Permafrost Modeling Toolbox

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with help of Elchin Jafarov, Scott Stewart, Kevin Schaefer

Objectives

- Learn about the development goals and status of implementation of the Permafrost Toolbox.

- Gain ability in running simulations in two models and visualize results of permafrost occurrence, soil temperature and active layer thickness for Alaska.

- Contribute to the discussion of future development of the modeling system.

Outline of Clinic

- Lecture (30 minutes)
- Demonstration of permafrost models in WMT

- Hands-on exercises with permafrost toolbox
- (60 minutes)

- Discussion on the future developments
- and more advanced models (30 minutes)

Why

- The state of Arctic permafrost is an essential climate indicator and carbon emissions from thawing permafrost will amplify anthropogenic warming.

- Observations can quantify the current state of permafrost, but we need models to make predictions of future permafrost conditions

Our team



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Mark Piper, CU Boulder
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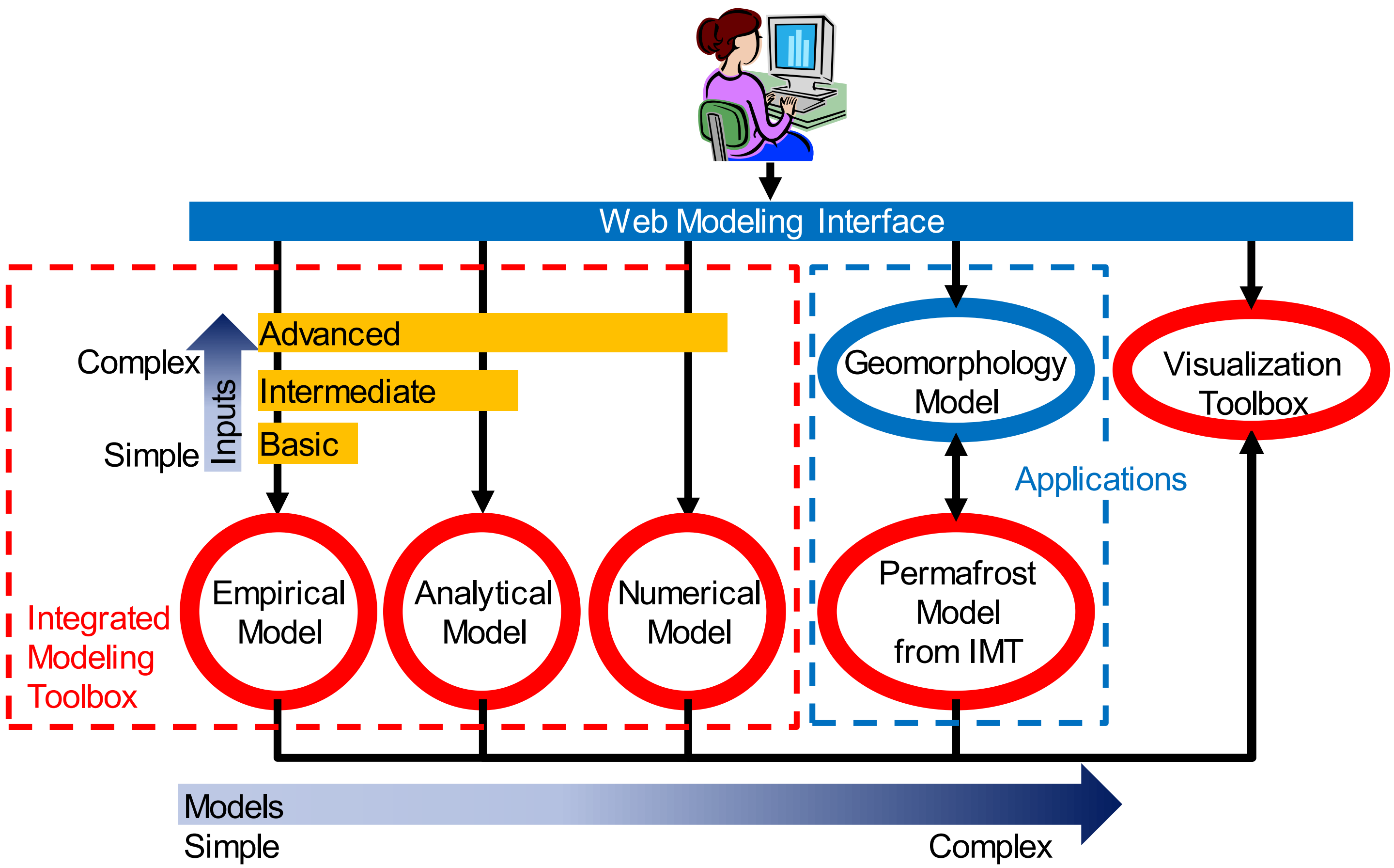
Gary Clow, USGS




Goal

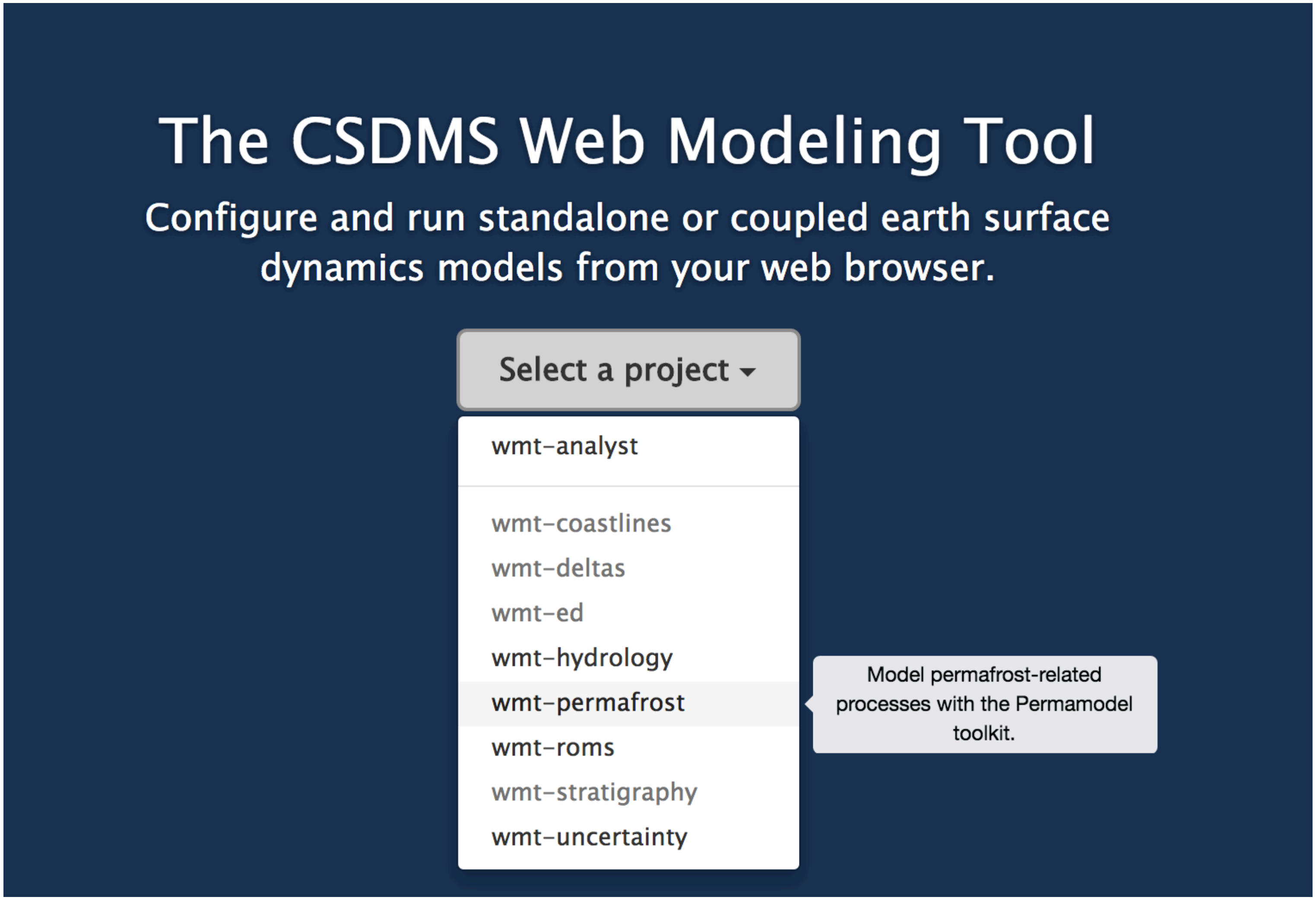
Permafrost Modeling toolbox develops easy-to-access and comprehensive cyberinfrastructure to promote permafrost modeling

Vision for Permafrost Modeling Toolbox



- Models ranging in complexity
- Allow input data to easily be ingested
- Web interface for ease of use
- Ultimate goal: coupled modeling across domains

