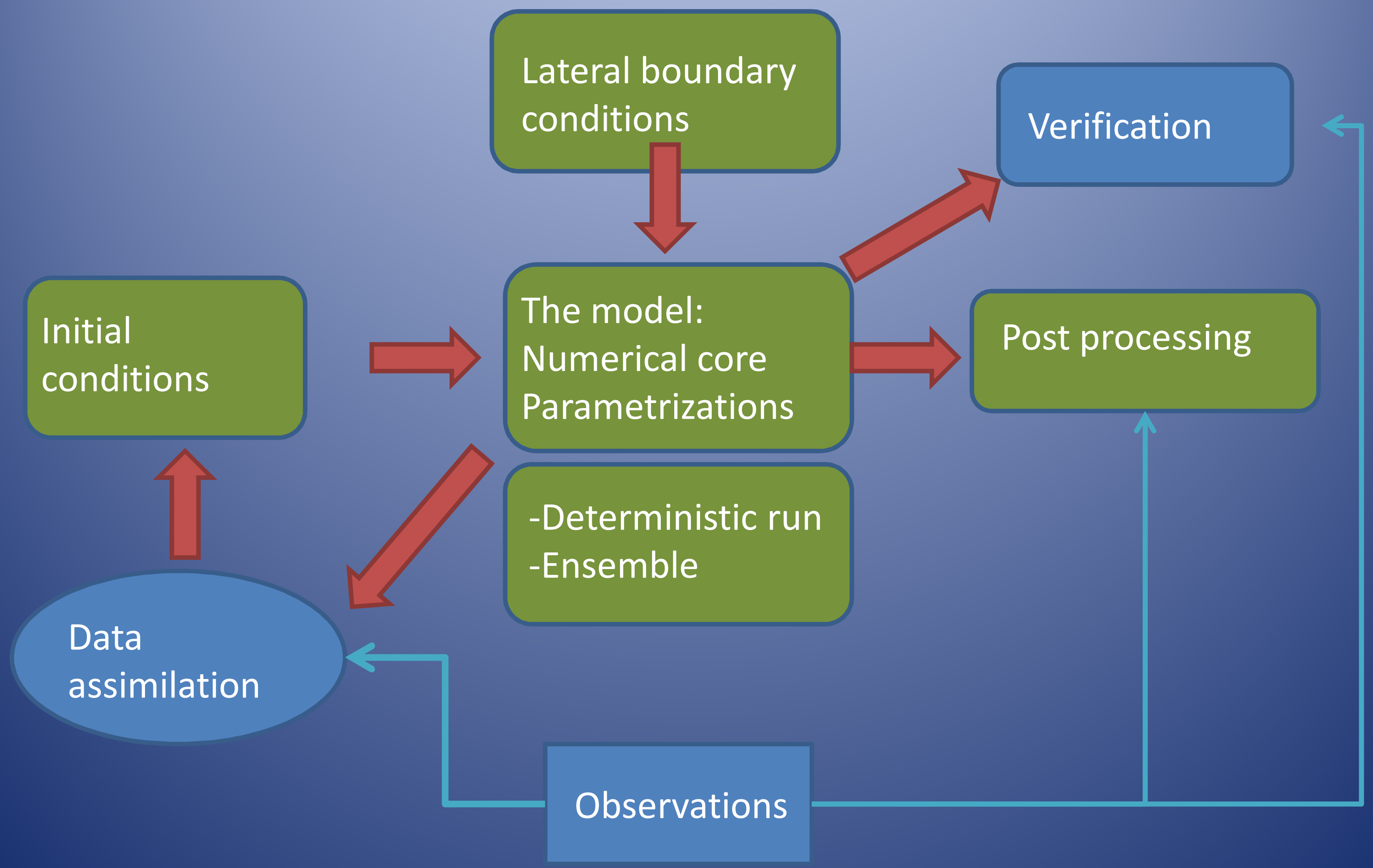
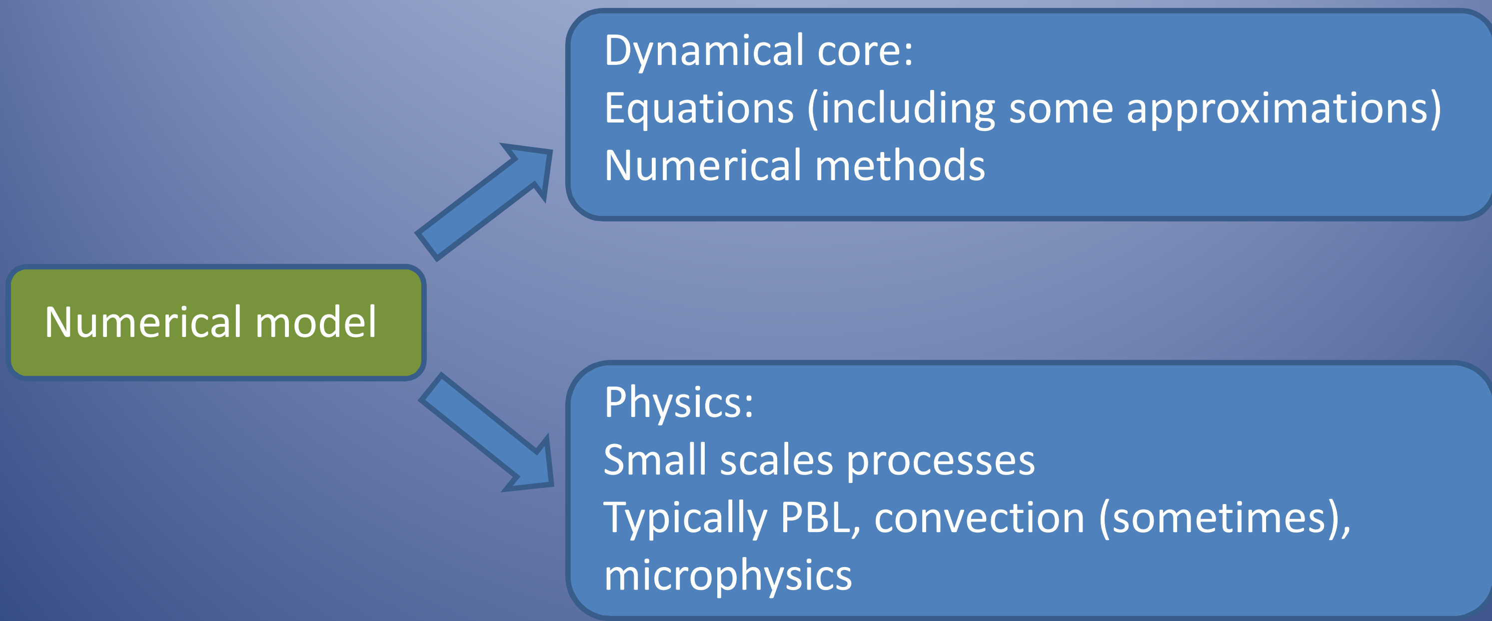
Numerical Weather Prediction

T-NOTE – Buenos Aires, 5-16 August 2013 –
Juan Ruiz and Celeste Saulo

A forecasting system based on numerical weather prediction models



Numerical model components



Forecast uncertainty

Uncertainty

Initial conditions:
Imperfect description of the initial state of the system (atmosphere, land surface, ocean…)

Model error:
Numerics (truncation errors), unresolved scales (parameterizations), not very well understood processes

Both are important sources of errors in the forecast

Error growth due to the chaotic nature of the atmosphere amplifies both sources of error.

Which information do numerical models provide about the occurrence of severe weather events?

NWP can provide information about these events at different spatial and temporal scales…

Which information do numerical models provide about the occurrence of severe weather events?

Information provided by NWP models depends on:

Model characteristics
i.e. resolution

Predictability
Error growth rate

Initialization
Observations, DA

Model characteristics: resolution

How well do model represent the different phenomena?

Severe weather events are usually associated with meso/micro scale phenomena:

-Tornadoes
-Bow-echoes
-Hail
-Persistent heavy rain/ snow fall
-many others …

Model characteristics: resolution

Are current resolutions enough for the representation of convective processes?

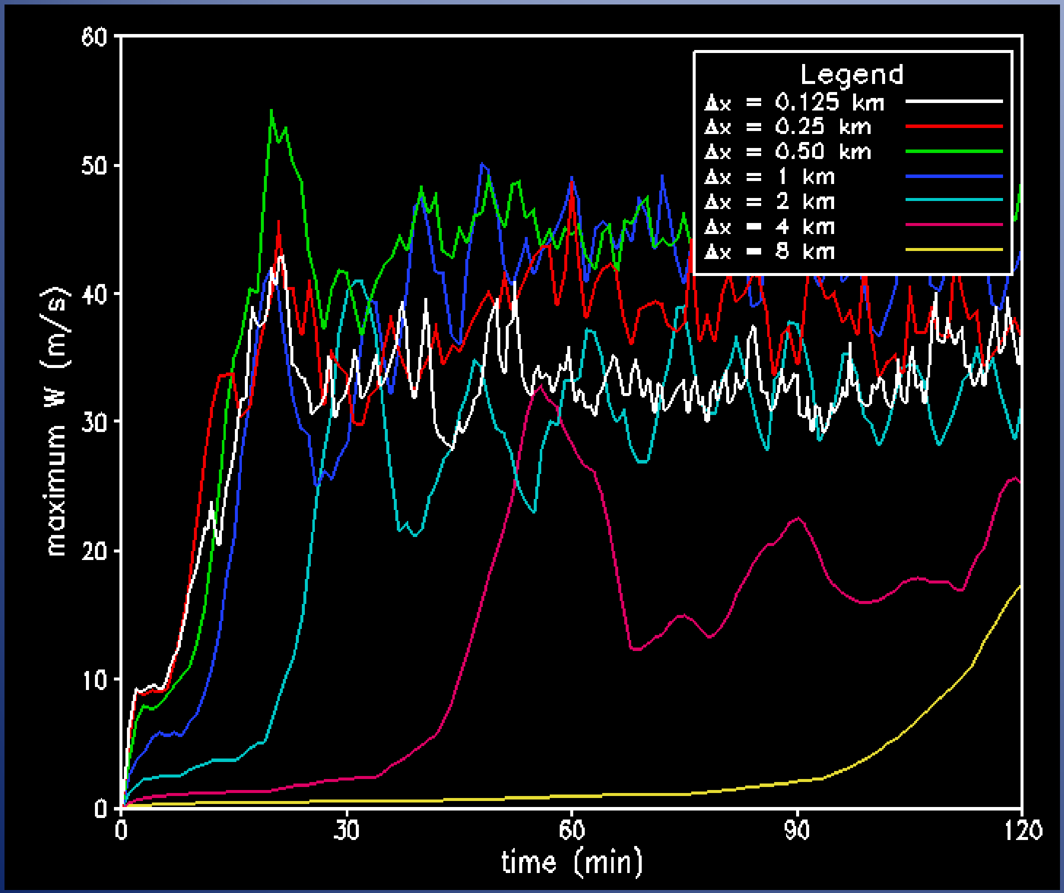
•Median convective updraft diameters are ~2-4 km

•High resolution models need ~6-8Δ to "resolve" a feature (effective resolution, model dependent)

Horizontal resolutions between 100-250 m would be needed to resolve individual convective cells

Model characteristics: resolution

How much resolution do we need to resolve individual convective cells?



