MOLECULAR PROFILES ABOVE THE CTA SITES

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CHERENKOV TELESCOPE ARRAY (CTA)

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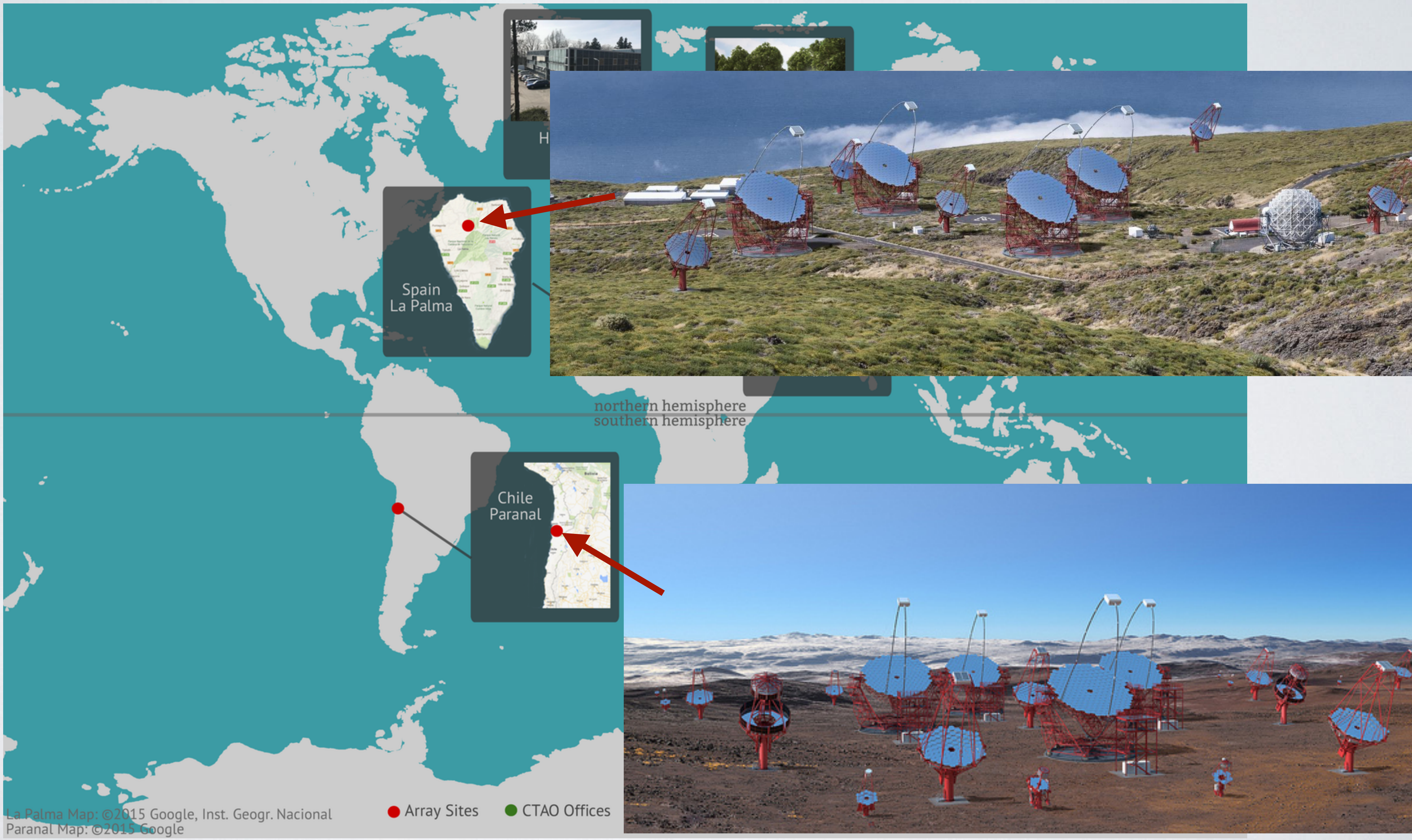
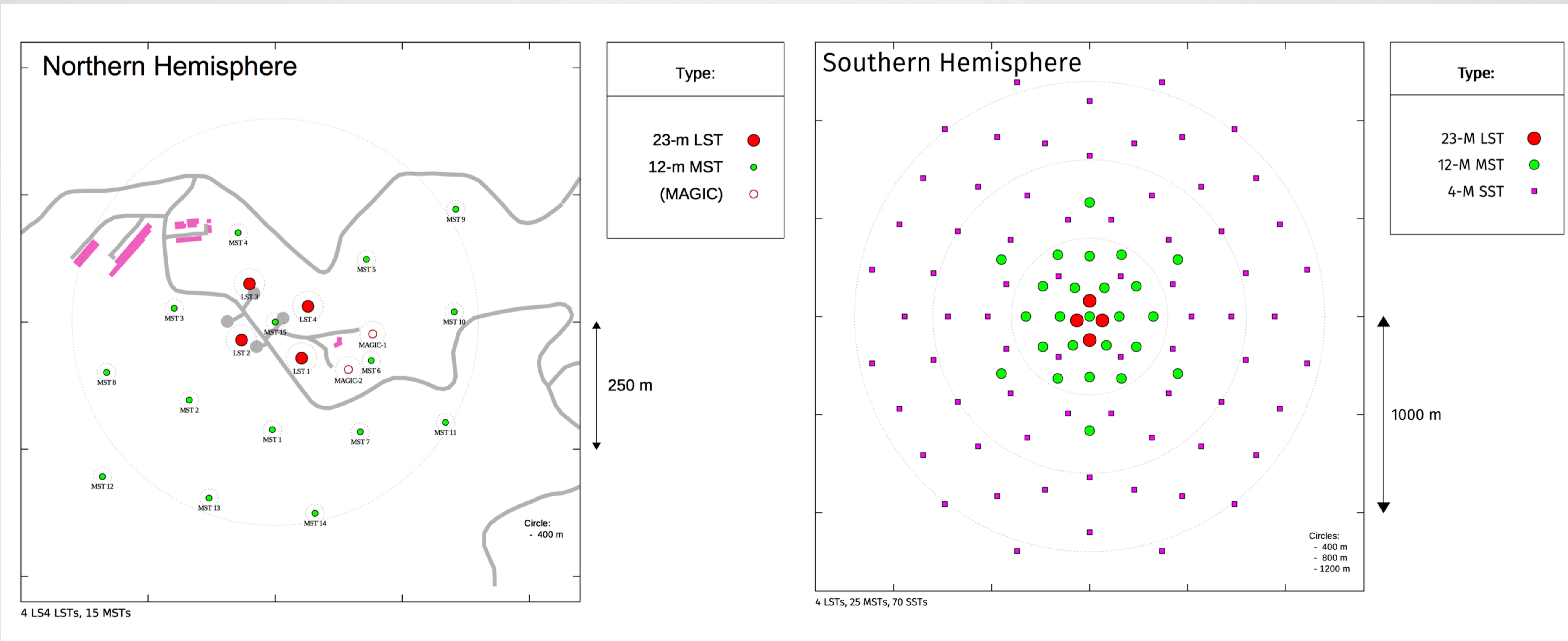


