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Next-generation forest carbon models for spatial GHG reporting objectives

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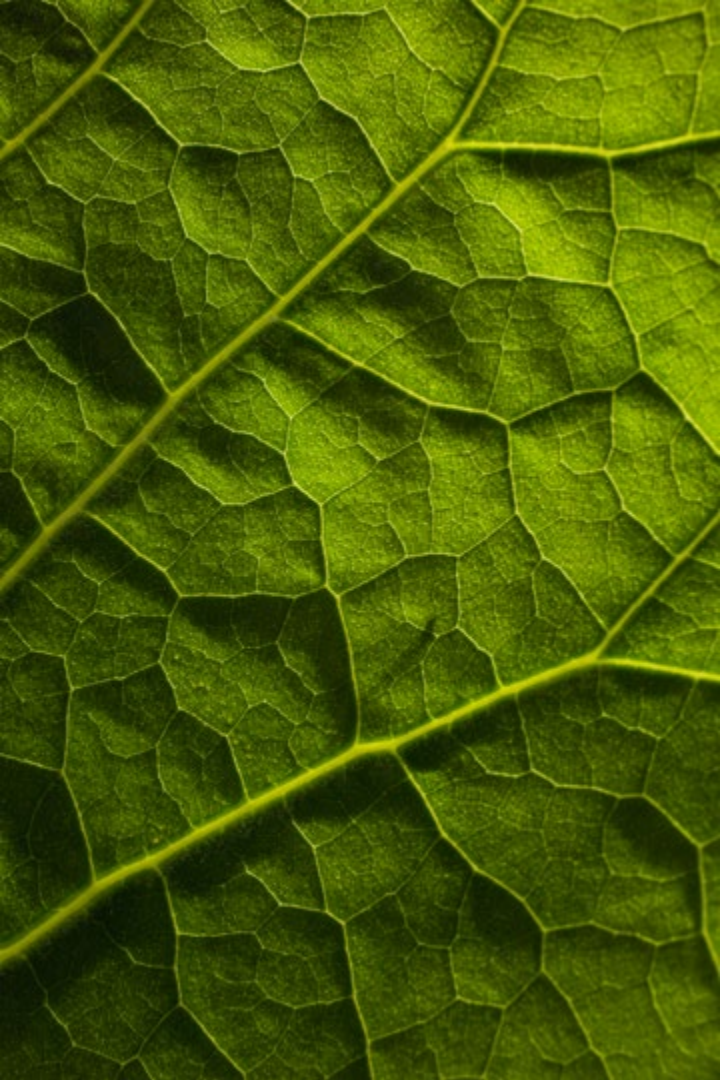
Canada

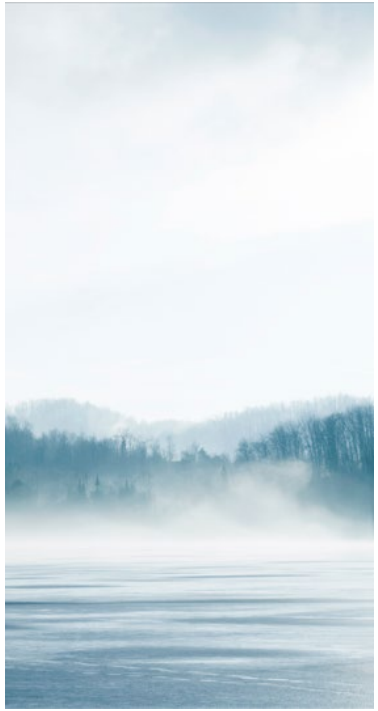


Outline

- Model objectives and requirements
- Development history
- Next-generation model: CBM4
- CBM4 features
- Example applications

Why do forest carbon modelling?

