The Mistral wind: large-scale controlling mechanisms and impact on air-sea interaction

Shira Raveh-Rubin
Department of Earth and Planetary Sciences
Weizmann Institute of Science
Rehovot 76100
Israel

Tel.: +972 8 934 3147
Email: shira.raveh-rubin@weizmann.ac.il
Web: http://www.weizmann.ac.il/EPS/raveh-rubin/

Philippe Drobinski
Laboratoire de Météorologie Dynamique - IPSL
(CNRS, Ecole polytechnique, ENS, Sorbonne Université)
INSU
Ecole polytechnique
91128 Palaiseau Cédex
France
Tel.: +33 169 33 5142
Email: philippe.drobinski@lmd.polytechnique.fr
Web: http://www.lmd.polytechnique.fr/~drobinski/

This application is submitted for consideration within the Weizmann - CNRS Collaboration Program.

PART B: Description of the scientific project

Mediterranean cyclones are the most prominent atmospheric system governing intense wind and rainfall in the region. The Mediterranean, in turn, is known to be one of the most sensitive regions to climate change (Giorgi 2006). In the northwestern Mediterranean, the Mistral wind is the most prevalent, having profound impact on the human and natural environment, including air quality, fire risk and wind energy production, to name a few. The Mistral is a strong northerly wind, channeled in the Rhône Valley between the Alps to its east and the Massif Central to its west. In the last decades, the Mistral has been studied in the context of mesoscale orographic flows, as detailed hereafter. However, the large-scale governing atmospheric dynamics of the Mistral have never been studied systematically, nor has the impact of the Mistral on the Mediterranean Sea circulation been quantified climatologically. These two large-scale aspects of the Mistral will be the focus of the proposed WIS-CNRS collaboration. In the following, we outline the state of the art in the field, the scientific interest and originality of the project together with the specific research objectives. We then describe the unique proposed methodological approaches, expected results and end with future perspectives.

The shape of the Rhône Valley, the surrounding mountains and the Mediterranean coastline at the valley exit lead to the genesis of the Mistral under favorable synoptic situations that give rise to the northerly wind direction (Pettre 1982, Jiang et al. 2003). Dedicated field campaigns paved the way for studying the dynamics that underlay the Mistral in the mesoscale: MAP in autumn 1999 (Bougeault et al, 2001), ESCOMPTE in summer 2001 (Cros et al. 2004) and HyMeX in winter 2013 (Drobinski et al., 2014; Estournel et al., 2016) enabled a detailed view on the variability of the Mistral. The field data and accompanying non-hydrostatic regional model simulations highlighted the typical scales of the Mistral dynamics and the resulting wind variability to be of less than 3 h in time and 10 km in the horizontal scale (Guénard et al. 2005). The governing mechanisms involve interaction with the inversion layer that separates the planetary boundary layer (PBL) from the free troposphere above, together with hydraulic jumps and mountain wakes and further interaction with sea breeze in summer (Drobinski et al. 2005, Guénard et al. 2005, Bastin et al. 2006).

The Mistral outflow in the Gulf of Lions is conductive for strong air-sea interaction, by inducing favorable conditions for heat and freshwater fluxes into the atmosphere and therefore decreased sea-surface temperature (SST) (Lebeaupin Brossier and Drobinski 2009). Mistral-forced SST modifications were shown to decrease precipitation downstream (Berthou et al. 2018), and are potentially an instrumental trigger of deep-water formation, a driver of the North Atlantic thermohaline circulation (Flamant 2003, Lebeaupin Brossier et al., 2011, 2012, Somot et al. 2018).

Case studies indicate that the Mistral occurs in association with a Genoa cyclone, and specifically with its cold sector, where cold and dry continental air from north/northwest is advected along the Rhône valley, towards the cold front (Jiang et al. 2003, Corsmeier et al. 2005, Drobinski et al. 2005, Bastin et al. 2006, Drobinski et al. 2017). Generally in the cold sector of extratropical cyclones, the dry intrusion (DI) airstream is typically located, i.e., synoptic- to large-scale slantwise descending air from the upper troposphere at higher latitudes (Browning 1997, Catto and Raveh-Rubin 2019). The DI reaches the lower troposphere and may interact with the warm sector of the cyclone at the cold front, where convective activity can be triggered (Raveh-Rubin and Wernli 2016). The temperature and moisture contrast between the DI air and the PBL controls the potential instability generated in the lower troposphere, the deepening of the PBL and increased wind gusts (Raveh-Rubin 2017). In addition, DIs are globally associated with intense ocean heat and moisture fluxes (Raveh-Rubin 2017), even when compared climatologically to similar cold front environments (Raveh-Rubin and Catto 2019).

