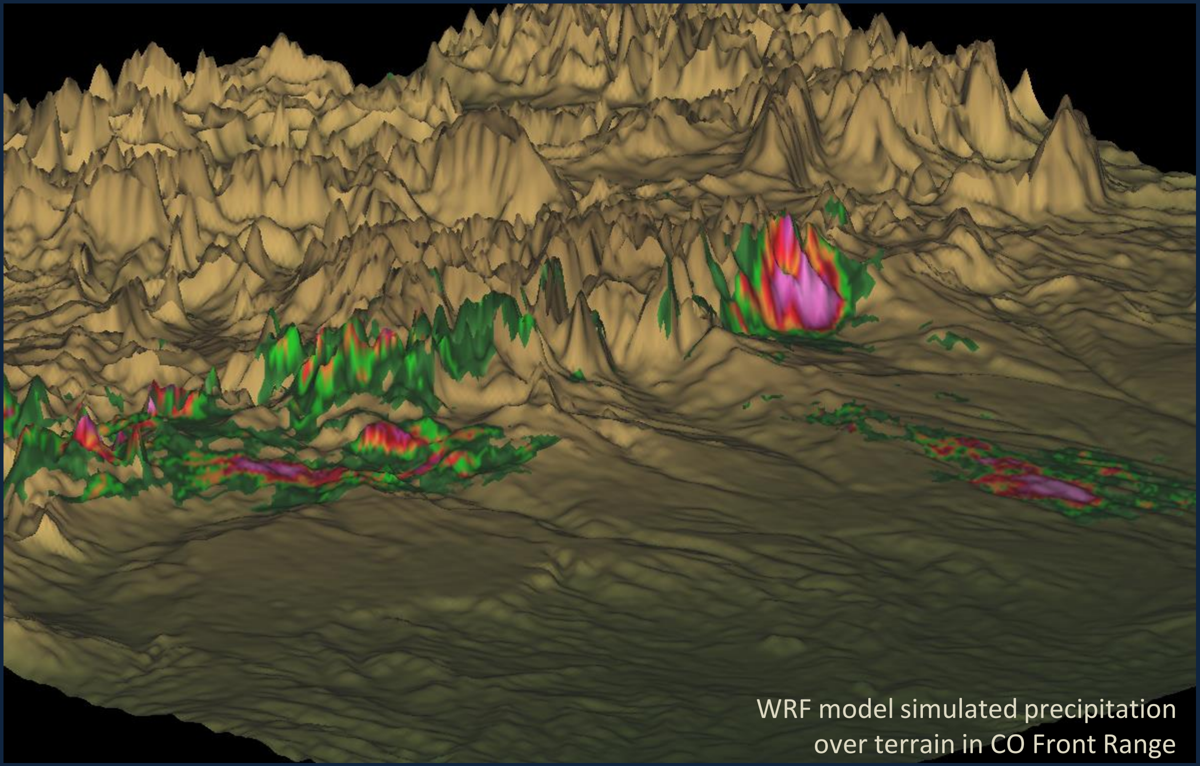
# The role of “gray zone” convective model physics in high-resolution simulations of the 2013 Colorado Front Range Flood



WRF model simulated precipitation
over terrain in CO Front Range

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GEWEX Convection-Permitting Climate Modeling Workshop
6 September 2016

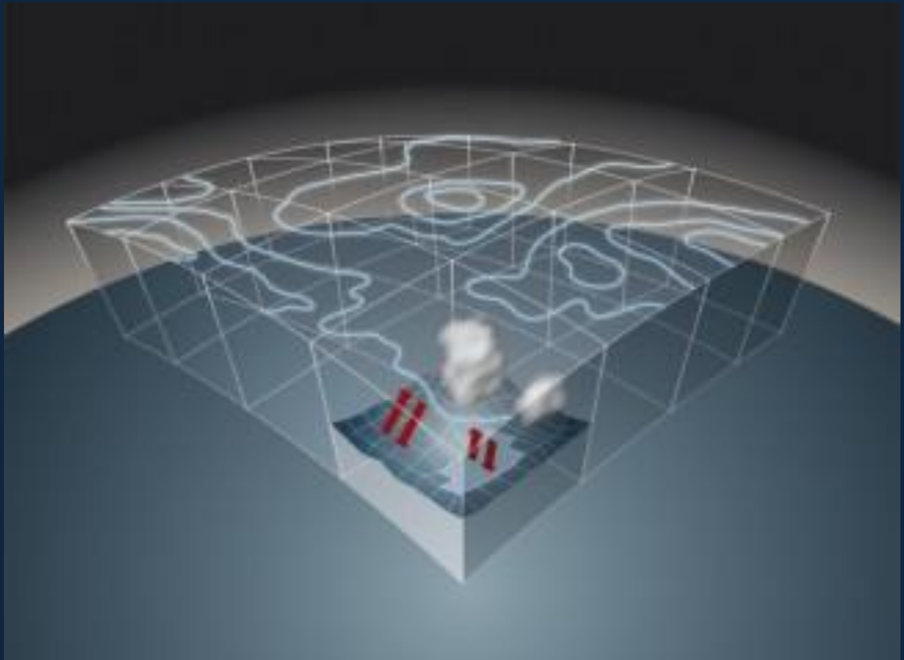
# Motivation

- Deep convection "gray zone"
  - ~1 – 5-km grid spacing: relatively "high-resolution," explicit convection (EC) often used
  - Assumes model is capable of explicitly resolving convection on grid scale
  - Many studies question aspects of this assumption: Grid spacing still too coarse to fully resolve deep convection
    - Bryan et al. 2003; Deng and Stauffer 2006; Lean et al. 2008; Bengtsson et al. 2012; Gerard 2015
  - Efforts to adapt convective parameterization schemes (CPSs) for gray-zone scales
    - e.g., Gerard 2015; Liu et al. 2015; Bengtsson and Kornich 2016; Zheng et al. 2016

*http://phys.org/news/2015-04-climate-important-cumulus-cloud-scale.html*

# Motivation: Explicit convection benefits

- CP assumptions that break down with increasing horizontal resolution:
  - Limitations of “grid-box” state (i.e., growing importance of horizontal fluxes, need for communication with neighboring grid points)
  - Cloud lifecycle/temporal mismatches, overlapping with explicitly-resolved convection
  - Coarse approximations of effects of convection: latent heat release, etc.