Web Modeling Tool

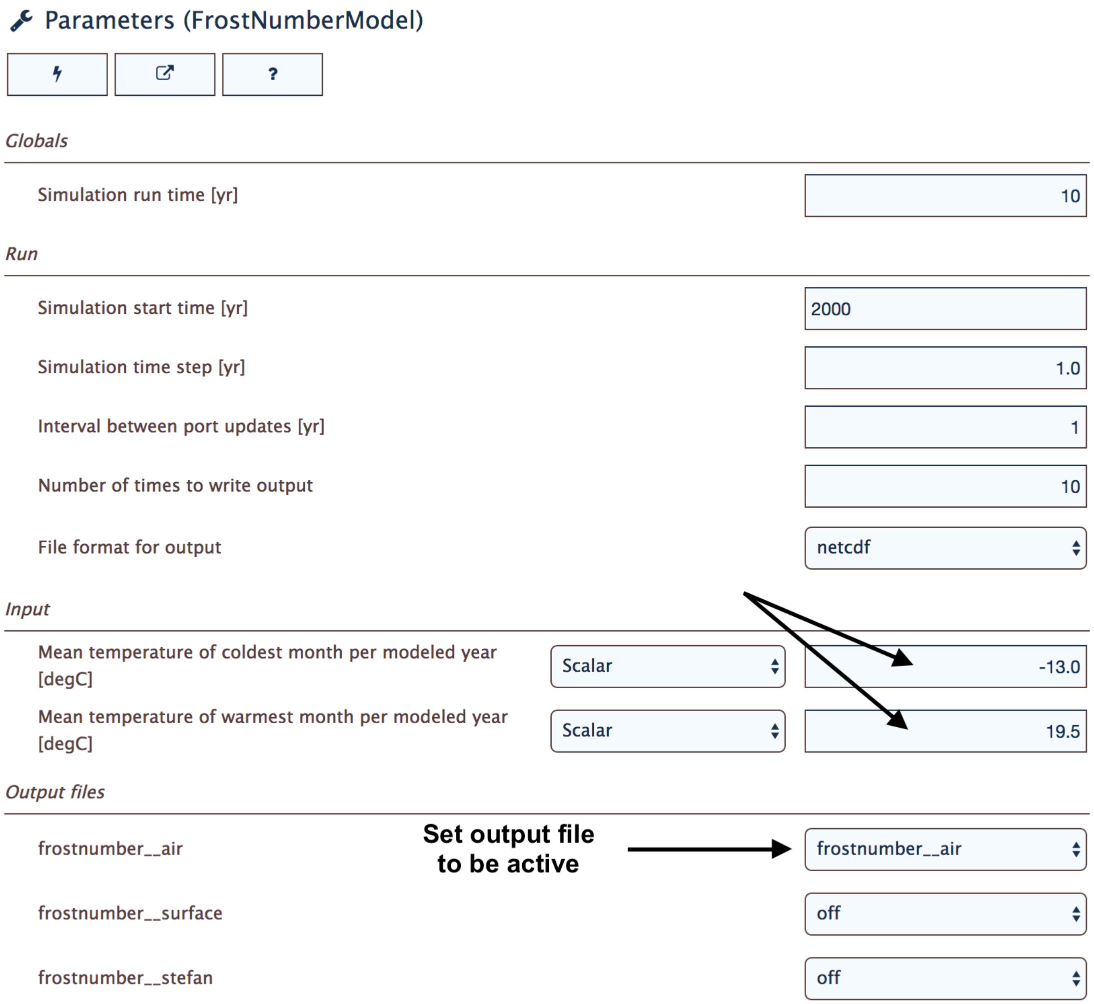


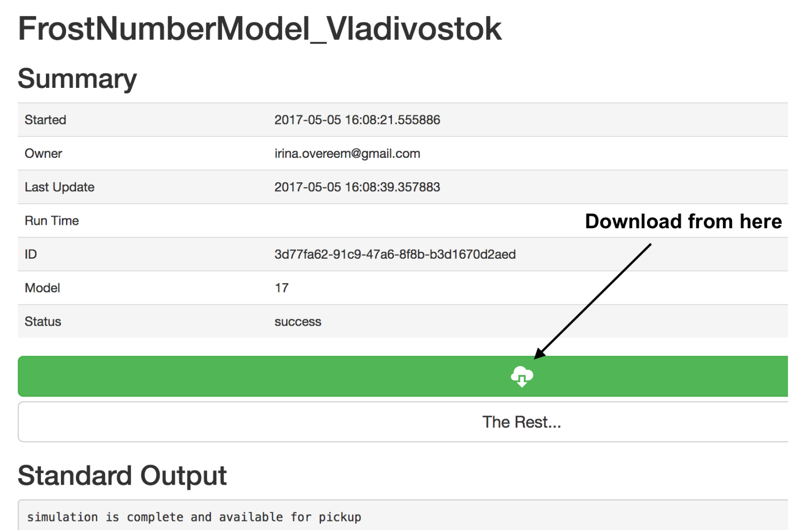
https://csdms.colorado.edu/wmt/

Develop Models as ‘Components’

- Models receive a ‘Basic Model Interface’
- Specify with precision which parameters components do need, which parameters do they generate (Standard Names).
- Components generate netCDF output

Web Modeling Tool





Web Modeling Tool allows new users to get familiar with main parameters of components in permafrost modeling toolbox, run simple simulations, download output.

Physical Models

- Air Frost Number model – 1D
- Air Frost number model –GEO

- Kudryavtsev model – 1D
- Kudryavtsev model – GEO

- GIPL model – daily time-series, continuous depth
- (UAF Geophysical Institute Permafrost Lab model)

- Continuum volume model (G. Clow, USGS)

Increasing complexity

‘Air’ Frost Number

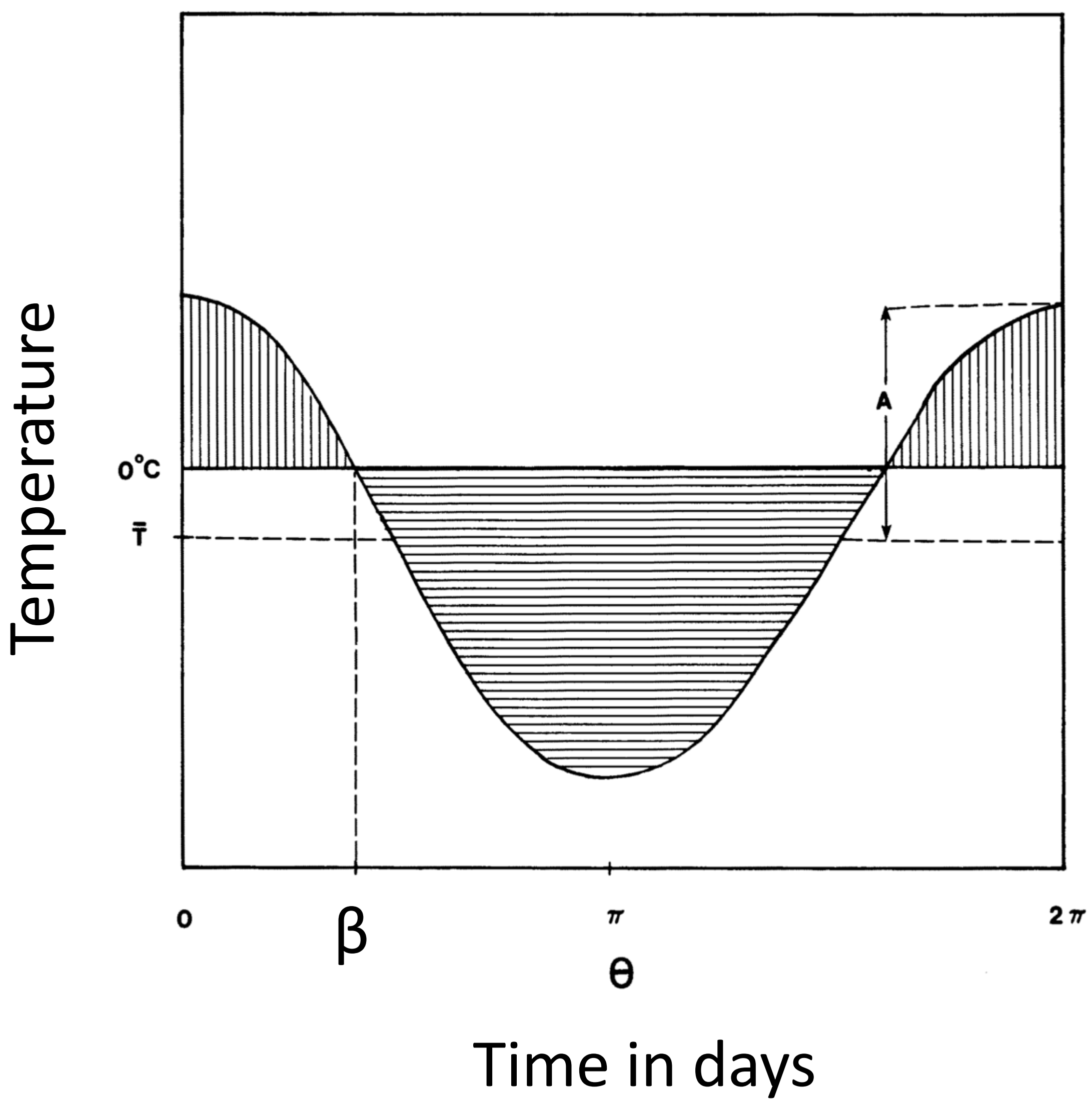
$$F = \frac{DDF^{1/2}}{DDF^{1/2} + DDT^{1/2}}$$

F = Frost Number (-)

DDF = freezing day index (°C days)
DDT = thawing day index (°C days)

(From: Nelson and Outcalt, 1987, AAAR.)