CHERENKOV TELESCOPE ARRAY (CTA)



CHERENKOV TELESCOPE ARRAY (CTA)

- Observe Cherenkov light from particle cascades
- Use atmosphere as calorimeter
  - Molecular content and aerosols affect transmission of Cherenkov light
  - Need for good characterization

COMPARED GLOBAL DATA ASSIMILATION MODELS

- GDAS Final analysis
- ECMWF ERA-Interim

} Study density profiles at different heights, select the best model and to check wether a single epoch was enough to describe the atmosphere

- MERRA-2
- CFRS

} Their reanalysis do not cover recent years

THE GDAS MODEL

- Model goes from 0 to 25 km with 26 pressure levels. 4 values per day for each variable
- The NCEP final analysis (GDAS) models can be downloaded from the web:

  ftp://arlftp.arlhq.noaa.gov/pub/archives/gdas1/
  - Not a reanalysis
- ~~Downloading all data means about 2.4 GB per month~~
- ~~A fortran code then allows to pick the corresponding grid point~~ (on a 1° grid)
  - Python script to select and download GDAS final analysis location specific data (2.5 Mb per month)
  - Many parameters available
- Grib files need to be read just once (slow to read. Python pygrib). We then transform to dataframe files

THE ECMWF MODEL

- Model goes from 0 to 50 km with 37 pressure levels and many parameters available (wind dir., rel. humidity, vorticity, T…). 4 values per day for each variable
- The ECMWF ERA Interim (reanalysis) data can be downloaded from:
  - https://www.ecmwf.int/en/research/climate-reanalysis/era-interim
- Registration on ECMWF needed
- The web server allows to pick the corresponding grid point (on a 0.75° grid)
- Downloading, once selected for La Palma or Paranal site, means about 7 Mb per month (done with a python script; only works with python 3.5)
- Grib files need to be read just once (slow to read. Python pygrib). We then transform to dataframe files

GDAS VS ECMWF

Table 1: Data assimilation systems overview

	ERA-Interim	GDAS
Availability	1979 - present	2006 - present
Grid spacing	0.75°	1.0°
Temporal resolution	6 h	6 h
Selected dataset time span	2012/01 - 2016/12	2012/01 - 2016/12
Closest grid point North	28.5°N 18.0°W	29.0°N 18.0°W
Closest grid point South	24.75°S 70.5°W	25.0°S 70.0°W
Pressure levels	37	26