Bryan et al. 2003, 2006

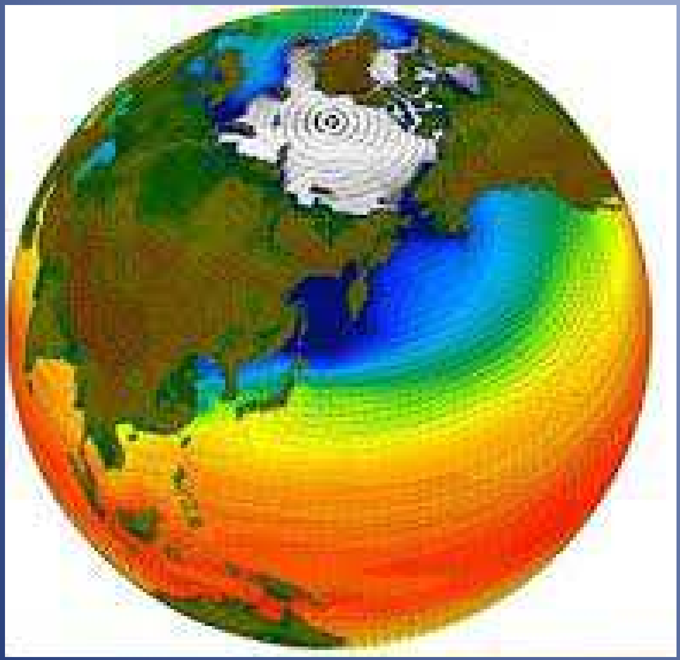
There are significant differences in convective structure of mesoscale convective systems simulated with 1km and 125 m horizontal resolution.

Numerically simulated convection is strongly sensitive to horizontal resolution in the range 4 km- 250 m

Model characteristics: resolution

Operational NWP systems and their current resolution

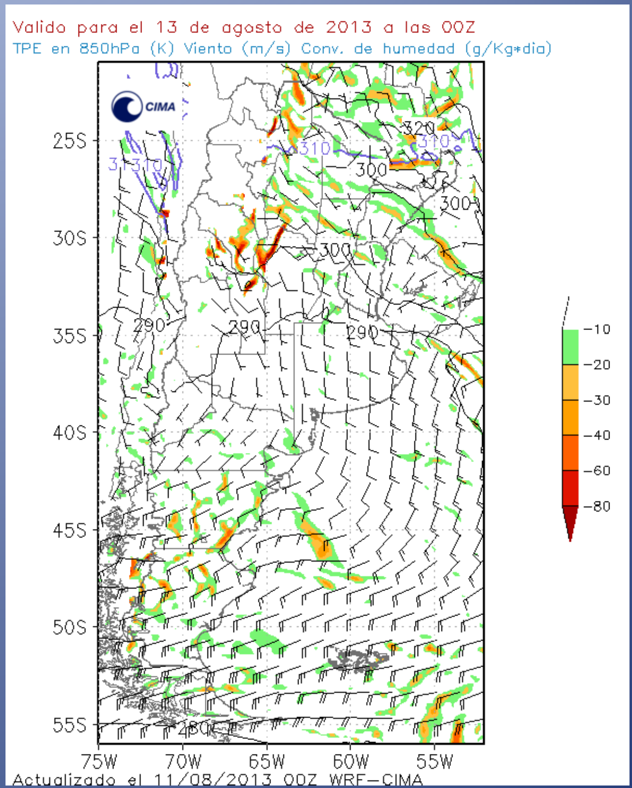
Global model



Initial conditions
Lower boundary conditions

~25 km

Limited area domain



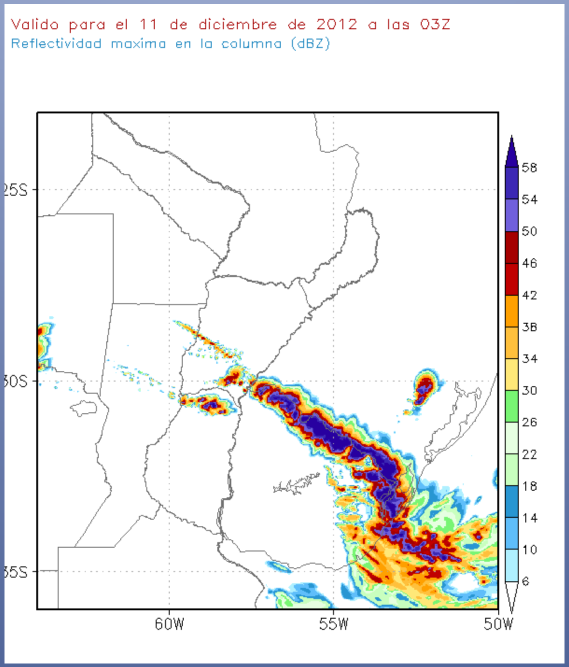
~1 – 15 km
Initial conditions
Lower and lateral boundary conditions

Doubling horizontal resolution and increasing the vertical resolution will produce a ~ 10 time increase in the computational power

Model characteristics: resolution

Operational NWP systems and their current resolution

Convection allowing model
No CP horizontal resolution less than 5 km

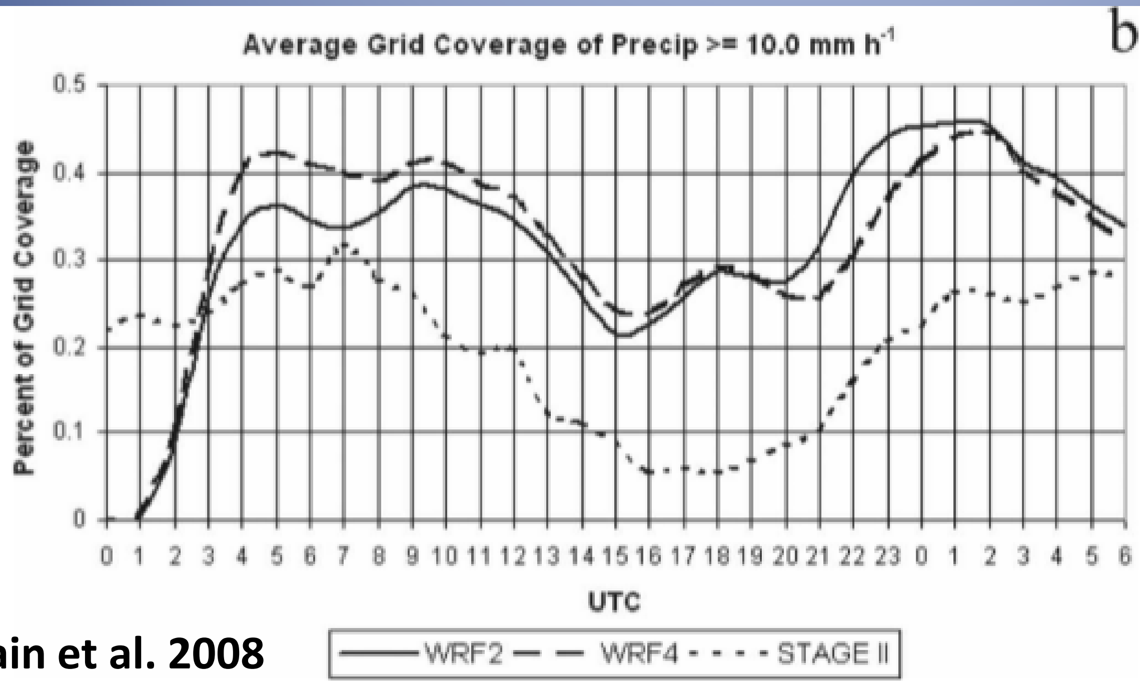


~1-4 km

Resolution of operational weather prediction models is insufficient to explicitly represent most phenomena associated with severe weather

