Nowcasting from Urban to Continental Scale: An Illustration of Scaling Characteristics

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Overview

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Introduction

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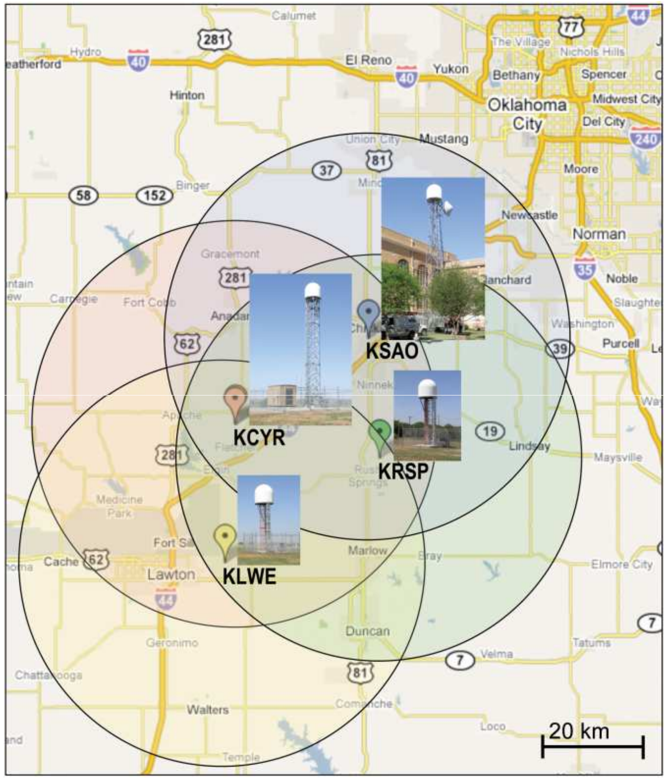
- The Collaborative Adaptive Sensing of the Atmosphere (CASA) radar nowcasting system was developed to provide highly localized urban-scale quantitative precipitation forecasts using networked X-band radars
- This presentation discusses
  - Scalability of the CASA nowcasting model to continental-scale
  - Model parameterization relative to the space-time characteristics of precipitation



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Methodology — Motion Estimation

- The Dynamic Adaptive Radar Tracking of Storms (DARTS) model is based on a discrete representation **(2)** of the general continuity equation **(1)** formulated as a linear system **(3)** in Fourier space

$$\frac{\partial}{\partial t}F(x,y,t) = -U(x,y)\frac{\partial}{\partial x}F(x,y,t) - V(x,y)\frac{\partial}{\partial y}F(x,y,t) + S(x,y,t) \quad \textbf{(1)}$$

FFT

$$\begin{aligned} k_t F_{\mathrm{DFT}}(k_x,k_y,k_t) = \\ -\left[\frac{1}{N_x N_y}\right]\sum_{k'_x=N_x^-}^{N_x^+}\sum_{k'_y=N_y^-}^{N_y^+}\left[\frac{U_{\mathrm{DFT}}(k'_x,k'_y)}{T_x/T_t}\right](k_x-k'_x)F_{\mathrm{DFT}}(k_x-k'_x,k_y-k'_y,k_t) \\ -\left[\frac{1}{N_x N_y}\right]\sum_{k'_x=N_x^-}^{N_x^+}\sum_{k'_y=N_y^-}^{N_y^+}\left[\frac{V_{\mathrm{DFT}}(k'_x,k'_y)}{T_y/T_t}\right](k_y-k'_y)F_{\mathrm{DFT}}(k_x-k'_x,k_y-k'_y,k_t) \\ -\left(\frac{i}{2\pi}\right)\left[T_t S_{\mathrm{DFT}}(k_x,k_y,k_t)\right] \end{aligned} \quad \textbf{(2)}$$

$$\mathbf{y} = \mathbf{Hx}$$ **Increased smoothness implies smaller model size** **(3)**

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Methodology — Advection

- An analytical based on sinc kernel interpolation (spatial domain)
- Used as a tool to characterize scales of precipitation

$$F_{kl}(t+\delta_t) = F_{kl}(t) - \left\{ \frac{U_{kl}}{\Delta x} \cdot [\mathbf{AF}(t)]_{kl} + \frac{V_{kl}}{\Delta y} [\mathbf{F}(t)\mathbf{Z}]_{kl} \right\} \delta_t$$

Controls resolution (step size)

