The North Atlantic Waveguide, Dry Intrusion, and Downstream Impact Campaign (NAWDIC)

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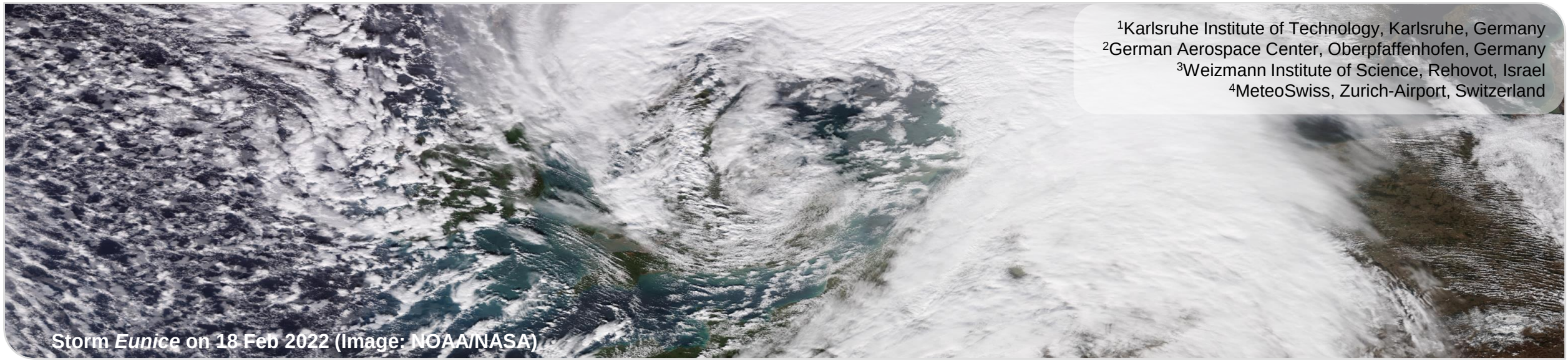
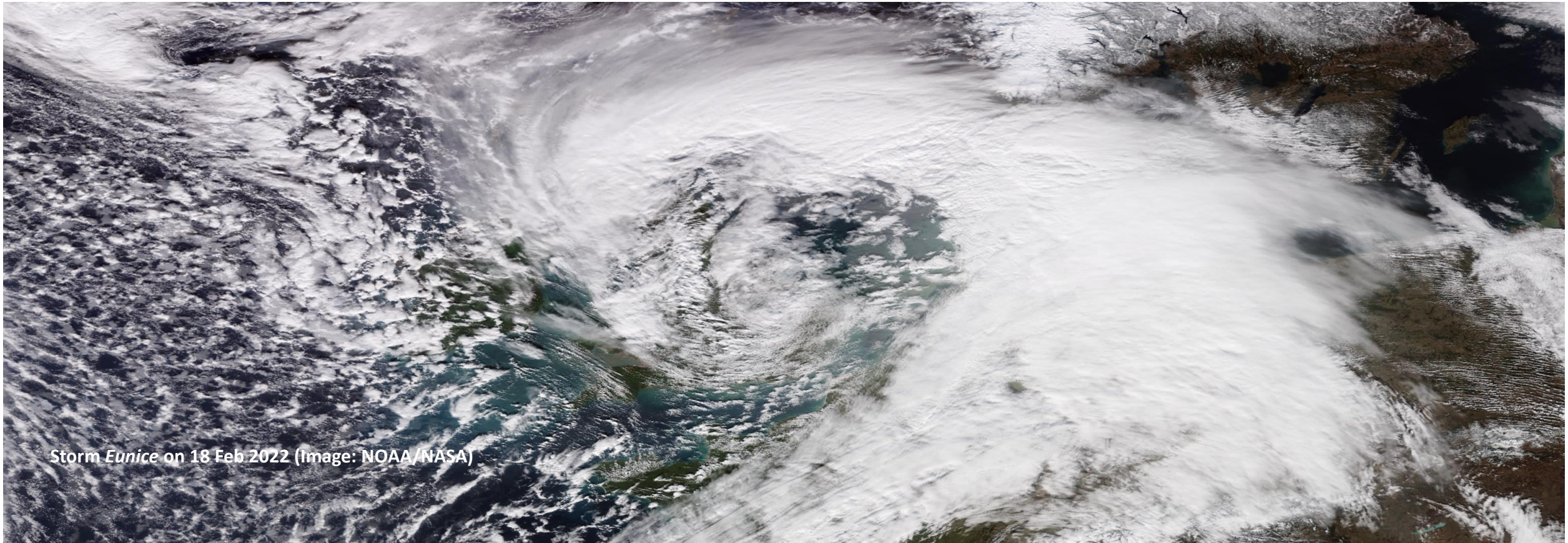


Storm *Eunice* on 18 Feb 2022 (Image: NOAA/NASA)

- Upstream dynamics govern HIW and its predictability
- New focus on dry intrusions (e.g., Eunice + Franklin)
- Current gaps in process understanding + model biases

✈ **NAWDIC**

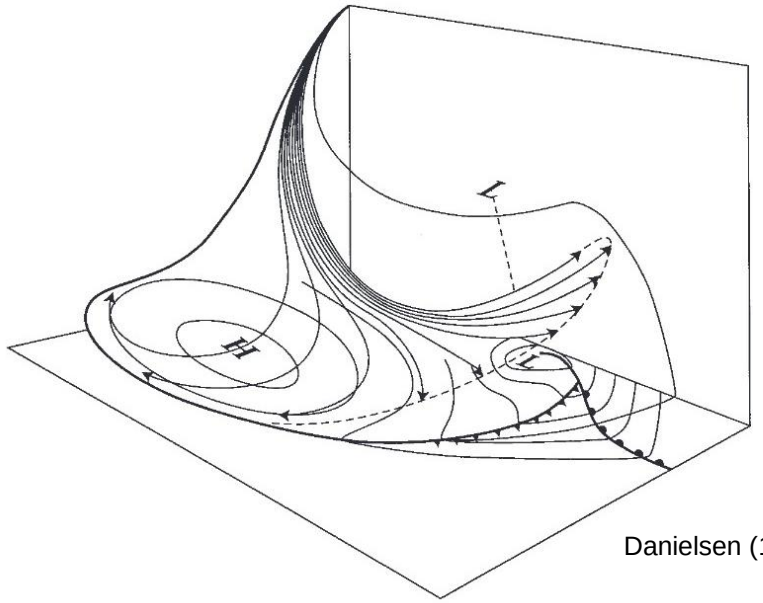


Storm *Eunice* on 18 Feb 2022 (Image: NOAA/NASA)

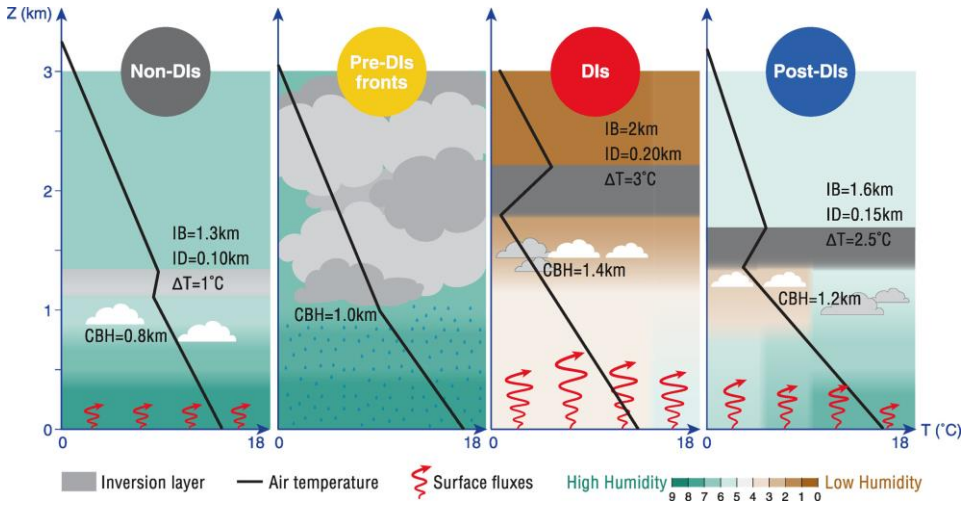
Dry air intrusions (DIs)

