Report on WRF met model simulations of Kenyan mountain sites

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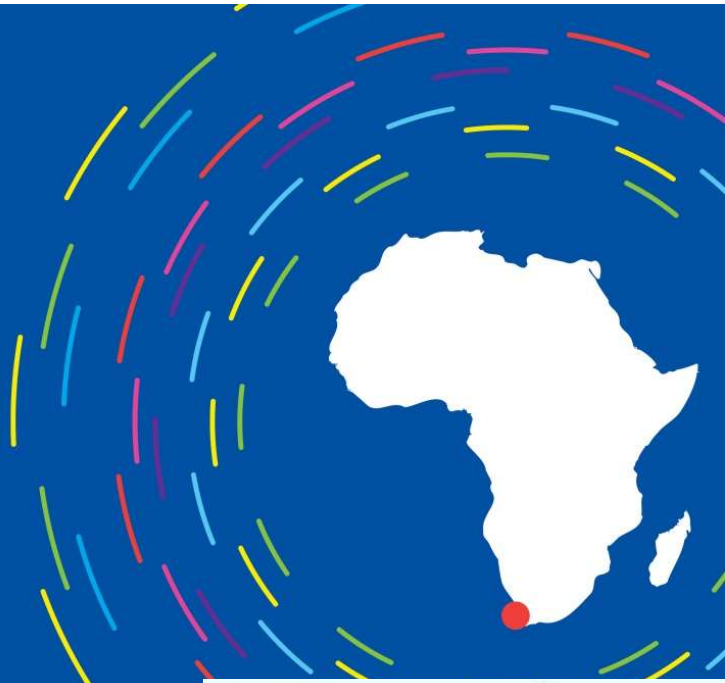

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University of the Highlands and Islands
Oilthigh na Gàidhealtachd agus nan Eilean

Department for Science, Innovation & Technology

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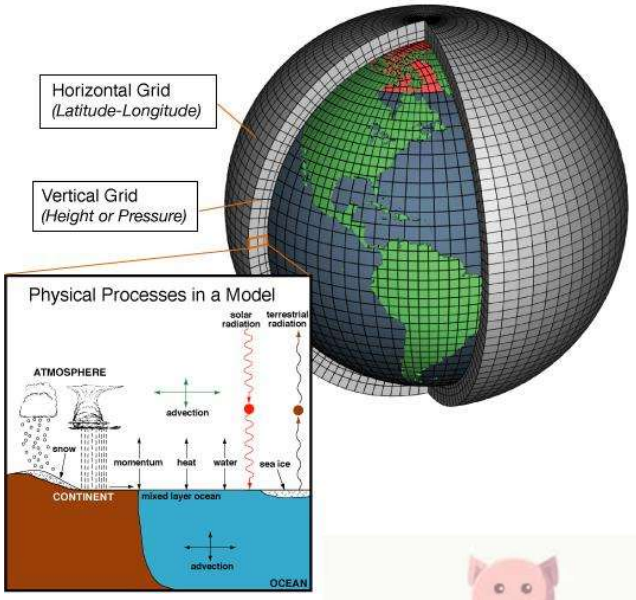
XXII IAU GENERAL ASSEMBLY
CAPE TOWN, SOUTH AFRICA, 2024

What is a met model?

- **Met (meteorological) models** are also known as **numerical weather prediction (NWP)** are mathematical **representations of the Earth's atmosphere**, in the form of a computer program
- There are only **seven fundamental equations** of **physics**, the **equations of motion**, and **thermodynamics** in a met model
- Earth is represented by a large set of discrete **grid boxes**, extending horizontally and up into the atmosphere and down into the oceans
- Size of each box depends on the computational resources available – **most equations are PDEs**



PDEs = Partial Differential Equations

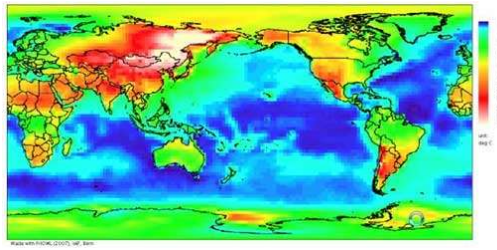
What are the seven fundamental equations?

The first three are known as **Euler's** or **the Navier-Stokes equations**, and depend on the Earth's **gravity**, **friction**, the rotation of the Earth [**Coriolis**], and **air density**

1. An equation to determine the **North/South** directional wind
2. An equation to determine the **East/West** directional wind
3. An equation to determine the **Vertical up/down** wind
4. '**The Vorticity Equation**', which states that air density is proportional to divergence (the amount that air can 'stretch')
5. The '**Equation of State**' (also known as the '**Ideal Gas Law**')
6. The '**1st Law of Thermodynamics**' which says the heating rate of air is proportional to the energy input, and vice versa
7. A **continuity equation** to simulate the **mass / water balance** in the atmosphere, in all forms (liquid, gas, ice), their phase changes (e.g. latent heat) and related energy exchanges

Are all PDEs…

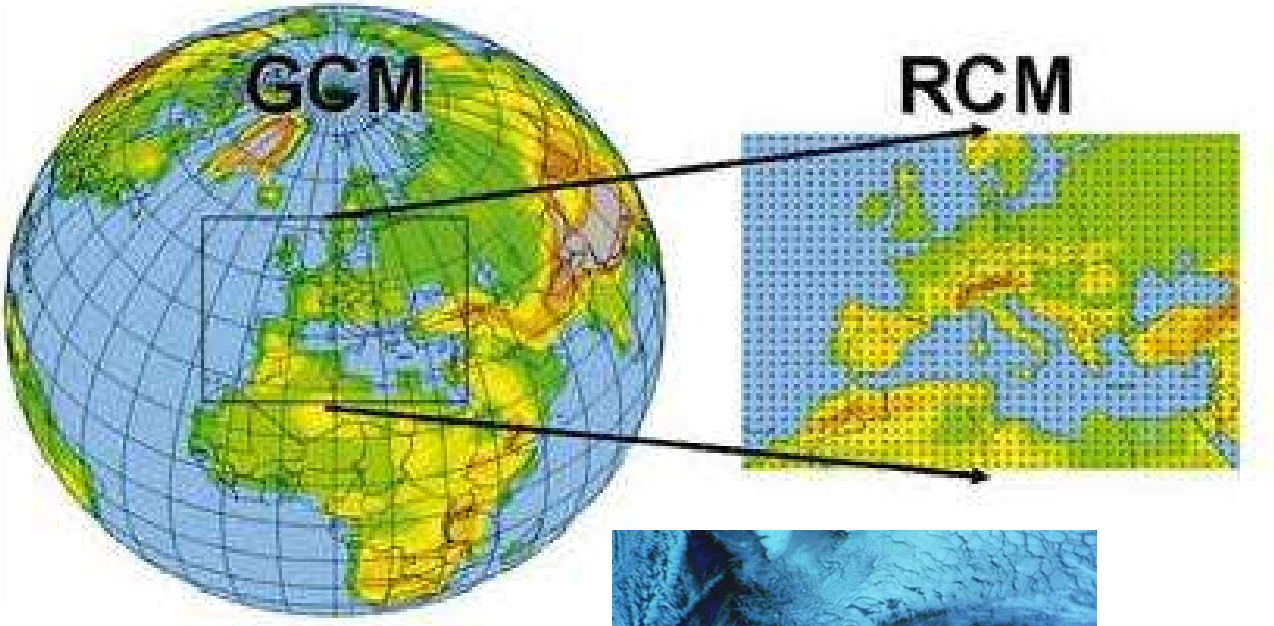
PV=nRT

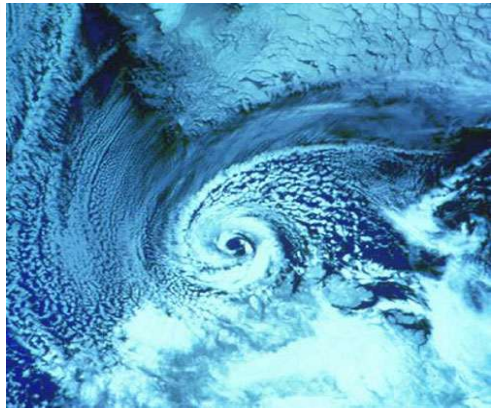


Another PDE…

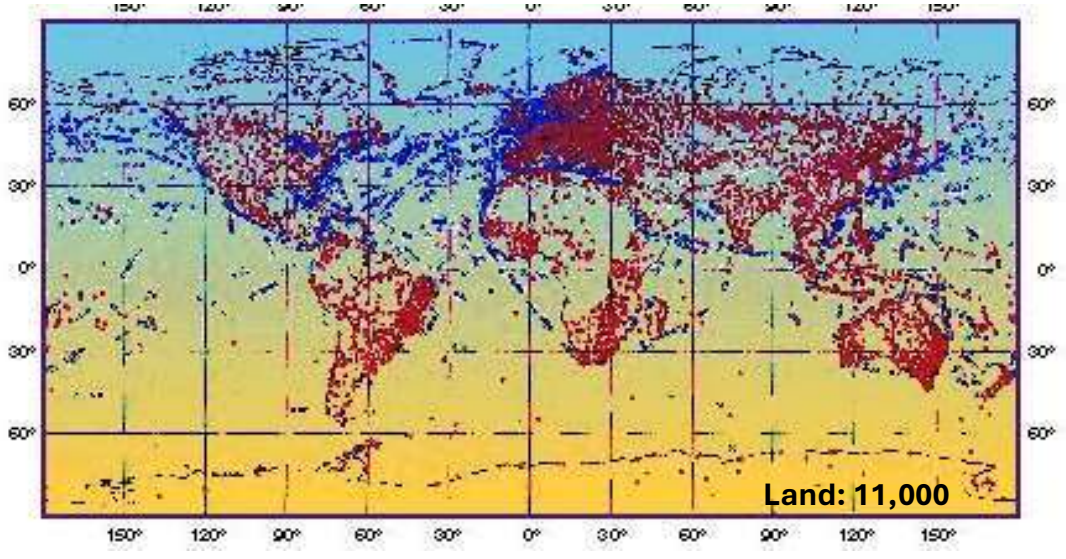
Different types of met models

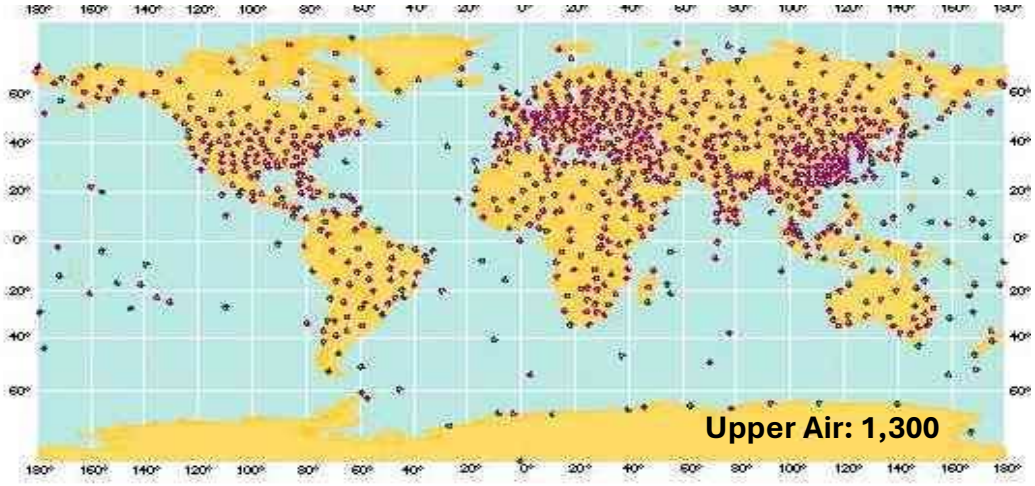
- **GCM** = Global Circulation Model
- **RCM** = Regional Climate/met Model
- **ESM** = Earth System Model (“digital twins”) combine all geoscience knowledge with Artificial Intelligence (**AI**) and Machine Learning (**ML**)…
- **Reanalysis** = making a GCM simulation for historic times in the past (back to ~1950)

