Current Developmental Activity on the Grell-Freitas Cumulus Parameterization Including the Addition of Number Concentrations and Storm Motion

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Overview of Grell-Freitas Cumulus Parameterization

Grell-Freitas Convective Parameterization

Scale-aware/Aerosol-aware

(Grell and Freitas, 2014, ACP); (Freitas et al. 2018, JAMES)

- Stochastic approach adapted from the Grell-Devenyi (2002) scheme, but changed to include temporal and spatial perturbation patterns
- Scale awareness through Arakawa approach (2011)
- Aerosol awareness is implemented with empirical assumptions based on a paper by Jiang and Feingold, also using a combination of memory and scavenging based on Lee and Feingold
- Many additions since 2014 paper: mixed phase physics impacts, momentum transport, memory impacts, Bechtold diurnal cycle method, PDF for vertical mass flux, cloud water detrainment profiles

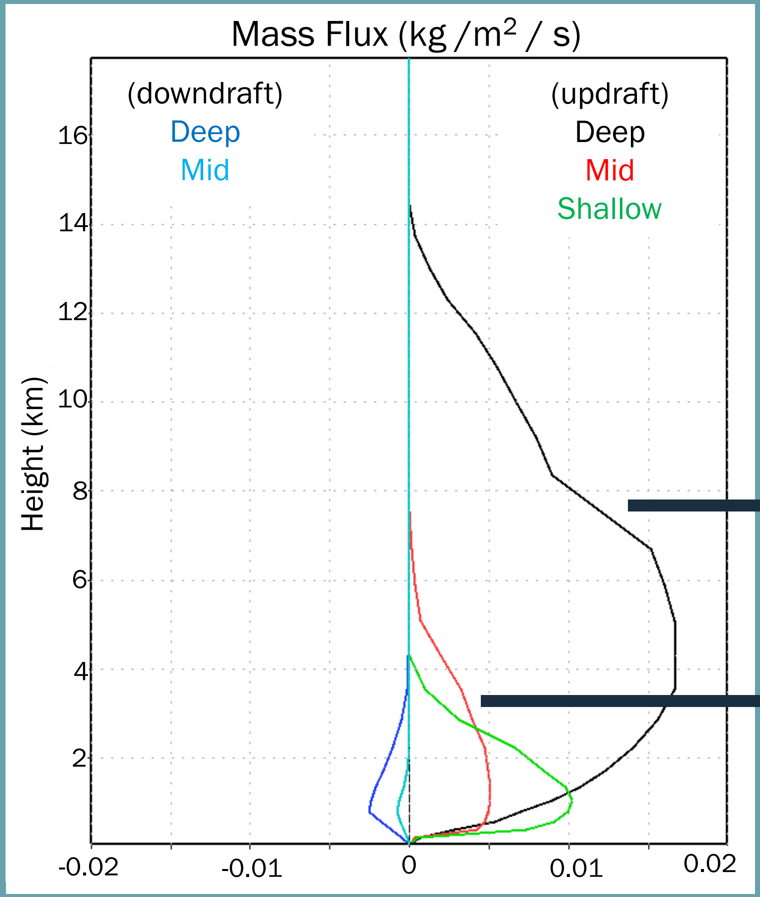
Recent New Implementations into GF (since ACP paper)

- Momentum transport (as in SAS and/or ECMWF)
- Additional closure for deep convection: Diurnal cycle effect (Bechtold 2014)
- PDF approach for normalized mass flux profiles was implemented
  - Originally to fit LES modeling for shallow convection
  - Represents deep plumes in grid box
  - Allows easy application of mass conserving stochastic perturbation of vertical heating and moistening profiles
  - Provides smooth vertical profiles
- Third type of plumes (congestus type convection)
- Changed cloud water detrainment treatment
- Stochastic part now coupled to Stochastic Parameter Perturbation (SPP), and Stochastic Kinetic Energy Backscatter (SKEBS) approach (J. Berner)
- Mixed phase physics and coupling to double moment microphysics

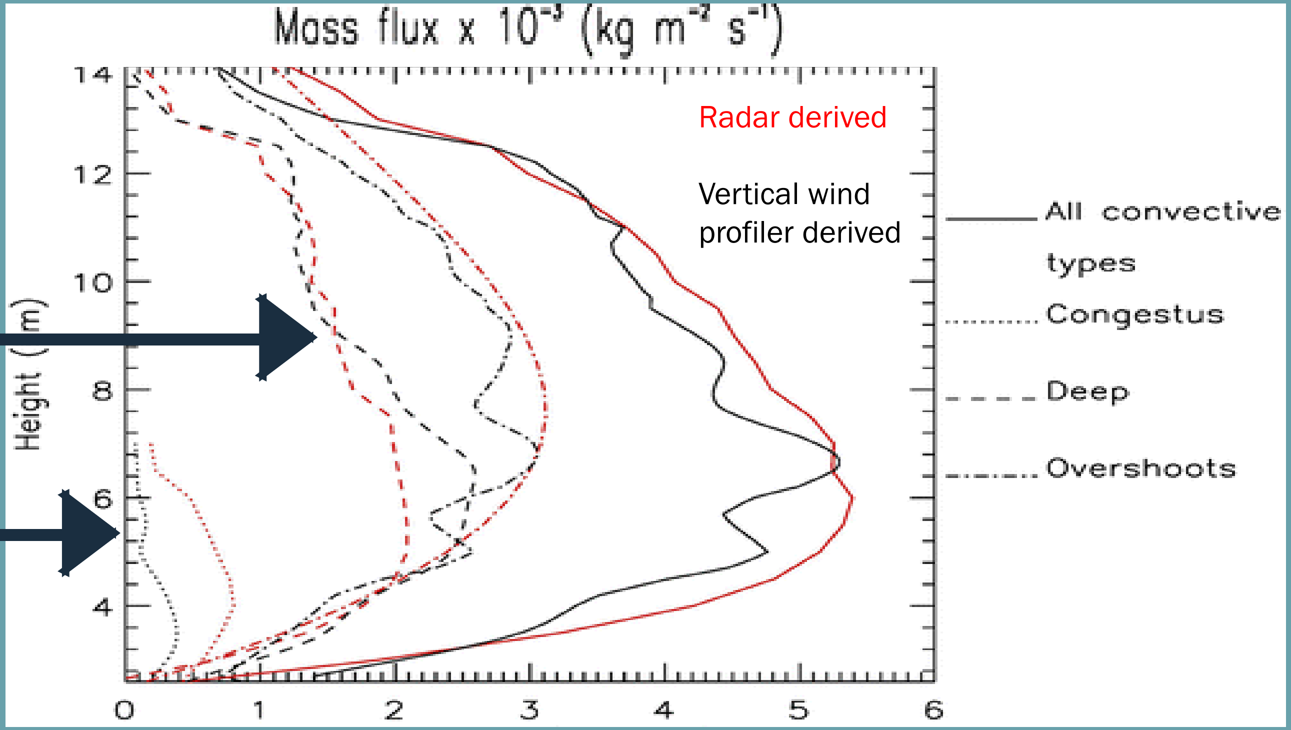
Versions now used in WRF, FIM, GFS, GEOS-5, will be operational in RAP

