Improving the analysis of the COSMO model by the assimilation of 2 metres observations

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Outline

1. Introduction
   - Motivation
   - Status of our previous experiments
2. The FASDAS technique
   - Short description
   - FASDAS performances
3. Analysis of two specific cases
   - November 2011: heavy rain event in Piemonte
   - March 2012: fair weather case
4. Conclusions

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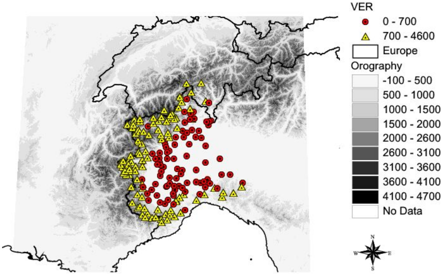
Taking advantage of the many stations in Piemonte

Goal of the work

- Few GTS observations points over Piemonte region
- Much denser station network owned by ARPA
- Take advantage for enhancing COSMO analysis production



Current COSMO-I2 configuration

- Very high resolution grid (2.8 km)
- Only temperature assimilation makes simulation differ significantly
- 2m temperature is not used operationally

COSMO land-surface and data assimilation

COSMO model implemented features

- Possibility of assimilating 2 metres observations (temperature, humidity,. . .)
- Assimilation of 2 metres observations affects directly the atmospheric state but not the soil

Soil state analysis

- Germany: variational soil moisture analysis from 2 metres temperature observations once a day
  - Indipendent procedure
  - Not part of official COSMO package
- Italy: no soil moisture analysis

COSMO performance with the standard assimilation of 2m temperature

- Temperature is positively affected
- Relative humidity and wind are neutrally or slightly negatively affected
- Soil-atmosphere turbulent energy fluxes show a neutral or a slighlty negative effect

The most important point

- The benefits of the assimilation of 2m temperature are very short lasting during the model forecast
- Need to introduce some “long memory” element in the DA system: the soil

Outline

The FASDAS technique

Fluxes Adjusting Surface Data Assimilation System

General description

- Nudging based, integrates the assimilation of screen level observations
- Explicit coupling between temperature and humidity increments in the atmospheric levels and soil state

Soil state increments calculations

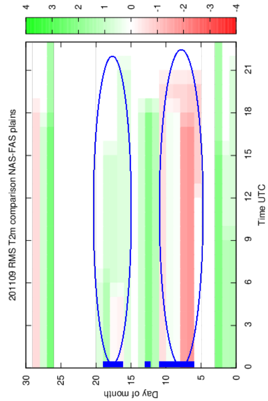
- Nudging of atmospheric temperature and humidity implies a correction of turbulent SH and LH fluxes
- Soil temperature explicit correction proportional to the land surface energy balance terms correction
- Land surface water storages moisture corrected proportionally to the LH flux correction
- The greater the contribution to the LH, the greater the correction

Experiment framework

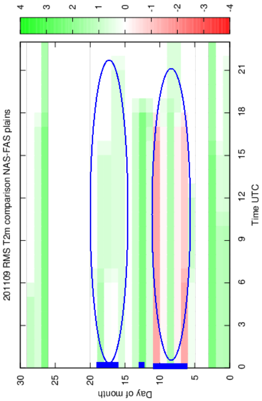
- Operational COSMO-I2 configuration
  - Exception: multilayer soil scheme
- Analysis mode: no forecast, only assimilation cycle
- Continuous assimilation cycle
- Comparison of no assimilation runs (NAS) and FASDAS (FAS)
- ARPA weather station half used for assimilation, half for verification
- Land surface energy balance: compared against UTOPIA model which is already operational in ARPA Piemonte

