ST WV
Sources and Transport of Water Vapour

5-year Science Review

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9th HyMeX Workshop, 21-25 September 2015, Mykonos, Greece

Objectives

Contribute to study of the multiscale interaction between ambient flow and deep convection governing the heavy precipitation events (HPEs)

Cross-validation studies and synergistic use of SOP observations and models in order to provide the best description of the water vapour flows.

Three main objectives are pursued:

- Produce error and bias estimates for the water vapour profiles and integrated products issued from the different water vapour measuring instruments,
- Provide a reference for validation of water vapour fields from model forecasts & reanalyses,
- Contribute to HPE related processes studies.

Objectives

WG1-SQ1

"What are the long-term mean values of the Mediterranean Sea Water Budget components and associated uncertainties?"

WG1-SQ1 (e) Evolution of atmospheric moisture transport

Seasonal variability; impact of the air-sea coupling; long-term observations

WG3-SQ2

"How can we improve heavy rainfall process knowledge and prediction?"

WG3-SQ2 (b) Characterization of the low-level mesoscale environment
WG3-SQ2 (e) Moisture monitoring
WG3-SQ2 (f) Identification of water vapour origin
WG3-SQ2 (g) Role of mid-level dry air masses

Mesoscale processes; soil moisture; mid-level dryness; new monitoring capabilities

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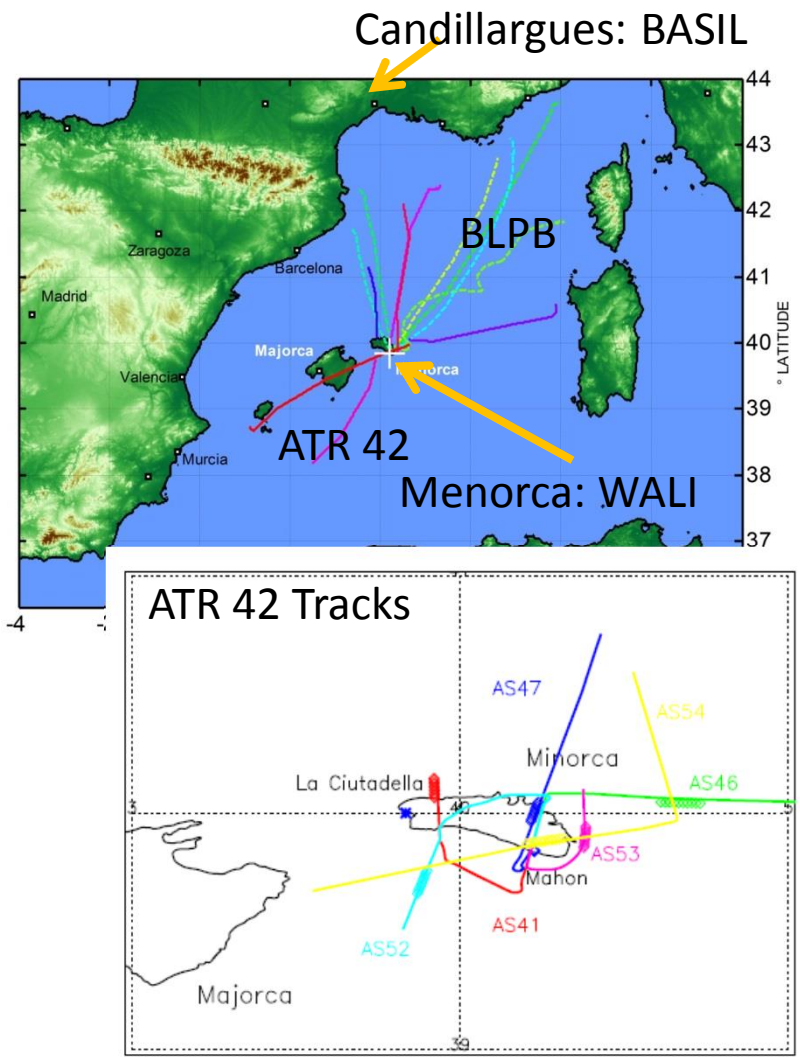
mesoscale assimilation systems; high-resolution regional models; Model & satellite validation

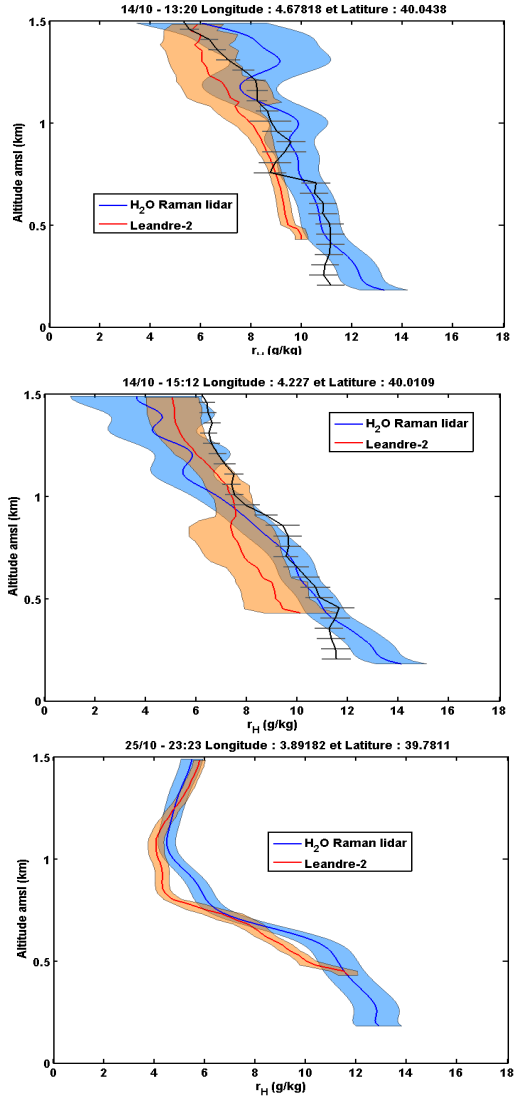
Moisture Monitoring

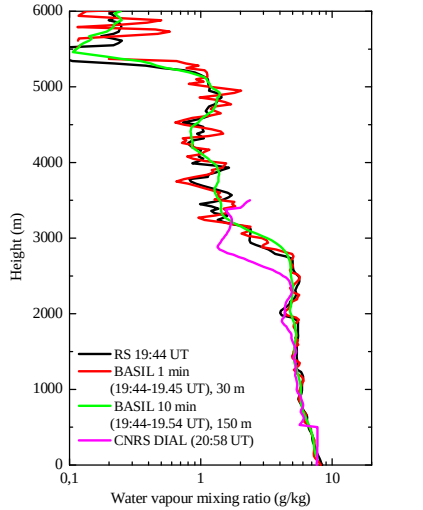
	ST-WV objective	
HyMeX WG & question	Erreur and bias estimates	Reference for validation
Moisture monitoring **Instruments** **H_2O lidars** **Ground-based and airborne** **GPS** **--** **Weather radars** **UHF radars** **--** **IASI, AIRS** **MODIS** **Space-borne**	➢ **Lidars** : Chazette et al. 2014, AMT Chazette et al. 2015a QJ Di Girolamo et al. 2015 QJ ➢ **Radars** : Said et al., 2015 QJ Besson et al., 2015 QJ	➢ **AROME** : Di Girolamo et al. 2015 QJ Duffourg et al., 2015 QJ Chazette et al., 2015a, QJ Bock et al., 2015 QJ ➢ **Meso-NH, COSMO, WRF, MOLOCH**: Di Girolamo et al., 2015 QJ Chazette et al., 2015a,b QJ Besson et al., 2015 QJ Barthlott & Davolio, 2015 QJ ➢ **Climate models** Kodahyar et al., 2015 QJ -- ➢ **IASI, AIRS, MODIS** : Chazette et al., 2014 ACP Chazette et al., 2015b QJ Lee et al., in prep

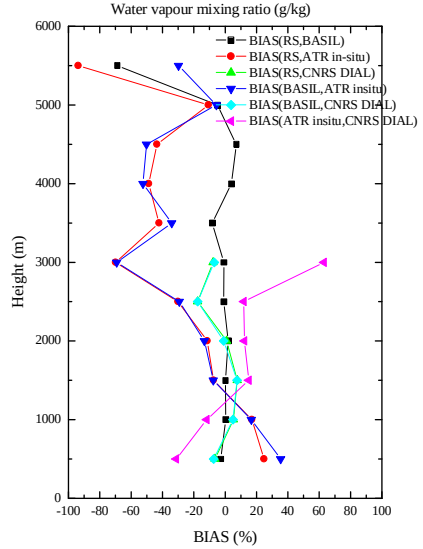
Error and bias estimates from water vapour lidars & other instruments

Chazette et al., 2015a
QJRMS SOP 1 Special Issue









Bias, RMSE and correlation: NWP and research models Vs WALI

Comparisons with Models

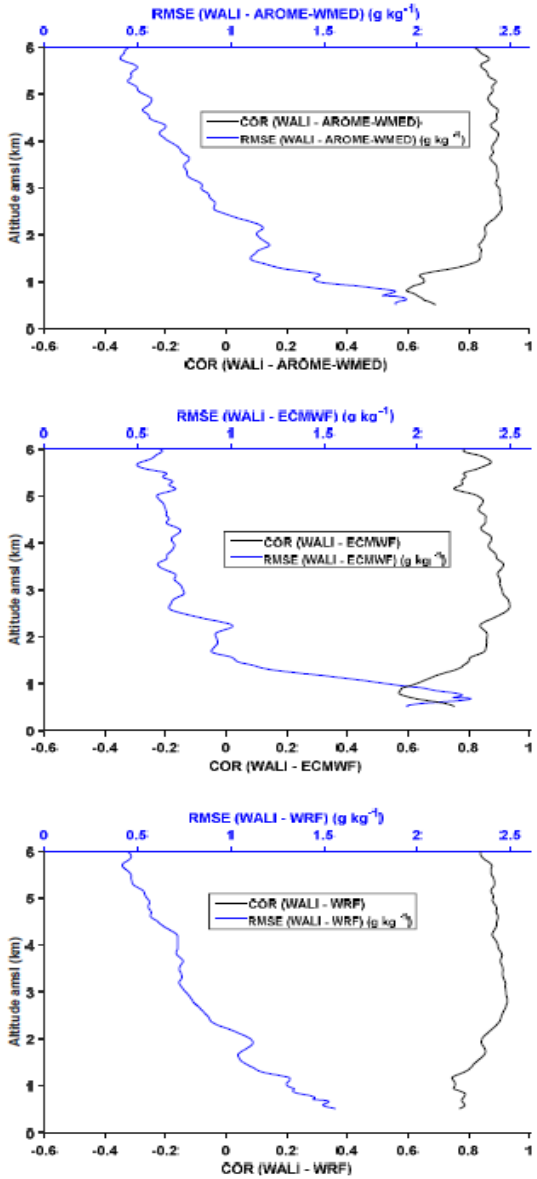
Chazette et al., 2015a
QJRMS SOP 1 Special Issue

Table 5: Statistics on the comparison between the integrated water vapour content derived from lidar measurements and others data set (GPS measurements, AROME-WMED, ECMWF and WRF models). The Pearson coefficient r^2 for the different linear fits is also given.

	Altitude range (km)	Slope	Bias (kg m^{-2})	RMSE (kg m^{-2})	r^2	Number of samples
GPS	0.5-6	1.0	5.1	1.5	0.93	284
AROME-WMED	0.5-6	0.95	1.3	2.3	0.84	92
	1.5-6	1.00	0.8	1.5	0.91	92
ECMWF	0.5-6	0.84	2.3	2.1	0.84	48
	1.5-6	0.89	1.2	1.3	0.91	48
WRF	0.5-6	0.88	3.3	1.8	0.88	1057
	1.5-6	0.95	1.8	1.4	0.91	1057

Table 6: Scores of inter-comparisons of WVMR retrieval by WALI and AROME-WMED (WALI – AROME-WMED), and WALI and ECMWF (WALI – ECMWF). The results are given during night-time for several atmospheric layers, in terms of correlation (COR) and root mean square error (RMSE).

