CALIFORNIA DEPARTMENT OF WATER RESOURCES

Wind Stilling on Recent Potential Evapotranspiration Trend

Presenter: Jianzhong (Jay) Wang
Modelling Support Office

Collaborators:

Hongbing Yin , Z. Richard Chen, Francis Chung, Hasan Mohammad, and James Polsinelli

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Outline

- Background
- CIMIS' ETo and Trend
- Wind Stilling and Other Trends
- Sensitivity Test on the Effect of Wind Stilling on ETo
- Summary

Background

- Detrend of CalSim3 input

GridMET ~4 km NLDAS ~0.125° JRA-55 ~55 km

~50 km ~0.25°

1980-2020
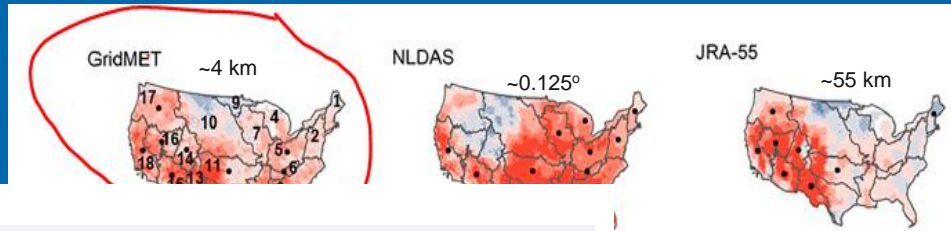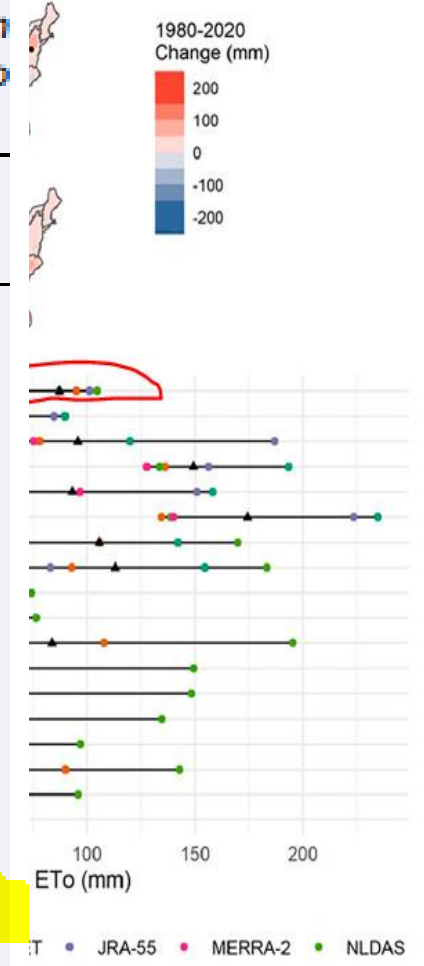Change (mm)

200
100
0
-100
-200

Table 3

Linear Trend Statistics (1983–2007) of the CIMIS Station Averaged (From Monthly Values of 10 Stations and From Daily Values, Aggregated to Monthly Values, of Six Stations [in Parentheses]) Annual Time Series

Trend variable	Trend value	Standard deviation	Mann-Kendall p value (−)
ET (mm per decade)	41 (31)	17 (17)	0.01** (0.076*)
P (mm per decade)	−96 (−36)	31 (22)	0.008** (0.25)
ET_r (decade^{-1})	0.5 (0.37)	0.12 (0.15)	0.001** (0.1*)
T_a (°C per decade)	0.19 (0.12)	0.12 (0.12)	0.23 (0.73)
T_d (°C per decade)	0.58 (0.47)	0.21 (0.22)	0.04** (0.02**)
VPD (hPa per decade)	−0.13 (−0.24)	0.17 (0.17)	0.29 (0.1*)
RH (% per decade)	1.4 (1.2)	0.79 (0.81)	0.052* (0.18)
R_s (Ly day^{-1} decade^{-1})	1.8 (−0.3)	3.5 (4.2)	0.53 (0.73)
u_2 (m s^{-1} decade^{-1})	−0.04 (−0.05)	0.016 (0.014)	0.01** (0.002**)
E_o (mm per decade)	−28 (−50)	16 (16)	0.058* (0.002**)
E_p (mm per decade)	−18 (−18)	23 (22)	0.41 (0.34)

*Test significant at the 10% level. **Test significant at the 5% level.

