Mesoscale Modeling During Mixed-Phase Arctic Cloud Experiment

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Motivation

Mixed-phase arctic stratus clouds are the predominant cloud type in the Arctic (Curry et al. 2000) and through various feedback mechanisms exert a strong influence on the Arctic climate. Perhaps one of the most intriguing of their features is that they tend to have liquid tops that precipitate ice. Despite the fact that this situation is colloidally unstable, these cloud systems are quite long lived–from a few days to over a couple of weeks. It has been hypothesized that mixed-phase clouds are maintained through a balance between liquid water condensation resulting from the cloud-top radiative cooling and ice removal by precipitation (Pinto 1998; Harrington et al. 1999). In their modeling study, Harrington et al. (1999) found that the maintenance of this balance depends strongly on the ambient concentration of ice forming nucleus (IFN). In a follow-up study, Jiang et al. (2002), using only 30% of IFN concentration predicted by Meyers et al. (1992) IFN parameterization, were able to obtain results similar to the observations reported by Pinto (1998). The IFN concentration measurements collected during the Mixed-Phase Arctic Cloud Experiment (M-PACE), conducted in October 2004 over the North Slope of Alaska and the Beaufort Sea (Verlinde et al. 2005), also showed much lower values then those predicted (Prenne, pers. comm.) by currently accepted ice nucleation parameterizations (e.g. Meyers et al. 1992). The goal of this study is to use the extensive IFN data taken during M-PACE to examine what effects low IFN concentrations have on mesoscale cloud structure and coastal dynamics.

Methods

Colorado State University version of Regional Atmospheric Modeling System (RAMS@CSU) (Cotton et al. 2003) with two-moment microphysics and a two-stream radiation scheme. It also incorporates the Los Alamos National Laboratory sea-ice model.

Domain

Three nested grids configuration (Figure 1):

grid #1 – 64 km resolution; covers the entire state of Alaska – 3392 x 2368 km;
grid #2 – 16 km, centered on the North Slope of Alaska, covers 1296 x 976 km;
grid #3 – 4 km resolution, centered on the north shore, covers 312 x 212 km;
vertical resolution – 50 m at surface, stretches to 1000 m aloft.

