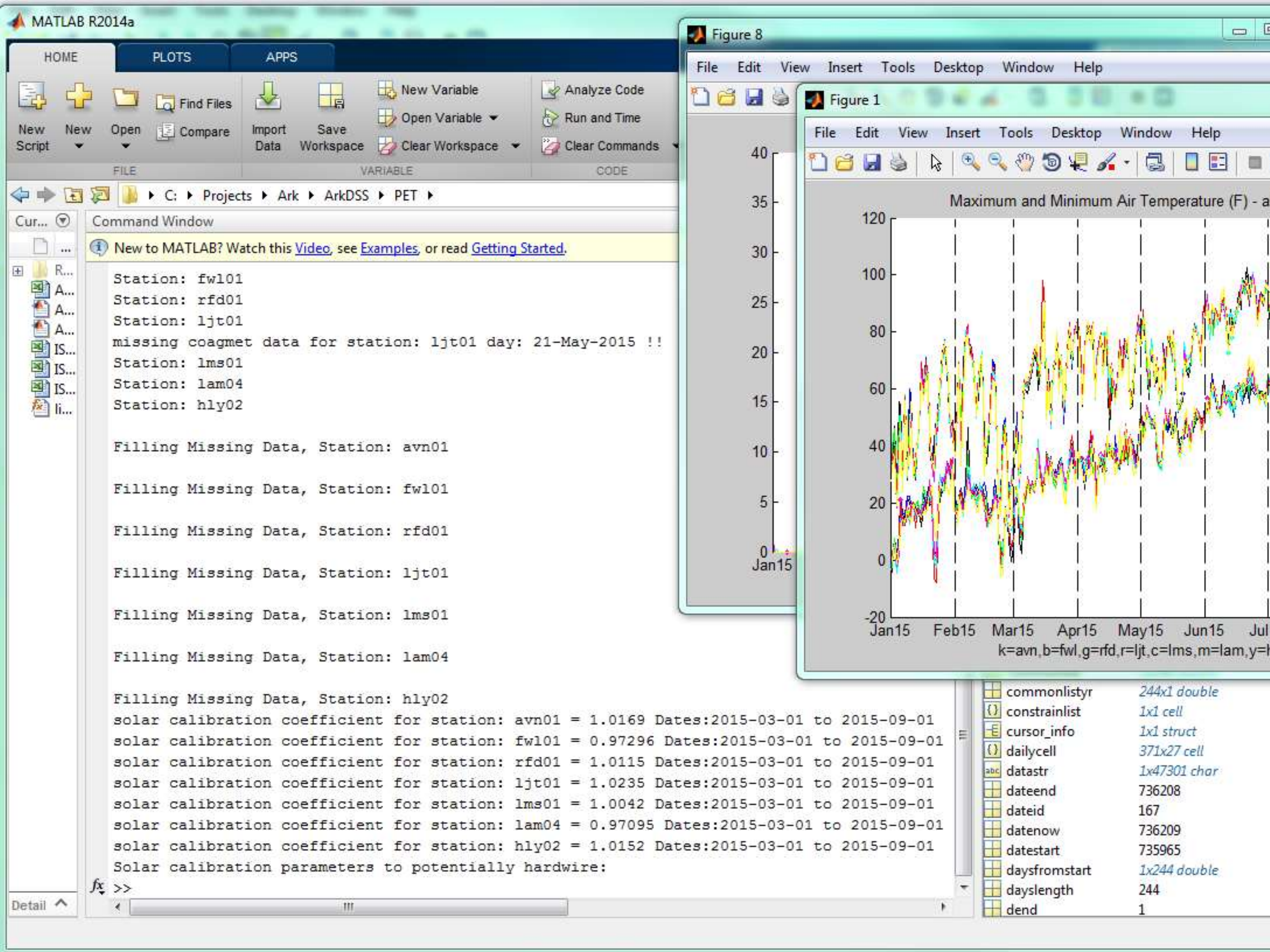
MATLAB R2014a
HOME
PLOTS
APPS
New Script
New
Open
Find Files
Compare
Import Data
Save Workspace
New Variable
Open Variable
Clear Workspace
Analyze Code
Run and Time
Clear Commands
FILE
VARIABLE
CODE
C: Projects Ark ArkDSS PET
Command Window
New to MATLAB? Watch this Video, see Examples, or read Getting Started.
Station: fwl01
Station: rfd01
Station: ljt01
missing coagmet data for station: ljt01 day: 21-May-2015 !!
Station: lms01
Station: lam04
Station: hly02
Filling Missing Data, Station: avn01
Filling Missing Data, Station: fwl01
Filling Missing Data, Station: rfd01
Filling Missing Data, Station: ljt01
Filling Missing Data, Station: lms01
Filling Missing Data, Station: lam04
Filling Missing Data, Station: hly02
solar calibration coefficient for station: avn01 = 1.0169 Dates:2015-03-01 to 2015-09-01
solar calibration coefficient for station: fwl01 = 0.97296 Dates:2015-03-01 to 2015-09-01
solar calibration coefficient for station: rfd01 = 1.0115 Dates:2015-03-01 to 2015-09-01
solar calibration coefficient for station: ljt01 = 1.0235 Dates:2015-03-01 to 2015-09-01
solar calibration coefficient for station: lms01 = 1.0042 Dates:2015-03-01 to 2015-09-01
solar calibration coefficient for station: lam04 = 0.97095 Dates:2015-03-01 to 2015-09-01
solar calibration coefficient for station: hly02 = 1.0152 Dates:2015-03-01 to 2015-09-01
Solar calibration parameters to potentially hardwire:
>>
Figure 8
Figure 1
File Edit View Insert Tools Desktop Window Help
Maximum and Minimum Air Temperature (F) - a
Jan15 Feb15 Mar15 Apr15 May15 Jun15 Jul
k=avn,b=fwl,g=rfd,r=ljt,c=lms,m=lam,y=
commonlistyr 244x1 double
constrainlist 1x1 cell
cursor_info 1x1 struct
dailycell 371x27 cell
datastr 1x47301 char
dateend 736208
dateid 167
datenow 736209
datestart 735965
daysfromstart 1x244 double
dayslength 244
dend 1

QA/QC of ASCE Std ET datasets
Automated Identification of Bad Data

- Missing
- Exactly zero (except precip)
- Outside Ranges:
  - Temp < -39C, >60C (-40F-131F)
  - RH <0.005 , >1.05 – (vapor-pressure listed bad)
  - RH>1,<1.05 within sensor accuracy – (evaluated recalculation of vapor pressure with hourly data)
  - Solar/wind/vapor pressure <0
  - Wind < 0.5 m/s - (per Manual 70 replace with 0.5m/s)
- If daily solar radiation not close at times to Rso clear sky envelope, solar data recalibrated

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QA/QC of ASCE Std ET datasets
Manual Identification of Bad Data

A Series of graphs are generated to identify:

- Visible bad data points
- Visible or known bad periods due to sensor problem
- Arid conditions visible in Tmin-Tdew
- Definition when station over alfalfa (for wind correction)
- Sensor change dates are identified from service logs to evaluate solar data over periods with same sensor

All manually identified data are listed in one excel spreadsheet for continued use in future as additional data becomes available.

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Manual Identification of Bad Data in Excel

	A	B	C	D	E	F	G	H	I	J
1	Station	Date1	Date2	Item	Repl station if different than typical replacement stations (spe					
2										
3	bnv01	12/8/2013	12/10/2013	solar.rad						
4	bnv01	3/24/2015	3/24/2015	solar.rad						
5	bnv01	11/19/2015	11/19/2015	solar.rad						
6	bnv01	3/13/2014	3/13/2014	solar.rad						
7	sld01	12/14/2015	12/14/2015	solar.rad						
8	sld01	3/24/2015	3/24/2015	solar.rad						
9	cnn01	9/22/2011	9/22/2011	solar.rad						
10	hne01	4/14/2007	4/14/2007	solar.rad						
11	hne01	3/12/2005	3/12/2005	solar.rad						
12	avn01	6/14/2014	12/31/2014	wind.speed	fwl01					
13	scm01	3/25/2009	4/2/2009	wind.speed						
14	scm01	1/8/2015	1/8/2015	solar.rad						
15	scm01	11/9/2012	11/9/2012	solar.rad						
16	hly02	1/1/2012	3/19/2012	wind.speed						
17	hly02	10/13/2011	12/31/2011	wind.speed						
18	hly01	7/24/2007	7/24/2007	solar.rad	lam04					
19	hly01	5/28/2007	5/28/2007	solar.rad	lam04					
20	hly01	12/22/2006	12/23/2006	solar.rad	lam04					
21	rfd01	6/4/1992	7/8/1993	vaporpres.vaporpres						
22	rfd01	8/3/1993	6/20/1995	vaporpres.vaporpres						
23	rfd01	6/21/1995	6/26/1995	vaporpres.vaporpres	vld01					
24	rfd01	6/27/1995	11/23/1997	vaporpres.vaporpres						
25	rfd01	11/24/1997	12/31/1997	vaporpres.vaporpres	vld01					
26	rfd01	1/1/1998	3/15/1999	vaporpres.vaporpres						
27	rfd01	3/16/1999	3/16/1999	vaporpres.vaporpres	vld01					
28	rfd01	3/17/1999	8/4/1999	vaporpres.vaporpres						

manualreplace | testtipreplace | straightreplace | solarbreaks | solarcoeffs | alfalfatograss

QA/QC of ASCE Std ET datasets

Automated Replacement of Missing/Bad Data

Linear Regression Filling of Missing/Bad Data: (y=mx+b)

- Uses up to 3 defined replacement stations (in priority)
  - i.e. if day to be replaced is also missing or bad in 1st and 2nd stations, looks at 3rd station for that day
- Replacement station can also be manually identified
- Only compares good to good data for regression statistics (so must know bad data for replacement stations too)
- Regressions are currently done on an annual basis due to sensor changes; unless sufficient good data in common is not available in which case it uses full dataset
- If absolutely no data available from nearby stations, does a linear interpolation between days with good data.
- Regression not used for vapor pressure

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QA/QC of ASCE Std ET datasets

Automated Replacement of Missing/Bad Data

Missing/Bad Vapor Pressure Data or Defined Aridity

- ASCE-EWRI (2005) Equation D.8
- tdew(station2)=tmin(station2) – (tmin-tdew)(station1)
- Uses 3 defined replacement stations or manually defined.

Straight Replacement of Missing/Bad Data: (no regression)

- If sensor is bad for significant time periods (ie many months or even years), linear regression is not appropriate
- Mainly used for solar and wind data
- Manually defined as straight replacement in spreadsheet
- Uses 3 defined replacement stations or manually defined

Filling missing daily data using available hourly data evaluated:

- Often introduced additional bad hourly data

QA/QC of ASCE Std ET datasets

Automated Replacement of Missing/Bad Data

Wind speed adjustment when station over alfalfa:

wind(grass) = wind(alfalfa)*1.04+0.13 (Ley et. al. 2013)

Solar Calibration: Script checks solar radiation data against the clear sky envelope (complex method) and may re-calibrate data (Hill and Ley 2002, HIM)

- compute 20 largest daily ratios between March 1 and October 31
- any of the 20 ratios that <>1 standard deviation from the mean thrown out
- the reciprocal of the mean is considered a calibration coefficient
- calibration coefficient is applied when it is more than 3% from unity
- if pyranometers are changed mid-season, calibration coefficients considered before and after change with number of ratios prorated based on days in period
- calibration coefficients can be automated or hardwired for future use

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Notes on Rso – use complex method

Complex method used to calculate Rso (clear sky envelope):

- ASCE-EWRI (2005) provides two methods to calculate clear sky radiation; simple and complex. Complex considers precipitable water in the atmosphere.
- The ASCE-EWRI ET committee recommended in 2009 that the more complex method should be used for both quality control and for calculation of net radiation using the ASCE standardized method (from Allen 2013).

Allen, R. (2013). "Users Manual - Ref-ET Reference Evapotranspiration Calculator Version - Windows 3.1.15". University of Idaho Research and Extension Center, Kimberly, Idaho.

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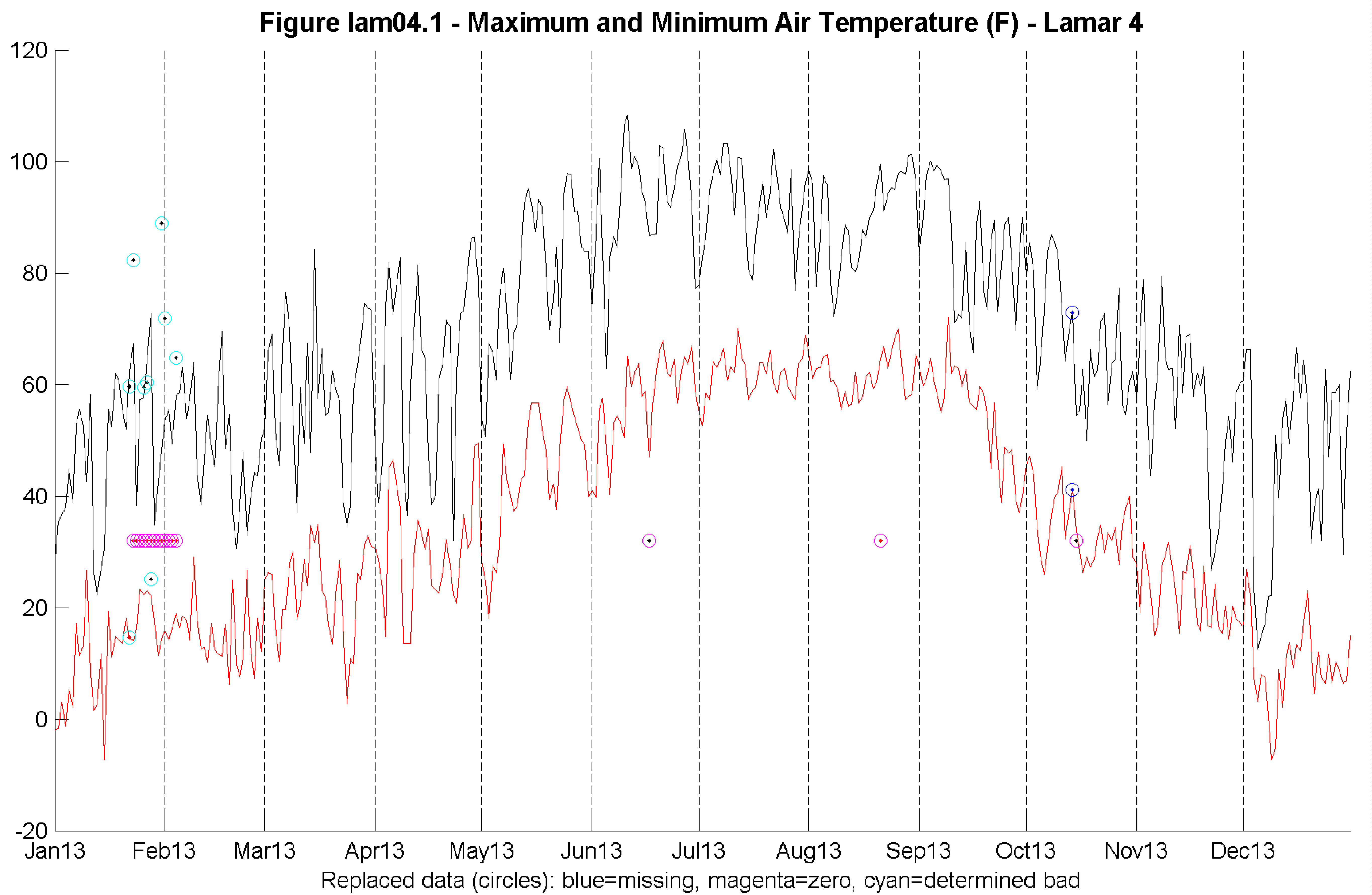
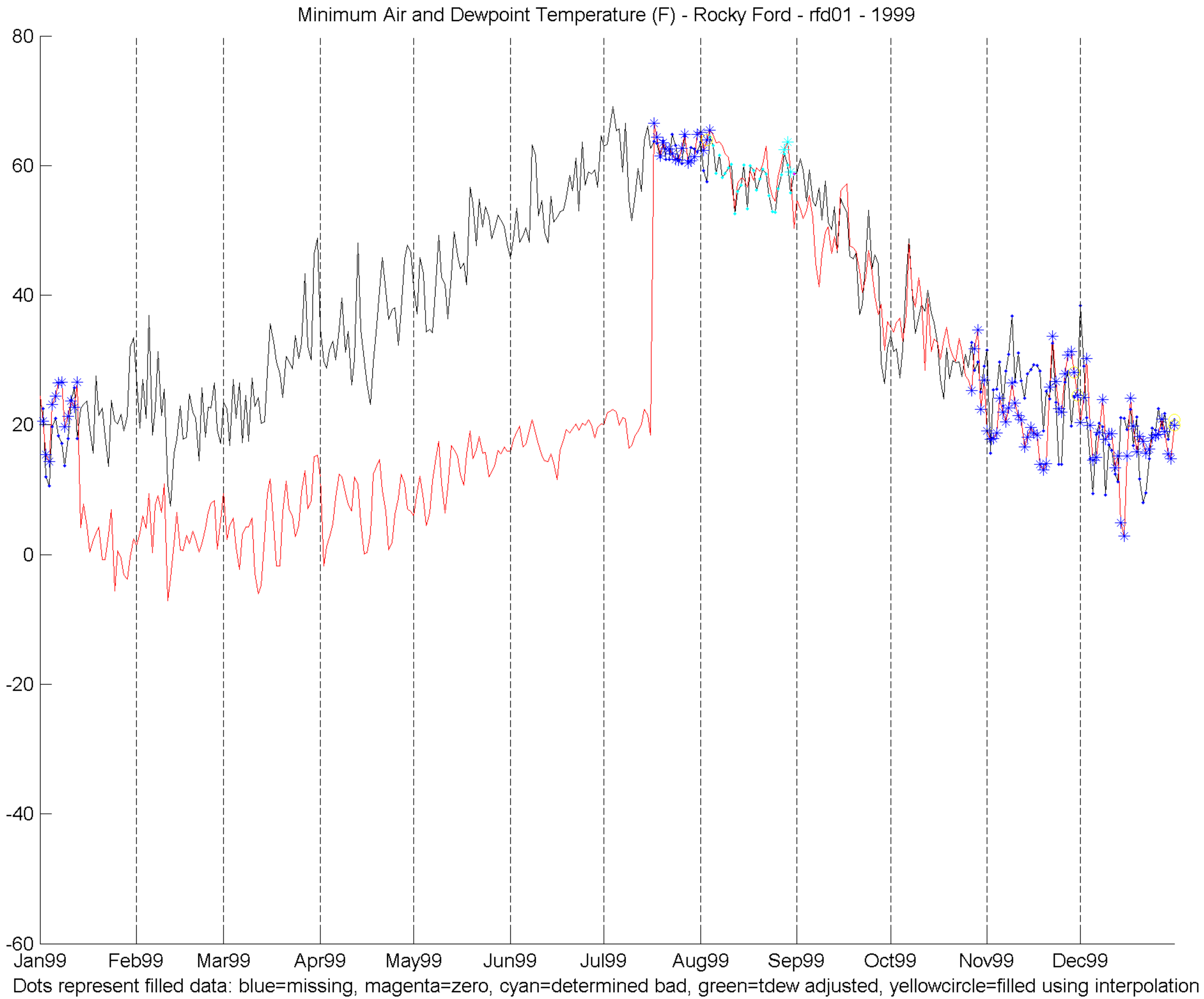
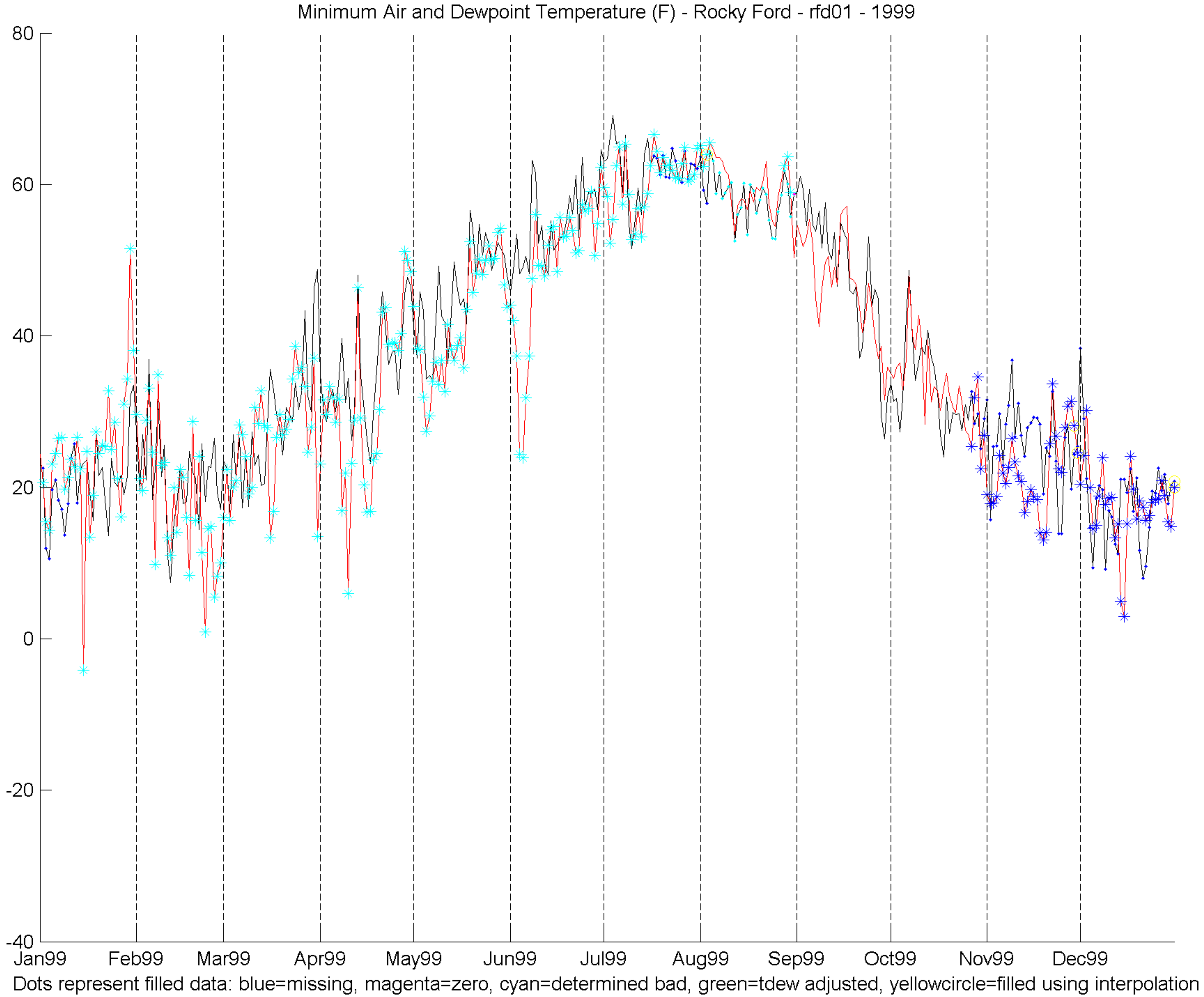
QA/QC Temperature Data