Cosine Approximation of Annual Temperature Distribution



A= amplitude in °C

How much time in a year are temperatures above or below freezing?

(From: Nelson and Outcalt, 1987, AAAR)

Calculate DDT and DDF

$$MAAT = (T_h + T_c)/2$$

$$A = (T_h - T_c)/2$$

$$\beta = \cos^{-1}(-MAAT / A)$$

$$T_s = MAAT + A((\sin\beta)/\beta)$$

$$T_w = MAAT - A((\sin\beta)/(\pi - \beta))$$

$$L_s = 365(\beta/\pi)$$

$$L_w = 365 - L_s$$

Symbol	Parameter	unit
MAAT	Mean annual temperature	°C
A	Yearly temperature amplitude	°C
beta	Frost angle	-
Ts	Mean summer temperature	°C
Tw	Mean winter temperature	°C
Ls	Length of summer	days
Lw	Length of winter	days

$$DDT = T_s L_s$$

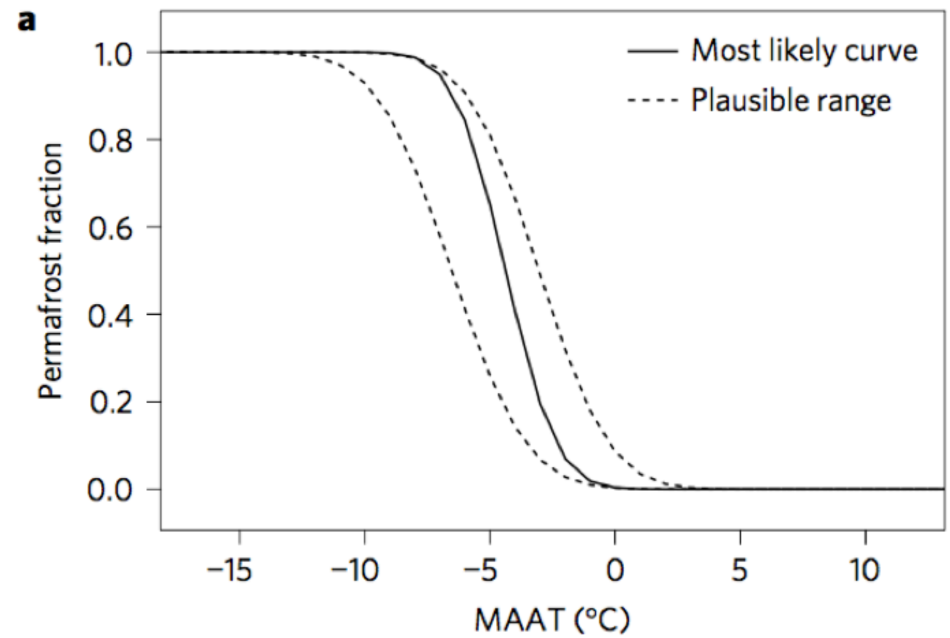
$$DDF = T_w L_w$$

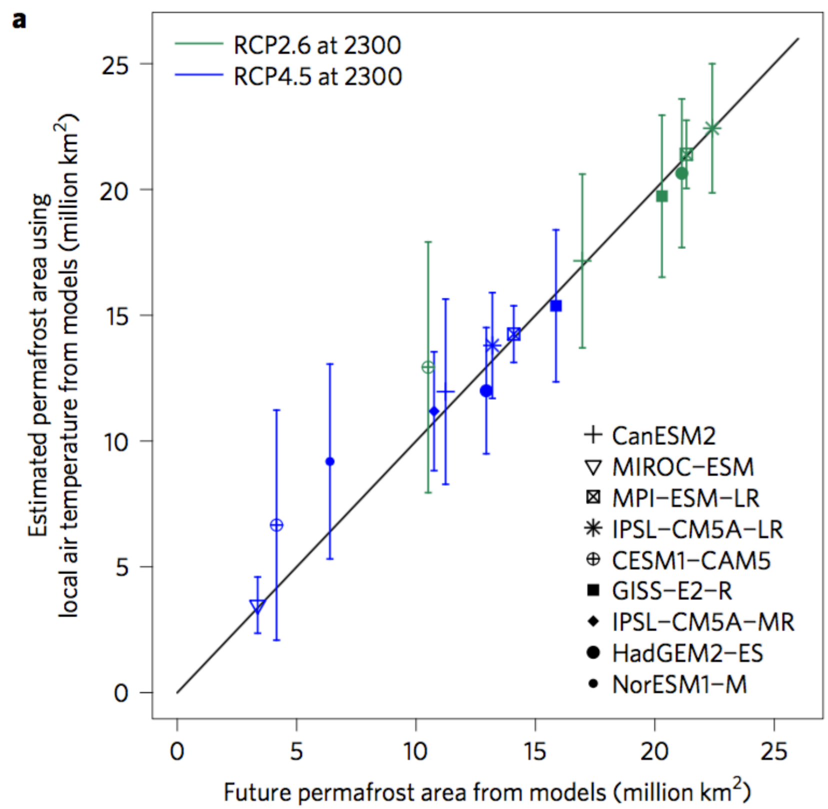
Defining the Permafrost Limit

- ‘Air Frost Number’ predicts that permafrost is theoretically possible:

- When the mean annual temperature is < 0°C
- When the freezing and thawing indices are equal; thus when Frost Number >= 0.5

What is the use of such a simple model?

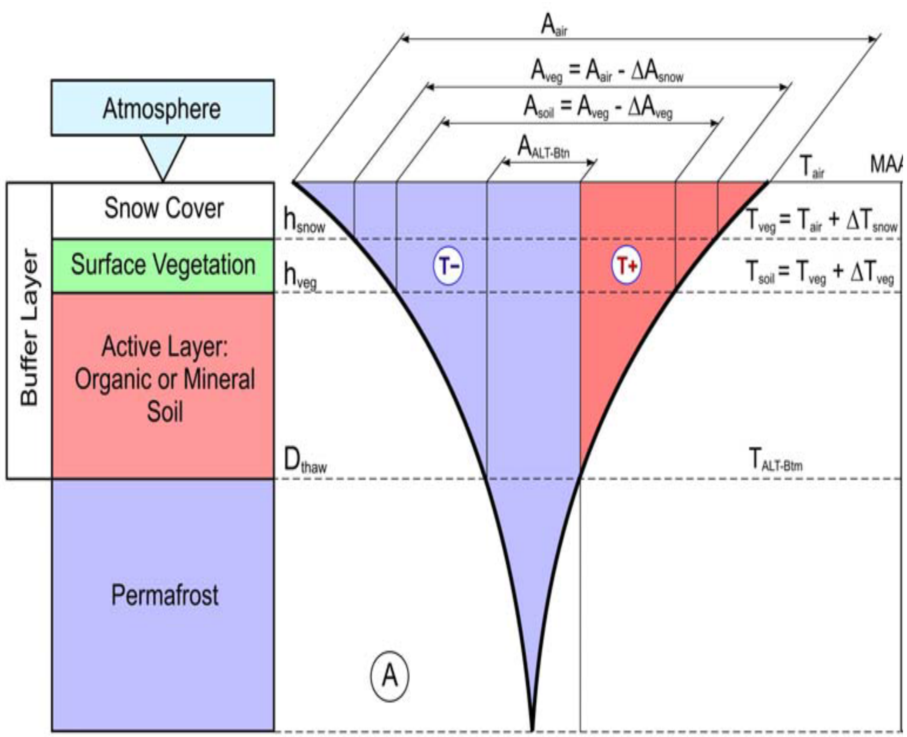




(From: Chadburn et al., 2017, Nature Climate Change)

Kudryavstev Model

- The Ku model is an semi-empirical model developed in 1970s.
- It essentially is an thermal equilibrium model.
- Calculates annual soil temperature, active layer thickness
- Includes layers of snow and vegetation.



