Investigation of Aerosol Effects on the Arctic Surface Temperature during the Diurnal Cycle

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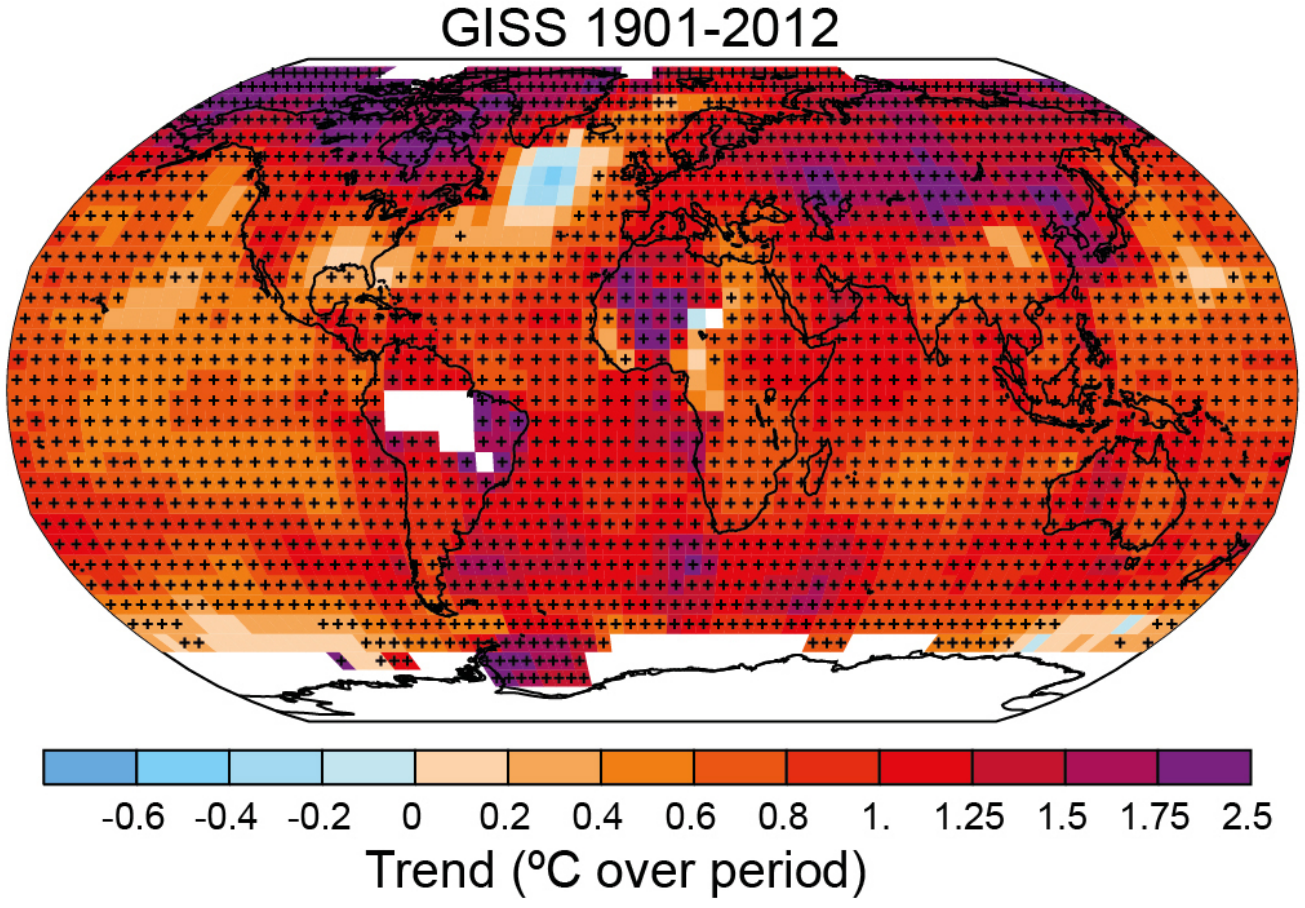
Outline

- Introduction
- Methodology
- Results: Part 1
  - Evaluation
  - Total Aerosol Effect
- Results: Part 2
  - Separating Aerosol Effects
- Conclusions

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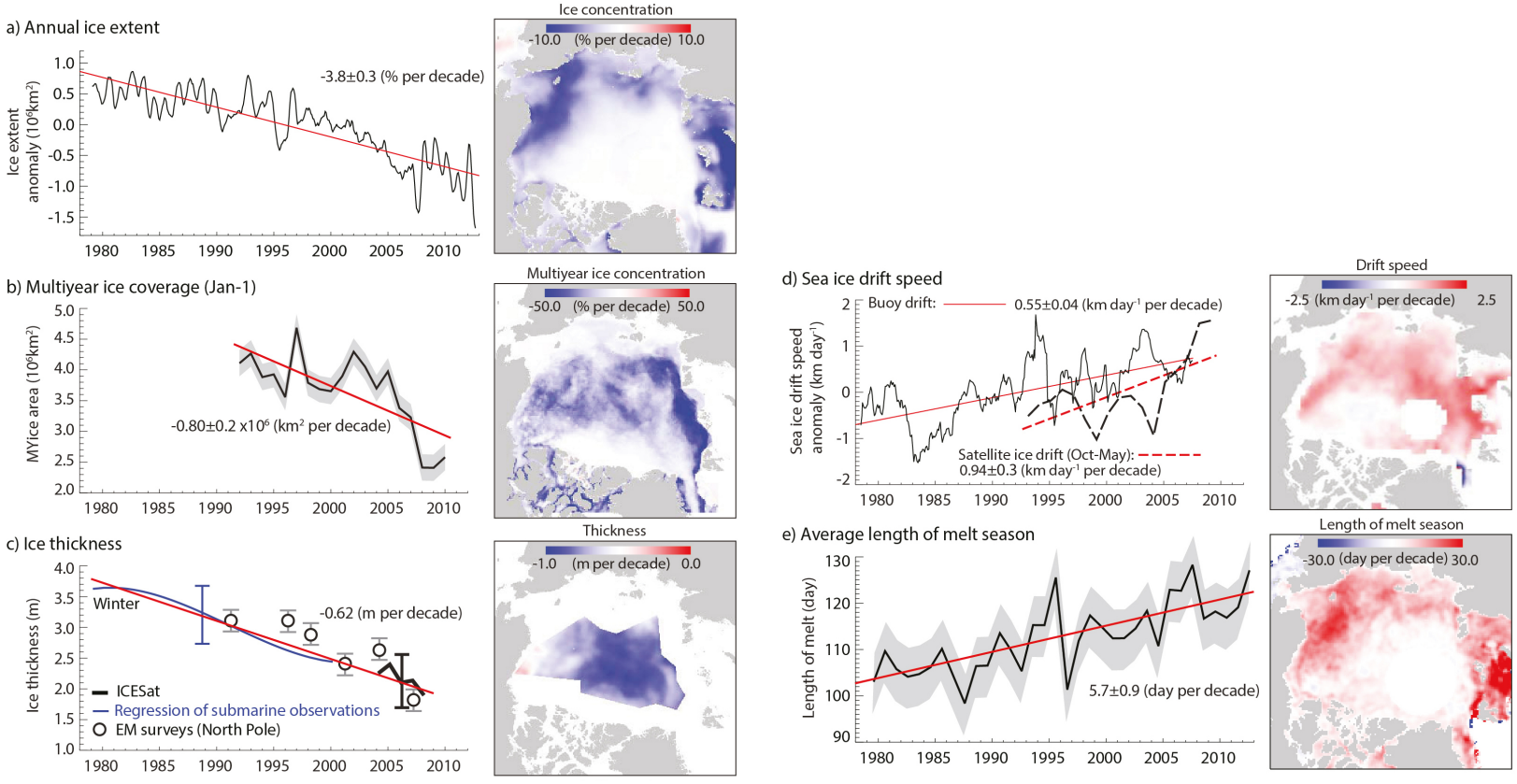
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Map of Trends in Surface Temperature



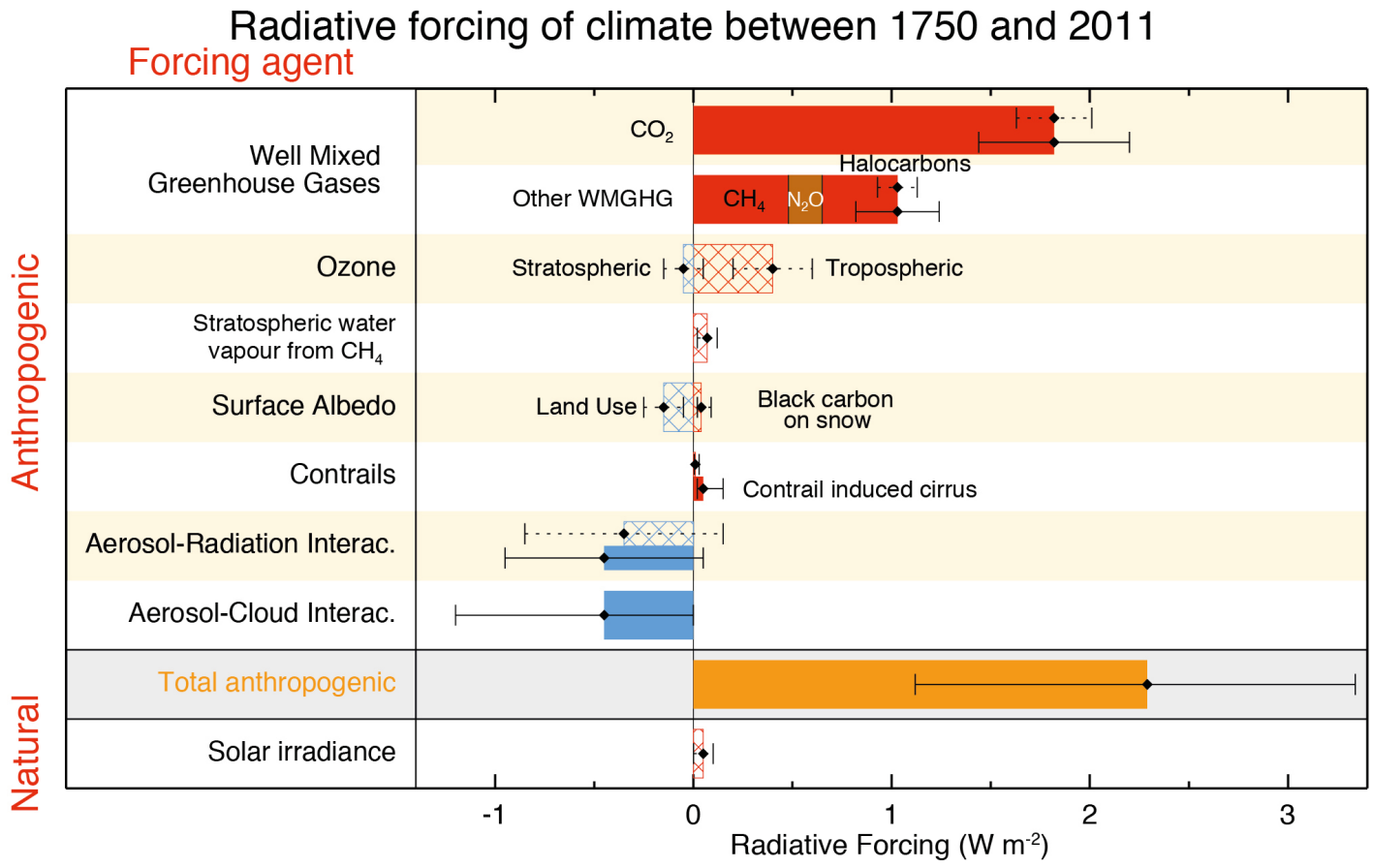
Map of trends in surface temperature for 1901-2012 from GISS.

