Cloud parameterization and cloud prediction scheme in Eta numerical weather model

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Introduction

- Models that have radiation effect included describe condensation with diagnostic formulations give little regard to consistency with model-produced condensation fields.
- Sundqvist, et al. (1988) had proposed parameterization scheme for convective and stratiform condensation that is using **cloud water and cloud fraction** as prognostic variables:

  - Good results when it comes to cloud water and precipitation forecasts.
  - Formulation of fractional cloud cover depended only on the relative humidity, due to that, amount of low fraction cloud cover were unpredicted.
  - The amount of model cloud water had magnitude that possibly was unrealistically large.
  - Because of this inconsistency, formula for fractional cloud cover did not produce good results when used in radiation scheme. This was the reason why the diagnostic formulation started to be used again.

Introduction

- New scheme implemented in the Eta model is based on using three prognostic equations:
  - fractional cloud cover,
  - cloud mixing ratio and
  - snow per cloud fraction.
- New fractional cloud cover formula, in addition to relative humidity, has cloud mixing ratio included.
- Adding new prognostic variable into the equation gives much more realistic description of cloud cover.
- Clouds predicted like this can be used in the model radiation calculations.

Thermodynamic wet bulb concept

- Thermodynamic wet bulb temperature as cloud temperature.

- Energy balance:

$$c_p \cdot T_s + L \cdot q_s\,(T_s) = c_p \cdot T + L \cdot q$$

- Moist static energy of model grid box and cloudy part inside the grid box stays the same. Principle of energy conservation is satisfied.

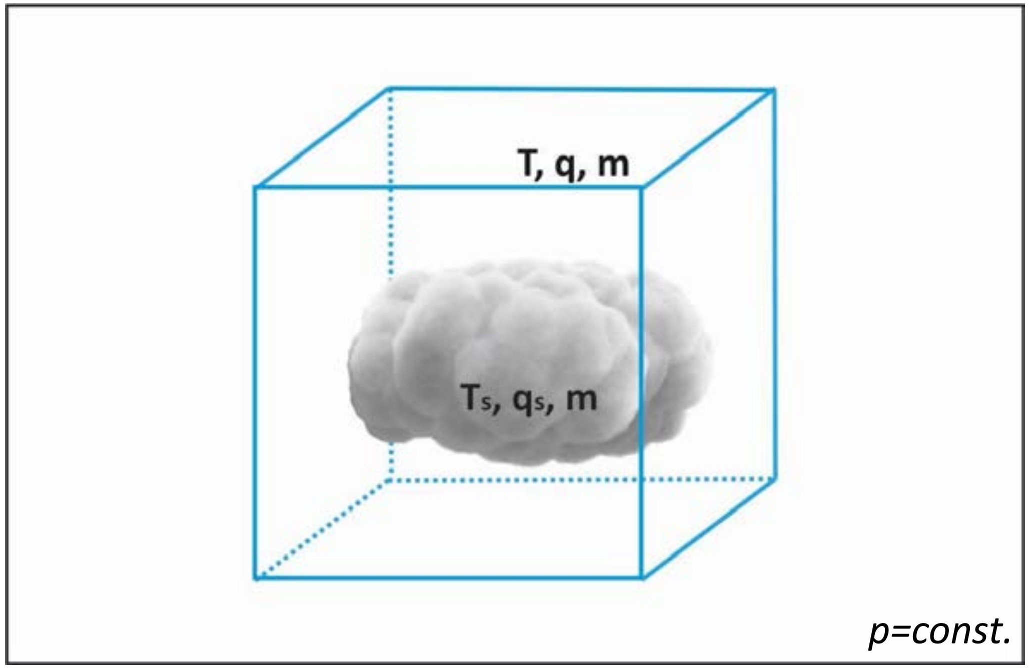

Figure 1. Grid box and cloud part inside the grid box

Description of the cloud prediction scheme

- Simplified prognostic equations for specific humidity, *q* temperature, *T* and cloud water/ice (both cloud liquid water and cloud ice) mixing ratio *m* are:

$$\frac{\partial q}{\partial t} = A_q - Q$$

$$\frac{\partial T}{\partial t} = A_T + \frac{L}{C_p} Q$$

$$\frac{\partial m}{\partial t} = A_m + Q$$

Description of the cloud prediction scheme

- Saturated specific humidity in cloud scheme is expressed as function of wet bulb temperature, $q_s^* = \ q_s(T_s)$

- The advantage of this approach is that saturated specific humidity is constant during water phase changes and can be written with advection tendencies part only:

$$\frac{\partial q_s^*}{\partial t} = A_{q_s^*}$$

- Relative humidity that is used in the scheme is presented with:

$$U^* = \frac{q}{q_s^*}$$

Description of the cloud prediction scheme

- Change of specific humidity can be expressed as:

$$\frac{\partial q}{\partial t} = \frac{\partial (U^* q_s^*)}{\partial t} = U^* \frac{\partial q_s^*}{\partial t} + q_s^* \frac{\partial U^*}{\partial t}$$

- Using prognostic equation for specific humidity and combining it with previous equation, we can obtain:

$$Q = A_q - \frac{\partial (U^* q^*)}{\partial t} = A_q - U^* \frac{\partial q_s^*}{\partial t} - q_s^* \frac{\partial U^*}{\partial t}$$

$$Q = M - q_s^* \frac{\partial U^*}{\partial t}$$

Description of the cloud prediction scheme

- M represents the convergence of available latent heat (s^{-1}) into the grid box, given as:

$$M = A_q - U^* \frac{\partial q_s^*}{\partial t} = A_q - U^* A_{q_s^*}$$

- The quantity M in a grid box is divided into two parts: one part goes into the cloudy portion and condenses and another part goes to into the cloud-free portion and increase the relative humidity. These parts will be (respectively):

$$Q = bM$$

$$q_s^* \frac{\partial U^*}{\partial t} = (1 - b)M$$

Cloud formula

- Cloud fraction b at grid point can be estimate using relative humidity and cloud humidity:

$$b = b(U^*, U_m^*, U_{00}^*, U_s) = 1 - \sqrt{(U_s - U^*)/(U_s + U_m^* - U_{00}^*)}$$

- U_{00}^* is critical relative humidity in function of wet bulb temperature.
- Cloud fraction b can be written also as:

$$b = 1 - \sqrt{(U_s - U^*)/(U_s - U^* + U^* + U_m^* - U_{00}^*)}$$

$$U^* \geq U_s \text{ » } b = 1$$

$$U_s + U_m^* - U_{00}^* = const. \leq \varnothing \text{ » } b = \varnothing$$

- $U^* < U_{00}^*$ **evaporation**, $U^* > U_{00}^*$ and $\mathrm{M} > 0$ **condensation**

Relation between U_{00}^{*} and U_{00}

- During water phase changes, temperature and specific humidity are changed to values T_{00} and q_{00}:

$$c_p \cdot T + L \cdot q = c_p \cdot T_{00} + L \cdot q_{00}$$

$$q_{00} = U_{00} \cdot q_s(T_{00}) = U_{00}^{*} \cdot q_s^{*}$$

- Finally, the relation between relative humidity and relative humidity as function of wet bulb temperature is:

$$U_{00}^{*} = U_{00} \cdot \frac{q_s(T_{00})}{q_s^{*}}$$

- Value of critical relative humidity changes with height. Near surface value of U_{00} is 0.95 and decreases with a height of up to a value of 0.80 over ocean, to avoid excessive condensation and 0.75 over land.

Cloud parameterization

- Stratiform clouds in this scheme consist of either liquid water or ice particles, depending on the thermodynamic ice bulb temperature (Ts).
- Parts of the cloud where $Ts \geq$ 0ºC consists only of liquid water, while in parts where Ts < -15ºC, the cloud consists of only ice particles (Figure 2).
- In the regions where -15ºC < Ts < 0ºC the phase of hydrometeors is determined by the cloud-top ice bulb temperature (Tp).
- If $Tp \geq -15$ ºC cloud consist of supercooled water if $Tp < -15$ ºC cloud consist of ice particles.

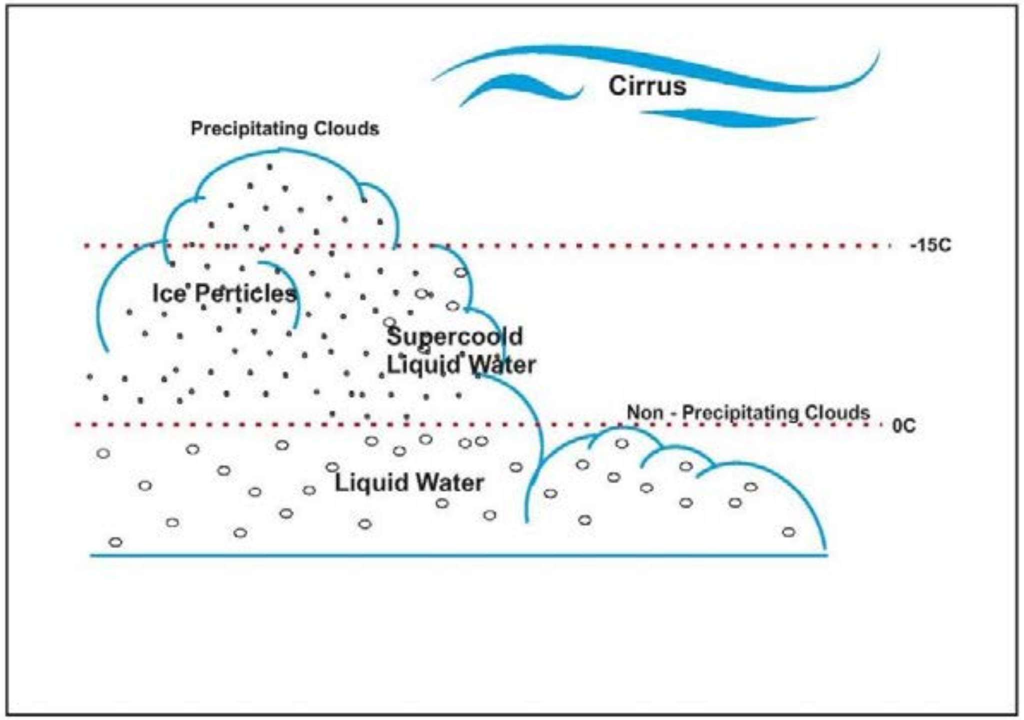

Figure 2. Distribution of cloud water and cloud ice inside the cloud

Precipitation

- **Autoconversion**
- $Praut = a_r \cdot (m - m_{i0})$
- $Psaut = a_s \cdot (m - m_{i0})$
- **Accretion and coalescence**
- $Pracw = m \cdot Cr \cdot (Pr + Ps)$
- $Psaci = m \cdot Cs \cdot Ps$
- **Evaporation and sublimation**
- $Err = evpr \cdot (q_{sw} - q)$
- $Ers = evps \cdot (q_{si} - q)$
- **Melting of the snow**
- $Psm = Psm_1 + Psm_2$
- $Psm_1 = evps \cdot Cp \cdot (T_{si} - 273.16)/eliw$
- $Psm_2 = Cws \cdot Cr \cdot m \cdot Ps$

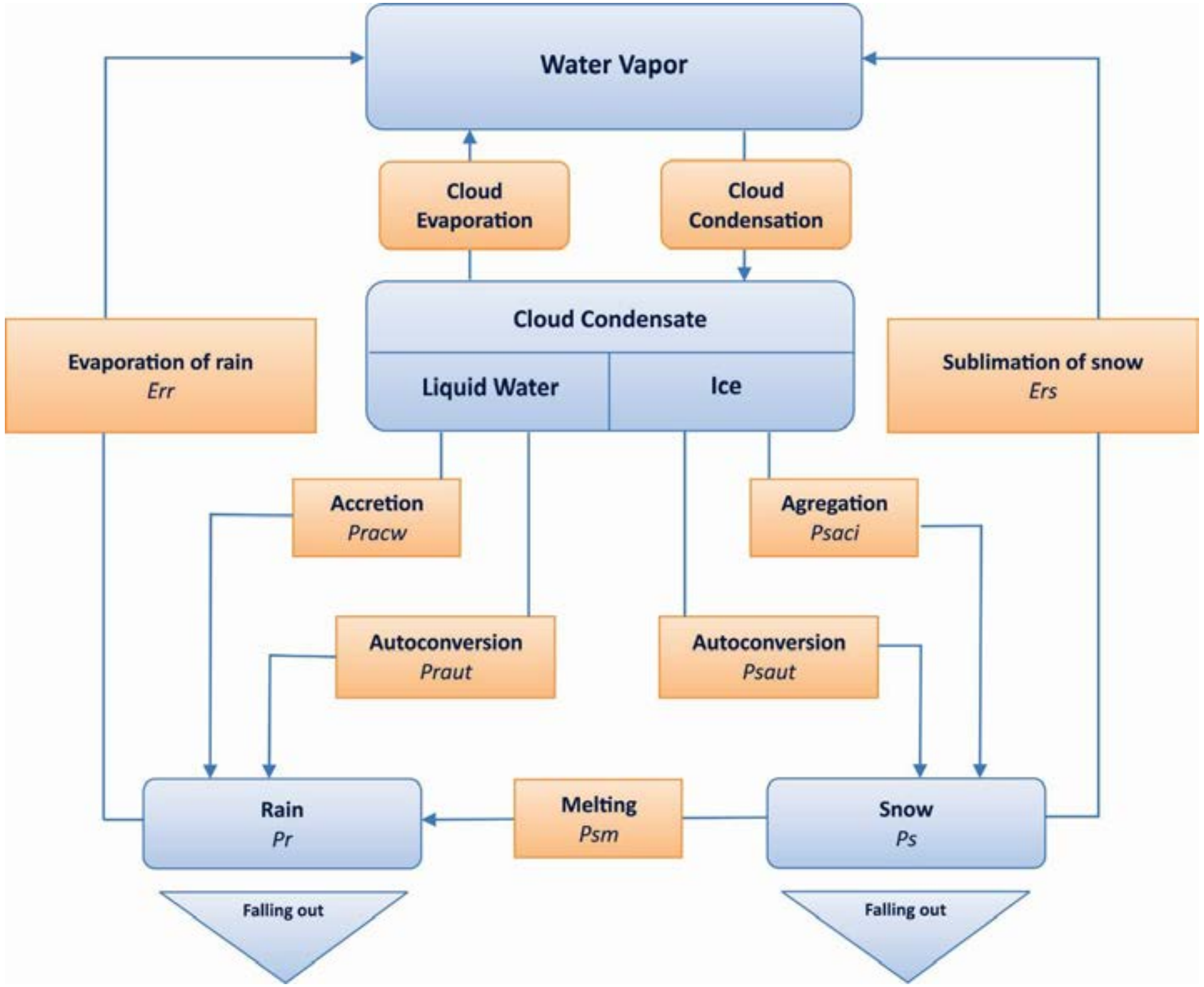

Figure 3. Schematic illustration of microphysical processes in the cloud prediction scheme

