Implementation and use of a global nonhydrostatic model (MPAS) for extended prediction

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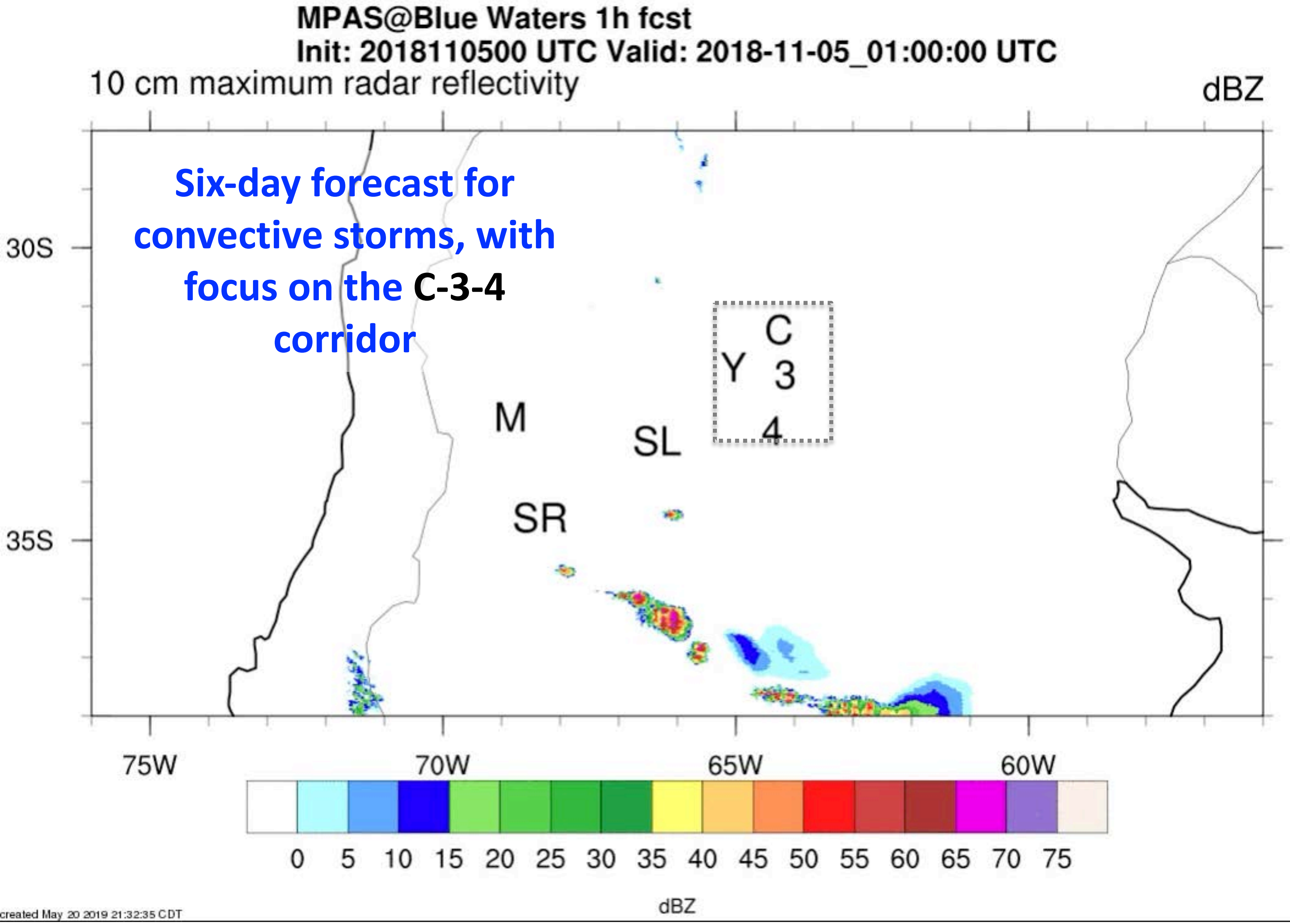
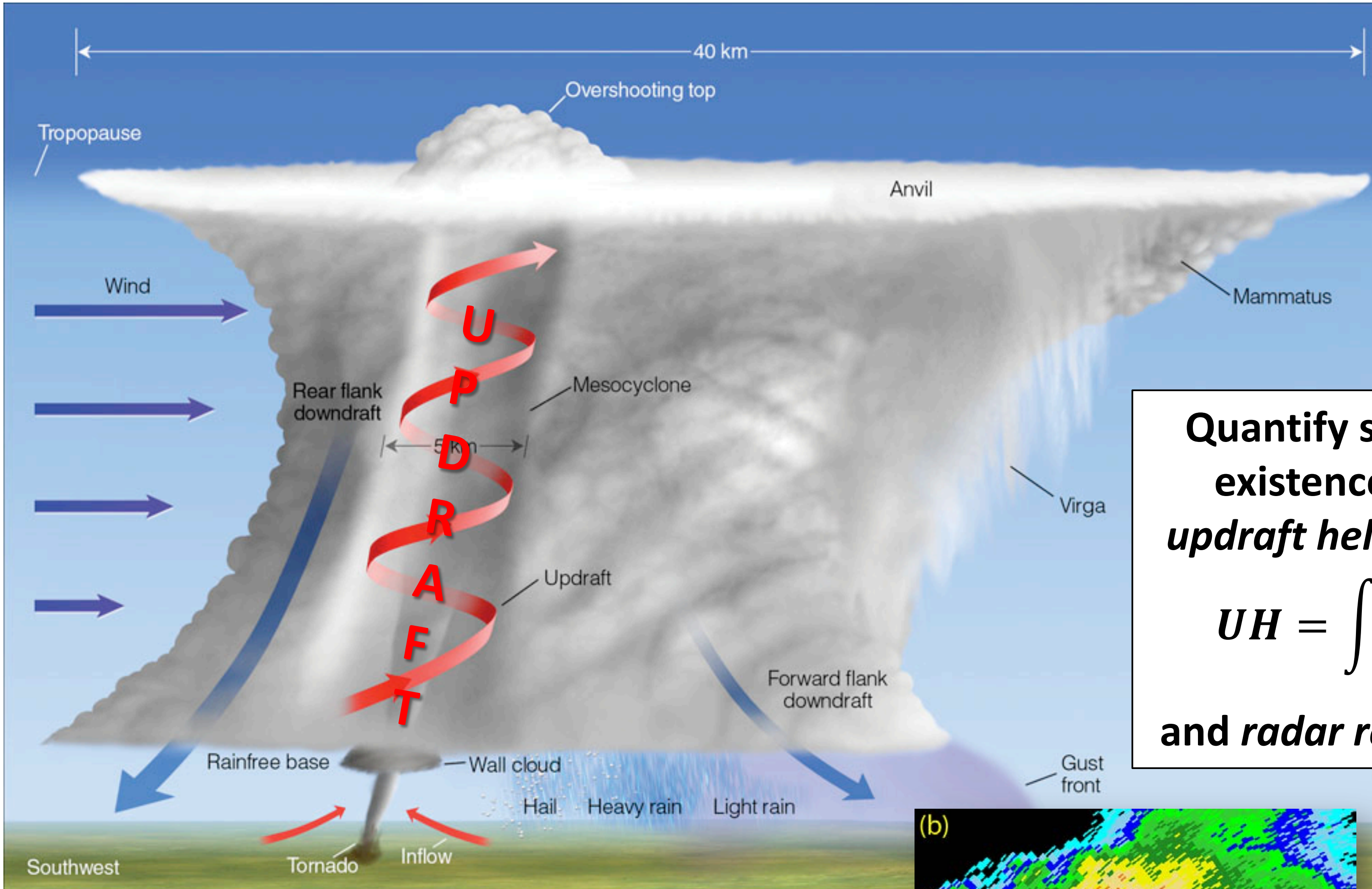
Blue Waters Symposium
Sunriver, Oregon
6/4/2019


MPAS@Blue Waters 1h fcst
Init: 2018110500 UTC Valid: 2018-11-05_01:00:00 UTC
10 cm maximum radar reflectivity
dBZ
Six-day forecast for convective storms, with focus on the C-3-4 corridor
30S
35S
C
Y
3
4
M
SL
SR
75W
70W
65W
60W
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75
dBZ
created May 20 2019 21:32:35 CDT

"Convection-allowing" prediction with a global model (MPAS)

- What/why "convection-allowing"?
  - horizontal gridpoint spacings ~4 km
    - precludes the need to *parameterize* the effects of cumulus convection
      - improved convective precipitation
    - allows explicit representation of thunderstorm morphology, e.g., *supercell thunderstorm*
      - allows quantification of morphological attributes like updraft rotation