TWP-ICE Single Column Model verse Observations

SCM model results for normalized mass flux PDF, deep, shallow, and downdraft mass fluxes



From "The Estimation of Convective Mass Flux from Radar Reflectivities" (JAMC, Kumar et al. 2016)



Mass flux profiles in GF similar to observations.

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Number Concentrations In Grell-Freitas

Number Concentrations in GF: Motivation

- Model performance is improved when double-moment microphysical parameterizations are used

- Potential problem at coarse resolution:
  - Cumulus parameterizations are single-moment
  - Creates artificial modification of the particle size distribution that is feed into the microphysics scheme
  - Can impact model performance

Total 12hr Accumulated Precipitation

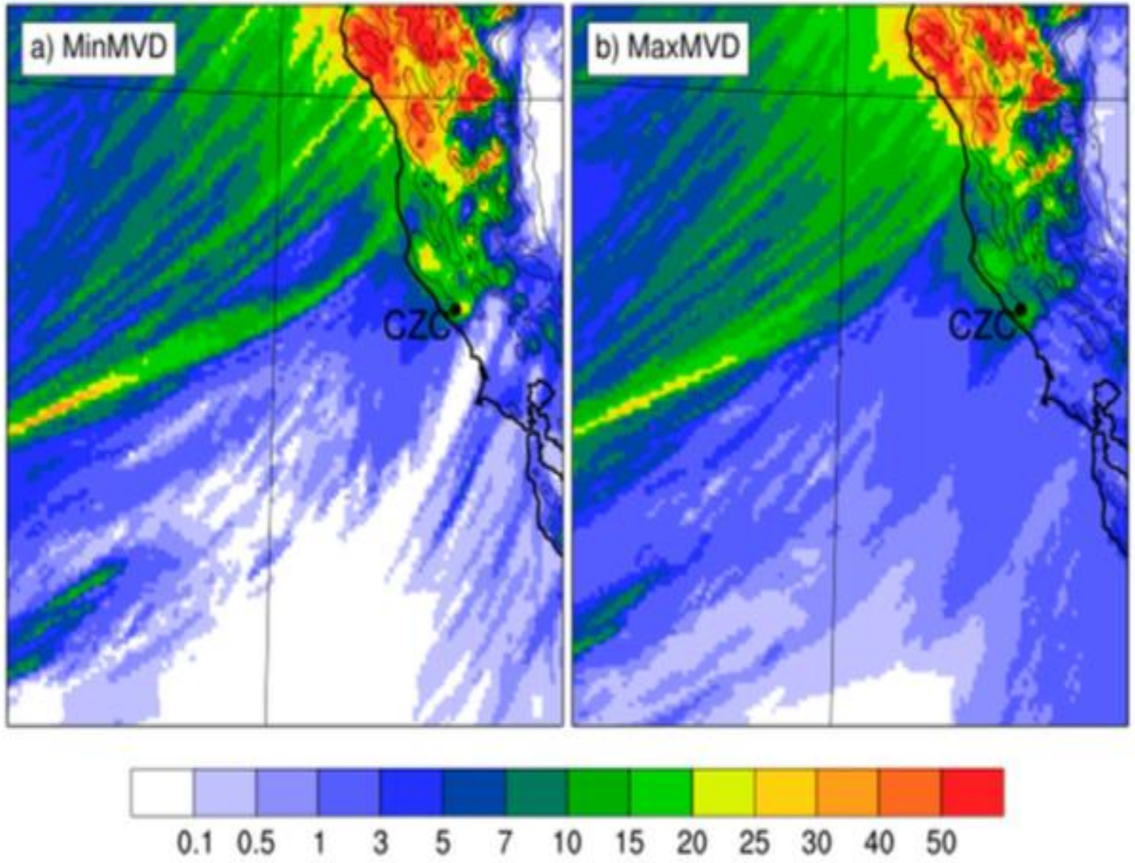


FIG. 12. Total accumulated precipitation (mm) at 12 h for the modified Thom-KF experiments using (a) minimum MVD for rain and (b) maximum MVD for rain. The region shown is the subdomain labeled box A in Fig. 1. The location of Cazadero, CA, is indicated by the black dot labeled CZC.

