



Southern Argentina Agile MEteor Radar - Novel Atmospheric Sounding (SAAMER-NOVA): a new multistatic meteor radar network for large and small-scale atmospheric wave studies above Tierra del Fuego and Quasi-two-Day-Wave case study

Loretta Pearl Poku^{1,2}, Gunter Stober^{1,2}, Diego Janches³, Brian Fuller⁴, Daniel O'Connor⁴, Leandro Maslov⁵, Eric Marderwald^{5,6}, Jose Luis Hormaechea⁵, and Marcelo Colazo⁷

¹Institute of Applied Physics, University of Bern, Switzerland

²Oeschger Center for Climate Change Research, University of Bern, Switzerland

³Space Weather Laboratory, Mail Code 674, NASA Goddard Space Flight Center, Greenbelt, MD 20771, USA

⁴Genesis Ltd, Adelaide, Australia

⁵Estación Astronómica Río Grande, Río Grande, Tierra del Fuego, Argentina

⁶Centro MAGGIA, Facultad de Ciencias Astronómicas y Geofísicas, Universidad Nacional de La Plata, La Plata, Argentina

⁷Comisión Nacional de Actividades Espaciales, Buenos Aires, Argentina

Correspondence: Loretta Pearl Poku (loretta.poku@unibe.ch)

Abstract. The Southern Argentina Agile MEteor Radar - Novel Atmospheric Sounding (SAAMER-NOVA) is the newest meteor radar network, an advancement to the SAAMER project, which has been operational since May 2008. The SAAMER-NOVA became fully operational in October 2025, using a monostatic meteor radar situated at Rio Grande (67.8° W, 53.8° S), alongside two passive receiver systems near the town of Tolhuin (67.1° W, 54.5° S) and the border crossing Radman (68.6° W, 54.0° S), south and west of Rio Grande, respectively. These remote receiver stations form an almost perfect rectangular triangle, which optimises measurement response, and the angular diversity permits analysis of small-scale divergent and vortical structures. This network successfully provides measurements with a default 15-30 min temporal resolution in the mesosphere and lower thermosphere (MLT). Daily meteor echoes detected at SAAMER-NOVA are approximately 20,639, with the highest counts at Tolhuin, followed by Radman and then Rio Grande. This extensive meteor detection permits the retrieval of spatially resolved, high-resolution three-dimensional wind fields from this network using sophisticated retrieval models such as 3DVAR+DIV, VVP, and SVVP. In this paper, we describe the statistics and cross-site validation of SAAMER-NOVA wind products spanning from October 2025 to January 2026 and 1st - 31st January 2026, respectively. We present snapshots of tomographic wind reconstructions retrieved from 3DVAR+DIV, Altitude-Time Wind (ATW) profiles, and zonal and meridional keograms of latitudinal and longitudinal cross-sections. The ATW Figures reveal diurnal variations and several wave activities across the region. The motivation for deploying the SAAMER-NOVA network at the southern tip of Argentina is to expand and enhance atmospheric measurements in a region recognised as a hotspot for atmospheric gravity wave (GW) activity. This strategic positioning at the southern tip of the Andes enables unique, advanced observations of MLT dynamics and the first imaging meteor radar network in Tierra del Fuego. The new SAAMER-NOVA capabilities provide a pathway to benchmark



existing circulation models for small-scale GW dynamics over one of the world's most significant GW source regions and to
20 guide investigations into the multistep vertical coupling between atmospheric layers.

1 Introduction

The mesosphere and lower thermosphere (MLT) is a region driven by a complex range of atmospheric waves and tides that span diverse temporal and spatial scales (Andrews et al., 1987). This region exhibits active atmospheric dynamical processes, with interactions of large-scale (atmospheric tides and planetary waves) and small-scale (gravity waves) atmospheric waves
25 (Fritts and Alexander, 2003; Liu, 2016). These wave activities and their interactions are the primary mechanisms driving variabilities in the MLT. The major variability at larger vertical and horizontal scales is attributed to planetary waves and tides, which propagate largely without significant attenuation from their source regions at the troposphere and stratosphere into the MLT and above. These waves and their interactions primarily serve as fundamental agents of energy and momentum transport, driving variability in the upper mesosphere and thermosphere by carrying these quantities from their source regions to locations
30 where they dissipate (Liu, 2019). The forcing and variability of the MLT are primarily driven by gravity waves (GWs), which generate significant vertical fluxes of horizontal momentum that govern MLT dynamics. Their breaking and dissipation deposit energy and momentum, leading to local flow accelerations, mixing, and feedback that results in an interhemispheric coupling and drives the summer mesopause temperatures far away from their radiative balance. This residual circulation provides a crucial transport mechanism critical for understanding trace gas transport and coupling among atmospheric layers, influencing
35 the atmospheric thermal and dynamical structure (Smith, 2012; Becker, 2012). Consequently, accurate measurement of neutral atmospheric winds is essential for investigating the dynamics in this region.

These dynamics have been studied using lidar, radar, and satellite measurements for years, thereby accounting for the major large-scale variability in the MLT. Observation and investigation of large-scale and small-scale dynamics are crucial for understanding and identifying the diverse processes that govern atmospheric variability, particularly in the MLT, where dynamics
40 are driven by energy and momentum fluxes. Passive optical instruments are designed to observe airglow emissions, which have revealed a rich tapestry of small-scale gravity waves and turbulent structure at the mesosphere and lower thermosphere (MLT) region (Taylor et al., 1997; Hecht et al., 2014; Sedlak et al., 2023; Zhang et al., 2025). These observations provide valuable insights into the morphology and evolution of wave phenomena at altitudes of approximately 80 to 100 km. However, a significant limitation of airglow observations is that the intrinsic parameters of gravity waves (e.g., frequency, phase speed, and momentum flux) cannot be accurately and reliably derived without knowledge of the background wind field. The observed wave characteristics are a combination of intrinsic wave properties and Doppler shifts induced by the ambient winds, making wind measurements essential for a proper wave characterisation (Smith et al., 2017; Sarkhel et al., 2022a). For the past three decades, monostatic meteor radars have become operational and measure winds and meteor fluxes in the MLT, thereby enabling measurements of horizontal wind components for investigations of atmospheric dynamics (Hocking et al., 1997, 2001;
45 Holdsworth et al., 2004; Meek et al., 2013). Multistatic meteor radar networks have been shown to provide valuable insights into the spatial and temporal variability of mesosphere-lower thermosphere (MLT) winds over timescales ranging from a few



minutes to hours (Stober and Chau, 2015; Chau et al., 2017; Spargo et al., 2019; Volz et al., 2021; Stober et al., 2021b, 2023a; Poblet et al., 2023; Zeng et al., 2022, 2024; Qiao et al., 2025). These systems provide spatially resolved wind measurements with unprecedented detail by employing multiple receiving stations, thus overcoming the limitations of traditional single-station radar systems and enabling the reconstruction of three-dimensional wind fields over extended spatial domains. The resulting high-resolution wind observations are particularly valuable for interpreting airglow measurements, providing the necessary background wind information to extract intrinsic gravity wave parameters from observed wave signatures.

The Southern Argentina Agile MEteor Radar (SAAMER) project employs a SKiYMET system (Hocking et al., 2001) that was installed in Rio Grande and has been operating continuously since May 2008. Building on this, the Southern Argentina Agile MEteor Radar (SAAMER) Orbital System (OS) expanded the system network to five passive receiver stations at distances between 3-14 km: SAAMER-C, SAAMER-N, SAAMER-W, SAAMER-S, and SAAMER-E. These stations provide accurate measurements of meteoroid orbits and velocity. The initial four stations became operational in 2012, with the fifth station added in 2019 (Janches et al., 2023). The Southern Argentina Agile MEteor Radar - Novel Atmospheric Sounding (SAAMER-NOVA) multistatic meteor radar network is the latest upgrade in this network, expanding observational capabilities at the southern tip of Argentina, a region recognized as a major hotspot for GW activity on Earth, centred over the Southern Andes, Drake Passage, and Antarctic Peninsula (both orographic and non-orographic wave generation sources). A hotspot because of the major sources of GW in this region, which include high mountains, strong jet streams, and frontal systems. (Fritts and Alexander, 2003; Fritts et al., 2012; Becker and Vadas, 2018; Vadas and Becker, 2018; Stober et al., 2021a). These sources generate a substantial GW activity and corresponding momentum fluxes through multistep vertical coupling, leading to strong interactions with the large-scale flow in the MLT. These systems provide particular sensitivity to the large-scale dynamical features, including the semidiurnal tide and the Quasi-2-day-wave (Lieberman et al., 2025). The SAAMER-NOVA provides valuable background wind information for airglow measurements conducted by experiments such as AWE or AMTM (Zhang et al., 2025).

In this study, we present statistics of Southern Argentina Agile MEteor Radar - Novel Atmospheric Sounding (SAAMER-NOVA) observations spanning October 2025 to January 2026. We show tomographic retrievals of the horizontal winds and higher-order kinematic variables using the 3DVAR+DIV algorithm. The analysis performed and presented is based on the geographic coordinate grid of the 3DVAR+DIV algorithm at 30-minute resolution. This paper is organised as follows: In Section 2, we describe the SAAMER-NOVA multistatic meteor radar network and its data. Section 3 provides a statistical overview. Section 4 presents the results of tomographic wind and Altitude-Time wind analysis. Section 5 provides the discussion, and finally, Section 6 concludes the study.