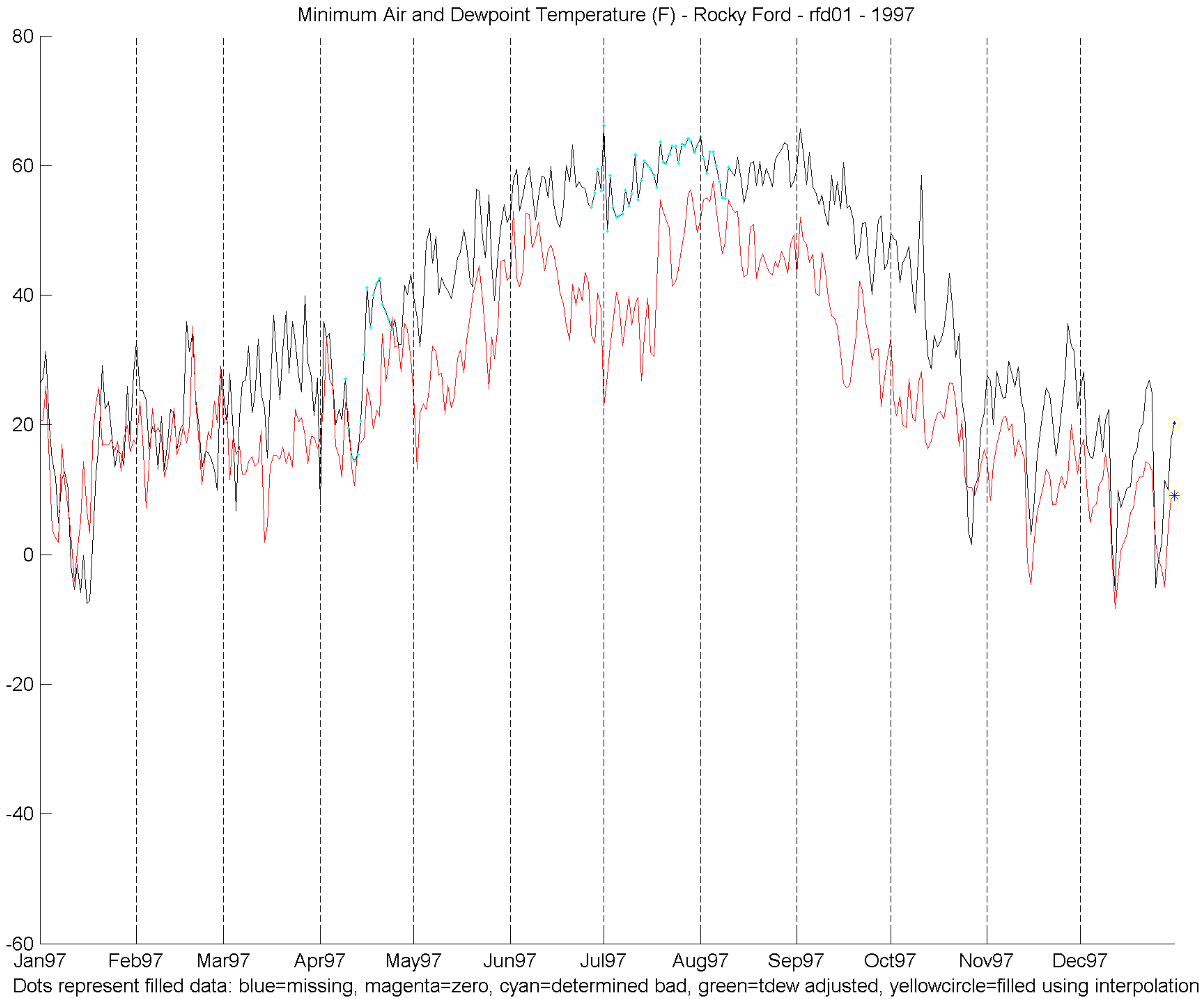
QA/QC Humidity Data (Tmin-Tdew)



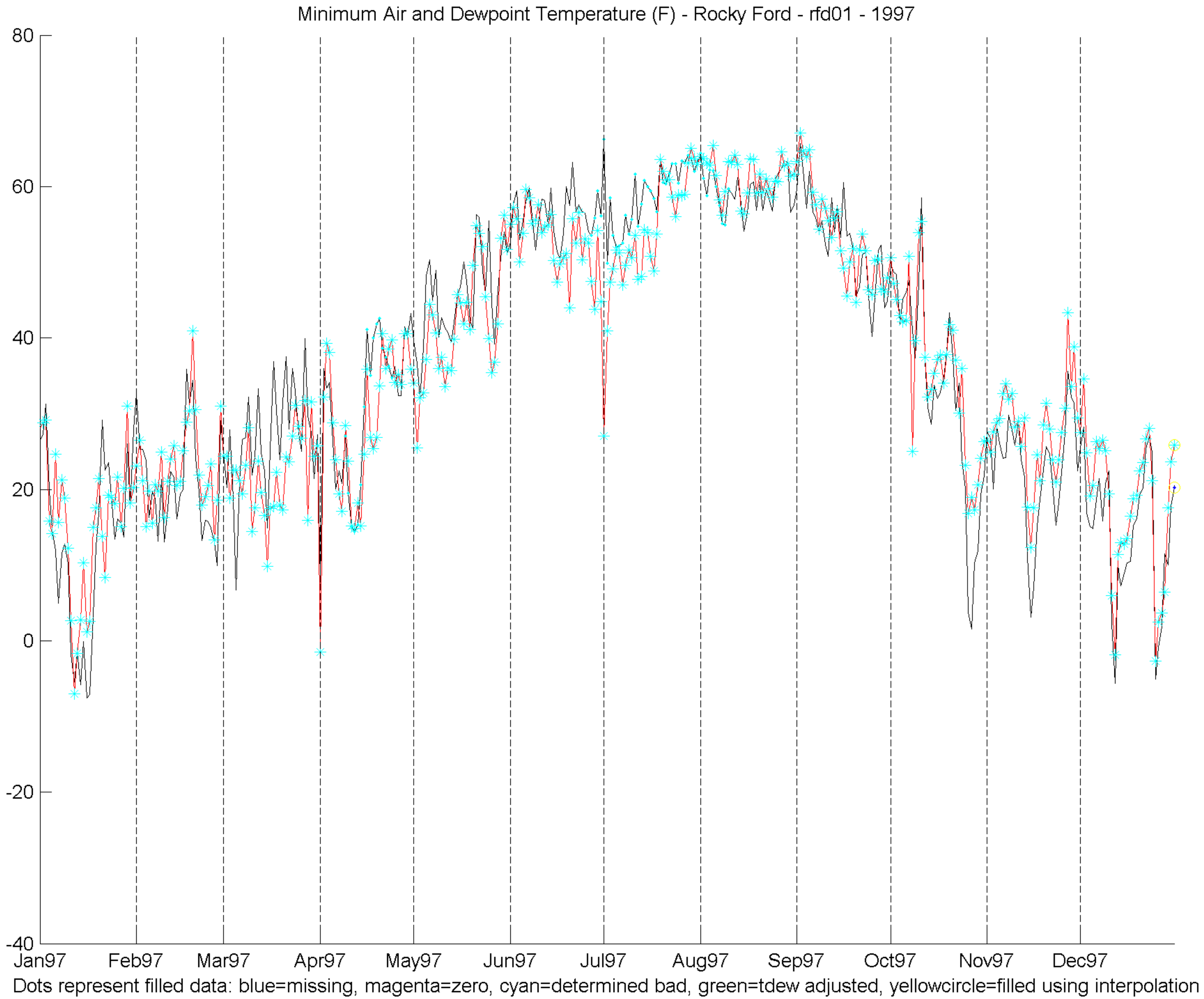
QA/QC Humidity Data (Tmin-Tdew)



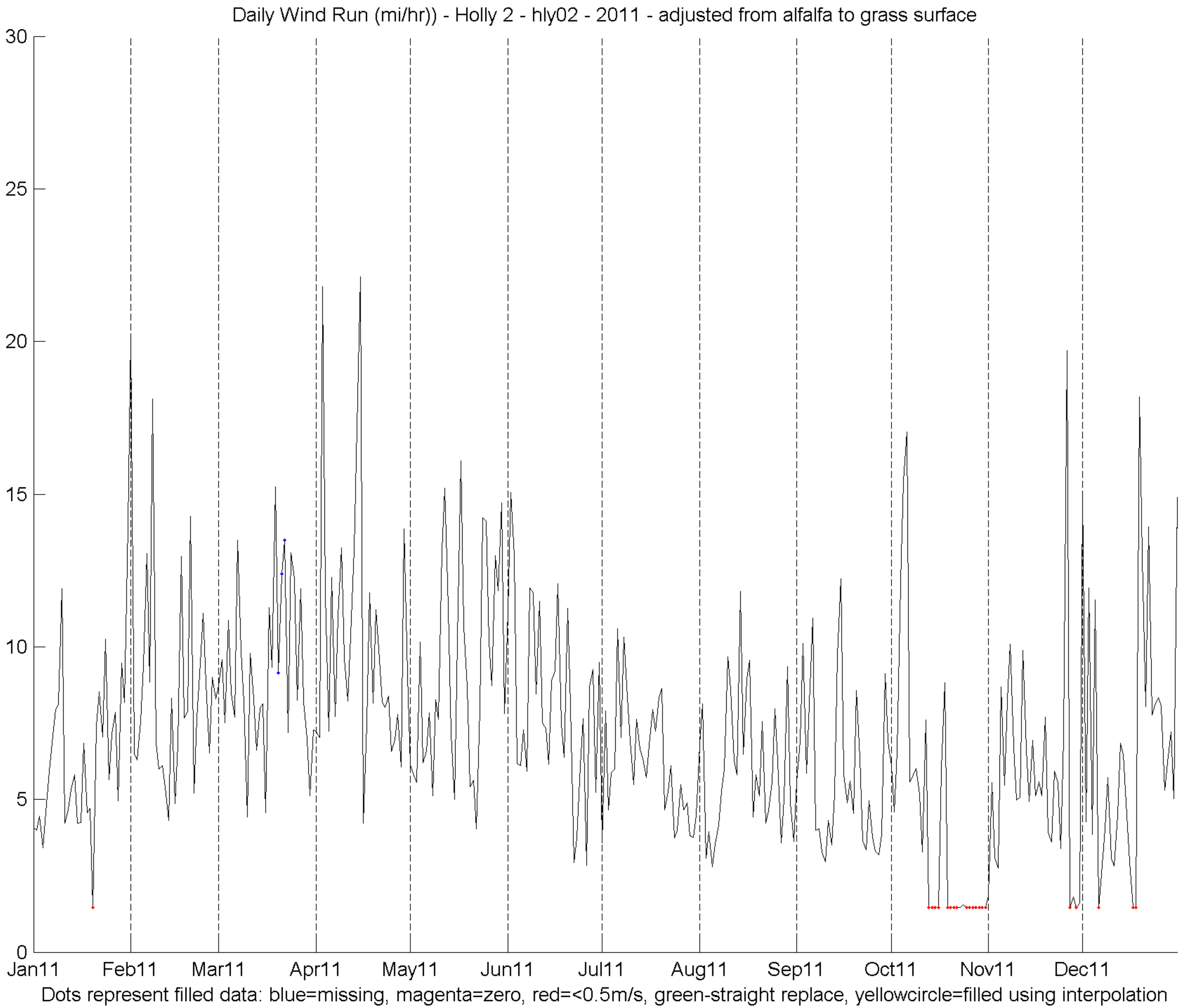
QA/QC Humidity Data (Tmin-Tdew)



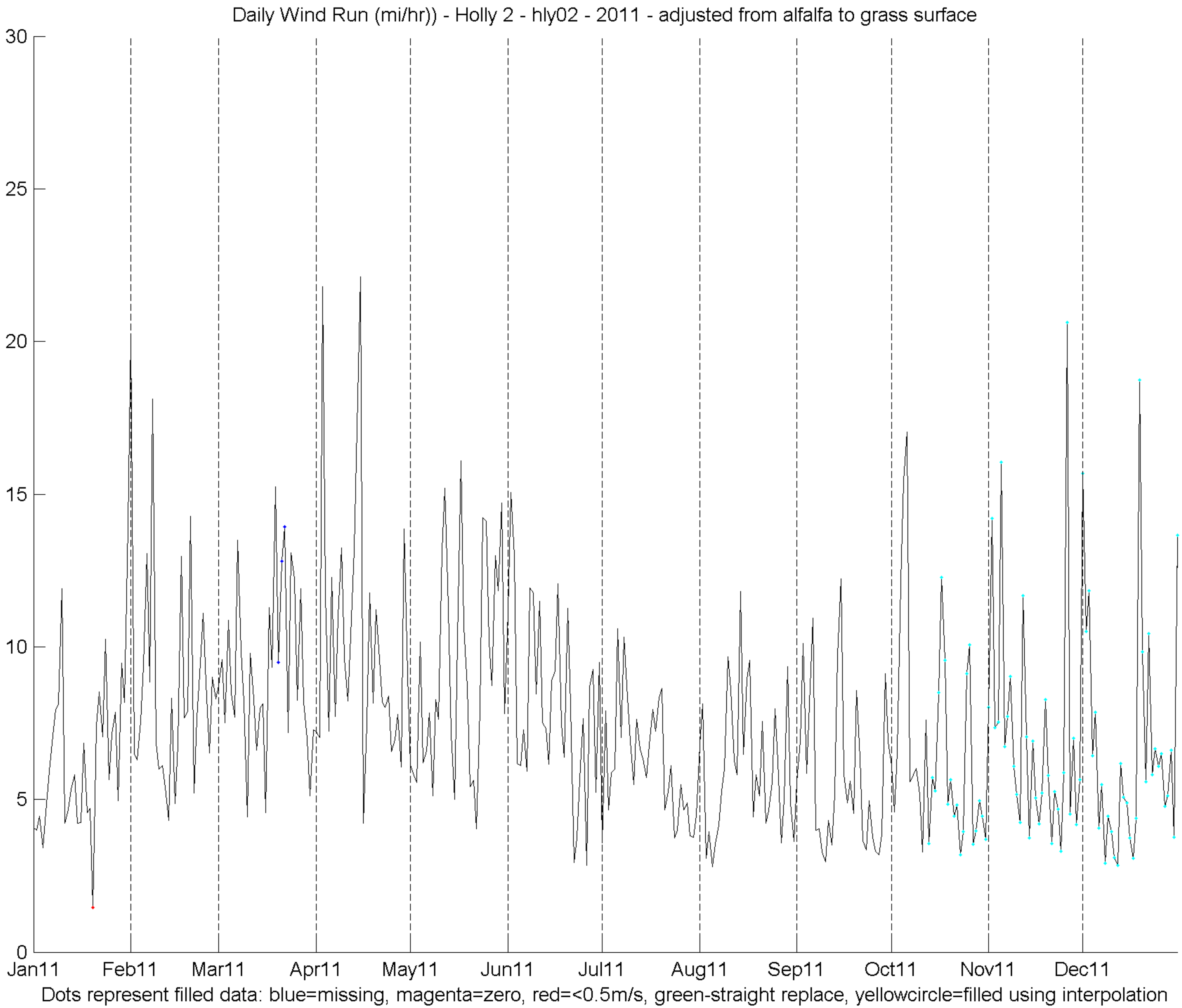
QA/QC Humidity Data (Tmin-Tdew)