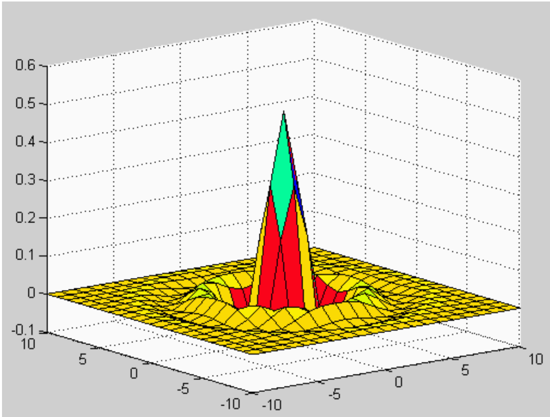
where,

$$\mathbf{A} \equiv [A_{km}] = [\mathrm{Dsinc}(k-m)]$$

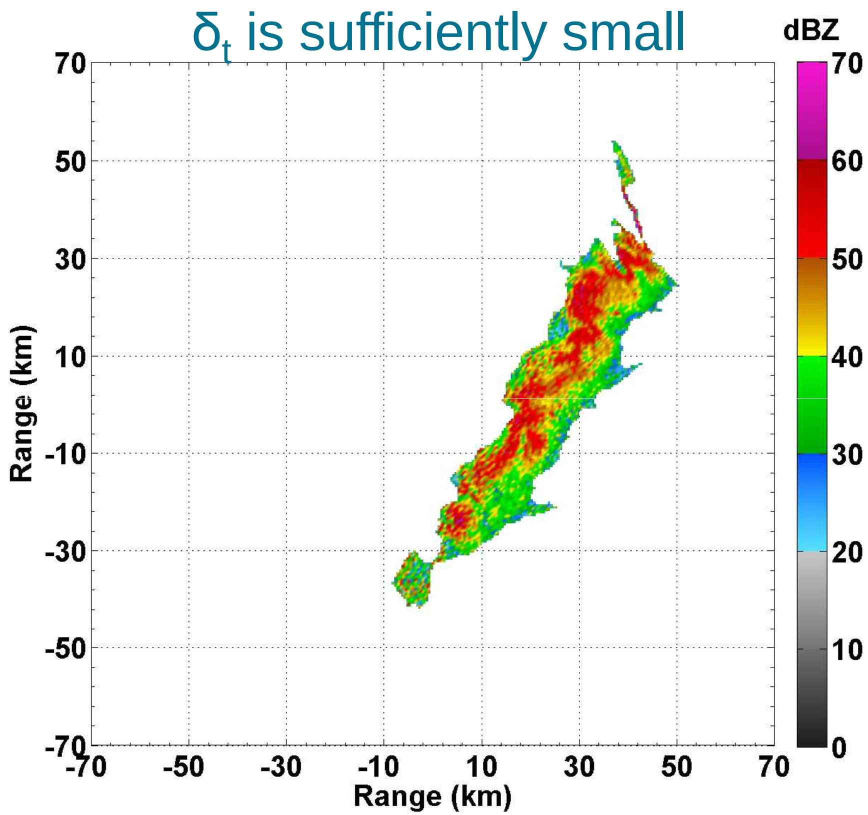
$$\mathbf{Z} \equiv [Z_{nl}] = [\mathrm{Dsinc}(n-l)]$$

$$\mathbf{F}(t) \equiv [F_{ml}(t)] \text{ or } \mathbf{F}(t) \equiv [F_{kn}(t)]$$

$$\mathrm{Dsinc}(x) \equiv \frac{d}{dx}\mathrm{sinc}(x) = \begin{cases} \frac{1}{x}[\cos(\pi x) - \mathrm{sinc}(x)] & x \neq 0 \\ 0 & x = 0 \end{cases}$$



