Using LIMP to refine Urban Water Management

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Ontario, California

How do we scientifically refine

Urban Water Management?

Landscape Irrigation Management Program

LIMP

Surface Renewal

SR

WUCOLS

$$ET_L = ET_o \times K_L$$

$$K_L = K_p \times K_d \times K_m$$

- K_p - plant species
- K_d - density
- K_m - microclimate

WUCOLS

K_p - plant species

- very low (<0.1)
- low (0.1-0.3)
- moderate (0.4-0.6)
- high (0.7-0.9)

K_p includes microclimate and stress

WUCOLS

K_d - density

- low (0.5–0.9) – sparse
- medium (1.0) – one species
- high (1.1-1.3) – mixed

WUCOLS

K_m - microclimate

- **low (0.5-0.9)**
  low radiation, temperature and/or wind
- **average (1.0)**
  microclimate like ET_o site
- **high (1.1-1.4)**
  high radiation, temperature, and/or wind

Landscape Irrigation Management Program (LIMP)

$$ET_L = (ET_o \times K_m) \times (K_v \times K_d) \times K_s$$

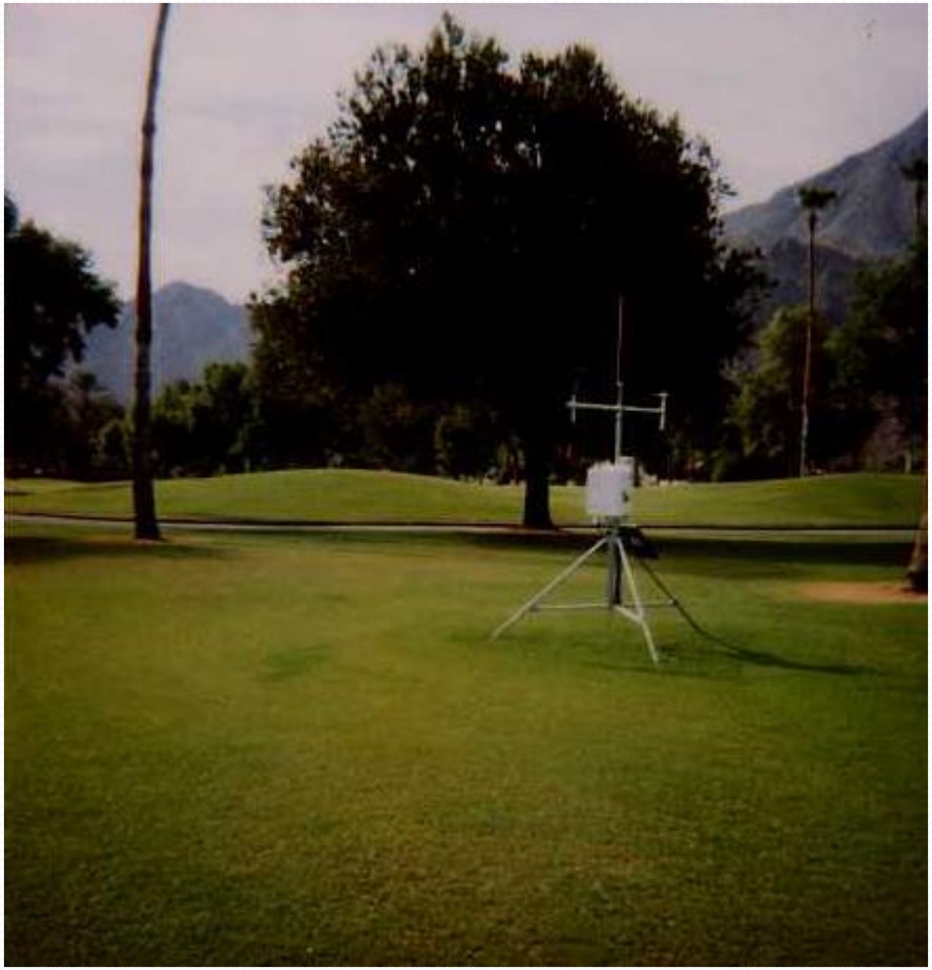
$$ET_L = (\quad ET_{oL} \quad) \times (\quad K_p \quad) \times K_s$$

- K_m – microclimate
- K_v – vegetation (≤1.30)
- K_d – density (≤1.00)
- K_s – stress (≤1.00)

Irrigation Water Requirements

Allen, R.G., Howell, T.A., and Snyder, R.L. 2011. Chapter 5. Irrigation Water Requirements. *Irrigation Sixth Edition*. Irrigation Association, Falls Church, VA 22042.

