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Exceptional service in the national interest

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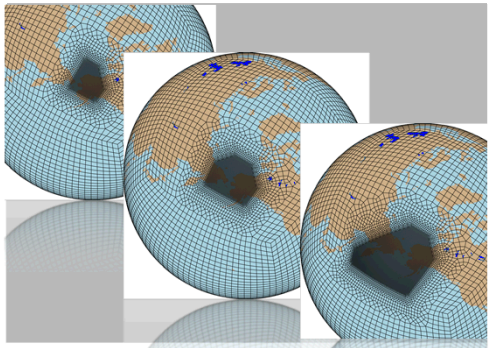

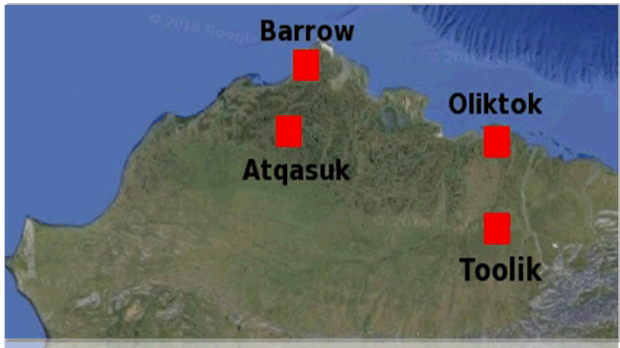

12/7/2016

High Resolution Measurements and Modeling over the Arctic

Sandia National Laboratories:

Erika L. Roesler, Ben Hillman, Dari Dexheimer, Lauren Dennis, Matt McChesney, Oksana Guba, Pete Bosler, Joe Hardesty, Mark Ivey, Mark Taylor

U.S. DEPARTMENT OF ENERGY | NNSA National Nuclear Security Administration

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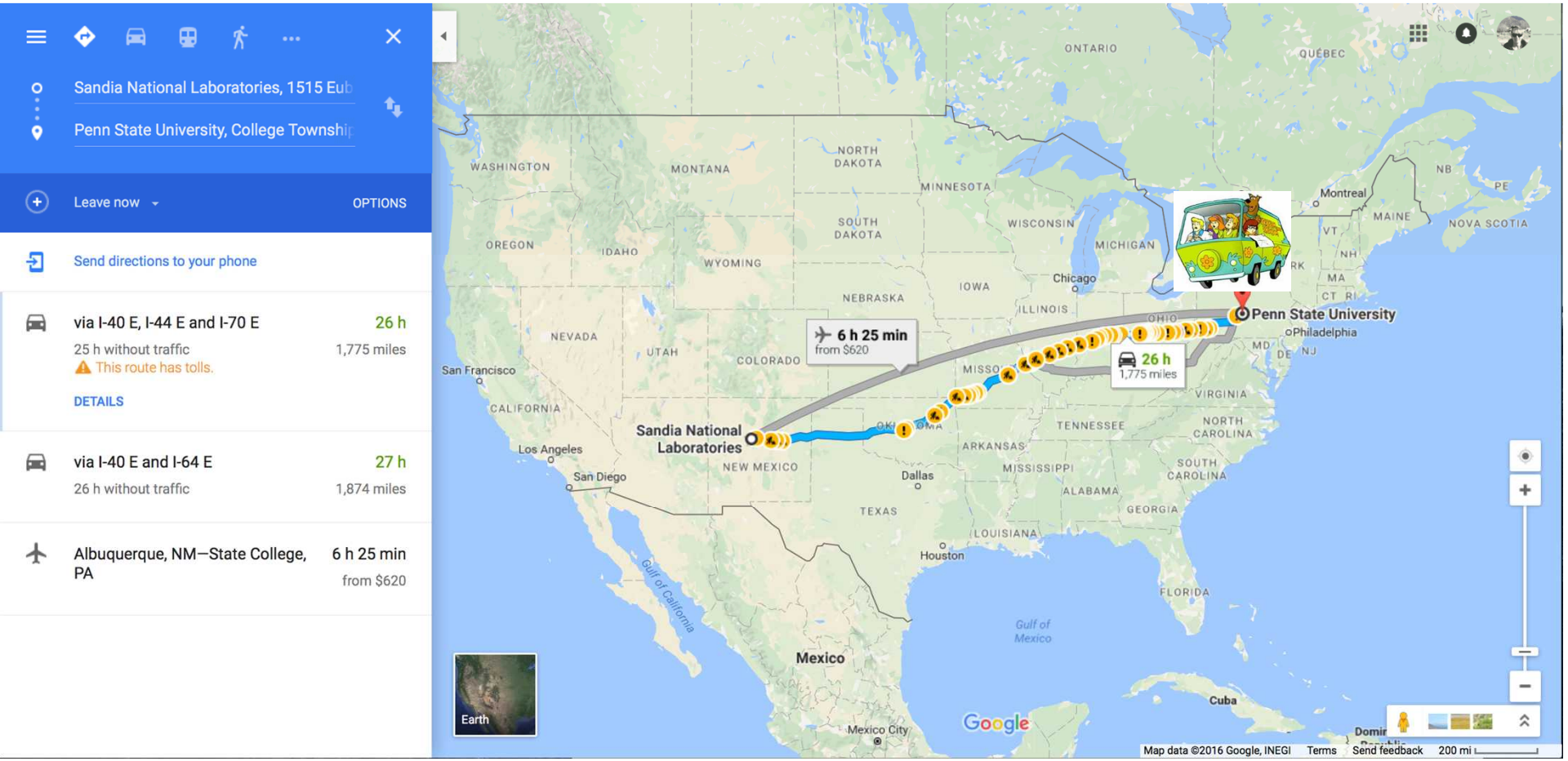
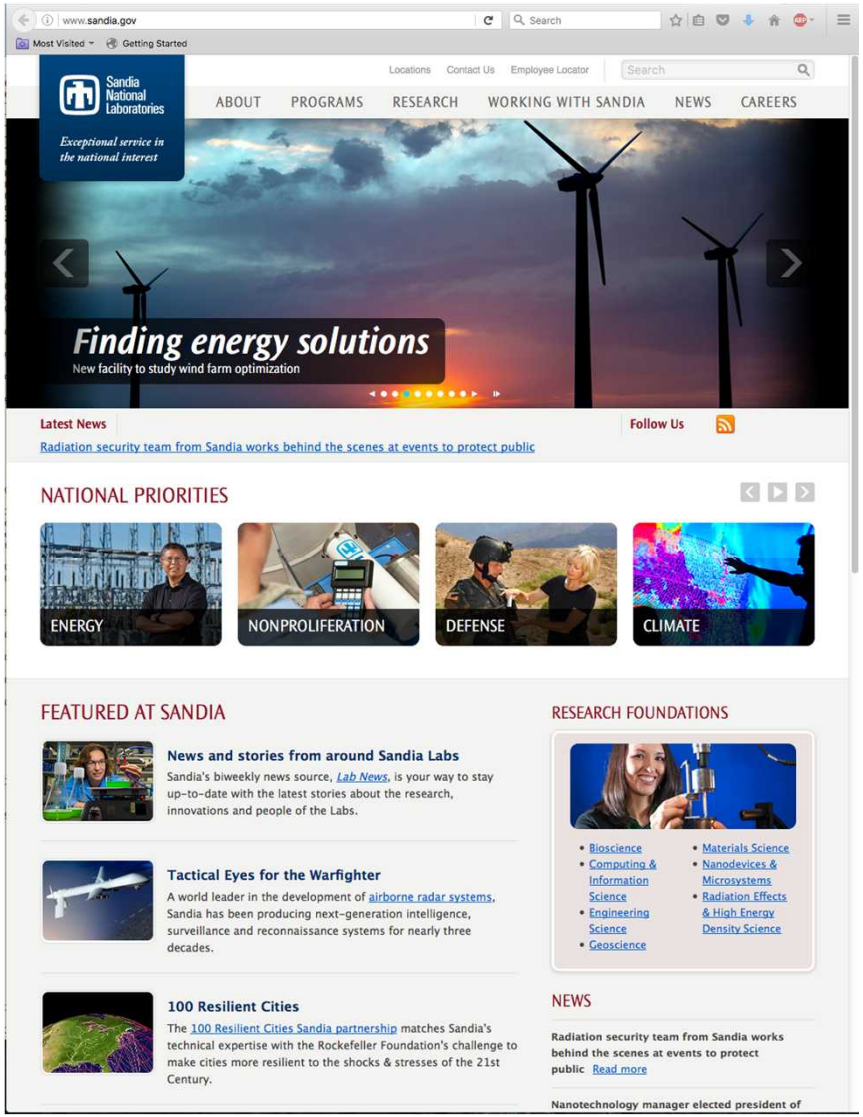
State College to Albuquerque

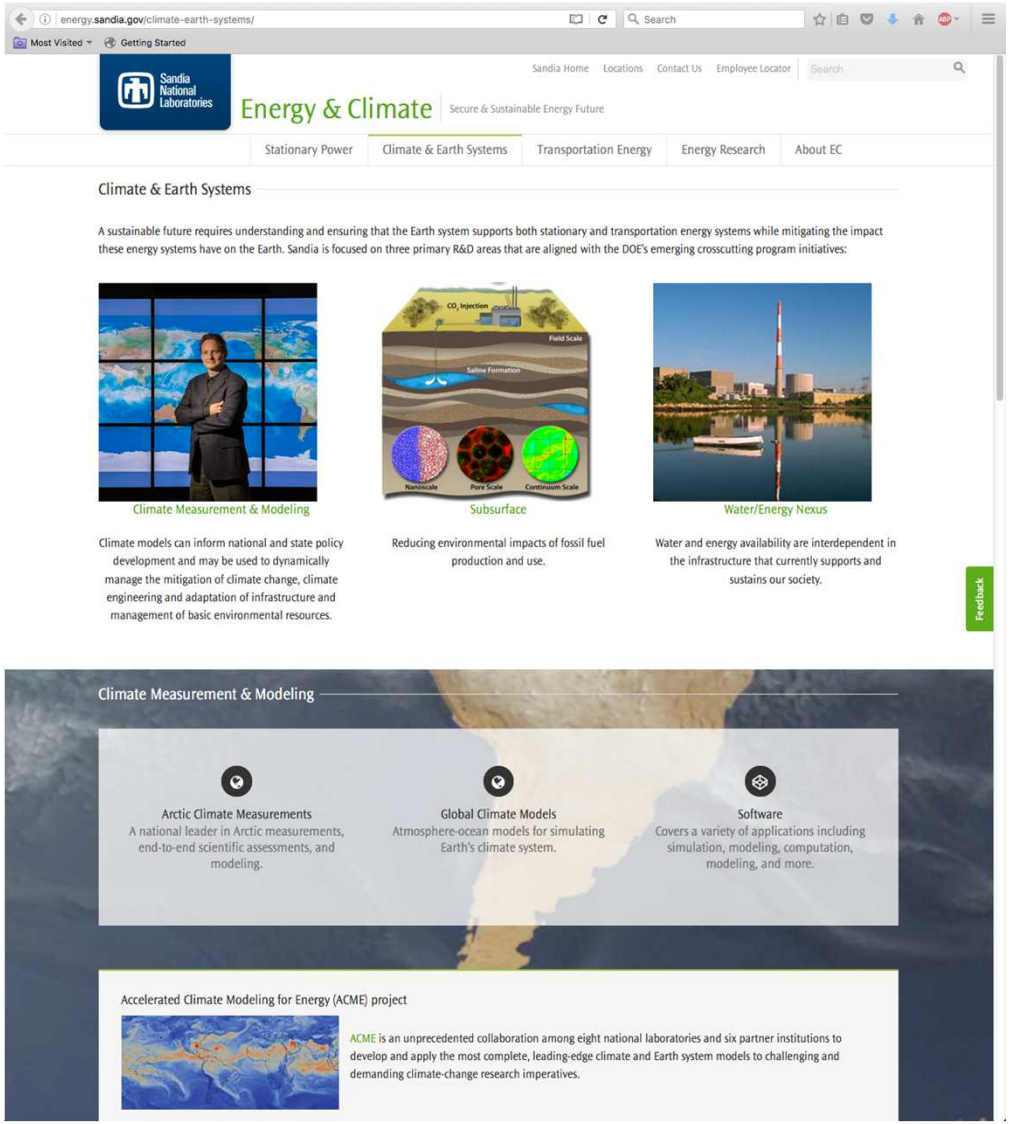


About Sandia – www.sandia.gov



- In operation since 1940s
- Multiple locations
  - Albuquerque, NM
  - Livermore, CA
  - Nevada
  - D.C.
- 10,000+ employees
  - Nearly 2000 holding Ph.D.

