Measuring and modelling evapotranspiration to understand water demands in a dairy farm

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OzFlux Meeting
July 4, 2012

NIWA

National Institute of Water & Atmospheric Research Ltd.

- Drivers: hydrology & water balance
- ET and drainage– least measured among water cycle components
- Initiatives & funding (2010-11)
  - Waterscape MSI & Capex
  - Local regional council's interest in drainage & groundwater recharge

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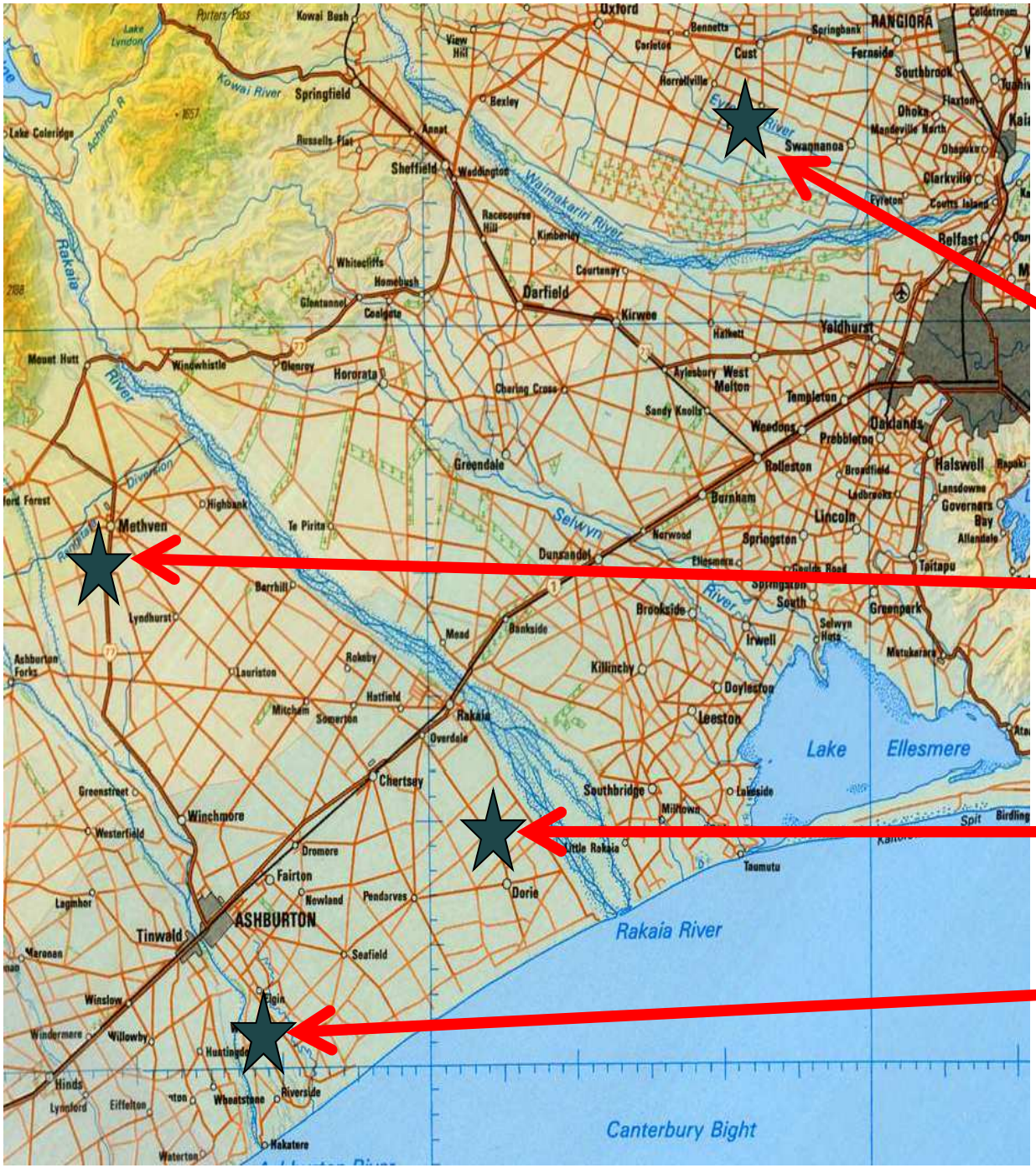
NIWA's Eddy Covariance towers

Methven tower

Wakanui tower



Lysimeter sites

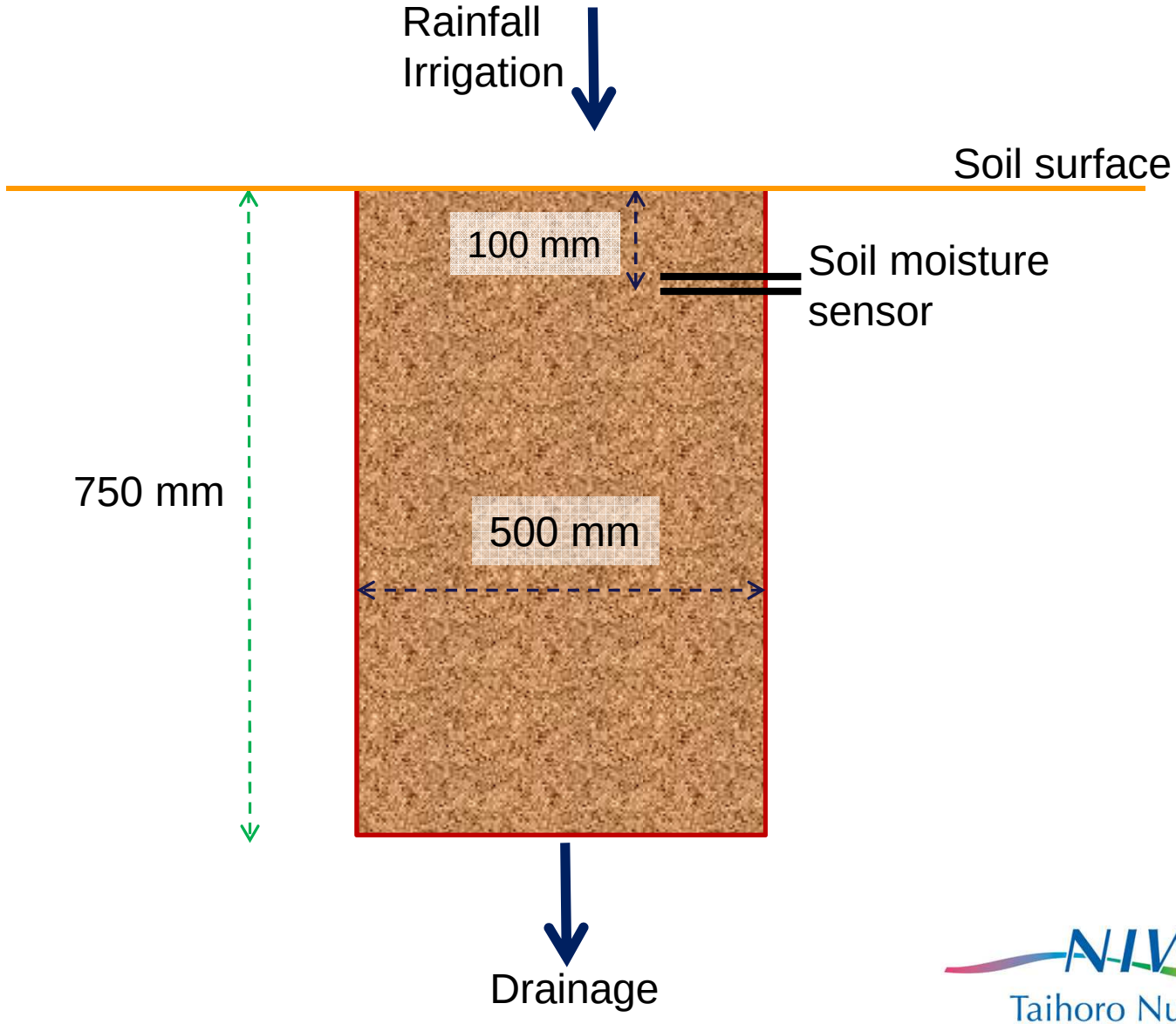
West Eyreton
- Rain ~550 mm/y
- shallow stony soils, dairy

Methven
- Rain ~900 mm/y
- shallow stony soils, dairy

Dorie
- Rain ~550 mm/y
- deep silt loam
- dairy

Wakanui
- Rain ~ 550 mm/y,
- deep silt loam
- cropping

Drainage Lysimeters



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Science opportunities

- Unique opportunity to compare evapotranspiration estimates from
  - Lysimeter-based water balance
  - Calculation from meteorological variables (Penman-Monteith, Penman and Priestley-Taylor methods)
  - Direct measurement from eddy covariance tower
- Measurement of groundwater recharge
- Check on irrigation efficiency

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Results from 2011-12 for Methven

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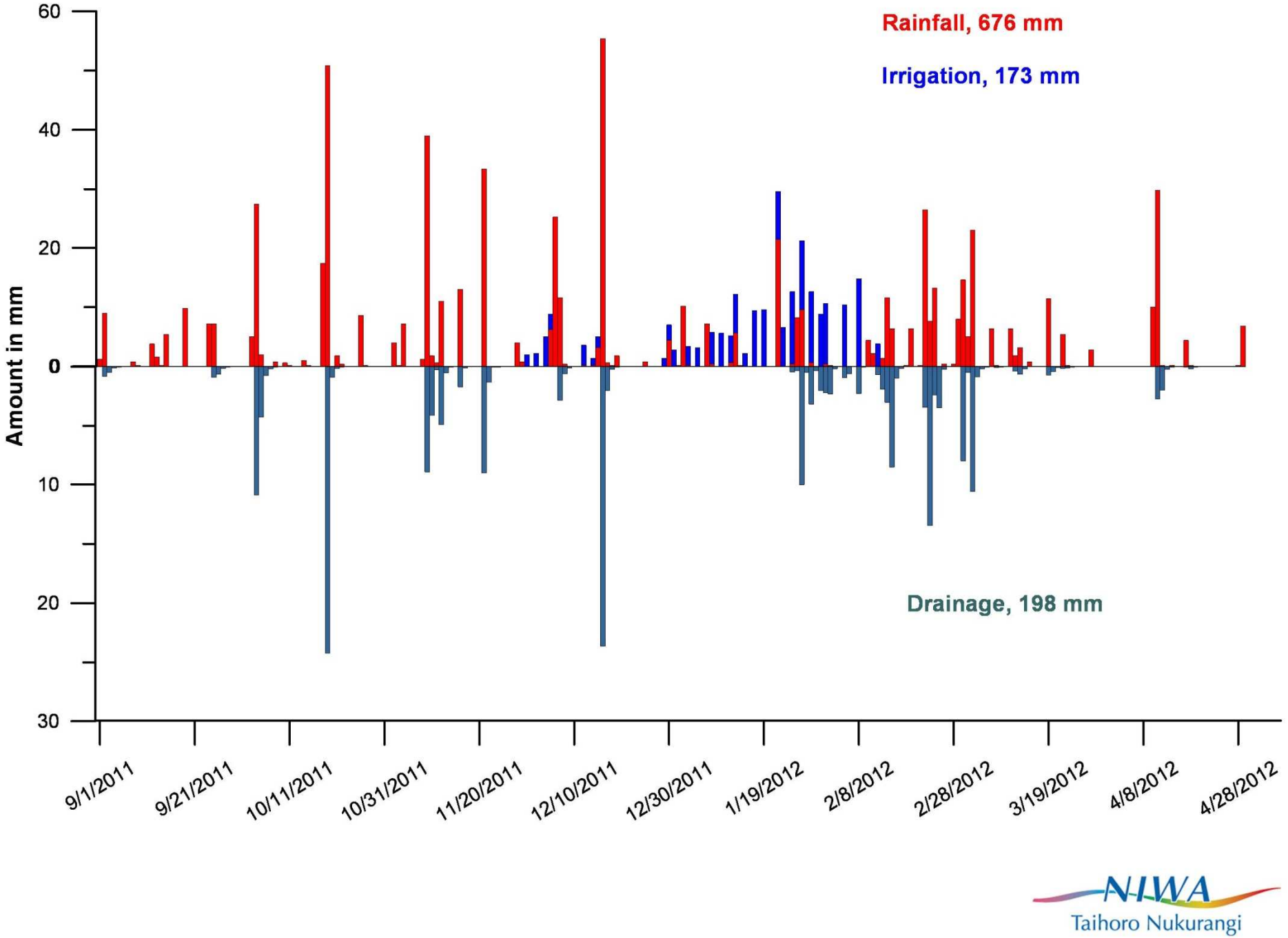

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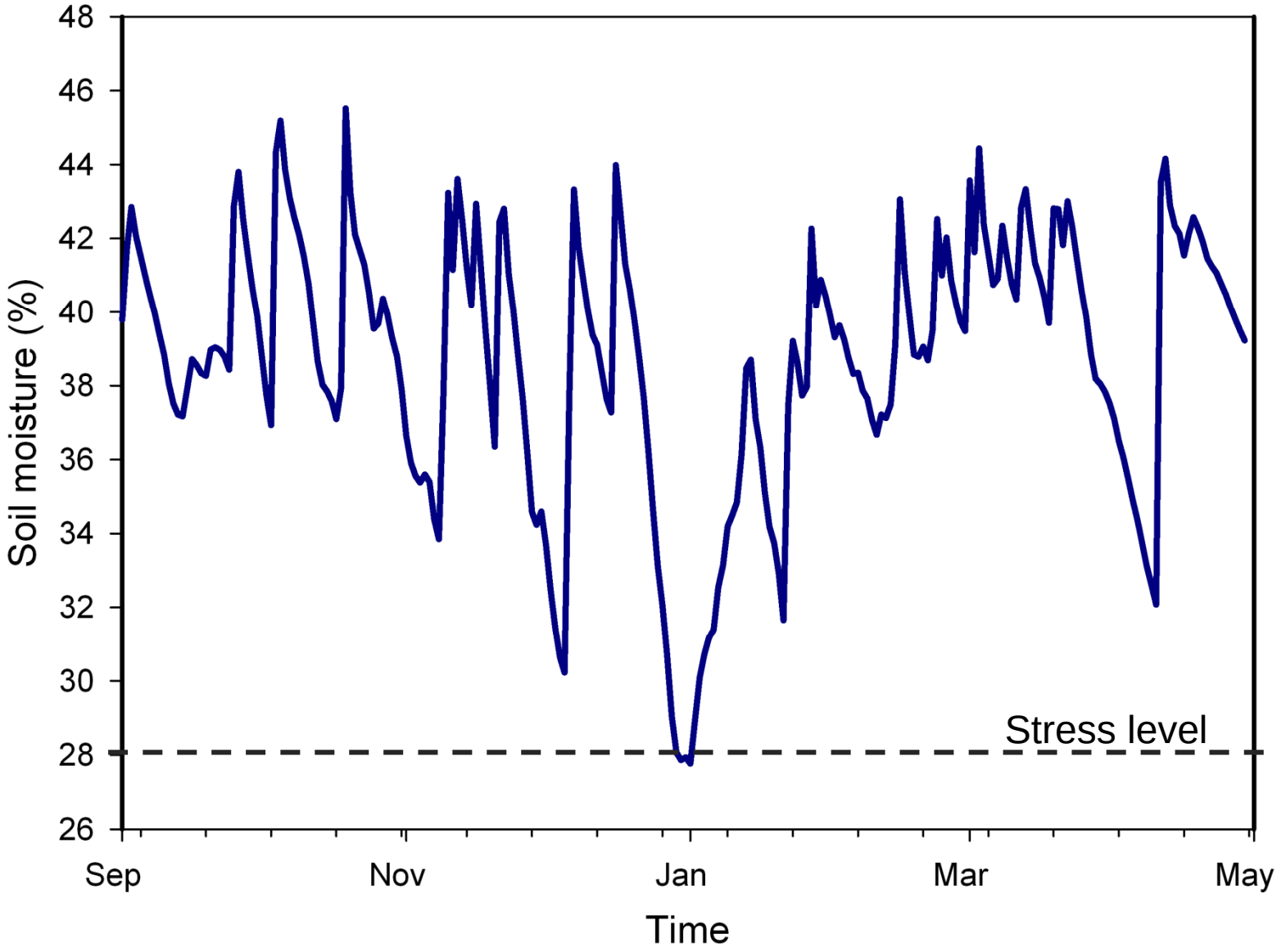
Soil moisture