Model characteristics: resolution

Example: Biases possible associated with model poorly resolved convection



Kain et al. 2008

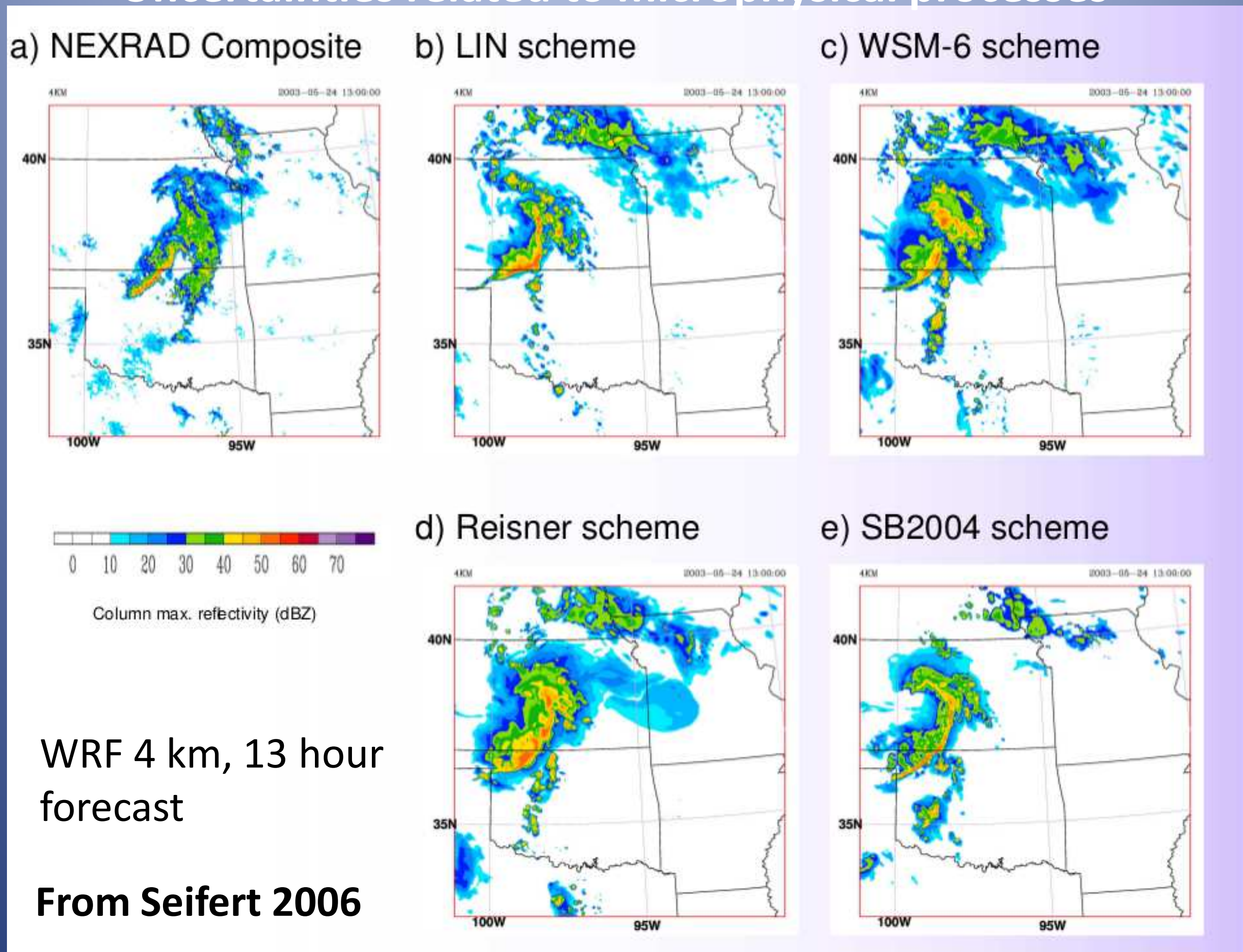
FIG. 12. Model climatology: Areal coverage of precipitation rate as a function of time exceeding the (a) 5 and (b) 10 mm h^{-1} thresholds, averaged over all days during the Spring Experiment.

Some convection allowing model biases are consistent with the findings of Bryan et al. 2003.

In this case convection allowing models with resolutions between 2-4 km tend to produce too much precipitation

Model characteristics: physics

Uncertainties related to microphysical processes



WRF 4 km, 13 hour forecast

From Seifert 2006

Microphysical processes are not accurately represented in NWP models.
Many characteristics of the solution at small scale are sensitive to the choice of the microphysics scheme (cold pool intensity, system propagation, etc).

Model characteristics: physics

Uncertainties related to boundary layer turbulence

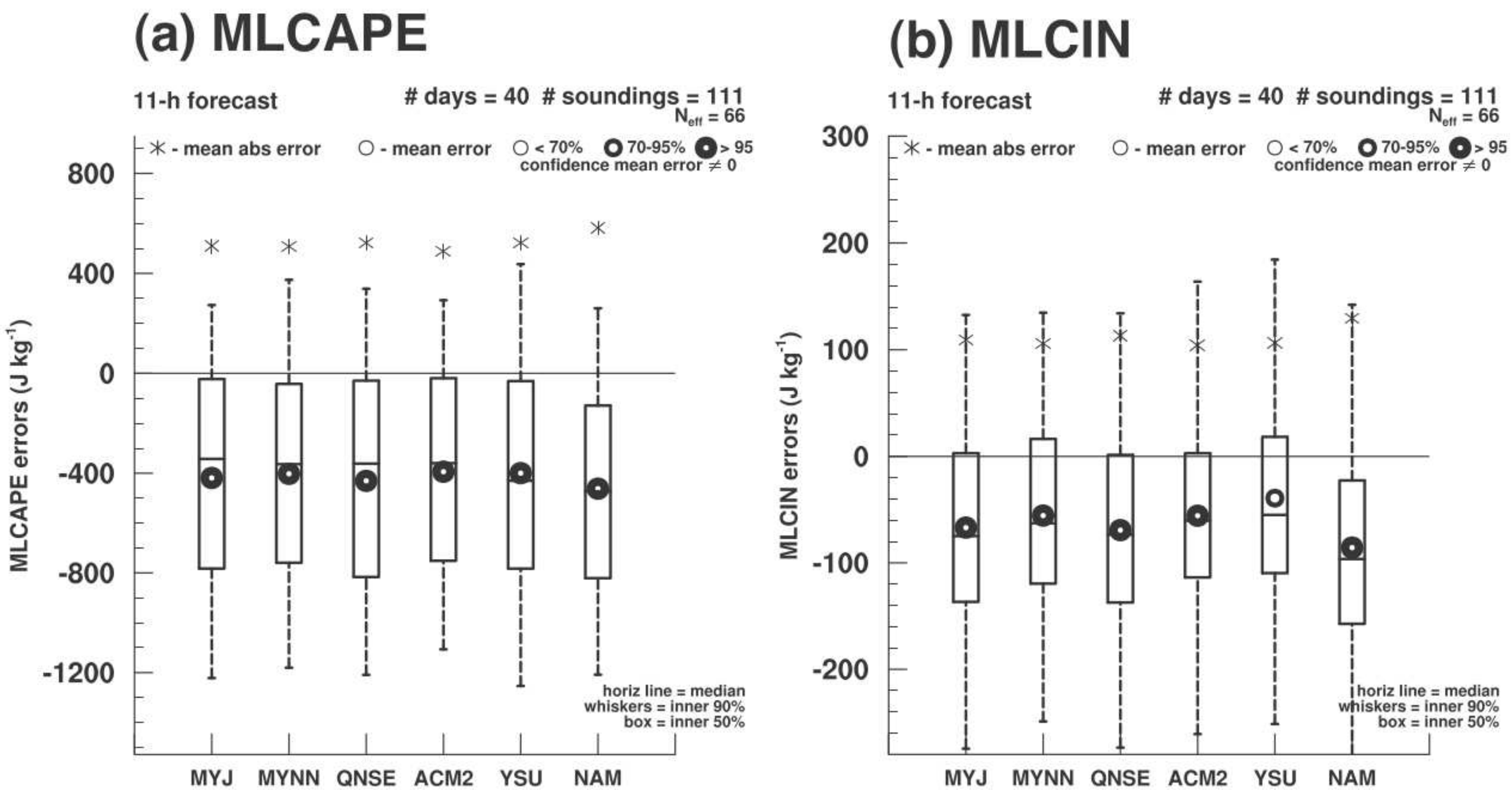


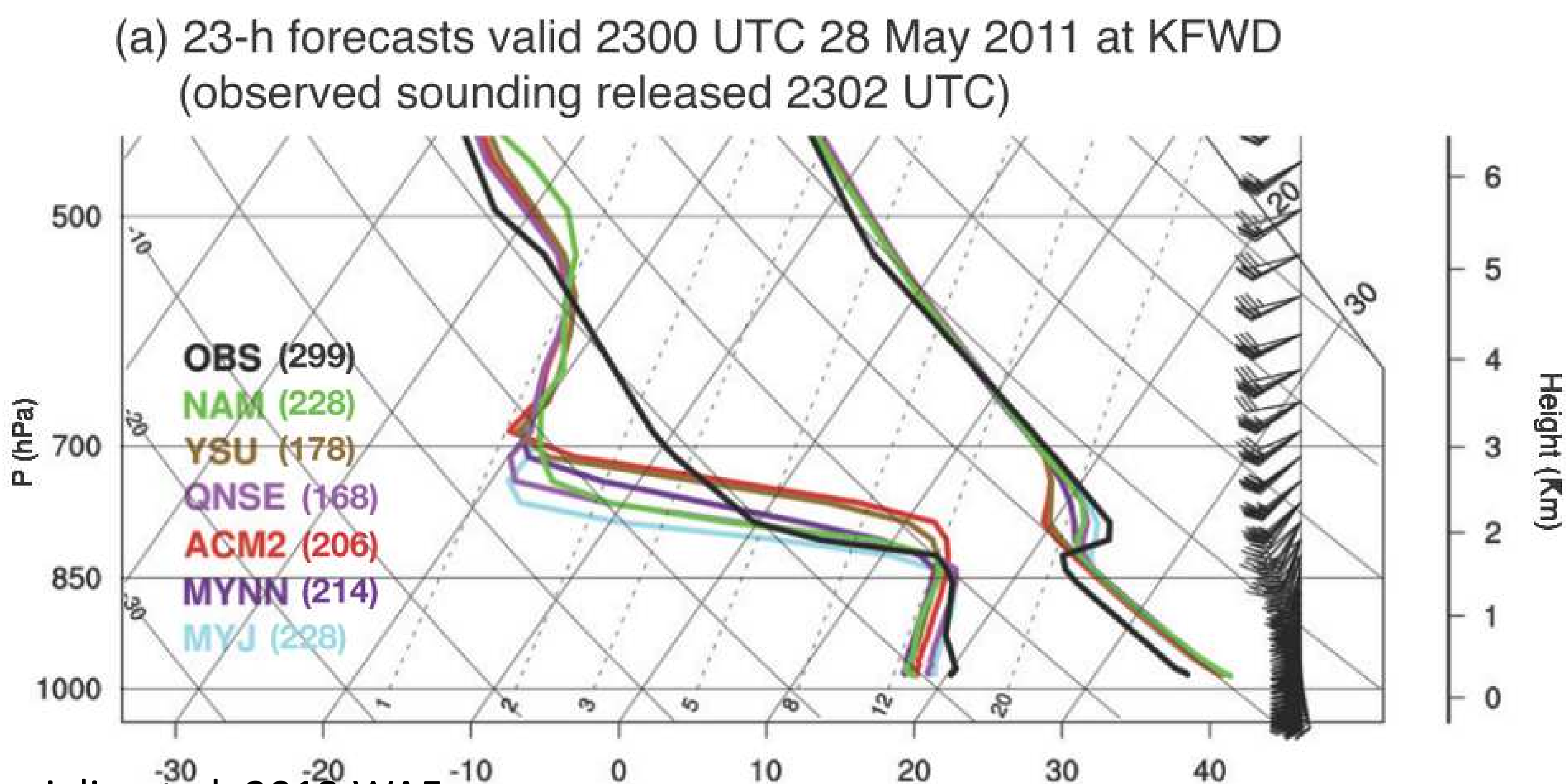
FIG. 12. As in Fig. 3, but for MLCAPE errors for 11-h forecasts (valid at 1100 UTC). Only those soundings that have positive CAPE in both the model forecasts and the observation are included here.

