ARPAE

Agenzia regionale per la prevenzione, l'ambiente e l'energia

dell'Emilia - Romagna

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Atti amministrativi

Determinazione dirigenziale	n. DET-2021-265 del 07/04/2021
Oggetto	Struttura Idro-Meteo-Clima. Approvazione e sottoscrizione dell'Accordo di collaborazione con l'Università di Monaco Ludwig Maximilians nell'ambito del progetto di ricerca, denominato Towards seamless prediction of EXtremes (TEX).
Proposta	n. PDTD-2021-278 del 07/04/2021
Struttura adottante	Struttura Idro-Meteo-Clima
Dirigente adottante	Cacciamani Carlo
Struttura proponente	Struttura Idro-Meteo-Clima
Dirigente proponente	Dott. Cacciamani Carlo
Responsabile del procedimento	Cacciamani Carlo

Questo giorno 07 (sette) aprile 2021 presso la sede di Viale Silvani, 6 in Bologna, il Responsabile della Struttura Idro-Meteo-Clima, Dott. Cacciamani Carlo, ai sensi del Regolamento Arpae per l'adozione degli atti di gestione delle risorse dell'Agenzia, approvato con D.D.G. n. 114 del 23/10/2020 e dell'art. 4, comma 2 del D.Lgs. 30 marzo 2001, n. 165 determina quanto segue.

Oggetto: Struttura Idro-Meteo-Clima. Approvazione e sottoscrizione dell'Accordo di collaborazione con l'Università di Monaco Ludwig Maximilians nell'ambito del progetto di ricerca, denominato Towards seamless prediction of EXtremes (TEX).

RICHIAMATI:

- l'art. 15 della L. 7 agosto 1990, n. 241, ai sensi del quale le Pubbliche Amministrazioni possono concludere tra loro accordi per disciplinare lo svolgimento in collaborazione di attività di interesse comune;
- la L.R. 19 aprile 1995, n. 44 che istituisce l'Agenzia Regionale per la Prevenzione e l'Ambiente dell'Emilia-Romagna (ARPA) ed in particolare l'art. 5 che definisce le attività nell'ambito delle quali il Servizio (ora Struttura Idro-Meteo-Clima) opera;
- l'art. 5 della stessa legge che, al comma 2, prevede: "per l'adempimento delle proprie funzioni, attività e compiti, ARPA può definire accordi o convenzioni con Aziende ed Enti pubblici, operanti nei settori di Meteorologia, Climatologia dell'ambiente;
- la L.R. n.13/2015 del 30/07/2015 "Riforma del sistema di governo regionale e locale e disposizioni su città metropolitana di Bologna, Province, Comuni e loro unioni" ; in particolare, l'articolo 16 della Sezione II, della medesima Legge, che reca: "l'Agenzia regionale per la prevenzione e l'ambiente (ARPA) dell'Emilia-Romagna) è ridenominata "Agenzia regionale per la prevenzione, l'ambiente e l'energia" (Arpae);

PREMESSO:

- che l'Università di Monaco (LMU) ha, tra i propri obiettivi istituzionali, lo svolgimento di attività di ricerca nei campi della meteorologia, e in particolare, nella dinamica atmosferica e nello studio della sua prevedibilità;
- che LMU, insieme ad altre università e enti di ricerca tedeschi, è capofila di un importante di progetto di ricerca, denominato Towards seamless prediction of EXtremes (TEX), che ha lo scopo di approfondire la conoscenza e migliorare la capacità previsionale di eventi estremi;
- che LMU, nell'ambito del progetto TEX, ha proposto ad Arpae SIMC una collaborazione per lo l'implementazione della previsione probabilistica di eventi di precipitazione estrema, da verificare nell'ambito delle procedure di allertamento per piene fluviali dei bacini regionali;
- che esiste un comune interesse allo sviluppo della ricerca finalizzata a carattere interdisciplinare, nonché l'esigenza di verificare, in termini operativi, l'impatto dei nuovi studi derivanti dall'attività di ricerca sopraindicata;

che, in particolare, Arpae SIMC svolge attività operative e di supporto nel settore della previsione meteorologica, idrologica, agrometeorologica, nella valutazione climatologica e della qualità dell'aria;

CONSIDERATO:

- che tale collaborazione scientifica potrà contribuire ad elevare il grado quantitativo e qualitativo del patrimonio informativo meteorologico e atmosferico, ottimizzando i compiti istituzionali di entrambi gli Enti;

RITENUTO

- pertanto, nell'interesse delle parti, di approvare e sottoscrivere l' Accordo di collaborazione con l'Università di Monaco Allegato A) che si allega quale parte integrante di tale atto per lo svolgimento di attività nei settori della meteorologia dinamica e dei suoi impatti operativi nell'ambito del progetto di ricerca, denominato Towards seamless prediction of EXtremes (TEX); dettagliato nell'Allegato Tecnico dello stesso Accordo;
- che tale Accordo avrà la durata di due anni dalla data di sottoscrizione;
- che le attività saranno svolte mediante l'utilizzo di personale proprio e ogni altro onere economico dovrà essere preventivamente discusso ed approvato dalle parti;

SU PROPOSTA:

- del Dott. Carlo Cacciamani Responsabile della Struttura Idro-Meteo-Clima il quale ha espresso parere favorevole in merito alla regolarità amministrativa e tecnica del presente atto, ai sensi del regolamento per l'adozione degli atti di gestione delle risorse dell'Agenzia approvato con la Delibera del Direttore Generale n. 114 del 23/10/2020;

DATO ATTO:

- che il responsabile, del presente Accordo, per l'Università di Monaco è il Dott. Rabea Samak (del Dipartimento del Budget e Finanze di LMU) e per Arpae Simc è il Responsabile Dott. Carlo Cacciamani;
- che il referente scientifico per l'Università di Monaco è il prof. George Craig;
- che il referente per l'implementazione del Progetto per Arpae Simc è il dott. Sandro Nanni e il referente scientifico per Arpae Simc è il dott. Federico Grazzini;

DETERMINA

1. di approvare e sottoscrivere l'Accordo di collaborazione con l'Università di Monaco (LMU allegato A) al presente atto quale parte integrante e sostanziale, per lo svolgimento di attività nei settori della meteorologia dinamica e dei suoi impatti operativi nell'ambito del progetto di ricerca,

denominato Towards seamless prediction of EXtremes (TEX), dettagliato nell'Allegato Tecnico dello stesso Accordo;

2. di dare atto che l'Accordo avrà la durata di due anni dalla data di sottoscrizione;
3. di dare atto che il referente scientifico per l'Università di Monaco è il prof. George Craig e per Arpae Simc è il dott. Federico Grazzini;
4. di dare atto che le attività saranno svolte mediante l'utilizzo di personale proprio, e ogni altro onere economico dovrà essere preventivamente discusso ed approvato dalle parti.

Allegato:

A) Accordo di collaborazione con Allegato tecnico.

IL RESPONSABILE DELLA

STRUTTURA IDRO-METEO-CLIMA

(F.to Dott. Carlo Cacciamani)

Cooperation Agreement

The following Agreement is hereby concluded
between
Ludwig-Maximilians-Universität München
Geschwister-Scholl-Platz 1
80539 Munich, Germany
represented by the Head of Research Finance

represented by the Administration of the Academic Research Institution on behalf of the

Institute:
Meteorological Institute - SFB TRR 165, Chair: Prof. Dr. George Craig, Atmospheric Science
Theresienstraße 37
80333 Munich, Germany
- hereinafter referred to as the "LMU" -

and Karlsruhe Institute of Technology (KIT)
Hermann-von-Helmholtz-Platz 1
76344 Eggenstein-Leopoldshafen
represented by its President (Prof. Dr.-Ing Holger Hanselka)

for its
Institute of Meteorology and Climate Research –Troposphere Research (IMK-TRO)
Hermann-von-Helmholtz-Platz 1
76344 Eggenstein-Leopoldshafen
- hereinafter referred to as the "KIT" -

and
ARPAE-SIMC Emilia-Romagna
Carlo Cacciamani (Director)
Viale Silvani 6, 40122 Bologna, Italy
phone: +39 051 6497510, email: ccacciamani@arpae.it
- hereinafter referred to as the "ARPAE" -

and
European Centre for Medium-Range Weather Forecasts, with its headquarters at Shinfield Park, Reading, RG2 9AX, United Kingdom
represented by Prof Florian Pappenberger, (Director of Forecasts)
phone: +44 118 9499000; email: florian.pappenberger@ecmwf.int
- hereinafter referred to as the "ECMWF" -

Article 1 - Subject of the Cooperation Agreement

The Parties agree to conduct a research project ("Cooperation Project") entitled:

Towards seamless prediction of extremes (TEX)

jointly on the basis of and during the term of this Agreement.

The subject of the Cooperation Project is:

to provide meteorological operation centers with an alternative forecasting method based on the knowledge of the dynamics of extreme events. This differs from classical approaches based only on evaluations of local surface variables. In particular it relies on the recognition of certain atmospheric states or dynamic indicators that are believed to be precursors of extreme events; to expand and generalize the successful approach achieved in transfer project T1 for other European regions and into sub-seasonal forecast ranges (10-45 days); to build a prototype of real-time objective extreme precipitation event identification and classification chain for Northern Italy in liaison with ARPAE; to test its value in the local operational chain for flood forecasting; to build a prototype real-time forecast suite visualising forecasts of dynamical predictors for extreme precipitation events in a given European region up to the sub-seasonal forecast range in liaison with ECMWF.

The details of the project-related work are laid out in the work plans agreed between the Parties, as included in the proposal submitted to the DFG.

Article 2 - Contributions by the Parties

Each Party shall make best effort to provide the staff and in-kind contributions required for the conduct of the Cooperation Project as is necessary on its part and bear the corresponding costs. The services to be provided by the LMU and KIT may be supplemented by funds from the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation). The details of the (research) contributions planned by the Parties are described in the proposal to the DFG.
The Parties name the following contact persons for the implementation of the Project:

LMU:
Prof. Dr. George Craig
Meteorological Institute, Ludwig-Maximilians-Universität
Theresienstr. 37, 80333 Munich, Germany
phone: +49 89 2180-4570, email: george.craig@lmu.de

KIT:
Dr. Christian Grams
Institut für Meteorologie und Klimaforschung, Karlsruher Institut für Technologie,
Postfach 3640, 76021 Karlsruhe, Germany
phone: +49 721 60826544; e-mail: grams@kit.edu

ECMWF:
Dr. Linus Magnusson
Forecast Department
European Centre for Medium-Range Weather Forecasts
Shinfield Park, Reading, RG2 9AX, United Kingdom
e-mail: linus.magnusson@ecmwf.int

ARPAE:
Dott. Sandro Nanni
Head of Forecast Office
Struttura Idrometeoclima Arpae
Viale Silvani 6, 40122 Bologna, Italy
phone: +39 051 6497552
email: snanni@arpae.it

Article 3 - Support by the DFG

(1) The Parties expect that the DFG shall decide on the support of the Cooperation Project once it has evaluated the proposal.

(2) The DFG’s current guidelines for the use of funds, award letter and general guidelines shall be deemed as the basis of this Agreement and shall be acknowledged as binding by the Parties; however, ARPAE and ECMWF shall only acknowledge these guidelines and terms to the extent that it will be affected by them.

Article 4 - Cooperation

(1) The Parties shall use the time and care necessary for the implementation of the Cooperation Project as required and in consideration of the generally accepted rules of science and technology applicable to LMU, KIT and ARPAE, and in case of ECMWF its own Charter of Ethics, in order to achieve an optimum result. The Parties shall conduct work-related discussions and agree on the progress of the work at reasonable intervals, involving the employees entrusted with the project-related work.

(2) Each Party shall name a contact person to be contacted with regard to all matters that will need to be agreed within the scope of the cooperation.

(3) Employees of either Party who work on defined tasks at the premises of the respective other Party for a limited time, within the scope of the project-related work, shall be subject to the instructions given by the employees responsible at the Party concerned, to the extent required for carrying out the work. The relationships under the relevant service regulations and employment contracts shall not be affected.

Article 5 - Work Results, Rights of Use

(1) All protectable and non-protectable work results generated under the Cooperation Project exclusively by the employees of one Party are the property of this Party.

(2) The Parties grant each other, for the duration and purposes of the Cooperation Project, the non-exclusive, non-transferable, non-sublicensable, irrevocable and royalty-free right of use to the protectable and non-protectable work results generated under the Cooperation Project.

(3) In addition, the Parties grant each other, for the duration and purposes of the Cooperation Project, the non-exclusive, non-transferable, non-sublicensable and royalty-free right of use to previously generated protectable and non-protectable work results to the extent necessary for the realisation of the Cooperation Project.

(4) The Parties shall agree in writing on a case-by-case basis on the granting of further rights of use, particularly for purposes outside of the Cooperation Project and after the expiration of the Cooperation Project. Such rights shall be granted on terms customary in the market.

The LMU and the KIT hereby grant to ARPAE and ECMWF a non-exclusive, irrevocable, worldwide license, free of charge and without limitation in time, allowing the licensee to use,

to modify the results and to grant sub-licenses, but only for purposes in conformity with ECMWF’s purposes, objectives and activities as detailed in Article 2 of the Convention establishing ECMWF, as amended with effect from 6 June 2010 (“the Convention”) and as implemented by the ECMWF Council.
In the event that the LMU and the KIT grant the ARPAE and the ECMWF an exclusive right of use, the LMU and the KIT shall retain for its own research and educational purposes a right of use that is non-exclusive, non-transferable, sublicensable only for research partnerships, irrevocable and royalty-free.

