NAWDIC

North Atlantic Waveguide, Dry Intrusion, and Downstream Impact Campaign

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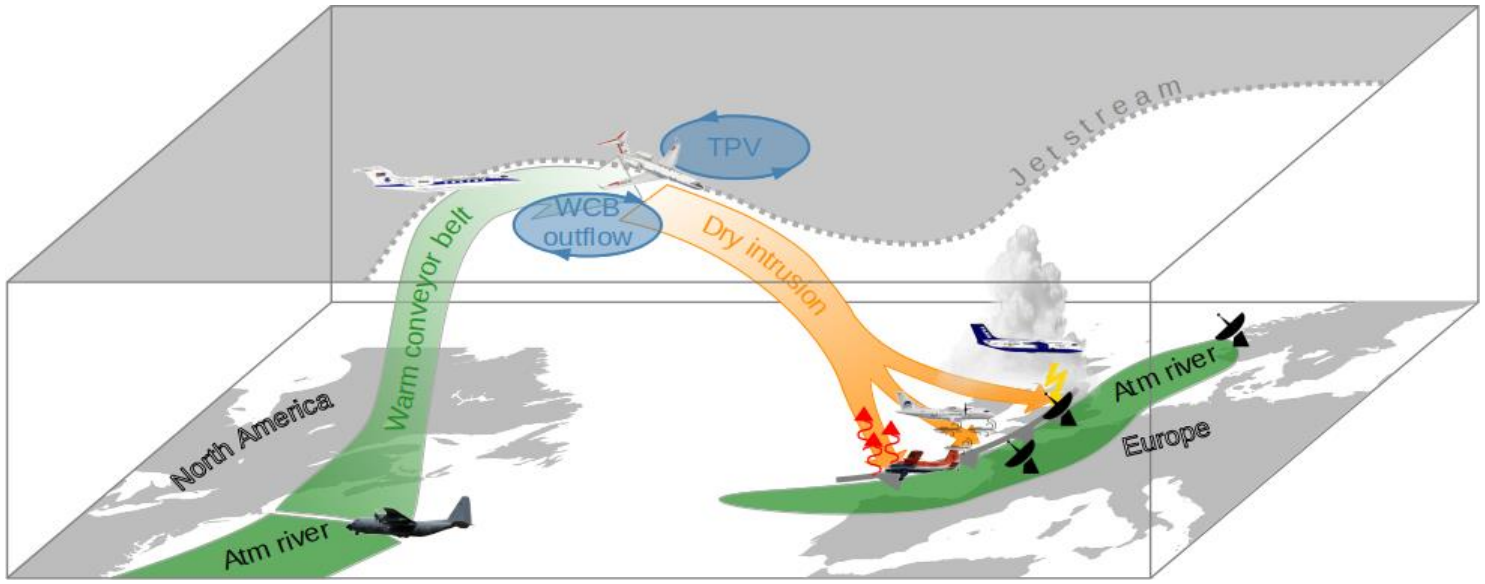
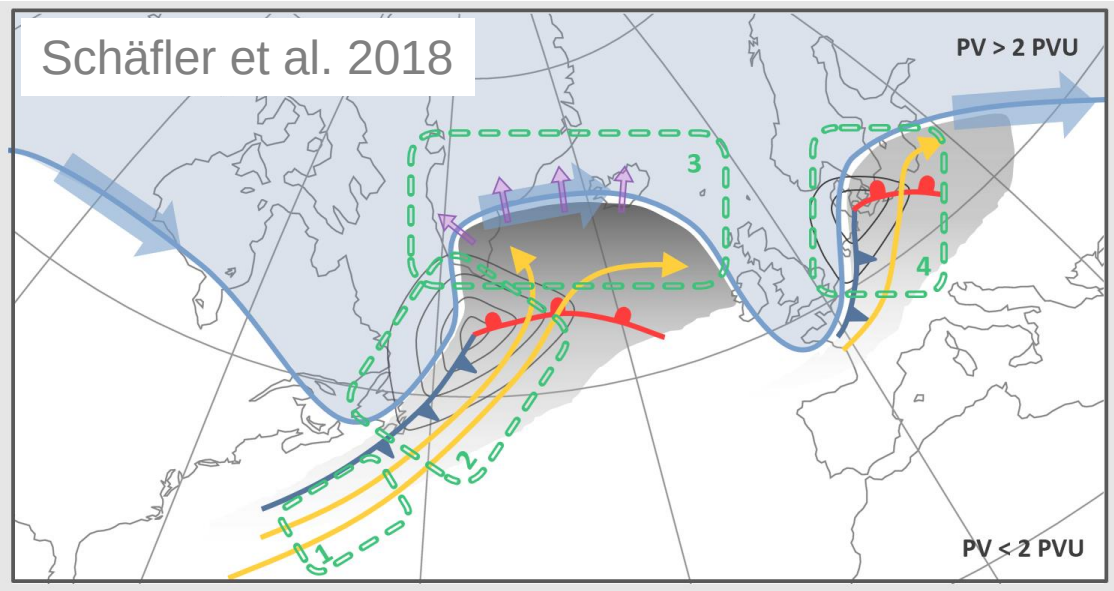


Status of NAWDIC - outline

- NAWDEX legacy
- NAWDIC goals
- NAWDIC components & international collaboration
  - NAWDIC-HALO and NAWDIC-KITcube
  - NAWDIC international components
- Next steps

NAWDIC North Atlantic Waveguide, Dry Intrusion, and Downstream Impact Campaign

In the legacy of NAWDEX 2016: 1st multi-aircraft campaign with HALO G-550 aircraft focusing on atmospheric dynamics



- strong international collaboration with partners from 8 countries
- joint operation of HALO, DLR-Falcon, SAFIRE Falcon, FAAM Bae-146
- unprecedented & surprising observations and emerging new theoretical concepts
- strong community building in post-campaign data evaluation

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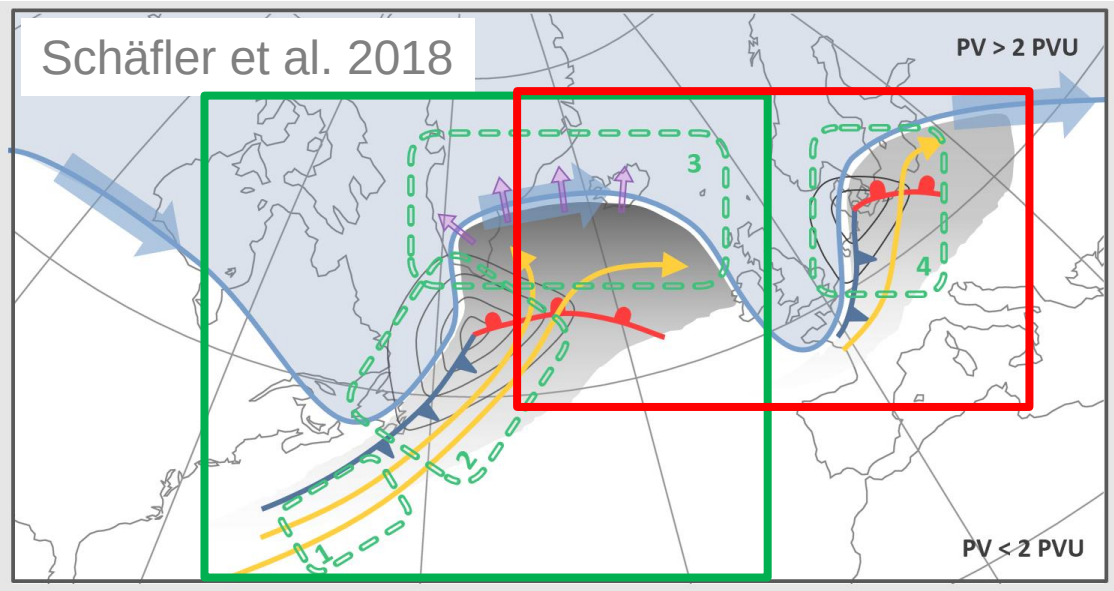
In the legacy of NAWDEX 2016: 1st multi-aircraft campaign with HALO focusing on atmospheric dynamics



