Synthesis of Initial-Condition Sensitivities during AR Recon Operations and the Impact of Dropsondes on Model Analysis and Forecasts

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Acknowledgement

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March 7, 2024
TCORF/IHC/Winter Season Meeting
Cross-section of key meteorological features in & near an AR

Clouds and precipitation in or above an AR block satellite wind measurements and degrade the quality of radiance data.

Adapted from
Zheng et al. 2021a; Ralph et al. 2017
Objectives

Atmospheric river reconnaissance missions fill observation gaps within and near ARs, aiming to improve forecast skill of the US West Coast at 1–5-day lead times.

Twofold objectives of this talk:

1. An overview of how initial condition sensitivity tools are synthesized to support flight planning during AR Recon operations.

IOP: Intensive Observing Period
**Goal:** Find critical regions at $T_o$ that can trigger most errors in the downstream at a later forecast time ($T_v$).

Need a set of model data created at initialization time ($T_i$) and calculate sensitivity (Sensi): 

$$\text{Sensi} \propto \frac{\Delta J}{\Delta X},$$

each model grid has a value, maxima $\rightarrow$ most sensitive regions.
Part 1: Synthesis of Initial-Condition Sensitivities during AR Recon

AR Recon 2024 Quantitative Tool Team and Roles

UAlbany Ensemble Sensitivity
Team Lead: Ryan Torn
Members: I. Fontanez
- Provide ECMWF 51-member ensemble-based sensitivity
- Synthesize all sensitivity products & lead 5-10 min sensitivity discussion in morning meetings

NCEP Ensemble Sensitivity
Team Lead: Xingren Wu/Vijay Tallapragada
Members: K. Wu, T. Elless
- Provide NCEP GEFS-CMCE 52-member ensemble-based sensitivity

NRL Moist Adjoint Sensitivity
Team Lead: James Doyle
Members: C. Reynolds
- Provide NRL COAMPS-model-based adjoint sensitivity

CW3E Quantitative Tool Team
Lead: Minghua Zheng

More quantitative tool coordinators & supporting members

Input from:
- Forecast Team;
- Mission Directors;
- Modeling & DA SC;
- WPC forecasters;
- Flight Track Coordination Team
Detailed procedure coordinating sensitivities & designing flight tracks

**Day 1**
- Sensitivity coordination
- Send out coordination emails & NWSChat slack messages
- Input: MD & Sensitivity & other team leads

**Day 2**
- Sensitivity calculations
- UAlbany calculates ECMWF sensitivity
- NCEP calculates GEFS-CMCE sensitivities
- NRL calculates COAMPS adjoint sensitivities

**6:30-8:00 AM PST**
- Quantitative tool preparation meeting
- Quantitative Tool Team synthesizes & prepares sensitivity slides
- Flight Track Coordination Team drafts flight tracks

**8:00-9:00 AM PST**
- Morning forecast briefing & planning meeting
- Present sensitivity slides
- Team discussion to optimize flight tracks on Google Earth Tool
- Forecast discussion
- Update sensitivity on forecast slide deck

**Make key decisions**
- Finalize flight tracks for tasked missions
- Decide if sensitivity tools are required for the next meeting

**Day 1**
- Finalize sensitivity metrics

**Day 2**
- CW3E teams receive products
- Update sensitivity on forecast slide deck

**Morning meeting outcomes**
An example of sensitivity coordination message on NWSChat Slack

Experimental year; we will move all the sensitivity coordination to NOAA NWSChat Slack channel in the future.
An example flight date: *ECMWF Ensemble Sensitivity Overview for a NE Pac flight on 00 UTC 29 Feb (To)*

**Model initialization time:** 00Z 27 Feb 2024 (Ti)

**Forecast metric (J):** 24-h precipitation between 12Z 29 Feb. to 12Z 1 Mar. (Tv, f60-84). Max: ~64 mm. **Variance explained:** 31%.

Positive EOF1 → more precipitation in central Oregon, less in the northern Sierra (a north shift).

**IVT sensitivities (X):** along the tail of the AR; shifting to the north → a northward precipitation shift (+EOF1).

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Ensemble mean IVT

Contours:
+EOF1

Shades:
Ensemble mean
Precipitation
An example flight date: *ECMWF Ensemble Sensitivity Overview for a NE Pac flight on 00 UTC 29 Feb* (To)

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**IVT sensitivities (X):** along the tail of the AR; shifting to the north → a northward precipitation shift (+EOF1).

**Theta-E sensitivities (X):** with the cold front along 40N; shifting to the north → +EOF1.

**PV sensitivities (X):** with the trough along 140W; shifting to the NW → +EOF1.

Contours: +EOF1

Shades: Ensemble mean

Precipitation
GEFS-CMC Ensemble Sensitivity Overview for a NE Pac flight on 00 UTC 29 Feb (To)

Model initialization time: 00Z 27 Feb 2024 (Ti)


Positive EOF1 → more precipitation over S. OR and N. CA.

IVT sensitivities (X): weak, along the tail of the AR; increasing values at the edge of the tail near 40N → an increase in precip. amount (+EOF1).

Theta-E sensitivities (X): with the cold front along 40N; increasing values at the cold front between 130-140W → +EOF1.