(Anisimov et al., 1997)

Depth to freezing or thawing (Z)

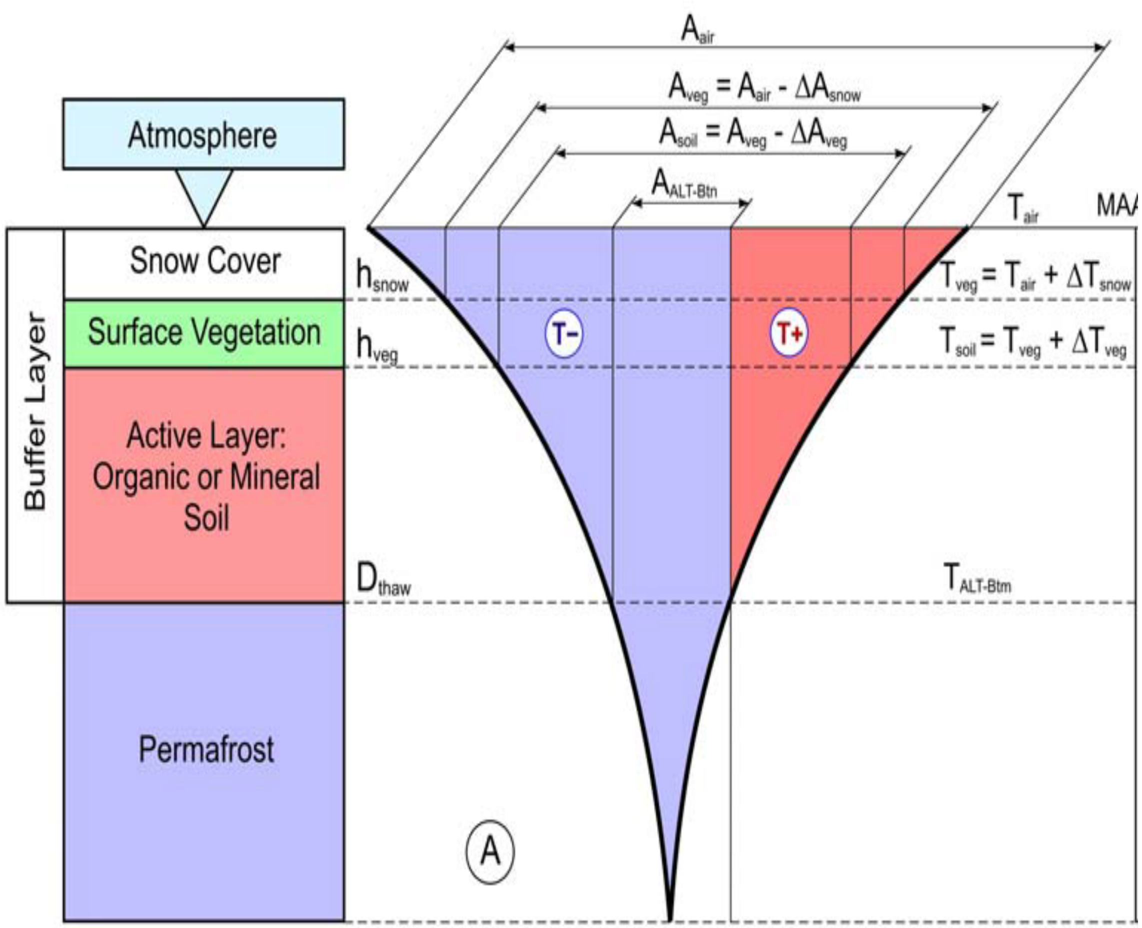
$$Z = \frac{2\left(A_s - \bar{T}_z\right)\cdot\left(\dfrac{\lambda\cdot P\cdot C}{\pi}\right)^{1/2} + \dfrac{\left(2A_z\cdot C\cdot Z_c + Q_L\cdot Z\right)\cdot Q_L\left(\dfrac{\lambda\cdot P}{\pi\cdot C}\right)^{1/2}}{2A_z\cdot C\cdot Z_c + Q_L\cdot Z + \left(2A_z\cdot C + Q_L\right)\cdot\left(\dfrac{\lambda\cdot P}{\pi\cdot C}\right)^{1/2}}}{2A_zC + Q_L}$$

$$A_z = \frac{A_s - \bar{T}_z}{\ln\left(\dfrac{A_s Q_L/2C}{\bar{T}_z + Q_L/2C}\right)} - \frac{Q_L}{2C}$$

$$Z_c = \frac{2\left(A_s - \bar{T}_z\right)\cdot\left(\dfrac{\lambda\cdot P\cdot C}{\pi}\right)^{1/2}}{2A_z\cdot C + Q_L}$$

A_s = annual amplitude of surface temperature
T_z = mean annual temperature at depth of seasonal thawing
λ = thermal conductivity $W\ m^{-1}\ C^{-1}$
C = volumetric heat capacity $J\ m^{-3}\ C^{-1}$
Ql = volumetric latent heat of fusion $J\ m^{-3}$

Consider temperature at each layer interface separately



$$\bar{T}_s = \bar{T}_a + \Delta T_{sn} + \Delta T_{veg}$$

$$A_s = A_a - \Delta A_{sn} - \Delta A_{veg}$$

Temperature and annual amplitude at the soil surface (s) depends on the thermal effects of snow and vegetation.

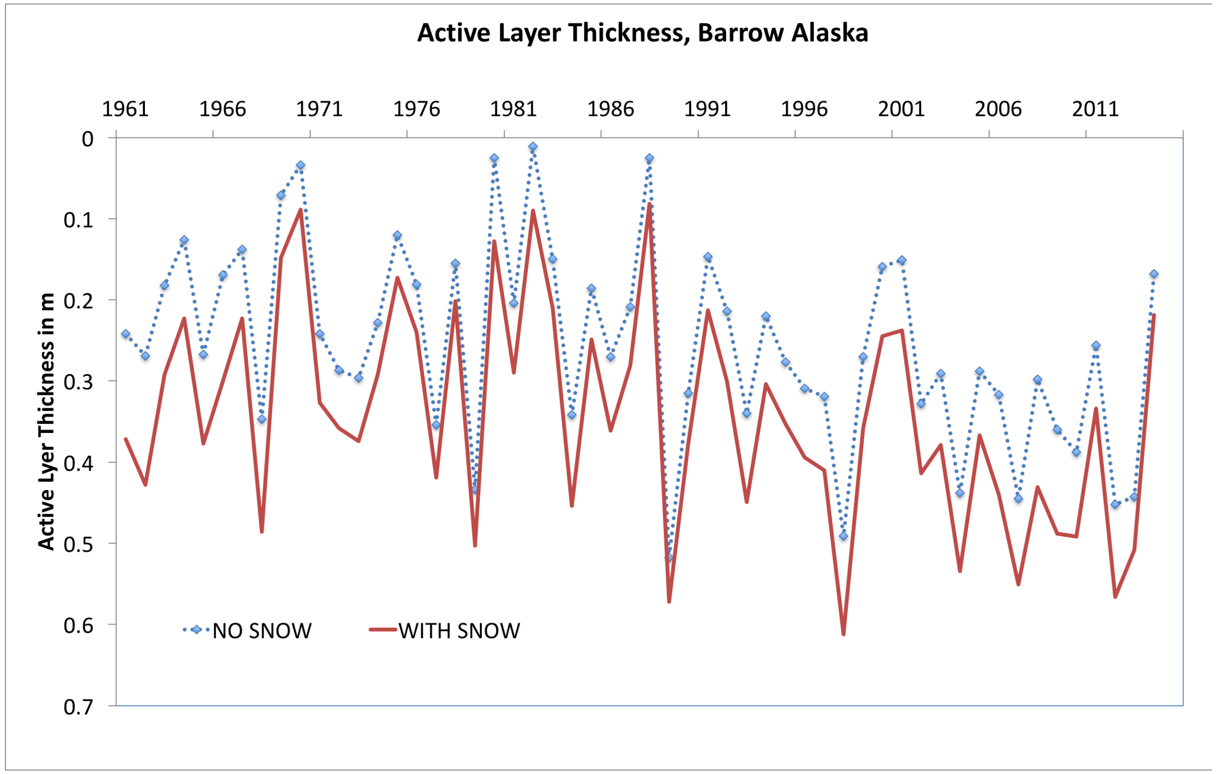
(Anisimov et al., 1997)

Snow thermal effect

$$\Delta T_{\mathrm{sn}} = A_{\mathrm{a}}\left\{1 -- \exp\left[-Z_{\mathrm{sn}}\left(\frac{\pi \cdot C_{\mathrm{sn}}\, \rho_{\mathrm{sn}}}{P \cdot \lambda_{\mathrm{sn}}}\right)^{1/2}\right]\right\}$$

Z_{sn} = snow cover thickness in m
λ_{sn} = snow thermal conductivity W m^{-1} C^{-1}
C_{sn} = snow volumetric heat capacity J m^{-3} C^{-1}
ρ_{sn} = density of snow in kg m^{-3}

What is the use of such a medium complexity model?



