Evaporation at Jasper Ridge Biological Preserve Using Pan Data and Hydrometeorological Estimates

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I Introduction and Background

Evaporation is quantity of water evaporated from an open water surface or from the ground. Estimates both of evaporation from free water surfaces and from the ground are of great importance to hydrological modeling and in hydrometeorological and agricultural studies. One example is the operation of the century-old Searsville Reservoir, which is a significant resource for Stanford University and its Jasper Ridge Biological Preserve (JRBP), but is now nearing the end of its useful life as a result of continuing sedimentation. For the reason that the evaporation losses from reservoirs will affect their water storage efficiency, so it is important to have good measurements of the evaporation. Scientists have developed several indirect ways to measure evaporation from water bodies, for example, evaporation pans and some theoretical and empirical equations using meteorological data from a weather station.

Fig. 3. Jasper Ridge Solar Station

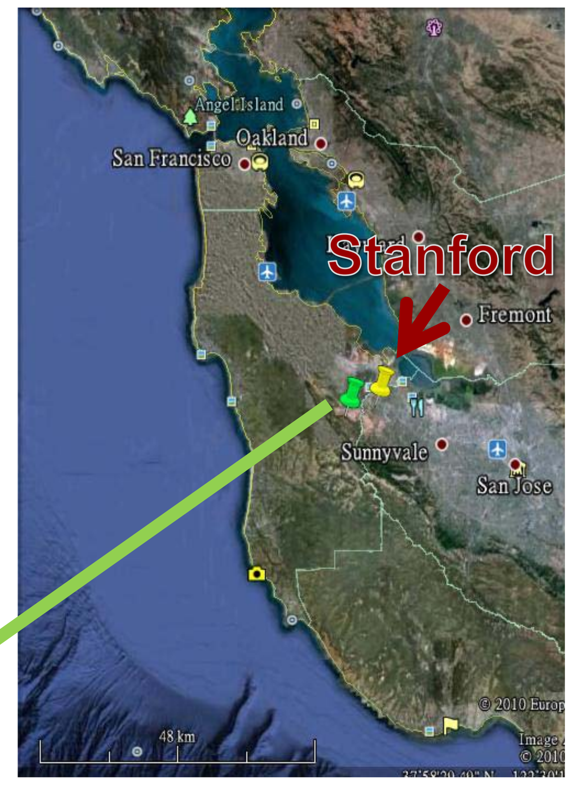

Fig. 1. Location of Jasper Ridge Biological Preserve in San Francisco Bay Area

Jasper Ridge Weather Station & Evaporation Pan (Class A Pan)

Fig. 2. Jasper Ridge Biological Preserve

II Objective

The goal of my project is to estimate the evaporation and do some comparison of the estimated evaporation pan data and the Penman-Monteith (P-M) model. In conducting this assessment, I restricted my attention to:

- Data cleaning and data analysis of the evaporation pan data
- Meteorological data analysis: converting PAR (Photosynthetically Active Radiation) to solar radiation
- Penman-Monteith method
- Field work: data collection

Fig. 4. Data Collection

IV Penman-Monteith Model

In order to compute water evaporation from vegetated surfaces, we use Penman-Monteith equation which is based on the meteorological data, such as the net solar radiation, air temperature, wind speed, relative humidity and air vapor pressure.

$$ET_0 = \frac{\Delta(R_n - G)}{\lambda[\Delta + \gamma(1 + C_d u_2)]} + \frac{\gamma \frac{37}{T_a + 273.16} u_2 (e_s - e_a)}{\Delta + \gamma(1 + C_d u_2)}$$

$$R_n = 0.77 R_s - R_{nl}$$

ET_0: grass reference evaportranspiration (mm/h)
R_n: net radiation (MJ/m^2/h)
R_s: solar radiation (MJ/m^2/h)
R_{nl}: net longwave radiation (MJ/m^2/h)
G: soil heat flux density (MJ/m^2/h)
T_a: air temperature (°C)
u_2: wind speed (m/s)
e_s: saturation vapor pressure (Kpa)
e_a: air vapor pressure (Kpa)
γ: psychrometric constant (Kpa/ °C)
λ: latent heat of vaporization (MJ/kg)
C_d: bulk surface resistance and aerodynamic resistance coefficient

