TRAM
(Triangle-based Regional Atmospheric Model)

A New Nonhydrostatic Fully Compressible Numerical Model

… now WITH PHYSICS

Romu Romero

CONCLUSIONS ...from previous talk

> **NEW MODEL** achieved (at present just dynamical core) **SUITABLE** to simulate processes ranging from small-scale thermal bubbles (≈ 10 m) to synoptic-scale baroclinic cyclones (≈ 1000 km), including orographic circulations

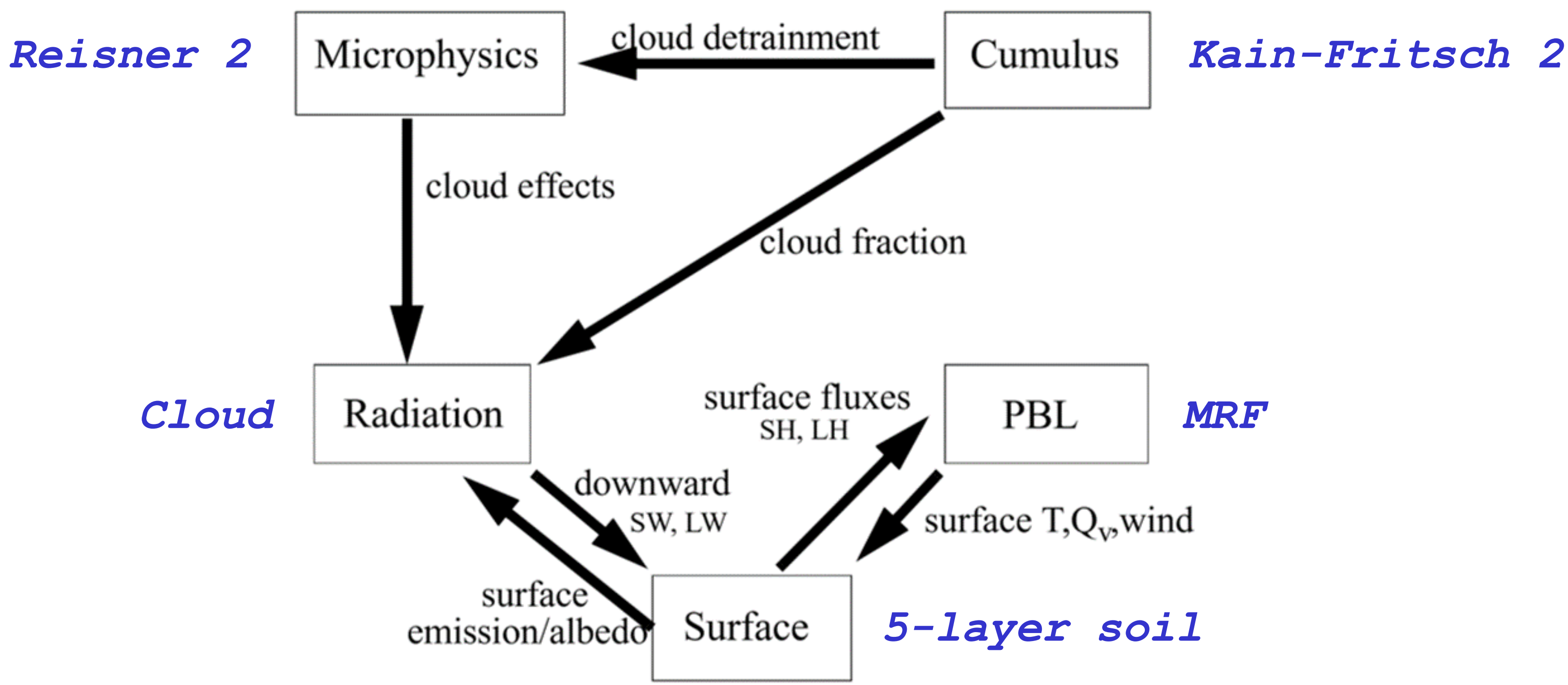
> **MAIN CHARACTERISTICS:** Advection form under REA approach (mass & energy not strictly conserved); Fully compressible & Non hydrostatic; Time-splitting strategy; Vertically semi-implicit; Triangle-based horizontal mesh (no staggering); Z-coordinate (no staggering) allowing arbitrary stretching (proper treatment of slopes and bottom BCs); Lambert projection with all Coriolis and curvature terms retained; No explicit filters needed

> A variety of comparison tests showed that **TRAM PERFORMS AT LEAST AS WELL** as state-of-the-art models

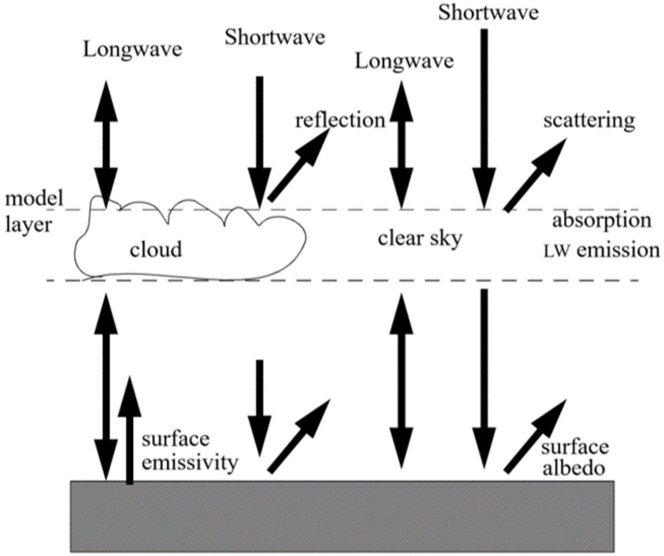
NEXT STEPS ...from previous talk

> COMPLETE TRAM with appropriate PHYSICS package (fast approach: ~~WR~~F-based parameterization schemes); Reexamine the real cases and consider new tests (e.g. simulation of convective & precipitation systems)

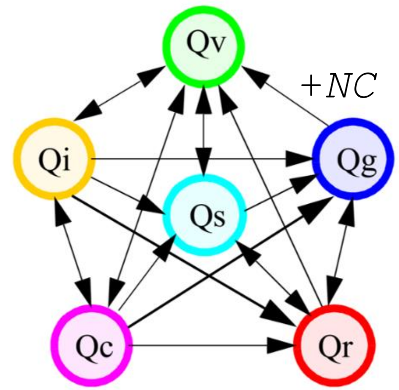
MM5-based



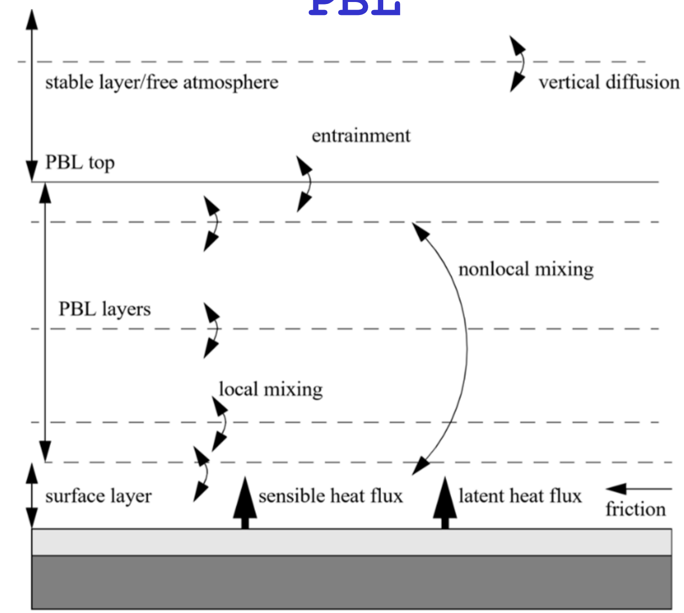
Radiation



Microphysics



PBL



NEW

Prognostic fields

Q_χ

Forcing terms

F_{Q_χ}

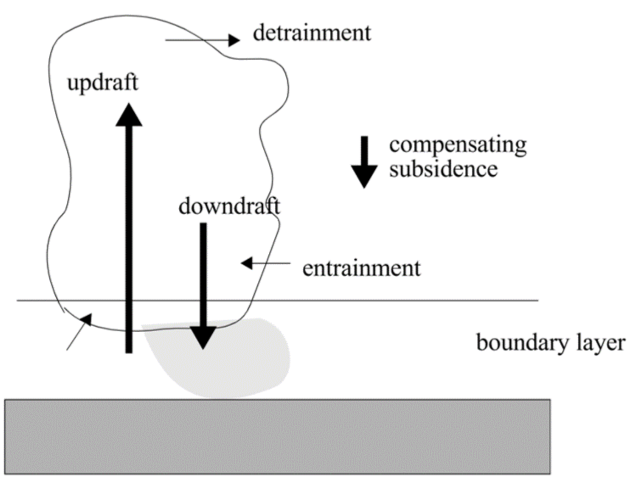
F_T

$F_u \quad F_v$

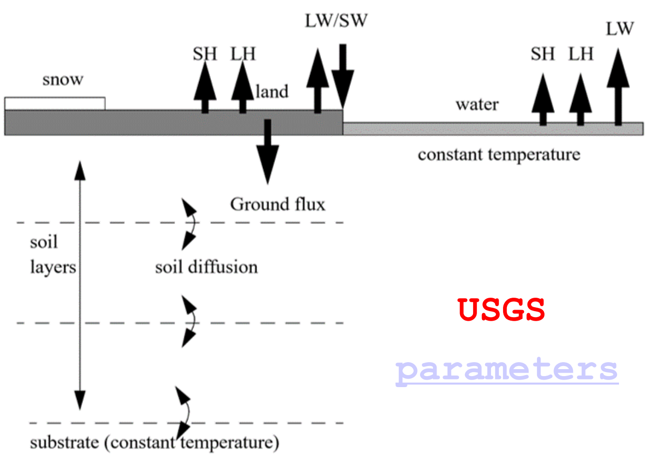
Surface variables

$T_g \quad R_{nc} \quad R_c \quad \ldots$

Cumulus



Surface



USGS

parameters

NEW Form of Equations: MESOSCALE-IDEALized

$$\frac{\partial \pi'}{\partial t} = -u\frac{\partial \pi'}{\partial x} - v\frac{\partial \pi'}{\partial y} - w\frac{\partial \pi'}{\partial z} - w\frac{\partial \bar{\pi}}{\partial z} - \frac{R_d}{c_p}\frac{c_{pm}}{c_{vm}}(\bar{\pi}+\pi')\left[\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}\right] + \frac{R_d}{c_{vm}}\frac{1}{\bar{\theta}+\theta'}F_T$$

$$+\frac{R_d}{c_p}\frac{R_v}{R_m}\frac{c_{pm}}{c_{vm}}(\bar{\pi}+\pi')F_{Q_v}$$

ALL moist effects on pressure and thermodynamics

$$\frac{\partial \theta'}{\partial t} = -u\frac{\partial \theta'}{\partial x} - v\frac{\partial \theta'}{\partial y} - w\frac{\partial \theta'}{\partial z} - w\frac{\partial \bar{\theta}}{\partial z} - \left(\frac{R_m}{C_{vm}} - \frac{R_d}{C_p}\frac{c_{pm}}{c_{vm}}\right)(\bar{\theta}+\theta')\left[\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}\right]$$

$$+\frac{c_v}{c_{vm}}\frac{1}{\bar{\pi}+\pi'}F_T + \frac{R_v}{c_{vm}}\left(1-\frac{R_d}{c_p}\frac{c_{pm}}{R_m}\right)(\bar{\theta}+\theta')F_{Q_v}$$

Physics computed in NSTEP-cycle

$$\frac{\partial u}{\partial t} = -u\frac{\partial u}{\partial x} - v\frac{\partial u}{\partial y} - w\frac{\partial u}{\partial z} - c_p(\bar{\theta}_\rho+\theta'_\rho)\frac{\partial \pi'}{\partial x} + fv - \hat{f}w + F_u$$

$$\frac{\partial v}{\partial t} = -u\frac{\partial v}{\partial x} - v\frac{\partial v}{\partial y} - w\frac{\partial v}{\partial z} - c_p(\bar{\theta}_\rho+\theta'_\rho)\frac{\partial \pi'}{\partial y} - fu + F_v$$

$$\pi = \left(\frac{P}{P_0}\right)^{R_d/c_p} \qquad \theta = \frac{T}{\pi} \qquad P = \rho R_d T\frac{1+Q_v/\varepsilon}{1+Q_v}$$

$$\theta_\rho = \theta\frac{1+Q_v/\varepsilon}{1+Q_v+Q_{liq}+Q_{ice}} \qquad c_p\bar{\theta}_\rho\frac{\partial \bar{\pi}}{\partial z} = -g$$

$$\frac{\partial w}{\partial t} = -u\frac{\partial w}{\partial x} - v\frac{\partial w}{\partial y} - w\frac{\partial w}{\partial z} - c_p(\bar{\theta}_\rho+\theta'_\rho)\frac{\partial \pi'}{\partial z} + g\frac{\theta'_\rho}{\bar{\theta}_\rho} + \hat{f}u - g(Q_{liq}+Q_{ice})$$

$$\frac{\partial Q_\chi}{\partial t} = -u\frac{\partial Q_\chi}{\partial x} - v\frac{\partial Q_\chi}{\partial y} - w\frac{\partial Q_\chi}{\partial z} + F_{Q_\chi}$$

$$R_m = R_d + R_v\,Q_v \qquad \varepsilon = R_d/R_v$$

$$c_{pm} = c_p + c_{pv}\,Q_v + c_l\,Q_{liq} + c_i\,Q_{ice}$$

$$c_{vm} = c_v + c_{vv}\,Q_v + c_l\,Q_{liq} + c_i Q_{ice}$$

NEW Form of Equations: SYNOPTIC-REALcase

$$\frac{\partial \pi'}{\partial t} = -mu\frac{\partial \pi'}{\partial x} - mv\frac{\partial \pi'}{\partial y} - w\frac{\partial \pi'}{\partial z} - w\frac{\partial \bar{\pi}}{\partial z} - \frac{R_d}{c_p}\frac{c_{pm}}{c_{vm}}(\bar{\pi}+\pi')\left[m^2\left(\frac{\partial(\frac{u}{m})}{\partial x} + \frac{\partial(\frac{v}{m})}{\partial y}\right) + \frac{\partial w}{\partial z}\right]$$

$$+\frac{R_d}{c_{vm}}\frac{1}{\bar{\theta}+\theta'}F_T + \frac{R_d}{c_p}\frac{R_v}{R_m}\frac{c_{pm}}{c_{vm}}(\bar{\pi}+\pi')F_{Q_v}$$

ALL Coriolis and curvature terms

$$\frac{\partial \theta'}{\partial t} = -mu\frac{\partial \theta'}{\partial x} - mv\frac{\partial \theta'}{\partial y} - w\frac{\partial \theta'}{\partial z} - w\frac{\partial \bar{\theta}}{\partial z} - \left(\frac{R_m}{C_{vm}} - \frac{R_d}{C_p}\frac{c_{pm}}{c_{vm}}\right)(\bar{\theta}+\theta')\left[m^2\left(\frac{\partial(\frac{u}{m})}{\partial x} + \frac{\partial(\frac{v}{m})}{\partial y}\right) + \frac{\partial w}{\partial z}\right]$$

$$+\frac{c_v}{c_{vm}}\frac{1}{\bar{\pi}+\pi'}F_T + \frac{R_v}{c_{vm}}\left(1 - \frac{R_d}{c_p}\frac{c_{pm}}{R_m}\right)(\bar{\theta}+\theta')F_{Q_v}$$

LAMBERT projection

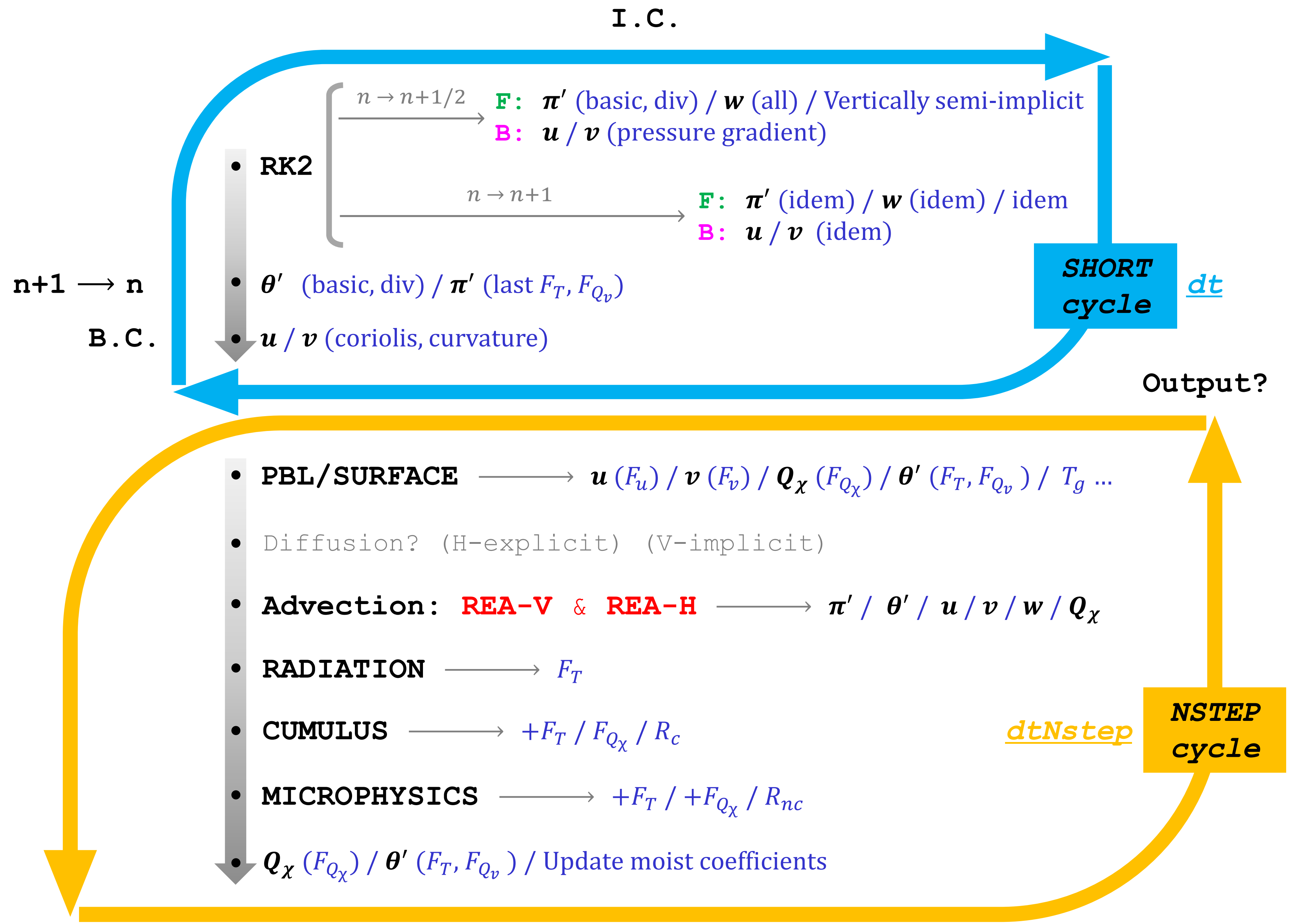
$$\frac{\partial u}{\partial t} = -mu\frac{\partial u}{\partial x} - mv\frac{\partial u}{\partial y} - w\frac{\partial u}{\partial z} - c_p(\bar{\theta}_\rho+\theta'_\rho)m\frac{\partial \pi'}{\partial x} + v\left(f + u\frac{\partial m}{\partial y} - v\frac{\partial m}{\partial x}\right) - \hat{f}w\cos\alpha - \frac{uw}{a} + F_u$$

$$\frac{\partial v}{\partial t} = -mu\frac{\partial v}{\partial x} - mv\frac{\partial v}{\partial y} - w\frac{\partial v}{\partial z} - c_p(\bar{\theta}_\rho+\theta'_\rho)m\frac{\partial \pi'}{\partial y} - u\left(f + u\frac{\partial m}{\partial y} - v\frac{\partial m}{\partial x}\right) + \hat{f}w\sin\alpha - \frac{uw}{a} + F_v$$

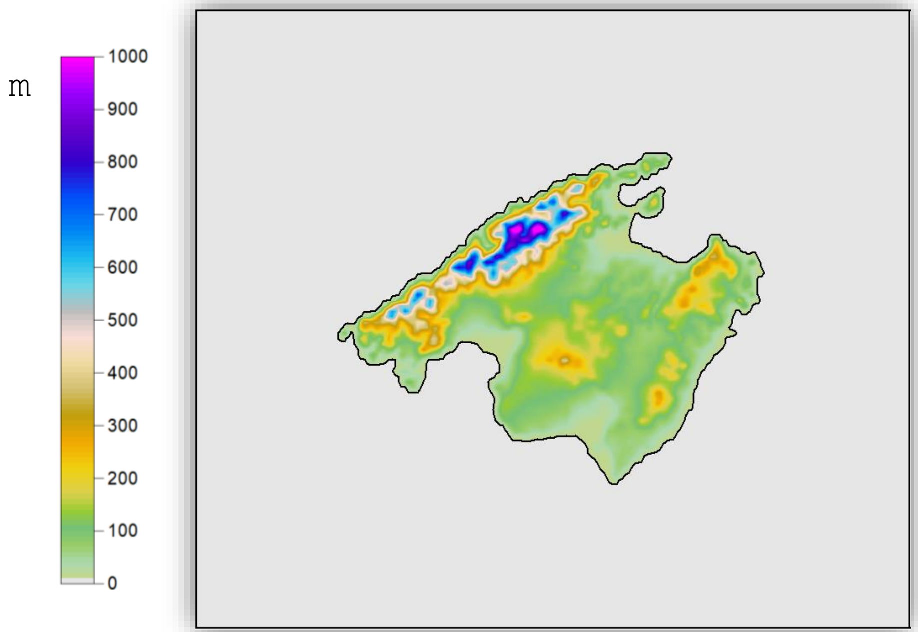
$$\frac{\partial w}{\partial t} = -mu\frac{\partial w}{\partial x} - mv\frac{\partial w}{\partial y} - w\frac{\partial w}{\partial z} - c_p(\bar{\theta}_\rho+\theta'_\rho)\frac{\partial \pi'}{\partial z} + g\frac{\theta'_\rho}{\bar{\theta}_\rho} + \hat{f}(u\cos\alpha - v\sin\alpha) + \frac{u^2+v^2}{a} - g(Q_{liq}+Q_{ice})$$

$$\frac{\partial Q_\chi}{\partial t} = -mu\frac{\partial Q_\chi}{\partial x} - mv\frac{\partial Q_\chi}{\partial y} - w\frac{\partial Q_\chi}{\partial z} + F_{Q_\chi}$$

