2026 AR Recon workshop

Assessing the Impacts of Airborne Radio Occultation Assimilation in AR Recon 2025 and Its Interactions with Other Observations in MPAS-JEDI

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AR RECON Research And Operations Partnership

Motivation

DA ARO observations has shown both **beneficial and adverse impacts** on forecast skill **across regions** (*Do et al., 2025, Banos et al., 2026, Davis et al., 2026*), yet the mechanisms behind these **mixed effects remain unclear**. How ARO interacts with other observation types within data assimilation systems remains poorly understood.

Scientific questions

(1) Whether **ARO improves satellite radiance assimilation** by bringing the initial state closer to the true atmosphere, thereby increasing radiance usage, and at which **vertical levels and timescales** these indirect effects emerge?

(2) How those impact **compares with other anchoring observations used for radiance bias correction**, such as spaceborne radio occultation (SRO)?

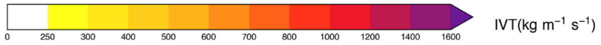
(3) Whether the **combined assimilation of ARO and dropsondes** produces a greater forecast impact than either dataset alone?

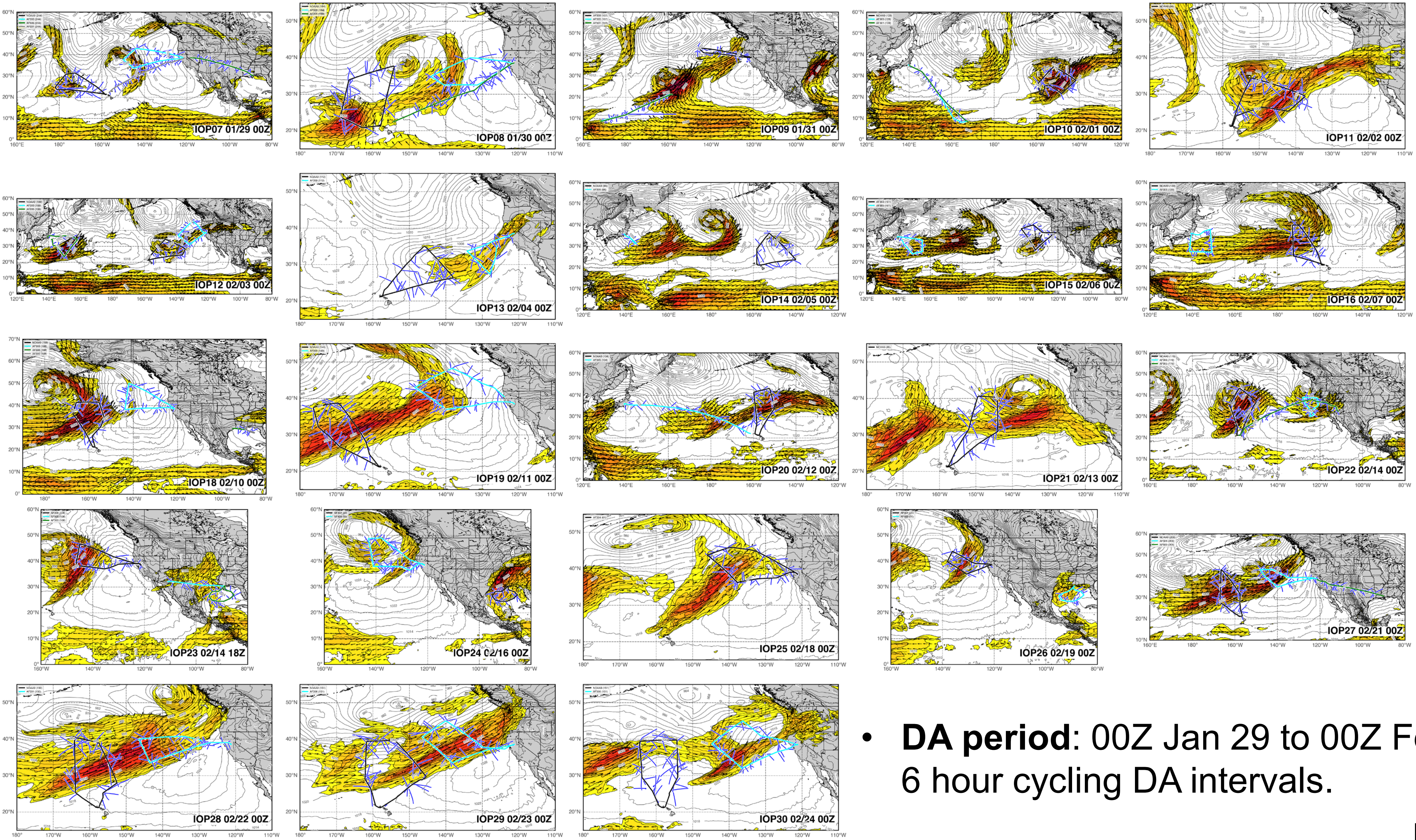
Case study

January 29 to February 28, 2025

IVT and ARO

GNSS ARO (final, blue lines), GFS IVT(kg m^{-1} s^{-1}; shaded), IVT Vectors, and SLP(hPa; contours)
Flights were executed in AR Recon 2026 field campaign.

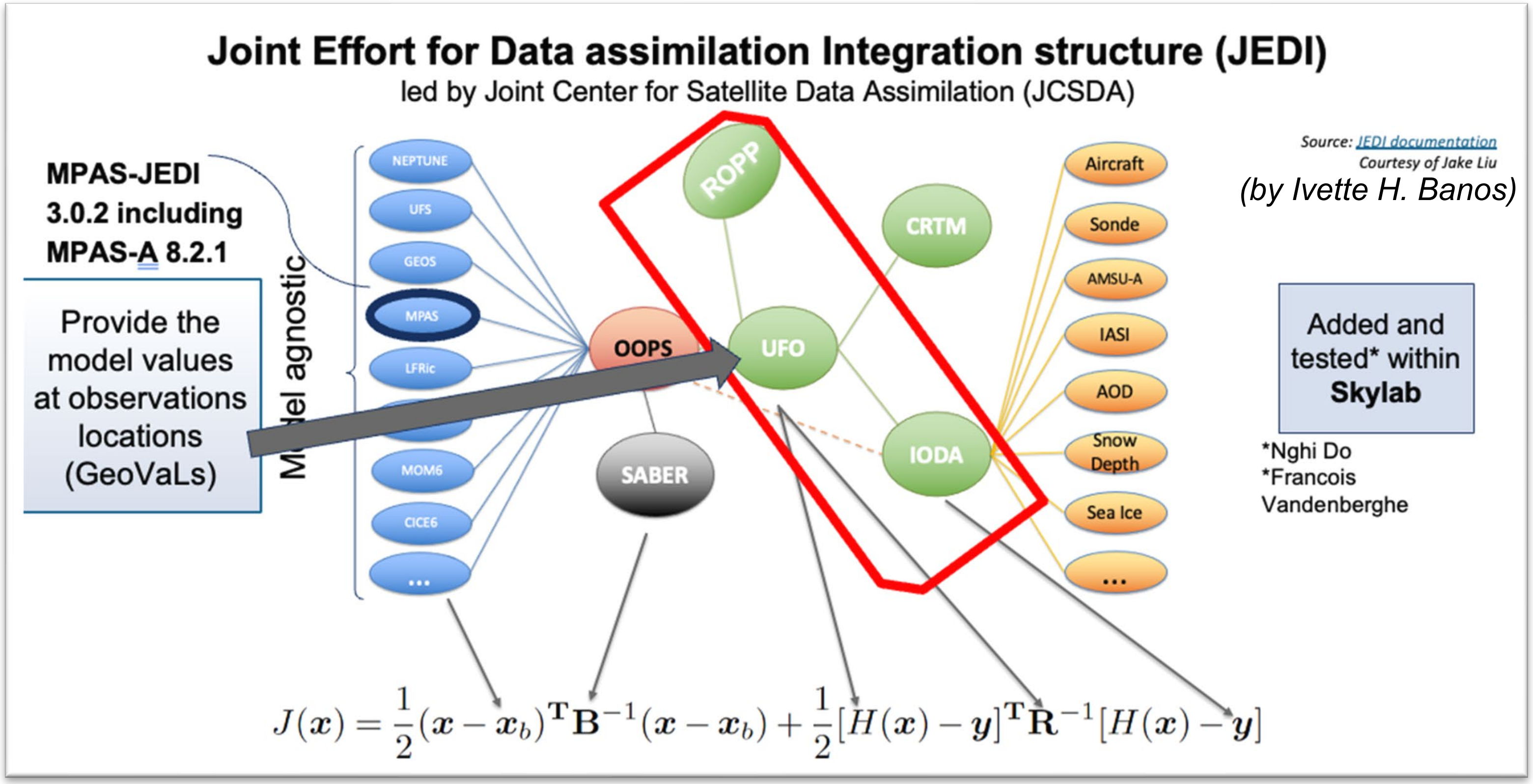




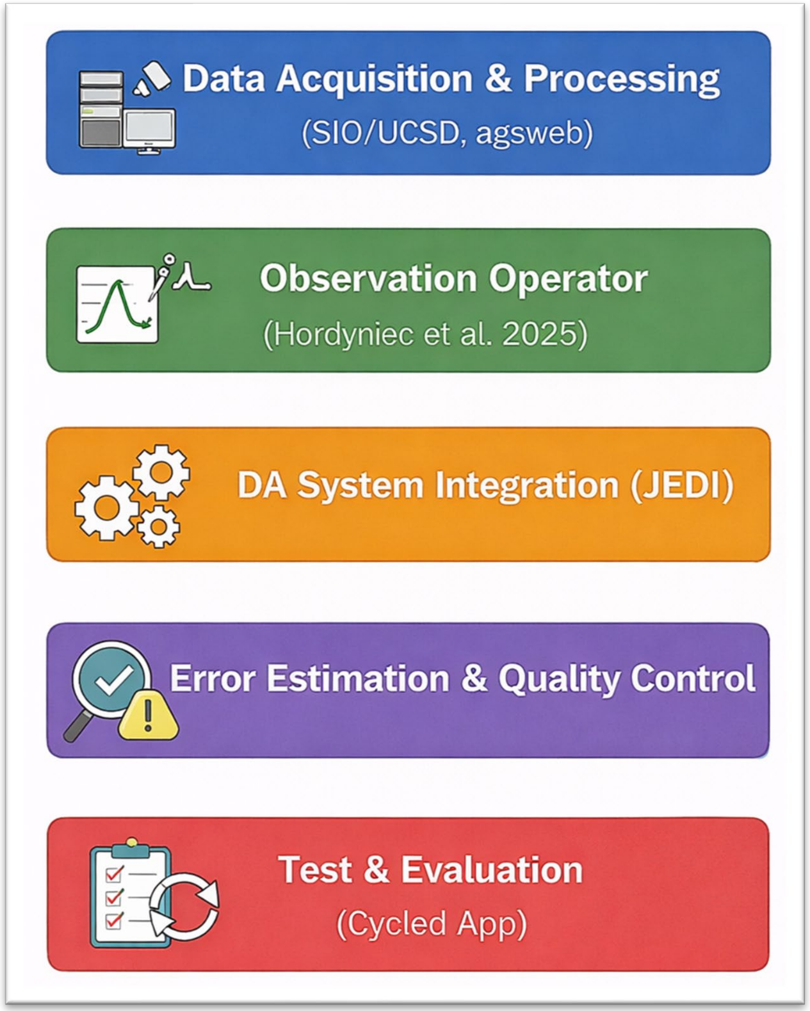
- 4 days of obs extending into the western Pacific.
- 2 sequences of dense multi-aircraft flights, including 21–24 February preceding 5 days of continuous coastal AR precipitation.

- **DA period**: 00Z Jan 29 to 00Z Feb 28, 2025, 6 hour cycling DA intervals.

Model and DA configuration



Assimilate ARO bending angles



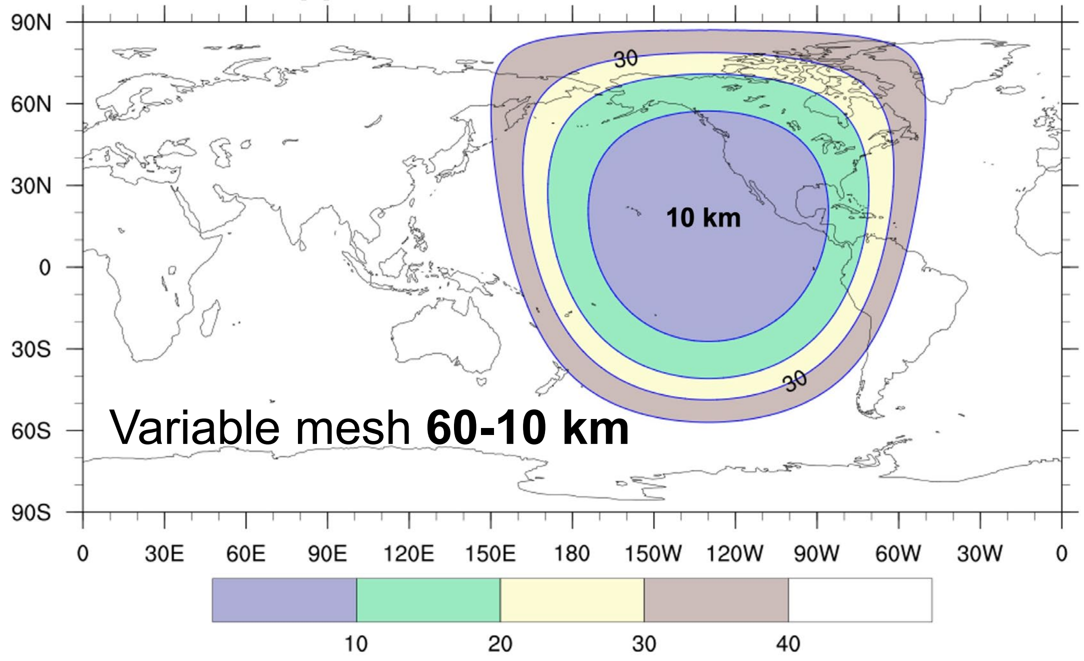
Configuration

- **MPAS-JEDI 3.0.2** and **MPAS-Workflow 3.0.2** tailored to assimilate the ARO observations.

Experimental design

Experiments	DA Conventional obs, AMV, AMSU-A, MHS	DA GNSS ARO	DA Dropsondes	DA GNSS RO
CTRL (All obs)	Y	Y	Y	Y
noARO	Y	N	Y	Y
noDROP	Y	Y	N	Y
noDROP_ARO	Y	N		Y
noSRO	Y	Y	Y	N

AMSU-A: NOAA-15, NOAA-18, NOAA-19, MetOp-b, MetOp-c
MHS: NOAA-19, MetOp-b, MetOp-c



Configuration

- **Hybrid 3DEnVar** (25 % of static BEC from *Jung et al. (2024)*) & 75 % of an GEFS ensemble based BEC (30 members)).
- Variational bias correction for satellite radiance.
- 1200 km horizontal and 6 km vertical localization length scales.

