# ALFRESCO Guide


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## I. What is ALFRESCO and what does it model?

ALFRESCO (ALaska FRame-based EcoSystem COde) is a computer model that simulates spatial processes of fire and vegetation in response to transient changes in climate. The model simulates fire and vegetation dynamics across a wide range of future conditions. As there are too many variables to be able to predict exactly where fire will occur on a landscape, ALFRESCO models many different possibilities for a single year. To address the natural variability of fire, it's best to use the full range of possible modeled futures to determine the likelihood and spatial distribution of fire on the landscape.

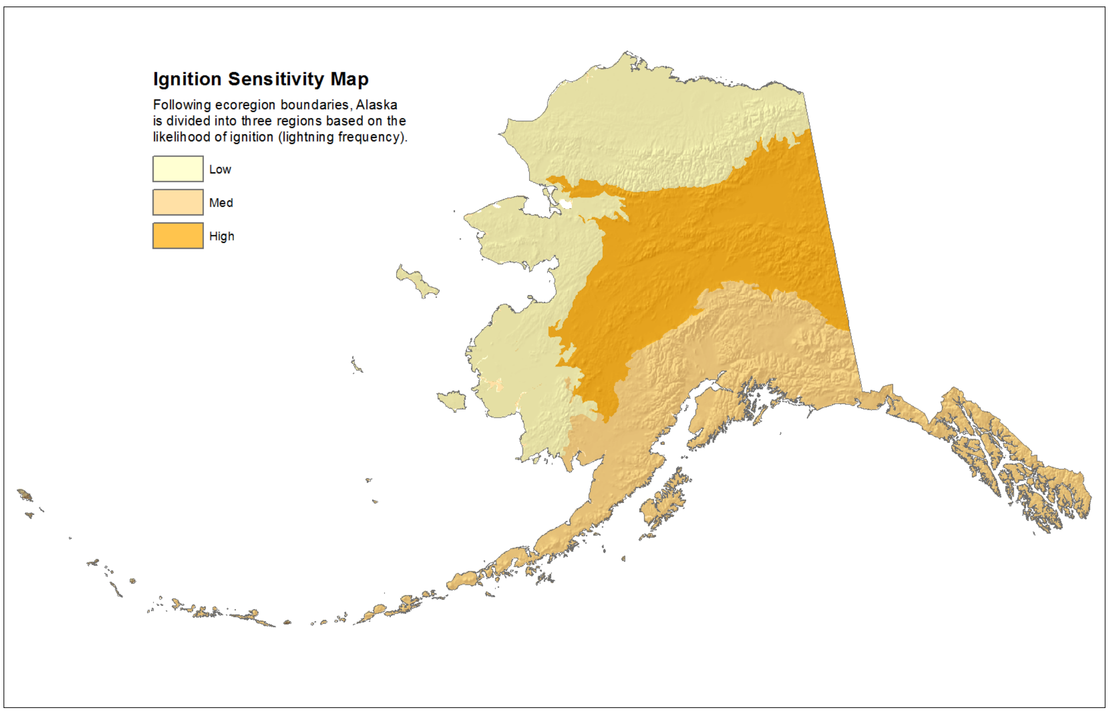
### A. Model basics

1. Temporal scale ⟶ ALFRESCO uses monthly inputs and outputs annual results.
2. Spatial scale ⟶  ALFRESCO operates on a landscape composed of 1 × 1 km pixels.
3. State-and-transition model ⟶ Pixels in ALFRESCO change based on probabilities. Probabilities are based upon our knowledge of ecosystem processes – fire ignition, fire spread, vegetation distribution, vegetation succession, and climate conditions.

### B. Model inputs

Inputs to the ALFRESCO model include vegetation, topography, climate, and fire:

1. **Vegetation Type** is based on broad reclassifications of existing land cover data (NLCD 2001, NALCMS 2005), and divided into two broad successional loops of "forest" or "tundra."
2. **Vegetation Age** is assigned to every pixel on the landscape based on *modeled* time since last fire or time since last vegetation transition.
3. **Topography** (elevation, slope, aspect) is based upon the Global 30 Arc-Second Elevation (GTOPO30), resampled to 1km. This is the same topographic dataset used to produce the PRISM climatology data that SNAP uses to downscale projected climate data input for ALFRESCO.
4. **Climate** (temperature, precipitation) is based on downscaled observed historical data (high-resolution CRU data), or downscaled future climate projections (SNAP).
5. **Ignition Sensitivity Map**, which follows ecoregion boundaries, divides Alaska into three broad regions based on the likelihood of ignition (lightning frequency).




