EXPERIMENTS WITH ASSIMILATION OF ZTD GPS DATA.

Jana Sánchez, B.Navascués, J.A. García-Moya.
INM

Abstract

Preliminary assimilation experiments have been performed at INM to find the impact of GPS Zenith Total Delay data with the HIRLAM 3DVar system. The two alternative background constraint formulations available in HIRLAM, namely analytical and statistical, have been tested. They have been done with emphasis in the diagnostic of the performance of the assimilation cycle using this new type of observations, as in the verification of the model forecasts.

These experiments have shown an impact of the assimilation of GPS data and the background constraint approach, both on precipitation and model humidity .

Introduction

Knowledge of the atmospheric distribution of water vapour is of key importance in weather prediction and climate research. However, currently there is lack of knowledge about the humidity field, both due to a shortage of observations and a sub-optimal handling of humidity in HIRLAM assimilation systems.

Global Positioning System (GPS) signals are particularly sensitive to water vapour. TOUGH (*Targeting Optimal Use of GPS Humidity Measurements in Meteorology*) project's objective is to develop and refine methods enabling the optimal use of GPS data from existing European GPS stations in numerical weather prediction models and to assess the impact of such data upon the skill of weather forecasts.

INM is a member of this project and one of its aims is to carry on extensive, full-scale data assimilation experiments with HIRLAM (Undén P. et al. 2002)**,** that implies a proper modelling of the GPS measurement errors and an adjustment of current assimilation techniques in order to assimilate this kind of data.

Preliminary assimilation tests of GPS data with HIRLAM 3Dvar

Some trial exercises have been performed as preparation for an extensive parallel, quasi-operational assimilation of GPS data at INM. In particular, NRT GPS data have been fetched from the 'thorn' and 'acri' ftp servers (at the UK Met-Office and ACRI-st) during last July. Maps of data coverage produced by the different processing centres have been obtained, the availability of the different observed variables (ZTD: Zenith Total Delay, IWV: Integrated Water Vapour, ZWD: Zenith Wet Delay, PS: Surface Pressure) has been investigated, and some routines have been coded to interface the NRT data to the expected format for the observations to be assimilated by the HIRLAM 3Dvar.

A first assimilation exercise has been run for a 15 days time period from 1st to 15th July 2003. It includes a severe weather event affecting the south-western coast of France. Météo-France reported very high rainfall rates and strong wind speeds during the storm that hit the Arcachon Bay in the evening of 15th July. (http://www.meteo.fr)

The experiments have been carried out using the ECMWF computer facilities, with HIRLAM 6.2. in a wide area covering the North Atlantic and Europe, with a maximum forecast length of 48h in a 6h assimilation cycle.

Two alternative background constraint formulations were developed and both are available in the HIRLAM 3Dvar system (Berre L. 2001 **)**. They imply different cross covariances between errors of the model variables producing analysis corrections significantly different in both approaches (mainly in wind and humidity), although the observation usage is the same (observation operators and observation error statistics). The so-called analytical balance is based on a geostrophic balance for the wind components and the humidity analysis is univariate (Gustafsson et al**.** 2001)**.** The alternative statistical balance makes use of linear regressions between errors of vorticity, divergence, temperature and surface pressure, and humidity, thus allowing errors of this last variable to be linked to those of the rest (Berre L. 2000**).**

The impact on forecasts produced by the additional assimilation of GPS ZTD data has been tested over this summer period using the different background error constraint approaches through a set of assimilation experiments:

- RAN (No GPS usage, analytical background constraint)
- GAN (GPS ZTD assimilated, analytical background constraint)
- RST (No GPS usage, statistical background constraint)
- GST (GPS ZTD assimilated, statistical background constraint)

GPS ZTD data were allowed to be introduced passively in the HIRLAM 3Dvar system in those experiments that did not assimilate GPS data. In this way the simulated by the model ZTD was calculated and compared to observations during the experiment run although GPS data were not assimilated. A simple redundancy check has been introduced to screen the ZTD data in the HIRLAM 3D variational system. It produces to only use in the analysis the observation closest to the analysis time from each GPS station. The observation error standard deviation for ZTD was initially set to 15mm, the same order of magnitude of the value of first guess ZTD error. As part of the observations screening a first guess check was switched on to remove from the minimization ZTD data with gross errors. No bias correction scheme has been yet applied to the data, although SMHI TOUGH partner has provided the software for it. All observations available for this period in the 'thorn' and 'acri' servers were presented to the analysis.