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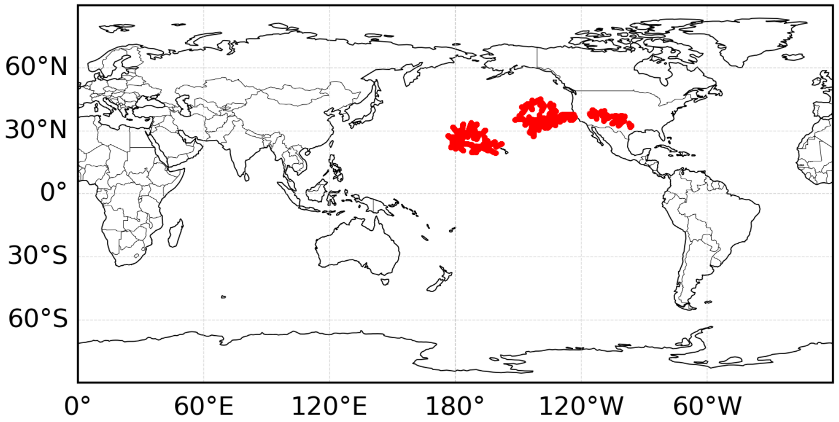
Spatial distribution DA OBS (1st cycle, 00 UTC January 29)

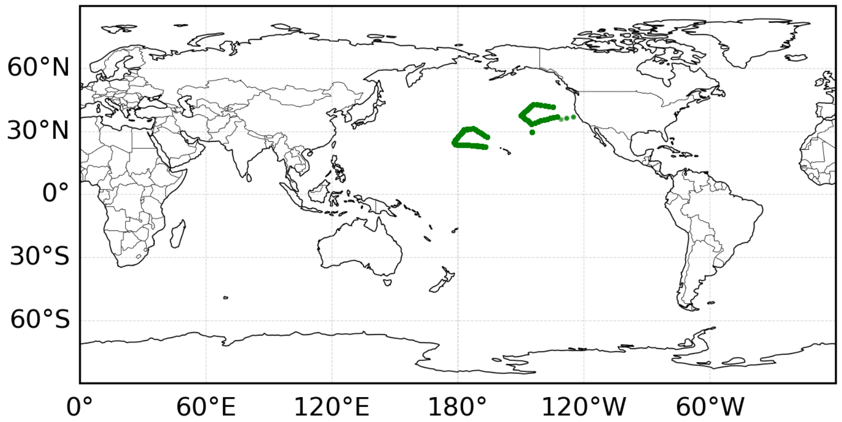
ARO

CTRL
N=13,379



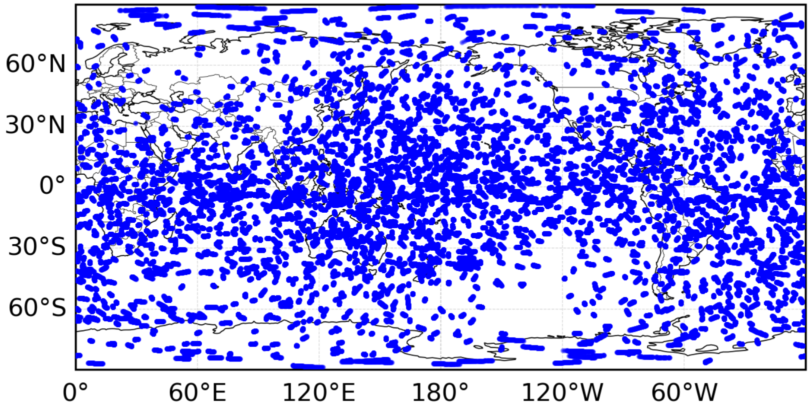
DROPSONDES

CTRL
N=10,068



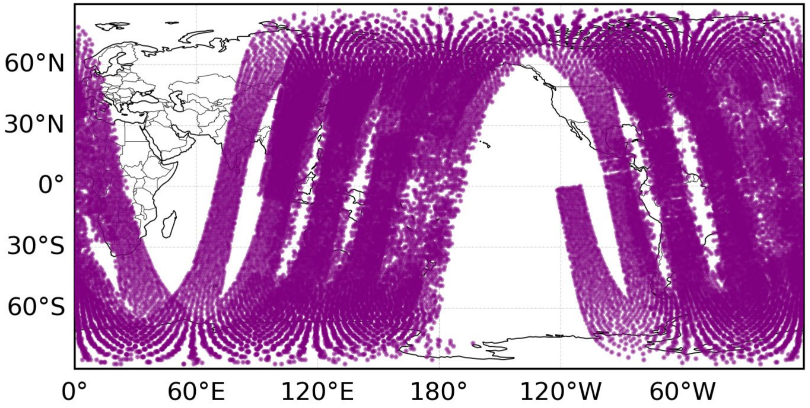
SRO

CTRL
N=405,456



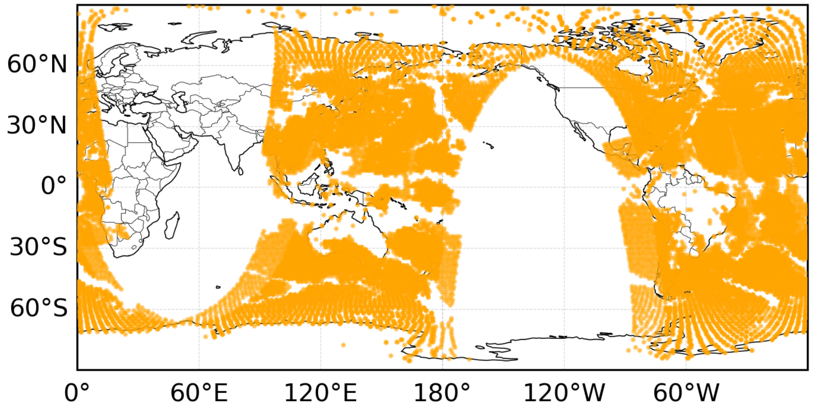
AMSU-A

CTRL
N=30,390

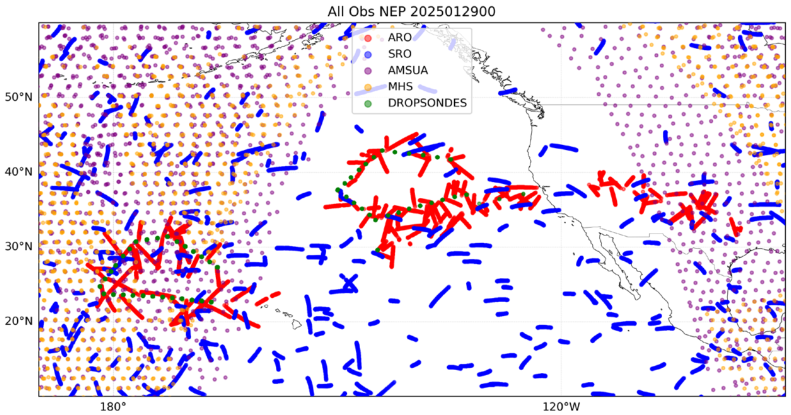


MHS

CTRL
N=23,222



Zoom in NEP



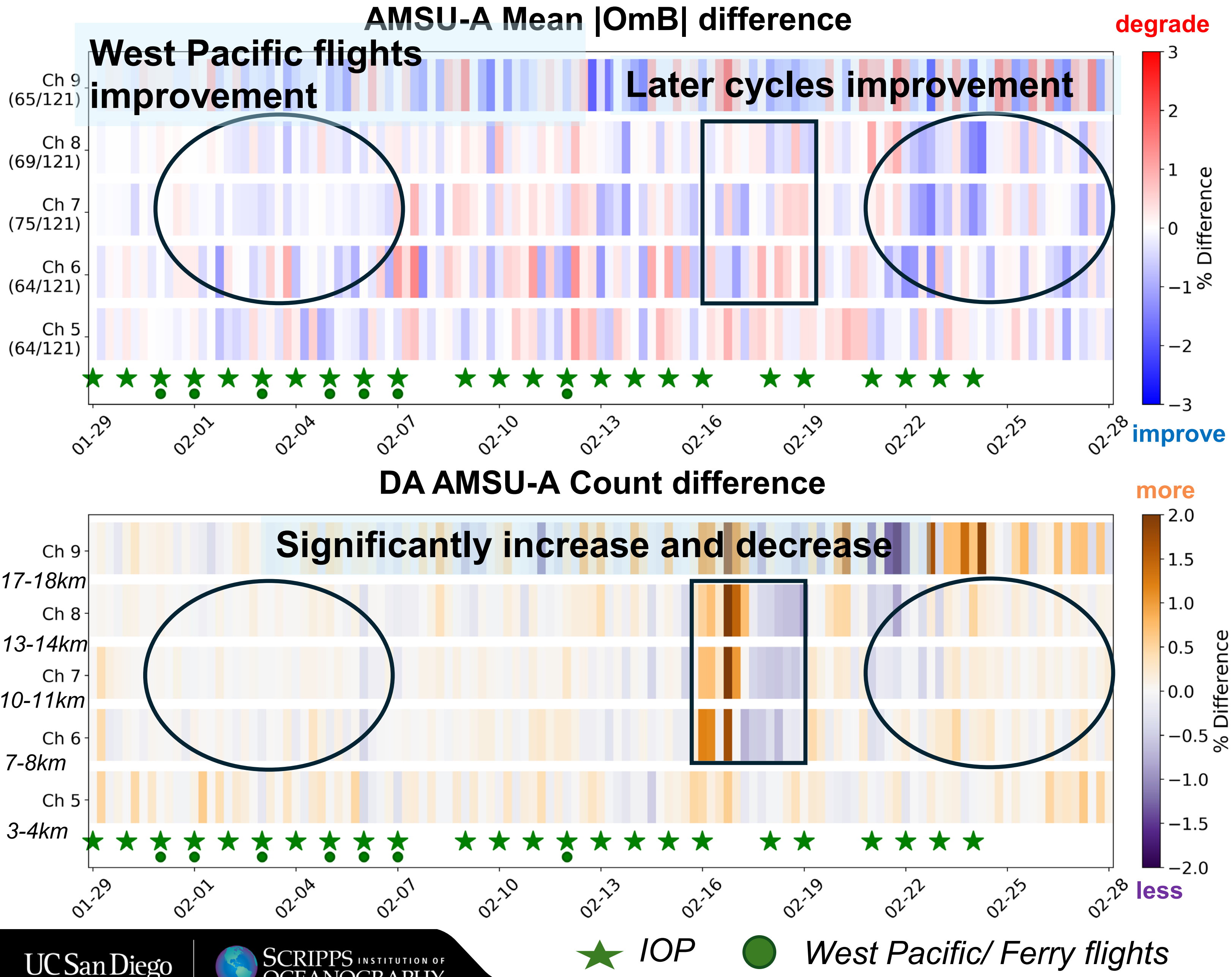
Scientific questions

(1) Whether **ARO improves satellite radiance assimilation** by bringing the initial state closer to the true atmosphere, thereby increasing radiance usage, and at which **vertical levels and timescales** these indirect effects emerge?

(2) How those impact **compares with other anchoring observations used for radiance bias correction**, such as spaceborne radio occultation (SRO)?

(3) Whether the **combined assimilation of ARO and dropsondes** produces a greater forecast impact than either dataset alone?

Impact of dropsondes on AMSU-A (CTRL vs noDROP, globally)

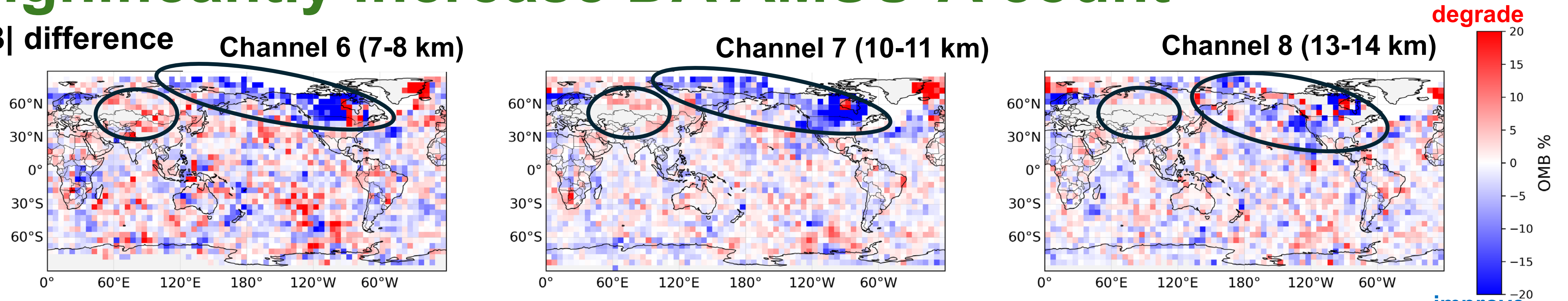


- **Dropsondes** increase the improvements **in later DA cycles**.
- **Dropsondes** gives the largest AMSU-A improvements at **7–14 km**.
- Improved AMSU-A fit does not imply increased AMSU-A usage. Dropsondes improve AMSU-A quality control by **retaining good observations and rejecting bad ones**.

