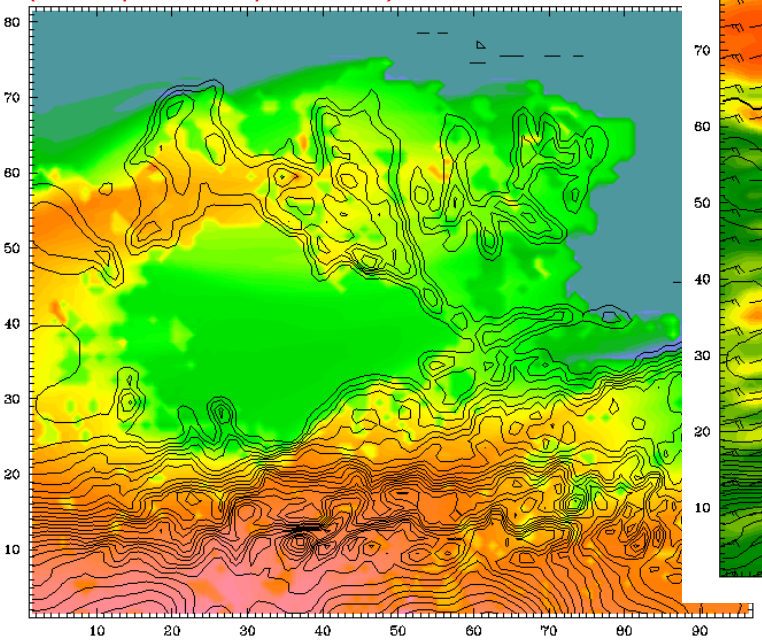
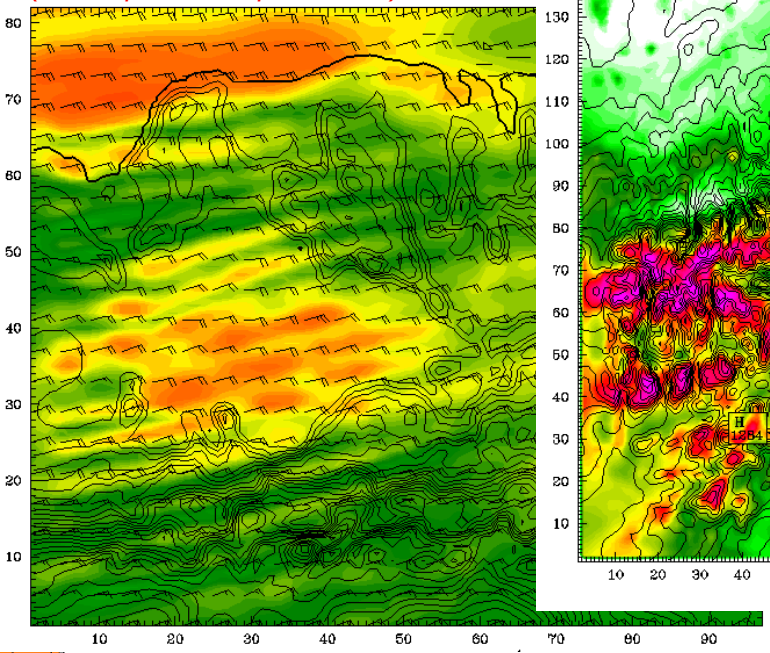
Projecting Future-Climate Scenarios to High-Resolution using Dynamical Downscaling

Gary Clow
USGS - Earth Surface Dynamics

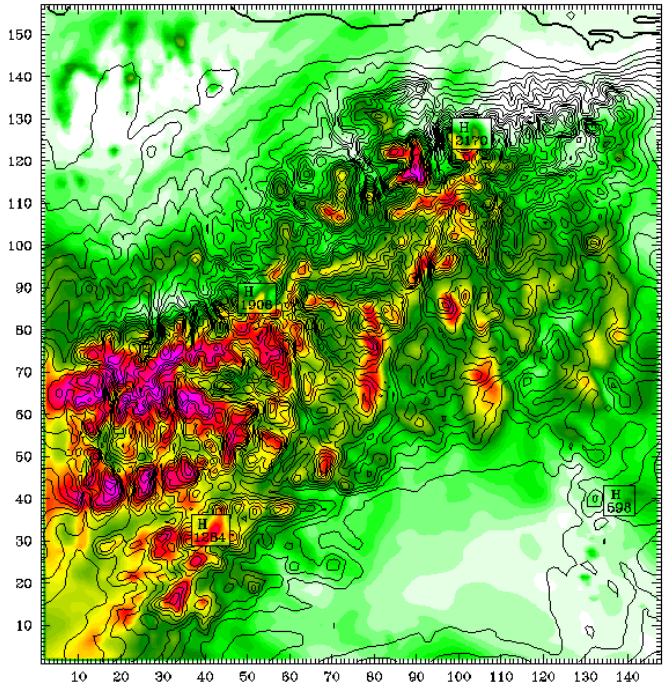
Surface Air Temperature
(Teshekpuk Lake Special Area)



Surface Winds
(Teshekpuk Lake Special Area)