ET over the entire irrigation season (Sep 1, 2011 – Apr 30, 2012)

Eddy Covariance tower	**542 mm**
Water balance approach	659 mm
Priestly-Taylor method	660 mm
Penman-Monteith method	691 mm
Penman method	842 mm

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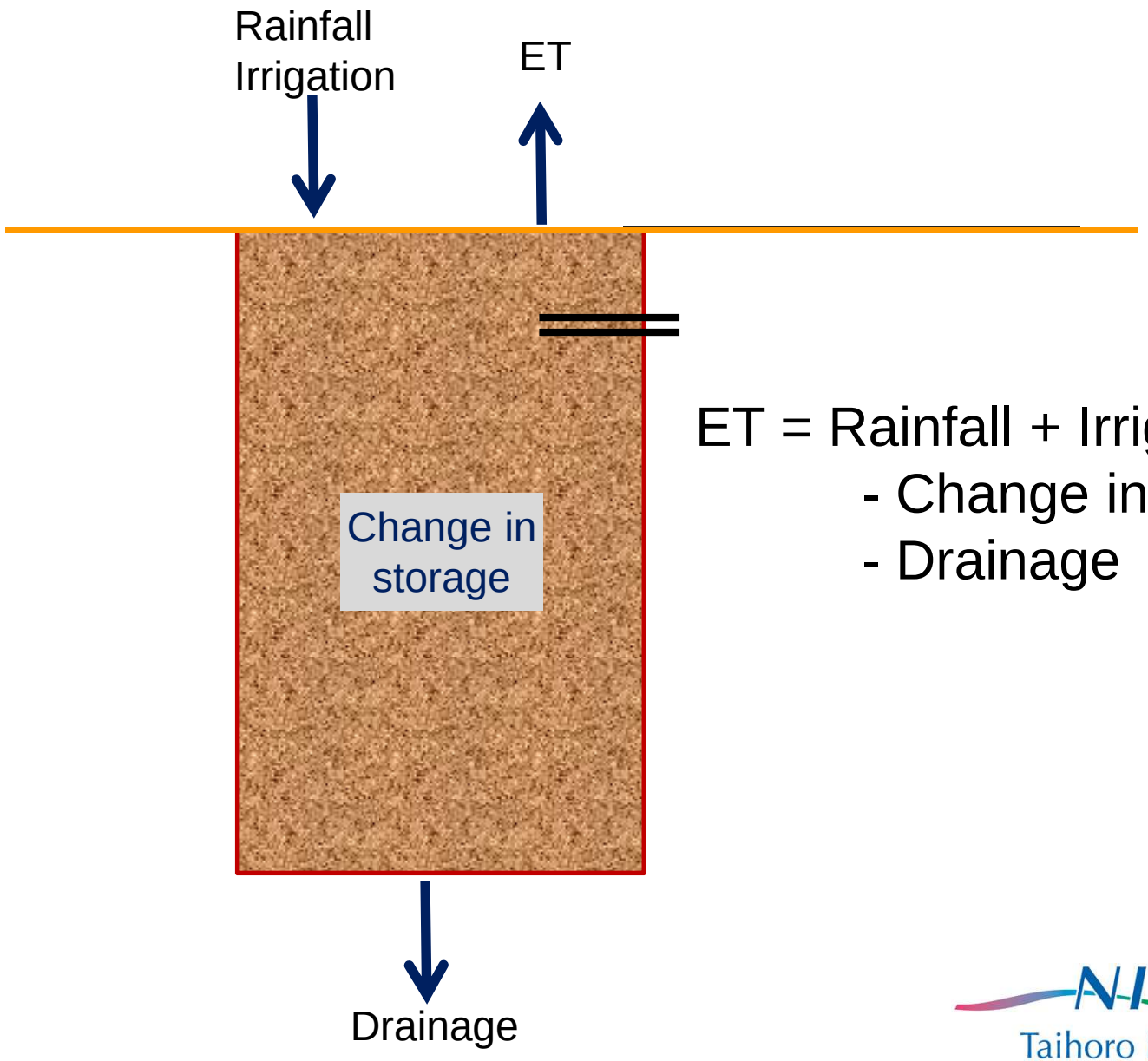
Water balance approach



ET = Rainfall + Irrigation
- Change in storage
- Drainage

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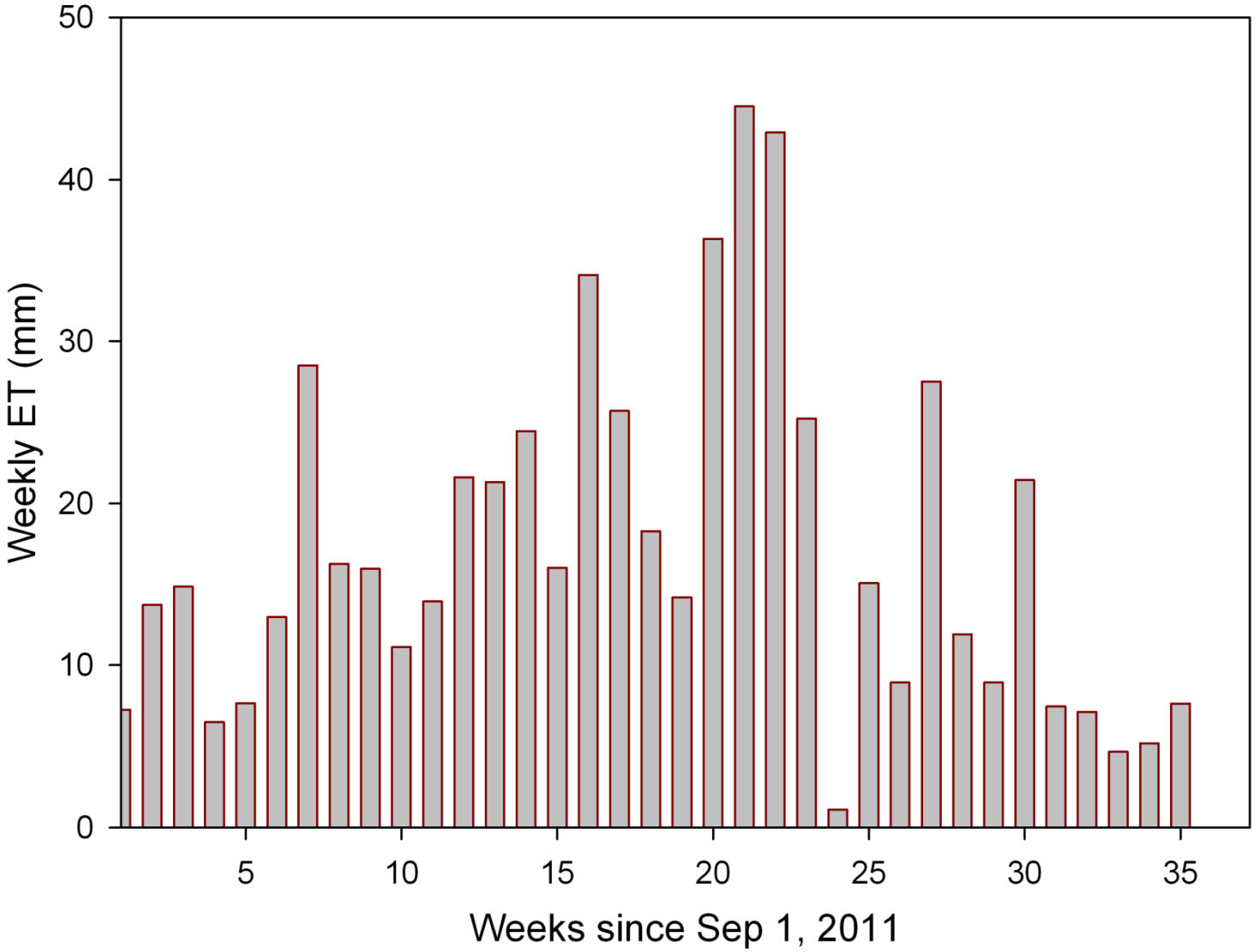
ET from water balance approach



Priestley-Taylor

- Based on energy balance
- Multiplicative scalar of 1.26, corrects for effect of wind and vapour pressure deficit
- Assumes aerodynamic ET increases linearly with radiation
- Won’t pick up night-time ET due to high wind.
- Good when radiation is dominant driver of ET
- Underestimates when wind speed is a significant driver
- Underestimates particularly in winter

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Penman

- Combined energy balance and turbulent transfer of heat/moisture
- Considers wind speed and vapour pressure deficit
- Assumes air at leaf surface is saturated
- Assumes resistance to heat and moisture transfers are equal
- Thought to overestimate ET when ET is high

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Penman-Monteith

- Adaptation of Penman method
- Defines a surface resistance for water movement between inside plant and air (depends on stomatal resistance and ‘active’ leaf area index)
- Defines an aerodynamic resistance for moisture movement away from plant which depends on roughness of surface

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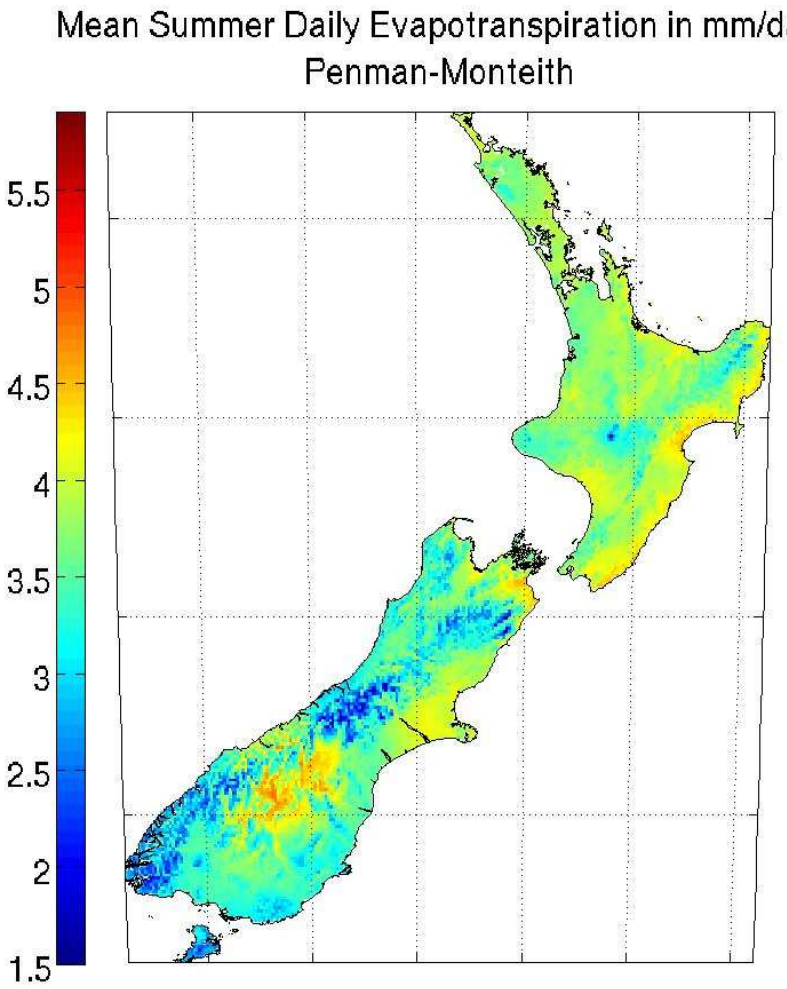
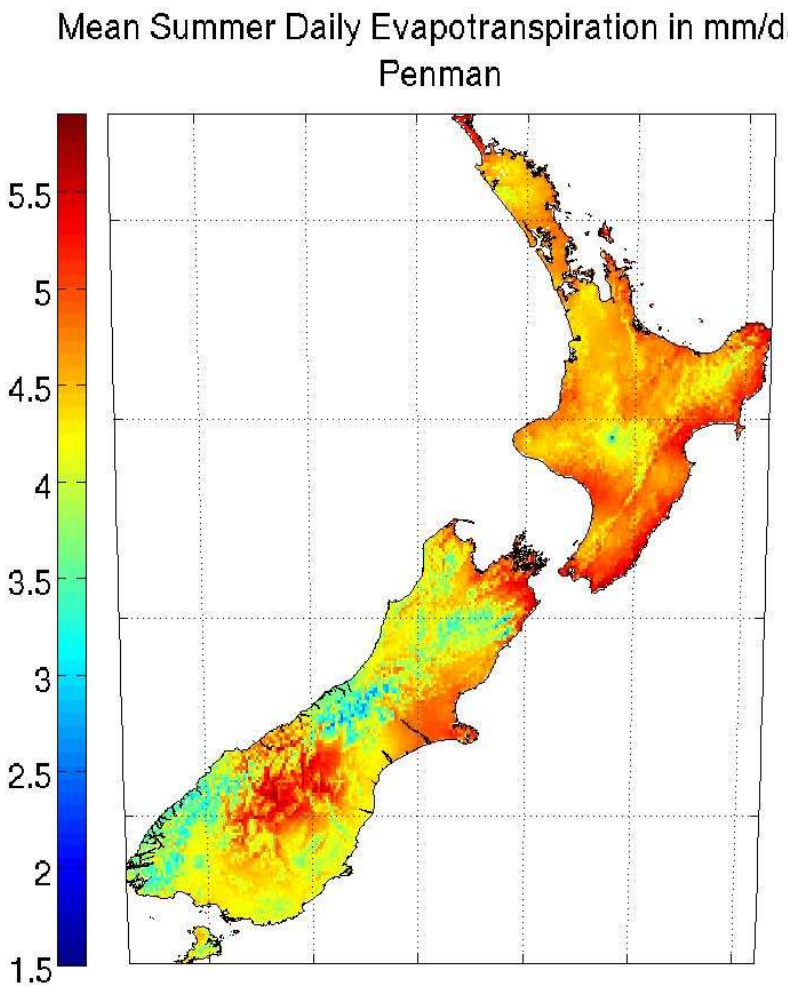
$$HT = \frac{D}{D+\gamma}\left(R_n - G\right) \qquad PET_{PT} = 1.26\frac{HT}{\lambda}$$

$$PET_{PEN} = \frac{1}{\lambda}\left(HT + \left(\frac{\gamma}{D+\gamma}\right)\left(6.43 \times \mathrm{v}pd \times (1 + 0.0062 \times \mathrm{WindRun}) \times \frac{\mathrm{timestep}}{3600 \times 24}\right)\right)$$

