A narrowband absorption approach for ARTS

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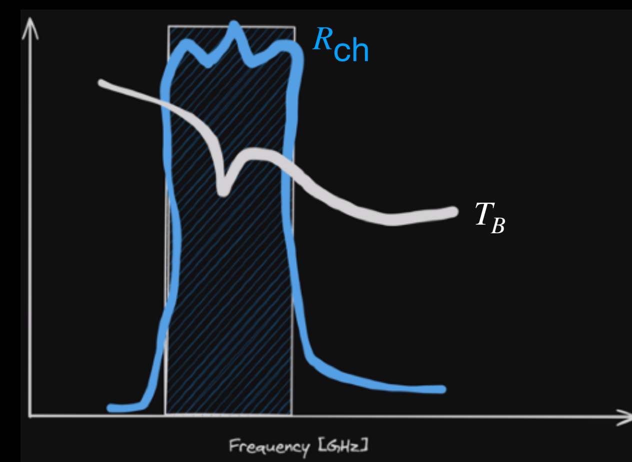
Channel response

$$y_{\text{ch}} = \int_{f_1}^{f_2} R_{\text{ch}}(f) T_B(f)\, \mathrm{d}f$$



$R_{\text{ch}}(f)$ - Spectral Response Function for channel
$T_B(f)$ - Brightness Temperature
f - Frequency
y_{ch} - Channel measurement

In arts we simulate and get Brightness temperatures.
Channels consisting of one or two bands of frequency that contribute to channel value (Weighted with Spectral Response Function).
To simulate an instrument, want the channel values.

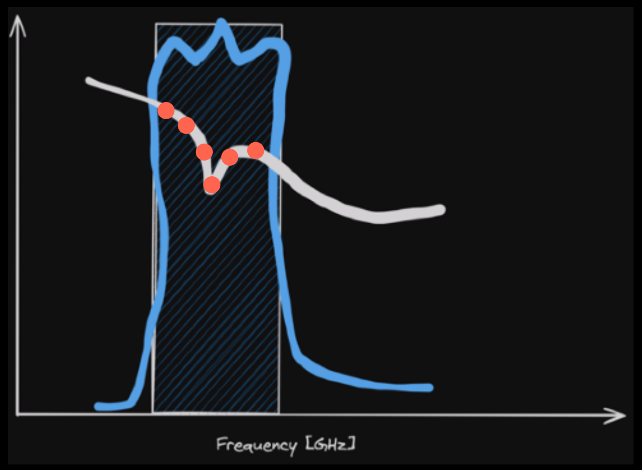
Problem at hand is to include the SRF in our simulations.

Channel response

Average multiple samples

$$y_{\text{ch}} = \int_{f_1}^{f_2} R_{\text{ch}}(f) T_B(f)\, \mathrm{d}f$$

$$\approx \frac{1}{N} \sum_{i=0} R_{i,\text{ch}} T_{B,i}$$

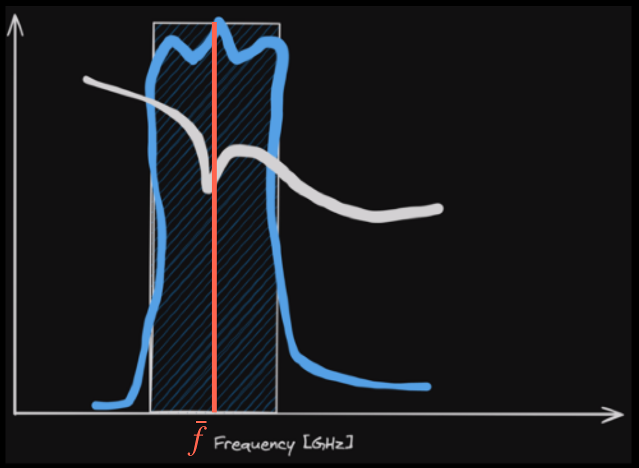


Straightforward way, sample at high enough resolution.
(We are doing something slightly more advanced here to make it more accurate, but beside the point of this presentation).