July 2011 T2m RMSE comparison

Official assimilation



FASDAS

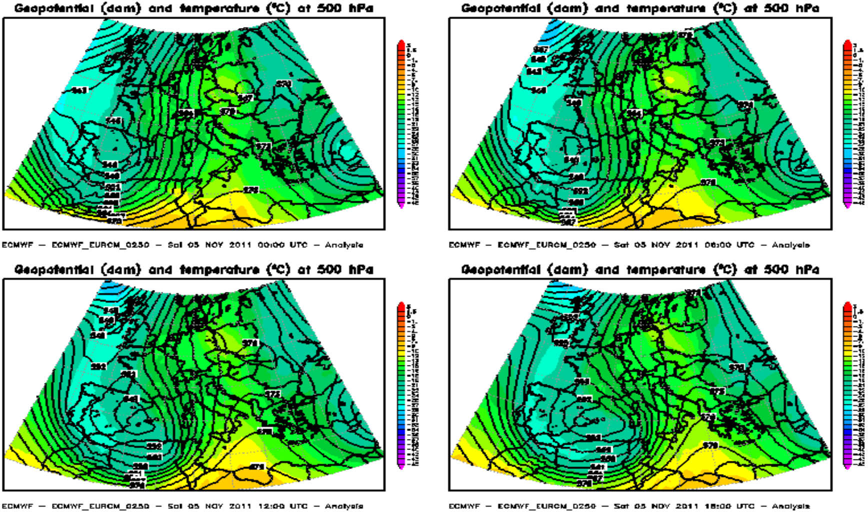


Worse results for RH2m ⇒ Tuning of FASDAS parameters

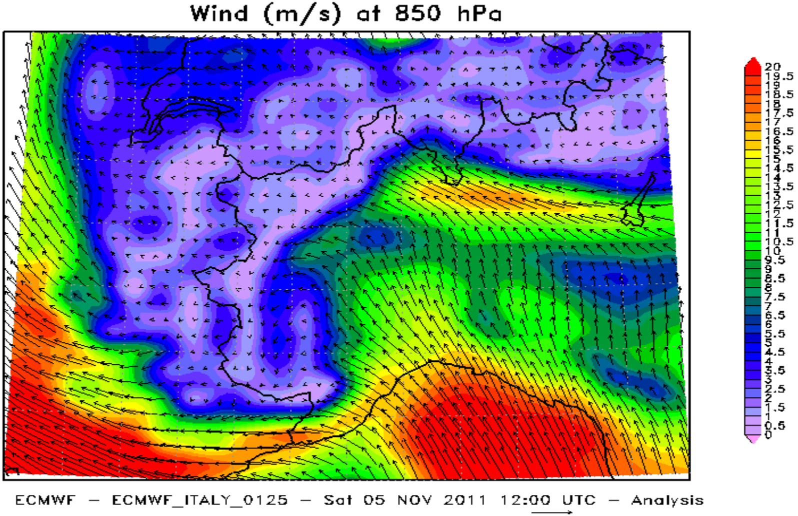
Outline

Synoptic view of the situation

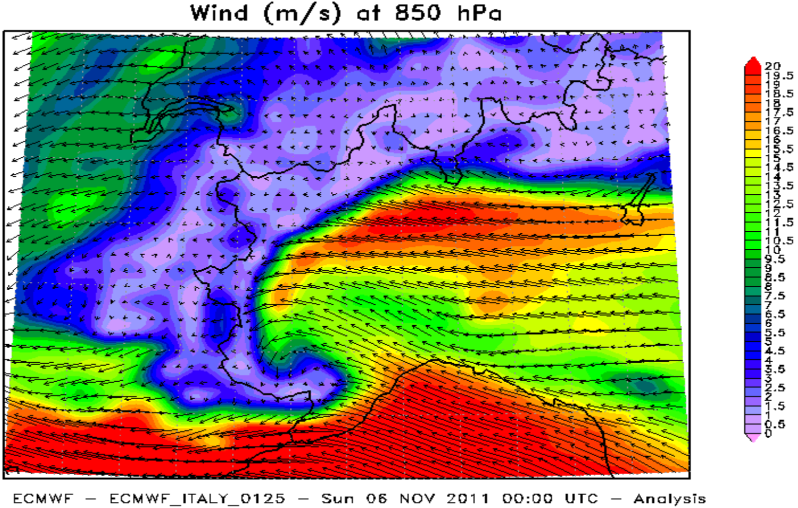
500 hPa height and temperature, 00UTC 5/11 to 00UTC 6/11 (ECMWF)



