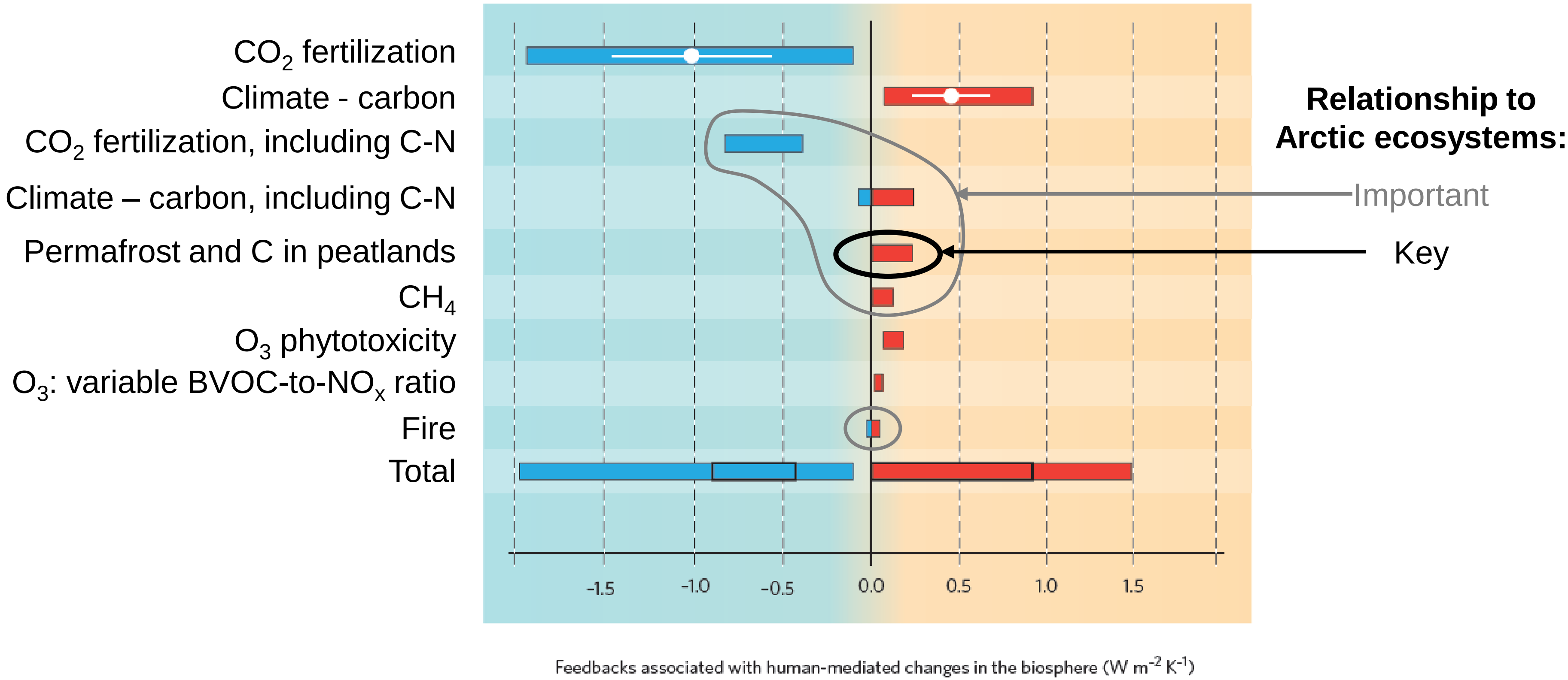
Modeling ecosystem-climate interactions in the high Arctic: Challenges and potential solutions

Presented by Peter Thornton, Oak Ridge National Laboratory

Arctic terrestrial ecosystem processes play a critical role in prediction of future climate response to GHG forcing



Recent assessment finds that Arctic processes make significant contributions to overall land ecosystem - climate feedbacks

Figure: Arneth et al. 2010, Nature Geosci.

Summary of recent Arctic modeling results from global/regional models

- CLM4 historical (ORNL and LBNL results)
  - CO_2 effect vs. climate change effect on total land C storage, influence of vertical structure on soil C.
- TEM historical (Hayes et al. 2011, GBC)
  - Single-forcing effects in Arctic and tundra
  - Highlights influence of active layer thickening
- ORCHIDEE historical and future (Koven et al. 2011, PNAS)
  - Active layer dynamics (no N cycle)
- CESM1 climate prediction (RCP4.5, ORNL results)
  - Changes in hydrology, surface energy exchange, vegetation dynamics, and total C storage.