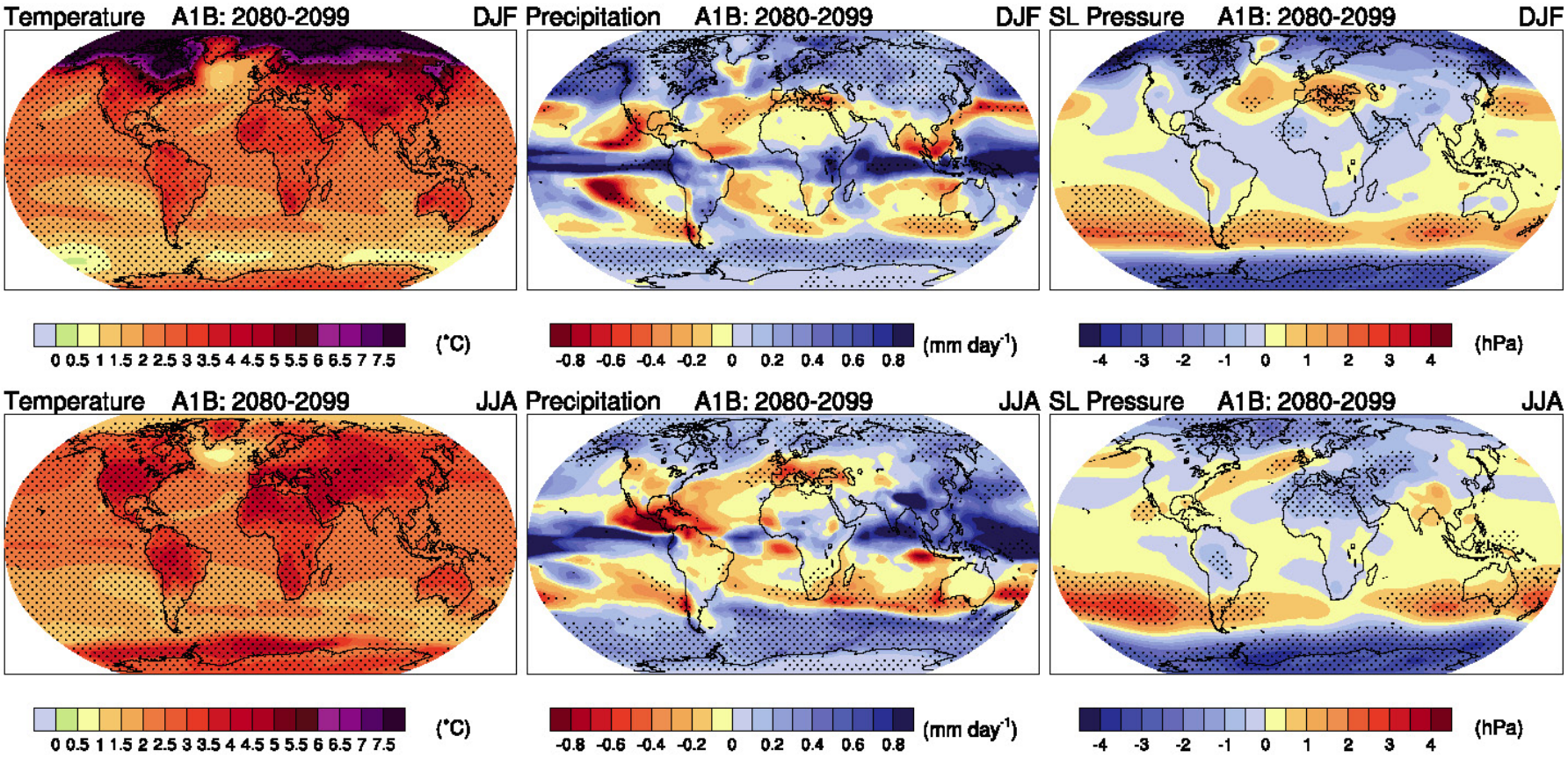


Total Precipitation
(Gates of the Arctic NP, Arctic NWR, Yukon Flats …)



(A1B, 2080-2099)

AOGCM Projections

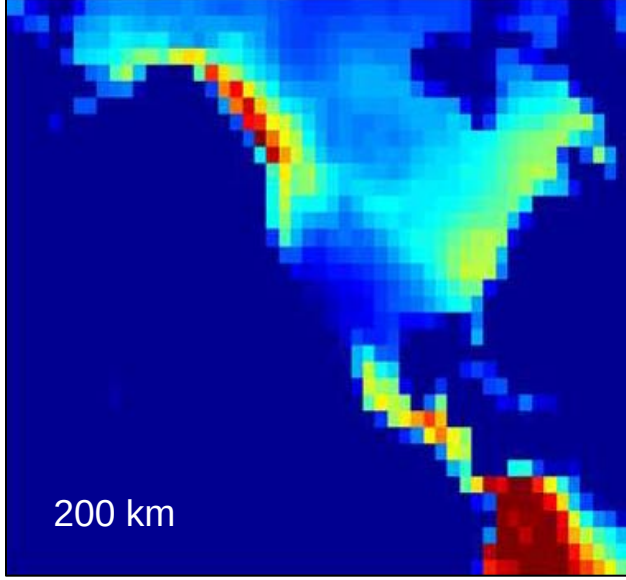


IPCC, 2007

AOGCM Limitations

- Horizontal grid scale is currently 150-300 km

- Unable to depict spatial structure of climate fields in regions of complex topography, complex coastlines, or heterogeneous land use



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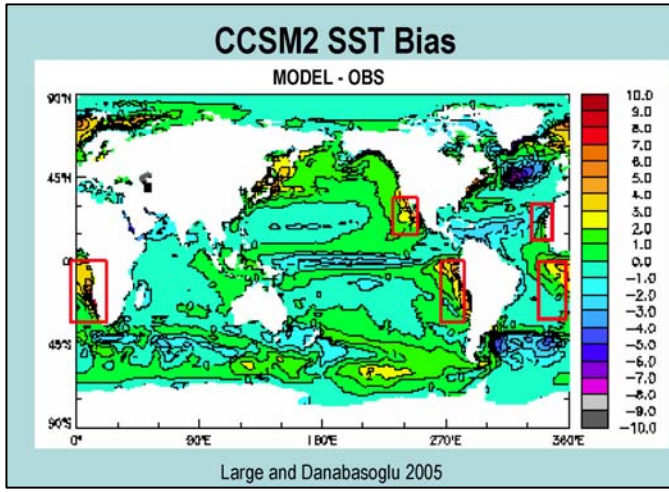
(subtropical eastern boundary regimes)