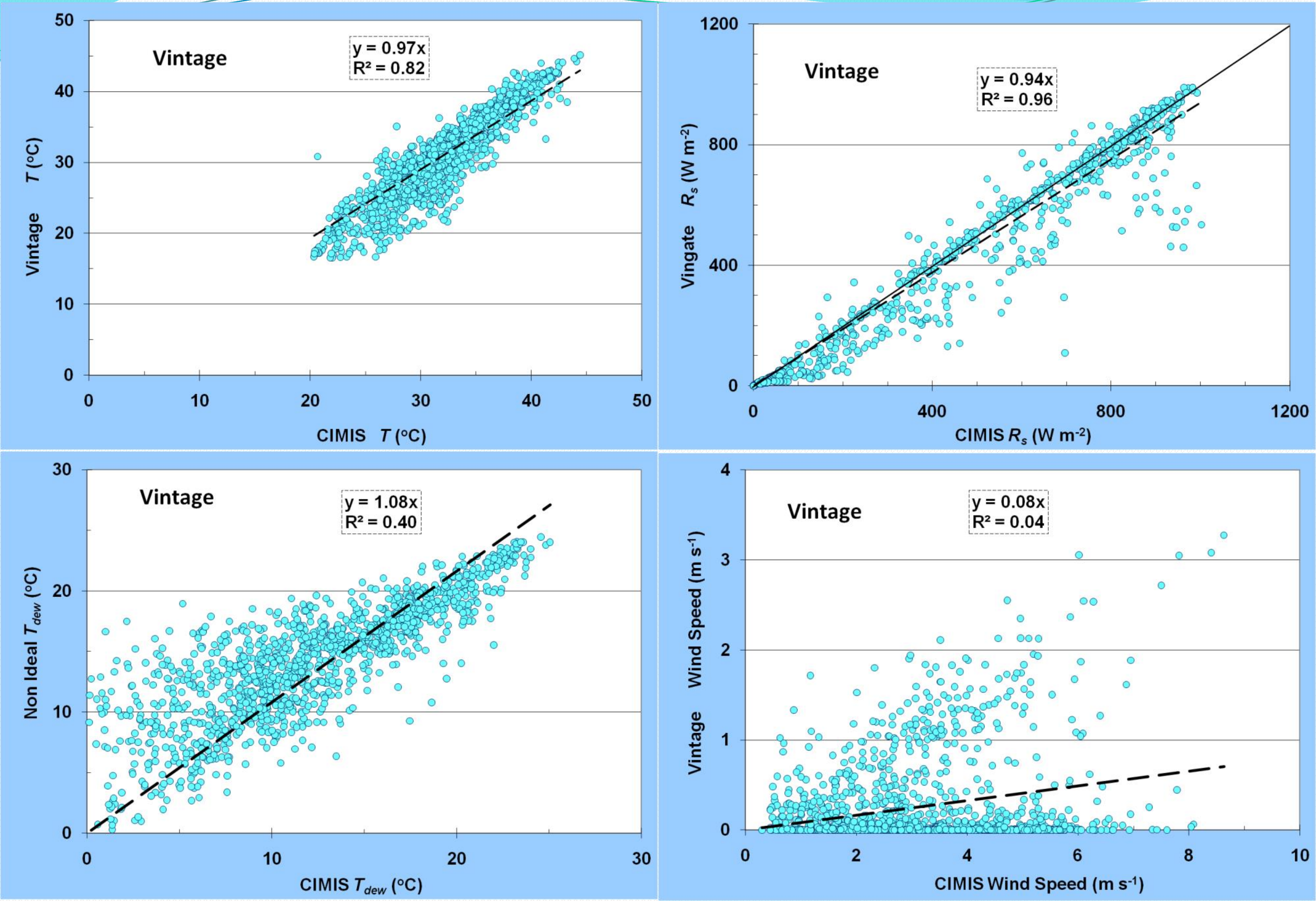
$ET_{oL} = ET_o \times K_m$



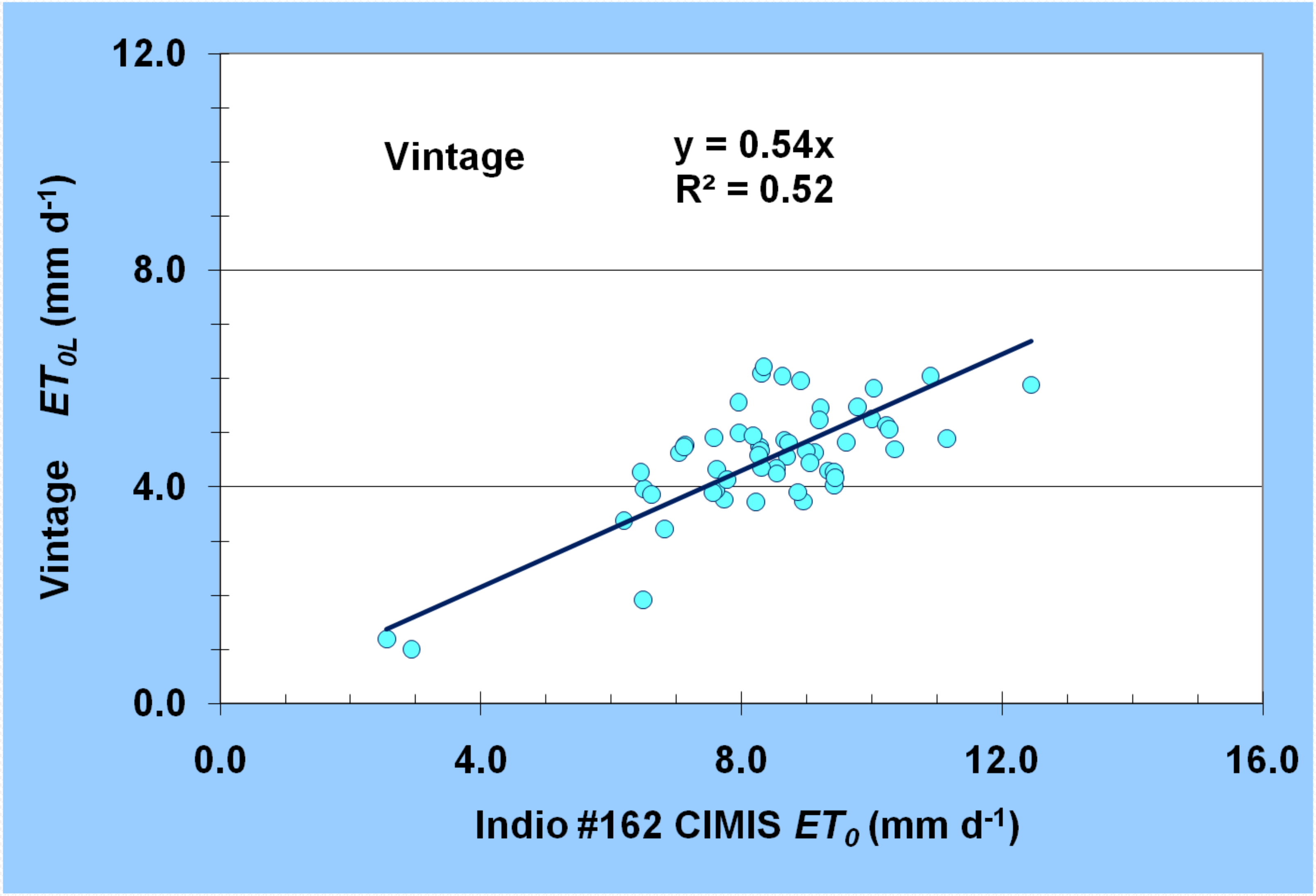
Vintage Non-Ideal Station

$$K_m = \frac{ET_{oL}}{ET_o}$$

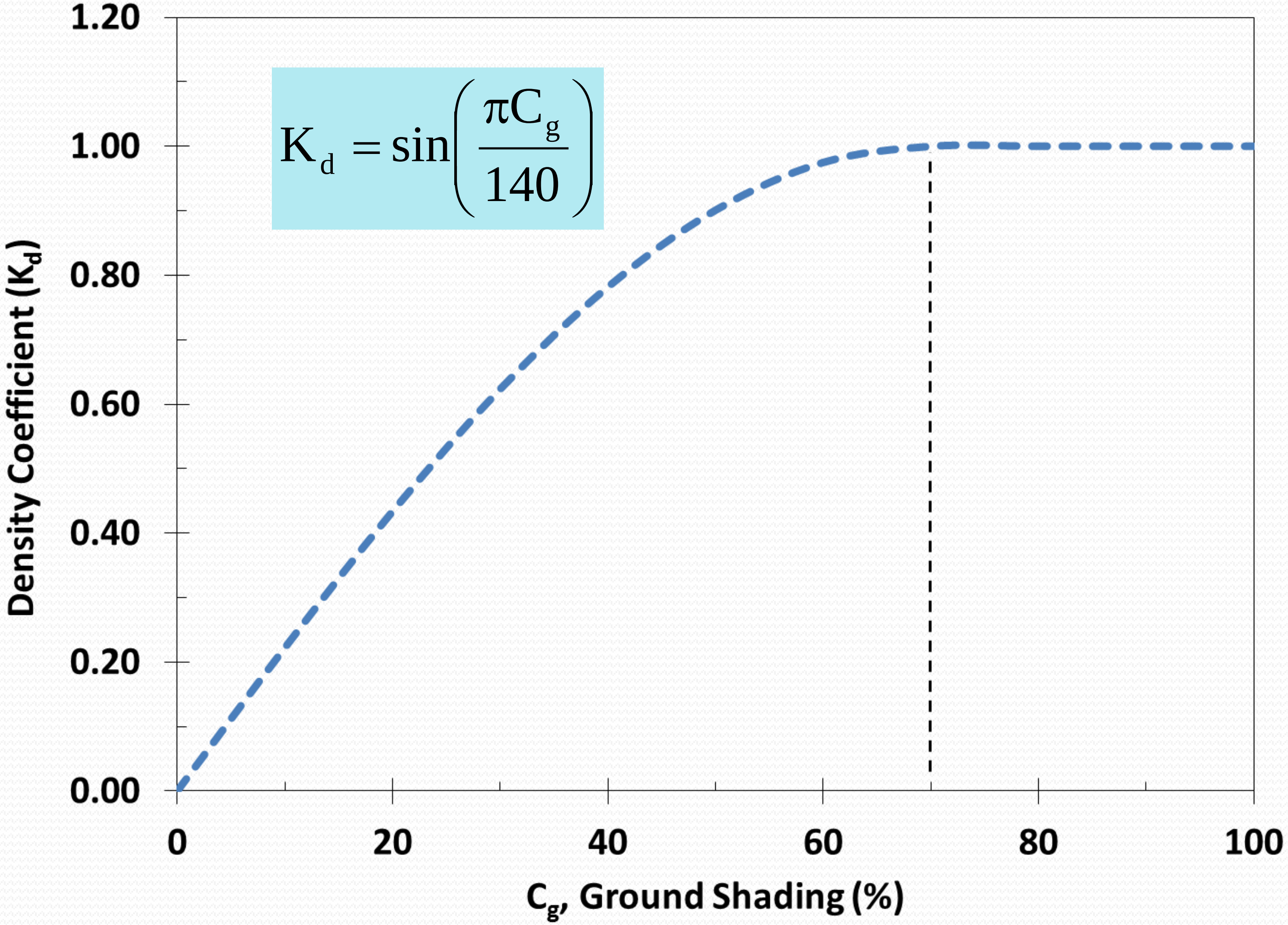
Hourly Weather



ET_{oL} versus ET_o



Density Coefficient (K_d)



Local = Regional

Leave slope blank to enter Rs directly

Year:	2010	Latitude:	38.5
Station Name:	Davis	Elevation (m):	18.5

Slope: [ ] 0° = horizontal; 90° = vertical

Aspect: [ ] + 90° east; 0° south; -90° west

	R_s	T_x	T_n	U_2	T_d	Pcp	NRD	Loc. ET_{0L}	Reg. ET_0	Input ET_0	PM ET_0	HS ET_0	$0<K_v$ Veg. Factor	0-100 Gnd. Cov.	$0<K_d<1$ Dens. factor	$0<K_s<1$ Stress factor	$0<K_m$ Clim. factor
												Default =	1.00	100		1.00	1.00
Mon	MJ $m^{-2}d^{-1}$	°C	°C	m s^{-1}	°C	mm	#	mm	mm	mm	mm	mm	K_v	%	K_d	K_s	K_m
