

Detection and Flagging of Radio Frequency Interference Contamination in SMAP Ocean Observations

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Thanks to SMAP L1 Processing Team:
Paolo de Matthaeis + Priscilla Mohammed

SMAP: Sensor + RFI Filter

- L-band radiometer (1.4 GHz).
 - Fully polarimetric.
 - Fore + aft looking.
- Elaborate RFI detection and filtering at Level 1 processing.
 - Time domain detection.
 - Frequency domain detection.
 - Kurtosis detection.
 - 4th Stokes detection.
- Time scale of L1 observation is $\sim 300 \mu\text{s}$.
 - If the RFI signal is constant in time and/or frequency over these time scales and bandwidth, the L1 detection will not work.
 - Unfortunately, that is the case.
- L1 detection is optimized for land application.
 - For ocean application tighter thresholds are required.
 - SSS retrieval requires 0.1 K radiometric accuracy.
- **Additional RFI detection and flagging is required on Level 2 for ocean retrievals.**

Metrics

Level of RFI Contamination

$$\Delta T_B = T_{B,SMAP} - T_{B,RTM} (SSS_{ext}, SSWS_{ext})$$

SSS_{ext}	HYCOM
$SSWS_{ext}$	ERA5, CCMP

Probability of Detection (POD)

$$POD(\Theta) = P(RFI_{detected} | \Delta T_B \geq \Theta)$$

Detection Threshold Θ

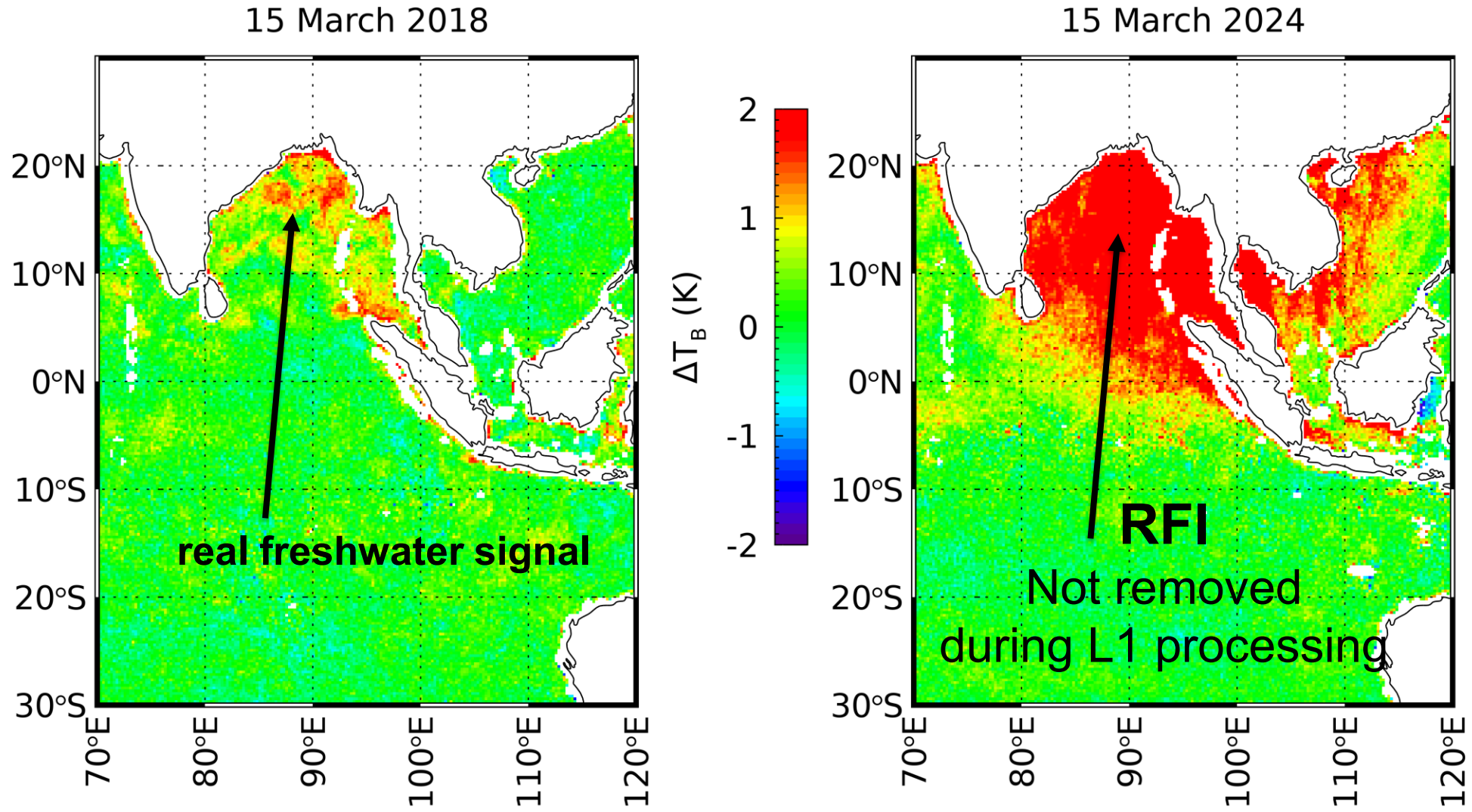
The value of Θ needs to be significantly larger than the typical noise (0.55 K for resampled L2 observations).

False Alarm Rate (FAR)