Sedimentation of ice and snow

- Ice sedimentation is the main sink of ice particles. Process of aggregation can increase ice sedimentation rate, (larger particles fall faster).
- Sedimentation is expressed as a function of variables that can affect the rates of ice growth and velocity, such as: *density of air, temperature and thickness of layer* in which certain cloud content mixing ratio is present.
- Specific temperature coefficient is used to account the temperature effects on these rates and it is defined by expression for terminal velocity of ice and snow respectively:

$$V_{ice} = 0.15 \cdot (\frac{p}{300 \cdot 10^2})^{-0.178} \cdot (\frac{T_s}{233})^{-0.394}$$

$$V_{snow} = 1.0 \cdot e^{0.025 \cdot (T_S - 273.16)}$$

- Sedimentation rate is calculated level by level from top to bottom using implicit solution method, which prevents sudden changes in values for ice parameters and further oscillations during calculation.

Results
17. November 2011.

- Eta model with ECMWF as boundary data. Model run for 72 hours in horizontal resolution of about 22 km and vertical resolution of 38 layers for the Europe domain.
- First test situation: fog.
- Satellite image and Eta model predicted cloud cover over Europe.
- Eta model predicted temperature inversion in the observed region.
- Sounding for main station in Belgrade, Serbia. Temperature inversion is measured.
- Reduced surface visibility.
- Significant weather map from SYNOP reports shows fog is observed in the specified area.

Results

17. November 2011.

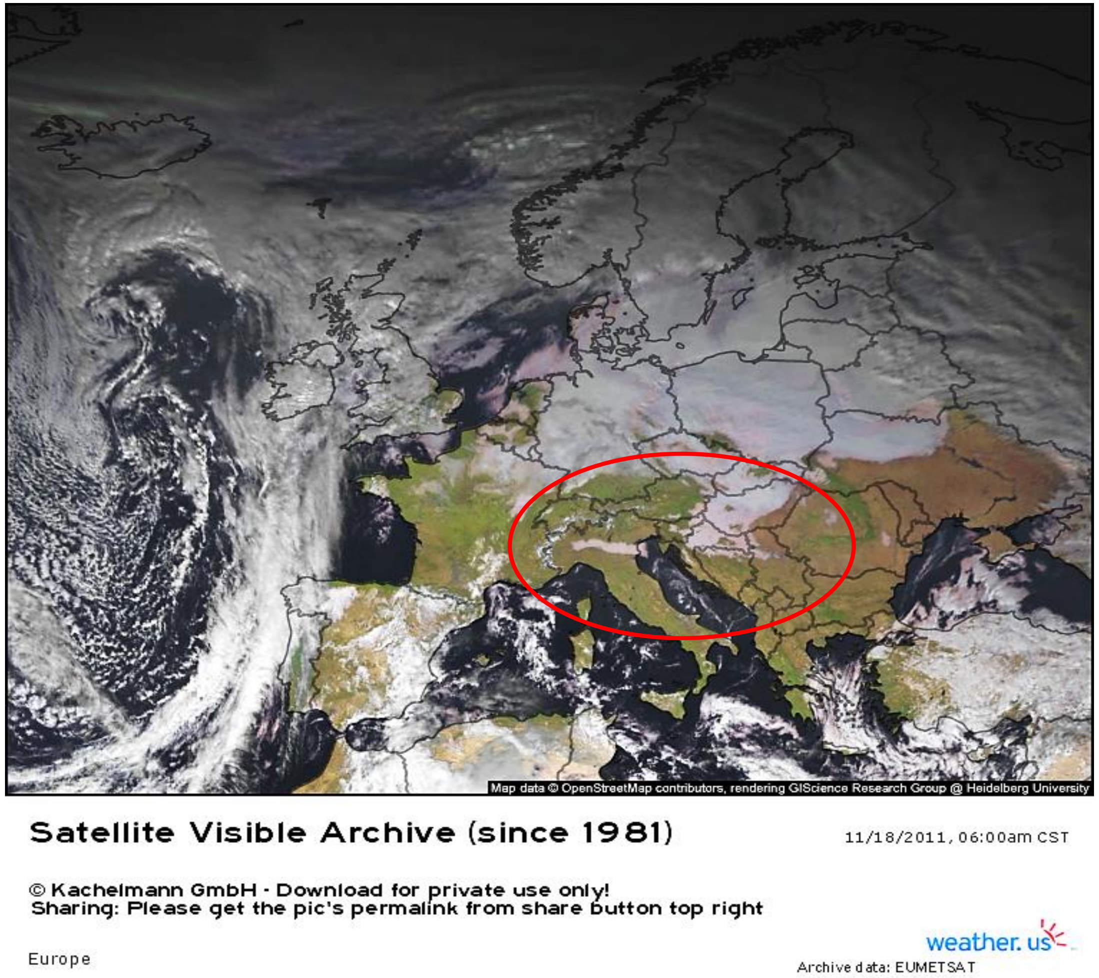

Figure 4. Satellite cloud picture at 18.11.2011 at 11 UTC

https://weather.us/satellite/europe/satellite-visible-archive/20111118-1200z.html

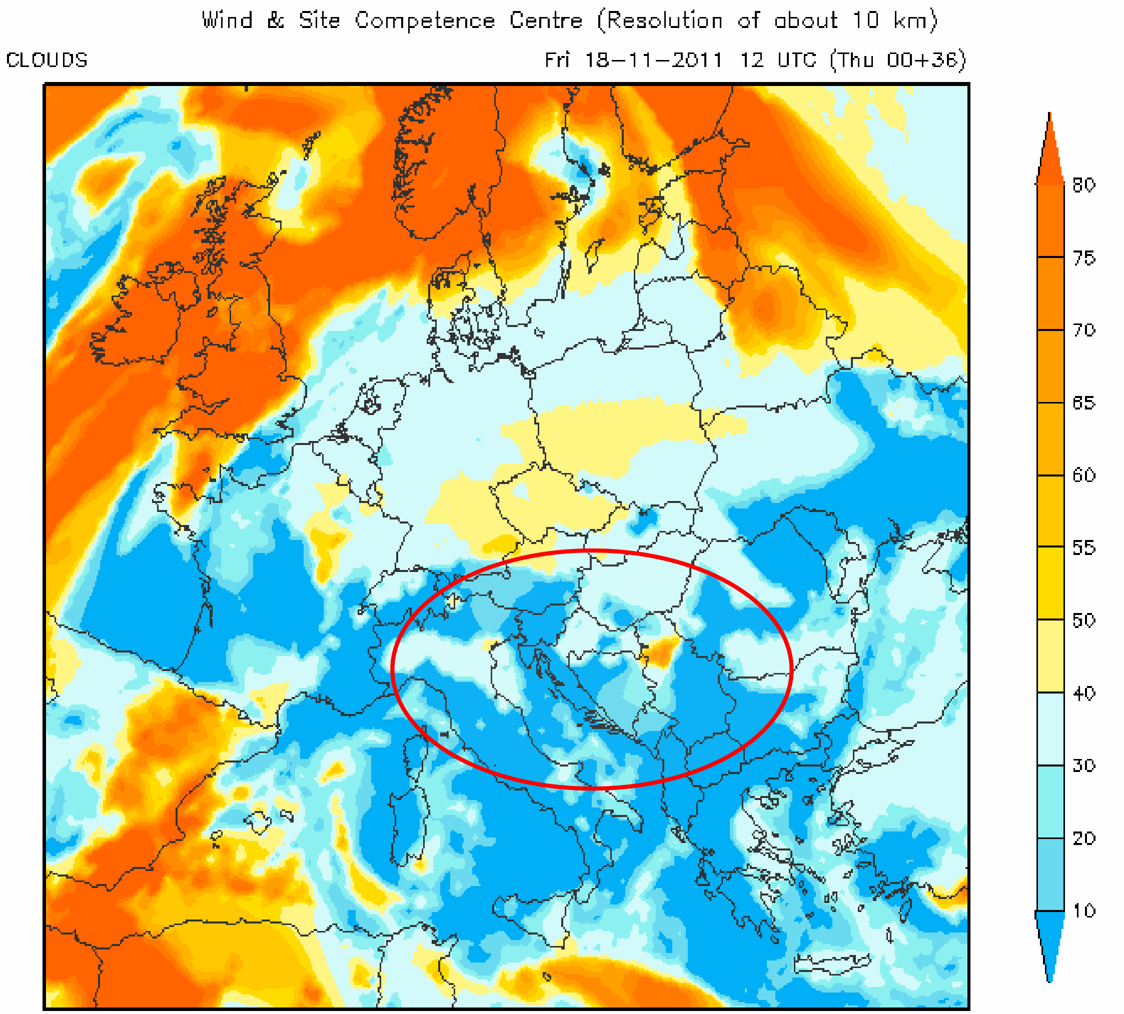

Figure 5. Predicted cloud cover from Eta model at 18.11.2017 at 12 am UTC

Results
17. November 2011.

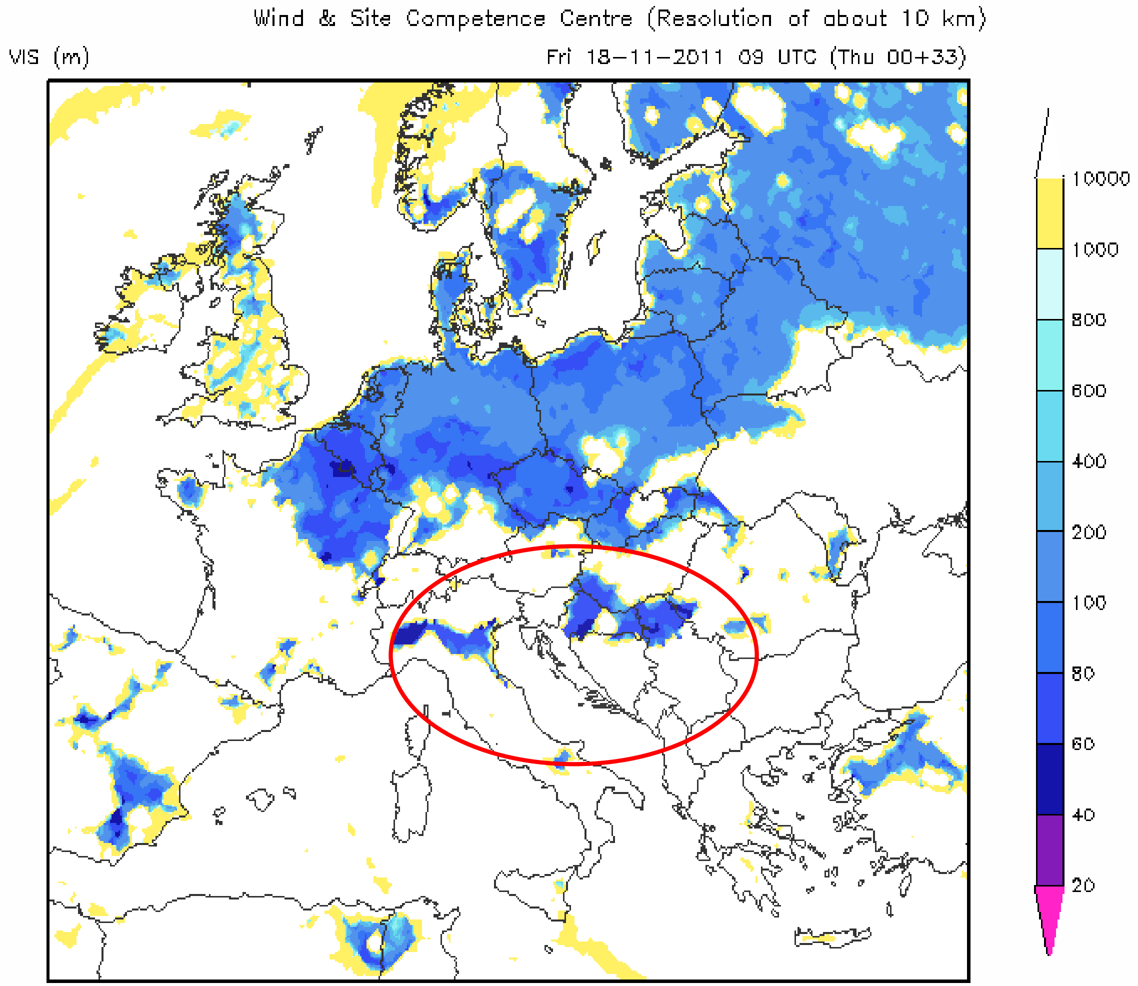

Figure 6. Predicted surface visibility (m) from Eta model at 18.11.2017 at 9 am UTC

Results
17. November 2011.