- Requirements of international climate change commitments
  - Greenhouse gas inventories (GHGIs)
  - Nationally determined contributions, a.k.a. emission reduction targets
- Sustainability reporting
  - European Union Corporate Sustainability Reporting Directive (EU CSRD)
  - GHG Protocol
  - Market access requirements
  - Expectations from the public, clients and investors
- Carbon markets
  - Offset credits (e.g. enhanced removals, avoided emissions)
  - Voluntary and compliance
- Landscape/resource management
  - Carbon as a value
  - Policy development and assessment



Common model requirements

Transparency

- Results can be traced back to inputs, model settings and assumptions
- Estimates are versioned controlled and auditable
- Code is open-source and well documented

Accuracy

- Best available data and methods are supported, regardless of data type
- Project/country specific conditions are represented

Comparability

- Provides standardized carbon pools (e.g. IPCC pools) in common units
- Output formats are compatible

Consistency

- Guidelines for project type are followed
- Time series and geographic consistency across analysis period

Completeness

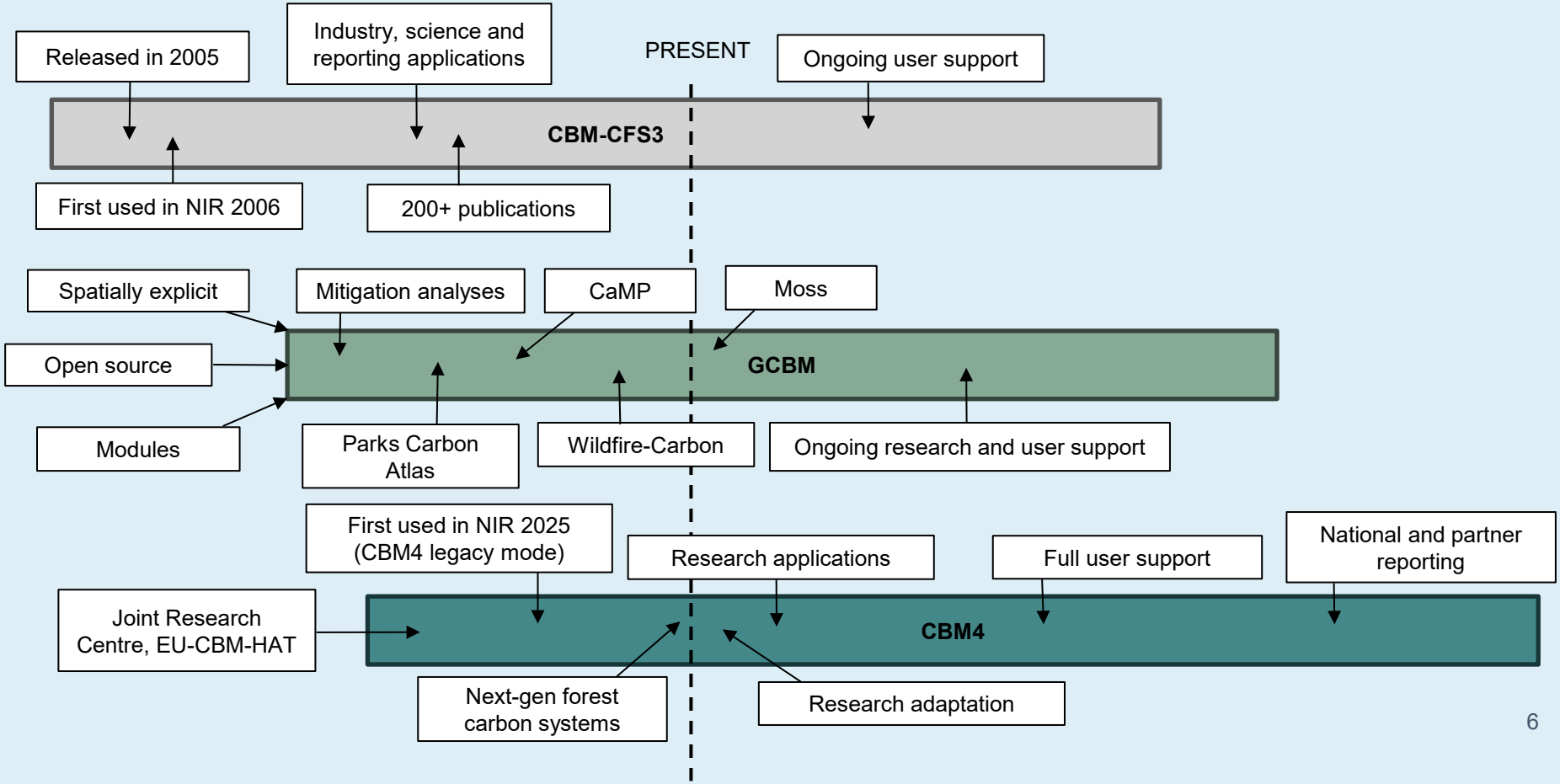
- Key activities, processes, pools, fluxes and ecosystems are represented
- Human-focused, drivers of trends, related to policy or investment, vulnerable to disturbance, etc.

