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Impact of GPS ZTD observations in HIRLAM[1] 3D-Var analysis and forecasts

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1) High Resolution Limited Area Model

Background

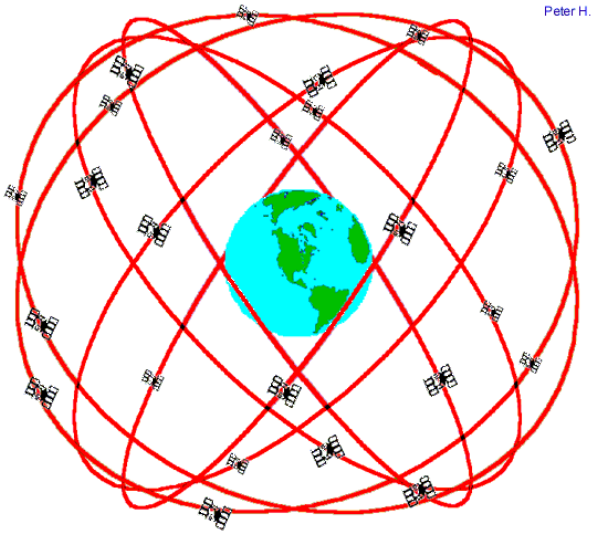
Concept of GPS meteorology

Atmospheric effect on microwave signal propagation can be expressed in terms of Zenith Total Delay (ZTD) at a ground-based GPS observing site

ZTD is interpreted as a vertically integrated measure of atmospheric water vapour

Advance of NWP towards forecasting severe weather underlines the importance of the model description of water vapour

Ground-based GPS receivers constitute an observing system for monitoring of atmospheric water vapour in high resolution



Motivation

Motivation

The HIRLAM[1]-CIS (Comprehensive Impact Study) will explore the impact of high-resolution observation types on 4D-Var analyses and forecasts of summertime convection

The number of GPS observing sites continues to increase

- Also GPS ZTD data from Finnish receiver stations has become available in May 2008

Improvements in GPS ZTD data assimilation code of HIRLAM

→ An impact study with 3D-Var was decided to be performed as a preparation to the HIRLAM-CIS experiment

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1) High Resolution Limited Area Model

GPS data

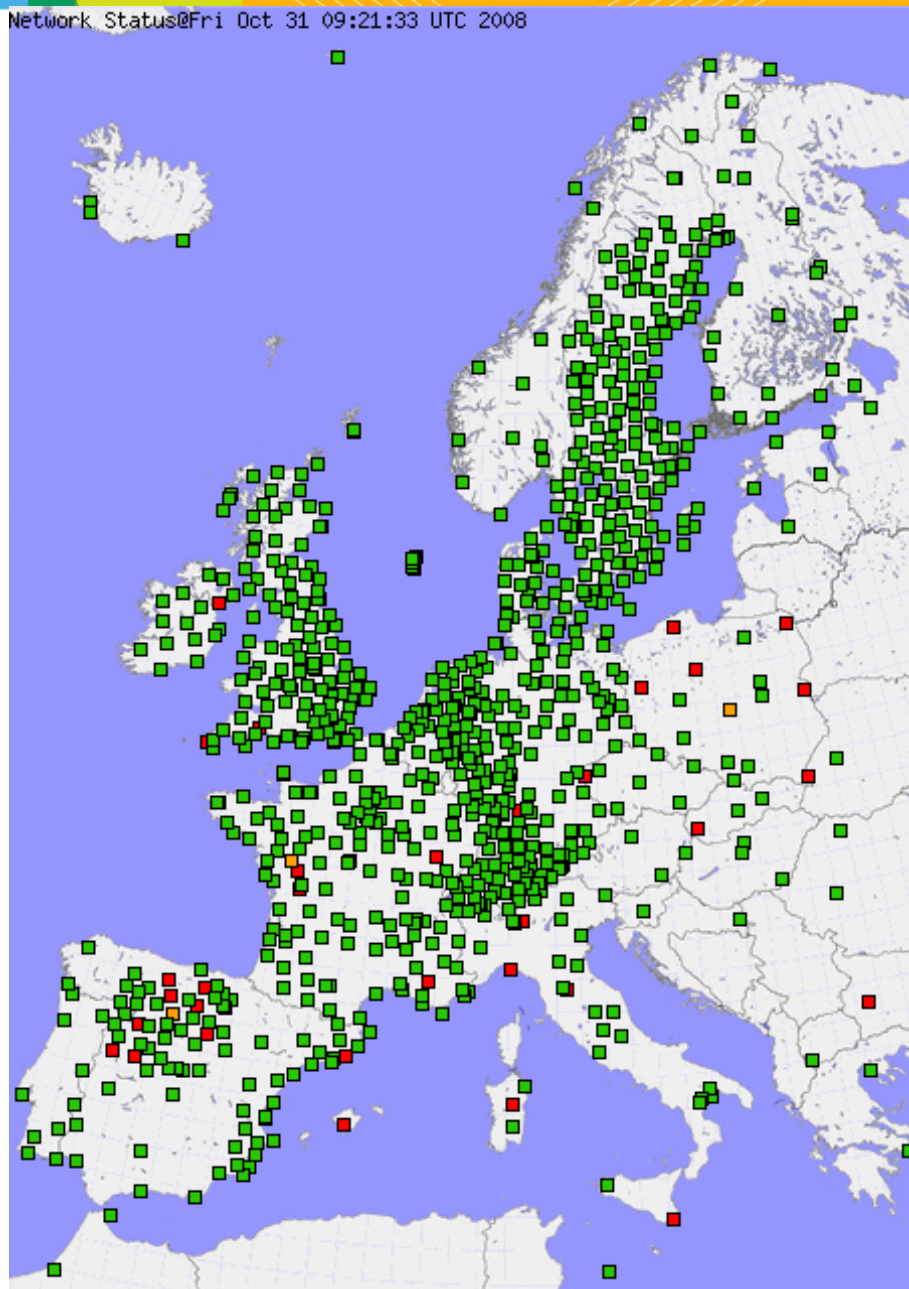
Observing system status in Europe

The observing system is controlled by EUMETNET programme E-GVAP

The observing system consists of ground-based receiver networks that are specific to each country

Increasing number (>1000) of receiver stations is included in near real time processing

The processing is done at ~10 processing centres, including both geodetic and meteorological institutes