1	6.6	12.4	3.0	2.5	4.6	68.1	6.7	1.0	1.0		1.0	1.2	0.80		1.00		1.00
2	10.3	15.8	4.3	2.7	5.7	82.9	5.5	1.7	1.7		1.7	1.9	0.80		1.00		1.00
3	15.3	18.9	5.9	2.7	6.8	98.8	7.6	2.8	2.8		2.8	2.9	0.80		1.00		1.00
4	21.0	22.1	7.0	2.9	6.4	15.9	0.9	4.2	4.2		4.2	4.2	0.80		1.00		1.00
5	25.0	26.3	9.9	3.0	8.2	12.4	0.6	5.6	5.6		5.6	5.5	0.80		1.00		1.00
6	28.2	30.1	12.4	3.0	10.3	5.4	0.1	6.7	6.7		6.7	6.4	0.80		1.00		1.00
7	28.7	32.9	13.6	2.7	12.1	0.0	0.0	7.0	7.0		7.0	6.9	0.80		1.00		1.00
8	26.7	32.8	13.1	2.5	12.0	0.6	0.0	6.5	6.5		6.5	6.2	0.80		1.00		1.00
9	22.1	31.4	12.5	2.5	10.0	9.1	0.3	5.5	5.5		5.5	4.9	0.80		1.00		1.00
10	16.5	27.7	10.4	2.4	7.6	13.1	0.9	4.1	4.1		4.1	3.3	0.80		1.00		1.00
11	10.3	20.4	6.8	2.4	6.1	55.4	4.7	2.3	2.3		2.3	1.8	0.80		1.00		1.00
12	6.9	13.9	3.3	2.6	4.5	74.7	7.0	1.3	1.3		1.3	1.2	0.80		1.00		1.00

