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Measuring and Modeling Carbon Stock Change Estimates for US Forests and Uncertainties from Apparent Inter-annual Variability

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Abstract

Our approach is based on a collection of models that convert or augment the USDA Forest Inventory and Analysis program survey data to estimate all forest carbon component stocks, including live and standing dead tree aboveground and belowground biomass, forest floor (litter), down deadwood, and soil organic carbon, for each inventory plot. The data, which include estimates of forest area, can then be used in calculations for total stocks or change. We describe our approach, which has been used to estimate forest carbon stocks and stock change for the annual US greenhouse gas inventory compiled by the USEPA for reporting to the United Nations Framework Convention on Climate Change. Results in the national stock change trends can exhibit relatively large annual changes in these change trends, which are called inter-annual variability. We examine the inter-annual variability and underlying data for the possible causes, and discuss implications.

Abbreviations: FIA, Forest Inventory and Analysis; FIADB, Forest Inventory and Analysis Database; IAV, inter-annual variability; NGHGI, national greenhouse gas inventory.

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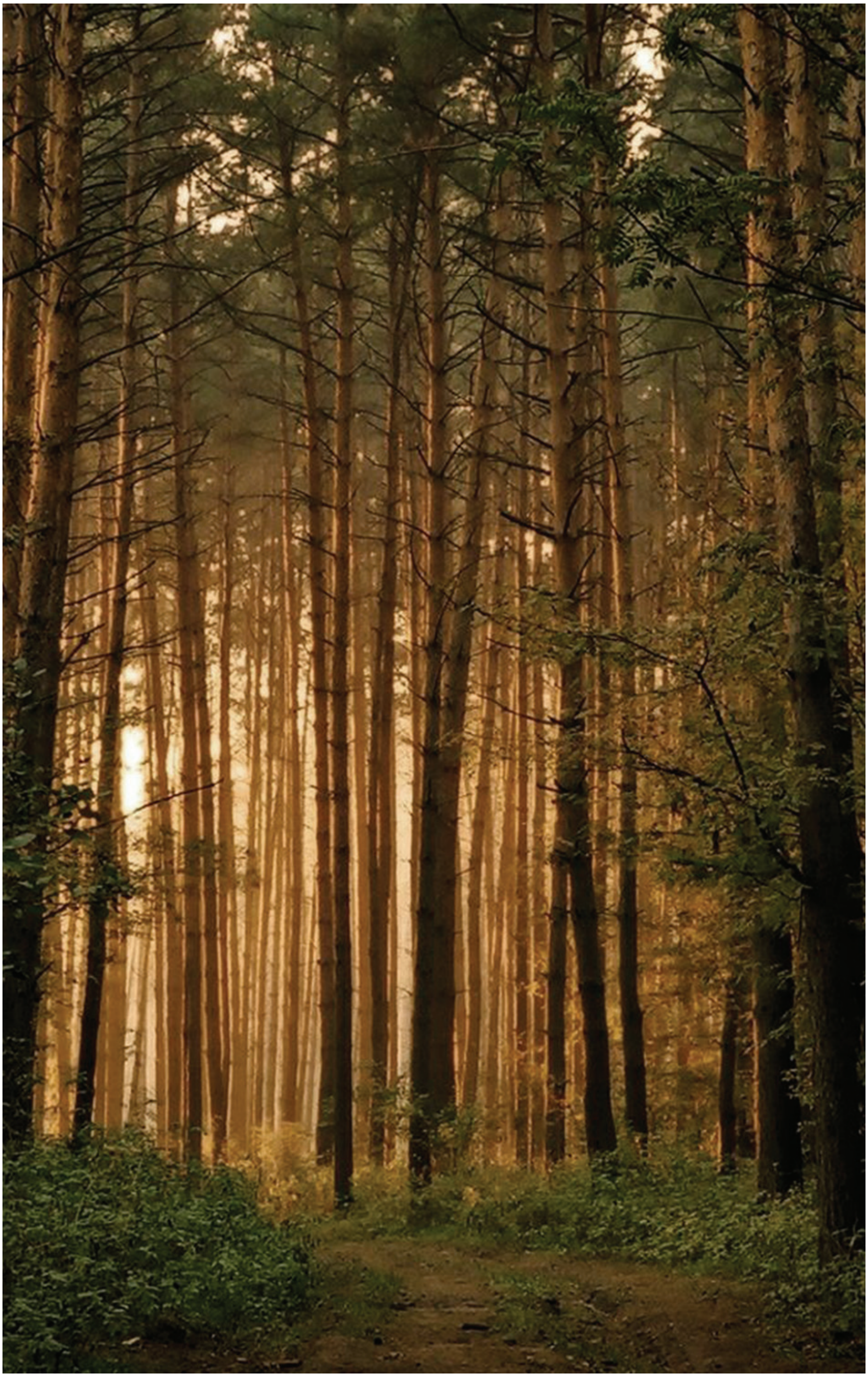

Sequestration by US forests could offset about 10% of emissions from fossil fuel annually.

