Model Hierarchies - Afternoon

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2018 CESM Polar Modeling Workshop

NCAR – August 2018

Image: Brian Medeiros

Afternoon activities

Your group will get a chance to run a simplified model and do some analysis.

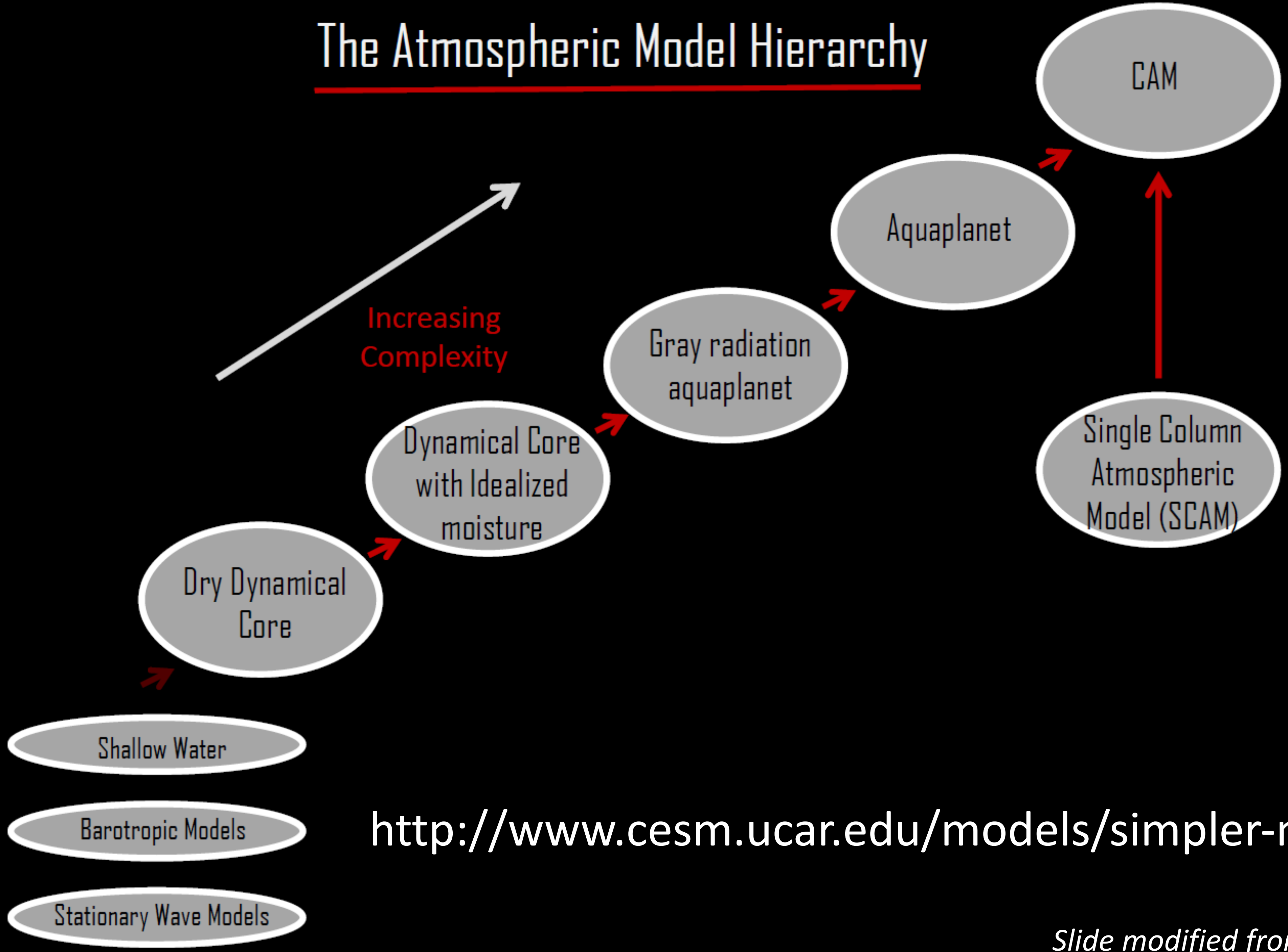
- Each group should choose **one** activity: Held Suarez or CLM single column

- Tell us which model your group has chosen (we'd prefer a balance)

- Try to get your group's simulations running **before** taking a break

Held and Suarez dry dynamical core

The Atmospheric Model Hierarchy



http://www.cesm.ucar.edu/models/simpler-models/

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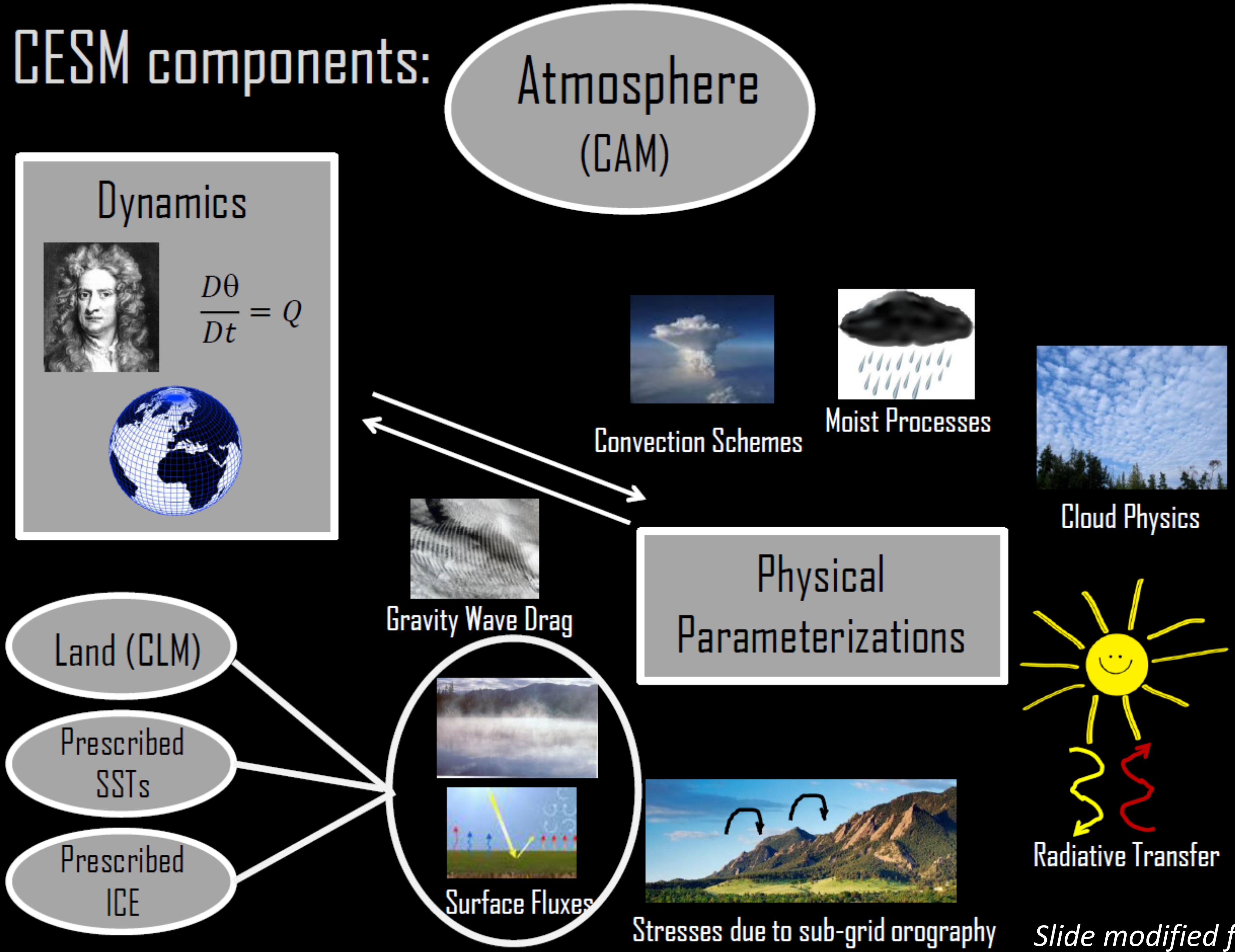
CESM components:



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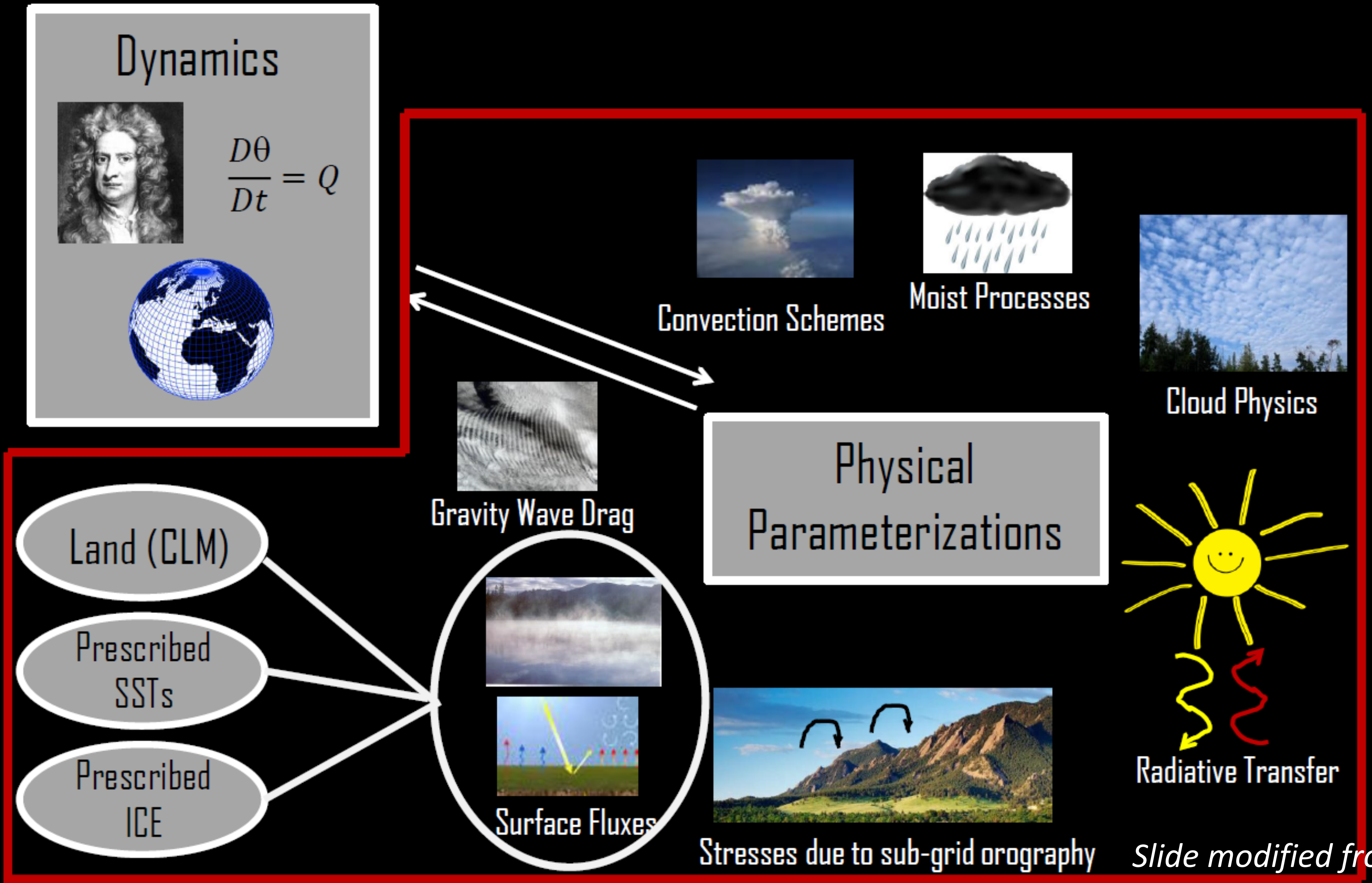
The Dry Dynamical Core