Feb 16: significantly increase DA AMSU-A count

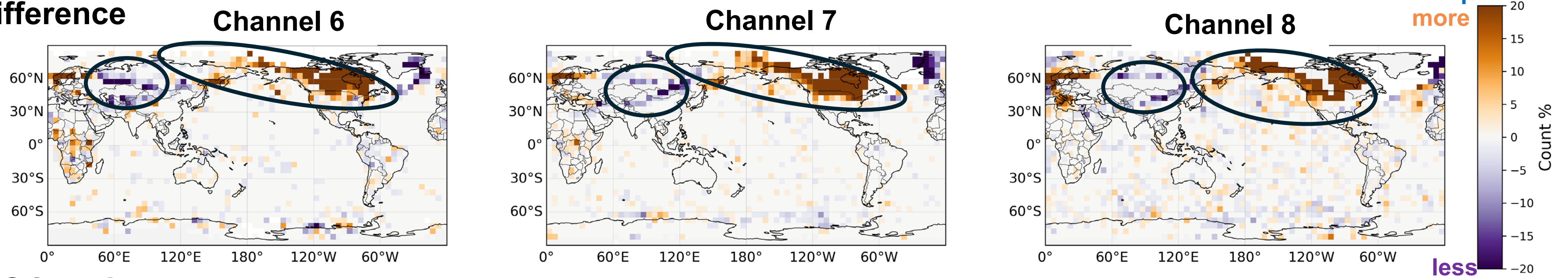
AMSU-A Mean |OmB| difference

Channel 6 (7-8 km) **Channel 7 (10-11 km)** **Channel 8 (13-14 km)**

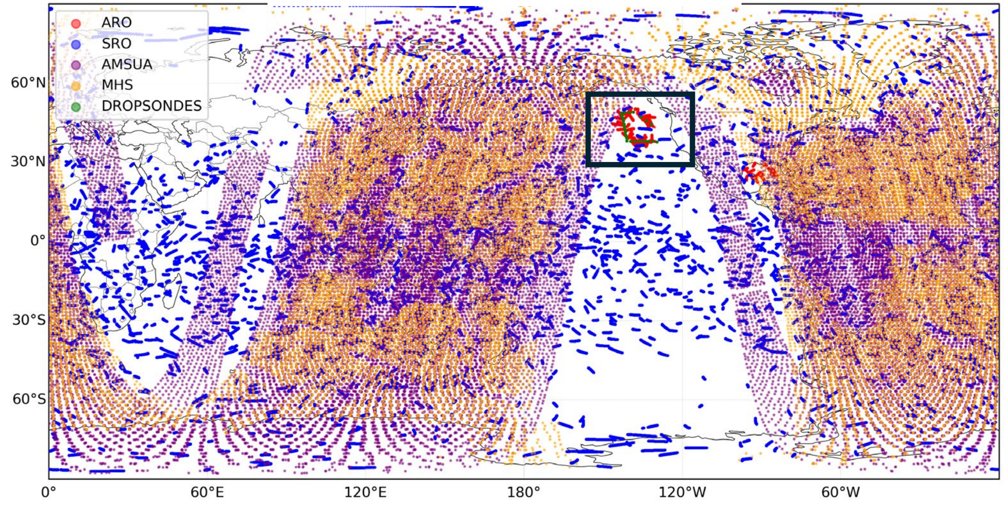


DA AMSU-A Count difference

Channel 6 **Channel 7** **Channel 8**



OBS location



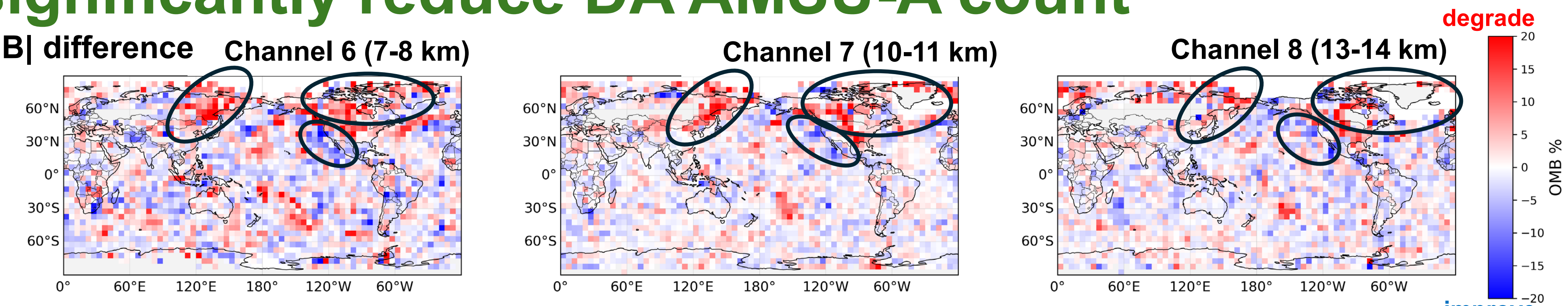
- Dropsondes do not overlap AMSU-A: assimilating dropsondes significantly **increases the number of DA AMSU-A** obs that are assimilated close and further north, northeast from dropsondes

→ **improve AMSU-A fit**.

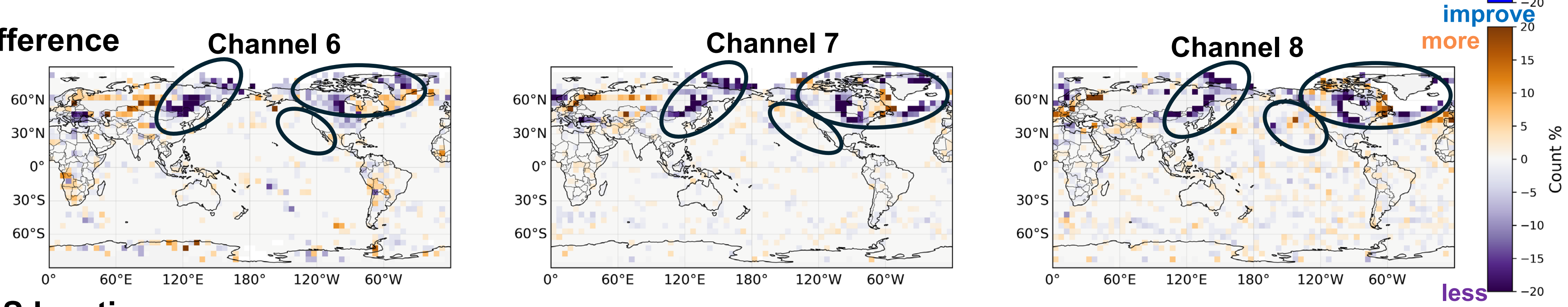
- Some degradation appear over China and Himalayas regions, which link to the reduction of assimilated AMSU-A obs.

Feb 18: significantly reduce DA AMSU-A count

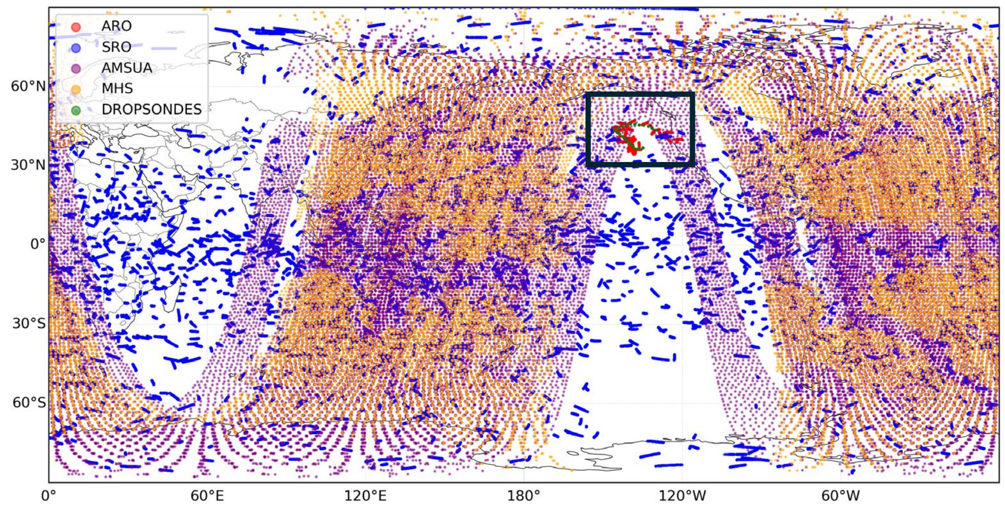
AMSU-A Mean |OmB| difference



DA AMSU-A Count difference



OBS location

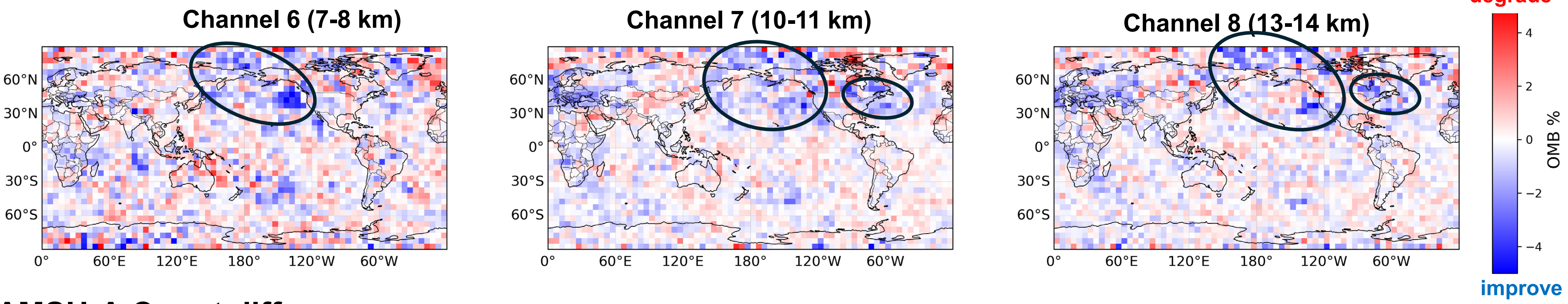


- Dropsondes overlap AMSU-A: assimilating dropsondes decreases the number of DA AMSUA obs that are far away to the NE and NW of dropsondes and degrades AMSU-A fit.

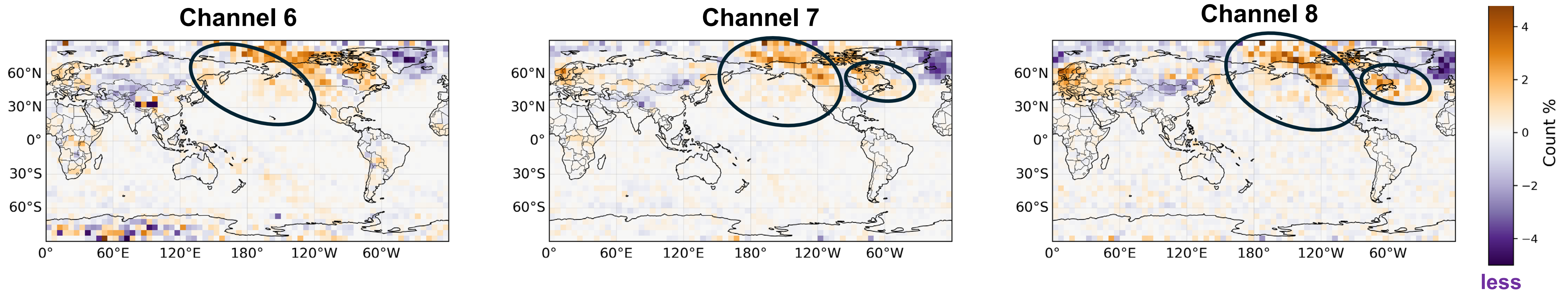
- Some improvement appear over west coast, corresponding to both increasing and reducing of assimilated AMSU-A obs.

Impact of dropsondes on AMSU-A (globally, all DA cycles)