The forest carbon estimates for the United States that are part of the nation's participation in the United Nations Framework Convention on Climate Change (UNFCCC) are succinctly summarized as net annual stock change as in Fig. 1. These estimates are included in the annual US national greenhouse gas inventory (NGHGI) compiled by USEPA (2011). Net uptake, or sequestration, by US forests averaged over 160 Tg C/yr over 20 yr, an amount that could offset on average about 10% of emissions from fossil fuel annually over the period. The approach that produced these estimates (Woodbury et al., 2007; Smith et al., 2010; Heath et al., 2011a) has also been used for region-, state-, and county-level estimates (e.g., Mickler et al., 2004; McKinley et al., 2011; also see Heath, 2012), and the models that produce the plot-level estimates have been adopted by the USDA Forest Service, Forest Inventory and Analysis (FIA) program and included in their national dataset called the FIADB (Woudenberg et al., 2010). A number of models have used the estimates for calibration, model validation, as input data, or for a mixture of these activities (e.g., Hayes et al., 2012; Heath et al., 2010; Liu et al., 2008; Potter et al., 2008).

As indicated in Fig. 1, the results are characterized by sometimes relatively large annual changes in this rate and trends such as the extreme around the year 2000 or the apparently steady multi-year changes before and after that time. Both the year-to-year variability and the trends can affect perception of the forest carbon estimates. For example, the variability can indicate rapidly changing conditions of US forest lands or alternatively be a reflection of the precision in the estimates. Similarly, any trend could suggest some sustained influence on forest land across the United States.

The year-to-year variability in NGHGI emissions or removals estimates is also known as inter-annual variability (IAV) in UNFCCC documentation, and its significance is related to how the change estimates are developed (Eggleston et al., 2006, in particular see volume 1, chapter 3, Uncertainties). Estimates developed around multi-year averages will use IAV to describe precision in the underlying data. However, where empirically based estimates are developed as specific to data of a given year, the expectation is that the IAVs serve to indicate change in activity data as influenced by specific, temporally linked human activity or biophysical processes (Richards, 2011; Eggleston et al., 2006). That is, the value and underlying cause of IAV is unique to each year's estimate. This single-year specificity of emission/removals estimates is considered good

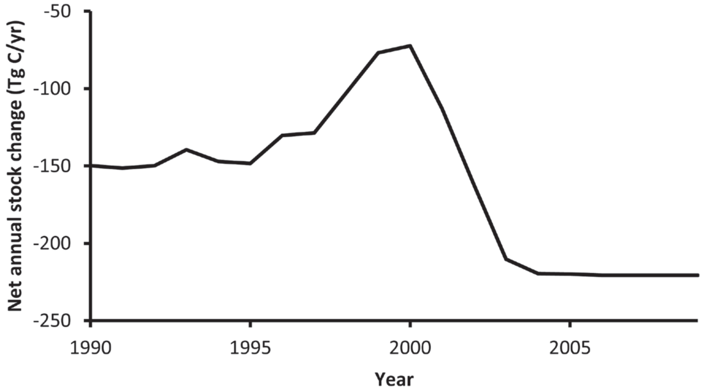

Fig. 1. Net annual carbon stock change (USEPA, 2011).

practice by some, especially for some reporting such as to the Kyoto Protocol. However, others recognize the limitations and costs of estimating change in forests for a single year.

Our approach is a collection of models that convert or augment the FIA forest survey data to estimate all forest carbon component stocks, including live and standing dead tree aboveground and belowground biomass, forest floor (litter), down deadwood, and soil organic carbon for each inventory plot. The plot data can then be used in calculations for total stocks or change. We first present a summary of the FIA data and briefly describe the models to calculate carbon and the approach used to derive the stock change estimates. We then use the results from an application that produced a series of the estimates reported in USEPA (2011) to examine and diagnose apparent year-to-year variability in the estimate, and discuss implications. Although carbon in harvested wood products is a notable contribution to sequestration related to the forest sector, we focus only on carbon in forests in this study. More information on the modeling approach for carbon in harvested wood products can be found in Skog (2008).