(5) Joint work results are work results in which employees from more than one Party or all Parties are involved and whose parts cannot be attributed to one Party alone. Rights of use shall be granted in accordance with Article 5, paragraph 7, sentences. 3 ff.

(6) Each Party may, according to its discretion, apply for a domestic and/or foreign patent or utility model for any invention made under the Cooperation Project based on work results generated by that Party, and claim the resulting industrial property rights.

(7) Joint inventions are inventions in which employees of more than one Party or all Parties are involved and whose parts cannot be the subject of industrial property rights applications filed separately by each Party. The respective Parties shall come to agreements on the treatment of joint inventions, especially the application for and maintenance of industrial property rights and on the responsibility for the associated costs. The Parties grant each other a non-exclusive, non-transferable, sublicensable, irrevocable and royalty-free right of use for the purposes and duration of the Cooperation Project. For purposes outside of the Cooperation Project or after the expiration of the Cooperation Project, the right of use shall be granted on terms customary in the market and agreed in writing.

(8) If a Party is not interested in filing an application for industrial property rights it will offer this intellectual property right or it’s share in it to the other Parties at conditions customary in the market. The details of assignment shall be agreed upon by the Parties in a separate agreement. In case of joint inventions, the offer shall be made to the other Parties involved in the joint invention first. Each Party shall pay for itself the employee invention compensations due to its staff members.

(9) The Parties are not responsible for ensuring that the rights of use granted under this Agreement are free of third-party rights. If they become aware of any third-party rights, they shall inform the other contracting Parties accordingly and without delay.

(10) If a Party uses Open-Source ("OSS") components for the execution of the work to be done by him under the scope of this Agreement, he shall inform the other Parties accordingly and make available the applicable OSS-license terms.
If a Party uses OSS-components with copyleft-effect for the execution of the work to be done by him under the scope of this Agreement and if these components will become part of the work results, he shall inform the other Parties about the manner of their utilization. The Parties must give their express consent to the utilization of OSS-components under licenses with copyleft-effect for the creation of work results.
Notwithstanding the provisions stated above, before the start of a work package, the Parties may determine in a separate written agreement that the utilization of specific OSS-components or of OSS as such is excluded or allowed for this defined work package.
The Party using OSS will provide the other Parties all documents and materials available and necessary to be able to comply with the duties resulting out of the OSS-license conditions. If a Party becomes aware of any potential incompatibilities of the OSS utilized in the joint project, he will inform the other Parties accordingly. The Party who introduces OSS into the project will work with reasonable means towards the prevention of such incompatibility.
The mere utilization of OSS-components as a tool (particularly as compiler or editor) for the creation of work results and non-contractual intellectual property does not require any approval or notice, provided that this utilization does not lead to the application of the OSS-conditions to the work results.
In case of contradiction between the OSS-license conditions and the license conditions contained in this Agreement, the OSS-license conditions will prevail.

Article 6 - Confidentiality

(1) The Parties hereby agree that they will not disclose any information that has been marked as confidential provided by the disclosing Party during the Cooperation Project; Oral or visual information shall be designated confidential, summarized in writing by the disclosing Party and sent to the receiving Party within 21 days upon original communication. This obligation of confidentiality shall also continue to apply for a period of three years beyond the term of this Agreement.

(2) This obligation (pursuant to Article 6, paragraph 1) shall not apply to information that
- is common knowledge through publications or the like,
- becomes common knowledge through no fault of the receiving Party,
- was demonstrably known to the receiving Party before the date on which it was provided,
- was generated by the receiving Party independently of such provision,
- was provided to the receiving Party by a third party without any obligation to confidentiality.

As far as information has to be disclosed due to a legal obligation or an order by court or another authority, such disclosure shall not be an infringement of the confidentiality obligations. If any Party becomes aware that it will be required, or is likely to be required, to disclose Confidential Information in order to comply with applicable laws or regulations or with a court or administrative order, it shall, to the extent it is lawfully able to do so, prior to any such disclosure

- notify the disclosing Party, and
- comply with the disclosing Party's reasonable instructions to protect the confidentiality of the information.

Apart from this disclosure the obligation according to Art. 6 (1) shall remain unaffected.

(3) The DFG is not deemed to be a "third party" within the meaning of this clause insofar as the DFG is entitled to such information according to its current grant conditions, award letter and general guidelines.

Article 7 - Publications

(1) Each Party shall have the right to publish the work results it has achieved within the scope of the Cooperation Project. However, the mutual protectable interests of either Party must also be taken into account.

(2) The Parties shall notify each other in due time about planned publications. Unless the other Parties object within a period of four weeks after they have received the proposed publication, their consent to the publication shall be considered granted. The publication date may be suspended for a limited time at the request of either Party, but no longer than for a period of five months, for example, in order to enable the respective Party to file an application for industrial property rights. In the event that the Parties are unable to reach an agreement on the content and/or the form of the planned publication within the said time limit, the publication in question may also be filed for publication without the consent of the other Parties provided that the publication does not disclose the other Parties' work results or confidential information.

(3) All publications shall refer explicitly to the Cooperation Project as the origin of the published results and to the DFG as the funder providing the funds.

(4) The employment rights and obligations of any staff members of the LMU and the KIT with regard to publications shall not be affected. The Parties shall take the legal obligations and justified interests of doctoral and postdoctoral researchers into account to a reasonable extent, i.e. also by granting their consent to a shortening of the compulsory waiting period

defined in Article 7, paragraph 2, if attainment of a doctorate or habilitation is affected by the work in the Cooperation Project.

(5) The rights of the DFG as the funder of this Cooperation Project, particularly its entitlement to report on the work and the results achieved within the scope of DFG funding, shall not be affected.

Article 8 - Warranty, Liability

(1) The Parties shall waive the enforcement of any warranty claims within the scope of the Cooperation Project with regard to the know-how provided and the achieved work results.

(2) Otherwise, each Party, to the extent permitted by law, shall only be held liable for any property damage or financial losses caused by wilful intent or gross negligence. Liability for consequential damages shall be excluded.

(3) The exclusions and limitations of liability shall not apply to claims according to the Product Liability Act (Produkthaftungsgesetz) based on fraudulent behaviour or claims based on the liability for guaranteed characteristics and for the injury of life, body, or health.

(4) Insofar as the liability of the partners is excluded or limited in accordance with the above provisions, this shall also apply to the personal liability of the representatives, employees and other vicarious agents of the partners.

Article 9 - Term of Agreement and Termination

(1) This Agreement shall take effect upon the DFG's granting of funds to the LMU and KIT. The Agreement shall expire upon completion of DFG funding, unless any arrangements or obligations beyond the end date have been agreed in writing.

(2) This Agreement may only be terminated early for good cause. "Good cause" is the fact that the results show that the objective of the Project cannot be achieved or can only be achieved with disproportionate effort. Termination must be made in writing. The DFG must be informed accordingly.

Article 10 - Final Provisions

(1) For the purposes of this paragraph, “Data Protection Law” shall mean (i) in respect each Party other than ECMWF, the General Data Protection Regulation 2016/679/EU, as amended (GDPR) and any alternative data protection law applicable to such Party, and (ii) in respect of ECMWF, its own policies and procedures as well as supervisory mechanisms in respect of the protection of personally identifiable information, notably the Policy for Personally Identifiable Information Protection, as amended, which is deemed to provide an adequate level of protection relative to the standards reflected in the GDPR.

Where the processing of personal data by either Party is required under this Cooperation Agreement, such Party shall process personal data in accordance with applicable Data Protection Law during the term of this Consortium Agreement. If either Party processes personal data outside the European Economic Area (EEA), or allows such personal data to be accessed from outside the EEA, it shall do so in a manner which satisfies applicable Data Protection Law for the implementation of adequate safeguards for transfers of personal data.

Upon termination or expiry of this Cooperation Agreement, each Party serving as processor shall either delete or return to the controller all personal data processed under this Cooperation Agreement, unless Data Protection Law requires otherwise.

In processing personal data pursuant to this Cooperation Agreement, each Party shall:

- process, or permit to be processed, personal data only for the purposes of the performance of this Cooperation Agreement;
- ensure that its personnel are subject to an obligation of confidentiality in respect of the processing of personal data under this Cooperation Agreement;
- ensure that appropriate technical and organisational measures shall be taken against unauthorised or unlawful processing of personal data and against accidental loss or destruction of, or damage to, personal data;
- not disclose or transfer personal data to any third-party other than where strictly necessary for the purposes of the performance of this Cooperation Agreement.

(2) If any individual provision of this Agreement is held to be or becomes ineffective, the validity of the remaining provisions shall not be affected. In such a case, the Parties shall endeavour to agree on a supplementary clause to this Agreement in the spirit of the initially intended purpose by mutual consent.

(3) Any amendments or supplements to this Agreement must be made in writing and shall be subject to the prior consent of the DFG. This shall also apply to an amendment of the written form clause itself.

(4) This Cooperation Agreement shall be construed in accordance with and governed by the laws of Belgium.

(5) The Parties shall endeavour to settle their disputes amicably. All disputes arising out of or in connection with this Cooperation Agreement, which cannot be solved amicably, shall be finally settled under the Rules of Arbitration of the International Chamber of Commerce by three arbitrators appointed in accordance with the said Rules. The place of arbitration shall be Brussels if not otherwise agreed by the conflicting Parties. The language to be used in the arbitral proceedings shall be English unless otherwise agreed upon. The award of the arbitration will be final and binding upon the Parties. This includes all matters of injunctive relief.

(6) Nothing in this Cooperation Agreement shall be deemed a waiver, explicit or implicit, of the privileges and immunities awarded to ECMWF, an inter-governmental organization, as per its Convention and Protocol by its Member States.

Munich, ... (Date)

......................… …….(LMU)

....
Dr. Rabea Samak
Leiterin des Referates VII.5 Drittmitel
(University Administration)

Karlsruhe, ... (Date)

Karlsruhe Institute of Technology (KIT)

....

Legal Affairs

Bologna, ... (Date)

.... (Arpae-SIMC)

....
Carlo Cacciamani
Arpae-SIMC Director

Reading, ... (Date)

.... (ECMWF)

....
Prof Florian Pappenberger
Director of Forecasts

3.1 General information about Transfer Project T2

3.1.1 Title: Towards seamless prediction of extremes (TEX)

3.1.2 Research area: *Atmospheric Science (313-01)*

3.1.3 Project leaders:

Prof Dr George C. Craig, born 02/10/1961, Canadian
Meteorologisches Institut, Ludwig-Maximilians-Universität,
Theresienstr. 37, 80333 München, Germany
phone: +49 89 2180-4570; e-mail: george.craig@lmu.de

Dr Christian Grams, born 12/06/1981, German
Institut für Meteorologie und Klimaforschung, Karlsruher Institut für Technologie,
Postfach 3640, 76021 Karlsruhe, Germany
phone: +49 721 608-26544; e-mail: grams@kit.edu

Is the employment of the project leader(s) at the institution(s) indicated contractually secured for the duration of the proposed funding period? **Yes.**

Do any of the above mentioned persons hold fixed-term positions? **Yes:** Dr. Christian Grams

End date of fixed-term contract: 30.9.2022

Further employment is planned until: Permanent pending evaluation of Dr. Grams' HGF Young Investigator Group in 2021

Funding for the position(s) of the project leader(s) at the institution(s) indicated is covered by core support (state funds or similar): **Yes**, base funding LMU / KIT.

3.1.4 Application partners

ARPAE-SIMC Emilia-Romagna
represented by **Dott. Carlo Cacciamani** (Director)
Viale Silvani 6, 40122 Bologna, Italy
Tel:+39 051 6497510; email: ccacciamani@arpae.it
Web: https://www.arpae.it/sim/

ARPAE-SIMC is the regional Hydro-Meteo-Climate Service belonging to the Regional Agency for Prevention and Environment and Energy of the Emilia-Romagna region in northern Italy. It provides meteo-hydrological information and forecasting to users across the Region and the Po basin. The Service is structured in seven technical divisions: hydrology, climate and agricultural meteorology, environmental meteorology, operational forecasting, numerical modelling, radar meteorology and nowcasting and computing division, accounting for about 90 staff people distributed between Bologna (headquarter) and Parma offices. It is one of the Center of Competence in Meteorology and Hydrology for the Italian Department of Civil Protection of the Presidency of the Council of Ministers.
ARPAE-SIMC manages a dense regional hydro-meteo-pluviometric network, produces daily weather forecasts using meteorological limited area models and maintains operational products for flood forecasting and water management. It also carries out development and implementation activities regarding: numerical model forecasting at high spatial resolution and the probabilistic forecasting system at the medium range for meteo-hydrological risks; nowcasting system for very short-range weather forecasts for extreme weather events; hydrological-hydraulic modelling to support the regional and interregional basins authorities; integrated systems, based on both GIS techniques and mathematical models to support decisions by the regional government in agro-environmental policies; monthly and seasonal forecasting techniques for regional and national purposes; regionalisation studies of global climate change. ARPAE-SIMC participates to the EU programmes, to the European Centre for Medium-range Weather Forecasts and to other international organisations and has already been beneficiary in over 30 international projects financed by EU in different programmes (H2020/LIFE Programmes, European Funds for Regional Development etc.). Its annual budget is in the order of 8 million EUR.
ARPAE-SIMC will benefit from the project results increasing its capability of developing forecasting products for the regional stakeholders and within the coordinated system of regional hydro-meteorological services in Italy.