Discussion within federal agency with request to support in-situ snow monitoring on the Alaskan North Slope……
If we'd would not have data on seasonal snow thickness, our predictions of permafrost active layer thickness would be impacted. Ku model can quickly demonstrate this bias for a given location.

Datasets

- User-specified at single location
- Time-series (Barrow and Fairbanks)
- Reanalysis grids (CRU-AKtemp)

- Soil properties, snow depths
- Other climate variables CRU-NCEP, e.g. prec
- Other climate datasets (e.g. CALM stations)
- ESM climate data, i.e. for future scenarios

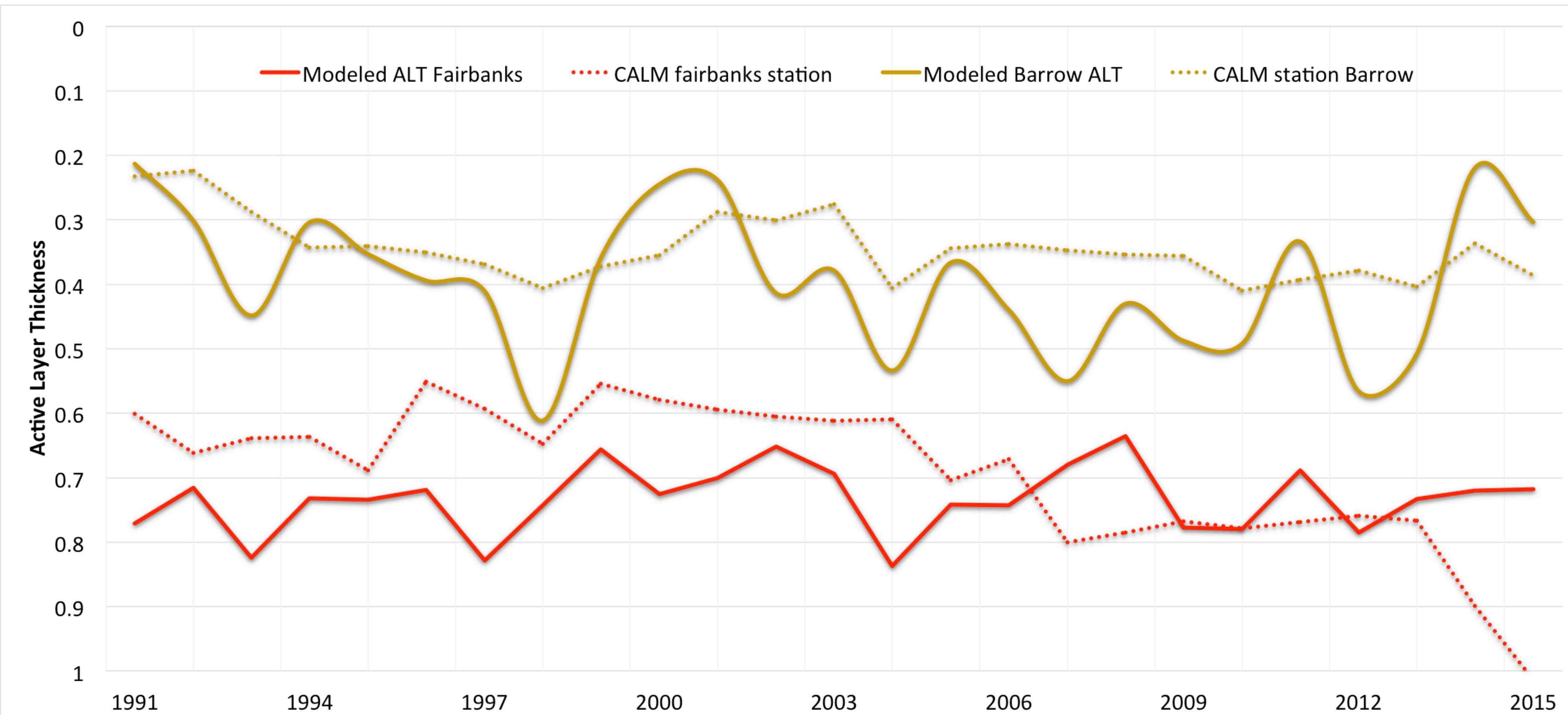
Increasing complexity

Time series of climate data

- Focus on Barrow and Fairbanks, Alaska
- 1961-2015 observed meteorological data
- Associated data of CALM stations 1991-2015

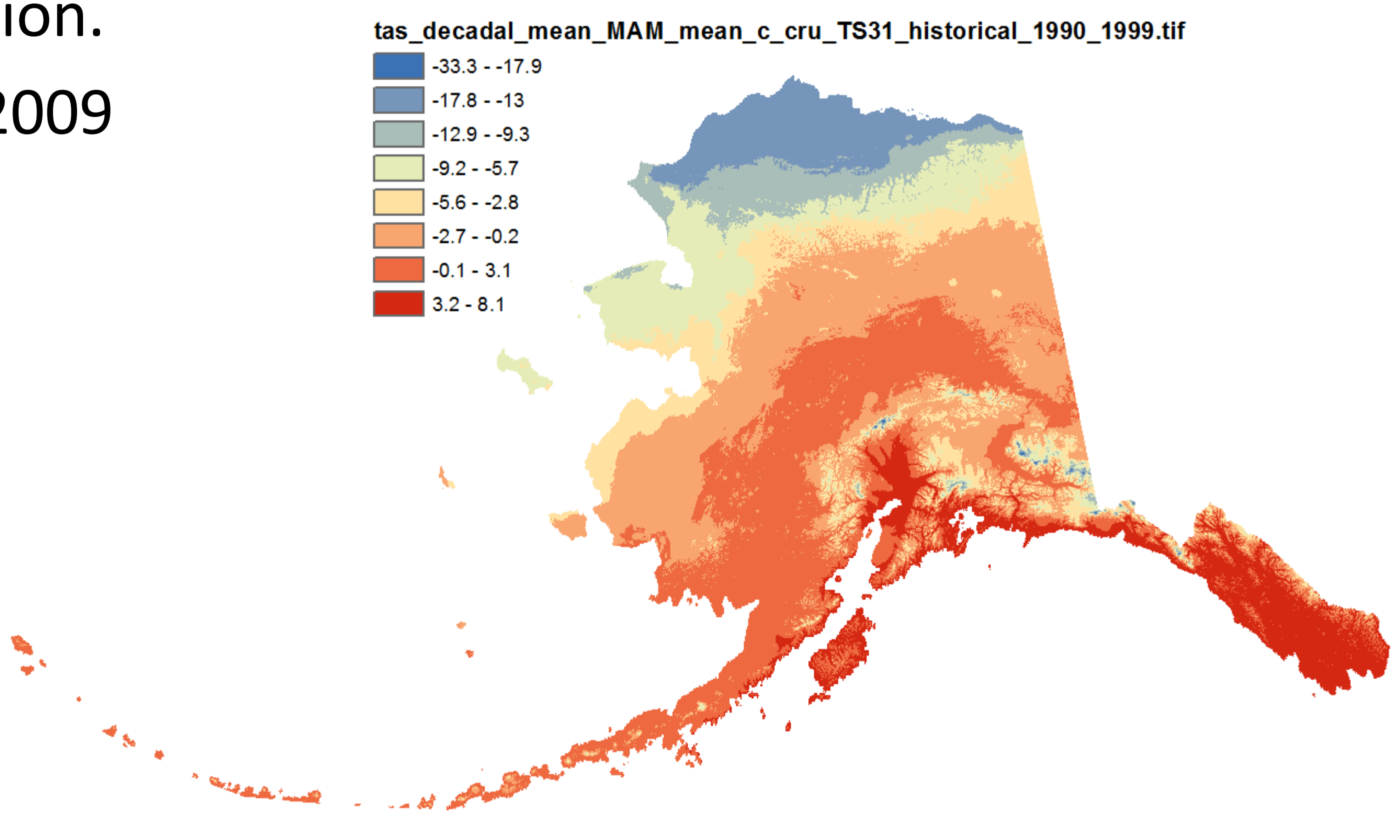
- CRU-NCEP SNAP reanalysis dataset with spatial coverage of climate characteristics over Alaska

Data-Model Comparison



Climate Reanalysis Data

- Original data source was CRU-TS3 monthly climate data at 771 * 771 m resolution.
- It covers 1900-2009



http://ckan.snap.uaf.edu/dataset/historical-monthly-and-derived-temperature-products-771m-cru-ts

CRU_AKtemp

What is specific for this dataset within the permafrost modeling tool:

- Data component, has an CSDM basic interface and can be coupled to models that need temperature data.
- Python 2.7 package that provides access to NetCDF file constructed from the original GeoTiffs.

- Geographical extent of this dataset reduced to Alaska.