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The Dry Dynamical Core

Dynamics

$$\frac{D\theta}{Dt} = Q$$

Newtonian Relaxation of the temperature field toward a specified equilibrium profile

$$\frac{\partial T}{\partial t} = \cdots - \frac{T - T_{eq}}{\tau}$$

Linear drag on wind at the lowest levels

$$\frac{\partial \vec{v}}{\partial t} = \cdots - k_v \vec{v}$$

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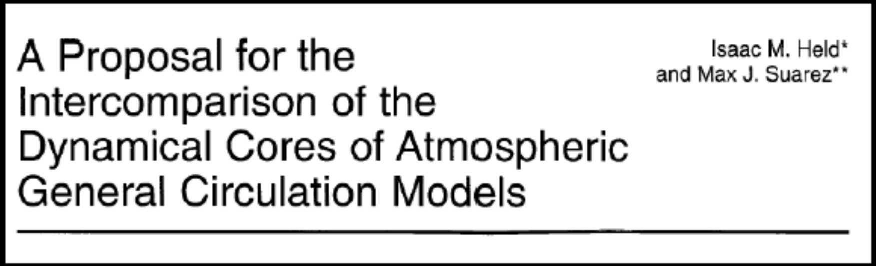
The Held-Suarez Configuration

Out of the box: T_{eq} and frictional drag following Held and Suarez (1994)

Flat sphere default

Perpetual equinox conditions


A Proposal for the Intercomparison of the Dynamical Cores of Atmospheric General Circulation Models

Isaac M. Held* and Max J. Suarez**

Compset = FHS94

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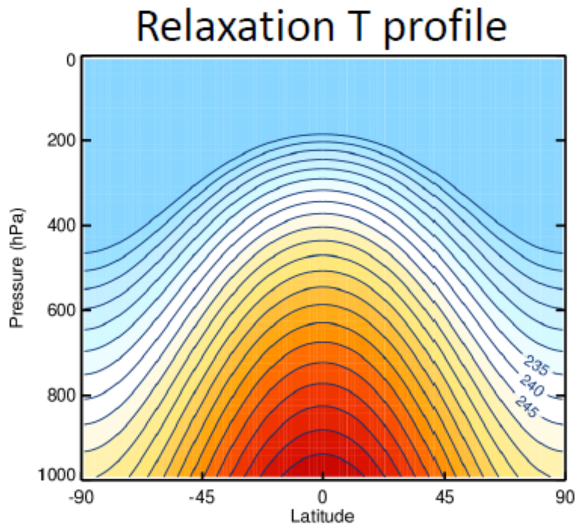

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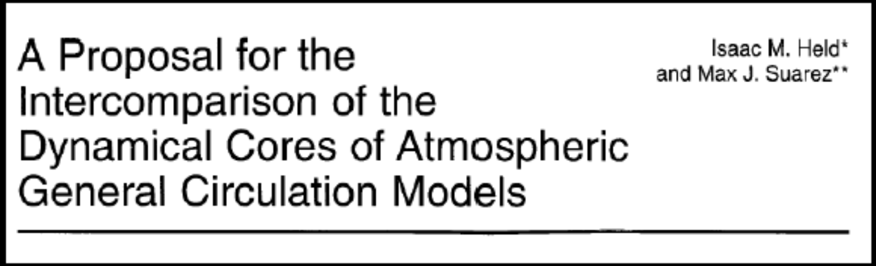
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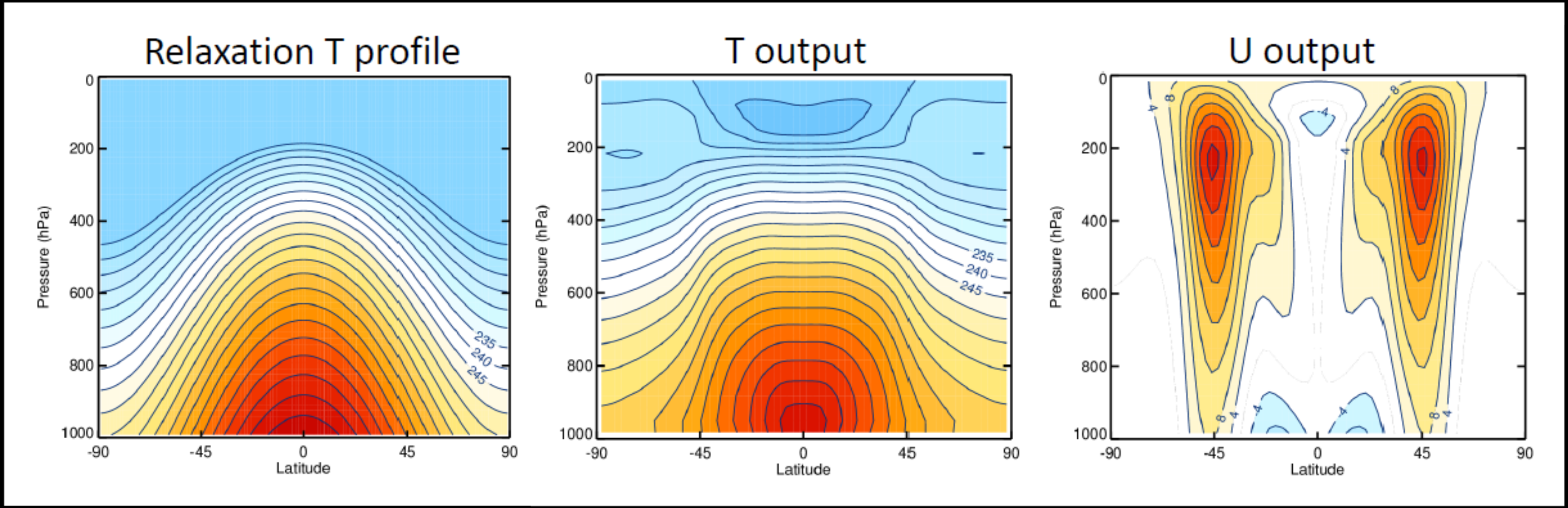

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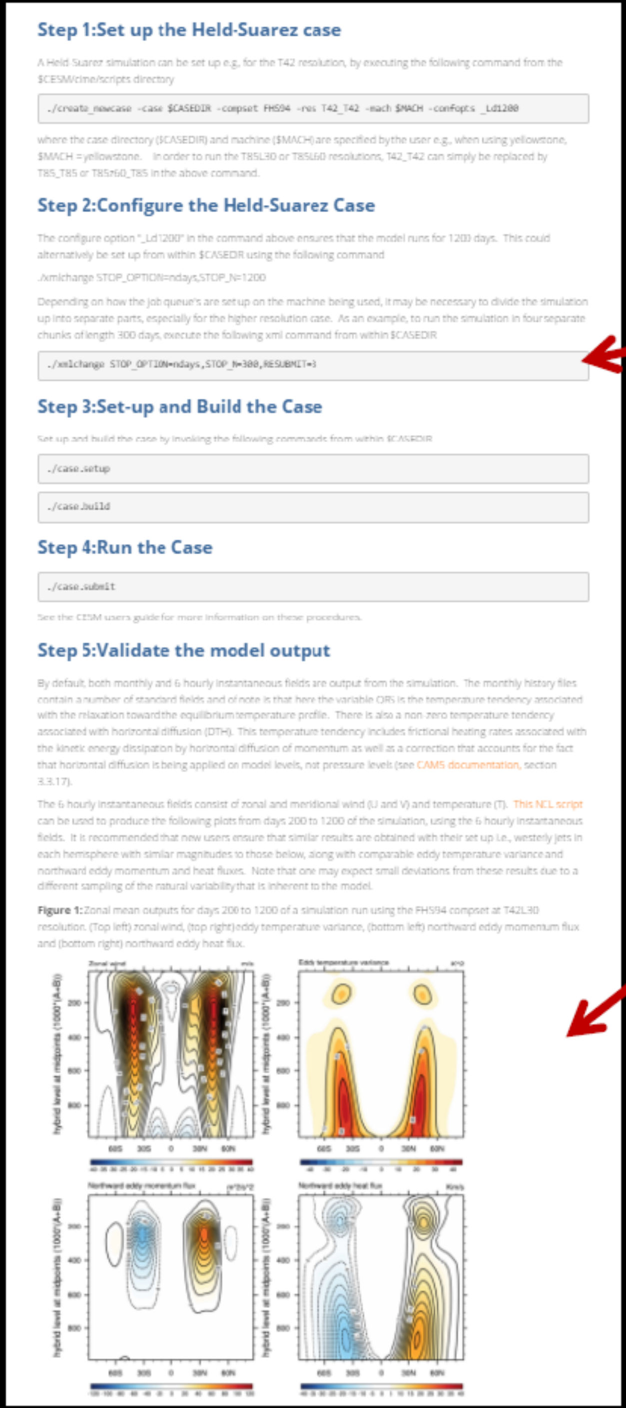

Step 1:Set up the Held-Suarez case

A Held-Suarez simulation can be set up e.g., for the T42 resolution, by executing the following command from the $CESM/cime/scripts directory

```
./create_newcase -case $CASEDIR -compset FHS94 -res T42_T42 -mach $MACH -confopts _Ld1200
```

where the case directory ($CASEDIR) and machine ($MACH) are specified by the user e.g., when using yellowstone, $MACH = yellowstone. In order to run the T85L30 or T85L60 resolutions, T42_T42 can simply be replaced by T85_T85 or T85z60_T85 in the above command.

Step 2:Configure the Held-Suarez Case

The configure option "_Ld1200" in the command above ensures that the model runs for 1200 days. This could alternatively be set up from within $CASEDIR using the following command

./xmlchange STOP_OPTION=ndays,STOP_N=1200

Depending on how the job queue's are set up on the machine being used, it may be necessary to divide the simulation up into separate parts, especially for the higher resolution case. As an example, to run the simulation in four separate chunks of length 300 days, execute the following xml command from within $CASEDIR

```
./xmlchange STOP_OPTION=ndays,STOP_N=300,RESUBMIT=3
```

Step 3:Set-up and Build the Case

Set up and build the case by invoking the following commands from within $CASEDIR

```
./case.setup
```

```
./case.build
```

Step 4:Run the Case

```
./case.submit
```

See the CESM users guide for more information on these procedures.

