Simulating the spread of flying insects using HTC

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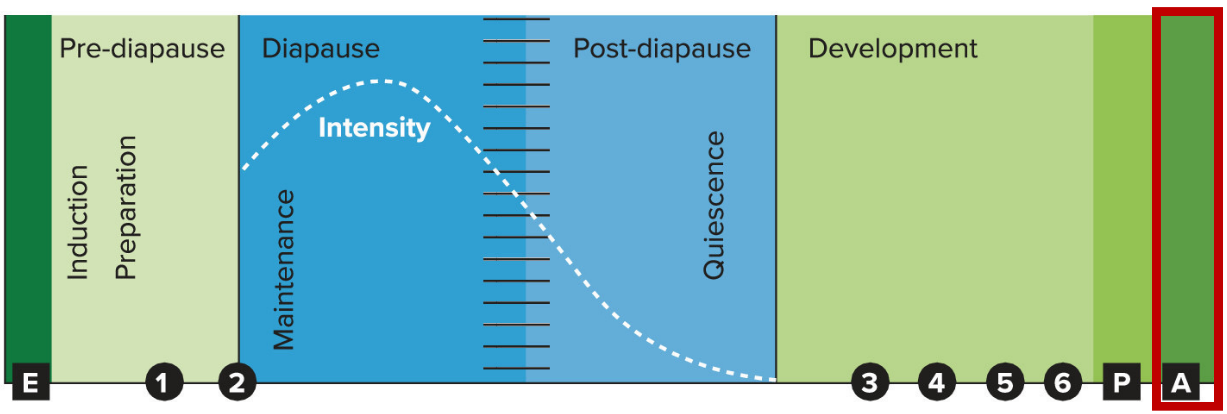
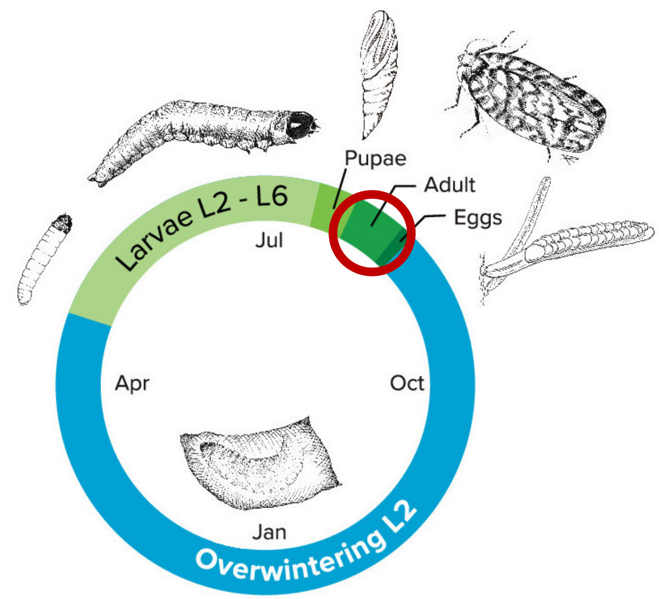
Multidisciplinary project: modeling dispersal of SBW moths

Eastern spruce budworm (SBW) in boreal spruce–fir forests

life cycle, defoliation, aerial dispersal, oviposition



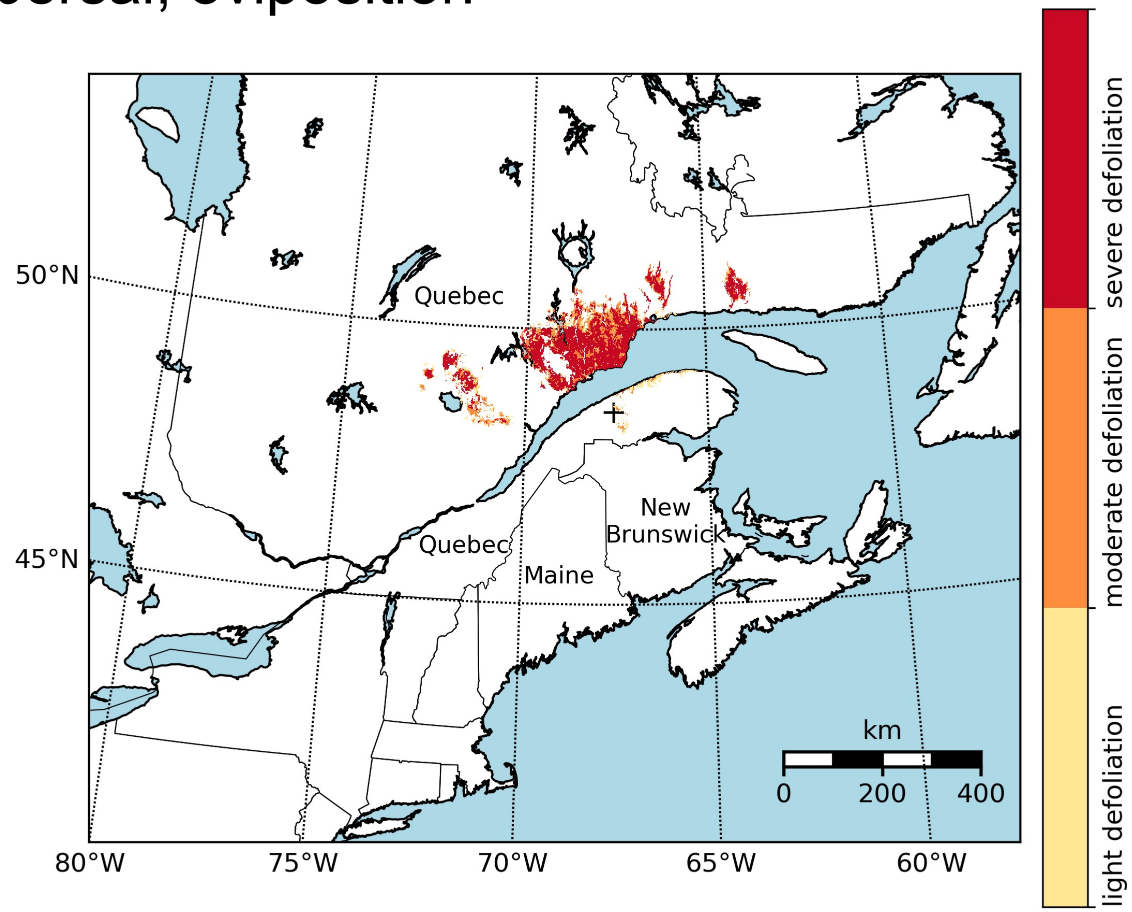


Development cycle graphics adapted from Marshall and Roe (2021, *Physiology*)