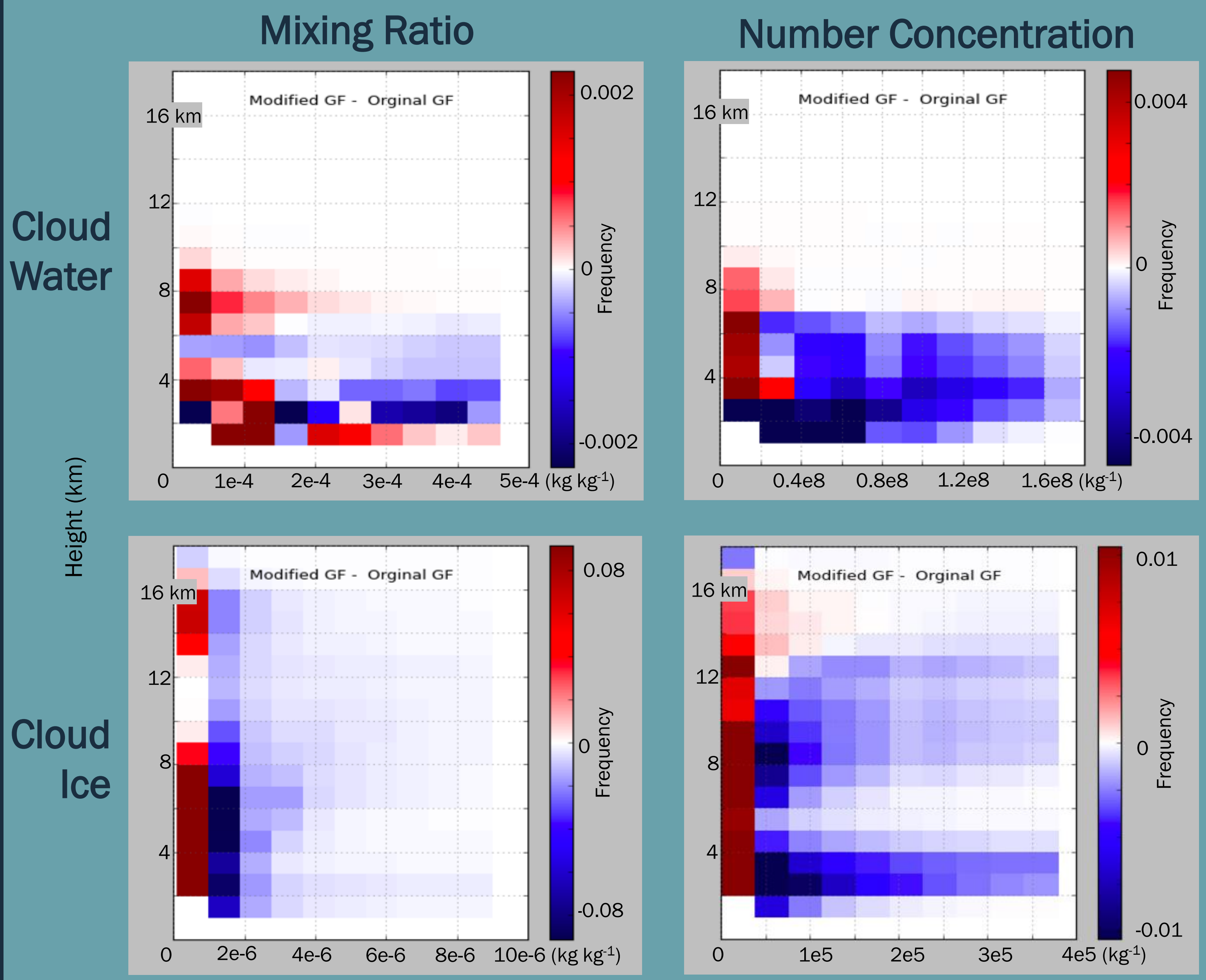
Grell et al., 2018

Number Concentrations in GF: Methodology

- Develop a simple, inexpensive, diagnostic method to output cloud water and cloud ice number concentrations from GF
  - Cloud water approximation based on:
    - Cloud water mixing ratio from GF
    - Water-friendly aerosol characteristics
  - Cloud ice approximate based on:
    - Cloud ice mixing ratio from GF
    - Ice size – temperature relationship
  - Methodology made to be consistent with the Aerosol-Aware Thompson Microphysical Parameterization

Difference CFADs

(Contour Frequency by Altitude Diagrams)



Number Concentrations in GF:

CCPP-FV3 Results

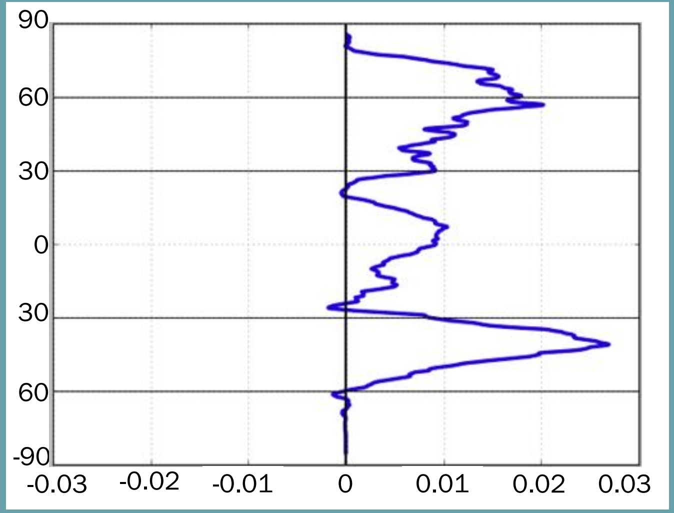
- Generally:
  - Small mixing ratios/ number concentrations increase
  - Large mixing ratios/ number concentrations decrease
- Changes in cloud ice greater than changes in cloud water