Coniglio et al. 2013

- PBL systematic errors depend on the time of the day and also on the large scale situation.
- These errors will significantly impact convective initiation and evolution as well as its strength.
- Other model errors probably involved (Land surface model biases)

Model characteristics: physics

Uncertainties related to boundary layer turbulence



Coniglio et al. 2013 WAF.

Capping inversion under prediction by several PBL schemes in a convection allowing model

Predictability

Predictability

Strongly related to error growth in the forecast

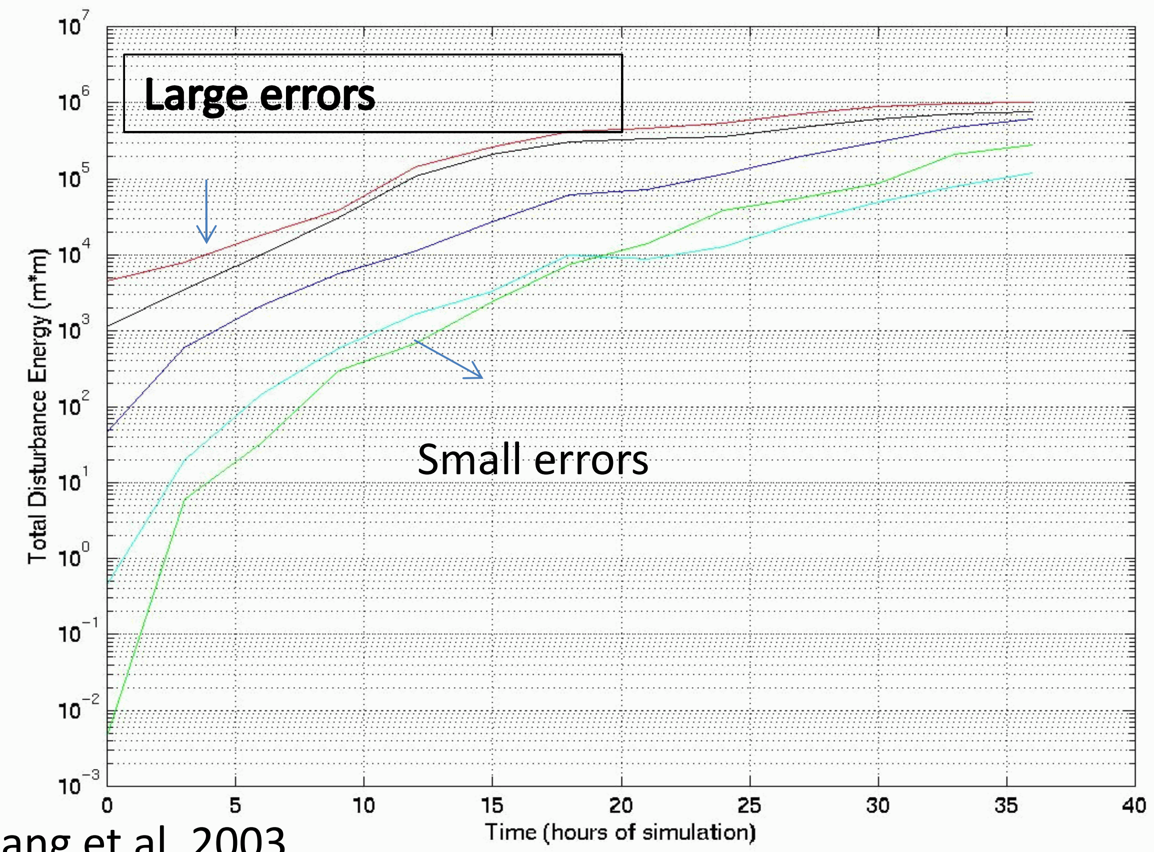
Do all phenomena have the same predictability limit?

Synoptic scale features are usually predictable up to more than 10 days.

Error growth is approximately 10 times faster at the mesoscale. 1day lead time roughly equivalent to a 10 day lead time in the synoptic scale. (Hohenegger and Schar 2007)

Predictability

At the mesoscale error growth is dependant on its amplitude, the smaller the error the faster it grows.

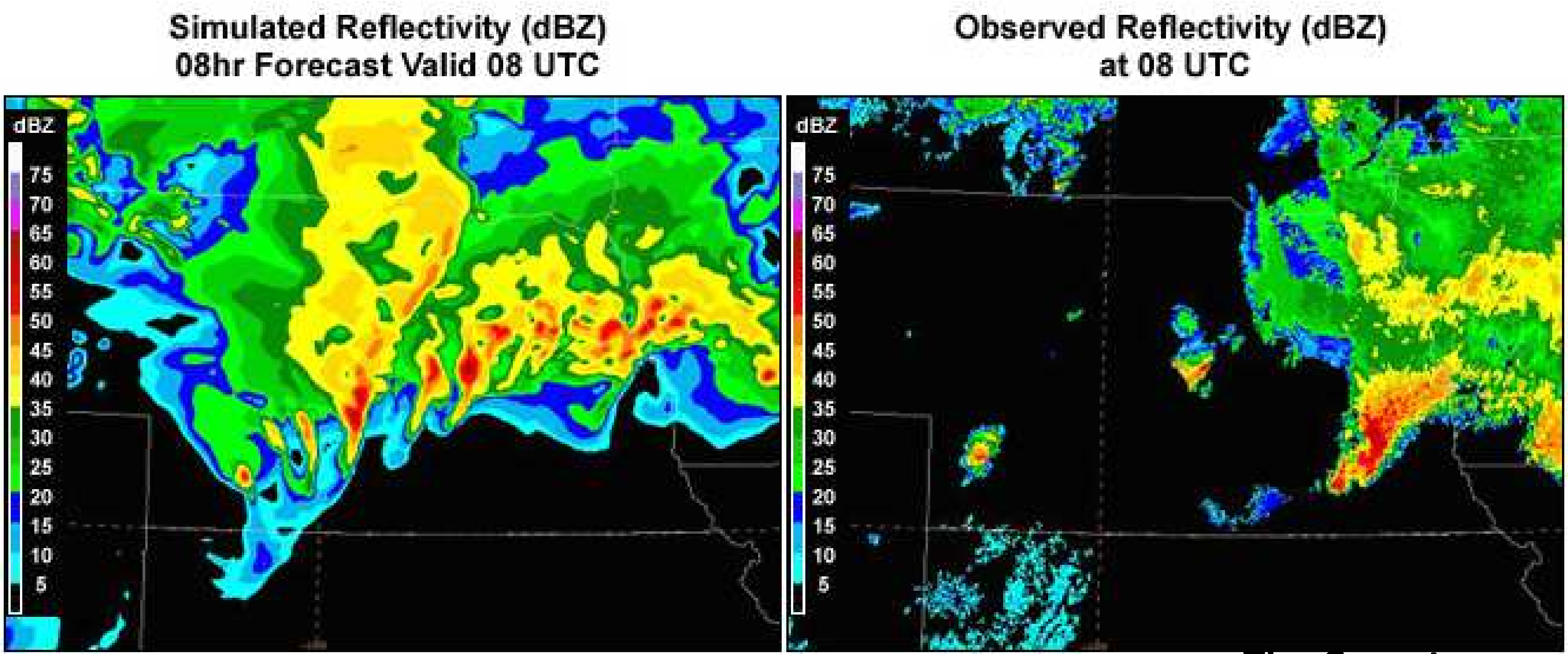


Zhang et al. 2003

A large improvement of the initial conditions will only produce a short extension of the predictability limit