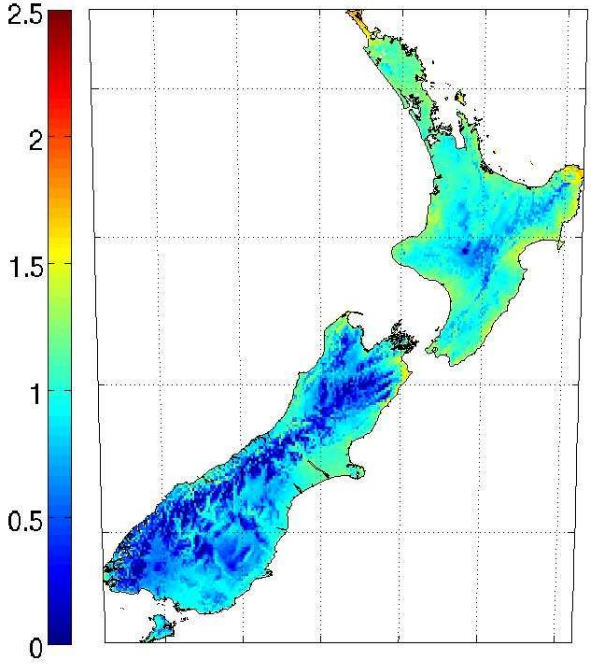
$$PET_{PM} = \frac{1}{\lambda}\frac{D(R_n - G) + \dfrac{\rho \times c_p \times vpd \times timestep}{r_a}}{D + \gamma\left(1 + \dfrac{r_s}{r_a}\right)}$$

$$\mathrm{r_a} = \frac{\ln\left(\dfrac{\mathrm{z_m - d}}{\mathrm{z_{0m}}}\right) \times \ln\left(\dfrac{\mathrm{z_h - d}}{\mathrm{z_{0h}}}\right)}{\mathrm{k^2 \times U}} \qquad \rho c_p = \frac{\gamma \varepsilon \lambda}{T_v R} \qquad r_s = \frac{LAI}{r_{stomatal}}$$

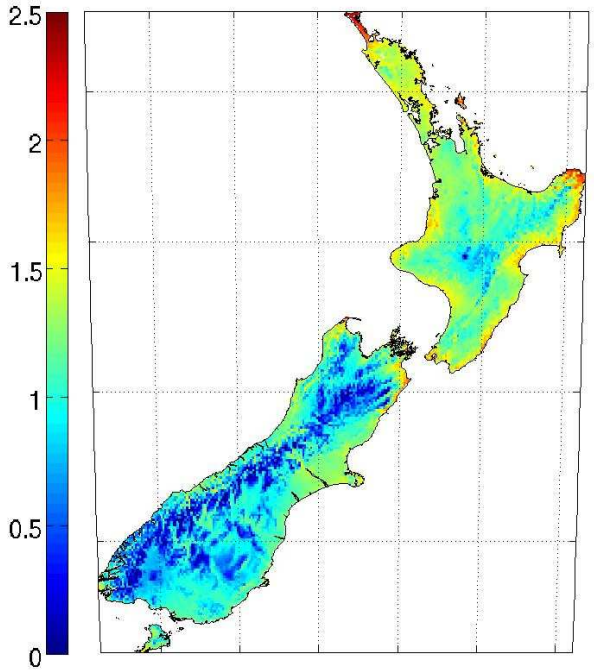

Mean Summer Daily Evapotranspiration in mm/day
Penman-Monteith
5.5
5
4.5
4
3.5
3
2.5
2
1.5


Mean Summer Daily Evapotranspiration in mm/day
Penman
5.5
5
4.5
4
3.5
3
2.5
2
1.5

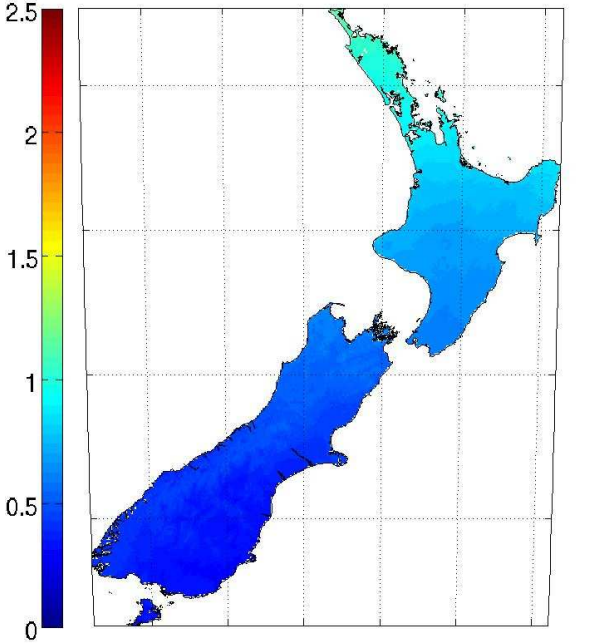
Mean Winter Daily Evapotranspiration in mm/day
Penman-Monteith

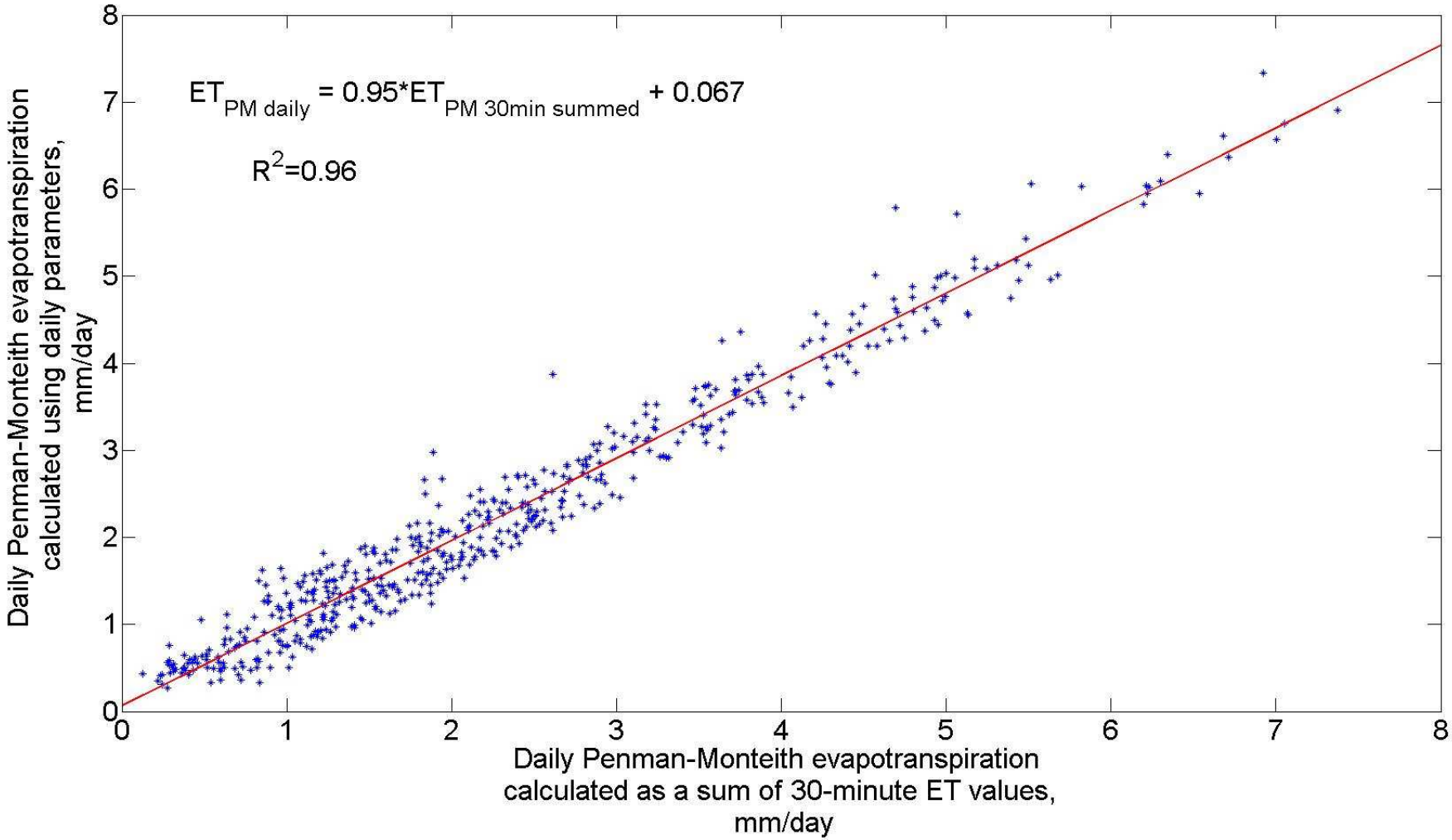


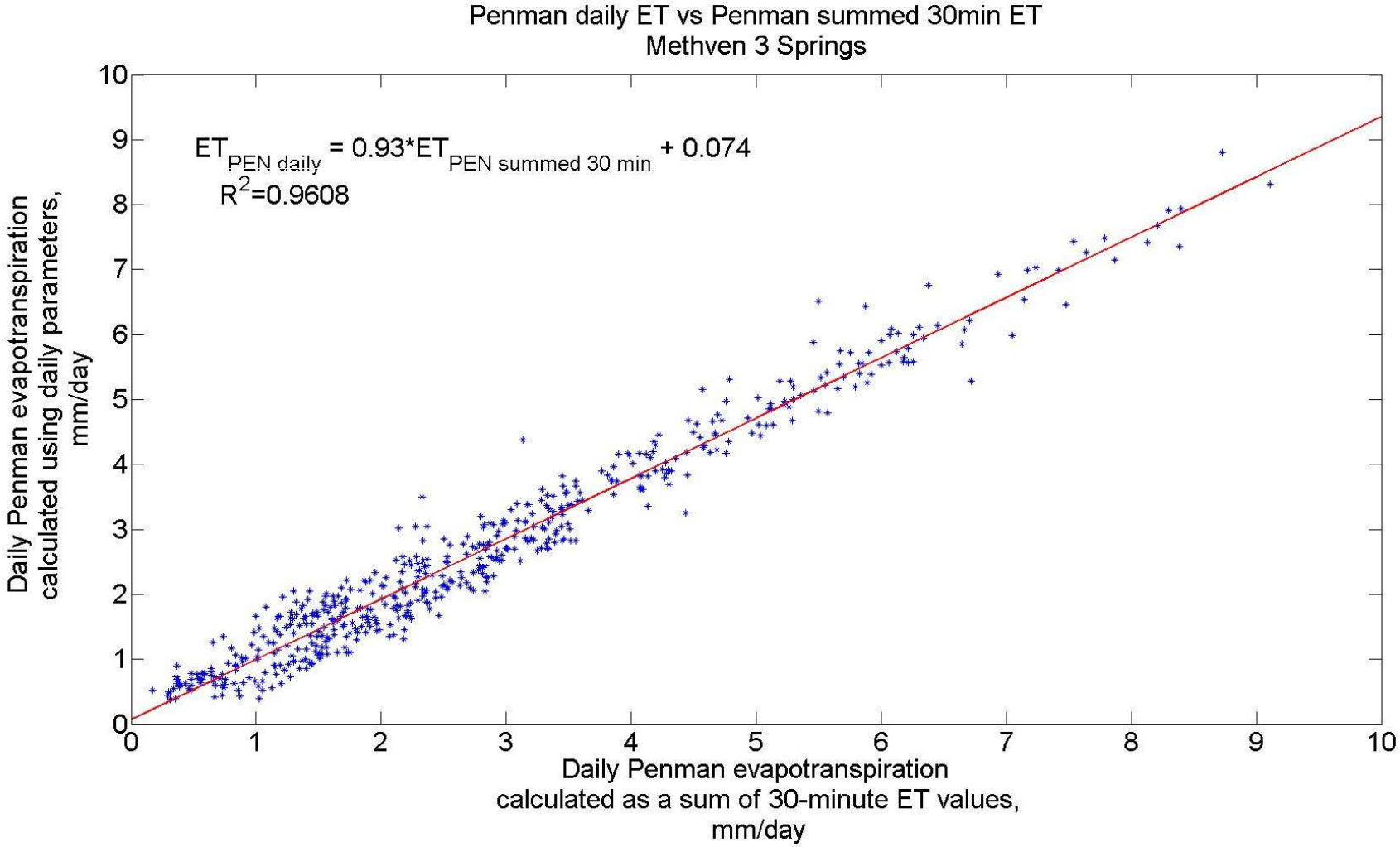
Mean Winter Daily Evapotranspiration in mm/day
Penman