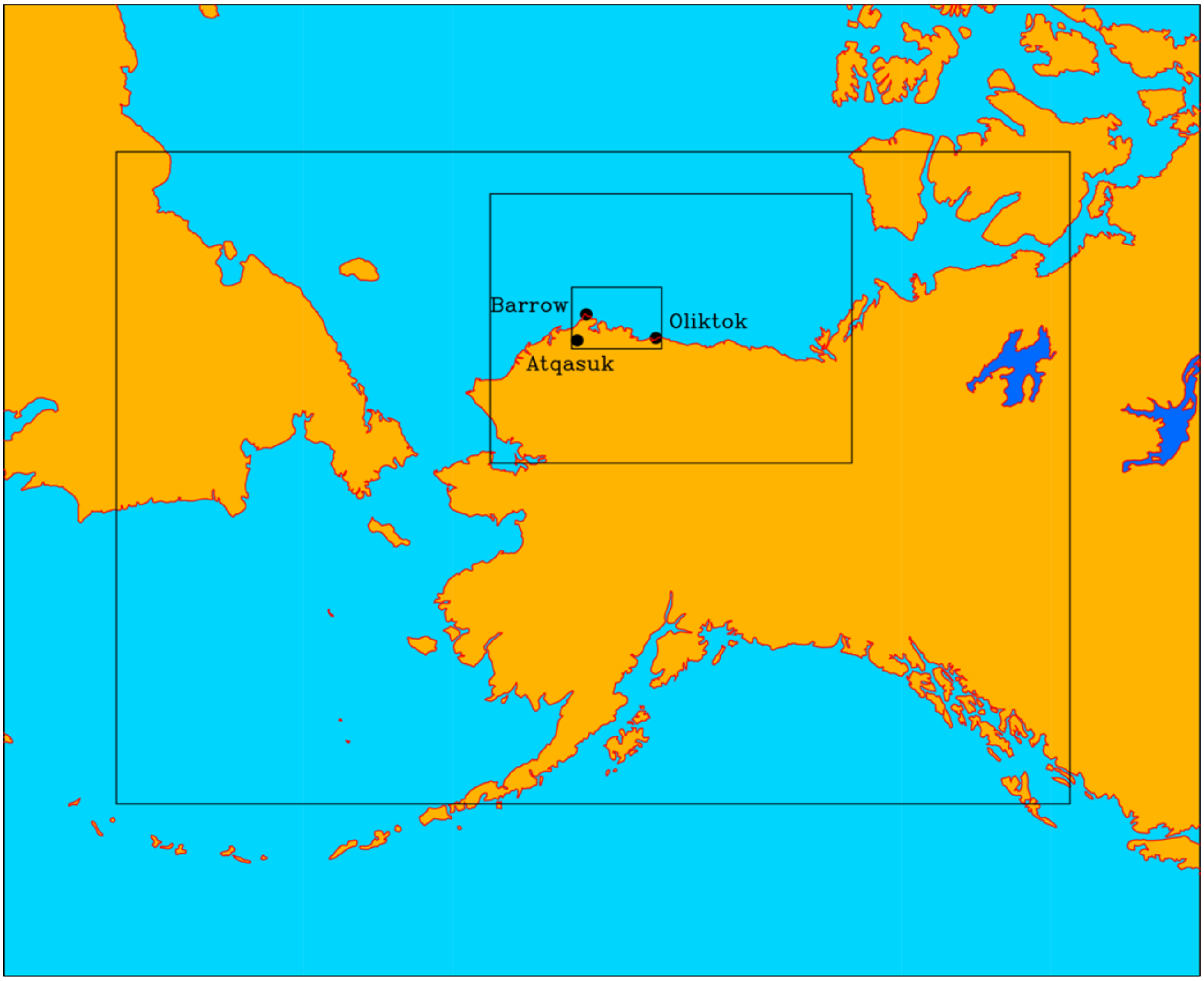


Figure 1. Map of the computational domain.

Initialization Data

ETA model Alaska grid analysis fields
DMSP special sensor microwave/imager daily ice dataset
National Centers for Environmental Prediction optimum interpolation sea-surface temperature weekly data

Control run – Meyers et al. (1992) IFN parameterization

Sensitivity run – new IFN parameterization based on IFN data, collected during M-PACE and improved pristine ice to snow conversion.

Results

The synoptic situation during the simulation period was determined mainly by the high pressure center developing over sea-ice pack to the northeast of the Alaska coast. This high, coupled with the surface low over the Aleutians, intensified the pressure gradient over the area and created favorable conditions for the strong easterly winds which persisted throughout the simulation period (Figure 2). Over the next several days, a series of wave-like disturbances originated near the pack ice and propagated southwest through the area. The moderate-resolution imaging spectroradiometer (MODIS) visible image shown on Figure 3 and the University of Wisconsin High Spectral Resolution Radar (HRSL) image (Figure 4) illustrate the structure of the observed cloudiness.