Capture dip, we manner we might need 10 or 20 samples.
Due to scattering and overhead from loading data, becomes prohibitive for simulating larger observations.
Especially when considering ~ 19 channels, x samples each.
-> Really want to reduce the number of samples.
OUR AIM IS TO GO AS FAR AS POSSIBLE (1 sim per band)

Mid-point

$$
\begin{aligned}
y_{\text{ch}} &= \int_{f_1}^{f_2} R_{\text{ch}}(f) T_B(f) \, \mathrm{d}f \\
&\approx R_{\text{ch}}(\bar{f}) T_B(\bar{f})
\end{aligned}
$$

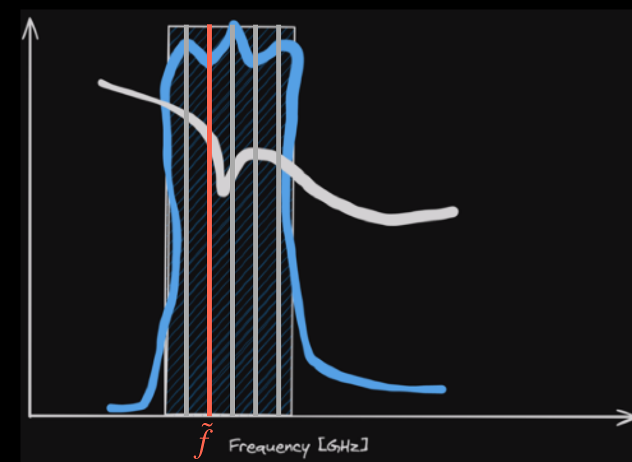


First thought, just take the midpoint.

Representative-frequency

$$y_{\text{ch}} = \int_{f_1}^{f_2} R_{\text{ch}}(f) T_B(f)\, \mathrm{d}f$$

$$\approx R_{\text{ch}}(\tilde{f}) T_B(\tilde{f})$$

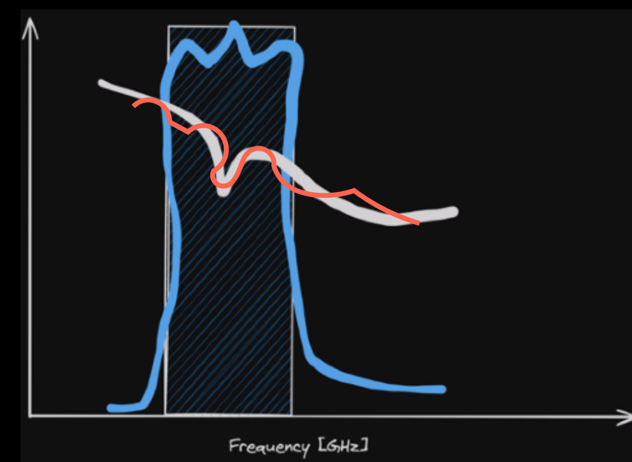


Another idea, by trail and error find the best frequency that represents the band.
Better, but still higher errors than wanted.

Narrow-band model

$$y_{\text{ch}} = \int_{f_1}^{f_2} R_{\text{ch}}(f)\overbrace{F(\alpha(f,p),\ldots)}^{T_B(f)}\,\mathrm{d}f$$

$$\approx F(\tilde{\alpha}(p))$$



Narrow band model paper
(Annette S. Fisher, Sarma L. Rani, 2021)

$F(\ldots)$ - Forward model (ARTS simulation)
α - Absorption
p - Pressure

Can we approximate the RT simulation to represent a full band with 1 sample?

- Operational solvers do this and it seems to work. RTTOV.
- But not directly applicable to how ARTS is working. Absorption and cross-sections to achieve something similar.
- Found a paper that looks at doing this! They call it “Narrow band model based on the absorption coefficient”. Thats where the name is from.