Blank for K_m = 1.0

Below, input the Local Microclimate Weather data or mean daily ETo for each month | x | ⇦ 'X' to copy from below

	R_s	T_x	T_n	U_2	T_d	$R_{s\beta\gamma}$	Loc. ET_{0L}	Reg. ET_0	Input ET_0	PM ET_0	HS ET_0				Clim. factor
Mon	MJ $m^{-2}d^{-1}$	°C	°C	m s^{-1}	°C	MJ $m^{-2}d^{-1}$	mm	mm	mm	mm	mm		Calculations		K_m
1	6.6	12.4	3.0	2.5	4.6		1.0	1.0		1.0	1.2				1.00
2	10.3	15.8	4.3	2.7	5.7		1.7	1.7		1.7	1.9				1.00
3	15.3	18.9	5.9	2.7	6.8		2.8	2.8		2.8	2.9				1.00
4	21.0	22.1	7.0	2.9	6.4		4.2	4.2		4.2	4.2				1.00
5	25.0	26.3	9.9	3.0	8.2		5.6	5.6		5.6	5.5				1.00
6	28.2	30.1	12.4	3.0	10.3		6.7	6.7		6.7	6.4				1.00
7	28.7	32.9	13.6	2.7	12.1		7.0	7.0		7.0	6.9				1.00
8	26.7	32.8	13.1	2.5	12.0		6.5	6.5		6.5	6.2				1.00
9	22.1	31.4	12.5	2.5	10.0		5.5	5.5		5.5	4.9				1.00
10	16.5	27.7	10.4	2.4	7.6		4.1	4.1		4.1	3.3				1.00
11	10.3	20.4	6.8	2.4	6.1		2.3	2.3		2.3	1.8				1.00
12	6.9	13.9	3.3	2.6	4.5		1.3	1.3		1.3	1.2				1.00

^ ^ ^

Leave blank to use slope & aspect for R_s

Wind speed = 4.0 m s^{-1}

Year: 2010
Station Name: Davis

Latitude: 38.5
Elevation (m): 18.5

Leave slope blank to enter Rs directly

Slope: (blank) — 0° = horizontal; 90° = vertical
Aspect: (blank) — + 90° east; 0° south; -90° west

													Default = 1.00	100		1.00	1.00
	R_s	T_x	T_n	U_2	T_d	Pcp	NRD	Loc. ET_{0L}	Reg. ET_0	Input ET_0	PM ET_0	HS ET_0	$0<K_v$ Veg. Factor	0-100 Gnd. Cov.	$0<K_d<1$ Dens. factor	$0<K_s<1$ Stress factor	$0<K_m$ Clim. factor
Mon	MJ $m^{-2}d^{-1}$	°C	°C	m s^{-1}	°C	mm	#	mm	mm	mm	mm	mm	K_v	%	K_d	K_s	K_m
1	6.6	12.4	3.0	2.5	4.6	68.1	6.7	1.2	1.0		1.0	1.2	0.80		1.00		1.19
2	10.3	15.8	4.3	2.7	5.7	82.9	5.5	2.0	1.7		1.7	1.9	0.80		1.00		1.14
3	15.3	18.9	5.9	2.7	6.8	98.8	7.6	3.0	2.8		2.8	2.9	0.80		1.00		1.10
4	21.0	22.1	7.0	2.9	6.4	15.9	0.9	4.6	4.2		4.2	4.2	0.80		1.00		1.08
5	25.0	26.3	9.9	3.0	8.2	12.4	0.6	6.0	5.6		5.6	5.5	0.80		1.00		1.08
6	28.2	30.1	12.4	3.0	10.3	5.4	0.1	7.3	6.7		6.7	6.4	0.80		1.00		1.08
7	28.7	32.9	13.6	2.7	12.1	0.0	0.0	7.9	7.0		7.0	6.9	0.80		1.00		1.12
8	26.7	32.8	13.1	2.5	12.0	0.6	0.0	7.5	6.5		6.5	6.2	0.80		1.00		1.15
9	22.1	31.4	12.5	2.5	10.0	9.1	0.3	6.6	5.5		5.5	4.9	0.80		1.00		1.19
10	16.5	27.7	10.4	2.4	7.6	13.1	0.9	5.1	4.1		4.1	3.3	0.80		1.00		1.25
11	10.3	20.4	6.8	2.4	6.1	55.4	4.7	3.0	2.3		2.3	1.8	0.80		1.00		1.27
12	6.9	13.9	3.3	2.6	4.5	74.7	7.0	1.6	1.3		1.3	1.2	0.80		1.00		1.19

Blank for K_m = 1.0
'X' to copy from below

Below, input the Local Microclimate Weather data or mean daily ETo for each month — X

	R_s	T_x	T_n	U_2	T_d	$R_{s\beta\gamma}$	Loc. ET_{0L}	Reg. ET_0	Input ET_0	PM ET_0	HS ET_0		Calculations		Clim. factor
Mon	MJ $m^{-2}d^{-1}$	°C	°C	m s^{-1}	°C	MJ $m^{-2}d^{-1}$	mm	mm	mm	mm	mm				K_m
1	6.6	12.4	3.0	4.0	4.6		1.2	1.0		1.2	1.2				1.19
2	10.3	15.8	4.3	4.0	5.7		2.0	1.7		2.0	1.9				1.14
3	15.3	18.9	5.9	4.0	6.8		3.0	2.8		3.0	2.9				1.10
4	21.0	22.1	7.0	4.0	6.4		4.6	4.2		4.6	4.2				1.08
5	25.0	26.3	9.9	4.0	8.2		6.0	5.6		6.0	5.5				1.08
6	28.2	30.1	12.4	4.0	10.3		7.3	6.7		7.3	6.4				1.08
7	28.7	32.9	13.6	4.0	12.1		7.9	7.0		7.9	6.9				1.12
8	26.7	32.8	13.1	4.0	12.0		7.5	6.5		7.5	6.2				1.15
9	22.1	31.4	12.5	4.0	10.0		6.6	5.5		6.6	4.9				1.19
10	16.5	27.7	10.4	4.0	7.6		5.1	4.1		5.1	3.3				1.25
11	10.3	20.4	6.8	4.0	6.1		3.0	2.3		3.0	1.8				1.27
12	6.9	13.9	3.3	4.0	4.5		1.6	1.3		1.6	1.2				1.19