The stock change estimates of carbon on US forest lands are primarily based on annualized forest inventory surveys. Briefly, forest inventory surveys are each defined in terms of tons of carbon at the mean date of field data collection—carbon stocks at a specific point in time. The difference between two such successive stocks provides change over an interval, which is expressed as tons of carbon per year. This inventory-to-carbon stock and stock change methodology (Penman et al., 2003) is based on whole-state estimates or substate disaggregation where necessary for consistency (USEPA, 2011; Smith et al., 2010). Additionally, the same methodology can be applied to less aggregate classifications, including individual counties (McKinley et al., 2011) or major ownerships such as National Forest lands by region (Heath et al., 2011b). Continuing development of the stock change method is applied for forest carbon estimates of the United States. The NGHGI continues with future modifications focused on increased availability of annual inventories and adaptation to separate land use and land use change classifications. This study represents a step in the process of refining and improving estimates.

We explicitly identify influences on the IAV of Fig. 1 through sensitivity analysis of the stock change method to the inventory-with-carbon data. The purpose is to examine the link between the year of the stock change estimate and the corresponding influence on IAV (Richards, 2011; Eggleston et al., 2006). The analysis is specific to the forest carbon estimates of USEPA 2011 because the IAV issue was highlighted in the review of that year's NGHGI (United Nations Framework Convention on Climate Change, 2012), which noted that "the signals of sudden change may not be registered in the estimates at the proper point in time." The signals of large sudden change will tend to be averaged over time using this approach, but the time period will bracket the time the change occurred. We identify influences on IAV, explain the mechanism, and discuss future approaches to address this issue.

Methods

Interpretation or understanding of an assessment of forest carbon change such as shown in Fig. 1 depends on an understanding the data and methods applied to produce the estimate. In this approach, the underlying data are the FIA forest inventories and the carbon conversion factors/models. These data are then applied using a stock change method (Penman et al., 2003). Commonly, "stock change" within the IPCC/UNFCCC publications is used to refer to relatively short time steps such as the difference between two successive stocks so that stock change reflects a rate unique to a particular year or an average over a short period of years. In this scenario, IAV would be the change between two successive short-interval stock changes, and the IAV would reflect activity or emissions events within that short interval.

Our inventory-based forest carbon stock change differs from this "standard" interpretation of stock change due to two important characteristics of the forest inventories. Specifically, the periodic intervals allocate an estimate of change to multi-year intervals, yet change-in-change, or IAV, is allocated to infrequent instances. Second, the total for the United States is a composite of many separate state-based stock change estimates at independent (i.e., out of phase) intervals. The following methods and analysis explain this distinction and provide a basis for interpreting the IAV of the estimates examined in this study.

Forest Inventory Data

Forest inventories are the basis for the carbon estimates, and these inventory data are obtained by continuous systematic sampling of US forest lands. The data are compiled and made available by the FIA program of the US Forest Service (USDA Forest Service, 2013a), and these publicly available surveys are the starting point for the carbon estimates. Some elements of the structure of FIA forest inventories are relevant to understanding the methods and analysis presented below. Forest land is defined for purposes of the inventory according to cover and land use (Smith et al., 2009). This includes information on a large system of permanent plots over forest land (currently representing about 270 million hectares) in the conterminous United States (i.e., 48 states), but generally excludes wooded agricultural or urban land. Inventory methods are established according to a national standard so that data are consistent, but surveys are organized, and conducted within individual states. Surveys from the last 10 to 15 yr are known as "annual inventory" where a portion of the survey data is collected each year on a continuous cycle, whereas older surveys are known as "periodic inventory" with all statewide data collected in 1 or 2 yr followed by a 5 to 15 yr interval before a state was resurveyed. The publically available data, the FIADB (Woudenberg et al., 2010), are organized as separate surveys by state and by years of data collection. Statewide inventory totals are summarized within the FIADB on completion of each survey cycle, that is, one pass through a state's inventory plots. Each cycle is identified by a nominal inventory year, which is usually the year the cycle is completed, but the data of the survey can also be summarized according to an average date for collection of all field data (i.e., average of all site visits; Smith et al., 2013). Thus, the basic inventory data are summarized as statewide totals, each associated with an average date associated with field data collection. Over time, series of these inventory year paired values accumulate at intervals of five or more years apart, depending on the state. Cycle length can vary, and whole-state forest inventories that focus on standing stocks rather than change within the FIADB are typically based on data collected over the number of years associated with each cycle, where possible (Roesch et al., 2002; Woudenberg et al., 2010). Our results focus on change, so the data we use for our calculations are based on different years than those data used for stock estimates.