Energy and Climate Research at Sandia



- National security is priority! We need to have a secure, sustainable (energy) future.
- Climate modeling and measurements programs exist to answer questions about our energy future
  - Accelerated Climate Model for Energy (ACME) model
    - Department of Energy-led multi-lab initiative to develop global model for future computer architectures

Where we do (most) of our work…

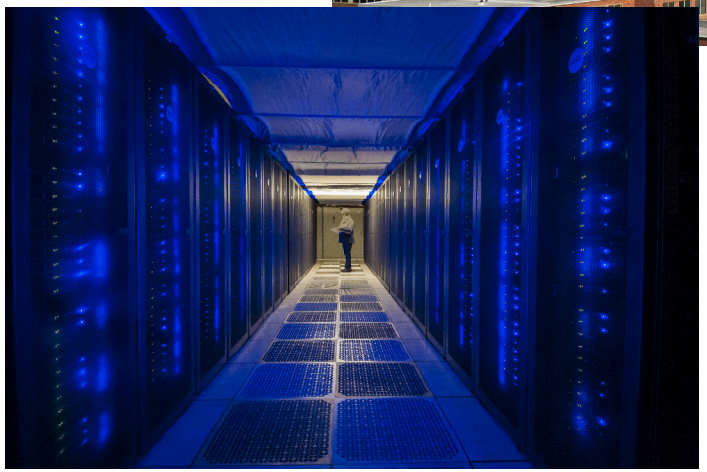
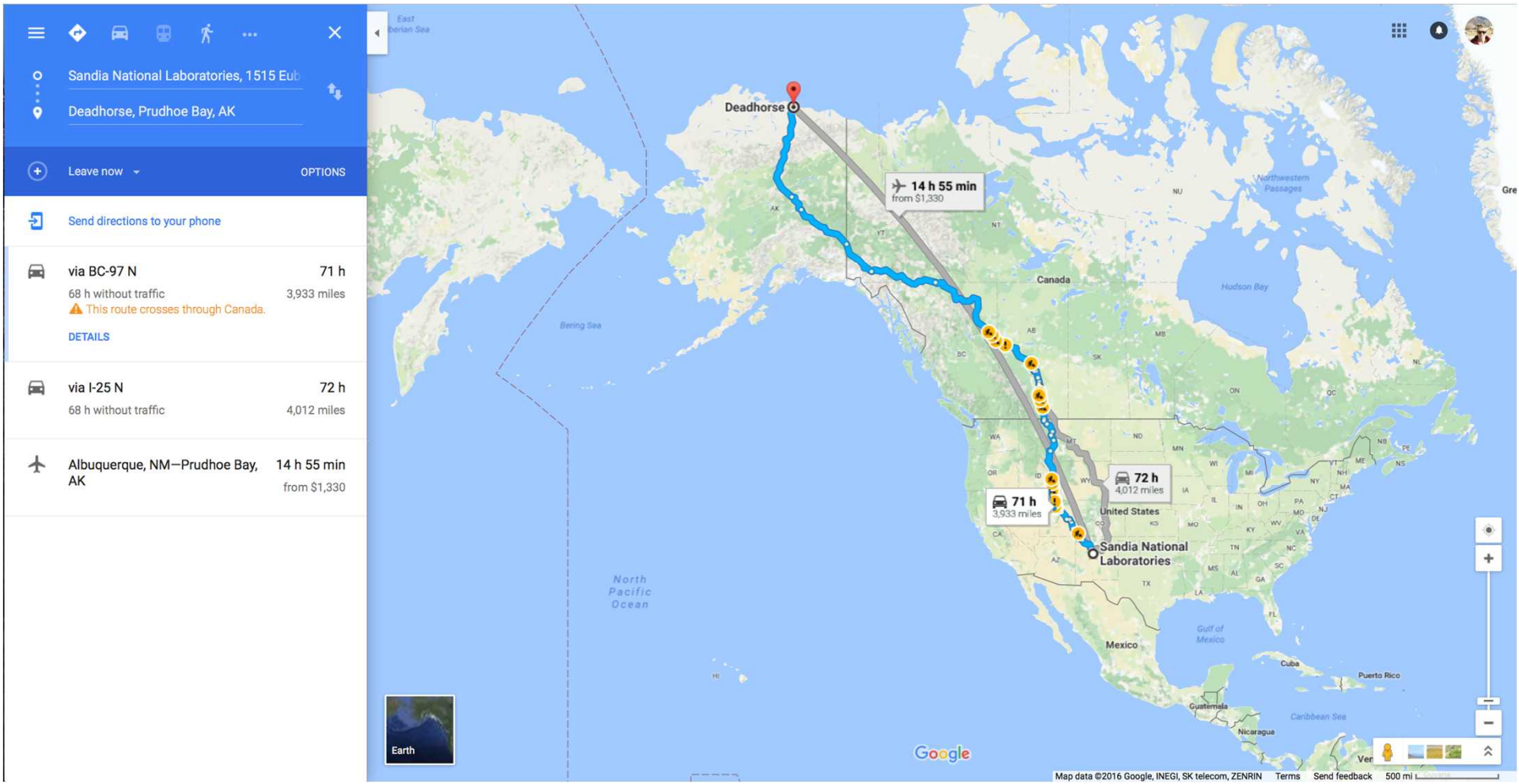
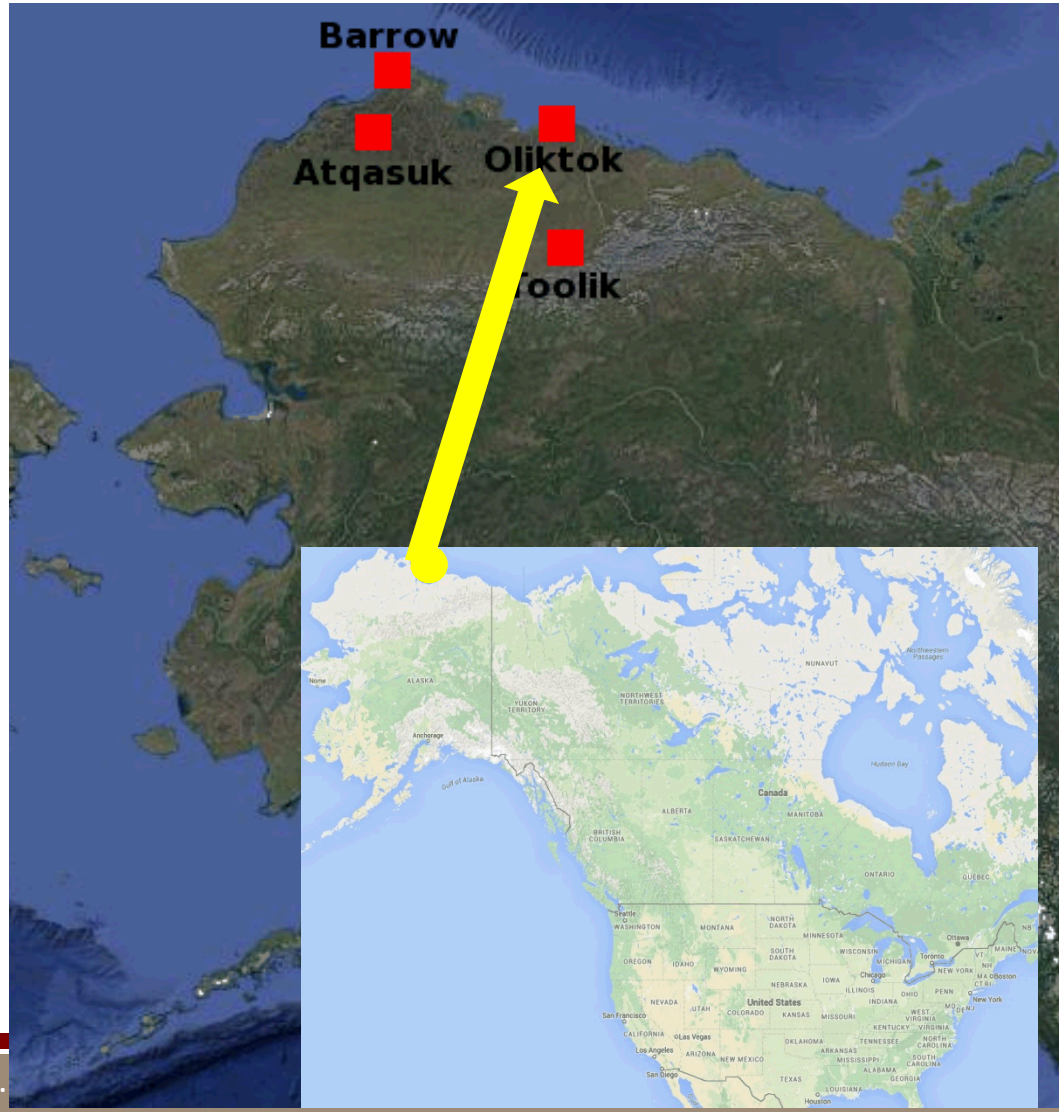


Photo credits: http://www.sandia.gov/news/image_gallery/index.html Sandia National Laboratories

And where we do the rest….
Albuquerque to Prudhoe Bay

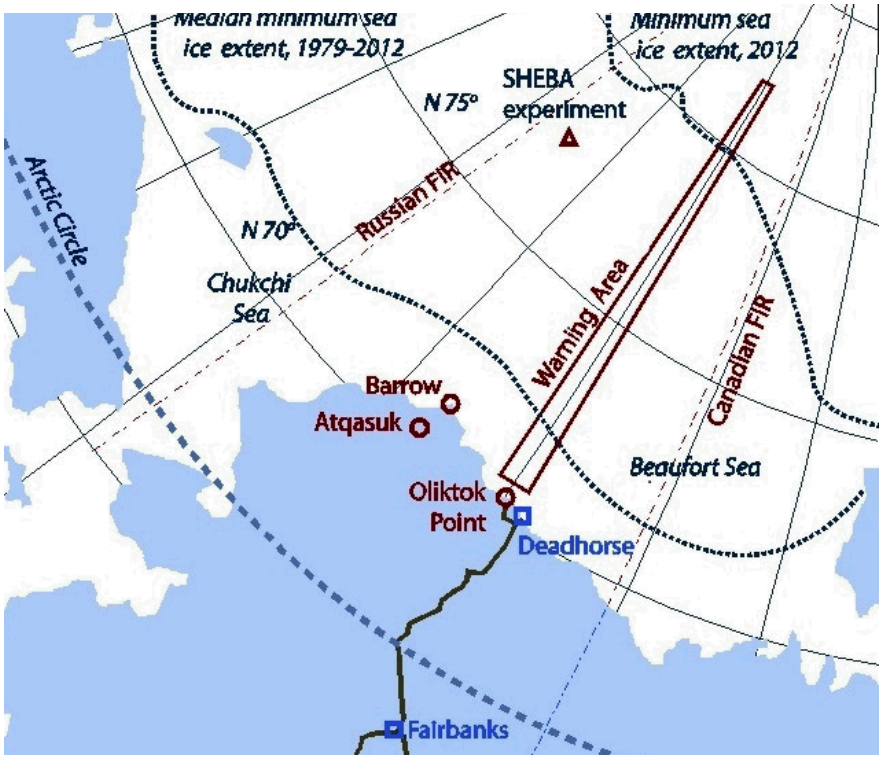


Atmospheric Radiation Measurement **(ARM)** – North Slope of Alaska **(NSA)**



Atmospheric Radiation Measurement **(ARM)** – North Slope of Alaska **(NSA)**

- ARM-NSA Sites:
  - **Barrow**: measure ocean-land-atmos interface conditions
  - **Atqasuk**: measure land-atmos interface & comparison to Barrow
  - **Oliktok (AMF-3)**: to measure ocean-land-atmos interface; use of R-2204 and W-220 for aerial atmospheric measurements



