Arctic System Reanalysis: Land Surface Parameter Assimilation and Model Updates

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Enhancements/Additions to WRF within ASR

- What is the Arctic System Reanalysis?
  - Modeling effort led by Ohio State University and NCAR
  - Funded by NSF to conduct a 10-year, 10km WRF-3DVAR simulation over the Arctic extending to ~40N

- Land surface state spin-up: more consistent initialization, less time for soil states in lower boundary to equilibrate

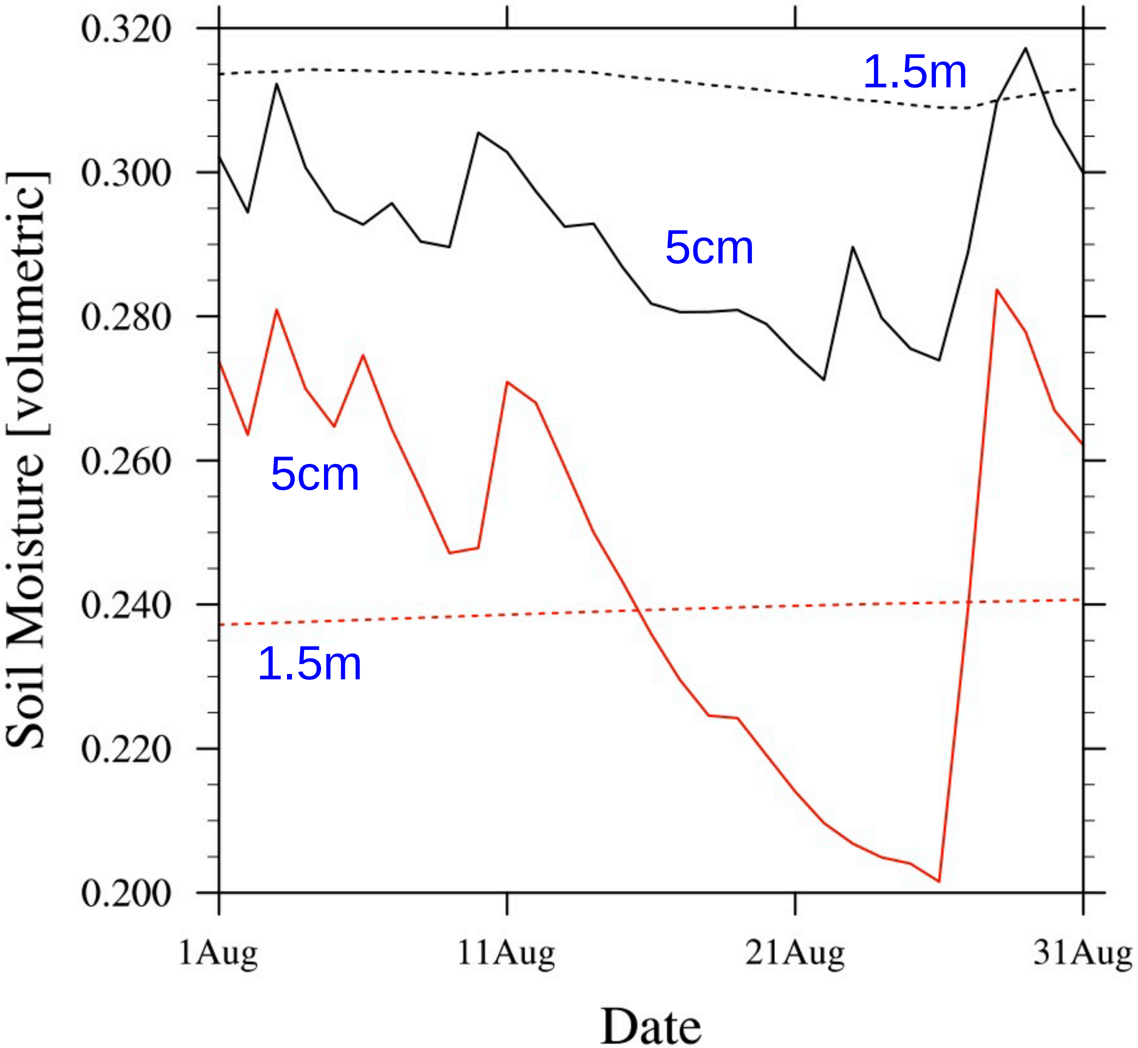
- Changes to model structure: add more and deeper soil layers, zero-flux lower boundary condition

- Land surface parameter and state assimilation: snow cover and snow depth, albedo, and green vegetation fraction inserted into model daily/weekly

Land Surface State Spin-up

- Use High Resolution Land Data Assimilation System (HRLDAS) with atmospheric forcing from reanalysis
- HRLDAS: uses WRF model grid and static fields (land cover, soil type, parameter tables) to run an offline version of the Noah LSM
- Use 6-hourly reanalysis output (precipitation, wind, temperature, pressure, humidity, shortwave and longwave radiation) from ERA-40 (1980 – 1999) and JRA-25 (2000 – 2009)
- Spatially interpolate forcing fields to WRF grid and adjust temperature for terrain height differences between reanalysis and WRF
- Use hourly timestep by linearly interpolating all but solar radiation; the total 24hr radiation is fit to a daily zenith angle curve
- Advantages are that initial fields (especially soil ice/moisture/temperature):
    - are already on the WRF grid
    - are consistent with terrain, land cover and soil types/levels
    - are consistent with WRF land model