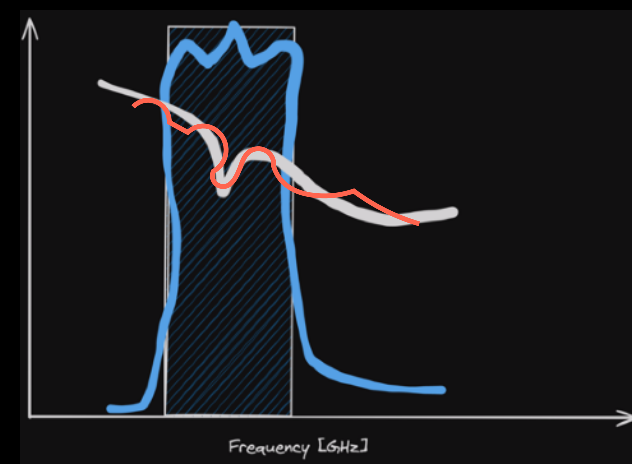
Narrow-band model

$$y_{\mathrm{ch}} = \int_{f_1}^{f_2} R_{\mathrm{ch}}(f)\overbrace{F(\alpha(f,p),\ldots)}^{T_B(f)}\,\mathrm{d}f$$

$$\approx F(\tilde{\alpha}(p))$$

$$\alpha(f,p) = n_1 x_1(f,p) + n_2 x_2(f,p) + \ldots$$

$$\boxed{\tilde{\alpha}(p) = \int R_{\mathrm{ch}}\alpha(f,p)\,\mathrm{d}f = n_1\int R_{\mathrm{ch}}x_1(f,p)\mathrm{d}f + n_2\int R_{\mathrm{ch}}x_2(f,p)\mathrm{d}f + \ldots}$$

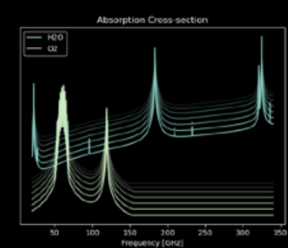


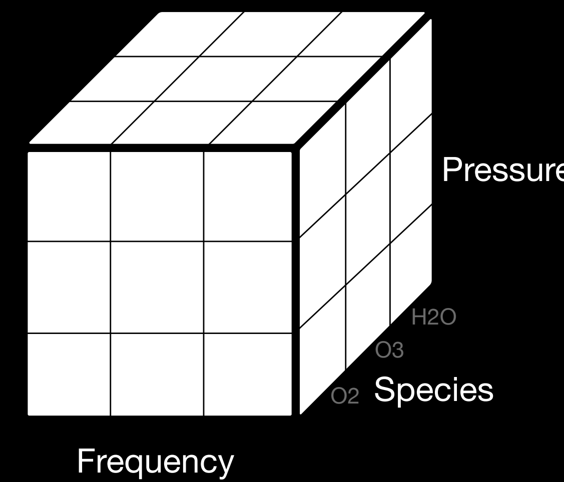
x_i - Absorption cross-section for species i
n_i - Number density for species i

- In ARTS, the absorption is generated by multiplying VMR/number density and abs. cross-sections for different species.
So we have the cross-section to play with.
- Looking at it, one might start with wanting to average the cross sections over the frequency bands for each species.
- ARTS actually has a mechanism that makes this quite straight forward.
-> Lookup-table

Absorption Cross-section Lookup Table (4D tensor)

