Rainfall modelling and assimilation into mesoscale NWP models

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BOLAM MODEL

- Hydrostatic, Limited Area Model
- Horizontal resolution 30 km – 7 km
- Multiple Nesting over specific area
- Parameterized deep convection (Kain-Fritsch)

MOLOCH MODEL

- Non hydrostatic, fully compressible
- Horizontal resolution 1-3 km
- Convection explicity resolved

Data assimilation

-OI (SYNOP and TEMP)

-Development of EKF methods based on the dynamical stability of the system (A.Trevisan)

-Nudging for rainfall assimilation

- The Mesoscale Alpine Programme (MAP), which focused on the region around the Alps, has been (and will be) a good opportunity for investigate the mechanisms responsible for severe precipitation events using state-of-the-art models

•The application of operational and experimental models at increasing resolution has allowed to better simulate small scale processes as:

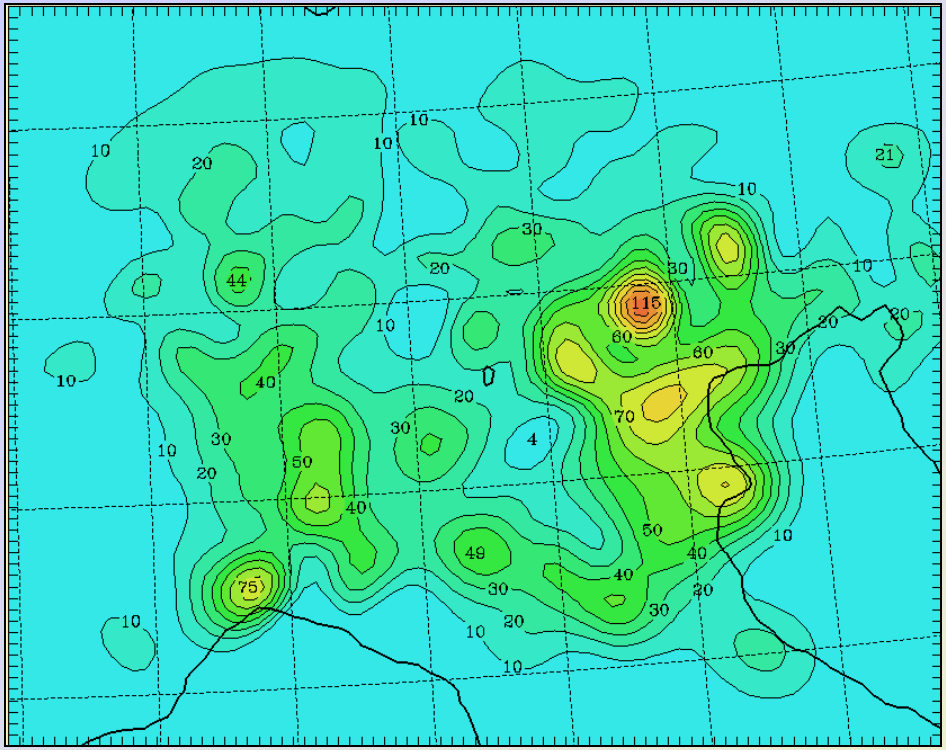
- orographic forcing
- microphysics
- convection

Results from many case studies of heavy precipitation events south of the Alps (in connection or not with MAP)

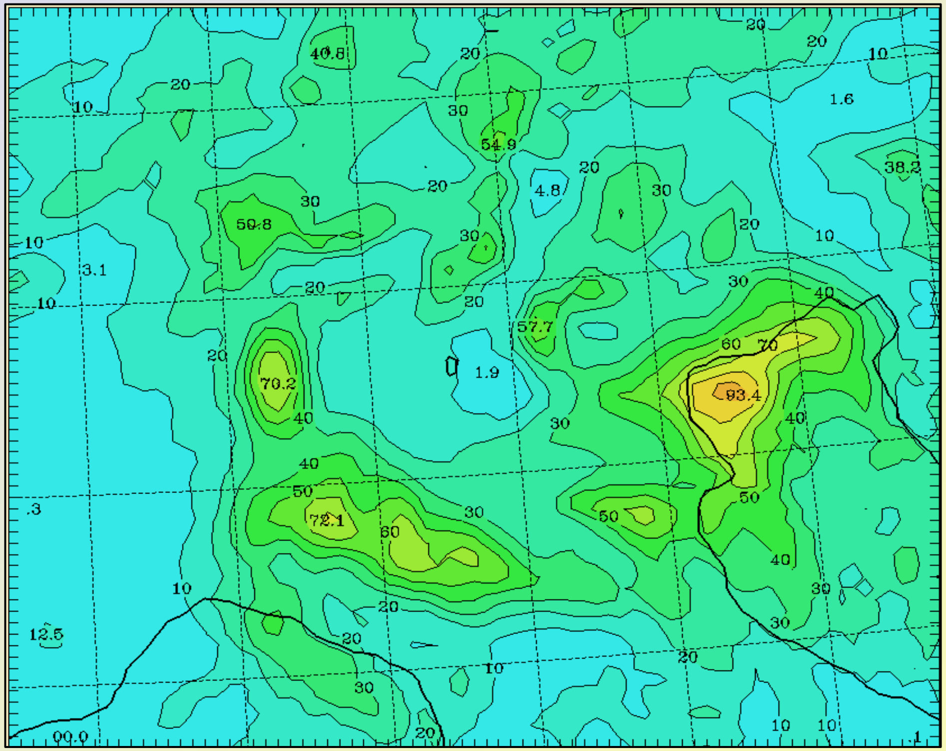
- Identification of “large-scale” precursor
- Identification of mesoscale *ingredients*:
  - pre-frontal low level jets;
  - orographic flow deviations (*barrier winds*) and convergence;
  - convective/precipitating bands over the sea.
- Identification of physical *processes* and *factors:*
  - orography
  - latent heat (condensation and evaporation of precipitation)
  - sensible and latent fluxes from the Mediterranaean sea, etc...

MAP-IOP15

24 hour acc. precipitation, 07 Nov 1999, 06 UTC
Contour interval 10 mm



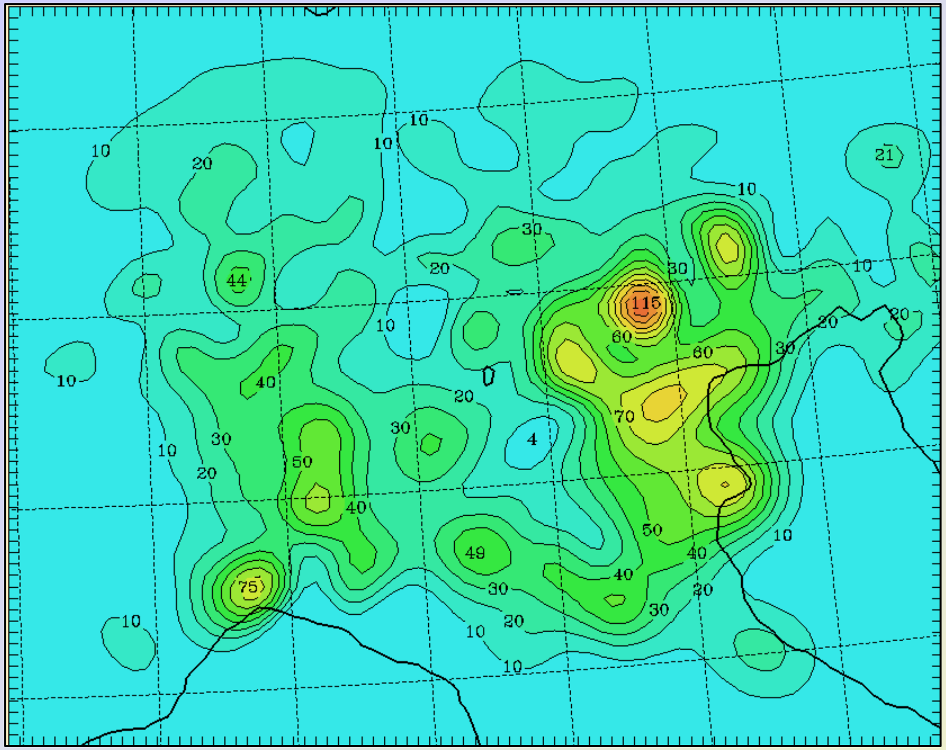
Observed



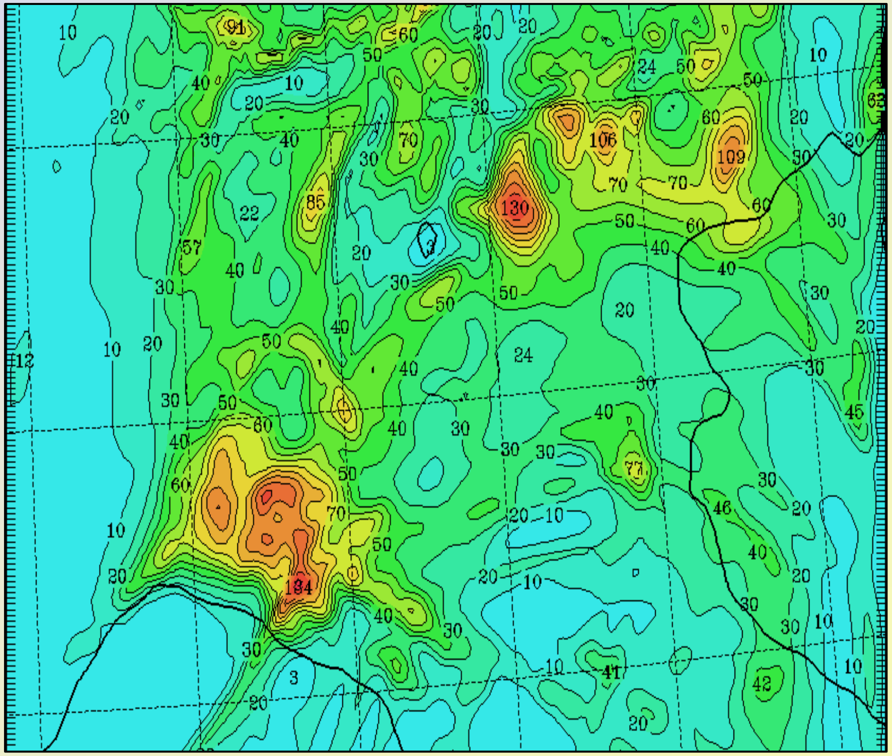
BOLAM (7km)

MAP-IOP15

24 hour acc. precipitation, 07 Nov 1999, 06 UTC
Contour interval 10 mm



Observed



MOLOCH (2km)

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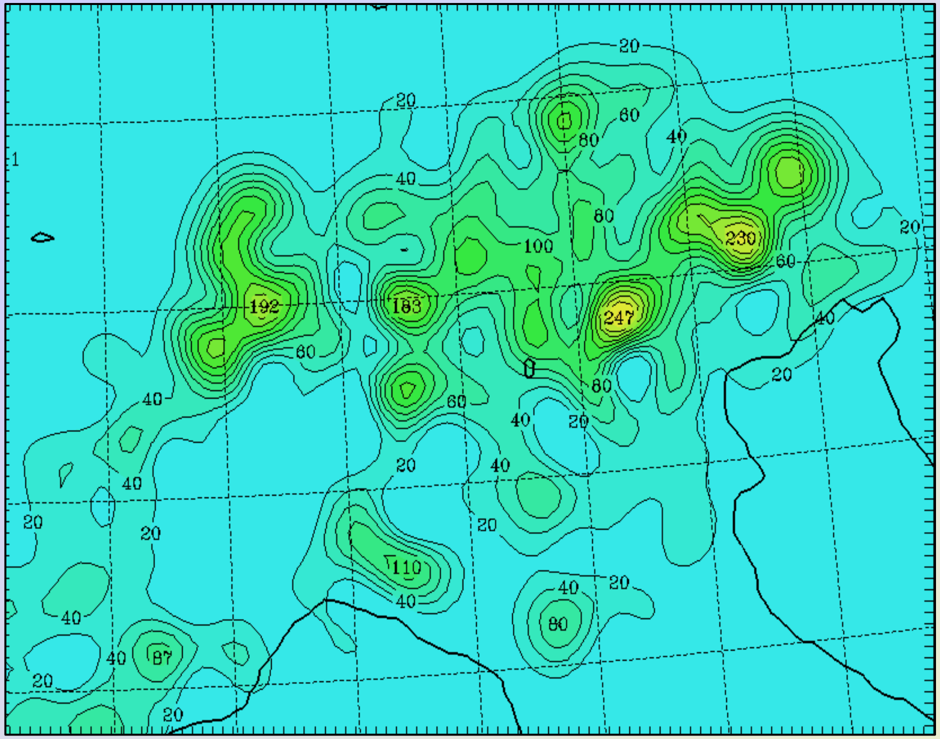
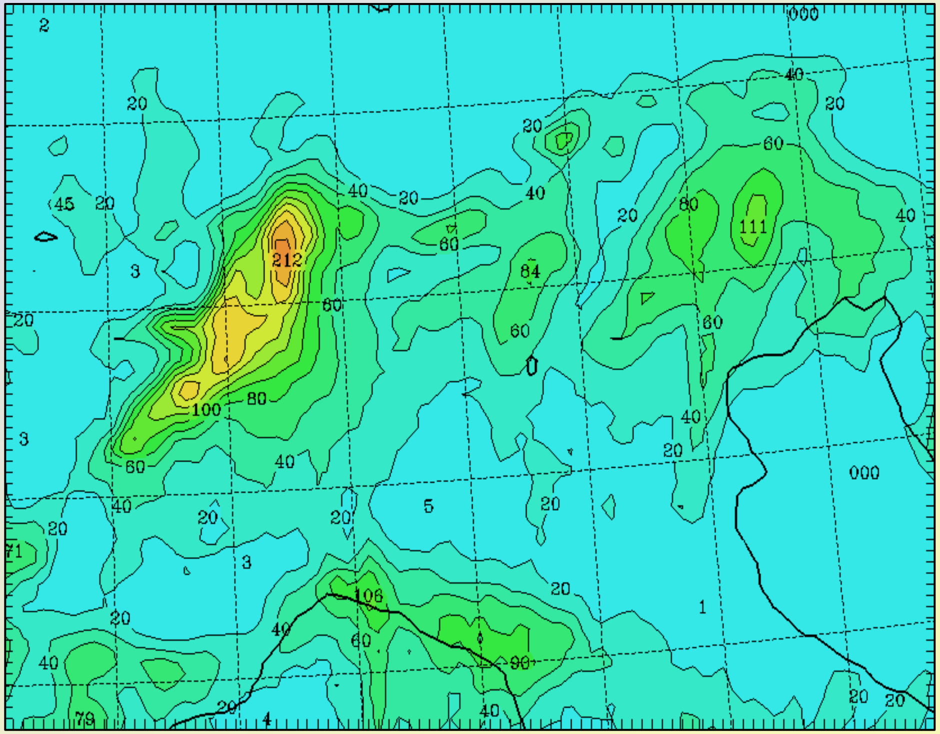
MAP-IOP2b

