Influence of the Laurentian Great Lakes on Regional Climate

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Computational Resources

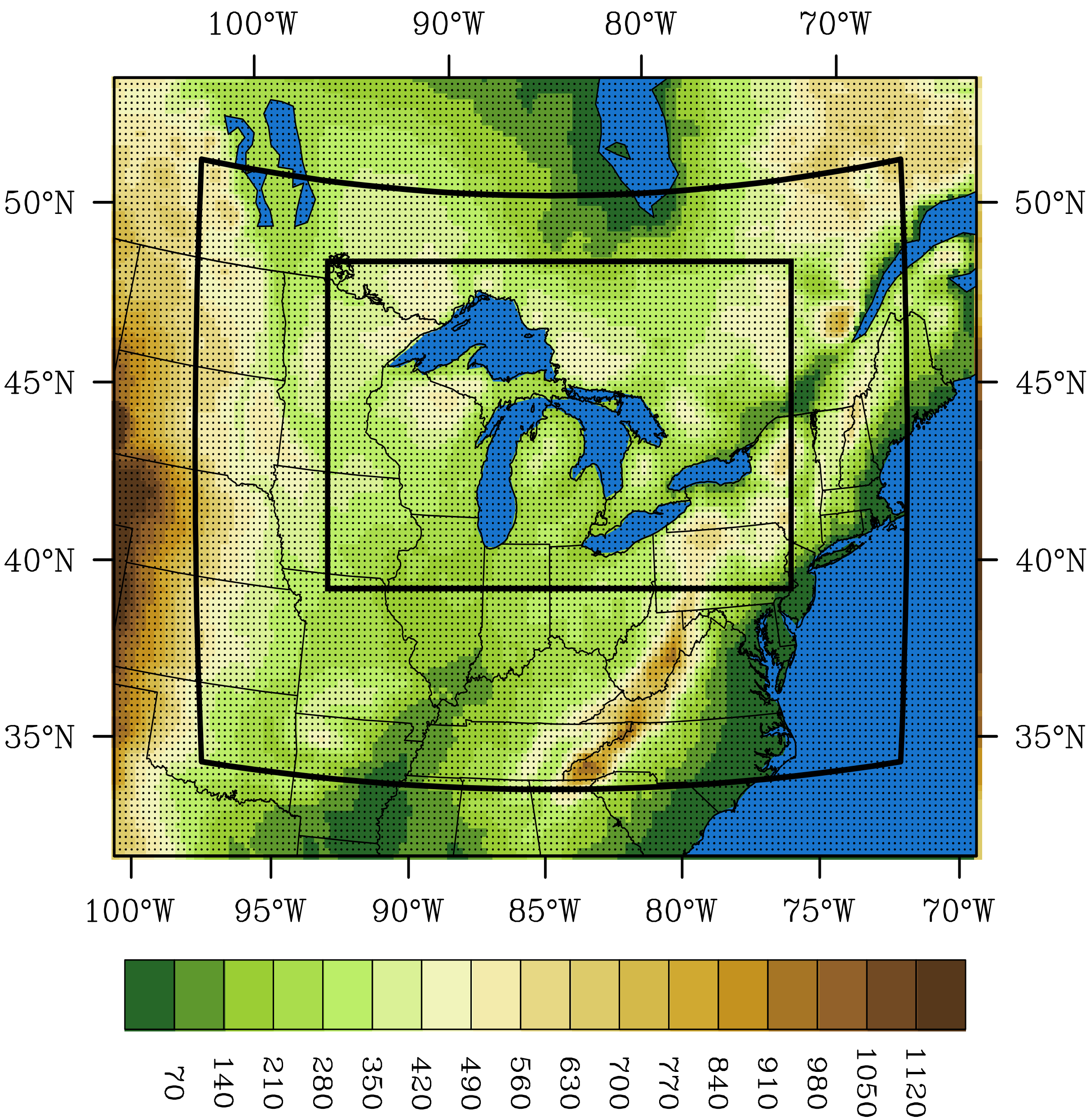
Teragrid

- University of Texas at Austin
- University of Illinois at Urbana-Champaign

Reference

Notaro, M., K. Holman, A. Zarrin, E. Fluck, S. Vavrus, and V. Bennington, 2012: Influence of the Laurentian Great Lakes on regional climate. Journal of Climate, in review.

Model Domain



ICTP RegCM4
(Pal et al., 2007; Elguindi et al., 2011; Giorgi et al., 2012)

Grid spacing: 20-km

NCEP-NCAR Reanalysis

UKMO Global Sea-Ice and Sea Surface Temperature

1980-1989

Hostetler and Bartlein (1990) lake module

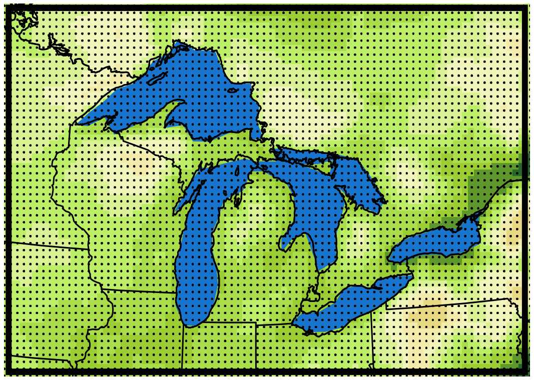
BATS land surface

Grell (1993) convective scheme

Great Lakes = 648 grid cells

LAKE vs. NOLAKE
(replaced Great Lakes with forest/field mosaic)

“Great Lakes Basin”



