Impact of data assimilation on short-term precipitation forecasts using WRF-ARW model

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Sozopol, Bulgaria

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Motivation

Importance of modelling precipitation

Population in urban areas:

- Flash flooding (including cases with light to moderate rain for several days)
- Thunderstorms

Air traffic:

- Dangerous working environment
- Intensive precipitation reduces visibility
- Reduced traffic and consequently losing profit

Transport system

Agriculture, Insurance and Reinsurance and etc.

How to represent the weather system state better?

★ *Good weather forecast depends on the well knowledge of the current state of the weather system.*

★ *Small uncertainty in initial conditions means good forecast*

★ *Greater uncertainties degrades the long-term weather forecasts.*

★ *DA gives useful tool for weather forecast improving*

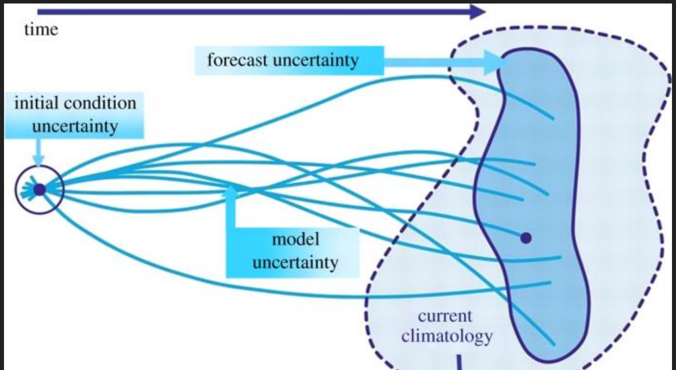
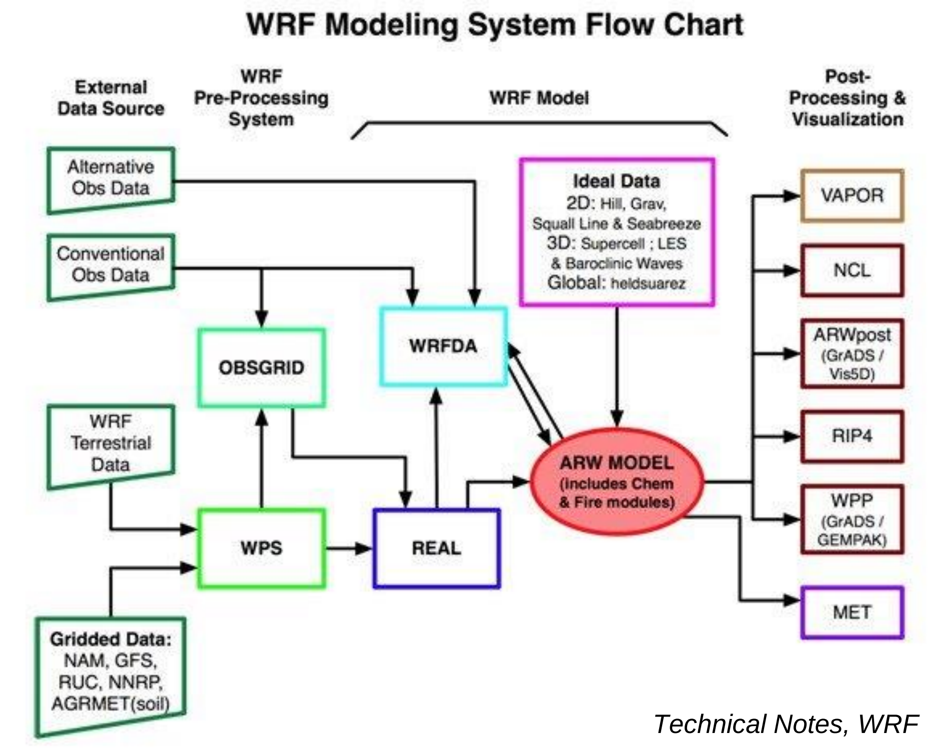


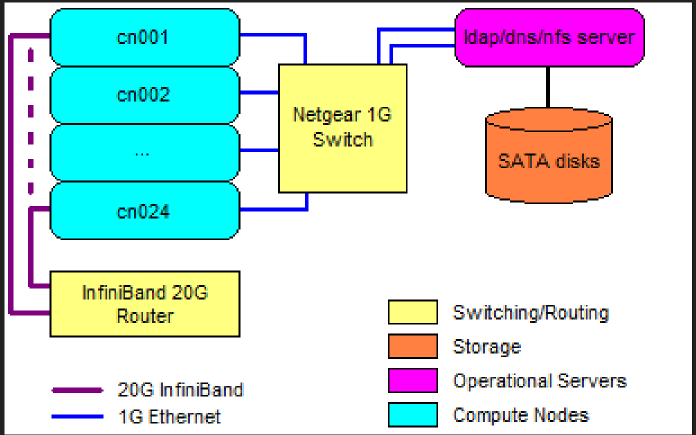
Image courtesy: The Royal Society

WRF ARW model v3.8



WRF model is a next-generation mesoscale numerical weather prediction system designed for both atmospheric research and operational forecasting applications. It features two dynamical cores, a data assimilation system, and a software architecture supporting parallel computation and system extensibility. The model serves a wide range of meteorological applications across scales from tens of meters to thousands of kilometers.

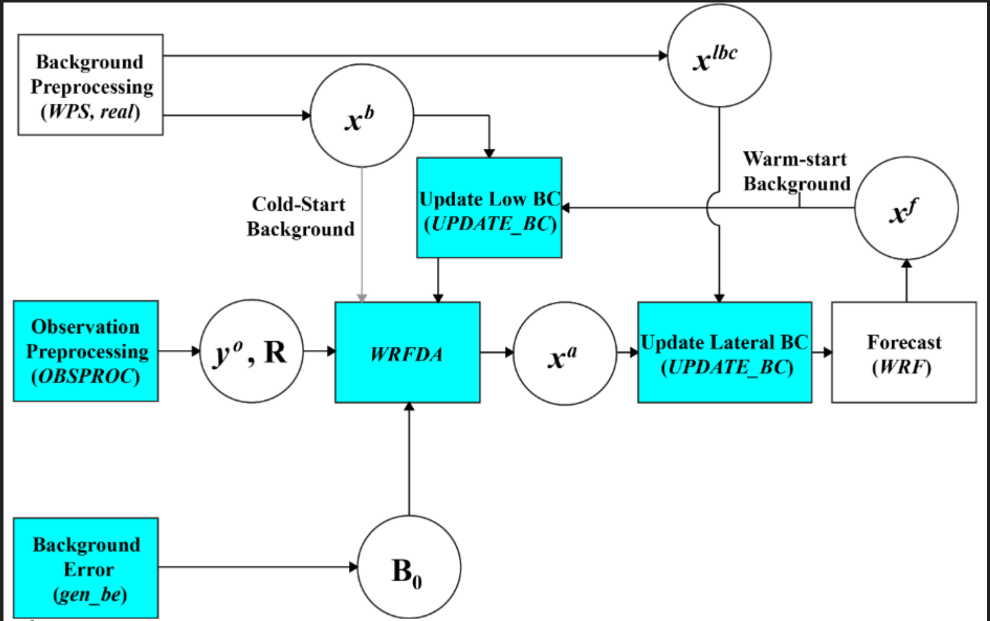
HPC system: PHYSON - 216 cores high performance linux cluster



Physon Cluster - Physics Faculty, Sofia University
http://physon.phys.uni-sofia.bg/hardware-en

WRFDA module in the WRF modeling system

What is data assimilation in brief?