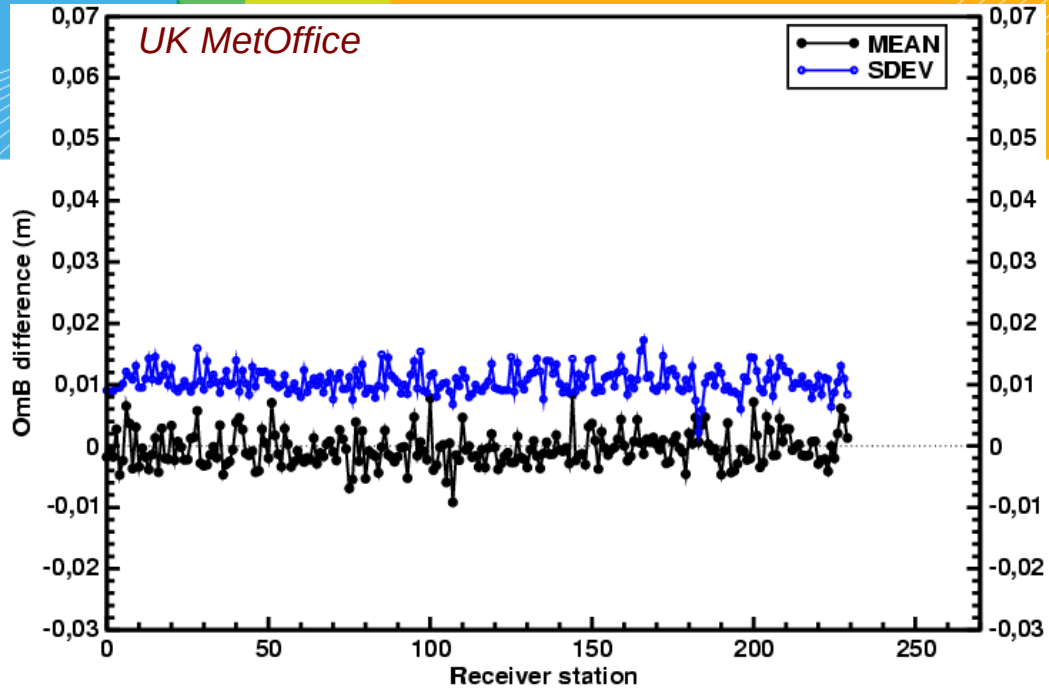


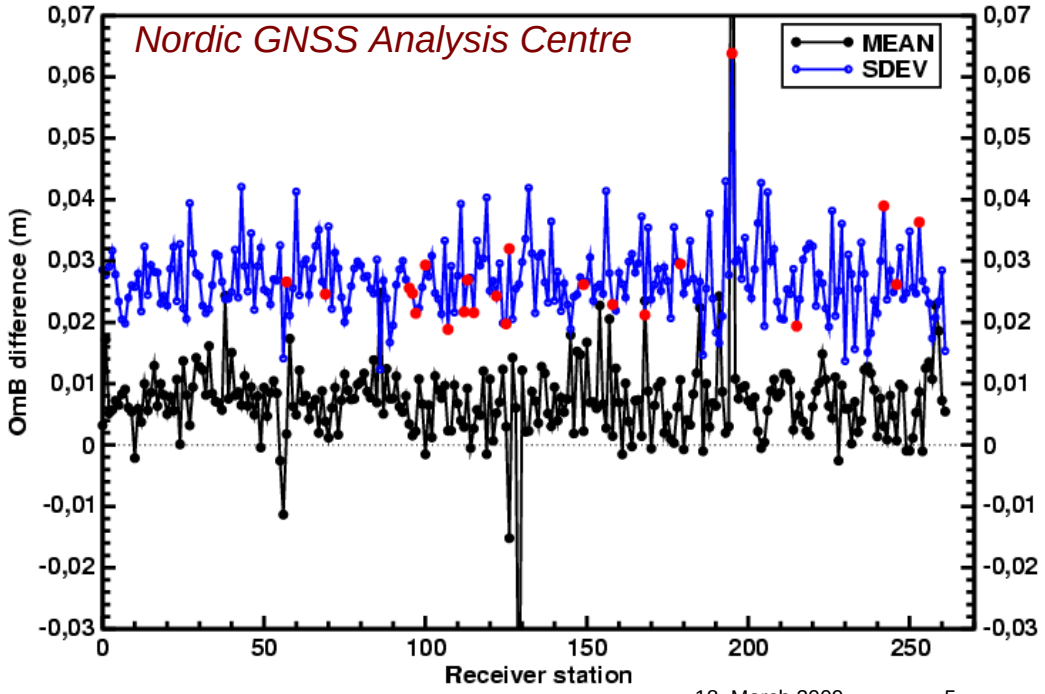
GPS data

OmB statistics from HIRLAM

GPS observation quality is inhomogeneous and OmB statistics are receiver-station dependent

OmB statistics depend also on strategies that are taken at the pre-processing centres





Experiment design

NWP model domain and time period

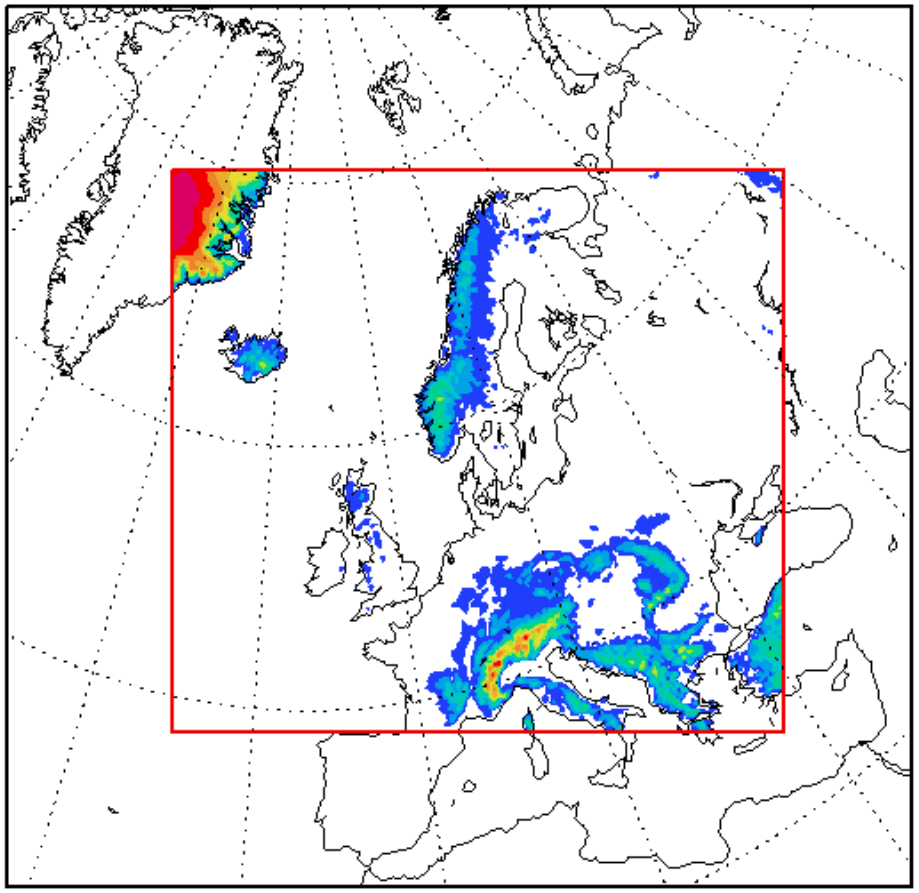
HIRLAM 3D-Var in a regular grid of 406 x 320 grid points

0.1º horizontal grid resolution at 60 model levels

A deterministic +48 hour forecast is produced every 6 hours

A 10-day ”warming up” period of 18—27 July 2008

A 35-day forecast period of 28 July—31 August 2008



Experiment design

Performed NWP model runs

Control run with only a few modification on top of the HIRLAM 7.1.4 reference system:

- Horizontal domain and grid spacing are modified
- ATOVS observations are not assimilated