Carbon Conversion Factors

Carbon factors and models were developed to provide plot-level estimates of carbon density (e.g., tons of carbon per hectare) for the following distinct, non-overlapping forest ecosystem carbon pools: live trees, understory vegetation, standing dead trees, down deadwood, forest floor, and soil organic carbon.

Expansion of plot estimates to whole-state total carbon stocks for each survey is according to the population estimates defined for the FIADB (also identified as evaluations within the FIADB; USDA Forest Service, 2013b; also see Woudenberg et al., 2010; Bechtold and Patterson, 2005). For additional details on the carbon conversion factors, their application to inventories, expansion to population totals, or approaches to determining stock change, see the Carbon Calculation Tool model (Smith et al., 2010), USEPA (2011), FIADB documentation (Woudenberg et al., 2010), early soil carbon methods (Heath et al., 2002), or Smith et al. (2013).

Forest Carbon Stock Change Calculations

The approach to developing the national estimates of carbon change in forest ecosystems using survey data following Smith et al. (2010) can be described by the steps outlined in Fig. 2. Resolution of forest inventory data as plot-level carbon stocks that are then expanded to statewide or population totals at specified times (i.e., the paired values of tons and year) are discussed above and represented in the upper dashed box of Fig. 2. The next step involves summarizing the series of carbon stocks for a state by interpolating or extrapolating to the annualized stock and stock change for the reporting interval starting with 1990 (Smith et al., 2010). This step is represented in the lower dashed box of Fig. 2.

To define the within-state series of stocks consistent over time, which is essential for stock change calculations, forest land of some states is subdivided so that the entire series of stock and stock change calculations were recast as sub-state populations (Smith et al., 2010). For example, in the past, National For-

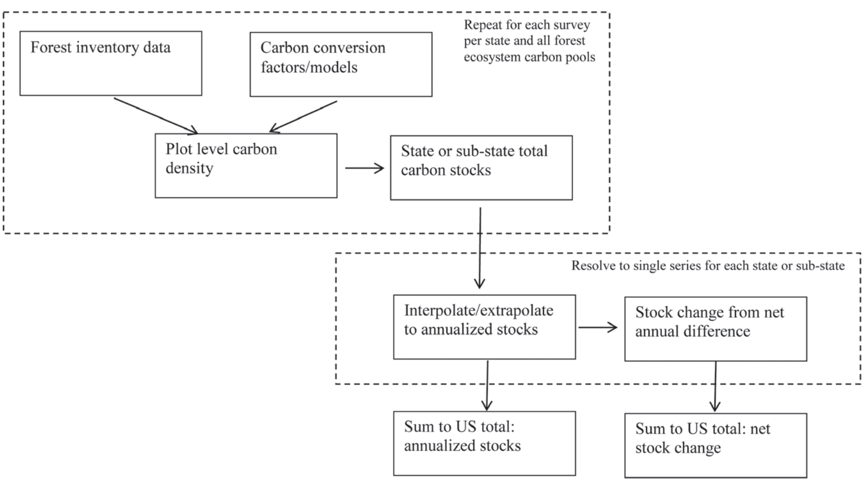

Fig. 2. Outline of basic approach to develop forest carbon stock change estimates based on forest inventory data.

est lands on western states were measured separately and at different intervals than most other forest land in those states; therefore "National Forest" versus "not National Forest" is the basis for many of the sub-state divisions. Once all surveys are defined as carbon stocks within consistent series, linear interpolation or extrapolation defines a series of annualized stocks for each state or sub-state series, for example, stocks defined for each year, 1990 through 2009 (USEPA, 2011). By convention, carbon stock for a given year is considered the stock at the beginning of the year so that when summed with stock change during that year the total is the next year's (beginning) stock value. Net annual stock change is the difference between annualized stocks, with negative values indicating sequestration, by convention. From this, the calculation for 2002, for example, is defined as the annualized stock for 2002 minus the annualized stock for 2003.

The annualized estimates for sub-state classification are then summed to the whole-state estimates, and all annualized net change estimates are summed to the US total (Fig. 1, and the lowest two boxes of Fig. 2). See USEPA (2011) for an exact list of inventory sources, sub-state classifications, and surveys used per state associated with the estimates presented here. In general, the years used to identify the surveys are the nominal years, which are associated with the state's data within the forest inventories.