- Air stream in ETCs descending equatorward from the upper troposphere into the cold sector (Reed, 1955; Browning, 1997)
- Emerge most frequently from the downstream flank of upper-tropospheric ridges (DI inflow region) (Raveh-Rubin 2017; Silverman et al. 2021)
- Downward momentum transfer in DIs linked to strong near-surface winds and ocean evaporation (Eisenstein et al. 2023; Givon et al. 2024)
- Interaction with trailing cold fronts (Catto and Raveh-Rubin 2019) and PBL (Ilotoviz et al., 2021) leads to high-impact weather (HIW) (Klaider and Raveh-Rubin 2023; Magaritz-Ronen and Raveh-Rubin 2023; Rai and Raveh-Rubin 2023)
- Involved cross-scale interactions of physical processes are insufficiently captured by operational observing systems (Schäfler et al., 2024)

→ Forecasting of HIW events remains a challenge



Danielsen (1964)

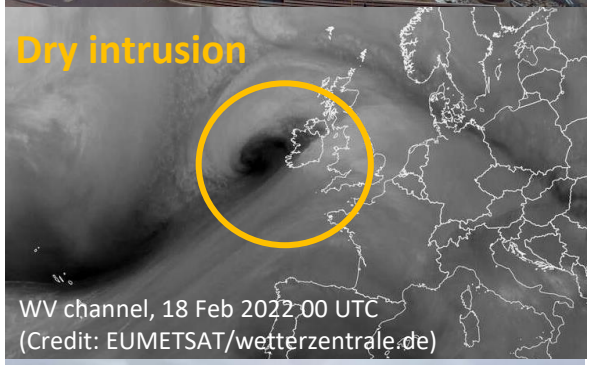


Ilotoviz et al. (2021)

Wind storm “Eunice” followed by storm “Franklin” (February 2022)

- Intense cyclones with severe weather impacts over western Europe, especially in the UK and Ireland
- Four fatalities, widespread loss of power and fallen trees, damage to buildings, and transport disruption (Volonté et al. 2024a)
- Mean wind speeds of 100 km/h over the English Channel and maximum gust of 198 km/h on 18 February 2022 (Volonté et al. 2024a)
- Peak winds caused by sting jet, cold conveyor belt, and dry intrusion airstreams (Volonté et al. 2024b)
- Precipitation and flooding in northern UK on 21 February 2022


Credit: The New York Times

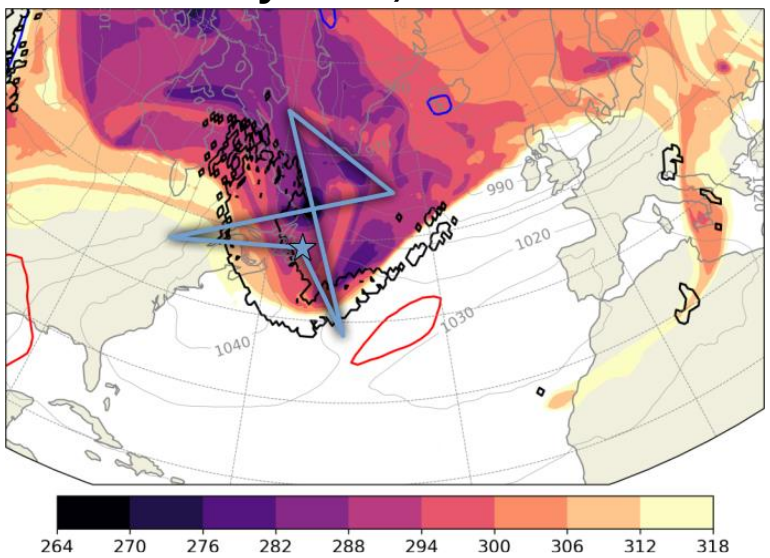


WV channel, 18 Feb 2022 00 UTC
(Credit: EUMETSAT/wetterzentrale.de)


Credit: BBC

DI and downstream HIW:
Cyclones Eunice and Franklin (Feb. 2022)

16 February 2022, 12 UTC

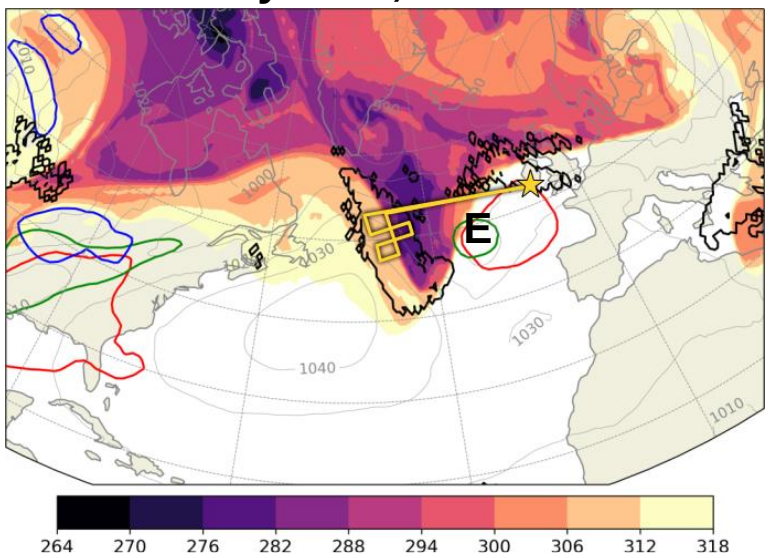


Potential temperature on the dynamic tropopause (K)

- Trough prior to genesis of cyclone Eunice

DI and downstream HIW:
Cyclones Eunice and Franklin (Feb. 2022)

17 February 2022, 12 UTC



Potential temperature on the dynamic tropopause (K)

- Genesis cyclone Eunice

DI and downstream HIW:
Cyclones Eunice and Franklin (Feb. 2022)

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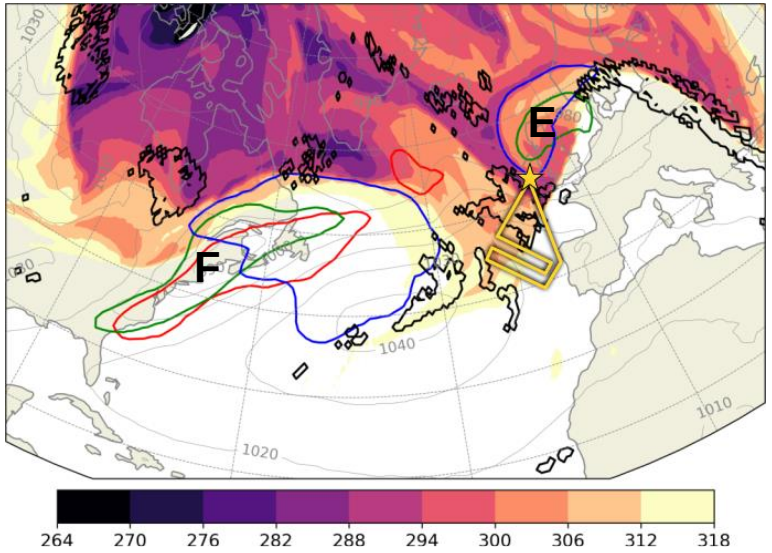

