Satellite based analysis of recent changes in ET and the terrestrial water balance over Canada and Alaska: Implications for vegetation productivity and the northern carbon cycle

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1. Abstract

We applied a satellite remote sensing based evapotranspiration (ET) algorithm using AVHRR/GPCP and GPCP, regionally corrected NCEP/NCAR reanalysis surface meteorology and NASA/GSDEV solar radiation inputs to assess spatial patterns and temporal trends in ET over Canada and Alaska from 1981 to 2005. We then showed associated scenario changes in the regional water balance (P-ET), where precipitation (P) was defined from GPCP and GPCP, monthly precipitation. We also examined linkage between the regional water balance and vegetation net primary production (NPP) derived using a satellite remote sensing based production efficiency model. The satellite-based ET results agree well (RMSE=8.8 mm month\textsuperscript{-1}, R=0.999) with in situ measurements from northern grizzly forested basins and tundra flat basins. The ET results showed positive trends over 35\% of the region, mainly in tundra regions, and corresponded with regional warming, vegetation growing and increasing NPP, 64\% of the forested northern and grizzly region show negative ET trend, while 66\% of the tundra regions display positive ET trends. Approximately 45-50\% of the study region exhibited a below-average water balance during the summer (June to August) from 2002 to 2003 indicated by the GPCP and GPCP, regions of which 20-30\% showed anomalies that were more than one standard deviation below 23-year average conditions. These recent large annual water deficits in boreal regions agree well with regional drought records and explain recent anomalous droughts in well-documented NPP and stand-level measures. Our results also show that the regional water balance is changing in complex ways in response to global warming, with shifts to freshwater to regional vegetation productivity, composition and distributions.

2. ET Algorithm and Study Domain

The study area encompasses the North American portion of the boreal forest and Alaska: (1) The MODIS\textsuperscript{30} Land Cover Map classifies vegetation into 8 classes, including open shrubland (OM), savanna (SA), grassland (GR), chapparal (CP), woodland savanna (WS), evergreen needleleaf forest (ENF), evergreen needleleaf forest (SNF), and mixed (MF) forest. The ET model was calibrated and validated using measurements from six eddy covariance flux basins representing dominant vegetation classes, including the Barrow one (BRW1) and two (BRW2), Anaktuvuk (AKQ), Northern Old Black Spruce (NOBS), Lethbridge (L317), and Old Alex (OA3) sites.

There is considerable spatial variability in water balance trends for the domain. The P-ET results show similar spatial patterns with respect to GPCP and GPCP, and P trends occur in boreal forests and grasslands indicated by GPCP and GPCP, and ET results show positive trends for 57\% of the domain. Approximately 62\% of areas with moderate to strong negative ET trends occur in forested boreal and temperate grassland areas.

3. Model vs. Tower based ET

The domain shows small positive P trends and a slightly increasing ET trend left. Annual P-ET results show significant positive trends indicated by both GPCP and GPCP, and P-ET trends. Mean annual snow depths (Q) from regional basin gauge show positive trends for the 10 out of 13 major subclasses 98.5\% of total basin area (right). Positive trends in ET, P, and Q imply that the regional water cycle is ameliorating over the 23-year period.

4. Annual Water Balance Changes

5. Spatial Patterns of Water Balance Changes

6. Recent Summer Drought Effects on Vegetation

7. Conclusions

- Satellite-derived LE/ET results agree well with tower observed fluxes within regionally dominant biomes.
- Regional patterns of wetting and drying are spatially complex with some boreal forest and grassland regions showing moderate to strong drying trends over the 23-year period, with recent (post-2000) summer droughts coinciding with anomalous decreases in satellite-detected annual vegetation productivity and stand-level measurements.
- Results indicate strong water/energy/carbon cycle coupling, a changing water balance is impacting regional NPP and C sequestration by altering plant-available moisture supply, while vegetation influences water and energy cycles through strong canopy controls to LE/ET.

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Selected References