

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

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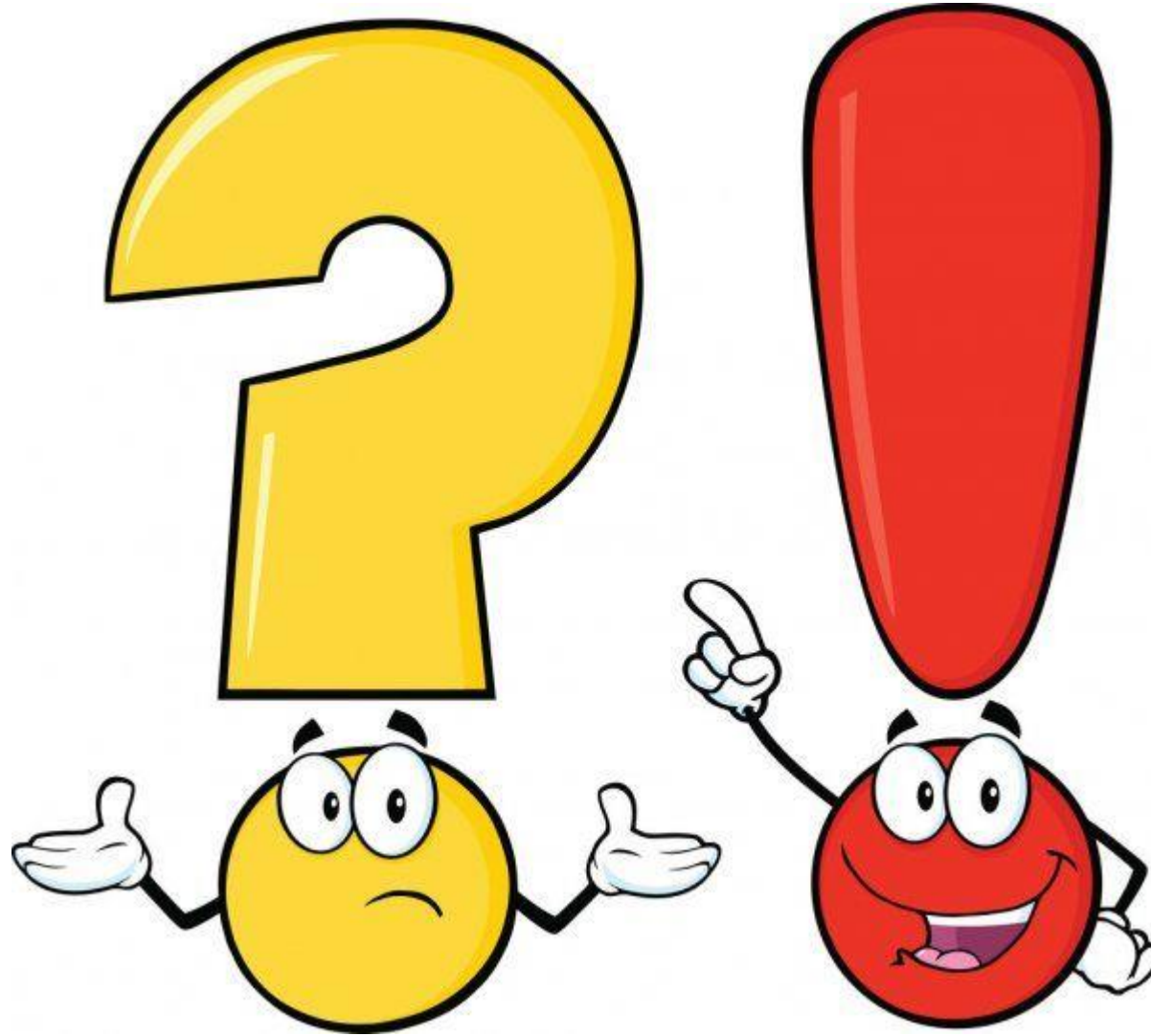
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A large, curved image of the Earth from space occupies the right half of the slide. It shows the blue of the oceans, the green of the continents, and the white of the clouds. The curve of the horizon is visible at the top.

Knowledge for Tomorrow

# Introduction



# Outline

- Python
- radio measurements
- daily variation
- approximation of curves
- seasonal changes
- the second dimension
- application checks...