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LAKE vs. NOLAKE
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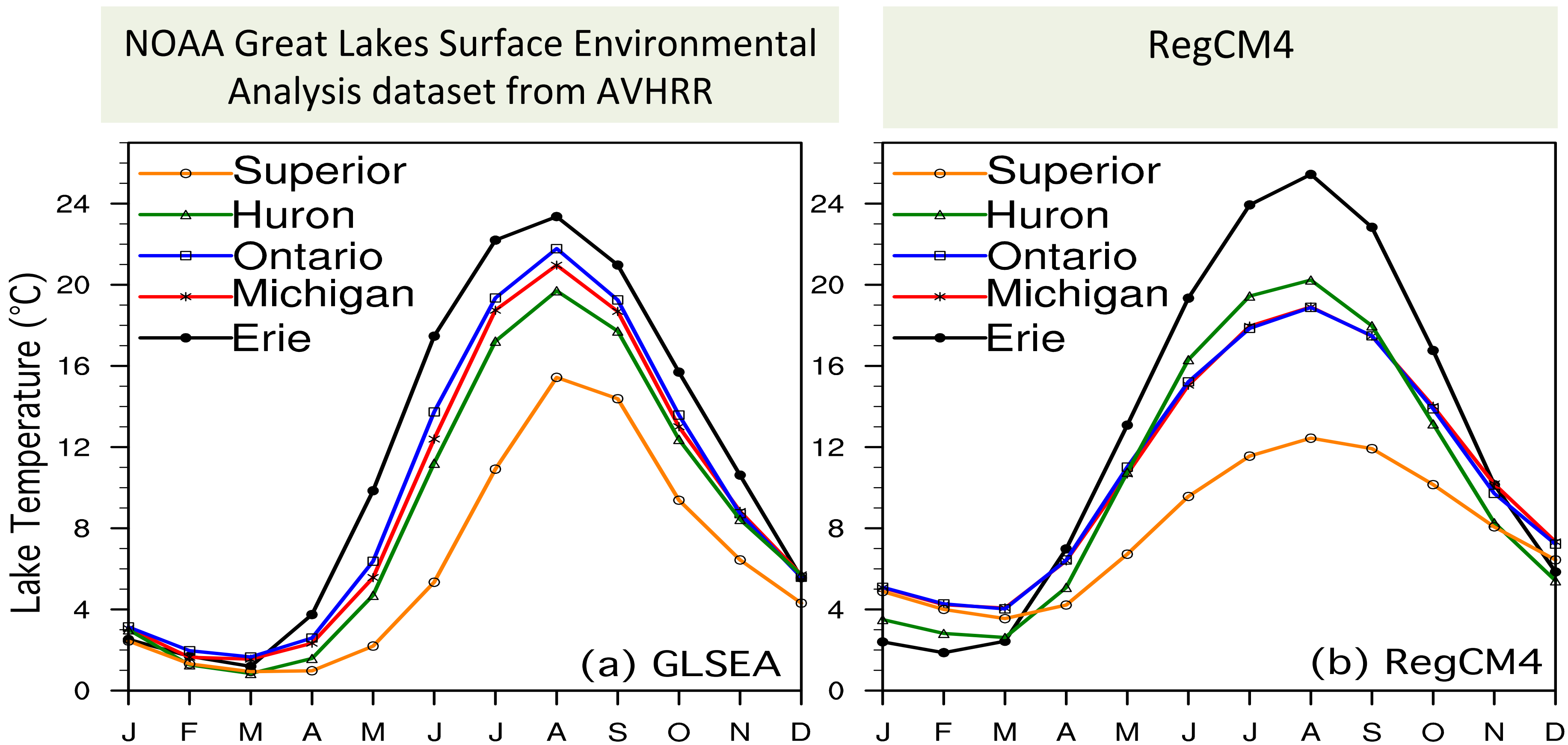
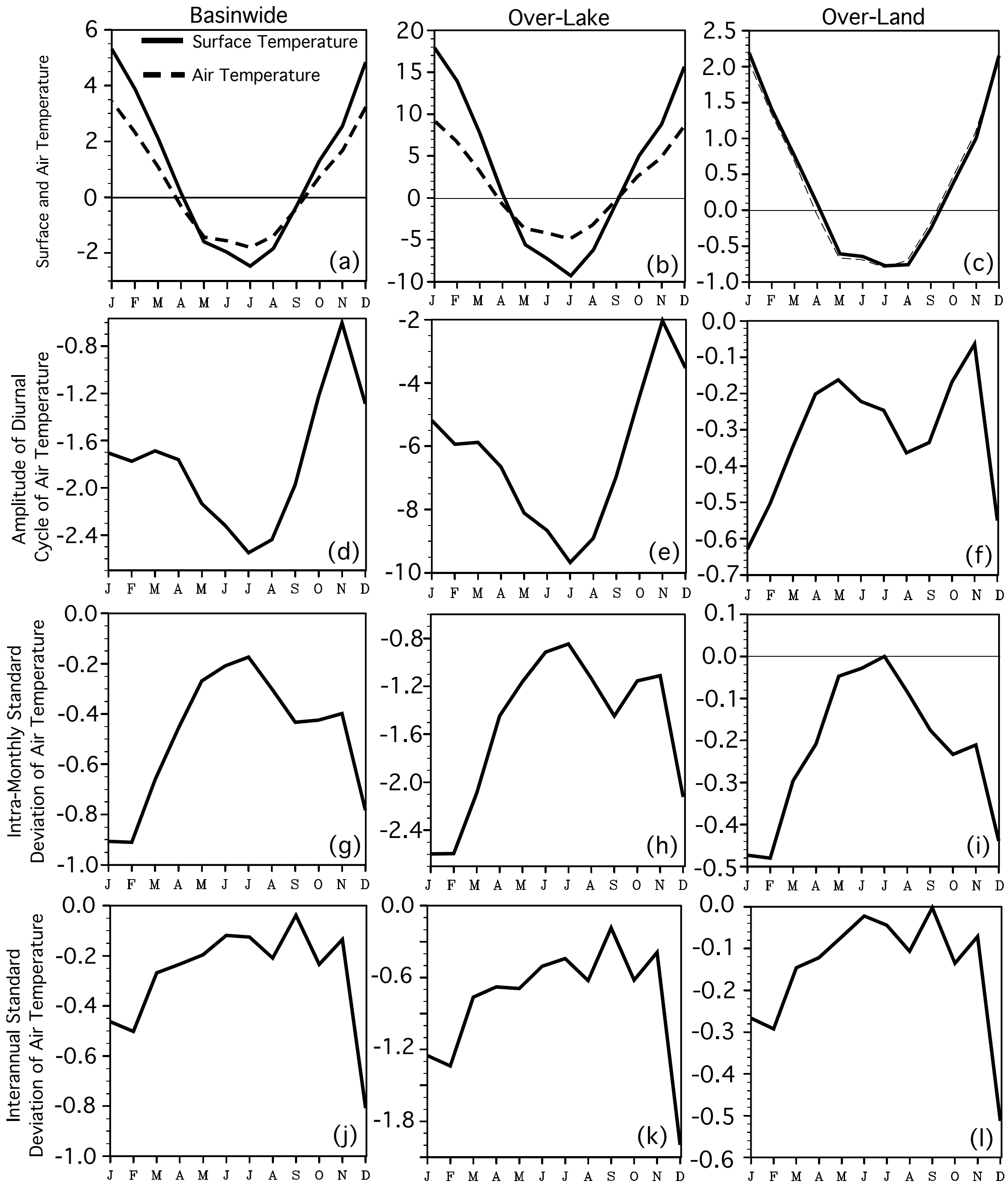
Climatology of lake surface temperatures (°C) for each Great Lake during 1995-2002