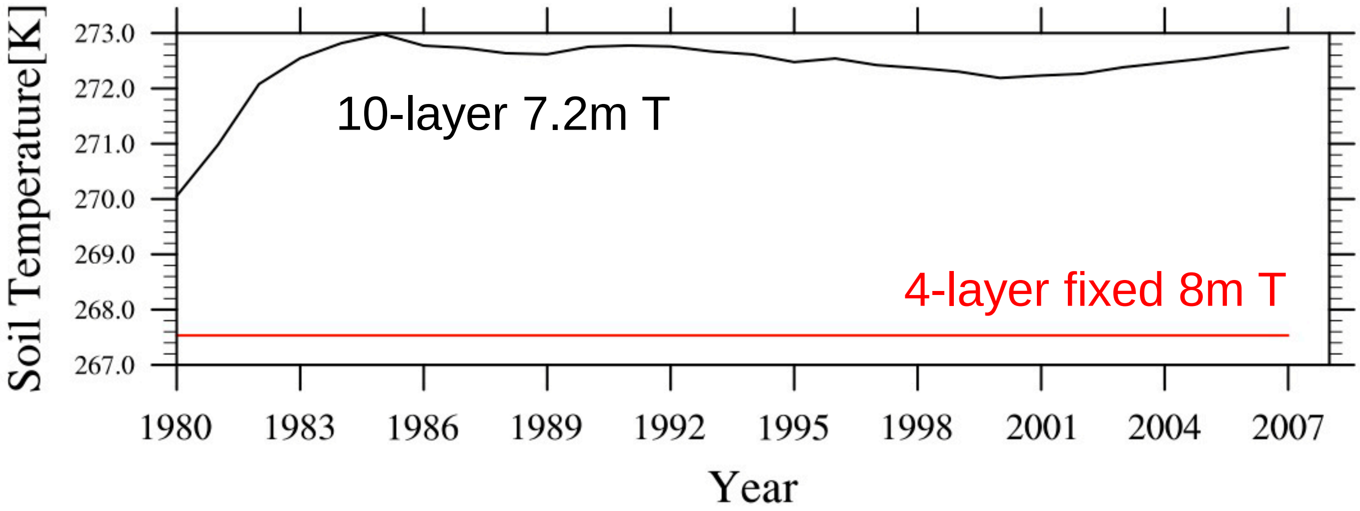
Land Surface State Spin-up



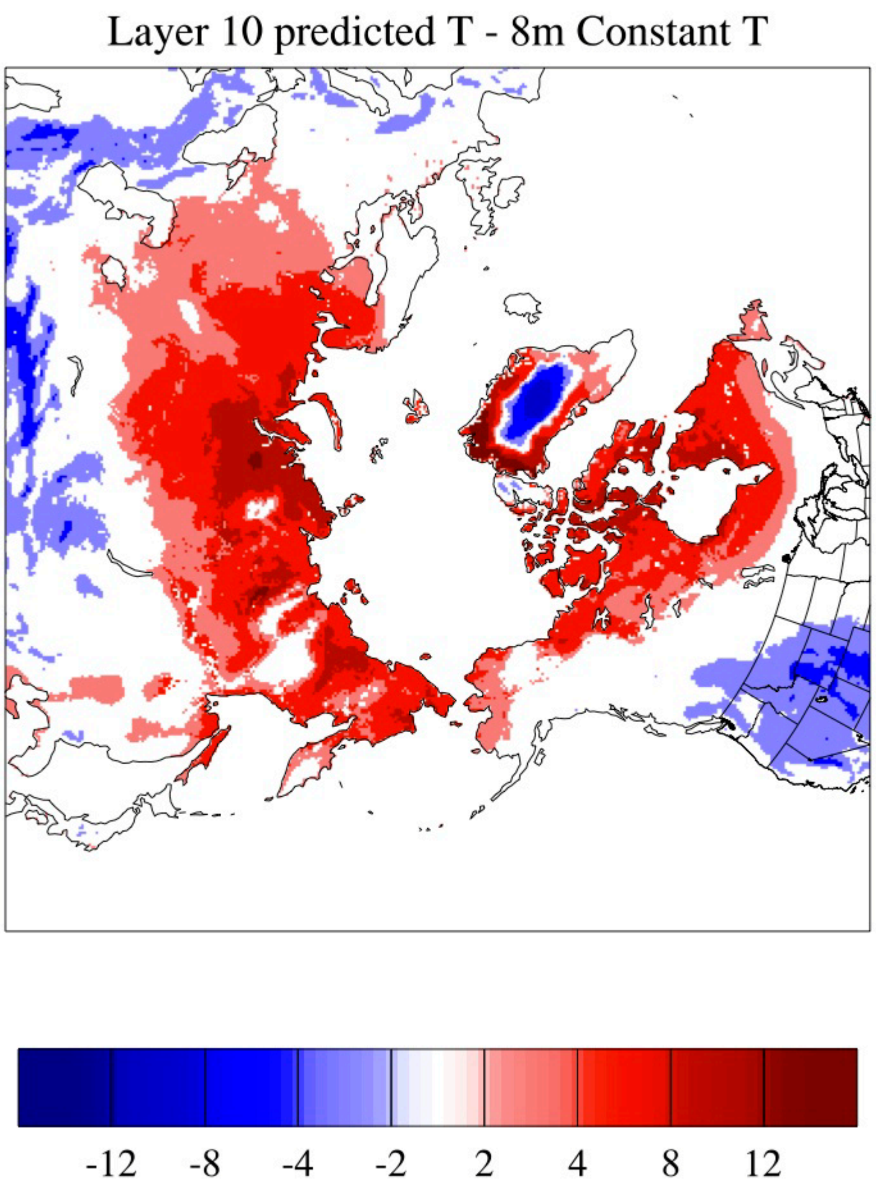
- August 2008 volumetric soil moisture in top and bottom layer for ERA-I initialization (black) and HRLDAS multi-year simulation (red)
- Region average near 64N, 158E (NE Siberia)
- Land models have their own climatology
- HRLDAS soil moisture is more likely to be in equilibrium for WRF cold start
- Especially important for cycling runs