# Python?!





# What is Python?

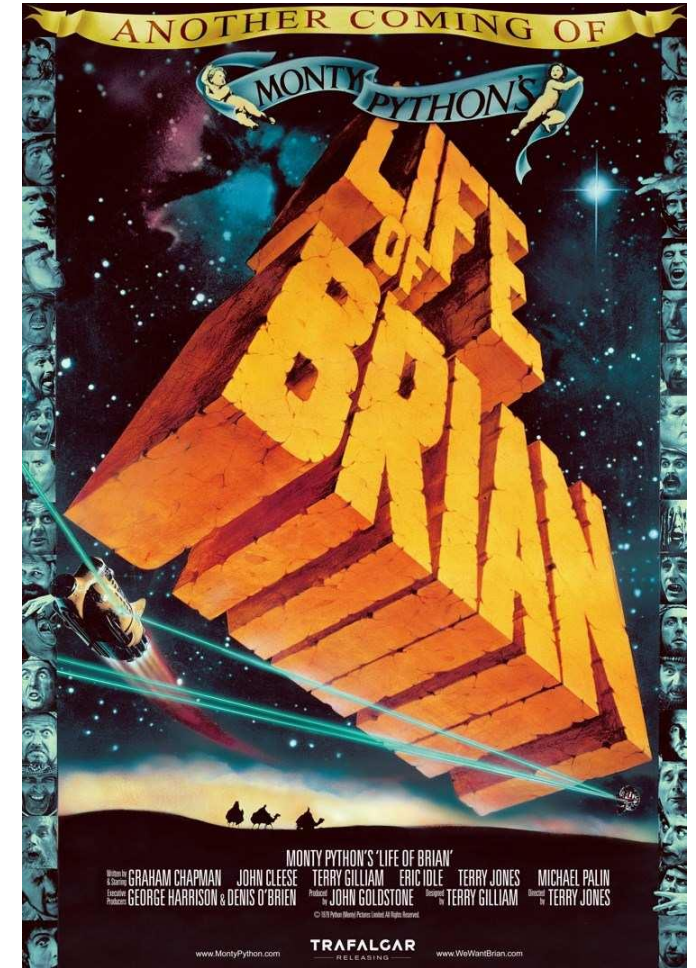
A snake – often quite long,  
but unrelated to what we have in mind





# What is Python?

A comedy group – indeed eponymous for the first release in 1991 of the meant **programming language**



# The Zen of Python

- Beautiful is better than ugly.
- Explicit is better than implicit.
- Simple is better than complex.
- Complex is better than complicated.
- Flat is better than nested.
- Sparse is better than dense.
- Readability counts.
- Special cases aren't special enough to break the rules.
- Although practicality beats purity.
- ...
- There should be one-- and preferably only one --obvious way to do it.
- ...
- If the implementation is hard to explain, it's a bad idea.
- ...



# Key features

- free
- open-source
- platform-independent
- high-level
- attachable to Java and C/C++
- readable
- short
- modular
- interpreted and/or compiled
- interactive
- object-oriented, functional, structured, scripting
- **dynamic** data typing
- multiple assignments or return values
- automatic garbage collection
- arbitrary precision
- positional, keyworded, optional arguments
- all **public**, nothing private

**Beware:** Some inconsistencies between versions 2 (outdated) and 3:

- `print x` vs. `print(x)`
- `/` is now always float (no longer type-dependent as in C), and `//` denotes integer division





# A tool for doing science

Do you know



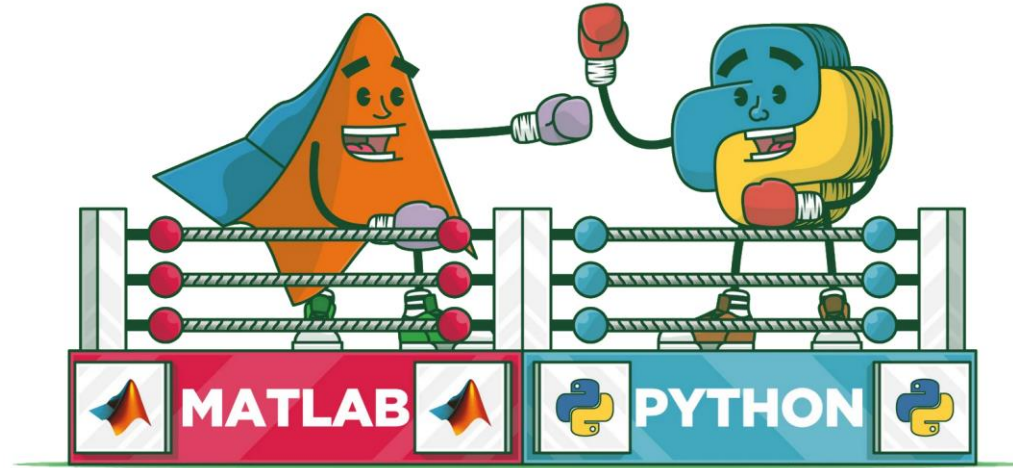
the (self-proclaimed) language of technical computing?



Python may serve as a similar programming language with huge standard library and computation environment or visualisation through additional packages, inspired by natural speech and mathematical notations.