Mean lake surface temperatures reach a minimum during Feb-Mar, when ice cover is most extensive, and a maximum during Aug, with the highest summer temperatures for Erie (most shallow) and lowest for Superior (deepest). Associated with the spring overturning of the lakes is a rapid warming of the lake surface in May-June. All of these observed features are well represented by RegCM4.

Simulated lake surface temperatures are too high during spring (April-June) and slightly too low during summer-autumn (July-December). The amplitude of the seasonal cycle of lake surface temperatures is underestimated by 20%.

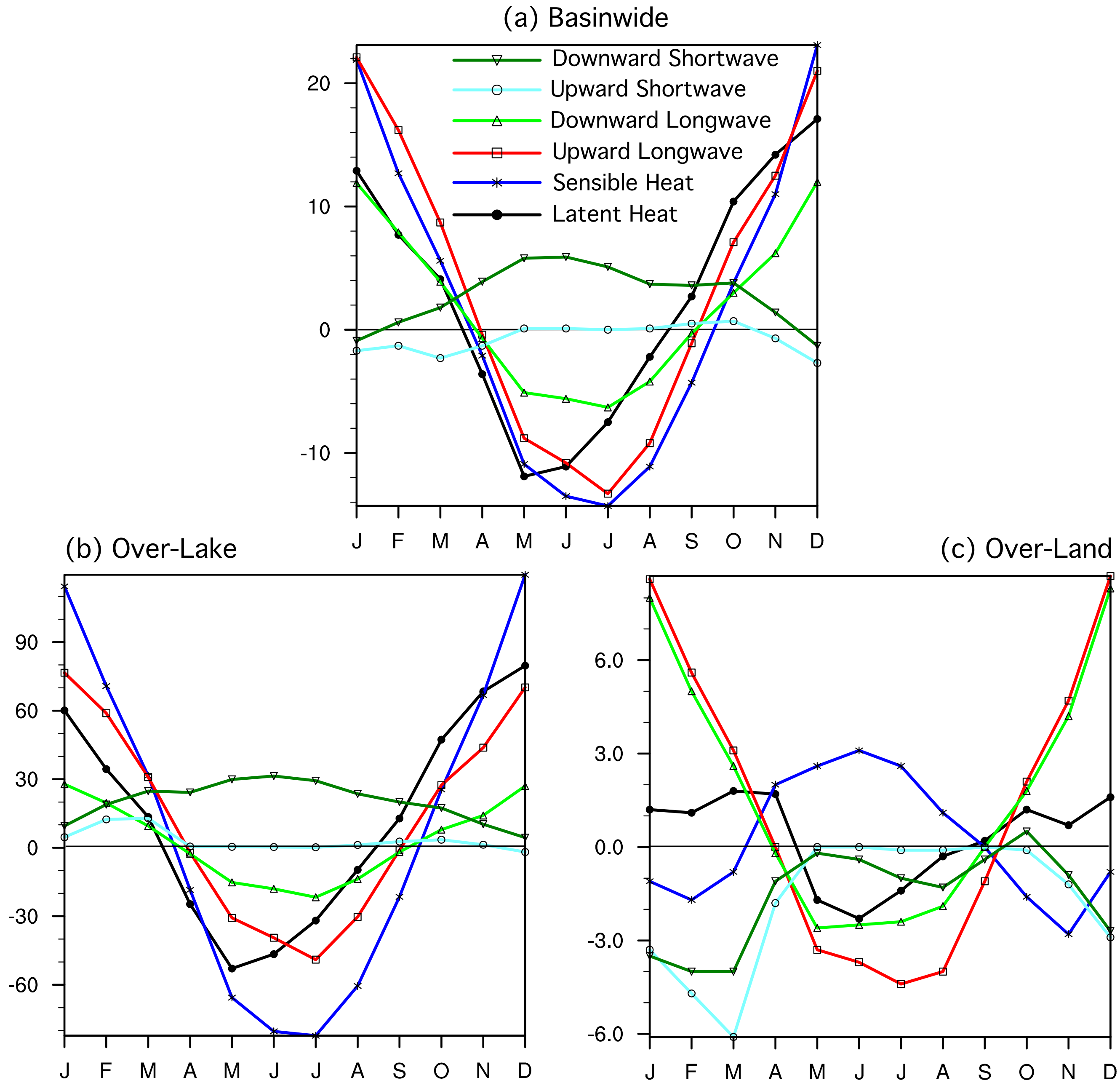


The presence of the lakes results in a 14% reduction in the amplitude of the annual cycle and a 20% reduction in the amplitude of the diurnal cycle of 2-m air temperature in the Great Lakes Basin.

Atmospheric stability is increased in the summer and decreased in the winter.

The Great Lakes dampen the amount of day-to-day fluctuations in air temperature across the basin. The standard deviation of daily 2-m air temperature in the Great Lakes Basin is reduced by 12%.