24 hour acc. precipitation, 21 Sep 1999, 00 UTC
Contour interval 10 mm



Observed

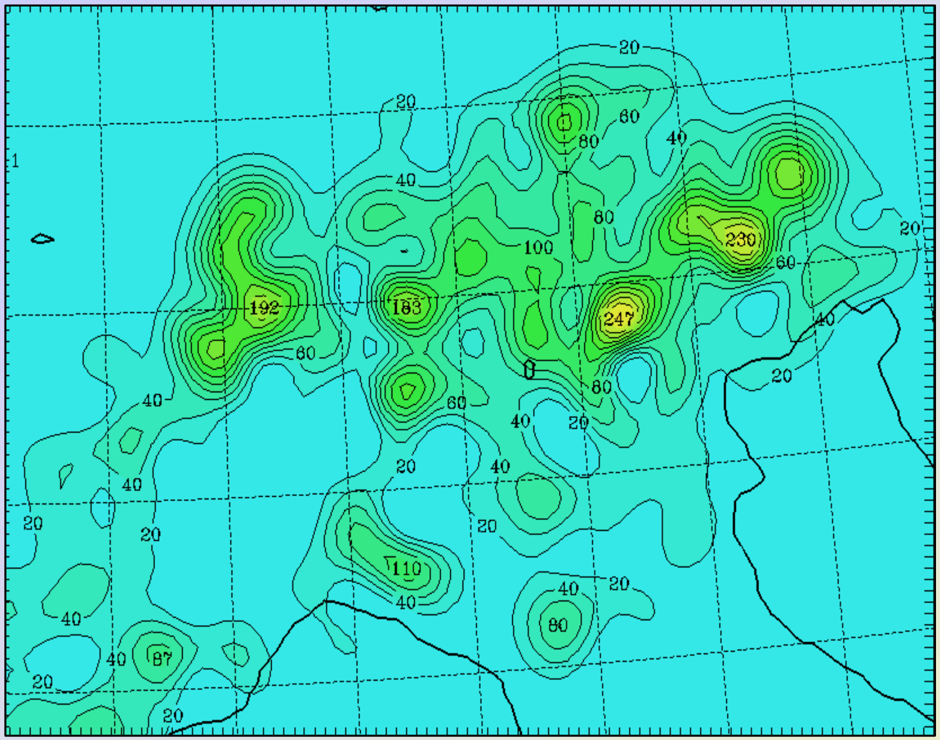


BOLAM (7km)

INSTITUTE OF ATMOSPHERIC SCIENCES AND CLIMATE , ISAC-CNR

MAP-IOP2b

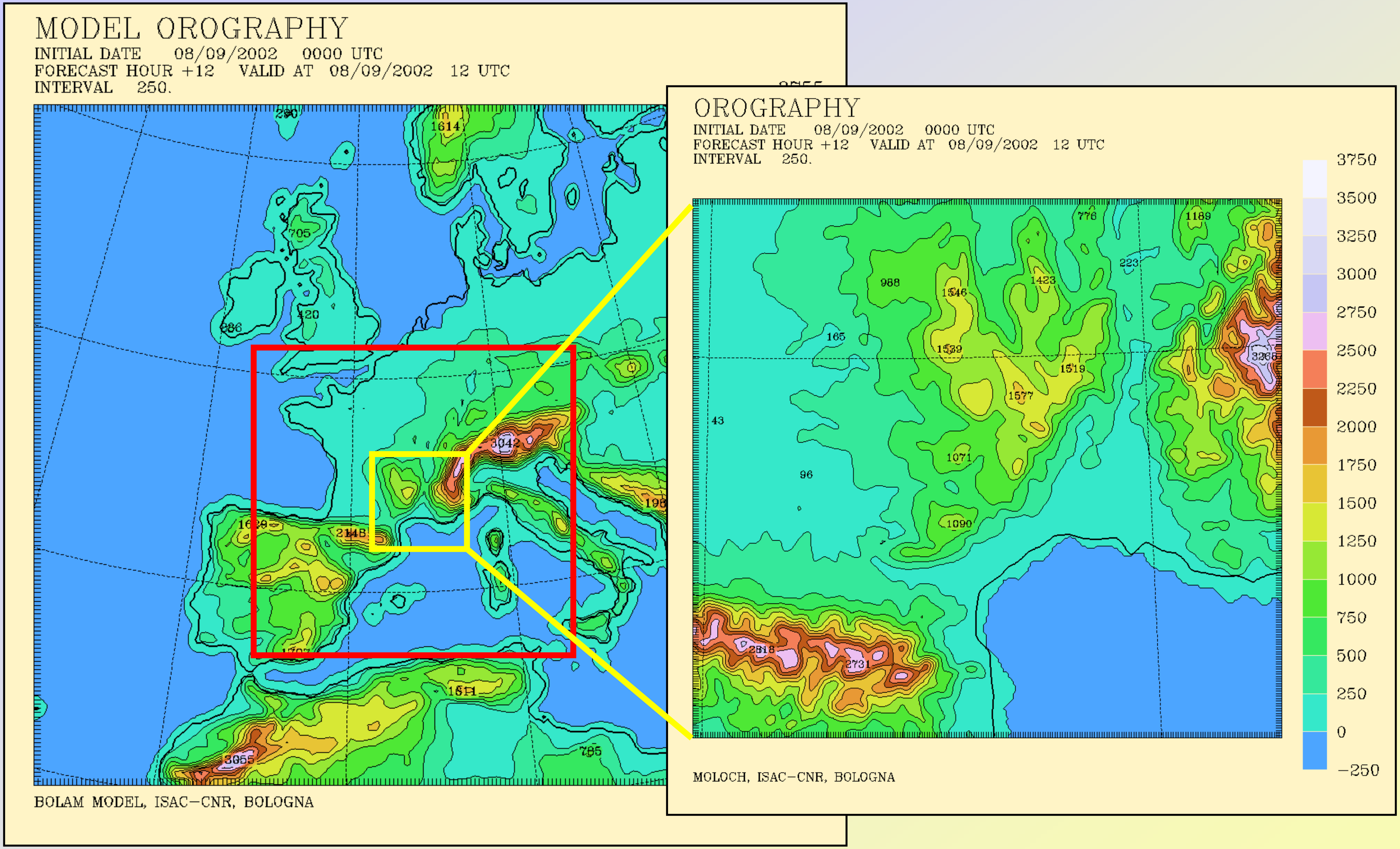
24 hour acc. precipitation, 21 Sep 1999, 00 UTC
Contour interval 10 mm



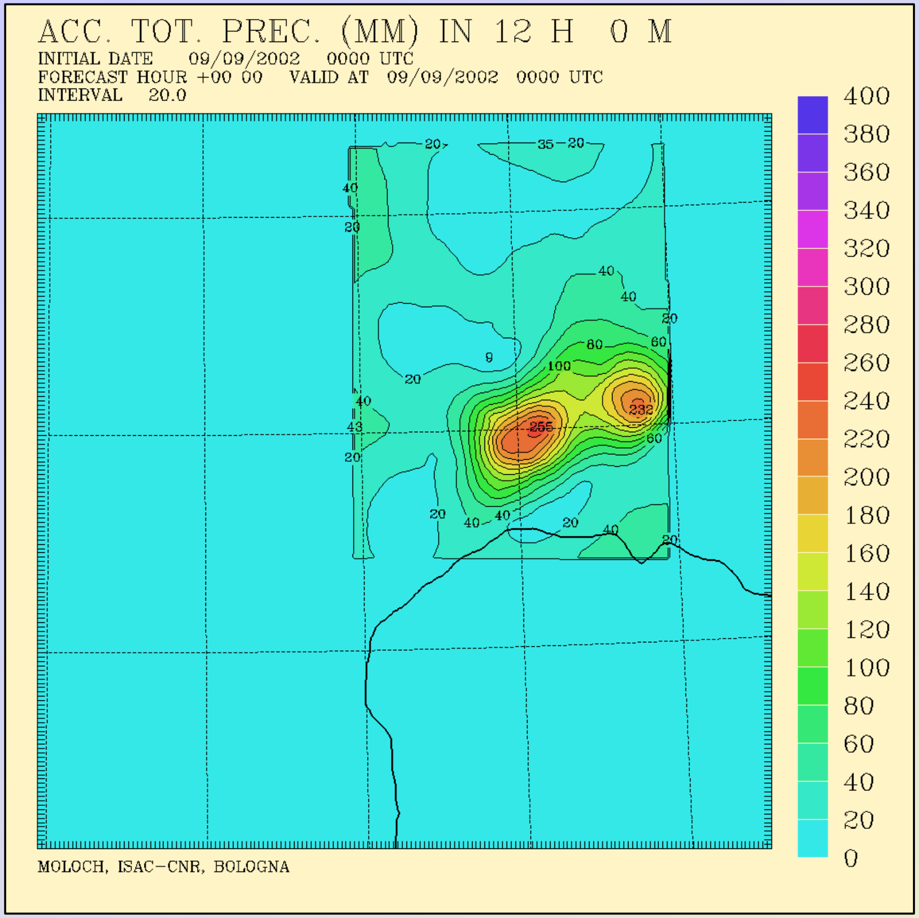
Observed

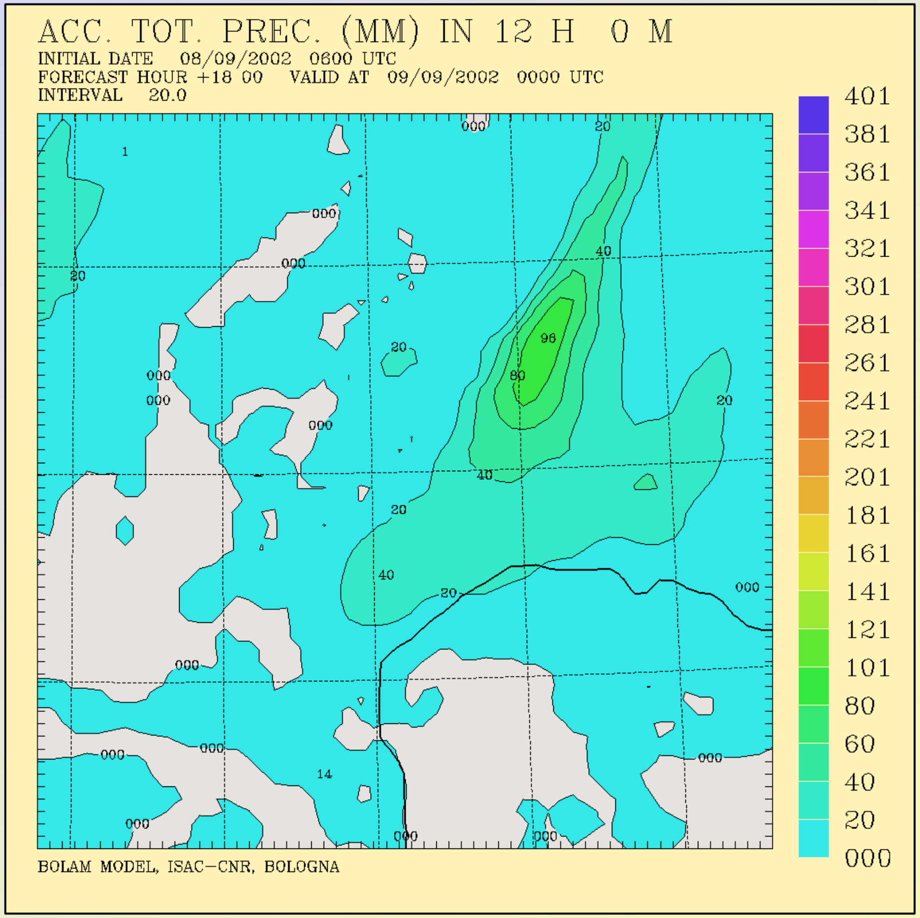
MOLOCH (2km)

GARD EVENT: 8-9 September 2002



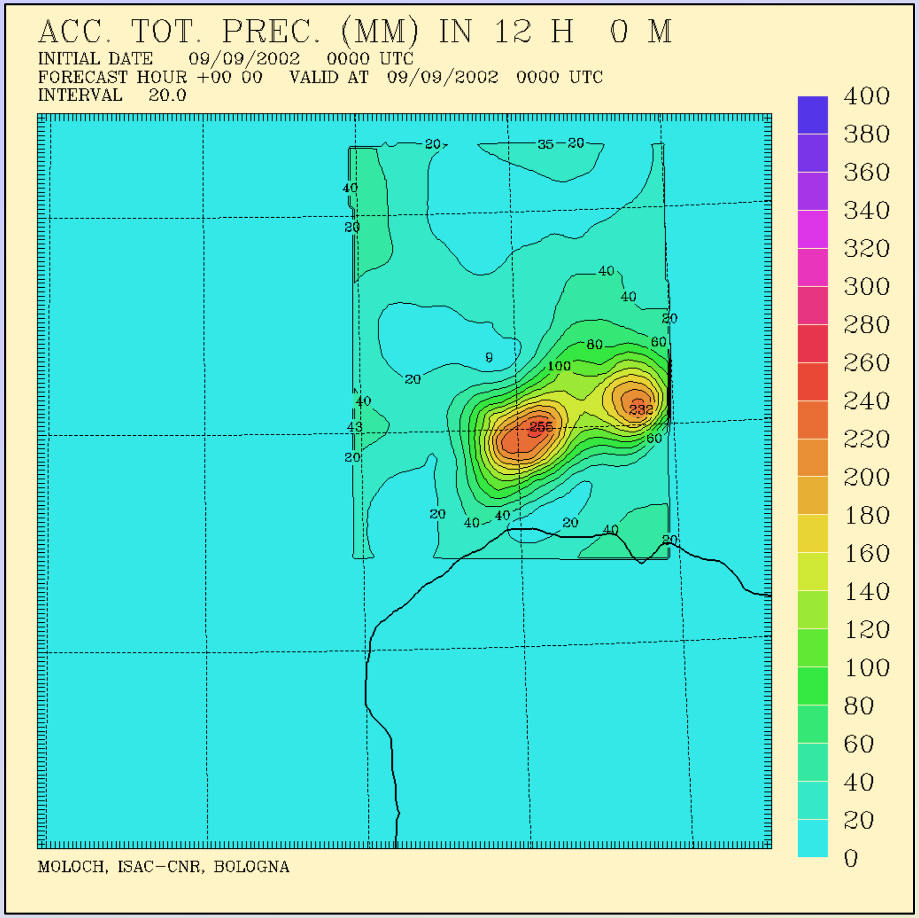
12 hour acc. precipitation, 9 Sep. 2002, 00 UTC

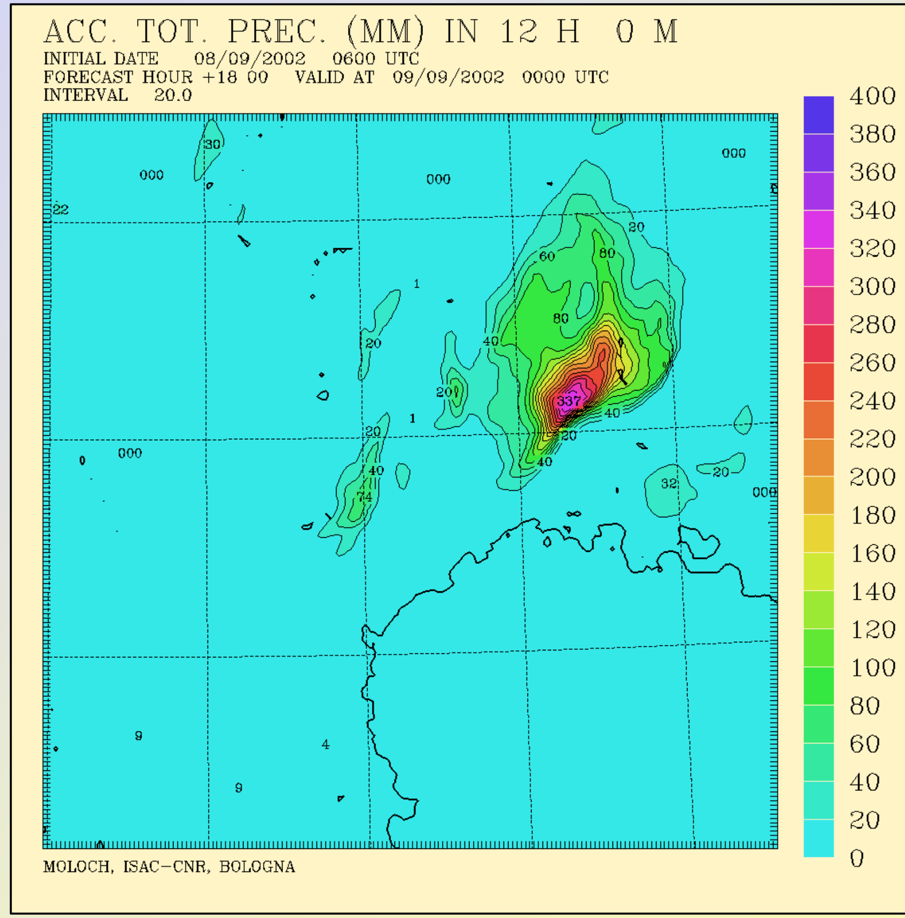




Convective instability is mainly released over the cost.
The rainfall max, located over the mountains, is produced by large scale uplift, due to flow interaction with orography.