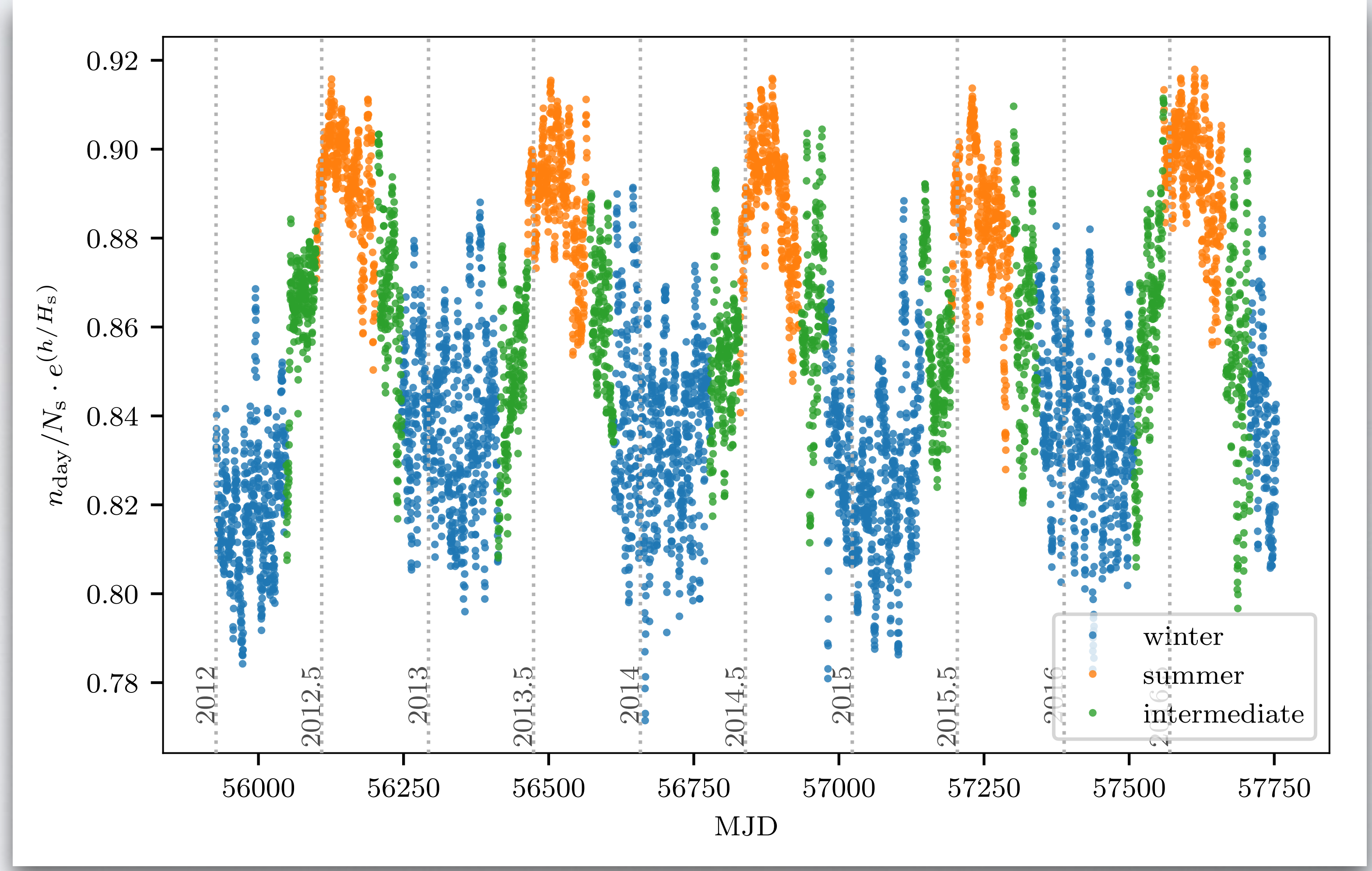
CHECKS ON THE MODEL

- Analyzed 5 years of data: from 2012-01-01 to 2016-12-31
- Compared to atmospheric models used in latest CTA instrument simulations (PROD3)
- Compared North and South sites density at 15 km a.s.l. where seasonal variations are largest
- Always selected data with good weather conditions: RH < 90% and low wind conditions on ground level
- Produced input files for simulations package (CORSIKA)

ECMWF NORTH SITE

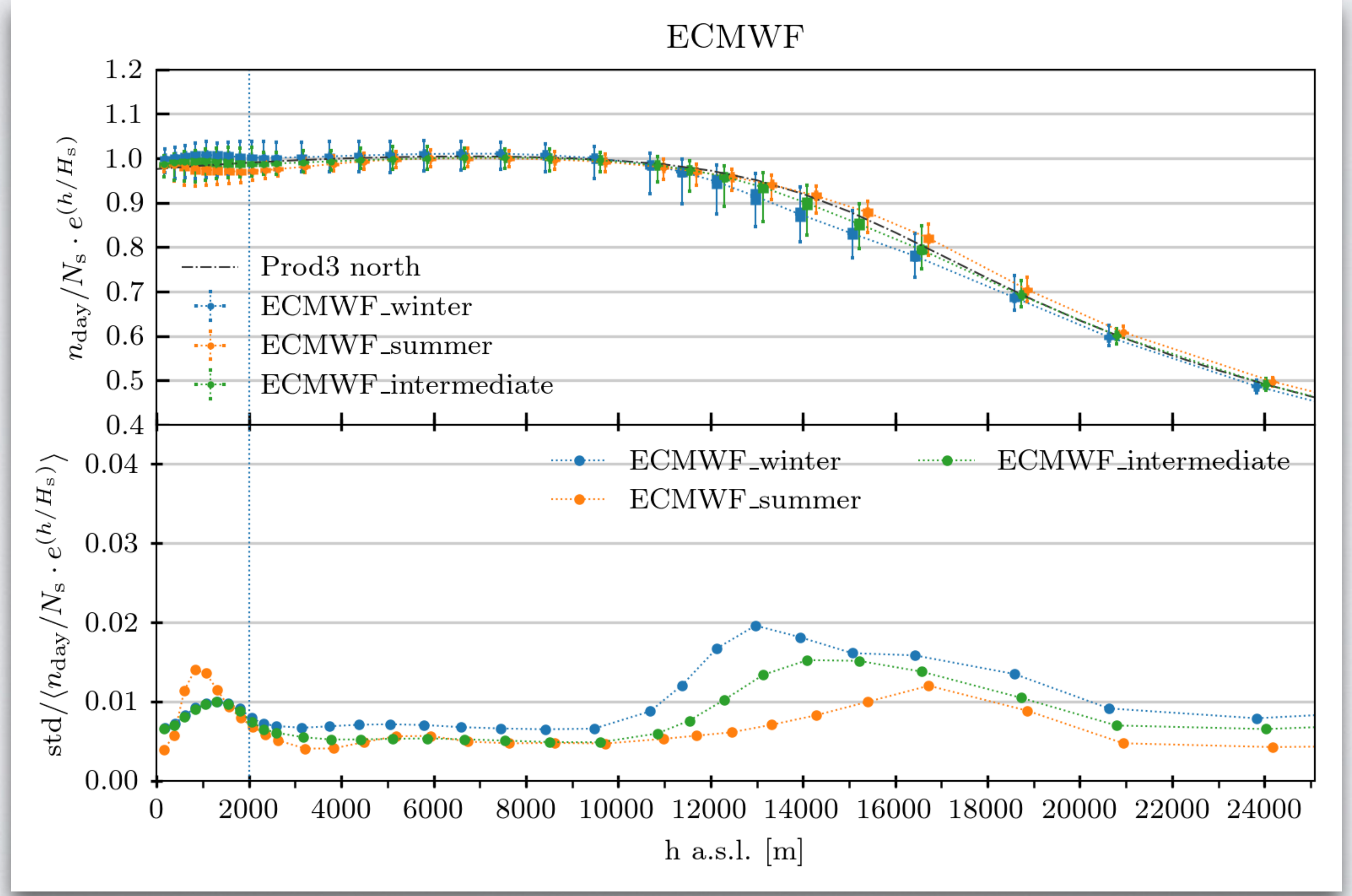
- 2012 to 2016 density at 15 km. We define 3 seasonal periods (W, S, I)

- Winter: Jan, Feb, Mar, Apr, 15-30 Nov, Dec
- Summer : 20 Jun, Jul, Aug, 1-15 Sep
- Intermediate: May, 1-19 Jun, 15-30 Sep, 1-15 Nov
  - October is a complicated month