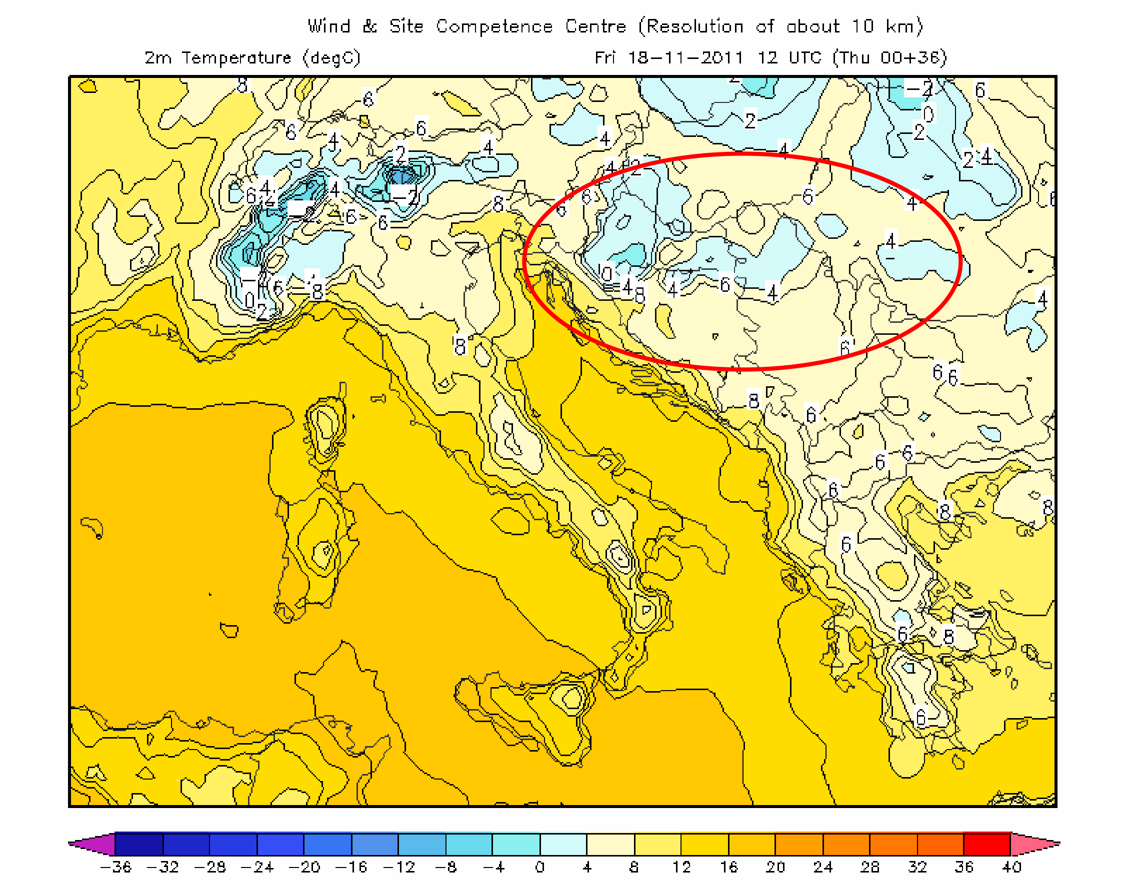

Figure 7a. Predicted 2m temperature (°C) from Eta model at 18.11.2017 at 12 am UTC

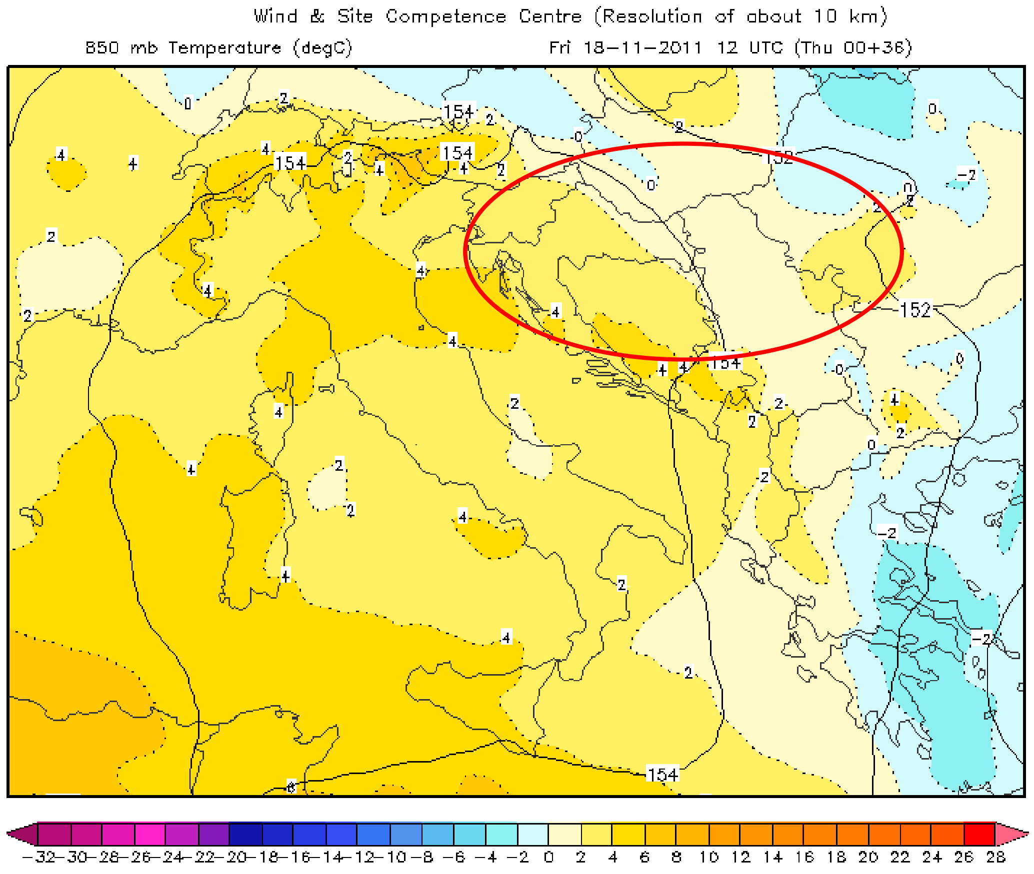

Figure 7b. Predicted 850mb temperature (°C) from Eta model at 18.11.2017 at 12 am UTC

Results
17. November 2011.

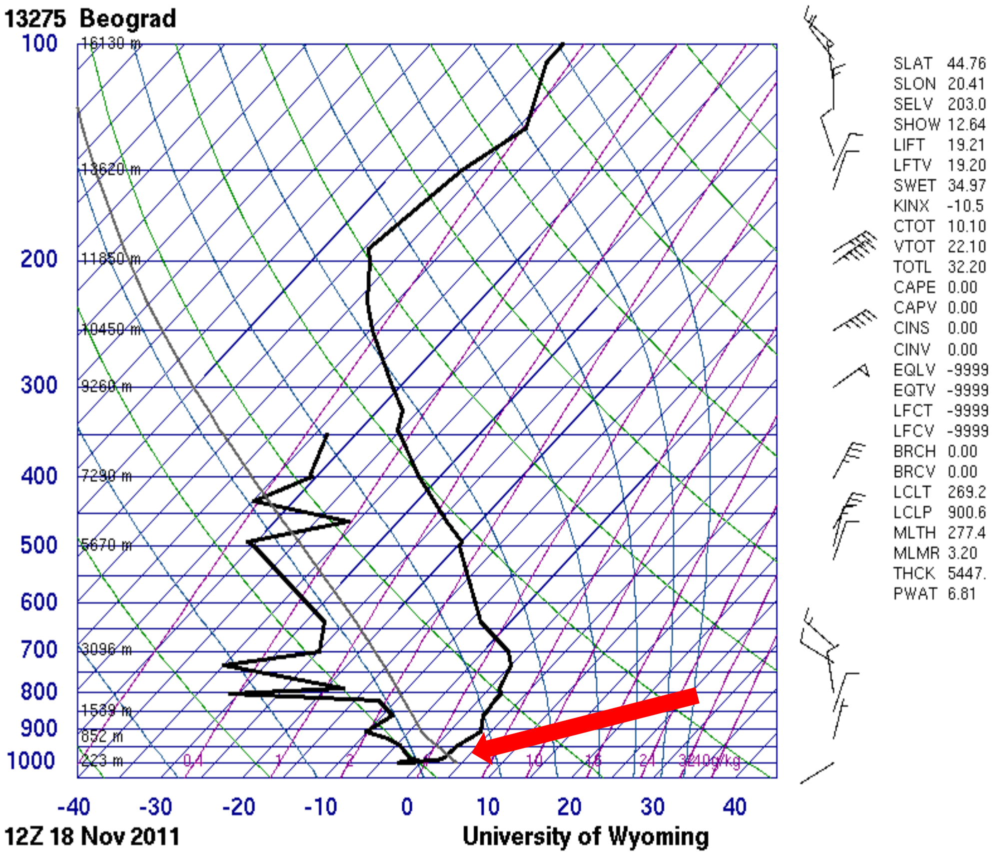

Figure 8. Sounding Skew-T for main weather station Belgrade, Serbia at 18.11.2017 at 12 am UTC
(http://weather.uwyo.edu/cgi-bin/sounding)

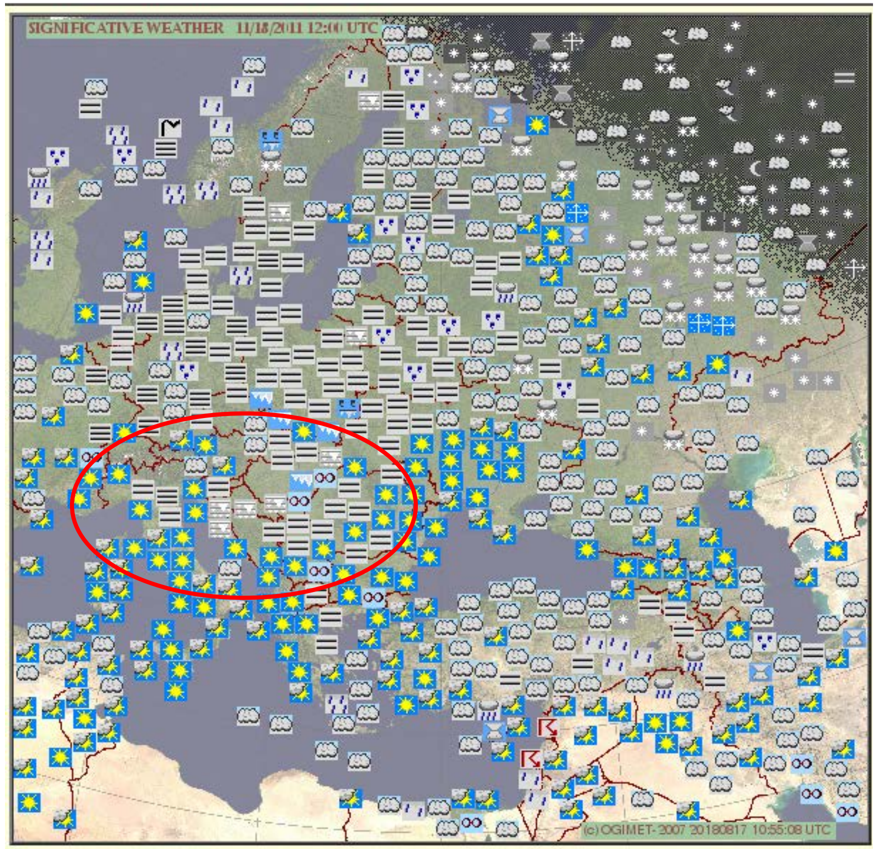

Figure 9. Significant weather map from SYNOP reports at 18.11.2011 at 12 am UTC
(https://www.ogimet.com/cgi-bin/gsynop)

Results
24. June 2015.

- Eta model with ECMWF as boundary data. Model was run for 24 hours in horizontal resolution of about 22 km and a vertical resolution of 38 layers for the Europe domain.
- Second test situation: mid-morning precipitation over northern Serbia.
- Satellite cloud picture and Eta model predicted cloud cover.
- GSOD 24h accumulated precipitation data (mm) from WMO and predicted 6h accumulated precipitation (mm) from Eta model for observed area.

Results
24. June 2015.