Trends and Patterns of Sea Ice Changes



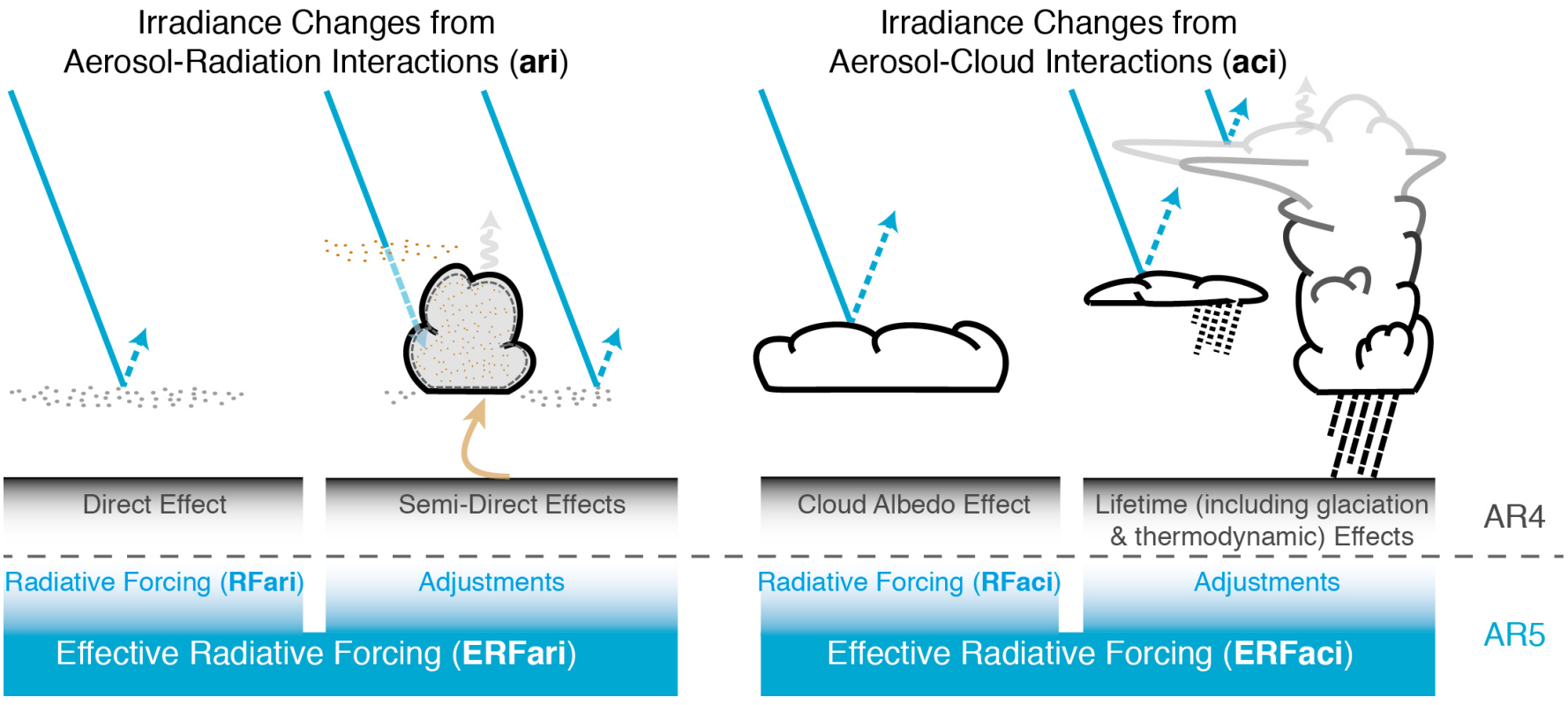
Summary of linear decadal trends and patterns of sea ice extent, multi-year sea ice coverage, sea ice thickness, sea ice drift speed, and length of melt season.

Radiative Forcing Bar Chart



Bar chart of sources for changes in radiative forcing from the 5th IPCC report. Positive forcing (red) and negative forcing (blue) are shown with uncertainty bars.

Schematic of Aerosol Effects



Schematic of aerosol direct, semi-direct, and indirect effects.

Objective

- **Address the uncertainties in the impact of aerosols on the changes in Arctic surface temperature, particularly during the diurnal cycle.**

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WRF-CHEM

- WRF-CHEM is based on WRF, the Weather, Research, and Forecasting Model, a fully compressible mesoscale meteorological model
- Time step, horizontal advection, and vertical advection are discretized in WRF
- WRF includes physics options for clouds and precipitation (microphysics) and radiation
- WRF-CHEM:
  - couples a chemistry package to the base WRF model
  - allows for emissions of gas and aerosol species
  - contains aerosol schemes to simulate full aerosol life cycle
  - modifies microphysics and radiation schemes to account for aerosols

MOSAIC Aerosol Bin Sizes

Bin Sizes		
Bin	**Minimum**	**Maximum**
1	39nm	78nm
2	78nm	156nm
3	156nm	313nm
4	313nm	625nm
5	625nm	1.25μm
6	1.25μm	2.5μm
7	2.5μm	5μm
8	5μm	10μm

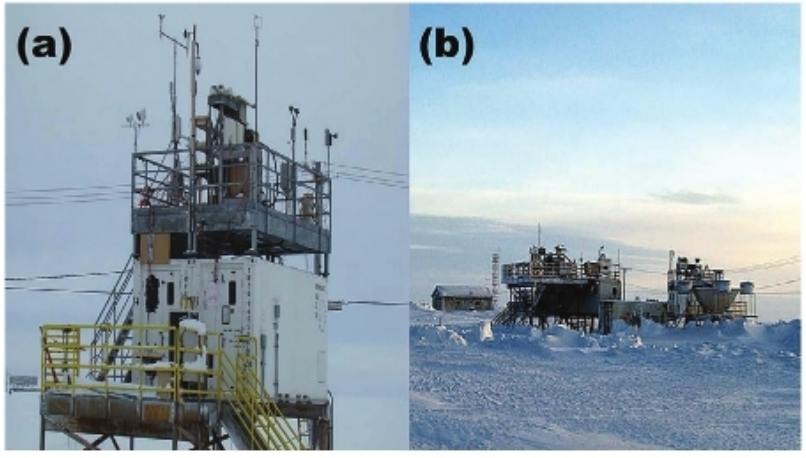
Model Settings for WRF-CHEM 3.1.1

Domain Setup	Description
Horizontal Grid Spacing	10km
Total Domain Size	3000km
Number of Vertical Levels	45
Control Run Start Time	April 15, 2008
Analysis Start Period	April 18, 2008
Analysis End Period	April 21, 2008

WRF Option	Selection
Microphysics	Lin et. al
Shortwave Radiation	Goddard
Longwave Radiation	RRTM
Chemistry Option	CBMZ
Aerosol Scheme	MOSAIC 8 bin
Emissions Option	CBMZ/MOSAIC

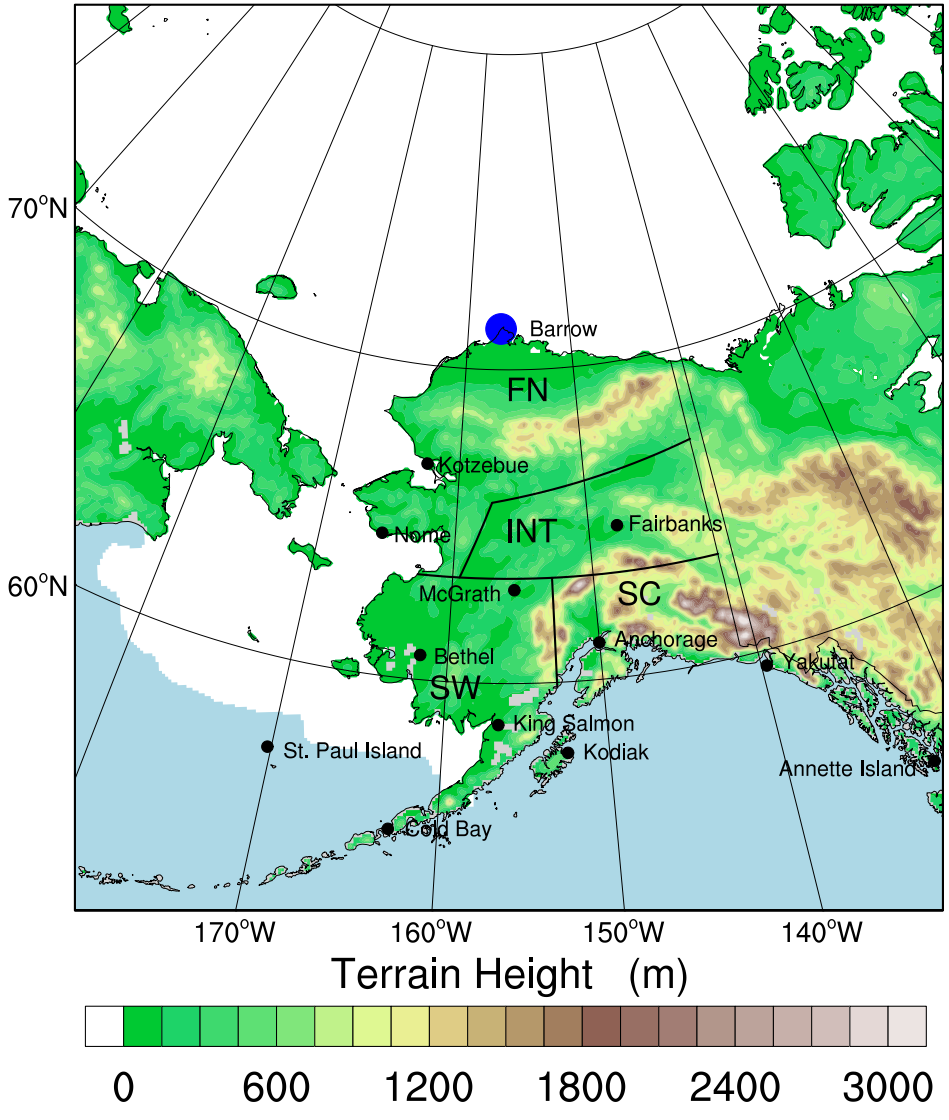
ISDAC

- Indirect and Semi-Direct Aerosol Campaign (ISDAC)
- Location and Date: North Slope of Alaska (NSA) Department of Energy Site, April 2008
- Series of ground and airborne measurements including 27 flights
- ISDAC measurements allow evaluation of model output



Instrumentation from ISDAC at the North Slope of Alaska (NSA) site.
a) ISDAC instruments at 5m height,
b) NSA standard instrumentation

Model Domain, Radiosonde and Surface Locations, and Regional Definitions



Horizontal extent of WRF-CHEM simulation domain along with the terrain height. Also shown, location of sea ice (white), open ocean (light blue), Alaska region boundaries (FN/Far North, INT/Interior, SW/Southwest, SC/South Central), radiosonde and surface observation stations, co-located at 13 airports (black dots), and the DOE NSA site at Barrow (large blue dot).