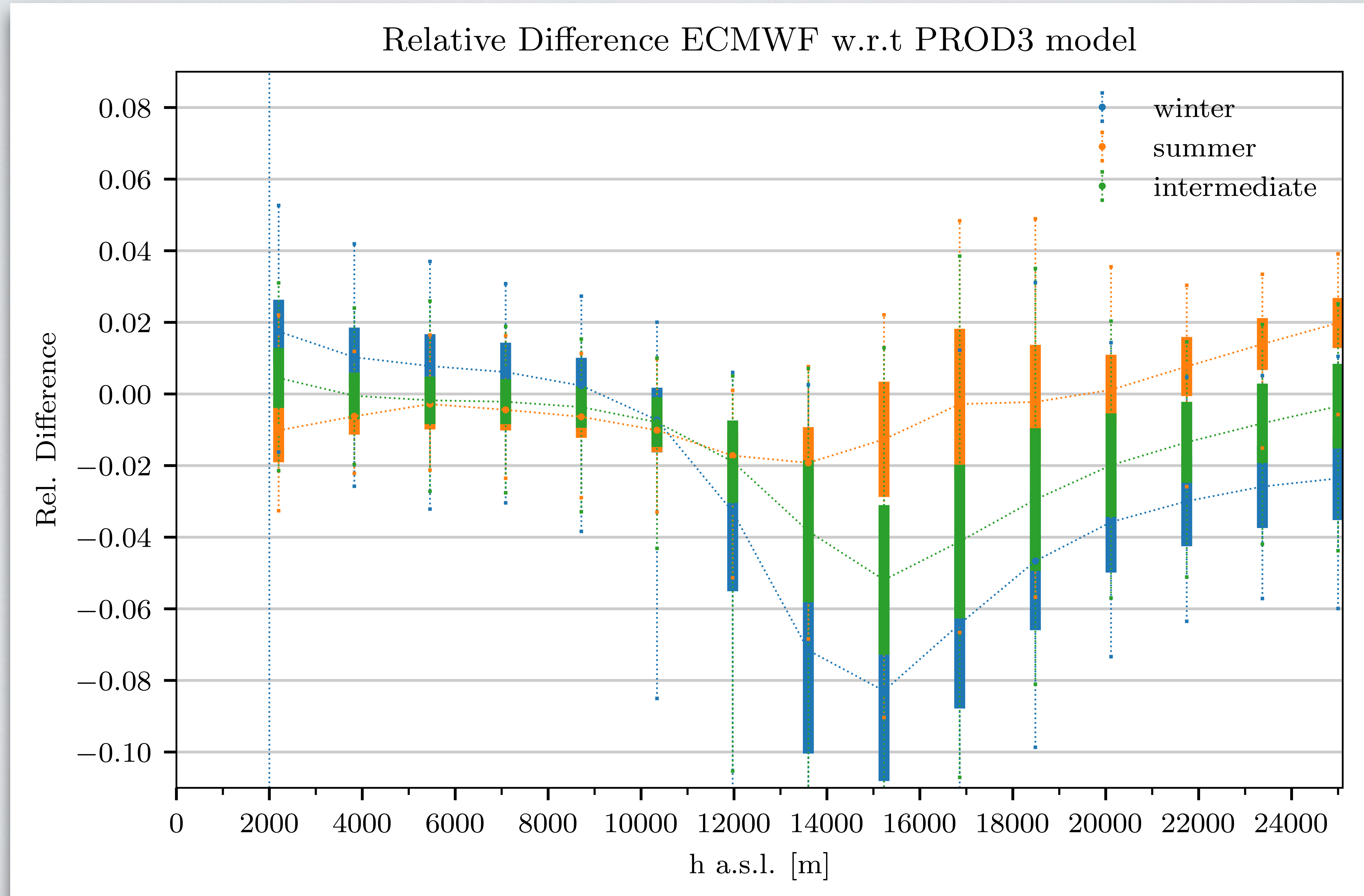
ECMWF NORTH SITE

- Averaged density over time for every height level
- Thick error bars represent standard deviation of the distribution
- Thin error bars represent peak to peak extremes
- Seasonal variations clearly visible above 12 km