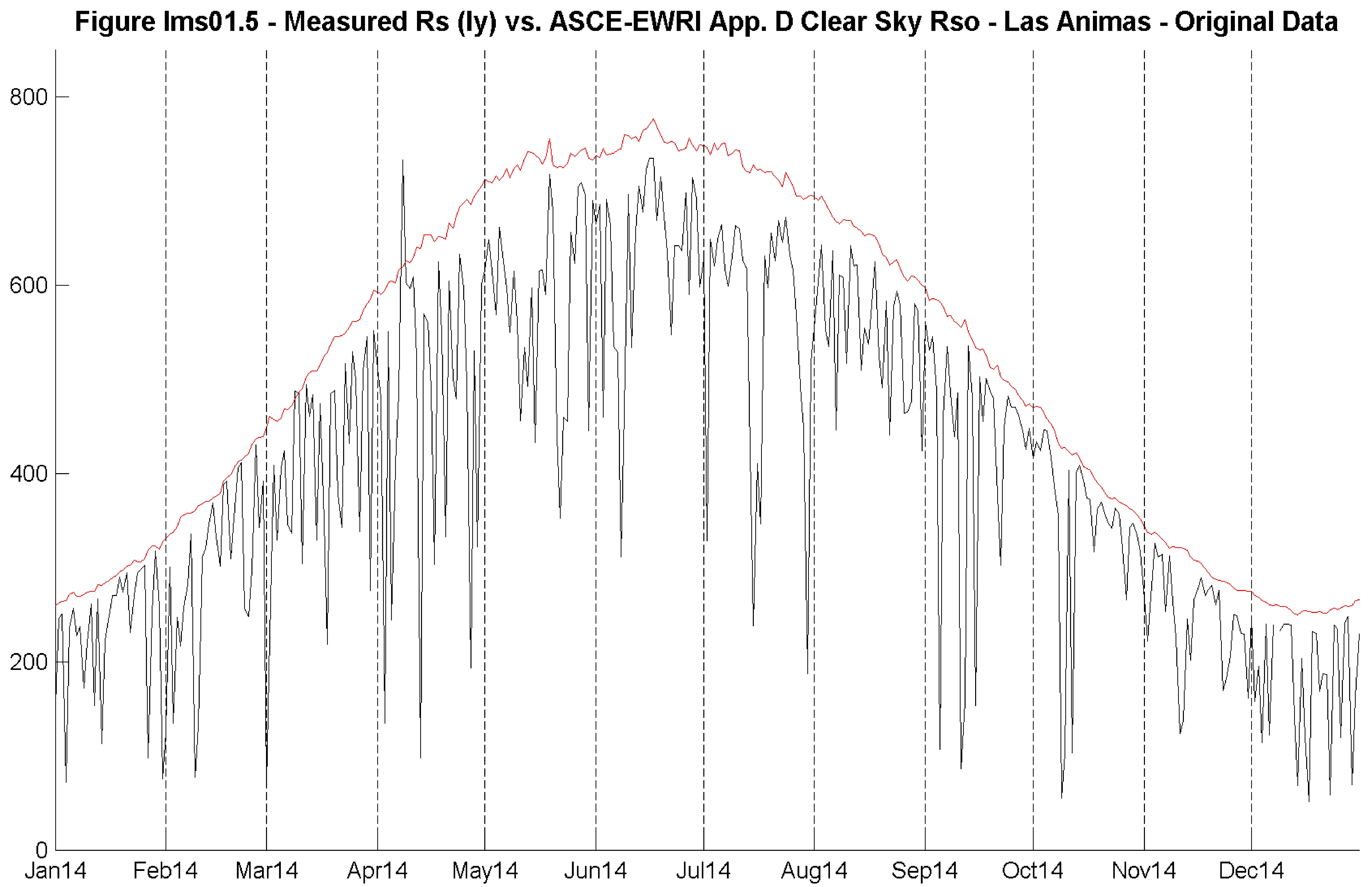
QA/QC Wind Data



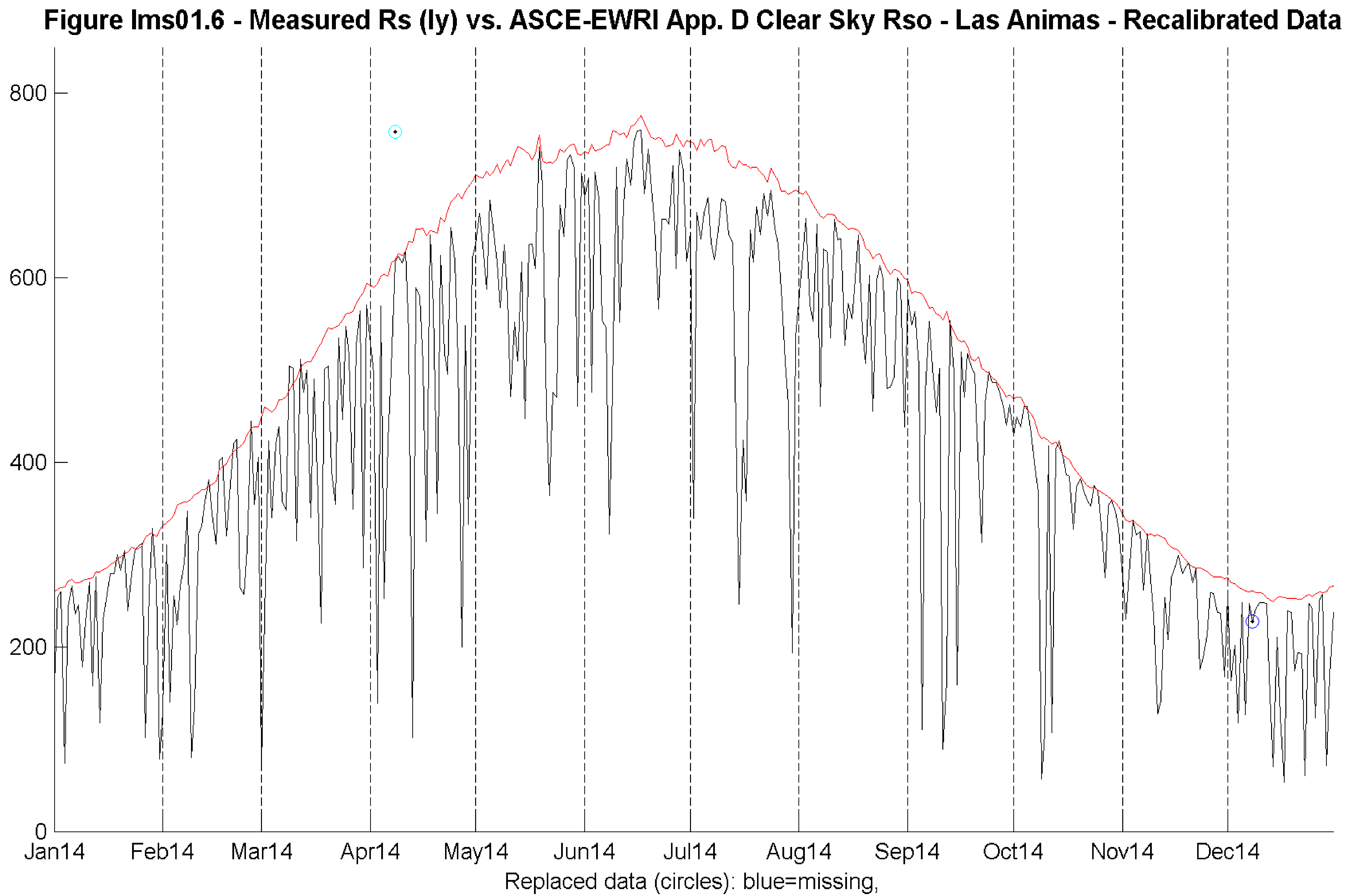
QA/QC Wind Data



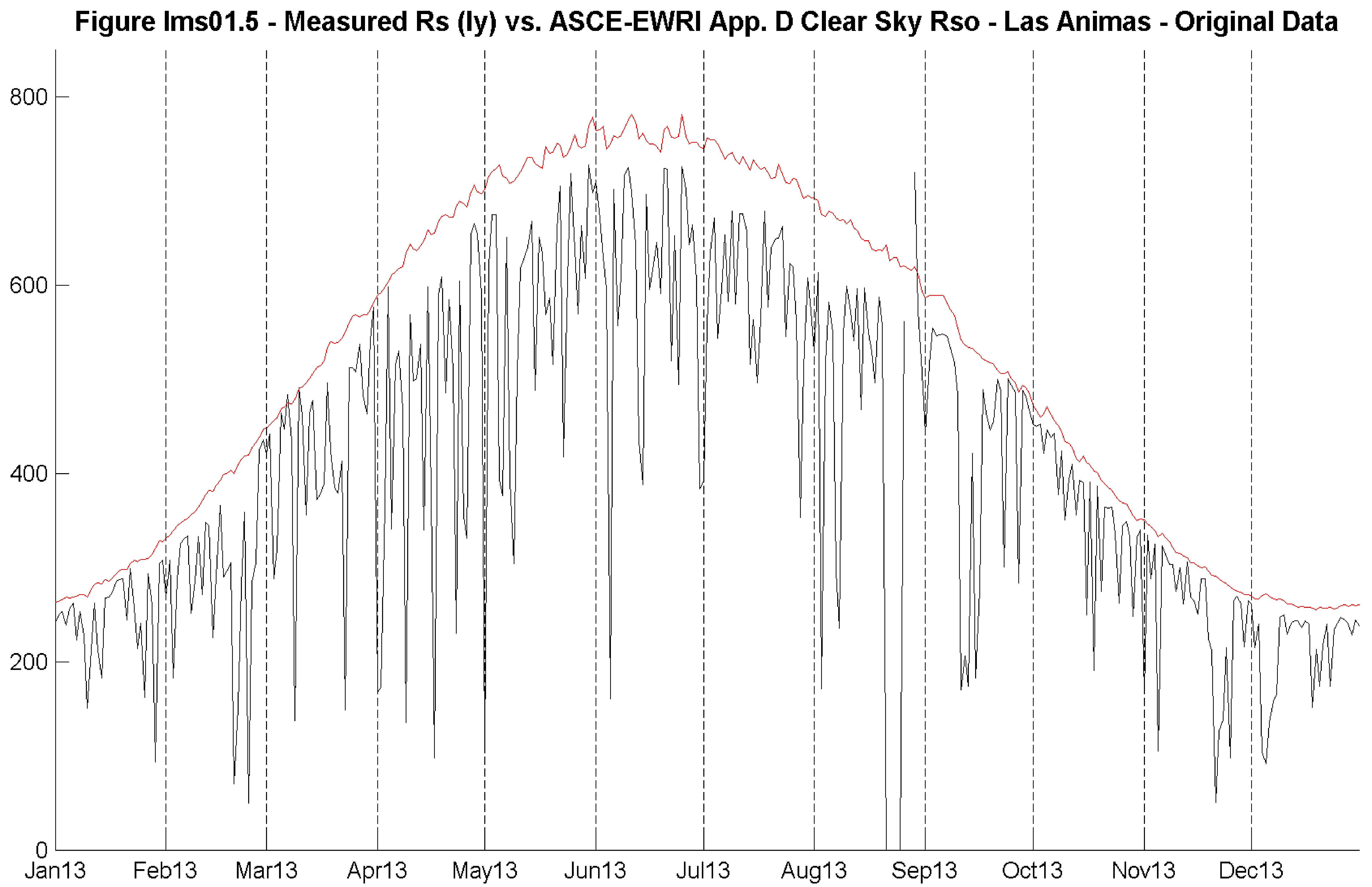
Solar Data - Raw



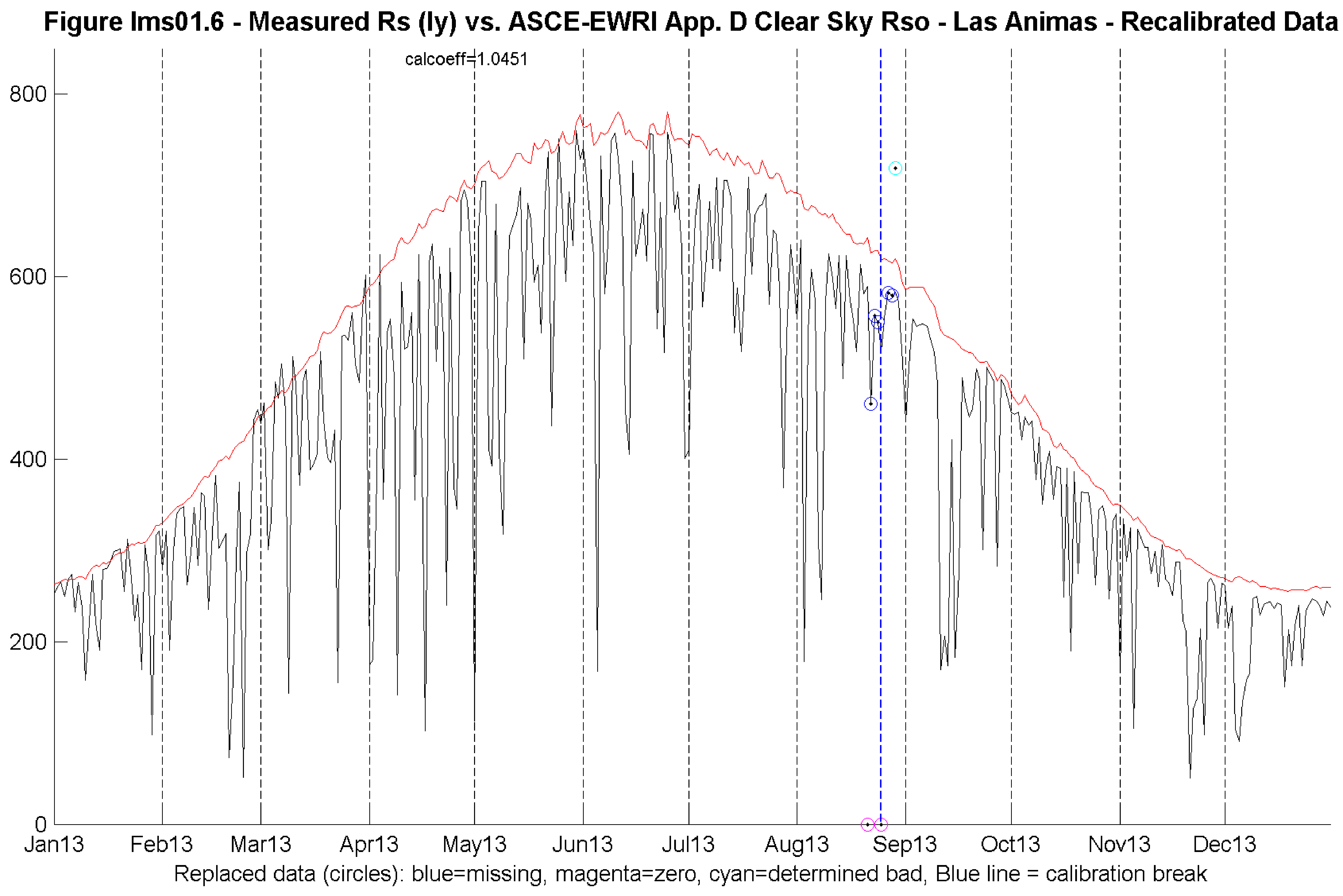
Solar Data – Recalibrated



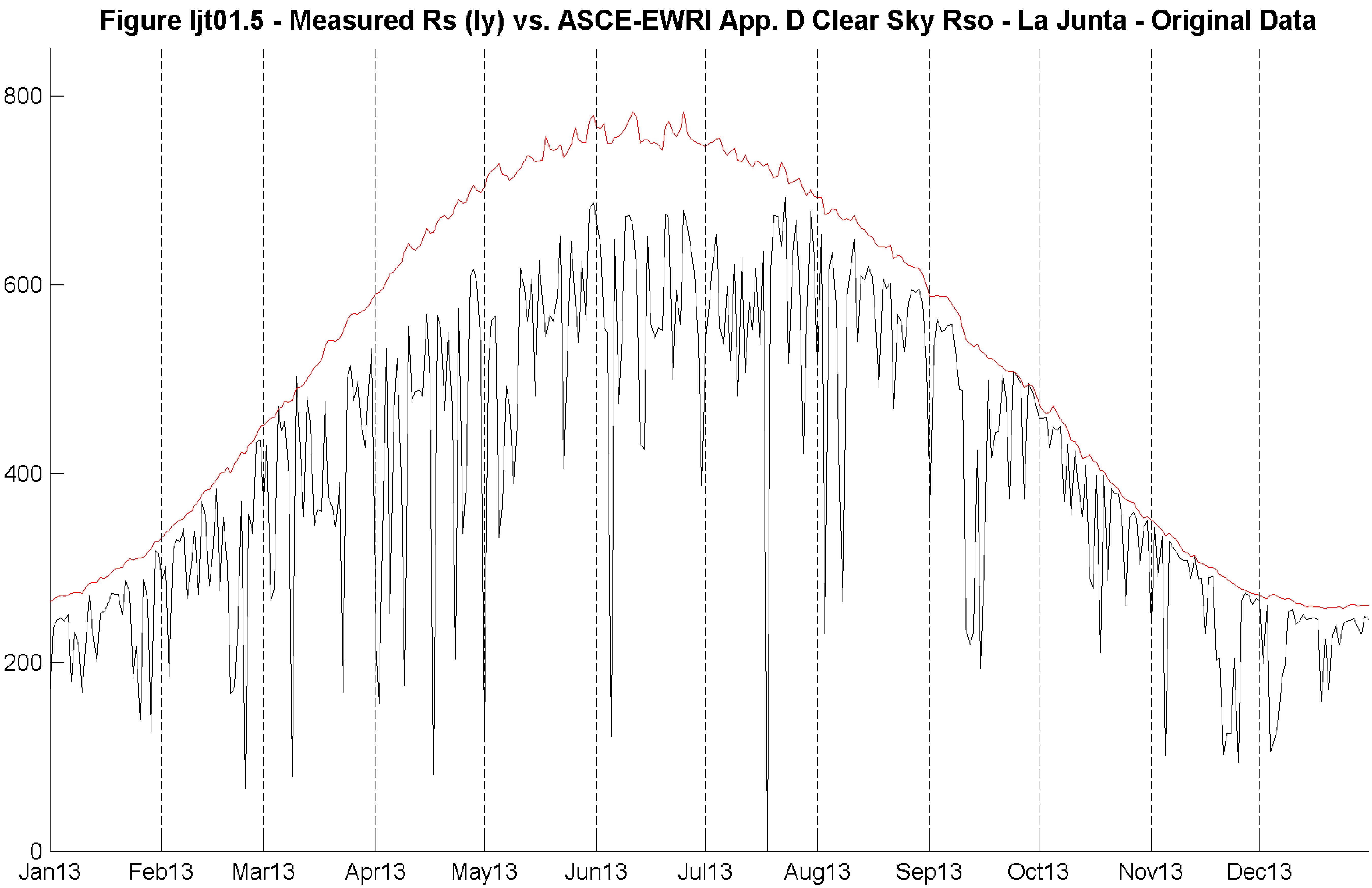
Solar Data - Raw



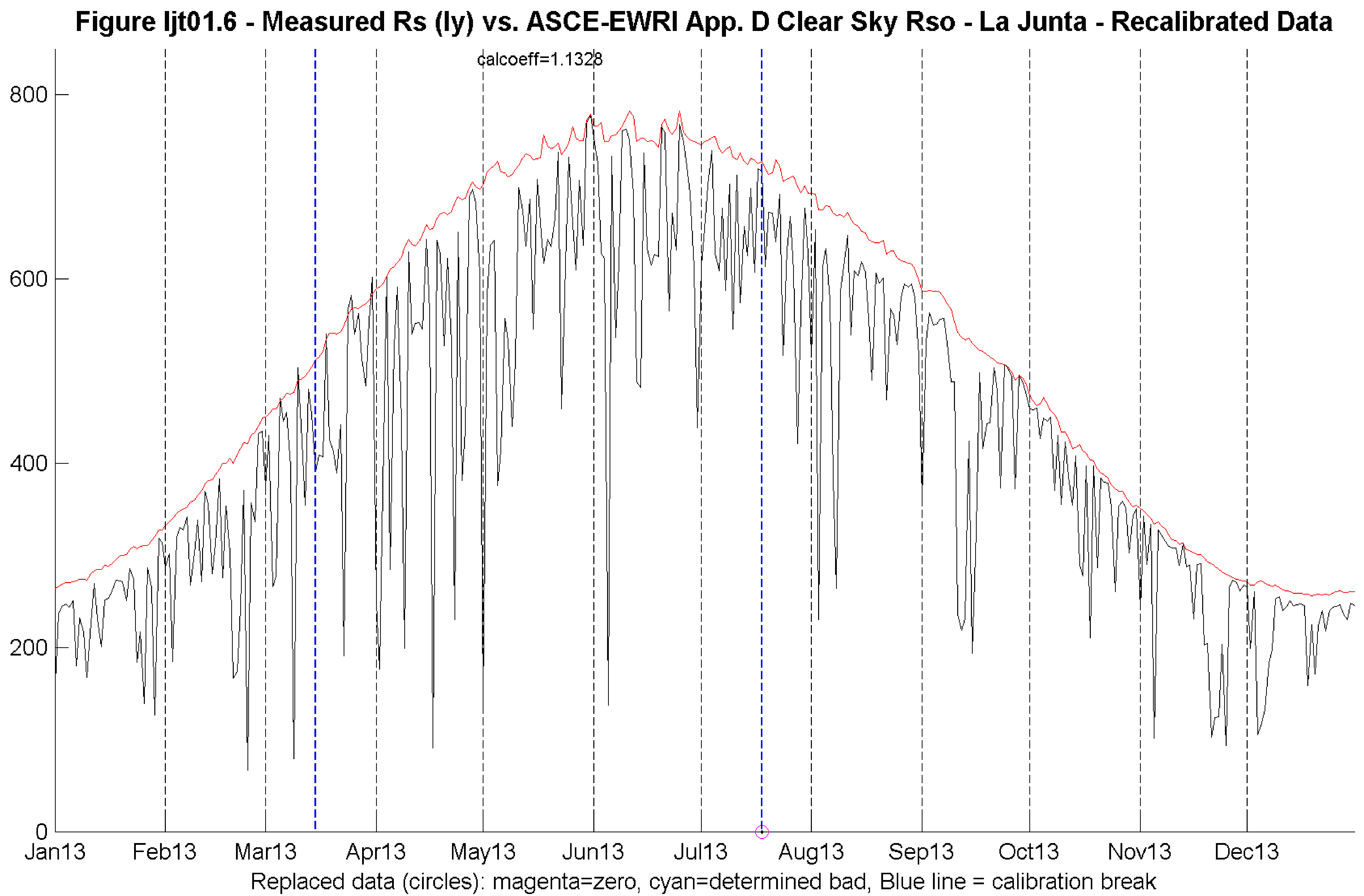
Solar Data – Recalibrated



Solar Data - Raw

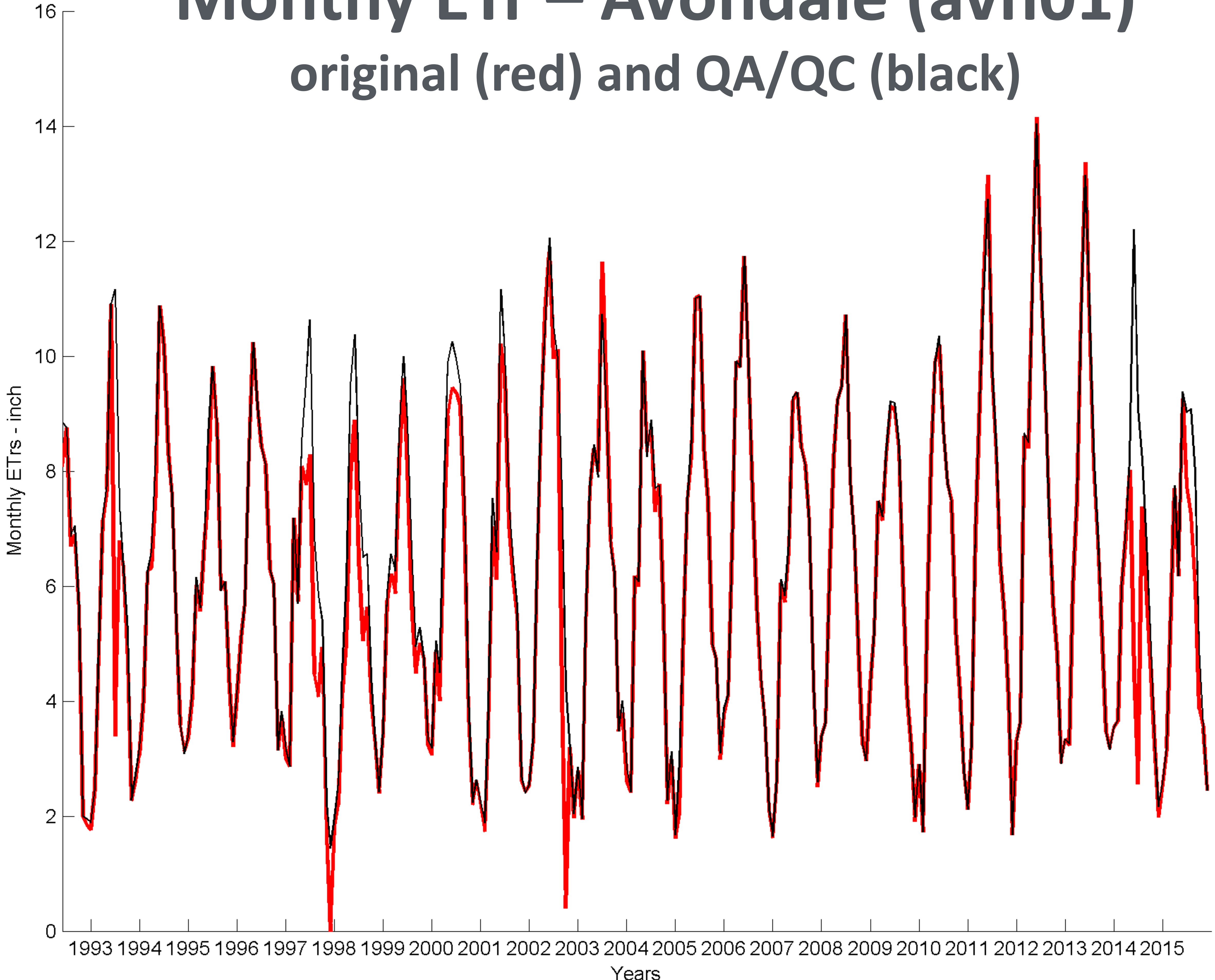


Solar Data – Recalibrated



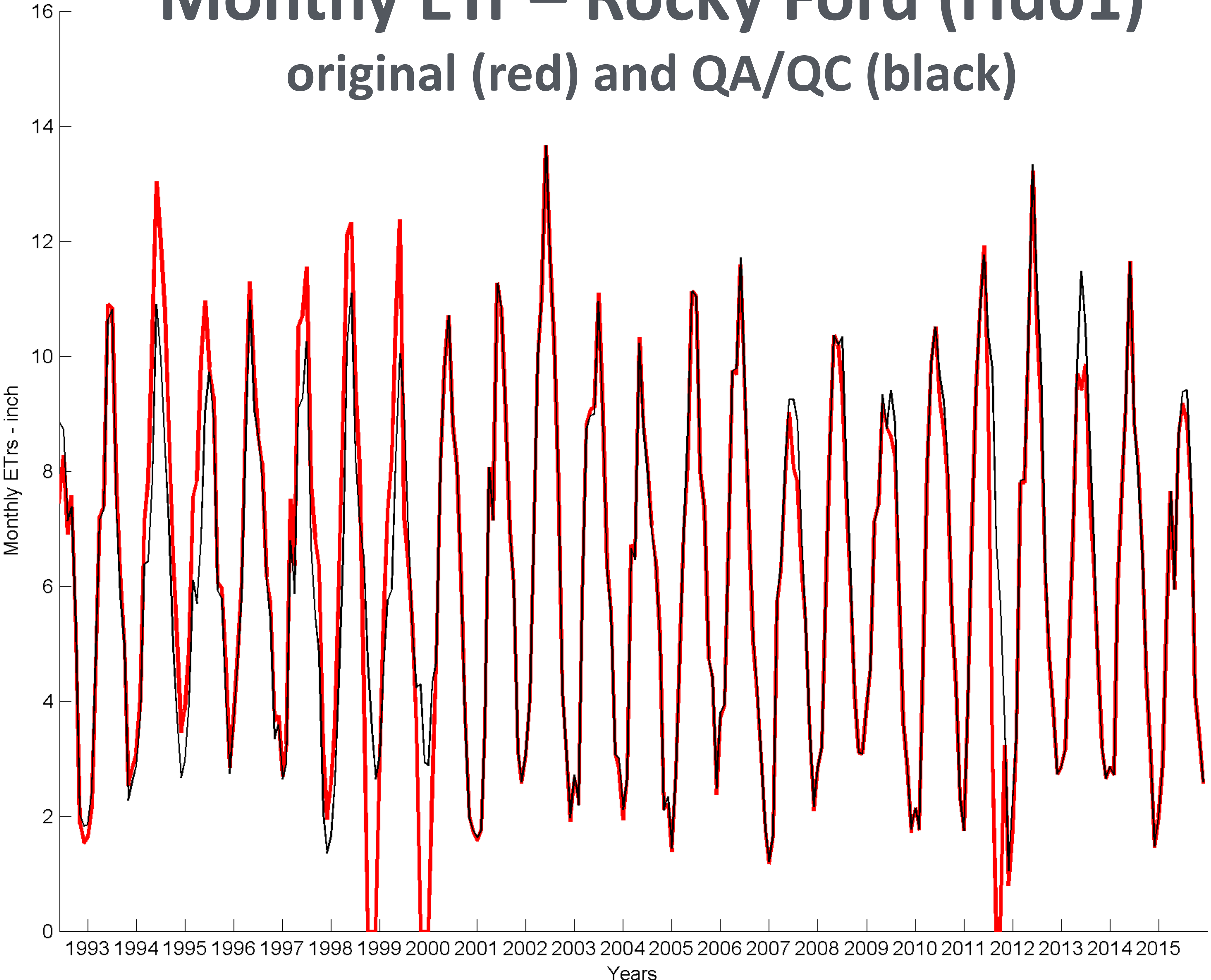
Monthy ETr – Avondale (avn01)

original (red) and QA/QC (black)



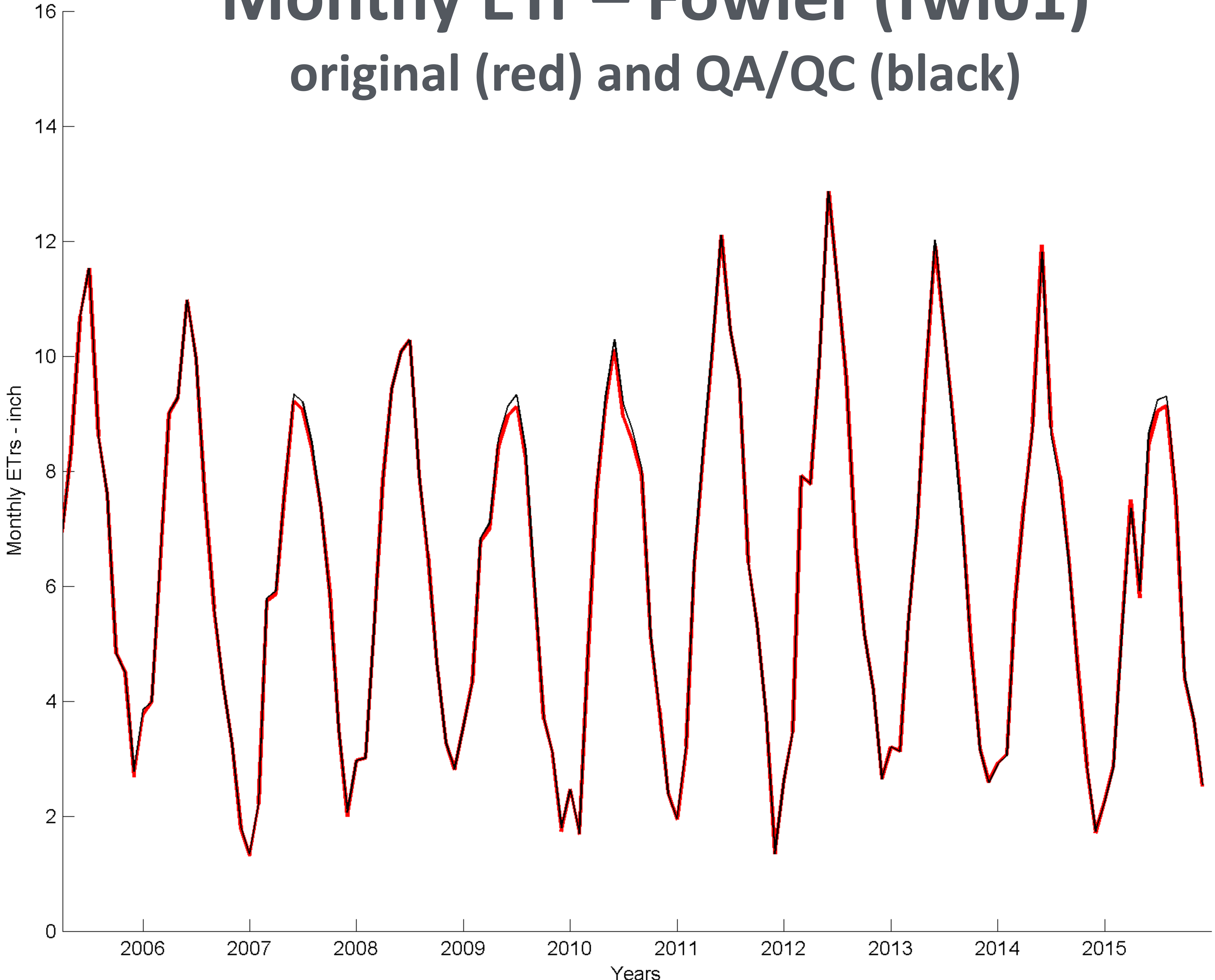
Monthy ETr – Rocky Ford (rfd01)

original (red) and QA/QC (black)



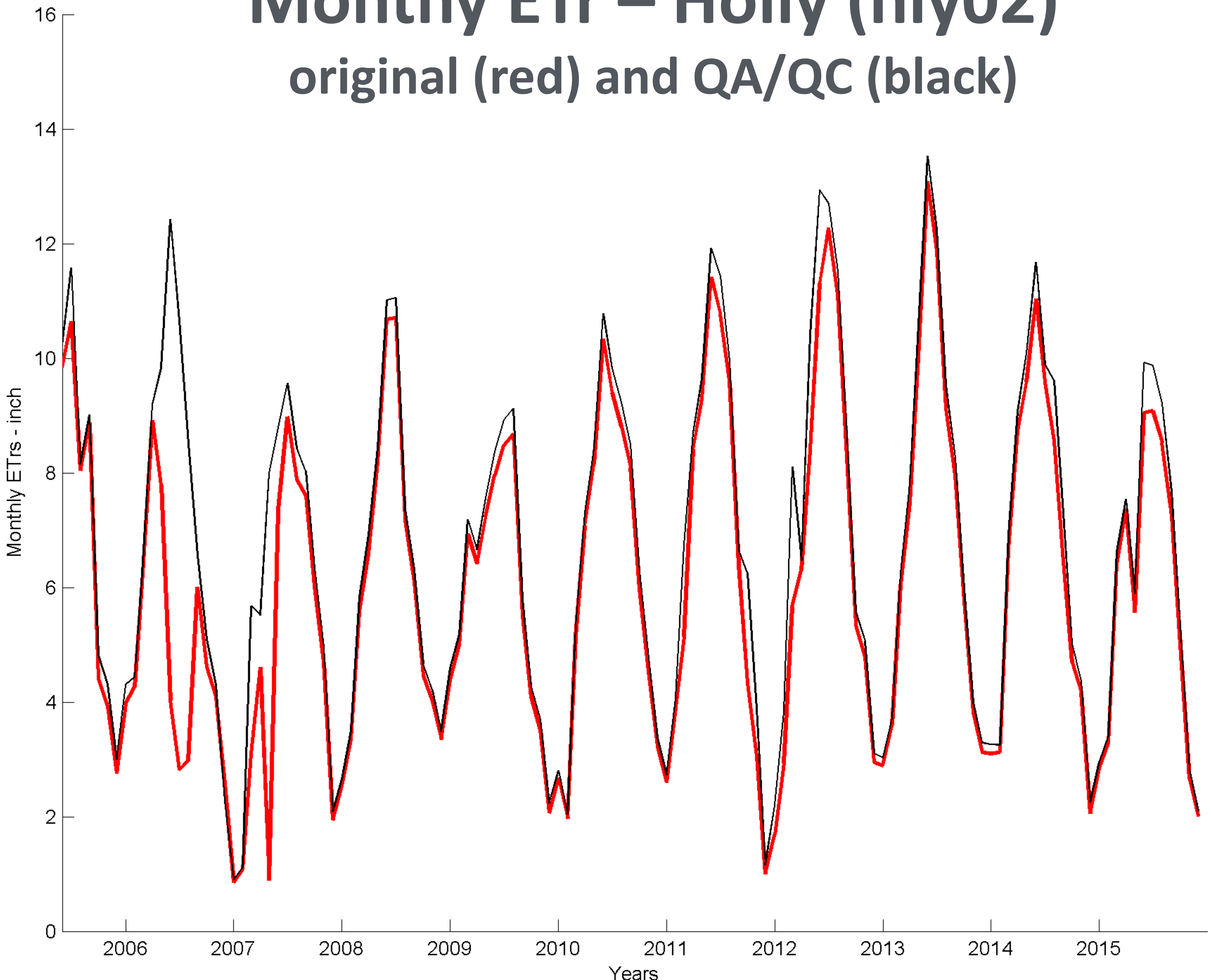
Monthy ETr – Fowler (fwl01)

original (red) and QA/QC (black)



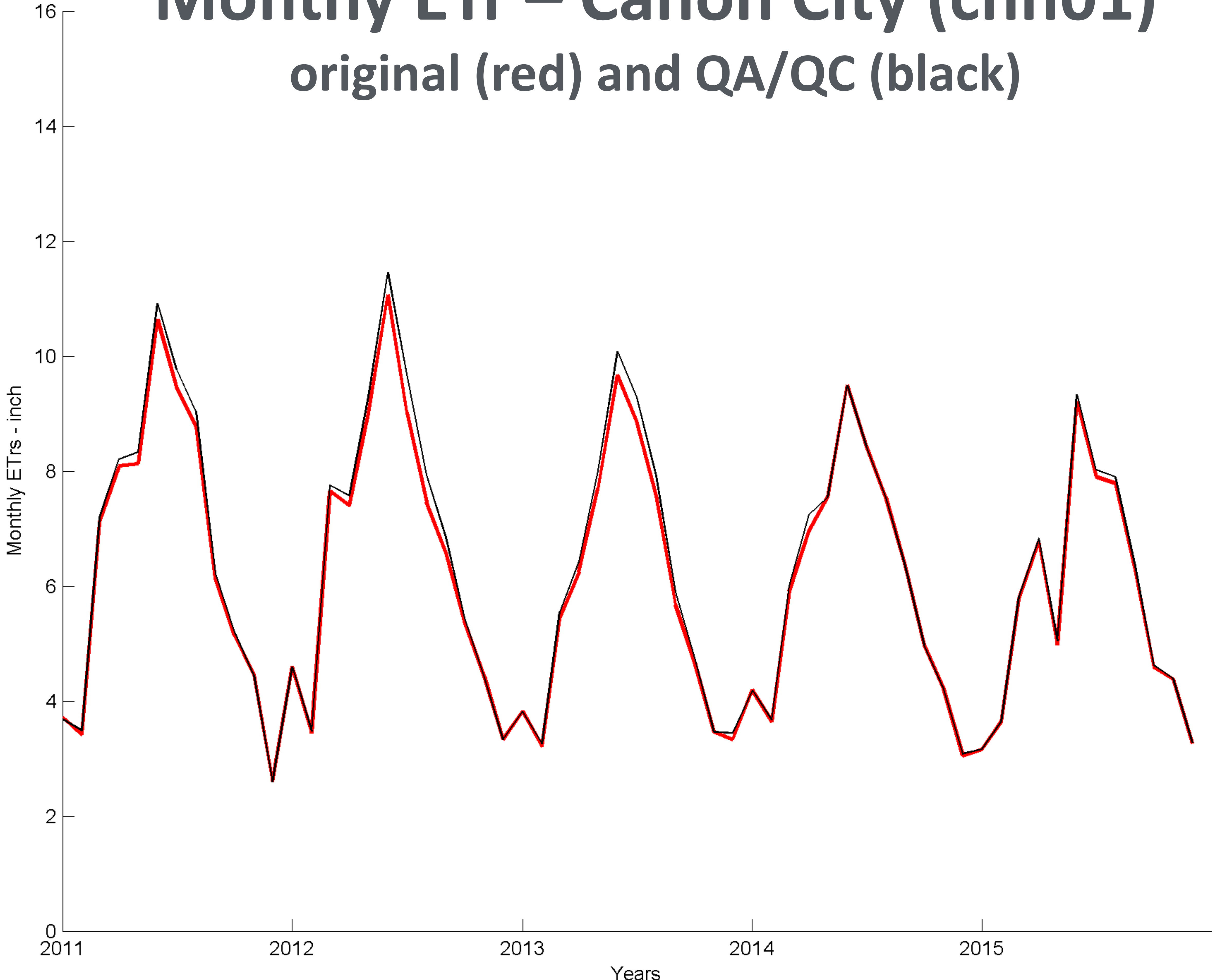
Monthy ETr – Holly (hly02)

original (red) and QA/QC (black)



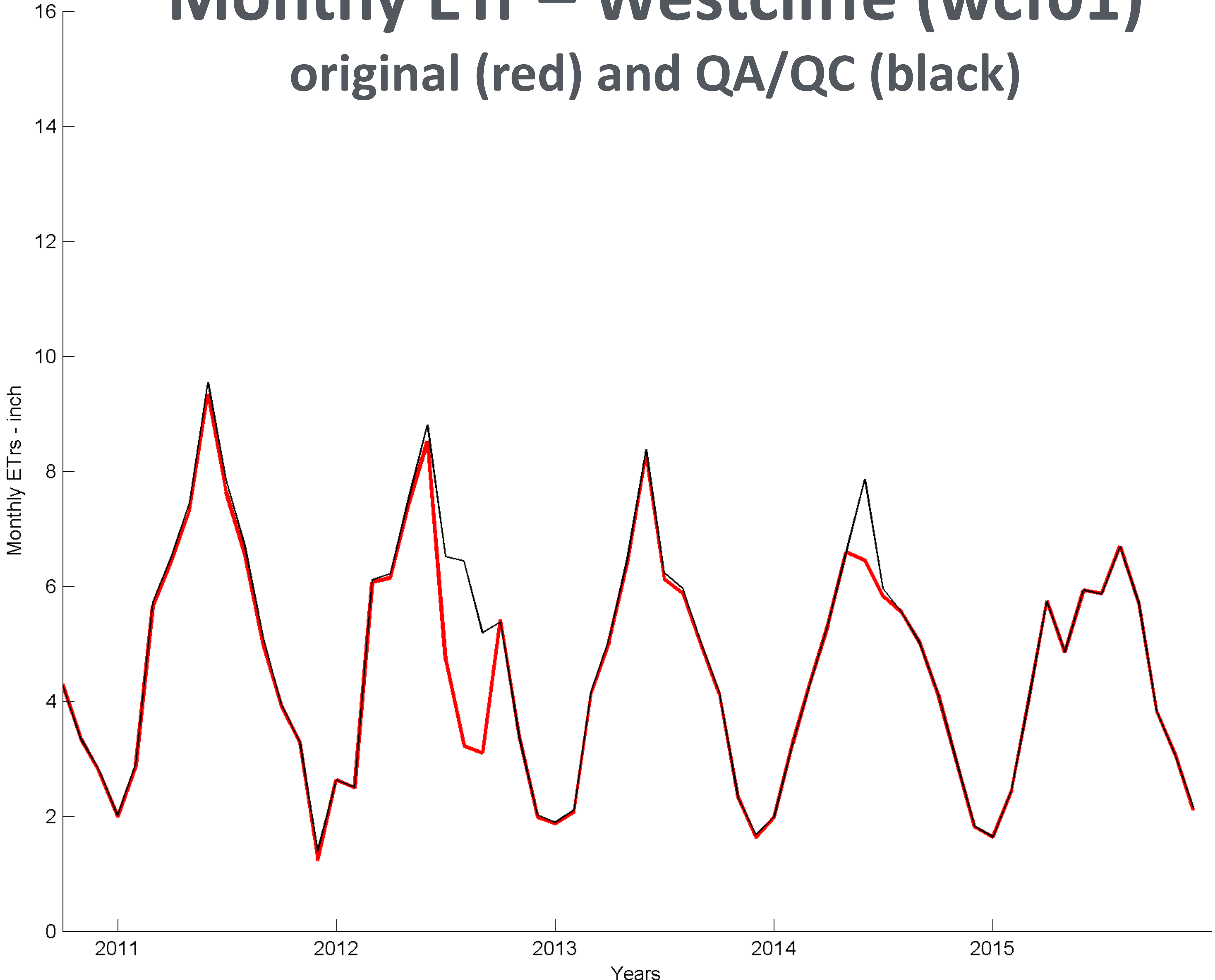
Monthy ETr – Canon City (cnn01)

original (red) and QA/QC (black)



Monthy ETr – Westcliffe (wcf01)

original (red) and QA/QC (black)




06/02/2015

WHY CALIBRATION? - study period

- **CoAgMet type station data is only available for recent period**
  - Ark Basin: 2-1992, 1-2000, 5-2005, 1-2008, 5-2010, 1-2012
- **Water right historical use analysis requires longer study period**
  - ie 1900-, 1950-, 1978-
- **Many NOAA stations DO have long-term temperature data**
- **Temperature-only ET methods do not provide accurate results without calibration to ET from ASCE Std ET equation using full (temp, RH, solar, wind) climate parameters.**
  - ➢ **Calibrate NOAA to CoAgMet Station ET for recent period**
  - ➢ **Apply Calibration to NOAA Station ET for historical period**
- **Simulation of non-temperature data for historical period (for use with ASCE Std) also requires period with full climate data**