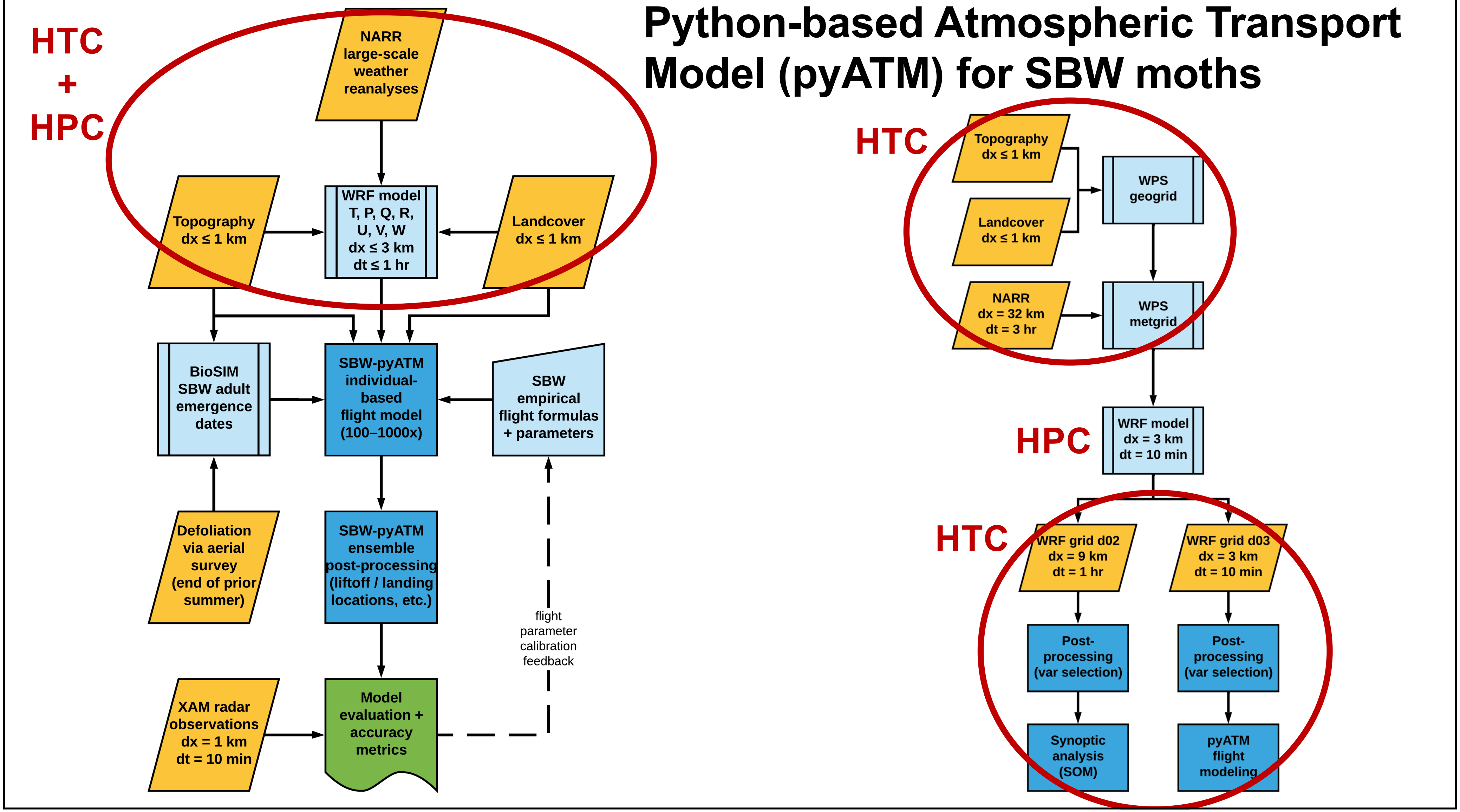
Multidisciplinary project: modeling dispersal of SBW moths

Eastern spruce budworm (SBW) in boreal spruce–fir forests
    life cycle, defoliation, aerial dispersal, oviposition

Focus on Quebec +
    New Brunswick +
    Maine



Python-based Atmospheric Transport Model (pyATM) for SBW moths



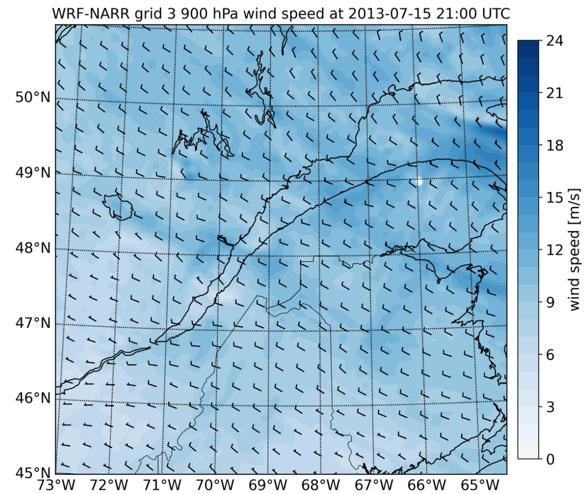
Weather Research & Forecasting (WRF) Model v4.1

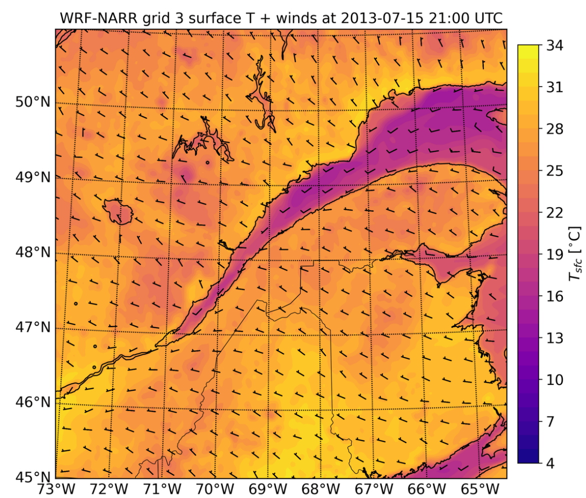
Pre-processing: 1 month at a time
- single-processor, high-memory