Synoptic view of the situation



Synoptic view of the situation



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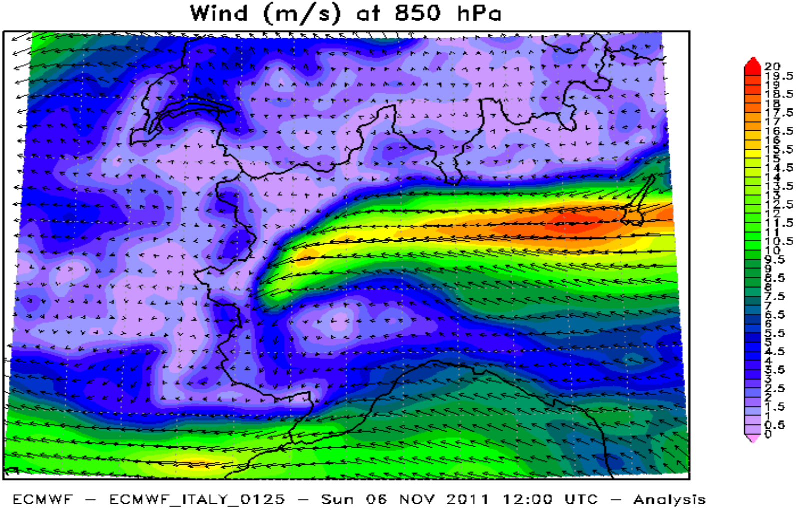
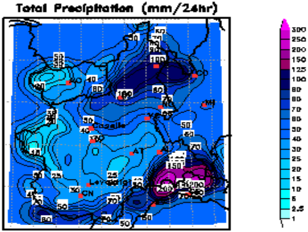
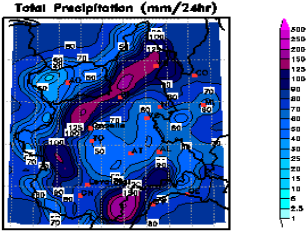


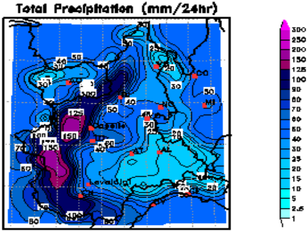
Observed rainfall



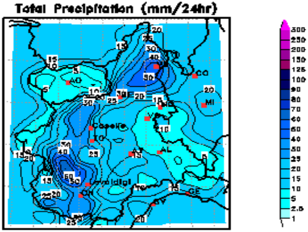
OPINT – OPINT_NWITA_0125 – Fri 04 NOV 2011 12:00 UTC – Analysis



OPINT – OPINT_NWITA_0125 – Sat 05 NOV 2011 12:00 UTC – Analysis



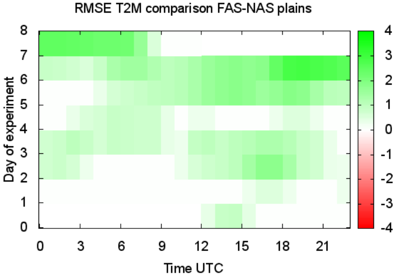
OPINT – OPINT_NWITA_0125 – Sun 06 NOV 2011 12:00 UTC – Analysis



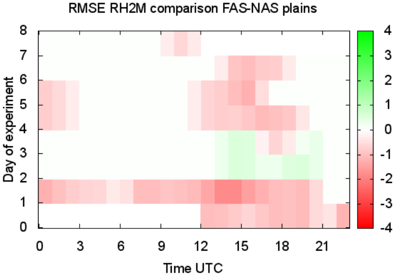
OPINT – OPINT_NWITA_0125 – Mon 07 NOV 2011 12:00 UTC – Analysis

