TIMED Science Highlight and Significant Discovery

SABER Data Help Citizen Scientists Explain Formation of the Newly Discovered “Dune” Aurora

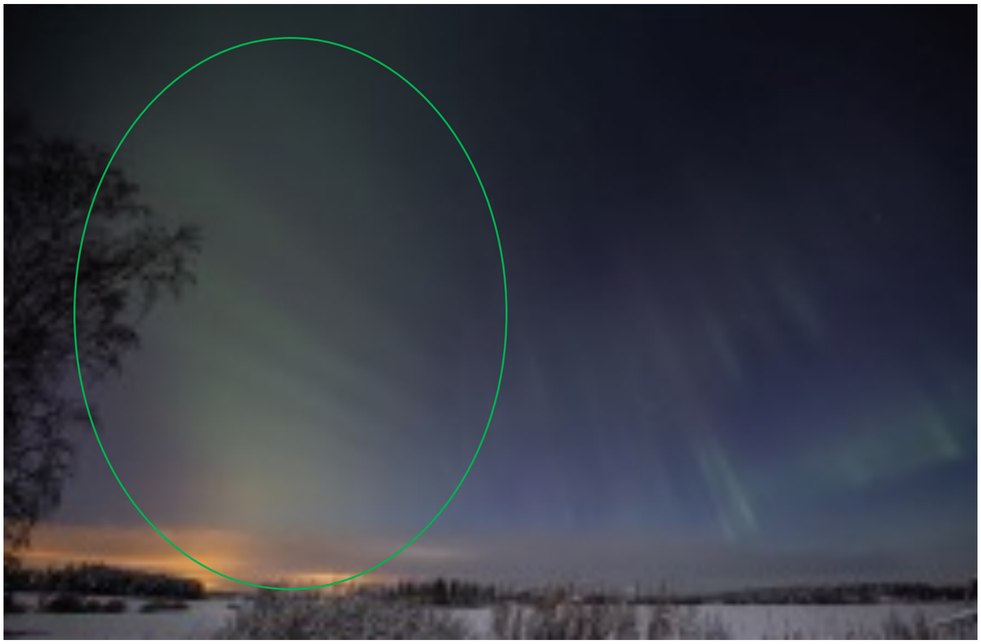


Image of a ‘dune’ aurora within the green oval. These features were photographed by a citizen scientist in Finland in February 2016, as described in the Reference below.

Science Finding: A new type of aurora was discovered recently by Citizen Scientists in Europe. The shape and appearance of these aurora are similar to dunes of sand on a beach and hence these new features are now called ‘dune’ aurora. SABER data was used in part to diagnose the mechanisms responsible for these ”dunes” at 100 km altitude.

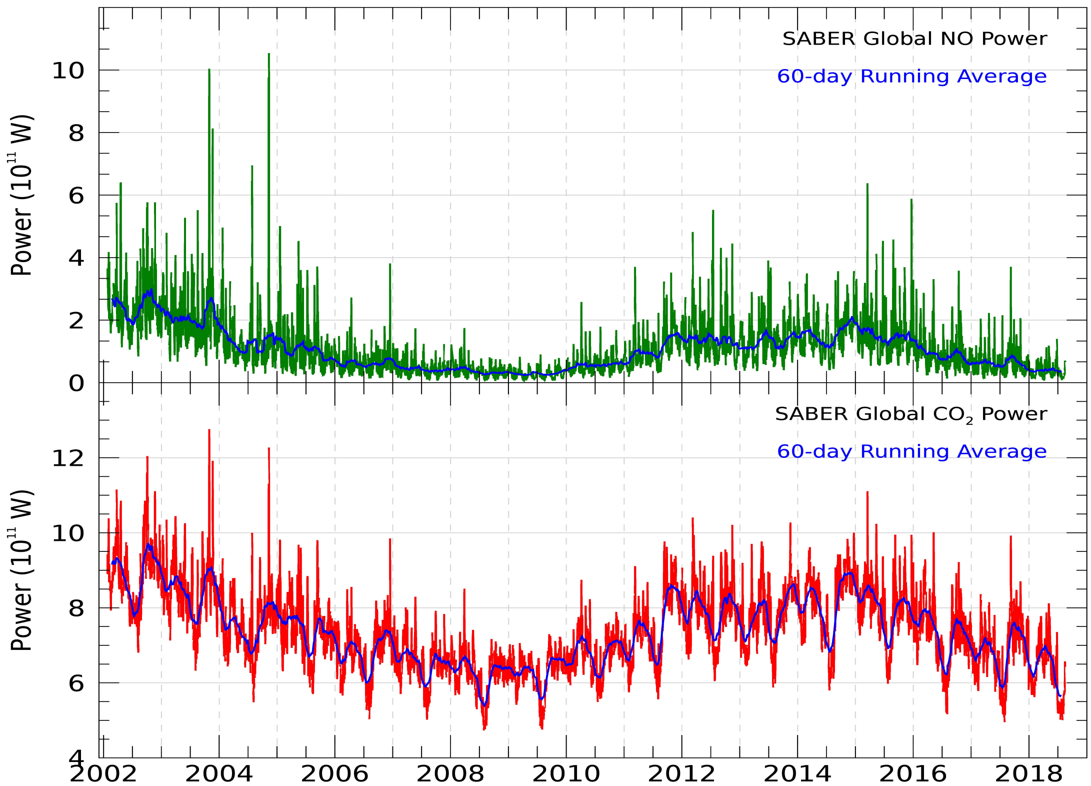
Significance: Aurorae have fascinated people for years. The discovery of a new type of aurora after decades of observations was unexpected. SABER data were used to diagnose the atmospheric conditions that could lead to the development of these beautiful and newly-observed aurora. Specifically, the analysis using SABER temperatures indicates that a ’bore’, a type of wave disturbance flowing through the atmosphere below 100 km, is likely responsible for the formation of the dunes.

Impact: Aurorae and bores are still not completely understood phenomena. The discovery and diagnosis of the dune aurora adds new knowledge. This work also demonstrates that new discoveries can by made by Citizen Scientists who thensuccessfully work with professional scientists to investigate their causes.