Predictability

Example: Forecast produced by a convection allowing model

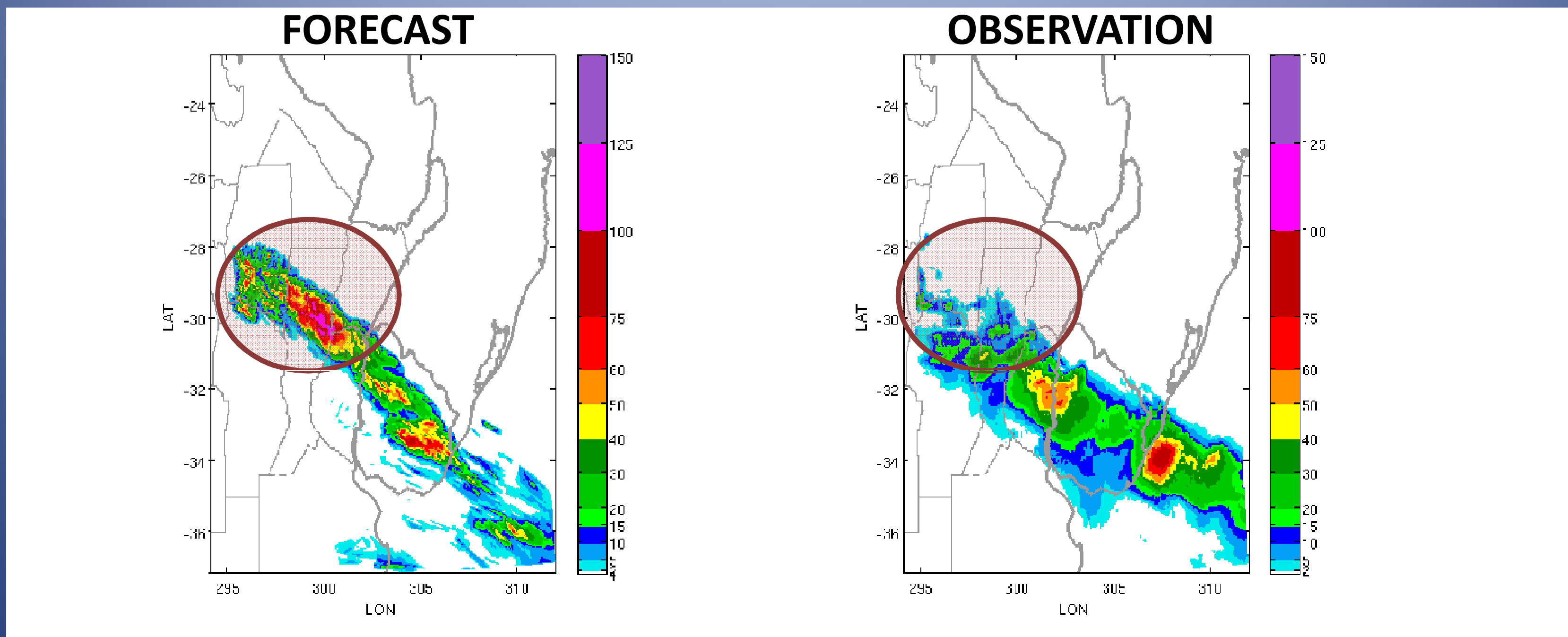


The Comet program

Some aspects of mesoscale structure are represented by the forecast but there are large errors in the location of individual cells and of the convective system.

Predictability

Example: Forecast produced by a convection allowing model

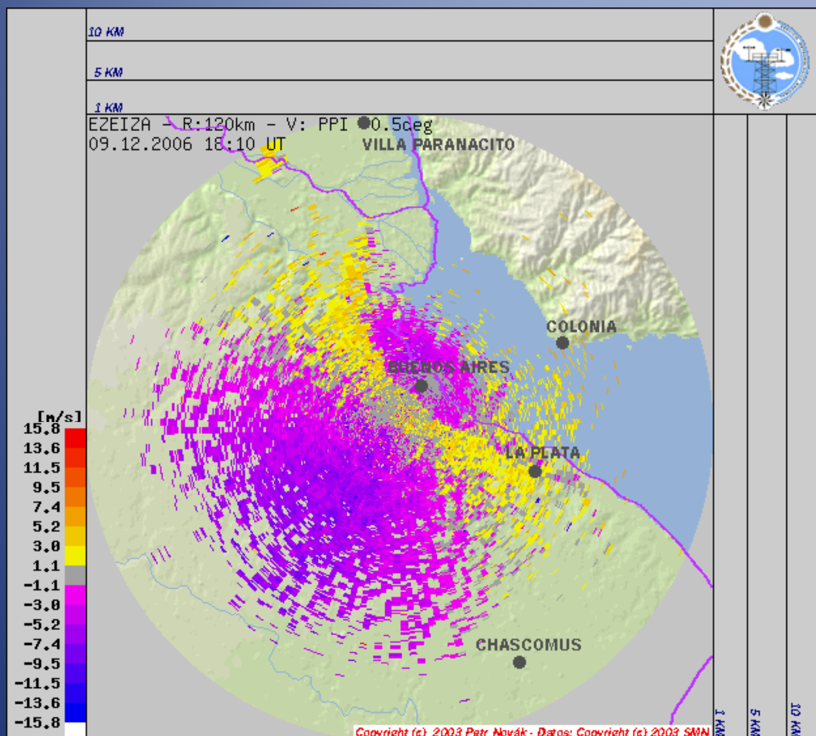


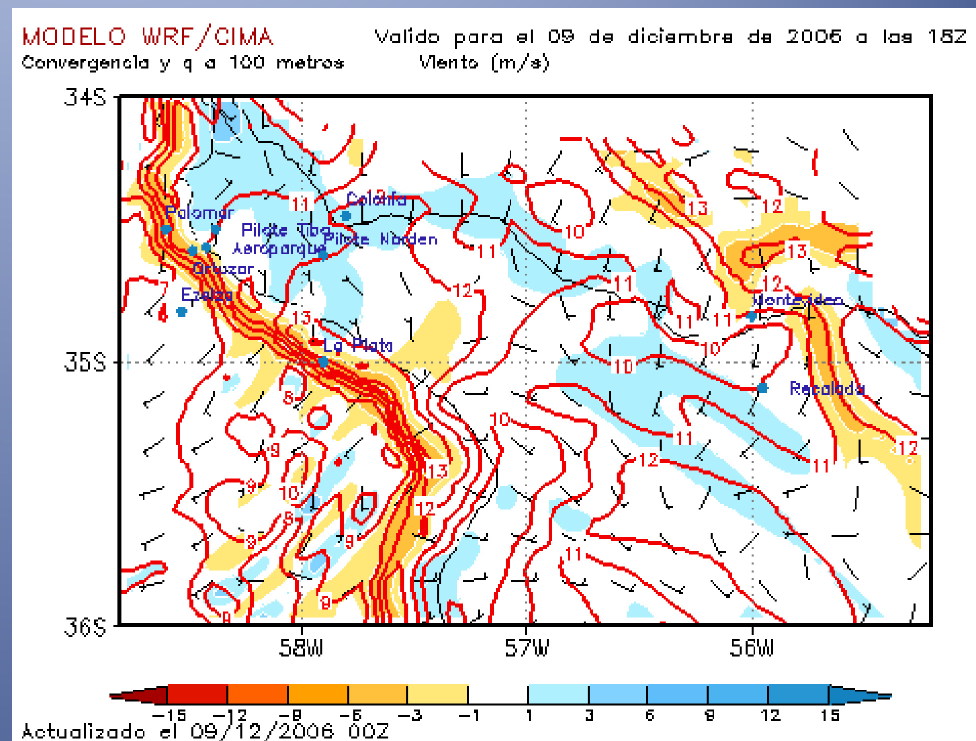
18 hr forecast with 4 km (WRF-Chuva).

Position and / or timing errors can be large, O (100 km) and O (1-3 hr) respectively (in the first 24 hours) and will continue growing with time

Predictability

Predictability is longer for small scale phenomena associated with land surface forcings or topography





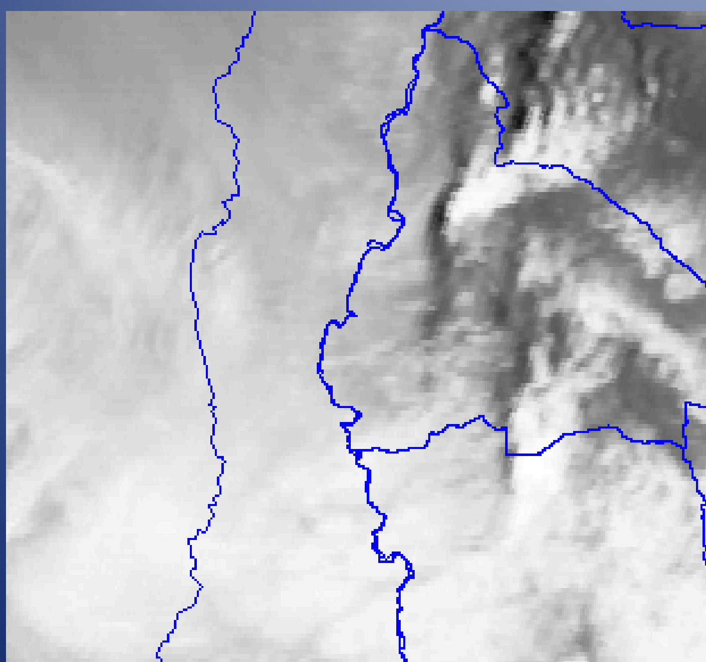
Sea breeze front well represented in the model forecast.

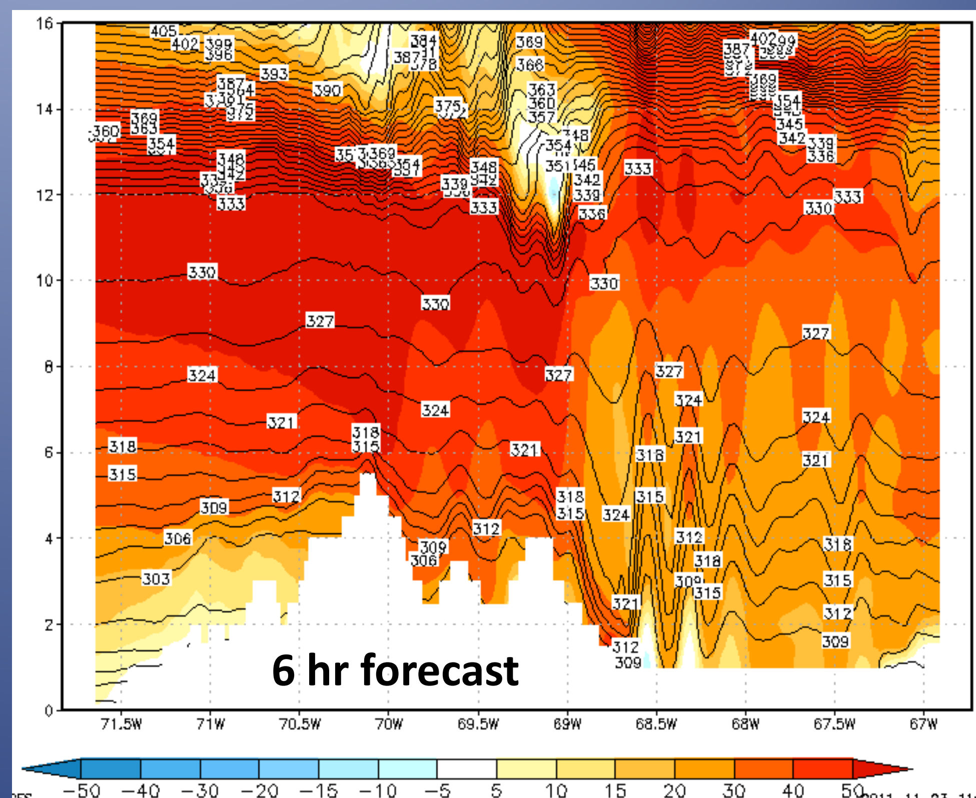
Land sea breezes may be forecasted even without a proper initialization of the mesoscale in the numerical model, given that the mesoscale forcing is well represented

Predictability

Predictability is longer for small scale phenomena associated with land surface forcings or topography

Down slope wind storms (Zonda) and small scale gravity waves.
Wind storm and associated turbulence forecast.