Surface Radiation Budget (LAKE-NOLAKE)



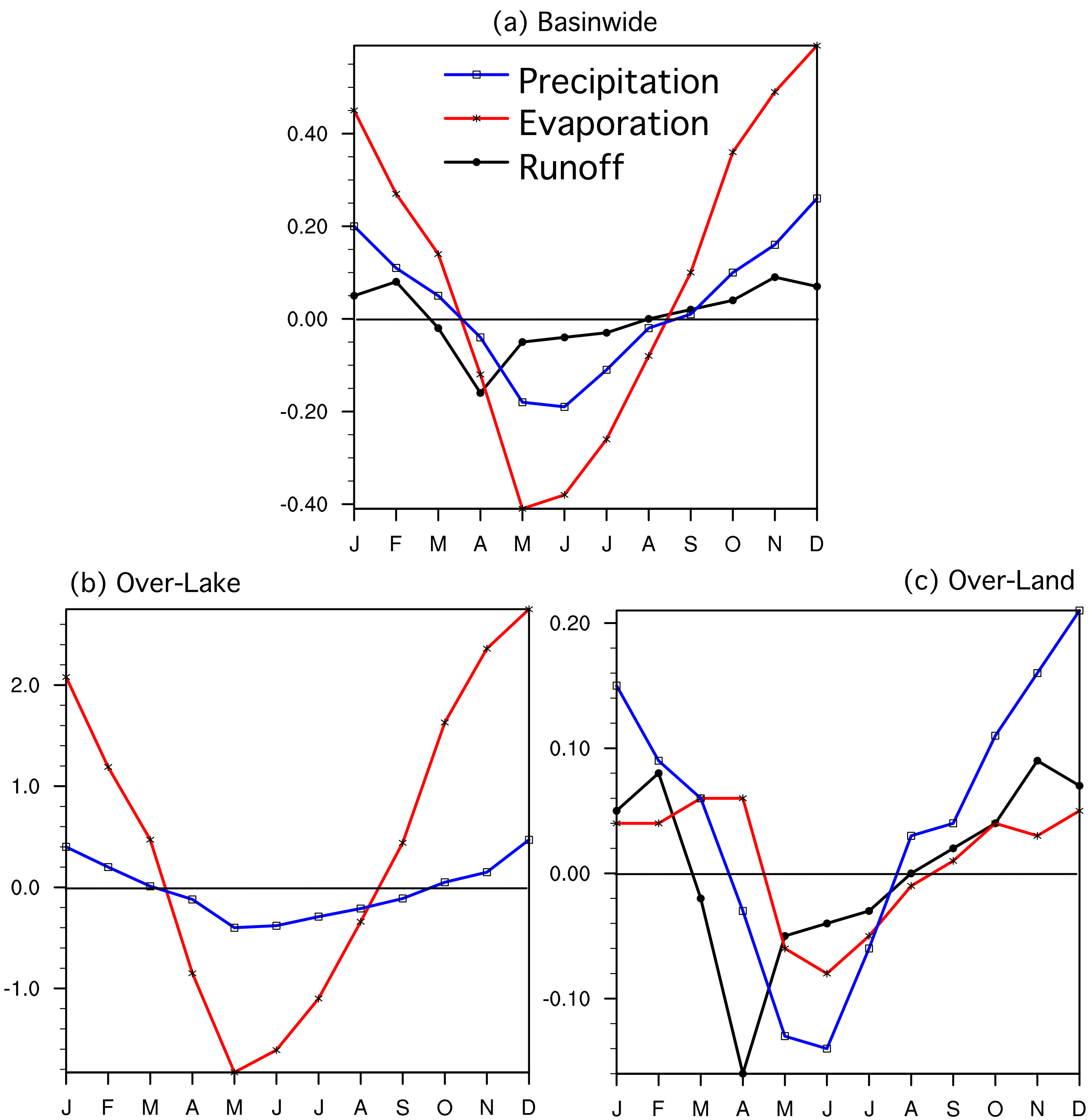
The downward surface shortwave radiation flux in the Great Lakes Basin is increased by +2.8 W/m^2 in LAKE compared to NOLAKE, primarily during the warm season when enhanced atmospheric stability reduces cloud cover and precipitable water.

The decrease in surface albedo, by replacing forests with lakes, leads to a greater absorption of solar energy into the surface during the warm season.

Upward longwave radiation is increased by +3.7 W/m^2, largely during the cold season, since the lakes maintain a higher surface temperature than either a forest or the overlying air.

In the presence of the lakes, the turbulent fluxes are enhanced during the cold season and diminished during the warm season, with annual increases of +1.8 W/m^2 and +2.7 W/m^2 for SH and LH fluxes, respectively (more of a moisture feedback than thermal feedback).

Hydrologic Budget (LAKE-NOLAKE)

