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Regional Land Surface Evaporation using MODIS Remote Sensing

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Acknowledgements to CSIRO Colleagues

- Ray Leuning and Yongqiang Zhang
- Edward King and WIRADA project on ET Intercomparisons

Context: Terrestrial carbon and water budget dynamics

- **Goal**: Fine space and time scale assessments of surface energy, water and carbon exchanges for regions and continents (10^2 – 10^3 m; weekly to monthly)

- Flux station measurements are key, but not sufficient
  - Net CO_2 and water vapour fluxes highly resolved temporally, but spatially-averaged at smaller scales only (up to 10^3 m)

- Advanced land surface models (e.g. CABLE) not yet adequate for near real time, operational delivery

- MODIS remote sensing provides space/time coverage
  - 250 m - 1 km resolution; global domain; 8 and 16 days
  - But, measure radiances not fluxes

- **Challenge**: Develop an operational model for land surface evapotranspiration (λE, ET) that combines the continuity of flux tower measurements with space/time coverage of MODIS remote sensing
  - Inputs: routinely available over large regions, continents
  - Robust: estimated ET constrained and insensitive to attributes of multi-temporal remote sensing
  - Validated: using ET from a range of bioclimates and ecosystems
  - Simple algorithm: for routine operational use

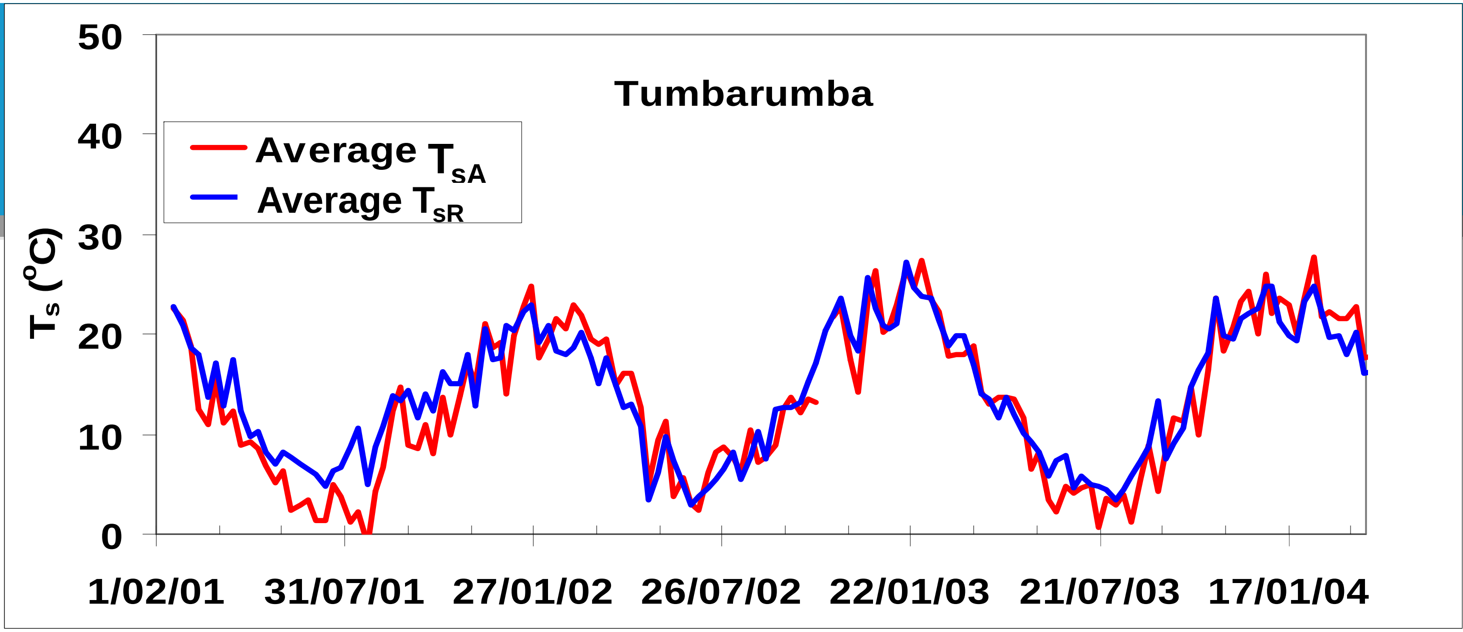
Surface energy balance and land surface evaporation from remote sensing

Traditionally, the "aerodynamic" model is used:

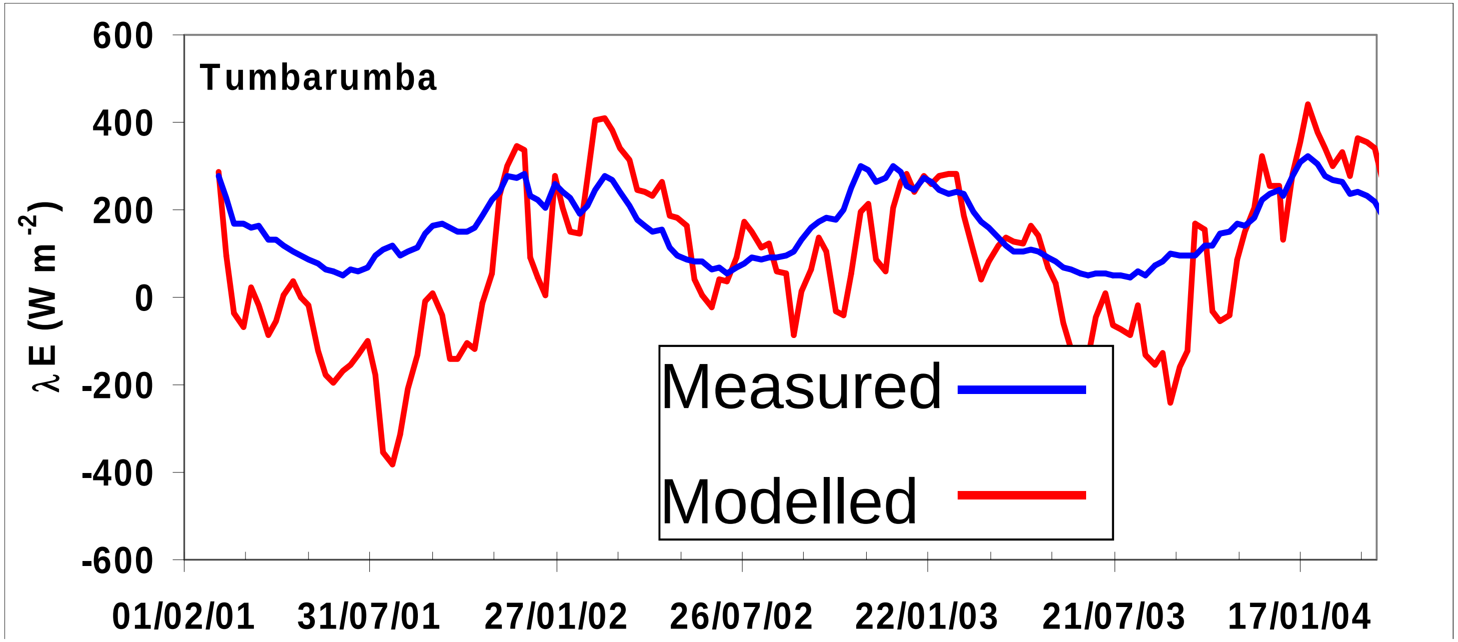
$$\lambda E = A - H = A - \left[\rho c_p (T_{sA} - T_a) / R_a \right]$$

where T_{sA} and T_a: aerodynamic surface and air temperatures

Assumes equality of radiative and aerodynamic surface temperatures (i.e. $T_{sR} = T_{sA}$)



Small differences between radiative and aerodynamic surface temperatures lead to large differences in estimated evaporation



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ET from Penman-Monteith

Penman-Monteith equation for surface evaporation:

$$\lambda E_{surface} = \frac{\varepsilon A + (\rho c_p / \gamma) D_a G_a}{\varepsilon + 1 + G_a / G_s} \qquad (1)$$

$A =$ available energy

$D_a =$ water vapour deficit

$G_a =$ aerodynamic conductance

$G_s =$ surface conductance - we model this

$\lambda =$ latent heat of vaporisation

$\varepsilon = s / \gamma$

ET from Penman-Monteith: Summary of Inputs

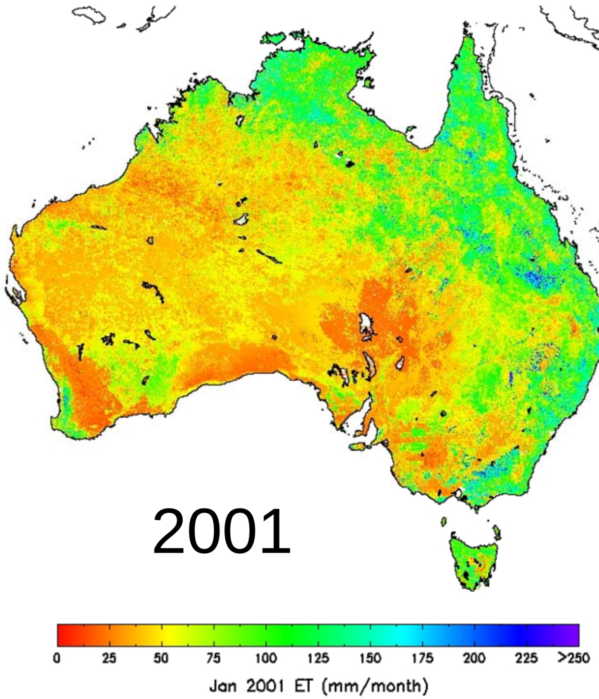
- Gridded meteorology (1 or 5 km) for the Australian continent from Bureau (daily)
  - Radiation
  - T and RH
  - Rainfall (where needed)
- MODIS remote sensing
  - Leaf Area Index: 8-day/1km MOD15A2 LAI product
  - Land Cover: Yearly/1km MOD12 land cover product
- Gridded annual albedo product
- Parameterisation and optimisation using:
  - Eddy fluxes from FluxNet
  - Catchment water balance in gauged catchments

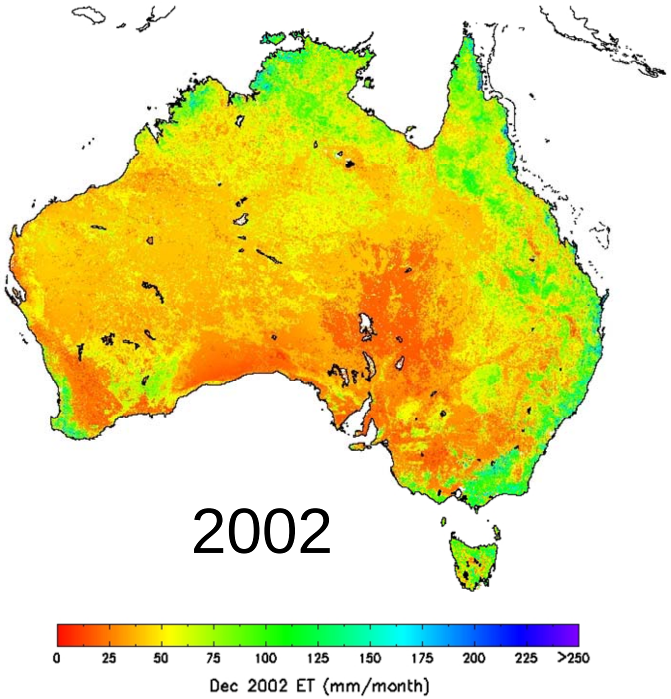
Modelling surface conductance for landscapes using MODIS Leaf Area Index (LAI) product

