The challenge of modeling liquid-bearing clouds in the Arctic and implications for DCV

Amy Solomon

Cooperative Institute for Research in Environmental Sciences, University of Colorado

NOAA Earth System Research Laboratory, Boulder, Colorado

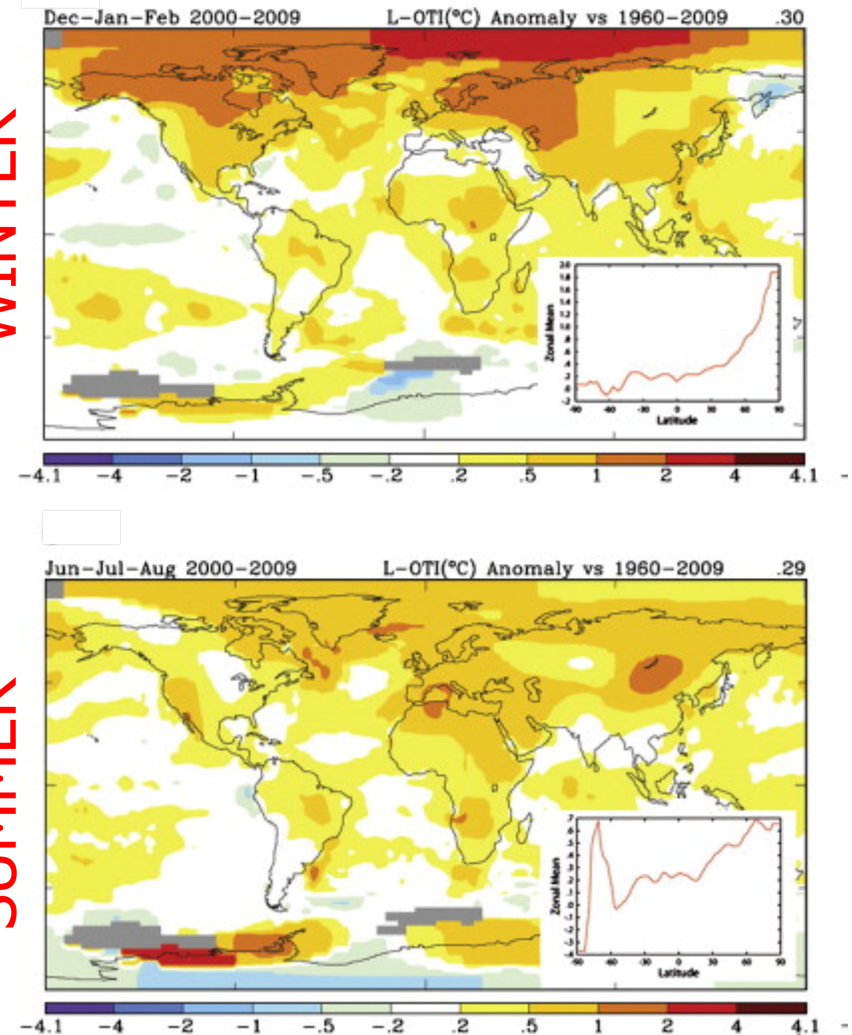
Arctic Amplification (AA)

- ◆ AA has been recognized since 1896 (Arrhenius 1896)
- ◆ Largest AA in winter – Not due to Sea Ice-Albedo Feedback
- ◆ Large spread in climate models of AA (Holland and Bitz 2003)
- ◆ ~50% of observed trend can be due to natural variability (Kay et al. 2015)

Surface Air Temperature Anomalies
(2000-2009) – (1960-2009)

WINTER

SUMMER



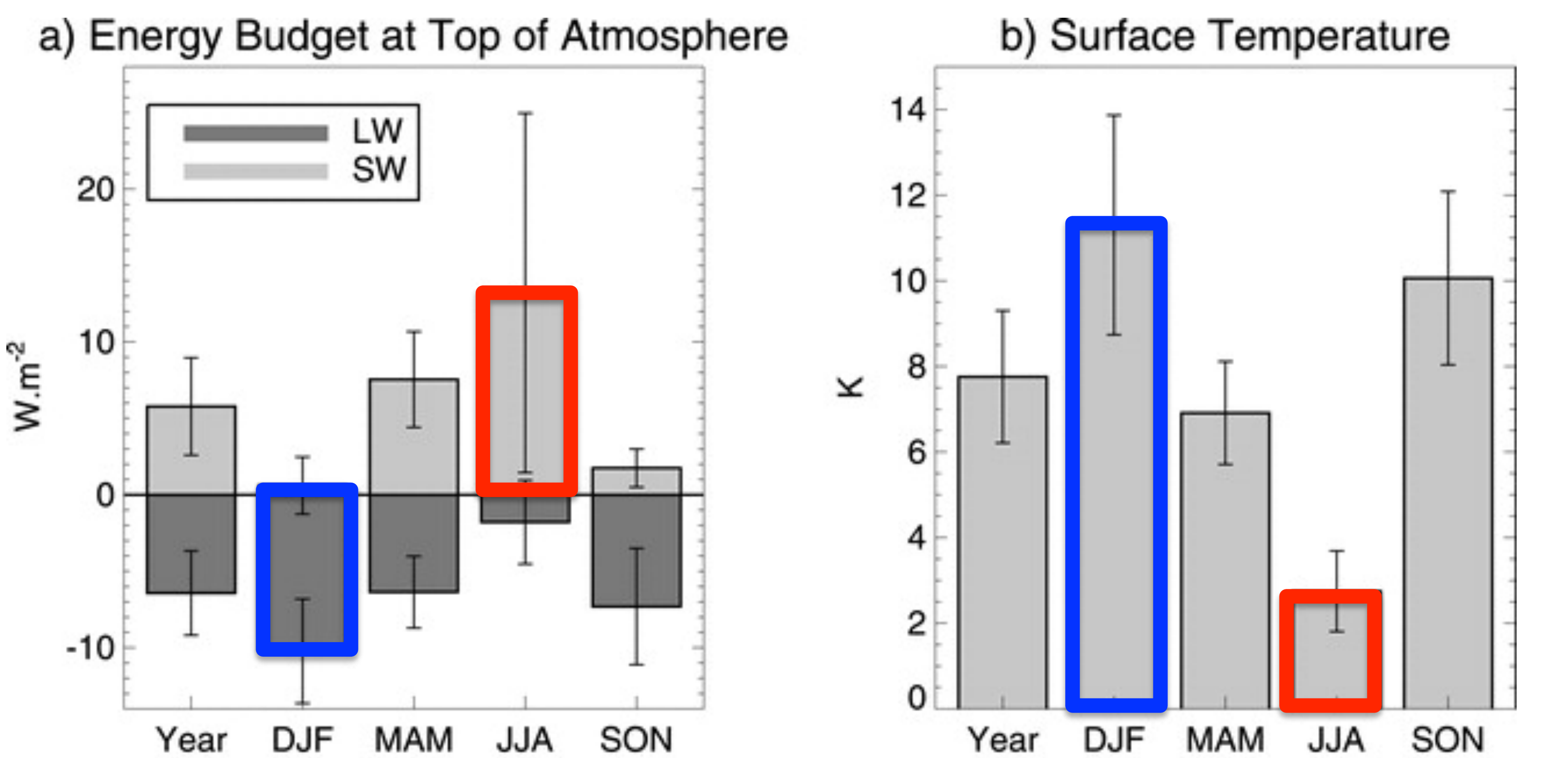
(Serreze and Barry 2011, GPC)

Outline

- Causes of Arctic Amplification
  - Seasonal Redistribution of Heat
  - Role of Surface Inversions
- Role of Liquid-Bearing Clouds
- Greenland Example to Illustrate the Impacts of Liquid-Bearing Clouds Beyond Cloud Radiative Forcing
- Challenge for CLIVAR?