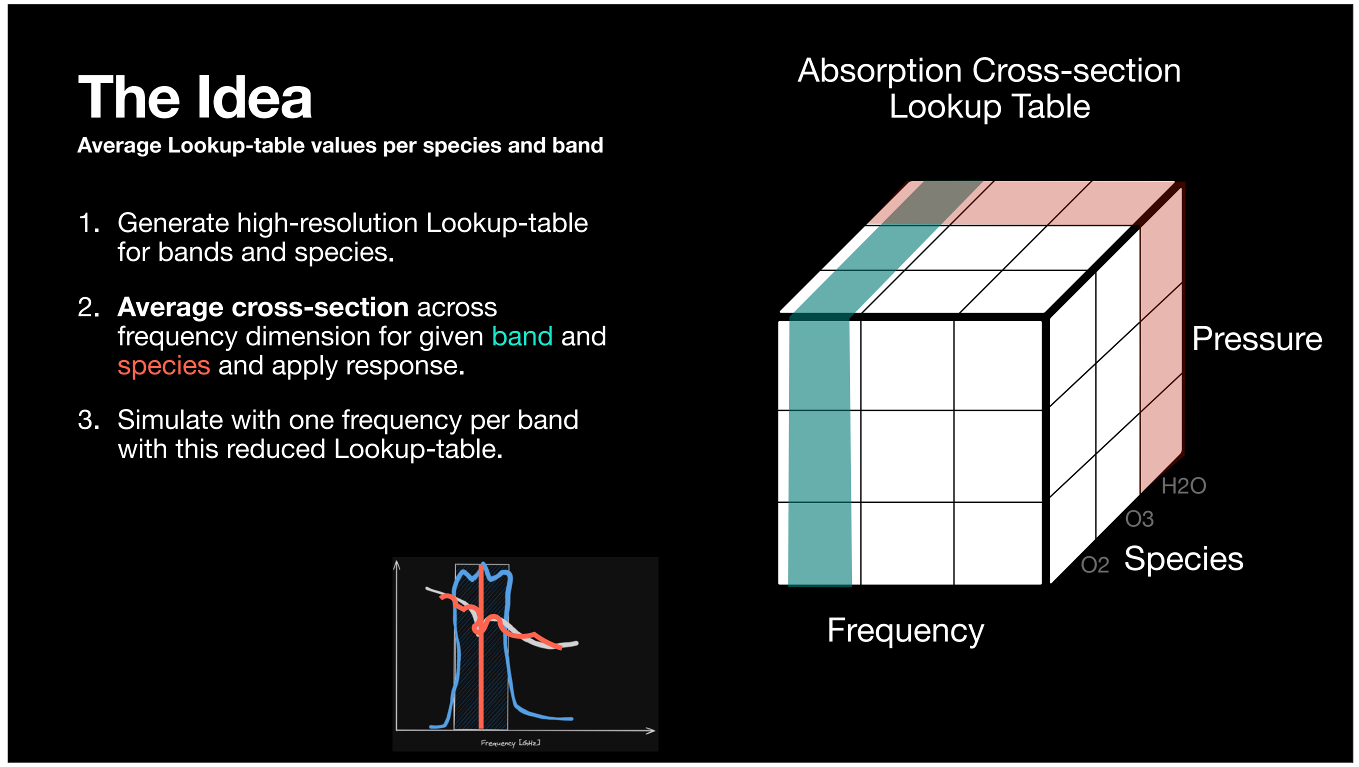
- `ws.abs_lookupCalc()`
- Used to pre-calculate absorption cross-section for frequency and pressure grid to improve simulation speed.
- See Section 6.6 in the “ARTS User Guide”





(Also a temperature dimension)

ARTS can pre-calculate the absorption cross-sections in a Lookup table.

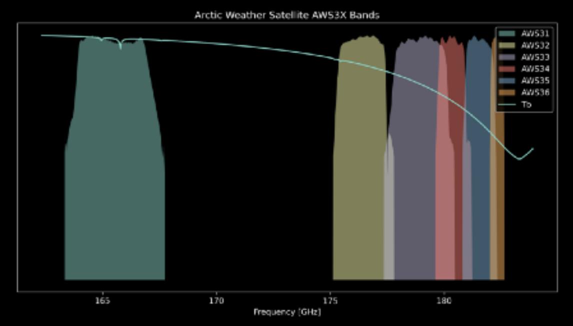


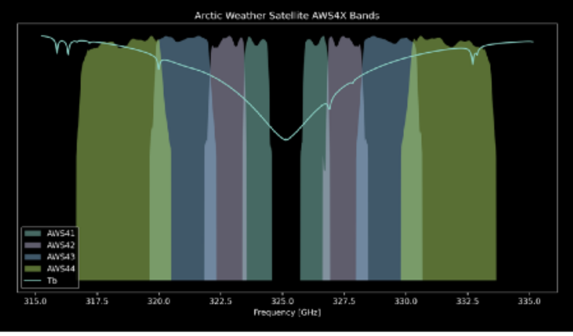
The main idea: modify this lookup table.

