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FURTHER EXPERIMENTS IN MESOSCALE ENSEMBLE FORECASTING IN THE WESTERN ARCTIC

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1. Introduction

Ensemble prediction techniques continue to be utilized among operational weather prediction centers and research groups. While approaches based on perturbing the initial model conditions (e.g., Kalnay and Toth, 1996) remain popular for operational forecast applications as well as for longer-range prediction research, approaches based on perturbing the model physics(e.g, Stensrud et al. 1999) have been seen to have some merit for specific applications on the mesoscale.

Previously, Tilley et. al (1999a,b) investigated the utility of ensemble techniques with the PSU/NCAR MM5 mesoscale modeling system for high latitude mesoscale prediction. In these previous papers we focused on the transition period between the Arctic warm and cold seasons as well as perturbations to the model physics available in MM5 versions 1 and 2.

In this paper, we extend this work by considering an ensemble simulation of an extended heavy rain event in Alaska during mid-August 2000. This time period is prior to the start of the aforementioned seasonal transition in the Western Arctic. As in Tilley et al. (1999a), the bulk of the ensemble members are generated by perturbing the model physics, but here we utilizeMM5v3 and generate a larger ensemble including members with varying land surface models as well as recently incorporated radiation and PBL schemes.

We evaluate the skill of the ensemble members through a statistical verification approach utilizing standard measures of skill applied to a comparison between the various forecast realizations and a verifying analysis.

2.Model Description and Data

MM5v3.4 (e.g., Chen and Dudhia 2000) was chosen for this study. The V3 version of the modeling system differs from its predecessor in that it contains several options for soil physics and land-atmosphere exchanges as well as new options for the treatment of the planetary boundary layer and atmospheric radiative transfer. A static sea ice scheme (Tilley and Wilkinson 1998) is included to crudely represent certain thermodynamic and radiative effects of sea ice, whose distribution and area extent are specified from the NCEP Analysis. Vegetation distribution is specified from the NASA Pathfinder "PAL" suite of products(e.g., Agbu and James 1994) and transformed into the USGS set of land use categories utilized by MM5. Fractional vegetation cover is included for the simulations with more sophisticated soil physics.

Atmospheric initial and boundary conditions are obtained from analyses, interpolated to the MM5 grid, produced by the Air Force Weather Agency utilizing the Local Analysis and Prediction System (LAPS) developed by NOAA's Forecast Systems Laboratory (e.g, Albers et al 1996). No additional observations are utilized in the initialization procedure.

The model simulations discussed here utilize a nested grid structure as shown in Figure 1. The coarse grid has a 45 km resolution and covers the North Pacific and Western Arctic regions to approximately 77^{o} N latitude; the nested grid has a 15 km resolution and encompasses most of mainland Alaska, as well as parts of the southeast Alaska Panhandle and Alaska Peninsula regions.

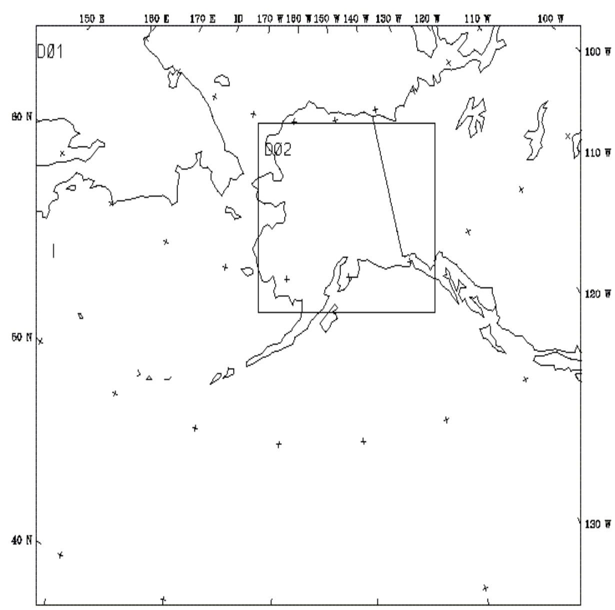

Figure 1. Domain configuration for the MM5 ensemble experiments. Grid resolution for domains 1 and 2 are 45 and 15 km, respectively