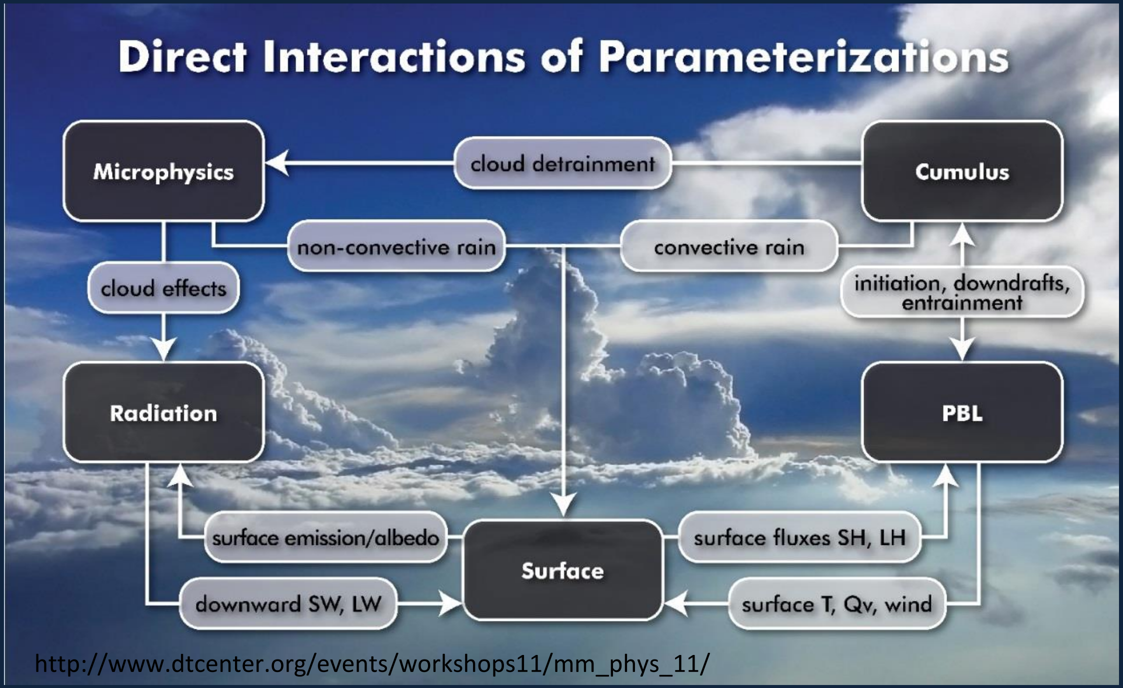


http://www.ecmwf.int/en/about/media-centre/news/2015/seminar-physical-processes-present-and-future-large-scale-models

# Motivation: Benefits of employing CP at relatively fine grid spacings

- Challenges with explicit convection only in gray zone? Can justify some CP to:
  - Avoid unrealistic buildup of CAPE, spurious convection, gridpoint storms/over-done updrafts
  - Supplement cloud microphysics parameterization where needed
  - Represent shallow mixing (omission → spurious stratus cloud cover)

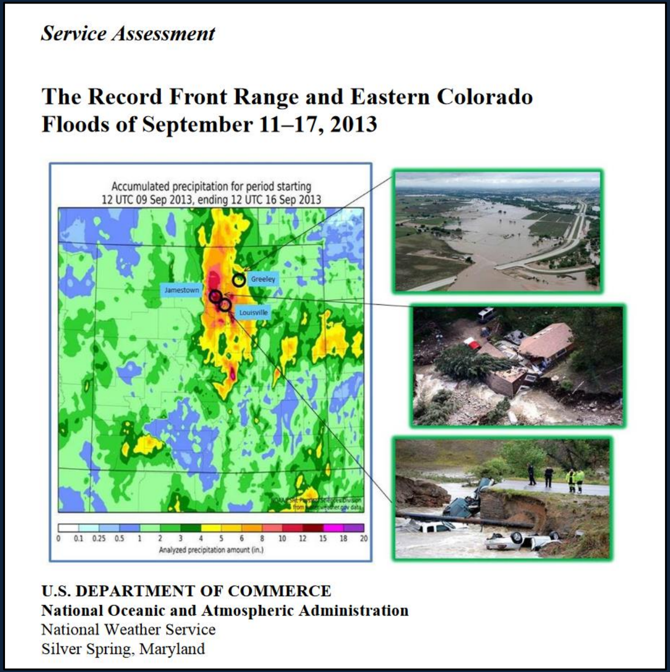
- To what extent should "scale-aware" CP be pursued? Versus addressing via other model parameterization schemes?



http://www.dtcenter.org/events/workshops11/mm_phys_11/

# Motivation: 2013 CO Front Range Floods

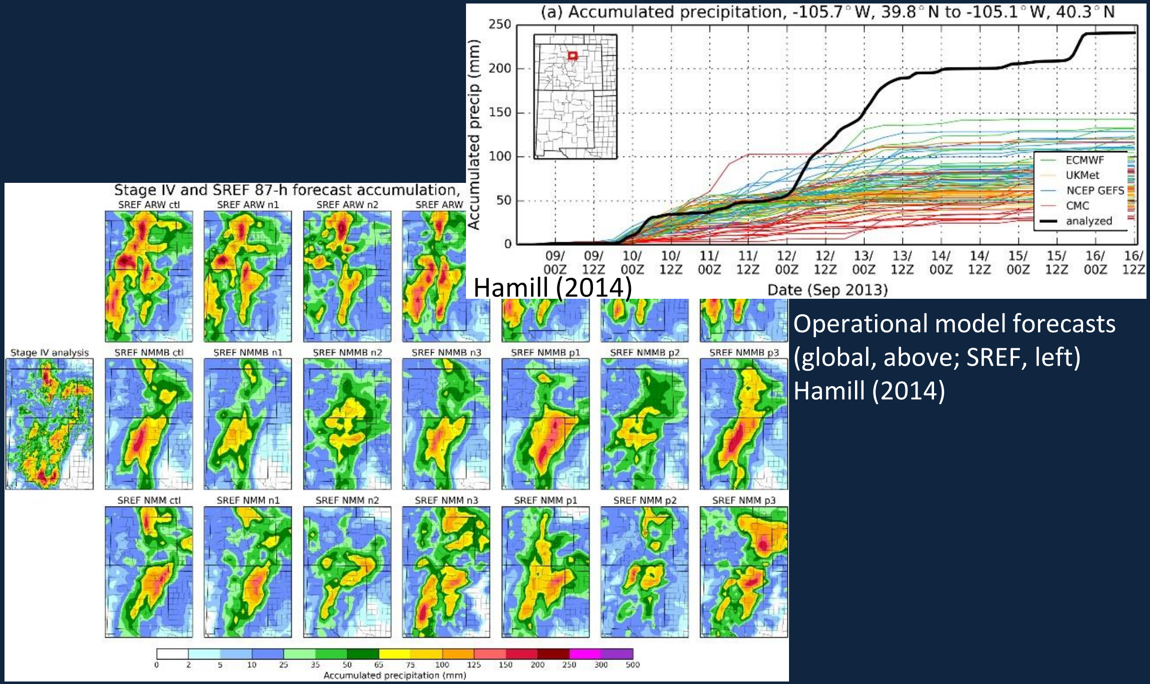
- 2013 Colorado Front Range Floods
  - 10 – 18 inches of rain, catastrophic flooding in north/central Colorado
  - Forecast challenges: role of model resolution, model physics?
  - Model gray zone relevance: extensive spatial and temporal scale + embedded convection
    - Breadth in space and time: sustained synoptic, mesoscale forcing → CP strengths?
    - Intense convective episodes: mesoscale convective organization → EC strengths?
  - Terrain-focused, yet significant forecast errors at many space, time scales



*Service Assessment*

**The Record Front Range and Eastern Colorado Floods of September 11–17, 2013**

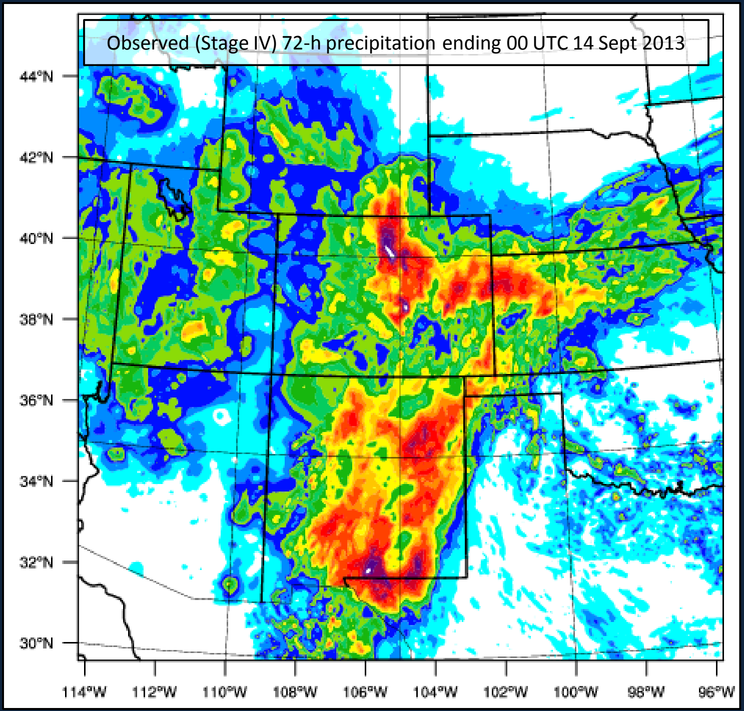
**U.S. DEPARTMENT OF COMMERCE**
**National Oceanic and Atmospheric Administration**
National Weather Service
Silver Spring, Maryland