Altitude Range (km amsl)	COR			RMSE (g kg^{-1})		
	WALI-AROME-WMED	WALI-ECMWF	WALI-WRF	WALI-AROME-WMED	WALI-ECMWF	WALI-WRF
0.5-1.5	0.68	0.68	0.78	1.59	1.78	1.33
1.5-3.0	0.87	0.88	0.88	1.06	0.86	0.96
3.0-6.0	0.88	0.85	0.89	0.62	0.66	0.62
0.5-6.0	0.84	0.83	0.87	0.99	1.01	0.88



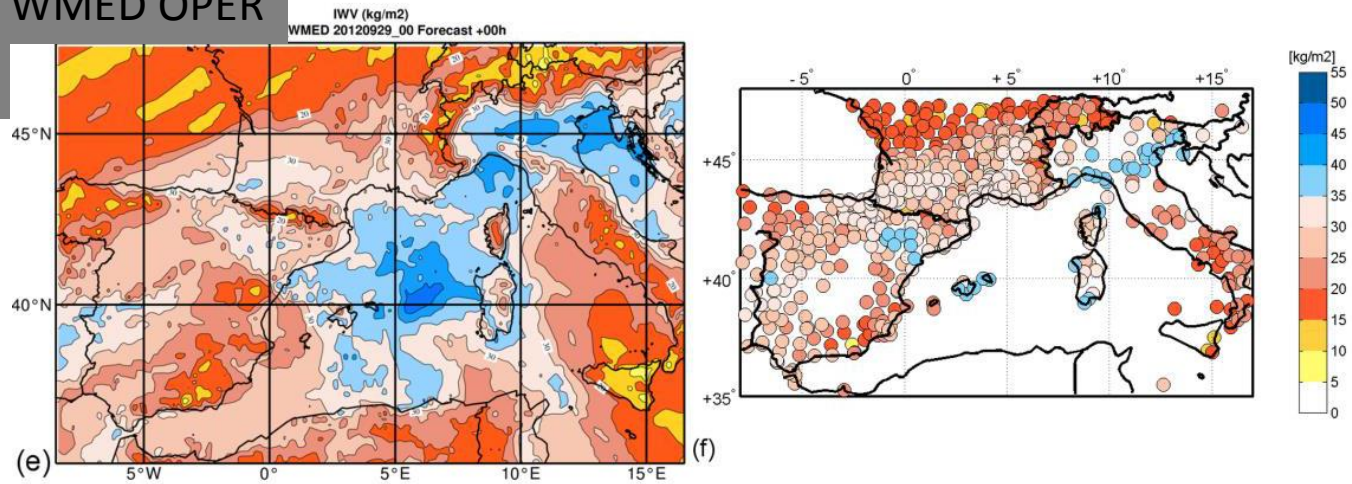
A consistent, self-coherent and validated GPS IWVC dataset

AROME WMED OPER

00 UTC

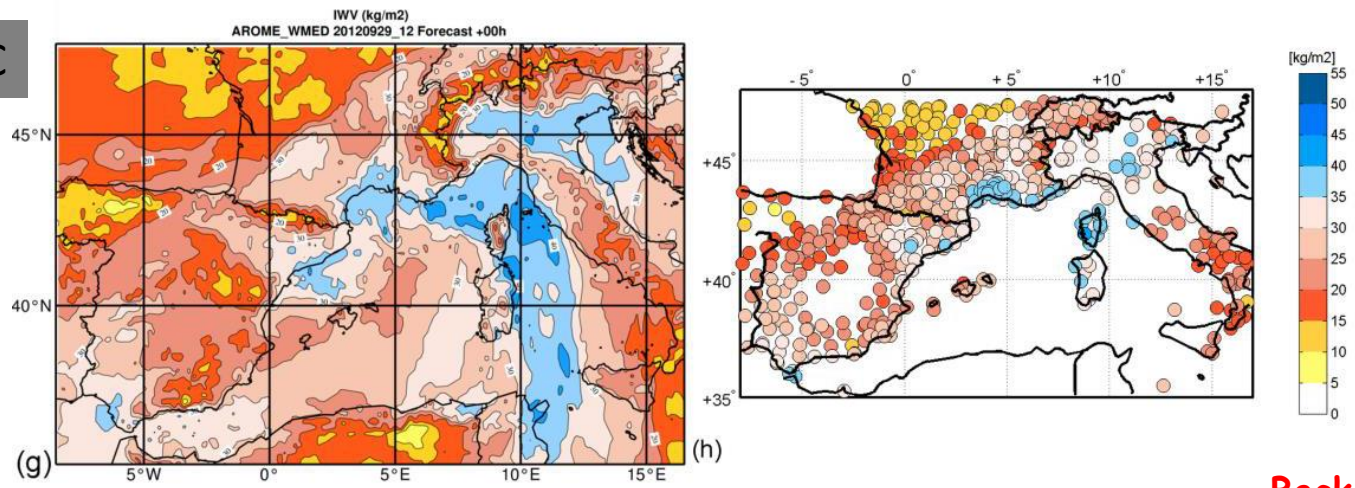
GPS

00 UTC



12UTC

12 UTC



Bock et al., submitted

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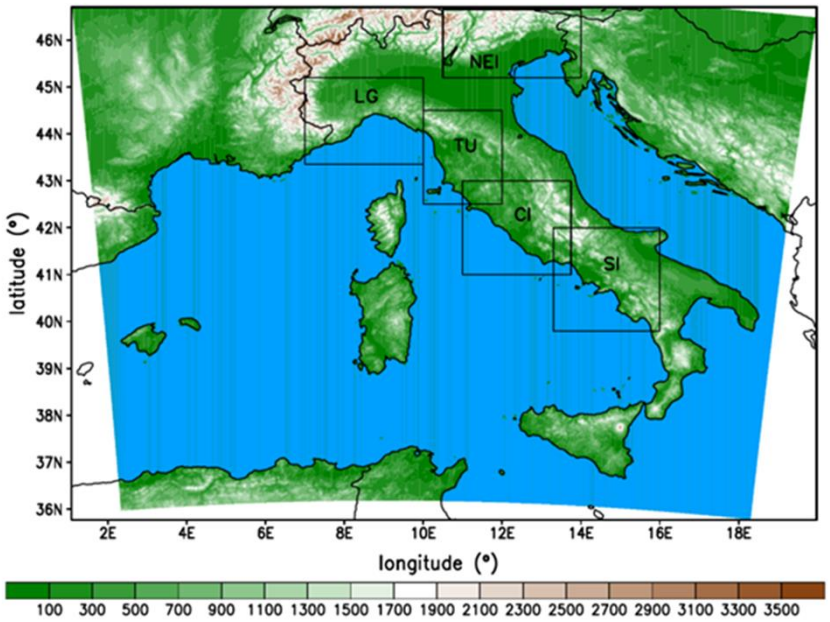
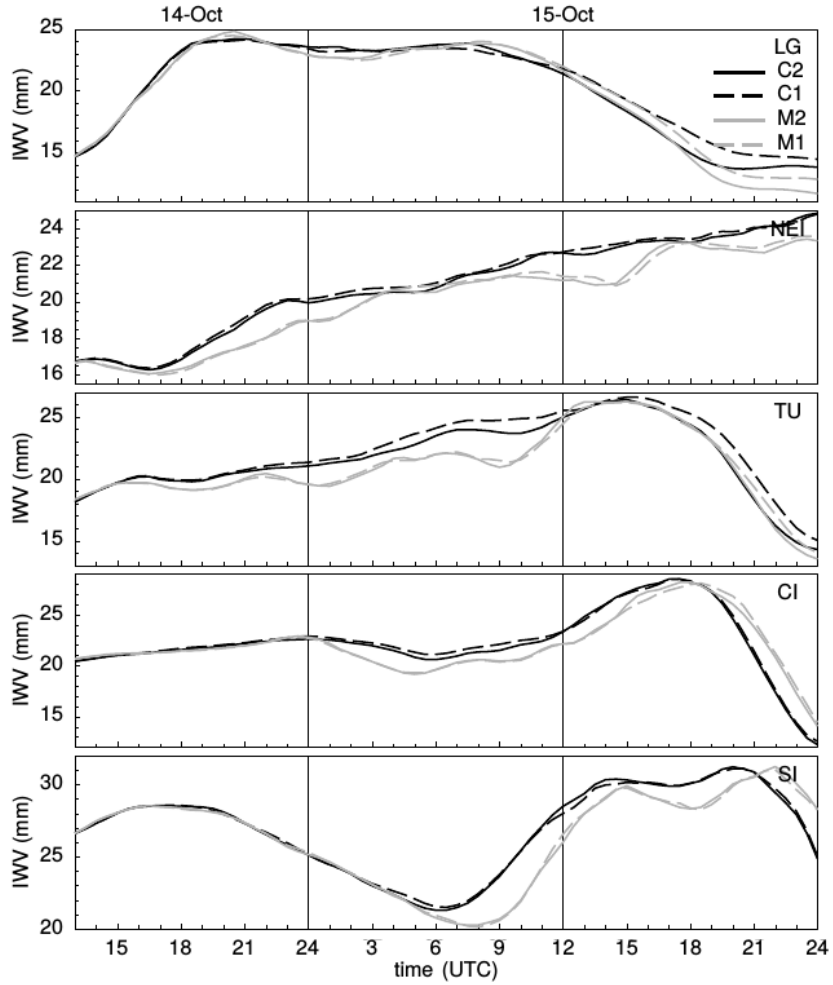
Model intercomparison over Italy: COSMO & MOLOCH during IOP 13

model	Δx (km)	name
COSMO	2.8	C2
COSMO	1	C1
MOLOCH	2.3	M2
MOLOCH	1.5	M1



Integrated water vapour content



Barthlott and Davolio, 2015
QJRMS SOP 1 Special Issue

Refractivity by weather radars

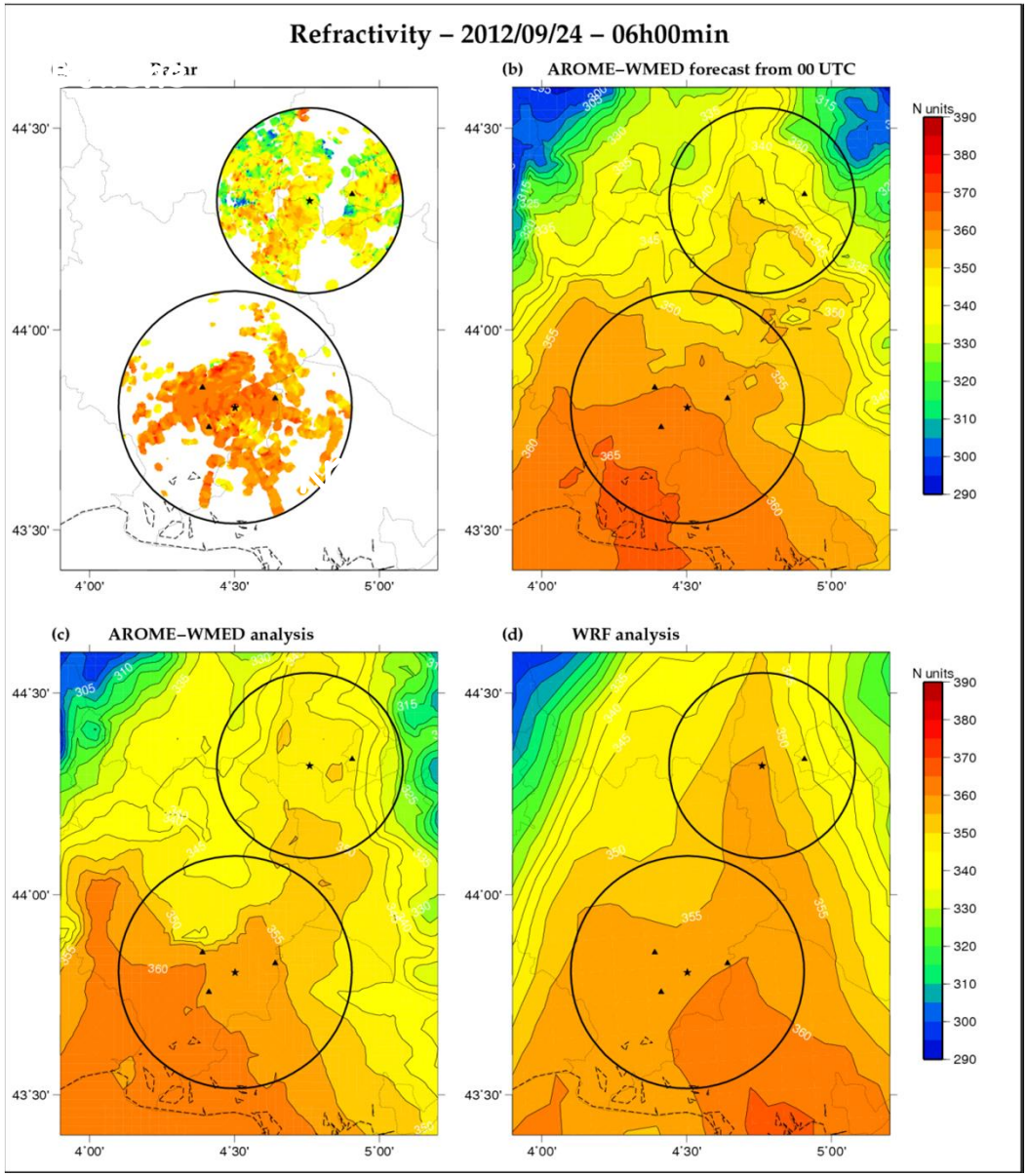
Near-ground refractivity collected by 5 radars in south-eastern France for a 3.5-month period encompassing SOP1

Å Comparisons with:

- Ground weather stations
- WRF and Arome-WMed analyses and forecasts

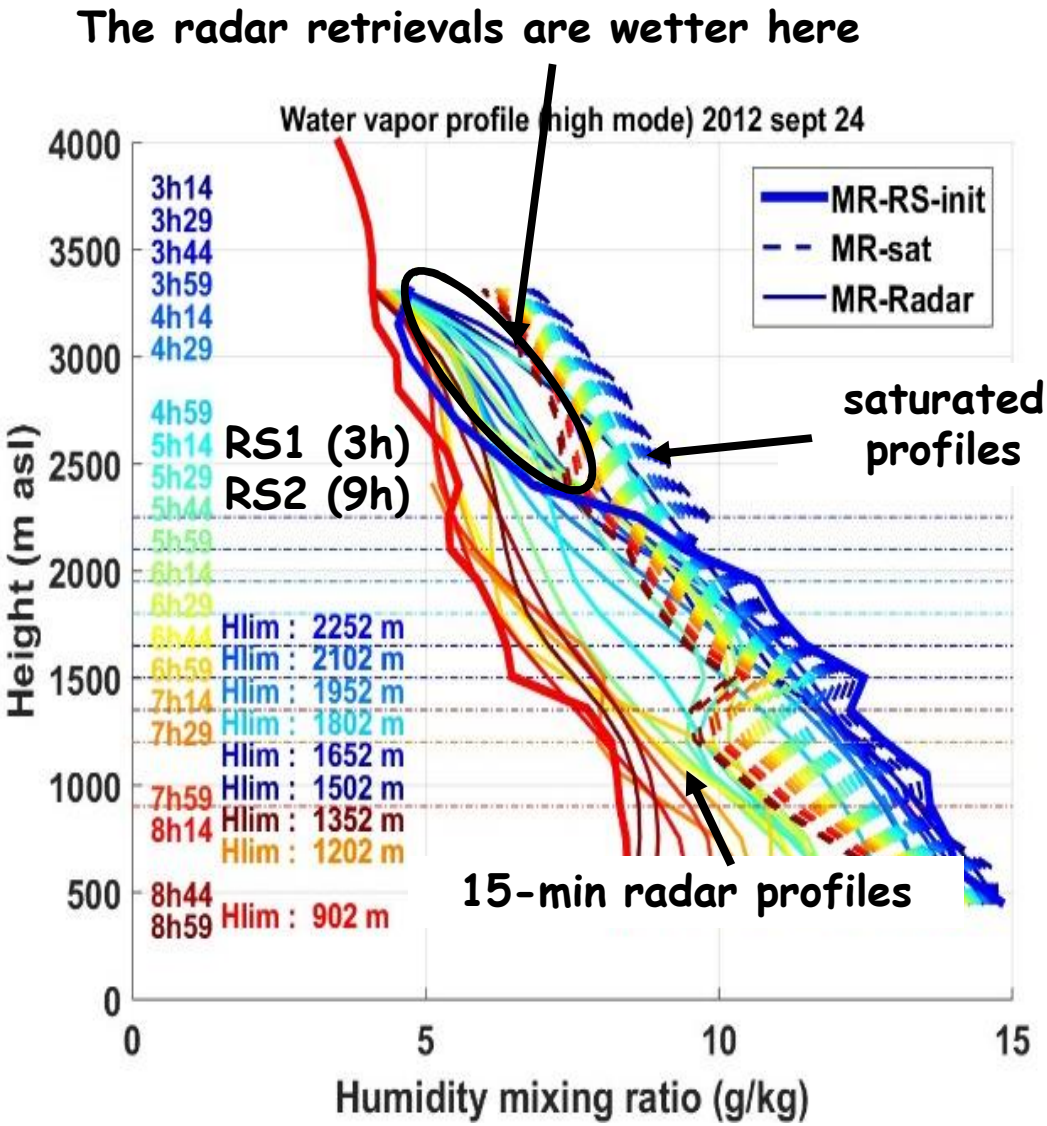
Å Main findings:

- Overall good consistency between all datasets
- Biases in radar refractivity which call for improvements in calibration
- Potential for data assimilation, verification, and fine-scale process studies
- Interpretation can be difficult in complex situations



Besson et al., submitted
QJRMS SOP 1 Special Issue

Humidity profiles retrieved by a wind profiler radar Vs radiosoundings



The Candillargues UHF wind profiler allows to retrieve vertical profiles of water vapour mixing ratio (thin lines) every 15 min, between 0300 and 0900 UTC showing :

- some moistening between 2500 and 3200m, that could not be captured by the RS.
- the drying of the low layers that are no longer saturated, and the growth of the boundary layer.

The initial and final radiosounding are in blue and red (thick lines), 0300 UC and 0900 UTC, respectively.

Saïd et al., submitted
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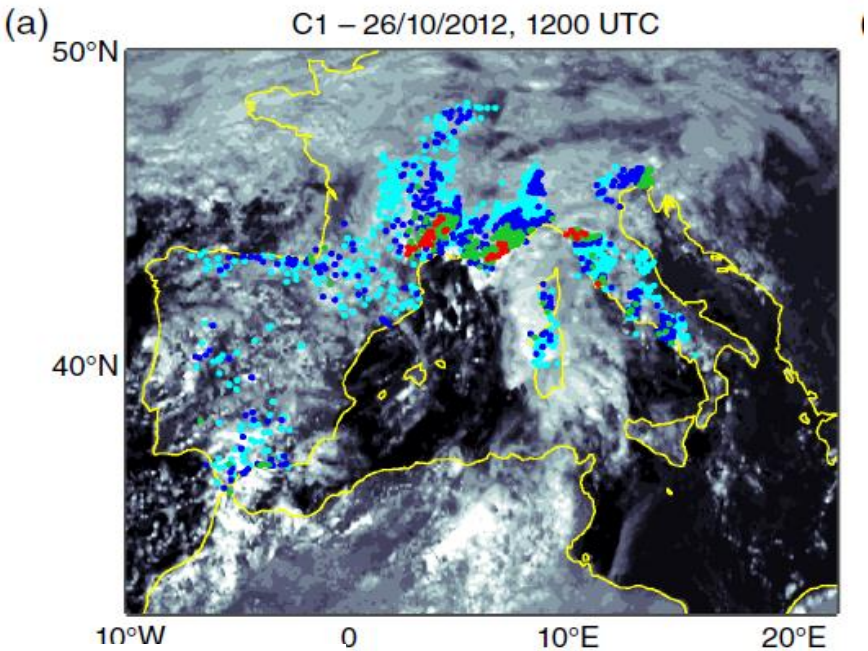
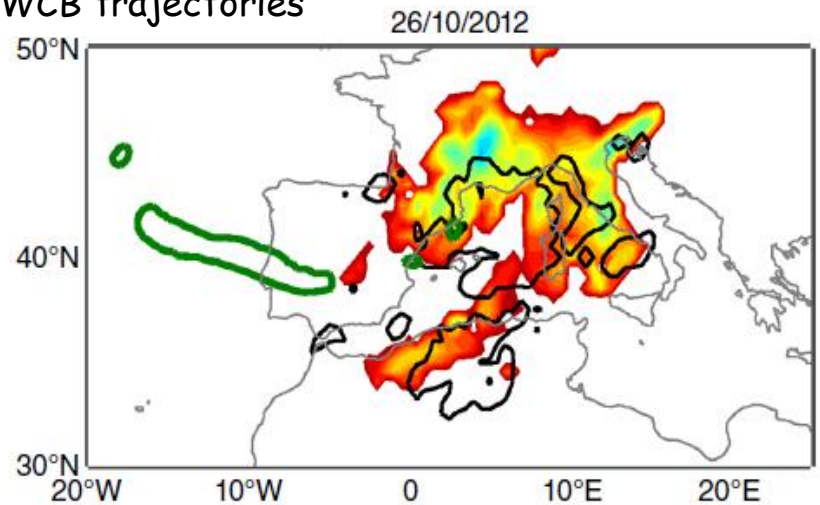
Characterization of the low-level mesoscale environment

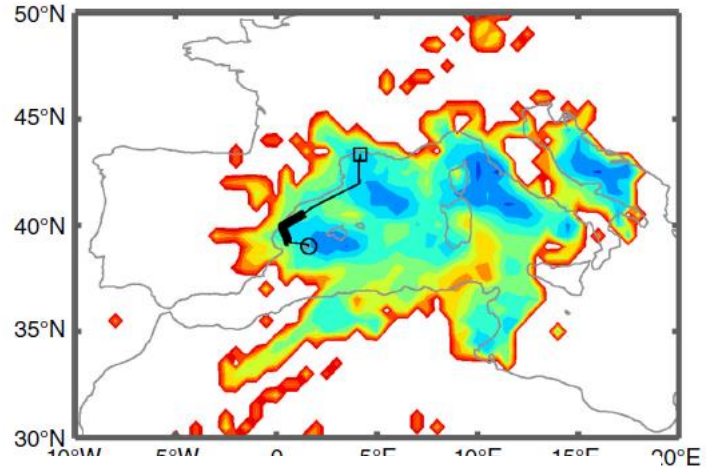
Moisture transport along a Mediterranean cyclone WCB



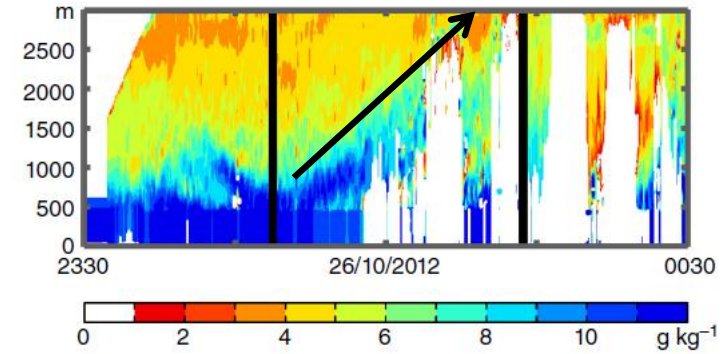
WCB trajectories



WVMR of WCB trajectories at 850 hPa



WVMR from H2O lidar LEANDRE 2



Ascending velocity of moist layer ~ 18 hPa/h
Consistent with expected WCB ascending velocities (600 hPa in 48 h)!

Flaounas et al., 2015
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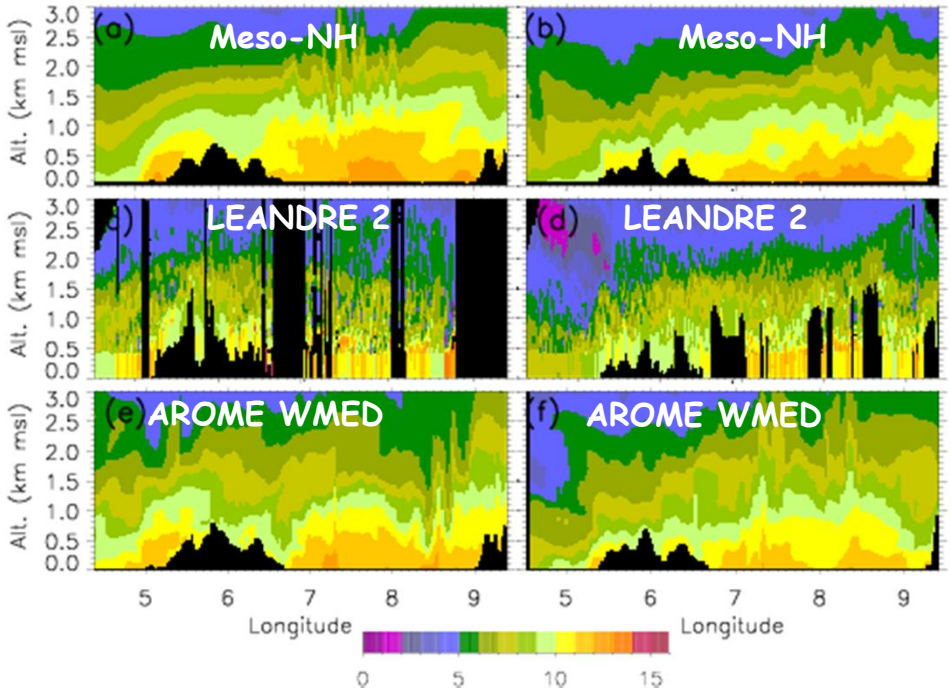
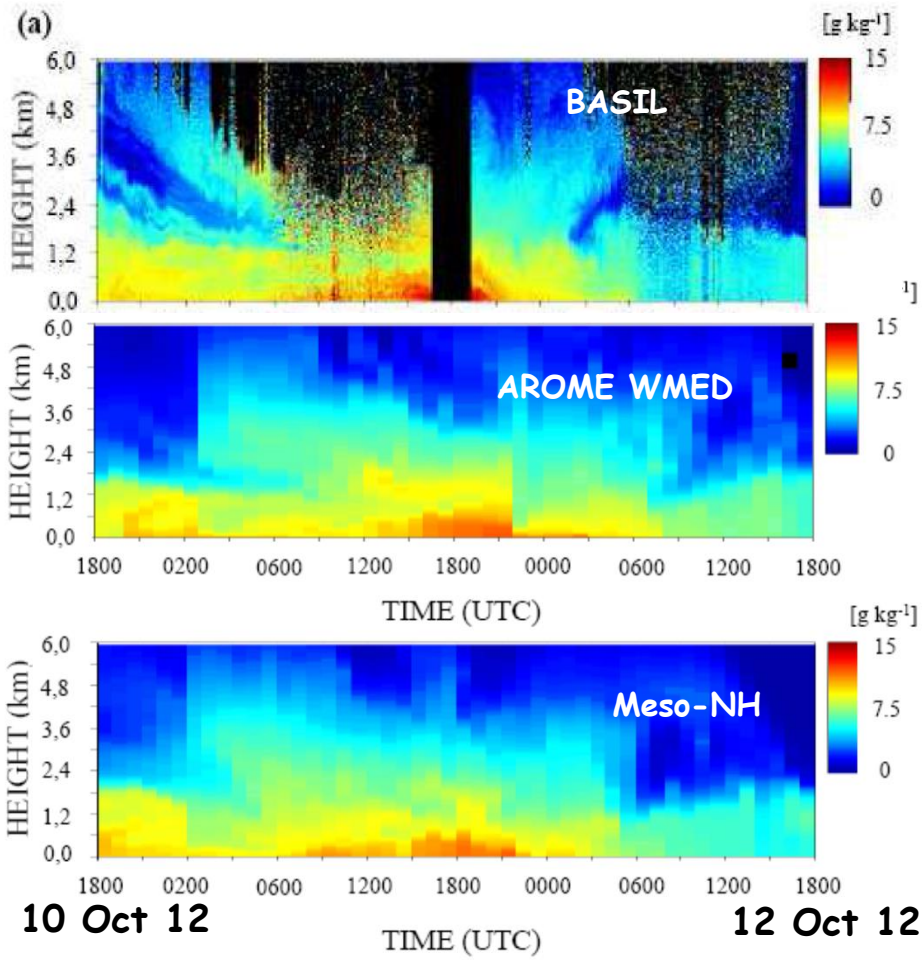
Low-level wind reversals over the Gulf of Lion: IOP 12 &

- Lidar monitoring of the time evolution of the three-dimensional water vapour field during transitions from northerly Mistral/Tramontane flow to southerly flow
- Transitions are correctly represented by the mesoscale models AROME and Meso-NH