Evaluation
Arctic Weather Satellite

19 channel radiometer

Channel group	Number of channels	Frequency range
AWS1X	8	50.3 - 57.3 GHz
AWS2X	1	89.0 GHz
AWS3X	6	165.5 - 182.3 GHz
AWS4X	4 (DSB)	324.0 - 331.8 GHz

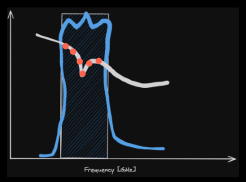




Introduce AWS…

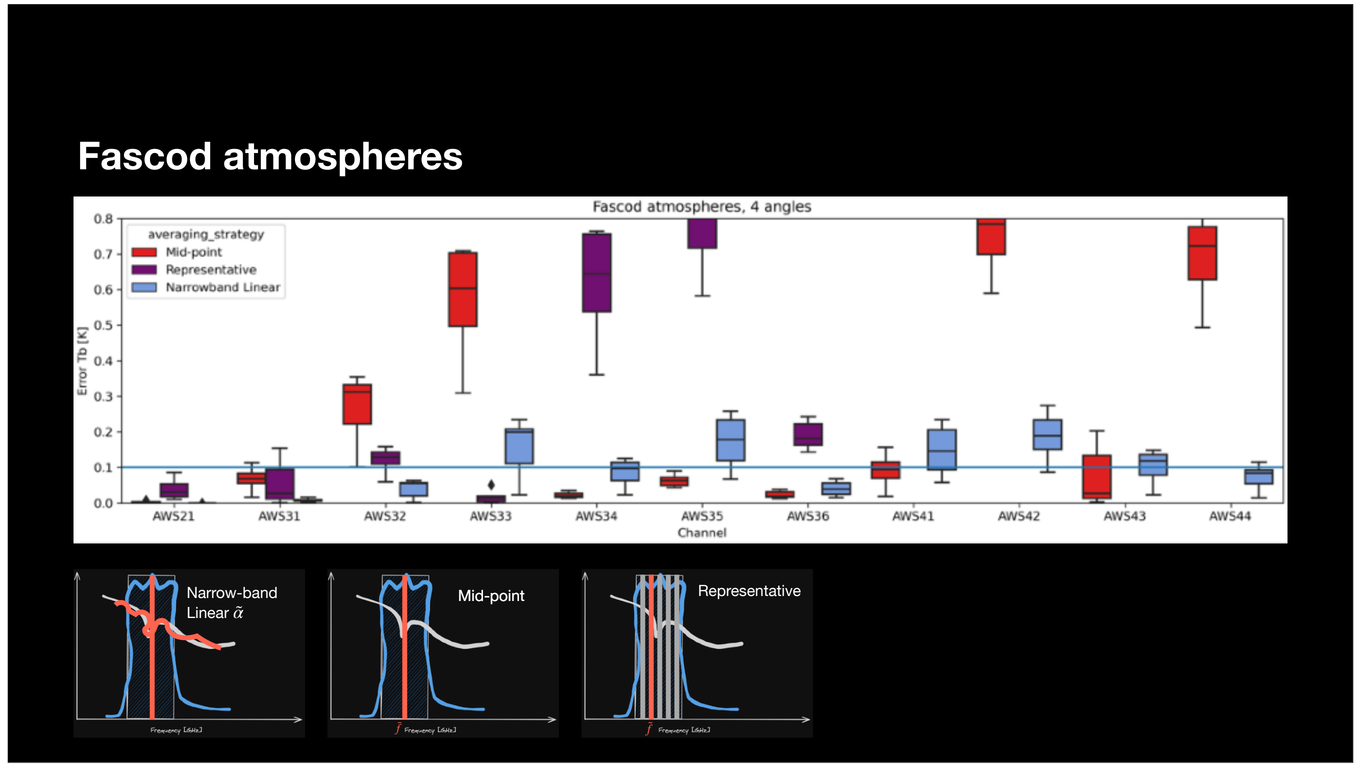
Evaluation

- Run tests for:
  - 5 atmospheres from the Fascod set
  - 4 beam angles



- As a baseline value for each band, average of 30 samples per band.
- For each channel, error is absolute difference between mean of 30 baseline samples and the value from narrow band model.

```
error = np.abs(y_banded - np.mean(y_monochromatic))
```