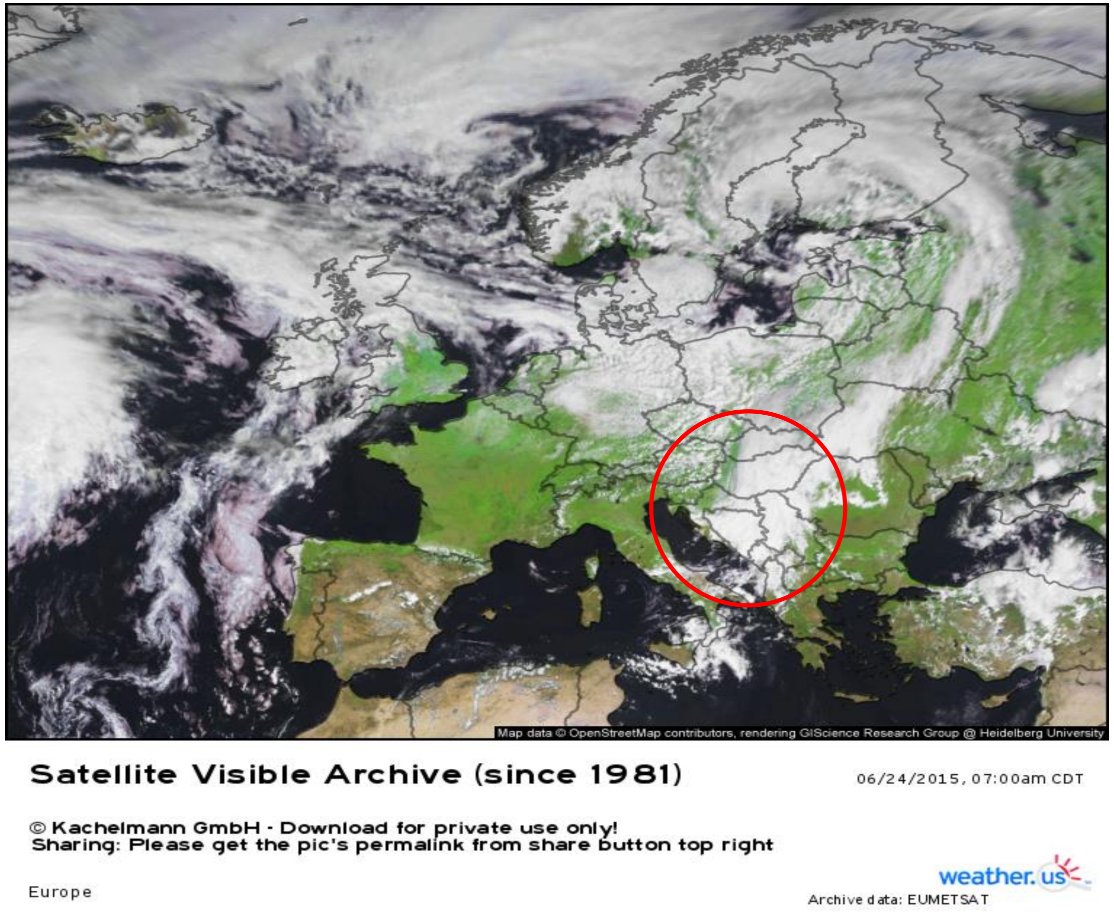

Figure 10. Satellite cloud picture at 24.6.2015 at 12 UTC

https://weather.us/satellite/europe/satellite-visible-archive/20150624-1200z.html

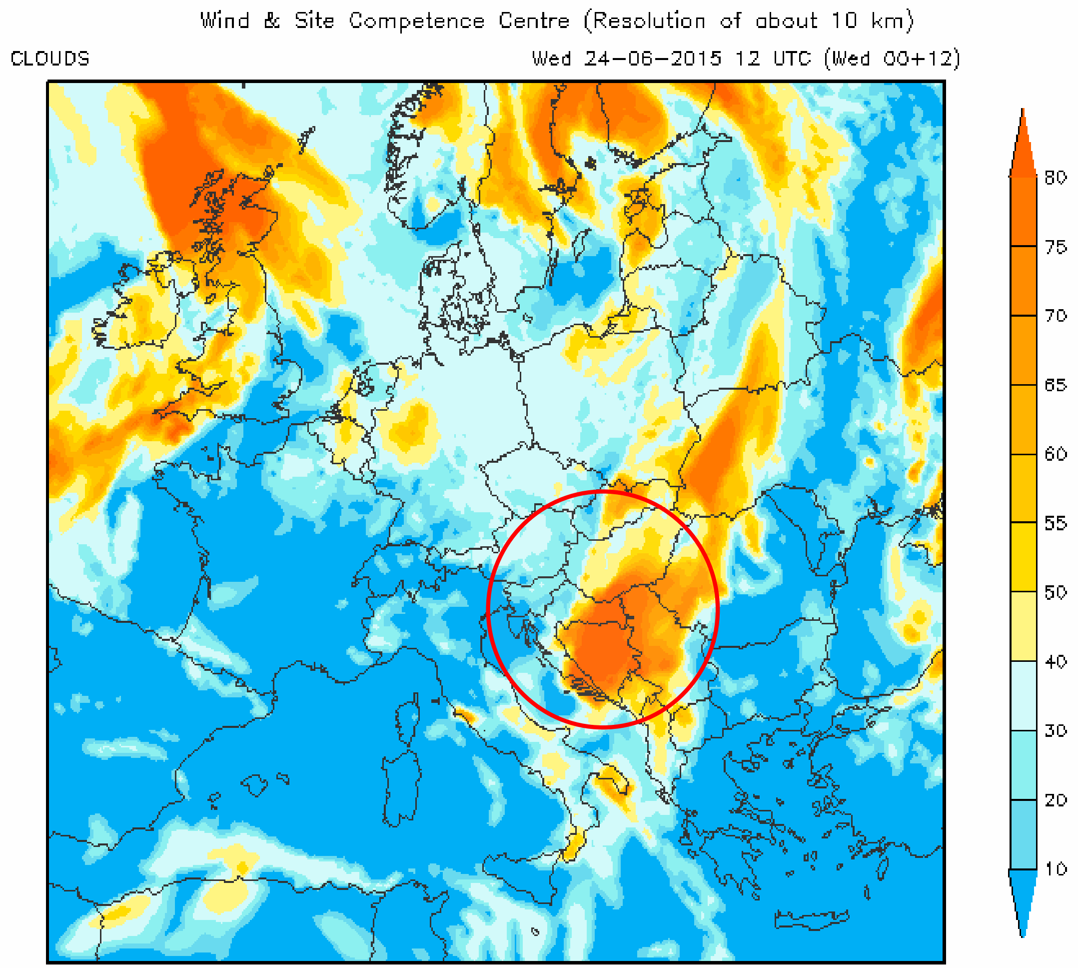

Figure 11. Predicted cloud cover from Eta model at 24.6.2015. at 12 UTC

Results
24. June 2015.

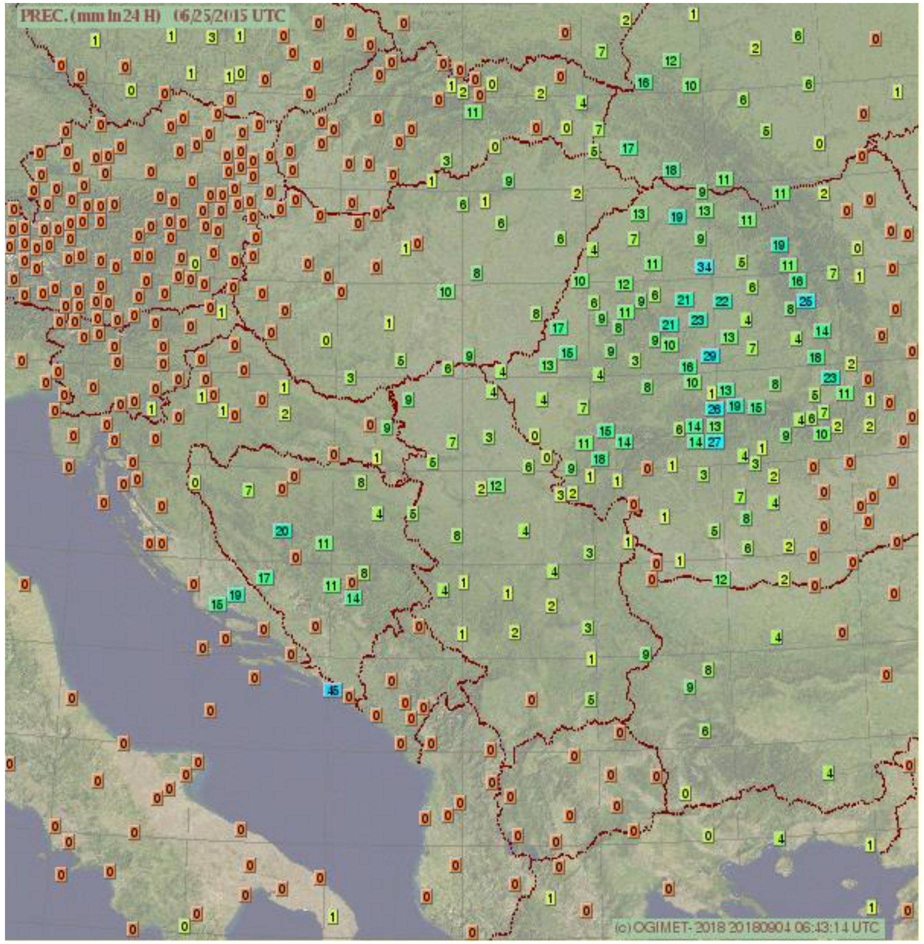

Figure 12. 24h accumulated precipitation (mm) from GSOD data at 25.6.2015 at 00 UTC

https://www.ogimet.com/cgi-bin/gsodnav

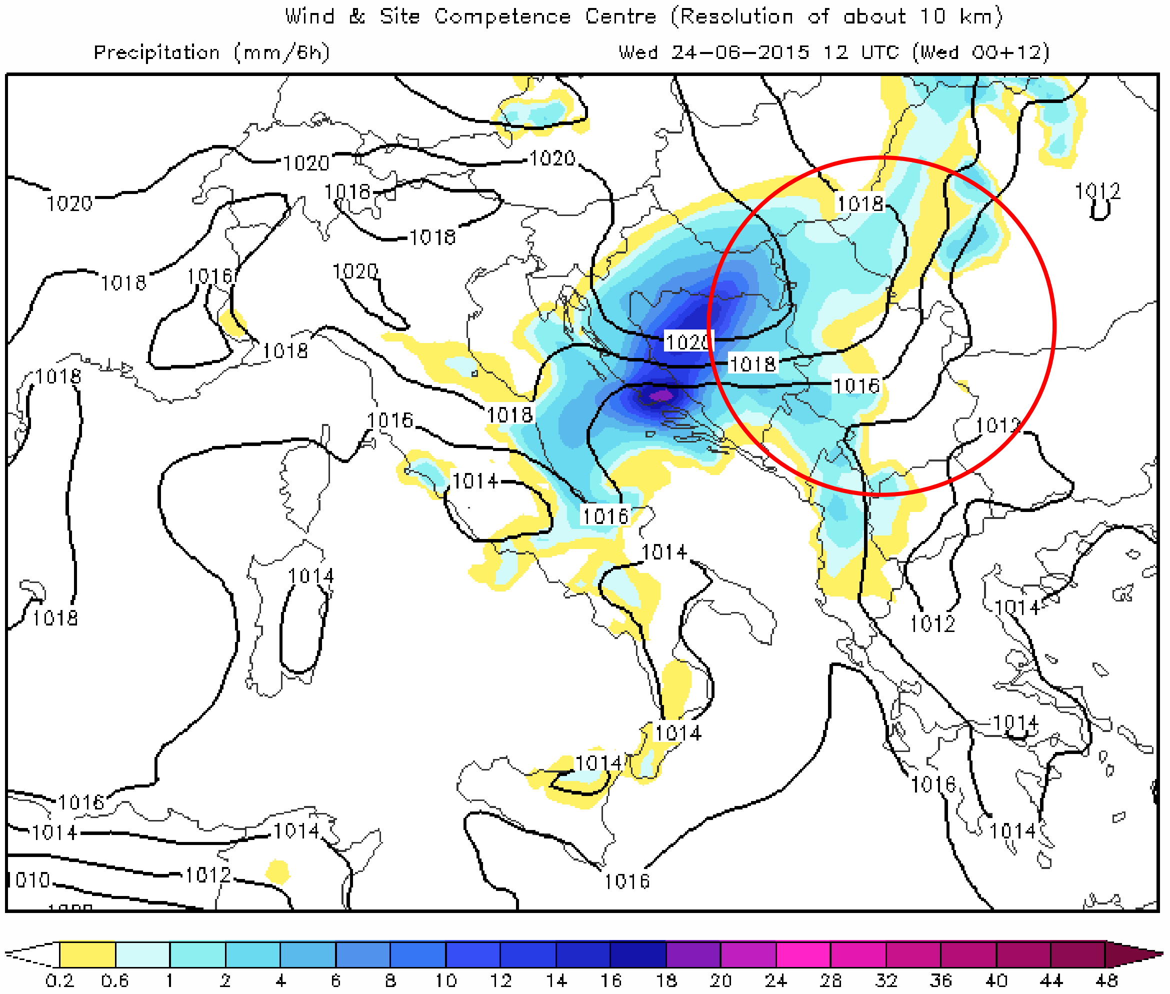

Figure 13. Predicted 6h accumulated precipitation (mm) from Eta model (mm/6h) at 24.6.2015. at 12 UTC

Mountain blocking and Eta model

- During the years of research, it was noticed that during the winter, Eta model in some situations does not forecast snow in the areas of Croatia, Slovenia and northern Italy.
- For a long time this was thought to be caused by the η coordinate, however using Eta model with σ and WRF model with hybrid coordinate gave similar results.
- In 2009 mountain blocking and gravity wave drag were implemented in the WRF model and that solved problems. After almost 10 years we now know that it is impossible to run σ or hybrid model in correct way without this option.
- We added mountain blocking and gravity wave drag in the Eta model by using same principle as in the WRF model. In that way Eta model with σ coordinate gave good results in same weather situations.

