J2.1

GRASSROOTS SCIENCE AND TECHNOLOGY TRANSFER IN A COLLABORATIVE RESEARCH/OPERATIONAL ENVIRONMENT

John S. Kain[*,**,***] , Michael E. Baldwin[**,***,****], Steven J. Weiss[****], Paul R. Janish[****], J. A. Hart[****], and A. Just[****]

[**]Cooperative Institute for Mesoscale Meteorological Studies

[***]NOAA/OAR/National Severe Storms Laboratory

[****]NOAA/NCEP/NWS/Storm Prediction Center

1. INTRODUCTION

Collaboration between operational weather forecasters and research meteorologists provides a unique opportunity to advance the science of meteorology by promoting better understanding and improved prediction of atmospheric processes, yet sustained collaborations between these two groups are relatively rare. Forecasters perform an in-depth analysis of atmospheric conditions nearly every day and they often observe processes or phenomena that are not well understood, but are critically important to forecasting accurately weather that can threaten life and property. Many forecasters have a keen insight into the weather and an interest in doing applied atmospheric research, but often they are provided little in the way of appropriate guidance or mentoring, diagnostic tools, or time for independent research projects (Doswell 1986; Auciello and Lavoie 1993). On the other hand, many meteorological research scientists have at their disposal a vast array of diagnostic tools, numerical models, theoretical knowledge, and experience in formal research efforts. Yet, most meteorological research does not have direct implications for improving weather forecasts, despite the obvious societal benefits of applied research (Serafin et al. 2002). The failure of meteorological researchers and forecasters to collaborate on a consistent and widespread basis appears to be a serious impediment to solving many of the science's most accessible problems (Doswell et al. 1981).

One way to promote collaboration between the two groups is to make their physical environment and proximity conducive to interactions. In early 1997 the Storm Prediction Center (SPC) moved into the National Severe Storms Laboratory (NSSL) building in Norman, Oklahoma, combining the scientific staff of NSSL and the forecasting expertise of the SPC under one roof. Prior to the arrival of the SPC, a "Science Support Area" was established adjacent to the SPC operational forecasting area. This area was designed to mirror the operational forecasting environment without interfering in daily forecast operations, so that the operations could be simulated realistically. A small group of NSSL scientists with an interest in applied research problems was assigned to work with the SPC to pursue operationally relevant research and to facilitate interactions between the SPC and the larger NSSL scientific community. After the arrival of the SPC, a routine of daily interactive map discussions was initiated in the SSA, in part to provide a forum where the common interests and concerns of forecasters and researchers could draw the two groups together and cultivate collaborative research efforts.

The combination of this unique work environment and a favorable evolution of the "human element" (Doswell 1986; Howard et al. 1986) fostered a productive interaction at the NSSL/SPC facility. Numerous collaborative research studies have been brought to fruition in recent years (e.g., Baldwin et al. 2002; Evans and Doswell 2001; Kain et al. 2000, 2002, 2003a) and others are underway. Organized interactions on a larger scale have matured as well, as exemplified by intensive multi-week research efforts conducted during the peak severe weather season each spring, known as the "Spring Program" (Kain et al. 2003b).

In this paper, we focus on one aspect of this collaboration. In particular, we concentrate on the infusion into SPC operations of fundamental concepts and tools related to the representation of moist convection in numerical weather prediction. We start with an overview of motivating factors for this collaboration, followed by examples of diagnostic information and tools that have been introduced in SPC operations, then a discussion and concluding remarks.

2. MUTUAL INTEREST AS A CATALYST FOR INTERACTION AT NSSL/SPC

As suggested in the Introduction, a number of factors are important for promoting interactions between forecasters and researchers. However, collaborative activities tend to be uninspired without a shared enthusiasm for particular meteorological problems. Mutual interest has played an important role in motivating collaborative activities at NSSL and SPC. In this section, the backgrounds and interests of the first four authors (and lead-

[*] *Corresponding author address:* Jack Kain, NSSL, 1313 Halley Circle, Norman, OK 73069

ers of the collaborative efforts) are reviewed, since they are very relevant to the success of the collaboration.