1. Cleugh et al (2007)

$$G_s = c_L \; L_{ai} + G_{s\,\min}$$

Mid Summer, Monthly ET





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2. Leuning et al (2008): Separating canopy and soil

$$\lambda E_{surface} = \lambda E_{canopy} + \lambda E_{soil} \qquad (2)$$

f varies from 0 (dry) to 1 (wet)

$$\lambda E_{soil} = f \frac{\varepsilon A_{soil}}{\varepsilon + 1} \qquad A_{soil} = A \exp(-k_A L_{ai}) \qquad (3)$$

$$\lambda E_{canopy} = \frac{\varepsilon A_c + (\rho c_p / \gamma) D_a G_a}{\varepsilon + 1 + G_a / G_c} \qquad (4)$$

$$G_c = \frac{g_{sx}}{k_Q} \ln \left[\frac{Q_h + Q_{50}}{Q_h \exp(-k_Q L_{ai}) + Q_{50}} \right] \left[\frac{1}{1 + D_a / D_{50}} \right] \qquad (5)$$

stomatal light humidity deficit

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Penman – Monteith – Leuning (PML) model for land surface evaporation

- Combine, rearrange and solve for surface conductance G_s

$$G_s = G_c \left[\frac{1 + \frac{\tau G_a}{(\varepsilon + 1) G_c} \left[f - \frac{(\varepsilon + 1)(1 - f) G_c}{G_a} \right] + \frac{G_a}{\varepsilon G_i}}{1 - \tau \left[f - \frac{(\varepsilon + 1)(1 - f) G_c}{G_a} \right] + \frac{G_a}{\varepsilon G_i}} \right]$$

- 6 parameters $g_{sx}, f, k_A, k_Q, Q_{50}, D_{50}$

but no significant loss in performance if all held constant except for g_{sx}, f which are optimised using daily fluxes

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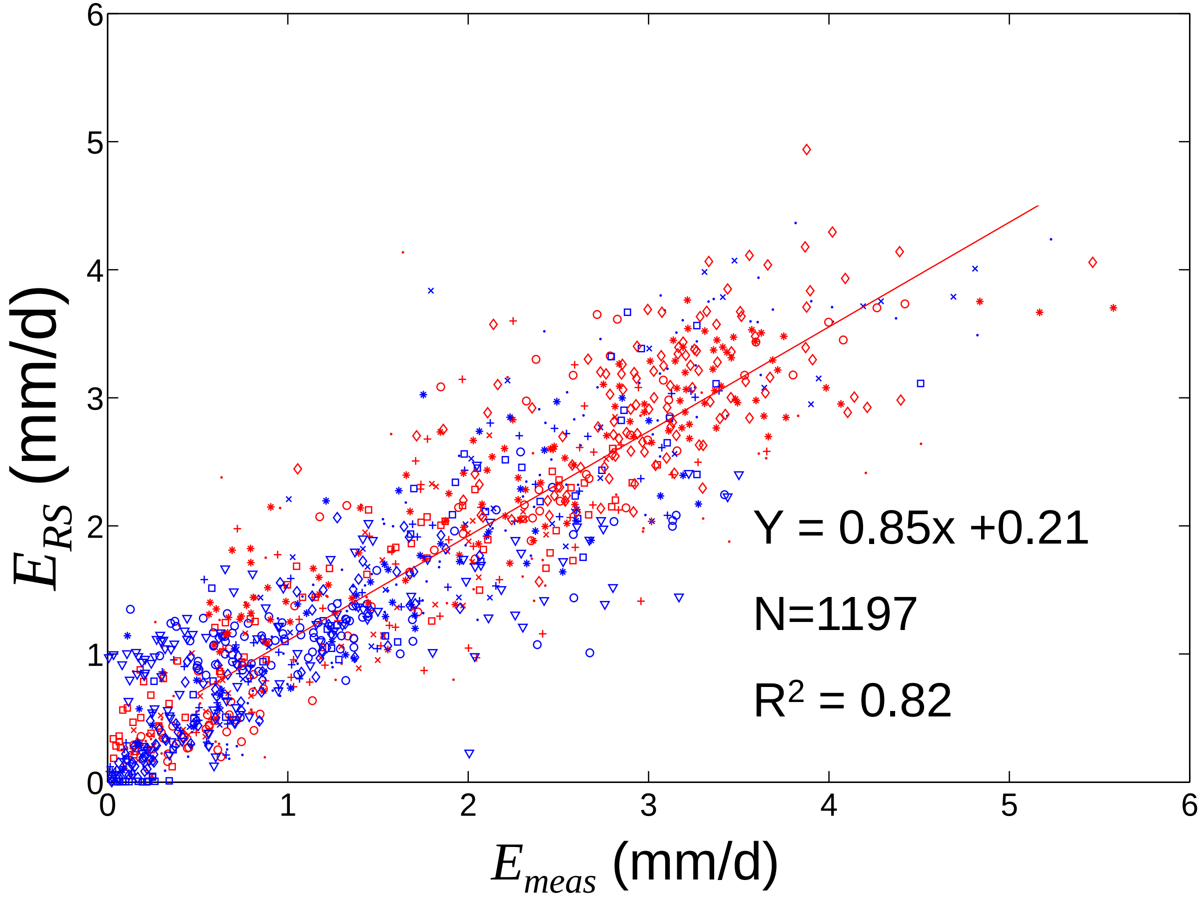
Parameterise and validate PML model at 15 Fluxnet sites across a range of ecosystems and climates