Reference: Grandin, M., Palmroth, M., Whipps, G., Kalliokoski, M., Ferrier, M., Paxton, L. J., et al. (2021). Large-scale dune aurora event investigation combining Citizen Scientists' photographs and spacecraft observations. AGU Advances, 2, e2020AV000338. https://doi.org/10.1029/2020AV000338

TIMED Science Highlight and Significant Discovery

SABER Chronicles Radiative Cooling of Thermosphere and Response to Solar and Geomagnetic Activity



Time series of SABER daily global power (Watts) radiated from the thermosphere in the infrared by nitric oxide (green, top frame) and by carbon dioxide (red, bottom frame).

Science Finding: SABER measures infrared radiative cooling of the thermosphere by infrared emission from carbon dioxide and nitric oxide. These emissions regulate the temperature of the thermosphere and are the balance to energy input from the Sun. The results above show the daily global power (W) radiated by these two molecules above 100 km. They illustrate variability on timescales from days to decades.

Significance: SABER data illustrate for the first time the relative roles of carbon dioxide and nitric oxide in the energy budget of the thermosphere. The data also show the extraordinary variability of the radiative cooling. The response to geomagnetic storms in 2003 and 2004 showed the infrared cooling increasing by more than an order of magnitude in the space of a day! The data also show that cooling by nitric oxide can vary by an order of magnitude over the 11-year solar cycle.

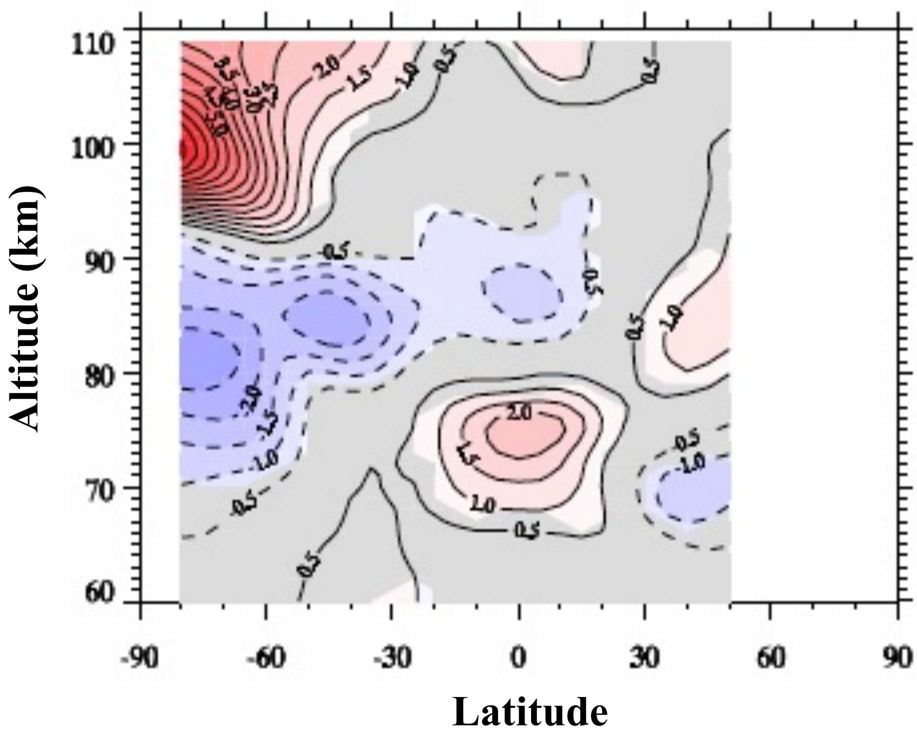
Impact: The SABER results provide a first-ever dataset to validate the fundamental processes that determine the structure of the thermosphere.

References:

Mlynczak, M. G., Hunt, L. A., Marshall, B. T., & Russell, J. M., III (2018). Infrared radiation in the thermosphere near the end of solar cycle 24. Geophysical Research Letters, 45. https://doi.org/10.1029/2018GL080389.

TIMED Science Highlight and Significant Discovery

SABER Observes Effects of El-Nino in Lower Thermosphere



SABER observations of the influence of the El-Nino Southern Oscillation (ENSO) on temperatures in the southern hemisphere mesosphere and lower thermosphere in December. Substantial warming in the 95 to 110 km range and cooling in the 70 to 95 km range.

Science Finding: With its long data record, SABER has observed several cycles of the El-Nino Southern Oscillation (ENSO). From these observations analysis of SABER temperatures shows a marked warming in the southern hemisphere lower thermosphere (red in upper left of the figure) and a cooling of the upper mesosphere (blue in center left of the figure) during ENSO.

Significance: The ENSO is a well-known tropospheric phenomenon in which tropical sea surface temperatures and cloud patterns shift markedly and significantly influence surface weather patterns across the Earth. The discovery that the effects of ENSO extend to the edge of space was unexpected and unprecedented.

Impact: Simulations of the effects of ENSO by the WACCM model of the National Center for Atmospheric Research confirm the SABER observations. The result is another example of how strong an influence the troposphere exerts on the near-space environment.

References: Li, T., N. Calvo, J. Yue, J. M. Russell III, A. K. Smith, M. G. Mlynczak, A. Chandran, X. Dou, and A. Z. Liu (2016), Southern hemisphere summer mesopause responses to El-Nino Southern Oscillation, *J. Climate*, doi: 10.1175/JCLI-D-15-0816.1.

TIMED Science Highlight and Significant Discovery

TIMED Data Highlight Need for Long-Term Observations to Understand Geospace Environment

Eos, Vol.102, No. 5, May 2021

Science Finding: Long-term change is occurring throughout the terrestrial atmosphere from the Earth's surface to the edge of Space. TIMED data indicate increasing carbon dioxide is leading to a cooler upper atmosphere, which leads to a decrease in density at orbital altitudes up to 1000 km.