100 150 200
ETo (mm)

T • JRA-55 • MERRA-2 • NLDAS

0 (mm) by dataset. Change is calculated as the trend slope
ots on the map indicate USGS water resource regions, out-
y significant ($p < 0.05$) based on the Mann–Kendall trend
ater resource region for each dataset. Black triangles in the

CIMIS's ETo and Trend

- Five CIMIS Stations: Gerber, Durham, Davis, Firebaugh/Teller, and Stratford

- Data Period:1983 to 2020

- CIMIS ETo calculated with the modified Perman equation

- Compare CIMIS ETo with other data sources (VIC, BCM, CalSim3)
  - All CIMIS stations shows decreasing ETo trend except Stratford
  - All VIC and BCM models' ETo show increasing trend
  - CalSim3 model's ETo shows increasing trend except Durham

Trend from 1983 to 2020 (inches/year)

	Gerber	Durham	Davis	Firebaugh	Stratford
CIMIS	-0.052	-0.135	-0.043	-0.051	0.095
BCM	0.032	0.026	0.018	0.027	0.030
BDO(CalSim3)	0.010	-0.022	0.002	0.025	0.065
Jacobs(VIC?)	0.044	0.008	0.014	0.075	0.081

Trend from 1983 to 2020
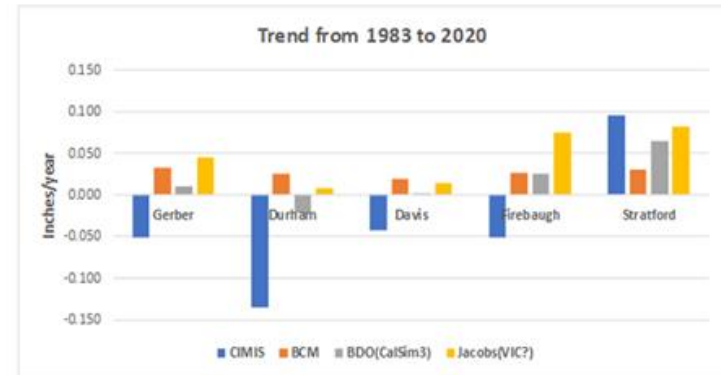
	Method	Scale	Calibration	Input Data
CIMIS	Modified Penman Equation	hourly	N/A	Rs, T, Td, wind, cloud cover
BCM	Modified Priestley-Taylor Equation	hourly	Yes	Tmax, Tmin, DEM
BDO(CalSim3)	Hargreaves–Samani Equation	monthly	Yes	Tmax, Tmin
Jacobs(VIC?)	Penman–Monteith Equation	daily/subdaily	No	Tmax, Tmin,Precip, wind