Effects on standard screen level variables

Temperature

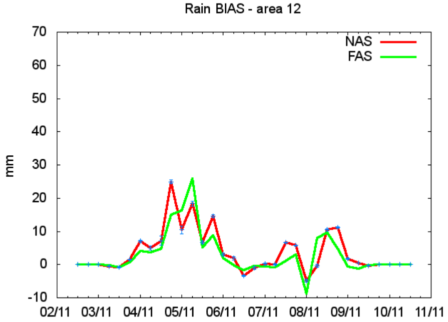


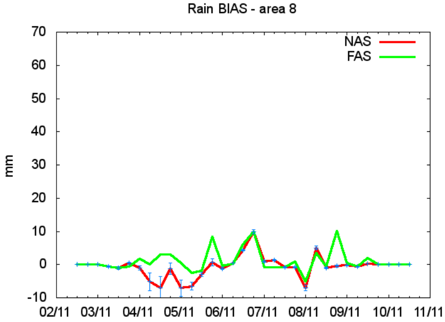
Relative humidity

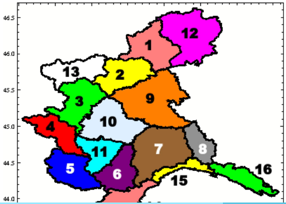


- Temperature description is improved during and expecially after the rainy period
- RH description gets worse except during the rainy period

Rain biases for "upstream areas"

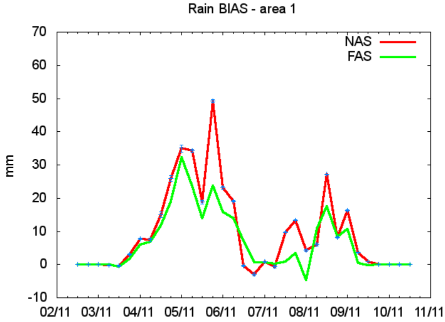


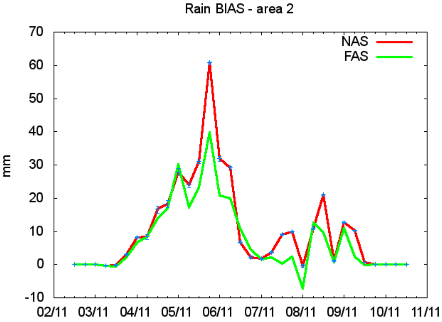


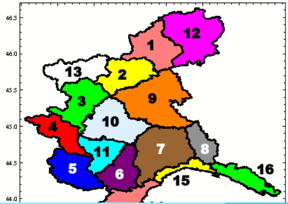


- The assimilation does not introduce any particular benefit on the precipitation

Rain biases for “downstream areas”