$$FAR = P(RFI_{detected} | \neg(RFI_{present}))$$

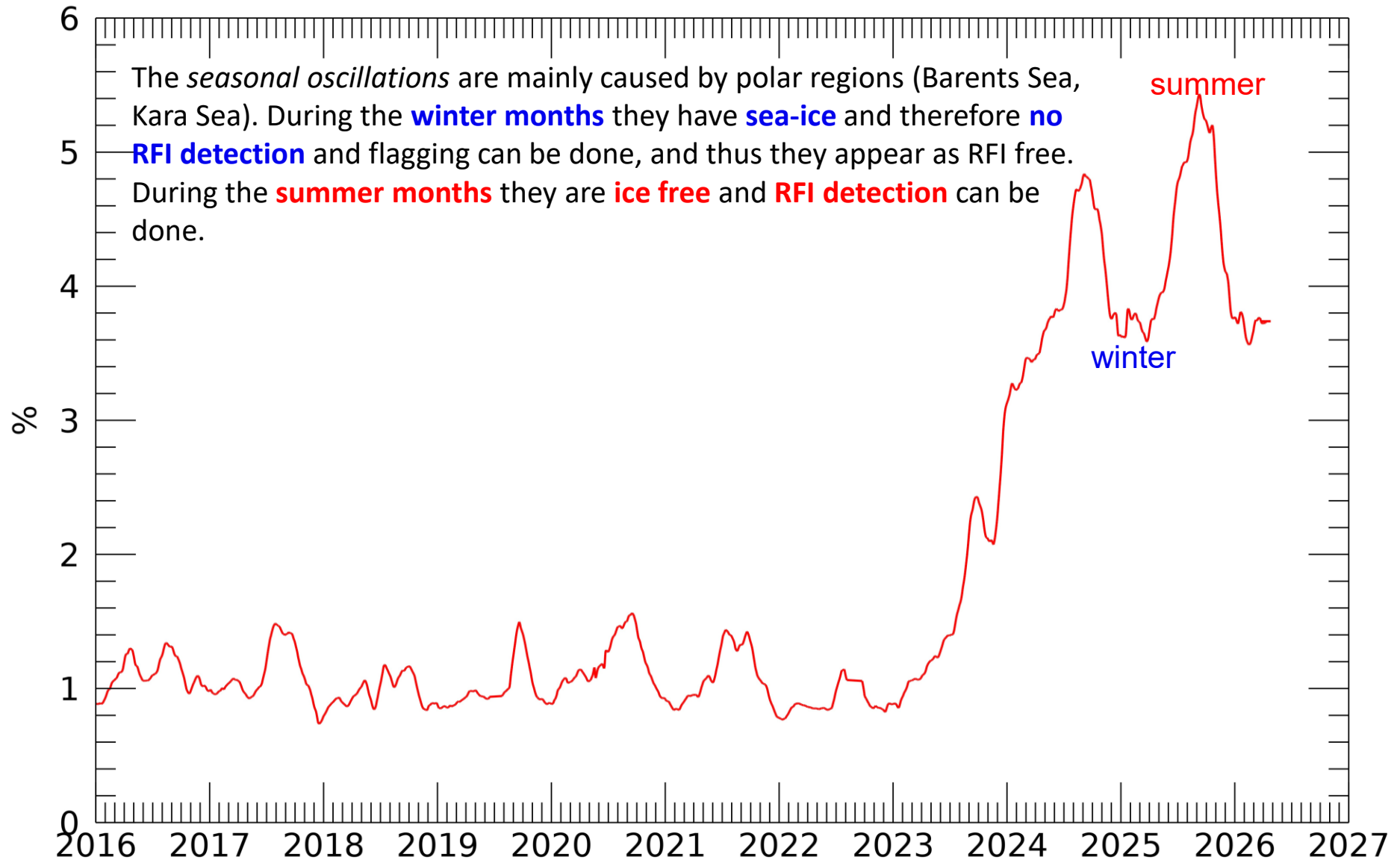
- FA caused by
 - noise
 - real signals that are not depicted by external fields
- Freshening (river outflows) has same signature as RFI: increases T_B
- FAR is determined for cases where no known RFI sources exist

The L2 RFI detection and flagging algorithm needs to work without external fields. RFI detection needs the ability to distinguish RFI from real signals (freshwater influx).

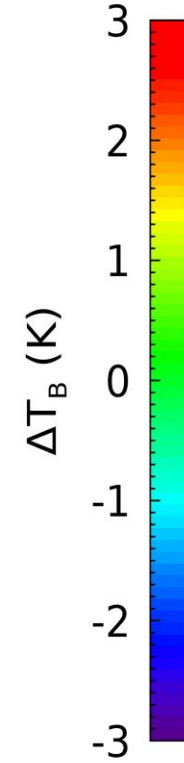
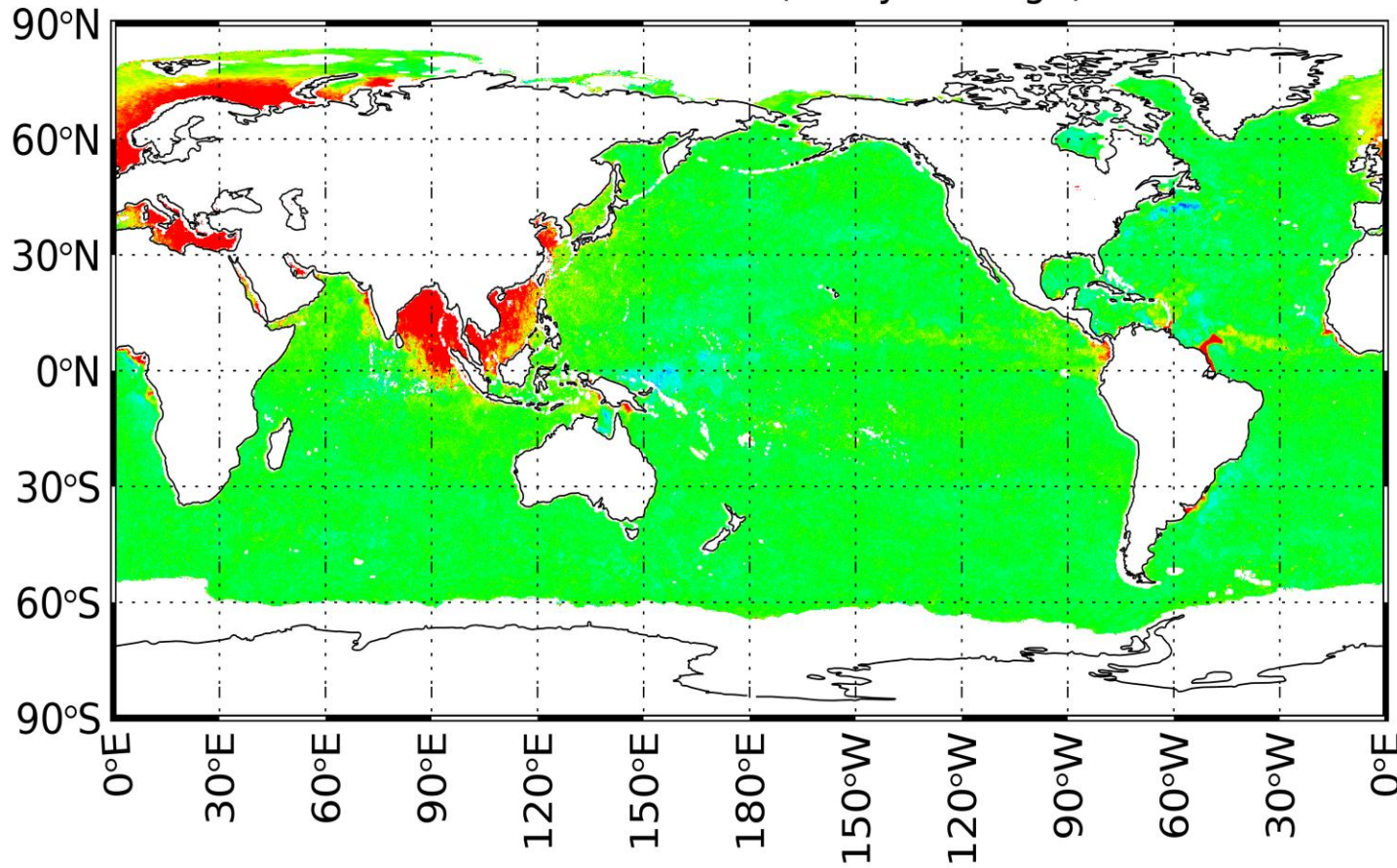


Reminder: Signature of **RFI contamination** $T_B \uparrow$ $SSS \downarrow$

% of RFI flagged SMAP open ocean obs (running monthly ave.)