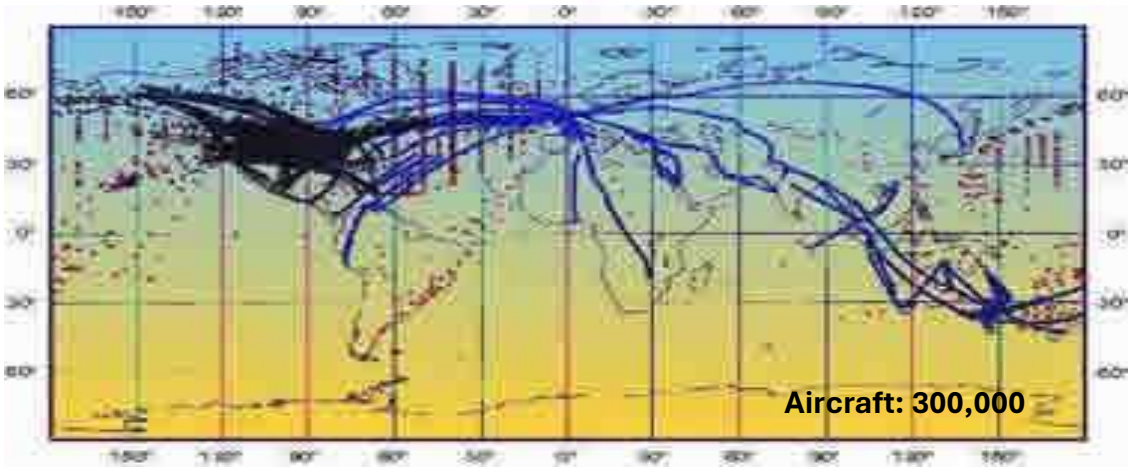




Met models need to be set with initial conditions

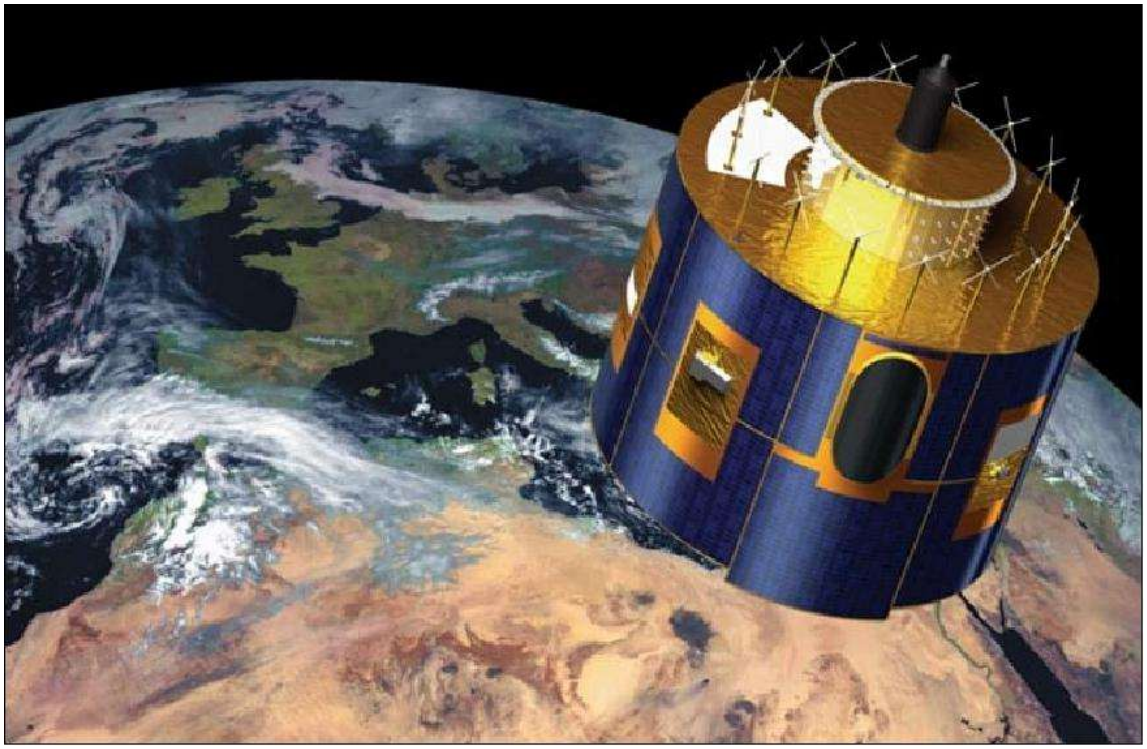






http://www.wmo.int/pages/prog/www/OSY/Gos-components.html

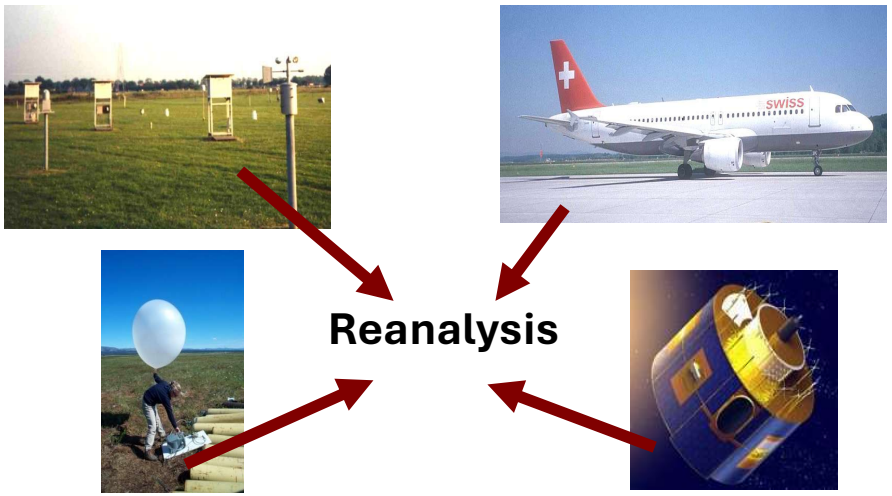
Initialisation (or “data assimilation”)

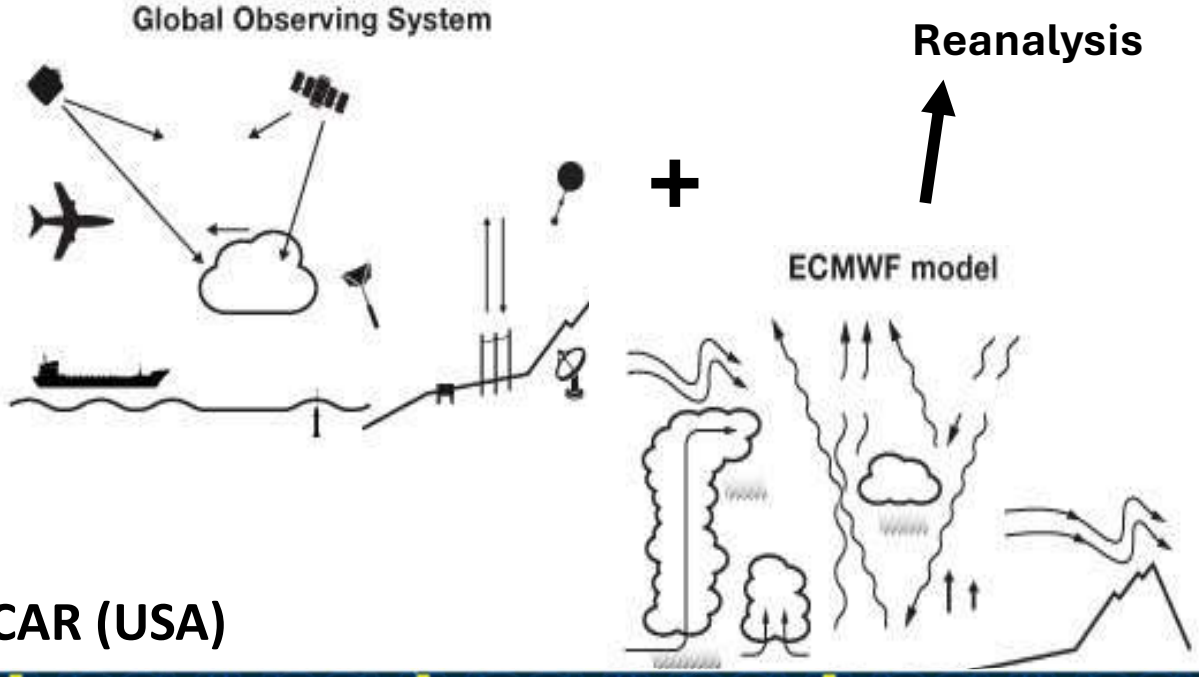


- Today, a huge amount of **satellite data** is incorporated daily met models
- Overall **~10 million observations per day**…
- Plus **10,000s** of surface reports (weather stations, aeroplanes, ships, buoys, weather balloons)…
- All shared globally – **an unprecedented amount of global co-operation**

Atmospheric & Climate Science *Reanalysis* (word of the day!)

Reanalyses = reconstructed weather analyses (~1950s-> today) **initialised with** available historic data, but using **an accurate met model of today.** They are **the best available picture** of the climate of past decades.