- Spatial resolution has been reduced by a factor of 13 in each direction, resulting in an effective pixel resolution of about 10km.

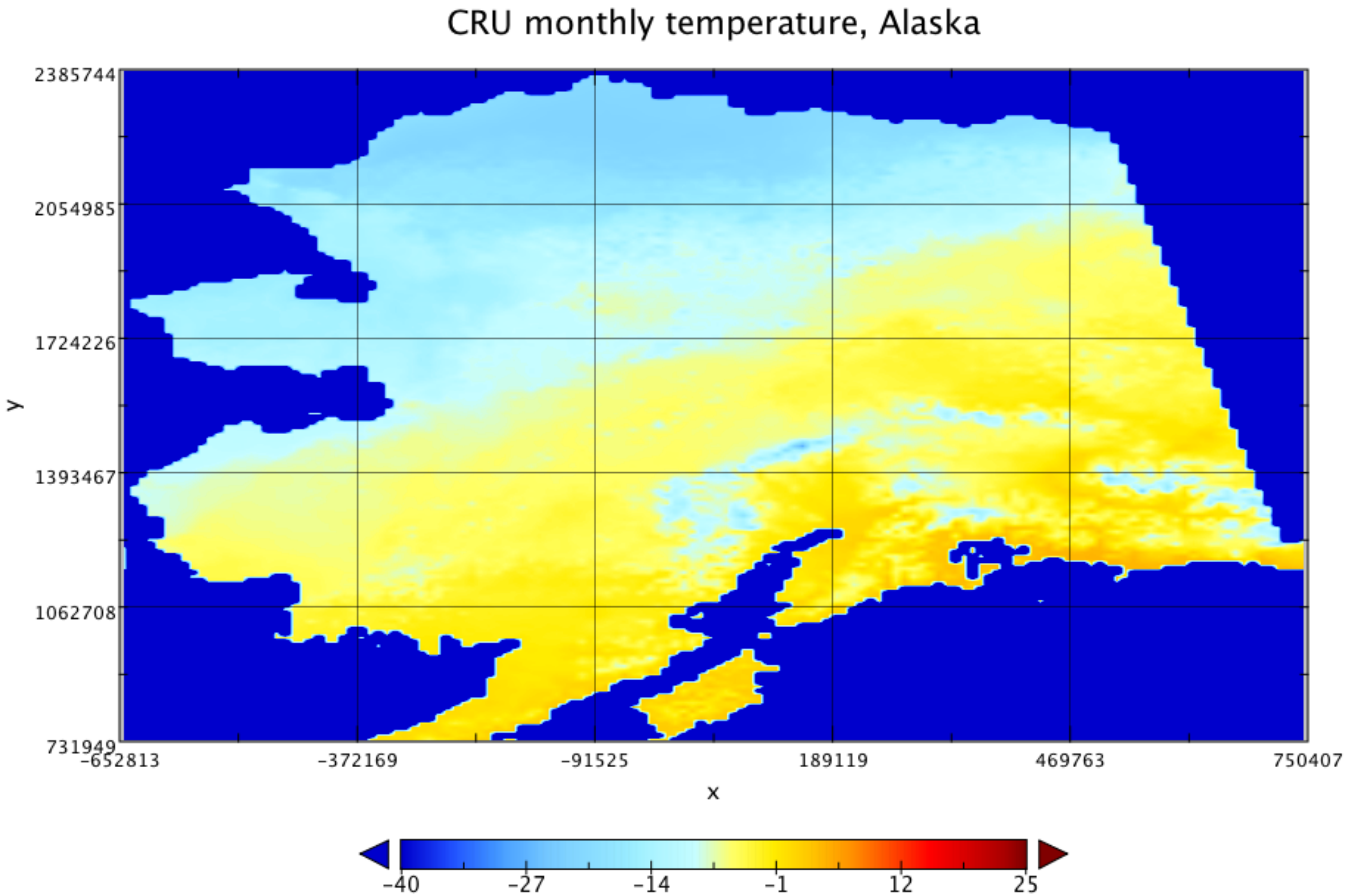
- The data are monthly average temperatures for each month from January 1901 through December 2009.

Config File with CRU-AKtemp

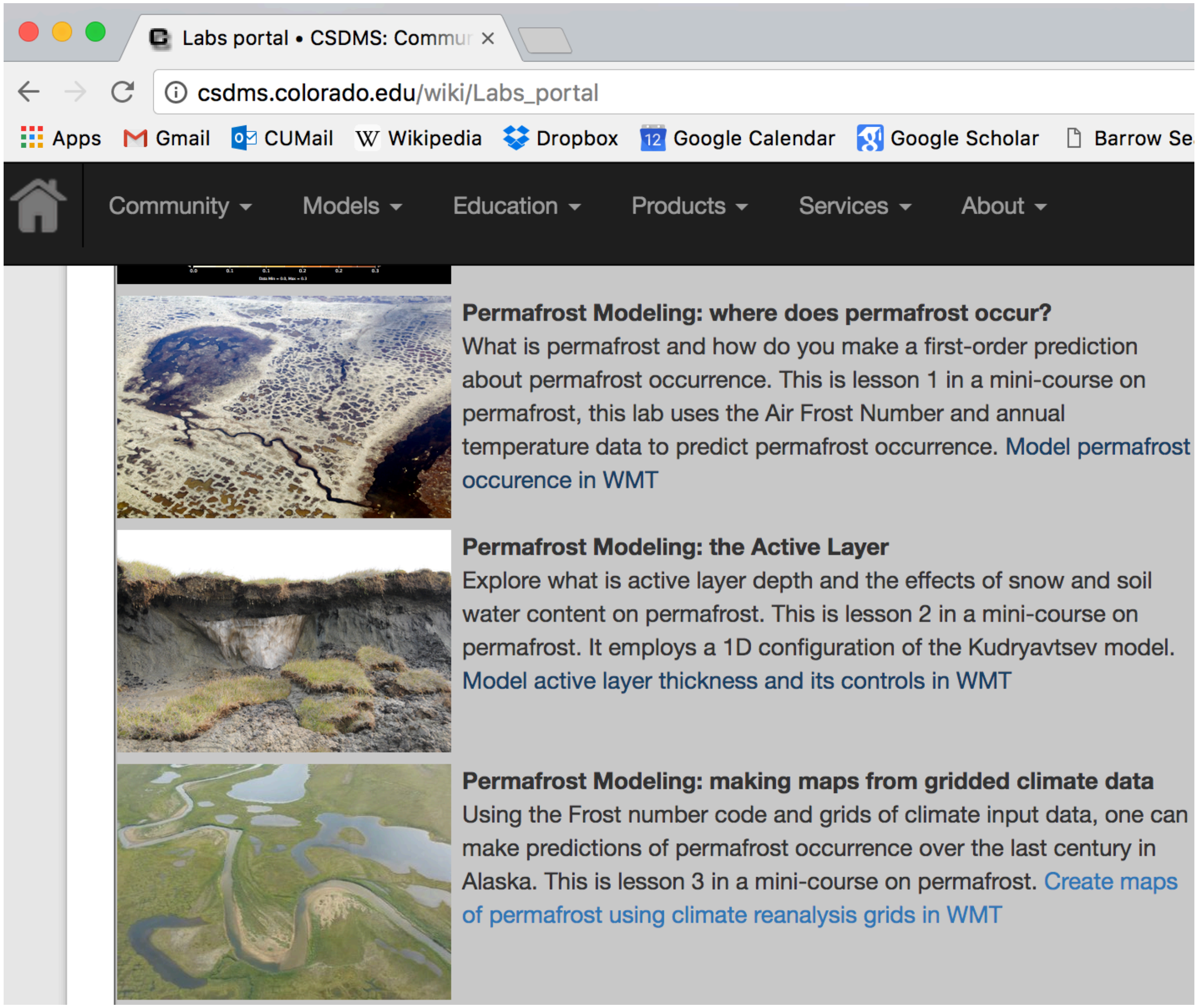
- #==
- # Config File for: cruAKtemp_method
- #==
- # Input
- filename | {filename} | string | name of this file
- run_description | {run_description} | string | description of this configuration
- run_region | {run_region} | string | general location of this domain
- run_resolution | {run_resolution} | string | highres or lowres
- # Dates are converted to datetime.date objects
- reference_date | {reference_date} | string | model time is relative to this date
- model_start_date | {model_start_date} | string | first day with valid model data
- model_end_date | {model_start_date} | string | last day with valid model data
- # Grid variables are processed separately after all config variables have been read in
- # need to create np.float array of grids
- grid_name | {grid_name} | string | name of the model grid
- grid_type | {grid_type} | string | form of the model grid
- grid_columns | {grid_columns} | int | number of columns in model grid
- grid_rows | {grid_rows} | int | number of columns in model grid
- # with temperature as np.zeros((grid_columns, grid_rows), dtype=np.float)
- i_ul | {i_ul} | int | i-coord of upper left corner model domain
- j_ul | {i_ul} | int | j-coord of upper left corner model domain
- # timestep is converted to datetime.timedelta(days=timestep)
- timestep | {timestep} | int | model timestep [days]
- # Output

Note, input is specified in 'grid rows' and 'grid columns', for now we have no proper geo-referencing and remapping tools in CSDMS, so we just use the original projection and its grid.