A summary of the WRF-CHEM model runs

Name of Run	Run Properties
Control Run	Baseline Run with Full Suite of Chemistry Options
NoChem	Chemistry Option Turned Off, No Aerosol Effects
Ensemble 1-6	Baseline Runs starting at April 14 (00Z, 06Z, 12Z, 18Z), 2008 and April 15 (06Z, 12Z), 2008
NoAerRad	No Direct Aerosol Impact on Radiation
NoAerRadorBC	No Direct or Semi-Direct Aerosol Impact on Radiation
BC0	Black Carbon Eliminated from Emissions, Initial and Boundary Conditions

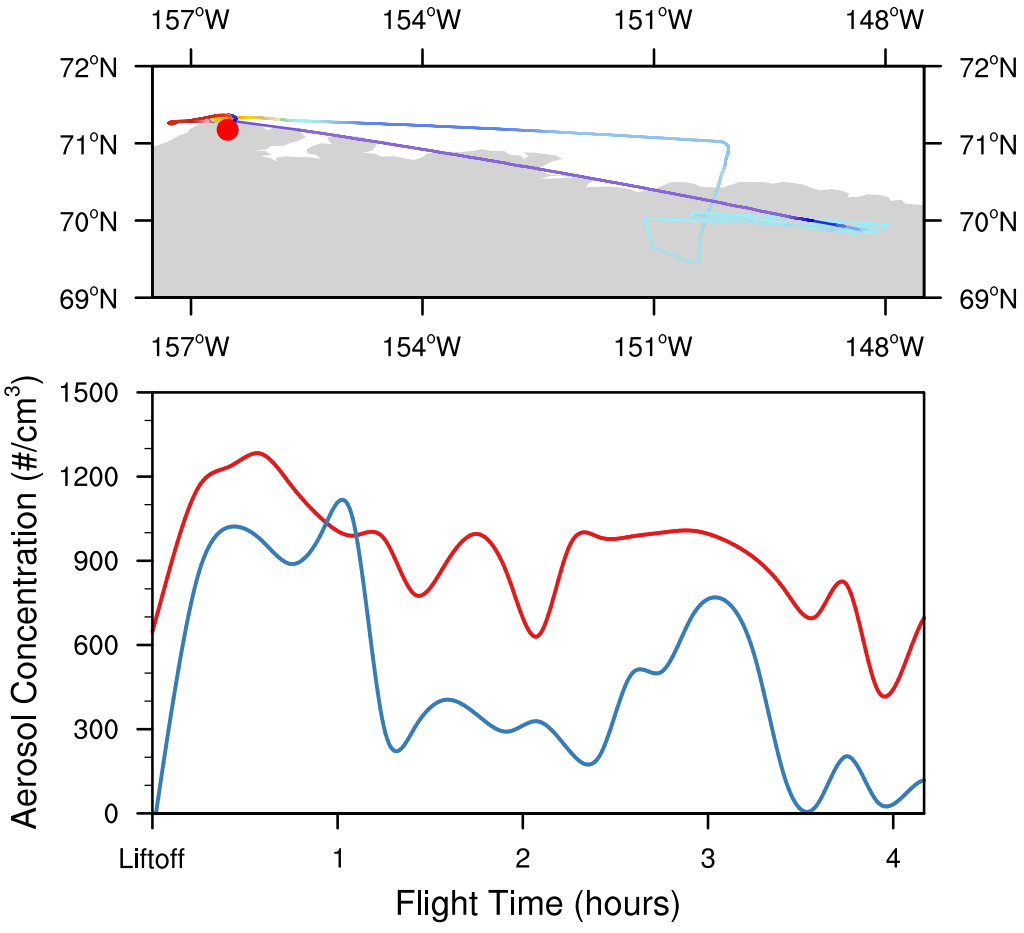
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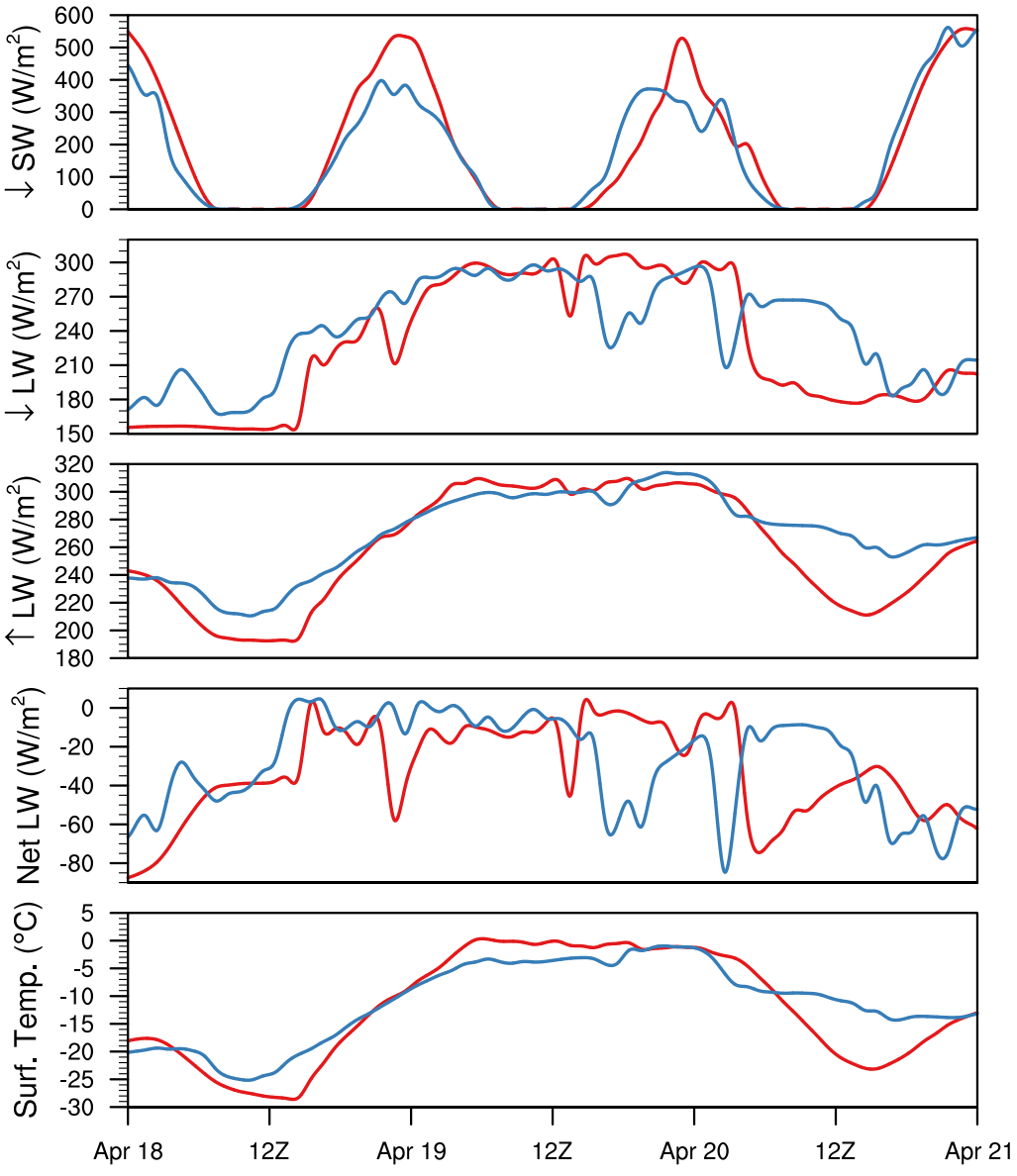
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Flight 23 Path and Aerosol Number Concentration



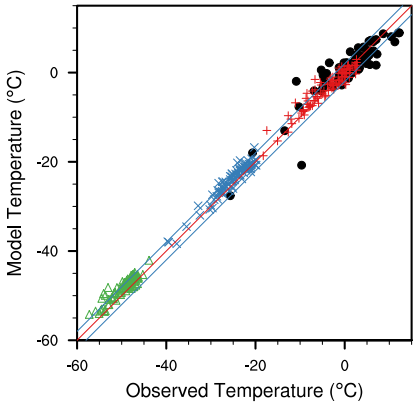
ISDAC Flight 23 path (top panel) which departed at 8:15pm on April 18th, 2008 and aerosol number concentration (bottom panel) for that flight. In the top panel, the multi-colored curve (red and orange - low altitude, cyan - middle altitude, dark blue and purple - high altitude) shows the horizontal flight path from Barrow (red circle). For the bottom panel, the Control Run aerosol number concentration (red) and flight data (blue) are averaged over 10 minute intervals.

Radiation and Surface Temperature at Barrow

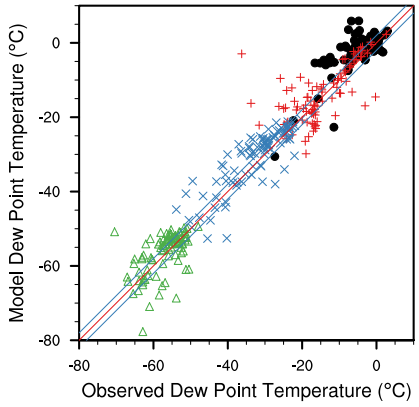


Downward shortwave radiation (top), downward longwave radiation (second), upward longwave radiation (third), net longwave radiation (fourth), and surface temperature (bottom) comparisons at Barrow from April 18th to April 21st, 2008. Control Run hourly output (red) and hourly averaged observations at Barrow (blue).

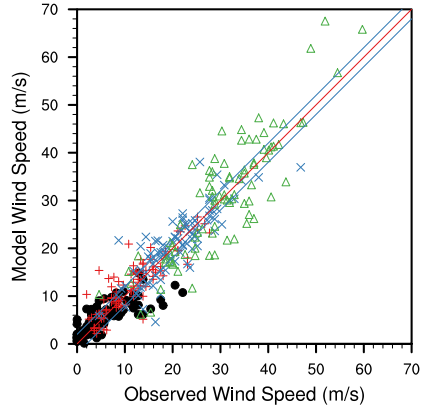
Scatter Plots and Statistics



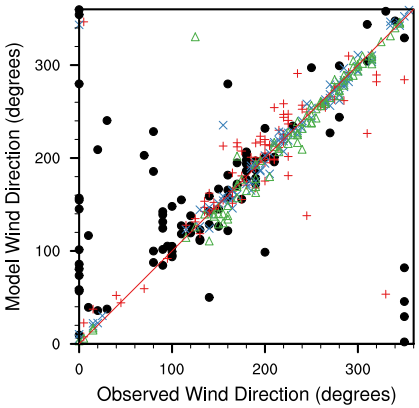
	NP	ME	MAE	RMSE
Surface	91	0.07	1.67	2.48
850 mb	90	0.40	1.19	1.59
500 mb	91	1.10	1.27	1.54
300 mb	74	1.58	1.67	2.56



	NP	ME	MAE	RMSE
Surface	91	2.45	3.23	4.54
850 mb	90	1.02	4.21	6.41
500 mb	91	1.77	3.54	4.73
300 mb	74	0.48	3.44	4.86



	NP	ME	MAE	RMSE
Surface	91	-0.18	2.17	3.13
850 mb	90	0.75	2.33	3.18
500 mb	91	0.03	2.89	3.94
300 mb	74	0.18	4.81	6.18



	NP	ME	MAE	RMSE
Surface	91	21.60	60.21	106.60
850 mb	90	3.09	23.25	52.50
500 mb	91	2.82	10.99	37.82
300 mb	74	-2.76	10.14	24.74

Scatter plots of temperature (top left), dew point temperature (top right), wind speed (bottom left), and wind direction (bottom right), Control Run vs observations, for 4 vertical levels: surface (black dot), 850 mb (red cross), 500 mb (blue x), and 300mb (green triangle). The red line indicates agreement between the model and the observation while the blue lines indicate agreement within 2 °C (temperature, dew point temperature) or 2 m s^{-1} (wind speed). Below each plot, the table of statistics shows the number of points (NP), the mean error (ME), the mean absolute error (MAE), and the root mean square error (RMSE) at each level.