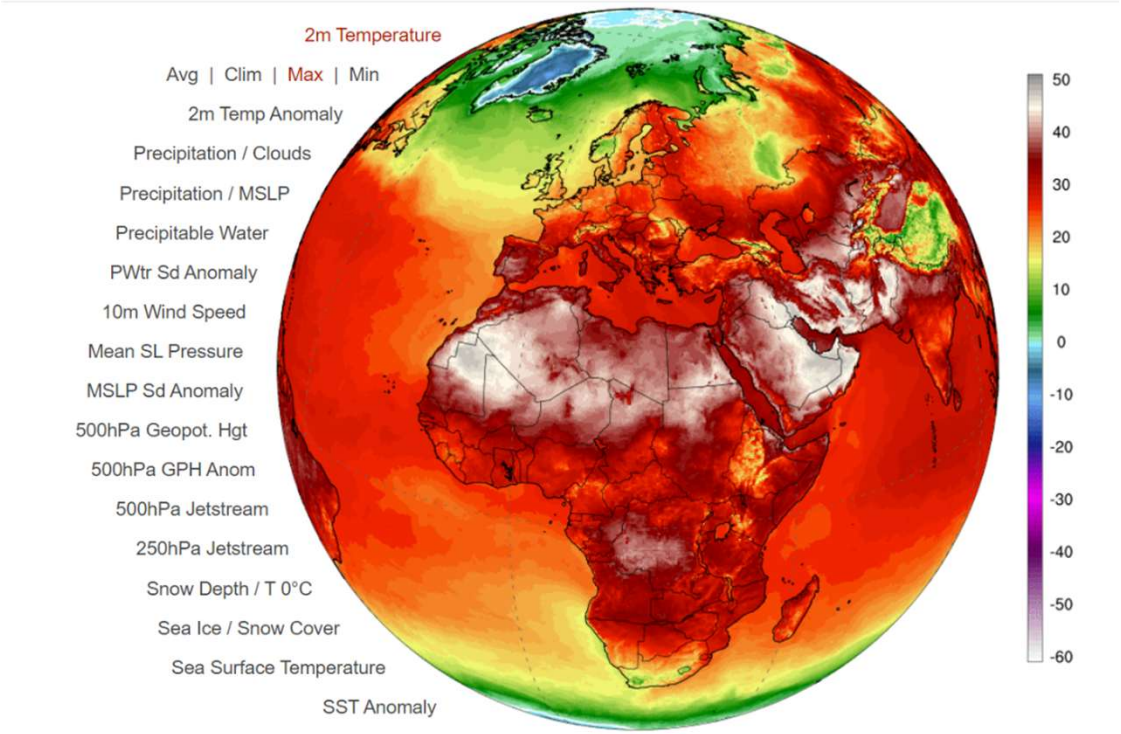


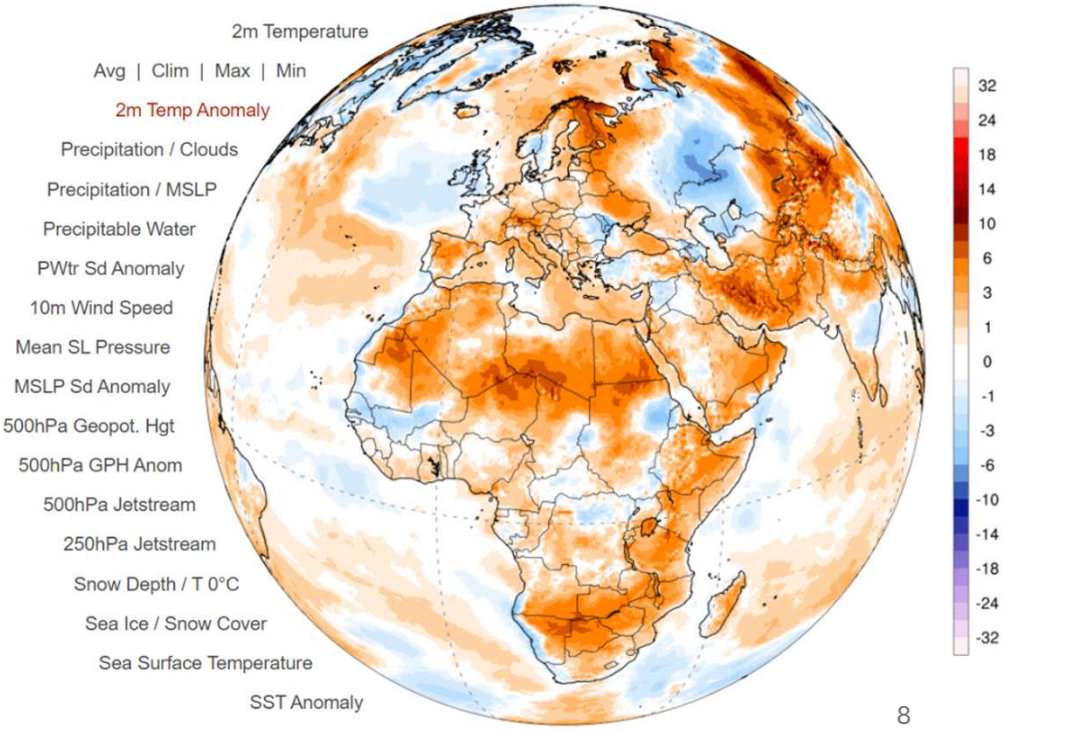
e.g. ERA5 (European reanalyses); NCEP-NCAR (USA)

Atmospheric & Climate Science - *Reanalyses*

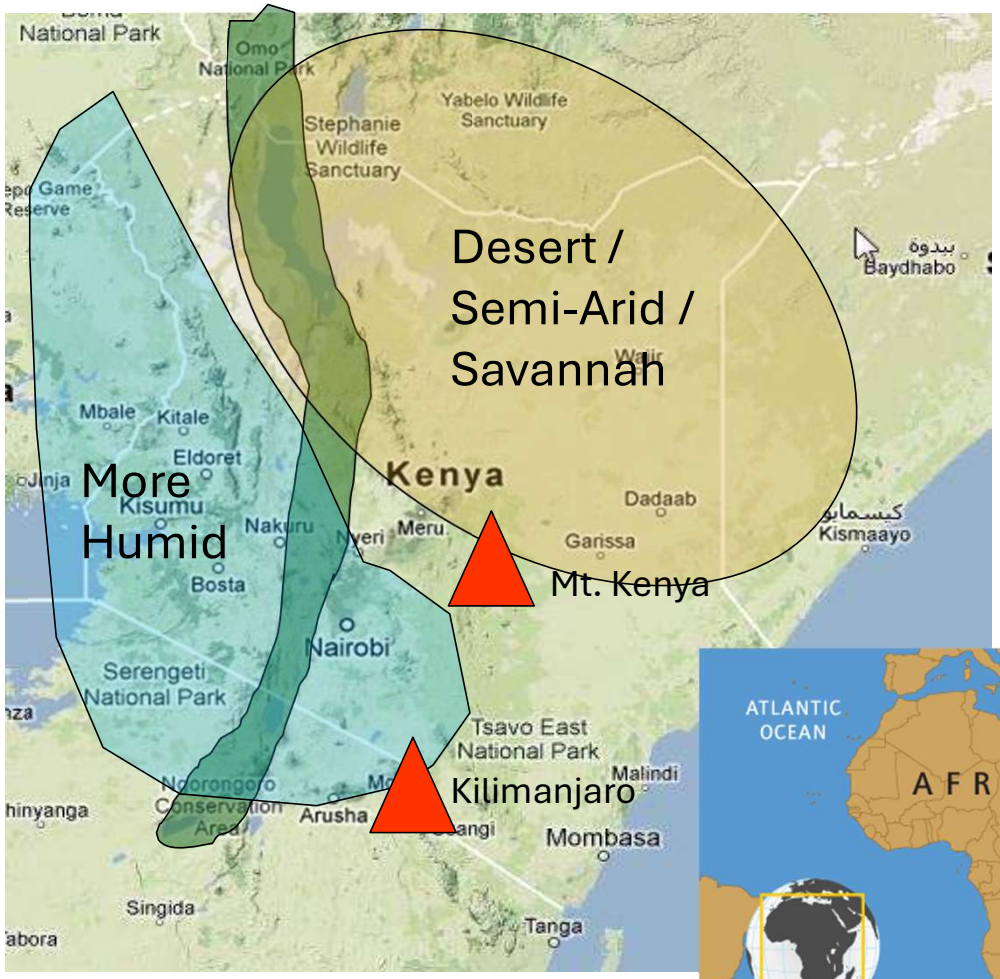
Climate Reanalyzer
Climate Change Institute | University of Maine