The first two authors of this paper began working at the NSSL facility around the time that the SPC operations commenced in Norman. The first author had a robust background in convective parameterization and experience using the MM5 model as a diagnostic and forecasting tool. He was attracted to NSSL by a desire to work with operations, but he had no experience with operational models nor with an operational forecasting environment. The second author arrived at NSSL/SPC while still working for the Environmental Modeling Center (EMC). He possessed a broad background in operational numerical modeling, with expertise in the Eta model and its physical parameterizations. He also had a strong interest in working with operational forecasters. These two authors soon forged a working relationship, establishing a realtime Eta model forecast at NSSL (hereafter EtaKF) using the Kain-Fritsch convective parameterization (Kain and Fritsch 1993 – hereafter KF) in place of the operational Betts-Miller-Janjic scheme (Janjic 1994 – hereafter BMJ). Before long, they developed the capability to display output from these parallel forecasts on operational SPC workstations

The third author arrived in Norman with more than twenty years of forecasting experience with the SPC (formerly the National Severe Storms Forecast Center), over a decade of that as a Lead Forecaster. He had an established record of scientific research related to severe storms forecasting. He had a distinct interest in numerical weather prediction, but was relatively isolated from numerical modeling research in the SPC's former home of Kansas City. The fourth author had a varied background in applied meteorology, with a particular interest in severe weather. He arrived in Norman as an employee of NSSL in 1992 and was instrumental in organizing seminal collaborative activities with the National Weather Service's Norman Weather Forecasting Office (WFO), such as the Experimental Forecast Facility (Janish et al. 1995). In 1996 (?) he joined the Science Support Branch of the SPC.

In the favorable environment that was established at the NSSL/SPC facility, collaborative activities between these individuals began to thrive. P. Janish and J. Kain established and organized daily map discussions. These discussions frequently included detailed examination of model output, with a particular emphasis on the evolution of model soundings and the impact of model convective parameterizations on sounding structure and other model output fields. Through these discussions a heightened awareness and understanding of model behavior developed among forecasters. Likewise, local numerical modelers developed a sense of appreciation for ways that forecasters utilize model output and the operational constraints that forecasters face.

M. Baldwin utilized his extraordinary skills in data management and his insight into the meteorological significance of model output to access and present experimental EMC datasets to SPC forecasters. He worked with J. Kain to extract and display unique information from the KF convective scheme that had direct implications for SPC convective initiation forecasts. S. Weiss mentored these interactions and served as the primary conduit into operations for the grassroots knowledge that emanated from the group. Finally, in the spring of 2000 and again in 2001 these four individuals rallied behind the organizational leadership of Paul Janish to conduct multi-week Spring Programs, experimental forecasting and model evaluation exercises that included forecasting and modeling experts from NSSL, SPC, the Norman WFO, EMC, Forecast Systems Laboratory, and Iowa State University (Kain et al. 2003b).

The mutual interests, complementary skills, and compatible personalities of these four individuals have played a critically important role in developing a relatively rare synergy between operations and research. In combination with strong technical support from individuals such as the fifth and sixth authors of this paper, the collaborative working relationship at NSSL/SPC "greased the skids" for effective infusion of science and technology into operations.

3. EXAMPLES OF SIMPLE BUT EFFECTIVE TECHNOLOGY TRANSFER

Although many of the benefits of the NSSL/SPC interactions are intangible, several unique output fields and diagnostic tools have made their way into operations as a direct result of the working relationships described above. In this section we provide examples of these more tangible benefits, all of which are inspired by semi-operational comparisons of the Eta and EtaKF forecast models.

3.1 Parameterized updraft mass flux

Operational NWP models do not provide explicit forecasts of the vigor of deep convection. They *do* provide predictions of convective rainfall rate, but forecaster experience suggests that *this field is not a reliable indicator of convective intensity.* When we first started running the KF parameterization in the Eta model several years ago, this contradiction became apparent. In examining several numerical forecasts of severe weather events, we noted that convective rainfall coverage was often correctly predicted by the model when severe weather occurred, but light rainfall amounts generated by the scheme failed to indicate the severity of the convection. Similar behavior occurred with other convective parameterizations that we evaluated.