Seasonal Redistribution of Heat

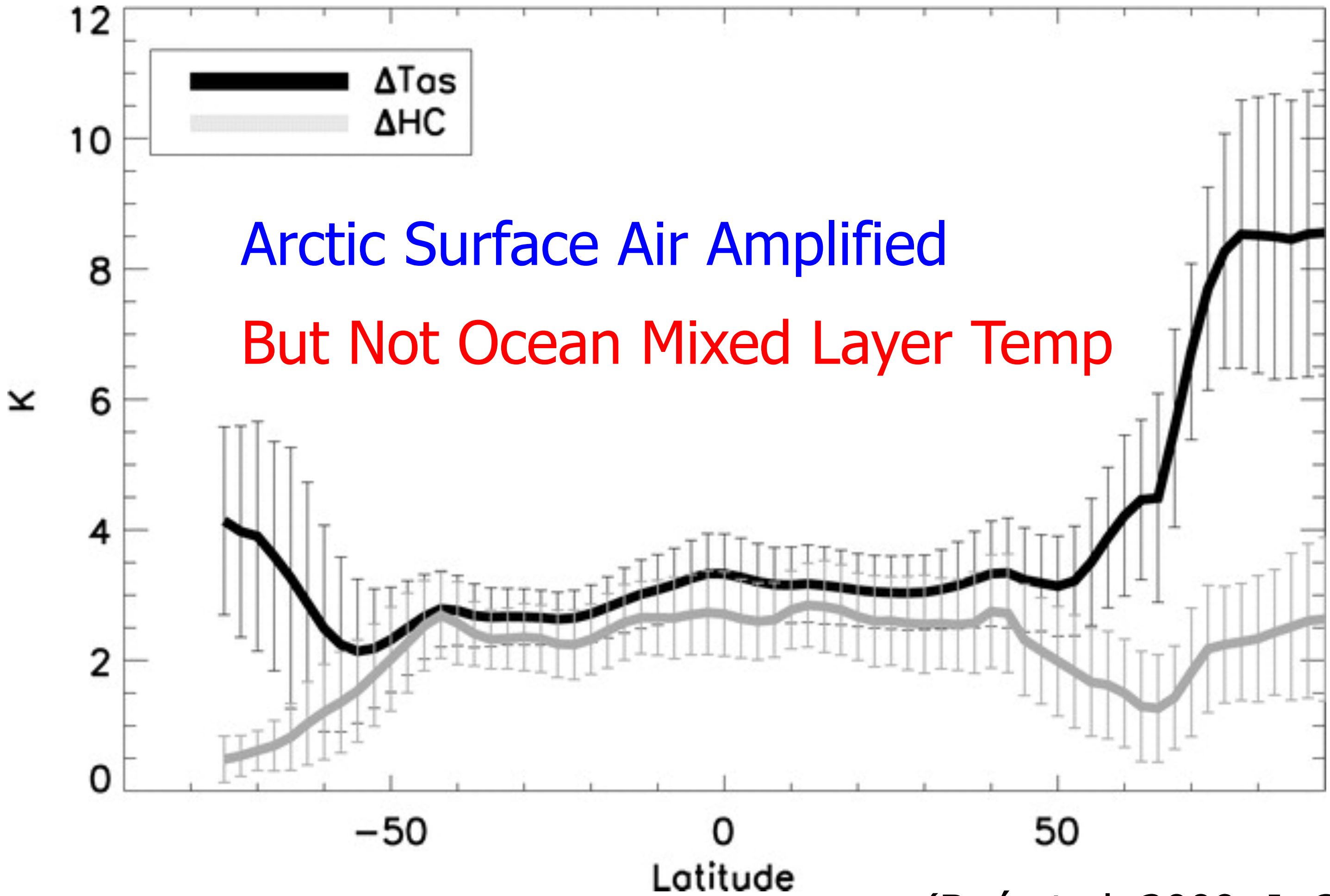
Arctic Mean From 13 CMIP3 A1B-20C3M Simulations



(Boé et al. 2009, J. Climate)

Seasonal Redistribution of Heat

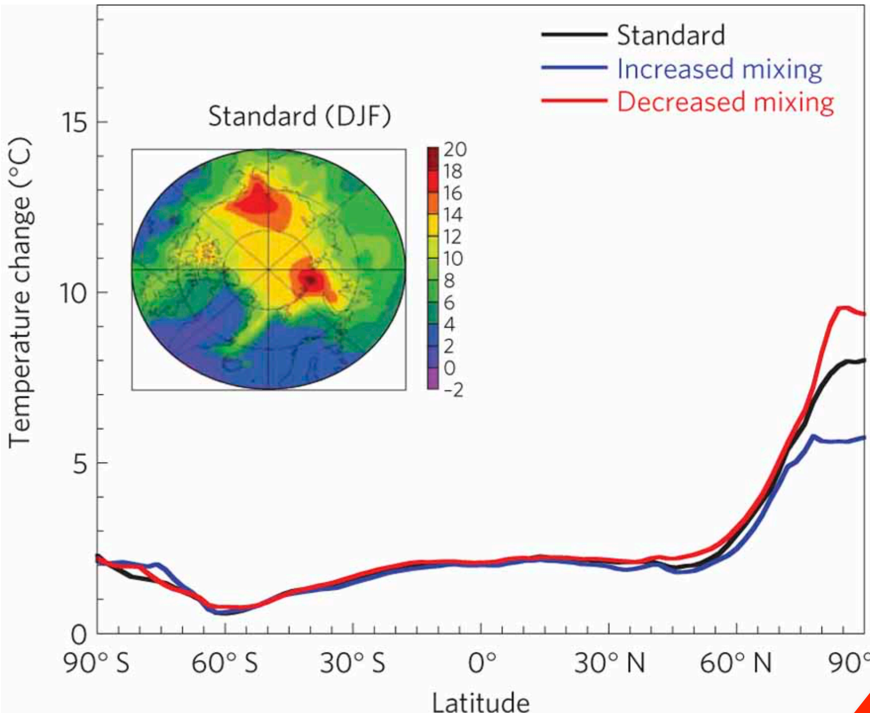
From 13 CMIP3 A1B-20C3M Simulations

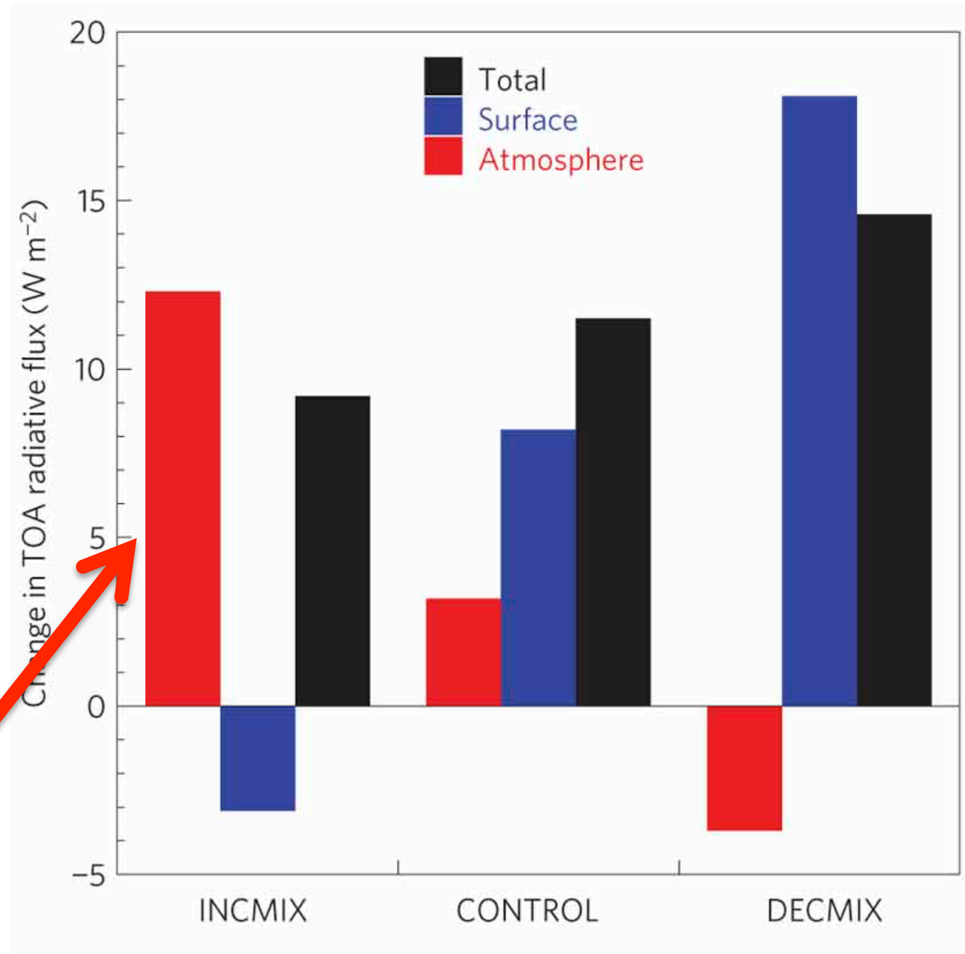


(Boé et al. 2009, J. Climate)

Role of Surface Inversions

Sensitivity of AA to Inversion Strength (CO2 Doubling Expts)