# Notable differences



Functionality:

Access:

built-in  
script- / function-based

import packages  
namespaced / objectified

Comments:

Names:

%  
length(), disp()  
function, elseif

# or ""  
len(), print()  
def, elif

Whitespace:

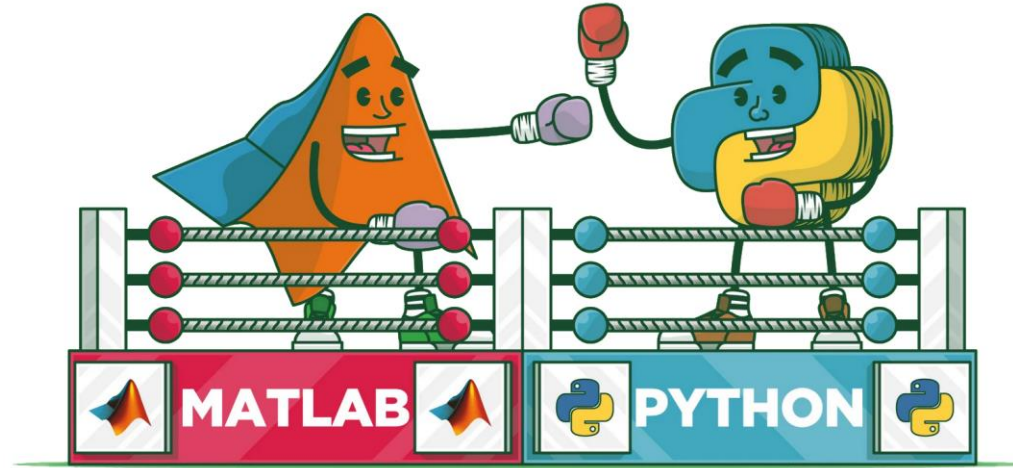
Assignment:

ignored  
copy

semantic  
view



# Notable differences



Previous result:

ans

—

Power:

$x^2$

$x^{**2}$

Logic:

&, |, &&, ||, ~

and, or, not

Matrix multiplication:

\*

@ or dot()

\*

Element-wise multiplication

.

\*

multiply

Evaluation:

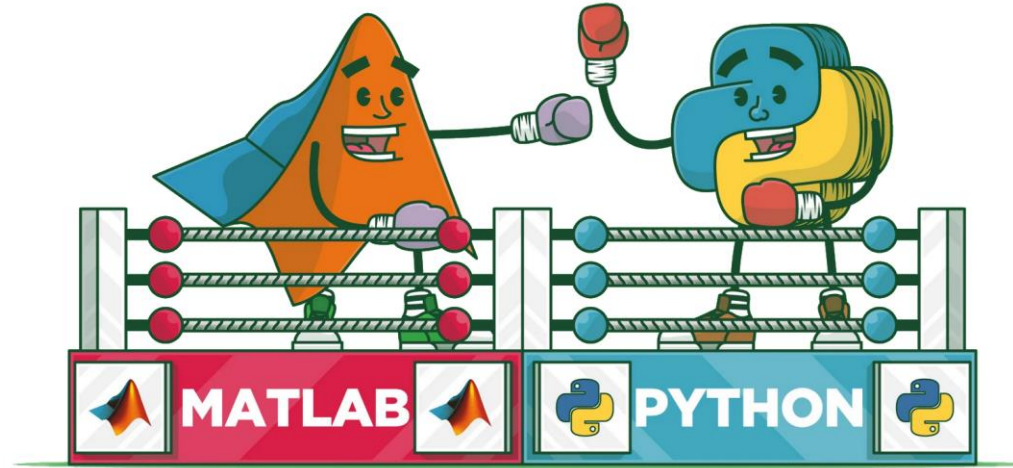
$A \setminus b$

solve(A,b)





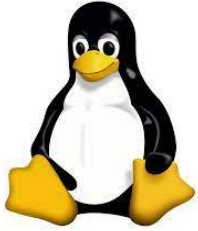
# Notable differences



Index:	$a(i)$	$a[i]$
First:	1	0
Last:	end	-1
Upper bound:	inclusive	exclusive
Slice sub:	$a(1:n)$	$a[0:n]$
Create range:	$m:n$	$\text{range}(m, n+1)$
Extension:	arbitrary assignment	append only



## Where to get?



Included in many distributions (even with IDE), so don't worry.  
Make sure to use python3 and not python2.



WinPython (portable)      <https://github.com/winpython/winpython/releases>



Anaconda (installer)      <https://www.anaconda.com/products/individual#Downloads>  
Available for Mac/Win/Lin.



# Experiencing Python

## Basics

- Spyder environment
- console use
- variables and types
- lists and tuples
- scripts and programs
- conditions and loops
- string processing



**SPYDER**

The Scientific Python Development Environment



DLR

## NumPy

- array, matrix
- arange, linspace
- operations and functions
- indices and slices
- variable access
- solve



[numpy.org/doc/stable/reference/](https://numpy.org/doc/stable/reference/)

## Matplotlib

- figure and axes
- plot and plot3D
- limits



[matplotlib.org/stable/py-modindex.html](https://matplotlib.org/stable/py-modindex.html)