Further examination of the EtaKF forecasts in these cases revealed that even though rainfall rates were low, the KF scheme was feeding back very strong temperature and moisture tendencies to resolved scales in the model. We sought to convey something about the character of convective activity to users by supplementing convective rainfall output with a measure of the strength of parameterized adjustments to the model's atmosphere. We settled on a normalized parameterized updraft mass flux (UMF*) because it can be readily conceptualized as the amount of mass flowing through cloud base and it can be simply expressed on a scale from 0 to 1 (Kain et al. 2002).

The distinctly different information provided by the UMF* field is exemplified in model forecasts from 9 May 2001. On this day, late afternoon convective activity was predicted by the model along the Gulf Coast States and over the Northern Plains. Three-hour precipitation totals for these two areas were comparable, with maximum values close to 0.25 in. (Fig. 1a and b). The precipitation fields suggested that convection would be organized in a band over Iowa and Nebraska, but would be more loosely organized over Louisiana. Otherwise, there was little indication of differences in the character of convective activity and the potential threat to life and property.

The UMF* field painted a different picture. The EtaKF predicted very high UMF* values over parts of the Upper Midwest (Fig. 1c). In contrast, comparatively weak values were predicted over Louisiana (Fig. 1d). Consistent with these differences in UMF*, widespread severe weather was observed over the Northern Plains while a single severe report came in from the Gulf Coast States (Fig. 2).

Forecasters at the SPC appreciate having this unique predictor of convective intensity as a supplement to more "traditional" model output fields. In addition, we also provide an "updraft source level" field from the EtaKF (not shown). This output field is simply a horizontal plan view of the pressure level from which the parameterized cloud draws its mass. This field has shown remarkable skill in distinguishing between thunderstorm potential from surface-based parcels versus elevated storms. The latter can still be severe but are much less likely to be associated with tornadoes, thus this distinction has direct implications for deciding what type of