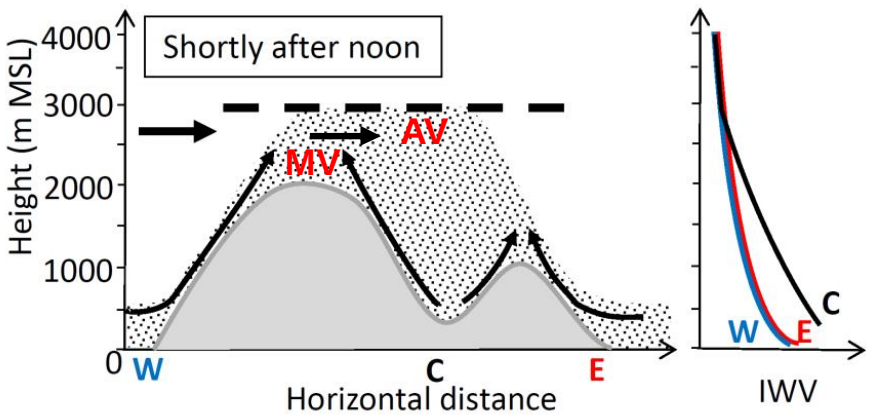




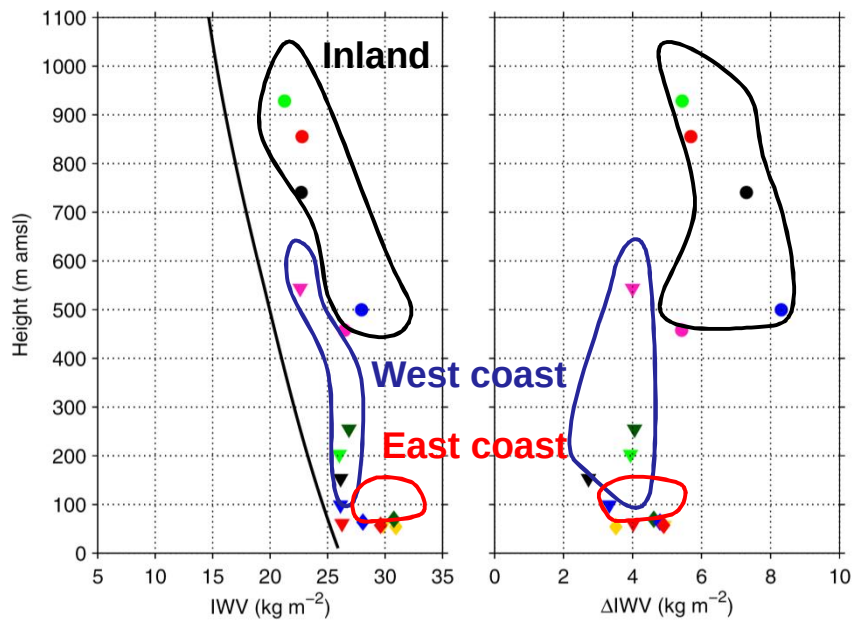
Di Girolamo et al., submitted
QJRMS SOP 1 Special Issue

Spatio-temporal variability of water vapour over Corsica

- Elevated humidity layers evolve under fair weather conditions due to mountain venting and advective venting
- Integrated water vapour (IWV) over and downstream of Corsica typically increases by several kg m^{-2} during the afternoon



Schematic diagram illustrating the transportation paths of water vapour shortly after noon (MV: mountain venting; AV advective venting)



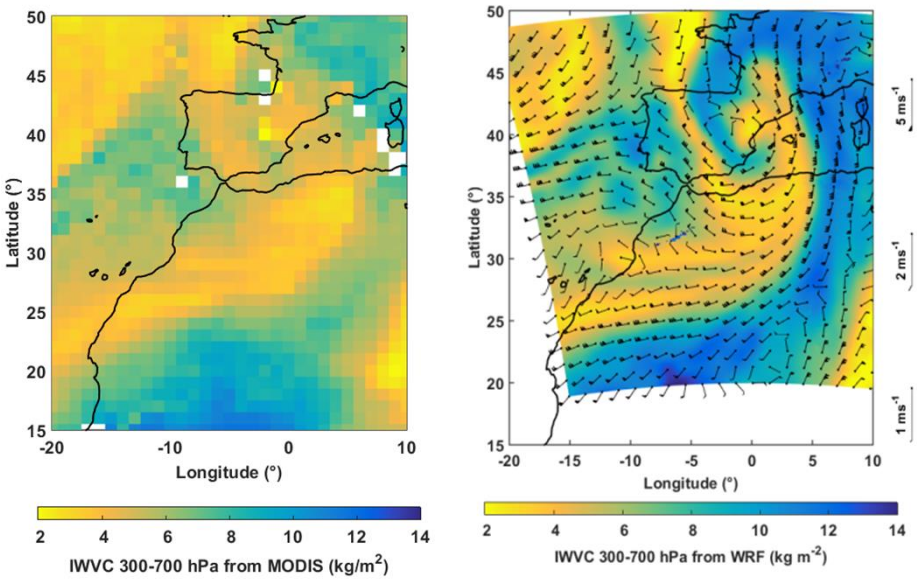
Height dependence of integrated water vapour (IWV) in the afternoon and of the diurnal IWV variation derived from GPS measurements

Adler et al., 2015
QJRMS SOP 1 Special Issue

Tropical moist plumes from West Africa

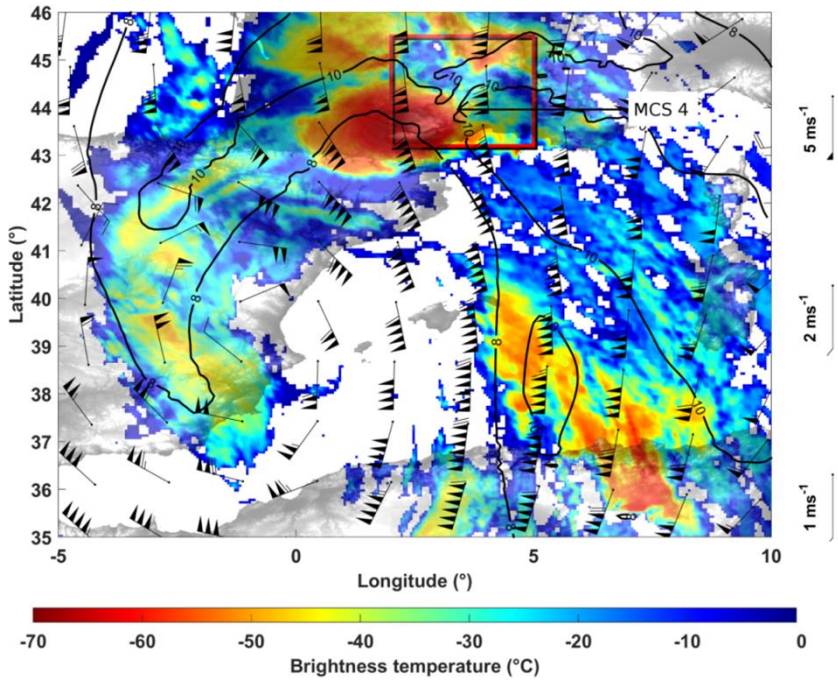
IOP 15b

MODIS Vs WRF: 21 October 2012



- Transport of moisture between 700 and 300 hPa from WA (observations and models)
- Tropical plume co-located with storm track (SEVIRI imager)
- Vertical structure of the plume documented by WV lidar WALI

MSG/SEVIRI
0600 UTC
21 October 2012



Chazette et al., 2015b
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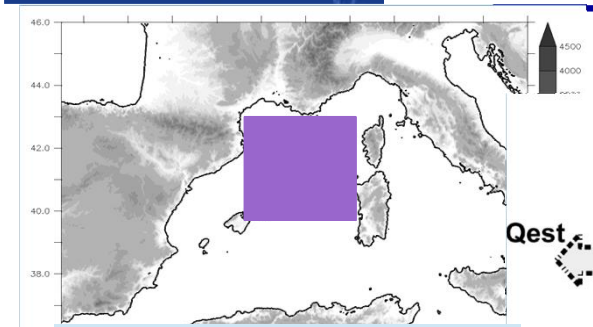
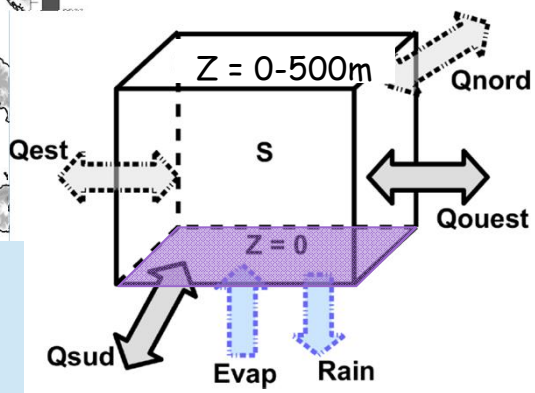
Evolution of atmospheric moisture transport & link with MSWB

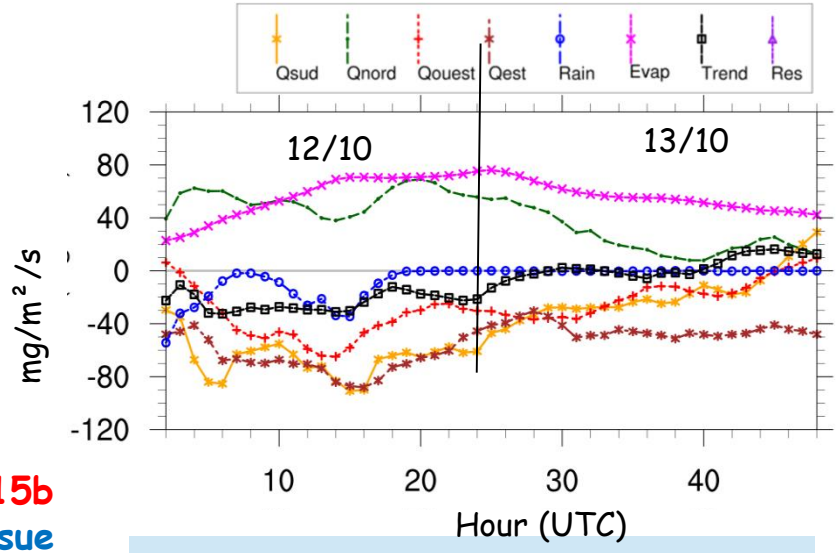
Air-sea interaction during a strong mistral case



Box for the water budget computation: over the NW Med and between 0-500m



Rainaud et al., 2015b
QJRMS SOP 1 Special Issue



Water budget terms in CPLOA

3 numerical experiments

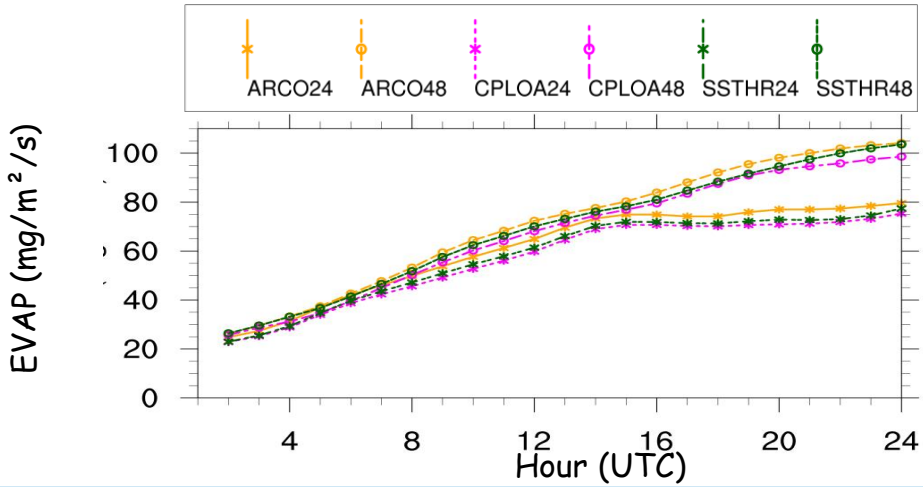
ARCO	*AROME-WMED (uncoupled)*
CPLOA	*AROME-NEMO =>O/A coupling*
SSTHR	*AROME-WMED (uncoupled) but same initial SST than CPLOA (00UTC)*

Water budgets

- Significant contribution of evaporation (up to 50% of the water inputs on 12 October)

O/A coupling impact

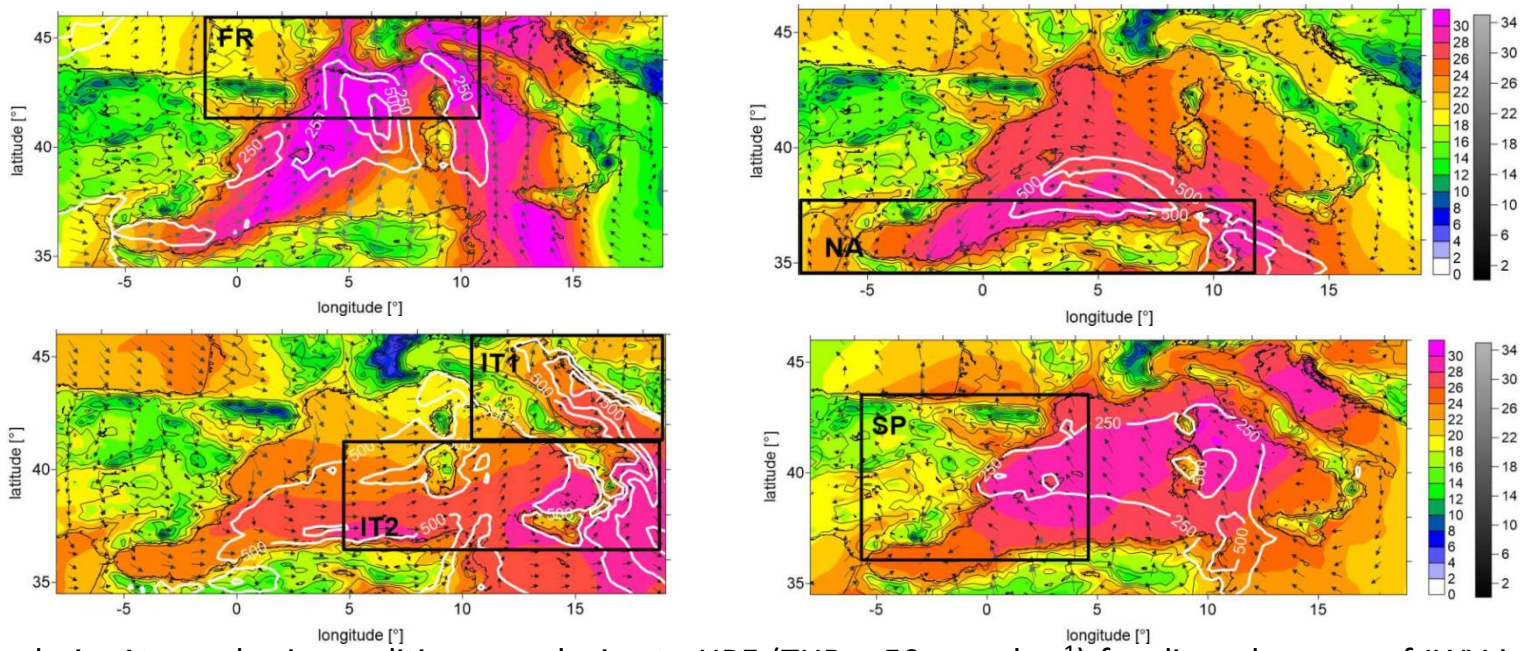
- Evaporation is progressively reduced because of the ocean surface cooling



