NMC NOTES

A Sea-Ice Albedo Experiment with the NMC Medium Range Forecast Model*

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ABSTRACT

The sea-ice albedo treatment currently used in the National Meteorological Center Medium Range Forecast Model was a carryover from earlier models. A more modern treatment is shown to improve forecast skill marginally, as measured by height field anomaly correlation, and to improve substantially the surface temperature field in sea-ice regions. The improvement reduces a systematic bias toward warm temperatures in winter and cold temperatures in summer. Even though the ice retreats once the sun rises, accurate sea-ice albedos are important to the forecast problem.

1. Introduction

The albedo of sea ice and of snow on sea ice seems at first glance to be a fairly unimportant factor in the forecast problem. Sea ice generally forms in polar areas and in wintertime, when there is little sunlight to be affected by an albedo parameterization. This picture neglects that ice may form in lower latitudes (for example, Hudson Bay at 50°–67°N, the Sea of Okhotsk at 45–60°N, and the Great Lakes at 40°–50°N), where the polar night does not extend through the entire day. Neglecting ice albedo also ignores the fact that in the Arctic summer, with the sun up nearly all day, there is still over 7 million-km^2 ice cover (Comiso and Zwally 1984).

It is commonly observed that the Medium Range Forecast (MRF) Model is biased toward overly warm temperatures over ice in winter and overly cold temperatures in summer (G. White 1993, personal communication). This is the sense of error expected from the difference between the currently operational albedo implementation and a more modern scheme. Consequently, I conducted a forecast experiment with a newer albedo algorithm. It was not expected, nor did it occur, that the albedo change could or would eliminate all the errors in surface temperatures. The parameterization chosen has been used in conjunction with a sea-ice model and was verified versus satellite observations of spring and summer Arctic sea-ice and snow albedo (Ross and Walsh 1987). The current albedo parameterization was indeed shown to contribute to the polar biases observed in the MRF. The albedo algorithms, the conduct of the numerical experiment, and the results are discussed in order.

2. Albedo parameterization

The current parameterization of albedo for sea ice and for snow on sea ice in the MRF is taken from the Geophysical Fluid Dynamics Laboratory *E*-Physics (Miyakoda and Sirutis 1981). This algorithm was used by Holloway and Manabe (1971) and is based for the snow cover part on observations by Kung et al. (1964). The sea-ice albedo was taken from a study by Posey and Clapp (1964). The albedo in the *E*-Physics is

$$|latitude| > 70° \quad A = 0.75 \quad H_s \neq 0 \qquad (1)$$

$$A = 0.60 \quad H_s = 0 \qquad (2)$$

$$|latitude| < 70° \quad A = 0.6 \quad H \geq 1 \text{ cm} \qquad (3)$$

$$A = 0.5 + H_s^{0.5} \quad H_s < 1 \text{ cm}, \qquad (4)$$

where A is the albedo and H_s is the snow thickness in centimeters. Holloway and Manabe (1971) used a latitude of 75° rather than 70° for the changeover in albedos, but the algorithm was otherwise the same.

The new albedo parameterization tested was developed by Ross and Walsh (1987) for use with a large-scale sea-ice model. It is designed to be compatible with measured albedo over snow and ice surfaces as reported by Strokina (1980). The albedos computed by the ice model were compared to observations by Robinson et al. (1986) of Arctic spring and summer

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(May–August) albedos. This encompasses most of the season in which polar ice melts back. Consequently, the albedos early in the period are those of cold snow or ice, while later the ice is snow-free and melting. Given the difficulty of measuring surface albedo by satellite, the agreements between the ice model and observations may be taken only as a consistency check.

For snow-covered ice surfaces,

$$A_{\rm snow} = 0.8 \quad T_s < -5°C \tag{5}$$

$$0.65 + 0.03(-T_s) \quad -5°C < T_s < 0°C \tag{6}$$

$$0.65 \quad T_s = 0°C, \tag{7}$$

where $A_{\rm snow}$ is the albedo of snow and T_s is the surface temperature of the snow in degrees Celsius. The surface temperature of melting snow is thermodynamically required to be 0°C. The decline of albedo prior to reaching 0°C reflects the partial melting of the surfaces of the snow crystals.

When the sea ice is bare of snow,

$$A_{\rm ice} = 0.65 \quad T_s < 0°C \tag{8}$$

$$0.65 - 0.04T_a \quad T_s = 0°C, \quad T_a < 5°C \tag{9}$$

$$0.45 \quad T_s = 0°C, \quad T_a > 5°C, \tag{10}$$

where $A_{\rm ice}$ is the albedo of the ice surface and T_a is the surface air temperature in degrees Celsius. The depression of albedo for temperatures between 0° and 5°C reflects the formation of melt ponds on the surface of the ice. Note that the newer algorithm does not depend on latitude. Snow and ice are treated the same regardless of location. Also, the thickness of the snow is not a factor in this albedo scheme. Only the presence of a snow cover matters to the albedo.

