JP2.12 REVISITING THE UTILITY OF NEWTONIAN NUDGING FOR FOUR DIMENSIONAL DATA ASSIMILATION IN HIGH LATITUDE MESOSCALE FORECASTS

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1. INTRODUCTION

Despite previous studies and increasing interest, four dimensional data assimilation (FDDA) for mesoscale forecast simulations in high latitudes remains a relatively unexplored research area. At high latitudes, the conventional data that enters an initializing analysis is spatially sparse compared to lower latitudes, making FDDA a challenging enterprise.

In previous work (Tilley et al 1996), the utility of a one dimensional variational approach (VA) for assimilating moisture variables in the Penn State/National Center for Atmospheric Research MM5 model (e.g, Grell et. al 1994) was explored, with and without more traditional Newtonian nudging (NN; Stauffer and Seaman 1990) of the wind fields. The VA approach, which attempted to utilize TOVS-derived precipitable water and specific humidity profiles, was quite computationally expensive and did not necessarily produce improved results. Indeed the quality of the resulting simulation turned out to be heavily dependent upon the degree of agreement between the MM5 background within which the variables were assimilated and the base state assumed in the retrieval of the TOVS moisture variables. It did not appear to uniformly improve upon the NN method for the domain of interest over the Beaufort Sea.

While there is hope for other approaches including intermittent data assimilation (explored in a companion paper , Fan and Tilley 2001), there is still a need for FDDA in modeling applications which are computationally expensive, (e.g., ensembles) or need to execute rapidly (e.g.,real-time forecasting), For such applications, the NN method, despite its limitations due to the sparse observational coverage, may still be worth considering.

In this paper we revisit the NN method for an extended heavy rain event (totals of 1-2 inches reported) that took place in interior Alaska during August 2000. Such an event is extremely rare climatologically for this region, even given the fact that August is typically the wettest month for interior sections of Alaska.

We conduct MM5 simulations in which we vary the variables nudged, the nudging approach (nudging to observations, to an analysis or to both) and the nudging coefficients. The results are compared with each other and with NCEP analyses interpolated to the MM5 grid. Measures of skill are also computed to aid in the verification.

2. THE HEAVY RAIN EVENT OF AUGUST 2000

Figures 1a- 1f present an overview of the synoptic conditions, which contributed to the heavy precipitation event during 12-13 August 2000 in the Tanana and upper Yukon River valleys in interior Alaska. Figure 1a shows the sea level pressure field (SLP) in Pa for 12 UTC 11 August 2000. An unusually strong cyclone for this time of year is tracking along the eastern Arctic coast of Alaska, with an attendant trough/cold front extending through eastern interior Alaska southward to the Alaska Range. A larger area of cyclonic flow, with two embedded cyclones, is also present over eastern Siberia , with a trough over the Chukotsk Peninsula into the Bering Strait region. After a brief period where low level ridging develops from the south over interior Alaska, the dominant feature is the trough/warm front developing across the Bering Strait into interior Alaska in advance of the large eastern Siberia cyclone (Figure 1b, at 06 UTC 12 August). By 00 UTC 13 August (Figure 1c), a mesoscale area of low pressure has developed along the now-stationary front in eastern interior Alaska, producing a localized zone of strong convergence and embedded convective activity within a larger stratiform region of precipitation. This mesoscale low maintains its identity as it drifts slowly eastward over the next 24 hours, and by 06 UTC 14 August (Figure 1d), has developed into a well-defined meso-α scale cyclone with attendant troughs representing boundaries between warm and cold sectors.

In addition to the presence of strong low level convergence along the frontal boundary, the