2 The Southern Argentina Agile Meteor Radar (SAAMER) - NOVA multistatic meteor radar network

Meteor radar observations have been conducted with SAAMER at Rio Grande (67.7° W, 53.7° S) since May of 2008. The system was originally designed to be the first system dedicated to momentum flux observations (Fritts et al., 2010, 2012, 2014). For that purpose, the transmitter (TX) configuration required the detection of meteors between zenith angles of 15° and 55°



85 and thus an eight three-element crossed Yagis were deployed, arranged in a circle of diameter 27.6 m. Each transmitting in opposite phasing to every other Yagi. Like most of meteor radars, SAAMER also has a 5 receiving three-element crossed Yagis arranged specifically to perform interferometry and geolocate each detected echo.

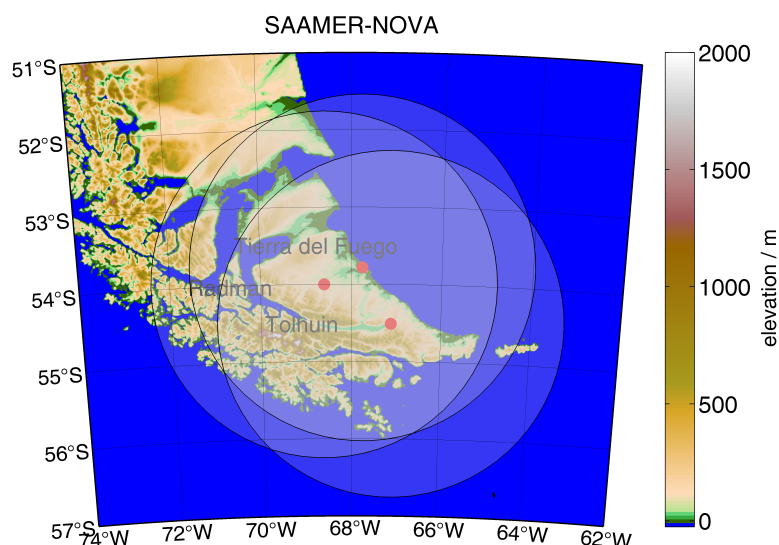


Figure 1. Geographic projection of the SAAMER-NOVA network at Tierra del Fuego. The shaded circles indicate the approximate detection area for each station.

Since its initial deployment, the system has undergone various upgrades, the most critical being 1) the addition of 5 single antennas remote receiving stations started in 2010 with SAAMER-N and SAAMER-W, in 2017 SAAMER-S, 2019 SAAMER-E and in 2022 SAAMER-SE, 5-15 km away from the TX, to form SAAMER-OS (orbital system) to measure meteoroid trajectories for orbit determination (Janches et al., 2015; Panka et al., 2021; Janches et al., 2023); 2) 2 additional antennas to measure linear polarization of each return echo for more precise electron density measurements, and meteoroid mass estimates (Stober et al., 2023b; Dawkins et al., 2023); and 3) a new transmission strategy with the deployment of a single new TX antenna to improve the detection rate of meteors at larger zenith angles (Janches et al., 2020). By concentrating the full power of SAAMER in one TX antenna, a more uniform detection pattern is achieved that satisfies this original requirement, but also increases the number of events detected at larger zenith angles. SAAMER operates at 32.55 MHz with 60 kW transmit power at a pulse repetition frequency of 625 Hz using a 7-bit Barker code with 1.5 km range sampling. In this study, we show only results using a single circularly polarized Yagi antenna for transmission.

100 This manuscript is focused on the introduction of the latest upgrade of the system, the SAAMER-NOVA network, which consists of the monostatic meteor radar at Rio Grande, and two 5 2-cross-elements yagi antenna receiving interferometers located approximately 80 km away from the TX, at Tolhuin (67.1° W, 54.5° S) and Radman (68.6° W, 54.0° S). For the case of the two remote interferometers, in order to geolocate the echoes, the forward scatter geometry is solved using the method presented



in Stober et al. (2021b). The network is designed to ensure that the observation volumes overlap among all three sites, which form a rectangular triangle. Figure 1 presents a scheme of the network layout projected on a topographic map. The shaded area indicates the observational volume for each link. SAAMER-NOVA covers the entire island of Tierra del Fuego in Argentina and Chile, which is known to be the northern edge of a GW hotspot over the Drake passage (Ern et al., 2004; Fritts et al., 2012; de Wit et al., 2016, 2017; Stober et al., 2021a; Reichert et al., 2021; Hindley et al., 2022; Vadas et al., 2018; Becker and Vadas, 2018).

Figure 2 presents the two-dimensional (2D) horizontal spatial distribution of meteors detected across the three radar stations for a period of five days from 1st to 5th November 2025, along with the vertical altitude distribution for the entire study period. The scatter plot on the map illustrates the spatial distribution of meteor echoes, with colours indicating the meteor echoes for each station: Cyan for Radman, blue for Tolhuin, and magenta for Rio Grande.

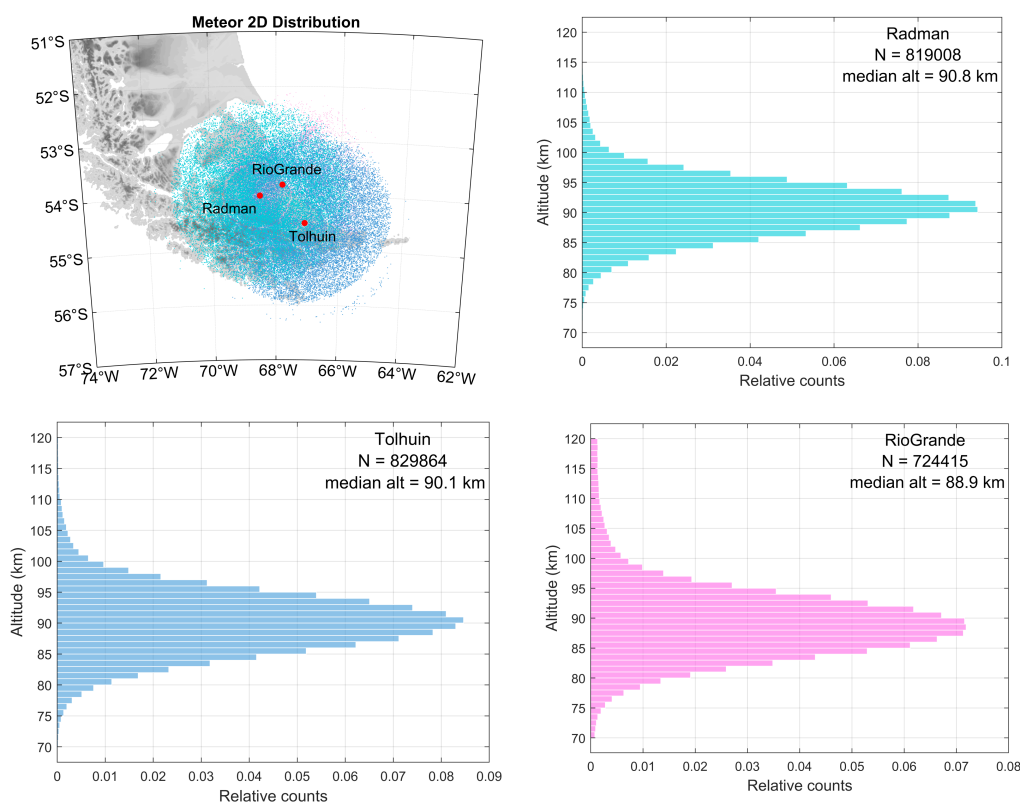


Figure 2. 2D Horizontal distribution of meteor positions detected by the meteor radar stations (indicated with colour-coded dots) from 1 - 5 November 2025, with each point representing a detected meteor. Red dots indicate station locations, and labels identify each station. The altitude distribution of meteors detected at each station is also shown, indicating the total number of meteors observed during the study period (October 2025 - January 2026) and the corresponding median altitude for each station. The colours cyan, blue, and magenta correspond to meteors detected at the Radman, Tolhuin, and RioGrande stations, respectively.



The observational volumes of these stations exhibit significant spatial overlap, enabling multistatic analysis. The altitude distributions of all stations exhibit approximately Gaussian profiles within the altitude range 70-120 km, peaking at approximately 90 km. Notably, Tolhuin exhibits the highest peak altitude at 90.8 km, followed by Radman at 90.1 km, while Rio Grande shows a lower peak at 88.9 km. This overall height distribution is consistent with expectations, as forward-scattering geometry typically produces slightly higher peak altitudes in dependence on the forward scattering angle, corresponding to an equivalent frequency. Both Tohuin and Radman detect more meteor counts compared to Rio Grande, reflecting differences in sensitivity and antenna patterns between the stations, as well as potential different interference environments. These characteristics align with the results from other multi-static meteor radar experiments and deployed networks (Qiao et al., 2025; Stober and Chau, 2015; Zeng et al., 2024).