Large and Danabasoglu 2005

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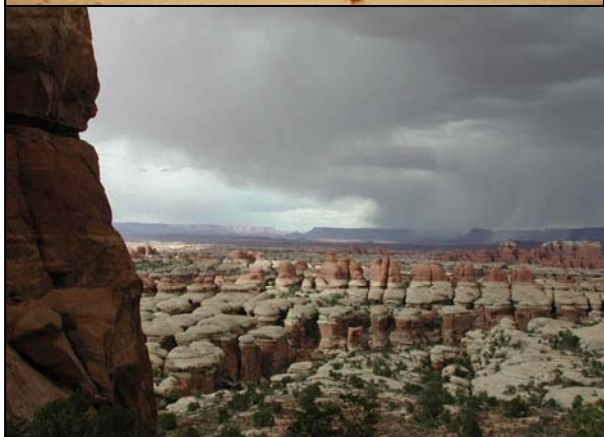
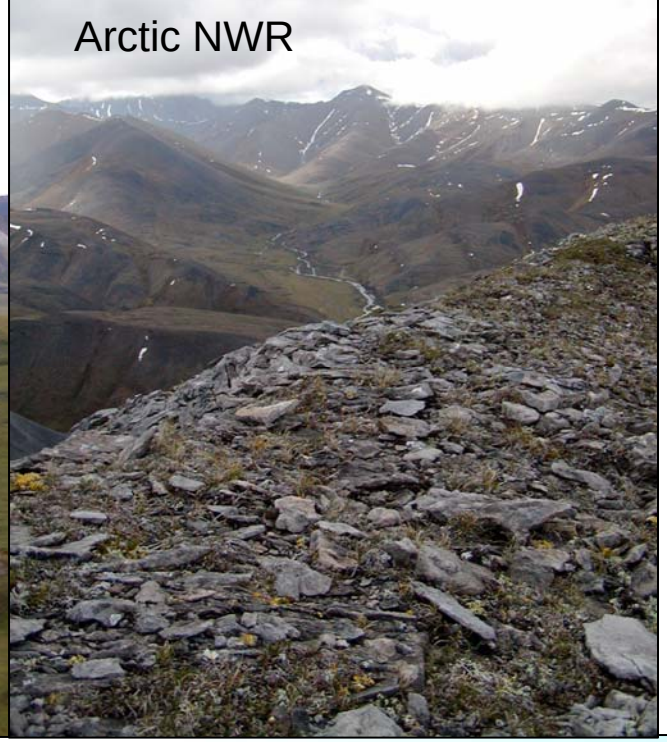
  (subtropical eastern boundary regimes)

- Some feedbacks important at local/regional scale are likely to be underestimated *(snow albedo fb, Rocky Mtns)*

- Processes at short time scales not well represented
  (intense wind or rain storms / rain-on-snow events)

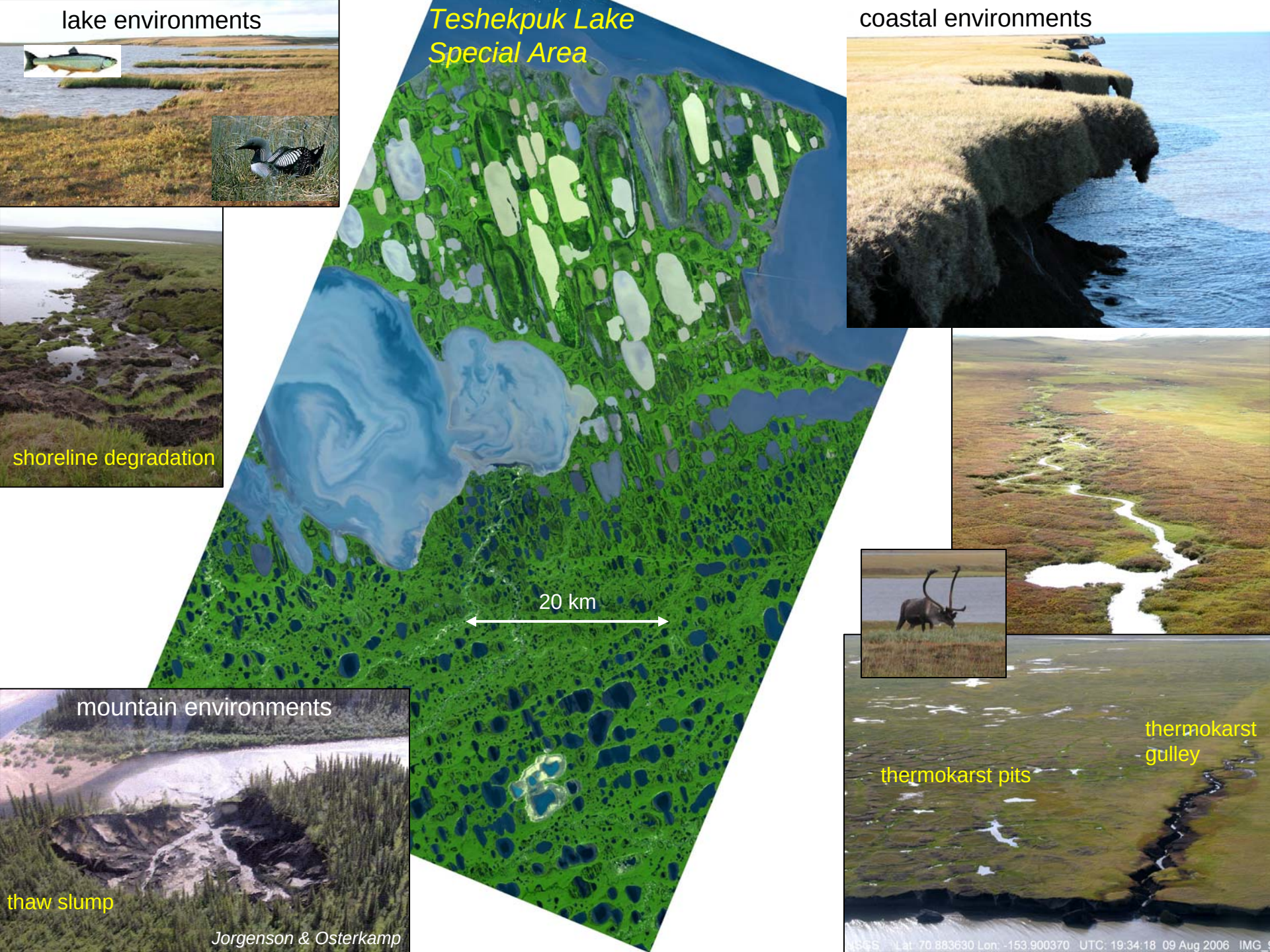


Arctic National Wildlife Refuge


Arctic NWR

Mojave National Preserve

Red Rock Lakes NWR


lake environments
Teshekpuk Lake
Special Area
coastal environments
shoreline degradation
20 km
mountain environments
thaw slump
Jorgenson & Osterkamp
thermokarst
gulley
thermokarst pits
Lat: 70.883630 Lon: -153.900370 UTC: 19:34:18 09 Aug 2006 IMG

AOGCMs

150-300 km
(macroscale)