Evaporation for 12 oct 2012 in ARCO, SSTHR and CPLOA for runs stating on 11 oct 2012 00UT (◦) and on 12 oct 2012 00UT (x)

Water-vapour transport over Wmed at seasonal scale (fall 2011 & 2012)

Atmospheric Conditions Associated with Heavy Precipitation Events in Comparison to Seasonal Means in the Western Mediterranean Region



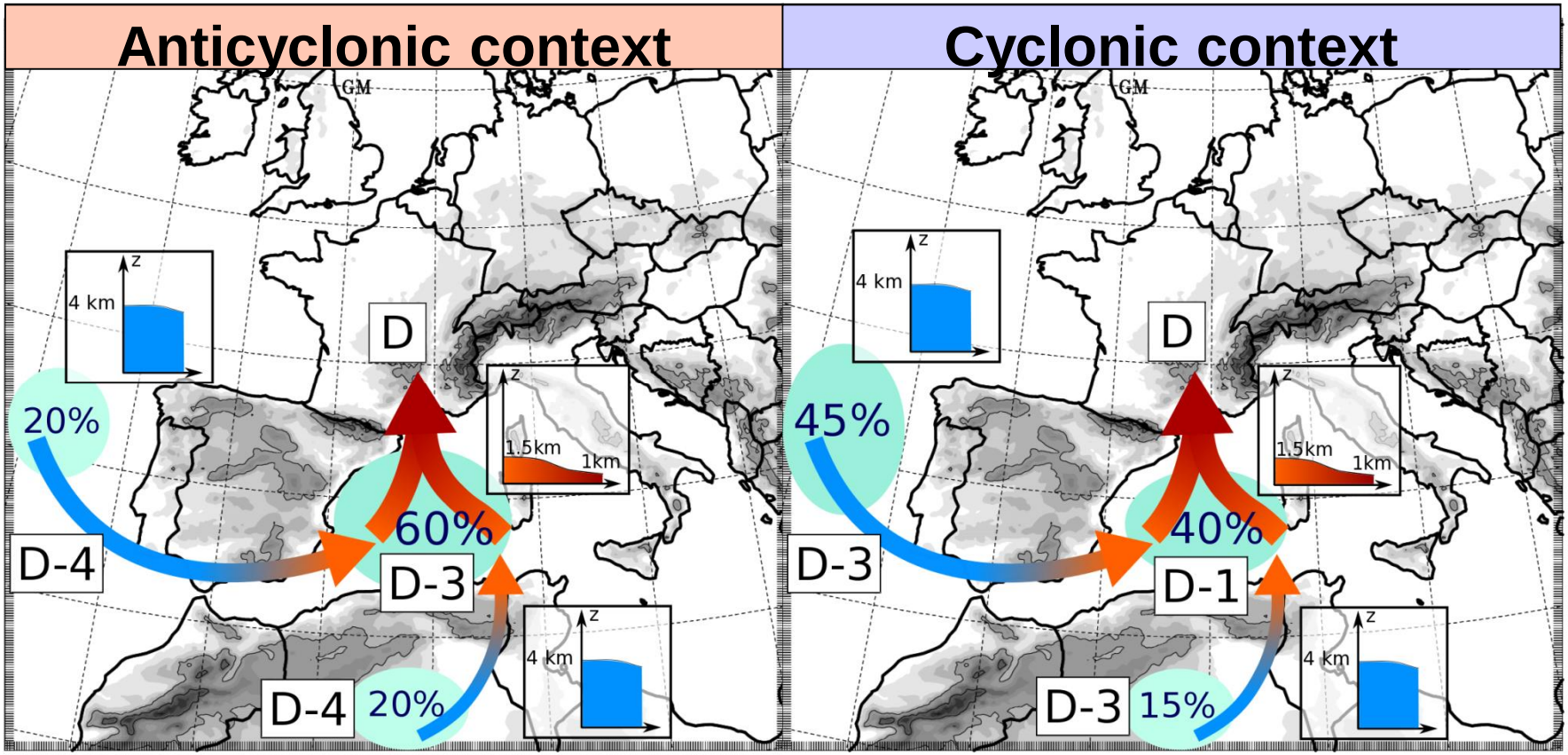
Composite analysis: Atmospheric conditions conducive to HPE (THR > 50 mm day^{-1}) for diurnal means of IWV in kg m^{-2} (colour scale), CAPE in J kg^{-1} (white isolines), and 950 hPa low-level winds in m s^{-1} at 1400 UTC (grey-black vectors).

- During HPE conditions, moisture and instability sources are located generally upstream of the target area over the sea, being transported by fast low-level winds towards the HPE areas.
- Concentration of high humidity over land and initiation of convection are highly related to orography.

Khodayar and Kalthoff, submitted

Identification of water vapour origin

Origin of the water vapour supply to HPEs in southern France



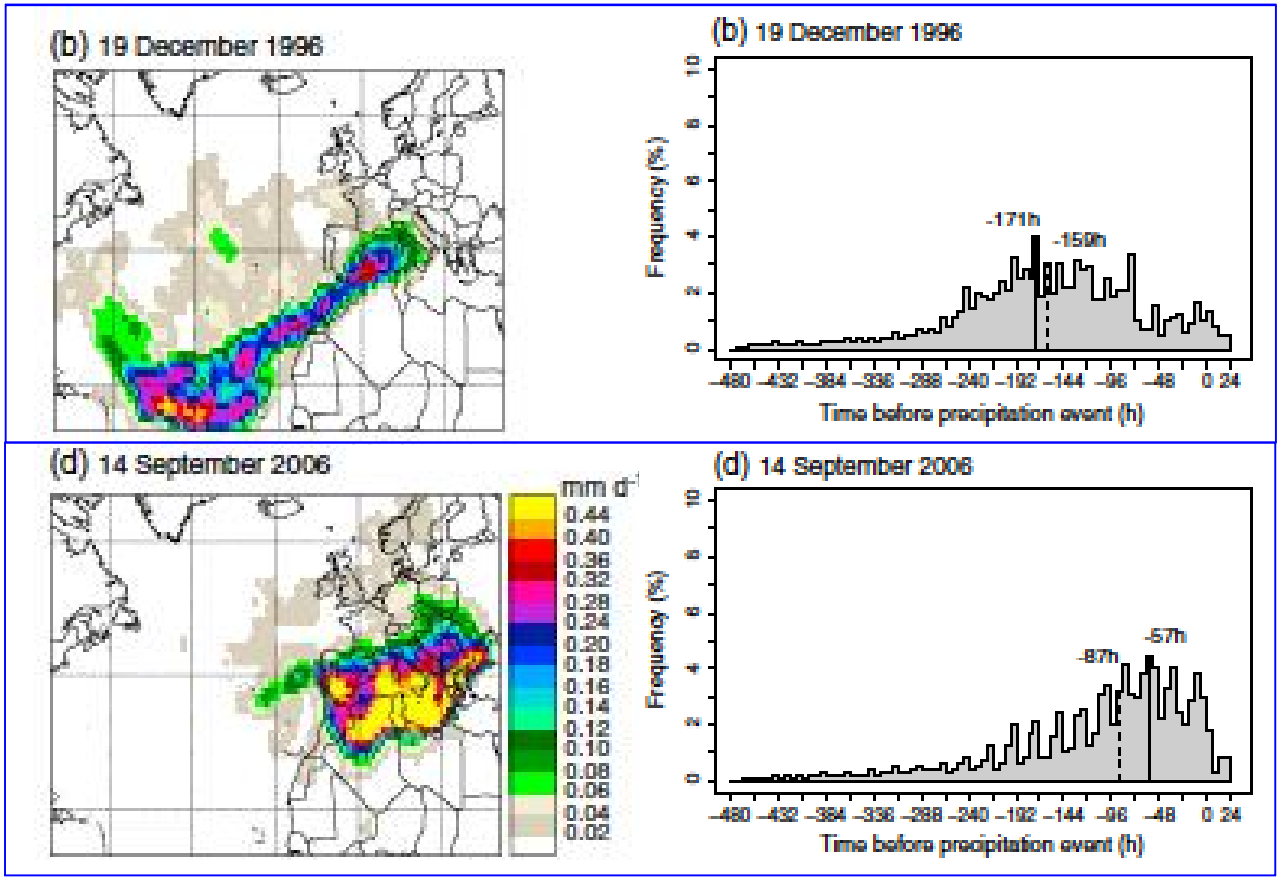
Duffourg and Ducrocq, 2013

How important is evaporation for Mediterranean precip extremes?

- Investigation of 200 heavy precipitation events in the western Med
- Individual cases: highly variable moisture source patterns and timing

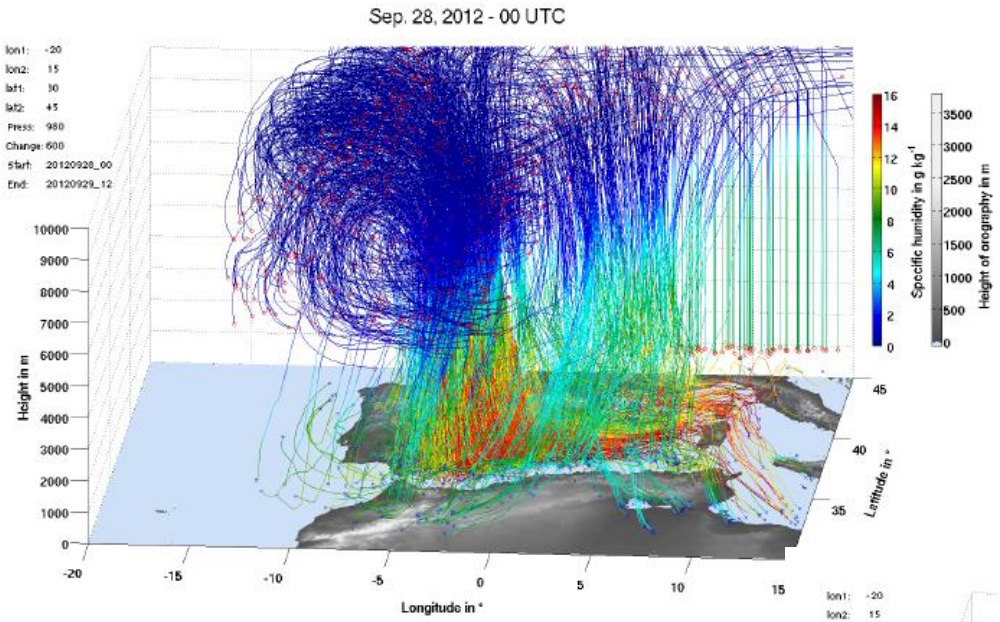
Case 1: subtropical moisture sources and >7 days between E and P

Case 2: mainly Med moisture sources, 2-3 days from E to P



Winschall et al., 2012

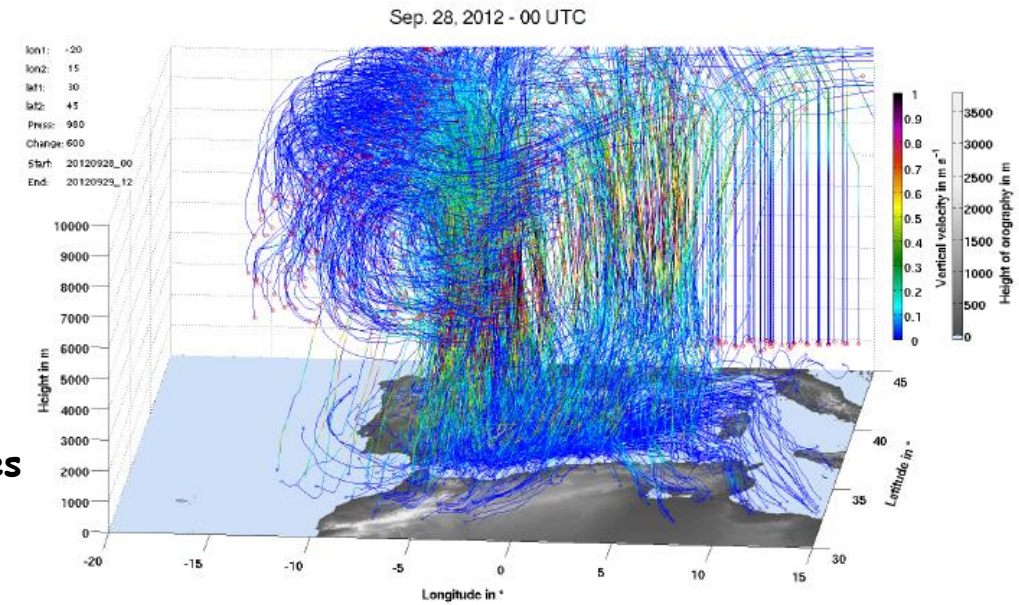
HPEs over Spain during IOP 8



Specific along trajectories

COSMO Model
Lagranto trajectory model

- HPE feeded by moisture from the Western Mediterranean
- Precipitation occurred few hours after moisture uptake due to strong vertical motion



