Development, Application, and Evaluation of a One-Dimensional Hail Growth Model (HAILCAST)

Rebecca Adams-Selin[1], Conrad Ziegler[2], Adam Clark[2]

[1]Atmospheric and Environmental Research (AER)
[2]NOAA/National Severe Storms Laboratory

2nd European Hail Workshop
20 Apr 2017

Acknowledgements

- Conrad Ziegler, NOAA/National Severe Storms Laboratory
  - Adams-Selin and Ziegler, 2016, *Mon. Wea. Rev.*
- Adam Clark, NOAA/NSSL
- Chris Melick, USAF 557th Weather Wing
- Scott Dembek NOAA/NSSL and OU/CIMMS
- Israel Jirak, NOAA/SPC

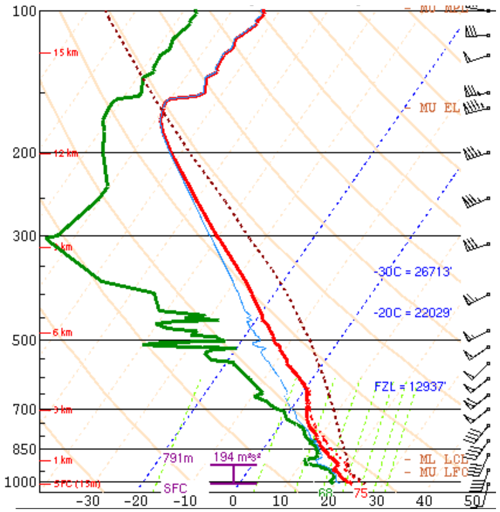
Outline

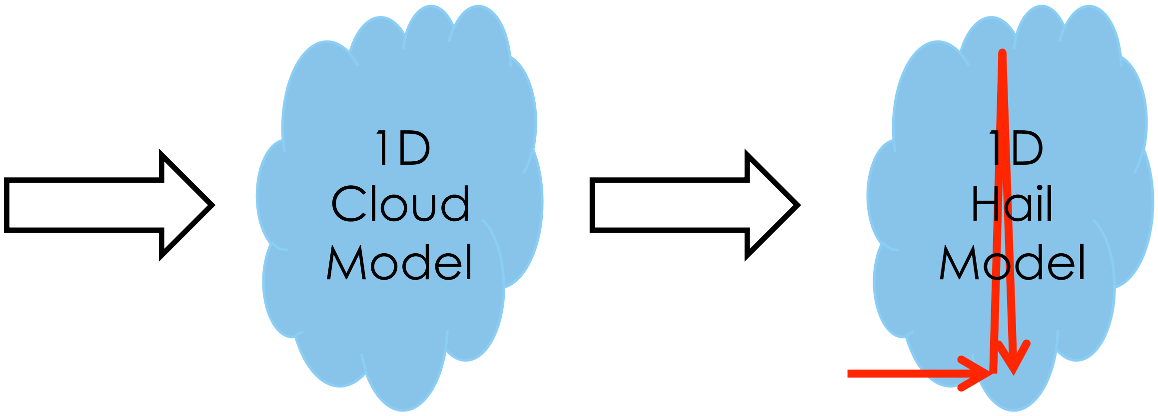
- Description/Design of HAILCAST
- Improvements in internal physics
- Verification results and subsequent improvement in model design
- Interesting applications and future research directions

Forecasting hail size

- Model environmental parameters
- Storm surrogate or hail proxy
  - radar reflectivity
  - updraft speed
  - updraft helicity
- Use the microphysical parameterization directly
- Machine-learning techniques
- Can we directly forecast hail size using a physically-based method?

Original HAILCAST





proximity sounding

model or observed

- calculates vertical profiles of:
  w, T, z, p, LWC, IWC, qv

- vertical profile assumed to be steady state

- 1 initial, liquid embryo inserted at cloud base
- updraft duration determined by CAPE and 0-6 km shear
- output: hail diameter

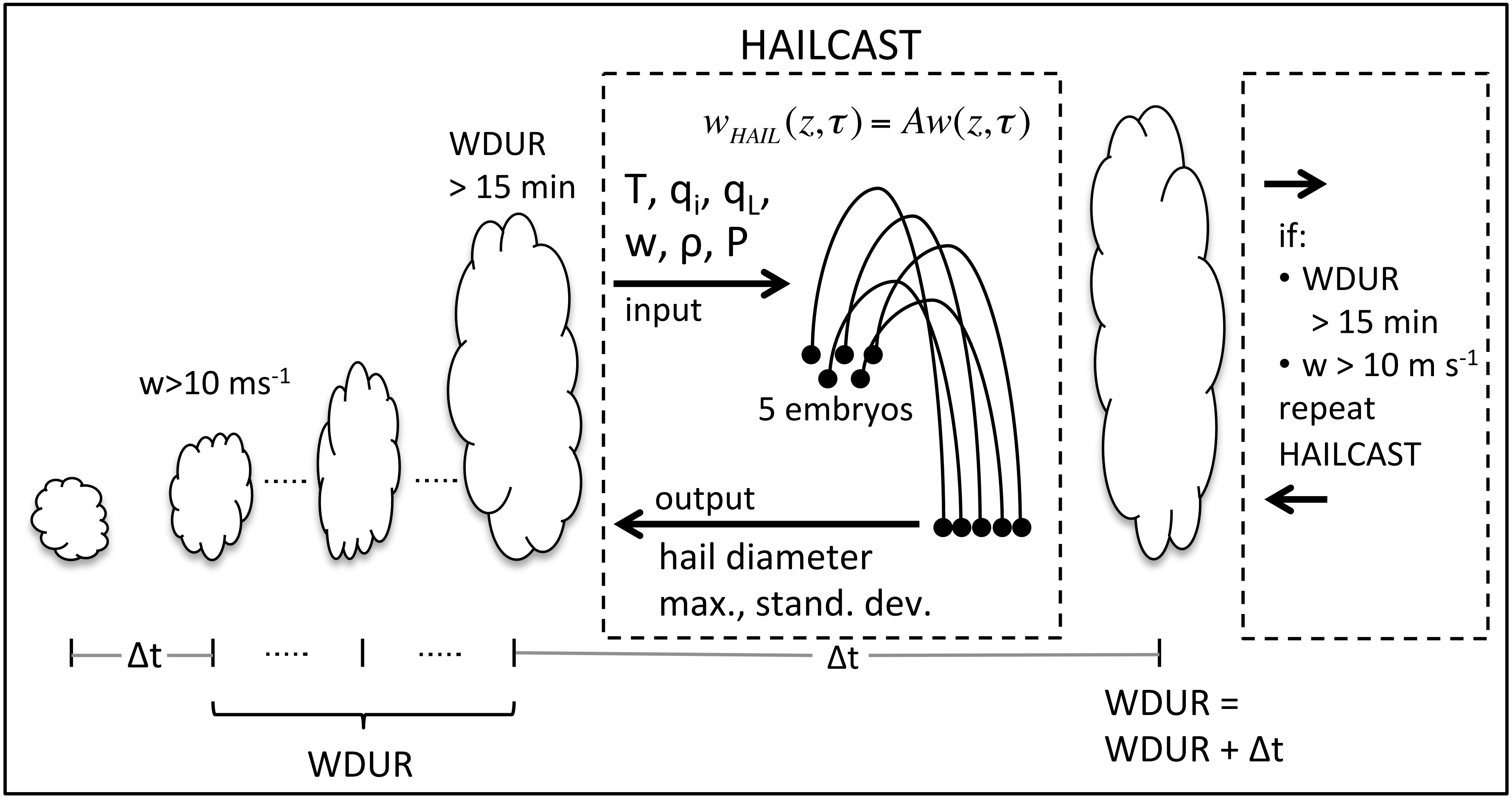
(Brimelow et al. 2002, Brimelow et al. 2006, Jewell and Brimelow 2009)

Original HAILCAST

- mass growth by accretion of ice and liquid water
- calculates hailstone temperature
- determines wet and dry growth regimes
- sheds liquid water

WRF-HAILCAST

WRF



HAILCAST

$$w_{HAIL}(z,\tau) = Aw(z,\tau)$$

$w>10$ ms^{-1}

WDUR > 15 min

T, q_i, q_L, w, ρ, P

input

5 embryos

output

hail diameter max., stand. dev.

if:

- WDUR > 15 min
- $w > 10$ m s^{-1}

repeat HAILCAST

Δt ····· ·····

WDUR

Δt

WDUR = WDUR + Δt

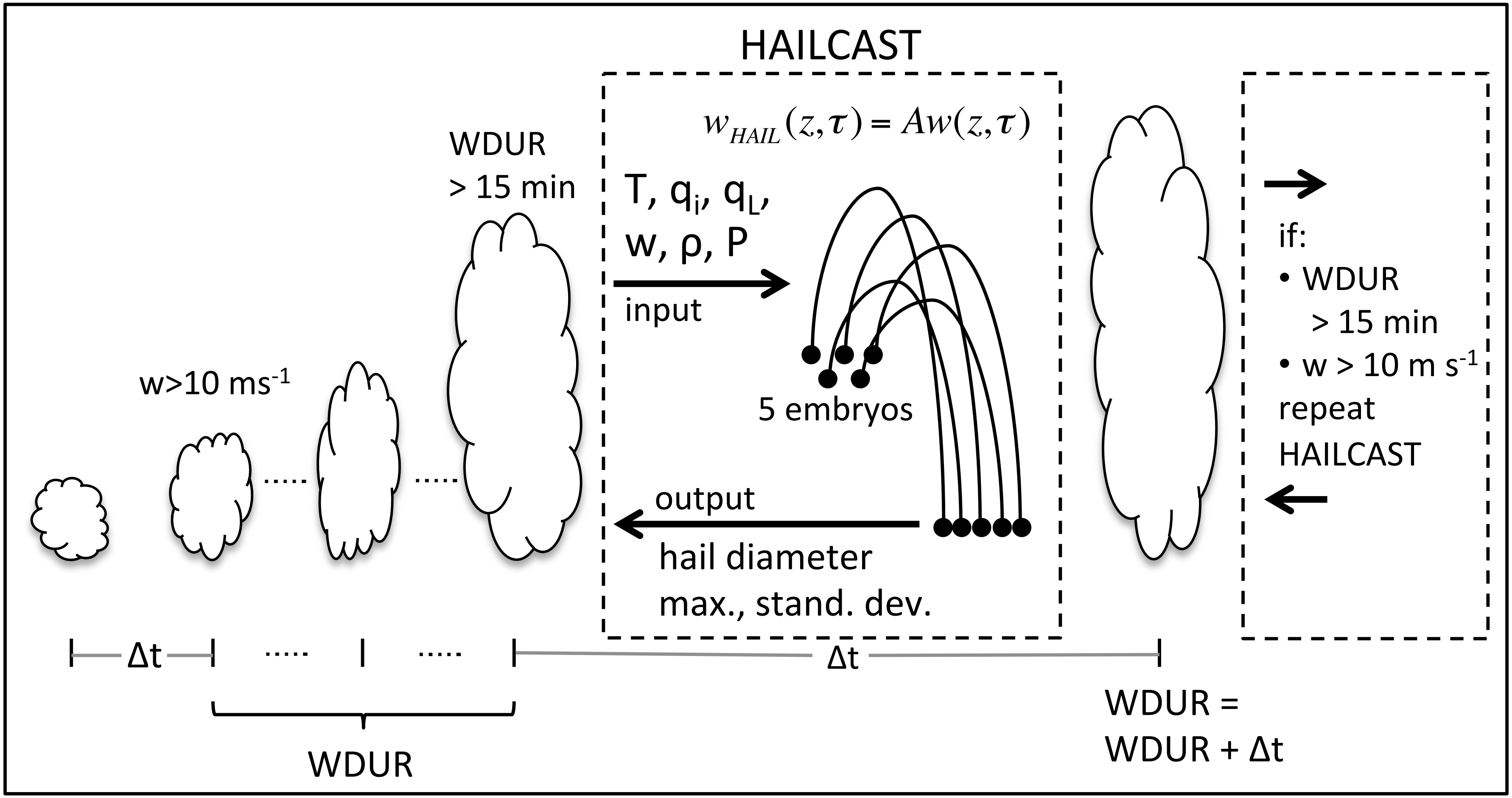
Δt = 1 WRF timestep

τ = HAILCAST time

Adams-Selin and Ziegler, 2016, MWR

~~WRF~~-HAILCAST

WRF



HAILCAST

$$w_{HAIL}(z,\tau) = Aw(z,\tau)$$

WDUR > 15 min

T, q_i, q_L, w, ρ, P

input

w>10 ms^{-1}

5 embryos

output

hail diameter max., stand. dev.

if:

- WDUR > 15 min
- w > 10 m s^{-1}

repeat HAILCAST

Δt .... Δt

WDUR

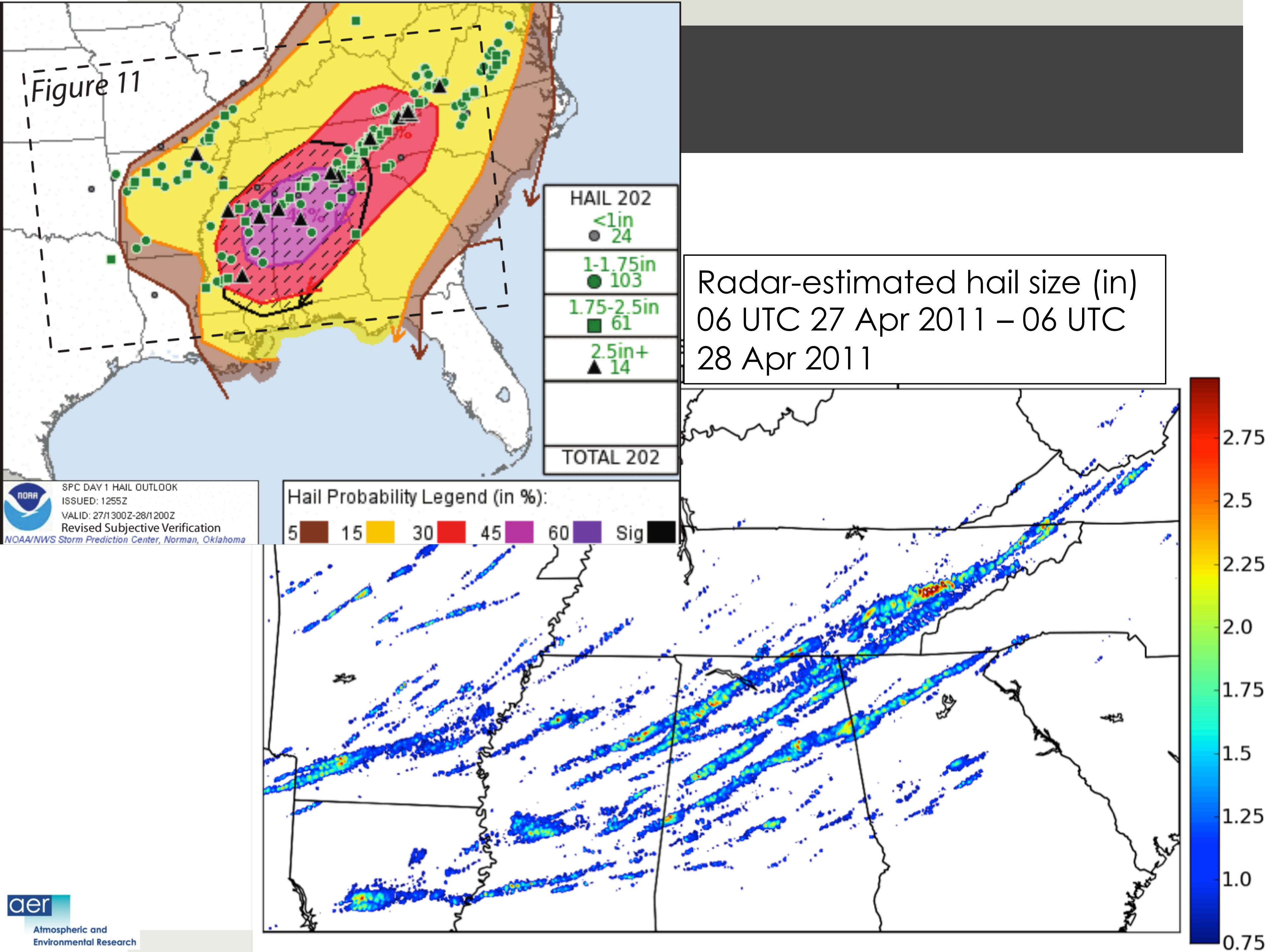
WDUR = WDUR + Δt

Δt = 1 WRF timestep

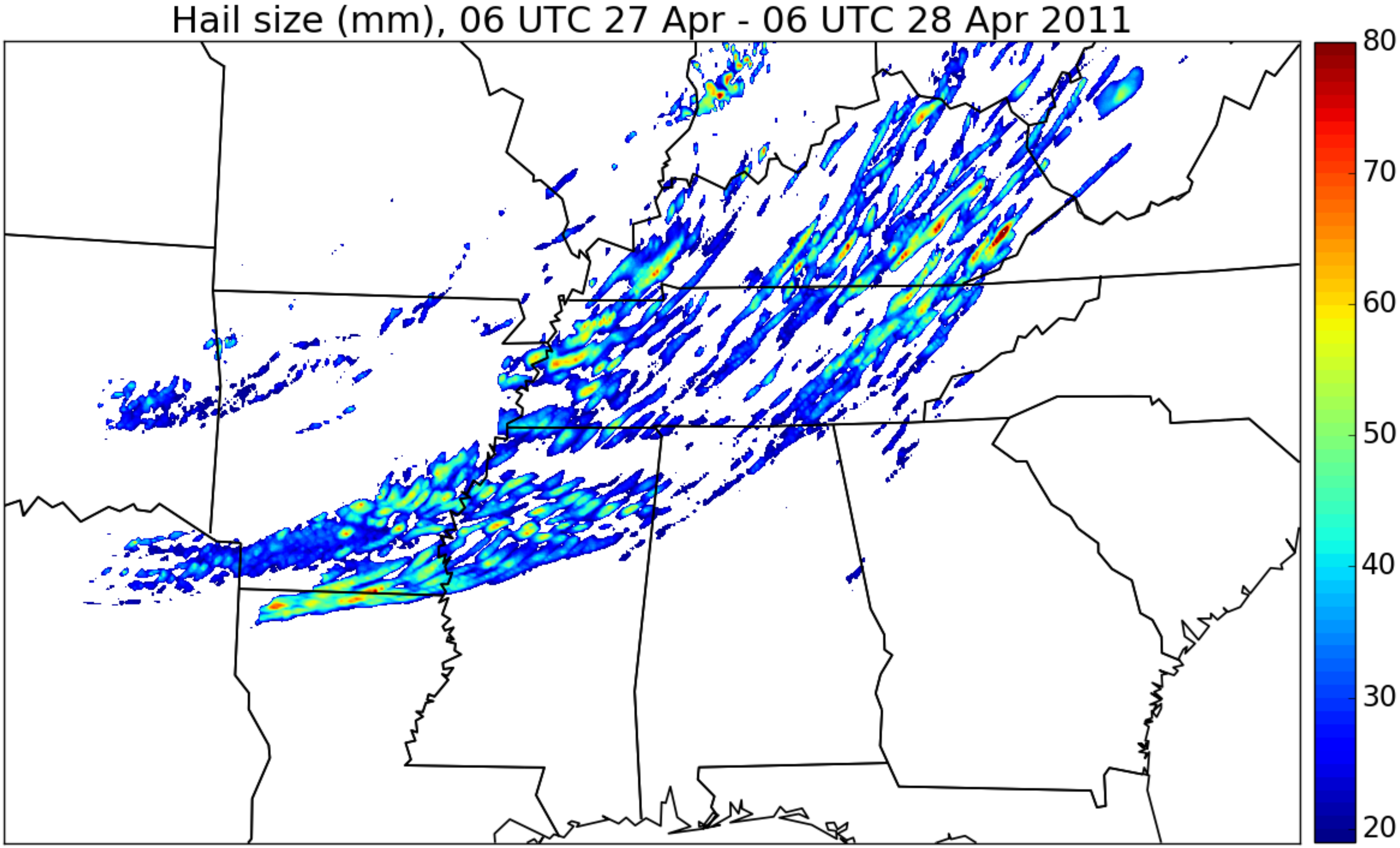
τ = HAILCAST time

Adams-Selin and Ziegler, 2016, MWR

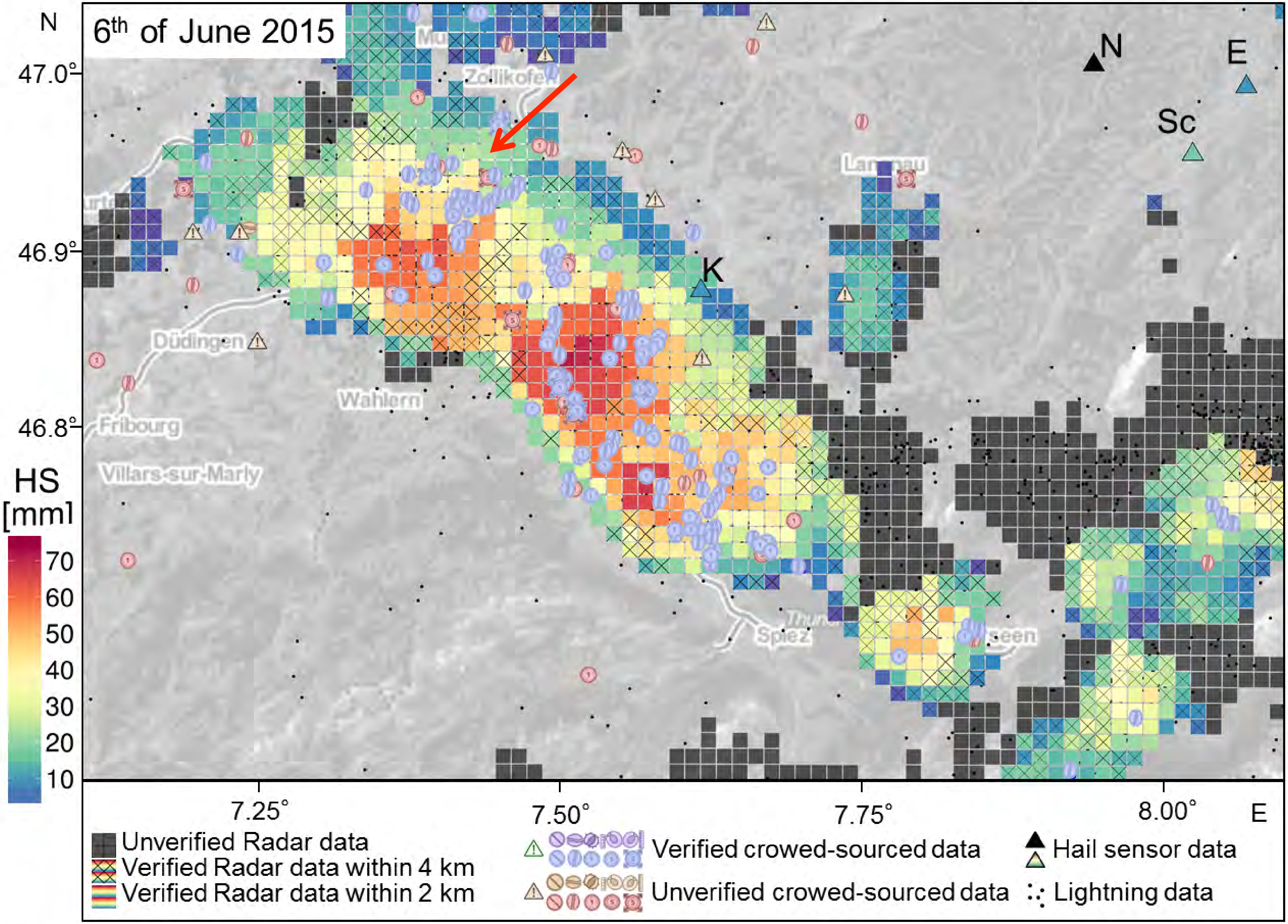
Figure 11



Radar-estimated hail size (in)
06 UTC 27 Apr 2011 – 06 UTC 28 Apr 2011



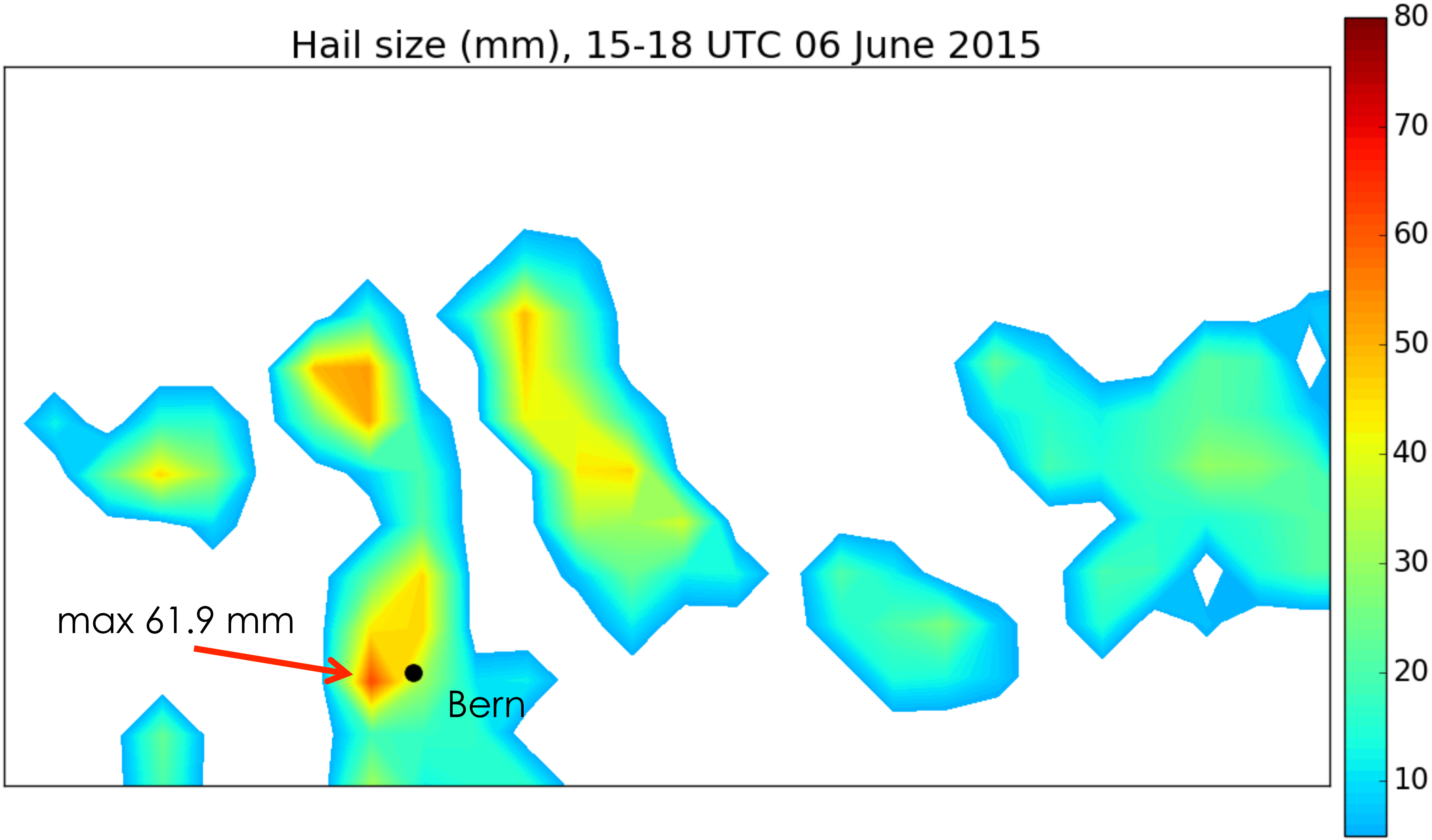
CONTROL



P.-A. Noti, Master's Thesis, U. Bern, 2016

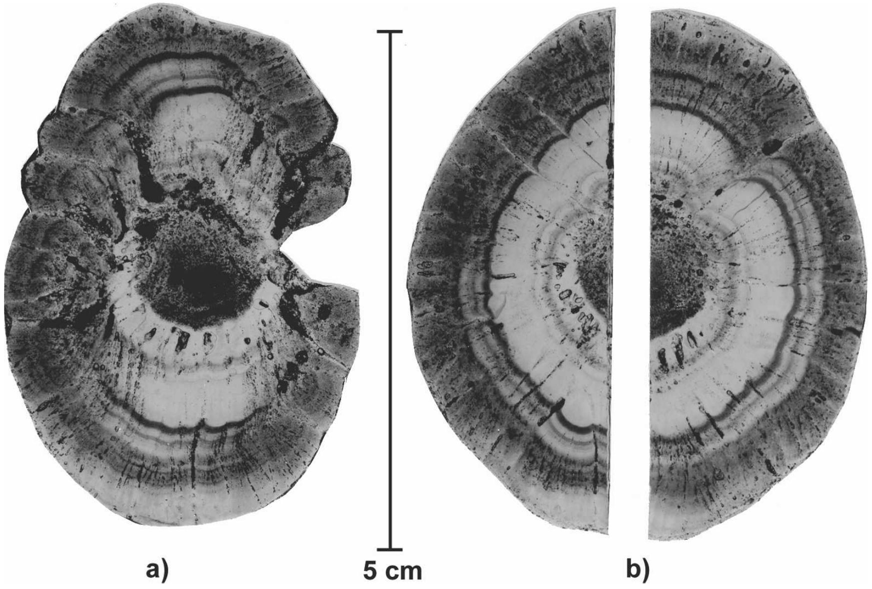
aer Atmospheric and Environmental Research

6 June 2015

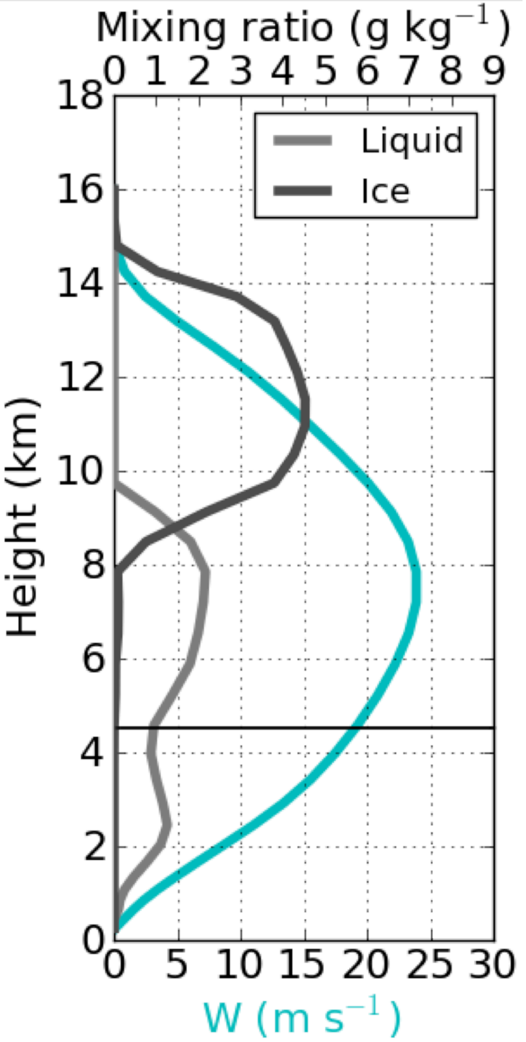

Hail size (mm), 15-18 UTC 06 June 2015
80
70
60
50
40
30
20
10
max 61.9 mm
Bern

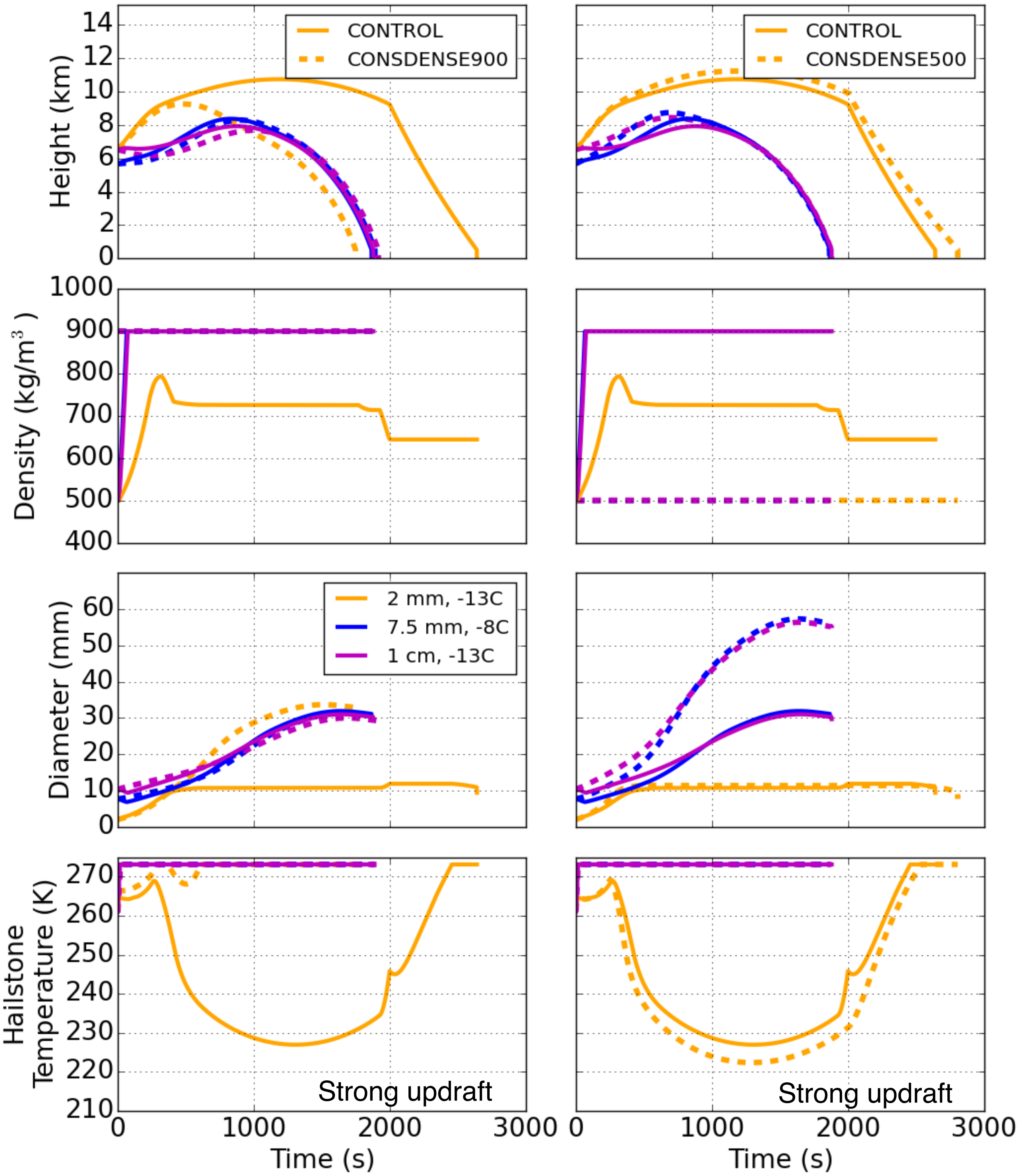
