Implementation and evaluation of a regional data assimilation system based on WRF-LETKF

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Outline

- Motivation
- Idealized experiments over SA
- Real observation experiments over Japan and SA
- Radar data assimilation with WRF-LETKF

Motivation:

Regional data assimilation systems are important

- Incorporate local observations
- Provide improved initial conditions for regional forecasts
- Generate rapid update cycles
- Can work on local model development and tuning
- Suitable for operations at small meteorological services

Goal:

Improve our understanding of regional data assimilation.

•Contribute to the development of the WRF-LETKF system (Miyoshi and Kunii 2012)

•Analyze the impact of errors in the boundary conditions and model errors.

•Cuantify the impact of using different strategies to deal with these error sources in realistic experiments.

•Analize the performance of LETKF-WRF for radar data assimilation

WRF-LETKF Idealized Experiments over South America

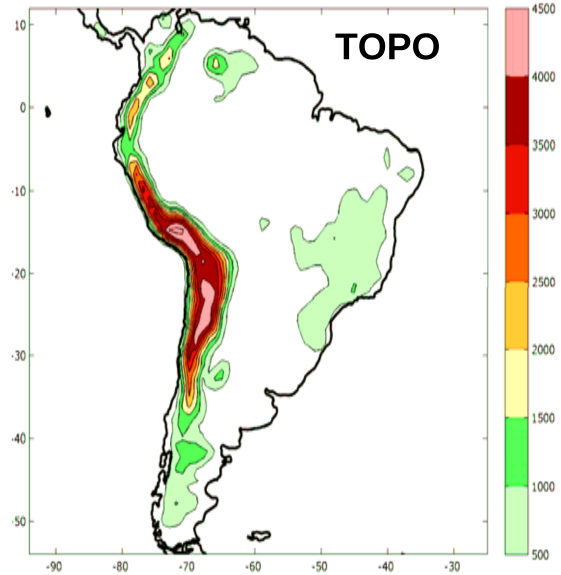
Configuration

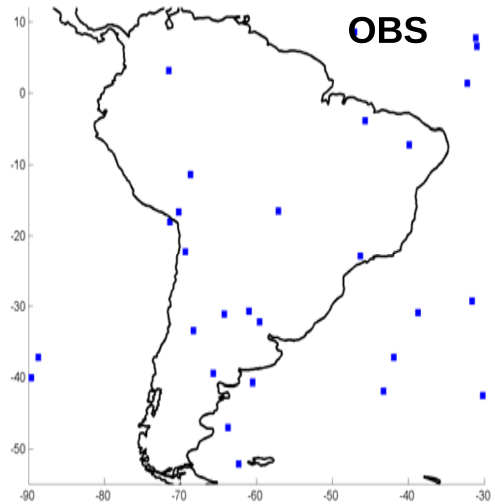
DX –> 100 km
Domain -> South America
IC and BC -> FNL
Experiment dates -> 01/06/2010 – 29/09/2010
Observations: Randomly located vertical profiles of T, Q, U and V as well as PS every 6 hours.

LETKF
LETKF-WRF system (Miyoshi and Kunii 2011)
Ensemble size -> 40 members
Horizontal loc. -> 400km
Vertical loc. -> 0.4 ln(P)
Inflation -> Adaptive multiplicative inflation (Miyoshi 2011)

Osse experiment

1 nature run using
Observations derived from the nature run using 1 m/s, 1K, 1g/kg and 1 hPa uncorrelated Gaussian errors.



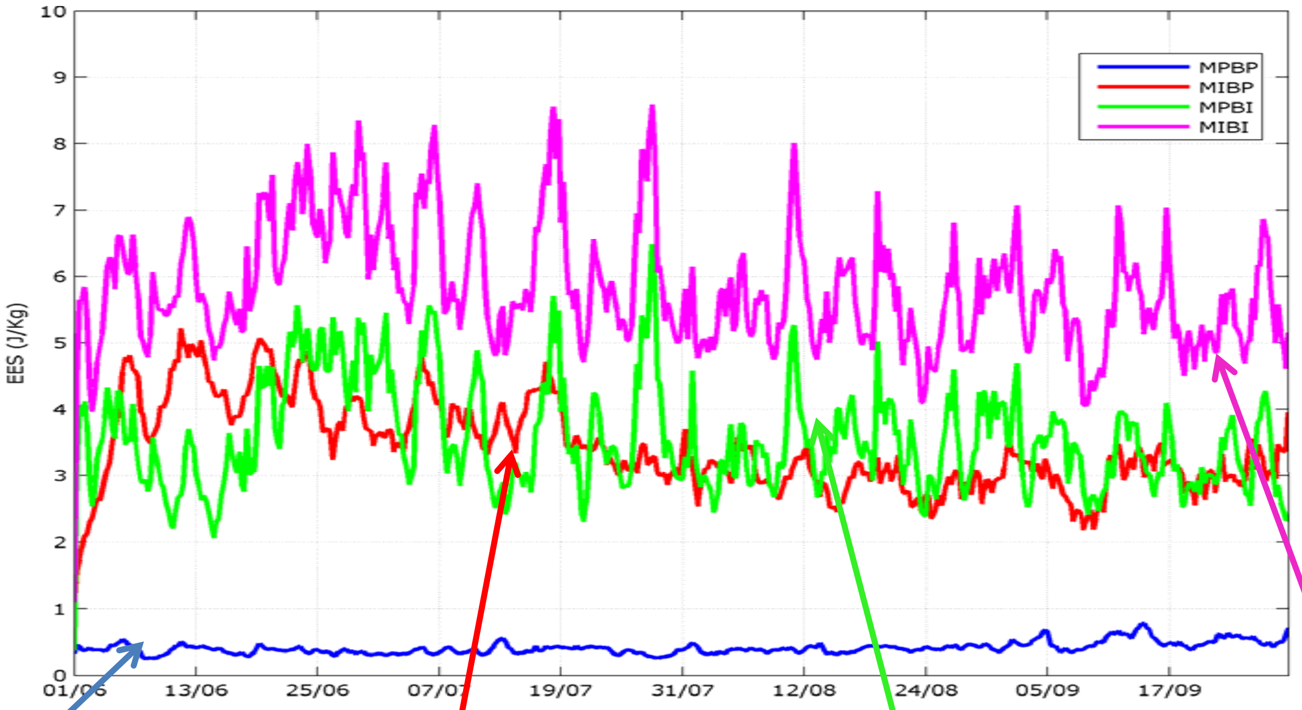


(Saucedo 2016)

WRF-LETKF Idealized Experiments over South America

Different error scenarios for the regional data assimilation system

$$EES_{i,j,k,t} = \frac{1}{2}\rho_{i,j,k,t}\left(U'^{\,2}_{i,j,k,t} + V'^{\,2}_{i,j,k,t} + \left(\frac{C_{pd}}{T_r}\right) * T'^{\,2}_{i,j,k,t} + (R_d * \frac{T_r}{P^2_{ref}}) * P'^{\,2}_{i,j,t}\right)$$



Perfect model and perfect boundaries

Imperfect model and perfect boundaries

Perfect model and imperfect boundaries

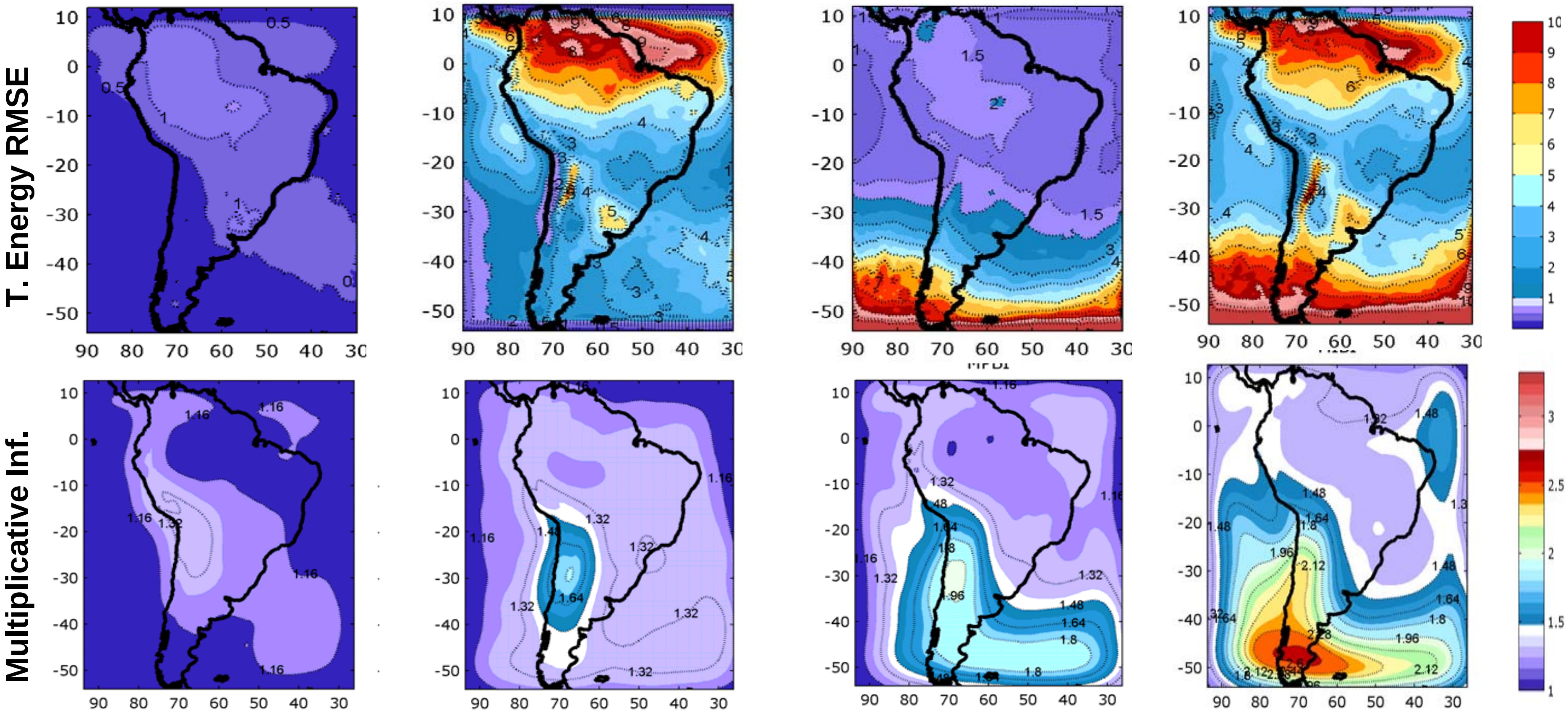
Imperfect model and imperfect boundaries

Model errors are generated by changing the cumulus, pbl and microphysics parametrizations in the model.
Boundary conditions errors are generated by using CFSR reanalysis as boundary conditions (instead of FNL)

WRF-LETKF Idealized Experiments over South America

Error spatial distribution and its associated estimated inflation

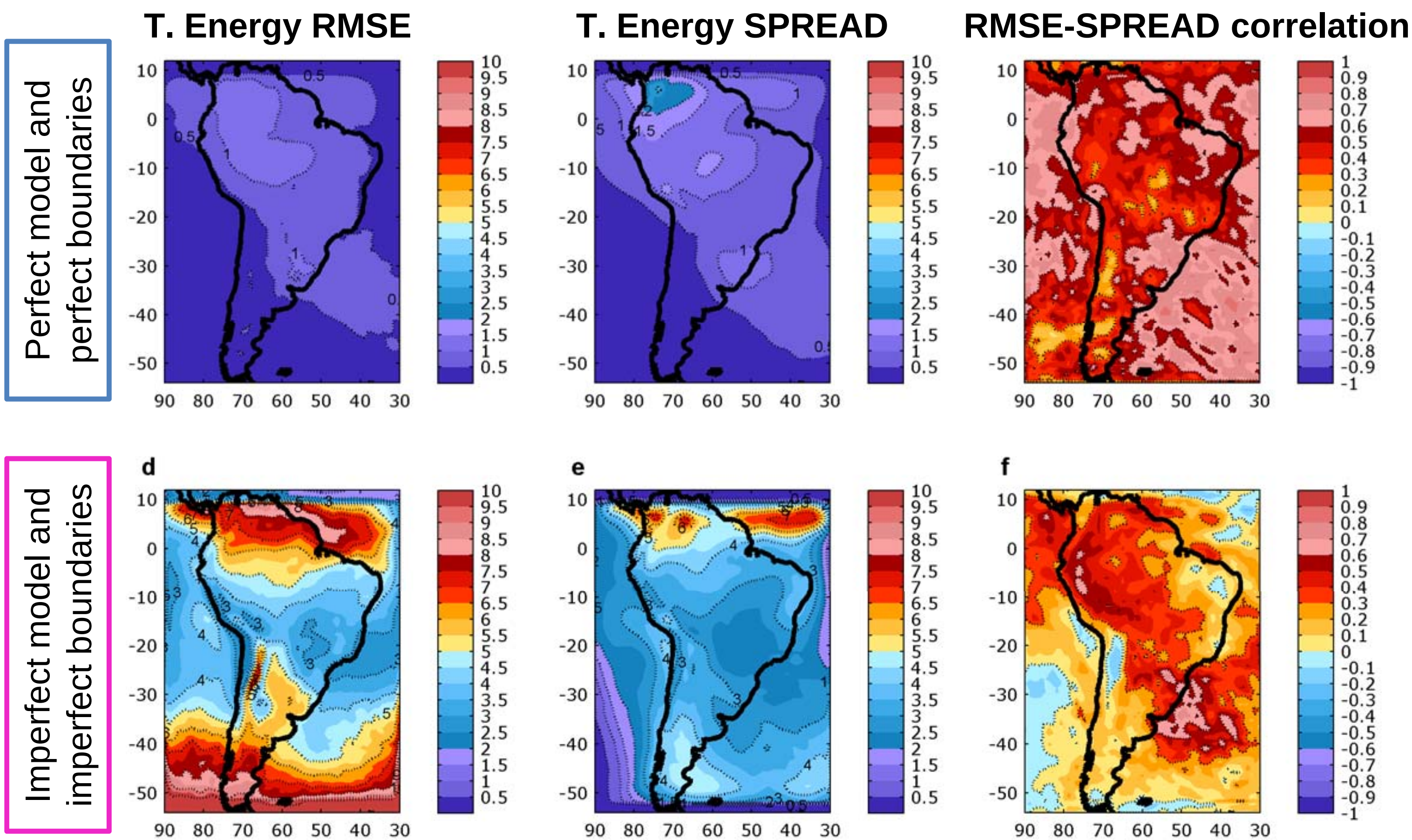
Perfect model and perfect boundaries	Imperfect model and perfect boundaries	Perfect model and imperfect boundaries	Imperfect model and imperfect boundaries



•Adaptive inflation adjusts to different error scenarios in the idealized experiments
•Different error scenarios impact different areas of the domain. Boundary conditions more critical at higher latitudes and model errors important everywhere but particularly over tropical areas.