15 October 2025 (8-day average)



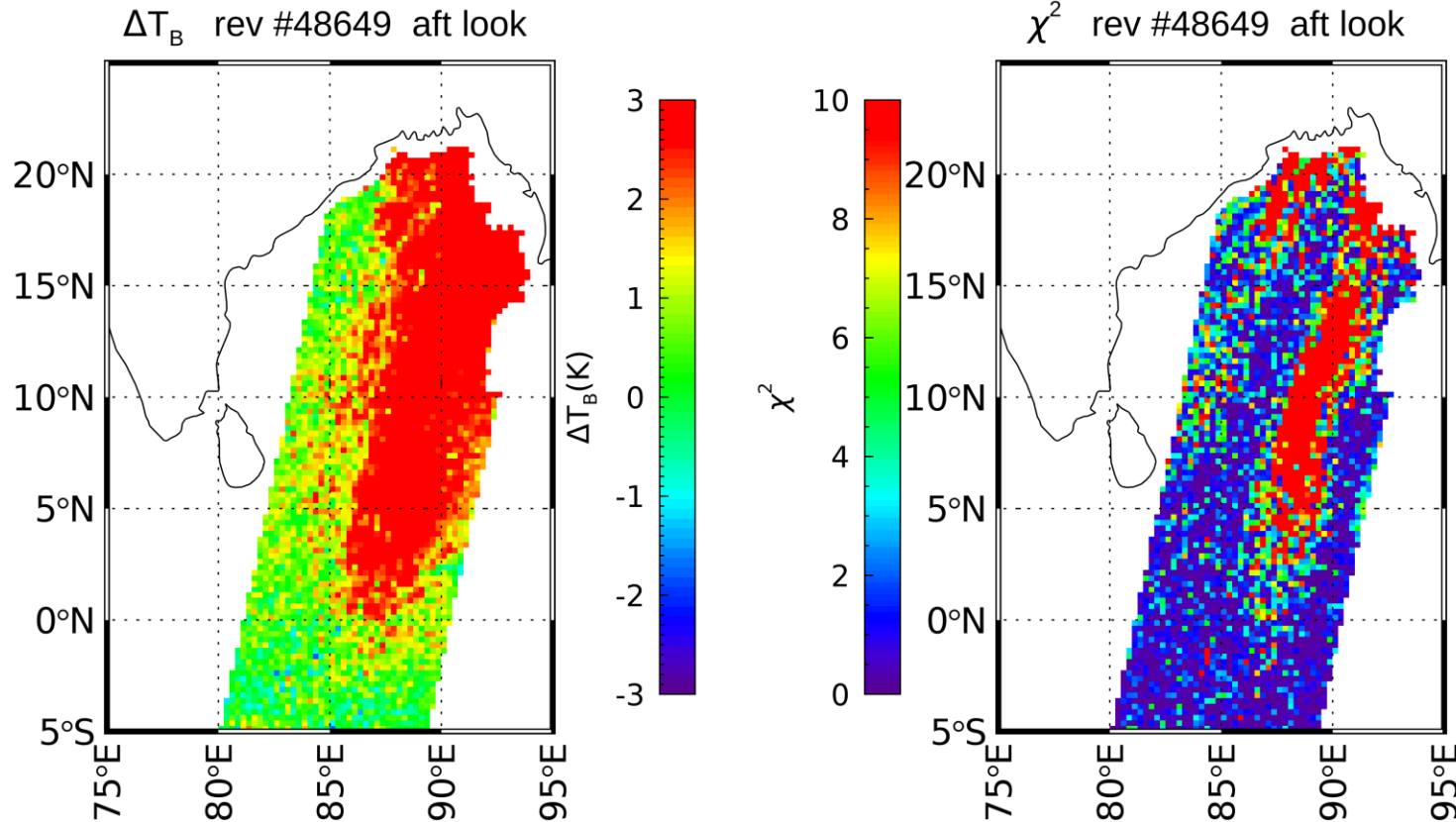
strong increase in RFI level over open ocean starting in late 2024

GPS jammers

geo-political conflicts

RFI signal can enter SMAP antenna through sidelobes

χ^2 Based RFI Detection for SMAP Ocean Scenes



Salinity Retrieval

$$\chi^2 = \sum_{P=V,H} \left[\frac{\Delta T_B (\text{SSS}_{\text{retrieved}})_P}{\sigma_P} \right]^2$$