Internal Physics Improvements

- Hail density is not constant
  - hail growth trajectories in radar-observed storms (Ziegler et al. 1983; Foote 1984; Miller et al. 1988, 1990)
  - three-dimensional cloud model simulations (Milbrandt and Morrison 2013; Morrison and Milbrandt 2015)
- Full rime soaking method, similar to Ziegler et al. (1983):
  - dry growth: ice density dependent on air and hailstone temperature, fall speed, and cloud droplet radius (Heymsfield and Pflaum 1985)
  - wet growth: rime soaking increases density of embryo until reaches maximum of 900 kg m^{-3}

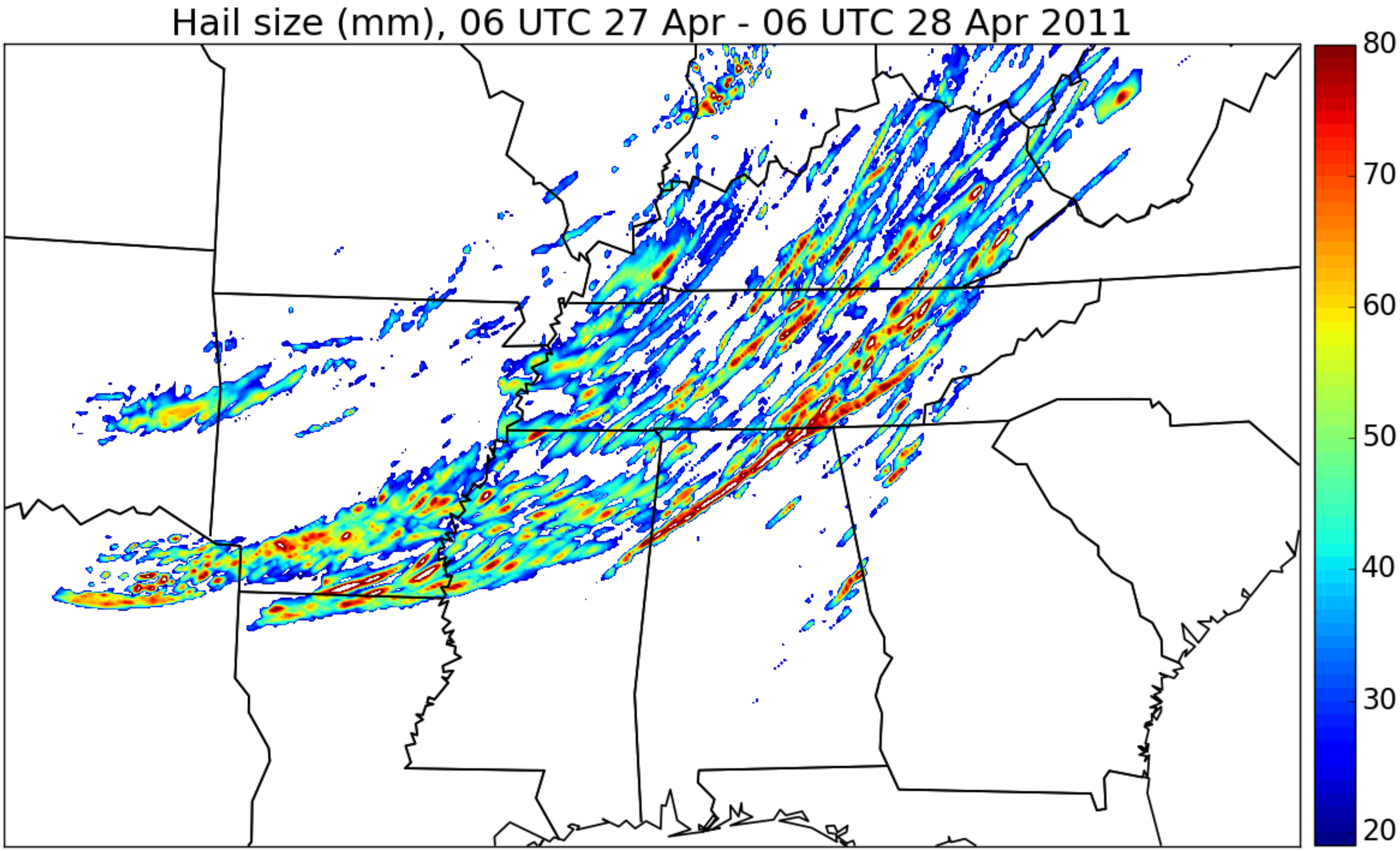


Cross-section of hailstone that fell in Boulder in 1970. From Knight (2008). Negative image.