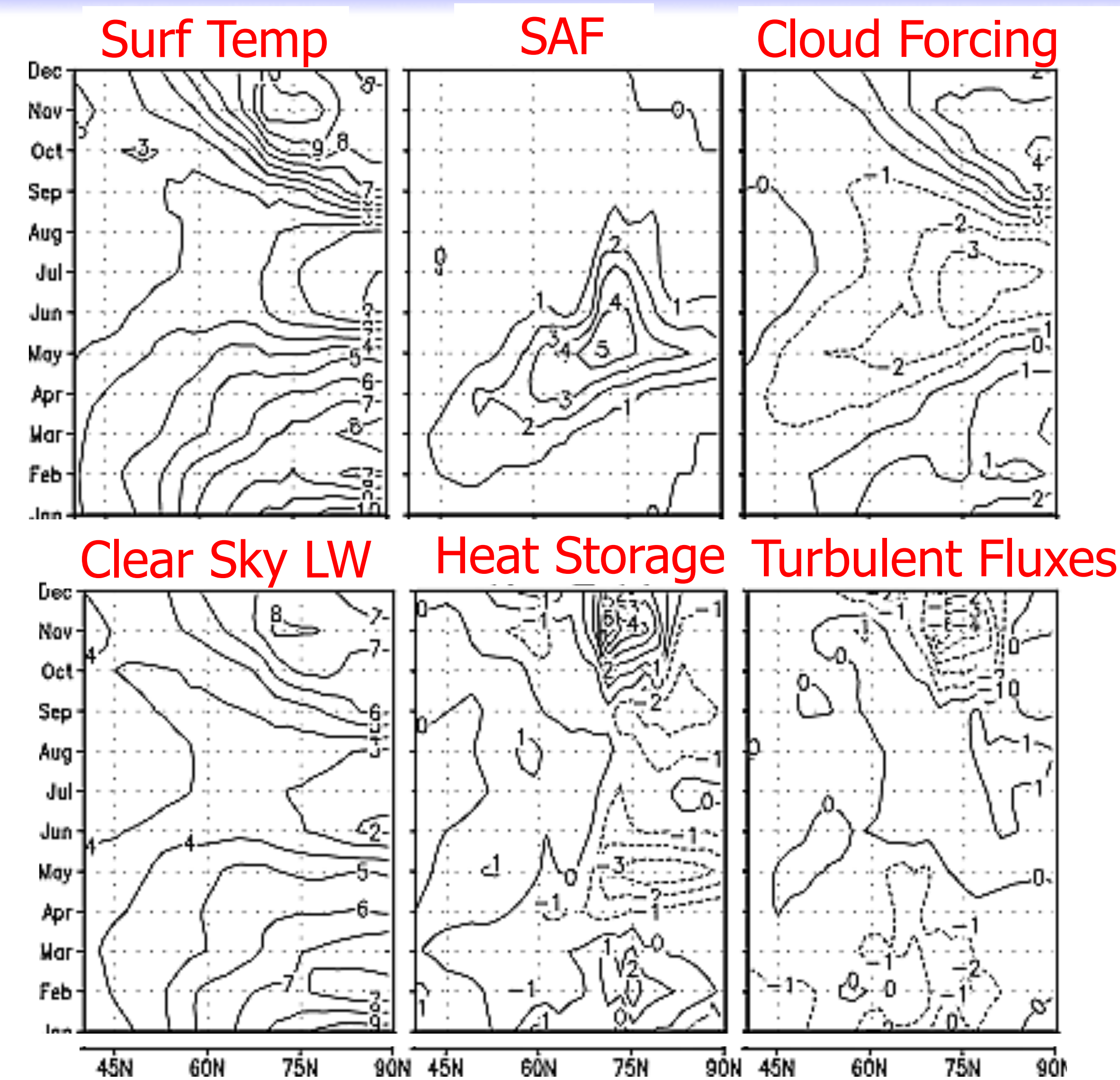


Increased mixing mixes heat upward where it can efficiently radiate to space

(Bintanja et al. 2011, Nature Geoscience)

Role of Liquid-bearing Clouds

Climate Model Response to a Doubling of CO_2 (GFDL CM2.0)

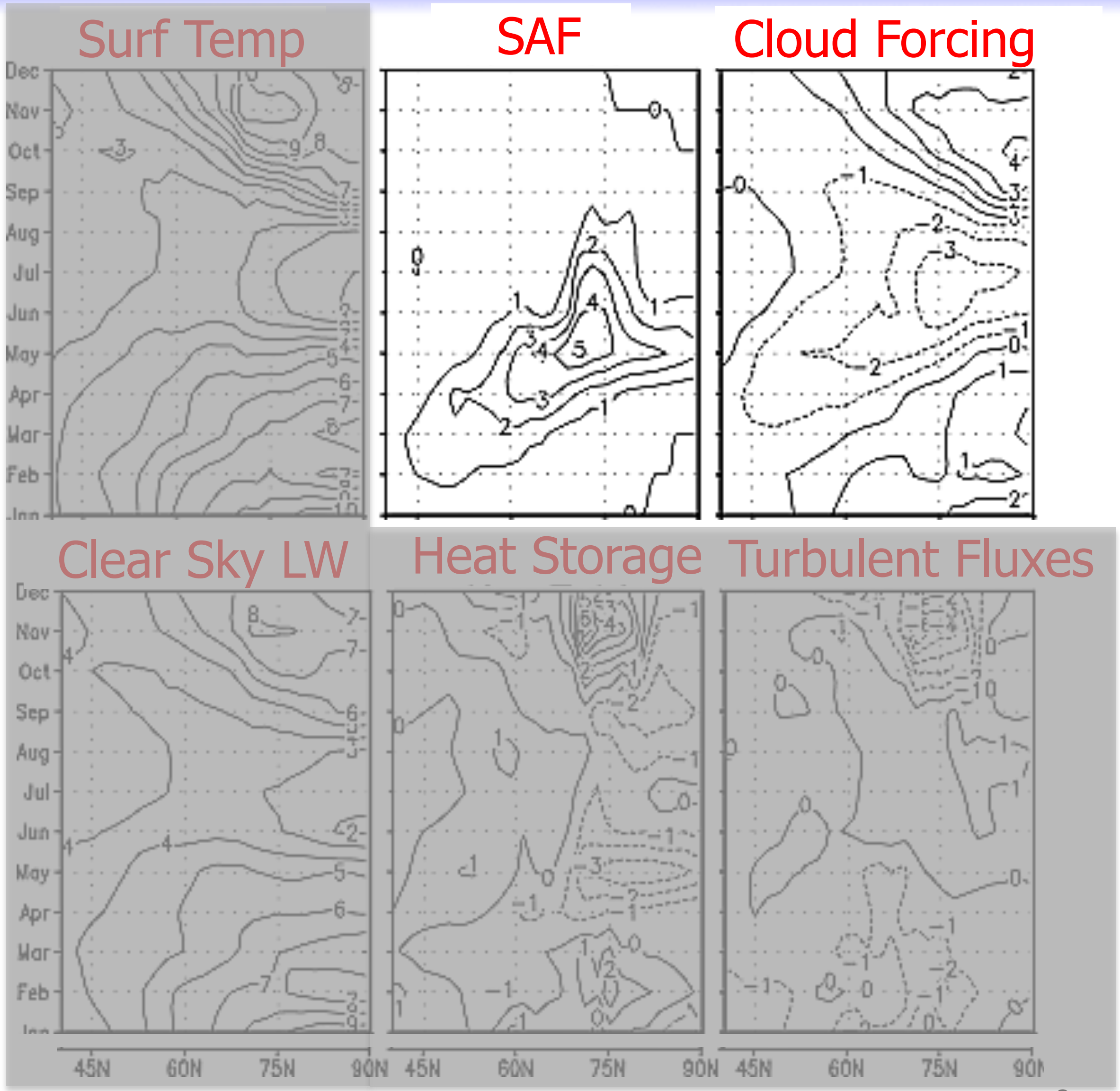


(All Figures In Units of K) (Lu and Cai 2009, GRL)

Role of Liquid-bearing Clouds

Climate Model Response to a Doubling of CO_2

Summertime Reflection of SW Radiation by Liquid-bearing Clouds Compensate for Warming due to the Sea Ice-Albedo Feedback

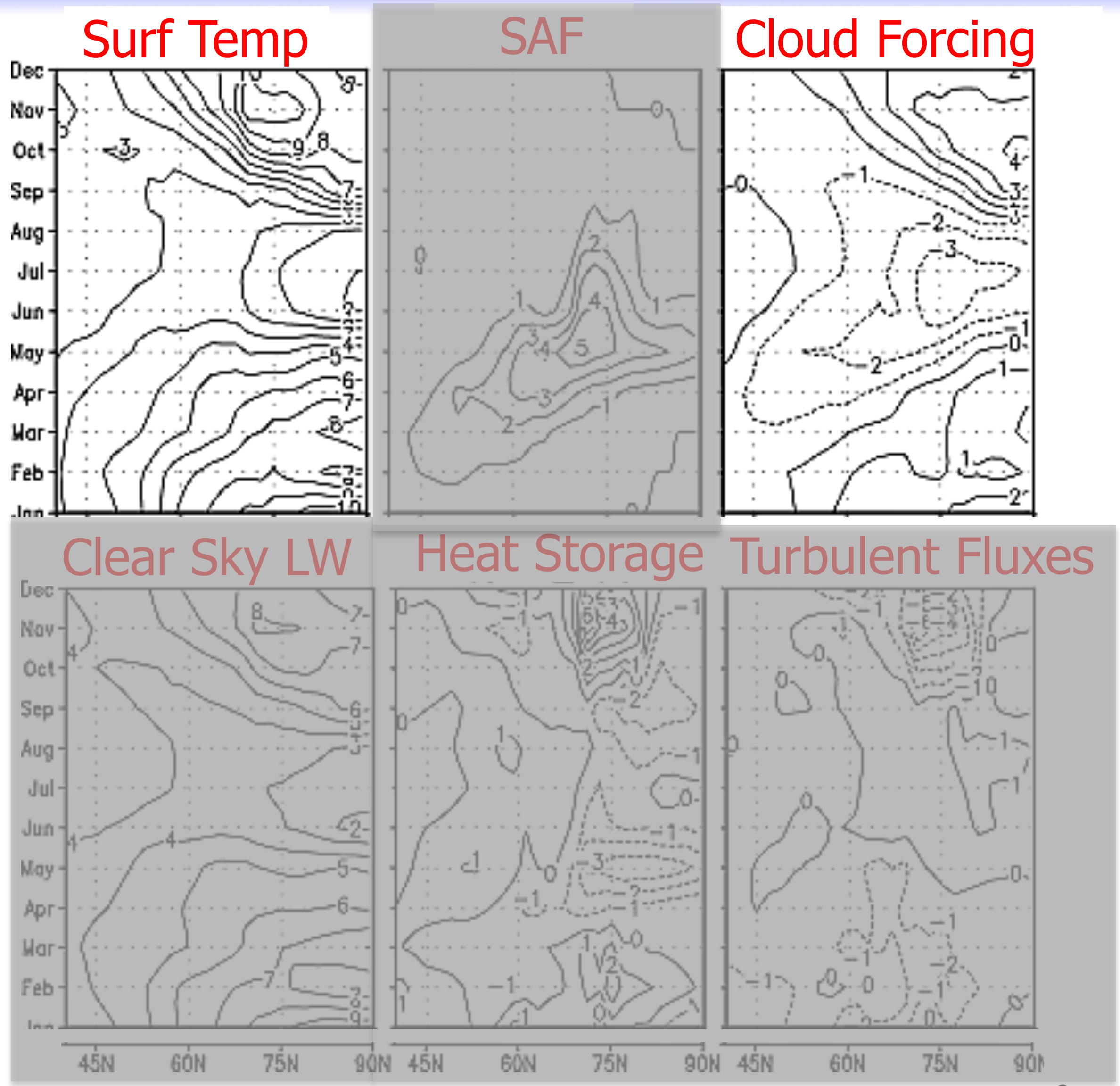


(All Figures In Units of K) (Lu and Cai 2009, GRL)