Mountain blocking and Eta model

- Next challenge was to achieve the effects of the mountain blocking and gravity wave drag, without their insertion, but using η coordinate.
- After long period of researching and testing the problem was solved by using a differently defined orography.
- After creating silhouette-mean step Eta topography, we are finding peaks which have more than 2000 m altitude. For those points instead standard Eta topography we will use silhouette-mean+stddev step Eta topography, which was made by adding standard deviation to mean altitude.
- With this definition of new orography of the model good sides of silhouette-mean step Eta topography were preserved.

Mountain blocking and Eta model

- Some weather situation regarding these changes in the Eta model will be represented using model with 0.15 resolution on weather situation from:
  - *17th December ,2011. (snow in Croatia)*
  - *9th December, 2010. (snow in Croatia and Slovenia) and,*
  - *13th January, 2017. (snow in Venice)*

Eta model with standard orography vs. Eta model with new orography

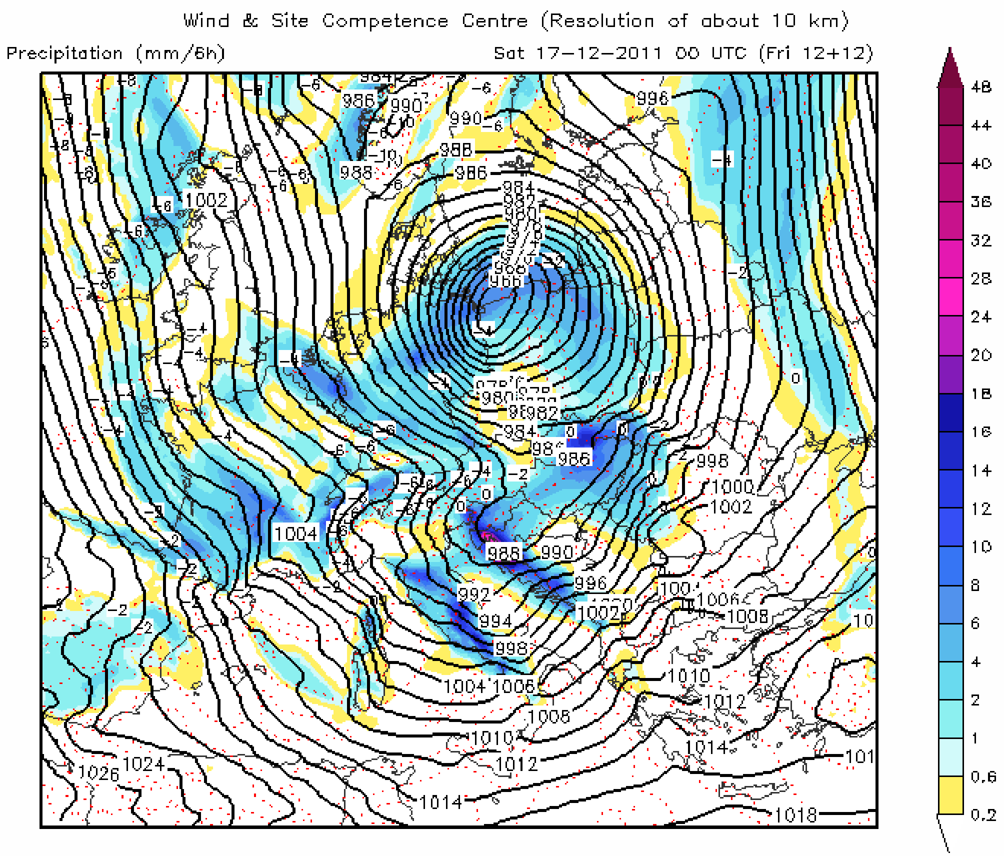

Figure 14. Predicted 6h accumulated precipitation (mm) from Eta model (mm/6h) with standard orography at 17.12.2011. at 00 UTC

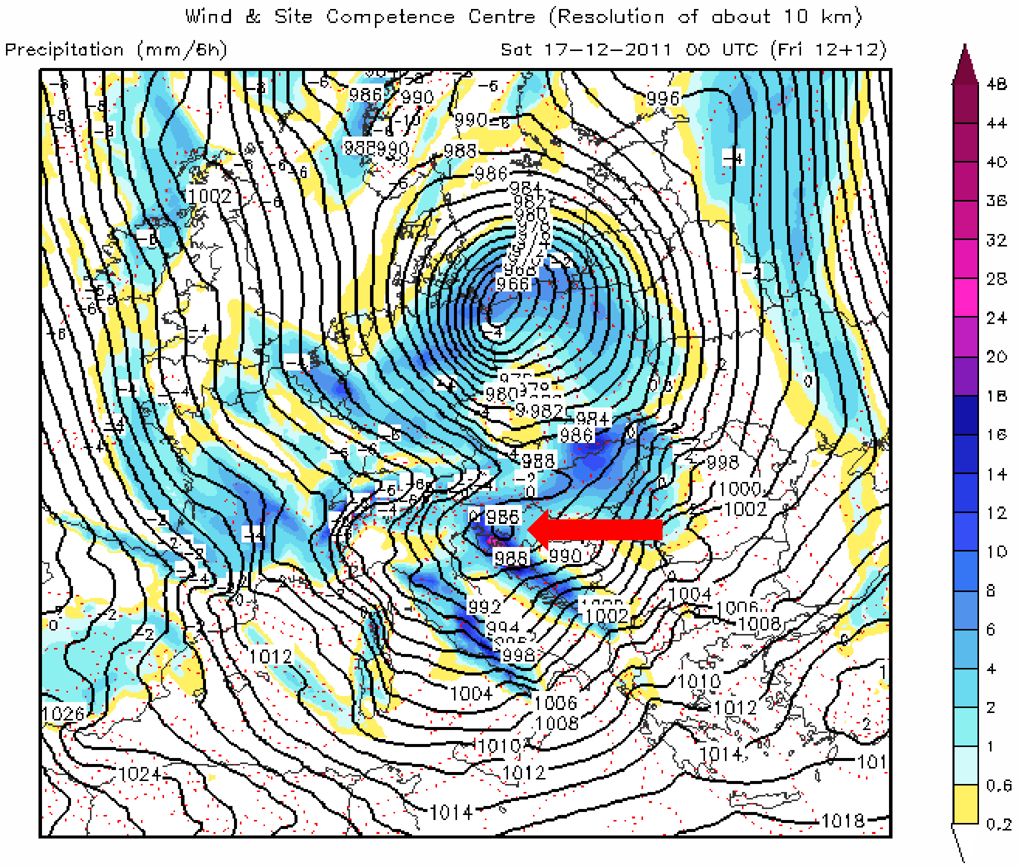

Figure 15. Predicted 6h accumulated precipitation (mm) from Eta model (mm/6h) with new orography at 17.12.2011. at 00 UTC

Eta model with standard orography vs. Eta model with new orography

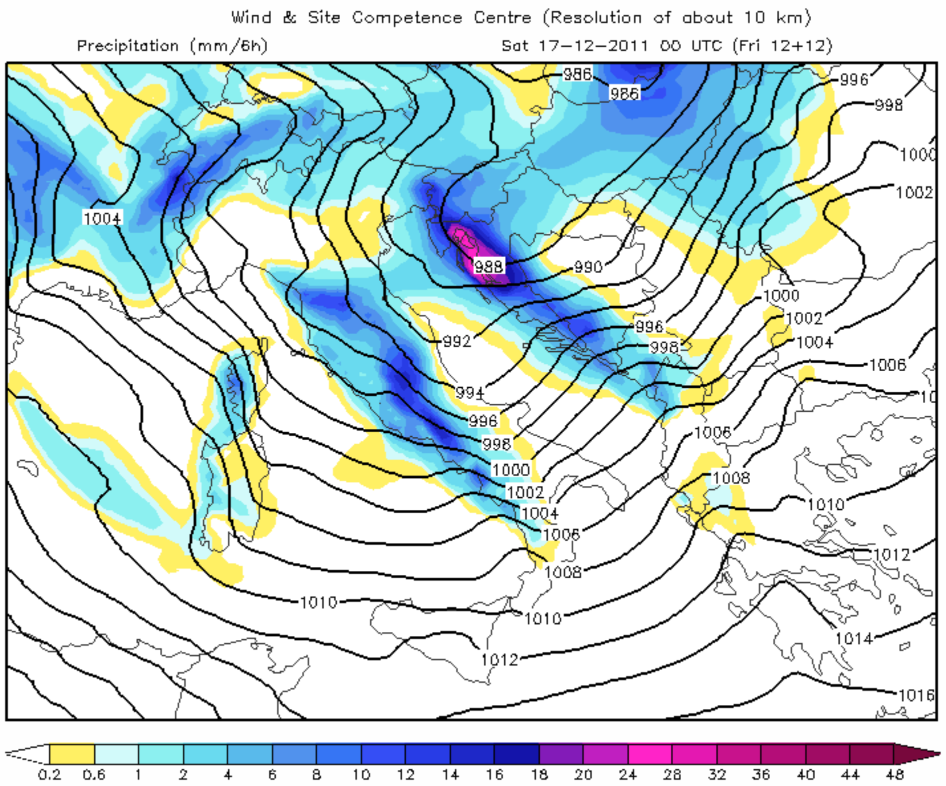

Figure 16. Predicted 6h accumulated precipitation (mm) from Eta model (mm/6h) with standard orography at 17.12.2011. at 00 UTC (zoomed region of Italy and Balkan)

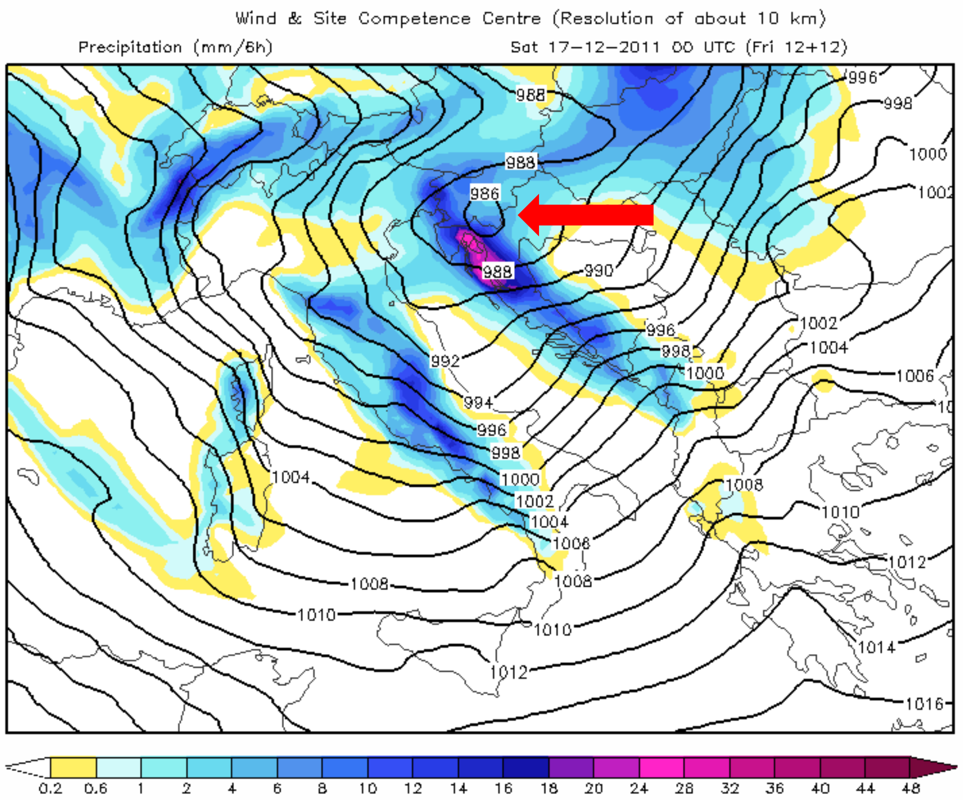

Figure 17. Predicted 6h accumulated precipitation (mm) from Eta model (mm/6h) with new orography at 17.12.2011. at 00 UTC (zoomed region of Italy and Balkan)

Eta model with standard orography vs. Eta model with new orography – snow in Croatia