ECMWF NORTH SITE

Relative difference w.r.t. PROD3

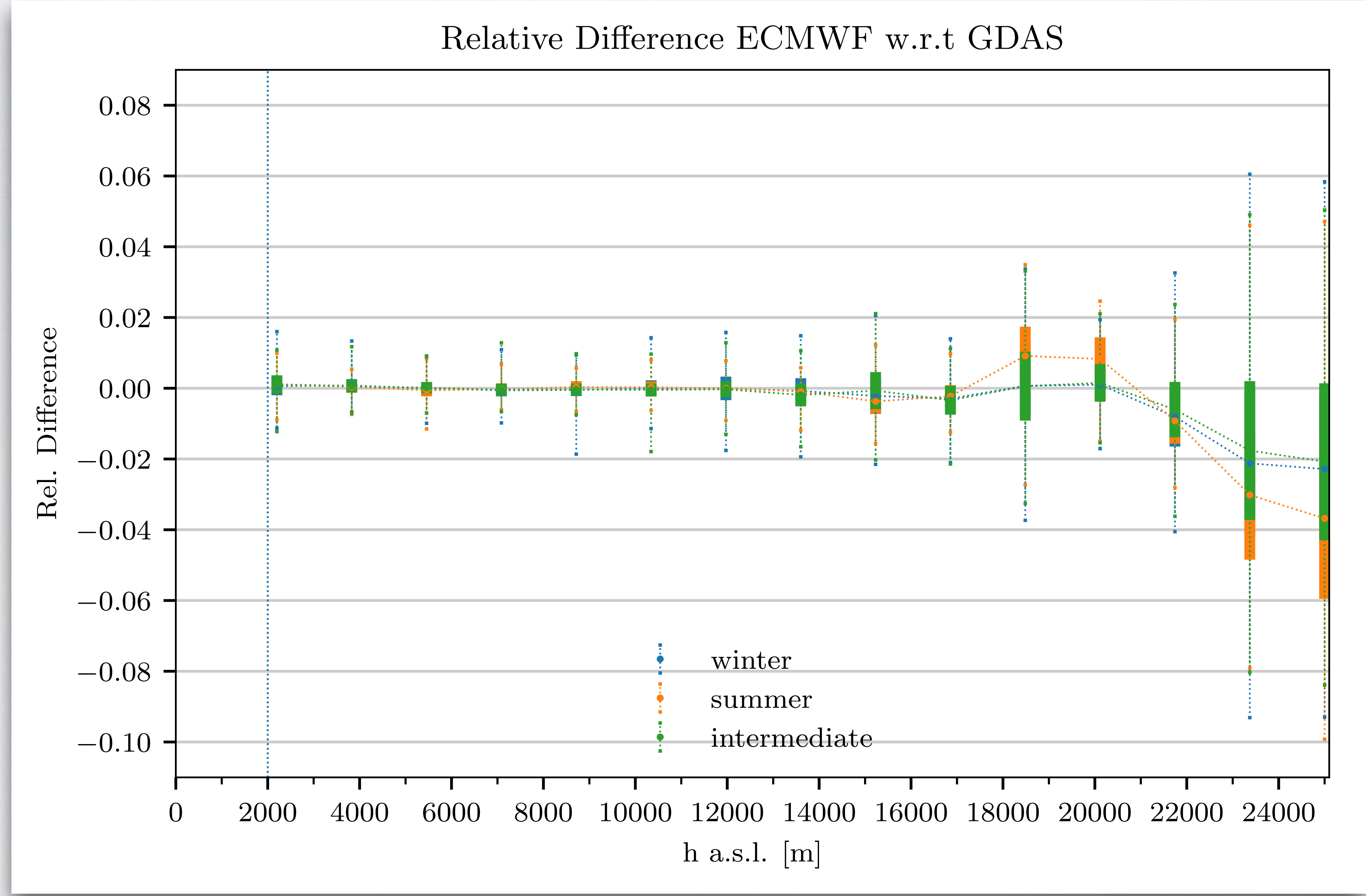


NORTH SITE

Relative difference between ECMWF and GDAS

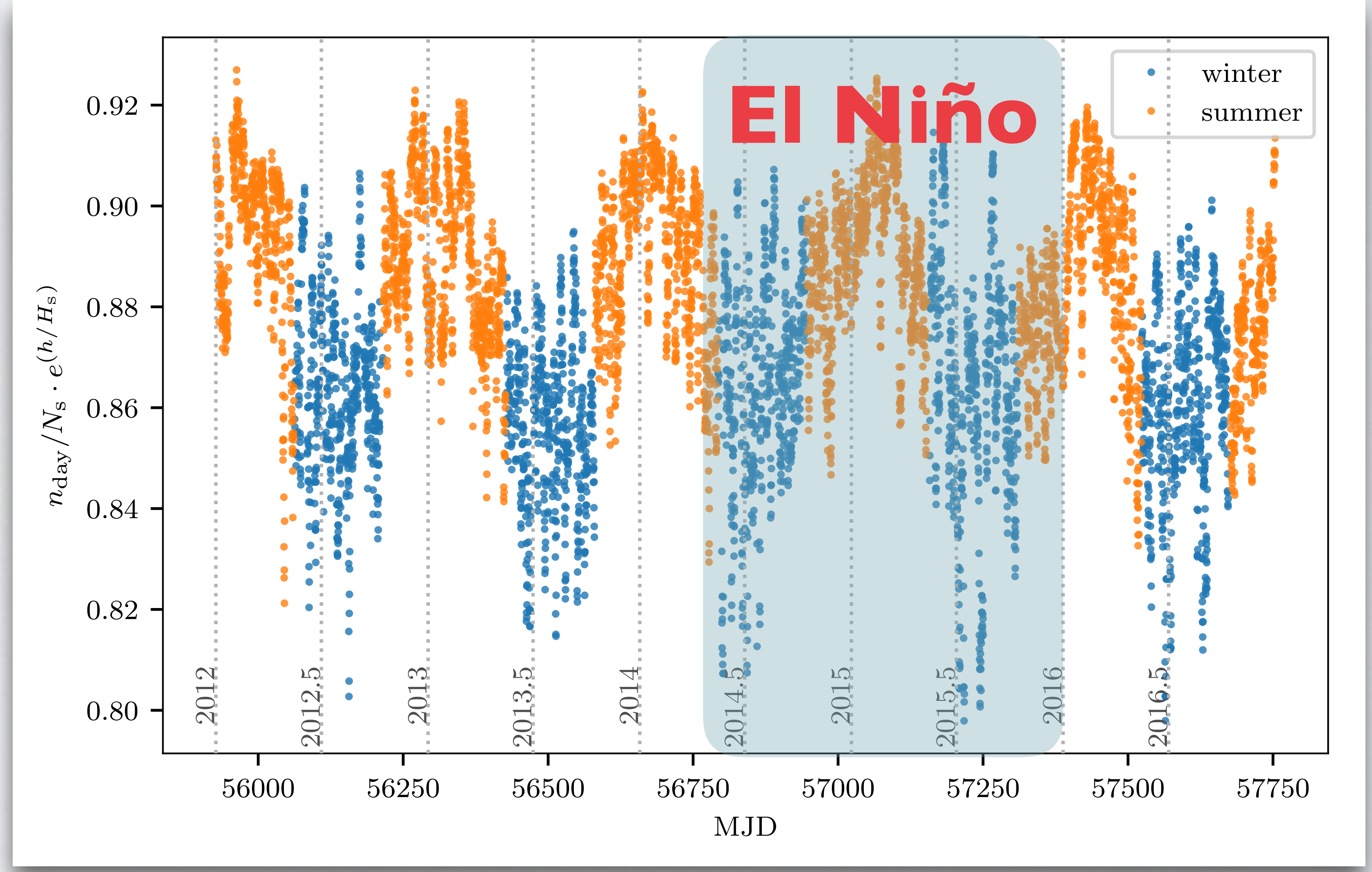
Small up to 20 km

GDAS not optimal for stratosphere