12 hour acc. precipitation, 9 Sep. 2002, 00 UTC





Trigger and rainfall location are now dissociated. The MCS develops over the coastal area and moves NE, becoming stationary at some distance from the main mountain slopes.

Rainfall Assimilation: the nudging scheme

After comparing RR_t and RR_f $\Longrightarrow$ nudging of specific humidity profile

$$\frac{\partial q(k)}{\partial t} = -\tau_{S,C}^{-1}(k)\left\{q(k) - \varepsilon_{S,C}\, q^{*}(k)\right\}$$

The forcing is a <u>function of the precipitation type</u>

$\varepsilon_{s,c}$ = over/under saturation coefficient

$\tau_{s,c}$ = relaxation time (vertically modulated)

- **Stratiform precipitation:**

  q is changed only in the middle-lower troposphere where large scale condensation takes place.

  $RR_f < RR_t$ $q(k) \Longrightarrow \varepsilon_s^{+}(k)q^{*}(k)$ $\varepsilon_s^{+}(k) = 1.1$

  $RR_f > RR_t$ $q(k) \Longrightarrow \varepsilon_s^{-}(k)q^{*}(k)$ $\varepsilon_s^{-}(k) = 0.8$

- **Convective precipitation:**

  q is changed only in the boundary layer.

  $RR_f < RR_t$ $q(k) \Longrightarrow \varepsilon_c^{+}(k)q^{*}(k)$ $\varepsilon_c^{+}(k) = 0.9$

  $RR_f > RR_t$ $q(k) \Longrightarrow \varepsilon_c^{-}(k)q^{*}(k)$ $\varepsilon_c^{-}(k) = 0.1$

REMARKS

- Physically based scheme, applied to a mesoscale model with parameterized convection (dependence on the model)
- Coefficients selected after experimenting
- The assimilation scheme allows the assimilation of precipitation also when the rain is not purely convective
- More: *Davolio and Buzzi, Wea. Forecasting, 2004.*

EXPERIMENTS:

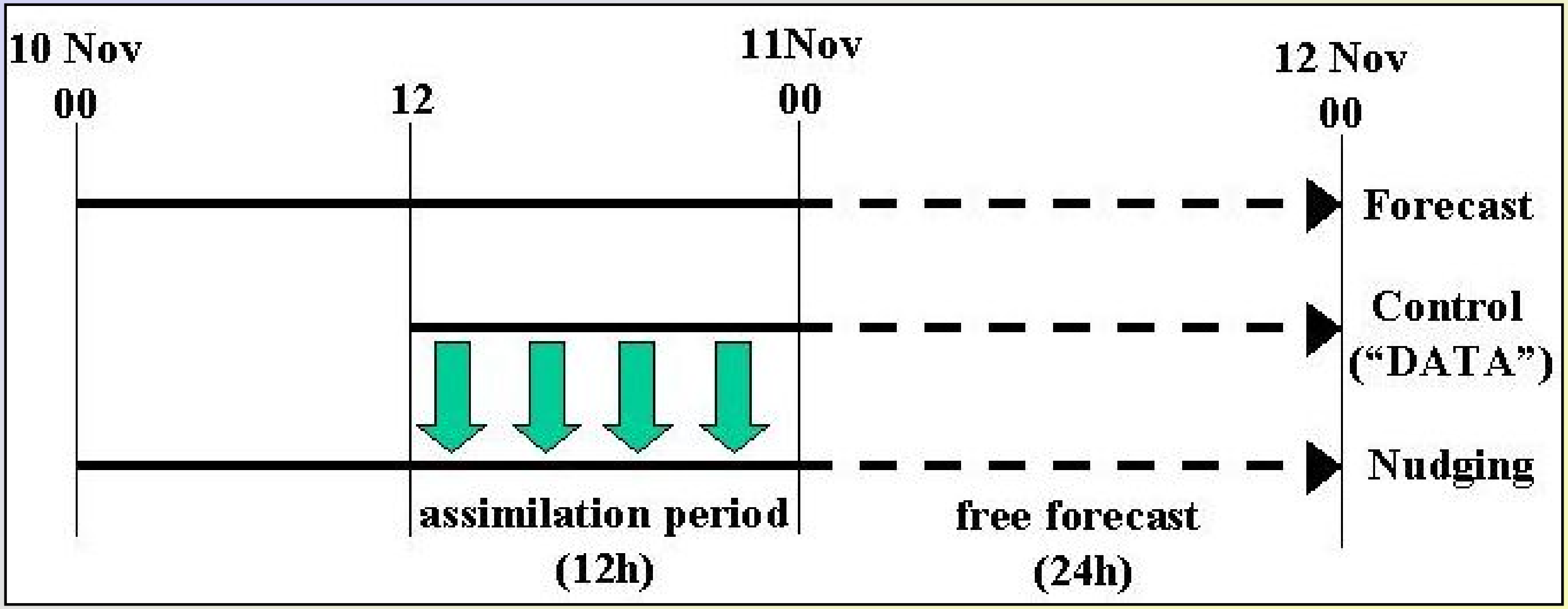
- real case, idealized data
- real case, real data
- idealized experiments

Real case, Idealized Data

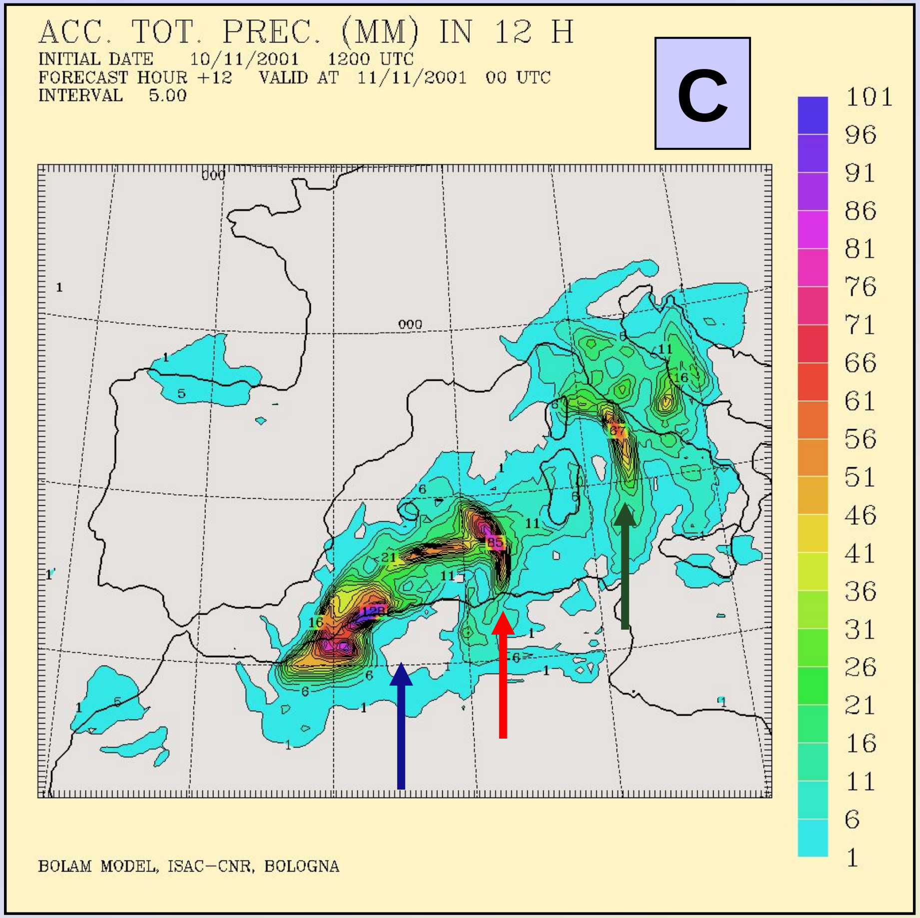
- **METHOD: Lagged Forecast scheme** (Algeria flood, Nov. 2001)

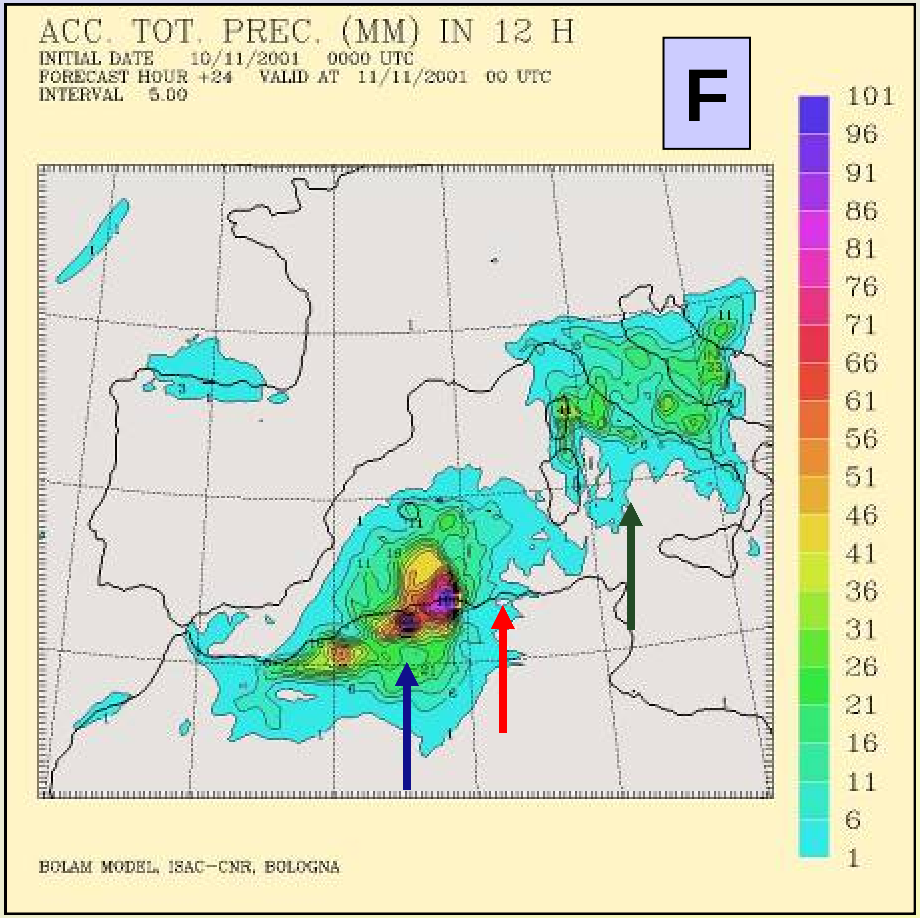
  Two different simulations from initial condition 12 hours apart:
  - "***Control Run***": represents the reference state and provides the target rain rate.
  - "***Forecast Run***": represents the real forecast to be improved.

  Nudging procedure applied for 12 hours to a simulation starting from the same initial condition of the Forecast Run ⟶ (***Nudging Run***).