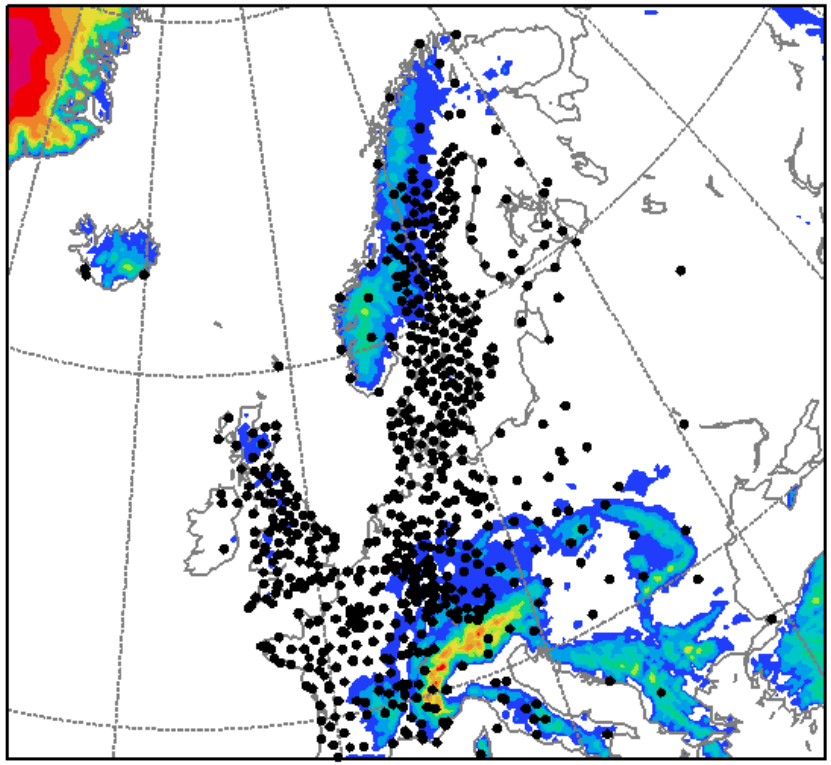
Regular GPS run: as control, but ZTD observations are included in data assimilation

Thinned GPS run: as regular GPS run, but a horizontally thinned subset of ZTD observations is used

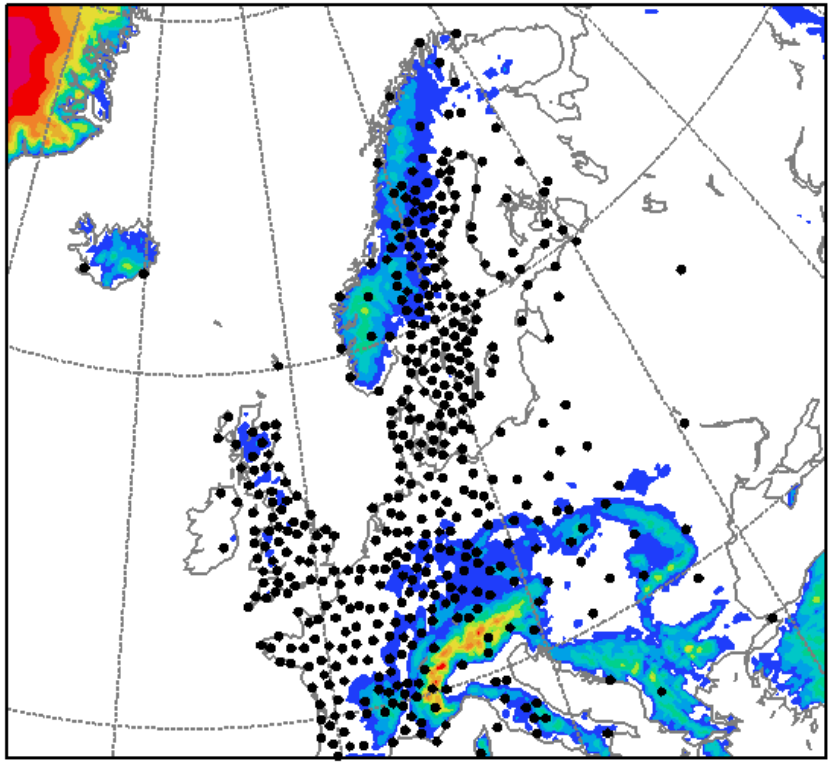
Bias-corrected GPS run: as regular GPS run, but ZTD observation biases are corrected using a simple algorithm

Observing network

Ground-based receiver stations



Original network (651 receiver stations)



Thinned network (437 receiver stations)

ZTD Observation operator

HIRLAM approach

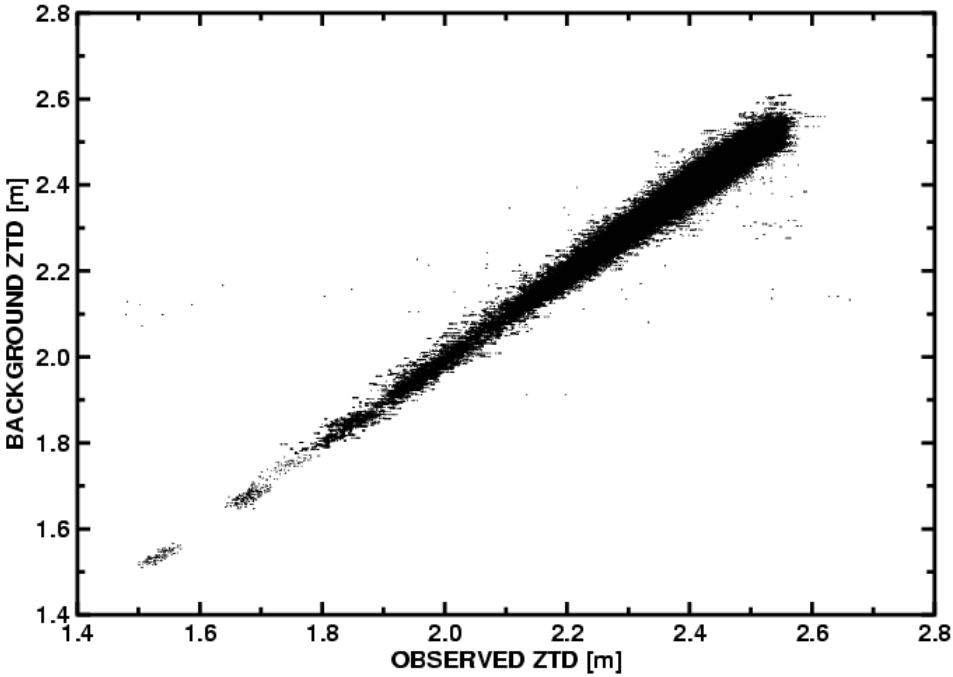
ZTD is a sum of hydrostatic and wet delay components

Hydrostatic delay is modelled as a function of surface pressure

Wet delay is modelled as a function of vertically integrated water vapour

Vertical profiles of temperature and humidity are used

Differences between observation and model orography height is taken into account



Scatterplot of observed vs. background ZTD

Observation selection

Preferences

The database of E-GVAP contains processed ZTD data for August 2008 from ~10 geodetic analysis centres

Receiver stations processed at different centres are partly overlapping

- Which analysis centre – receiver station -combinations one should prefer?

The differing GPS data processing practices can lead to inconsistencies between ZTD estimates provided by different analysis centres

The more analysis centres are used, the more there will be ZTD data to be assimilated

A compromise is made by adopting the data from five ”most productive” analysis centres only

Observation error specifications

Analysis-centre dependent observation error standard deviations σ_o are determined on the basis of OmB statistics over a three-week period in July 2008

These are specified as follows:

- σ_o=10 mm for ZTD processed at METO and GFZ
- σ_o=11 mm for ZTD processed at SGN
- σ_o=15 mm for ZTD processed at NGAA and ROB