TIME-MARCHING ALGORITHM



MESOSCALE-IDEALized TESTS



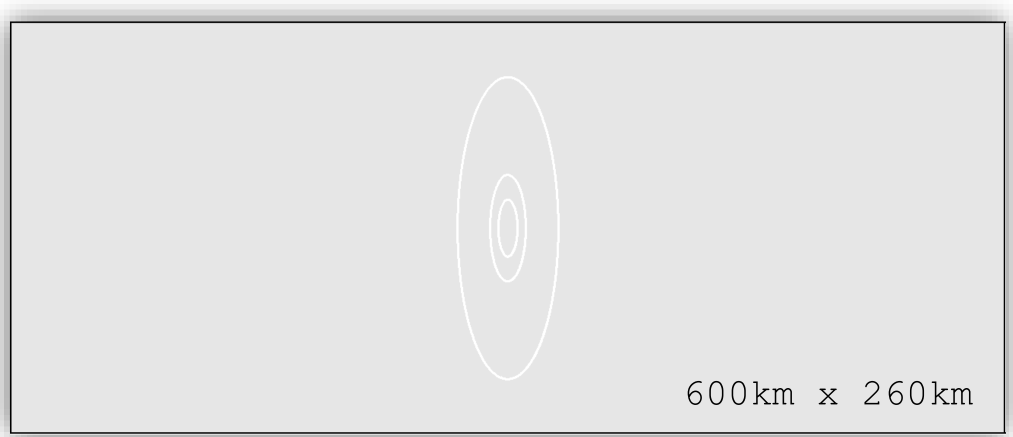
Breeze Circulation in MALLORCA dx=1.5km

RECALL

$$dx_{\square} \approx \frac{2}{3} dx_{\triangle}$$

Supercell dx=0.75km

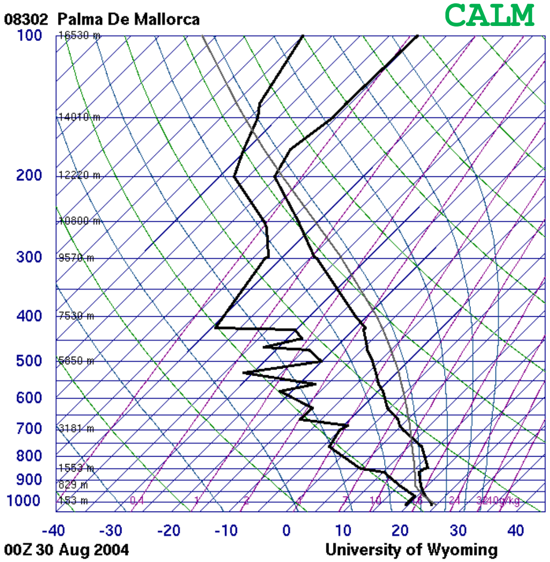
Squall-Line dx=1.5km



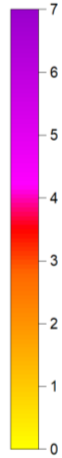
> Breeze Circulation in Mallorca (IC: Sounding 00 UTC 30 Ago 2004)

(dx=1.5km,dzm=400m,stretch=20,dt=3s,Nstep=10,30h)

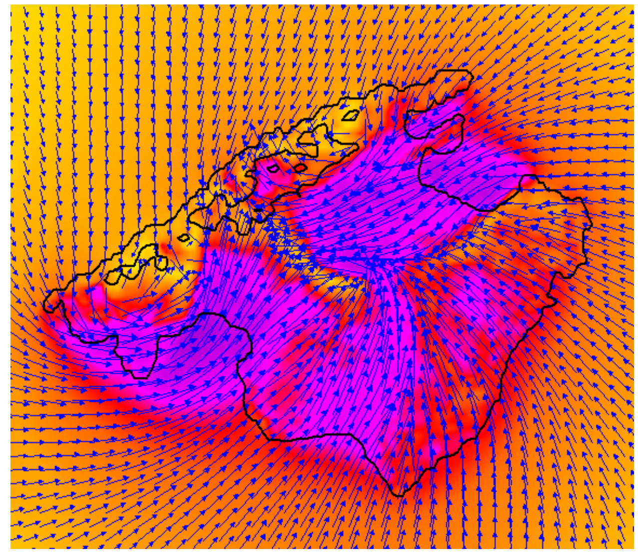
CALM



m/s



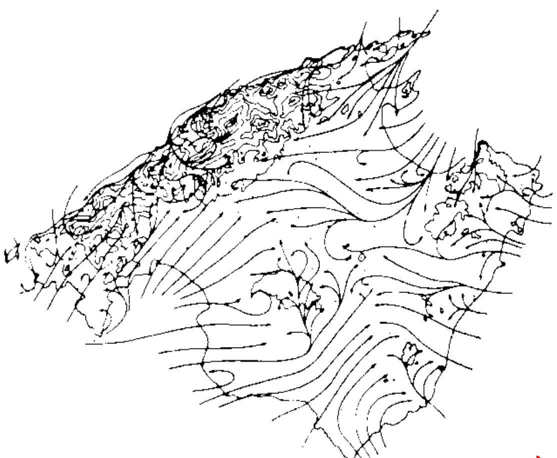
Run

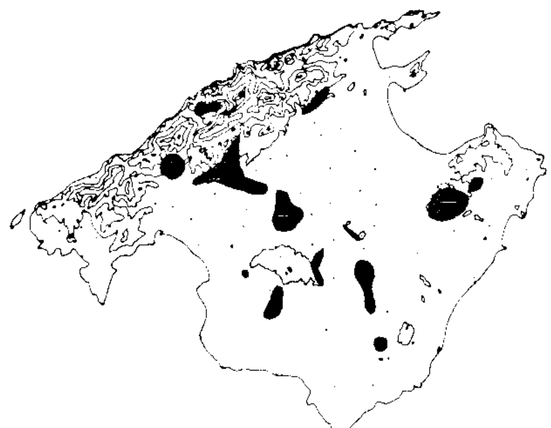


t=13h

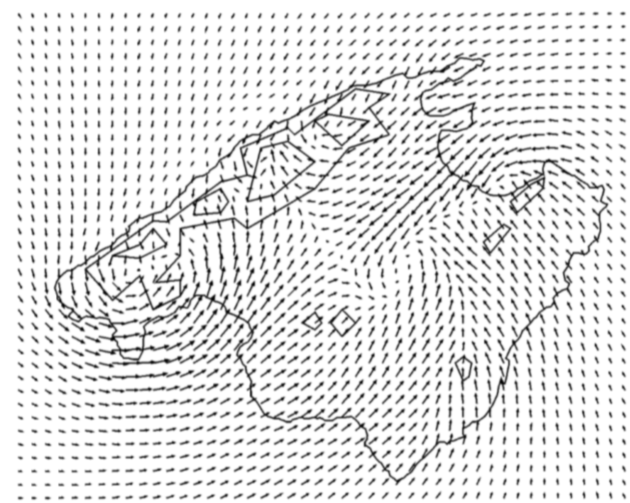
Clouds

Rainfall





Jansà & Jaume (1946)

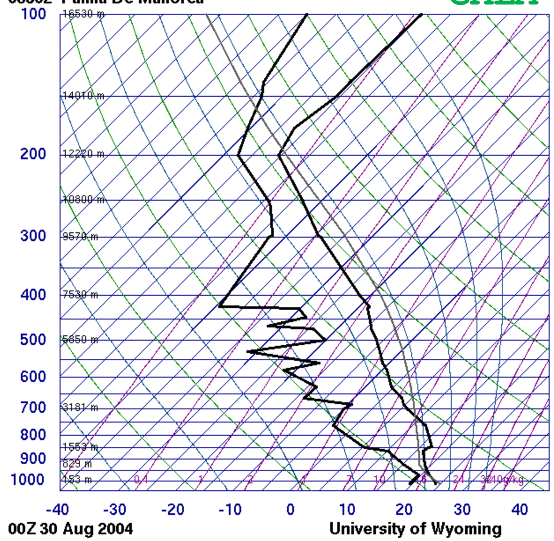


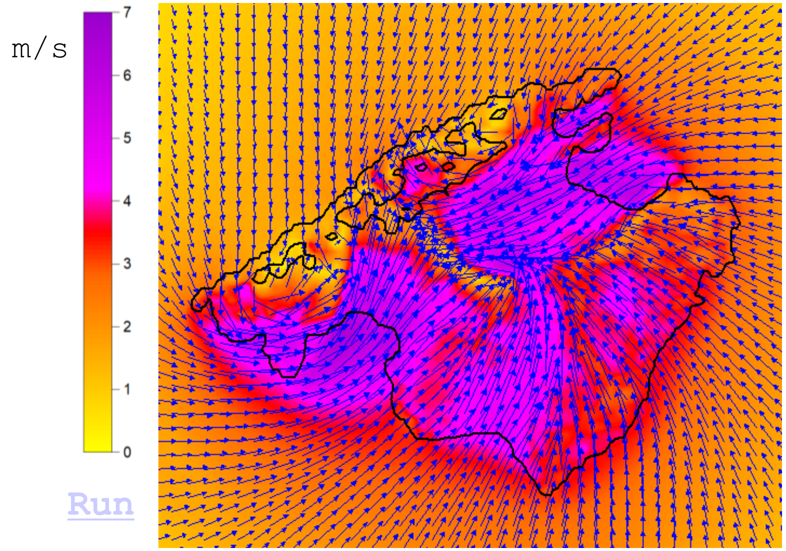
Ramis & Romero (1995)

> Breeze Circulation in Mallorca (IC: Sounding 00 UTC 30 Ago 2004)

(dx=1.5km,dzm=400m,stretch=20,dt=3s,Nstep=10,30h)

CALM





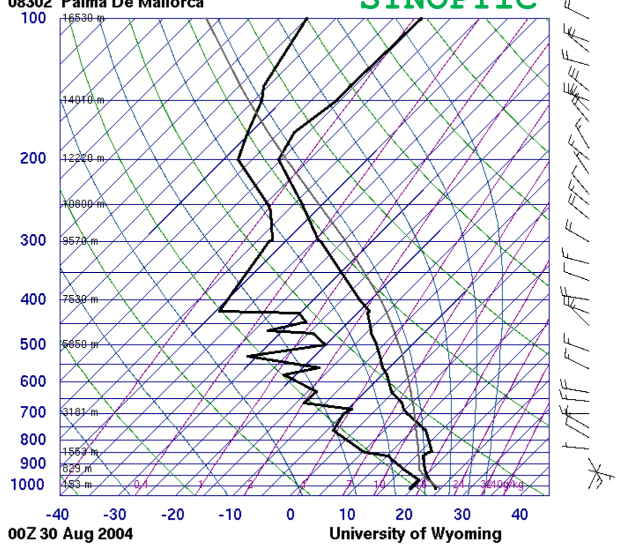
Run

t=13h

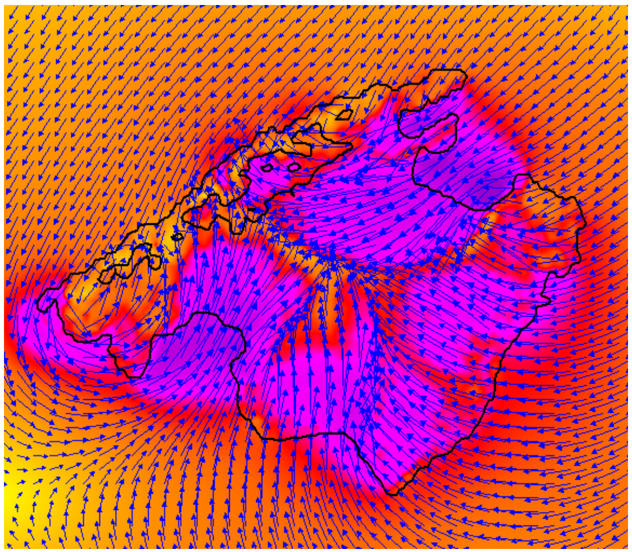
Clouds

Rainfall

SYNOPTIC



Run

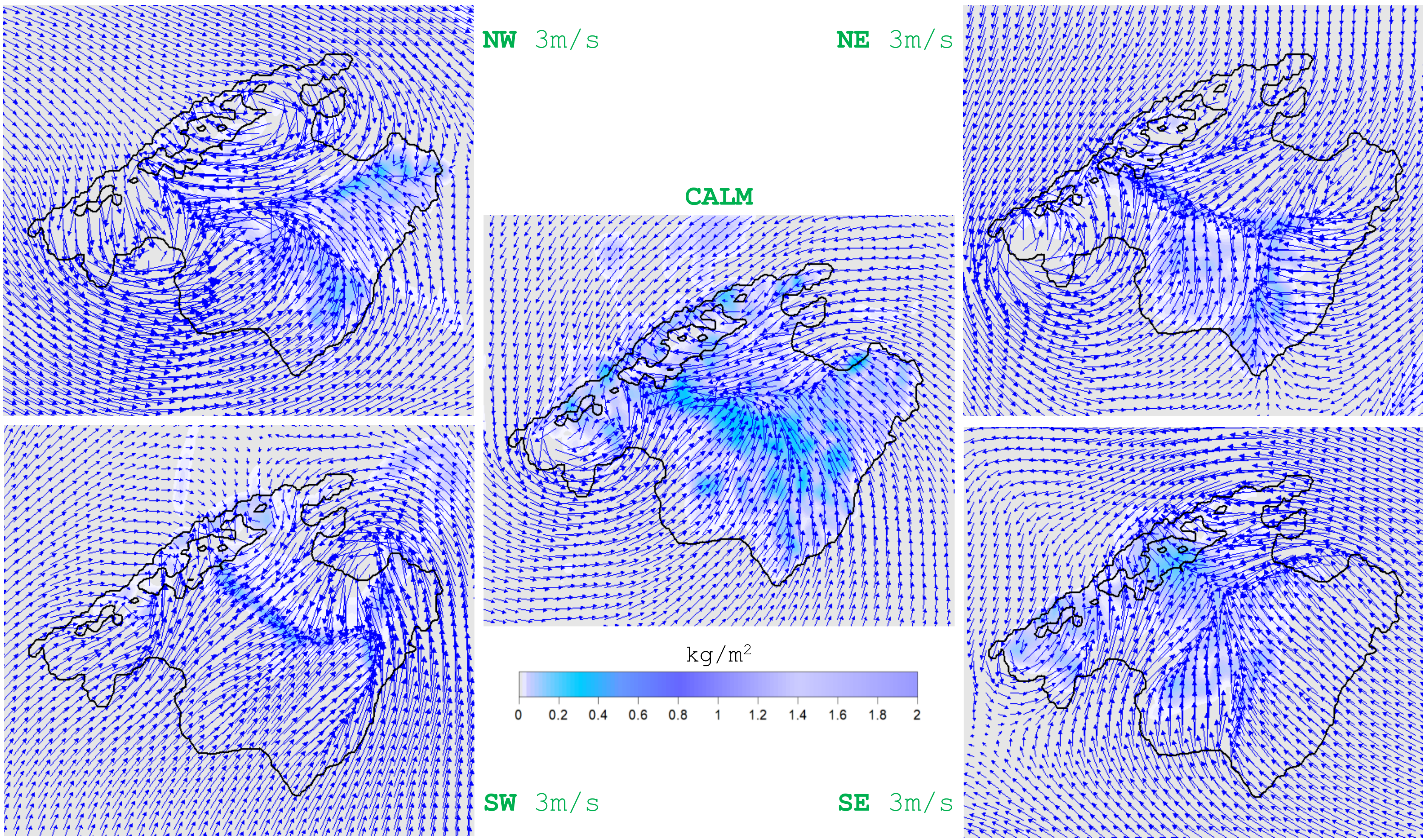


Clouds

Rainfall

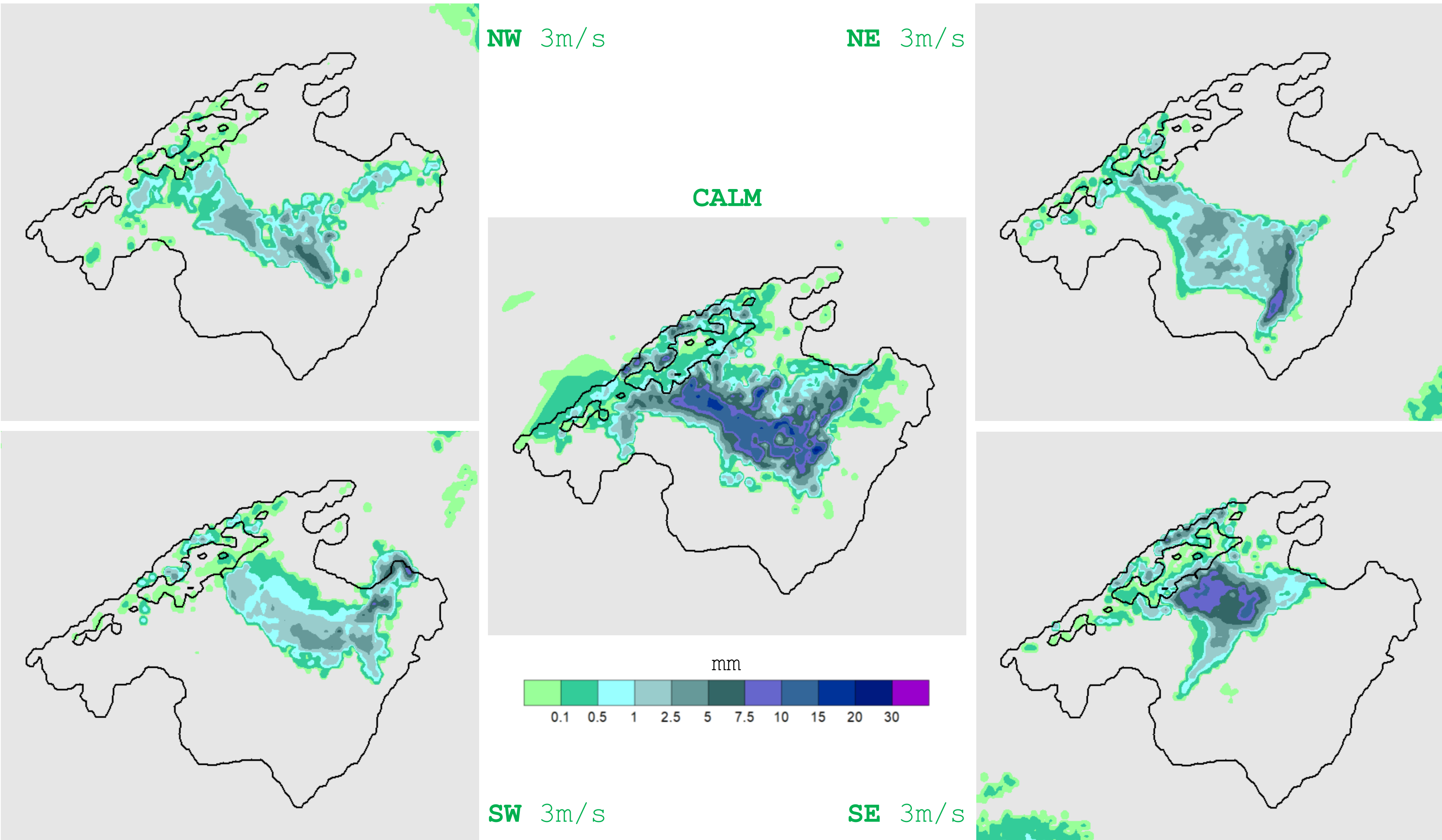
> Breeze Circulation in Mallorca (IC: Sounding 00 UTC 30 Ago 2004)

(dx=1.5km,dzm=400m,stretch=20,dt=3s,Nstep=10,30h) t=15h



> Breeze Circulation in Mallorca (IC: Sounding 00 UTC 30 Ago 2004)

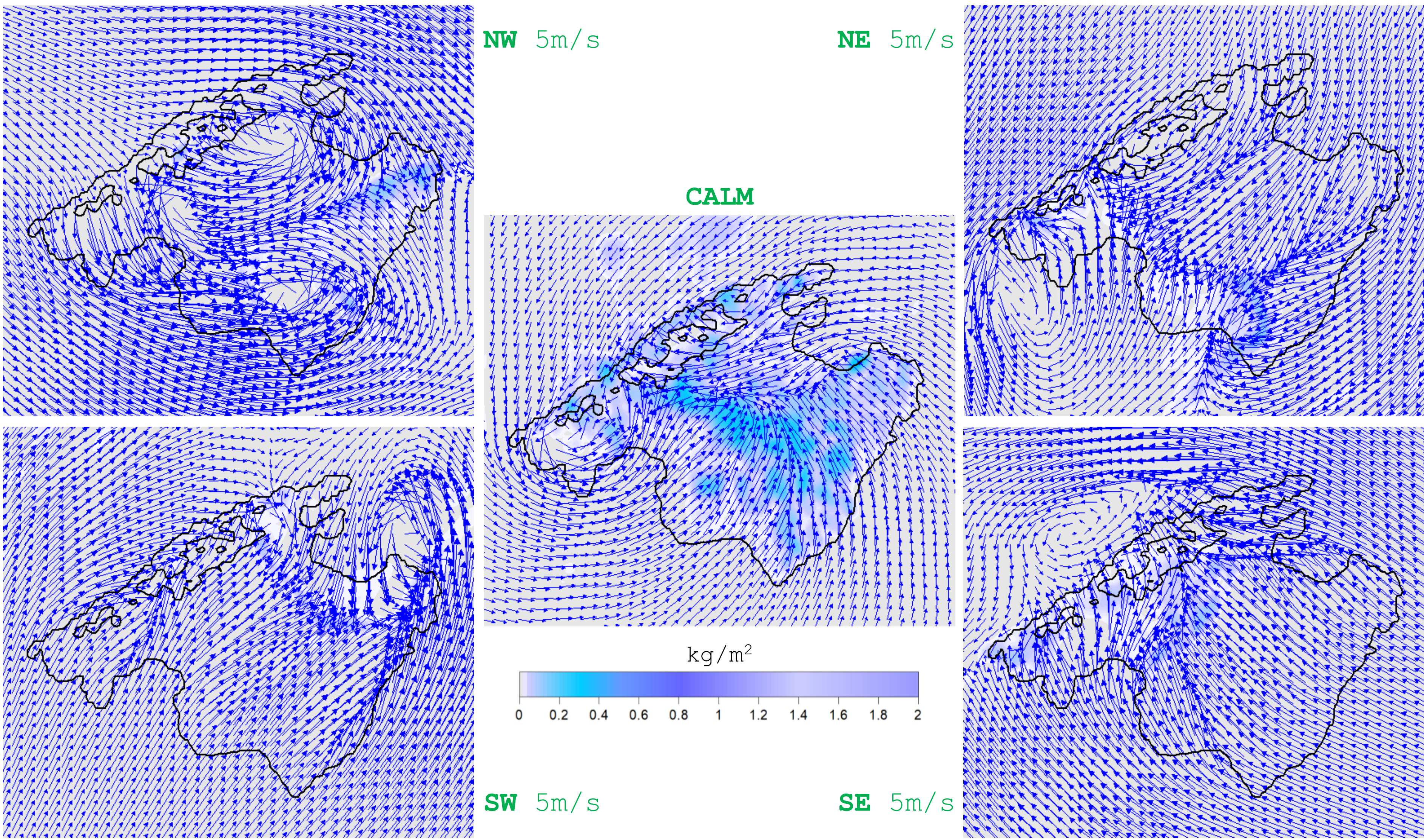
(dx=1.5km,dzm=400m,stretch=20,dt=3s,Nstep=10,30h) **t=30h**



TRAM_physics_3D (MESOSCALE-IDEALized)