Canada's forest carbon model – CBM-CFS3

Carbon Budget Model of the Canadian Forest Sector (CBM-CFS3)

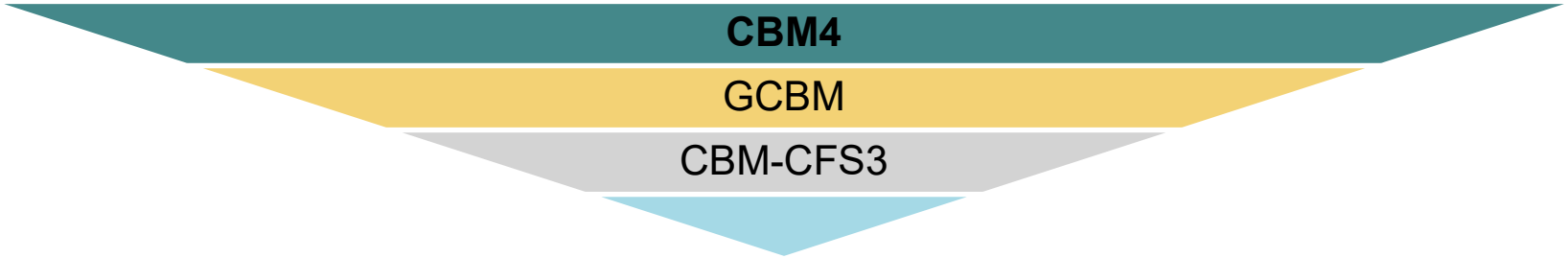
- Tier 3 approach - one inventory plus change information
- Science-based and data driven
- Developed to assess historic & future role of Canadian forests in the global C cycle
- Meets UNFCCC reporting requirements
- Over 200 publications from applications around the world
- 20+ years of GHGI reporting including continuous improvement

Forest carbon model history



CBM4

- Canada’s next-generation forest carbon budget model
- Fully consistent with the science of CBM-CFS3
- Leverages concepts and workflow from the GCBM
- Open-source and publicly available (latter half of 2026)
- Enhanced features that the modelling, science and policy communities require now and in the near future
- Maintenance, support and improvement by NRCan-CFS and partners

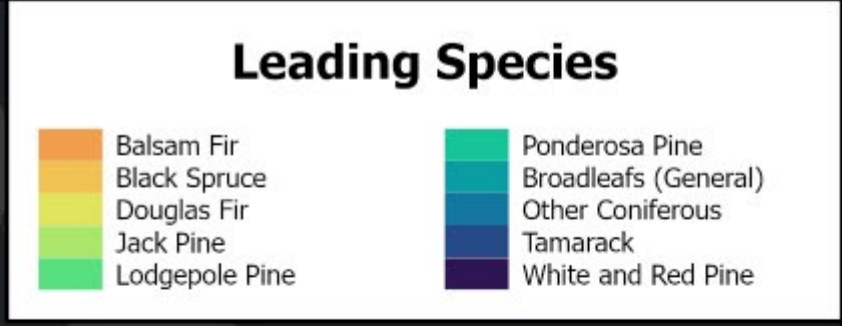


Why develop a new forest carbon model?

- Increased requirement in reporting frameworks that forest carbon estimates be **spatially explicit**
- Spatial modelling is computationally intensive and must be **fast and scalable**
- GHGI approaches still rely on non-spatial data, requiring **support for different types of input data**
- Continuous scientific improvement requires **flexible pool and parameter design** to support new concepts
- Multiple and interacting reporting objectives require that carbon and non-carbon simulation **modules work together**
- Detailed and complex input data stacks at high-resolution require **efficient and expandable data structures**