E_{meas} = daily ET measured at flux towers

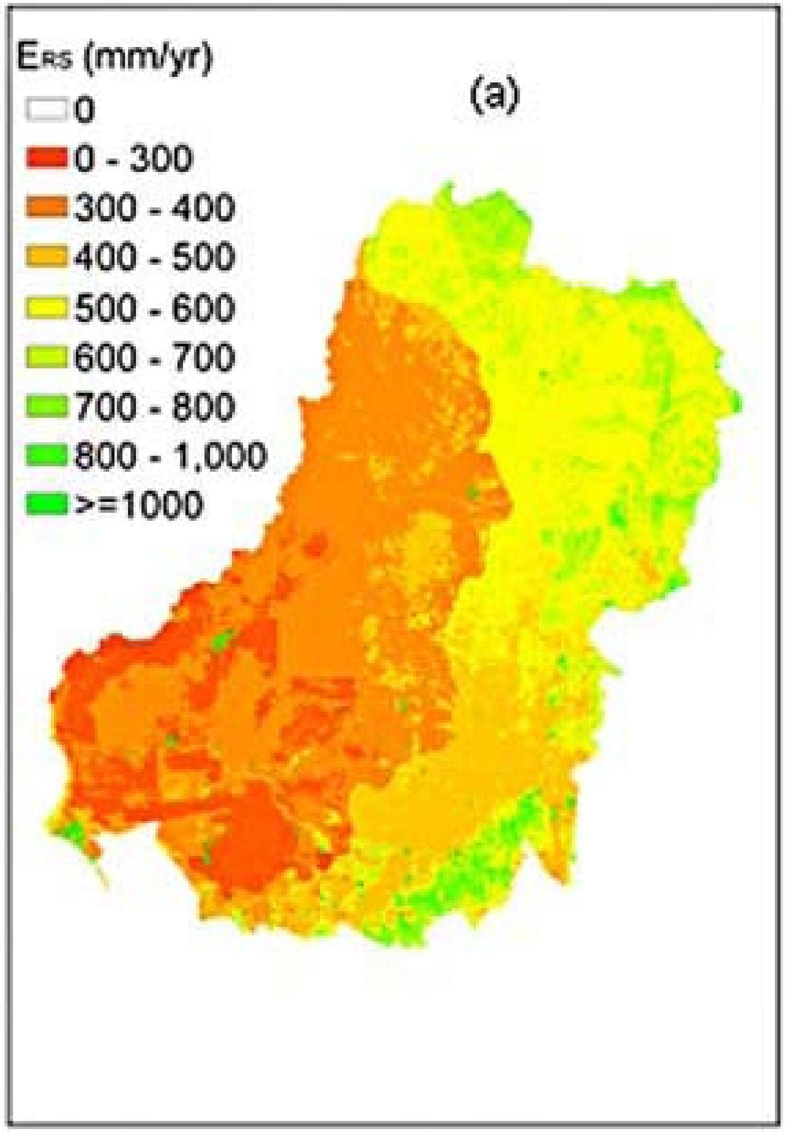
E_{RS} = PML model (2-parameter for G_s) and MODIS L_{ai}



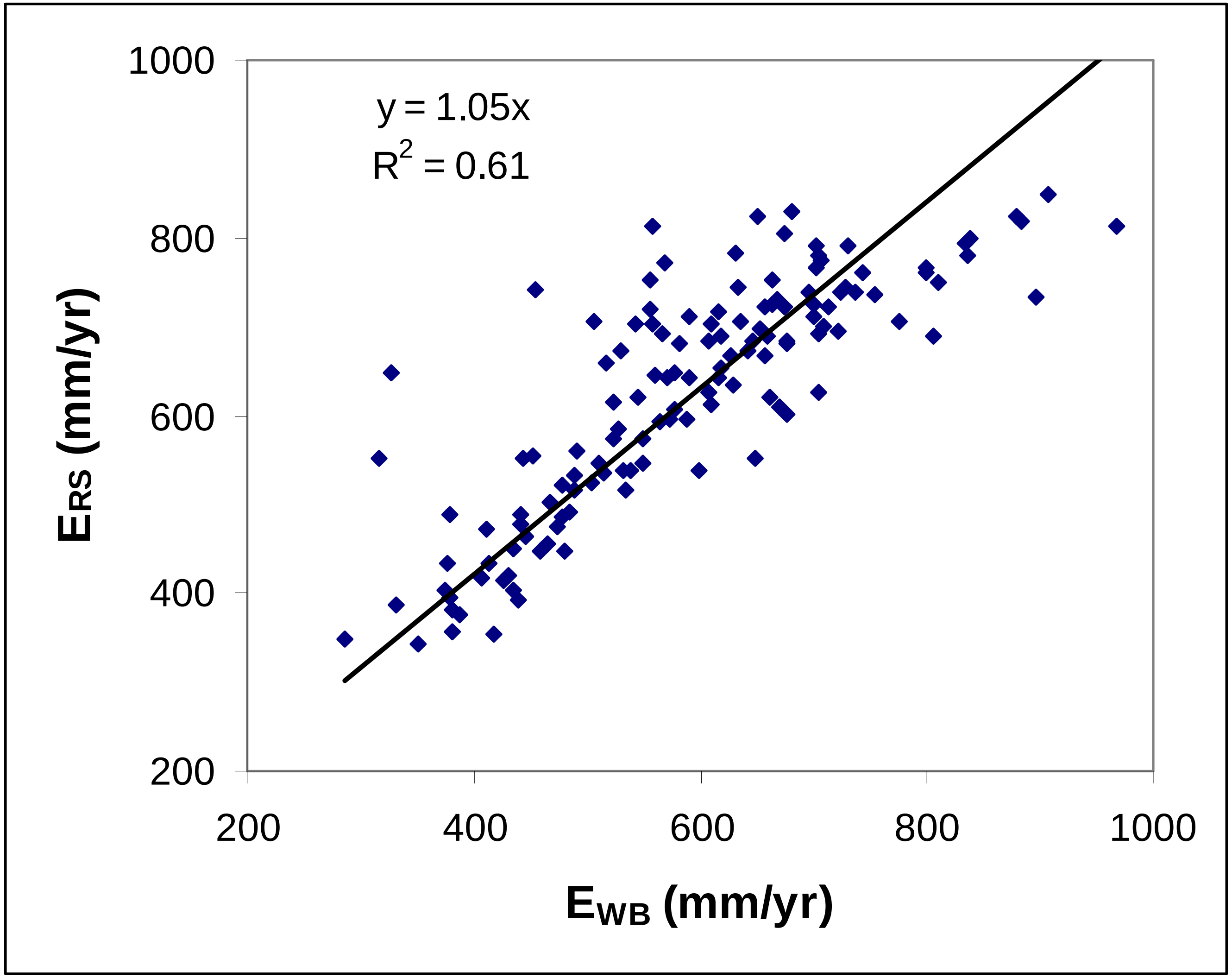
Leuning et al (2008)