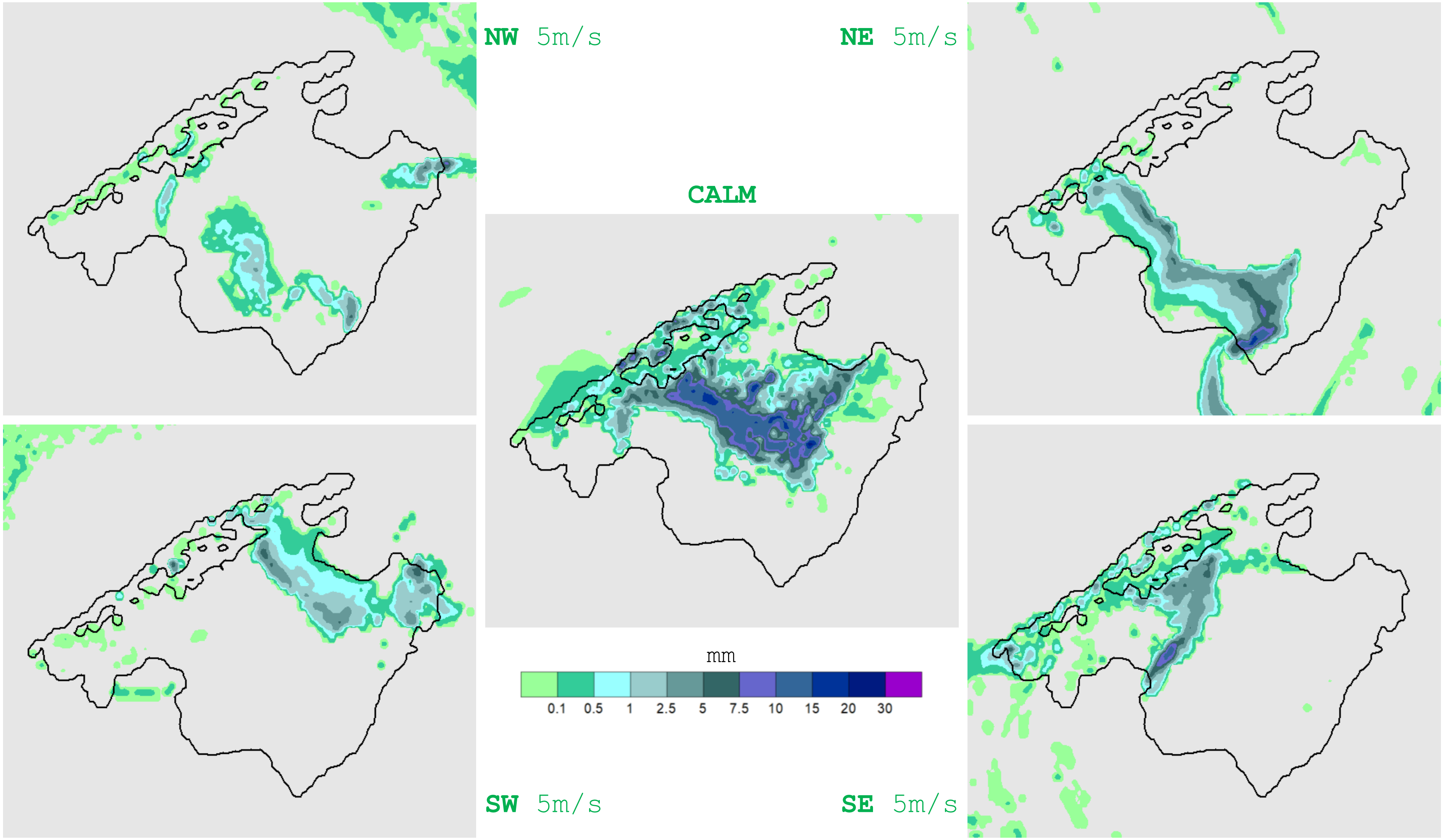
> Breeze Circulation in Mallorca (IC: Sounding 00 UTC 30 Ago 2004)

(dx=1.5km,dzm=400m,stretch=20,dt=3s,Nstep=10,30h)   t=15h



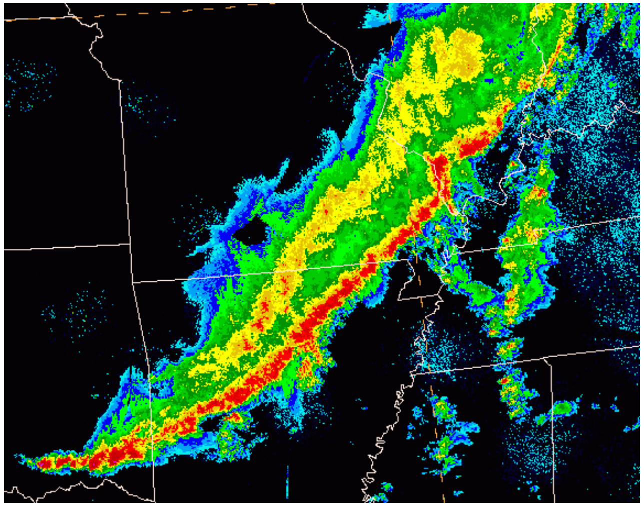
> Breeze Circulation in Mallorca (IC: Sounding 00 UTC 30 Ago 2004)

(dx=1.5km,dzm=400m,stretch=20,dt=3s,Nstep=10,30h) t=30h



> Squall-Line Simulation (NO Coriolis, Radiation, PBL and Cumulus)

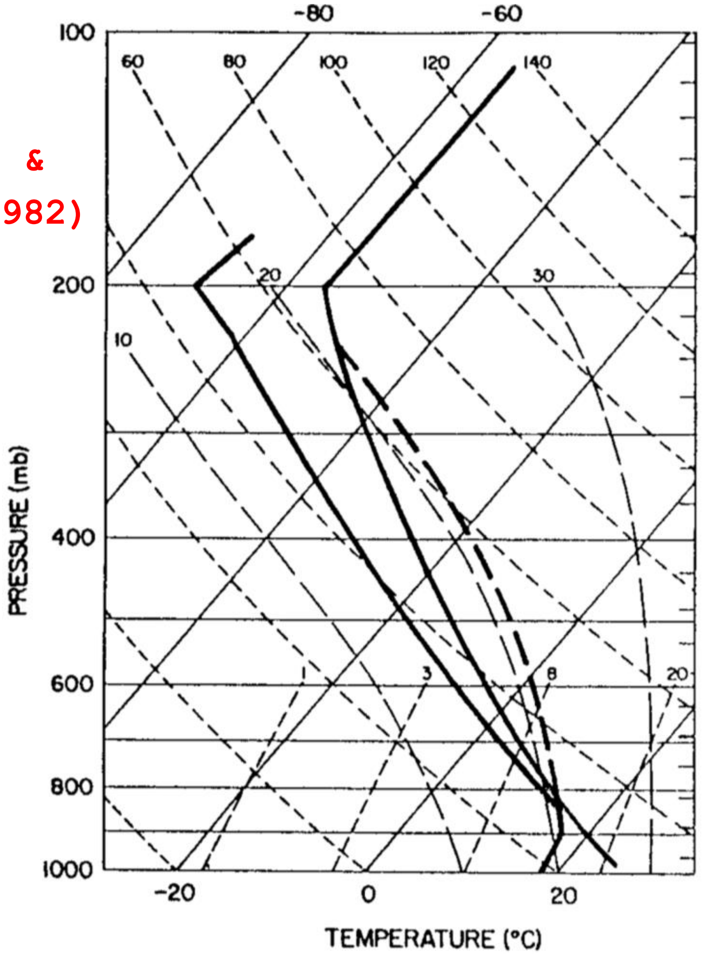
(dx=1.5km,dzm=200m,stretch=10,dt=3s,Nstep=5,10h)



IC: WK82 SOUNDING + 8K Surface Cold Pool

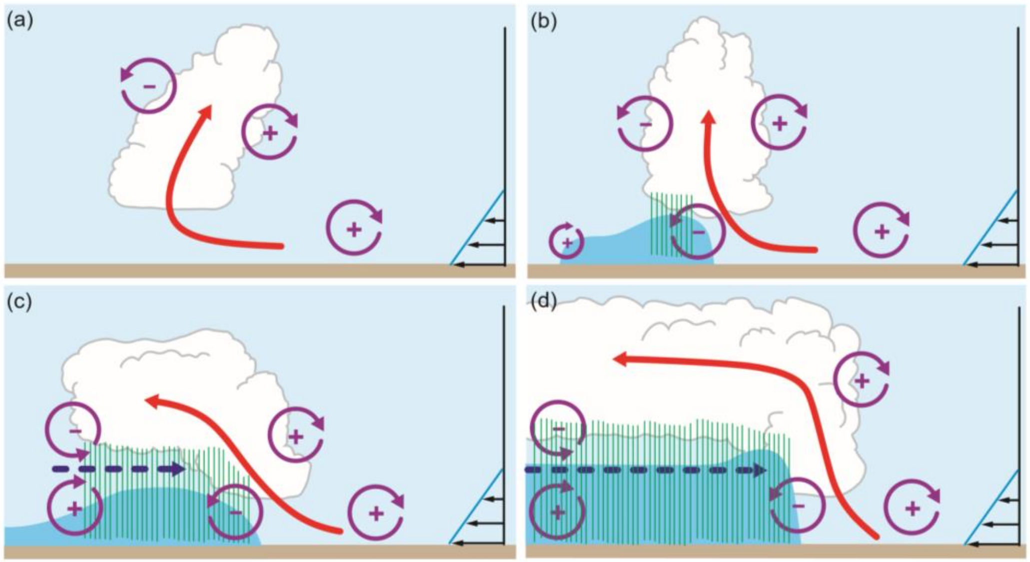
... and 3 different wind profiles

Weisman & Klemp (1982)



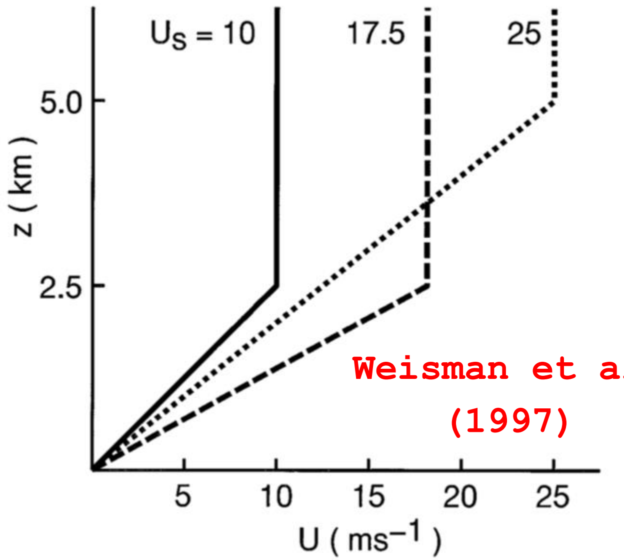
> Squall-Line Simulation (NO Coriolis, Radiation, PBL and Cumulus)

(dx=1.5km,dzm=200m,stretch=10,dt=3s,Nstep=5,10h)

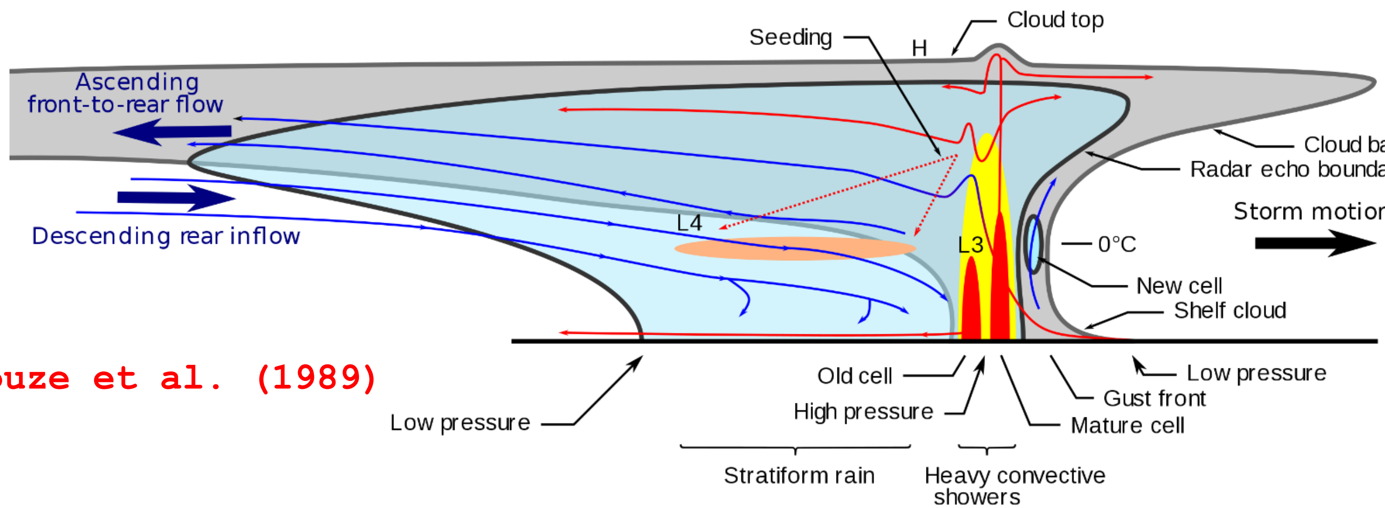


Weisman (1993)

SHEAR: Weak Moderate Deep



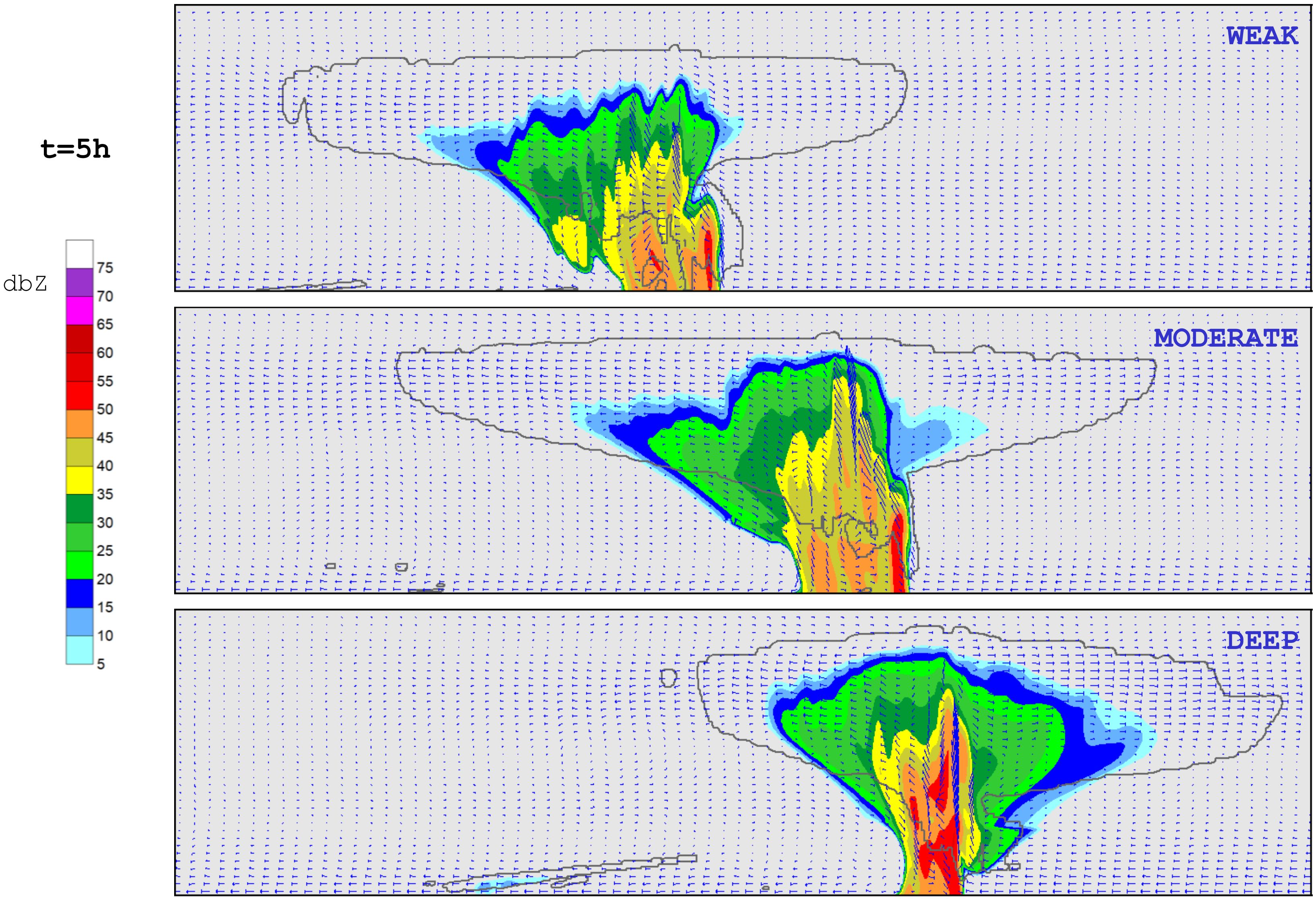
Weisman et al. (1997)



Houze et al. (1989)

> Squall-Line Simulation (NO Coriolis, Radiation, PBL and Cumulus)

(dx=1.5km,dzm=200m,stretch=10,dt=3s,Nstep=5,10h)



Run

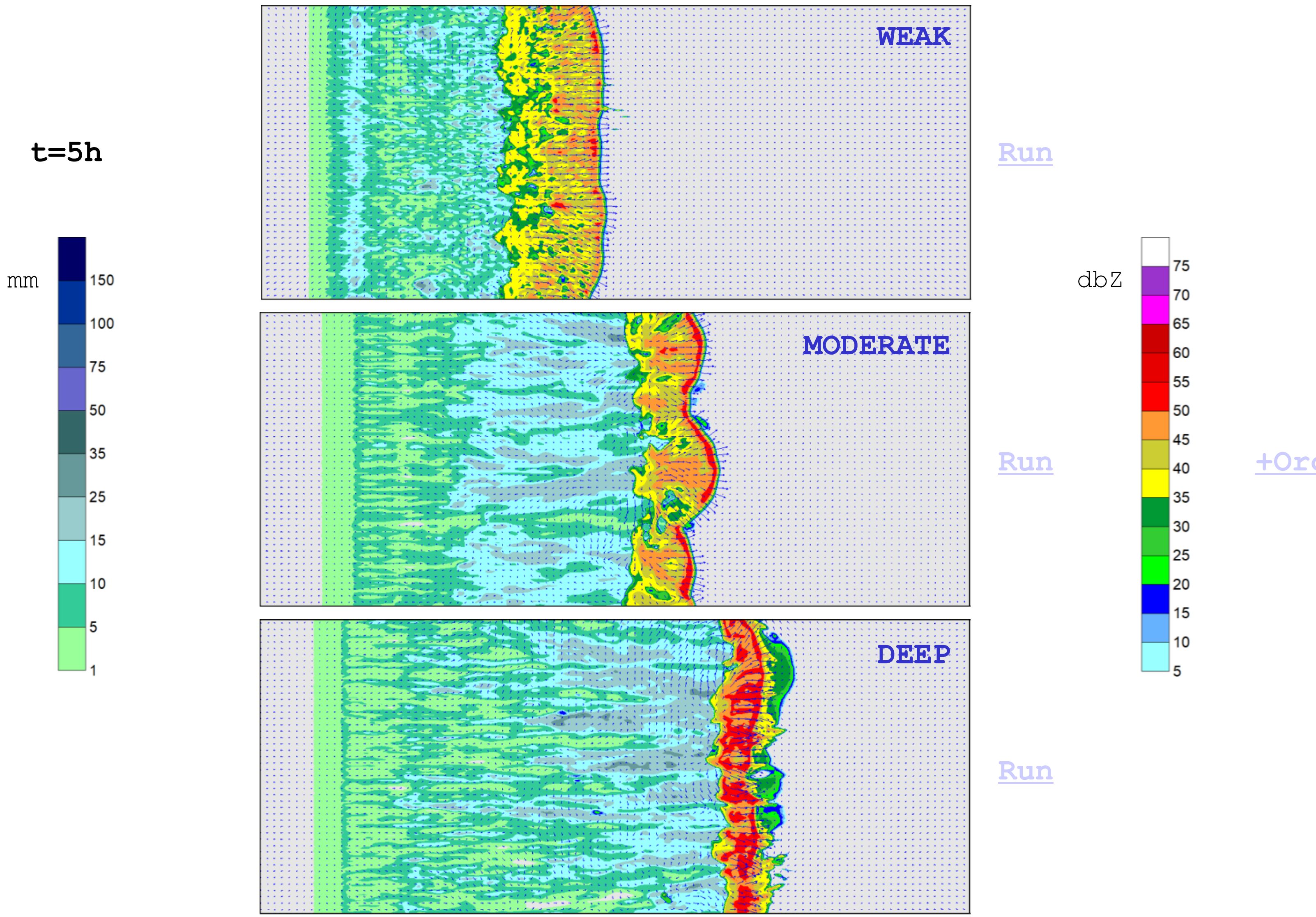
Run +Oro

v.2D

Run

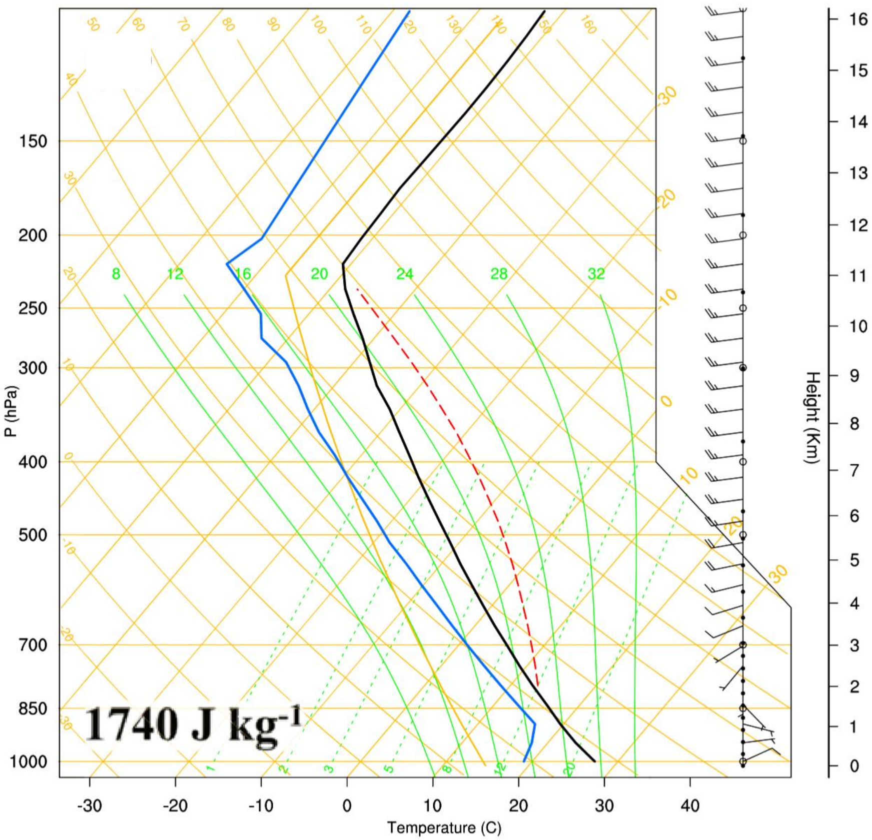
> Squall-Line Simulation (NO Coriolis, Radiation, PBL and Cumulus)

(dx=1.5km,dzm=200m,stretch=10,dt=3s,Nstep=5,10h)



> Supercell Simulation (NO Coriolis, Radiation, PBL and Cumulus)