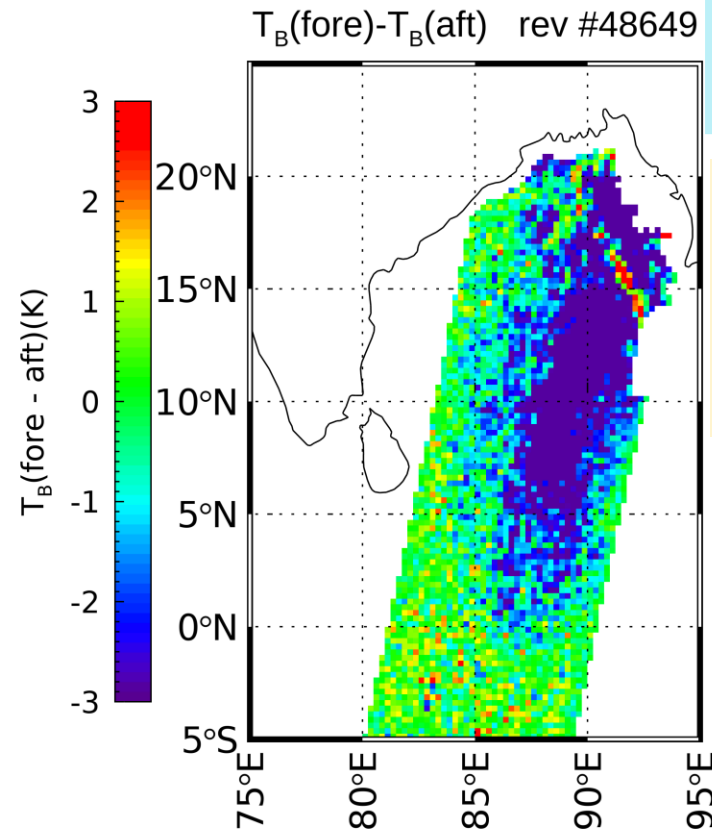
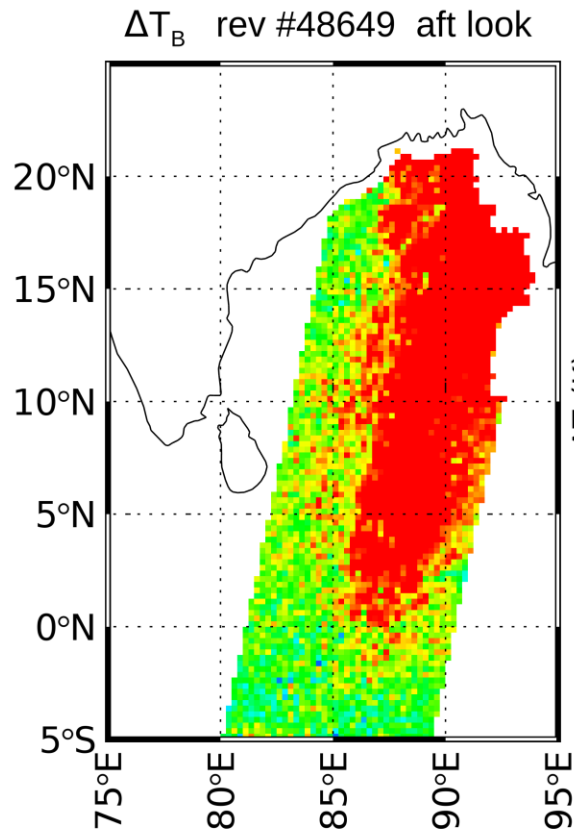
RFI Detection

$$\chi^2 \geq \chi^2_{thr}$$

No external SSS data required

Fore-Aft Based RFI Detection for SMAP Ocean Scenes

RFI Detection



$$\left[T_{B \text{ sur0}}(\text{fore} - \text{aft}) \right] \geq \Delta_{\text{FA}} \Rightarrow \text{RFI in fore swath}$$
$$\left[T_{B \text{ sur0}}(\text{fore} - \text{aft}) \right] \leq -\Delta_{\text{FA}} \Rightarrow \text{RFI in aft swath}$$

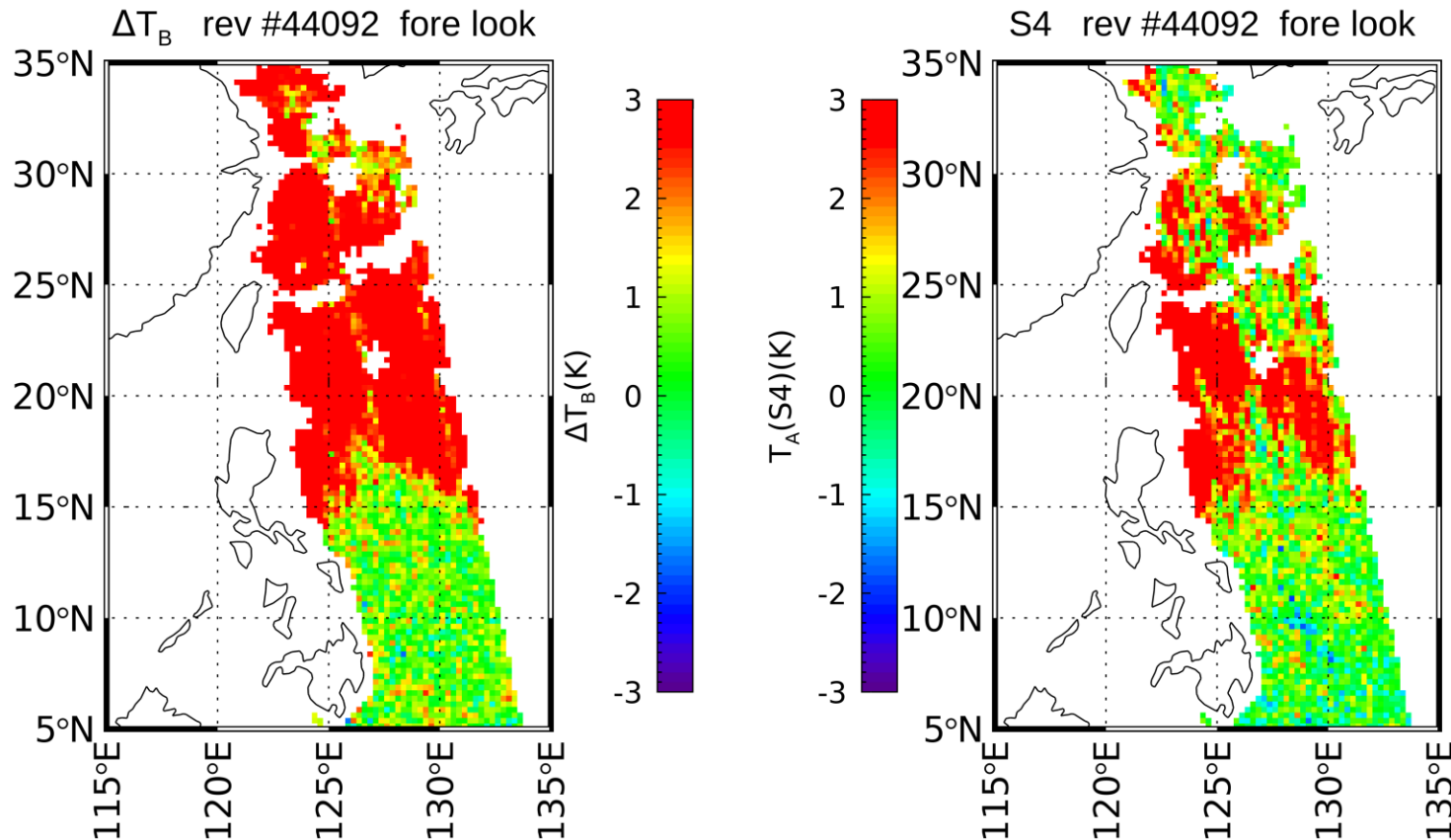
assumes that all other fore-aft signals (ionosphere, footprint orientation, wind direction...) are significantly below Δ_{FA} level

No external SSS data required

Limitation

If there is **RFI in both the fore and the aft swaths**, only the RFI in the swath with the highest RFI level can be detected.