CLM4 results: adding vertical structure

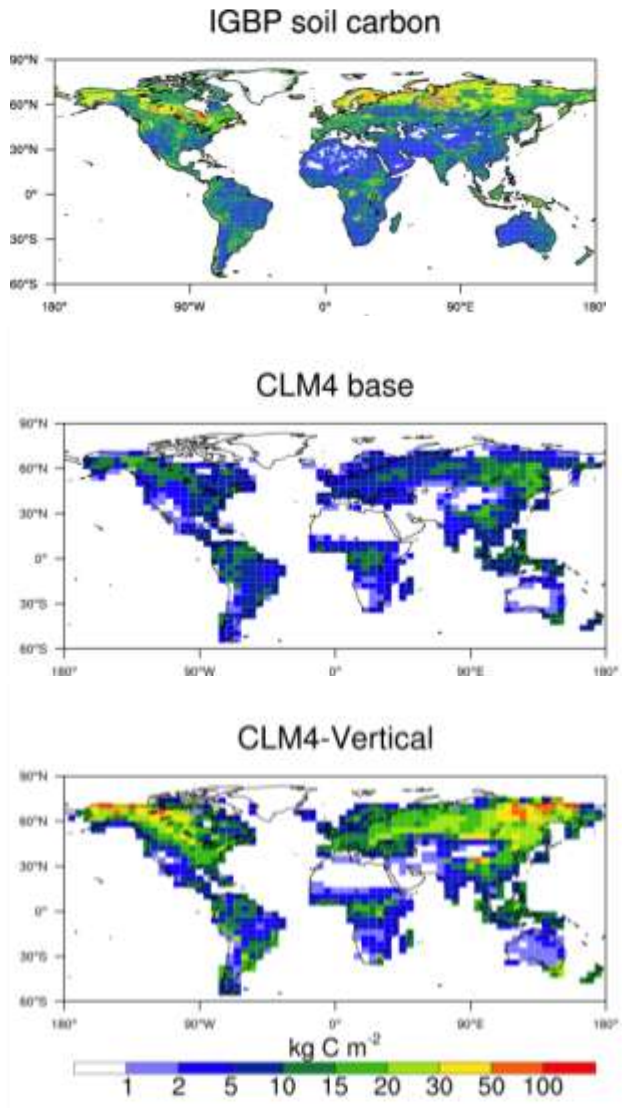
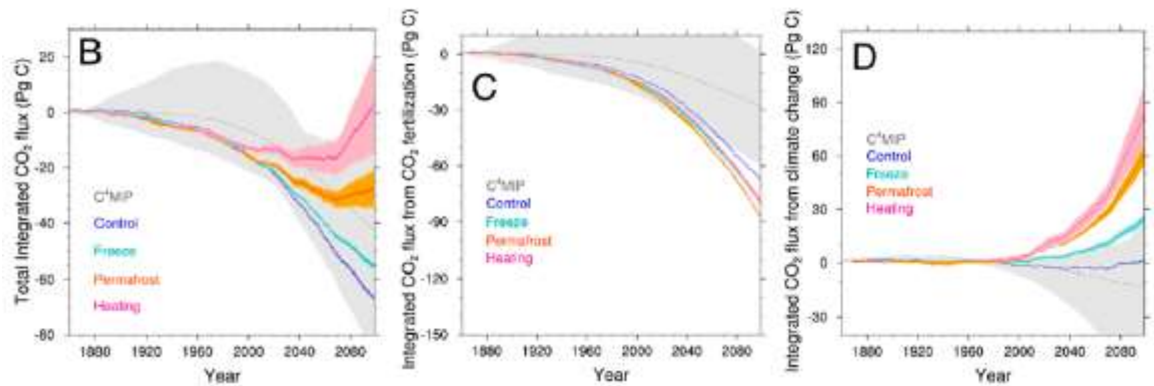


Figure: Koven et al., in prep.