AMSU-A Mean |OmB| difference

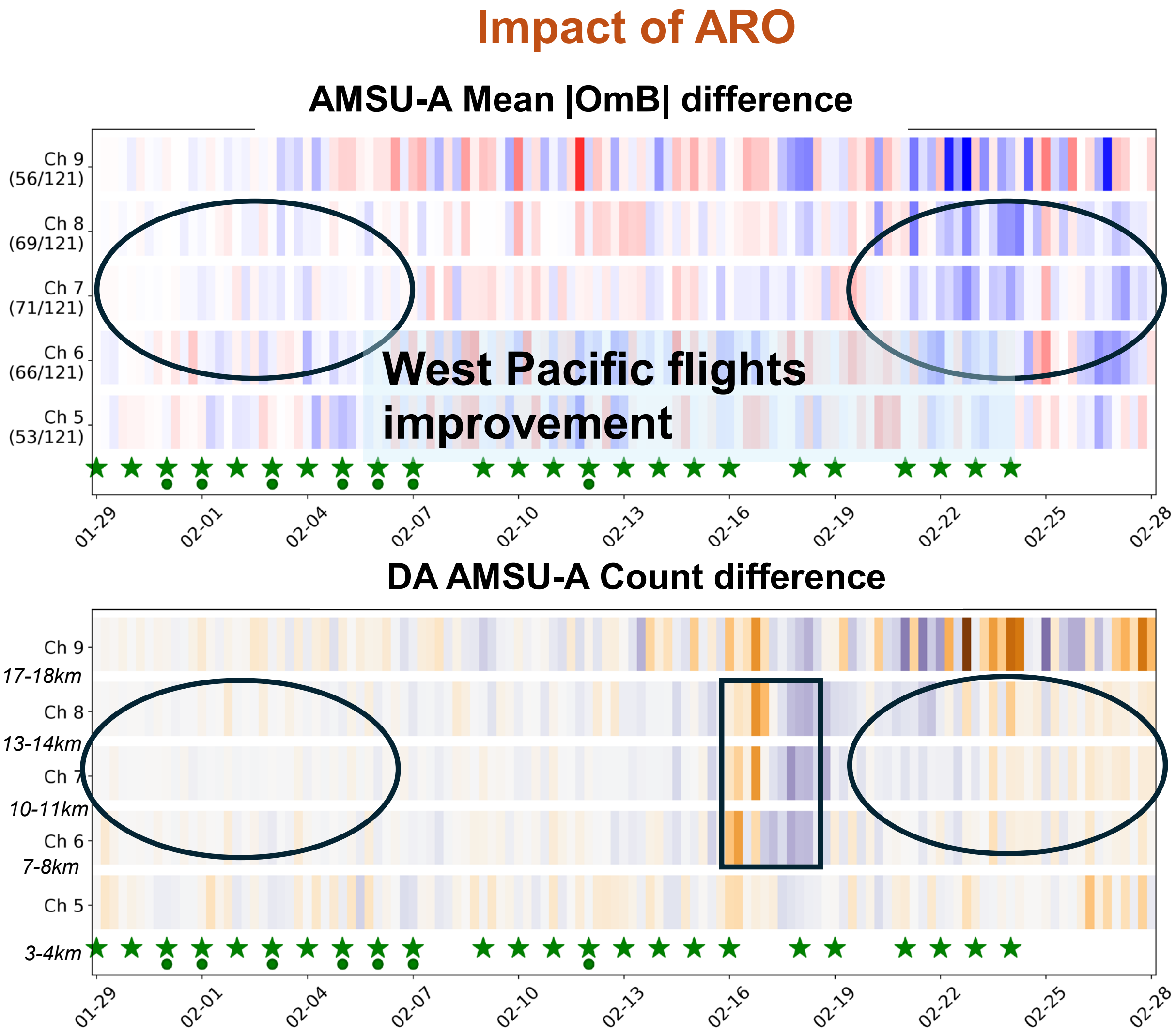


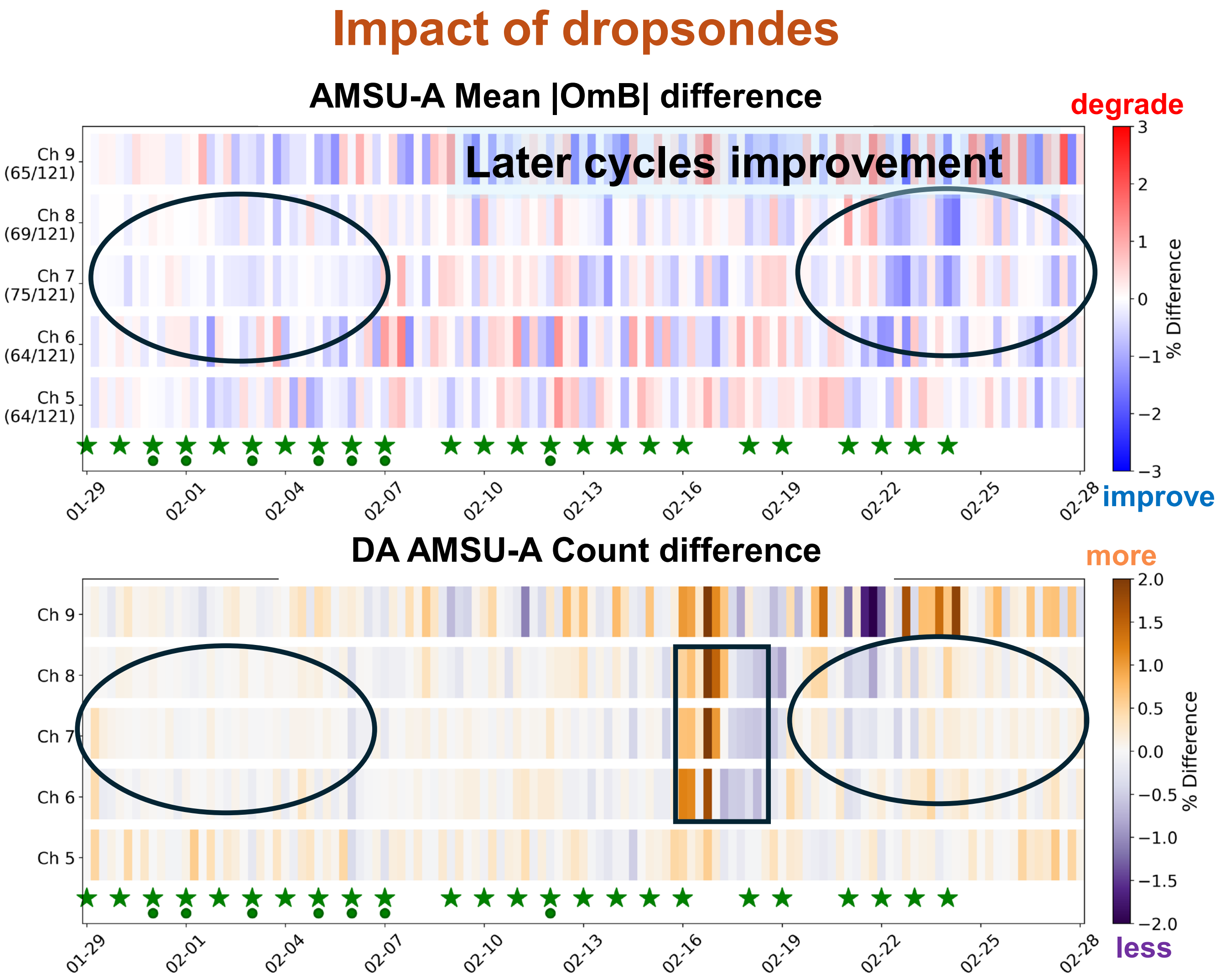
DA AMSU-A Count difference



- Assimilating dropsondes improve AMSU-A fit over the **North Pacific and Northern Hemisphere** midlatitudes, especially for in channel 7. These largest positive impact link to the increasing of DA AMSU-A number.

Impact of ARO on AMSU-A (CTRL vs noARO, globally)



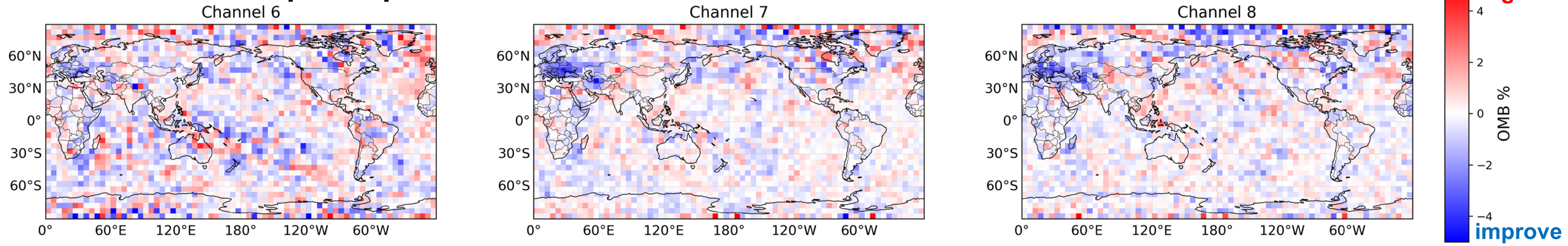


- Similar to dropsondes, ARO improves AMSU-A fit in **later DA cycles**, with the largest improvements at **7–14 km**.
- Dropsondes give more improving cycles.
- ARO improves AMSU-A quality control by retaining good observations and rejecting bad ones.

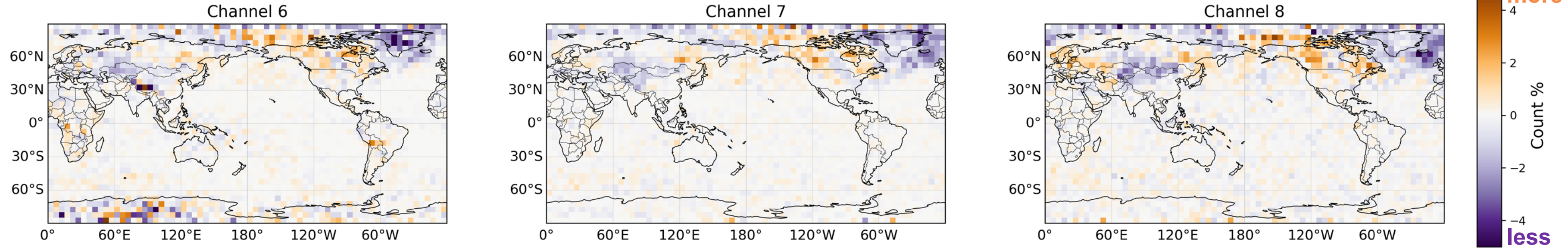
Impact of ARO on AMSU-A (CTRL vs noARO, globally)

Impact of ARO

AMSU-A Mean |OmB| difference

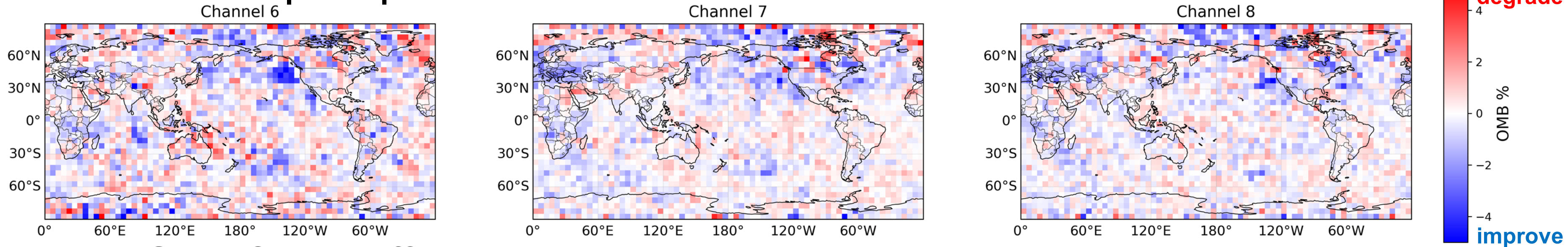


DA AMSU-A Count difference

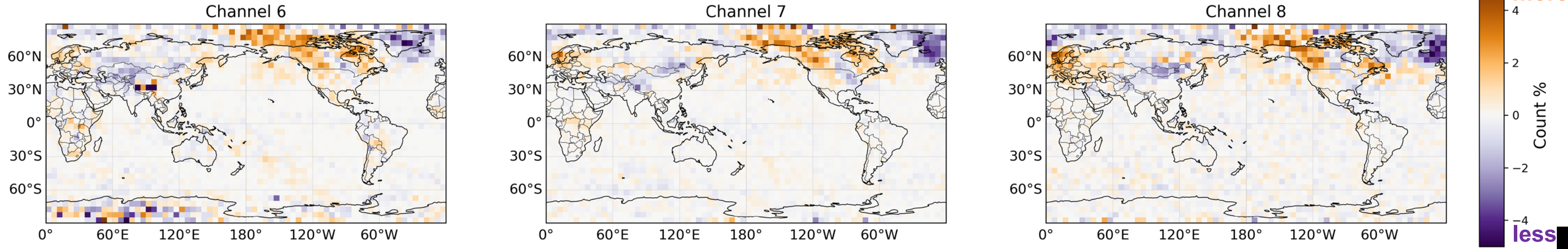


Impact of dropsondes

AMSU-A Mean |OmB| difference



DA AMSU-A Count difference



Like dropsondes, assimilating ARO increases AMSU-A observation usage and improves the AMSU-A fit over the **North Pacific and Northern Hemisphere** midlatitudes.