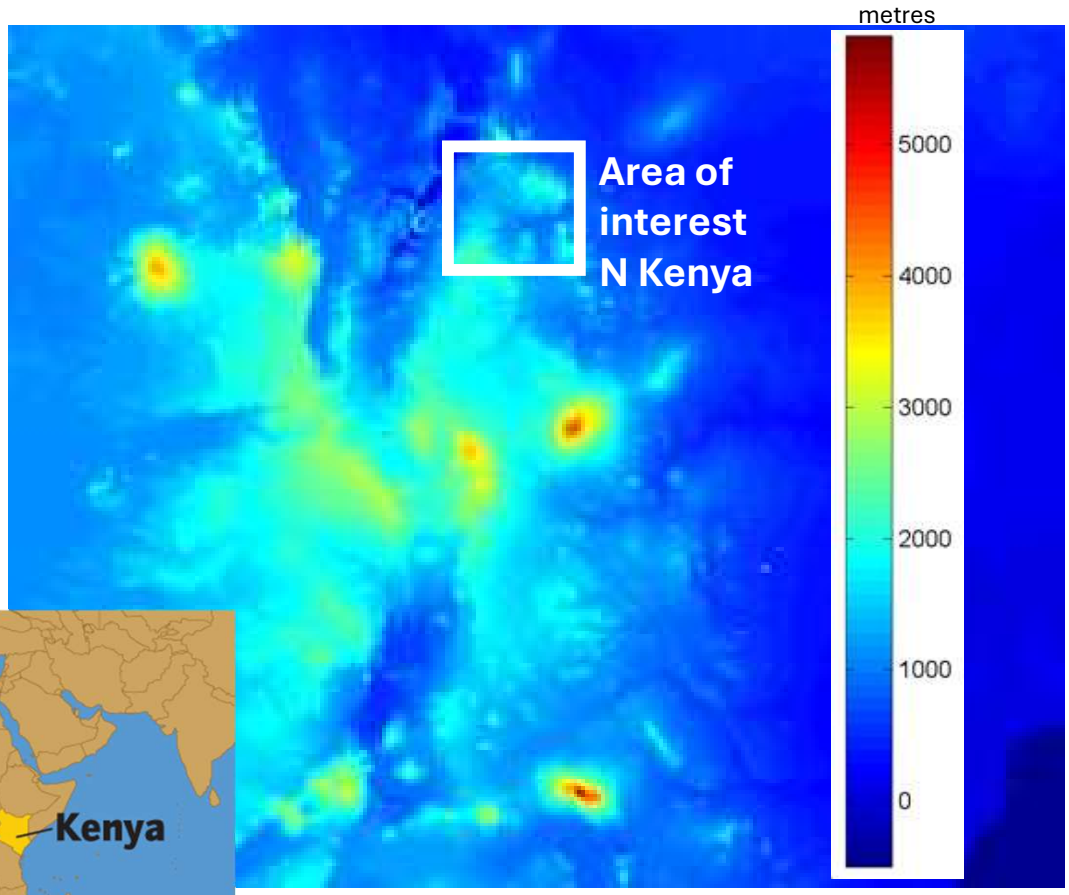
https://climatereanalyzer.org





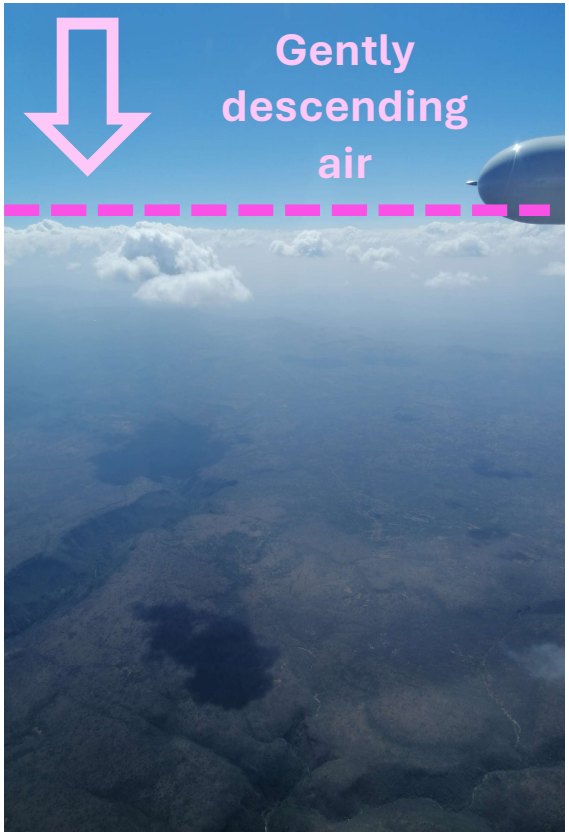
Back to Kenya… How can a regional met model helps us?



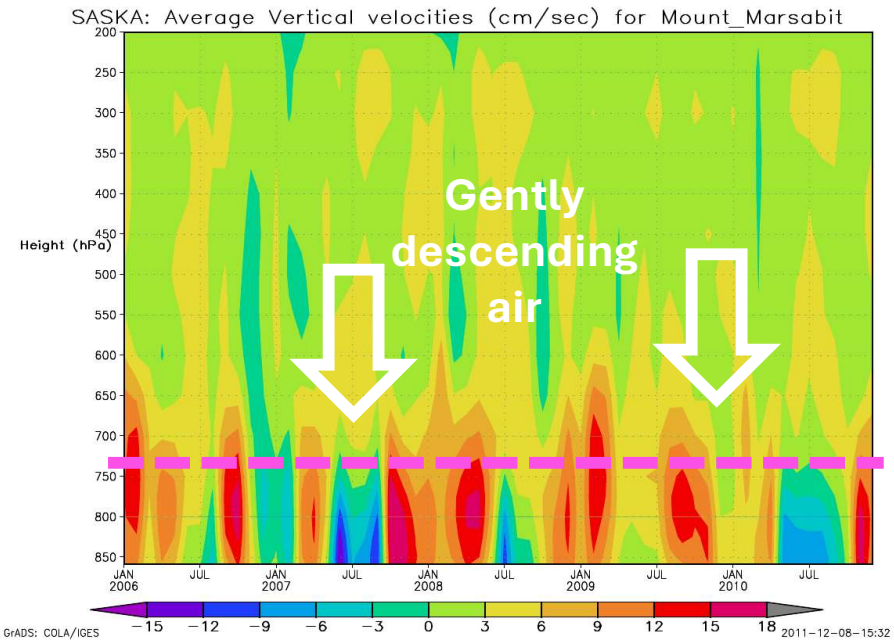


Altitude (m); United States Geological Survey)

What we want: Dry and stable conditions above a semi-permanent inversion

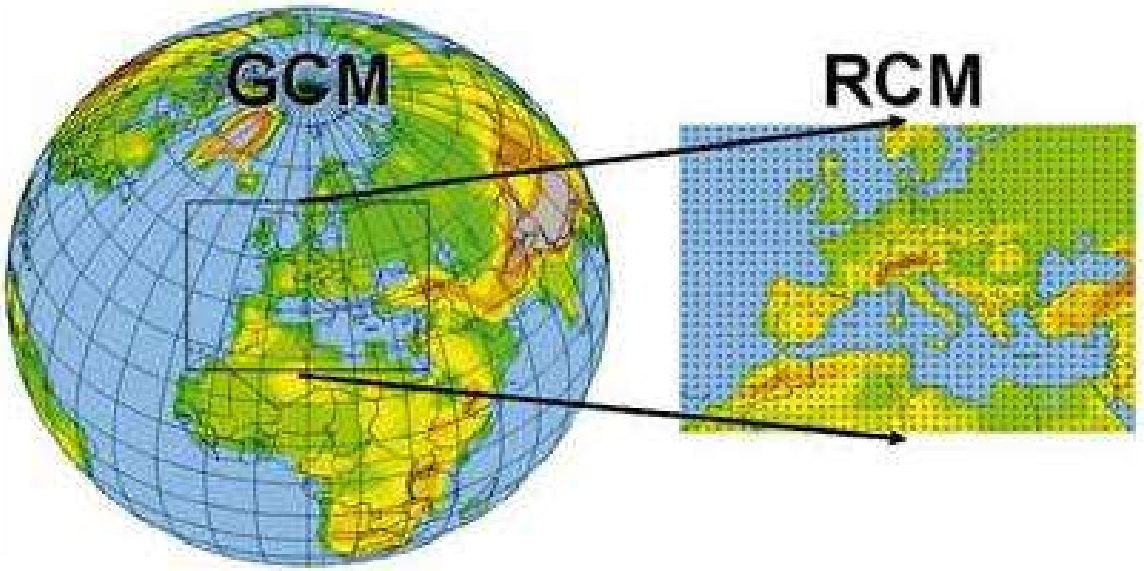


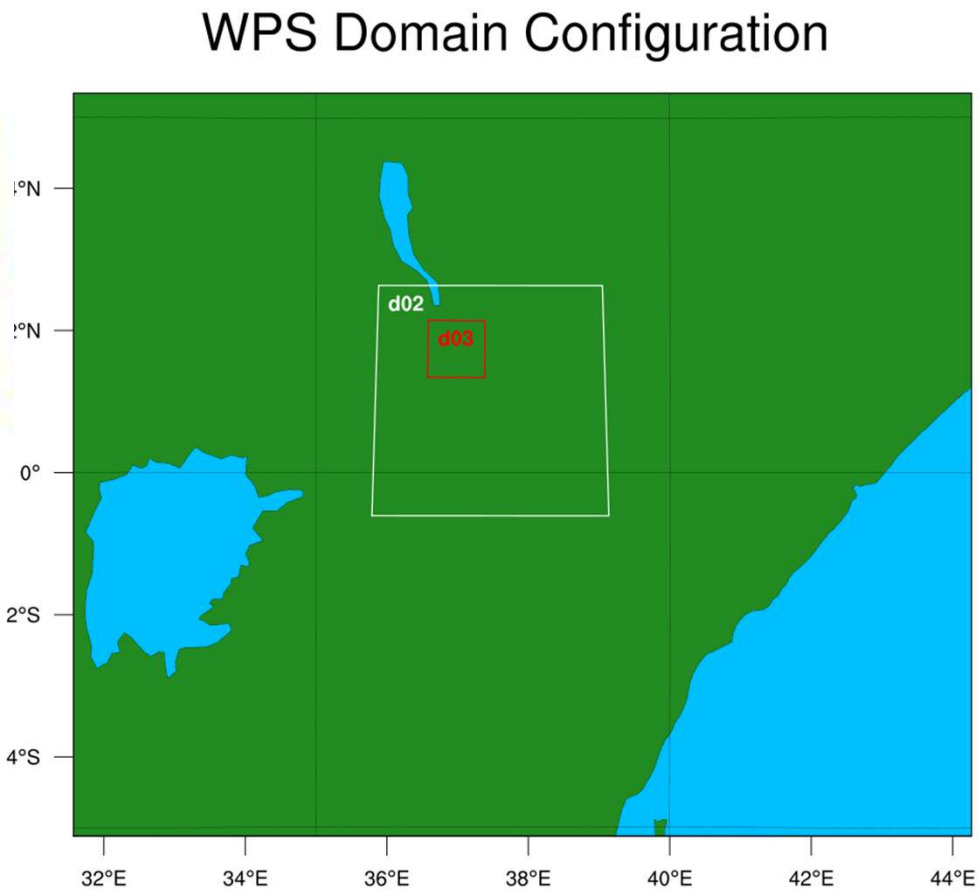
Cruising at 2,500-3.500m at inversion height



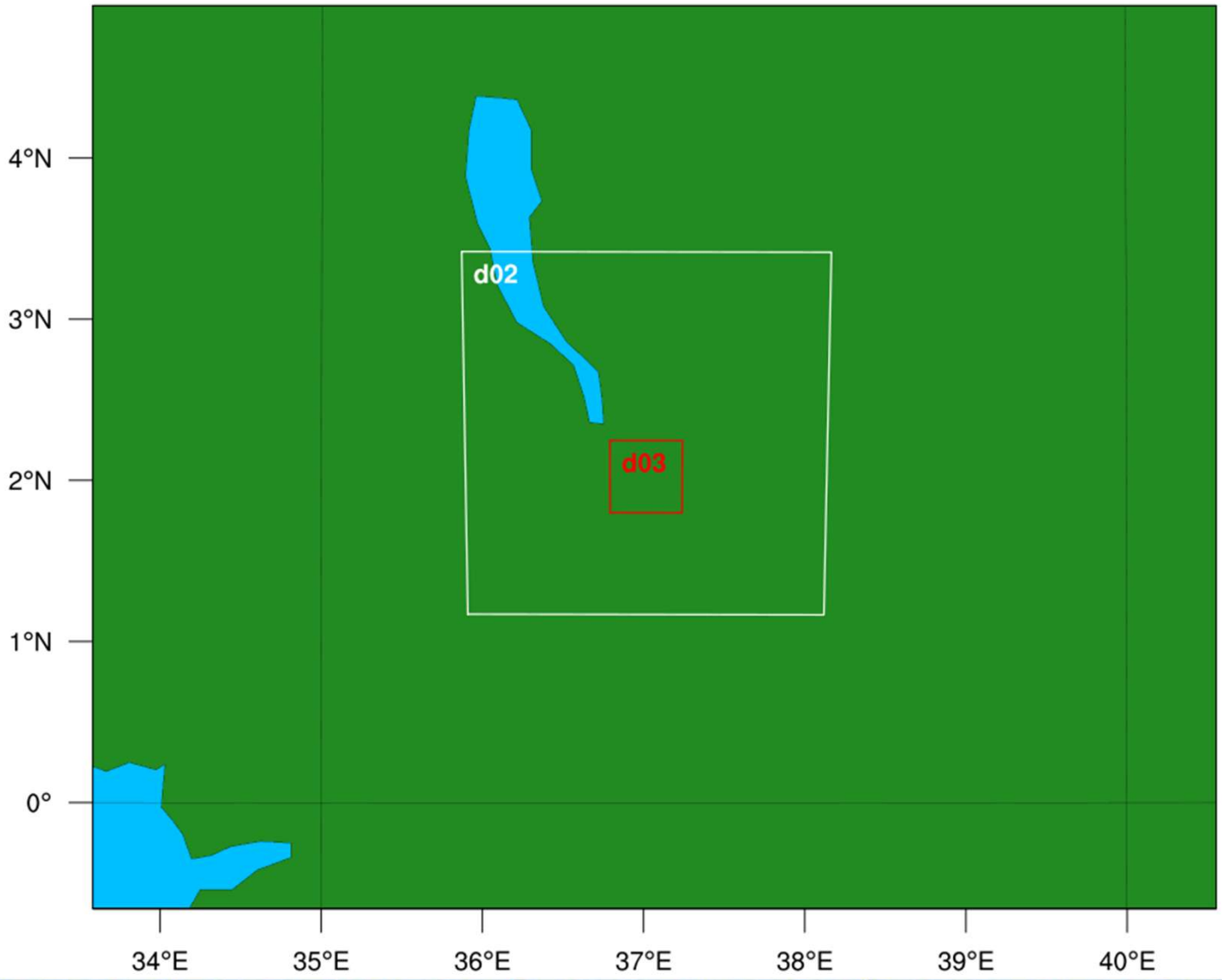
Met models indicate the same -> inversion near 3,000m -> so we need a high mountain top (Graham *et al.* 2016)