ORCHIDEE results: pan-Arctic

Figure: Koven et al. 2011, PNAS

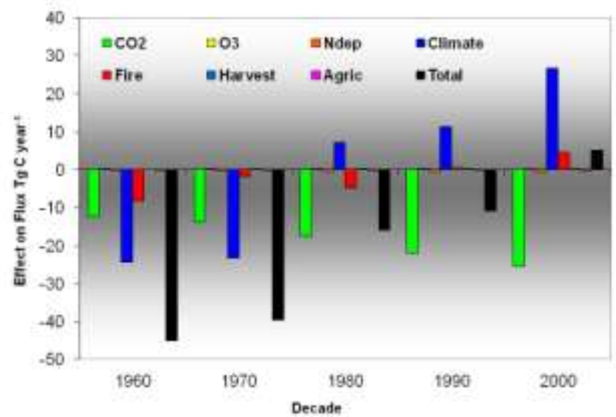


Influence of CO_2 and climate on total carbon

Influence of rising CO_2 on total carbon

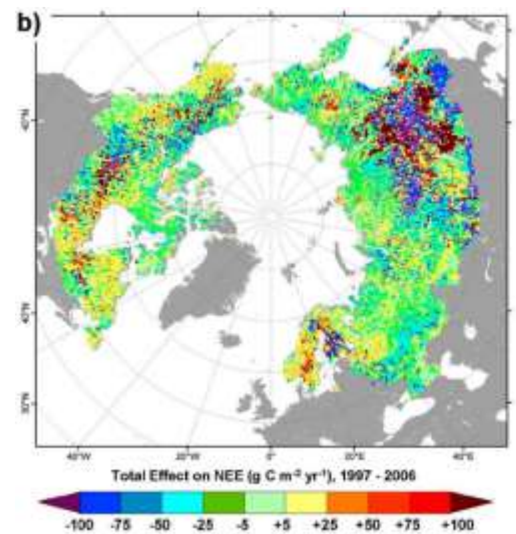
Influence of climate on total carbon

TEM results: Boreal and Arctic



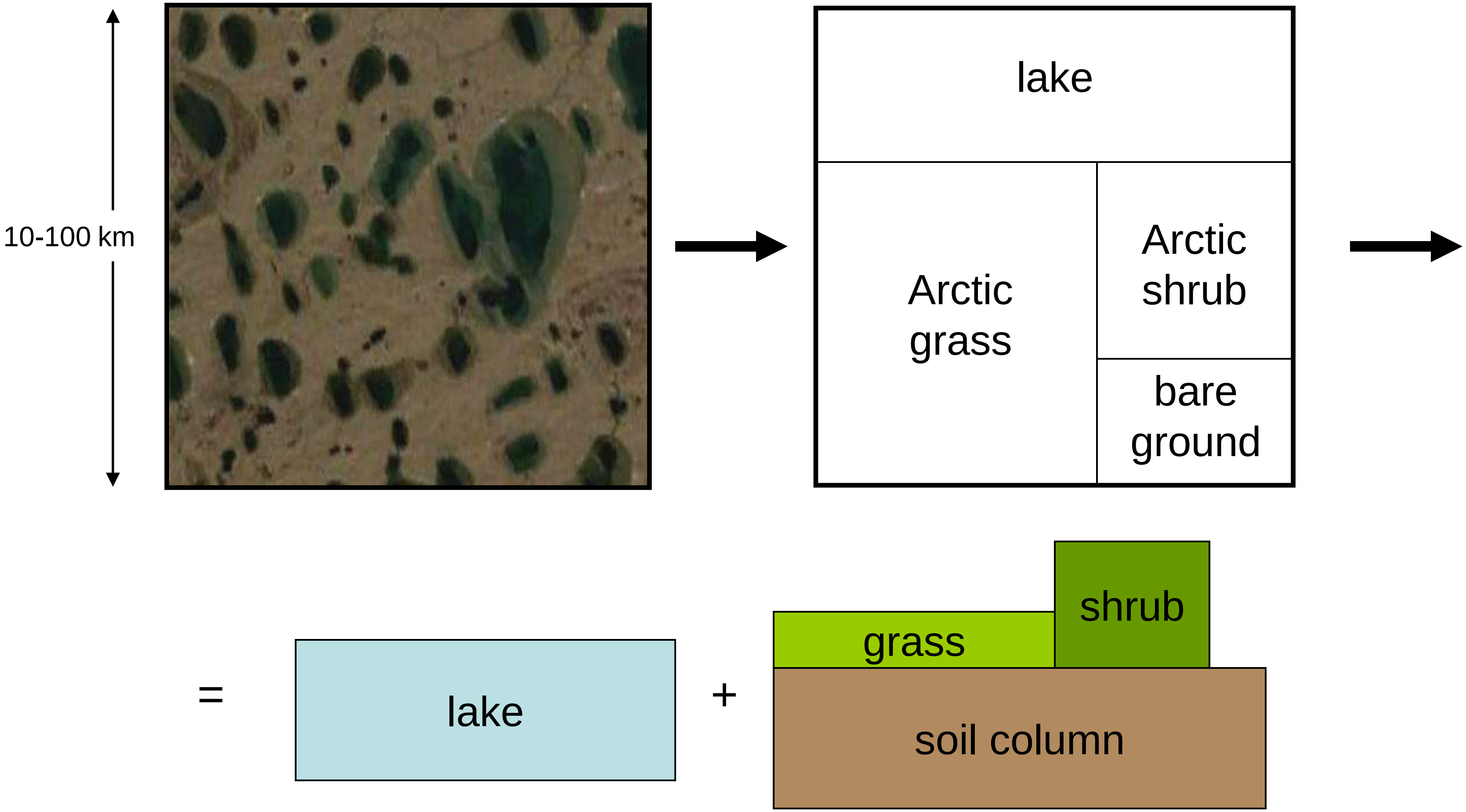
Influence of multiple forcing factors on decadal NEE over tundra regions of North America