European Centre for Medium-Range Weather Forecasts (ECMWF)
with its headquarters at
Shinfield Park, Reading, RG2 9AX, United Kingdom
represented by **Prof Florian Pappenberger**, (Director of Forecasts)
phone: +44 118 9499000; email: florian.pappenberger@ecmwf.int
web: https://www.ecmwf.int/

The European Centre for Medium-Range Weather Forecasts (ECMWF) is an independent intergovernmental organisation supported by 34 states. ECMWF is both a research institute and a 24/7 operational service, producing and disseminating numerical weather predictions to its member states. This data is fully available to the national meteorological services in the member states. The Centre also offers a catalogue of forecast data that can be purchased by businesses worldwide and other commercial customers. The supercomputer facility (and associated data archive) at ECMWF is one of the largest of its type in Europe and member states can use 25% of its capacity for their own purposes.
The organisation was established in 1975 and now employs around 360 staff from more than 30 countries. ECMWF is one of the six members of the Co-ordinated Organisations, which also include the North Atlantic Treaty Organisation (NATO), the Council of Europe (CoE), the European Space Agency (ESA), the Organisation for Economic Co-operation and Development (OECD), and the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT).
ECWMF will benefit from the transfer of fundamental understanding of processes driving extremes and process diagnostics. The outcome from TEX will serve as a showcase for refined products based on the ECMWF forecasts. ECMWF will provide access to the operational forecast archive and to computing facilities such as the newly established European Weather Cloud or equivalent to implement the pre-operational forecast suite. This collaboration goes in the direction of member states' demand for specific products for extreme events and contributes the World Meteorological Organisation's (WMO) HIWeather project.

3.1.5 Legal issues

This project includes:
(1) Research on human subjects or human material . . . . .no
(2) Clinical trials . . . . .no
(3) Experiments involving vertebrates . . . . .no
(4) Experiments involving recombinant DNA . . . . no
(5) Research involving human embryonic stem cells . . . . no
(6) Research concerning the Convention on Biological Diversity . . . . no
(7) Investigations involving dual use research of concern . . . . no

3.2 Summary

There is a growing interest in the weather forecast community to complement direct output from numerical weather prediction (NWP) models with other diagnostics that convey the underlying physical processes which make a meteorological event an extreme event. In a previous transfer project T1 of the SFB-Transregio “Waves to Weather” (W2W) a strategy was designed to classify precipitation extremes in Northern Italy and to provide additional information on the physical and dynamical drivers associated with it. Working in collaboration with the regional meteorological service ARPAE-SIMC, we developed diagnostics to follow the unfolding of the extreme event across scales from its earliest stage in the forecast, and thus from longer lead times, to its actual occurrence. This allowed us to consider the changing predictability of different scales of motion and processes depending on the forecast lead time.

Building on this success for a particular type of weather event in a particular region, we now propose a new transfer project T2 “Towards seamless prediction of EXtremes” (TEX). The goal is to expand and generalize this dynamical methodology to other regions and into the sub-seasonal forecast range (10-30 days) to create prototype forecast products at ECMWF as well as at ARPAE-SIMC. TEX will provide the forecaster a “narrative” of the unfolding of an extreme event, which describes the predictability of the relevant dynamical processes at different lead times. Thus, TEX will support the forecasting and warning chain with important dynamical understanding which goes beyond relying on black box forecast products from imperfect models. To this end we will develop a truly seamless diagnostic framework which allows to compile a systematic documentation of the meteorological evolution of relevant predictors at different lead times. The accompanying prototype forecast products will demonstrate how dynamical thinking and process-oriented predictors can serve as a “warning bell” for a critical meteorological evolution at different lead times ranging from the sub-seasonal forecast horizon down to medium- and short-range forecasts. In a first step TEX will transfer the insight of T1 into an operational forecast and warning system for extreme precipitation events in Northern Italy (WP1) in close collaboration with

ARPAE-SIMC. Next, we will develop a unified, seamless framework which systematically documents the linkage of the large-scale flow to extremes and their dynamical drivers for other European regions from sub-seasonal down to short-range forecast ranges (WP2). This will be complemented by a prototype forecast framework which integrates existing forecast products for extremes with forecast probabilities for a hierarchy of indices describing the large-scale flow and respective dynamical predictors following the evolution of the forecast leading to an extreme (WP3). The diagnostic framework and prototype forecast products will be implemented in close collaboration with ECMWF and for both precipitation and temperature extremes. Focusing on the predictable scales of motion and processes, our proposed seamless approach will provide a way to increase preparedness for forecasting extremes at the medium and extended forecast ranges (10-30 days), compared to classical forecast products for local extremes which lack skill at these forecast ranges. The need for better guidance across lead times is becoming even more substantial in view of the increasing likelihood of extreme events in a warming climate and remaining deficiencies in numerical models for the foreseeable future. Finally, TEX will contribute to the key goal of WMO's HIWeather project to strengthen warning procedures across scales and its "Warning Value Chain" sub-project.

3.3 Research rationale

3.3.1 State of the art and preliminary work by participating researchers

The idea that extreme events could be associated with particular large-scale atmospheric states, so that owing their higher predictability we could infer the probability of a local extreme, is an active research topic in the theory of dynamical systems (e.g. Messori et al. 2018). Likewise, forecaster experience has shown many examples of the linkage of large-scale atmospheric flows and extreme weather events. ECMWF has compiled a comprehensive catalogue of extreme events and their forecast evolution (**Magnusson 2019**). For most cases, this highlights the forecast's ability to capture sudden changes in weather patterns potentially leading to extremes at medium and even extended forecast ranges. At the same time, forecasts of the detailed impact in terms of surface weather were only possible at short range. Higher predictability in the larger scale compared to the smaller scales and direct weather impact has also been reported for the Central-European flood of 2002 (**Grazzini and Van der Grijn 2003**), for the exceptional European heat wave in 2003 (**Grazzini et al. 2003**), and for the exceptional snowfall events in southern Europe of February 2012 (**Grazzini 2013**).

The linkage between extreme precipitation events (EPEs), temperature extremes, and extreme winter storms and the large-scale circulation has been established in past research with a significant contribution of the researchers participating in this proposal (citations highlighted in bold font) and other scientists in W2W. For example, Martius et al. (2008) have indicated that 73% of days with extreme precipitation over the Swiss Alps are associated with an elongated trough over Western-Europe and also **Grazzini (2007)** recognised a similar archetypal large-scale flow pattern associated with EPEs on the southern side of the Alps. **Grazzini (2007)** and Martius et al. (2008) also have shown that the synoptic wave generating the precipitation extremes is part of an incoming Rossby wave packet propagating from upstream regions. Likewise, a systematic link of incoming Rossby wave packet and amplified large-scale flow patterns to extreme winter storms and temperature extremes has been reported (e.g. Coumou et al. 2014, Wirth and Eichhorn 2014, Fragkoulidis et al. 2018; Fragkoulidis and Wirth 2020). When coherent and long-lasting Rossby wave packets are already present in the forecast initial conditions, the atmosphere is consistently better predictable than in average conditions (**Grazzini and Vitart 2015**) corroborating that the large-scale circulation might give better guidance for the likelihood of extremes. Enhanced forecast guidance due to linkages to the large-scale circulation have also been shown for cold spells (**Ferranti et al. 2018, Büeler et al. 2020**), drought and heat waves (e.g. Lavayasse et al. 2018), and not only in Europe, but also other extratropical regions (e.g. Vigaud et al. 2018).

Beyond Rossby wave packets, several studies emphasised the often remote sources of moisture (e.g. Winschall et al. 2012, 2014) and the link between weather systems such as extratropical cyclones or blocking anticyclones embedded in the amplified Rossby wave packet and surface extremes (e.g. Pfahl 2014). For EPEs, Lavers and Villarini, 2013 emphasised the systematically enhanced integrated water vapor transport (IVT) and atmospheric river activity prior to EPEs in Europe. This often occurs at the flanks of a blocking anticyclone or in a region of strong pressure gradients south of an extratropical cyclone (e.g. **Grams et al. 2014, Piaget et al. 2015, Pasquier et al. 2019**). More recently, **Pohorsky et al. (2019),** for the first time, proved the systematically enhanced occurrence of EPEs in Europe downstream of North Atlantic extratropical transition of tropical cyclones. They further showed that this is due to enhanced IVT in a highly amplified Rossby wave packet downstream of extratropical transition.

A recent example of an EPE highlights the importance of the large-scale flow configuration and enhanced IVT. In early October 2020, Southern-France and Northern-Italy were hit by extreme precipitation which caused

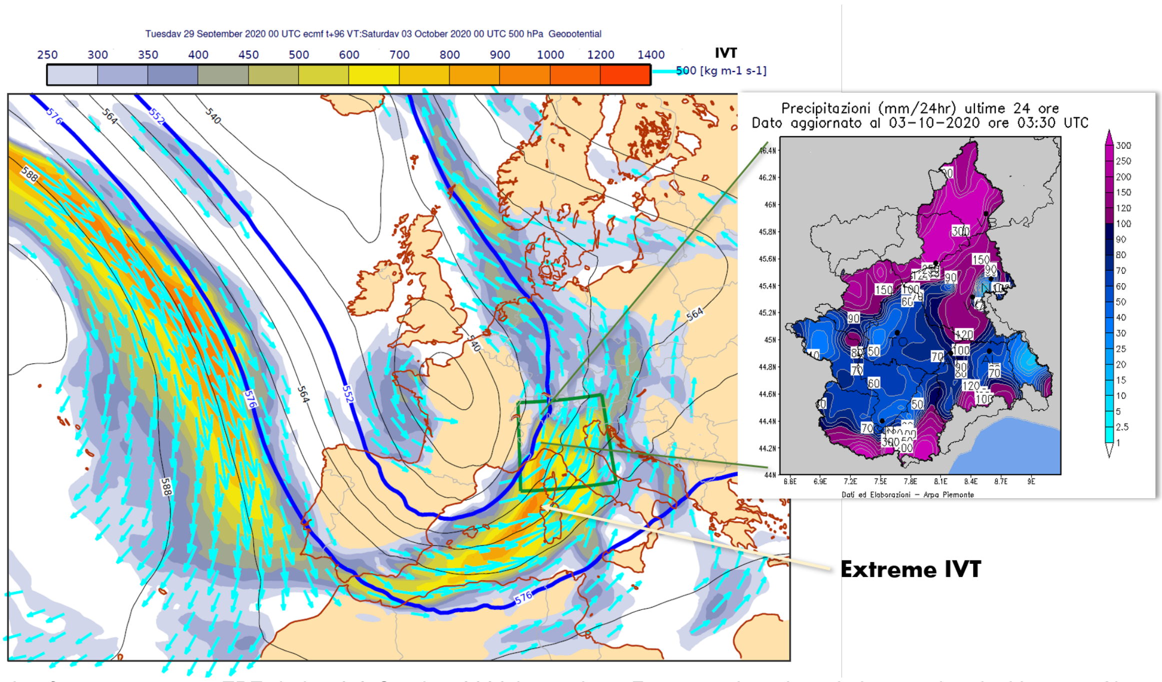

***Figure 1**: Example of a recent severe EPE during 2-3 October 2020 in southern France and northern Italy associated with storm Alex. Exceptional high values of IVT (color shading) indicate an atmospheric river along the flanks of the Rossby Wave (reflected in the curved and dense blue contours of geopotential height at 500hPa) and enters the target region (green box) from south-west. The inset on the right shows the observed precipitation amount (24h accumulation) recorded in the Piedmont region, with record-breaking values in excess of 600mm/24h on the southern border with France and on the northern border with Switzerland (data provided by ECMWF and ARPA-PI).*

enormous damages to infrastructures and 15 deaths, plus a number of missing people (Fig. 1). In places, along the border of the two countries, the precipitation amount broke the all-time record at daily and sub-daily time scales (ARPA Piemonte Tech. Report 2020; inset Fig. 1). The flow situation was characterised by a highly amplified upper-level trough over France and an upstream ridge. In addition, IVT was strongly enhanced at the flanks of the amplified Rossby wave packets where the geopotential height (and pressure) gradients were strongest (Fig. 1).

In general, different configurations of the large-scale circulation and upper-tropospheric Rossby wave pattern can be described in terms of so-called weather regimes, which are defined by their quasi-stationarity, persistence, and recurrence (e.g. Vautard 1990, Michelangeli et al. 1995, **Ferranti et al. 2015**). For the Atlantic-European region multiple regime definitions exist ranging from a simple differentiation of the bimodal North Atlantic Oscillation (NAO), via the widely used categorisation of seasonal 4 regimes, to complex year-round definitions including a weather regime life cycle (**Grams et al. 2017**). In essence, all these definitions stress different aspects of the large-scale situation but in concert they allow a full description of large-scale flow variability in the Atlantic-European region **(Grams, Ferranti, and Magnusson, 2020)**.