Step 5:Validate the model output

By default, both monthly and 6 hourly instantaneous fields are output from the simulation. The monthly history files contain a number of standard fields and of note is that here the variable QRS is the temperature tendency associated with the relaxation toward the equilibrium temperature profile. There is also a non-zero temperature tendency associated with horizontal diffusion (DTH). This temperature tendency includes frictional heating rates associated with the kinetic energy dissipation by horizontal diffusion of momentum as well as a correction that accounts for the fact that horizontal diffusion is being applied on model levels, not pressure levels (see CAM5 documentation, section 3.3.17).

The 6 hourly instantaneous fields consist of zonal and meridional wind (U and V) and temperature (T). This NCL script can be used to produce the following plots from days 200 to 1200 of the simulation, using the 6 hourly instantaneous fields. It is recommended that new users ensure that similar results are obtained with their set up i.e., westerly jets in each hemisphere with similar magnitudes to those below, along with comparable eddy temperature variance and northward eddy momentum and heat fluxes. Note that one may expect small deviations from these results due to a different sampling of the natural variability that is inherent to the model.

Figure 1: Zonal mean outputs for days 200 to 1200 of a simulation run using the FHS94 compset at T42L30 resolution. (Top left) zonal wind, (top right) eddy temperature variance, (bottom left) northward eddy momentum flux and (bottom right) northward eddy heat flux.

http://www.cesm.ucar.edu/models/simpler-models/held-suarez.html

Step-by-step instructions

Example plots and scripts for validation

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http://www.cesm.ucar.edu/models/simpler-models/held-suarez.html

Instructions on:

Running with a different dynamical core

Running with different horizontal/vertical resolutions

Running with topography

Running with a different analytical relaxation temperature profile (Polvani and Kushner 2002 stratosphere as an example)

Running with a relaxation temperature profile from netcdf

Modifying the default configuration

- Change the initial conditions
- Change the vertical resolution
- Running with a different dynamical core
- Change the output fields
- Adding in Topography
- Define a new history field e.g., the relaxation temperature profile
- Running with a different analytical relaxation temperature profile and damping settings e.g., the Polvani and Kushner (2002) setup
- Reading in a relaxation temperature profile from a netcdf file

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The Dry Dynamical Core

Example uses:

- Tropospheric response to stratospheric cooling (ozone hole like)

  Kushner and Polvani (2004)

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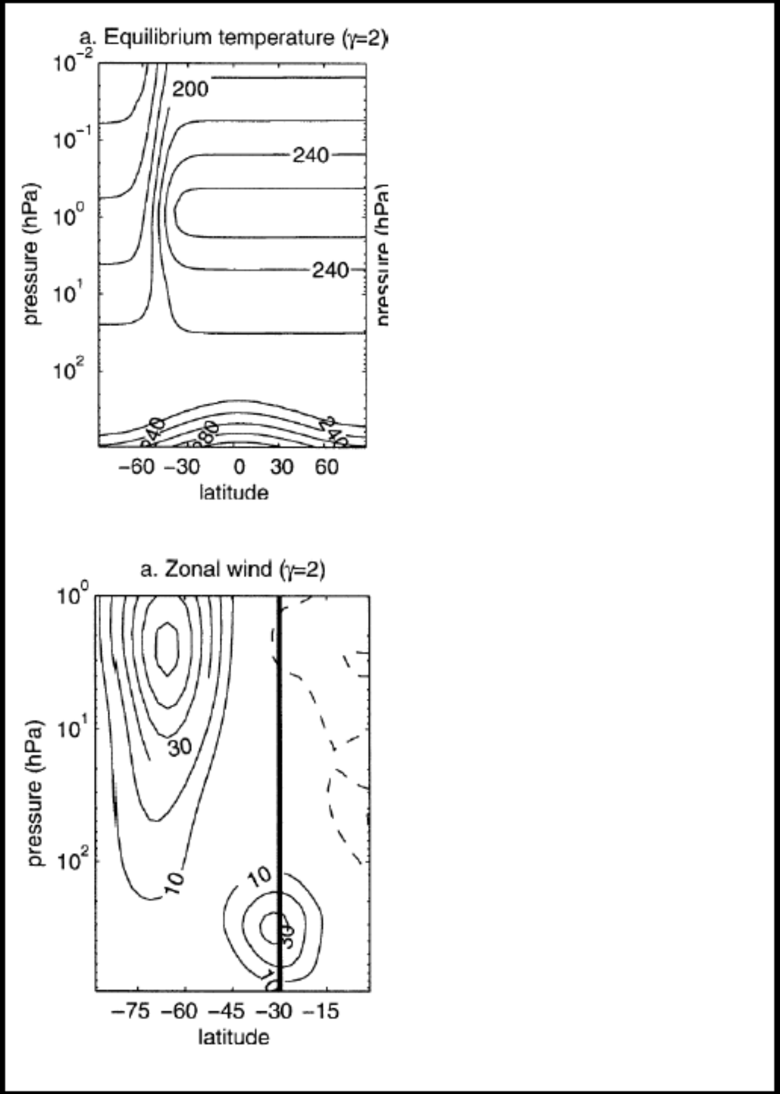

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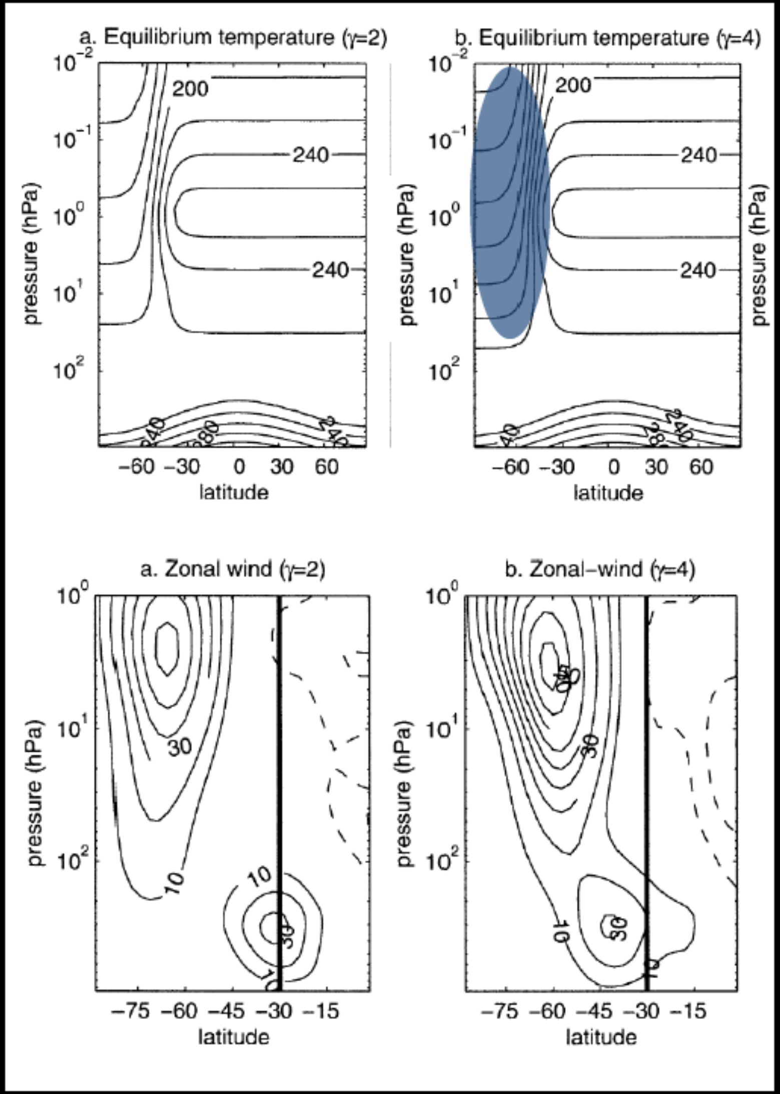

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The Dry Dynamical Core

Good for:

- Problems in large scale atmospheric dynamics that are not highly dependent on moisture

  e.g., mid-latitude jet dynamics, eddy-mean flow interactions, tropical-extra-tropical connections, stratosphere-troposphere coupling

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The Dry Dynamical Core

Good for:

- Problems in large scale atmospheric dynamics that are not highly dependent on moisture

  e.g., mid-latitude jet dynamics, eddy-mean flow interactions, tropical-extra-tropical connections, stratosphere-troposphere coupling

Not good for:

- Aspects of the atmospheric circulation where moisture is key e.g. Hadley circulation, tropical dynamics

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Choice of Experiment with the Held Suarez model

- 1. Pick a parameter to halve/double
- 2. Add a polar amplification heating anomaly

Simple representation of atmosphere:

$$\frac{\partial \boldsymbol{v}}{\partial t} = \boxed{dynamics} + physics$$

$$\frac{\partial T}{\partial t} = \boxed{dynamics} + physics$$

Plug in the dynamics equations and numerical methods of your choice

Held and Suarez (1994) made decisions for a very simple representation of atmospheric physics where the dynamics cores could be easily swapped and compared.

Simple physical representation of dissipation of winds

$$\frac{\partial \boldsymbol{v}}{\partial t} = dynamics - k_v(\sigma)\boldsymbol{v}$$

Linear damping: a very simple representation of dissipation and boundary layer processes

$$\frac{\partial T}{\partial t} = dynamics + physics$$

Plug in the dynamics equations and numerical methods of your choice

$$\sigma = \frac{p}{p_s}$$

$$k_v(\sigma) = k_f \max\left(0, \frac{\sigma - \sigma_b}{1 - \sigma_b}\right)$$

Parameters you can alter are in red

Radiation and moist processes replaced by Newtonian cooling

$$\frac{\partial \boldsymbol{v}}{\partial t} = dynamics - k_v(\sigma)\boldsymbol{v}$$

$$\frac{\partial T}{\partial t} = dynamics - k_t(\phi,\sigma)\left[T - T_{eq}(\phi,p)\right]$$

Newtonian cooling: relax temperature values toward a prescribed equilibrium temperature profile

$$T_{eq}(\phi,p) = \max\left\{200K, \left[315K - (\Delta T)_y \sin^2(\phi) - (\Delta\theta)_z \log\left(\frac{p}{p_s}\right)\cos^2(\phi)\right]\left(\frac{p}{p_s}\right)^{\kappa}\right\}$$

$$k_t = k_a + (k_s - k_a)\max\left(0, \frac{\sigma - \sigma_b}{1 - \sigma_b}\right)\cos^4(\phi)$$

Parameters you can alter are in red

Experiment 1: Default parameters

$\sigma_b = 0.7$	Below this sigma level, wind dampening occurs and has different T relaxation
$k_a = \frac{1}{40} day^{-1}$	E-folding time for equilibrium T profile (above σ_b)
$(\Delta T)_y = 60K$	Meridional T gradient for equilibrium T profile
$k_f = 1\, day^{-1}$	E-folding time for wind damping
$k_s = \frac{1}{4} day^{-1}$	E-folding time for equilibrium T profile (near surface)
$(\Delta \theta)_z = 10K$	Sets stratification for equilibrium T profile

Experiment 1: Pick a parameter to halve/double

- 10 years of output exist already for:
  - 2x $(\Delta\theta)_z$
  - 0.5 $(\Delta\theta)_z$
  - 1.5x $(\Delta T)_y$
  - 0.5 $(\Delta T)_y$
  - 2x k_f
  - 0.5x k_f
  - 2x k_a
  - 0.5x k_a

- Pick one or two experiments to configure and run in your group and then compare it against a default Held-Suarez simulation

Experiment 2: Explore heating from polar amplification in Held-Suarez

- Implementation of forcing used in *Butler et al. (2010)* and *McGraw and Barnes (2015)*:

$$F = q_0 \left\{ - \left(\frac{(y-y_0)^2}{2\sigma_y^2} + \frac{(z-z_0)^2}{2\sigma_z^2} \right) \right\}$$

$$T_{eq}(\phi, p) = \max\left\{200K, \left[315K - (\Delta T)_y \sin^2(\phi) \; - (\Delta\theta)_z \log\left(\frac{p}{p_s}\right) \cos^2(\phi) + \boldsymbol{F}\right] \left(\frac{p}{p_s}\right)^{\kappa} \right\}$$

- Run a polar-amplification simulation for one year (Longer time series available).