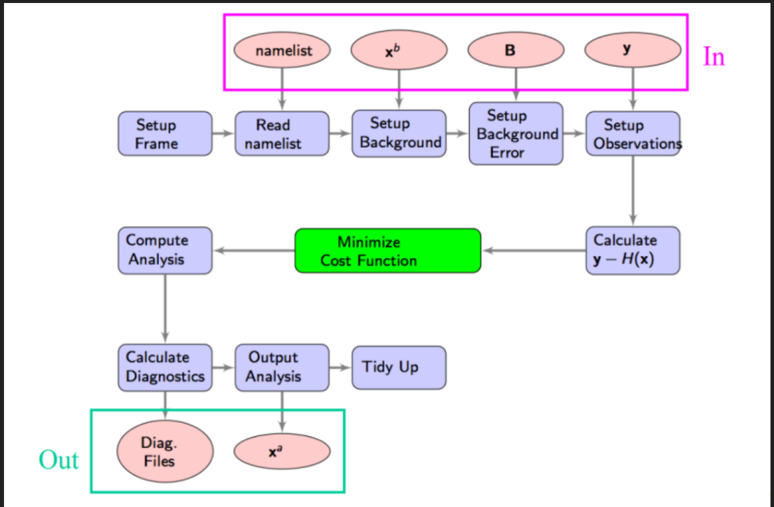
x^b	first guess, either from a previous WRF forecast or from WPS/real.exe output.
x^{lbc}	lateral boundary from WPS/real.exe output.
x^a	analysis from the WRFDA data assimilation system.
x^f	WRF forecast output.
y^o	observations processed by OBSPROC
$\mathbf{B}_0$	background error statistics from generic BE data (CV3) or gen_be.
$\mathbf{R}$	observational and representative error statistics.

Running WRFDA module:

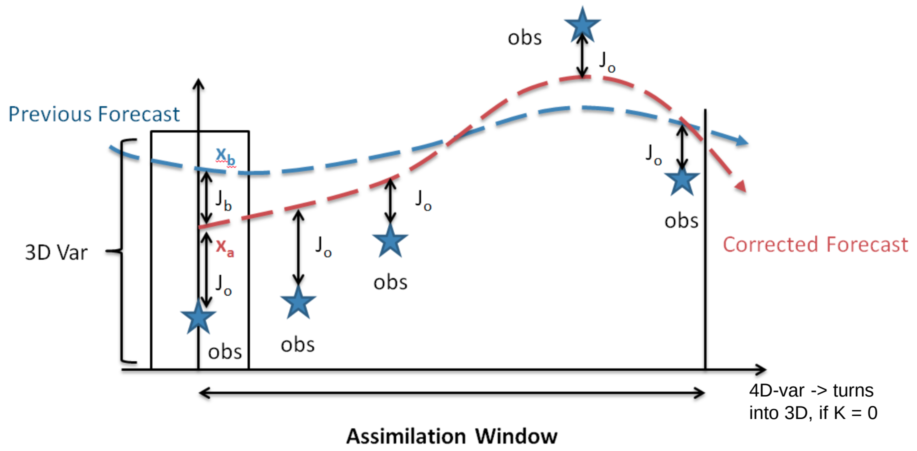
1) Linux (preferably with INTEL compilers, on intel processors)

2) Libraries:

- NETCDF (network data common form)
- BUFR (Binary universal form for representing meteorological data) for conventional data
- CRTM (Community radiative transfer model) for assimilating brightness temperature



WRFDA module: 3D-var vs 4D-var assimilation method?



$$J(\mathbf{x}) = \frac{1}{2}(\mathbf{x}_0 - \mathbf{x}_0^b)^T \mathbf{B}_0^{-1}(\mathbf{x}_0 - \mathbf{x}_0^b) + \frac{1}{2}\sum_{k=0}^{K}(\mathbf{y}_k - \mathbf{H}_k\mathbf{x}_k)^T \mathbf{R}_k^{-1}(\mathbf{y}_k - \mathbf{H}_k\mathbf{x}_k)$$

X_a = model variable $\quad J_o$ = distance to observations

X_b = background field $\quad J_b$ = distance to forecast

4D-var aims to find the best estimate of the true state of the system (analysis), consistent with both observations distributed in time and the system dynamics.

In this case we can consider the observation operator to include the dynamical model.

3D-var assimilation method equation

$$J(\mathbf{x}) = \frac{1}{2}(\mathbf{x}-\mathbf{x}_b)^T \mathbf{B}^{-1}(\mathbf{x}-\mathbf{x}_b) + \frac{1}{2}(\mathbf{y}-H(\mathbf{x}))^T \mathbf{R}^{-1}(\mathbf{y}-H(\mathbf{x}))$$

***J*(x)**: Scalar cost function

x: The analysis: what we're trying to find!