Role of Liquid-bearing Clouds

Climate Model Response to a Doubling of CO_2

Wintertime Downward LW Radiation by Liquid-bearing Clouds Responsible for ~40% of High-Latitude Warming

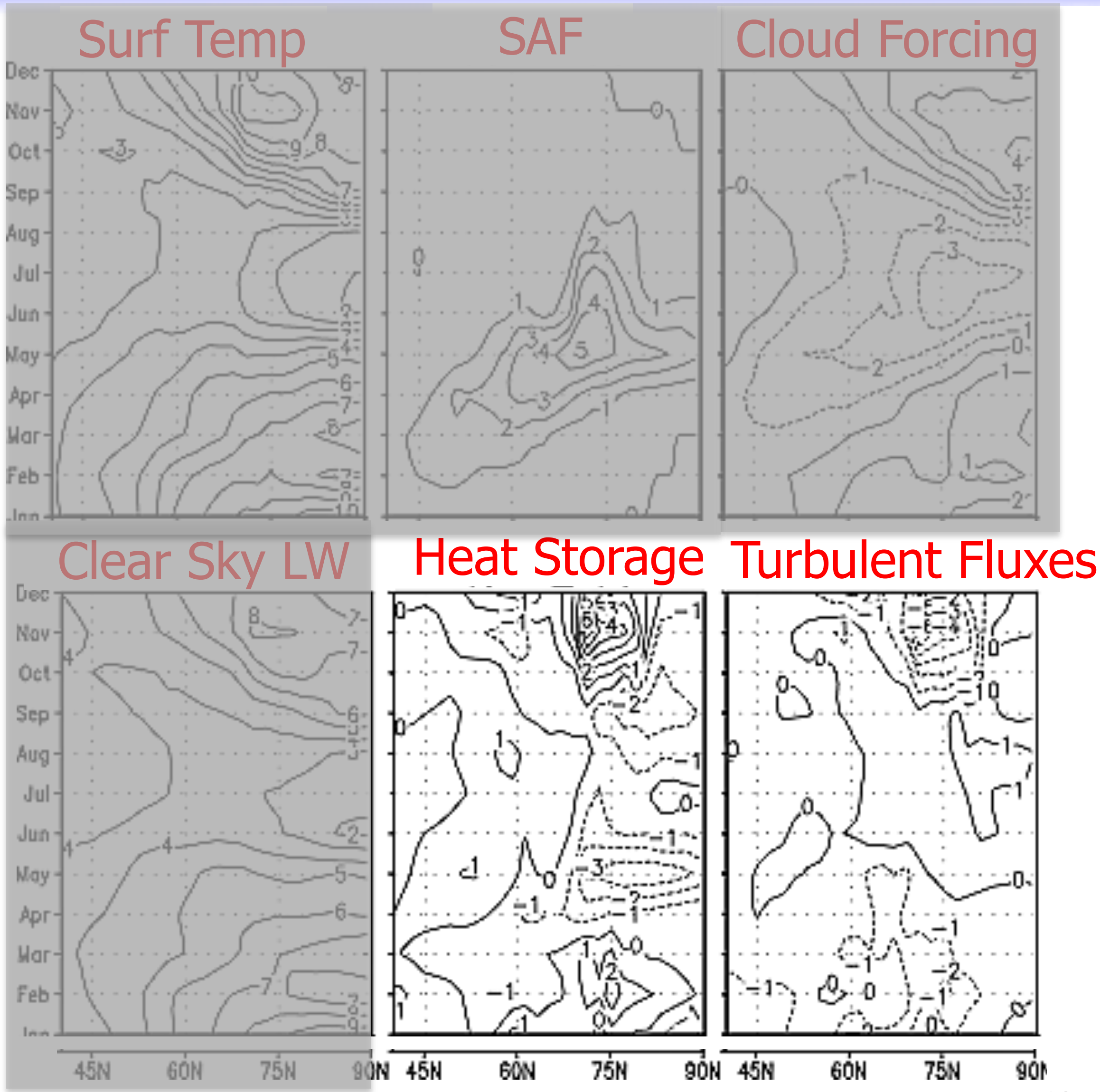


(All Figures In Units of K) (Lu and Cai 2009, GRL)

Role of Ocean Fluxes

Climate Model Response to a Doubling of CO_2

Loss of Wintertime Ocean Heat Storage Compensated by Increased Turbulent Fluxes

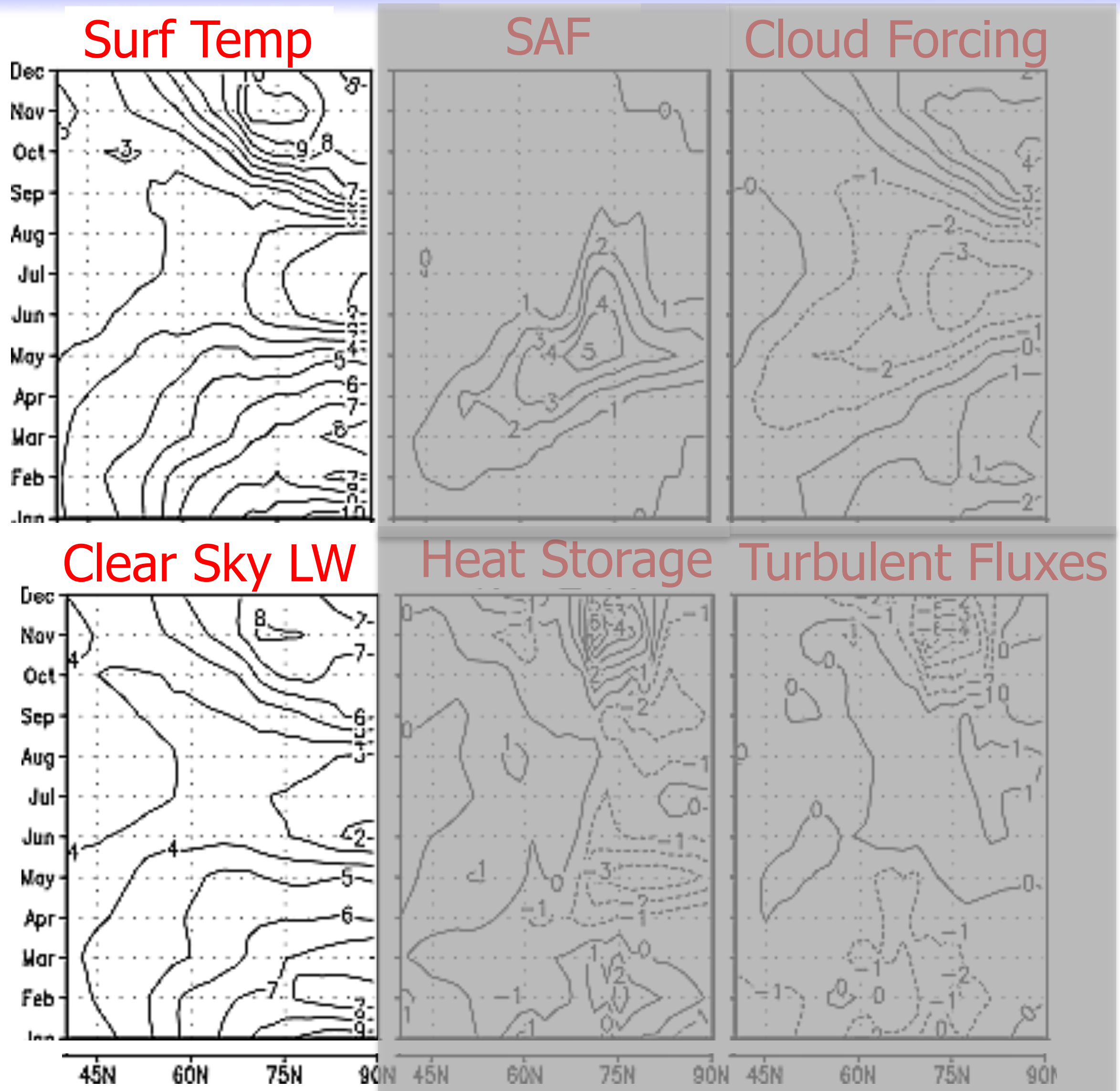


(All Figures In Units of K) (Lu and Cai 2009, GRL)