Single Column Community Land Model

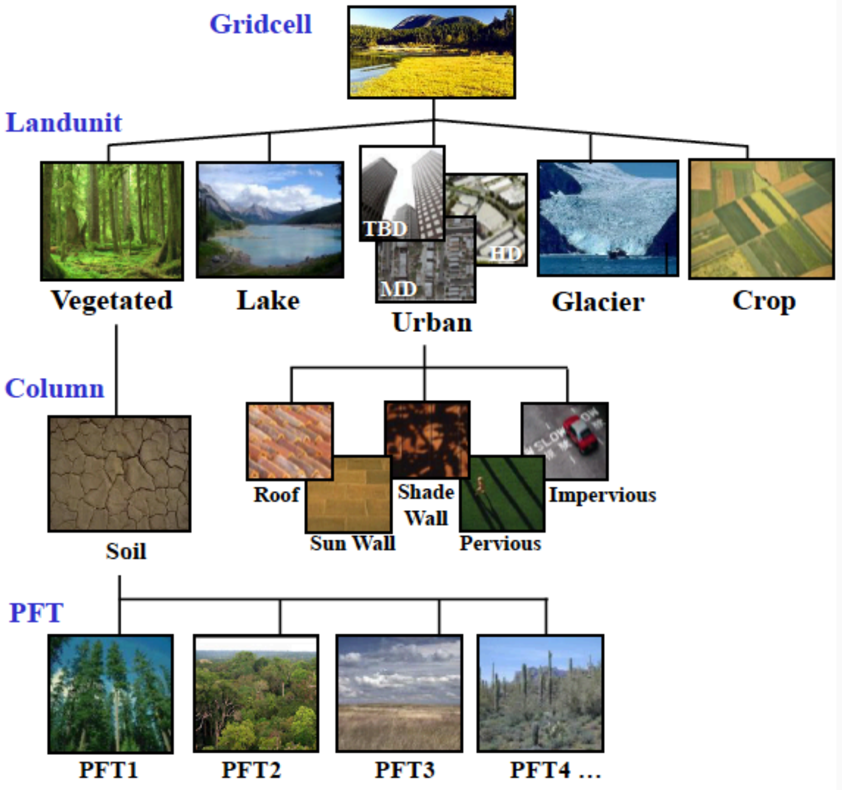
Land modeling at high latitudes

Boreal Forest – Siberia

Tundra – Barrow, AK

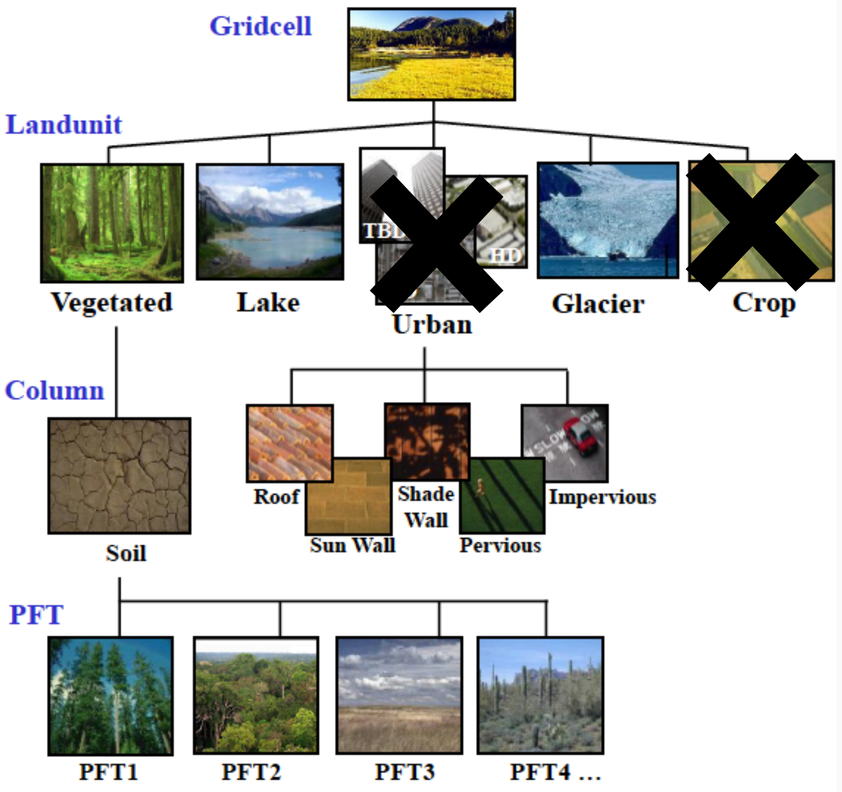
Tundra – Ellesmere Is. (http://www.arcticphoto.co.uk/gallery2/arctic/landscape/tundra/ce0014-13.htm)

High-latitude landunit and plant functional types



*Resolution will matter in fractions of each PFT

High-latitude landunit and plant functional types



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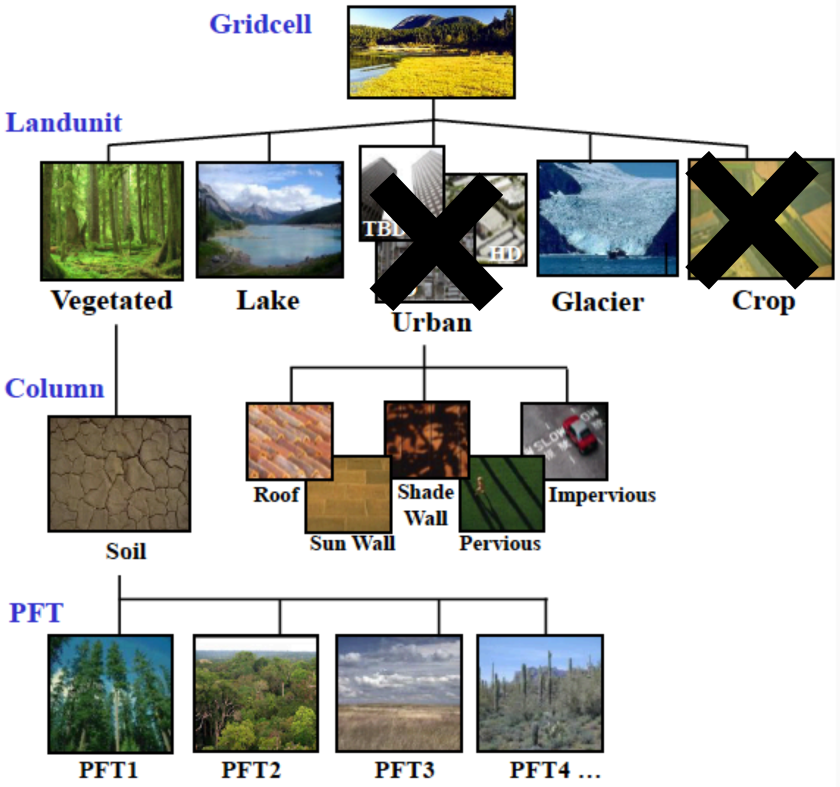


Plant Functional Types:

0. Bare

Tree:

1. Needleleaf Evergreen, Temperate
2. Needleleaf Evergreen, Boreal
3. Needleleaf Deciduous, Boreal
4. Broadleaf Evergreen, Tropical
5. Broadleaf Evergreen, Temperate
6. Broadleaf Deciduous, Tropical
7. Broadleaf Deciduous, Temperate
8. Broadleaf Deciduous, Boreal

Herbaceous / Understorey:

9. Broadleaf Evergreen Shrub, Temperate
10. Broadleaf Deciduous Shrub, Temperate
11. Broadleaf Deciduous Shrub, Boreal
12. C3 Arctic Grass
13. C3 non-Arctic Grass
14. C4 Grass
15. Crop

*Resolution will matter in fractions of each PFT

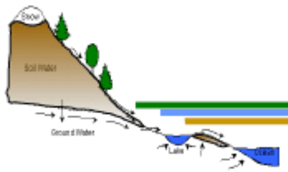
Slides adapted from D. Lawrence

High-latitude landunit and plant functional types

Main Arctic Landunit/PFTs:

- Needleleaf Evergreen Tree, Boreal
- Needleleaf Deciduous Tree, Boreal
- Broadleaf Deciduous Tree, Boreal
- Broadleaf Deciduous Shrub, Boreal
- C3 Arctic Grass
- Glacier
- Lake
- Bare ground