4th Stokes Based RFI Detection for SMAP Ocean Scenes



4th Stokes antenna temperature over open ocean

$$\langle T_A(S_4) \rangle \approx 0 \quad \sigma(S_4) \approx 0.7K$$

RFI Detection

$$|T_A(S_4)| \geq \Delta_{S4}$$

No external SSS data required

Improving Receiving Operating Characteristics

1. Clustering (example χ^2 detection)

$$N_{\text{cluster}}(i, j; w, \chi^2) = \sum_{\substack{k=i-w, i+w \\ l=j-w, j+w}} \delta_{kl} \quad \delta_{kl} = \begin{cases} 0, & \text{if } \chi^2 \leq \chi^2_{\text{thr}} \\ 1, & \text{if } \chi^2 > \chi^2_{\text{thr}} \end{cases}$$

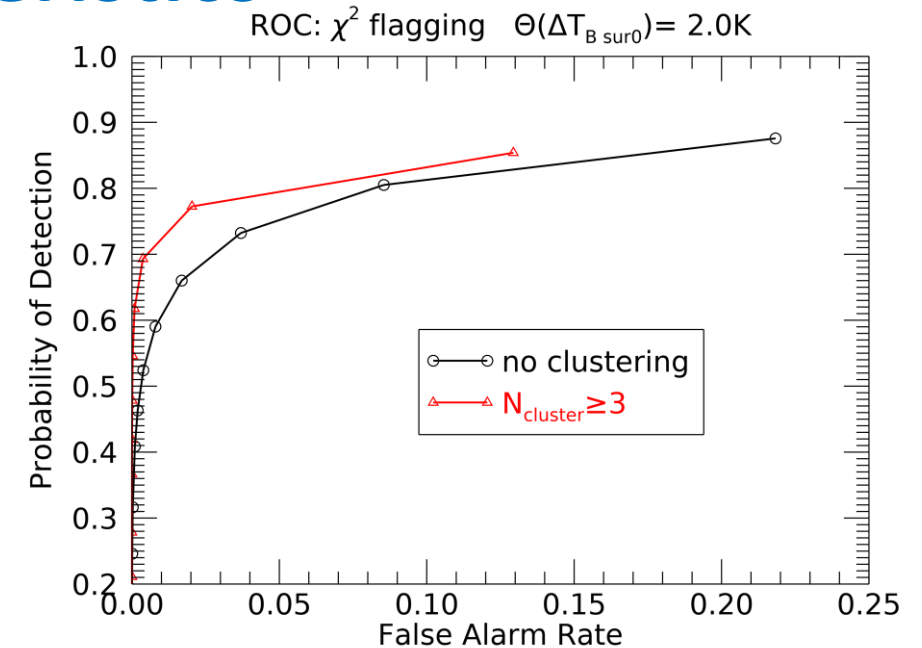
(i,j): grid cell w: window size (typically $w = 1$)
require detection in at least N_{cluster} cells for flagging

2. Neighboring Flagging

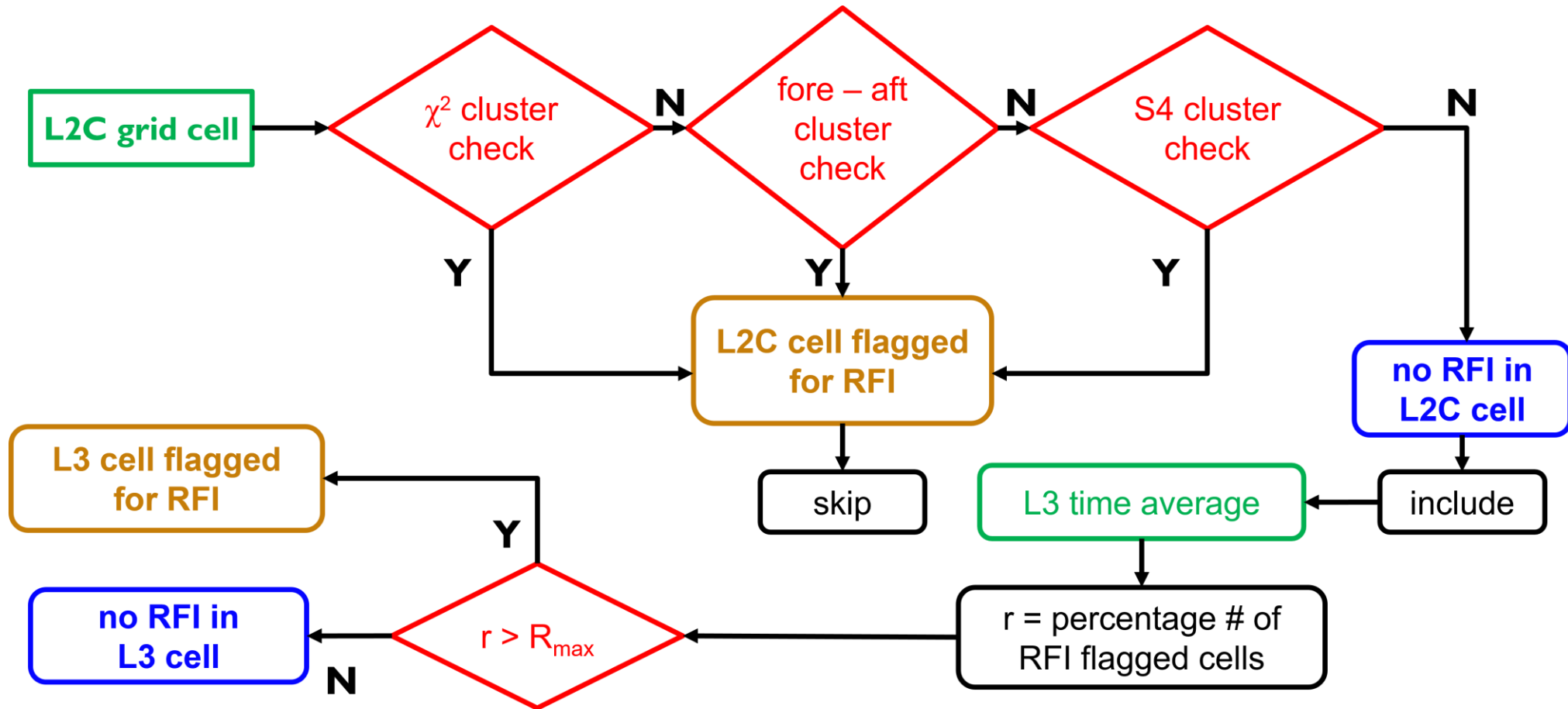
- If RFI is detected in a cell by one of the basis methods (χ^2 , FA, S_4), then all neighboring cells within a window of size w are flagged (typically $w = 1, 2, 3$).