WRF-LETKF Idealized Experiments over South America

Is adaptive multiplicative inflation enough?

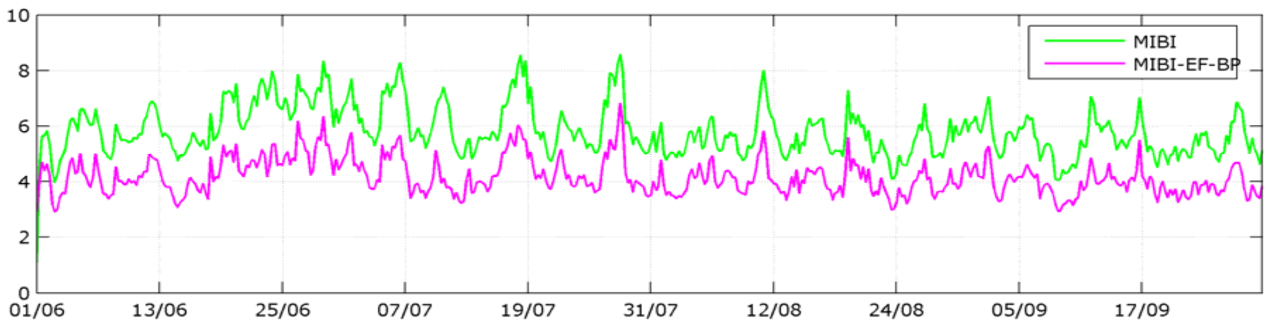


•When boundary conditions errors and model errors are present the ensemble is underdispersive and the estimated multiplicative inflation cannot take into account all the sources of uncertainty.
•RMSE-SPREAD correlation is affected by the presence of model and boundary conditions errors.

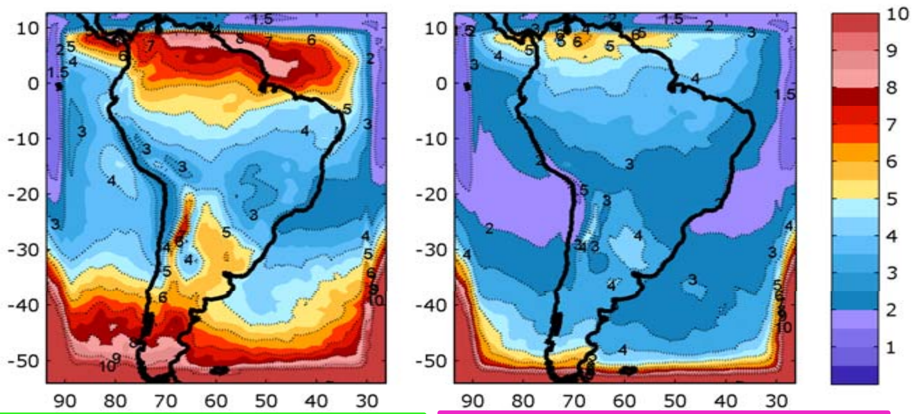
WRF-LETKF Idealized Experiments over South America

Including boundary perturbations and multi-physics ensemble

T. Energy RMSE areal average



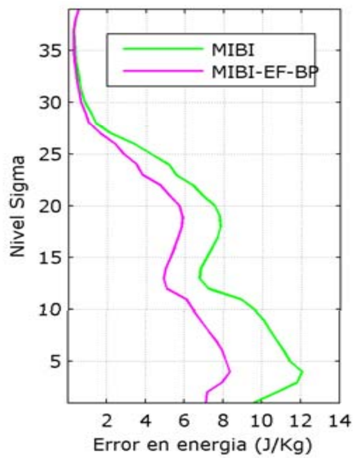
T. Energy RMSE **T. Energy RMSE**



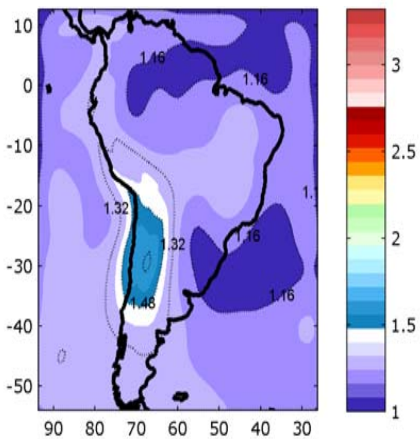
Without boundary and physics perturbations

With boundary and physics perturbations

RMSE vert. profile



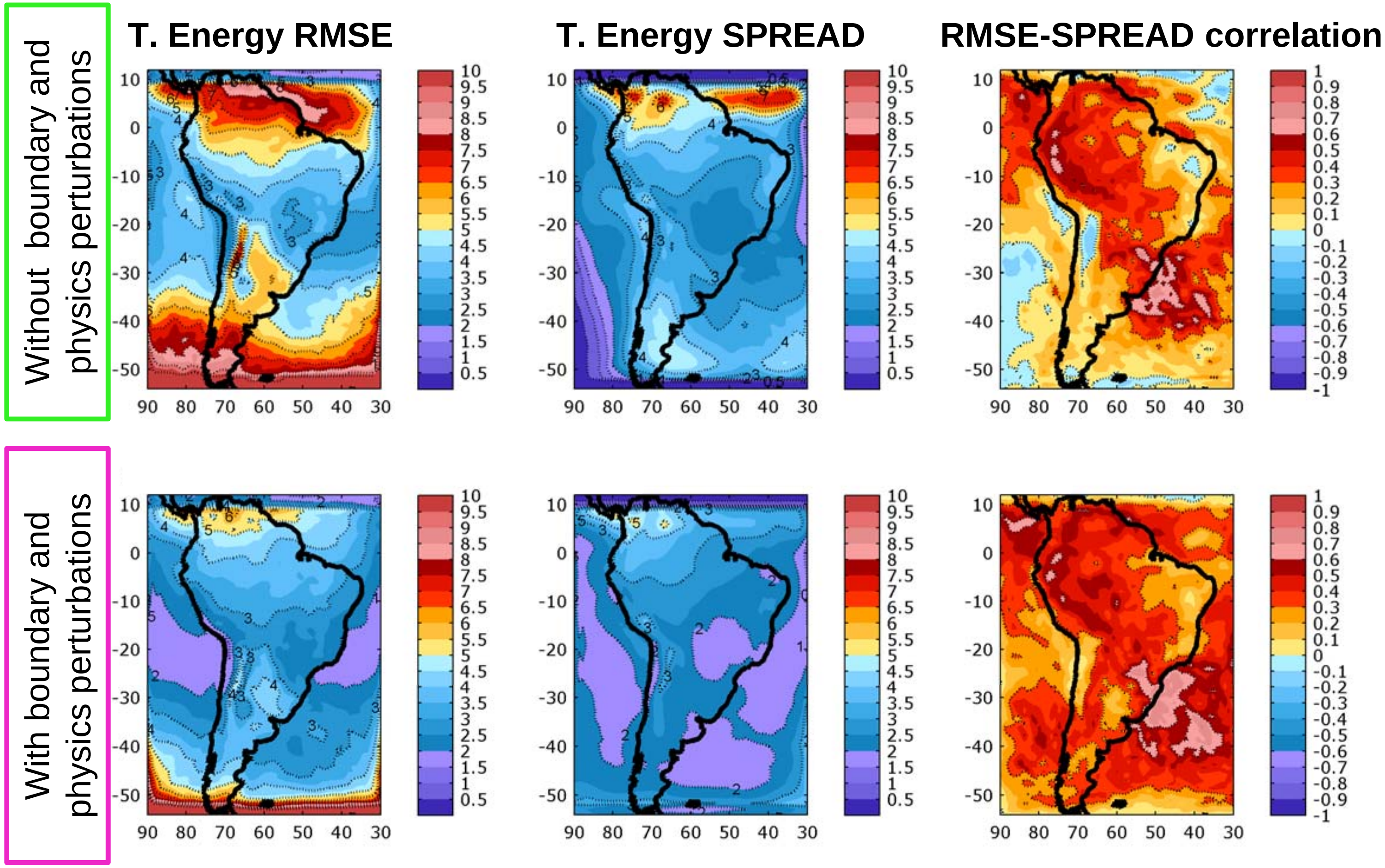
Multiplicative Inf.



- Boundary and physics perturbations produce a large impact, not only at the boundaries but also inside the domain.
- Both tropical regions and mid-latitudes are improved by introducing these two approaches.

WRF-LETKF Idealized Experiments over South America

Including boundary perturbations and multi-physics ensemble

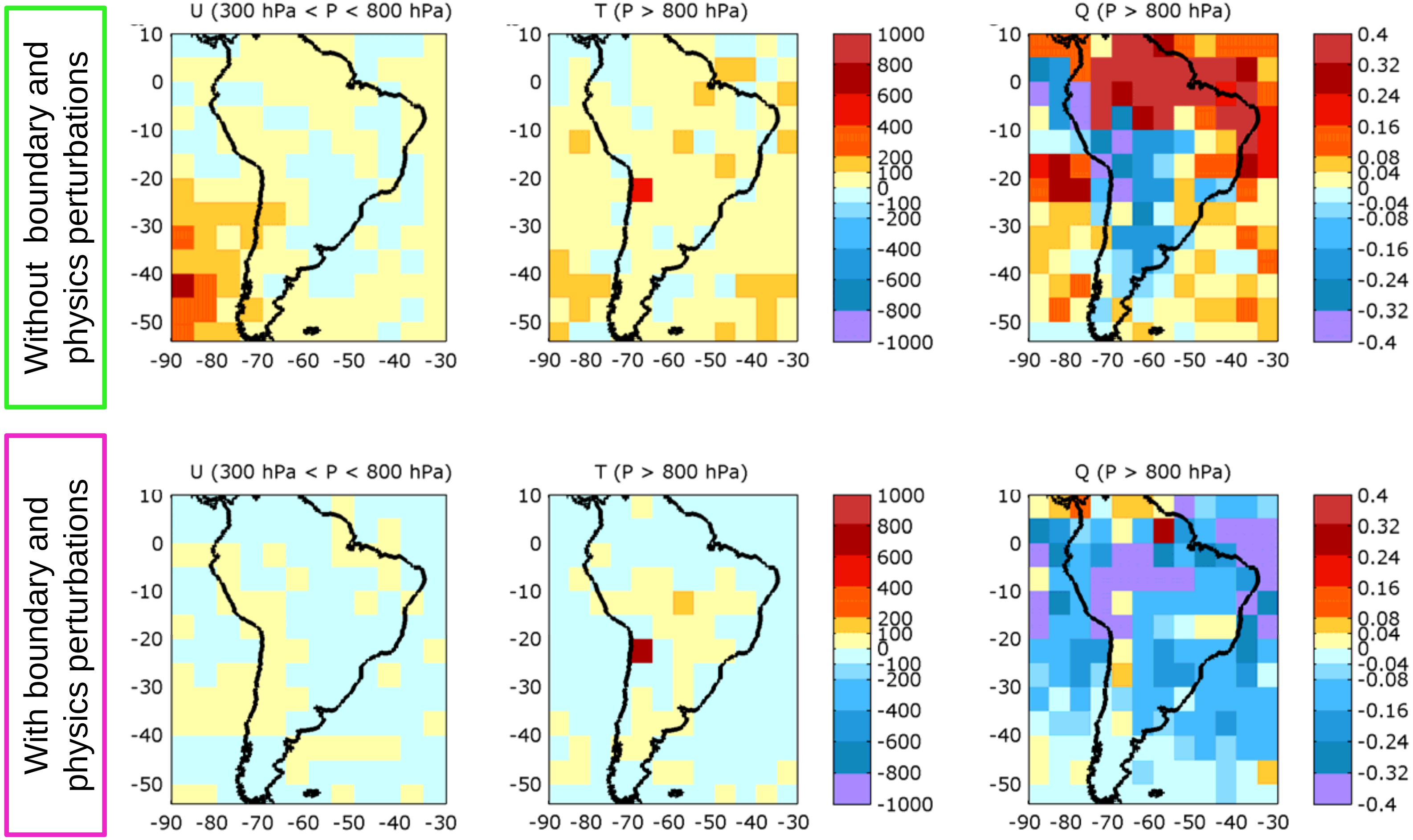


- Lower error and spread within the domain. When multi-phisycs and boundary perturbations are usec
- Better RMSE-SPREAD correlation, even closer to the inflow boundaries (i.e. western boundary).