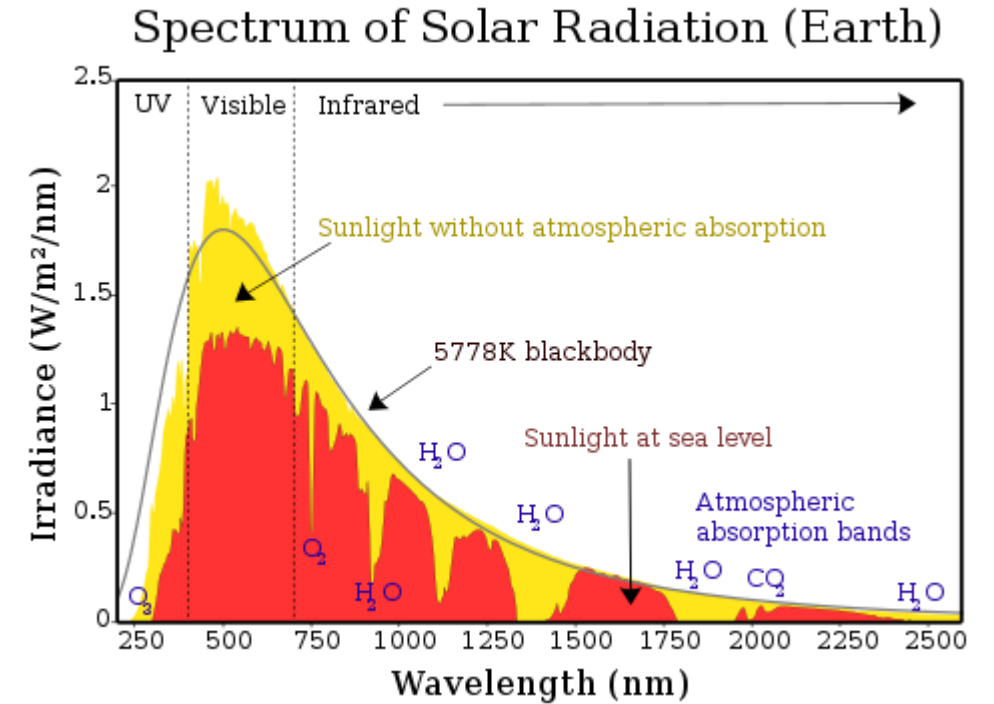
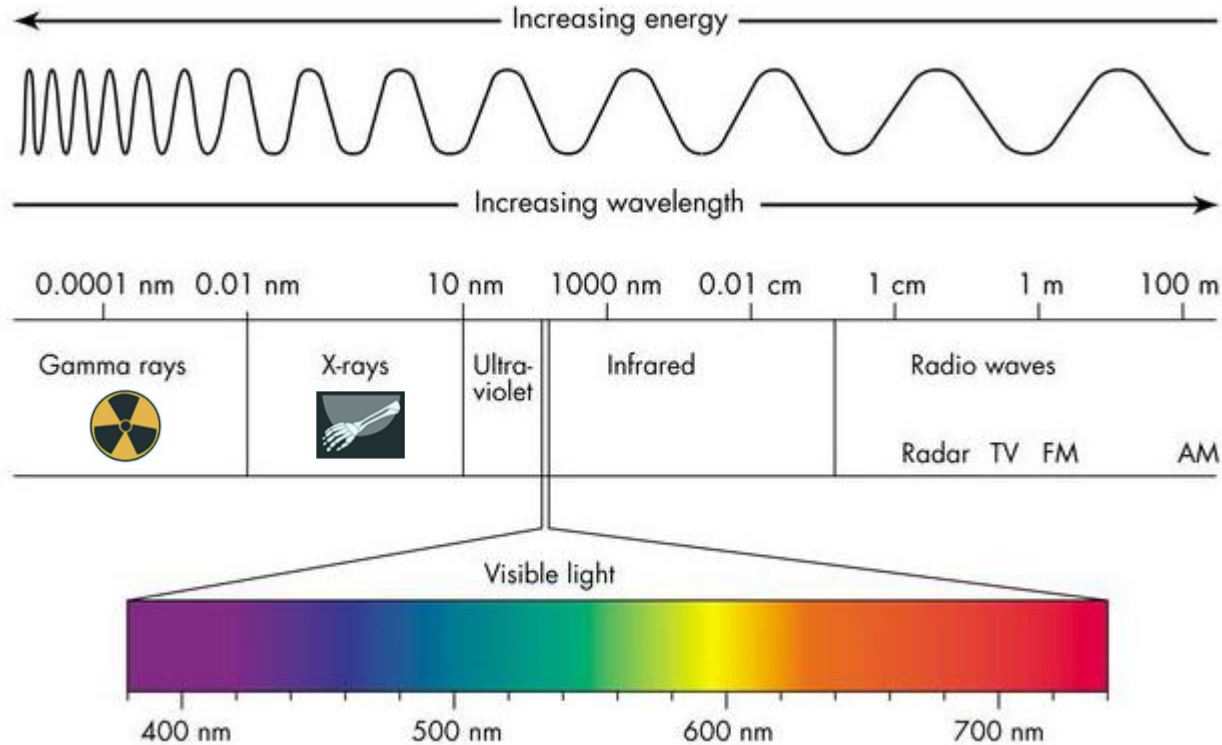




# Radio measurements



# The EM spectrum



- Sun emits typical range for a yellow dwarf → high-energy (ionizing) radiation mostly absorbed at Earth
- technology often uses less-energetic wavelengths/frequencies → non-natural source



