Analysis of climate and vegetation variability on erosion using a coupled dynamic vegetation and landform evolution model

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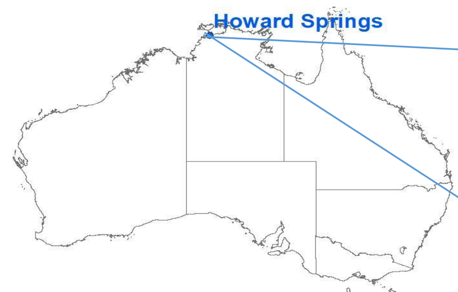
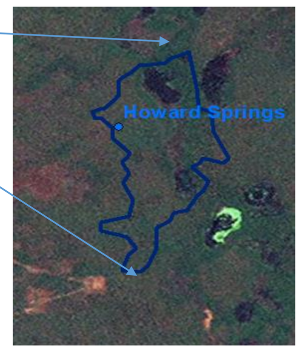
1. Introduction

- Erosion can decrease agriculture productivity, affect infrastructure and ecosystems (e.g. Great Barrier Reef), and generate siltation of watercourses
- Vegetation controls erosion
- Under climate change (CC) conditions alterations in temperature, carbon dioxide concentration (CO_2) and precipitation are expected
- It is not yet well understood how CC could affect vegetation and how could it be reflected on the erosion rates





Study Area: Howard Springs (NT, Australia), 1700 mm/year of rainfall, tropical climate (temperatures between 20 – 33 °C), open woodland savannah governed by Eucalyptus

2. Objectives

- Analyse the response of erosion to CC under variations in temperature (T), carbon dioxide concentration (CO_2) and rainfall (P)
- Develop a model (COPLAS) that couples erosion and deposition processes, with dynamic vegetation and carbon pools modules and that respond to variations with CC

3. Model conceptualization: COPLAS

- COPLAS is a new model which couples erosion, hydrology, dynamic vegetation processes and carbon pools modules (see **Figure 1**)
- The vegetation module includes a coupled photosynthesis-stomatal conductance representation to estimate Net Primary Production (NPP)
- NPP is allocated into five carbon pools: leaves, wood, roots, litter and soil carbon

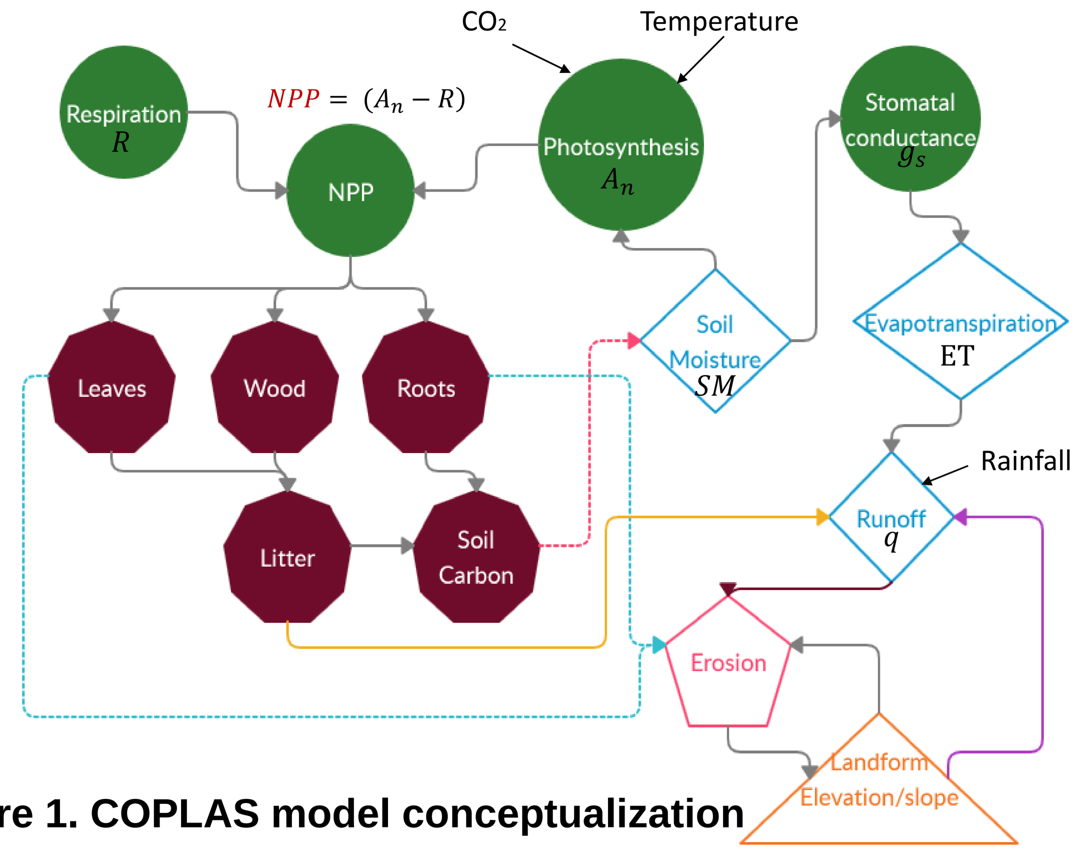


Figure 1. COPLAS model conceptualization

- Variation in elevation depends on the tectonic uplift (U), fluvial (qs) and diffusive erosion (qd), (ƀ) porosity and (ρ) density of the sediment (Willgoose et al., 1991)

$$\frac{\partial Z}{\partial t} = U - \left(\frac{\nabla q_s}{\rho(1-ƀ)} + \nabla q_d\right)$$