Number Concentrations in GF: CCPP-FV3 Results

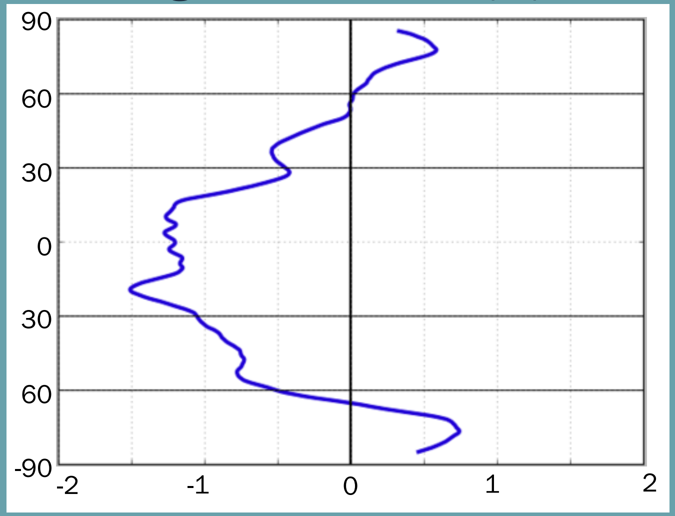
Zonally Averaged Changes (Modified – Original)

Latitude

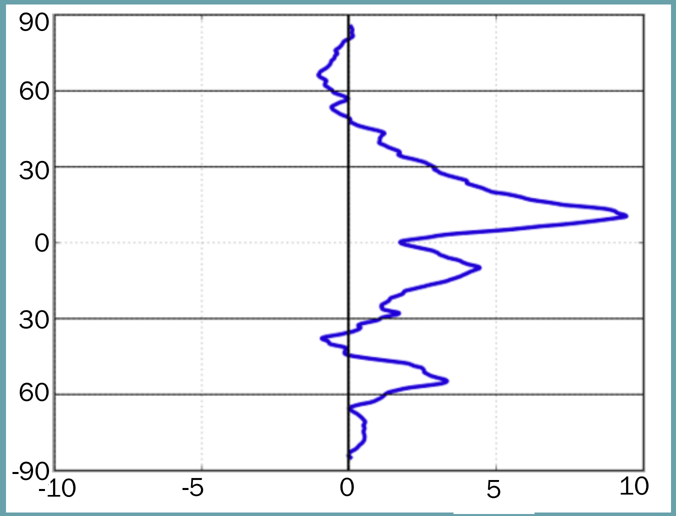
Convective Precipitation Fraction



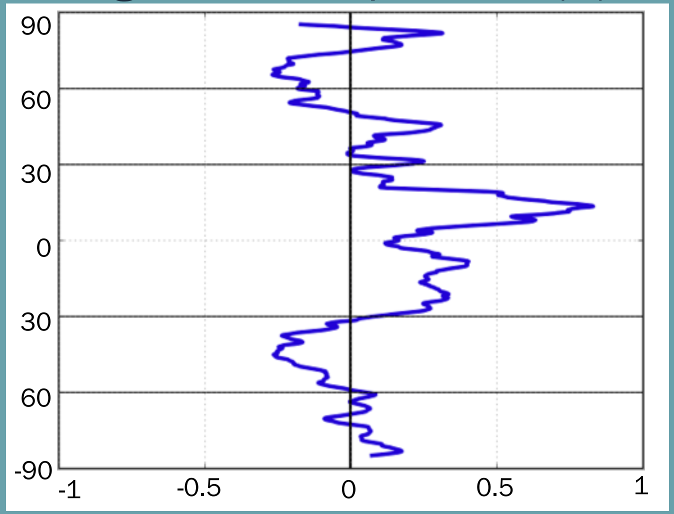
High Cloud Cover (%)



Downward Shortwave Flux (Wm^{-1})



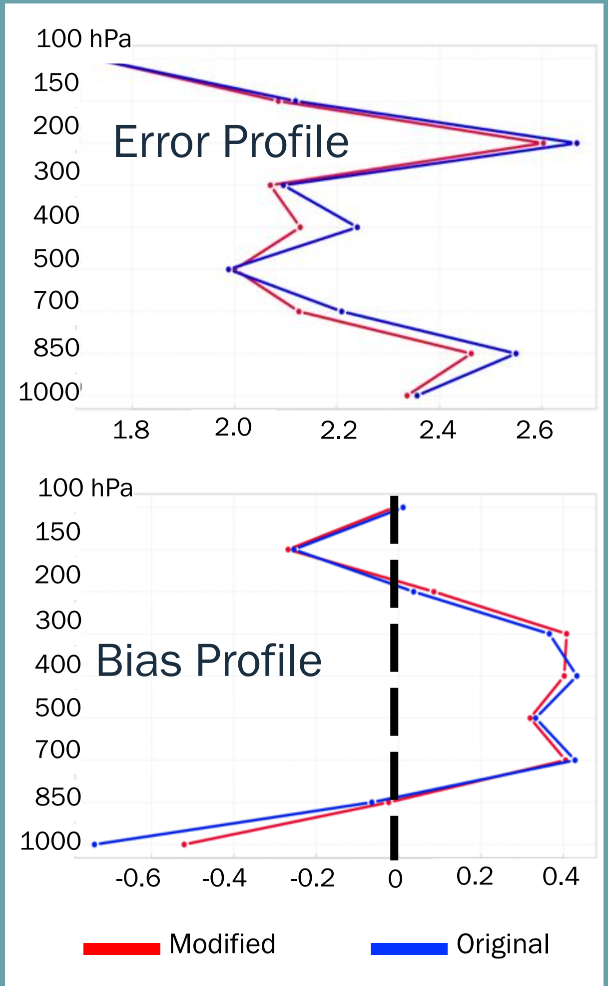
Brightness Temperature (K)