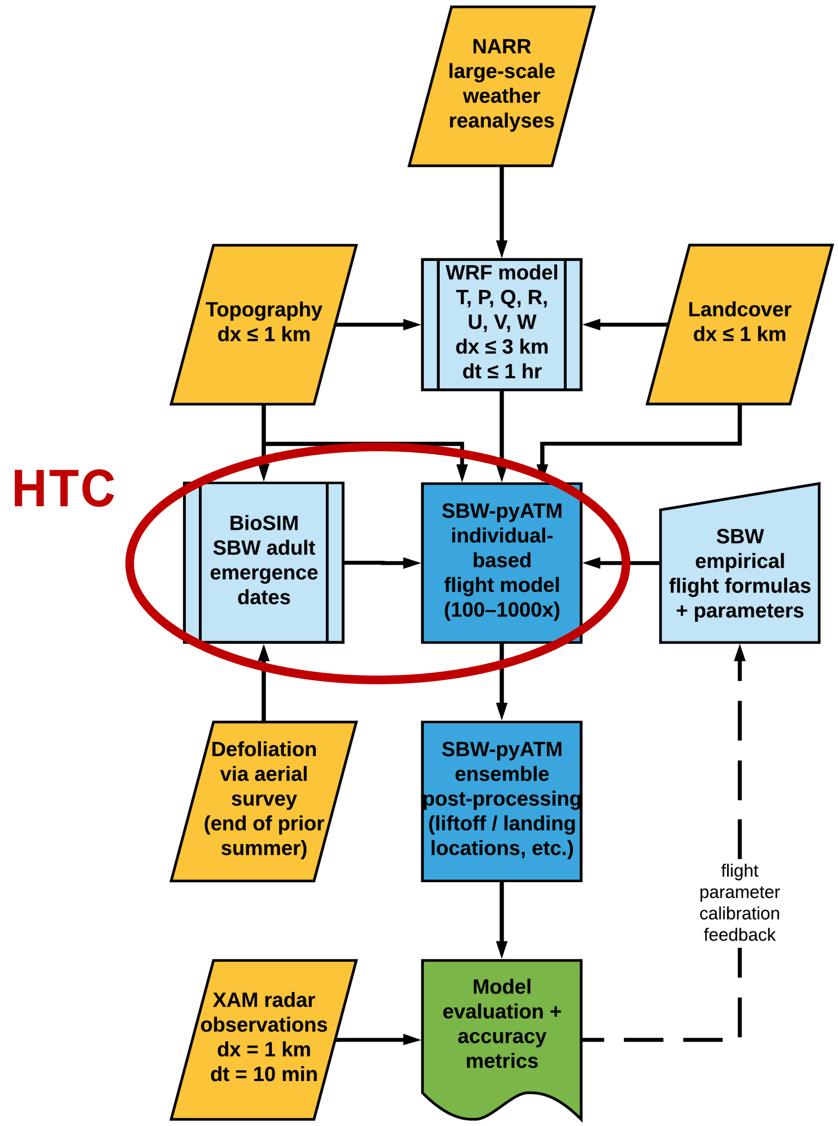
Main WRF model: 1 day (30h) at a time
- 60+ processors, ~2GB memory each
- separate days can run concurrently

Post-processing: 1 output file at a time
- single-processor, distributed

HTCondor DAGMan script(s)
- with mixed submission protocols
  - HTC → HPC → HTC







Python-based Atmospheric Transport Model (pyATM) for SBW moths

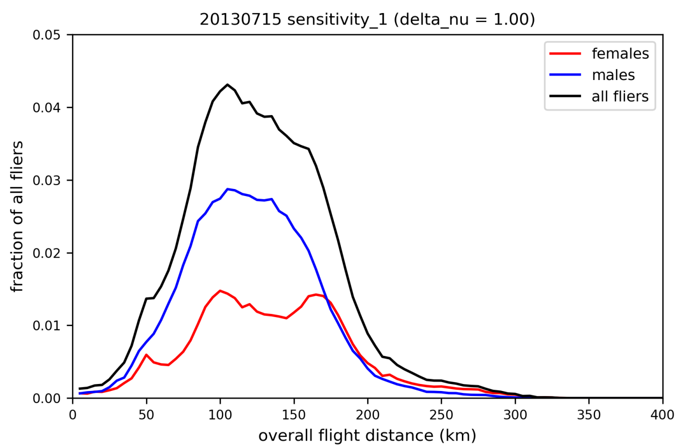
There is no way (yet) to count the SBW moth population, but say ~10^{11}