Objectives: The recent global climatological studies confirm the importance of DIs for surface winds, indicating that the DI is potentially a key large-scale feature controlling the Mistral strength, occurrence, variability and impact. Moreover, the Mistral has a pivotal role in building up deep-water formation in the northwestern Mediterranean (Somot et al. 2018). However, the large-scale upper-tropospheric dynamical control of the Mistral has never been systematically examined nor the build-up of deep-water formation by the Mistral during fall and winter. In the proposed research, we aim to place the Mistral in a larger-scale dynamical context, and understand its impact on air-sea interaction extending to the seasonal timescale. Specifically, the three objectives of the proposed collaborative research are to understand

(1) How the large-scale processes affect the strength, occurrence and location of the Mistral,

(2) How the Mistral forces deep water formation in the Gulf of Lions region, and

(3) How these processes evolve in a warming climate

Methodology: In the collaborative effort, we will address the research questions by employing the main expertise of both dynamical meteorology groups in CNRS and WIS, in two PhD projects (see Parts C and D). To encompass the multi-scale aspects of the work, unique and complementary data and methodologies will be employed.

Detailed case studies will be carried out to establish our understanding of the underlying mechanisms and understand the role of synoptic-scale forcing, beyond its role in providing the "right" wind direction. Specific key aspects from the case studies will be then quantified as long-term climatologies. For example, case studies may highlight a specific DI-related large-scale feature that plays an important role in triggering or intensifying the Mistral. Specific candidate features may be a specific upper-tropospheric jet configuration conductive for DIs (e.g., Rossby wave breaking, tropopause fold, amplified ridge), a preferred location of DIs that reach the PBL top, lower tropospheric temperature/humidity front characteristics, etc. The specific dynamical feature will be then diagnosed in long-term data, to generalize and quantify the identified link. Statistical bootstrapping methods and principle component analysis will corroborate the long-term climatological studies.

The impact of the Mistral on deep water formation in the Gulf of Lions region will focus on the fall (pre-conditioning ocean mixed layer by Mistral sequences) and winter (deep-water formation triggering) periods of the case studies for the synoptic-scale forcing analysis. A multi-scale analysis (i.e., scale filtering, wavelet, orthogonal decompositions) will be used to quantify the ocean response of Mistral events, to isolate clusters of events with different type of ocean response (e.g. immediate return to its original state, transition to a new stable ocean state, destabilization of the ocean mixed-layer).

Data and tools: *Observational data:* We will analyze atmospheric and oceanic data from the HyMeX field campaign special observation periods in autumn 2012 – spring 2013 (Drobinski et al. 2014, Estournel et al. 2016), which provides unprecedented wealth of coupled atmosphere, land and ocean measurements.

Reanalysis and modeling: Specific events of interest will be simulated with the non-hydrostatic model COSMO (Steppeler et al. 2003) and the MORCE-MED ocean-atmosphere coupled model (Drobinski et al., 2012), verified against observations. The simulations will be complemented by multi-decadal reanalysis (e.g. ERA-Interim or ERA5 from ECMWF) or hindcast and climate scenarios from the MED-CORDEX regional model simulations (Ruti et al. 2016). The MED-CORDEX simulations combine atmosphere only and ocean-atmosphere simulations driven by ERA-Interim reanalysis (hindcast mode) or by CMIP5 global climate models (historical and scenario simulations). The use of both atmosphere only and ocean-atmosphere coupled simulations allow an unprecedented insight into the build-up of deep-water formation by sequences of Mistral events during the fall and winter seasons. Idealized ocean-atmosphere coupled simulations will also be performed using the MORCE-MED platform to delineate the complex interactions that force deep-water formation.

Diagnostic tools: Eulerian and Lagrangian feature-based diagnostic tools will be developed, using the Lagrangian Analysis Tool LAGRANTO 2.0 (Sprenger and Wernli 2015), cyclone identification and tracking (Wernli and Schwierz 2006) and the Lagrangian DI dataset, based on ECMWF ERA Interim reanalysis (Raveh-Rubin 2017), adapted for ERA5 and for the Mediterranean region.