WRF-LETKF Idealized Experiments over South America

Consistency of the error covariance matrix

$$\frac{100 * \left(\sum_{i=1}^{T} \frac{n(i) * tr(H(x_i^a) - H(x_i^b) * (y_i^o - H(x_i^b))^T)}{N} - \sum_{i=1}^{T} \frac{n(i) * tr(HP_i^b H^T)}{N}\right)}{\sum_{i=1}^{T} \frac{n(i) * tr(HP_i^b H^T)}{N}}$$



- Model physics and boundary conditions produce more consistent estimation of the error covariance matrix.
- Moisture shows systematic over-dispersion.

WRF-LETKF Real observation experiments

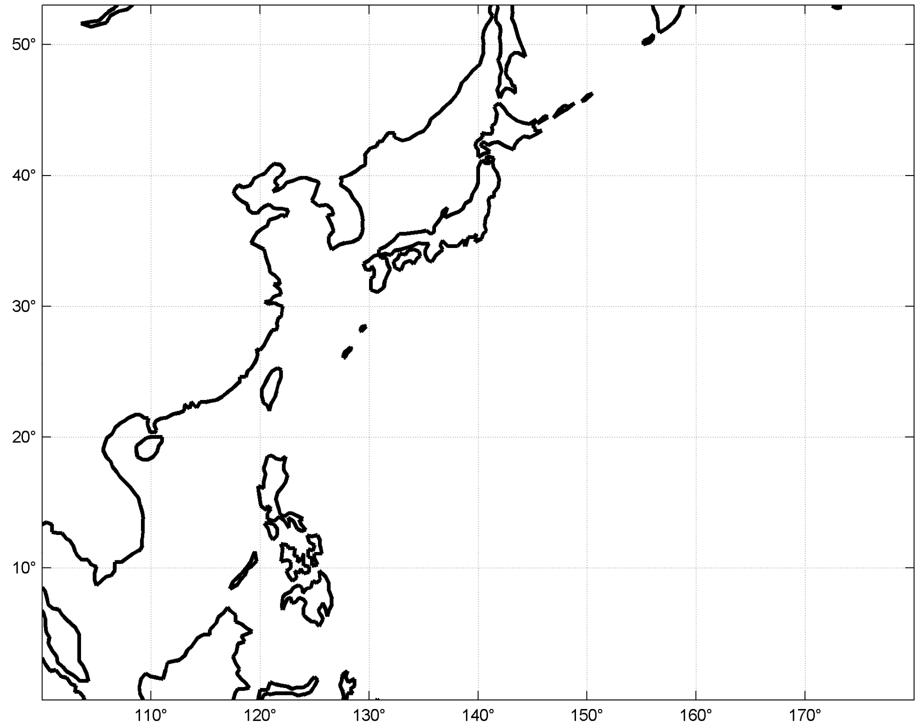
Settings of the real observations experiments

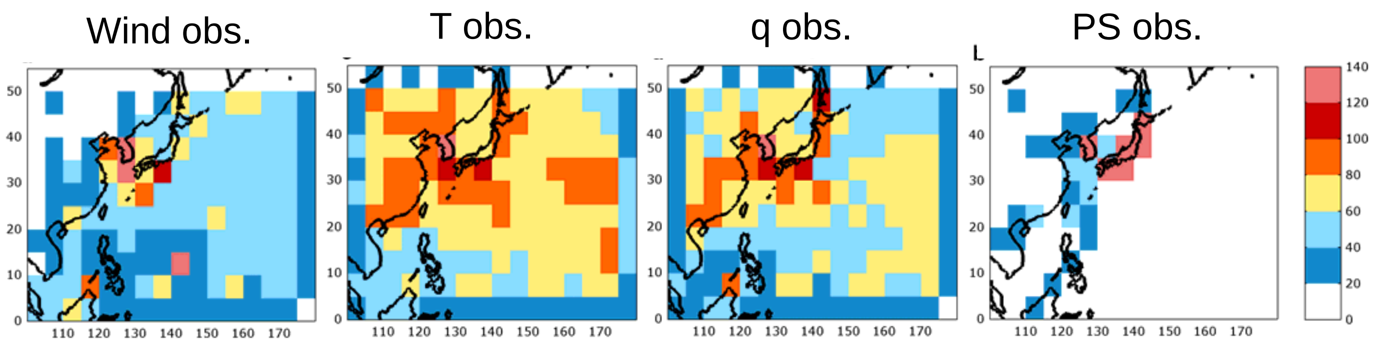
Configuration (Kunii and Miyoshi 2011, Miyoshi and Kunii 2012)

DX –> 60 km / 20 km
Domain -> Eastern Pacific
IC and BC -> FNL
Experiment dates -> 07/08/2008-30/09/2008
Observations: Prep-bufr + AIRS T and q

LETKF

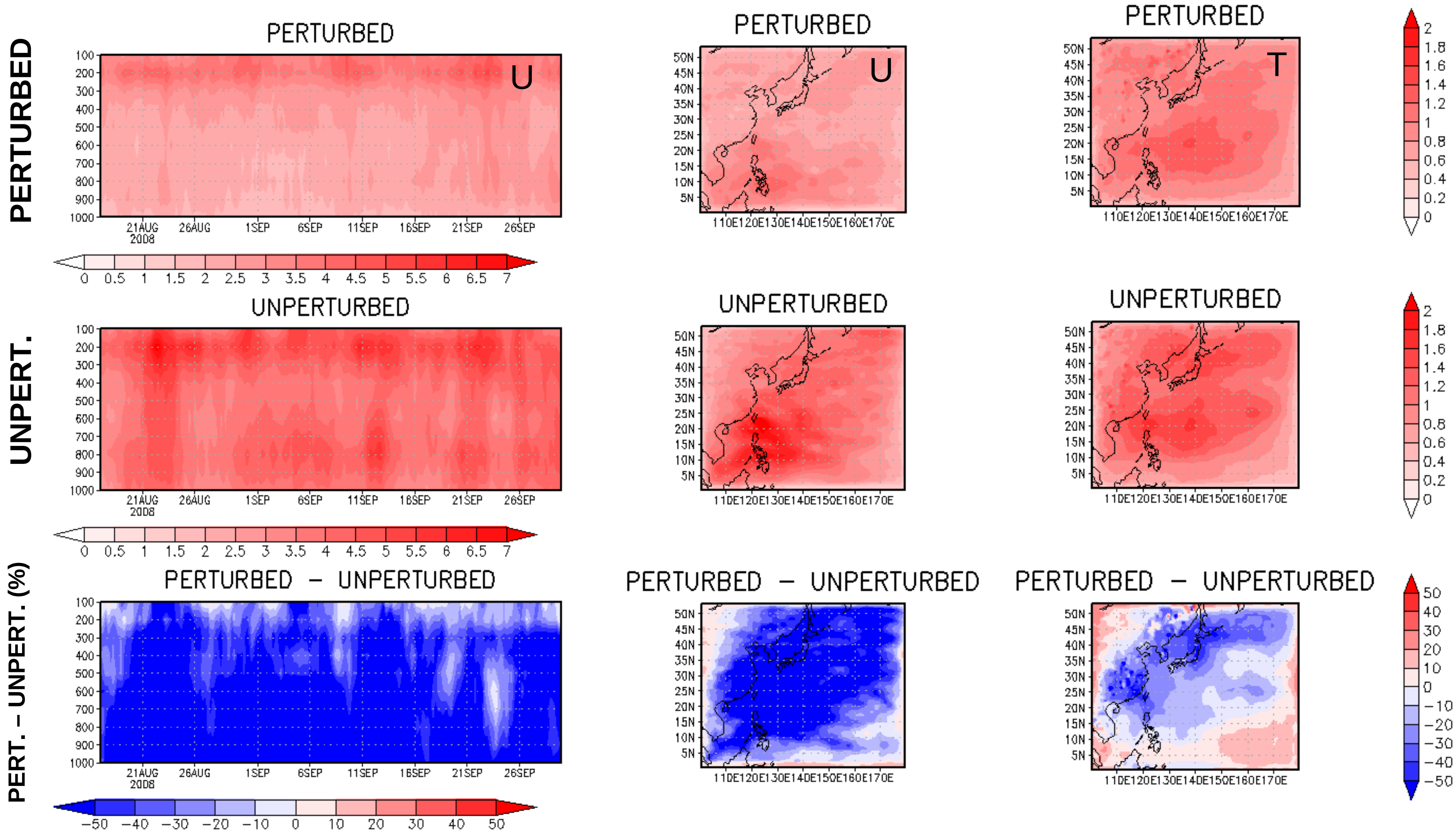
LETKF-WRF system (Miyoshi and Kunii 2011)
Ensemble size -> 40 members (control experiment)
Horizontal loc. -> Resolution dependent
Vertical loc. -> 0.4 ln(P)
Inflation -> Estimated or RTPS.





WRF-LETKF Real observation experiments

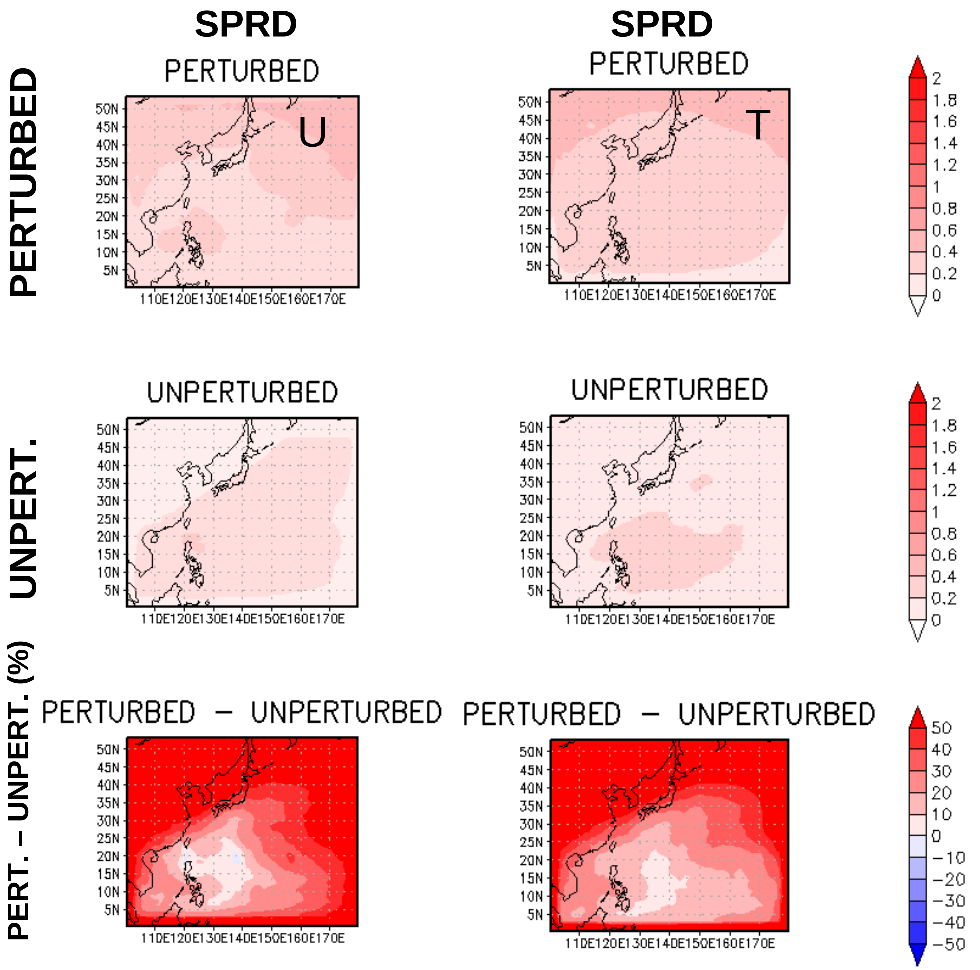
Sensitivity to the inclusion of boundary perturbations



Perturbations at the boundary produce a positive impact upon the analysis. T is more improved at mid-latitudes and U is improved at mid and low latitudes. U shows big improvements at the domain center.