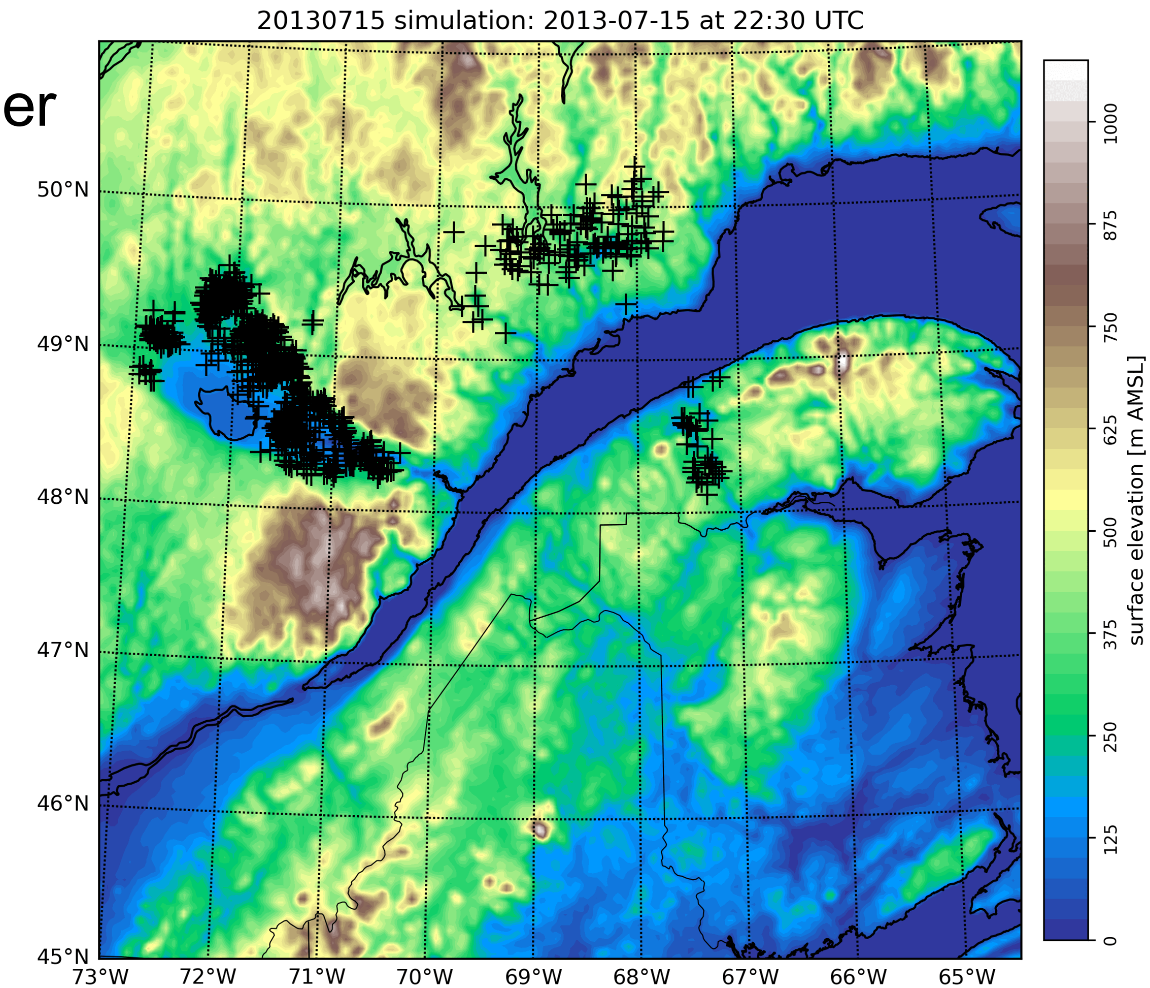
Simulate 10^3 random moths

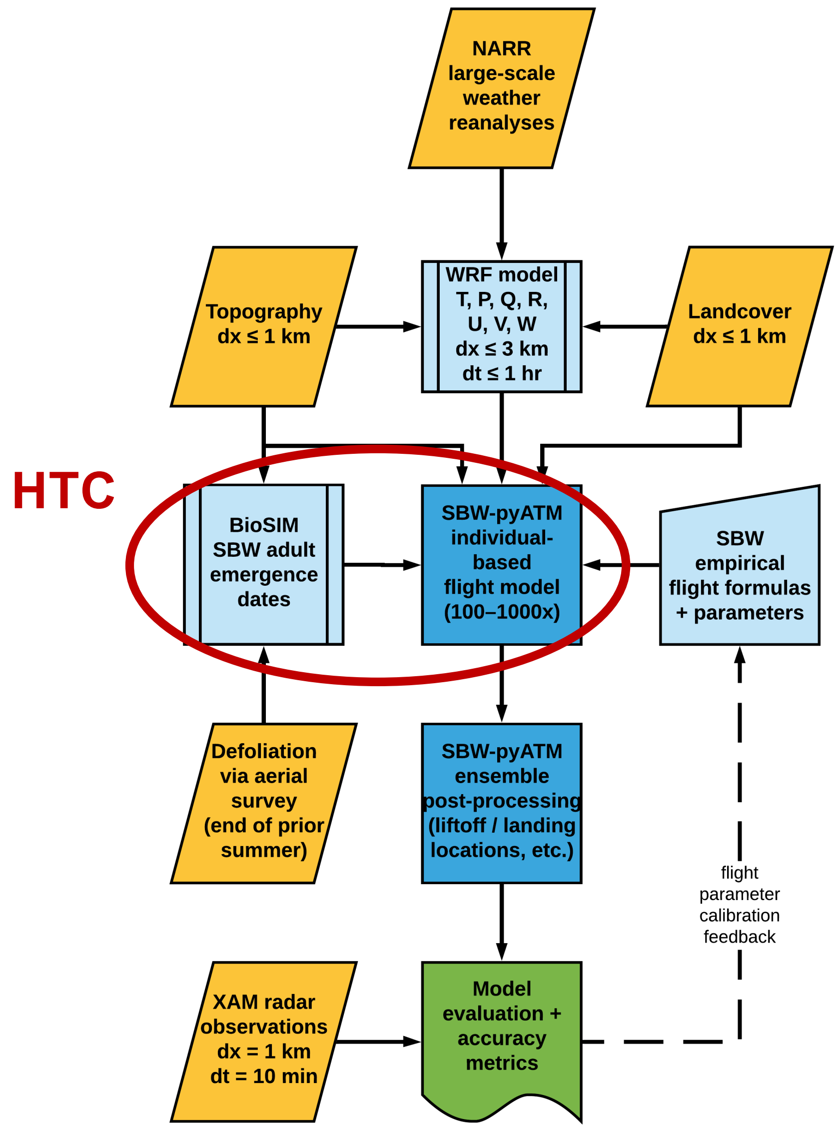
Python-based Atmospheric Transport Model (pyATM) for SBW moths

Adult dispersal is weather-driven,
occurs almost nightly in summer

M + F have diff. flight capabilities
→ flight altitudes + distances







Python-based Atmospheric Transport Model (pyATM) for SBW moths

There is no way (yet) to count the SBW moth population, but say ~10^{11}

Simulate 10^3 random moths
→ 2–12 GB mem, 10–18 GB disk, 2–8 h

Consider a representative (?) sample
→ 10^6 moths (~$1/10^5$ × the pop. guess)

So, simulate 10^3 random moths 10^3 times
→ Monte Carlo ensemble approach
→ HTC with UW + OSG resources

Also: calibration w/ radar, uncertain parameters, sequential nights, etc.

Python-based Atmospheric Transport Model (pyATM) for SBW moths

Part 1: Model description (pub'd Jan 2022)


Agricultural and Forest Meteorology 315 (2022) 108815

Contents lists available at ScienceDirect

Agricultural and Forest Meteorology

journal homepage: www.elsevier.com/locate/agrformet

Modeling weather-driven long-distance dispersal of spruce budworm moths (*Choristoneura fumiferana*). Part 1: Model description

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[b] USDA–Forest Service, Northern Research Station, Rhinelander, WI 54501, USA
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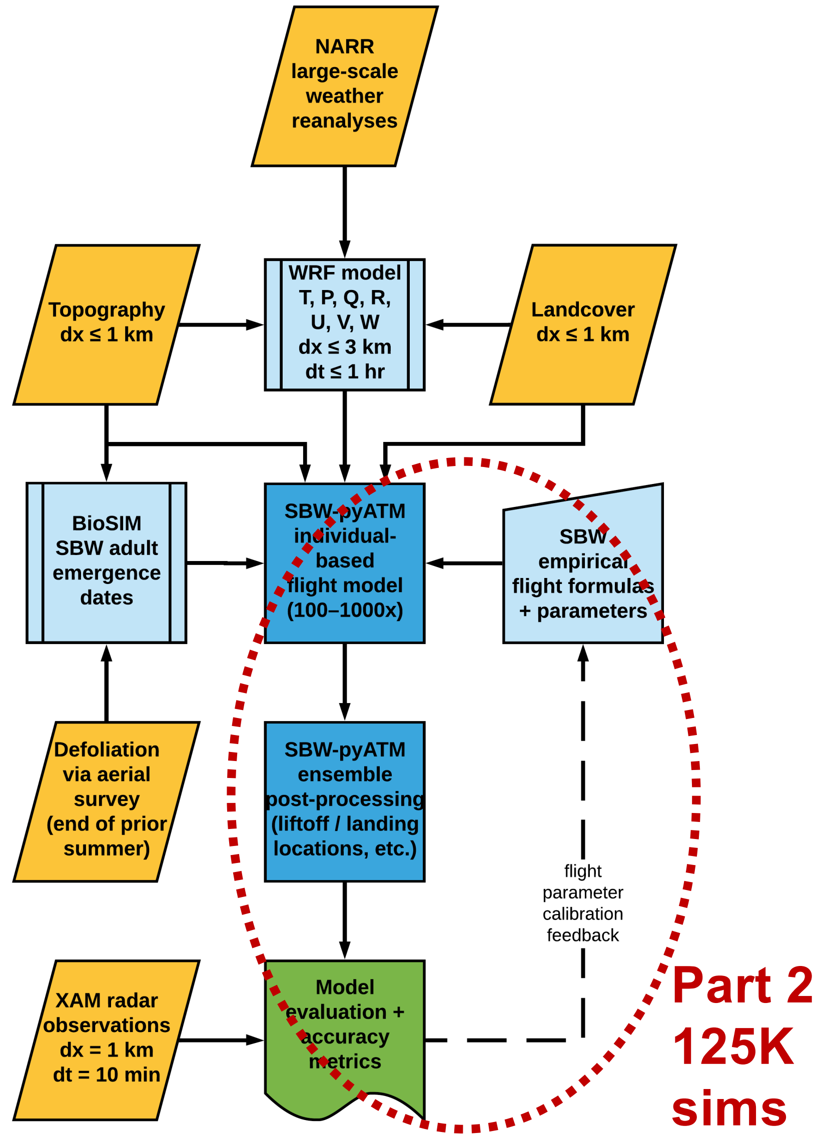
ARTICLE INFO