Background error standard deviation σ_b is assumed to be 9 mm

The OmB dataset serves as the basis for bias-corrections as well

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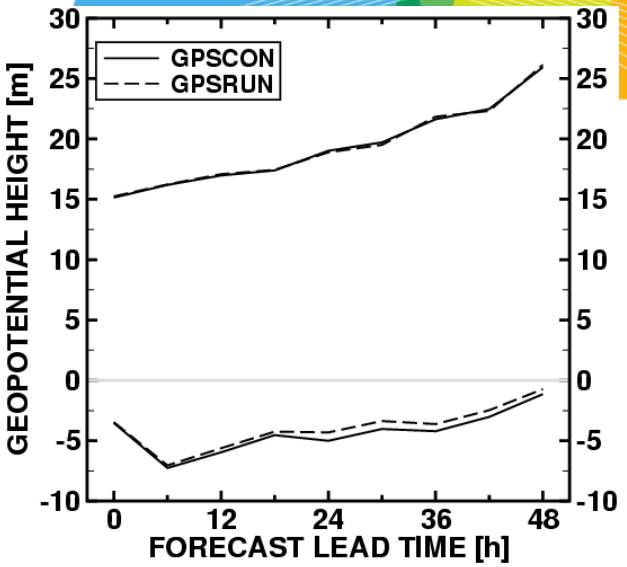
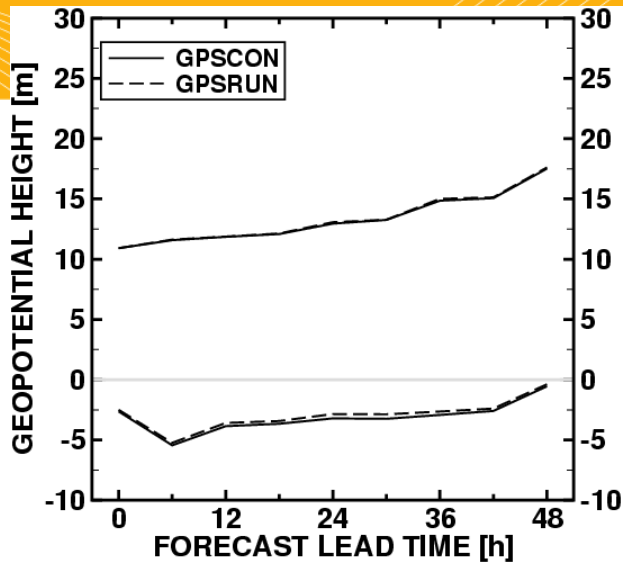
Verification of mean sea level pressure and geopotential height forecasts at EWGLAM stations

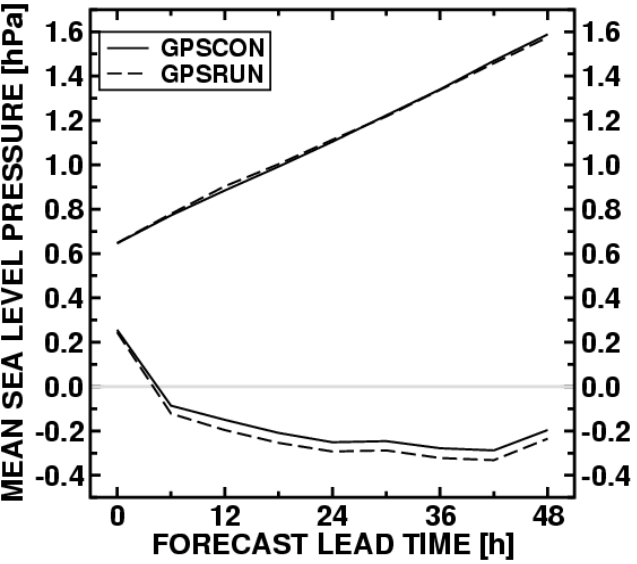


300 hPa

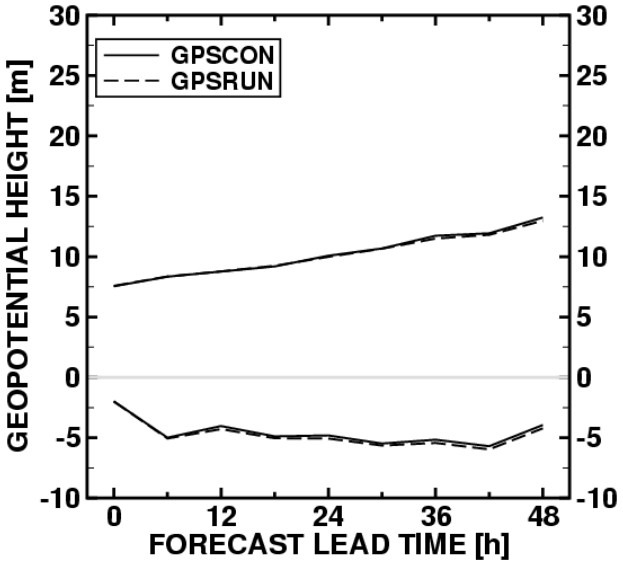


500 hPa

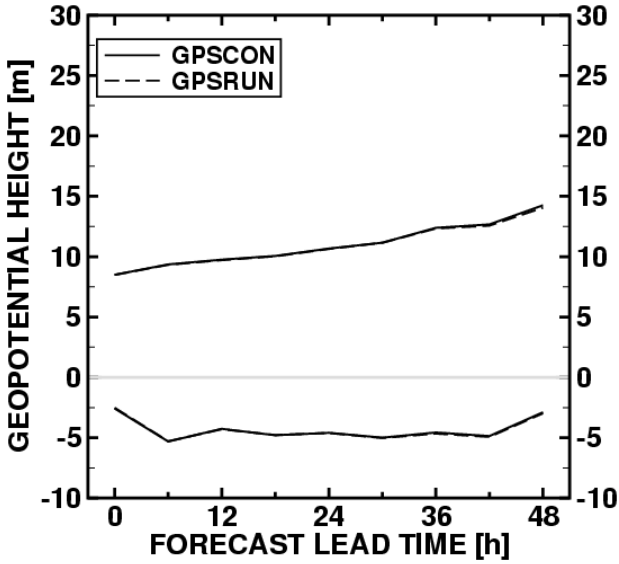
Mean Sea Level Pressure



850 hPa



700 hPa



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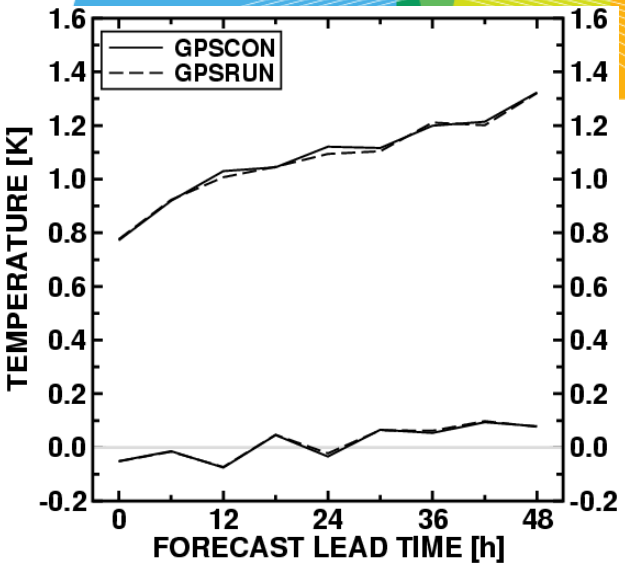
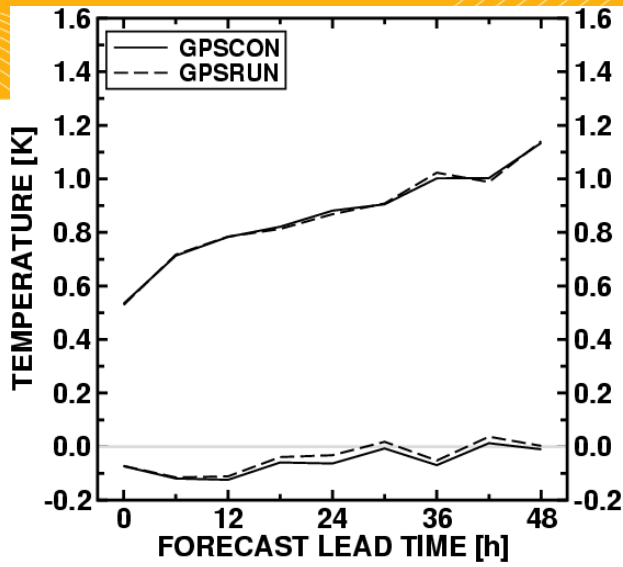
Verification of temperature forecasts at EWGLAM stations