Barrow
1997 - present

Atqasuk
1999 – 2010

Oliktok (AMF-3)
2013 - present

Atmospheric Radiation Measurement **(ARM)** – North Slope of Alaska **(NSA)**

- ARM-NSA Sites:
  - **Barrow**: measure ocean-land-atmos interface conditions
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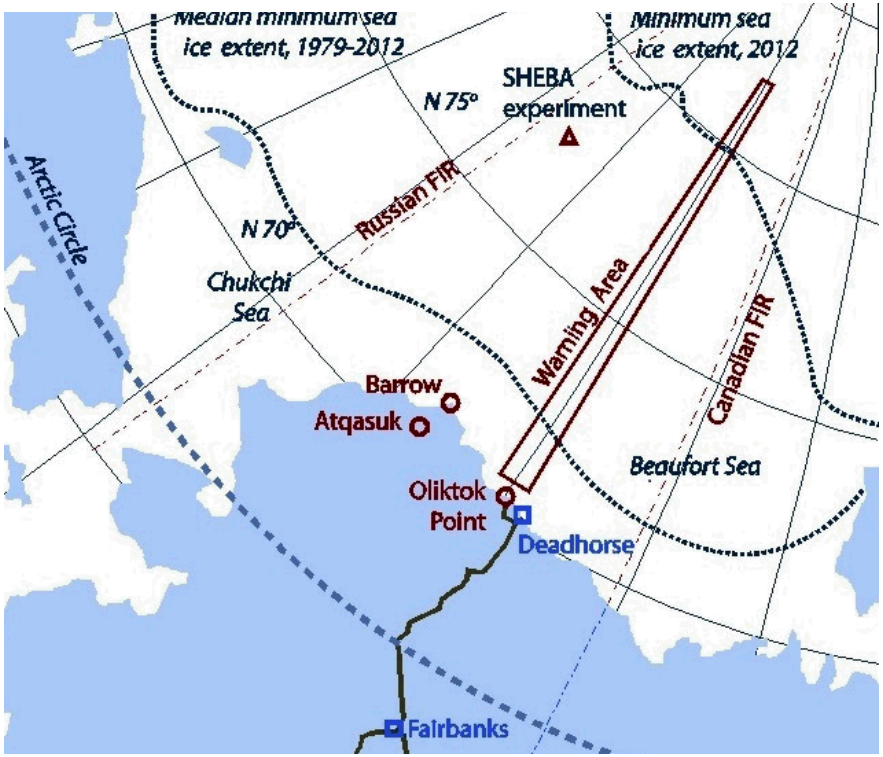
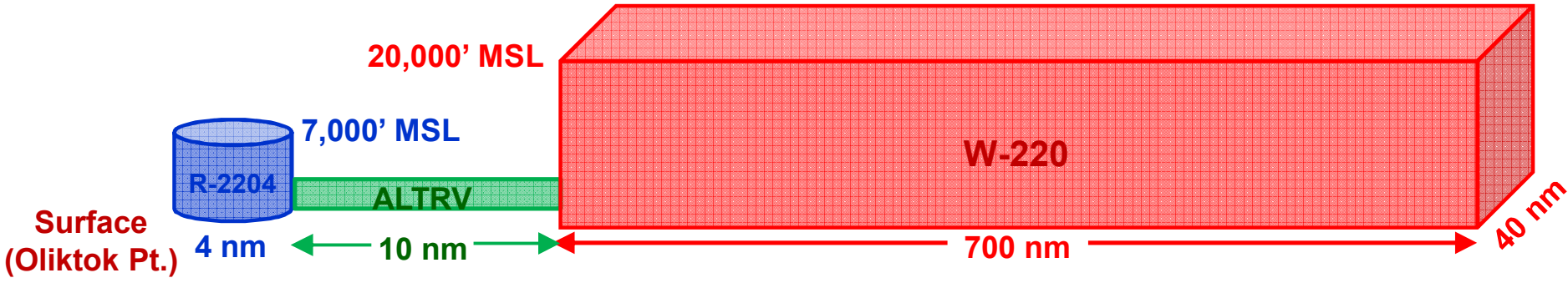
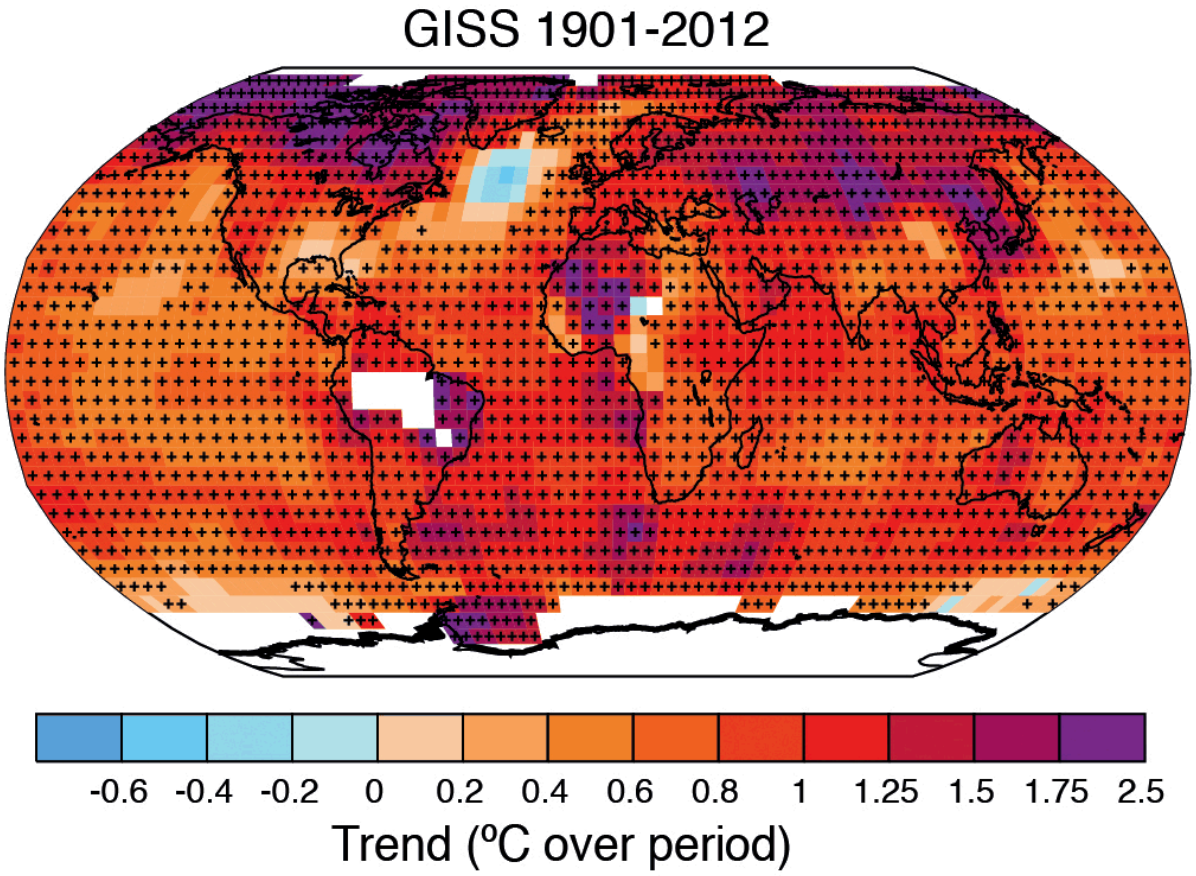




Why study the Arctic?

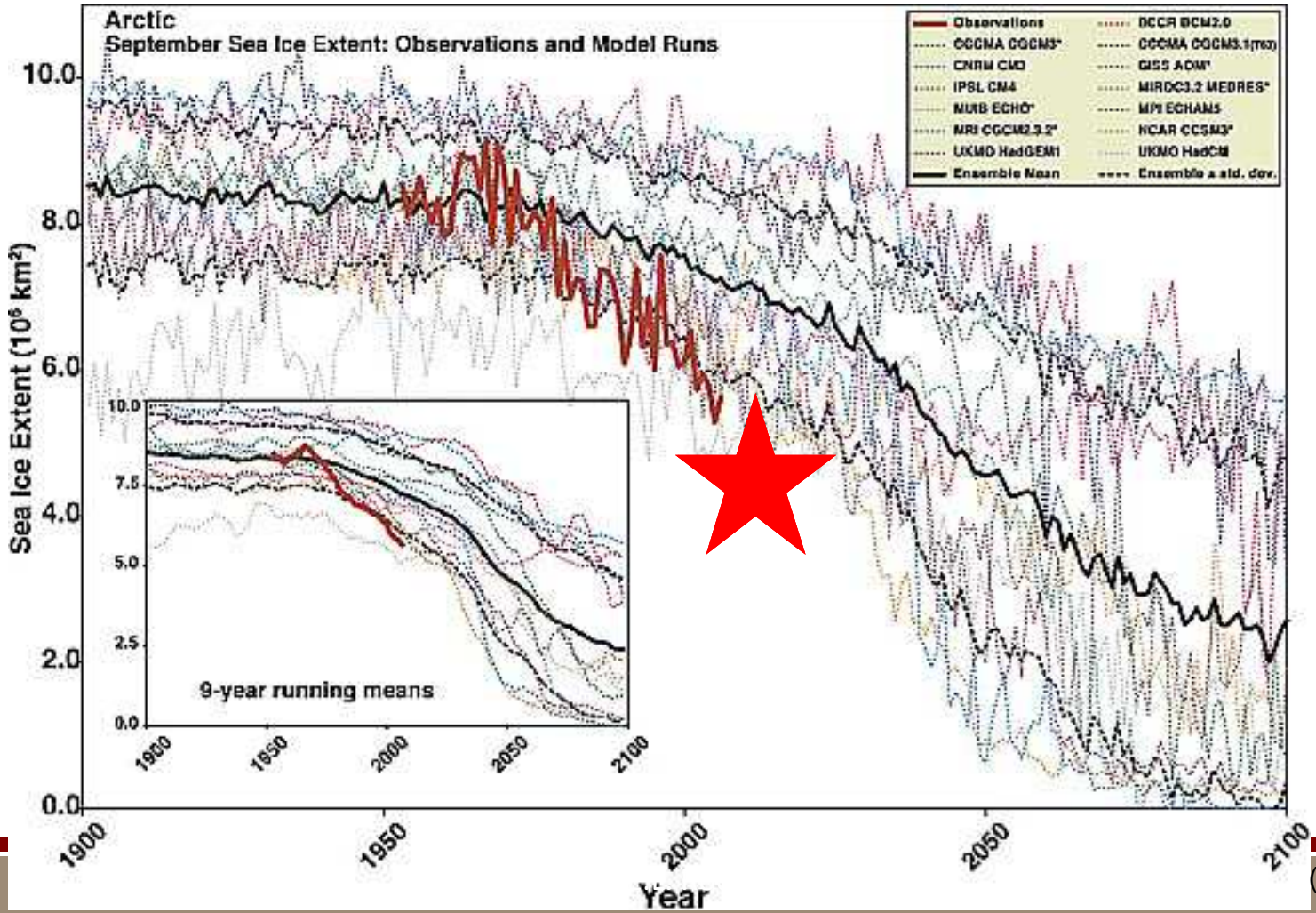
- Warming **more** than any other region



From IPCC AR5 Technical Summary (2013)

Why study the Arctic?