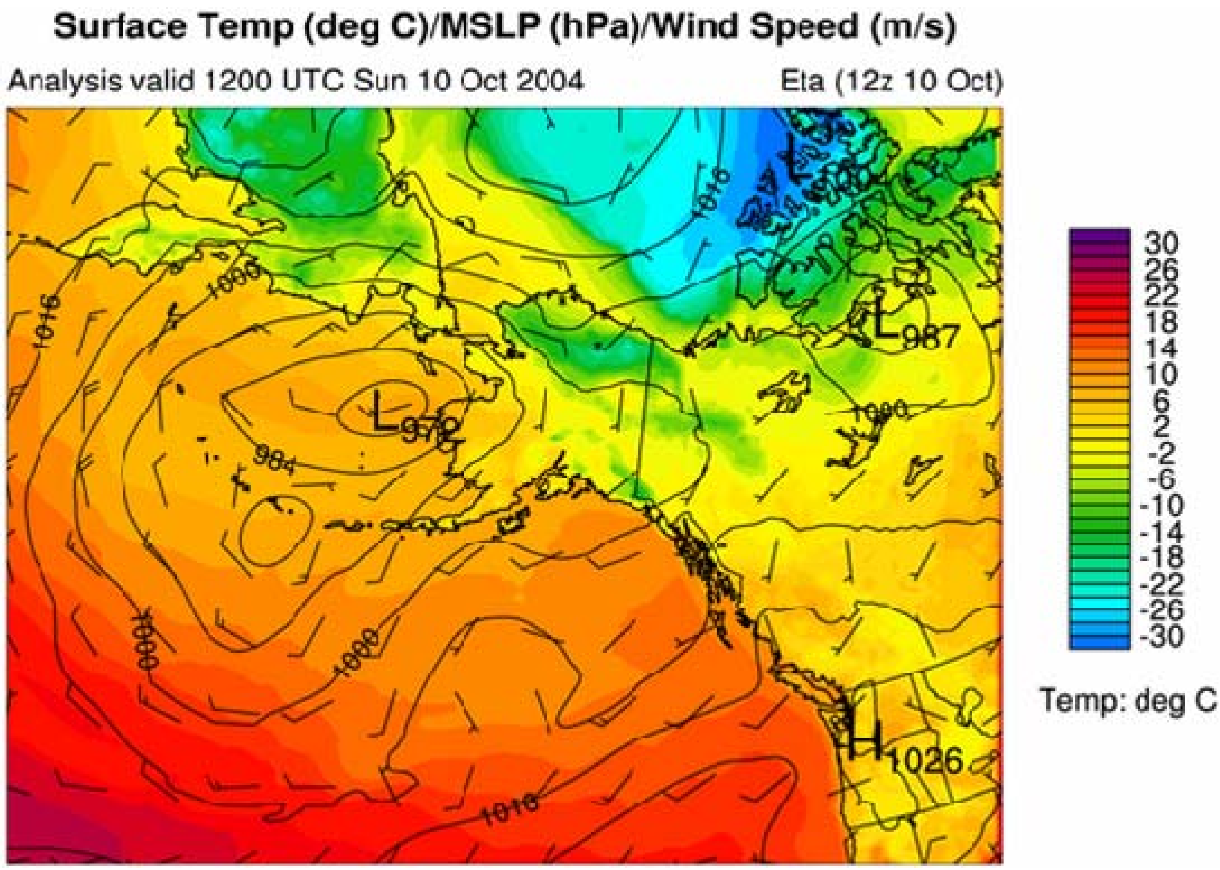


Figure 2. ETA surface analysis for 12 UTC October 10, 2004.

Figure 3. MODIS visible image of the North slope of Alaska on October 10, 2004.

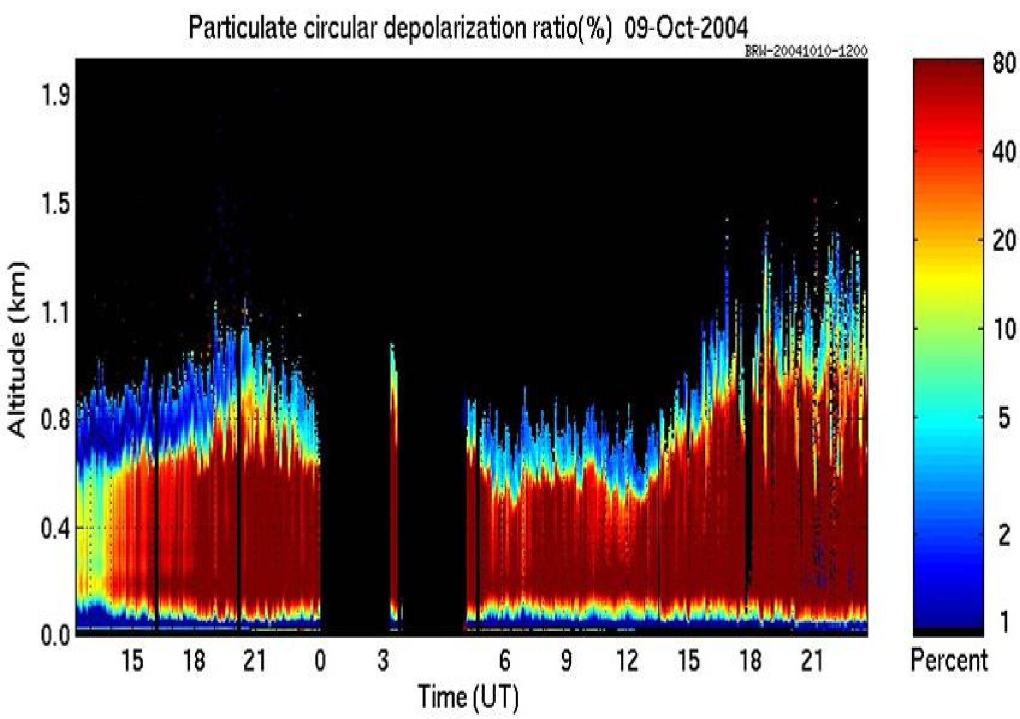


Figure 4. Lidar depolarization ratio (<2 liquid, >2 ice) over Barrow, Alaska on October 9, 2004.