Estimated uncertainties are calculated using Monte Carlo simulation, following IPCC guidance (Penman et al., 2003; Eggleston et al., 2006). Probability density functions are defined for each of the plot-level conversion factors. The sampling error is also determined for each carbon pool and included in the uncertainty estimates using Monte Carlo sampling. More details of the methods to estimate uncertainty are given in Heath and Smith (2000), Smith and Heath (2001), and Smith et al. (2013). The 95% confidence interval for the 2009 stock change estimates for all forest ecosystem pools is –261.6 to –180.5 Tg C/yr, which would often be written in the format –220.6 ± 18% Tg C/yr.

Examining Inter-annual Variability

The set of forest inventory data available and applicable to USEPA (2011) was classified as 88 separate state and sub-state series (i.e., as in the lower dashed box of Fig. 2). The number of surveys available for each series varied and was generally 2 to 4, with a total of 236 surveys (i.e., as in the last box within the upper dashed box of Fig. 2). To illustrate the basic process described above, we use the forest inventories for Tennessee, which was one of the 88 series and had 4 surveys available, all from the FIADB (Fig. 3). The four surveys resolved to carbon stocks at year 1989.0, 1998.2, 2002.7, and 2005.8 (which are the nominal inventory years

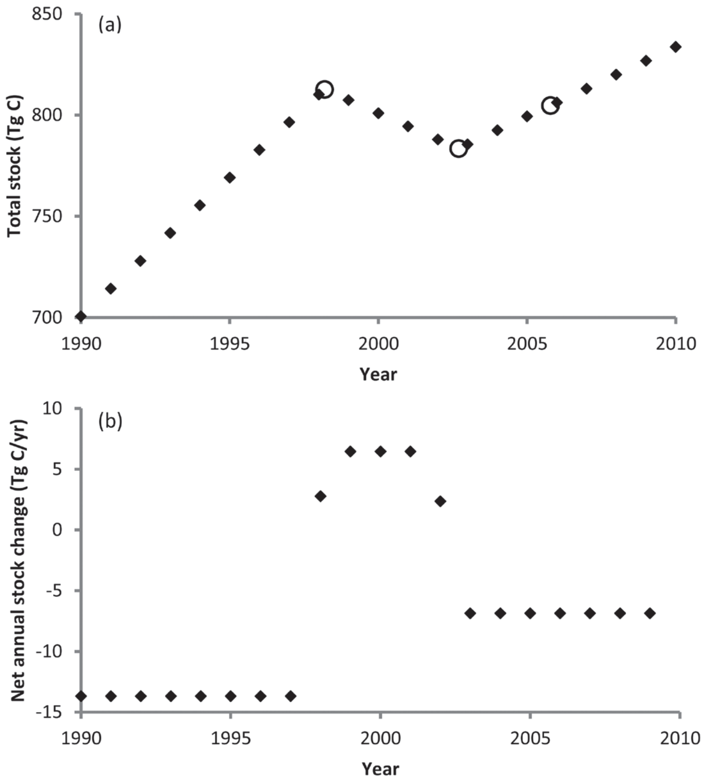

Fig. 3. Example of individual state forest (a) stock and (b) stock change (b) for Tennessee. Circles represent carbon stock summaries from forest surveys, and other symbols represent annualized (a) carbon stock and (b) carbon stock change. Note in Fig. 3a that the stock estimate for the first survey is 687 Tg C in the year 1989. It is not shown here to keep the year axis the same throughout.

1989, 1999, 2004, and 2007; Fig. 3a, noted by circle symbols). Note that the stock for the first survey is not shown because it is for year 1989, at 687 Tg C. These four carbon stocks (three visible in Fig. 3a) represent the effect of the first three steps in the approach described above and in Fig. 2. The annualized stocks (diamond symbols) are from linear interpolation/extrapolation. The values for net annual stock change are determined as described above (Fig. 3b); for example, net stock change for 1998 is based on the difference between the 1999 and 1998 stocks (Fig. 3a). The annualized series from 1990 to 2009 (Fig. 3a and 3b) are the result of step four (above and Fig. 2).

The inter-annual variability is defined as the change in annualized estimate for 1 yr relative to the previous years; that is, the annual steps in Fig. 1. While change in net change is expected, our interest is in the patterns or extremes and our ability to link each state's survey-with-carbon to the values of Fig. 1.

As illustrated in Fig. 3, interpolation between successive periodic stocks (Fig. 3a) produces constant values for net stock change over the interval (Fig. 3b) so that all of the change-in-change (or IAV) is confined to the two short 2-yr intervals 1998 to 1999 and 2002 to 2003. The plotted point indicating stock change for 1998 is the first positive value in the sequence, and the IAV for 1998 is that value minus the estimate for 1997, a large positive IAV. The stock change graph for Tennessee (Fig. 3b) is typical of the state-level stock change pattern in that IAV occurs over very brief intervals, with constant net stock change over most of the reporting years 1990 to 2009. This is a different pattern than for the summed stock change for the United States (Fig. 1), with IAV occurring between most years.