# Radio bands in application

**Table 1.1** *The radio spectrum*

Name	Frequency range	Primary propagation modes	Primary uses
Extremely low frequency (ELF)	< 3 kHz	Earth-ionosphere waveguide penetrates sea water	Land-to-submarine communications
Very low frequency (VLF)	3 – 30 kHz	Waveguide (between ground and lower ionosphere), Ground wave	Navigation, Communication, Standard frequency and time
Low frequency (LF)	30 – 300 kHz	Waveguide, Ground wave	Maritime, Loran C, Broadcasting
Medium frequency (MF)	300 – 3000 kHz	E-region reflection (night), Ground wave	Maritime, Aeronautical, International distress, AM broadcasting, Maritime and land mobile
High frequency (HF)	3 – 30 MHz	Reflection from E and F regions	Maritime and aeronautical fixed services, Broadcasting (amateurs, citizens)
Very high frequency (VHF)	30 – 300 MHz	Line of sight, Scatter from ionosphere	Television, FM broadcasting, Public safety, Aeronautical
Ultra high frequency (UHF)	300 – 3000 MHz	Line of sight (affected by ionospheric irregularities)	Space communications, Television, Radar, Broadcasting, Navigation (fixed, mobile)
Super high frequency (SHF)	3000 – 30 000 MHz	Line of sight (tropospheric, affected by ionospheric irregularities)	Space communications, Television, Radar, Broadcasting, Navigation (fixed, mobile)





# VLF radio signal use



German Navy VLF Transmitter „Marinefunksendestelle Rhauderfehn (callsign: DHO38)“

Sources: [https://de.wikipedia.org/wiki/Marinefunksendestelle\\_Rhauderfehn](https://de.wikipedia.org/wiki/Marinefunksendestelle_Rhauderfehn)  
Google Maps