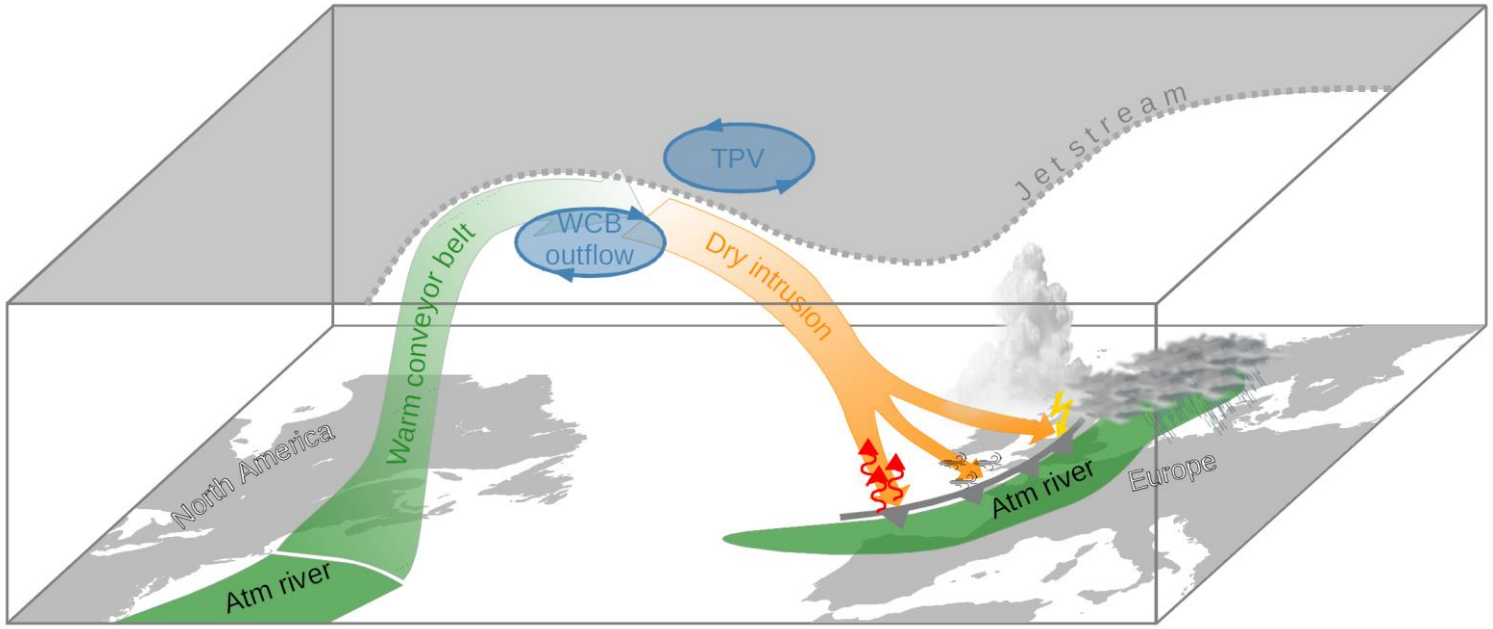
Main objective of NAWDEX 2016:

1. low-level moisture inflow in ascending WCB airstream ✓
2. mixed phase clouds and diabatic effects on cyclones ✓
3. tropopause structure and ridgebuilding ✓
4. downstream high impact weather (high winds, heavy rainfall) ✗

Scientific idea and goals

- Focus on **high-impact weather related to frontal systems of extratropical cyclones** in the North Atlantic-Euro-Mediterranean region in winter

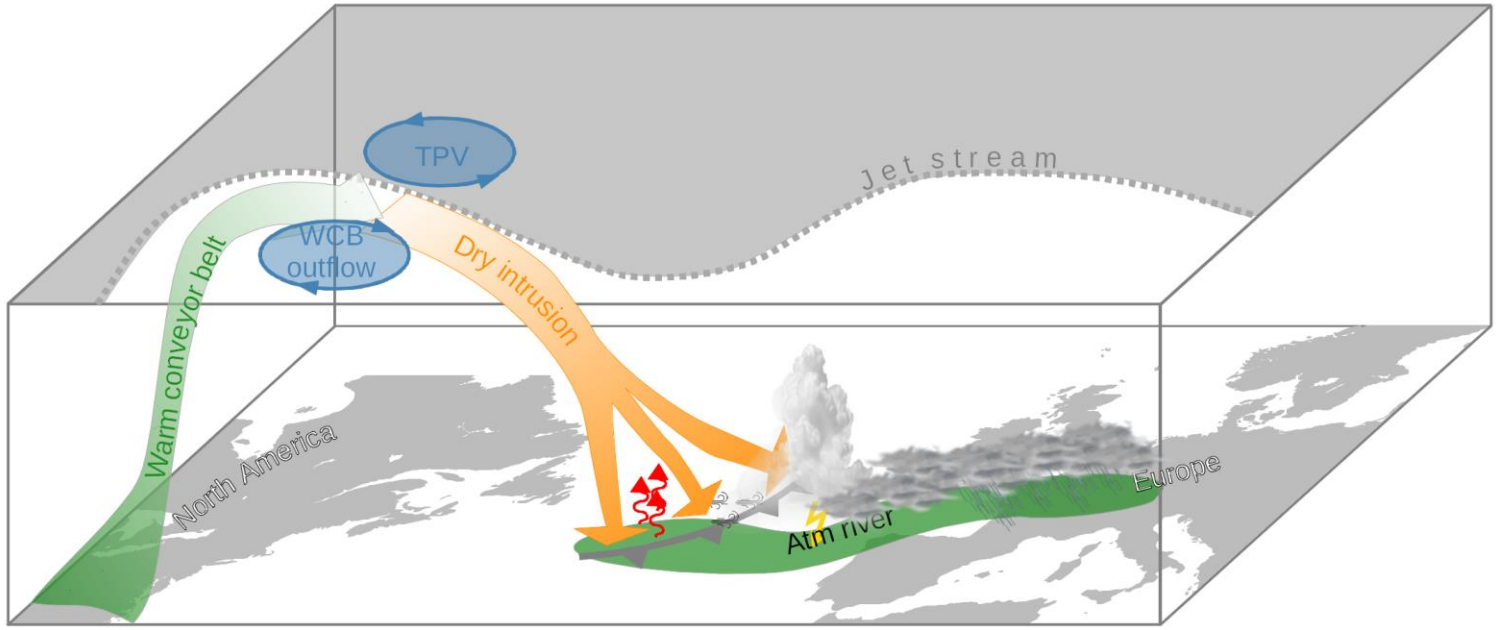
Scenario 1: wind gusts related to cold frontal passage and cold sector



Scientific idea and goals

- Focus on **high-impact weather related to frontal systems of extratropical cyclones** in the North Atlantic – Euro – Mediterranean region in winter

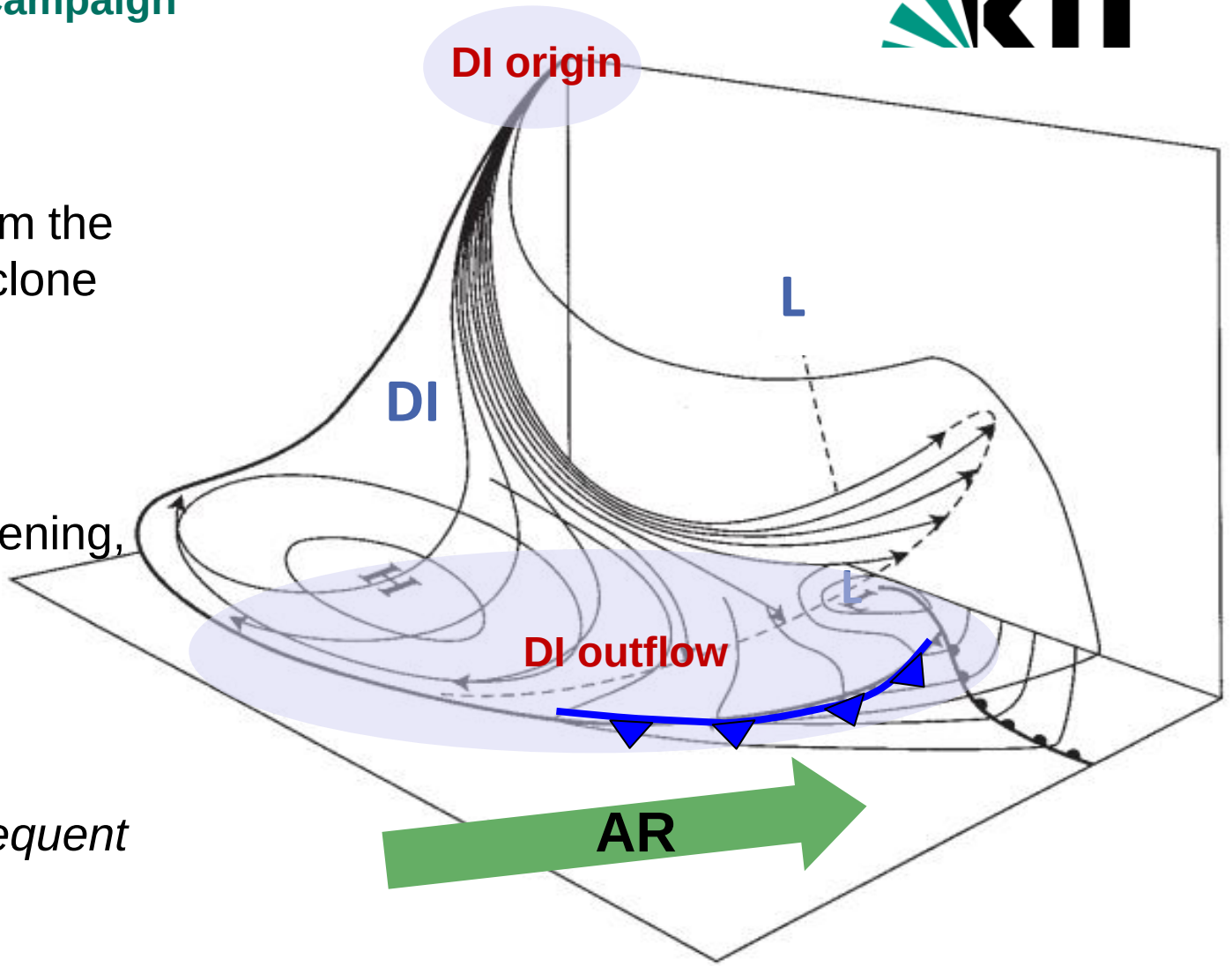
Scenario 2: heavy precipitation related to atmospheric river landfall