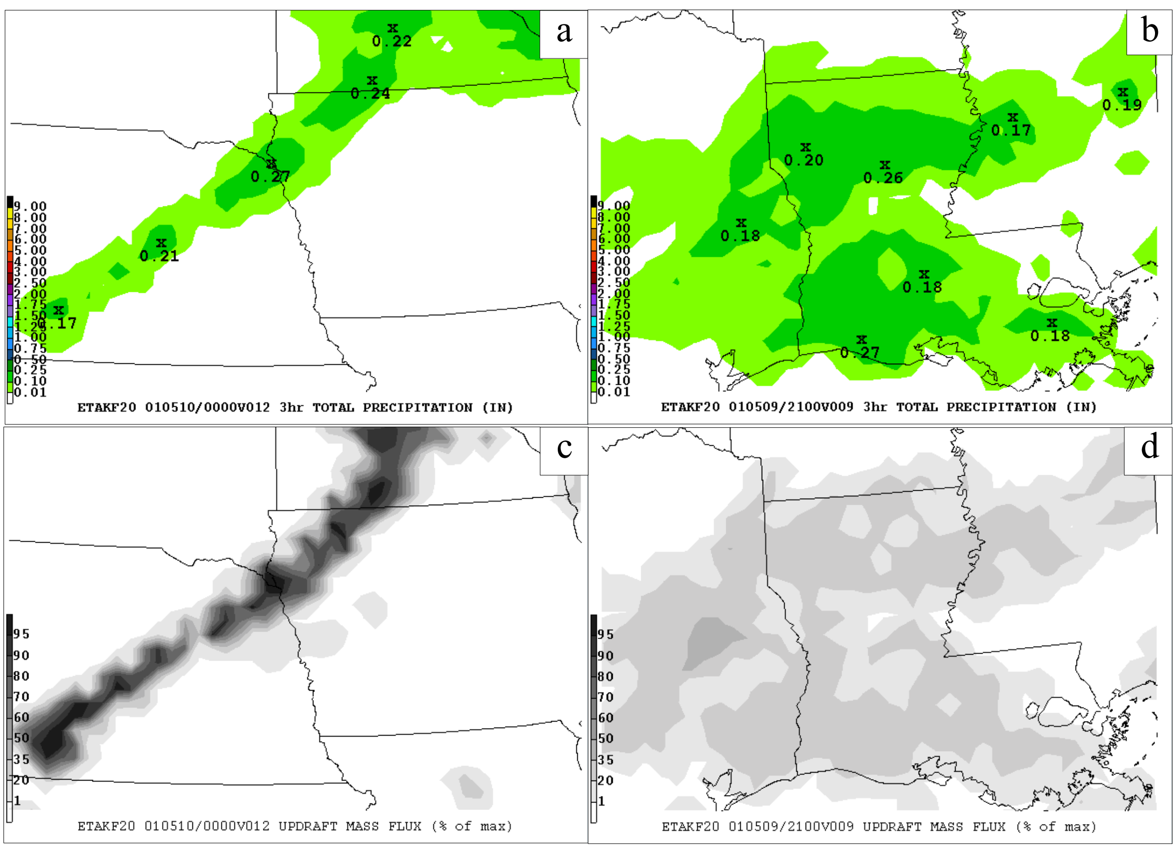

Fig. 1. Comparison of convective characteristics predicted by the EtaKF for late afternoon/early evening 9-10 May 2001. Left-side panels are for the Iowa/Nebraska region while right-side panels are for Louisiana and surrounding areas. a) and b) show 3 h accumulated precipitation ending 10/0000 UTC and 09/2100 UTC, respectively; c) and d) show UMF (%, maximum during previous hour) valid 10/0000 UTC and 09/2100 UTC, respectively.*

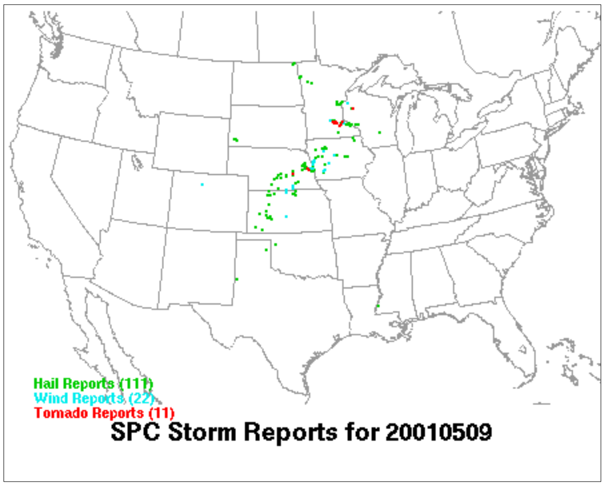

Fig. 2. Local storm reports for the 24 h period ending 1200 UTC 10 May 2001.

severe weather may threaten in a given situation.

3.2 On-line diagnostic versions of the BMJ and KF parameterizations

While this unique output from the EtaKF run can have a direct impact on forecasting decisions, it also intrigues forecasters about convective parameterization techniques and the impact of parameterizations on model forecasts. It arouses curiosity and motivates forecasters to become more educated users of numerical models.

In recent years, many SPC forecasters have become quite adept at identifying and interpreting the impacts of parameterized shallow (non-precipitating) clouds on the evolution of model forecast soundings, particularly impacts related to the BMJ convective scheme. This skill has been developed as a direct result of a collaborative infusion of knowledge about this scheme. This infusion began with frequent examination of model sounding structure and evolution during daily NSSL/SPC map discussions. When it became apparent that valuable information could be gleaned from these examinations, characteristic behaviors of the BMJ scheme were documented, disseminated internally, and submitted for formal publication (Baldwin et al. 2002). This information was reinforced in formal SPC training sessions. Finally, NSSL scientists collaborated with SPC forecasters and support personnel to incorporate *diagnostic versions of the BMJ and KF convective schemes* in the SPC's N-SHARP sounding analysis program.

The utility of these routines can be demonstrated by examining 48 h forecast soundings from the Eta and EtaKF, valid 0000 UTC 29 March 2002. At Shreveport, LA (SHV) the Eta predicted a very unstable structure, with CAPE values of 3100 J kg^{-1} and little convective inhibition (CIN; Fig. 3a). In contrast, a sounding for the same time and place from the parallel EtaKF run produced a distinctly different vertical structure, with CAPE of less than 1400 J kg^{-1} and a significant inhibition layer near 800 mb (Fig. 3b). Differences of this magnitude are fairly common as the BMJ scheme tends to be much more aggressive than the KF in parameterizing shallow convection, sometimes resulting in a spurious erosion of the CIN layer (Baldwin et al. 2002).