WRF-LETKF Real observation experiments

Sensitivity to the inclusion of boundary perturbations

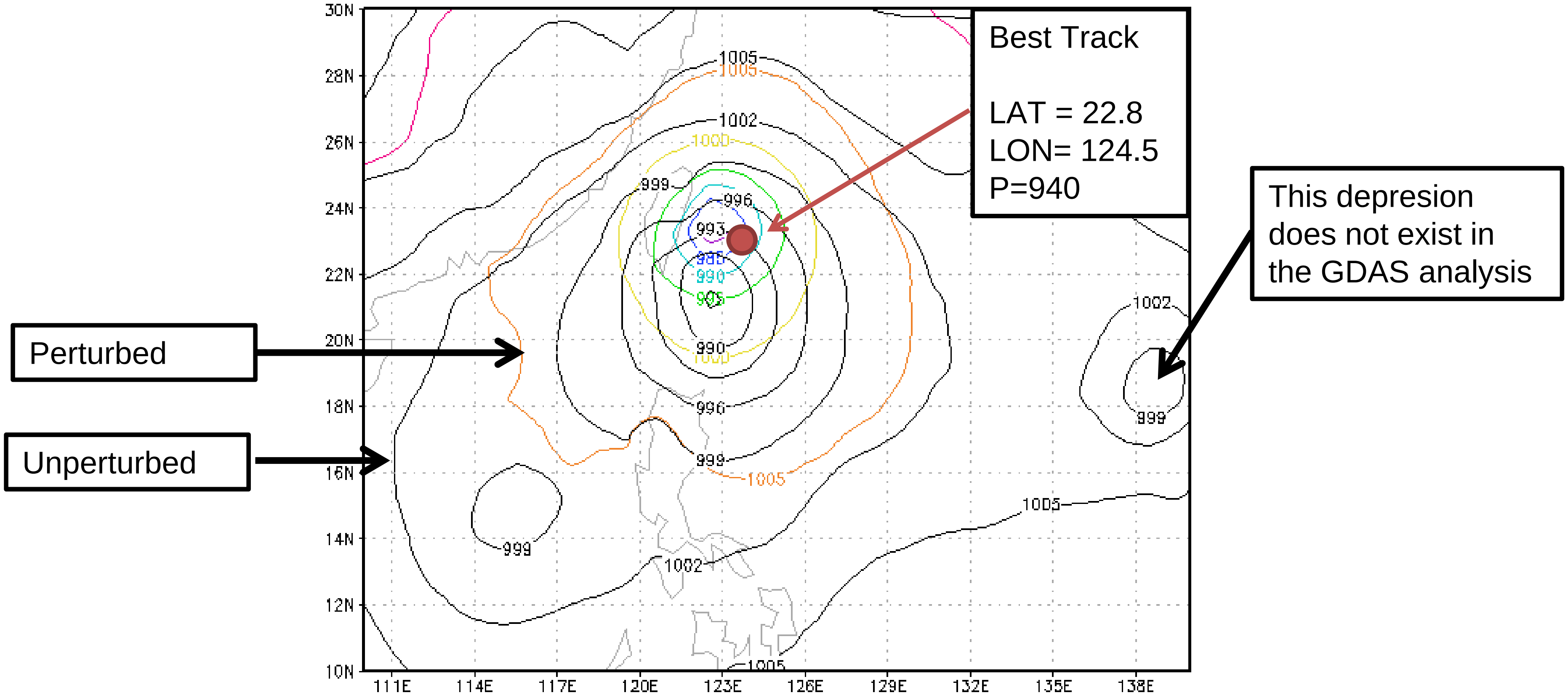


Including boundary perturbations produce a significant increase in the ensemble spread, particularly at mid-latitudes.
The spread inside the domain in the tropics is not increased as much, however we can still found improvements in the analysis in those regions.

WRF-LETKF Real observation experiments

Sensitivity to the inclusion of boundary perturbations

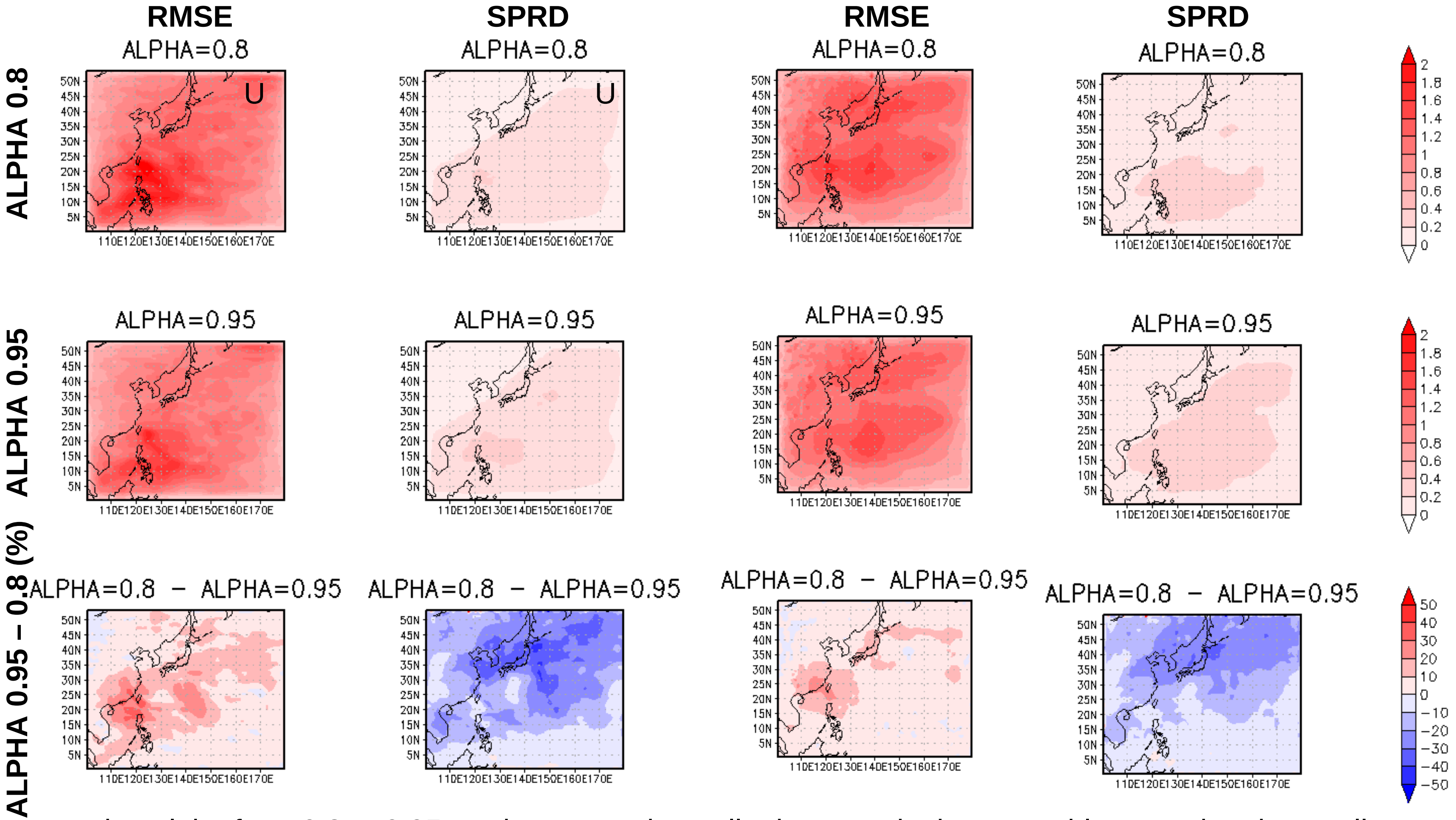
MSLP 18Z 12 SEPT 2008 SINLAKU



•This particular date was selected because was one of the dates in which the positive impact of perturbed boundary conditions was observed.
•The system with perturbed boundary conditions produce a more accurate analysis of the location and intensity of tropical storm Sinlaku.

WRF-LETKF Real observation experiments

Can we get a similar improvement by tuning RTPS?

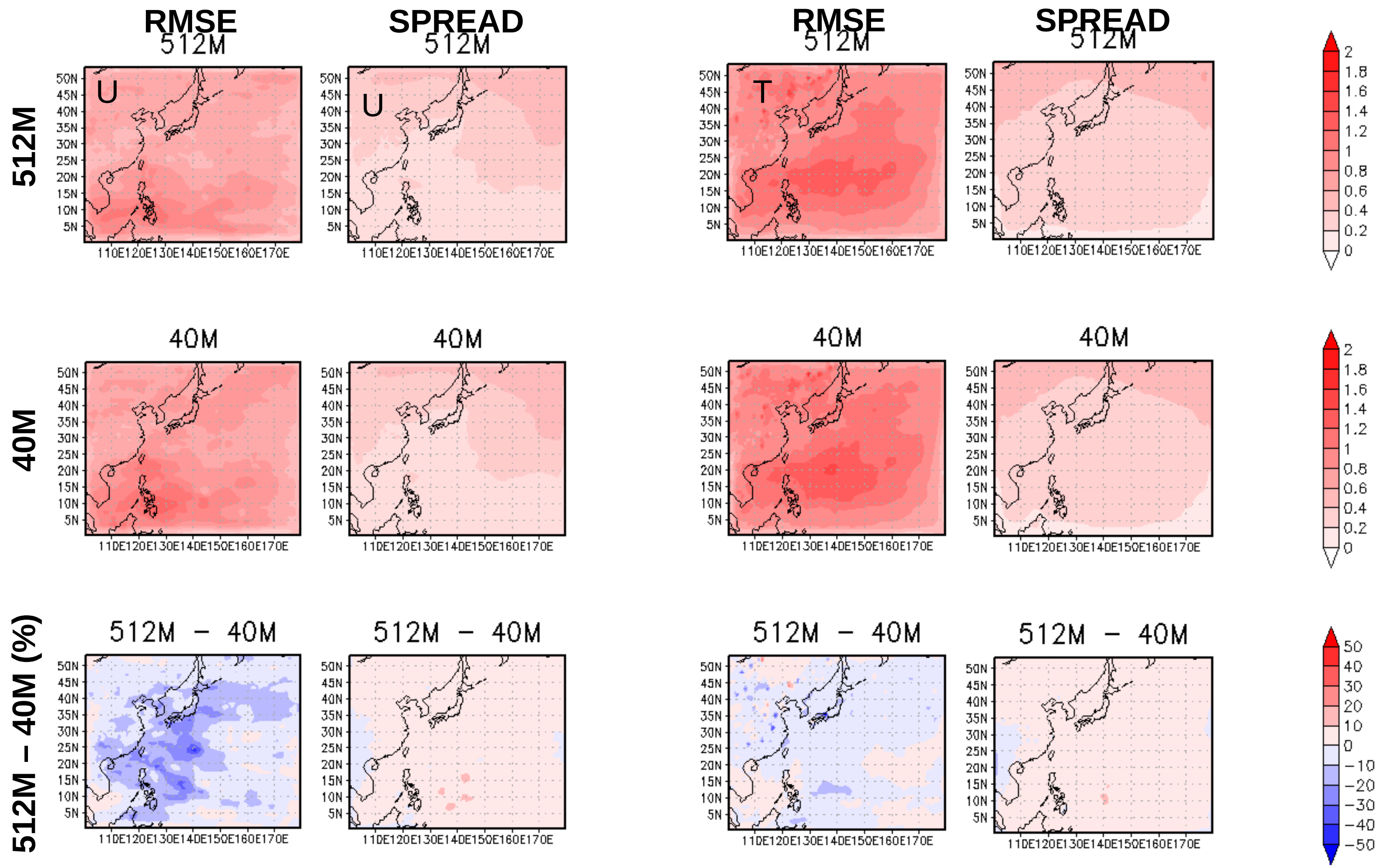


Increasing alpha from 0.8 to 0.95 produce a much smaller increase in the ensemble spread and a smaller impact upon the RMSE of the analysis.

In all cases the ensemble is under dispersive.