Dry air intrusions (DIs)

- DIs: synoptic-scale slantwise **descent** from the upper troposphere equatorward to the cyclone cold sector

- DIs affect:
  - PBL (destabilization from above, deepening, mixing, evaporation)
  - front intensity and associated impact (precipitation, wind gusts)
  - moisture sources, moisture transport, structure and associated HIW of *subsequent* AR



Danielsen (1964)

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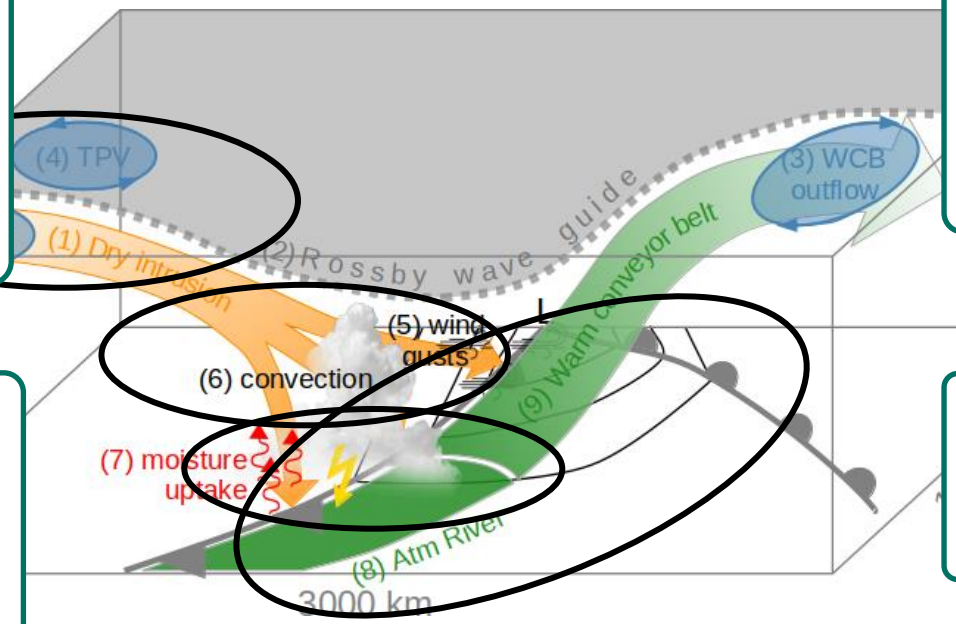
Overarching goal and scientific topics

- NAWDIC aims to **advance our understanding of the synoptic- to micro-scale dynamical and physical processes** associated with the triggering of **severe wind gusts, heavy precipitation, and cold air outbreaks** in the North Atlantic-Euro-Mediterranean region and of their **representation in NWP models**.

a) Tropopause Structure
- tropopause gradients (wind, humidity, composition) near jet stream and in DI initiation region
- meso-scale dynamics at the tropopause
- transport and mixing at the tropopause
- tropopause leakiness

b) DI influence on PBL
- interaction of DI airstream with top of the PBL→PBL deepens
- downward momentum transfer
- (role of evaporative cooling and scale of organized structures)



c) Near surface DI and HIW
- surface sensible and latent heat fluxes
- ocean-atmosphere interaction
- sea surface roughness under high wind conditions
- destabilization and convection

d) Dynamics and air mass interactions near the cold front
- horizontal moisture transport
- AR/DI outflow interaction

a) Tropopause Structure

- *Mesoscale circulations oriented across the jet stream axis affect the timing and structure of vertical motion and the coherent descent of air in dry intrusions*
- few observational evidence of meso-scale structure and circulations near tropopause, unclear connection of tropopause uncertainties to downstream weather

first observational evidence of meso-scale negative PV structure

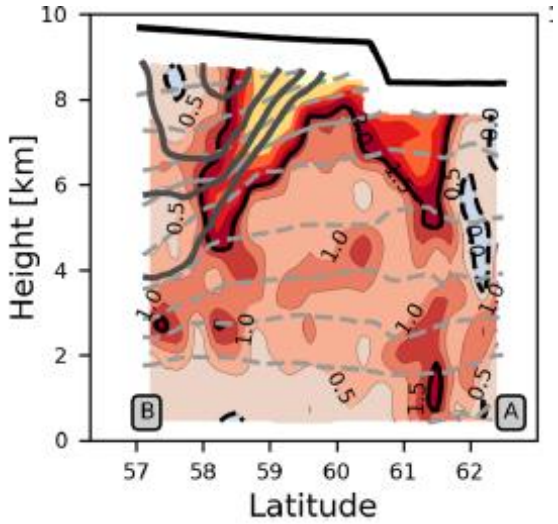


Fig. 3 from Harvey et al. 2020, doi: 10.1002/qj.3747

tropopause windspeed error in short-range IFS forecasts during NAWDEX

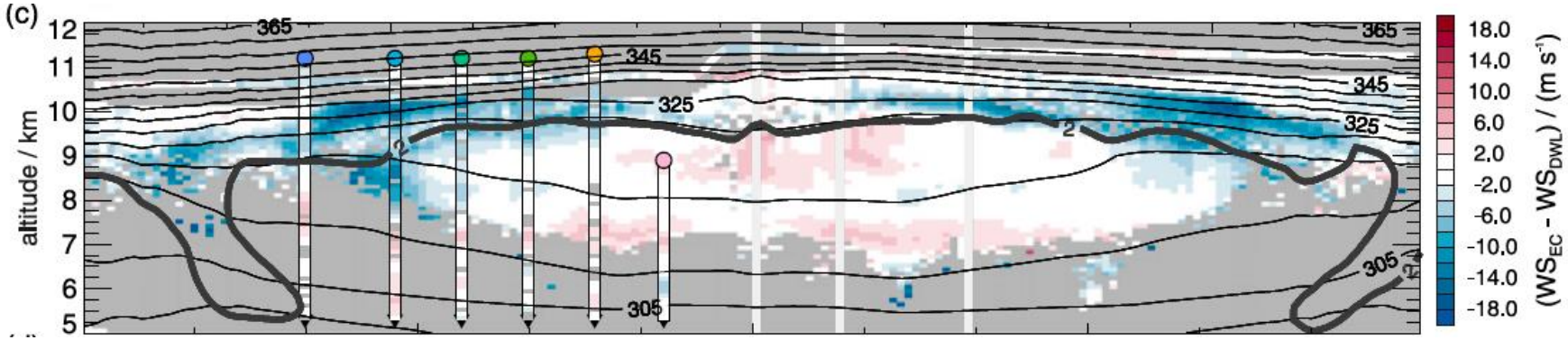


Fig 5c from Schäfler et al. 2020, doi: 10.1175/MWR-D-19-0229.1

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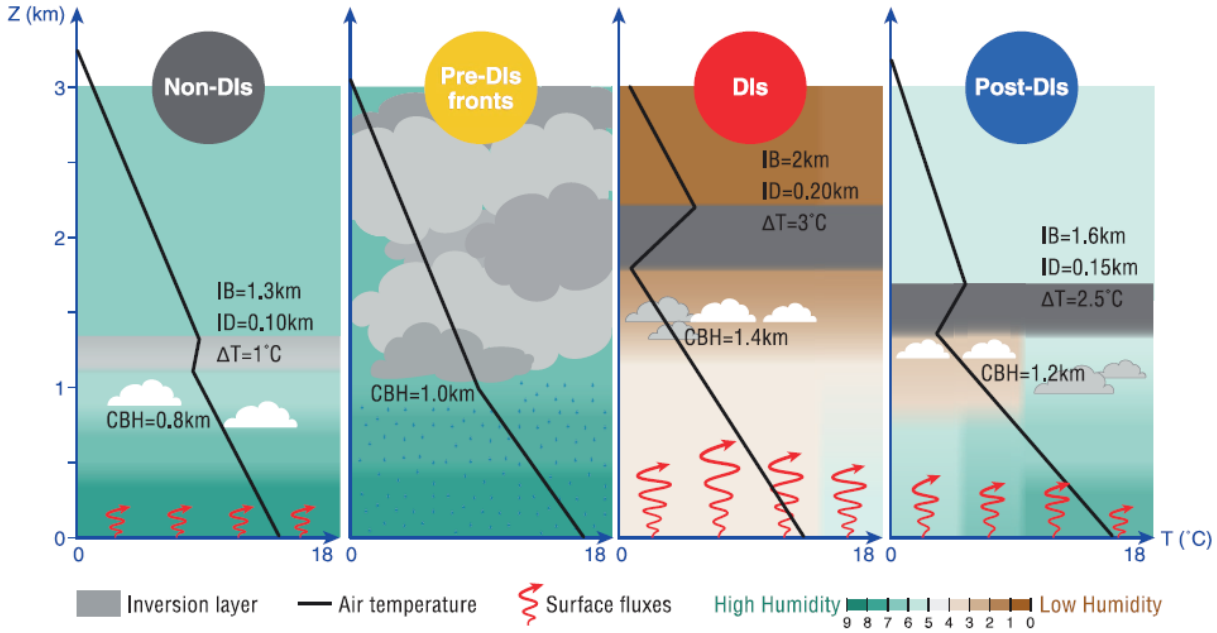
b) Dry intrusion influence on the PBL

- *DI – PBL interaction enhances vertical mixing in PBL through downward momentum transfer, resulting in PBL deepening, strengthened inversion layer, and severe surface winds*
- due to lack of observations it is unclear how well clouds and related feedbacks are represented in NWP & climate models and whether such error propagates upscale.