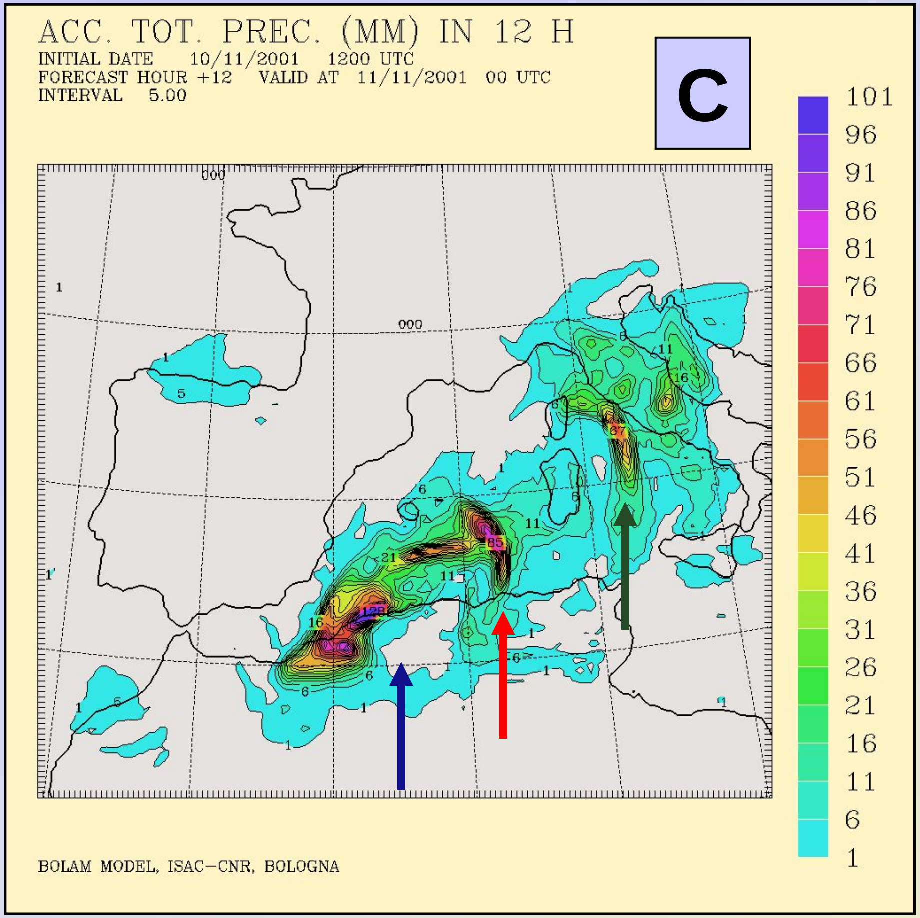
Results at the end of the nudging stage

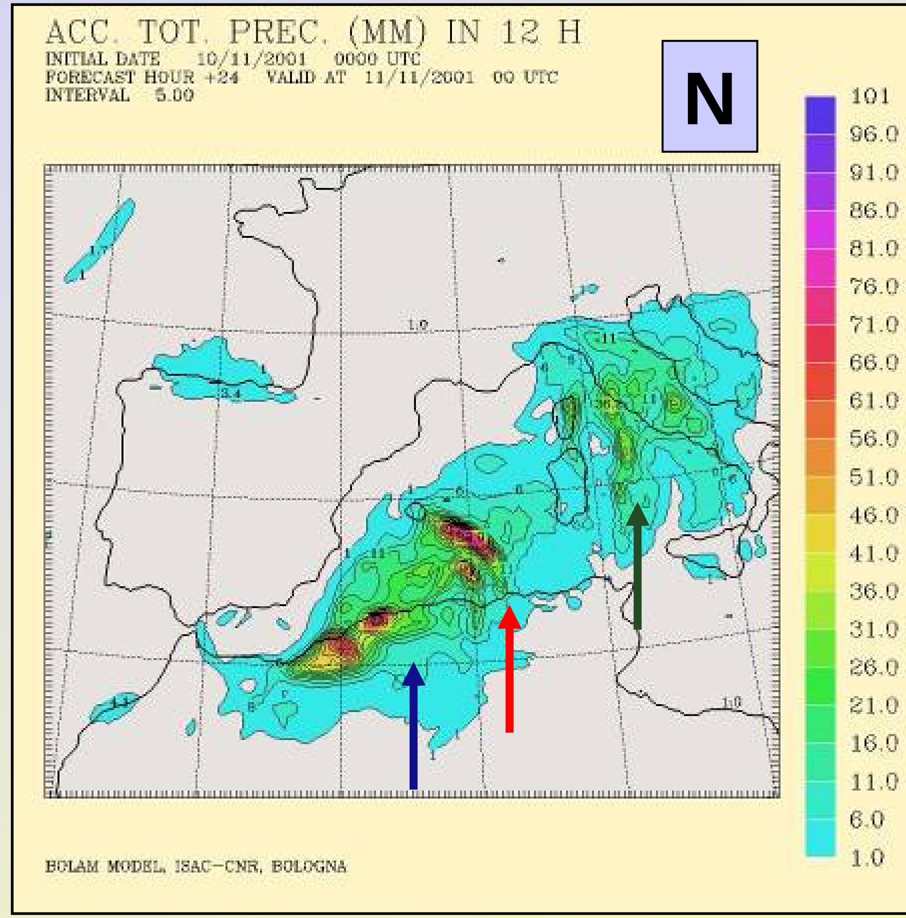




- Different rainfall patterns over the coast and south of the Balearic Islands
- Rain band missing in the forecast run
- Rain band and area of light rainfall around Sardinia

Results at the end of the nudging stage





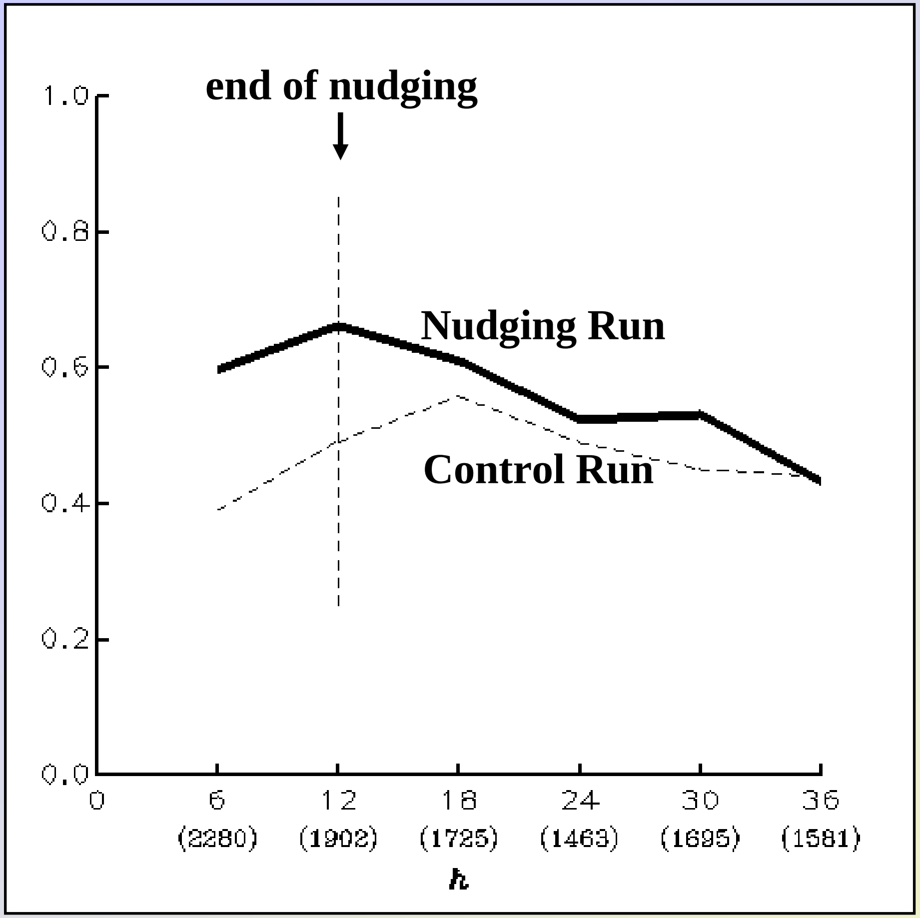
Improved!

Rain band slightly shifted westward but correct in intensity

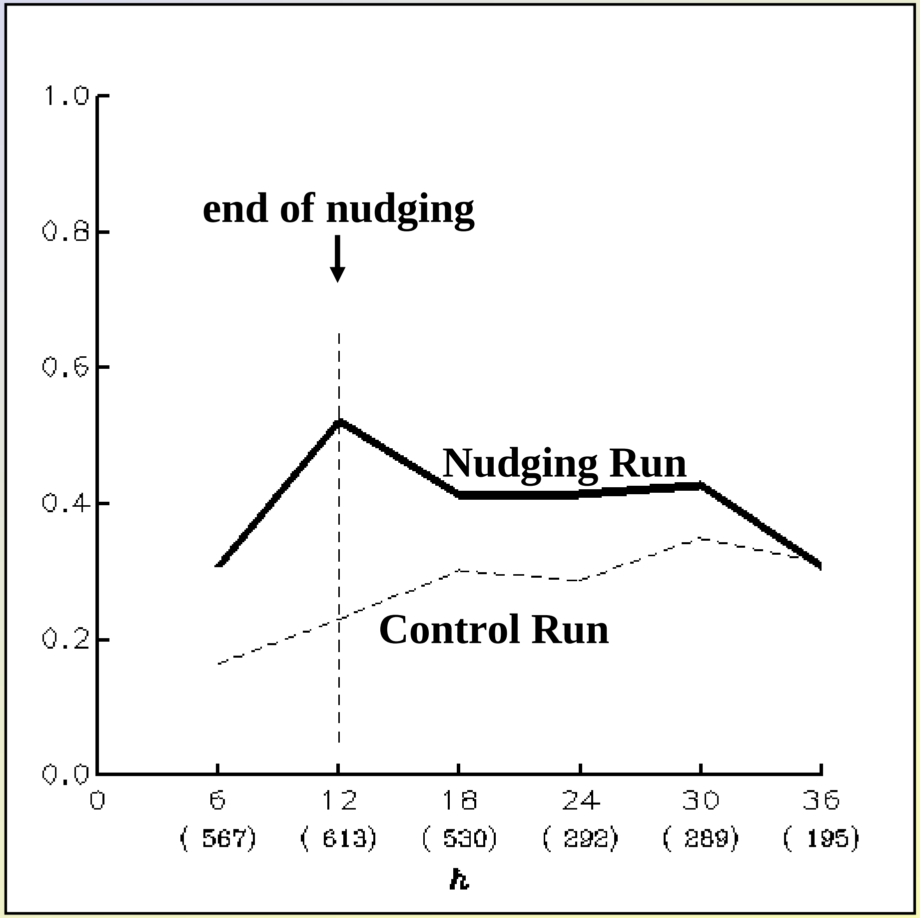
Rain band in phase but intensity too low (36 mm/12h instead of 67 mm/12h)

RESULTS after the nudging stage

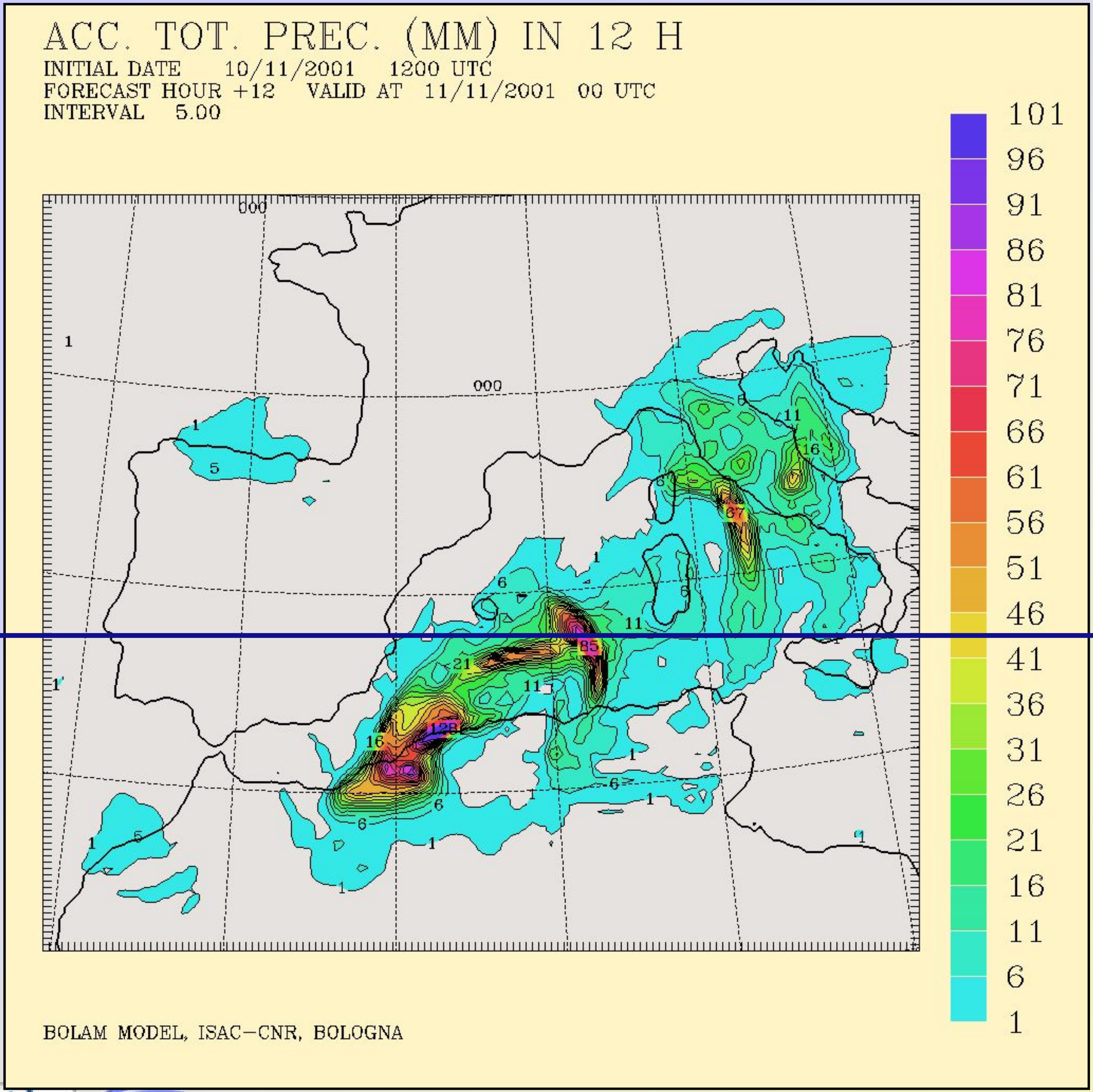
Equitable Threat Score vs simulation time



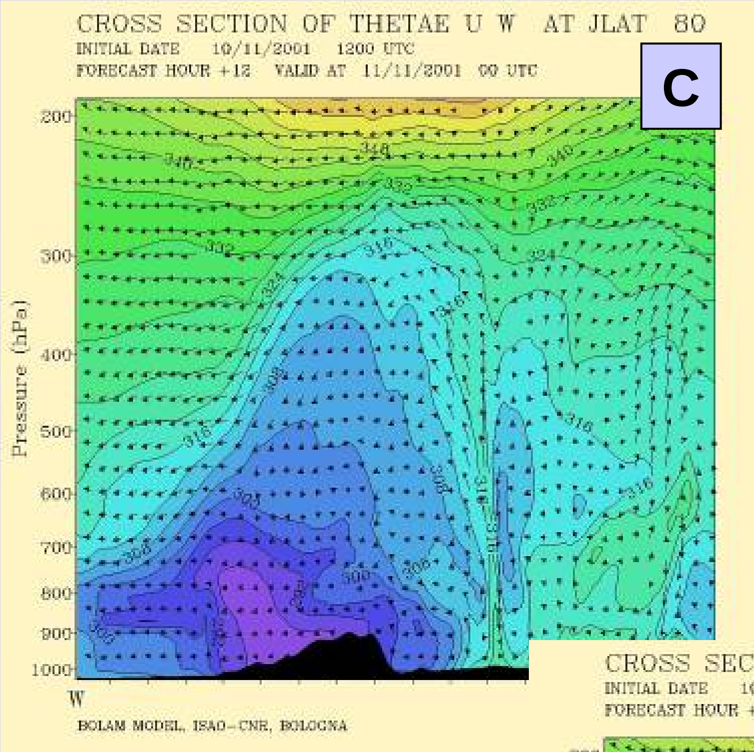
Threshold: 2mm/6h

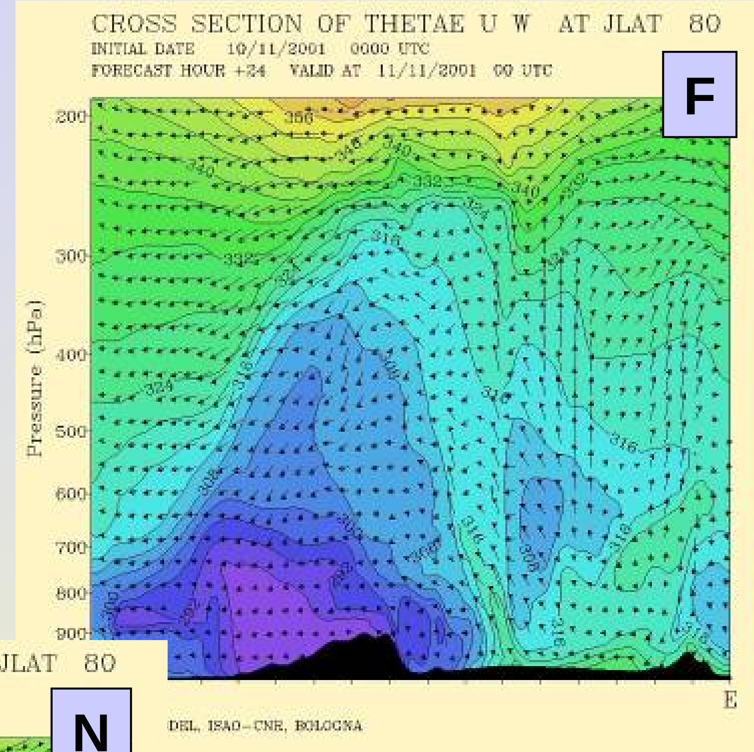


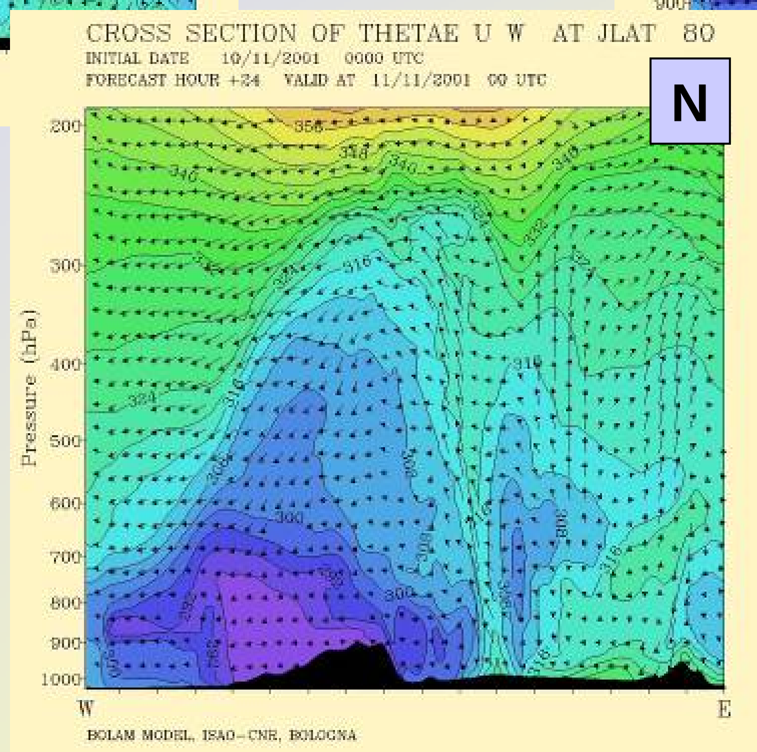
Threshold: 10mm/6h



Cross section


CROSS SECTION OF THETAE U W AT JLAT 80
INITIAL DATE 10/11/2001 1200 UTC
FORECAST HOUR +12 VALID AT 11/11/2001 00 UTC
C
Pressure (hPa)
W
BOLAM MODEL, ISAO-CNR, BOLOGNA