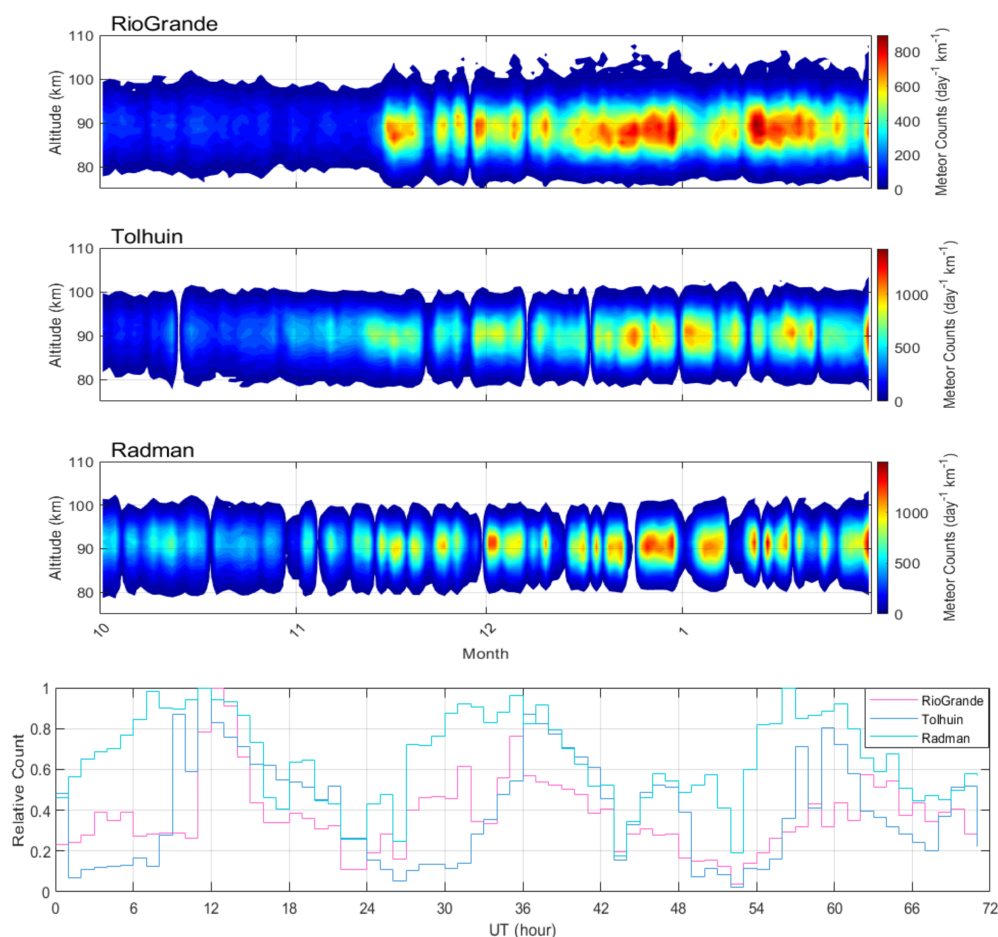


Figure 3. Altitudinal profile of daily meteor echoes detected at RioGrande, Tolhuin, and Radman meteor radar stations for the entire study period. The bottom stair-step diagram illustrates the hourly temporal distribution of meteors from April 1-3, 2021. The four colours have the same meaning as in the previous figure.



The altitude-resolved temporal evolution of meteor echo rates for all stations over the study period, along with the hourly distribution of detected meteor events over three representative days (27 to 29 January 2026), are illustrated in Figure 3. Meteor echoes are predominantly detected between the altitudes of approximately 85 and 95 km. The white lines represent gaps in measurements. It is noted that more gaps are observed at the Radman and Tolhuin stations than at the Rio Grande station. Meteor detection rates are more consistent and higher from mid-November onward at all stations, whereas before this period, particularly at Rio Grande, detection counts are lower. The reduced detection rate was mainly the result of RF (Radio Frequency) interference caused by other emitters located more to the north of the network, whereas the most southern station was not impacted. These patterns show both the temporal variability in meteor rates and the relative performance of each station. Diurnal variations in meteor detection are evident in the temporal distribution across all stations. Detection rates are highest during the afternoon hours around 8-12 UT, 36 UT, and 58-62 UT, and lowest during midnight and evening hours 18 UT, 24 UT, and 42 UT.

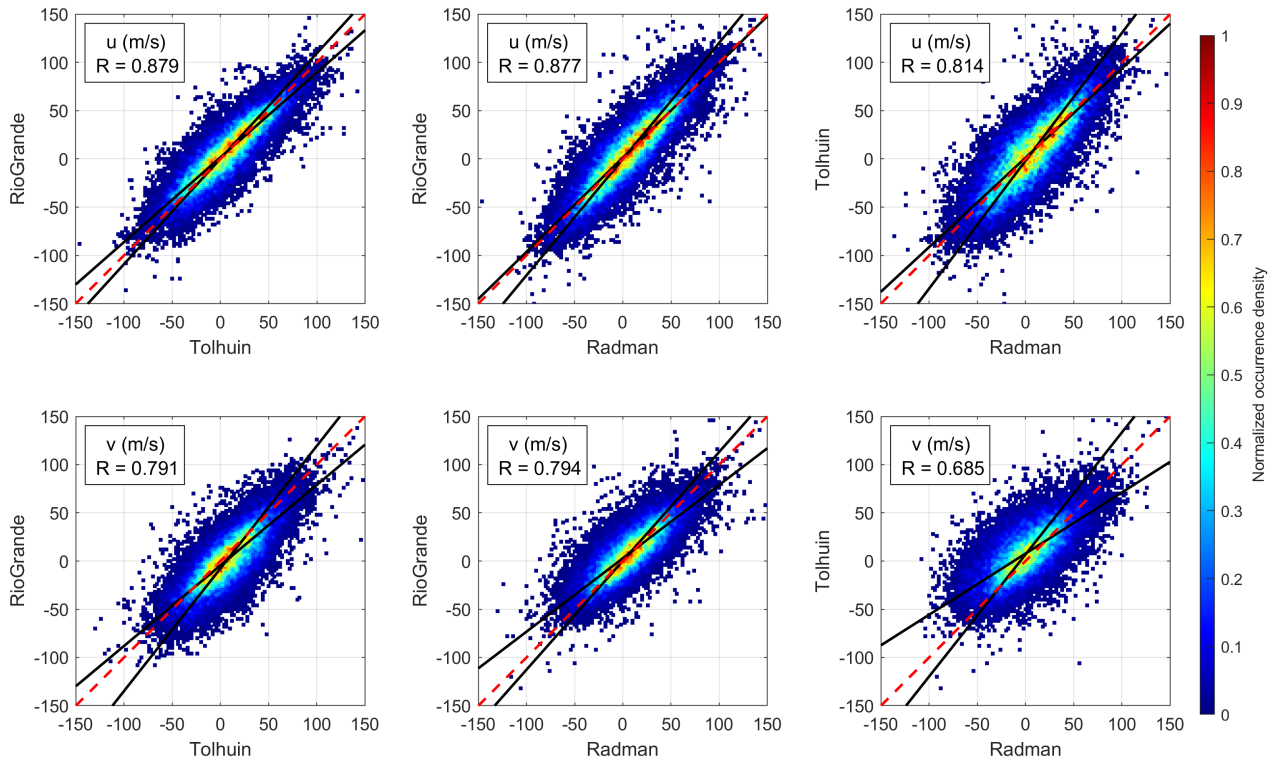


Figure 4. Scatter plots of zonal (u) and meridional (v) winds at Rio Grande, Tolhuin, and Radman. Each panel shows the coefficient correlation (R) and its wind component (top left), robust regression fits, and a 1:1 reference line. The top row presents the zonal winds, whereas the bottom row presents the meridional winds. The color denotes the normalized occurrence density of data from 1 to 31 January 2026.

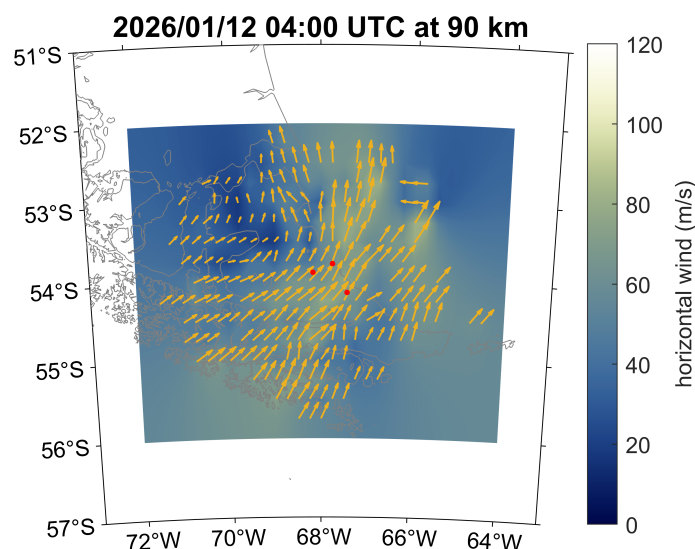


135 The cross-site validation of SAAMER-NOVA is performed through a correlation analysis of measured winds applying a mono-static wind analysis to the data recorded at each site in January 2026 at 30-minute temporal resolution, within the altitudes 70 to 110 km. In Figure 4, we present scatter plots of winds at the three sites, showing normalized occurrence density (color coded) and correlation coefficients in the top left corner.

Winds measured at SAAMER-NOVA are robust, as confirmed by the high correlation coefficients ranging from approximately
140 0.7 to 0.9 presented in the panel plots. The densest measured winds are expected to cluster around the reference line ($y=x$), with the zonal winds ranging between approximately 70m/s easterlies to 70m/s westerlies (top panels) and meridional winds between approximately -50m/s and 50m/s (lower panels). Zonal winds are noted to dominate with easterlies, whereas the meridional cluster is around the zero wind. The correlations between sites are presented as Rio Grande against Tolhuin, Rio Grande against Radman, and Tolhuin against Radman for both the zonal and meridional components. The zonal wind correlation coefficients are 0.879, 0.877, and 0.814, respectively, and the meridional wind coefficients are 0.791, 0.794, and 0.685,
145 respectively. The scattering around the slope one is expected as each station is sensitive to a slightly different observation volume and will detect the small-scale GW with different viewing geometries.