Operational model forecasts (global, above; SREF, left)
Hamill (2014)

# Study objectives

- Evaluate relative benefits of convective parameterization, explicit convection for 2013 CO Front Range Flood in 4-km grid spacing model deep convection “gray zone”
  - Community-available CP schemes (formulated for, used across various scales)
  - Newly-developed, “scale-aware” Kain-Fritsch scheme
  - Examine representation of convection both upstream and in location of observed flooding


Observed (Stage IV) 72-h precipitation ending 00 UTC 14 Sept 2013

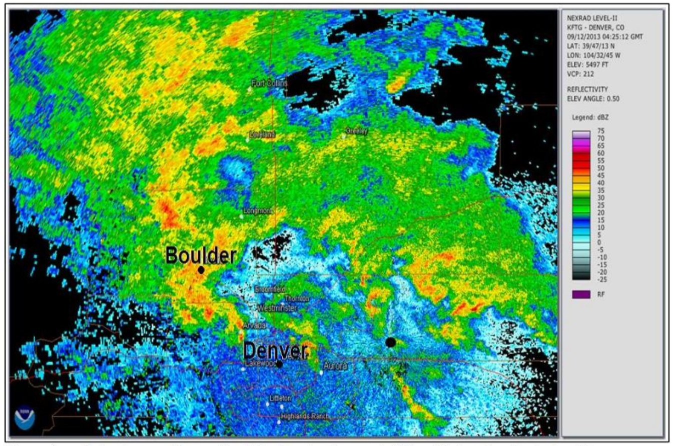
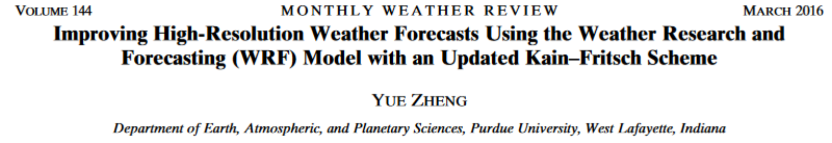


**Figure 4:** Radar image of base reflectivity showing heavy rainfall on Wednesday, September 11, at 10:25 p.m. MDT


VOLUME 144 MONTHLY WEATHER REVIEW MARCH 2016

**Improving High-Resolution Weather Forecasts Using the Weather Research and Forecasting (WRF) Model with an Updated Kain–Fritsch Scheme**

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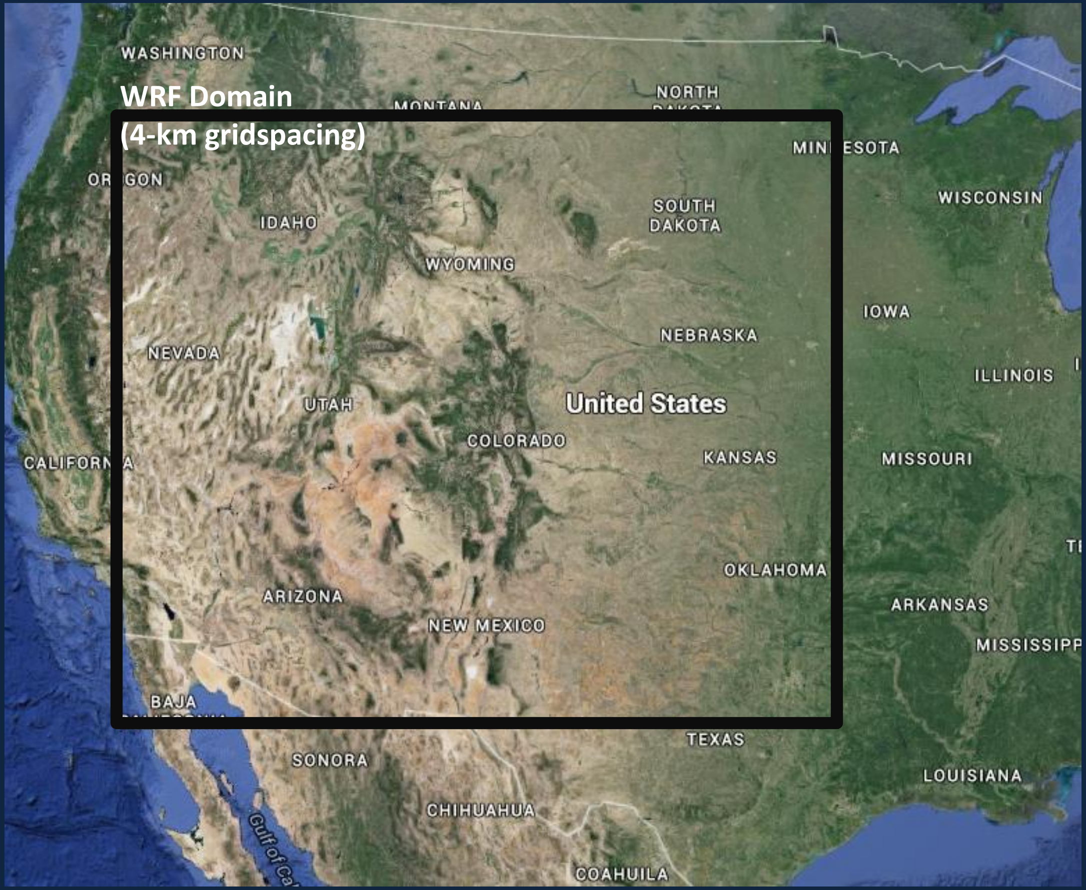
# Weather Research and Forecasting (WRF) Model set-up



- Version 3.7.1
- 4-km horizontal grid spacing
- Explicit convection (Control)
- Thompson cloud microphysics
- CFSR initial, lateral boundary conditions
- 72-h simulations
- 00 UTC 11 Sept – 00 UTC 14 Sept 2013

