Carbon Fluxes in a Managed Landscape: Drivers of Temporal and Spatial Variability Across the Cascade Mountains

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1. Introduction

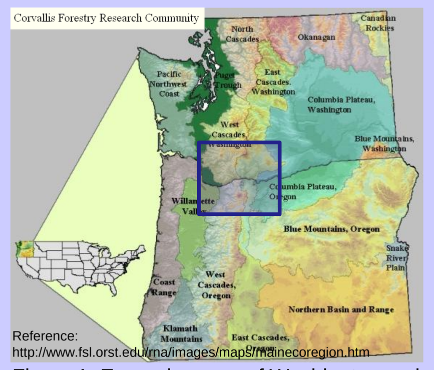
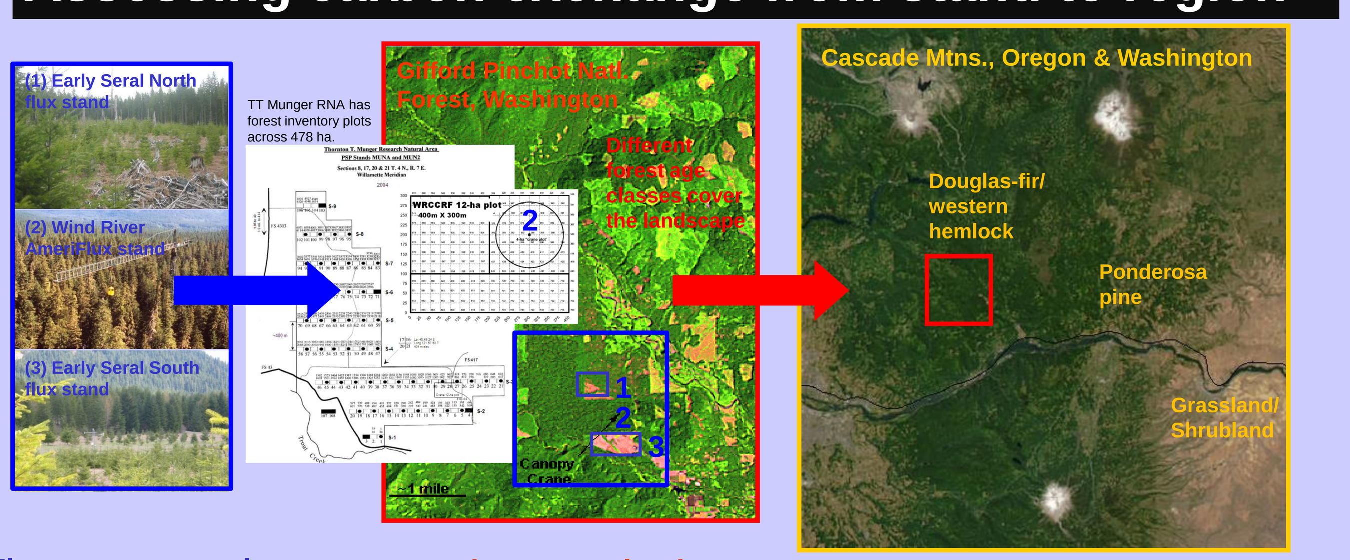


Figure 1. Ecoregion map of Washington and Oregon with the area of interest in purple. A sharp precipitation gradient across the Cascade Mountains causes distinct ecosystems over a short distance (Douglas-fir in the West Cascades, Ponderosa pines in the East Cascades and shrub/grassland in the Columbia Plateau).

This study examines the climatic drivers of spatial and temporal variability in carbon exchange across the Cascade Mountains.

- First, we identify the regional climatic drivers.
- Next, we link stand-to-landscape variability in carbon exchange to climate using a flux tower chronosequence, forest inventory, and tower-pixel MODIS data.
- Finally, we use MODIS and the Advanced Canopy-Atmosphere-Soil Algorithm (ACASA) model to see if climatic drivers can be linked to regional vegetation anomalies.