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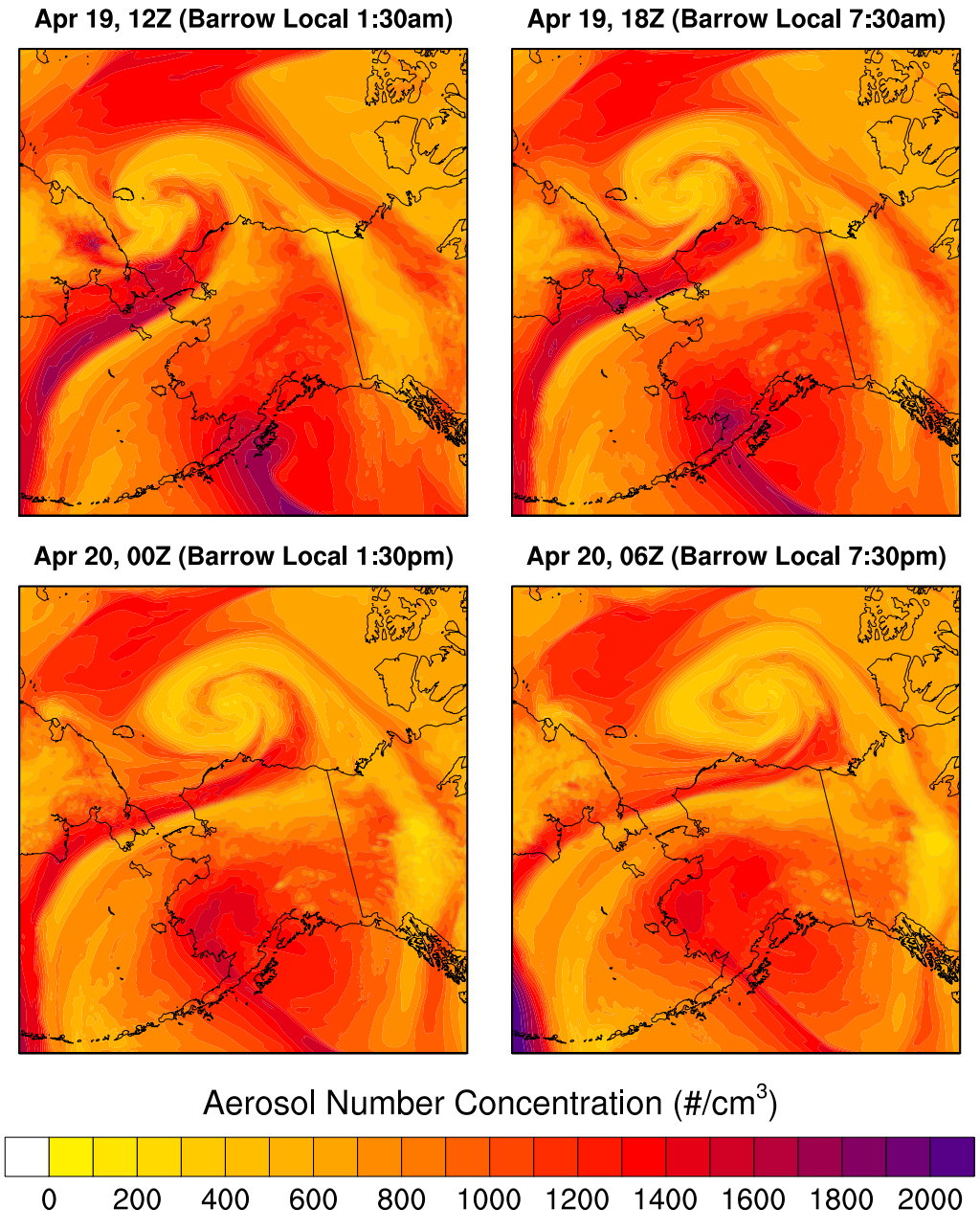
Statistics

$$T = \frac{\bar{C} - w}{\hat{\sigma}\sqrt{1 + \frac{1}{E}}}$$

$$\hat{\sigma}^2 = \frac{1}{E-1}\sum_{e=1}^{E}(C_e - \bar{C})^2$$

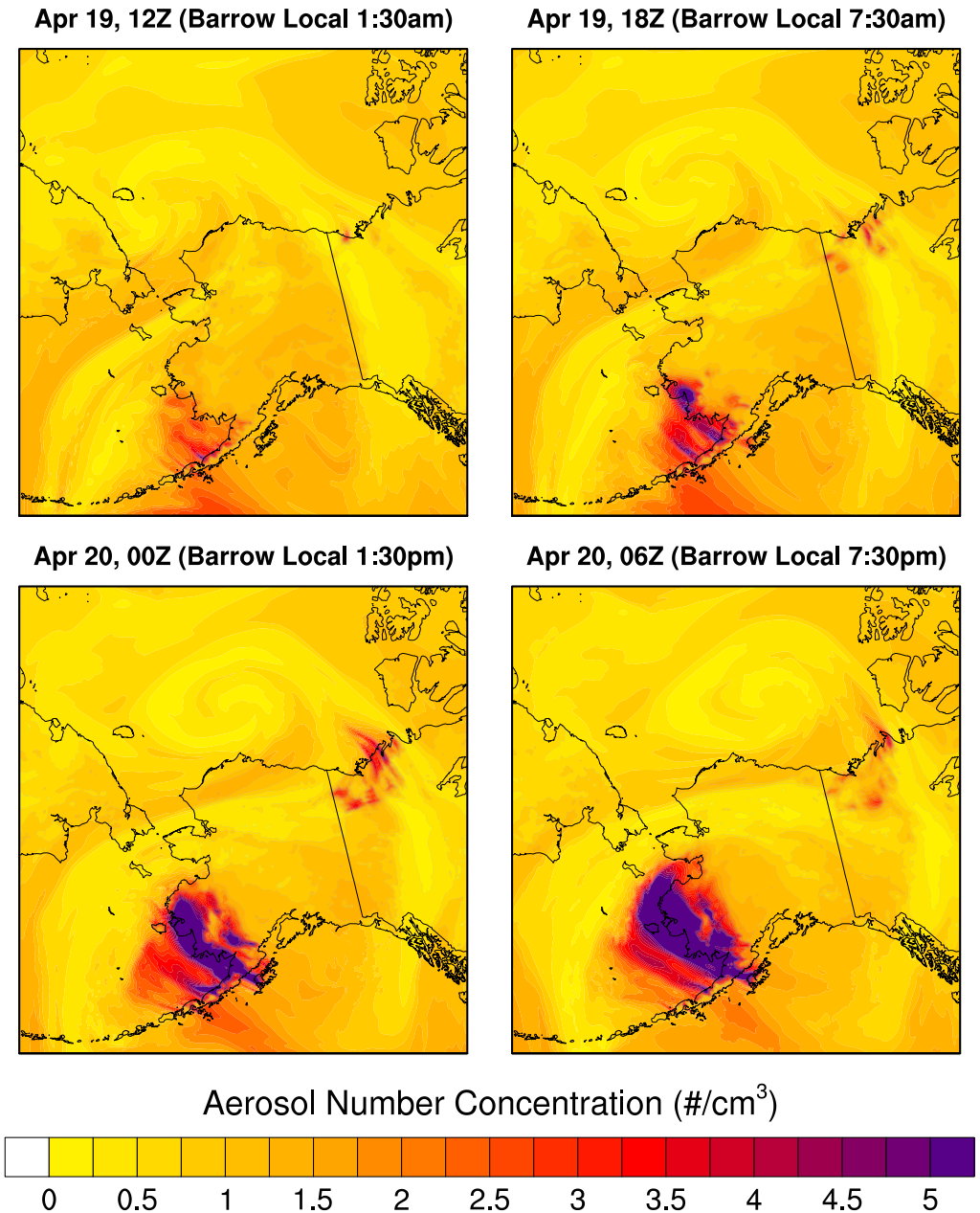
T - test statistic
$\bar{C}$ - ensemble mean
w - NoChem mean
E - number of ensemble members
$\hat{\sigma}^2$ - sample variance
C_e - ensemble member value

Aerosol Number Concentration - Fine



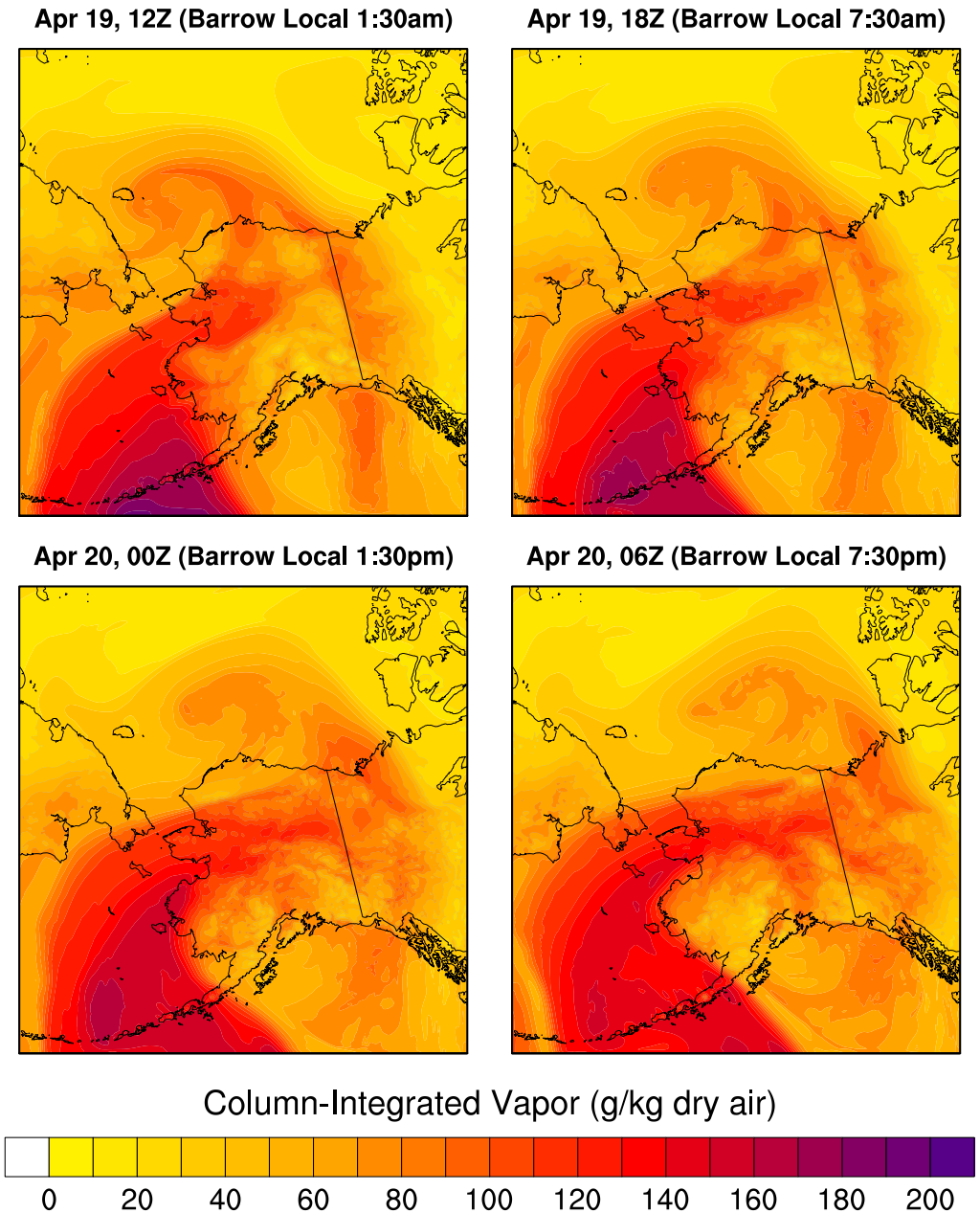
Column-averaged fine aerosol number concentration (Bins 1-5) from the Control Run for the study domain at four different times during the diurnal cycle of April 19-20, 2008.