Supercell Thunderstorm

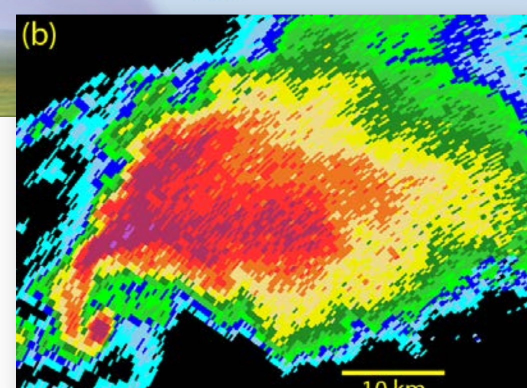


Courtesy J. Frame, UIUC

Quantify supercell existence using *updraft helicity* (UH)

$$UH = \int w\zeta dz$$

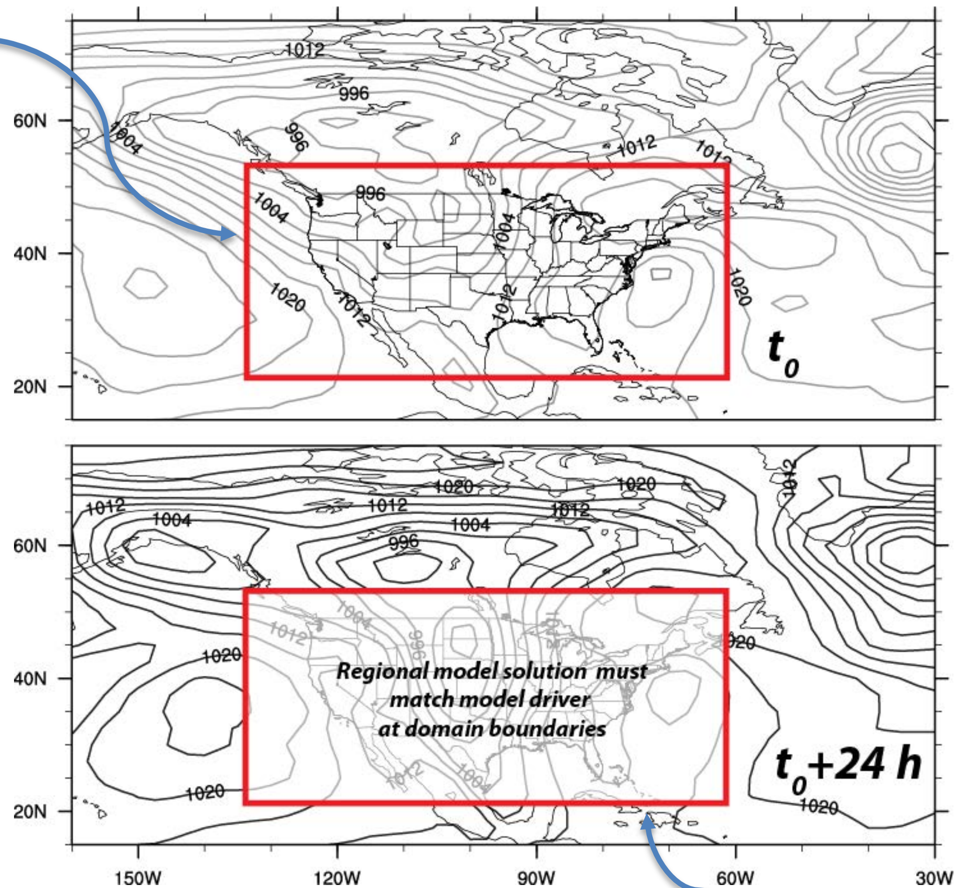
and *radar reflectivity*



"Convection-allowing" prediction with a global model (MPAS)

- Why global?
  - the atmosphere is a global fluid
  - the alternative to global modeling is regional modeling, which requires initial/boundary conditions … from a global model
    - places a constraint on evolution of processes within the regional domain…

regional domain



initial *condition from global model*

boundary *conditions from global model*

restricts range of internally generated processes/feedbacks

"Convection-allowing" prediction with a global model (MPAS)

- Why global?
  - the atmosphere is a global fluid
  - regional-modeling require initial/boundary conditions from a global model
    - places a constraint on evolution of processes within the regional domain…
  - thus, a global model is better suited longer time integrations, & thus for extended range predictions

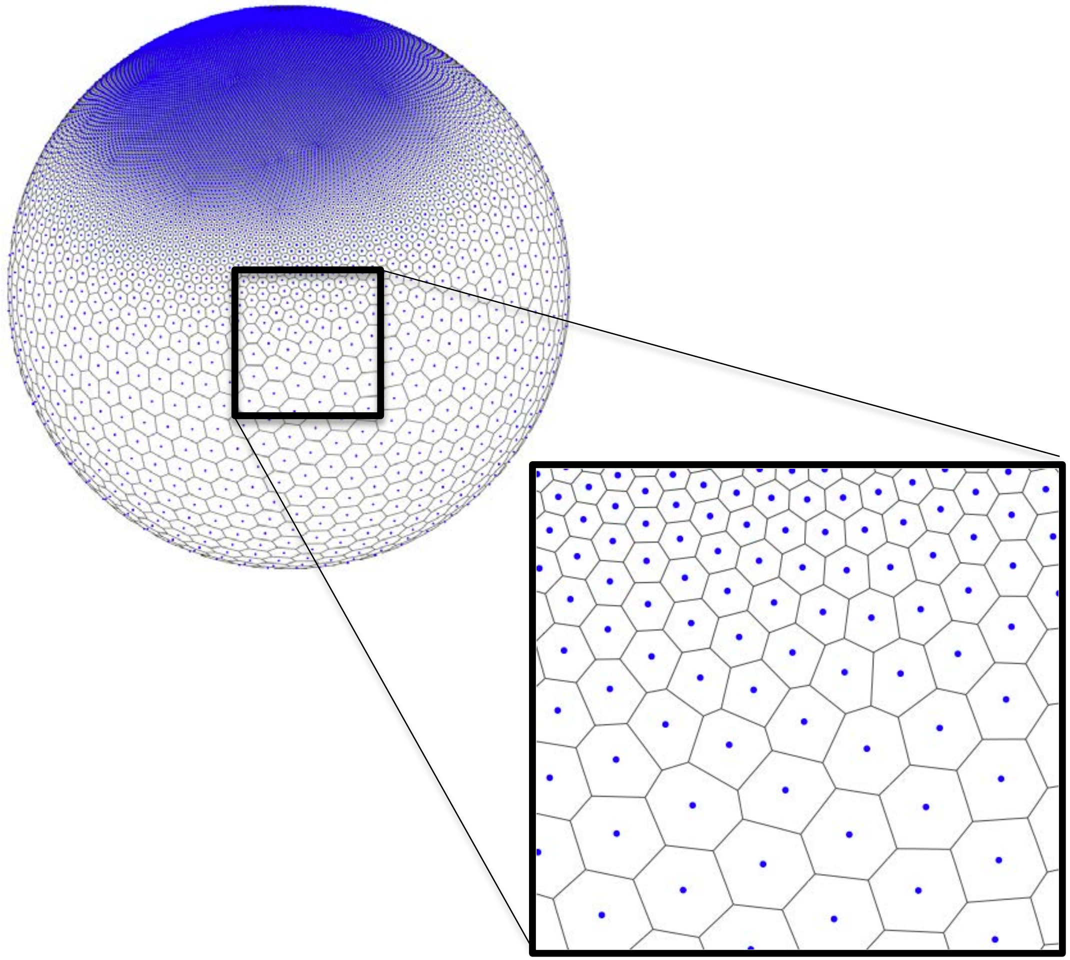
“Convection-allowing” prediction with a global model (MPAS)

- Limitations of global modeling …
  – often *hydrostatic*
    - i.e., no A in $F = mA$ for vertical direction … but vertical A is at heart of our interest
  – the large number of global gridpoints has made it more difficult to enable convection-allowing resolution
    - compromise: grid refinement!

MPAS: Model for the **P**rediction **A**cross **S**cales

- Both limitations are addressed by MPAS:
  - nonhydrostatic and fully compressible global model, with capability for regional grid refinement (Skamarock et al. 2012, *MWR*)

equations are discretized/solved on centroidal Voronoi (quasi-uniform, nominally hexagonal) meshes