Initialization

Initialization deals with the generation of the initial conditions for the forecast

Several data assimilation techniques provide ways to combine observations and short range forecasts to obtain initial conditions approximately consistent with model dynamics.

Initialization

Initialization strategy depends on the scale of the phenomena that we want to forecast

Models for synoptic scale prediction are usually initialized every 6 hours using different types of observations (soundings, satellite, surface, etc)

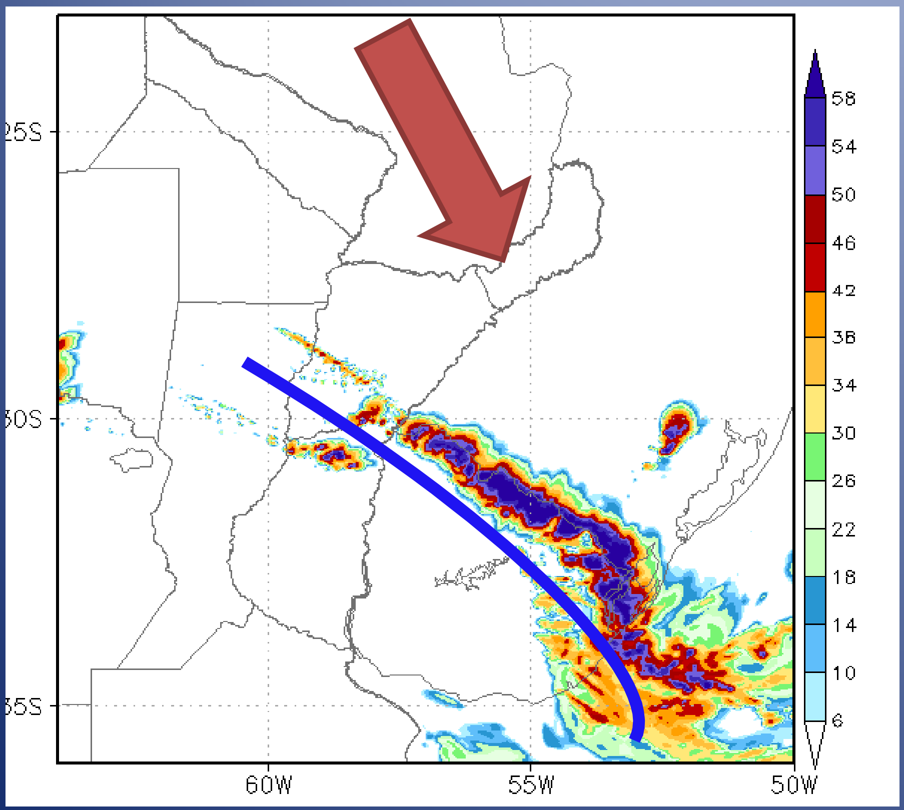
Models for mesoscale forecasts have to be initialized more frequently (1 hour to 15 minutes) using dense observational networks , radars and other observations when they are available.

The smaller the scale the larger the number of observations that we need and the higher the assimilation frequency.

Initialization

Convection resolving models with no mesoscale initialization

Sometimes these models are initialized using larger scale analysis with no information about mesoscale circulations.



In this case mesoscale circulations emerge during the forecast due to influence of large scale forcing (energy cascade) or because of mesoscale forcings.

Chuva experiment
4km WRF
MCS associated with a cold front.

Errors in large scale circulation will produce errors in the associated mesoscale circulation

Initialization

In cold start initialization, it takes some time for the model to develop mesoscale circulations

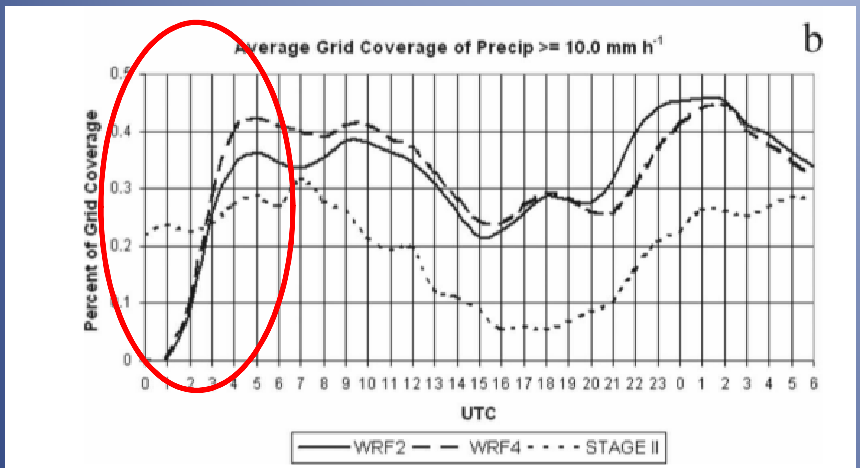


FIG. 12. Model climatology: Areal coverage of precipitation rate as a function of time exceeding the (a) 5 and (b) 10 mm h^{-1} thresholds, averaged over all days during the Spring Experiment.

It takes more that 6 hours for a convection allowing model to fully develop precipitating systems.

Early model forecast suffers from significant systematic under prediction of rainfall.

Kain et al. 2008

Without an adequate initialization process, convection allowing models are not a useful tool for nowcasting (i.e. 0-6 hr forecasting)

Initialization

Cold start initialization:

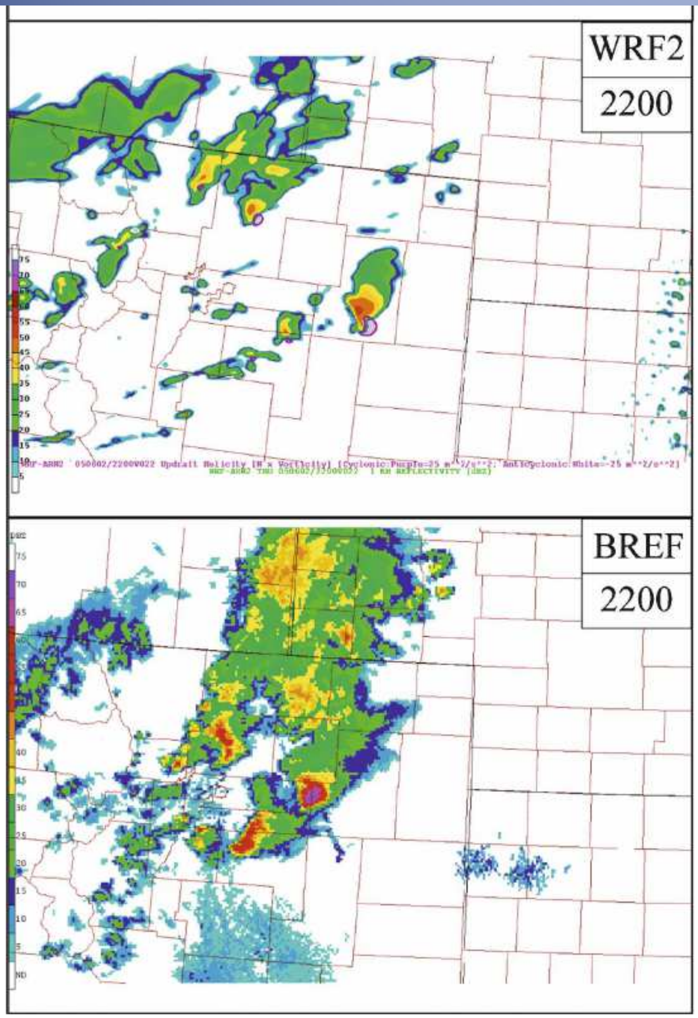


FIG. 14. As in Fig. 5 but zoomed-in on northeastern CO and with purple hatching in the top two panels indicating areas where UH $\geq 25\ m^2\ s^{-2}$.

Example of convective mode forecast using a convective allowing model.

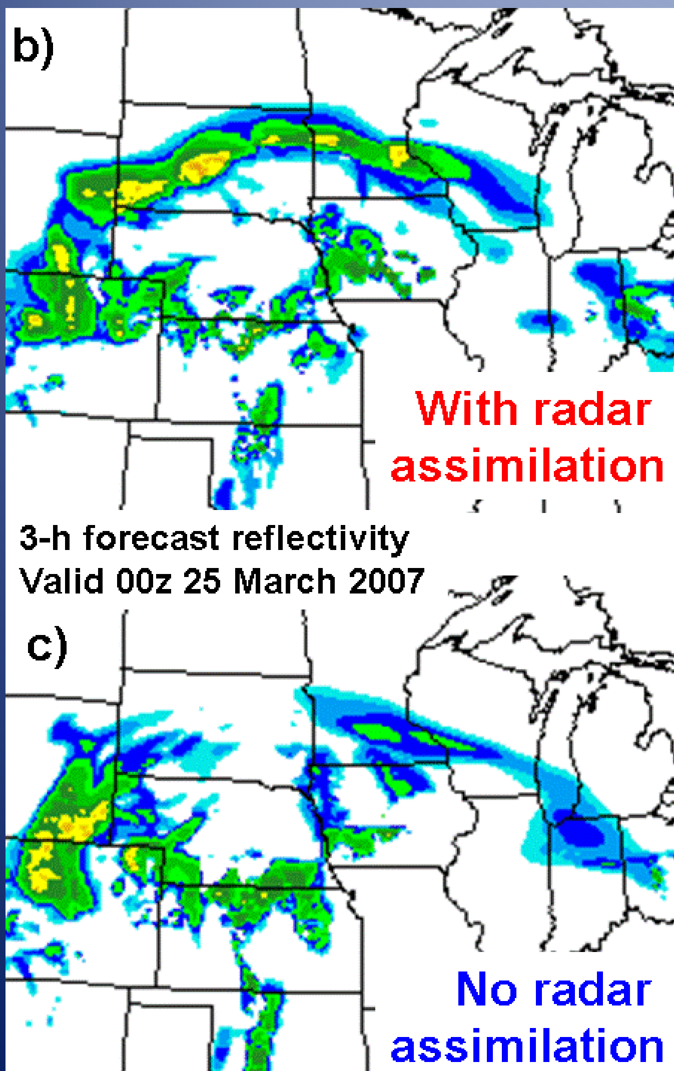
(22 hours forecast, 2 km resolution WRF, cold start).