Keywords:
Aerobiology
Individual-based modeling
Insect outbreaks
Lepidoptera
Numerical modeling
Weather radar

ABSTRACT

Long-term studies of insect populations in the North American boreal forest have shown the vital importance of long-distance dispersal to the maintenance and expansion of insect outbreaks. In this work, we extend several concepts established previously in an empirically-based dispersal flight model with recent work on the physiology and behavior of the adult eastern spruce budworm (SBW) moth, *Choristoneura fumiferana* (Clemens). An outbreak of defoliating SBW in Quebec, ongoing since the mid-2000s, already covers millions of hectares of forests in eastern Canada and threatens to spread into neighboring areas through annual summertime episodes of long-distance dispersal. Such flight events in favorable conditions frequently include billions of SBW moths dispersing in the warm atmospheric boundary layer, typically starting around sunset and often lasting through several hours of wind-driven transport over hundreds of kilometers. Successful SBW dispersal to possibly distant host forest areas depends acutely on the weather. Here we describe the components and results of SBW–pyATM, an open-source individual-based modeling framework developed in Python for the simulation of these weather-driven SBW dispersal events. Using seasonal SBW phenology results from BioSIM at known outbreak locations and high-resolution Weather Research and Forecasting (WRF) model output, we focus on modeling dispersal flights over two successive nights in July 2013 in southern Quebec. Our flight model closely reproduces the SBW spatial patterns and motions observed by weather surveillance radar over the St. Lawrence estuary. With SBW–pyATM we can estimate landing locations for both male and female SBW and the resulting spatial patterns of egg distribution, allowing us eventually to forecast future larval defoliation activity in new locations where immigration could help overcome local limitations on SBW populations. This information could then support forest management decisions where SBW outbreaks threaten valuable resources.

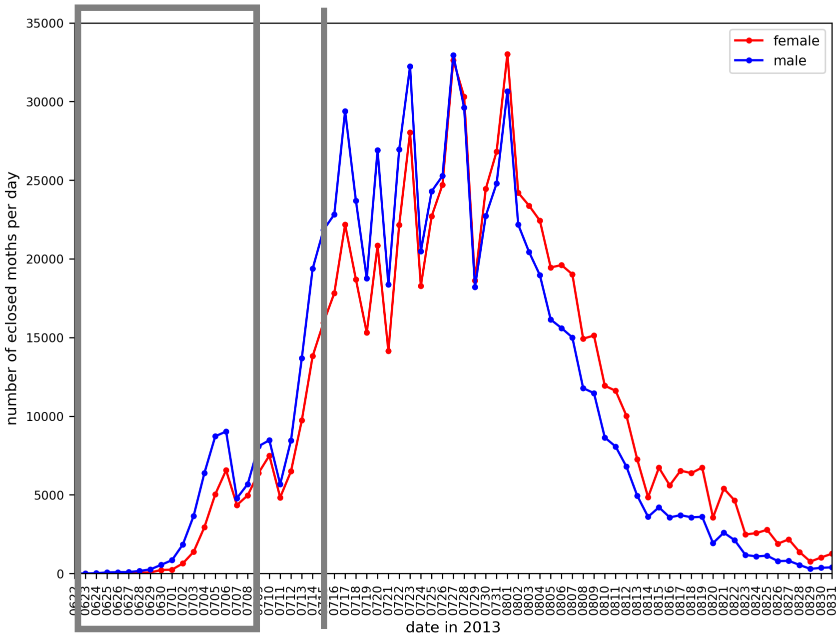
doi: 10.1016/j.agrformet.2022.108815



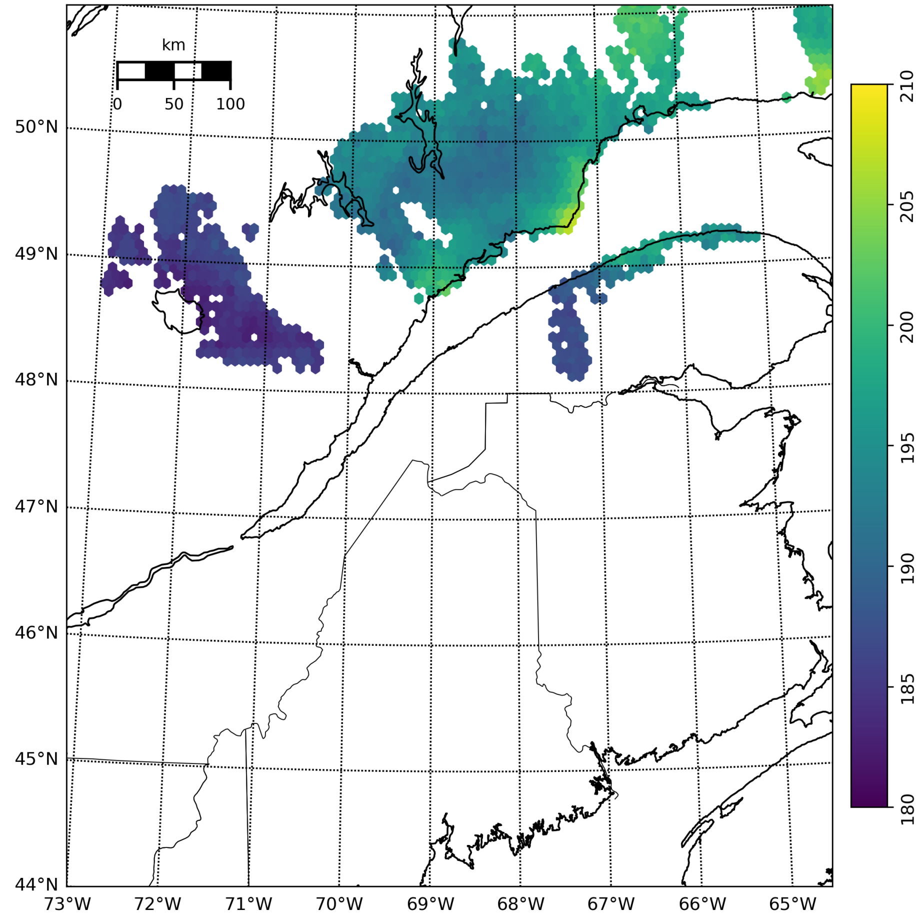
Python-based Atmospheric Transport Model (pyATM) for SBW moths