All experiments have assimilated the same conventional observation types apart of GPS ZTD: surface geopotencial observations from land stations, ships and buoys, aircraft temperature and wind measured data, and vertical profiles of wind (PILOT balloons and radiosonde), temperature and humidity (radiosonde). No satellite data from geostationary or polar platform instruments have been assimilated in these experiments.

Some assimilation diagnostics have been produced for all the experiments. In particular, the root mean square (rms) of innovations (observation minus first guess values) and analysis residuals (observation minus analysis values) of ZTD for the whole period have been obtained for each GPS station. The rms of innovations seems to be decreased when GPS ZTD data are assimilated, as it is shown in figures 1 and 2 for the experiments RST and GST based on the same statistical background constraint. The rms of innovations is of the order of 13 mm. Some stations in Spain and Scandinavia show larger departures of model ZTD from observations.

The root mean square of humidity analysis increments for each experiment has been obtained. Humidity analysis increments for experiments RST, RAN, GST and GAN, in model level 26 (around 850 hPa), are shown in figures 3, 4, 5 and 6. Contouring interval is 0.5g/kg. Main features are observed over Europe in all experiments. The largest analysis increments appear in experiments using the analytical background constraint (RAN and GAN). The impact of assimilating GPS ZTD data produces higher analysis increments over Scandinavia and the Iberian Peninsula whatever the background constraint approach was used. These areas correspond to the largest ZTD innovations according to figures 1 and 2.

Also rms of the differences between humidity analyses for the different experiments have been calculated. Maps of these differences at 850hPa are shown in figure 7 (RAN vs RST), 8 (GAN vs RAN), 9 (GST vs RST) and 10 (GAN vs GST). Figures 7 and 10 indicate that the different background error constraint formulation is affecting mainly to the southern part of the model area, in particular over the Atlantic Ocean. As it is shown in figures 3, 4, 5 and 6, the analysis increments are negligible in this area, so these differences seem to be produced during the model integration. Figure 10 also shows that the assimilation of GPS data with the different background constraints is also affecting the humidity analysis in northern Scandinavia. The impact of GPS data assimilation is again observed in those areas showing the largest innovations, (Scandinavia, the Iberian Peninsula and Italy) according to figures 8 and 9. They also show some areas over the Atlantic influenced by the assimilation of GPS data.

The fit of first guess and analysis to humidity radiosonde measurements has been calculated for the different experiments to investigate the impact of GPS measurements in the assimilation cycle (figures 11, 12 and 13). In both background constraint formulations the distance to the first guess from radiosonde humidity observations seems to be the same in the vertical regardless the experiment had assimilated or not GPS data, with the exception of the lowest atmospheric levels. Below 800hPa, the usage of ZTD data increases the distance of radiosonde humidity observations to first guess. In these figures it is also observed that the fit of the analysis to radiosonde humidity is larger in case of experiments based on the analytical background error constraint. However this closer distance is lost during the next model integration.

Objective verification against radiosonde of the subsequent forecasts does not show any impact of GPS data on any variable with the exception of humidity. Verification of the reported precipitation in land synoptic stations has been produced as part of the HIRLAM suites. Contingency Tables of observed/forecast precipitation for different forecast lengths corresponding to different precipitation categories have been obtained. Some standard scores have been calculated from them showing a clear impact of the usage of GPS data in both background constraint formulations: True Skill Score (TSS), Equitable Threat Score (ETS), Hit Rate, Probability of Detection, False Alarm Rate and Frequency Bias (Wilks, D.S**.** 1995).

As it has been already mentioned, this trial period includes a severe weather event over France in the evening of 15th July 2003. Météo France reported strong winds and intense rainfall in south west France. INM radar located in the Basque Country also detected heavy precipitation over this area. Maps of forecast precipitation valid for this date from each of four experiments are shown in figures 14 to 17. The impact of GPS assimilation is clear in this case. Both experiments assimilating GPS are able to predict significant precipitation over a coastal area in south-western France although the maximum is shifted towards the north of the region where it produced.

Conclusions and future plans

Preliminary assimilation experiments have been done to prepare for the coming work in TOUGH, with emphasis in the diagnostic of the performance of the assimilation cycle using this new type of observations, as in the verification of the model forecasts. In this respect, the preliminary tests carried out show an impact of the assimilation of GPS data on the model humidity and precipitation.

Next step will be an improvement/development of *hirvda Observation Operator* for RH2M, in cooperation with SHMI. The aim is to test if the combined assimilation of RH2m and ZTD observations helps the analysis to distribute the humidity analysis increments in the vertical.