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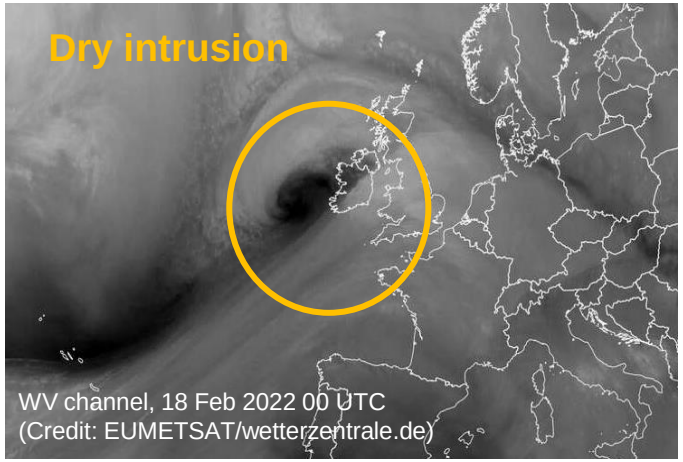
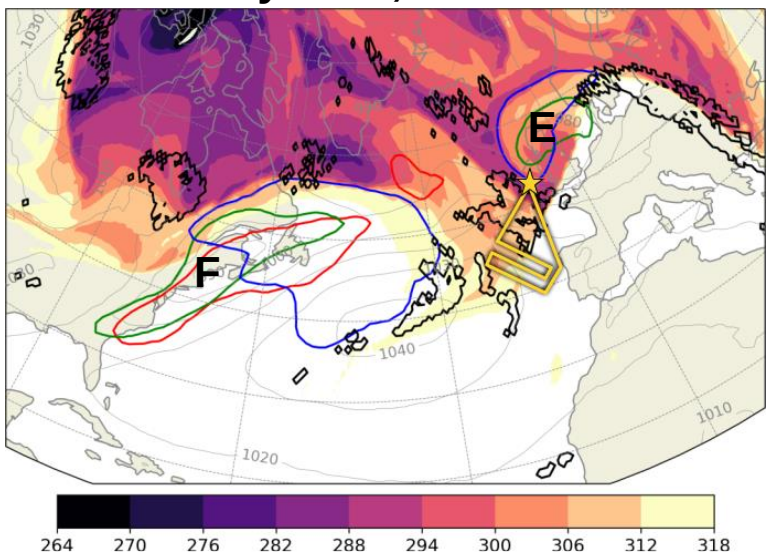


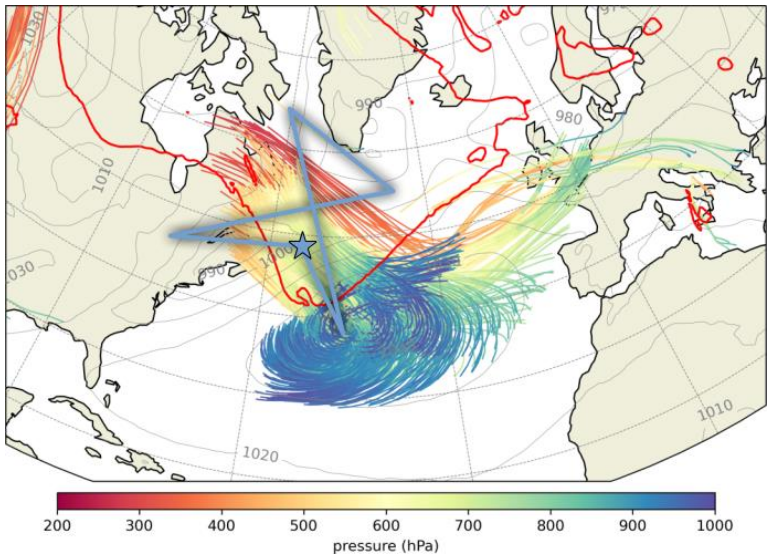
- Peak winds in UK at this time with passage of Eunice. Maximum wind gust of 198 km/h, caused by a sting jet, cold conveyor belt and DI (Volonté et al., 2024)

DI and downstream HIW:
Cyclones Eunice and Franklin (Feb. 2022)

18 February 2022, 12 UTC



Potential temperature on the dynamic tropopause (K)



2 PVU contour on 300-K, 48-h DI traj. ending at same time (colored by pressure, hPa)

- Peak winds in UK at this time with passage of Eunice. Maximum wind gust of 198 km/h, caused by a sting jet, cold conveyor belt and DI (Volonté et al., 2024)

DI and downstream HIW:
Cyclones Eunice and Franklin (Feb. 2022)

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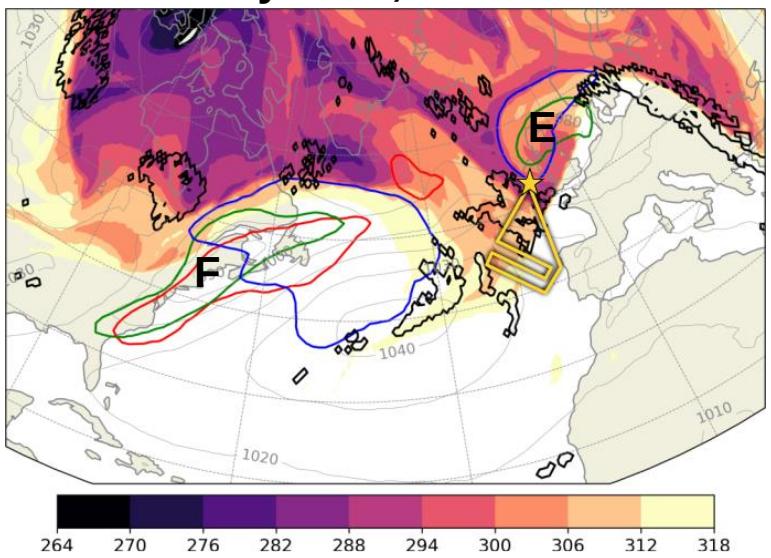
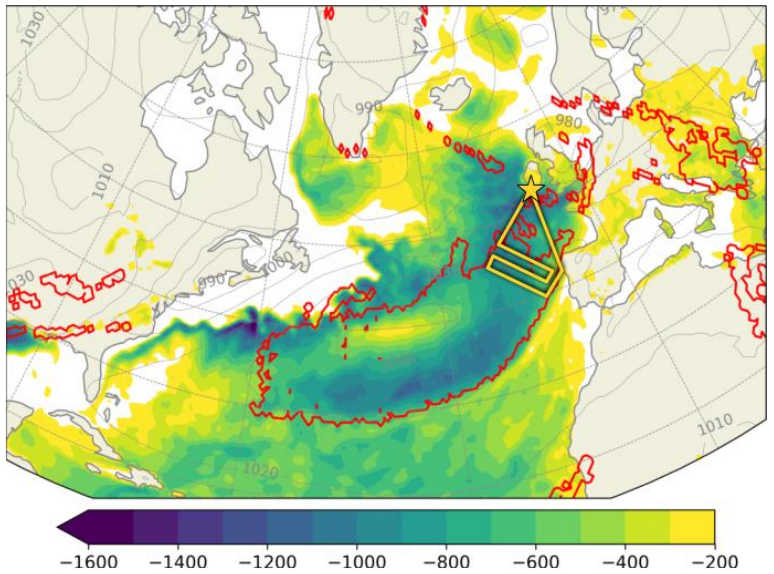


Potential temperature on the dynamic tropopause (K)