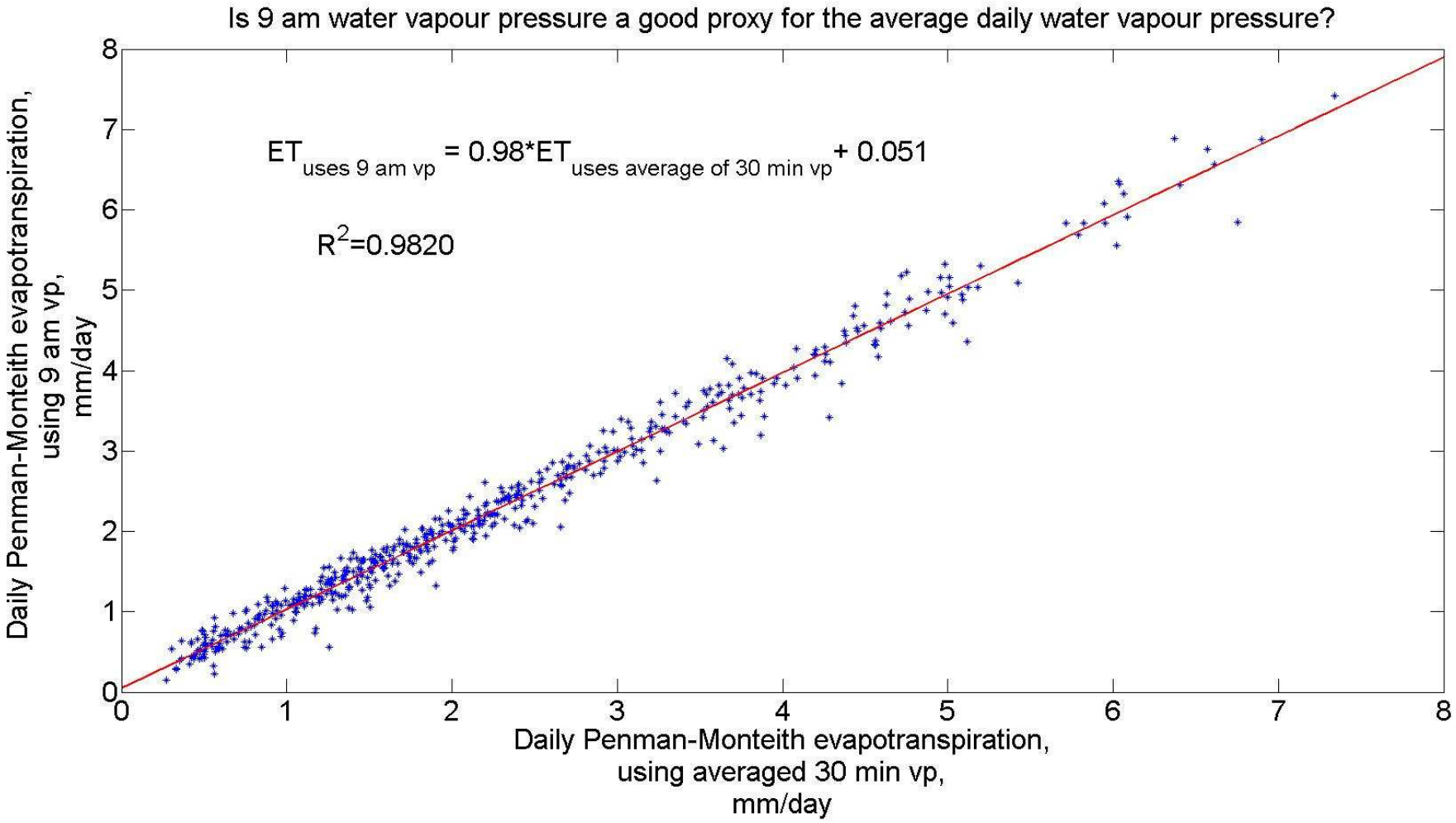


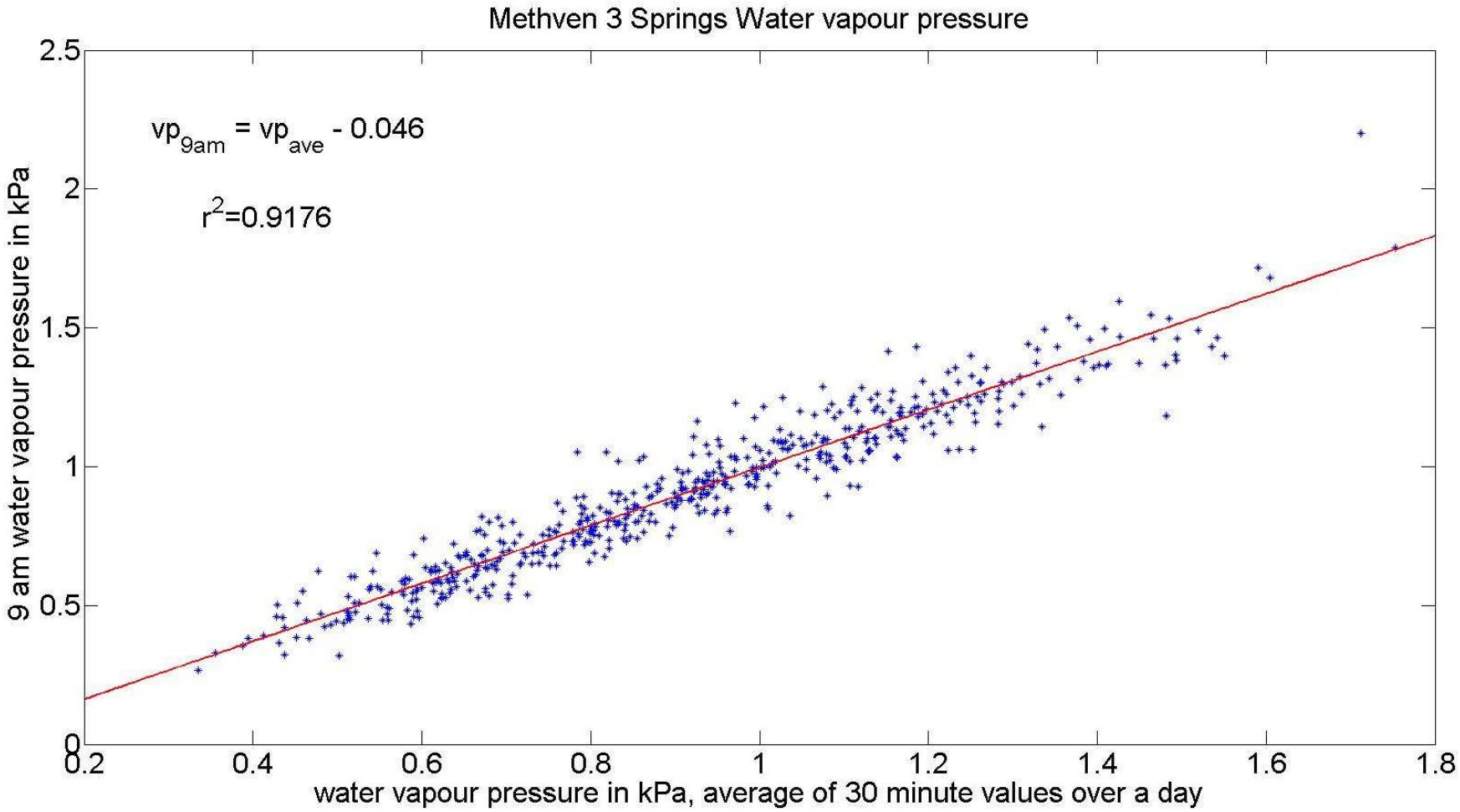
Mean Winter Daily Evapotranspiration in mm/day
Priestley-Taylor

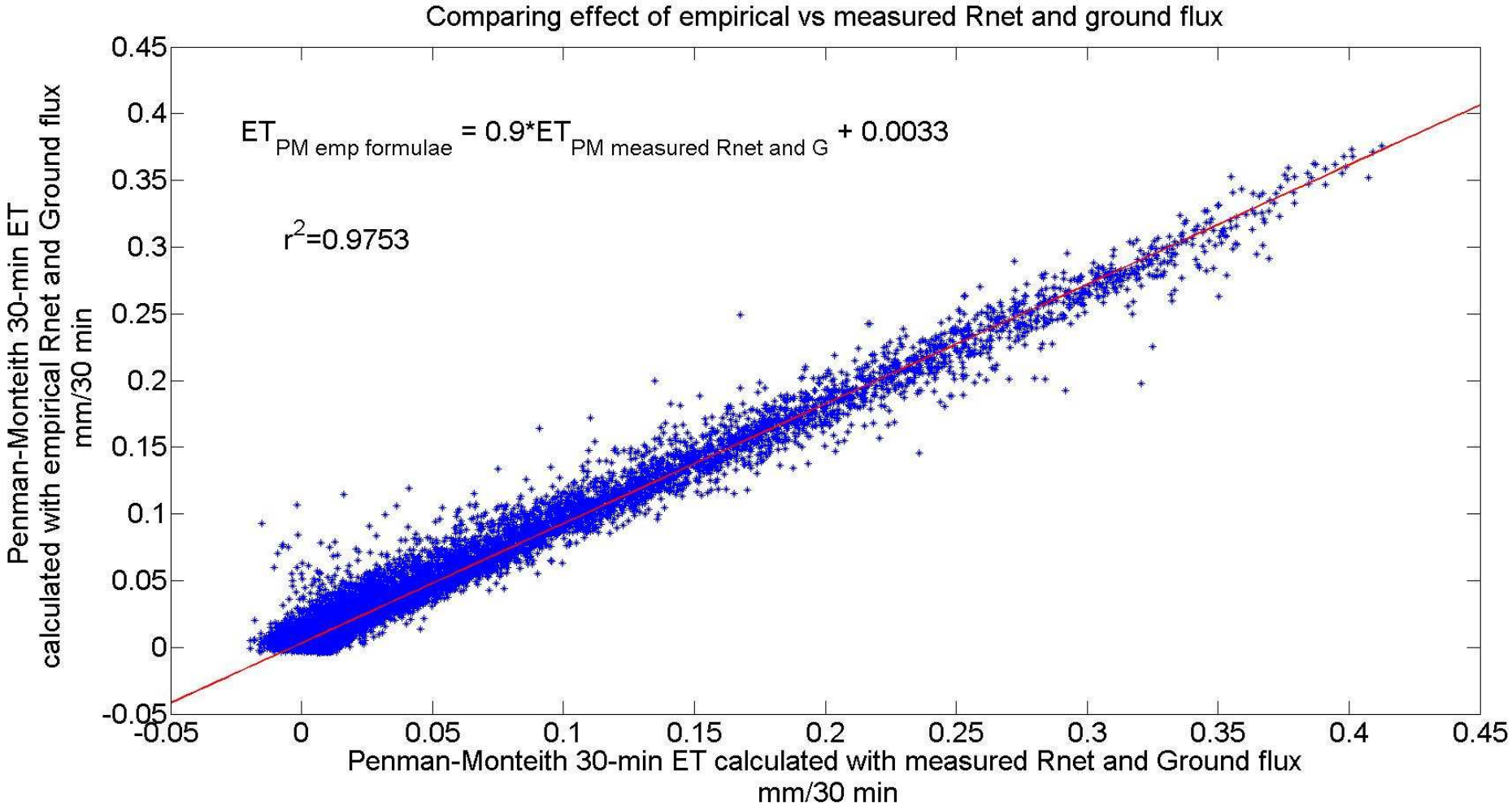


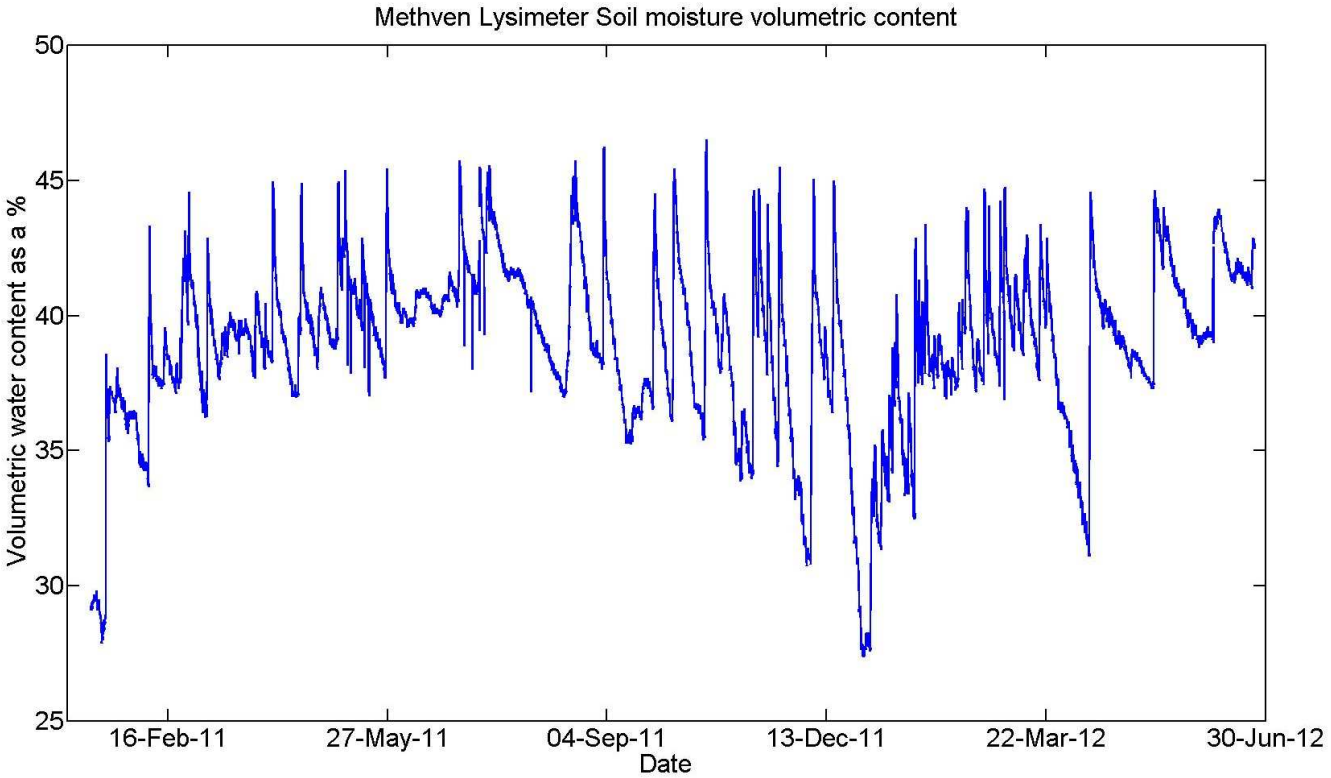

$ET_{PM\ daily} = 0.95*ET_{PM\ 30min\ summed} + 0.067$
$R^2=0.96$
Daily Penman-Monteith evapotranspiration calculated using daily parameters, mm/day
Daily Penman-Monteith evapotranspiration calculated as a sum of 30-minute ET values, mm/day
0
1
2
3
4
5
6
7
8


Penman daily ET vs Penman summed 30min ET
Methven 3 Springs
$ET_{PEN\ daily} = 0.93*ET_{PEN\ summed\ 30\ min} + 0.074$
$R^2=0.9608$
Daily Penman evapotranspiration calculated using daily parameters, mm/day
Daily Penman evapotranspiration calculated as a sum of 30-minute ET values, mm/day
0
1
2
3
4
5
6
7
8
9
10


Is 9 am water vapour pressure a good proxy for the average daily water vapour pressure?
ET uses 9 am vp = 0.98*ET uses average of 30 min vp + 0.051
R2=0.9820
Daily Penman-Monteith evapotranspiration, using 9 am vp, mm/day
Daily Penman-Monteith evapotranspiration, using averaged 30 min vp, mm/day
0
1
2
3
4
5
6
7
8


Methven 3 Springs Water vapour pressure
vp9am = vpave - 0.046
r2=0.9176
9 am water vapour pressure in kPa
water vapour pressure in kPa, average of 30 minute values over a day
0
0.5
1
1.5
2
2.5
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8


Comparing effect of empirical vs measured Rnet and ground flux
ET PM emp formulae = 0.9*ET PM measured Rnet and G + 0.0033
r2=0.9753
Penman-Monteith 30-min ET calculated with empirical Rnet and Ground flux mm/30 min
Penman-Monteith 30-min ET calculated with measured Rnet and Ground flux mm/30 min
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
-0.05
-0.05
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45