Schematic impact of DI on marine PBL

Fig 14 from Illotoviz et al. 2021, doi:10.1029/2020JD033879

c) DI influence on surface fluxes and air-sea interaction

- *intense ocean heat loss and evaporation triggered when DI descends into marine PBL may restore baroclinicity and moisture for subsequent cyclones and / or atmospheric rivers.*
- model representation of surface fluxes and surface roughness over the ocean unclear due to lack of observations

monthly mean first-guess departure of wind direction (°) in IFS

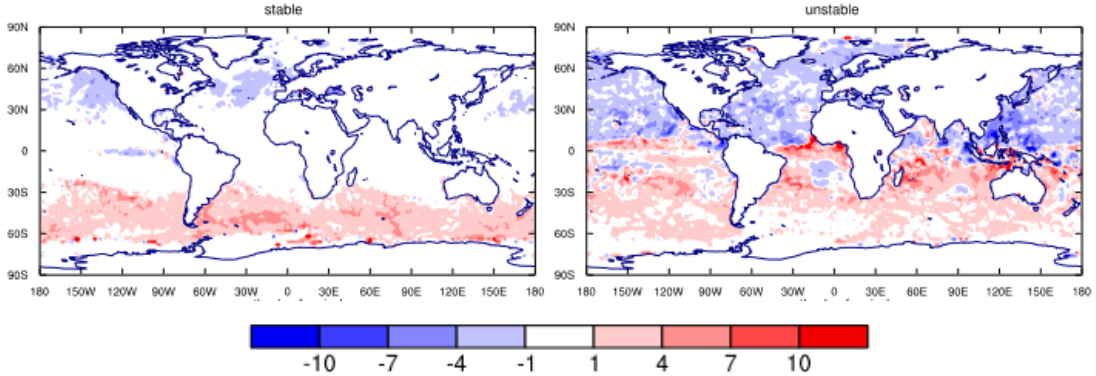


Fig 6 from Sandu et al. 2020, doi: 10.21957/wggbl43u

difference in wind gusts (m s^{-1}, shading), sfc sensible heat flux (blue W m^{-2}), latent heat flux (red W m^{-2}) for cold fronts with DI minus without DI

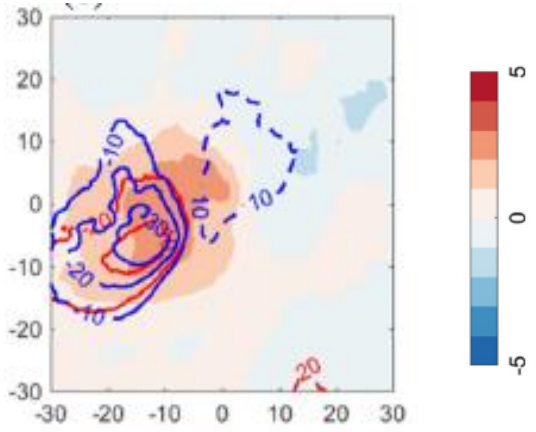
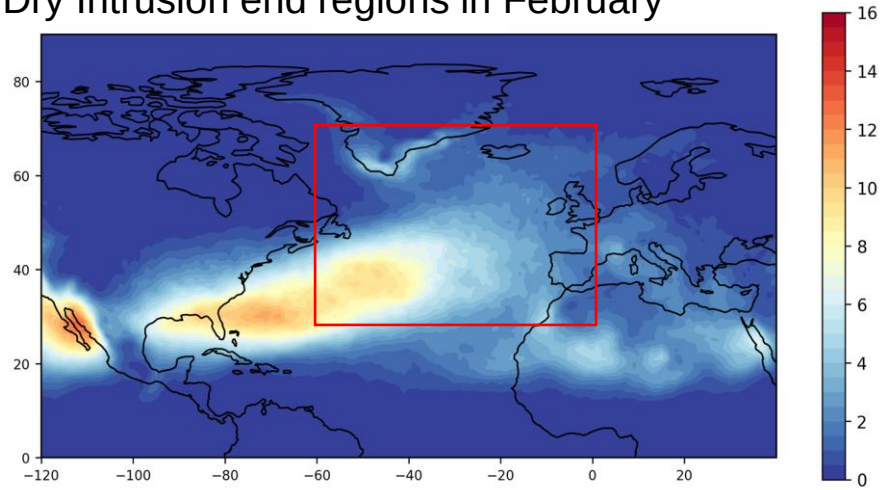


Fig 5c from Raveh-Rubin and Catto 2019, doi:10.1007/s00382-019-04793-2

d) Dynamics and air-mass interaction near cold fronts

- *systematic error of strong horizontal moisture transport in atmospheric rivers (e.g. Lavers et al. 2018, GRL) might be related to uncertainty of wind shear and surface heat and moisture flux variations as well as mesoscale cross-frontal circulations during DI – AR interaction*
- detailed observations of horizontal and vertical moisture fluxes and air mass tracers in marine PBL needed

Dry Intrusion end regions in February



Moisture source region for AR landfalling in France

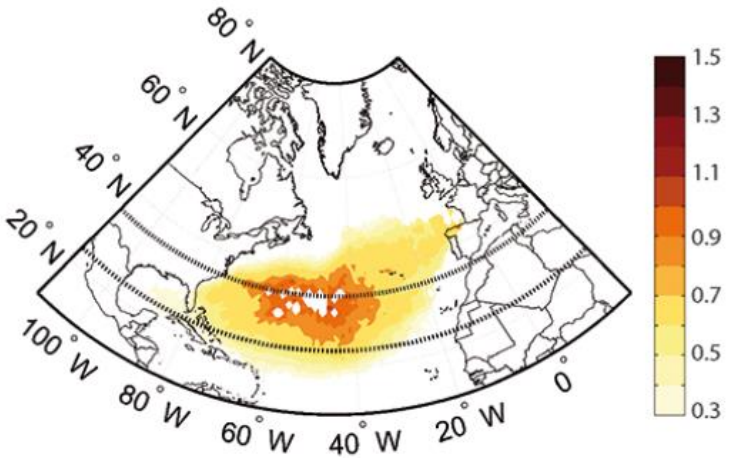
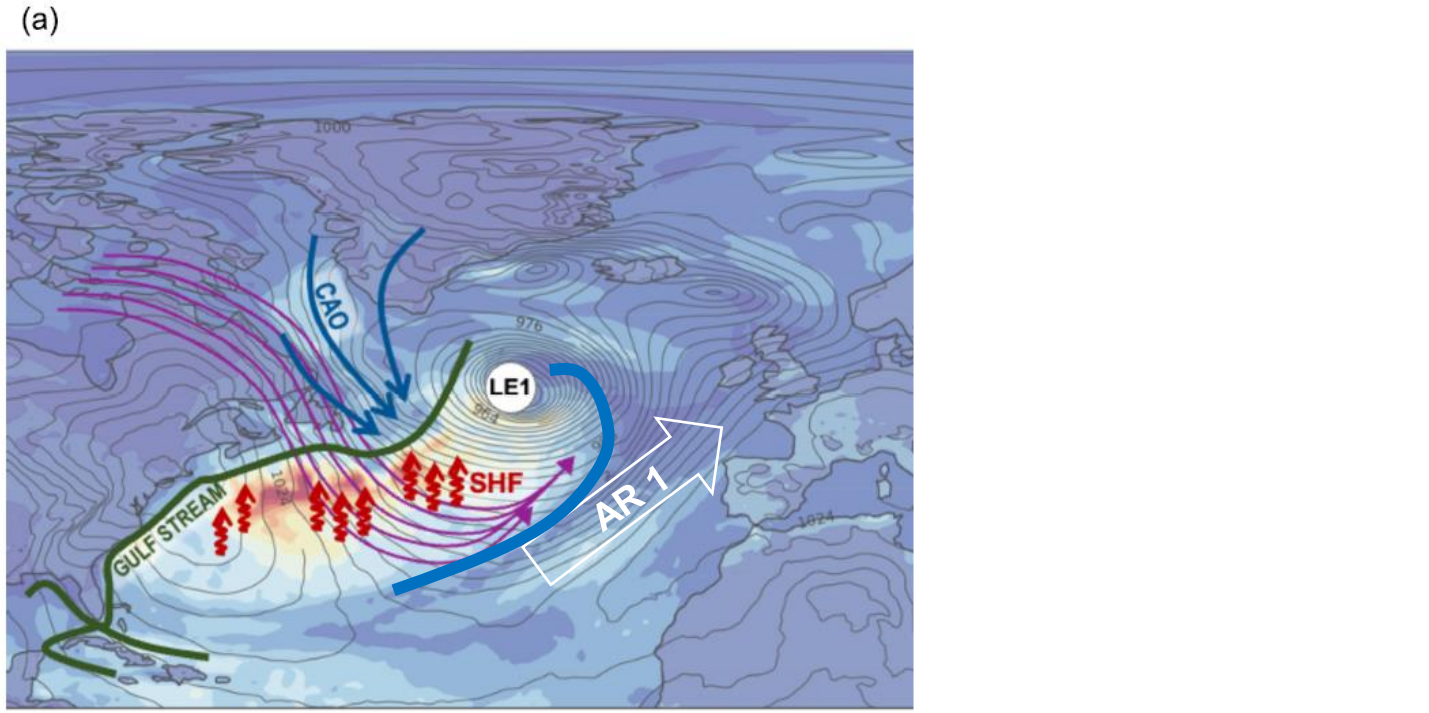