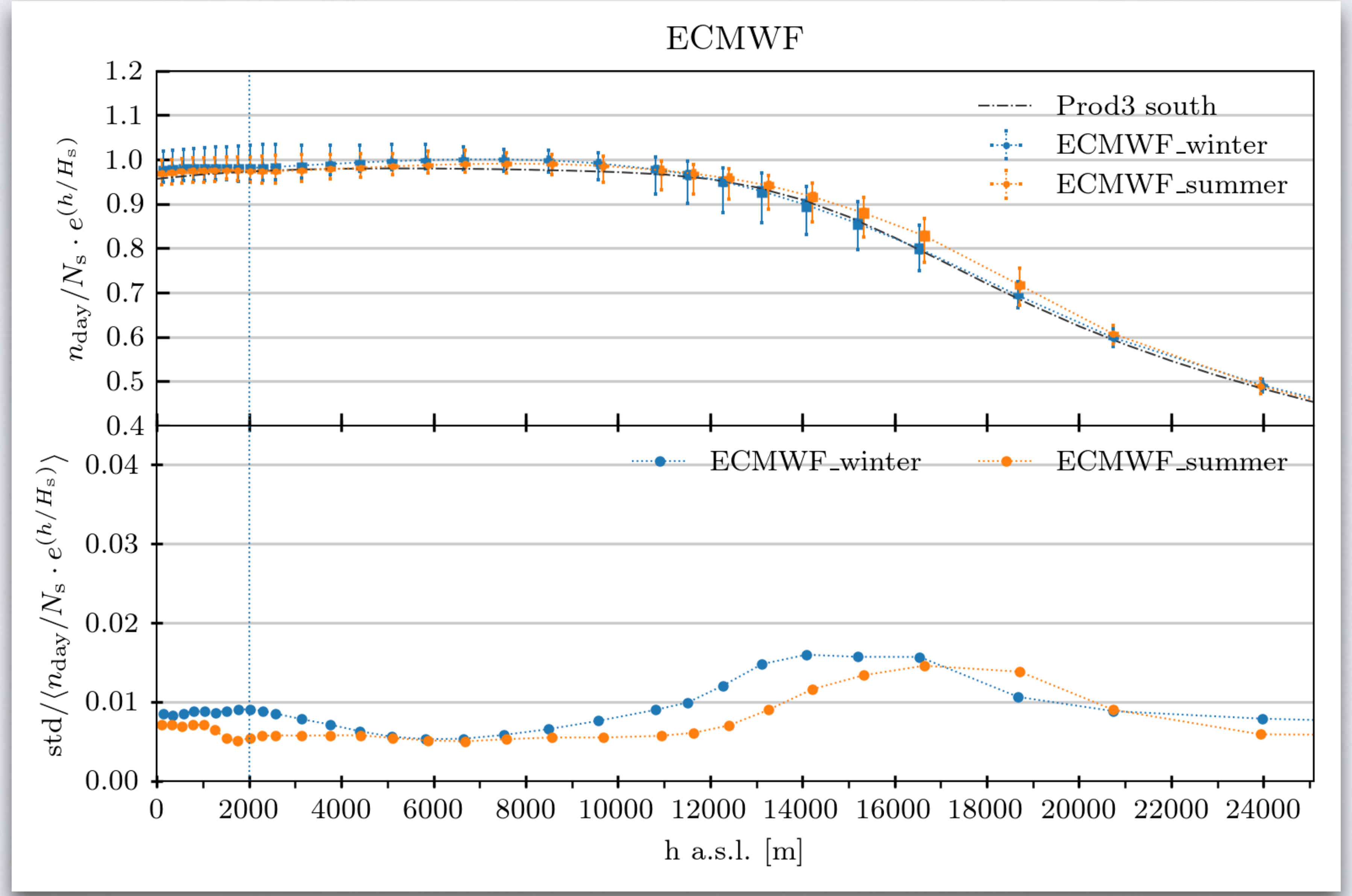
ECMWF SOUTH SITE

- 2012 to 2016 density at 15 km. We define 2 seasonal periods (W, S)
- Winter: 15-31May, Jun, Jul, Aug, Sept, 1-15 Oct
- Summer: Jan, Feb, March, 1-15May, 15-31 Oct, Nov, Dec
- Less amplitude than in North