Introduce plot

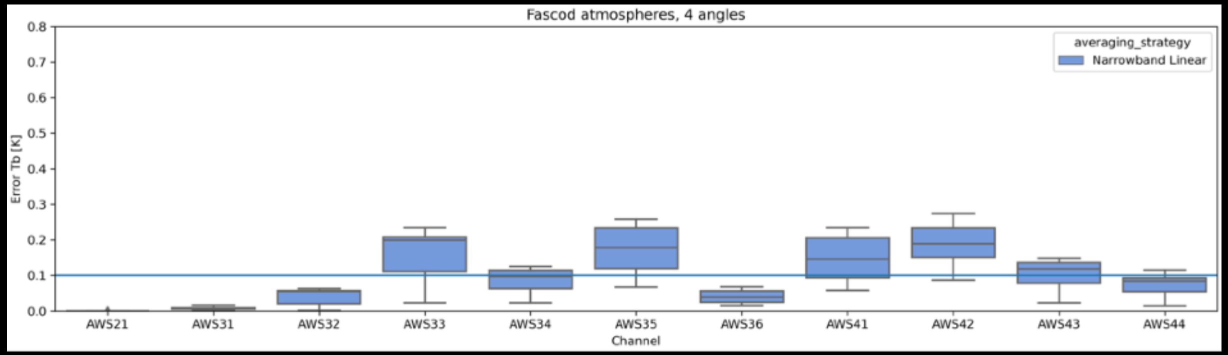
Box shows quartiles (first median 3rd), whiskers extend to points that lie within 1.5 IQR of upper and lower quartile

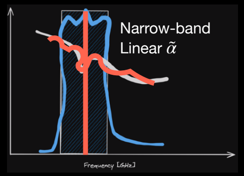
Used 0.1 K as a threshold. (Clear sky atmosphere, around this magnitude of error we can expect from other discretisation such as atm. Layers and streams)

Mid-pint is clearly worse than the alternatives (except for AWS36, where it is the best)

-> Focus on NB-Linear

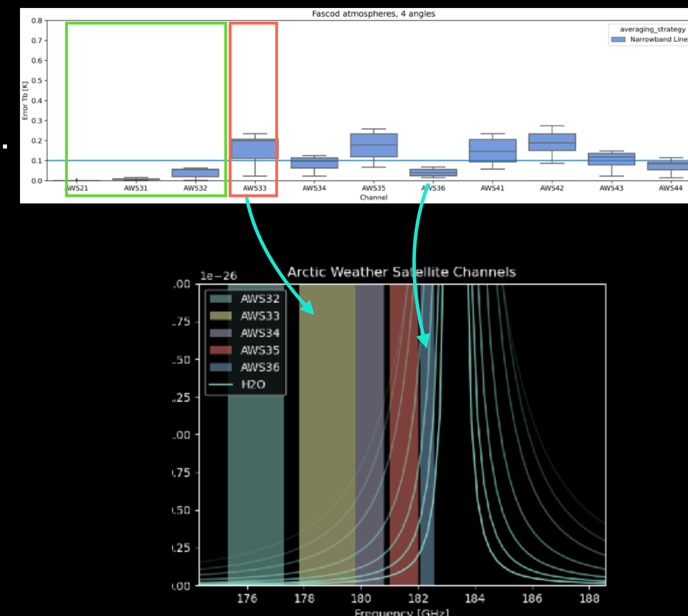
Fascod atmospheres





Log averaging
Motivation

- Good: AWS21, AWS31, AWS32.
- Bad: From AWS33 and on.



Good results up until AWS33 (set a threshold error of 0.1K).
- But getting mixed results after AWS33.
- Can be understood by looking at bands and nearby H_2O absorption line.
- AWS33 is getting more of the exponential increase in absoprtion.
- But AWS36 is getting even more? Yes, but the band is much more narrow.