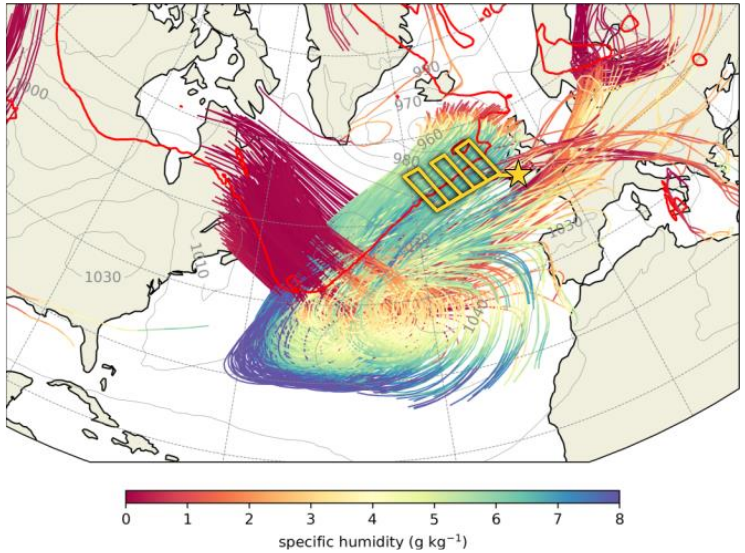


Surface latent heat flux (W m^{-2})
DI outflow

- Peak winds in UK at this time with passage of Eunice. Maximum wind gust of 198 km/h, caused by a sting jet, cold conveyor belt and DI (Volonté et al., 2024)
- Peak evaporation behind Eunice's cold front spanning the DI outflow
- Cyclone Franklin in W. Atlantic

DI and downstream HIW:
Cyclones Eunice and Franklin (Feb. 2022)

20 February 2022, 00 UTC



84-h DI trajectories coloured by specific humidity (g kg^{-1}) ending on 20 February 00 UTC

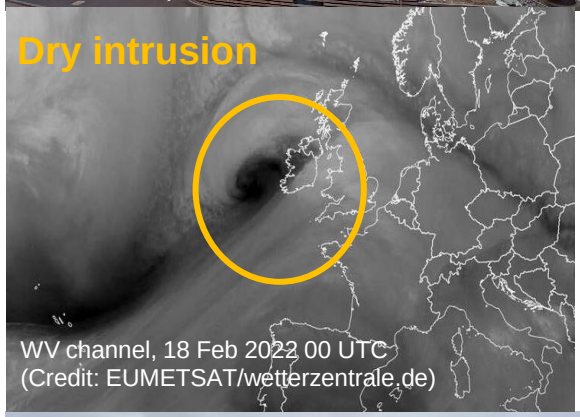
- New moisture feeds an atmospheric river of cyclone Franklin
- Downstream heavy precipitation and flooding in Northern UK and Ireland

DI and downstream HIW:
Cyclones Eunice and Franklin (Feb. 2022)

- DI linked directly to wind impact on 18 February (Eunice)
- Precipitation and flooding in northern UK on 21 February 2022 from atmospheric river (Franklin)
- DI-induced evaporation key for downstream precipitation
- Demirjian et al. (2023) and Papritz et al. (2022): moisture handover from cold sector of a cyclone to warm sector of the next. Important to predict
- But - bulk formula breaks down under strong winds and rough seas
- How do NWP models represent the lower troposphere during DIs?

Need ground-truth observations!


Credit: The New York Times



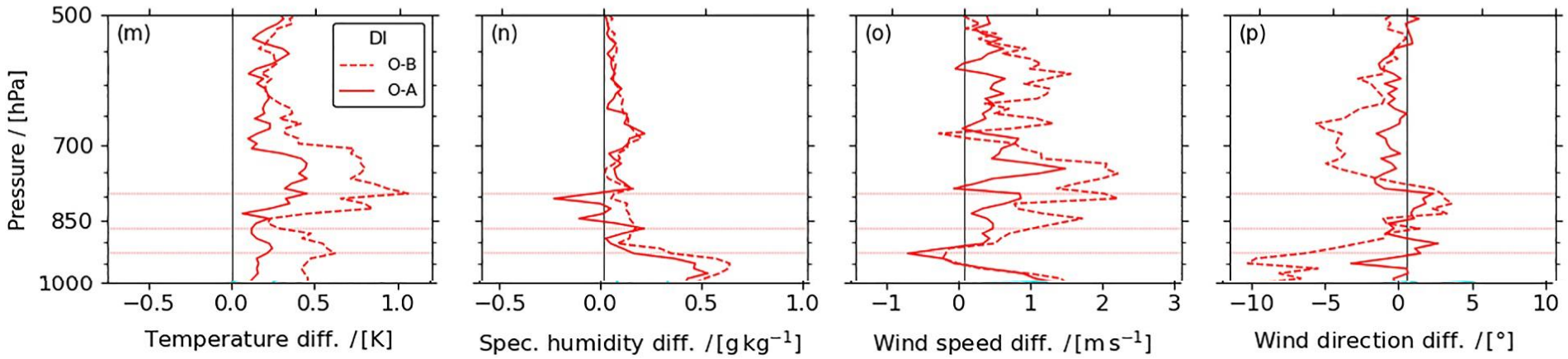
WV channel, 18 Feb 2022 00 UTC
(Credit: EUMETSAT/wetterzentrale.de)


Credit: BBC

Indication for IFS model biases during DIs

- Indication for biases in PBL during DIs and intense ocean evaporation
- Near-surface cold bias improved during DA
- Persistent near-surface dry bias
- Persistent too-weak wind speed bias

✈ Need for ground truth: moisture, winds, turbulent moisture fluxes and transport