Aerosol Number Concentration - Coarse



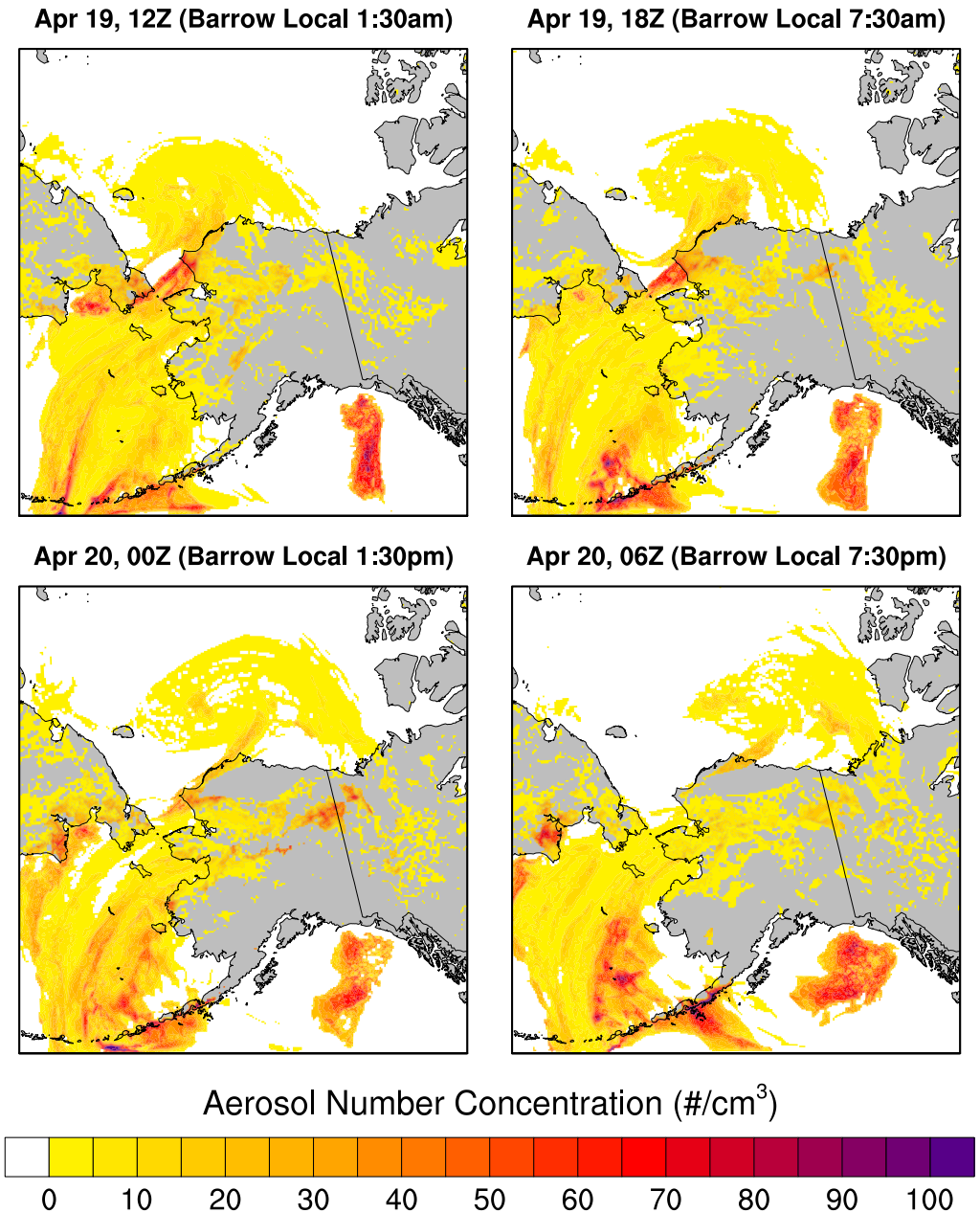
Column-averaged coarse aerosol number concentration (Bins 6-8) from the Control Run for the study domain at four different times during the diurnal cycle of April 19-20, 2008.

Total Column Vapor



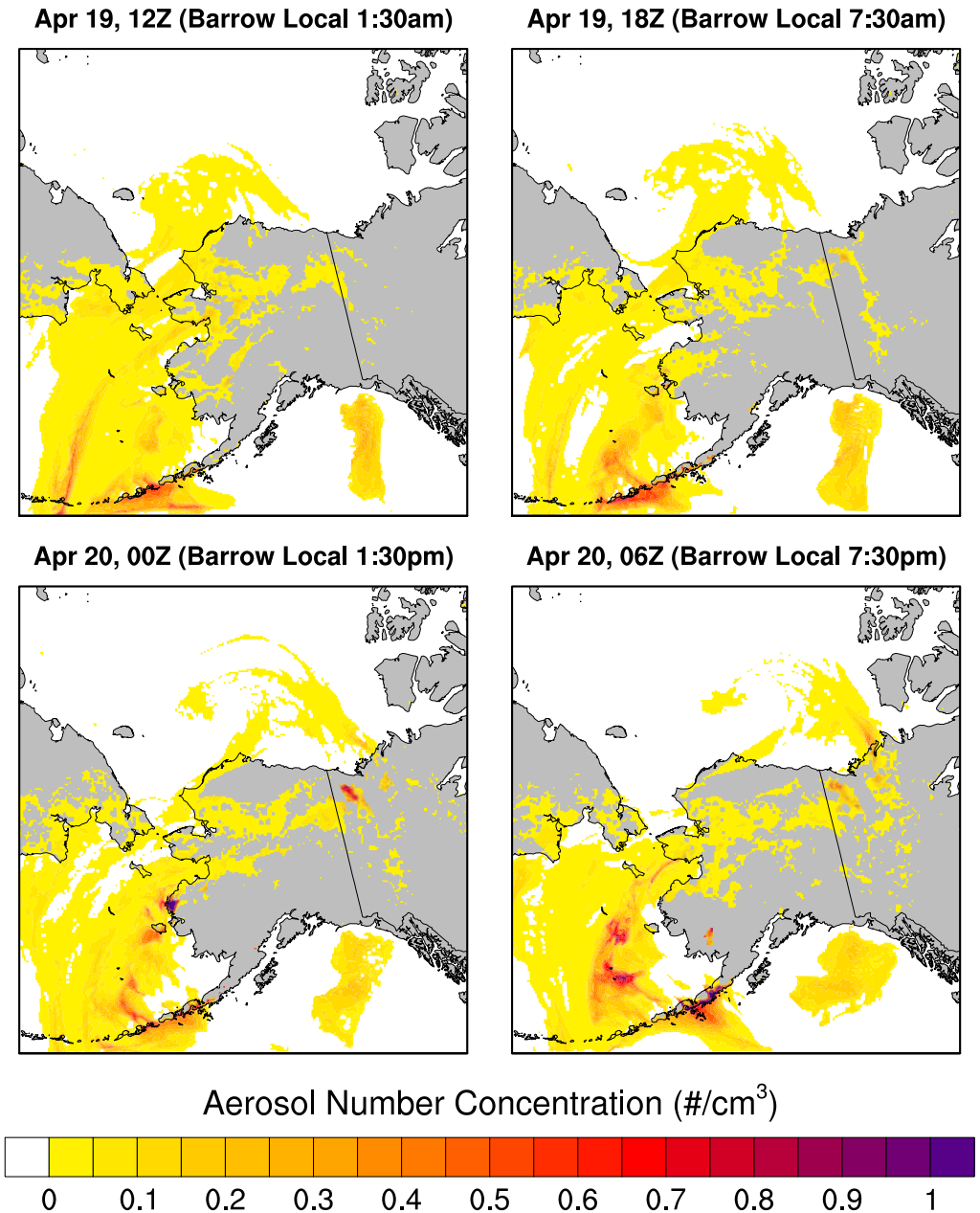
Column-integrated water vapor concentration from the Control Run for the study domain at four different times during the diurnal cycle of April 19-20, 2008.