Saturation 46%
Field Capacity 40%
Minimum 27%

Not water limited

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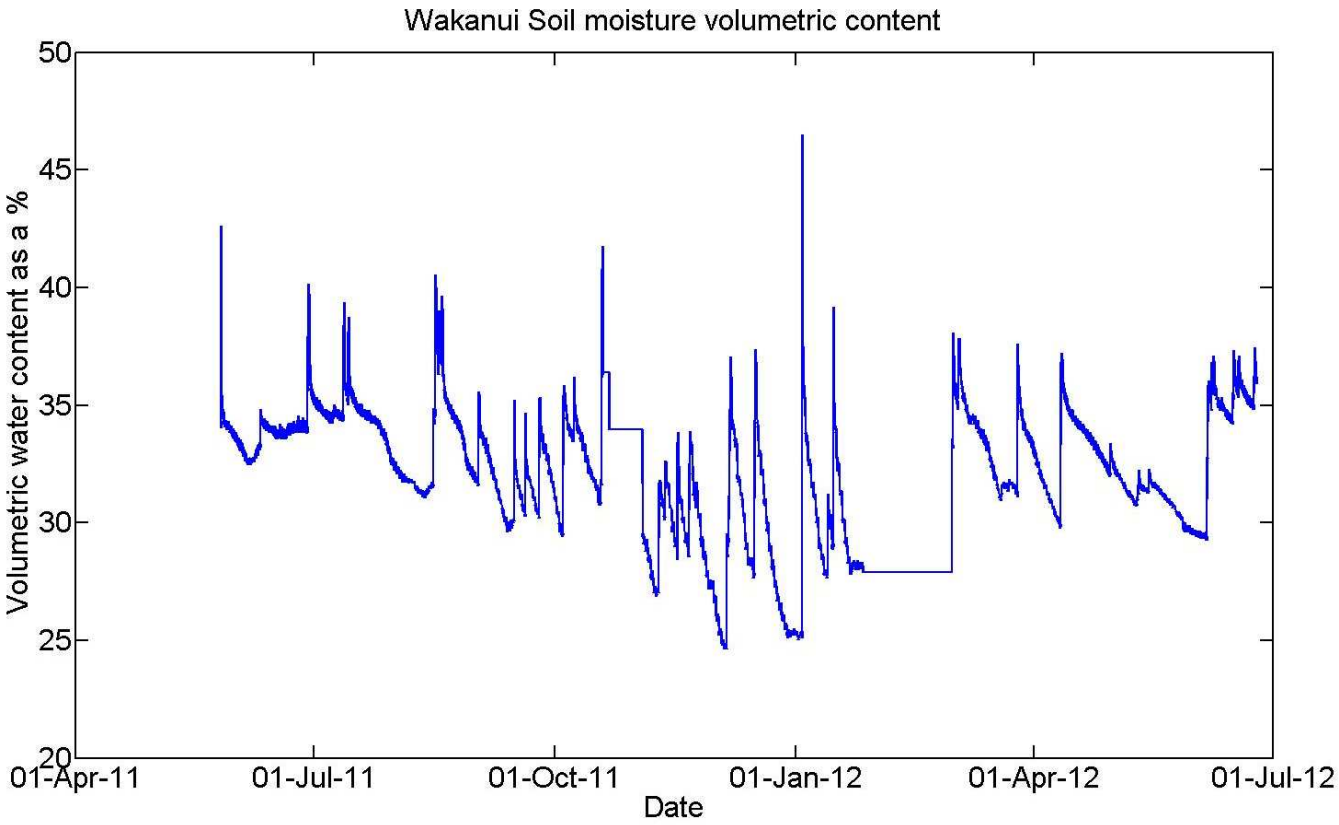

Saturation >46%
Field Capacity 30-34 %
Minimum 24%

Not water limited

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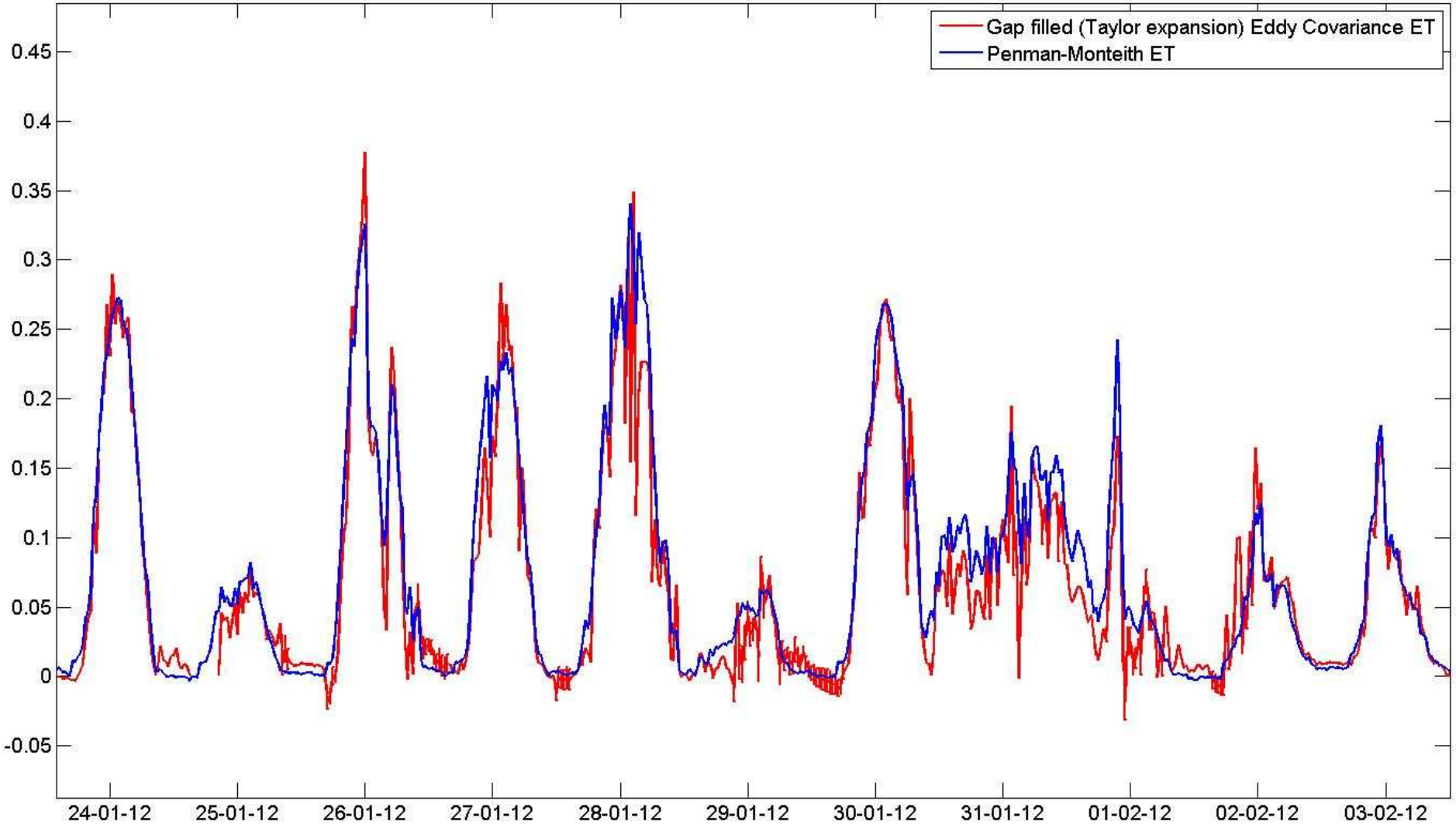
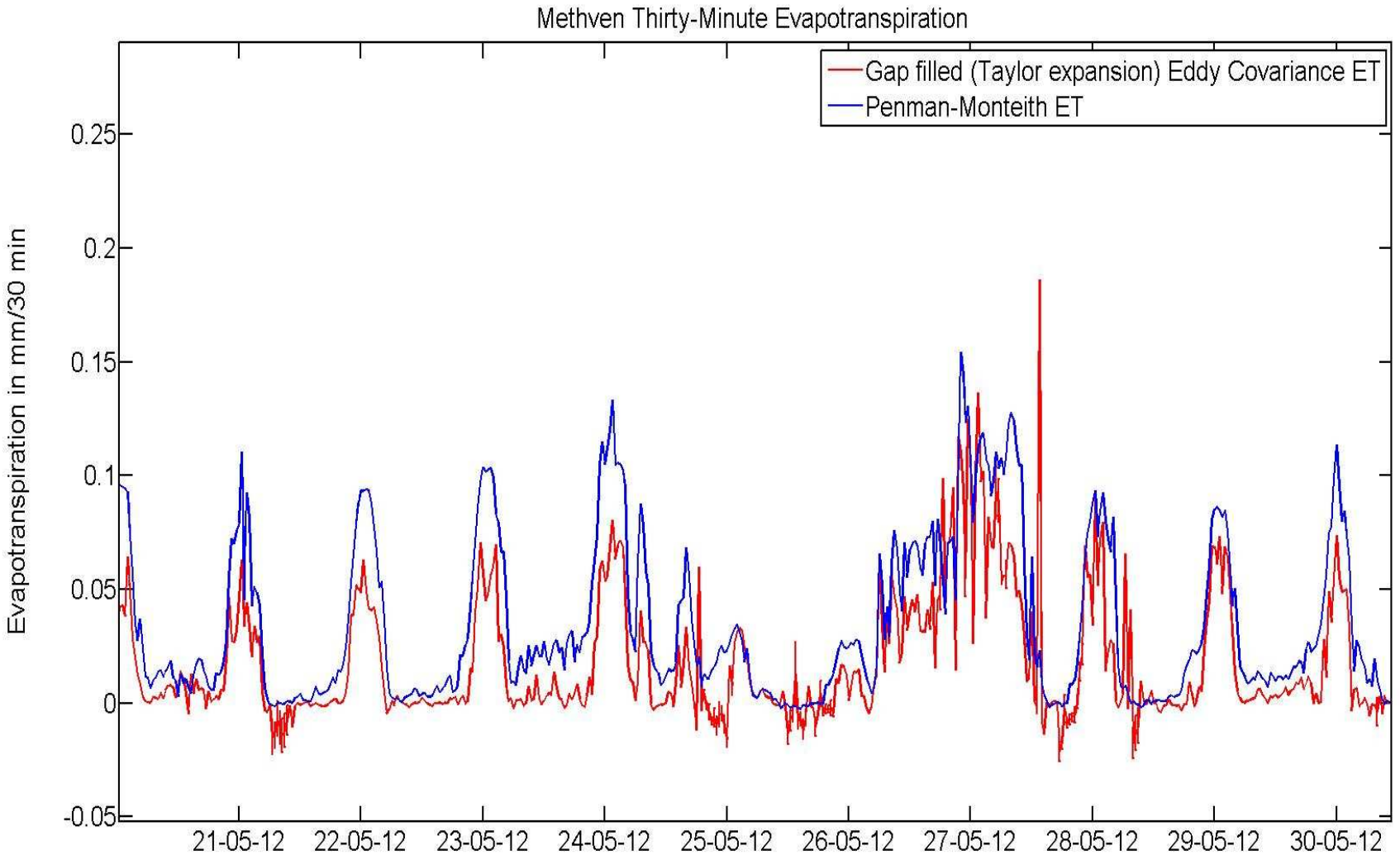
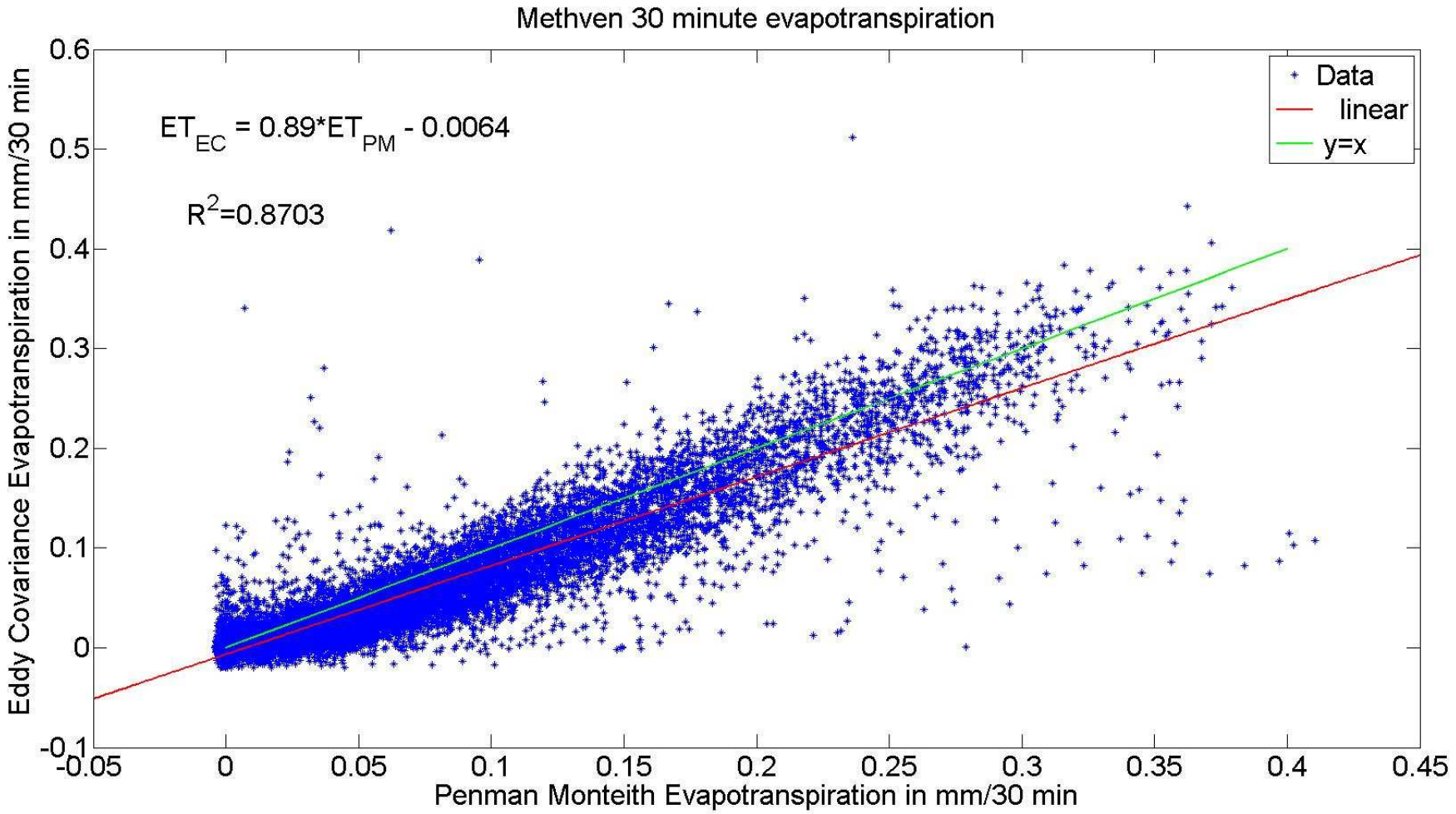
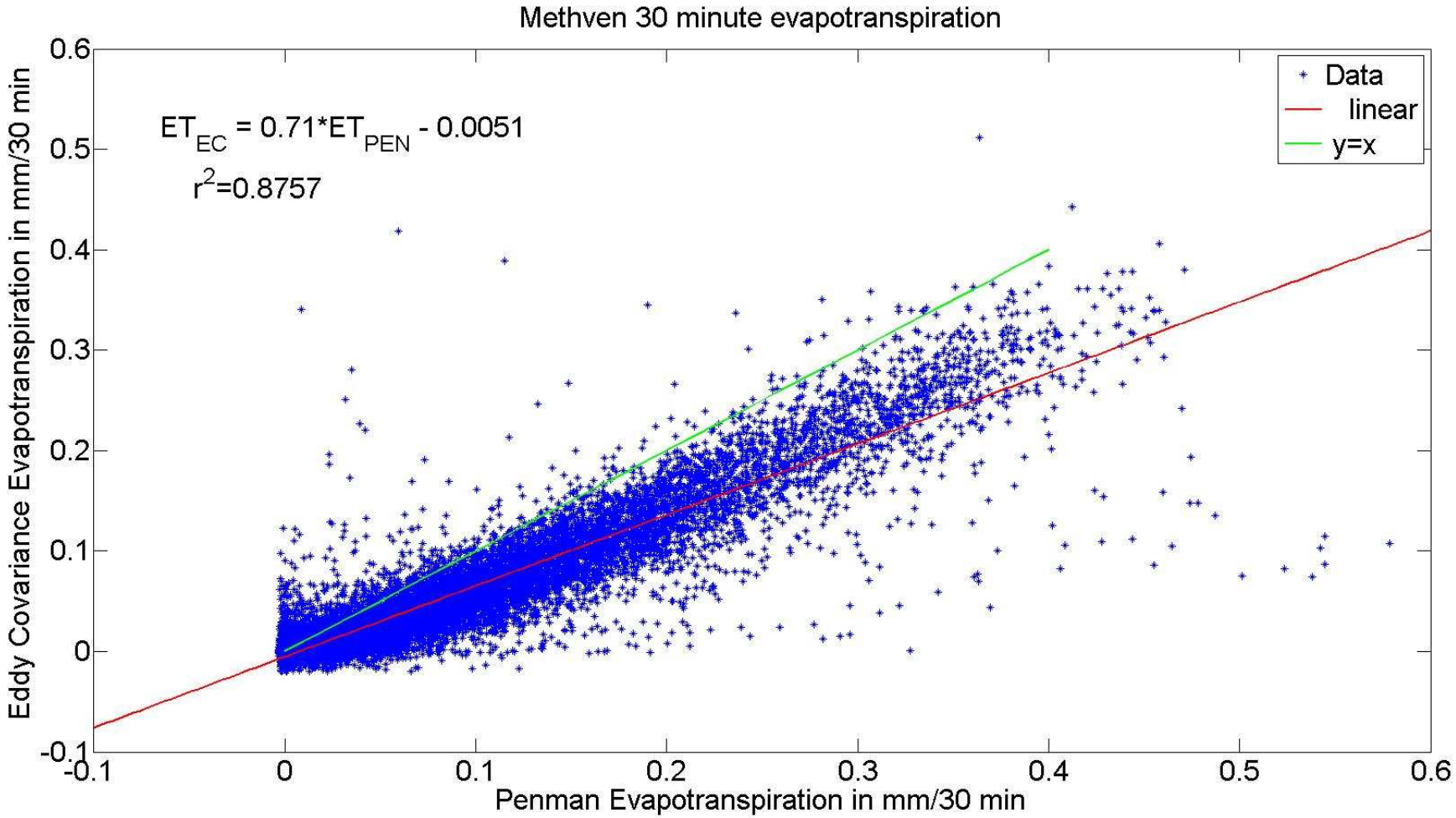
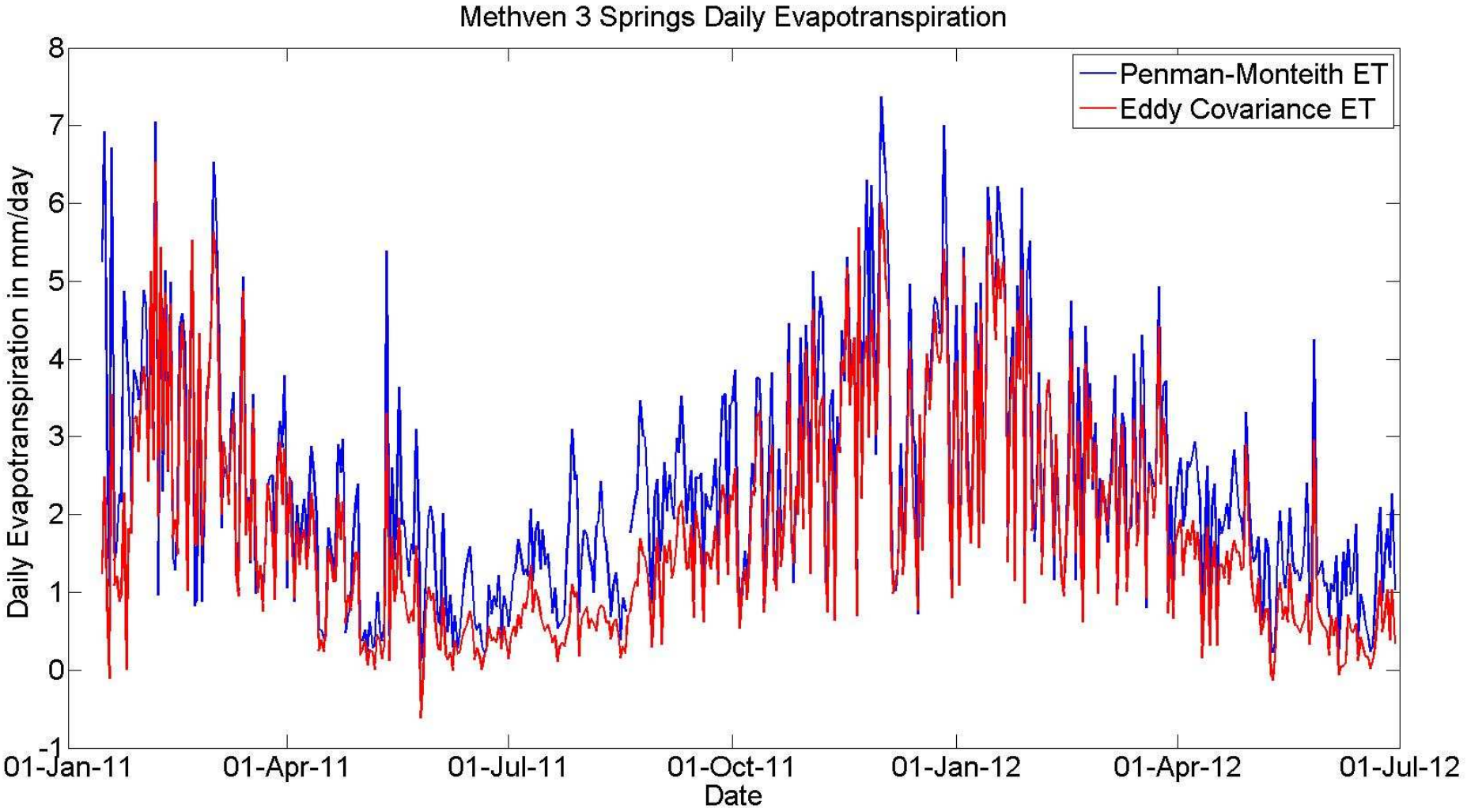
Methven 30 minute Evapotranspiration in mm/ 30 minutes

