International Space Weather Summer Camp 2022: How to turn measurements into an analytical model – at the example of VLF data

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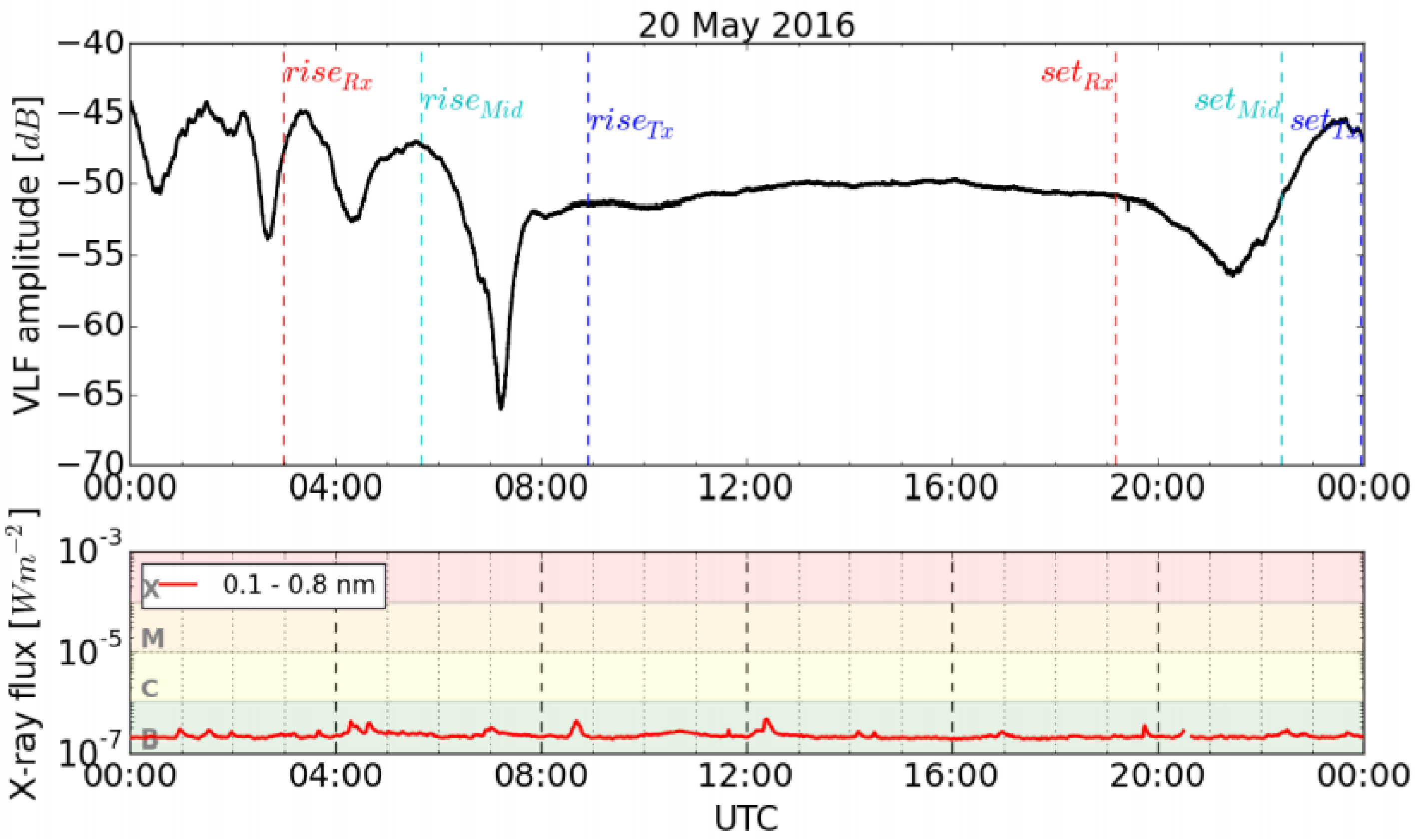
VLF measurements