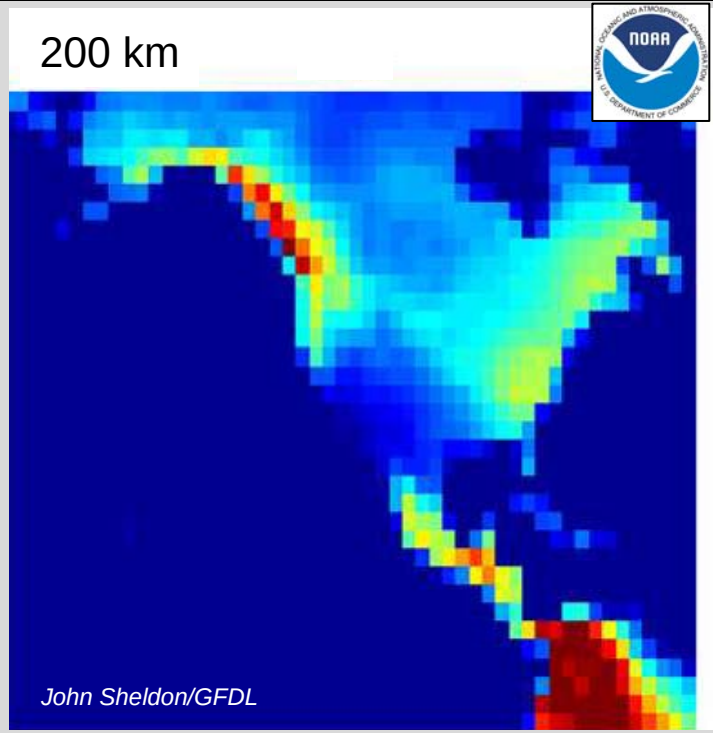
Downscale

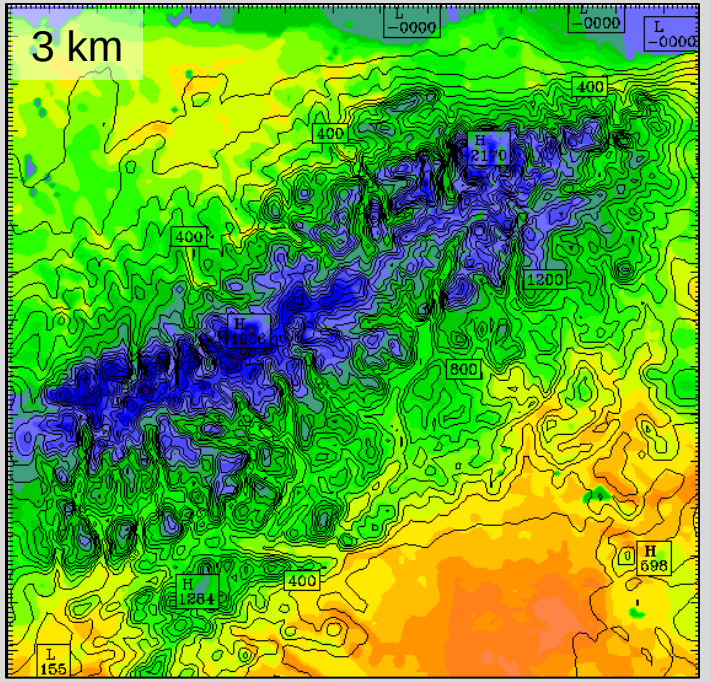
“empirical” methods

space

“dynamical” methods

space & time

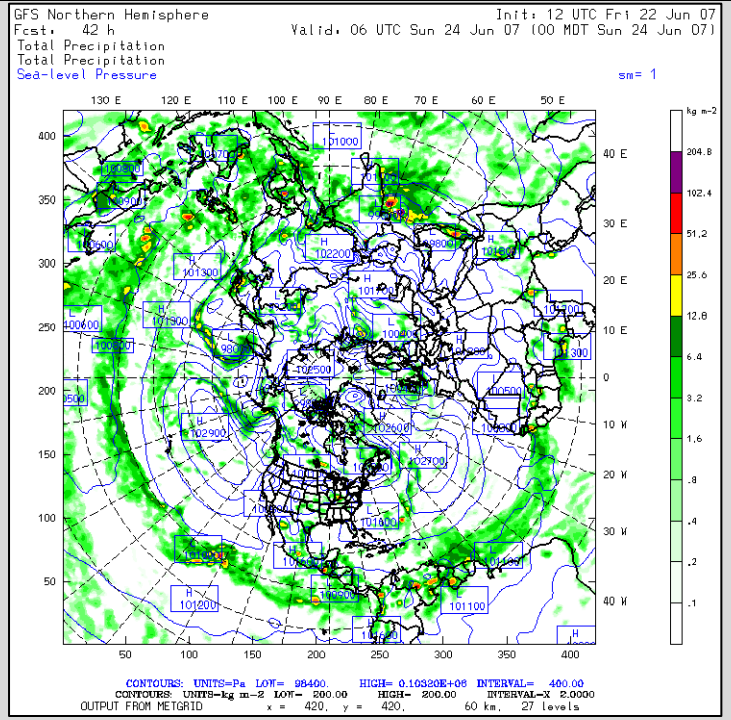




large-scale circulation

↓

Empirical Downscaling



Advantages

- can do a good job predicting surface conditions from large-scale circulation under present-day climate conditions
- computationally inexpensive

Disadvantages

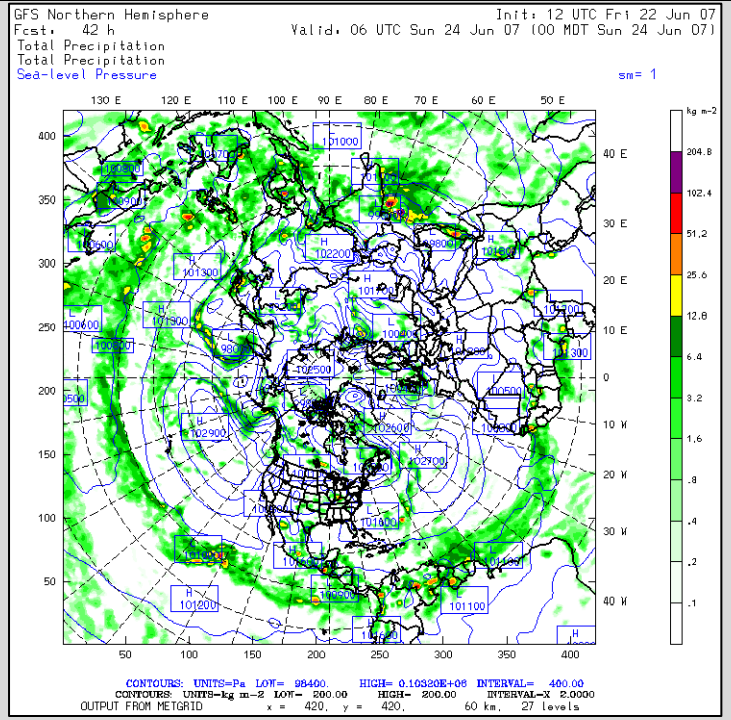
- assumes relationships between the atmosphere and surface environment are time-invariant
- lack of physical coherency among climate variables
- difficult to develop improved understanding of physical linkages underlying the atmosphere/surface relationships

large-scale circulation

↓

Dynamical Downscaling

regional climate models



Advantages

- physically based (physical coherency among climate variables)
- capture nonlinear mesoscale effects (convective storms, land-sea breezes, …)
- high-temporal resolution potentially allows simulation of extreme events
- enables the coupling of processes from global to local

Disadvantages

- computationally expensive!