CBM4 Features

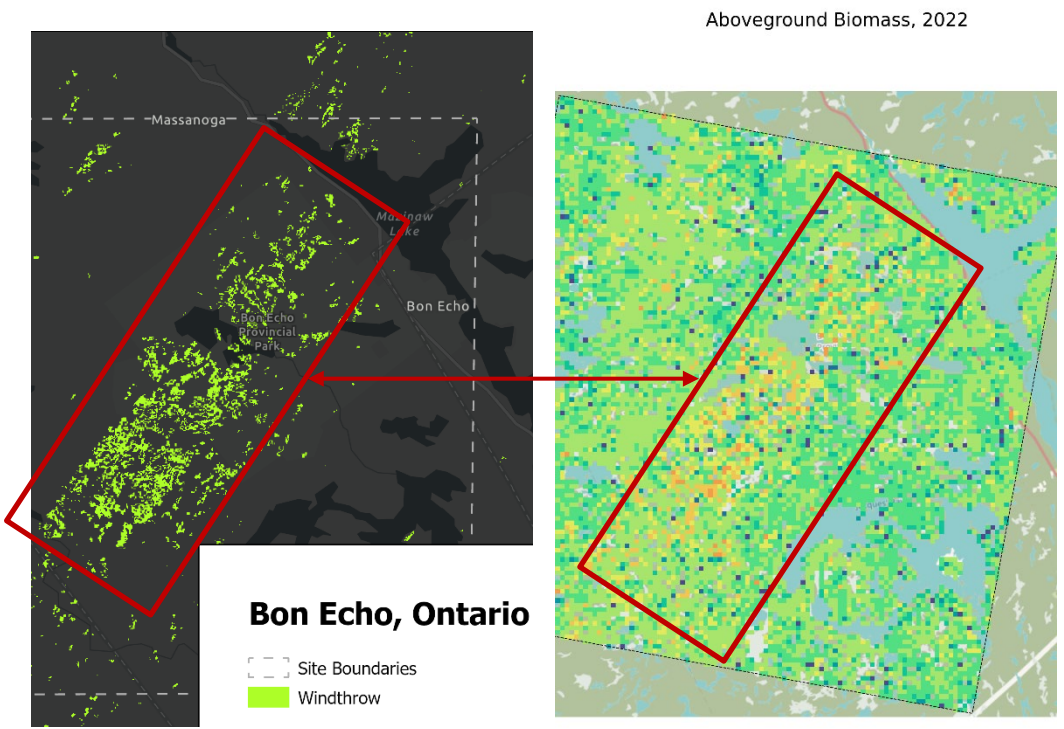
Spatial modelling



- CBM4 supports high-resolution spatial data as model inputs and can generate high-resolution maps as outputs.
- Data preparation workflows, adapted from GCBM, streamline the import of mapped data (e.g. raster and vector data) with a range of configuration options.
- Spatial resolution has no limit besides practical limitations (e.g. desired simulation run time and data storage requirements)
- Spatial outputs can be exported after a simulation is complete, significantly reducing compute time and output data size

Spatial validation and model feedback

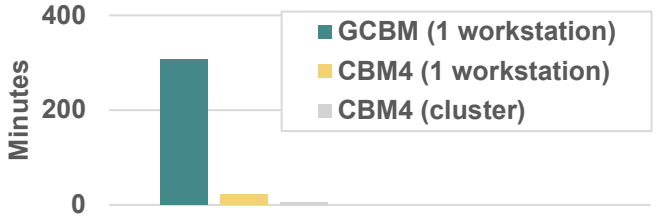
- Spatial modelling with traceable inputs and outputs enables results to be inspected at the pixel level
- Carbon stock and stock change estimates can be attributed to events and location specific conditions
- Comparison to alternate products, such as those from remote-sensing, creates calibration and model learning opportunities



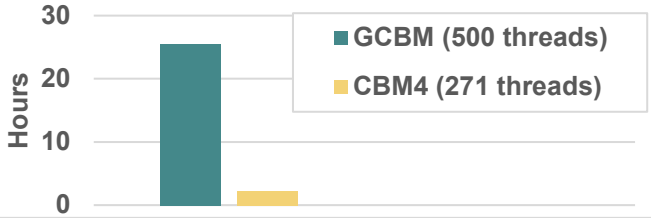
Computationally powerful

- CBM4 has increased computational performance and scalability
- Faster on individual workstations and effectively makes use of cluster computing resources

Project #1
Time steps: 29
Simulated landscape: 7.8 million pixels (376 kha)
CBM4 run-time (workstation): 23 minutes