Characteristics of VLF amplitudes:

- Diurnal variations
  -> dependent on solar irradiation
- Seasonal variations
- Spatial differences
- Sudden Ionospheric Disturbances (SIDs)
  -> caused by solar flares



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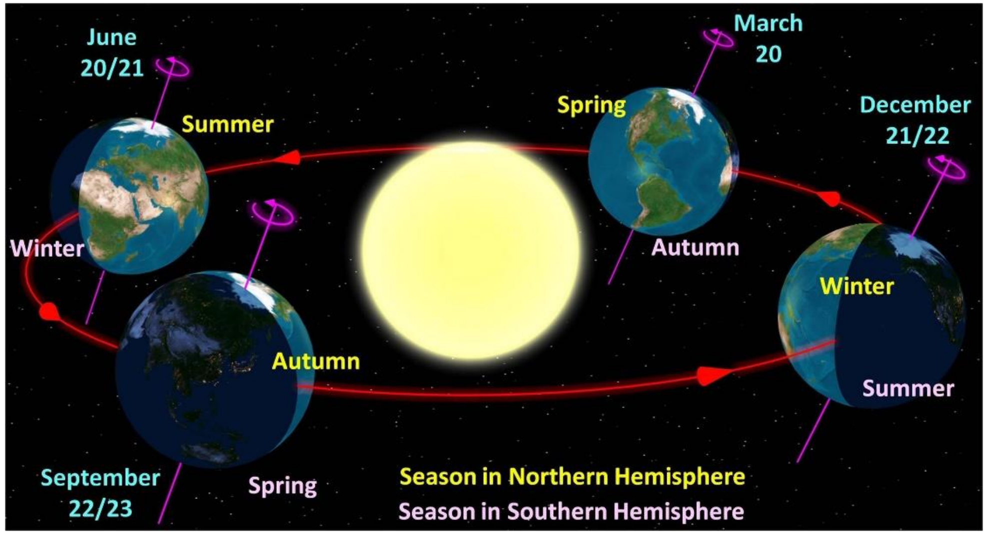