Significance: Decreasing density increases the lifetime of all objects in orbit, including space debris. With rapidly increasing numbers of satellites (and debris) the probability of debris collisions with high value space assets only increases. Understanding the long-term evolution of the geospace environment is essential. However, the region is facing a pending gap in measurements as aging satellites have no defined replacements.

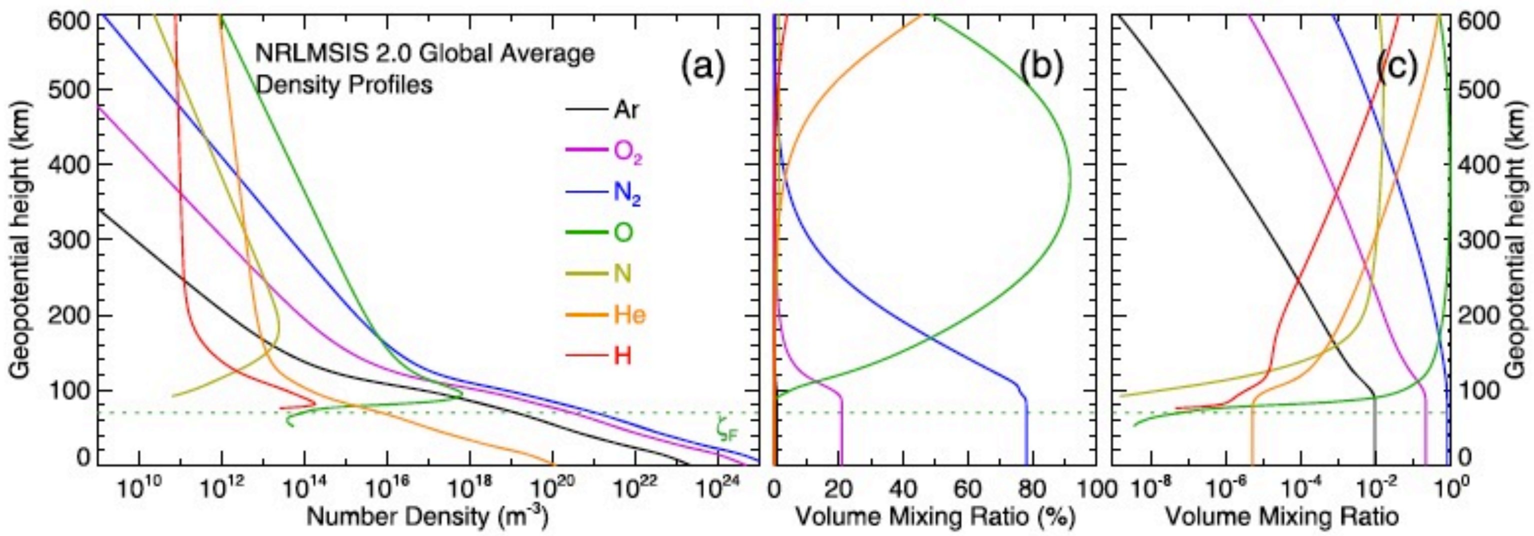
Impact: Space debris mitigation is already a major issue. The effects of climate change are just now being appreciated. The need for long-term measurements is becoming apparent. These issues will become increasing important in space policy, space law, and space insurance underwriting. An observation-based ability to predict long-term change appears essential.

References:

Mlynczak, M. G., J. Yue, J. McCormack, R. S. Liebermann, and N. J. Livesey (2021), An observational gap at the edge of space, *Eos, 102,* https://doi.org/10.1029/2021EO155494

TIMED Science Highlight and Significant Discovery

SABER Data Extensively Applied in New Version of Widely-Used MSIS Empricial Model



Example profiles of atmospheric species in the new MSIS 2.0 empirical model.

Science Finding: SABER temperature and composition data are extensively used to update the MSIS empirical model of mesospheric and thermospheric temperature and neutral composition. The new version is called MSIS 2.0.

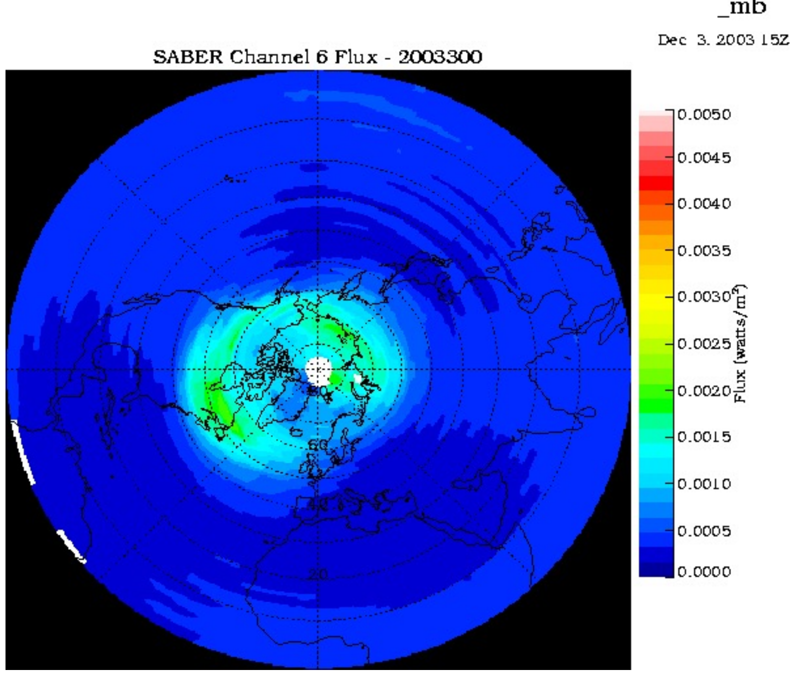
Significance: The MSIS empirical model is one of the most widely used community models in the fields of aeronomy, space weather, and space climate. The original version was developed in the 1980’s and the last significant revision was in the early 2000’s. MSIS 2.0 is a new version comprehensively updated with data from multiple satellites. SABER temperature, atomic oxygen, and atomic hydrogen data were used to develop the new version of MSIS.