WRF-LETKF Real observation experiments

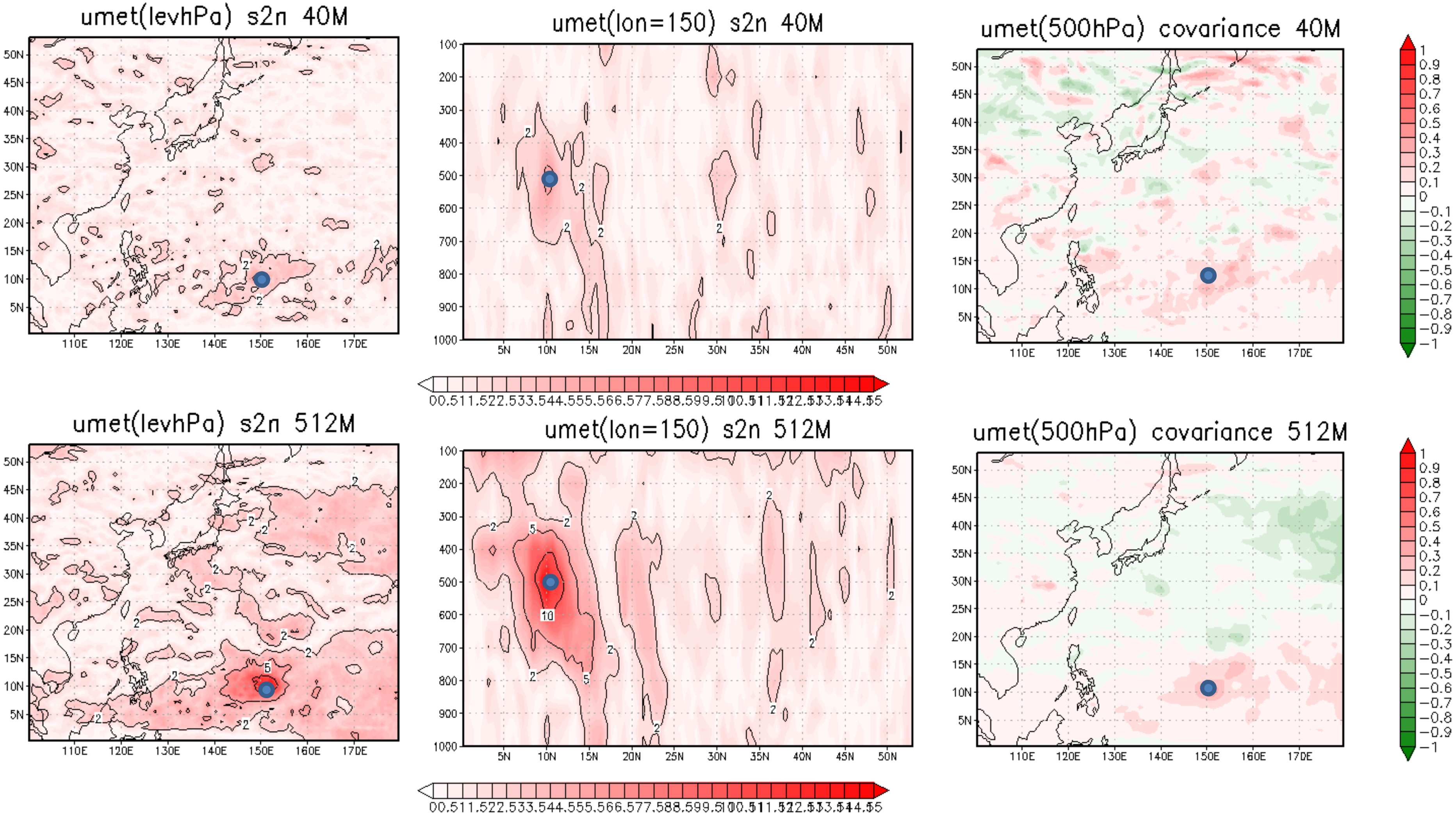
Sensitivity to the ensemble size



•Larger ensemble size produce an impact upon U and V but not so large on temperature.
•The ensemble spread also increases but in less than 10%.
•Larger improvements in wind are observed at the tropics and subtropics.

WRF-LETKF Real observation experiments

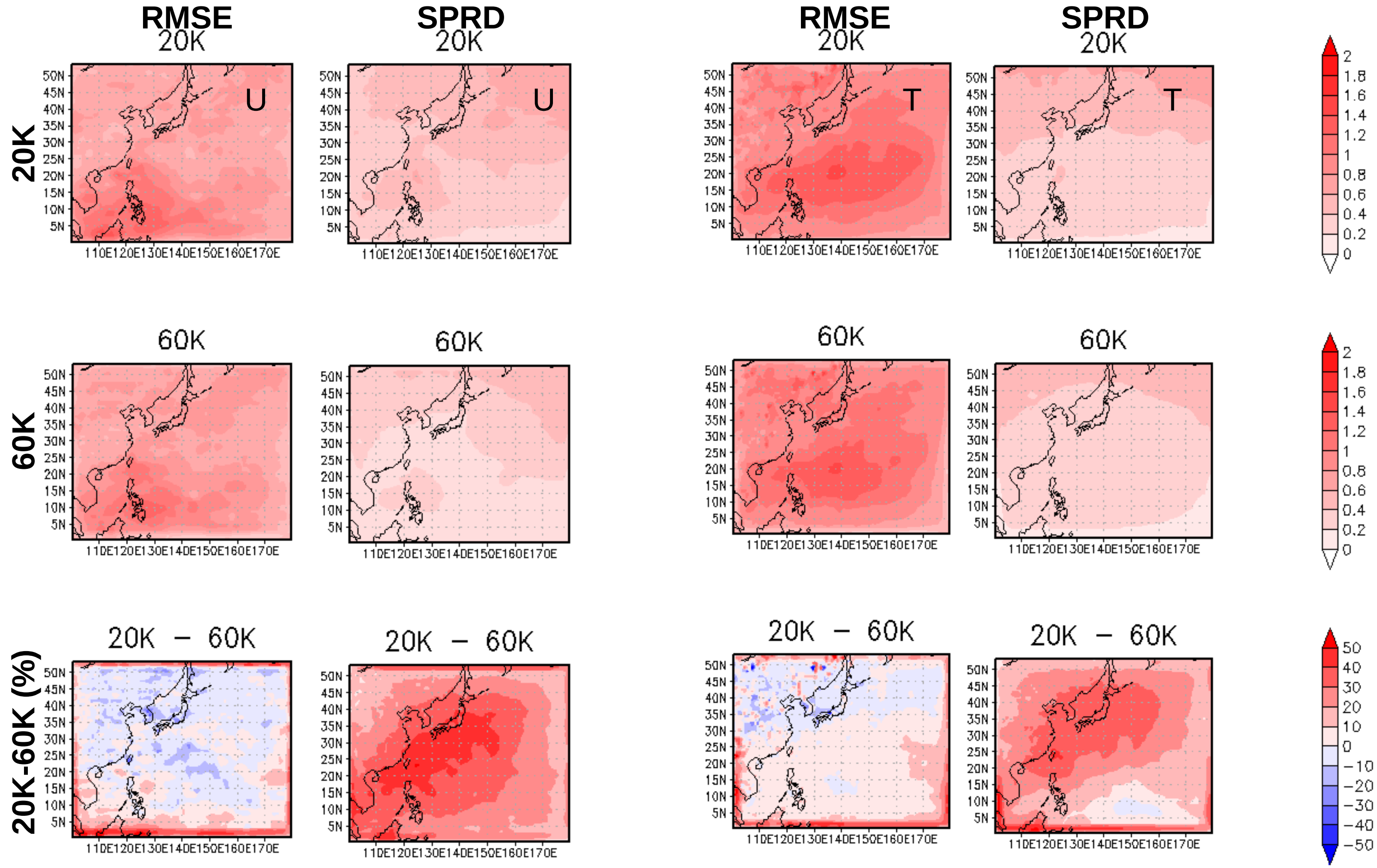
Impact of ensemble size upon the estimation of the covariance matrix



The signal to noise analysis reveals some distant covariances that can be detected with the 512 members ensemble. This covariance might be produced by the climatological data used to perturb the boundary conditions and may be related to known modes of variability.

WRF-LETKF Real observation experiments

Sensitivity to the horizontal resolution from 60k to 20k (at larger scales)



•Comparing with GDAS at low resolution we can not conclude if the 20K experiment is better or not.

•Ensemble spread is significantly affected by the horizontal resolution generating larger spread inside the model deomain.

WRF-LETKF Real observation experiments in South America

Settings of the real observations experiments

Configuration

DX –> 40 km
Domain -> South America
IC and BC -> FNL
Experiment dates -> 01/11/2012-31/12/2012
Observations: Prep-bufr

LETKF
LETKF-WRF system (Miyoshi and Kunii 2011)
Ensemble size -> 40 members
Horizontal loc. -> 400 km
Vertical loc. -> 0.4 ln(p)
Inflation -> Estimated
Ensemble type -> Single model and multi-physics

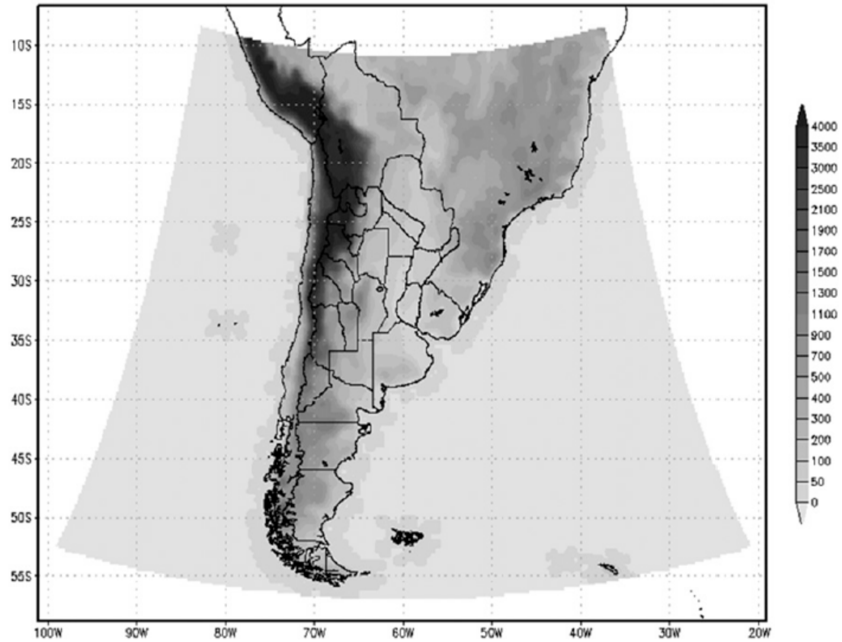
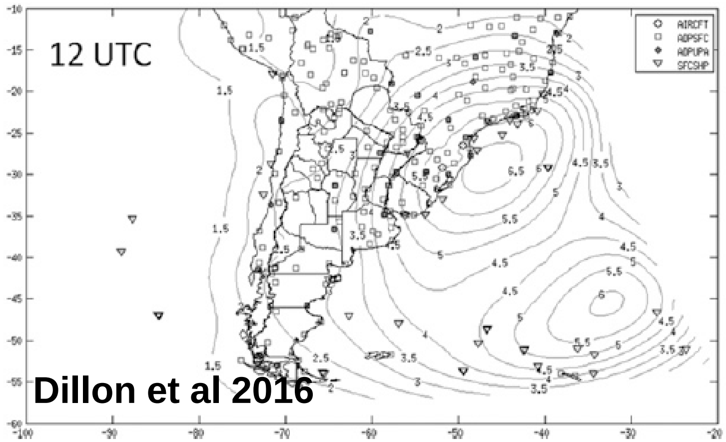
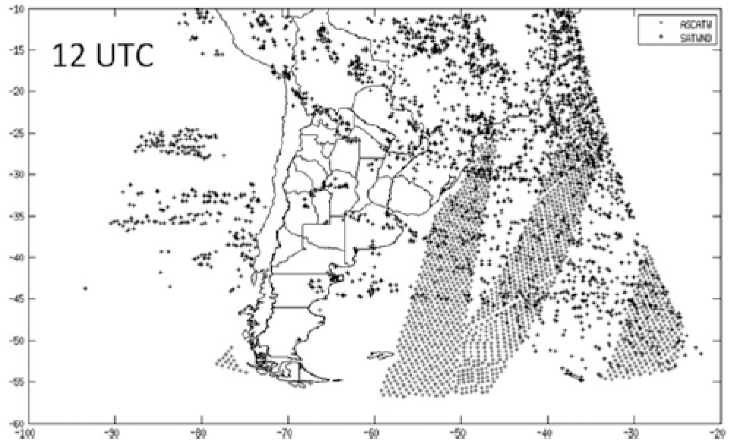


FIG. 1. Model domain and topography (m MSL; shaded).

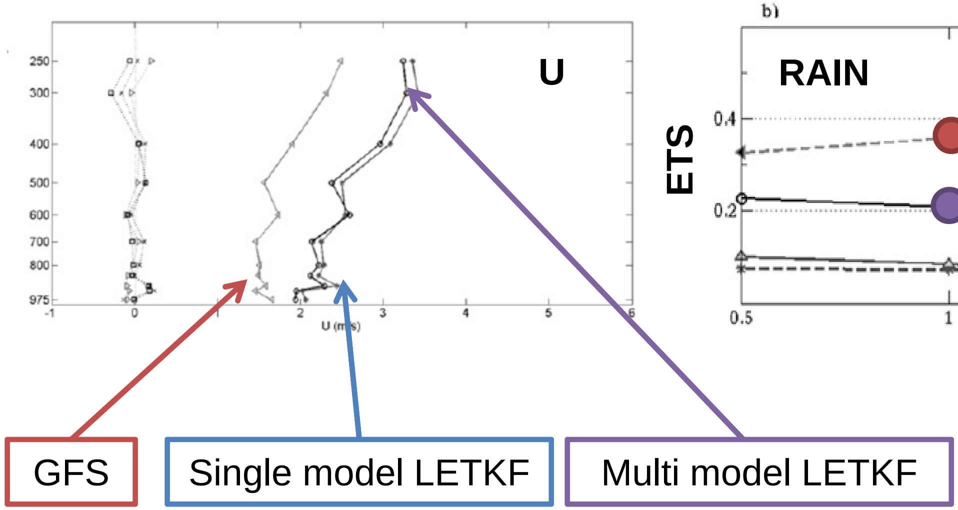




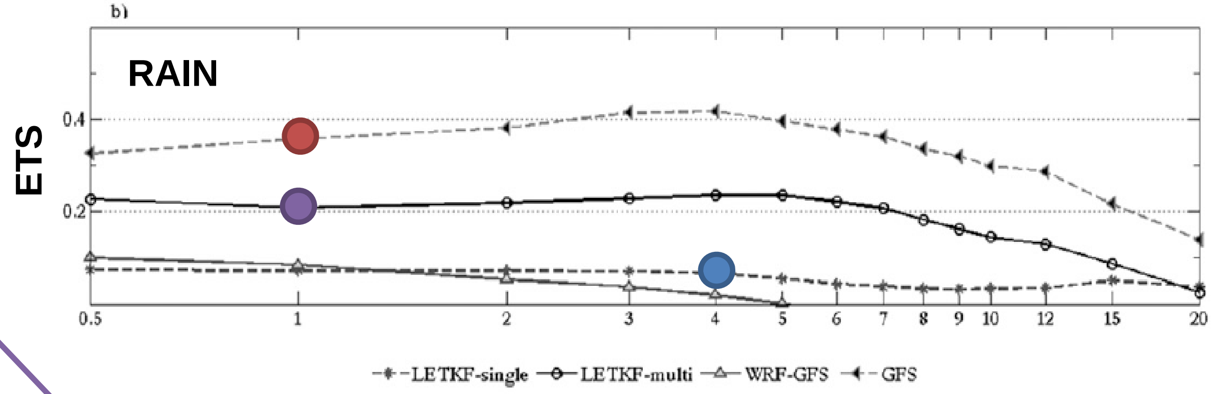
WRF-LETKF Real observation experiments in South America