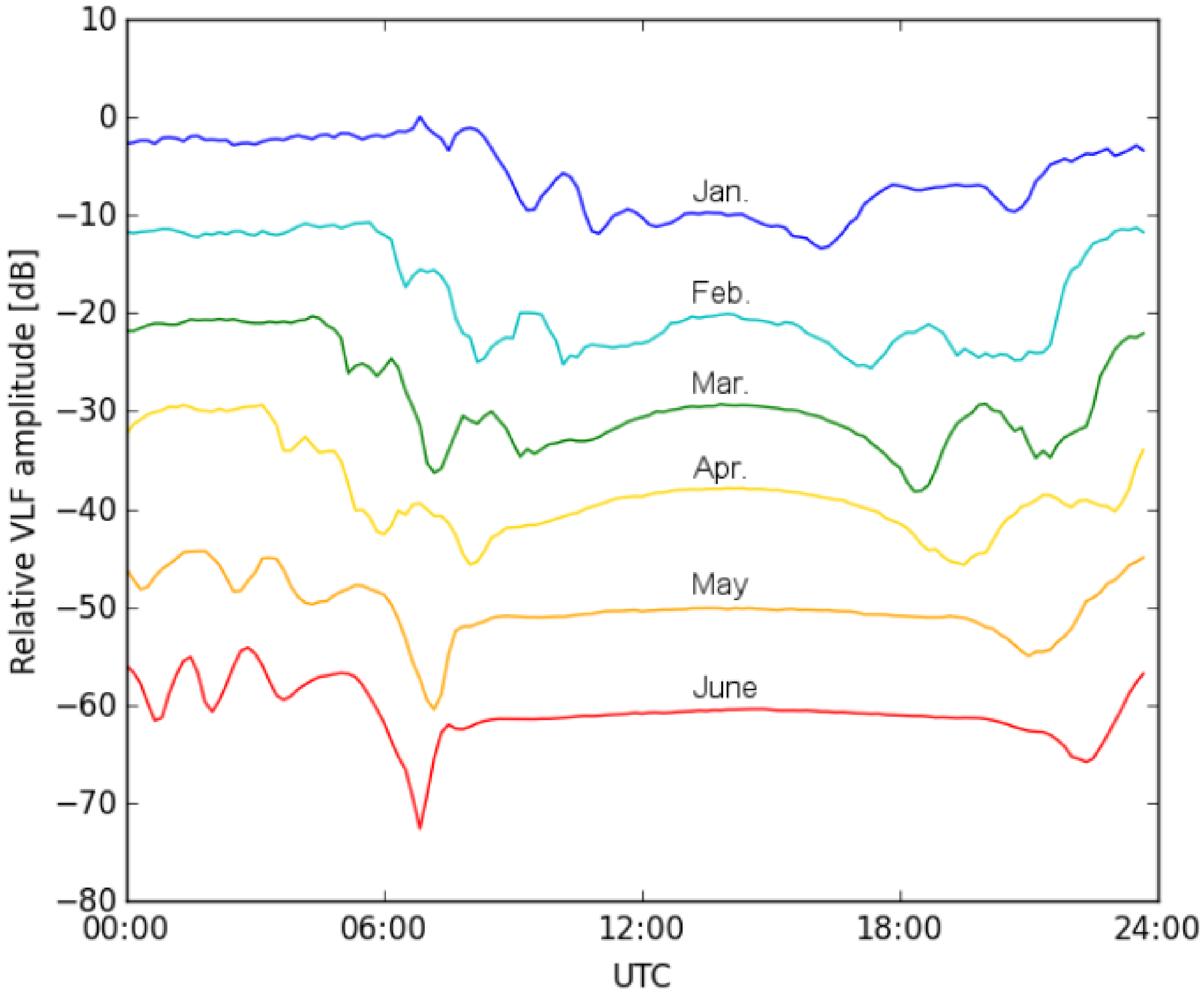

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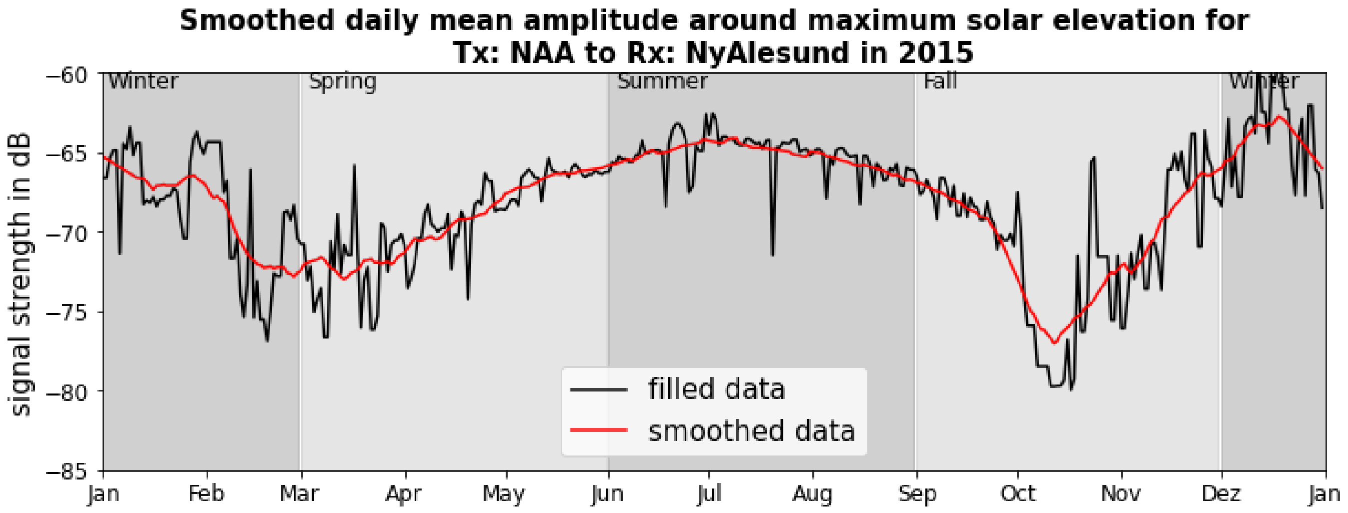