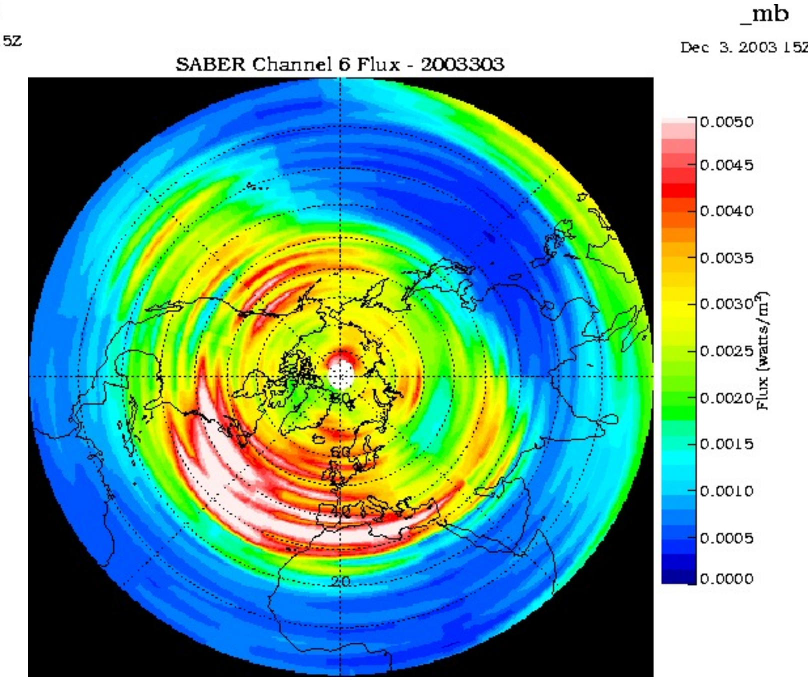
Impact: The peer-reviewed papers describing prior versions of MSIS are among the top 10 all-time most cited papers in the Journal of Geophysical Research-Space Physics. MSIS 2.0 presents an empirical model that comprehensively represents the latest and best data from multiple satellites including TIMED and SABER. For example, the new data in MSIS 2.0 accurately represents the long-term cooling of the mesosphere and lower thermosphere that has occurred over the last 20 to 30 years due to increasing CO_2 seen in SABER data. It is expected that MSIS 2.0 will be the standard community model for the next 20 years.

References: Emmert, J. T., Drob, D. P., Picone, J. M., Siskind, D. E., Jones, M. Jr., Mlynczak, M. G., et al. (2020). NRLMSIS 2.0: A whole-atmosphere empirical model of temperature and neutral species densities. Earth and Space Science, 7, e2020EA001321. https://doi.org/ 10.1029/2020EA001321

TIMED Science Highlight and Significant Discovery

SABER Discovers the Natural Thermostat Effect of Nitric Oxide





Flux (Watts per square meter) of energy emitted by nitric oxide before (left frame) and during (right frame) the geomagnetic storm of November 2004.

Science Finding: Infrared emission from nitric oxide (NO) acts as a ‘natural thermostat’ during highly disturbed conditions to cool the thermosphere (above 100 km). During these conditions, the thermosphere heats dramatically due to energy from the solar wind. We are used to seeing the aurora (“northern lights”) at visible wavelengths. SABER discovered an infrared aurora that sheds enormous amounts of energy, allowing the thermosphere to cool down in a few days.

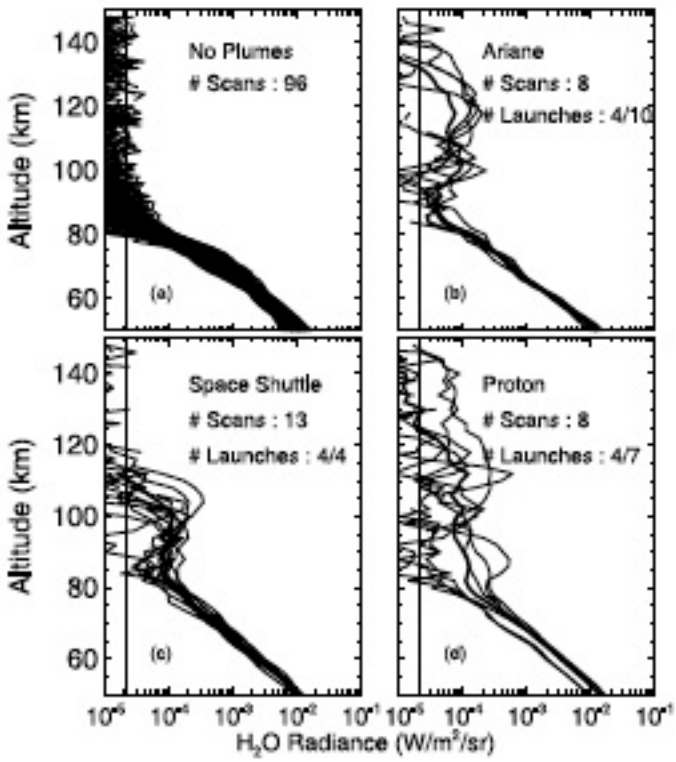
Significance: Earth’s thermosphere is strongly disturbed by geomagnetic storm events that cause incredible increases in temperature in less than one day. These events make forecasting positions of orbiting satellites and the International Space Station very difficult. Understanding the thermostat effect allows accurate forecasts of thermospheric density (”space weather”) and thus protects valuable space assets.

Impact: SABER observations of the natural thermostat of nitric oxide quantified this process for the first time. It led to identifying a mechanism not considered in space weather forecasts, causing them to fail during storm conditions. Methods to include the thermostat effect of nitric oxide are being developed and implemented in state-of-the-art forecast models.

References: Mlynczak, M., et al. (2003), The natural thermostat of nitric oxide emission at 5.3 μm in the thermosphere observed during the solar storms of April 2002, *Geophys. Res. Lett.*, 30, 2100, doi:10.1029/2003GL017693, 21.