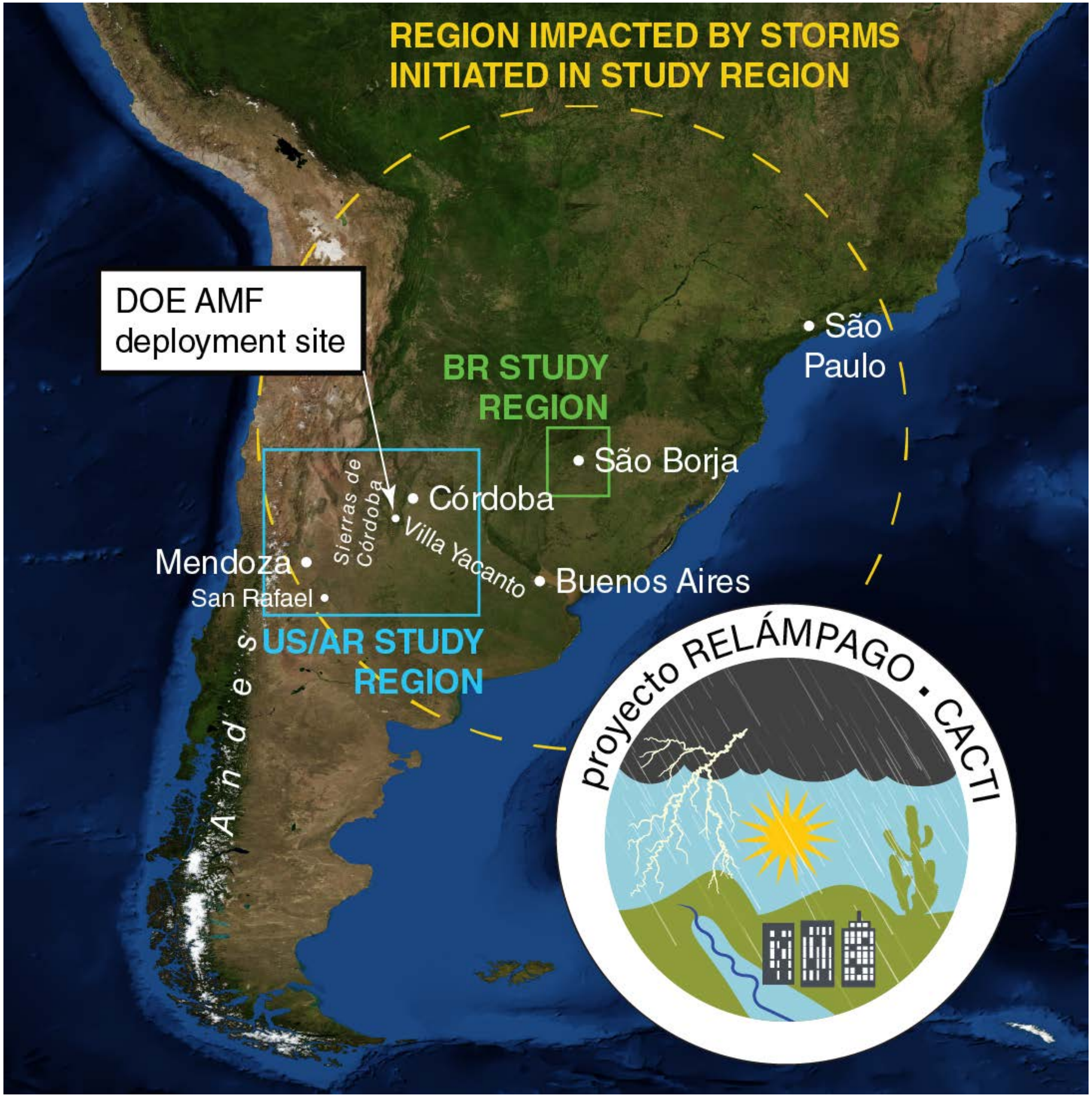


Example variable-resolution grid

courtesy MPAS documentation

MPAS application: Operational support for RELAMPAGO operations

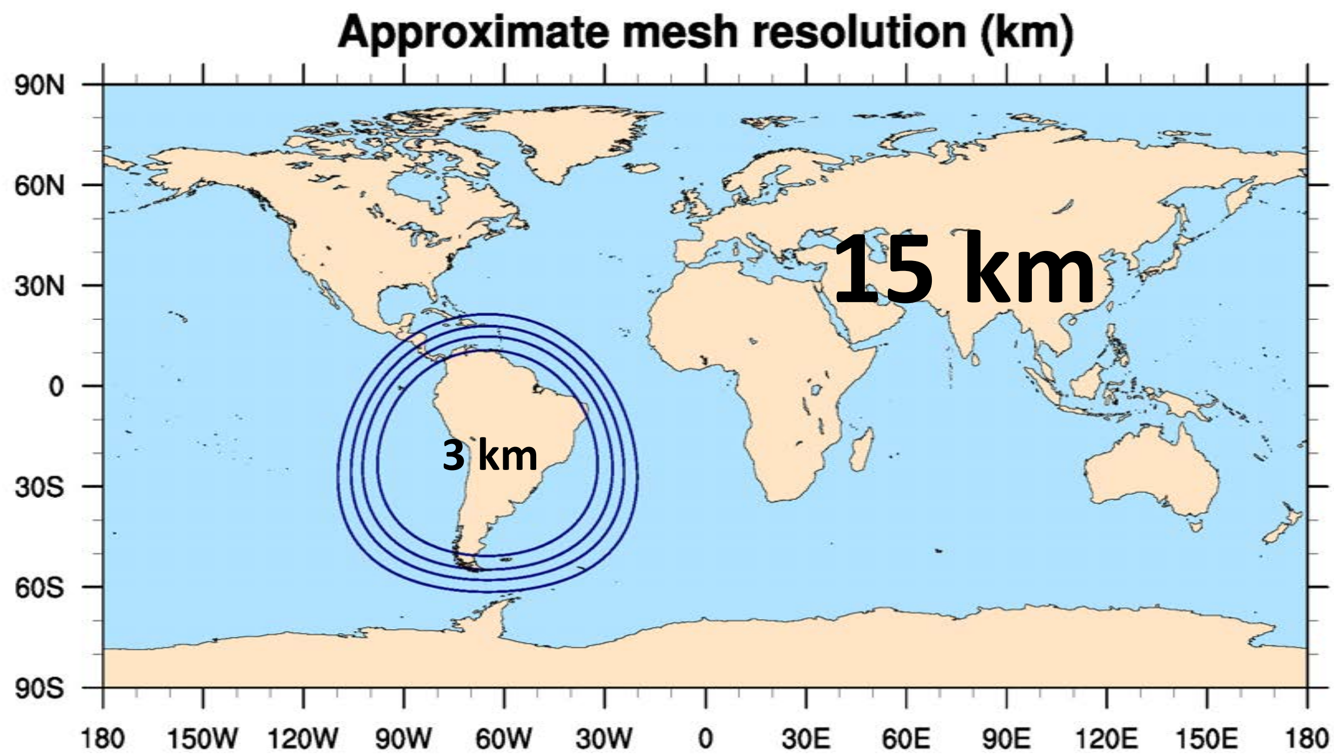
- The **RELAMPAGO** Remote sensing of Electrification, Lightning, And Mesoscale/microscale Processes with Adaptive Ground Observations field campaign, was conducted in November and December 2018 in Argentina
  - **key objective of RELAMPAGO is to understand why some of most intense thunderstorms on the planet form in southeastern South America**



Courtesy S. Nesbitt, UIUC

MPAS setup

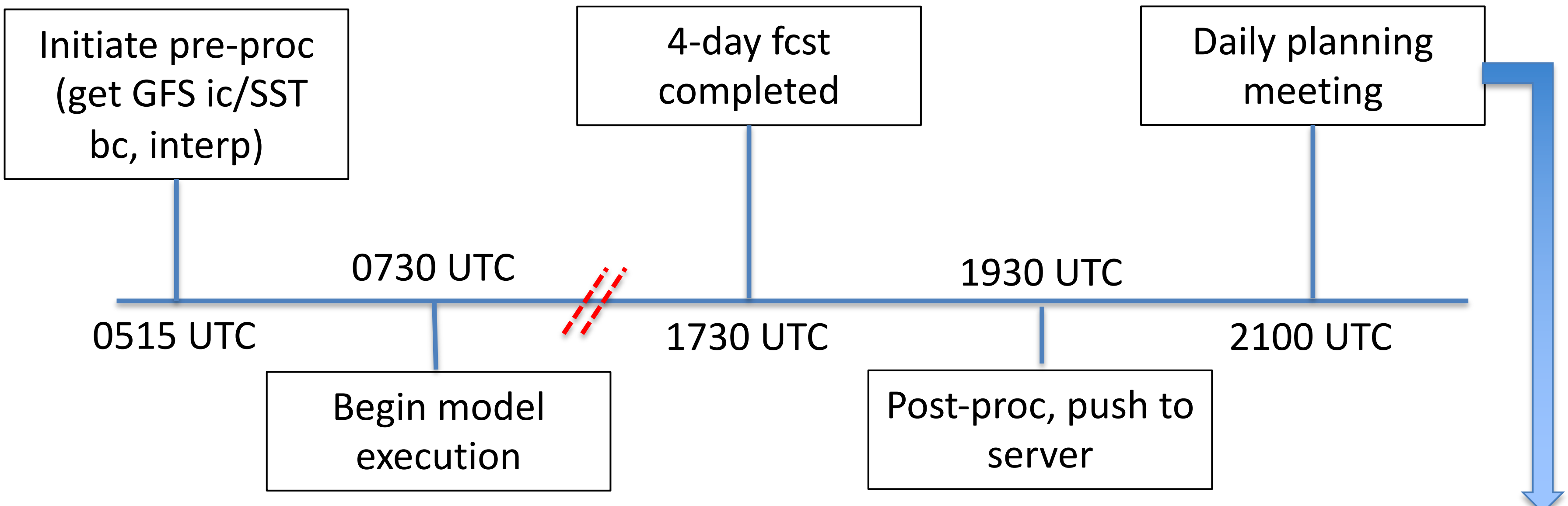
- Horizontal grid spacing: 15 km (globe) – 3 km (South America)



MPAS setup

- Horizontal grid spacing: 15 km (globe) – 3 km (South America); 41 levels
  - total 6488066 grid points
- Daily integrations from 00 UTC Day 0 to 00 UTC Day 4 (18-s time step, hourly output)
- "Convection-permitting"–suite of physical parameterizations
  - Grell-Freitas "scale-aware" convection scheme
- MPAS-Atmosphere only
  - thus, need we lower bc updates … *which we derive from the GFS model*

Logistics/details of MPAS implementation



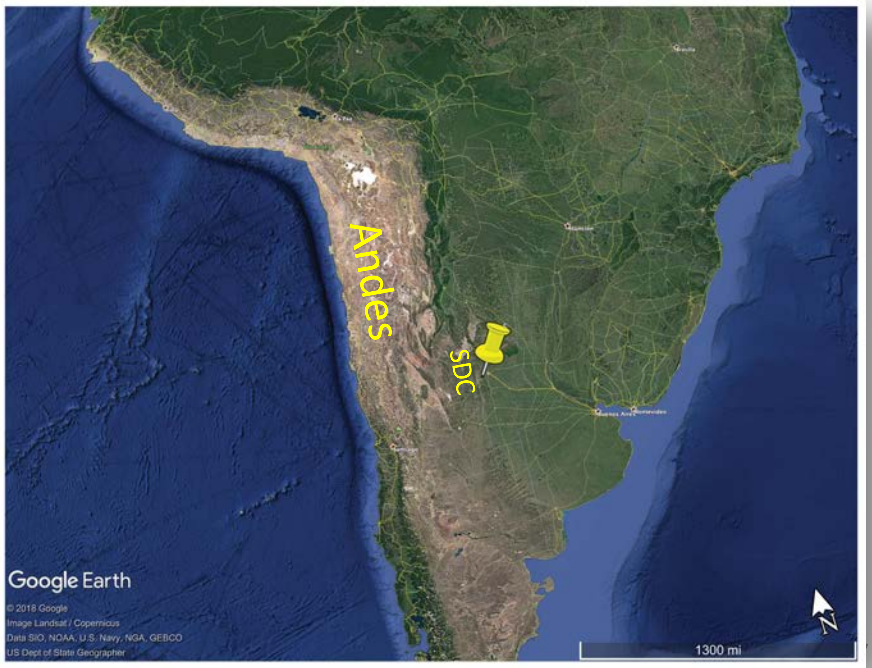
… thankfully, all done on a reservation

Why the need for extended range forecasts?