CROSS SECTION OF THETAE U W AT JLAT 80
INITIAL DATE 10/11/2001 0000 UTC
FORECAST HOUR +24 VALID AT 11/11/2001 00 UTC
F
Pressure (hPa)
E


CROSS SECTION OF THETAE U W AT JLAT 80
INITIAL DATE 10/11/2001 0000 UTC
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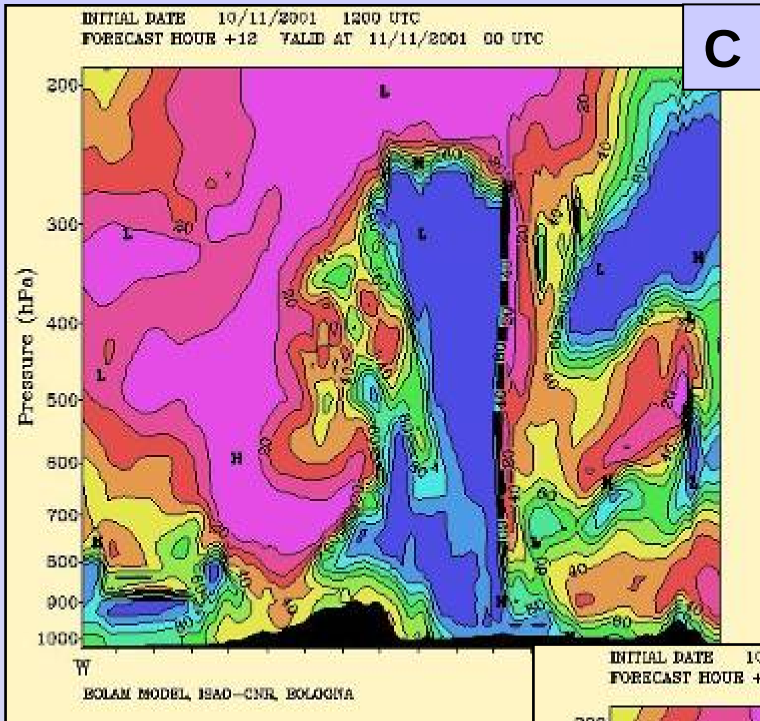
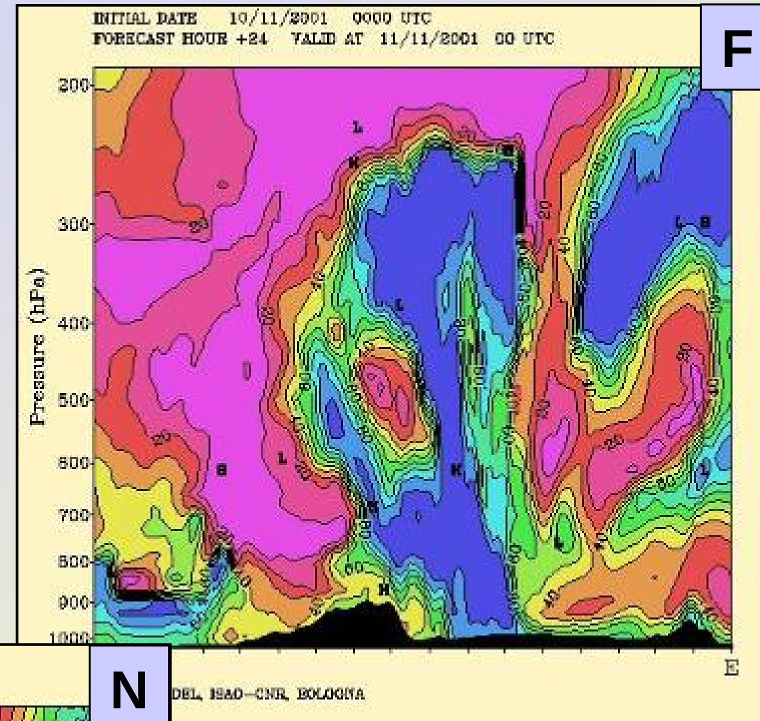
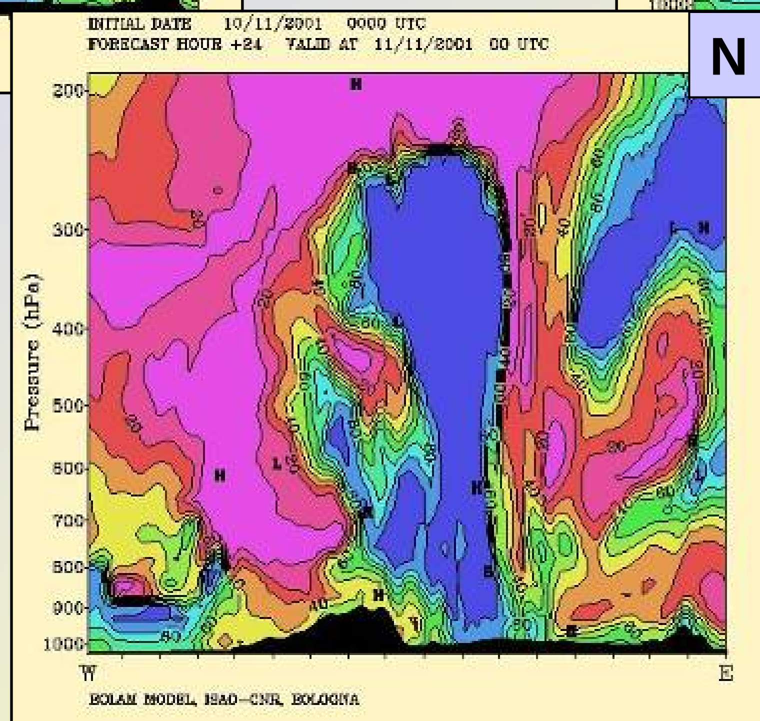
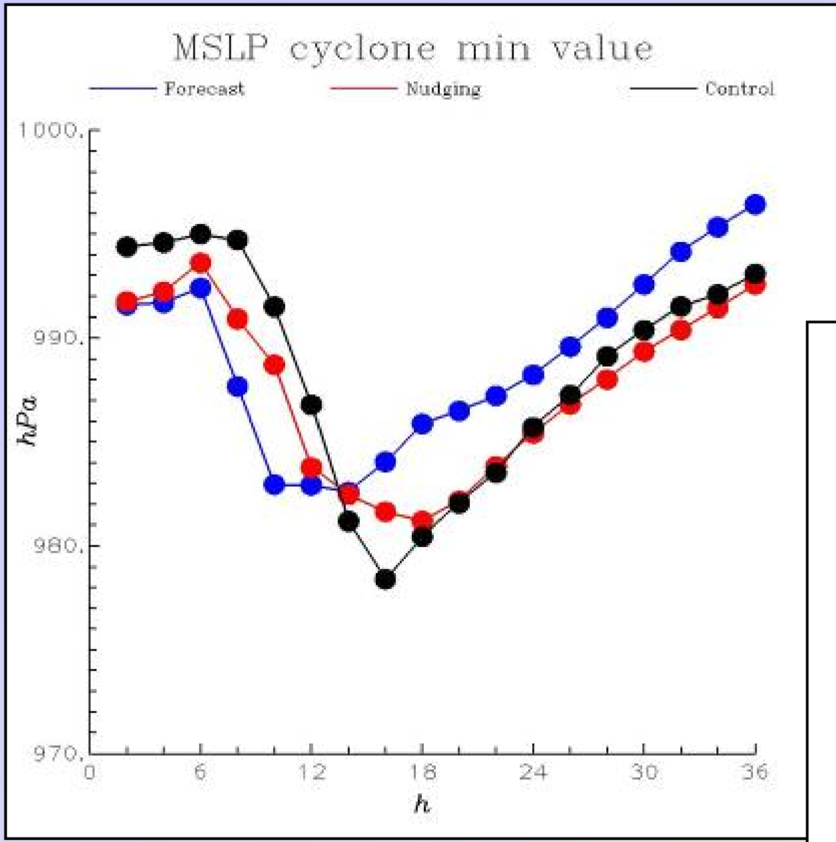
N
Pressure (hPa)
W
E
BOLAM MODEL, ISAO-CNR, BOLOGNA

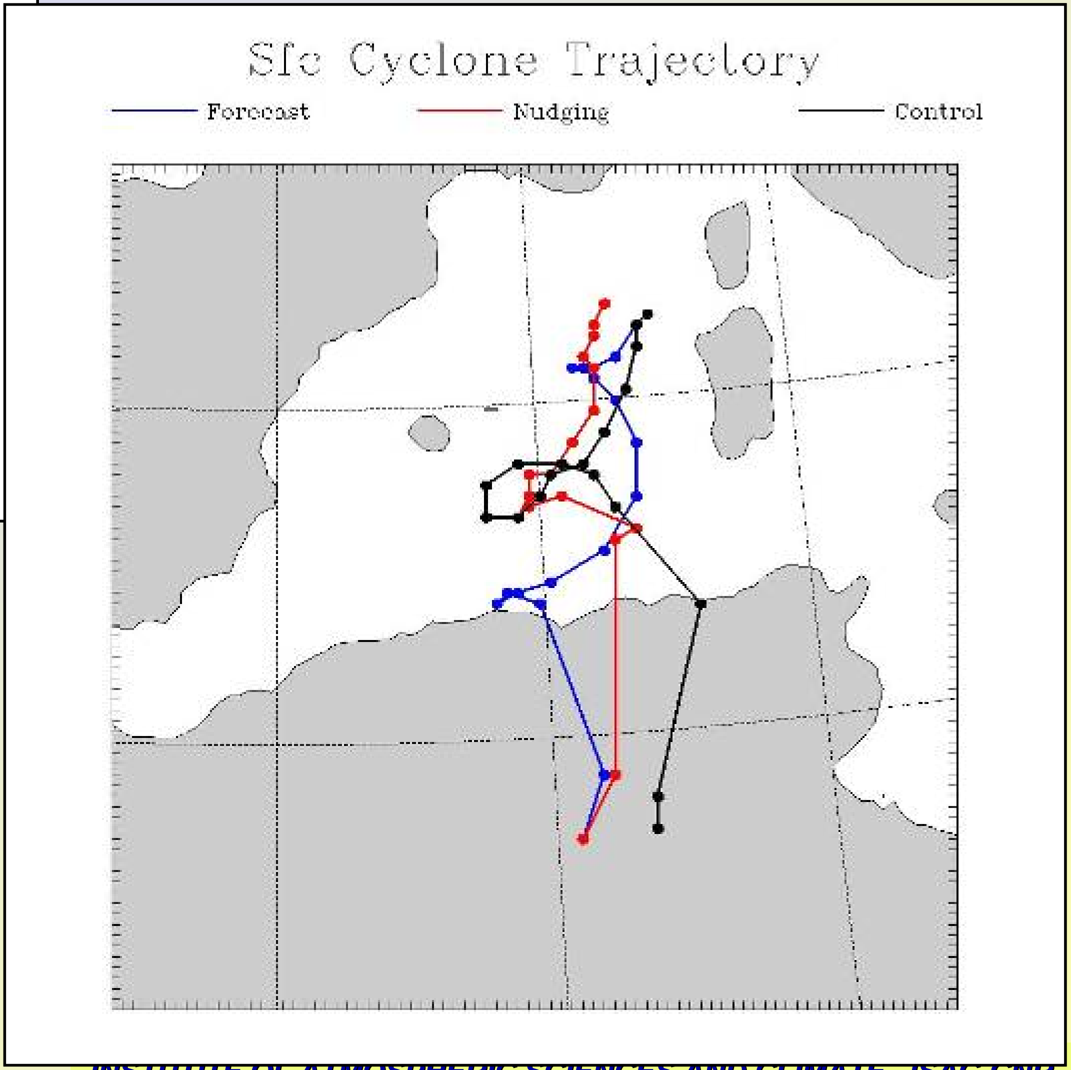
RH


C
INITIAL DATE 10/11/2001 1200 UTC
FORECAST HOUR +12 VALID AT 11/11/2001 00 UTC
Pressure (hPa)
W
BOLAM MODEL, ISAO-CNR, BOLOGNA