Assessing carbon exchange from stand to region



Flux towers: stand-level scale (< 1km) → Forest inventory: landscape scale (5 X 5 km) → MODIS and WRF-ACASA: regional scale (200 km X 200 km)

2. Methods

This project compares CO2 exchange from multiple sources and scales: (1) flux tower chronosequence, (2) MODIS, (3) forest inventory, and (4) WRF-ACASA to access the role of Pacific climate indices (5)

	(1) Flux tower chronosequence	(2) MODIS
Scales of Interest	**stand-level** (Wind River AmeriFlux old-growth forest and 2 early seral stands)	**tower-pixel and regional**
Primary Data	CO_2, H_2O, energy fluxes (30-min data), net ecosystem production (NEP)	Enhanced Vegetation Index (EVI) (16-day, 1-km resolution)
Footprint Area	1-2 km max fetch at old-growth, < 0.4 km at early seral stands (regenerated clear-cuts)	tower-pixel (2.25 km X 2.25 km), regional (201 km X 201 km)
Data Period	old-growth: 1998-2008, Early Seral North: 2006, Early Seral South: 2007	tower-pixel: 2000-2007 regional: 2000-2004
Tower Instrumentation/ MODIS Details	LiCor7000 & Gill HS R3 (old-growth), Li7500 & CSAT3 (early seral stands)	MOD13A2, Collection 5.0, Terra satellite, source: ORNL-DAAC
Dominant Land Cover Types	evergreen needleleaf (100%): old growth is Douglas-fir/western hemlock, early seral stands are Douglas-fir	evergreen needleleaf (40%), grassland (13%), open shrubland (13%), mixed forest (10%)

	(3) Forest inventory plots	(4) WRF-ACASA model
Scales of Interest	**landscape scale**	**landscape-to-regional scale**
Primary Data	aboveground live net primary production (ANPP)	CO_2, H_2O, energy fluxes
Footprint Area	inventory plot = 17.84 m radius. 40 plots in the 478-ha old-growth forest (TT Munger RNA)	pixel (4 km X 4 km), nested domain (290 km X 290 km)
Data Period	1947-2008, sampled every ~7 years	June 2004
Variables measured/ modeled	growth + recruitment + mortality (ΔANPP = mean change in live tree carbon stores plus tree mortality and recruitment during measurement interval)	CO2, H2O, energy fluxes, NPP, NEP
Dominant Land Cover Types	evergreen needleleaf (100%)	evergreen needleleaf (50%), cropland (15%), grassland & shrubland (20%)

(5) Climate Indices	Definition	Periodicity	Data source	Reference
PDO	Pacific Decadal Oscillation	10 to 30 years (interdecadal variance)	ftp://ftp.atmos.washington.edu/mantua/pnw_impacts/INDICES/PDO.latest	Mantua et al. 1997
PNA	Pacific/North American circulation	approx. 10 years (decadal variance)	http://www.cpc.ncep.noaa.gov/data/teledoc/pna	Wallace and Gutzler 1981
MEI	Multivariate ENSO Index	2 to 7 years (interannual variance)	http://www.cdc.noaa.gov/people/klaus.wolter/MEI/table	Wolter and Timlin 1998