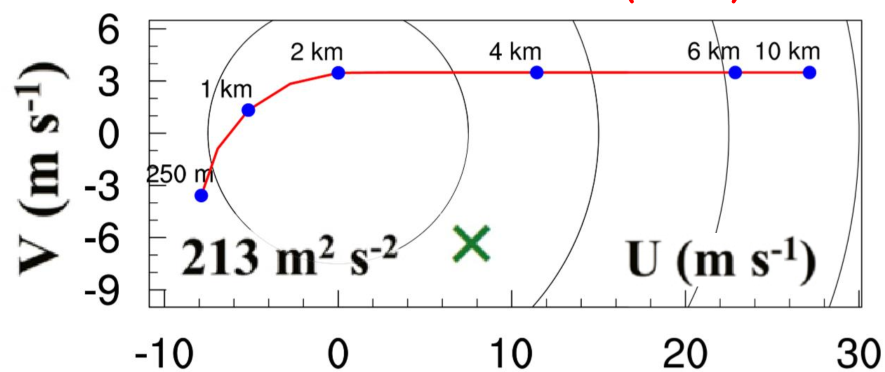
(dx=0.75km,dzm=400m,stretch=20,dt=1.5s,Nstep=5,8h)

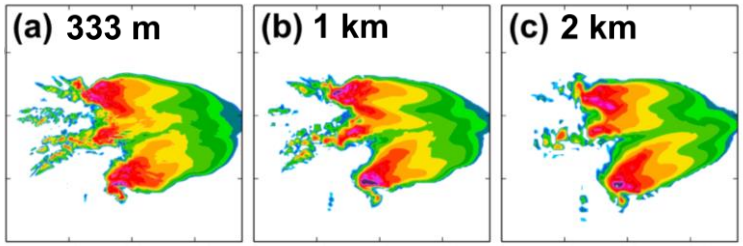


IC: WK82 SOUNDING + 3K Thermal Bubble

... and QUARTER-CIRCLE hodograph

Potvin & Flora (2015)

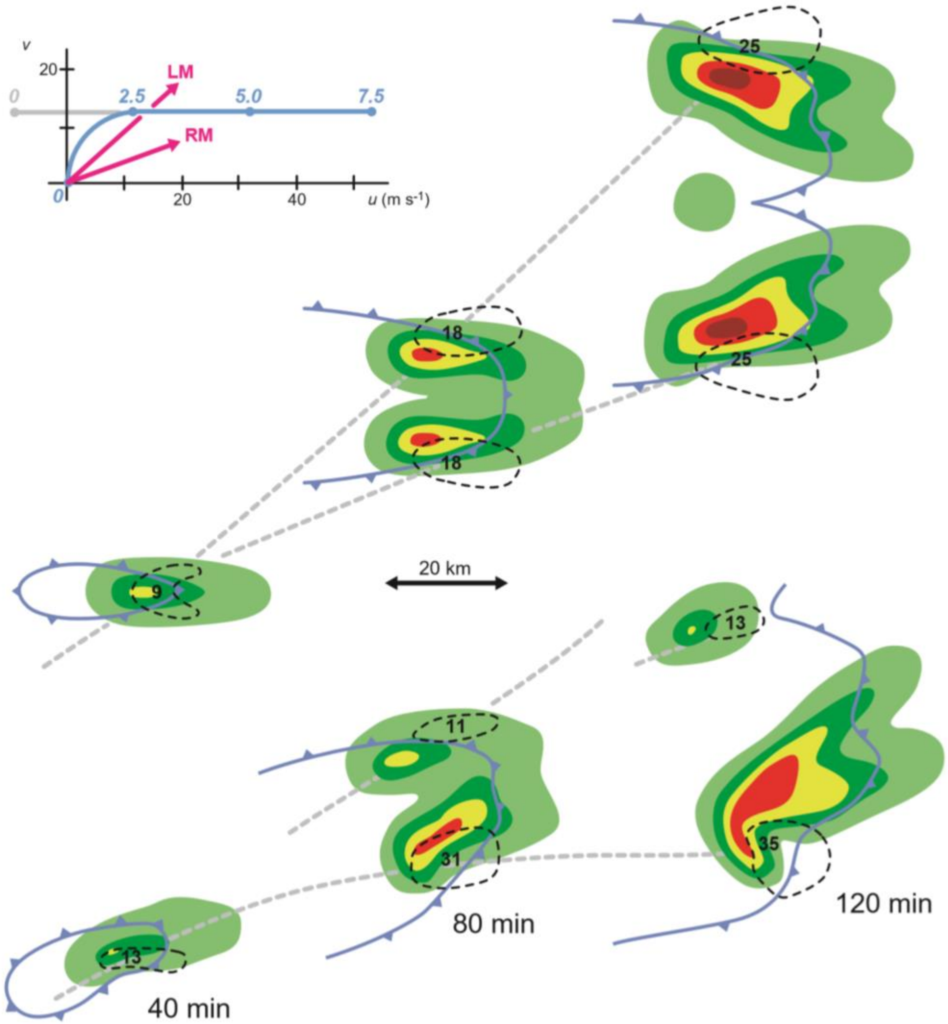




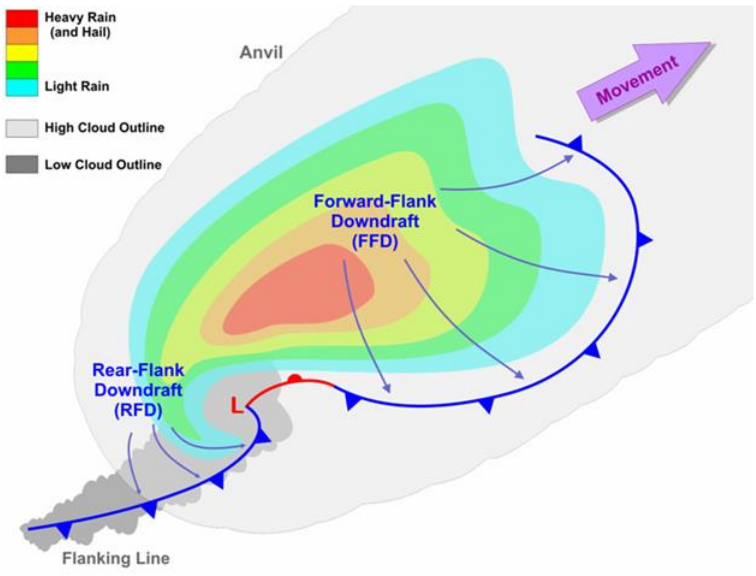
TRAM_*physics_3D* *(MESOSCALE-IDEALized)*

> Supercell Simulation (NO Coriolis, Radiation, PBL and Cumulus)

(dx=0.75km,dzm=400m,stretch=20,dt=1.5s,Nstep=5,8h)



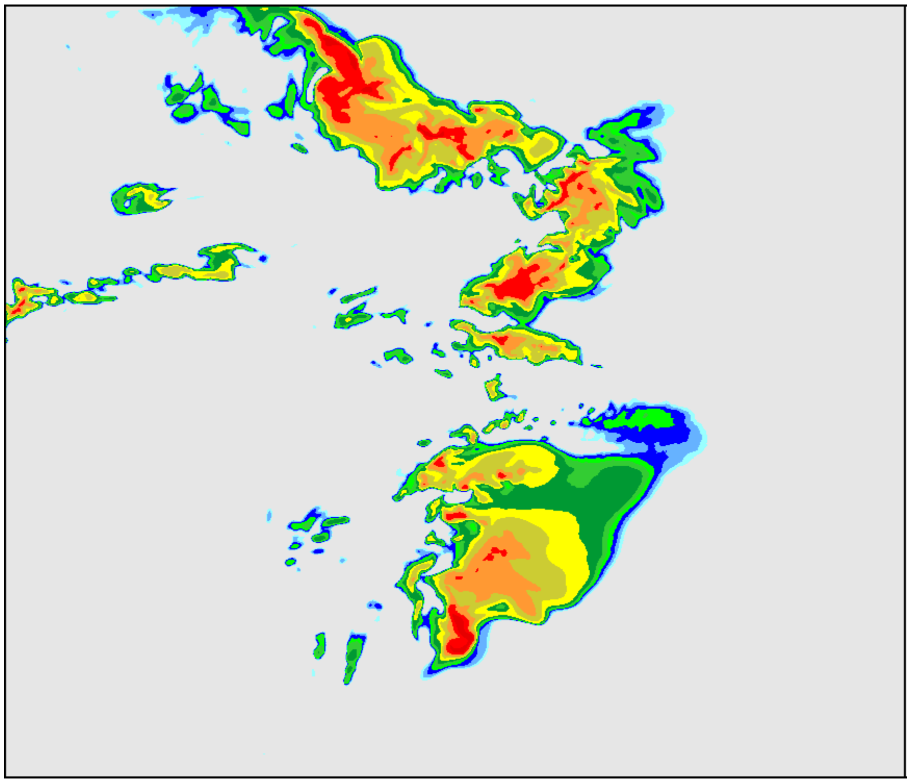
Klemp (1987)

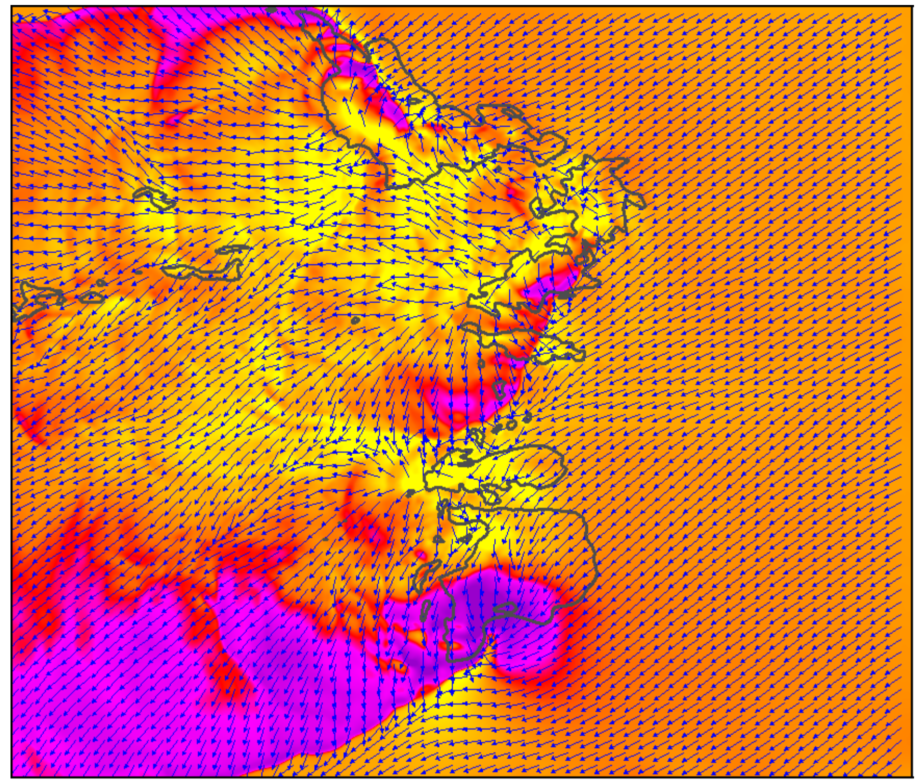


> Supercell Simulation (NO Coriolis, Radiation, PBL and Cumulus)

(dx=0.75km,dzm=400m,stretch=20,dt=1.5s,Nstep=5,8h)

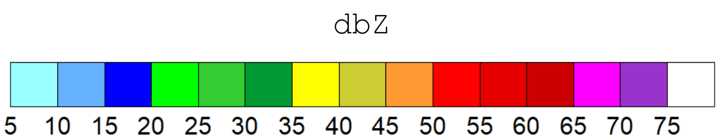
t=4.5h

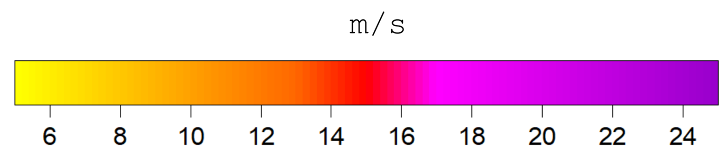




Straight Run +Oro

Run

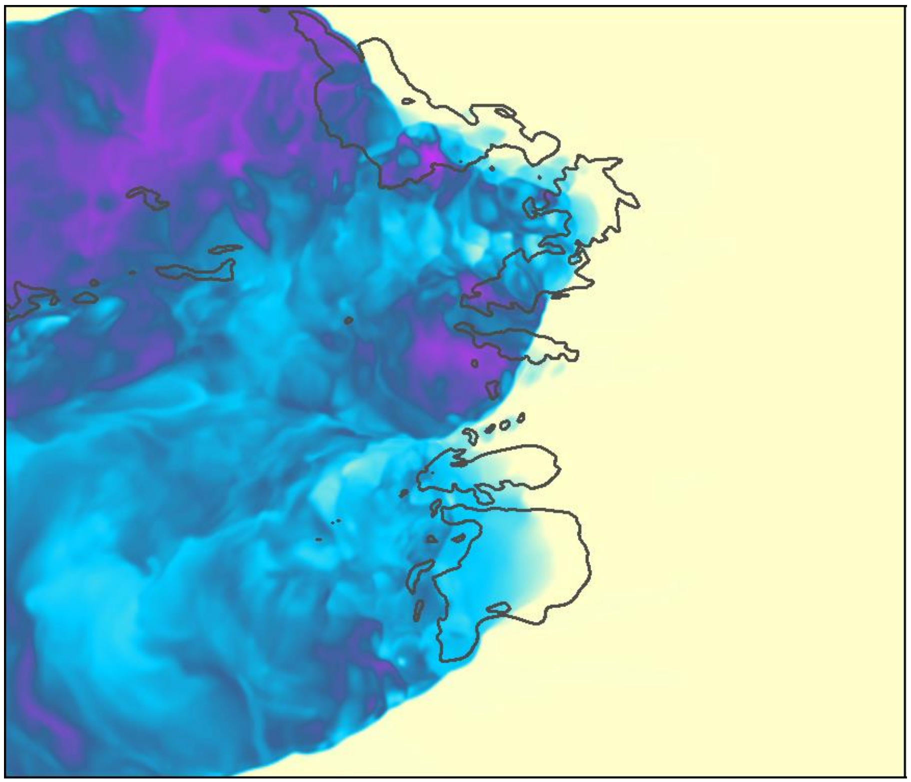


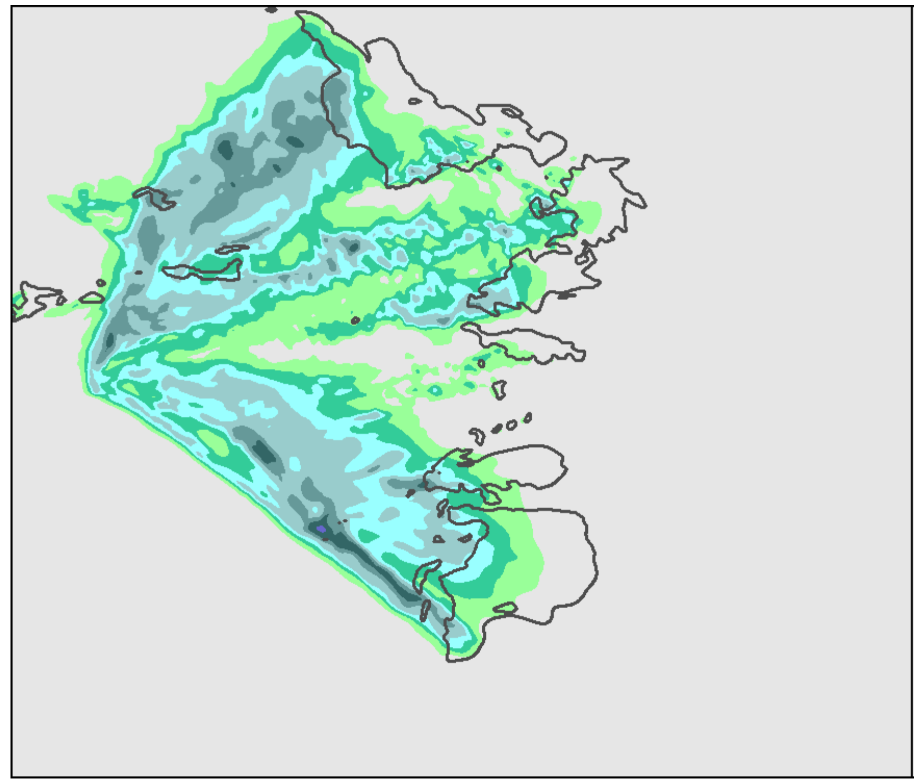


> Supercell Simulation (NO Coriolis, Radiation, PBL and Cumulus)

(dx=0.75km,dzm=400m,stretch=20,dt=1.5s,Nstep=5,8h)

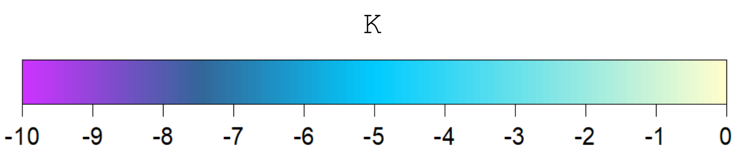
t=4.5h

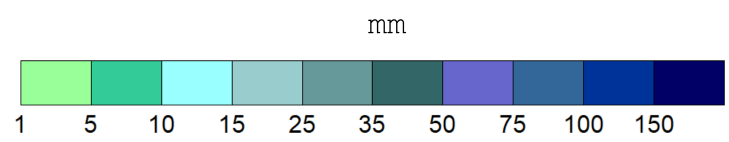




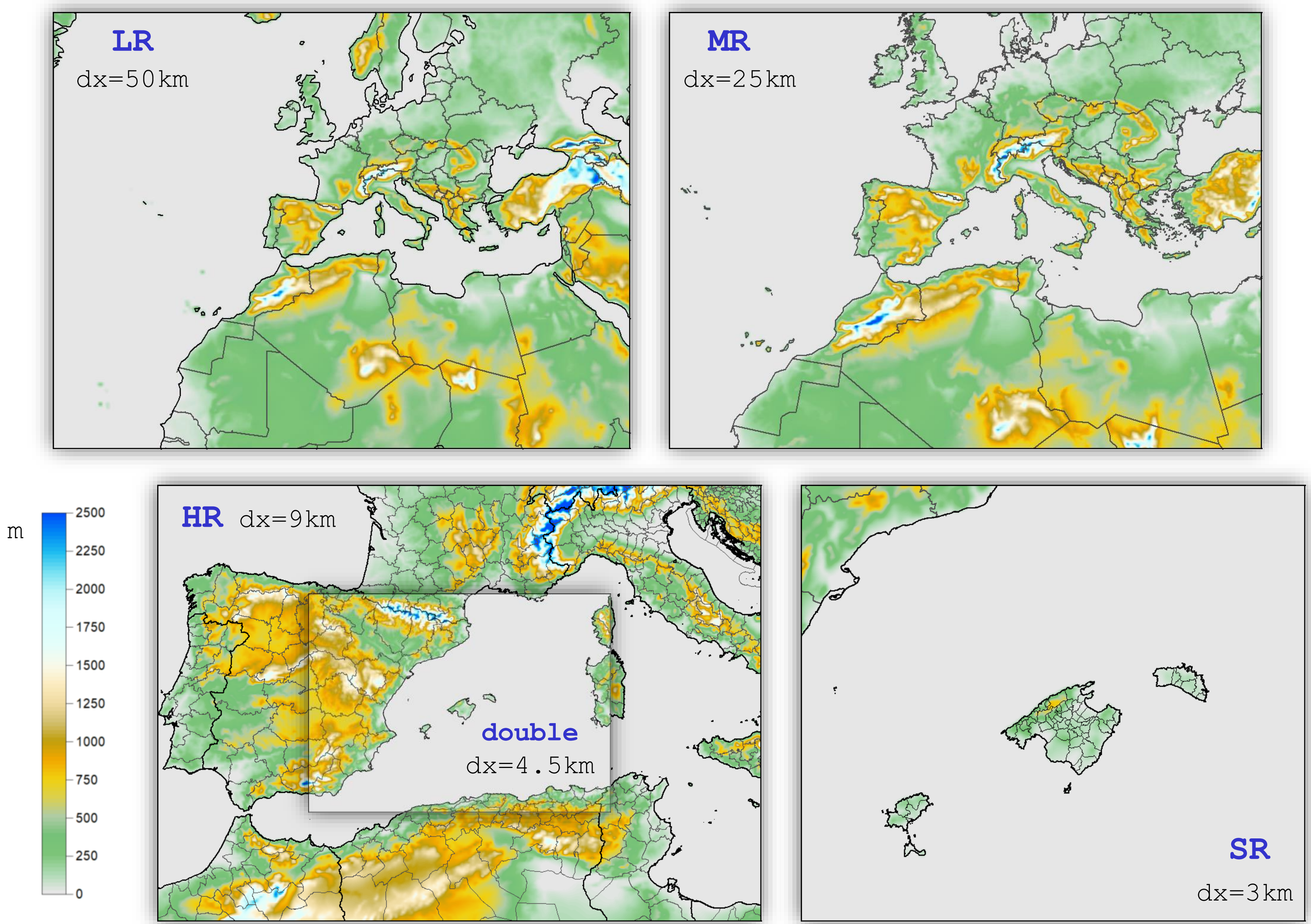
Run

Run



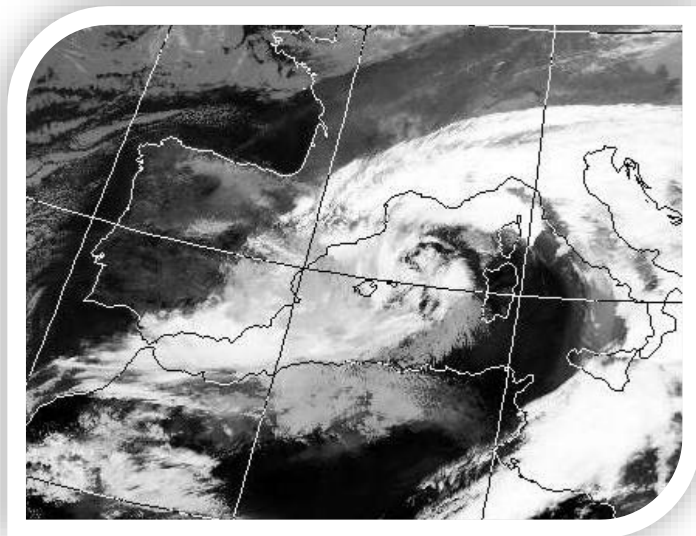


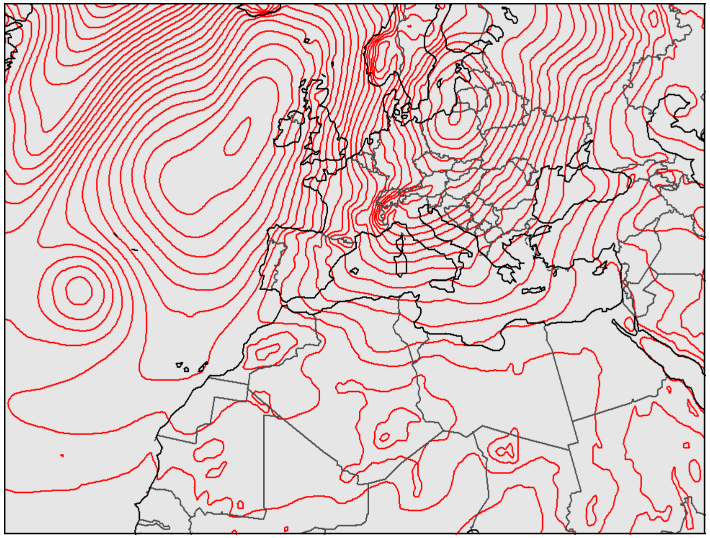
SYNOPTIC-REALcase TESTS



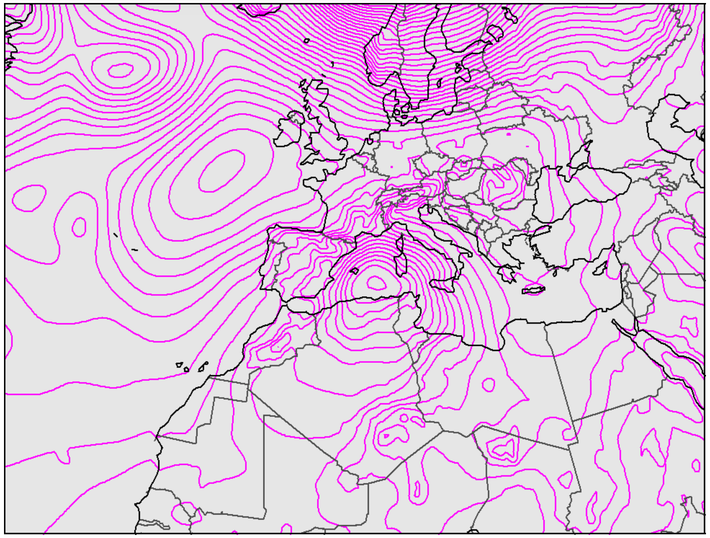
> "SUPERSTORM" Baroclinic Cyclone (IC: 00 UTC 9 Nov 2001)