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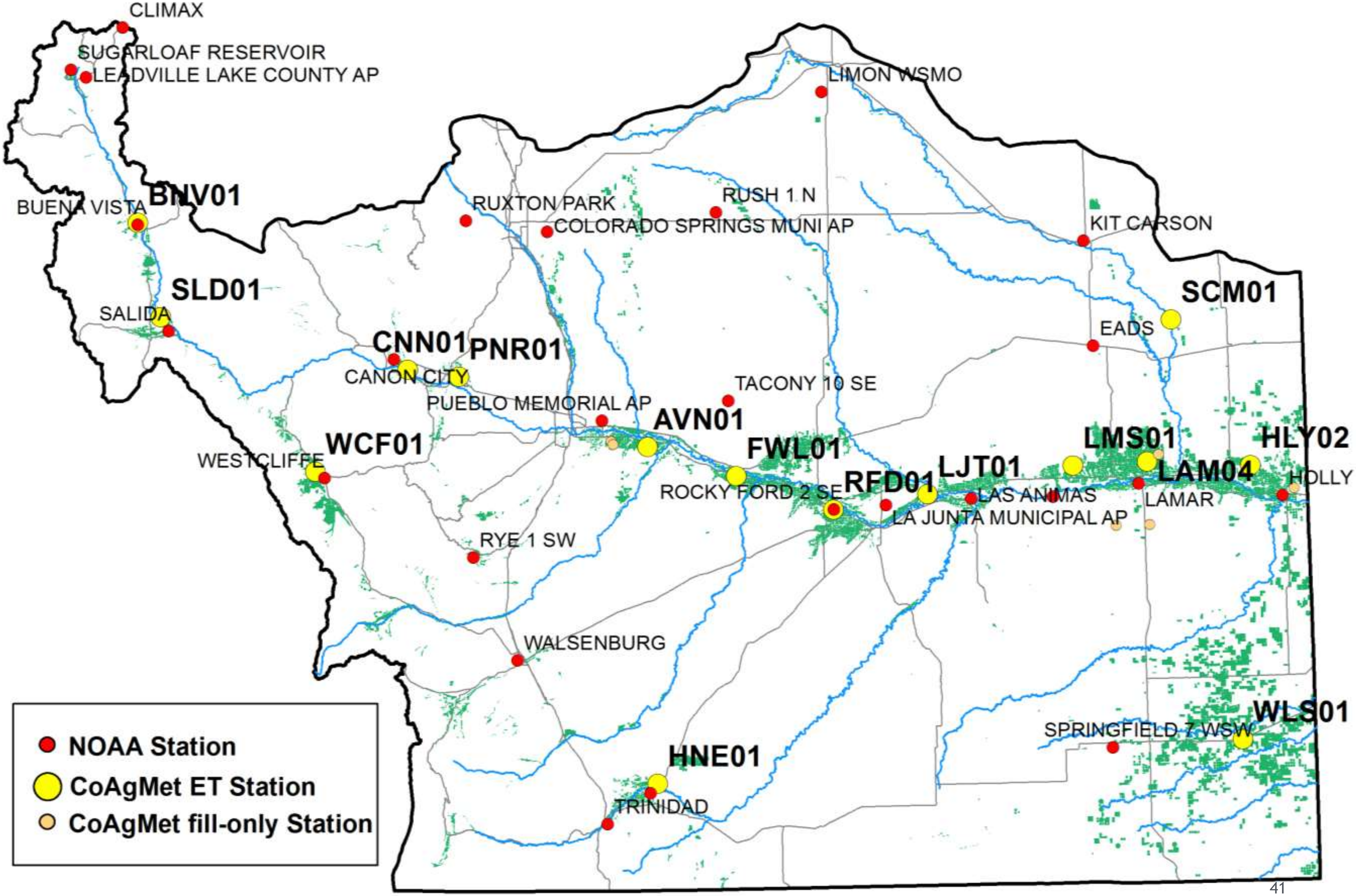
Station Locations - Arkansas River Basin



Why Calibration?
Surface Conditions

This:

Why Calibration? - Station Conditions

Versus This:

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Comparison of Calibration Methods

Modified Blaney Criddle – SCS TR21 1970

ETc=kc* kt * Tmean**p*/100 (*p*=percent daily hours)

kt = max(0.3,0.0173*Tmean-0.314) (kc=crop coefficient*for*

- *Monthly temperature-only method commonly used in CO for historical analyses and DSS projects (so far)*
- *TR21 crop coefficients are not accurate in Colorado without elevation based correction or local calibration*
- *Calibrations typically have been applied to crop coefficients*
  - *Calibrations could be applied to base (calibrate to ETref) in which case ASCE Std (ETr) crop coefficients could be used.*
- *For comparisons here, the base equation (MBC= kt*Tmean*p/100) was calibrated to ASCE Std ETref*

Comparison of Calibration Methods

<u>Modified Hargreaves</u> – Hargreaves and Samani 1985

ETo=0.0023 * (Tmax-Tmin)^(0.5)*(Tmean+17.8)*Ra/(2.45*1)

(Ra (extraterrestrial radiation) if in MJ/m/d need 2.45 MJ/kg = latent heat of vaporation, 1Mg/m3=water density

- *Daily temperature only method; some use in Colorado*
- *Tmax-Tmin component used to generally represent humidity and cloudiness conditions (with Ra represents solar rad)*
- *ASCE Manual 70 - highest ranked temperature only method for calculating ETo and recommended by ASCE Manual 70 etc as one (of two) methods to use with limited data*
- *Should be used with calibration coefficient to represent local conditions (typically monthly coefficient with zero intercept)*

Comparison of Calibration Methods

ASCE Standardized Reference ET Equation – ASCE/EWRI 2005

$$ETref = \frac{0.408\Delta(Rn - G) + \gamma \dfrac{Cn}{T + 273} u2(es - ea)}{\Delta + \gamma(1 - Cd\ u2)}$$

ETref = standardized reference ET for short (ETos) or tall (ETrs) surfaces
Rn = calculated net radiation at the crop surface MJ/m2/d
G = soil heat flux density at the soil surface (0 for daily timestep)
T = mean air temperature, $^{\circ}C$
u2 = mean wind speed at 2-m height, m/s
es = saturation vapor pressure, kPa
ea = mean actual vapor pressure, kPa
Δ = slope of the saturation vapor pressure-temperature curve, kPa/$^{\circ}C$
γ = the psychrometric constant, kPa/$^{\circ}C$
Cn = a numerator constant that changes with reference type and timestep
Cd = a denominator constant that changes with reference type and timestep

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Comparison of Calibration Methods

<u>Simulation of Weather Data for ASCE Standardized Reference ET Equation</u> – ASCE/EWRI 2005, Manual 70, FAO-56, etc

- *ASCE/EWRI 2005 Appendix D&E, and other literature, contains methods and recommendations for estimating missing weather parameters*
- *Physical parameterizations are maintained. Therefore, more flexibility to work with base parameters (temp, RH, solar, wind) and reduced need for additional calibration of ETref.*
- *ASCE Manual 70, Allen et al., etc. also recommend as method to use with limited data*
- *FAO-56 recommends over other methods for most situations.*

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Comparison of Calibration Methods
Calibration of NOAA to CoAgMet station data

Base Equations

1) Monthy Modified Blaney Criddle – MBC
2) Daily Modified Hargreaves - ETo
3) Simulation of Daily Climate Data for ASCE Std. – ETos/ETrs
   - ASCE/EWRI (2005) Eq D.8/E.4, regressions, monthly avgs

Calibration Method

1) Base Equation Estimate
2) ETref(coagmet)= $\mathbf{mult_{month}}$ * ET(noaa)
   - Linear regression with zero intercept (i.e. least squares)
3) ETref(coagmet)= $\mathbf{m_{month}}$ * ET(noaa) + $\mathbf{b_{month}}$
   - Linear regression with intercept to find
4) Adjustment of simulated climate data to calibrate

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Comparison of Calibration Methods
Average Annual Difference from ETrs (inch)

Station	Mod. Blaney Criddle			Modified Hargreaves			Simulated ASCE PM Std ET			
	x	m*x	m*x+b	x	m*x	m*x+b	x	m*x	m*x+b	x adj
avn01	-35.92	-0.29	0.00	-21.67	0.28	0.00	1.16	0.25	0.00	0.00
fwl01	-33.74	-0.19	0.00	-20.03	0.15	0.00	0.89	0.13	0.00	0.00
rfd01	-31.26	-0.14	0.00	-16.87	0.23	0.00	1.85	0.15	0.00	0.00
ljt01	-36.10	-0.12	0.00	-25.61	0.28	0.00	2.47	0.30	0.00	0.00
lms01	-39.34	-0.17	0.00	-28.61	0.37	0.00	2.78	0.38	0.00	0.00
lam04	-38.70	-0.07	0.00	-28.42	0.37	0.00	3.09	0.37	0.00	0.00
hly02	-37.98	-0.09	0.00	-26.41	0.32	0.00	2.84	0.26	0.00	0.00
pnr01	-40.62	-0.40	0.00	-30.10	0.14	0.00	-1.07	0.17	0.00	0.00
cnn01	-35.62	-0.38	0.00	-25.14	0.07	0.00	0.11	0.10	0.00	0.00
sld01	-33.36	-0.19	0.00	-15.29	0.03	0.00	1.28	0.02	0.00	0.00
bnv01	-32.08	-0.34	0.00	-15.42	0.02	0.00	0.62	0.04	0.00	0.00
wcf01	-30.56	-0.23	0.00	-12.79	0.01	0.00	0.20	-0.01	0.00	0.00
hne01	-37.92	-0.16	0.00	-25.19	0.22	0.00	0.88	0.22	0.00	0.00
wls01	-51.36	-0.19	0.00	-39.08	0.17	0.00	2.49	0.20	0.00	0.00
scm01	-39.11	-0.20	0.00	-28.89	0.27	0.00	4.09	0.29	0.00	0.00
Avg	**-36.91**	**-0.21**	**0.00**	**-23.97**	**0.19**	**0.00**	**1.58**	**0.19**	**0.00**	**0.00**

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Comparison of Calibration Methods
R Squared (monthly vs ETrs) - R^2

Station	Mod. Blaney Criddle			Modified Hargreaves			Simulated ASCE PM Std ET			
	x	m*x	m*x+b	x	m*x	m*x+b	x	m*x	m*x+b	x adj
avn01	0.68	0.90	0.91	0.86	0.93	0.95	0.94	0.94	0.95	0.94
fwl01	0.75	0.95	0.96	0.91	0.96	0.97	0.96	0.96	0.97	0.96
rfd01	0.74	0.93	0.93	0.90	0.94	0.95	0.94	0.94	0.95	0.94
ljt01	0.72	0.93	0.94	0.89	0.94	0.96	0.95	0.95	0.97	0.95
lms01	0.74	0.89	0.92	0.88	0.92	0.95	0.92	0.93	0.96	0.93
lam04	0.76	0.93	0.94	0.92	0.95	0.97	0.96	0.96	0.98	0.96
hly02	0.72	0.91	0.93	0.89	0.94	0.96	0.94	0.95	0.96	0.95
pnr01	0.67	0.85	0.89	0.84	0.89	0.94	0.90	0.90	0.95	0.89
cnn01	0.63	0.93	0.96	0.84	0.97	0.98	0.97	0.97	0.98	0.97
sld01	0.56	0.91	0.92	0.74	0.93	0.95	0.93	0.93	0.95	0.93
bnv01	0.61	0.94	0.96	0.81	0.96	0.97	0.96	0.96	0.97	0.96
wcf01	0.60	0.90	0.93	0.79	0.93	0.93	0.92	0.92	0.93	0.92
hne01	0.73	0.95	0.95	0.91	0.96	0.97	0.96	0.96	0.97	0.96
wls01	0.80	0.93	0.97	0.92	0.95	0.99	0.95	0.95	0.99	0.95
scm01	0.82	0.94	0.97	0.95	0.96	0.98	0.95	0.96	0.98	0.96
Avg	**0.70**	**0.92**	**0.94**	**0.87**	**0.94**	**0.96**	**0.94**	**0.95**	**0.96**	**0.95**

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Comparison of Calibration Methods
Standard Error of Estimates - SEE

Station	Mod. Blaney Criddle			Modified Hargreaves			Simulated ASCE PM Std ET			
	x	m*x	m*x+b	x	m*x	m*x+b	x	m*x	m*x+b	x adj
avn01	3.31	0.86	0.80	2.04	0.69	0.63	0.68	0.67	0.62	0.67
fwl01	3.11	0.66	0.60	1.86	0.57	0.54	0.58	0.57	0.54	0.57
rfd01	2.94	0.77	0.75	1.69	0.69	0.65	0.71	0.69	0.67	0.69
ljt01	3.39	0.85	0.77	2.41	0.73	0.60	0.74	0.70	0.58	0.69
lms01	3.58	1.03	0.89	2.63	0.88	0.71	0.86	0.82	0.67	0.81
lam04	3.50	0.87	0.76	2.59	0.70	0.56	0.68	0.63	0.51	0.61
hly02	3.43	0.87	0.79	2.40	0.73	0.62	0.71	0.67	0.62	0.66
pnr01	3.63	0.99	0.83	2.70	0.82	0.62	0.83	0.82	0.60	0.82
cnn01	3.24	0.61	0.44	2.23	0.41	0.31	0.42	0.41	0.30	0.41
sld01	3.03	0.61	0.54	1.67	0.53	0.46	0.54	0.52	0.46	0.52
bnv01	2.95	0.56	0.41	1.57	0.42	0.39	0.43	0.42	0.40	0.42
wcf01	2.81	0.62	0.53	1.43	0.54	0.51	0.55	0.54	0.52	0.54
hne01	3.42	0.66	0.62	2.27	0.57	0.46	0.57	0.57	0.46	0.56
wls01	4.62	0.94	0.59	3.63	0.83	0.42	0.82	0.79	0.41	0.78
scm01	3.53	0.82	0.63	2.69	0.70	0.51	0.76	0.68	0.50	0.67
Avg	**3.37**	**0.78**	**0.66**	**2.26**	**0.65**	**0.53**	**0.66**	**0.63**	**0.52**	**0.63**

Comparison of Calibration Methods
Mean (Abs) Percent Difference from Monthly ETrs

Station	Mod. Blaney Criddle			Modified Hargreaves			Simulated ASCE PM Std ET			
	x	m*x	m*x+b	x	m*x	m*x+b	x	m*x	m*x+b	x adj
avn01	54.0%	13.2%	12.6%	32.7%	10.5%	9.0%	9.8%	9.6%	8.3%	9.5%
fwl01	51.3%	10.8%	9.6%	30.4%	9.2%	8.2%	9.2%	9.1%	8.3%	9.1%
rfd01	48.9%	11.9%	11.6%	26.1%	10.6%	9.8%	10.9%	10.2%	9.8%	10.1%
ljt01	51.2%	12.4%	11.2%	34.7%	10.3%	8.5%	10.4%	9.5%	7.3%	9.2%
lms01	53.6%	13.9%	12.1%	37.6%	11.3%	8.7%	10.9%	10.1%	7.6%	9.8%
lam04	54.2%	12.7%	11.0%	38.0%	9.5%	7.5%	9.5%	8.0%	6.2%	7.5%
hly02	54.0%	13.0%	11.3%	36.7%	10.2%	7.9%	9.5%	8.3%	6.7%	8.0%
pnr01	57.1%	12.9%	9.2%	41.9%	10.1%	8.0%	10.3%	10.1%	7.9%	10.2%
cnn01	53.6%	8.8%	5.5%	38.1%	5.6%	4.4%	5.8%	5.6%	4.4%	5.5%
sld01	57.1%	9.1%	7.5%	33.0%	8.3%	7.2%	9.0%	8.6%	7.5%	8.6%
bnv01	59.0%	8.0%	5.9%	33.2%	6.2%	5.8%	7.1%	6.8%	6.4%	6.9%
wcf01	59.2%	9.7%	7.8%	31.9%	8.7%	8.1%	10.0%	9.7%	9.0%	9.7%
hne01	55.1%	9.3%	8.7%	36.1%	7.1%	5.9%	6.8%	6.7%	5.4%	6.7%
wls01	59.7%	10.9%	6.6%	44.7%	9.0%	5.4%	8.7%	8.2%	5.1%	8.0%
scm01	55.5%	11.2%	9.3%	38.5%	8.3%	6.9%	10.4%	7.4%	5.4%	7.0%
Avg	**54.9%**	**11.2%**	**9.3%**	**35.6%**	**9.0%**	**7.4%**	**9.2%**	**8.5%**	**7.0%**	**8.4%**

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Comparison of Calibration Methods

Application of monthly non-zero intercept (mx+b) calibration

- Application to historical time period can produce unstable results, particularly for CoAgMet climate stations with a shorter data set (recently installed)
- Application of an annual calibration is more stable

Examples (simulated avg annual ETrs without/with mx+b)

CANON CITY cnn01	74.3	67.9	(1900-2015)
HOENHE hne01	75.6	66.0	
SAND CREEK scm01	81.9	71.2	
LAS ANIMAS lms01	82.8	72.8	
WALSH wls01	89.5	61.9	

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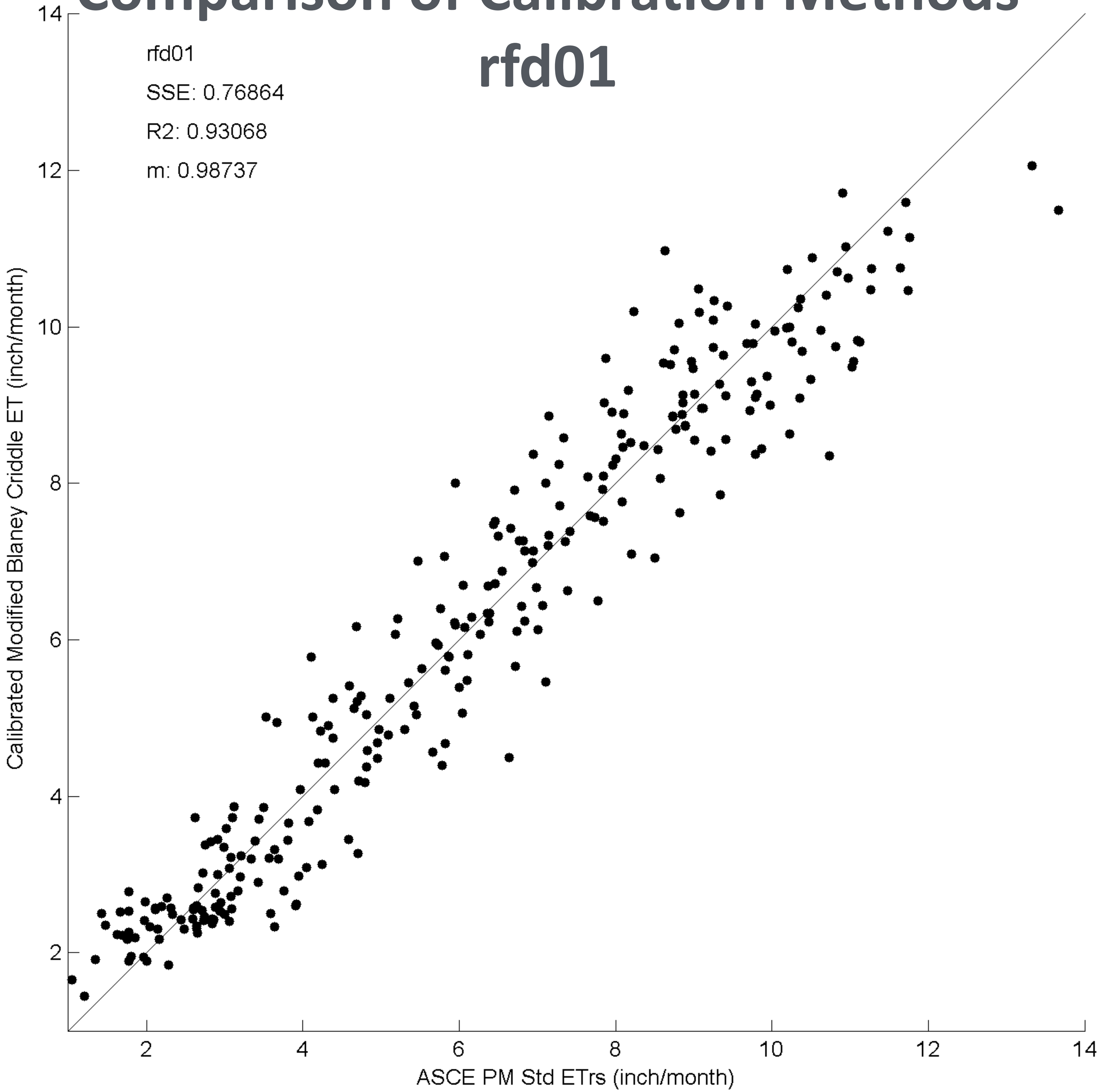
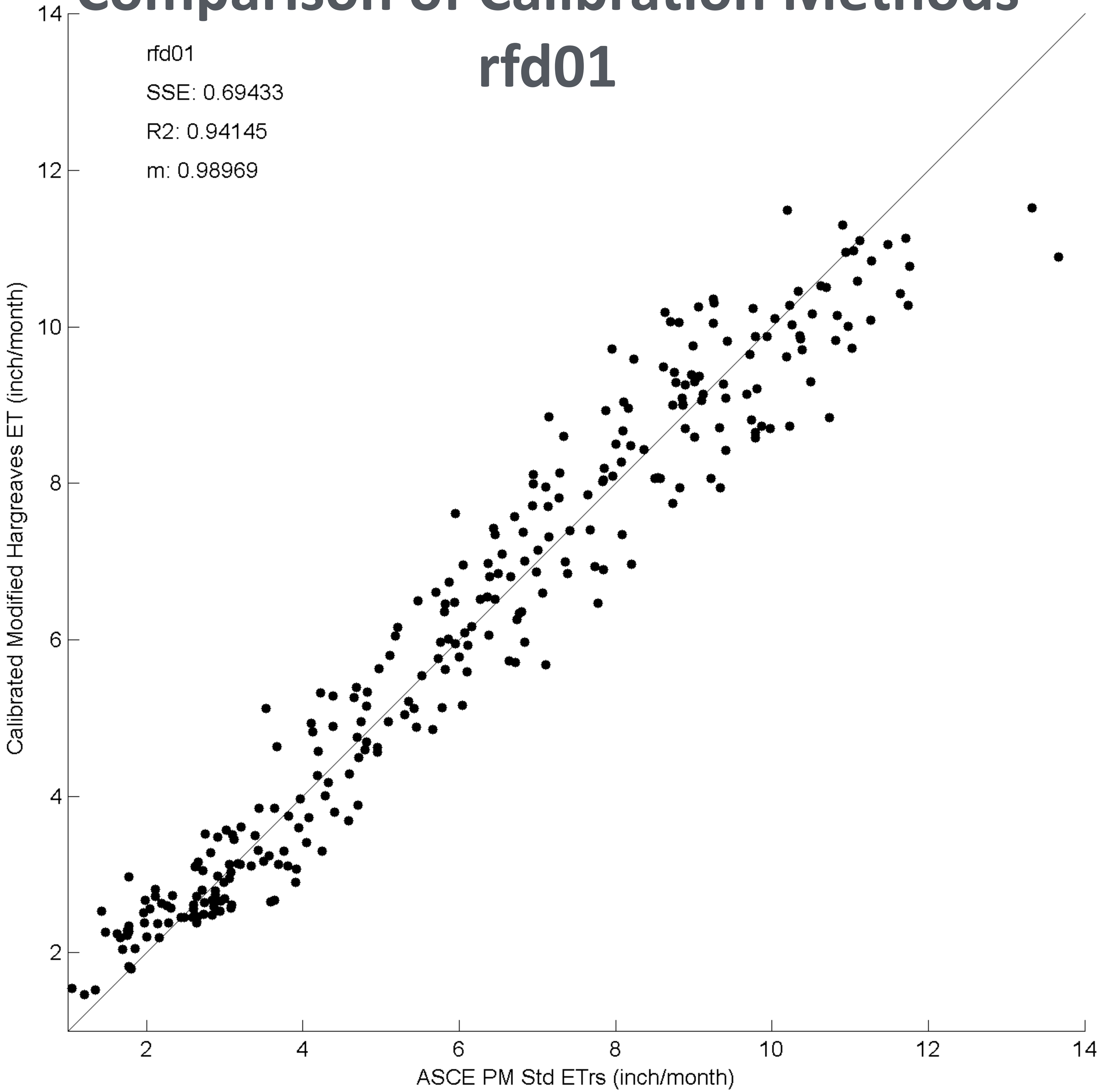
Comparison of Calibration Methods
rfd01