Validation of GPS data assimilation experiments will be extended to include:

- Verification against surface synoptic stations and radiosonde over Europe.
- Verification against rain gauge data from the INM Climate stations network for a better verification of the model precipitation.
- Verification using model radar reflectivities, in selected case studies, calculated by a *Radar Simulation Model* for a enhanced comparison of model precipitation with the INM radar network data.

Acknowledgements

TOUGH (*Targeting Optimal Use of GPS Humidity Measurements in Meteorology*) is a shared-cost project (contract EVG1-CT-2002-00080) co-funded by the Research DG of the European Commission within the RTD activities of the Environment and Sustainable Development sub-programme (5'th Framework Programme).

References

- **Undén P. et al. 2002** : ‘ HIRLAM-5 Scientific Documentation’, SMHI Norrköping, SWEDEN.
- **Berre L. 2001** : ‘Représentation des covariances spatiales des erreurs de prévision pour une assimilation variationelle dans un modele atmospherique à aire limitée’. Ph Thesis Météo France/CNRM/GMAP, Toulouse, France.
- **Gustafsson et al**. **2001** : ‘ Three-dimensional variational data assimilation for a limited area model . Part I: General formulation and the background error constraint. *Tellus*, 53A, 425-446.
- **Berre L**. **2000** : ‘Estimation of synoptic and mesoscale forecast error covariances in a limited area model’. MWR, 128,644-667.
- **Wilks, D.S**. **1995**: ‘Statistical Methods in the Atmospheric Sciences’. Academic Press.

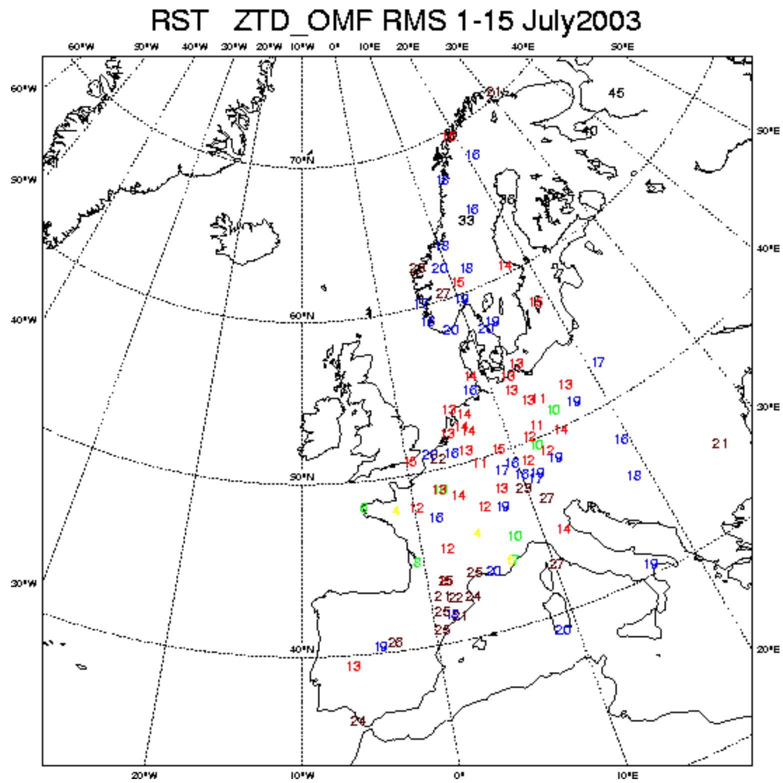


Fig.1. **RST**: rms of innovations for each GPS station.