Settings of the real observations experiments

6-hr Fcst RMSE & BIAS



24-hr Precipitation forecast for a convective rain event



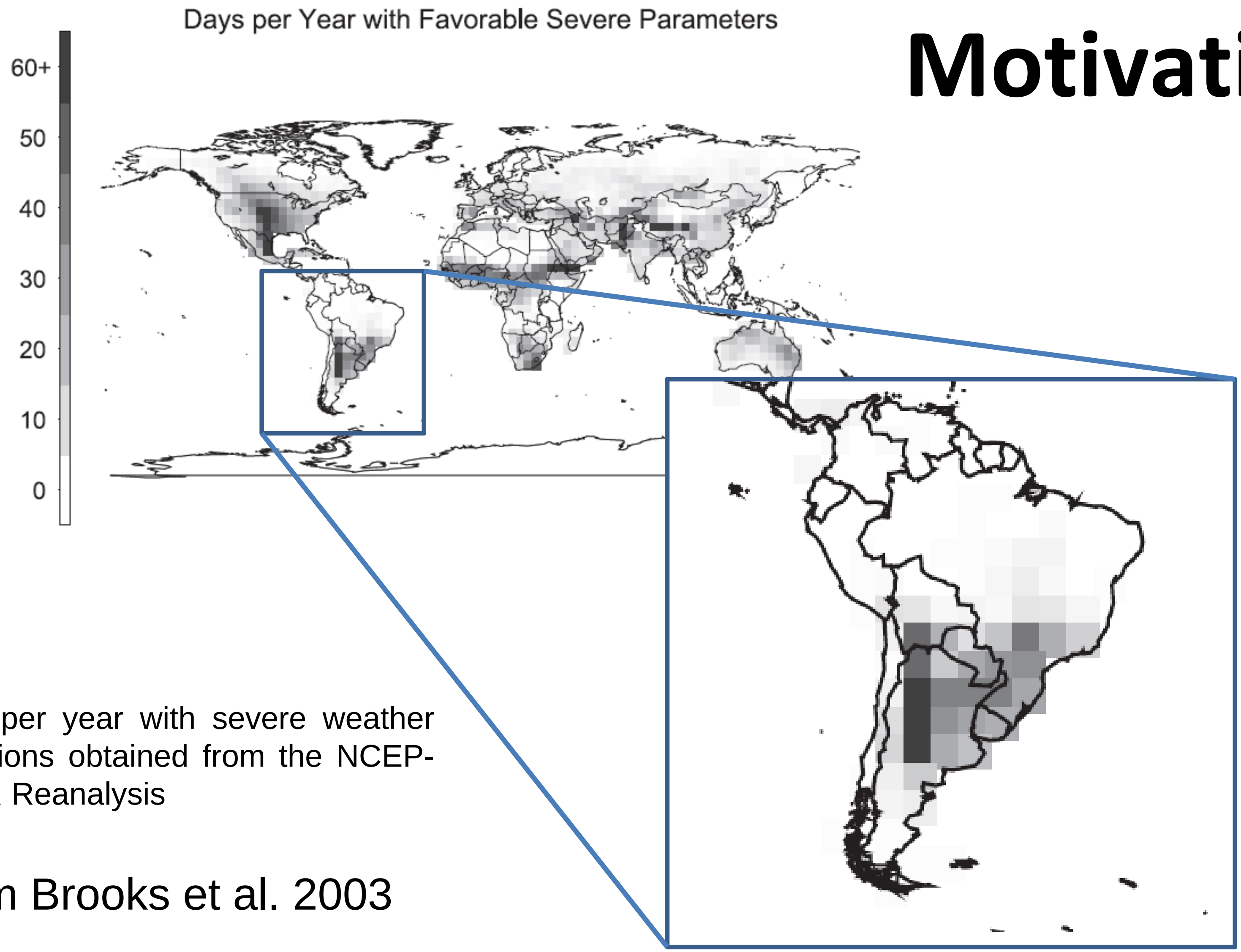
•Regional system still far from GFS operational analysis and forecast.
•Use of multi physics produce some improvement in the 6hr forecast and also promising results regarding precipitation forecast in a convective rain event.

Future / ongoing improvements:

•Inclusion of lateral and lower boundary conditions perturbations.
•Assimilating more data: AIRS, pwv estimations, radar winds, local aircraft data.
•Implementation of RTPS or RTP inflation parameters.

High resolution data assimilation in South America

Motivation



Days per year with severe weather conditions obtained from the NCEP-NCAR Reanalysis

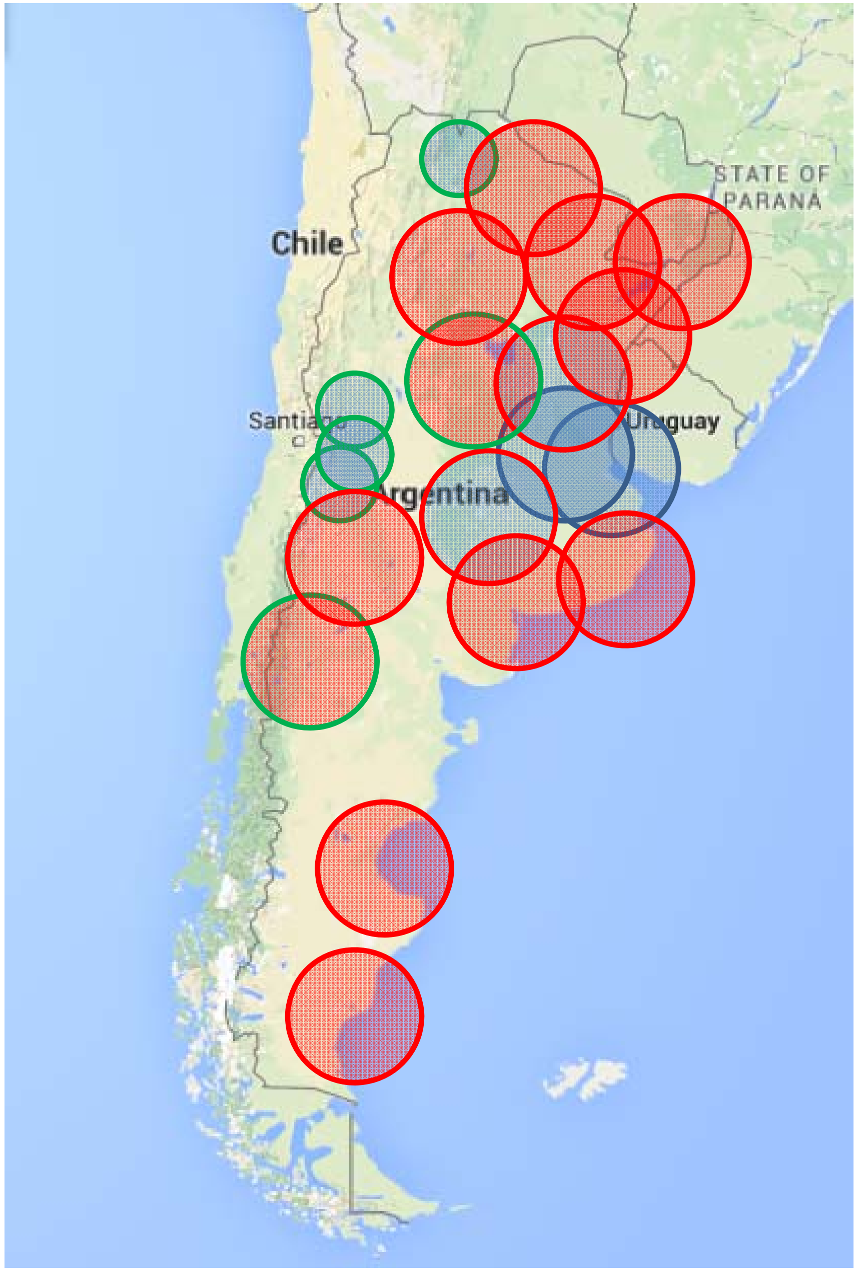
From Brooks et al. 2003

South America and in particular central-Northern Argentina are hot spots for severe weather.

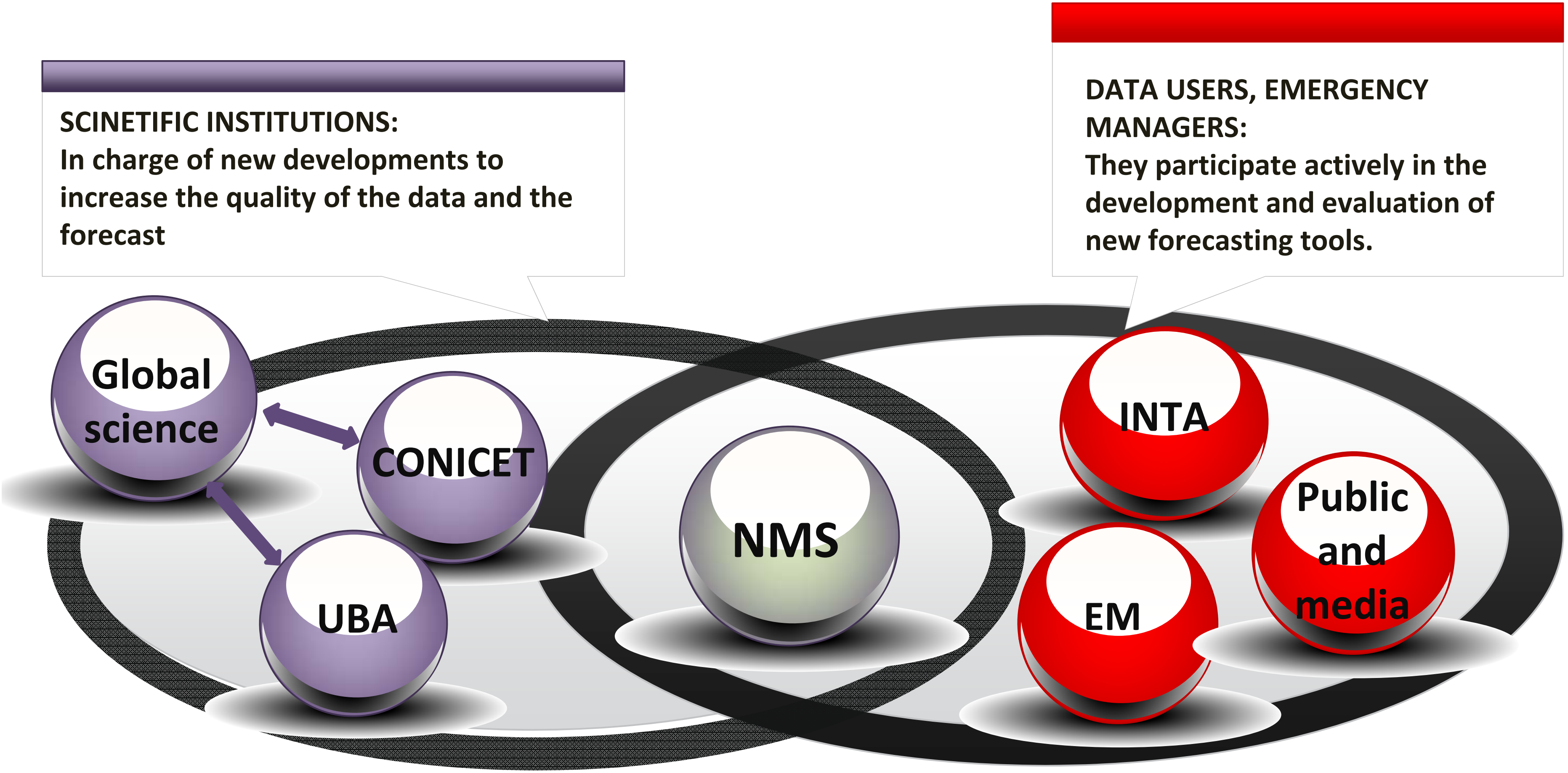
SINARAME National Network of Weather Radars

RMA0 at Bariloche

Argentina's weather radar network has improve recently and will continue to grow due to the addition of 12 state-of-the-art weather radars. These radars are being developed and built in Argentina by INVAP (a public-private company) since 2011.