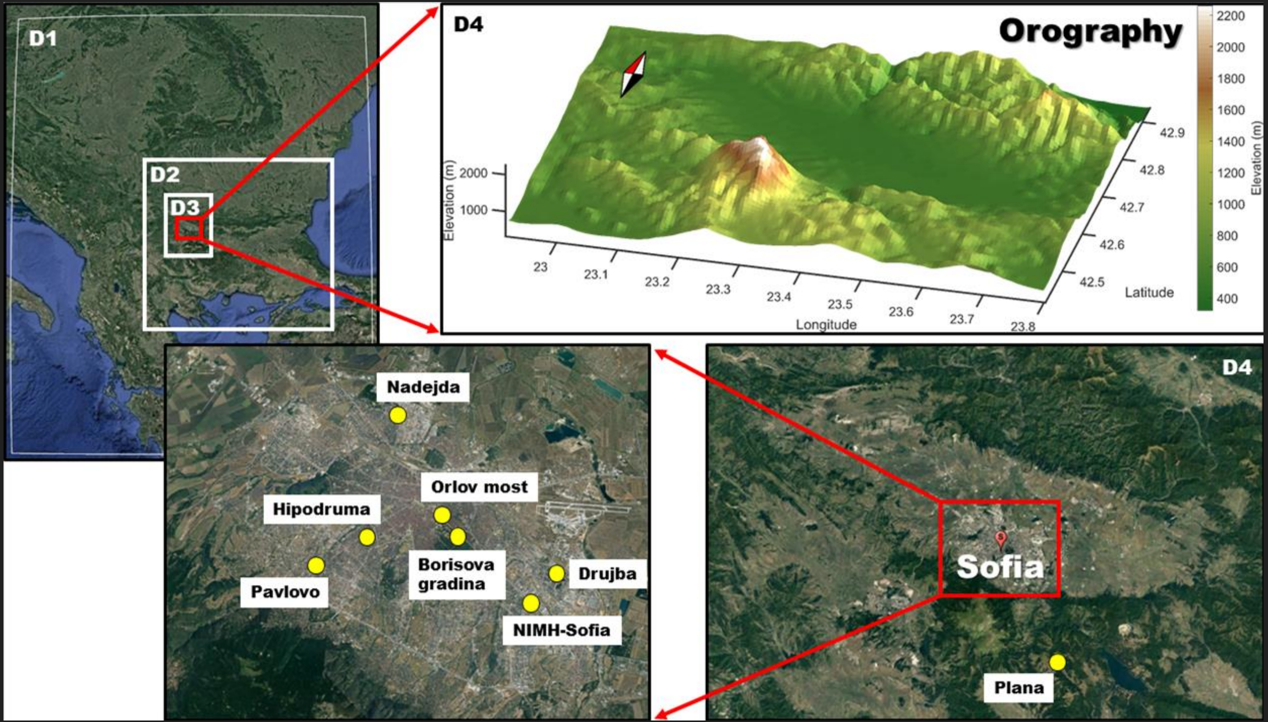
$\mathbf{x}_b$: Background field

B: Background error covariance matrix

y: Observations

H: Observation operator: computes model-simulated obs

WRF model set up



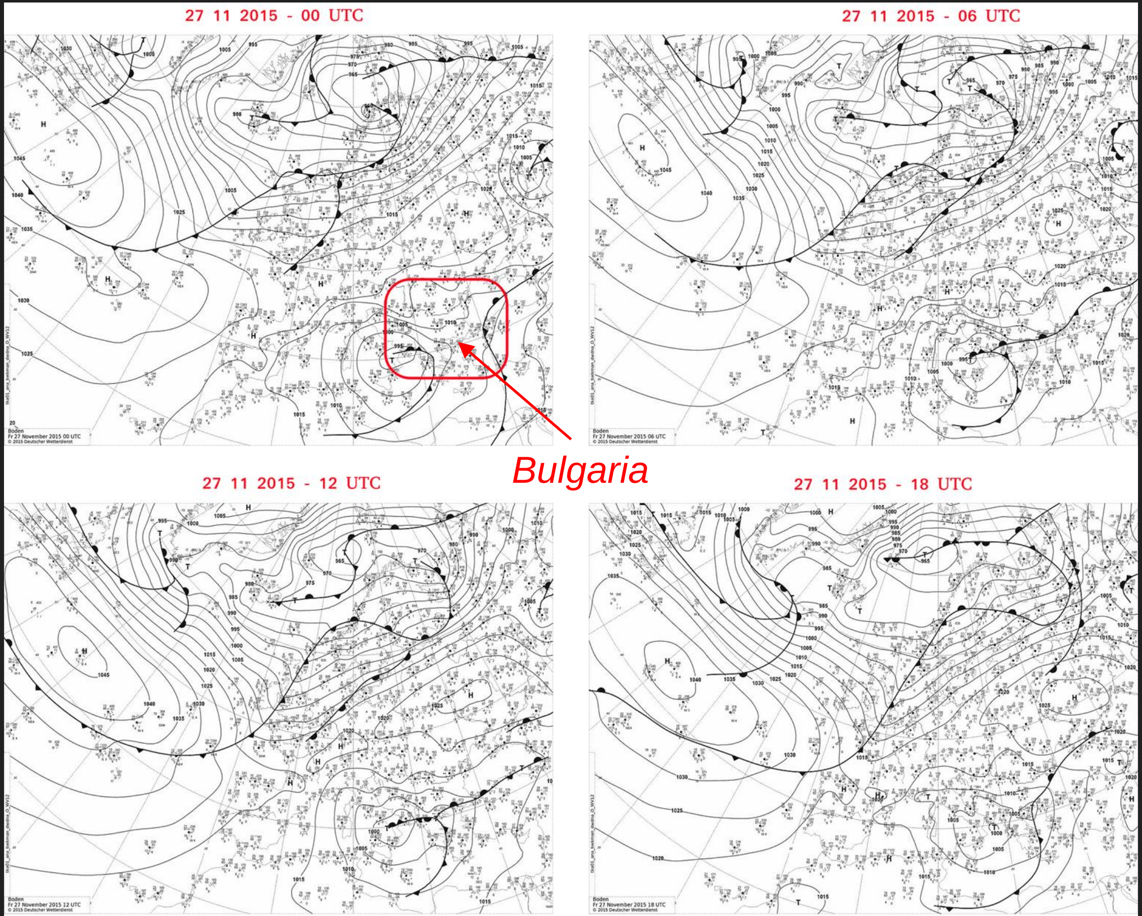
Configuration:

- Lambert projection (23.4°E, 42.68°N)
- 4 nested domains with grid sizes of 32, 8, 2 and 0.5 km
- Resolution of the inner domain: 157x129x51 (~78 km X ~65 km)

Parametrization:
Radiation: RRTM and Dudhia schemes
Moisture: Lin et al. scheme
PBL: Yonsei University scheme
Land surface: Noah Land Surface Model

- Topography: High terrain resolution 1-arcsec: https://lta.cr.usgs.gov/SRTM1Arc
- Land-cover: High land-use resolution 3-arcsec: Corine adopted to USGS classes: http://land.copernicus.eu/pan-european/corine-land-cover/clc-2012
- Input data: NCEP 6-h operational forecast grid at 0.25 deg resolution: http://rda.ucar.edu/datasets/ds083.1;

Study case - 27.11.2015



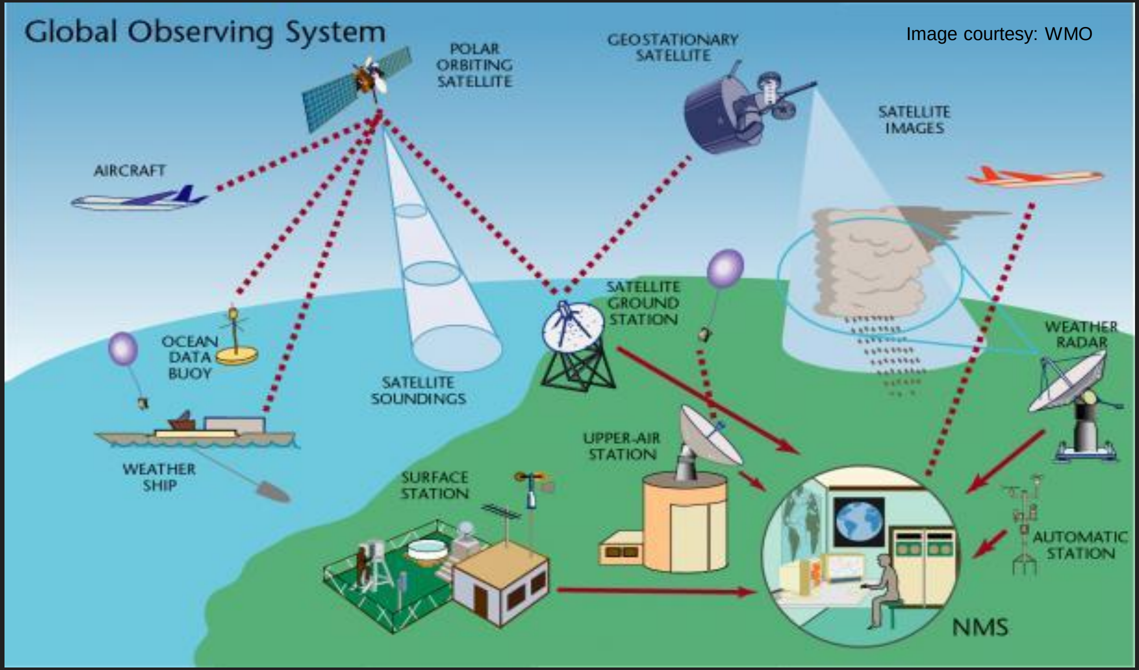
A well-defined low pressure system over the Ionian sea

South-western flow transport warm and humid air mass over the Balkan peninsula and Sofia valley

An occlusion front is situated over Bulgaria; rain event with maximum intensity on 27.11.2015 from 12 until 17:00 UTC

Bad weather conditions caused difficulties in air traffic and in electricity provision.