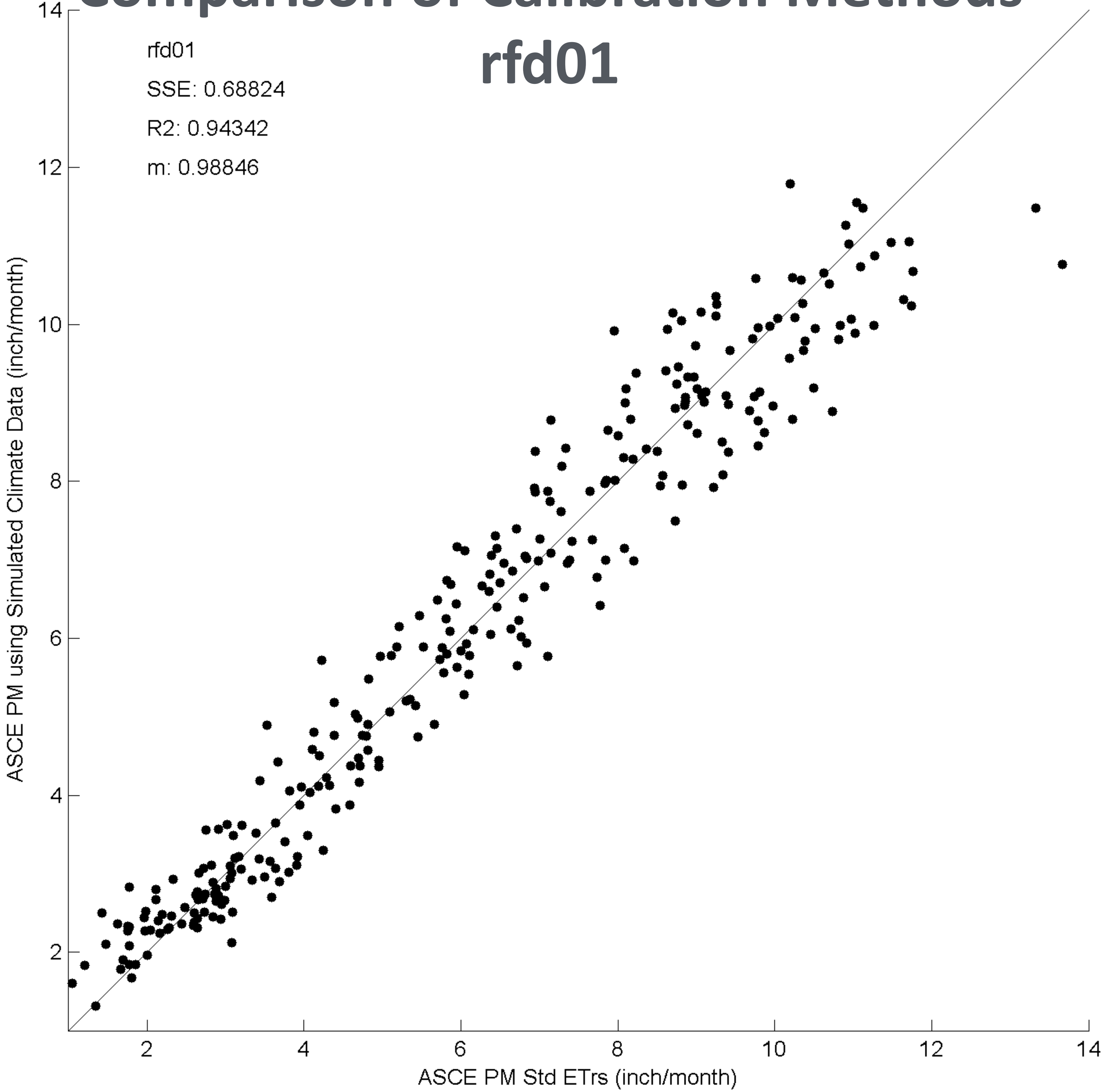
Modified Blaney Criddle (mx) vs ASCE Std ETrs

Comparison of Calibration Methods rfd01



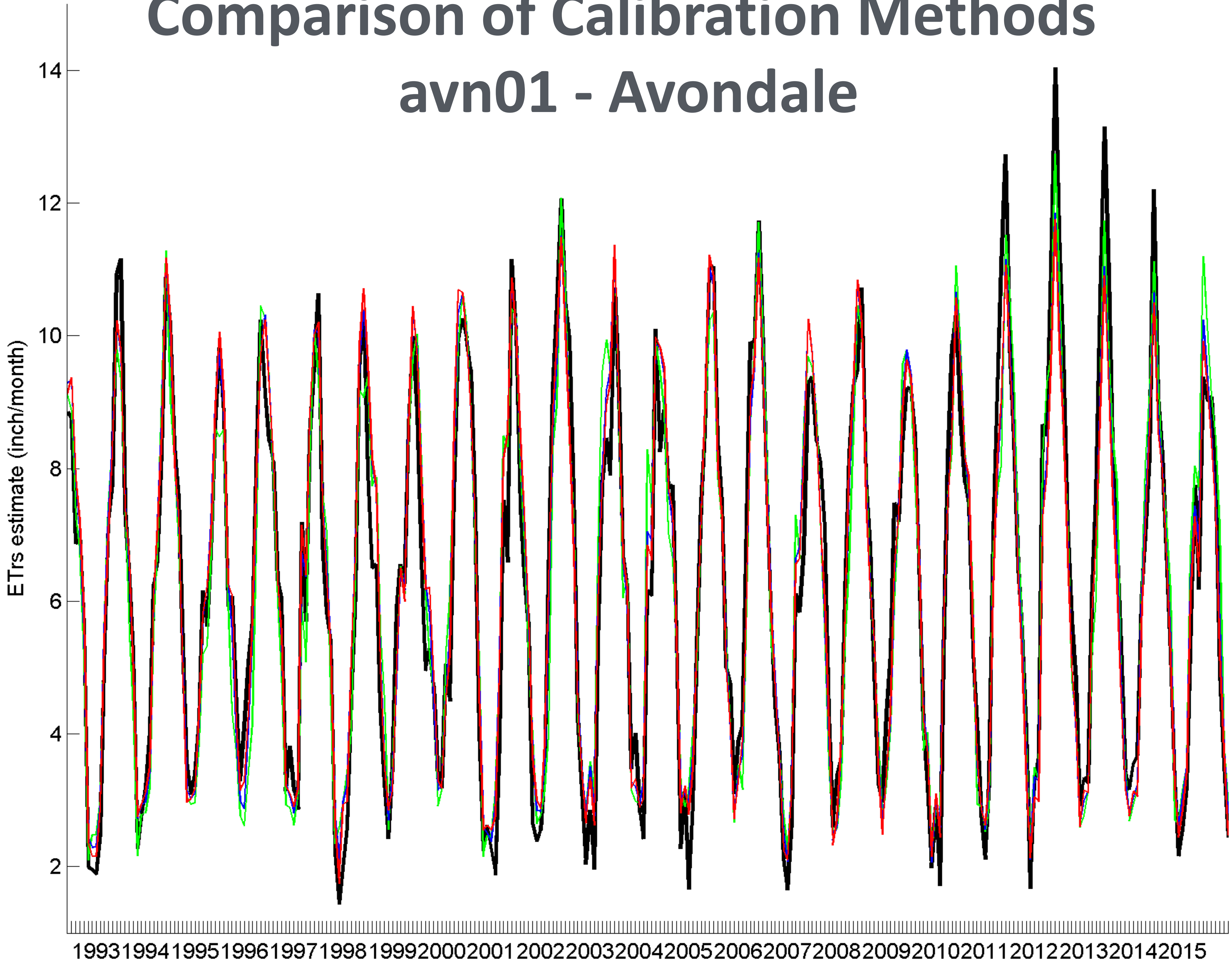
Modified Hargreaves (mx) vs ASCE Std ETrs

Comparison of Calibration Methods rfd01



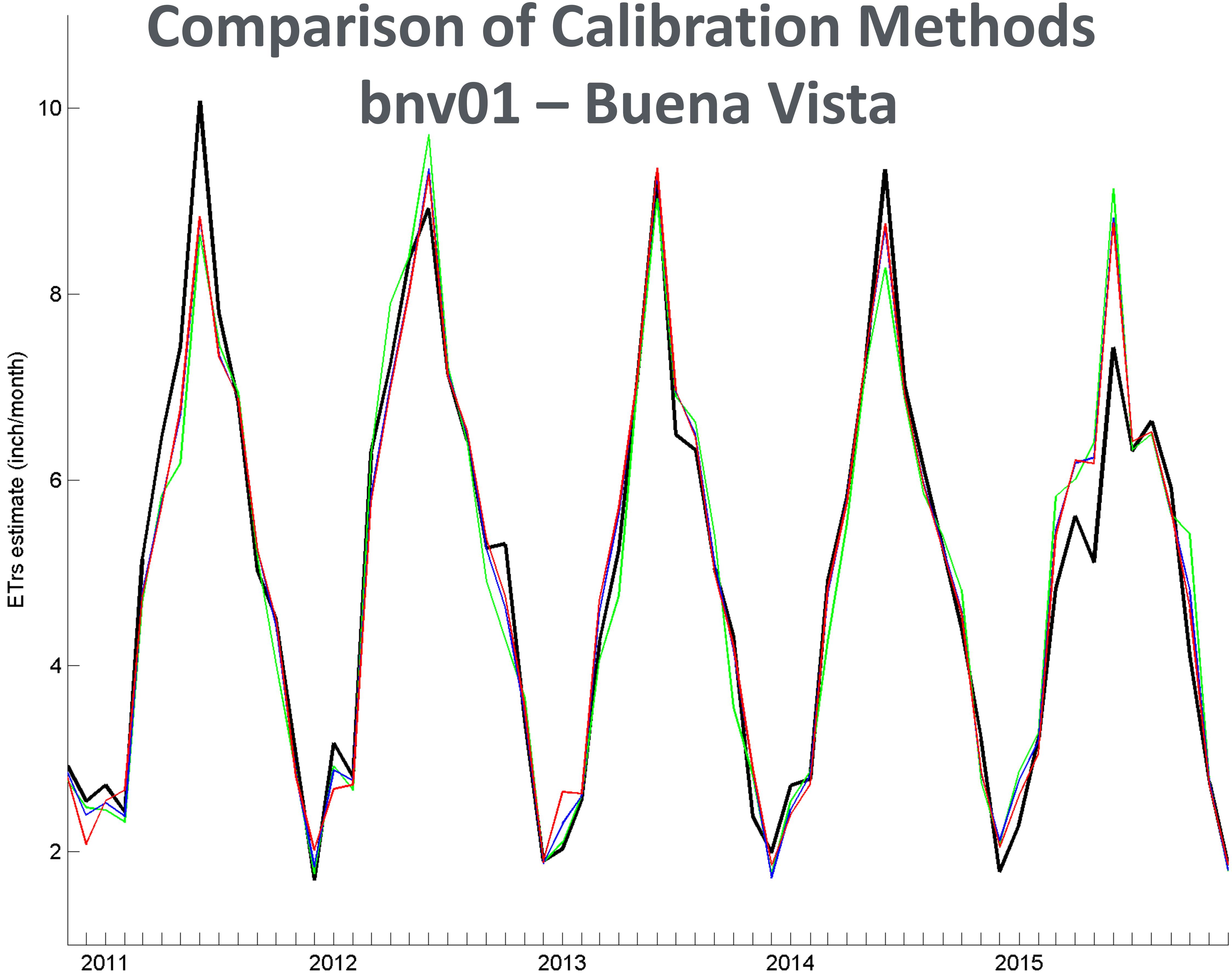
Simulation (adj) vs ASCE Std ETrs

Comparison of Calibration Methods
avn01 - Avondale



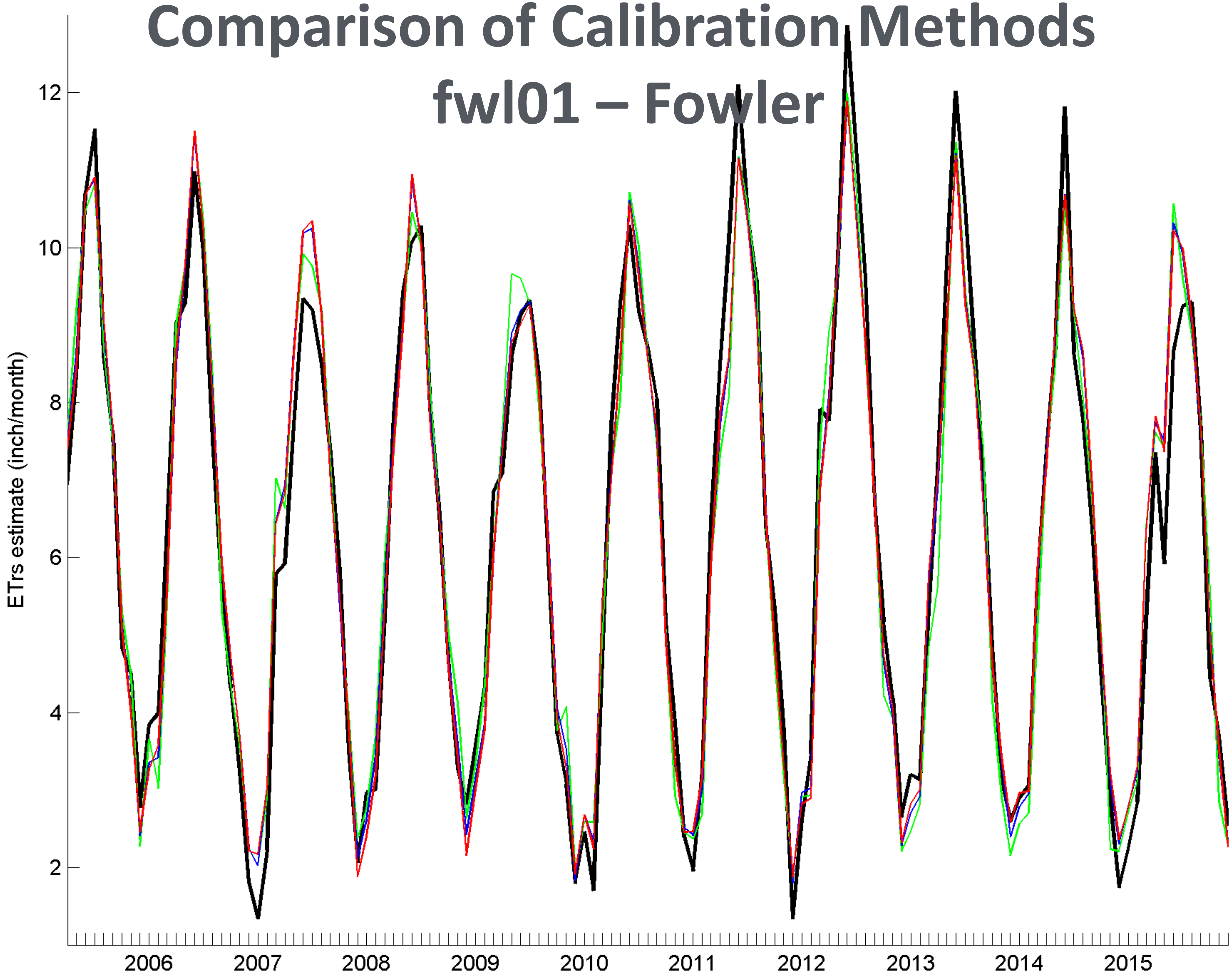
Black = CoAgMet ETrs, green = MBC(mx), blue=MH(mx), red=sim(adj)

Comparison of Calibration Methods
bnv01 – Buena Vista



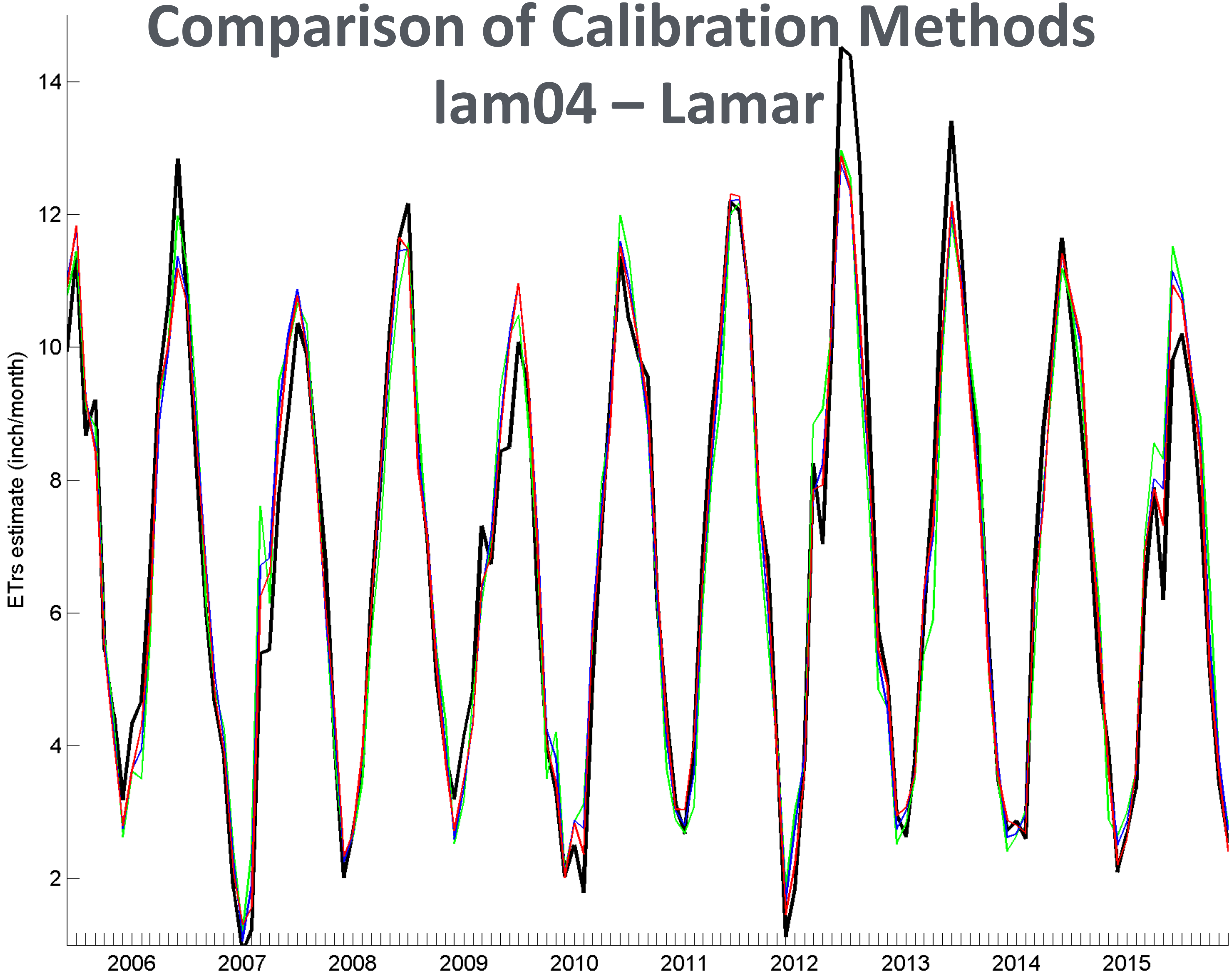
Black = CoAgMet ETrs, green = MBC(mx), blue=MH(mx), red=sim(adj)

Comparison of Calibration Methods
fwl01 – Fowler



Black = CoAgMet ETrs, green = MBC(mx), blue=MH(mx), red=sim(adj)

Comparison of Calibration Methods
lam04 – Lamar



Black = CoAgMet ETrs, green = MBC(mx), blue=MH(mx), red=sim(adj)