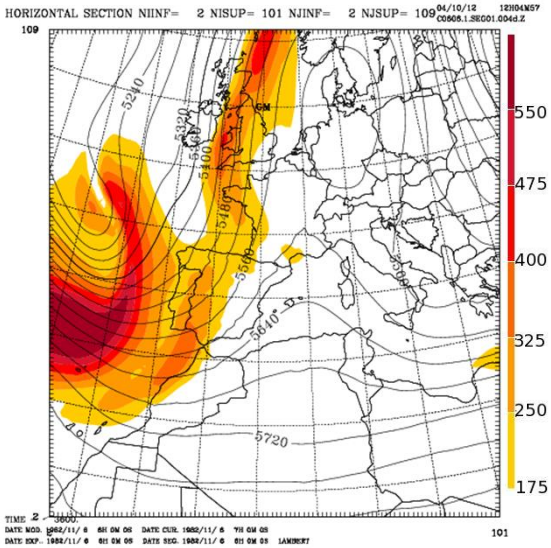
Vertical velocity along trajectories

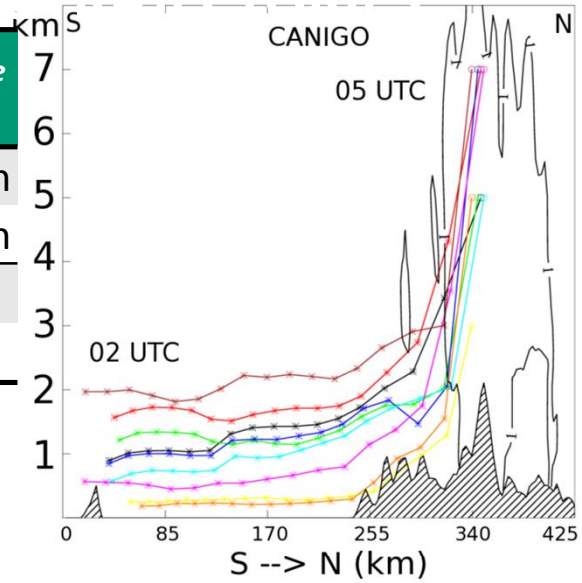
Nerding, Röhner and Corsmeier

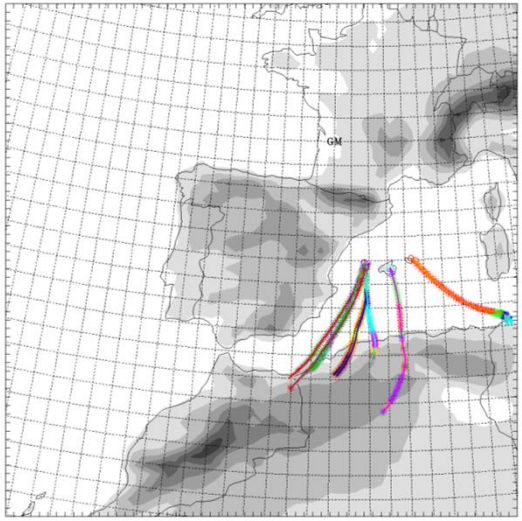
HPEs over the eastern Pyrenees in 1982

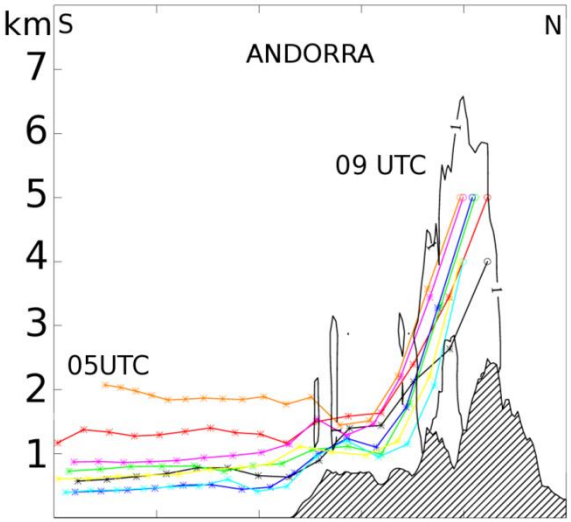
SYSTEM	LEVEL	Rv final g/kg	Rv initial g/kg	Rv Medit. contribution	*Time sea*
STAGE 2 – Canigó	< 1 km	8-11	8	**2.0 g/kg**	12 h
	1 -2 km	7	4-7	**2.0 g/kg**	12 h
STAGE 3 – Andorra	< 1 km	9-10	6,5	**3.5 g/kg**	8 h
	1-2 km	7.8	7,2	**1.0 g/kg**	--

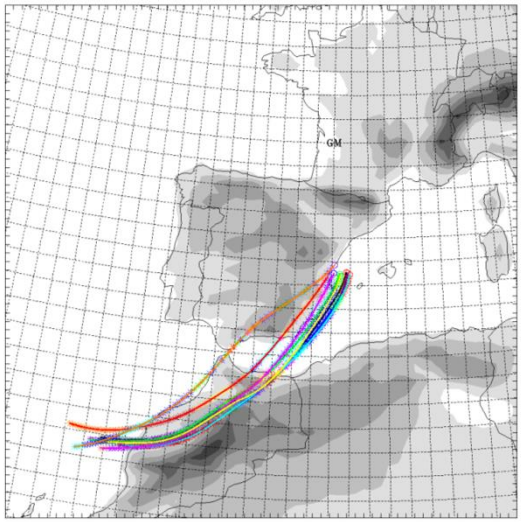
LIMITED MEDITERRANEAN CONTRIBUTION









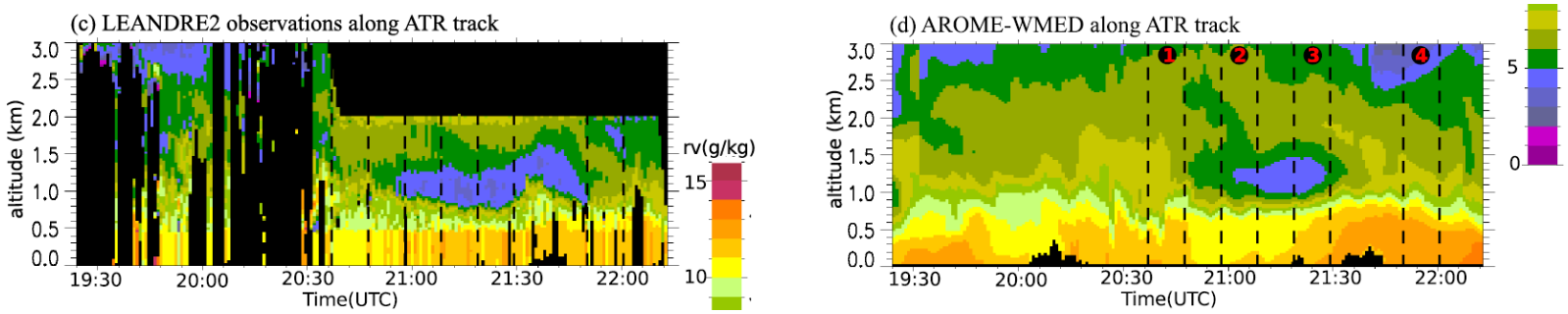


Trapero et al., 2013

Concluding remarks

➲ What is missing with respect to the HyMeX Science Plan ?

WG1-SQ1 (e) Evolution of atmospheric moisture transport
WG3-SQ2 (g) Role of mid-level dry air masses



➲ What has been achieved that was not in the HyMeX Science Plan ?

Assessment of space-borne water vapour related products to accurately represent moisture variability across the WMED bassin

Use of space-borne observations for understanding the moisture environment of HPEs

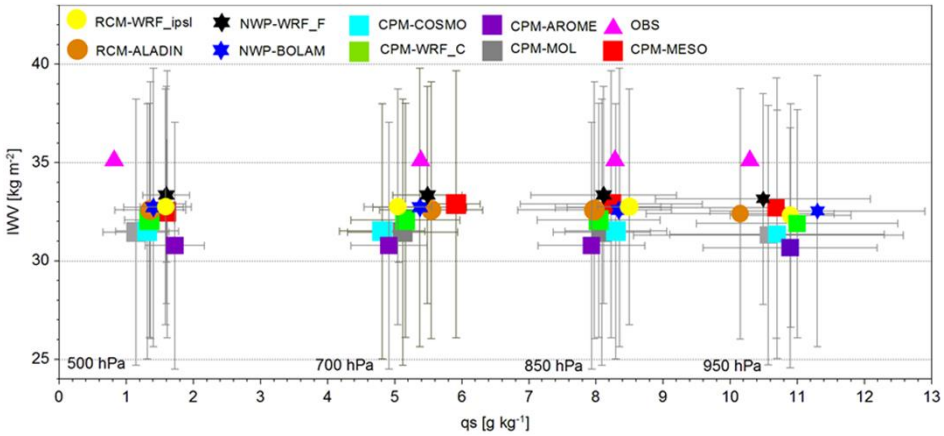
Supplementary slides

Seamless model intercomparison over WMed

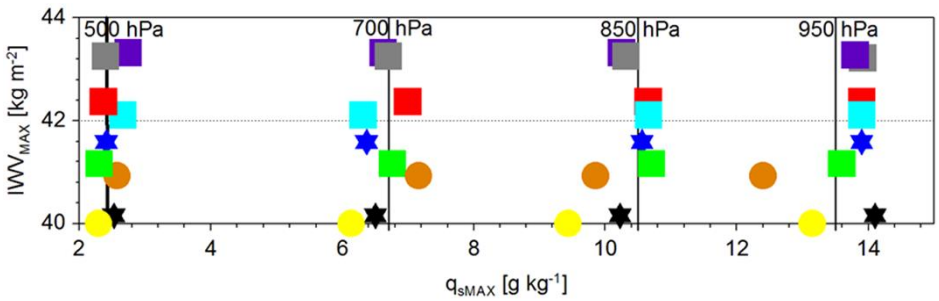
Seamless approach IOP12b

Khodayar S., Fosser G., Berthou S., Davolio S., Drobinski P., Ducrocq V., Ferretti R., Nuret M., Pichelli E., Richard E. 2015: A seamless weather-climate multi-model intercomparison on the representation of high impact weather in the Western Mediterranean: HyMeX IOP12, *under review QJRMS.*

(a)



(b)



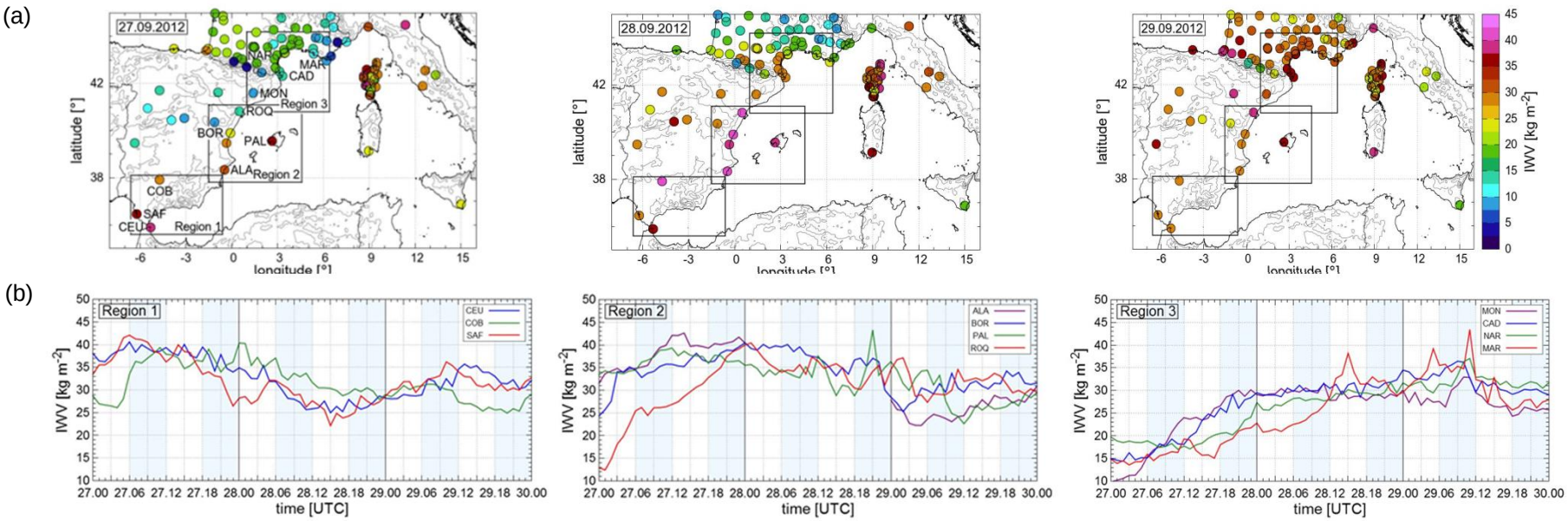
Areal and temporal (4 h period before maximum precipitation) average of, (a) specific humidity (q_s) versus IWV, including correspondent standard deviations, and (b) maximum q_s versus maximum IWV, at 500 hPa, 700 hPa, 850 hPa and 950 hPa. Lines of constant q_{sMAX} in the x-axis indicate the CPMs-q_{sMAX} average at the indicated levels. Observations (OBS) included in (a) correspond to the q_s values from the 11 October 17 UTC radiosounding information at San Giuliano (east coast of Corsica), and IWV values from a GPS station.

The RCMs and NWP models do mostly sample the moisture mean and the variability associated to the CPMs.