(LR:dx=50km,dzm=200m,stretch=1,dt=75s,Nstep=6,120h)

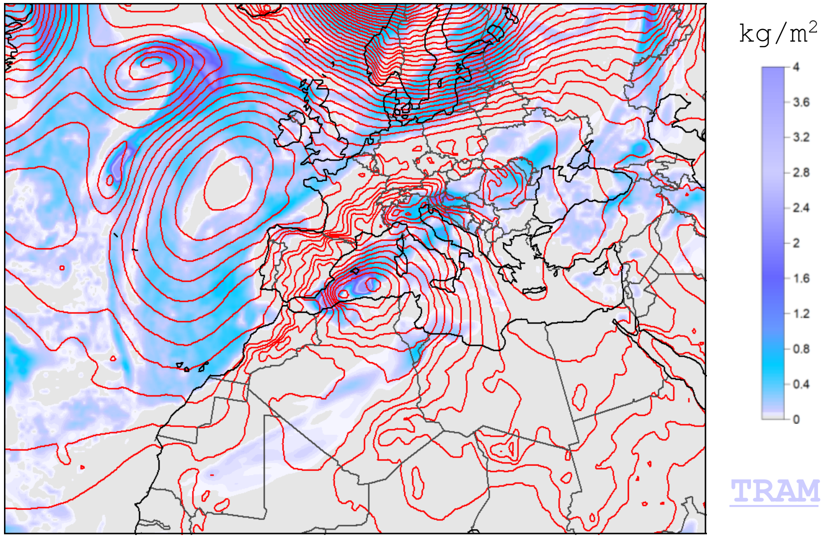




t=0h



t=48h



NCEP

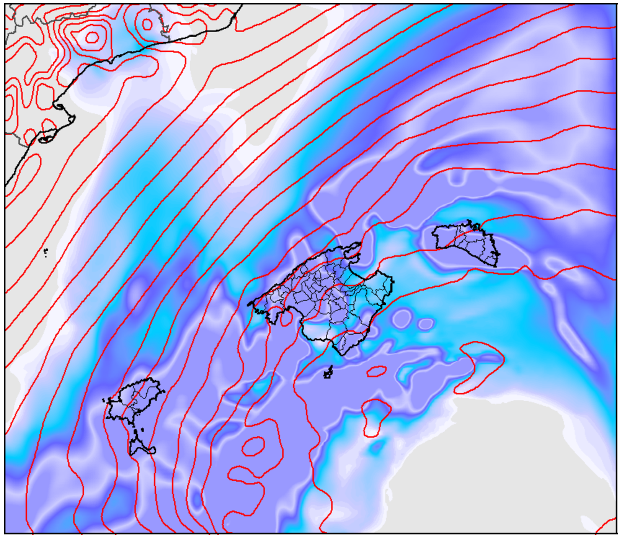
TRAM

Winds

Rainfall

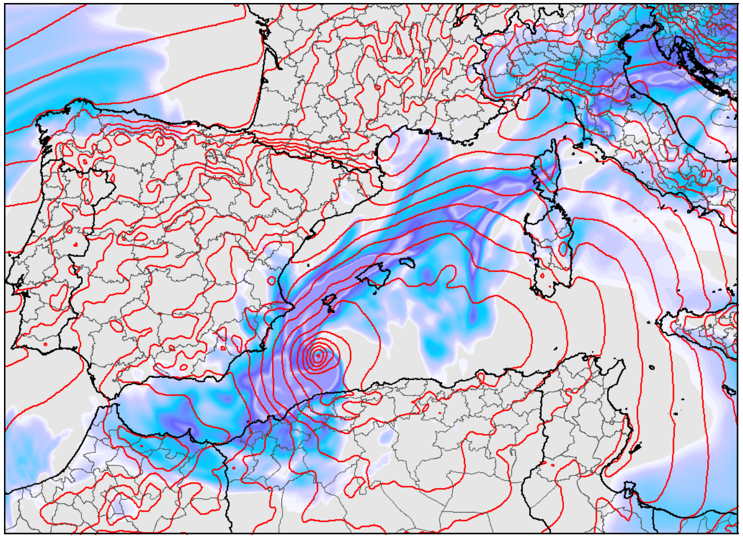
> "SUPERSTORM" Baroclinic Cyclone (IC: 00 UTC 9 Nov 2001)

(Influence of DOMAIN & RESOLUTION on predicted SLP/CLOUD field)

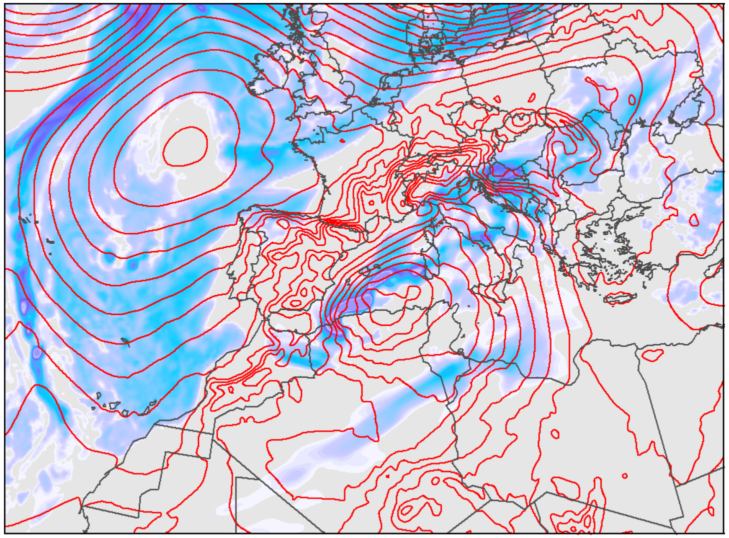


SR

t=48h

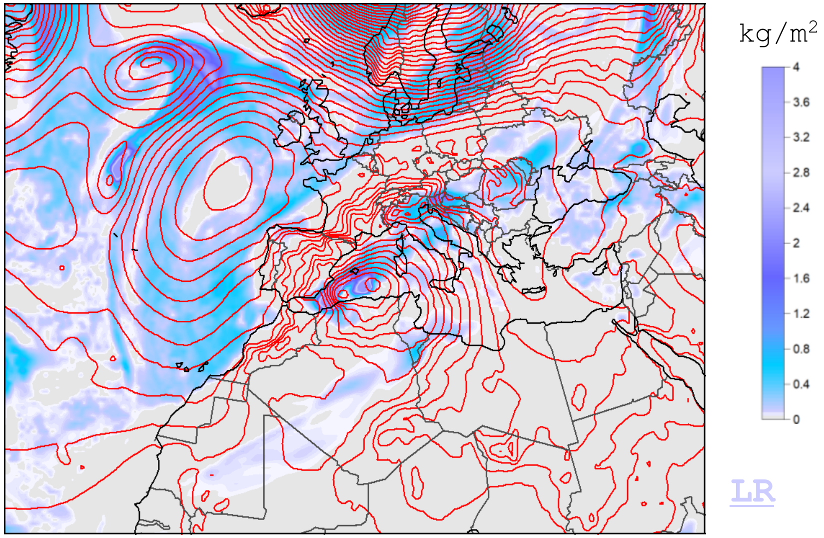


HR



MR

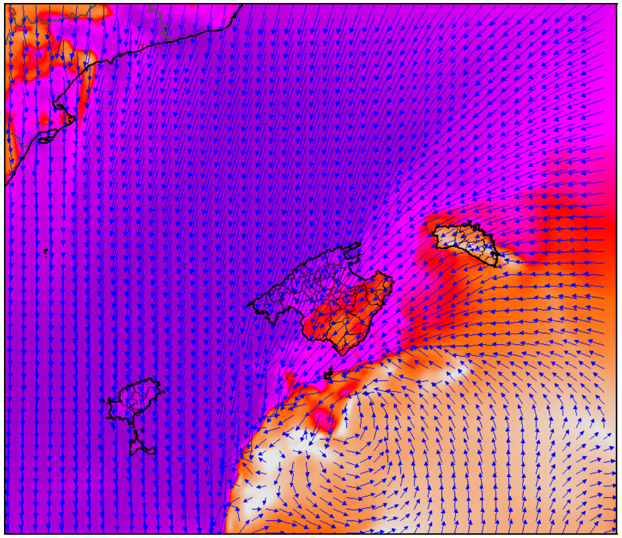
t=48h



LR

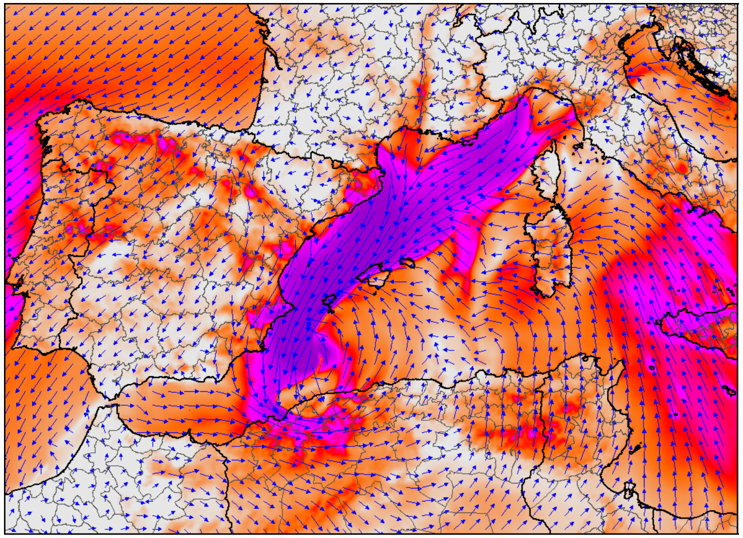
> "SUPERSTORM" Baroclinic Cyclone (IC: 00 UTC 9 Nov 2001)

(Influence of DOMAIN & RESOLUTION on predicted WIND field)

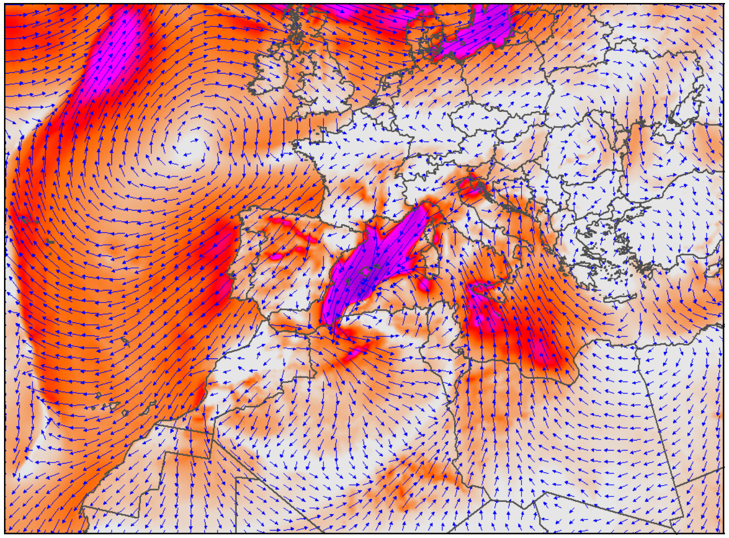


SR

t=48h

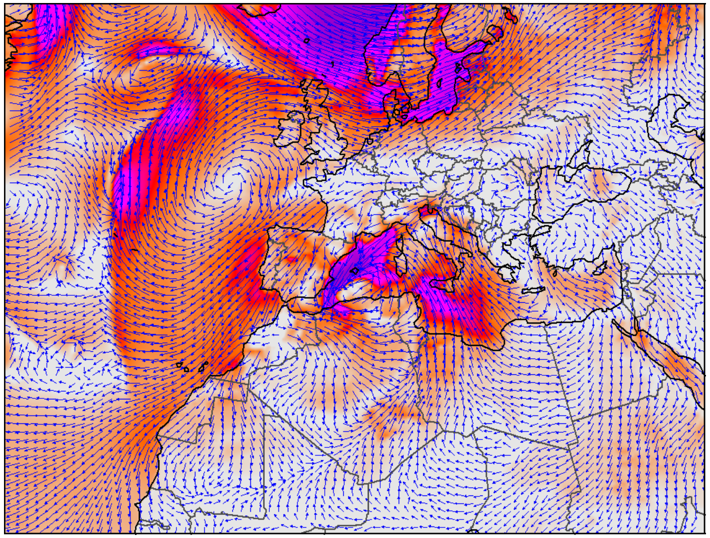


HR

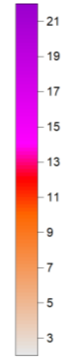


MR

t=48h

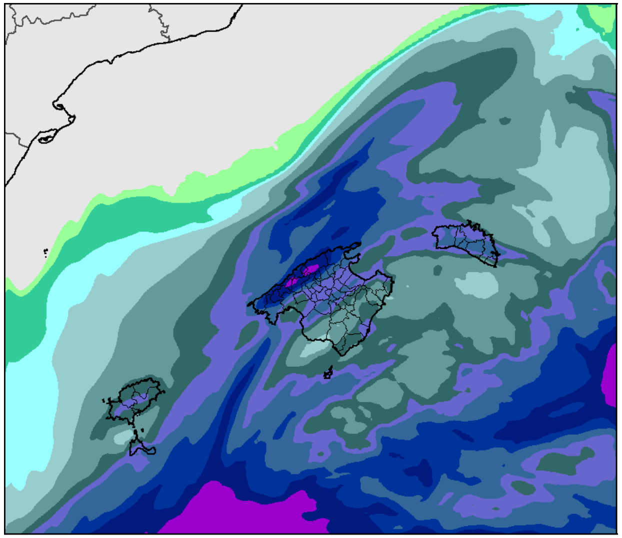


LR



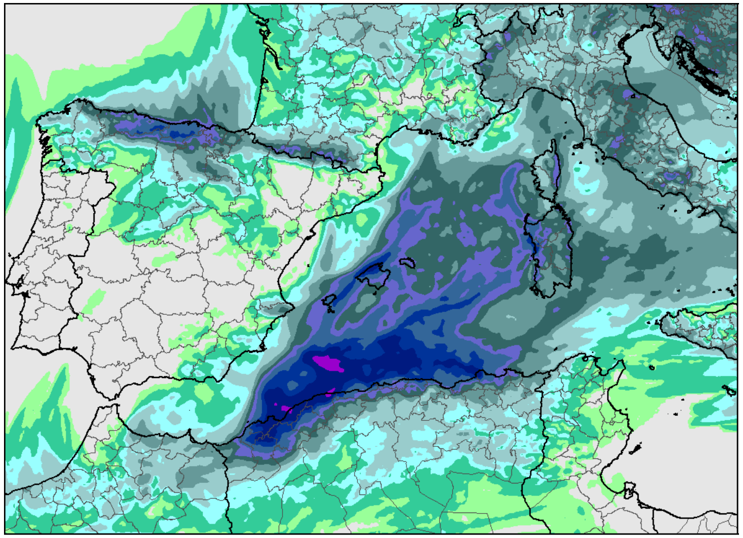
> "SUPERSTORM" Baroclinic Cyclone (IC: 00 UTC 9 Nov 2001)

(Influence of DOMAIN & RESOLUTION on predicted RAINFALL field)

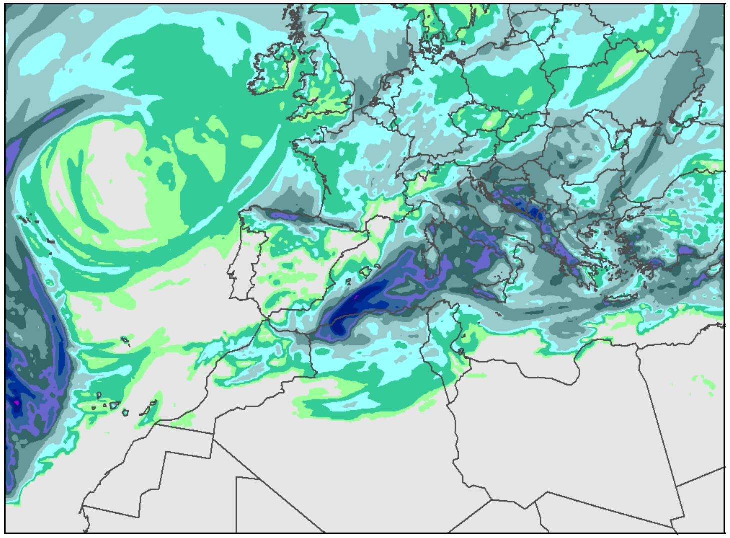


SR

total

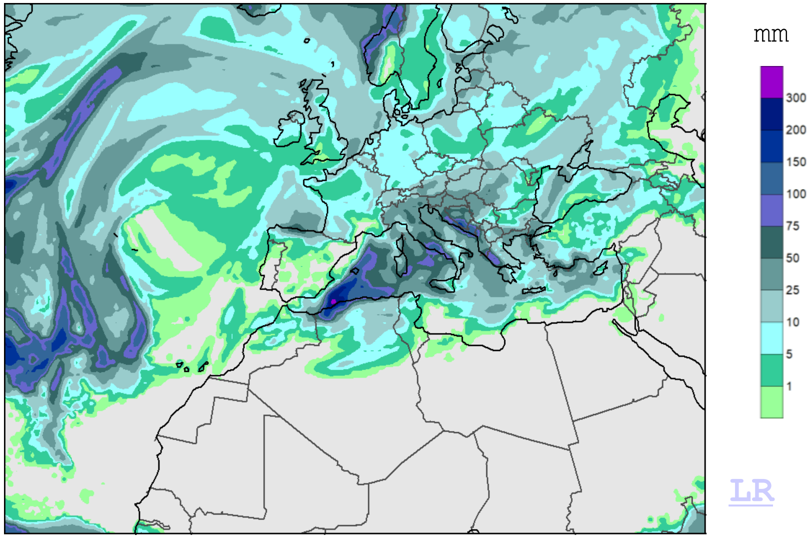


HR



MR

total

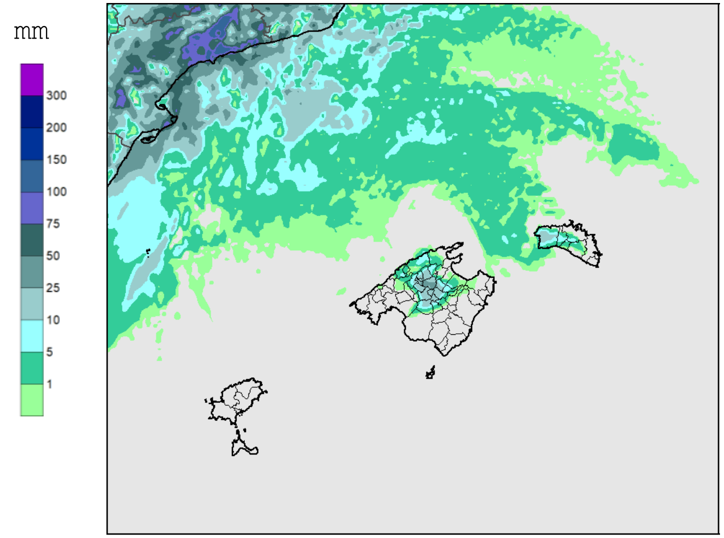


LR

> "BREEZE-CONVECTION" in Mallorca (IC: 00 UTC 30 Ago 2004)

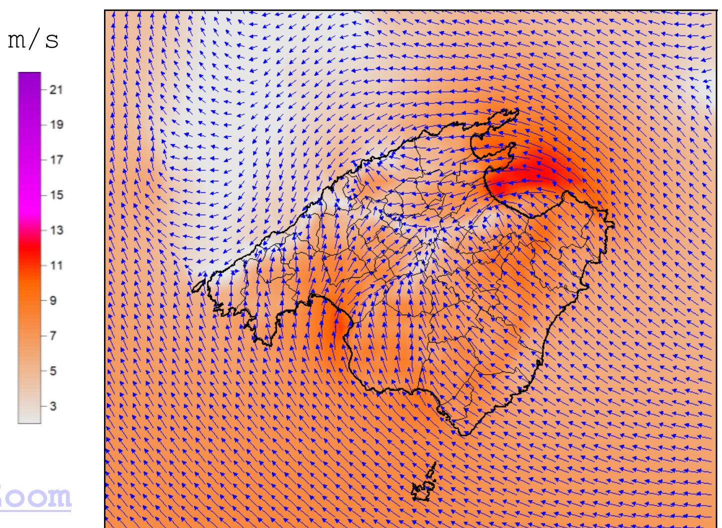
(SR:dx=3km,dzm=200m,stretch=10,dt=6s,Nstep=6,42h)