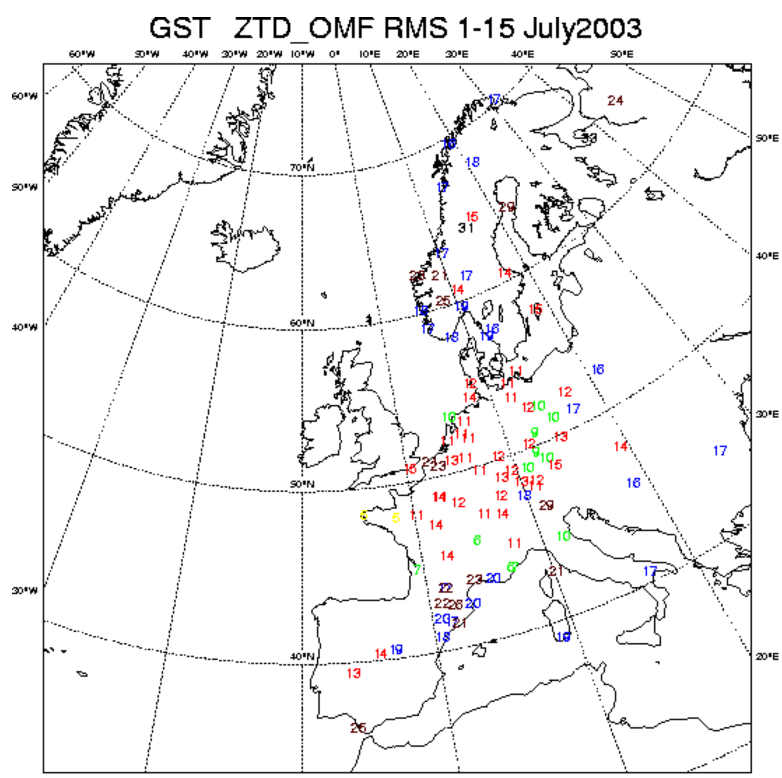


Fig.2. **GST**: rms of innovations for each GPS station.

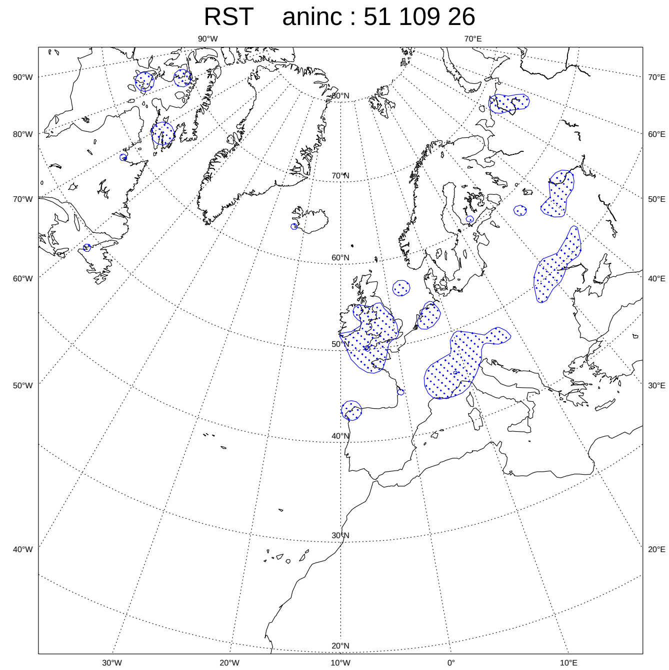


Fig.3. RST: rms of humidity analysis increments at model level 26 (850 hPa) Contour int. 0.5g/kg.

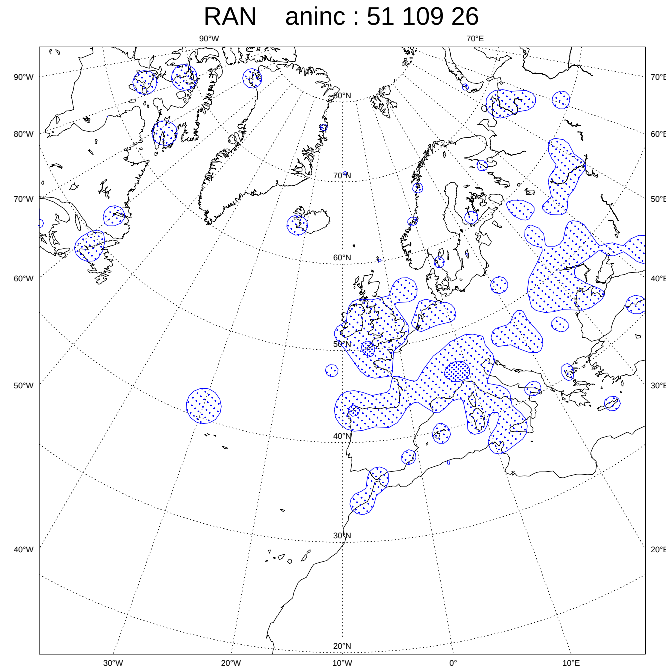


Fig.4. RAN: rms of humidity analysis increments at model level 26 (850 hPa) Contour int. 0.5g/kg