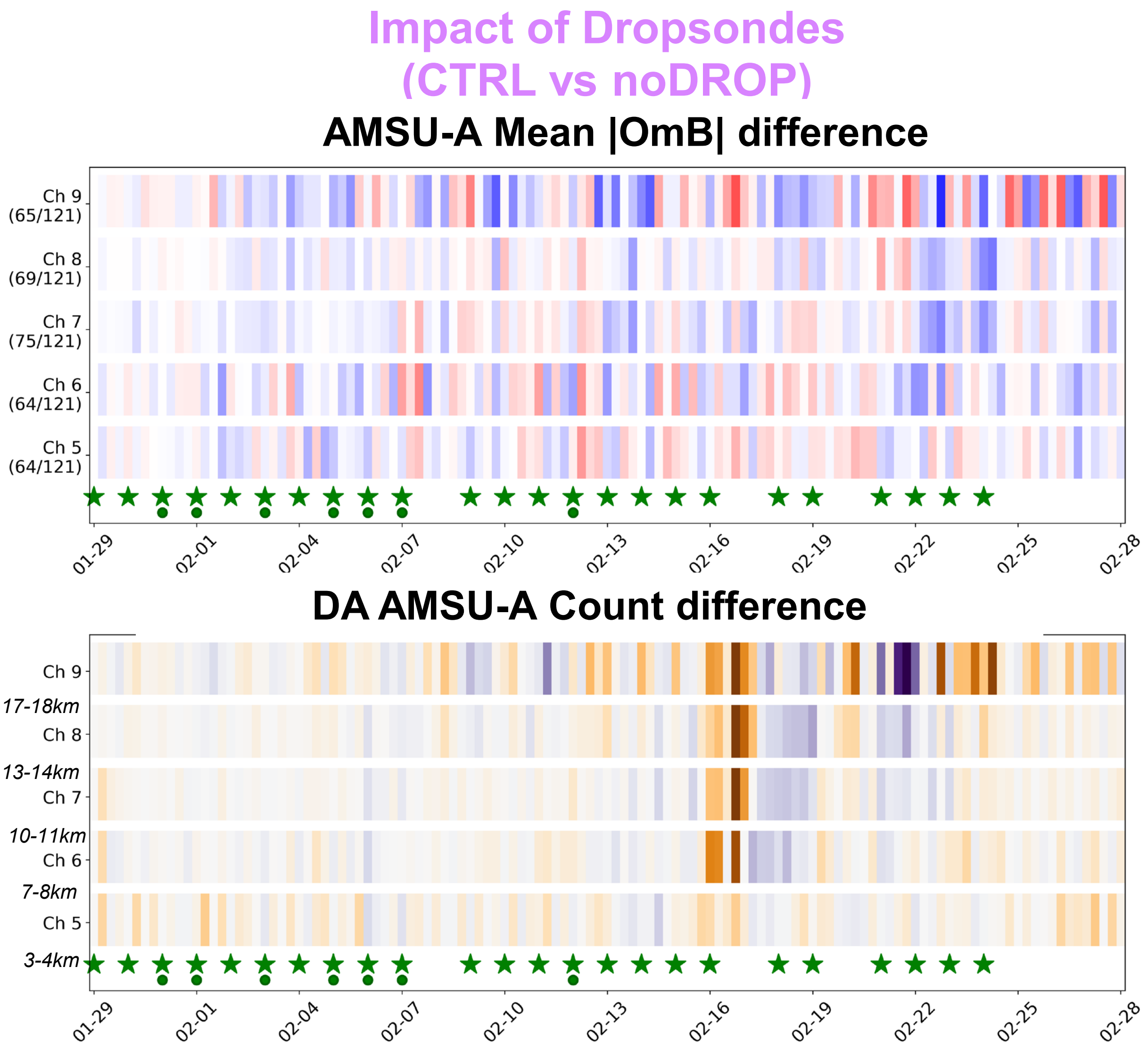
Scientific questions

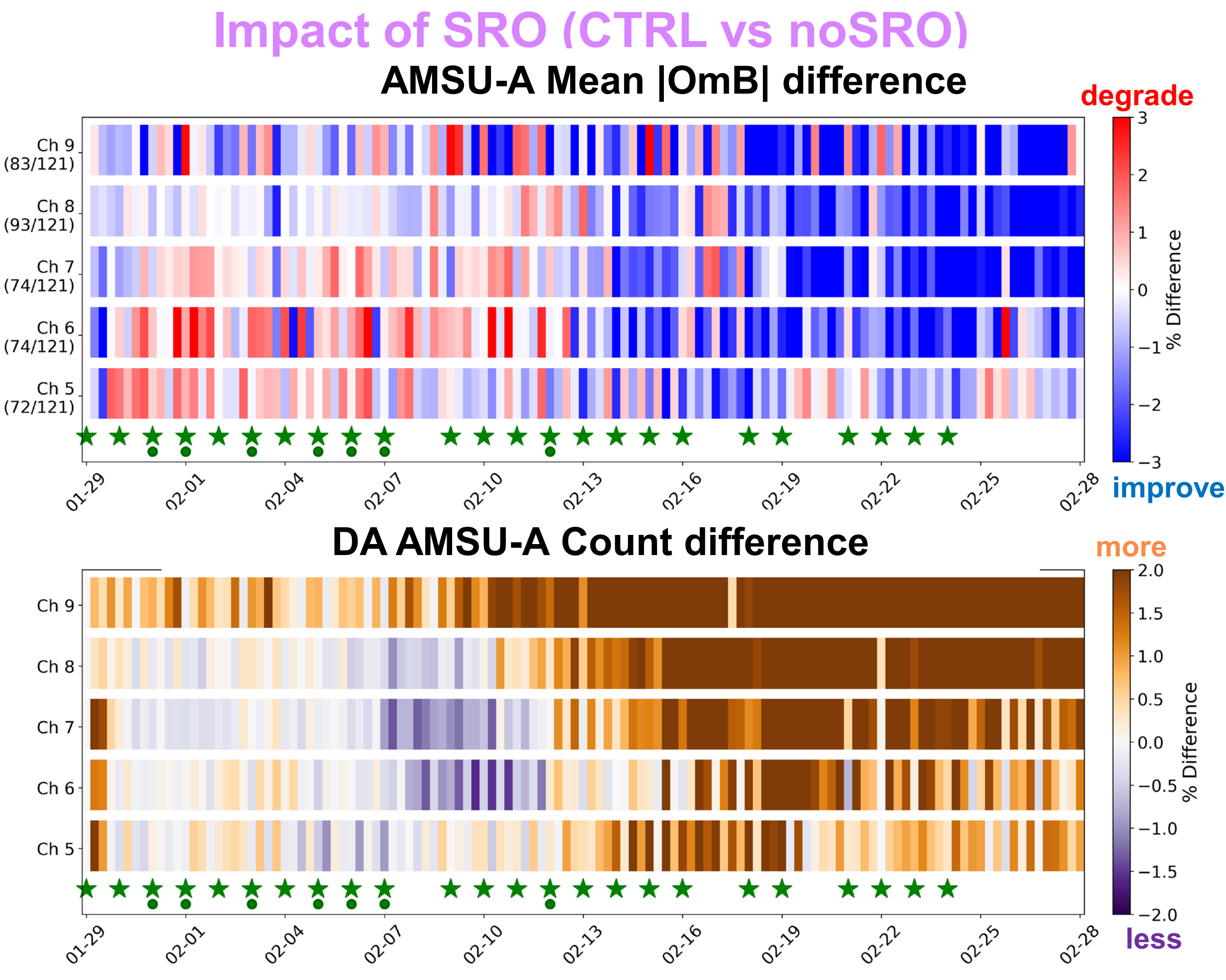
(1) Whether **ARO improves satellite radiance assimilation** by bringing the initial state closer to the true atmosphere, thereby increasing radiance usage, and at which **vertical levels and timescales** these indirect effects emerge?

(2) How those impact **compares with other anchoring observations used for radiance bias correction**, such as spaceborne radio occultation (SRO)?

(3) Whether the **combined assimilation of ARO and dropsondes** produces a greater forecast impact than either dataset alone?

Impact of Dropsondes & SRO on AMSU-A (globally)

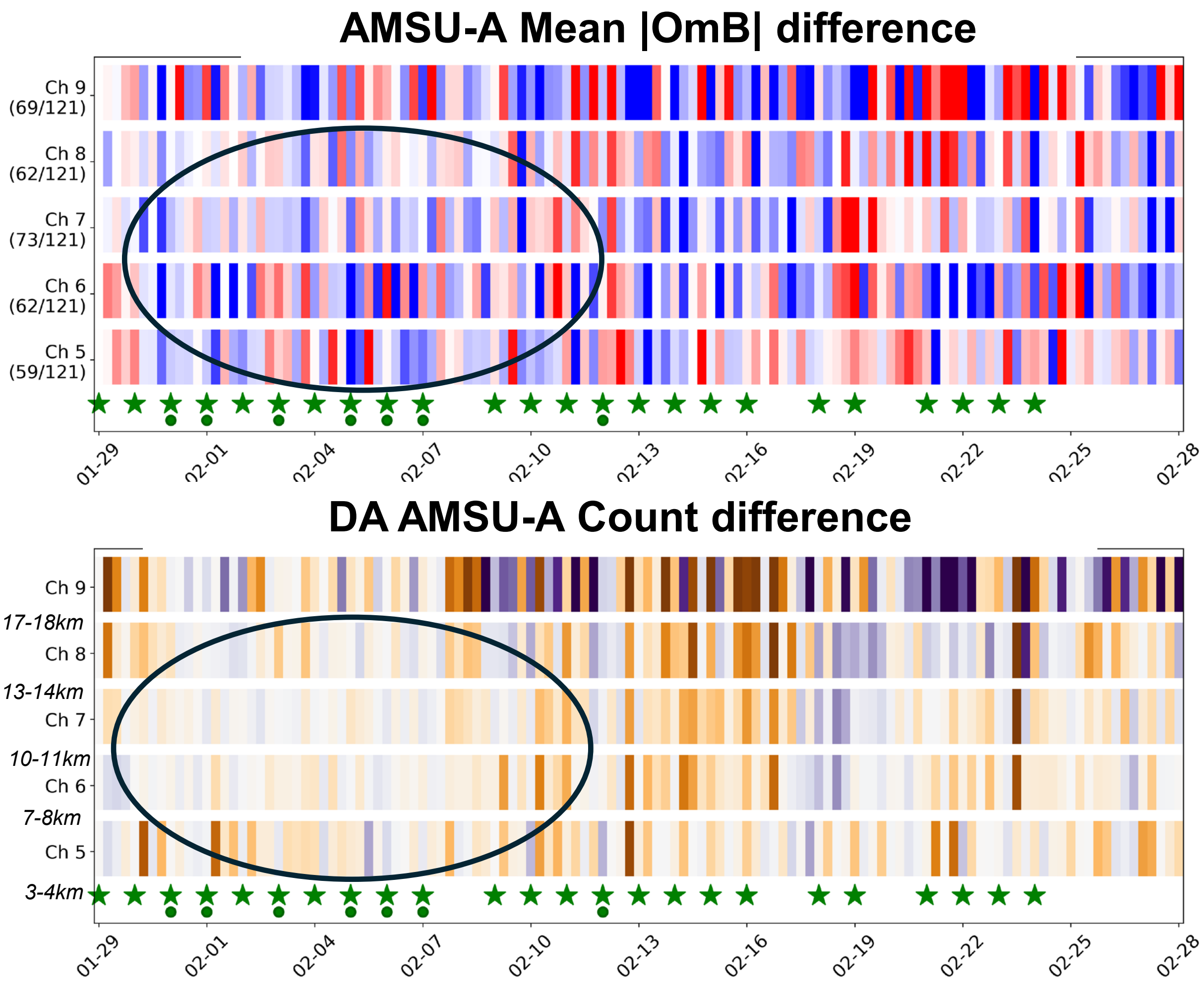




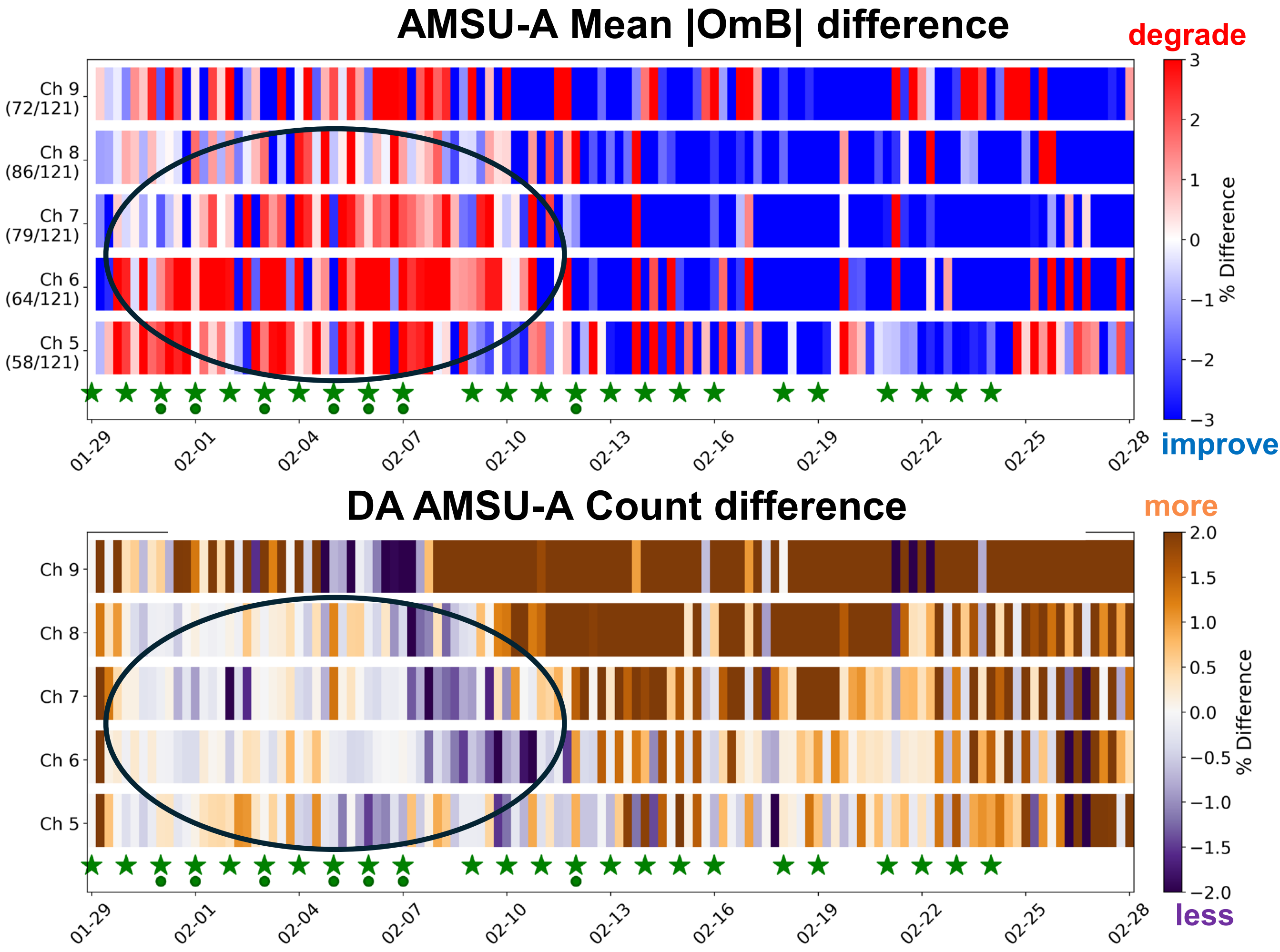
- **SRO** assimilation shows **much significant improvement** than dropsondes, with benefits accumulating through cycling.
- Improved radiance **fit well** with **increased radiance usage** when DA SRO.

Impact of Dropsondes & SRO on AMSU-A (over North Pacific)

Impact of Dropsondes (CTRL vs noDROP)



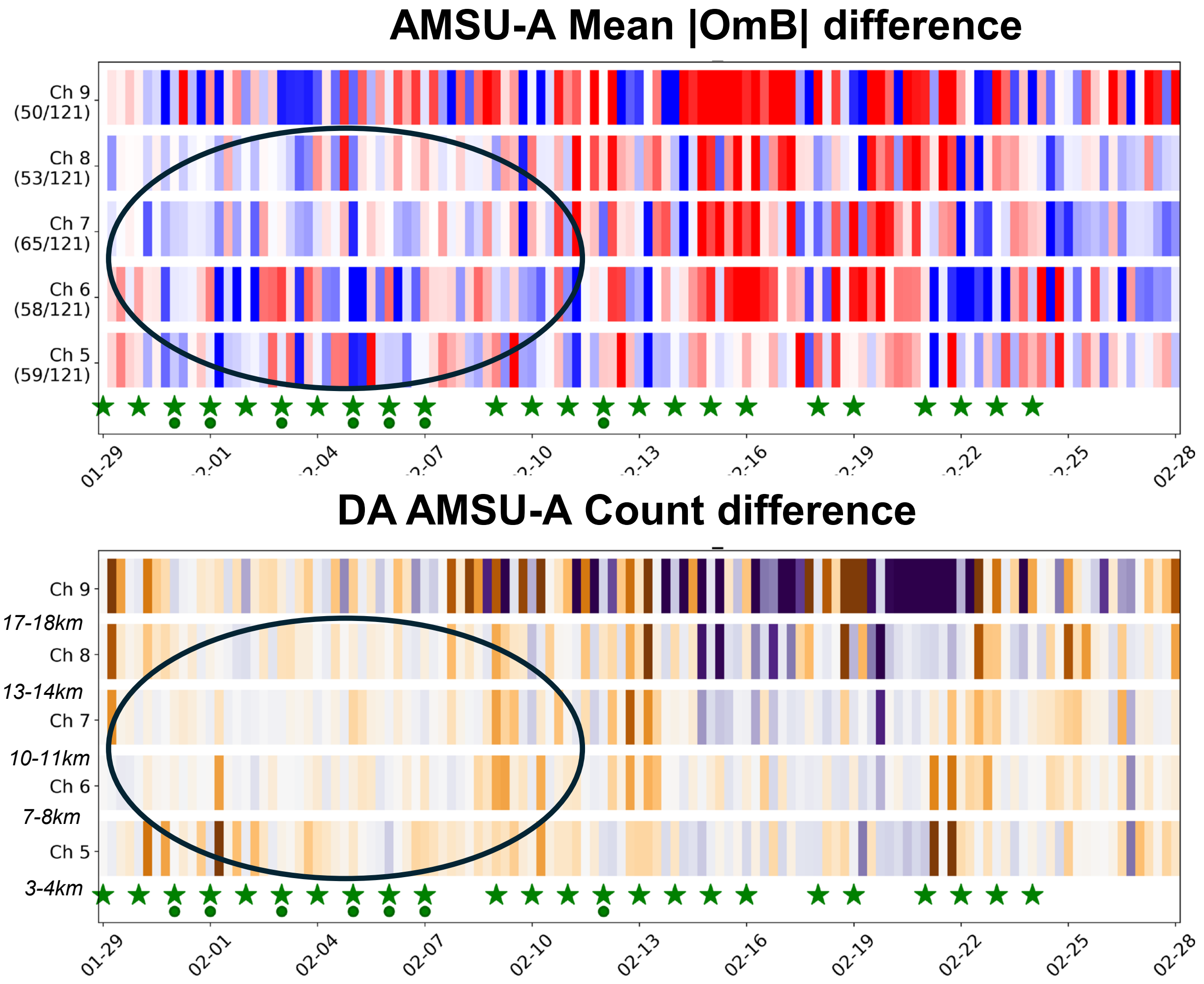
Impact of SRO (CTRL vs noSRO)