- Arctic sea ice decline: **faster** than forecasted
- Rapidly declining sea ice is changing environment



(Stroeve et al. 2007)

Why study the Arctic?

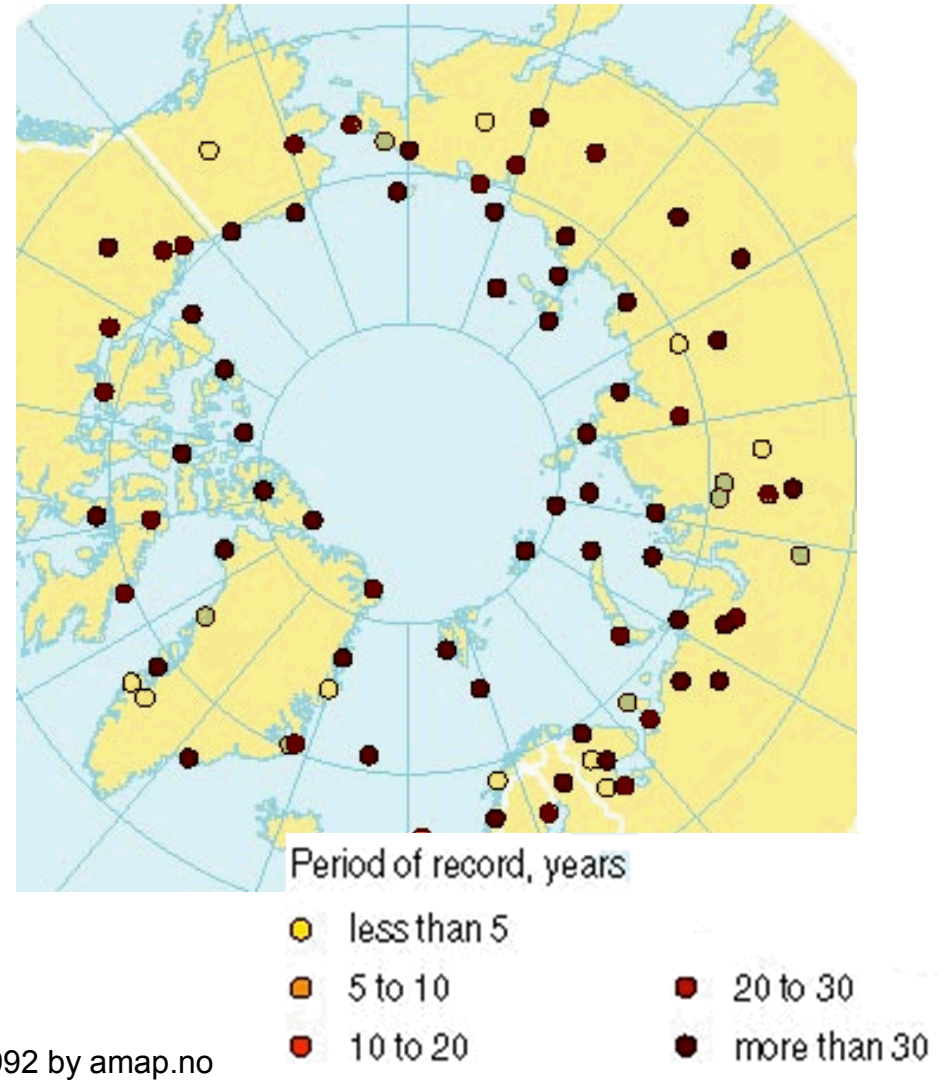
- Warming **more** than any other region
- Arctic sea ice decline: faster than forecasted
- Rapidly declining sea ice changing environment
- Fragile ecosystem – How will adaptation, mitigation occur?
- Affects northern hemisphere circulation – Our Weather!

Kivalina Village, Chukchi Sea, Source: http://www.avec.org

Motivation: Reducing uncertainty in Regional Climate Change Projections

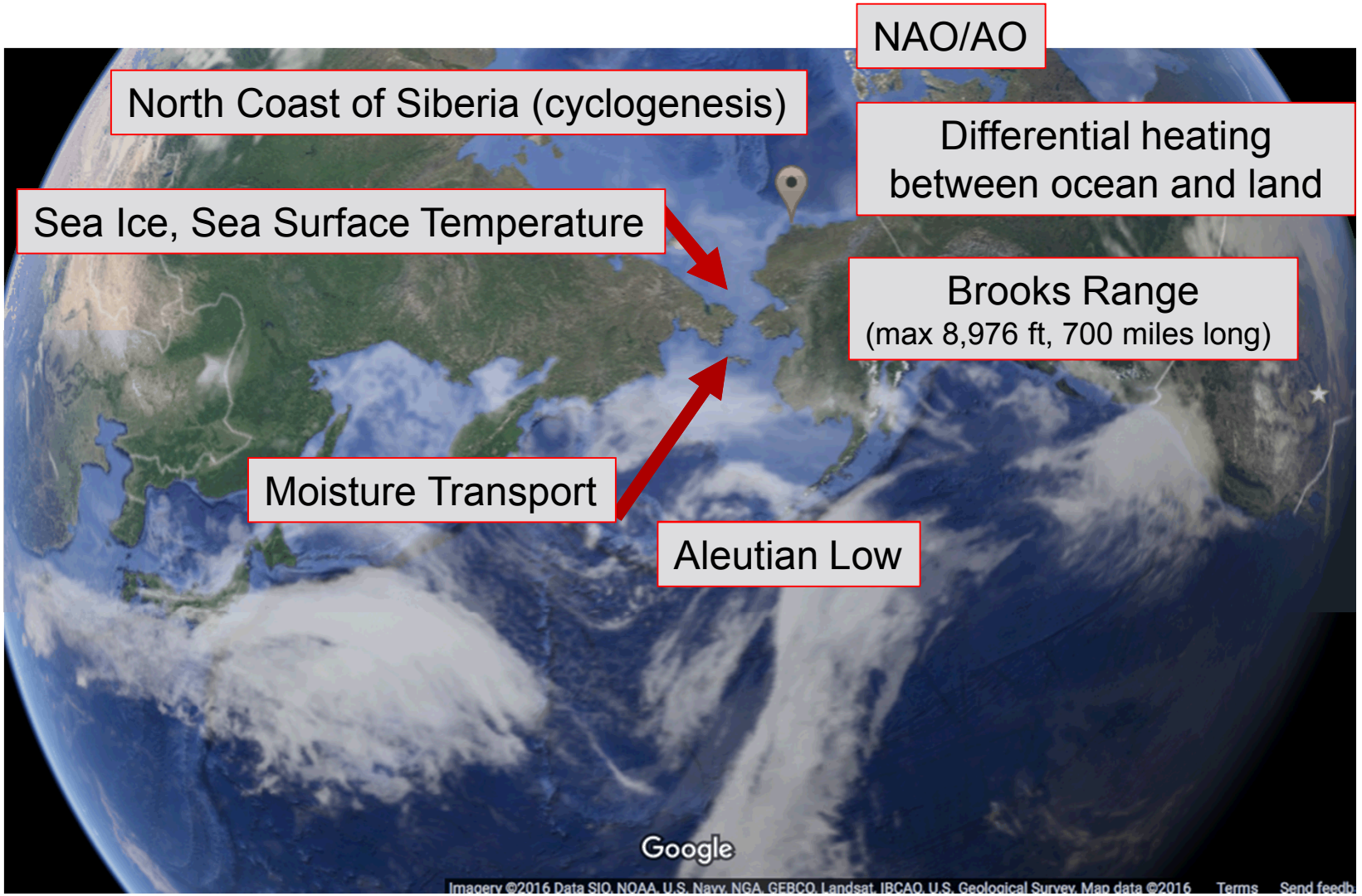
- Data **sparsity** leads to uncertainty in climate forecasting and process understanding

- **What might influence climate of the Arctic?**



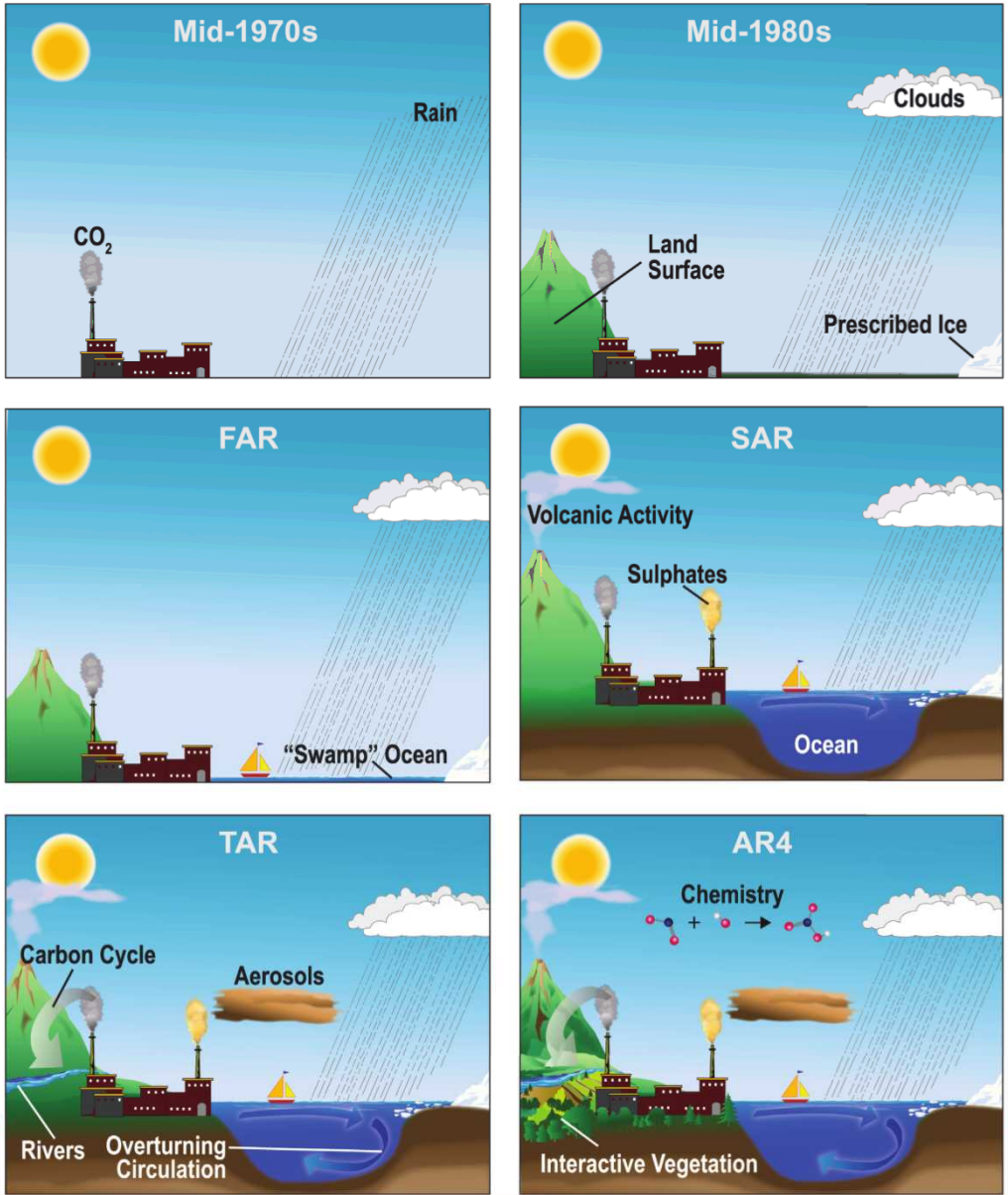
Adapted from Kahl, et al. BAMS 1992 by amap.no