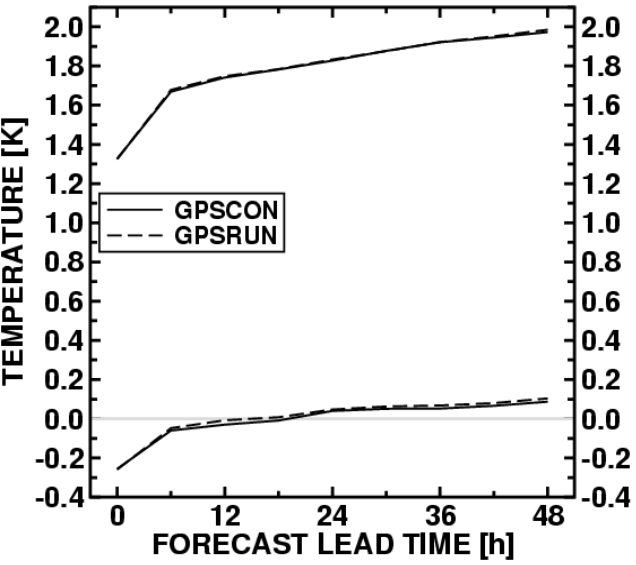


300 hPa

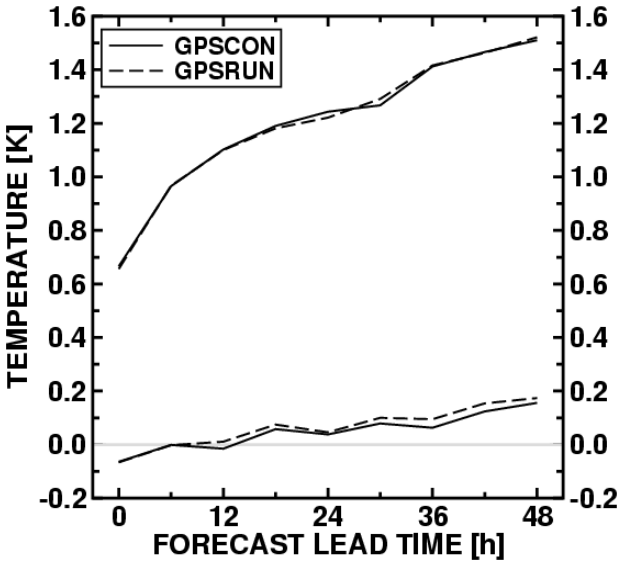


500 hPa

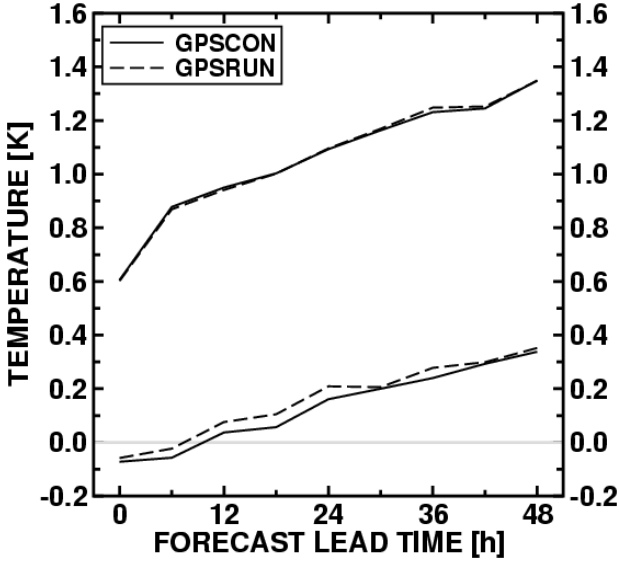
2m



850 hPa



700 hPa



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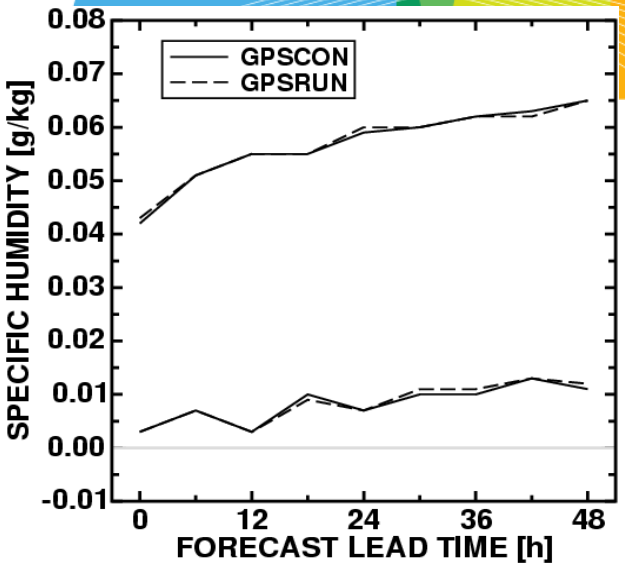
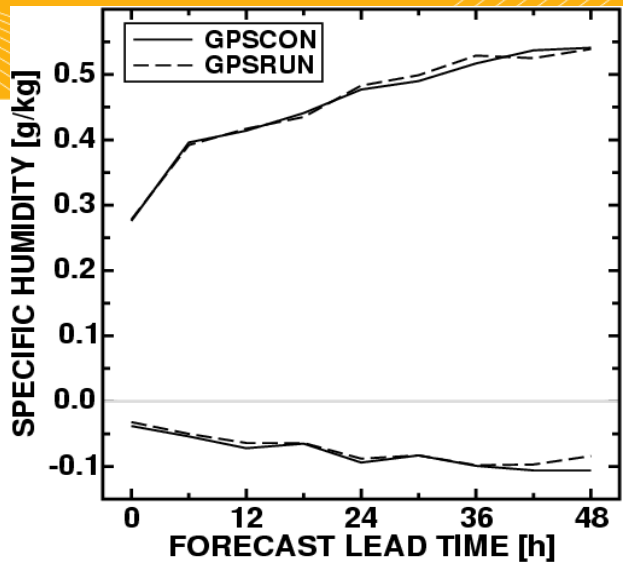
Verification of specific humidity forecasts at EWGLAM stations