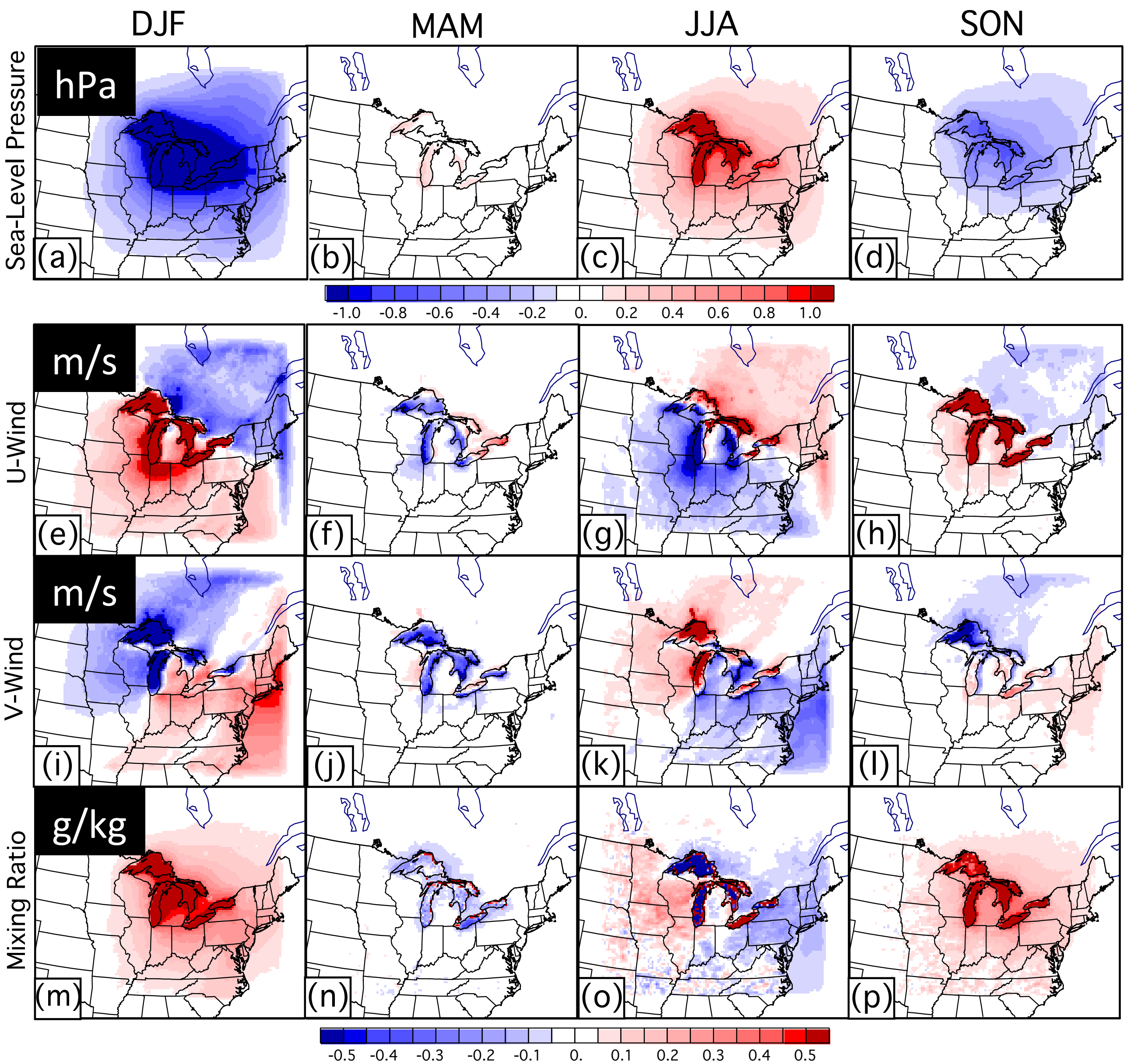


The presence of the Great Lakes causes an increase in cold-season precipitation and evaporation during Sep-Mar and a decrease in both variables during the warm-season of Apr-Aug, with minimal effect on annual hydrologic terms.

Evaporation and precipitation increase by +0.59 mm/day and +0.26 mm/day in December and decrease by -0.41 mm/day and -0.18 mm/day, respectively. Greater moisture enters the atmosphere as vapor and clouds during the cold season.

The lakes increase the air temperatures during the cold season, which leads to a smaller fraction of falling precipitation occurring as snow (-17%). Diminished snowpack results in less springtime snowmelt, thereby reducing runoff during Mar-Apr.

LAKE-NOLAKE



The largest responses in atmospheric circulation and moisture to the Great Lakes occur in winter and summer.

The lakes induces lower sea-level pressure across the Great Lakes Basin, Midwest, Mid-Atlantic, and Northeast US during winter, peaking at -2.9hPa.

Lower pressure during autumn-winter results from the lake surfaces' temperature exceeding the temperature of the overlying air.

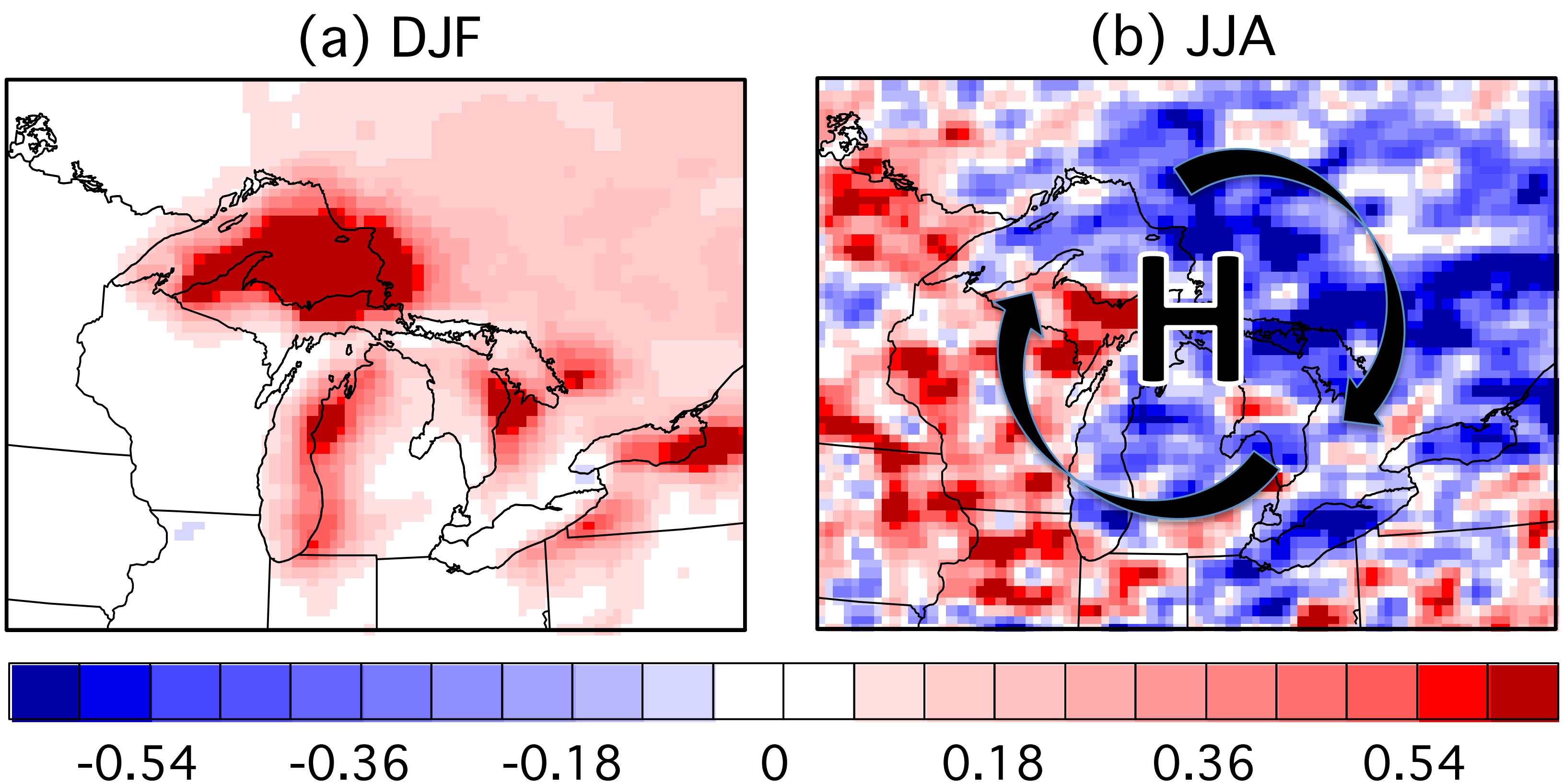
Relatively cool lake surfaces cause anomalously higher pressure in summer, with differences between LAKE and NOLAKE peaking at +1.5 hPa.