3 Three-Dimensional wind fields: Tomographic reconstruction and Altitude-Time Winds profiles

The 3DVAR+DIV algorithm has been used to retrieve the horizontal wind field, vertical winds, and the higher-order kinematic
150 variables, specifically horizontal divergence and vorticity. This algorithm is based on Bayesian inversion and the optimal estimation technique, adapted to the Tierra del Fuego region (SAAMER-NOVA network) to reconstruct three-dimensional wind fields. The results presented in this section are based on the geographical grid coordinates of the 3DVAR+DIV described in Stober et al. (2022), with a temporal resolution of 30 minutes.



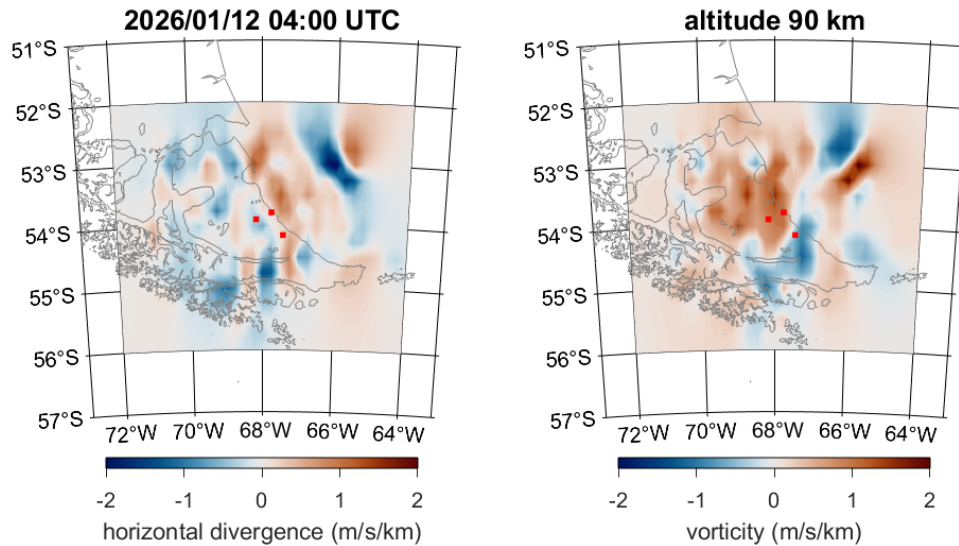


Figure 5. Horizontal winds, horizontal divergence, and relative vorticity derived from the horizontal winds using the 3DVAR+DIV algorithm and SAAMER-NOVA observation data. The red dots indicate the location of the stations in the same way as in Figure 1.

155 Snapshots of horizontal wind field, horizontal divergence, and vorticity at 90 km altitude for 12 January 2026, 04:00 UTC are presented in Figures 5, respectively. The top panel shows the horizontal wind magnitude (colour coded, m/s) and wind direction (orange vectors), and the lower panels show the horizontal divergence (lower left) and relative vorticity (lower right). The horizontal wind field shows a coherent circulation with some underlying spatial variability, with wind speed exceeding 100 m/s. The wind vectors show a southwesterly streamline accelerating toward the central domain, with an anticyclonic structure to its left and a cyclonic structure to its right, suggesting pronounced horizontal shear and convergence.

160 The horizontal divergence exhibits structures indicative of gravity-wave-like features, with magnitudes of approximately ± 2 m/s/km. The vorticity field exhibits distinct patches with a magnitude of ± 2 m/s/km and occasional higher values.

Figure 6 illustrates the zonal, meridional, vertical winds, and horizontal divergence derived vertical winds (top panels), along with their corresponding measurement response (bottom panels) (Shannon and Weaver, 1949; Shannon, 1948; Stober et al.,

165 2021b) for the same date and time as the previous Figure. The zonal and meridional winds are shown as bluish (westward and **southward**) and reddish (eastward and **northward**), respectively, as well as wind direction denoted with black arrows. Both horizontal wind components exhibit a substantial variability that exceeds 100 m/s, with higher values in the meridional wind. The 3DVAR+DIV algorithm retrieves two vertical winds. One is analyzed directly from the Doppler measurements, and the second vertical velocity is obtained from the integrated horizontal divergence. The Doppler-derived vertical wind and the

170 horizontal divergence integrated vertical wind exhibit magnitudes within ± 4 m/s and a very similar spatial pattern. In the vertical wind plot, bluish and brownish colours indicate downward and upward motion, respectively. A measurement response close to 1 (whitish) indicates that the solution in this area and for this wind component is driven by measurements, whereas bluish areas represent a low measurement response. The more bluish an area of the domain, the more the solution is dominated



by a priori information (zero wind field) and the smoothness constraint corresponding to a decreased spatial resolution or long
175 correlation lengths.

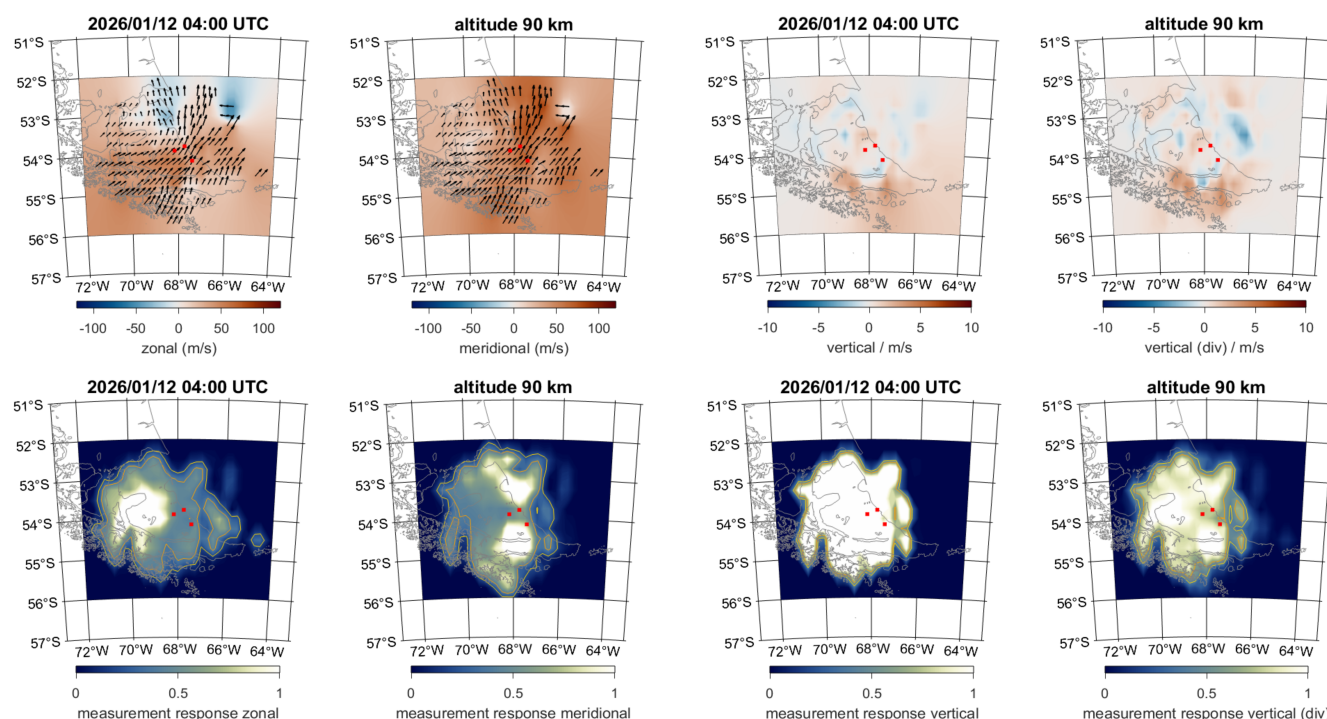


Figure 6. Zonal, meridional, vertical winds, and vertical divergence (top panel), along with corresponding measurement response (bottom panel) derived using the 3DVAR+DIV algorithm and SAAMER-NOVA measurements. The red dots are represented the same way in Figure 1.

Figure 7 presents the Altitude-Time Wind (ATW) plots of the horizontal winds and their corresponding residuals, obtained from the adaptive spectral filter 2D (ASF2D) (Stober et al., 2020; Baumgarten and Stober, 2019; Stober et al., 2021a) for January 2026. The ASF decomposes the wind field into a mean wind, tidal components (diurnal, semidiurnal, and terdiurnal),
180 and a GW residual. The ATW winds show a pronounced diurnal tide throughout the month and a strong Quasi-two-day-wave (Q2DW) within this region. Such strong enhancements of the Q2DW are regularly observed above the Andes (Lieberman et al., 2025).

The GW residuals (right panel of the figure) show the high-frequency fluctuations after subtracting the mean and tides in the horizontal winds, highlighting short-term and small-scale fluctuations relative to the background wind field. These residual
185 structures are characterised by GWs that propagate through the MLT and modulate the mean flow. The generally smaller magnitude of the residuals relative to the Q2DW amplitude indicates that the large-scale flow dominates the circulation, with the superimposed perturbations representing transient processes that contribute to momentum deposition and mixing at these alti-



tudes. The black vertical lines enclose periods of interest, during which marked increases in wind amplitude indicate intensified atmospheric wave activity, including possible gravity-wave activity, wave breaking, or localised instabilities.