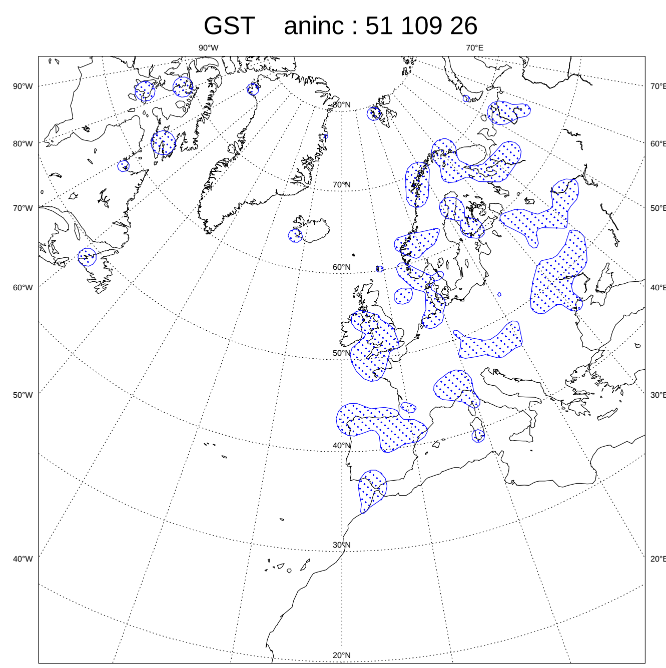


Fig.5. GST: rms of humidity analysis increments at model level 26 (850 hPa) Contour int. 0.5g/kg.

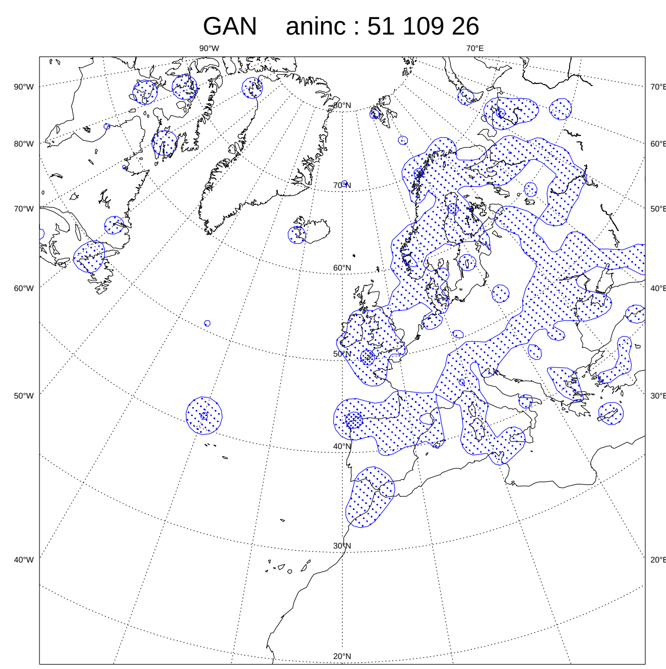
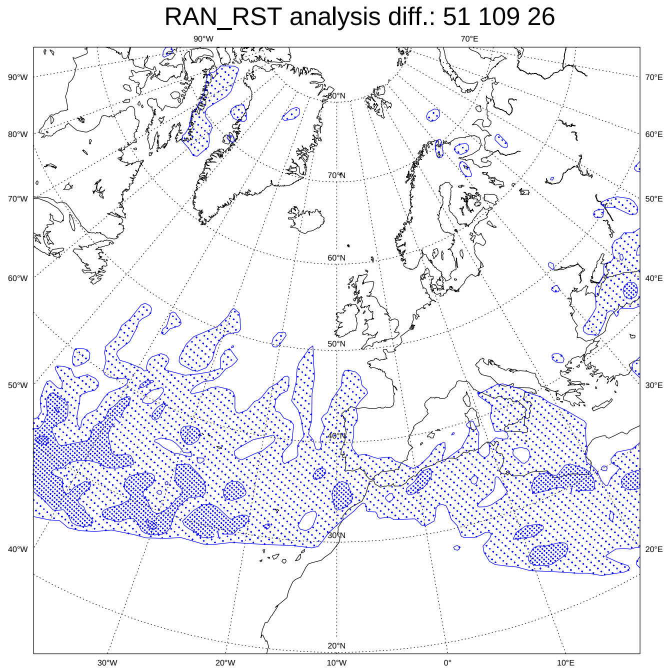


Fig.6. GAN: rms of humidity analysis increments at model level 26 (850 hPa) Contour int. 0.5g/kg