Modified Penman   PET = $W*R_n + (1-W)*VPD * FU2$

Modified Priestley-Taylor   PET = $\alpha* (R_n-G)* \Delta/(\Delta+\gamma)$

Hargreaves–Samani Equation   PET= $0.0023*R_a \cdot (T_{max} - T_{min})^{0.5} *(T_m + 17.8)$
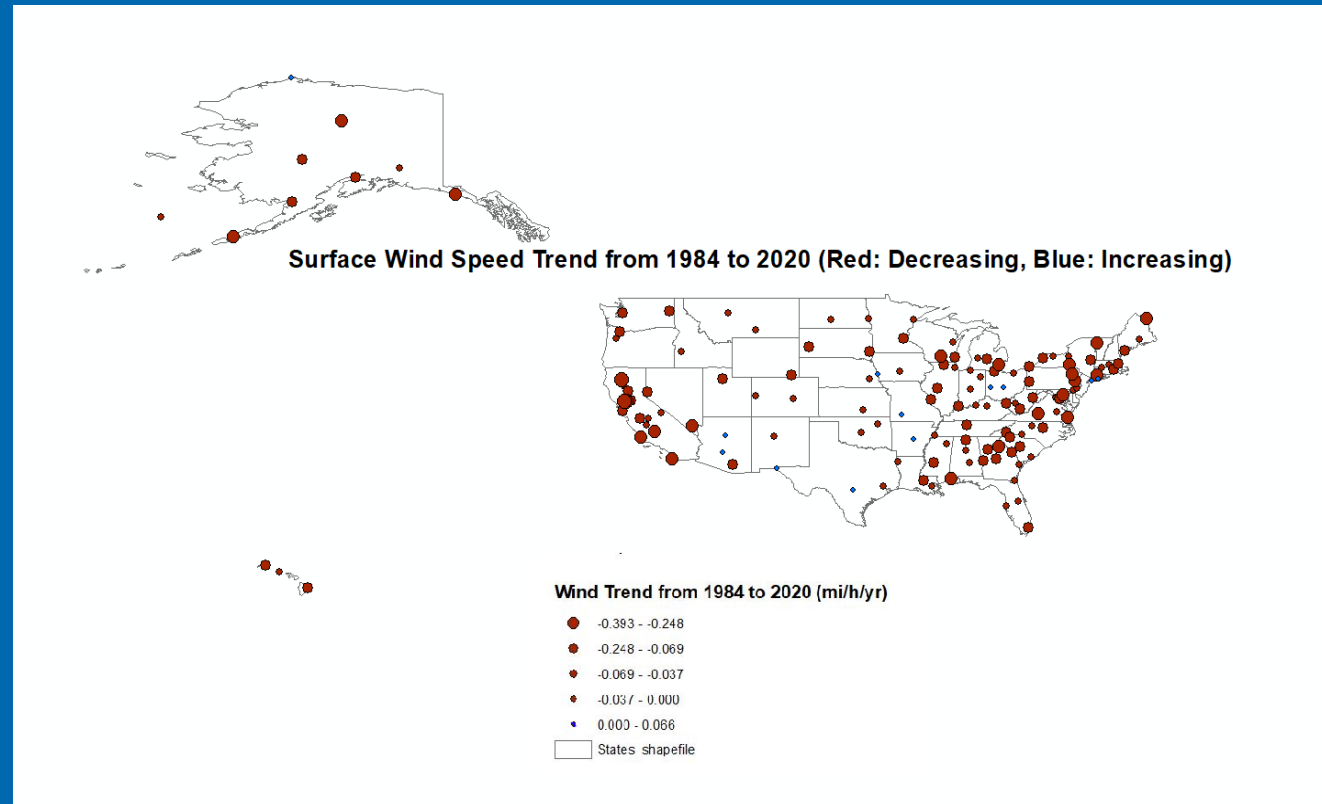
Penman–Monteith Equation   PET=

$$\frac{\Delta \cdot (R_n - G) + \rho_a \cdot c_p \cdot \left(\frac{e_s - e_a}{r_a}\right)}{\Delta + \gamma \cdot \left(1 + \frac{r_s}{r_a}\right)}$$

Wind Stilling and Other Trends

- Major factors affecting ETo (1984 to 2020):
  - solar radiation
  - wind Speed
  - VPD
- Wind is stilling from 1984 to 2020
  - CIMIS
  - California
  - USA
  - World
- Received solar radiation is increasing
- VPD is also increasing

CIMIS Station	Solar Radiaton (cal/year)	Wind Speed (mph/year)	T (°F/year)	VPD (mb/year)
Davis	0.1139	-0.0258	0.0389	0.0178
Durham	0.6603	-0.0487	0.0031	-0.0319
FireBaugh	0.8817	-0.0218	0.0646	0.0259
Stratiford	0.9213	-0.0081	0.0606	0.0532

Surface Wind Speed Trend from 1984 to 2020 (Red: Decreasing, Blue: Increasing)

Wind Trend from 1984 to 2020 (mi/h/yr)
- -0.393 - -0.248
- -0.248 - -0.069
- -0.069 - -0.037
- -0.037 - 0.000
- 0.000 - 0.066
- States shapefile