TIMED Science Highlight and Significant Discovery

SABER Observes Water Vapor from Exhaust Plumes of Space Shuttle and Rocket Launches



SABER water vapor radiance profiles. Figure (a) shows a complete orbit of SABER data in the absence of rocket launches. Figures (b) to (d) show water vapor radiance signatures for launches of Ariane rockets, the Space Shuttle, and Proton rockets. The total number of SABER radiance scans is listed as is the number of launches during in which radiance enhancements were detected. For the Space Shuttle, radiance enhancements were detected in 4 of 4 launches observed.

Science Finding: SABER observed elevated levels of infrared radiance in its water vapor channel (6.8 micrometers in wavelength) at altitudes above where emission from water vapor is not normally observed. These elevated radiances were associated with exhaust plumes from rocket and Space Shuttle launches using liquid fuels.

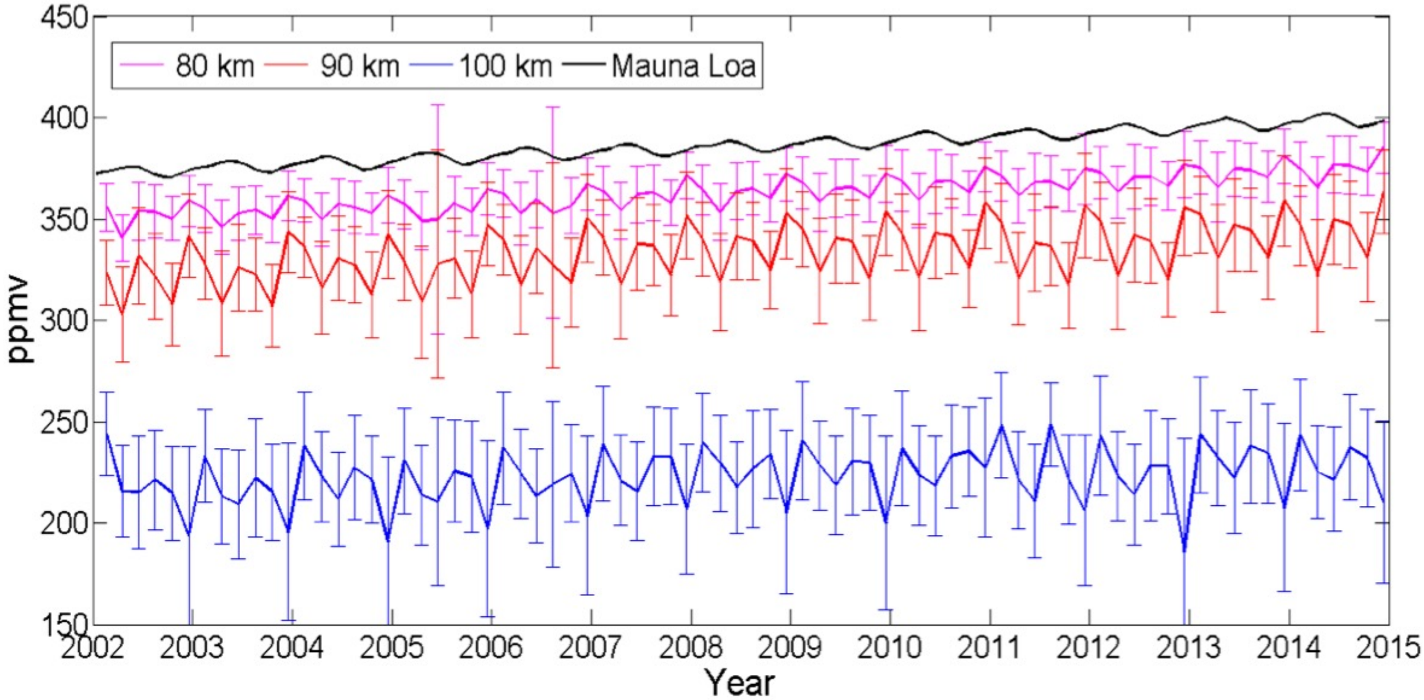
Significance: This unanticipated discovery confirmed the injection of significant amounts of water vapor into the mesosphere from rocket launches. In addition, assessment of the evolution and transport of the plumes provided a unique look at meridional and latitudinal dynamics of the mesosphere and lower thermosphere. By tracking the motion of the water vapor through the enhanced radiance, scientists discovered rapid transport of material in the lower thermosphere of which the direction had a distinct dependence on local time.

Impact: The dynamics of the mesosphere and lower thermosphere are still a frontier of research in middle atmosphere science as there are few measurements of wind in this region. The ability to track plumes of water vapor for several days allowed scientists to see dynamics of this region for the first time.

References: Siskind, D. E., Stevens, M. H., Emmert, J. T., Drob, D. P., Kochenash, A. J., Russell, J. M., Gordley, L. L., and Mlynczak, M. G. (2003), Signatures of shuttle and rocket exhaust plumes in TIMED/SABER radiance data, *Geophys. Res. Lett.*, 30, 1819, doi:10.1029/2003GL017627, 15.

TIMED Science Highlight and Significant Discovery

SABER Observes Increasing Carbon Dioxide in the Upper Mesopshere and Lower Thermosphere



Time series of increasing carbon dioxide at 80 km, 90 km and 100 km. The time series in black is the measured concentration of carbon dioxide at Earth's surface

Science Finding: SABER observes increasing carbon dioxide in the mesosphere and lower thermosphere (MLT, 80 to 100 km). The observed rate of increase is the same as at Earth's surface.

Significance: Increasing carbon dioxide at Earth's surface has been observed for over 60 years. Carbon dioxide has a very long lifetime and through atmospheric mixing processes eventually increases into Earth's atmosphere at all altitudes. The measurement and verification of carbon dioxide increasing the MLT represents a fundamental confirmation of of our understanding of the entire atmosphere.

Impact: Infrared radiation from carbon dioxide controls the thermal structure of the mesosphere, lower thermosphere (MLT) and the geospace environment. Increases in carbon dioxide are projected to cool these regions appreciably. Verification of the increasing carbon dioxide enables accurate predictions of future changes to the MLT and geospace. These predictions are essential for assessment of space debris lifetimes and mitigation.