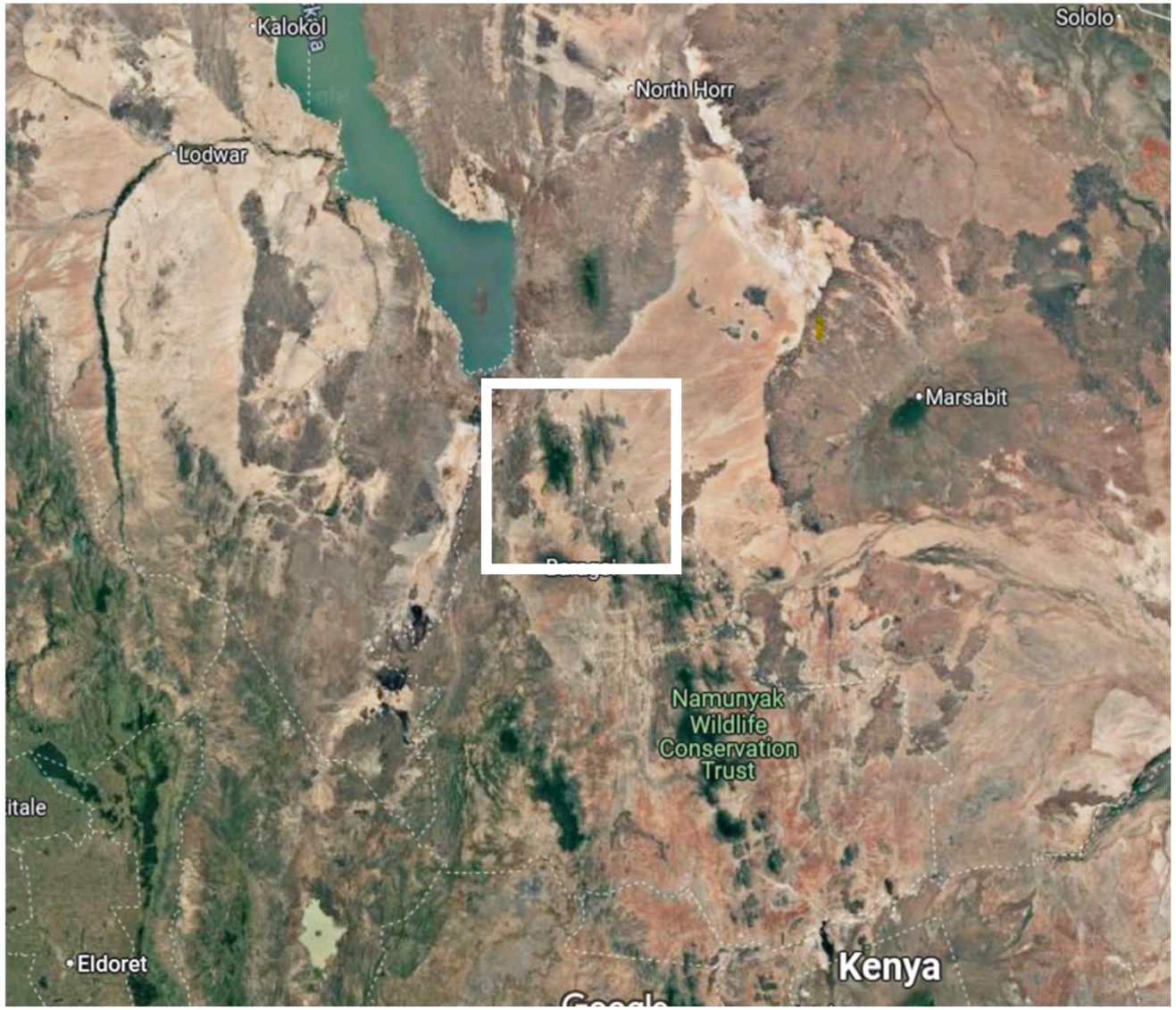
Weather and Research Model (WRF) Skamarock et al. 2008





GFS Global Forecasting System (GFS) initialisation -> Regional "nested" met model (RCM) for northern Kenya


4°N
3°N
2°N
1°N
0°
34°E
35°E
36°E
37°E
38°E
39°E
40°E
d02
d03

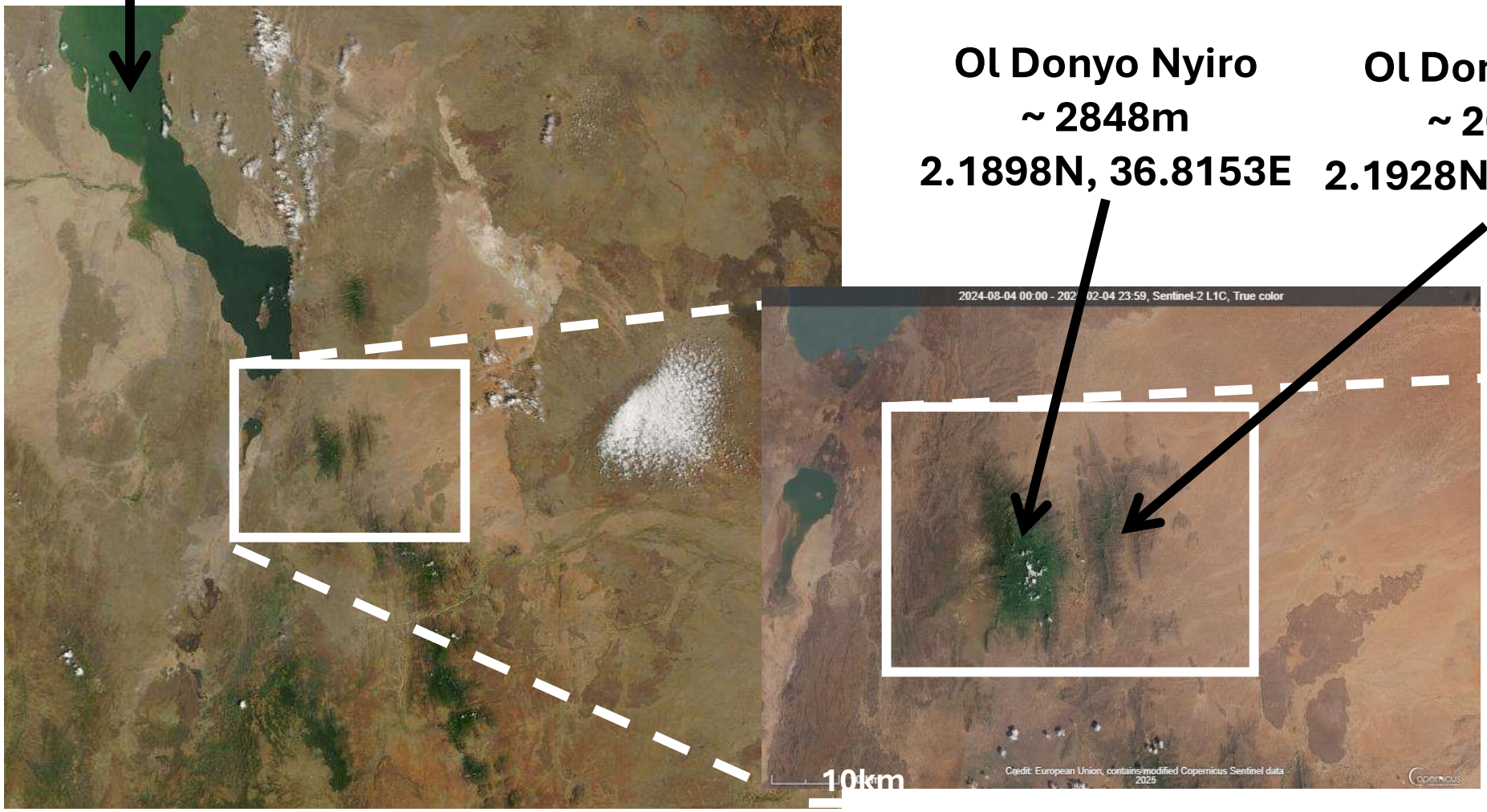

Kalokol
Sololo
North Horr
Lodwar
Marsabit
Namunyak
Wildlife
Conservation
Trust
Eldoret
Kenya