Expected results and future perspectives: The collaborative research will build comprehensive quantitative understanding of the most severe Mediterranean wind system and its impact as the driver of dense water formation. Fundamental understanding of the nesting of the Mistral within the synoptic and large-scale dynamics will be achieved through a unique combination of datasets and analysis techniques. Immediate deliverables will be an atlas of characteristic atmospheric environments for the occurrence of the Mistral, and their precursor signals. It is expected that robust regional atmospheric anomaly patterns will highlight a characteristic timescale prior to the Mistral onset, allowing extended predictability of the Mistral, and potentially of the associated Mediterranean heat and freshwater fluxes and dense-water formation episodes. Climatological feature-based datasets of the DIs, Mistral, and associated ocean fluxes will be available for future studies. Often, the Mistral is accompanied by the westerly Tramontane winds (Obermann et al. 2018), and/or followed by the northeasterly Bora winds in the N. Adriatic. Understanding the large-scale setting in which the Mistral is embedded is expected to shed light on the other regional and local wind systems as well.

The research theme of the WIS group encompasses large-scale and synoptic scale atmospheric dynamics, and its relation to severe weather. Special focus is dedicated to Mediterranean cyclones and extreme weather. The COSMO model is run in the group for single case studies with targeted sensitivity tests. The group develops state-of-the-art feature-based Eulerian and Lagrangian diagnostic tools for use in large reanalysis datasets. Current activities in the group relate to the dynamics of DIs, its triggering mechanism, interaction with fronts and cyclones, role in extreme weather and PBL modification, and impact on the water cycle.

The research theme of the CNRS group encompasses large-scale and synoptic scale atmospheric dynamics, mainly in the Atlantic, and mesoscale processes associated with Mistral dynamics and Mediterranean thermohaline circulation (including deep-water formation). The WRF atmosphere model and NEMO ocean model are run in the group either in idealized configuration, or in atmosphere-only or ocean only mode or in coupled mode in the MORCE-MED platform. Current activities in the group relate to the impact of air-sea interaction in cyclogenesis, to the mesoscale processes driving extreme weather in the Mediterranean (heavy precipitation, droughts) and Mistral and Tramontane regional winds, as well as the Mediterranean ocean circulation at the basin scale and the evolution of the Mediterranean climate.

PART C: Added-value of the international cooperation

The ambitious research goals combine for the first time the study of the regional Mistral wind, and a rigorous investigation of their governing large-scale mechanisms and impact on the ocean circulation. Each of the two research pillars is the main expertise of the WIS and CNRS groups, respectively. The proposed research can therefore only be carried out in the framework of full collaboration and continuous exchange between the two PhD students working on the project, and between the two groups in general, facilitated by regular mutual visits of the PIs and PhDs. The added value of the exchange will encompass the sharing of unique feature-based datasets, codes, model simulations and analysis tools, and training of the PhD students on the models and their combined usage. We plan ongoing broad exchange of ideas, expertise and scientific knowhow throughout the project duration. Ideally, we will engage and exchange Master students as well (using other funding sources).

The French team will benefit from the socially relevant knowledge on predictable aspects of the Mistral, potentially leading to future operational research avenues. Comprehensive datasets of large-scale features relevant for Mistral variability will serve as a basis for future studies on Mistral predictability at various time scales (from days to climate scales) and impact on extreme weather.

The Israeli team will extend its expertise towards studying PBL processes, orographic flows and air-sea interaction. They will gain knowledge and experience with detailed analysis of observational data and model verification techniques. Sharing of coupled simulation data will be a valuable source for subsequent studies of air-sea interaction near weather systems, and its role in moisture transport and downstream precipitation.

PART D: Planned activities

Two PhD students will work full time on the project. They will collaborate with each other, with both PIs and with other group members. At WIS (PhD 1), the PhD student will work on the large-scale dynamics of the Mistral with Eyal Ilotoviz, Vered Silverman, Reuven Heiblum and Stav Nahum (WIS), in collaboration with the CNRS group and in particular with Gwendal Rivière and Riwal Plougonven. At CNRS (PhD 2), the PhD student will work on the Mistral as a driver for dense-water formation, with additional input from Guillaume Lapeyre, Romain Pennel and Thomas Arsouze from CNRS, and Eyal Ilotoviz, and Vered Silverman from WIS. In the following we outline the planned work timeline.