North Slope Climatology

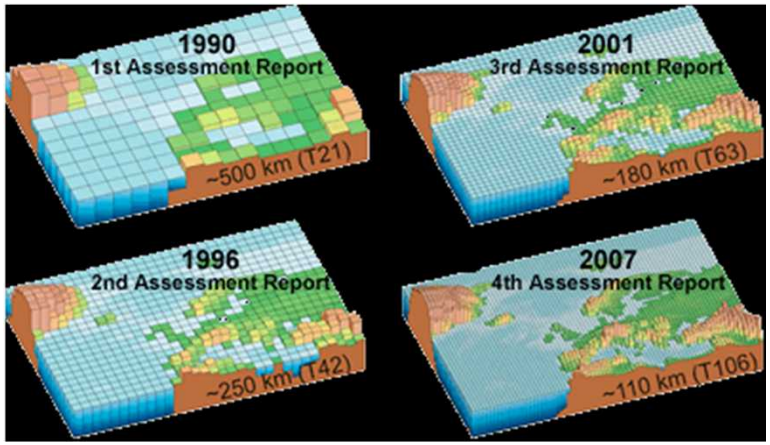


(Serreze et al. 2001, Vavrus 2013, Crawford and Serreze 2014, Carton et al. 2015, Liu and Barnes 2015, F. Krikken and W. Hazeleger 2015)

What can a global model give us?

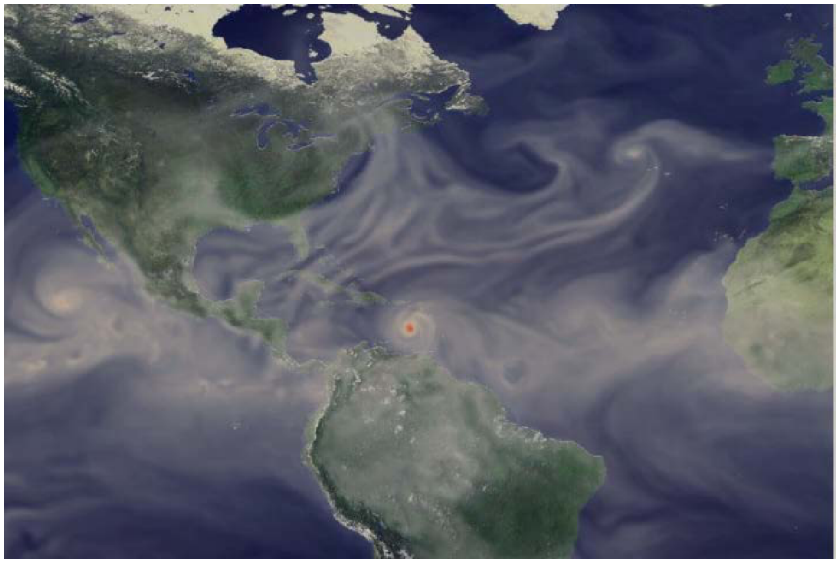


- Process understanding of climate system
- View into chaotic system
- Estimates of future climate

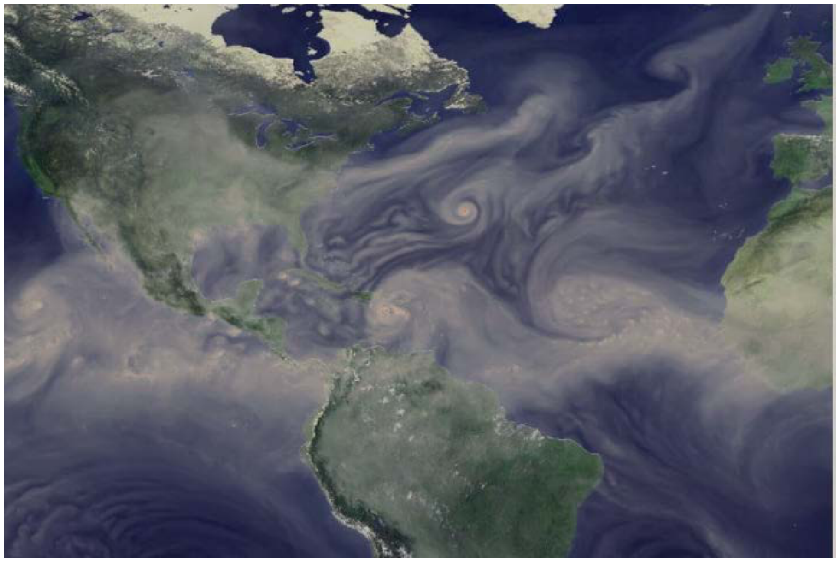


(IPCC AR4 WG1 2007)

What can a global model give us?



%27km%

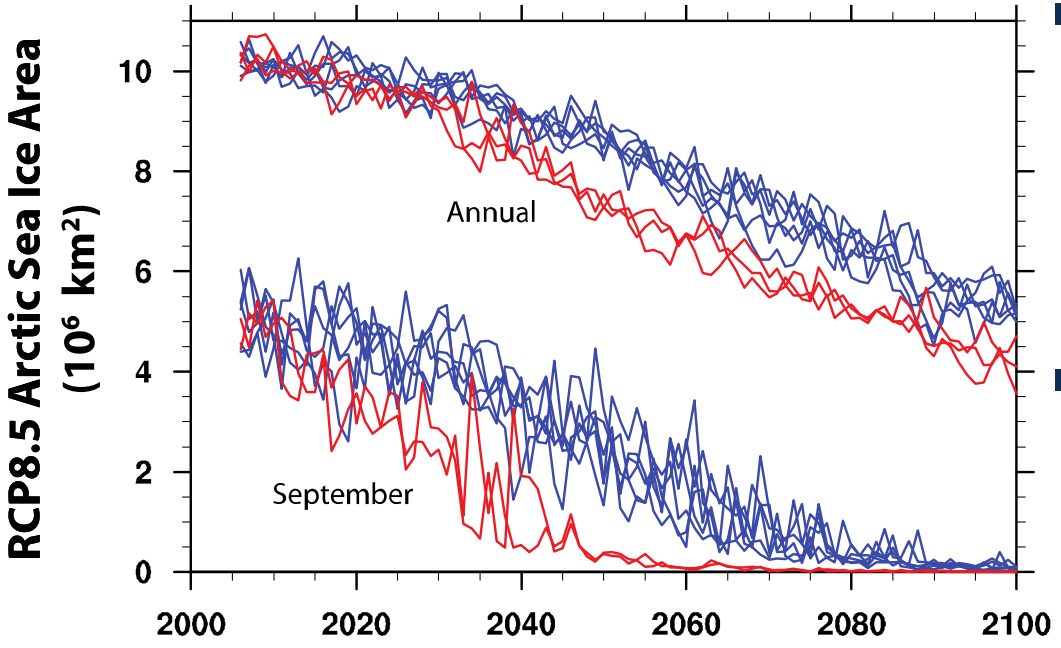


%13.5km%

- Higher Resolution
  - More realistic gradients over topography
  - Extreme events
    - Cat 5 hurricane in Gulf of Mexico at 2 different resolutions
  - Expensive computation!
    - CAM 27km: 0.6M core-hours per year!
    - CAM 13.5km: 4.4M core-hours per year!

(Mark Taylor, OLCF Users Meeting)

What can a global model give us over the North Slope?



(Meehl, Washington et al. 2013)

- Improvements in sea ice predictions
  - 2040-2060 instead of 2010
- Estimate increasing precipitation and freshwater runoff

(Koenigk et al 2013)

What can a global model give us over the North Slope?

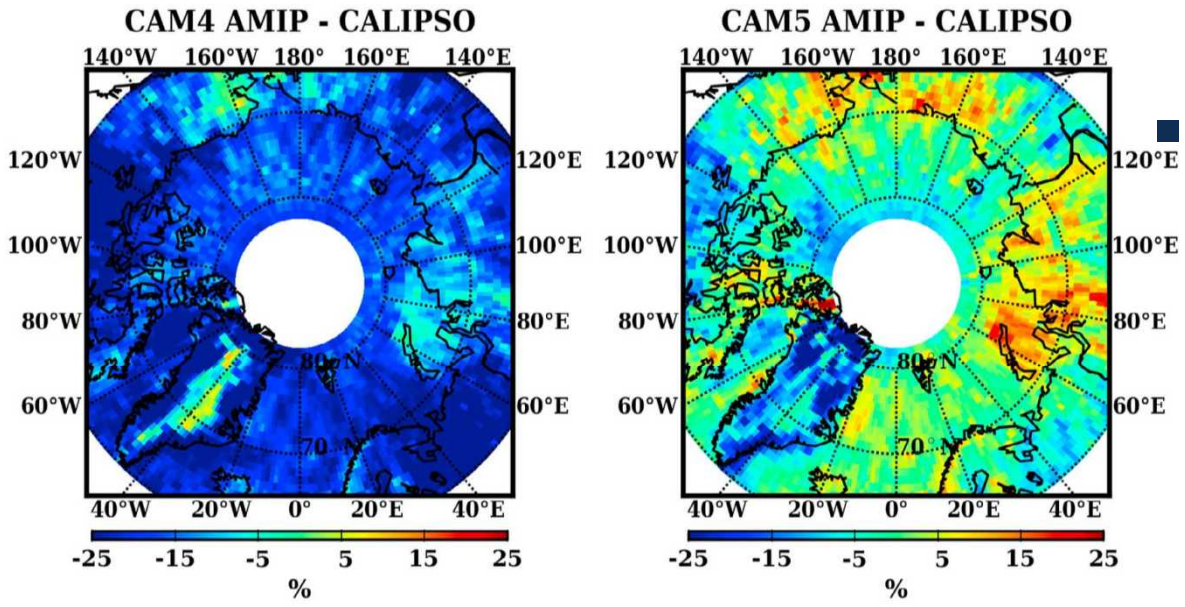


Figure 1. Total cloud percentage from COSP CALIPSO simulator output in (left) CAM4 and (right) CAM5 minus total cloud percentage from CALIPSO averaged from May 2008 to March 2010. The models were run in (top) forecast mode and analyzed using day two output and (bottom) AMIP mode.