Lake Turkana

Zoom into northern Kenya

Ol Donyo Nyiro
~ 2848m
2.1898N, 36.8153E

Ol Donyo Mara
~ 2060m
2.1928N/ 36.9553E



NASA Terra / MODIS 9/2/25

EU Copernicus Sentinel 2-L1C 9/2/25

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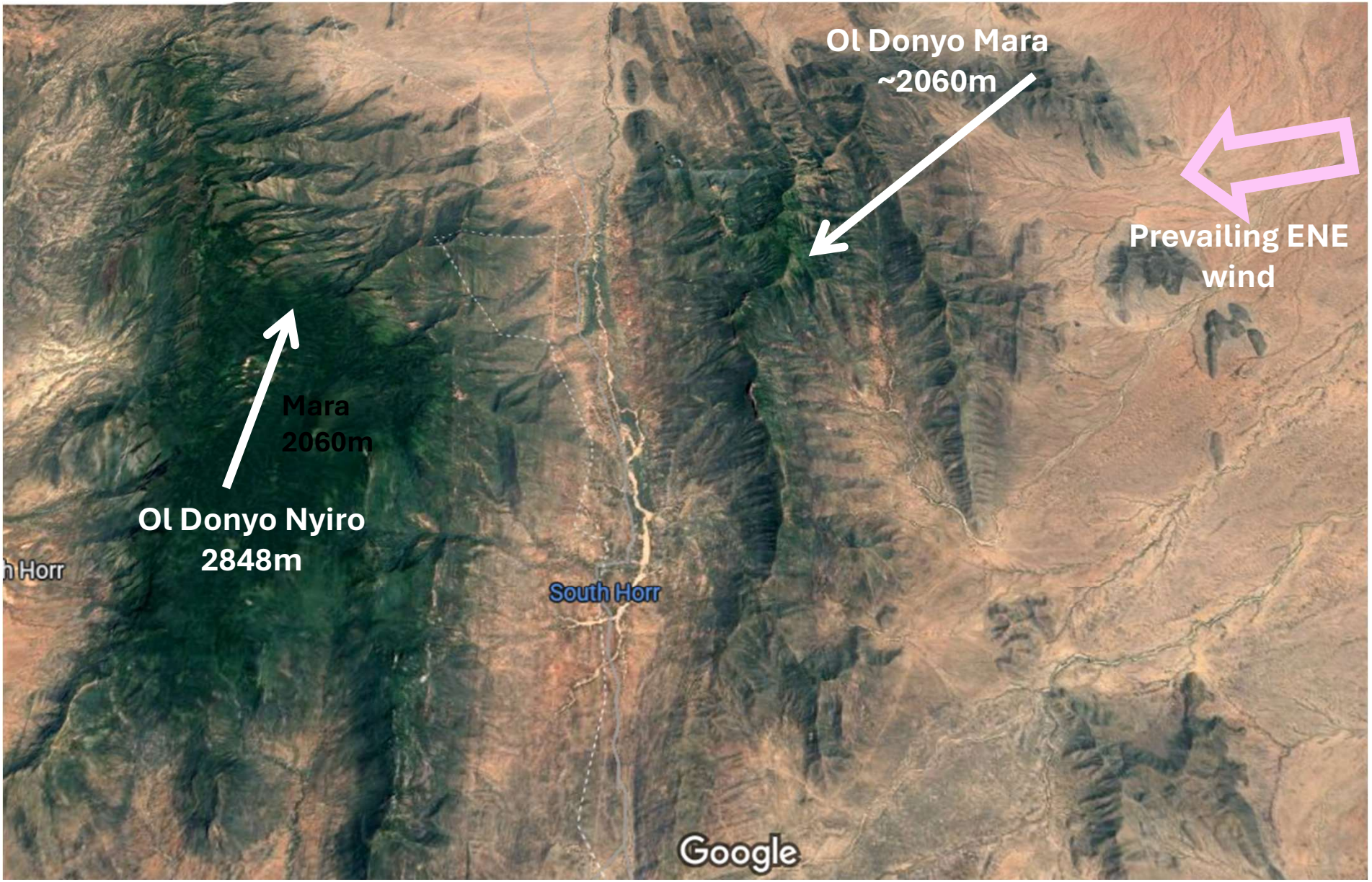
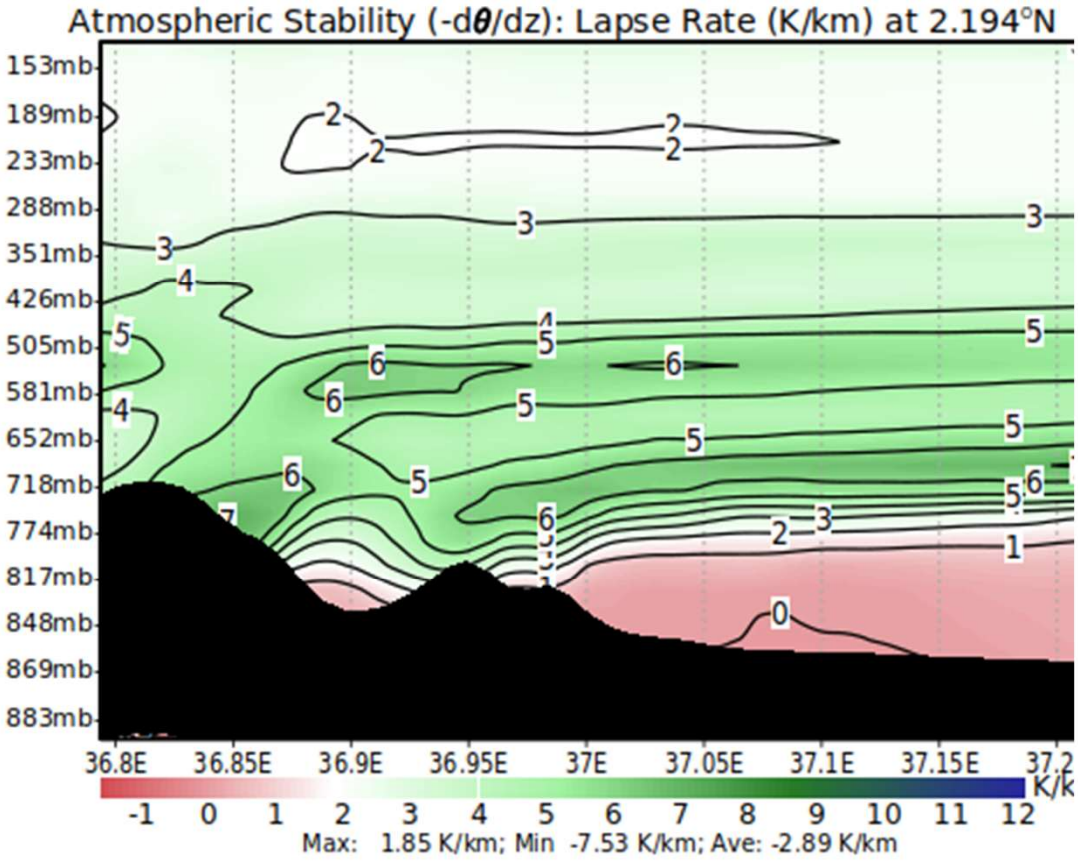
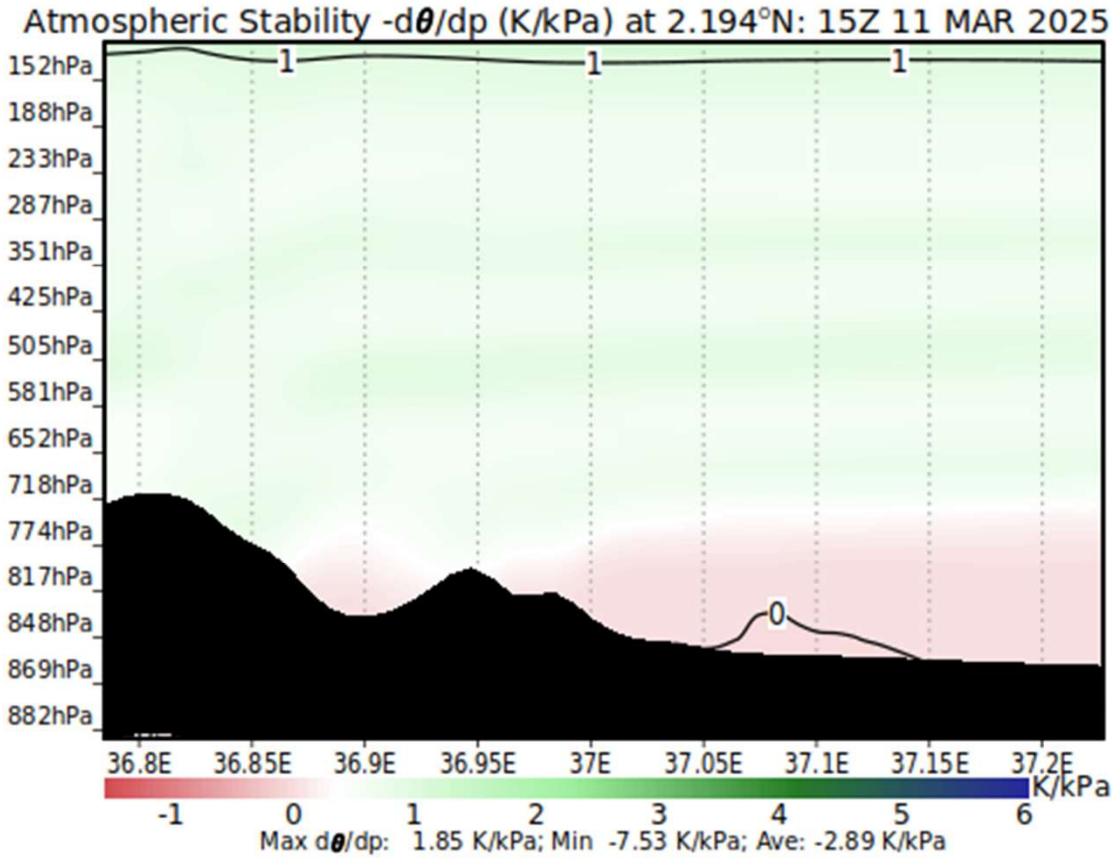

Ol Donyo Mara
~2060m
Prevailing ENE
wind
Mara
2060m
Ol Donyo Nyiro
2848m
South Horr
Google