VI References and Acknowledgements

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C.P. Jacovides, F.S. Timvios, et al. (2003). "Ratio of PAR to broadband solar radiation measured in Cyprus." Agricultural and Forest Meteorology 121: 135-140.
S.O. Udo, T.O. Aro. (1999). "Global PAR related to global solar radiation for central Nigeria." Agricultural and Forest Meteorology 97: 21-31.
Hossein Tabari, Safar Marofi, et al. (2010)"Estimation of daily pan evaporation using artificial neural network and multivariate non linear regression." Irrigation Science 28(5):399-406.

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III Evaporation Pan Data（2009）

Class A evaporation pans are widely used as the basis for estimating lake evaporation and potential evapotranspiration. Pan performance is affected by instrumental limits and operational problems such as the thermal properties of the pan, human errors, instrumentation errors, turbidity of water, watering of birds or other animals, as well as other maintenance problems, which can affect the accuracy of evaporation measurements.

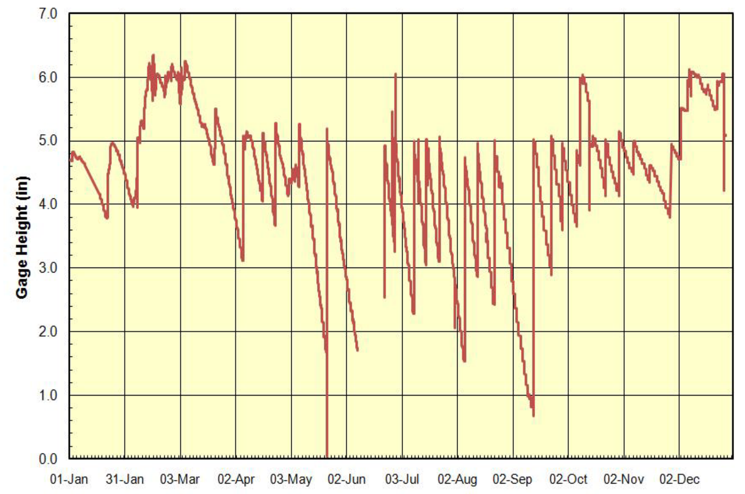


Fig. 5. JRBP Pan Evaporation Raw Data

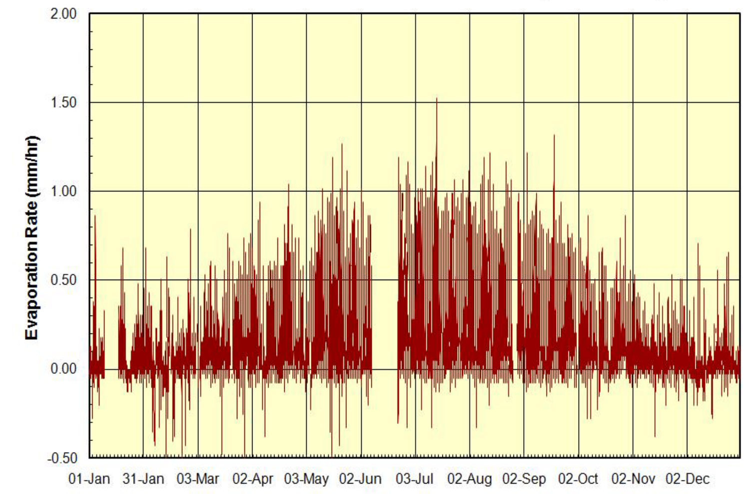


Fig. 6. JRBP Pan Evaporation Rate estimated by differencing raw gage height data

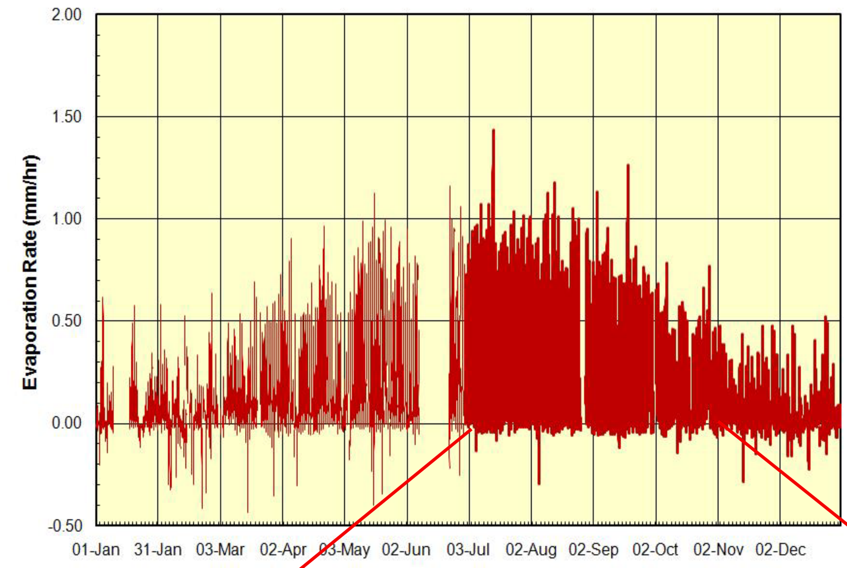


Fig. 7. JRBP Pan Evap Rate smoothed using a 30-min. moving average

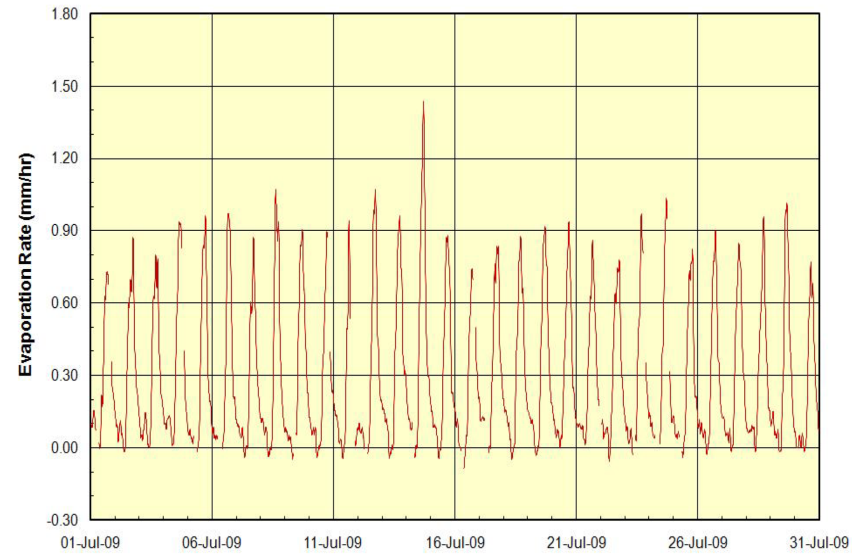


Fig. 8. JRBP Pan Evap Rate in July (Moving average of cleaned data) Dry season

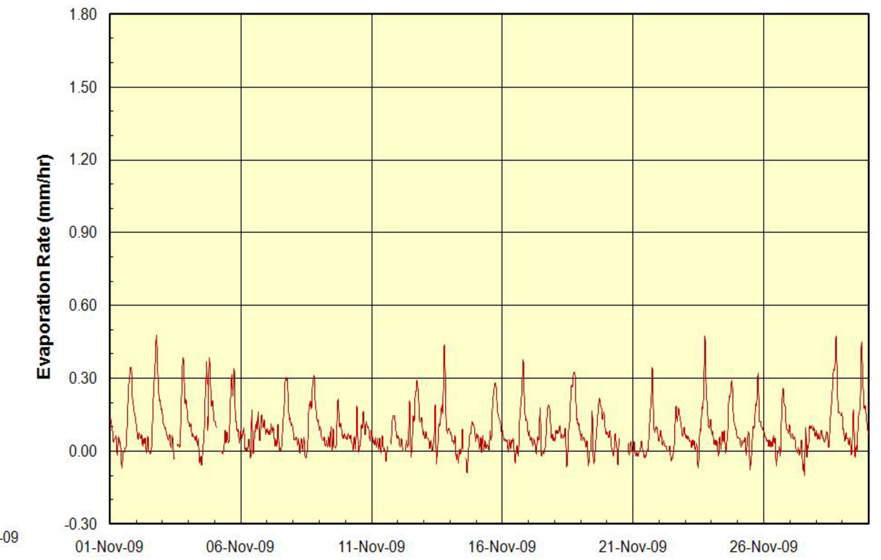


Fig. 9. JRBP Pan Evap Rate in November (Moving average of cleaned data) Wet season