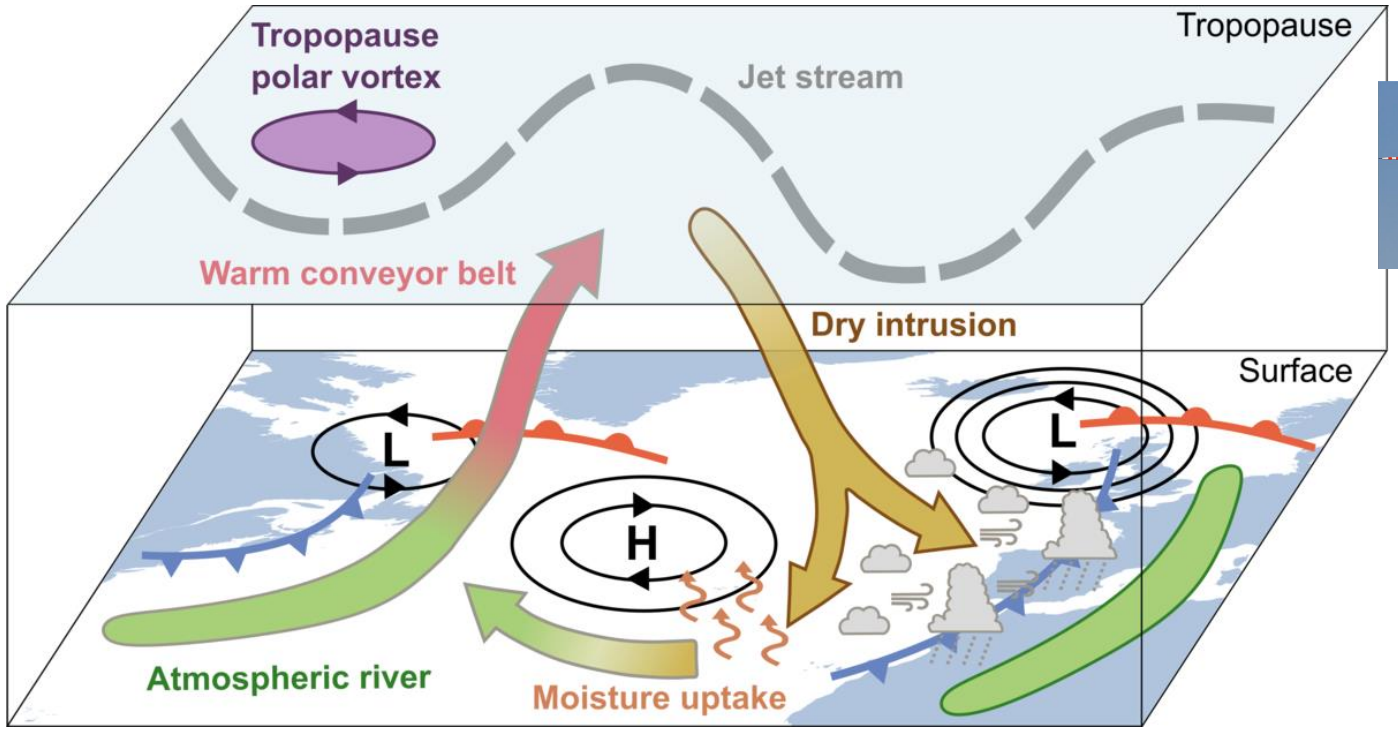


Observation-background forecast (O-B) = background departures (innovation)
Observation-analysis (O-A) = analysis departures (residual)

Ilotoviz et al. (2021, JGR-A); Schäfler et al. (2024, GRL)

The **N**orth **A**tlantic **W**aveguide, **D**ry Intrusion, and Downstream **I**mpact **C**ampaign (**NAWDIC**)

NAWDIC aims to advance our understanding of the **synoptic- to micro-scale processes** associated with the triggering of high-impact weather (HIW) such as **severe wind gusts, heavy precipitation, and cold air outbreaks** and of their **representation in NWP models**

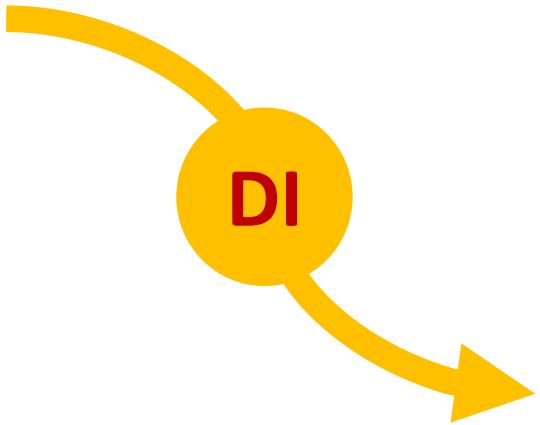


Core period: 12 Jan – 20 Feb 2026 / www.nawdic.kit.edu

Scientific idea of NAWDIC

NAWDIC aims to advance our understanding of the **synoptic- to micro-scale processes** associated with the triggering of high-impact weather (HIW) such as **severe wind gusts, heavy precipitation, and cold air outbreaks** and of their **representation in NWP models**

Hypothesis 1: tropopause dynamics
Mesoscale dynamics near the jet stream and in the DI inflow region affect the downstream development of HIW.



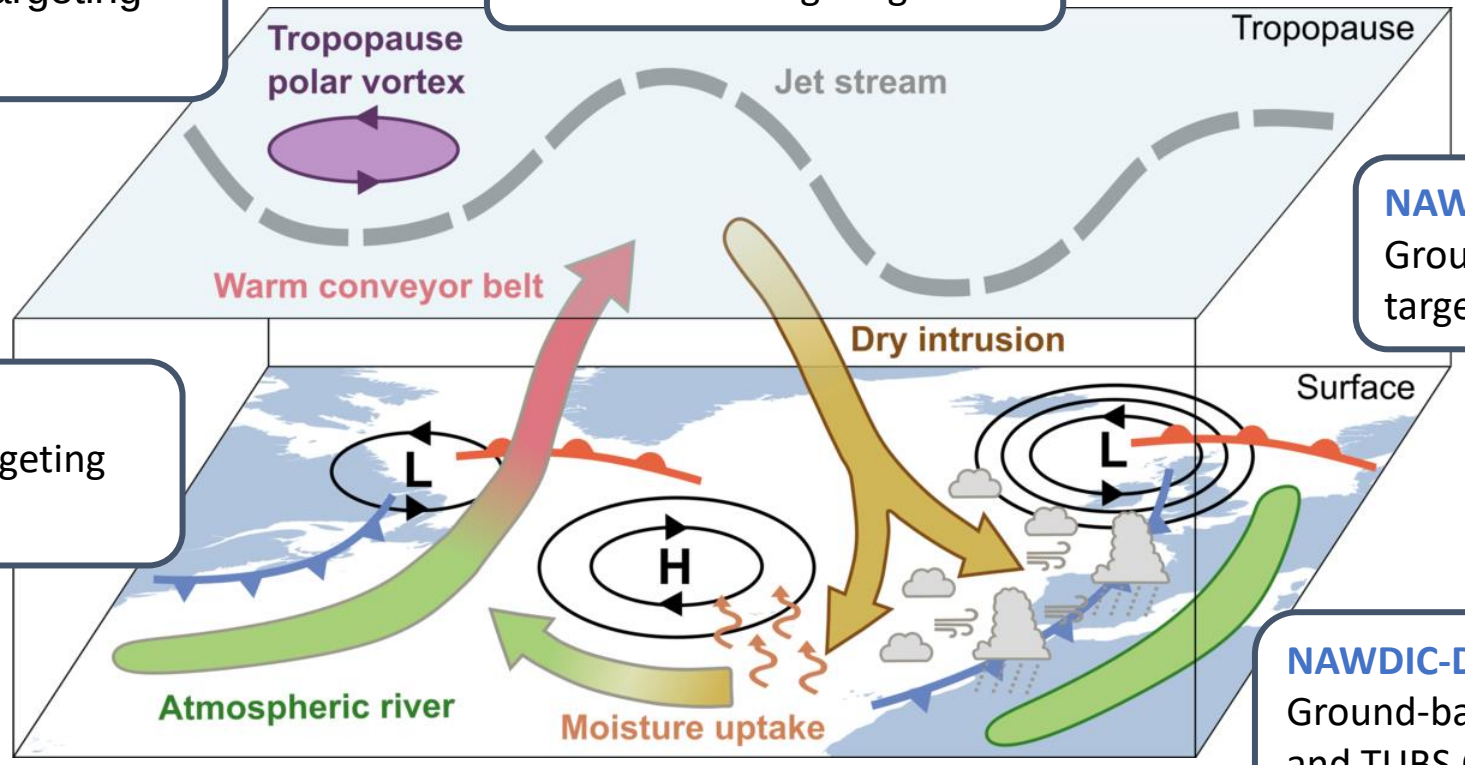
Hypothesis 2: PBL interactions
Interactions of the DI with the PBL below and the cold front ahead are key for the local evolution of HIW.

Observation strategy: Internationally coordinated effort for combined airborne and ground based observations across multiple scales complemented by a seamless modelling strategy.