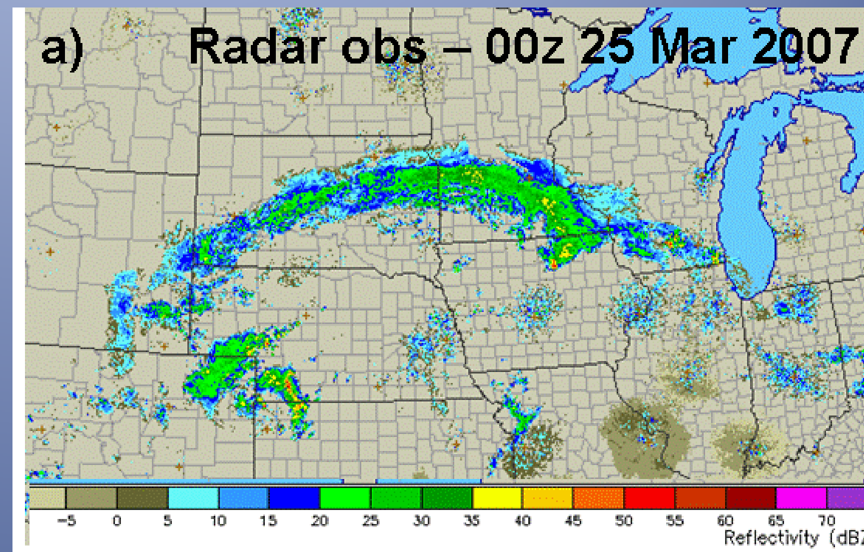
Kain et al. 2008 WAF.

Mesoscale organization of convection can be captured even if the exact position and timing can not be predicted

Initialization

Mesoscale initialization (Jenny Sun will talk about high resolution data assimilation on Wednesday)





Radar data assimilation can reduce spin-up and improve forecast skill for the first 12 hours.

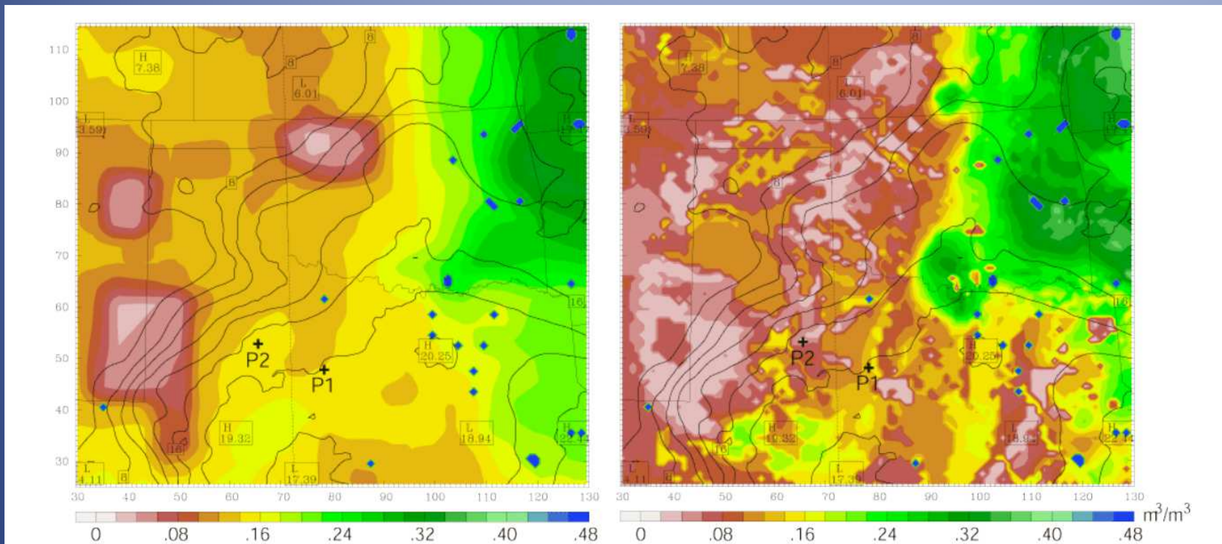
Lightning observations can also provide information to constrain the small scales.

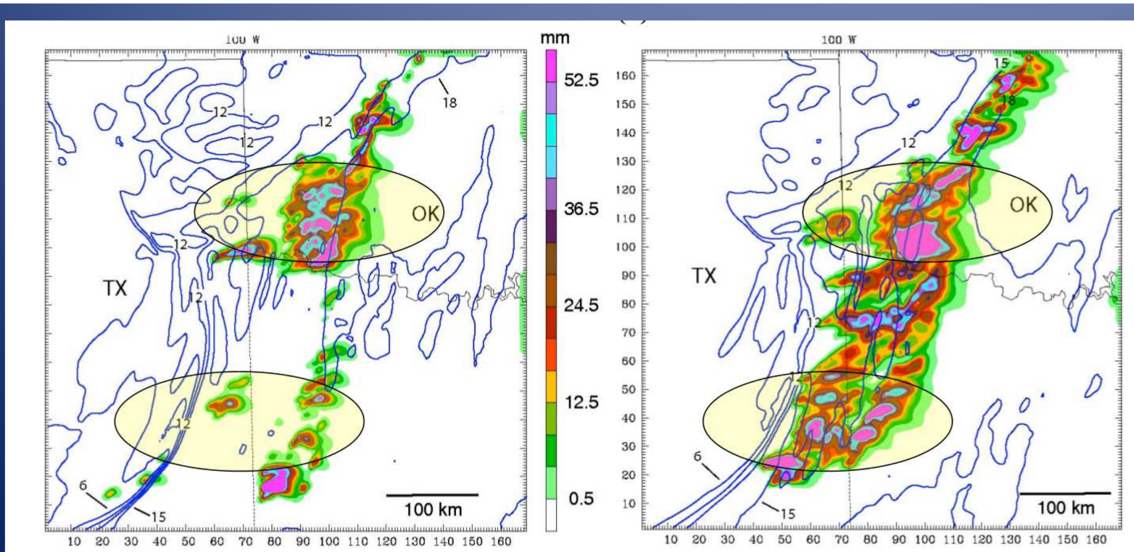
NWP TOOL FOR NOWCASTING

Initialization

Land surface initialization also important for convective scale forecasting

Low resolution soil moisture **High resolution soil moisture**





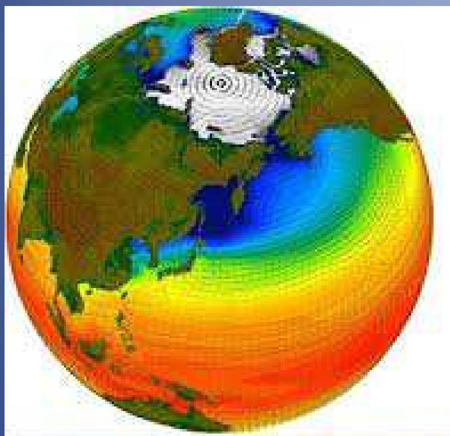
Better representation of precipitation along a dry line.

Probably due to stronger heat fluxes and stronger convective rolls in the PBL that help to trigger convection along the dry line.

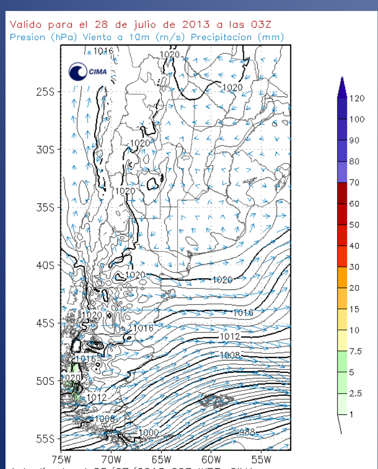
Trier, Chen, and Manning, Mon. Wea. Rev., 2004

Summary

Global model



Regional (no convection allowing) model



NOT FOR NOWCASTING

Can provide:

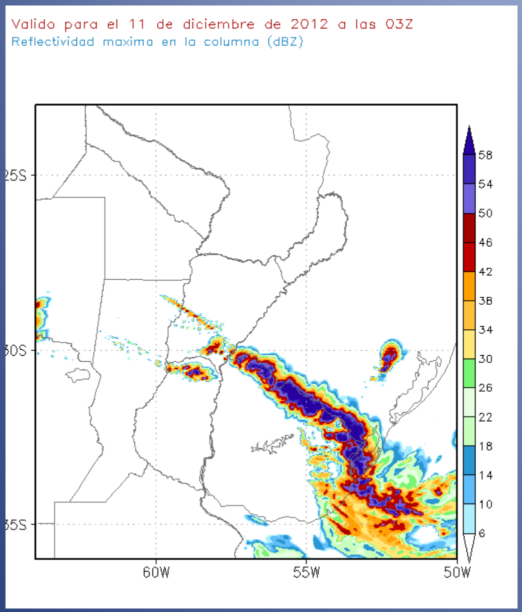
- **Forecast for large scale conditions**
- **Anticipation of conditions that could lead to dangerous weather phenomena**
- **Large scale conditions that help to anticipate possible convective modes (i.e. supercells)**

Can't provide:

- **Exact position / timing of extreme weather events**
- **Explicit indication of phenomena intensity (i.e. convective updraft intensities)**
- **Explicit information about the mesoscale organization of convection**

Cold start:

Convection allowing models



This information can be obtained 24-36 hours in advance due to predictability constrains in this scale and computational requirements.

NOT FOR NOWCASTING

Can provide:

•Information about possible convective modes

•Approximated location of <u>areas</u> favorable for convection and approximate initiation time

•Details about possible mesoscale organization of the convection.

•Details about other mesoscale phenomena as sea and mountain breezes.