ALERTAR Warning system for HIWEs in Argentina



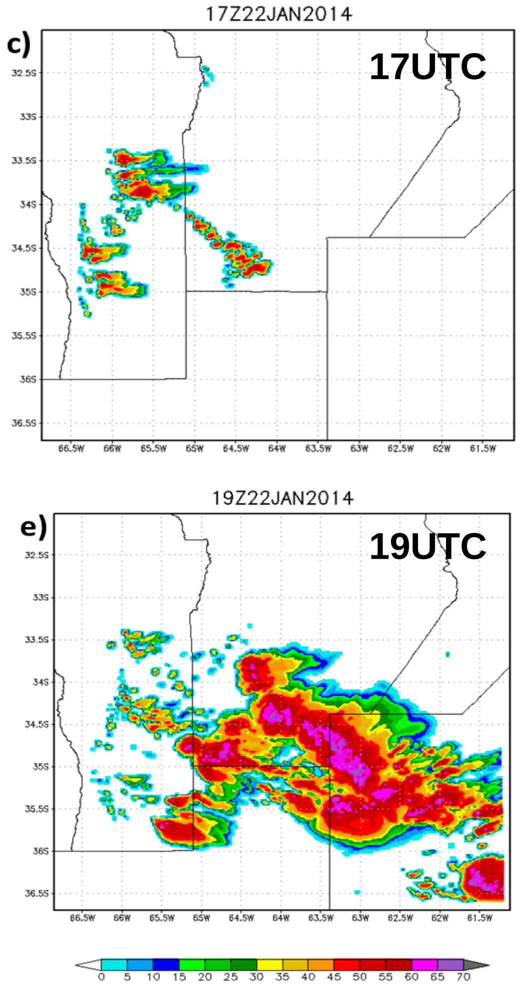
CONICET: National Scientific and Technical Research Council
UBA: University of Buenos Aires
NMS: National Meteorological Service
INTA: National Institute of Agricultural Technology
EM: Emergency managers

WRF-LETKF for radar data assimilation

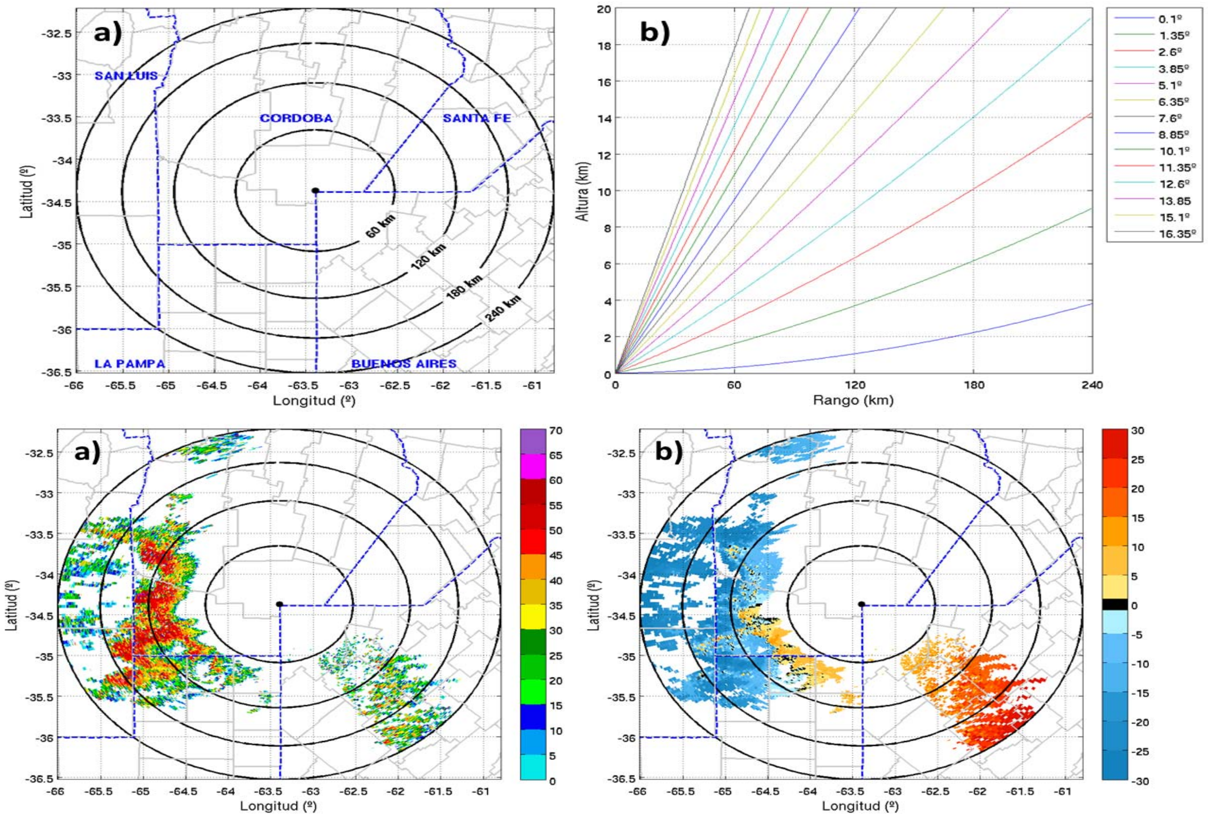
OSSE experiments to evaluate the performance of the system – Perfect model

Implementation of the observation operator used in Miyoshi et al. 2016 into WRF-LETKF system.

A rapid upscale growing MCS has been selected for this experiment.

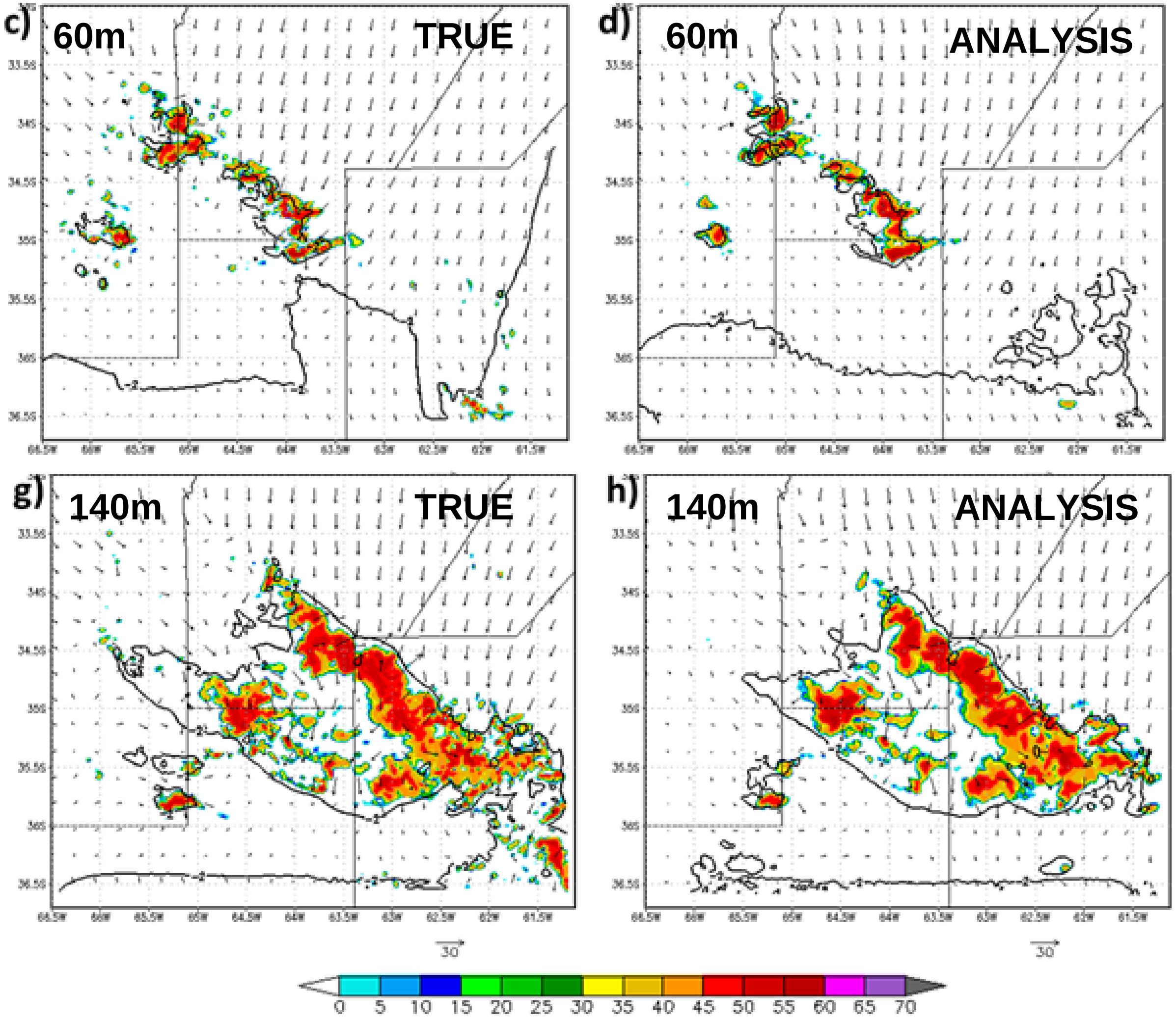


Observation strategy, reflectivity and Doppler radar observations every 5 minutes. Radar located at the domain center. 14 elevation angles.



WRF-LETKF for radar data assimilation

OSSE experiments to evaluate the performance of the system – Perfect model



Assimilation settings:

Model: 2km horizontal resolution (same settings as the true run).

Domain size: 500km x 500 km.

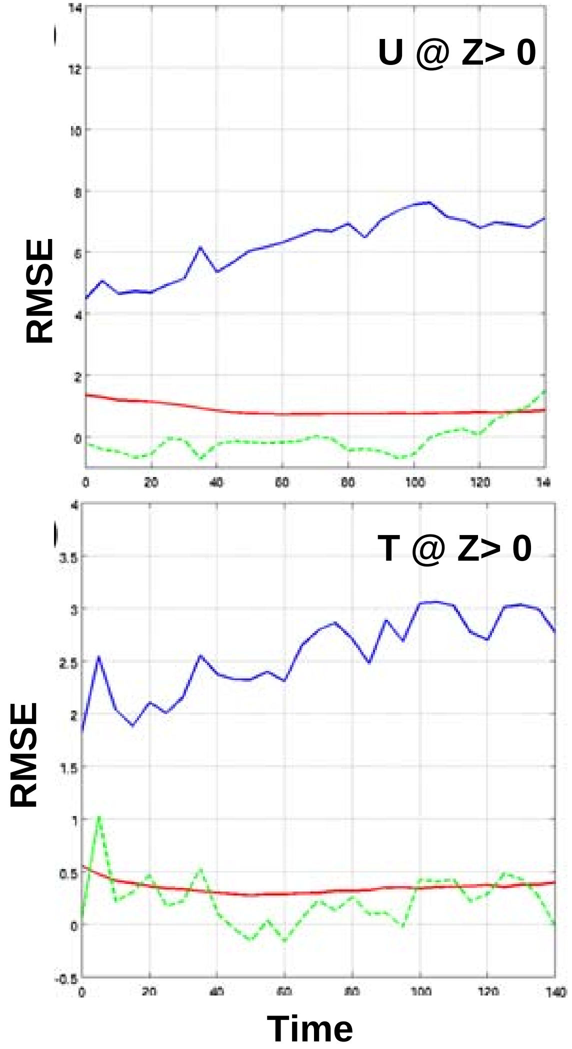
obs: Reflectivity and Doppler velocity every 5 minutes.

Ensemble size: 60 members
Experiment length: 2 hs 30 min
Multiplicative inflation: Constant 1.1
Covariance localization: 1 km in the horizontal and vertical directions.

Results shows a good correspondence between the location of the convective line in the analysis and in the true.
The cold pool and low level winds are also well represented by the analysis.

WRF-LETKF for radar data assimilation

OSSE experiments to evaluate the performance of the system – Perfect model



General performance looks ok, but….

Analysis RMSE is greater than those reported in other similar studies.

Possible causes:

•Inflation too small and also not adequate for this problem. Doing tests with RTPS.

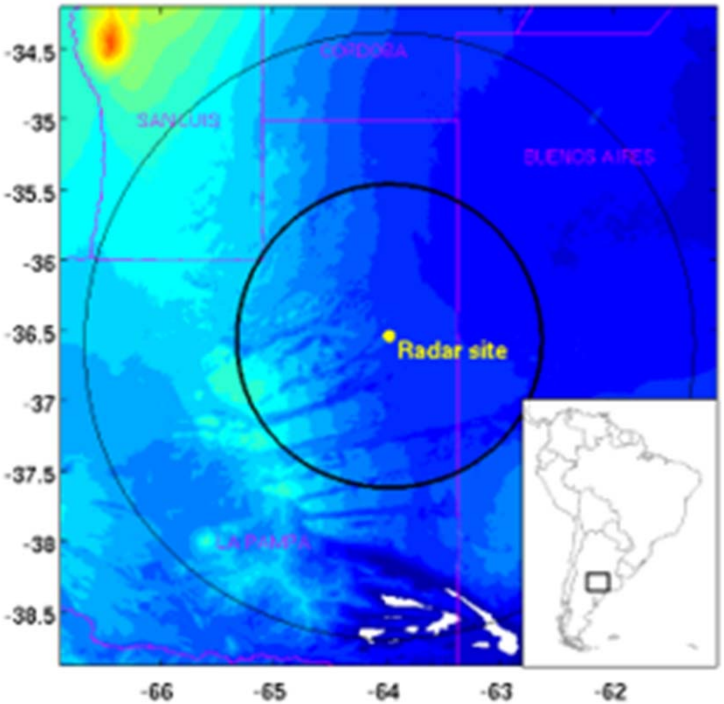
•Random initial perturbations may be too strong. Too strong initial perturbations can trigger lots of convective cells that will modify the vertical temperature and moisture profile. Even if they are damped by the data, their effect upon the vertical temperature and moisture profile can remain.