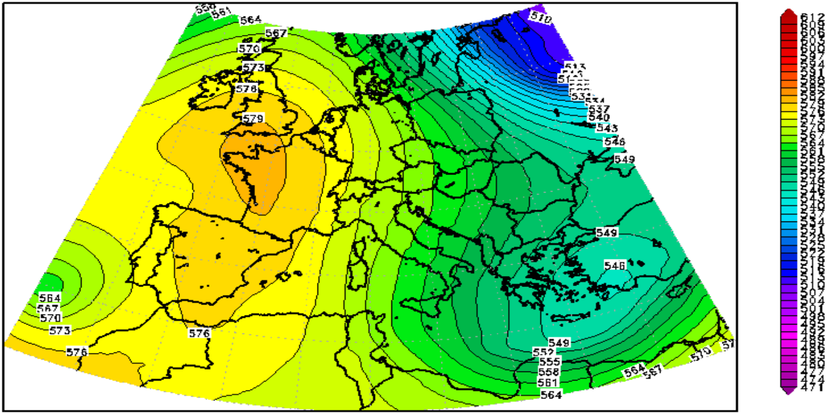




- The assimilation does improve the description of the precipitation

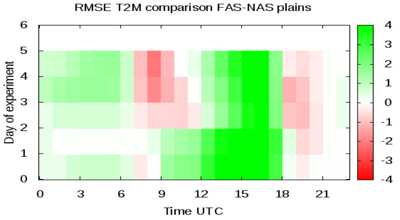
March 2012, fair weather case

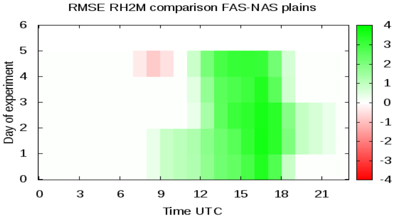
Geopotential Height (dam) at 500 hPa

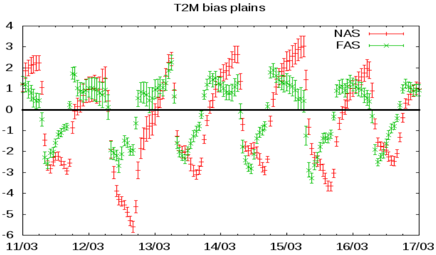


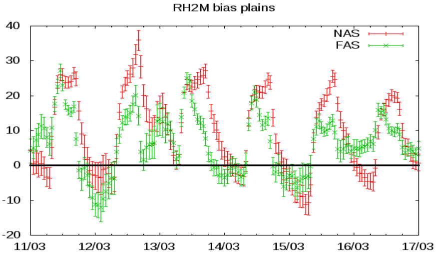
ECMWF – ECMWF_EURCM_0250 – Wed 14 MAR 2012 00:00 UTC – Analysis

Screen level variables comparison



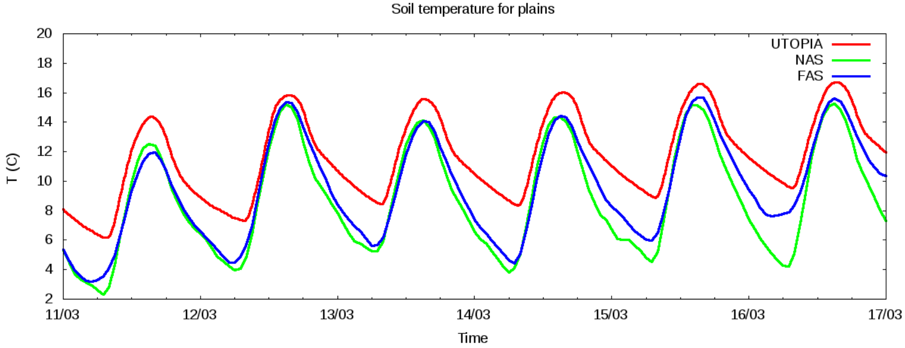






Soil temperature

- Serious problem in the description of the land surface energy balance components
- Both in rainy and fair weather cases
- Anyway, reasonable soil temperature trends



Further developments

Calibration of FASDAS

- Further tuning of the parameters that take part in the scheme
  - Thickness of soil layer which is temperature corrected
  - Artificially adjusting soil moisture more for the top soil layers than the deeper ones

Completing the soil moisture analysis

- Use radar and rain gauges data to correct errors in soil moisture due to bad precipitation representation

Outline

Conclusions

- Deficiencies in the assimilation by nudging to the surface observations
- Development of FASDAS
- Tests on the official operational model
- Good results running COSMO and FASDAS in wet days
- After tuning, good results also in dry days

Thank you for the attention

Thanks to:
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for their help and suggestions.