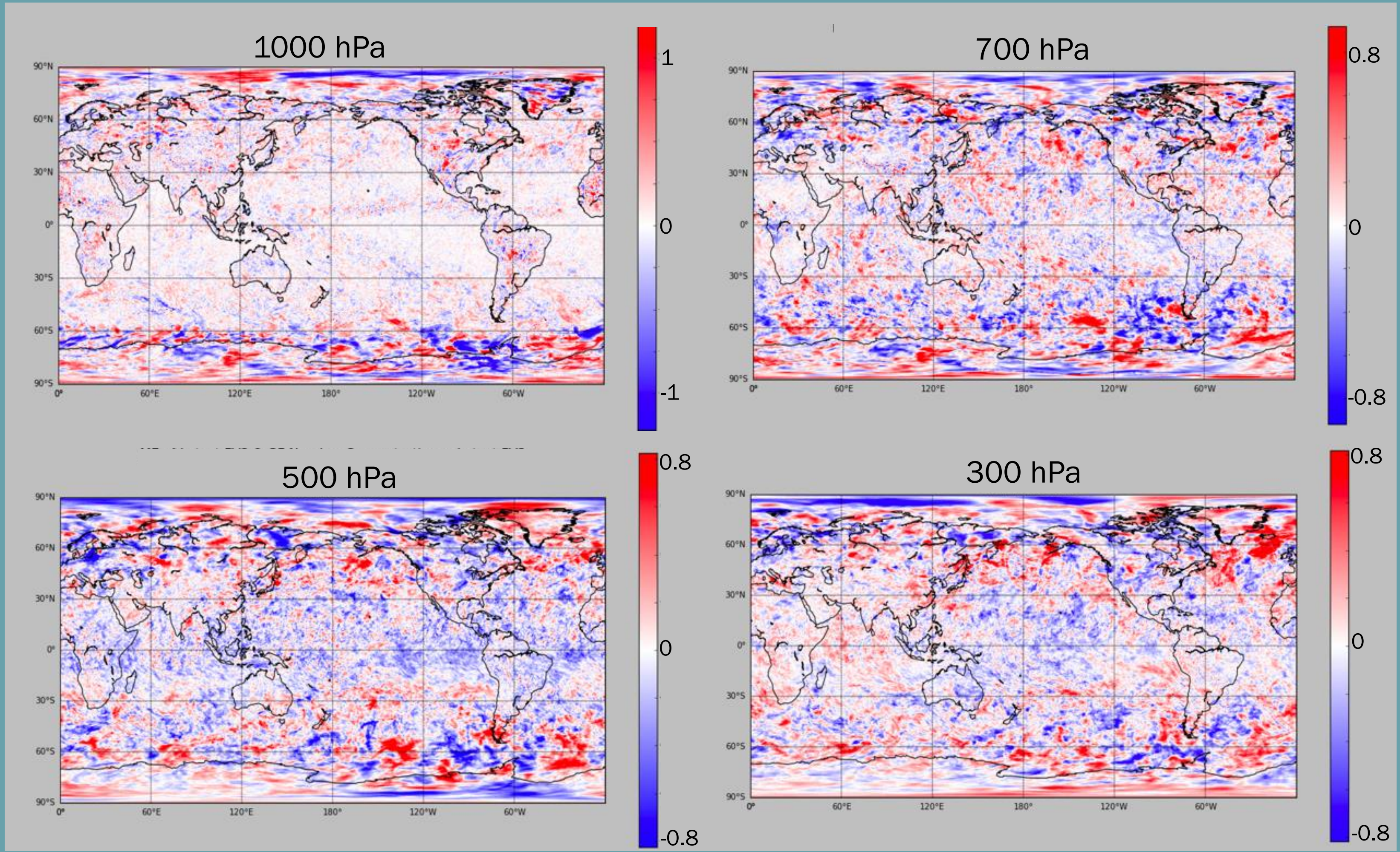
- Tropics
  - Magnitude of change often largest here
  - Convective precipitation Fraction, shortwave flux and brightness temperatures increase
  - High cloud cover decreases
- Mid-latitudes
  - Larger increase in convective precipitation fraction
  - High cloud cover decreases
  - Shortwave flux increases
  - Brightness temperature change varies by hemisphere

Number Concentrations in GF: CCPP-FV3 Results

Northern Hemisphere
120h Temperature



120hr Temperature Differences [Modified – Original] (K)

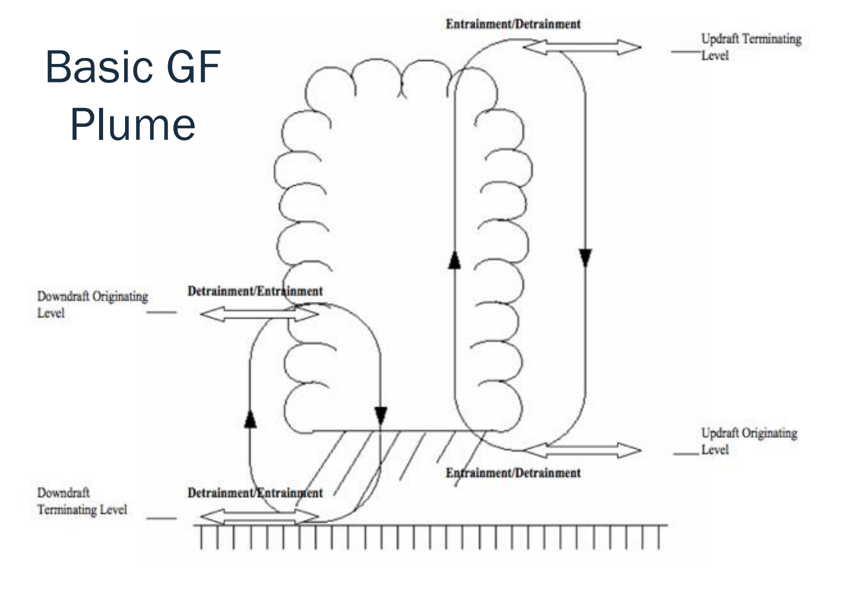


Slightly improves low- and mid-level temperature errors.