Data used in assimilation - conventional and satellite based observations



Observations used in the case are valid for 12:00 UTC

The observation data have to be transformed if they are not represented explicitly, e.g. temperature, relative humidity, wind speed etc

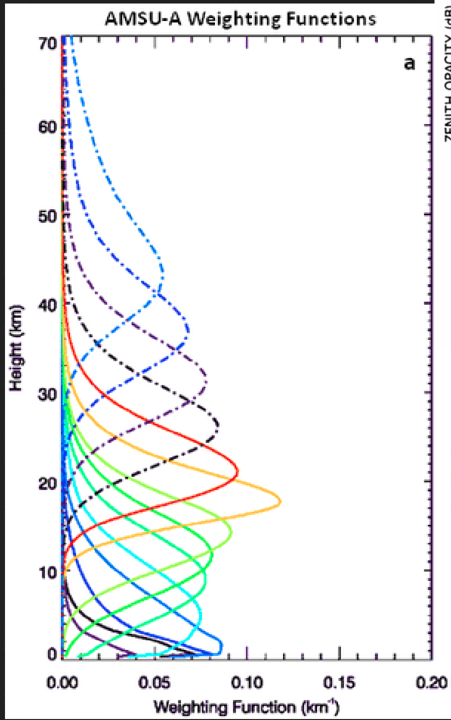
For example satellite radiance > radiative transfer model > brightness temperature > observation operator = model level + model grid point

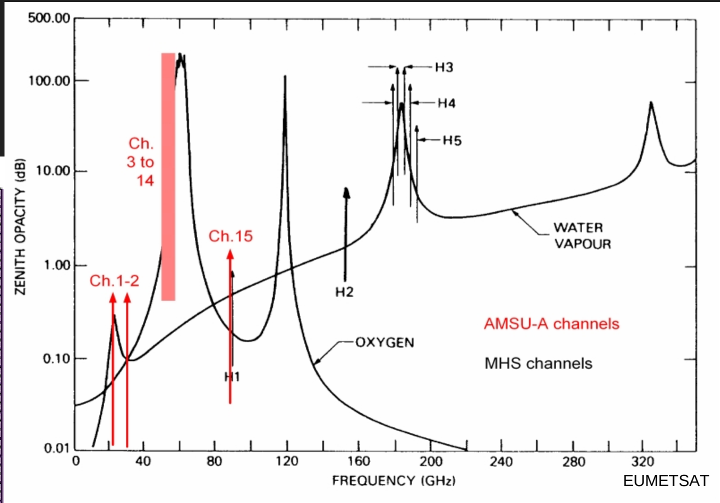
Conventional observations	D1	D2	D3	D4
Sounding reports	9	1	1	1
Synoptic reports	359	58	4	2
Geostationary satellite atmospheric motion vectors	480	90	3	0
GPS Refractivities	300	0	0	0
METAR reports	99	15	1	1
Ship reports	7	0	0	0

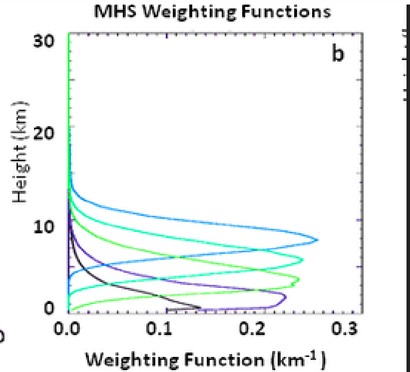
Satellite instruments

D1	D2	D3	D4
noaa19-amsua	noaa19-amsua	noaa19-amsua	noaa19-amsua
eos2-airs	eos2-airs	-	-
eos2-amsua	eos2-amsua	eos2-amsua	eos2-amsua
jpss0-atms	jpss0-atms	jpss0-atms	jpss0-atms
noaa19-mhs	noaa19-mhs	noaa19-mhs	-

Satellite data assimilation - how to extract data from satellite observations





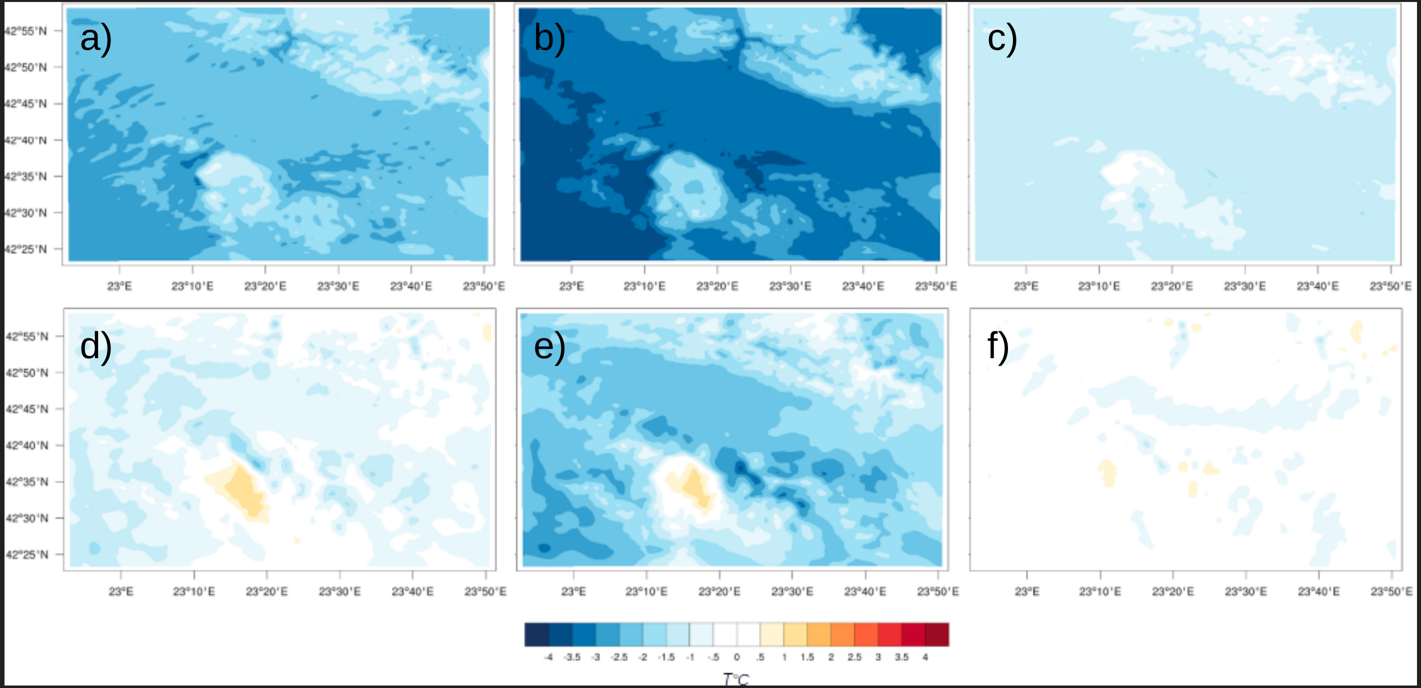


AMSU A microwave radiometer:
AMSU-A is a multi-channel microwave radiometer which measure scene radiances in 15 discreet frequency channels (23-90 GHz)

MHS a microwave humidity sounder:
The Microwave Humidity Sounder (MHS) is a self-calibrating, cross-track scanning, five-channel microwave, full-power radiometer, operating in the 89 to 190 GHz region.