3. L3 Time Aggregates

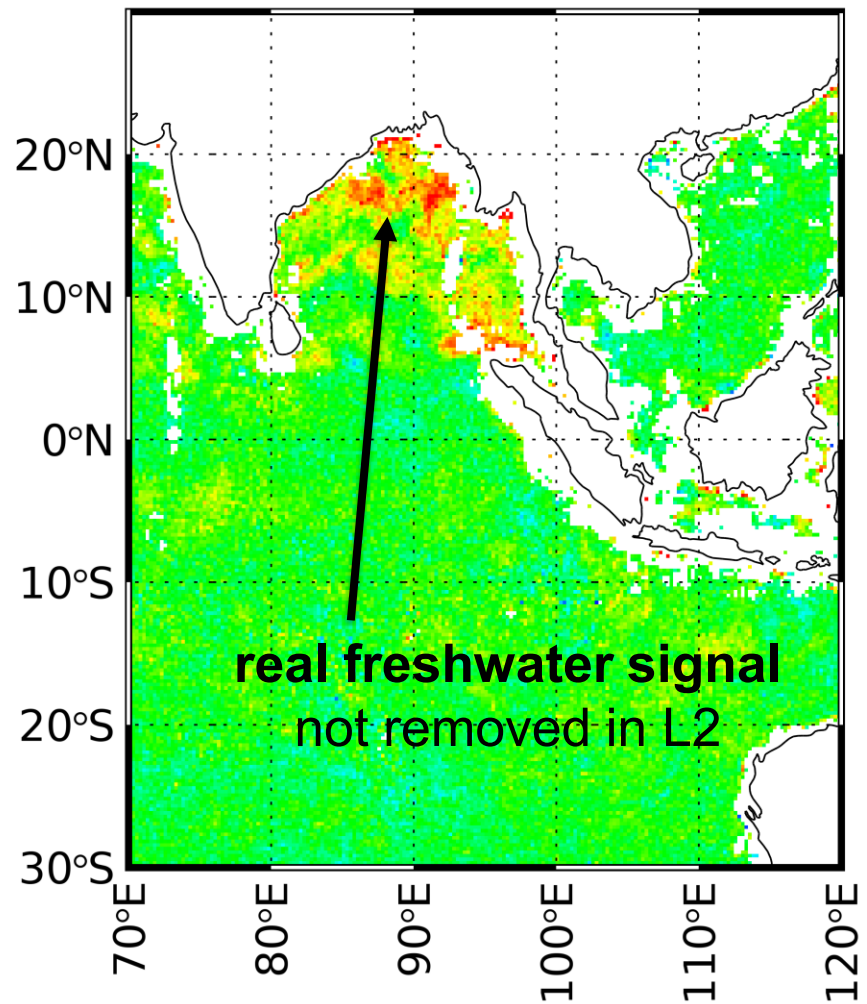
- 8-day average salinity maps
- Flag cell if percentage of RFI detected observations in the 8-day time average exceeds R_{max} ($\approx 50 - 70\%$).



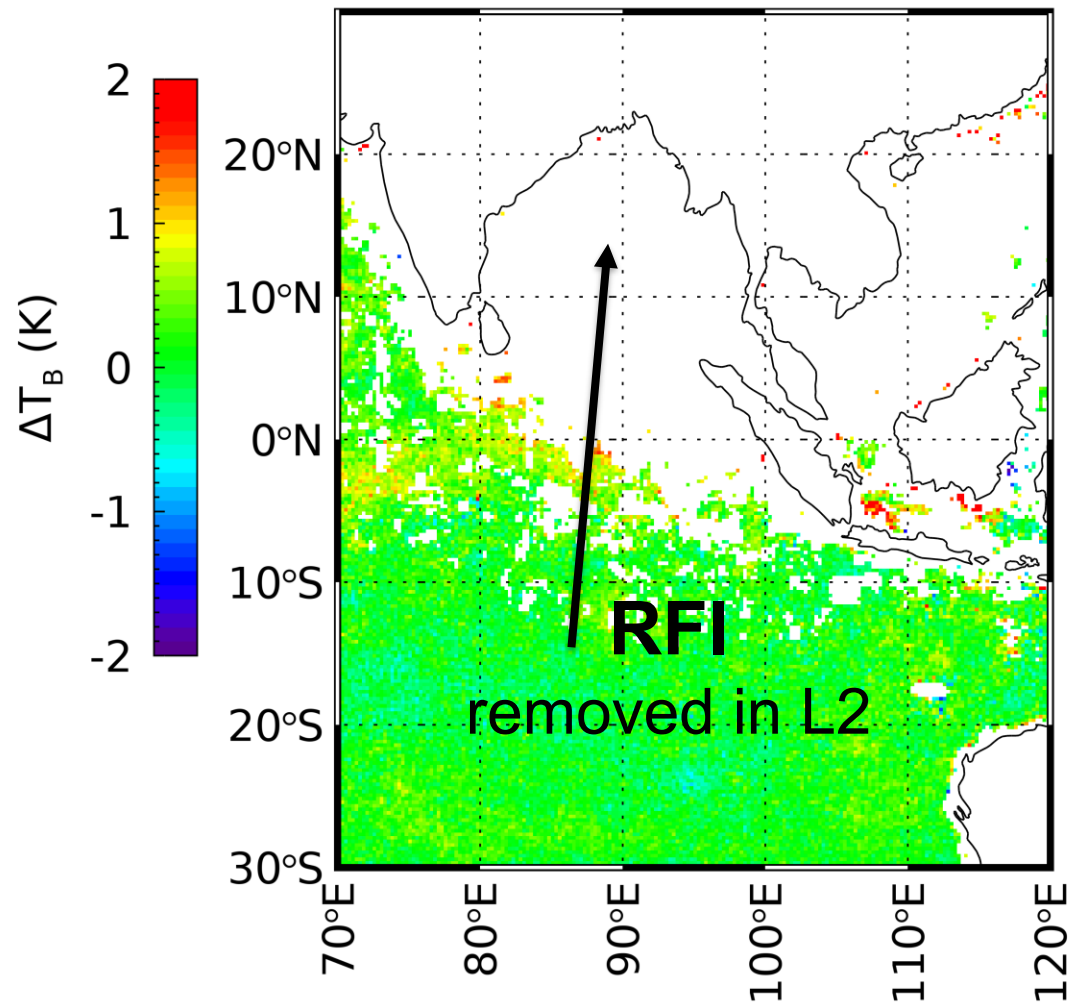
Ocean RFI Detection and Flagging: Flowchart