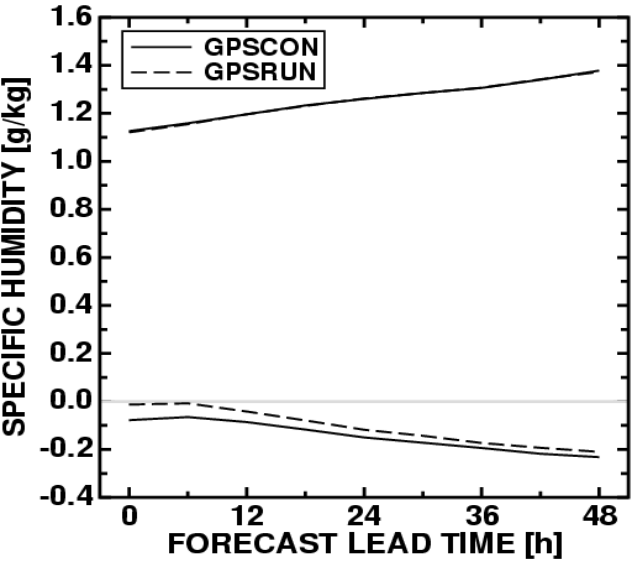


300 hPa

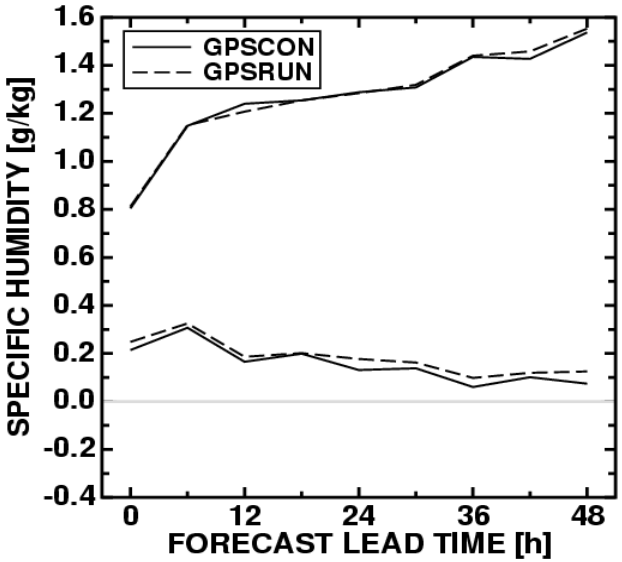


500 hPa

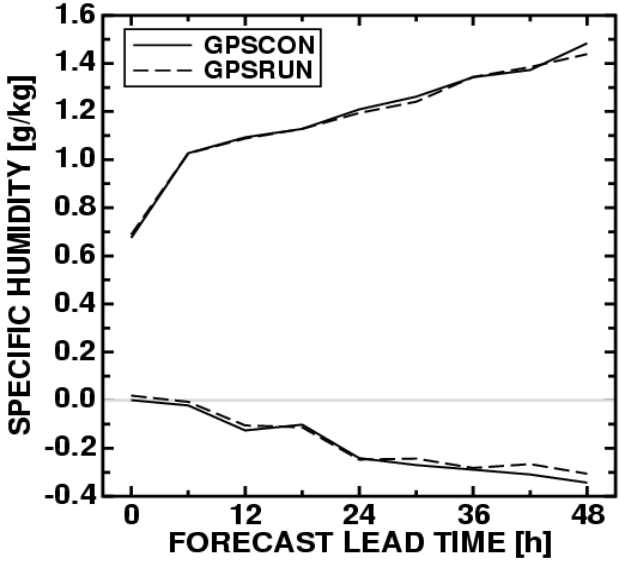
2m



850 hPa



700 hPa



Conclusions from observation verification

Control run vs. regular GPS run

Systematic effect of GPS data assimilation is to

- *increase specific humidity, in particular in the lower troposphere*
- *increase temperature, in particular in the middle troposphere*
- *increase geopotential height in the upper troposphere*
- *decrease surface pressure and geopotential height in the lower troposphere*

In general, the systematic impact is positive in the upper troposphere, but negative in the lower troposphere

No big differences are detected in forecast error standard deviations

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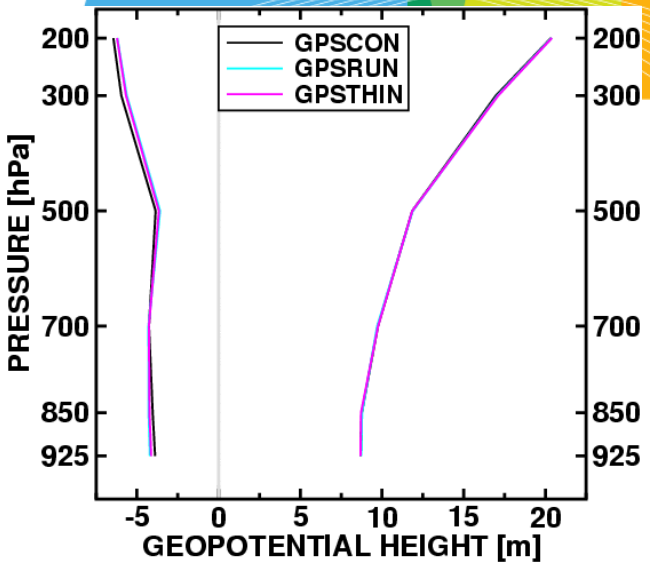
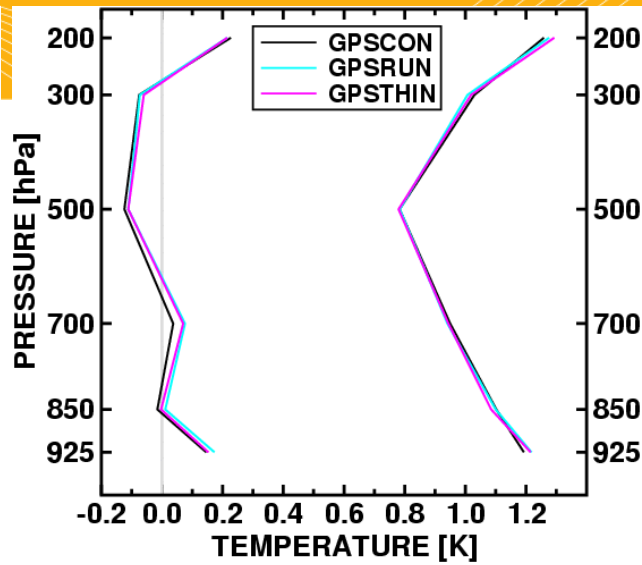
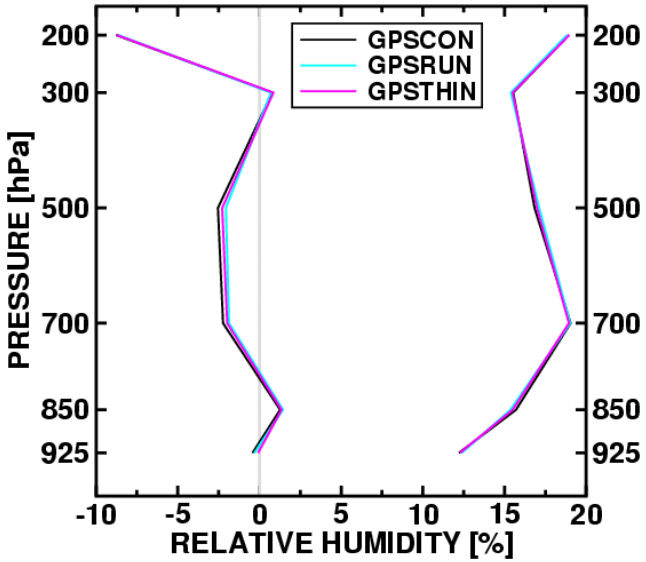
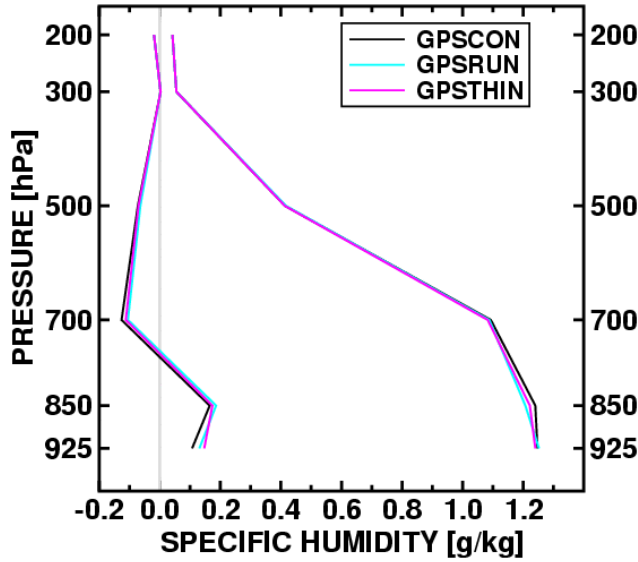
Impact of horizontal thinning of the GPS data