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TABLE 1. Characteristics of Ensemble Simulations

Simulation (s)	*PBL Scheme*	*Vertical Levels*	*Radiative Scheme*	*Moist Physics Treatment*	*Soil Physics Treatment*
Control	Blackadar	41	2-stream	Grell (1993) cumulus; Reisner (1988) mixed-phase cloud microphysics	None
MRFPBL	MRF (Hong and Pan, 1996)	41	2-stream	Grell cumulus; Reisner mixed-phase	None
Gayno-Seaman	Gayno Seaman	41	2-stream	Grell cumulus; Dudhia simple ice	None
27Level Interpolated	Blackadar	27->41	2-stream	Grell cumulus; Reisner mixed-phase	None
Shallow Conv	Blackadar	41	2-stream	Grell cumulus + shallow convection; Reisner mixed phase	None
Fake Dry	Blackadar	41	2-stream	MM5 “fake dry” => no latent heating	None
CCM2	Blackadar	41	CCM2	Grell cumulus; Reisner mixed-phase	None
RRTM	MRF	41	RRTM	Grell cumulus; Reisner mixed-phase	Multilayer
Micro	Blackadar	41	2-stream	Grell cumulus; Goddard microphysics	None
Kuo simple ice/ mixed phase	Blackadar	41	2-stream	Kuo cumulus; Dudhia simple ice and Reisner mixed-phase microphysics	None
KF simple ice/ mixed phase	Blackadar	41	2-stream	Kain-Fritsch (1990) cumulus; Dudhia simple ice/ Reisner mixed-phase microphysics	None
BM simple ice/ mixed phase	Blackadar	41	2-stream	Betts-Miller (1986)cumulus; Dudhia simple ice/Reisner mixed-phase microphysics	None
NO simple ice/ mixed phase	Blackadar	41	2-stream	Explicit microphysics (Dudhia simple and Reisner mixed-phase) only; no cumulus	None
BMKF simple ice/mixed phase	Blackadar	41	2-stream	Betts-Miller/Kain Fritsch cumulus on coarse/fine grid; microphysics as Control	None
SOIL 1	Blackadar	41	2-stream	Grell cumulus; Reisner mixed phase	Multilayer
SOIL 2	MRF	41	2-stream	Grell cumulus; Reisner mixed phase	MM5 LSM
IC +/-	Blackadar	41	2-stream	as in Control; initial conditions perturbed	None

2.Experiment Design

The characteristics of the ensemble members are described in Table 1. As was the case in Tilley et. al (1999), we have constructed the ensemble primarily by perturbing the model physics. Many of the ensemble members are the same as in the previous work, but we have added members SOIL1, SOIL2, RRTM, Micro and Gayno-Seaman. Each of these members contains physical parameterizations for either the soil, radiation, microphysics and boundary layer that were not available in our previous work utilizing MM5v2. In theory, the different parameterization schemes should span more of the possible solution space and lead to a more robust ensemble. Another primary difference from the previous work is in the utilization of more vertical levels for most simulations but allowing for an ensemble member with degraded vertical resolution compared to the ”Control” simulation.

A suite of members (ten in all) utilize different cumulus parameterization schemes. Although Tilley et. al (1999a) found that these ensemble members tended to form a tight cluster in their solutions, and thereby not contributing greatly to the ensemble, we wish to test whether that remains the case for a warm season event not dissimilar to those found in lower latitudes. Other ensemble studies (e.g., Stensrud et. al 1999) of this type for mid-latitude domains found significant variations among ensemble members with different convective schemes. Thus there is reason to believe that these members should make a significant contribution to the ensemble for a warm season Alaskan heavy rain event.

