Interpreting atmospheric CO_2 observations with the novel coupled model WRF-SPA

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A new coupled model WRF-SPA

Research justification
The land surface is a key driver of climate at regional and global scales (Cox *et al.,* 2000; Piekle *et al.,* 1997); however its full importance and related feedbacks remain relatively poorly explored.

Approach
This study uses a coupled SVAT (Soil-Plant-Atmosphere, SPA) model (Williams *et al.,* 2001) and a mesoscale weather model (Weather Research and Forecasting, WRF) (www.mmm.ucar.edu/wrf/users) to investigate land atmosphere interactions. WRF provides meteorological drivers to the surface (e.g. temperature, CO_2, short wave radiation) and SPA provides surface fluxes of heat, water and CO_2 to WRF.

Atmospheric CO_2 pools have been added to WRF-SPA to allow for tracing of CO_2 exchanged with the land surface. This determines the origin of CO_2 (i.e. from forest, crop land, anthropogenic emissions, grasslands) at any given location within the domain. This allows for comparison with observation to investigate the contributing land surfaces. Atmospheric CO_2 concentrations used for initial and boundary conditions within WRF-SPA is provided by Carbon Tracker Europe.

Weather Research and Forecasting model
WRF is a state of the art non-hydrostatic numerical weather prediction model. The model is capable of operating at very high horizontal spatial resolutions (< 1km) which allows for explicit modelling of small scale features which may be important to regional scale exchange.

Soil Plant Atmosphere
SPA is a process based multi-canopy layer biosphere model, capable of representing both natural and managed systems such as intensively managed crops. The model uses a novel representation of stomatal conductance, which is ecologically based, that maximises carbon assimilation per unit foliar nitrogen within the limits of hydrological tolerances. SPA also models momentum and radiative transfer through its canopy and water movement through the soil – plant continuum.

Observations
WRF-SPA operates in a model domain at 12 km resolution over Scotland and Northern England (Figure 1). Observations used for validation are atmospheric CO_2 concentrations (from both tall tower and airborne measurements), Net Ecosystem Exchange (NEE) and air temperature (surface measurements).

Observations used in validation are from two CarboEurope surface flux sites and a Tall Tower in Scotland. Aircraft profiles of CO_2 were collected above Griffin forest.

Locations shown on map:
1) Griffin forest, a Sitka Spruce plantation (56.6 N, 3.8 W, 340 m a.s.l.)

2) East Saltoun, barley crop land (55.9 N, 2.85 W, 73 m a.s.l.)

3) Tall tower Angus (TTA) (222m above surface 56.5N, 2.98E)

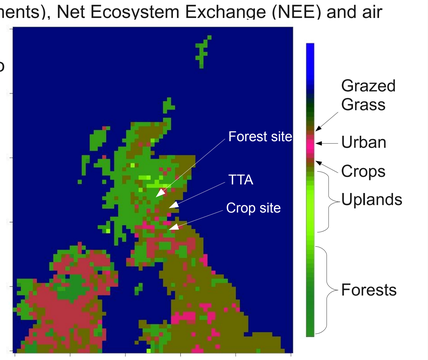

Figure 1. Land cover map of WRF-SPA model domain. Also shown are the locations of the observation sites.

REFERENCES

Cox PM, Betts RA, Jones CD, Spall SA, Totterdell IJ (2000) Acceleration of global warming due to carbon - cycle feedbacks in a coupled climate model. *Nature*, **408**, 184 – 187.
Piekle RA, Lee TJ, Copeland JH, Eastman JL, Ziegler CL, Finley CA (1997) Use of USGS - provided data to improve weather and climate simulations. *Ecological Applications,* **7**, 3 - 21.
Williams M, Law BE, Anthoni PM, Unsworth MH (2001) Use of a simulation model and ecosystem flux data to examine carbon - water interactions in ponderosa pine. *Tree Physiology*, **21**, 287 - 298.

How well does WRF-SPA scale?

Surface Validation
The model is able to explain a significant amount of variation in surface temperature and NEE for both crops and forest covers (Figure 2 + 3; Table 1). In 2004 we can see that WRF-SPA correctly predicts harvest while in 2005 harvest occurs earlier than observed (Figure 2).

Table 1. Spearman's correlation analysis between WRF-SPA and observations. R^2 mean bias (model - obs) and root mean square error (RMSE) values provided.

	Evergreen Forest			Crop land		
	R^2	Bias	RMSE	R^2	Bias	RMSE
NEE (μmolC m^{-2} s^{-1})	0.51	1.91	7.39	0.34	-6.8	7.22
Air temperature (ºC)	0.88	-0.77	1.9	0.75	-0.70	2.6

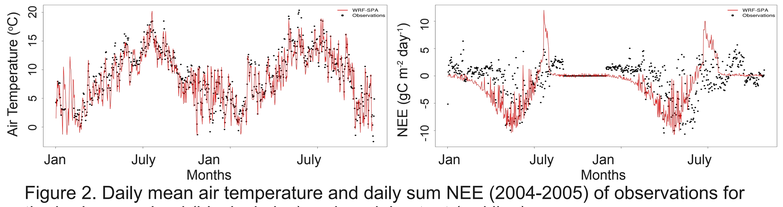

Figure 2. Daily mean air temperature and daily sum NEE (2004-2005) of observations for the barley crop land (black circles) and model output (red line).