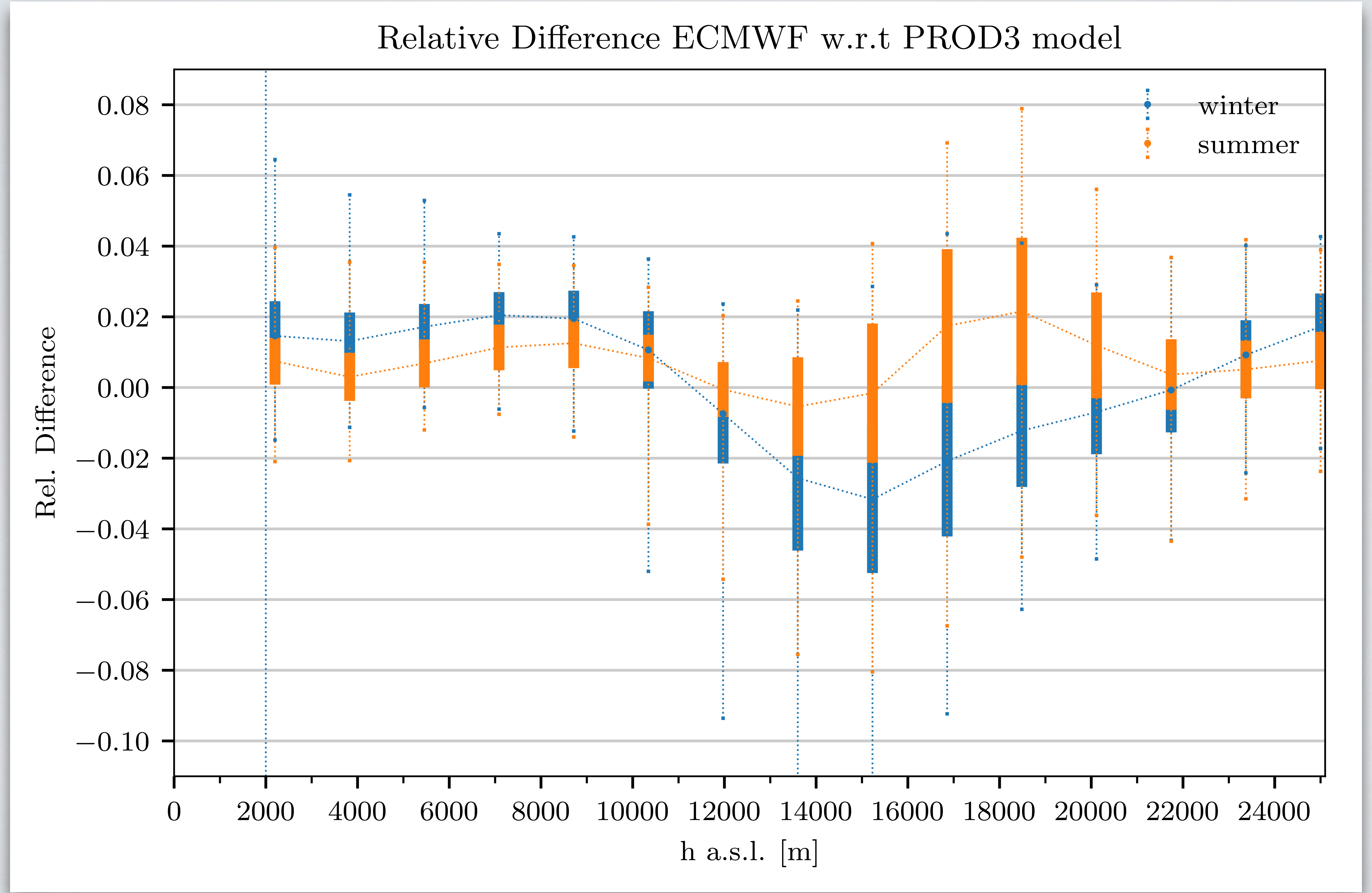
ECMWF SOUTH SITE

- Averaged density over time for every height level
- Thick error bars represent standard deviation of the distribution
- Thin error bars represent peak to peak extremes
- Seasonal variations clearly visible above 10 km



ECMWF SOUTH SITE

Relative difference w.r.t. PROD3

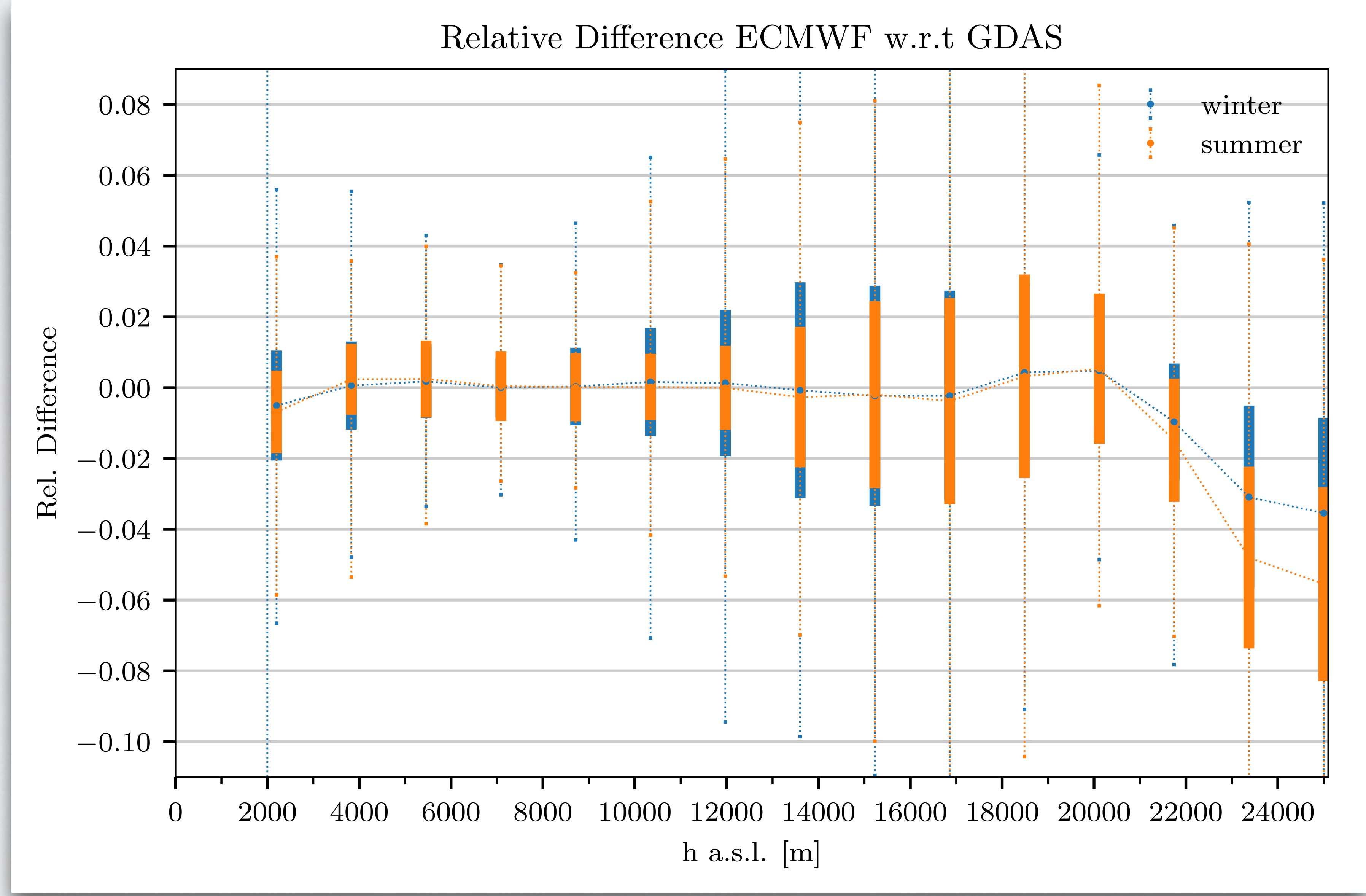


NORTH SITE

Relative difference between ECMWF and GDAS

Bigger than in the North

Less coverage by radio-sondes



ECMWF CORSIKA INPUT FILE

Produced Corsika input file

- For each site
- For each epoch
- For extreme values in the density profiles

Produce MC and check differences between epochs in reconstructed E, among other quantities