Changes to Land Model Structure

- The default WRF model uses the Noah land surface model with four soil layers that have nodes at 0.05m, 0.25m, 0.7m, and 1.5m and a fixed deep soil (8m) temperature
- It has been suggested that the fixed deep soil temperature is likely too low over much of the Arctic because it is based on annual mean air temperature
- Within the ASR WRF model, the Noah LSM is modified to have 10 soil layers and a free, zero-flux lower boundary condition (3 subroutine + namelist changes)
- The 10 soil layers have interfaces at 0.05m, 0.15m, 0.25m, 0.4m, 0.65m, 1.05m, 1.7m, 2.75m, 4.45m and 7.2m
- For example, below is the 60-70N average bottom 10-layer T vs 4-layer 8m fixed T



Changes to Land Model Structure



- Difference between lowest layer (7.2m) temperature [K] after a 28 year simulation and the assumed 8m deep soil temperature in standard WRF
- Most of the Arctic region is much warmer in the 10-layer zero-flux model
- Implications for soil temperature/moisture related processes, e.g., permafrost prediction

Assimilation Products

Data assimilation - infrastructure added to HRLDAS/WRF(+WRF-Var) to include:

- IMS snow cover: daily, 2004 to current at 4km; pre-2004 at 24km; this product is used operationally at NCEP

- SNODEP snow depth: daily, obs/model product; on GFS T382 (~30km) grid; used as guidance to put snow where IMS says snow exists

- MODIS albedo: 8-day 0.05º global; available from Feb 2000; also use MODIS snow cover and cloud cover

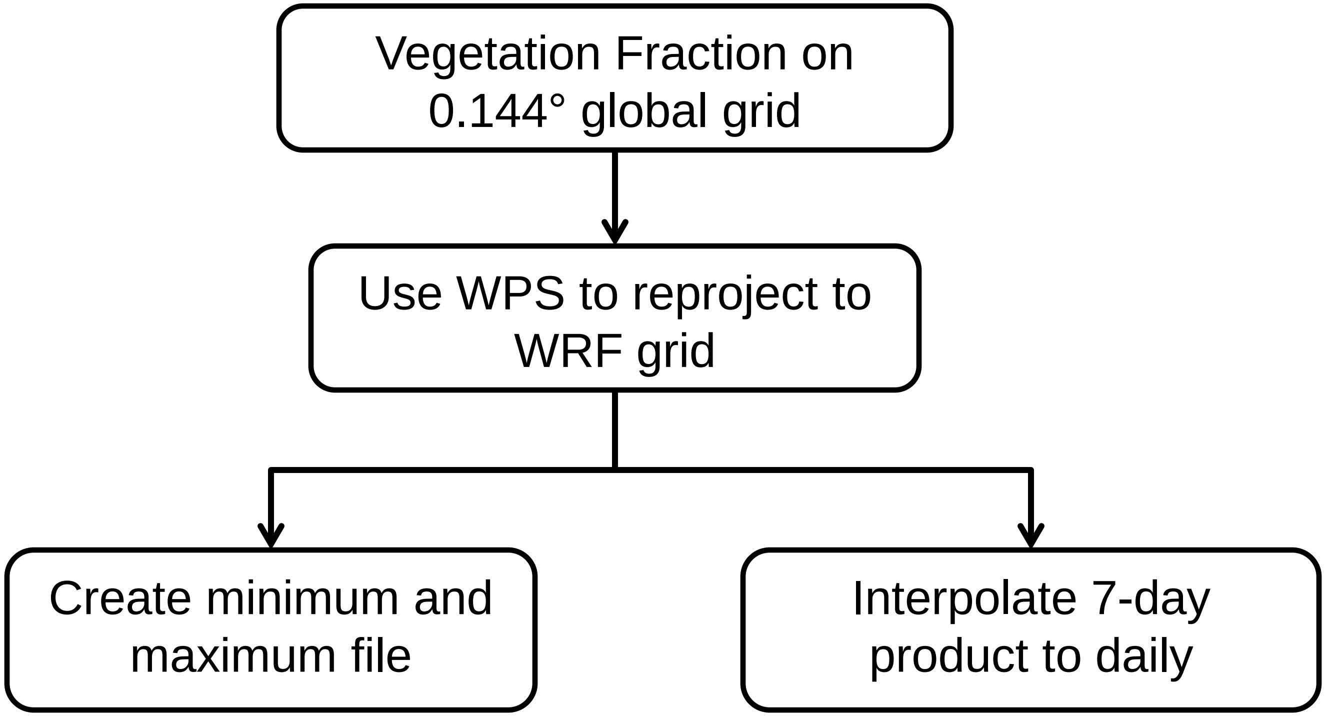
- NESDIS vegetation fraction: weekly, 0.144º global; transitioning to use in NCEP operations