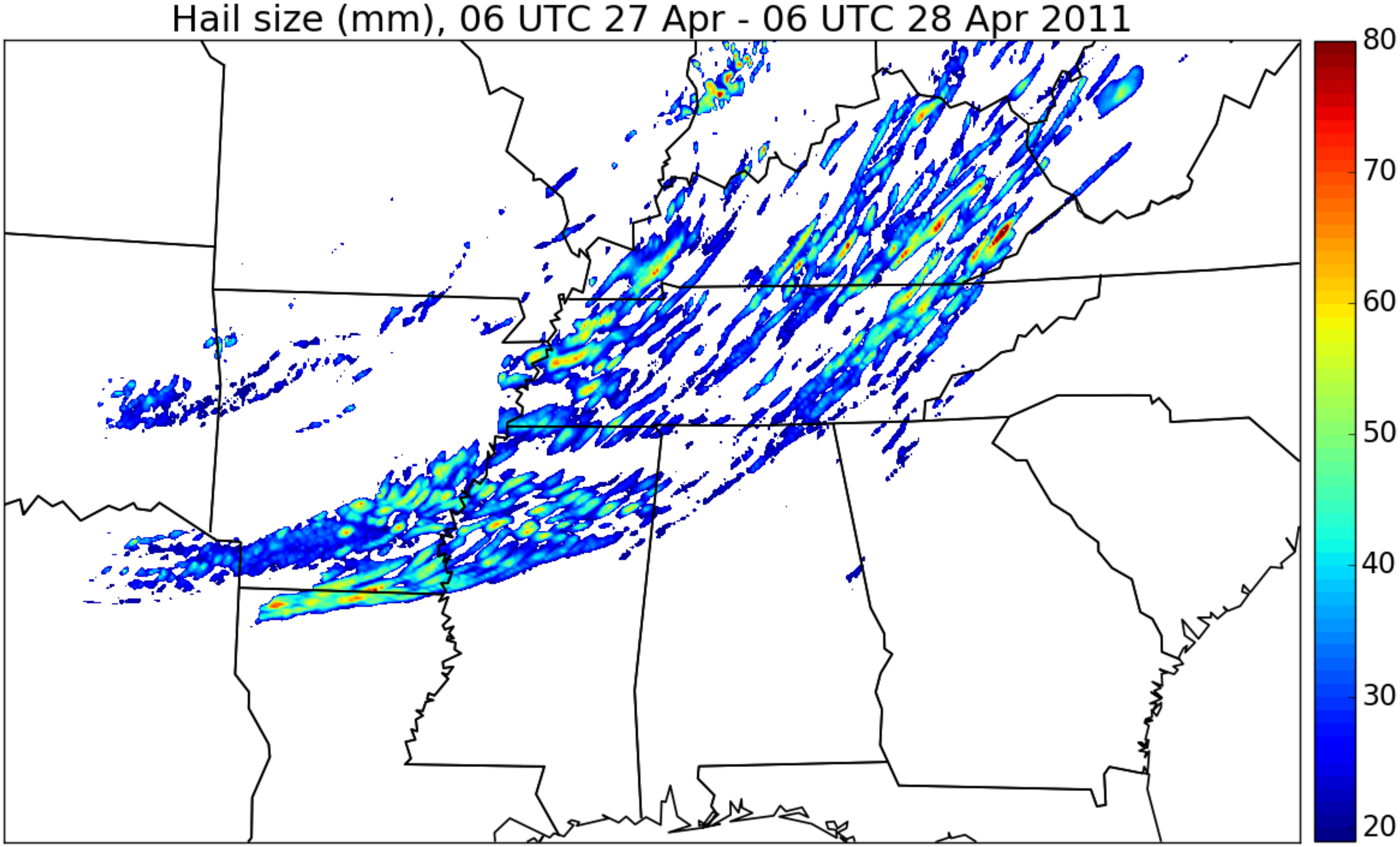


aer
Atmospheric and Environmental Research

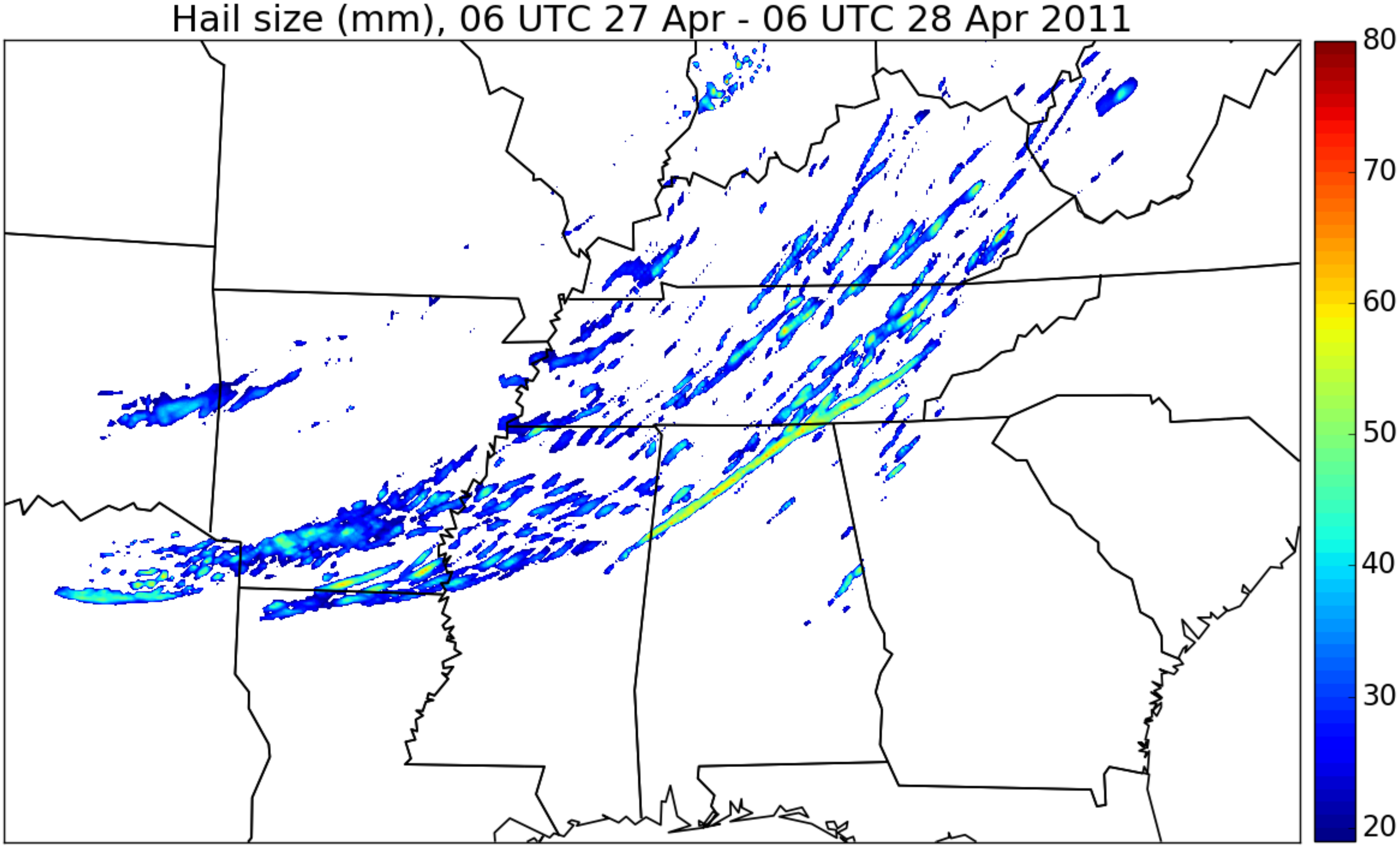


CONSDENSE500

Atmospheric and Environmental Research



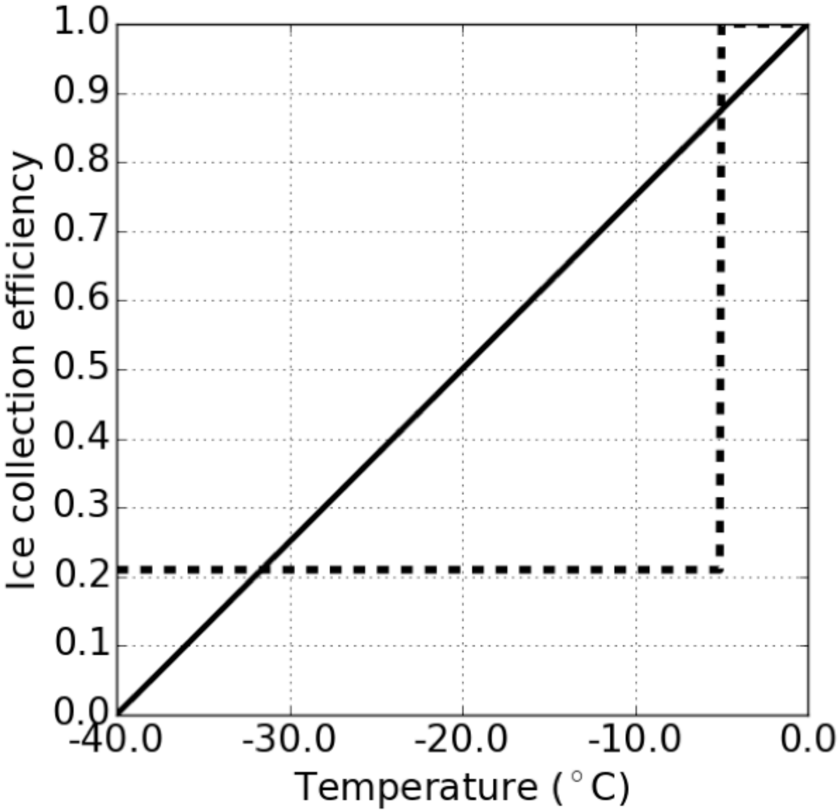
CONTROL



CONSDENSE500

Internal Physics Improvements

- temperature-dependent ice collection efficiency
- mass growth by vapor deposition or condensation
- liquid water shedding threshold that accounts for hailstone tumbling
- enhanced melting by collisions with > 0C liquid water



WRF-HAILCAST at the HWT

- 2014-2016, 4 km:
  - NSSL-WRF: 9-10 member WRF-ARW ensemble run as part of HWT starting in 2014
    - variety of IC/LBCs from GFS analysis or SREF forecasts
    - constant physics (WSM6 microphysics)
    - initialized daily at 0 and 12 UTC

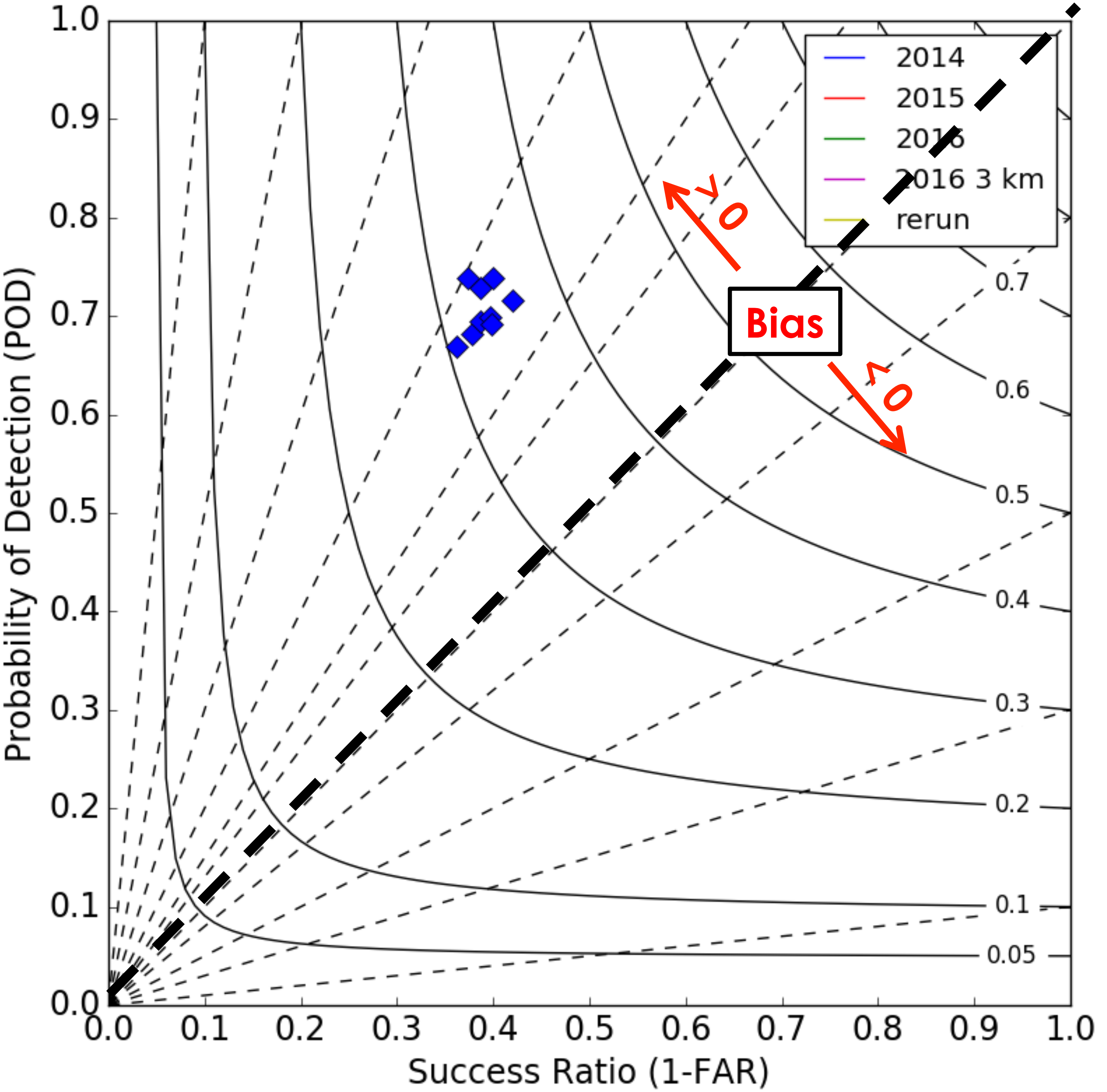
- 2016, 3 km:
  - CLUE single-physics 10 member ensemble
    - WRF-ARW core
    - IC/LBCs from SREF members
    - constant physics (Thompson microphysics)
    - initialized daily at 0 UTC