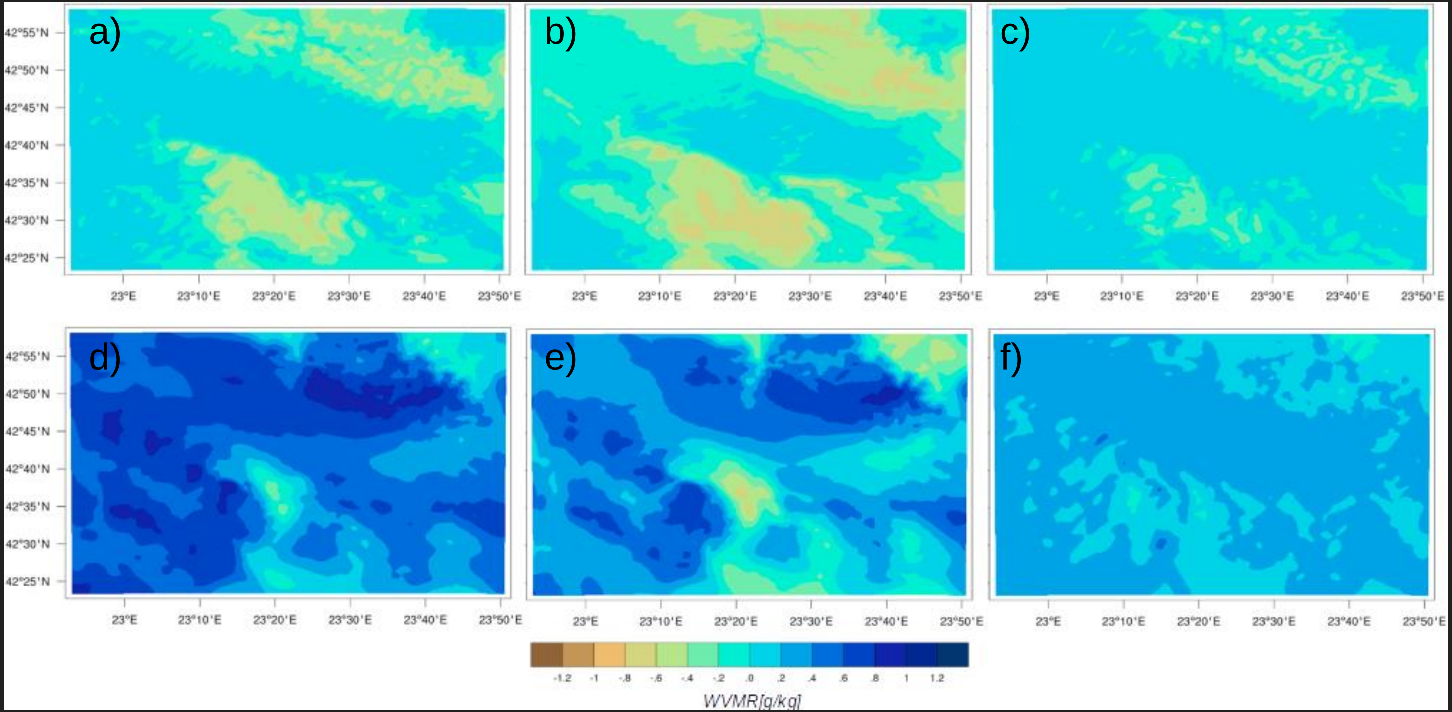
Impacts of AMSU-A, MHS and IASI data assimilation on temperature and humidity forecasts with GSI–WRF over the western United States

Temperature at near surface level and at 850 hPa (~1500m)



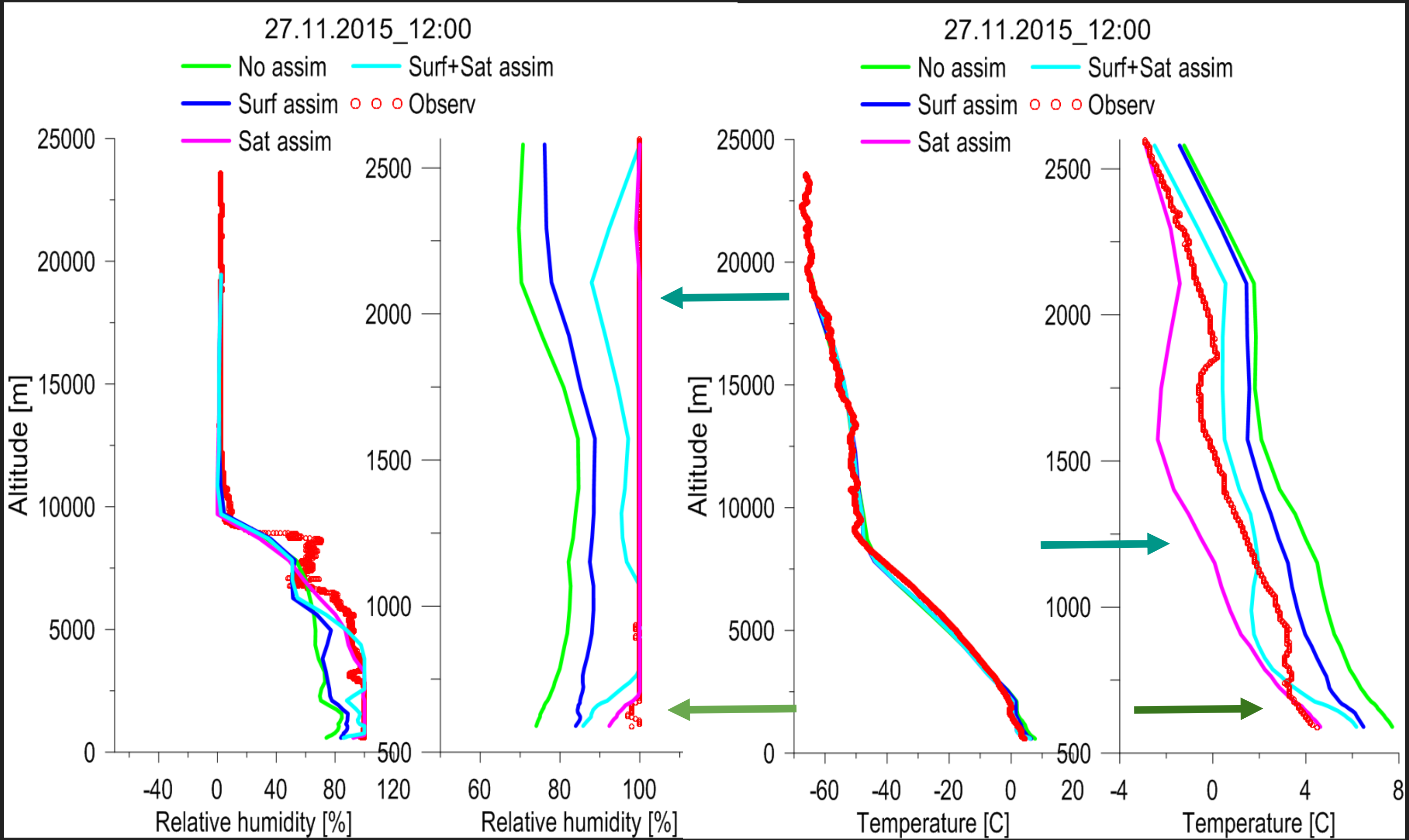
Temperature (T) field differences at first sigma model level (~10 m) c); and at the 30-th sigma model level (~1500 m) - d), e), f). T field difference the case with all data assimilation and the field without assimilation (a, d); satellite observations assimilation and the field without assimilation (b, e); non-satellite data assimilation and the field without assimilation

Water vapour mixing ratio - at near surface and at 850 hPa (~1500m)