As a consequences of these SLP anomalies in LAKE, the 10-m wind field is anomalously cyclonic in winter and anticyclonic in summer.

The 2-m water vapor mixing ratio is increased regionwide during autumn-winter, up to +2 g/kg, due to enhanced evaporation.

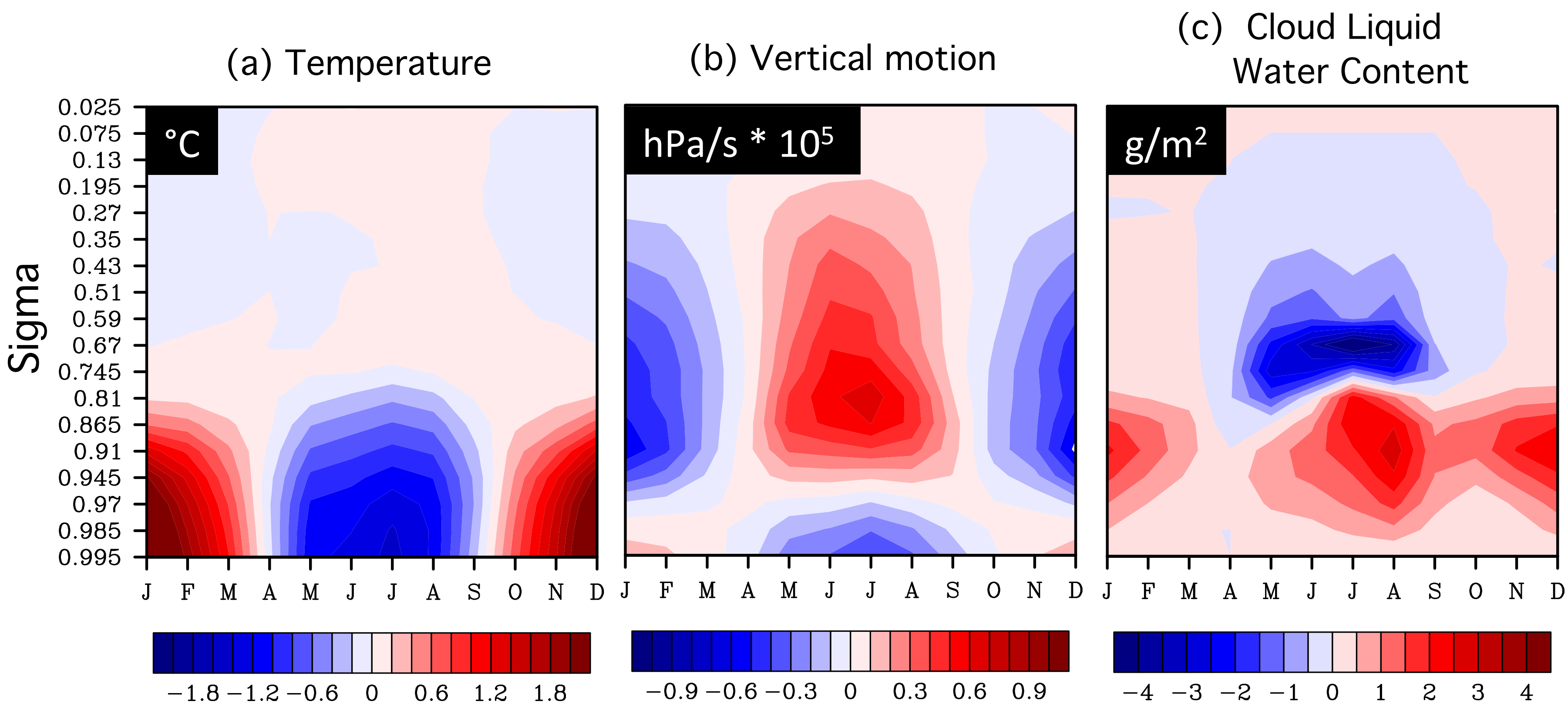
The response in mixing ratio to the Great Lakes during summer is dynamically-driven, in response to enhanced higher pressure.

Mean differences (LAKE-NOLAKE) in total precipitation (mm/day)



In LAKE compared to NOLAKE, wintertime precipitation is increased over and to the northeast of the Great Lakes Basin, while summertime precipitation response to the change in wind flow, with increases in precipitation to the west of the lakes and decreases over and to the east of the lakes.

Vertical profile of monthly mean differences (LAKE-NOLAKE) across Great Lakes Basin

