9.9 INFERENCES OF PREDICTABILITY ASSOCIATED WITH WARM SEASON PRECIPITATION EPISODES

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1. INTRODUCTION

The skill associated with warm season rainfall predictions is low, both by absolute standards and relative to predictions of cool season precipitation. Our main purpose is to report the existence of coherent warm season precipitation patterns that are continental in scale and exhibit durations well in excess of typical mesoscale convective lifecycles. We refer to the coherent rainfall patterns as "episodes" to draw a distinction between the largest and longest duration events and individual convective complexes (e.g. Laing and Fritsch, 2000). The time-space coherence of precipitation patterns is suggestive of intrinsic predictability associated with warm season rainfall. Our presentation will provide a statistical description of episodes for the warm seasons 1997-2000, as derived from continent-scale analyses of WSR-88D data. A complete description of this work is provided by Carbone et al. (2001).

2. GENERAL APPROACH

Our strategy is to apply very simple treatments to massive quantities of data over a continent-scale domain. The focal point of this paper is examination of WSR-88D national composite data as provided by the WSI Corporation NOW*rad*™ product. Products such as NOW*rad*™, while inadequate for some research purposes, have been the only practical vehicle for access to complete spatial and temporal coverage at high horizontal resolution within the WSR-88D network. The properties of this NOW*rad*™ product include a ~2 km latitude/longitude grid with 15 min. resolution and 16 levels of radar reflectivity factor data (10 log Z_e (mm^6 m^{-3})) at 5 dBZ$_e$ intervals. The precise algorithm for creating this composite is information proprietary to WSI Corporation, however, it is commonly described in the following manner. The maximum level of dBZ$_e$, as measured by any WSR-88D radar at any height in a given vertical column, is assigned to the appropriate horizontal grid location.

While WSR-88D data are limited in their capacity to represent local rainfall rates or cumulative rainfall amounts (e.g. Klazura et al., 1999), these are satisfactory to identify practically all areas that experience precipitation east of the continental divide. While observational gaps exist west of the divide, the fractional area of coverage is sufficiently large to permit (at least) intermittent detection and tracking of major mesoscale events. We examine these data with respect to space-time coherency given the tacit assumption that coherency provides clues as to the spatial and temporal scales of intrinsic predictability.

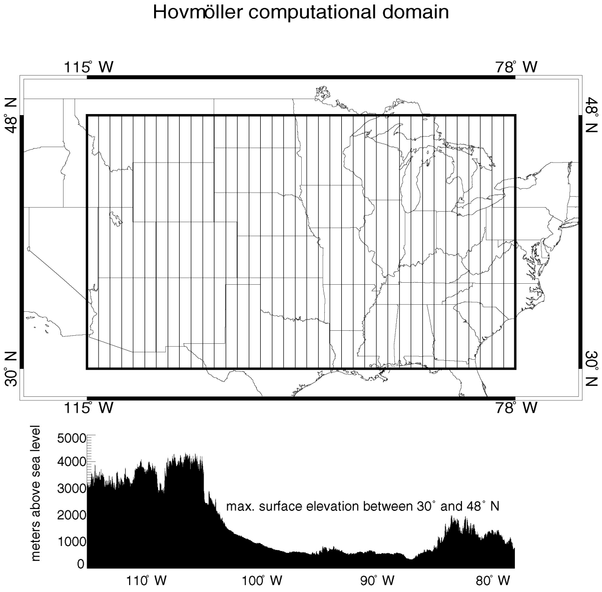

Fig. 1. Computational domain (upper) and maximum elevation (m, msl) of terrain vs. longitude (lower).

The "warm season" is defined as May-August and we have compiled data within the domain (Fig. 1) for seasons 1997 through 2000. We apply a power-law transformation of the form $Z = aR^b$ in order to linearize the signal with respect to rainfall rate. We have set $a = 300$ and $b = 1.5$ since these values render a relatively small net bias in the global average when compared to national analyses of rainfall (Klazura et al., 1999). The particular values are of little consequence to our analyses since rainfall estimation per se is peripheral to our application.