By clicking on the "BMJ" button located on the bottom right side of the N-SHARP window (Figs. 3a, b), SPC forecasters can activate the BMJ scheme with the input sounding shown on their computer screen. A secondary window appears, prompting the forecaster to proceed step-by-step (2-3 steps) through a graphical depiction of the BMJ algorithm. The final step shows the "adjusted" BMJ sounding structure overlaid on the input sounding (Fig. 3c). In this case, it can be seen that the BMJ scheme activates shallow convective tendencies and imposes characteristic smooth profiles of temperature and moisture between about 925 and 725 mb. Note

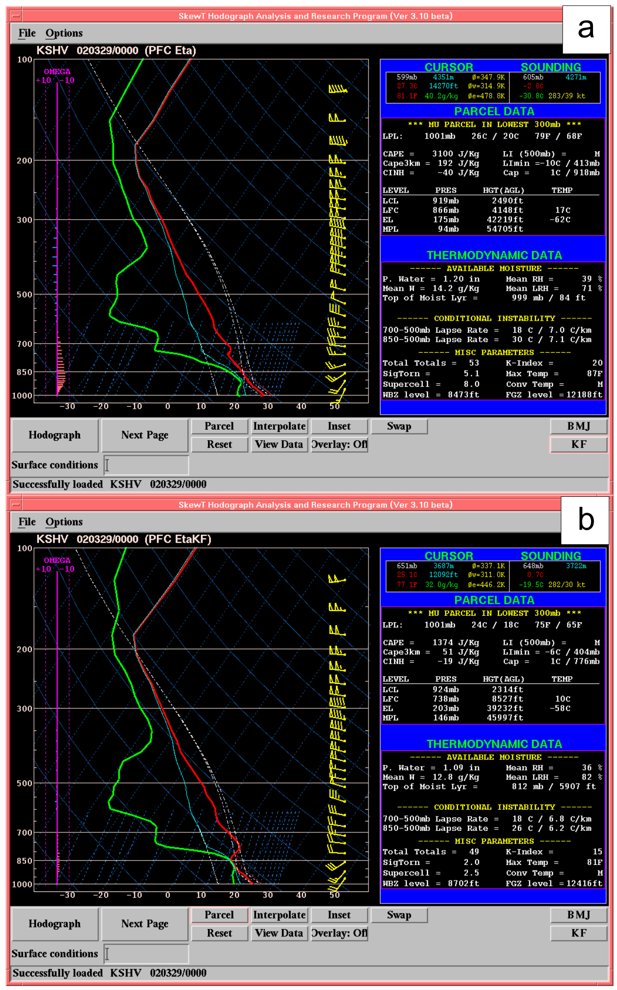

Fig. 3. Model forecast soundings for 48 h forecasts valid 0000 UTC 29 March 2002 from the a) Eta and b) EtaKF. Images are taken from the N-SHARP sounding analysis

that the scheme's temperature adjustment extends up into the stable layer near 700 mb. Examination of previous hours' soundings (not shown) reveals that this process of chipping away at the "cap" in a stepwise fashion results in the elimination of the CIN layer in the Eta forecast. Similar analysis of the EtaKF soundings and diagnostic output from the KF scheme reveals more intermittent shallow convective activity and a more shallow layer of influence (not shown).

The diagnostic tools and output fields described above have been very effective at reinforcing the topics covered in SPC training sessions, at enhancing forecaster interest in numerical models, and in helping SPC forecasters to interpret the evolution of model forecast soundings during operations. Collaborative activities at NSSL/SPC effectively function as an educational program that generates interaction, discussion, and relatively simple diagnostic tools to help remove the shroud of mystery from numerical weather prediction models and other forecasting tools. This ultimately makes forecasters better equipped to do their jobs.

4. SUMMARY

Collaboration between operational forecasters and research scientists has the potential to stimulate significant advances in weather forecasting and applied meteorological research. Yet, sustained collaborations between these two groups are quite rare. In order to promote collaborative efforts between forecasters at the SPC and like-minded research scientists at the NSSL, the SPC (formerly the Severe Local Storms unit of the National Severe Storms Forecast Center) was directed to relocate from Kansas City to Norman in the mid 1990s (McPherson 1994). The NSSL created space in its building for the SPC, and complete forecast operations were officially transferred to Norman in early 1997.