- to avoid missing a favorable event …
  - ground crews: human resource limitations (~4 consecutive days); expendables (weather balloons, etc.); competing objectives
  - also, two domains, with 1-day transit

Potential success of extended range forecasts in Argentina?

- **<u>Hypothesis</u>**: multi-scale atmospheric processes are strongly controlled by terrain (Andes, Sierras de Córdoba Mountains), thus contributing to higher predictability

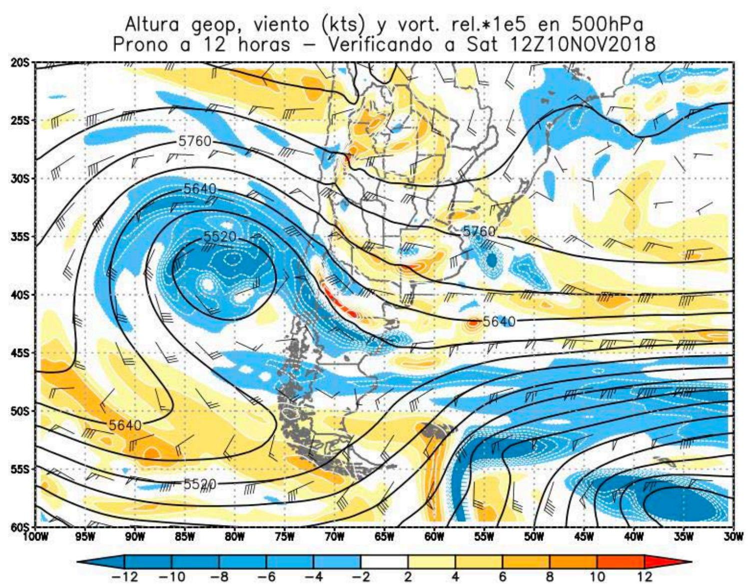


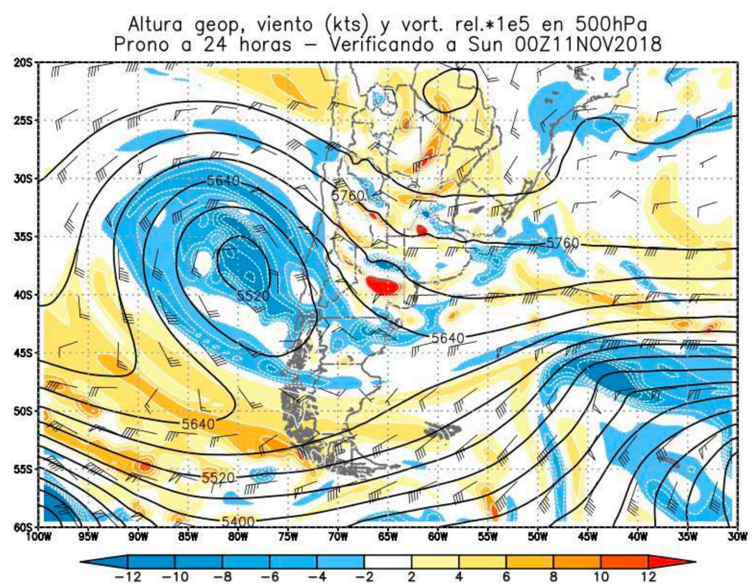
Why Blue Waters?

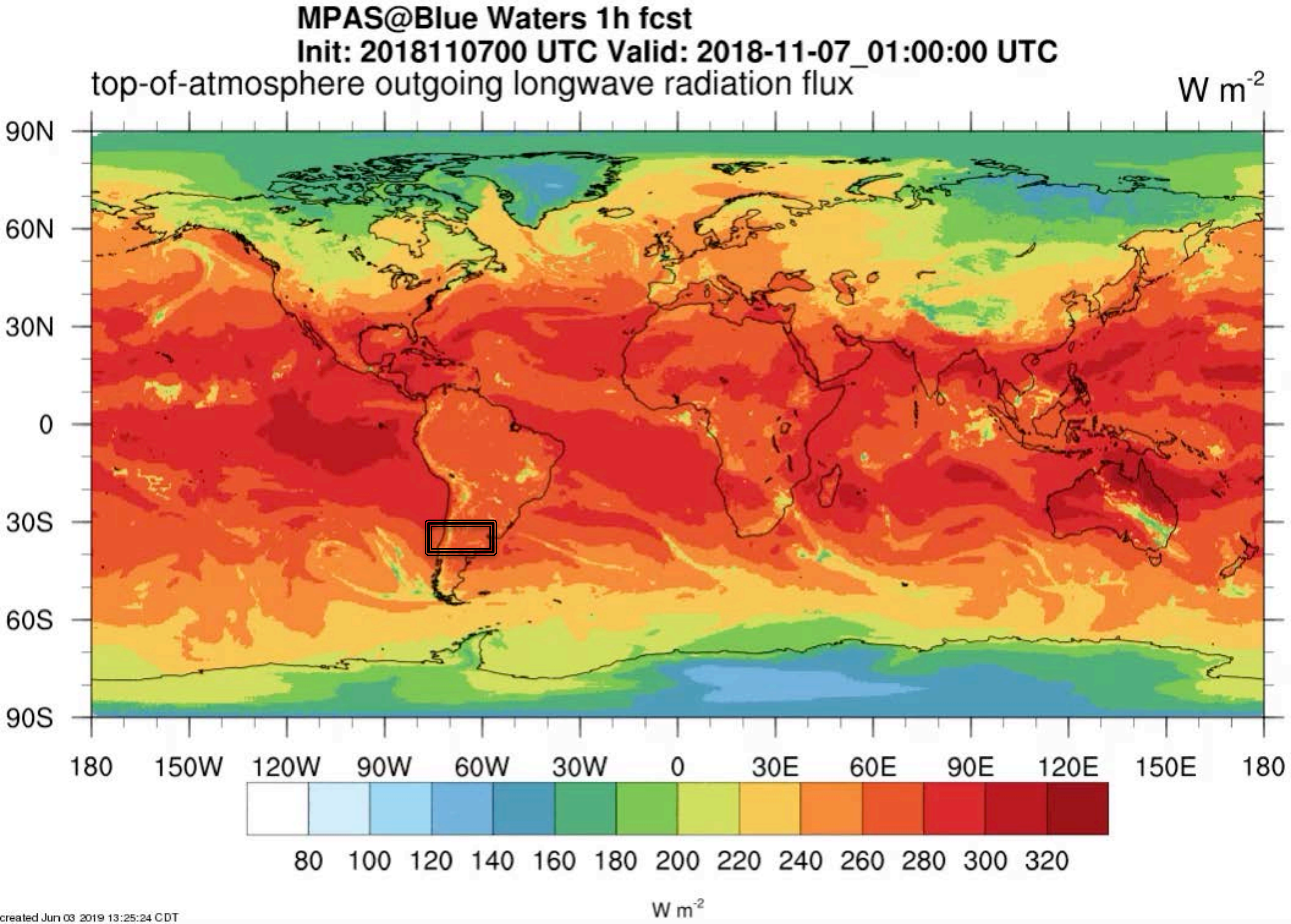
- stable, reliable platform
- sufficient resources for this project to run at high resolution
  - MPAS execution: 192 nodes, ~10 hr wallclock, but daily for 45+ days
- sufficient resources on machine, such that this project was not too burdensome