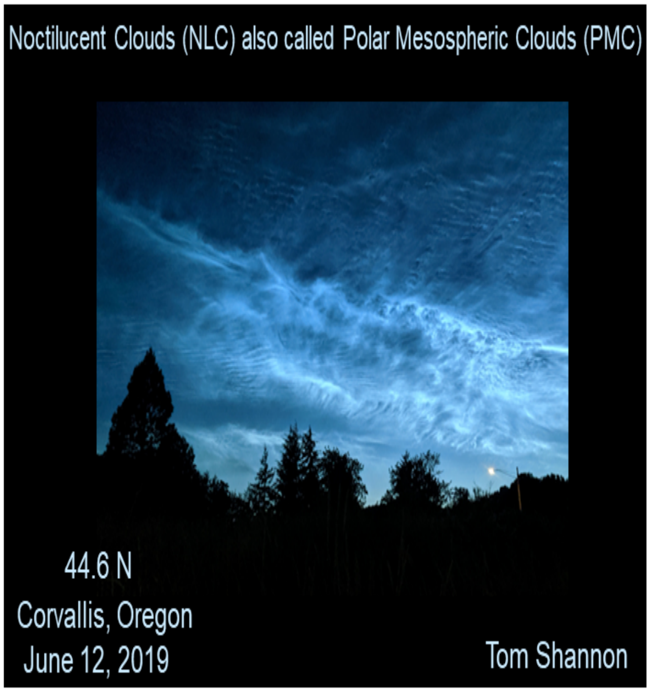
References:

Rezac, L., Yue, J., Yongxiao, J., Russell, J. M. III, Garcia, R., Lopez-Puertas, M., and Mlynczak, M. G. (2018).. Journal of Geophysical Research: Space Physics, 123. https://doi.org/10.1029/2018JA025892**.**

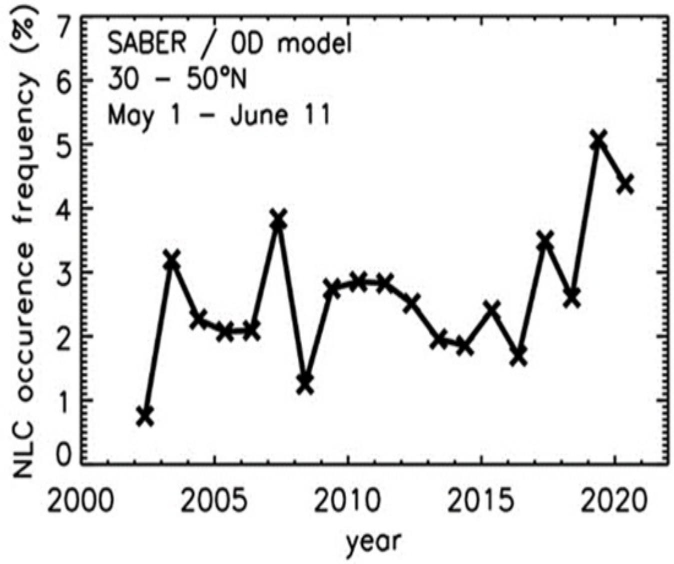
Yue, J., J. Russell III, Y. Jian, L. Rezac, R. Garcia, M. López-Puertas, and M. G. Mlynczak (2015), Geophys. Res. Lett., 42, 7194–7199, doi:10.1002/2015GL064696**.**

TIMED Science Highlight and Significant Discovery

SABER and AIM together reveal long-term MLT changes and new heliophysics processes



Noctilucent Clouds over Corvallis Oregon in 2019; A very active season



Long-term NLC increase at 83km, 30 – 50N, using SABER T and H_2O with the AIM model

Science Findings: The combined data sets show an increasing PMC frequency in the 30N-50N range over the last 19 years due to decreasing T and increasing H_2O; also the "normal" anti-correlation between PMC peak frequency and solar cycle changes has broken down in recent decades; PMC particle growth causes a significant decrease in atomic hydrogen near the polar summer mesopause and a local mesopause region ozone maximum; PMC formation is strongly affected by both vertically launched polar region gravity waves in the stratosphere and waves that obliquely propagate from the tropics.

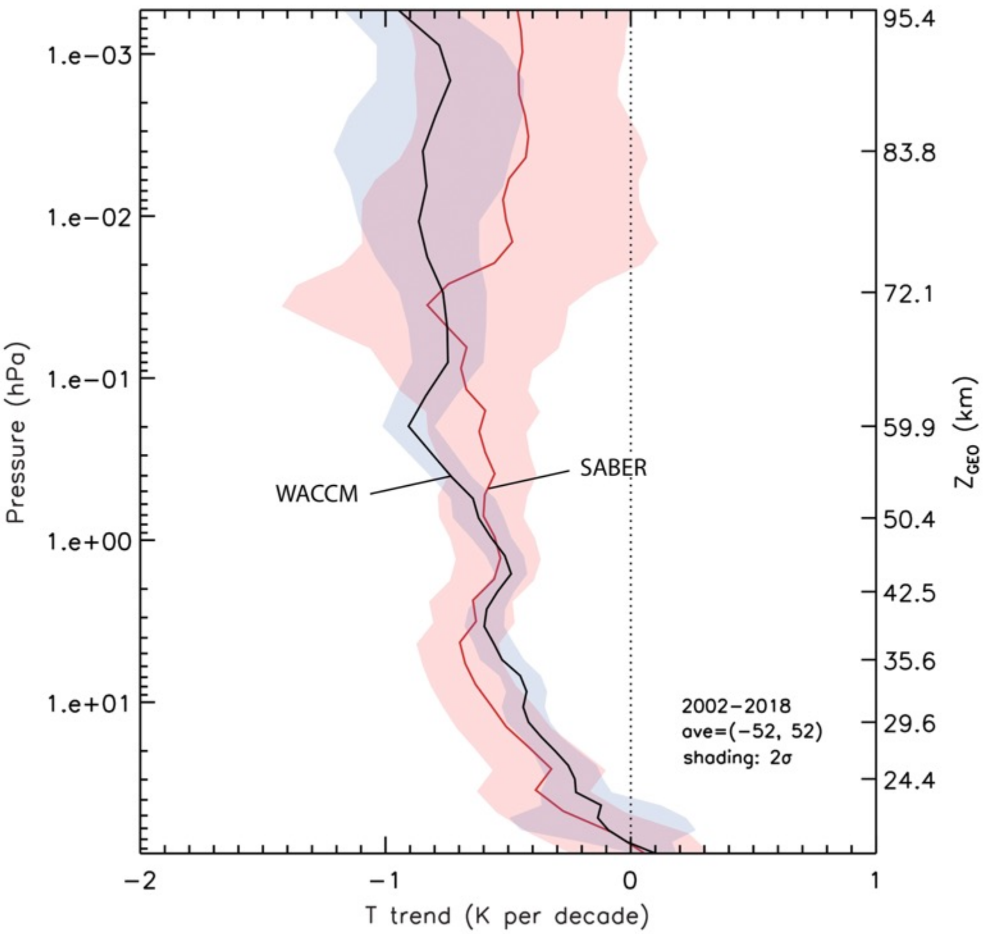
Significance: PMC, T and H_2O data combined suggest a changing MLT climate; Decadal scale PMC variability raises questions about our basic understanding of mesopause region Sun-Earth connections; PMCs have an important effect on MLT hydrogen chemistry and data show clear coupling between the MLT and stratosphere; combined low latitude and polar region dynamical coupling has a strong effect on PMC and other constituent variability.