Methodology — Advection



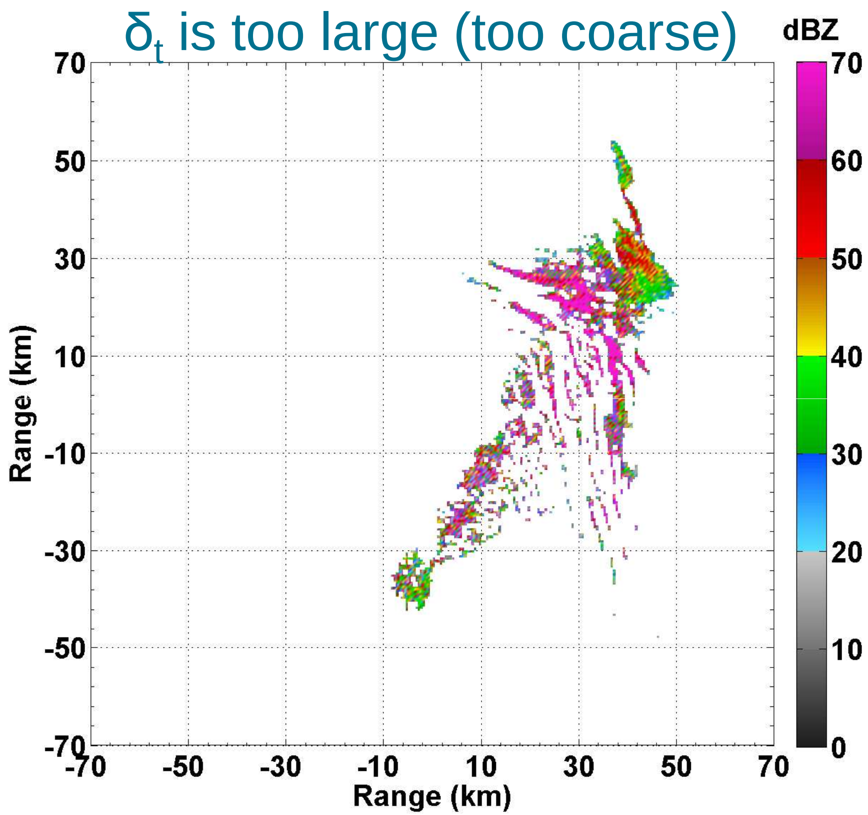


Illustration advection instability used as the reference for parameterization

Methodology — Advection

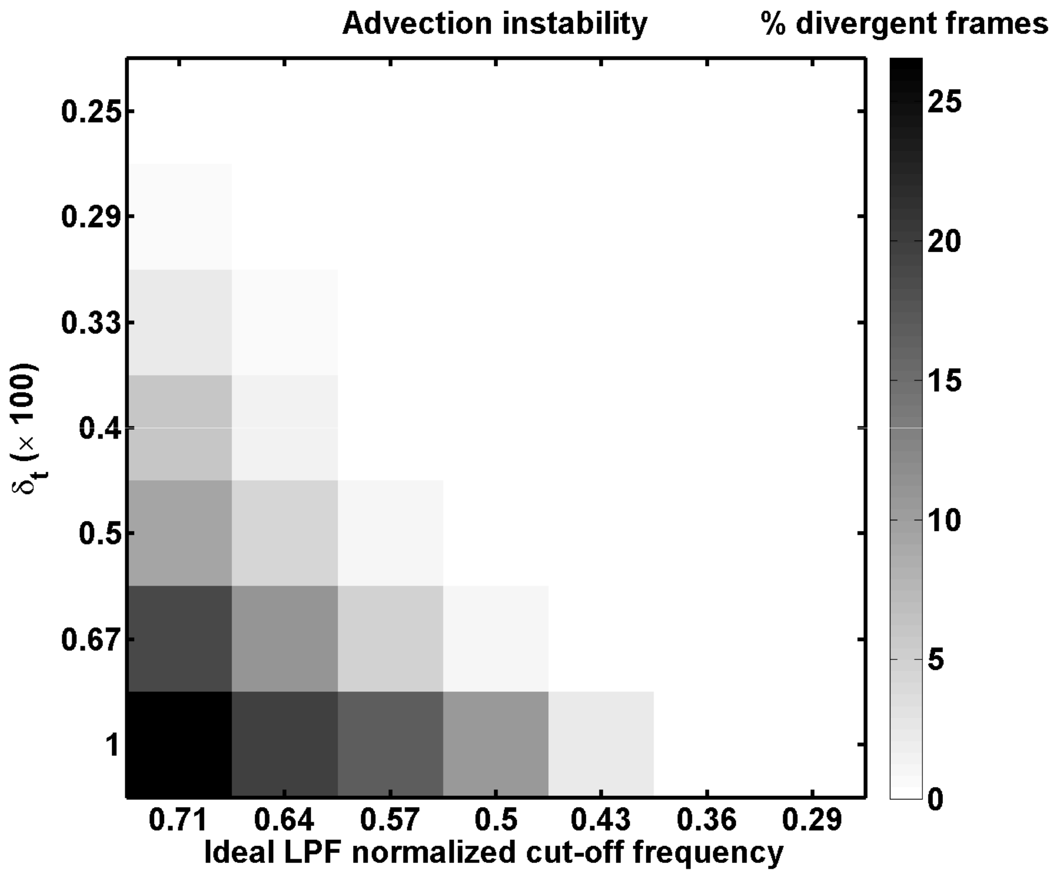


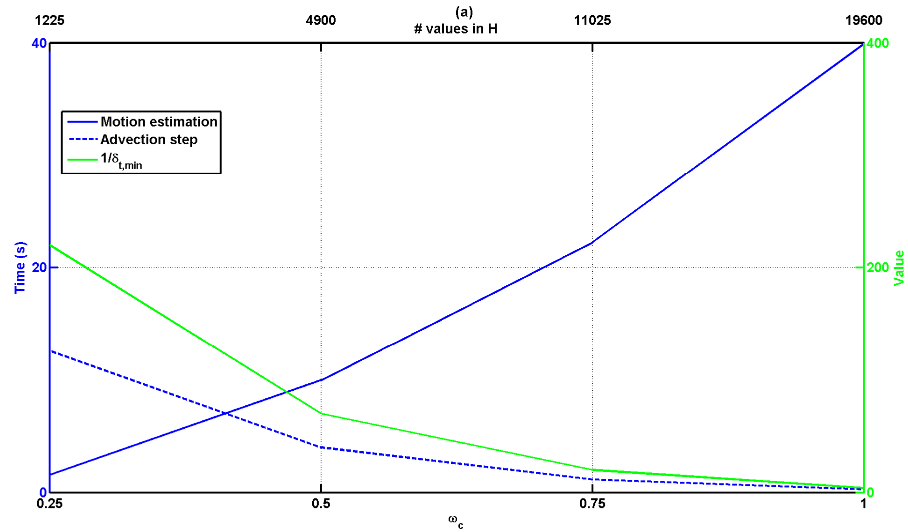
Illustration of advection parameterization vs. advection stability

Experimental Description

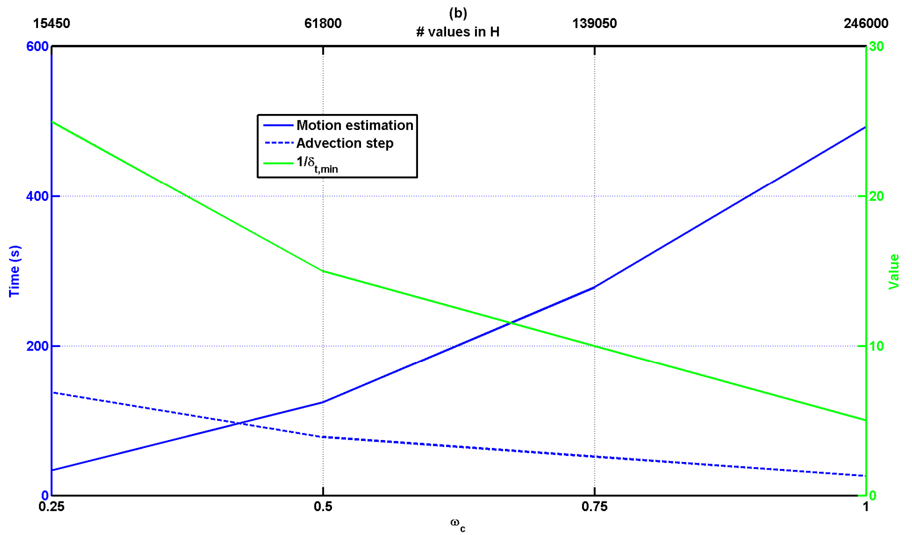
- Considered CASA and NEXRAD (N0R) national composite data
- Two experiments were performed to assess the characteristics of the nowcasting model relative to the size of the data and precipitation scales being tracked
  - Fixed size of input radar data fields while varying the normalized cut-off frequency of the LPF represented by the dimensions of **H**
    - Grid spacing: 0.5 km (CASA); 4 km (N0R)
    - LPF cut-off frequency: 0.25 to 1.0 in steps of 0.25
  - Varied sizes of data fields/grid spacing and fixed the cutoff frequency of the LPF
    - Grid spacing: 0.5, 1, 2, 4 km (CASA); 4, 6, 8, 12 km (N0R)
    - LPF cut-off frequency: 0.20
- Considered maximum value (coarsest) of δ_t to achieve stability

Results

CASA



N0R



Runtime (blue) and advection parameter characteristics (green) considering a fixed data size and varying size of the model design matrix **H** for (a) CASA and (b) N0R data