Global Wind Trend over Land and Ocean
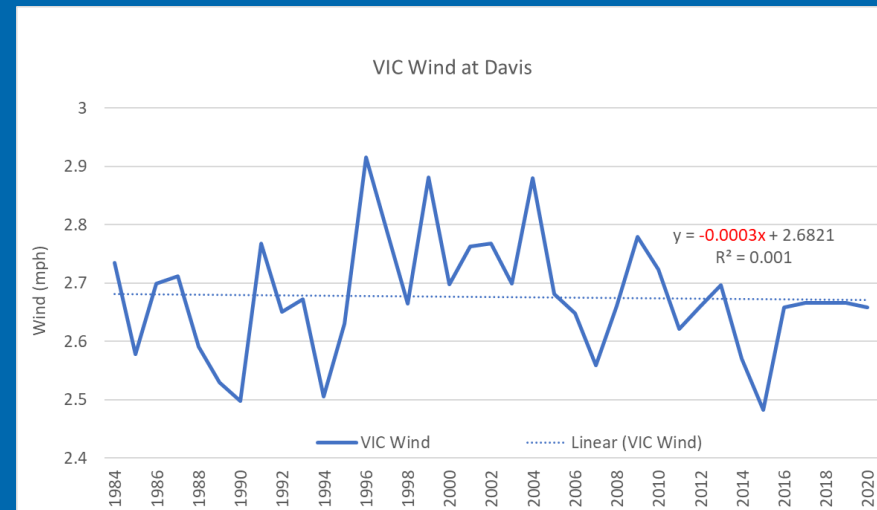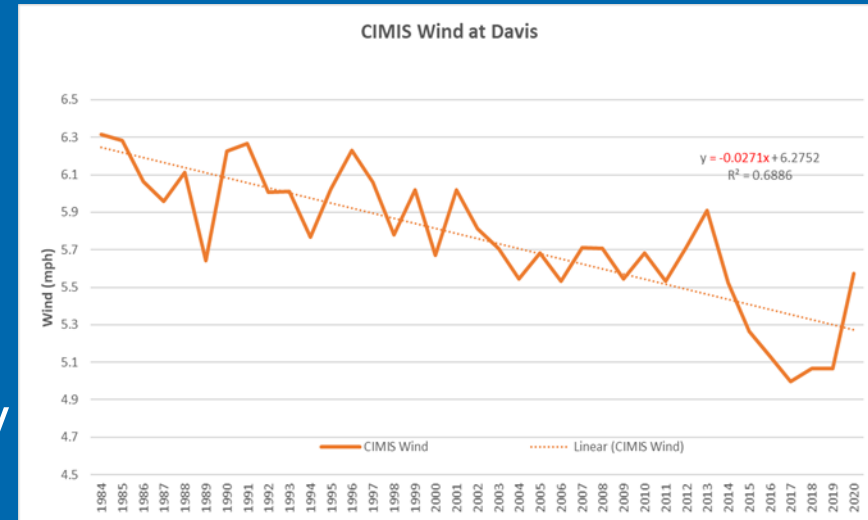
● McVicar *et al*'s review in 2012 in Journal of Hydrology