Past research has shown that weather regimes systematically modulate the environmental conditions conducive to extreme events and thus the occurrence of a regime is indicative of the likelihood of extreme surface weather (e.g. Yiou and Nogaj, 2004). Recent research in the group of PI Grams made a strong effort in developing a robust definition of weather regime life cycles including important life cycle stages such as the onset, decay and transition (**Grams et al. 2017**). Based on this definition the systematic modulation of surface weather and extremes by weather regimes has been documented for heat waves in summer (**Schaller et al. 2018, Spensberger et al. 2020**), cold spells in winter (**Papritz and Grams 2018**), thunderstorm activity (**Mohr et al. 2020**), and for EPEs (**Pasquier et al. 2019**). The latter study emphasised the strong modulation of IVT and atmospheric river activity leading towards EPEs in Europe. In addition, extremes in terms of the societal impact were investigated with an emphasis on extreme temperature, wind, and precipitation events affecting the energy sector (**Grams et al. 2017, Beerli et al. 2017, Beerli and Grams 2019, Büeler et al. 2020**). Common to all these studies is the fact that weather regimes often provide multiple pathways to extreme events and substantially change the odds of an extreme in specific regions. The occurrence of these regime pathways and associated extremes is modulated by remote drivers such as tropical convection or the stratosphere which thus provide an additional potential source of predictability on sub-seasonal time scales (e.g. Cassou et al. 2005, **Beerli and Grams 2019**).

A first important systematization of process understanding and knowledge about the dynamics and large-scale drivers of EPEs has been carried out in project T1 (Oct 2017 - Nov 2020). For the first time, T1 provides a comprehensive and systematic investigation of different EPE categories (over a test region) and their linkage with the large-scale dynamics by bringing together the knowledge accumulated in the previous literature. The statistics was built over more than 800 cases and a EPE classification method was proposed in **Grazzini et al. 2020a** (Part I). The method successfully identifies three EPE categories (see WP1.1 for a brief explanation). **Grazzini et al. 2021** (Part II) show that the categories have different large-scale precursors. Finally, in **Grazzini et al. 2020b** we analyse a historical case using this classification framework envisaging a possible application in real-time forecast operations. Independently, recent work by **Mastrantonas et al. 2020** reconfirmed the robust linkage between large-scale circulation patterns and EPEs in different parts of Europe.

3.3.2 Current state of understanding and challenges in application

The devastating effects of EPEs justify the effort in trying to build an early warning system for preparation of all those actions necessary to ensure the safety of people and limit damage to infrastructure. Transport limitations, lowering dam levels, suspending activities in hazardous areas usually require good anticipation to be effective and at the same time to not cause sudden disruptions. For this reason, it would be ideal to design specific meteorological products that help to recognize the potential for an extreme, including an estimate of how exceptional it is in relation to the climatological record. Precipitation has intrinsically high spatial variability and its predictability is highly sensitive to the dominant processes involved, with weakly convective cases being very difficult to predict even at short range (**Keil et al. 2011**). This sensitivity of predictability is even more critical in case of EPE. For example, in terms of probabilistic skill of direct grid-point precipitation, the limit of utility (ROC area above the climatological forecast) is just above one day (global average) for high precipitation thresholds indicative of extreme events (Hewson and Pillosu, 2020). For Italy a detailed verification of precipitation forecasts in the ECMWF high resolution (HRES) run and COSMO local area model is carried out every season by ARPAE, using the dense network of precipitation observation as a reference. These routine verifications also reveal that a useful skill in terms of precipitation (Threat Score greater than 0.5) can be achieved only 1 to 2 days in advance for high thresholds representative of EPEs (e.g. greater than 20mm/24 for an area average) in winter and autumn. However, in spring and especially in summer the skill horizon of the aggregated precipitation forecast is even shorter due to the prevailing convective nature (personal communication M. Tesini, Verification reports ARPAE-SIMC). To overcome this severe and intrinsic limitation due to the exclusive usage of local forecast data like direct model precipitation output, we propose to apply a dynamical approach to weather forecasting, using also the information contained in the more predictable large-scale and time-averaged flow. In this respect, recognizing key drivers and incorporating them during forecast calibration, can be strategic to achieve an innovative approach to weather forecasting.

The recent case of the EPE in southern France and Northern Italy in early October 2020 is a good example for the prospects of this endeavour. Based on direct precipitation forecasts, the highest warning levels were issued only 36h before the start of the event (Arpa Piemonte, 2020). Although the synoptic setting was consistently well predicted from the medium-range up to the short-range, unavoidable uncertainty in the fine positioning of precipitation maxima actually prevented issuing precipitation warnings at longer ranges. This is a typical warning for extreme precipitation cases where great attention is put in minimizing false alarms at expenses of anticipation of the event. To illustrate this typical forecast behaviour and the main concept of the project, we briefly compare the already available extreme forecast index[1] (EFI) for direct precipitation forecast and the large-scale flow quantity IVT in the ECMWF medium-range ensemble forecast for this event (Fig. 2). Four to five days before the event, the IVT product clearly indicated that a very unusual and likely extreme event was going to occur. This is reflected in high values of EFI for IVT above 0.8 extending over a large region from the Atlantic towards the western Alps (Fig. 2 left).

In contrast, the EFI for precipitation had a much smaller amplitude and spatial coherence compared to IVT (Fig. 2 right). In addition, the shift of the tail of the distribution (SOT; black contours in Fig. 2), indicated a significant shift toward extremes and unprecedented values in the IVT, with values exceeding 1.0 in the French-Italian border region (Fig. 2 left). The SOT for precipitation at the same time does not give hint of the extreme nature of the event (values around 0 in Fig. 2 right). Although we here discussed only IVT, this recent example illustrates the potential for extending warning methods and the anticipation of extremes by focusing on the detection and monitoring of the multiple drivers of the hazard in the forecasts. By this approach forecasters could make better use of the predictable scales of atmospheric variability also for predicting extremes.

The results presented in this section show the potential of using dynamical knowledge of the chain of events leading to weather extremes to aid forecasters in interpreting and applying numerical model output. The previous Transfer Project T1 showed how this could be done by developing new diagnostics based on recent

[1] For an explanation and interpretation of the EFI refer to https://confluence.ecmwf.int/display/FUG/Extreme+Forecast+Index+-+EFI

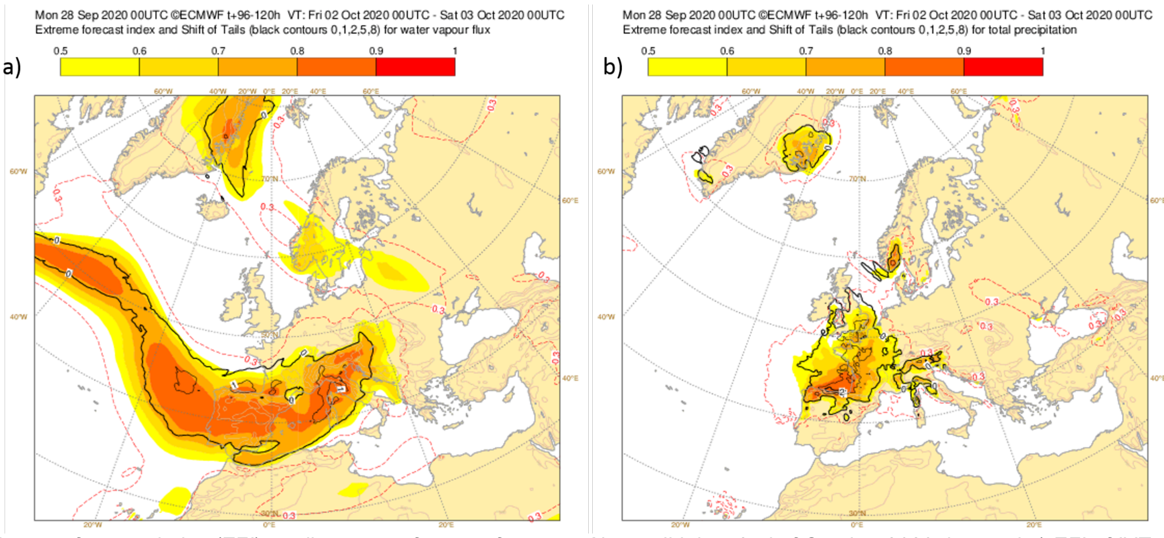

***Figure 2**: Extreme forecast index (EFI) medium-range forecast for storm Alex, valid time 2nd of October 2020; in panel a) EFI of IVT and in panel b) EFI for total precipitation in 24h. Note the higher values of IVT EFI (shading in excess of 0.8 already at D+4) compared to the EFI for total precipitation over the Alpine area which is also remarkable but slightly lower. In addition, the Shift of Tail distribution (black contours) is above 1 for IVT while precipitation is just above 0 meaning that the upper part of the tail of the IVT distribution is very extreme compared to the model climate distribution (plots provided by ECMWF).*

research results in W2W and elsewhere. This initial attempt focused on a particular weather hazard, extreme precipitation, in a particular region, Northern Italy, but the successful results immediately suggest that the work be developed in two directions. First, the methods developed in T1 should be brought into a prototype system where they can be deployed and evaluated by forecasters in real-time. Second, there is an opportunity to extend and develop the methodology for a wider variety of weather events across Europe. To realize this potential will require additional expertise and the partnership of a leading European weather service. The purpose of the Transfer Project T2 (TEX) is to address these needs.

3.3.3 Project-related publications by participating researchers

a) Peer-reviewed articles and books

Beerli, R., and **C. M. Grams, 2019**: Stratospheric modulation of the large-scale circulation in the Atlantic–European region and its implications for surface weather events. *Q.J.R. Meteorol. Soc.*, **145**, 3732–3750, doi:10.1002/qj.3653.

Grams, C. M., R. Beerli, S. Pfenninger, I. Staffell, and H. Wernli, 2017: Balancing Europe's wind-power output through spatial deployment informed by weather regimes, *Nature Climate Change*, **7**, 557–562, doi:10.1038/nclimate3338.

Grazzini, F., 2007: Predictability of a large-scale flow conducive to extreme precipitation over the western Alps. *Meteorology and Atmospheric Physics*, **95** (3-4),123–138, doi:10.1007/s00703-006-0205-8.

Grazzini, F. and F. Vitart, 2015: Atmospheric predictability and Rossby wave packets, *Q.J.R. Meteorol. Soc.*,**141** (692), doi:10.1002/qj.2564.

Grazzini, F., Craig, G., Keil, C., Antolini, G., Pavan, V., 2020a: Extreme precipitation events over northern Italy. Part I: A systematic classification with machine-learning techniques.,*Q.J.R. Meteorol. Soc.*, doi:10.1002/qj.3635.

Grazzini, F., Fragkoulidis, G., Teubler, F., Wirth, V., **Craig G. C.**, 2021: Extreme Precipitation events over northern-central Italy. Part II: Dynamical precursors, *Q.J.R. Meteorol. Soc.*, doi: 10.1002/qj.3969.

Pasquier, J. T., S. Pfahl, and **C. M. Grams**, 2019: Modulation of Atmospheric River Occurrence and Associated Precipitation Extremes in the North Atlantic Region by European Weather Regimes, *Geophys. Res. Lett.*, **46**, 1014–1023, doi:10.1029/2018GL081194.

Piaget, N., P. Froidevaux, P. Giannakaki, F. Gierth, O. Martius, M. Riemer, G. Wolf, and **C. M. Grams**, 2015: Dynamics of a local Alpine flooding event in October 2011: moisture source and large-scale circulation, *Q.J.R. Meteorol. Soc.*, **141**, 1922–1937, doi:10.1002/qj.2496.

b) Other publications, both peer-reviewed and non-peer-reviewed

Grams C., Ferranti L., Magnusson L., 2020: How to make use of weather regimes in extended-range predictions for Europe, *ECMWF Newsletter*, **165**, Autumn 2020.

Grazzini F. and G. Van der Grijn, 2003: Central European floods during summer 2002, *ECMWF Newsletter*, **96**, Winter 2002/2003.

3.4 Project plan

3.4.1 Objectives

The ultimate aim of this project is to provide operational meteorological centres with new forecasting methods based on recently acquired dynamical knowledge of extreme weather events. This complements standard approaches using direct prediction of local surface variables such as precipitation or two-meter temperature. Where certain atmospheric states and dynamic indicators have been identified as precursors of extreme events, a consistent narrative of such dynamical thinking and its predictability would support forecasters in their decision-making, in particular for medium- and extended-range predictions. A considerable body of evidence relating dynamical processes and extreme weather had been accumulated in W2W and other research activities, but there is an urgent need to present this knowledge in the form of a consistent narrative to support forecasters.

The specific goals of the proposed new transfer project are:

1) in WP1, to build a prototype of real-time objective extreme precipitation event identification and classification chain based on the results of T1. This will be applied to medium-range forecasts (1-10 days) over the test region Northern Italy, and the potential value of the additional dynamical information will be assessed by forecasters. New predictors will be incorporated in the regional operational chain for flood forecasting, and their quantitative impact evaluated;
2) in WP2, to demonstrate that such dynamical thinking can be applied to other regions and extended into the sub-seasonal forecast ranges (10-30 days). We will develop a framework that - for a given European region - automatically identifies the large-scale flow configurations and additional dynamical predictors that are indicative of an extreme event dependent on the lead time, from the medium range up to the extended range;
3) in WP3, to transfer the knowledge gained in WP2 into a prototype forecast suite for the extreme event in any given region. This forecast suite will provide probabilistic information about the occurrence and intensity of the predictors at different lead times, and information about the respective skill and reliability in the model.

A unified documentation of the meteorological background and relevance of each predictor will complement these forecast products.

Project partners include two W2W institutions and two operational weather services. The prototype forecast tools will be implemented and run at ECMWF using either the European Weather Cloud[2] service or the ecgate platform. ECMWF and EUMETSAT are currently setting up the European Weather Cloud platform with the purpose to test innovative methods requiring fast access to large amounts of data.