F
INITIAL DATE 10/11/2001 0000 UTC
FORECAST HOUR +24 VALID AT 11/11/2001 00 UTC
Pressure (hPa)
E

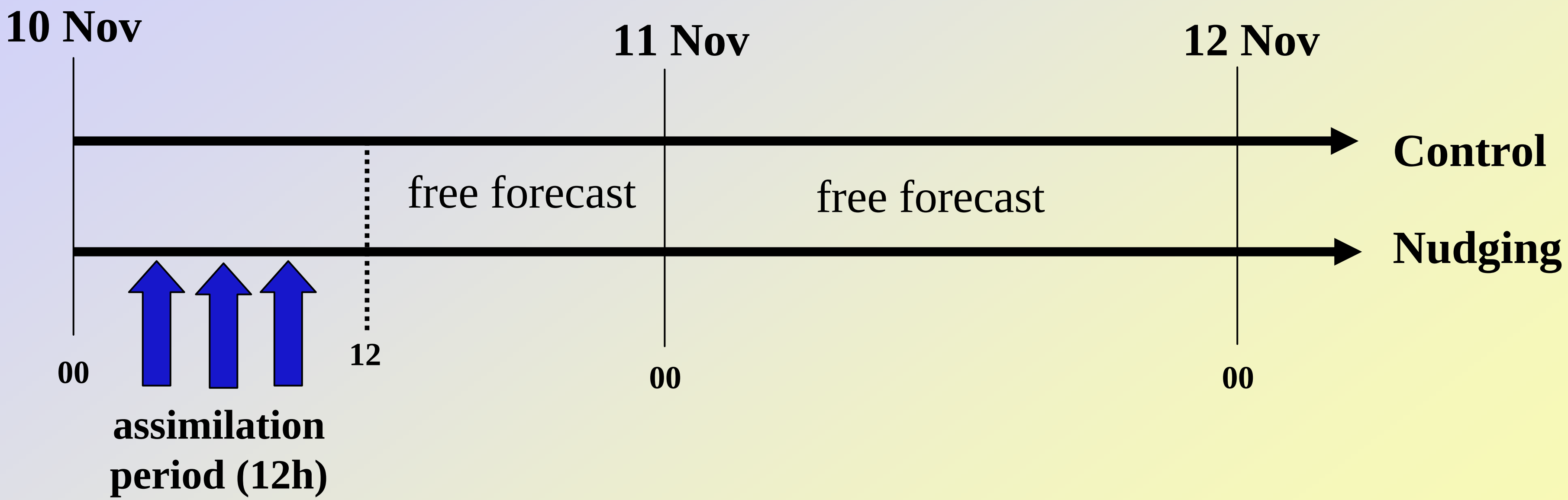

N
INITIAL DATE 10/11/2001 0000 UTC
FORECAST HOUR +24 VALID AT 11/11/2001 00 UTC
Pressure (hPa)
W
E
BOLAM MODEL, ISAO-CNR, BOLOGNA


MSLP cyclone min value
Forecast
Nudging
Control
1000.
990.
980.
970.
hPa
0
6
12
18
24
30
36
h

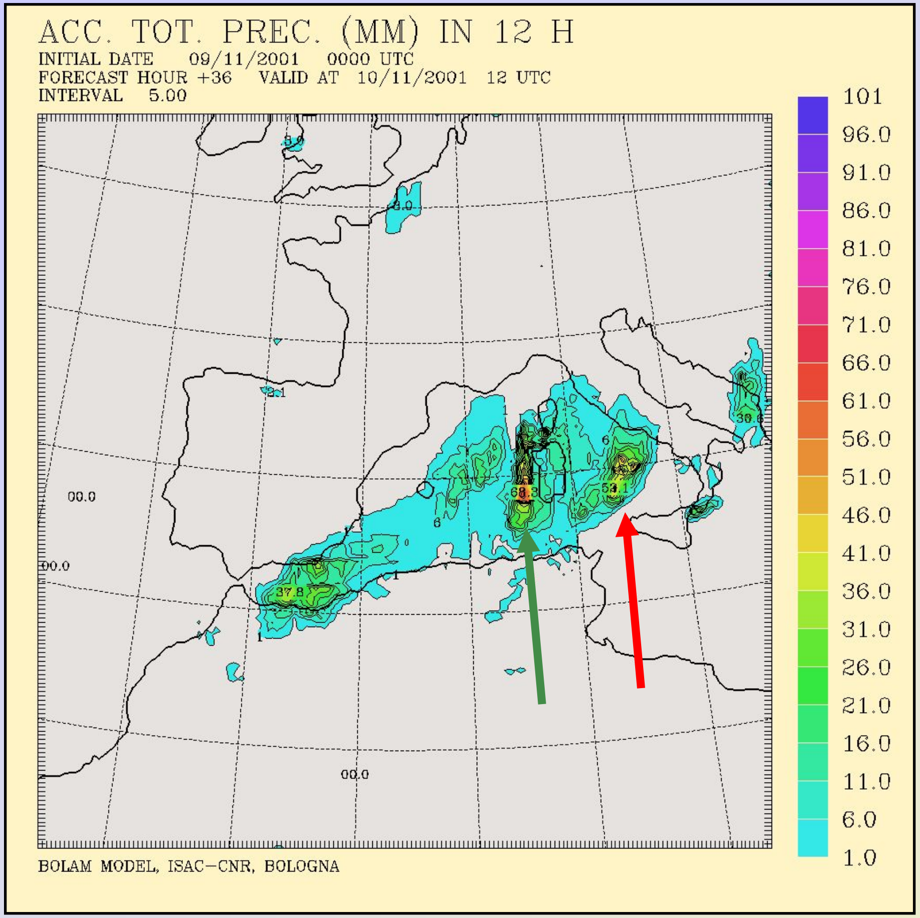

Sfc Cyclone Trajectory
Forecast
Nudging
Control

Real case, Real data: assimilation of satellite rainfall data

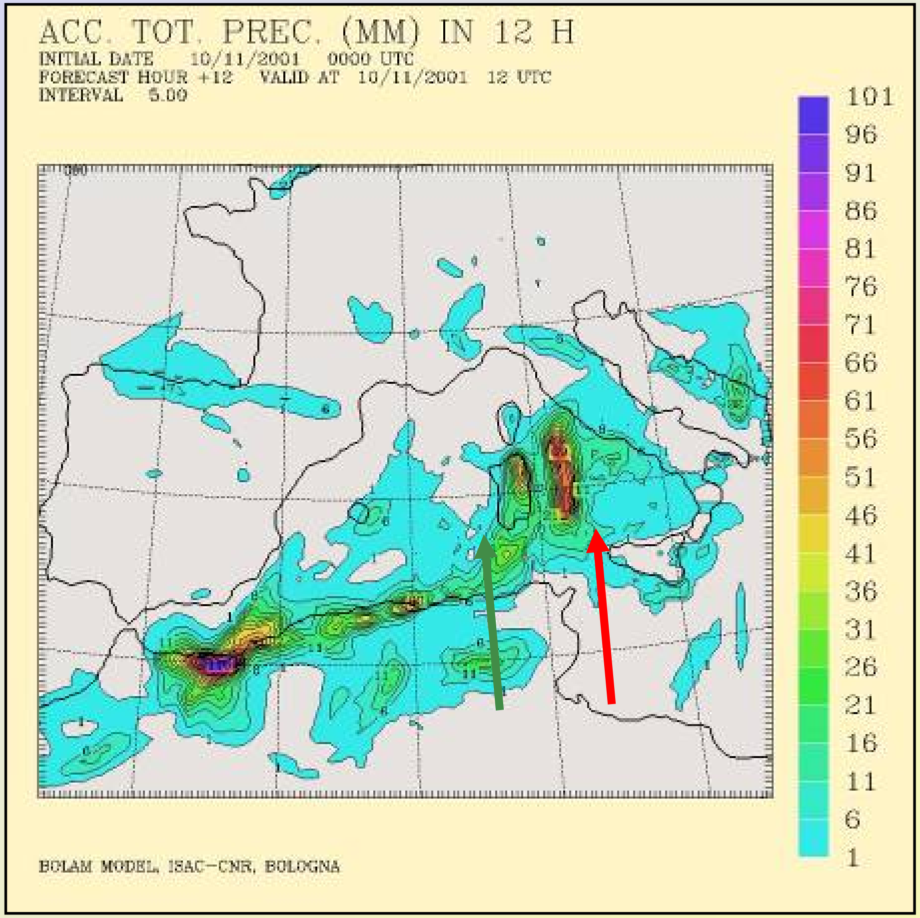
- **2-h accumulated satellite rainfall**
  - (seems to be the best interval from sensitivity tests)
- **Satellite data: IR/PMW**
- **Assimilation ONLY OVER THE SEA**



Satellite data

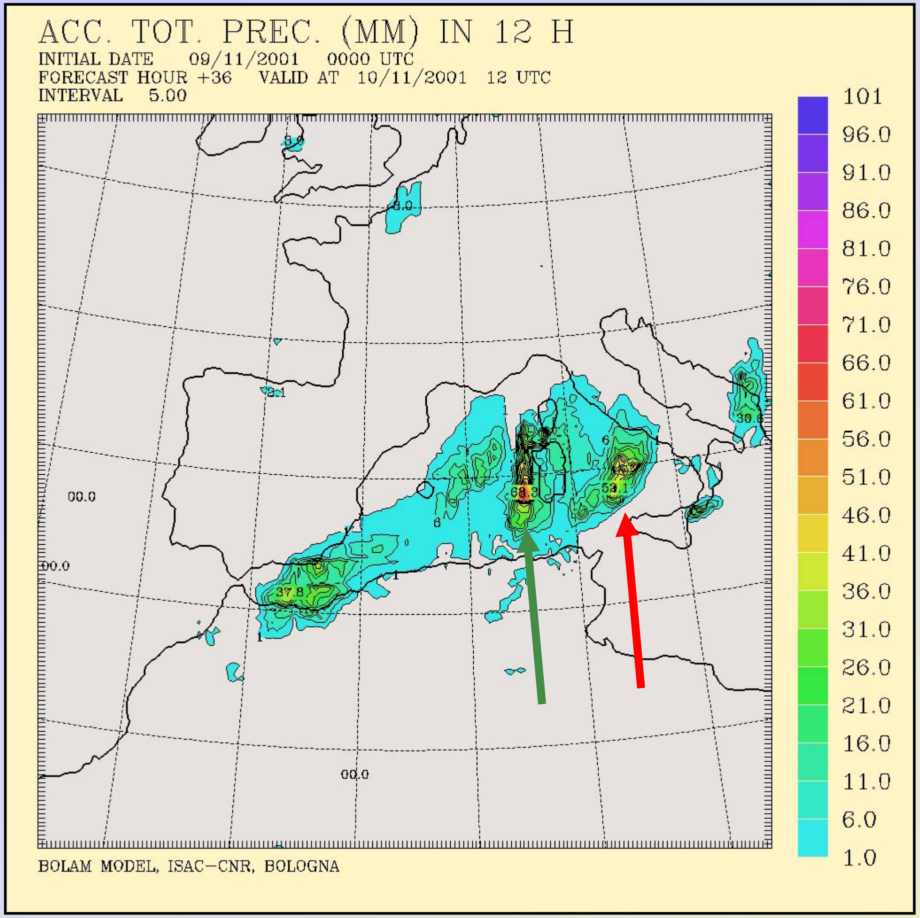


Control Run

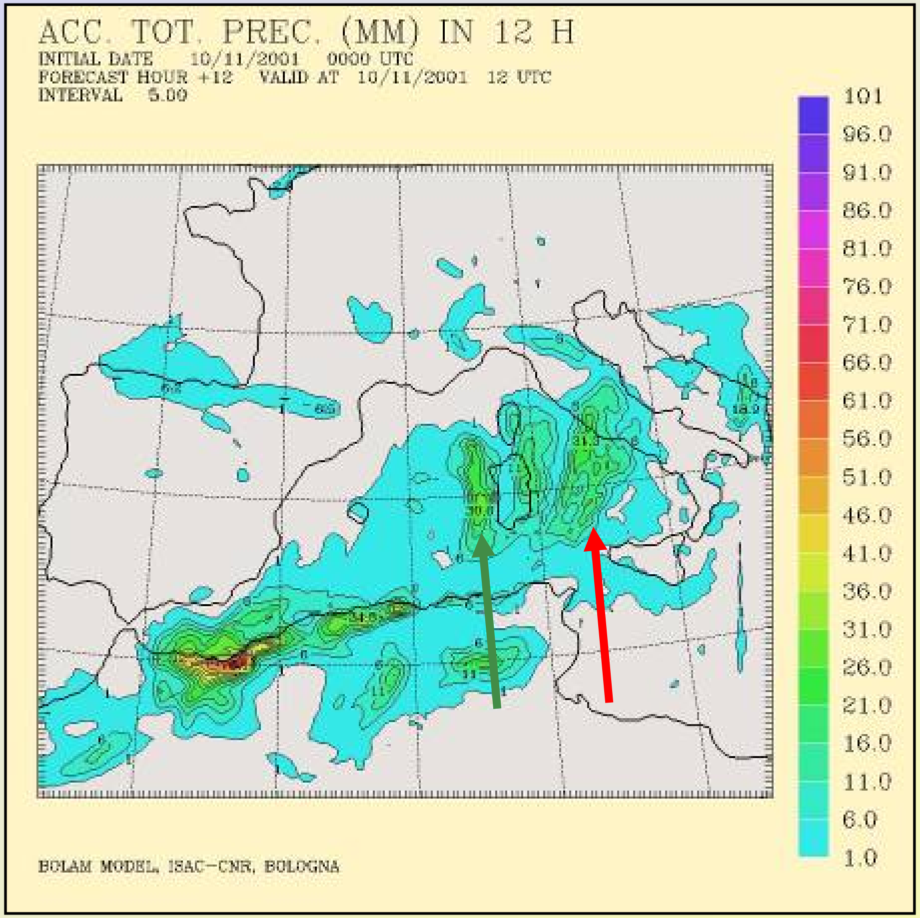


- Heavy precipitation west of Sardinia (satellite data).
- Area of rainfall over Tyrrenian Sea.

Satellite data



Nudging



- Precipitation west of Sardinia (position ok, intensity 30 instead of 68 mm/12h).
- Improvement over Tyrrenian Sea.

Idealized experiments:

Impact of rainfall assimilation on baroclinic wave development

Motivation:

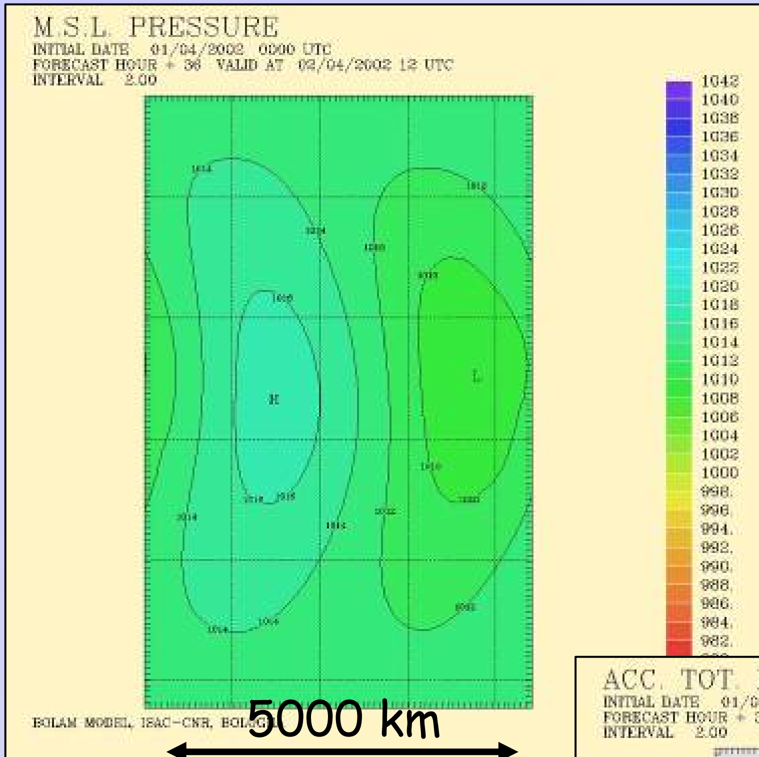
- Investigate the effect of rainfall assimilation using a conceptual/physical model of meteorological phenomena.
- GOOD TOOL to interpret the results obtained in the realistic framework.