Storm Motion In Grell-Freitas

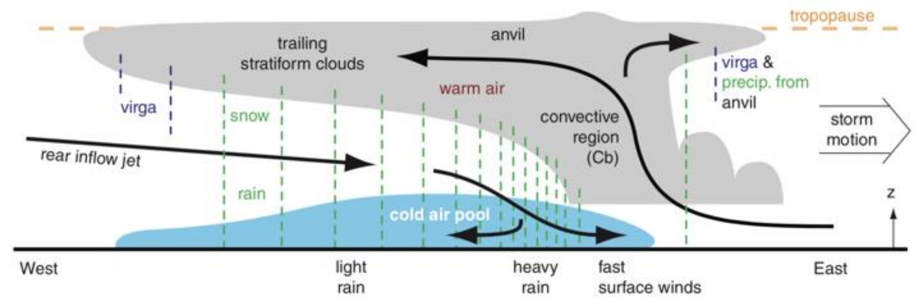
Storm Motion in GF: Motivation

- Downdrafts are one mechanism that can foster convective propagation and organization
- GF already simulates downdrafts
  - This work tries to use the downdrafts represented in GF to foster storm propagation



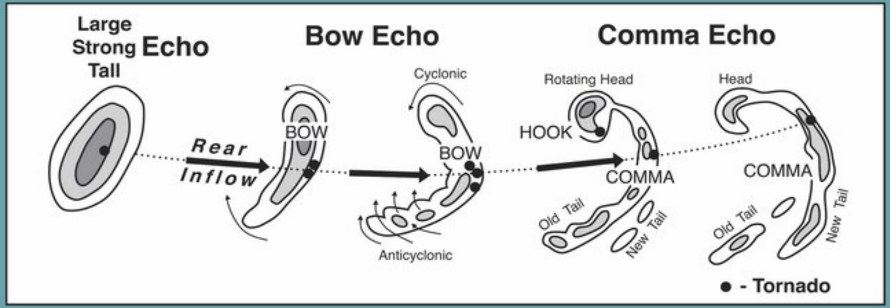
http://cires1.colorado.edu/science/groups/pielke/classes/at730/AWangFinal.pdf

Mesoscale Convective Systems



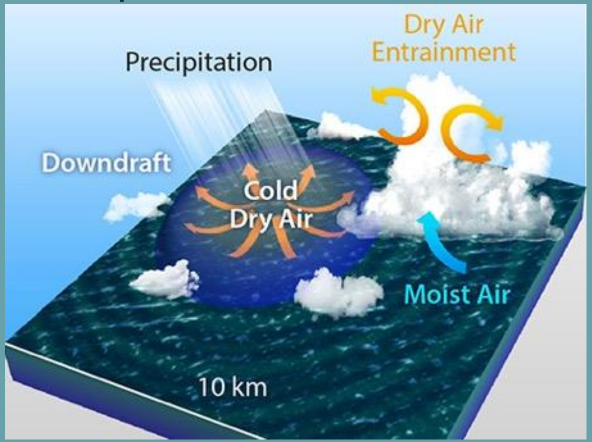
https://www.eoas.ubc.ca/courses/atsc113/flying/met_concepts/04-met_concepts/04a-Tstorm_types/index-mcs.html

Squall Lines



Wakimoto et al., 2006

Cold pools



Zhe et al., 2015

Storm Motion in GF: WRF Methodology

- Introduces a term to represent downdraft mass flux
  - Downdraft mass flux = (total cloud base mass flux) * (ratio of downdraft to updraft cloud base mass flux) * (normalized downdraft profile)
  - Classified as an advective scalar

Time Step 1

1. Calculate downdraft mass flux after the deep GF scheme is completed
2. Advect the downdraft mass flux (3D)
3. Advance to next time step