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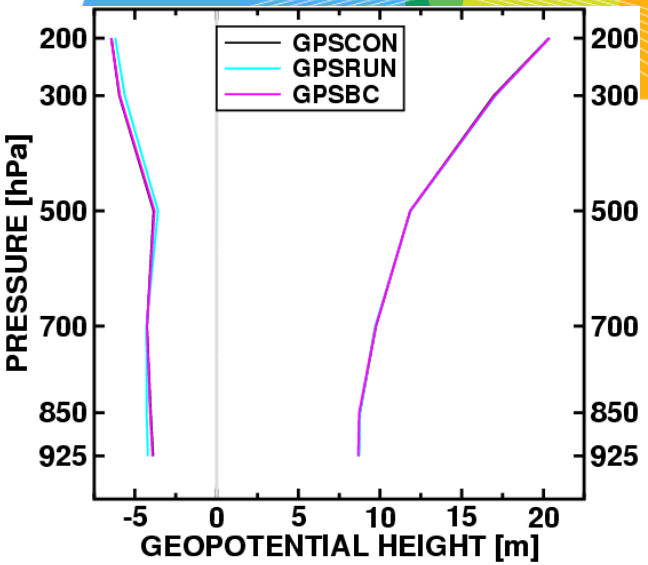
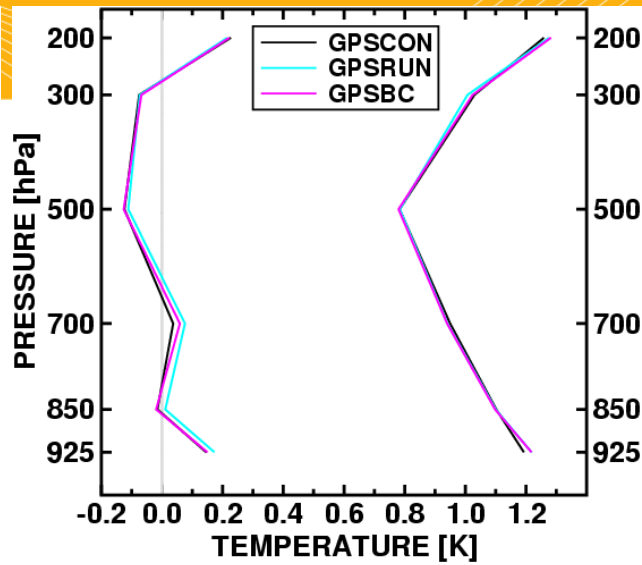
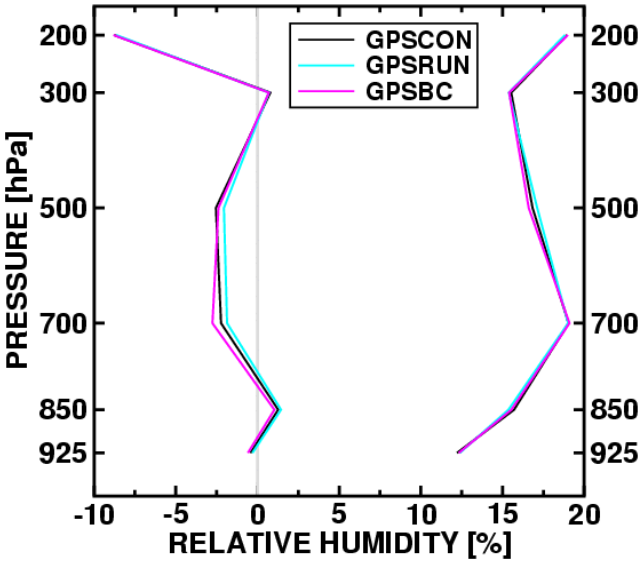
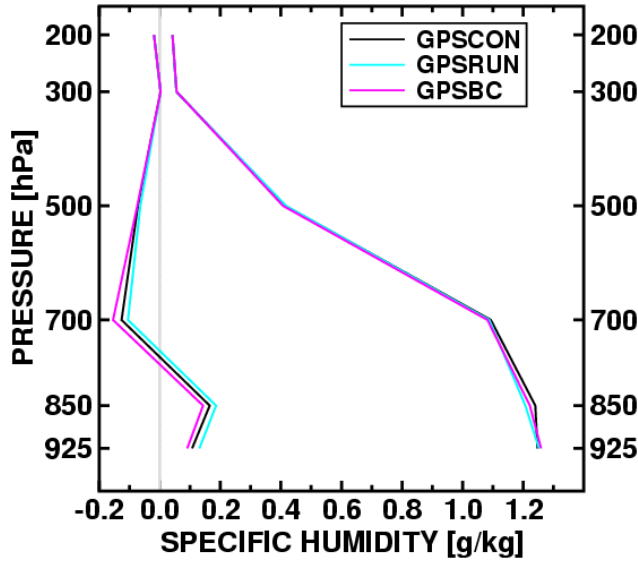
Impact of bias-correction of the GPS data









Conclusions from observation verification

Impacts of horizontal thinning and bias-correction

Thinning has very little impact as compared with the regular GPS run

Bias-correction reduces the impact of GPS data

- *A positive impact in the lower troposphere, but a negative impact in the upper troposphere*
- *In particular, the systematic impact on specific and relative humidity is reversed compared with the regular GPS run*

Impacts on forecast error standard deviations are very small

Verification of categorical forecasts

Accumulated precipitation at EWGLAM stations

Categorical forecasts of 12-hour accumulated precipitation at EWGLAM synoptic stations are verified by applying 2x2 contingency tables

Forecast	Observed	
	Yes	No
Yes	a	b
No	c	d

Probability of Detection: $$POD = \frac{a}{a+c}$$

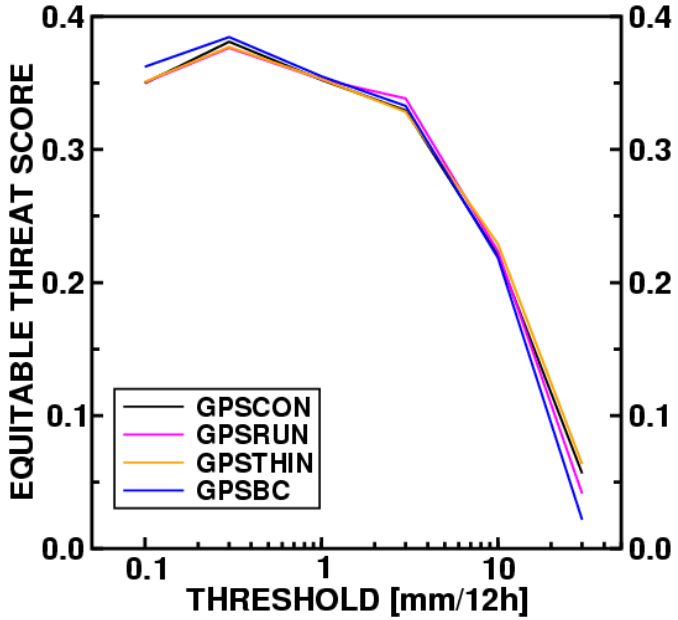
False Alarm Rate: $$FAR = \frac{b}{a+b}$$