First X-sections of South Horr: Snapshot 11 March 2025

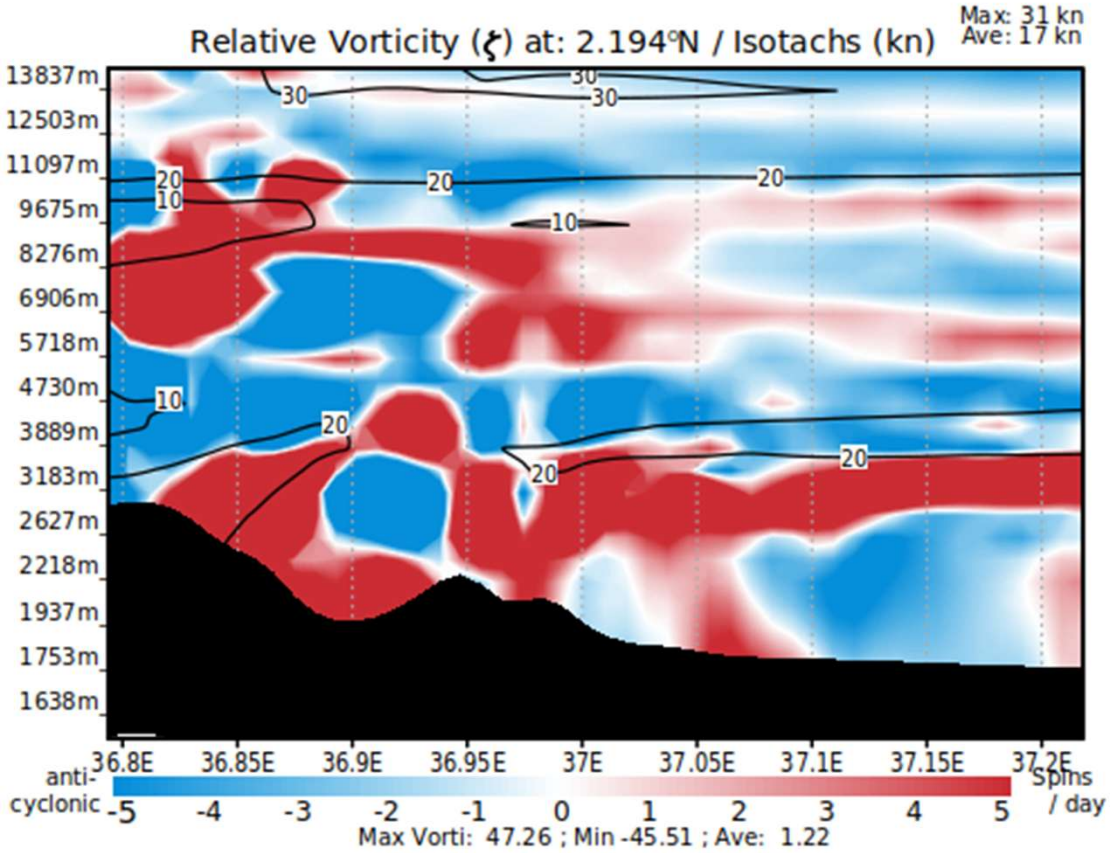
Atmospheric Stability

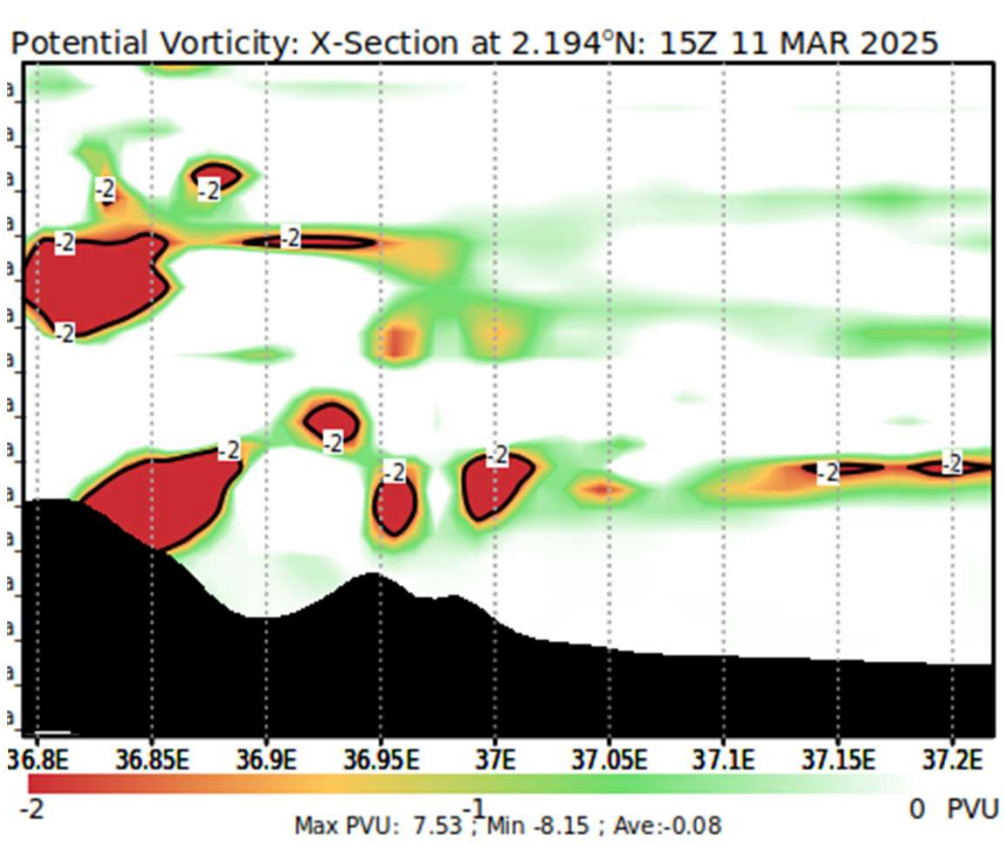




X-sections of South Horr valley: Snapshot 11 March 2025

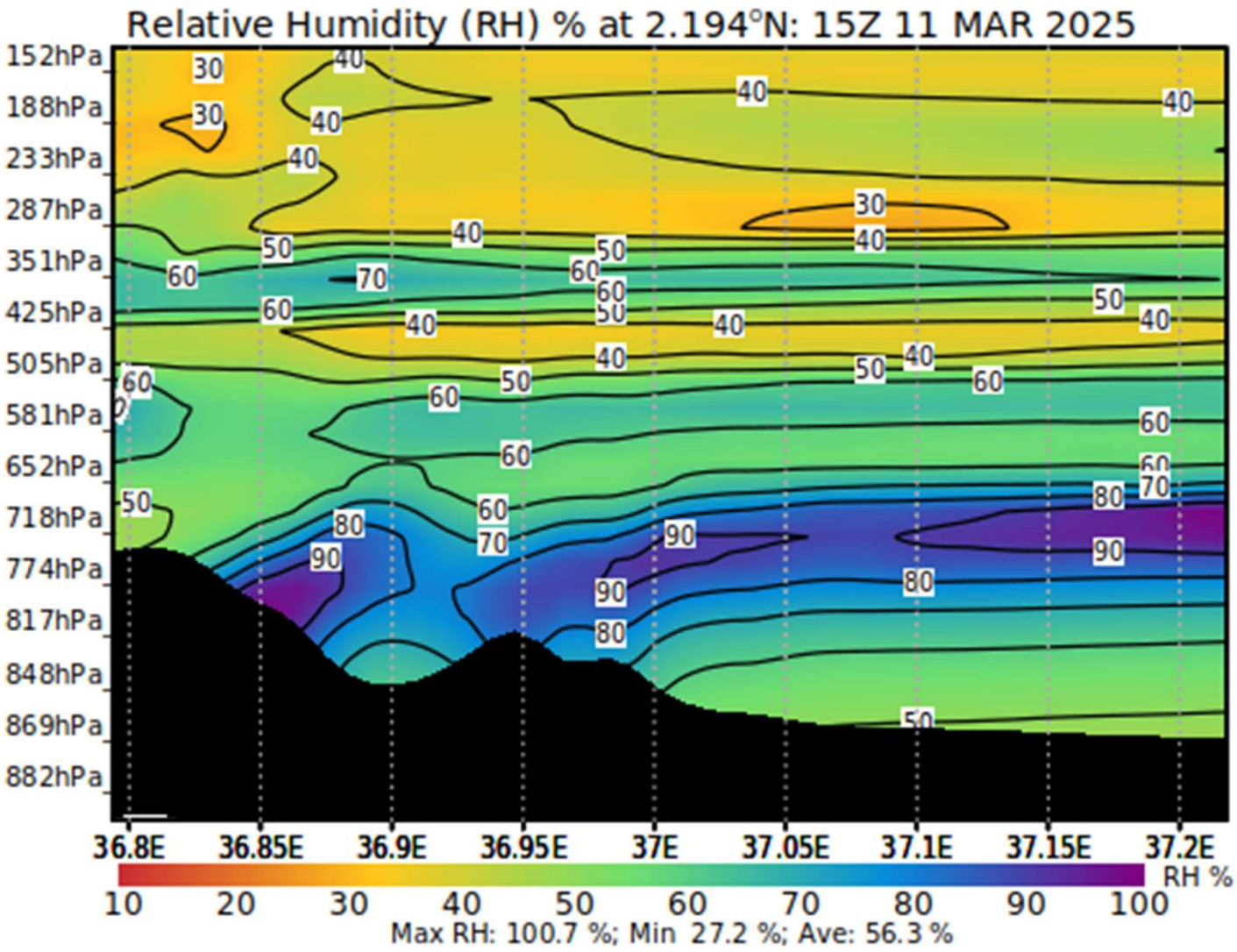
Atmospheric dynamics



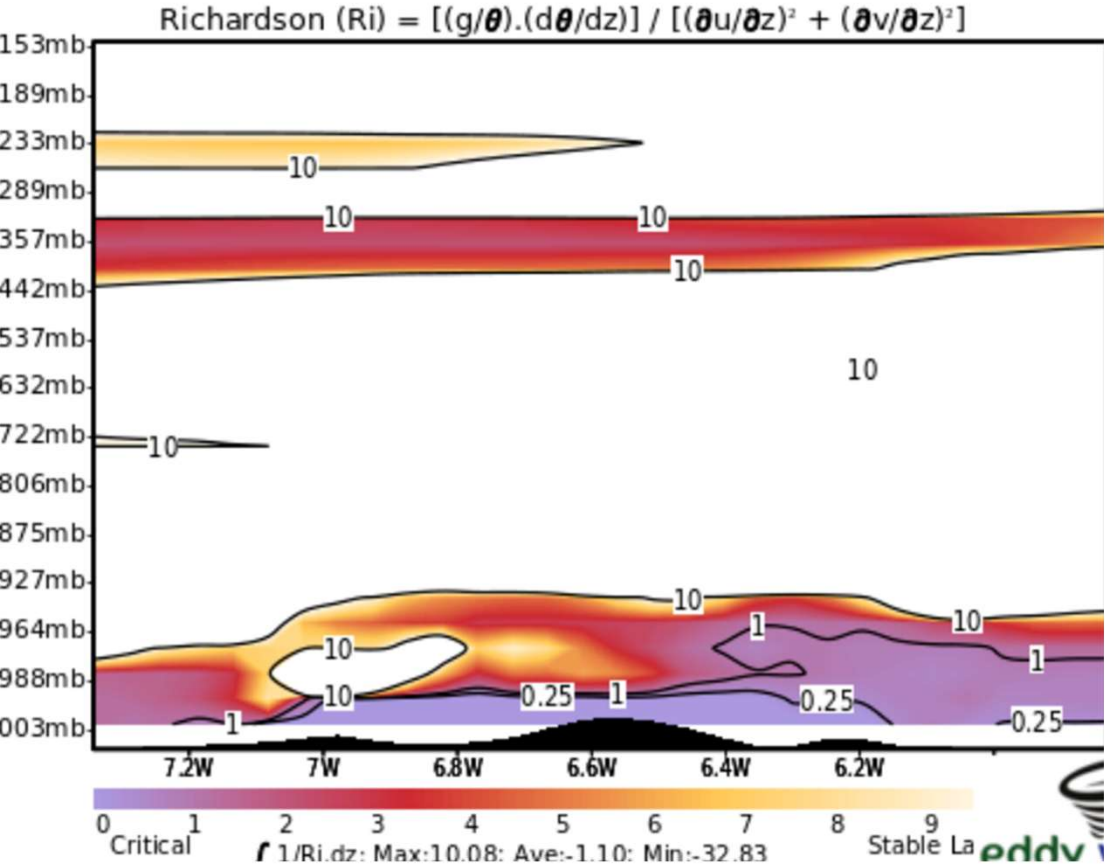


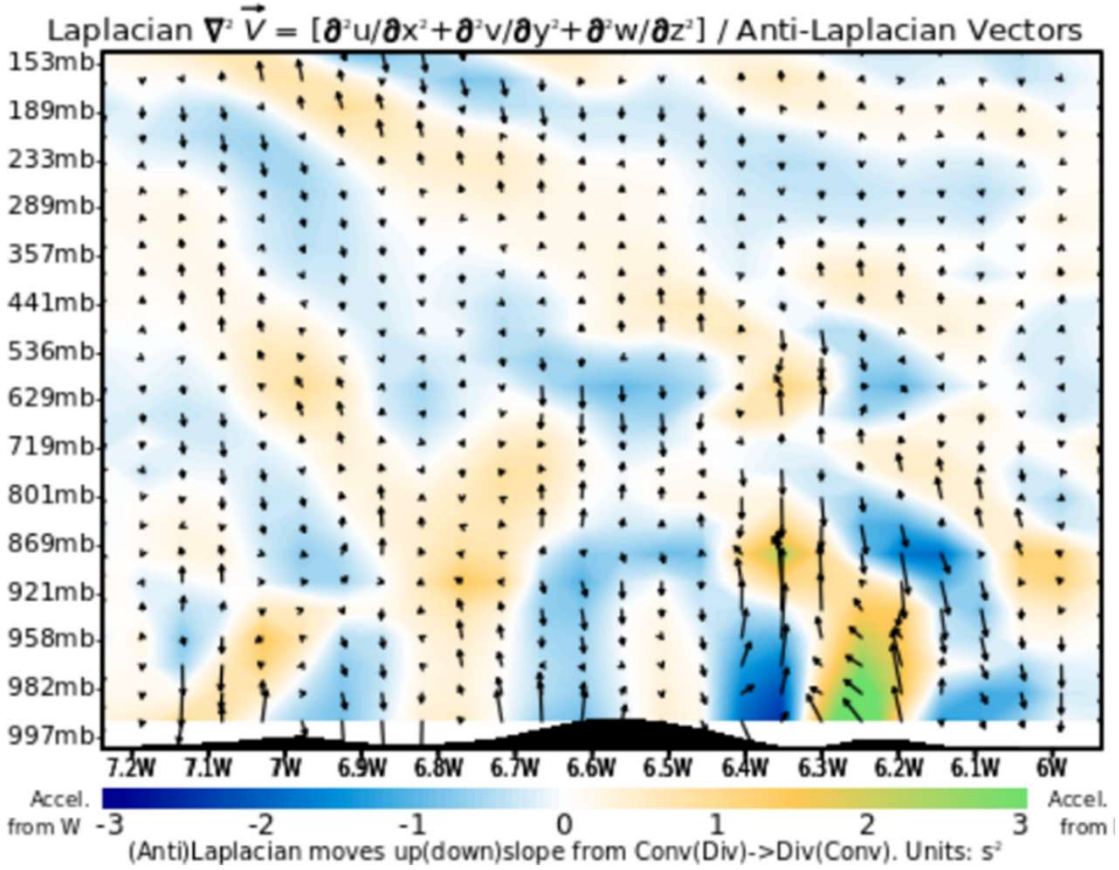
X-sections of South Horr valley: Snapshot 11 March 2025

Relative humidity



How to relate meteorology to astronomical viewing?
e.g. Need to use indices - flow over a hill using WRF

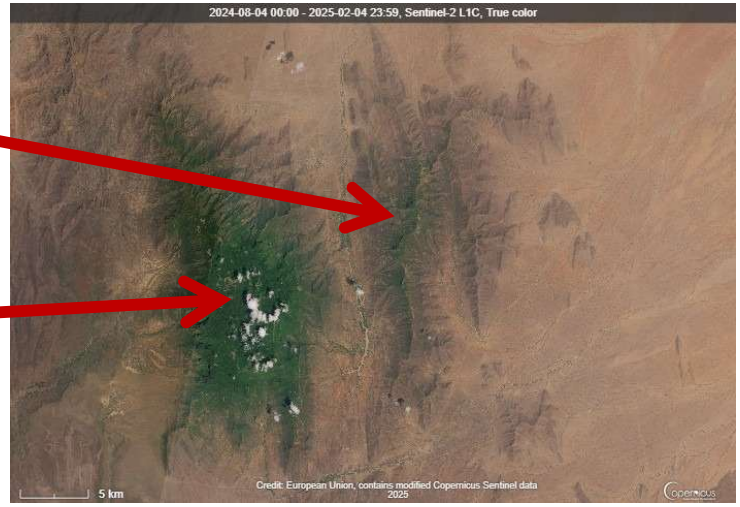




Local wx: A “cloud forest” on ‘Nyiro seems to self-generate its own rain

‘Mara 2060m

‘Nyiro 2848m



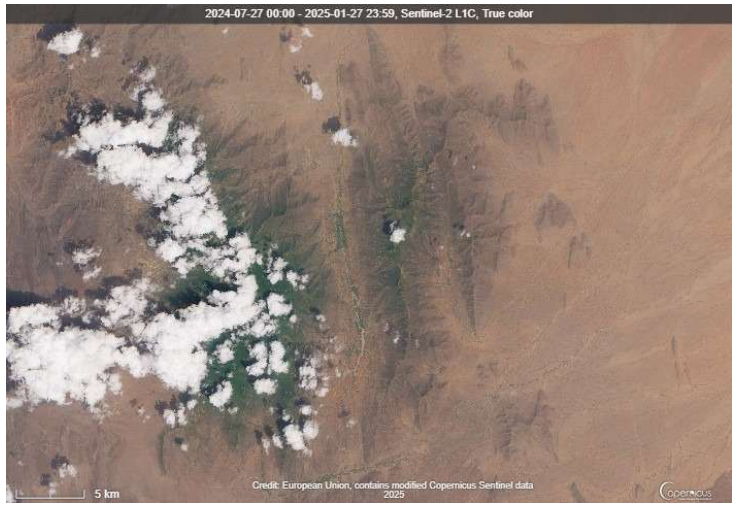
8/2/25

9/2/25

Nyiro is green

Mara is brown

European Union Copernicus Sentinel-2_L1C satellite images (200m resolution)



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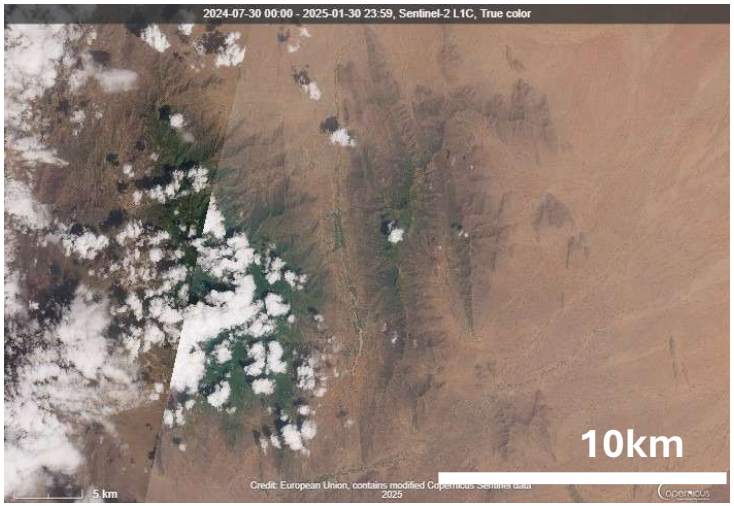