*Resolution will matter in fractions of each PFT

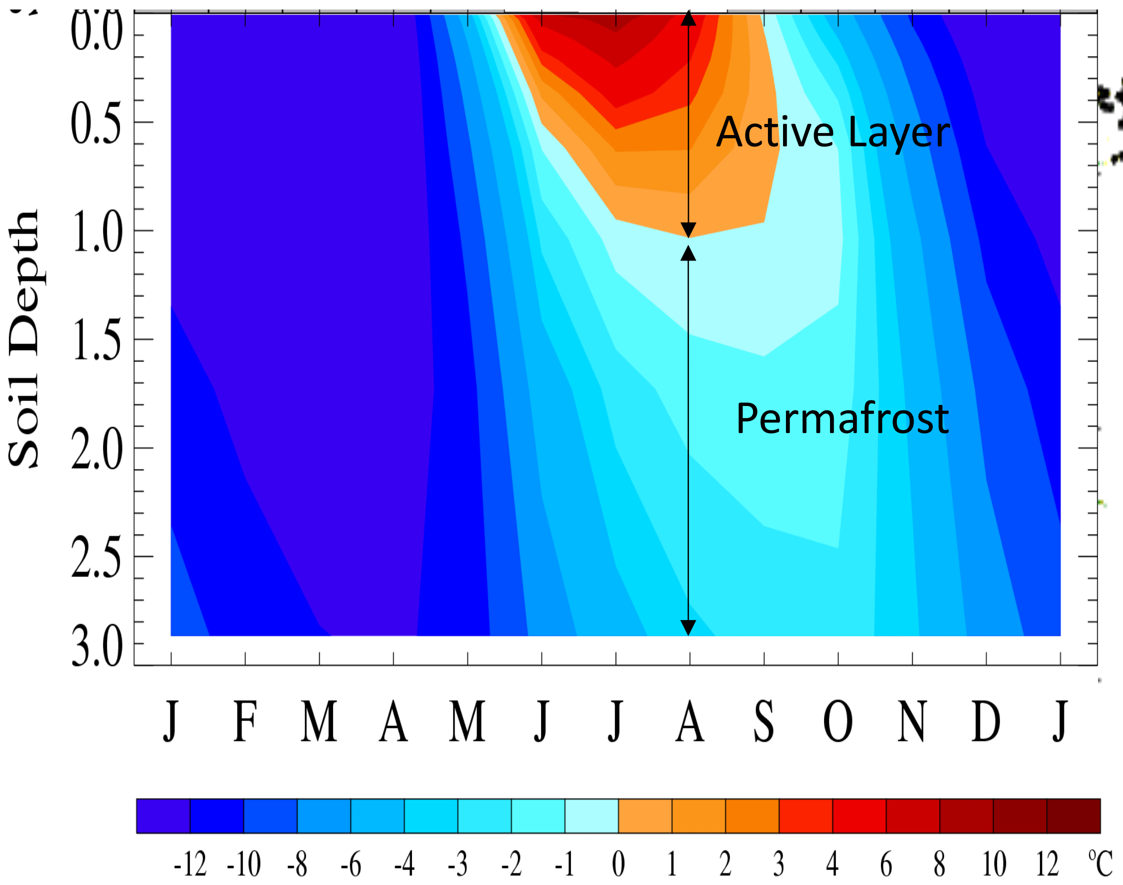


Plant Functional Type Parameters

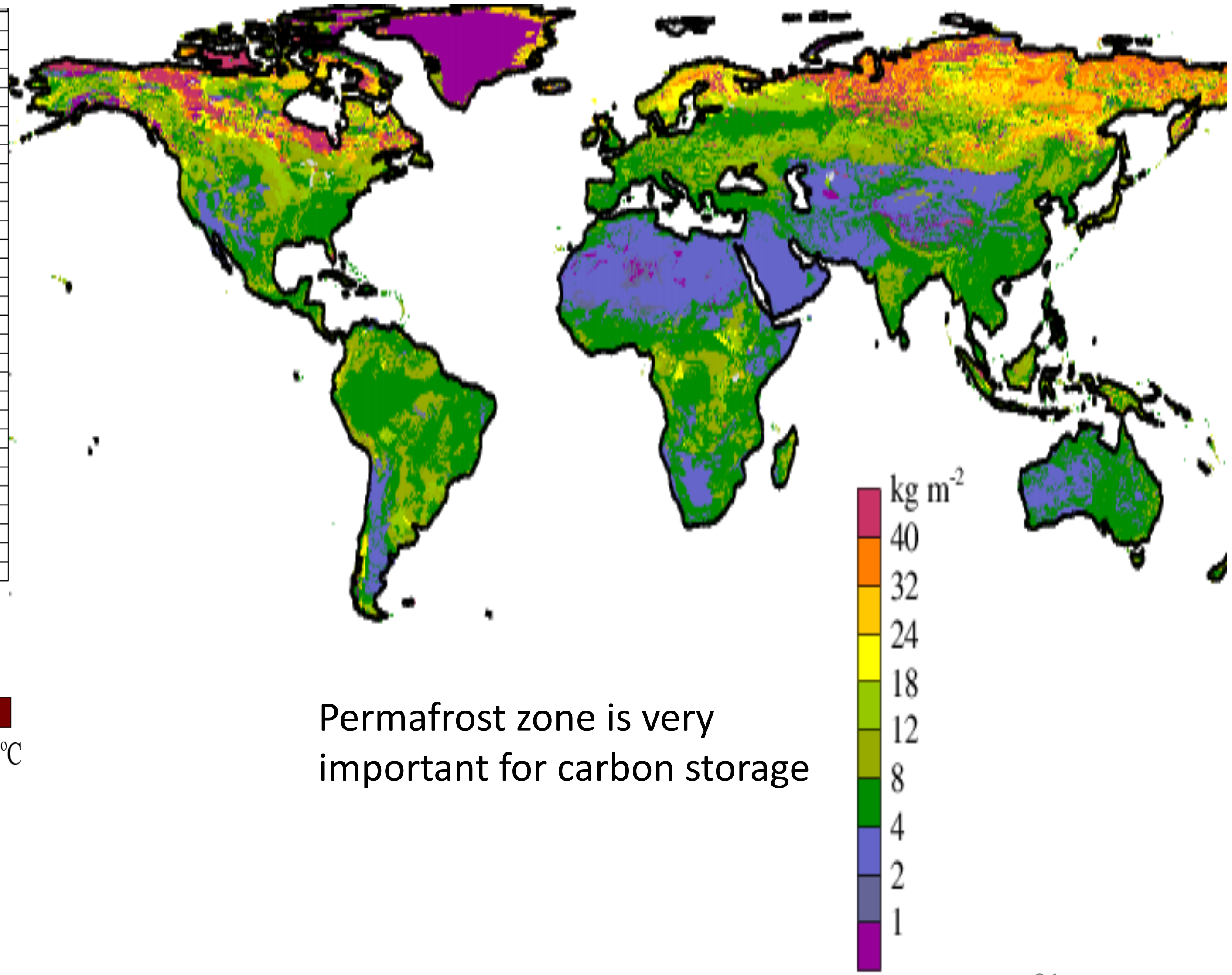
- Optical properties (visible and near-infrared):
  - Leaf angle
  - Leaf reflectance
  - Stem reflectance
  - Leaf transmittance
  - Stem transmittance
- Fire:
  - Combustion completeness
  - Fire mortality
- Land models are parameter heavy!!!
- Morphological properties:
  - Leaf area index (annual cycle)
  - Stem area index (annual cycle)
  - Leaf dimension
  - Roughness length/displacement height
  - Canopy top and bottom height
  - Root depth and distribution
- Photosynthetic parameters:
  - Specific leaf area
  - m (slope of conductance-photosynthesis relationship)
  - Vcmax (maximum rate of carboxylation)
  - Leaf carbon to nitrogen ratio
  - Fraction of leaf nitrogen in Rubisco
  - Soil water potential at stomatal open/closure

Slides adapted from D. Lawrence

Permafrost exists only in high latitudes

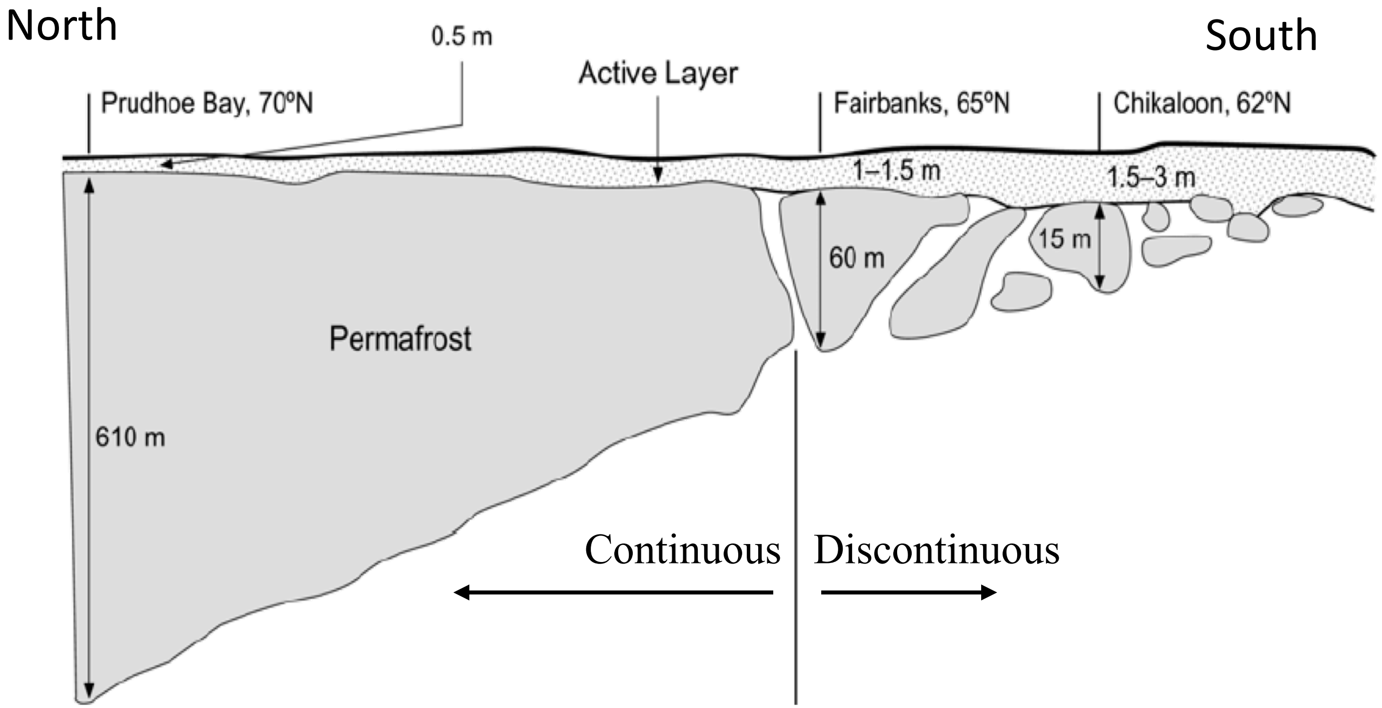


Permafrost: Soil or rock that remains below freezing for 2 or more consecutive years

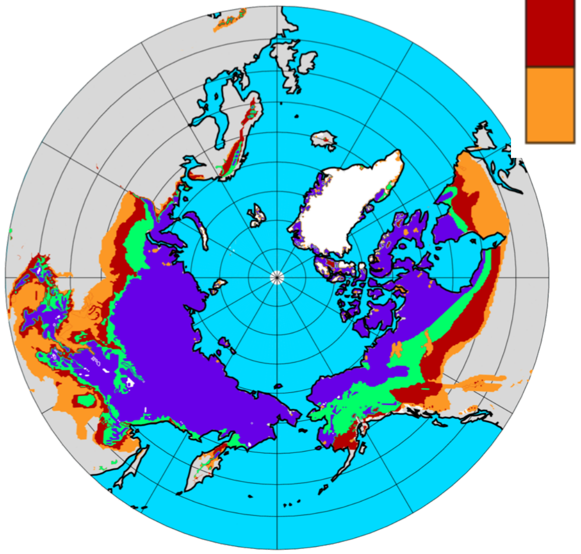


Permafrost zone is very important for carbon storage

Permafrost exists only in high latitudes



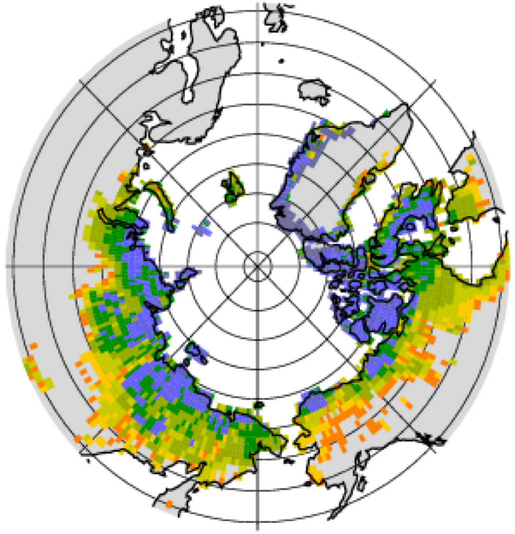
IPA Permafrost Distribution
~15-16 million km^2