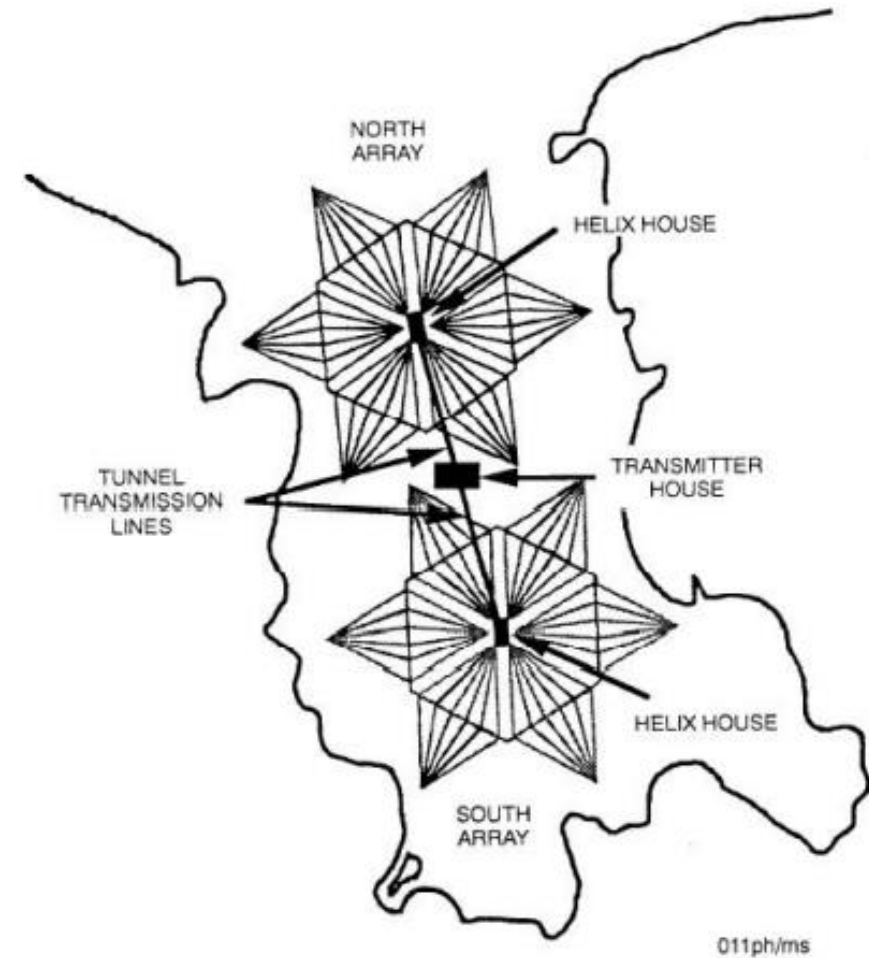


# VLF radio signal use

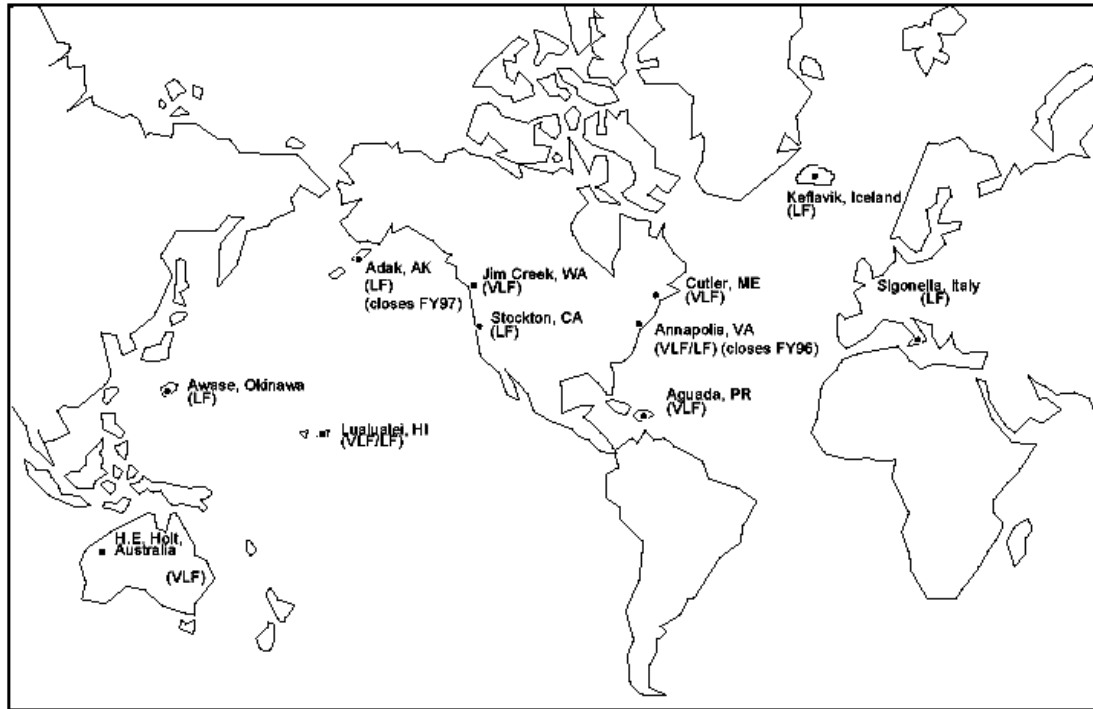


VLF Transmitter Cutler from the US Navy (callsign: NAA)

Sources: [https://en.wikipedia.org/wiki/VLF\\_Transmitter\\_Cutler](https://en.wikipedia.org/wiki/VLF_Transmitter_Cutler)



# VLF transmitters around the globe



Very Low Frequency/Low Frequency Site Locations



VLF penetrate water → used for submarine communication → permanent signals available