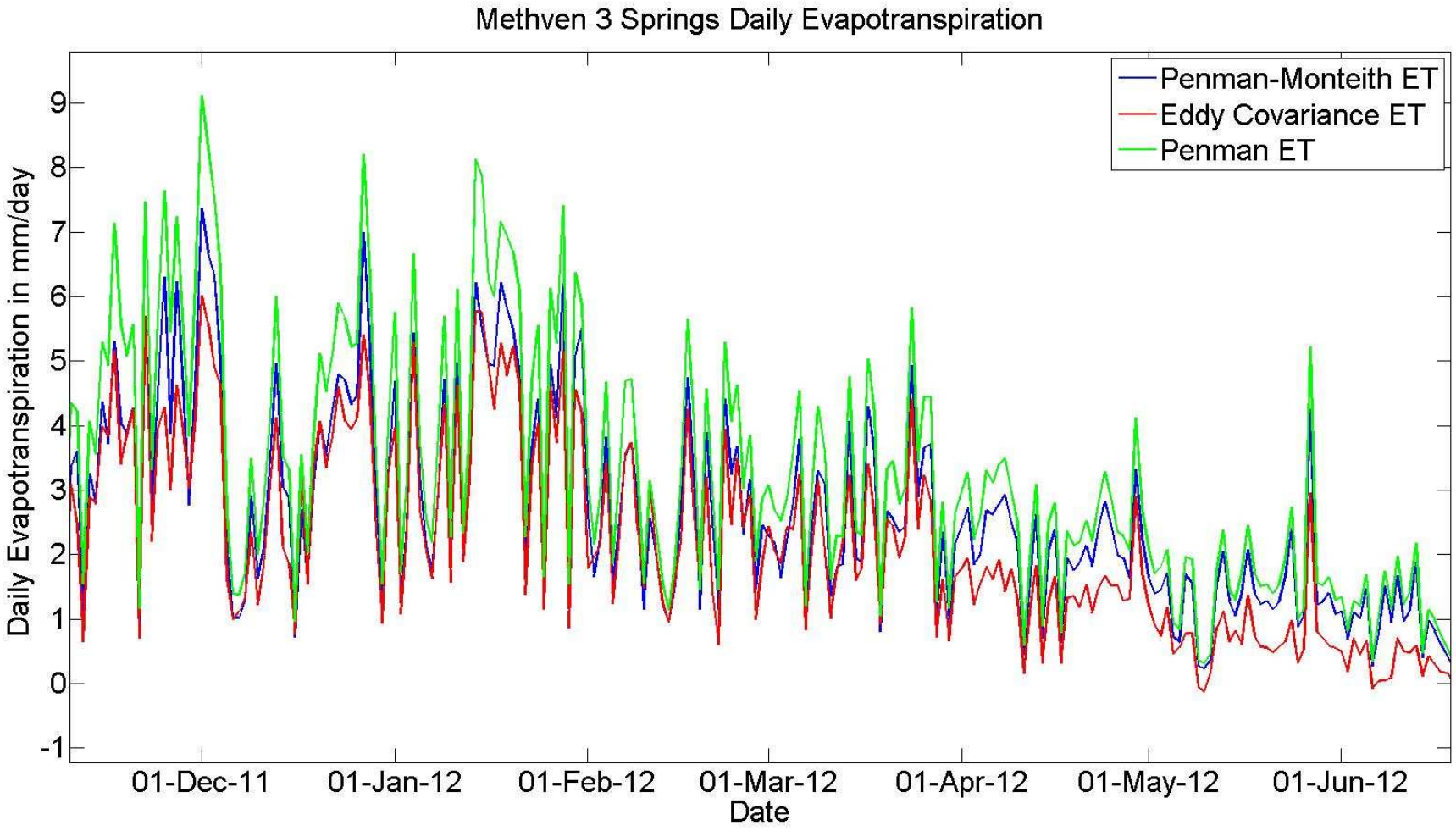


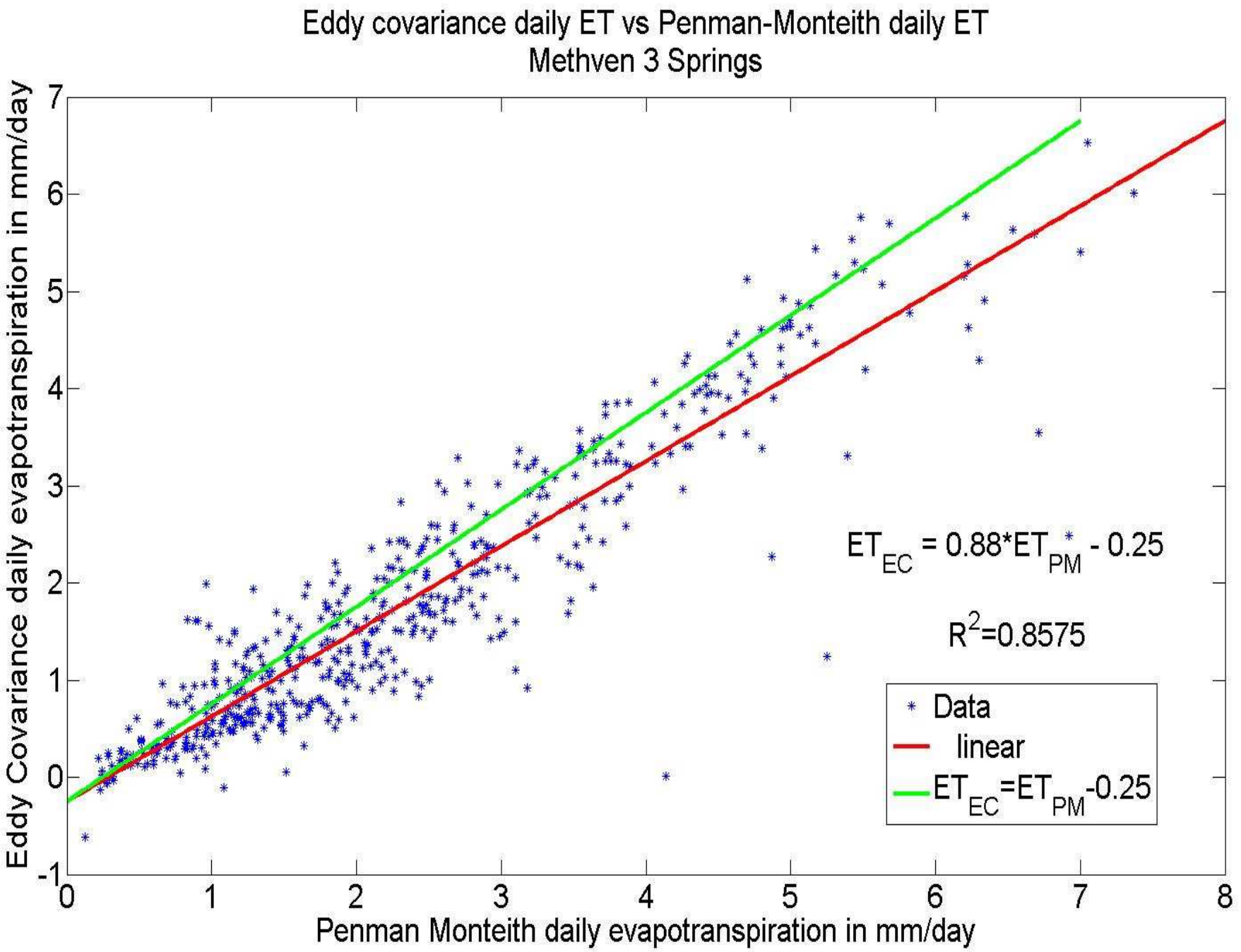

Methven Thirty-Minute Evapotranspiration
Gap filled (Taylor expansion) Eddy Covariance ET
Penman-Monteith ET
Evapotranspiration in mm/30 min
0.25
0.2
0.15
0.1
0.05
0
-0.05
21-05-12
22-05-12
23-05-12
24-05-12
25-05-12
26-05-12
27-05-12
28-05-12
29-05-12
30-05-12