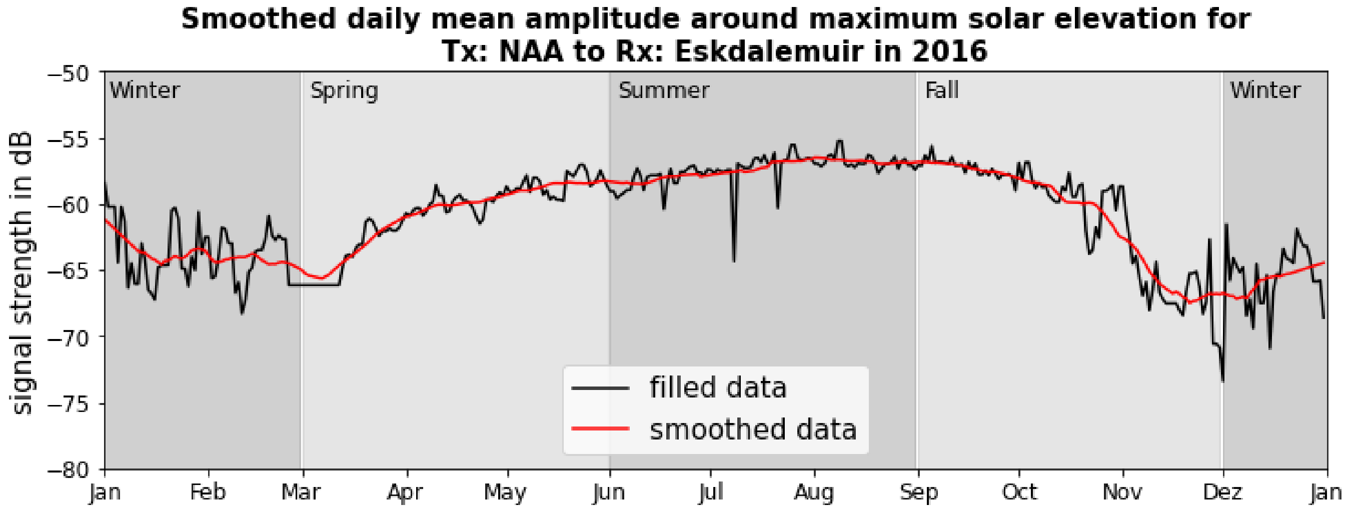

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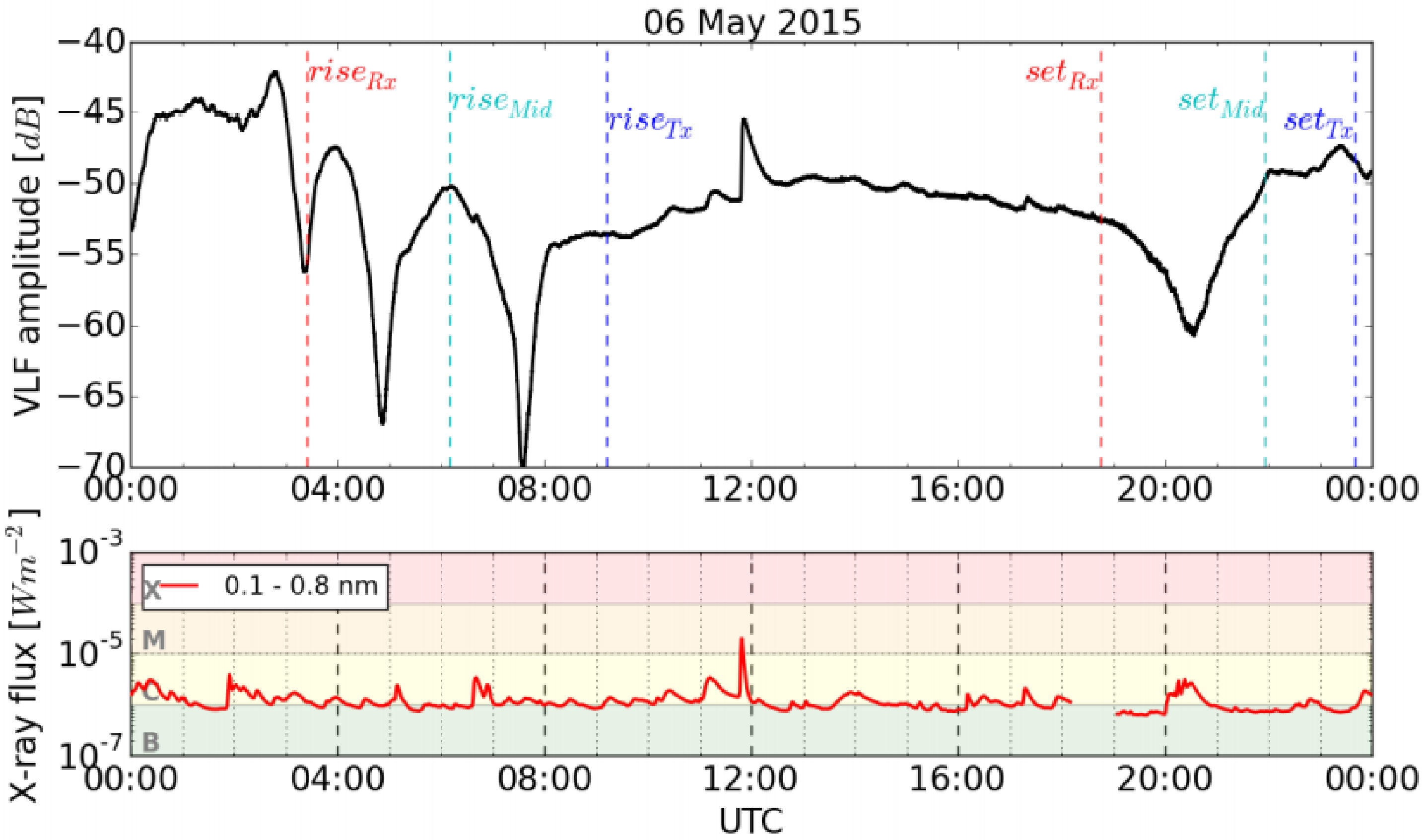


The 2nd dimension

Previously…

There's actually just one ongoing time "indexing" the measured data, but!

We used two dimensions for plotting:

- ToD (time of day)
- DoY (day of year)

The distinction is motivated by physical effects:

- Earth's rotation about the own axis
- revolution of the Earth around the Sun

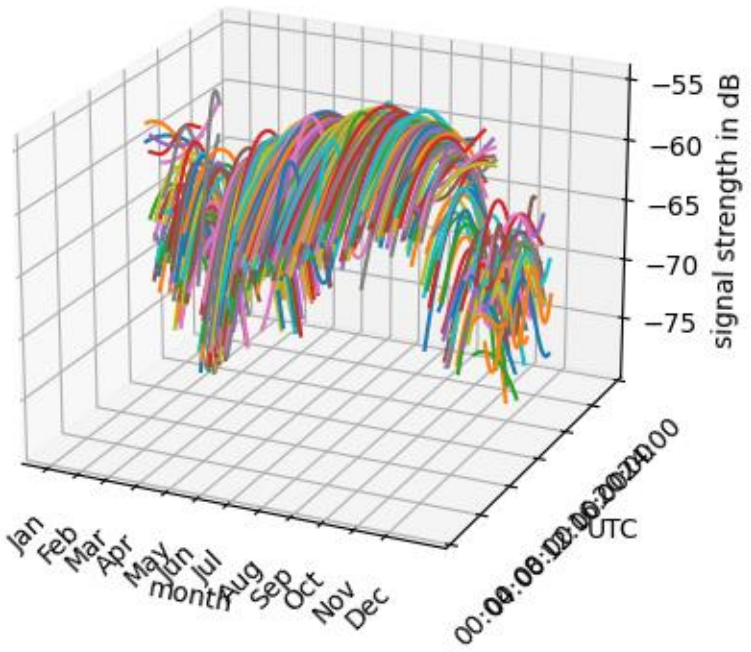
With major influence unveilling periodicities:

- diurnal variation
- seasonal changes

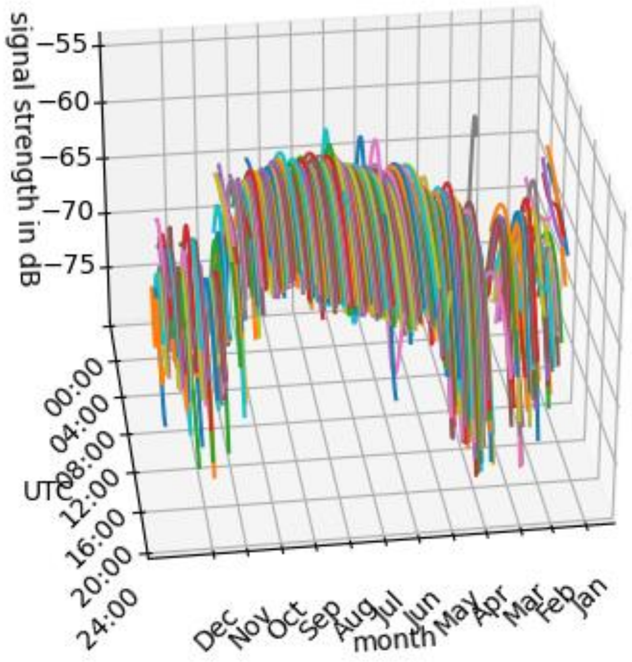
What we've done so far:

- fit a curve to a(ny) day‘s "sunlit" part of data
- average/filter or fit the zenith value measurements

Previously…



−55
−60
−65
−70
−75
signal strength in dB
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
month
UTC



signal strength in dB
−55
−60
−65
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00:00
04:00
08:00
12:00
16:00
20:00
24:00
UTC
Dec Nov Oct Sep Aug Jul Jun May Apr Mar Feb Jan
month

Modelling

Model = simplified description

Observation and analysis:

- Goal: cutting the big (complicated / not fully understood) relation into smaller portions
- Idea: try to find fundamental influences and the corresponding periods
- Key: both investigated influences are basically independent
  → 2D plot is meaningful and separation is reasonable

Classifications:

- qualitative vs. quantitative
- mathematical vs. simulative
- analytical vs. algorithmical
- axiomatic vs. empirical
- …

The plan

Types of models:	*Example usage:*
• physical (full case is rare)	
→ desire	*daytime windows*
• physical-statistic (quality founded by known relations, quantity estimated via observations)	
→ works well if there are no other big ingredients	*daily variation*
• statistic (no clues on inter-dependencies)	
→ other influences indistinguishable	*seasonal change*
➔ weak isolated statement but door to comparative analysis	*(wheather?)*

How to glue together two "independent" models?

- (linear) regression with two variables → possibly restricted to additive functions like $f(u,v) = au + bv^2$

- fit the smaller period for every instance with the same ansatz → set of parameters $a, b, c, \ldots$
- fit the parameters over the larger period ➔ adjust the smaller period's law

Tasks

- plot each parameter of your ToD fits varying with DoY
- calculate fitting curves for these parameter data
  → What progression could/should be assumed over the year?

- recalculate the ToD fits with the adjusted parameters
- visually compare a new ToD fit with the original fit and the underlying measurements data
  → How are "outage" days tackled?

- plot the obtained ToD-DoY surface/colorplot, respecting the ToD curve‘s model restrictions
- determine the surface values along the zenith curve and match raw, smoothed and approximate values
  → Where are all the outliers gone?