Following Tilley et. al (1999a), two members are generated by varying the initial conditions in a simple manner. This decision is based on the fact that our previous work suggested that some value was added to the ensemble through the inclusion of such members. The altered initial conditions are obtained by deriving averaged departure fields (Experiment-Control) at 12 hourly intervals from the entire set of “model physics” ensemble members. These departure fields are then further averaged over time to produce a single perturbation departure field, which is then added to and subtracted

Table 2: Root Mean Square Deviation, Surface Layer Temperature, 15 km MM5 Domain

Valid Time/ Simulation	8/11/00 18 UTC	8/12/00 06 UTC	8/12/00 18 UTC	8/13/00 06 UTC	8/13/00 18 UTC	8/14/00 06 UTC	8/14/00 18 UTC	time mean	rank
BMFC/.mixed phase	0.958	1.788	1.818	1.993	2.237	2.746	2.602	2.020	19
BMFC/ simple ice	0.977	1.768	1.883	1.938	2.165	2.558	2.463	1.965	10
BM/ mixed phase	0.958	1.775	1.817	1.987	2.237	2.841	2.632	2.035	21
BM/ simple ice	0.973	1.746	1.889	1.953	2.159	2.671	2.510	1.986	13
CCM2	1.144	1.955	1.732	2.038	2.154	2.51	2.191	1.961	9
Ensemble Mean	**0.878**	**1.755**	**1.764**	**1.961**	**2.171**	**2.625**	**2.433**	**1.941**	**4**
Fake Dry	0.957	1.74	1.823	1.985	2.261	2.747	2.610	2.018	17
KF/ mixed phase	0.958	1.763	1.816	1.962	2.233	2.679	2.575	1.998	14
KF/ simple ice	0.970	1.728	1.890	1.926	2.15	2.502	2.432	1.943	5
Gayno-Seaman PBL	0.983	1.861	1.729	1.928	1.983	2.494	2.235	1.888	1
Grell/ mixed phase (Control)	0.959	1.735	1.824	1.978	2.254	2.737	2.629	2.017	16
Grell/ simple ice	0.975	1.707	1.889	1.938	2.150	2.565	2.457	1.954	6
27Lev Interpolated	0.885	2.063	1.654	2.079	1.997	2.760	2.421	1.980	11
Kuo mixed phase	0.98	1.707	1.669	2.083	2.209	2.484	2.372	1.929	3
Kuo simple ice	0.981	1.676	1.743	2.027	2.129	2.386	2.296	1.891	2
Micro	0.957	1.815	1.819	1.975	2.226	2.572	2.496	1.980	11
MRF PBL	1.34	2.056	2.190	2.242	2.743	3.032	2.904	2.358	23
NO/ mixed phase	0.958	1.741	1.82	1.979	2.254	2.754	2.624	2.019	18
NO/ simple ice	0.972	1.711	1.892	1.940	2.152	2.580	2.459	1.958	7
IC -	0.956	1.736	1.822	1.981	2.257	2.739	2.622	2.016	15
IC +	0.972	1.711	1.892	1.940	2.152	2.580	2.459	1.958	7
RRTM	0.905	1.705	2.045	2.023	2.453	2.703	2.479	2.045	22
Shallow Conv	0.968	1.720	1.847	1.958	2.275	2.802	2.661	2.033	20
SOIL1	1.330	1.969	2.244	2.287	2.865	3.071	2.991	2.394	24
SOIL2	1.586	2.526	2.368	2.633	2.671	3.210	2.981	2.568	25

from the control initial conditions to produced two sets of perturbed initial conditions.