Given the algorithmic differences, we expect some changes in the energy budget. For cold snow, the albedo change is to increase albedo by 0.05 poleward of 70°, and 0.2 equatorward of that line. For bare but frozen ice the albedo increases by 0.15. In the melting season the albedo of snow decreases by 0.10 poleward of 70° but increases by only 0.05 equatorward of 70°. The albedo of melting ice under a warm atmosphere (above 5°C) decreases by 0.05 everywhere.

With these changes, we expect the model to show ice-covered areas to be cooler with the new albedo in winter conditions. In melting, we expect the model to show bare ice-covered regions or snow-covered ice areas poleward of 70° to be warmer in the new scheme, and cooler over snow-covered ice. Note that this experiment tested only albedo over sea-ice-covered regions, for which the algorithm was developed, and no change was made for snow-covered land regions.

3. Model experiment

The computational experiment was conducted through paired runs of a T-62 version of the operational MRF and a version with the changed albedo parameterization. A set of 40 5-day forecasts was made, verifying 6–15 March, 15–24 April, 15–24 May, and 15–24 June, all in 1993. The days 16 April and 18 May could not be verified due to archival problems for the T-62 model. The experiments cover a period when the forecast model had extremely good forecasts (e.g., the blizzard of 1993) and some poorer than typical forecasts. By spanning a period of both good and poorer forecasts, we should gain a better knowledge of the range of effect on the model. By covering parts of different months through a seasonal transition, we also can determine if the expected seasonal dependence in improvements is observed.

The anomaly correlation (AC) is a common measure of the skill of an atmospheric forecast model (cf. Keyser et al. 1989). It measures the correlation between forecast deviations from climatology and the observed deviations from climatology. I computed the anomaly correlations for the control and new albedo runs for each of the verifying forecasts, for levels from 1000 to 100 mb, for 50°–87.5°. Table 1 presents the results, grouped by forecast month. Values have been multiplied by 100, so that the typical minimal standard of skill, 0.60, would be 60. The summed difference in anomaly correlation between the two albedo schemes is given. The average improvement per forecast is given in the last column. The 23 April verification was

TABLE 1. Difference in anomaly correlation as functions of month and level between old and new albedo schemes. A positive value marks that the new scheme was superior. The * denotes that 23 April had a pathological verification and so was not used in the averaging.

Pressure level (mb)	March	April	May	June	Average
		Northern Hemisphere 50°–87.5°N			
1000	−0.15	−0.25*	2.88	−0.88	0.04
850	−0.33	0.82	3.05	−0.67	0.08
700	−0.55	2.34	2.98	−0.36	0.12
500	−0.74	2.74	2.28	0.14	0.12
400	−0.66	2.74	1.53	1.86	0.14
300	−1.14	2.34	0.50	1.09	0.07
250	−0.98	2.37	−0.10	1.39	0.07
200	−0.18	2.25	−0.20	1.36	0.09
150	1.00	1.26	−0.77	1.48	0.08
100	1.60	1.04	0.24	−0.12	0.07
		Southern Hemisphere 50°–87.5°S			
1000	−0.79	−1.26*	−0.72	1.79	−0.03
850	−0.03	−1.07	0.52	1.57	0.03
700	0.40	−0.87	1.42	1.11	0.05
500	0.59	−0.85	2.70	2.26	0.12
400	0.59	−0.65	1.66	2.26	0.10
300	0.85	−0.79	3.52	2.75	0.17
250	0.74	−0.78	3.95	2.46	0.17
200	0.42	−0.74	4.38	1.69	0.15
150	0.34	−0.67	3.37	0.16	0.08
100	0.38	−0.66	4.93	0.70	0.14

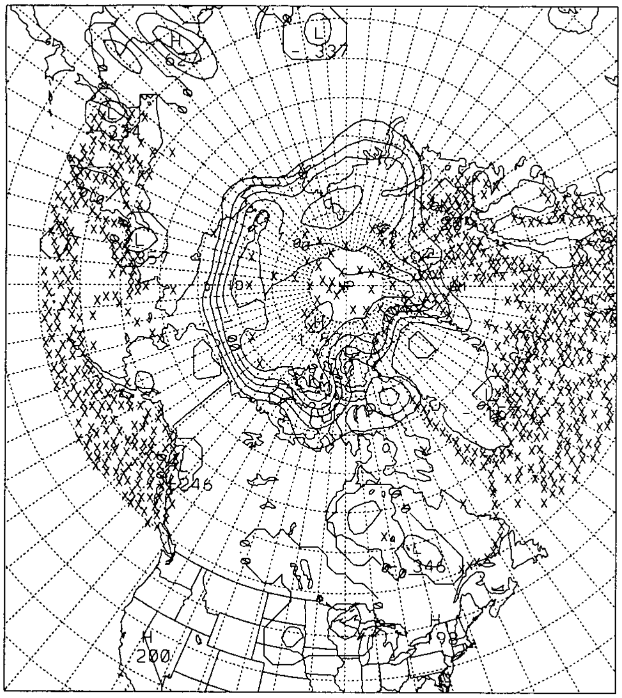

FIG. 1. Average surface atmospheric difference, new − current, between the two albedo schemes tested. Average is for the 5-day forecasts verifying 15–24 June at 1200 UTC. The X marks buoy and ship report locations sampled to be no closer than 110 km to each other. Temperature differences less than 0.125° were set to zero for contouring.