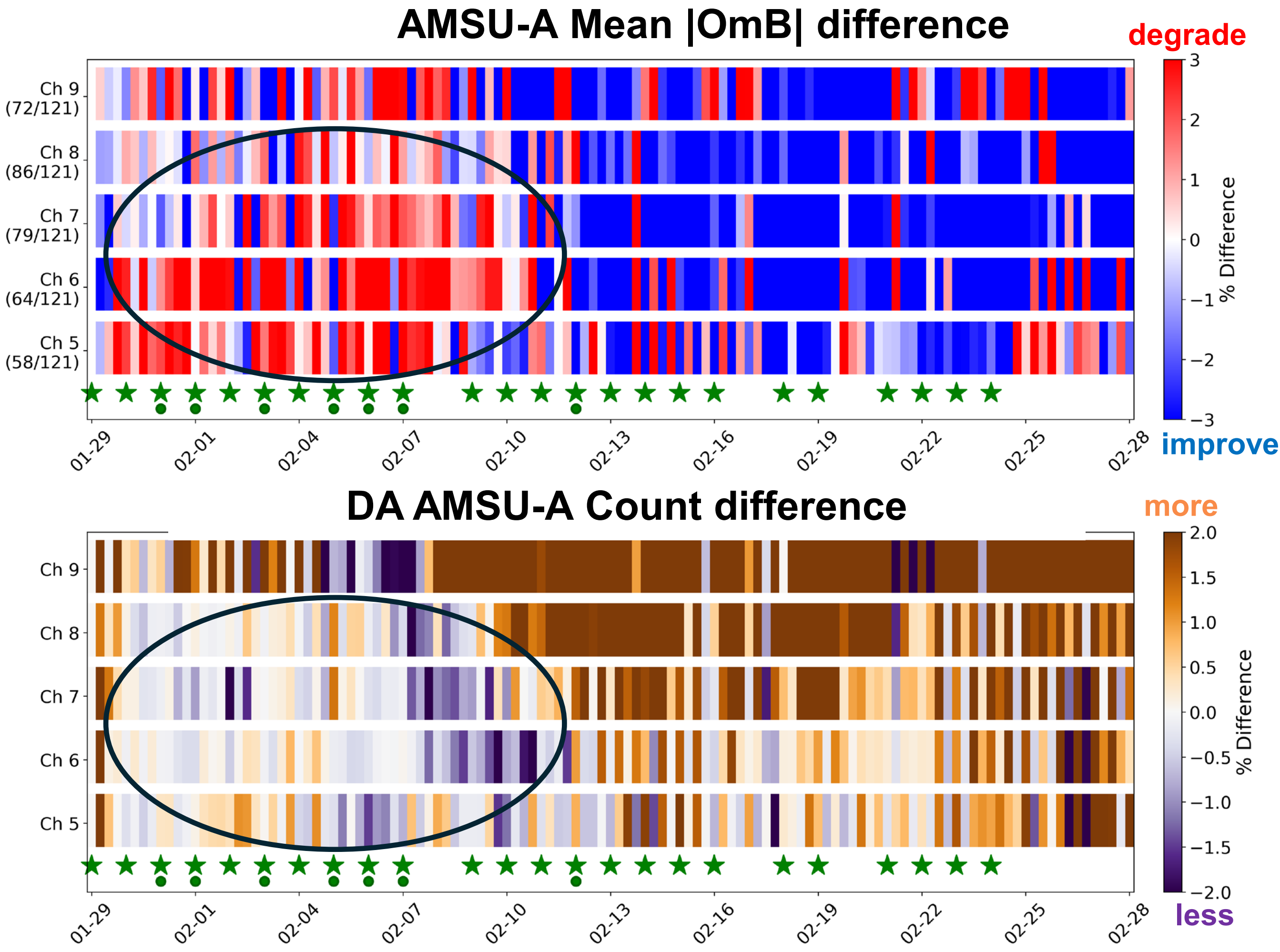
Over the North Pacific, dropsondes **retain more AMSU-A and improve AMSU-A fit in the early DA period** while SRO rejects more and degrades the OmB. It may link to the impact of **West Pacific flights**, which provides more dropsondes.

Impact of AR Recon & SRO on AMSU-A (over North Pacific)

Impact of AR Recon (CTRL vs noDROP_ARO)



Impact of SRO (CTRL vs noSRO)



Over the North Pacific, assimilating dropsondes and ARO leads to **more AMSU-A observations** being assimilated and generally **improves AMSU-A OmB** during the **early DA cycles** compared with SRO assimilation. This is likely because the West Pacific flights provide enhanced dropsonde and ARO coverage in the region.

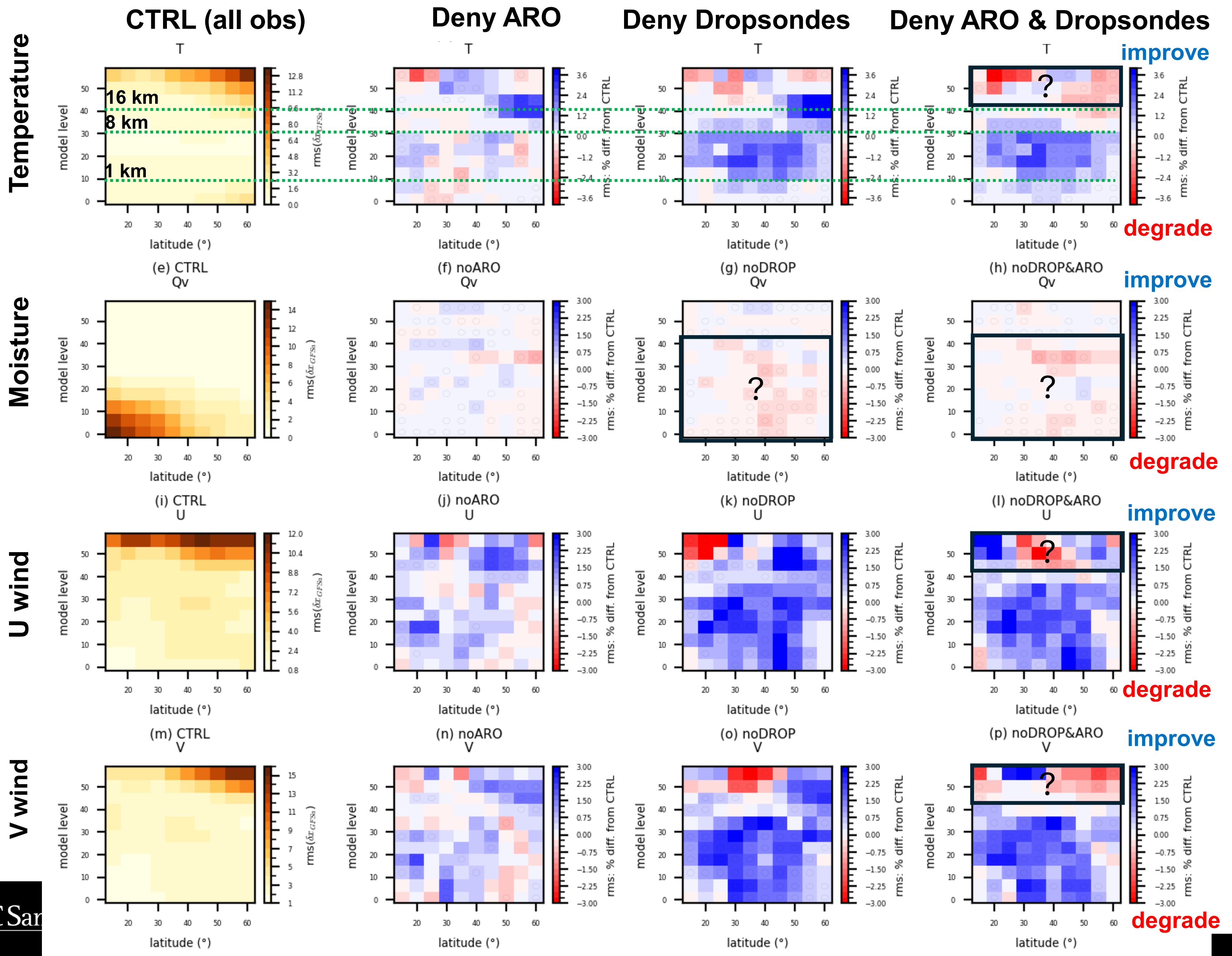
Scientific questions

(1) Whether **ARO improves satellite radiance assimilation** by bringing the initial state closer to the true atmosphere, thereby increasing radiance usage, and at which **vertical levels and timescales** these indirect effects emerge? How its impact **compares with other anchoring observations used for radiance bias correction**, such as spaceborne radio occultation (SRO)?

(2) Whether higher-accuracy **dropsonde observations influence the acceptance or rejection of nearby ARO** data, and how this interaction varies with altitude?

(3) Whether the **combined assimilation of ARO and dropsondes** produces a greater forecast impact than either dataset alone?

Dropsondes & ARO performance (vs ERA5 over NEP)



Deny obs (red = obs degrade fcst, blue =obs improve fcst)

Need more investigation

- ARO and dropsondes assimilation shows a **positive impact on T, U, and V**, whether assimilated individually or together.
- For **moisture**, assimilating dropsondes alone or in combination with ARO leads to degradation, whereas assimilating **ARO** alone results in **improvement**.

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Summary

Impact of Dropsondes & ARO on AMSU-A

- **Dropsondes and ARO largest impact** occur in AMSU-A channels 6–8 (**7–14 km**). Benefits become more evident in **later DA cycles**.
- **Dropsondes** show generally **stronger impacts**.
- Dropsondes and ARO improve AMSU-A QC by **retaining good** observations and **rejecting bad** ones.
- The impact on AMSU-A **extends beyond the dropsondes and ARO observation region.**

Impact of AR Recon & SRO on AMSU-A

- **SRO** assimilation provides the **stronger improvement** in radiance bias correction, with benefits increasing through cycling DA.
- SRO is also associated with **greater radiance usage**.
- **Dropsondes and ARO** produce **stronger early-cycle improvements** in AMSU-A fit **over the North Pacific**, but their impact is more regional and less sustained.

Dropsondes & ARO performance

- ARO and dropsondes **improve temperature and wind** (U, V) analyses when assimilated individually or together.
- For **moisture**, **ARO** assimilation **improves** the analysis, while **dropsonde** assimilation leads to **degradation**.

Thank you!

Comments/questions?

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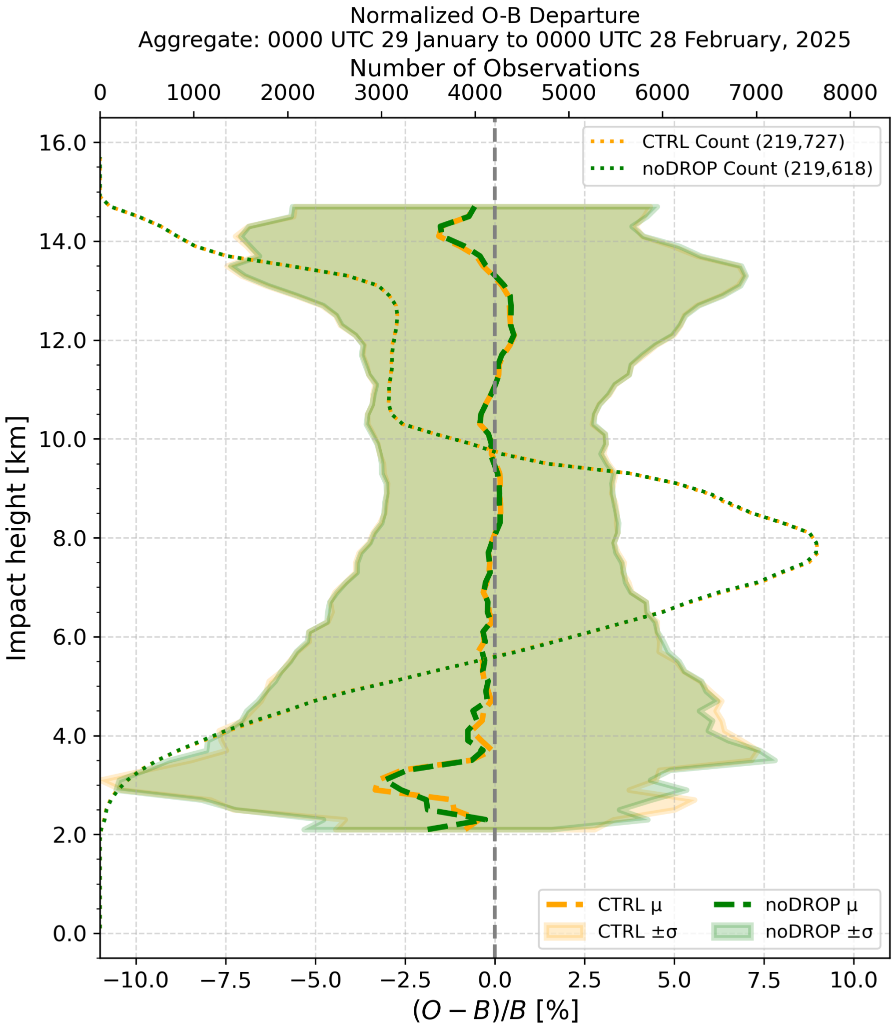
Extra slides

Instrument	Channel	Peak Sensitivity (hPa)	Peak Sensitivity (km)	Primary Variable
AMSU-A	5	~850–700 hPa	~3–4 km	Temperature
AMSU-A	6	~700–400 hPa	~7–8 km	Temperature
AMSU-A	7	~400–250 hPa	~10–11 km	Temperature
AMSU-A	8	~250–200 hPa	~13–14 km	Temperature
AMSU-A	9	~200–100 hPa	~17–18 km	Temperature
MHS	3	~500–300 hPa	~7–9 km	Humidity
MHS	4	~400–250 hPa	~8–11 km	Humidity
MHS	5	~250–150 hPa	~11–14 km	Humidity