Products are assimilated into the wrfinput file at 00Z of each cycle

Feel free to contact me with questions regarding converting MODIS and other data to WPS format and how to get data into simulation

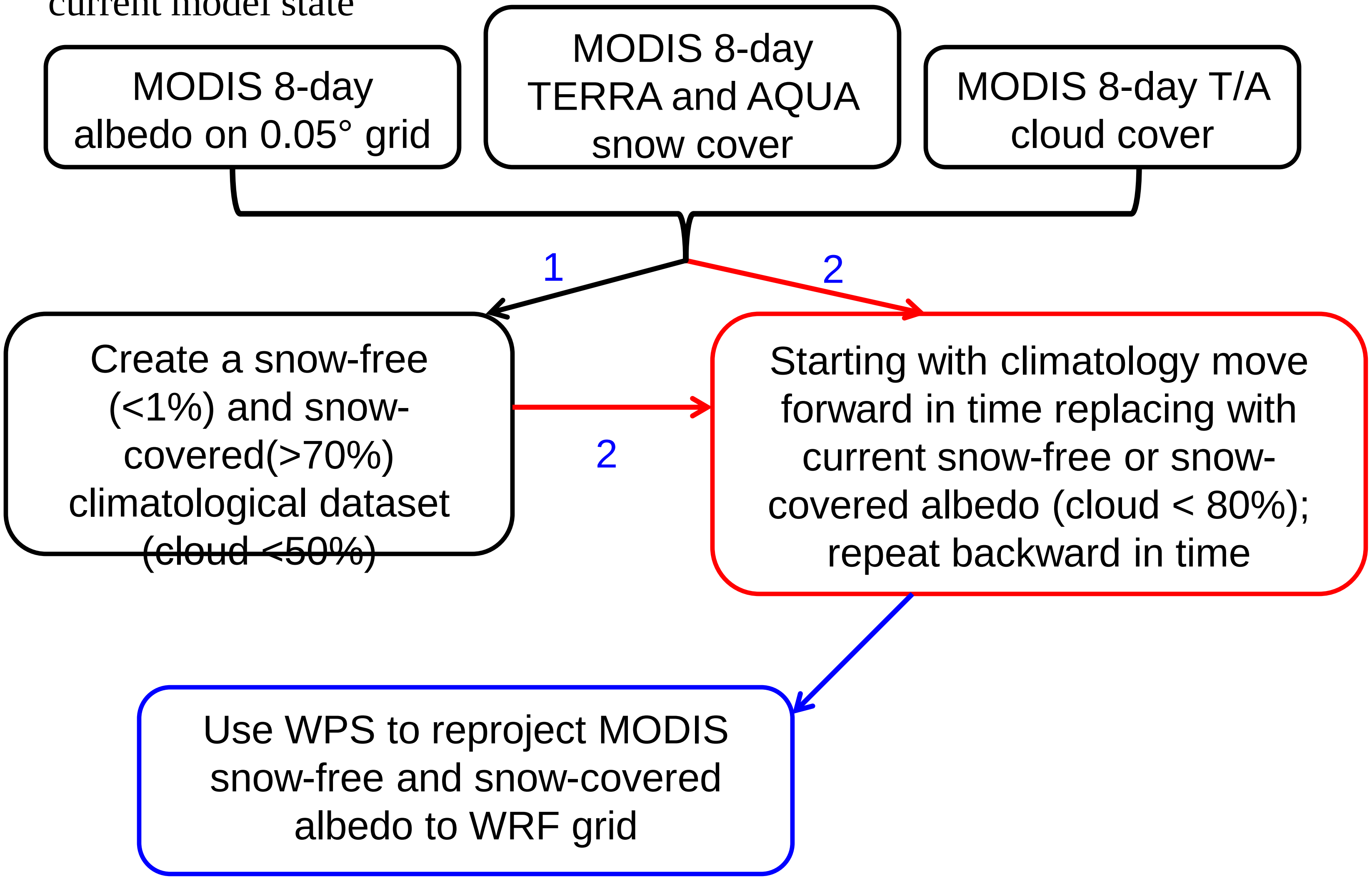
Assimilation Procedure: Green Vegetation Fraction

- Product created in near real-time by NESDIS/STAR
- Based on smoothed AVHRR NDVI product to remove satellite drift and sensor degradation
- Available as a 7-day product from 1984 to present
- Very similar procedure to existing WRF climatological vegetation so use product directly after interpolation to WRF grid