6. **Spread Sensitivity Map**, based on model calibrations to match historical values, shows the likelihood of fire spread based on suppression efforts. The map is a proxy for how likely a fire is to grow based on FMOs (fire management options).

C. Direct model outputs

ALFRESCO outputs do not reflect real vegetation or real fire for a given pixel in a given year. The model simply produces one possible reality for a pixel in one year based on its modeled history. By looking at the full range of "possible realities" for each pixel across the landscape, ALFRESCO determines the likelihood that a pixel will burn and the spatial distribution of future fire on the landscape. See these examples of annual model outputs from ALFRESCO.

1. **Vegetation Type** is defined as the dominant vegetation in each 1x1 km pixel.

*0 = Not Modeled*
*1 = Black Spruce*
*2 = White Spruce*
*3 = Deciduous Forest*
*4 = Shrub Tundra*
*5 = Graminoid Tundra*
*6 = Wetland Tundra*
*7 = Barren/Lichen/Moss*
*8 = Temperate Rainforest*

2. **Vegetation Age** is based on the time since a pixel last burned or the time since successional vegetation.
3. **Basal Area** is the accumulation of basal area of white spruce in tundra cells, and is influenced by seed dispersal, growth of biomass, climate data, and other factors.
4. **Burn Severity** is determined by vegetation type and topography. For example, a long-standing black spruce forest has a high burn severity - burning for a long time and deep into the duff layer - while a young deciduous forest on a steep slope has a lower burn severity - burning quickly and less severely.
5. **Fire Scar** is an area on the landscape after a fire. It has a vegetation age of 0 and therefore a flammability index of 0 - meaning it will not burn again until it has reestablished vegetation.

## II. How ALFRESCO actually works

A. Model Reps

1. Each replicate runs through all 1km x 1km pixels of the grid covering the entire state of Alaska. Each replicate starts with the top left (northwest) pixel, and looks at each individual pixel across the row, then continues at the start of the next row.
2. Each replicate is "seeded" with an initial number so that the replicates can be reproduced for multiple model runs.

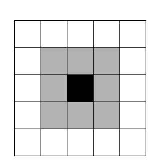
B. Fire Ignition

Fire Ignition is based on a single pixel's vegetation type and age, climate (temperature and precipitation), and the Ignition Sensitivity Map. Ignitions only happen once per fire.

1. **Random lightning**: Fires are ignited by randomly-generated lightning strikes. Lightning data for Alaska is too sparse - both spatially and temporally - to be reliable.
2. **Pixel flammability**: When lightning strikes a pixel in the model, that pixel will ignite based on the relative flammability of the pixel, and if that flammability 'score' (based on vegetation and climate conditions) is higher than a randomly-generated threshold.
3. **Fire ignition sources** (lightning strikes) occur randomly. Whether or not a pixel ignites is a function of that pixel's flammability – determined by vegetation (age and type) and climate conditions (temperature and precipitation), then modified by ignition sensitivity.

C. Fire Spread

Fire Spread is based on the vegetation type and age, climate (temperature and precipitation), and the Spread Sensitivity Map. Once a pixel ignites, ALFRESCO



checks all 8 neighboring pixels, and continues until all burn checks fail (everything around it burns or all pixels fail the flammability check).