Adult dispersal is weather-driven, occurs almost nightly in summer

Each night's cohort includes "new" moths *and* those that survived the previous night(s)



2013 BioSIM median DOY for adult SBW eclosion



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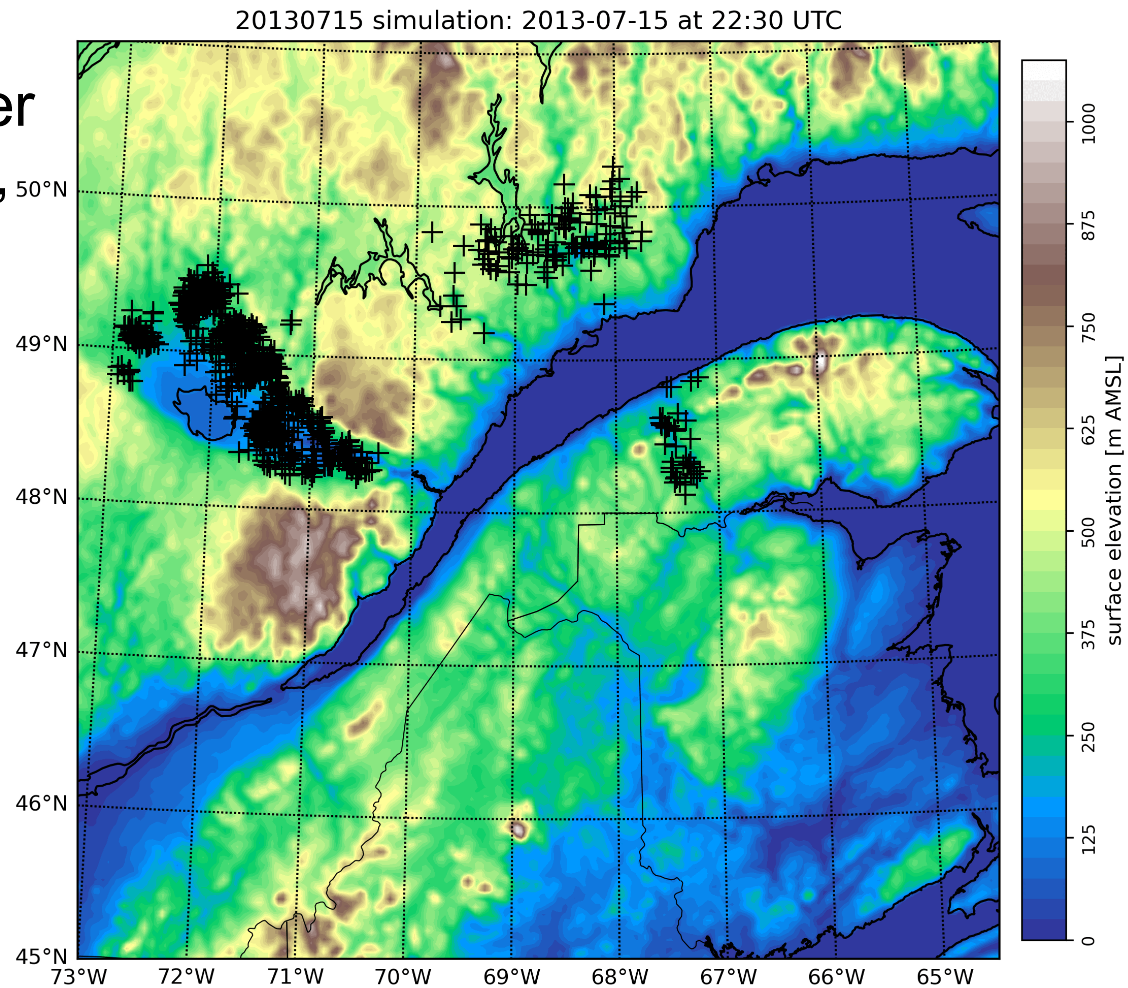


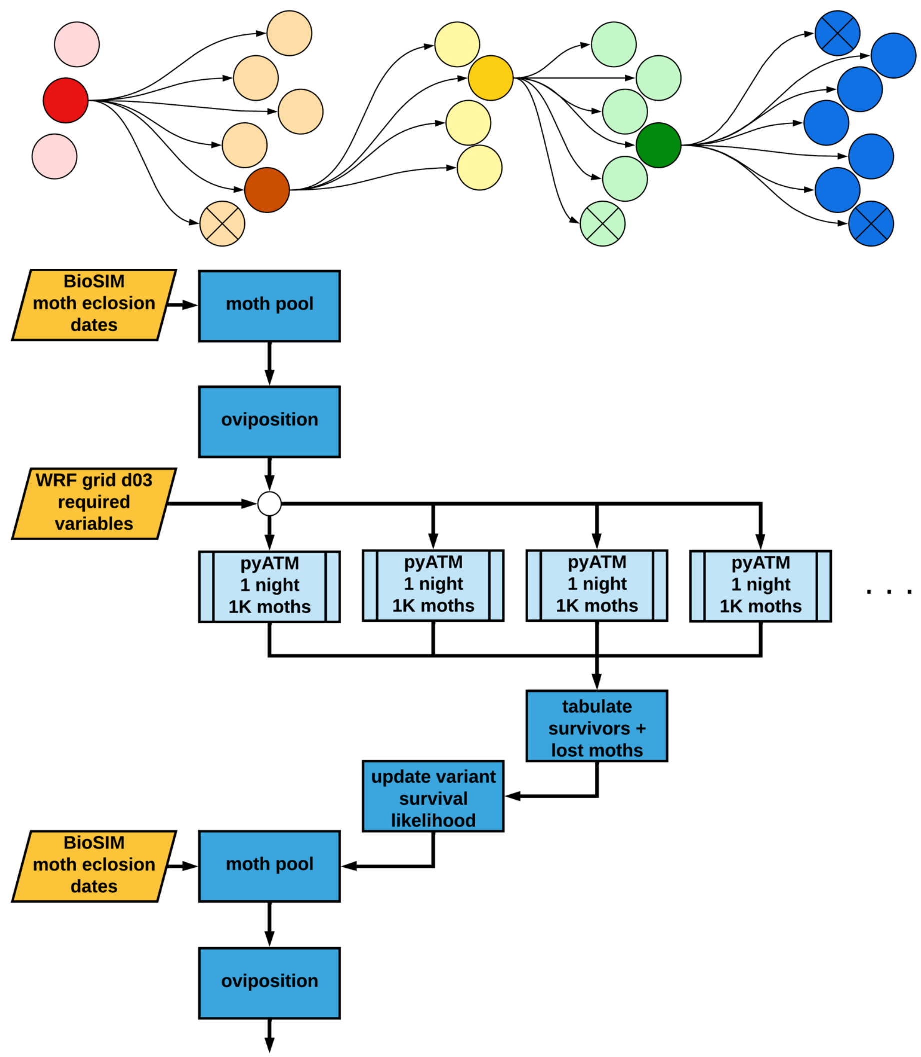
Python-based Atmospheric Transport Model (pyATM) for SBW moths