Table 1: Example of Corsika input file. South summer

Altitude [km]	ρ [g/cm^3]	thick [g/cm^2]	n-1	T [K]	P [mbar]	pw / p
0.0	1.18×10^{-3}	1.03×10^{3}	2.75×10^{-4}	2.98×10^{2}	1.01×10^{3}	2.31×10^{-2}
1.0	1.07×10^{-3}	9.18×10^{2}	2.49×10^{-4}	2.93×10^{2}	9.00×10^{2}	1.80×10^{-2}
2.0	9.58×10^{-4}	8.17×10^{2}	2.23×10^{-4}	2.91×10^{2}	8.01×10^{2}	1.32×10^{-2}
3.0	8.63×10^{-4}	7.27×10^{2}	2.01×10^{-4}	2.88×10^{2}	7.13×10^{2}	6.55×10^{-3}
4.0	7.79×10^{-4}	6.45×10^{2}	1.82×10^{-4}	2.83×10^{2}	6.33×10^{2}	3.16×10^{-3}
5.0	7.06×10^{-4}	5.71×10^{2}	1.65×10^{-4}	2.76×10^{2}	5.60×10^{2}	4.06×10^{-3}
6.0	6.38×10^{-4}	5.04×10^{2}	1.49×10^{-4}	2.70×10^{2}	4.95×10^{2}	1.49×10^{-3}
7.0	5.76×10^{-4}	4.44×10^{2}	1.35×10^{-4}	2.63×10^{2}	4.35×10^{2}	6.38×10^{-4}
8.0	5.19×10^{-4}	3.90×10^{2}	1.21×10^{-4}	2.56×10^{2}	3.82×10^{2}	9.75×10^{-4}
9.0	4.66×10^{-4}	3.41×10^{2}	1.09×10^{-4}	2.49×10^{2}	3.34×10^{2}	1.06×10^{-3}
10.0	4.19×10^{-4}	2.97×10^{2}	9.78×10^{-5}	2.42×10^{2}	2.91×10^{2}	1.01×10^{-3}
11.0	3.76×10^{-4}	2.57×10^{2}	8.78×10^{-5}	2.34×10^{2}	2.52×10^{2}	5.63×10^{-4}
12.0	3.35×10^{-4}	2.22×10^{2}	7.83×10^{-5}	2.26×10^{2}	2.17×10^{2}	1.92×10^{-4}
13.0	2.98×10^{-4}	1.90×10^{2}	6.96×10^{-5}	2.18×10^{2}	1.87×10^{2}	6.99×10^{-5}
14.0	2.63×10^{-4}	1.62×10^{2}	6.14×10^{-5}	2.11×10^{2}	1.59×10^{2}	3.33×10^{-5}
15.0	2.30×10^{-4}	1.38×10^{2}	5.36×10^{-5}	2.05×10^{2}	1.35×10^{2}	1.74×10^{-5}
16.0	1.99×10^{-4}	1.17×10^{2}	4.65×10^{-5}	2.00×10^{2}	1.14×10^{2}	1.21×10^{-5}
17.0	1.72×10^{-4}	9.82×10^{1}	4.01×10^{-5}	1.95×10^{2}	9.63×10^{1}	9.83×10^{-6}
18.0	1.46×10^{-4}	8.25×10^{1}	3.41×10^{-5}	1.93×10^{2}	8.09×10^{1}	8.25×10^{-6}
19.0	1.22×10^{-4}	6.93×10^{1}	2.85×10^{-5}	1.94×10^{2}	6.79×10^{1}	8.74×10^{-6}
20.0	1.01×10^{-4}	5.83×10^{1}	2.35×10^{-5}	1.98×10^{2}	5.71×10^{1}	1.08×10^{-5}
21.0	8.25×10^{-5}	4.92×10^{1}	1.93×10^{-5}	2.04×10^{2}	4.82×10^{1}	9.42×10^{-6}
22.0	6.82×10^{-5}	4.17×10^{1}	1.59×10^{-5}	2.09×10^{2}	4.09×10^{1}	2.63×10^{-6}
23.0	5.69×10^{-5}	3.56×10^{1}	1.33×10^{-5}	2.13×10^{2}	3.49×10^{1}	5.72×10^{-10}
24.0	4.80×10^{-5}	3.05×10^{1}	1.12×10^{-5}	2.17×10^{2}	2.99×10^{1}	7.73×10^{-6}
25.0	4.07×10^{-5}	2.61×10^{1}	9.50×10^{-6}	2.19×10^{2}	2.56×10^{1}	1.62×10^{-5}

CONCLUSIONS

- Investigated long-term variations in the molecular density profiles above both CTA sites
- By observing density at 15 km:
    - Smoother transitions between seasons and smaller amplitude in South
    - This allows us to propose 3 seasonal periods in the North site and 2 in the South

- Comparing density profiles:
    - Confirmed that one seasoal period does not describe well the atmosphere
    - Differences between the defined seasonal periods and the PROD3 simulations model:
        - PROD3 is more consistent with the *summer* seasonal period in the North and with the *winter* in the South
        - Differences between our profiles and PROD3 can be as large as 9%

- Differences between GDAS and ECMWF are of a ~%
- Created CORSIKA input files for each site and epoch and for selected extreme cases

Future prospects:

- Produce MC with new input cards and evaluate the differences in reconstructed energy.
- Implement in CTA Pipeline (CTApipe)
- Drafting a paper