Model:

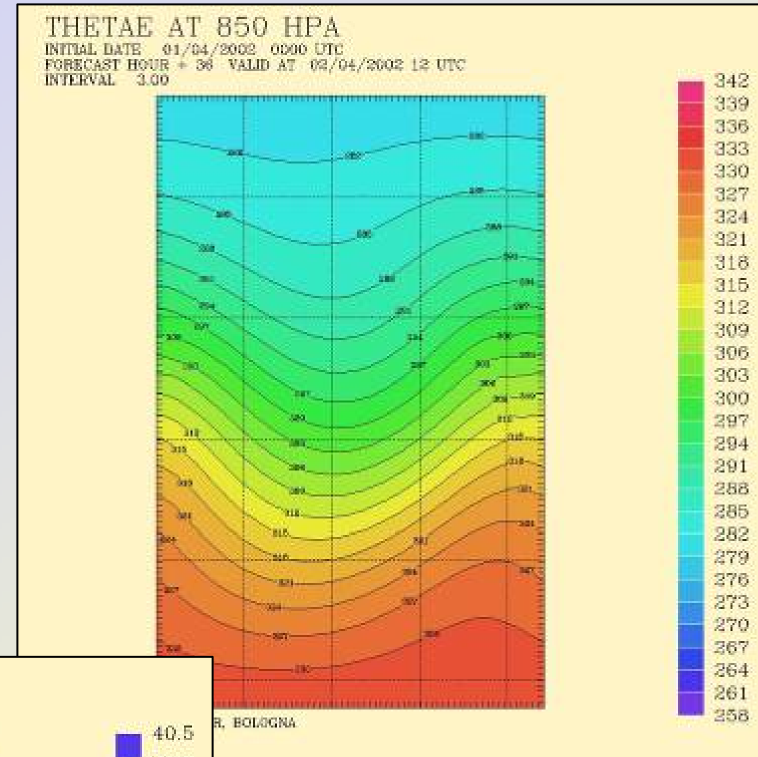
Bolam model in channel version, representing a midlatitude belt, hor.res. ≈ 50km

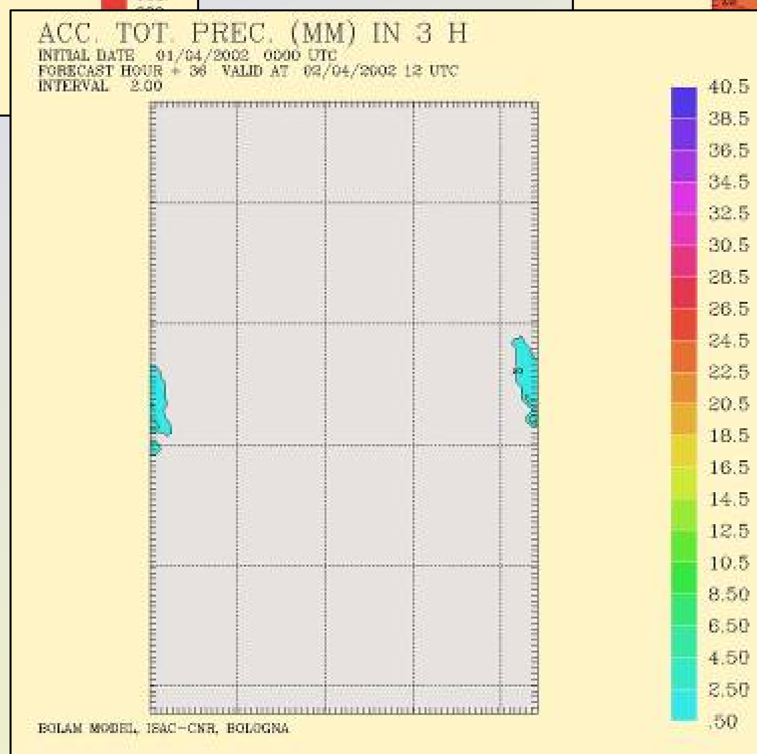
Initial state: unstable baroclinic zonal jet. A baroclinic wave develops into large amplitude cyclones and anticyclones.

1) Nudging to investigate effects of intensity error
2) Nudging to investigate effects of phase error

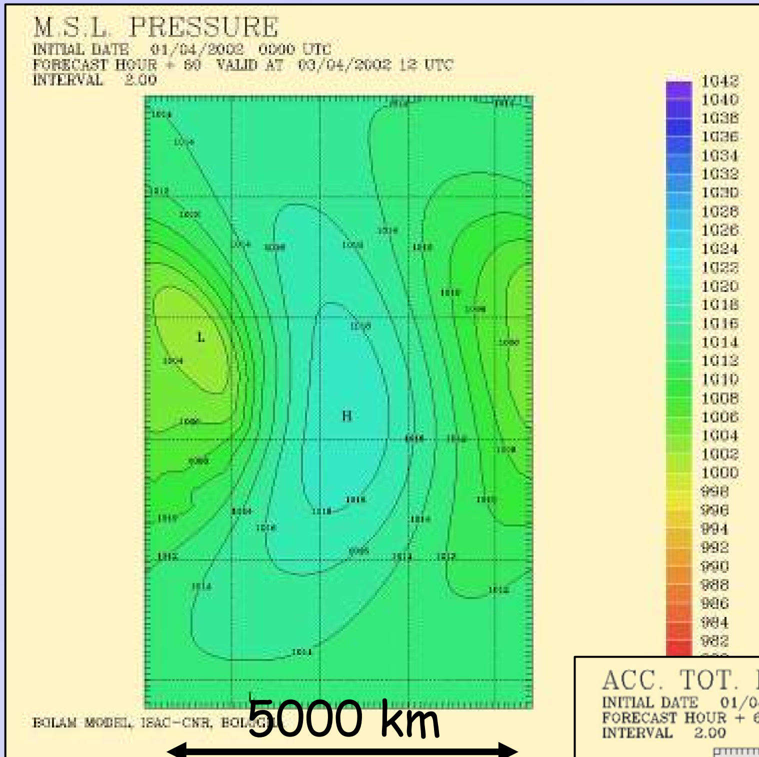

M.S.L. PRESSURE
INITIAL DATE 01/04/2002 0000 UTC
FORECAST HOUR + 36 VALID AT 02/04/2002 12 UTC
INTERVAL 2.00
1042 1040 1038 1036 1034 1032 1030 1028 1026 1024 1022 1020 1018 1016 1014 1012 1010 1008 1006 1004 1002 1000 998. 996. 994. 992. 990. 988. 986. 984. 982.
H
L
BOLAM MODEL, ISAC-CNR, BOLOGNA
5000 km

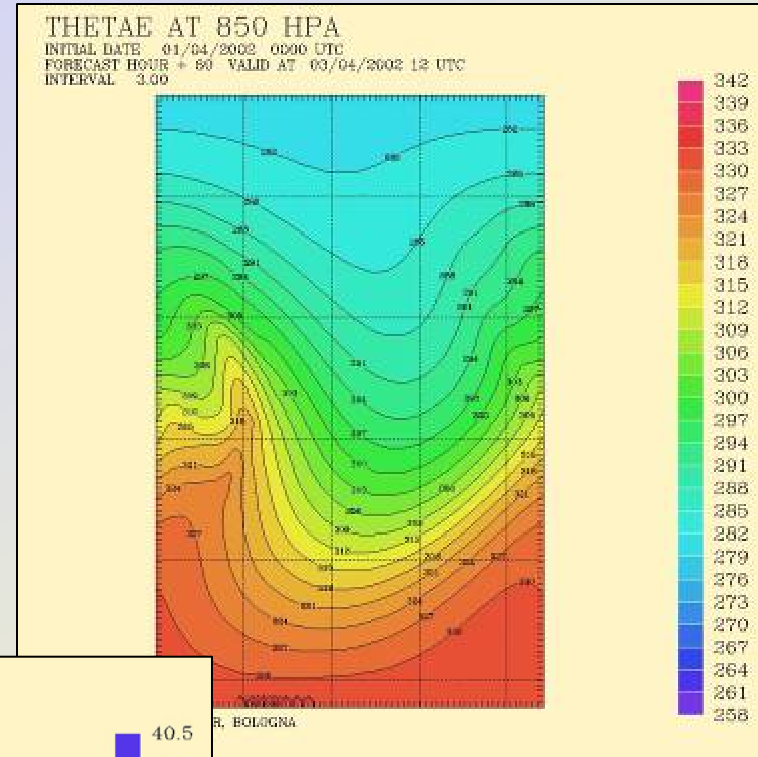
36 h

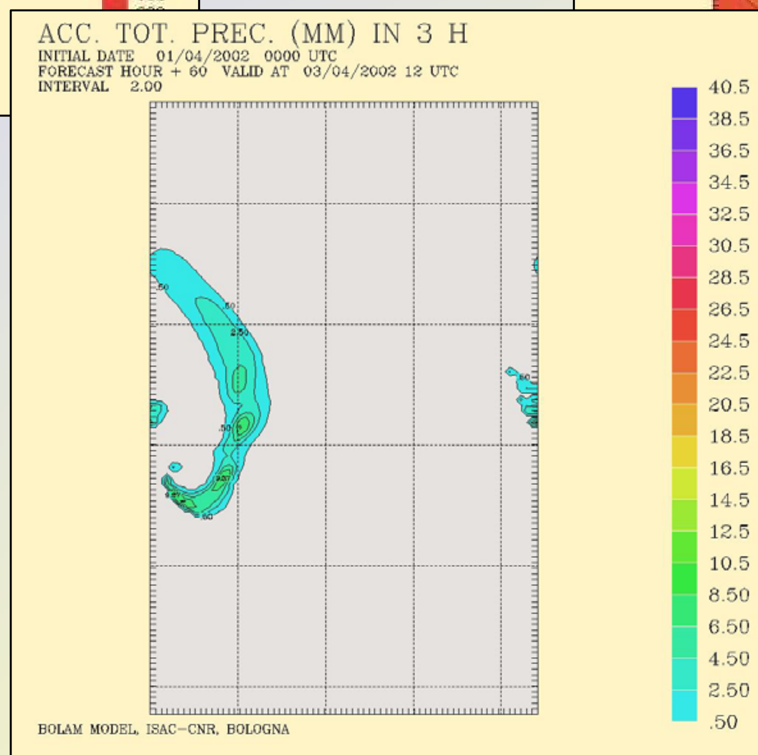

THETAE AT 850 HPA
INITIAL DATE 01/04/2002 0000 UTC
FORECAST HOUR + 36 VALID AT 02/04/2002 12 UTC
INTERVAL 3.00
342 339 336 333 330 327 324 321 318 315 312 309 306 303 300 297 294 291 288 285 282 279 276 273 270 267 264 261 258
R, BOLOGNA

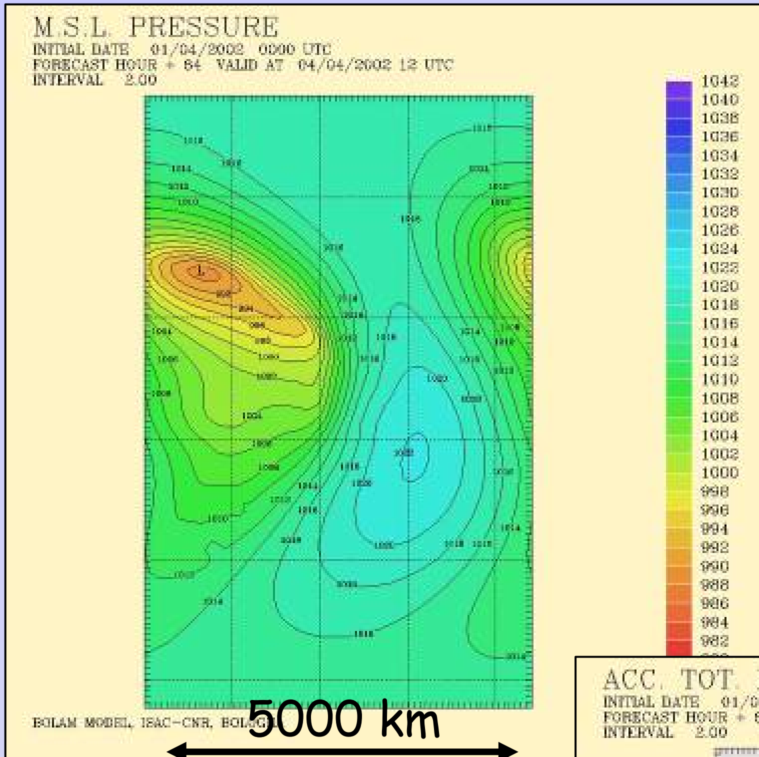

ACC. TOT. PREC. (MM) IN 3 H
INITIAL DATE 01/04/2002 0000 UTC
FORECAST HOUR + 36 VALID AT 02/04/2002 12 UTC
INTERVAL 2.00
40.5 38.5 36.5 34.5 32.5 30.5 28.5 26.5 24.5 22.5 20.5 18.5 16.5 14.5 12.5 10.5 8.50 6.50 4.50 2.50 .50
BOLAM MODEL, ISAC-CNR, BOLOGNA

60 h

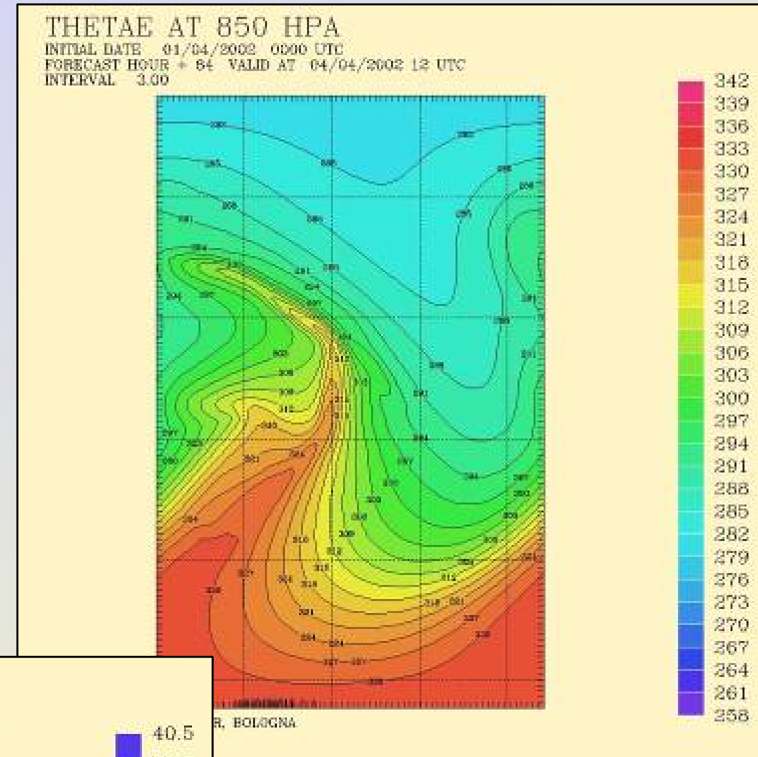

M.S.L. PRESSURE
INITIAL DATE 01/04/2002 0000 UTC
FORECAST HOUR + 60 VALID AT 03/04/2002 12 UTC
INTERVAL 2.00
BOLAM MODEL, ISAC-CNR, BOLOGNA
5000 km