Role of Clear-Sky Fluxes

Climate Model Response to a Doubling of CO_2

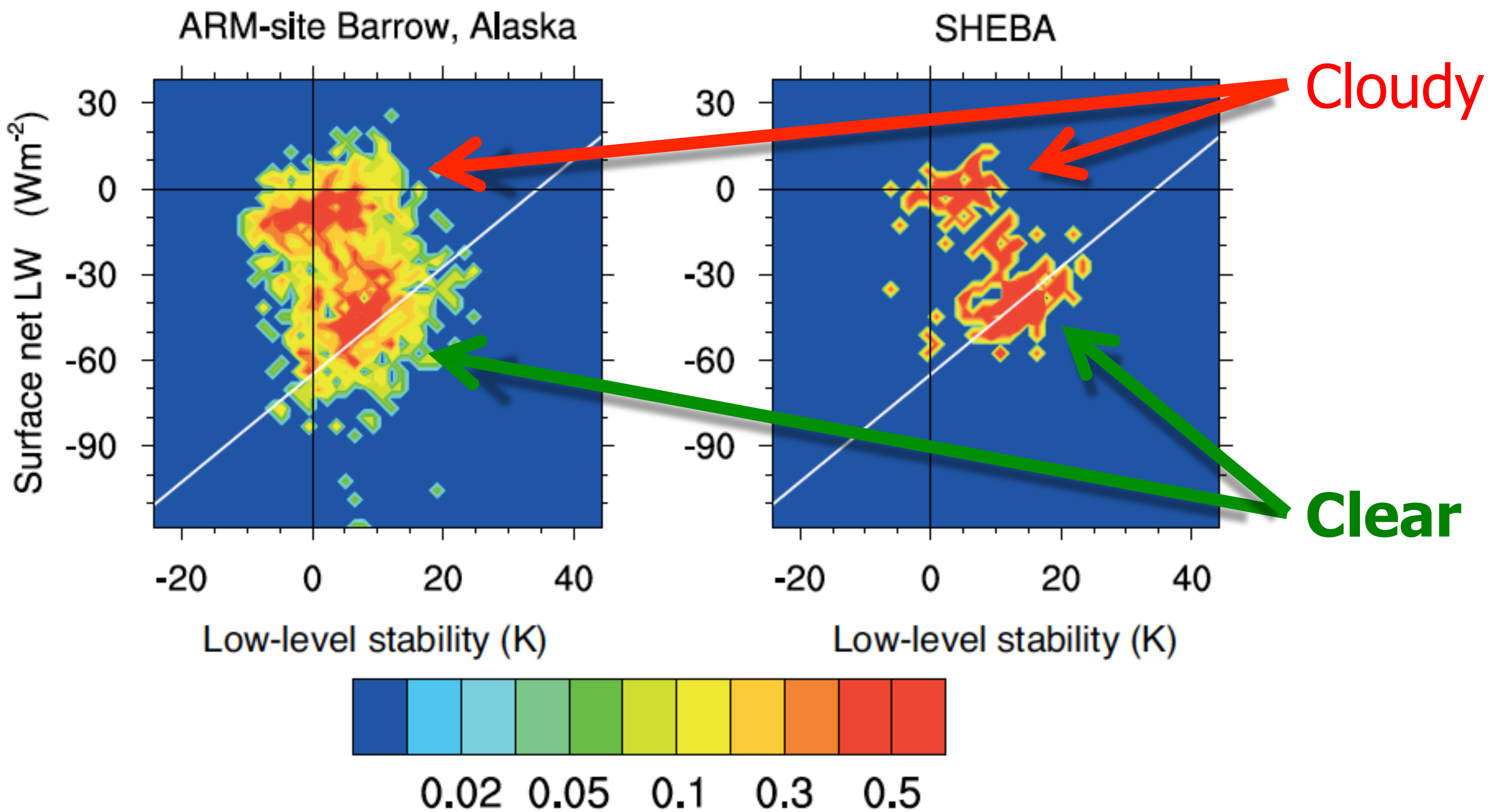
Largest Wintertime Tendencies due to Changes in Atmospheric Moisture and Temperature



(All Figures In Units of K) (Lu and Cai 2009, GRL)

Role of Liquid-bearing Clouds

Observed NDJF Bimodal Distribution of Net Surface LW

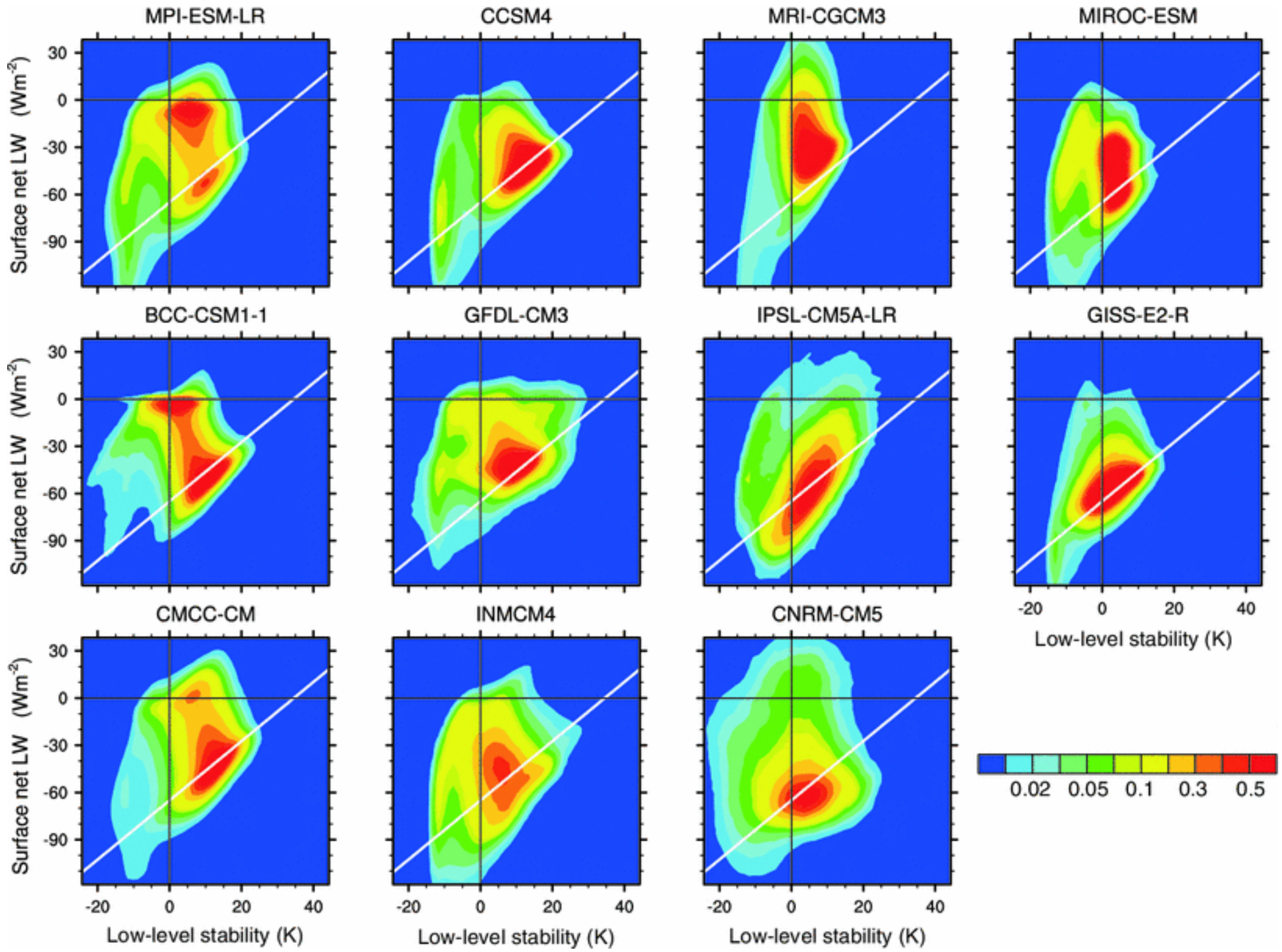


(Pithan et al. 2014, Climate Dynamics)

Liquid-Bearing Cloud Biases in Climate Models

11 NDJF CMIP5 1990-1999 Historical Runs
Ocean North of 64°N

Surface Net Longwave Radiation



low-level stability

(Pithan et al. 2014, Climate Dynamics)

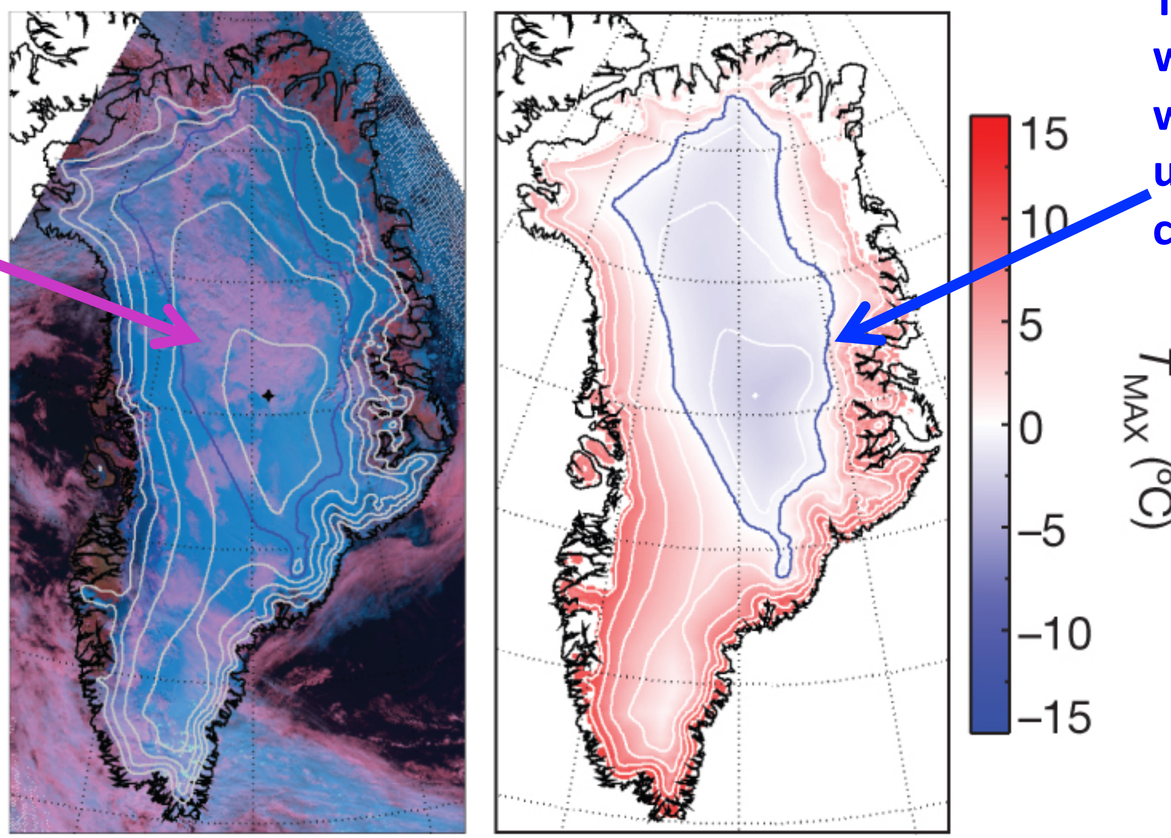
Going Beyond Radiative Forcing – Greenland Example