3. Zhang et al (2008): Modelled E_{RS} for Murray Darling Basin (MDB)

- Optimise g_{sx}, f by minimizing difference between mean annual E_{PML} *and* E_{WB}
- Single value for each rainfall zone in the MDB
- E_{WB} are 5-year averages using water balance for 120 gauged catchments

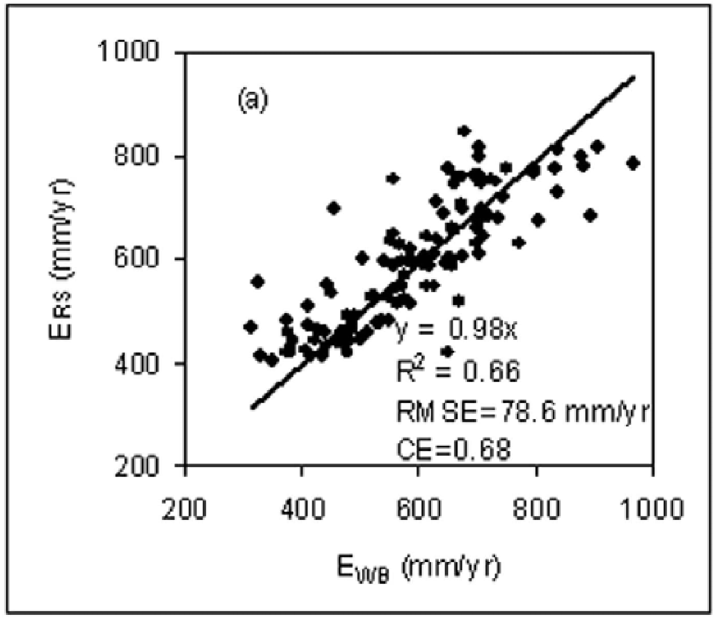


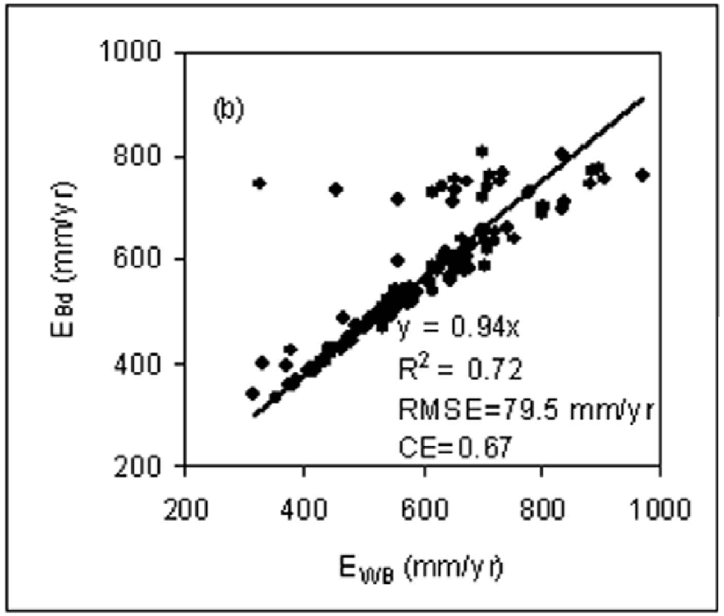
5-year average E_{RS} vs E_{WB} for 135 catchments



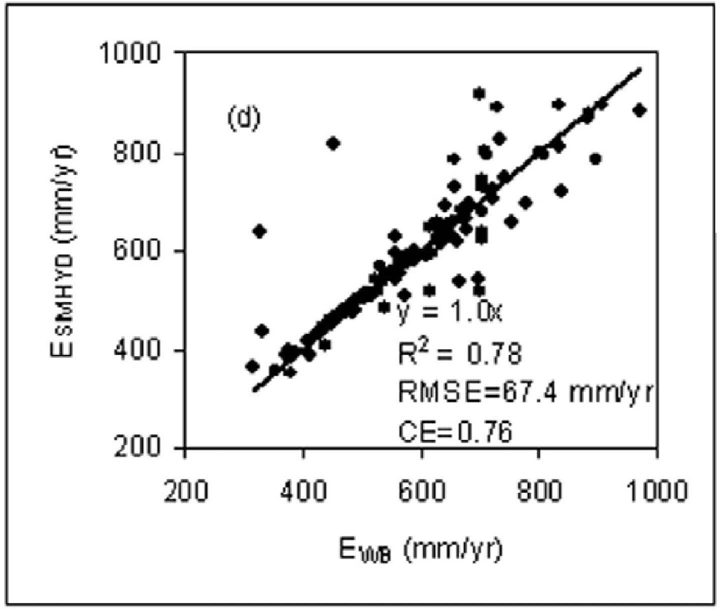
Zhang et al (2008)

5-year average E_{RS} vs E_{WB} for 120 gauged catchments in MDB (Zhang et al, 2008)