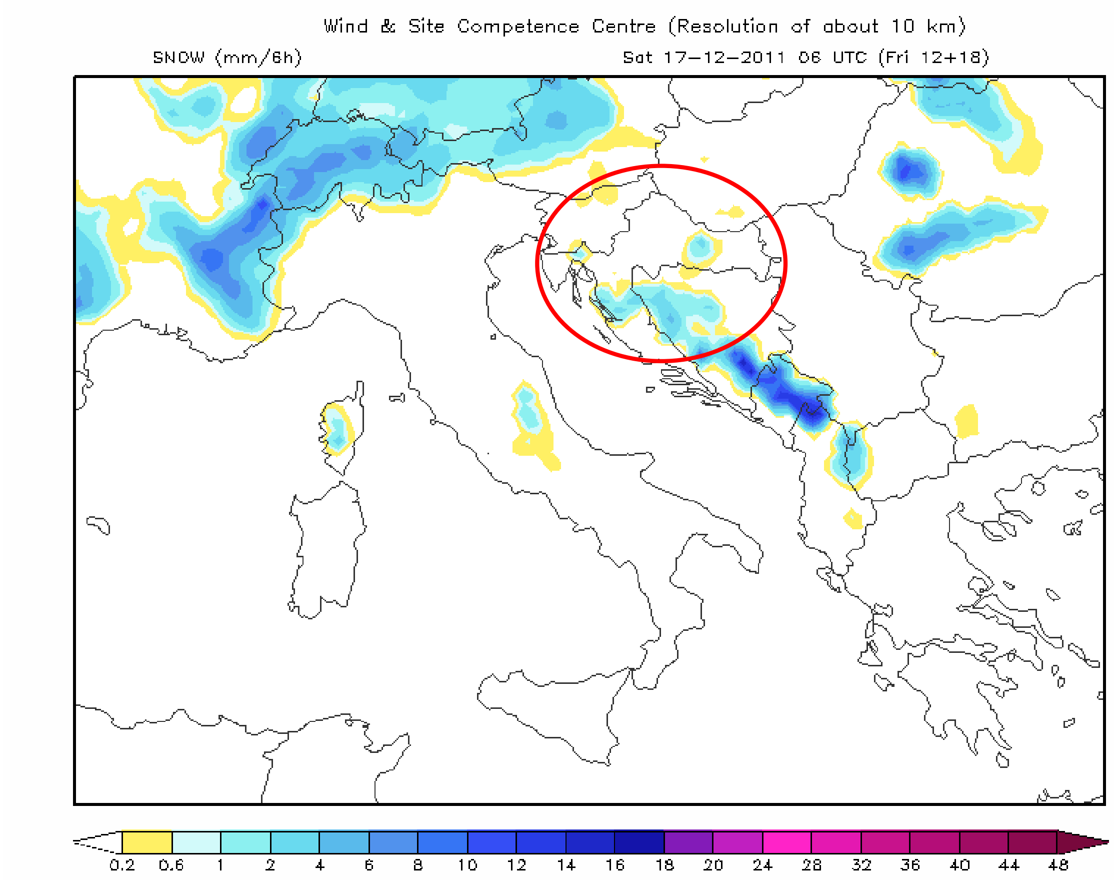

Figure 18. Predicted 6h accumulated snow (mm) from Eta model (mm/6h) with standard orography at 17.12.2011. at 06 UTC (zoomed region of Italy and Balkan)

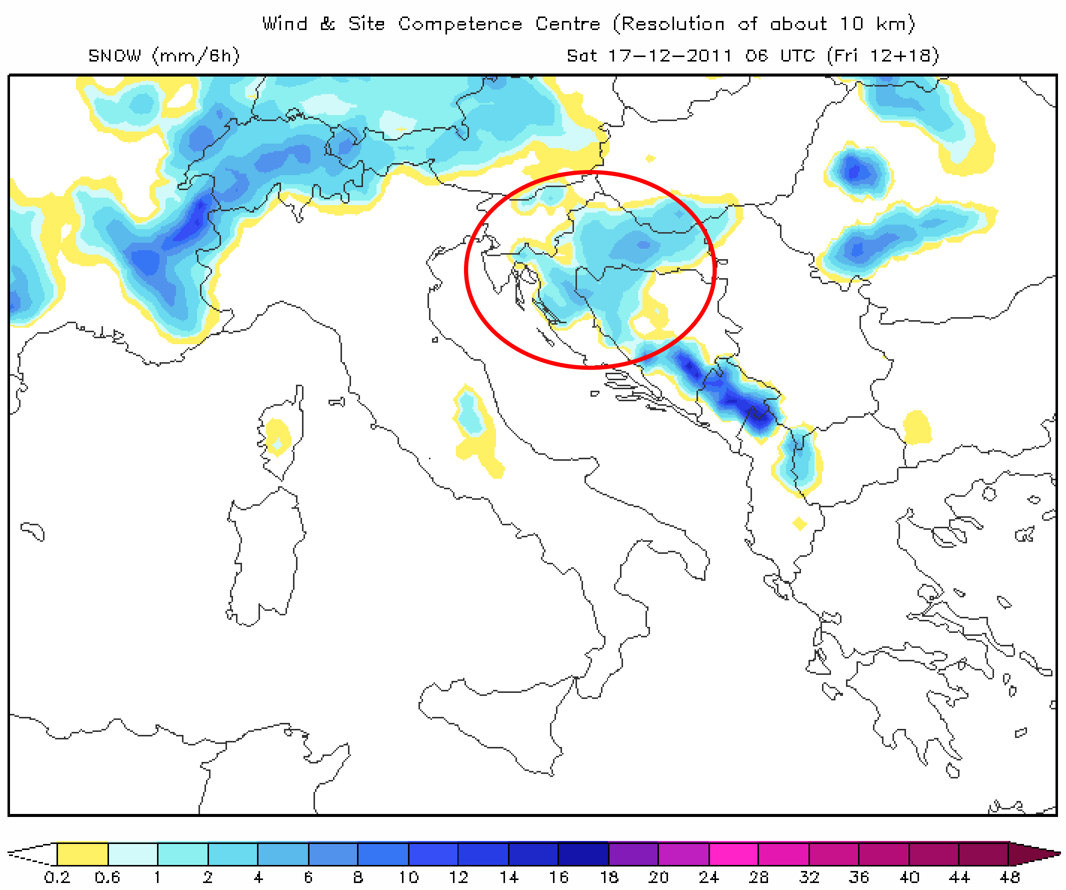

Figure 19. Predicted 6h accumulated snow (mm) from Eta model (mm/6h) with new orography at 17.12.2011. at 06 UTC (zoomed region of Italy and Balkan)

Eta model with standard orography vs. Eta model with new orography

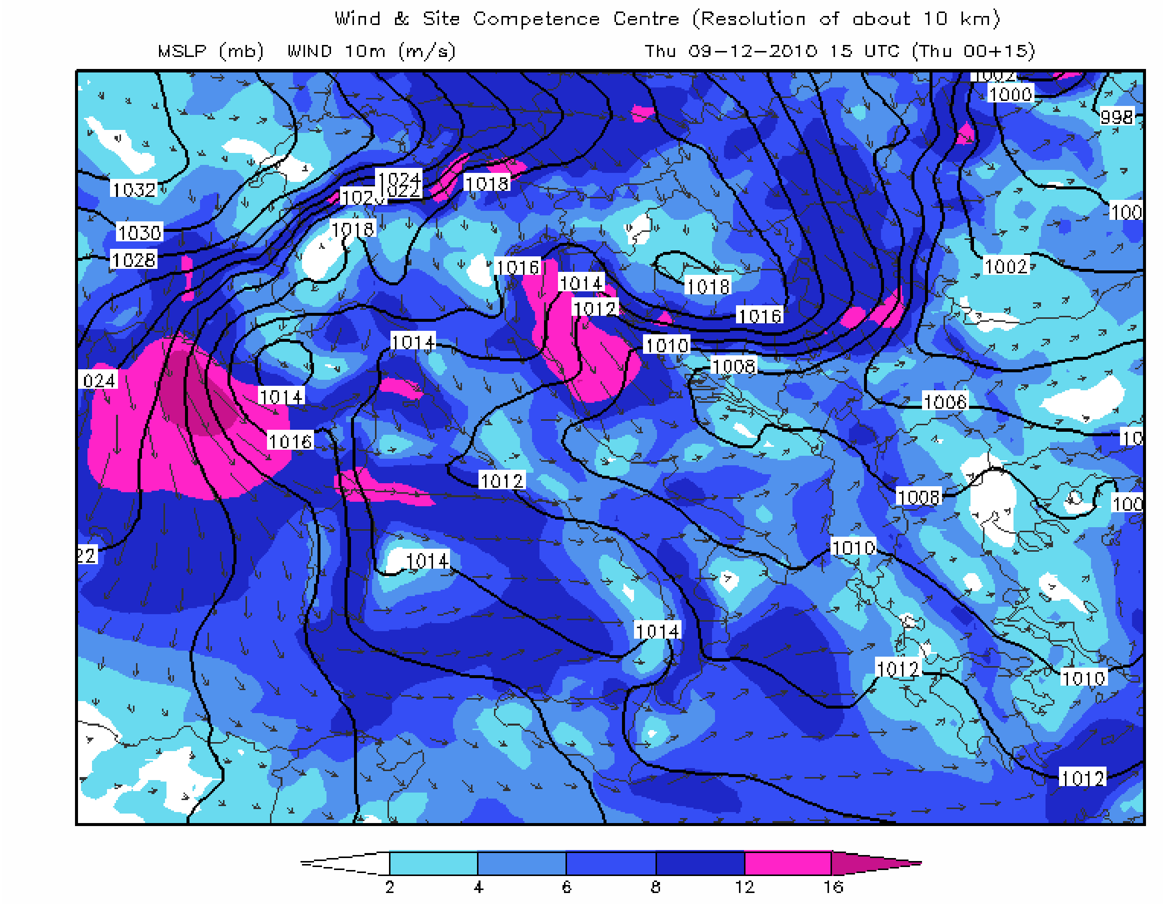

Figure 20. Predicted mean sea level pressure and wind speed at 10m from Eta model (m/s) with standard orography at 9.12.2010. at 15 UTC (zoomed region of Italy and Balkan)

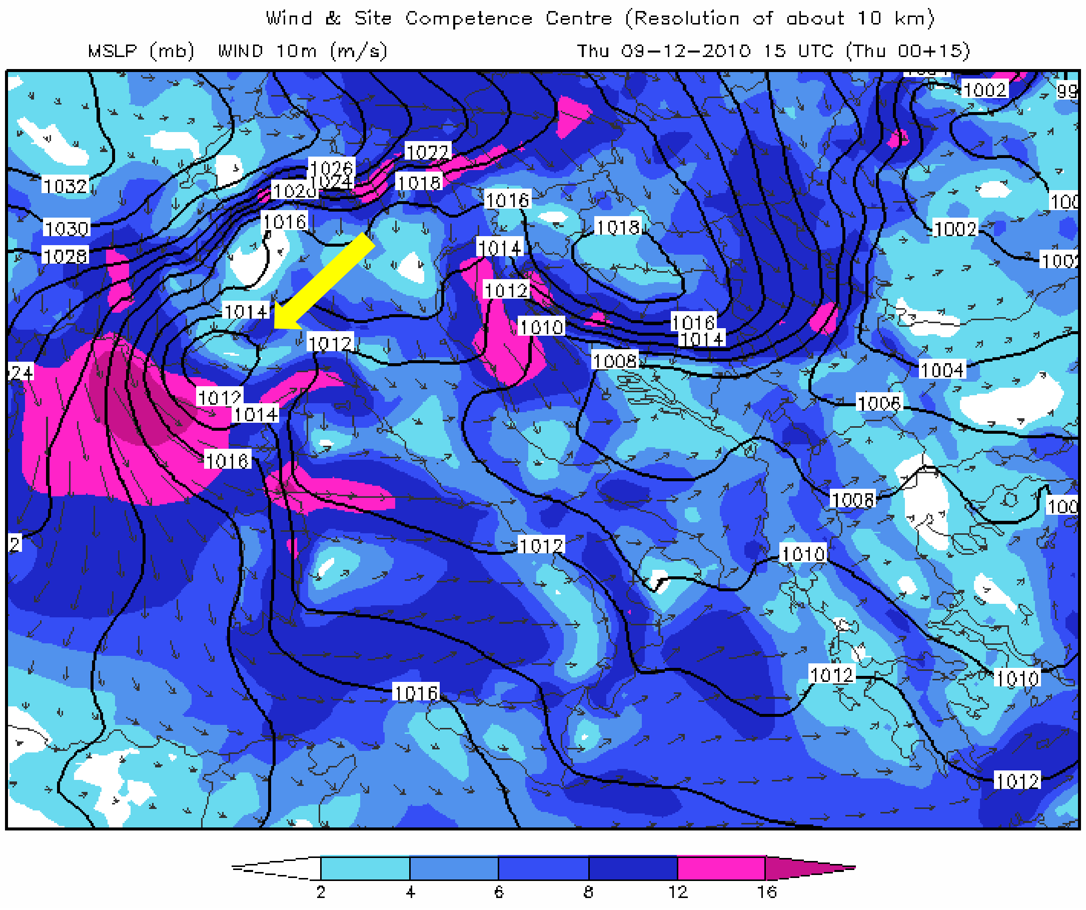

Figure 21. Predicted mean sea level pressure and wind speed at 10m from Eta model (m/s) with new orography at 9.12.2010. at 15 UTC (zoomed region of Italy and Balkan)

Eta model with standard orography vs. Eta model with new orography-snow in Croatia and Slovenia