Ice Forming Nucleus Impact On Cloud Structure

Lidar observations during the simulation period depict a common Arctic picture–liquid topped mixed-phase stratus precipitating ice (Figure 4). Although very common in the Arctic, these clouds are hard to simulate, particularly because of their inherent colloidal instability. These difficulties are better illustrated by Figure 5 and Figure 6, where the time evolution of the simulated clouds is shown. The relatively high IFN concentration in the "control" run leads to a rapid conversion of the liquid phase to ice through the Bergeron-Findeisen process, which then precipitates, and consequent cloud dissipation (Figure 6a). Twenty-fout hours after the beginning of the simulation the cloud water throughout the domain of grid #2 is completely depleted (Figure 5b).

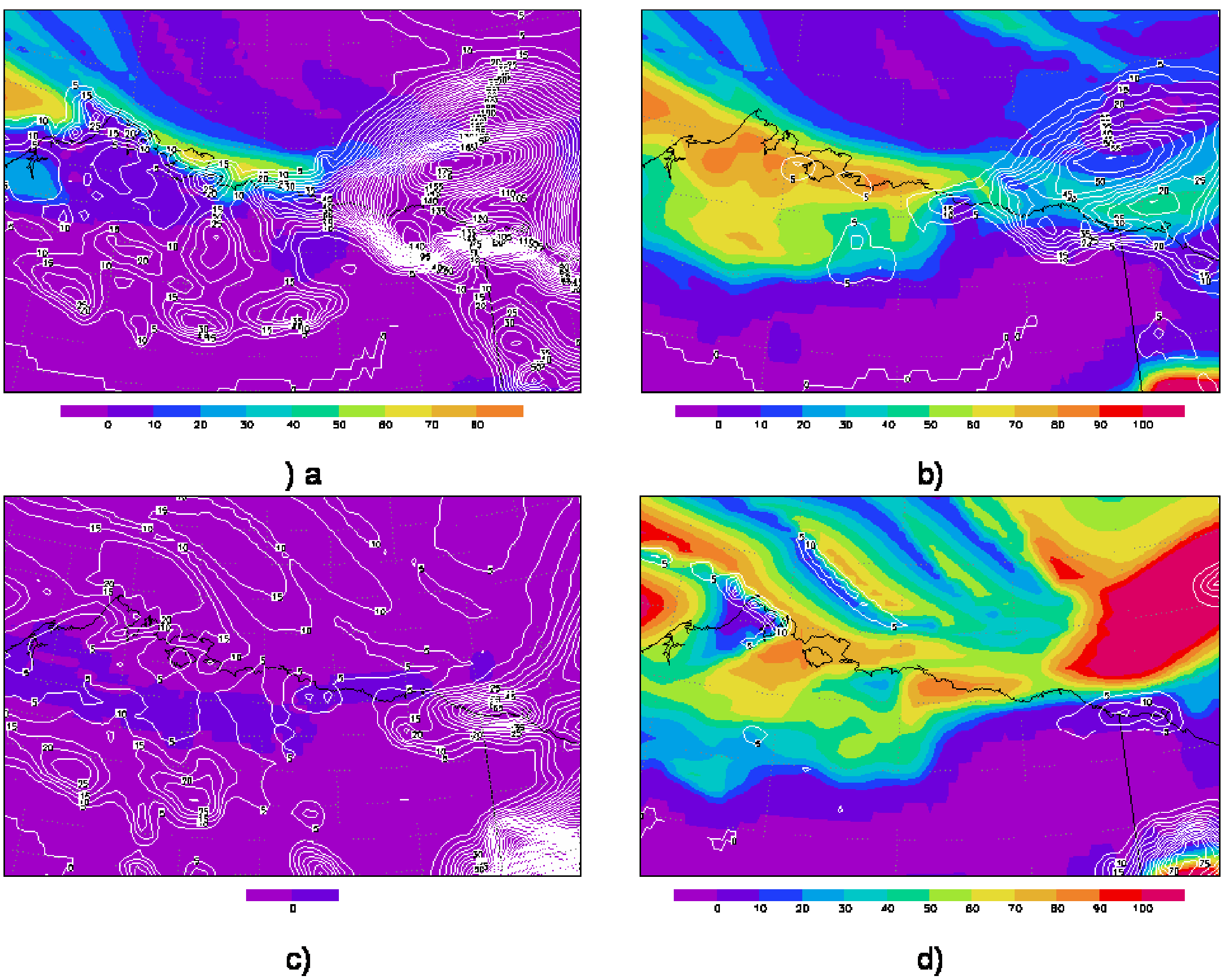


Figure 5. Liquid water (shaded) and ice water (contoured) path for control (a, c) and sensitivity (b, d) run 3 (a, b) and 24 hours (c, d) after the beginning of the simulation

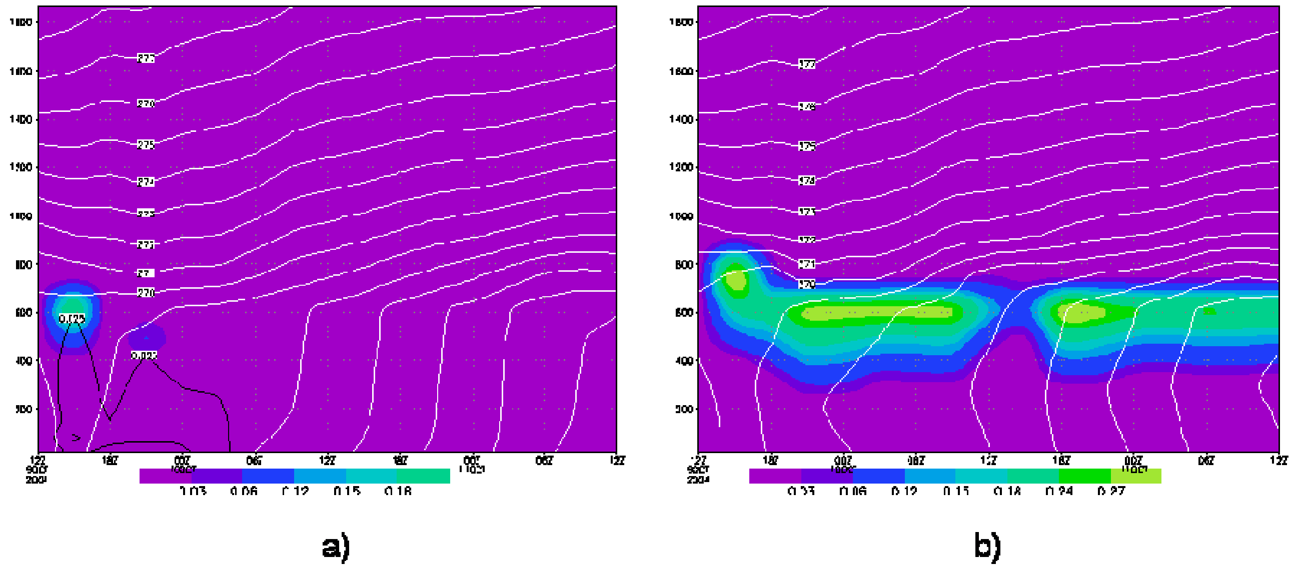
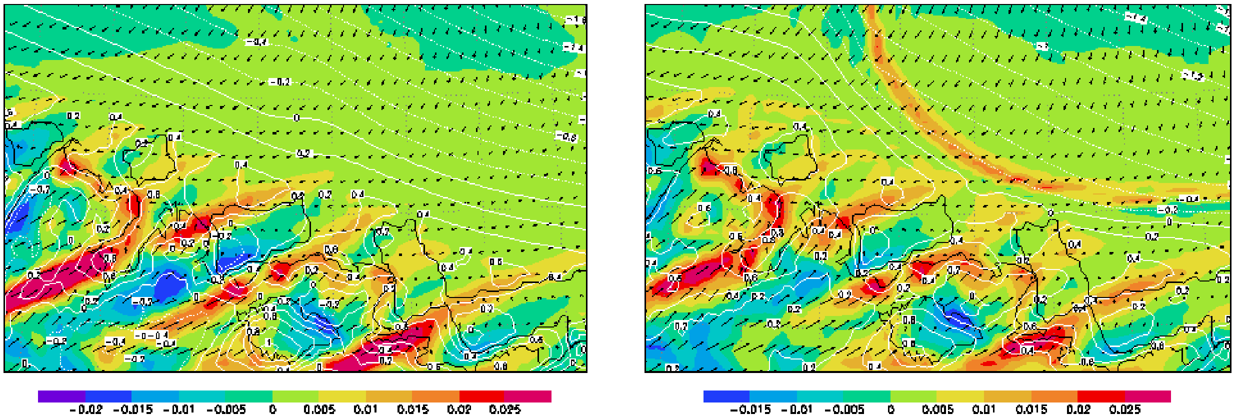