IOP4: Supercell mission on 10 November 2018

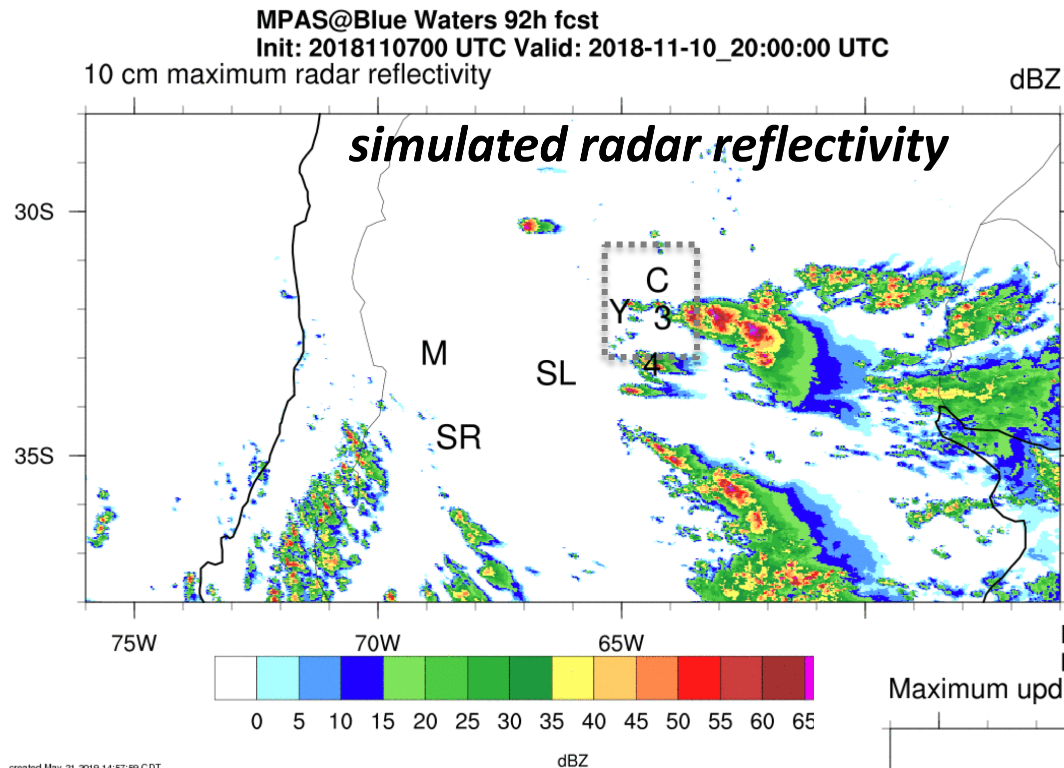
- coarse resolution global models indicated vigorous pressure trough by 10 November, which appeared supportive of *supercell thunderstorms*, but necessary granular details not provided by such models



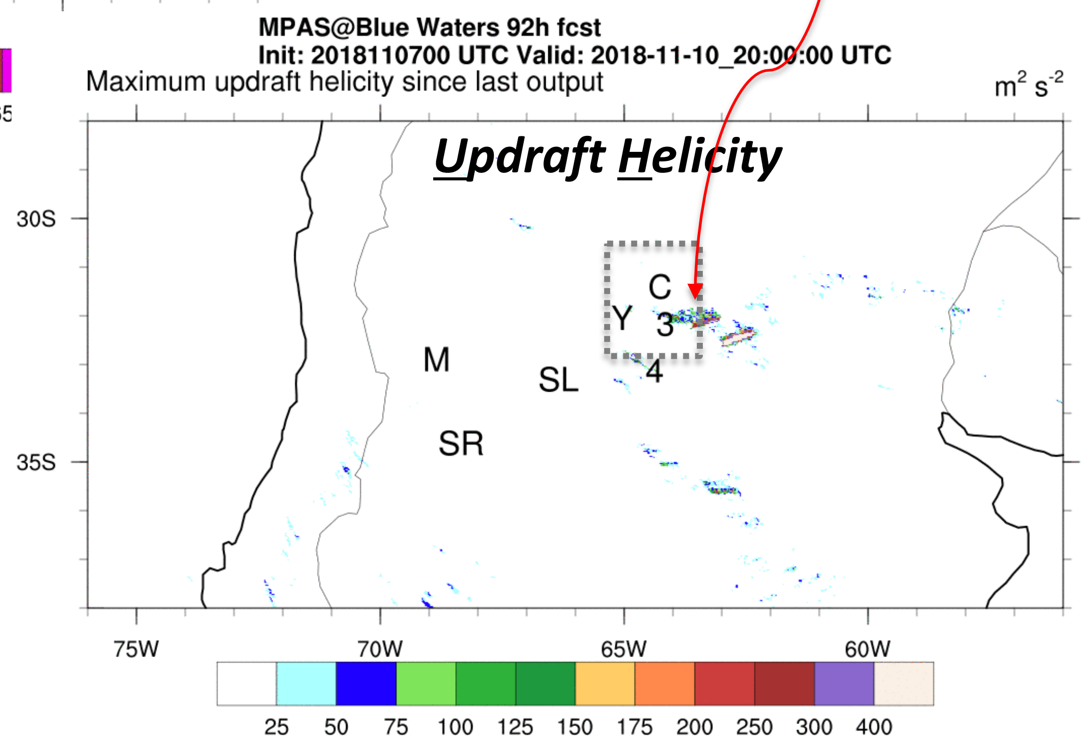




MPAS@Blue Waters 1h fcst
Init: 2018110700 UTC Valid: 2018-11-07_01:00:00 UTC
top-of-atmosphere outgoing longwave radiation flux
W m-2
90N
60N
30N
0
30S
60S
90S
180
150W
120W
90W
60W
30W
0
30E
60E
90E
120E
150E
180
80
100
120
140
160
180
200
220
240
260
280
300
320
W m-2
created Jun 03 2019 13:25:24 CDT



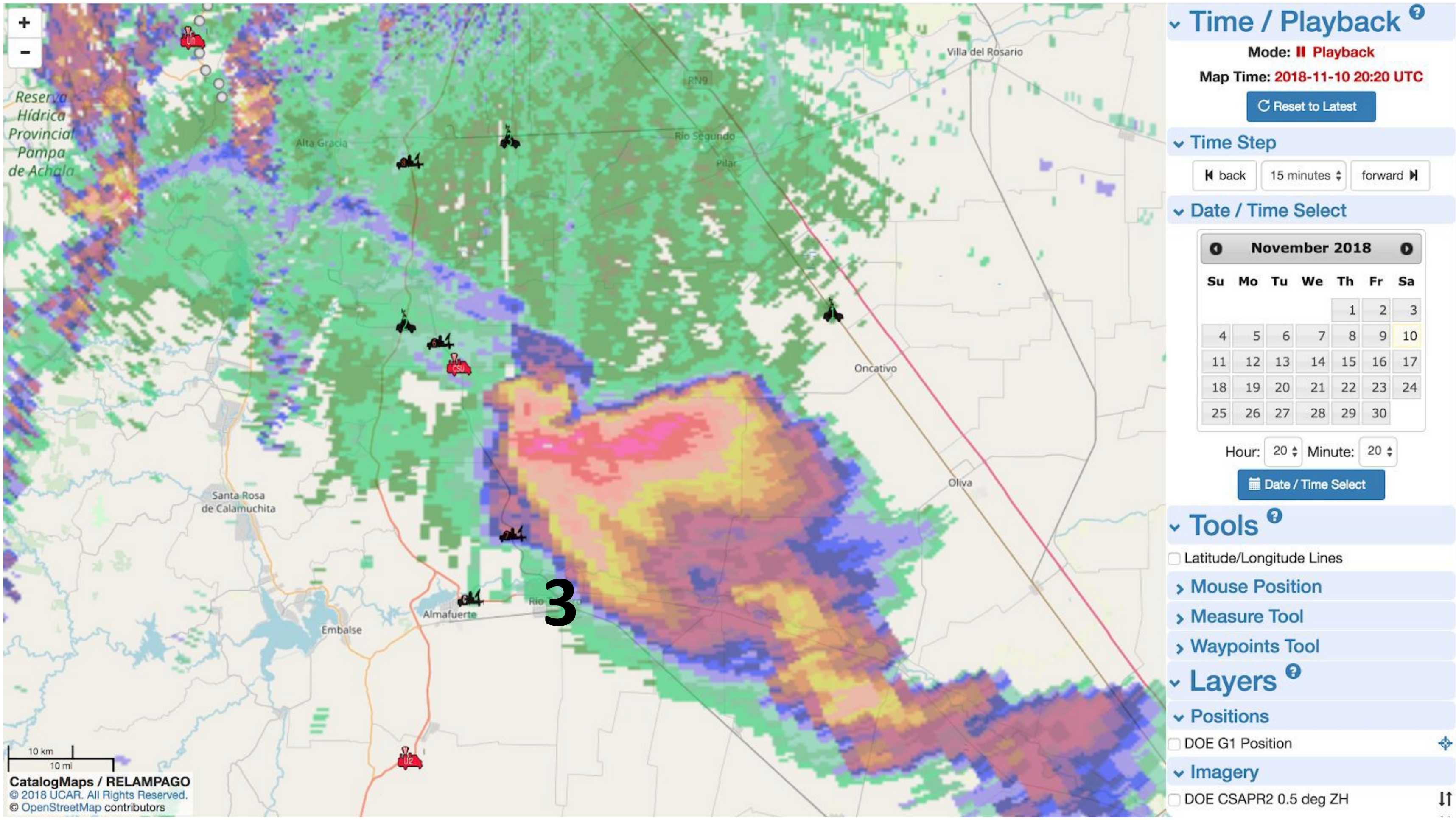
“swath” of UH indicating supercell track