Continuous (90 – 100%)
Discontinuous (50 – 90%)
Sporadic (10 – 50%)
Isolated (0 – 10%)

Brown et al. 1998

CLM5
15.1 million km^2



Slides adapted from D. Lawrence

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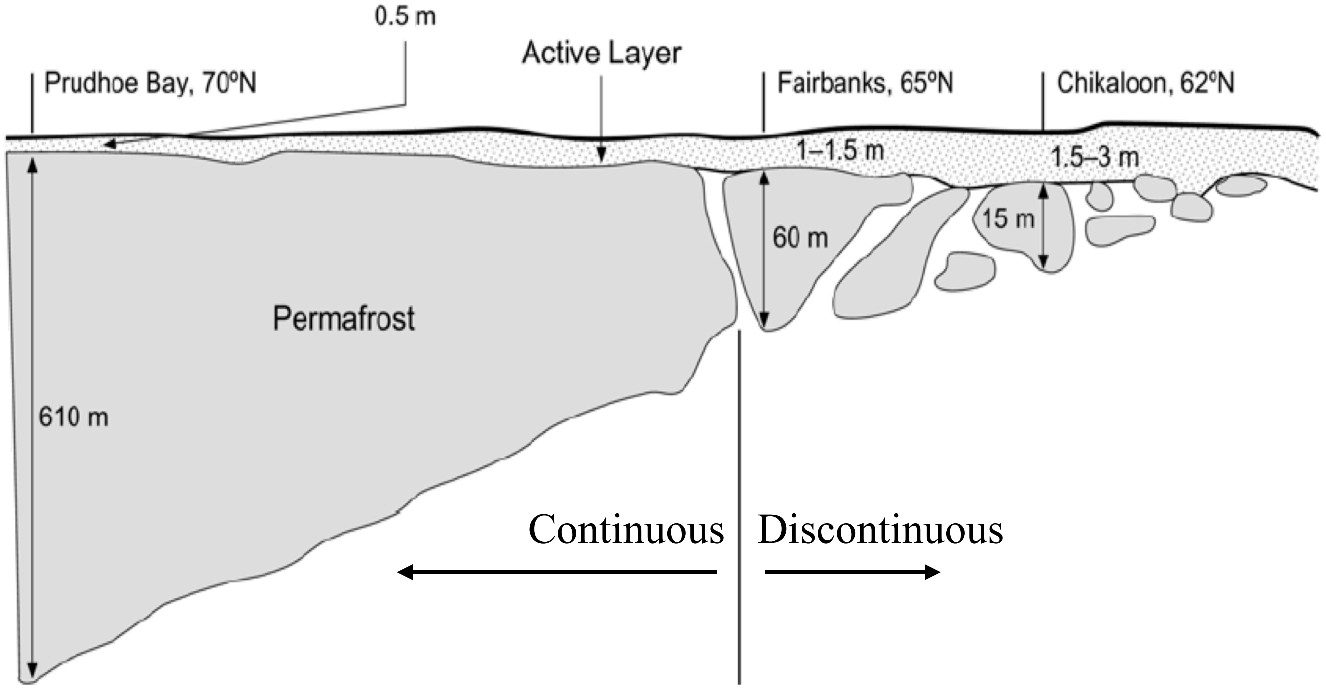

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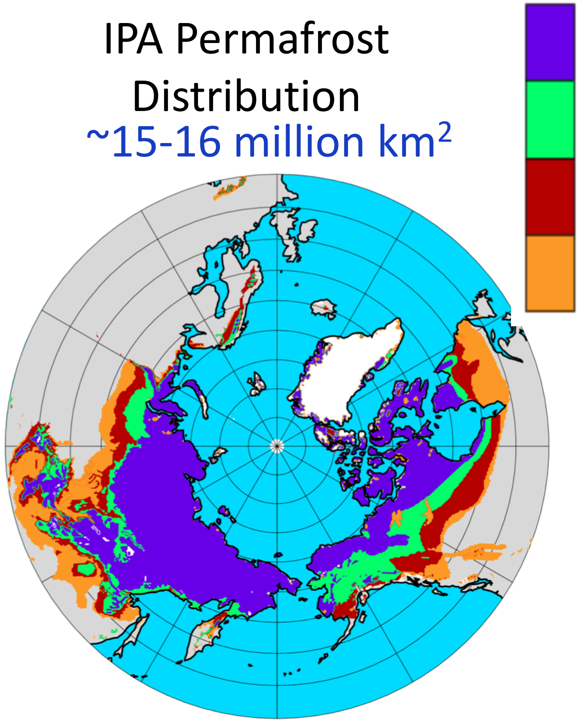

Brown et al. 1998

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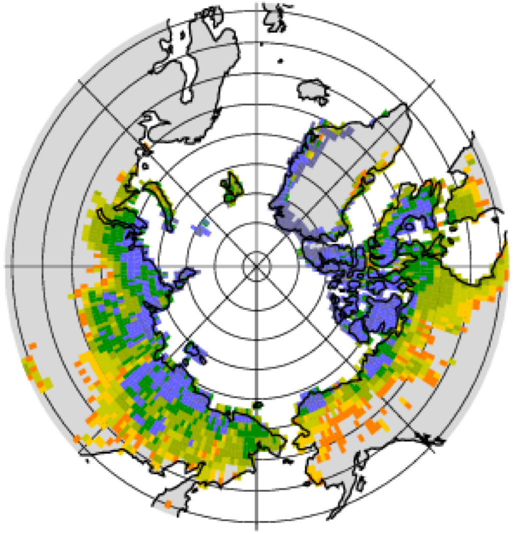


Land Model features needed to model permafrost

- Snow model that treats snow insulation reasonably (Koven et al. 2013)
- Soil water phase change and freezing temperature
- Explicit treatment of thermal and hydraulic properties of soil organic matter (Nicolsky et al. 2007, Lawrence and Slater, 2008)
- Deep ground column ~50m depth (Alexeev et al. 2007, Lawrence et al., 2008)
- Cold region hydrology, ice impedance, perched water table (Swenson et al. 2012)

Slides adapted from D. Lawrence

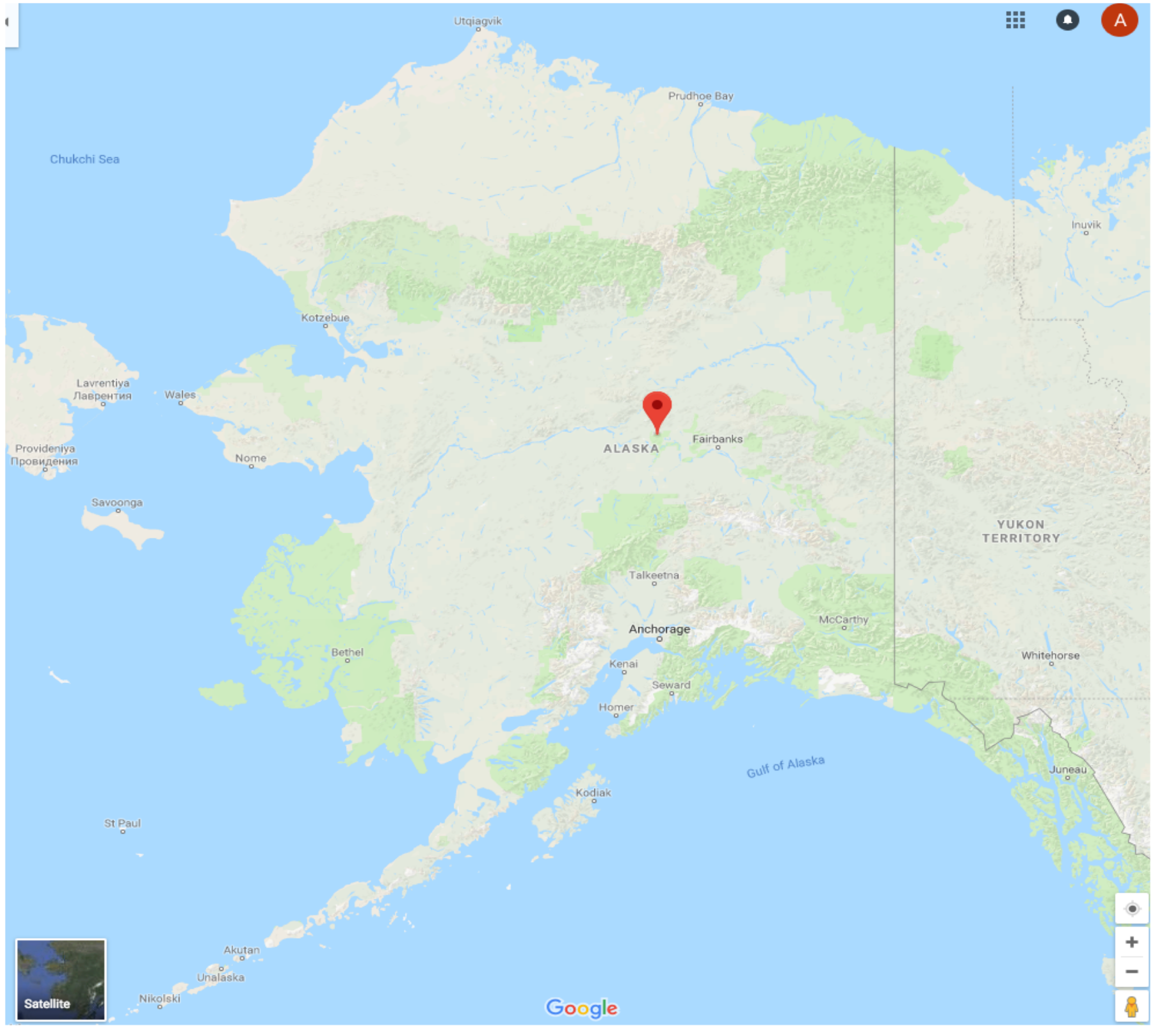
CLM Activity: How do snow conditions impact permafrost?

Tools:

- Single Column CLM near Fairbanks, AK
- Jupyter notebook activity

Suggested experiment options:

- Decrease number of surface snow levels from 12 to 3.
- Turn off wind impact on snow density, which was the default configuration for CLM4.5.
- Change soil evaporative resistance to CLM4.5 default method.
- Decrease fresh snow radius maximum to equal CLM4.5 default.
- Decrease leaf area index buried by snow, which affects albedo.