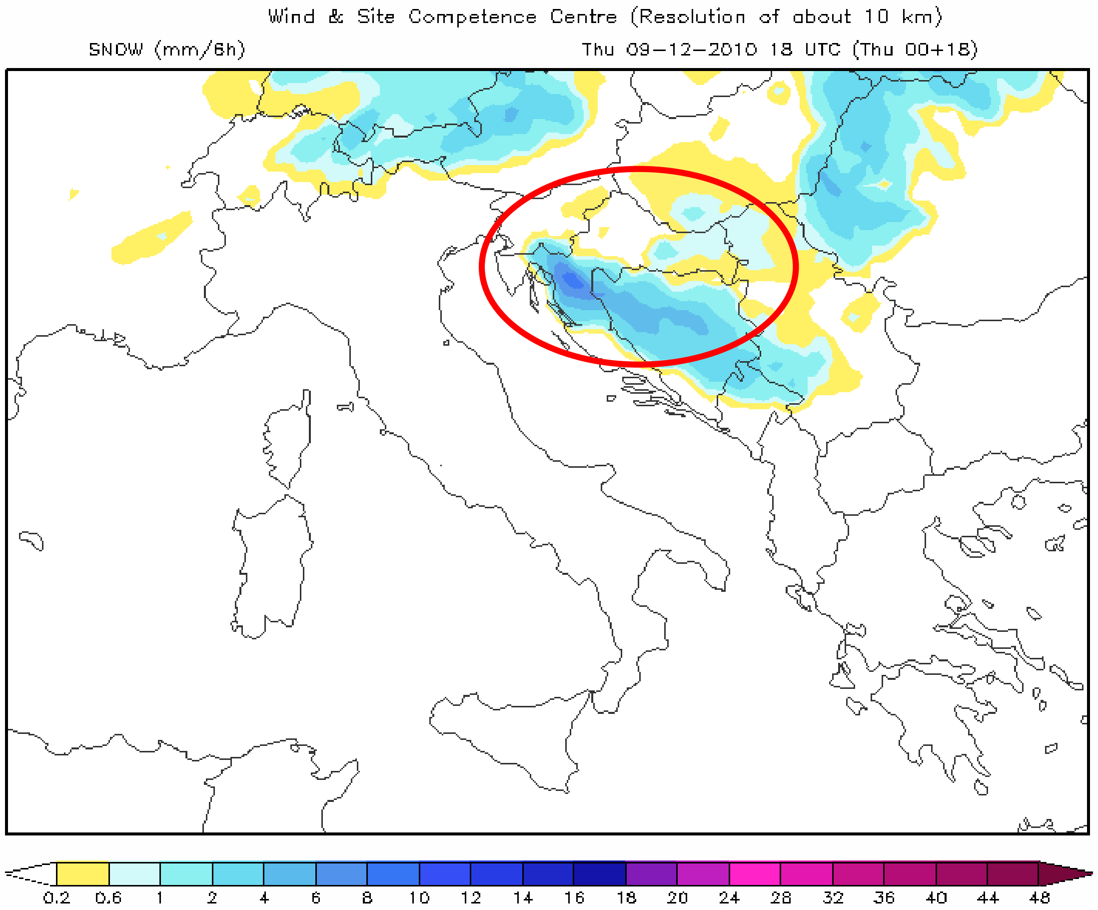

Figure 22. Predicted 6h accumulated snow (mm) from Eta model (mm/6h) with standard orography at 9.12.2010. at 18 UTC (zoomed region of Italy and Balkan)

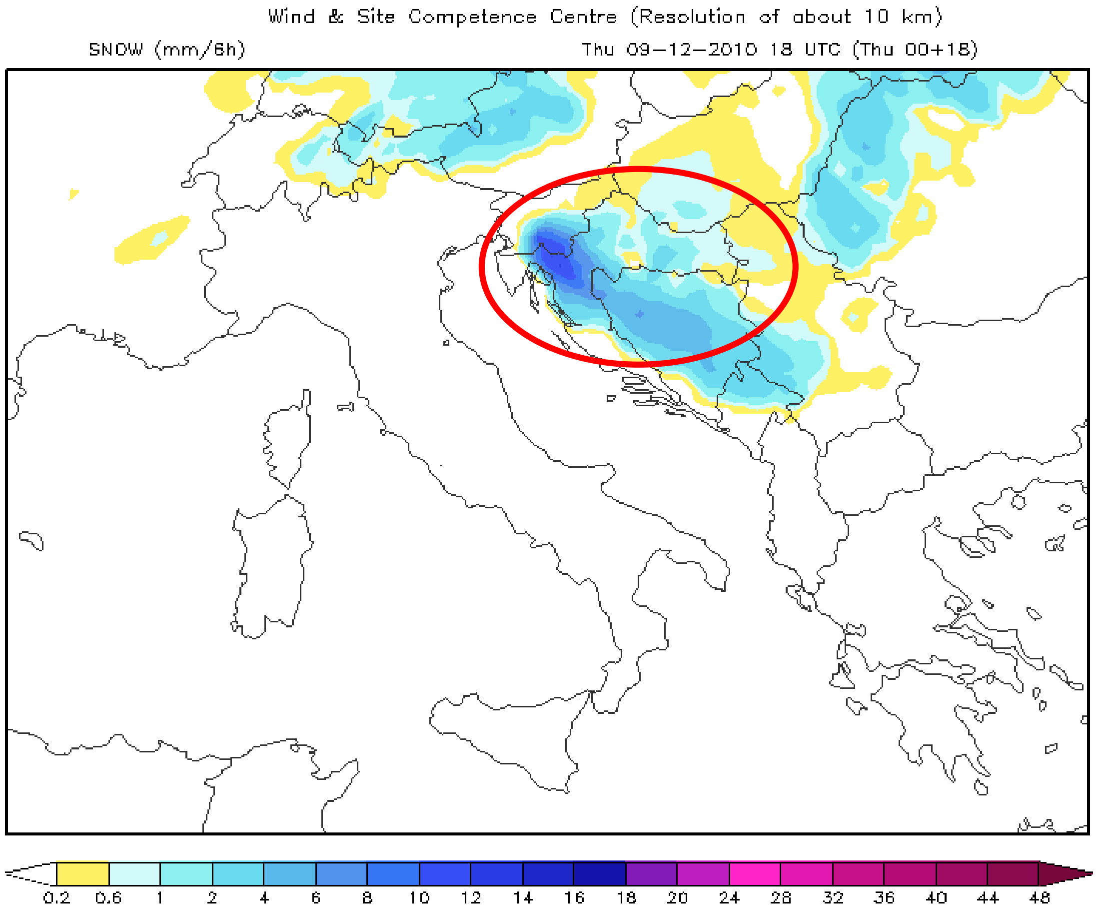

Figure 23. Predicted 6h accumulated snow (mm) from Eta model (mm/6h) with new orography at 9.12.2010. at 18 UTC (zoomed region of Italy and Balkan)

Eta model with standard orography vs. Eta model with new orography-snow in Venice (Italy)

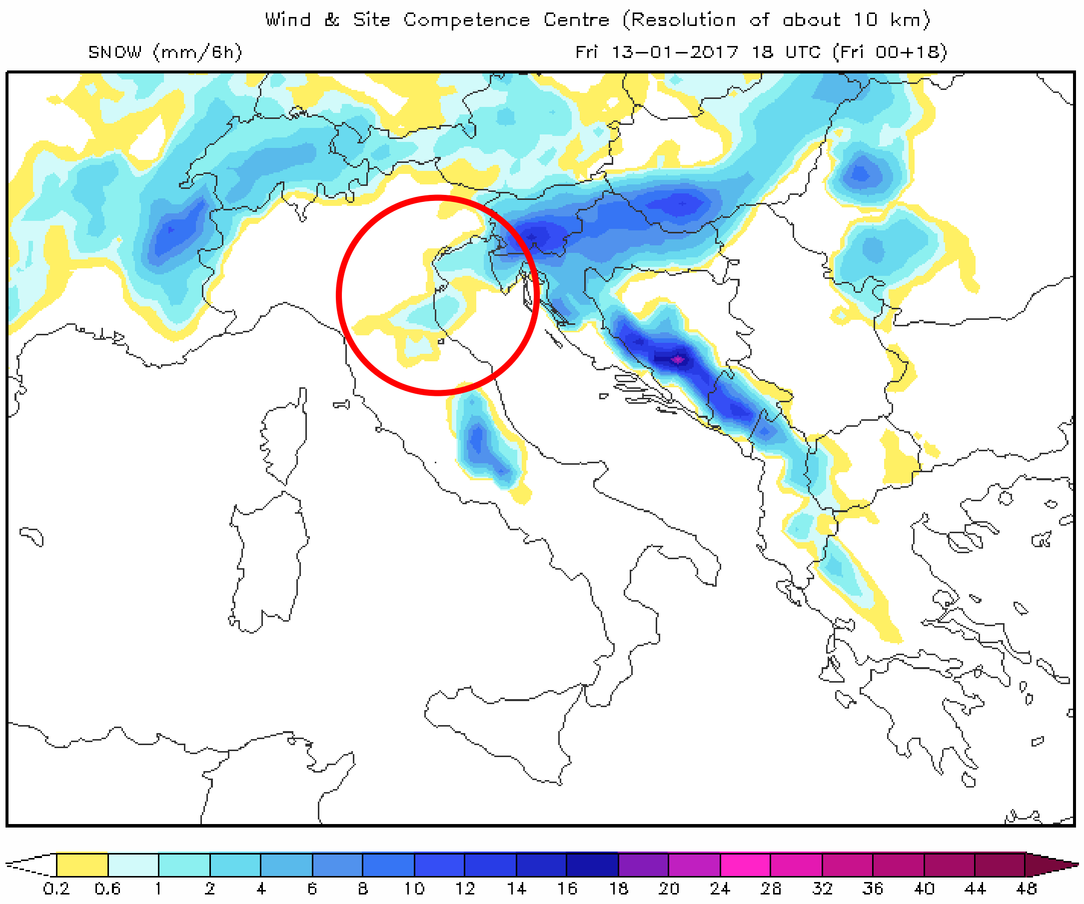

Figure 24. Predicted 6h accumulated snow (mm) from Eta model (mm/6h) with standard orography at 13.1.2017. at 18 UTC (zoomed region of Italy and Balkan)

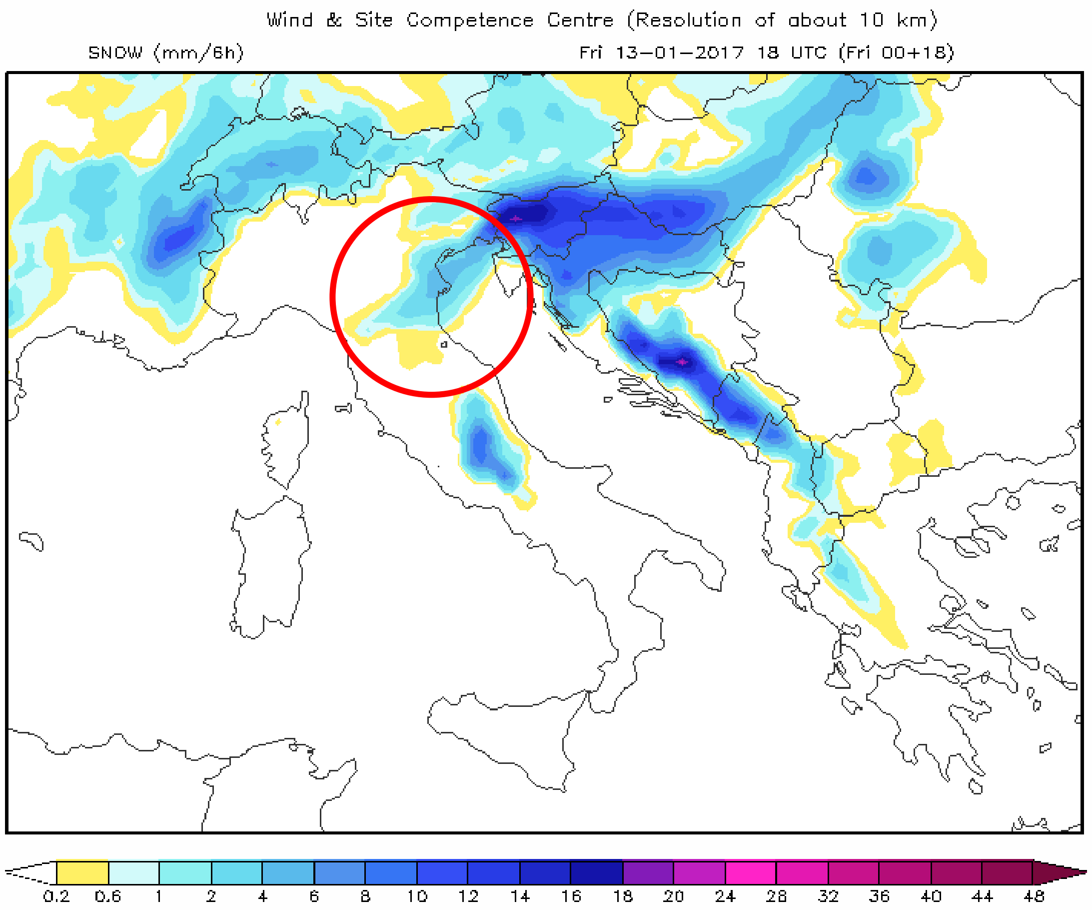

Figure 25. Predicted 6h accumulated snow (mm) from Eta model (mm/6h) with new orography at 13.1.2017. at 18 UTC (zoomed region of Italy and Balkan)