PV sensitivities (X): with the trough along 140W; increasing values from the tail to the NW (amplifying the trough) → +EOF1.

Contours: +EOF1

Shades: Ensemble mean Precipitation
NRL COAMPS Adjoint Sensitivity Overview for Flight on 00 UTC 29 Feb (To)

Model initialization time: 00Z 27 Feb 2024 (Ti)

Forecast metric (J): Response function (RF) of the 24-h total precip. from 12Z 29 Feb to 12Z 1 Mar (Tv) over N. CA/PacNW

Perturbation pattern → increase precip. over N. CA

Growth = 10

**Moisture sensitivity** is a max near the inflow/tail of the AR and extending W/NW to the Aleutians along the broad trough.

**Momentum sensitivity** is large near the inflow/tail of the AR along the broad trough.

**PV sensitivity** is a max NW of the AR along a PV strip at 500 hPa (reshaping and intensifying the PV strip leads to an increase in precip over N. CA).

Summary

- **Model initialization time**: 00Z 27 Feb 2024 (Ti)
- **Forecast metric (J)**: Response function (RF) of the 24-h total precip. from 12Z 29 Feb to 12Z 1 Mar (Tv) over N. CA/PacNW
- **Perturbation pattern** → increase precip. over N. CA
- **Growth** = 10

**Moisture sensitivity** is a max near the inflow/tail of the AR and extending W/NW to the Aleutians along the broad trough.

**Momentum sensitivity** is large near the inflow/tail of the AR along the broad trough.

**PV sensitivity** is a max NW of the AR along a PV strip at 500 hPa (reshaping and intensifying the PV strip leads to an increase in precip over N. CA).
**Example:**

**Consistency**
- Low-level IVT, theta-E, moisture, and momentum sensitivities are along the tail and the inflow of the AR.
- Upper-level PV sensitivities are with the trough along 140W. The position of the trough impacts the N-S shift of the precipitation, and the amplitude impacts precipitation amount.
- Both ECMWF and adjoint sensitivities show values extending further west toward the Aleutians.

**Differences**
- Ensemble sensitivities show large values along the northern edge and the cold side of the landfalling AR, while adjoint sensitivities show minimal values there.
- GEFS-CMC sensitivities don’t show coherent signals further upstream.

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### EOF-based Forecast Metrics

<table>
<thead>
<tr>
<th></th>
<th>NE Pacific Flights</th>
<th>GoM &amp; W. ATL Flights</th>
<th>Guam Flights</th>
</tr>
</thead>
<tbody>
<tr>
<td>24-h/36-h accumulated precipitation</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>River basin precipitation</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Landfall IVT along the USWC</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>IVT over the targeted AR</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Sea Level Pressure</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Frozen precipitation</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
</tbody>
</table>

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The team regularly creates 200+ plots per day.

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*Center for Western Weather and Water Extremes*
Part 2: dropsonde impacts on model analysis & forecasts for ARs

Impacts on IVT analysis — 4DEnVar WithDROP vs NoDROP in six cases

Dropsonde DA can change the analyzed IVT amplitude by 5-40%.

Modified from Zheng et al. 2021b
Dropsonde impacts on IVT/IWV forecasts – WithDROP vs. NoDROP

Positive impacts from dropsondes show an average of 9.0% “improvement” on analysis w.r.t. NoDROP. Positive impacts on IVT are maximized in the first 78 h and beyond 102 h, and on IWV throughout the 144 h.

Verification domain: 15°N–60°N, 115°W–170°W

Modified from Zheng et al. 2021b
Conclusion and future work

Major findings:
1. Three sets of sensitivity products have been employed, along with essential atmospheric structures, in operational planning to support the decision-making and track design.
2. New development in 2024: Sensitivity to support Guam’s flights, river basin precipitation metrics, frozen precipitation, and downstream metrics.
3. Positive impacts from dropsondes show an average of 9.0% “improvement” on analysis w.r.t. NoDROP. Positive impacts on IVT are maximized in the first 78 h and beyond 102 h, and on IWV throughout the 144 h.

Ongoing and future work
- Explore impacts of AR Recon data on the further downstream over the Middle and Eastern US.
- Impacts of high-reso dropsondes, drifters, satellite data, and radar data on ARs.

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Dropsonde data can lead to an increase of 5-10% in the amount of assimilates tropospheric radiance. The positive impact lasted for about one week after the last mission of AR Recon 2020.

Zheng et al. 2024 JTECH, under review
References for sensitivity and AR Recon data impacts

8. Zheng, M., and co-authors. Comparison of hybrid 4DEnVar and 3DEnVar data assimilation methods for atmospheric river forecasts in the WRF model. In-prep for *JGRA*.

Acknowledgements

The dropsonde data were collected during several field campaigns involving many scientists, engineers, air crews, project managers, program managers, including individuals from NOAA, the U.S. Air Force (USAF), and elsewhere. Special thank you to Dr. Anna Wilson (CW3E), Lt. Col. Ryan Rickert (USAF), Capt. Garrett Black (USAF) and Jack Parrish (NOAA), for advice on the operational component of collecting dropsonde observations.

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