Integrated effects of all factors on NEE for most recent decade



Figures: Hayes et al. 2011, GBC

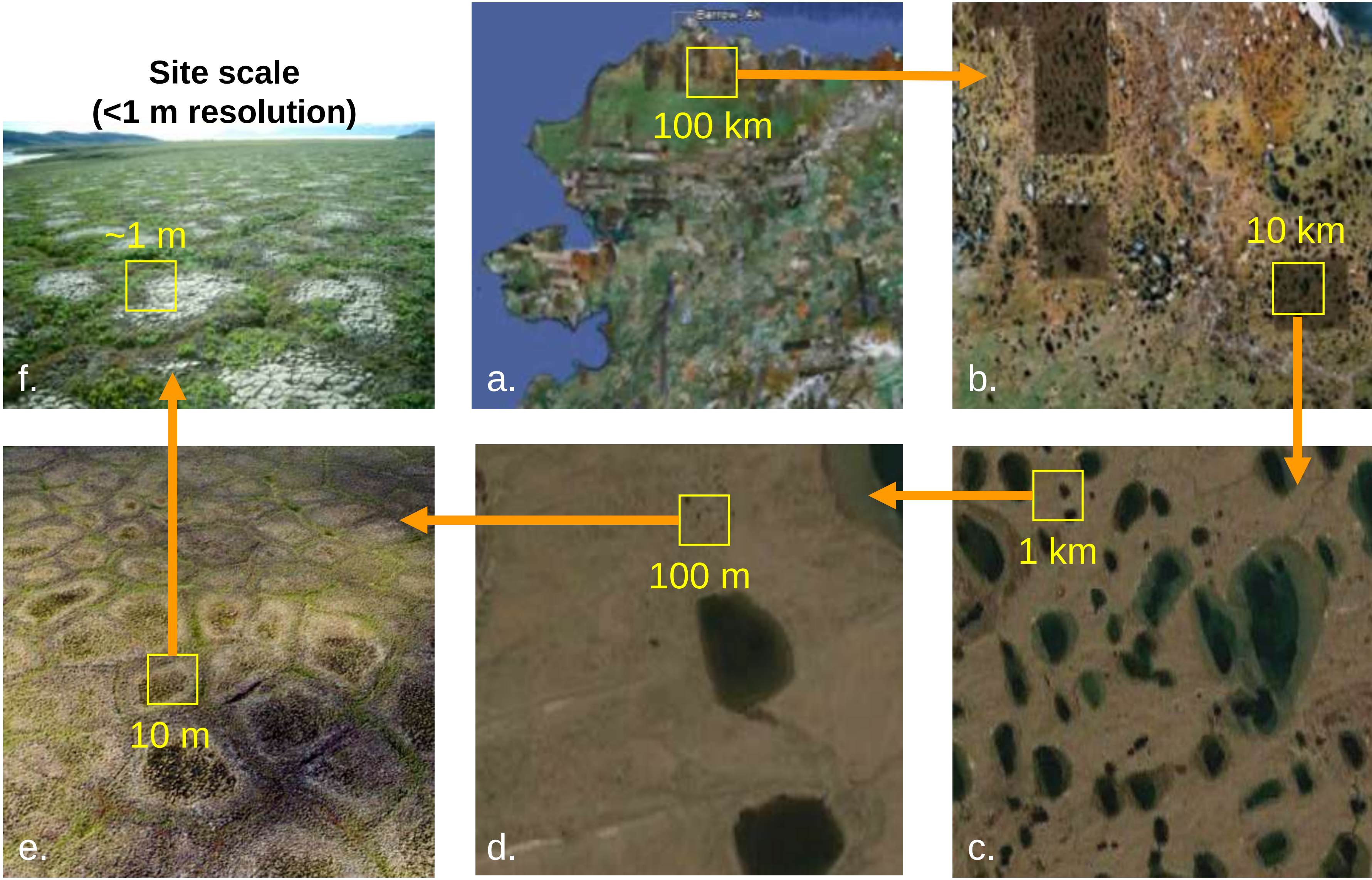
Current scaling approach for land component of climate prediction model (e.g. CLM4)



Best ESMs currently use quasi one dimensional approach, with assumption of linear scaling

Hypothesis: Linear scaling not a good assumption in Arctic tundra landscapes under warming scenario

Typical GCM / ESM scales (1°x1°) ≈ 100km

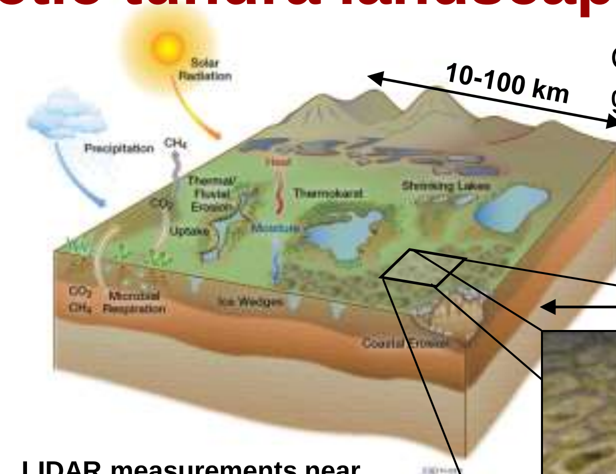


Landscape scales (100 m to 10 km)

3-D process-resolving Arctic tundra landscape simulator

Process requirements

- Subsurface
  - Permafrost
  - Differential ice concentrations
  - Active layer
  - Biogeochemistry
- Surface
  - Deformable topography
  - Surface flow and dynamic flow paths
  - Snowpack dynamics
  - Vegetation dynamics
- Near-surface atmosphere
  - Canopy interactions with surface wind, humidity, temperature, and radiation balance
  - Influence of microtopography on near-surface weather