Aerosol Number Concentration of CCN - Fine



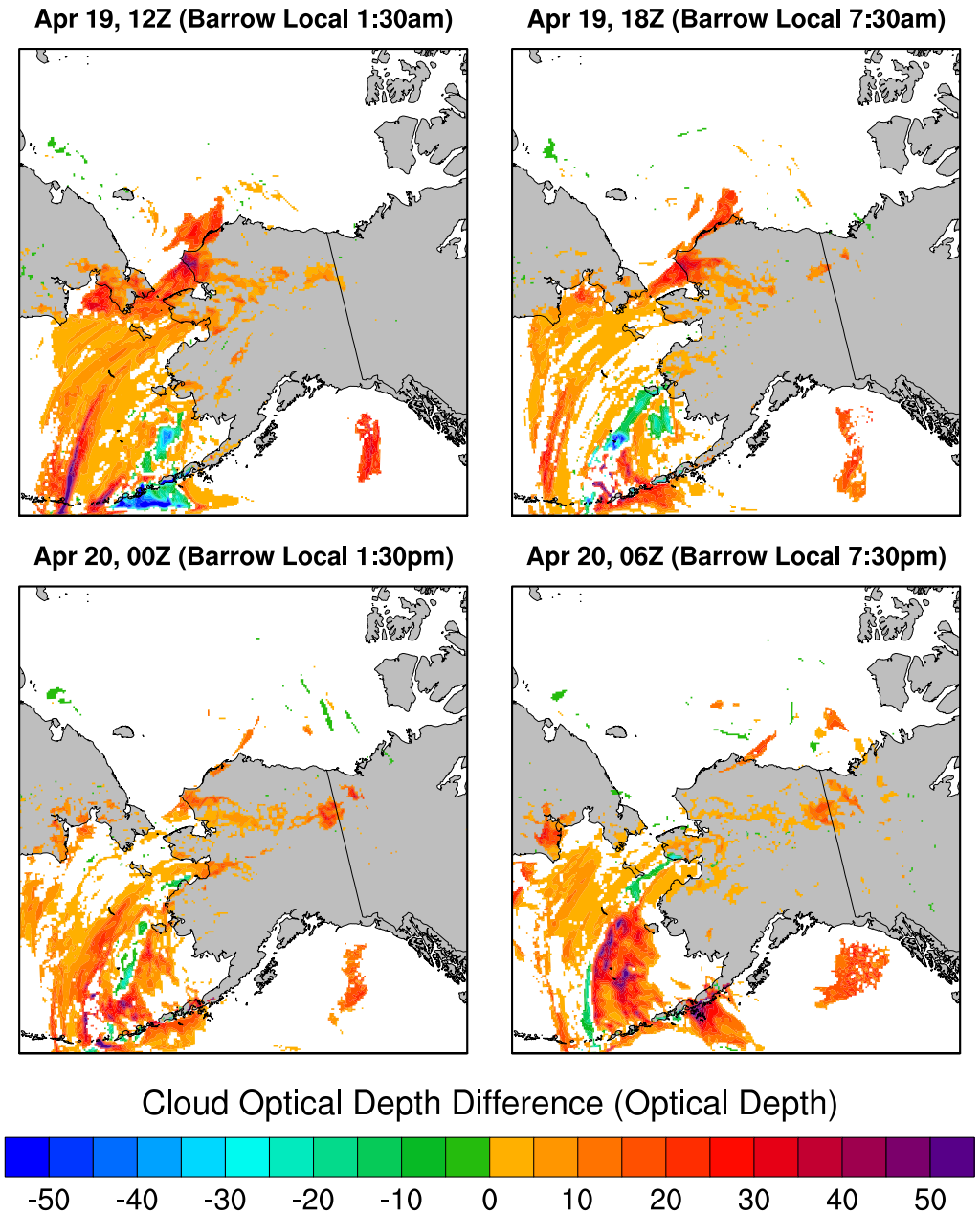
Column-averaged fine aerosol number concentration of CCN (Bins 1-5) from the Control Run for the study domain at four different times during the diurnal cycle of April 19-20, 2008.

Aerosol Number Concentration of CCN - Coarse



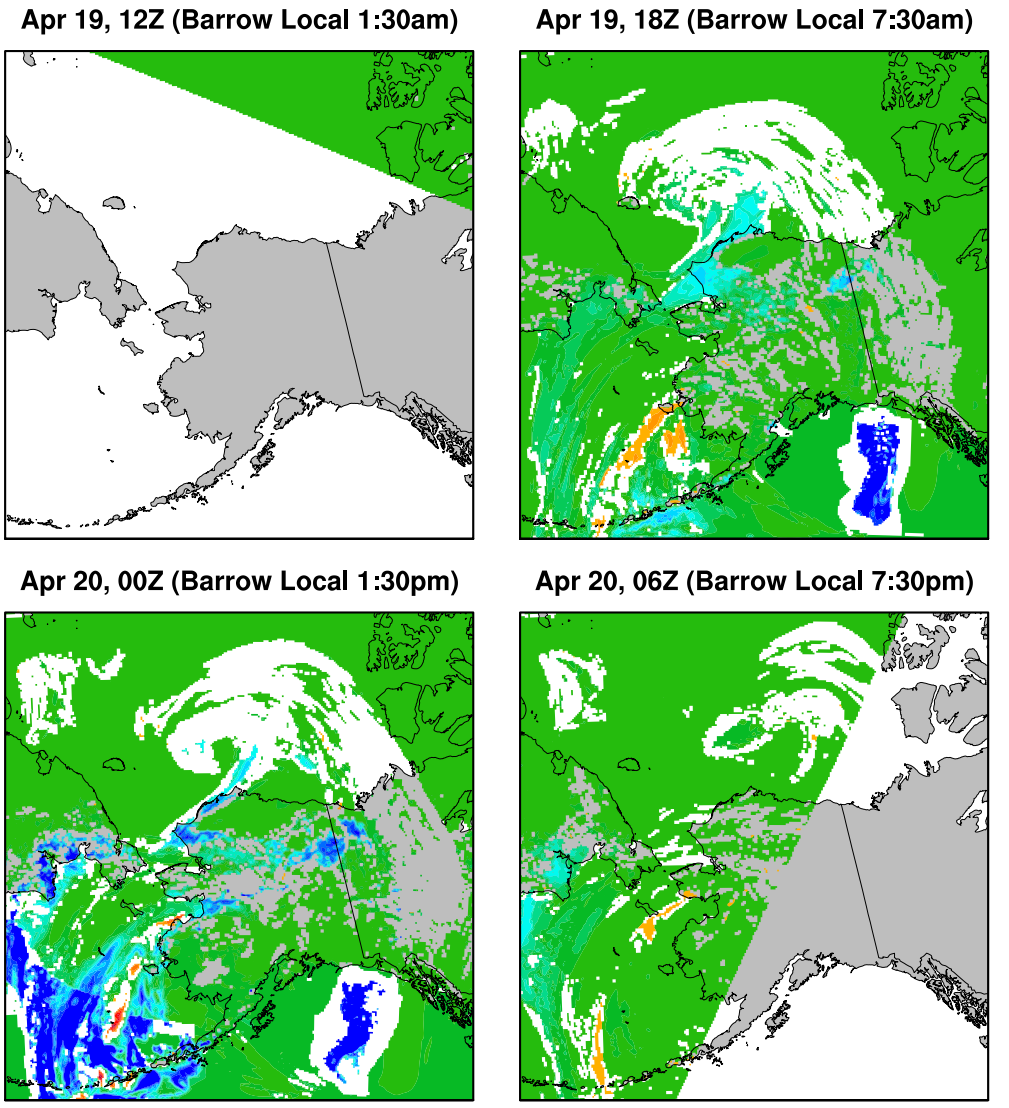
Column-averaged coarse aerosol number concentration of CCN (Bins 6-8) from the Control Run for the study domain at four different times during the diurnal cycle of April 19-20, 2008.

Cloud Optical Depth



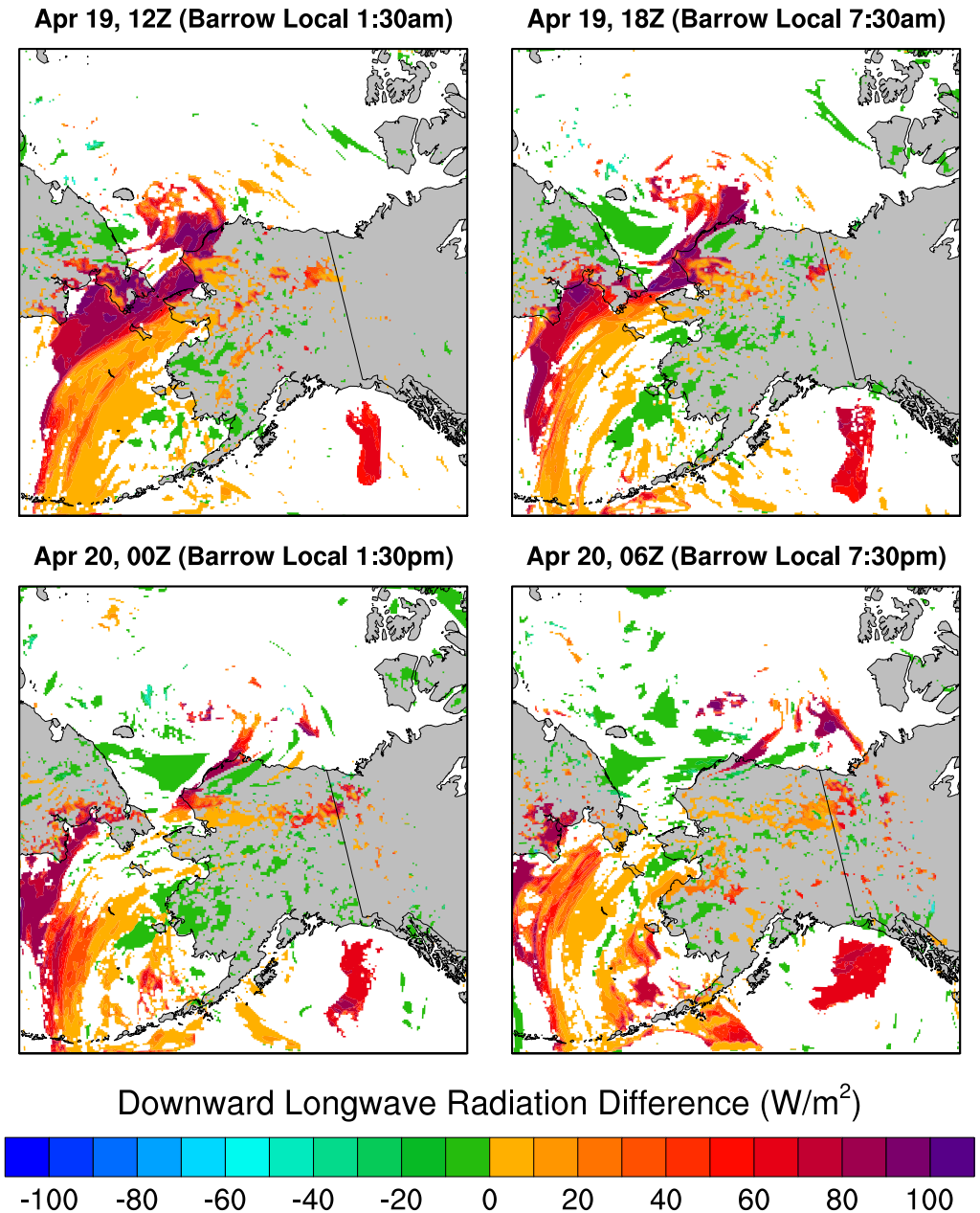
Cloud optical depth difference between the Control Run and the NoChem run for the study area, with cells of low T value filtered out ("masked") at four different times during the diurnal cycle of April 19-20, 2008.