The potential benefits of the proposed transfer project are manifold: 1) it will provide independent information regarding the probability of an extreme event compared to estimates based on direct model output; 2) through a systematic identification of precursors on larger scales it will create a coherent narrative for forecasters, providing a solid background to deal with forecast jumps and inconsistencies; 3) it will demonstrate the scalability and the generalisation of this approach to other regions and overall contribute to strengthen the “end-to-end warning chain” envisaged by the WMO HIWeather project[3].

3.4.2 Work Program

Strategy

The work is organised in three work packages which will be performed in a 2-year work program in close collaboration between a Postdoctoral researcher at LMU, Munich (**Federico Grazzini** - PD1, **only year 1**), a Postdoctoral researcher at KIT, Karlsruhe (**tbd** - PD2, **year 1 and 2**), and the partners at the operational weather forecasting centres. At ARPAE-SIMC in Northern Italy, the partners are Dr Maria Stefania Tesini (forecaster, specialized in verification), Daniele Branchini (IT system administrator) and Dr Tommaso Diomede (hydrologist). At ECMWF, the partners are Dr Laura Ferranti (expert on model diagnostic and forecast products development), Dr Linus Magnusson (expert on representation of synoptic processes in numerical models and forecast evaluation), and Dr Frédéric Vitart (expert on sub-seasonal prediction and the representation of the large-scale circulation in numerical models).

2 https://www.europeanweather.cloud/

3 http://www.hiweather.net/Content/20.html

In year 1, WP1, led by PD1 at LMU Munich, will transfer the knowledge about the dynamics and physical processes driving EPEs in Northern Italy, gained in the past T1, into operational procedures in support of the official warning chain of ARPAE-SIMC. The implementation will be tested with forecasters at ARPAE-SIMC. In parallel, WP2, led by PD2 and PI Grams at KIT Karlsruhe, will adopt the dynamical thinking of T1 and focus on aspects of the large-scale flow situation that is indicative of an evolving extreme in various regions of Europe, and extend the approach into the sub-seasonal forecast range (10-30 days). This work will be done in close consultation with Federico Grazzini (PD1) at LMU and the ECMWF colleagues named above. The postdoc at KIT will focus on generalizing the methodology for EPEs, Dr Laura Ferranti will adopt the methodology for temperature extremes and meteorological droughts at ECMWF. Finally, in year 2, WP3, PD2 at KIT together with PI Grams, Dr Linus Magnusson, and Dr Frédéric Vitart from ECMWF, will develop and implement a seamless toolkit to design prototype forecast visualisations for the sub-seasonal to short-range forecast horizons. A key novelty of the frameworks developed in WP2 and WP3 will be their versatile adaptation to different regions, the seamless integration of relevant predictors up to the sub-seasonal forecast range, and the systematic documentation of the meteorological background. This will provide a forecaster a coherent narrative of the large-scale indicators and dynamical predictors during the unfolding of an extreme event and thus support the warning process from longer to short lead times by dynamical understanding in addition to classical forecast products based on standard model output. The timeline of the work packages is given in the Gantt-chart below (Fig. 3).

***Figure 3**: Gantt-Chart for the time planning of work packages and sub work packages.*

Work Package 1: EPE probability forecast and classification over a demonstration area *(months 1-12, LMU, ARPAE-SIMC, ECMWF)*

WP1 has the goal to implement a prototype operational EPE identification and classification method to be applied to medium-range forecasts for the demonstration area Northern-Central Italy. The new products will be available to forecasters on a daily basis, and will be evaluated and refined based on their feedback.
This will be achieved in two steps:

WP1.1) implementation of the probability of an EPE and classification of the type of the event, in operational medium-range forecasts according to the methodology developed in T1 (**Grazzini et al. 2020a)**;

WP1.2) assessing the value of forecasts based on the EPE classification method through its application in the flood warning procedures of the Emilia-Romagna region.

The expected advantage for forecasters of having the classification in real time is twofold: they can make a more informed use of classical precipitation forecast, knowing the expected skill based on past statistics stratified by EPE category, and at the same time extend the forecasting range, which is not possible with classical methods due to intrinsic limitations of precipitation.

WP 1.1: EPE probability forecast and classification type *(months 1-9, LMU, ARPAE-SIMC, ECMWF)*

We aim to identify the dynamical precursors and the types of a potential EPE in the forecast. To do so we apply the EPE classification method developed in project T1.

Relying on the reanalysis as a training dataset, we will compute the probability of four EPE categories (NoEPE day, and EPE days of Cat1, Cat2, Cat3), for each day in real-time forecast, with a random forest classifier algorithm. Once a day is classified, additional information on the deterministic limit over each area and for each category (measured by threshold on selected indexes like the equitable threat score of fractional skill score) obtained from the past verification statistics, will also be provided. The probability of an EPE in any category (yes/no) computed with this new method will be contrasted with the standard probability of an EPE derived from raw ensemble model output as a benchmark. The probability of EPE in one of the categories will be compared against the climatological probability obtained from reanalysis. Independently of the result of the comparison, this effort towards greater contextualization of the information allows forecasters a much-informed assessment than simply evaluating the rainfall model output.

Here we recall the definition of the three categories in which EPEs are subdivided following **Grazzini et al. 2020a**. Category 1 (Cat1) events originate from intense frontal structures, including slantwise ascent in the warm sector of the associated cyclones (warm conveyor belt). Mechanical (orographic) uplift of low-level marine, statically stable air is the key factor to attain extreme precipitation that is mostly confined over upwind steep topography. Category 2 (Cat2) events originate from a synergic combination of frontal uplift and embedded deep convection. They are characterized by a stronger southerly flow component and a reduced moist static stability (almost neutral conditions). Category 3 (Cat3) events are associated with weakly-forced convection (non-equilibrium convective events) in a potentially unstable environment (i.e., with very high CAPE).

According to results from paper **Grazzini et al. 2021**, in which we show a dependence of EPEs probability from Rossby Wave Packets (RWP) amplitude (waves in their linear stage) and PV anomaly (PV´) (representing wave breaking), we could test the inclusion of these two additional predictors for the probability estimate of EPE yes/no. In particular, the recognition of these two predictors could be used in tandem (or isolation) with IVT to extend the probability estimate of EPE yes/not in the extended range (on aggregated time periods), going already in the direction of generalization which will be fully developed in WP2. The backward extension of the statistics to 1961 based on ERA5 and the inclusion of a fourth class NoEPE day requires some preparatory work and changes in the classification method which will be carried out by Federico Grazzini (PD1), with an estimated duration of 3 months.

Algorithm implementation; step 1

ARPAE will produce a first demo-suite based on the deterministic ECMWF HRES forecast running daily. The output will be displayed in the form of a bar graph showing on the x-axis the forecast days, and on the y-axis the probability (estimated through the random forests algorithm) to have an EPE, over the demonstration area, and the relative probability of the different categories (see the example below in Fig. 4). Once a day in the forecast is classified as No EPE day, Cat1, Cat2, or Cat3 day, additional information from the past verification statistics, on the deterministic limit over each area and for each category (computed for example as the forecast time when the critical success index (or ETS) become smaller equal or smaller than 0.5) will be provided. The suite developed in step 1 serves as a test bed for optimising the classification algorithm to real-time products. In this phase, PD1 will organize regular meetings with ARPAE forecasters in order to train them on the methodology and collect their feedback on the value of the classification in the warning procedure. Once the optimal configuration will be completed, including the format of the output products, the classification suite will be applied to the ensemble (step 2). This part of the project will be carried out by PD1 in close liaison with Maria Stefania Tesini (ARPAE) and Daniele Branchini (ARPAE) with an estimated duration of 3 months.

Algorithm implementation; step 2

After the successful setup and calibration of the algorithm with deterministic forecasts, we will extend the method to ensemble forecasts using the European Weather Cloud[4] resources run by ECMWF. The cloud infrastructure allows to run the classification algorithm on each ENS member locally, avoiding the transfer of large amounts of data. EPE probability and classification will be based on a random forest classifier applied to each EPS ensemble member. As proposed for step 1, information will be presented with two main graphical products: the first, showing a complete overview of the EPE probability and class for each forecast step; the second, a “heatmap” graphic showing calibrated probabilities for each area and each forecast step. Taking advantage of the ECMWF reforecast dataset, EFI for precipitation averaged over each warning area could complement the EPE probability estimate obtained with the classification method and also presented as a heatmap or chess-board image. This option will also require ECMWF expertise for setting up the EFI calculation and the efficient use of the reforecast products. Estimated time 3 months with involvement of PD1, Dr Linus Magnusson, and Dr Frédéric Vitart from ECMWF.

[4] https://www.europeanweather.cloud/

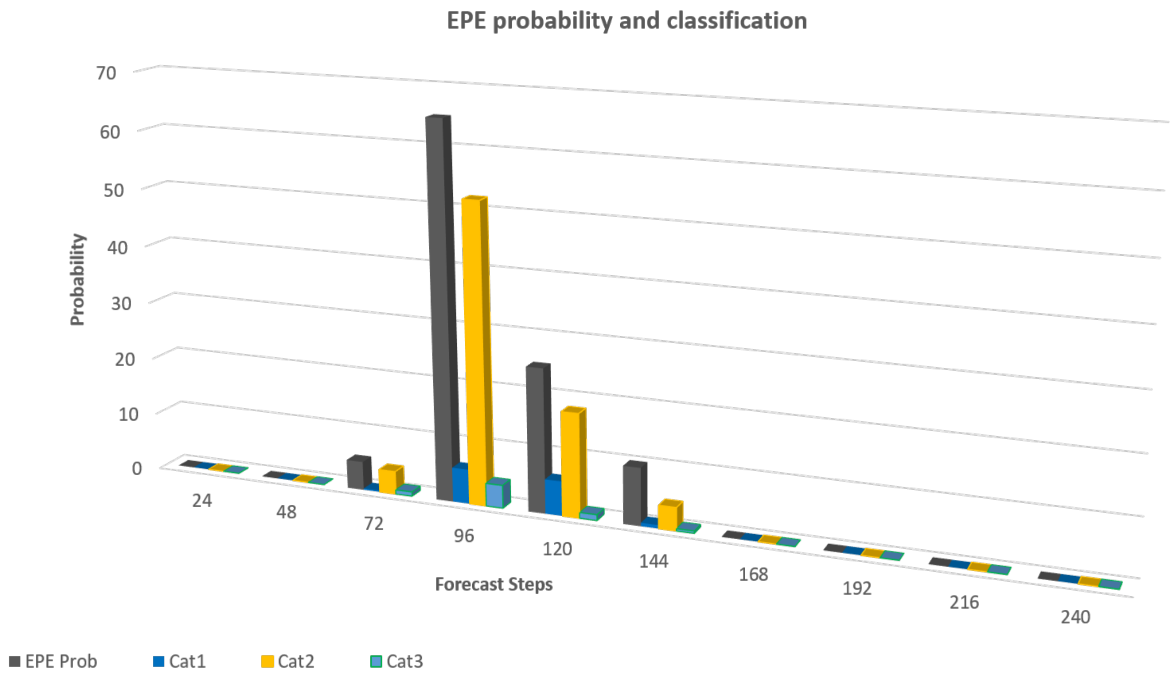

Figure 4*: An example of graphical output of the EPE recognition and classification method for Northern-Italy area.*

WP 1.2: Application of EPE classification in a flood prediction system *(months 10-12, LMU and ARPAE-SIMC)*

For integration in forecasters' workflow and comparison with current methods, the probabilistic forecast of the EPE category can be translated into different expected hydrological effects on river basins; potentially very valuable information not yet considered in warning procedures. These three categories are often associated with different types of flooding with Cat1 producing high discharges of large rivers and on the opposite side, Cat3 is typically associated with flash-floods. Cat2 instead, is the worst-case scenario since events in this category are characterized by very high rainfall intensities over large areas and effects can range from small streams to large river basins. With ARPAE partners we plan the introduction of the EPE category estimate among the predictors of the logistic regression algorithm, which is currently tested as an operational tool for the warning system of Emilia-Romagna region **(Diomede et al., 2016)**. Currently, this system has three explanatory variables in input derived from precipitation (observed and forecast) aggregated over basin catchments at a different time. We propose to add the output of the EPE classification method as a further variable characterizing the "state of the atmosphere". This will implicitly inform the regression model about the large-scale ingredients favourable (or not) to an EPE, and the atmospheric processes which can be associated with it. A performance comparison of the logistic regression with or without the EPE classification type will enable a quantitative evaluation of the benefit of the new information. This work package will be carried out by ARPAE by Tommaso Diomede, with the supervision of PD1, and the assistance of Daniele Branchini. Expected duration of 3 months.

Work Package 2: Dynamical drivers of extremes in different European regions *(months 1-12, KIT and ECMWF)*

WP2 will go beyond the specific scope of Northern Italy and heavy precipitation and aims to demonstrate that dynamical thinking can be applied to other regions and extended into the sub-seasonal forecast range. We will develop a framework that - for a given European region - automatically identifies the large-scale flow configurations and additional dynamical drivers that are indicative of an extreme event dependent on the lead time. This approach will provide a consistent narrative and thus broaden the dynamical understanding of the meteorological evolution towards an extreme. A simple visualisation that summarizes this information in a quantitative way (see the example in Fig. 5) and a comprehensive documentation will be implemented in WP3. Led by KIT and supported by Dr Laura Ferranti and Dr Linus Magnusson, the framework will be developed initially for heavy precipitation events informed by WP1. Moreover, preparatory work will be done for the application to other extremes. Dr Laura Ferranti at ECMWF will adapt the framework for European heat waves and associated meteorological drought. The framework will be developed in three steps: WP2.1 preparation of data for extreme definition and potential predictors; WP2.2 identification of the relation of extremes to large-scale precursors at different lead times; WP2.3 identification of the relation of extremes to dynamical predictors and external forcing.

