ST WV
Sources and Transport of Water Vapour

5-year Science Review

C. Flamant, P. Di Girolamo, N. Kalthoff

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

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

<table>
<thead>
<tr>
<th>HyMeX WG &amp; question</th>
<th>ST-WV objective</th>
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<tr>
<td><strong>Moisture monitoring</strong></td>
<td>Erreur and bias estimates</td>
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<td><strong>Instruments</strong></td>
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<tr>
<td>H$_2$O lidars</td>
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<td>Ground-based and airborne GPS</td>
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<td>Weather radars</td>
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<td>UHF radars</td>
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<tr>
<td>IASI, AIRS MODIS</td>
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<td>Space-borne</td>
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<td><strong>Lidars</strong></td>
<td>Chazette et al. 2014, AMT Chazette et al. 2015a QJ Di Girolamo et al. 2015 QJ</td>
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<td><strong>Radar</strong></td>
<td>Said et al., 2015 QJ Besson et al., 2015 QJ</td>
</tr>
<tr>
<td><strong>Climate models</strong></td>
<td>Kodahyar et al., 2015 QJ</td>
</tr>
<tr>
<td><strong>IASI, AIRS, MODIS</strong></td>
<td>Chazette et al., 2014 ACP Chazette et al., 2015b QJ Lee et al., in prep</td>
</tr>
</tbody>
</table>
Error and bias estimates from water vapour lidars & other instruments

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

Candillargues: BASIL

Menorca: WALI

ATR 42 Tracks

ATR 42 Tracks

Water vapour mixing ratio (g/kg)

BIAS (%) vs. Height (m)

RS 19:44 UT
BASIL 1 min (19:44-19:45 UT), 30 m
BASIL 10 min (19:44-19:54 UT), 150 m
CNRS DIAL (20:54 UT)

Water vapour mixing ratio (g/kg)

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BASIL 10 min (19:44-19:54 UT), 150 m
CNRS DIAL (20:54 UT)
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.

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

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).

<table>
<thead>
<tr>
<th>Altitude Range (km amsl)</th>
<th>COR</th>
<th>RMSE (g kg$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>WALI-AROME-WMED</td>
<td>WALI-ECMWF</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.5-1.5</td>
<td>0.68</td>
<td>0.68</td>
</tr>
<tr>
<td>1.5-3.0</td>
<td>0.87</td>
<td>0.88</td>
</tr>
<tr>
<td>3.0-6.0</td>
<td>0.88</td>
<td>0.85</td>
</tr>
<tr>
<td>0.5-6.0</td>
<td>0.84</td>
<td>0.83</td>
</tr>
</tbody>
</table>
A consistent, self-coherent and validated GPS IWVC dataset

Bock et al., submitted
QJRMS SOP 1 Special Issue
Model intercomparison over Italy: COSMO & MOLOCH during IOP 13

Table:

<table>
<thead>
<tr>
<th>model</th>
<th>Δx (km)</th>
<th>name</th>
</tr>
</thead>
<tbody>
<tr>
<td>COSMO</td>
<td>2.8</td>
<td>C2</td>
</tr>
<tr>
<td>COSMO</td>
<td>1</td>
<td>C1</td>
</tr>
<tr>
<td>MOLOCH</td>
<td>2.3</td>
<td>M2</td>
</tr>
<tr>
<td>MOLOCH</td>
<td>1.5</td>
<td>M1</td>
</tr>
</tbody>
</table>

Barthlott and Davolio, 2015
QJRMS SOP 1 Special Issue
Near-ground refractivity collected by 5 radars in south-eastern France for a 3.5-month period encompassing SOP1

- Comparisons with:
  - Ground weather stations
  - WRF and Arome-WMed analyses and forecasts

- 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 radar retrievals are wetter here

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 UTC and 0900 UTC, respectively.
Characterization of the low-level mesoscale environment
Moisture transport along a Mediterranean cyclone WCB

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

Flaounas et al., 2015
QJRMS SOP 1 Special Issue
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

- 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

HyMeX

MODIS Vs WRF: 21 October 2012

MSG/SEVIRI
0600 UTC
21 October 2012

Chazette et al., 2015b
QJRMS SOP 1 Special Issue
Evolution of atmospheric moisture transport & link with MSWB
Air-sea interaction during a strong mistral case

Rainaud et al., 2015b

QJRMS SOP 1 Special Issue

3 numerical experiments

<table>
<thead>
<tr>
<th>ARCO</th>
<th>AROME-WMED (uncoupled)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPLOA</td>
<td>AROME-NEMO =&gt; O/A coupling</td>
</tr>
<tr>
<td>SSTHR</td>
<td>AROME-WMED (uncoupled) but same initial SST than CPLOA (00UTC)</td>
</tr>
</tbody>
</table>

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

Water budget terms in CPLOA

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)
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

**COSMO Model**
- Lagranto trajectory model
  - HPE fed by moisture from the Western Mediterranean
  - Precipitation occurred few hours after moisture uptake due to strong vertical motion

Nerding, Röhner and Corsmeier
HPEs over the eastern Pyrenees in 1982

<table>
<thead>
<tr>
<th>SYSTEM</th>
<th>LEVEL</th>
<th>$R_v$ final g/kg</th>
<th>$R_v$ initial g/kg</th>
<th>$R_v$ Medit. contribution</th>
<th>Time sea</th>
</tr>
</thead>
<tbody>
<tr>
<td>STAGE 2</td>
<td>&lt; 1 km</td>
<td>8-11</td>
<td>8</td>
<td>2.0 g/kg</td>
<td>12 h</td>
</tr>
<tr>
<td></td>
<td>1-2 km</td>
<td>7</td>
<td>4-7</td>
<td>2.0 g/kg</td>
<td>12 h</td>
</tr>
<tr>
<td>STAGE 3</td>
<td>&lt; 1 km</td>
<td>9-10</td>
<td>6,5</td>
<td>3.5 g/kg</td>
<td>8 h</td>
</tr>
<tr>
<td></td>
<td>1-2 km</td>
<td>7,8</td>
<td>7,2</td>
<td>1.0 g/kg</td>
<td>--</td>
</tr>
</tbody>
</table>

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
Seamless model intercomparison over WMed

- Seamless approach IOP12b

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

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

30 simultaneous observations, nighttime, cloud free conditions
For altitudes ranging from 2 to 7 km:

- HyMeX: RMSE ~0.5 g kg⁻¹, Correlation ~0.77
- ChArMeX: RMSE ~1.1 g kg⁻¹, Correlation ~0.72
Comparison of NRT and post-processed ZTD

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

Good agreement between AROME WMED OPER and GPS IWV

Bock et al., 2015
QJRMS SOP 1 Special Issue
Contribution to WG3-SQ2 (f) Identification of water vapour origin

How important is intensified evaporation for Mediterranean precipitation extremes?

Andreas Winschall, Harald Sodemann, Stephan Pfahl, and Heinl Wernli

- 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

JGR, 2014
1982 HPE: FEEDING FLOW

http://dx.doi.org/doi:10.5194/nhess-13-2969-2013
IOP13 (phase 1): from 12 October 2012 09UTC to 13 October 2012 10UTC

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

- Strong Mistral wind (~12 m/s)
- Rain around 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?