Stochastic simulations
- random subsets of available moths
- liftoff times vary with local conditions
- weather, esp. near the surface (BL)

→ Monte Carlo ensemble of simulations

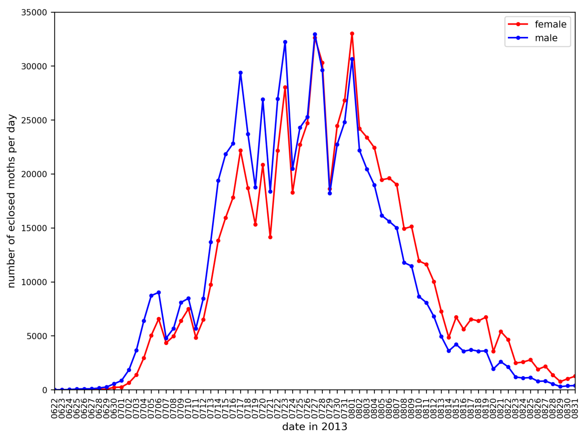
Sequential nightly simulations
- accounting variety of prior results
- compounded timelines + variants

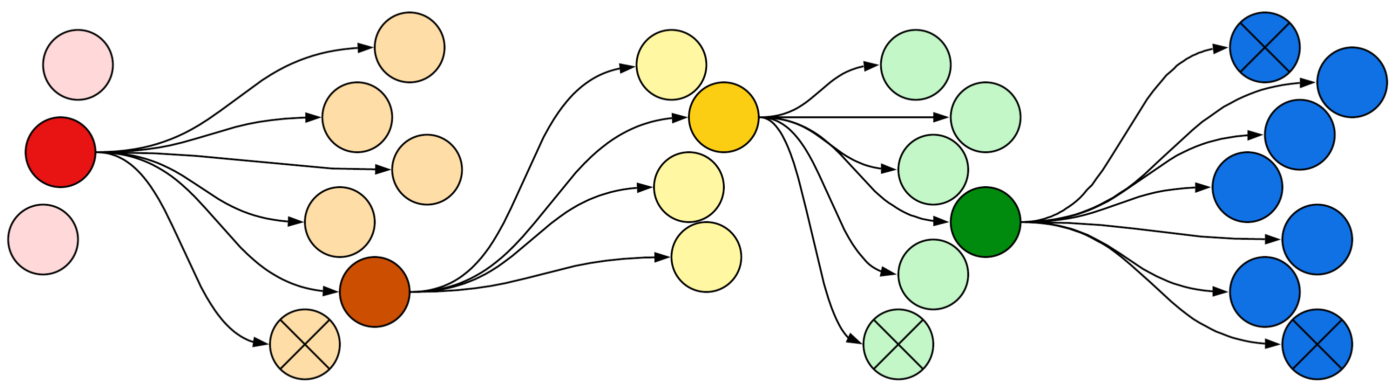
→ Markov chain Monte Carlo process with Bayesian likelihood updating



Python-based Atmospheric Transport Model (pyATM) for SBW moths

```
# 2013_sequential_dag.sub with daily accounting of moth population and dynamic generation of flight modeling ensembles

JOB SBM_20130624 ATM_WRF-NARR_preprocessing_first.sub
VARS SBM_20130624 grid="d03" begin_date="20130624" begin_year="2013"
SCRIPT POST SBM_20130624 ATM_WRF-NARR_preprocessing_post.sh d03 20130624 20130625

SUBDAG EXTERNAL ATM_20130624 ATM_WRF-NARR_d03_20130624_subdag.sub
PARENT SBM_20130624 CHILD ATM_20130624

JOB SBM_20130625 ATM_WRF-NARR_preprocessing.sub
VARS SBM_20130625 grid="d03" prev_date="20130624" begin_date="20130625" begin_year="2013"
SCRIPT PRE SBM_20130625 ATM_WRF-NARR_preprocessing_pre.sh d03 20130624
SCRIPT POST SBM_20130625 ATM_WRF-NARR_preprocessing_post.sh d03 20130625 20130626
PARENT ATM_20130624 CHILD SBM_20130625

SUBDAG EXTERNAL ATM_20130625 ATM_WRF-NARR_d03_20130625_subdag.sub
PARENT SBM_20130625 CHILD ATM_20130625

...
```





Python-based Atmospheric Transport Model (pyATM) for SBW moths

```
# ATM_WRF-NARR_d03_20130624_subdag.sub using dynamic generation of flight modeling ensemble

JOB ATM_20130624 ATM_WRF-NARR.sub
VARS ATM_20130624 grid="d03" begin_date="20130624" end_date="20130625" nreps="10"
SCRIPT PRE ATM_20130624 ATM_WRF-NARR_pre.sh d03 20130624 20130625
SCRIPT POST ATM_20130624 ATM_WRF-NARR_post.sh d03 20130624 20130625
```

```
# ATM_WRF-NARR.sub template submit file using Flocking + Glide-In (OSG) with daily moth input and WRF-based input

universe = vanilla
log = ATM_WRF-NARR_$(grid)_$(begin_date)_default_$(Process).log
output = ATM_WRF-NARR_$(grid)_$(begin_date)_default_$(Process).out
error = ATM_WRF-NARR_$(grid)_$(begin_date)_default_$(Process).err
requirements = (OpSys == "LINUX") && (OpSysMajorVer >= 7)
transfer_input_files =
    miniconda.tar.gz,Circadian_calculations.py,Clock.py,Flier_class.py,Flier_grids.py,Flier_setup.py,Flier_summary.py,
    Geography.py,Interpolation.py,Map_class.py,Model_control.py,Model_initialization.py,Model_wrapup.py,Plots_gen.py,
    Radar_class.py,SBW_empirical.py,Simulation_specifications_WRF-NARR_$(grid)_$(begin_date).py,Solar_calculations.py,
    Temporal_operations.py,WRFgrids_class.py,ATM_WRF-NARR_$(grid)_$(begin_date)_ready_moths.csv,
    WRF_out_reduced_$(grid)_$(begin_date)06-$(end_date)12.tar.gz
executable = ATM_WRF-NARR.sh
arguments = $(grid) $(begin_date) $(end_date) $(Process)
request_cpus = 1
request_memory = 8GB
request_disk = 36GB
+WantFlocking = true
+WantGlideIn = true
queue $(nreps)
```