Impact: These findings will have a strong effect on future research. Significant long-term changes in the MLT climate, questions about a fundamental Sun-Earth connection previously believed to be well known, and new results on MLT chemistry and dynamical coupling establishes the pathway for future work.

References: Hervig et al., 2019; Thurairajah et al., 2017;2020; Siskind et al., 2018

TIMED Science Highlight and Significant Discovery

SABER Observes Long-Term Cooling of the Mesosphere and Lower Thermosphere



SABER observed (red profile) and WACCM model calculations of trends in middle atmosphere temperature. The observed modeled trends agree to within their respective uncertainties

Science Finding: SABER has observed a long-term cooling trend over 17 years in the stratosphere, mesosphere, and lower thermosphere. The observed trend is between 0.5 K/decade and 0.7 K/decade above 30 km.

Significance: Increasing carbon dioxide in Earth's middle atmosphere is predicted to result in a cooling of the region. SABER observations confirm that the middle atmosphere is indeed cooling, thus validating one of the fundamental predictions of climate change theory. The observed trends also agree well with the trends predicted by the Whole Atmosphere Community Climate Model (WACCM) developed at the National Center for Atmospheric Research.

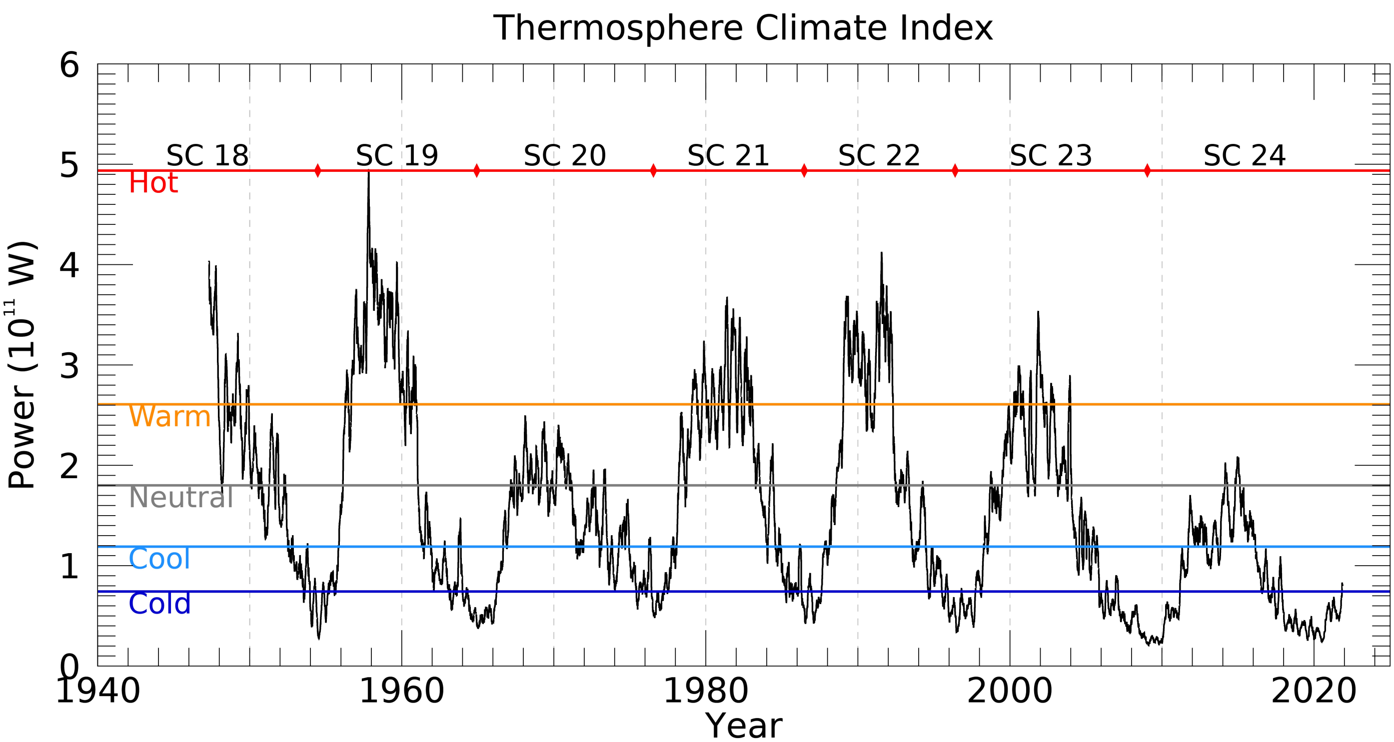
Impact: Observation and validation of the cooling trend in temperature represents a major scientific achievement in climate science over the past 30-plus years. It now gives scientists confidence in their model predictions for the evolution of the middle atmosphere, including evolution of ozone abundance as the ozone layer and ozone hole recover over the next 50 to 70 years.