3. Climatic Drivers: Pacific Teleconnections

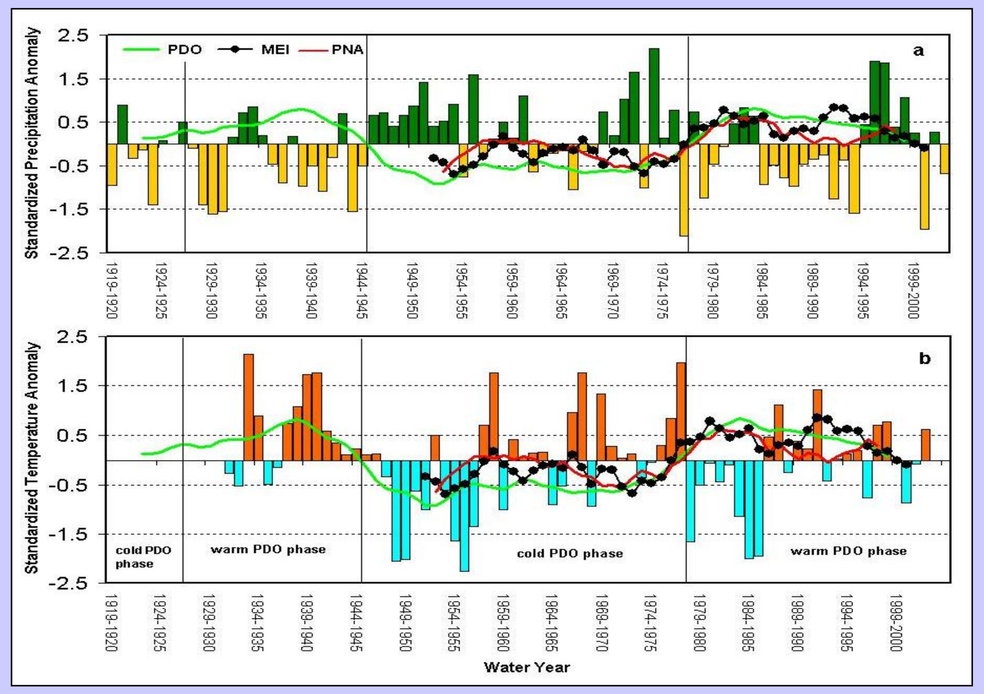


Fig. 2 **Negative** (cool) phases of the PDO, PNA and MEI are associated with historically **cooler** (blue) and **wetter** (green) weather. **Positive** (warm) phases of the PDO, PNA and MEI bring **warmer** (orange) and **drier** (yellow) weather to the region.

CCI = PDO + PNA + MEI

Based on the composite climate index (CCI), 1999, 2000 & 2008 are defined as cool phase years, 2003 & 2005 are warm phase years, and 2001, 2002, 2004, 2006 & 2007 are neutral-phase years. The **CCI highlights additive effects** (when all 3 are in-phase).

4. Stand Level Results: Flux Tower, Forest Inventory and MODIS tower pixel

"Changes in ecosystem carbon exchange, forest inventory measurements, and tower-pixel EVI are correlated with Pacific teleconnection events."

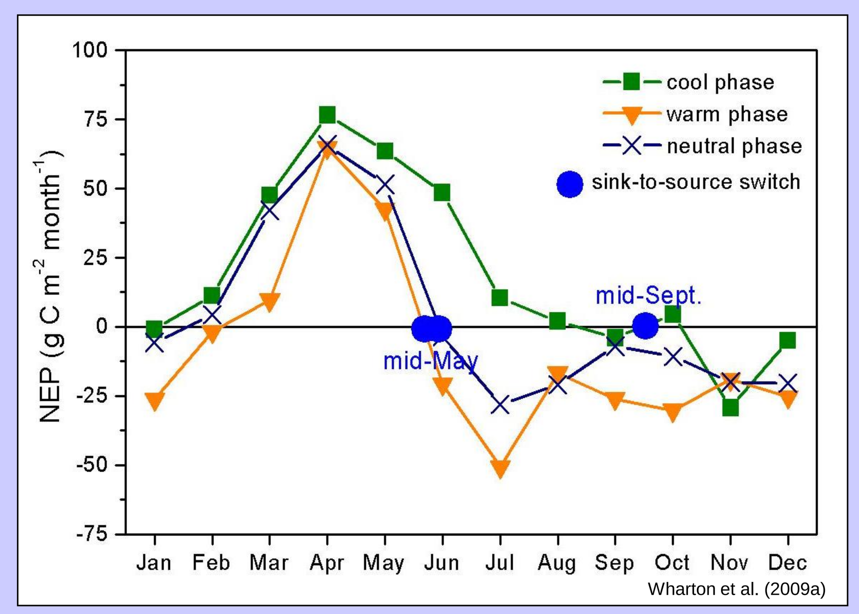


Fig. 3 Old-growth monthly NEP (1999-2007) categorized by climate phase. The transition from net carbon sink to source varies according to phase strength (mid-Sep. for cool, mid-May for warm, and early June for neutral phase years).