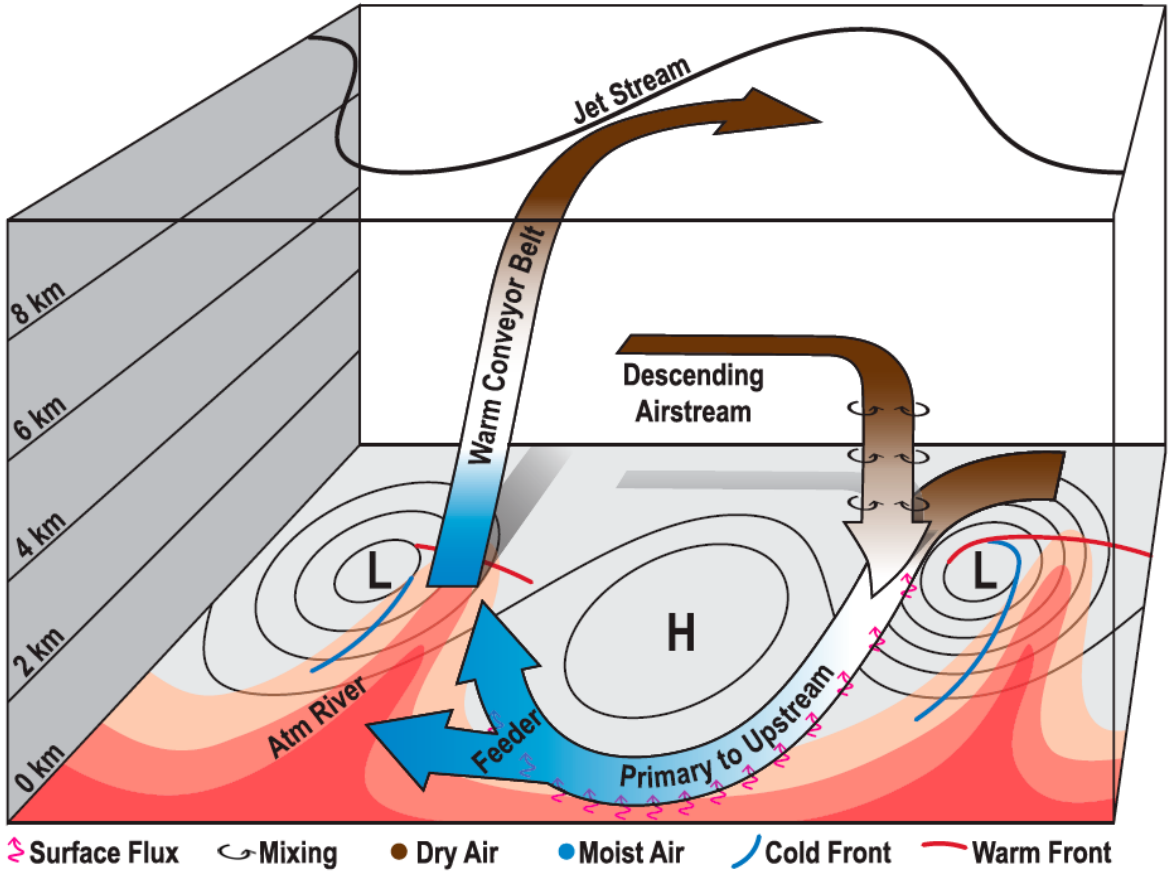
Fig 4 from Ramos et al. 2016 ESD

Relevance of DI for moisture uptake



Wenta et al. 2023, WCD https://doi.org/10.5194/egusphere-2023-905

Relevance of DI for moisture uptake



Demirdjian et al. 2023, JAS https://doi.org/10.1175/JAS-D-22-0251.s1

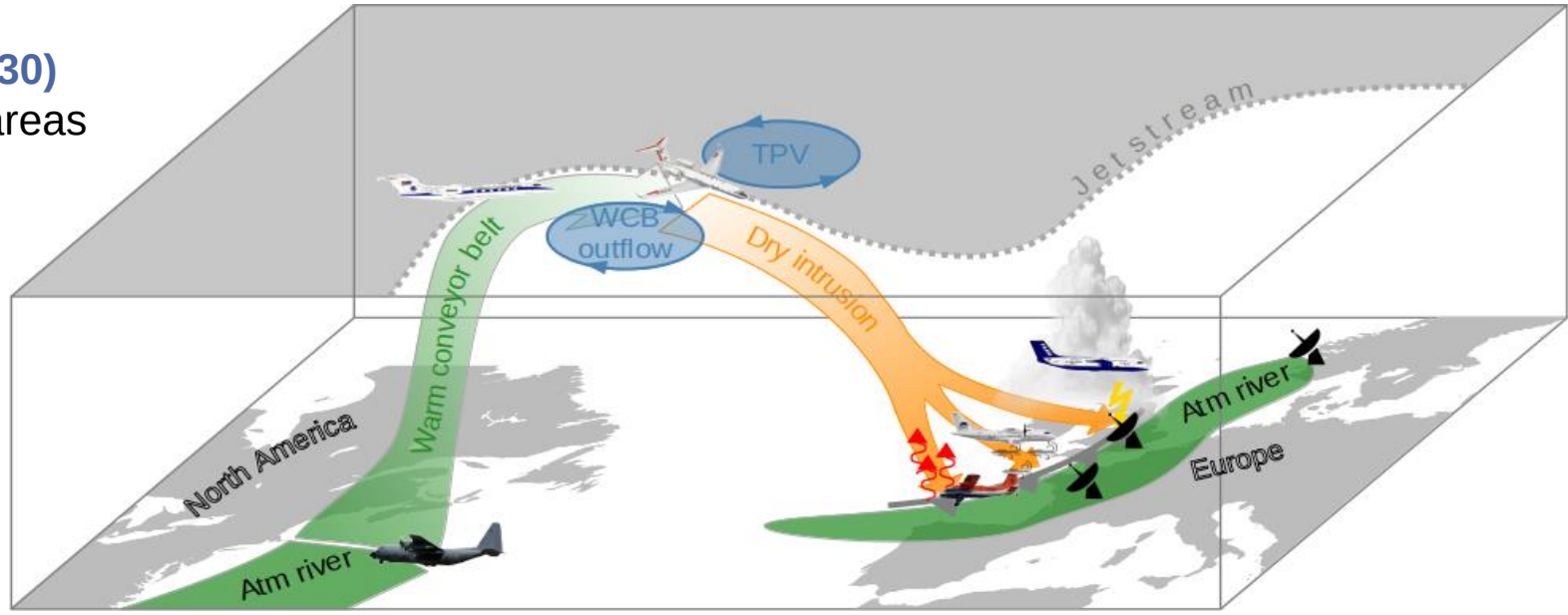
Seamless Observation Strategy – NAWDIC components

- *NAWDIC observations will be made across multiple scales using airborne and ground-based observations complemented by a **seamless modelling component** incl. data assimilation*

Long-range aircraft (HALO / NASA / NOAA?)
Sample tropopause structure, DI-PBL interaction, and moisture uptake & transport with remote sensing instruments/dropsondes

Mid-range aircraft (ATR42/UK FAAM/US-C130)
DI-PBL and ocean-atmosphere interaction in areas related to HIW

Ground-based observations
Dense observation network along the European coastline: **KITcube** supersite + FR mobile radars + UK radars, wind profilers, lidars + NO lidar