Figure 6. Time series of the vertical profiles of liquid (shaded), ice (black contours) mixing ratios [g/kg] and potential temperature (white contours) for control (a) and sensitivity (b) runs over Oliktok point, Alaska.

In the "sensitivity" run we implemented a new IFN parameterization, derived from the "insitu" IFN data collected during M-PACE. When those much lower and more realistic for the Arctic environment values of IFN concentration were used in "sensitivity" run, the cloud structure drastically changed (right pane of Figure 5-6). While closer to the observed fields than the previous case, the resulting cloud field is mostly liquid suggesting that perhaps the IFN concentration is too small and formed crystals can easily precipitate. Nevertheless, the result is promising as it shows some definite improvement over the "control" run.

Ice Forming Nucleus Impact on Boundary Layer Dynamics

Although the cloud fields in both runs are quite different, the perturbation fields of potential temperature and the wind are almost the same over the land part of the domain (Figure 7). Over the ocean though, "sensitivity" run produces frontal-like features which are clearly pronounced in both temperature and wind fields but are almost completely missing in the "control run."

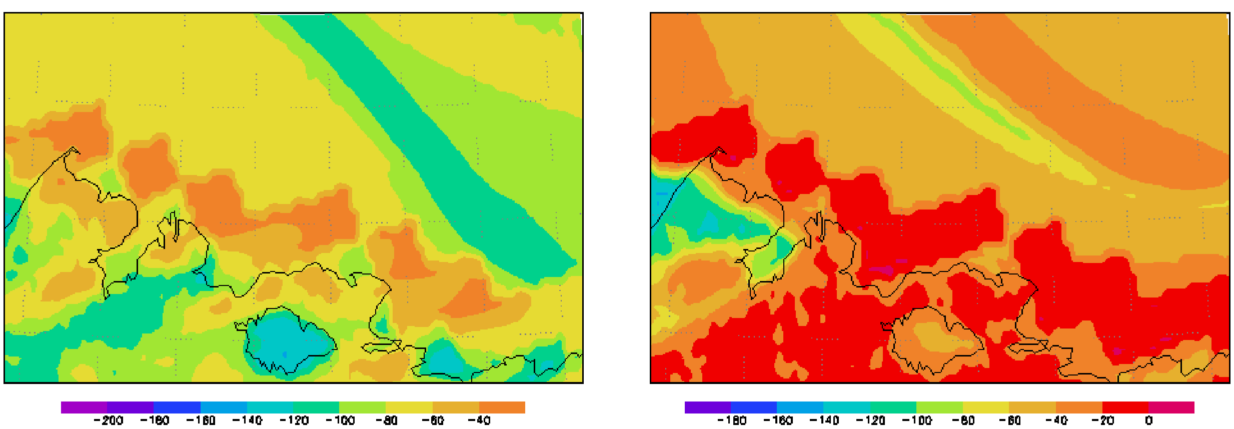


a) b)

Figure 7. Perturbation fields of the vertical (shaded) and horizontal (arrows) wind velocity components and potential temperature (contoured) 24 hours after beginning the simulation for control (a) and sensitivity (b) runs.

IFN impact on the surface energy budget

The longwave radiative fluxes are significantly different for "control" and "sensitivity" run as a consequence of differences in the cloud cover in both runs. The difference in the net longwave radiative flux, shown on Figure 8, is of the order of 20-30 W/m^2 but differences of up to 50 W/m^2 were noted later in the simulation. As others have pointed out, variations in IFN concentrations may exert a substantial influence on important climate feedback mechanisms through their impact on the surface energy budget.



a) b)

Figure 8. Net longwave radiative flux [W/m^2] 24 hours after beginning the simulation for control (a) and sensitivity (b) runs.

Acknowledgments

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