Dynamical Downscaling (using WRF)

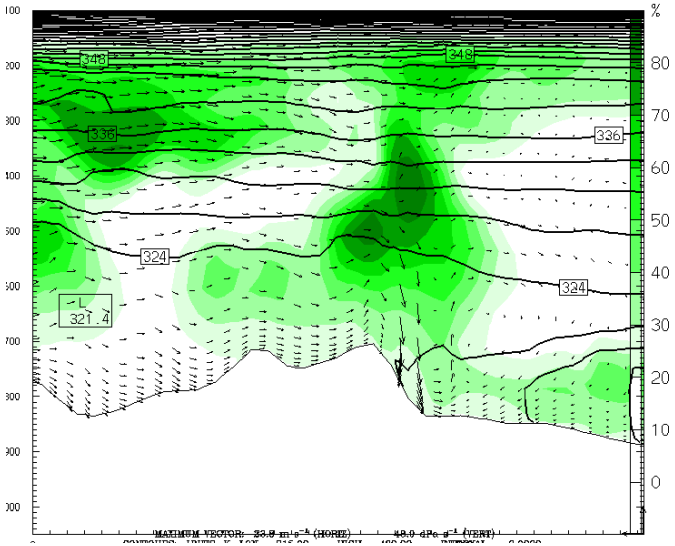
- Next-generation mesoscale weather research & forecasting system

- Community model: *NCAR, NOAA, AFWA, NRL, FAA, universities*

- Fully compressible nonhydrostatic equations
  (designed for use at scales ranging from meters to 1000s of kilometers)

- Suitable for a wide range of applications

- Cloud-resolving when dx < 10 km



WRF Physics Options

Longwave Radiation

- RRTM, GFDL, CCSM3

Shortwave Radiation

- Dudhia, Goddard, GFDL, CCSM3

Cloud Microphysics

- Kessler; Lin et al.; NCEP; WSM 3,5,6 class; Ferrier; Thompson; Morrison

Cumulus Parameterization

- Kain-Fritsch, Betts-Miller-Janjic, Grell-Devenvi

Planetary Boundary Layer

- YSU, Mellor-Yamada-Janjic, MRF

Land Surface Model

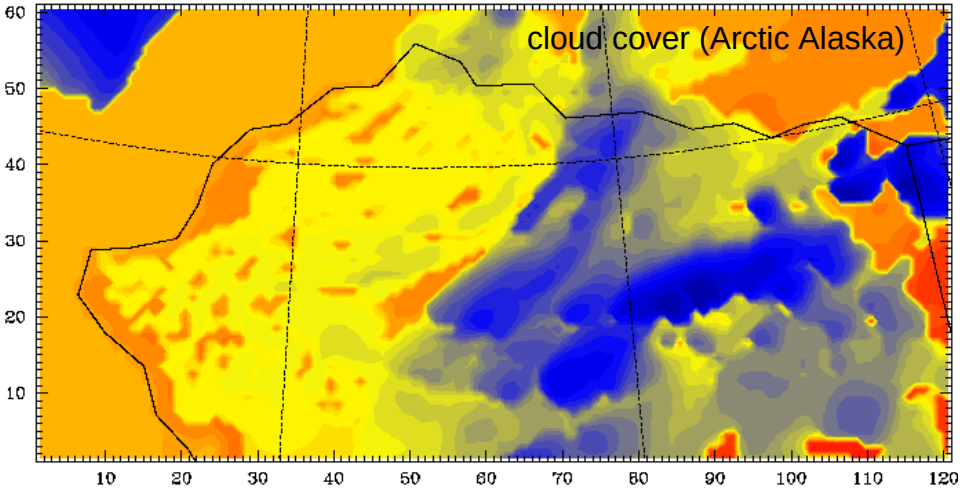
- 5 slab soil model, RUC LSM, Noah LSM, Urban Canopy model, CLM (2008/9)

WRF Output and Diagnostic Fields

- ground temperature
- soil moisture
- snow cover
- surface dewpoint temperature
- surface frost point temperature
- wind shear
- sensible heat flux
- latent heat flux
- BL relative humidity

- precipitation
- precip. type (rain, graupel, snow)
- convective vs. non-convective precip.
- column-integrated cloud liquid mass
- cloud cover
- cloud water mixing ratio
- cloud ice mixing ratio
- cloud ceiling
- cloud-top temperature

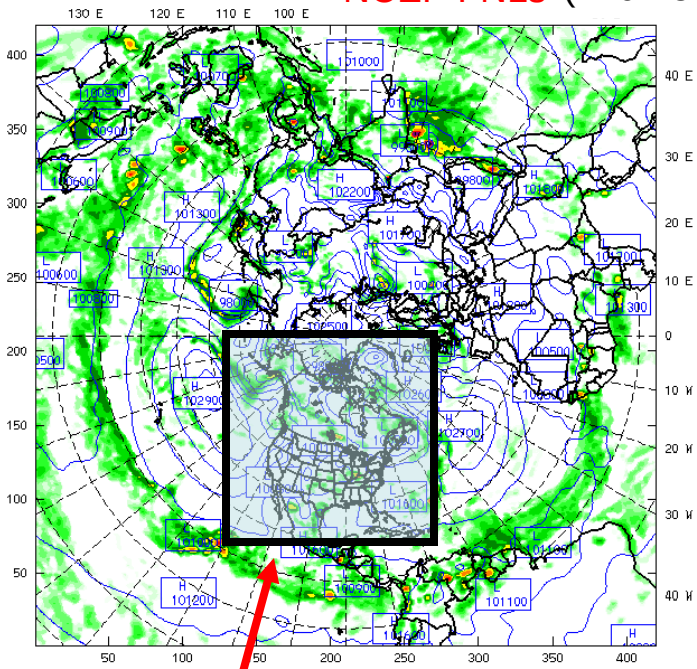
- air temperature
- pressure
- density
- wind speed & direction
- vorticity
- convective instability
- water vapor density