NAWDIC-HALO Coordinating team

- **KIT:** Christian M. Grams, Annika Oertel, Alexandre Ramos, Julian Quinting
  + Scientific Coordinator (tbd)
- **DLR:** Andreas Schäfler
- **Weizmann**: Shira Raveh-Rubin

Annika

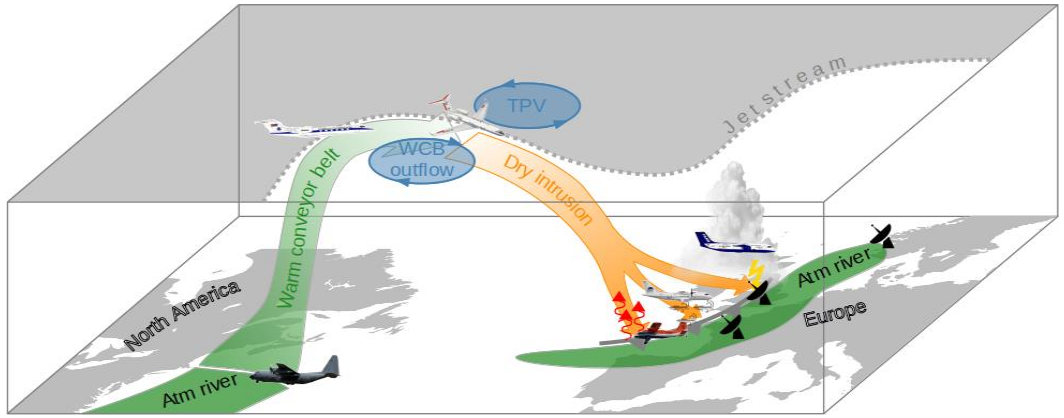
Alexandre

Andreas, Julian, Shira, Christian

- **German University partners** Peter Knippertz (**KIT**), George Craig (**LMU**), Volkmar Wirth (**JGU Mainz**), Peter Hoor (**JGU Mainz**)

NAWDIC-components and primary contact points - Overview

- **NAWDIC-HALO**: DE community. Long-range HALO aircraft (C. Grams, A. Ramos, A. Schäfler, S. Raveh-Rubin)
- **NAWDIC-KITcube:** DE/KIT community. Ground-based measurements with KITcube (J. Quinting, A. Oertel)
- **NAWDIC-AR:** US AR community. Mid-range aircraft targeting atmospheric rivers. (M. Ralph, A. Wilson)
- **NAWDIC-US:** US academic community. long-range aircraft tropopause region (S. Cavallo, A. Lang, R. Torn)
- **NAWDIC-UK:** UK community. Ground-based measurements and mid-range aircraft (J. Methven, D. Parker)
- **NAWDIC-FR:** FR community. Ground-based measurements and mid-range aircraft (F. Pantillon, G. Rivière)
- further contributions / support by
  - **WWRP** (C. Davis)
  - **ECMWF** (D. Lavers)
  - **DWD** (R. Potthast, T. Göcke)
  - **CA** (R. McTaggart-Cowen)
  - **CH** (H. Wernli)
  - **IL** & **COST-MED** (S. Raveh-Rubin, F. Pantillon)
  - **NO** (H. Sodemann, T. Spengler)

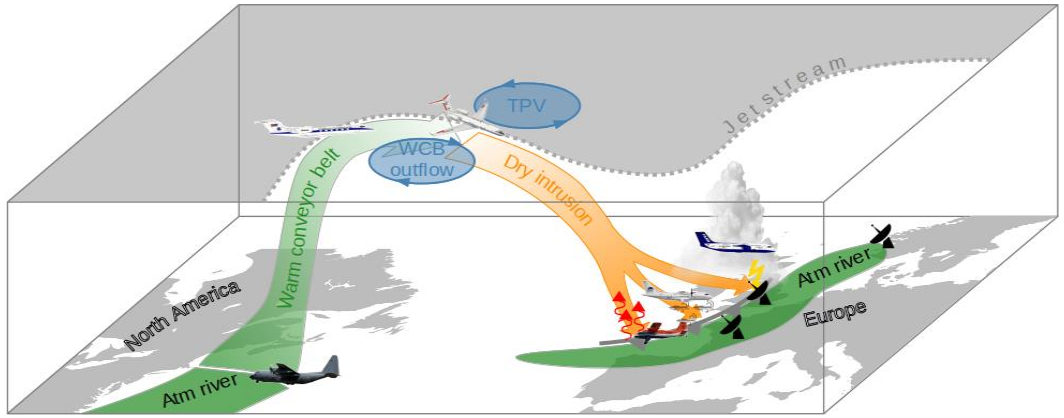


Status of international NAWDIC components

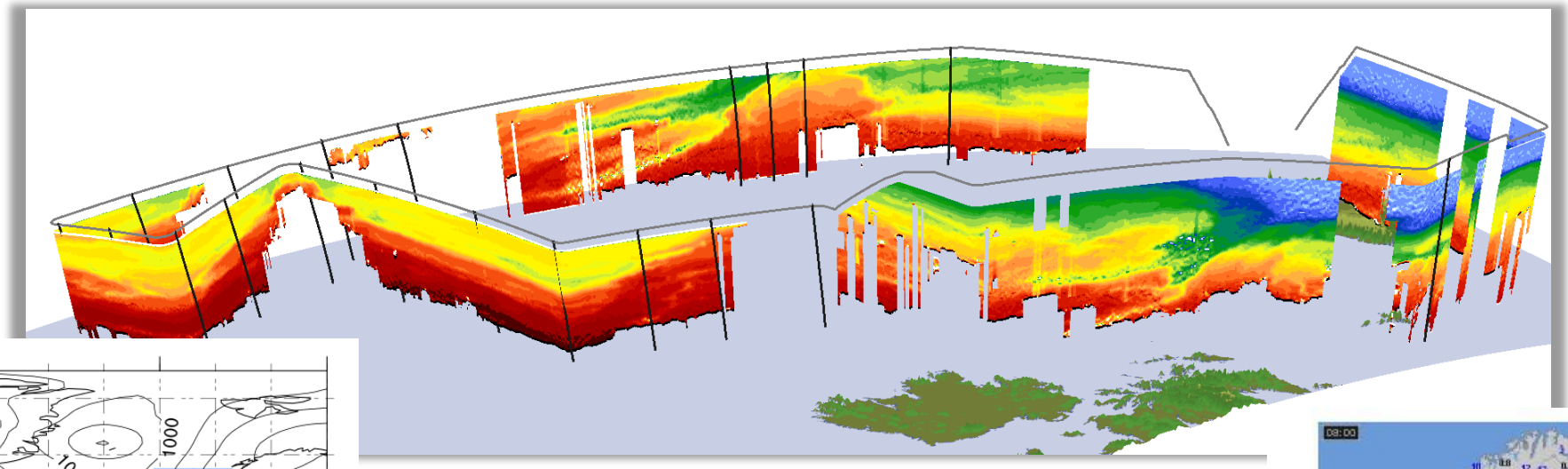
- **AR-RECON** (**USA**, working title NAWDIC-AR)**:**
  - vision of a global atmospheric river reconnaissance program. Roadmap with expanding C130 recon flights in Gulf of Mexico and western Atlantic in the next years. 2026 would as a demo mission coordinated with NAWDIC.
  - coordination **Workshop NAWDIC-AR Recon** on 30 June 2023 at ECMWF, Reading, UK
- **CAPRI:** (**UK**, working title NAWDIC-UK)
  - NERC Large Grant outline proposal CAPRI submitted 9 March 2023. FAAM Bae 146 aircraft.
- **NAWDIC-US:** (US-academic community)
  - discussions at AMS annual meeting Jan 2023. Ongoing discussions with NASA and NOAA to decide which aircraft to propose. Coordination of proposal writing with us from July 2023
- **NAWDIC-FR:** (French academic community)
  - Ideas: Lidar / Radar array in coordination with KITcube. Support with mid-range, mid-level aircraft Saffire ATR42 based in Toulouse

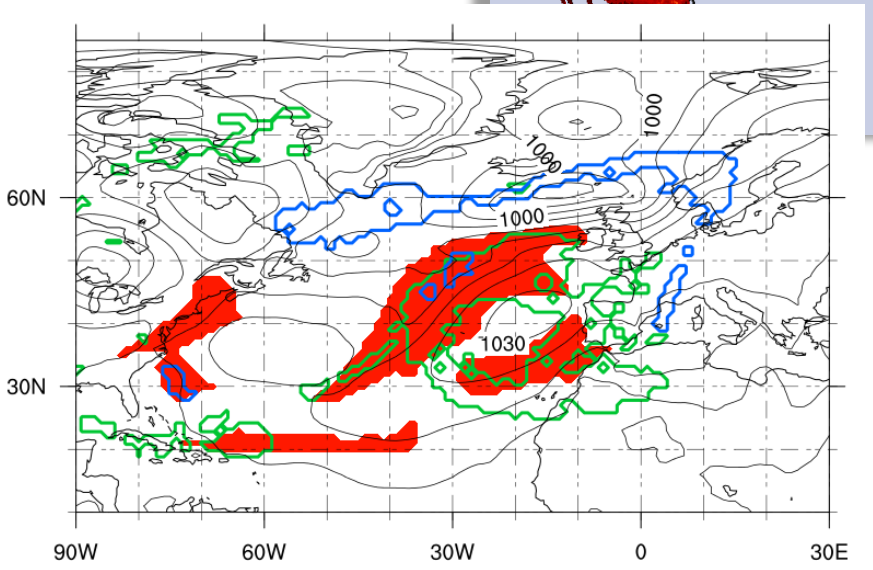
NAWDIC-HALO deployment

- **HALO instrumentation**
  - KITsonde https://www.imk-tro.kit.edu/english/7894.php
  - DIAL lidar (WALES: H2O, O3)
  - Doppler-WIND lidar
  - insitu air chemistry for air mass characterisation
- **HALO Area of Operation:** *North Atlantic*
  - HALO based either in Ireland, Iceland, or France
- **Time period:** *Winter*
  - 6 weeks in **January – February 2026**
  - DI occurrence frequency maximum in winter