^ ^ ^

Leave blank to use slope & aspect for R_s

Local T_x = Regional 1.1×T_x

Leave slope blank to enter Rs directly

Year: 2010
Station Name: Davis

Latitude: 38.5
Elevation (m): 18.5

Slope: [ ] 0° = horizontal; 90° = vertical
Aspect: [ ] + 90° east; 0° south; -90° west

Mon	R_s MJ m^{-2}d^{-1}	T_x °C	T_n °C	U_2 m s^{-1}	T_d °C	*Pcp* mm	NRD #	Loc. ET_{0L} mm	Reg. ET_0 mm	Input ET_0 mm	PM ET_0 mm	HS $ET_)$ mm	0<K_v Veg. Factor K_v	0-100 Gnd. Cov. %	0<K_d<1 Dens. factor K_d	0<K_s<1 Stress factor K_s	0<K_m Clim. factor K_m
												Default =	1.00	100		1.00	1.00
1	6.6	12.4	3.0	2.5	4.6	68.1	6.7	1.2	1.0		1.0	1.2	0.80		1.00		1.15
2	10.3	15.8	4.3	2.7	5.7	82.9	5.5	2.0	1.7		1.7	1.9	0.80		1.00		1.13
3	15.3	18.9	5.9	2.7	6.8	98.8	7.6	3.1	2.8		2.8	2.9	0.80		1.00		1.12
4	21.0	22.1	7.0	2.9	6.4	15.9	0.9	4.6	4.2		4.2	4.2	0.80		1.00		1.10
5	25.0	26.3	9.9	3.0	8.2	12.4	0.6	6.1	5.6		5.6	5.5	0.80		1.00		1.10
6	28.2	30.1	12.4	3.0	10.3	5.4	0.1	7.4	6.7		6.7	6.4	0.80		1.00		1.10
7	28.7	32.9	13.6	2.7	12.1	0.0	0.0	7.7	7.0		7.0	6.9	0.80		1.00		1.09
8	26.7	32.8	13.1	2.5	12.0	0.6	0.0	7.1	6.5		6.5	6.2	0.80		1.00		1.10
9	22.1	31.4	12.5	2.5	10.0	9.1	0.3	6.1	5.5		5.5	4.9	0.80		1.00		1.10
10	16.5	27.7	10.4	2.4	7.6	13.1	0.9	4.5	4.1		4.1	3.3	0.80		1.00		1.10
11	10.3	20.4	6.8	2.4	6.1	55.4	4.7	2.6	2.3		2.3	1.8	0.80		1.00		1.12
12	6.9	13.9	3.3	2.6	4.5	74.7	7.0	1.5	1.3		1.3	1.2	0.80		1.00		1.14

Below, input the Local Microclimate Weather data or mean daily ETo for each month [x] Blank for K_m = 1.0; 'X' to copy from below

Mon	R_s MJ m^{-2}d^{-1}	T_x °C	T_n °C	U_2 m s^{-1}	T_d °C	$R_{s\beta\gamma}$ MJ m^{-2}d^{-1}	Loc. ET_{0L} mm	Reg. ET_0 mm	Input ET_0 mm	PM ET_0 mm	HS ET_0 mm	Calculations		Clim. factor K_m
1	6.6	13.7	3.0	2.5	4.6		1.2	1.0		1.2	1.3			1.15
2	10.3	17.4	4.3	2.7	5.7		2.0	1.7		2.0	2.1			1.13
3	15.3	20.8	5.9	2.7	6.8		3.1	2.8		3.1	3.2			1.12
4	21.0	24.4	7.0	2.9	6.4		4.6	4.2		4.6	4.6			1.10
5	25.0	28.9	9.9	3.0	8.2		6.1	5.6		6.1	6.1			1.10
6	28.2	33.1	12.4	3.0	10.3		7.4	6.7		7.4	7.2			1.10
7	28.7	36.2	13.6	2.7	12.1		7.7	7.0		7.7	7.7			1.09
8	26.7	36.1	13.1	2.5	12.0		7.1	6.5		7.1	7.0			1.10
9	22.1	34.5	12.5	2.5	10.0		6.1	5.5		6.1	5.5			1.10
10	16.5	30.5	10.4	2.4	7.6		4.5	4.1		4.5	3.7			1.10
11	10.3	22.4	6.8	2.4	6.1		2.6	2.3		2.6	2.0			1.12
12	6.9	15.3	3.3	2.6	4.5		1.5	1.3		1.5	1.3			1.14

^ ^ ^

Leave blank to use slope & aspect for R_s

Slope = 10° & Aspect = 180°

Year: 2010
Station Name: Davis

Latitude: 38.5
Elevation (m): 18.5

Leave slope blank to enter Rs directly
Slope: 10 — 0° = horizontal; 90° = vertical
Aspect: 180 — + 90° east; 0° south; -90° west