# Weather Research and Forecasting (WRF) Model set-up


**WRF Domain**
**(4-km gridspacing)**

- Version 3.7.1
- 4-km horizontal grid spacing
- Explicit convection (Control)
- Thompson cloud microphysics
- CFSR initial, lateral boundary conditions
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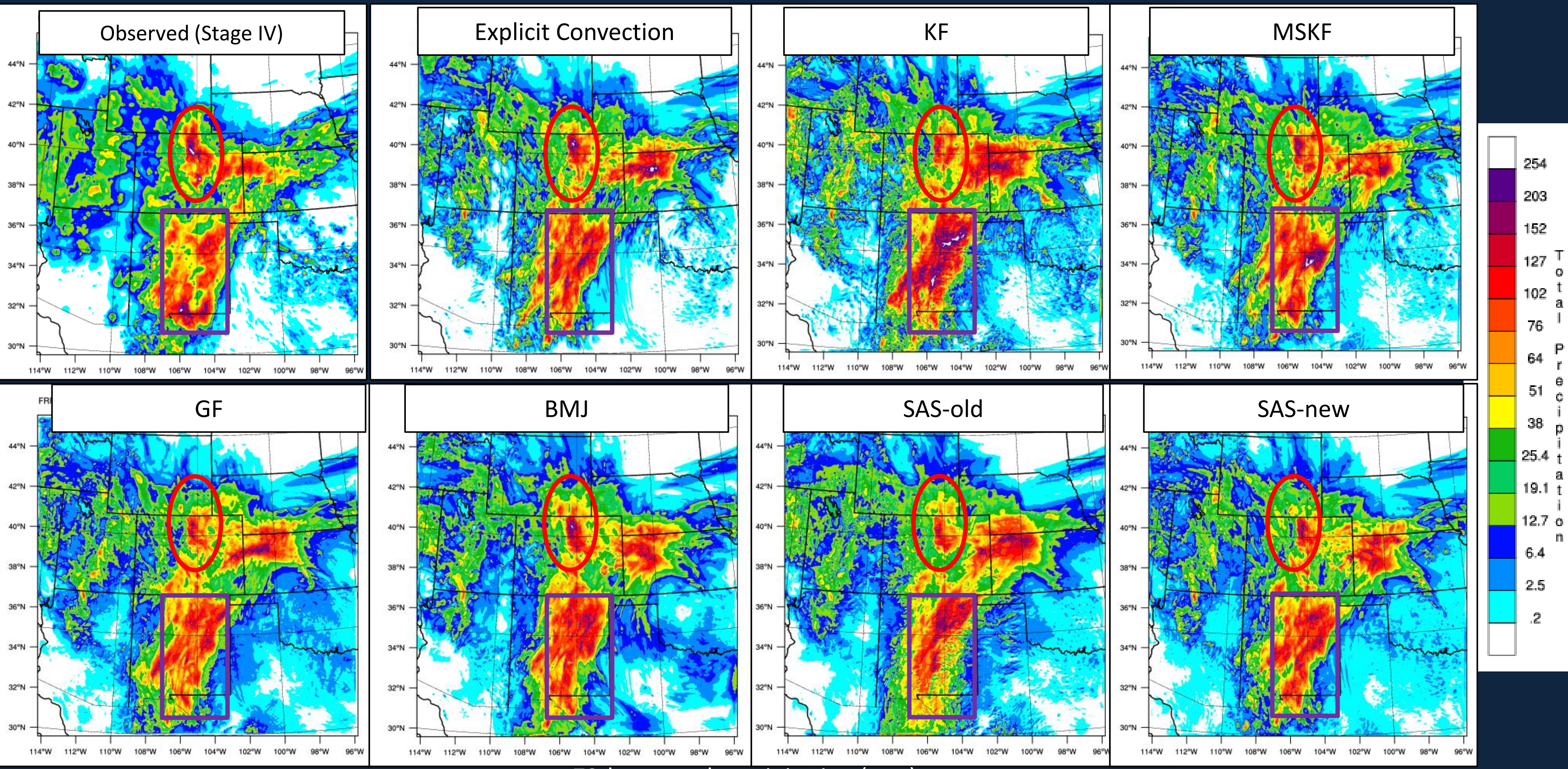
| Treatment of convective parameterization | Experiment name |
|---|---|
| Explicit convection (No convective parameterization used) | EC |
| Kain-Fritsch (new Eta) scheme (Kain and Fritsch 1993) | KF |
| Multi-scale Kain-Fritsch scheme (Zheng et al. 2016) | MSKF |
| Betts-Miller-Janjic scheme (Janjic 1994) | BMJ |
| Grell-Freitas ensemble scheme (Grell and Freitas 2013) | GF |
| Old GFS simplified Arakawa-Schubert scheme (Pan and Wu 1995) | SAS-old |
| New GFS simplified Arakawa-Schubert scheme (Han and Pan 2011) | SAS-new |

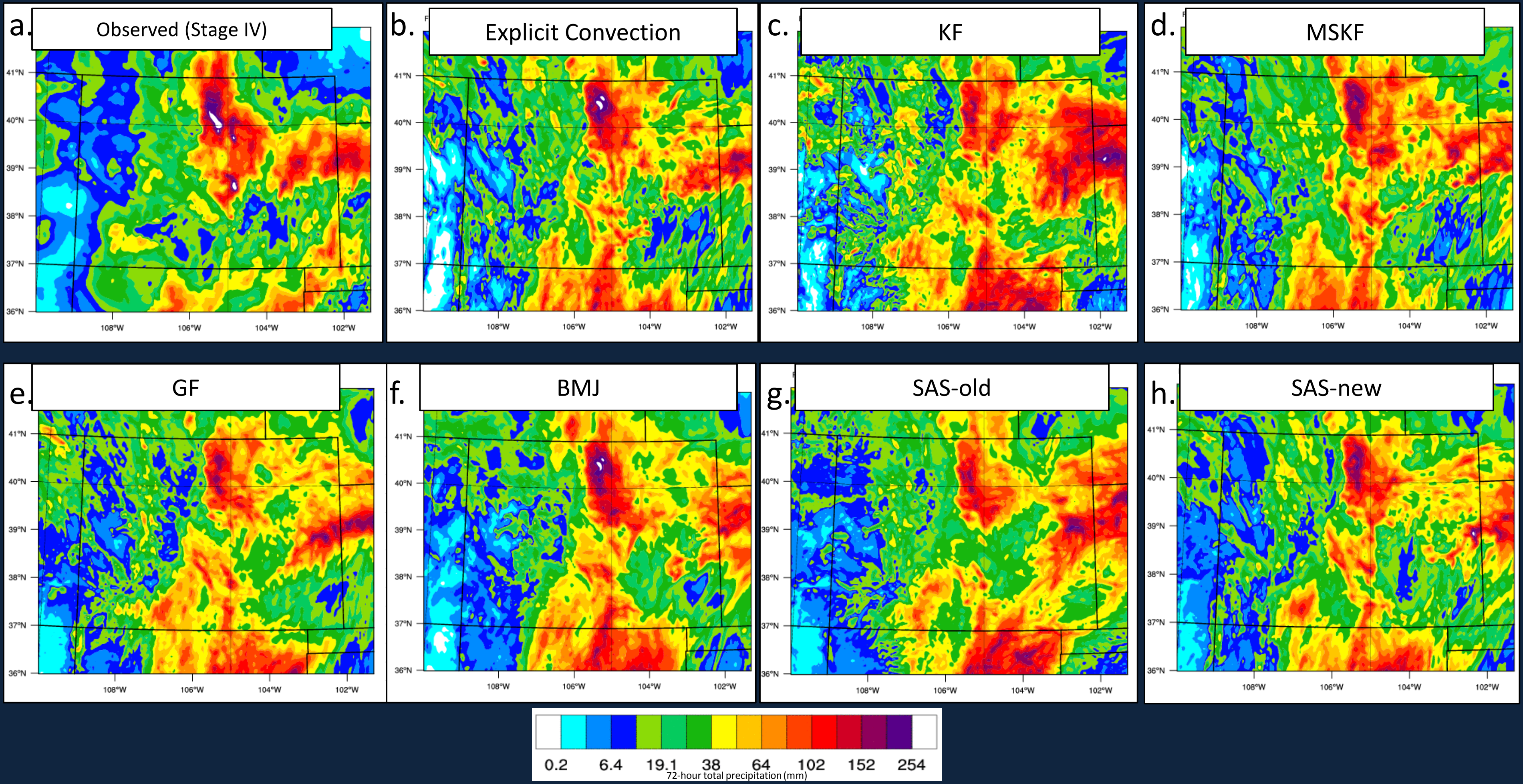
# Results: 72-hour precipitation vs. observations