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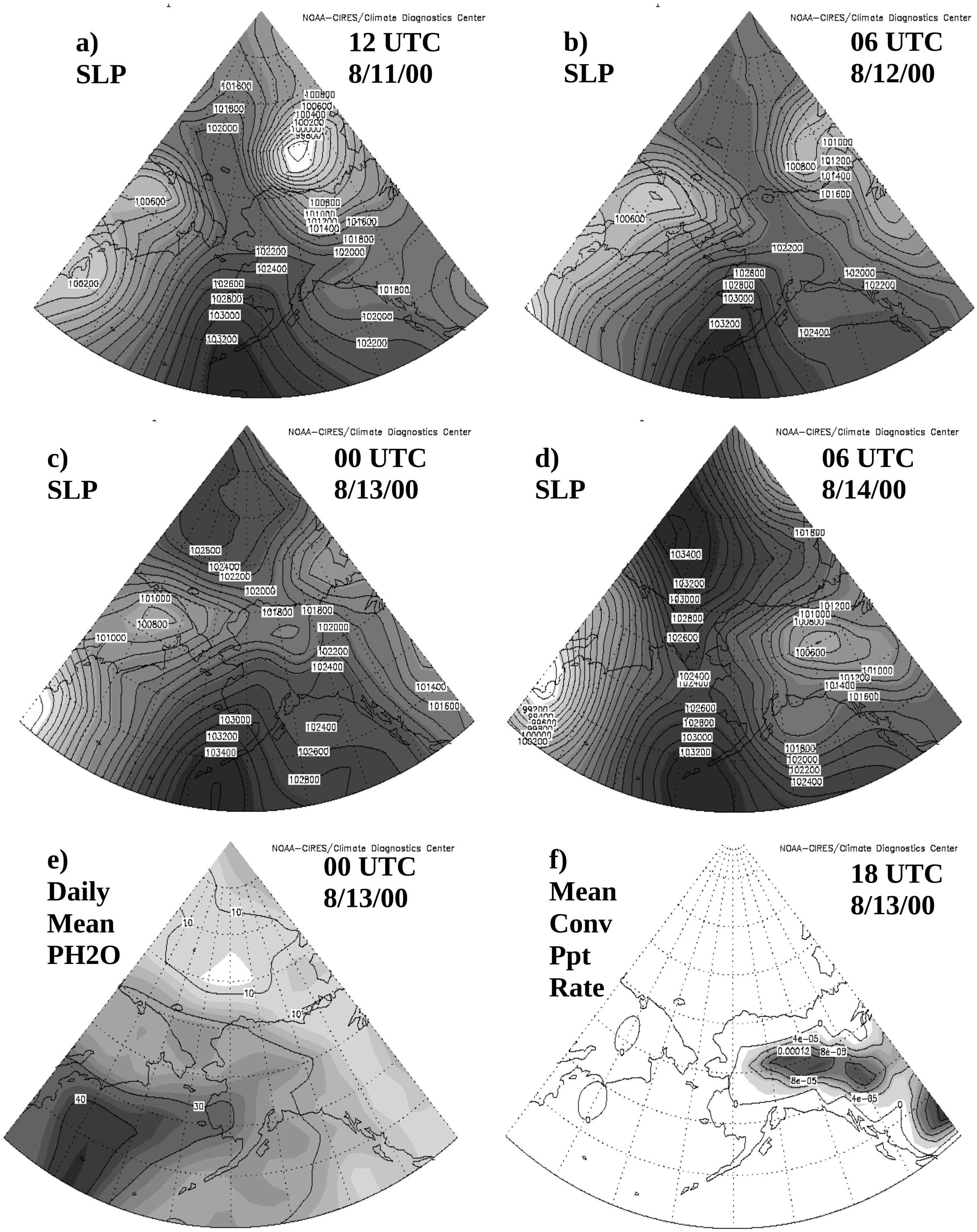

Figure 1. Charts illustrating salient features of the 12-13 August 2000 interior Alaska heavy rain event. Dates, times, fields are as indicated. SLP (a-d) in Pa; Precipitable Water (e) in kgm^{-2}; mean convective precipitation rate (f) in $kgm^{-2}s^{-1}$.

event was also facilitated by a strong inflow of moisture at low to mid-tropospheric levels into interior Alaska. The geopotential height fields at 700hPa during 12 August (not shown) indicate a strong ridge centered just south of the Aleutian Island chain, with a ridge axis extending through extreme Western Alaska. This pattern allowed for inflow of extremely moist air from the high subtropical latitudes northward into the Bering sea and then eastward into interior Alaska, as evidenced by a tongue of high precipitable water contents (> 20 kg/m2/sFigure 1e).

The strong low level convergence coupled with the embedded convective elements combined to produce rainfall totals in excess of 1 inch over a broad area of interior Alaska and totals in excess of 2 inches over sections of the Tanana Valley. Coupled with pre-existing high soil moisture and river levels from a wetter than normal summer, this rain event, itself climatologically extreme, produced the highest river levels in more than a decade on the Tanana River and its tributaries. Localized flooding was reported over the next 50 hours in areas directly adjacent to the Tanana River system.

3. EXPERIMENTAL DESIGN

Figure 2 shows the domains for the MM5 simulations. Two nested domains are used with grid resolutions of 45 and 15 km. 41 vertical computational levels are used in all simulations, which are run for a total duration of 48 hours.

We have performed several experiments along with a control run, which uses the standard MM5 initialization procedure with no FDDA applied. In all FDDA experiments the Newtonian nudging method (e.g., Stauffer and Seaman 1990) is utilized. Nudging to both an analysis and the observations are included in some experiments; others utilize only nudging to an analysis (derived from the NCEP analysis fields) or the observations alone. Other experiments examine the impact of varying the nudging coefficients or varying the actual variables nudged (e.g, winds vs. temperatures vs. mixing ratios). These last experiments were motivated by previous studies (e.g., Simpson and Stauffer 1996) where significantly different results were found by nudging different combinations of variables. Table 1 summarizes the experiments reported on here.