References

- Kiran Alapaty, Dev Niyogi, Fei Chen, Patrick Pyle Anantharman Chandrasekar and Nelson Seaman, **Development of the Flux-Adjusing Surface Data Assimilation System for Mesoscale Models**, Journal of Applied Meteorology and Climatology, 2008
- Kiran Alapaty, Nelson L. Seaman, Devdutta S. Niyogi,Adel F. Hanna, **Assimilating Surface Data to Improve the Accuracy of Atmospheric Boundary Layer Simulations**, Journal of Applied Meteorology and Climatology, 2001

Fluxes Adjusting Surface Data Assimilation System (FASDAS)

Alapaty et al. (2001, 2008)

Problem statement

Errors in PBL description are reduced if T2m and Q2m assimilation does not have heavy consequences on the equilibrium of the model

$$\frac{\partial \alpha}{\partial t} = \mathcal{M}(\alpha, z, t) + N_\alpha \left(\hat{\alpha} - \alpha\right) \equiv \frac{\partial \alpha^{\mathcal{M}}}{\partial t} + \frac{\partial \alpha^{N}}{\partial t}$$

Recalling that

$$\frac{\partial \alpha}{\partial t} = -\frac{H_1^\alpha - H_S^\alpha}{\rho C \Delta z}$$

then

$$H^{\alpha,N} = \rho C_\alpha \left(\frac{\partial \alpha^N}{\partial t}\right) \Delta z$$

Influence on soil of fluxes correction: temperature

$$\Delta T_g^N = \left(\frac{\partial T_g^N}{\partial t}\right)\Delta t = (H_{\theta,S}^N - H_{q,S}^N)\frac{\Delta t}{C_g}$$

A positive (negative) adjustment of H_q causes a reduction (growth) of T_g, because it is a function of the saturation vapour pressure calculated at T_g

Warning

The fluxes are adjusted so that T2m and Q2m converge towards observed values. The fluxes are altered to allow the atmospheric structure in a realistic way, regardless of the reason of errors in simulated T2m and Q2m.

Putting together soil moisture correction and 2m DA

State of art (including COSMO soil moisture operational analysis)

- Many data assimilation tecniques attribute the main source of T2m errors in wrong estimates of soil moisture
- Sometimes errors in T2m values are due to indipendent model errors and not to the data assimilation scheme; in this case, the correction of soil moisture would be an additional source of problems

Preliminary definitions

- q_a: mixing ratio of surface layer (a measure of humidity)
- Δq_a: time change in mixing ratio in surface layer due to mixing
- $\psi_a \equiv \Delta q_a / q_a$: normalization
- $E = E_{\mathrm{sfc}} + E_{\mathrm{can}} + \sum_{\mathrm{layers}} E_{\mathrm{trasp}}$: evapotranspiration

Adjusting the water balance components

Evaluation of the correction of the water balance components

$$E_{\xi}^{N} = \left(\frac{E_{\xi}}{E} \right) \psi_a \left(\frac{H_q^N}{\rho_w L} \right)$$

$\xi =$ surface, vegetation, soil layers

Then sum the terms obtained from this step to the appropriate water balance equations (soil layers, vegetation,. . .)

FASDAS in COSMO

Direct assimilation

- Quality control and weight the 2m data (not reported for brevity)
- Assimilation of T2m and Q2m (observation nudging of the atmospheric fields)
- Estimation of turbulent fluxes adjustment

Indirect assimilation

- Calculation of weighting factor for latent heat flux (ψ_a)
- Weight evapotranspiration terms
- Partition the weighted adjustment of evaporation
- Sum the water balance corrections in the appropriate equations
- Add the fluxes adjustment to the predicted ones

In case of snow

Modification of the snow energy balance:

$$\Delta E = (H_{\theta,S}^{N} - H_{q,S}^{N})\Delta t$$

Energy thresold to reach the snow melting point:

$$\Delta E_0 = (T_0 - T_{sn})\rho_{sn} c_{sn} \Delta z_{sn}$$

If $\Delta E < \Delta E_0$, only snow warming
Otherwise, snow starts to melt and top soil layer moisture must increase:

$$\Delta z_{sn,new} = \Delta z_{sn,old} - \frac{\Delta E - \Delta E_0}{L_{sn}\rho_{sn}}$$

$$w_{1,new} = w_{1,old} + \frac{\Delta E - \Delta E_0}{L_{sn}\rho_w}$$