Verification and Model Design

- Multi-Radar Multi-Sensor Maximum Estimated Size of Hail (MRMS MESH)
  - radar-derived hail estimate
  - single-pol only, possible overestimate (Cintineo et al. 2012)
- Accumulate maximum hail obs/fcst at a gridpoint over 24 hours
  - match hail swath to hail swath using MODE object-based verification
  - compare maximum size within hail swaths
  - use a threshold of 50 mm to construct contingency table statistics

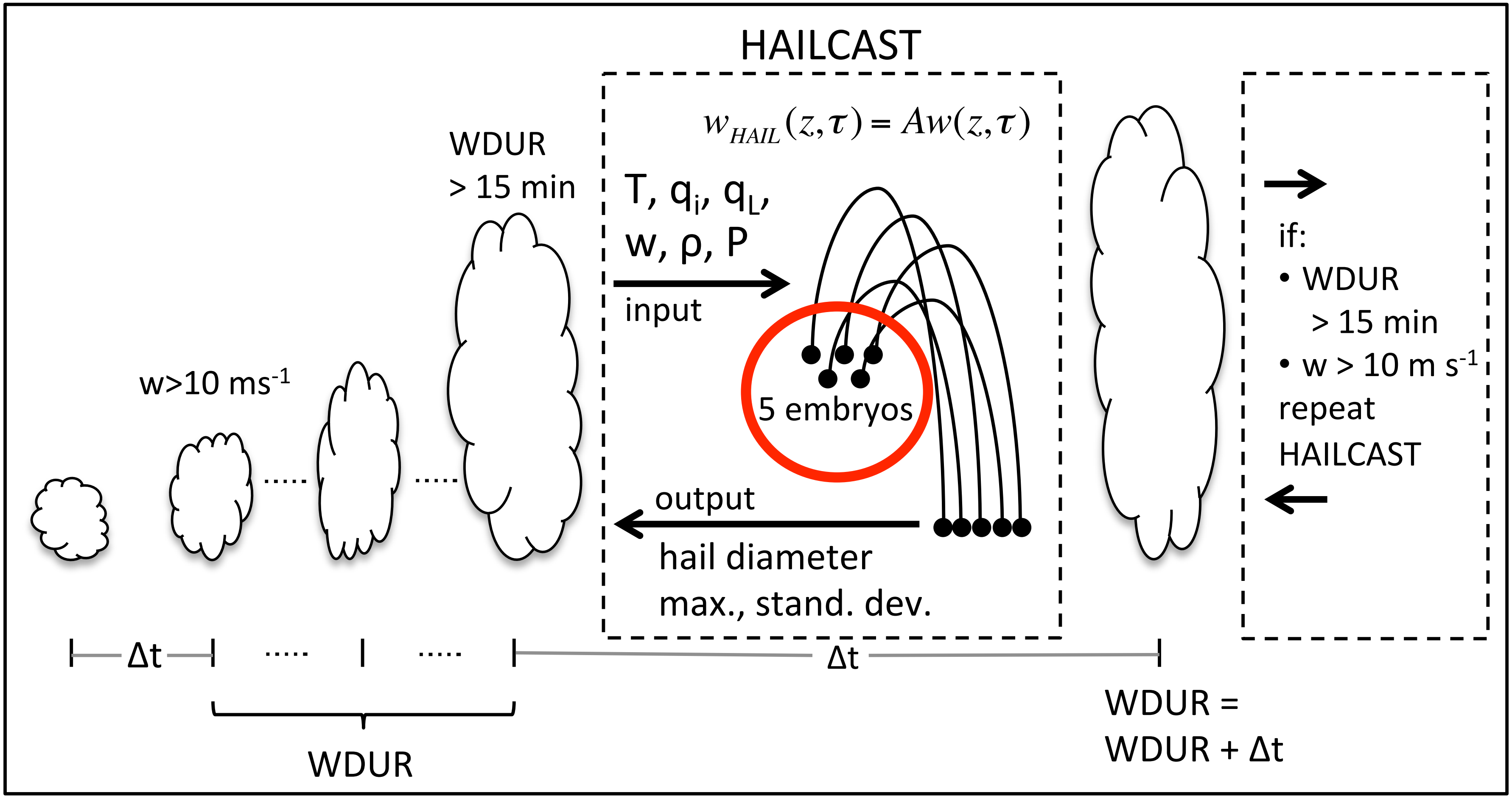
2014

- 9 NSSL-WRF members
- high bias
- micro-physical variability



WRF-HAILCAST

WRF



HAILCAST

$w_{HAIL}(z,\tau) = Aw(z,\tau)$

w>10 ms^{-1}

WDUR
> 15 min

T, q_i, q_L,
w, ρ, P

input

5 embryos

output

hail diameter
max., stand. dev.

if:
- WDUR
  > 15 min
- w > 10 m s^{-1}

repeat
HAILCAST

Δt

Δt

WDUR

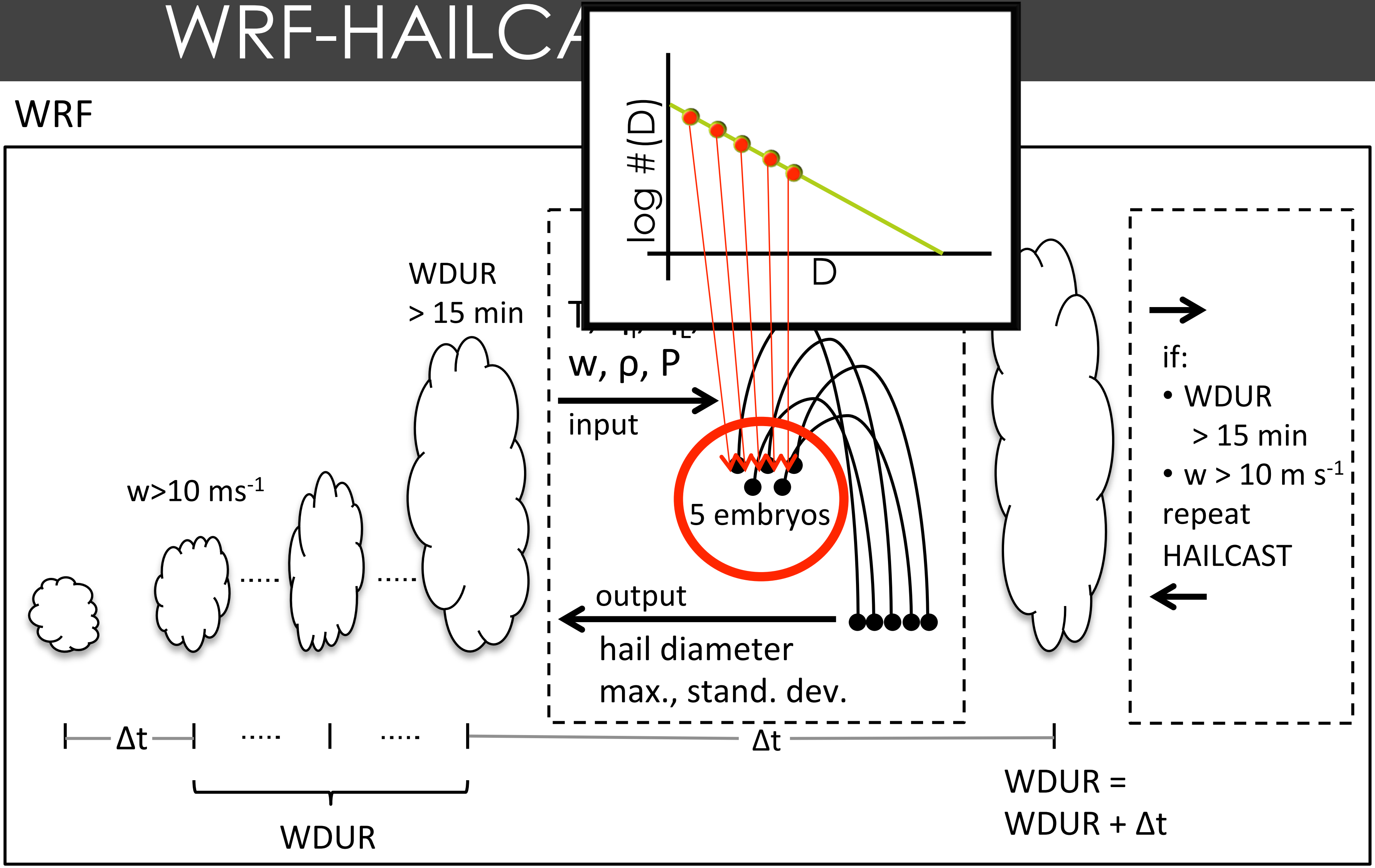
WDUR =
WDUR + Δt

Δt = 1 WRF timestep

τ = HAILCAST time

Adams-Selin and Ziegler, 2016, MWR

WRF-HAILCA



WRF

WDUR
> 15 min

w>10 ms^{-1}

T

w, ρ, P

input

5 embryos

output

hail diameter
max., stand. dev.