4. SAMPLING OF EXPERIMENTAL RESULTS

In this paper we focus on a sampling of the results of the FDDA experiments, specifically

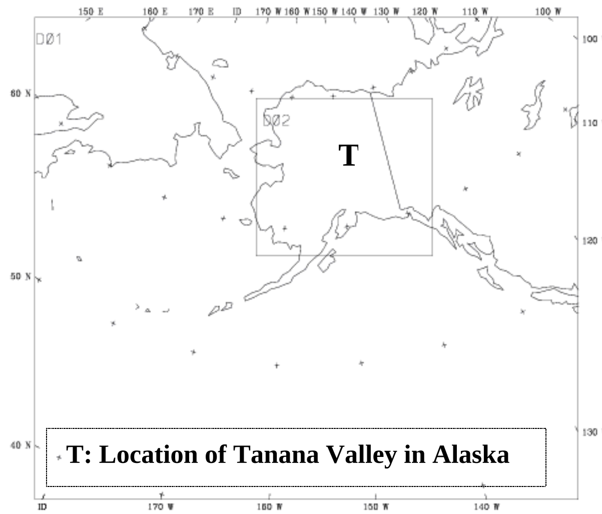

Figure 2. MM5 Domains used in the assimilation experiments. Grid resolutions are 45 and 15 km.

Experiment	Nudging Approach	Fields Nudged	Nudging Coefficient
Control	none	none	N/A
ObsWTQ	Obs Nudging	U,V, T, Q	U/V=2.0 10^{-4} T= 2.0 10^{-4} Q= 2.0 10^{-5} Both doms
ObsW	Obs Nudging	U,V only	U/V as in ObsWTQ
ObsQ	Obs Nudging	Q only	Q as in ObsWTQ
ObsAnal	Obs +Analysis Nudging	U,V, T, Q	Obs U,V, T, Q as in ObsWTQ; Analysis: U/V=1.0 10^{-4} T = 1.0 10^{-4} Both doms. Q_1 = 1.0 10^{-4} Q_2 = 1.0 10^{-5}

Table 1. Specifications of MM5 Nudging FDDA experiments presented in this paper. U and V designate wind components, T is temperature, Q is mixing ratio. Subscripts refer to domains.

the results on the 45 km domain for the 48 hour precipitation forecasts (12 UTC 13 August 2000). A more complete presentation of our results will be provided at the conference.

Figure 3a shows the NCEP analysis of accumulated precipitation during the 24 hour period from 12 UTC 12 August to 12 UTC 13 August, interpolated to our 45 km MM5 grid. Maxima are found immediately west of Attu Island at the western end of the Aleutian chain, the southern Chukchi Sea coast, northeastern British Columbia and Alaska's western Tanana valley near the confluence of the Tanana and Yukon Rivers. This latter maximum is slightly west of that reported by observing stations, though this is to be expected from a smoothed and relatively coarse analysis field. The analysis does, however, properly capture a tongue of large values extending southeastward through the remainder of the Tanana valley. The Control Run, shown in Figure 3b, reproduces many of the large scale precipitation patterns but differs substantially in the mesoscale details. Some of this is to be expected as the nested mesoscale MM5 grids should produce more mesoscale detail than the analysis, especially in the vicinity of complex terrain. Nonetheless the Control Run simulation considerably overforecasts precipitation over the oceanic areas, displaces the Chukchi Sea maximum northwards and fails to produce sufficient precipitation in British Columbia. On a more positive note, forecasted precipitation in the Tanana valley (denoted by the arrow labeled 'T' in Figures 2 and 3) more closely resembles the observations.

Figure 3c shows results from the ObsWTQ experiment. Overall there is some improvement from the Control Run in terms of the aforementioned oceanic areas (e.g, less precipitation forecast) and in terms of the precipitation coverage over British Columbia. The Chukchi Sea maximum is still displaced north and east from the analysis. In the Tanana valley, precipitation amounts are in excess of 34 mm, in good agreement with observations and an improvement from the Control Run.

Experiments ObsW and ObsQ, shown in Figures 3d and 3e respectively, do not show as much improvement from the Control Run as does experiment ObsWTQ. Comparing the ObsW and ObsQ results, it appears that wind nudging gives slightly better results over the oceanic areas and approximately 1-2 mm more precipitation over the Tanana Valley. The ObsQ simulation, on the other hand, produces a better simulation of precipitation in British Columbia.

The results from the ObsAnal experiment (Figure 3f), show the most improvement over the oceanic areas while at the same time reducing some of the terrain-associated variability in the precipitation field over Alaska seen in the ObsWTQ experiment. Simulated precipitation over the Tanana Valley, however, is reduced relative to ObsWTQ and so does not agree as well with observations.