Downward Shortwave Radiation



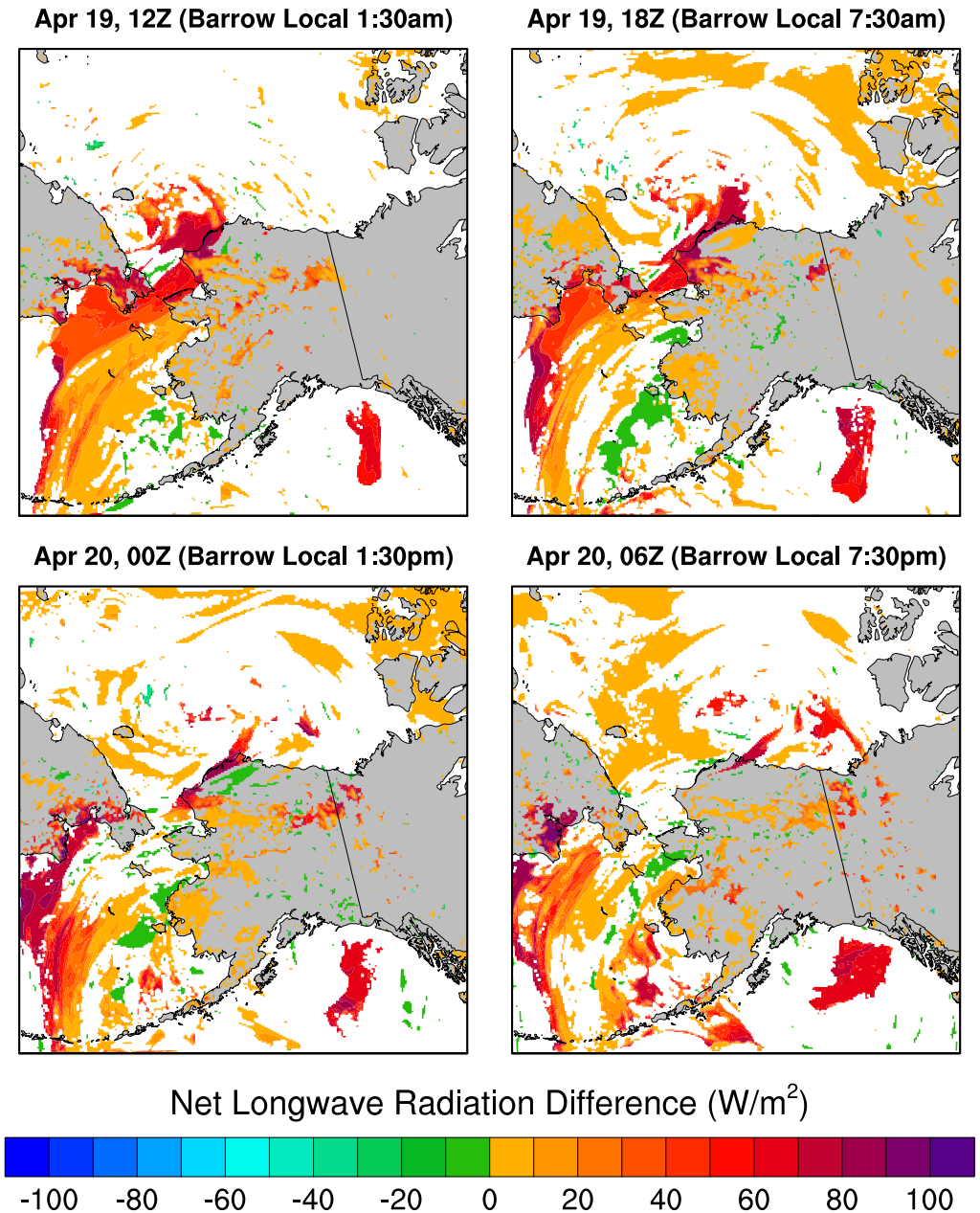
Downward shortwave radiation difference between the Control Run and the NoChem run for the study area, with cells of low T value filtered out ("masked") at four different times during the diurnal cycle of April 19-20, 2008.

Downward Longwave Radiation



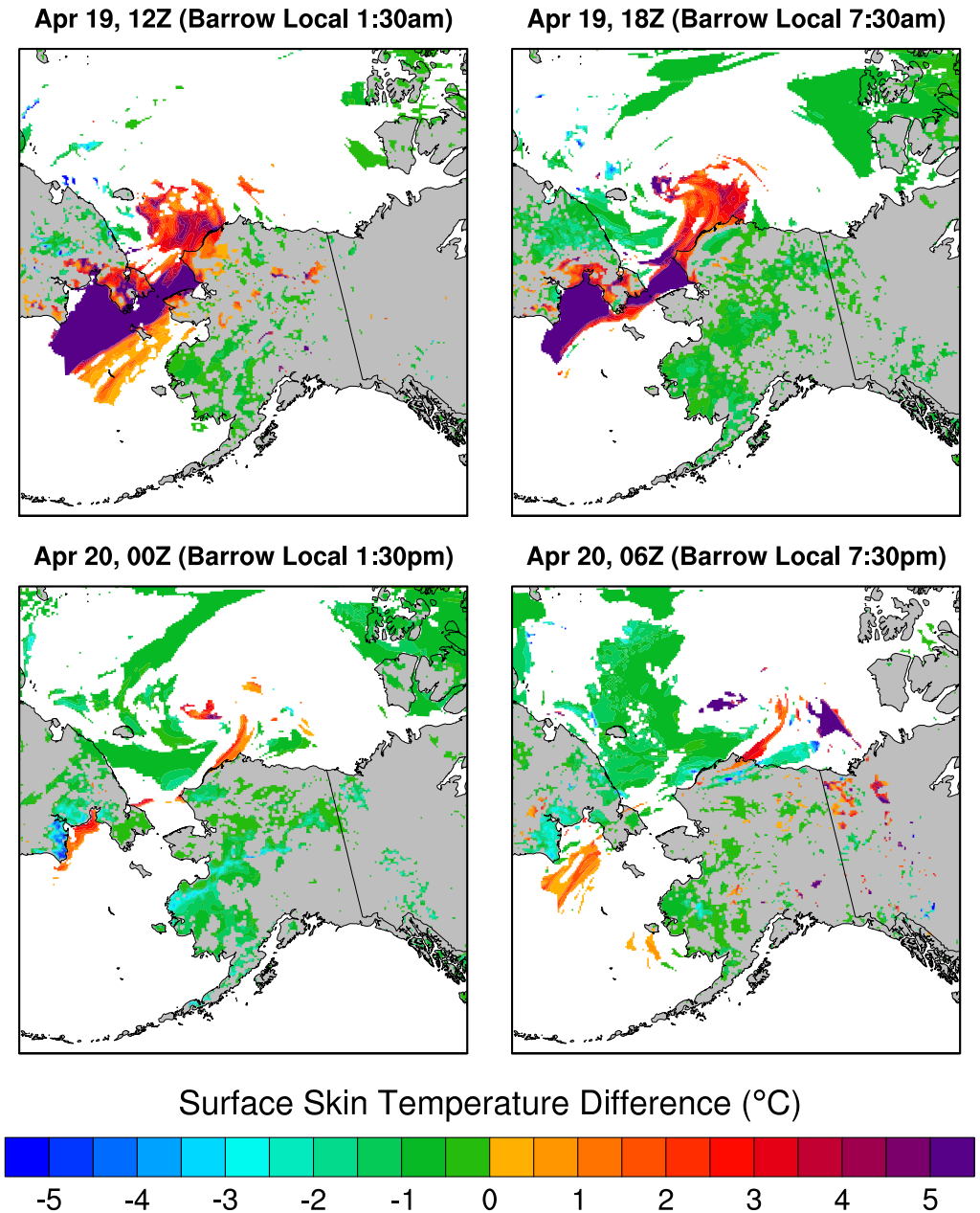
Downward longwave radiation difference between the Control Run and the NoChem run for the study area, with cells of low T value filtered out ("masked") at four different times during the diurnal cycle of April 19-20, 2008.

Net Longwave Radiation



Net longwave radiation difference between the Control Run and the NoChem run for the study area, with cells of low T value filtered out ("masked") at four different times during the diurnal cycle of April 19-20, 2008.

Surface Temperature



Surface temperature difference between the Control Run and the NoChem run for the study area, with cells of low T value filtered out ("masked") at four different times during the diurnal cycle of April 19-20, 2008.

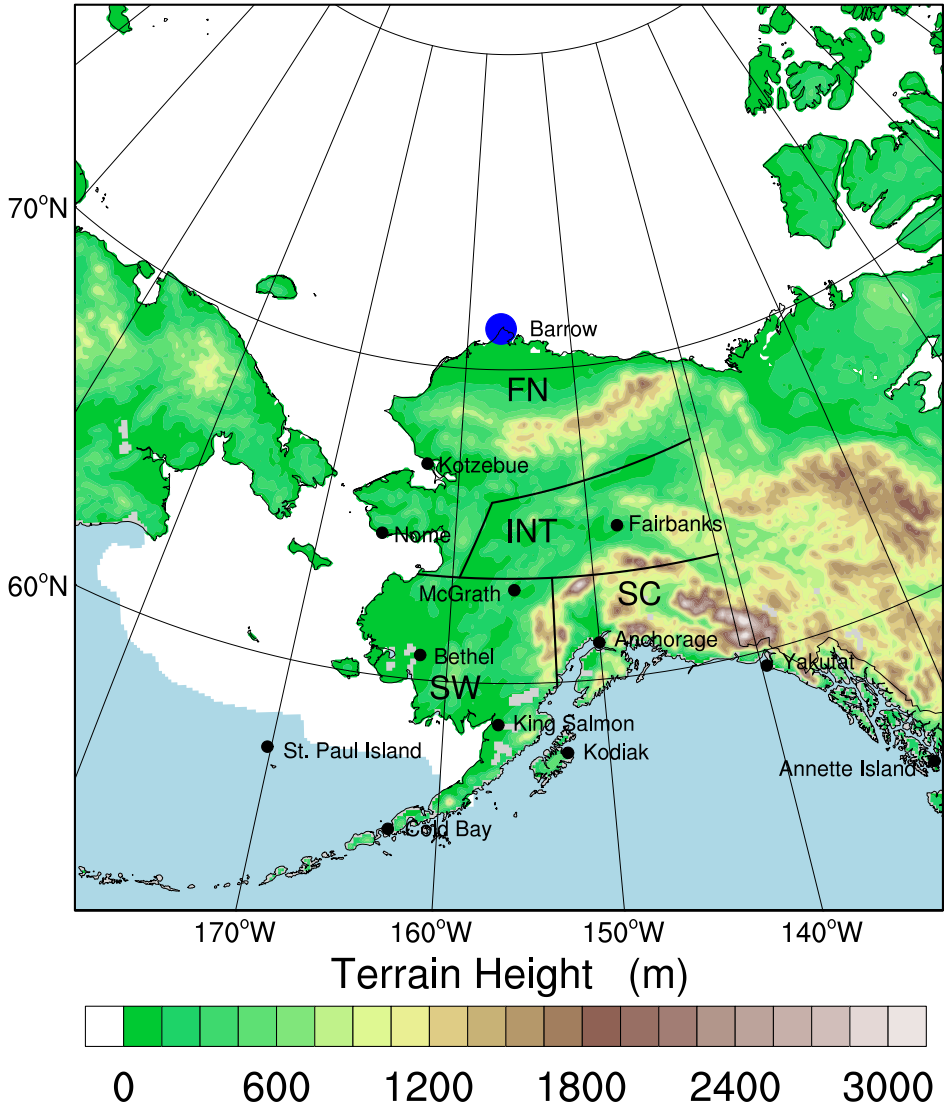
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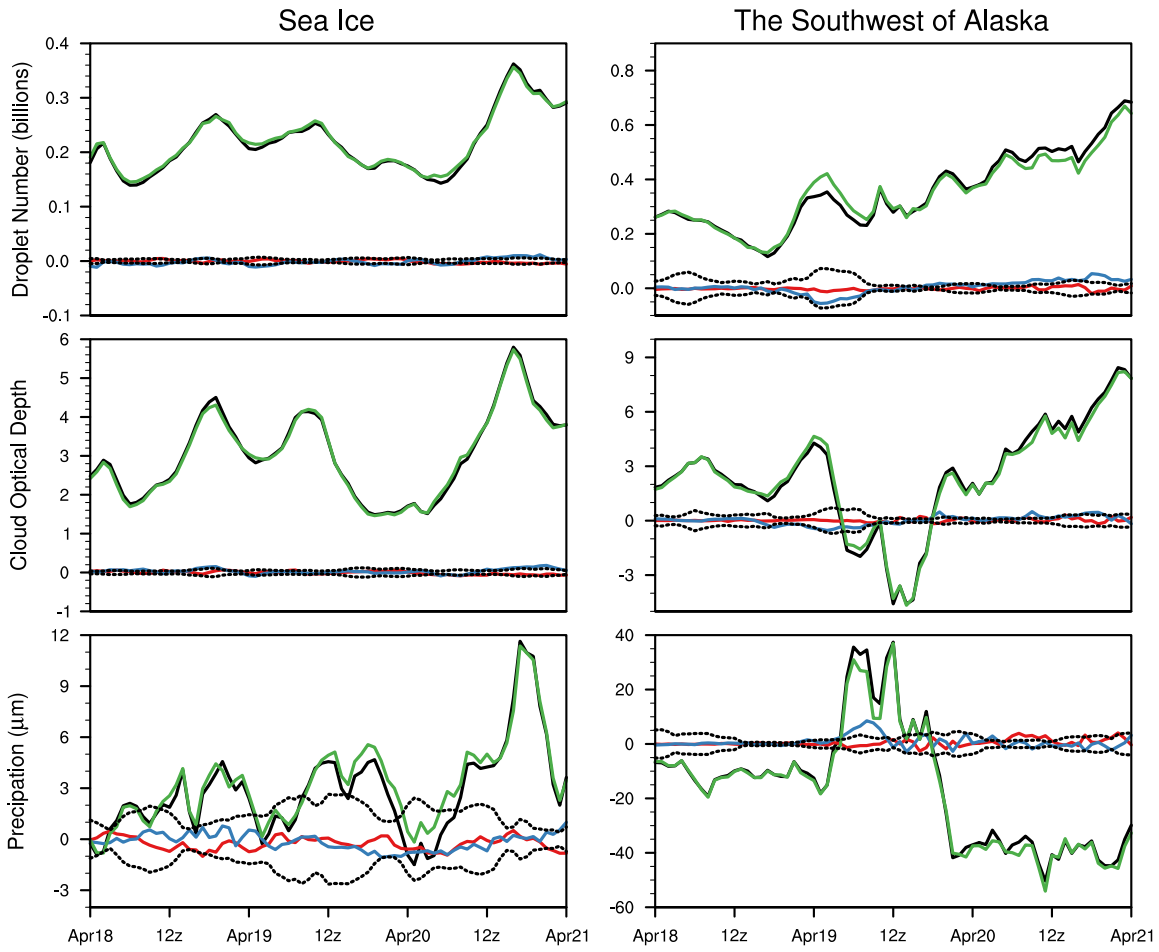
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Model Domain, Radiosonde and Surface Locations, and Regional Definitions