if:
- WDUR
  > 15 min
- w > 10 m s^{-1}

repeat
HAILCAST

Δt .... Δt

WDUR

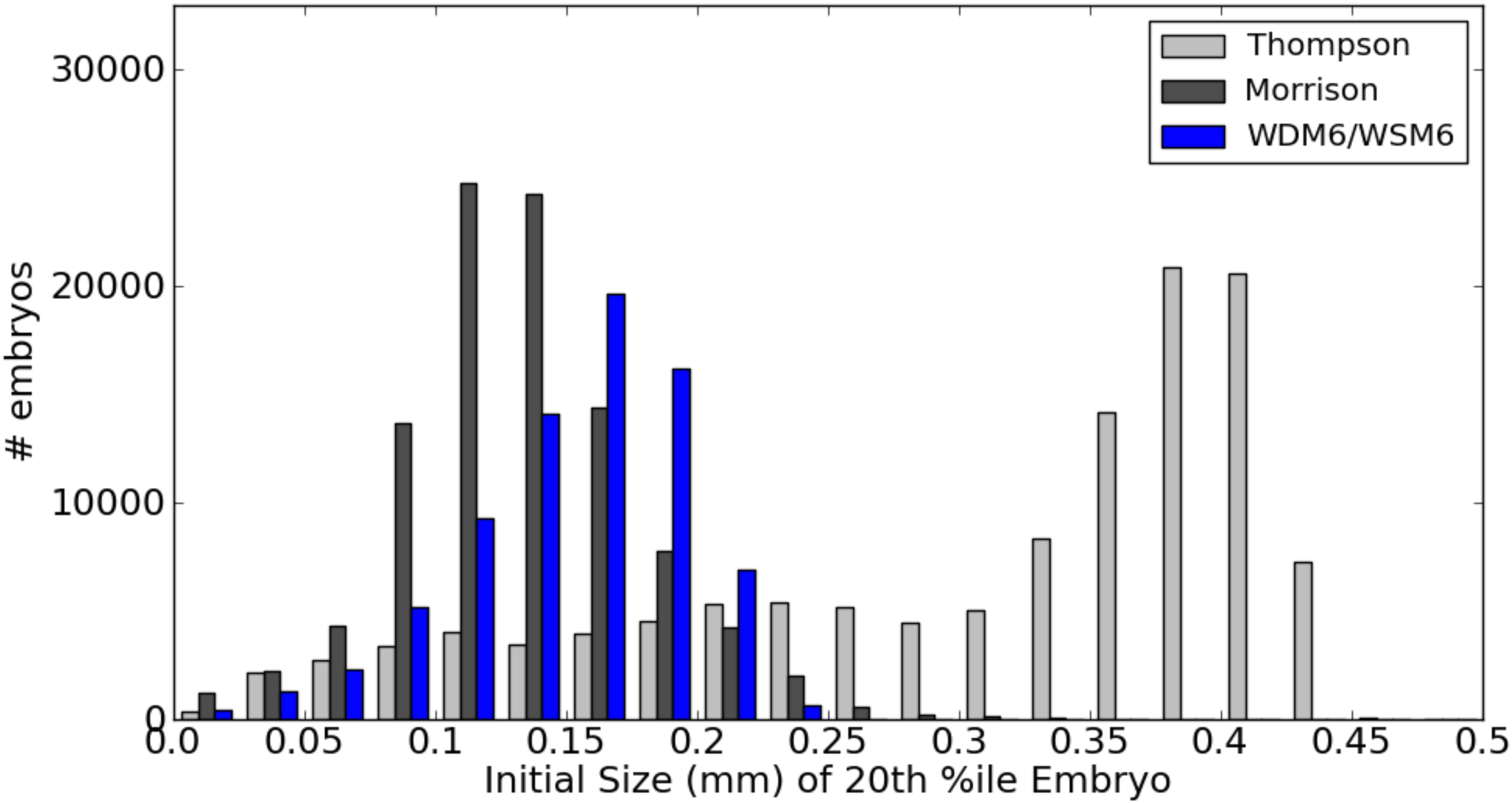
WDUR =
WDUR + Δt

Δt = 1 WRF timestep

τ = HAILCAST time

Adams-Selin and Ziegler, 2016, MWR

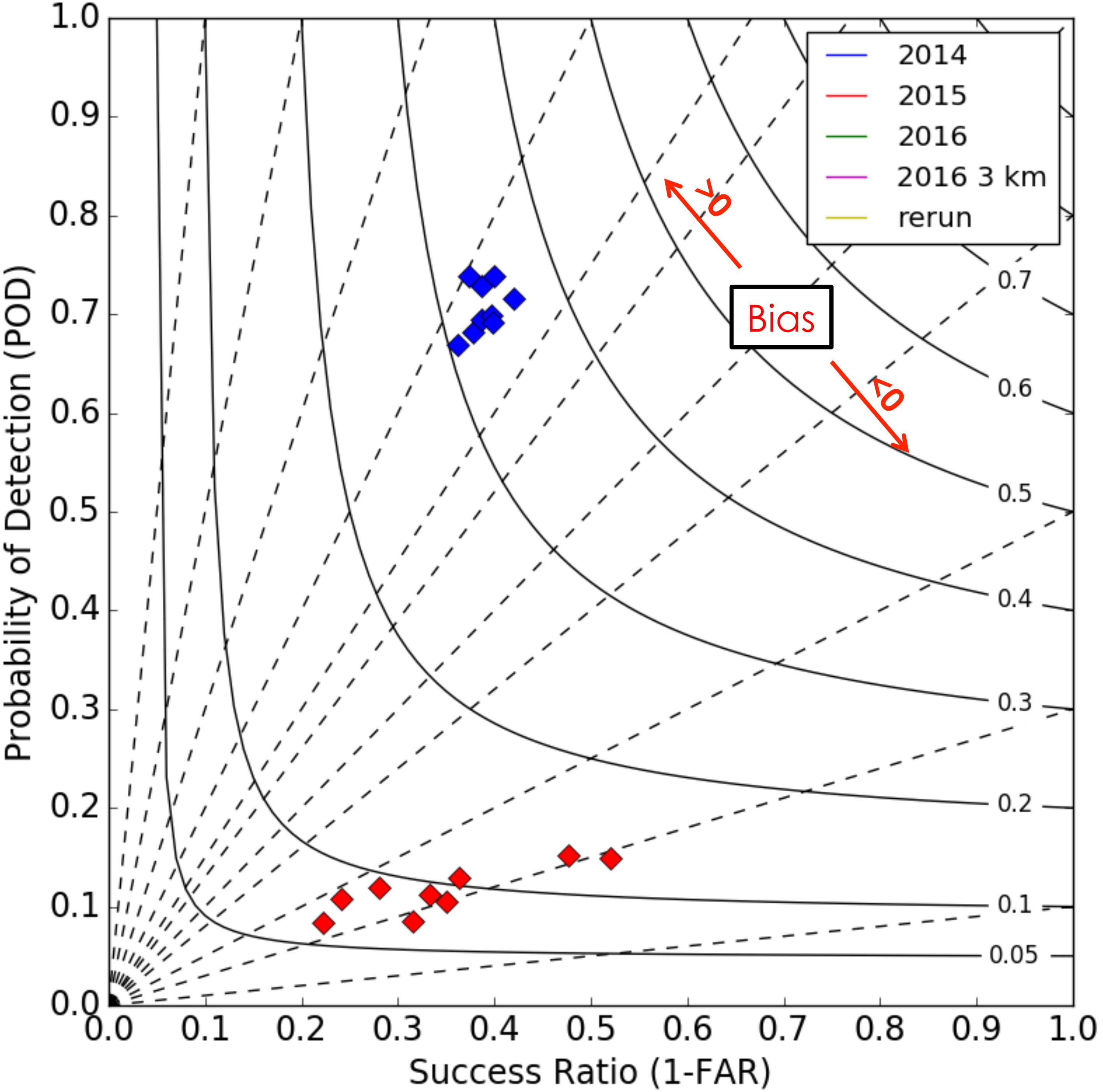
Initial embryo sizes



Atmospheric and Environmental Research

2015

- HAILCAST version in WRFV3.6.1
- Constant initial embryo size, but very small (10-50 microns)



2016 WRF-HAILCAST

- Hailstones aren't "stuck" in the middle of an updraft until they can fall out
- Embryos form around the edge and are advected across the core
- Added a time-dependent multiplier to the updraft speed in WRF-HAILCAST to simulate hailstone's horizontal motion relative to the updraft

$$W_{hail}(z,\tau) = \begin{cases} 0.6\sin\left(\frac{\pi\tau}{W_{dur}}\right)+0.6 & \text{if } \tau \le W_{dur} \\ 0 & \text{if } \tau > W_{dur} \end{cases}$$

τ: time relative to hailstone

W_{dur}: updraft duration

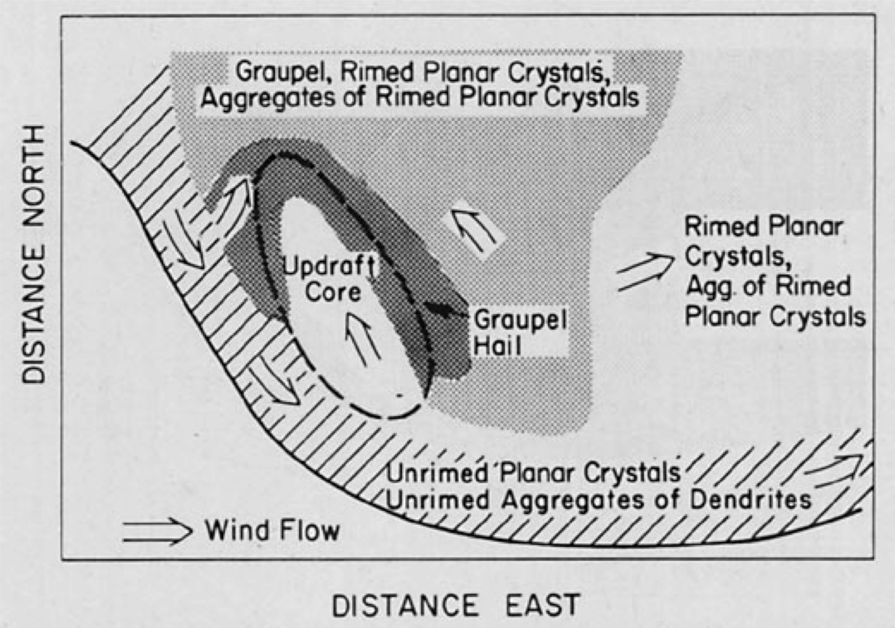
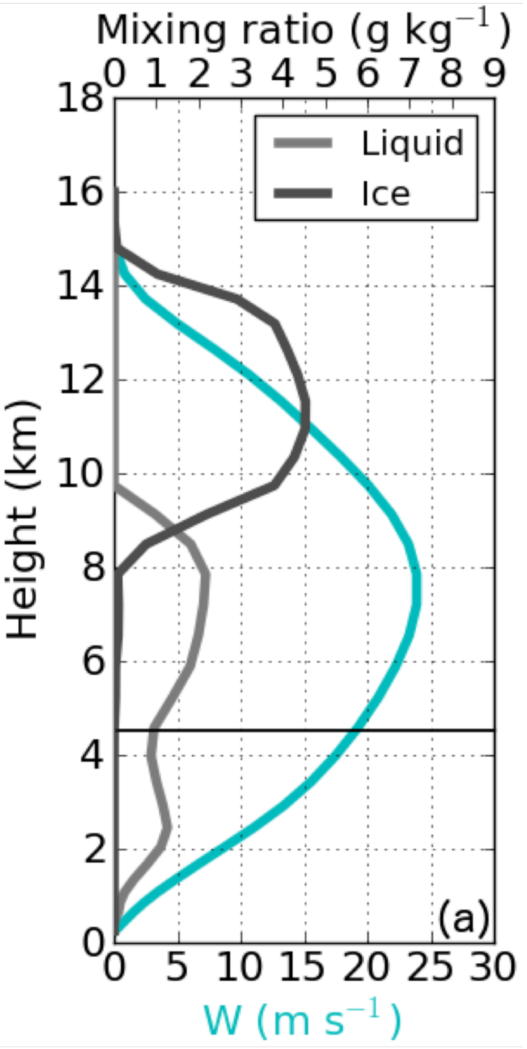
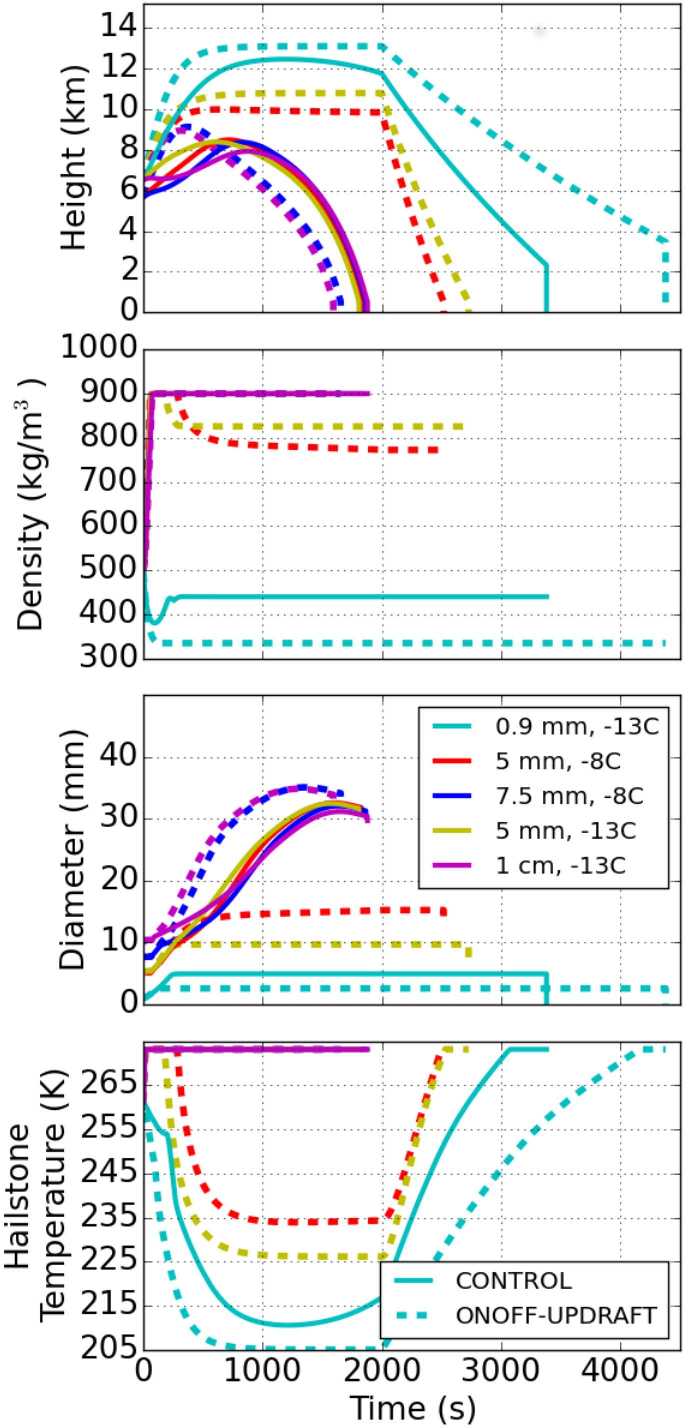


FIG. 13. Summary of observed ice particle habits in the midlevels of the storm, based upon the correlation between radar echo intensity and habit. Predominant wind flow in each region is indicated.

Heymsfield and Musil 1982





- unrealistic-looking hail trajectories

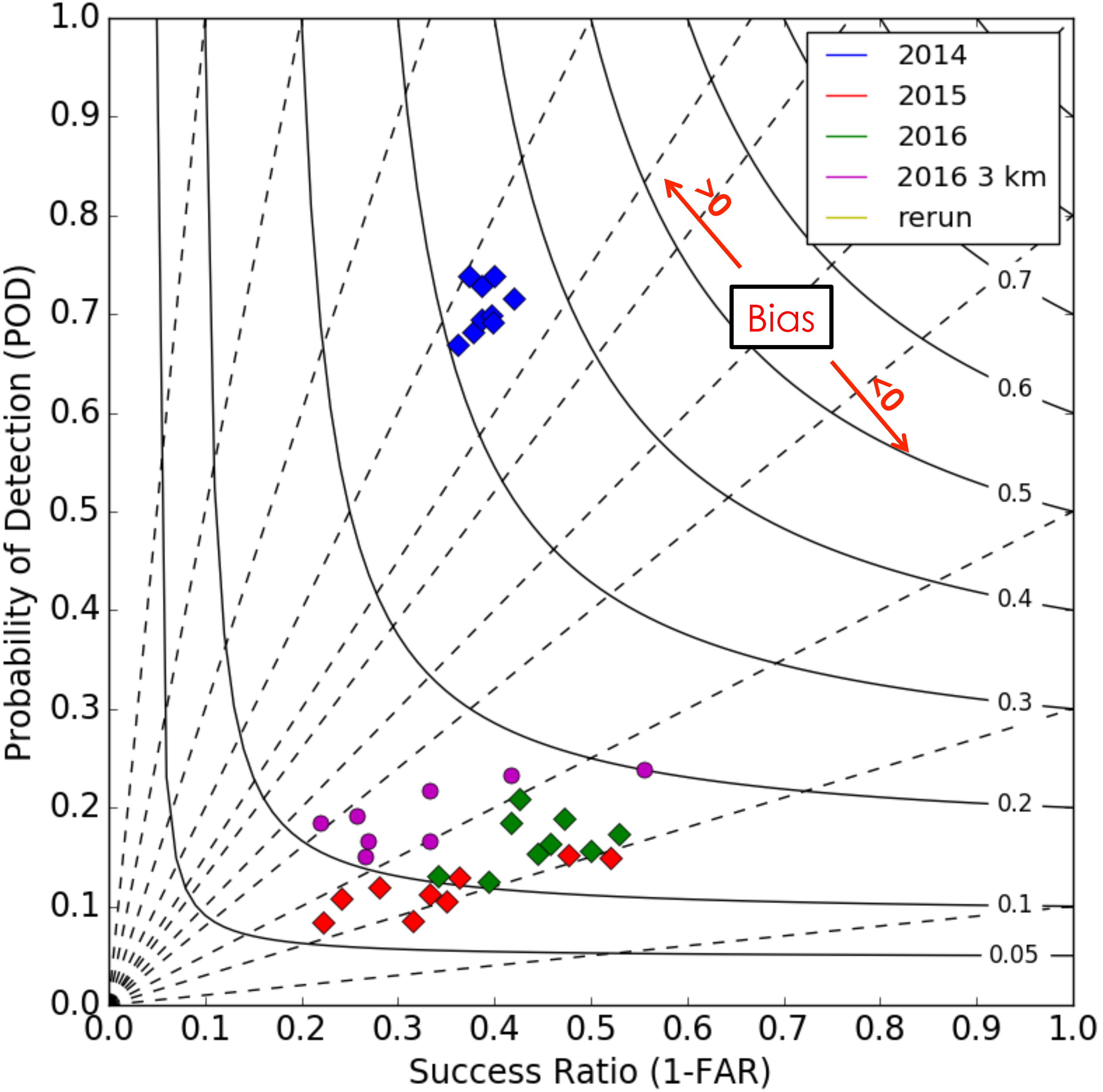
aer Atmospheric and Environmental Research

