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Detailed temporal modelling of carbon and water fluxes from pastures in New Zealand: Case study of an experimental dairy farm in the Waikato region

A thesis presented in partial fulfilment of the

Requirements for the degree of

Doctor of Philosophy

In

Soil Science

Massey University, Palmerston North, New Zealand

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2017

ABSTRACT

The terrestrial biosphere is an important pool of carbon, with its size governed by the opposing processes of CO_2 uptake through photosynthesis and release through respiration. It is therefore critically important to understand and reliably and accurately model these processes and predict changes in carbon exchange in response to key drivers. Pasture-based livestock production is particularly important for the New Zealand's economy but it is also a main contributor to NZ's greenhouse gas budget. My Ph.D. work used half-hourly eddy-covariance (EC) data, previously collected over 2 consecutive years from a grazed pasture in the Waikato region. The main aims of this study were to assess whether there was any bias in gap-filled eddy covariance measurements, to assess whether incomplete capture of cow respiration during grazing events could have led to biased observations, and to quantify the resulting difference on the net carbon budget of the farm. I approached the work by developing a new process-based model, CenW_HH, running at a half-hourly time step, to predict the energy and CO_2 exchange of grazed pastures. I implemented and evaluated different photosynthesis models and upscaling schemes and modelled the energy budget separately for the canopy, litter layer, and the soil. CenW_HH was then parameterised and validated with the available EC measurements. The paddocks surrounding the EC tower were rotationally grazed, which caused heterogeneities in respiratory pulses when grazing events were in the flux footprint and subsequent vegetation cover on the different paddocks. To deal with that heterogeneity, the model was run independently for each individual paddock and a footprint model was used to estimate resultant net fluxes at the EC tower. Modelled fluxes agreed well with half-hourly observed fluxes as seen by model efficiencies of 0.81 for net ecosystem productivity, 0.75 for gross primary production, 0.70 for ecosystem respiration, 0.87 for latent heat flux, 0.76 for sensible heat flux, 0.94 for net radiation, and 0.92 for soil temperature. CenW_HH was then used to test for any biases in gap-filled data for times without the presence of grazing animals, but identified no consistent systematic deviations. Eddy covariance measurements often failed to capture carbon losses due to cattle respiration, especially when measurements had to rely on gap-filled data. By replacing gap-filled NEP fluxes affected by grazing cattle by estimates generated by CenW_HH, the farm carbon budget was reduced by 31% and 113% (and turning from a positive into a slight negative balance) in 2008 and 2009, respectively.

ACKNOWLEDGEMENTS

Firstly, I would like to express my sincere gratitude to my advisor Doctor. Miko Kirschbaum for the continuous support during my Ph.D., for his patience, motivation and immense knowledge on many different topics and for the talks that we had. His feedbacks and guidance helped me at all steps of this research project and on the writing of the thesis and I could not imagine having done it without such a great supervisor.

My sincere thanks also go to Professor. Mike Hedley for his guidance and useful insights and suggestions. I am grateful that despite is busy schedule he was always able to meet me at short notice and for going through and making comments and suggestions that improved drafts of my thesis.

I also thank Associate Professor Marta Camps Arbestain for accepting to be one of my co-supervisor and for organising the “journal club” sessions in which most of the presentations and discussions where far away of my research project but widen my view on soil science in general.

I am thankful to my other co-supervisors, Professor Louis Schipper and Doctor Michael Dodd for being part of my Ph.D. advisory panel and for providing the data that were needed to accomplish this project.

I am grateful to the NZAGRC (New Zealand Agricultural Greenhouse Research Centre) for providing me the funding to complete my Ph.D. and to Landcare Research for accepting me to use their facilities; this was an awesome place to work with kind and brilliant persons.

A big thanks also goes to all friends and persons that encouraged me pursue my studies towards the completion of this thesis, without your encouragements this would have not been possible.

And last but not least, I would like to thanks my family and family in law for they support and understanding during all stages of my Ph.D. and specially my wife Justine which followed me abroad for 4 years, I am very grateful for your support during hard times, for your patience and for all the good time we had.

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LIST OF ABBREVIATIONS

NH_4^+	Ammonium
NO_3^-	Nitrate
°C	Degree Celsius
A	Instantaneous single leaf photosynthesis
A/PPFD	Photosynthesis light response curves
A_c	Daily canopy net CO_2 assimilation rate
ADP	Adenosine Di-Phosphate
AGC	Automated gain control
ATP	Adenosine Tri-Phosphate
BL	Big-leaf upscaling scheme
C	Carbon
CH_4	Methane
CO_2	Carbon dioxide
EC	Eddy-covariance
ER	Ecosystem respiration
ET	Evapotranspiration
FvCB	Farquhar et al. (1980) photosynthesis model
G	Soil heat flux
GCM	Global climate models
GHG	Greenhouse gas
GPP	Gross primary production
H	Sensible heat flux
H_2O	Water
IPCC	Intergovernmental Panel for Climate Change
IRGA	Infrared gas analyser
LAI	Leaf area index
LE	Latent energy flux
LSM	Land surface model
LUC	Land use change
LUE	Light use efficiency
MBE	Mean bias error
N	Nitrogen
N_2O	Nitrous oxide
$NADP^+$	Nicotinamide Adenine Dinucleotide Phosphate
NADPH	Nicotinamide Adenine Dinucleotide Phosphate Hydrogen
NECB	Net ecosystem carbon balance
NEE	Net ecosystem exchange
NEP	Net ecosystem production
NOAA	National oceanic and atmospheric organisation
NPP	Net primary production
NRHC	Non-rectangular hyperbolic curve
NSE	Nash-Sutcliff criteria or model efficiency
NZ	New Zealand
OM	Organic matter
P	Phosphorus
P	Energy flux associated with photosynthesis
PFT	Plant functional type
PKE	Palm kernel expeller
PPFD	Photosynthetic photon flux density

ppm	Part per million
PR	Photorespiration
PS	Photosynthesis
r^2	Coefficient of determination
R_a	Autotrophic respiration
R_g	Growth respiration
R_h	Heterotrophic respiration
RH	Atmospheric relative humidity
RHC	Rectangular hyperbolic curve
R_m	Maintenance respiration
RMSE	Root mean squared error
R_n	Net radiation
RuBP	Ribulose 1.5-bisphosphate
SG 90	Shuttleworth and Gurney (1990) model
SOC	Soil organic carbon
SOM	Soil organic matter
SS	Sun/shade canopy integration scheme
SVA	Soil-vegetation-atmosphere
SVAT	Soil-vegetation-atmosphere-transfer model
SW 85	Shuttleworth and Wallace (1985) modelling scheme
Tac 86	Taconet et al. (1986) model
TPU	Triose phosphate utilisation
Tsoil	Soil temperature
VPD	Vapour pressure deficit
WUE	Water use efficiency
ΔS	Heat storage of the vegetation canopy