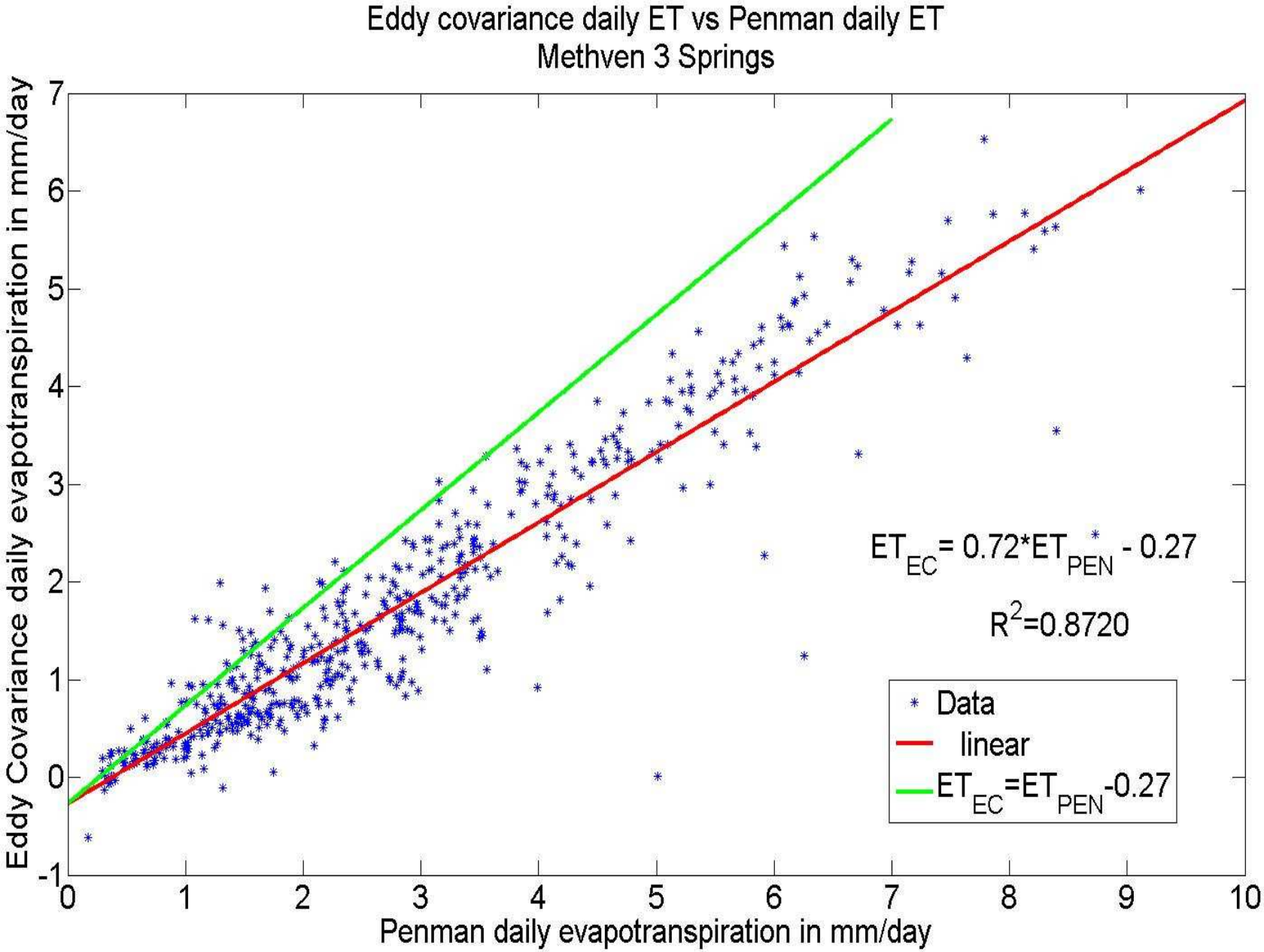

Methven 30 minute evapotranspiration
$ET_{EC} = 0.89*ET_{PM} - 0.0064$
$R^2=0.8703$
Data
linear
y=x
Eddy Covariance Evapotranspiration in mm/30 min
Penman Monteith Evapotranspiration in mm/30 min
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.05
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45

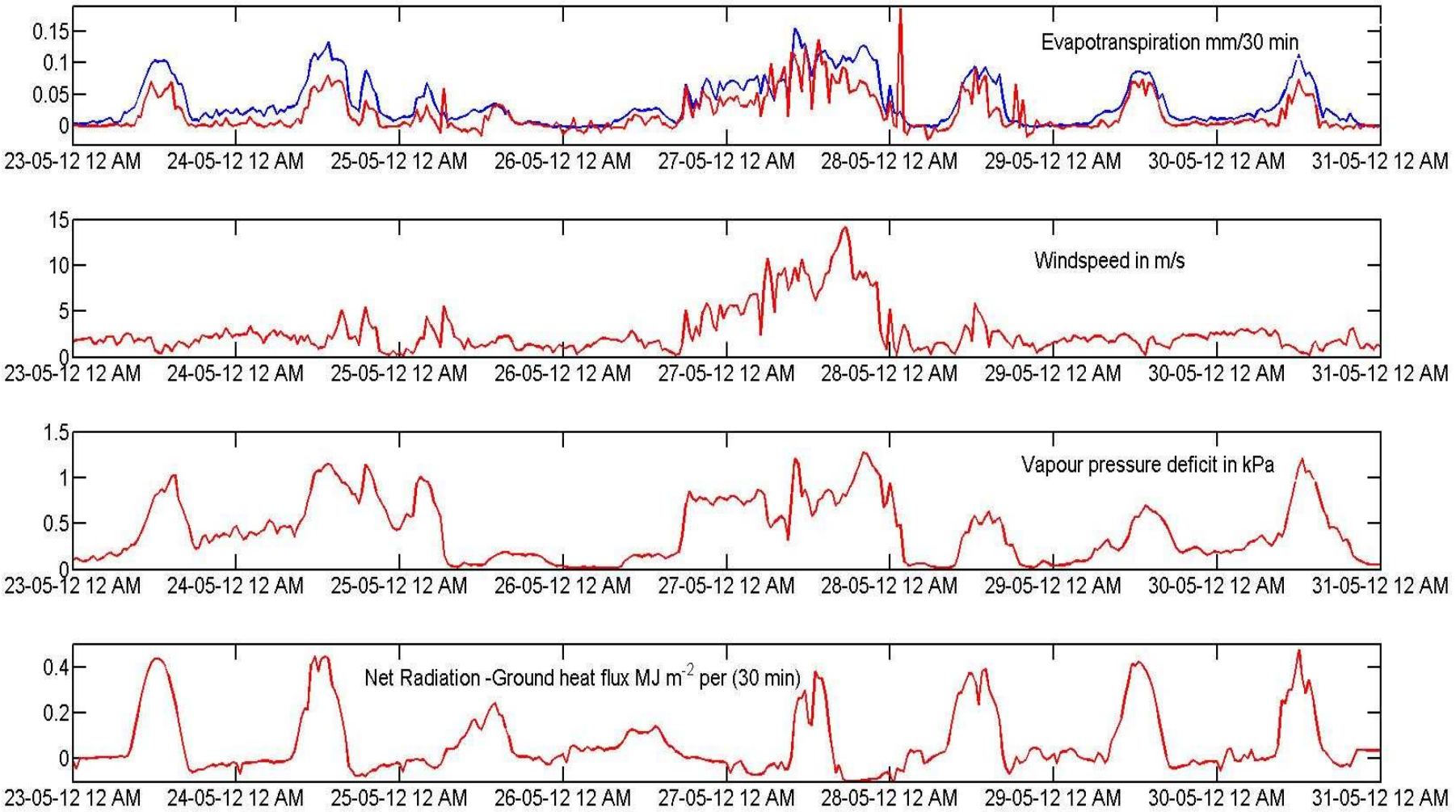

Methven 30 minute evapotranspiration
$ET_{EC} = 0.71*ET_{PEN} - 0.0051$
$r^2=0.8757$
Data
linear
y=x
Eddy Covariance Evapotranspiration in mm/30 min
Penman Evapotranspiration in mm/30 min
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.1
0
0.1
0.2
0.3
0.4
0.5
0.6

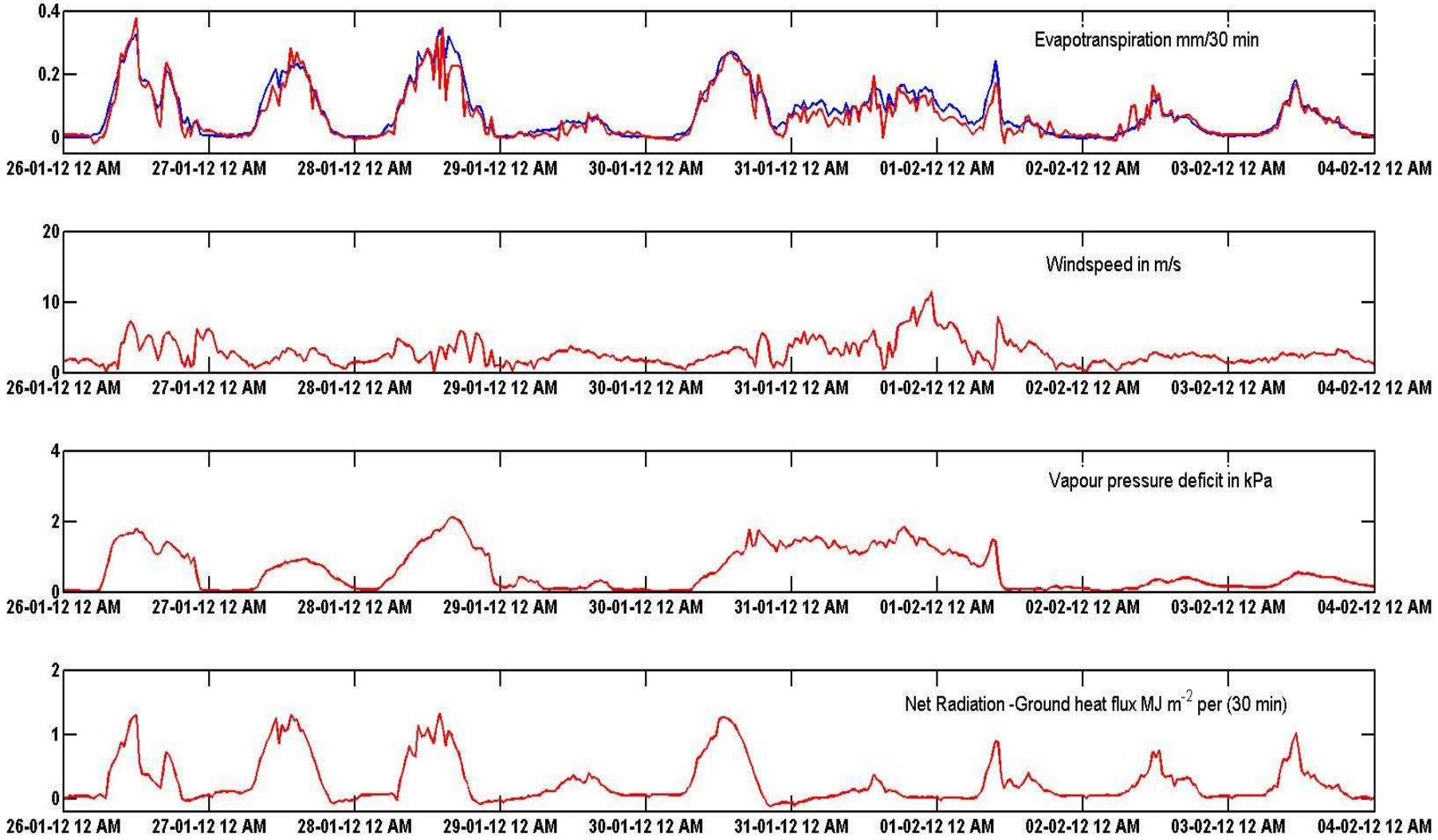

Methven 3 Springs Daily Evapotranspiration
Penman-Monteith ET
Eddy Covariance ET
Daily Evapotranspiration in mm/day
8
7
6
5
4
3
2
1
0
-1
01-Jan-11
01-Apr-11
01-Jul-11
01-Oct-11
01-Jan-12
01-Apr-12
01-Jul-12
Date

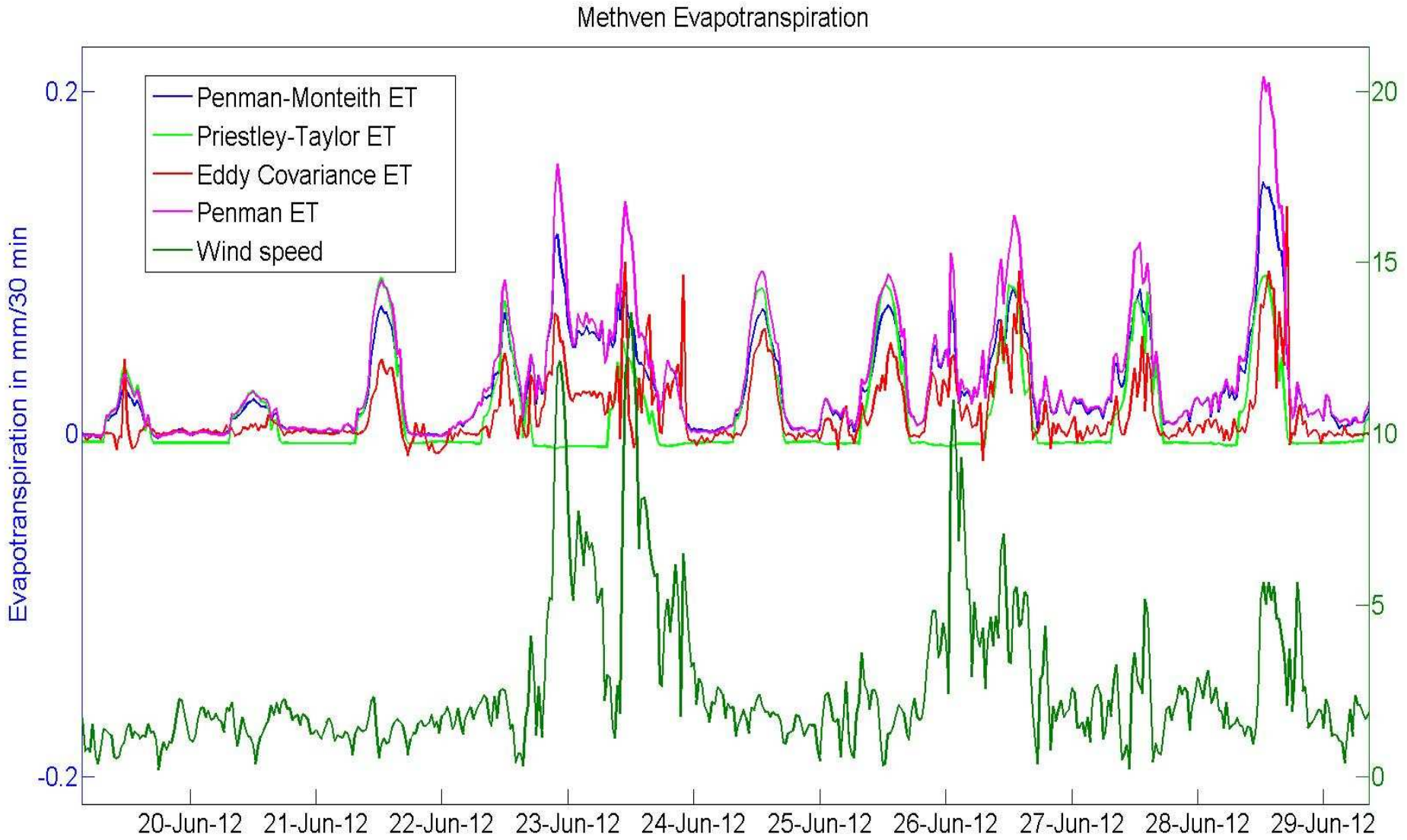

Methven 3 Springs Daily Evapotranspiration
Penman-Monteith ET
Eddy Covariance ET
Penman ET
Daily Evapotranspiration in mm/day
9
8
7
6
5
4
3
2
1
0
-1
01-Dec-11
01-Jan-12
01-Feb-12
01-Mar-12
01-Apr-12
01-May-12
01-Jun-12
Date