WP2.1: Definition of extremes, large-scale flow predictors, dynamical drivers, and external forcing *(month 1-3, ECMWF and KIT)*

Extremes

We will compile a time series of spatially aggregated surface weather variables (precipitation, 2m temperature anomaly, wind speed) in a given region based on ERA5 reanalysis data. For simplicity ECMWF will provide us here the region definitions already available at ECMWF for the investigation of cold extremes (**Ferranti et al. 2018**). In addition, and as a plausibility check, we will use the Northern Italy region of WP1. A regional extreme will be defined as the exceedance / undercutting of a percentile threshold, accounting for seasonal variability. Based on the first results also refined region definitions will be discussed with ECMWF to integrate the expertise of Dr Laura Ferranti and Dr Linus Magnusson.

Time series of predictors

Next, we will compile time series of potential predictors for an extreme. Here we investigate three groups of potential predictors, namely reflecting:

1. the large-scale circulation in the Atlantic-European region,
2. dynamical and physical processes,
3. external forcing.

The specific predictors are described in detail below. Most of them can be considered either in a categorical or continuous way (e.g. stating that the NAO index is positive, or above a certain threshold vs. the actual value of the NAO index). A secondary aim in compiling these time series is to use them also as predictors in statistical models based on machine learning which we develop in WP3.

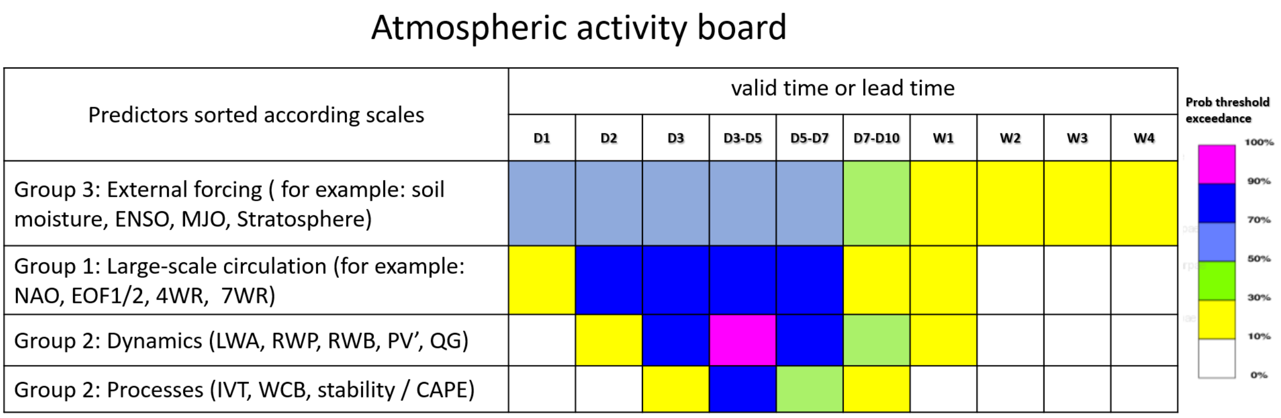

***Figure 5**: Exemplary illustration of the interactive atmospheric activity board. The rows will contain a hierarchy of predictors from the different groups, sorted according scales. The columns will contain either the forecast for increasing valid times (for a single initialisation time) or the different lead times for a fixed valid time (for consecutive initialisation times). The cells will be interactive with information on the skill and reliability of the respective predictor and lead time. In addition, it will be possible to retrieve interactively background information on each predictor.*

Group 1: Large-scale circulation

For describing the large-scale circulation in the Atlantic-European region we opt for a hierarchy of descriptors with increasing complexity for which previous work (e.g. Yiou and Nogaj 2004, **Ferranti et al. 2018**, **Pasquier et al. 2019**) already unveiled a link to extreme weather. These descriptors are generally used for research and forecasting in the Atlantic-European region. Using several instead of only one descriptor of the large-scale circulation allows more flexibility in situations of flow-dependent predictability (see **Grams, Ferranti, and Magnusson 2020**). We will use the following descriptors:

- NAO (EOF1),
- EOF1/2 phase space (**Ferranti et al. 2018**),
- seasonal 4 weather regimes (**Ferranti et al. 2015**),
- year-round 7 weather regimes (**Grams et al. 2017**).

In addition, we will test the use of flow descriptors developed for a specific application, i.e. the composite mean signature in 500hPa geopotential height of the Cat. 1, Cat. 2, and Cat. 3 events of T1 and WP1, and specific flow patterns related to heavy precipitation in the Mediterranean basin and temperature extremes developed in the CAFE-ITN (**Mastrantonas et al. 2020**) sub-projects hosted at ECMWF.

All these descriptors of the large-scale circulation allow a categorical description as well as a continuous description in terms of a normalized index which reflects the projection in the respective pattern.

Group 2: Dynamical and Physical Processes

T1 and previous work by others showed that there are distinct dynamical and physical processes active prior and during heavy precipitation extremes. Here we will compile scalar time series depicting the activity of these descriptors in spatial relation to the target region informed by T1, WP1, and other literature.

The descriptors are:

- Rossby wave activity in terms of the existence of a RWP locally and/or upstream, its amplitude and phase (the latter via the PV anomaly upstream of the target region) based on diagnostics developed in W2W (e.g. **Grazzini and Vitart 2015**, Fragkoulidis et al. 2018; Fragkoulidis and Wirth 2020),
- Rossby wave breaking in combination with IVT (De Vries 2020),
- Quasi-geostrophic (QG) forcing for ascent in the target region (Clough et al. 1996, Deveson et al. 2002, **Grams and Blumer 2015**),
- IVT and total precipitable water (IWV/TPW) in the target region and in sectors around it / or upstream (cf. Froidevaux et al. 2016, **Grazzini et al. 2020a**, Lavers and Villarini 2013, **Pasquier et al. 2019**),
- warm conveyor belt activity and diabatic outflow (e.g. **Grams and Archambault 2016**, **Quinting and Grams 2020**),
- stability and convective environment.

Group 3: External forcing

In order to give guidance also at longer, sub-seasonal lead times we will use a set of descriptors of slowly varying modes of the climate system. These are mostly defined on a global scale and are thus independent of the target region:

- Madden-Julian-Oscillation (MJO) in terms of the projection into the Real-time Multivariate MJO series 1/2 (RMM1/RMM2) phase space (also categorical in terms of sector occupied),
- intensity and state of the stratospheric polar vortex in terms of polar cap geopotential height anomaly or strength of zonal mean wind speed,
- the state of the quasi-biennial-oscillation (QBO) hypothesised to affect North Atlantic synoptic activity (Attard and Lang 2019),
- El Nino Southern Oscillation,
- sea surface temperature in selected regions,
- Snow cover and soil moisture in selected regions.

Most of the group 2 and 3 predictors are continuous in nature. Critical thresholds defined in WP2.2 and WP2.3 will transfer these also into additional categorical predictors. Although the description of WP2.1 appears comprehensive, we expect an easy start for PD2 into the project with WP2.1 within the first 1-3 months as most data are readily available and the PIs and ECMWF collaborators' previous experience in compiling and working with such time series.

WP2.2: The link of extreme weather and the large-scale circulation *(month 3-6, KIT and ECMWF)*

In this work package we will establish the linkage of extreme events and the large-scale circulation in the ERA5 reanalysis in a statistical sense based on the predictors in group 1. We adopt a two-way perspective:

A. with a focus on the large-scale circulation we ask how the odds of an extreme precipitation event in a given region change during different large-scale flow configurations.
B. with an event-centric perspective we ask which are the most frequent large-scale flow situations during which a specific event type occurs in a given region. As we expect some seasonal dependency we will stratify this investigation according to seasons. We expect a stronger link for the refined weather regime definitions of 4WR, 7WR, and Mediterranean regimes, as well as the specific composites for Northern Italy extreme precipitation compared to the NAO. However, we expect a longer forecast skill horizon for the latter (see WP3).

With the large-scale flow-centric perspective we will compute the occurrence frequency of an extreme event in the predefined regions during the positive and negative phases of the NAO, in the eight sectors of the EOF1/2 space, and the categorical 4 WR and 7 WR classification for the given region. This will provide first guidance about how prone to the occurrence of the respective extreme a certain flow situation is. In addition, we will compute the distributions of the continuous index values during an extreme to elucidate the potential ranges indicative of an extreme. These will be related to the climatological distribution of the respective index to assess if only the tails of the distribution relate to extreme events. Informed by that we will elucidate how the odds of an extreme change by a combined categorical and continuous consideration (e.g. the probability of heavy precipitation given an active Greenland Blocking regime and a Greenland Blocking regime index above the climatological 90% percentile). This will give important guidance for the design of forecast products in WP3. The sketched diagnostic approach is meant to be applied to each of the predefined regions. As an optional task we might also explore the spatial (co-) variability of extreme occurrence in different regime categories and/or index ranges following the approach of e.g. **Pasquier et al. (2019)** (their Fig. 3).

With an event-centric perspective we will document during which large-scale flow situation extreme events occur in each target region. With regard to a continuous description we will also consider the combination of several indices and define index threshold for the later visualization and forecast tools (WP3). With regard to a categorical characterisation we will identify the most important “pathways” to an extreme following **Beerli and Grams (2019)** which are reflected in the frequency of the categorical regime in which they occur. Preliminary work by **Grazzini et al. (2020b)** and **Beerli and Grams (2019)** suggests that there are multiple pathways to a similar regional extreme. In addition to the mere regime frequencies we will compile a catalogue of synoptic maps of the composite signature in meteorological fields (e.g. geopotential height at 500 hPa / 50 hPa, IVT, wind speed at 200 hPa, upper-level potential vorticity, SST, soil moisture anomaly, snow cover) for the different pathways as well as “stamp” plots for each individual extreme event. This transfers the idea of **Grazzini et al. (2021)** of specific extreme categories to the general large-scale flow descriptors. The map catalogue will give an impression how the large-scale flow situation differs in cases of an extreme event from the climatological mean regime pattern and in different regions.

The systematic documentation of the linkage of the large-scale flow situation to extremes in terms of regime descriptors and composite maps will be the first important cornerstone of our “narrative to the forecaster" about the relevant atmospheric indicators towards a regional extreme. This will be complemented by dynamical thinking reflected in the process-oriented predictors documented in WP2.3. The forecast guidance given by these linkages will be investigated in WP3. All diagnostic steps will be converted into a workflow which allows a relatively easy adaptation to another target region or refinements in the parameters. Laura Ferranti at ECMWF will consult in the setup of the workflow with her expertise and apply it for extreme temperatures and meteorological drought in selected regions.

WP2.3: Role of dynamical processes and external forcing in the occurrence of extremes *(month 7-12, KIT and ECMWF)*

While the distinct “pathways” in a given region represents a necessary condition for an extreme to happen, they are not sufficient and additional “ingredients” are needed to trigger an extreme during a particular large-scale flow situation. WP2.3 will investigate if the occurrence of additional physical and dynamical processes (Group 2) or external forcing (Group 3) prior and during an extreme event are indicative or characteristic of the event.

We will investigate the meteorological fields documented in WP2.2 for signatures of the predictors in Group 2 and Group 3. Therefore, we will first compare the composite fields of non-extreme situations vs. situations in which the extreme event happened. This analysis will be done at different lead times prior and during the event and stratified according to season. Depending on the predictor the spatial focus is on the target region, continent, hemisphere or even global. E.g. Froidevaux et al. (2016) showed that IVT is a relevant predictor for flooding events even on the sub-national level and in complex terrain, but the sector where IVT is enhanced relative to the target region is different for different regions. On the other hand, studies like Winschall et al. (2013, 2014), Lavers and Villarini (2013), **Pasquier et al. (2019)** and **Grazzini et al. (2021)** highlighted the long-range transport of water vapour into the target region and remote moisture sources partly reflected in IVT signatures. This investigation might refine our understanding of the spatio-temporal relation of the predictors to the extreme event in the target region and thus might require a reprocessing of the time-series of WP 2.1. Therefore, the compilation of time series of Group 2 and Group 3 might be done in concert with the task here.

The meteorological insight gained from the composite study will then be transferred in a quantitative description of the activity (categorical) and of the intensity (continuous) based on the timeseries of the scalar variants of the predictors in Group 2 and Group 3. This will also help determining the relevant range of their continuous depiction during an extreme which will inform the visualisation and forecasting tools developed in WP3.

Finally, the insight from WP2.2 and WP2.3 will be summarized in a systematic way with a documentation of the different pathways to an extreme in the respective region. This includes a characterisation of the specific large-scale flow descriptors the range of the respective indices and the additional fields reflecting the activity of dynamical processes and external forcing. The description will be complemented by a selection of the synoptic maps in standard meteorological fields and the variability in individual cases as compiled by the composites and stamp maps in WP2.2. This documentation is thought of as a manual to the forecaster to broaden the understanding of the evolution of the meteorological conditions, relevant dynamical and physical processes, and external forcing during an extreme event. At the same time, it forms the basis for the development of visualisation and forecasting tools in WP3. The PD at KIT will develop the framework initially for heavy precipitation. Again, Laura Ferranti will apply the framework for extreme temperatures and meteorological drought in selected regions.