2016 WRF-HAILCAST

- Embryos now inserted at -13°C instead of 0°C (Heymsfield 1982)
- Initial embryos sizes now range from 2 mm – 1 cm; formerly on the order of microns (Heymsfield 1982; Heymsfield and Musil 1982)
- Others:
    - Enhanced melting below melting level when hailstone collides with cloud water, rain
    - Only returns diameter of unmelted ice

2016

- HAILCAST in WRFV3.9
- Hailstone travels across updraft
  - reduces such a large sensitivity to updraft strength – important for varying resolutions
- More realistic embryo sizes



2017 Improvements

- Convective structure typically includes a localized Bounded Weak Echo region (BWER) in updraft core
    - reduced precipitation content, scavenging – increased cloud water content
- Not (or partially) resolved in 1-4 km convection-allowing models
    - increase precipitation "unfairly" scavenging cloud water content

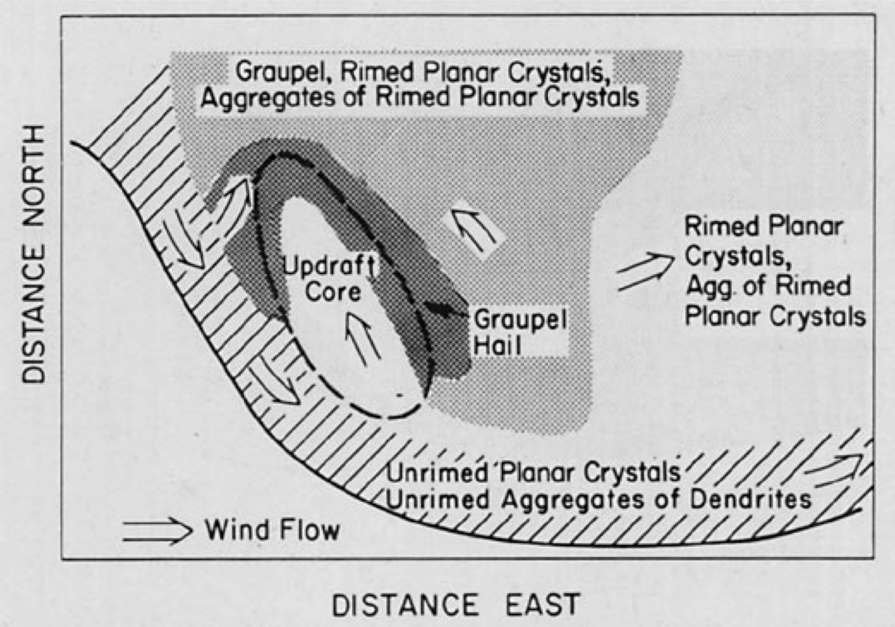
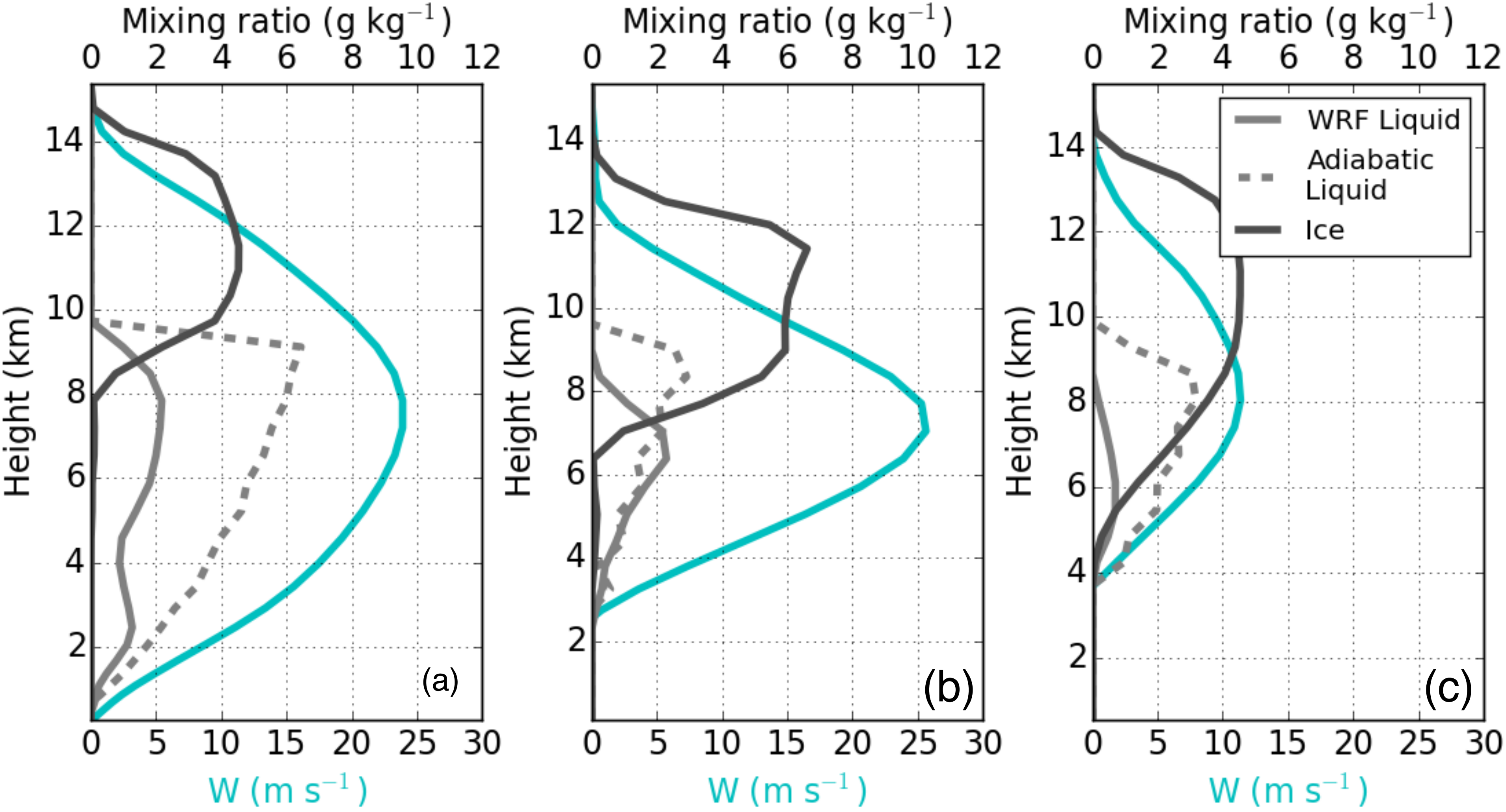


FIG. 13. Summary of observed ice particle habits in the midlevels of the storm, based upon the correlation between radar echo intensity and habit. Predominant wind flow in each region is indicated.