92-hr forecast

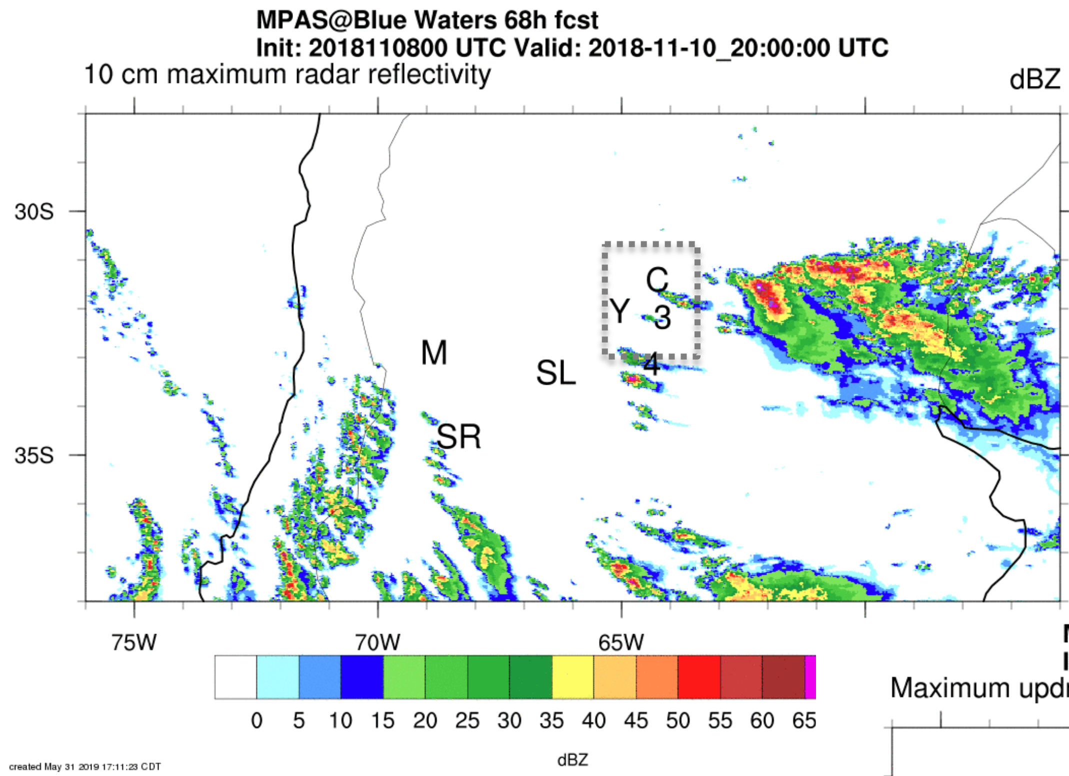
(valid 20 UTC 10 Nov)

C

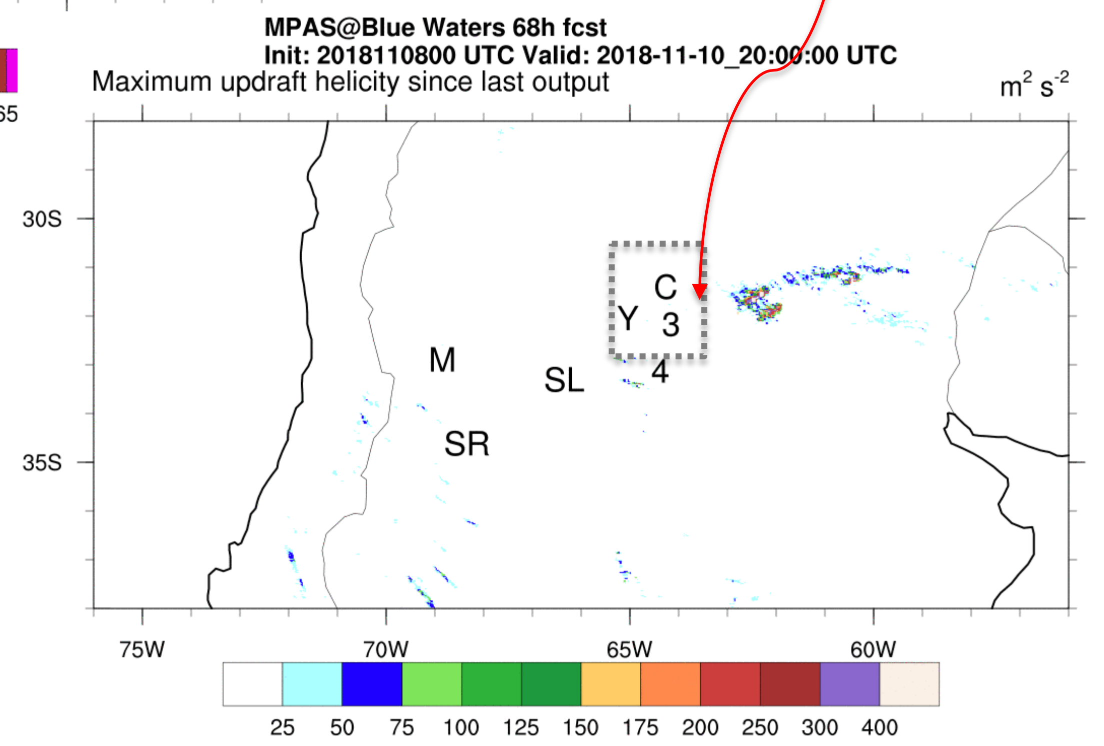


4

Cordoba radar 2020 UTC

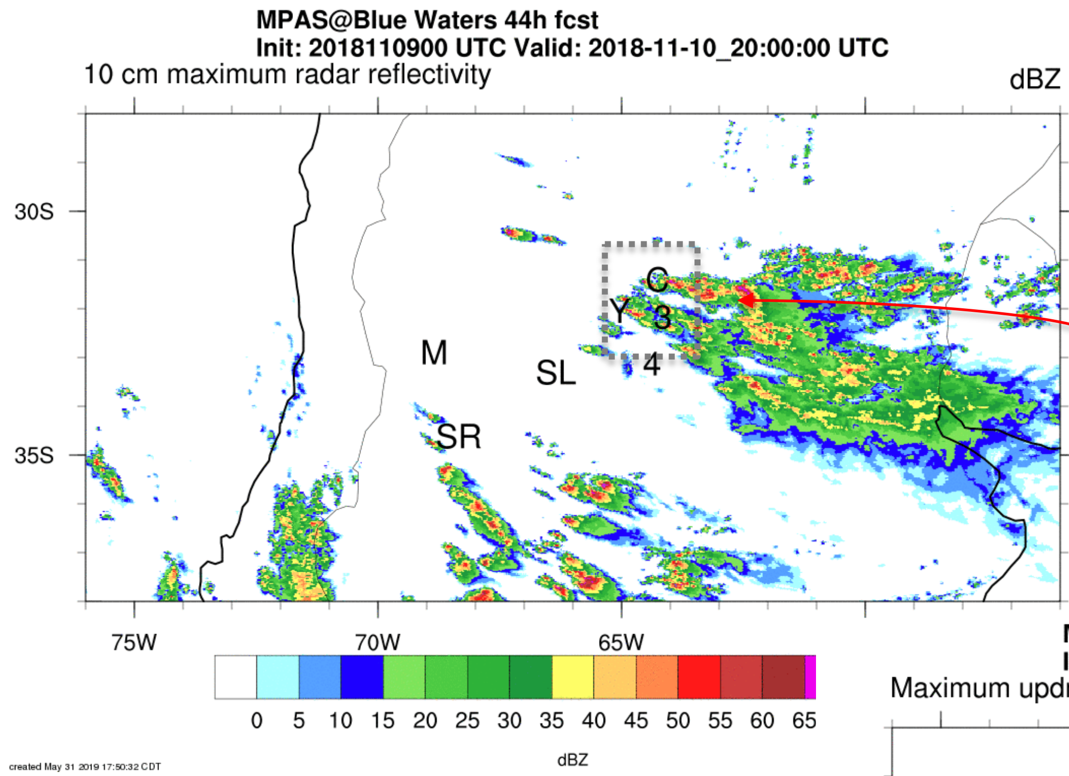


change in evolution?

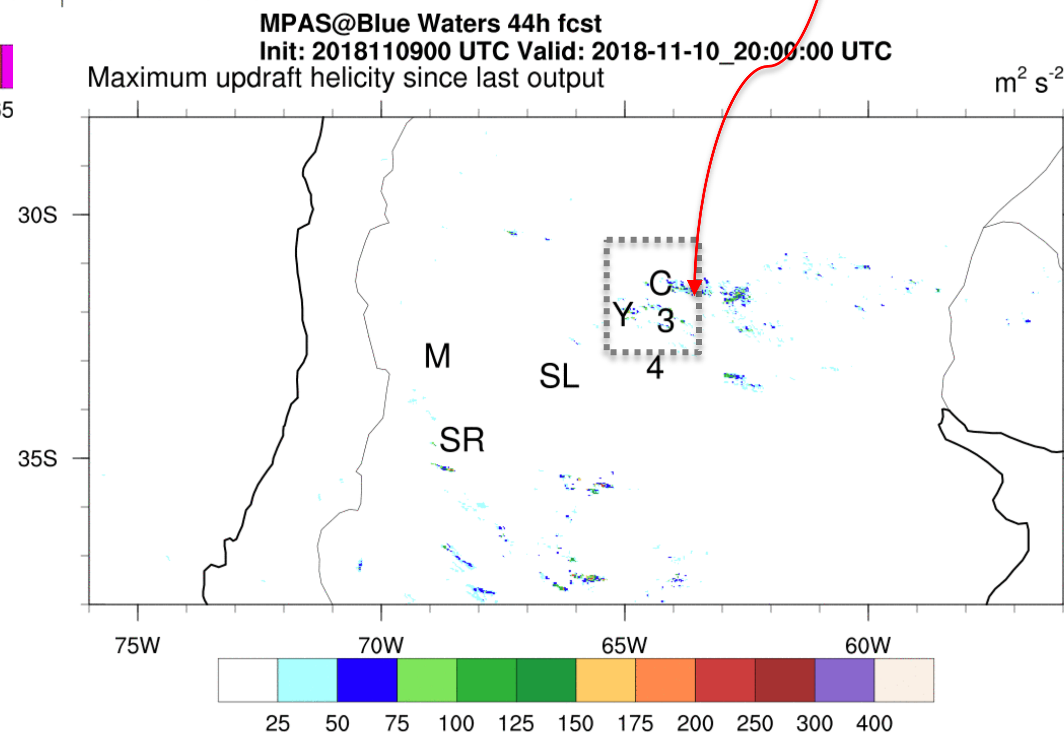


68-hr forecast

(valid 20 UTC 10 Nov)