Reference:

Garcia, R. R., Yue, J., & Russell, J. M., III (2019). Middle atmosphere temperature trends in the twentieth and twenty-first centuries simulated with the Whole Atmosphere Community Climate Model (WACCM). Journal of Geophysical Research: Space Physics, https://doi.org/10.1029/2019JA026909

TIMED Science Highlight and Significant Discovery

Thermosphere Climate Index (TCI)
A New Look at Climate Above 100 km



Science Finding:

The Thermosphere Climate Index (TCI) is developed from SABER measurements of infrared radiation emitted by the nitric oxide molecule above 100 km altitude (the thermosphere). The TCI represents amount of energy radiated by nitric oxide globally on a daily basis. The amount of energy depends non-linearly on temperature and on the nitric oxide abundance. It is extremely variable and may change by a factor of 10. The TCI is accurately computed from two other solar-terrestrial indexes, F10.7 and Ap.

Significance:

The TCI is a direct indicator of the global temperature of the thermosphere. With the dependence on F10.7 and Ap, the index is extended back in time to 1947 when these indexes were first recorded. We now have a 75+ year record of the daily thermal state of the thermosphere (Hot, Warm, Neutral, Cool, Cold)

Impact:

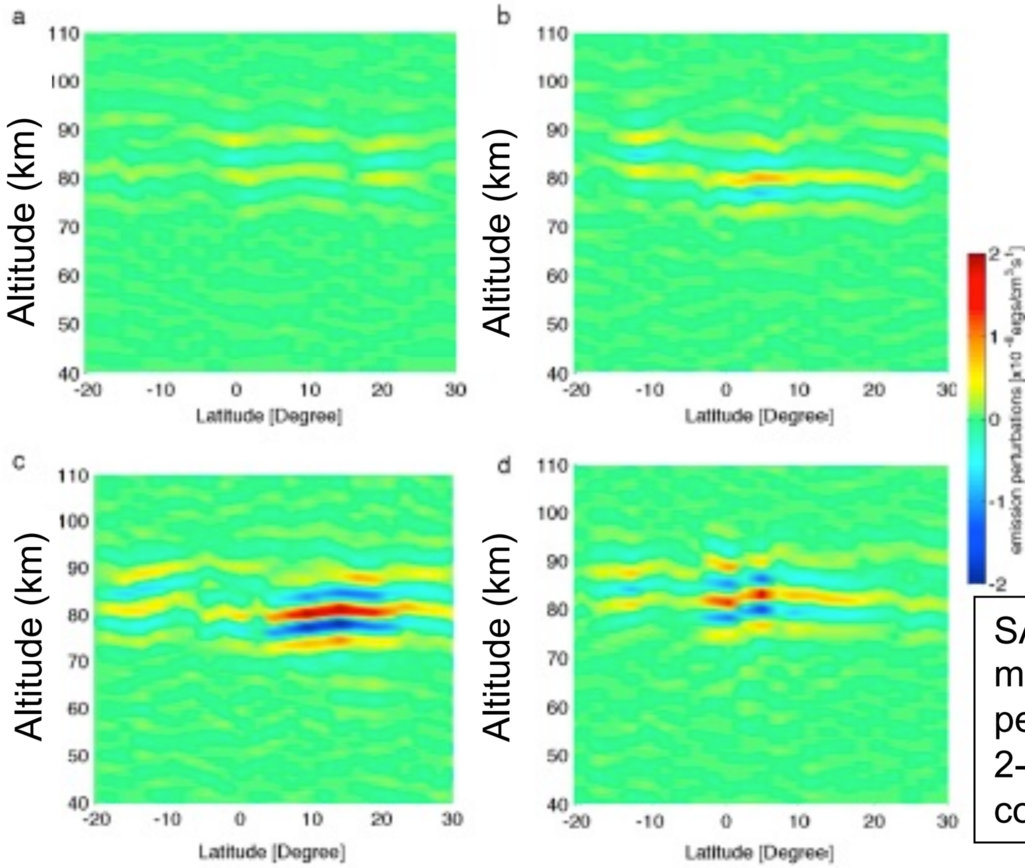
The TCI is now widely used as a monitor of short and long-term solar activity and its effect on the thermosphere. It is hosted on Spaceweather.com, a popular website for information about solar variability and the near-space environment

References:

Mlynczak, M. G., et al., (2015), A combined solar and geomagnetic index for thermospheric climate. *Geophys. Res. Lett.*, 42, doi: 10.1002/2015GL064038.

TIMED Science Highlight and Significant Discovery

SABER Observes Tsunami-Induced Perturbations to Mesospheric Airglow



SABER measurements of mesospheric 1.27 μm emission perturbations that are made by a 2-D cubic interpolation over the coherent variations of limb scans

Science Finding:

During and shortly after the Tohoku-Oki earthquake on 11 March 2011 and the Chile earthquake on 16 September 2015, SABER was viewing over the Pacific Ocean. Significant and coherent nighttime airglow ($O_2(^1\Delta)$ at 1.27 micrometers) were observed in the mesosphere and attributed to tsunami-induced atmospheric gravity waves.

Significance:

Mesospheric airglow perturbations due to tropospheric weather events have been frequently observed. However, this is the first time that airglow emission rate perturbations associated with tsunamis have been detected with space-based measurements.

Impact: These results show the influence that processes in the Earth's interior have on the Earth's atmosphere. The observations and analysis techniques pave the way for future space telescopes to study planetary seismology and planetary dynamics.

References: Yang, Y.-M., O. Verkhoglyadova,M. G. Mlynczak, A. J. Mannucci, X. Meng, R. B. Langley, and L. A. Hunt (2016), Satellite-based observations of tsunami-induced mesosphere airglow perturbations, Geophys. Res. Lett., 43, doi:10.1002/2016GL070764.