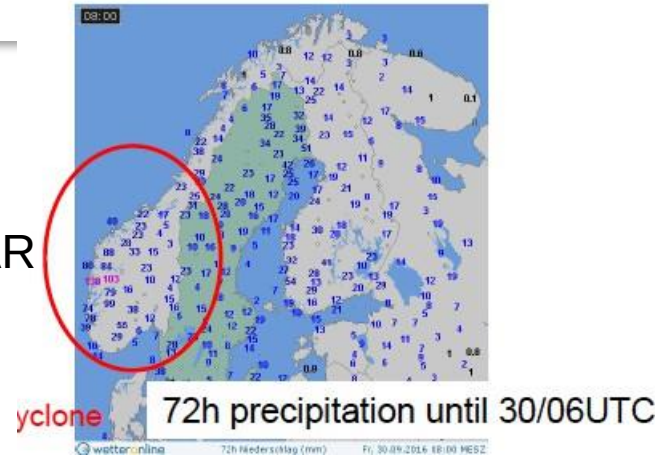


Co-located observations of water vapour and wind





example: NAWDEX case 2016
water vapour lidar observations in forming AR



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KITcube integrated atmospheric observation system

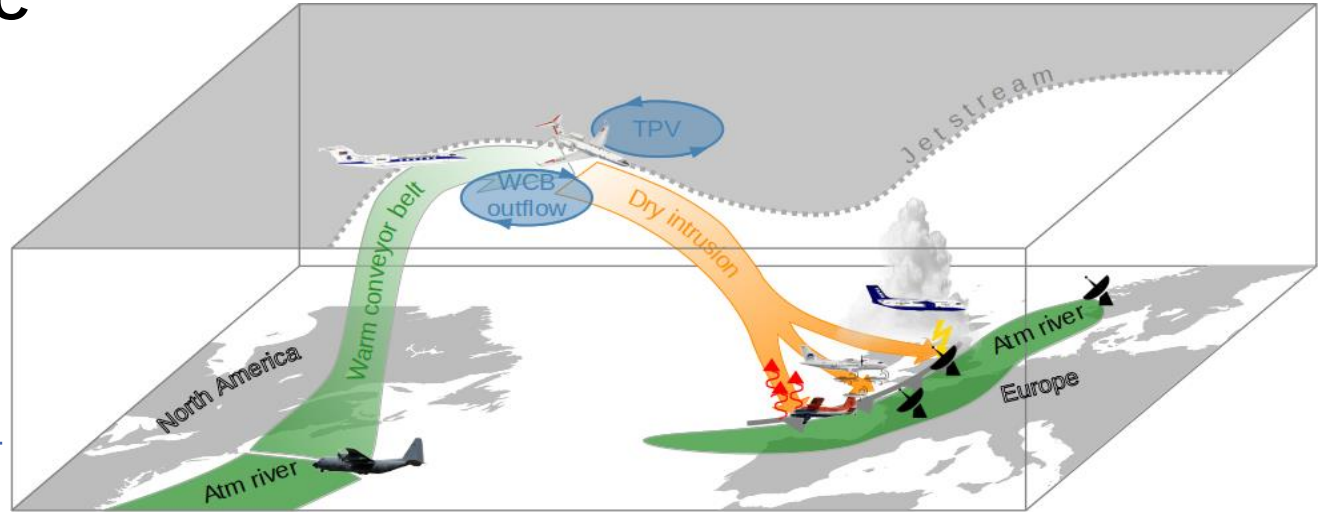
https://www.imk-tro.kit.edu/7858.php

NAWDIC-KITcube - deployment

- **local measurements at a supersite and / or observational array**
- **key instruments:**
  - Cloud, X-, and K-band radars
  - Doppler-Lidars (wind)
  - Microwave radiometers (q, T profiler)
  - Ceilometer, Autolauncher radiosoundings,…
- **area:** *French Coastline*
  - supersite at Atlantic Coast
  - coordinated with mobile French facilities
- **Time period:** *Winter 2025/26*
  - can be operated remotely in extended winter
  - pre-campaign envisioned in winter 2024/25

Summary Next steps

- 2023: NAWDIC-AR Recon Workshop & international coordination
- 2023: HALO proposal
- 2024: NAWDIC white book
- 2025: NAWDIC dry run
- **Jan-Feb 2026 implementation of NAWDIC**



Information and references:

- NAWDIC planning wiki

https://internal.wavestoweather.de/campaign/projects/nawdic/wiki

- NAWDIC International Science Plan

https://internal.wavestoweather.de/campaign/projects/nawdic/wiki/Science_Plan

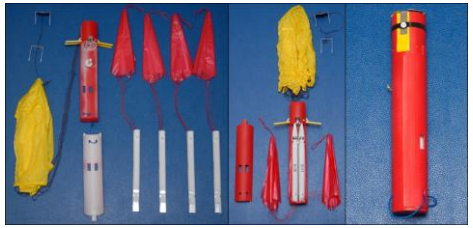
additional slides

Roadmap towards campaign implementation

- *May-December 2023: Definition of HALO instrumentation, HALO cost estimate, HALO-SPP umbrella proposal*
- *June 2023: Coordination with AR-RECON community at AR-RECON annual workshop*
- *June – December 2023: consultation with US-academic community in preparation of US proposal*
- *February 2024:* ***HALO proposal submission in March/April 2024***
- *2023-2024 ongoing consultation with UK component CAPRI, NAWDIC-KITcube, ECMWF, DWD, and French colleagues*
- *2024 NAWDIC white book with detailed mission scenarios*
- *winter 2024/25 NAWDIC dry run*
- *2025 refined mission scenarios, detailed implementation planning*
- ***Jan-Feb 2026 Implementation of NAWDIC***

NAWDIC-HALO and NAWDIC-KITcube deployment

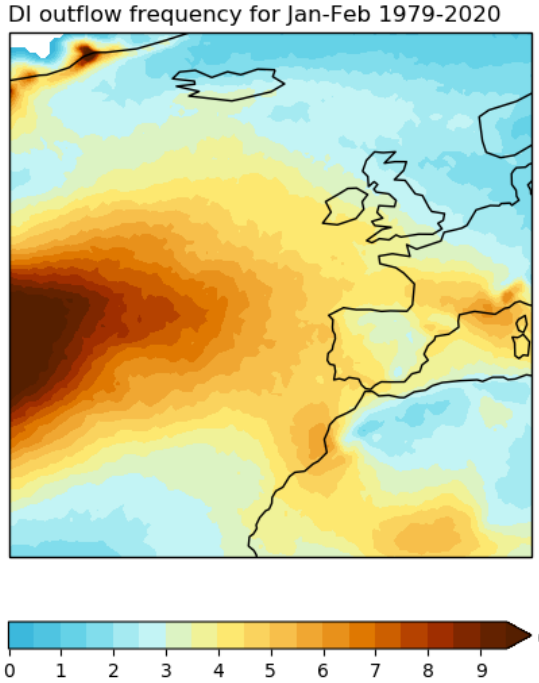
- local **KITcube** supersite will allow
  - detailed and high-frequent observations of local weather, in particular wind gusts and change of air-mass characteristics during cold frontal / DI passage.
  - realtime high-resolution data assimilation
- Long-range flights with **HALO** will allow
  - **observations of DI-PBL interaction** in the **moisture origin regions** as well as of the interaction with DIs **affecting HIW** over Europe (→ moisture transport, moisture uptake and winds)
  - detailed observations of the **mesoscale tropopause structure** in remote **DI origin** areas over the North Atlantic and a **quasi-Lagrangian tracking of** the **descending DI** air masses (→ trace gas gradients and wind gradients)