												Default =	1.00	100		1.00	1.00
	R_s	T_x	T_n	U_2	T_d	Pcp	NRD	Loc. ET_{0L}	Reg. ET_0	Input ET_0	PM ET_0	HS ET_0	$0<K_v$ Veg. Factor	0-100 Gnd. Cov.	$0<K_d<1$ Dens. factor	$0<K_s<1$ Stress factor	$0<K_m$ Clim. factor
Mon	$MJ\ m^{-2}d^{-1}$	°C	°C	$m\ s^{-1}$	°C	mm	#	mm	mm	mm	mm	mm	K_v	%	K_d	K_s	K_m
1	6.6	12.4	3.0	2.5	4.6	68.1	6.7	0.8	1.0		1.0	1.2	0.80		1.00		0.75
2	10.3	15.8	4.3	2.7	5.7	82.9	5.5	1.4	1.7		1.7	1.9	0.80		1.00		0.83
3	15.3	18.9	5.9	2.7	6.8	98.8	7.6	2.5	2.8		2.8	2.9	0.80		1.00		0.89
4	21.0	22.1	7.0	2.9	6.4	15.9	0.9	4.0	4.2		4.2	4.2	0.80		1.00		0.95
5	25.0	26.3	9.9	3.0	8.2	12.4	0.6	5.5	5.6		5.6	5.5	0.80		1.00		0.98
6	28.2	30.1	12.4	3.0	10.3	5.4	0.1	6.7	6.7		6.7	6.4	0.80		1.00		1.00
7	28.7	32.9	13.6	2.7	12.1	0.0	0.0	7.0	7.0		7.0	6.9	0.80		1.00		0.99
8	26.7	32.8	13.1	2.5	12.0	0.6	0.0	6.2	6.5		6.5	6.2	0.80		1.00		0.96
9	22.1	31.4	12.5	2.5	10.0	9.1	0.3	5.1	5.5		5.5	4.9	0.80		1.00		0.92
10	16.5	27.7	10.4	2.4	7.6	13.1	0.9	3.5	4.1		4.1	3.3	0.80		1.00		0.86
11	10.3	20.4	6.8	2.4	6.1	55.4	4.7	1.9	2.3		2.3	1.8	0.80		1.00		0.81
12	6.9	13.9	3.3	2.6	4.5	74.7	7.0	1.0	1.3		1.3	1.2	0.80		1.00		0.77

Blank for K_m = 1.0
'X' to copy from below: X

Below, input the Local Microclimate Weather data or mean daily ETo for each month

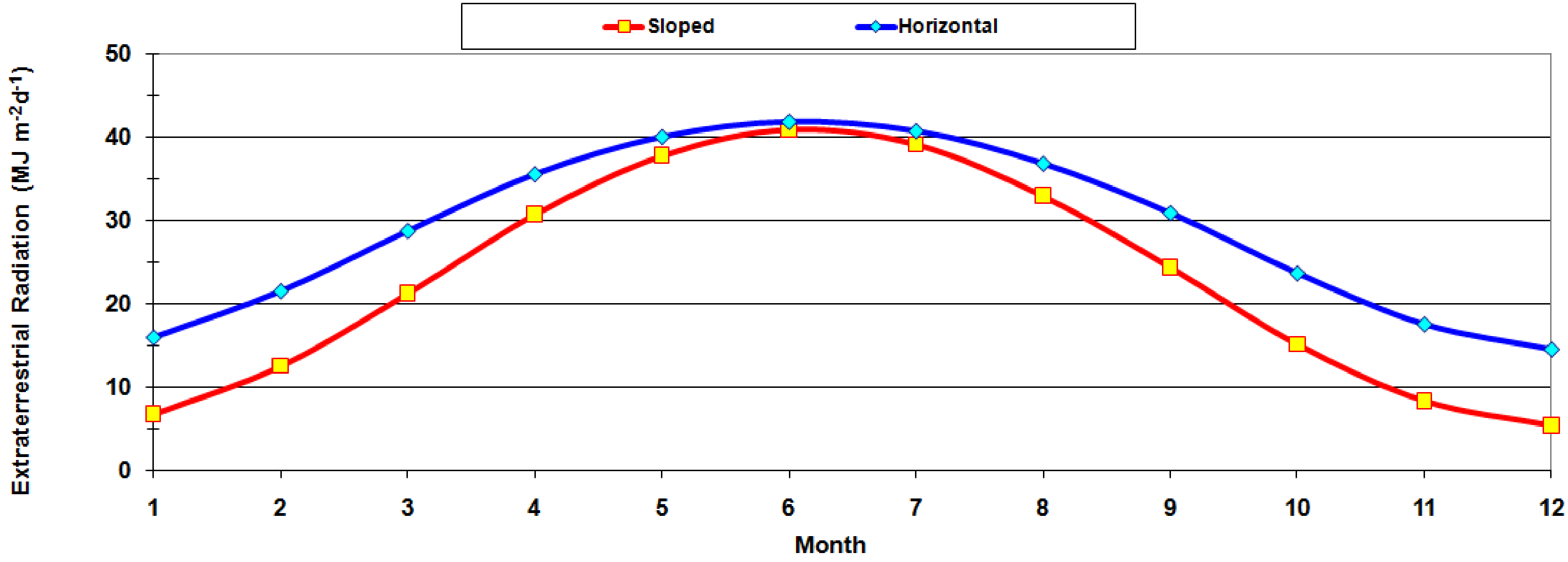
	R_s	T_x	T_n	U_2	T_d	$R_{s\beta\gamma}$	Loc. ET_{0L}	Reg. ET_0	Input ET_0	PM ET_0	HS ET_0			Clim. factor
Mon	$MJ\ m^{-2}d^{-1}$	°C	°C	$m\ s^{-1}$	°C	$MJ\ m^{-2}d^{-1}$	mm	mm	mm	mm	mm	Calculations		K_m
1	6.6	12.4	3.0	2.5	4.6	4.5	0.8	1.0		0.8	1.2			0.75
2	10.3	15.8	4.3	2.7	5.7	7.9	1.4	1.7		1.4	1.9			0.83
3	15.3	18.9	5.9	2.7	6.8	13.1	2.5	2.8		2.5	2.9			0.89
4	21.0	22.1	7.0	2.9	6.4	19.5	4.0	4.2		4.0	4.2			0.95
5	25.0	26.3	9.9	3.0	8.2	24.4	5.5	5.6		5.5	5.5			0.98
6	28.2	30.1	12.4	3.0	10.3	28.0	6.7	6.7		6.7	6.4			1.00
7	28.7	32.9	13.6	2.7	12.1	28.3	7.0	7.0		7.0	6.9			0.99
8	26.7	32.8	13.1	2.5	12.0	25.3	6.2	6.5		6.2	6.2			0.96
9	22.1	31.4	12.5	2.5	10.0	19.6	5.1	5.5		5.1	4.9			0.92
10	16.5	27.7	10.4	2.4	7.6	13.2	3.5	4.1		3.5	3.3			0.86
11	10.3	20.4	6.8	2.4	6.1	7.3	1.9	2.3		1.9	1.8			0.81
12	6.9	13.9	3.3	2.6	4.5	4.4	1.0	1.3		1.0	1.2			0.77