  ► Globally 148 regional studies reviewed; average wind speed trend = ~-0.014 m s^{-1} a^{-1}
  ► Globally 55 pan evaporation studies were reviewed; average trend = -3.19 mm a^{-2}
  ► Twenty-six crop ETo studies reviewed; average trend = -1.31 mm a^{-2}
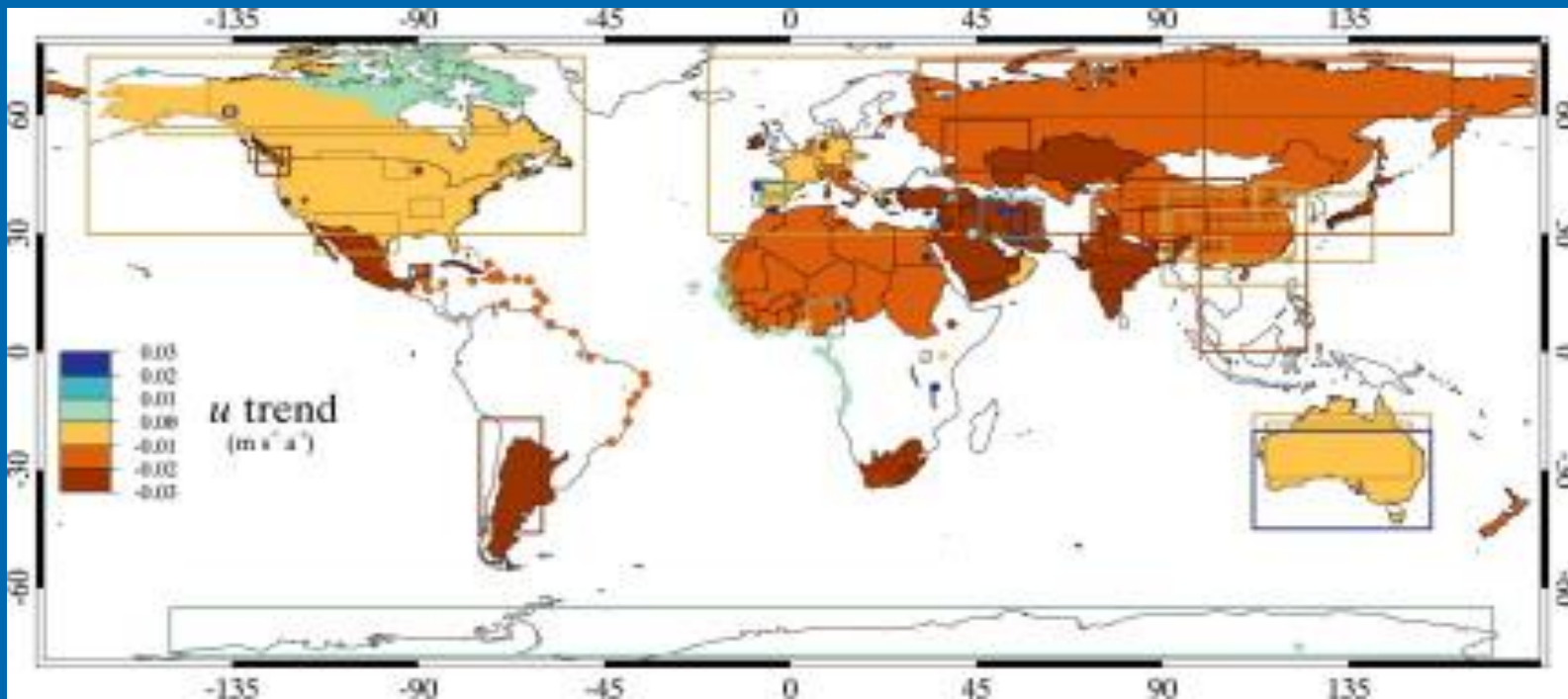
● Zhao *et al'* work: The global oceanic sea-surface wind speeds increased at a significant overall rate of 0.0335 m s^{-1} a^{-1} for the period 1988–2011
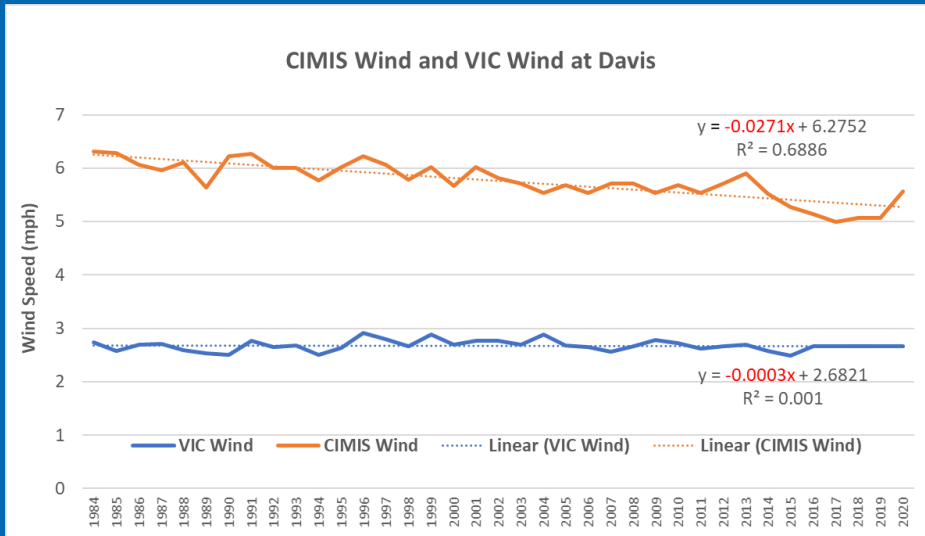
Sensitivity Test: Effect of Wind Stilling on ETo