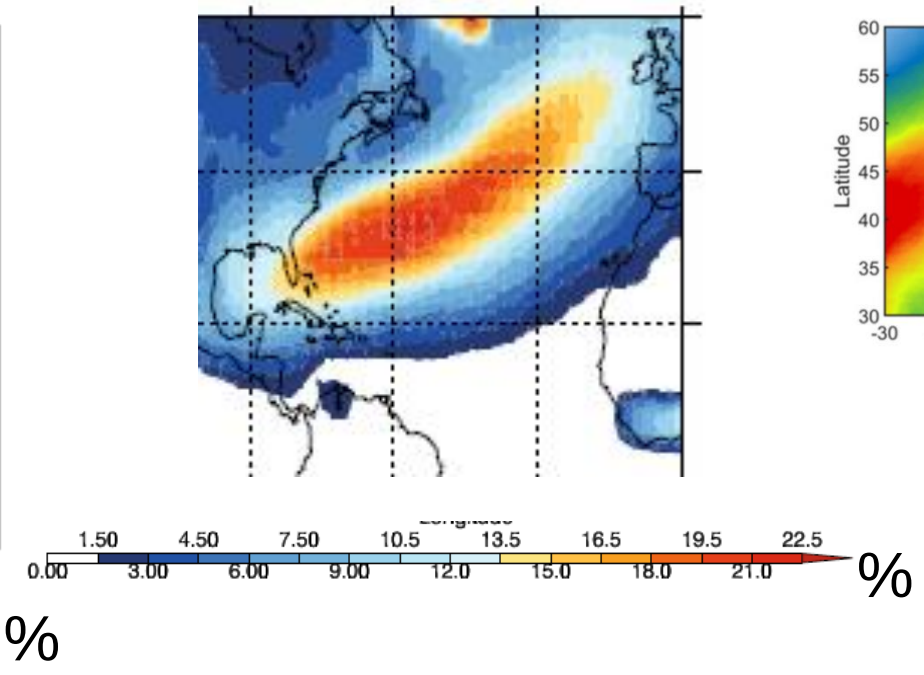
Seamless Observations– targeted weather features

- AR, cold front, DI outflow, DI descent, DI origin in the upper troposphere

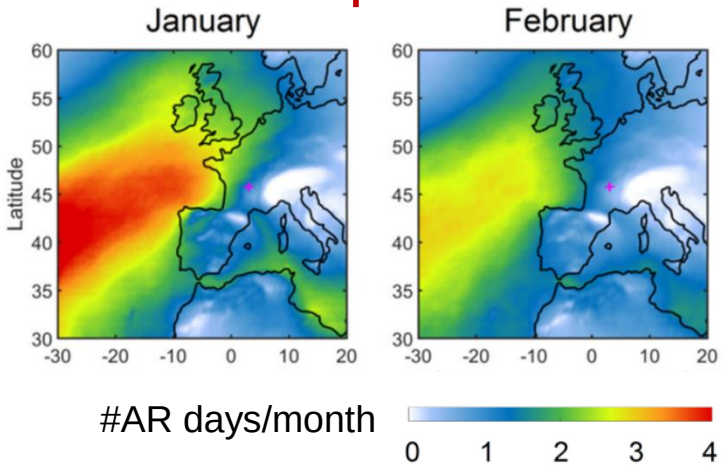
DI outflows



Cold trailing fronts



Atmospheric rivers



Doiteau et al. 2021

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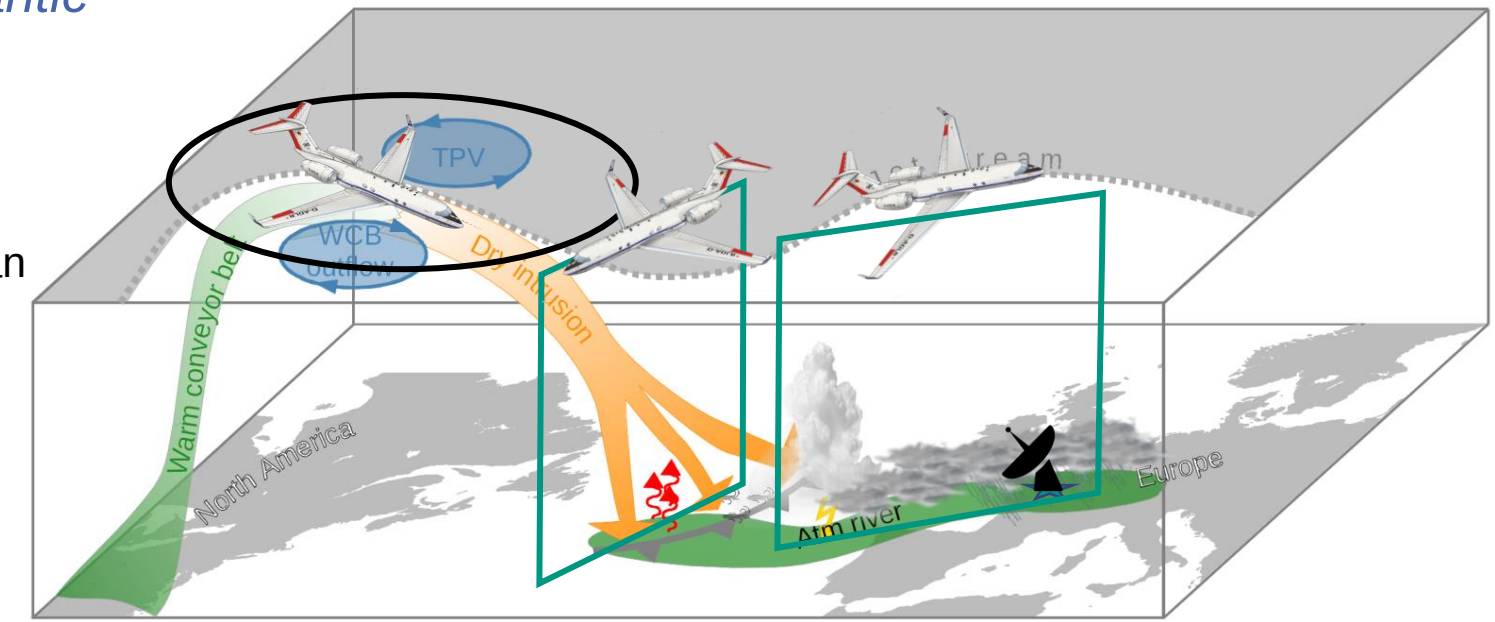
Seamless observation strategy combining HALO and KITcube

- **HALO Area of Operation:** *North Atlantic*
  - HALO likely based in Ireland
- **KITcube:** *French Coastline*
  - supersite at Atlantic Coast or Mediterranean
  - coordinated with mobile French facilities
- **Time period:** *Winter*
  - 6 weeks in **January – February 2026**
  - storm track activity maximal in winter



TP structure

DI-PBL interaction moisture uptake

moisture transport / lower level winds

NAWDIC-HALO instrumentation *(in discussion)*

- **In-situ package BAHAMAS**
  - SHARC
  - turbulence
- **Remote sensing**:
  - KITsonde
  - DIAL lidar (WALES)
  - WIND lidar
- **In-situ instruments**
  - SpecMACS
  - UMAQS
  - FISH
  - FAIRO

Instrument	Parameter	Institution	PI
KITsonde	U, V, W, T, RH	KIT	Wieser
WALES	H2O/O3	DLR	Wirth
1.6 mu Wind Lidar	U, V, W	DLR	Witschas
SpecMACS	cloud structure	LMU	Mayer/Zinner
UMAQS	CO, N2O, …	U Mainz	Hoor
FISH	H2O	FZ Jülich	Krämer/Rolf
FAIRO	O3	KIT	Zahn

A brief history of the NAWDIC idea …

May – July 2019

- discussion about a HALO campaign with focus on atmospheric dynamics initiated at KIT

July – December 2019

- reaching out to selected international partners and NAWDEX SG (07/2019)
- submission of a white paper by KIT, LMU, JGU, DLR, W2W and presentation as a potential mission at the HALO Planning workshop (10/2019)

January – November 2020

- international discussion via NAWDIC email list and NAWDIC wiki including the US AR Recon community

→ *overwhelming interest from academic community and weather services (07/2020)*

November 2020

- ***1st international workshop*** *(online)*
  (49 participants, 10 countries, 29 institutions including 5 weather services)

December 2020 – July 2021

- preparation and discussion of **NAWDIC International Science Plan** (published in July 2021)
- NAWDIC-HALO **scheduled for Jan 2026**

August 2021 – ongoing

- status presentation at HALO status colloquium (09/2021)
- discussion of NAWDIC-HALO component and HALO instrumentation with national community
- discussion of KITcube component

2023 – ongoing

- UK-CAPRI pre-proposal (March 2023)
- US-academic component discussion at AMS 2023
- **HALO instrumentation Workshop KIT** (May 2023)
- **NAWDIC-AR Recon Workshop ECMWF** (June 2023)

NAWDIC

North Atlantic Waveguide, Dry Intrusion, and Downstream Impact Campaign

- **1st international workshop** (Nov 2020 online)
  (49 participants, 10 countries, 29 institutions including 5 weather services)
- NAWDIC **International Science Plan** (July 2021)
  https://internal.wavestoweather.de/campaign/projects/nawdic/wiki/Science_Plan

International Campaign with modular observation strategy

and different national components