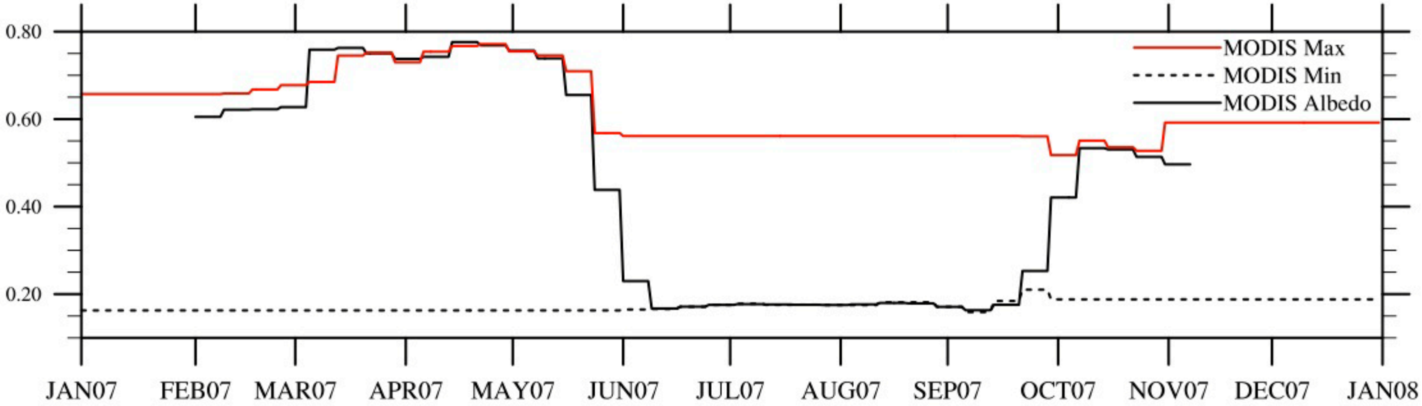


Assimilation Procedure: MODIS Albedo

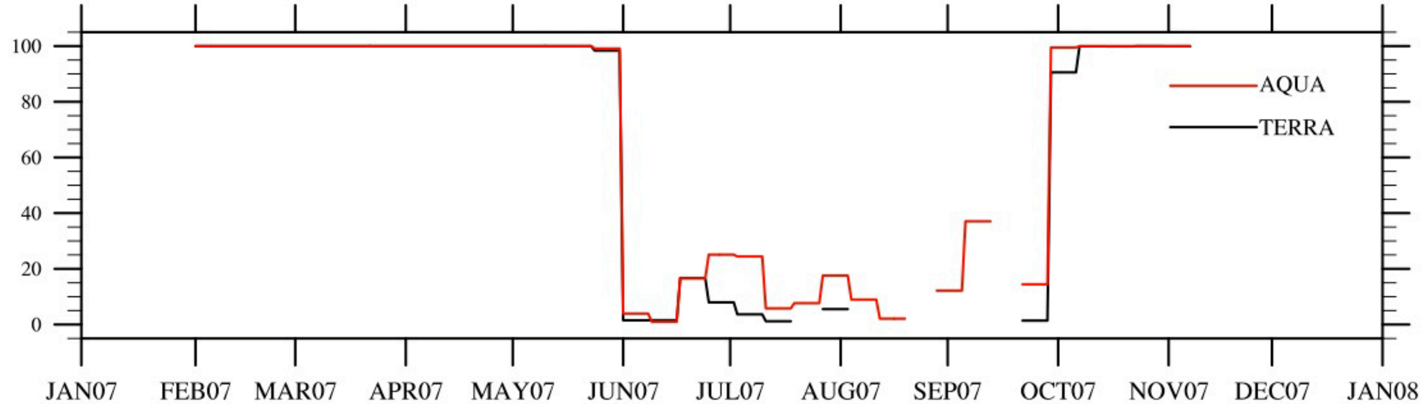
Albedo highly dependent on snow so how to use MODIS albedo to be consistent with current model state



Data Generation Procedure: MODIS Albedo



MODIS albedo and running min/max



MODIS Terra/ Aqua snow cover

– Develop snow-covered and snow-free albedo based on MODIS albedo and snow cover products

Assimilation Procedure: Snow

Use IMS daily snow cover to determine snow coverage and SNODEP daily snow depth as guidance for quantity