Eta model with standard orography vs. Eta model with new orography

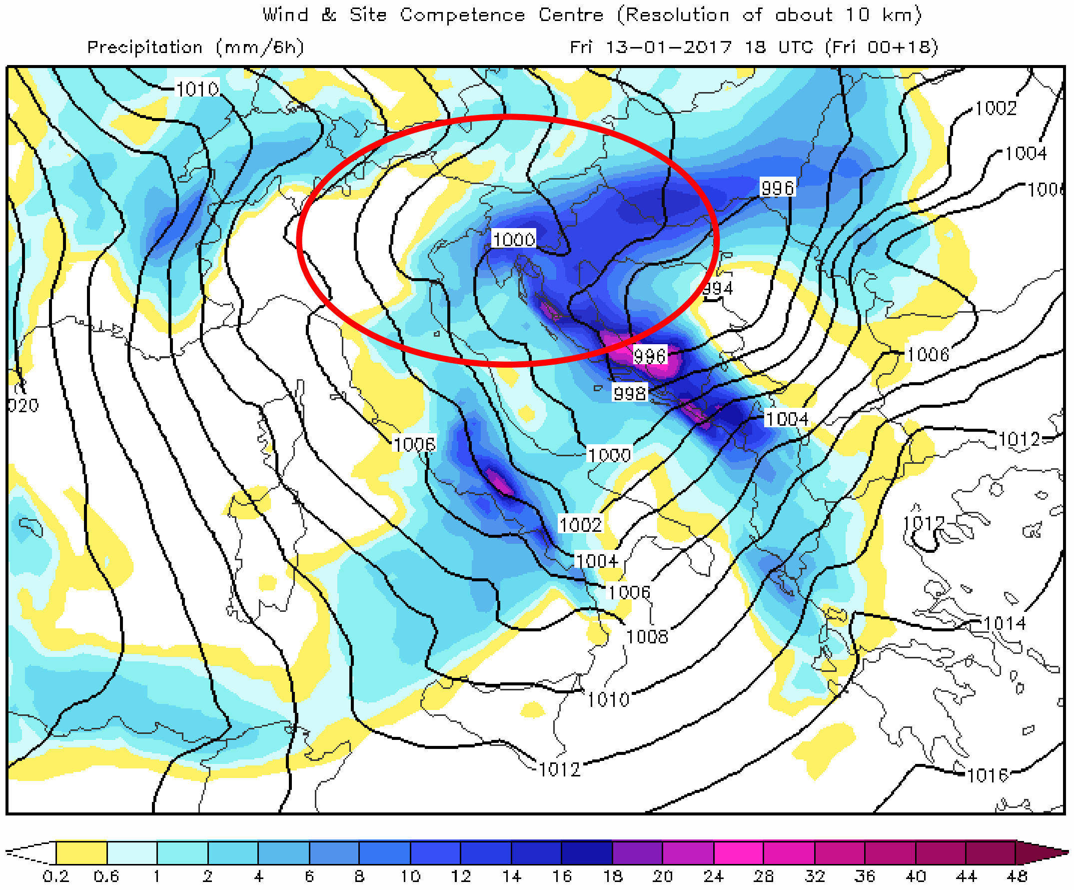

Figure 26. Predicted 6h accumulated precipitation (mm) from Eta model (mm/6h) with standard orography at 13.1.2017. at 18 UTC (zoomed region of Italy and Balkan)

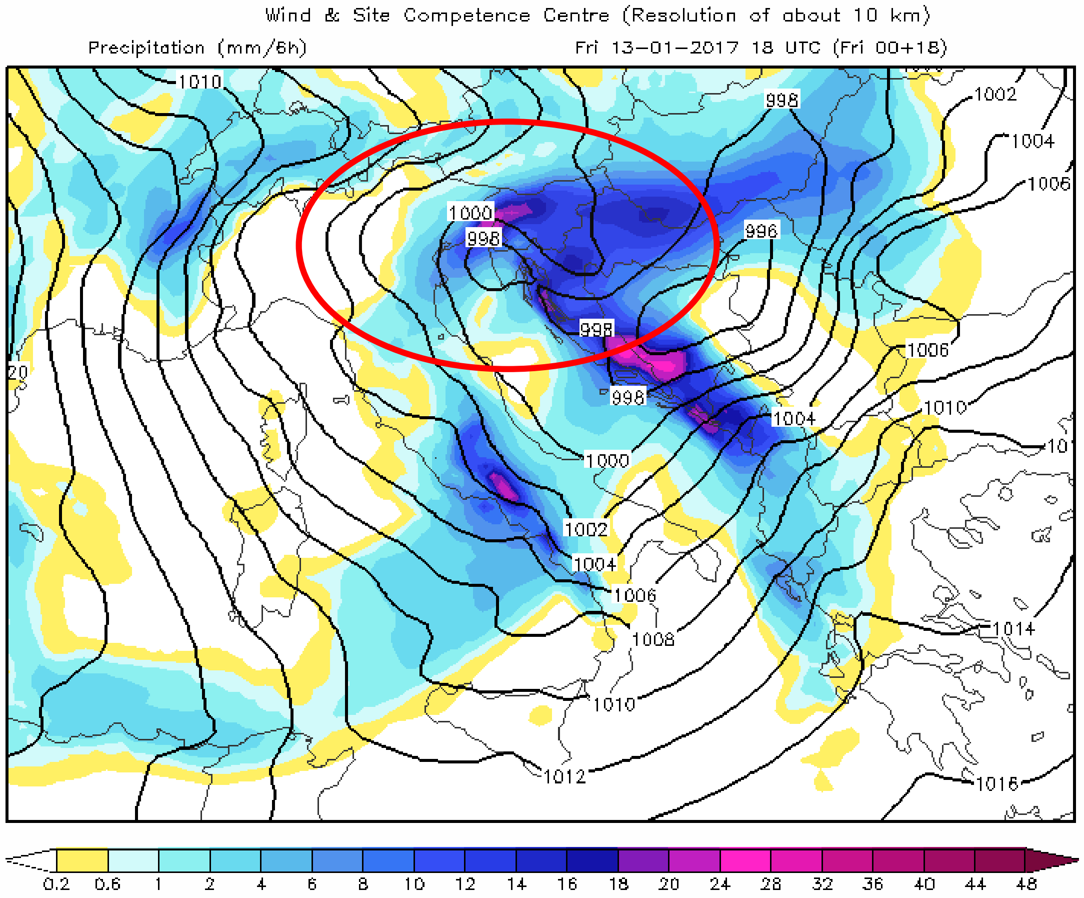

Figure 27. Predicted 6h accumulated precipitation (mm) from Eta model (mm/6h) with new orography at 13.1.2017. at 18 UTC (zoomed region of Italy and Balkan)

Eta model with standard orography vs. Eta model with new orography

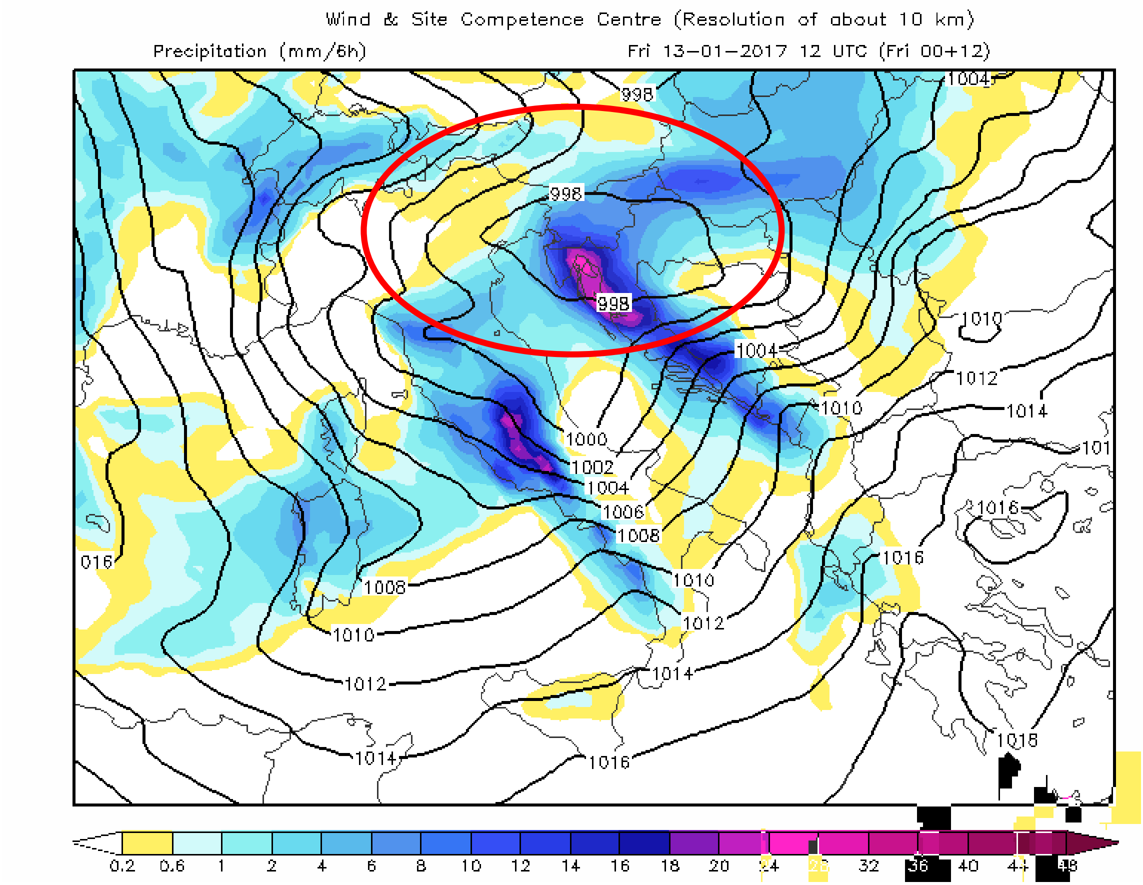

Figure 28. Predicted 6h accumulated precipitation (mm) from Eta model (mm/6h) with standard orography at 13.1.2017. at 12 UTC (zoomed region of Italy and Balkan)

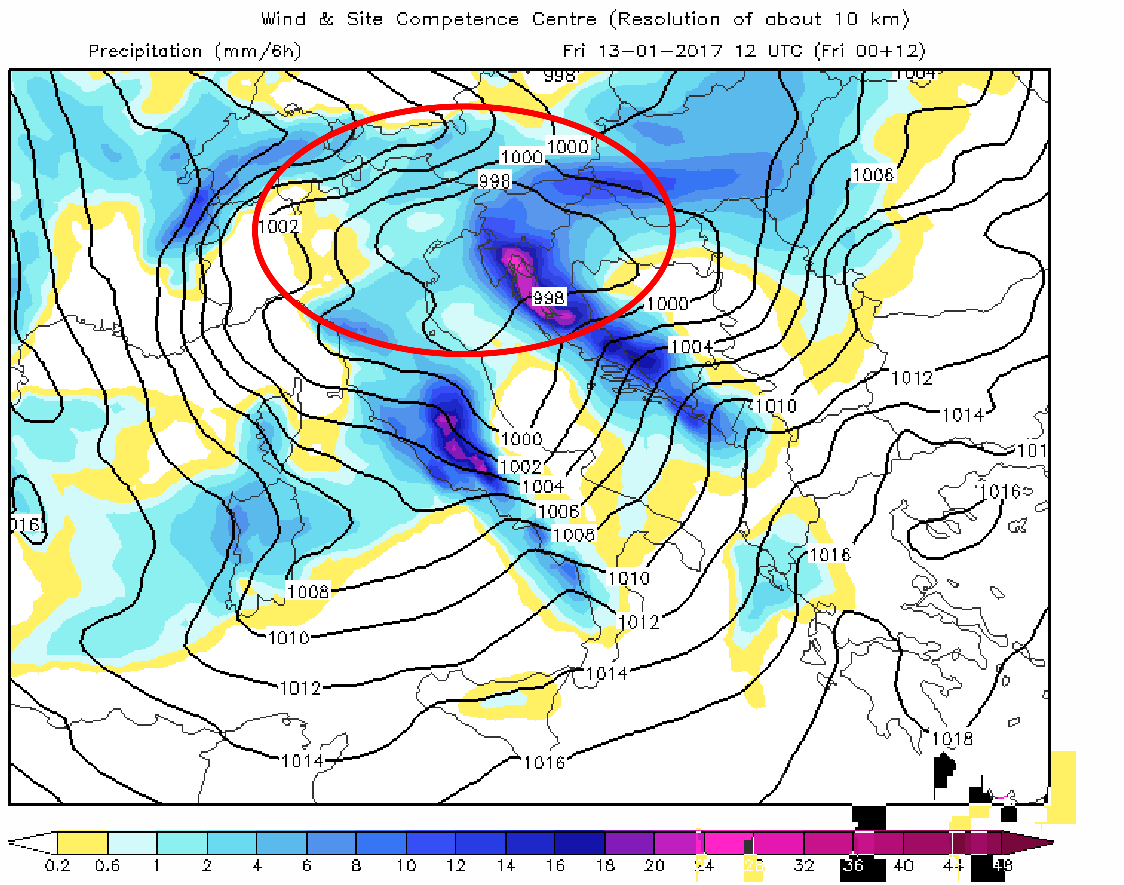

Figure 29. Predicted 6h accumulated precipitation (mm) from Eta model (mm/6h) with new orography at 13.1.2017. at 12 UTC (zoomed region of Italy and Balkan)

Thank you for your attention.