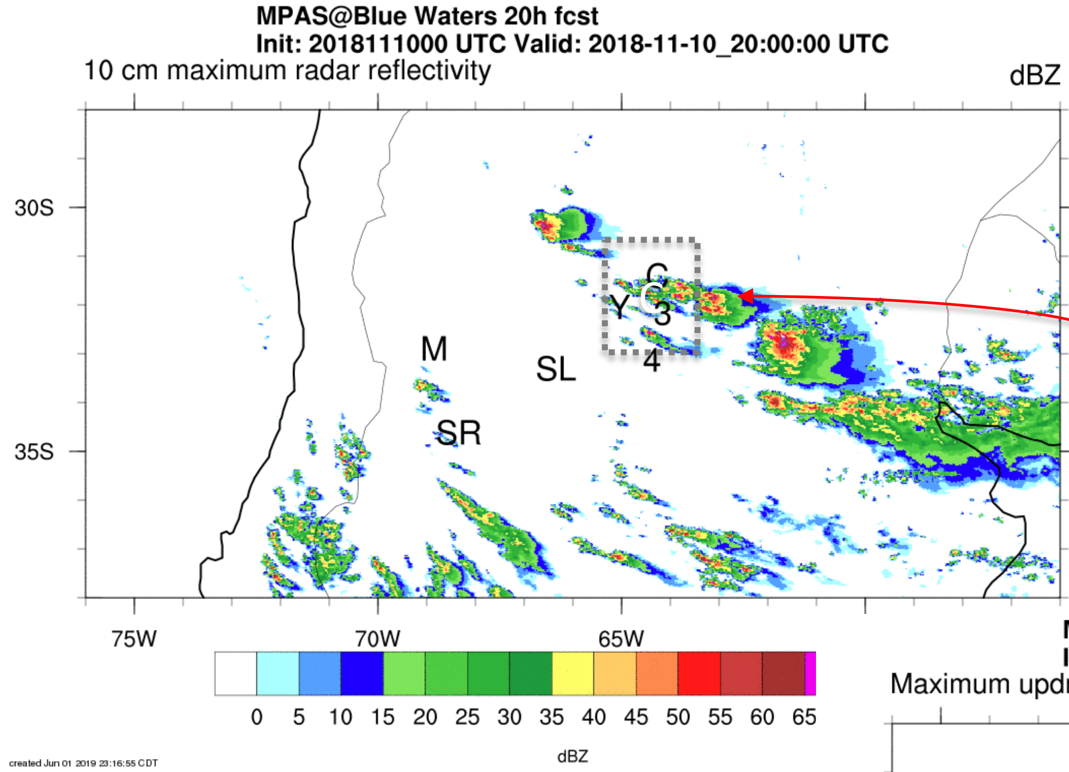


less organized storms…



44-hr forecast

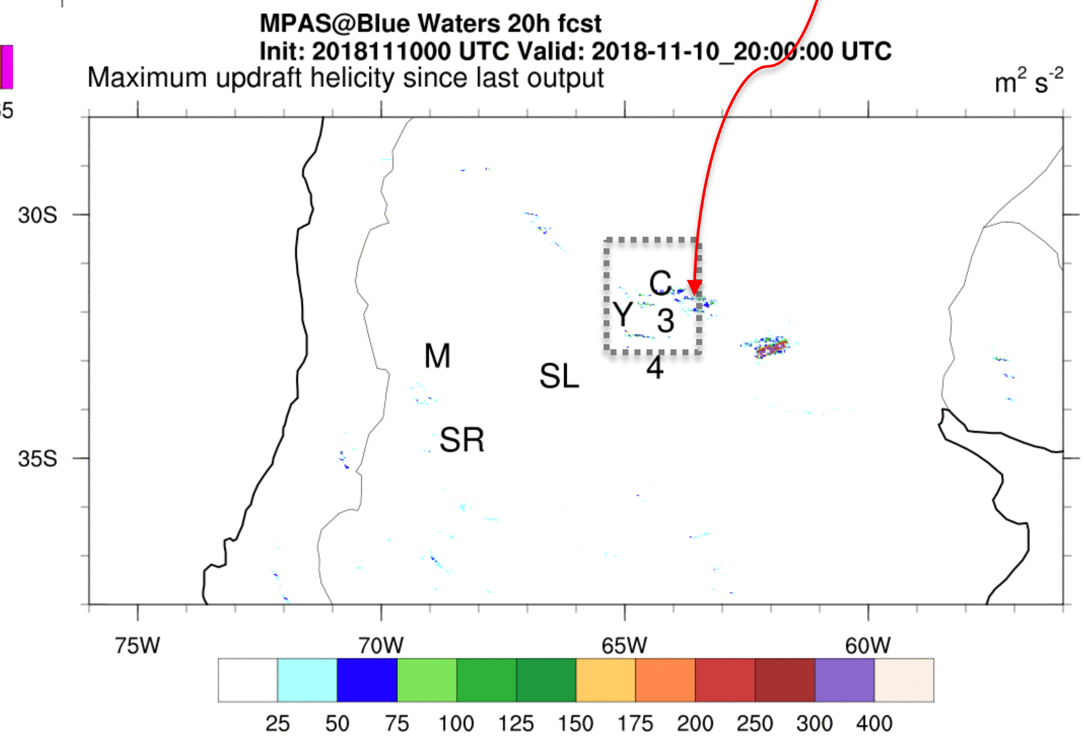
(valid 20 UTC 10 Nov)