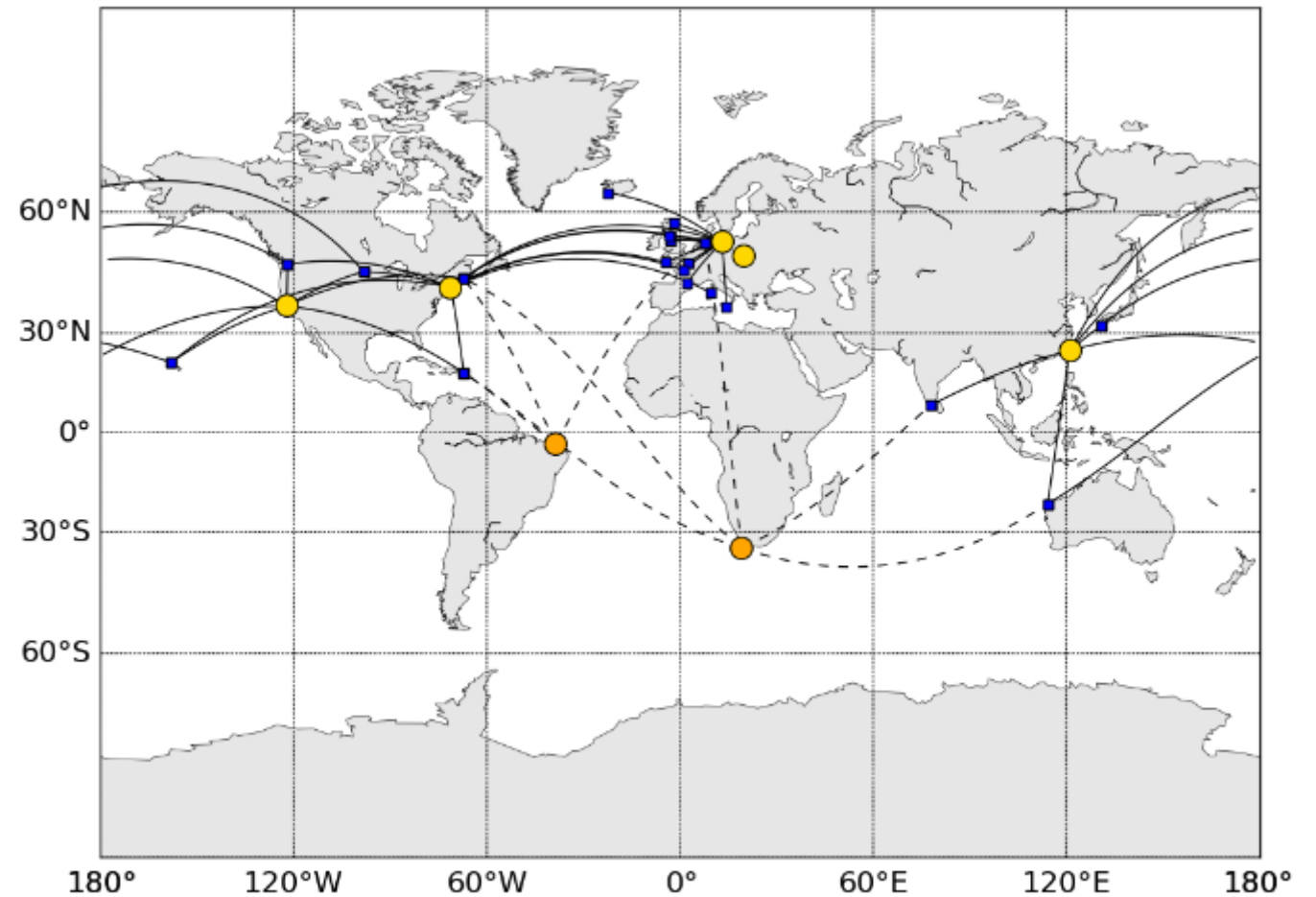
# GIFDS

VLF receivers continuously monitoring several transmitters

Aims:

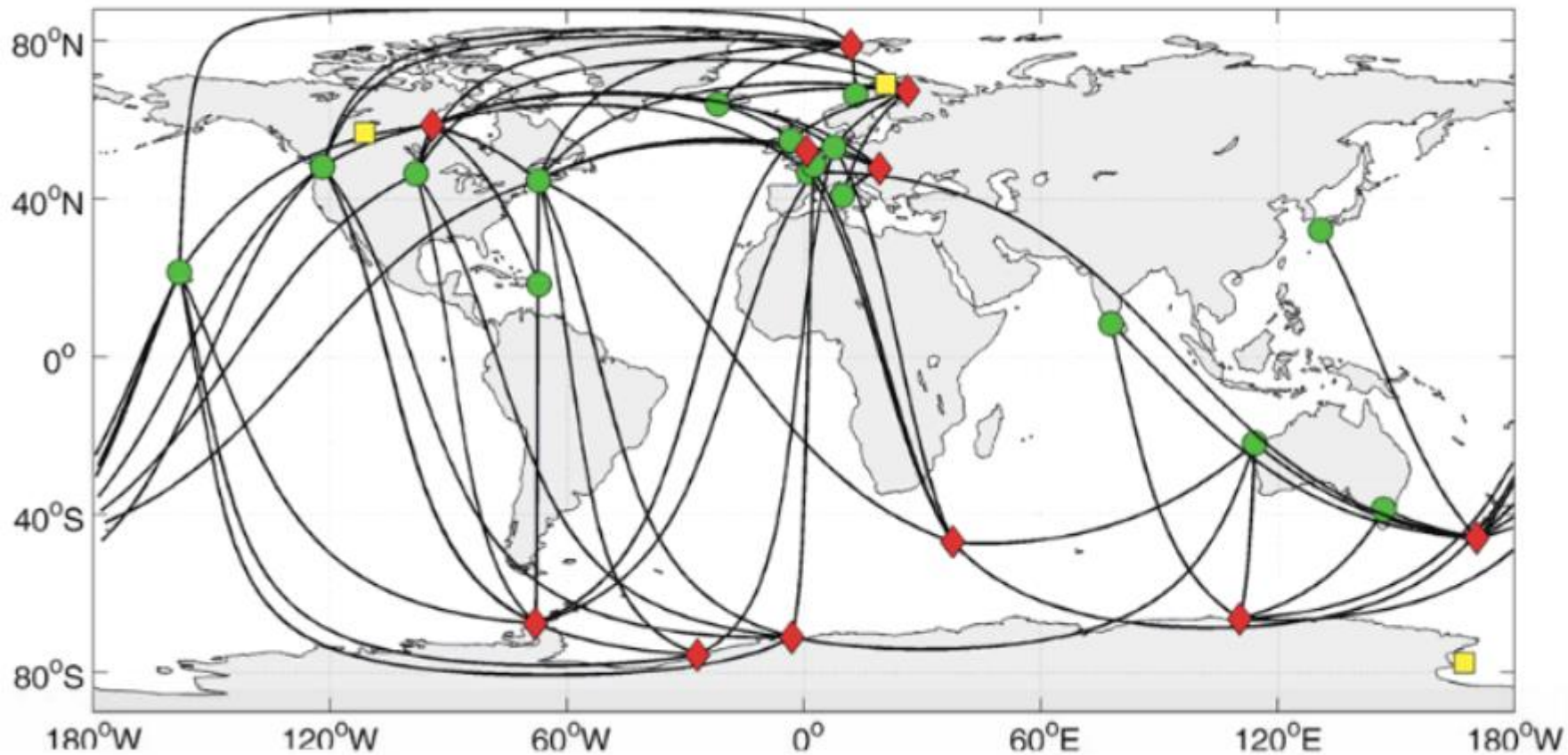
- study influence of solar irradiation
- detect so-called solar flares