Months 1-2	Kickoff meeting of WIS and CNRS groups in France, identify potential events for case studies. Literature review by PhD 1 and 2.
Months 3-5	PhD 1 to adapt the global DI definition to the Mediterranean, prepare datasets (ERA5, cyclone tracks), familiarize with analysis codes at WIS. PhD 2 to prepare datasets from the CNRS MED-CORDEX simulations (atmosphere only and ocean-atmosphere coupled simulations) and from HyMeX observations for validation.

Months 6-12	PhD 1 to learn the COSMO model and conduct first simulation for a case study, with additional analysis of ERA5 and observations. PhD 2 to apply multi-scale filtering on the atmospheric forcing from the WRF atmosphere simulations of the coupled runs and conduct oceanic simulations with NEMO model forced by the filtered forcings.
Months 13	Second meeting of the two groups, in Israel. PhD 1 and PhD 2 to present the case study at an international conference (e.g. HyMeX, Pilnius, AGU or EGU).
Months 14-15	PhD 1 extended visit to France. PhD 2 to lead 1st publication on the impact of Mistral events on deep-water formation during HyMeX period (fall 2012 and winter 2013).
Months 16-19	PhD 1 to carry out a second case study, identify key large-scale features. PhD 2 extended visit to Israel.
Month 20	PhD 1 to lead 1st publication on the large-scale drivers of the Mistral. PhD 2 to configure and run idealized simulations with HyMeX forcing to investigate how initial ocean state affects the response to Mistral events in the pre-conditioning period (fall) and deep-water formation (winter) period.
Months 21-24	PhD 1 to develop diagnostic tools for climatological study and check the sensitivity to their design. PhD 2 to conduct sensitivity analysis from idealized simulations with HyMeX atmospheric forcing.
Months 25-32	PhD 1 statistical climatology of large-scale dynamics during Mistral, and its impact on Mistral variability in present and future climate. PhD 1 to lead 2nd publication on present-day climatological study. PhD 1 extended visit to France, exchange climatological data for identifying Mistral variability important for air-sea interaction. PhD 2 to lead 2nd publication on idealized sensitivity analysis to quantify initial ocean state impact on deep-water formation. PhD 2 extended visit to Israel, evaluate impact of large-scale dynamics and air-sea fluxes on pre-conditioning and deep-water formation using clustering techniques
Months 33-36	Third groups meeting; PhD 1 to lead 3rd publication on climatological precursor dynamics and future trends of impactful Mistrals, and write PhD manuscript. PhD 2 to lead 3rd publication on impact of large-scale dynamics and air-sea fluxes on pre-conditioning and deep-water formation and write PhD manuscript. Presentation at an international conference/workshop (e.g. HyMeX, Plinius, AGU or EGU)

PART E : Budget

WIS	Year 1	Year 2	Year 3
PhD Student fellowship	21,952	21,952	21,952
Travel	5,000	5,000	5,000
Total	**26,952**	**26,952**	**26,952**

The travel budget for each year will cover visits of the WIS PI and student to CNRS, and will cover flights, domestic travel and expenses of a 1-week stay in France for the PI, and 4 weeks stay for the PhD (the length of stay may vary slightly from year to year).

CNRS	Year 1	Year 2	Year 3
PhD Student fellowship	40,927	40,927	40,927
Travel	5,000	5,000	5,000
Total	**45,927**	**45,927**	**45,927**

The PhD student fellowship is based on the 2017 CNRS salary grid for PhD students (gross salary + social charges + employment bonus). The travel budget for each year will cover visits of the CNRS PI and student to WIS, and will cover flights, domestic travel and expenses of a 1-week stay in Israel for the PI, and 4 weeks stay for the PhD (the length of stay may vary slightly from year to year).

PART F: Perspective & external funding

Ecole polytechnique and the Weizmann Institute will support additional funding for short stay visiting scientists and longer stay post-doc on both sides to strengthen the collaboration between Laboratoire de Météorologie Dynamique and the Department of Earth and Planetary Sciences. Opportunities will be sought through bilateral calls (ANR, HCP), in the ENI CBC Med 2014-2020 framework with some project content adjustment (European Neighbouring Instrument – Cross-Border Cooperation in the Mediterranean). We will apply to Israel Ministry of Science - France collaborative calls and Chateaubriand Fellowships of the French Embassy in Israel once issued.

PART G: Scientific quality of the teams

Please refer to the Annex.