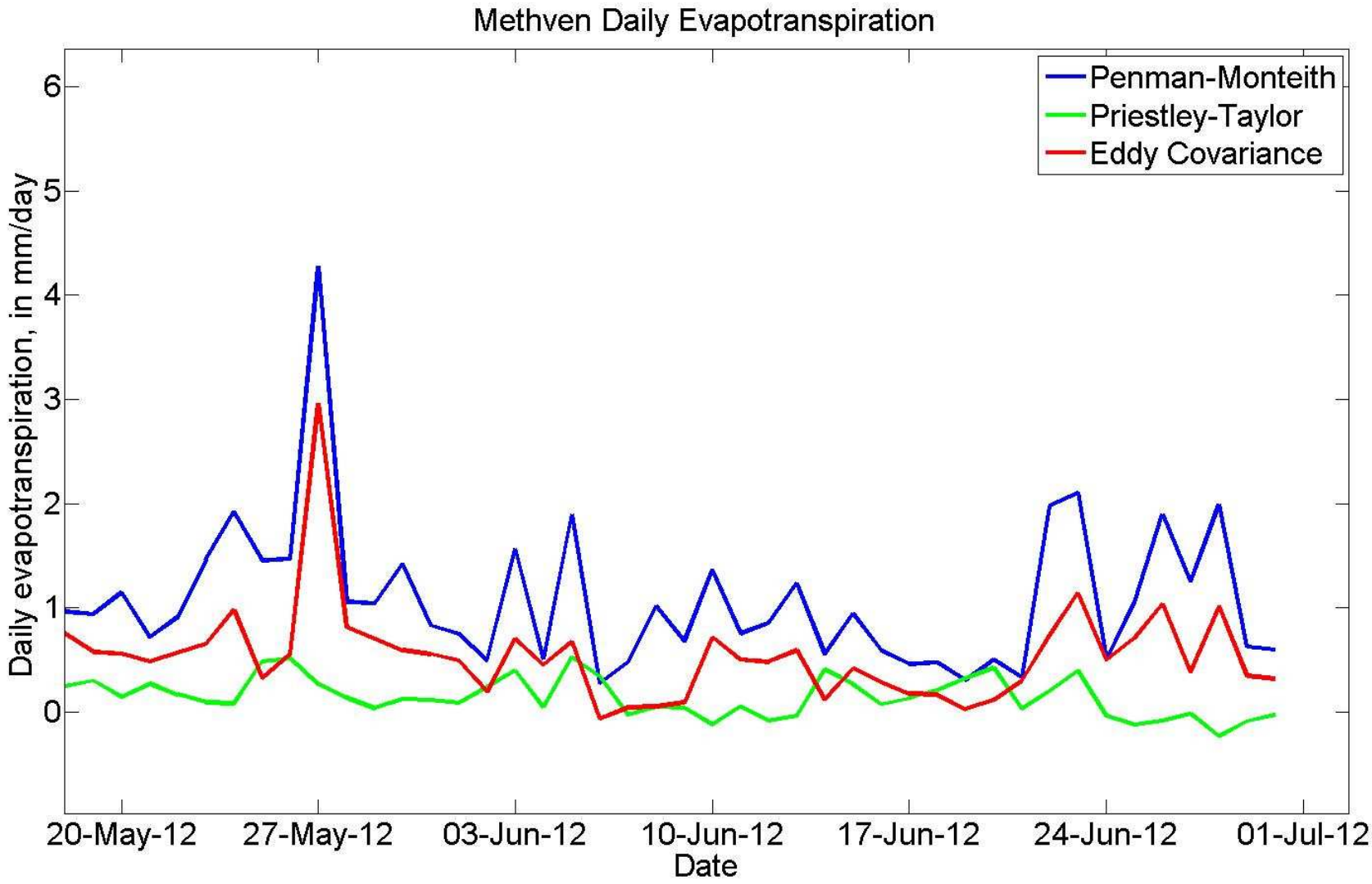

Eddy covariance daily ET vs Penman-Monteith daily ET
Methven 3 Springs
Eddy Covariance daily evapotranspiration in mm/day
Penman Monteith daily evapotranspiration in mm/day
ET_EC = 0.88*ET_PM - 0.25
R^2=0.8575
Data
linear
ET_EC=ET_PM-0.25
-1
0
1
2
3
4
5
6
7
8

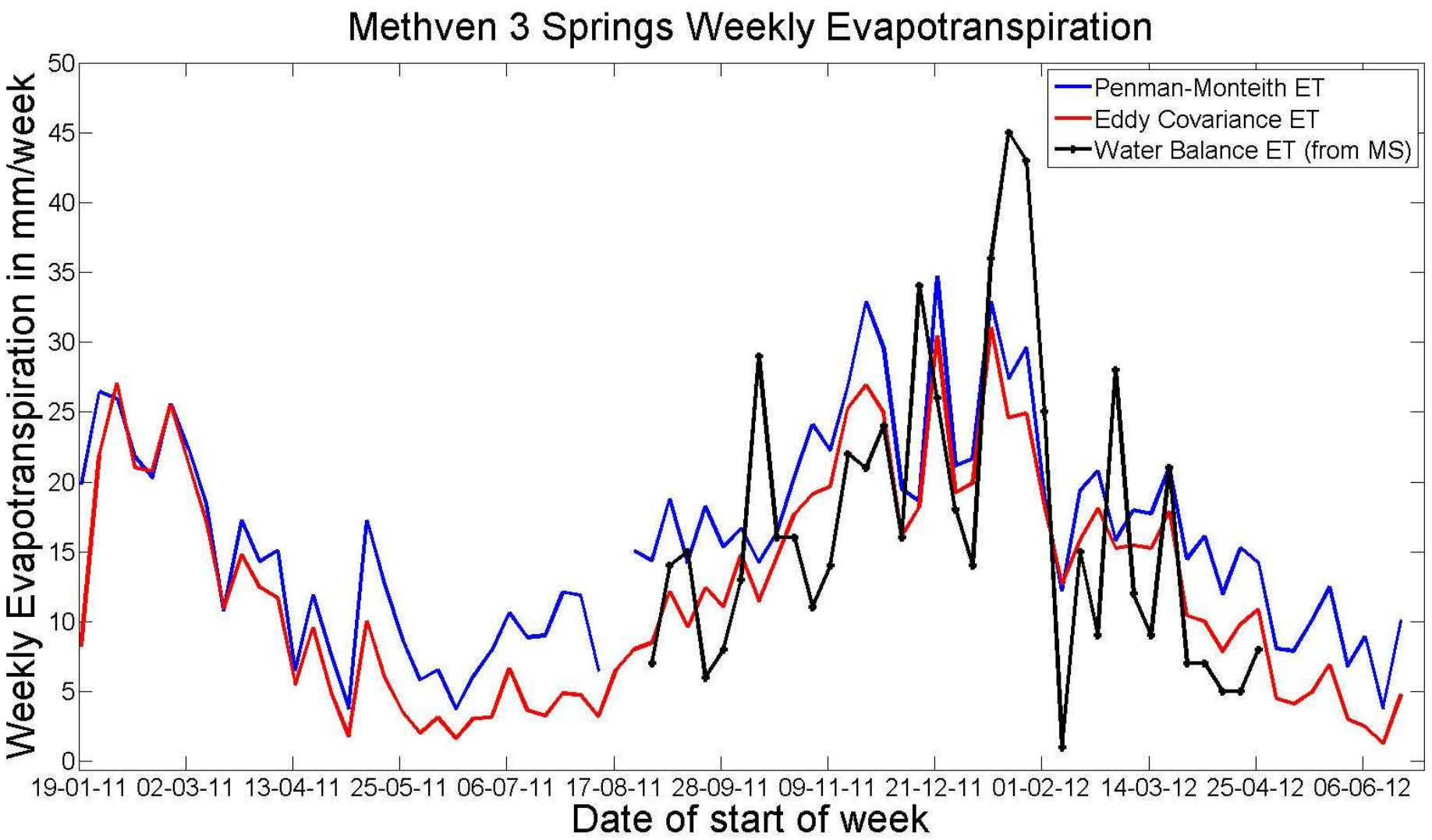

Eddy covariance daily ET vs Penman daily ET
Methven 3 Springs
Eddy Covariance daily evapotranspiration in mm/day
Penman daily evapotranspiration in mm/day
ET_EC= 0.72*ET_PEN - 0.27
R^2=0.8720
Data
linear
ET_EC=ET_PEN-0.27
-1
0
1
2
3
4
5
6
7
8
9
10

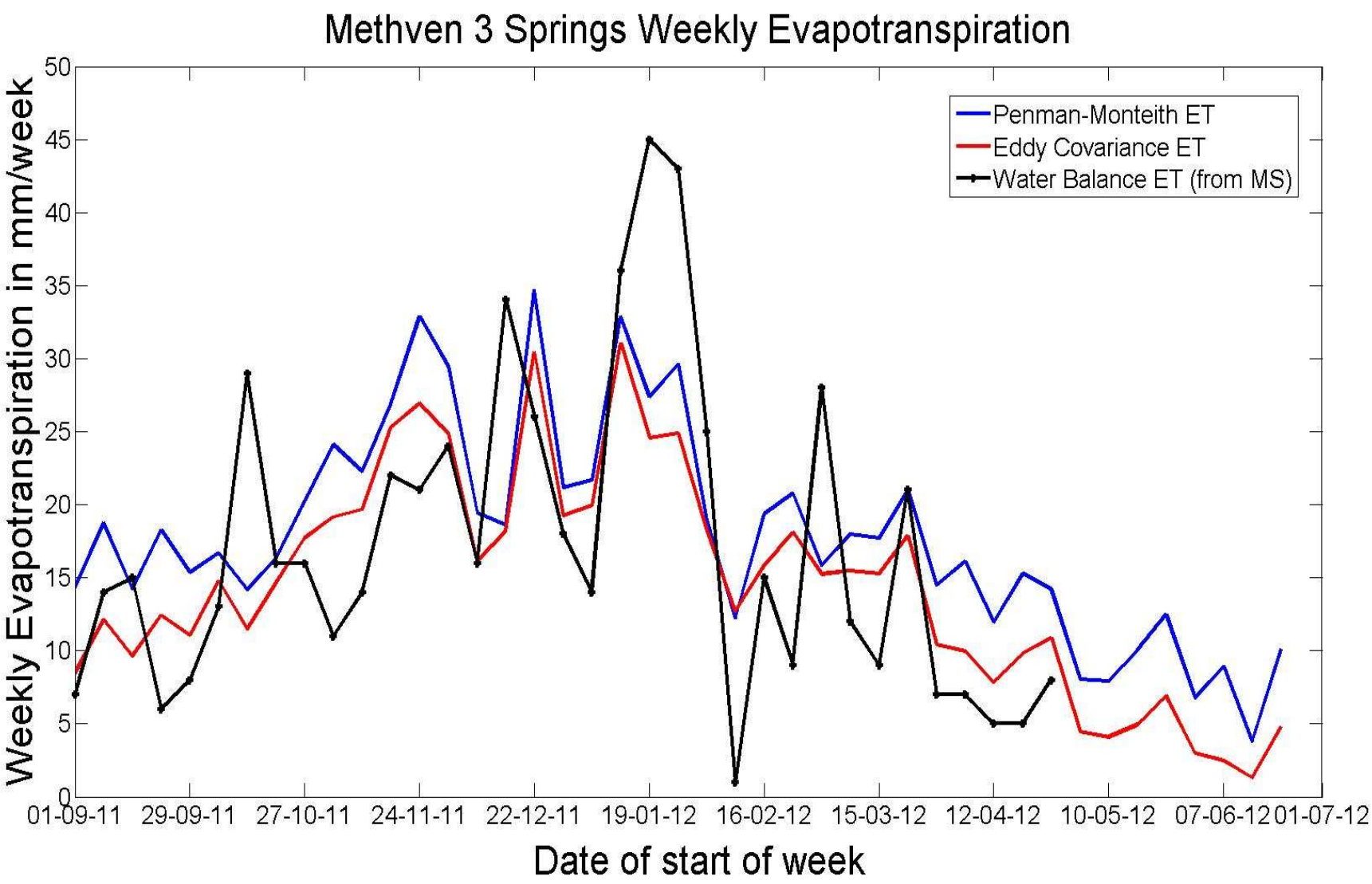

Evapotranspiration mm/30 min
0.15
0.1
0.05
0
Windspeed in m/s
15
10
5
0
Vapour pressure deficit in kPa
1.5
1
0.5
0
Net Radiation -Ground heat flux MJ m-2 per (30 min)
0.4
0.2
0
23-05-12 12 AM
24-05-12 12 AM
25-05-12 12 AM
26-05-12 12 AM
27-05-12 12 AM
28-05-12 12 AM
29-05-12 12 AM
30-05-12 12 AM
31-05-12 12 AM


Evapotranspiration mm/30 min
0.4
0.2
0
Windspeed in m/s
20
10
0
Vapour pressure deficit in kPa
4
2
0
Net Radiation -Ground heat flux MJ m-2 per (30 min)
2
1
0
26-01-12 12 AM
27-01-12 12 AM
28-01-12 12 AM
29-01-12 12 AM
30-01-12 12 AM
31-01-12 12 AM
01-02-12 12 AM
02-02-12 12 AM
03-02-12 12 AM
04-02-12 12 AM


Methven Evapotranspiration
Penman-Monteith ET
Priestley-Taylor ET
Eddy Covariance ET
Penman ET
Wind speed
Evapotranspiration in mm/30 min
0.2
0
-0.2
20
15
10
5
0
20-Jun-12
21-Jun-12
22-Jun-12
23-Jun-12
24-Jun-12
25-Jun-12
26-Jun-12
27-Jun-12
28-Jun-12
29-Jun-12


Methven Daily Evapotranspiration
Penman-Monteith
Priestley-Taylor
Eddy Covariance
Daily evapotranspiration, in mm/day
6
5
4
3
2
1
0
20-May-12
27-May-12
03-Jun-12
10-Jun-12
17-Jun-12
24-Jun-12
01-Jul-12
Date


Methven 3 Springs Weekly Evapotranspiration
Weekly Evapotranspiration in mm/week
0
5
10
15
20
25
30
35
40
45
50
Penman-Monteith ET
Eddy Covariance ET
Water Balance ET (from MS)
19-01-11
02-03-11
13-04-11
25-05-11
06-07-11
17-08-11
28-09-11
09-11-11
21-12-11
01-02-12
14-03-12
25-04-12
06-06-12
Date of start of week


Methven 3 Springs Weekly Evapotranspiration
Weekly Evapotranspiration in mm/week
Date of start of week
Penman-Monteith ET
Eddy Covariance ET
Water Balance ET (from MS)
0
5
10
15
20
25
30
35
40
45
50
01-09-11
29-09-11
27-10-11
24-11-11
22-12-11
19-01-12
16-02-12
15-03-12
12-04-12
10-05-12
07-06-12
01-07-12

Summary

ET over the entire irrigation season
(Sep 1, 2011 – Apr 30, 2012)

Eddy Covariance tower	**542 mm**
Water balance approach	659 mm
Priestly-Taylor method	660 mm
Penman-Monteith method	691 mm
Penman method	842 mm

NIWA
Taihoro Nukurangi

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NIWA
Taihoro Nukurangi