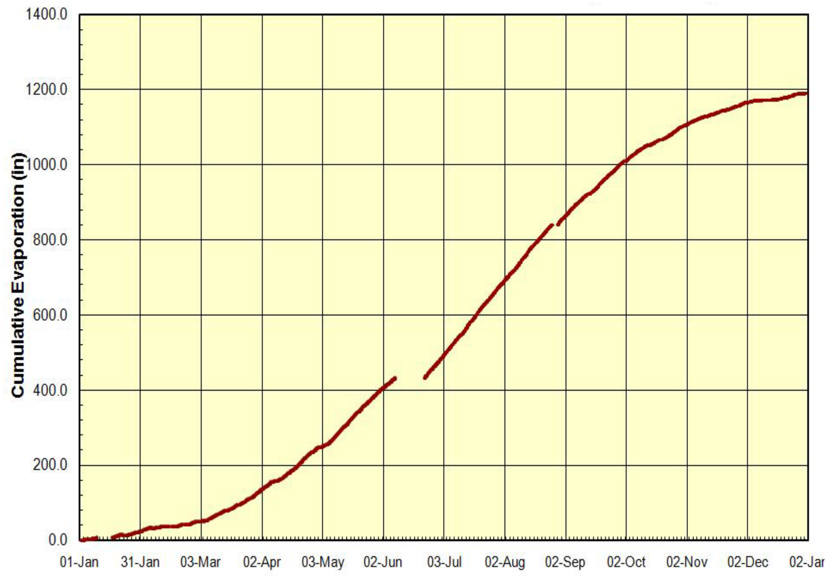


Fig. 10. JRBP Cumulative Pan Evap

To clean the data we removed data points suggesting negative evaporation, either because of data errors or precipitation.

Missing values from Jun 9 to Jun 22.

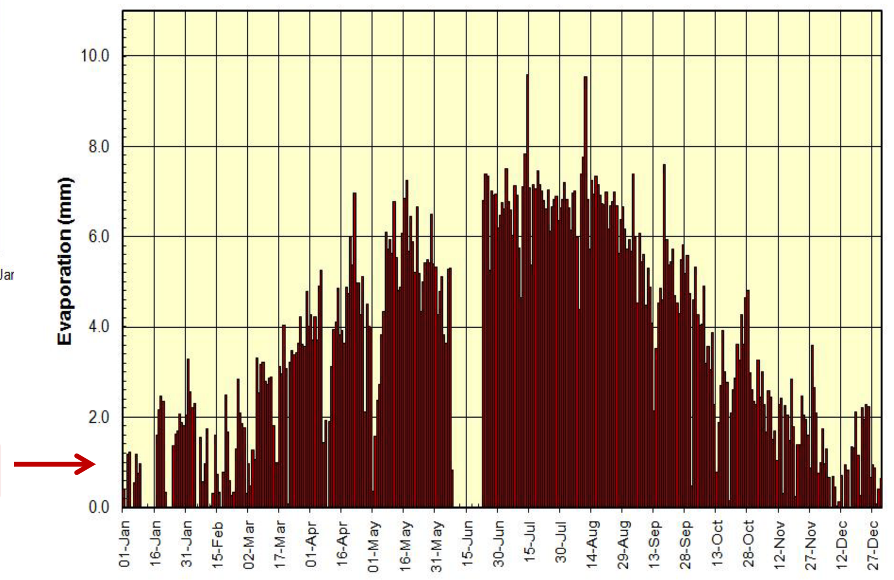
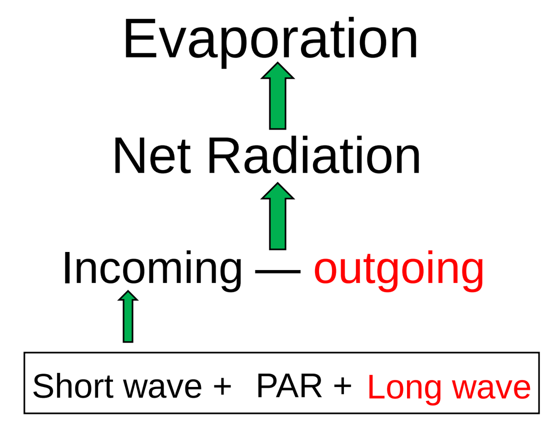