Comparison of Calibration Methods
General Findings

- Use of monthly non-zero intercept (mx+b) calibration provides best fit for calibration period but can produce unstable results when applied to historical time period (annual is more stable).
- Monthly calibration using Modified Blaney Criddle provides adequate monthly results when applied to base equation (ie calibration of ETref for subsequent use of ETref coefficients)
- Modified Hargreaves with monthly calibration multiplier (mx) provides accurate results
- Simulating Data for ASCE Std ET Eq provides slightly more accurate results than Modified Hargreaves (as above) while maintaining physical representation of climate parameters
- Simulated data for ASCE Std Eq can be used in CDSS StateCU software while other evaluated methods currently cannot

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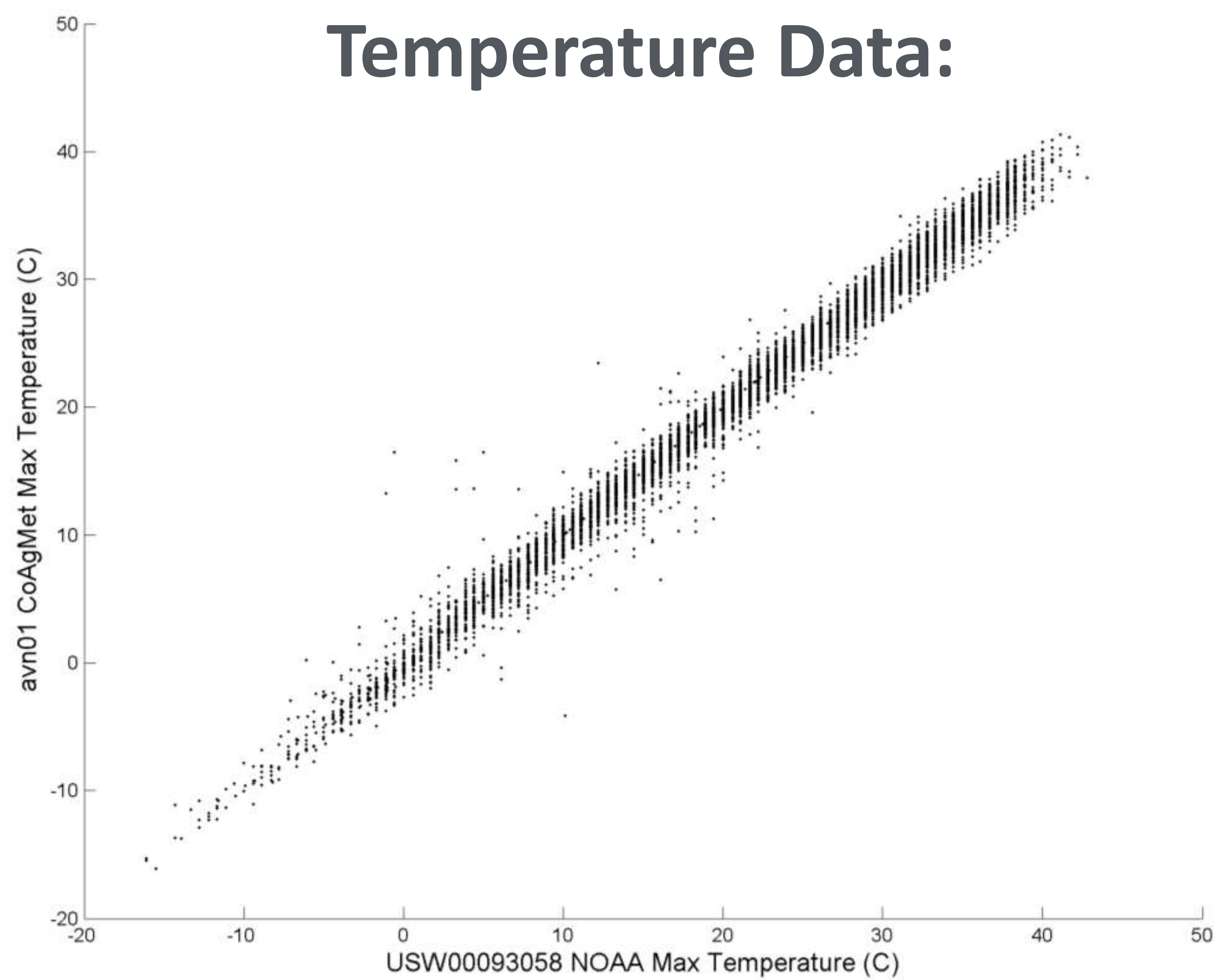
More Details on: Simulation/Calibration of Daily Climate Data for use in ASCE Std ET Equation

- Method chosen to produce Arkansas Basin Datasets:
  - As accurate or slightly more accurate than Modified Hargreaves method
  - Recommended by FAO-56 and one of two methods recommended by Manual 70.
  - Simulated Data could be used by StateCU for DSS

Simulation/Calibration of Daily Climate Data
Temperature Data:



Pueblo Memorial Airport

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Simulation/Calibration of Daily Climate Data
Temperature Data:

- **Because of surfaces (ie grass/alfalfa vs gravel/pavement) it is not expected that temperatures will be the same at CoAgMet and NOAA stations even if very close in proximity.**
- **FAO56/Man70/ASCE-EWRI do not provide method**
- **Relationship does appear slightly different by month**
- **Two Monthly Methods were investigated:**

➢ Tmax/min(coagmet)= $\mathbf{m}_{\mathbf{month}}$ * T°C(noaa) + $\mathbf{b}_{\mathbf{month}}$ (linear regression)

➢ Tmax/min(coagmet)= K$\mathbf{m}_{\mathbf{month}}$ * (T°C(noaa) + 273.15) – 273.15
(Based on Kelvin degrees - linear regression zero Kelvin intercept)

- **Similar results, but Kelvin Based Method appeared slightly more stable particularly when applied to long term datasets and was used**

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Simulation/Calibration of Daily Climate Data
Temperature Data:

Month	Kelvin Method - m			Celsius Method - m			Celsius Method - b		
Stat:	**avn01**	**fwl01**	**rfd01**	**avn01**	**fwl01**	**rfd01**	**avn01**	**fwl01**	**rfd01**
Jan	0.9991	1.0004	0.9985	0.961	1.009	0.990	0.091	0.021	-0.335
Feb	0.9994	1.0008	0.9962	0.980	1.017	0.968	0.042	0.055	-0.726
Mar	0.9997	1.0003	0.9946	0.987	0.970	0.972	0.108	0.584	-1.057
Apr	0.9991	0.9988	0.9934	0.973	0.980	0.950	0.252	0.069	-0.833
May	0.9988	0.9986	0.9946	0.971	0.941	0.962	0.379	1.083	-0.595
Jun	0.9979	0.998	0.9954	0.943	0.961	0.978	1.173	0.652	-0.700
Jul	0.9967	0.9991	0.9957	0.926	0.895	0.936	1.525	3.343	0.931
Aug	0.9973	0.9994	0.9957	0.939	0.936	0.989	1.165	1.944	-0.948
Sep	0.9985	0.9978	0.9947	0.964	0.999	1.030	0.562	-0.627	-2.490
Oct	0.9995	0.9988	0.9952	0.966	1.009	0.964	0.556	-0.540	-0.590
Nov	0.9996	1.002	0.9983	0.993	1.004	0.984	-0.010	0.508	-0.237
Dec	0.9991	1.0005	0.999	0.967	1.018	1.010	0.040	-0.005	-0.380

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Simulation/Calibration of Daily Climate Data
Solar Data:

- Hargreaves-Samani / ASCE-EWRI E.4 suggests relationship between solar rad and temperature [(Tmax-Tmin)^0.5* Ra]
- Ra (extraterrestrial radiation) based on latitude/day
- Rso-complex (clear sky short wave radiation) is based also on elevation and water in atmosphere. Elevation relationship (more solar as go up) seems to be physical process that would affect application of solar radiation data between stations.
- Appeared to vary slightly by month
- Therefore, used following equation to estimate solar data:
  - ➢ $Rs = \mathbf{kRs_{month}} * (Tmax - Tmin)^{0.5} * Rso$

($\mathbf{kRs_{month}}$ = monthly regression zero intercept of CoAgMet data)

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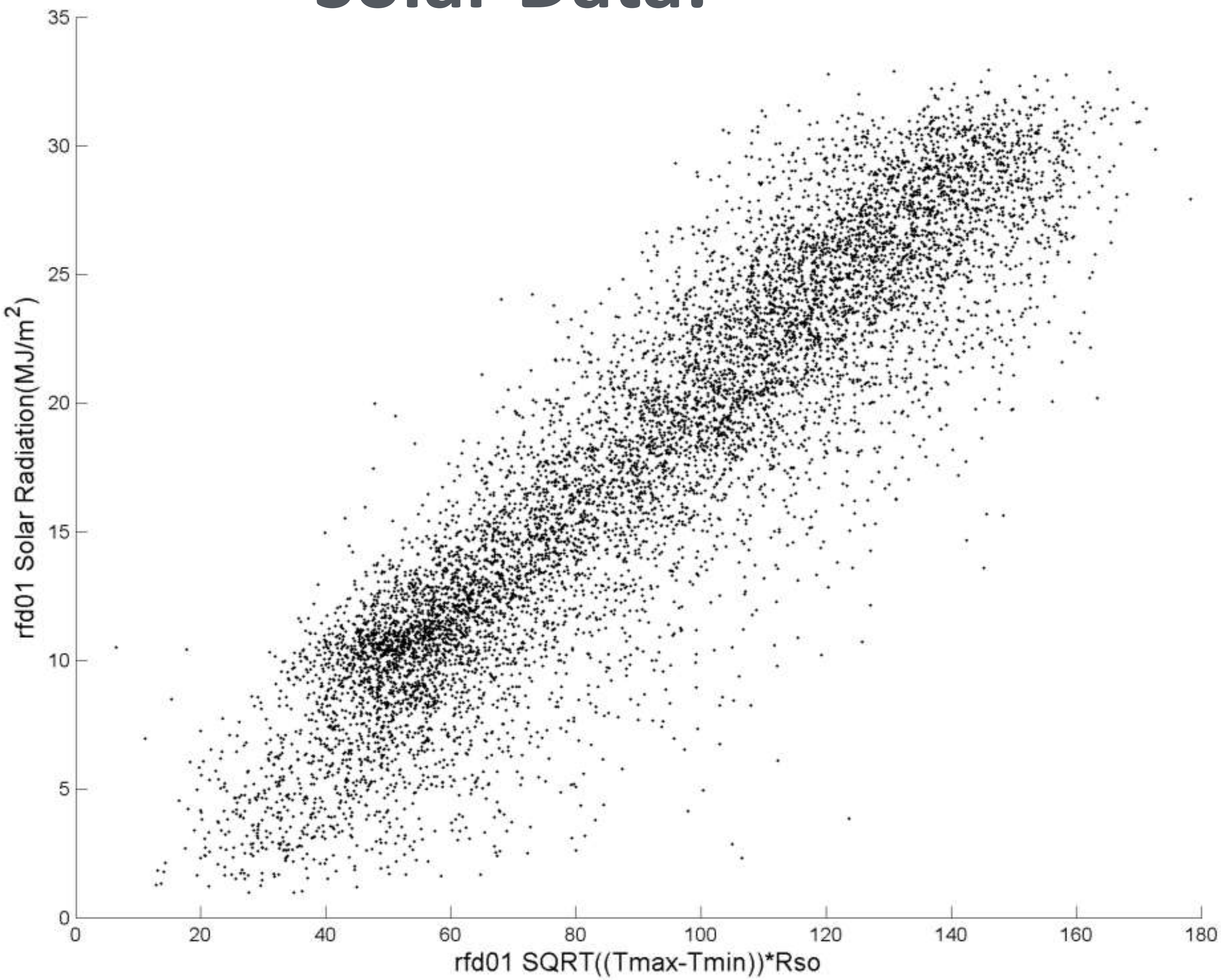
Simulation/Calibration of Daily Climate Data

Solar Data:

Mean kRs	
Jan	0.178
Feb	0.185
Mar	0.177
Apr	0.177
May	0.180
Jun	0.189
Jul	0.194
Aug	0.200
Sep	0.192
Oct	0.190
Nov	0.182
Dec	0.174



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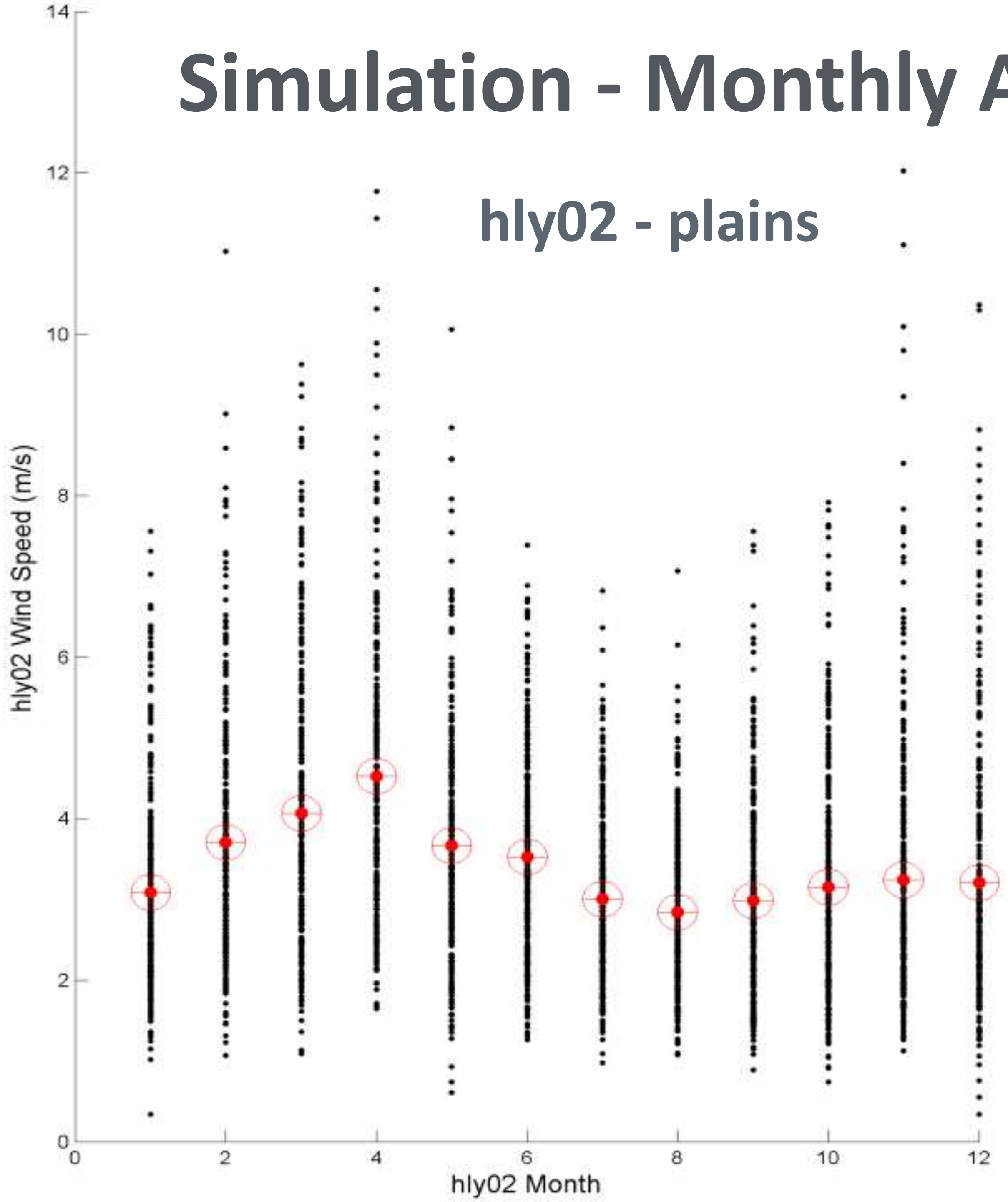
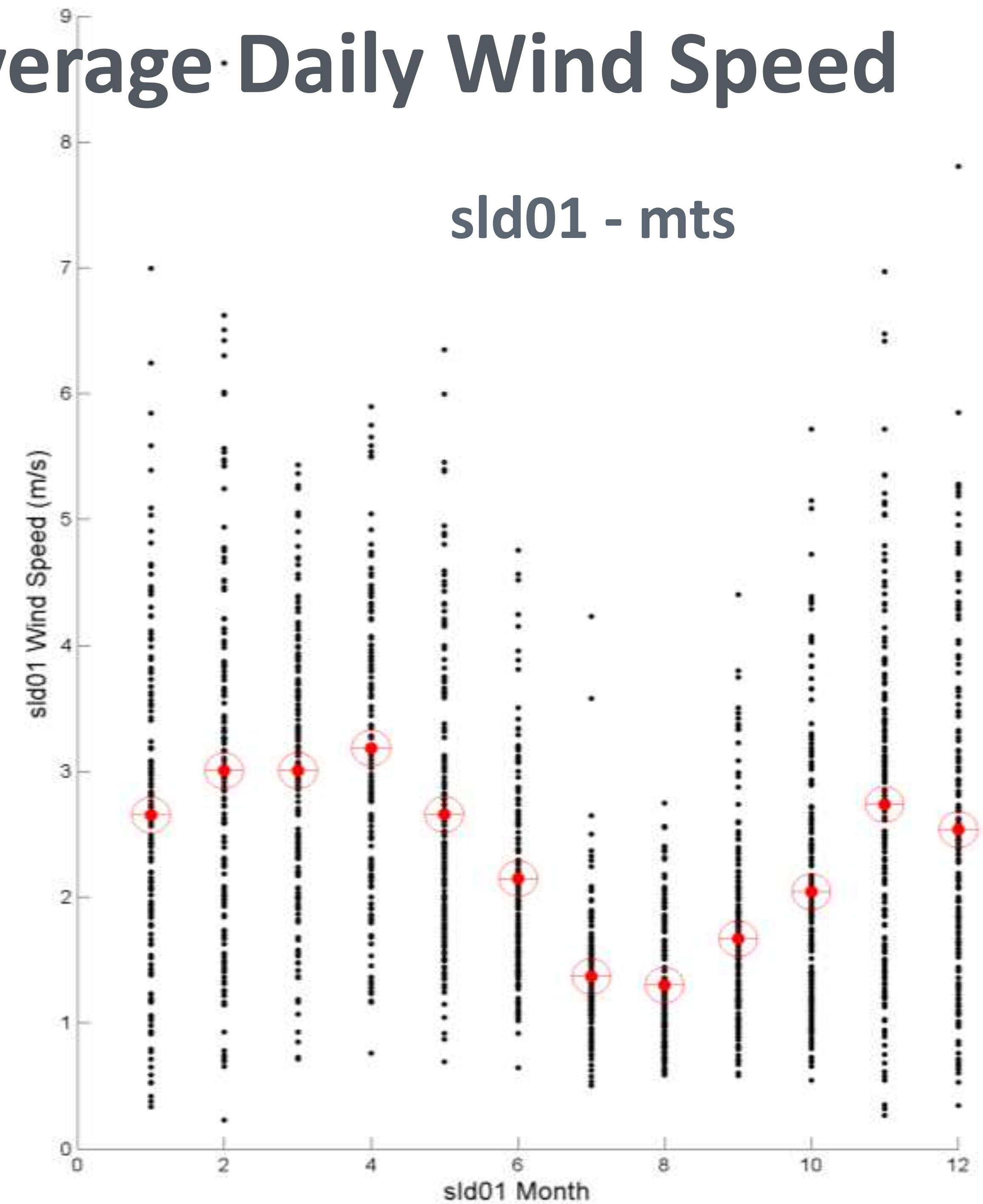
Simulation/Calibration of Daily Climate Data
Wind Data:

Simulation - Monthly Average Daily Wind Speed





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Red marker = monthly average daily wind speed (m/s)

Simulation/Calibration of Daily Climate Data
Humidity Data:

ASCE-EWRI (2005) Equation D.8 (Tdew=dewpoint temperature)

$Tdew_{station2} = Tmin_{station2} - (Tmin - Tdew)_{station1}$ (D.8)

(Tdew-Tmin referred to by ASCE-EWRI as Ko)

Applied per D.8 except as monthly value as monthly differences were observed.

- $Ko_{month} = (Tmin - Tdew)_{CoAgMet}$ (monthly average)
- $Tdew_{NOAA} = Tmin_{NOAA} - (Tmin - Tdew)_{CoAgMet}$

Average Monthly INITIAL Ko for all CoAgMet Stations:

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
-1.23	-0.68	1.74	2.23	2.03	3.18	1.96	1.26	1.05	0.26	0.18	-1.55

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Simulation/Calibration of Daily Climate Data

Calibration to reduce monthly/annual ETref difference

- Simulation alone slightly over-estimates ETrs/ETos on an monthly and annual basis in almost all cases
- Instead of applying calibrations to final ETrs/ETos, climate data can be adjusted to result in same corrections. Used humidity (tmin-tdew factor) as most Ark CoAgMet stations have slight to moderate aridity and reduction to factor may be justified.
- Iterate on Ko (tmin-tdew factor) to first meet total monthly amounts (so that monthly regression slopes equal one) and then equally on average annual amount.
- Results are as statistically accurate as m*x calibration, with annual ETrs difference as accurate as m*x+b but without instability issues. And, could then also still use StateCU.