Melting of the Greenland Ice Sheet: July 2012

Melting due to thin mixed-phase stratocumulus

MODIS (on the Aqua satellite) on 11 July 2012

Liquid-bearing clouds in purple



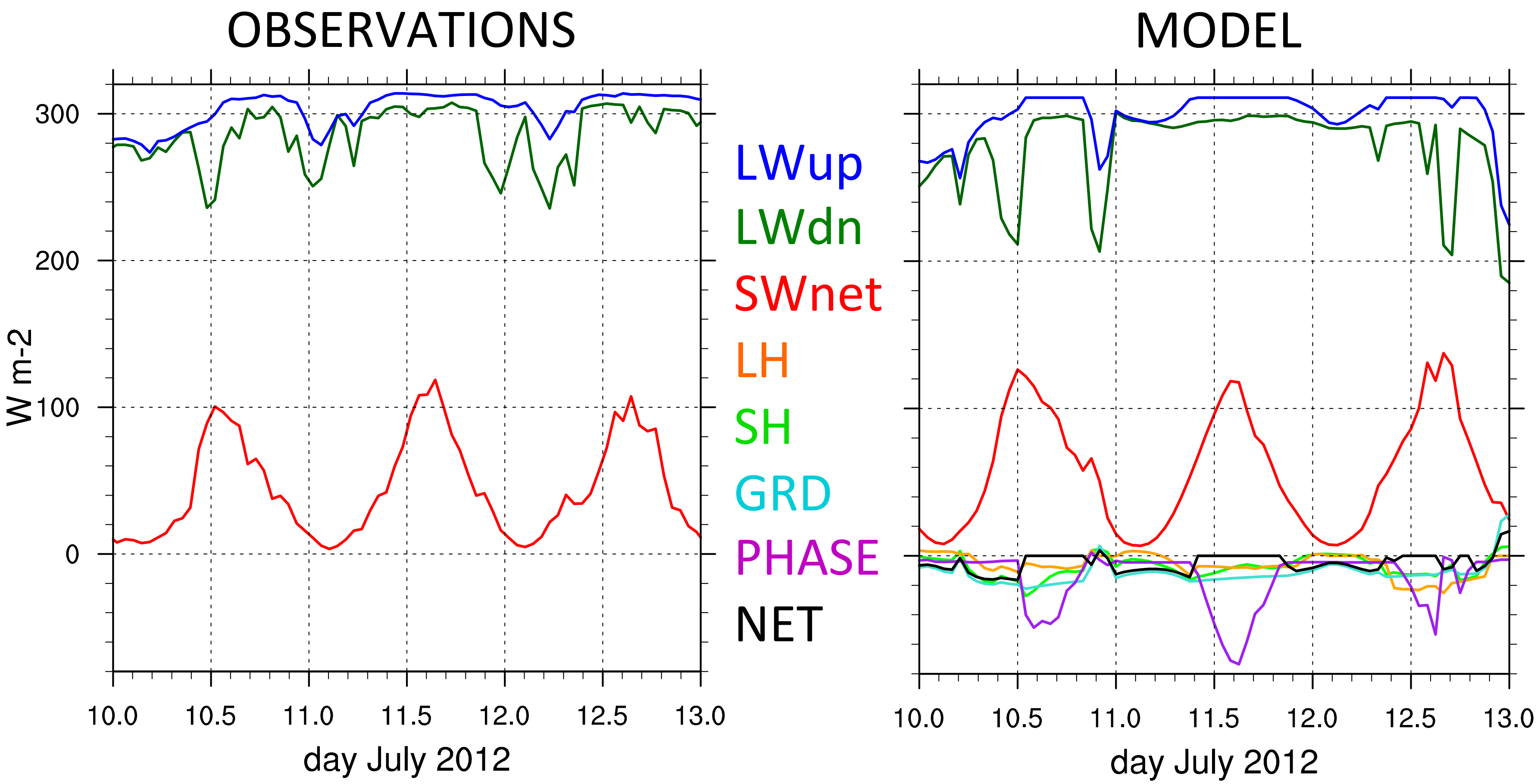
The height below which melting would occur under cloud-free conditions

(Bennartz et al. 2013, Nature)

Going Beyond Radiative Forcing

–

Surface Energy Budget Terms at Summit, Greenland
10-13 July 2012

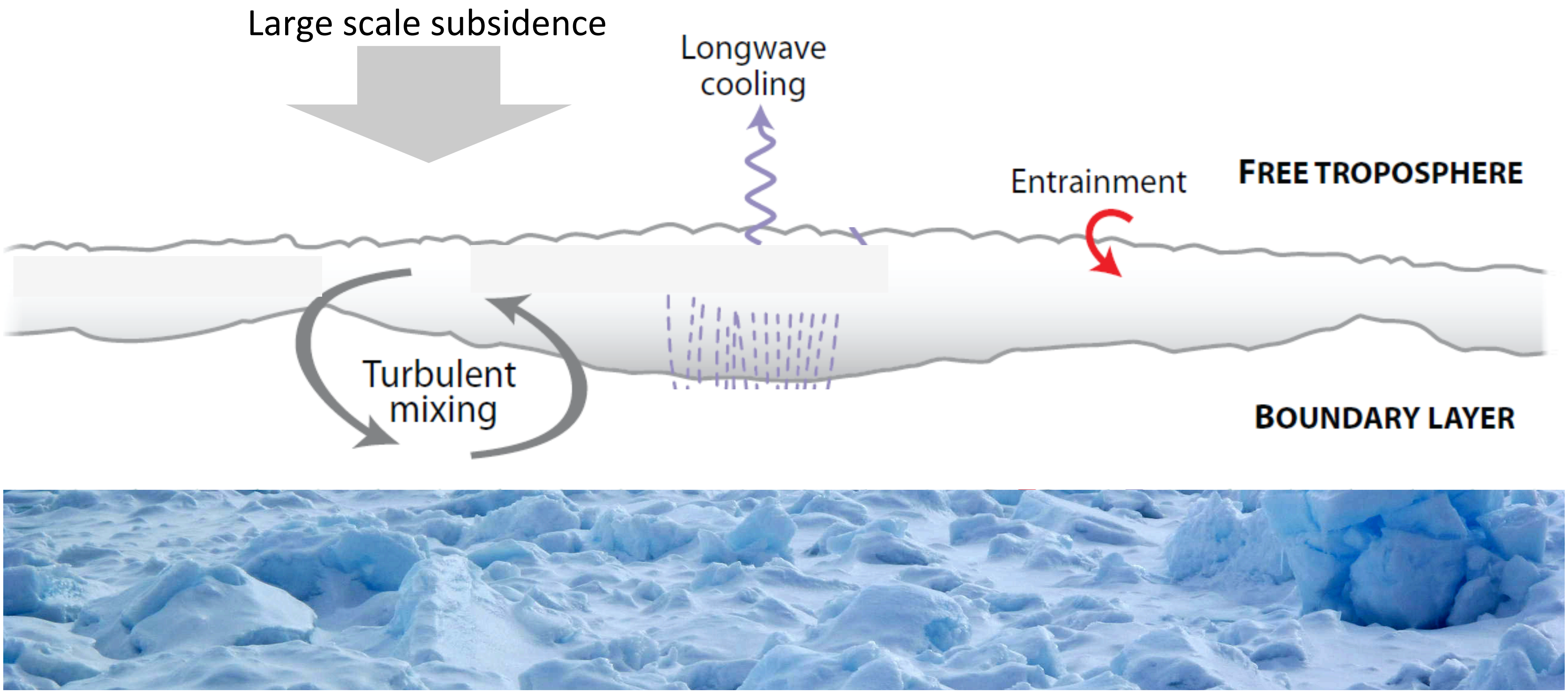


(Solomon et al. 2015)