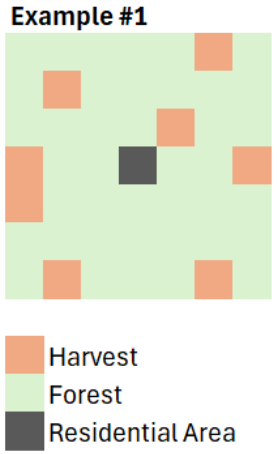
Project #2
Time steps: 80
Simulated landscape: 360 million pixels (360 Mha)
CBM4 run-time (271 threads): 2.25 hrs



Project #3
Project #2 simulated 4 times simultaneously
CBM4 run-time (1084 threads): 3.25 hrs

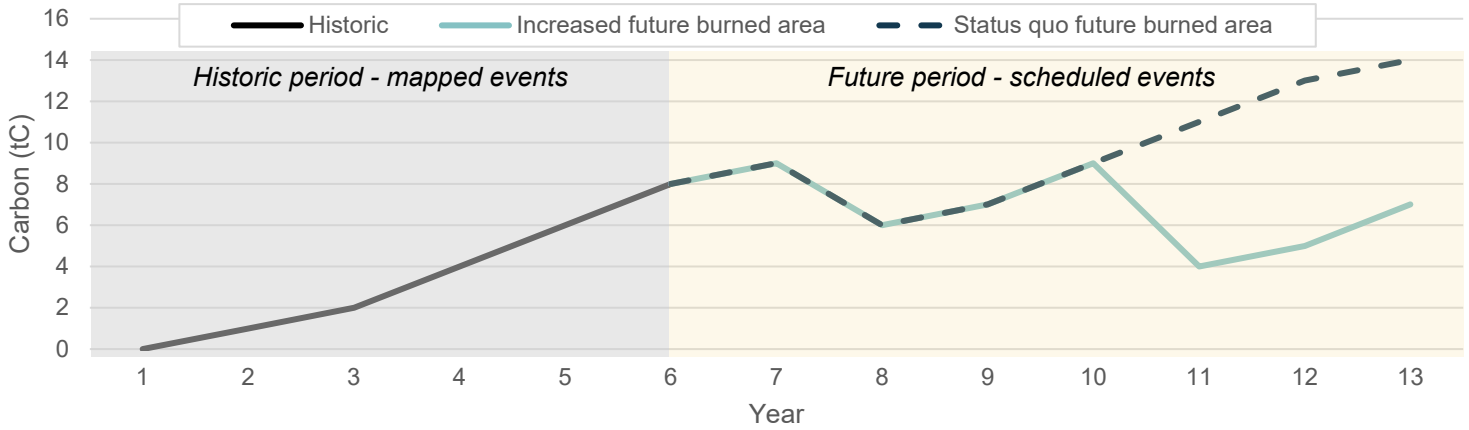
Support for non-spatial

- Forest disturbance and management data is not all spatial GHGIs require complete and accurate accounting of key activities like wood extraction and biomass burning.
- CBM supports “rule-based” events that can be scheduled based on targets, filters and criteria.
    - Example #1: Harvest 100 tC for firewood
- Combined with CBM4’s ability to import and utilize more input data, and understand the geographic position of pixels, rules can be complex and meaningful
    - Example #2: Harvest 100 tC for firewood closest to a residential area