-> Log averaging

Log averaging

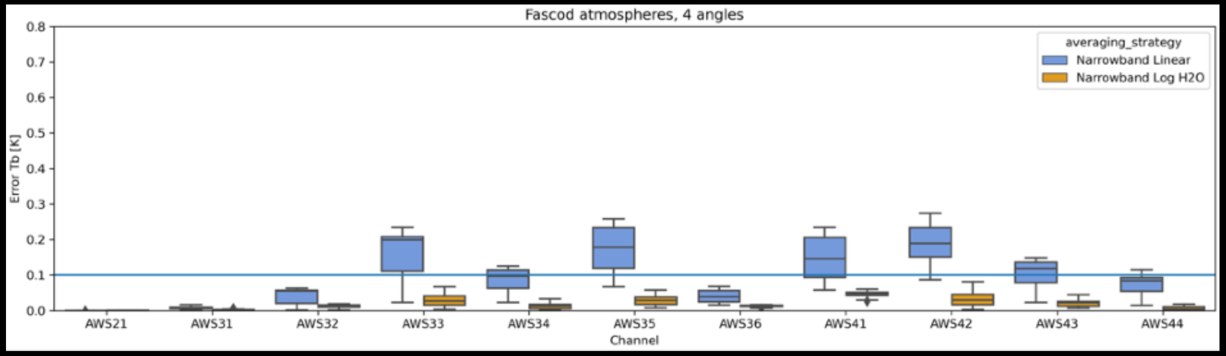
- Use geometric-averaging?

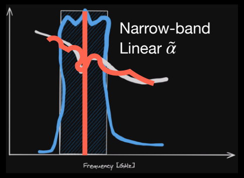
$$\bar{x} = \exp\left(\frac{1}{N}\sum_{i=0}^{N} \log x_i\right)$$

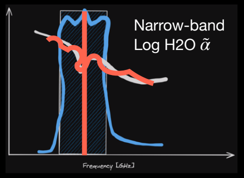
ch_name	averaging_strategy	Error Mean [K]	Error Max [K]
AWS33	Narrowband Linear	0.15	0.22
	Narrowband Log H2O	0.03	0.06
	Narrowband Log H2O O2 N2	0.03	0.06

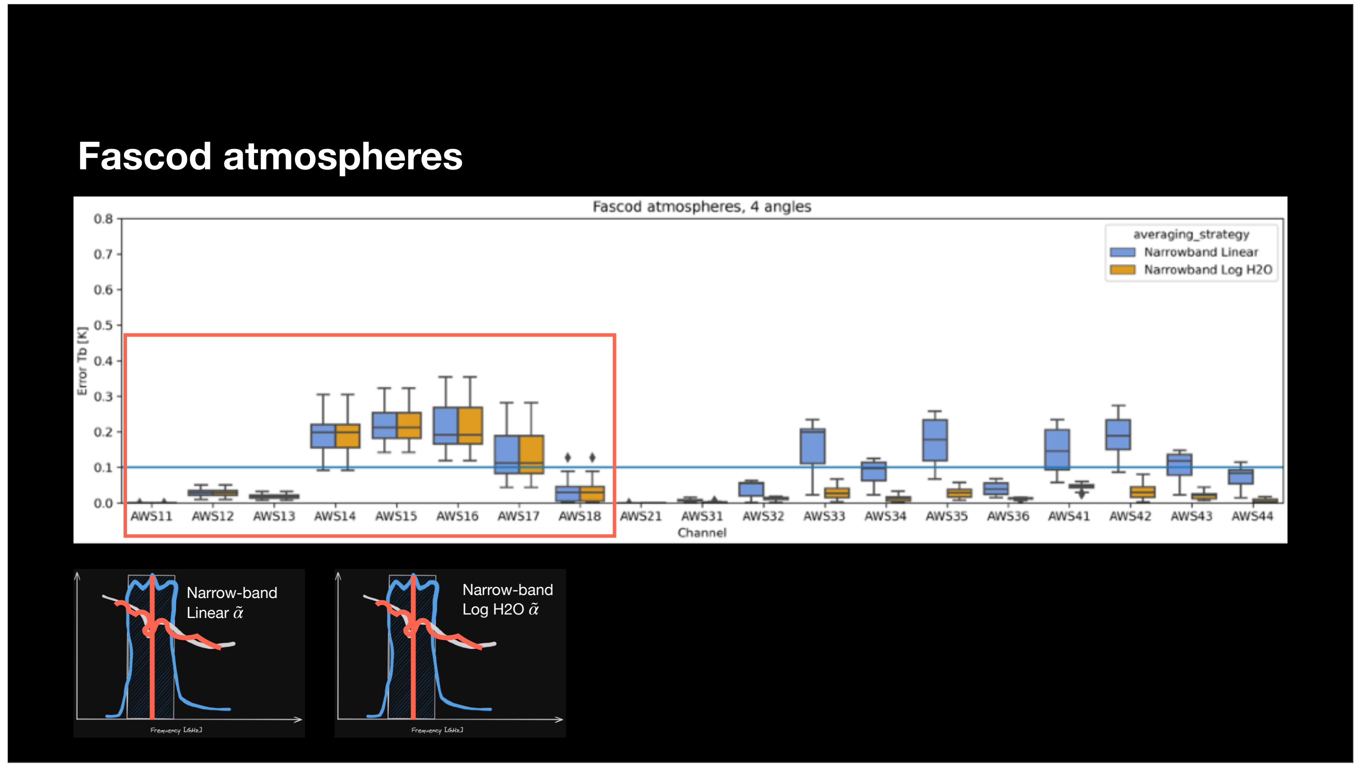
Average the Lookup-table with this exponential changes in mind?
- For AWS33, we see lower errors when performing “log-averaging” on H2O in the lookup-table.