WVMR field differences at first sigma model level (~10 m) - a), b), c); and at the 30-th sigma model level (~1500 m) - d), e), f). WVMR difference between assimilated all data and without assimilated data (a, d); between satellite observations assimilation and without assimilation (b, e); between non-satellite data assimilation and without

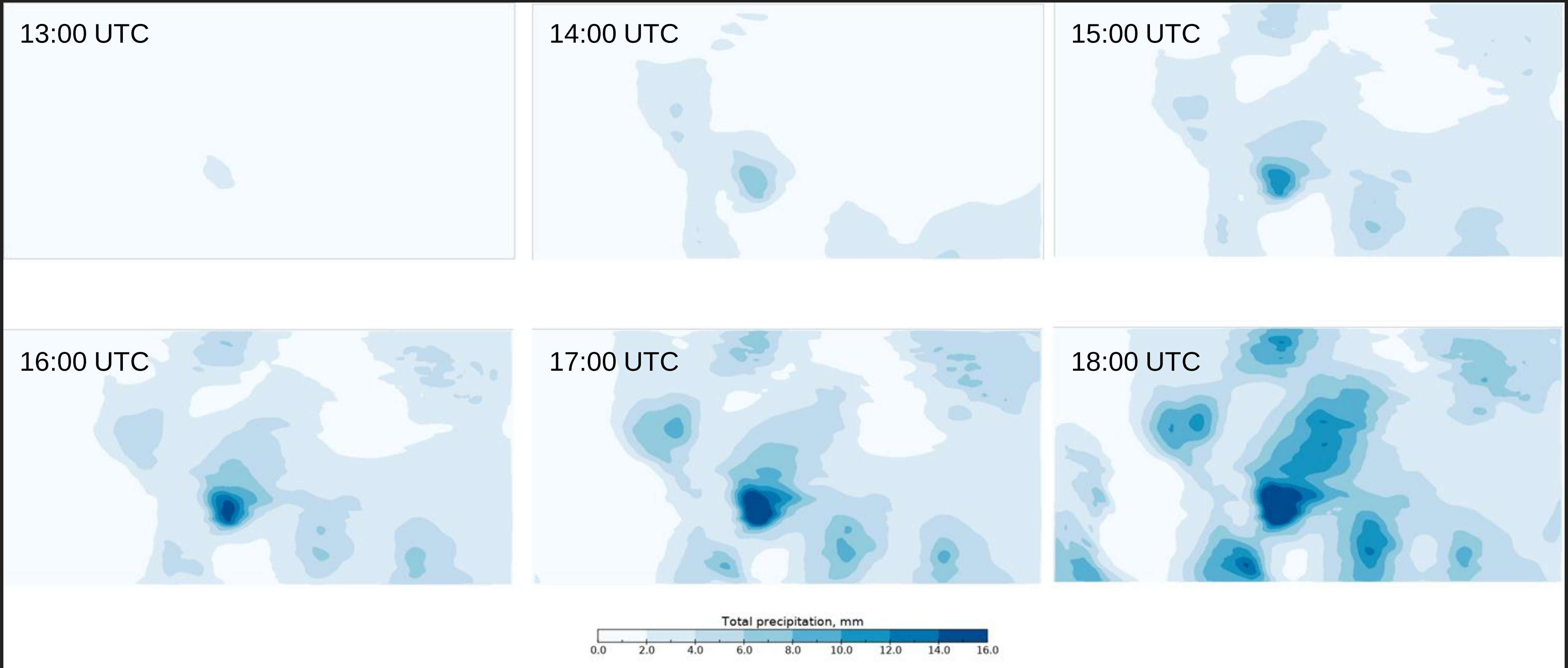
Vertical profiles from actual radiosounding compared to model results at NIMH Sofia site



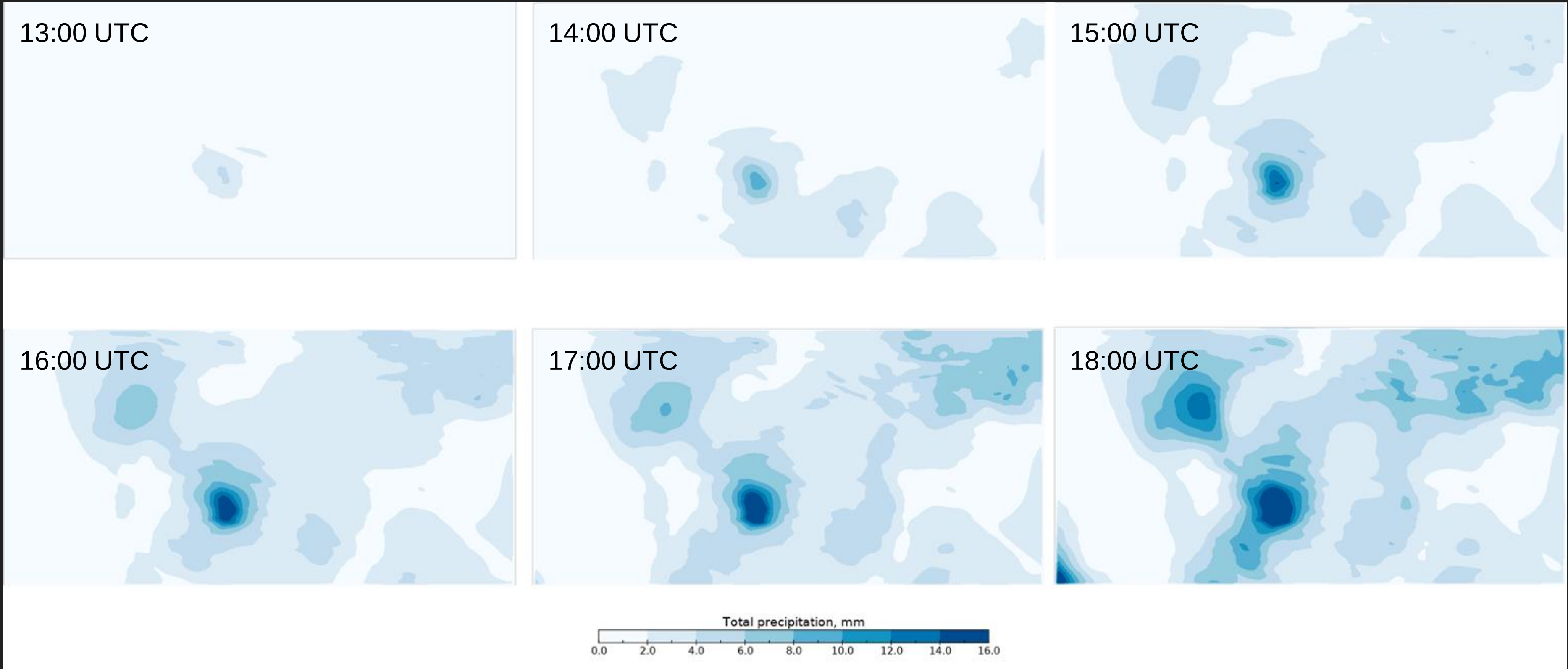
The radiosounding is provided only once per day (at 12:00 UTC) at NIMH Sofia in 2015

Simulations with assimilated only *satellite data* represents better humidity and temperature profiles in the lower layers – *very good forecasting for precipitation!*