•Possible improve in QPF.

Can't provide:

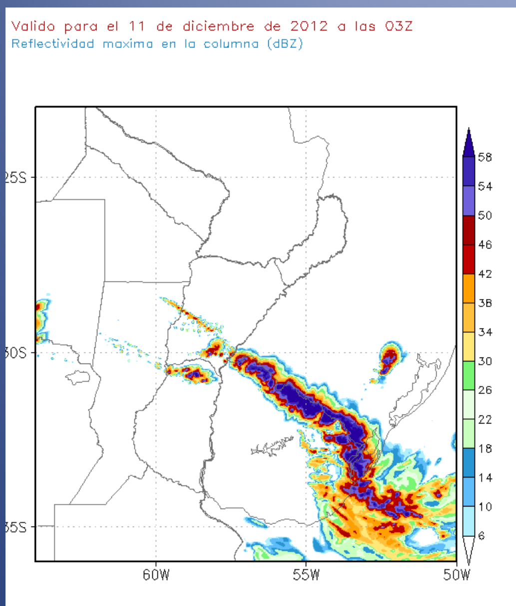
•Accurate information in the first 6-9 hours due to model spin-up

•Exact location or timing of individual cells or MCSs

•Realistic storm scale features (i.e. updraft intensity, size, etc)

Mesoscale initialization:

Convection allowing models



Can provide:

- **Less spin up issues**
- **Information about the convective modes**
- **Approximated location of convection (limited by predictability issues)**
- **Details about mesoscale organization of the convection**

Can't provide:

- **Realistic storm scale features (i.e. updraft intensity, size, etc)**

Location and timing can be obtained with 1-3 hours in advance due to predictability constrains at this scale. Skill even more limited by model errors.

NWP BASED NOWCASTING TOOL

Post proccessing

Some high resolution diagnostics for severe weather applications

Convection allowing models are able to generate some features that resemble circulations associated with observed convective storms as for example mesocyclones that characterize supercells.

Although cold start convective allowing models won’t provide a detailed location, timing and strength of these features model outputs can be used as a guidance for evaluation of possible occurrence.

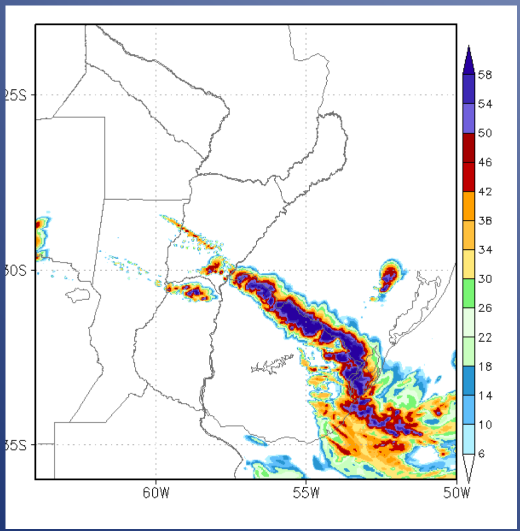
Simulated radar reflectivity:

Derived from different condensates produced by microphysics schemes.

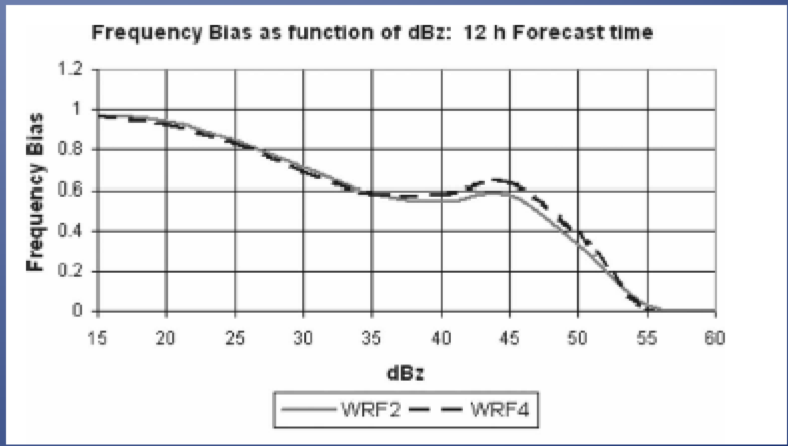
Provides guidance about mesoscale structure (i.e. MCS organization) and in some cases supercell features (V-notch), smaller scale features (depending on model resolution).

Caution: Simulated radar reflectivity is not mathematically equivalent to observed reflectivity (microphysics schemes limitations, sampling strategies, unresolved scales, etc)

Simulated radar reflectivity of convective allowing models is systematically lower than observed reflectivity, particularly at higher thresholds.



Example from Chuva
Convective allowing models inter comparison



Kain et al. 2008

Updraft helicity:

Vertically integrates the product of updraft intensity and vorticity.

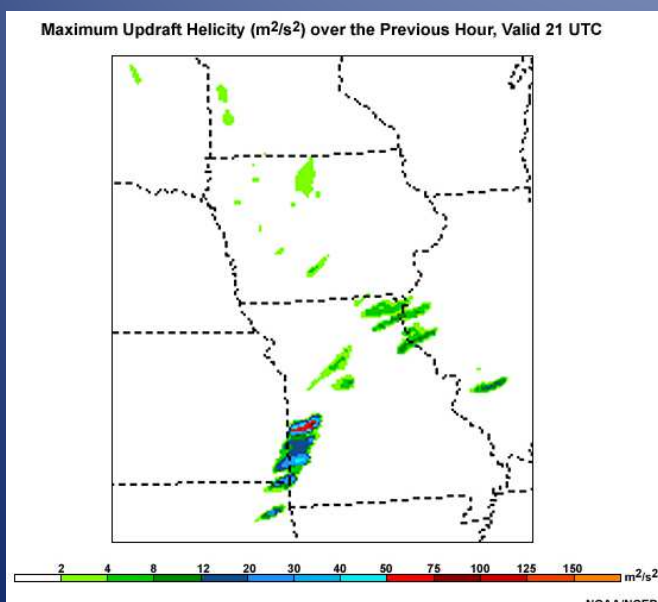
$$\mathrm{UH} = \int_{z_0}^{z_t} w\zeta \, dz,$$

Provides guidance about simulated rotating updrafts.

Caution:

Thresholds are determined empirically to match the simulated frequency of mesocyclones with the observed frequency. The threshold is resolution dependent!

Different sign combinations might lead to similar results (i.e. rotating downdrafts) or opposite results (anticiclonically rotating updrafts).



The Comet program

Kain et al. 2008

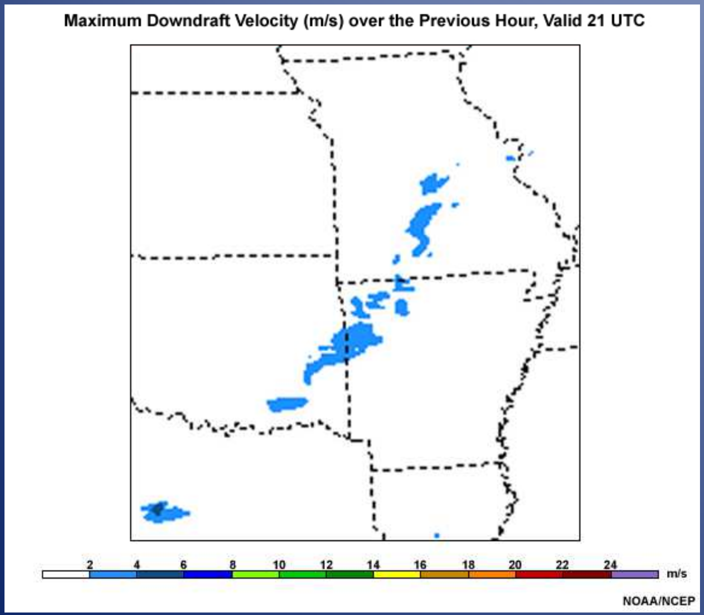
Maximum downdraft:

This is a proxy of downdraft intensity and can be useful to anticipate possible strong winds associated with strong downdrafts.

Cautions:

Downdraft intensity usually weak in convective allowing models.

Warning thresholds will depend on model resolution and the selected vertical level.



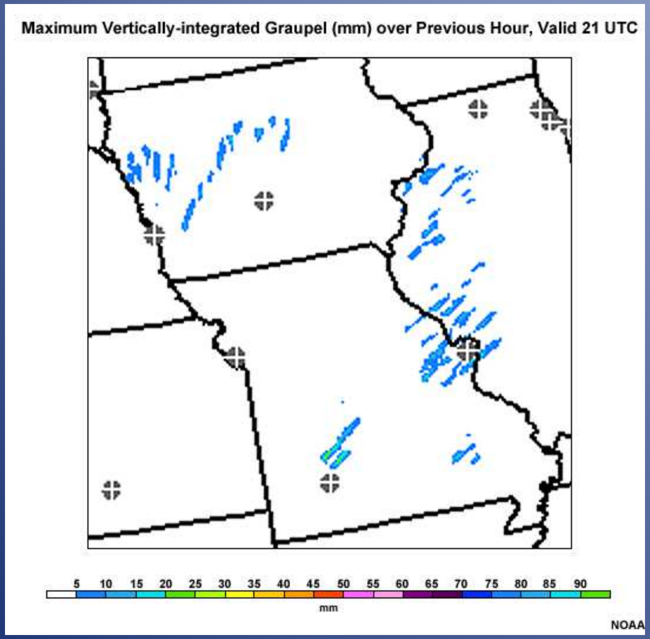
The Comet program

Maximum vertically integrated graupel:

This quantity may be useful for anticipating hail hazard and updraft strength.

Cautions:

Thresholds will depend upon model resolution and microphysics scheme.



The Comet program.

Conclusions:

High resolution (convection allowing models) are useful tools for forecasting areas likely to be affected by extreme weather events.

They provide information about the mesoscale structure of convection.

They may improve QPF due to a better representation of mesoscale processes.

They can be used as part of a nowcasting system if they are initialized with high resolution data.

They suffer from very limited predictability, even when initialized with high resolution data.

They suffer from model errors associated with unresolved (or poorly understood) smaller scale processes.

We suffer as well…