Going Beyond Radiative Forcing

–

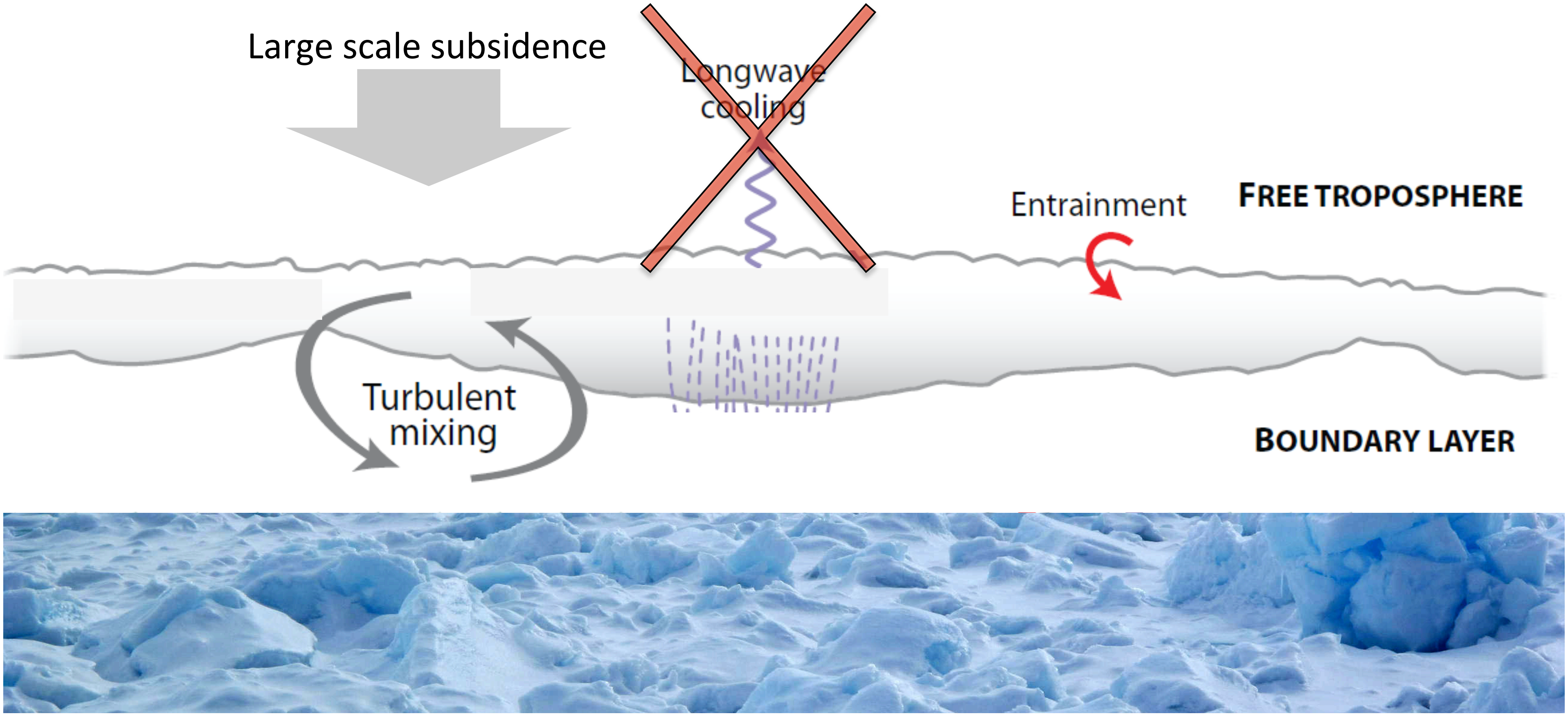
Stratocumulus over The Ice Sheet



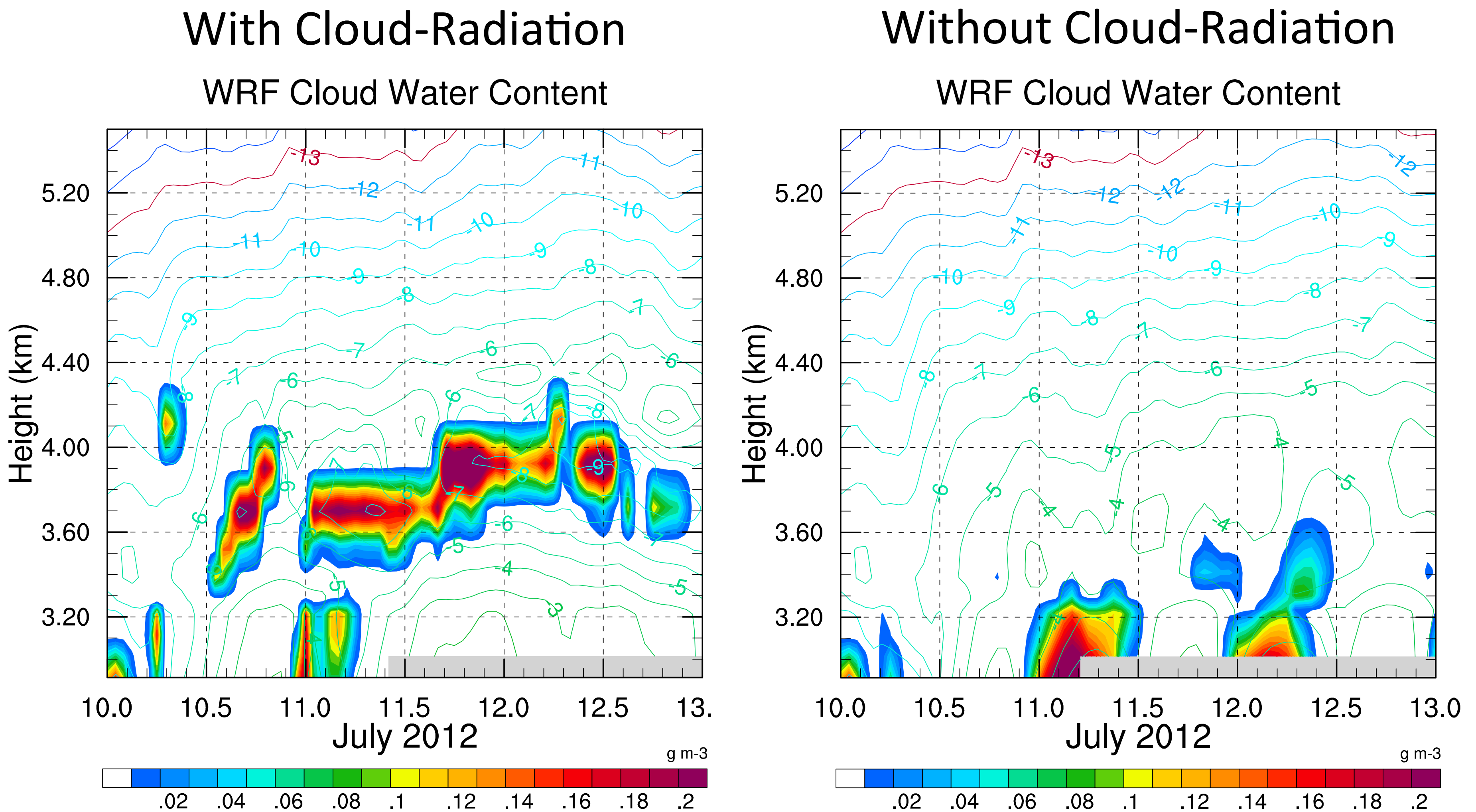
Going Beyond Radiative Forcing

–

Radiation Doesn't See Cloud Ice and Liquid



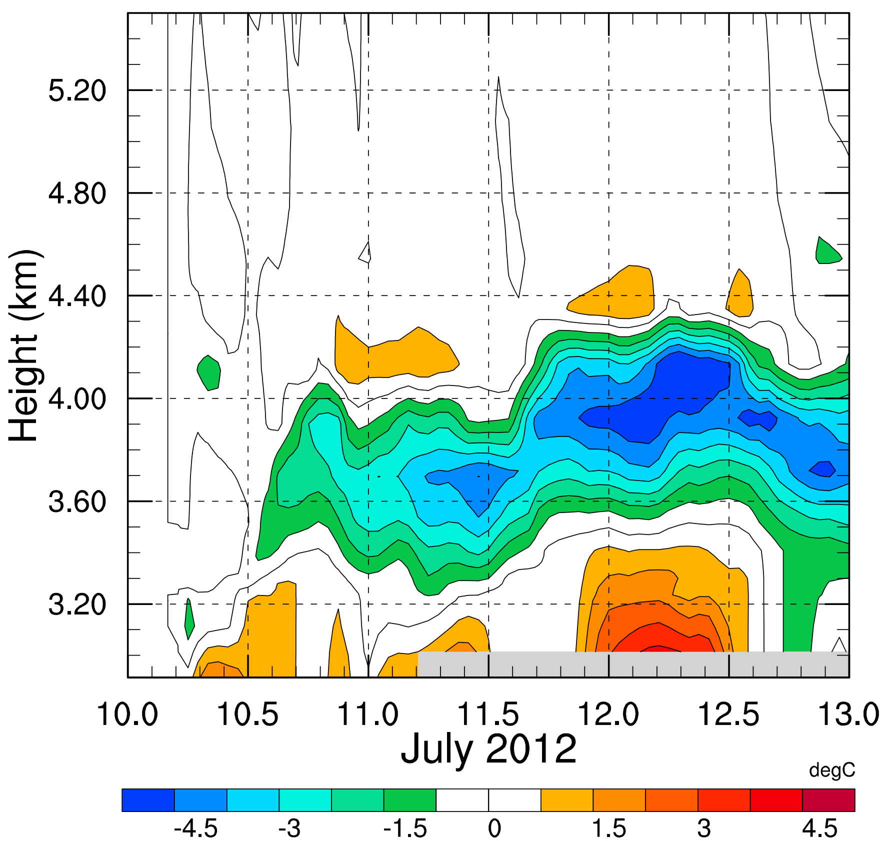
Going Beyond Radiative Forcing: Impact on Cloud Liquid Water