Work Package 3: Visualisation and forecast products *(months 12-24, ECMWF and KIT)*

WP3 will transfer the knowledge gained in WP2 into a prototype forecast suite for the extreme event in the given region implemented at ECMWF. This forecast suite will provide probabilistic information about the occurrence and intensity of the predictors at different lead times, information about the respective reliability and skill of the model, and complemented with the documentation of the meteorological background and relevance of each predictor. Thus, we aim not only to provide forecast products for an extreme but also context in terms of the necessary metainformation to yield a concise but complete picture of the meteorological conditions towards a potential extreme. A major task will be the adaptation of the insight from WP2 to forecast data and test its representation in model climate done in WP3.1. Next WP3.2 will implement the computation for operational forecast data and interactive forecast visualisations for the different predictors. Here we will use the infrastructure provided by the European Weather Cloud or ecgate service at ECMWF. Finally, if time permits, we will try to combine the different predictors using statistical modelling or machine learning in order to directly forecast the probability of an extreme similar to the extreme category forecast and flood warning of WP1. This would demonstrate the potential gain in forecast skill based on dynamical thinking compared to forecasts based on raw model output as a benchmark.

WP 3.1: Representation of the linkage between extremes and predictors in the IFS model at different lead times *(months 7-18, ECMWF and KIT)*

In parallel to the progress in WP2.2 and WP2.3 the representation of relevant pathways in terms of the large-scale circulation (Group 1 predictors), and processes (Group 2), and external forcing (Group 3), which are based on ERA5 reanalysis data, will be investigated in the operational IFS medium-range and extended-range ensemble for a recent 3-10 year period. If the data basis appears too small this investigation will additionally be performed for the IFS ensemble reforecast for the last 20 years. The reforecast data will also be used to construct a model climatology for the predictors based on anomalies rather than absolute values (e.g. the geopotential height anomalies required to compute weather regime indices). This task of model evaluation will be led and primarily performed by Dr Frédéric Vitart at ECMWF in consultation with PD2 and PI Grams at KIT in the middle of the project.

The main goal of this work package is to elucidate if the found linkages of an extreme event to the Group 1-3 predictors holds in the forecast model at different lead times. It is likely that there are lead time-dependent differences in the strength and thus relevant ranges or thresholds of the continuous variants of predictors between reanalysis and forecast world. This might be tackled either by bias correction or adapting the threshold ranges. It might turn out that the linkages are not represented and different pathways lead to extremes in the model climate world. In this case we will focus on the actual extremes in reanalysis data and focus on the representation and forecast skill of the pathways in the model rather than requiring them to produce an extreme in the model forecast. By doing so we unveil a way to improve predictions for extremes by dynamical thinking even in imperfect models.

Beyond the identification of the pathways in each ensemble member we will assess the best way how to aggregate the ensemble data for probabilistic forecast products (WP3.2): We will test if the categorisation of ensemble members according to the identified "pathways to an extreme" based on Group 1 predictors and the respective means of dynamical and external forcing predictors in these categories give already guidance for an extreme. I.e. we ask for the conditional probability of Group 2 and Group 3 predictors reaching a critical range or threshold given the members are in pathway X. The task of adapting details of the relevant predictors to model climate will be performed jointly by KIT (PD and PI Grams) and Dr Frédéric Vitart at ECMWF.

In line with our seamless approach we do all these investigations for different aggregation periods depending on lead time: daily averages, 3 to 5-day averages, and weekly averages. These are roughly forecast ranges considered in short- to medium-range (0 to about 10 days), medium-range (about 10 to 15 days), and sub-seasonal (about 15-45 days) forecasting.

The tasks outlined above will yield probabilistic forecast information about the different predictors (categorical and reaching critical values). Thus, we finally also assess forecast quality in terms of forecast reliability and forecast skill at different lead times for each predictor. This will be led and performed primarily by Dr Frédéric Vitart at ECMWF. The different predictors in each group have been selected with regard to assumed different forecast skill horizons. The latter task will inform about the actual reliability and skill horizon. Combined with the documentation of their link to extremes this is a crucial information in the forecasting context.

WP 3.2: Implementation of a prototype forecast suite *(months 13-24, ECMWF & KIT)*

WP3.2 deals with the implementation of the predictors in operational medium-range and extended-range ensemble forecasts. Ultimately this yield forecasts of the probability of the different predictors at all relevant lead times. WP 3.2. will be led by PD2 at KIT, and Dr Frédéric Vitart and Dr Linus Magnusson will assist in the design of forecast products and the implementation on ECMWF computing platforms.

These probabilistic forecasts will be visualised in a versatile way, which allows to explore the evolution of a forecast for a single initialisation with lead time, as well as the evolution of multiple forecasts from the latest initialisation times at a fixed verification time. Each probabilistic forecast information will be complemented by information on the reliability and skill. For longer lead times temporal aggregate probabilities for several days to weekly-averaged will be computed as developed in WP3.1. In the following we briefly sketch two ideas for such a visualisation:

1. The interactive "atmospheric activity board" will give a comprehensive overview of the probability of the relevant predictors (Fig. 5 above). Predictors from the different groups, including the group 2 and group 3 predictors conditioned on pathways derived from group 1 (see WP3.1), will be hierarchically sorted according to their expected relevance at different lead times. An easy "traffic light system" colours the probability of reaching a critical threshold for the given predictor in 3-5 levels. The other dimension shows the temporal evolution. Either verification time is fixed and each column represents an initialisation time, which allows observing the evolution towards an extreme, or the initialisation time is fixed and each column indicates a different lead time, which allows to assess at which forecast time an extreme is more likely to happen. Ultimately the "activity board" will be interactive in the sense that a user can easily switch between the two modes, and, by clicking on a cell, retrieve additional information on the skill of the respective predictor and lead time and on the reliability as well as metainformation.
2. The "Atmospheric Activity monitor" visualises the probability in reaching critical levels of each predictor for a given verification time and lead time (Fig. 6). An animation of this plot type can be used either for animating a single initialisation time or for animating the evolution of different forecasts towards a fixed verification time. The predictors in each group will be sorted in a hierarchy according to their expected relevance at different lead times. The height and colour of the bar changes according to the level of "activity" reached (i.e. probability in the ensemble that critical thresholds are exceeded.

If time permits the work will be extended in the direction of implementing a tool for statistical post processing based on a logistic regression model or machine learning providing a probabilistic warning of an extreme or not solely on the dynamical predictors. The reliability and skill of such a model would be tested against warnings based on the raw model output fields, but for EPEs also against advanced techniques such as EC-Points. If promising results emerge the probabilistic warning will be included in our prototype forecast

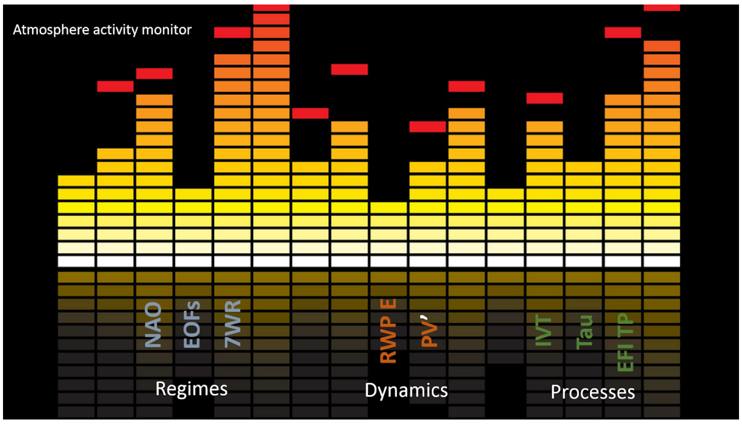

***Figure 6**: An example of the atmospheric activity monitor for a given forecast lead time and area*

suite. This task would be informed by related work done in WP1 and initially be developed based on reanalysis data alone.

3.5 Role within the Collaborative Research Centre

The Collaborative Research Centre (CRC) "Waves to Weather" conducts fundamental research into the mechanisms limiting the predictability of weather. Such knowledge should provide a basis for producing the best possible forecasts in operational practice, and the impact of our research in operations is an important measure of its value for society. The first Transfer Project T1 showed that the dynamical principles developed in the first Phase of W2W can be applied to practical forecasting problems. This work was well-received, both at the regional meteorological service ARPAE-SIMC, and at the European level at ECMWF. The new project T2 will represent a crucial milestone on the way to an operational application by developing a real-time prototype that can be evaluated as part of the daily forecasting system, and generalizing the methodology to a much broader range of potential applications.

Project T2 also plays an important role within the W2W consortium. An new focus of the second Phase of W2W is the study of predictability on sub-seasonal timescales. This project provides a strong bridge between this new research effort and the stakeholder community. In particular, Projects A1, A8 and C4 are developing and testing theories and diagnostics for the predictability of weather on these timescales, and will interact with T2.

3.6 Differentiation from other funded projects

Since this project is a new application of methods developed in other W2W projects that focuses on evaluation and application to forecasting, it is complementary to those projects but there is no overlap.

3.7 Project funding

3.7.1 *Previous funding*

The project is currently not funded and no funding proposal has been submitted.

3.7.2 *Contribution of the application partners*

ARPAE-SIM	2021/2	2022	2023/1
Staff (in hours per week)	7	7	7
Funding for direct costs	-	-	-
Major research instrumentation	-	-	-

ECMWF	2021/2	2022	2023/1
Staff (in hours per week)	*	*	*
Funding for direct costs	-	-	-
Major research instrumentation	-	-	-

* ECMWF is unable to provide estimates of staff hours. The work to carried out by ECMWF staff members is substantial and is described in the Work Plan.

(Figures on direct costs and instrumentation in euros)

3.7.3 *Requested funding*

Funding for	2021/2		2022		2023/1	
Staff	Quantity	Sum	Quantity	Sum	Quantity	Sum
PD1 (LMU), 100%	0.5	37.800	0.5	37.800	0	0
PD2 (KIT), 100%	0.5	37.800	1	75.600	0.5	37.800
Total		75.600		113.400		37.800
Direct costs		Sum		Sum		Sum
Travel		8100		9200		4200
Consumables / Pub. charges		0		0		0
Total		8100		9200		4200
Major research equipment		Sum		Sum		Sum
Total		0		0		0
Grand total		83.700		122.600		42.000

(All figures in euros)

3.7.4 *Requested funding for staff*

	Sequential no.	Name, academic degree, position	Field of research	Department of university or non-university institution, collaboration partner	Project commitment in hours per week	Category	Funding source
Existing staff							
Research staff	1	George Craig	theoretical meteorology	LMU	3		LMU
	2	Christian Grams	large-scale atmospheric dynamics	KIT	3		KIT
	1	Robert Redl	IT support	LMU	1		LMU

Non-research staff							
Application partner staff							
Research staff	1	M. Stefania Tesini	verification, operational forecasting	ARPAE-SIMC	3		ARPAE
	2	Tommaso Diomede	hydrology and flood forecasting	ARPAE-SIMC	3		ARPAE
	3	Daniele Branchini	IT support	ARPAE-SIMC	1		ARPAE
	4	Linus Magnusson		ECMWF	*		ECMWF
	5	Frederic Vitart		ECMWF	*		ECMWF
	6	Laura Ferranti		ECMWF	*		ECMWF
Requested staff							
Research staff	1	Federico Grazzini	predictability, extreme precipitation	LMU	40		Project
	2	NN	predictability, physical processes	KIT	40		Project

* ECMWF is unable to provide estimates of staff hours. The work to carried out by ECMWF staff members is substantial and is described in the Work Plan.

Existing Staff
Job descriptions of staff for the proposed funding period (supported through existing funds **LMU and KIT**):
Research Staff
1. Prof. George Craig (LMU): PI and primary supervisor of PD1 Federico Grazzini.
2. Dr. Christian Grams (KIT): PI and primary supervisor of PD2.

Non-Research Staff

Application Partner Staff
Job descriptions of staff for the proposed funding period (supported by application partner **ARPAE-SIMC**):

1. Dott. Maria Stefania Tesini: Setting up verification procedures to score precipitation forecasts against observations over warning areas from the ArCIS database. In general, she will take care of computational aspects related with WP1.1 in strict coordination with PD1.
2. PhD Tommaso Diomede: Setting up of scripting procedures related to the logistic regression used in ARPAE-SIMC warning system for flood forecasting. He will coordinate the activities of WP 1.2.
3. Daniele Branchini: ARPAE-SIMC IT expert, he will assist for the pre-operational implementation and consolidation of procedures in WP1.1 and WP1.2.

Job descriptions of staff for the proposed funding period (supported by application partner **ECMWF**):

4. Dr. Frédéric Vitart: Assistance in verification of predictor variables in operational forecasts (WP3.1) and implementing forecast products (WP1, WP3.2).
5. Dr. Linus Magnusson: Provision of extreme definition and Mediterranean weather regimes in WP2.1. Support of implementation on European Weather cloud or ecgate in WP3.
6. Dr. Laura Ferranti: support in development of diagnostics and application to temperature extremes in WP2. Evaluation of predictors and assistance in the development of forecast products (WP3).