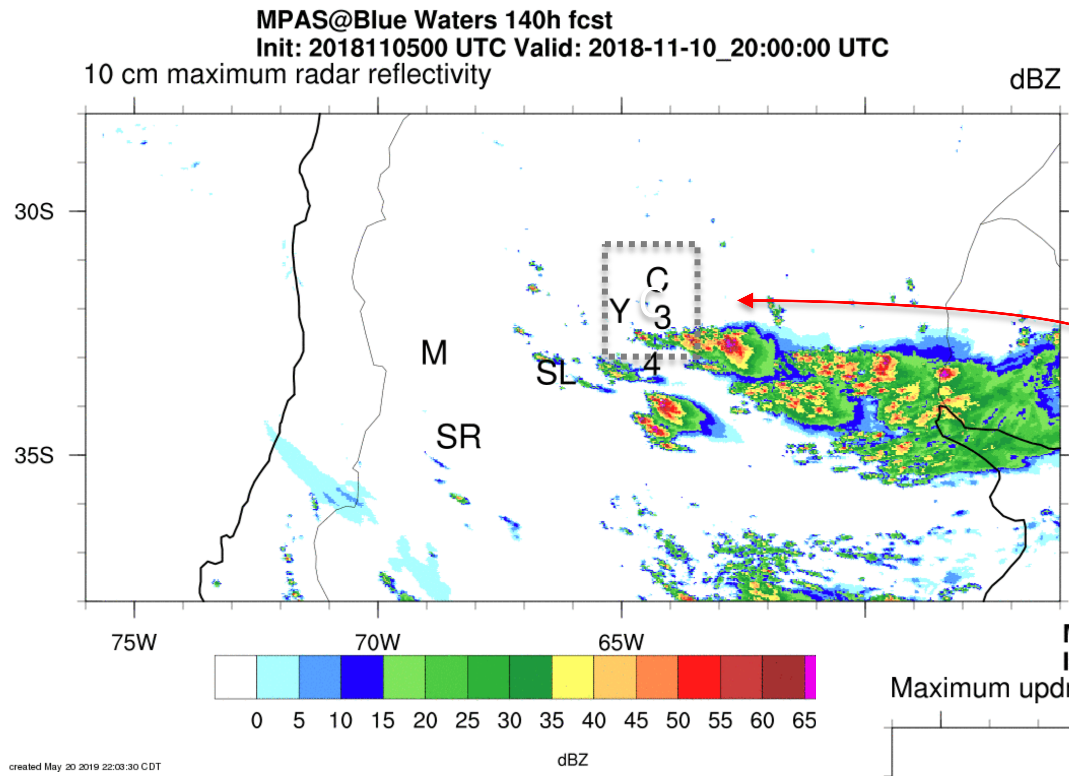


still different evolution

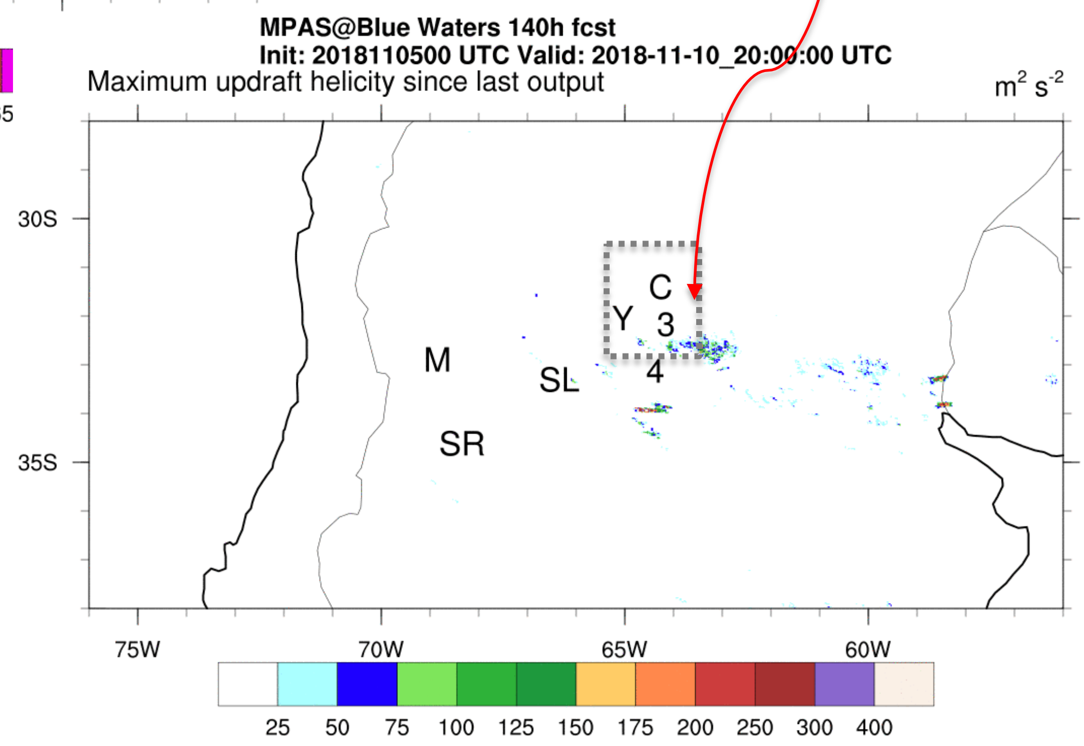
20-hr forecast

(valid 20 UTC 10 Nov)





return to a more accurate evolution!



140-hr forecast

(valid 20 UTC 10 Nov)

Preliminary thoughts…

- useful extended range guidance (even out to 6 days) for many, but certainly not all events
  - planned objective evaluation
- degradation of guidance with time?
  - for shorter-range forecasts, less spinup time from coarse ic from global model?
  - counter to recent finding by Schwartz (2019, *MWR*) in U.S.
- still need comparison with regional model forecasts to determine if MPAS/global modeling adds value

Thanks to Ryan Mokos for his assistance in building MPAS on BW, and Roland Haas/David King for their help in setting up BW reservation

Questions/comments?

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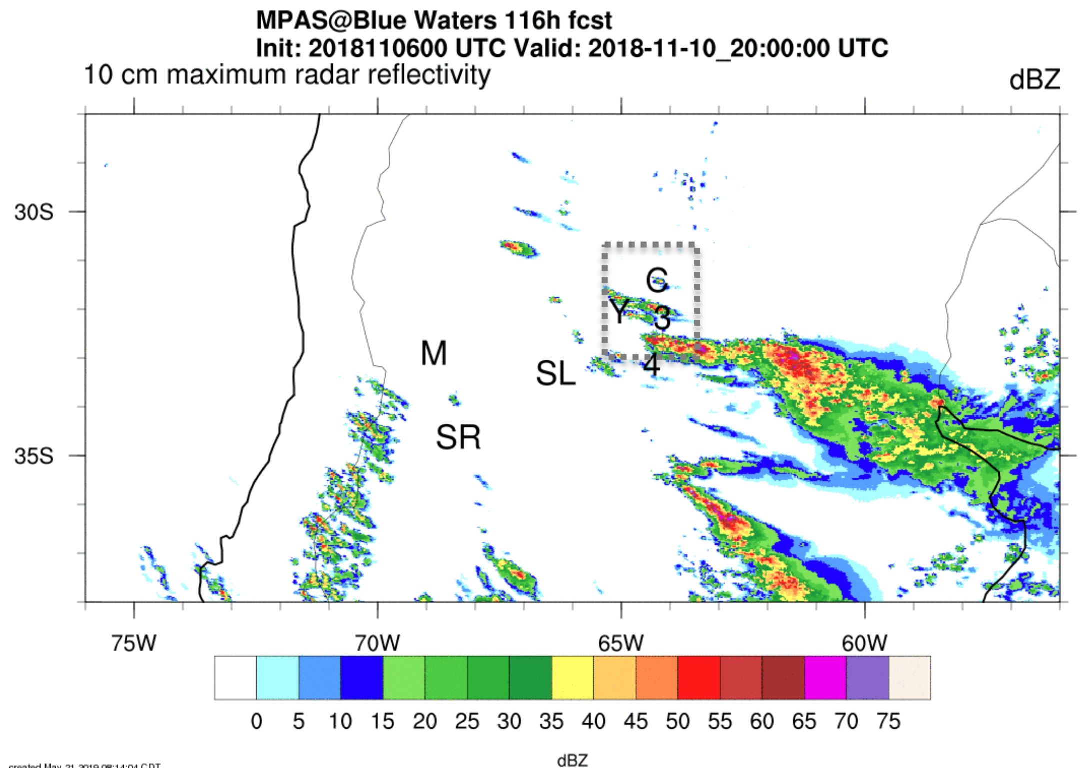
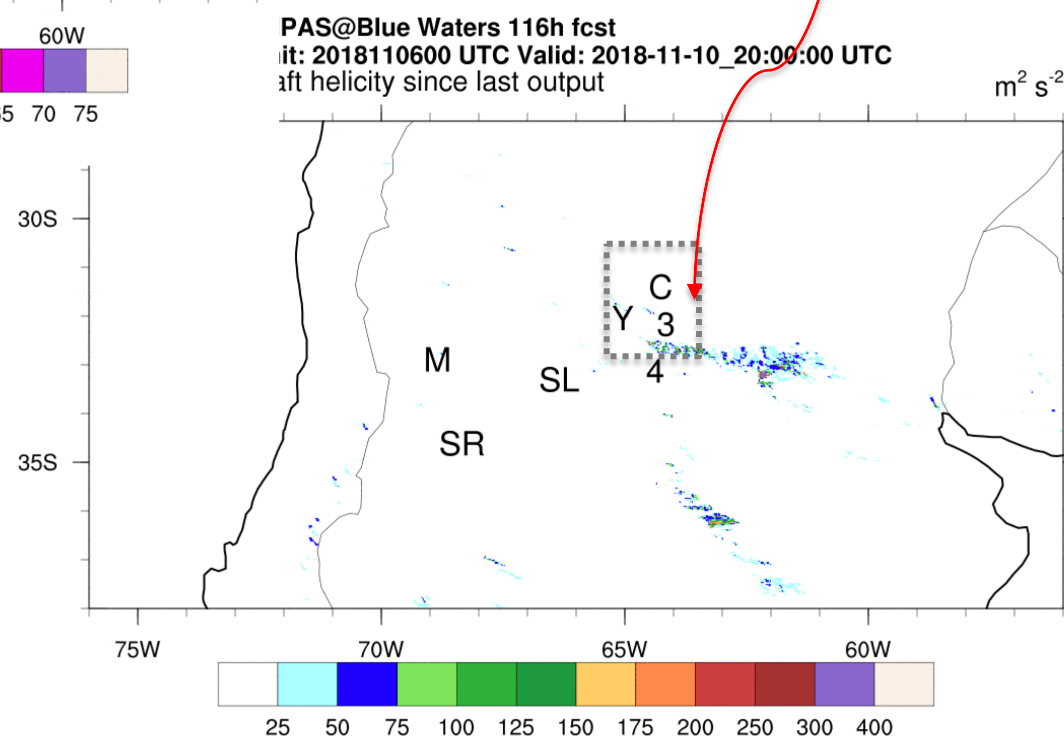
RELAMPAGO is sponsored by the National Science Foundation

Brief digression: Building MPAS on Blue Waters…

- It took a while …
- MPAS uses the Parallel IO (PIO) library (as used in CESM), and with help from NCAR team (Michael Duda) and NCSA's Ryan Mokos, we determined that PIO did not install properly with PGI compilers



more favorable…



116-hr forecast

(valid 20 UTC 10 Nov)

grid refinement is not a new concept, but is fundamental to the success here

A Fast Dynamic Grid Adaption Scheme for Meteorological Flows

BRIAN H. FIEDLER AND R. JEFFREY TRAPP

School of Meteorology, University of Oklahoma, Norman, Oklahoma

(Manuscript received 5 October 1992, in final form 27 April 1993)

ABSTRACT

The continuous dynamic grid adaption (CDGA) technique is applied to a compressible, three-dimensional model of a rising thermal. The computational cost, *per grid point* per time step, of using CDGA instead of a fixed, uniform Cartesian grid is about 53% of the total cost of the model with CDGA. The use of general curvilinear coordinates contributes 11.7% to this total, calculating and moving the grid 6.1%, and continually updating the transformation relations 20.7%. Costs due to calculations that involve the gridpoint velocities (as well as some substantial unexplained costs) contribute the remaining 14.5%. A simple way to limit the cost of calculating the grid is presented. The grid is adapted by solving an elliptic equation for gridpoint coordinates on a coarse grid and then interpolating the full finite-difference grid. In our application, the additional costs per grid point of CDGA are shown to be easily offset by the savings resulting from the reduction in the required number of grid points. In the simulation of the thermal, we are able to reduce costs by a factor of 3, as compared with those of a companion model with a fixed, uniform Cartesian grid.