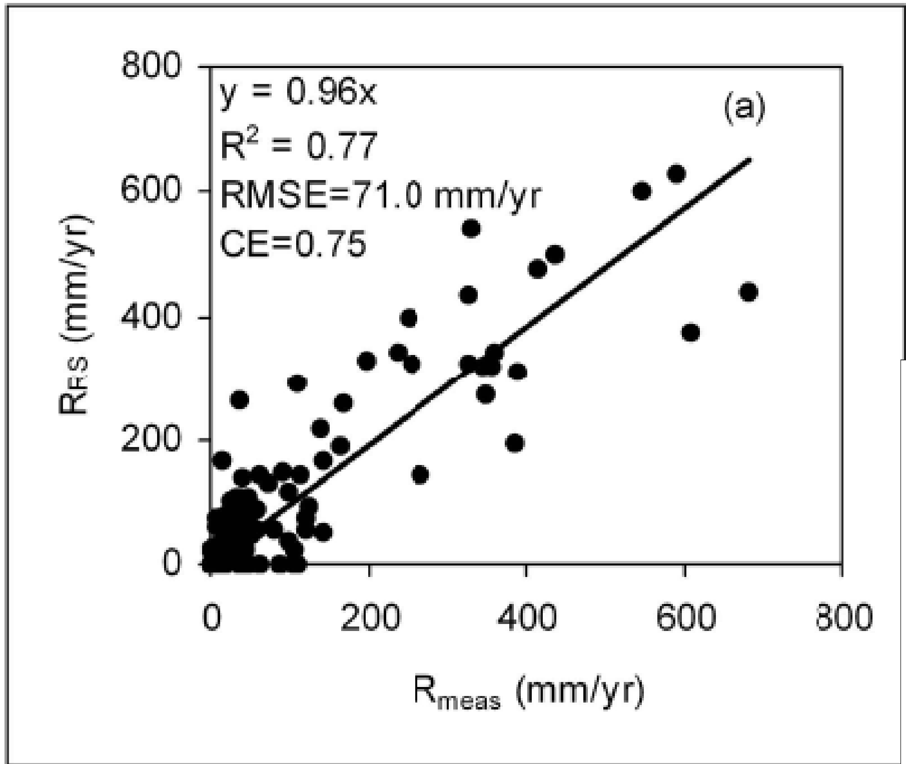


E_{WB} are 5-year averages using water balance for 120 gauged catchments in MDB



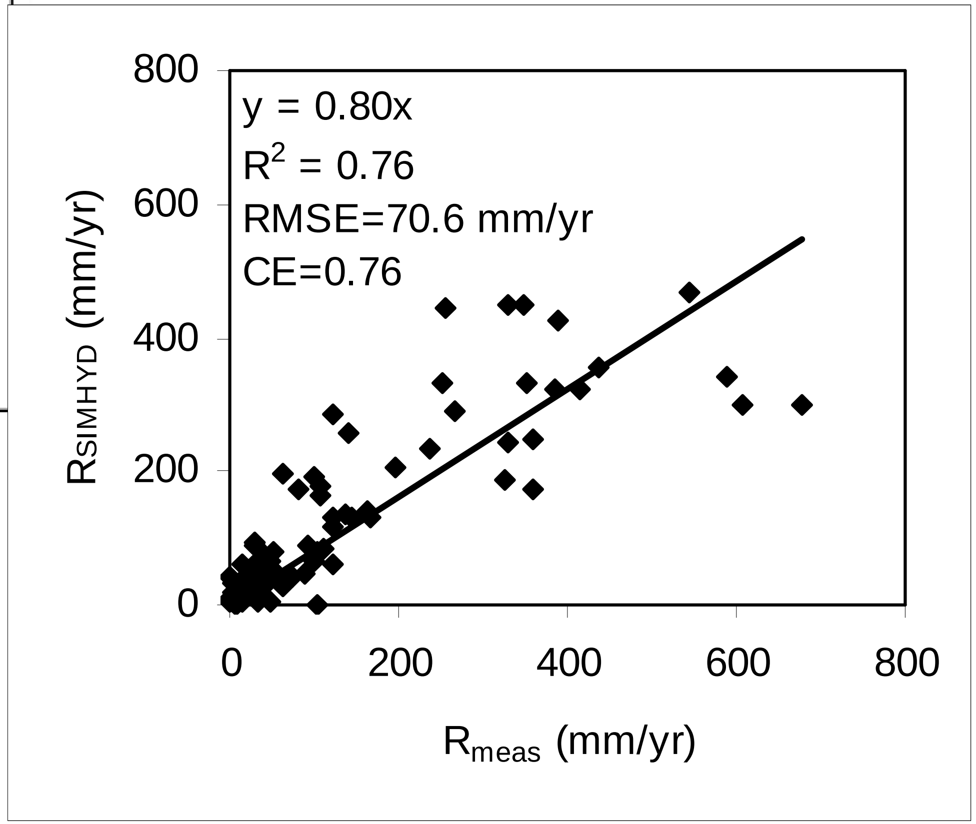
Performance comparable to calibrated rainfall runoff model (SIMHYD) and better than Budyko climatological approach