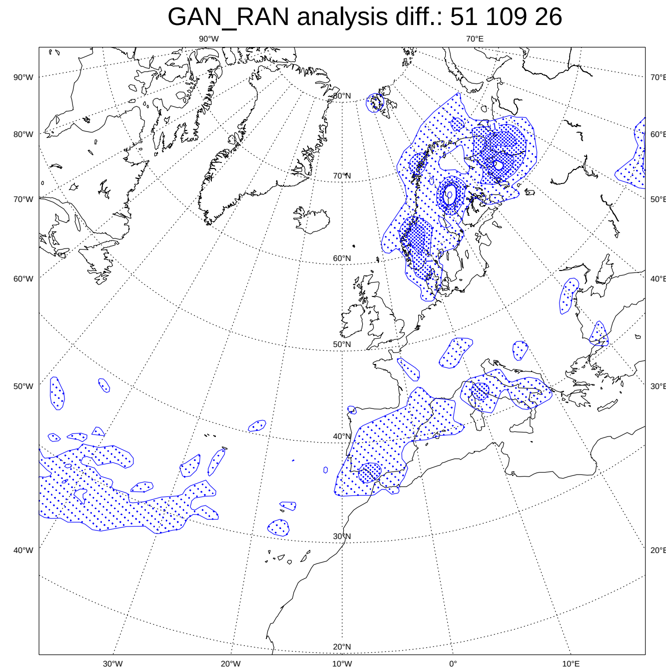
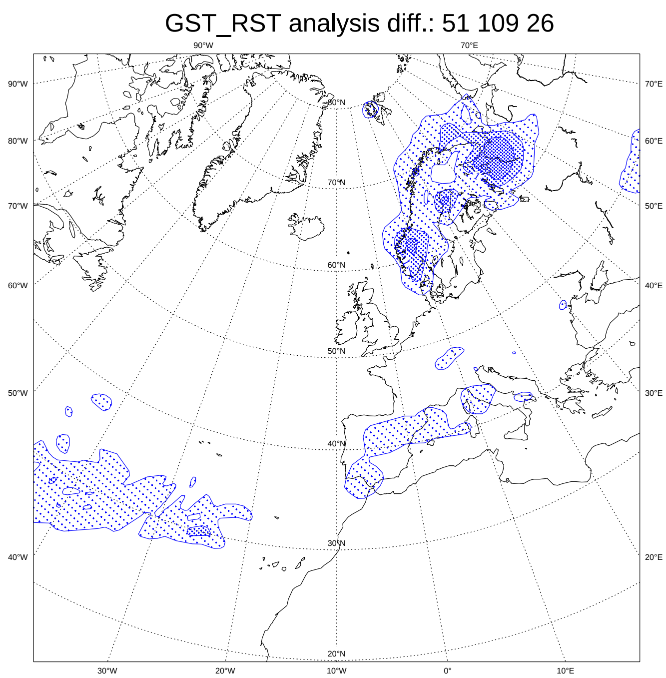


Fig.7. RAN-RST humidity analysis increment differences at model level 26 (850 hPa) Cont int. 0.5g/kg

Fig.8. GAN-RAN humidity analysis increment differences at model level 26 (850 hPa). Cont int. 0.5g/kg



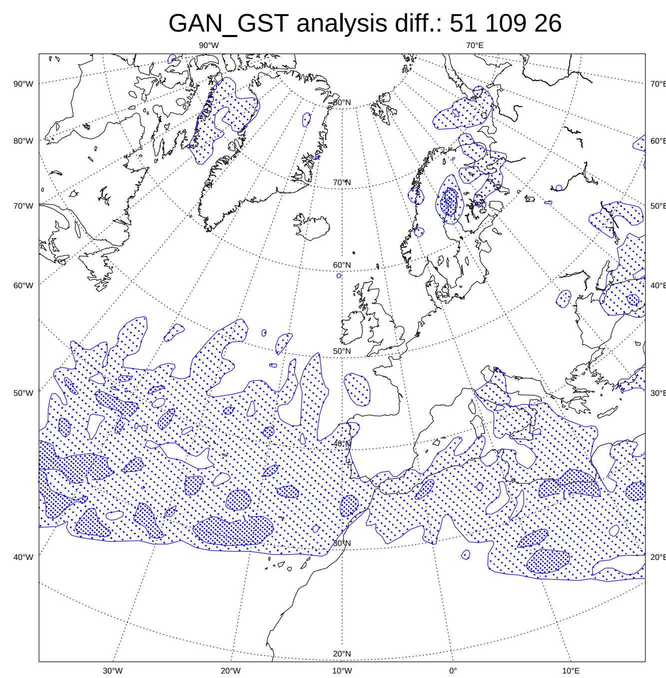


Fig.9. GST-RST humidity analysis increment differences at model level 26 (850 hPa) Cont int. 0.5g/kg