2 Modes

1) Retrospective Analyses

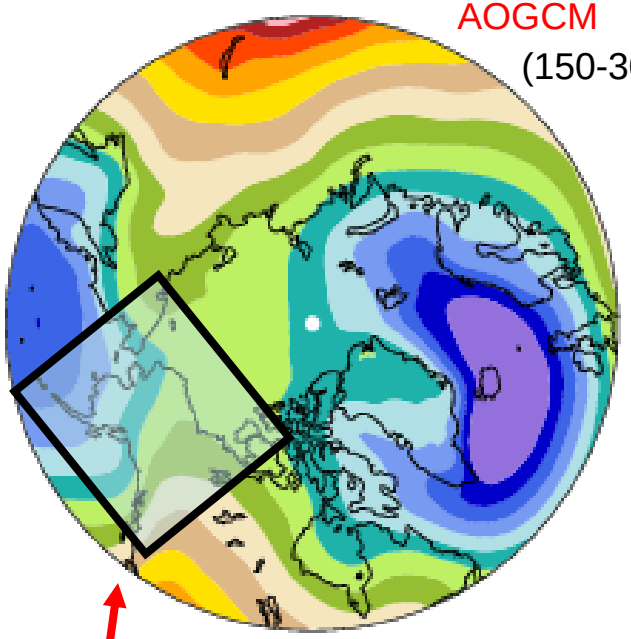
NCEP FNLs (110-250 km)



Nest WRF within observed large-scale circulation.

2) Future Climate Projections

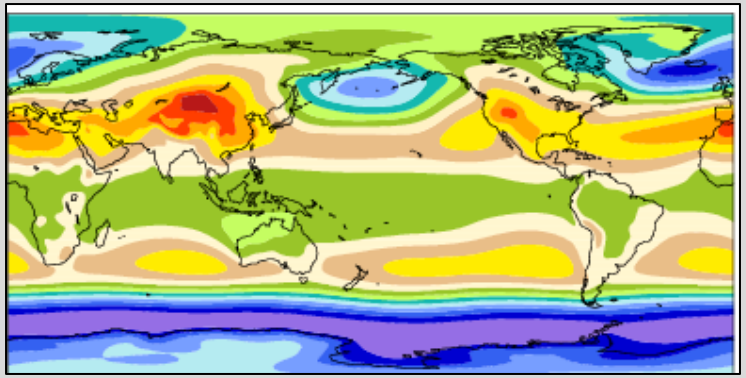
AOGCM
(150-300 km)



Nest WRF within large-scale circulation projected by an AOGCM.

NCEP/FNLs or AOGCMs

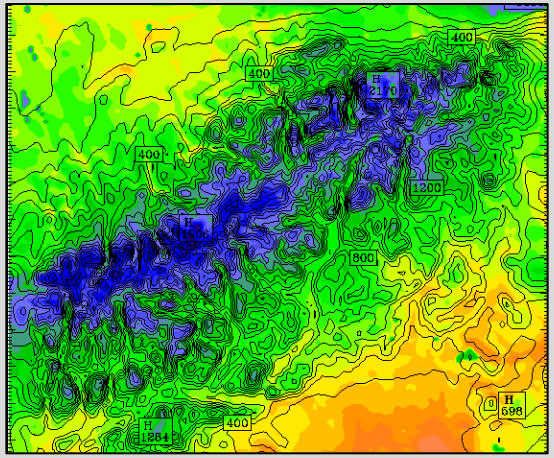
110-300 km
(macroscale)



WRF

(primarily an atmospheric model)

0.01 - 100 km



Landscape Change models

Ecosystem Change models

The Future of WRF

Model Development

- Interactive coupling with sea ice and ocean models
- More comprehensive treatments of land surface and hydrologic processes
- Interactive coupling with marine and terrestrial ecosystem models
- Interactive coupling with chemistry and aerosol models, including dust

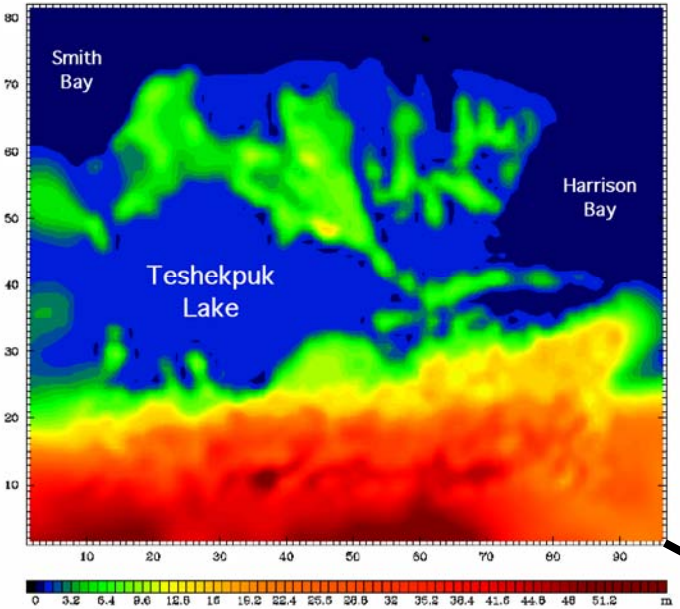
WRF at USGS

- Currently running on an AlphaServer
- Migrating soon to the 500-processor INSTAAR-USGS supercomputer