Fig. 11. JRBP Daily Pan Evaporation

V Converting PAR to Solar Radiation



In the P-M equation, net radiation is needed to estimate evaporation. The full spectrum of incoming solar radiation contributes to the net radiation that drives evaporation. In some settings, particularly in agriculture and ecology, deployed radiation sensors measure Photosynthetically Active Radiation (PAR), which is that portion of the incoming radiation between 400 and 700 nm in wavelength. Thus, there is a need for methods for estimating total solar radiation from PAR measurements. A number of models have been developed to reduce total solar radiation to PAR in specific locations, but there have been relatively few attempts to develop models to expand PAR observations to full-spectrum solar radiation. Building on preliminary work by Jun Young Kim in Prof. Freyberg's group, I have used simultaneous observations of PAR and total solar radiation for a short time period at the Jasper Ridge site to construct a statistical model of total solar radiation based on PAR to allow implementation of the Penman-Monteith model over the much longer time period for which PAR data are available at Jasper Ridge.

Material and Data Analyses

Fig. 12. Pyranometer

The data for this study were collected using pyranometers at the JRBP. We got the data set of total solar radiation (W/m^2) from 2003-2009 and the data set of PAR [Photosynthetic photon flux density (PPFD), (mol/m^2/s)] from 1996-2009.

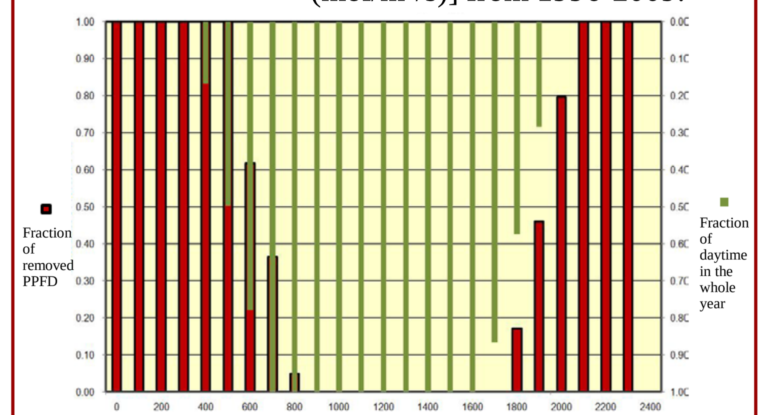


Fig. 13. Cleaning the PAR data in 1996: removing spurious values based on sunrise and sunset (Pacific Standard Time, no shift for daylight saving time)