30 Ago
31 Ago



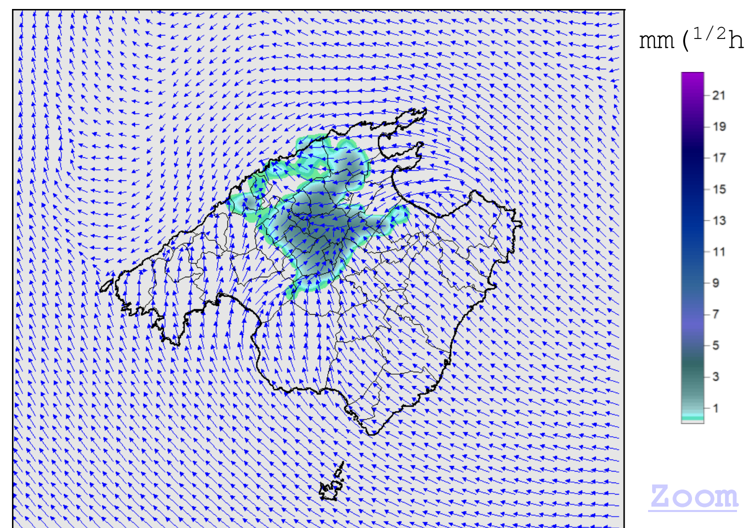
total

SR



Zoom

t=15h



Zoom

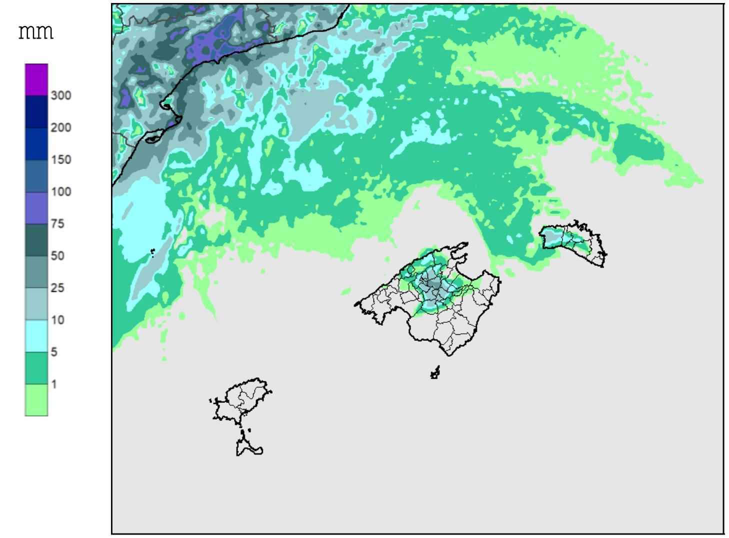
Wind-Clouds

> "BREEZE-CONVECTION" in Mallorca (IC: 00 UTC 30 Ago 2004)

(Influence of **DOMAIN** & **RESOLUTION** on predicted **RAINFALL** field)

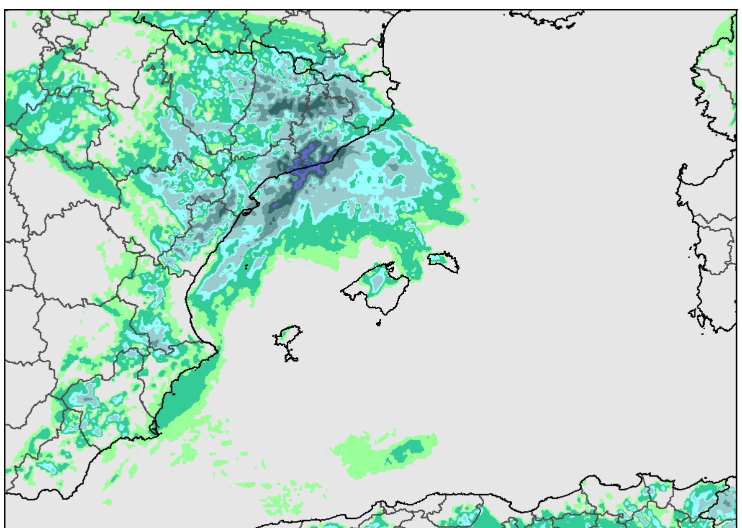
30 Ago

31 Ago

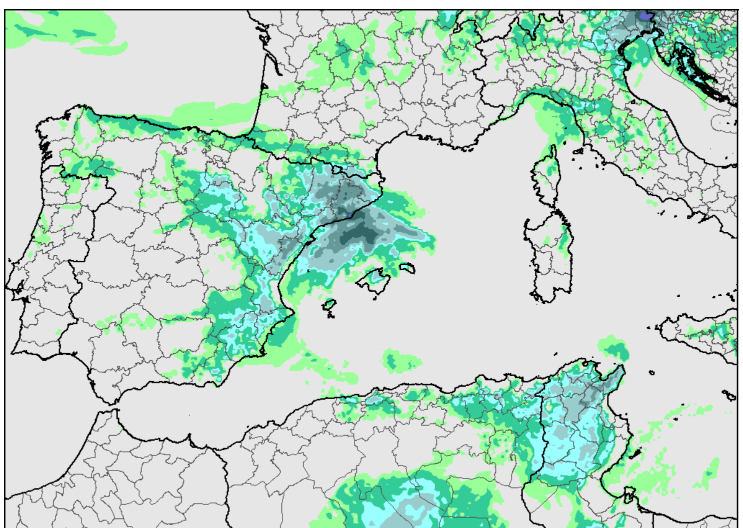


total

SR



total



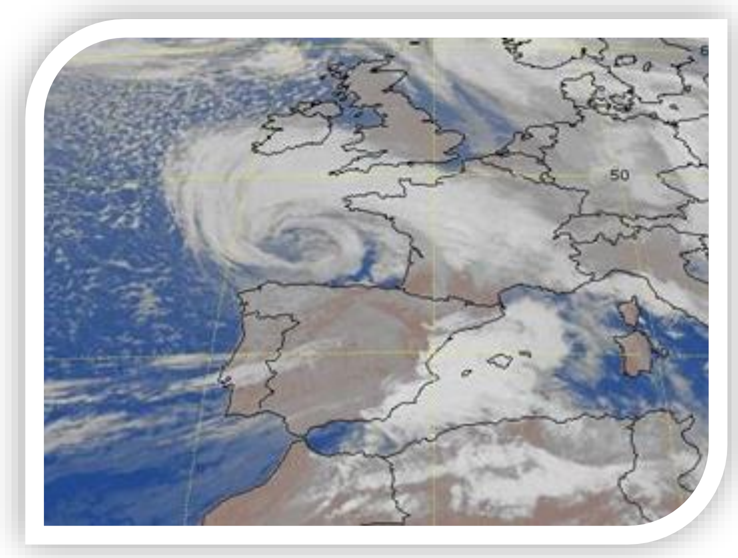
HR

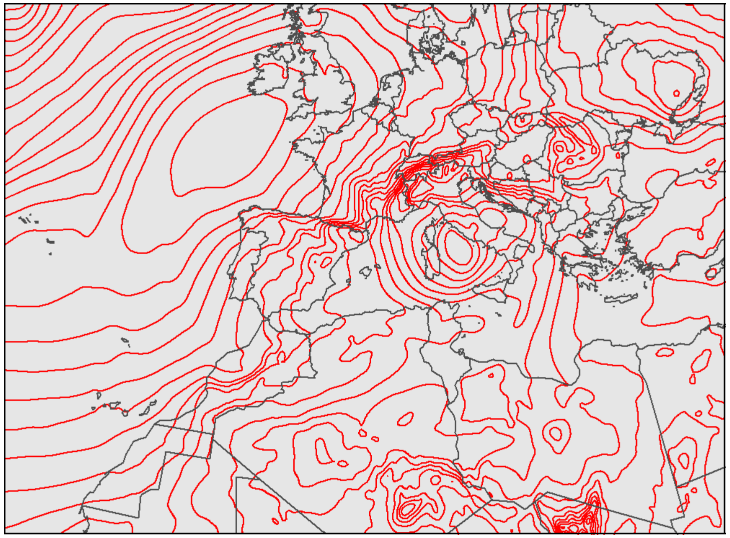
HR-double

TRAM_*physics_3D* (*SYNOPTIC-REALcase*)

> "HUGO" Intense Cyclonic Storm (IC: 00 UTC 21 Mar 2018)

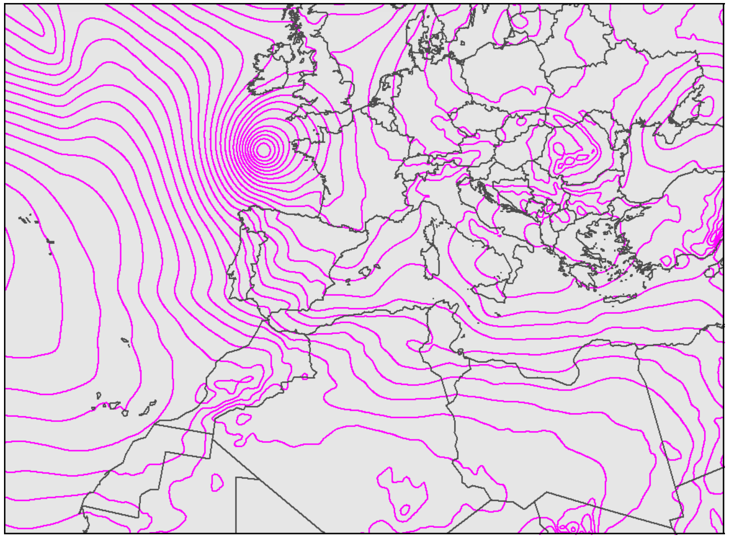
(MR:dx=25km,dzm=200m,stretch=10,dt=45s,Nstep=5,90h)



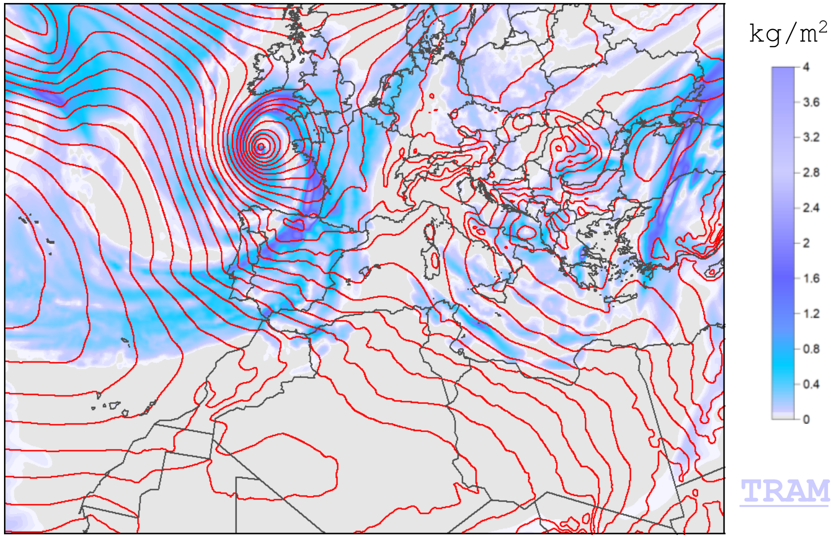


t=0h

ERA-5



t=72h



TRAM

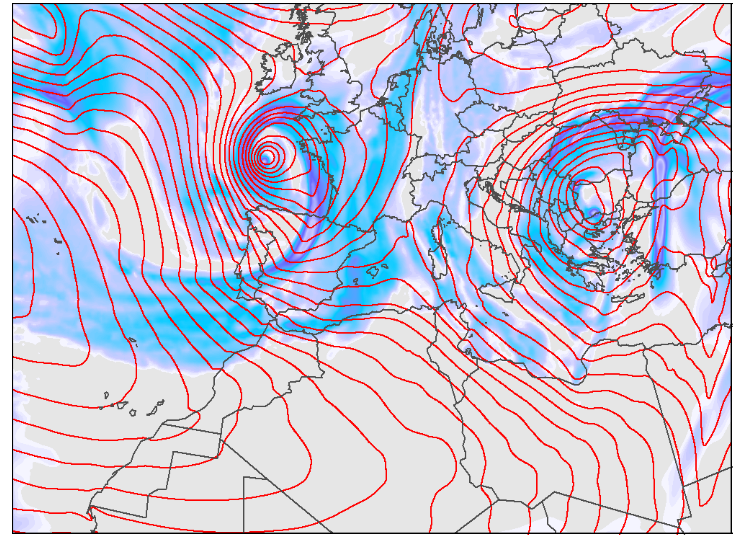
Winds Rainfall

> "HUGO" Intense Cyclonic Storm (IC: 00 UTC 21 Mar 2018)

(MR:dx=25km,dzm=200m,stretch=10,dt=45s,Nstep=5,90h)

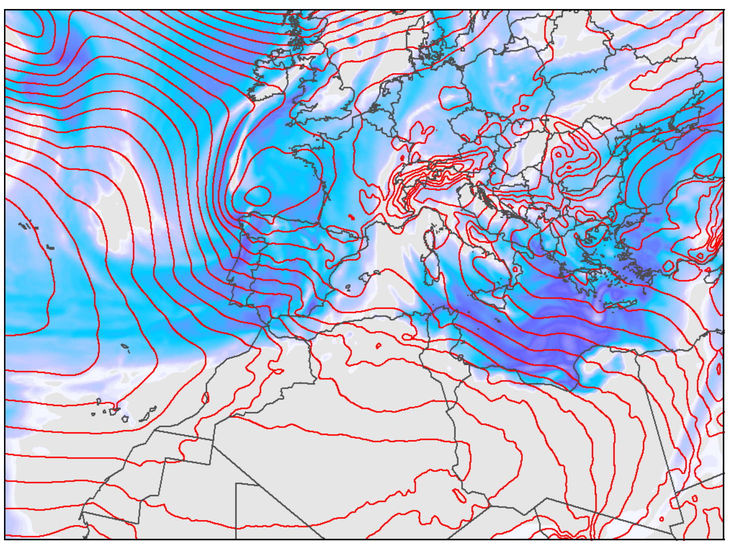
Role of FACTORS

NO_ORO

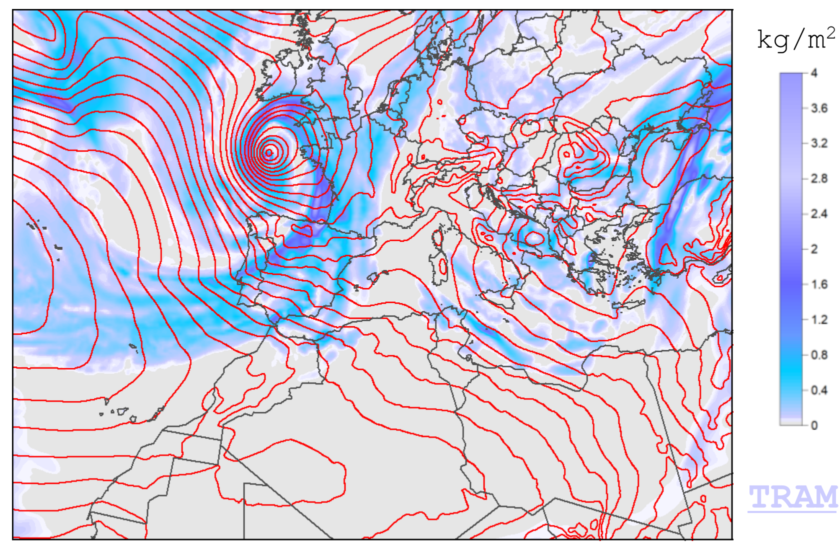


t=72h

NO_LH



t=72h

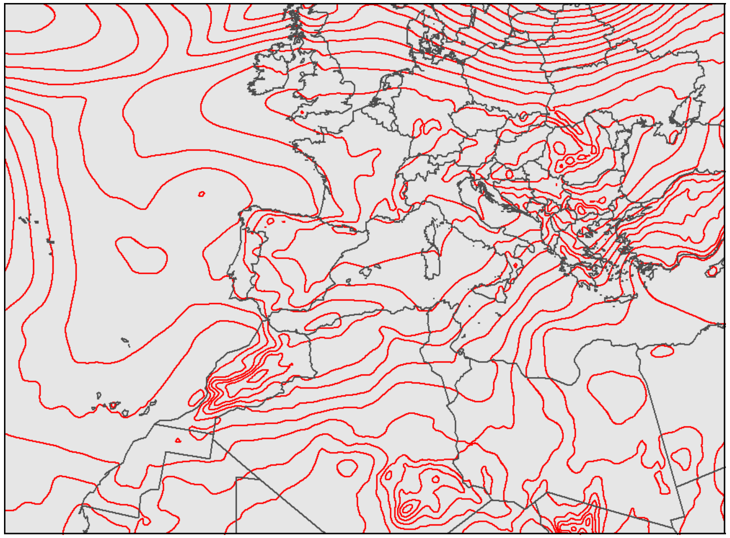


TRAM

Winds Rainfall

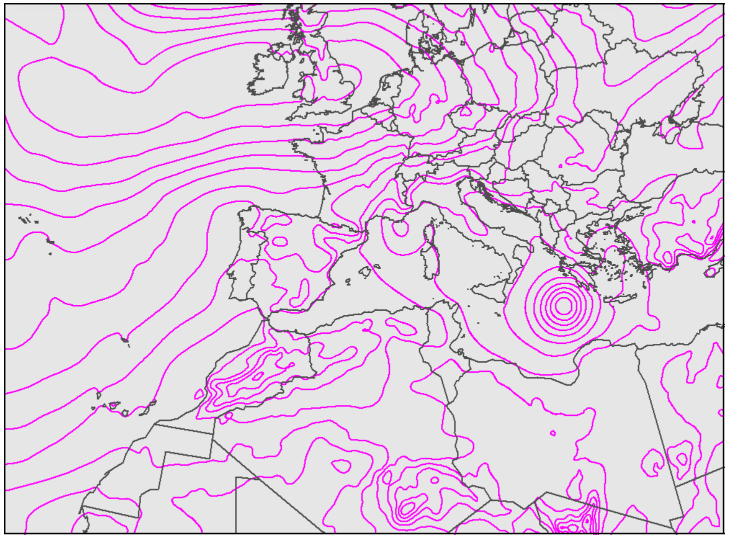
> "ZORBAS" Ionian Sea Medicane (IC: 00 UTC 27 Sept 2018)

(MR:dx=25km,dzm=200m,stretch=10,dt=45s,Nstep=5,90h)

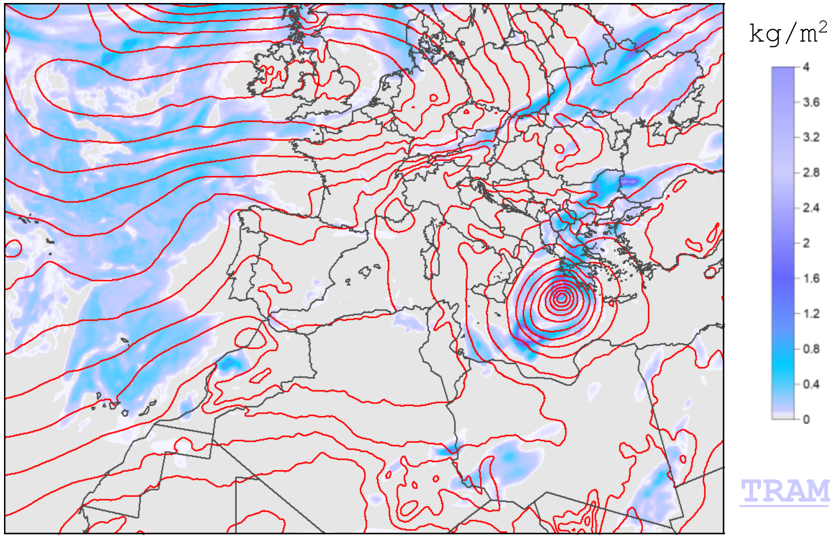


t=0h

ERA-5



t=48h



TRAM

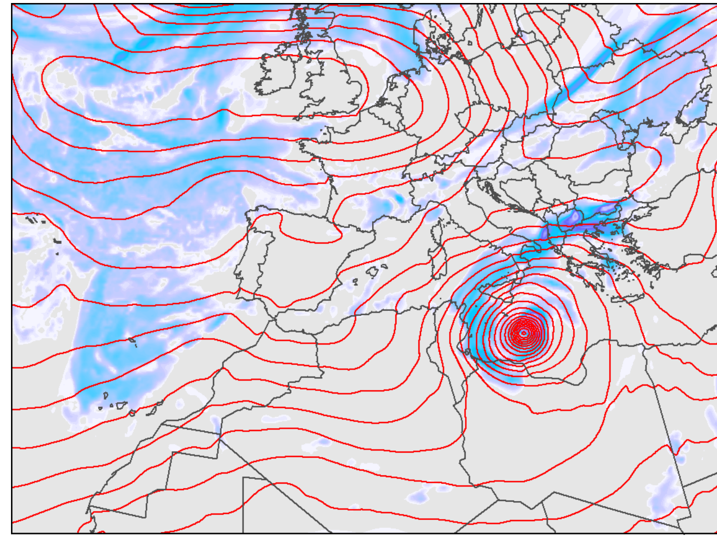
Winds Rainfall

> "ZORBAS" Ionian Sea Medicane (IC: 00 UTC 27 Sept 2018)

(MR:dx=25km,dzm=200m,stretch=10,dt=45s,Nstep=5,90h)

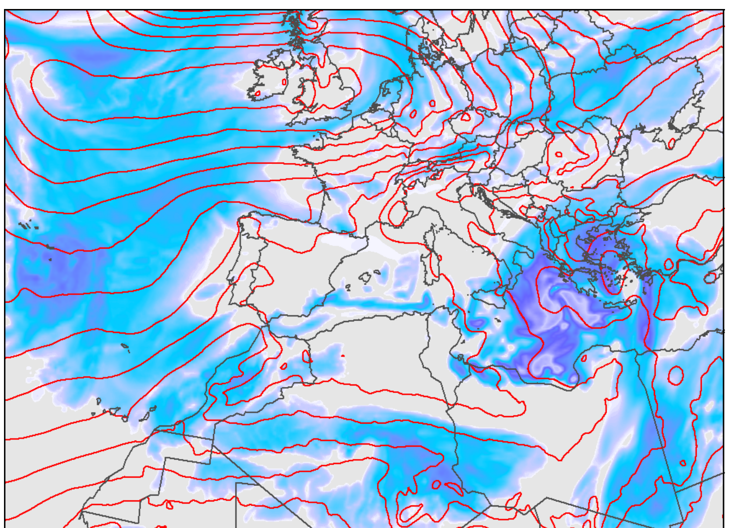
Role of FACTORS

NO ORO

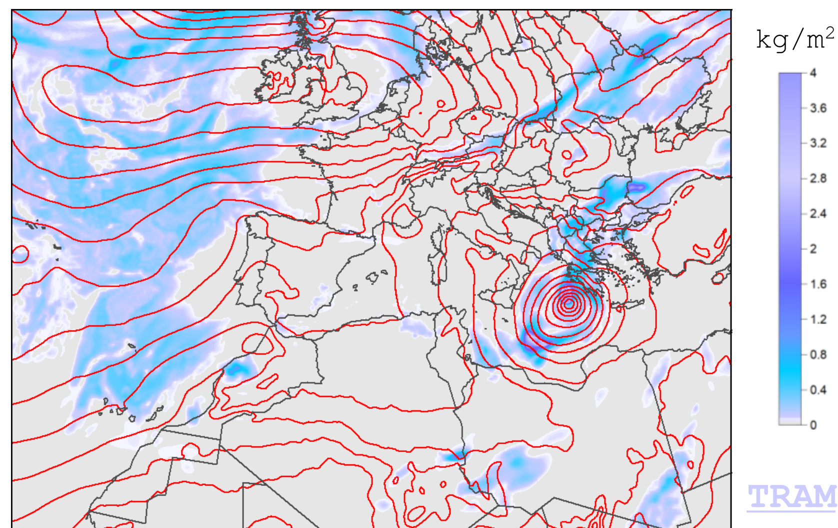


t=48h

NO LH



t=48h

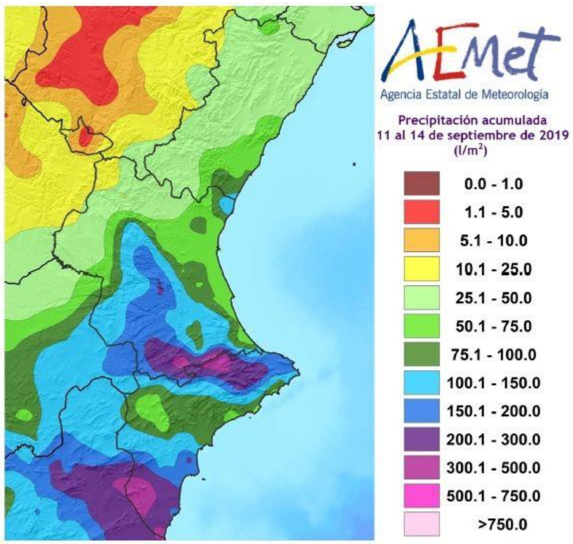


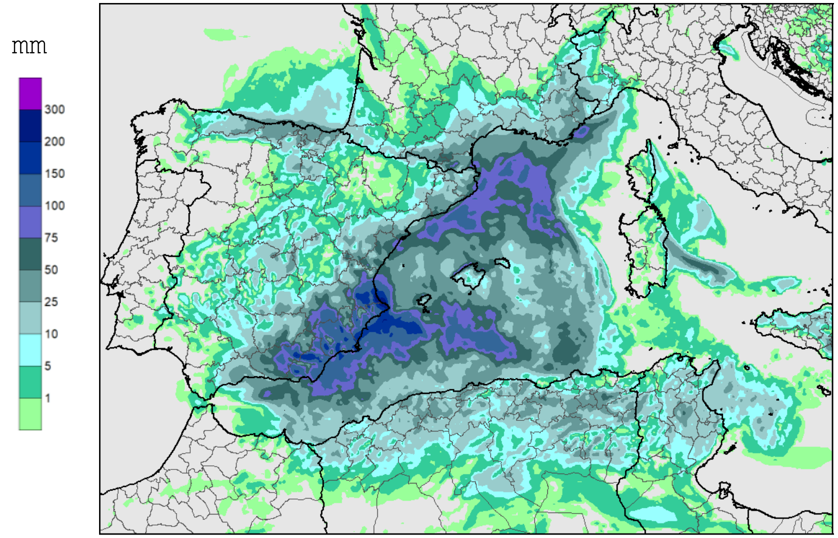
TRAM

Winds Rainfall

> "DANA" Valencia-Murcia Floods (IC: 00 UTC 10 Sept 2019)