WRF Examples

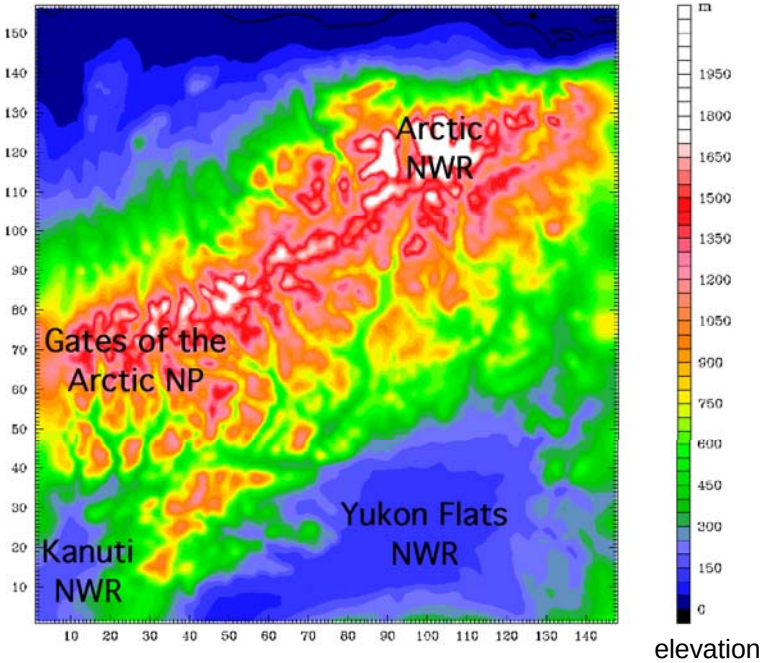
Teshekpuk Lake Special Area

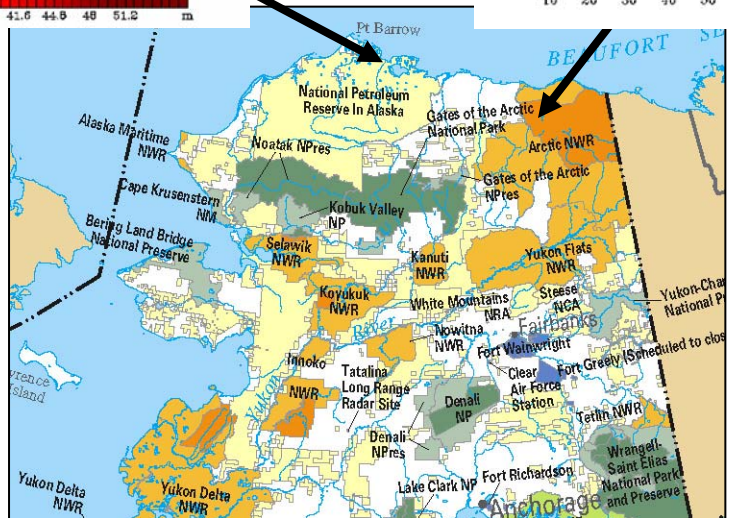
1-km resolution 1-14 June 2005



Gates of the Arctic NP, Arctic NWR

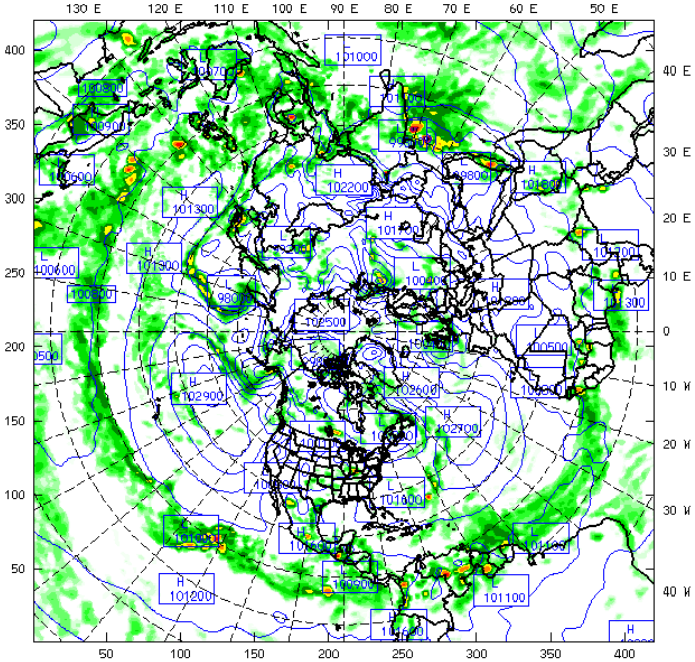
3-km resolution 8-22 June 2006

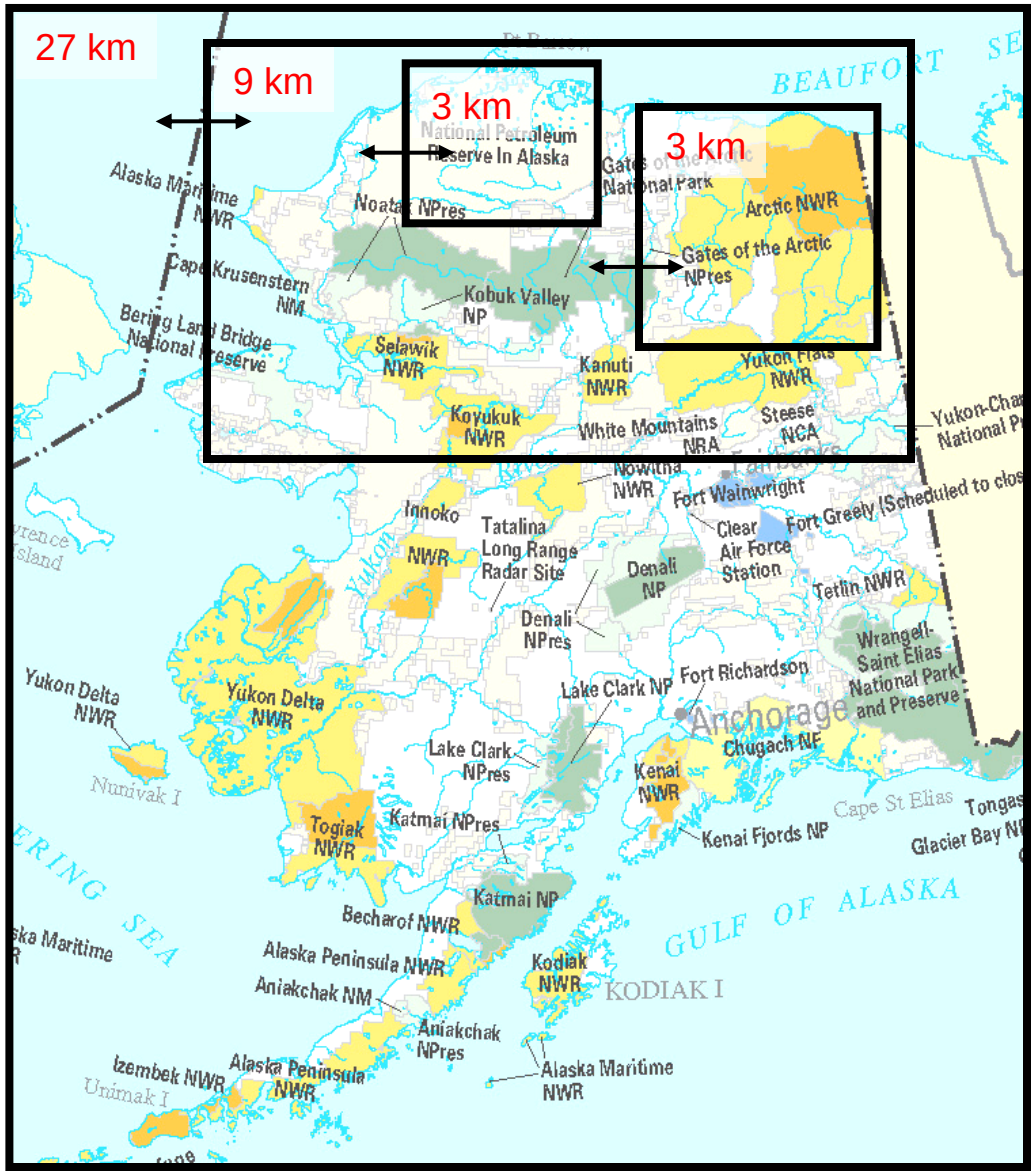




NCEP FNLs

(110 km)