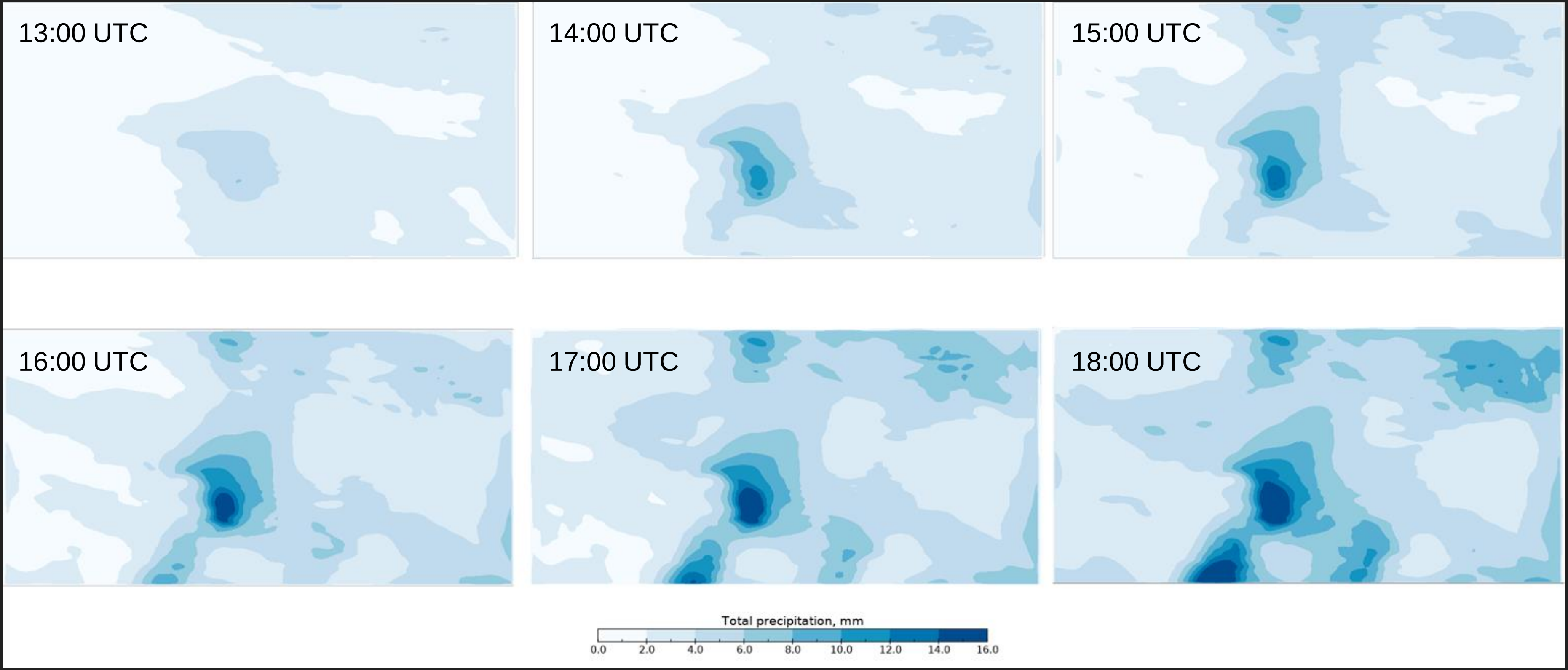
Simulated precipitation - without data assimilated



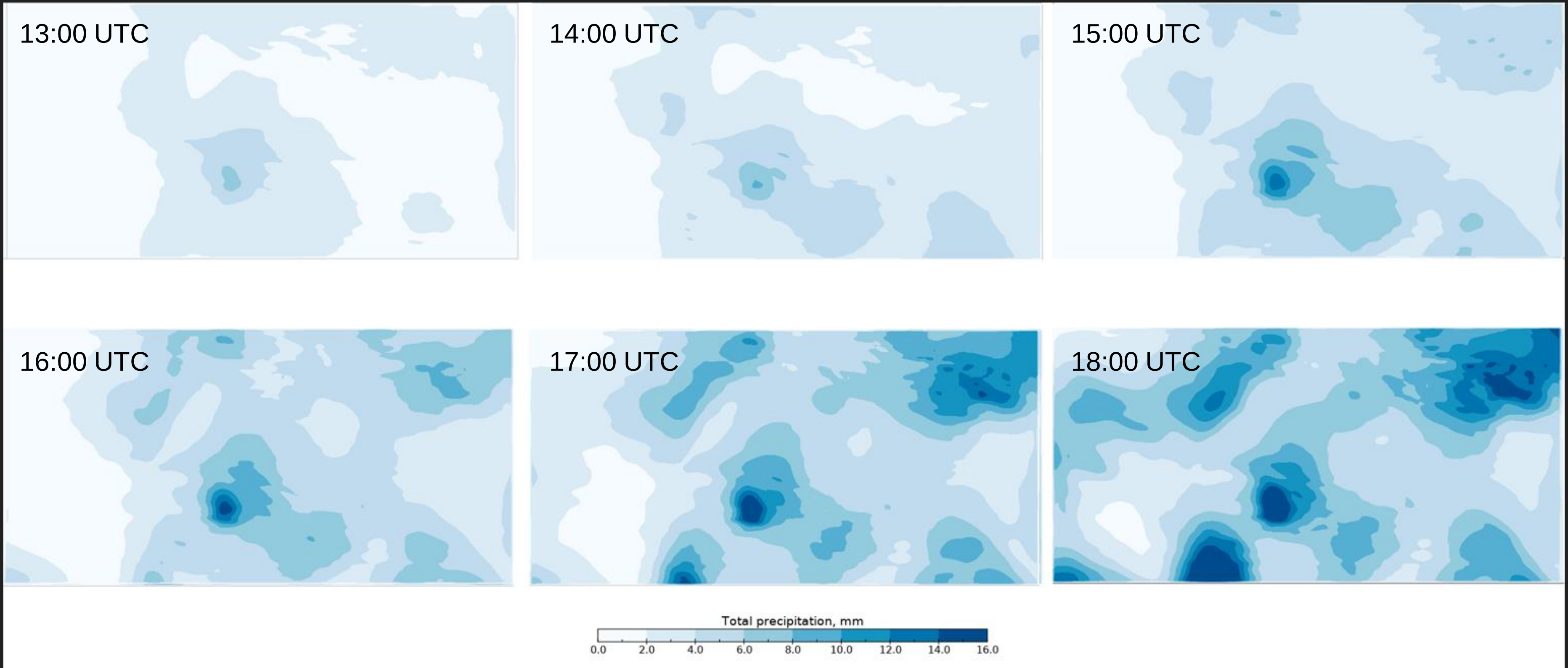
Simulated precipitation - conventional data assimilated



Simulated precipitation - satellite based instruments data assimilated

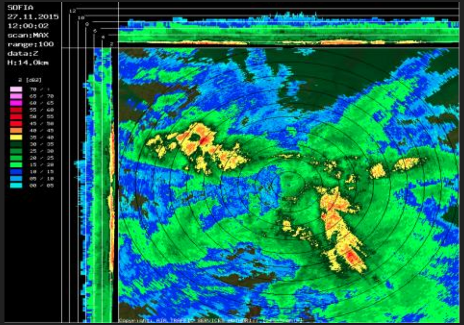


Simulated precipitation - conventional and satellite based instruments data assimilated

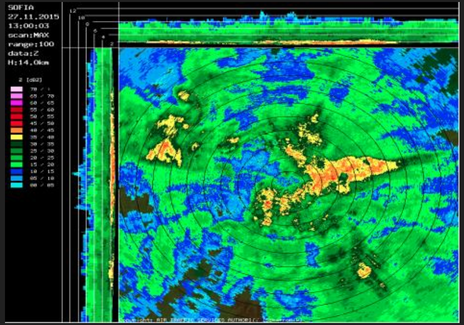


Spatial distribution of precipitation from actual Doppler weather radar data (larger data interval was taken for better representation)