15 March 2018 RFI flagging applied



15 March 2024 RFI flagging applied



Typical ROC for L3 8-day Time Aggregates

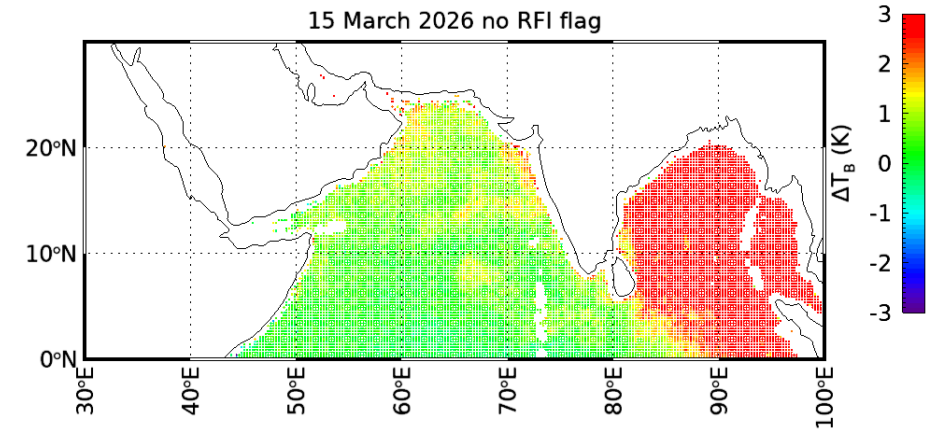
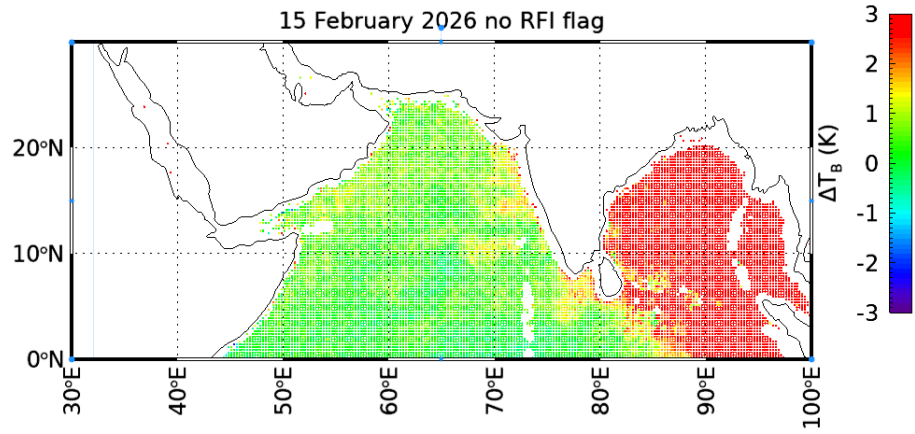
RFI Detection Threshold Θ (K)	2.0	1.0
POD (Bay of Bengal)	97.0	80.6
POD (Mediterranean Sea)	98.8	97.4
POD (Norwegian Sea)	98.6	95.2
FAR	1.8	
$R_{\max} = 60\%$		

Closing Remarks

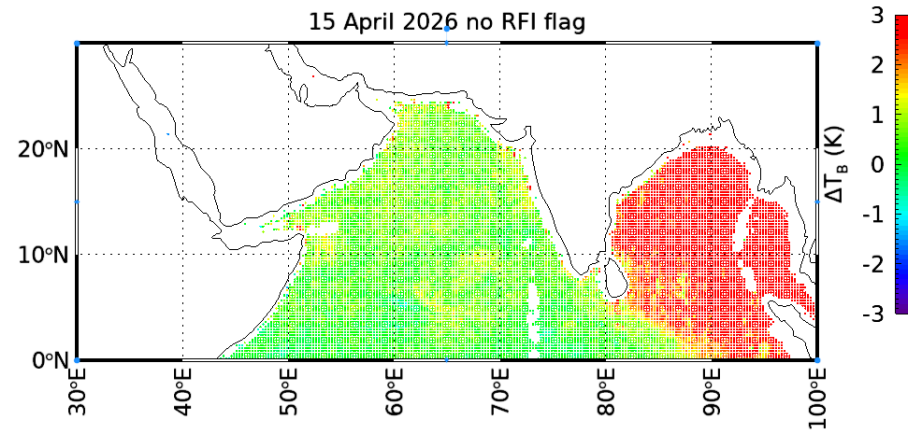
- The RFI detection methods presented are designed to **work for open ocean scenes**.
 - All 3 methods (χ^2 , Fore – Aft, 4th Stokes) have elevated thresholds near geographic interfaces (coast, sea-ice edge) naturally without RFI.
- Evaluation Version 6.3.
 - Available at RSS server: www.remss.com.
 - Level 2C.
 - Flag: QC bit 17.
 - If RFI is detected, SSS is still retrieved.
 - If RFI is detected the observation is not used in spatial (70-km) or temporal (8-day, monthly) average.
 - User has the option to take the RFI flagged data and investigate if the data can be used for scientific purposes.
 - Not encouraged: RFI sources are highly variable (turned on and off, fluctuating power, depend on looking geometry, ...).
 - Level 3 8-day.
 - We keep track of and output the number of RFI flagged observation in each cell.
 - RFI index map: set if the ratio exceeds $R_{\max} = 60\%$.
 - User can easily change.
- Validated Release V7.0.
 - Late 2026.
 - RFI detection and flagging will be the major update.
- T. Meissner + A. Manaster. 2025: Detection and Flagging of Radio Frequency Interference Contamination in SMAP Ocean Observations. J. Atmos. Oceanic Technol., 42, 1585–1600, <https://doi.org/10.1175/JTECH-D-25-0062.1>.

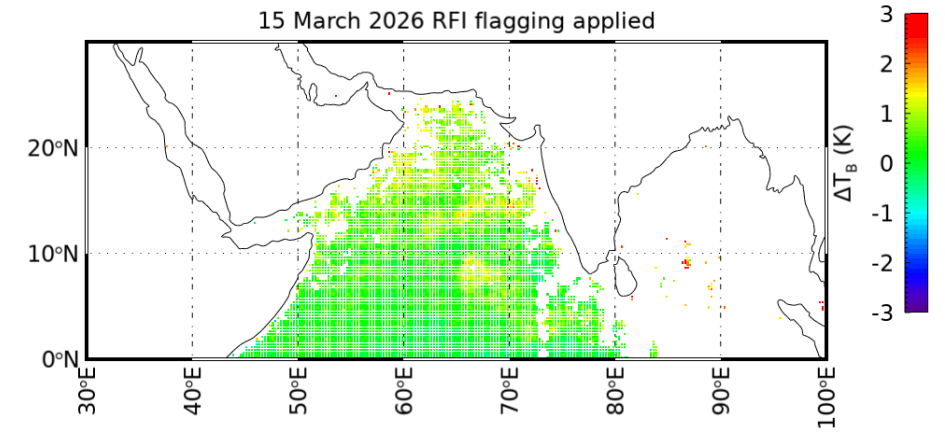
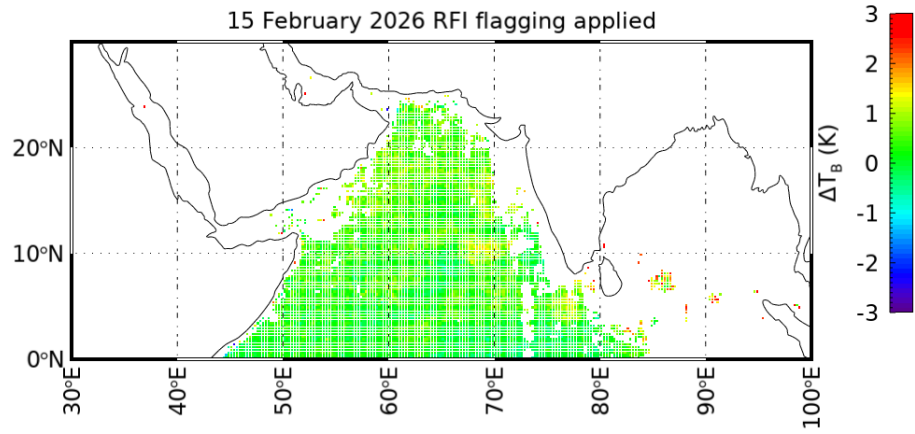
Backup Slides