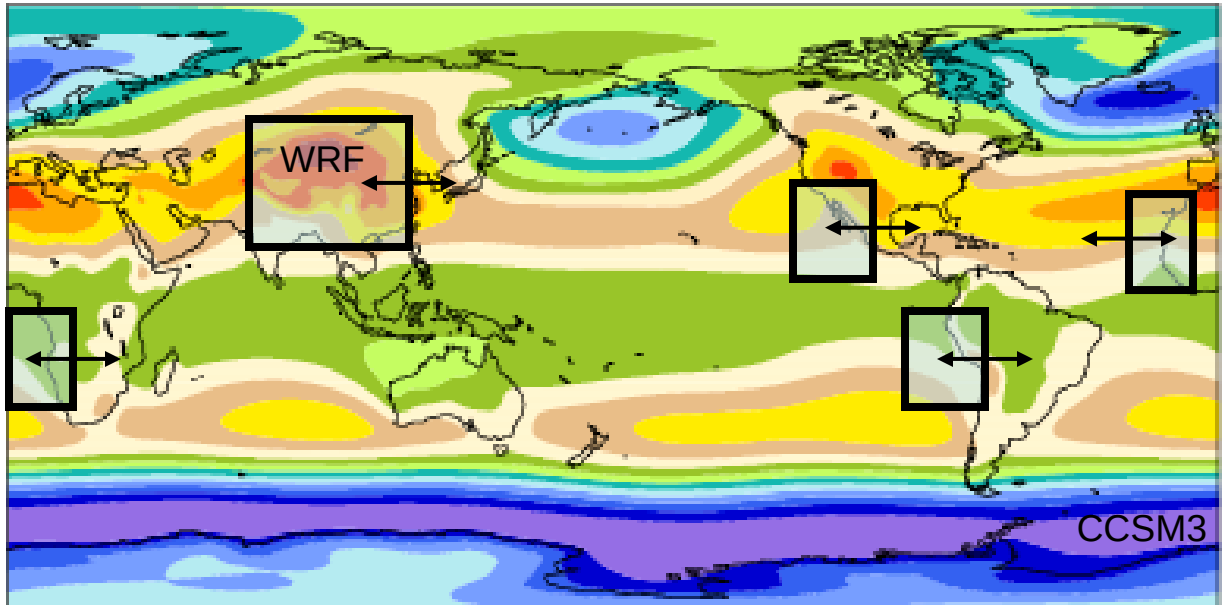




The Future of WRF

Integration of WRF with CCSM3

- Finish adding CCSM3 physics as standard WRF options (CLM …)
- 2-way nesting WRF within CCSM3, "Upscaling"



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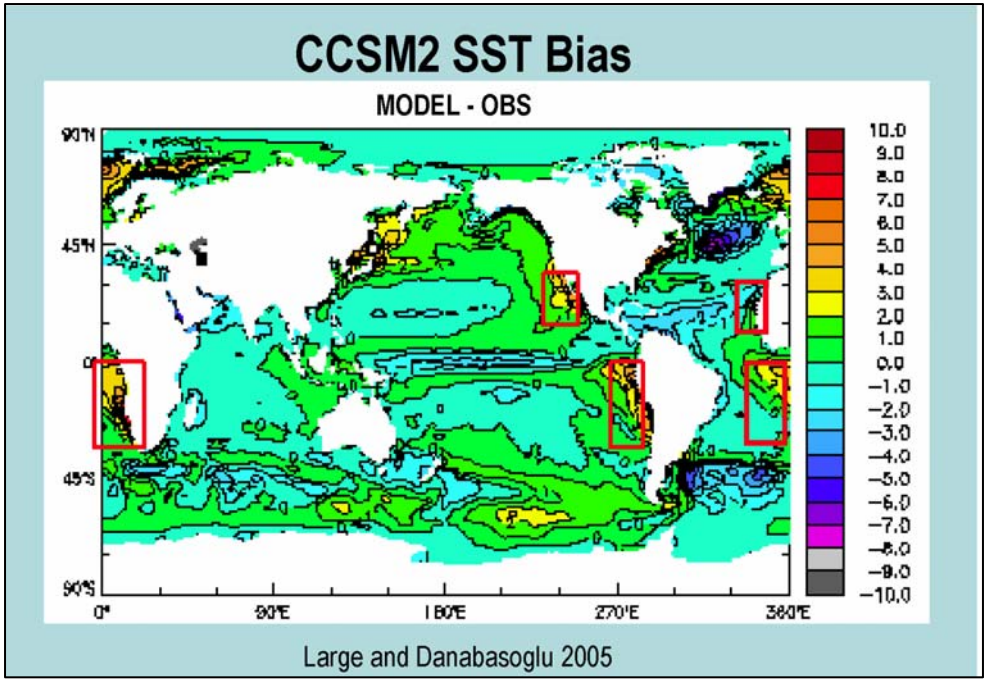

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