Find instructions for running CLM and opening the jupyter notebook here:
/glade/u/home/duvivier/PWS2018/day3/afternoon/clm/clm_singlept_running_instructions.txt

CESM single column

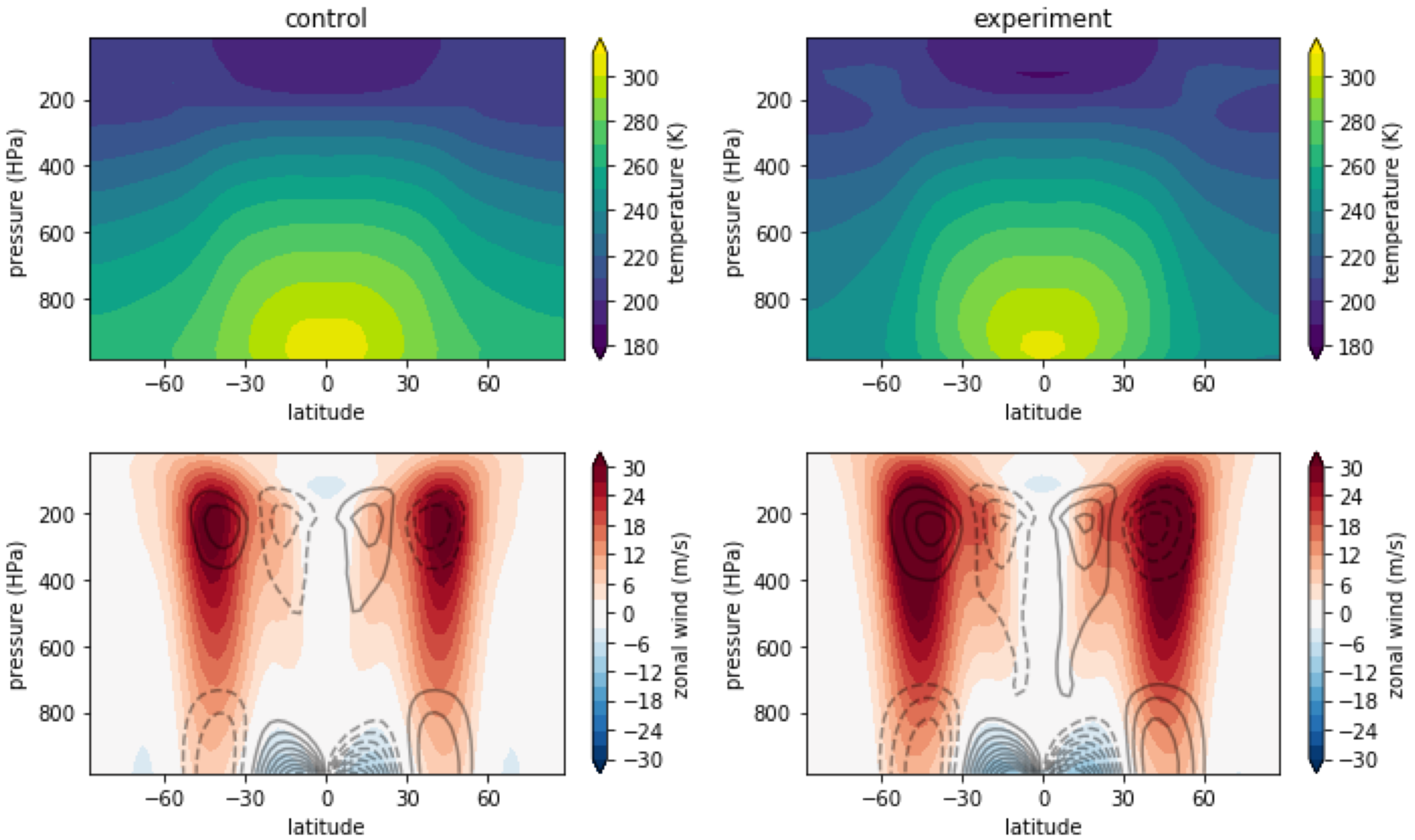
- Atmosphere → SCAM
  - Andrew Gettleman, Isla Simpson
  - https://ncar.github.io/CAM/doc/build/html/users_guide/atmospheric-configurations.html#cam-single-column-fscam-compset
- Land → CLM option
  - Sean Swenson, Danica Lombardozzi
  - https://escomp.github.io/ctsm-docs/doc/build/html/users_guide/running-single-points/index.html
  - **Activity option with this configuration**
- Sea Ice → Icepack
  - Dave Bailey, Alice DuVivier
  - https://github.com/CICE-Consortium/Icepack/
- Ocean → "Pencil" Model
  - Gokhan Danabasoglu, Alice DuVivier

Go Play!

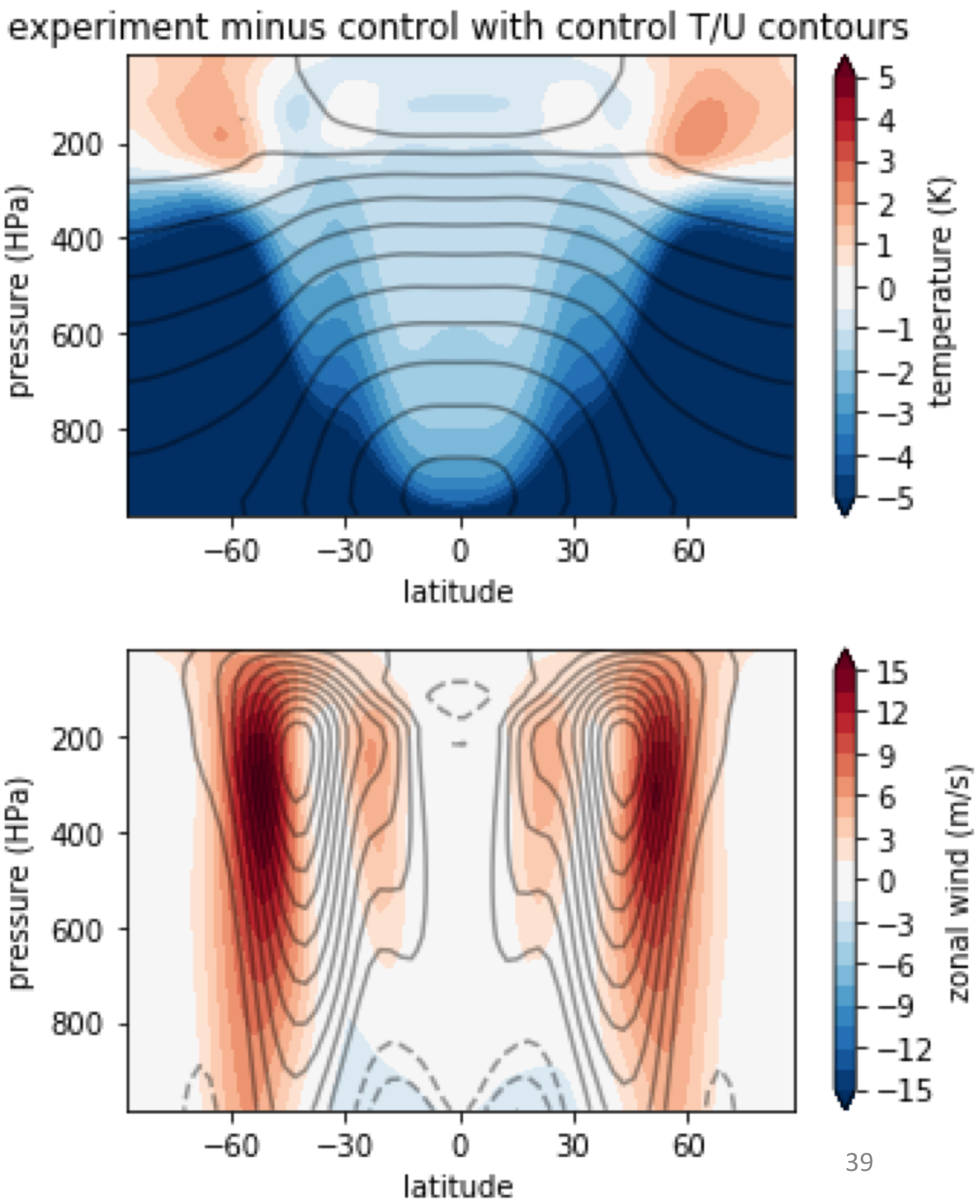
Afternoon debrief/discussion

- Our results for activities
- What did you learn?
- What further questions do you have?

Held Suarez model debrief



- Where are the largest changes in the zonal mean wind strength?
- Where does the meridional temperature gradient change the most? The stratification?



Polar work that has used the Held Suarez model:

Pedram Hassanzadeh and Zhiming Kuang. (2015) Blocking variability: Arctic Amplification versus Arctic Oscillation. *Geophysical Research Letters* **42**:20, 8586-8595.

Cory Baggett, Sukyoung Lee, and Steven Feldstein. (2016) An Investigation of the Presence of Atmospheric Rivers over the North Pacific during Planetary-Scale Wave Life Cycles and Their Role in Arctic Warming. *Journal of the Atmospheric Sciences* **73**:11, 4329-4347.

Masaru Yamamoto and Masaaki Takahashi. (2018) Effects of Polar Indirect Circulation on Superrotation and Multiple Equilibrium in Long-Term AGCM Experiments With an Idealized Venus-Like Forcing: Sensitivity to Horizontal Resolution and Initial Condition. *Journal of Geophysical Research: Planets* **123**:3, 708-728.

Bryn Ronalds, Elizabeth Barnes, and Pedram Hassanzadeh. (2018) A Barotropic Mechanism for the Response of Jet Stream Variability to Arctic Amplification and Sea Ice Loss. *Journal of Climate* **31**:17, 7069-7085.

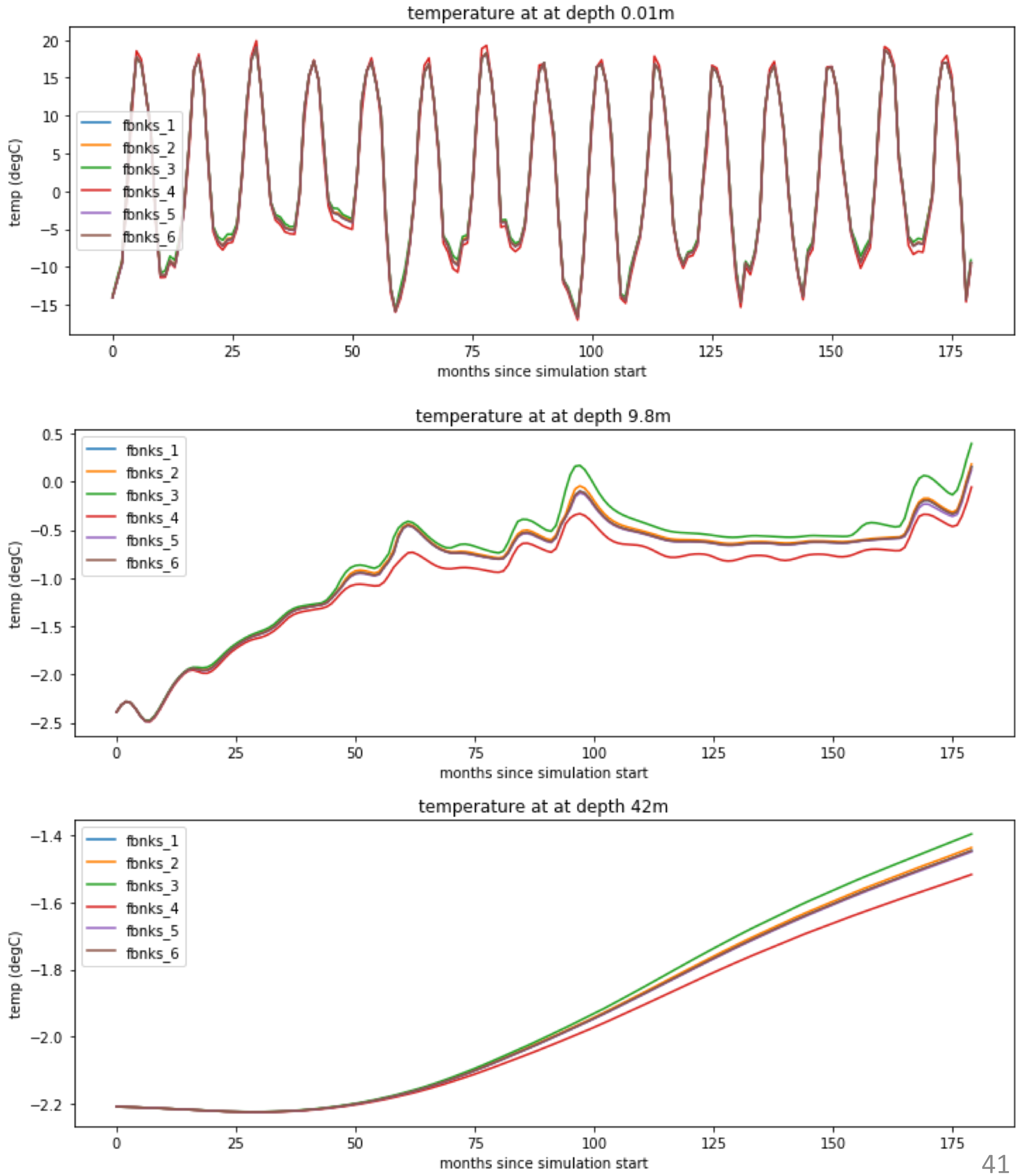
Xichen Li, Edwin P. Gerber, David M. Holland, and Changhyun Yoo. (2015) A Rossby Wave Bridge from the Tropical Atlantic to West Antarctica. *Journal of Climate* **28**:6, 2256-2273.