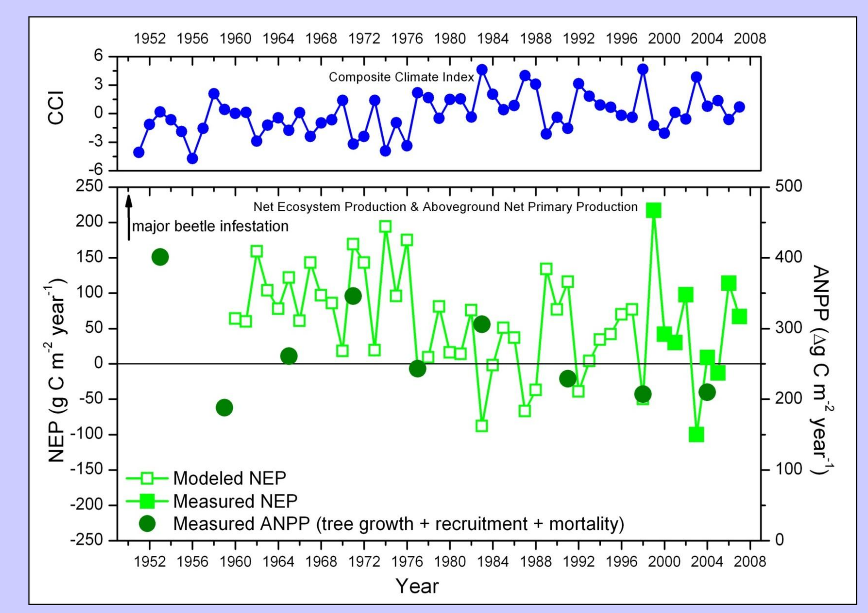


Fig. 5 Time series of annual CCI, NEP and forest inventory ANPP at the old-growth forest from 1952-2008. Note that NEP is modeled from 1959-1997. Here, ANPP includes mortality as well as growth and recruitment.

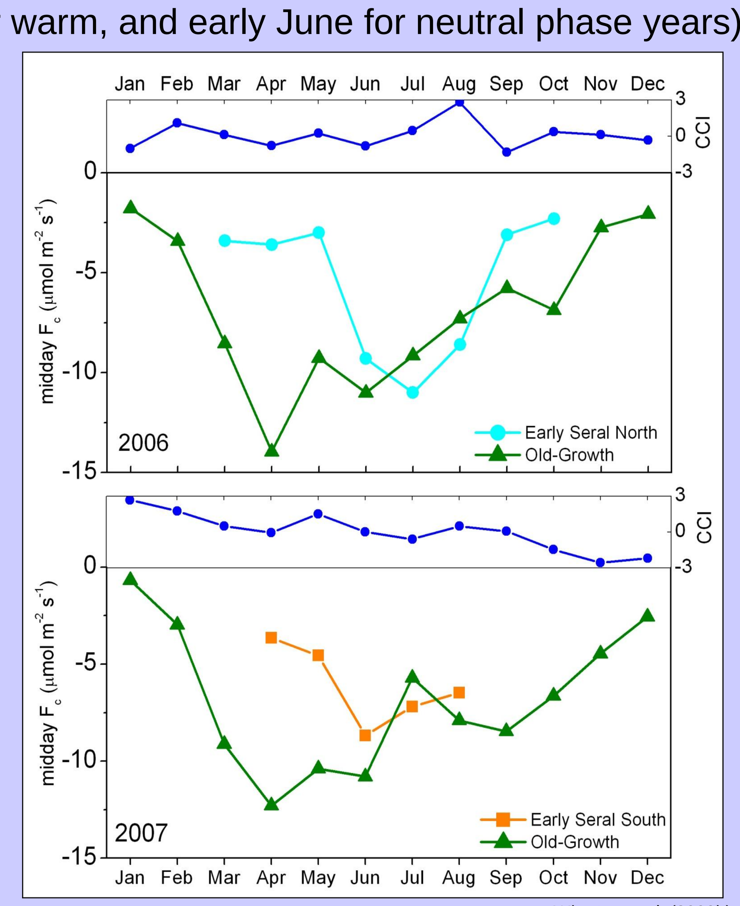


Fig. 4 Monthly mean midday CO2 flux for the old-growth forest, 10-year old Early Seral North stand, and 9-12 year old Early Seral South stand and monthly mean CCI. NEP peaks in April at the old-growth forest while in the younger stands, maximum NEP occurs in the summer months. Interannual CO2 variability is also present at the old-growth stand and is linked to variability in the climate indices.