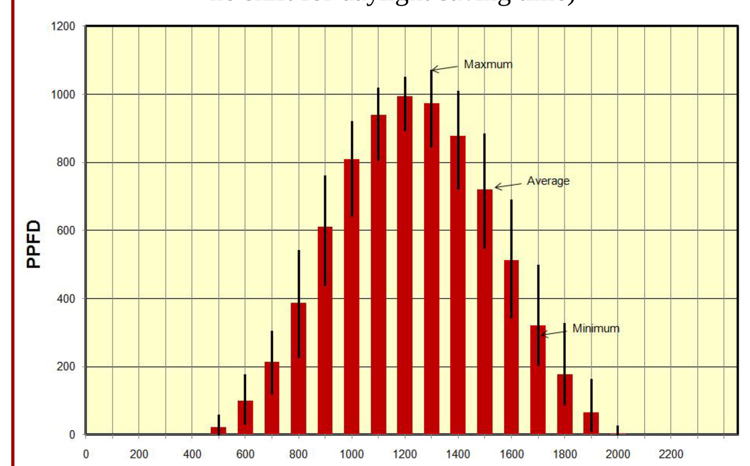


Fig. 14. JRBP Hourly PPFD from 1996 to 2009

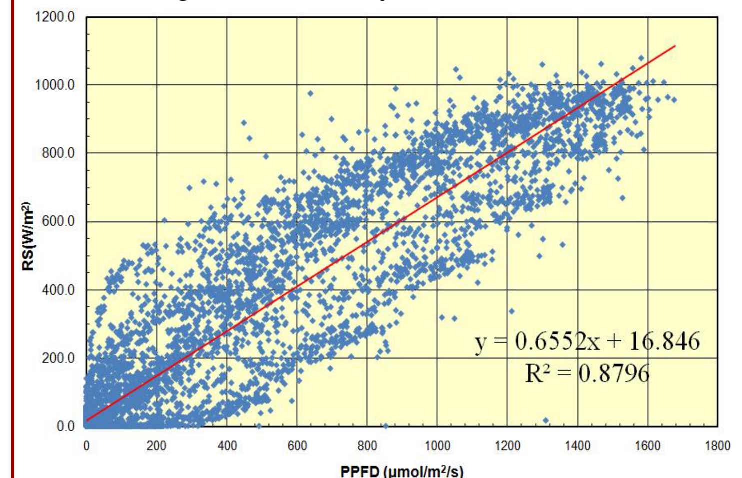


Fig. 15. Scatter plot for comparison between measured PPFD and solar radiation for the year 2003

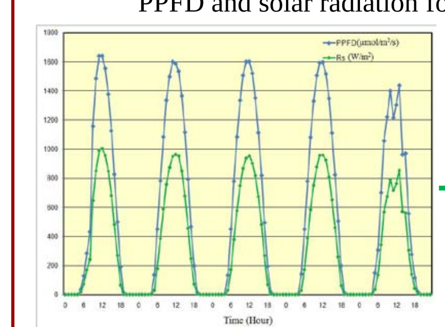


Fig. 16. Comparison of PPFD and R_s from Jun 10~Jun 14 in dry season

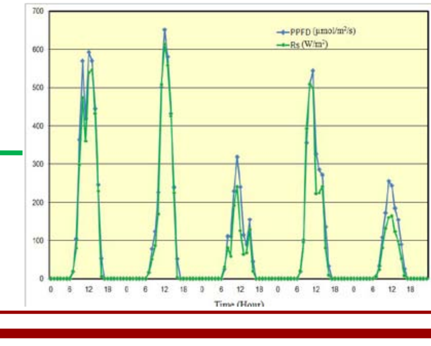


Fig. 17. Comparison of PPFD and R_s from Dec 10~Dec 14 in wet season

Modeling

Simple regression model

The data set for the year 2003 shows an R^2 value for PAR and solar radiation that is relatively low. Therefore, the data for 2004 & 2005 are used to develop Model 1 (Fig. 18).

Jasper Ridge is characterized by strong seasonality, with a rainy season from November to March, and a dry season from April to October. So a seasonal model, using a dry season submodel (Model 2D) and a wet season submodel (Model 2W) is constructed. (Model 2)

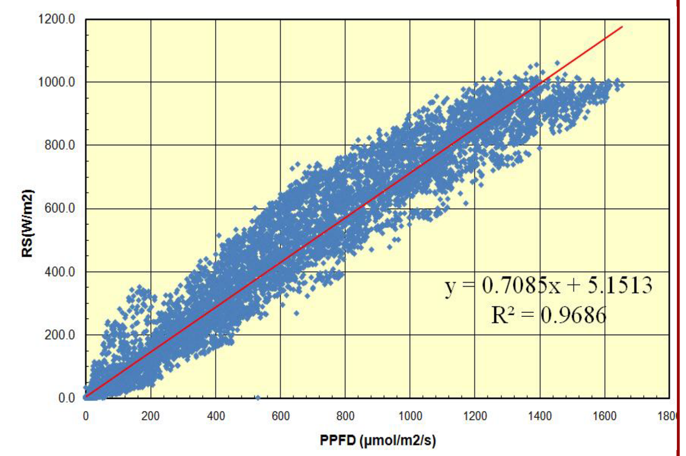


Fig. 18. Scatter plot for comparison between measured PPFD and solar radiation for the year 2004&2005 (Model 1)