pathological, so it was not used in computing the averages for 1000 mb. For that day, the current albedo scheme had a collapse of skill, with near-zero or negative AC at 1000 mb. No other level was affected in this way. The new albedo scheme continued with skill comparable to prior days at all levels and so was tens of points better than the current scheme that day. It was a general feature that the new scheme was comparatively best on the days that the current scheme was worst. The rest of the time, the differences were very small and split between favoring one scheme over the other. Compared to the natural variation in AC, say 10 points, the change is small. Even when compared to the differences between different models (NMC MRF versus the European Centre for Medium-Range Weather Forecasts model), a few points, the change is small.

The significance of the anomaly correlations is that the changes are generally improvements and that they occur for both hemispheres. Even though the change was made at the surface, the effect is felt throughout the depth of the atmosphere. This follows because the shortwave radiation, which propagates through the whole atmosphere, is being changed. The anomaly correlations were computed using the current model's analysis. This tends to bias this comparison in favor of that model.

Changing the albedo should also affect the surface energy balance. To test for improvement here, the models' forecasts were verified versus polar ocean (taken to be north of 50°N) observations from ships and buoys as collected in the Ocean Product Center Monthly Platform Statistical Database (Waters et al. 1993). The observations in the ice pack are primarily from drifting buoys. The buoys generally report surface pressure, surface air temperature, and sea surface temperature. Sea surface temperature cannot be verified as this is not a forecast field in the MRF. The surface pressure was verified and did show the same general sense of improvement as temperatures. The difference between the two models, though, was so small (hundredths of a millibar) that recording precision (tenths of a millibar) would be a significant element in computing the statistics. The MRF version tested did not compute surface (or buoy level) air temperatures. Temperatures at the buoy level were obtained by adiabatically lowering air parcels from the lowest sigma level in the model to the buoy level. This typically represented 0.4°C warming. The value is important only in terms of detecting improvement in the point forecasts in those cases where the models are wrong in the opposite sense. This was an unusual occurrence. The models generally have the same bias (either warm or cold), though with differing magnitude.

The models' temperatures at the grid point nearest the buoy location are the point forecasts. The temperatures were interpolated from the spectral domain to a polar stereographic grid with 127-km spacing. The domain is shown in Fig. 1, which also displays the mean differences between the new and current model for the 5 June day forecasts (verifying 15–24 June 1200 UTC). Differences between the two models of less than half the contour interval (absolute value less than 0.125°) were set to zero for contour legibility. Also shown on that figure are the locations of buoy reports that were used for model verification. For plotting purposes, the locations are subsampled so that the marks are no closer than 110 km. This reduces the number of report locations from approximately 22 000 to 728. The full set was used for verification.

The result of the comparison of model forecast to buoy observation is given in Table 2 as averaged over each month's set of forecasts. (This was not affected

TABLE 2. Buoy verification of 5-day surface temperature forecasts. A positive bias denotes that the model is too warm. A positive verification means that the newer albedo scheme is an improvement on the older on the point forecasts.

Case	March	April	May	June
Bias—new	2.46	1.34	2.66	−0.95
Bias—old	2.66	2.58	2.38	−2.13
Verification	0.01	0.43	0.09	0.54

by the archive problem, so all 40 experiments could be tested.) The three rows for each month are the bias ("positive" means the model is warm) for each albedo scheme and the mean improvement for the point forecasts. The mean improvement is not equal to the difference in bias, because a model can have lower bias by being either too warm or too cold (at different times of course) in such a way that it is wrong by more than the other model at that time.

In early March, there is little sun, and we see little improvement. But it is indeed there, both on the point forecasts and in the biases. In April, solar radiation has become significant, and we see substantial improvement both in the point forecasts and the biases. In May, the snow has begun to melt at many of the buoy locations. The new scheme has a higher bias but still better point forecasts in this period. In June, with melting well under way, the newer albedo scheme has lower bias and much improvement on the point forecasts. Note too that we have the expected sense of bias in the temperatures in both models—warm in winter and cold in summer.

4. Conclusions

These experiments show that a modification of the albedo scheme in the MRF can result in slightly better height fields and significantly more realistic surface temperature fields in sea-ice regions. Although the ice retreats with sunrise and the sun is always at low angles to the ice, sea-ice surface albedo does need to be modeled accurately. This has been commonly considered true for climatic models, and here we see that it is also true on the shorter weather forecast timescales. This work is part of a continuing effort designed to improve the representation of the polar regions in the MRF as prelude to coupling a sea-ice model to it.

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