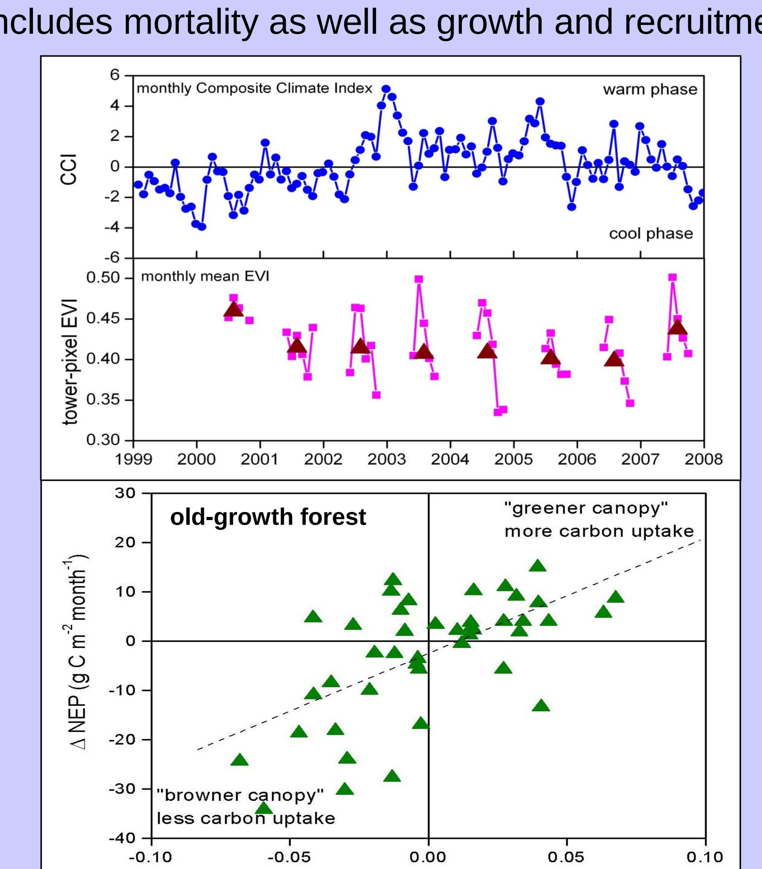
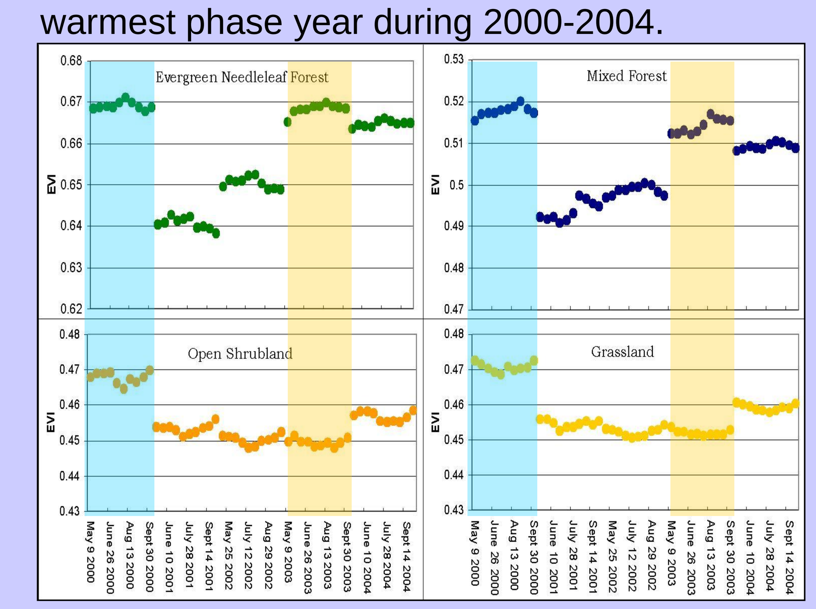


Fig. 6 (top) MODIS Enhanced Vegetation Index is correlated with variability in CCI. Higher EVI is associated with cooler climate phases during 2000-2007. (lower) Higher flux tower NEP is also associated with greater than normal EVI. Here, NEP and EVI are shown as deviations from the mean to remove any seasonal correlations.