Fascod atmospheres









These channels are not of interest for us at the moment, so we've decided to skip these.
AWS1X, O2. Log treatment better results for some channels but worse for others. Ways to go forward here.

Evaluation

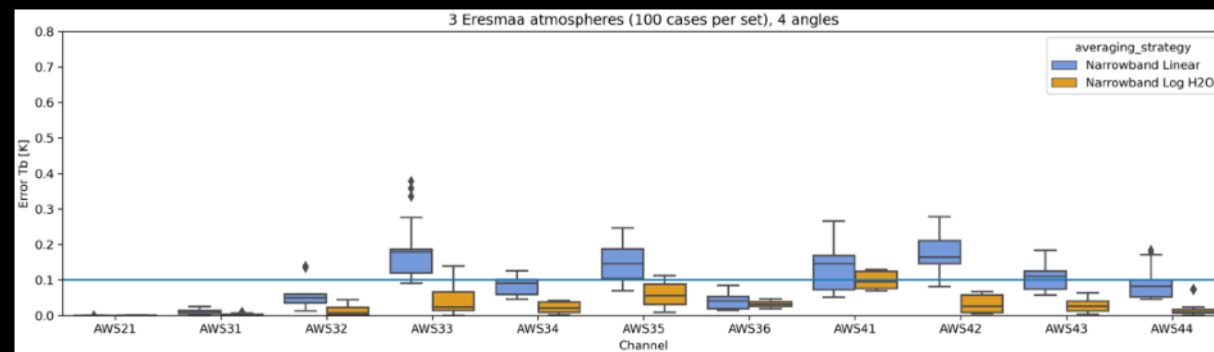
Eresmaa atmospheres

- Representative atmosphere profiles covering a broad range of cases.
- 4 angles * 3 Eresmaa sets * 100 cases = 1200 cases per channel.

Previously we simulated with Fascod atmospheres which has representative atmosphere profiles for a set of regions and seasons.

To get a more exhaustive results, we also compared error for many different Eresmaa cases; set atmosphere profiles for that aim to capture the more of distribution of possible profiles we might see.

Eresmaa atmospheres



See slightly higher errors. Bit higher for 41.
See similar trend with treating H2O with log-averaging.

Summary

- Modify ARTS' absorption cross-section lookup-table with averaging per band and species.
- Treat H2O with log-averaging
- Allows 1 sample per band
- Errors of 0.1 - 0.2 K compared to baseline
- Error of ~0.5 K for AWS1X group (50 GHz - 57 GHz)
- Using it now to simulate AWS 2X, 3X, 4X