Multivariable regression model (Using stepwise method)

No. of variables	Regression coefficients				Intercept (MJ/m^2/h)	Adj R^2	RMSE (MJ/m^2/h)
	PPFD (mol/m^2/s)	Air Tem (℃)	RH	Wind Vel (m/s)			
1	0.6744				5.9128	0.9672	56.6207
2	0.7020	-2.4394			30.3168	0.9686	55.415
3	0.6880	-5.0154	-129.951		172.66	0.9707	53.5469
4	0.6898	-4.9392	-129.194	-2.613	173.507	0.9708	53.4564

We tried using three weather parameters, air temperature, relative humidity and wind speed to improve estimation of solar radiation. The improvement is slight, so we just consider the simple regression model.

Model Validation

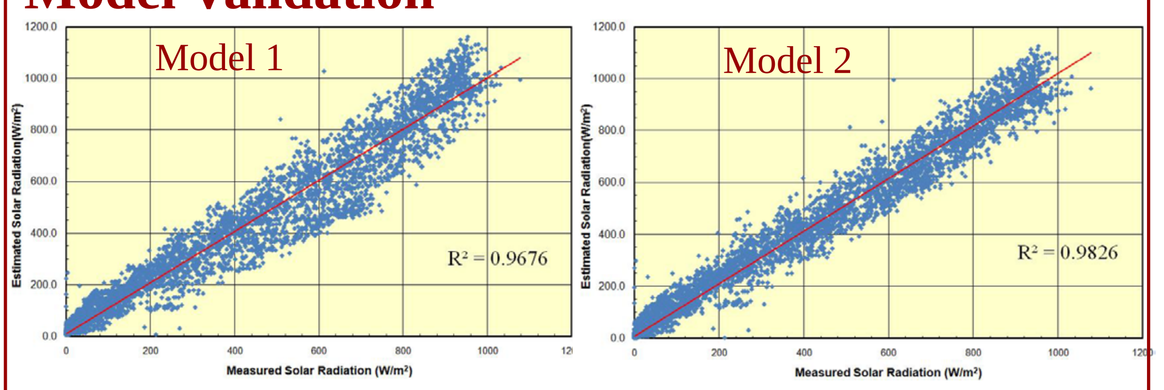
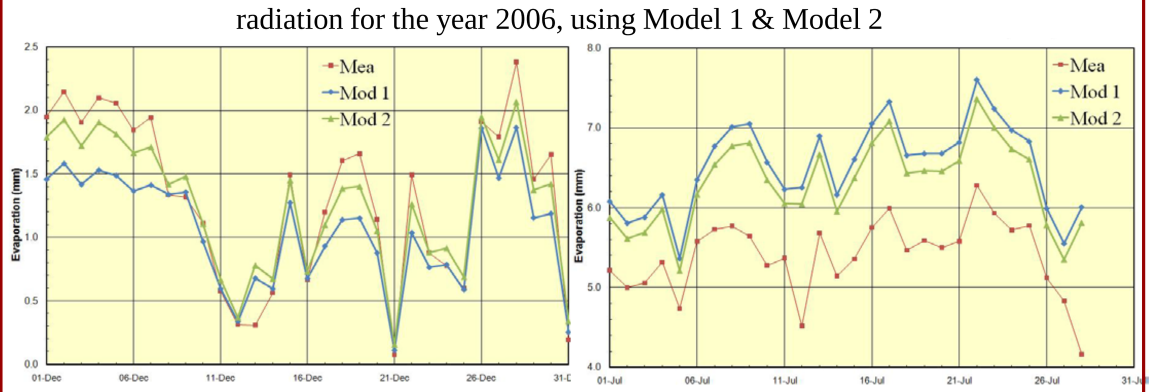


Fig. 19. Scatter plot for comparison between measured solar radiation and estimated solar radiation for the year 2006, using Model 1 & Model 2



Wet season | Dry season

Fig. 20. Comparison between Penman-Monteith ET_0 estimates using measured solar radiation and estimated solar radiation for 2006, using Model 1 & Model 2.

Model 2 is better, it does better in the wet season than the dry season, maximum estimated ET errors are on the order of 1 mm.