IMS daily 4km/24km snow cover

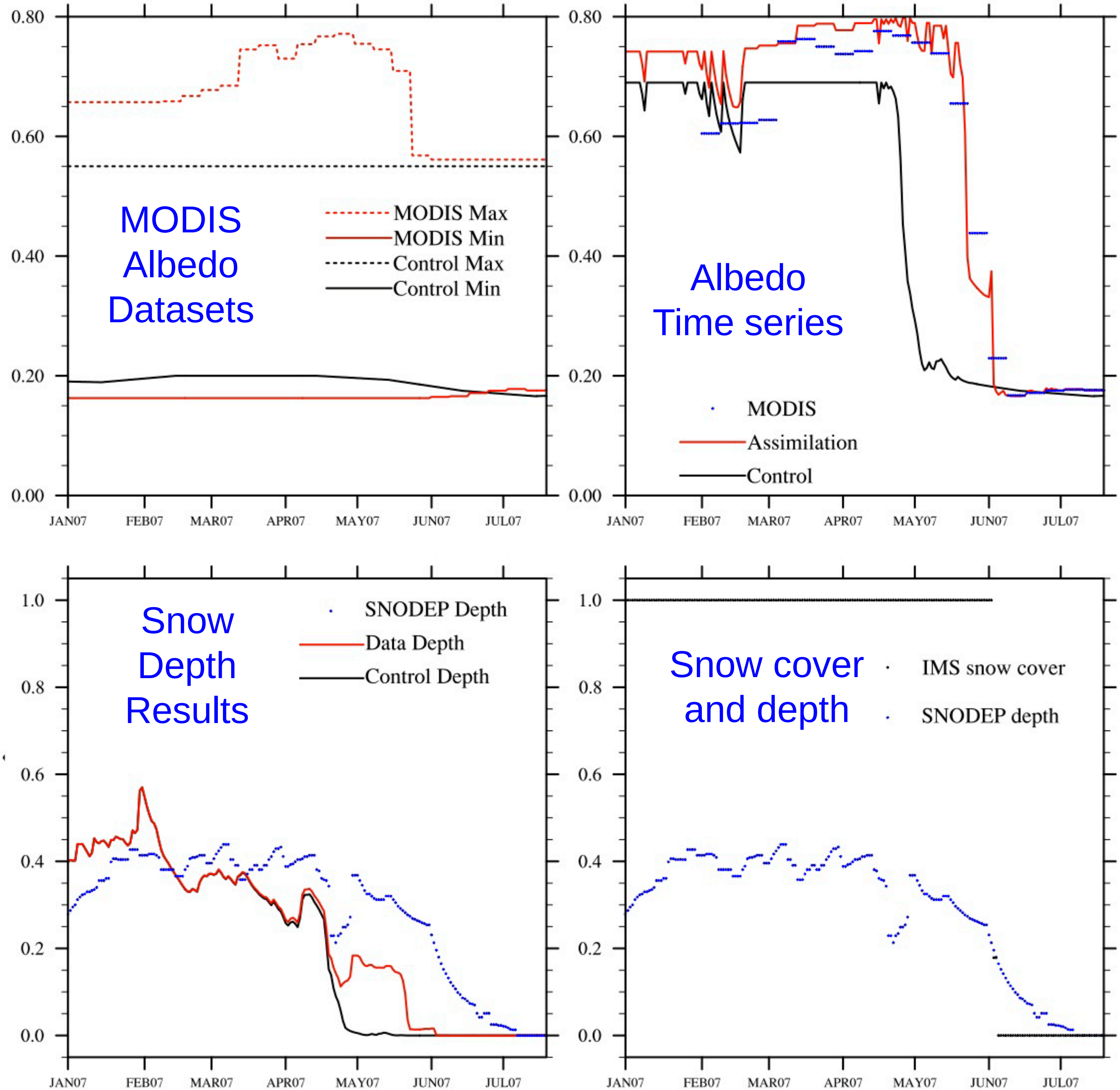
Air Force SNODEP 32km snow depth

Use WPS to reproject to WRF grid

Use WPS to reproject to WRF grid

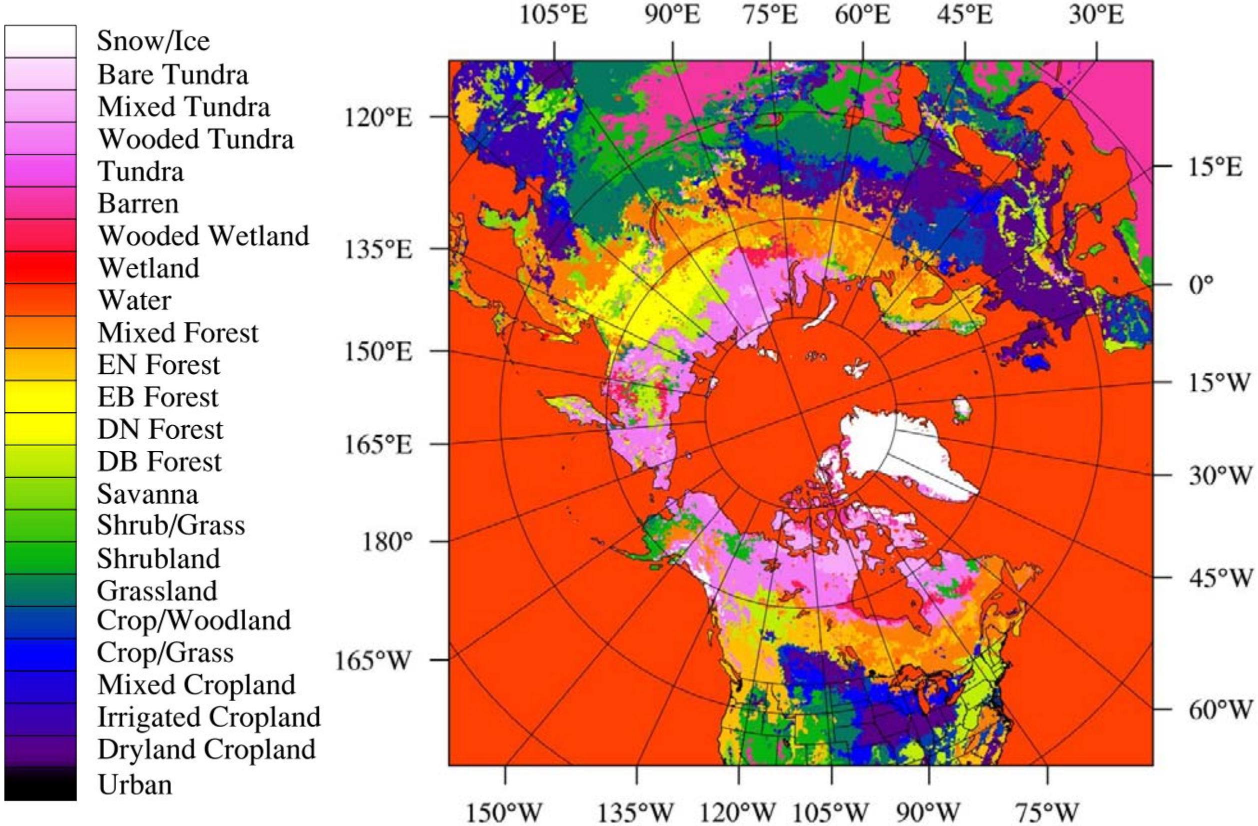
Run both products through a 5-day median smoother to remove snow “flashing”

1. If IMS < 5%, remove snow if present
2. If IMS > 40% and SNODEP > 200% model snow or < 50% model snow, use existing model snow density to increase/decrease model snow by half observation increment
3. If IMS > 40%, don’t let SWE go below 5mm independent of SNODEP