5. Regional Scale Results: MODIS and WRF-ACASA

"Regional changes in MODIS EVI are correlated with Pacific teleconnections for grasslands and shrublands but forest regions are harder to assess due to varying age classes. Higher resolution runs are needed."

Fig. 7 EVI averages for 4 land cover types during the growing season. The blue box indicates the coolest phase year, the tan box the warmest phase year during 2000-2004.



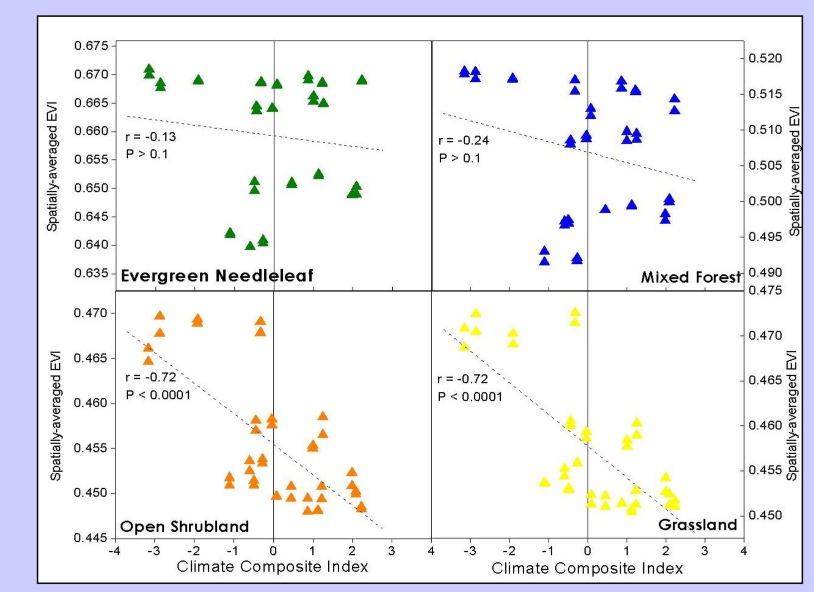


Fig. 8 EVI is correlated with climate phase strength in shrubland and grassland areas east of the Cascades but a general relationship is not apparent in forested regions (western Cascades). These forests are comprised of various age classes over short distances which likely masks any relationship between CCI and vegetation changes.