•Localization scale may be too small. Localization scales on the order of 12 km are suggested by Sobash and Stensrud 2013.

•Simplify the observation setting for the OSSE. The realistic observation strategy used in this case produce big changes in observation density which can affect the results (compared with other studies that assume observations at every grid point).

WRF-LETKF for radar data assimilation

Real case experiment

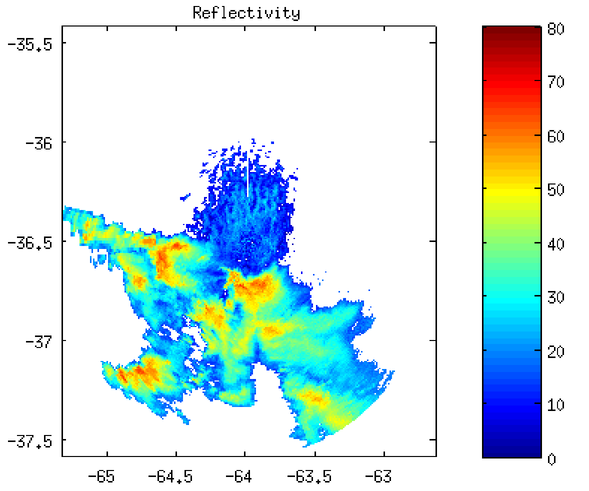


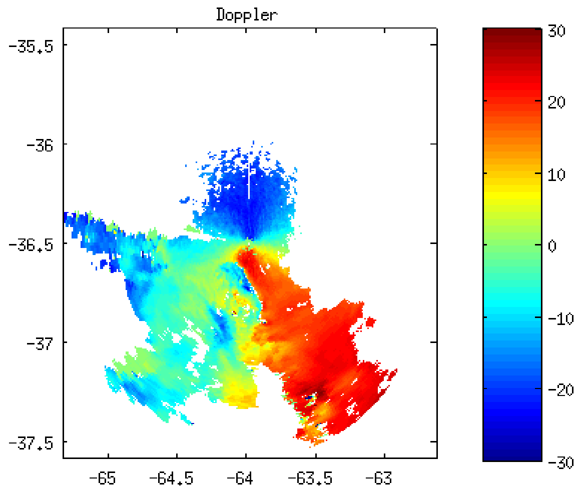
The **4D Local Ensemble Transform Kalman Filter** (LETKF) coupled with WRF-ARW is used to assimilate radar data.
Ensemble size: 60 ensemble members
Model: 2 km horizontal resolution, 60 vertical levels.
Domain: 240 x 240 km domain.
Initial ensemble: Initialization using random perturbations.
Localization: Horizontal and vertical localization ~ 2 km (R-localization)
Inflation: Multiplicative inflation factor 1.1
Boundary conditions: GFS forecasts (0.5 degree)
4D LETKF: Data split into 1 minute slot for 4D assimilation.

Radar type: Conventional antenna C-Band dual polarization Doppler radar
Domain Maximum range (in this experiment) 120 km
Obs: Reflectivity and Doppler velocity every10 minutes. 500 meters range resolution and 10 elevation angles (from 0.5 to 19.2)

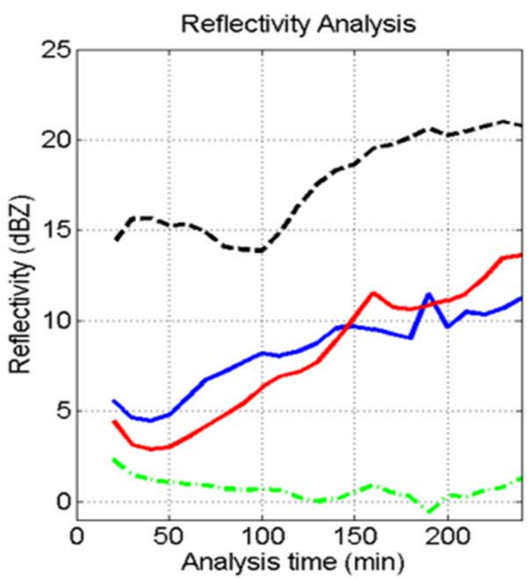
WRF-LETKF for radar data assimilation

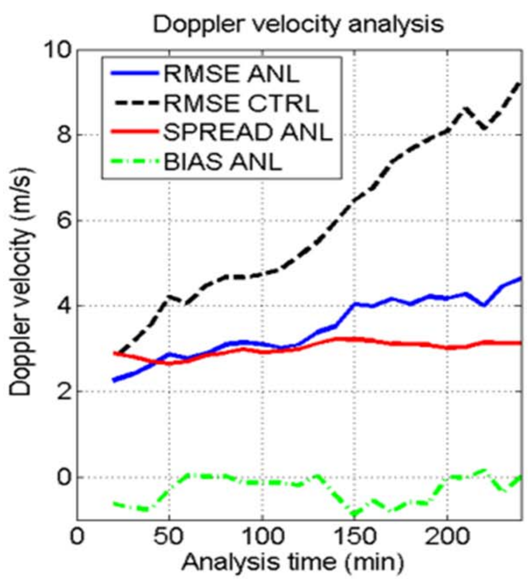
Real case experiment





Observations are not quality controled.
A simple QC has been applied based on polarimetric variables and Pyart dealiasing algorithm.

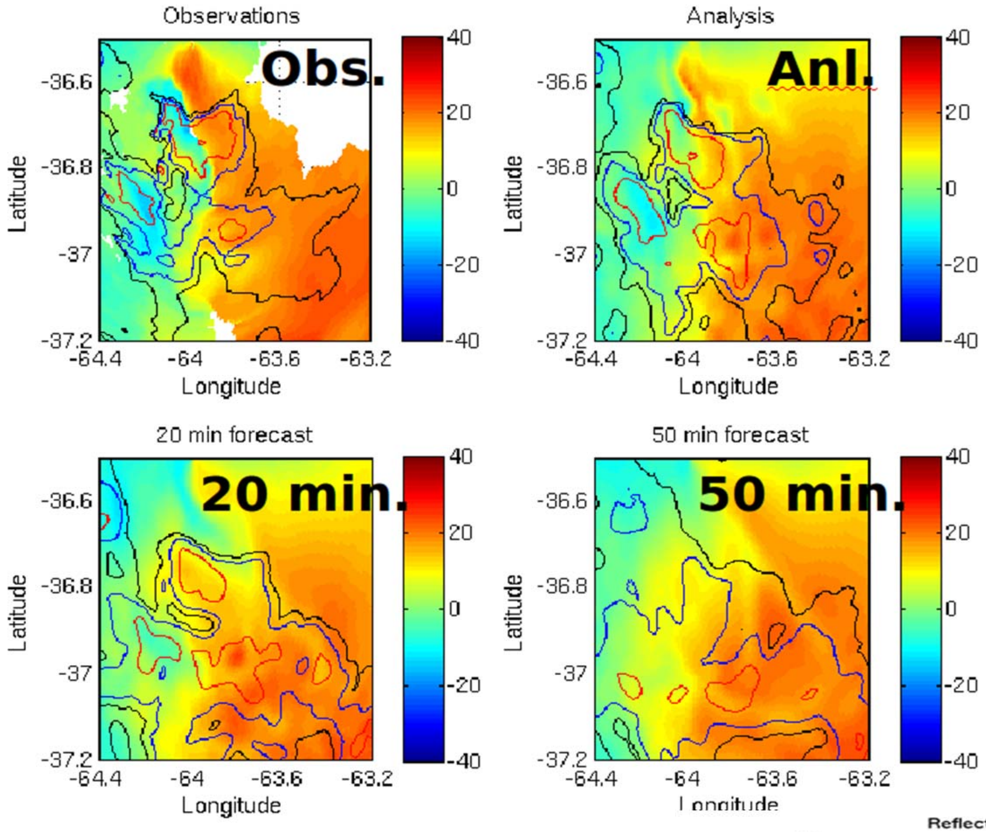




The assimilation successfully pull the analysis towards the observations.
However as in the OSSE experiment there is an increase of RMSE with time suggesting that filter divergence may be taking place.
This might be related to some of the causes previously discussed.

WRF-LETKF for radar data assimilation

Real case experiment – forecast verification



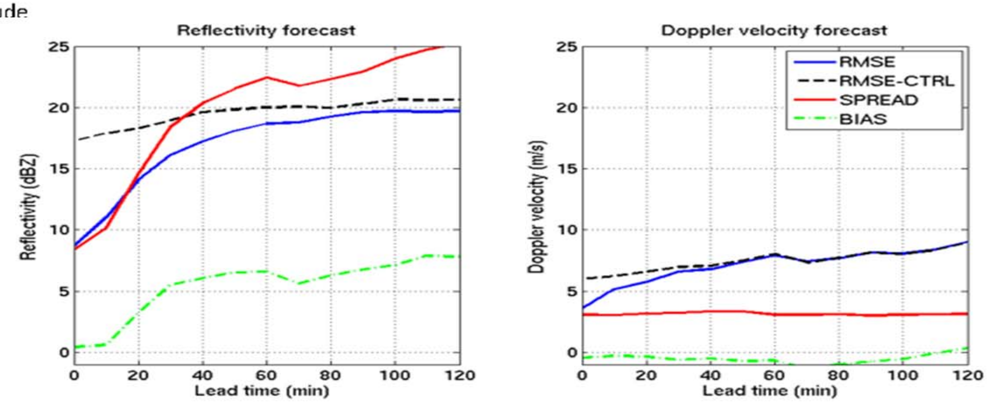
Every 30 minutes a 2 hour forecast was initialized from the LETKF analysis.

In this example we can see a supercell that is present in the analysis and in the observations.

The ensemble mean forecast initialized 20 minutes before reproduce the supercell (although the associated wind pattern is shifted in space with respect to the reflectivity field).

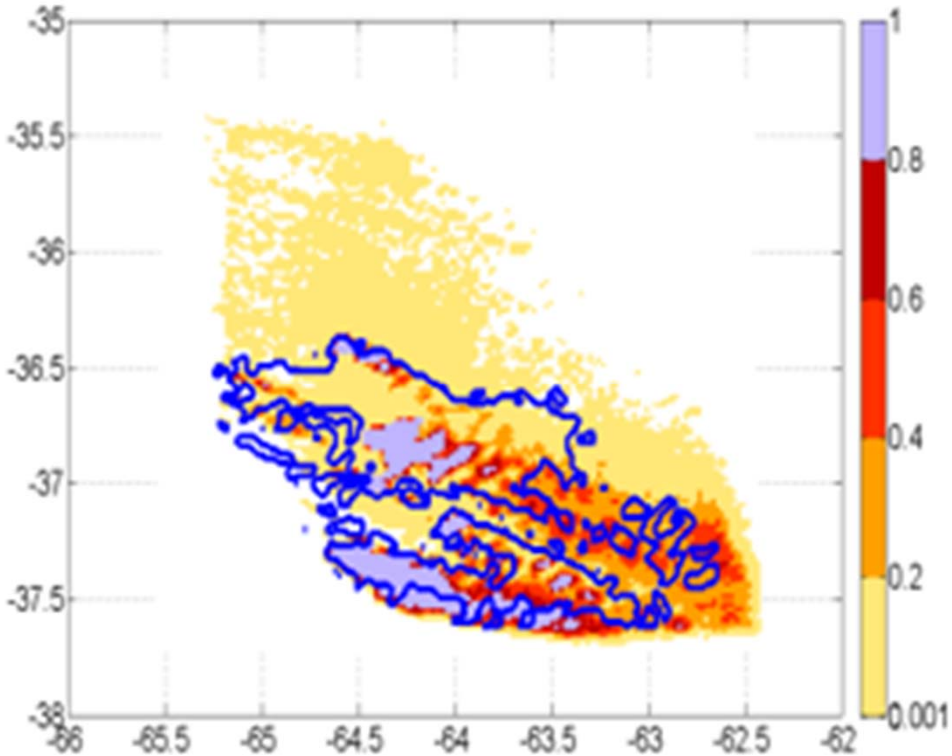
The forecast initialized 50 minutes before do not have the supercell (or may be its location is too uncertain).

In general we can see that after 20-30 minutes the RMSE of the ensemble mean converge to the RMSE of the control run that has been initialized from the GDAS analysis at the beginning of the experiment.



WRF-LETKF for radar data assimilation

Convective scale probabilistic forecasts?



One way to cuantify the uncertainty is to use probabilistic forecasts.

At convective scales LETKF provides initial conditions to generate an ensemble of forecast from which probability of occurrence of several phenomena can be derived.

In this example the probability of Z > 50 dBz in the first forecast hour is shown.

The blue countour indicates the area in which the reflectivity in the analysis was over 50 dBz.


Thank you very much!!!