CRU_Aktemp example

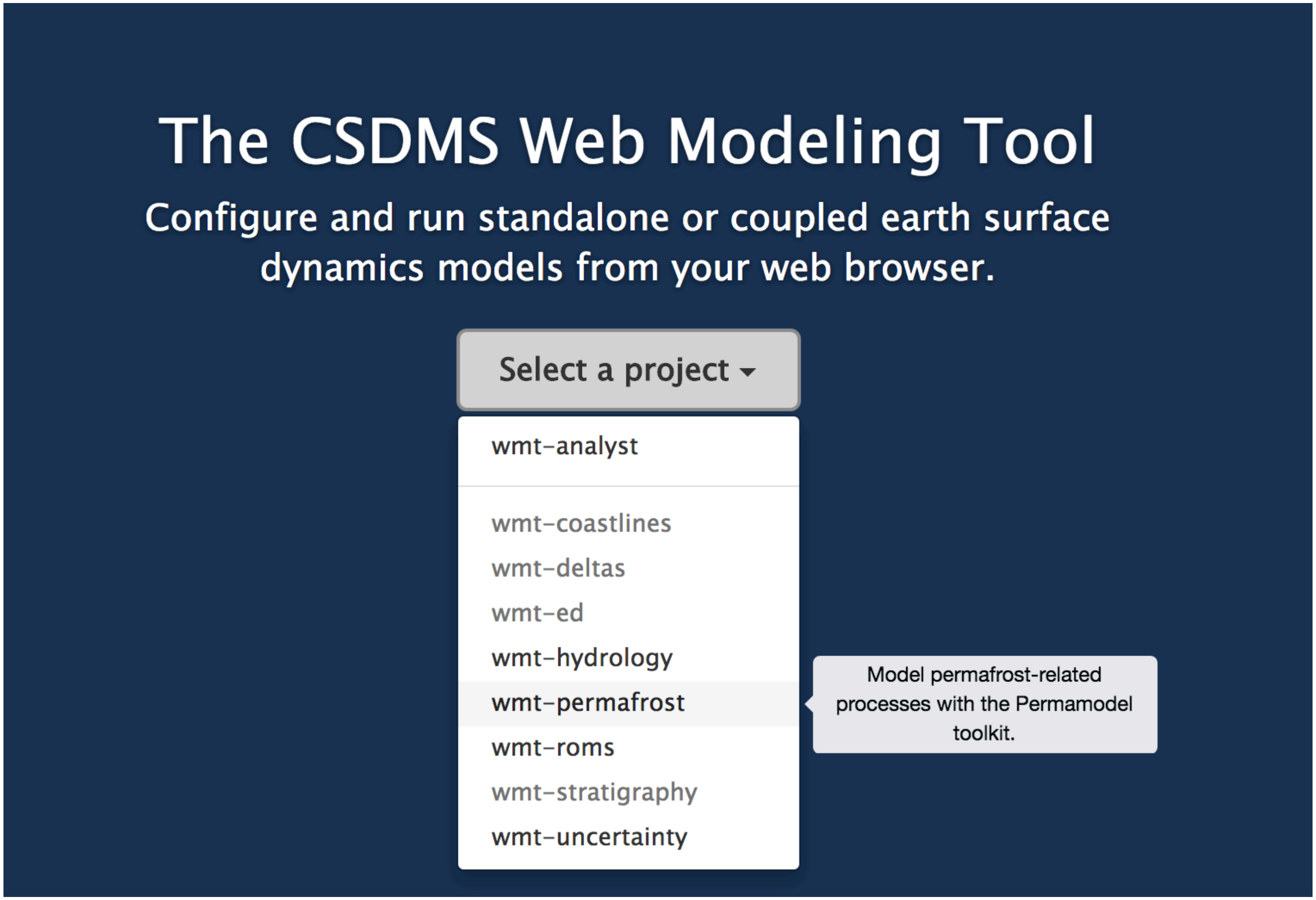


Demonstration



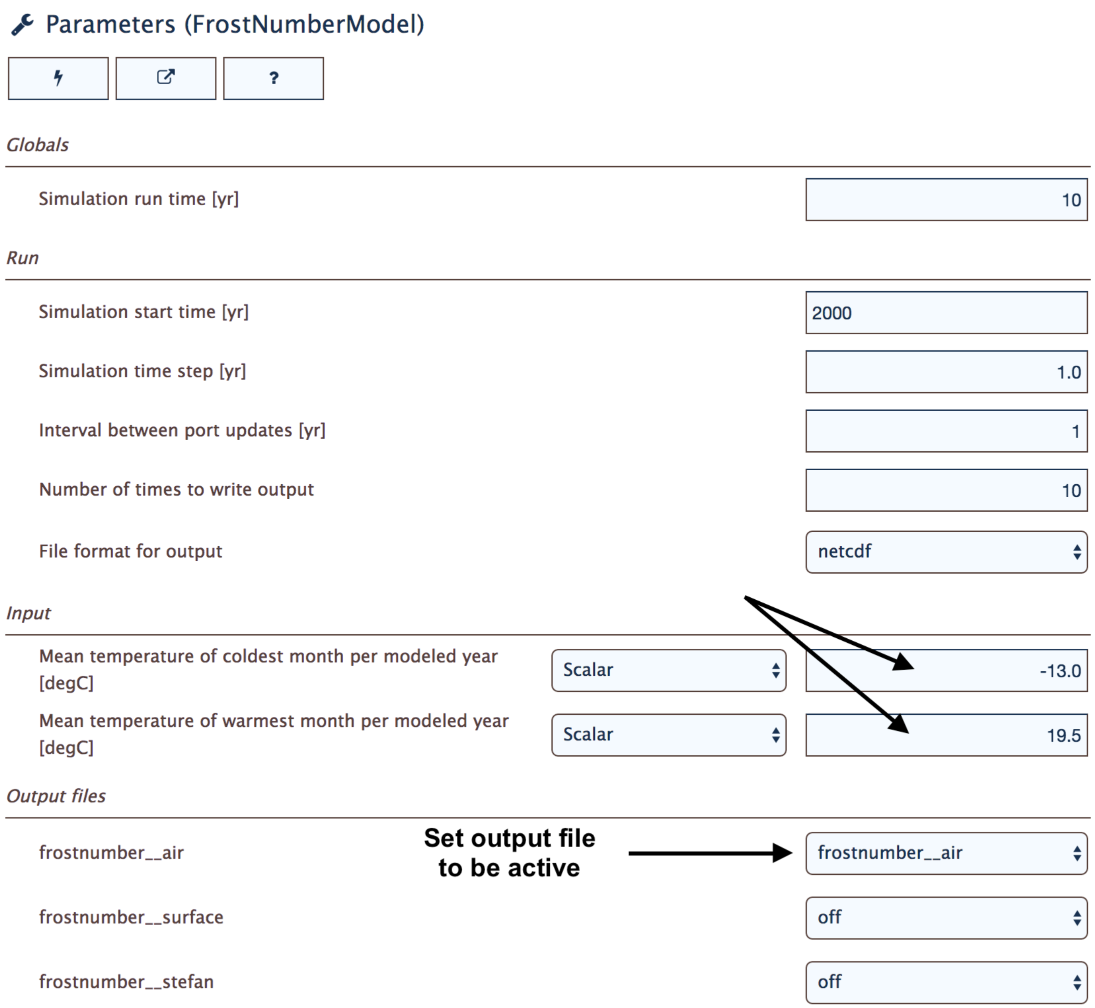
http://csdms.colorado.edu/wiki/Labs_portal