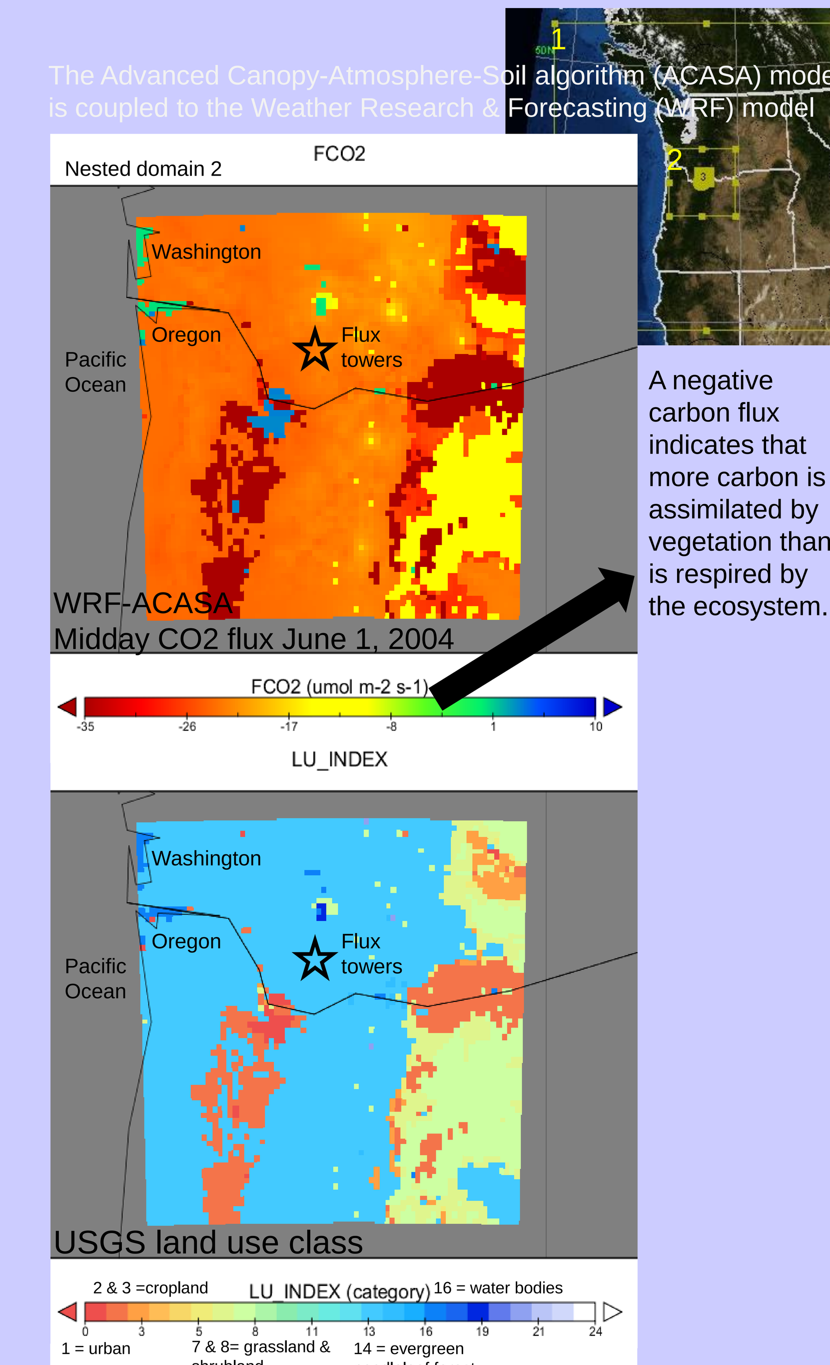


Fig. 9 WRF-ACASA CO2 fluxes at 4 X 4 km resolution captures spatial CO2 variability across ecoregions (grassland versus forest) and within the greater forested area but misses landscape-scale variability due to coarse land cover and LAI data. For comparison, midday CO2 flux was -21 μmol m^{-2} s^{-1} at the old-growth AmeriFlux tower.

6. Conclusions

- The Composite Climate Index accurately represented regional climate variability and explained much of the interannual variability in old-growth carbon exchange as seen in the flux tower, forest inventory measurements, and tower-pixel EVI.
- The flux tower chronosequence showed that age-effects significantly change the timing and magnitude of peak carbon uptake. Forest age must be taken into account in landscape and regional carbon studies across the heavily-logged Cascade Mtns, where clear-cuts are often less than 1 km^2 in area.
- On a regional-scale, MODIS EVI anomalies were not linked to teleconnection events for forested areas, likely due to age-effects, while variability in non-forested areas was linked to the climate indices. The MOD13A2 (1-km) is too coarse to capture age-related forest variability in this region.
- Next steps are to use MOD13Q1 (250-m) and run WRF-ACASA at 1-km with MODIS LAI and high resolution land use data to tease out small-scale variability in the highly fragmented forests.

References and Acknowledgments: Wharton et al. 2009a. Strong links between teleconnections and ecosystem exchange found at a Pacific Northwest old-growth forest from flux tower and MODIS EVI data. Global Change Biol. 15:2187-2205. **Wharton et al. 2009b.** Turbulence considerations for comparing ecosystem exchange over old-growth and clear-cut stands for limited fetch and complex canopy flow conditions. Agr. For. Meteor. 149:1477-1490. **Mantua, N.J., et al. 1997.** A Pacific interdecadal climate oscillation with impacts on salmon production. Bull. Amer. Meteor. Soc. 78:1069-1079. **Wallace, J.M. and Gutzler, D.S. 1981**. Teleconnections in the geopotential height field during the Northern Hemispheric winter. Mon. Weather Rev. 109:784-812. **Wolter, K. and Timlin, M.S. 1998**. Measuring the strength of ENSO events: How does 1997/1998 rank? Weather 53: 315-324. **Oak Ridge National Laboratory Distributed Active Archive Center (ORNL-DAAC) 2008.** MODIS subsetted land products, Collection 5. Available on-line [http://www.daac.ornl.gov/MODIS/] from ORNL-DAAC, Oak Ridge, Tennessee, USA. Accessed July 1, 2008.
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