Simulation/Calibration of Daily Climate Data
Humidity Data:

Average Monthly Ko (Tmin-Tdew) for all CoAgMet Stations:

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Ko-orig	-1.23	-0.68	1.74	2.23	2.03	3.18	1.96	1.26	1.05	0.26	0.18	-1.55
Ko-adj	-1.15	-0.49	1.01	1.26	1.44	2.68	1.75	0.91	0.25	-0.93	-0.83	-1.84
Diff (°C)	0.08	0.19	-0.72	-0.97	-0.58	-0.50	-0.21	-0.35	-0.80	-1.18	-1.01	-0.29

- **On Average, 0.5˚C degree addition in Tdew**
- **Largest adjustment in Mar-Apr and Sep-Nov when surfaces are generally quite dry (ie arid).**

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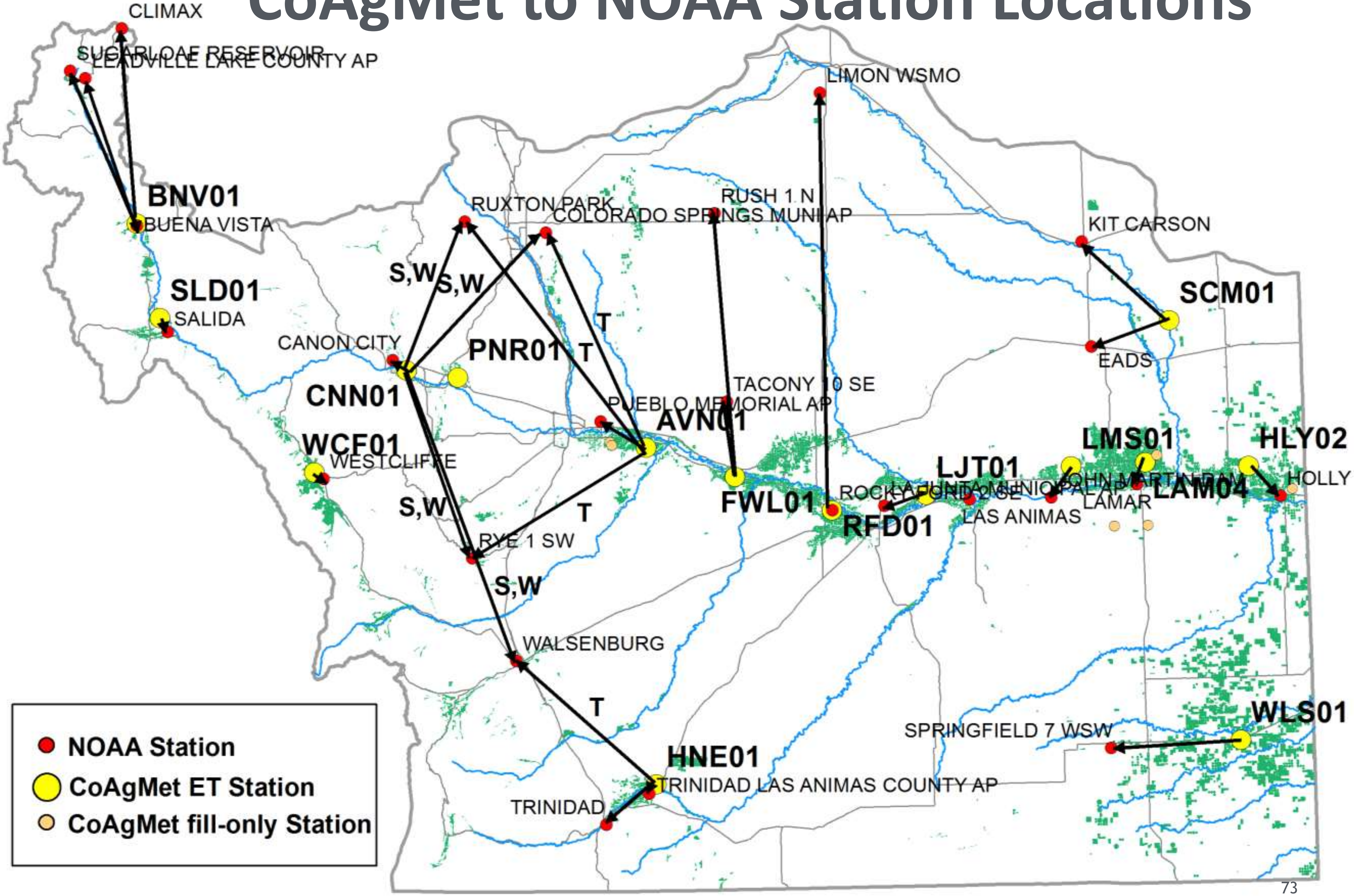
Generation of Long Term Datasets

CoAgMet to NOAA Station Locations



Simulation/Calibration of Daily Climate Data

Temperature Data:

- Due to surface differences; NOAA temperatures should be calibrated if applying at CoAgMet OR NOAA station locations
- Calibration of Temperatures from NOAA station AT COAGMET STATION LOCATION would incorporate any elevation correction
- When temperatures are calibrated AT A NOAA STATION, the environmental lapse rate is used adjust for elevation
- lapse rate is used to estimate what the CoAgMet temperatures would be if at NOAA station elevation prior to calibration
- Environmental Lapse Rate: -1.98 °C/1,000 ft
- Environmental Lapse Rate: rate of decrease of temperature with altitude in non-saturated stationary atmosphere. *Used by airplane avionics to determine altitude above airport.*

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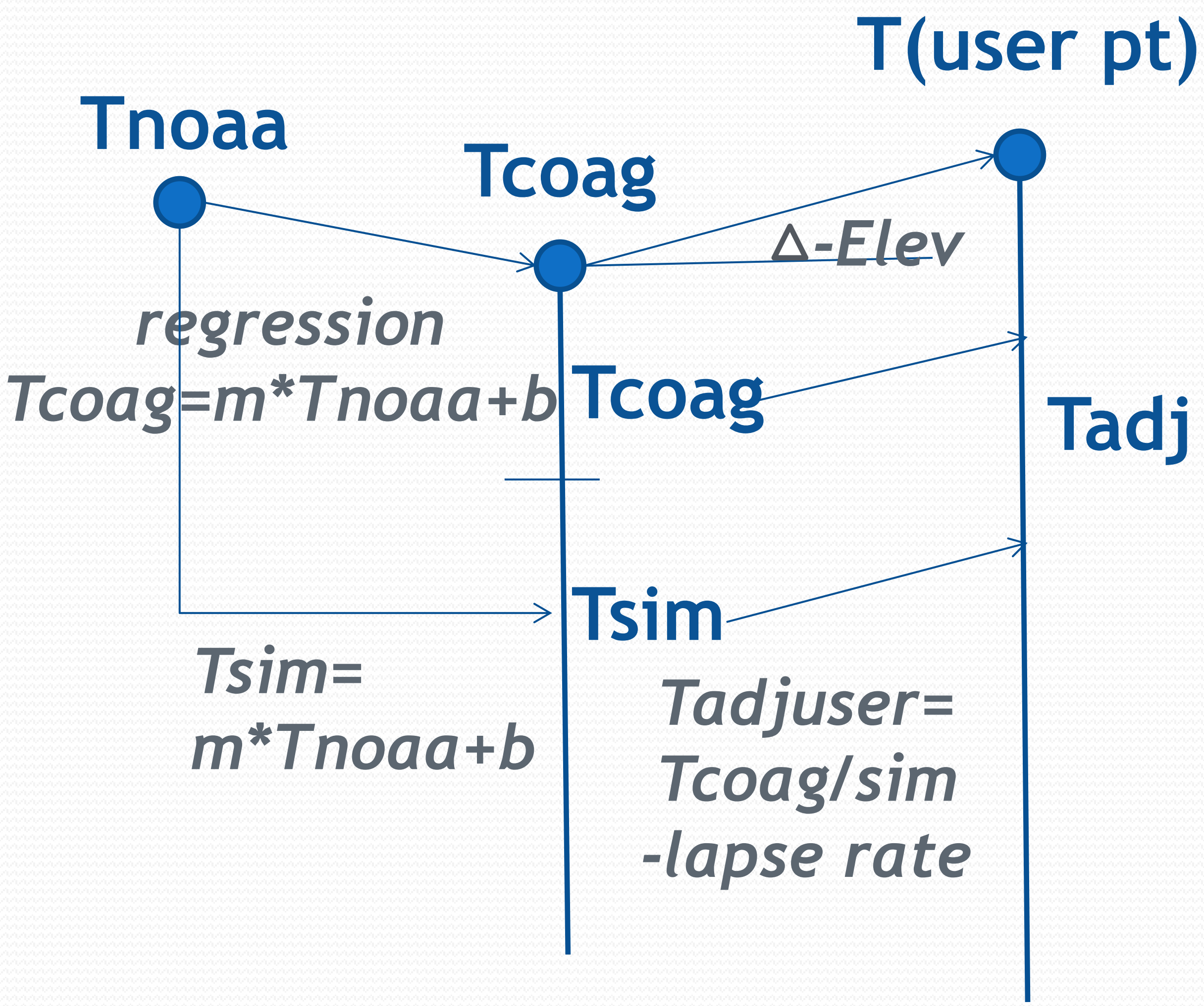
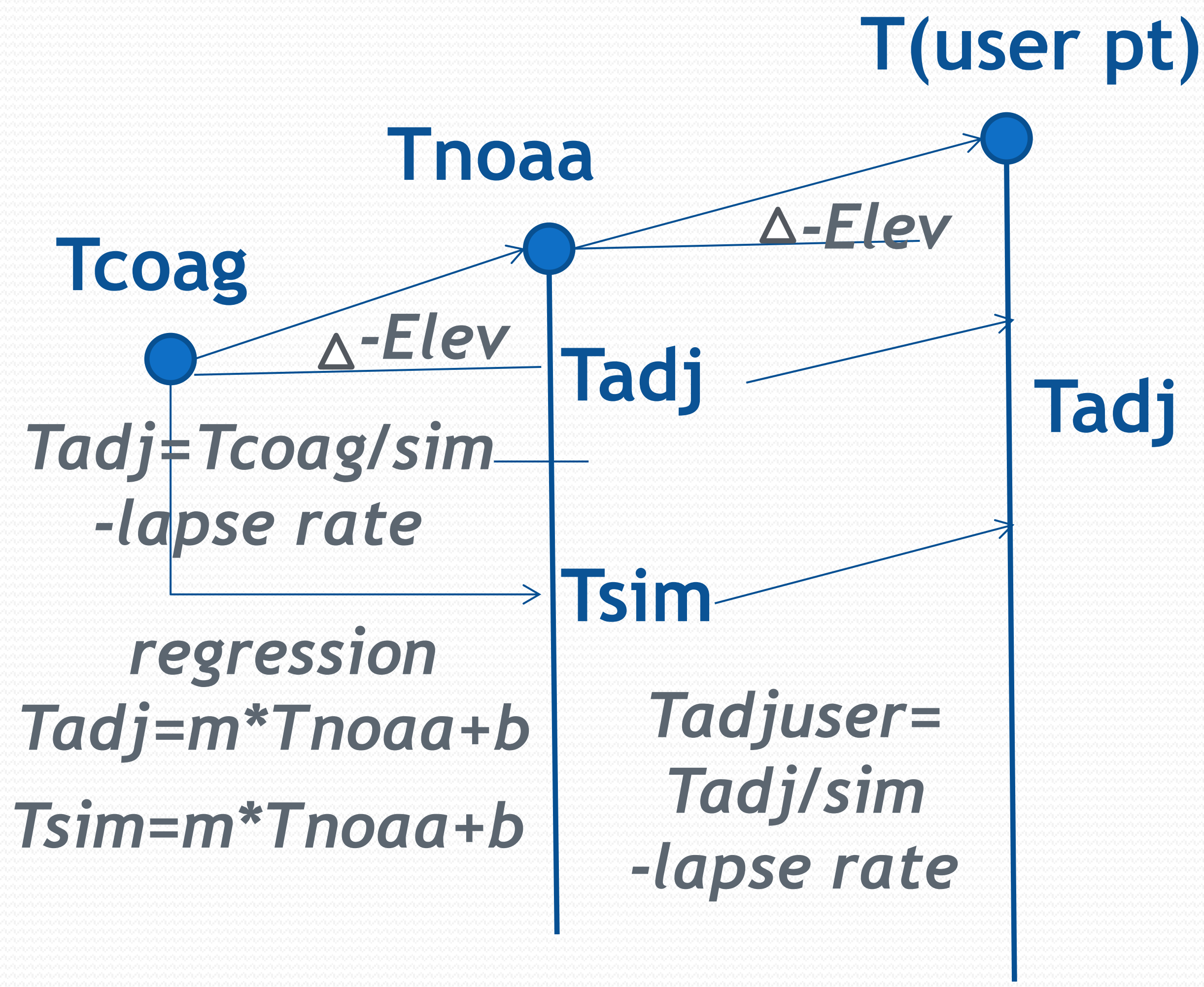
Schematic of Temperature Adjustment For Translation between Locations

From CoAgMet Station - To User Point



From NOAA Station - To User Point



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Simulation/Calibration of Daily Climate Data for ASCE PM std – AT COAGMET STATION

Simulation/Calibration Parameters are Developed during process:

Temp: Tmax/min(coagmet)= $\mathbf{m_{month}}$ * T (noaa) + $\mathbf{b_{month}}$ (linear regression)

- T(sim) = m_{month} * T (noaa) + b_{month}

Hum: Tdew(2) = Tmin(2) - (Tmin – Tdew) (1) (EWRI Eq D.8*)

$\mathbf{Ko_{month}}$ = $mean_{month}$ (Tmin – Tdew) (coagmet) (* using monthly Ko)

- Tdew(sim) = Tmin(sim) - Ko_{month} (coagmet)

Solar: Rs(coag) =$\mathbf{kRs_{month}}$*(Tmax-Tmin) (coag) ^0.5* Rso (EWRI Eq E.4*)

- Rs(sim) =$\mathbf{kRs_{month}}$*(Tmax-Tmin) (sim) ^0.5* Rso (*using Rso not Ra)

Wind: u_{2month} = $mean_{month}$ (u_2)(coagmet) (monthly average)

- u_{2month} (sim)= $mean_{month}$ (u_2)

Ko adjusted using iteration so that a) average monthly ETrs(sim) matches ETrs(coagmet) and then b) average annual ETrs(sim) matches ETrs(coagmet)

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Simulation/Calibration of Daily Climate Data for ASCE PM std – AT NOAA STATION

Temp: Tmax/min(adj)= T (coagmet) – 1.98 elevdiff/1000ft (env. lapse rate)
Tmax/min(adj)= $\mathbf{m_{month}}$ * T (noaa) + $\mathbf{b_{month}}$ (linear regression)

- T(sim) = m_{month} * T (noaa) + b_{month}

Hum: Tdew(sim) = Tmin(sim) - Ko_{month} (coagmet) (EWRI Eq D.8*)

Solar: Rs(sim) =$\mathbf{kRs_{month}}$*(Tmax-Tmin) (sim) ^0.5* Rso(sim) (EWRI Eq E.4*)

Wind: u_{2month} (sim)= $mean_{month}$ (u_2)(coagmet) (monthly average)

For time period when CoAgMet climate data available:

For close weather stations: Tmax/min(sim)=Tmax/min(adj)
Tdew(sim) = Tmin(sim) – (Tmin – Tdew) (coagmet)
Rs(sim) = Rso (sim) – (Rso – Rs) (coagmet) (Rso is function of Tdew)
u_{2month} (sim)= u_2(coagmet)
(different T/RH and s/w coagmet stations can be used)

Simulation/Calibration of Daily Climate Data
Mean Annual ETrs (inch/yr) at Stations

CoAgMet Stations			NOAA Stations			NOAA Stations		
Avondale	70.6	77.9	Pueblo Memorial Ap	70.0	77.3	Climax	48.4	48.8
Fowler	70.0	74.6	Tacony 10 SE	67.9	72.4	Sugarloaf Reservoir	52.8	53.9
Rocky Ford	69.9	75.3	Rocky Ford 2 SE	69.9	75.3	Leadville Lake County Ap	55.7	54.3
La Junta	79.7	79.7	La Junta Municipal Ap	75.5	78.9	Ruxton Park	53.8	57.0
Las Animas	82.8	83.4	Las Animas	83.7	80.2	Colorado Springs Muni Ap	63.9	67.1
Lamar 4	83.0	81.6	John Martin Dam	83.1	83.8	Rye 1 Sw	65.5	61.9
Holly 2	80.4	79.9	Lamar	83.3	82.0	Walsenburg	69.3	69.7
Penrose	79.2	80.1	Holly	81.2	80.8	Trinidad	72.1	74.3
Canon City	74.4	75.1	Canon City	74.0	74.7	Rush 1 N	67.6	68.3
Salida	62.9	64.3	Salida	63.2	64.5	Limon WSMO	66.0	70.1
Buena Vista	58.7	60.0	Buena Vista	58.5	59.9	Kit Carson	74.7	78.0
Westcliffe	57.8	56.8	Westcliffe	57.4	56.4			
Hoehne	75.6	77.1	Trinidad Las Animas C	75.1	76.6			
Walsh	89.4	92.5	Springfield 7 WSW	85.9	89.0			
Sand Creek	82.2	80.0	Eads	81.0	78.9			

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For 1900-2015 and 2006-2015 Periods

Simulation/Calibration of Daily Climate Data for ASCE PM std – AT USER DEFINED POINT

Temp: Tmax/min(sim)= T (coagmet/sim) – 1.98 elevdiff/1000ft (lapse rate)

Hum: Tdew(sim) = Tmin(sim) - Ko_{month} (coagmet) (EWRI Eq D.8*)

Solar: Rs(sim) =**kRs_{month}***(Tmax-Tmin) (sim) ^0.5* Rso(sim) (EWRI Eq E.4*)

Wind: u_{2month} (sim)= $mean_{month}$ (u_2)(coagmet) (monthly average)

ETref: ETref(cal)= **$mult_{month}$** * ETref (sim)

For time period when CoAgMet climate data available:

Tdew(sim) = Tmin(sim) – (Tmin – Tdew) (coagmet)

Rs(sim) = Rso (sim) – (Rso – Rs) (coagmet) (Rso is function of Tdew)

u_{2month} (sim)= u_2(coagmet)

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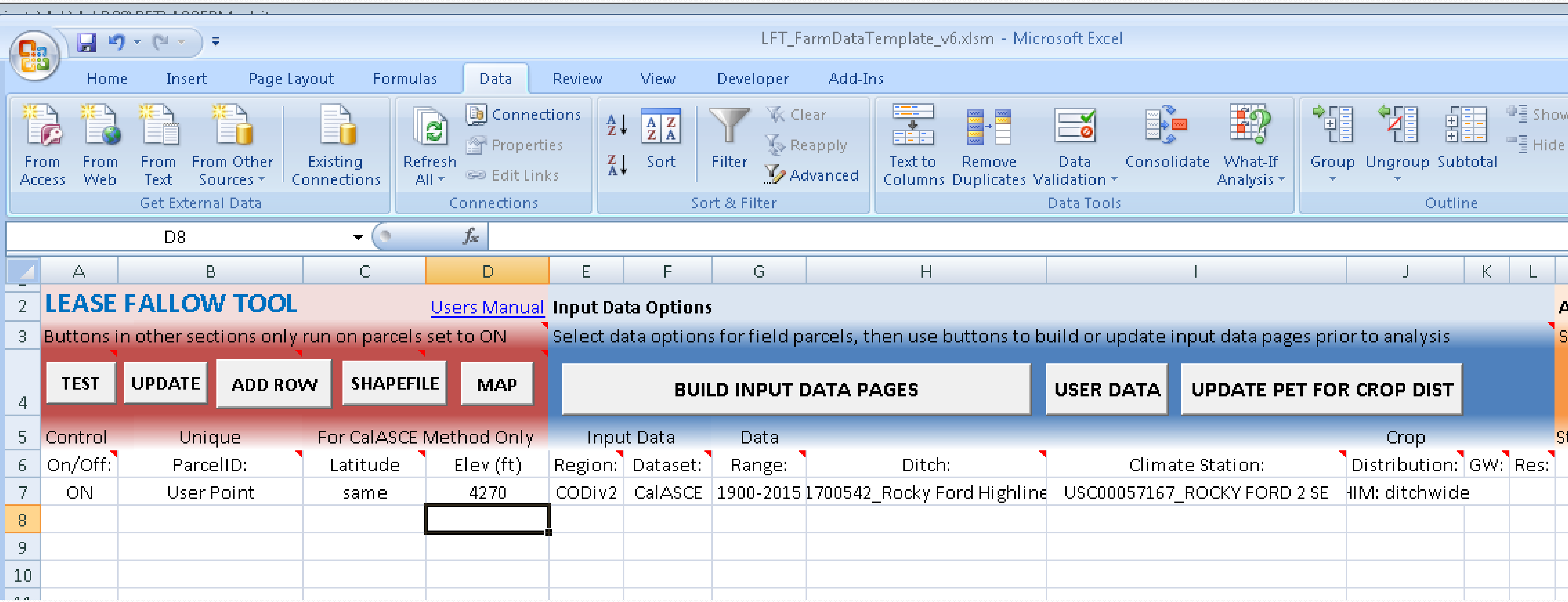
Simulation of Daily Climate Data and Calculation of ETref at User Defined Points

- ETref can be calculated in new Lease Fallow Tool (version 7) for user defined points based on elevation / latitude



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Where we are now:

Ready Now: For Arkansas River Basin:

- Full QA/QC CoAgMet datasets for CoAgMet period of record available in Excel spreadsheets
- Full calibrated long term ETrs/ETos datasets (1900-2015) available for all CoAgMet and NOAA station locations (41 stations in Div2)

Before the End of the Year:

- Lease Fallow Tool version 7 with full station ETrs datasets including crop ET and non-growing season ET usable for full HCU analysis
- Calibrated long term datasets prepared as StateCU input

Probably as a part of LFT:

- Ability for Lease Fallow Tool to estimate ETref at any user defined location near station; and also wetland ET (using R. Allen coefficients)

At some point pending input:

- Datasets for other basins if desired by water resources community

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Questions - Input - Opinions

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