All simulations consider a protracted heavy rain event, including scattered embedded convective elements, over Interior Alaska during the period 13-17 August 2000. Rainfall accumulations of 2.5” occurred at several locations, and accumulations exceeding an inch were widespread throughout the central Tanana and Yukon River valleys, an area exceeding the size of the state of Connecticut denoted roughly by the shaded area in Figure1. The heavy rain resulted in the Tanana River and its tributaries exceeding flood stage for periods of up to two days following the event.

3. Preliminary Results

In this paper we present some early results of the ensemble simulations with an emphasis on skill score results for the 15 km domain shown in Figure 1. Skill score based validation measures examine the ability of the model to produce a correct grid-averaged forecast. Verifying data in this study consist of the LAPS-generated MM5 analyses on the two grids. One difficulty with this type of verification approach in this region lies in the fact that the amount of conventional and satellite data from the Arctic routinely incorporated into analyses through any analysis/assimilation system is still relatively sparse compared to lower latitudes. The result is that the analyses tend to contain less mesoscale information than is actually present. Accordingly, the skill scores measure not only how well the model forecasts the correct atmospheric state, but also how much mesoscale structure is captured in the forecast that is not present in the verifying analysis.

Table 2 presents root mean square (RMS) errors for surface layer temperature for the various ensemble runs and the ensemble mean (in bold type). Statistics are presented at 12 hour forecast intervals out to a maximum of 84 hours, plus a time mean of the statistics and a ranking based on the time mean values. Note that the 27 level experiment is represented only in this table as verified after the results are interpolated to 41 model sigma coordinate levels.

The RMS data reveal an expected general decrease in skill with time in all experiments out to approximately a forecast time of 60 hours; past this point the RMS errors slowly decrease with forecast time. We interpret this result as being related to the fact that after approximately a 60 hour period, much of the mesoscale structures associated with the precipitation event have begun to propagate out of the domain or dissipate. The MM5 simulation is then more influenced by the smoother synoptic scale structures that would be expected to be captured by the verifying analysis.

Except for the results of the two soil members, the range in this statistic is relatively small for this variable. The ensemble mean does provide modest improvement over most of the other members of the ensemble, including the Control run (Grell/mixed phase). The fact that both soil runs are strong outliers needs further study but suggests that the soil models may be introducing, through their more sophisticated land-atmosphere exchanges, significant mesoscale structure not present in the verifying analysis. We intend to investigate this hypothesis further in the future.

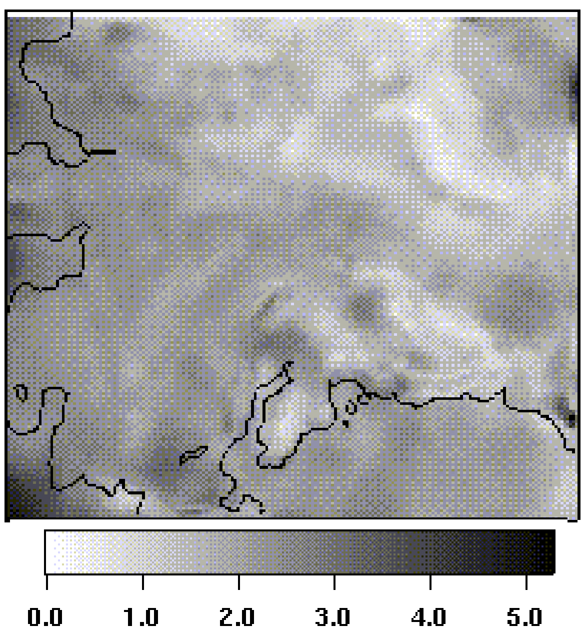

Figure 2. Time averaged root mean square error (K) of surface temperature for 15 km Ensemble Mean.

Figure 2 shows the time-averaged (12 to 84 hour forecast times) RMS error plot for the 15 km Ensemble Mean simulation. In general, the largest errors are found in those regions (Gulf of Alaska coast and western Alaska) most affected by maritime airmasses. and is consistent with the mixing ratio errors (not shown). We will explore this feature of the Ensemble Mean further in future work.

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