Phenology, Climate, Fire, and Remote Sensing

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Ozflux Course, Creswick

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Health warning: this talk contains differential equations
• Started work with WLEF Tower data (Nov 1996)
• Installed micromet and soil moisture/temp data
• Bear (Bigfoot?) knocks down solar panel (Feb 1998)
• Power out (March 1998)
• Squirrels cut TDR cables (Pete’s Hot Sauce doesn’t work)
• Helped set up Willow Creek site (Park Falls, WI, May 1998)
• Large gap in data at WLEF, post-doc on holiday (Jul-Aug 1998)
• Dennis Baldocchi asks me a question at Ag & For Met Conf. (Nov 1998)
• Bill Clinton impeached (Dec 1998)
• Skukuza (Kruger National Park, SA) LAI measurements (Jan 2003)
• Tumbarumba biometric measurements (2009)
• Helped install Sturt Plains NDVI sensor (Nov 2009)

Knowledge is power --- Francis Bacon

The only true wisdom is knowing you know nothing --- Socrates
• Introduction
• An exercise in fire and remote sensing
• Vegetation structure, climate, and phenology
• Fire and phenology
• Decoupling tree and grass components
• Mitchell grasslands and ecohydrological modeling
• An exercise in GPP: finding the flux tower game
• Summary comments
Phenology is the study of periodic plant and animal life cycle events and how these are influenced by seasonal and interannual variations in climate. (Wikipedia)

Examples:

Kyoto, Japan cherry tree record of flowering times from the 9th Century

My grandma’s record of spring ‘leaf out’ dates (1936-83)
Most phenological studies have been descriptive and have focused on N. America or Europe

Few studies have taken an LAI or quantitative viewpoint

Few studies have been done on tropical, water-limited systems
Two main approaches to phenology

- Diagnostic studies
  - mostly at the global scale using remote sensing
  - curve fitting of phenological responses
  - statistical models to identify the main drivers of vegetation response

- Process-oriented models
  - mostly at the local scale using data from highly instrumented sites
  - ecohydrological modelling coupling soil water content dynamics and plant growth

- A combination of empiricism and quantitative ecosystem modelling in most LSM-GCM
Exercise 1: MODIS subsetting tool

MODIS Global Subsets: Data Subsetting and Visualization

Select Center of Area of Interest
Lat/Lon OR Field Site
then Continue

http://daac.ornl.gov/MODIS/
Kinglake, Victoria (Ozflux site subject to fire 2009)
MODIS phenology

Graph showing MODIS Coll 5 FPAR for different locations over a period from 2000 to 2010.
Conceptual Model

Vegetation Index (e.g. NDVI, LAI)

- Undisturbed canopy
- Recovery time
- Defoliation level

Time
Phenology data comes from MODIS Collection 5.0 FPAR/LAI composite data (2000-2009).

Vegetation structure

Vegetation structure data comes from the Australian Major Vegetation Group map. Eight classes studied for mixed tree-grass systems.

Fire

Fire record from WA DOLA dataset derived from AVHRR fire scars. Each polygon is painstakingly verified manually (1997-2008).

Climate data

Precipitation data comes from QLD gov’t SILO-grid project (2000-2008).

All data is aggregated to ~ 5 x 5 km
Randomized sampling in northern Australia

5000 sites in one of the 8 “mixed” vegetation classes, with mean monthly $T_{\text{max}} > 28 \, ^{\circ}\text{C}$, excluding winter dominated rainfall climates.

~125,000 km$^2$
Woodiness gradient in eucalypt woodlands
Acacia vs. Eucalypt woodlands

MAP (600-900 mm/yr)
‘Production’ along a climate gradient

Mean Annual Precipitation (mm) vs. Annual Integrated FPAR

- All Classes
- EW
Putting it together

Vegetation Class

Annual Integrated FPAR

600-900 mm

900-1200 mm

~ 2-3
Inclusion of fire: ensemble averages

- May fires
- July fires
- October fires
- No fires
For the entire time series (2000-2009)

Fires refers to sites with > 1 in 3 year fire return
Decomposition into Tree and Grass Components