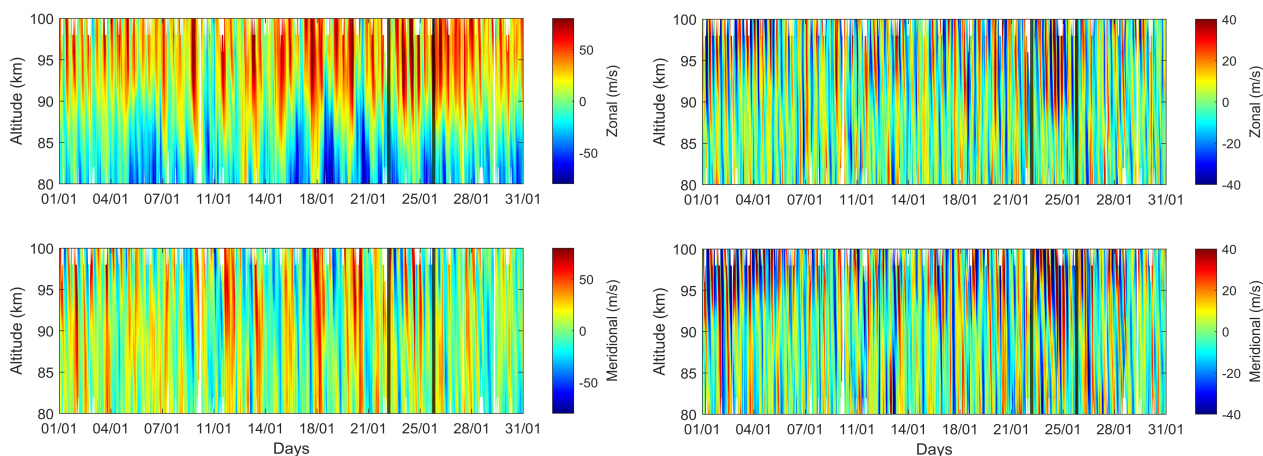


Figure 7. Altitude-Time Wind (ATW) plots of horizontal winds observed by the SAAMER-NOVA multistatic meteor radar network for January 2026. The left two columns show the zonal (top left) and meridional (bottom left) wind components. The right column shows the corresponding zonal and meridional residual winds. The vertical black lines (from 23rd to 26th January) enclose gravity wave (GW) events.

190

Figure 8 illustrates the wavelet power spectrum of zonal and meridional wind components at 90km altitude for January 2026. The wavelet spectrum was obtained with the wavelet implementation following Torrence and Compo (1998). The wavelet amplitudes are normalized by a customized normalization factor to account for the sampling time of the measurement wind time series.

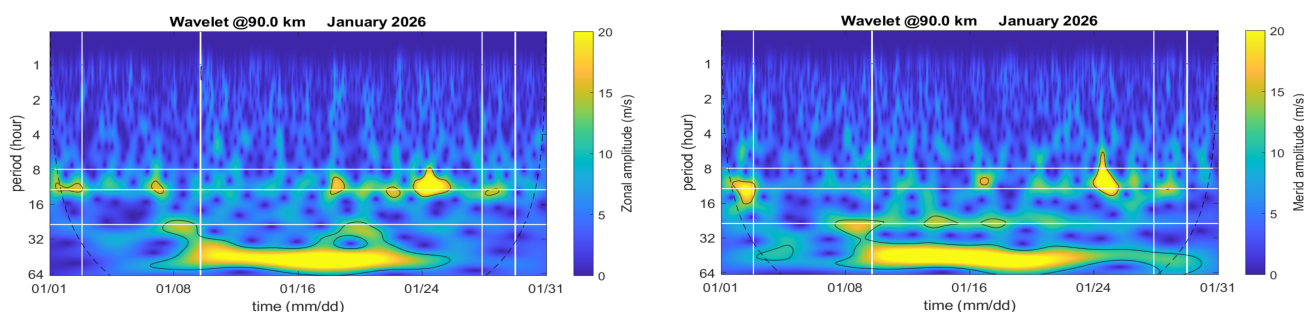


Figure 8. Wavelet power spectrum for zonal and meridional winds using the Morlet wavelet for a period January 2026. The black solid contours outline the 95% significance contour, and the black dashed line indicates the cone of influence. The white horizontal lines represent, from top to bottom, the terdiurnal, semidiurnal, and diurnal tides.

195



In this Figure, we display the 95% significance contour with black solid lines and the cone of influence with black dashed lines. The terdiurnal (8-hour), semidiurnal (12-hour), and diurnal (24-hour) tides are indicated by the white horizontal lines, from top to bottom. In both components, a dominant spectral signature is observed around 48 hours corresponding to the Q2DW, indicating enhanced activity that emerges around January 9 and persists through to approximately January 25 in the zonal component, while in the meridional wind component, it diminishes towards the end of the month, with peak amplitudes exceeding 20m/s. The Q2DW occurs frequently in the southern hemisphere around mid-January and has been studied previously (Lieberman et al., 2025). The wavelet analysis reveals several strong semidiurnal tidal enhancements (exceeding the 95% significance confidence, delimited by black contours), in both zonal and meridional components. A particular burst of the semidiurnal tide is observed between 23rd and 26th January for the zonal and meridional components. These dates correspond to the period enclosed in black lines in ATW Figures (see Figure 7, suggesting a potential link between the dissipating/decaying Q2DW and the sudden enhancement of the 12-hour tide. The diurnal tidal amplitude only reached significant magnitudes during the active period of the Q2DW.

In Figure 9, we show the corresponding latitudinal and longitudinal keograms for the same period as Figure 8 at an altitude of 90 km. The keograms represent latitude or longitude time slices at 90 km altitude through the 3DVAR+DIV domain. Thus, Keogram plots exhibit the temporal evolution of wind dynamics at a specific latitude (56-52 °S) or longitude (72-64 °W) and altitude, thereby providing a cross-sectional slice of the domain. This approach effectively visualises atmospheric tides or planetary waves and their spatial characteristics. Here, we present the keograms corresponding to the ATW analysis presented in Figure 7, which illustrate the evolution of winds at latitudes 56-52 °S and longitudes 72-64 °W. The black vertical lines again highlight a period with enhanced GW activity. During this period, the Q2DW suddenly decays. Intense zonal winds are observed in the region enclosed within the black lines, consistent with the ATW analysis plots in Figure 7.

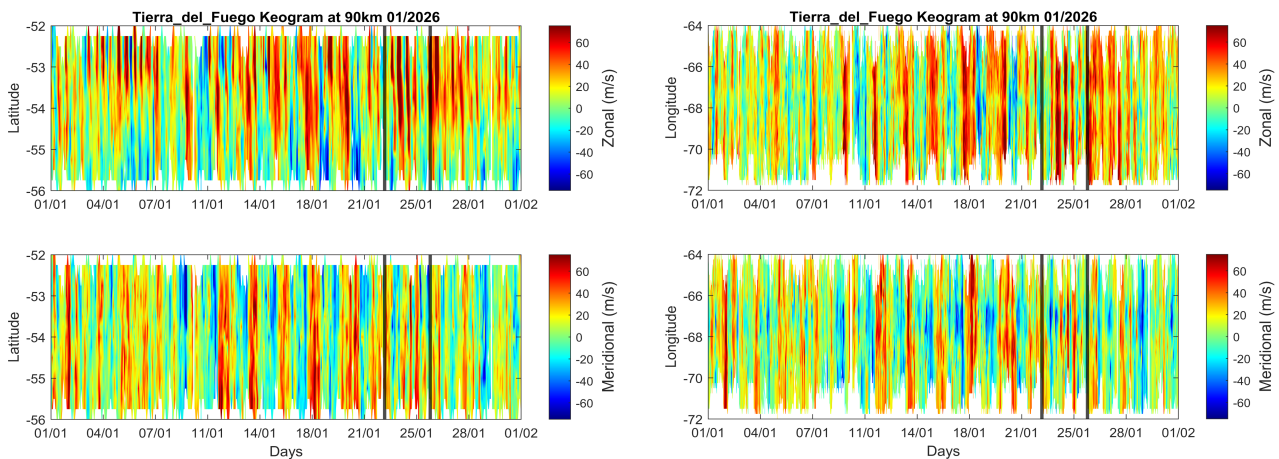


Figure 9. Latitudinal (right column) and longitudinal (left column) keogram of zonal(top panels) and meridional (bottom panel) wind components for 1-31 January 2026. The vertical black lines are explained in Figure 7 and enclose the same period.



4 Spatial and temporal characteristics of the decaying Q2DW

The 3DVAR+DIV algorithm enables the retrieval of the spatial and temporal wave fields, aspects of resolved wave activity, and its interactions. The study domain is located at the southern tip of Argentina, a region recognized as a hotspot for wave activity (especially gravity waves) due to its unique geographic features (both orographic and non-orographic; Ern et al., 2004).