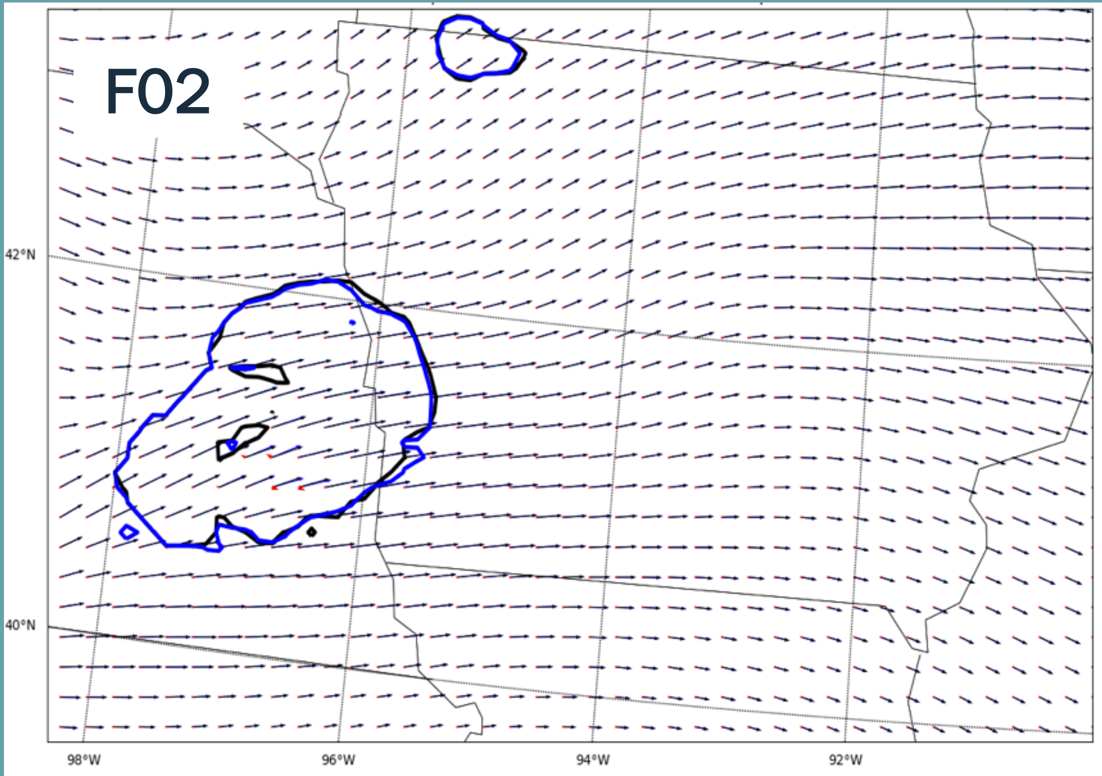
Time Step 2

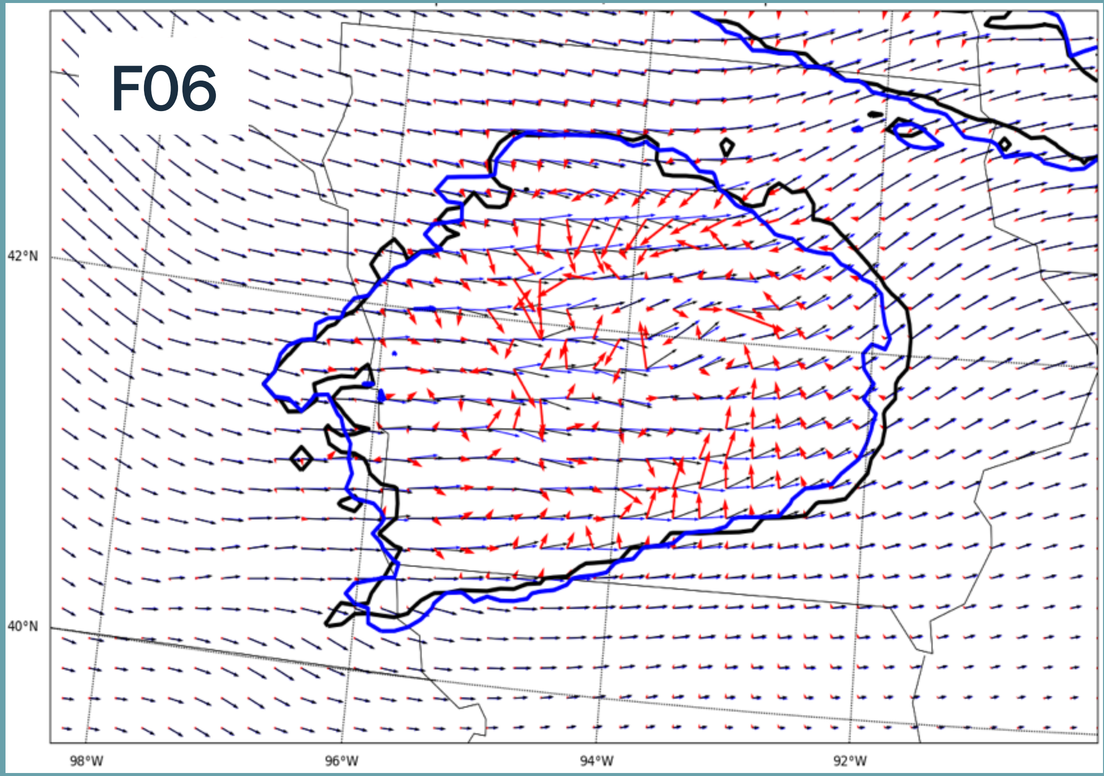
1. Calculate the total cloud base mass flux
2. Select one value from each advected downdraft mass flux column
   - *Represents advection from Time Step 1*
   - *Currently use the 850 – 650 hPa average*
3. Add selected downdraft mass flux to the total cloud base mass flux