Time-distance plots (referred to as "Hovmöller diagrams") are often used for the diagnosis of coherent signals in climate science. Carbone et al. (1998), among others, have recently applied this tool at the mesoscale to study the lifecycle of precipitation systems using Doppler radar data. Most of our diagrams exhibit longitude as the distance dimension, since this is the principle direction of precipitation system motion over North America. The 1° vertical columns in Fig. 1 are symbolic of meridional averaging intervals, which are

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actually 0.05° (~ 4 km) wide. The estimated rainfall rate is arithmetically averaged over each column.

We have performed various calculations from the Hovmöller diagrams for the purpose of quantifying event coherency, longevity, zonal distance (hereinafter referred to as "span") and rate of propagation. Two-dimensional autocorrelation functions have been fit to the rainfall data in Hovmöller space. These functions define the coherent span, duration and propagation characteristics for each "rain streak," which is a time-longitude swath of rainfall. Most major episodes in Hovmöller space continuously produce at least some detectable precipitation throughout the episode duration. Coincidence errors (simultaneous events at different latitudes) occur in approximately 2% of all autocorrelation fits and have been manually corrected after review of the three dimensional data.

An additional set of Hovmöller diagrams, based upon the frequency of echoes at each UTC time/longitude coordinate, has been created to examine the phase-locked behavior of precipitation echo at diurnal and higher frequencies. Every radar echo above ~10 dBZ_e constitutes an "event" at a longitude/time coordinate. The cumulative event frequency was averaged for monthly and seasonal periods as well as the entire 16-month period of record. Discrete Fourier Transforms (DFTs) and harmonic decomposition analyses were performed on these data to quantify diurnal and semi-diurnal signals as well as to reveal intra-seasonal variations.

3. DISCUSSION AND CONCLUSIONS

a. Principal findings

The analyses and the statistics derived therefrom support the following conclusions:

- Coherent rainfall events, of order 1000 km in zonal span and one-day duration, occur with high frequency (nearly one per day).
- Many of these events are of longer duration and a larger zonal extent than is normally associated with mesoscale convective systems.
- Such occurrences are believed to be *compound events*, a coherent succession of convective systems. We refer to these as "episodes."
- Coherent dissipation and regeneration of convective rainfall within episodes suggests a causal relationship among successive systems.
- Owing to the spectrum of phase speeds associated with episodes, a wave-like propagation mechanism of convective origin is suggested.
- Steering Level is not a strong function of wind speed (i.e. propagation is additive to the wind).
- A significant portion of episodes exhibits phase-locked behavior, consistent with the combined effects of thermal and topographical forcing.
- The principal signals resulting from phase-locked events are (1) diurnal forcing over the eastern and western cordilleras and (2) semi-diurnal forcing between the cordilleras.

b. Discussion

Adequate representation of convection is generally regarded as an unsolved problem in numerical weather and climate prediction. Our findings contain inferences of predictability by reason of precipitation coherence patterns that exceed the dimensions of convective system lifecycles. Furthermore, the coherence properties are not "tightly held" by transient disturbances in the westerlies. We hypothesize that the principal significance of this study has its roots in dynamics at the mesoscale and the capacity of organized convective effects to scale upwards and to act remotely.

The statistics establish a *prima fascia* case for dynamical linkages among successive convective systems. The linkages exhibit phase coherence with respect to antecedent convective systems that are often forced diurnally. Because rain streaks are often not located optimally with respect to large scale forcing, there is presumed to be a causal "upscale" or "downstream" effect resulting from the antecedent convection. Judging from the amplifications and dissipations along many rain streaks, several generations of organized convection may be causally related in this manner.

Convective precipitation lifecycles are essentially unknown in today's weather and climate forecast models. It would seem advisable to communicate such forcings to the grid scale to permit the propagation of convection and the attendant rainfall. As will be shown in our presentation, the precipitation patterns are suggestive of a "remote response" to the North American monsoon, linking precipitation systems over central and eastern North America to the western cordillera. The challenge is to understand these dynamical linkages as a necessary step toward proper representation.