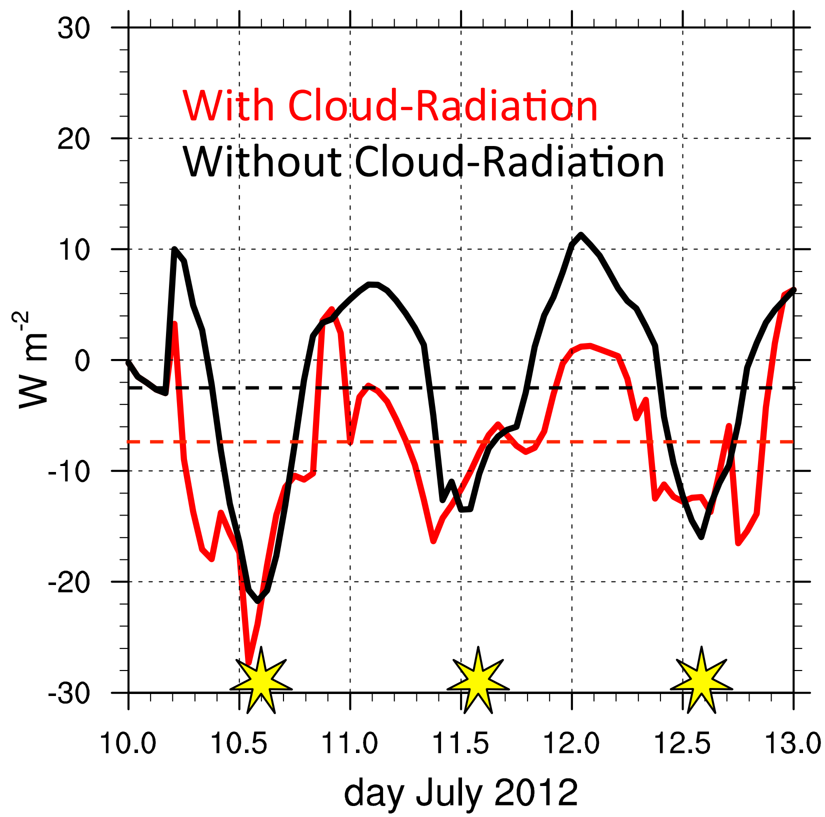
(Solomon et al. 2015)

Going Beyond Radiative Forcing: Impact on Atm Structure and Surface Fluxes

Temperature
(With-Without Cloud-Radiation)

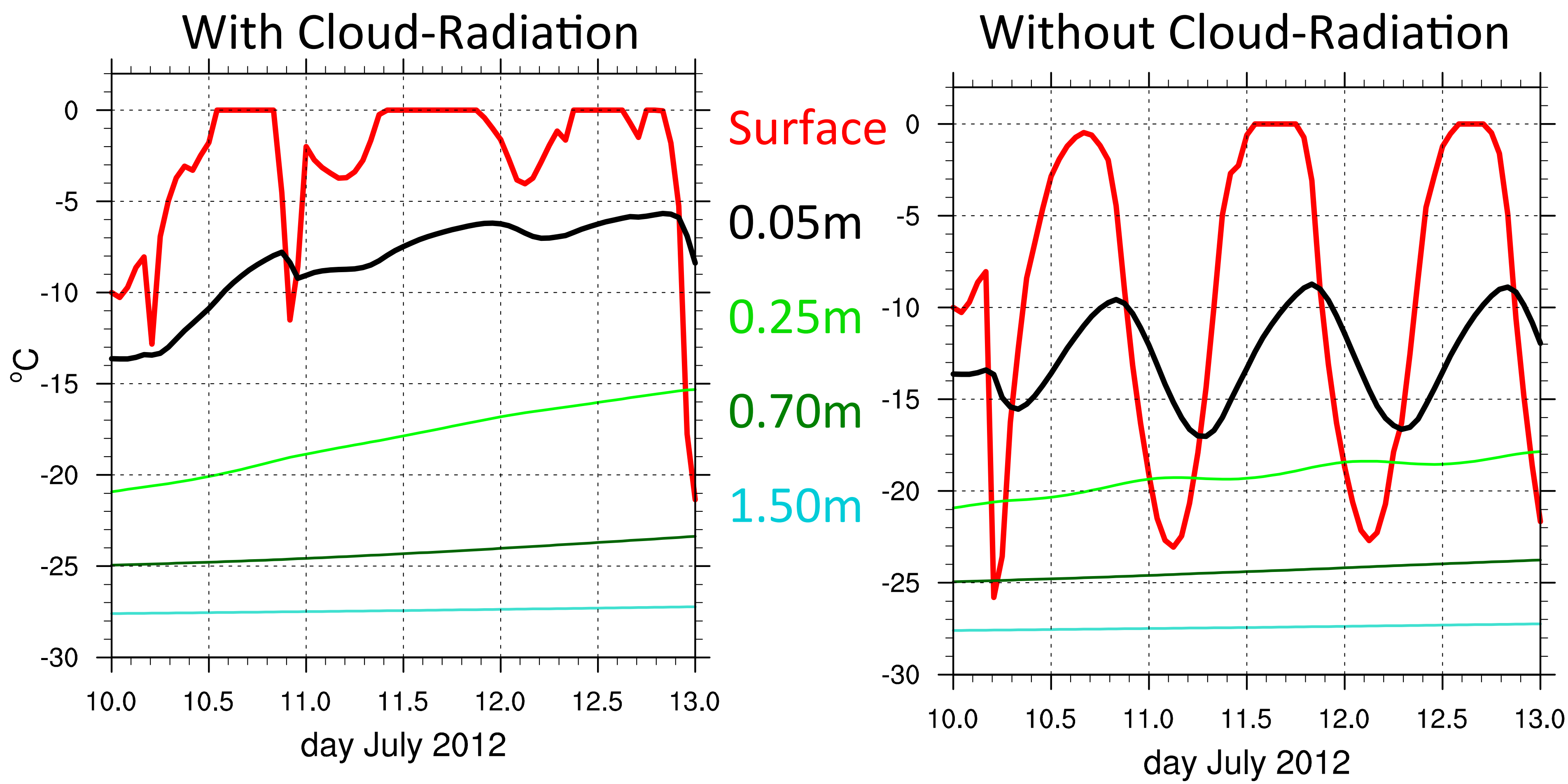


Sensible Heat Fluxes



(Solomon et al. 2015)

Going Beyond Radiative Forcing: Impact on Ice Temperatures



(Solomon et al. 2015)

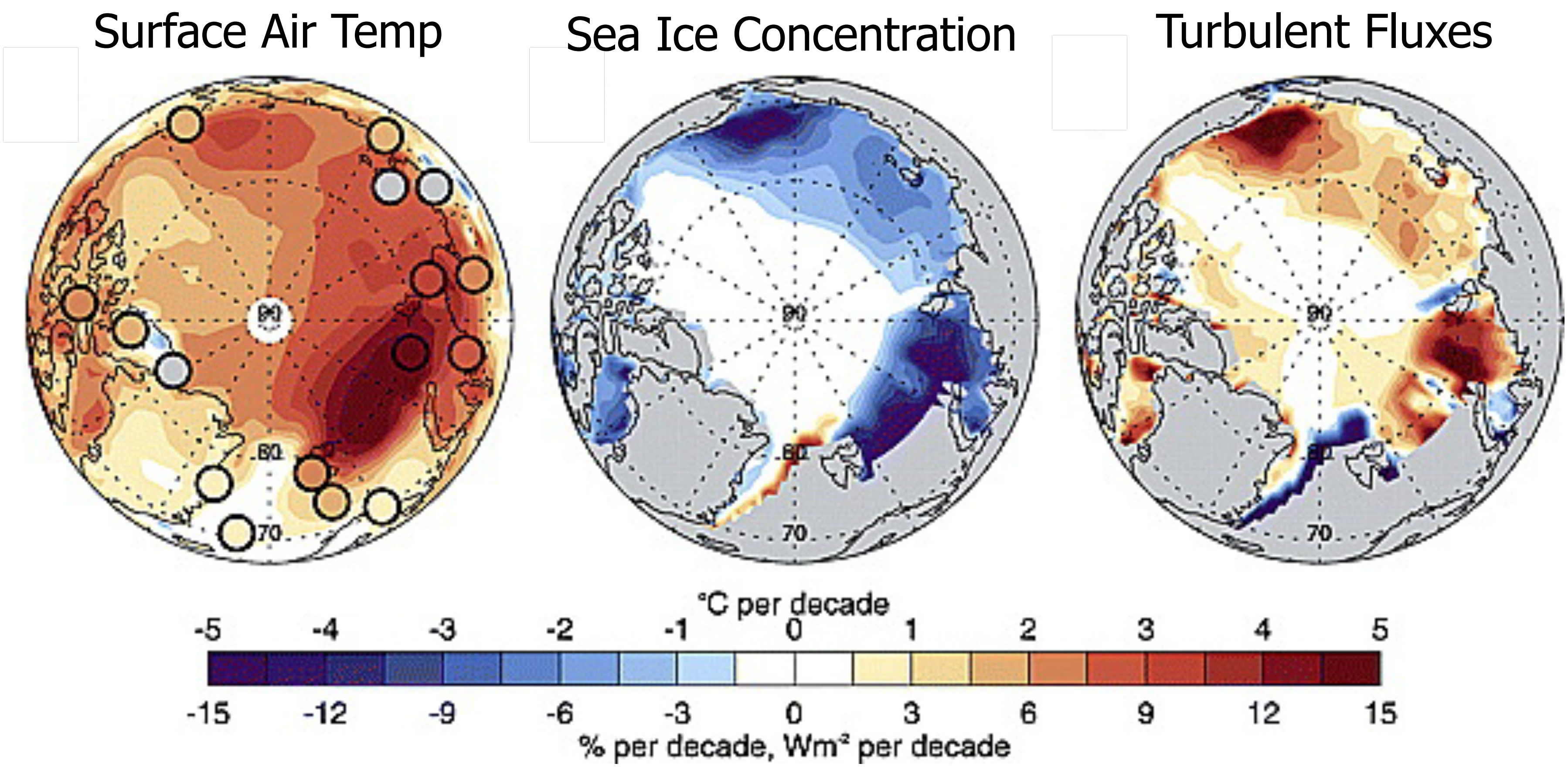
Summary

- Focus of this talk has been on local processes but there are just as many issues related to extrapolar-polar interactions
- Issues partly related to sparsity of observations
- In order to improve our understanding of AA we need to focus on the integrated impact of fast processes
- Need a focused idealized model study to sort out these issues

Extra Slides

Role of Liquid-bearing Clouds

Oct-Jan 1989-2009 trends Using ERA-Interim



(Screen and Simmonds 2010, GRL)