- COPLAS uses a hydrology bucket in each cell to estimate soil moisture (SM)

$$\frac{dSM}{dt} = \text{Infiltration}(SM) - \text{ET}(SM) - \text{Percolation}(SM)$$

- Runoff is generated by infiltration (when infiltration capacity is exceeded) and saturation excess (when the soil becomes saturated) and it is routed using a Kinematic Wave approximation (Manning equation for a wide rectangular channel)

$$q = \frac{1}{n} H^{\frac{5}{3}} s^{\frac{1}{2}}$$

3.1 Vegetation Module

- Photosynthesis (An) and Stomatal conductance (gs) are computed in the vegetation module. They respond to changes in T, P and CO_2

$$A_n = \left(1 - \frac{\Gamma^*}{CO_2}\right) * \min[W_c(T, CO_2), W_j(T, CO_2)]$$

CO_2 released by photorespiration

Maximum rate of carboxylation

Electron transport rate

$$g_s = b + f_{sv}(SM)\frac{m(A_n)}{\left(C_s\left(1 + \frac{VPD}{D_{s0}}\right)\right)}$$

Minimum stomatal conductance

Dependency of gs to vapour pressure deficit, carbon assimilation rate and CO_2

Response of gs to soil water content (indirectly depends on rainfall)

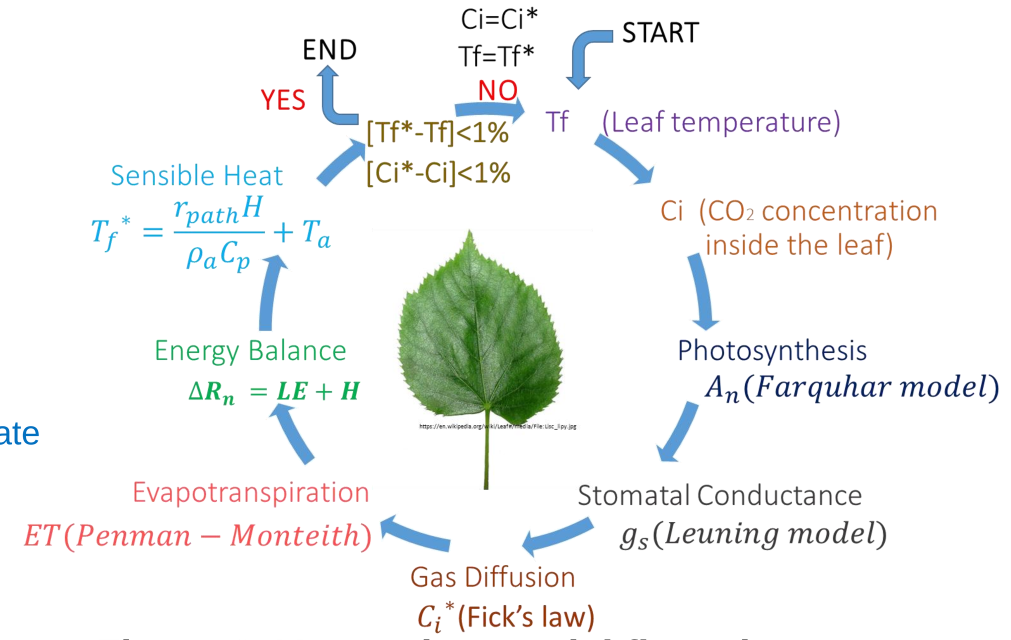


Figure 2. Vegetation model flow chart

- COPLAS uses an iterative method similar to Kowalczyk et al., 2006 to determine the values of the leaf temperature Tf and CO_2 concentration inside the leaf Ci (**Figure 2**)

4. Simulation Scenarios

- Simulations for 100 years, daily time step
- Scenarios under variations in temperature, CO_2 and rainfall (see **Table 1**) were run
- The model was calibrated using data from the OZFLUX Howard Springs station (soil moisture, evapotranspiration and CO2 flux) from 2002 until 2016
- The erosion model was calibrated with caesium-137 measurements found in Loughran & Elliott, 1996.