It is important to note that the forecast results of other meteorological fields do not exactly mirror the results of the precipitation forecasts. Some of the simulations with relatively good precipitation forecasts do not always have the best temperature, wind and moisture forecasts, a point we will discuss more at the conference. Although it is difficult to make general statements based on a small sample of simulations, if nudging FDDA is to be used it may be necessary to determine the fields of greatest priority in terms of forecast quality. Once that is done, a nudging strategy could then be devised to optimize the resulting forecasts.

5. REFERENCES

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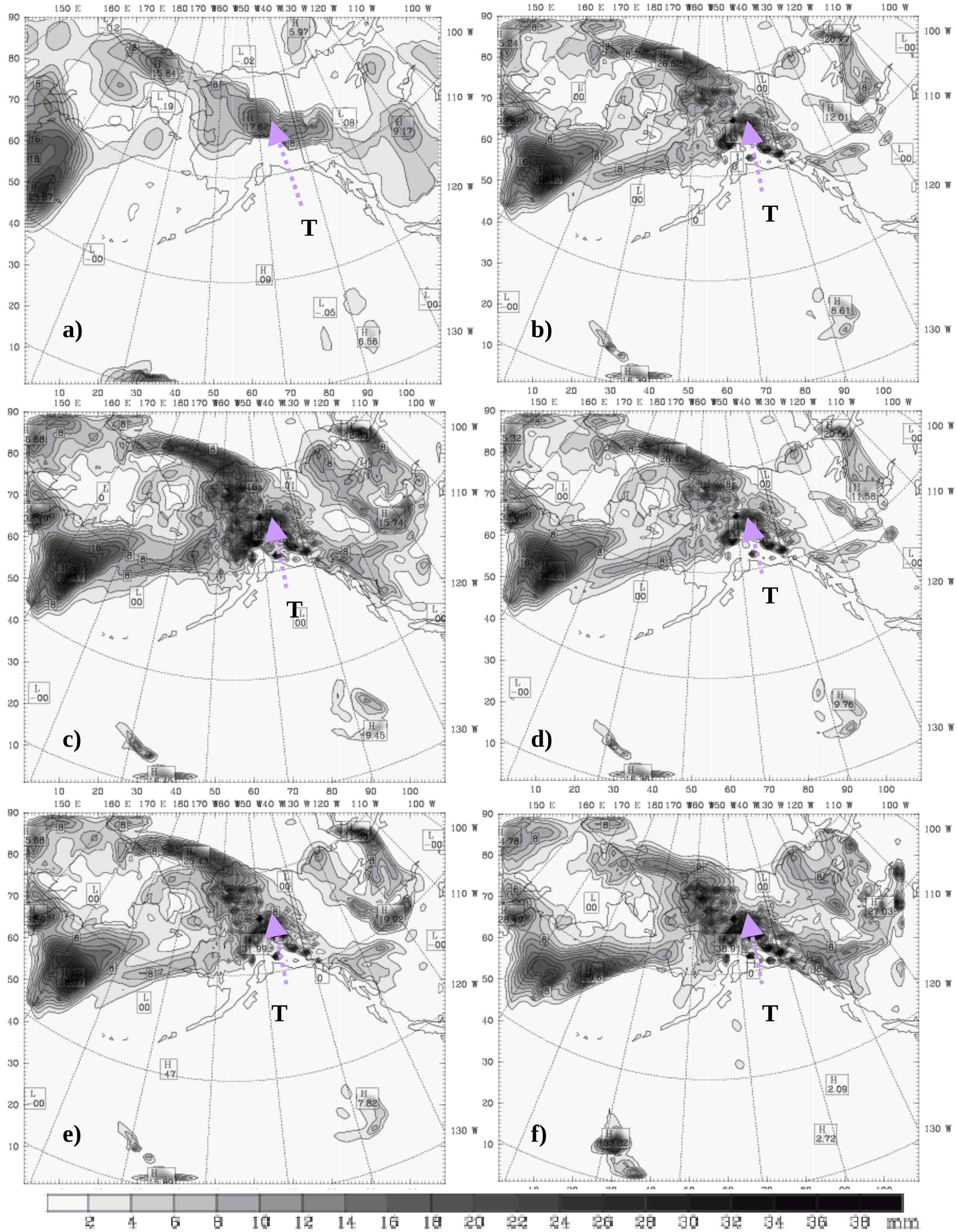

Figure 3. 24-hour accumulated precipitation (mm) for the period 12 UTC 12 August - 12 UTC 13 August 2000, on the 45 km domain, for (a) NCEP analysis; b) Control Run; c) Exp. ObsWTQ; d) Exp. ObsW; e) Exp. ObsQ; f) Exp. ObsAnal. Arrow marked 'T' points to the Tanana Valley (also cf. Fig. 2).