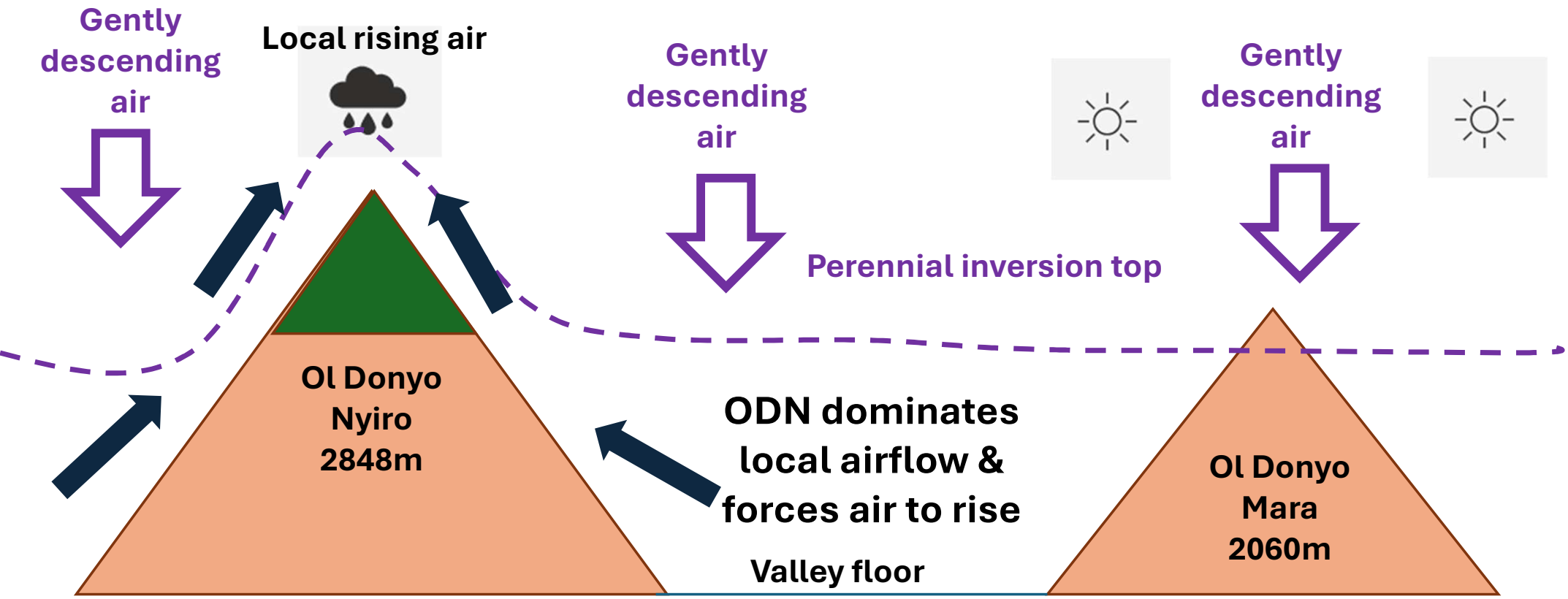


30/1/25

“The cloud forest” is a unique ecosystem in its own right

But what may be happening...

...inversion locally rises above ODN..?



-> wx station data and analyses of WRF will tell us more...

Conclusions and next stages: Kenya

- Best sites **NE of the Rift Valley**, with **E/NE prevailing wind off desert**
- **Reanalyses** indicate **reasonably favourable conditions ~8-9 months/year**
- **Dust** an issue below inversion; **inversion** close to highest summits **(2,000-4,000m**)
- **Remote** areas are difficult to access, however
- **The 3 automatic weather stations** will help to characterise each site
- Future **DARA African Masters student** to analyse weather station data and compare with reanalyses and validate weather models
- **Climate Change:** we are now the **weather makers**…

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