RFI Level in Arabian Sea 2026

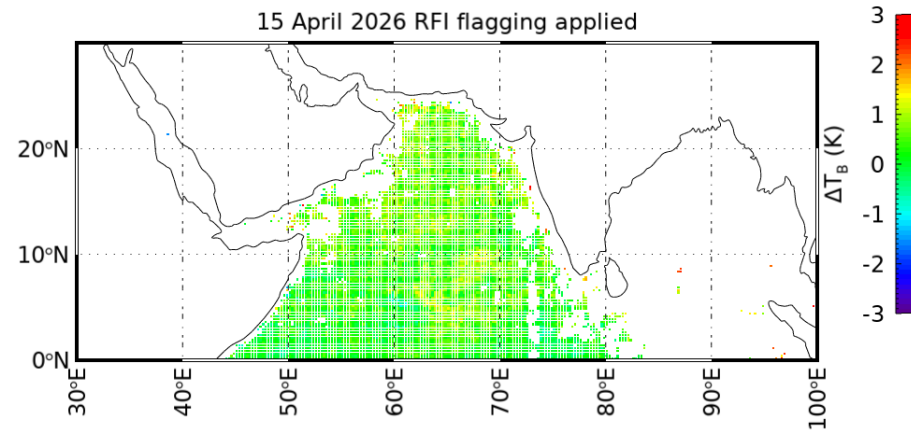


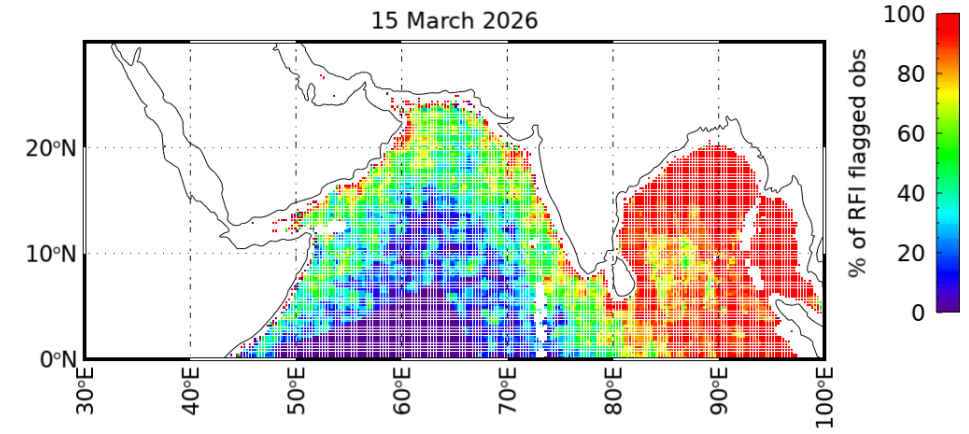
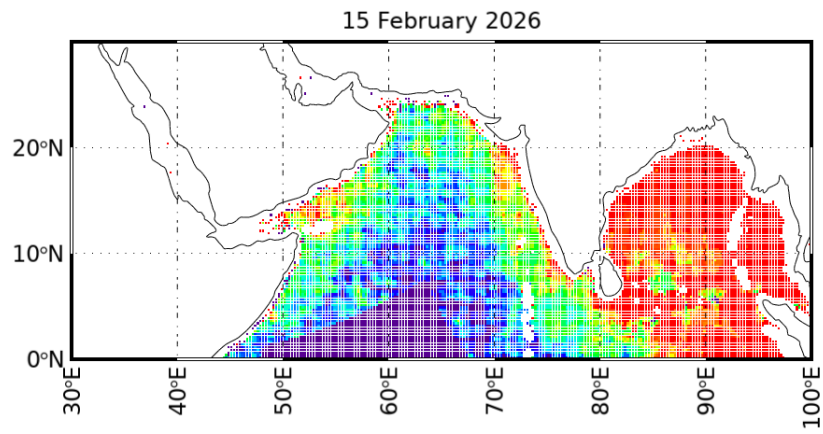
RFI Level in Arabian Sea 2026 without RFI flagging





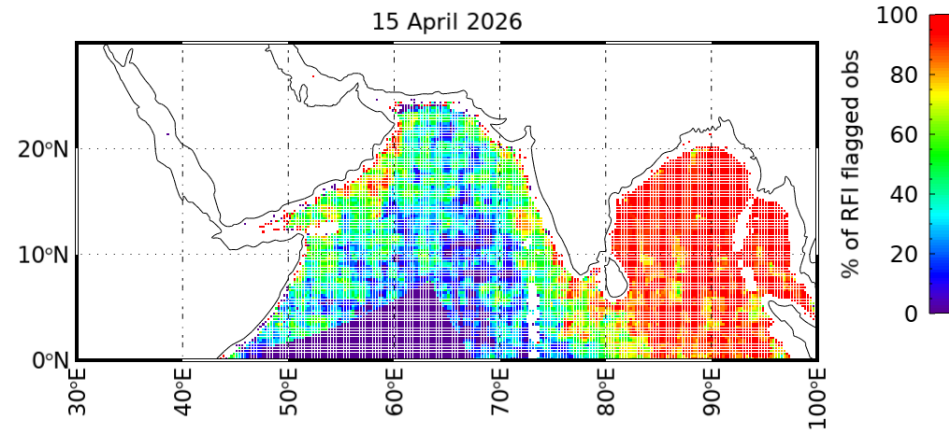
RFI Level in Arabian Sea 2026 with RFI flagging





RFI Level in Arabian Sea 2026

RFI flagged observations



Receiver Operating Characteristics (ROC) for Ocean L2 RFI Detection