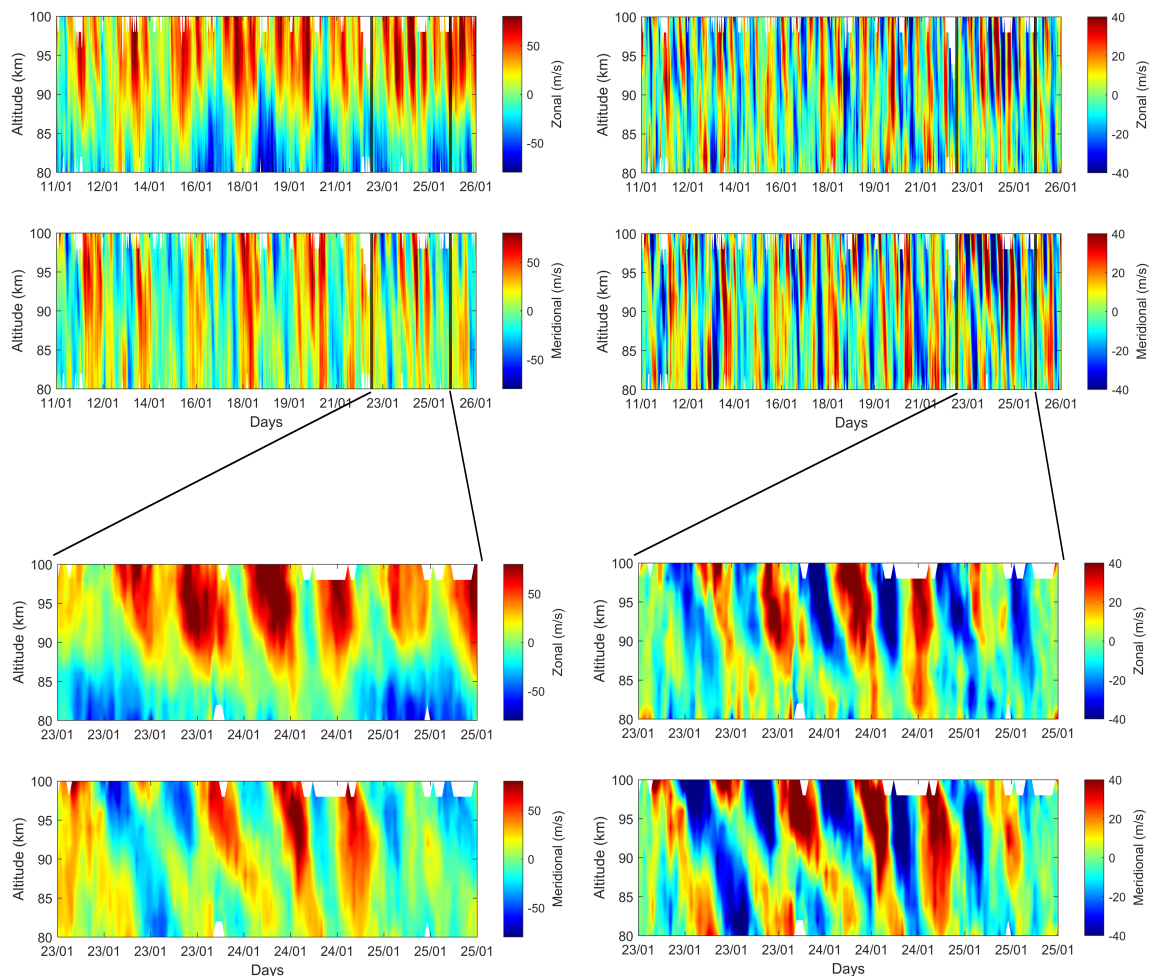


Figure 10. Altitude-Time Wind (ATW) plots of zonal and meridional winds observed by the SAAMER-NOVA multistatic meteor radar network for two zoomed intervals, 11th to 26th January 2026 (upper four panels), and 23rd to 25th January 2026 (lower four panels). The right column shows the corresponding residual winds. The vertical black lines are explained in Figure 8 and enclose the same period.

In Figure 10, we present the ATW plots along with their filtered profile for two periods: a zoom-in from days 11th - 26th January and a further zoom-in from days 23rd - 25th January. We perform keogram analysis of the second zoomed-in period above



(see Figure 11) to confirm the presence of wave activity in this region. Multiple wave-like events are observed throughout the
225 analysed duration, reflecting the region's propensity for frequent wave generation and a strong diurnal oscillation, indicating
wind variations over the course of each day. A well-structured wave-like feature is revealed within the enclosed period with an
amplitude exceeding 50 m/s, indicating a signature of atmospheric wave activity. The black line in the top four panels encloses
the selected wave activity of interest and zooms in on the bottom four panels, which reveal a clearer structure.

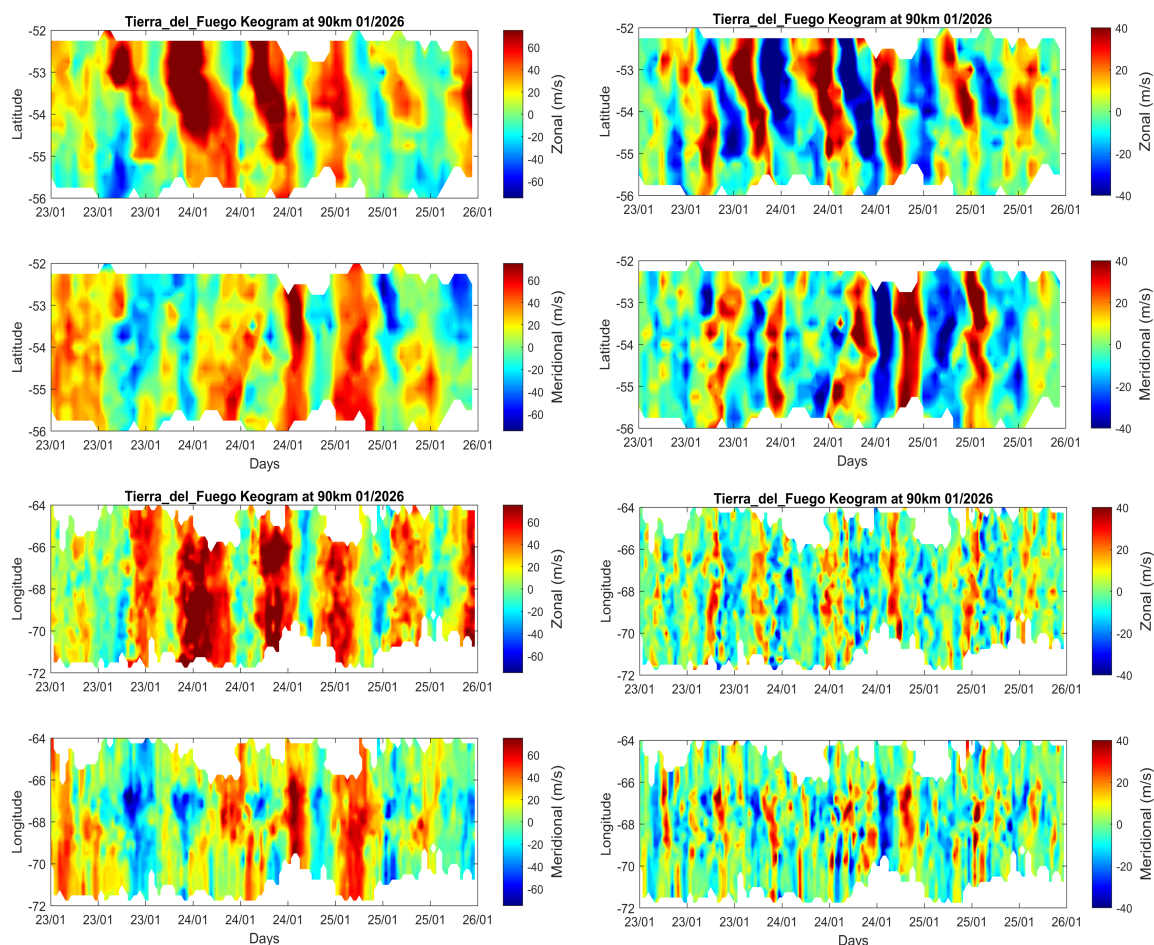


Figure 11. Latitudinal (top four panels) and longitudinal (lower four panels) keogram of zonal and meridional wind components for 23rd - 25th January 2026.

230 Interestingly, a shift in the wind structures is observed over the region. This shift is more evident in the lower four panels
(11th to 25th January 2026), from slanted to almost vertical structures. This same shift is also observed in the keogram Figures
(see Figures 11). This shift may indicate evolving atmospheric dynamics, atmospheric wave activity, wind variations, or large-
scale climatic processes. This can be associated with highly sheared wind structures, likely due to the breaking of atmospheric



gravity waves or wind fields dominated by large-scale migration of diurnal and semidiurnal tides, driven by the transition from
235 gravity-wave-dominated to tidal-dominated dynamics, as well as a change in background thermal wind balance.

5 Discussion

SAAMER-NOVA is a new multistatic meteor radar network at the southern tip of Argentina, a region known as GW hotspot. The passive receiver stations, together with the SAAMER main site, are configured to form a triangle that maximizes angular diversity. The total domain size is smaller compared to other networks such as the Nordic Meteor Radar Cluster (Stober et al.,
240 2021b), CONDOR (Qiao et al., 2025), or the Chinese network around Hefei (Zeng et al., 2022, 2024).

All three stations have nearly complete overlap of their fields of view, which allows more detections within a relatively narrow geographic region. This configuration permits the retrieval of 3D winds and their underlying structure with a still high temporal resolution, though the absolute number of detections is a bit lower compared to other networks. The measurement response for all three wind components exhibits a similar pattern, reflecting a sufficient angular diversity to obtain all wind parameters
245 with sufficient accuracy within the core region of the domain. However, the shorter distance between the main site and the remote stations limits the total domain size. In particular, at the domain edges at distances beyond 250 km from the core site, the angular diversity is already reduced, leading to decreased measurement response in those areas.

The biggest benefit of the new SAAMER-NOVA network is the location at the GW hotspot. Considering NASA's Atmospheric Wave Experiment (AWE) mission (Lamborn et al., 2024) and the requirement to have reliable mean winds or even spatially
250 resolved 3D winds over certain domains provides a crucial contribution for the derivation of the intrinsic GW parameters from optical systems such as airglow images (Taylor et al., 1997; Sarkhel et al., 2022b; Zhang et al., 2025).