A smaller advection step size must be used when estimating motion of larger precipitation scales (faster propagation than smaller scales)

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Results

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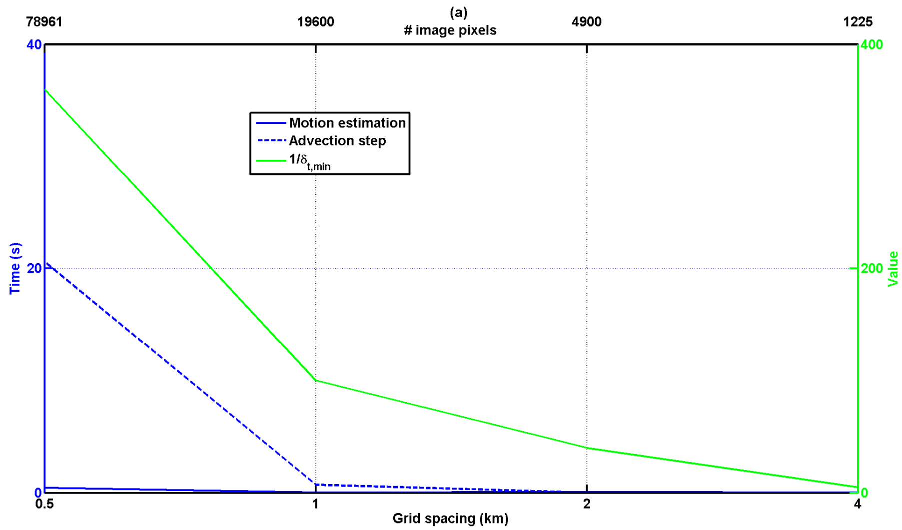
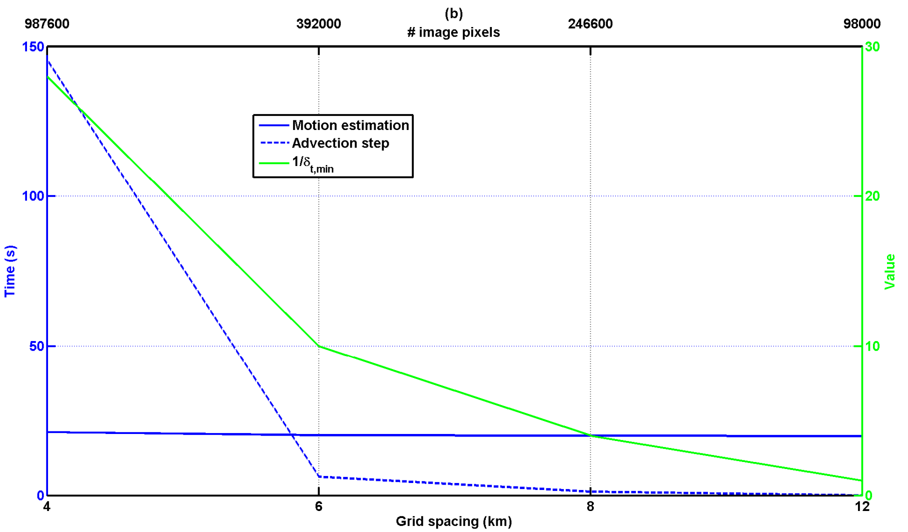
CASA



N0R



Runtime (blue) and advection parameter characteristics (green) considering a fixed size of the model design matrix **H** and varying data size for (a) CASA and (b) N0R

A larger advection step size can be used with data that has been smoothed to lower resolutions

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Summary and Conclusions

- Illustrated the scalability of the CASA nowcasting system to continental-scale
  - CASA (0.5 km; 140 km × 140 km) vs. NEXRAD composite (4 km; 4800 km × 3200 km)
- Discussed model parameterization relative to the space-time characteristics of precipitation
  - LPF cut-off frequency (motion estimation model)
  - Step size (advection model)
- Quantified the relative differences in propagation speed of large- and small-scale precipitation features using the model parameters
  - Larger-scale features propagate faster thus requiring a finer advection step (smaller δ_t)

Summary and Conclusions

- Showed the nonlinear scaling behavior of the nowcasting model
  - Suggests the motion estimation model design matrix **H** should be truncated to facilitate reasonable computation times and thus the tracking of larger scales shown to be more representative of precipitation pattern envelope motion
  - An alternate advection scheme should be considered when using data projected onto large grids, with size dependent on the application requirements

Questions?