and measured vs modelled runoff R_{RS} and R_{SIMHYD}



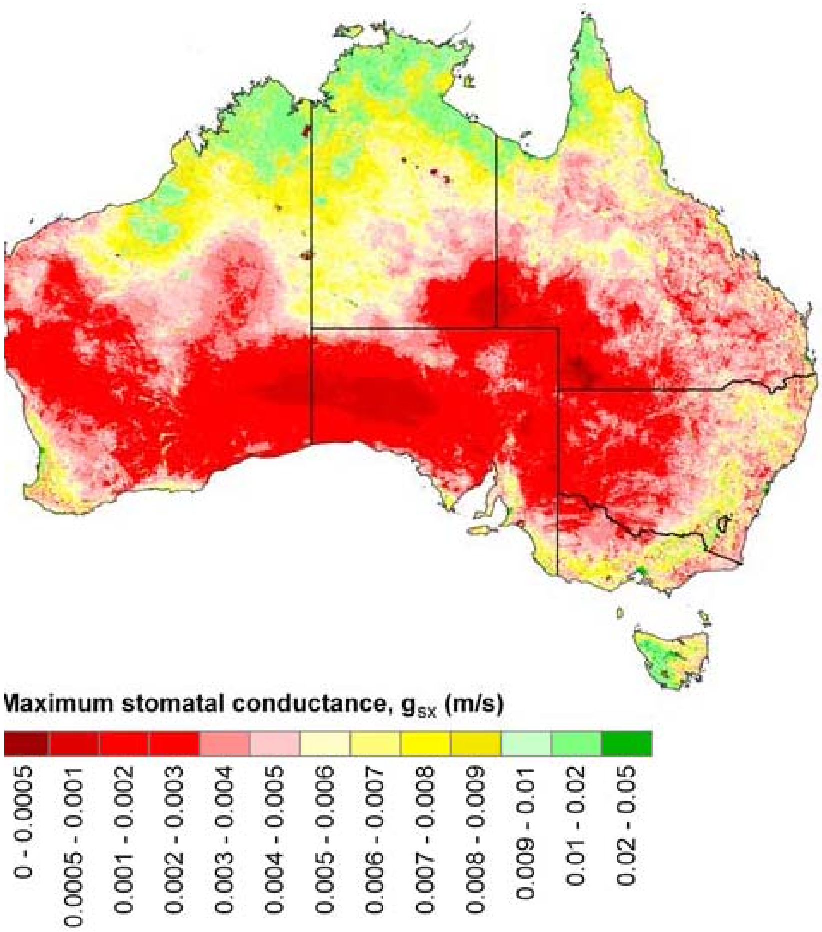
Annual runoff from SIMHYD, a rainfall – runoff model calibrated using runoff from gauged catchments