What mechanisms exist? We offer a statistical result pointing toward wave-like propagation. At least two broad categories are evident:

- Density (or gravity) currents and various forms of trapped gravity waves in the planetary boundary layer, associated with diabatic cooling from the evaporation and melting of hydrometeors.
- Buoyancy waves in the free troposphere, associated with condensation of cloud water and freezing of hydrometeors at mid- to upper-tropospheric levels

There is ample evidence for the excitation of secondary convection from convectively-generated boundary layer disturbances of both the gravity current and gravity wave types. Carbone et al. (1990) established linkages among three successive mesoscale systems over one diurnal cycle and approximately 1000 km distance, including both the gravity current and undular bore mechanisms.

If one attempts to employ envelope calculations of propagation speed as a means to identify dominant mechanisms of MCS maintenance and regeneration, such efforts are thwarted by results that are all too uncertain and inclusive. Density current speed, V, is approximated by $V^2 = k^2gh(\Delta\rho/\rho)$, where k is of order unity, g is gravitational acceleration, h is the current depth and ρ is ambient air density. This leads to a plausible range of results (10 to 22 m s^{-1}) for commonly observed (buoyancy -1 to -5 %, 1 km deep) cold pools.

Observations and calculations of trapped gravity wave phase speeds are similarly plausible. Koch et al. (1991) have summarized observed cases over the US that propagate from 13 to 24 m s^{-1}. Shallow-water equation approximations under constant stratification and no shear also yield plausible results (10 to 40 m s^{-1}) for observed nocturnal boundary layer conditions (N= 0.01 to - 0.02 s^{-1}, h = 1 km) where N is the Brunt-Vaisala frequency. Calculations in shear and/or non-constant stratification yield differing results but span a similar dynamic range.

Are planetary boundary layer disturbances the "connecting tissue" among successive convective events that span and duration statistics suggest? Long-lived density current propagation in neutral (daytime) boundary layers followed by trapped gravity waves in the stable nocturnal boundary layer offer a plausible continuum but these mechanisms are either inherently dissipative or dispersive and conditions may often be unfavorable for the generation or maintenance of either.

Convective gravity wave excitation and maintenance by the ensemble of latent heating in the free troposphere has considerable appeal in its application to propagating episodes. Related studies (e.g. Moncrieff and Miller, 1976; Raymond, 1984, 1986; Tripoli and Cotton, 1989) are mainly theoretical. Experimental attempts to verify the concepts have been modest with inconclusive results.

A third category of coherent regeneration is convective forcing of quasi-balanced mesoscale circulations that can either retain a capacity to maintain organized convection or later gain the capacity to regenerate it. A circulation that fits this description is the mesoscale convectively-generated vortex (MCV), a well known by-product of some mesoscale convective systems. Recently Trier et al. (2000) and Davis et al. (2001) have established that there exists a greater number of MCVs than previously documented. It is unclear how frequently MCVs are associated with significant regeneration of convection and to what extent these are related to the “long” episodes herein. MCVs are often associated with leading-line MCSs.

Exploration of the dynamical linkages between successive convective events constitutes a large piece of unfinished business. We are presently conducting detailed case studies to improve our knowledge of such sequences. A principal discriminator that we (and others before us) have identified is propagation with respect to the steering level winds. Both weather and climate prediction are heavily dependent upon an adequate representation of such processes. A speculative conclusion of this study is that probabilistic precipitation forecasts of 6 to 48 h range might be substantially improved through the combined use of dynamical and statistical methods. Antecedent convection and its observed propagation routinely place narrow bounds on the future meridional position of heavy precipitation episodes, up to 48 h range. Dynamical forecast models routinely identify the latitudinal bands of mesoscale ascent and the associated production of thermodynamic instability. The combined strengths of meridional prediction by means of statistical expectation and latitudinal prediction by means of numerical forecast models may prove to markedly increase skill in warm season rainfall forecasts at the short-range.

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