- VIC wind vs CIMIS Wind
  - VIC wind trends up or slightly downward from 1984 to 2020
  - CIMIS wind trends downward significantly
- 'Ref ET' software, developed by University of Idaho.
  - DWR's CIMIS group do not have its own ETo software in house
- Sensitivity Test:
  - Base: CIMIS wind and other CIMIS data
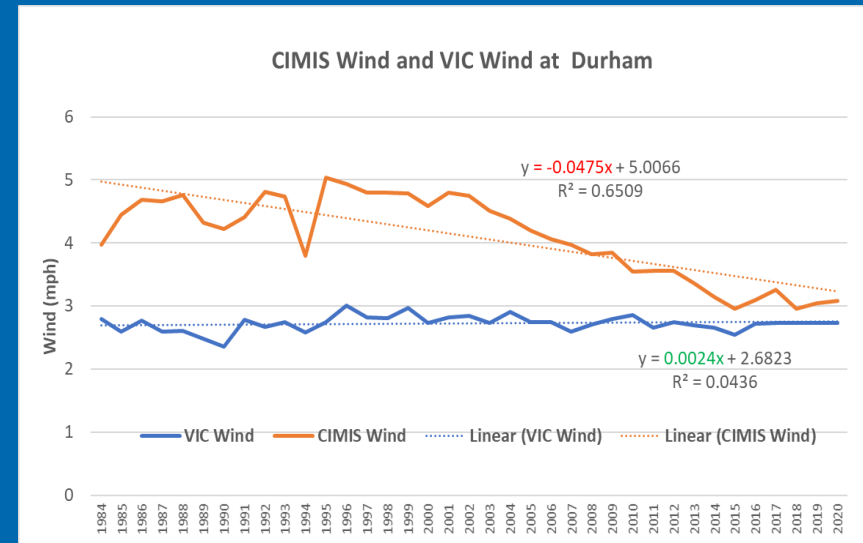 - Sensitivity Test: VIC wind and other CIMIS data

CIMIS Wind at Davis

$y = -0.0271x + 6.2752$
$R^2 = 0.6886$

— CIMIS Wind   ⋯⋯ Linear (CIMIS Wind)

VIC Wind at Davis

$y = -0.0003x + 2.6821$
$R^2 = 0.001$

— VIC Wind   ⋯⋯ Linear (VIC Wind)

Sensitivity Test: Effect of Wind Stilling on ETo
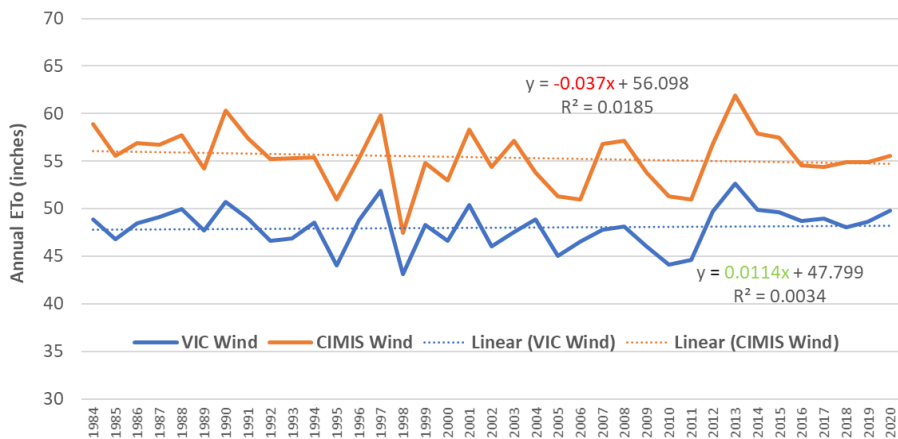
- Sensitivity test for Davis
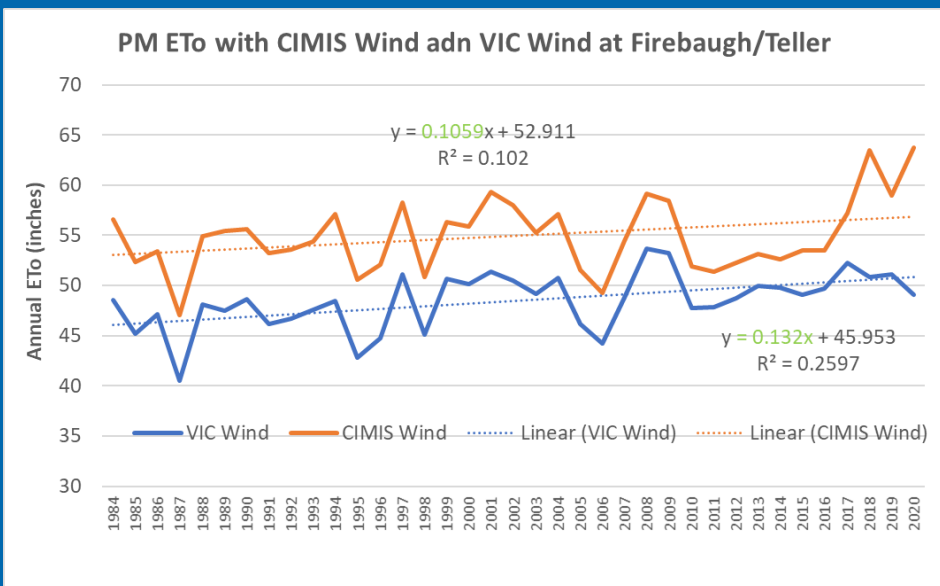- Sensitivity test for Durham