- Seven-month HRLDAS run with land data assimilation
- Region near 69N, 155W (North Slope)
- Model albedo agrees better with MODIS albedo
- SNODEP snow is inconsistent with IMS snow cover in June
- Report snow increments so users can recreate model snow

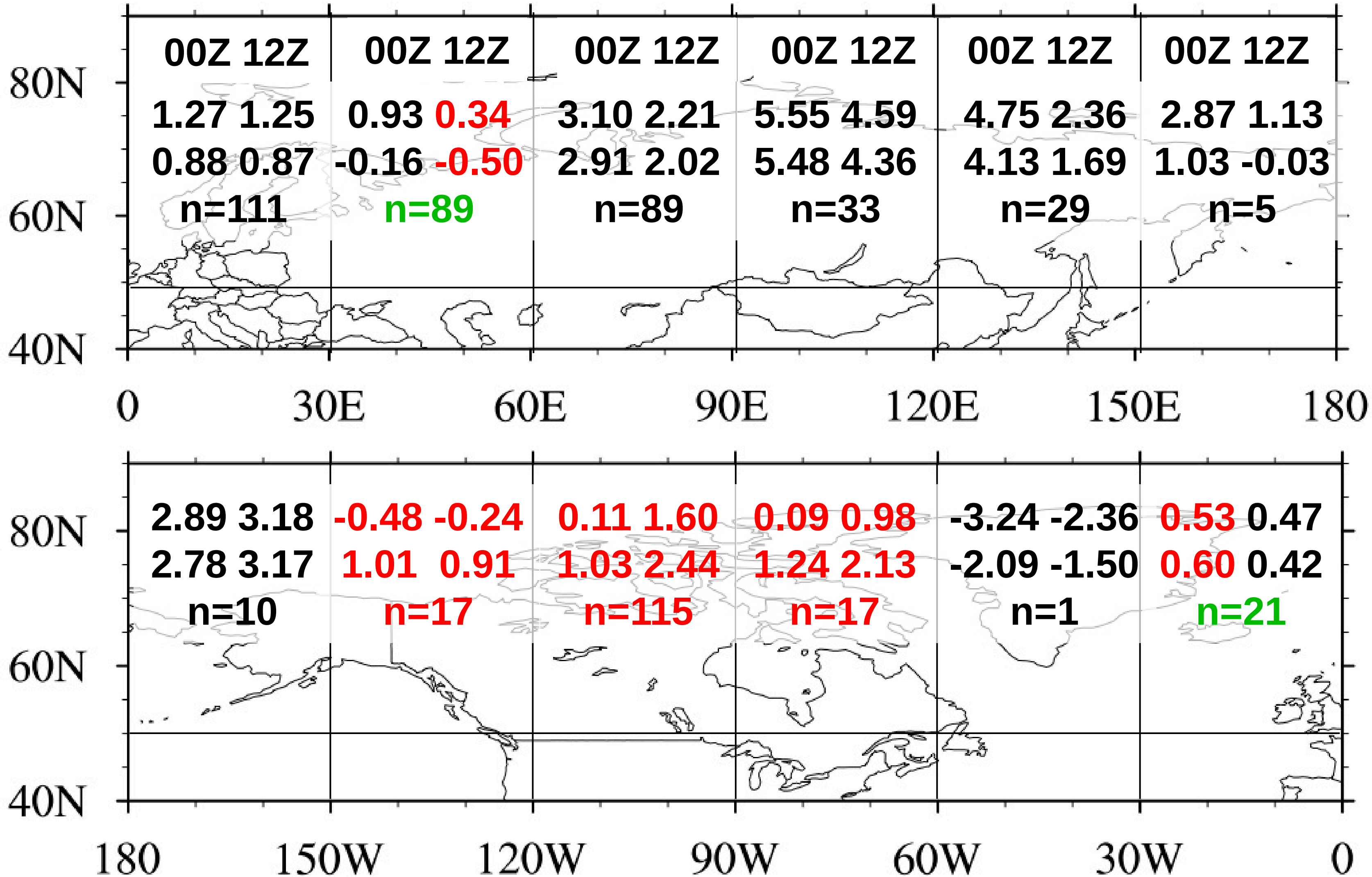
Test Simulation



- WRF-3DVAR simulation
- 6 hour cycling
- 3 hour obs time window
- January 2007
- 60km
- Physics options
  - Morrison MP
  - MYNN
  - Grell 3D
  - Noah LSM
- Land surface parameter and state assimilation
  - snow cover and snow depth
  - Albedo max/min (MODIS satellite)
  - green vegetation fraction
- Observations
  - METAR T_{2m}
  - SYNOP T_{2m}

Comparison to SYNOP 2-meter Temperature

Net positive results: Improved bias in 32 of 48 region/times



Summary

- Land surface state spin-up: use 20+ years of reanalysis data to make land states more consistent with model, land cover, terrain, and soil type