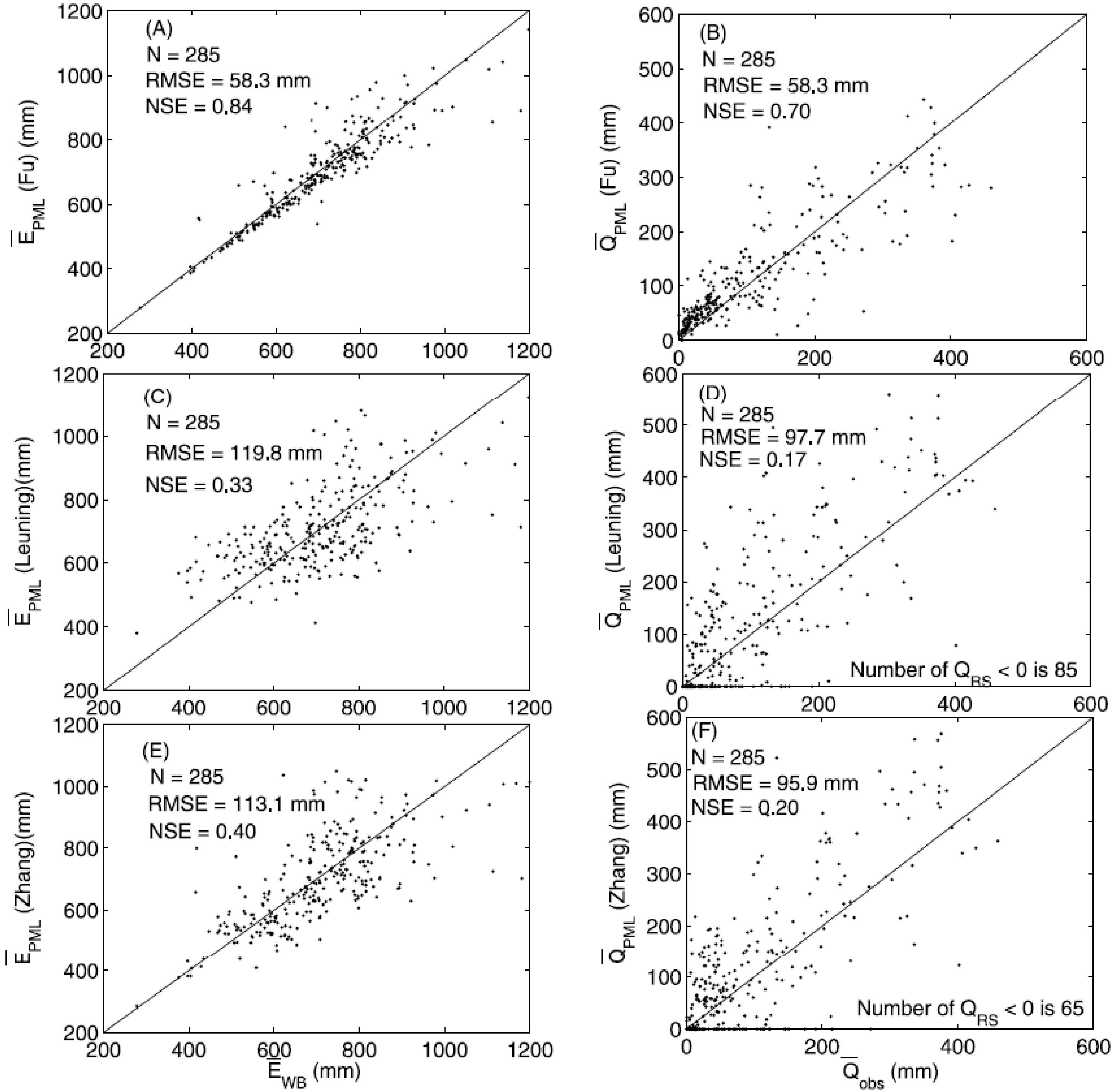
Annual modelled runoff from P - E_{RS}



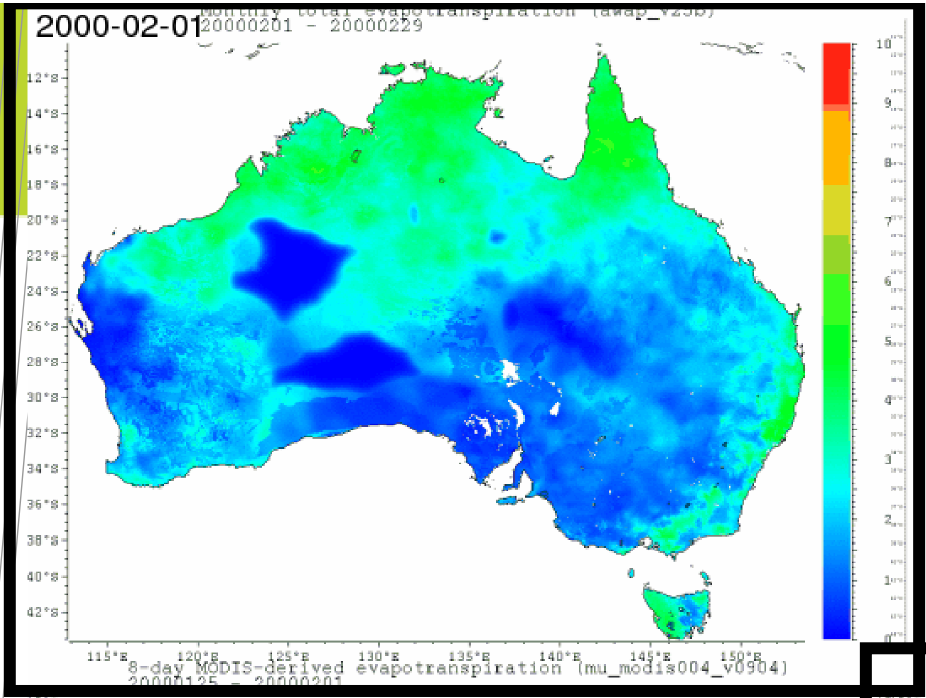
4. Zhang et al (2010): Including soil water constraint and finer scale information

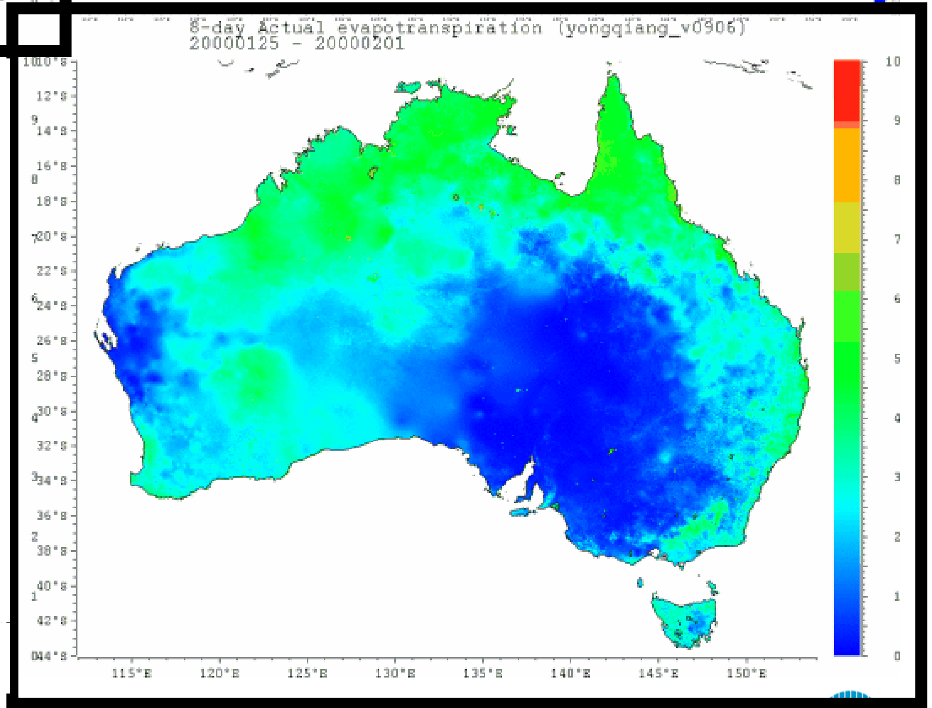
- PML model overestimates ET in some semiarid and arid catchments
- Improve parameterisation of g_{sx} and f:
  - Using water balance to constrain
  - Better knowledge of their spatial distribution
- Optimise g_{sx} for each grid cell by optimising PML against a calibrated water balance model (Budyko-style, Fu model)





(A)
N = 285
RMSE = 58.3 mm
NSE = 0.84
$\overline{E}_{PML}$ (Fu) (mm)
(B)
N = 285
RMSE = 58.3 mm
NSE = 0.70
$\overline{Q}_{PML}$ (Fu) (mm)
(C)
N = 285
RMSE = 119.8 mm
NSE = 0.33
$\overline{E}_{PML}$ (Leuning)(mm)
(D)
N = 285
RMSE = 97.7 mm
NSE = 0.17
Number of Q_{RS} < 0 is 85
$\overline{Q}_{PML}$ (Leuning) (mm)
(E)
N = 285
RMSE = 113.1 mm
NSE = 0.40
$\overline{E}_{PML}$ (Zhang)(mm)
$\overline{E}_{WB}$ (mm)
(F)
N = 285
RMSE = 95.9 mm
NSE = 0.20
Number of Q_{RS} < 0 is 65
$\overline{Q}_{PML}$ (Zhang) (mm)
$\overline{Q}_{obs}$ (mm)





From Dr Edward King, CSIRO's Water for a Healthy Country Flagship (2009)

Concluding Comments

- ET measurements can improve estimates of catchment yield in ungauged basins and water availability
  - Energy constraint
  - Largest term and spatially-averaged

- Developed an approach combining flux measurements, Penman Monteith model and remote sensing
  - Energy constraint and robust
  - Biophysical model for G_s using remote sensing
  - Reasonable performance for ET and runoff

- Further work:
  - Remotely-sensed measurements to quantify f
  - Carbon fluxes (GPP, NEE)

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Thank you

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