Summary report on the NAWDIC AR-Reconnaissance Workshop 2023, 30 June 2023, ECMWF, Reading, UK

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On 30 June 2023, the international NAWDIC community, met at ECMWF, Reading, UK, for a full-day workshop following the 2023 Atmospheric River Reconnaissance workshop. Almost all international NAWDIC components were represented by participants from the US-AR Recon community, US academic community, UK, and Germany (see list of participants attached).

The workshop started with status updates on the major international contributions. A general overview on the state of NAWDIC was already given at the AR Recon Workshop on 29 June 2023.

Christian Grams (KIT) discussed the plans for the core NAWDIC-HALO component and NAWDIC-KITcube. Key instruments on the German HALO G-V aircraft will be a water vapor / ozone Lidar, a new wind lidar, and the KITsonde system. The latter allows releasing 4 dropsondes with one container and up to 30 sondes at once in the air which facilitates measurements of meso-scale variability in atmospheric profiles. About 14 IOPs with HALO in a 6 week window from 12 January to 20 February are envisioned. Furthermore, Christian presented plans for deploying the KITcube ground-based measurement facilities for local measurements at the Atlantic French coast from November 2025 to March 2026.

Marty Ralph, (SCRIPPS) presented the long-term vision for the AR-Recon team for a Global AR Reconnaissance Programme (GARRP) with the ultimate goal to reduce initial condition uncertainty through targeted observations in ARs over the entire Northern Hemisphere. Herein, NAWDIC would be a first GARRP pilot study with AR-RECON operating routinely in the East Pacific, additional operations in the West Pacific, potentially supported by colleagues in East Asia (Japan, Korea, Taiwan), and a NAWDIC contribution in the North Atlantic. AR Recon would operate with one C130 aircraft along the US East Coast for about 5 IOPs and ideally AR Recon would once operate in all Northern Hemispheric ocean basins for a 10 day period, coordinated with other NAWDIC components.

John Methven (University of Reading) presented the vision for a UK contribution to NAWDIC – CAPRI. The focus will be on how atmosphere- surface interactions affect cyclone impacts around the UK, in particular extreme winds, extreme waves, and catchment scale heavy precipitation events and flooding. Thereby CAPRI aims to improve the understanding of the coupling of the PBL with the ocean interface and moisture transport with precipitation. The Bae 146 aircraft would likely operate out of Belfast to the North West of the British Isles (low- and mid-troposphere, including flux measurements near the ocean surface) complemented by ground-based observations in Chilbolton.

On behalf of the French contact points (Gwendal Rivière and Florian Pantillon), Julian Quinting (KIT) presented the plans for a French NAWDIC component focussing on strong winds ahead of bent-back fronts and in the vicinity of cold fronts near the Atlantic French coasts. The primary platform would be the SAFIRE ATR42 aircraft operating out of Shannon, Ireland in the low to mid troposphere with a radar-lidar combination. On the ground, it is envisioned to deploy cloud radars coordinated with the NAWDIC-KITcube component. Preparatory modelling studies up to the 100m LES scale are already being conducted.

Steven Cavallo (University of Oklahoma) virtually presented the plans of the US academic community. Their focus lays on poleward precursors of winter high-impact weather (HIW) related to UTLS interactions over the Northeastern US: UTLS influences on jet stream dynamics and tropopause structure, processes controlling TPVs prior to jet stream interaction, and the role of the stratosphere. Platforms under consideration are the NASA 777 and NCAR / NSF GV equipped to provide humidity and temperature profiles via remote sensing. Potential targets for an IOP were explained based on a case study for February 2020.

Finally Andrew Wade form the University of Reading provided a hydrological perspective on AR landfall in UK, thereby emphasising the societal relevance of NAWDIC research. His presentation stressed that

80% of severe flooding events in the UK were related to ARs and the detailed interaction on the catchment scale matters a lot for correct prediction with catchment orientation relative to the AR and IVT being important parameters. A better hydrological assessment of AR impacts would require more coverage of precipitation in remote areas.

The remainder of the workshop was dedicated to discussions. We started with two breakout groups, focussing on (A) atmospheric rivers (ARs) and (B) dry intrusions (DIs). Both group discussed knowledge gaps, measurement strategies, and ways forward in improving models with respect to ARs and DIs, respectively.

In the afternoon, Julian Quinting and Alexandre Ramos (both KIT) lead an extensive discussion on a case study from December 2022 featuring HIW events across the Northern Hemisphere (from Hawaii, via North America, to western Europe) through the downstream propagation of Rossby waves. The episode would be a golden case for GARRP and included several cyclogenesis events, ARs, and intense jet streams. It has been decided that some groups further investigate the episode jointly, in particular looking into its predictability and mimicking how flight operations would be planned under this situation. This joint investigation will provide illustrative material for the proposals of individual components and highlight the connection and collaboration between the NAWDIC components. Interest in use of Met.3D for flight planning was stated. It was also asked if the name NAWDIC (North Atlantic Waveguide Dry intrusion and downstream Impact Campaign) is still suitable regarding the extended spatial focus of GARRP.