72-hour total precipitation (mm)

- Two main areas of heavy precipitation:
  - “Upstream” central-eastern New Mexico
  - “Downstream” Colorado Front Range
- EC simulation reasonably captures Front Range precipitation max (~250 mm/72 hours)

# Results: 72-hour precipitation vs. observations – Colorado only



- Two main areas of heavy precipitation:
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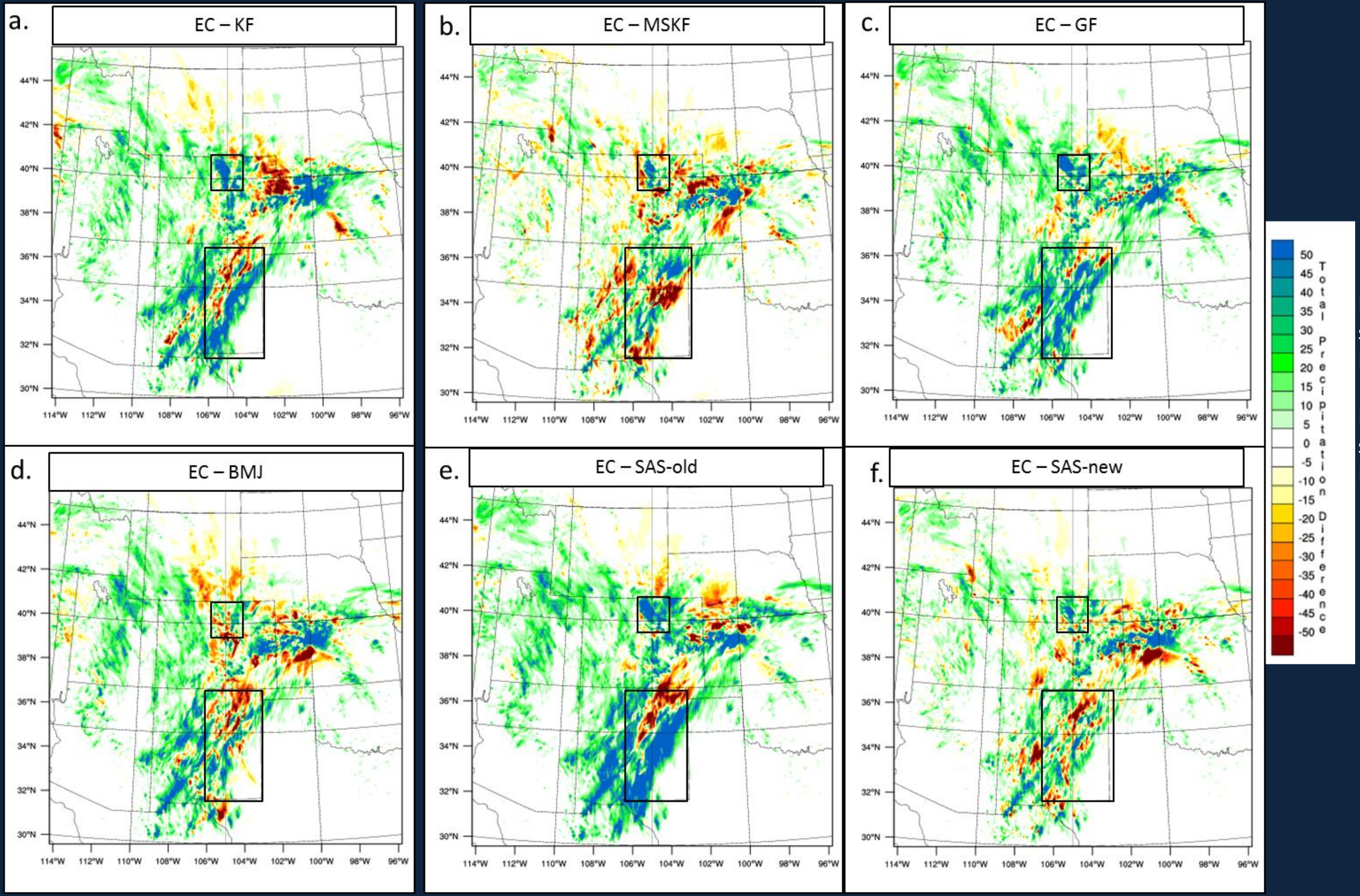
# 72-hour precipitation differences: Explicit – CP experiments



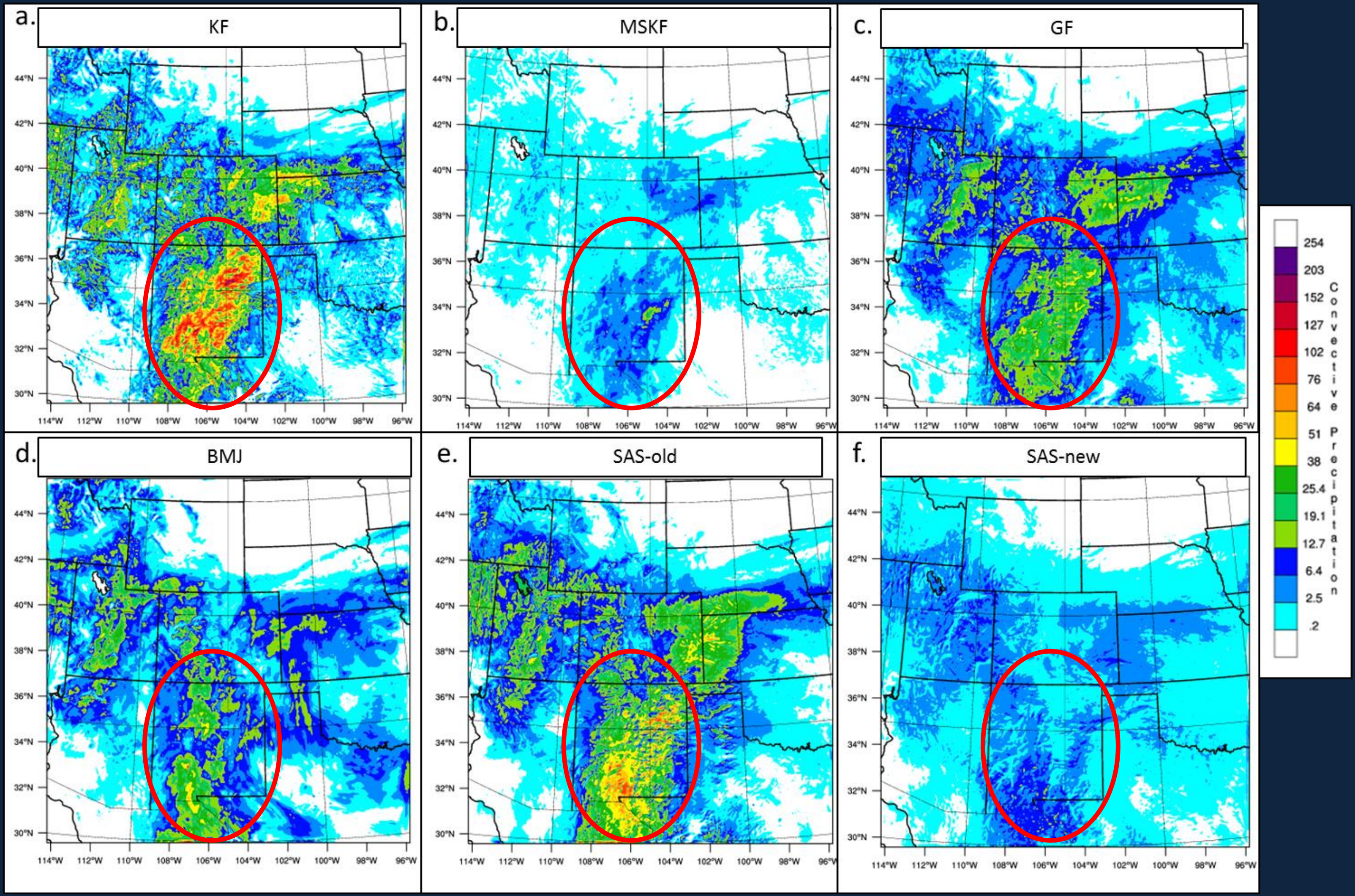
Red shading: EC < CP

Blue shading: EC > CP

72-hour total precipitation differences (mm)