Fig.10. GAN-GST humidity analysis increment differences at model level 26 (850 hPa). Cont int. 0.5g/kg

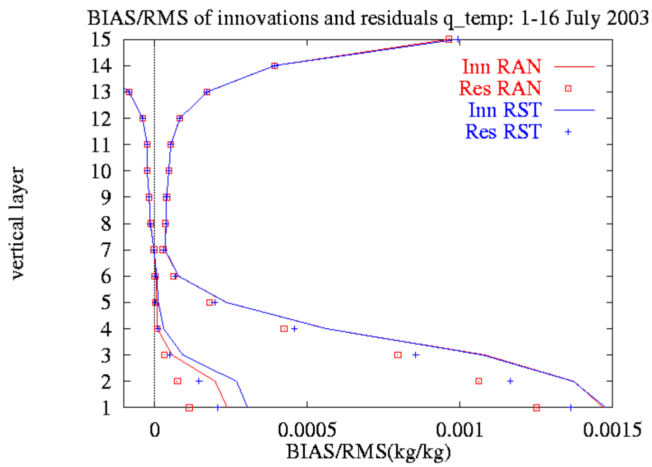


Fig.11. RAN-RST BIAS and rms of innovations and residuals for radiosonde humidity observations.

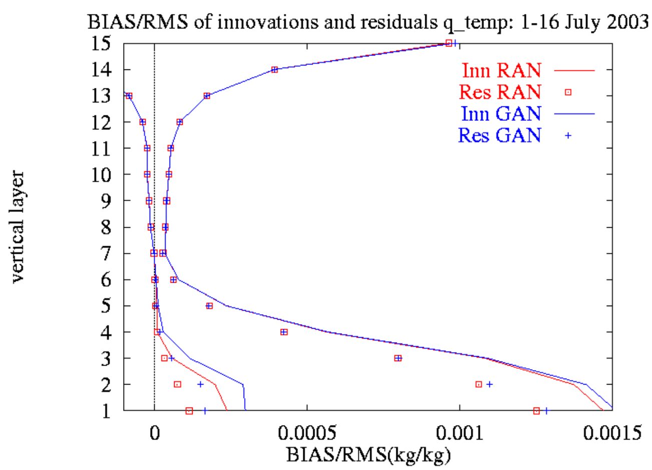


Fig.12. RAN-GAN BIAS and rms of innovations and residuals for radiosonde humidity observations .

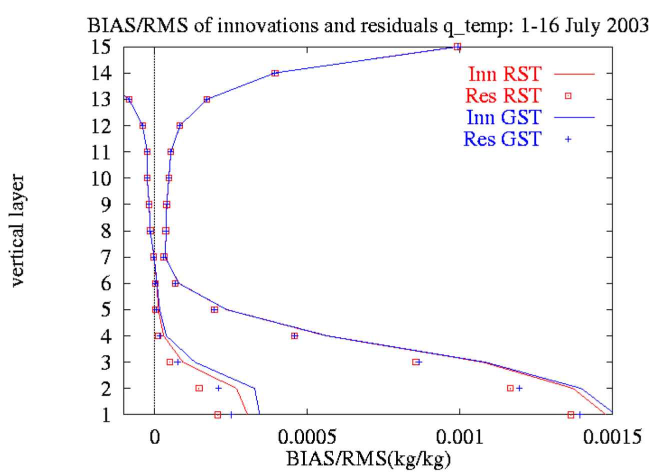


Fig.13. RST-GST BIAS and rms of innovations and residuals for radiosonde humidity observations**.**

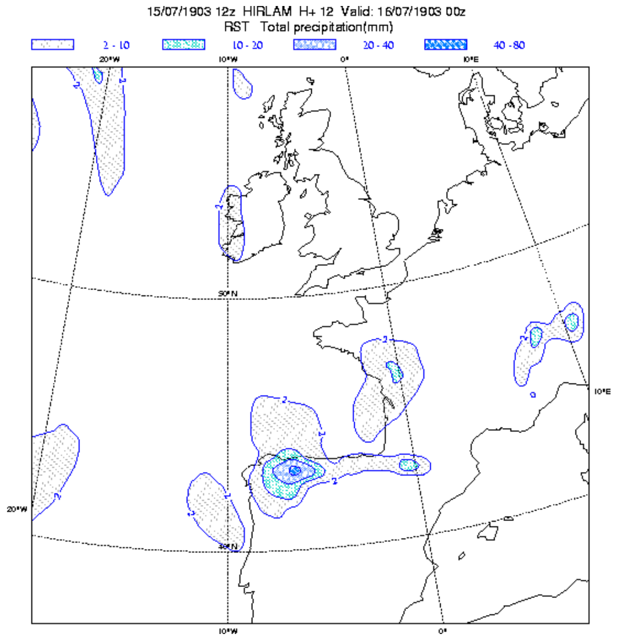


Fig.14. RST 12 h accumulated Total precipitation in mm .