The discussion smoothly transitioned into a general discussion including brief summaries of the break groups. Next steps are now to form a group jointly working on the case study and towards a NAWDIC international white book, further evolve the engagement with weather services, namely NOAA, DWD, and ECMWF. A next international workshop should take place mid 2024, and winter 2024/25 will be used for a joint dry run.

Slides and recordings of the presentations in the morning can be accessed via the workshop webpage https://events.ecmwf.int/event/338/ . Protocols of the and breakout groups, a participant list, and the raw workshop protocal are accessible via the internal part of the NAWDIC wiki at https://internal.wavestoweather.de/campaign/projects/nawdic-internal/wiki/NAWDIC_international_workshop_2023

Appendix: Summaries of Breakout discussions

The AR group discussed three scenarios: 1) heavy precipitation related to AR landfall, 2) wind gusts related to the cold frontal passage and in the cold sector, 3) potential skill improvements in week 2 by observing ARs in multiple basins. Discussed knowledge gaps are: an unclear effect of observations in different basins on the AR representation, HIW connected to Rossby wave packets vs. isolated events, their climatology, making use of AI models for initial condition sensitivity studies, the role of observations and IC sensitivity in moisture uptake regions for **subsequent** ARs and the role of cyclone clustering, predictability of the orientation of ARs, processes in the stable PBL, its microphysics and impact on HIW. Extensive discussion time was dedicated to questions regarding moisture uptake, the role of PBL dynamics therein (decoupling of the lowest layers from AR above), and the role cyclone clustering / AR families (moisture hand-over mechanism). Regarding measurement strategies, flux and moisture transport measurements with lidars are found promising to shed light on the cross and along AR meso-scale structure. Regarding coordination, ideally one 10 day extended period capturing a full Rossby wave development from the West Pacific in the North Atlantic should be selected. This requires careful observation of RW precursors / initiation, and involve Japanese, Korean colleagues or windborne ballons for measuerments farther north. For insitu measurements soil moisture was identified potentially being important. A potential conflict arises from IOPs aiming for improving forecast vs. understanding of processes and dynamics. A strategy for best deploying drifting buyos on the global scale must be developed. Regarding models, the biggest challenge is representing the stable boundary layer and its effect on moisture uptake: turbulence under an AR, unclear structure and interaction with the LLJ, some LES study might help in advance. The HALO, FAAM, ATR42 vertical velocities from wind lidars can help

for verifying turbulent structures. Challenges in the parametrized shallow and deep convection in the cold sector were mentioned and the underdispersiveness of multi-model ensembles. As additional platforms for model verification NOAA sondes with SST sensors, saildrones, airborne ballons, and radiosoundings from ships are desired. However, this requires someone taking the lead in organising such additional platforms.

The DI group discussed intensively the interaction of the DI with the lower-levels, the ocean surface, its potential role in modulating the PBL and affecting moisture uptake for replenishing moisture for a subsequent AR. Open questions concern: the situation when anomalous surface fluxes are generated as a result of ocean-atmosphere interaction, e.g. when waves and surface winds are out of sync after the passage of fronts, the role of decoupled lowest levels stable marine PBLs vs. more turbulent, convective PBLs above in the AR and destabilisation through downward momentum transport by the DI; processes driving the downward momentum transport and causing high surface winds (the role of CSI, PBL instability in high shear; data to verify theories currently missing), interface DI-WCB-AR and its effect on recharging moisture, role of diffluent part of DI outflow for moisture uptake, PBL modulation and low-level frontogenesis / overturning circulation, stratospheric intrusions observed around TP fold during NAWDEX, role of TPV – DI interaction in the DI origin region, processes determining TP structure role of radiation therein and TP gradients – important for setting initial DI trajectory, Measurements strategies should be developed around the UK and French mid-range aircraft to capture more the local processes and HALO for the synoptic context. Temperature profiles are essential and additional radiousoundings should be facilitated also from operational sites. Different ocean basins may require different strategies. Model improvements needed in terms of representation of PBL, fluxes, structure. Coupled wave models would benefit from better observational data currently lacking, DA systems should be able to better assimilate in regions of strong gradients and boundary layer inversion. We must better use observations to identify areas where models are unable to use observations due to model or DA deficiencies. The systematic investigation of analysis increments during AR and DI situations would be one suitable approach. The group concluded that simply having PBL measurements over the ocean will be beneficial as this is a data sparse region. On the larger scale, it is of interest to understand regime changes (from a highly active AR / DI situation to a non-active), teleconnections, better understanding forecast dropouts and raising awareness during these periods of modified forecast skill horizion. Identifiying sensitive regions related to DI-AR interaction or RW formation might be a way forward to better understand flow-dependent skill / ensemble spread (example of NAWDEX case study Norway and adjoint sensitivities)

Further notes from the break out discussions are provided on the NAWDIC internal wiki pages.