The importance of continuous and spatially resolved wind measurements is demonstrated for larger-scale perturbations during a Q2DW burst in January 2016. Advanced tomographic wind algorithms and the multistatic layout of SAAMER-NOVA permits to investigate the characteristics of a Q2DW of the altitude-time, latitude-time, and longitude-time cross-section over the
255 southern tip of Argentina and how the wave evolves from day-to-day. In particular, the latitude cross-sections at fixed longitude reveal phase changes in the zonal and meridional wind indicative of baroclinic instability. Zonal and meridional wind components of the wave show a clear vertical shear and also different tilts of the wave phase lines in latitude. Combining these data with other networks, such as CONDOR, will shed even more light on the spatial wave features of the Q2DW over the South American continent.

260 6 Conclusion

The Southern Argentina Agile MEteor Radar - Novel Atmospheric Sounding (SAAMER-NOVA) is a new multistatic meteor radar network optimally suited for gravity wave studies at the southern tip of the Andes. It is the first imaging meteor radar network at high southern latitudes, specifically located in a region known as a hotspot for gravity wave activity. The measurement deployed at SAAMER-NOVA enables the retrieval of resolved three-dimensional wind fields. This paper presents the statistics



265 of three-dimensional spatially resolved wind fields in the mesosphere and lower thermosphere (MLT) using the advanced re-
trieval technique 3DVAR+DIV. The 3DVAR+DIV retrieval used in this study was implemented with a temporal resolution of
30 minutes covering the altitude region from 70 to 110 km. We present three-dimensional tomographic retrievals of wind fields
at the MLT in geographic grid coordinates, altitude-time wind plots, and keogram analyses, which reveal large-scale dynamics
and multiple atmospheric wave activities. We conclude that SAAMER-NOVA's strategic location, almost perfect rectangular
270 triangle positioning form of the stations, and angular diversity provide a uniquely robust and continuous measurement to the
research community. The performance of the network is demonstrated by retrieving the spatial characteristics of a Q2DW and
the associated GW residuals for January 2026.

Author contributions. LP, DJ, and GS conceptualized the data analysis presented in this manuscript. DJ, BF, DC, JLH, LM, EM, and MC
built SAAMER-NOVA and guided the software development and ensured the SAAMER-NOVA operation. All authors edited the manuscript.

275 *Competing interests.* The authors declare no competing interests.

Acknowledgements. Loretta Pearl Poku is supported by the Schweizerischer Nationalfonds zur Förderung der wissenschaftlichen Forschung
(grant no. 200021L-228107). Gunter Stober and Loretta Pearl Poku are members of the Oeschger Centre for Climate Change Research.
The development of the algorithm was motivated by discussions at the International Space Science Institute (ISSI) in Bern, through the
ISSI International Team on Meteors and Phenomena at the Boundary between Earth's Atmosphere and Outer Space (project no. 23-580).
280 SAAMER is funded through NASA Engineering Safety Center (NESC) assessment TI-17-01204. DJ was partially funded for this work by
NASA's Atmospheric Wave Experiment (AWE) mission.



References

- Andrews, D., Holton, J., and Leovy, C.: Middle Atmosphere Dynamics, International Geophysics, Elsevier Science, ISBN 9780120585762, 1987.
- 285 Baumgarten, K. and Stober, G.: On the evaluation of the phase relation between temperature and wind tides based on ground-based measurements and reanalysis data in the middle atmosphere, *Annales Geophysicae*, 37, 581–602, <https://doi.org/10.5194/angeo-37-581-2019>, 2019.
- Becker, E.: Dynamical Control of the Middle Atmosphere, *Space Science Reviews*, 168, 283–314, <https://doi.org/10.1007/s11214-011-9841-5>, 2012.
- 290 Becker, E. and Vadas, S. L.: Secondary Gravity Waves in the Winter Mesosphere: Results From a High-Resolution Global Circulation Model, *Journal of Geophysical Research: Atmospheres*, 123, 2605–2627, <https://doi.org/10.1002/2017JD027460>, 2018.
- Chau, J. L., Stober, G., Hall, C. M., Tsutsumi, M., Laskar, F. I., and Hoffmann, P.: Polar mesospheric horizontal divergence and relative vorticity measurements using multiple specular meteor radars, *Radio Science*, pp. n/a–n/a, <https://doi.org/10.1002/2016RS006225>, 2016RS006225, 2017.
- 295 Dawkins, E. C., Stober, G., Carrillo-Sánchez, J. D., Janches, D., Weryk, R., Hormaechea, J. L., Bruzzone, J. S., and Plane, J. M.: A novel methodology to estimate pre-atmospheric dynamical conditions of small meteoroids, *Planetary and Space Science*, 238, 105 796, <https://doi.org/https://doi.org/10.1016/j.pss.2023.105796>, 2023.
- de Wit, R. J., Janches, D., Fritts, D. C., and Hibbins, R. E.: QBO modulation of the mesopause gravity wave momentum flux over Tierra del Fuego, *Geophysical Research Letters*, 43, 4049–4055, <https://doi.org/10.1002/2016GL068599>, 2016.
- 300 de Wit, R. J., Janches, D., Fritts, D. C., Stockwell, R. G., and Coy, L.: Unexpected climatological behavior of MLT gravity wave momentum flux in the lee of the Southern Andes hot spot, *Geophysical Research Letters*, 44, 1182–1191, <https://doi.org/10.1002/2016GL072311>, 2017.
- Ern, M., Preusse, P., Alexander, M. J., and Warner, C. D.: Absolute values of gravity wave momentum flux derived from satellite data, *Journal of Geophysical Research (Atmospheres)*, 109, D20103, <https://doi.org/10.1029/2004JD004752>, 2004.
- 305 Fritts, D. and Alexander, M. J.: Gravity wave dynamics and effects in the middle atmosphere, *Reviews of Geophysics*, 41, 1–64, <https://doi.org/doi:10.1029/2001RG000106>, 2003.
- Fritts, D. C., Janches, D., Iimura, H., Hocking, W. K., Mitchell, N. J., Stockwell, R. G., Fuller, B., Vandepeer, B., Hormaechea, J., Brunini, C., and Levato, H.: Southern Argentina Agile Meteor Radar: System design and initial measurements of large-scale winds and tides, *Journal of Geophysical Research: Atmospheres*, 115, <https://doi.org/10.1029/2010JD013850>, 2010.
- 310 Fritts, D. C., Janches, D., Hocking, W. K., Mitchell, N. J., and Taylor, M. J.: Assessment of gravity wave momentum flux measurement capabilities by meteor radars having different transmitter power and antenna configurations, *Journal of Geophysical Research: Atmospheres*, 117, n/a–n/a, <https://doi.org/10.1029/2011JD017174>, d10108, 2012.
- Fritts, D. C., Pautet, P.-D., Bossert, K., Taylor, M. J., Williams, B. P., Iimura, H., Yuan, T., Mitchell, N. J., and Stober, G.: Quantifying gravity wave momentum fluxes with Mesosphere Temperature Mappers and correlative instrumentation, *Journal of Geophysical Research: Atmospheres*, 119, 13,583–13,603, <https://doi.org/10.1002/2014JD022150>, 2014.
- 315 Hecht, J. H., Wan, K., Gelinas, L. J., Fritts, D. C., Walterscheid, R. L., Rudy, R. J., Liu, A. Z., Franke, S. J., Vargas, F. A., Pautet, P. D., Taylor, M. J., and Swenson, G. R.: The life cycle of instability features measured from the Andes Lidar Observatory over Cerro Pachon on