Storm Motion in GF: Results

Maps of Precipitation and Winds at Advection Level

Blue: No Advection, Black: Advection, Red: Advection – No Advection



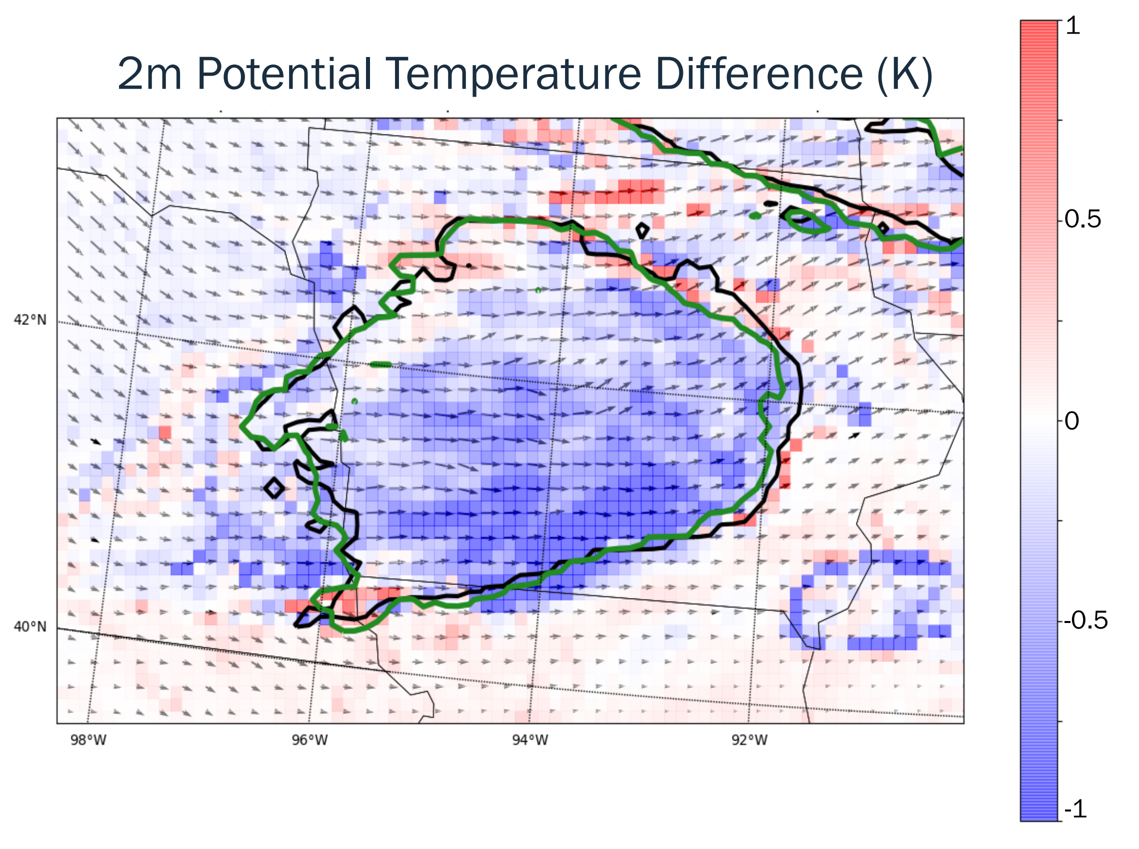


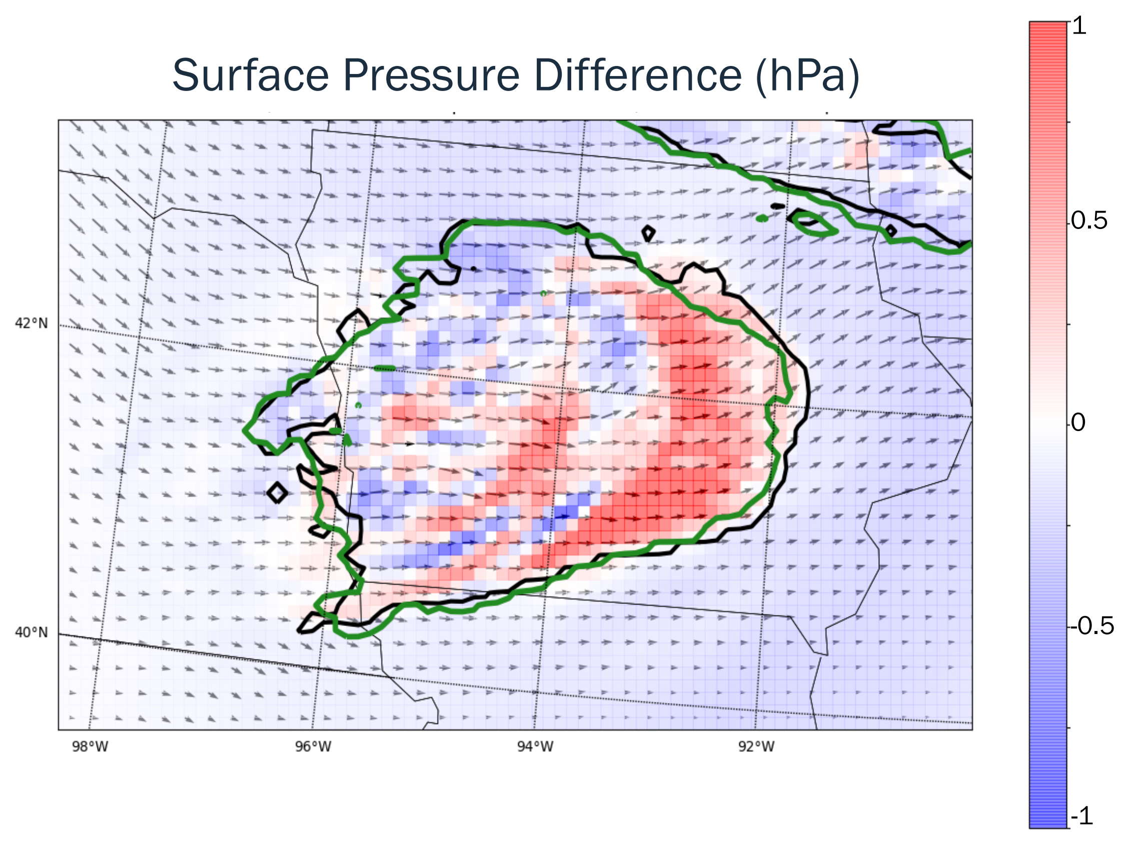
Winds at advection level have an extra component in the direction of advection

Storm Motion in GF: Results

Difference Maps

Shading: Advection – No Advection, Green: No Advection, Black: Advection





The simulation with advection has a stronger cold pool and larger surface pressure perturbations.

Conclusions

- **Overview of the Grell-Freitas Cumulus Parameterization (GF)**
  - Stochastic, scale-aware, and aerosol aware (Grell and Freitas, 2014; Freitas et al., 2018)
  - Since the scheme was published developmental activities include
    - Modifications to stochastic approaches and detrainment
    - Adding momentum transport, diurnal cycle closure, and a PDF approach to mass flux

- **Highlight two ongoing developmental activities**
  - <u>Address particle size distribution differences in cumulus and microphysics schemes</u>
    - Add diagnostic number concentrations of cloud water and cloud ice to GF
    - Distribution of cloud water and ice shift to smaller mixing ratios and lower number concentrations
    - Impacts precipitation, cloud cover, radiation, and temperature

  - <u>Enable convection to propagation through the advection of downdraft mass flux</u>
    - Simulations with advection have enhanced winds in the direction of advection
    - Increases pressure anomalies and strength of cold pool

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