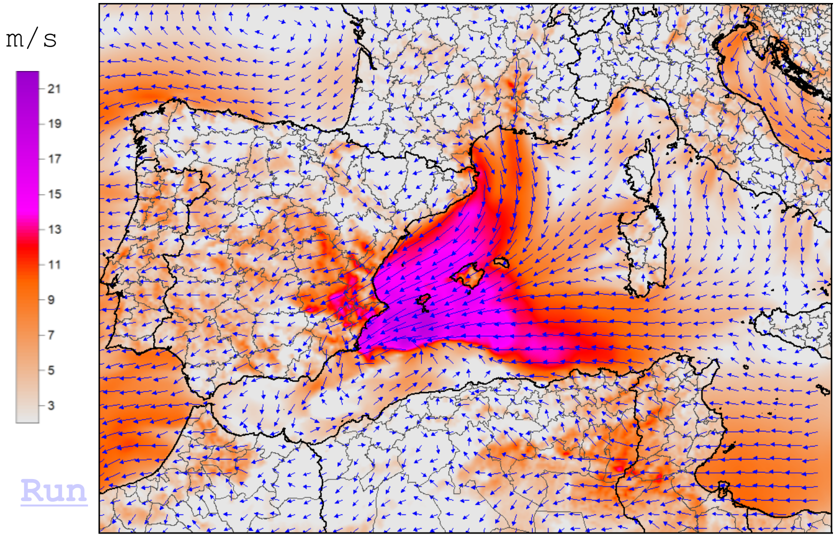
(HR:dx=9km,dzm=200m,stretch=10,dt=15s,Nstep=6,90h)



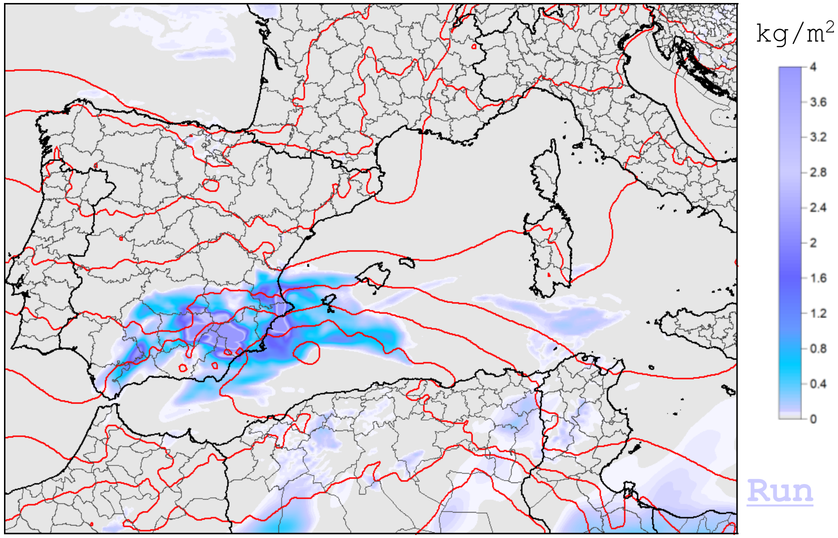


total

Run



t=54h

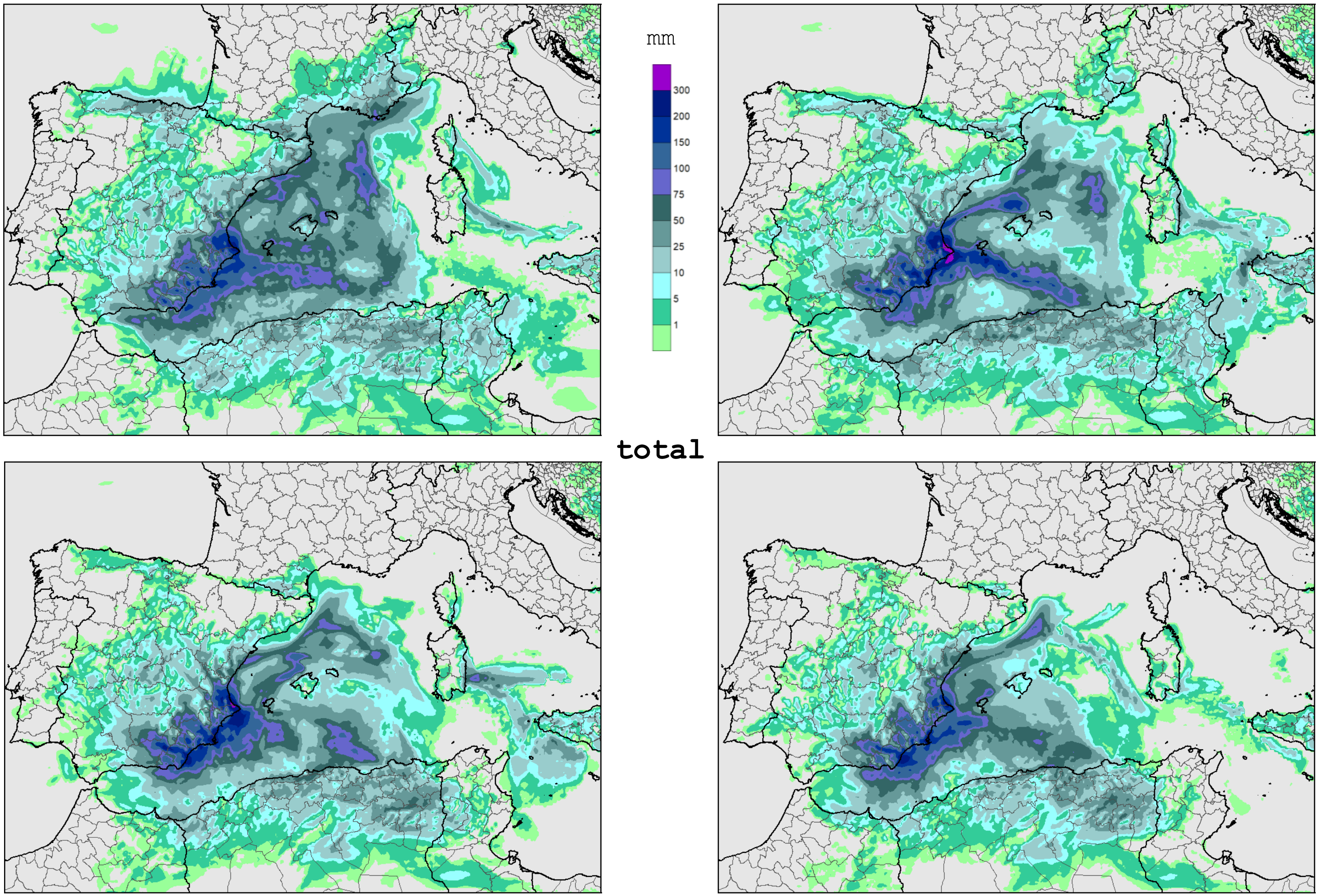


Run

Run

> "DANA" Valencia-Murcia Floods (IC: 06 to 24 UTC 10 Sept 2019)

(Influence of START TIME on predicted RAINFALL field)



10/06

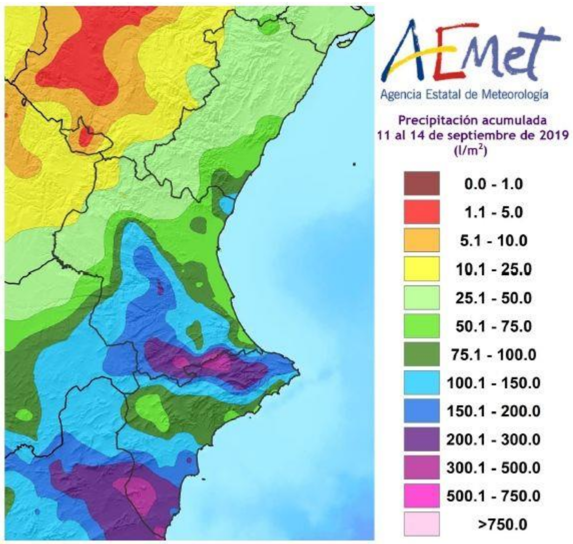
10/12

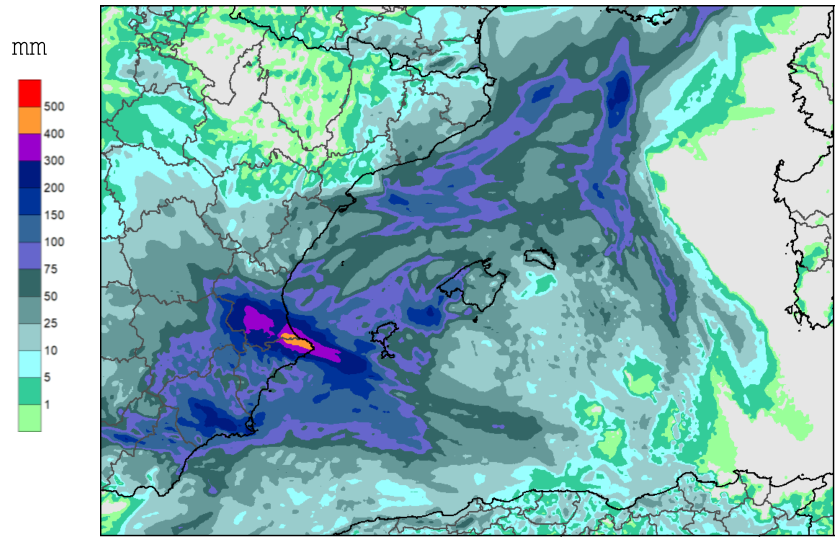
10/18

11/00

> "DANA" Valencia-Murcia Floods (IC: 00 UTC 10 Sept 2019)

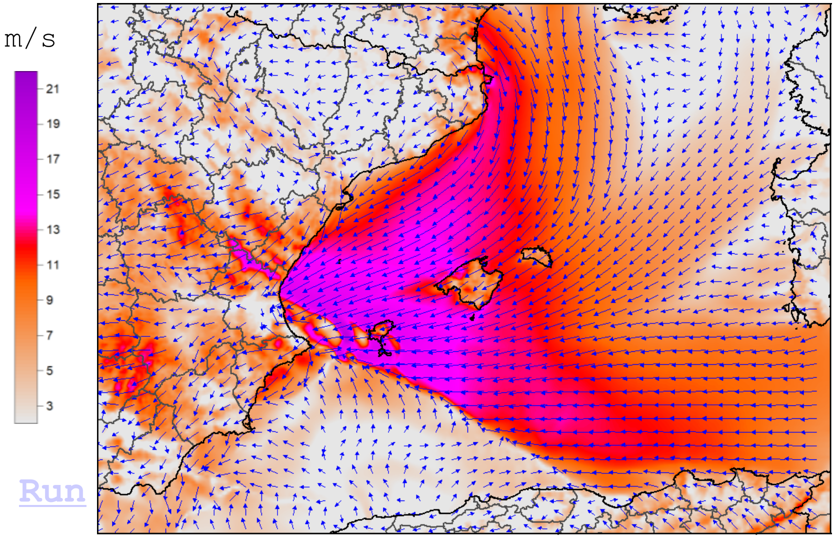
(**HR_double**:dx=4.5km,dzm=200m,stretch=10,dt=9s,Nstep=5,**90h**)





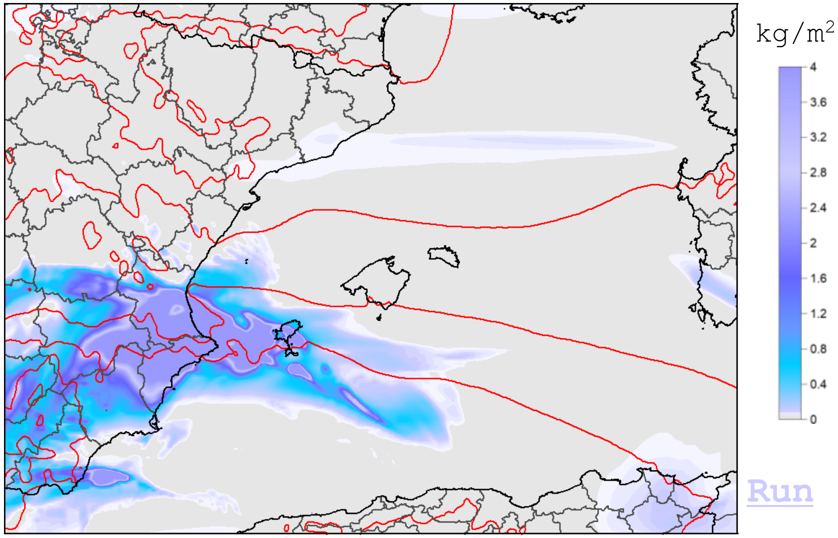
total

Run



Run

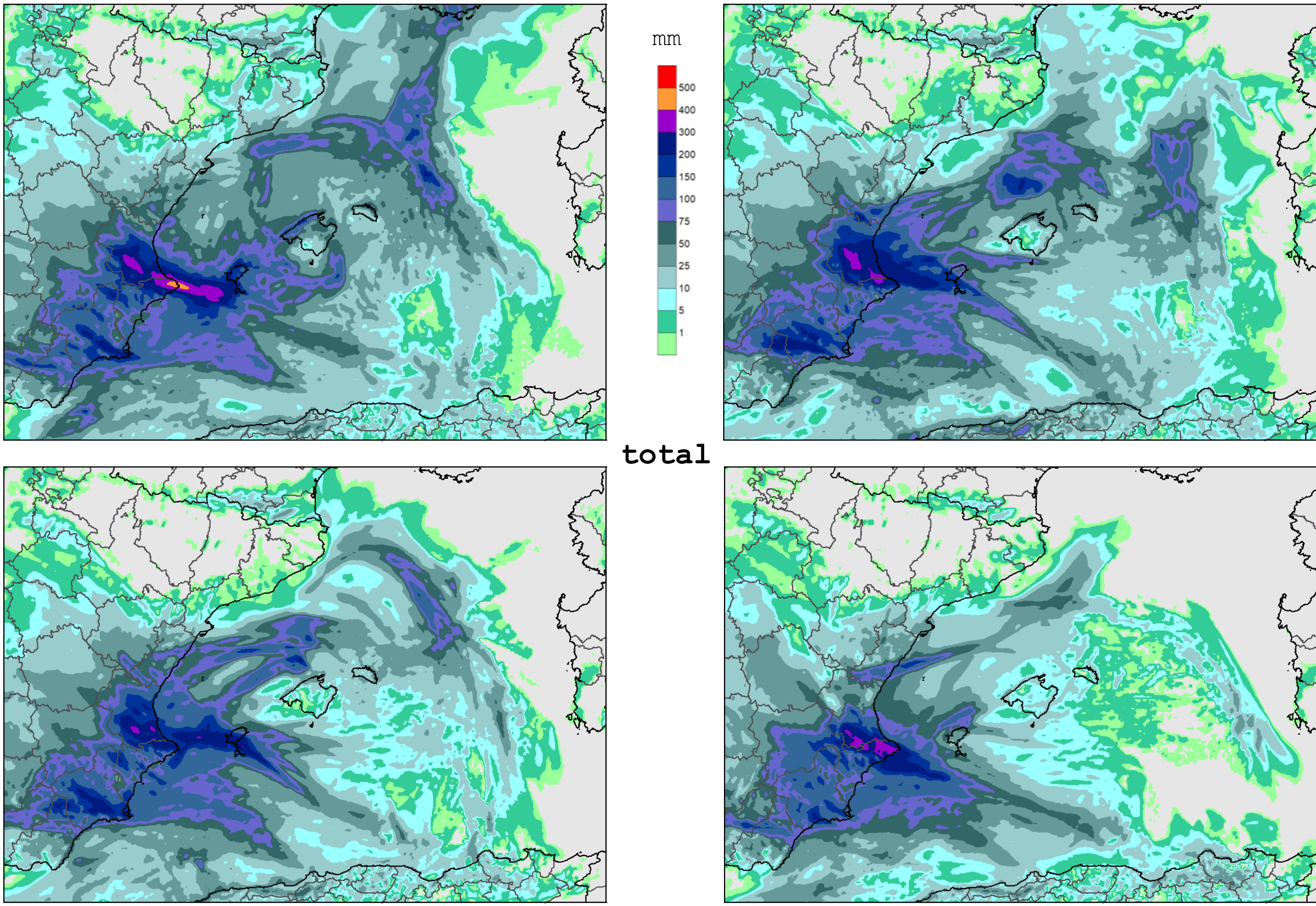
t=54h



Run

> "DANA" Valencia-Murcia Floods (IC: 06 to 24 UTC 10 <u>Sept 2019</u>)

(Influence of START TIME on predicted RAINFALL field)



10/06

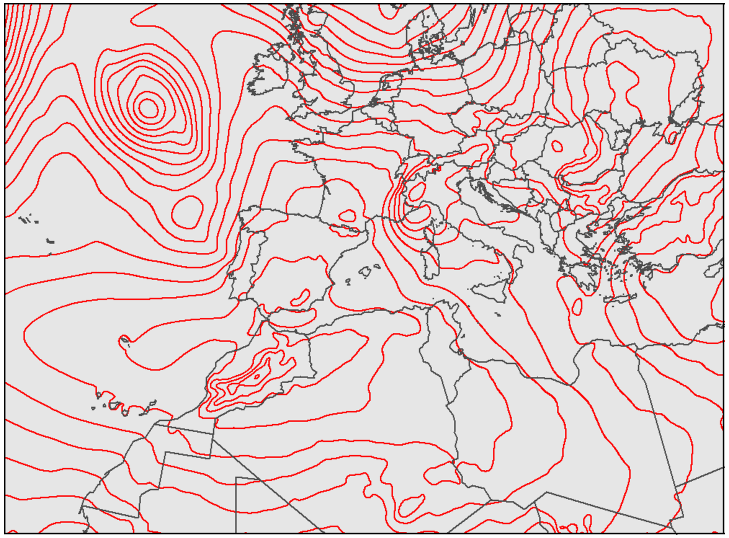
10/12

10/18

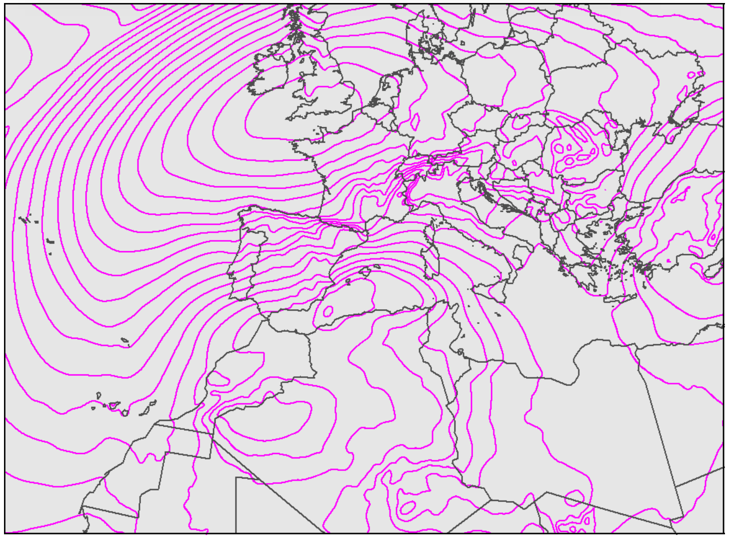
11/00

> "GLORIA" Extraordinary Storm (IC: 00 UTC 18 Jan 2020)