→ Navy stations especially valuable



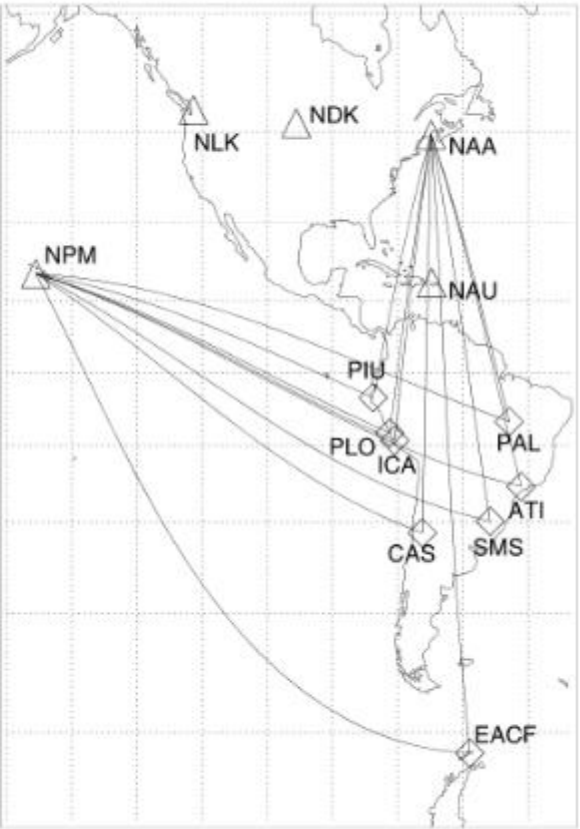
THE GIFDS network and the some radio propagation paths.

# Monitoring networks:



AARDDVARK

Source: Cliverd et al. (2009)



SAVNET

Raulin et al. (2010)

# Signal modulation

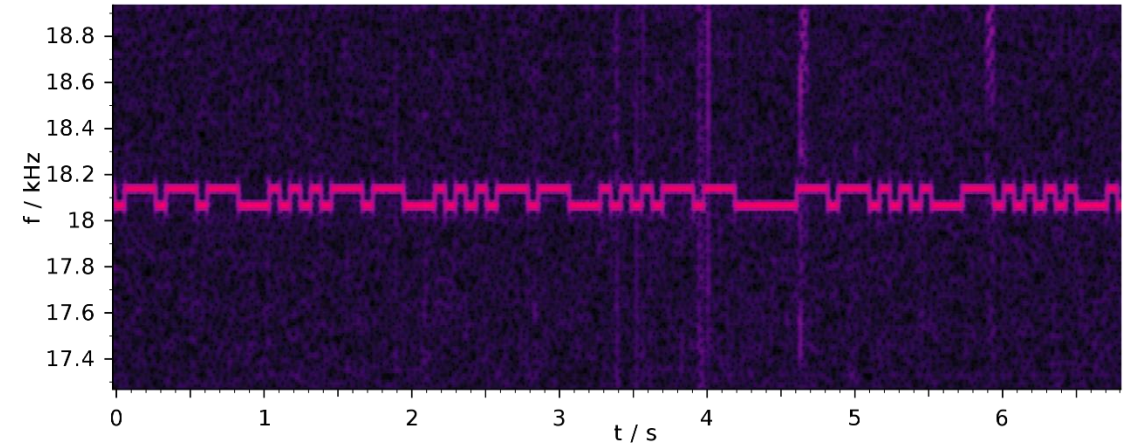
Transporting information via radio requires modulation

→ for a carrier wave one ("slightly") changes one of

- **frequency**
- phase
- amplitude

Navy VLF signals in general use Frequency Shift Keying  
(in particular so-called Minimum Shift Keying is common)

→ Good as we are interested in amplitude and phase developments of signals around a frequency!  
(modifying amplitudes would distort measurements additionally)



Frequency-shift-keyed VLF signal

Source: [https://en.wikipedia.org/wiki/Very\\_low\\_frequency](https://en.wikipedia.org/wiki/Very_low_frequency)



## First programming task: Get the data!

- Rx: Ny-Alesund
- 21 December 2008 – 21 December 2009
- <http://psddb.nerc-bas.ac.uk/data/access/download.php?searchterm=ultra&page=4&cat=item&year=2009&class=232&type=ULTRA&site=Ny-Alesund&v=Data>

Tx: NAA, NRK, NLK, DHO

Useful libraries: `urllib.request`, `datetime`

## Second programming task: Present the data!

Useful libraries: `numpy`, `matplotlib`