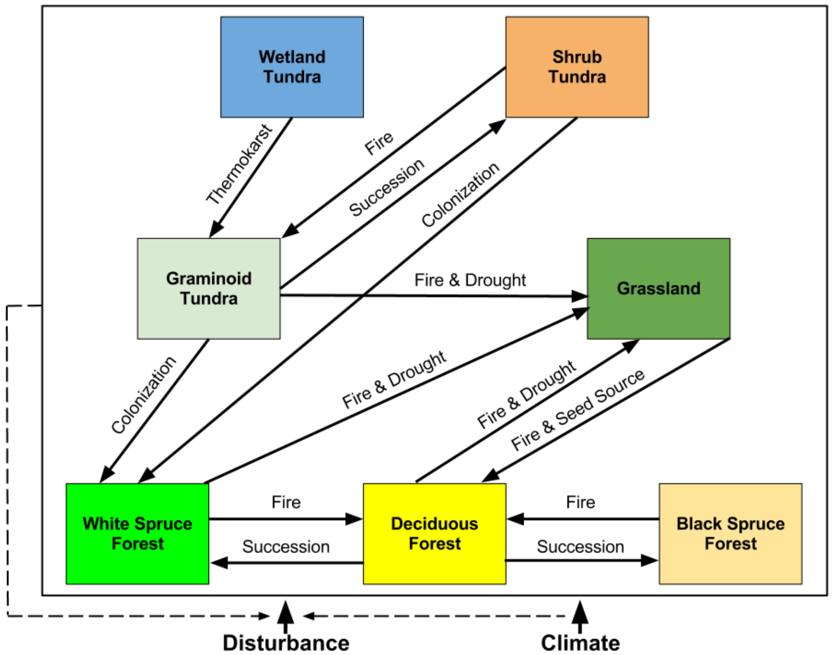
Burn Loop: Fire dynamics (does a pixel burn?) → For each pixel, calculate a probability score, generate a random number, compare that number to the probability score to determine if it burns.

1. **Moore neighbor**: Once a pixel ignites, the surrounding 8 pixels are each 'checked' for relative flammability.
2. **Pixel flammability**: If a neighboring pixel's relative flammability is higher than the randomly-generated threshold number, that pixel will also burn.
3. **Fire spread** depends on a pixel's flammability, modified by the spread sensitivity map, and modified by the number of adjacent pixels that burn. The more adjacent pixels that burn, the more likely a pixel is to burn.
4. **Fire burns out** when the flammability of all neighboring pixels is so low that they do not burn, or the fire hits non-flammable areas that act as a fire break (e.g. non-vegetated or water pixels).
5. Back to fire ignition (B).

D. Vegetation Succession Loops

ALFRESCO is a state-and-transition model whose probabilities are based on best knowledge of ecosystem processes, including vegetation dynamics and transitions. Primary vegetation establishment immediately after fire or long-term secondary vegetation succession after a fire. This is where all transitions occur, including Forest Loop, Tundra Loop, Tundra to Forest. Succession is "speckled" due to increasing probability of vegetation type transition as time goes on.

- Each pixel: mixed vegetation, identified by one dominant vegetation type
- Transitions: based on fire, growing season temperature (rolling 10-year average), seed source, and/or time
- Probabilities: a * age + b




1. Tundra (Graminoid or Shrub) to Forest: seed dispersal checks only the immediate 8 neighbors, with bounded exponential growth until you reach a maximum biomass (growing basal area value until 20 $m^2$/ha, which is considered average maturity for a pixel to become a spruce pixel). Basal area accumulation rate is determined by growing season temperature centered on a normal distribution at 15 degrees C.
2. Graminoid to Shrub: Graminoid tundra depends on temperature thresholds to transition to a shrub tundra. When graminoid tundra burns, it stays graminoid tundra. If it doesn't burn and establishes basal area and if it gets warm enough, it can become shrub tundra. Tundra loops check for 1) seed source/dispersal and 2) 10-year temperature means to cross 10℃.
3. Shrub to Graminoid: If shrub tundra burns, it comes back as either graminoid tundra under high fire severity, or as shrub tundra under low fire severity. Shrub tundra can only transition to forest with seed establishment, and is limited by distance of seed dispersal (see #1 above).
4. Spruce <-> Deciduous: When spruce burns, the vegetation type transitions immediately to deciduous. For both deciduous and spruce types, depending on the fire severity, one of 4 different transition probability curves are chosen.
   a) Black spruce burns at low or moderate severity, the probability of returning to a spruce dominant pixel starts at age 50 and increases each year
   b) Black spruce burns at high severity, the probability of returning to a spruce dominant pixel starts at age 75 and increases each year
   c) White spruce burns at low or moderate severity, the probability of returning to a spruce dominant pixel starts at age 75 and increases each year
   d) White spruce burns at high severity, the probability of returning to a spruce dominant pixel starts at age 90 and increases each year

   **Transitions between white and black spruce do not occur.*

## III. ALFRESCO Model Phases

### A. PHASE 1: Spin-up (1000-1900)

The model runs hundreds of model replicates (reps) in each phase, with a minimum of 200 reps. Initial age is assigned at year 1000 based on fire intervals and type of vegetation. 800 years of spin-up allow the model to end up with "patch dynamics" representative of a possible natural landscape. In Phase 1, vegetation can only burn and regrow as what it was (tundra or forest only). Basal area accumulation does not begin until late in the spin up phase (~1860).