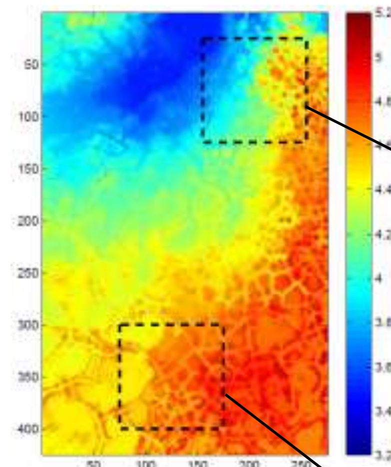
10-100 km

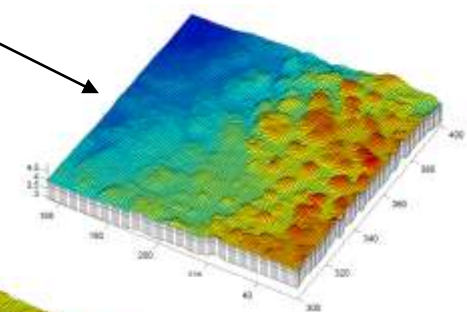
Climate model grid-scale

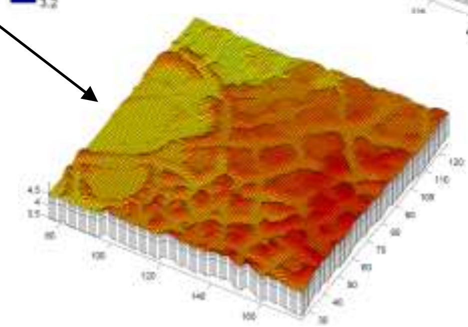
3-D landscape model scale

~100 m

LIDAR measurements near Barrow



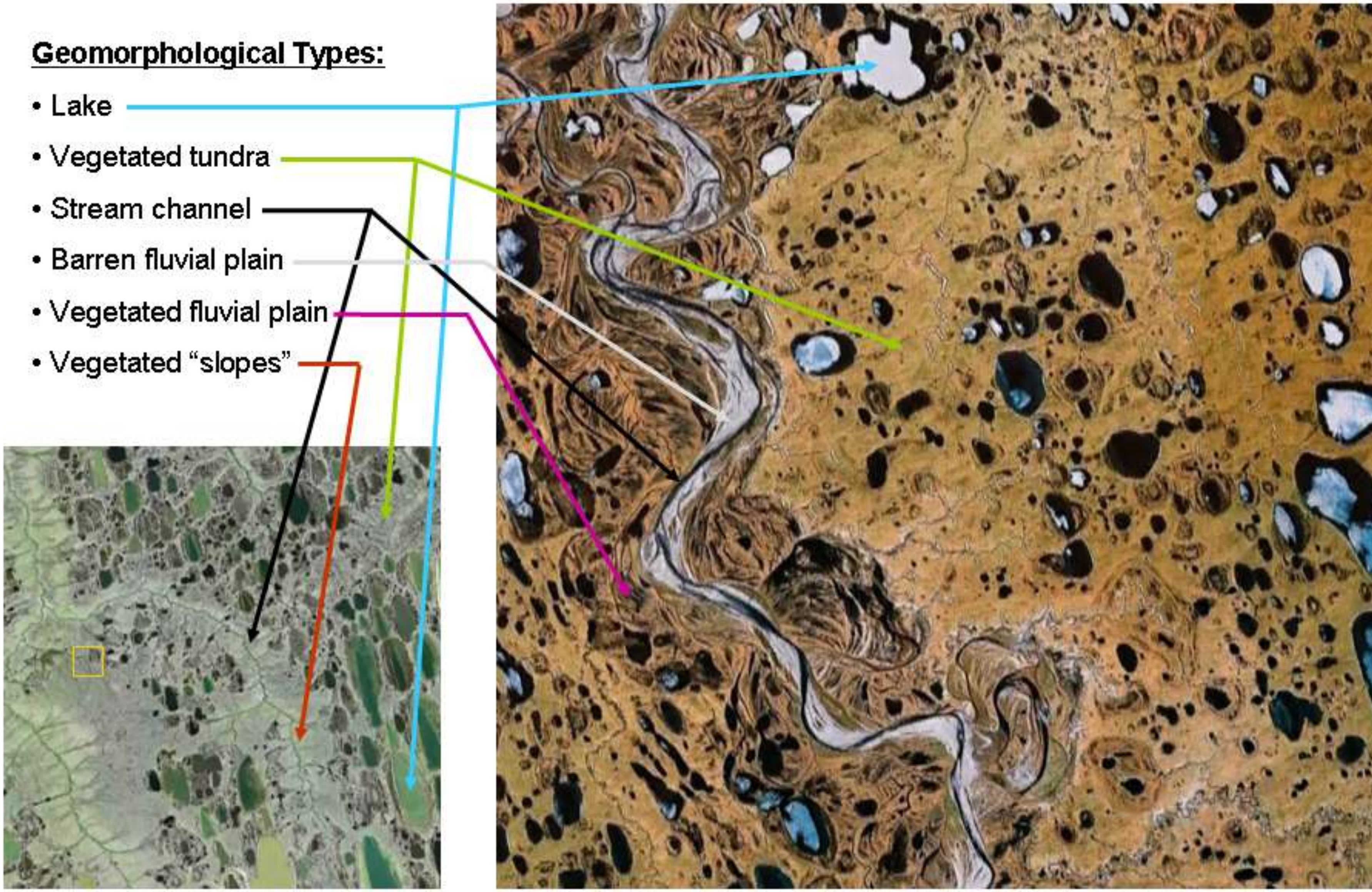




Example 3-D landscape model grids

Spatial characteristics:
Domain: approx. 100m x 100m
Resolution: ~10 cm (horiz), variable cm+ (vert)
Temporal characteristics:
Domain: decades to century
Resolution: sub-hourly