^ ^ ^

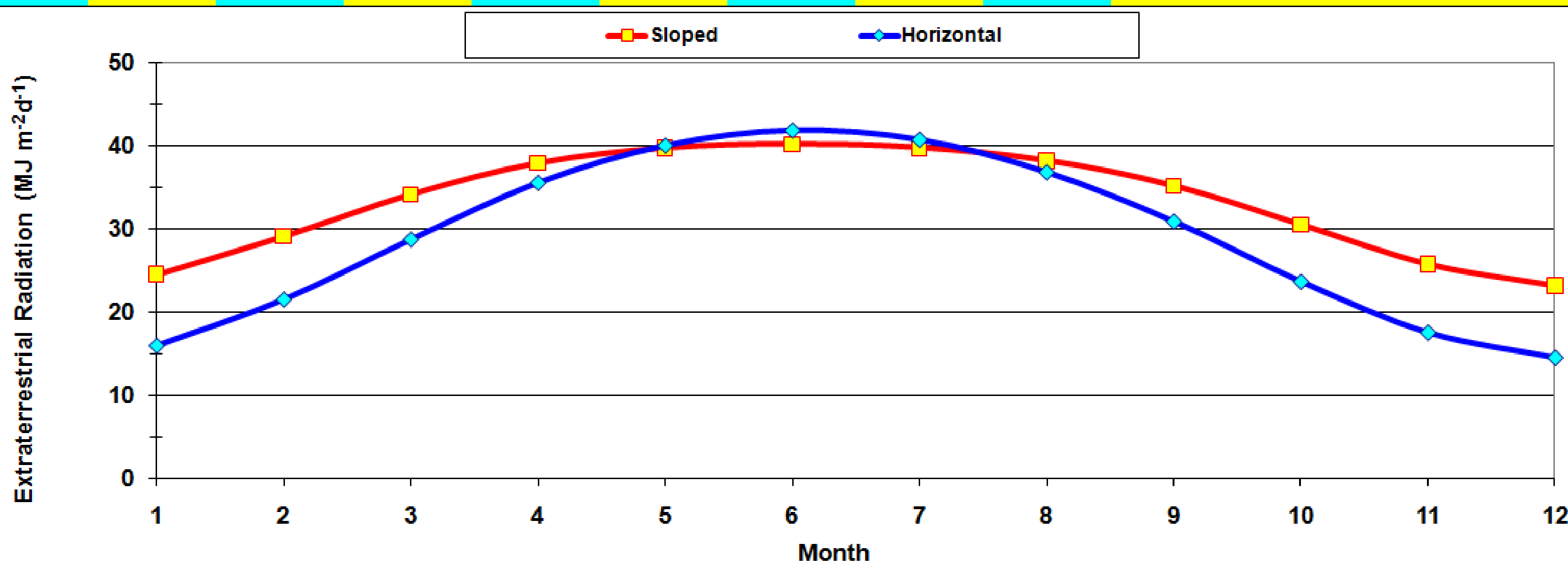
Leave blank to use slope & aspect for R_s