Inter-annual Variability Sensitivity to Forest Surveys

Sensitivity of net annual stock change to the underlying forest inventory surveys is identified by repeated stock change calculations while systematically removing individual surveys. The point of this process is to look at each national level annual step change—or IAV of stock change—to identify (i) specific surveys that have an influence and (ii) the relative level, or percent, effect of each. Again, we define IAV for a particular year as the difference, or change, relative to the previous year; for the Fig. 1 example, the change in net change for 1999 is 26 Tg C (a positive value because the 1999 stock change is less negative than that for 1998).

Sensitivity to the individual surveys is based on the base stock change (Fig. 1, as in USEPA, 2011) and an additional 236 similar annualized totals for 1990 to 2009, which are each based on deleting a single survey. Pairwise comparisons were made for each year between each partial model and the base (complete) model. Each pairwise non-zero contribution of one survey for a particular year is divided by the summed absolute values of all contributions for that particular year to attribute a portion of change to each influential survey. This same process can be applied to identify sensitivity of IAV to each of the 88 state or sub-state series of surveys as well.

Results

Summed net annual stock change for US forests and the pattern in Fig. 1 are from the sum of the 88 separate stock change sequences such as the one illustrated in Fig. 3b. Each yearly estimate for each state or sub-state sequence contributes to the magnitude of net stock change for the country. However, only a few of the annualized estimates of stock change contribute to the year-to-year change, or IAV of the total. For example, from Fig. 3b for Tennessee forests the annualized estimates for 1998, 1999, 2002, and 2003 are the only values that affect the IAV of Fig. 1.

Identifying sensitivities of IAV, as in Fig. 1, is based on the effect of the selective deletion of components. This process as applied to the 88 series of state or sub-state stocks is illustrated for the sensitivity of the 1999 estimate (Fig. 4). The solid line represents the base estimates (same as Fig. 1), and the dashed line represents the estimates without the Georgia inventory, which has the greatest effect on the magnitude of net annual stock change for 1999 but no effect on IAV for 1999 (result not shown). The dotted line represents the estimates without the Oregon non–National Forest Eastside sequence, which has the greatest influence/effect on IAV for 1999. That is, the net change in 1999 relative to that in 1998 where the addition of those particular Oregon surveys changes the annual interval from the dotted to the solid line has the greatest effect on the summed slope in Fig. 1 for those years. The surveys (the set of 236) with the greatest influence on each of the yearly IAVs is shown in Table 1, which includes the 3 most influential surveys for

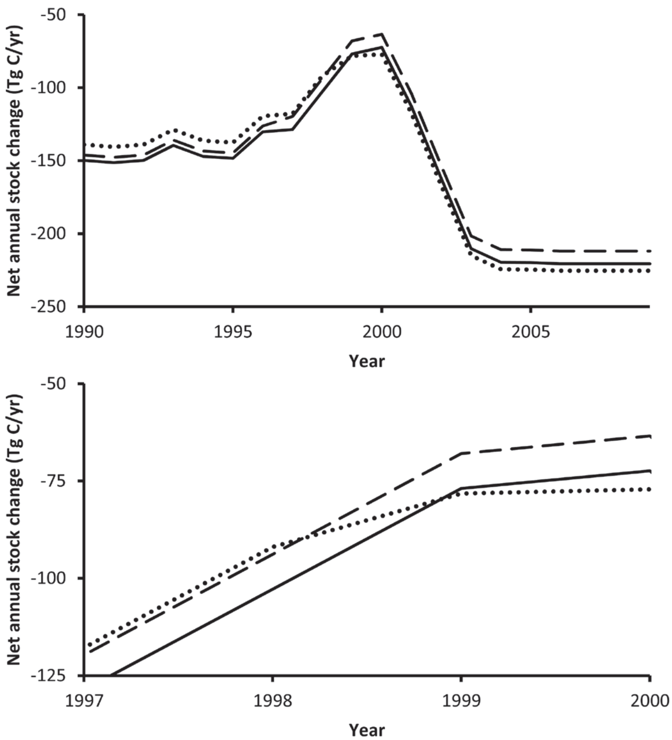

Fig. 4. Example of influence on net forest stock change, or inter-annual variability (IAV), for 1999, with the second figure providing detail about the 1999 estimates. The solid line represents the base stock change totals as in Fig. 1. The dashed line represents the totals without the Georgia inventories, which have the greatest effect on the magnitude of net annual change for 1999 but not the effect on IAV for 1999 (i.e., the change between 1998 and 1999). The dotted line represents the totals without the Oregon non–National Forest Eastside forest survey, which has the greatest effect on total IAV for 1999 (i.e., the change between 1998 and 1999).