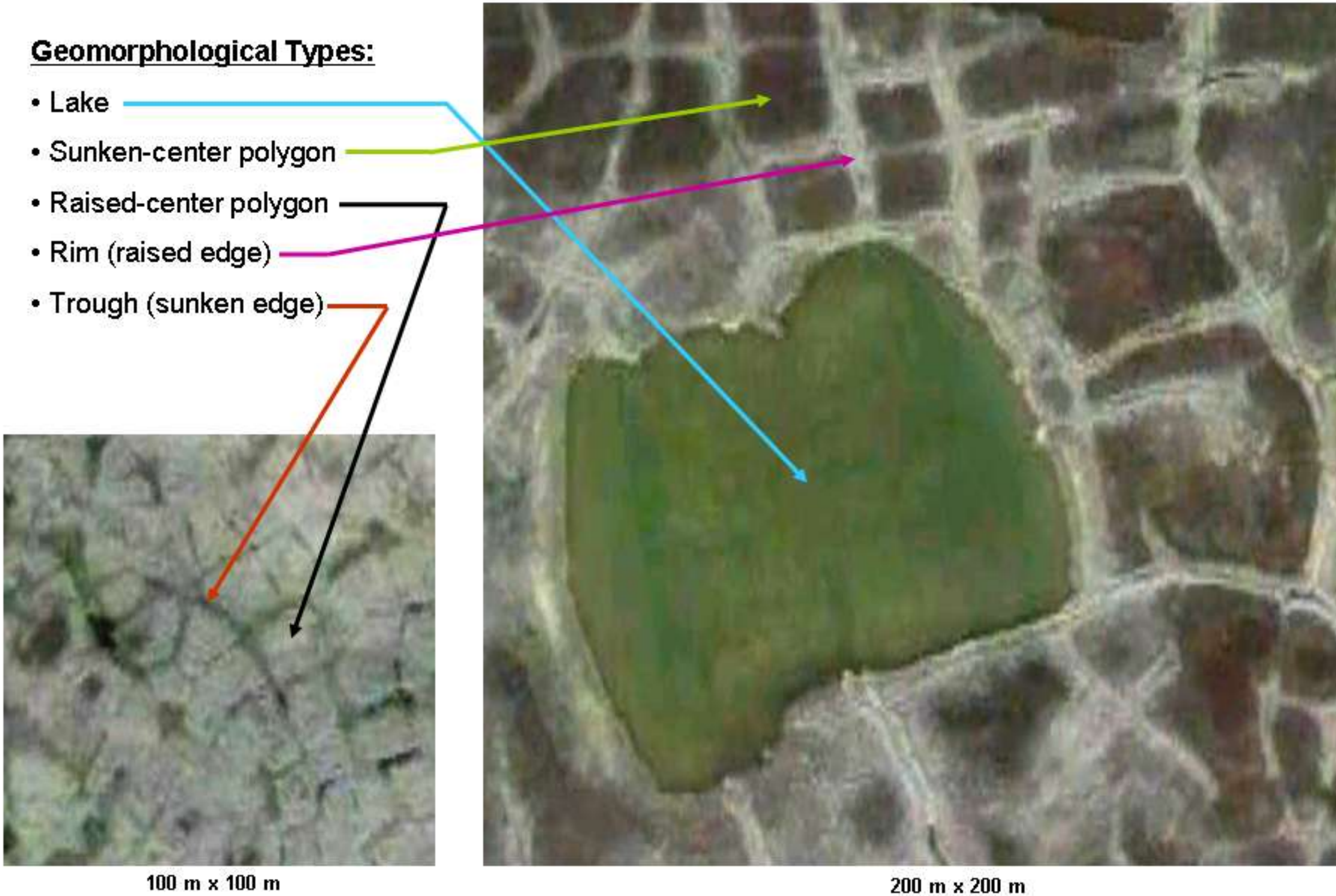
Sub-grid representation of geomorphologically distinct landscape elements