Donahue, McVicar, and Roderick GCB (2008)

\[ F_{p1}(t) = \min[F_{t}(t-3), \ldots, F_{t}(t), \ldots, F_{t}(t+3)], \quad (1) \]

\[ F_{p2}(t) = \frac{1}{9} [F_{p1}(t-4) + \cdots + F_{p1}(t) + \cdots + F_{p1}(t+4)]. \quad (2) \]

\[ F_{r1}(t) = F_{t}(t) - F_{p2}(t). \quad (3) \]

Where an \( F_{r1} \) value was negative, its absolute value was subtracted from \( F_{p2} \) to yield the final estimate of \( F_{p} \):

\[ F_{p}(t) = F_{p2}(t) - |F_{r1}(t)|, \quad \text{where} \quad F_{r1}(t) < 0 \quad (4a) \]

\[ F_{p}(t) = F_{p2}(t), \quad \text{where} \quad F_{r1}(t) \geq 0. \quad (4b) \]

Lastly, \( F_{r} \) was calculated as

\[ F_{r}(t) = F_{t}(t) - F_{p}(t). \quad (5) \]
Trends in persistent FPAR in northern Australia: fire vs. no fire

MAP (600-900 mm)  MAP (900-1200 mm)
Can we scale changes in absorbed FPAR with changes in carbon exchange at flux towers?
Ecohydrological Modeling
Specific problems in water-controlled ecosystems include:

- spatial and temporal variability of the main driver (precipitation)
- difficulties to model soil water balance
- feedback between plant growth and soil water content

50% of terrestrial ecosystems NPP primarily controlled by water
**Semi-arid perennial grasslands**

- Perennial grasslands dominated by tussock forming species (*Astrebla, Dichanthium*...). Mostly Mitchell grass dominated grasslands.

- Mainly found on cracking clay soils

- Support an extensive pastoral industry
  - one sheep/ha, one cow/10ha
  - $500 million AUD (2001) from sheep and cattle products
A diagnostic study
Nonlinear ecohydrological modelling

Choler & al. *Biogeosciences* (in revision)

\[
\begin{align*}
\text{d}W/\text{d}t &= P - \beta_1 (1-V) \left( \frac{W}{W_{\text{cap}}} \right) E - \beta_2 V W \\
&\quad \text{Soil Evap.} \quad \text{Plant Transp.} \\
\text{d}V/\text{d}t &= \beta_3 \left( \frac{W}{W_{\text{cap}}} \right) V \left( 1 - \frac{V}{V_{\text{max}}} \right) - \beta_4 V \\
&\quad \text{Logistic Growth} \quad \text{Leaf Mortality}
\end{align*}
\]

with \( W \in [0, W_{\text{cap}}] \)

with \( V \in [0, V_{\text{max}}] \)
Residual analysis shows

- performance of nonlinear models is more consistent across the precipitation gradient
- no significant effect of the uncertainty in rainfalls (distance to raingauge)
- no significant effect of distance to watering point (proxy of grazing pressure) (not shown)

Choler & al. *Biogeosciences* (in revision)
Currently three instrumented sites in Mitchell grass country

Newcastle Waters (NT)

Toorak - Julia Creek (Qld)

Rosebank – Longreach (Qld)

Collaboration with Queensland Department of Primary Industries

Discovery Project 0772281
CI. Jason Beringer
On ground measurements

\[ NDVI = \frac{NIR - RED}{NIR + RED} \]
MODIS phenology at Rosebank
How is it doing?

[Graph showing Raw NDVI data for Toorak and Rosebank with dates from 28/12/2009 to 27/01/2010]
Exercise 2: GPP, finding the flux tower?

A  21.0 tons C ha\(^{-1}\) yr\(^{-1}\)

B  10.0 tons C ha\(^{-1}\) yr\(^{-1}\)

C  18.6 tons C ha\(^{-1}\) yr\(^{-1}\)

D  21.4 tons C ha\(^{-1}\) yr\(^{-1}\)
Summary

- Remote sensing products are “tailored-made” for phenology studies.
- Additional datasets such as gridded climatology and fire scars allow us to study the drivers of phenology.
- Remote sensing allows to potentially scale up from our flux tower measure to the larger scales.
- Simple ecohydrology models are elegant alternatives to more complex model, and when fairly compared, may do a better job.