Table 1. The three individual surveys of state or sub-state populations that have the greatest influence on each inter-annual change in net stock change, that is, change in change or inter-annual variability (IAV). The year represents the nominal year associated with the survey. The proportion is the summed relative influence on IAV of the three listed surveys. Surveys listed in italics are influential, but in the opposite direction of the summed IAV as shown in Fig. 1.

Year	Influence on change in net change	Proportion
1991	Louisiana 1991, 2005; Alabama 1990	0.47
1992	Michigan 1993, 1980; Texas (East) 1986	0.47
1993	Michigan 1993, 1980, 2004	0.69
1994	Florida 1995, 2007, 1987	0.76
1995	Florida 1995, 2007; *Wisconsin 1995*	0.45
1996	Montana National Forest 1989, 2009; Arkansas 1995	0.48
1997	*Georgia 1997*; Indiana 1986, 1998	0.30
1998	Tennessee 1999; Indiana 1986, 1998	0.48
1999	Oregon non–National Forest Eastside IDB† (1999), 2009; Alabama 2000	0.43
2000	Idaho other National Forest 1991, 2009; *North Carolina 2002*	0.36
2001	North Carolina 2002, 2007; Minnesota 2003	0.43
2002	Wisconsin 2004, 2008; Minnesota 2003	0.26
2003	Michigan 2004, 2008; Tennessee 1999	0.36
2004	Illinois 2005, 2008; Arkansas 2005	0.59

† IDB is a periodic inventory dataset for California, Oregon, and Washington. See http://www.fs.fed.us/pnw/fia/publications/data/data.shtml or Smith et al. (2010) for more information.

each year and the summed relative effect of the 3 in determining IAV. Note that sensitivities to the series of surveys (the set of 88) are not separately provided, but the most influential state or sub-state series is that listed first in Table 1 (i.e., the most influential series includes the most influential survey).

The Tennessee 1999 survey appears in Table 1 as influential for 1998 and 2003 IAV; the effect of that one survey on national totals is shown in Fig. 5. Additionally, the effect of a few highly influential surveys is shown in Fig. 6, which is based on removing only 5 of the 236 surveys: those most influential in each of the 5 highest IAV years—1998, 1999, 2001, 2002, and 2003. The surveys are as follows: Tennessee 1999, Oregon non–National Forest Eastside (1995/IDB), North Carolina 2002, Wisconsin 2004, and Michigan 2004 (Table 1).

Discussion

A relatively small number of the 236 surveys underlying Fig. 1 have a significant influence on IAV in any 1 yr; frequently, the 3 surveys listed in Table 1 account for a large proportion of the influence. In addition, sensitivity to surveys changes continually so that the influence is generally only for one or 2 yr. The pattern of annualized stock change estimates in Fig. 3b is consistent with these observations; 4 of the 20 estimates affect IAV with 2-yr intervals each.

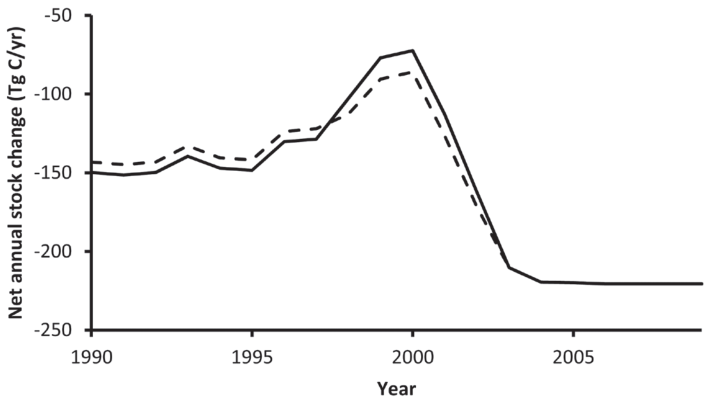

Fig. 5. Effect of removing only the 1999 Tennessee survey (dashed line) relative to the total of Fig. 1 (solid line).

Fig. 6. Effect of removing 5 (of the 236) surveys: those most influential in each of the 5 highest IAV years—1998, 1999, 2001, 2002, and 2003. The surveys are as follows: Tennessee 1999, Oregon non–National Forest Eastside (1995/IDB), North Carolina 2002, Wisconsin 2004, and Michigan 2004. The dashed line is the reduced model (231 surveys) relative to the total of Fig. 1 (solid line).