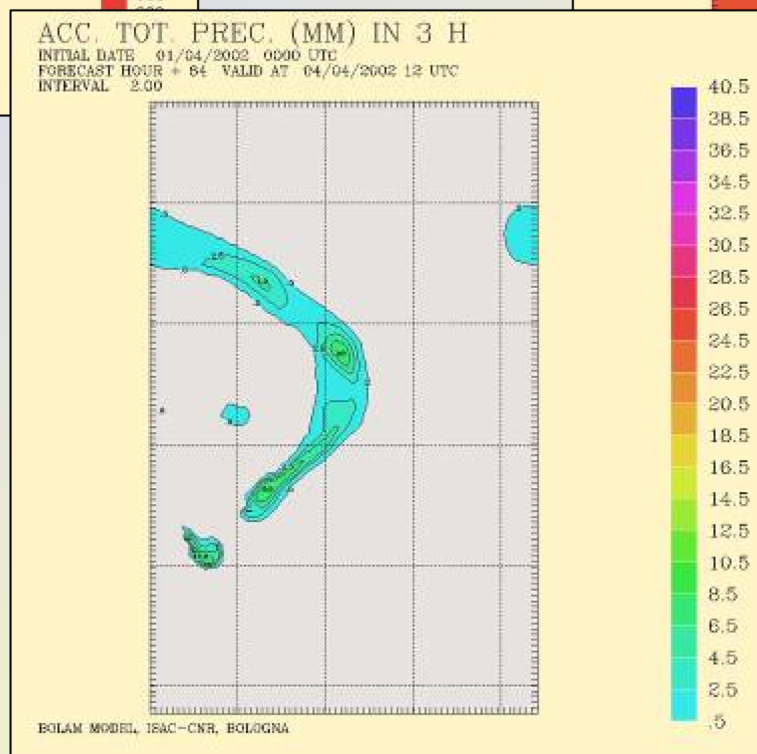

THETAE AT 850 HPA
INITIAL DATE 01/04/2002 0000 UTC
FORECAST HOUR + 60 VALID AT 03/04/2002 12 UTC
INTERVAL 3.00


ACC. TOT. PREC. (MM) IN 3 H
INITIAL DATE 01/04/2002 0000 UTC
FORECAST HOUR + 60 VALID AT 03/04/2002 12 UTC
INTERVAL 2.00
BOLAM MODEL, ISAC-CNR, BOLOGNA

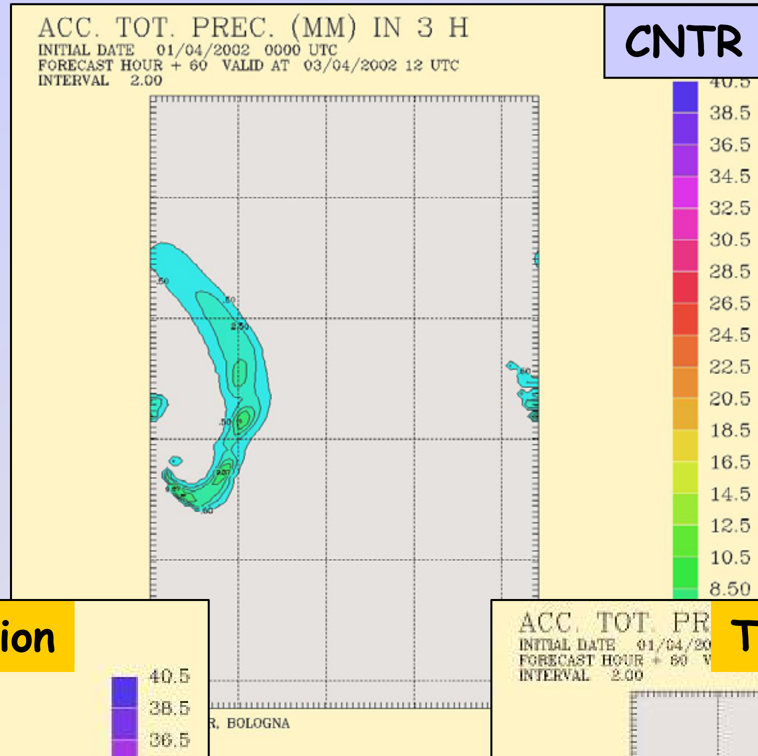

M.S.L. PRESSURE
INITIAL DATE 01/04/2002 0000 UTC
FORECAST HOUR + 84 VALID AT 04/04/2002 12 UTC
INTERVAL 2.00
1042 1040 1038 1036 1034 1032 1030 1028 1026 1024 1022 1020 1018 1016 1014 1012 1010 1008 1006 1004 1002 1000 998 996 994 992 990 988 986 984 982
BOLAM MODEL, ISAC-CNR, BOLOGNA
5000 km

84 h

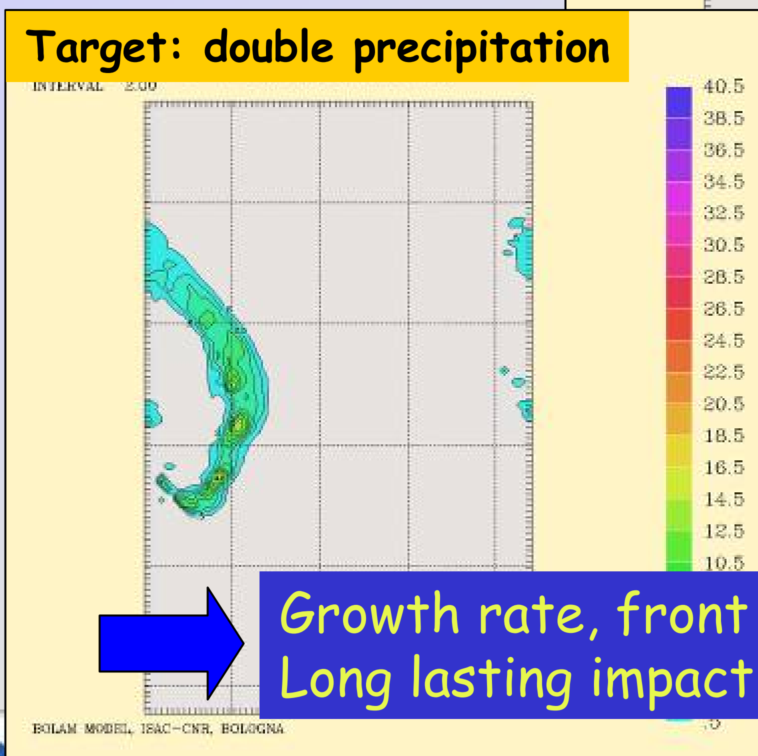

THETAE AT 850 HPA
INITIAL DATE 01/04/2002 0000 UTC
FORECAST HOUR + 84 VALID AT 04/04/2002 12 UTC
INTERVAL 3.00
342 339 336 333 330 327 324 321 318 315 312 309 306 303 300 297 294 291 288 285 282 279 276 273 270 267 264 261 258
R, BOLOGNA


ACC. TOT. PREC. (MM) IN 3 H
INITIAL DATE 01/04/2002 0000 UTC
FORECAST HOUR + 84 VALID AT 04/04/2002 12 UTC
INTERVAL 2.00
40.5 38.5 36.5 34.5 32.5 30.5 28.5 26.5 24.5 22.5 20.5 18.5 16.5 14.5 12.5 10.5 8.5 6.5 4.5 2.5 .5
BOLAM MODEL, ISAC-CNR, BOLOGNA

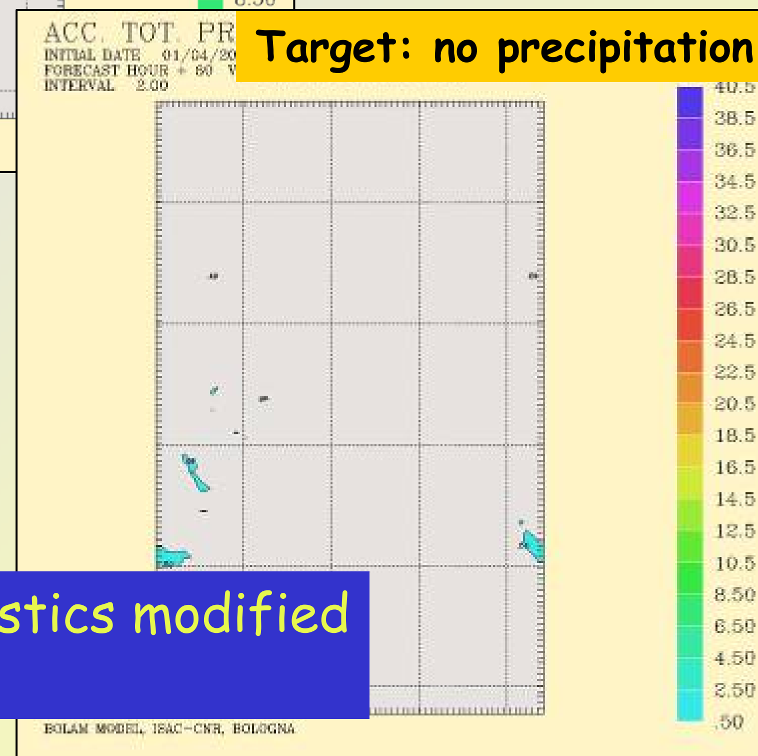
3h accumulated rainfall at the end of the assimilation period



Target: double precipitation

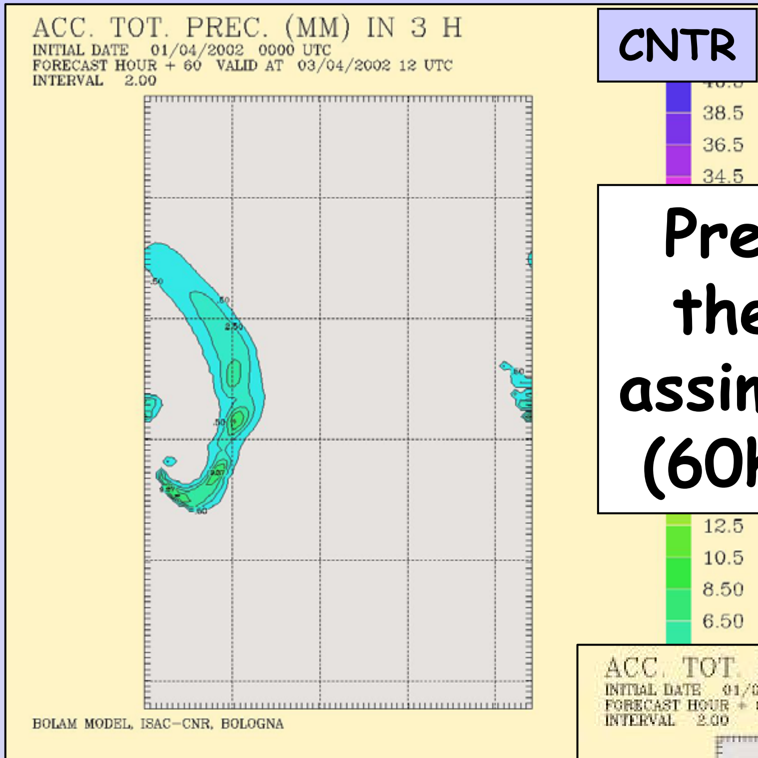


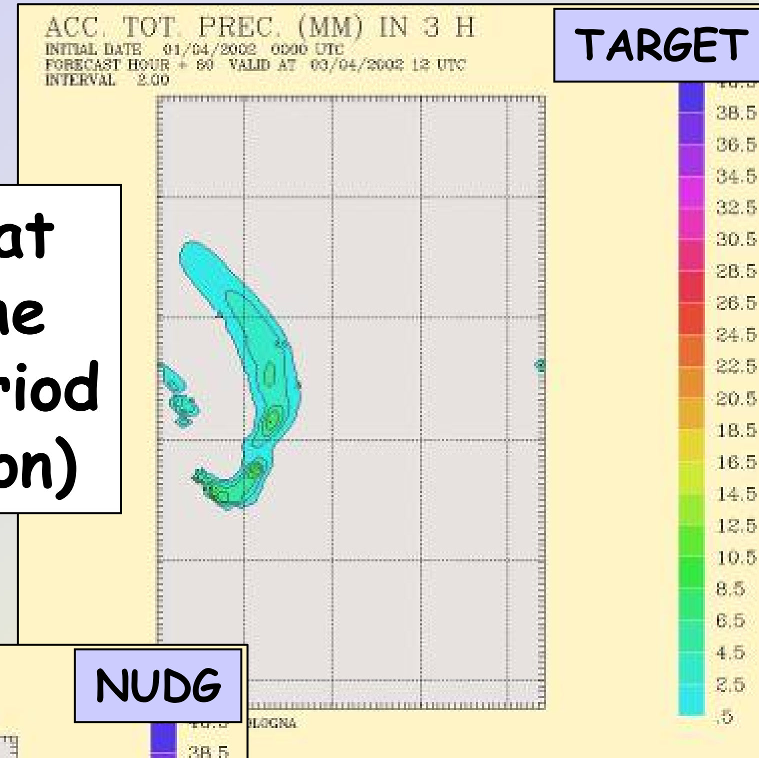
Target: no precipitation

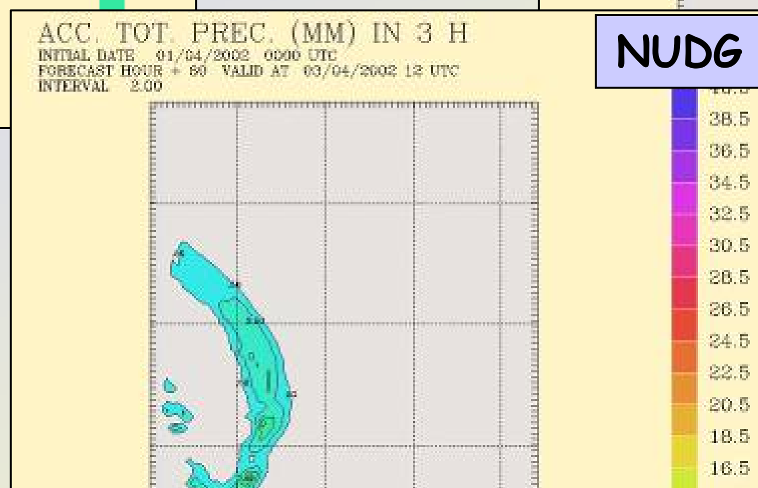


Growth rate, front characteristics modified
Long lasting impact

Precipitation at the end of the assimilation period (60h integration)







Precipitation pattern and frontal features (T, q, low level jet, cloud cover, area of upward vertical motion) corrected during the nudging, BUT the correction tends to disappear (as in the realistic experiments).

Conceptual model behaviour useful to explain real assimilation results.

- Intensity errors: local modification (rainfall area) affects the global evolution because the forcing (LH) amplifies (reduces) the large scale growing mode.
- Phase errors: local modification that imposes a forcing far from the structure of the growing mode is unable to modify the large scale evolution. For a small scale precipitation system associated with small scale instability (e.g. MCS) it may have impact, but not on large scale dynamical evolution.

In order to effectively modify the large scale, acting locally, it is necessary to localize areas where the leading instabilities are growing (e.g. bred vectors).

OPEN PROBLEMS AND PERSPECTIVE

- Assimilation of real satellite data shows positive impact even if limited to sea areas
- Problems in case of orographic precipitation
- Gard Case Study: assimilation of IR precipitation estimates:
    - data error
    - need for more complex scheme (advection)
- Application of assimilation schemes, for rainfall and clouds, to high resolution CRM
    - no partitioning problem
    - time scales convection/data
    - precipitation alone is not enough. What else? (Cloud information?)