CIMIS Wind and VIC Wind at Davis

$y = -0.0271x + 6.2752$
$R^2 = 0.6886$

$y = -0.0003x + 2.6821$
$R^2 = 0.001$

CIMIS Wind and VIC Wind at Durham

$y = -0.0475x + 5.0066$
$R^2 = 0.6509$

$y = 0.0024x + 2.6823$
$R^2 = 0.0436$

PM ETo with CIMIS Wind and VIC Wind at Davis

$y = -0.037x + 56.098$
$R^2 = 0.0185$

$y = 0.0114x + 47.799$
$R^2 = 0.0034$

PM ETo with CIMIS Wind and VIC Wind at Durham

$y = -0.0291x + 49.722$
$R^2 = 0.0194$

$y = 0.0764x + 44.756$
$R^2 = 0.1556$
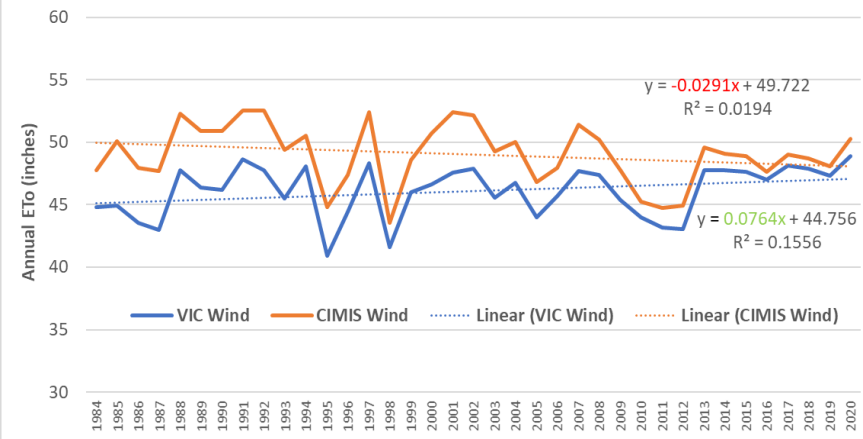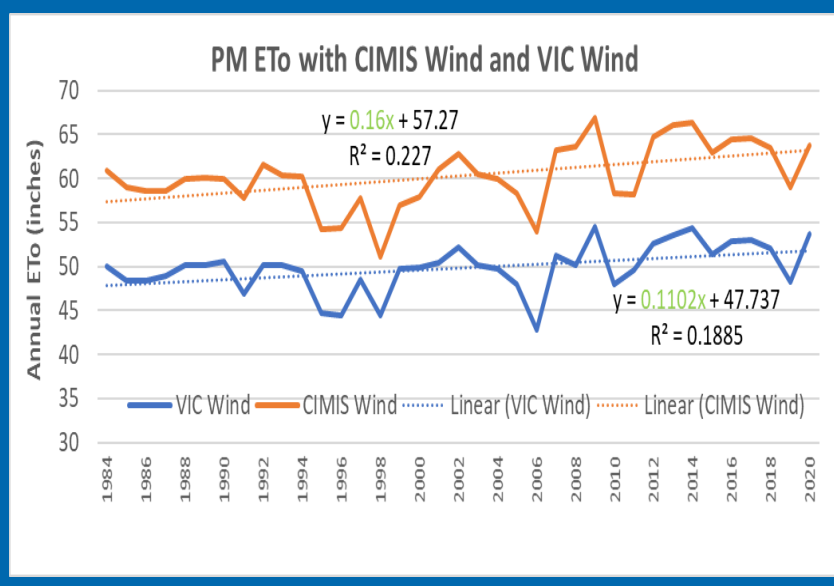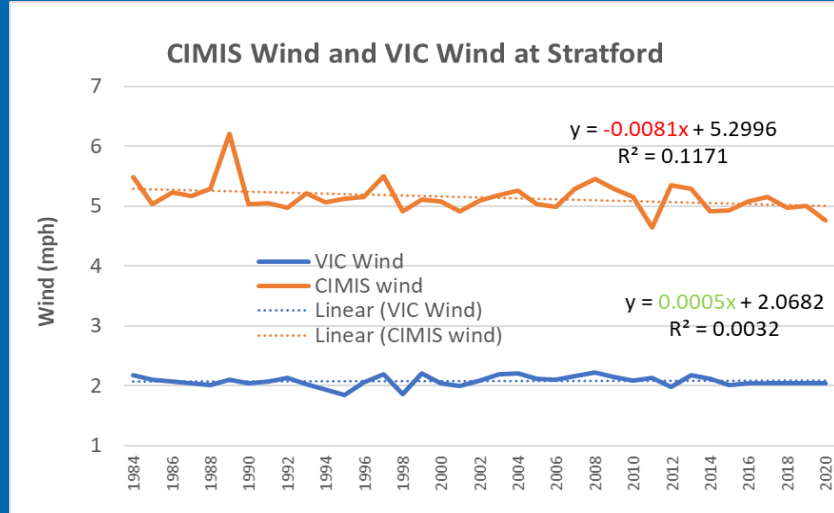
Sensitivity Test: Effect of Wind Stilling on ETo