NEE in 2005 is overestimated by WRF-SPA for the Griffin forest (Figure 3), this is likely due to forest thinning which occurred in the previous year. While in 2006 the overall seasonal behaviour is well captured.

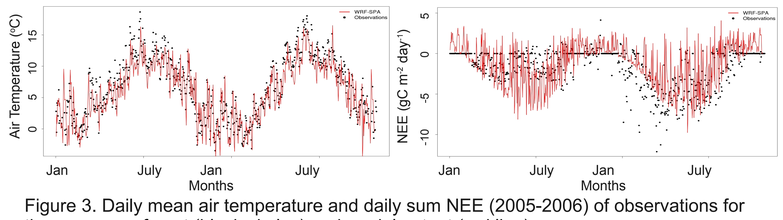

Figure 3. Daily mean air temperature and daily sum NEE (2005-2006) of observations for the evergreen forest (black circles) and model output (red line).

Atmospheric Profiles
The University of Edinburgh's research aircraft was used to collect atmospheric profiles of CO_2 concentrations (Figure 4, insert) over Griffin.

WRF-SPA is capable of realistically reproducing atmospheric profiles of CO_2 concentrations (Figure 4). This indicates that WRF-SPA is both transporting CO_2 correctly but also that exchange of CO_2 at the regional scale is consistent with real world exchanges represented by the observations.

'Forcing CO_2' (Figure 4) represents CO_2 which originated from outside the model domain with no exchange with the surface.

Total CO_2 pool contains all CO_2 with surface exchange allowed.

The difference between total and forcing profiles is the impact of the vegetation as modelled by WRF-SPA.

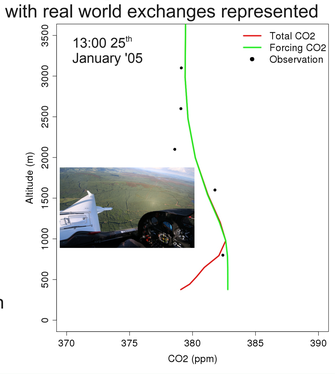

Figure 4. Profiles of atmospheric CO_2 concentration from model and observations. Insert is view from aircraft over Griffin

Crop Harvest observable at regional scales

Case study: Tall Tower Angus 2006
WRF-SPA captures the seasonal behaviour of observed CO_2 at tall tower Angus (R^2 = 0.59) (Figure 5). The novel arrangement of CO_2 tracers in WRF-SPA allow us to determine the origin of features found in the observations. Indicated below is a signal that occurs each year in the observations.

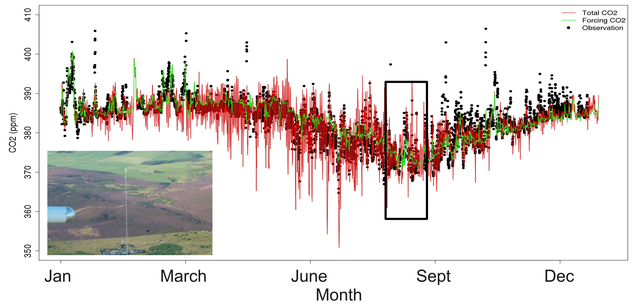

Figure 5. Tall Tower Angus (TTA) atmospheric CO_2 observations with modelled total CO_2 and forcing only CO_2 at 222 m above surface. Highlighted (in box) is an annually occurring CO_2 profile. Insert is TTA showing its relative location.

Interpreting tower CO_2 observations
The CO_2 peak in observations (box, Figure 5), is due to respired CO_2 from crop land cover. When crop released CO_2 is removed from total CO_2 the signal is removed (Figure 6). Crops release a pulse post harvest time due to decomposing surface litter.

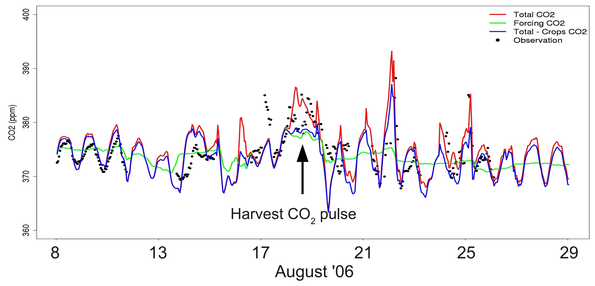

Figure 6. Observed atmospheric CO_2 concentrations compared to modelled CO_2 and modelled with crop land component subtracted.

CONCLUSIONS

1) WRF-SPA is capable of re-creating CO_2 observations across multiple scales.

2) We are able to disentangle CO_2 from different land surfaces.

3) Crop harvest generates an observable response in regional scale CO_2 observations.