Since that time, collaborative research between the SPC and NSSL has begun to thrive. Significantly, an important component of the NSSL/SPC interaction has occurred at a grassroots level. During the first couple of years after the transfer, forecasters and research scientist from the two organizations developed a comfortable working relationship through casual interactions, daily map discussions, and a mutual interest in the weather. Additional interactions came from sharing responsibilities during organized, externally driven programs. These interactions catalyzed a number of smaller research efforts. Beginning in 2000, the SPC and NSSL's Mesoscale Applications Group took an important step by designing collaborative multi-week experiments driven by *internal* research objectives. These annual events are called the "Spring Program" and have attracted enthusiastic participation from EMC, the Forecast Systems Laboratory, the Norman WFO, and Iowa State University.

Several tangible benefits have been generated as a direct result of NSSL/SPC collaborative activities. Routine examination and interrogation of model-forecast soundings from the Eta model allowed us to document common irregularities in sounding structure associated with the model's convective parameterization scheme. This documentation was recently compiled in a paper designed to provide forecasters with guidance in interpreting Eta-model soundings (Baldwin et al. 2002). Parameterized updraft mass flux, a unique predictor of convective intensity from the KF convective scheme, has earned the confidence of forecasters at the SPC and elsewhere. This output parameter is described in Kain et al. (2002). Subjective evaluations and verifications of model forecasts from the Spring Program have been summarized and compared to objective verification measures. Summary statistics for precipitation fields are provided in Kain et al. (2003a). In addition, sounding analysis programs in SPC operations have recently been modified to include diagnostic versions of the BMJ and KF convective parameterizations. This software infusion came about because significant differences between Eta and EtaKF model soundings have been documented during Spring Programs and daily map discussions. SPC forecasters rely quite heavily on model forecast soundings in assessing the potential for convective initiation and intensity. The

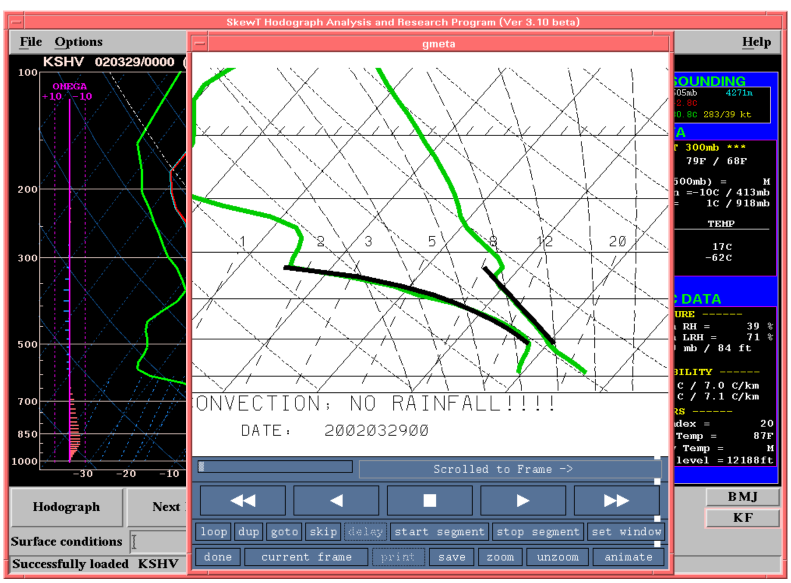

Fig. 4. "pop-up" window (inset) showing a graphical depiction of the convective tendencies introduced by the BMJ scheme. Input sounding is depicted by thick, gray lines while the "convectivelyadjusted" sounding introduced by the BMJ scheme is depicted by thick black lines.

diagnostic versions of the schemes have proven to be very helpful in facilitating educated interpretations of model soundings and understanding the behavior of the two convective schemes.

The collaboration has also produced many intangible benefits. Model developers have worked side by side with the end users of their product – operational forecasters. They have gained valuable insight into how their products are being used and how they might be improved to meet the needs of forecasters more effectively. At the same time, forecasters have been given a rare opportunity to discuss various applications and interpretations of NWP models with their developers in the context of a simulated operational forecasting environment. Thus, forecasters have became more confident and educated users of one of their primary guidance tools. Perhaps most importantly, the interactions at the NSSL/SPC facility promoted solid working relationships between the operational and research communities. These relationships will form the foundation for expanding collaborative efforts in coming years.