- Sensitivity test for Firebaugh/Teller
- Sensitivity test for Stratford
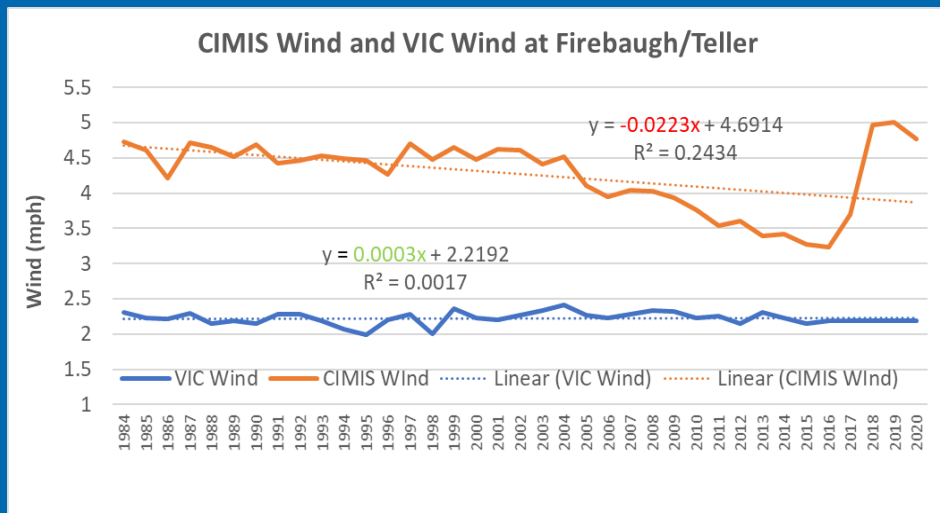
CIMIS Wind and VIC Wind at Firebaugh/Teller

$y = -0.0223x + 4.6914$
$R^2 = 0.2434$

$y = 0.0003x + 2.2192$
$R^2 = 0.0017$

CIMIS Wind and VIC Wind at Stratford

$y = -0.0081x + 5.2996$
$R^2 = 0.1171$

$y = 0.0005x + 2.0682$
$R^2 = 0.0032$

PM ETo with CIMIS Wind adn VIC Wind at Firebaugh/Teller

$y = 0.1059x + 52.911$
$R^2 = 0.102$

$y = 0.132x + 45.953$
$R^2 = 0.2597$

PM ETo with CIMIS Wind and VIC Wind

$y = 0.16x + 57.27$
$R^2 = 0.227$

$y = 0.1102x + 47.737$
$R^2 = 0.1885$

Summary**

- Surface wind stilling is a dominant and significant trend in the data period of 1984 to 2020 in USA.

- Wind stilling can affect potential ET (ETo) to the extent that it can flip ETo trend from upward to downward.

- This work reveals the vital importance of wind speed and its data quality in the estimate of potential ET (ETo).

Question?