- Large errors/differences in upstream NM, downstream CO Front Range regions – also across CO-KS border
- KF, GF, and SAS-old schemes under-represent (> 100 mm difference) in heavily flood-impacted COFR

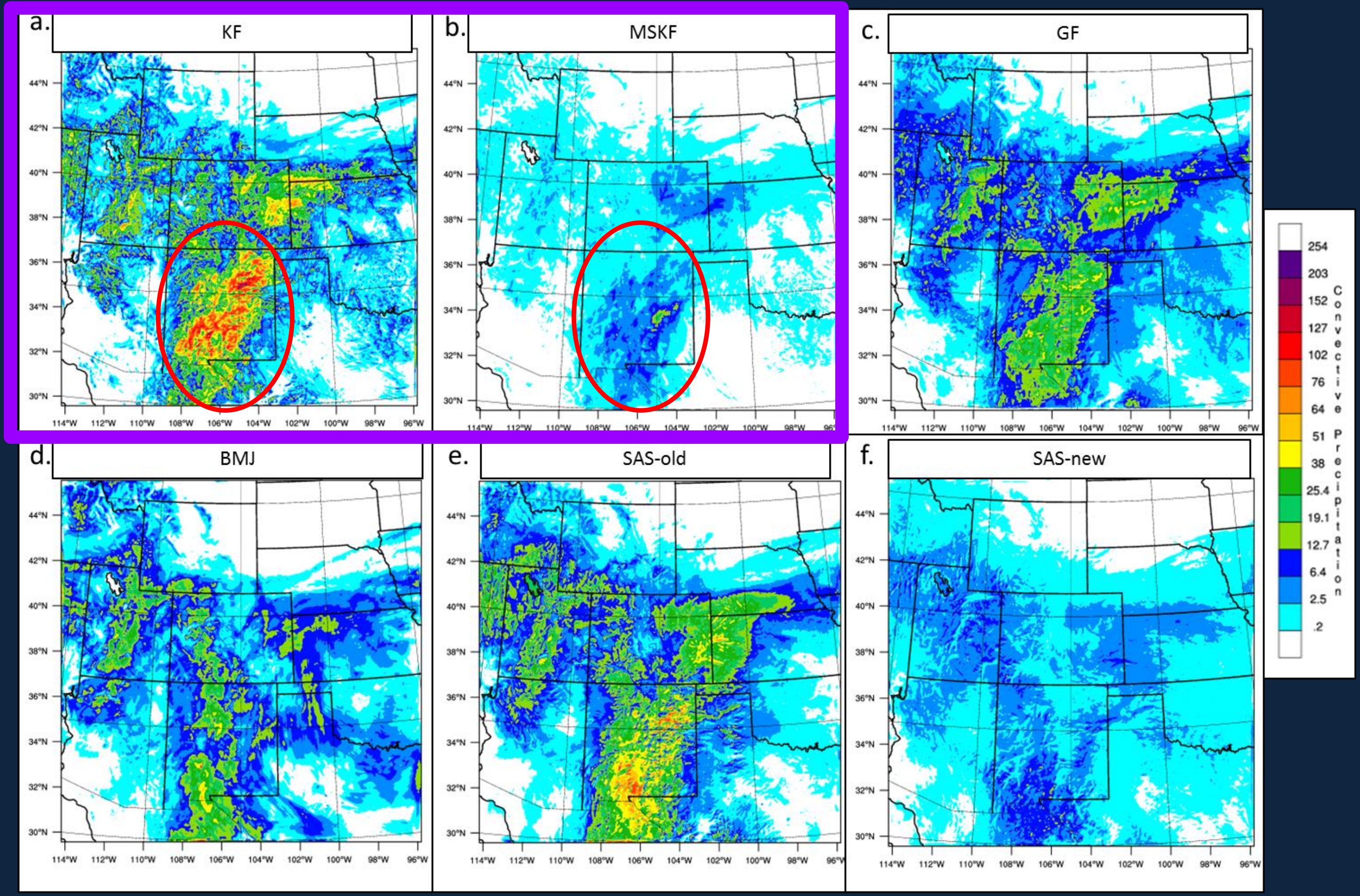
# How active were the various CP schemes at 4-km grid spacing? Convective precipitation only:



72-hour convective precipitation (mm)

- Original KF most active, particularly upstream
- Scale-aware schemes notably less active

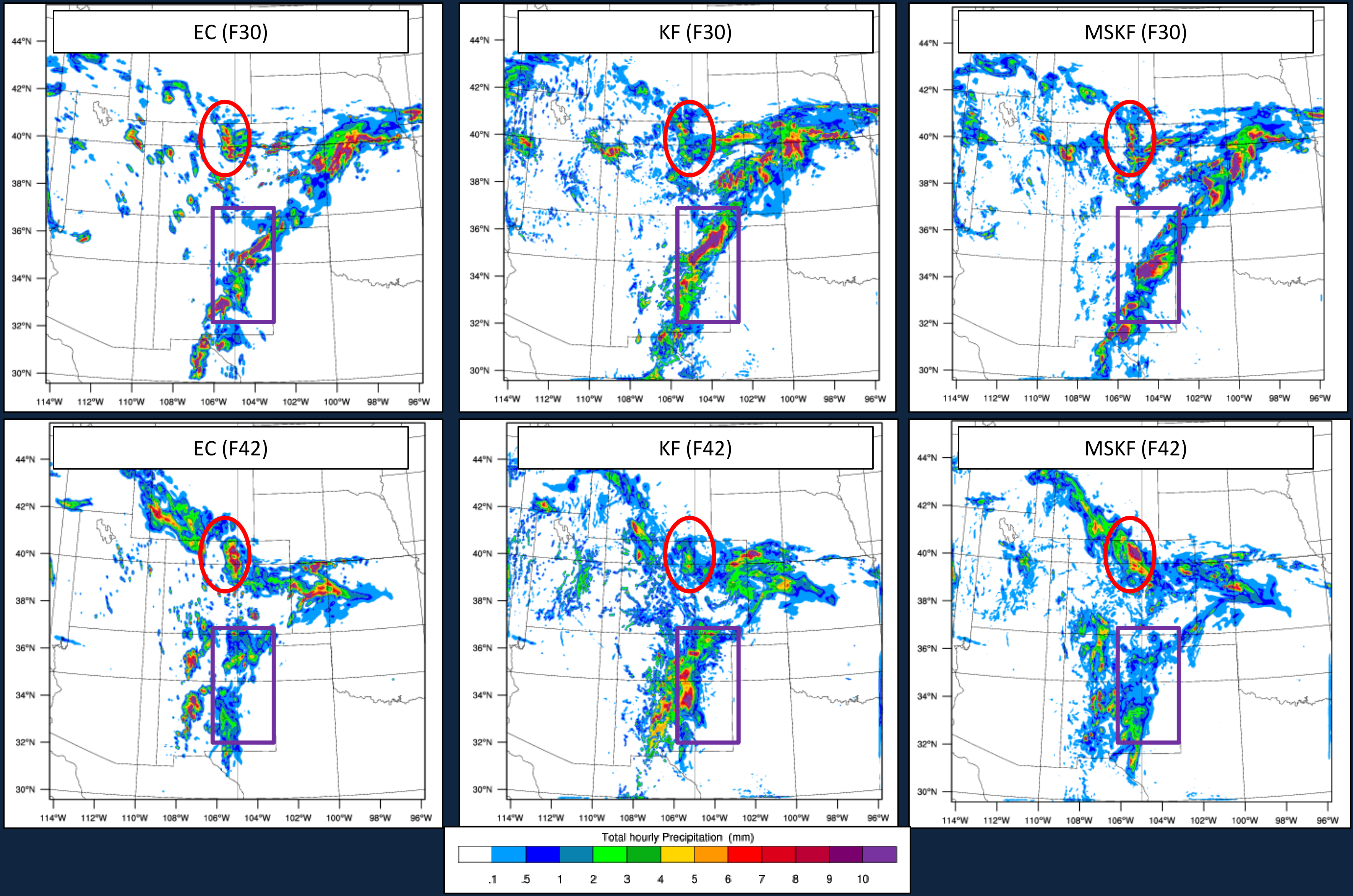
# How active were the various CP schemes at 4-km grid spacing? Convective precipitation only:



72-hour convective precipitation (mm)

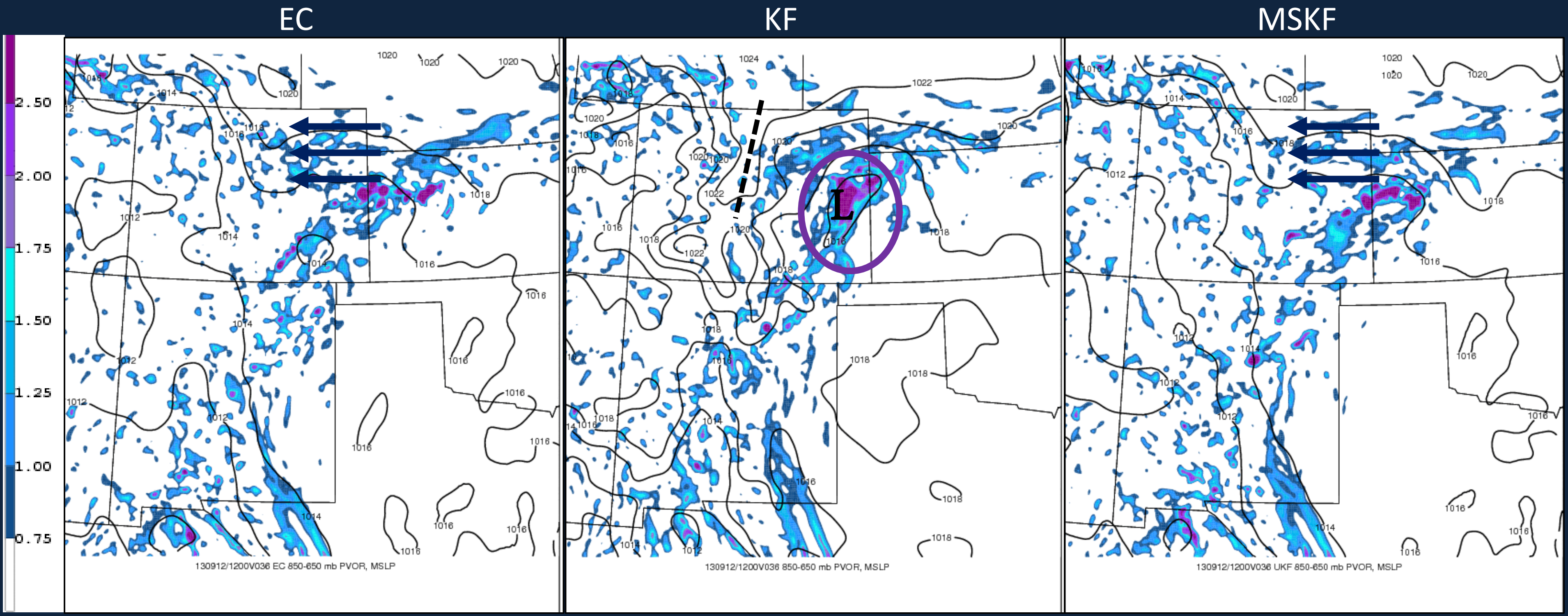
- KF, MSKF represent ends of the CP experiment spectrum → focus on EC, KF, MSKF

# Influence of upstream CP error on downstream precipitation



- EC, KF Precipitation starts to diverge strongly in Eastern NM, CO Front Range ~24+ hours into simulation

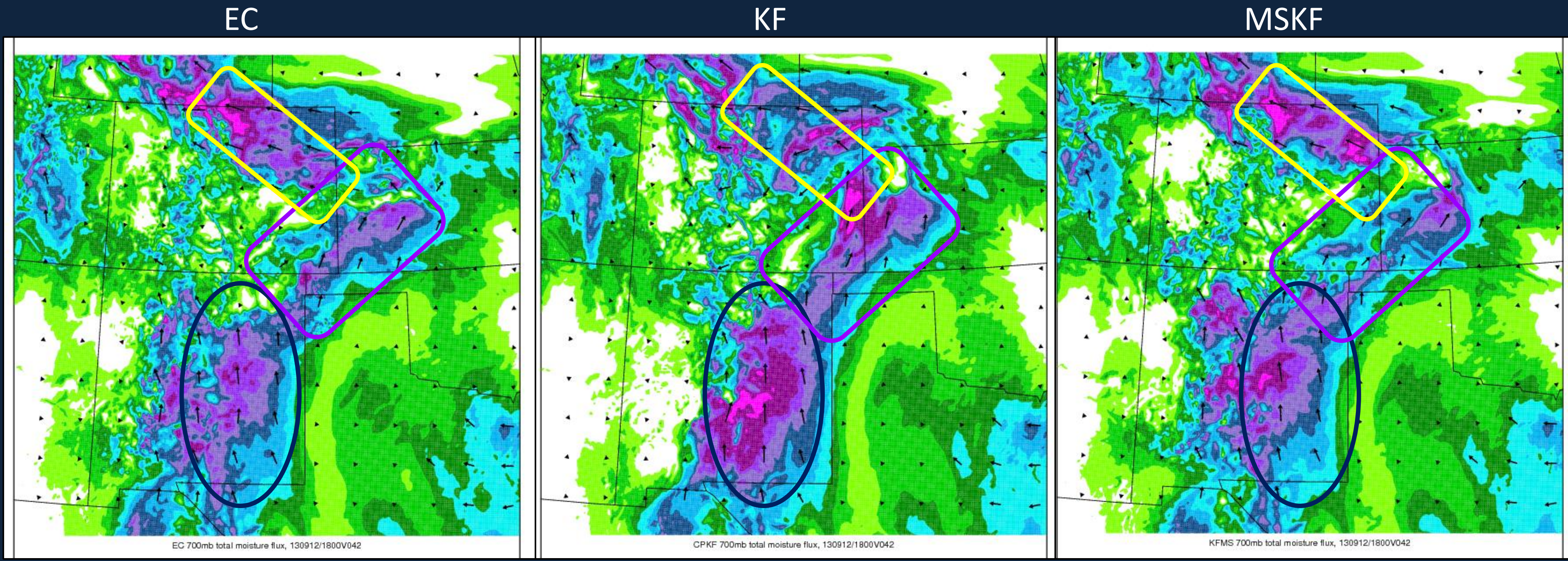
# Influence of upstream CP errors on downstream precipitation: Low-level PV and sea-level pressure