(Barton et al 2012)

- Net improvements in cloudiness between model versions
  - Cloud phase, type, height is identified as area for improvement

Model's clouds have too much ice, not enough liquid

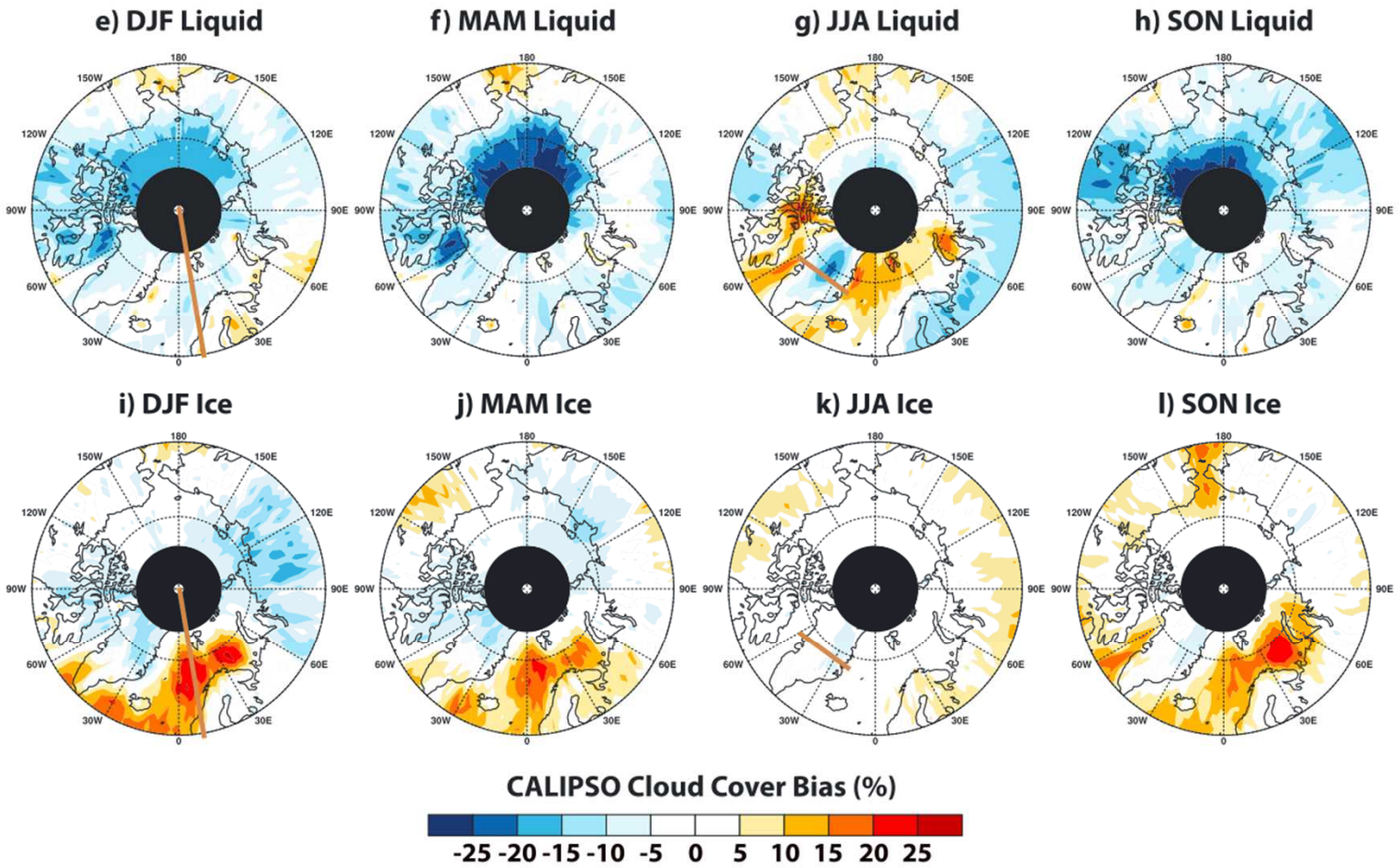
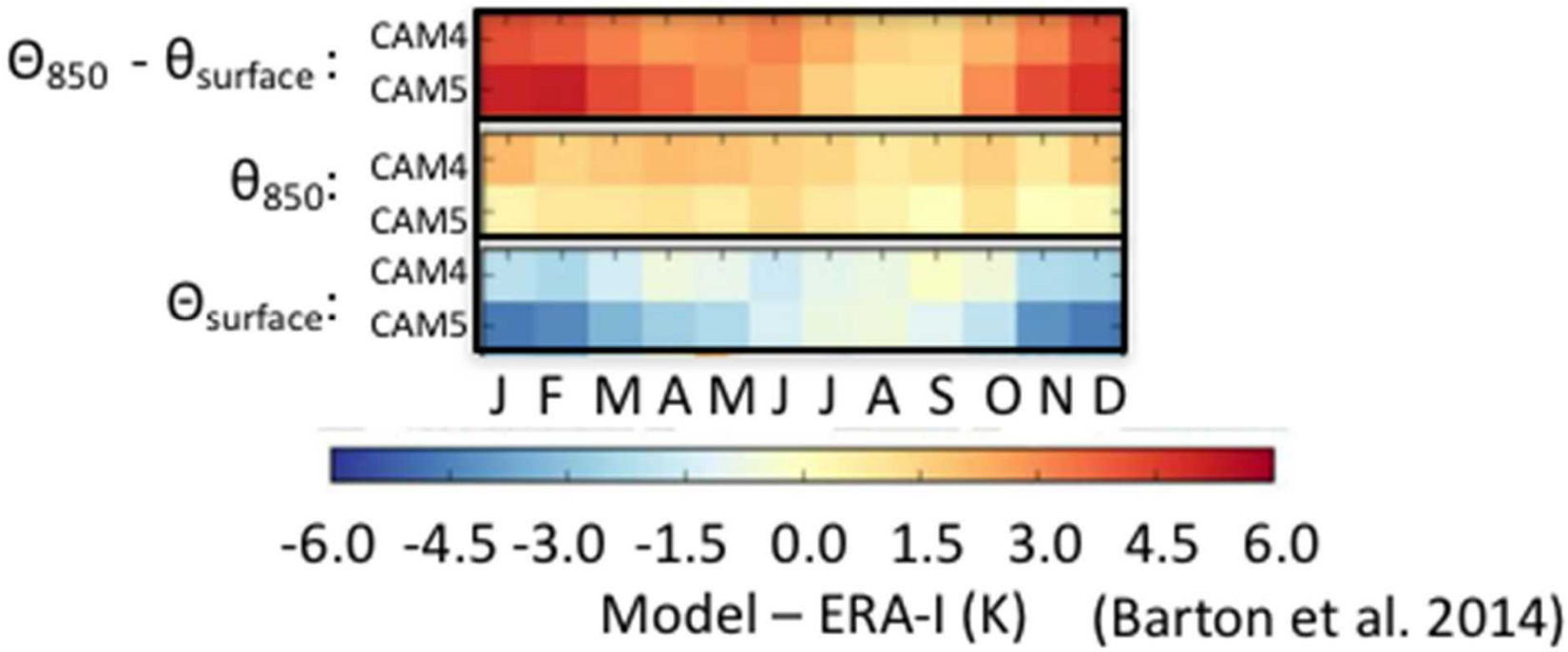


Figure 4. North Pole maps (60–90°N) of CALIPSO cloud cover bias (CAM5 simulated – observed, units %) by season: (a) DJF total, (b) MAM total, (c) JJA total, and (d) SON total. (e–h) Same as in Figures 4a–4d but for liquid cloud cover. (i–l) Same as in Figures 4a–4d but for ice cloud cover. The brown lines indicate the location of the cross section shown in Figures 5a, 5e, and 5i and for Figures 6c, 6g, and 6k.

(Kay et al 2016)

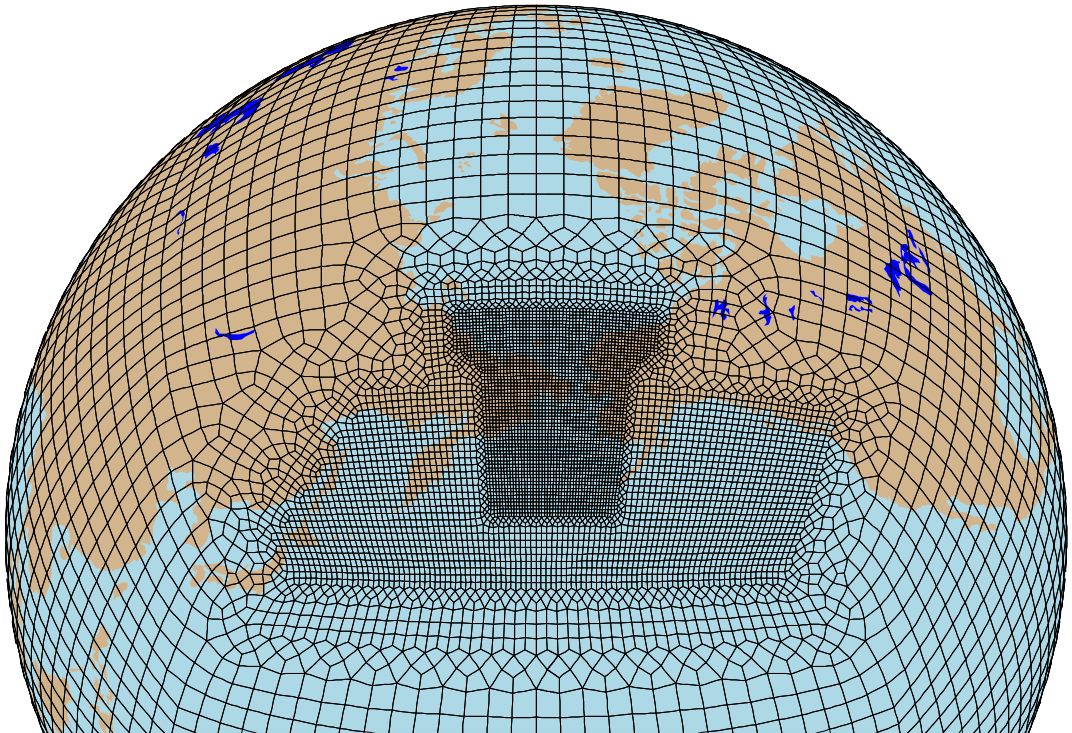
How can we improve a global model's climate on the North Slope?

- Looking at the near-surface environment….
  - Too cold, too stable in boundary layer



Could higher-resolutions improve cloud climatology in Arctic?

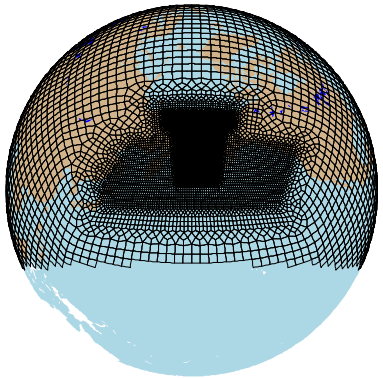
- Resolution-dependence of extreme events, like storms
- Reanalysis shows resolution dependence of extratropical storms (Tilinina et al., 2013)
- Global high res would be cool, but here's the alternative:



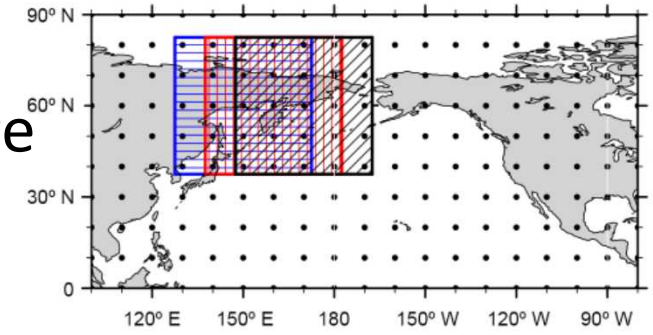
Could higher-resolution improve cloud climatology in Arctic?