The pattern of the most influential surveys (Table 1) where consecutive pairs of surveys within a state are frequently listed is readily explained because sensitivity is related to the slope over a 1-yr interval as illustrated in Fig. 4. If either of the points defining a line segment (as in Fig. 3a) is modified, then the change in net change at each node is also modified. The Tennessee 1999 survey represents an example where paired stocks do not have equal influence. This survey is most influential for overall IAV in 1998, but the 1989 survey would be fourth on the Table 1 list for 1998. Similarly, Tennessee 1999 is listed as influential for the 2003 IAV; the Tennessee 2004 survey would be fourth on this list. These examples demonstrate that sensitivity can be separated from the inventory field data collection by varying numbers of years.

The apparent disconnect between sensitivity of IAV and what are most likely the actual in-the-forest changes in net annual changes in carbon stocks can be interpreted from Fig. 3. In the interval between the carbon stocks at the approximate average years of 1989 and 2003 (Fig. 3a), the stock change construct places all the IAV in 1998 and 1999 (Fig. 3b). In reality, change is continuous, probably not linear, and abrupt step changes are unlikely. This is repeated for the intervals on either side of the stock plotted for 2003 as well. The important point here is that this combination of data and methods means that the IAV apparent for a single year is not the product of change—or activity data—exclusive to that year as is expected of IAV (Richards, 2011; Eggleston et al., 2006). Figures 5 and 6 also provide examples of sensitivity of IAV to one or a few surveys, where the two lines are not parallel.

In contrast to our use of periodic surveys, stock change developed on the basis of true annual stock estimates would, by definition, place IAV and activity as jointly occurring in the same year. The difference of USEPA (2011) (Fig. 1) with the presumed definition of IAV of Eggleston et al. (2006) is the multi-year intervals of the stocks from FIA data. These data tend toward the step changes such as in Fig. 3b. A mechanism to smooth the stock-to-stock series, and thus the stock change, would be one step toward better linking cause and IAV. If done properly, the sensitivities would be more dispersed and Fig. 1 and the respective IAVs would be smoothed, yet accurate. The ideal approach to clearly link activity and resulting removals/emissions would likely be to transform the entire series of periodic surveys to annual estimates where each year is based on an estimate of inventory characteristic of that year rather than the current interpolated-between-estimates approach. However, in many forest types, the change within a year is so small that if one tried to take measurements every year for a validation dataset, the change would likely be within the measurement error. It may be difficult to prove the attribution to a specific year.

Conclusions

Carbon stocks and stock change estimation in forests often employ a more data-driven approach. The major carbon changes in forests are typically in trees; changes in tree carbon are relatively more rapid and responsive to influences on change, such as forest management, relative to soil organic carbon. Trees are relatively easy to measure than carbon change in soil. Soil carbon can appear to change rapidly depending on how the accounting framework accounts for the changing forest land base. Trees in forests have been measured and statistically sampled for volume estimation for decades, if not centuries (Scott and Gove, 2002). These same measurements can be used for estimating carbon, although additional measurements may be needed to improve carbon estimates with this type of approach. Note that carbon is not directly measured with this approach; models must be used with the measurements although the models may be fairly basic, direct, well-documented, and considered accurate. The estimates produced with the approach discussed here are often used as the standard with which process models and remote-sensing-based models are calibrated or validated.

Because the forest surveys in the United States are conducted at the state level, because the survey data were often traditionally associated with ending survey dates rather than the year of survey, and because the survey design has changed during the period of interest, calculations using the plot data can be complicated. These changes have contributed to what appears to be inter-annual variability at the national level. However, in the example we investigated, the IAV appears to be due to new data from individual states or sub-state areas representing estimates for a short, but multi-year, time period that nonetheless was noticeably influential when summed with all the other forested areas of the United States. The change is a true change, and the inventory-based estimates of stock change are specific to each of the reported years, but the IAV cannot be attributed to specific activity data for each of those years.

More research is needed to continue to reduce perceived uncertainties of the estimates and ensure the estimates correspond to the true years the sequestration or emissions occurred.

Population totals as presented for the FIADB are not currently provided as true annual estimates because fewer data can be used for evaluating annual estimates according to single inventory years and this results in a lower precision that has been considered unacceptable (Roesch et al., 2002; Bechtold and Patterson, 2005). However, techniques are under development that may provide estimates closely matched to year that the activity occurred with only a small loss of precision (e.g., see Eskelson et al., 2009). Development of optional approaches and improved estimates are expected over time as more years of annual data become available.

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