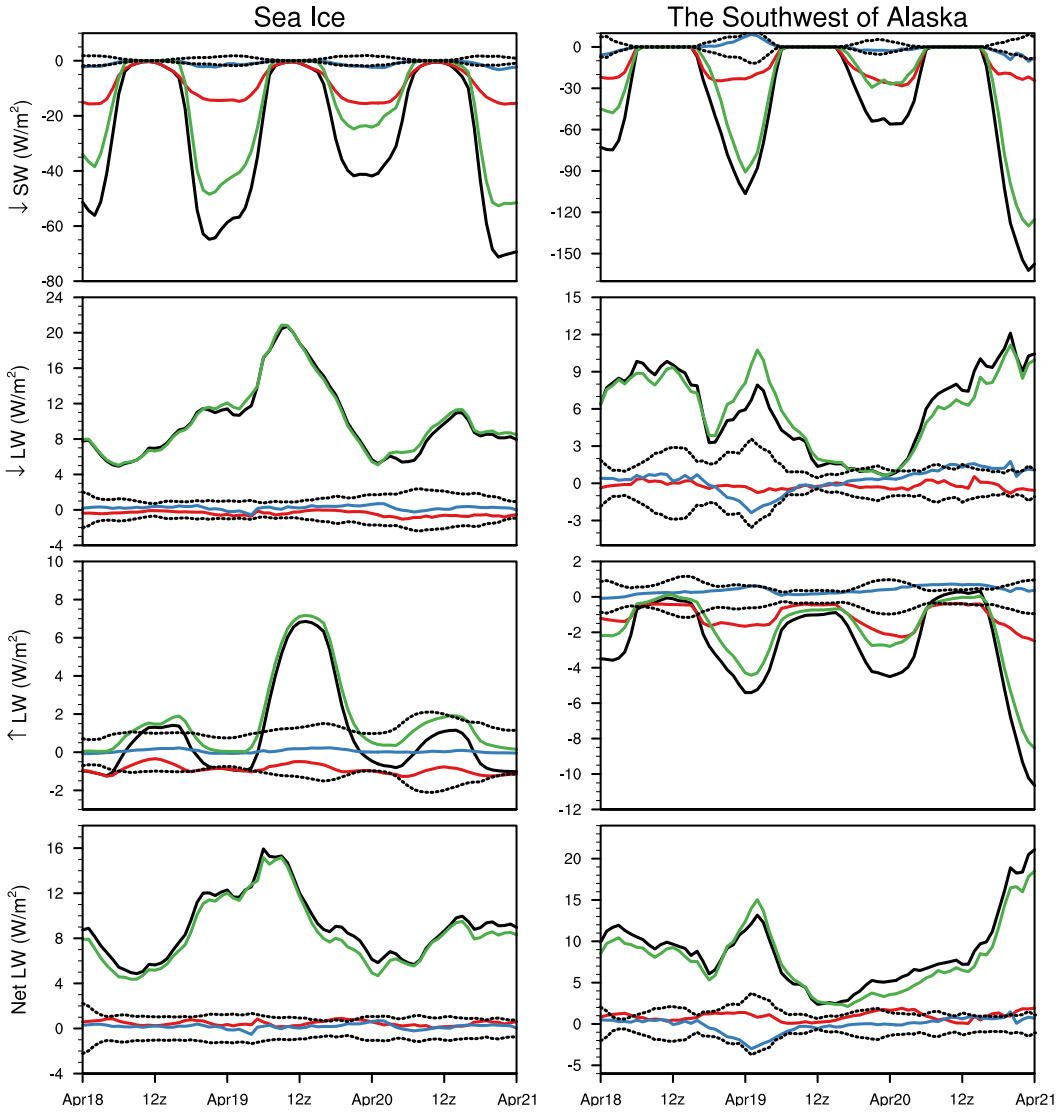
Horizontal extent of WRF-CHEM simulation domain along with the terrain height. Also shown, location of sea ice (white), open ocean (light blue), Alaska region boundaries (FN/Far North, INT/Interior, SW/Southwest, SC/South Central), radiosonde and surface observation stations, co-located at 13 airports (black dots), and the DOE NSA site at Barrow (large blue dot).

Cloud Time Series



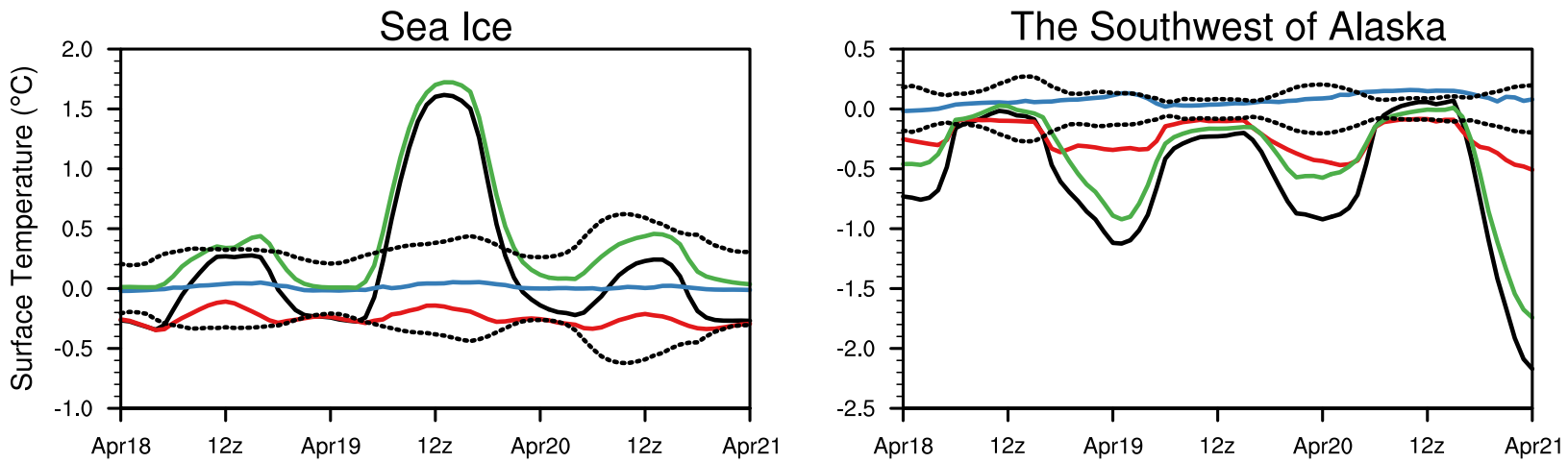
Droplet number (top), cloud optical depth (middle), and precipitation (bottom) changes broken down by aerosol effect over the sea ice (left column) and Southwest Alaska (right column) for the period April 18th to April 21st. The total aerosol effect (black), direct effect (red), semi-direct effect (blue), and indirect effects (green) are shown with the 95% confidence interval (dashed black).

Radiation Time Series



Downward shortwave radiation (top), downward longwave radiation (second), upward longwave radiation (third), and net longwave radiation (bottom) changes broken down by aerosol effect over the sea ice (left column) and Southwest Alaska (right column) for the period April 18th to April 21st. The total aerosol effect (black), direct effect (red), semi-direct effect (blue), and indirect effects (green) are shown with the 95% confidence interval (dashed black).

Temperature Time Series



Surface temperature changes broken down by aerosol effect over the sea ice (left column) and Southwest Alaska (right column) for the period April 18th to April 21st. The total aerosol effect (black), direct effect (red), semi-direct effect (blue), and indirect effects (green) are shown with the 95% confidence interval (dashed black).

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Conclusions

- Aerosol effect on Arctic surface temperature varies during the diurnal cycle
- Aerosol effect depends upon aerosol loading, moisture, and underlying surface properties
- Surface temperature changes due almost exclusively to aerosol indirect effects
- Strong warming over sea ice at night
- Cooling over land regions during the day

Table: Summary of aerosol effects on surface temperature

	Land		Sea Ice	
	Day	Night	Day	Night
Direct Effect Impact	Low	Negligible	Low	Negligible
Semi-Direct Effect Impact	Negligible	Negligible	Negligible	Negligible
Indirect Effects Impact	High	Low	Low	High
Cloud Optical Depth Impact	High	Low	Low	High
Downward Shortwave Impact	High	Negligible	High	Negligible
Downward Longwave Impact	Low	Low	Low	High
Effect on Surface Temperature	Strong Cooling	Weak Warming	Weak Cooling	Strong Warming