Tell me where and when, can I tell you your Na?

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May the Na be with you

1. Why trying to set a model of Na?
2. Na density at Paranal latitude
3. Getting more data for a global Earth model
4. Yearly model
5. Sun cycle
6. Conclusions
• AO developments are often using one number of return flux for LGS, with some boundaries.

• Short-term, medium-term, long-term evolutions not much integrated. Partly due to lack of data in the AO instrumentation community.

• Instruments developments take 10+ years, with then operation for 15+ years. Long-term variations are important.

• Optimisation of night planning knowing the possible return flux in coming weeks/months.

• Observatories at different locations on Earth; need to consider also this parameter.

• Can we develop a SW program to predict the Na column abundance and its standard deviation as a function of the following parameters:
  • Latitude, longitude.
  • Day of the year.
  • Year (capture the influence of the Sun cycle; climate change? Other effects?).
Desperately seeking data @ 23S

- Mix of data found:
  - From observatories: GALACSI/GRAAL + LPC, Haguenauer+ 2022, Paranal; Neichel+ 2013, Gemini, Cerro Pachón.
  - From LIDARs: Simonich+ 1979, São José dos Campos, Brazil; ALO sodium Lidar, Cerro Pachón.
  - From atmosphere studies: SCIAMACHY (Scanning Imaging Absorption Spectrometer for Atmospheric Chartography); Langowski+ 2017; Andrioli+ 2019.
  - From atmosphere models: WACCM (Whole Atmosphere Community Climate Model).
• SCIAMACHY (SCanning Imaging Absorption spectrometer for Atmospheric CHartography) instrument on ESA’s environmental research satellite ENVISAT. Measurements twice per month for a full day each, between 75km and 150km.
• Langowski model based on SCIAMACHY, GOMOS and OSIRIS satellite data.
• Important database of LIDAR data exists. Publicly available.
• Very different locations on Earth.
• But time coverage and frequency of measurements very variable between locations.
LIDAR data

- ALOMAR: Covering a good range of time, but only few measurements.
- ARECIBO: Covering a good range of time, but only few measurements.
- UCB: Good amount of data, but not covering a big range of time. Not enough time range to fit a Sun cycle.
Yearly semi-empirical model from Langowski+ 2017. Global level of the model adjusted to reflect the global one of Paranal each year. Comparison for three complete years of Paranal measurements:

- 2018: similar evolution but Paranal trend in advance of phase to the model.
- 2019: increase of the Na coherent with the model but decrease starting earlier.
- 2022: good match.

There might be other effects in the atmosphere leading to these phasing differences.
Sun cycle and Na?

But does the Sun cycle really influence the Na layer or not?

Lidar data: 1972-1987
• No measurable solar cycle effect.

Lidar data: 1972-1994
• 10-year solar cycle effect on the change of centroid height with an amplitude of 170+/−110 m.

Lidar data: 1972-2001
• Negligible amplitude for an 11-years fit on the centroids data.
• Important month to month variations of the centroid heights, but no long-term trend.

Lidar data: 1972-2001
• Fit with 7- and 14-years harmonics, with amplitudes of 182+/−95 m and 145+/−94 m.

Meteor radar data: 2000-2005
• Evolution of height distribution of meteor trails shows an 11-years trend, amplitude of 540 m.
Sun cycle effect.

- Fit including annual, semi-annual, and Sun cycle effects:
  \[ N_{\text{fit}} = \alpha + \delta F_{30} + A \cos(2\pi t + t_2) + B \cos(4\pi t + t_4) \]
- With F30 the 30 days moving average of the solar radio flux at F10.7cm (in FSU).
- Fitting gives a relative sensitivity to the Sun cycle of **16.5% per 100 SFU**.
Can we derive the Sun cycle effect into a model for the Paranal latitude with a shorter time coverage?

Paranal and SCIAMACHY data for 23S combined.

Same model for the fit as the CSU+USU data. Weights for fitting between high and low Na adjusted due to incomplete Sun cycle.

Fitting gives a relative sensitivity to the Sun cycle of 9% per 100 SFU (45% per 100 SFU if fitting SCIAMACHY only).
Conclusions

- Na density can be retrieved from AO telemetry data. Automatic logging allows generating a very good dataset.
- More data sets available from other observatories, LIDAR measurements, Earth atmosphere observation satellites. But it is not always easy to combine the datasets and be sure they compare.
- Annual and semi-annual models in good agreement with measurements, available for all latitudes.
- Sun cycle influence found in some data set around the world, but not much reported and quantified.
- Computed Na column abundance matches atmosphere studies:
  - Seasonal variations linked to temperature
  - 11 years cycle correlated to Sun activity
  - Semi-annual variations linked to dynamic and chemistry of the Mesosphere
- Many more effects can affect the Na density: Meteor showers, gravity waves propagation in the atmosphere, sudden stratospheric warmings, anomalies in the Earth magnetic field, global warming, ... .
- Statistics of Na density available for development of future instruments.
Thank you!

This is the LGS way...