Table 1. Model scenarios

Variable	Condition	Value	Units	Period
CO_2 concentration	Normal	369	ppm	2002–2016
	Increased	940	ppm	by 2090
Rainfall	Decreased -26%	1331	mm/year	by 2090
	Normal	1802	mm/year	1986–2005
	Increased +23%	2215	mm/year	by 2090
Temperature	Normal	27.0	◦C	2002–2005
	Increased (3.7 C)	30.6	◦C	by 2090

7. Selected References

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5. Results

- Vegetation plays an important role in protecting the soil from erosion: an increase of rainfall generates more erosion; however, the effect is substantially reduced when vegetation is present (Figure 3. A)
- More rainfall triggers more vegetation growth, but this additional protective effect of the new vegetation is not enough to protect the soil from increased amount of rainfall (Figure 3. A)
- An increase in temperature generates more erosion due the reduction in vegetation (Figure 3. B)
- Seasonality is important: less vegetation after the dry season due the higher temperatures and soils less protected when the rainfall events of the wet season occurs bring more erosion (Figure 3. B)
- The combination of temperature and rainfall effects generate 34% and 84% more erosion when comparing with single effects respectively (Figure 3. C)
- Higher temperatures and rainfall generate more erosion while greater CO_2 and lower rainfall reduce it (Figure 3. C)
- CO_2 fertilization effect: increased rate of photosynthesis in plants, and more protection against erosion (Figure 3. D)
- CO_2 effect could controls erosion and overpass the effect of temperature and rainfall (Figure 3. D) (assuming no nutrient limitation)

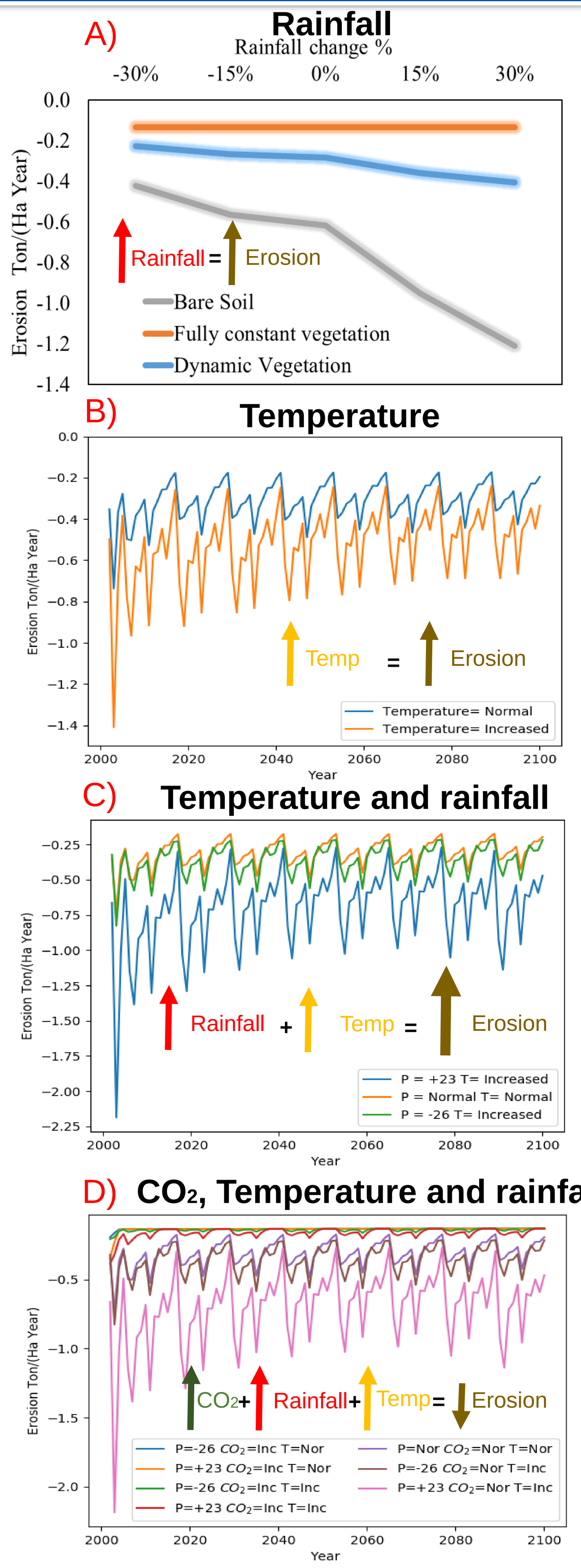

Figure 3. impacts of CC on erosion

6. Conclusions

- Impact of CC on erosion could be different depending on the location, climate scenarios and response of the species
- It was shown the importance of studying the effects together and not separately: different erosion patterns when the effects are combined
- For Howard Springs:
  - Increased temperature and rainfall produce higher erosion
  - Higher CO_2 concentration and less rainfall generates lower erosion
  - If there is no nutrient limitation, CO2 fertilization could control de negative effects of rainfall and temperature on erosion