Yutian Wu and Karen L. Smith. (2016) Response of Northern Hemisphere Midlatitude Circulation to Arctic Amplification in a Simple Atmospheric General Circulation Model. *Journal of Climate* **29**:6, 2041-2058.

Jianhua Lu and Ming Cai. (2010) Quantifying contributions to polar warming amplification in an idealized coupled general circulation model. *Climate Dynamics* **34**:5, 669-687.

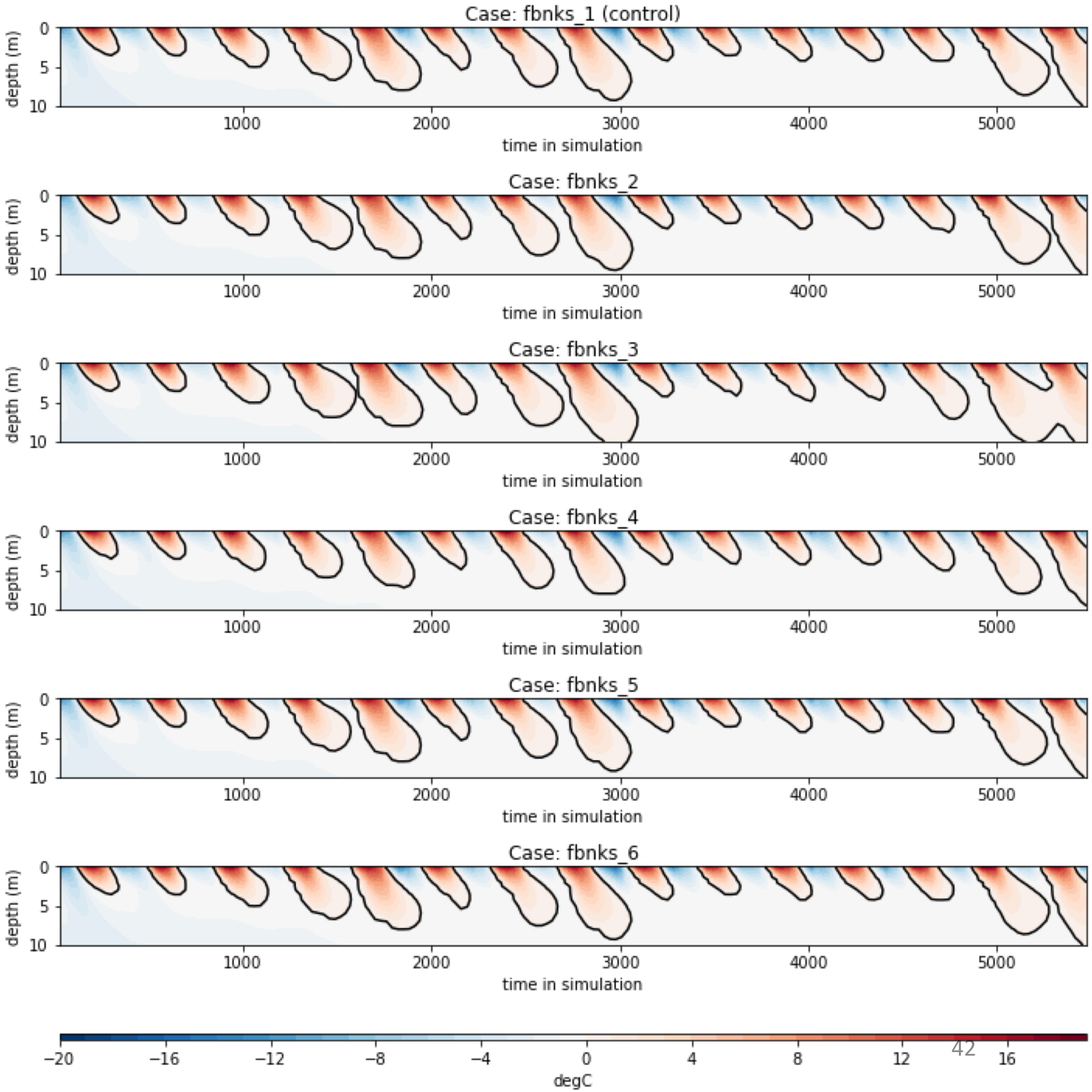
CLM activity results 1/4

- Big seasonal cycle at surface with no trend and same for all cases.
- Lower layers have smaller seasonal changes though trend toward increasing temperatures and see experiments diverge.
- Deepest layers don't have any real seasonal signal.
- Lower levels show spin up of soil temperature.



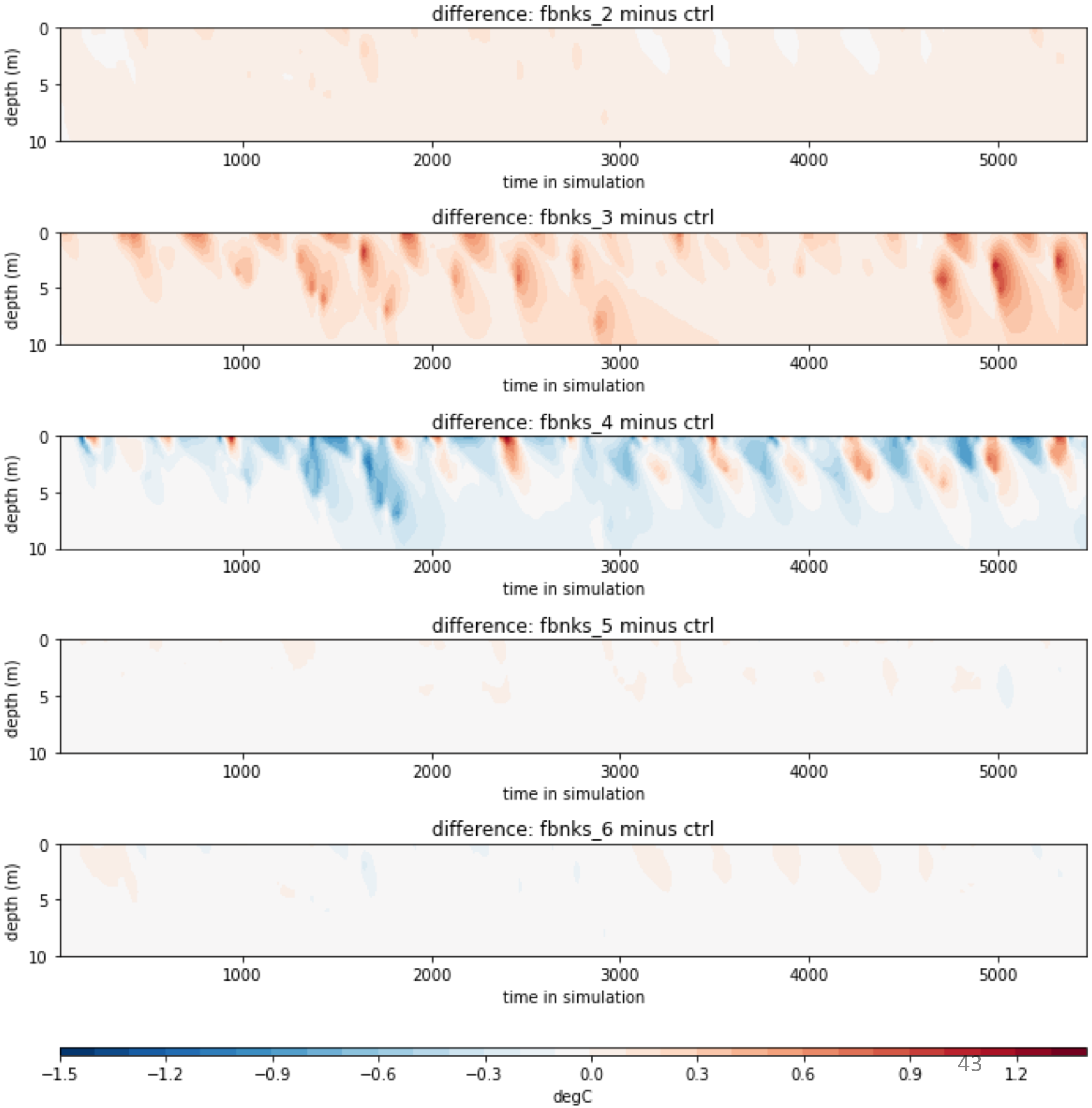
CLM activity results 2/4

- The heating from summer propagates downward even after autumn freezing begins. The shape is consistent for all simulations.
- There is a lot of internannual variability and this is consistent in the simulations because all have the same surface forcing.
- ALT can range from ~2m (e.g. yr 1, 10) to ~10m (e.g. yr 8). There does not appear to be a consistent trend.



CLM activity results 3/4

- Generally the differences tend to be small:
  - fbnks_2 → decreasing # snow levels leads to slightly warmer temps.
  - fbnks_3 → Turning off the wind impact on snow has much warmer temperature.
  - fbnks_4 → changing soil evaporative resistance leads to colder soil.
  - fbnks_5 → decreasing fresh snow radius has small warming impact at depth.
  - fbnks_6 → decreasing leaf area buried by snow has small, mostly surface impact.



CLM activity results 4/4

- Not all snow modifications change ALT much. But can have impacts up to 3m in some years.
- Look into plant types at this location. Try other locations with different PFTs, lake, etc fractions. Resolution could impact this as well.
- Fast and easy to run perturbations once set up, but not clear results are applicable elsewhere.