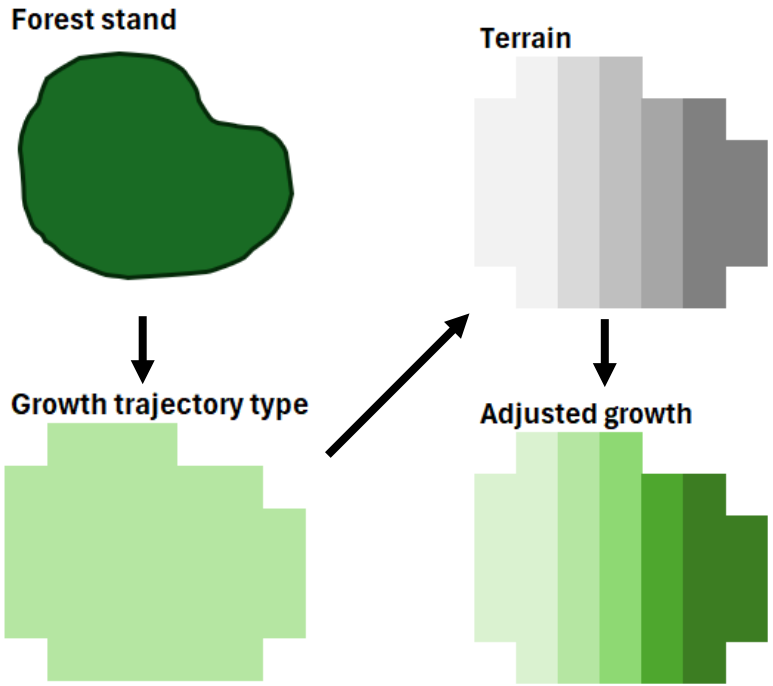


Scenario development

- Blended support for spatially explicit and rule-based events is useful for testing and projecting scenarios (e.g. different levels of natural disturbance risk)
- Involves scheduling model events that have no real-world record
- Seamless transition from historic spatially explicit estimates → to future rule-based estimates based on management and policy scenarios
  - Seamless transition supports progress tracking towards emission reduction targets based on historical references



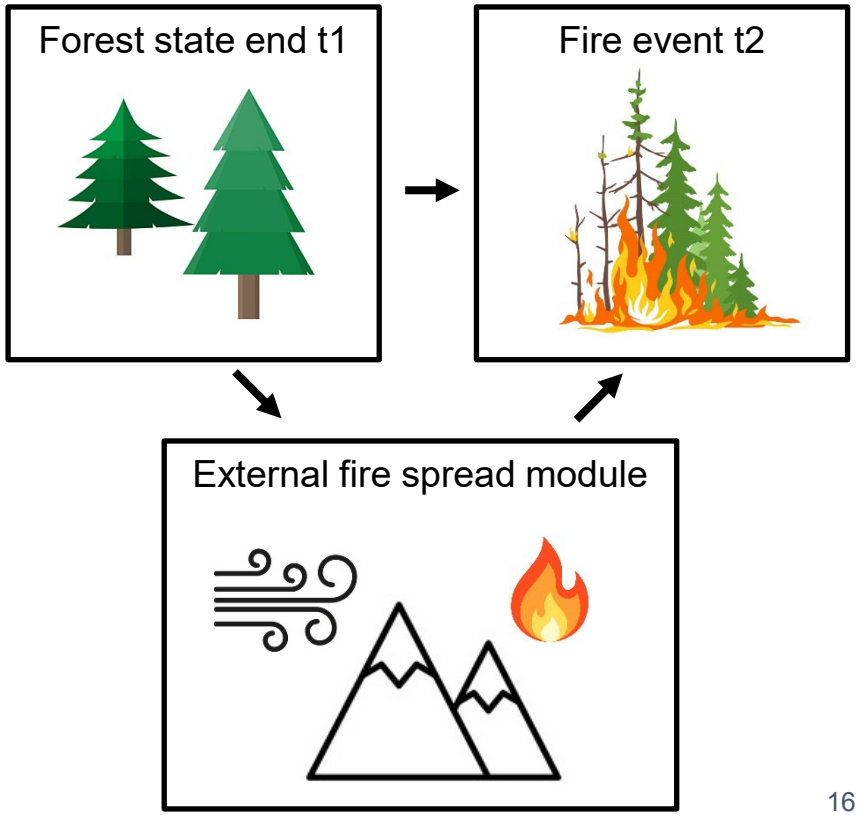
Flexible parameters



- CBM4 model parameters, including growth increment, can be adjusted at the pixel level based on supplementary factors such as climate or terrain.
- Growth increment tables can also be provided directly to a pixel rather than via the CBM-CFS3 method of converting from volume-age curves
    - Customization per timestep supports climate-sensitive growth dynamics
- Pool types and dynamics can also be customized; however, this feature requires extensive science-based development

