Regional Land Surface Evaporation using MODIS Remote Sensing

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**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 (\( \lambda E, ET \)) 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
Traditionally, the “aerodynamic” model is used:

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

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.
Penman-Monteith equation for surface evaporation:

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

\(A\) = 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


\[ G_s = c_L L_{ai} + G_{s\text{min}} \]

Mid Summer, Monthly ET

2001

2002

\[ \lambda E_{\text{surface}} = \lambda E_{\text{canopy}} + \lambda E_{\text{soil}} \] (2)

\[ \lambda E_{\text{soil}} = f \frac{\varepsilon A_{\text{soil}}}{\varepsilon + 1} \]

\[ A_{\text{soil}} = A \exp(-k A L_{ai}) \] (3)

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

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

stomatal light humidity deficit

\( f \) varies from 0 (dry) to 1 (wet)
Penman – Monteith – Leuning (PML) model for land surface evaporation

• Combine, rearrange and solve for surface conductance $G_s$

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

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

\[ E_{\text{meas}} = \text{daily ET measured at flux towers} \]

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

\[
\begin{align*}
Y &= 0.85x + 0.21 \\
N &= 1197 \\
R^2 &= 0.82
\end{align*}
\]


- 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

$y = 1.05x$, $R^2 = 0.61$

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

Annual modelled runoff from $P - E_{RS}$

Graph: Scatter plot showing the relationship between measured and modelled runoff $R_{RS}$ and $R_{SIMHYD}$.

- PML model overestimates ET in some semiarid and arid catchments
- Improve parameterisation of $g_{sv}$ and $f$:
  - Using water balance to constrain
  - Better knowledge of their spatial distribution
- Optimise $g_{sv}$ 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  

(B)  
N = 285  
RMSE = 59.3 mm  
NSE = 0.70  

(C)  
N = 285  
RMSE = 119.8 mm  
NSE = 0.33  

(D)  
N = 285  
RMSE = 97.7 mm  
NSE = 0.17  

(E)  
N = 285  
RMSE = 113.1 mm  
NSE = 0.40  

(F)  
N = 285  
RMSE = 95.9 mm  
NSE = 0.20  

Number of $Q_{RS} < 0$ is 85  

Number of $Q_{obs} < 0$ is 65
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)