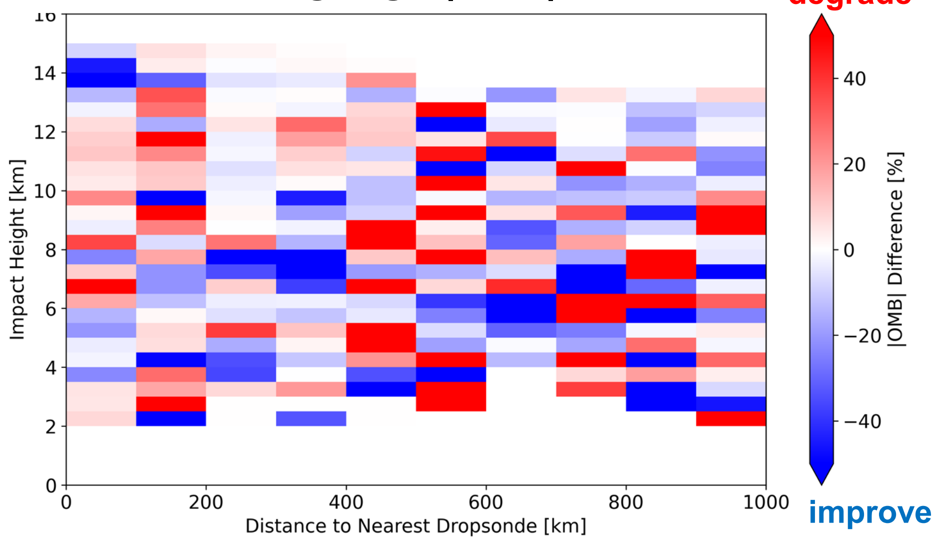
Dropsondes impacts on ARO

Bending angle OmB, CTRL vs noDROP

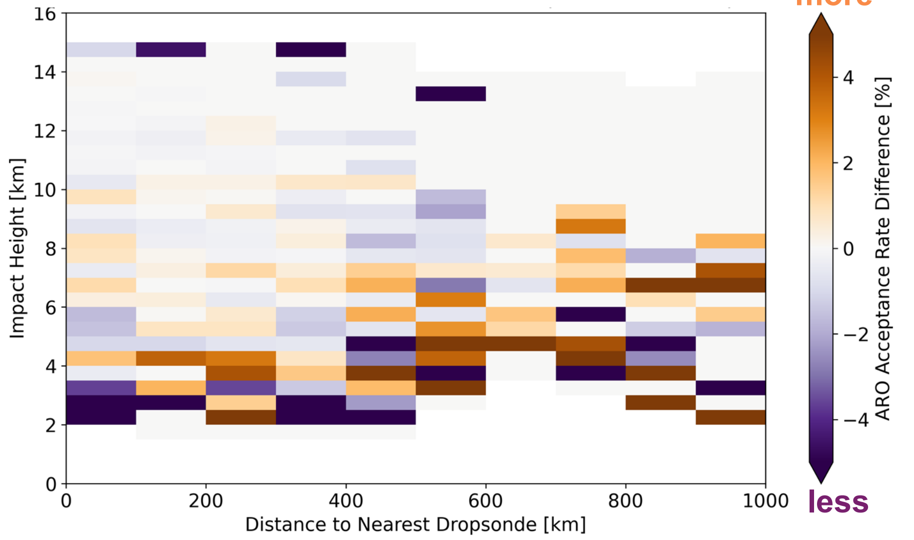


Assimilated ARO difference, CTRL vs noDROP

ARO bending angle |OmB| difference

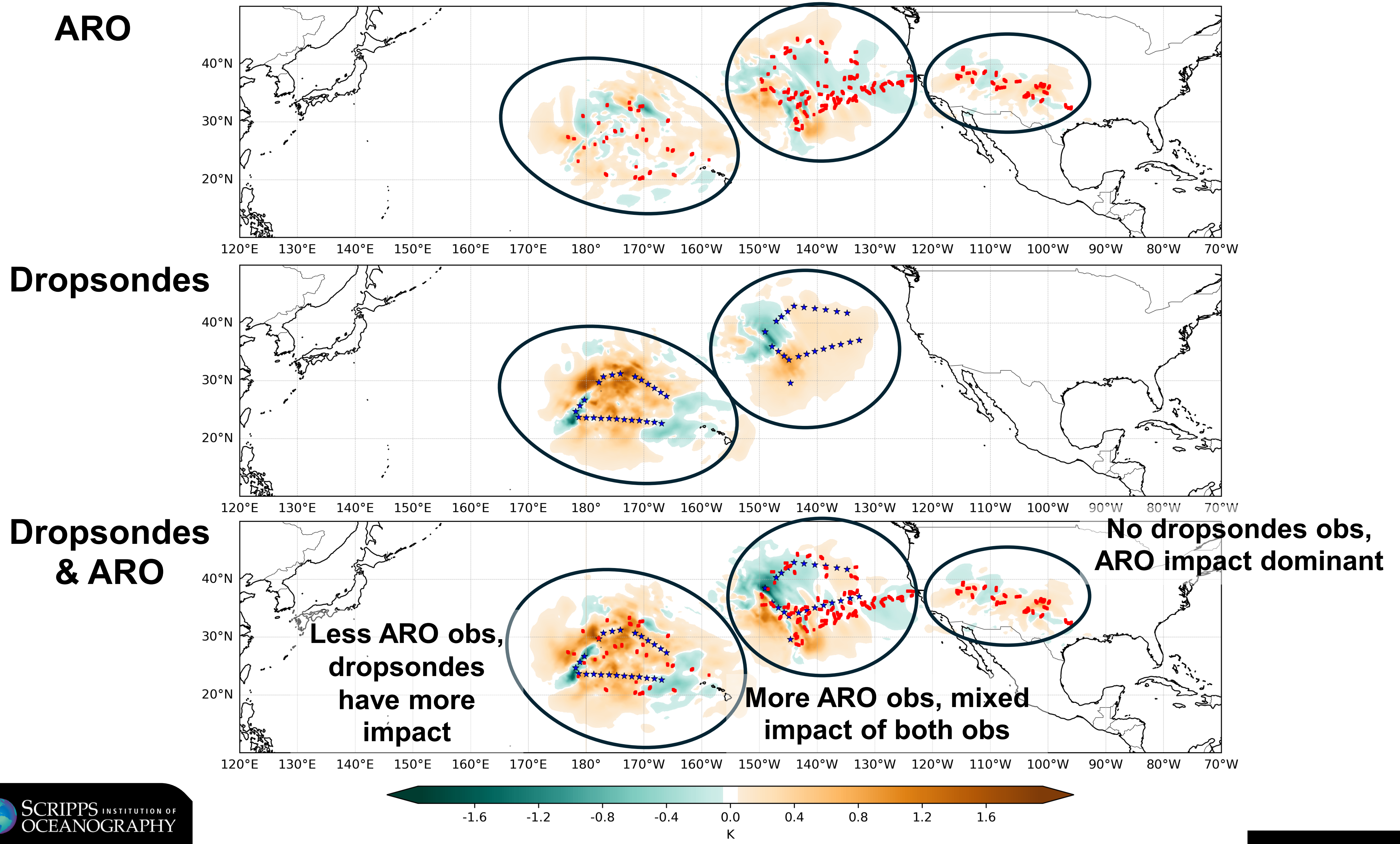


DA ARO bending angle Count difference



- For the whole DA period, dropsondes did not significantly change ARO fit and DA ARO count.
- Dropsondes **improve ARO fit** most strongly at **6–10 km**.
- ARO **acceptance increases** mainly at **3–5 km**.
- Better ARO fit does not always lead to higher ARO acceptance.
- Impacts extend **300–400 km** from dropsonde locations.

Dropsondes & ARO performance *(T Increment @ 6km, 1st cycle)*



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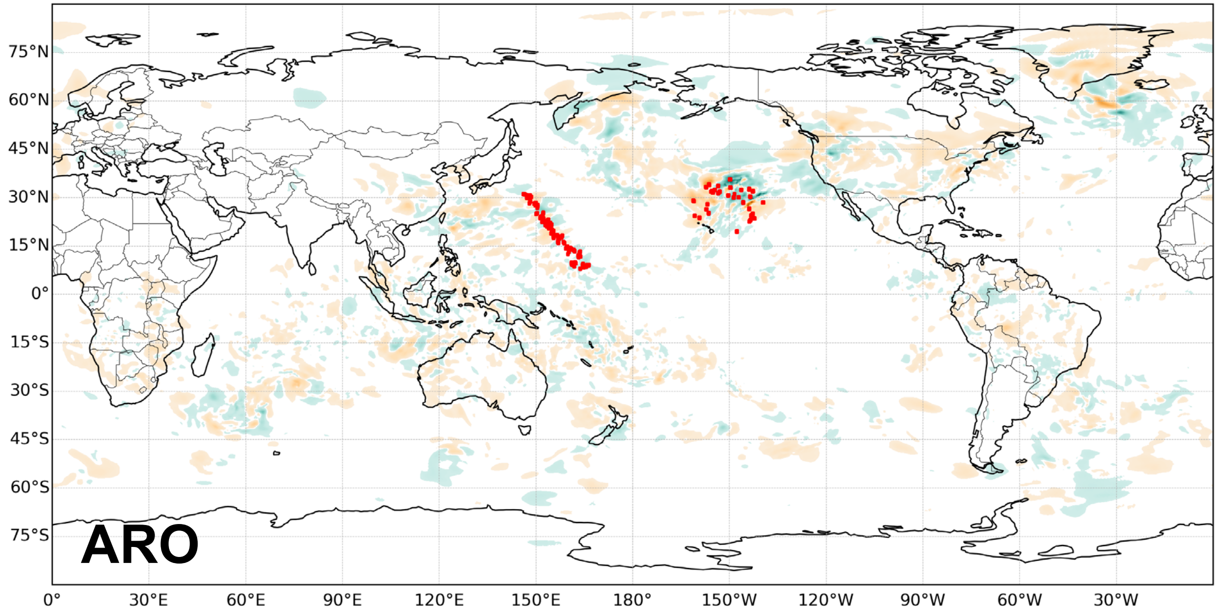
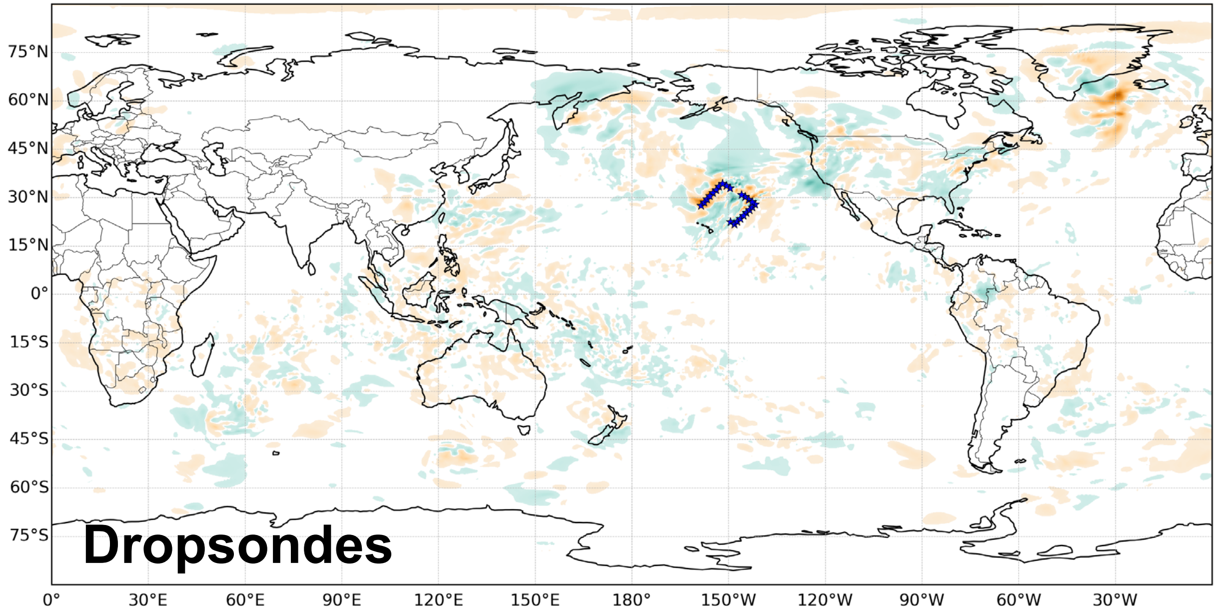
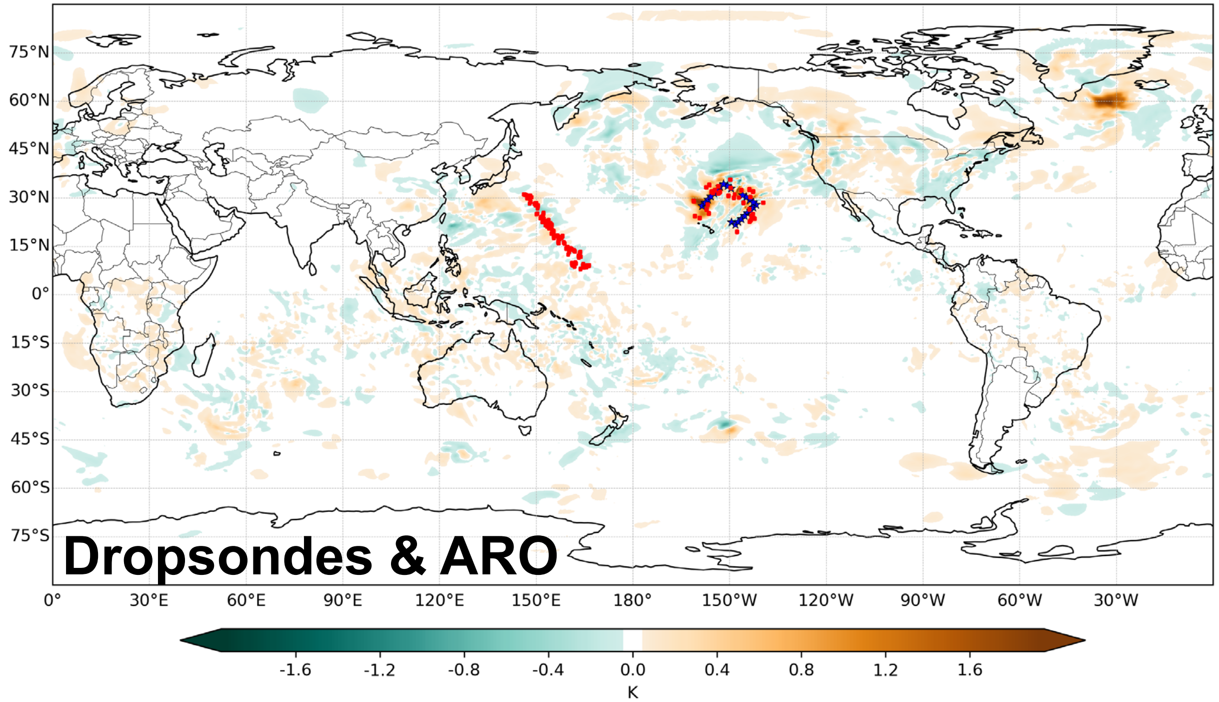
Dropsondes & ARO performance *(T Increment @ 6km, after 3 days DA)*