Accessible simulation approach - contagion

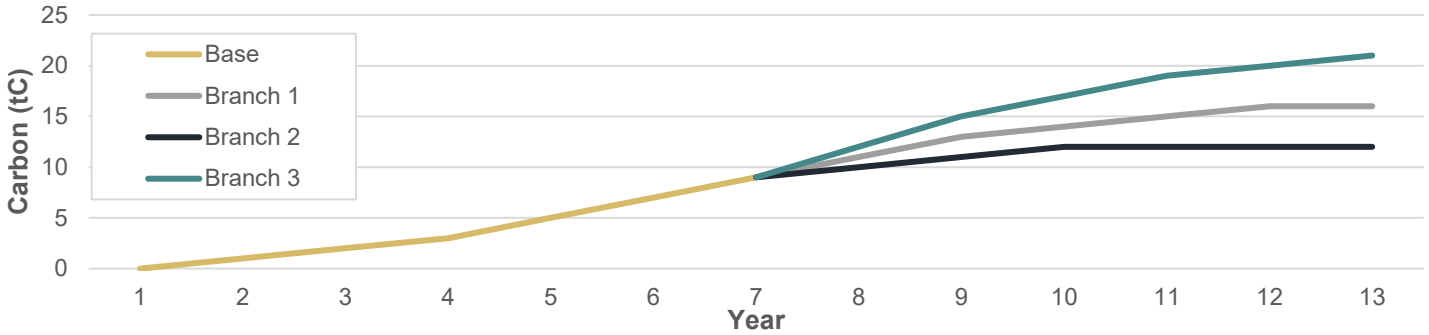
- CBM4 simulates the entire project landscape for a single time step before moving to the next
- Users can evaluate the simulation state of a prior time step and design decisions and inputs before proceeding to the next time step.
- Enables interactions with internally provided or externally linked modules (e.g. fire or insect spread) between timesteps



Accessible simulation approach - iterations

- Step-by-step simulation allows users to cache and return to a prior state
- This supports scenarios that repeatedly iterate forward and backward to optimize for desired outcomes or that branch out to assess uncertainties
- Simulations can be subset to regions-of-interest to reduce computational burden

Example: Branch 1, 2 and 3 are only run from Year 7 onwards



Expandable data structure

- The data structure for the CBM4 is a custom-built format that utilizes hive partitioning and de-duplication techniques
- Can support higher complexity (e.g., eliminates the 10-classifier limit present in the CBM-CFS3) and larger inputs and outputs
- Supplementary parameter data can be joined to the simulation dataset, including continuous variables like elevation or categorical variables
- Each pixel can support multiple cohorts:
  - After partial disturbances, can track disturbed and undisturbed portions separately
  - Unique representation of specific species-age components within a stand

CBM4 summary

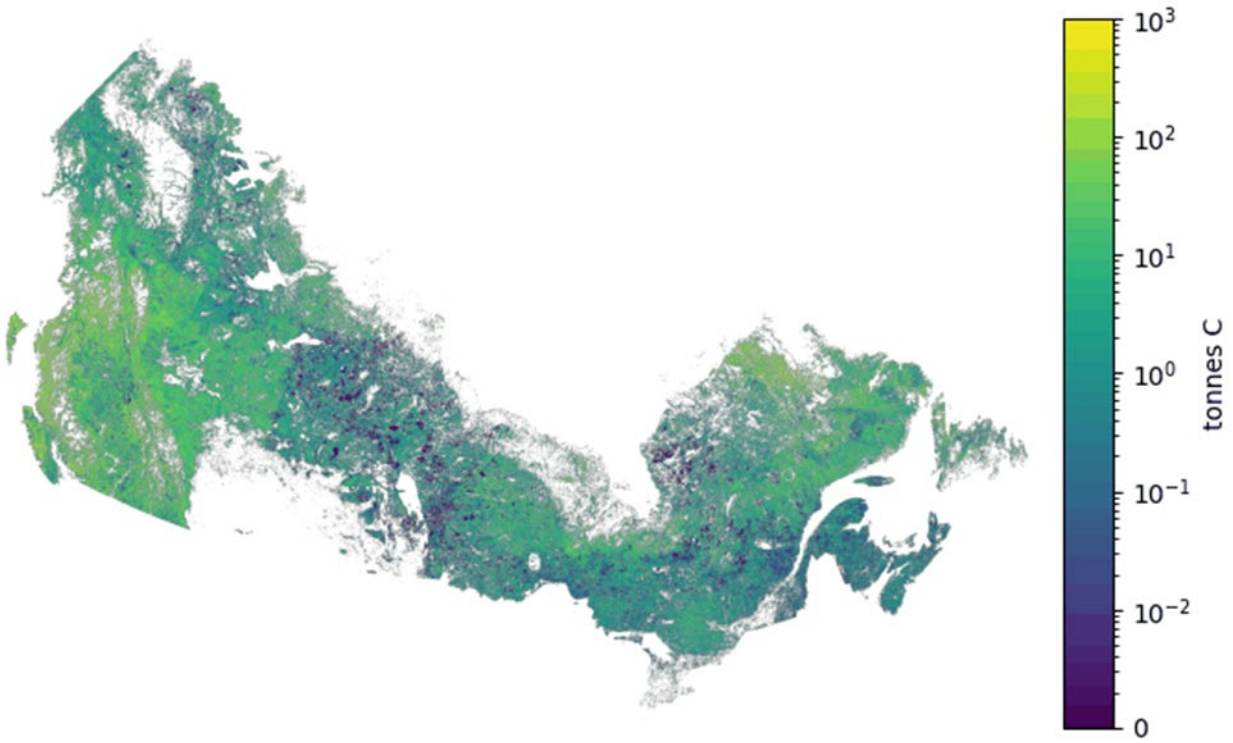
- CBM4 is positioned to solve complex forest carbon modelling challenges
- Detailed spatial data can be accepted and utilized in meaningful ways (e.g. parameter customization, complex rule-based events)
- Performance supports spatial modelling systems feasible for annual reporting requirements, policy scenario analyses and long-term projections
- Flexibility provides many improvement pathways
- Reporting requirements can be met, such as inclusion of non-spatial events and assessment of carbon drivers due to specific activities