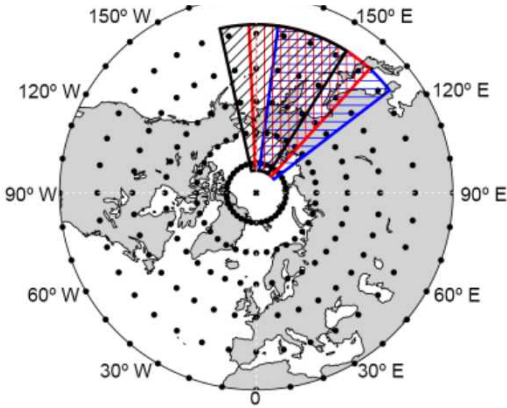
- Variable Resolution Grid
  - 1 → 1/4 → 1/8 degree (111 km → 25 km →14 km)
- 5 yrs of climo yr. 1850, Community Atmosphere Model (CAM), v5
- Stride Search: an algorithm for storm detection (Bosler et al. 2016)

https://github.com/pbosler/StrideSearch

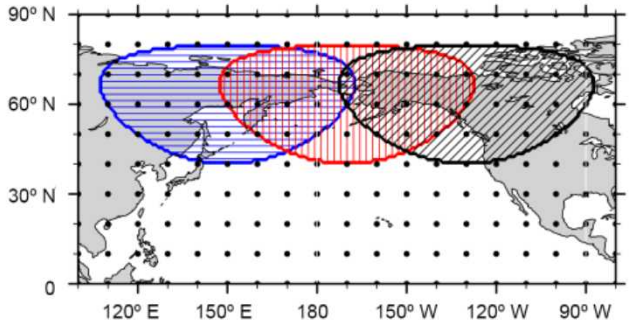


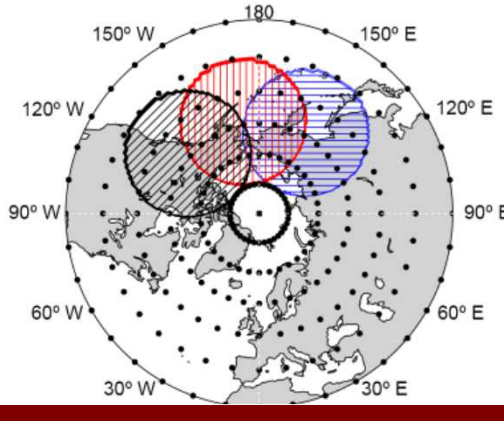
(a) Grid point search sectors



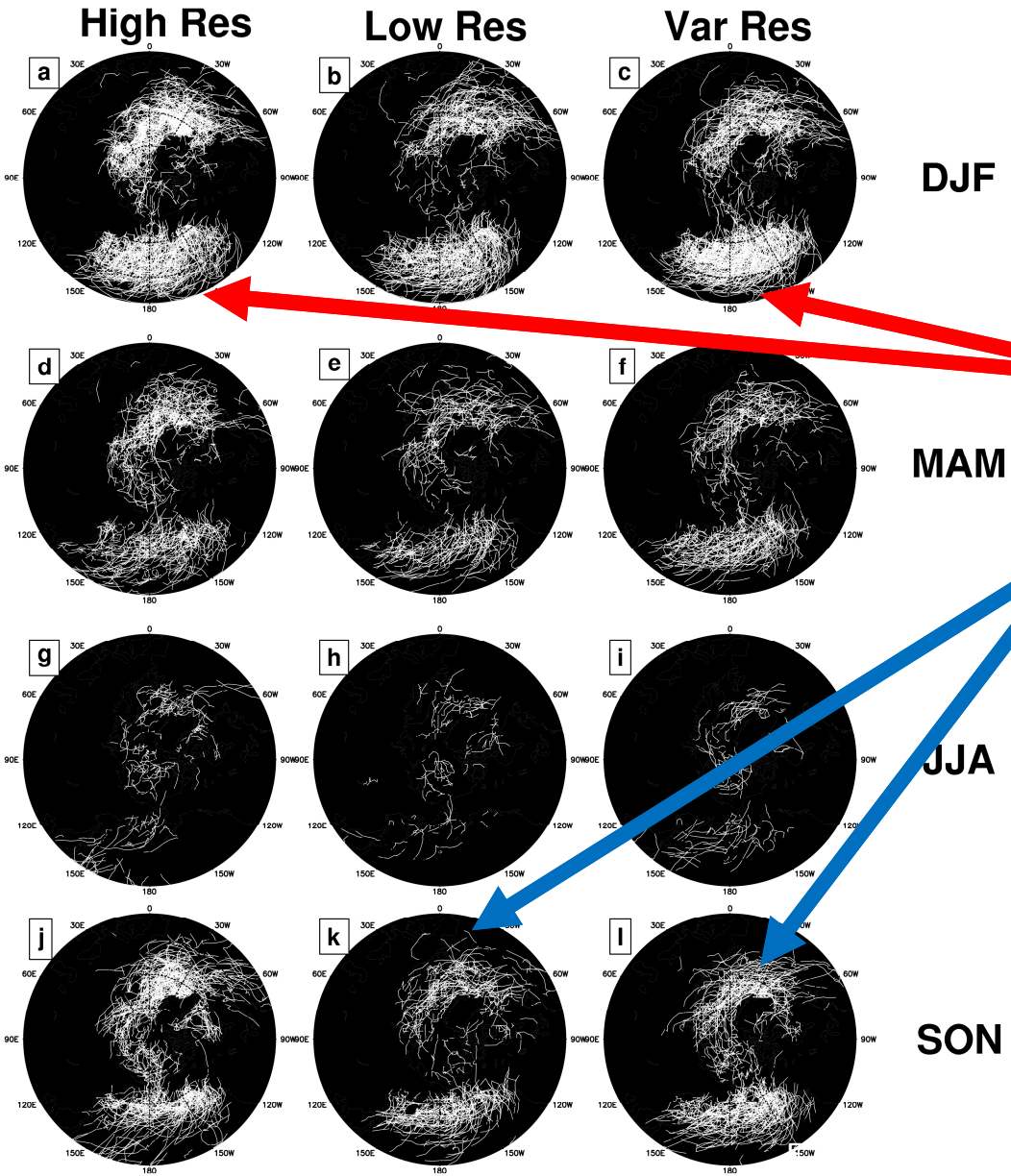


(b) Stride Search sectors





More Extra Tropical Storms with Righ Res

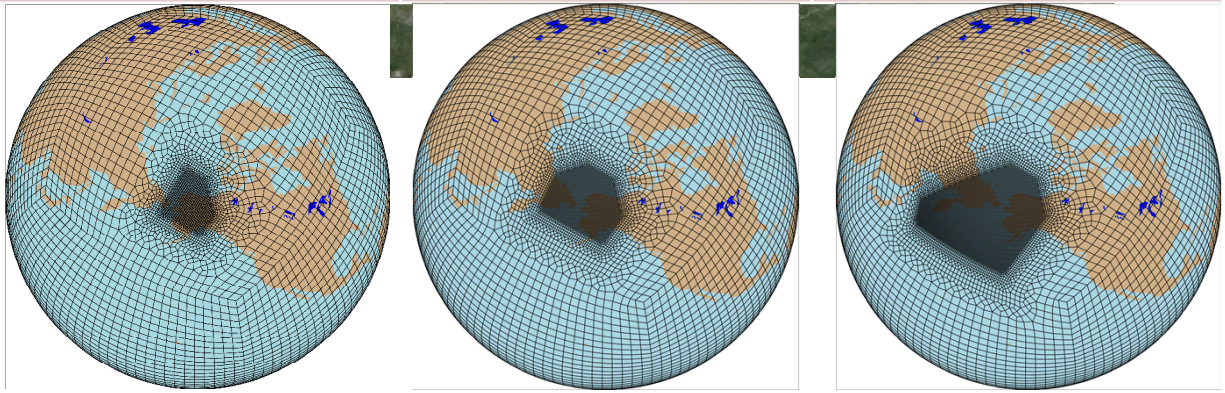


- ~25% increase in storms total storms over 5 yr period (idealized)
- Downstream effects of high resolution grid
- Variable Resolution
  - 30X cheaper than global high res
  - 2X more expensive than global low res

Could higher-resolutions improve cloud climatology in Arctic?

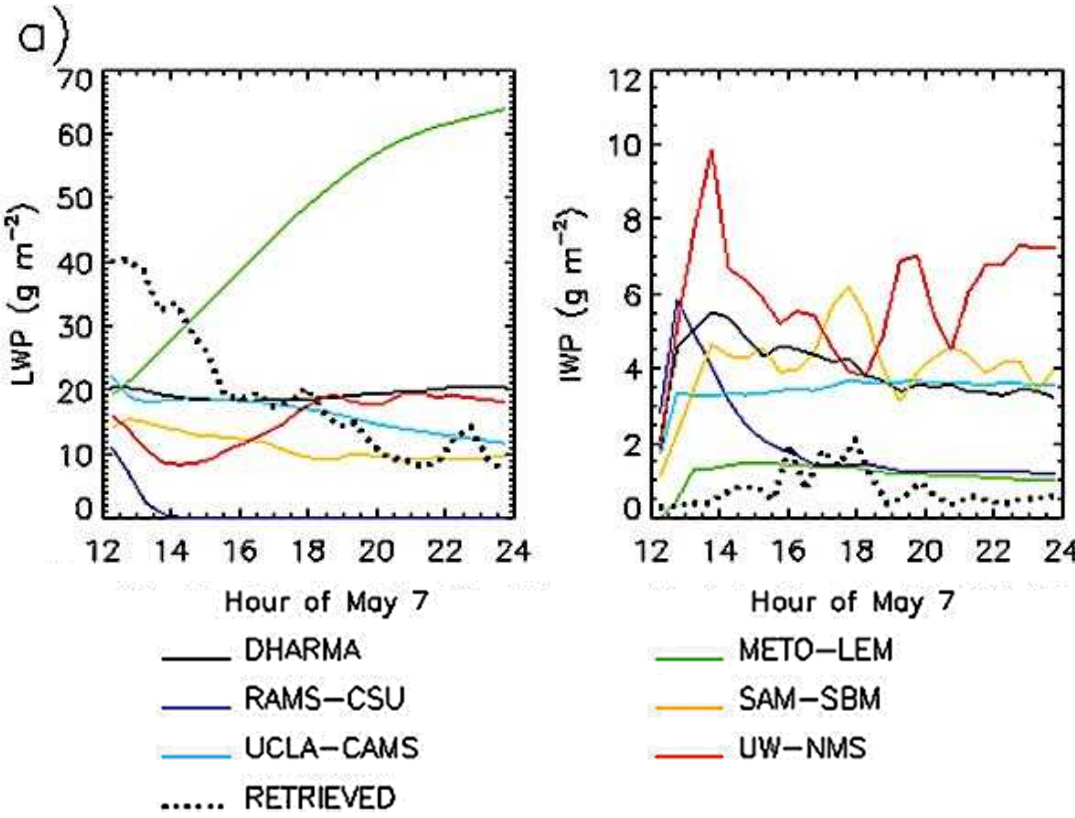
- Developing family of grids to determine resolution sensitivity of climate drivers of North Slope.