PART H : Short curriculum vitae

Shira Raveh-Rubin

Education

2012	PhD, Weizmann Institute of Science
2006	M.Sc., the Hebrew University in Jerusalem, cum laude
2004	B.Sc. atmospheric sciences (major) and physics (minor), the Hebrew University in Jerusalem, cum laude

Employment

2017-present	Senior scientist, Department of Earth and Planetary Sciences, Weizmann Institute of Science
2012-2017	Post-doctoral fellow, ETH Zurich. Host: Prof. Heini Wernli

Selected grants and awards

2018-2022	Israel Science Foundation, Individual Research Grant 1347/18: "Multi-scale dynamical interactions of dry intrusions" (218,500 US$)
2018	Israel Science Foundation, New-Faculty Equipment Grant 2179/18 (259,700 US$)
2015-2017	Marie Heim-Vögtlin grant, Swiss National Science Foundation: "Dry intrusions: climatology, dynamics and link to extreme weather" (255,000 US$)
2012-2014	ETH Zurich Postdoctoral Fellowship (Co-funded by Marie Curie actions): "Governing mechanisms of large-scale strong winds and heavy precipitation in the Mediterranean region" (200,000 US$)

Philippe Drobinski

Education

1998	PhD, Ecole polytechnique, France
1994	M.Sc. in engineering, Ecole Centrale de Lille
1994	M.Sc. in meteorology, oceanography and environment, Université Paris 6

Employment

2007-present	Professor at Ecole polytechnique, Department of Mechanics
2001-present	CNRS senior scientist, Laboratoire de Météorologie Dynamique
1999-2001	Post-doctoral fellow, Laboratoire de Météorologie Dynamique. Host: Dr. Pierre H. Flamant
1999	Post-doctoral fellow, University of Washington. Host: Prof. Robert A. Brown

Selected grants and awards

2014-2023	Multi industrial grants – project coordinator: "TREND-X - Transdisciplinary approach for Renewable Energy Development" (> 6M€)
2010-2020	Multi-agencies support at national and international levels – project coordinator: "Hydrological cycle in the Mediterranean Experiment" (>20 M€)
2014-2017	European FP7 - partner coordinator: "EartH2Observe - Global Earth Observation for Integrated Water Resource Assessment" (255 k€)
2013-2017	French National Research Agency (ANR) - project coordinator: "REMEMBER - Understanding and modelling the REgional climate system ModEls in the Mediterranean for BEtter water-related Risk prevention in the context of global change"

Publications

Author or co-author of 146 articles and 8 books or book chapters (H factor = 33; average citation per year = 23.63)

PART I : Ethics

The project does not raise ethical questions.

References

Bastin S., Drobinski P., Guénard V., Caccia J.L., Campistron B., Dabas A.M., ... Werner C., 2006: On the interaction between sea breeze and summer mistral at the exit of the Rhône valley. Mon. Wea. Rev., 134, 1647-1668

Berthou S., Mailler S., Drobinski P., Arsouze T., Bastin S., Béranger K., Brossier C.L., 2018: Lagged effects of the Mistral wind on heavy precipitation through ocean-atmosphere coupling in the region of Valencia (Spain). Clim. Dyn., 51, 969-983

Bougeault P., Binder P., Buzzi A., Dirks R., Houze R., Kuettner J., Smith R.B., Steinacker R., Volkert H., 2001: The MAP Special Observing Period, Bull. Amer. Meteorol. Soc., 82, 433-462

Browning K.A., 1997: The dry intrusion perspective of extra-tropical cyclone development. Meteorol. App., 4, 317-324

Catto J.L., Raveh-Rubin S., 2019: Climatology and dynamics of the link between dry intrusions and cold fronts during winter. Part I: Global climatology. Clim. Dyn., in revision

Corsmeier U., Behrendt R., Drobinski P., Kottmeier C., 2005: The mistral and its effect on air pollution transport and vertical mixing. Atmos. Res., 74, 275-302

Cros B., Durand P., Cachier H., Drobinski P., Fre´jafon E., Kottmeier C., … Wortham H., 2004: The ESCOMPTE Program: An Overview, Atmos. Res., 69, 241-279

Drobinski P., Bastin S., Guénard V., Caccia J.L., Dabas A.M., Delville, P., ... Werner C., 2005: Summer mistral at the exit of the Rhône valley. Quart. J. Roy. Meteorol. Soc., 131, 353-375