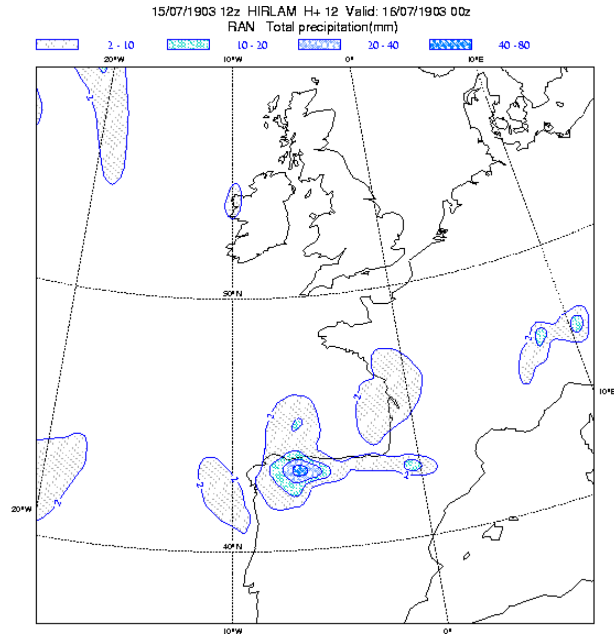


Fig.15. RAN 12 h accumulated Total precipitation in mm.

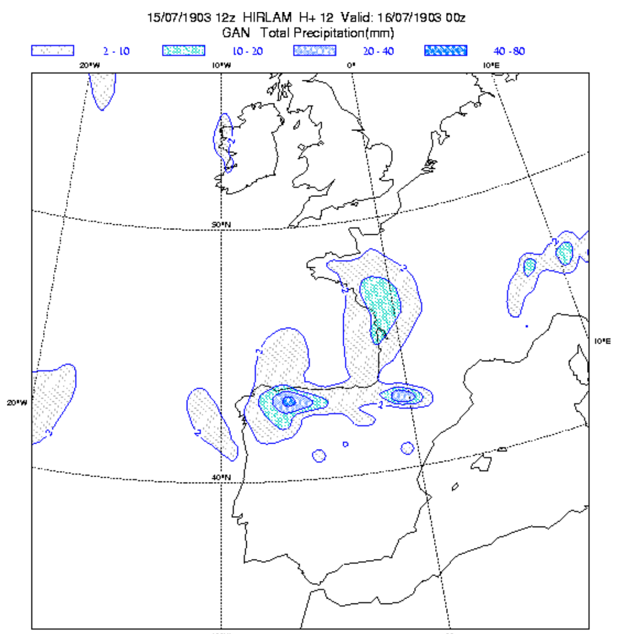


Fig.16. GAN 12 h accumulated Total precipitation in mm.

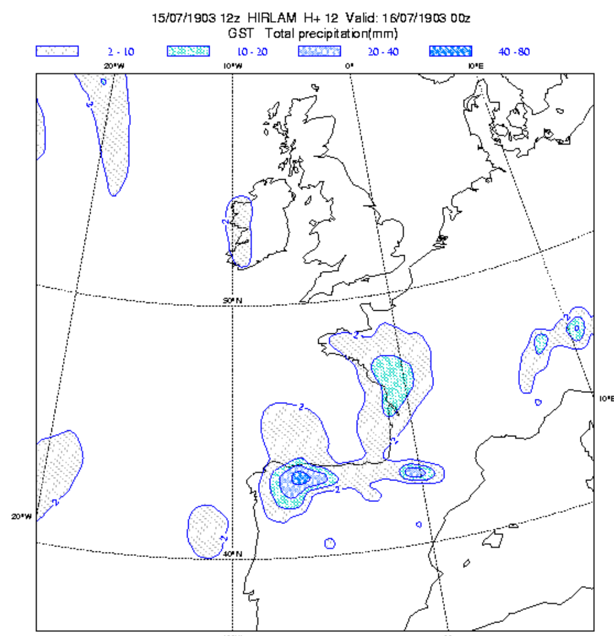


Fig.17. GST 12 h accumulated Total precipitation in mm.