Demonstration

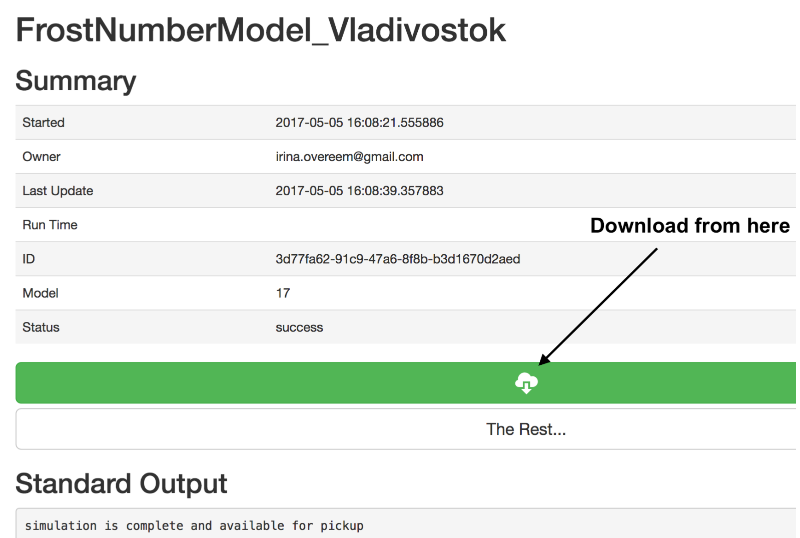


https://csdms.colorado.edu/wmt/

Demonstration

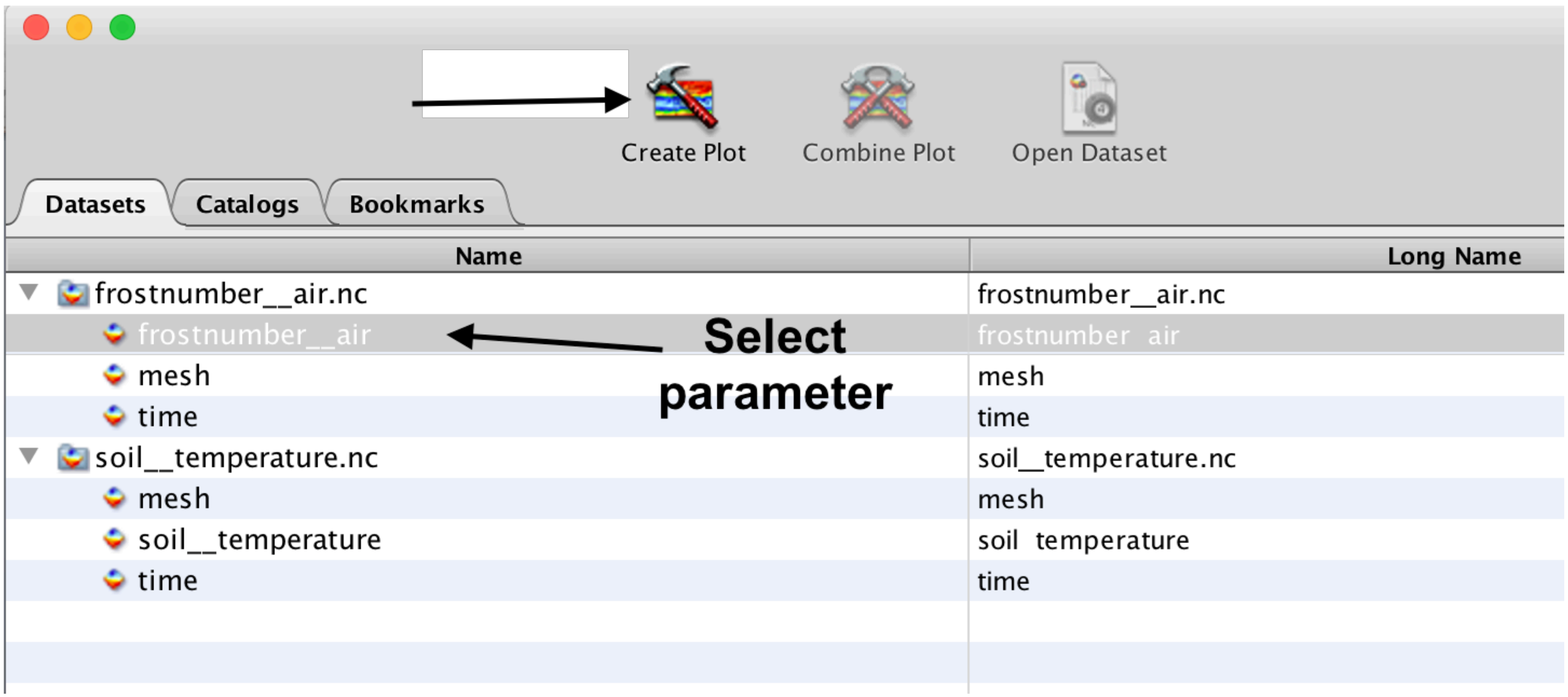


Set up parameters



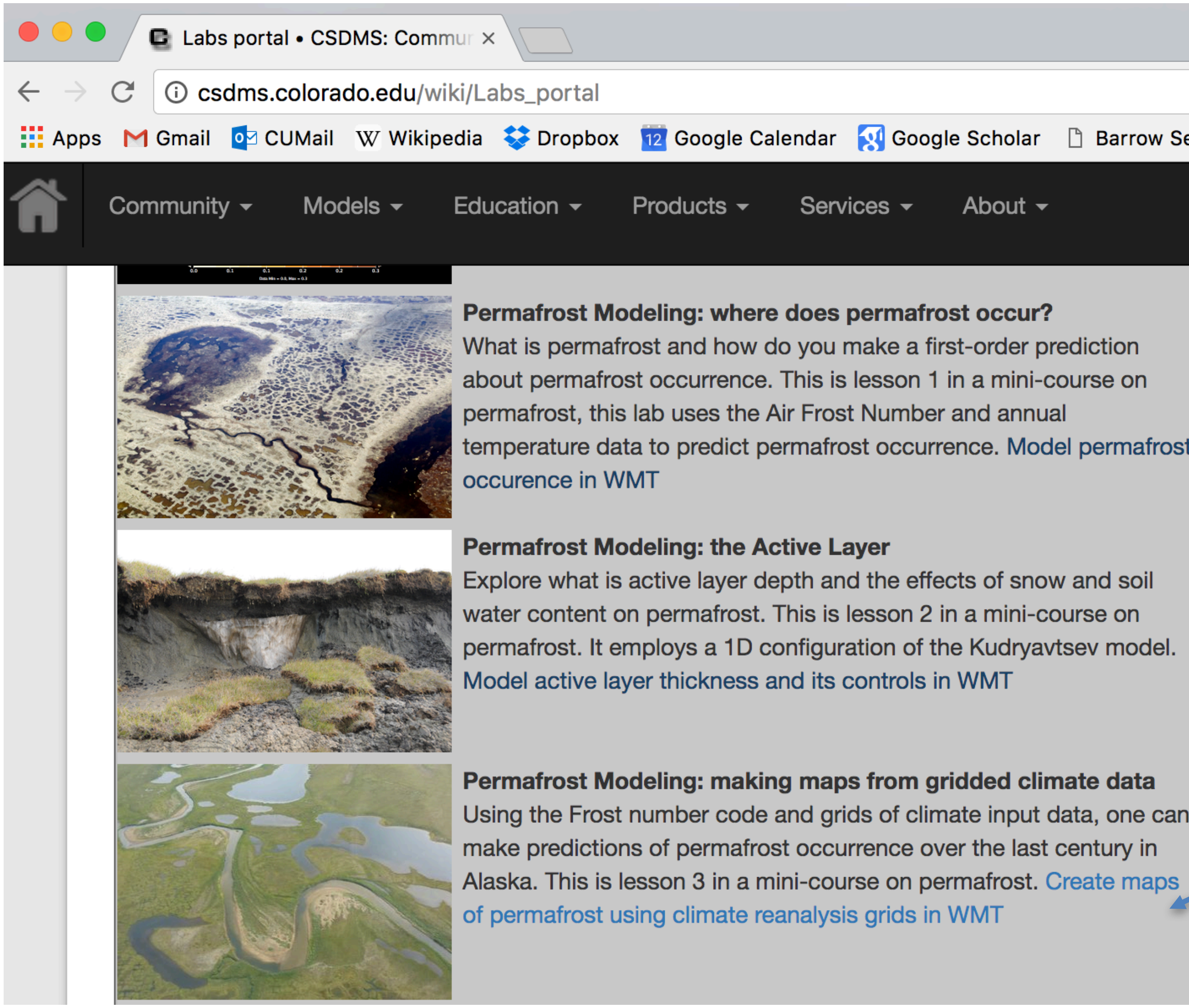
Retrieve Output

Visualize Output with Panoply



https://www.giss.nasa.gov/tools/panoply/

Hands-on



Ku-model 1D

Frost-model GEO

http://csdms.colorado.edu/wiki/Labs_portal

More advanced modeling

- Elchin’s overview of GIPL and other LANL models

Ipython notebooks

https://github.com/permamodel/permamodel/blob/master/notebooks/Ku_2D.ipynb

What's next: Collaborate

- https://github.com/permamodel

- You can download codes
- You can use codes and report issues

- You can become part of the team and contribute datasets or code

- Coupled model challenge for summer 2017

What’s next: cyberinfrastructure development

- What major questions could we tackle with this tool?

- Who is interested in collaborating?

- What models could be brought in and useful?
- What data could be brought in and useful?

- Other ideas?????

Acknowledgements

NSF Polar Programs Grant 1503559, ‘Towards a Tiered Permafrost Modeling Cyberinfrastructure’

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