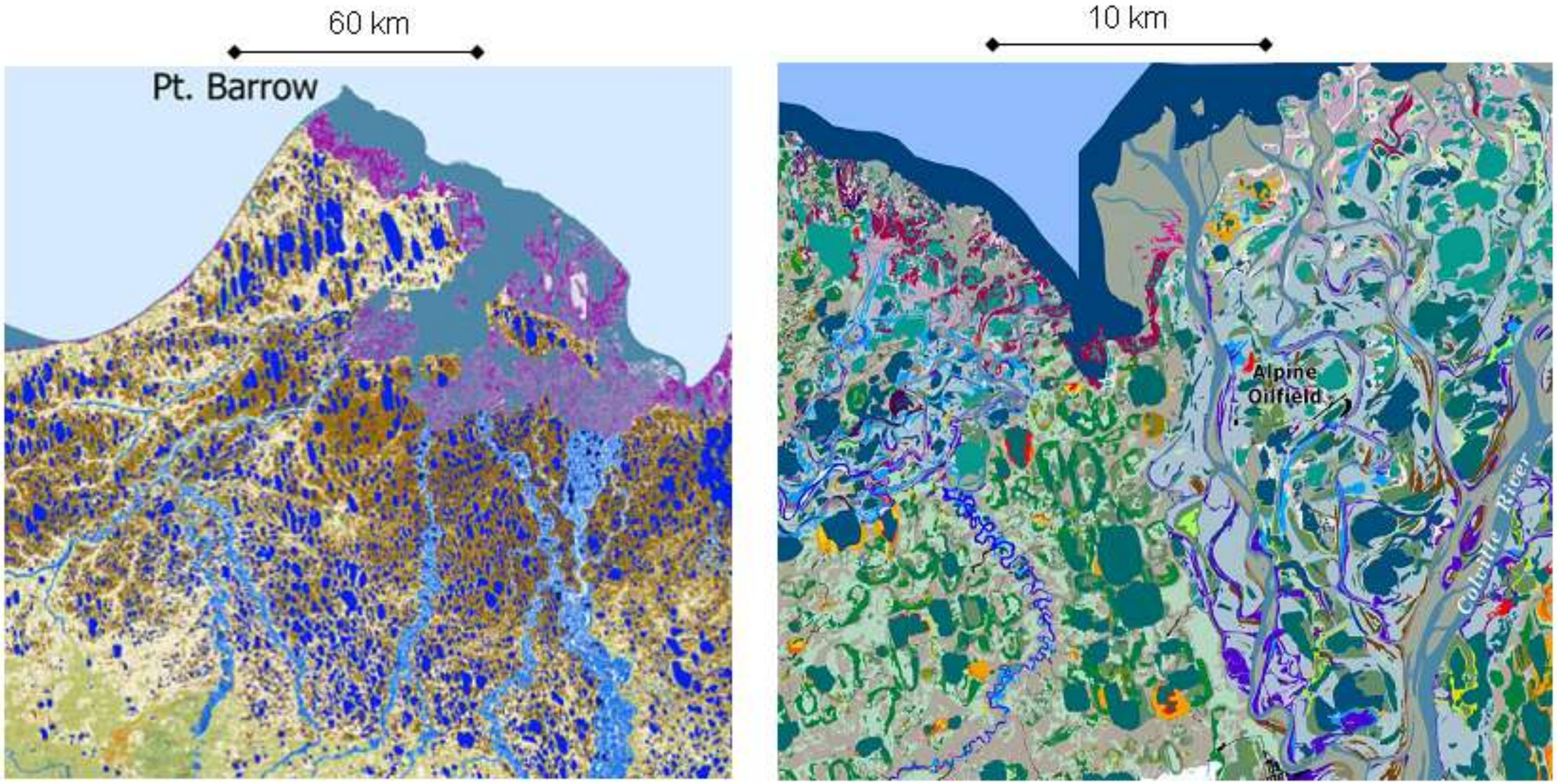
15 km x 15 km

30 km x 30 km

Sub-grid representation of geomorphologically distinct landscape elements

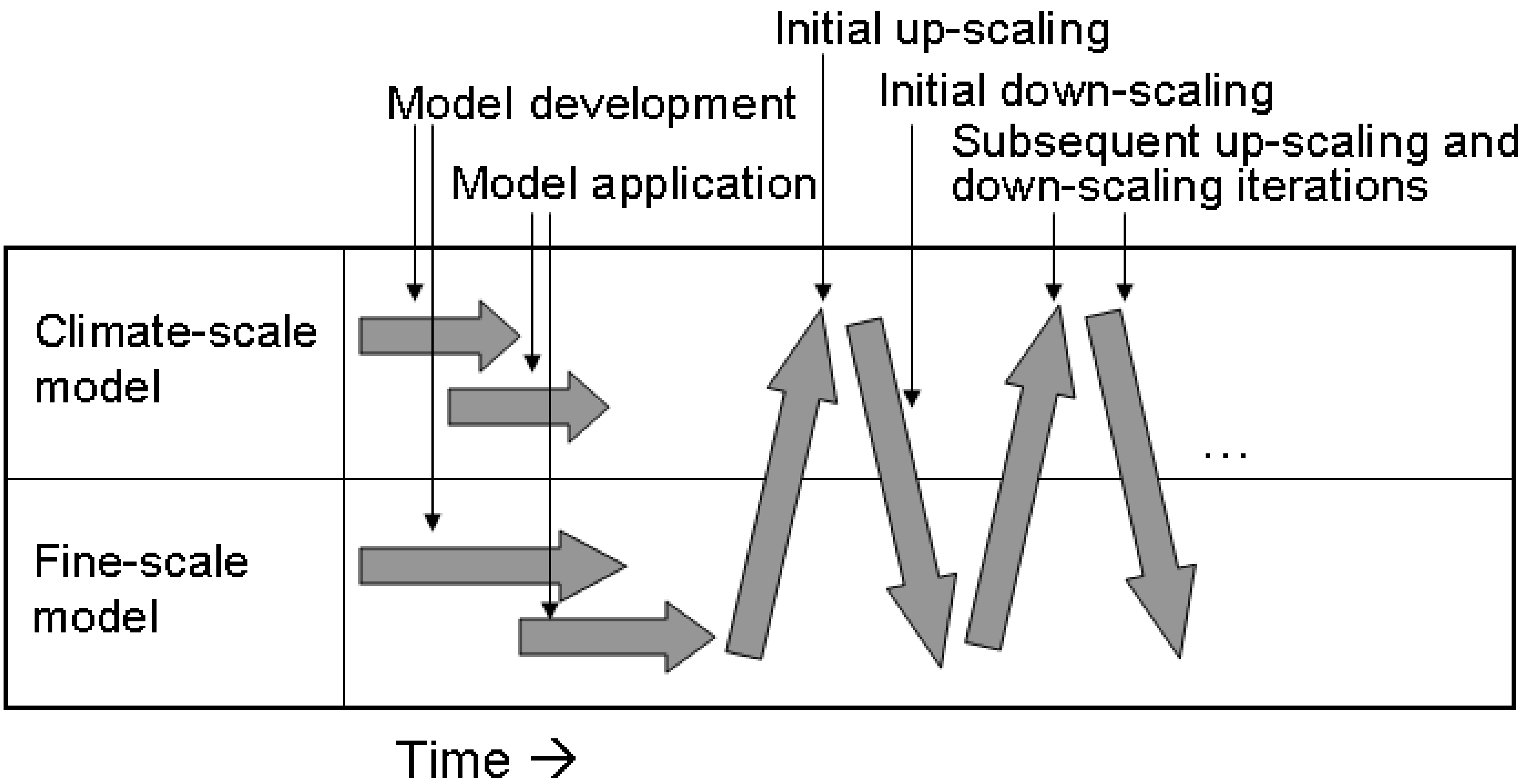


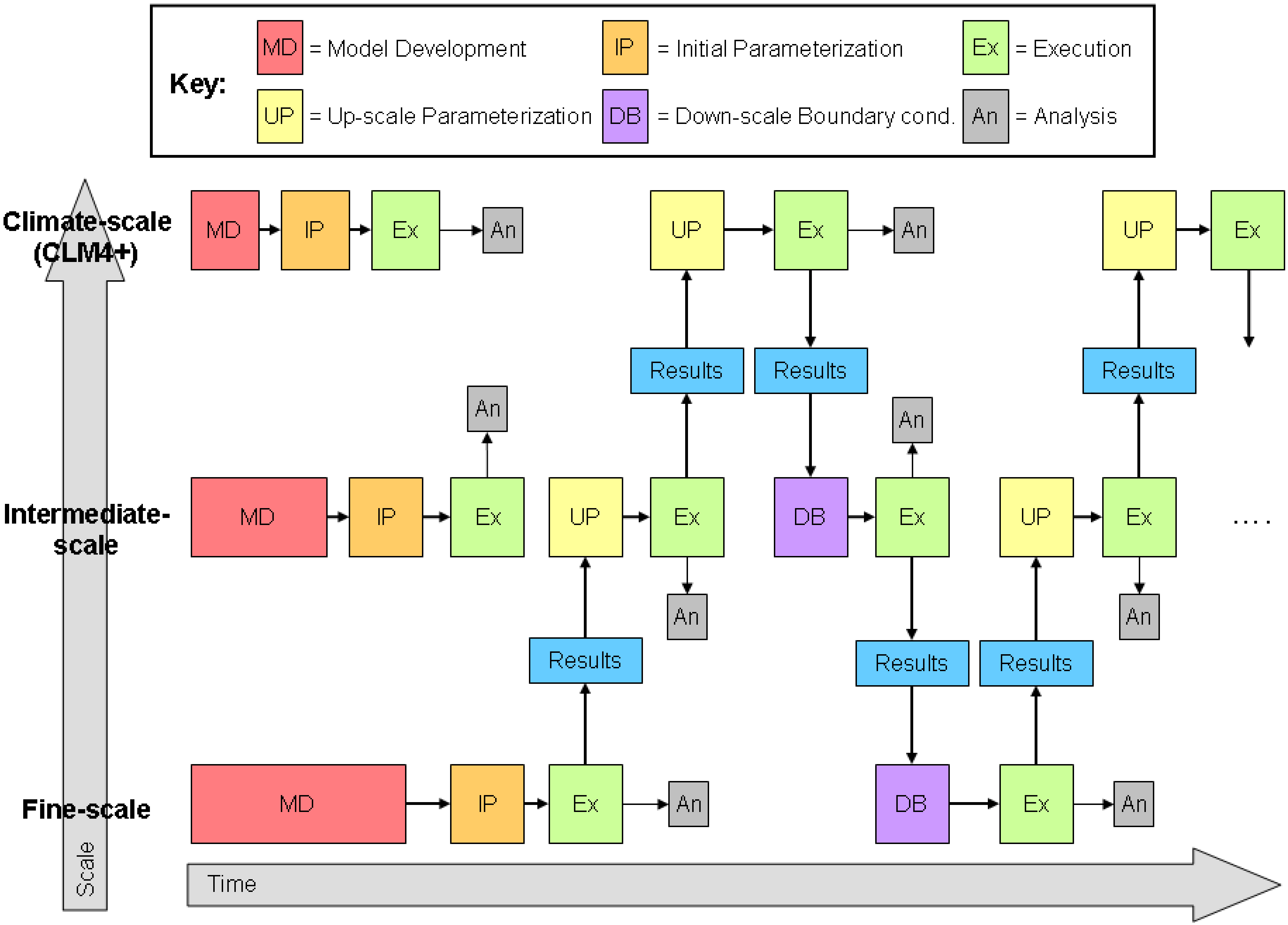
Automated mapping of geomorphological units on Arctic coastal plain



Subsets from two recent remote sensing based efforts to map geomorphological units across the Alaskan North Slope tundra region. Left: from Jorgensen and Heiner, 2004. Right: from Jorgensen et al. 2005.

Up-scaling and down-scaling to achieve improved climate prediction





Key:
MD = Model Development
IP = Initial Parameterization
Ex = Execution
UP = Up-scale Parameterization
DB = Down-scale Boundary cond.
An = Analysis
Climate-scale (CLM4+)
Intermediate-scale
Fine-scale
MD
IP
Ex
An
UP
Ex
An
UP
Ex
Results
Results
Results
An
MD
IP
Ex
UP
Ex
DB
Ex
An
UP
Ex
....
An
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Results
Results
Results
MD
IP
Ex
An
DB
Ex
An
Scale
Time