Spatio-temporal variability of water vapour over WMed

- **Diagnostic Study IOP 8**

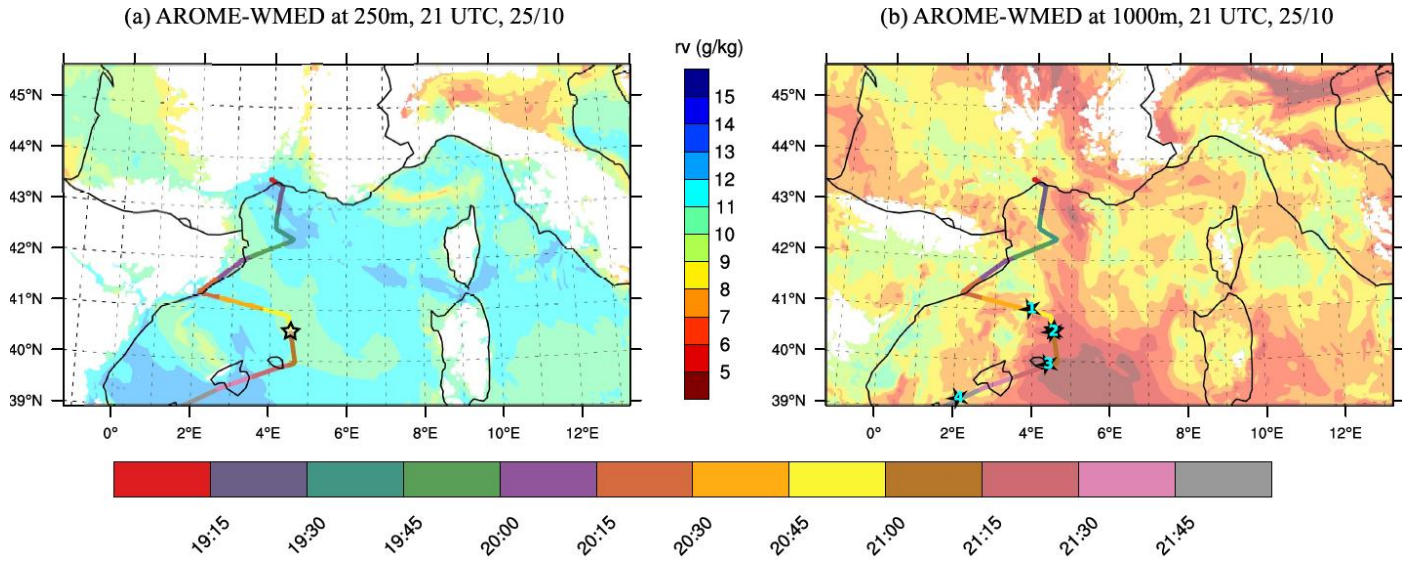
Khodayar, Raff, Kalthoff 2015: Diagnostic study of a high-precipitation event in the Western Mediterranean: adequacy of current operational networks. ***QJRMS, DOI:10.1002/qj.2600***



(a) Spatial distribution of GPS-retrieved IWV in kg m^{-2} at 00 UTC for the 27, 28 and 29 September 2012. Black boxes indicate the three study regions. (b) Diurnal evolution of IWV for selected stations in a.

- Observational and model studies agree showing maximum values of IWV few hours before the respective precipitation maximum.

Representation of the ambient moisture for IOP16a

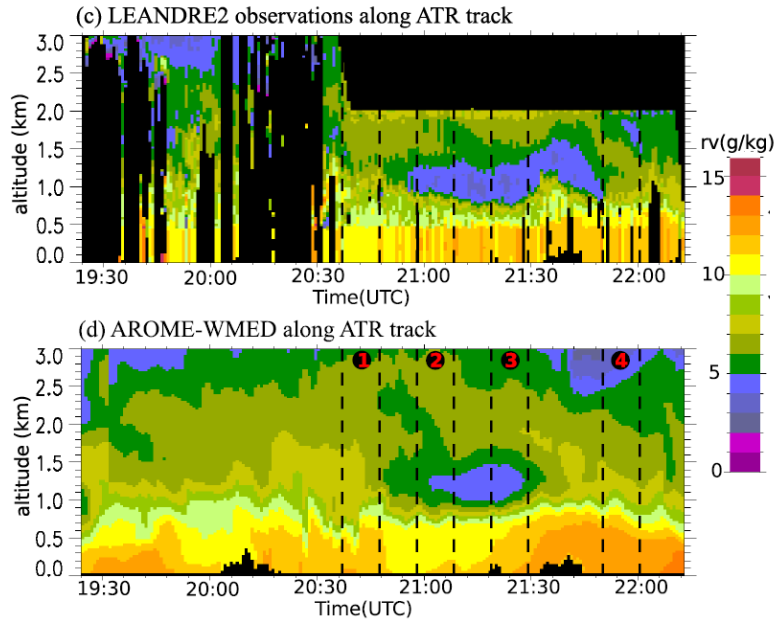


Low-level moist air mass overall well represented:

- Water vapour content very realistic
- Depth of the moist layer slightly too large

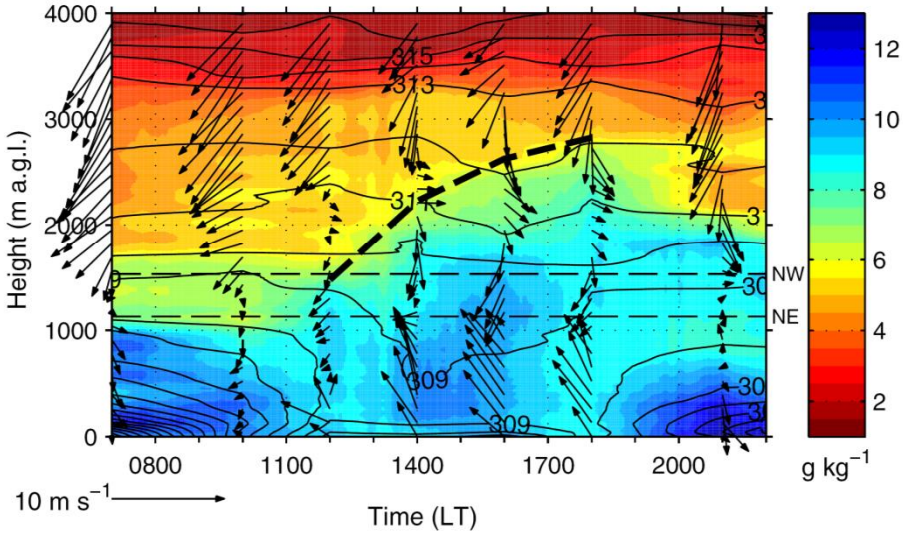
Drier air mass at 1000m:

- Slightly too high

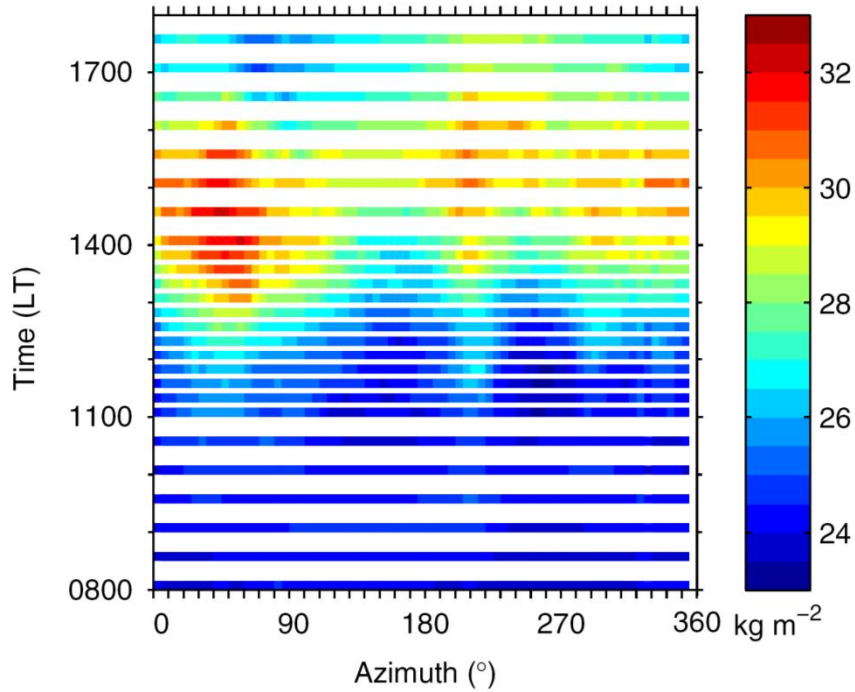


Water-vapour transport over Corsica

- Both convection and thermally driven flows control the diurnal cycle of water vapour over Corsica under fair weather conditions
- Water vapour is transported up the slopes and moistens the atmosphere far above the mountain ridges



Specific humidity, potential temperature and horizontal wind vector in a valley in the centre of Corte.



Azimuthal time plot of integrated water vapour in a valley in the centre of Corte

Adler and Kalthoff, 2014

MUSIC/Task 1C (ambient flow)

D1C.1- C. Flamant, P. Chazette, J. Totems, P. Di Girolamo, A. Doerenbecher

Date	Profiles acquired time (UTC)		RMSE (g kg^{-1})		
	LEANDRE 2 (hhmm)	in situ (from hhmm to hhmm)	WALI – LEANDRE-2	WALI – in situ	LEANDRE-2 – in situ
28/09/2012 (event 2): AS41 landing	1620	1618-1633	3.1	2.2	4.7
14/10/2012 (event 4): AS46 landing	1122	1113-1135	1.3	0.6	1.2
14/10/2012 (event 4): AS47 take-off	1312	1305-1326	1.3	1.0	1.5
20/10/2012 (event 5): AS52 landing	1241	1237-1256	0.5	0.7	0.8
20/10/2012 (event 5): AS53 take-off	1420	1415-1424	1.6	0.8	1
25/10/2012 (event 6): AS54 overpass	2116	-	1.1	-	-

Chazette et al., 2015
QJRMS SOP 1 Special Issue

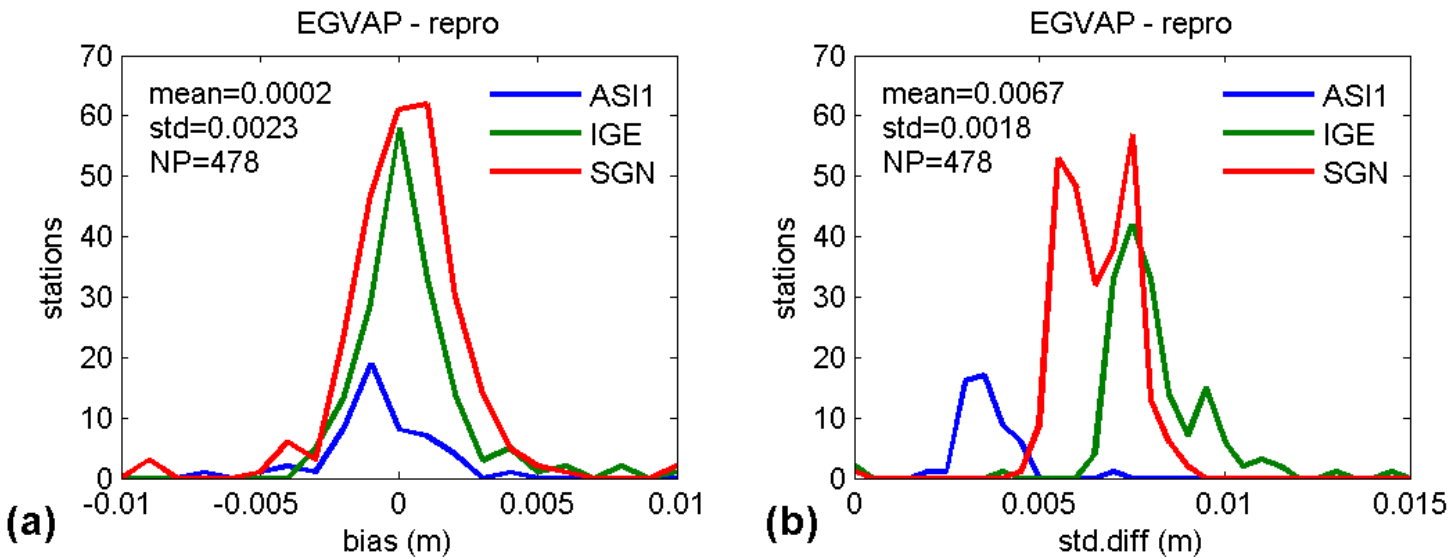
Date	RMSE (g kg^{-1})
	WALI-BLPB
26/09/2012 0157 UTC	0.8
11/10/2012 0202 UTC (event 4)	1.2
14/10/2012 0814 UTC (event 4)	1.3
18/10/2012 0255 UTC (event 5)	0.9
25/10/2012 2100 UTC (event 6)	1.1
26/10/2012 0536 UTC (event 6)	0.9

Chazette et al., 2015 ACP

WALI Vs IASI (operational products)
30 simultaneous observations, nighttime, cloud free conditions
For altitudes ranging from 2 to 7 km:

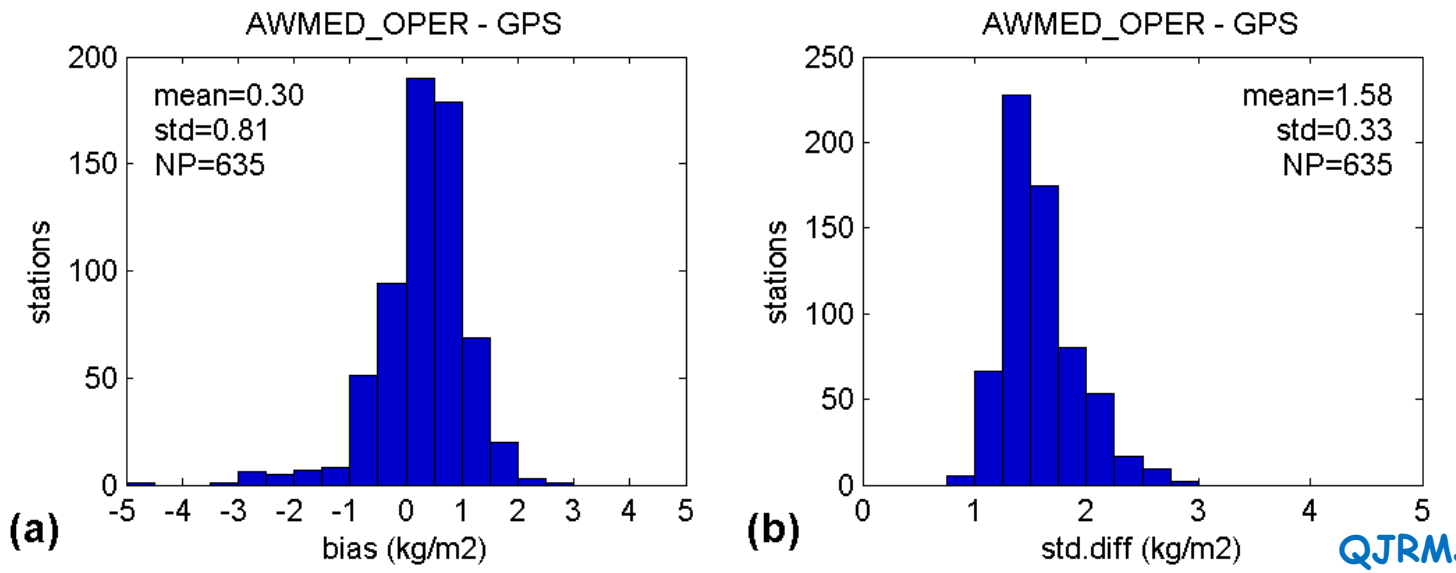
Å HyMeX RMSE ~0.5 g kg–1 Correlation ~0.77
Å ChArMeX RMSE ~1.1 g kg-1 Correlation ~0.72

Comparison of NRT and post-processed ZTD



Histograms of (a) mean differences and (b) standard deviation of differences between E-GVAP operational GPS ZTD data and reprocessed GPS ZTD data, sorted by analysis centres and country: Italy (ASI1), Spain (IGE) and France (SGN).