Drobinski P., Anav A., Lebeaupin Brossier C., Samson G., Stéfanon M., Bastin S., … Viovy N., 2012: Modelling the Regional Coupled Earth system (MORCE): Application to Process and Climate Studies in Vulnerable Regions. Env. Modelling and Software, 35, 1-18

Drobinski P., Ducrocq V., Alpert P., Anagnostou E., Béranger K., Borga M., ... Estournel C., 2014: HyMeX: A 10-year multidisciplinary program on the Mediterranean water cycle. Bull. Amer. Meteorol. Soc., 95, 1063-1082

Drobinski P., Alonzo B., Basdevant C., Cocquerez P., Doerenbecher A., Fourrié N., Nuret M., 2017: Lagrangian dynamics of the mistral during the HyMeX SOP2. J. Geophys. Res.: Atm., 122, 1387-1402

Estournel C., Testor P., Taupier-Letage I., Bouin M.N., Coppola L., Durand P., ... Belamari S., 2016: HyMeX-SOP2: The field campaign dedicated to dense water formation in the northwestern Mediterranean. Oceanography, 29, 196-206

Flamant C., 2003: Alpine lee cyclogenesis influence on air-sea heat exchanges and marine atmospheric boundary layer thermodynamics over the western Mediterranean during a Tramontane/Mistral event. J. Geophys. Res.: Oceans, 108(C2)

Giorgi F., 2006: Climate change hot-spots. Geophys. Res. Let., 33(8)

Guenard V., Drobinski P., Caccia J.L., Campistron B., Bench B., 2005: An observational study of the mesoscale mistral dynamics. Boundary Layer Meteorol., 115, 263-288

Jiang Q., Smith R.B., Doyle J., 2003: The nature of the mistral: observations and modelling of two MAP events. Quart. J. Roy. Meteorol. Soc., 129, 857-876

Lebeaupin Brossier C., Béranger K., Deltel C., Drobinski P., 2011: The Mediterranean response to different space-time resolution atmospheric forcings using perpetual mode sensitivity simulations. Ocean Mod., 36, 1-25

Lebeaupin Brossier C., Béranger K., Drobinski P., 2012: Sensitivity of the North-Western Mediterranean coastal and thermohaline circulations as simulated by the 1/12° resolution oceanic model NEMO-MED12 to the space-time resolution of the atmospheric forcing. Ocean Mod., 43-44, 94-107

Lebeaupin Brossier C., Drobinski P., 2009: Numerical high-resolution air-sea coupling over the Gulf of Lions during two tramontane/mistral events. J. Geophys. Res.: Atm., 114(D10).

Obermann A., Bastin S., Belamari S., Conte D., Gaertner M.A., Li L., Ahrens B., 2018: Mistral and tramontane wind speed and wind direction patterns in regional climate simulations. Clim. Dyn., 51, 1059-1076

Pettre P., 1982: On the problem of violent valley winds. J. Atmos. Sci. 39, 542-554

Raveh-Rubin S., 2017: Dry intrusions: Lagrangian climatology and dynamical impact on the planetary boundary layer. J. Clim., 30, 6661-6682

Raveh-Rubin S., Catto J.L., 2019: Climatology and dynamics of the link between dry intrusions and cold fronts during winter. Part II: Front centered perspective. Clim. Dyn., in revision

Raveh-Rubin S., Wernli H., 2016: Large-scale wind and precipitation extremes in the Mediterranean: dynamical aspects of five selected cyclone events. Quart. J. Roy. Meteorol. Soc., 142, 3097-3114

Ruti P.M., Somot S., Giorgi F., Dubois C., Flaounas E., Obermann A., ... Ahrens B., 2016: MED-CORDEX initiative for Mediterranean climate studies. Bull. Amer. Meteorol. Soc., 97, 1187-1208

Somot S., Houpert L., Sevault F., Testor P., Bosse A., Taupier-Letage I., ... de Madron X.D., 2018: Characterizing, modelling and understanding the climate variability of the deep water formation in the North-Western Mediterranean Sea. Clim. Dyn., 51, 1179-1210

Sprenger M., Wernli H., 2015: The LAGRANTO Lagrangian analysis tool - version 2.0. Geo. Mod. Dev., 8, 2569-2586

Steppeler J., Doms G., Schättler U., Bitzer H.W., Gassmann A., Damrath U., Gregoric G., 2003: Meso-gamma scale forecasts using the nonhydrostatic model LM. Met. Atm. Phys., 82, 75-96