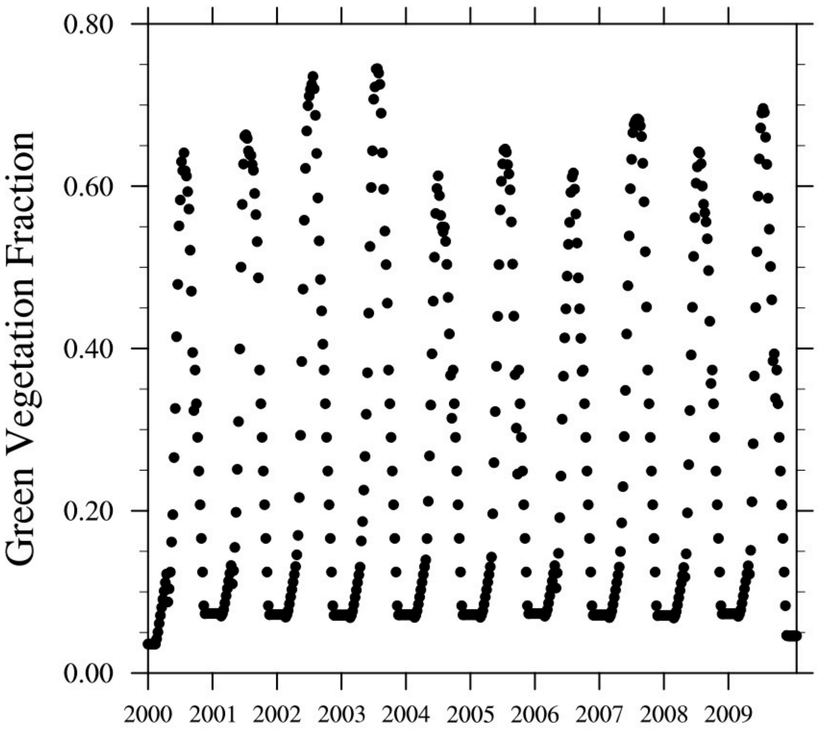
- Changes to model structure
  - use 10 soil layers instead of the default 4 layers
  - soil layers go down to ~7m instead of 1.5m
  - zero-flux lower boundary condition to improve on fixed lower temperature

- Land surface parameter and state assimilation
  - snow cover (satellite) and snow depth (in situ/model)
  - albedo (MODIS satellite)
  - green vegetation fraction (AVHRR satellite)
  - parameters/states updated daily/weekly

- Initial test simulation results
  - model bias improved in a majority of regions compared to SYNOP and METAR 2-m temperature
  - in general, simulation with no data assimilation has high T_{2m} bias
  - over regions except Canada, data assimilation tends to lower T_{2m}

Product Comparison: Green Vegetation Fraction

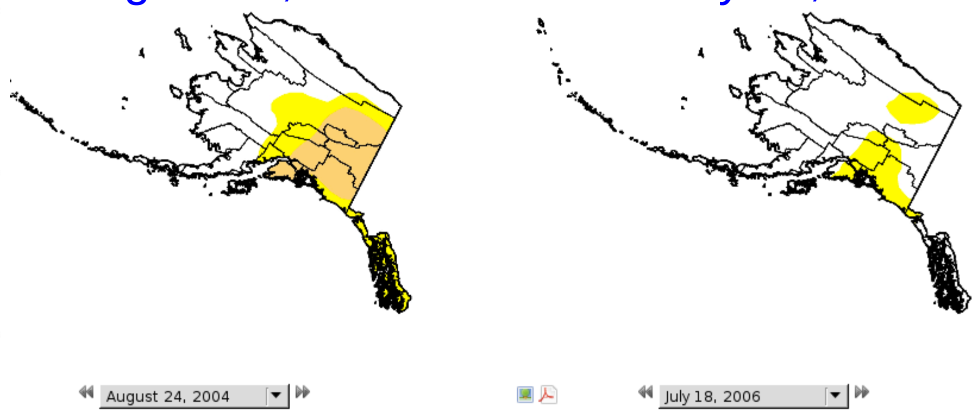
GVF Timeseries for east-central Alaska

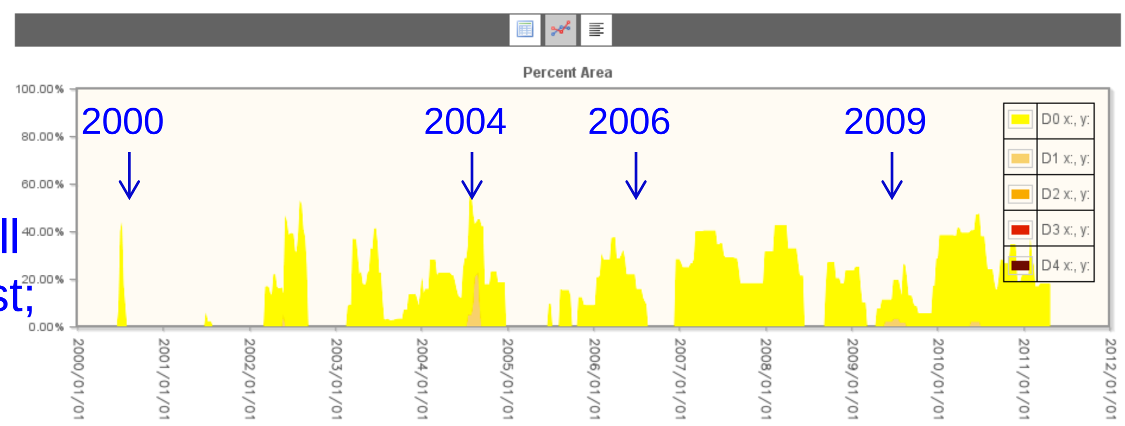


Qualitative comparison to Drought Monitor

August 24, 2004

July 18, 2006





- 2004: largest “D2” area
- 2006: not significant statewide but dry in eastern Alaska
- 2009: small spike in “D2” but all concentrated on southern coast; east has no drought