ACKNOWLEDGEMENTS

Special thanks to NSSL and SPC management for establishing and supporting a collaborative framework. We appreciate the many contributions of Mike Kay and Greg Carbin of the SPC. In addition, Brett Morrow and Steve Fletcher of NSSL and Phillip Bothwell, Jay Liang, Gregg Grosshans, and Doug Rhue of SPC provided invaluable support. The last author, Andrew Just, is a participant in the DOC Student Career Experience Program (SCEP). He works at WFO Marquette, MI during the summer and at the SPC during the school year. This work was partially funded by COMET grant S01-32796.

References

Auciello, E. P., and R. L. Lavoie, 1993: Collaborative research activities between national weather service operational offices and universities. *Bull. Amer. Meteor. Soc.*, **74**, 625-629.

Baldwin, M. E., J. S. Kain, and M. P. Kay, 2002: Properties of the convection scheme in NCEP's Eta Model that affect forecast sounding interpretation. *Wea. Forecasting,* in press. [Also available from http://www.nssl.noaa.gov/mag/bmj_paper_all.pdf]

Doswell, C. A., III, L. R. Lemon, and R. A. Maddox, 1981: Forecaster training – a review and analysis. *Bull. Amer. Meteor. Soc.*, **62**, 983-988.

Doswell, C. A., III, 1986: The human element in weather forecasting. Nat. Wea. Digest, 11, 6-17.

Evans, J. S., and C. A. Doswell III, 2001: Examination of Derecho Environments Using Proximity Soundings. *Wea. Forecasting*, **16**, 329–342.

Howard, K. W., D. R. Devore, R. A. Maddox, C. A. Doswell, III, and K. Crawford, 1986: Fundamental considerations for designing and implementing the experimental forecast center concept. *Preprints, 11th Conference on Weather Analysis and Forecasting*, Kansas City, MO, 359-363.

Janish, P. R.*, M. L. Branick, and L. J. Ruthi, 1995: The experimental forecast facility: establishing collaboration between applied research and NWS operations. Preprints, 14th Conf. on Weather Analysis and Forecasting, Dallas, TX, 17-22

Janjic, Z.I., 1994: The step-mountain eta coordinate model: Further developments of the convection, viscous sublayer, and turbulence closure schemes. *Mon. Wea. Rev.*, **122**, 927-945.

Kain, J.S., and J.M. Fritsch, 1993: Convective parameterization for mesoscale models: The Kain- Fritsch scheme. The representation of cumulus convection in numerical models. Meteor. Monogr., No. 24, Amer. Meteor. Soc., 165-170.

Kain, J. S., S. M. Goss, and M. E. Baldwin, 2000: The melting effect as a factor in precipitation-type forecasting. *Wea. Forecasting*, **15**, 700-714.

Kain, J. S., M. E. Baldwin, and S. J. Weiss, 2002: Parameterized updraft mass flux as a predictor of convective intensity. Submitted to *Wea. Forecasting.* [Also available from http://www.nssl.noaa.gov/mag/UMF_paper.pdf]

Kain, J. S., M. E. Baldwin, and S. J. Weiss, P. R. Janish, M. P. Kay, and G. Carbin, 2003a: Subjective verification of numerical models as a component of a broader interaction between research and operations. Submitted to *Wea. Forecasting*.

Kain, J. S., P. R. Janish, S. J. Weiss, M. E. Baldwin, R. S. Schneider, and H. E. Brooks, 2003b: Collaboration betweeen forecasters and research scientists at the NSSL and SPC. Submitted to *Bull. Amer. Meteor. Soc.*

McPherson, R. D., 1994: The National Centers for Environmental Prediction: Operational climate, ocean, and weather prediction for the 21st century. *Bull. Amer. Meteor. Soc.*, **75**, 363-373.

Serafin, R. J., A. E. MacDonald, and R. L. Gall, 2002: Transition of weather research to operations: Opportunities and challenges. *Bull. Amer. Meteor. Soc.*, **83**, 377-392.