Wernli H., Schwierz C., 2006: Surface cyclones in the ERA-40 dataset (1958-2001). Part I: Novel identification method and global climatology. J. Atmos. Sci., 63, 2486-2507

Annex

WIS publications (in bold, contributors to the proposal)

Beusch L., **Raveh-Rubin S**., Sprenger M., Papritz L., 2018: Dynamics of a Puelche foehn event in the Andes. Meteorol. Z., 27, 67-80

Catto J.L., **Raveh-Rubin S.**, 2019: Climatology and dynamics of the link between dry intrusions and cold fronts during winter. Part I: Global climatology. Clim. Dyn., in revision

Raveh-Rubin S., 2017: Dry intrusions: Lagrangian climatology and dynamical impact on the planetary boundary layer. J. Clim., 30, 6661-6682

Raveh-Rubin S., Catto J.L., 2019: Climatology and dynamics of the link between dry intrusions and cold fronts during winter. Part II: Front centered perspective. Clim. Dyn., in revision

Raveh-Rubin S., Flaounas E., 2017: A dynamical link between deep Atlantic extratropical cyclones and intense Mediterranean cyclones. Atmos. Sci. Lett., 18, 215-221

Raveh-Rubin S., Wernli H., 2015: Large-scale wind and precipitation extremes in the Mediterranean: a climatological analysis for 1979-2012. Quart. J. Roy. Meteorol. Soc., 141, 2404-2417

Raveh-Rubin S., Wernli H., 2016: Large-scale wind and precipitation extremes in the Mediterranean: dynamical aspects of five selected cyclone events. Quart. J. Roy. Meteorol. Soc., 142, 3097-3114

Rubin S., Paldor N., Ziv B., 2007: On the dominance of changes in planetary angular momentum in large scale extra-tropical flows. Geophys. Res. Lett., 34, L23814

CNRS publications (in bold, contributors to the proposal)

Books and book chapters

Drobinski P., Alpert P., Cavicchia L., Flaounas E., Hochman A., Kotroni V., 2016: Strong Winds: Observed Trends, Future Projections, in The Mediterranean Region under Climate Change - A Scientific Update. IRD Editions, 115-122

Peer-reviewed articles

Flaounas E., **Raveh-Rubin S.**, Wernli H., **Drobinski P.**, Bastin S., 2015: The Dynamical Structure of Intense Mediterranean Cyclones. Clim. Dyn., 44, 2411-2427

Berthou S., Mailler S., **Drobinski P.**, **Arsouze T.**, Bastin S., Béranger K., Lebeaupin Brossier C., 2014: Prior History of Mistral and Tramontane Winds Modulates Heavy Precipitation Events in Southern France. Tellus, 66, 24064

Lambaerts J., **Lapeyre G.**, **Plougonven R.**, Klein P., 2013: Atmospheric response to sea surface temperature mesoscale structures. J. Geophys. Res., 118, 9611-9621

Lebeaupin Brossier C., **Drobinski P.**, Béranger K., Bastin S., Orain F., 2013: Ocean Memory Effect on the Dynamics of Coastal Heavy Precipitation Preceded by a Mistral Event in the North-Western Mediterranean. Quart. J. Roy. Meteorol. Soc., 139, 1583-1597

Rivière G., Arbogast P., **Lapeyre G.**, Maynard K., 2012: A potential vorticity perspective on the motion of a mid-latitude winter storm. Geophys. Res. Lett., 39, L12808

Salameh T., **Drobinski P.**, Menut L., Bessagnet B., Flamant C., Hodzic A., Vautard R., 2007: Aerosol Distribution over the Western Mediterranean Basin during a Tramontane/Mistral Event. Ann. Geophys., 11, 2271-2291

Guénard V., **Drobinski P.**, Caccia J.L., Tedeschi G., Currier P., 2006: Dynamics of the MAP IOP-15 Severe Mistral Event: Observations and High-Resolution Numerical Simulations. Quart. J. Roy. Meteorol. Soc., 132, 757-778

Corsmeier U., Behrendt R., **Drobinski P.**, Kottmeier C., 2005: The Mistral and its Effect on Air Pollution Transport and Vertical Mixing. Atmos. Res., 74, 275-302

Bastin S., Champollion C., Bock O., **Drobinski P.**, Masson F., 2005: On the Use of GPS Tomography to Investigate Water Vapor Variability During a Mistral/Sea Breeze Event in Southeastern France. Geophys. Res. Let., 32, L05808, doi:10.1029/2004GL021907