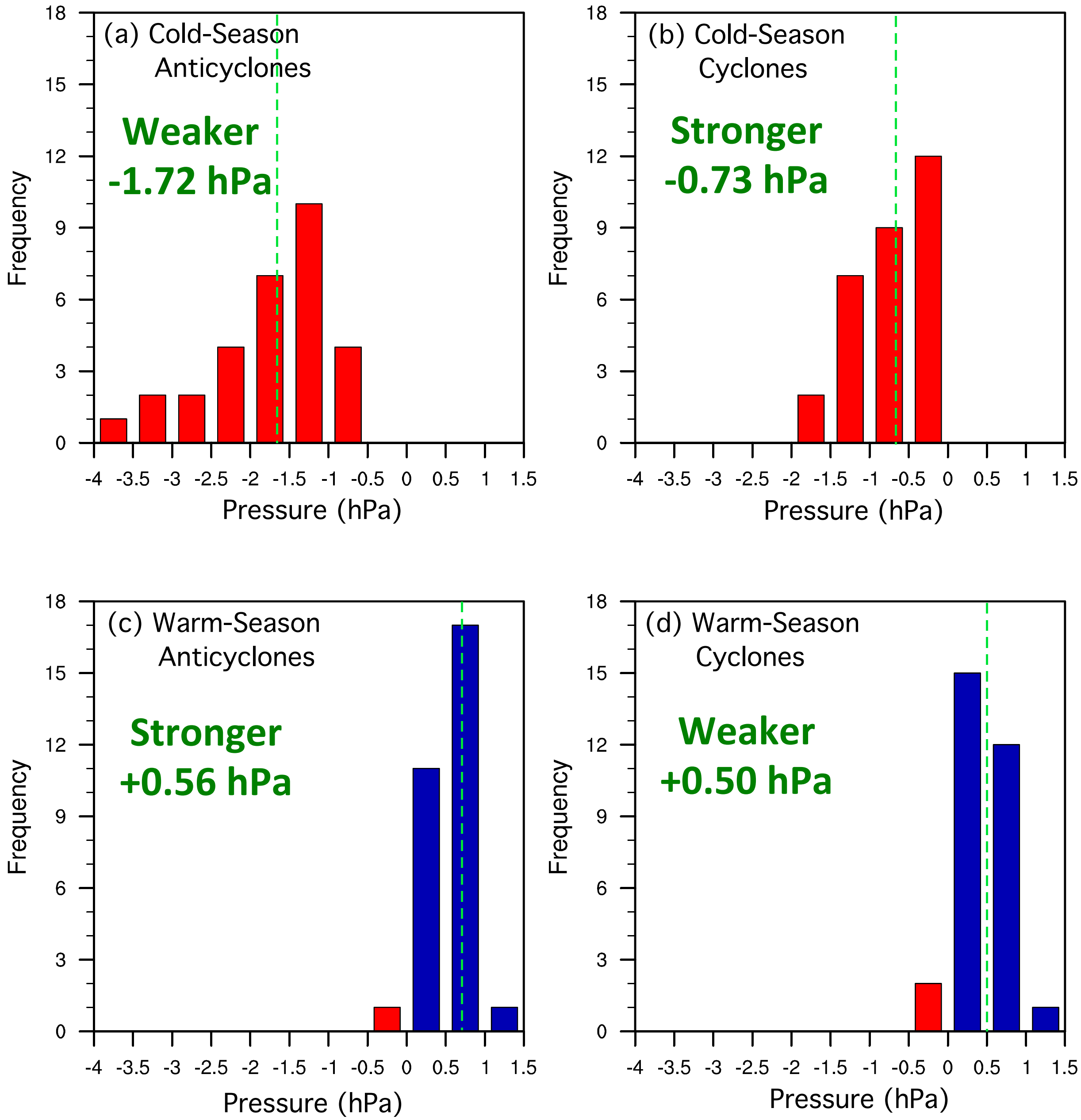


Air temperature is increased during Oct-Mar and decreased during May-Aug in the boundary layer.

Due to the inclusion of the lakes, enhanced instability and low-level convergence during the cold season support anomalous ascent in the low-mid troposphere, with the opposite response during the warm season.

Low-level cloud liquid water content is greater in LAKE than NOLAKE across the basin during the cold season due to greater evaporation, while deep convection is limited during summer due to enhanced atmospheric stability and subsidence.

Effect of Lakes on Synoptic Systems (LAKE-NOLAKE)

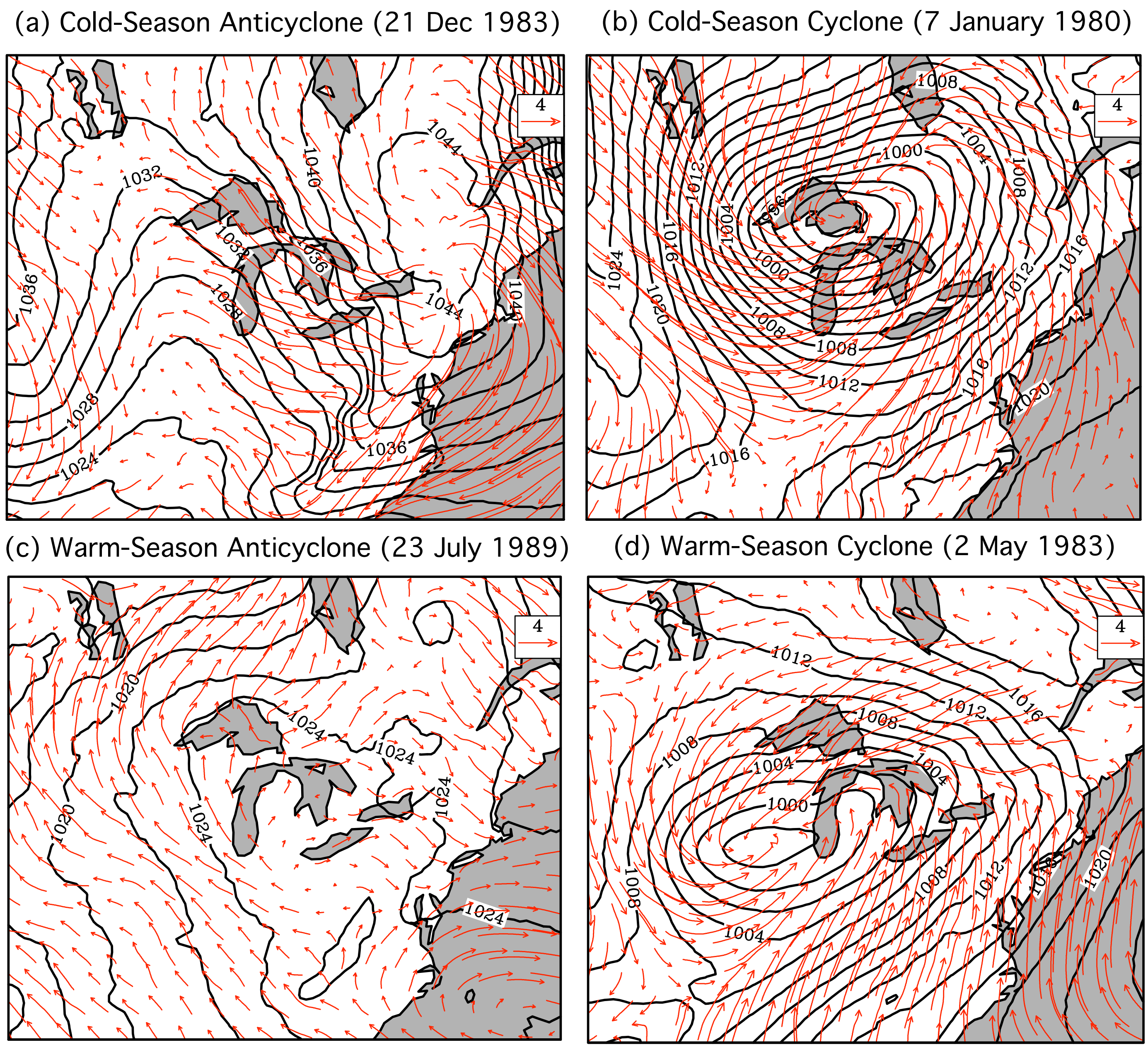


Method: Daily sea-level pressure in NOLAKE is averaged across the Great Lakes Basin and used to identify 30 of the strongest cold-season anticyclones (P≥1035 hPa), cold-season cyclones (P≤1004 hPa), warm-season anticyclones (P≥1022 hPa), and warm-season cyclones (P≤1005 hPa).