NAWDIC: An international effort

NURTURE (US):
Long-range aircraft targeting tropopause region

NAWDIC-HALO (DE):
HALO aircraft targeting DIs



NAWDIC-KITcube (DE):
Ground-based measurements targeting DI-PBL interactions

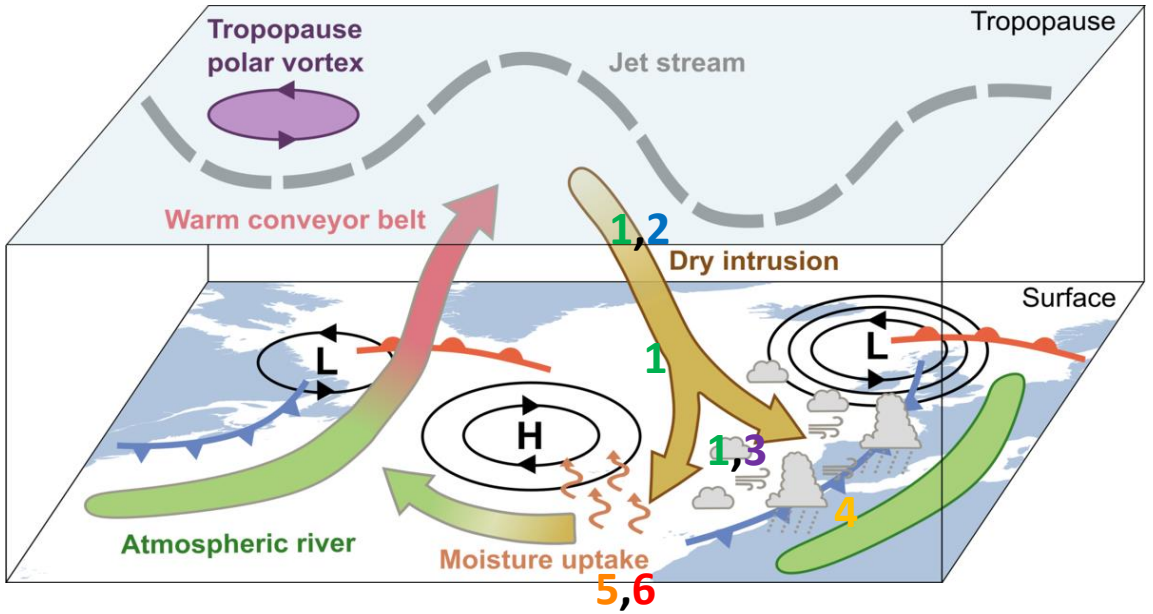
AR Recon (US):
Mid-range aircraft targeting atmospheric rivers

NAWDIC-DICHOTOMI (FR/DE):
Ground-based measurements, ATR42 and TUBS Cessna targeting downward momentum transport

+ NAWDIC-related projects at Weizmann Institute, ETHZ, Uni Bern, Uni Bergen

NAWDIC-HALO: The nucleus

- Tailored instrumentation:
  - Differential absorption lidar (H_2O, O_3)
  - Novel Doppler wind lidar (u, v, w)
  - Multi-sensor dropsonde system (T, q, u, v)
  - Imaging cloud spectrometer (size, phase, geometry)
  - In-situ air chemistry measurements (CO, C_2H_6, CH_4, N_2O)

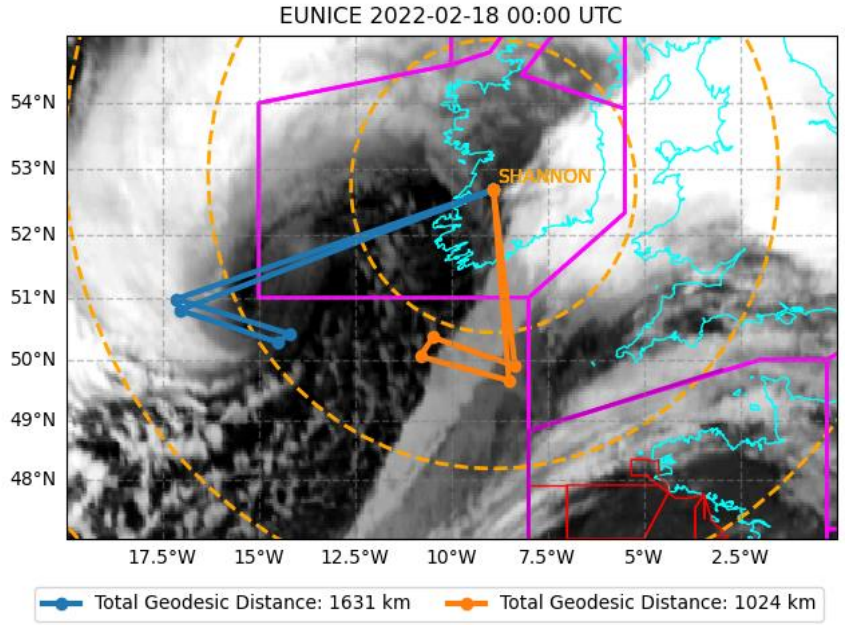


Umbrella proposal for **120 flight hours** and four individual **science proposals** funded by DFG:

1) Transport and mixing in DIs
2) Moisture structure in the DI origin region
3) Influence of dry intrusions on cloud distributions and microphysics
4) Convection at the cold front
5) Latent heat flux profiles in cold sector
6) Moisture source regions of ARs

DICHOTOMI: Dry Intrusion and Cloud Head winds On Top Of Marine Interfaces

- DI descends behind the cold front into the PBL leading to enhanced surface heat fluxes and modified cloud macro- and microphysics.
- French-German project focused on km-scale observations and modeling of downward momentum transport and cloud physics during high-wind events (funded by ANR/DFG)
- Two mid-range aircraft operating during NAWDIC:



French SAFIRE ATR42

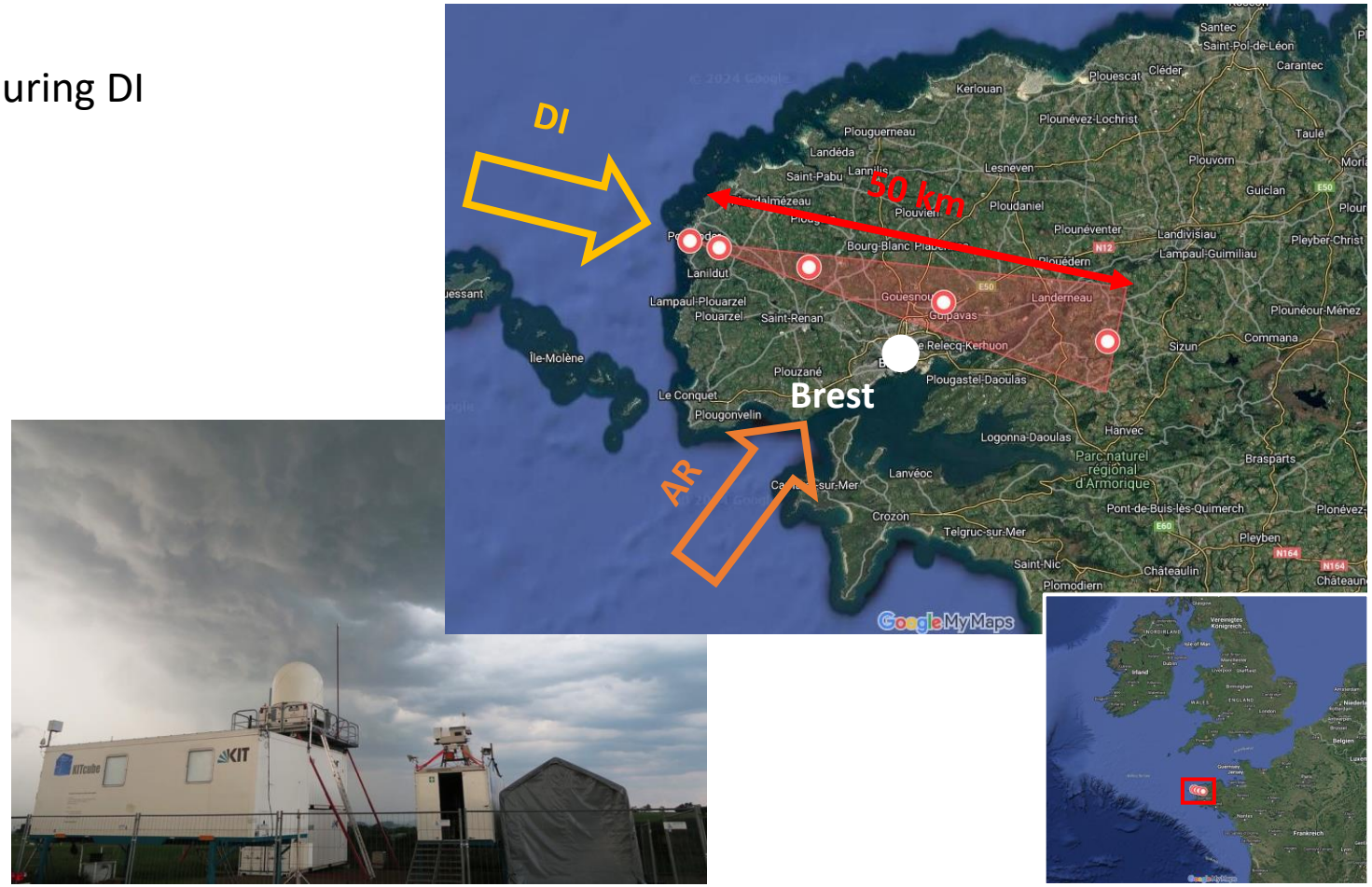
- Based in **Shannon (Ireland)**
- 70 flight hours
- Instrumentation for aerosols, clouds and precipitation properties, in-situ and remote sensing radar and lidar