Small	Medium	Large
~ 8k elements	~9k elements	~14k elements



An insight into high resolution model behavior is through Cloud-Resolving Studies

- Mixed-phase, boundary layer cloud persists in simulations as in observations
  - Mostly idealized cases with simulations < 24hrs
  - Ice crystal concentration is subjected to constraints



(Klein et al 2009)

SAM – LES

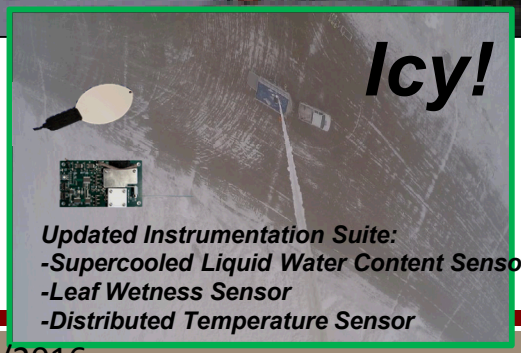
System for **A**tmospheric **M**odeling
Large **E**ddy **S**imulation

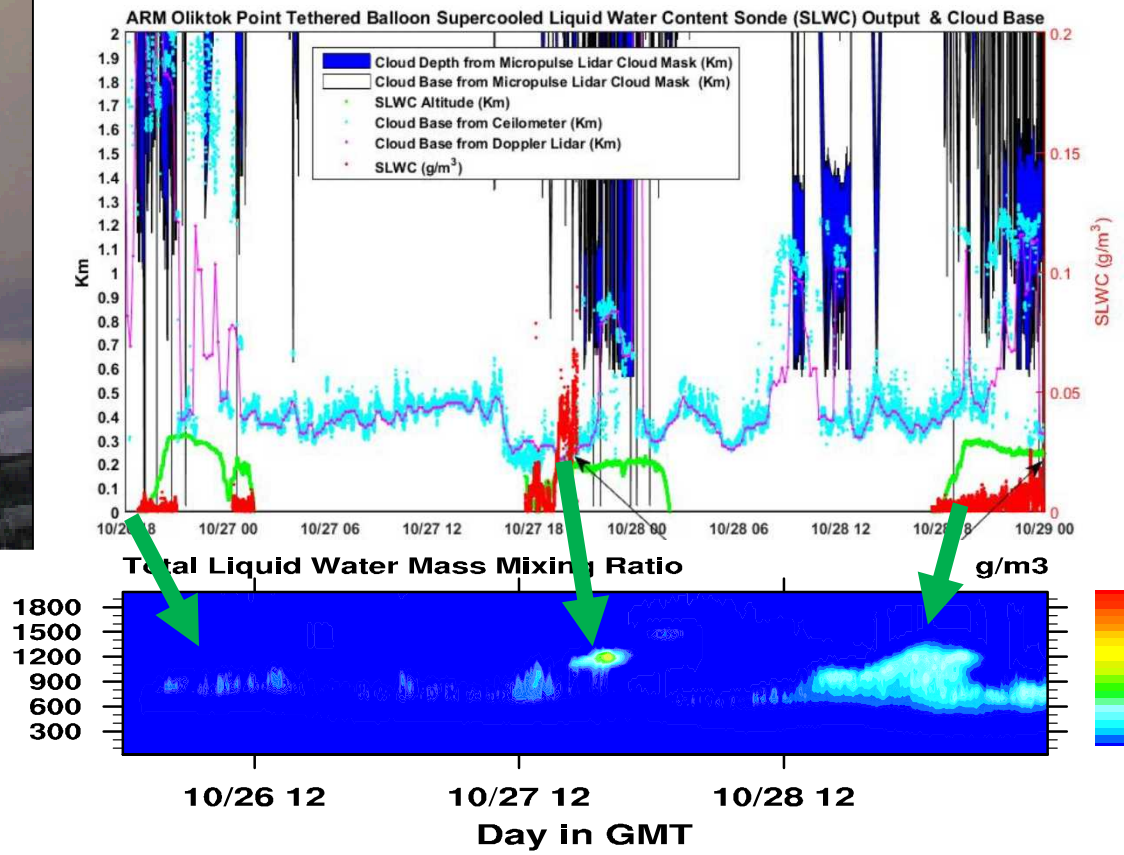
- Owner: Marat Khairoutdinov **http://rossby.msrc.sunysb.edu/~marat/SAM.html**
- 2D or 3D non-hydrostatic cloud resolving atmospheric model
- Morrison 2-moment microphysics for cloud liquid, rain, cloud ice, snow, hail, and graupel
- Smagorinsky, 1.5 SGS, CLUBB (experimental) closures
- Tested with Horizontal resolution of 10's m to 1000+ m
- Tested with Vertical resolution of 1's m to 10's m
- MPI

AALCO:

Observations taken to compare with LES

- **A**erial **A**ssessment of **L**iquid **W**ater in **C**louds IOP ongoing until December 2016 with first flights at end of September



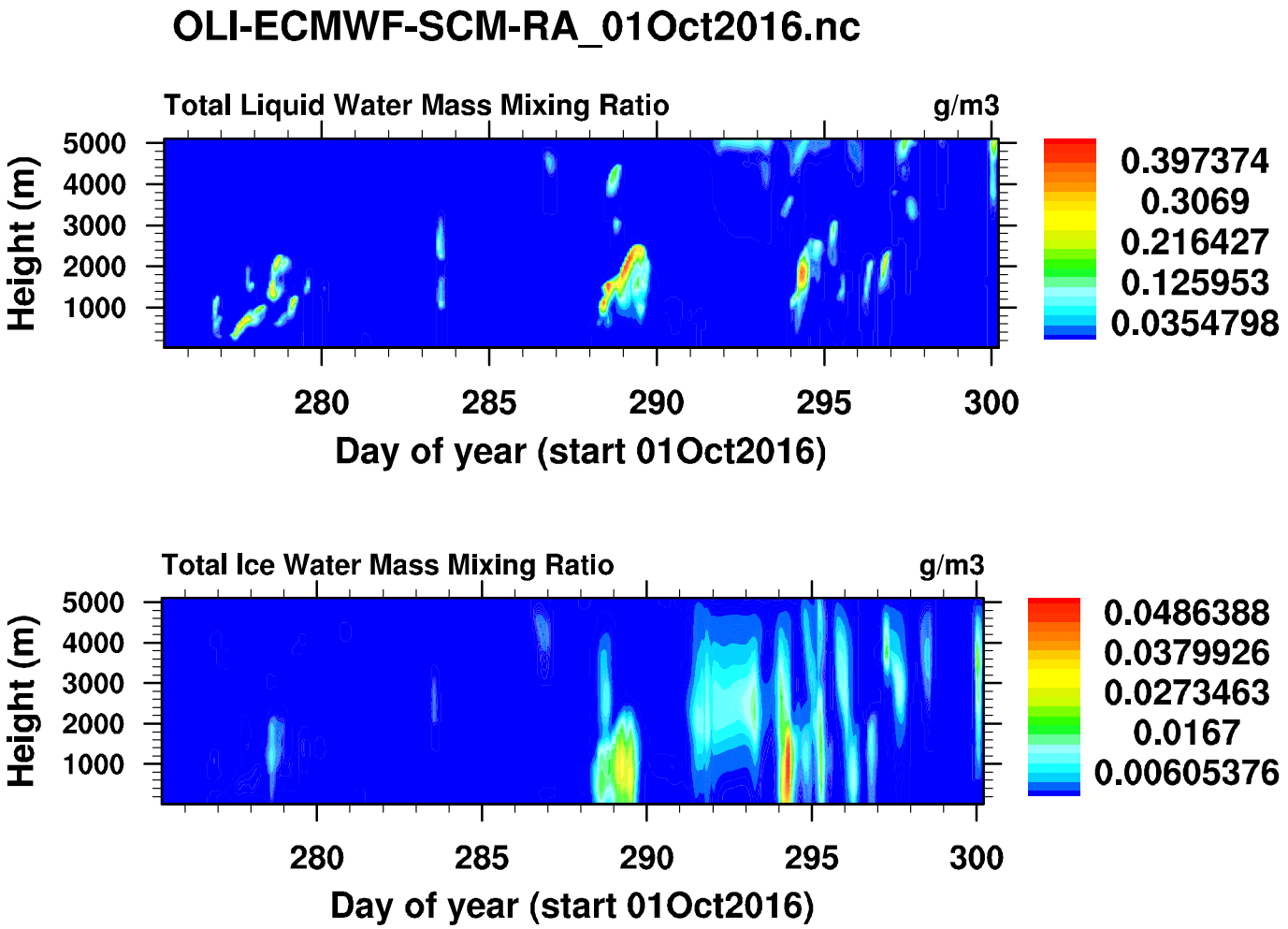


AALCO at Oliktok Point, Alaska in October, 2016

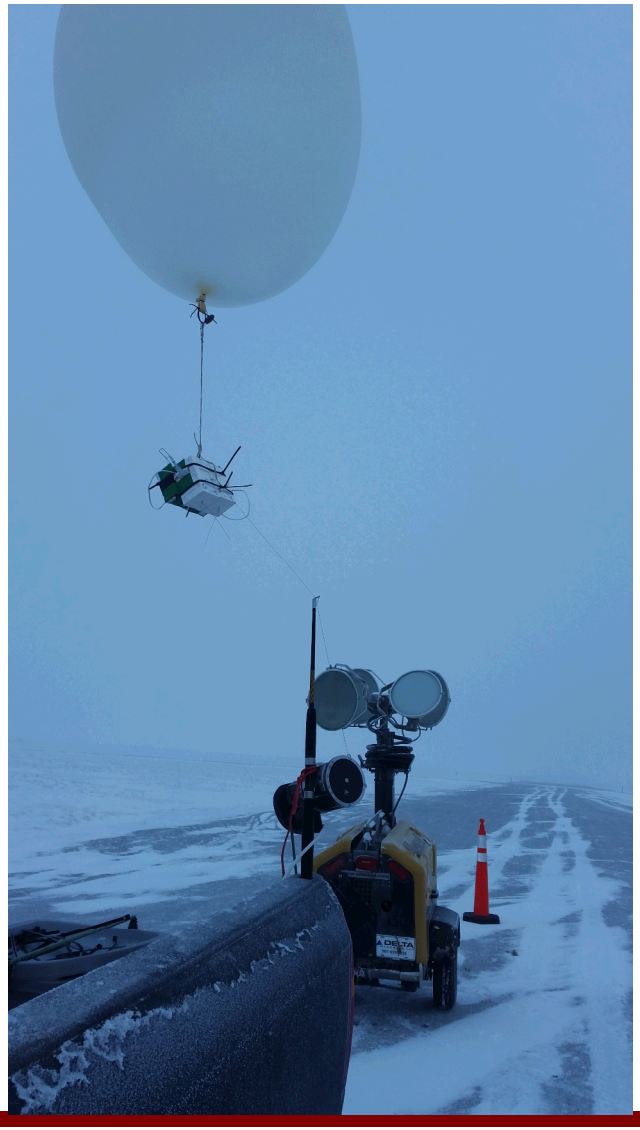
The AMF-3 and ARM tethered balloon, as seen by a DataHawk in October 2016

Photo Credit: http://ciresblogs.colorado.edu/alaska-unmanned-3/2016/10/19/more-good-weather/
http://ciresblogs.colorado.edu/alaska-unmanned-3/2016/10/20/beginning-to-feel-like-the-arctic/

SAM-LES for AALCO, October 2016



AALCO in November 2016: Fishing for Sky Halibut



AALCO in November

Summary

- Sandia National Laboratories has national security mission, including working towards a secure, sustainable (energy) future.
- Climate change will impact our energy and security infrastructure, and stakeholders have questions about the future.
- Climate models can provide insight to the future climate of regions.
- High resolution climate models provides more realistic extreme events and more, but much more work is needed
- Variable Resolution is path to understanding High Resolution, without Exascale computing
- Cloud-resolving model studies give direction to High Resolution global model future
- In situ measurements constrain the cloud-resolving models.

Thank you! For more information, please see www.sandia.gov, Thank you!

or email me, Erika at elroesl@sandia.gov

Acknowledgements

- Hans Verlinde for this opportunity
- Colleagues at Sandia (front slide)
- ARM data, ECMWF data product
- *NOAA High Resolution SST data provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their Web site at http://www.esrl.noaa.gov/psd/* Reynolds, Richard W., Thomas M. Smith, Chunying Liu, Dudley B. Chelton, Kenneth S. Casey, Michael G. Schlax, 2007: Daily High-Resolution-Blended Analyses for Sea Surface Temperature. J. Climate, 20, 5473-5496. Reynolds, Richard W., Thomas M. Smith, Chunying Liu, Dudley B. Chelton, Kenneth S. Casey, Michael G. Schlax, 2007: Daily High-Resolution-Blended Analyses for Sea Surface Temperature. J. Climate, 20, 5473-5496.