There are differences between NRT and repro datasets => impact expected on assimilation



3-hrouly IWV differences between AWMED_OPER and reprocessed GPS for the SOP1 period.

Bock et al., 2015
QJRMS SOP 1 Special Issue

Good agreement between AROME WMED OPER and GPS IWV

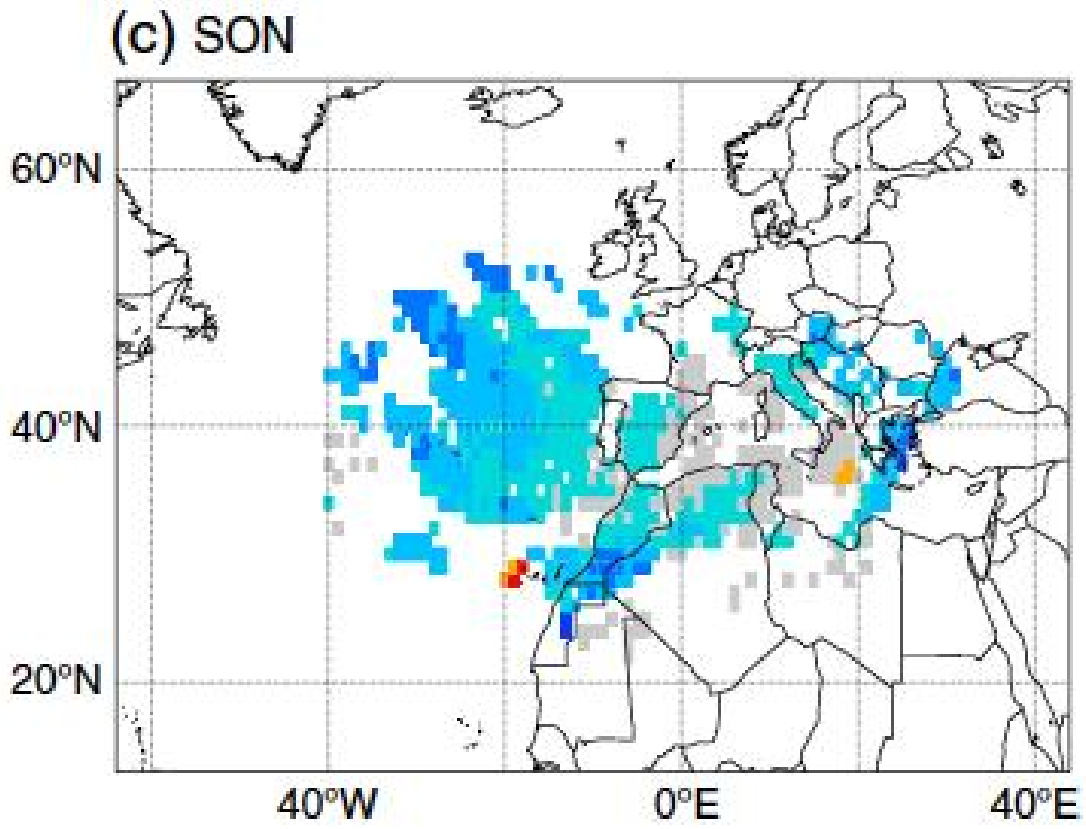
Contribution to WG3-SQ2 (f) Identification of water vapour origin

How important is intensified evaporation for Mediterranean precipitation extremes?

Andreas Winschall[1], Harald Sodemann[1], Stephan Pfahl[1], and Heini Wernli[1]

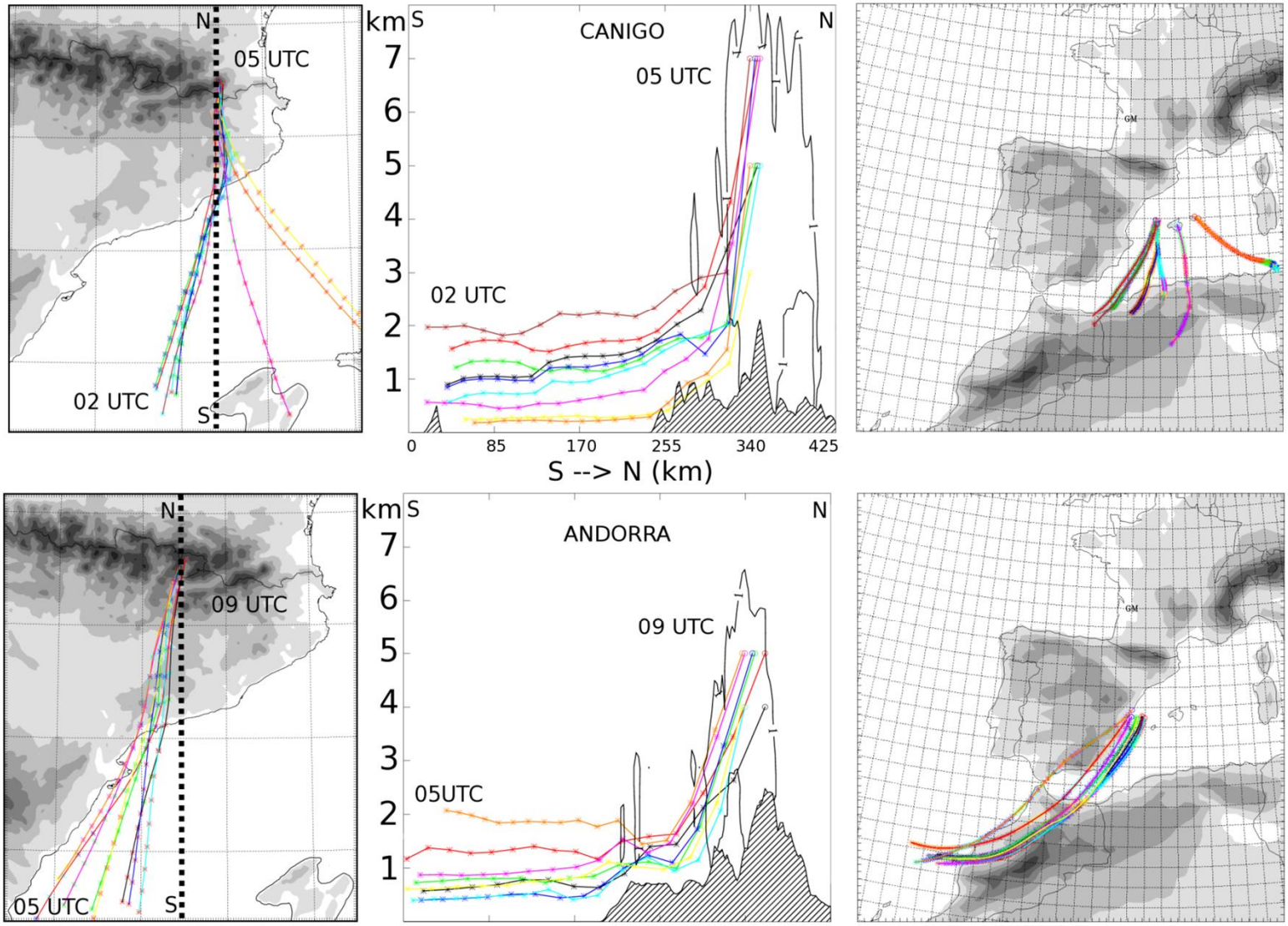
- North Atlantic moisture sources associated with anomalously intense ocean evaporation (- but not Med moisture sources)

Blue region shows (strongly) enhanced surface evaporation (compared to climatology) for remote moisture sources of Mediterranean heavy precipitation

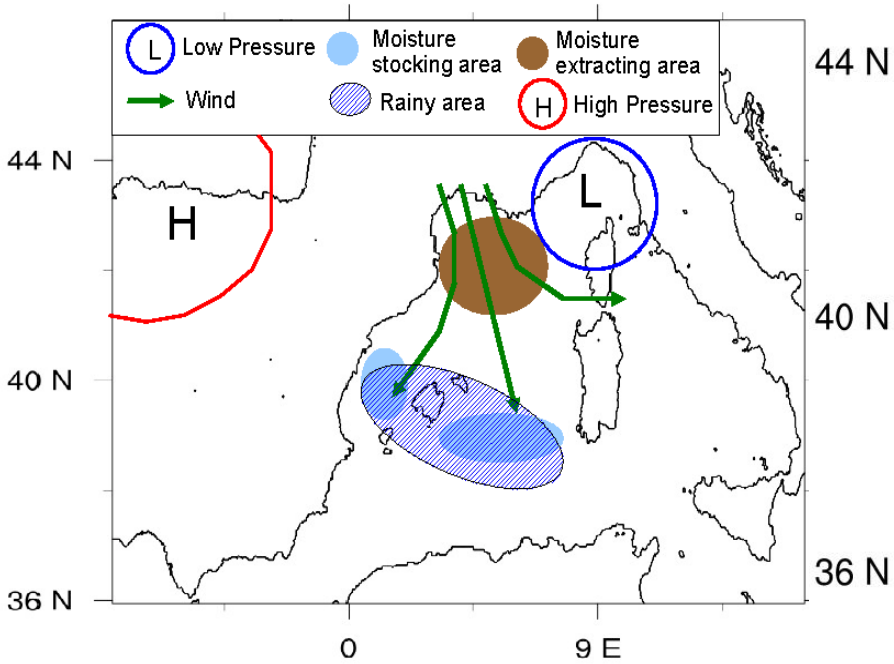


http://dx.doi.org/doi:10.5194/nhess-13-2969-2013

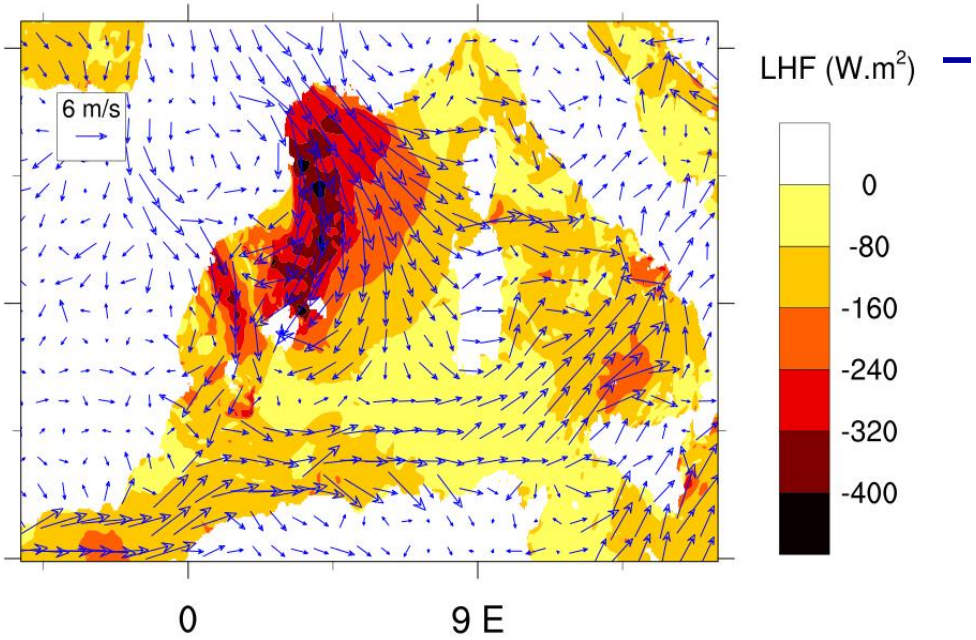
1982 HPE: FEEDING FLOW



IOP13 (phase 1): from 12 October 2012 09UTC to 13 October 2012 10UTC



Schematic synthesis of the first phase of IOP13



12 oct 2012 12UTC: Latent heat flux (W/m²) and 10m-wind (m/s) from AROME-WMED forecasts

Characterization of the air-sea exchanges from AROME-WMED forecasts

- **Strong Mistral wind (~12 m/s)**
- **Rain arround Balearic Islands (BA region)**
- **Strong fluxes on Gulf of Lion => moisture extraction area**

Rainaud et al. (2015)

Guidelines

- Science review should be organized along the 5 HyMeX topics (WG1,WG2,WG3,WG4,WG5)
- When possible organize Science review along the HyMeX Science Plan questions (WGx-SQn)
- It should be as much of possible a review of **science advances and NOT a review of activities** => highlight new results and findings over the 5 years.
- Outreach activities and beneficial impacts on operational forecasting and tools, practices,… could be mentioned
- It will not be possible to illustrate all the studies, you should make choices!
- Last slide: What are missing with respect to the HyMeX Science Plan ? What have been achieved that were not in the HyMeX Science Plan ?