German Cessna F406

- Based in **France**
- 65 flight hours
- Novel fixed-beam Doppler wind lidar and in-situ turbulence probes

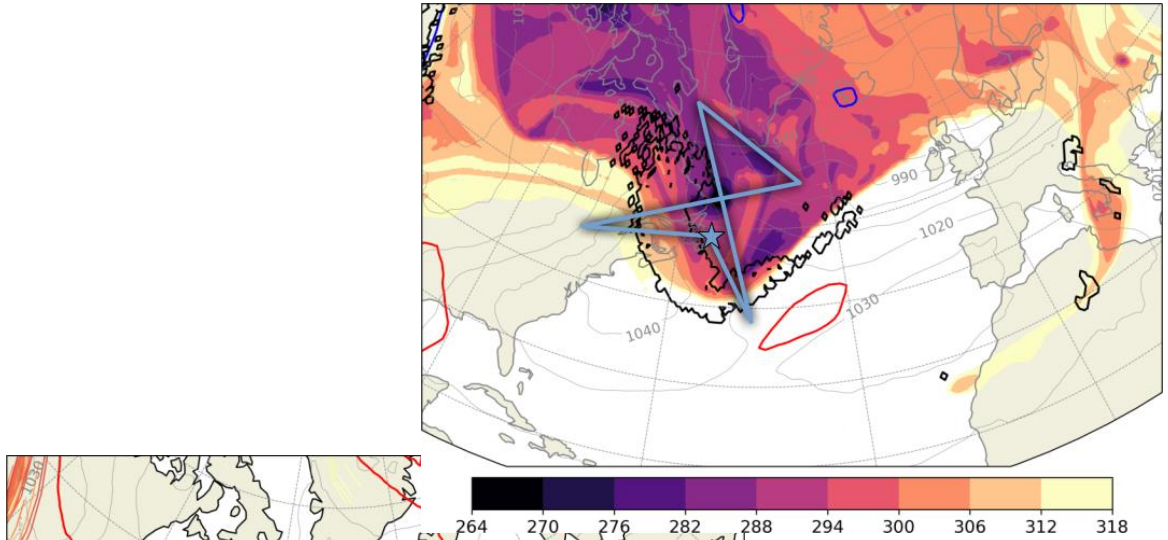
NAWDIC-KITcube: PBL modification during DIs

- Mobile integrated observation facility operated by KIT
- Focus on downward momentum transport during DI events and modification of PBL
- AR mesoscale features and impacts
- Deployment period: Nov 2025 – Mar 2026
- Instrumentation:
  - 5 water vapour lidars
  - 5 Doppler wind lidars
  - 2 cloud radars
  - 1 radiosonde autolauncher
  - 3 energy balance stations
  - 2 X-band rain radars
- Aircraft overflights for intercomparison

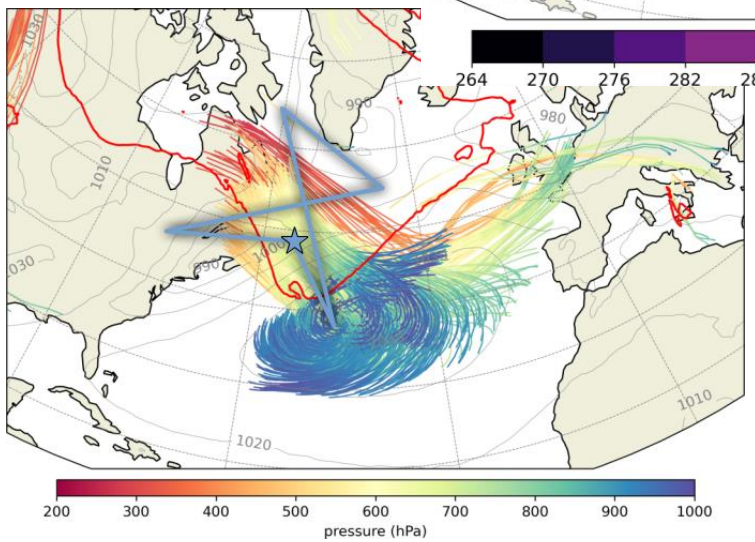


NAWDIC-US/NURTURE: Tropopause dynamics

- DI of storm Eunice originated from tropopause polar vortex (TPV) over the western North Atlantic and led to HIW over western Europe two days later.
- NURTURE: Proposed airborne campaign on the impact of UTLS dynamics on PBL processes and HIW events
- NASA long-range aircraft based in eastern North America during NAWDIC core period
- Coordinated effort to sample of DI inflow region from both sides of the Atlantic



Theta (K) on dynamic tropopause, 16 Feb 2022 (ERA5)



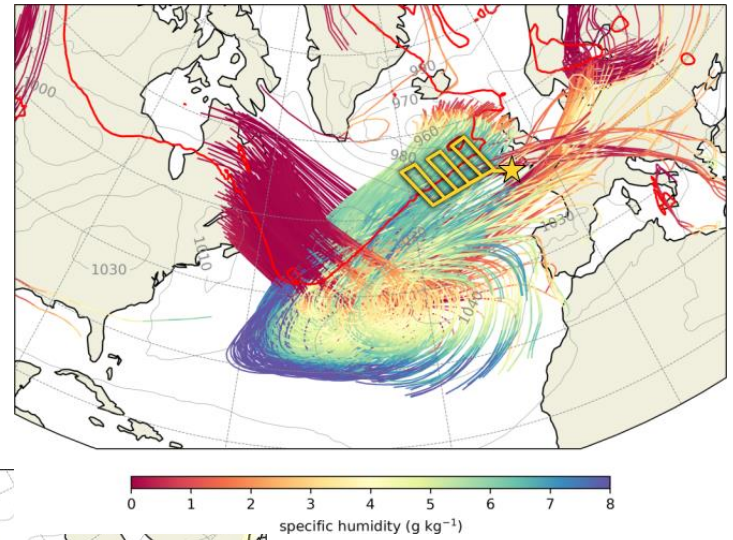
48-h DI trajectories starting on 16 Feb 2022 (ERA5)