Extraterrestrial Radiation Horizontal & Sloped

Davis	Latitude:	38.50	Elevation:	18.5	Slope:	15.0	Orientation:	180.0	



Davis	Latitude:	38.50	Elevation:	18.5	Slope:	15.0	Orientation:	0.0	

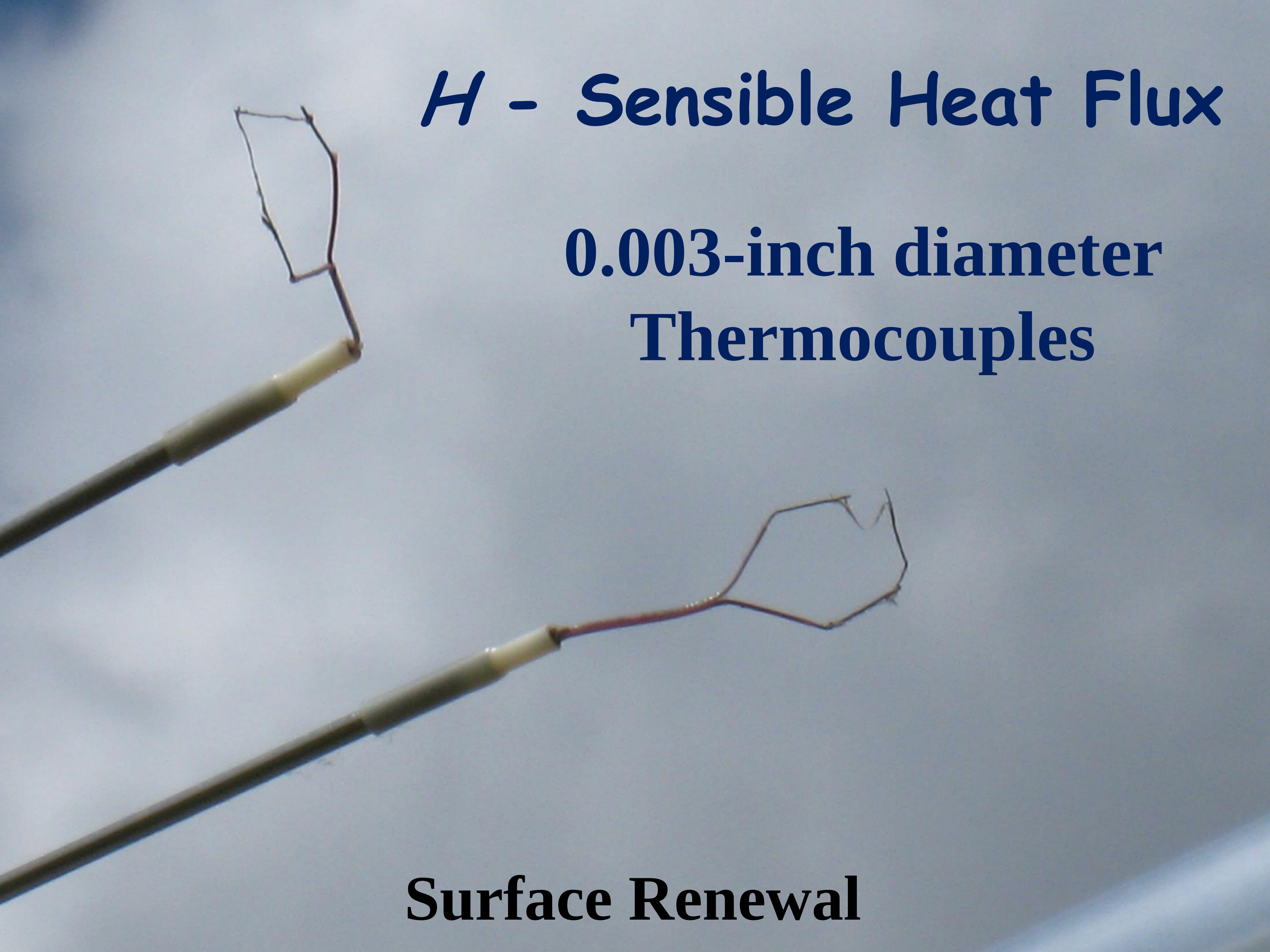


Measuring ET_L

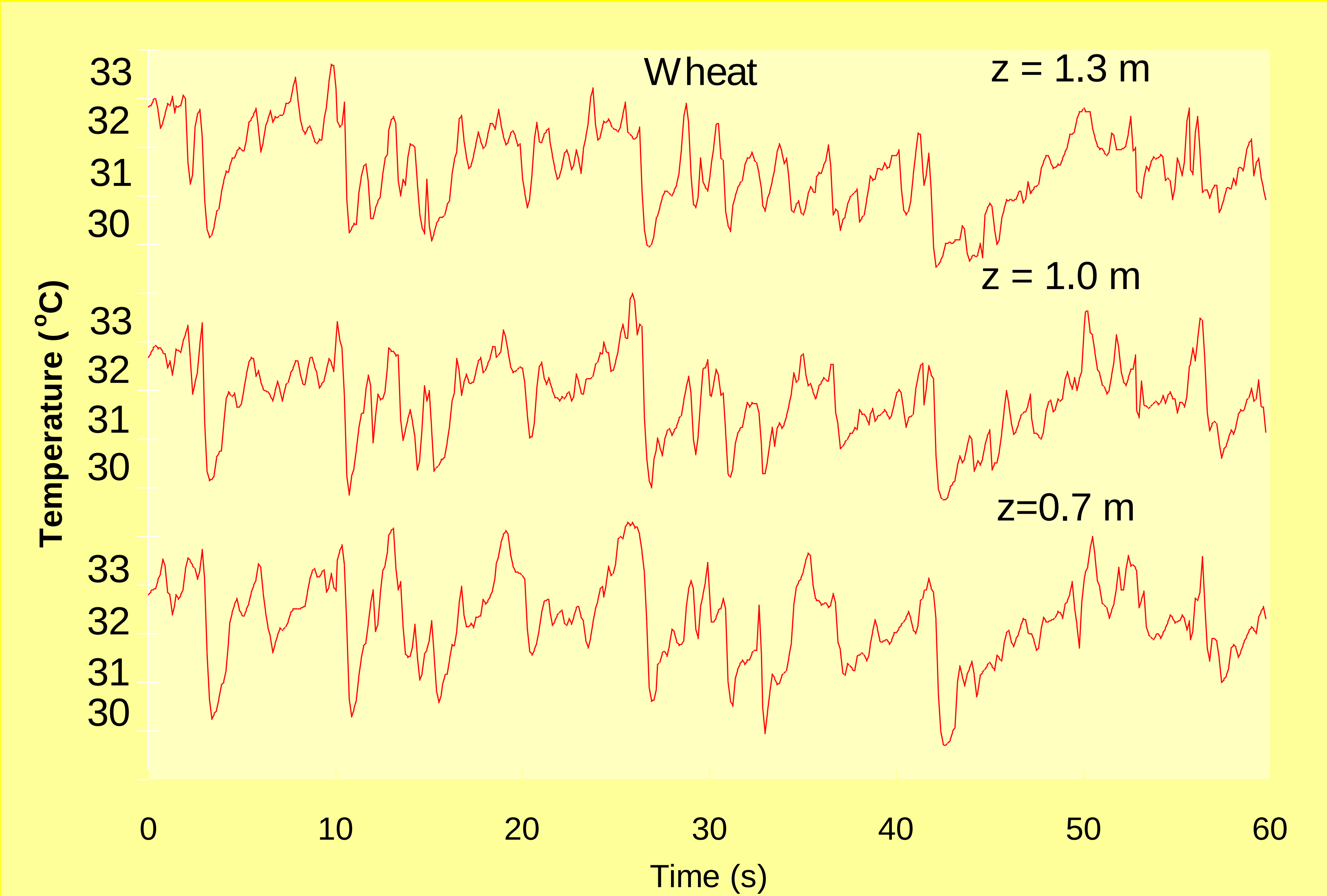
$$ET_L = R_n - G - H$$

- ET_L – Landscape
- R_n – Net radiation
- H – Sensible Heat Flux
- G – Ground Heat Flux

$$ET_L = R_n - H$$


H - Sensible Heat Flux
0.003-inch diameter
Thermocouples
Surface Renewal

One minute of 8 Hz temperature data



CONCLUSIONS

- WUCOLS – good start
- LIMP – more science based

$$ET_L = (ET_o \times K_m) \times (K_v \times K_d) \times K_s$$

- K_m – climate (slope) correction
- $K_p = K_v \times K_d$ - *vegetation & density*
- K_s – water stress

- Surface renewal - Validation

Questions

Thanks
Thanks
Thanks
Thanks
Thanks
Thanks