1. **Phase 1 inputs**:
   a) 2005 NALCMS vegetation map
   b) Random age map: classes are randomly assigned at the beginning of model spin-up
   c) Elevation
   d) Slope & Aspect
   e) Climate: randomly-selected year (temperature and precipitation) from downscaled CRU data from March through September from one year between 1901 and 1999.
      - Temperature is from the months March - Sept
      - Precipitation is from the months June - Sept
      - A random year is chosen, then the temperature and precipitation months are all taken from that same year.
2. **Phase 1 outputs**:
   a) 200 veg type maps
   b) 200 veg age maps

### B. PHASE 2: Calibration/Historical (1901 - 2015)

The goal of model calibration is to obtain model outputs that closely match the available observed historical fire patterns on the landscape from the same time period. We only have observed fire data from 1950-present, so we can only calibrate to this shorter time period.

In Phase 2, each replication uses an observed historical climate (temperature and precipitation) from a fire season (May through September) between 1901 and 2015.

For model calibration, we run the model from 1901-2015 and see how well the model output for 1950 onward matches observed fire for the same time period (annual area burned, cumulative area burned, fire size). These decisions are based on time series plots for the entire period of observed fire (1950-2015). The best-fit calibration run then becomes the historical run for all projected (phase 3) model runs.

1. **Phase 2 inputs**:
   a) 200 veg type maps (outputs from Phase 1)
   b) 200 veg age maps (outputs from Phase 1)
   c) Elevation
   d) Slope & Aspect
   e) Climate data:
      (1) 1901-2015: Actual CRU data (temperature and precipitation) from a given year
2. **Phase 2 outputs:**

a) 200 veg type maps
b) 200 veg age maps
c) Mean fire activity map
d) Additional plots (for calibration)

C. PHASE 3: Projected (2016 - 2100)

The model runs hundreds of model replicates (reps) in each phase, with a minimum of 200 reps. This is to look at the full range of possible futures since it's impossible to predict where fire will occur. In Phase 1, vegetation can only burn and regrow as what it was (tundra or forest only). Basal area accumulation does not begin until late in the spin up phase (~1860). Projected model outputs start at 2016 using modeled outputs from 2015.

1. **Phase 3 inputs**:
   a) 200 veg type maps (Phase 2 outputs)
   b) 200 veg age maps (Phase 2 outputs)
   c) Elevation
   d) Slope & Aspect
   e) Climate data: Projected SNAP climate data (temperature and precipitation) for a specific year 2016-2100: Projected SNAP climate data (temperature and precipitation) for a given year → several options depending on which GCMs and RCPs are selected (resampled to 1km resolution).
2. **Phase 3 outputs**:

   From the model outputs you can produce vegetation and fire maps, but any one map is only representative of one model replicate. Each model run produces 200 reps, and with the 5 different climate models, 3 scenarios, and 5 variables, (200x5x3x5) we end up with 15,000 output maps for a single ALFRESCO run.

   a) 200 veg type maps
   b) 200 veg age maps
   c) Burn Severity maps
   d) Fire Scar maps
   e) Basal Area maps

## IV. Additional Model Details

A. Derived products

Model outputs can be used in many ways, depending on the goal and parameters of a given project. We can take the main outputs and create these other products:

1. Fire and vegetation plots: X-Y graphs of all 200 reps from a model run.
2. Vegetation type ratios
3. Subregional summaries
4. Relative flammability: the likelihood of a pixel to burn
5. Maps of treeline dynamics (projected changes in treeline)
6. Habitat mapping
7. Relative vegetation (vulnerability of vegetation to change, i.e. treeline)