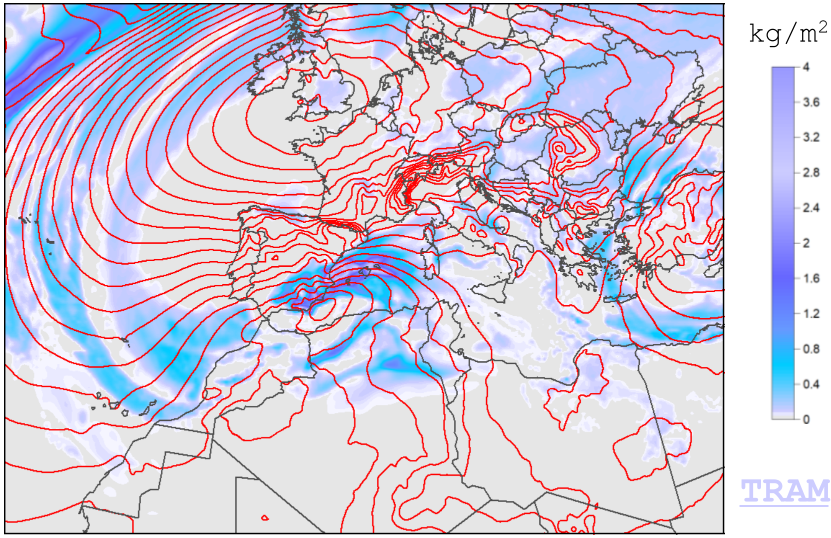
(MR:dx=25km,dzm=200m,stretch=10,dt=45s,Nstep=5,138h)



t=0h



t=48h



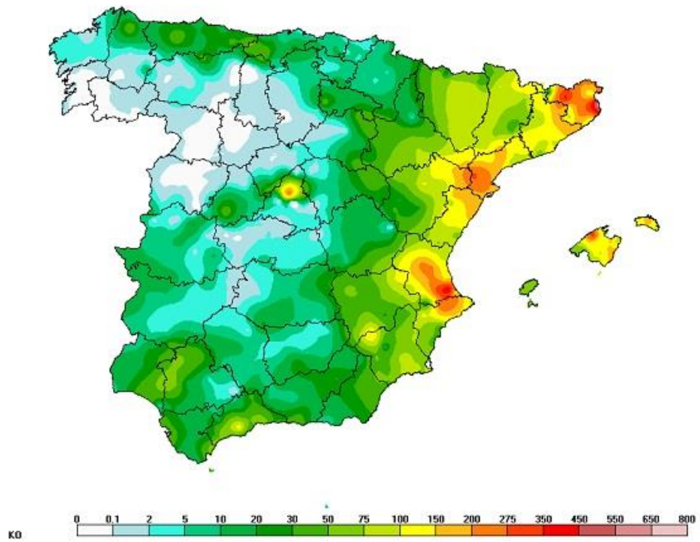
ERA-5

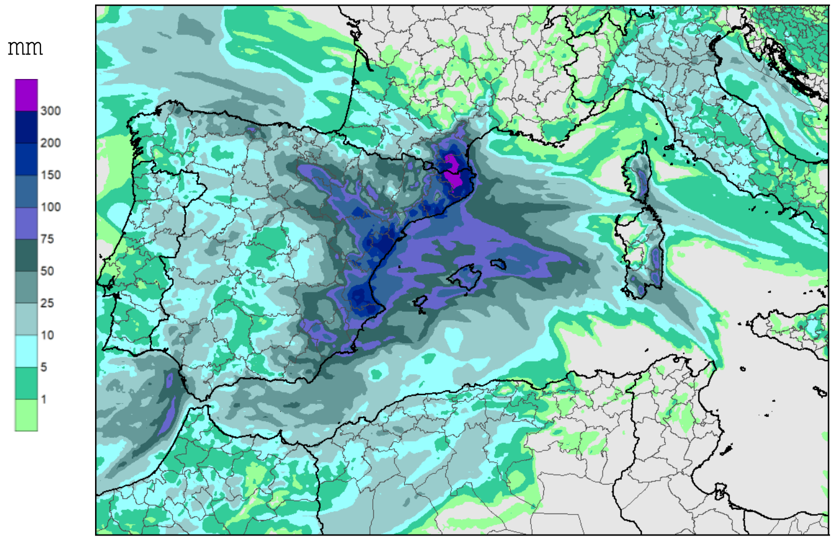
TRAM

Winds Rainfall

> "GLORIA" Extraordinary Storm (IC: 00 UTC 18 Jan 2020)

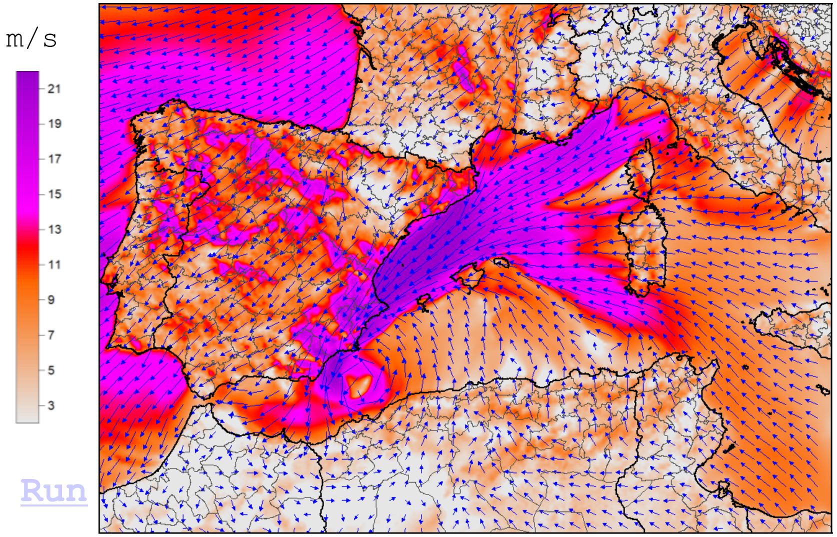
(HR:dx=9km,dzm=200m,stretch=10,dt=15s,Nstep=6,138h)





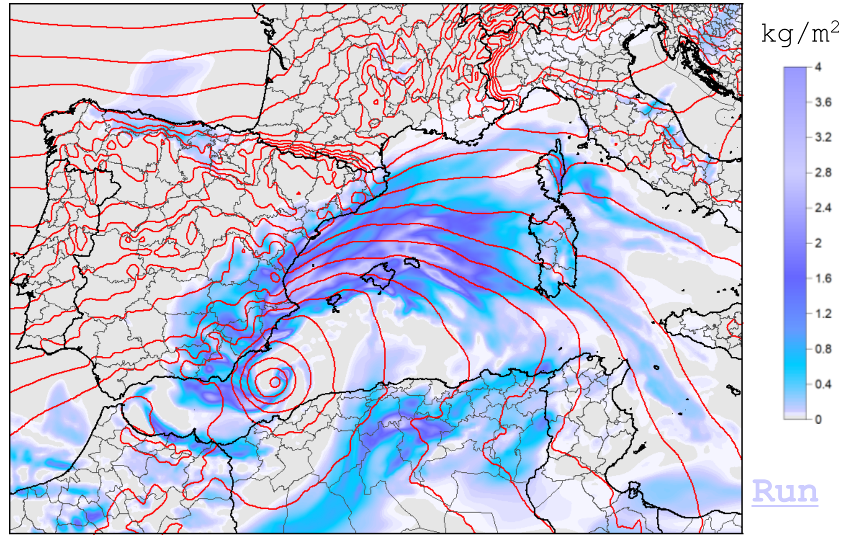
total

Run



Run

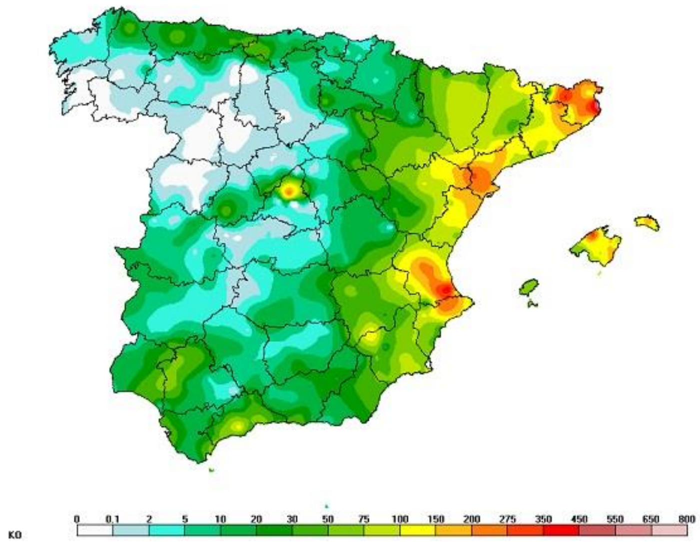
t=48h

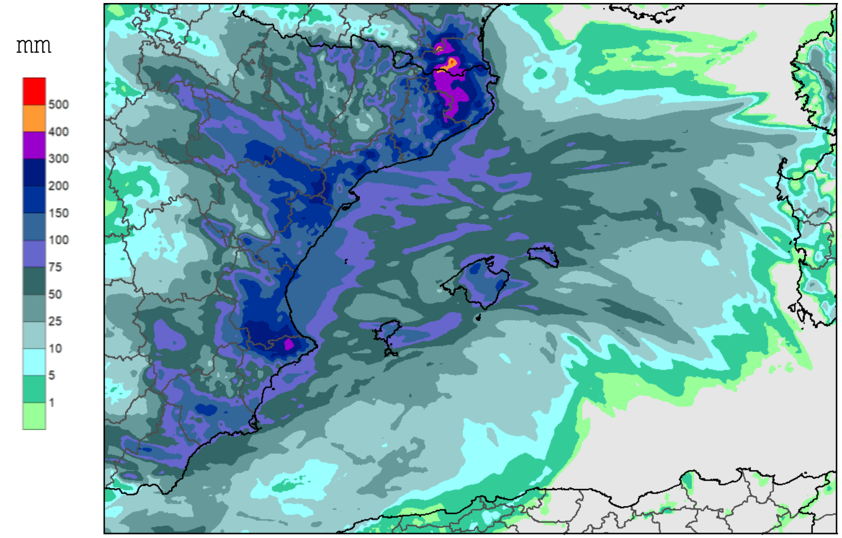


Run

> "GLORIA" Extraordinary Storm (IC: 00 UTC 18 Jan 2020)

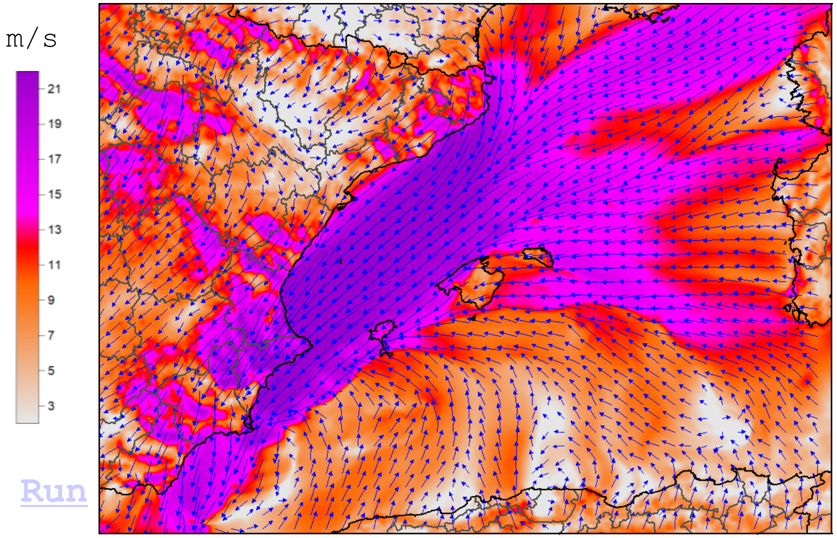
(**HR_double**:dx=4.5km,dzm=200m,stretch=10,dt=9s,Nstep=6,**138h**)





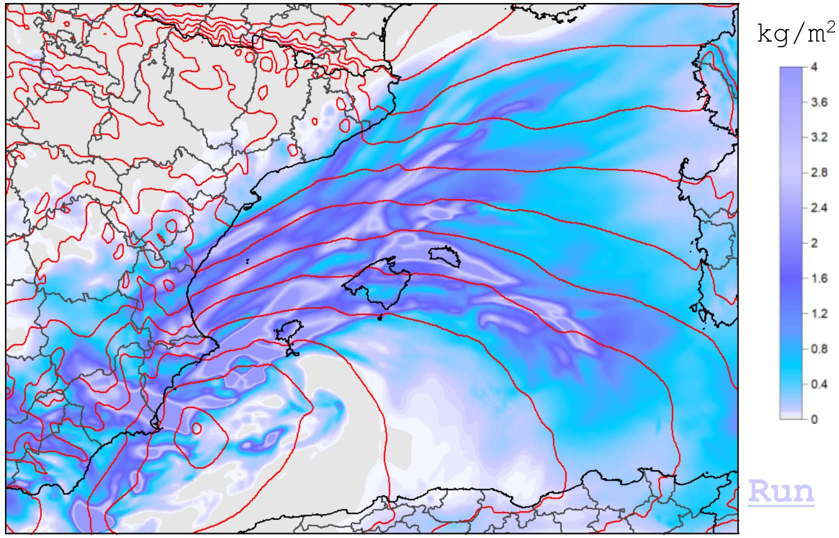
total

Run



Run

t=48h



Run

> TRAM HAS BEEN COMPLETED with a proper set of physical parameterizations of the effects of cloud microphysics, cumulus convection, short and long-wave radiation, PBL processes and surface fluxes

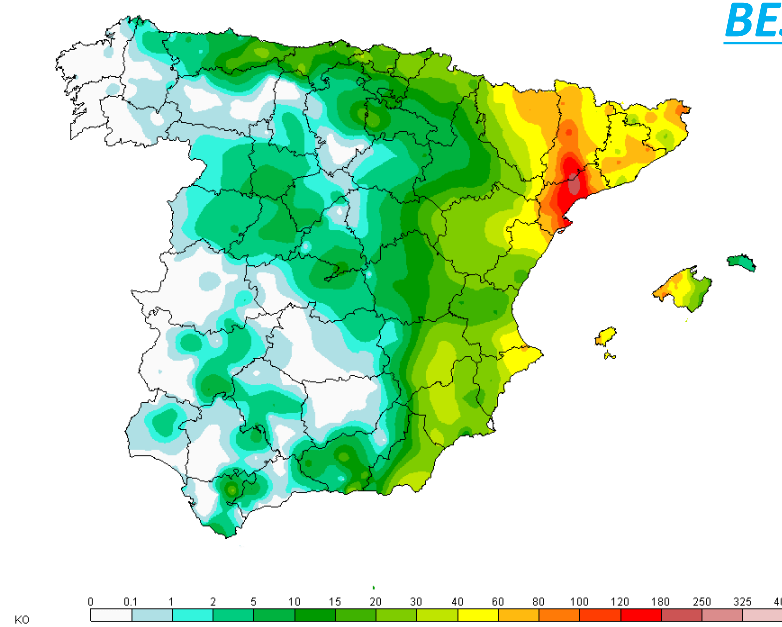
> Now we have a MODEL SUITED to simulate all kinds of of atmospheric circulations, from small-scale thermal bubbles (≈ 100 m scale) to synoptic-scale baroclinic cyclones (> 1000 km size), including orographic circulations, thermally-driven flows, squall lines, supercells, precipitation systems, medicanes, etc...

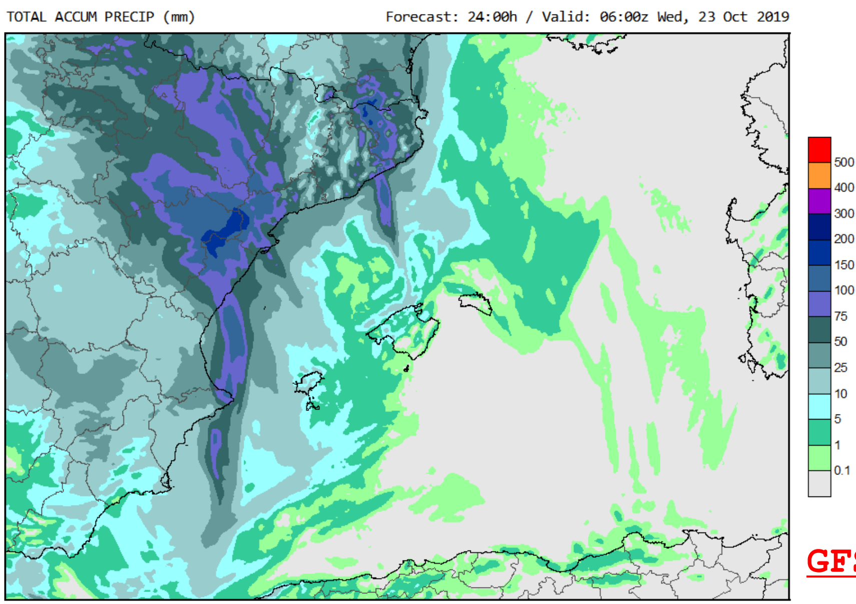
> Besides opening a myriad of academic and research applications, TRAM REGIONAL FORECASTS at different resolutions are already being disseminated in the web: see http://meteo.uib.es/tram

FRANCOLÍ Floods (22-23 October 2019): GFS-fcst vs ***ERA5***

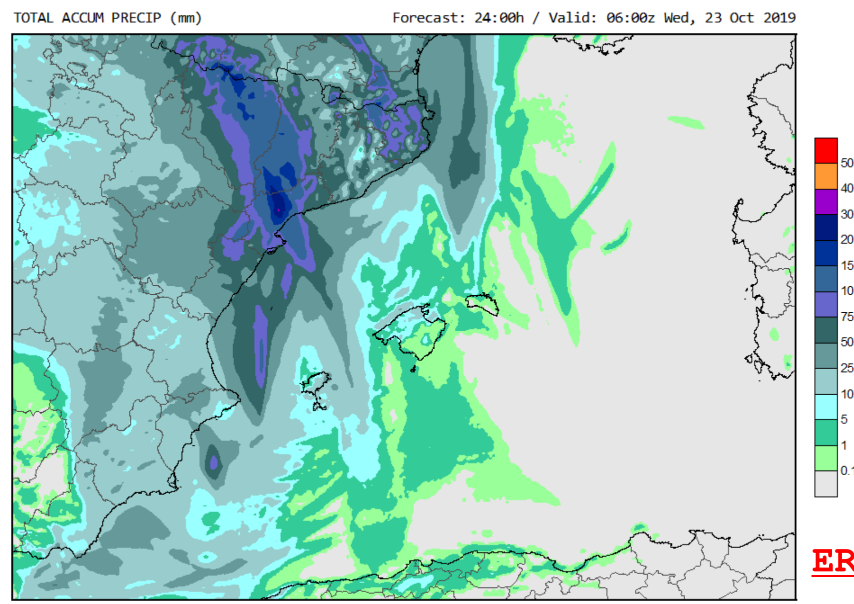
BEST

> 22/06-23/06 **24h PRECIP** (START TIME is 22/00)





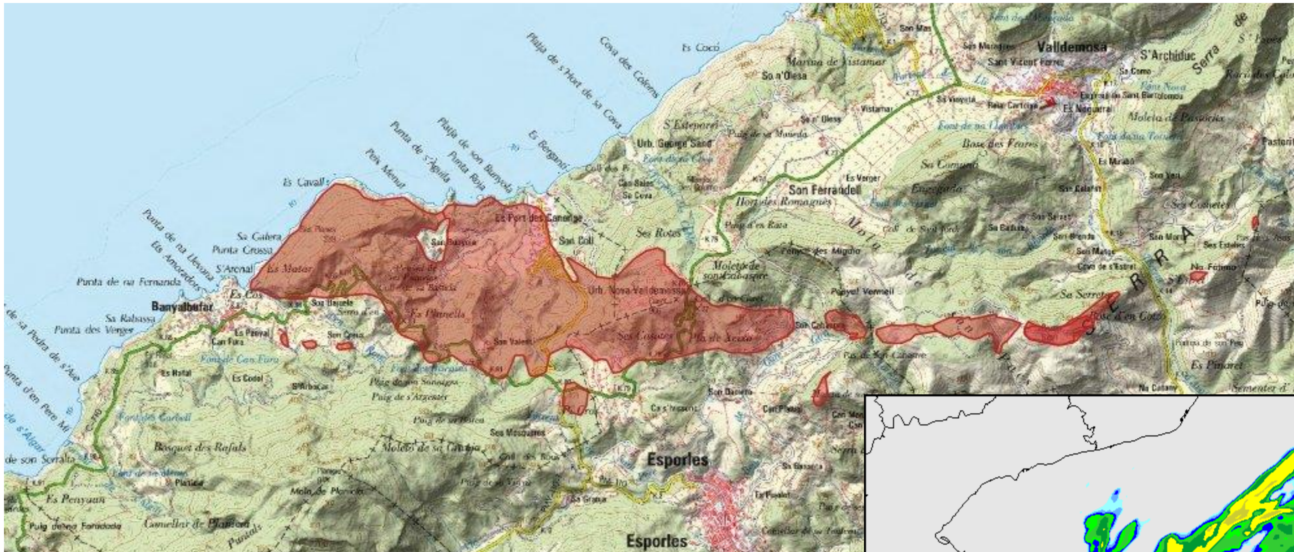
GFS



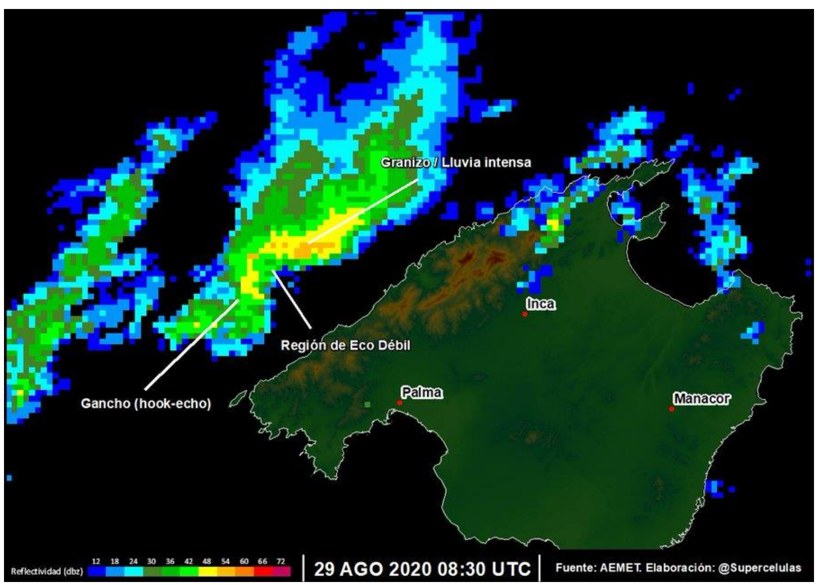
ERA5

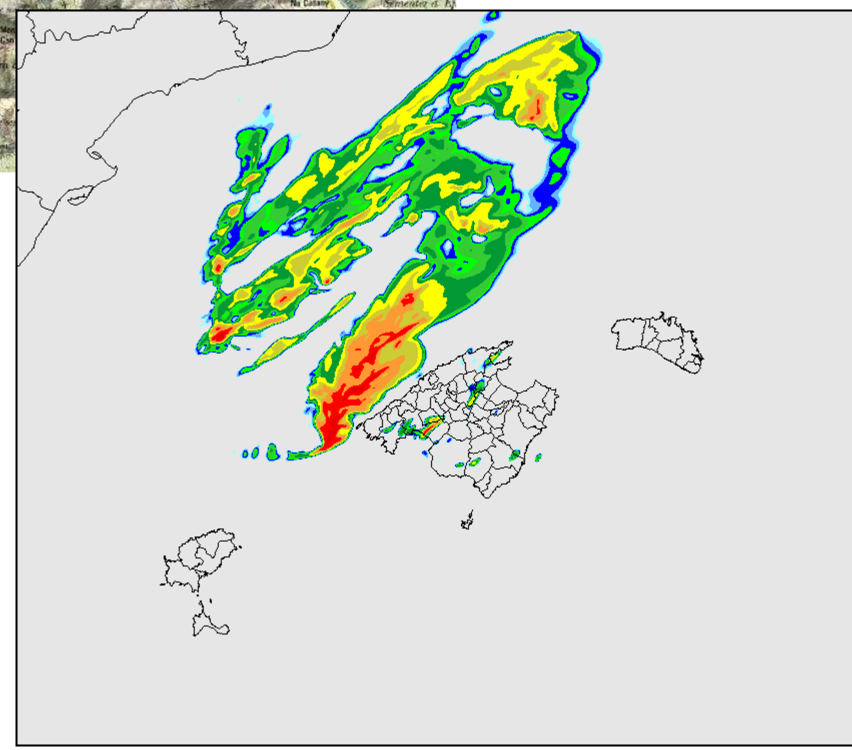
BANYALBUFAR-ESPORLES *Severe Supercell (29 August 2020)*

> 29/00-29/18 **TRAM Simulation** (dx=0.75km, GFS-fcst)



Run





Wind Speed Rainfall Temperature

THANK YOU

for

your attention