Cold season = November - March
Warm season = May – August

Only 3 of 120 analyzed weather systems deviated from these results.

Synoptic Case Studies (NARR)



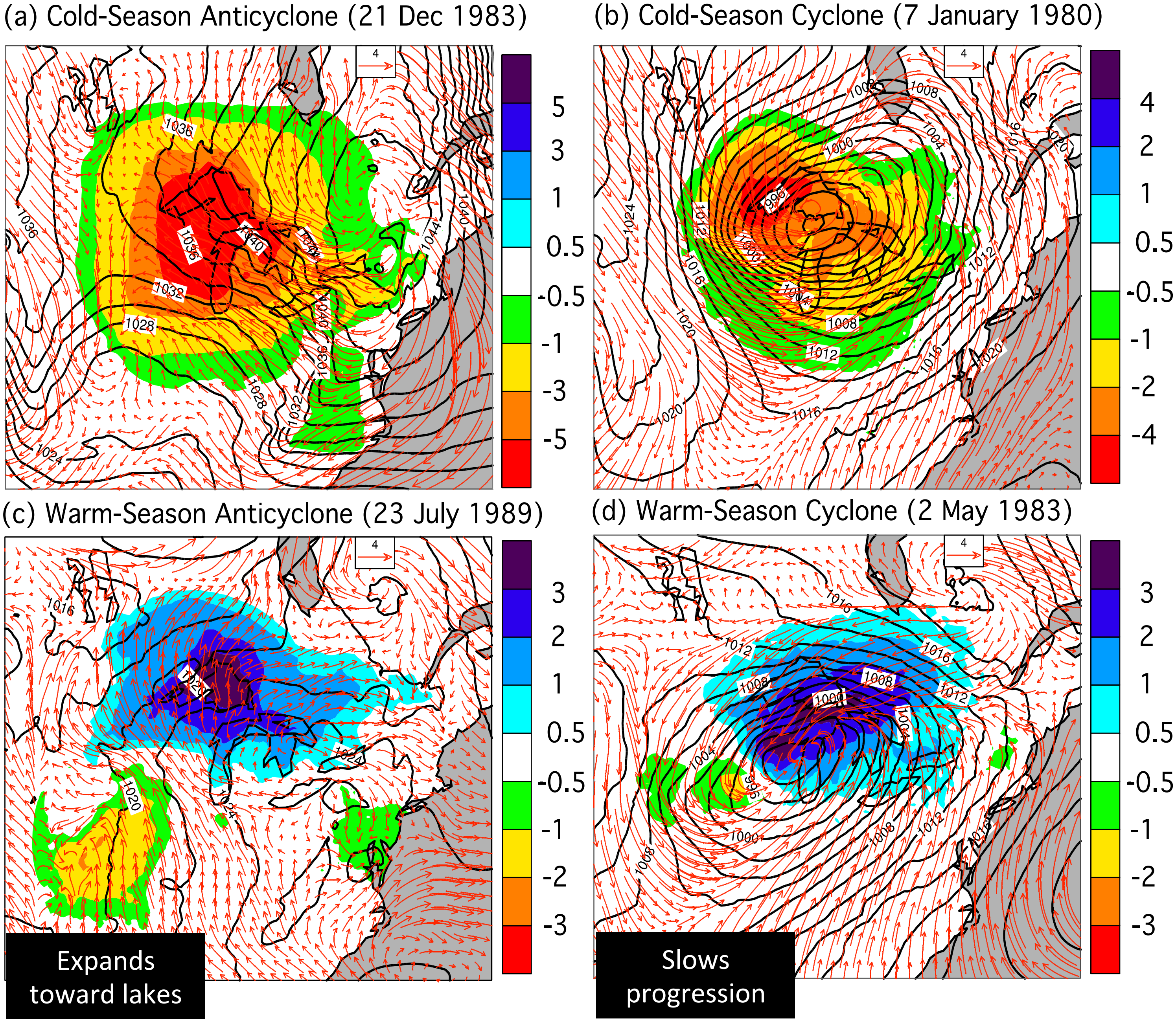
North American Regional Reanalysis (NARR) (Mesinger et al., 2006)

Daily sea-level pressure and 10-m wind vectors

Synoptic Case Studies (LAKE-NOLAKE)

Western flank is weakened

Deepens and shifts NW



Contours and streamlines represent daily-mean sea-level pressure (hPa) and 10-m wind (m/s) from NOLAKE.

Shading indicates the difference (LAKE-NOLAKE) in sea-level pressure (hPa).

CONCLUSIONS

The Great Lakes dampen the variability in near-surface air temperature across the surrounding region, while reducing the amplitude of the diurnal cycle and annual cycle of air temperature.

The impacts of the Great Lakes on the regional surface radiation budget include an increase (decrease) in turbulent fluxes during the cold (warm) season and an increase in surface downward shortwave radiation flux during summer due to diminished atmospheric moisture and convective cloud amount.

Changes in the hydrologic budget due to the presence of the Great Lakes include increases in evaporation and precipitation during October-March and decreases during May-August, along with springtime reductions in snowmelt-related runoff.

Circulation responses consist of a regionwide decrease in sea-level pressure in autumn-winter and an increase in summer, with enhanced ascent and descent in the two seasons, respectively.

The most pronounced simulated impact of the Great Lakes on synoptic systems traversing the basin is a weakening of cold-season anticyclones.