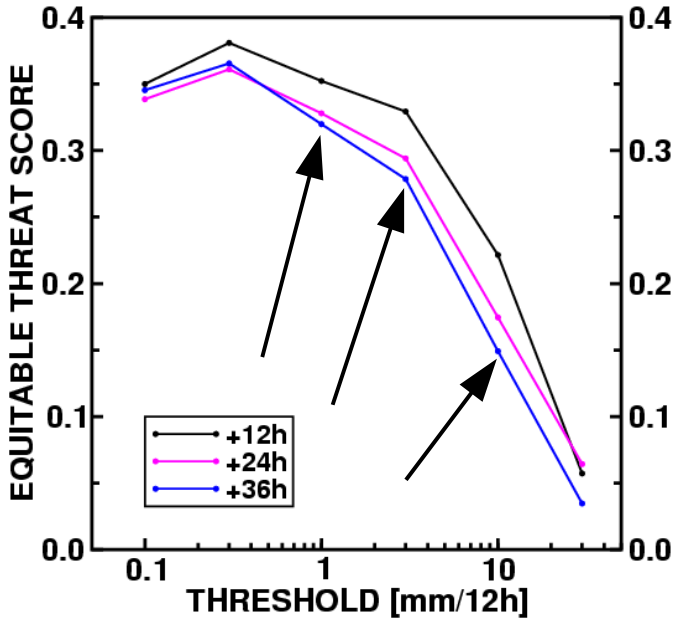
True Skill Score: $$TSS = POD - FAR = \frac{a}{a+c} - \frac{b}{a+b}$$

Equitable Threat Score: $$ETS = \frac{a - a_r}{a+b+c-a_r}$$

$$a_r = \frac{(a+b)(a+c)}{a+b+c+d}$$

Verification of categorical forecasts





An initial inspection reveals differences in the categorical forecast scores between the model runs

Thresholds 1, 3 and 10 mm/12h are chosen for the verification of 12-, 18- and 24-hour forecasts of accumulated precipitation

Verification of categorical forecasts

12-hour forecasts

		≥1 mm	≥3 mm	≥10 mm
Probability of Detection	control run	.794	.648	.433
	regular GPS run	+.008	+.020	+.005
	thinned GPS run	+.002	+.010	+.019
	bias-corrected GPS run	-.008	-.012	-.019
False Alarm Rate	control run	.507	.523	.656
	regular GPS run	+.002	-.004	-.003
	thinned GPS run	.000	+.006	-.006
	bias-corrected GPS run	-.005	-.011	-.007
True Skill Score	control run	.287	.126	-.223
	regular GPS run	+.006	+.024	+.008
	thinned GPS run	+.002	+.004	+.025
	bias-corrected GPS run	-.003	-.001	-.011
Equitable Threat Score	control run	.352	.329	.221
	regular GPS run	.000	+.009	+.003
	thinned GPS run	+.001	-.001	+.008
	bias-corrected GPS run	+.003	+.003	-.002

Verification of categorical forecasts

18-hour forecasts

		≥1 mm	≥3 mm	≥10 mm
Probability of Detection	control run	.766	.620	.384
	regular GPS run	+.012	+.013	-.016
	thinned GPS run	+.011	-.004	-.025
	bias-corrected GPS run	-.003	-.004	-.007
False Alarm Rate	control run	.515	.537	.674
	regular GPS run	+.006	+.009	+.009
	thinned GPS run	+.005	+.009	+.021
	bias-corrected GPS run	+.001	-.001	+.008
True Skill Score	control run	.251	.083	-.290
	regular GPS run	+.005	+.003	-.024
	thinned GPS run	+.006	-.012	-.046
	bias-corrected GPS run	-.004	-.003	-.014
Equitable Threat Score	control run	.337	.310	.198
	regular GPS run	-.003	-.003	-.008
	thinned GPS run	-.002	-.007	-.017
	bias-corrected GPS run	-.002	-.001	-.005

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Verification of categorical forecasts

24-hour forecasts

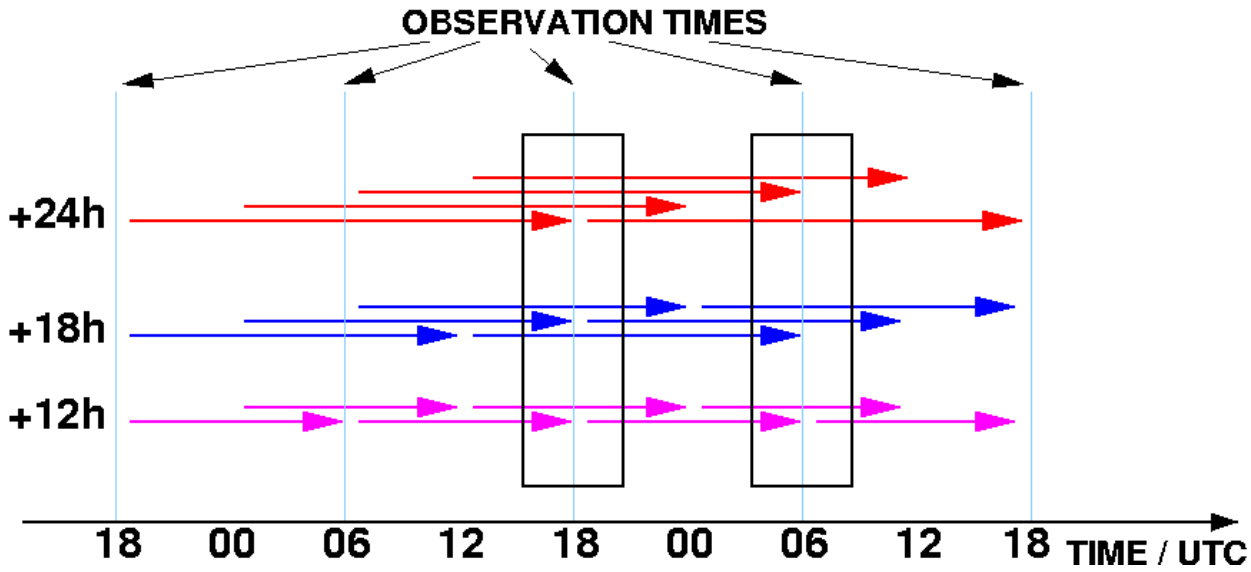
		≥1 mm	≥3 mm	≥10 mm
Probability of Detection	control run	.761	.606	.349
	regular GPS run	+.012	+.012	+.016
	thinned GPS run	+.012	+.009	+.032
	bias-corrected GPS run	-.002	-.008	+.021
False Alarm Rate	control run	.524	.554	.706
	regular GPS run	-.007	-.001	-.002
	thinned GPS run	-.001	+.004	-.006
	bias-corrected GPS run	-.008	+.001	-.013
True Skill Score	control run	.237	.051	-.357
	regular GPS run	+.020	+.014	+.018
	thinned GPS run	+.014	+.005	+.038
	bias-corrected GPS run	+.006	-.008	+.034
Equitable Threat Score	control run	.328	.294	.173
	regular GPS run	+.010	+.005	+.005
	thinned GPS run	+.004	.000	+.011
	bias-corrected GPS run	+.007	-.003	+.012

Verification of categorical forecasts

Conclusions

In general, the impact of GPS data assimilation is positive in 12- and 24-hour forecasts, but neutral or negative in 18-hour forecasts

→ *a possible consequence of observing practices at the synoptic and radiosonde stations*



Verification of categorical forecasts

Conclusions

The horizontal thinning is most beneficial when high precipitation accumulations are considered

The bias correction does not systematically improve verification scores

Overall conclusions

The impact of GPS data assimilation in standard verification scores is small

- *specific humidity, temperature and geopotential height in the upper troposphere are systematically increased*

Verification of categorical forecasts of 12-hour accumulated precipitation shows a positive impact in 12- and 24-hour forecasts

- *this highlights the power of high sampling rate of GPS observations*

Horizontal thinning improves forecasts in cases of heavy precipitation

ZTD observation bias correction decreases forecast humidity and precipitation but does not provide a clear impact on verification scores