NAWDIC-AR: Atmospheric River Reconnaissance

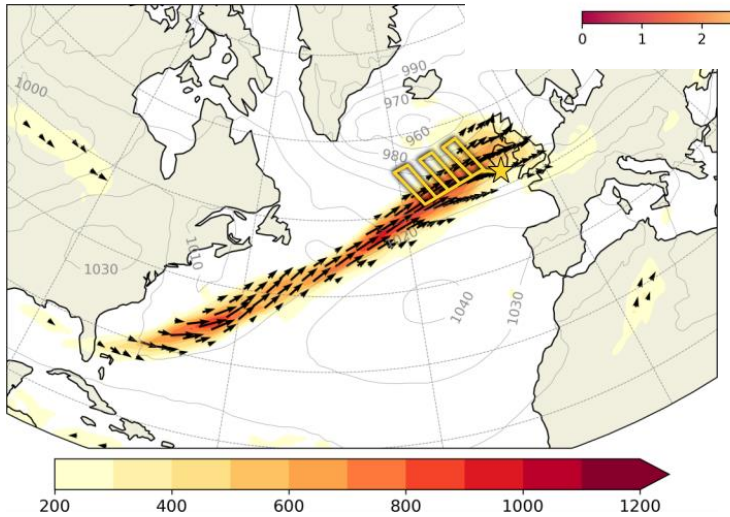
- Moisture uptake inside cold sector of “Eunice” contributed to AR of consecutive cyclone “Franklin”, causing heavy precipitation in UK two days after “Eunice”

- AR Recon program intends to extend reconnaissance flights from the eastern Pacific into the Gulf of Mexico and the Western North Atlantic in winter 2025/2026

- Linking upstream moisture sources with upper-tropospheric DI formation and downstream high-impact weather



q along 84-h DI trajectories starting on 16 Feb 2022 (ERA5)



IVT (kg m^{-1} s^{-1}) on 20 Feb 2022 (ERA5)

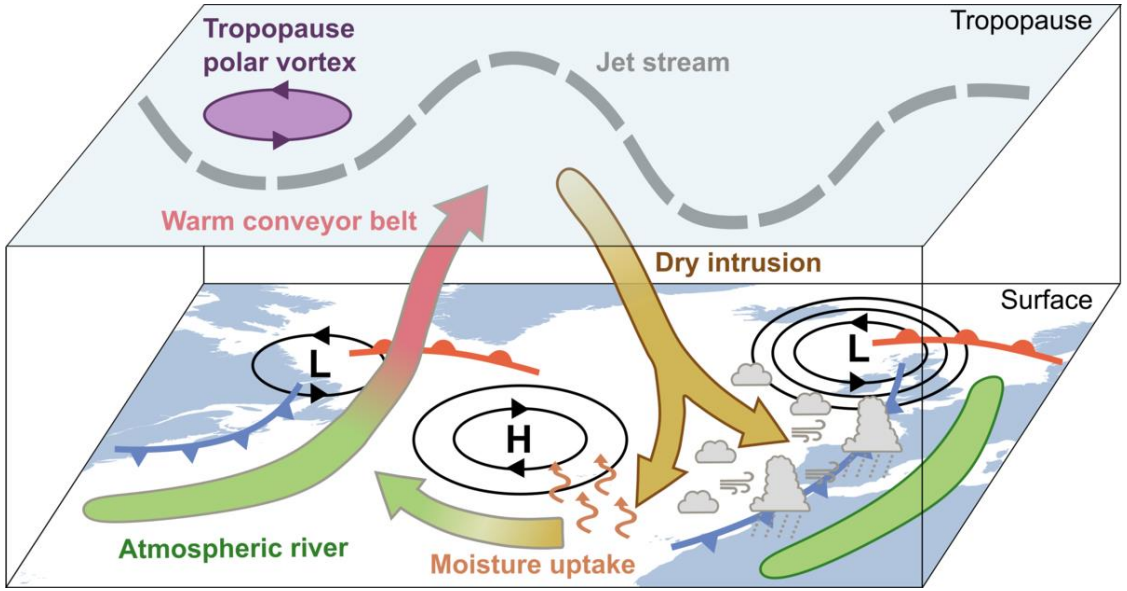
Summary and next steps

- NAWDIC aims to advance our understanding of dynamics leading to high-impact weather in ETCs over the North Atlantic region.

- Multiple airborne and ground-based observation platforms will target synoptic- to micro-scale processes near the tropopause as well as the interaction of DI air stream and cold front in the PBL.

- The international components will form a coordinated, cross-hemispheric observation campaign.

- Next steps towards campaign implementation:
  - Jan-Feb 2025: Dry run together with international partners
  - Mar 2025: KITsonde test deployment during ASCCI
  - Oct 2025: KITcube installation in NW France
  - Jan/Feb 2026: Core observation phase



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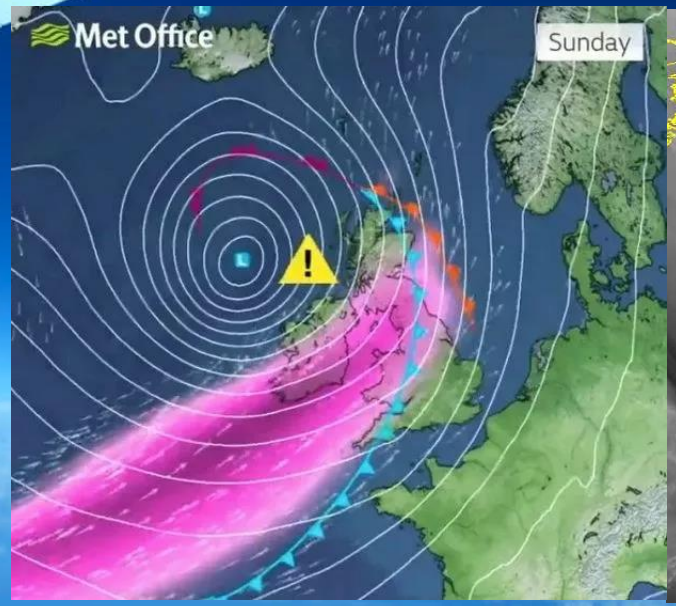

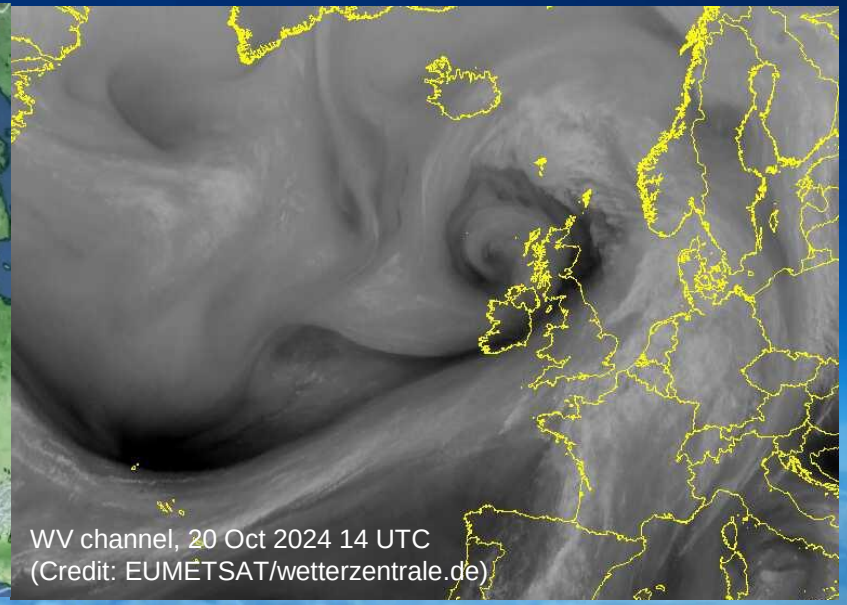

WV channel, 20 Oct 2024 14 UTC
(Credit: EUMETSAT/wetterzentrale.de)

Credit: Julian Quinting