Increment spreads globally

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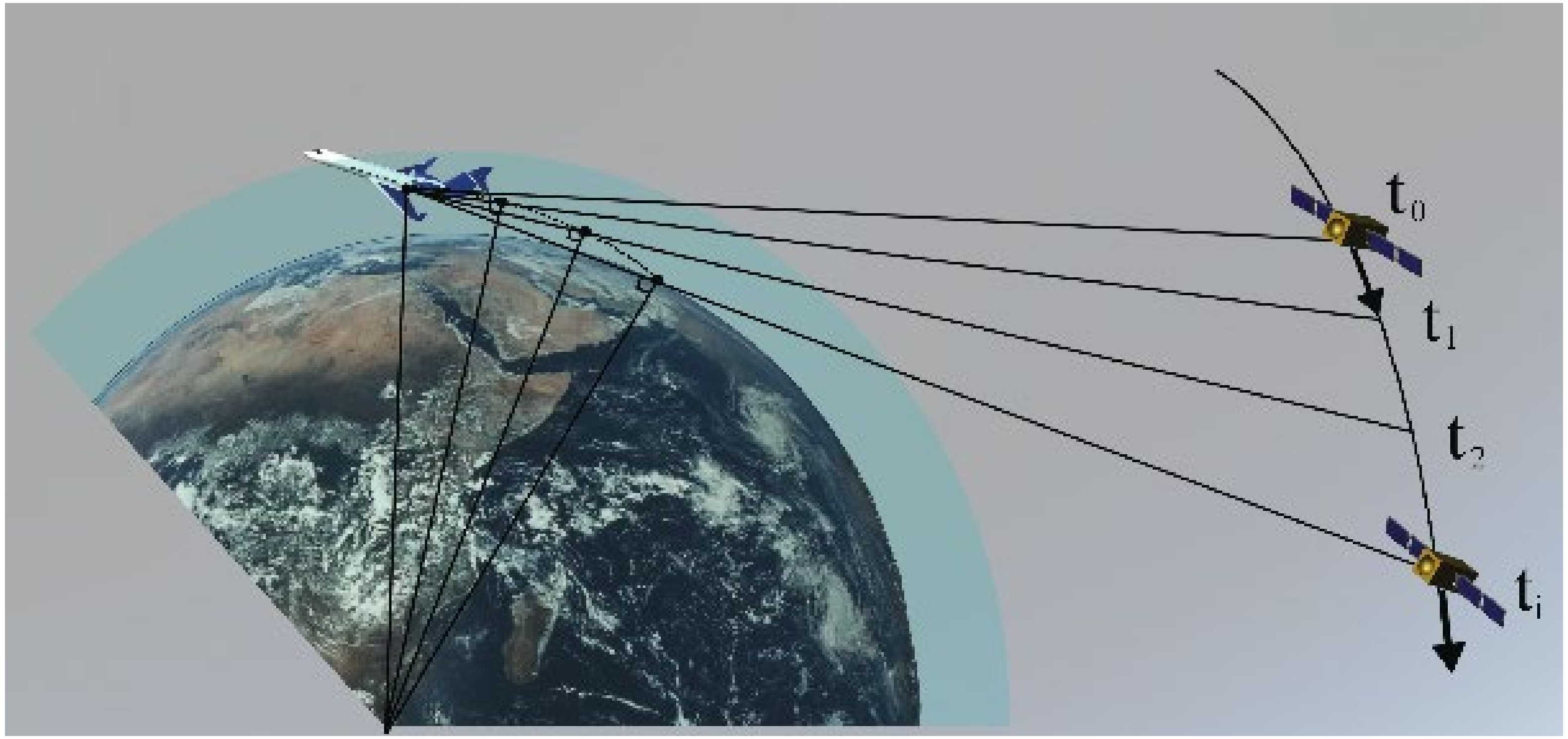
GNSS Airborne Radio Occultation

- Side-looking GNSS receiver tracks setting and rising satellites
- Nearly horizontal ray paths experience a refractive delay
- Atmospheric refractivity, temperature, and humidity profile is derived from refractive delay

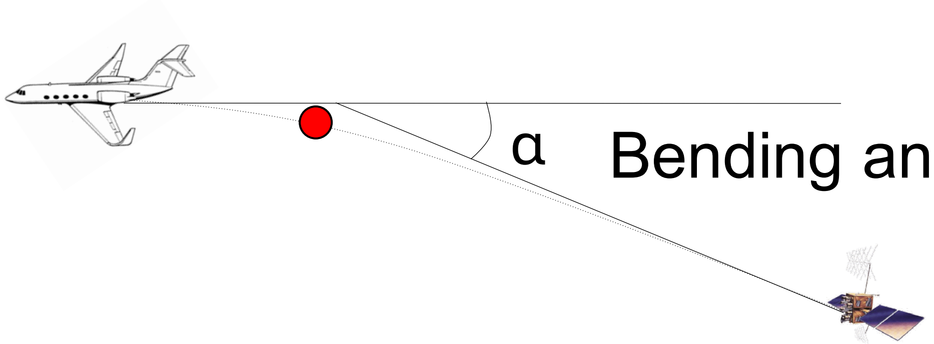
- Atmospheric refractivity is a function of pressure, temperature, water vapor pressure

$$N = (n-1) \cdot 10^6 = k_1 \frac{P_d}{T} + k_2 \frac{e}{T} + k_3 \frac{e}{T^2}$$



Haase et al., 2014, GRL.

Refractive bending angle



$$\alpha'(a) = \alpha_N(a) - \alpha_P(a) = -2a \cdot \int_{r_t}^{r_R} \frac{1}{n}\frac{dn}{dr}\frac{dr}{\sqrt{(nr)^2 - a^2}}$$

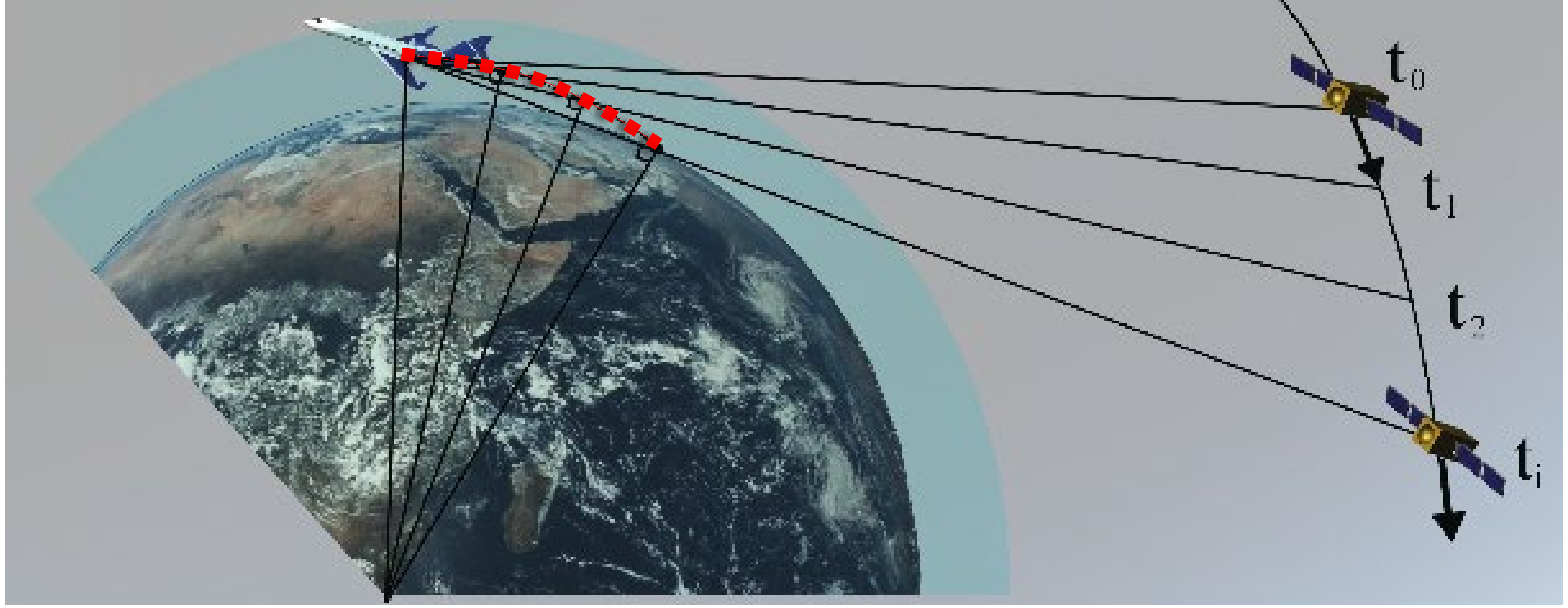
Inverse Abel Transform:

$$n(a) = n_R exp\left[\frac{1}{\pi}\int_{a=x=nr_t}^{x=n_R r_R} \frac{\alpha'(x)}{\sqrt{x^2 - a^2}} dx\right]$$

Refractivity at a given height depends on

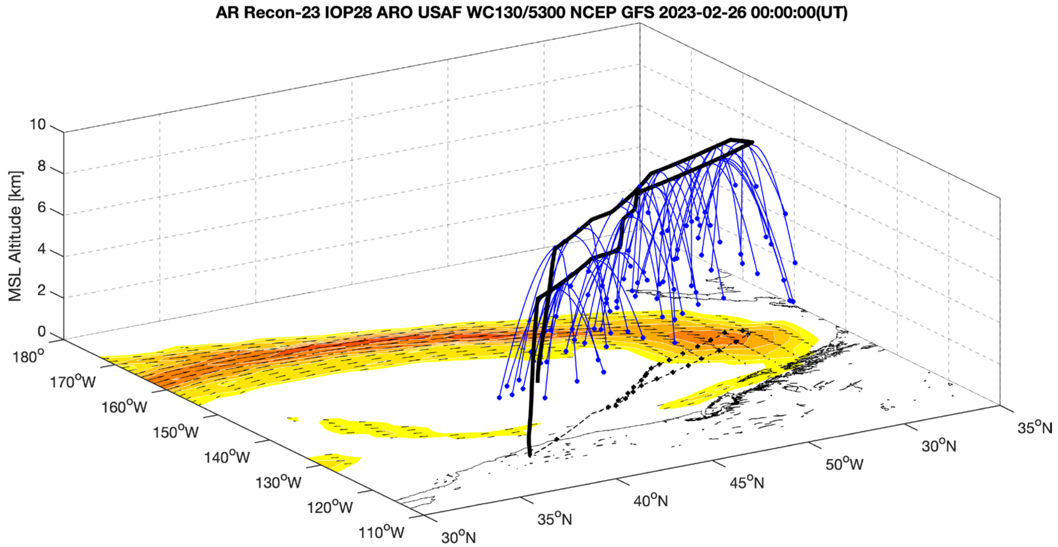
integral of all values of bending from the given height to the profile top

Atmospheric parameters are retrieved at a representative tangent point – point closest to Earth surface

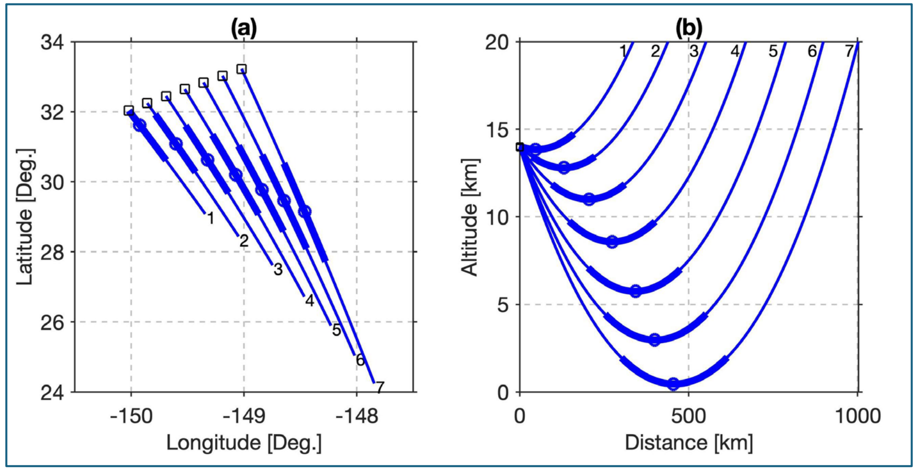


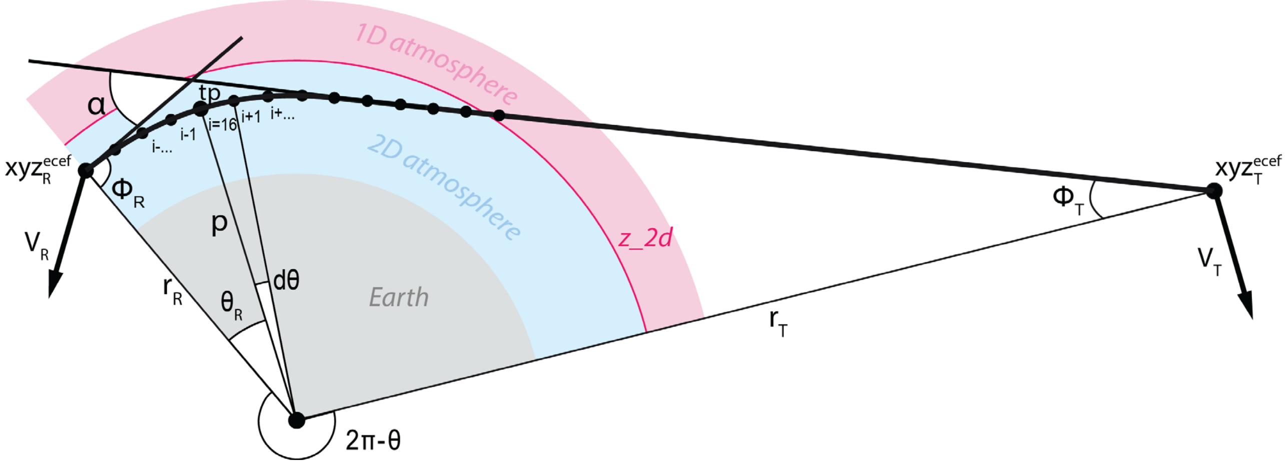
Haase et al., 2014, GRL.

The atmosphere is not 1D, especially not in ARs



- Removed assumption that observation is made at a point
- Developed an operator that raytraces through a 2D background field along the occultation plane
- Creates model increments at every point sampled by the ray path
- It also takes into account tangent point horizontal drift
- Now available for any NWP model with a JEDI interface





Hordyniec et al., 2025, JAMES

https://github.com/jhaaseresearch/sio-aro-ropp

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