850 hPa – 650 hPa layer-average potential vorticity (PVU, shaded) and (terrain-corrected) sea-level pressure (hPa; black contours) valid 12 UTC 12 September (36 hours into simulation period)

- Low-level PV: latent heating “footprint” on low-level dynamic fields
- KF simulation:
  - Heavy CP precip in eastern NM, CO → low-level PV maximum in eastern CO
  - Surface low pressure deepens beneath, inverted ridge strengthens to west
  - Diminished upslope flow in CO Front Range, enhanced forcing further northeast
- EC, MSKF simulations → sustained low-level easterly flow in the COFR → prolonged upslope precipitation

# Influence of upstream CP errors on downstream precipitation



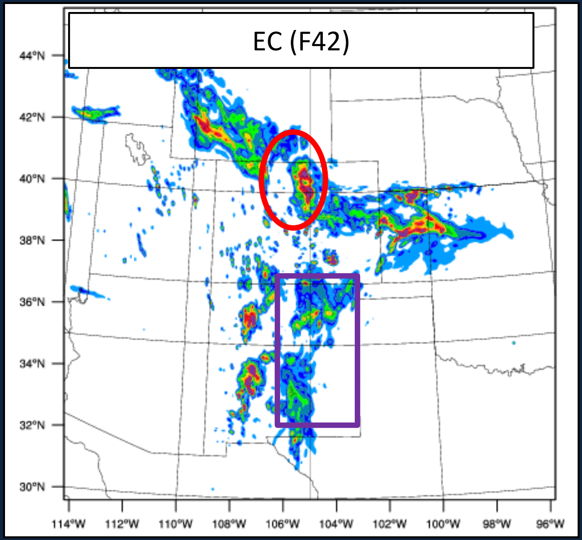
EC KF MSKF

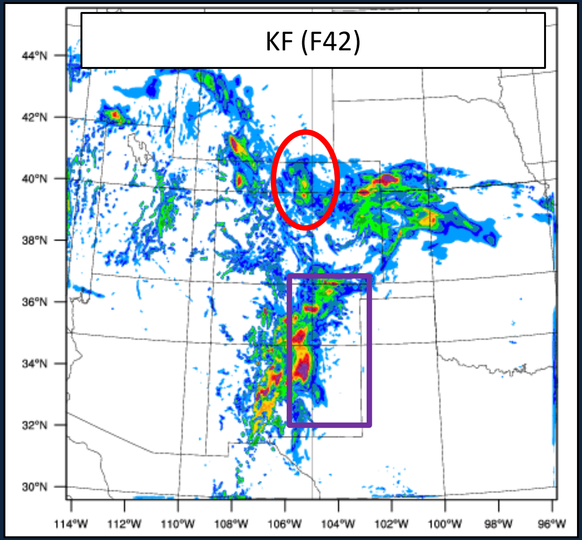
700-hPa moisture flux (x10 g kg−1 m s−1, shaded & vectors, valid 18 UTC 12 September (42 hours into simulation)

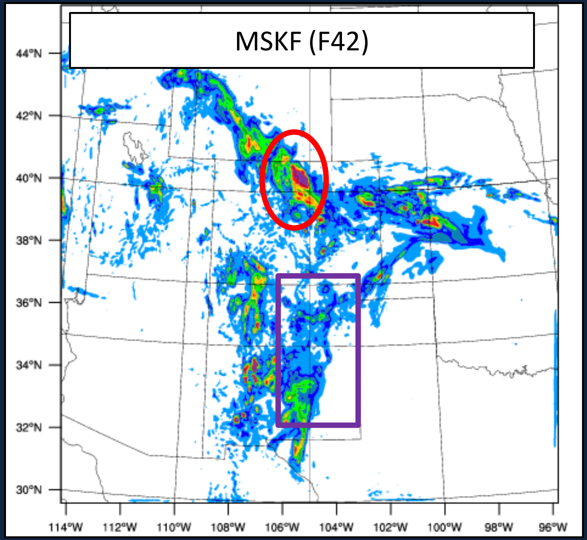
- See evolution clearly in moisture flux/transport as well
- Upstream KF precip overdone; enhances moisture flux too far east (CO-KS); disrupts moisture flux and upslope flow in CO Front Range

# Summary and future work

- 2013 Colorado Front Range flood simulations run in 4-km Δx “deep convection gray zone”
- Large sensitivity to CPS choice in Colorado Front Range (COFR), eastern New Mexico (ENM)
  - KF, GF, and SAS-old schemes: active CP upstream in NM; far under-predict (> 100mm) in COFR
  - Greater CPS activity upstream → errors in latent heating and low-level flow/moisture transport → significant downstream model error
  - New scale-aware KF scheme very similar to EC simulation/observations
- Notable sensitivity:
  - Experiments run as simulations (i.e., boundaries updated with analyzed – not forecast – conditions)
  - 4-km Δx: expect most precipitation to be explicit
  - Surprising that CPS choice at these space, time scales → 3-day precipitation differences > 100 mm?

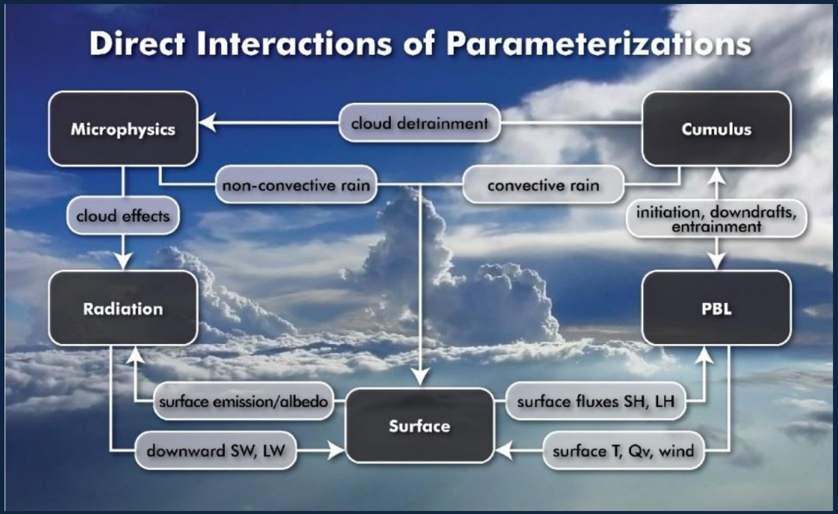

EC (F42)


KF (F42)


MSKF (F42)

# Summary and future work

- ~4-km Δx increasingly common for operational weather, regional climate
  - Explicit convection likely best for extreme precipitation, propagating convection
  - Omission of CP may be problematic for climate simulation of land-surface, PBL, shallow mixing processes
  - Do we really understand the types of cases, events, environments where even scale-aware CP may fail? Where EC fails?
- How to best address gray zone considerations of shallow convection, PBL mixing/processes, etc?
- Treat separately and forego CP from now on, or dig into scale-aware CP?
- Future work: Assess NA-CORDEX extreme precipitation for related issues



Direct Interactions of Parameterizations

Microphysics

cloud detrainment

Cumulus

non-convective rain

convective rain

cloud effects

initiation, downdrafts, entrainment

Radiation

PBL

surface emission/albedo

Surface

surface fluxes SH, LH

downward SW, LW

surface T, Qv, wind

# Acknowledgements

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- Associated paper available via Early Online Release:

http://journals.ametsoc.org/doi/abs/10.1175/MWR-D-16-0211.1

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