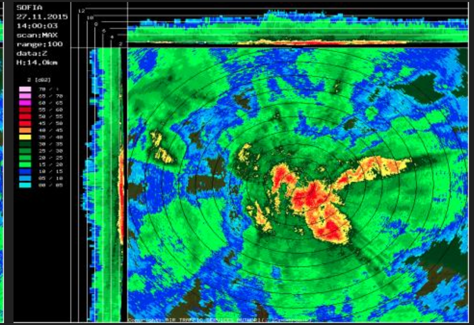
12:00 UTC



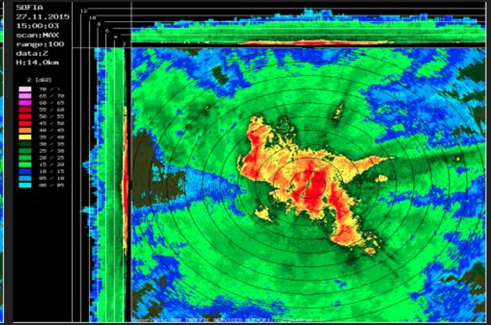
13:00 UTC



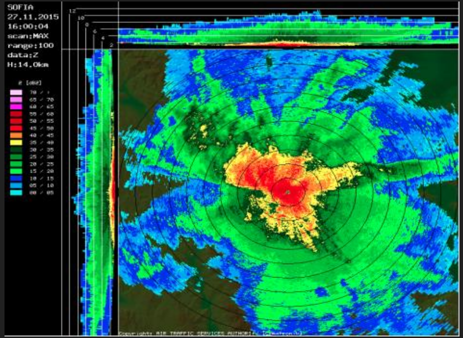
14:00 UTC



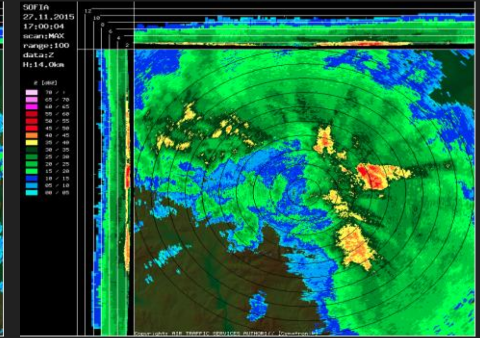
15:00 UTC



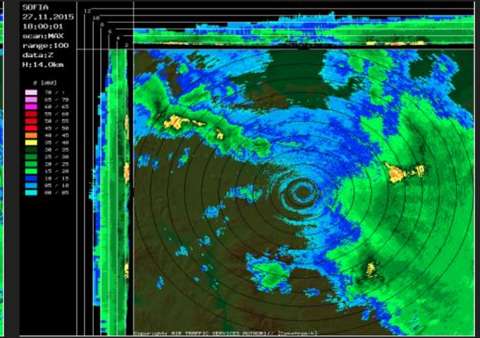
16:00 UTC



17:00 UTC



18:00 UTC



19:00 UTC

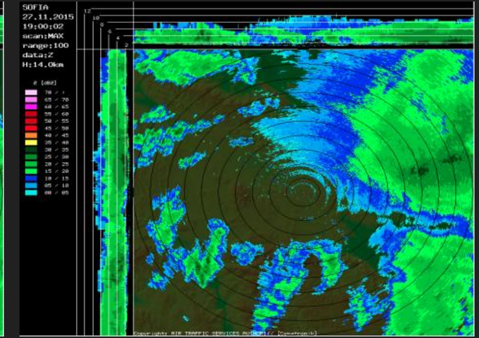


Image source: BULATSA

METAR reports from Sofia airport

SA 27/11/2015 12:00->
METAR LBSF 271200Z 34004KT 2800 RA OVC004 06/06 Q1008 TEMPO 1200 RA BKN002=

SA 27/11/2015 12:30->
METAR LBSF 271230Z 36004KT 4800 -RA SCT005 OVC007 05/04 Q1008 RERA TEMPO 1200 RA BKN002=

SA 27/11/2015 13:00->
METAR LBSF 271300Z 02005KT 7000 -RA FEW005 BKN007 OVC014 05/04 Q1007 TEMPO 1200 RA BKN002=

SA 27/11/2015 13:30->
METAR LBSF 271330Z 30003KT 260V340 9999 -DZ OVC008 04/03 Q1007 NOSIG=

SA 27/11/2015 14:00->
METAR LBSF 271400Z VRB02KT 8000 -RA SCT006 SCT012 OVC016 04/03 Q1007 NOSIG=

SA 27/11/2015 14:30->
METAR LBSF 271430Z VRB01KT 7000 -RA FEW009 SCT012 OVC016 07/06 Q1007 NOSIG=

SA 27/11/2015 15:00->
METAR LBSF 271500Z 11002KT 5000 RA OVC017 05/04 Q1007 NOSIG=

SA 27/11/2015 15:30->
METAR LBSF 271530Z 12005KT 5000 RA FEW006 BKN015 OVC022 05/05 Q1006 NOSIG=

SA 27/11/2015 16:00->
METAR LBSF 271600Z 15005KT 5000 RA FEW014 BKN016 OVC038 05/05 Q1006 NOSIG=

SA 27/11/2015 16:30->
METAR LBSF 271630Z 15008KT 4600 RA SCT015 BKN020 OVC024 06/06 Q1007 NOSIG=

SA 27/11/2015 17:00->
METAR LBSF 271700Z 06006KT 030V090 9999 RA FEW009 SCT012 OVC016 04/03 Q1006 NOSIG=

SA 27/11/2015 17:30->
METAR LBSF 271730Z 36003KT 300V050 8000 -RA FEW004 OVC017 05/05 Q1006 NOSIG=

SA 27/11/2015 18:00->
METAR LBSF 271800Z 32003KT 290V010 9999 -RA FEW006 SCT017 OVC025 04/03 Q1006 NOSIG=

SA 27/11/2015 18:30->
METAR LBSF 271830Z 04006KT 9999 SCT021 OVC024 04/03 Q1006 NOSIG=

SA 27/11/2015 19:00->
METAR LBSF 271900Z 05007KT 9999 OVC022 04/03 Q1006 NOSIG=

The precipitation has started at 12:00 UTC

High intensive precipitation from 15:00 UTC to 17:00 UTC

The precipitation has ended at 18:00 UTC

Results & Conclusions

- Data assimilation experiment has been conducted for a case with an excessive precipitation for the Sofia region
  - Four assimilation scenarios were tested:
    - No data assimilation was employed
    - Only conventional observations were assimilated
    - Data acquired from satellite based instruments was assimilated
    - All available data was assimilated
  - A qualitative comparison was made with Doppler radar and METAR reports
- More data assimilated with the initial conditions – better representation of the actual state of the atmosphere
- Satellite data assimilation improves the temperature and relative humidity prediction for Sofia region, especially at lower altitudes.
- 3D-var data assimilation method could be used to improve prediction of temperature and humidity, which are crucial for the precipitation forecasts in Sofia region.
- Future research – to include better BE files for the specific domain with specific parametrization settings of the modeled area.

Acknowledgements:

This research is developed within the scope of the project DN4/7 (Study of the PBL structure and dynamics over complex terrain and urban area), funded by Research Fund at the Bulgarian Ministry of Education and Science.

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Thank you for your attention!