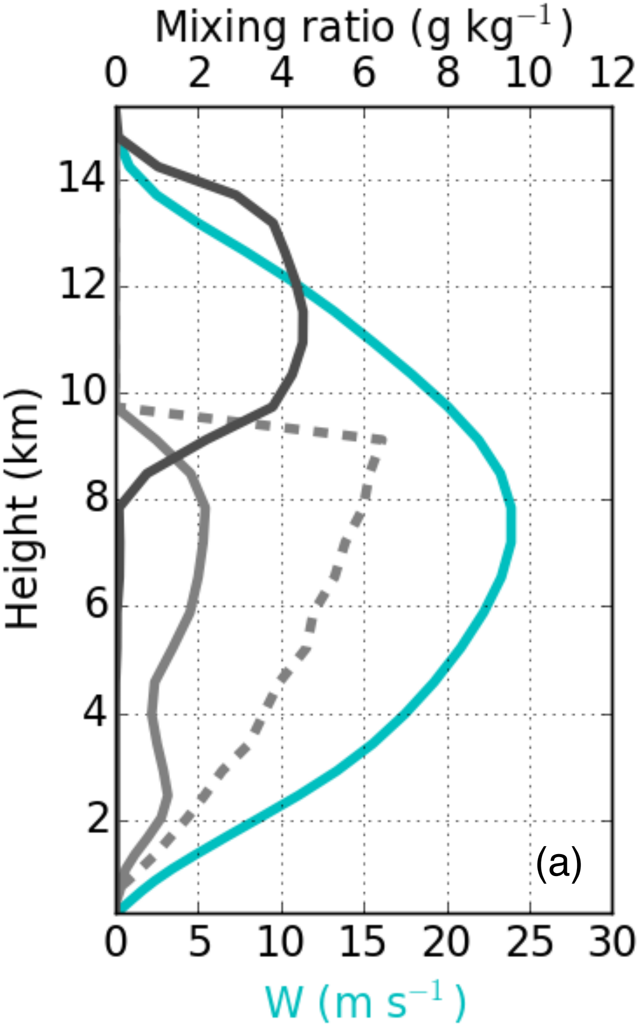
Heymsfield and Musil 1982

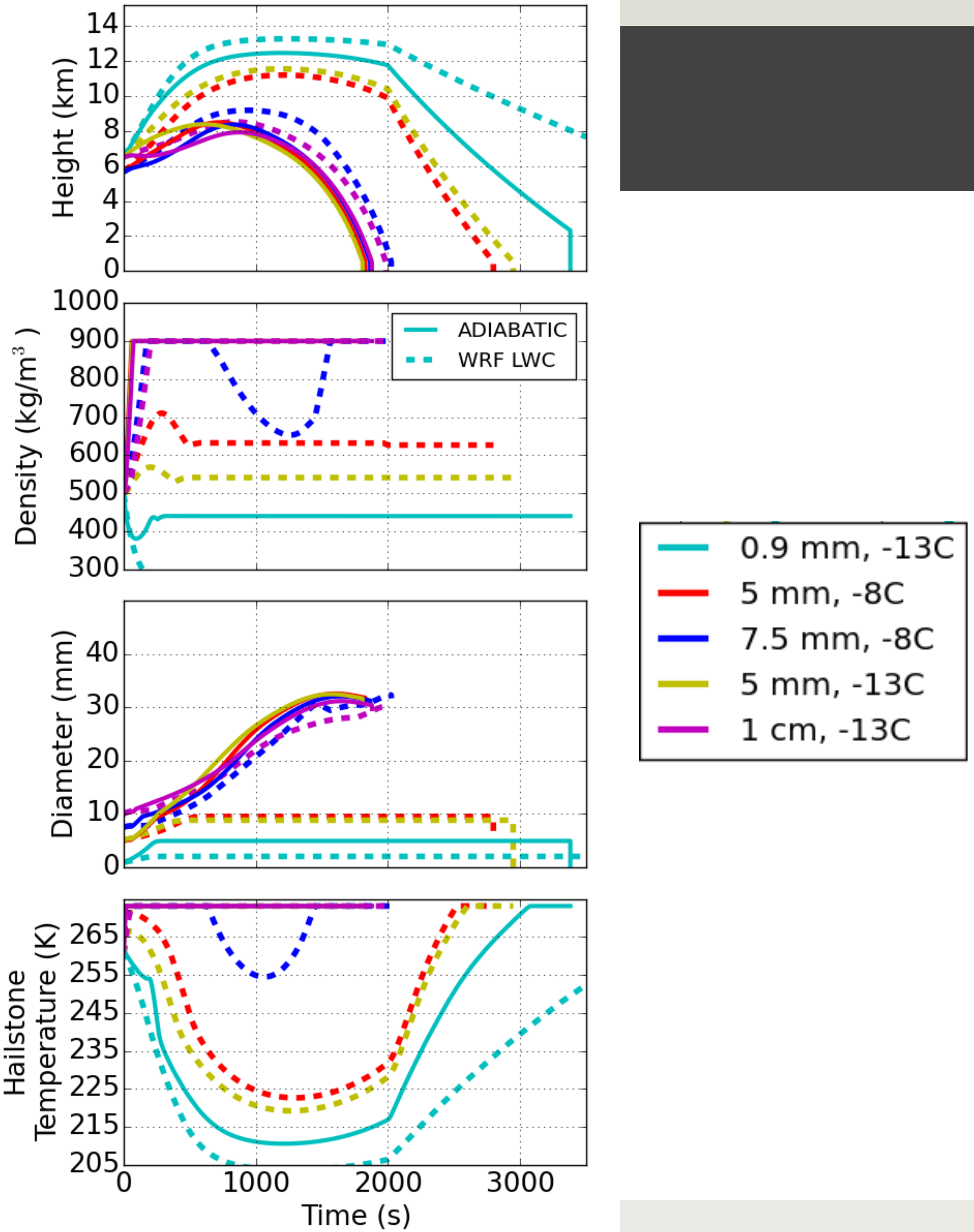
2017 Improvements



calculate adiabatic cloud water water profiles

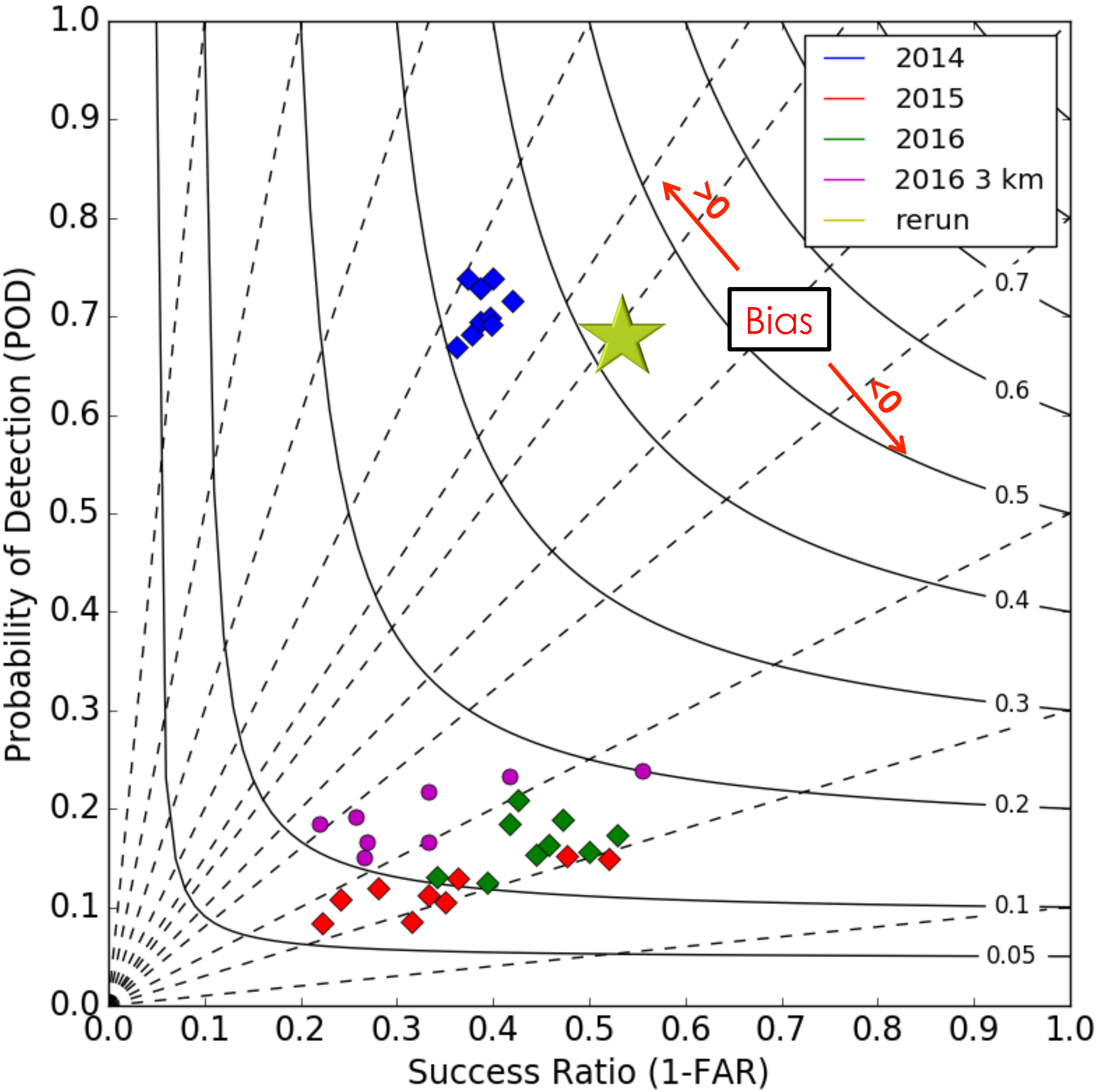
Atmospheric and Environmental Research





aer
Atmospheric and Environmental Research

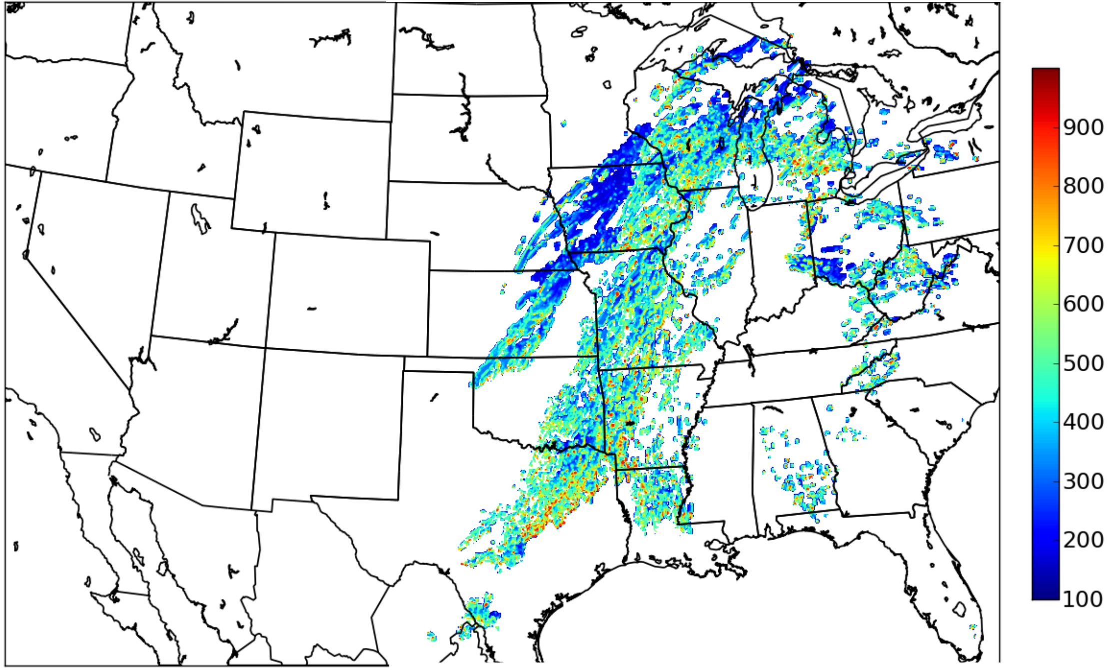
- reran 2014, 2015 dates
    - single member, WRF-ARW, Thompson physics
- Adiabatic cloud water profiles



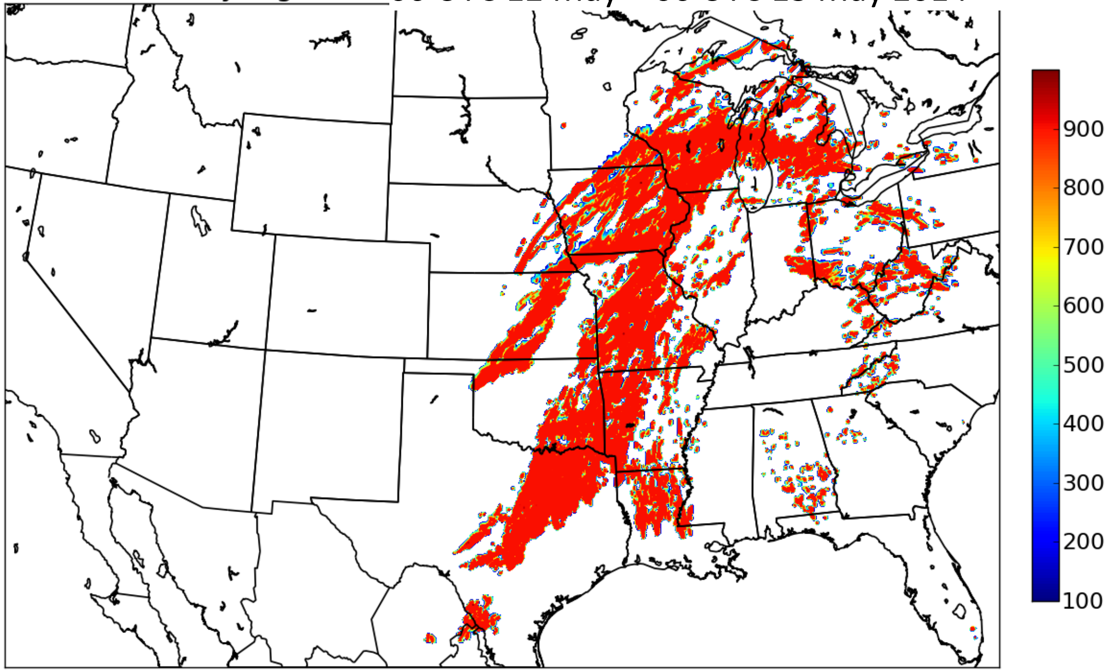
How can I use HAILCAST?

- Official release of WRFV3.9 (no adiabatic water profile correction):
  - in phys namelist: hailcast_opt = 1
  - outputs:
    - HAILCAST_DIAM_MAX – hail diameter (mm)
    - HAILCAST_DIAM_STD – hail diameter standard deviation (mm)
- Can keep processing time increase to 1% if only call every few timesteps
- Not specific to WRF!
- Email me to join the HAILCAST listserv : rselin@aer.com

Min. hail density (kg m^{-3}), 06 UTC 12 May – 06 UTC 13 May 2014



Max. hail density (kg m^{-3}), 06 UTC 12 May – 06 UTC 13 May 2014

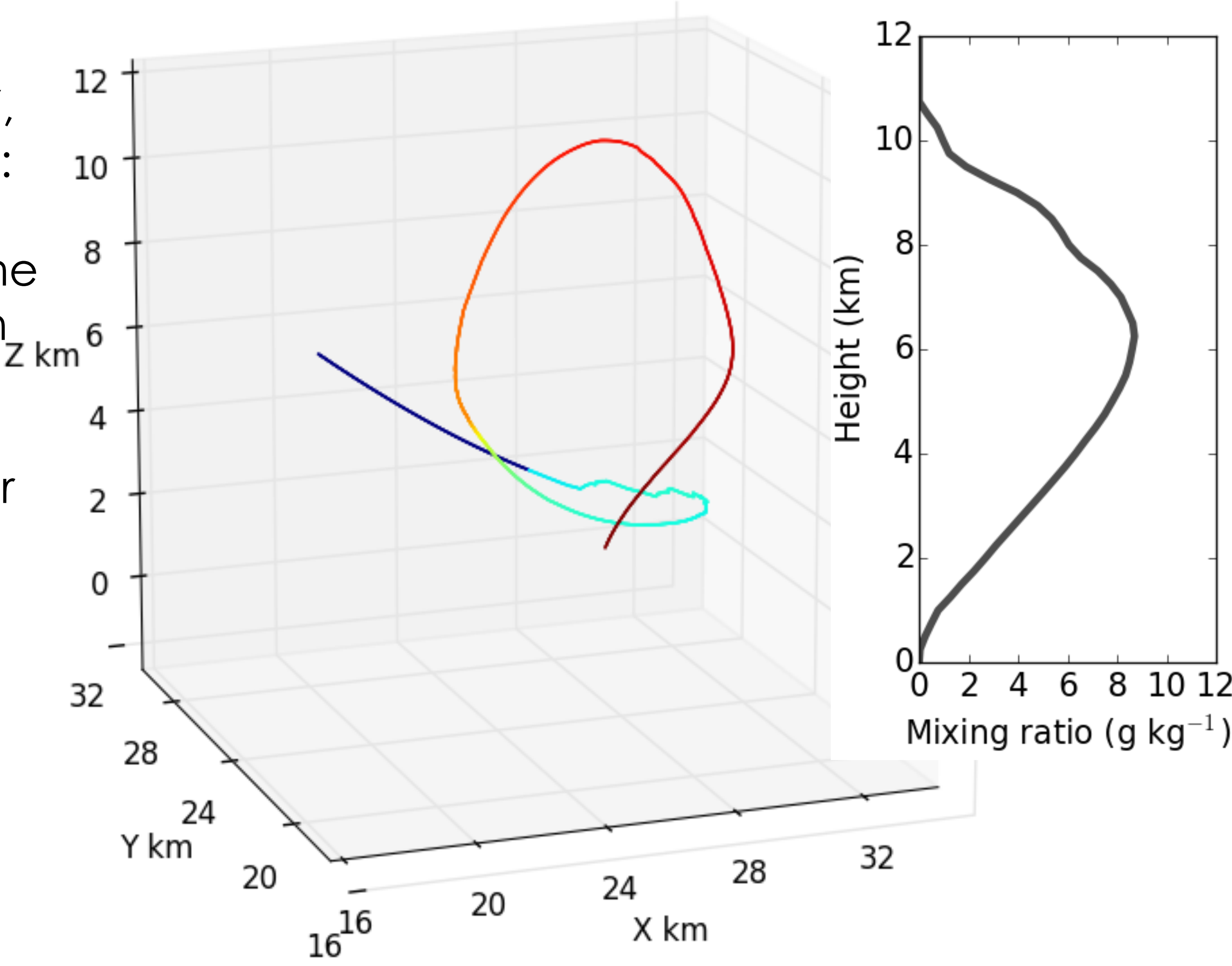


- Hail density, terminal velocity, kinetic energy all available as output

aer
Atmospheric and Environmental Research

Future research

- Dennis and Kumjian (2017, J. Atmos. Sci.): increased updraft volume in regions with strong deep layer shear leads to larger hail



Conclusions

- WRF-HAILCAST offers a physically-based hail size forecast
  - takes advantage of WRF convective modeling capabilities
  - AND advanced physical parameterizations available in a 1D column model for less processing time
- Improvements in physics and model design:
  - variable density
  - temperature dependent ice collection efficiency
  - constant range of embryo sizes, insertion temperatures
  - updraft multiplier mimics motion of embryo across updraft
  - adiabatic liquid water profile to account for “unfair” particle scavenging
- Questions?
  - rselin@aer.com