Applications

Canada's next-generation forest carbon system

- CBM4 will used to re-build an enhanced version of Canada's National Forest Carbon Monitoring Accounting and Reporting System for Canada's NGHGI.
- Spatial inventory and activity data is being prepared for CBM4 simulations
- Regional systems developed collaboratively with provincial/territorial partners
  - Extend partner carbon modelling capacity to facilitate maintenance and improvements
  - Provide system for analysis and reporting needs beyond GHGIs
- Expanded capacity of CBM4 is enabling:
  - Model inputs and outputs at 30 m resolution
  - Spatial harvest (mapped) plus non-spatial harvest (scale volumes)
  - Detailed growth classifiers with management interventions like fertilization
  - *Incorporation of variable severity wildfire impacts*
  - *Improved representation of post-insect growth response*

National-scale demonstration model



- Publicly available input data supported by a peer-reviewed methodological paper (in progress)
- Uses novel remote sensing-derived products: inventory, disturbance and growth
- *Animated aboveground biomass carbon stocks per year (may not display correctly)*

CBM4 - Availability and support

- CBM4 will be released to the public in the latter half of 2026

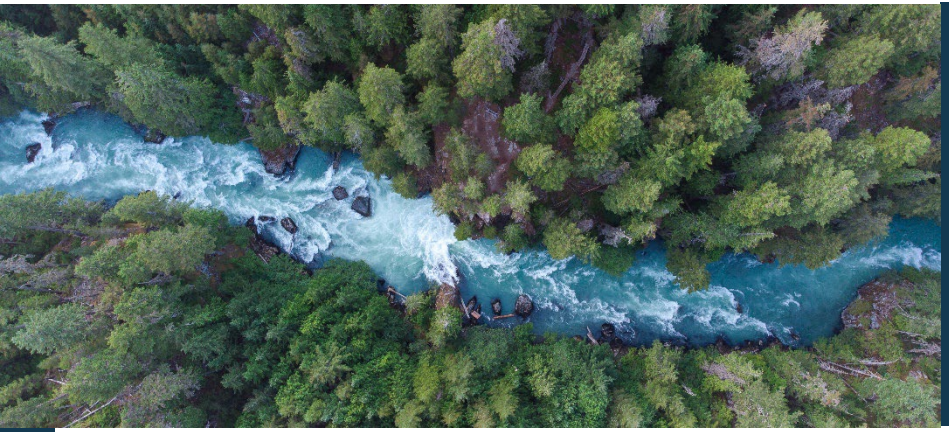
Beta-testing (by invite), feedback

Training systems, documentation, and licensing

Example projects and open data

CFS support, maintenance, improvements

CBM4 - Compatibility



- CBM4 is a model to which any forest data can be applied
- Input data and project-specific model settings significantly impact accuracy

- Country-specific default model parameters from CBM-CFS3 (a.k.a. AIDB) can be imported
- Existing CBM-CFS3 and GCBM projects can be converted

Thank you. Questions?

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