Requested Staff
Job descriptions of staff for the proposed funding period (**requested funding**):
1. PD1 Federico Grazzini: We propose to employ Federico Grazzini as Postdoctoral researcher 1 at LMU (see attached CV). His experience in operational weather forecast, and his specific research on extreme precipitation events and their linkage with large-scale dynamics make him an ideal candidate for this project. His specific duties are the following: (i) to coordinate, in liaison with principal investigators and

research staff, all activities related with WP1 and to actively collaborate in WP2, (ii) to develop, in close collaboration with all participants, software, scripts, data analysis and other tools.

2. PD2 NN: An experienced researcher is needed to handle and compile the different datasets required in WP2 and WP3. The candidate requires a scientific background in atmospheric dynamics to make informed choices about the relevant predictors in WP2. We therefore request funding for 2-year salary of a postdoctoral researcher at KIT.

3.7.5 Requested funding for direct costs

	2021/2	2022	2023/1
Existing funds	0	0	0
Application partner	0	0	0
Sum of existing funds	0	0	0
Sum of requested funds	8100	9200	4200

(All figures in euros)

Details of requested funds per financial year

Explanation	**2021/2**	**2022**	**2023/1**
Kick-of meeting at LMU or KIT (2 persons from ECMWF, 2 persons from ARPAE (1000 EUR each), 1 KIT or LMU staff (700 EUR))	4700	0	0
Project meeting at ARPAE (PD1; 2 visits à 700 EUR)	700	700	0
Project meeting at ECMWF (PD2; 2 visits à 700 EUR)	700	0	700
Project meeting at KIT (project partners joining, duration 1 week, 1500 EUR per meeting))	0	1500	1500
1-month research visit at ECMWF (PD2)	0	3000	0
International workshops and conferences, e.g., EGU (€2000 per person, 4 conferences)	2000	4000	2000
Publications	0	0	0
Sum	**8100**	**9200**	**4200**

(All figures in euros)

3.7.6 Requested funding for major research instrumentation

None

Appendix: List of others references cited in the text

ARPA-Piemonte Tech. Report on storm 2-3 October 2020 (in Italian). Last accessed: 24/11/2020 https://www.arpa.piemonte.it/news/rapporto-evento-alluvionale-del-2-3-ottobre-2020-in-piemonte

Attard, H. E., and A. L. Lang, 2019: The Impact of Tropospheric and Stratospheric Tropical Variability on the Location, Frequency, and Duration of Cool-Season Extratropical Synoptic Events. *Mon. Wea. Rev.*, **147**, 519–542, doi:10.1175/MWR-D-18-0039.1.

Beerli, R., H. Wernli, and **C. M. Grams**, 2017: Does the lower stratosphere provide predictability for month-ahead wind electricity generation in Europe? *Q.J.R. Meteorol. Soc.*, **143**, 3025–3036, doi:10.1002/qj.3158.

Büeler, D., R. Beerli, H. Wernli, and **C. M. Grams**, 2020: Stratospheric influence on ECMWF sub-seasonal forecast skill for energy-industry-relevant surface weather in European countries. *Q.J.R. Meteorol. Soc.*, **146**, 3675–3694, doi:https://doi.org/10.1002/qj.3866.

Cassou, C., L. Terray, and A. S. Phillips, 2005: Tropical Atlantic Influence on European Heat Waves. *J. Climate*, **18**, 2805–2811, doi:10.1175/JCLI3506.1.

Coumou, D., V. Petoukhov, S. Rahmstorf, S. Petri, and H. J. Schellnhuber, 2014: Quasi-resonant circulation regimes and hemispheric synchronization of extreme weather in boreal summer. *PNAS*, **111**, 12331–12336, doi:10.1073/pnas.1412797111.

Clough, S. A., C. S. A. Davitt, and A. J. Thorpe, 1996: Attribution concepts applied to the omega equation. *Q.J.R. Meteorol. Soc.*, **122**, 1943–1962, doi:10.1002/qj.49712253610.

Diomede, T., L. Trotter and M.S. Tesini, 2016: "Predictions of flood warning threshold exceedance computed with logistic regression", Atti del XXXV Convegno Nazionale di Idraulica e Costruzioni Idrauliche, Bologna, Italy, 14-16 Settembre 2016, Last accessed 16/12/2020 (http://amsacta.unibo.it/5400/1/ATTI_IDRA16.pdf)

Deveson, A. C. L., K. A. Browning, and T. D. Hewson, 2002: A classification of FASTEX cyclones using a height-attributable quasi-geostrophic vertical-motion diagnostic. *Q.J.R. Meteorol. Soc.*, **128**, 93–117, doi:10.1256/00359000260498806.

De Vries, A. J., 2020: A global climatological perspective on the importance of Rossby wave breaking and intense moisture transport for extreme precipitation events, *Weather Clim. Dynam. Discuss.*, https://doi.org/doi:10.5194/wcd-2020-44 , in review.

Ferranti, L., S. Corti, and M. Janousek, 2015: Flow-dependent verification of the ECMWF ensemble over the Euro-Atlantic sector. *Q.J.R. Meteorol. Soc.*, **141**, 916–924, doi:10.1002/qj.2411.

Ferranti, L., L. Magnusson, F. Vitart, and D. S. Richardson, 2018: How far in advance can we predict changes in large-scale flow leading to severe cold conditions over Europe? *Q.J.R. Meteorol. Soc.*, **144**, 1788–1802, doi:10.1002/qj.3341.

Fragkoulidis, G., and V. Wirth, 2020: Local Rossby Wave Packet Amplitude, Phase Speed, and Group Velocity: Seasonal Variability and Their Role in Temperature Extremes. *Journal of Climate*, **33**, 8767–8787, doi:10.1175/JCLI-D-19-0377.1.

Fragkoulidis, G., V. Wirth, P. Bossmann, and A. H. Fink, 2018: Linking Northern Hemisphere temperature extremes to Rossby wave packets. *Q.J.R. Meteorol. Soc.*, **144**, 553–566, doi:10.1002/qj.3228.

Froidevaux, P. and Martius, O. (2016): Exceptional integrated vapour transport toward orography: an important precursor to severe floods in Switzerland. *Q.J.R. Meteorol. Soc.*, **142**: 1997-2012. doi:10.1002/qj.2793

Grams, C. M., H. Binder, S. Pfahl, N. Piaget, and H. Wernli, 2014: Atmospheric processes triggering the central European floods in June 2013. *Nat. Hazards Earth Syst. Sci.*, **14**, 1691–1702, doi:10.5194/nhess-14-1691-2014.

Grams, C. M., and S. R. Blumer, 2015: European high-impact weather caused by the downstream response to the extratropical transition of North Atlantic Hurricane Katia (2011). *Geophys. Res. Lett.*, **42**, 2015GL066253, doi:10.1002/2015GL066253.

Grams, C. M., and H. M. Archambault, 2016: The key role of diabatic outflow in amplifying the midlatitude flow: a representative case study of weather systems surrounding western North Pacific extratropical transition. *Mon. Wea. Rev.*, **144**, 3847–3869, doi:10.1175/MWR-D-15-0419.1.

Grazzini F., 2013: Cold spell prediction beyond a week: extreme snowfall events in February 2012 in Italy, *ECMWF Newsletter*, **136**, Summer 2013

Grazzini, F., Fragkoulidis, G., Pavan, V., Antolini, G., 2020b: The 1994 Piedmont flood: an archetype of extreme precipitation events in Northern Italy, *Bull. of Atmos. Sci.& Techn.*, doi: 10.1007/s42865-020-00018-1

Hewson Tim, D., Pillosu, Fatima, M., 2020: A new low-cost technique improves weather forecasts across the world. arXiv:2003.14397, Submitted to *Nature*

Keil, C. and G. **C. Craig**, 2011, Regime-dependent forecast uncertainty of convective precipitation, *Meteorologische Zeitschrift*, **20**, 145-151

Lavaysse, C., J. Vogt, A. Toreti, M. L. Carrera, and F. Pappenberger, 2018: On the use of weather regimes to forecast meteorological drought over Europe. *Natural Hazards and Earth System Sciences*, **18**, 3297–3309, doi:10.5194/nhess-18-3297-2018.

Lavers, D. A., and Villarini, G. (2013), The nexus between atmospheric rivers and extreme precipitation across Europe, *Geophys. Res. Lett.*, **40**, 3259– 3264, doi:10.1002/grl.50636.

Martius, O., C. Schwierz, and H. C. Davies, 2008: Far-upstream precursors of heavy precipitation events on the Alpine south-side. *Q.J.R. Meteorol. Soc.*, **134**, 417–428, doi:10.1002/qj.229.

Magnusson, L., 2019: ECMWF Severe event catalogue for evaluation of multi-scale prediction of extreme weather. ECMWF Technical Memoranda 851. Last accessed 02/12/2020, https://www.ecmwf.int/sites/default/files/elibrary/2019/19230-ecmwf-severe-event-catalogue-evaluation-multi-scale-prediction-extreme-weather.pdf

Mastrantonas, N., Herrera-Lormendez, P., **Magnusson, L.**, Pappenberger, F. and Matschullat, J. (2021), Extreme precipitation events in the Mediterranean: Spatiotemporal characteristics and connection to large-scale atmospheric flow patterns. I*nt J Climatol*.https://doi.org/10.1002/joc.6985

Messori, G., and Coauthors, 2018: An Interdisciplinary Approach to the Study of Extreme Weather Events: Large-Scale Atmospheric Controls and Insights from Dynamical Systems Theory and Statistical Mechanics. *Bull. Amer. Meteor. Soc.*, **99**, ES81–ES85, https://doi.org/10.1175/BAMS-D-17-0296.1.

Michelangeli, P.-A., R. Vautard, and B. Legras, 1995: Weather Regimes: Recurrence and Quasi Stationarity. *J. Atmos. Sci.*, **52**, 1237–1256, doi:10.1175/1520-0469(1995)052<1237:WRRAQS>2.0.CO;2.

Mohr, S., and **Coauthors**, 2020: The role of large-scale dynamics in an exceptional sequence of severe thunderstorms in Europe May–June 2018. *Weather and Climate Dynamics*, **1**, 325–348, doi:https://doi.org/10.5194/wcd-1-325-2020.

Papritz L. and **C. M. Grams**, 2018: Linking Low-Frequency Large-Scale Circulation Patterns to Cold Air Outbreak Formation in the Northeastern North Atlantic. *Geophys. Res. Lett.*, **45**, 2542–2553, doi:10.1002/2017GL076921.

Pfahl, S., 2014: Characterising the relationship between weather extremes in Europe and synoptic circulation features. *Natural Hazards and Earth System Science*, **14**, 1461–1475, doi:10.5194/nhess-14-1461-2014.

Pohorsky, R., M. Röthlisberger, **C. M. Grams**, J. Riboldi, and O. Martius, 2019: The Climatological Impact of Recurving North Atlantic Tropical Cyclones on Downstream Extreme Precipitation Events, *Mon. Wea. Rev.*, **147**, 1513–1532, doi:10.1175/MWR-D-18-0195.1.

Quinting J. F. and **C. M. Grams, 2020**: Towards a systematic evaluation of warm conveyor belts in numerical weather prediction and climate models. Part I: Predictor selection and logistic regression model. *J. Atmos. Sci.*, *in revision.*

Schaller, N., J. Sillmann, J. Anstey, E. M. Fischer, **C. M. Grams**, and S. Russo, 2018: Influence of blocking on Northern European and Western Russian heatwaves in large climate model ensembles. *Environ. Res. Lett.*, **13**, 054015, doi:10.1088/1748-9326/aaba55.

Spensberger, C., and **Coauthors**, 2020: Dynamics of concurrent and sequential Central European and Scandinavian heatwaves. *Q.J.R. Meteorol. Soc.*, **146**, 2998–3013, doi:https://doi.org/10.1002/qj.3822.

Vautard, R., 1990: Multiple weather regimes over the North Atlantic: analysis of precursors and successors. *Mon. Wea. Rev.*, **118**, 2056–2081, doi:10.1175/1520-0493(1990)118<2056:MWROTN>2.0.CO;2.

Vigaud, N., A. W. Robertson, and M. K. Tippett, 2018: Predictability of Recurrent Weather Regimes over North America during Winter from Submonthly Reforecasts. *Mon. Wea. Rev.*, **146**, 2559–2577, doi:10.1175/MWR-D-18-0058.1.

Winschall, A., S. Pfahl, H. Sodemann, and H. Wernli, 2012: Impact of North Atlantic evaporation hot spots on southern Alpine heavy precipitation events. *Quarterly Journal of the Royal Meteorological Society*, **138**, 1245–1258, doi:10.1002/qj.987.

Winschall, A., H. Sodemann, S. Pfahl, and H. Wernli, 2014: How important is intensified evaporation for Mediterranean precipitation extremes? *J. Geophys. Res. Atmos.*, **119**, 5240–5256, doi:10.1002/2013JD021175.

Wirth, V., and J. Eichhorn, 2014: Long-lived Rossby wave trains as precursors to strong winter cyclones over Europe: Rossby Wave Train Precursors to Strong Cyclones. *Q.J.R. Meteorol. Soc.*, **140**, 729–737, doi:10.1002/qj.2191.

Yiou, P., and M. Nogaj, 2004: Extreme climatic events and weather regimes over the North Atlantic: When and where? *Geophys. Res. Lett.*, **31**, doi:10.1029/2003GL019119. https://agupubs.onlinelibrary.wiley.com/doi/abs/10.1029/2003GL019119.

Signature of Principal Investigators
Cooperation Agreement
Short CV Principal Investigators