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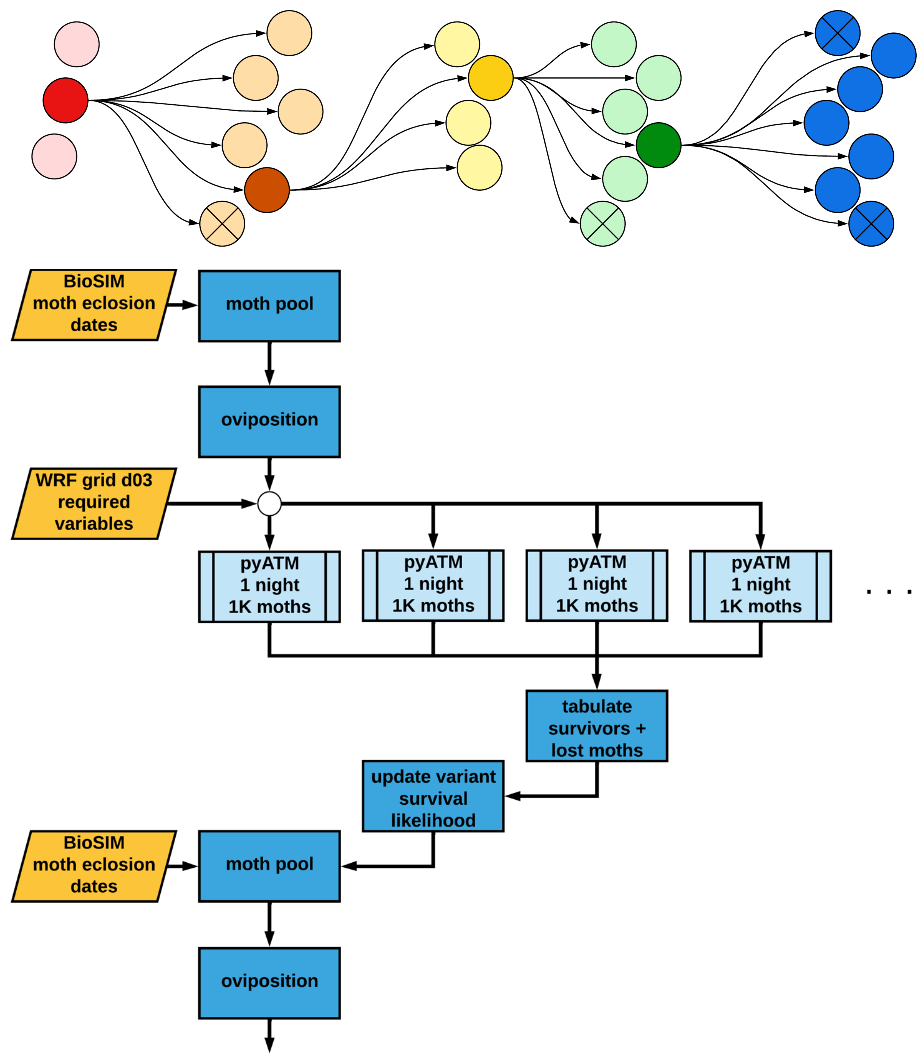
→ Markov chain Monte Carlo process with Bayesian likelihood updating

→ Probabilistic outcomes over the mating + dispersal + oviposition period



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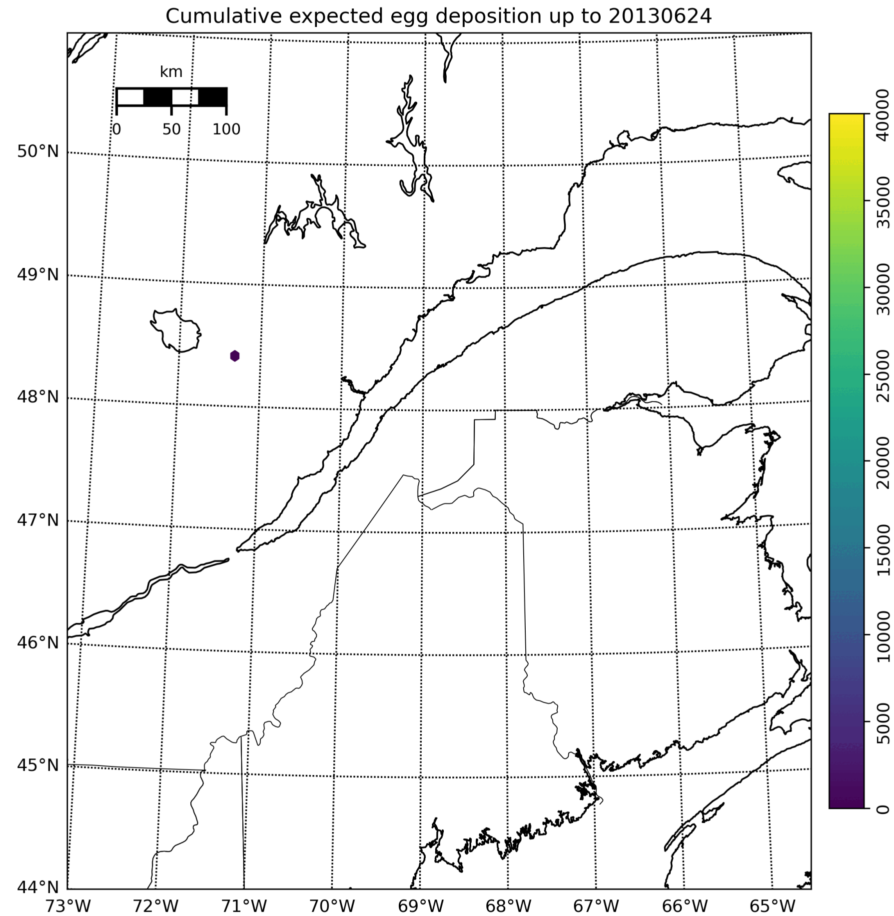
Simulated 2013 daily cumulative egg deposition up to 9 July



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M immigration → increased poss. of mating success

Simulated 2013 daily M landings + F eclosion up to 9 July