- 24 March 2012, *Journal of Geophysical Research: Atmospheres*, 119, 8872–8898, <https://doi.org/https://doi.org/10.1002/2014JD021726>, 2014.
- 320 Hindley, N. P., Mitchell, N. J., Cobbett, N., Smith, A. K., Fritts, D. C., Janches, D., Wright, C. J., and Moffat-Griffin, T.: Radar observations of winds, waves and tides in the mesosphere and lower thermosphere over South Georgia island (54° S, 36° W) and comparison with WACCM simulations, *Atmospheric Chemistry and Physics*, 22, 9435–9459, <https://doi.org/10.5194/acp-22-9435-2022>, 2022.
- Hocking, W., Fuller, B., and Vandepeer, B.: Real-time determination of meteor-related parameters utilizing modern digital technology, *Journal of Atmospheric and Solar-Terrestrial Physics*, 63, 155 – 169, [https://doi.org/http://dx.doi.org/10.1016/S1364-6826\(00\)00138-3](https://doi.org/http://dx.doi.org/10.1016/S1364-6826(00)00138-3),
325 radar applications for atmosphere and ionosphere research - PIERS 1999, 2001.
- Hocking, W. K., Thayaparan, T., and Jones, J.: Meteor decay times and their use in determining a diagnostic mesospheric Temperature-pressure parameter: Methodology and one year of data, *Geophysical Research Letters*, 24, 2977–2980, <https://doi.org/10.1029/97GL03048>, 1997.
- Holdsworth, D. A., Reid, I. M., and Cervera, M. A.: Buckland Park all-sky interferometric meteor radar, *Radio Science*, 39, n/a–n/a,
330 <https://doi.org/10.1029/2003RS003014>, rS5009, 2004.
- Janches, D., Close, S., Hormaechea, J. L., Swarnalingam, N., Murphy, A., O'Connor, D., Vandepeer, B., Fuller, B., Fritts, D. C., and Brunini, C.: THE SOUTHERN ARGENTINA AGILE METEOR RADAR ORBITAL SYSTEM (SAAMER-OS): AN INITIAL SPORADIC METEOROID ORBITAL SURVEY IN THE SOUTHERN SKY, *The Astrophysical Journal*, 809, 36, <https://doi.org/10.1088/0004-637x/809/1/36>, 2015.
- 335 Janches, D., Bruzzone, J. S., Weryk, R. J., Hormaechea, J. L., Wiegert, P., and Brunini, C.: Observations of an Unexpected Meteor Shower Outburst at High Ecliptic Southern Latitude and Its Potential Origin, , 895, L25, <https://doi.org/10.3847/2041-8213/ab9181>, 2020.
- Janches, D., Bruzzone, J. S., Weryk, R. J., Hormaechea, J. L., and Brunini, C.: Radar Observations of the Arid Meteor Shower Outburst from Comet 15P/Finlay, , 4, 165, <https://doi.org/10.3847/PSJ/ace82a>, 2023.
- Lamborn, B., Scherliess, L., Ruley, L., Latvakoski, H., Syrtstad, E., Sevilla, P., Zhao, Y., Cantwell, G., Taylor, M., and Pautet, D.: Atmospheric waves experiment (AWE) mission overview, in: *Infrared Remote Sensing and Instrumentation XXXII*, edited by Strojnik, M. and Helbert, J., vol. 13144 of *Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series*, p. 131440Q, <https://doi.org/10.1117/12.3027141>, 2024.
- 340 Lieberman, R. S., Stober, G., Becker, E., Janches, D., Ma, J., and Liu, A.: Two-Day Wave Modulation of Gravity Wave Momentum Fluxes Observed Over South America, *Journal of Geophysical Research: Atmospheres*, 130, e2024JD042788, <https://doi.org/https://doi.org/10.1029/2024JD042788>, e2024JD042788 2024JD042788, 2025.
- 345 Liu, H.-L.: Variability and predictability of the space environment as related to lower atmosphere forcing, *Space Weather*, 14, 634–658, <https://doi.org/10.1002/2016SW001450>, 2016.
- Liu, H.-L.: Quantifying gravity wave forcing using scale invariance, *Nature Communications*, 10, 2019.
- Meek, C. E., Manson, A. H., Hocking, W. K., and Drummond, J. R.: Eureka, 80°N, SKiYMET meteor radar temperatures compared with
350 Aura MLS values, *Annales Geophysicae*, 31, 1267–1277, <https://doi.org/10.5194/angeo-31-1267-2013>, 2013.
- Panka, P. A., Weryk, R. J., Bruzzone, J. S., Janches, D., Schult, C., Stober, G., and Hormaechea, J. L.: An Improved Method to Measure Head Echoes Using a Meteor Radar, *The Planetary Science Journal*, 2, 197, <https://doi.org/10.3847/psj/ac22b2>, 2021.
- Poblet, F. L., Chau, J. L., Conte, J. F., Vierinen, J., Suclupe, J., Liu, A., and Rodriguez, R. R.: Extreme Horizontal Wind Perturbations in the Mesosphere and Lower Thermosphere Over South America Associated With the 2022 Hunga Eruption, *Geophysical Research Letters*,
355 50, e2023GL103 809, <https://doi.org/10.1029/2023GL103809>, 2023.



- Qiao, Z., Liu, A. Z., Stober, G., Fuentes, J., Vargas, F., Adami, C. L., and Reid, I. M.: Chilean Observation Network De Meteor Radars (CONDOR): multi-static system configuration and wind comparison with co-located lidar, *Atmospheric Measurement Techniques*, 18, 1091–1104, <https://doi.org/10.5194/amt-18-1091-2025>, 2025.
- Reichert, R., Kaifler, B., Kaifler, N., Dörnbrack, A., Rapp, M., and Hormaechea, J. L.: High-Cadence Lidar Observations of Middle Atmospheric Temperature and Gravity Waves at the Southern Andes Hot Spot, *Journal of Geophysical Research: Atmospheres*, 126, e2021JD034683, <https://doi.org/10.1029/2021JD034683>, e2021JD034683 2021JD034683, 2021.
- 360 Sarkhel, S., Stober, G., Chau, J. L., Smith, S. M., Jacobi, C., Mondal, S., Mlynczak, M. G., and Russell III, J. M.: A case study of a ducted gravity wave event over northern Germany using simultaneous airglow imaging and wind-field observations, *Annales Geophysicae*, 40, 179–190, <https://doi.org/10.5194/angeo-40-179-2022>, 2022a.
- 365 Sarkhel, S., Stober, G., Chau, J. L., Smith, S. M., Jacobi, C., Mondal, S., Mlynczak, M. G., and Russell III, J. M.: A case study of a ducted gravity wave event over northern Germany using simultaneous airglow imaging and wind-field observations, *Annales Geophysicae*, 40, 179–190, <https://doi.org/10.5194/angeo-40-179-2022>, 2022b.
- Sedlak, R., Welscher, A., Hannawald, P., Wüst, S., Lienhart, R., and Bittner, M.: Analysis of 2D airglow imager data with respect to dynamics using machine learning, *Atmospheric Measurement Techniques*, 16, 3141–3153, <https://doi.org/10.5194/amt-16-3141-2023>, 2023.
- 370 Shannon, C. E.: A Mathematical Theory of Communication, *Bell System Technical Journal*, 27, 379–423, <https://doi.org/10.1002/j.1538-7305.1948.tb01338.x>, 1948.
- Shannon, C. E. and Weaver, W.: *The Mathematical Theory of Communication*, University of Illinois Press, Urbana, IL, ISBN 978-0-252-72548-7, 1949.
- Smith, A. K.: Global Dynamics of the MLT, *Surveys in Geophysics*, 33, 1177–1230, <https://doi.org/10.1007/s10712-012-9196-9>, 2012.
- 375 Smith, S. M., Stober, G., Jacobi, C., Chau, J. L., Gerding, M., Mlynczak, M. G., Russell, J. M., Baumgardner, J. L., Mendillo, M., Lazzarin, M., and Umbriaco, G.: Characterization of a Double Mesospheric Bore Over Europe, *Journal of Geophysical Research: Space Physics*, 122, 9738–9750, <https://doi.org/10.1002/2017JA024225>, 2017.
- Spargo, A. J., Reid, I. M., and MacKinnon, A. D.: Multistatic meteor radar observations of gravity-wave–tidal interaction over southern Australia, *Atmospheric Measurement Techniques*, 12, 4791–4812, <https://doi.org/10.5194/amt-12-4791-2019>, 2019.
- 380 Stober, G. and Chau, J. L.: A multistatic and multifrequency novel approach for specular meteor radars to improve wind measurements in the MLT region, *Radio Science*, 50, 431–442, <https://doi.org/10.1002/2014RS005591>, 2014RS005591, 2015.
- Stober, G., Baumgarten, K., McCormack, J. P., Brown, P., and Czarnecki, J.: Comparative study between ground-based observations and NAVGEM-HA analysis data in the mesosphere and lower thermosphere region, *Atmospheric Chemistry and Physics*, 20, 11 979–12 010, <https://doi.org/10.5194/acp-20-11979-2020>, 2020.
- 385 Stober, G., Janches, D., Matthias, V., Fritts, D., Marino, J., Moffat-Griffin, T., Baumgarten, K., Lee, W., Murphy, D., Kim, Y. H., Mitchell, N., and Palo, S.: Seasonal evolution of winds, atmospheric tides, and Reynolds stress components in the Southern Hemisphere mesosphere–lower thermosphere in 2019, *Annales Geophysicae*, 39, 1–29, <https://doi.org/10.5194/angeo-39-1-2021>, 2021a.
- Stober, G., Kozlovsky, A., Liu, A., Qiao, Z., Tsutsumi, M., Hall, C., Nozawa, S., Lester, M., Belova, E., Kero, J., Espy, P. J., Hibbins, R. E., and Mitchell, N.: Atmospheric tomography using the Nordic Meteor Radar Cluster and Chilean Observation Network De Meteor Radars: network details and 3D-Var retrieval, *Atmospheric Measurement Techniques*, 14, 6509–6532, <https://doi.org/10.5194/amt-14-6509-2021>, 2021b.
- 390 Stober, G., Liu, A., Kozlovsky, A., Qiao, Z., Kuchar, A., Jacobi, C., Meek, C., Janches, D., Liu, G., Tsutsumi, M., Gulbrandsen, N., Nozawa, S., Lester, M., Belova, E., Kero, J., and Mitchell, N.: Meteor radar vertical wind observation biases and mathematical debiasing strate-



- gies including the 3DVAR+DIV algorithm, *Atmospheric Measurement Techniques*, 15, 5769–5792, [https://doi.org/10.5194/amt-15-5769-](https://doi.org/10.5194/amt-15-5769-2022)
395 2022, 2022.
- Stober, G., Liu, A., Kozlovsky, A., Qiao, Z., Krochin, W., Shi, G., Kero, J., Tsutsumi, M., Gulbrandsen, N., Nozawa, S., Lester, M., Baumgarten, K., Belova, E., and Mitchell, N.: Identifying gravity waves launched by the Hunga Tonga–Hunga Ha’apai volcanic eruption in mesosphere/lower-thermosphere winds derived from CONDOR and the Nordic Meteor Radar Cluster, *Annales Geophysicae*, 41, 197–208, <https://doi.org/10.5194/angeo-41-197-2023>, 2023a.
- 400 Stober, G., Weryk, R., Janches, D., Dawkins, E. C., Günzkofer, F., Hormaechea, J. L., and Pokhotelov, D.: Polarization dependency of transverse scattering and collisional coupling to the ambient atmosphere from meteor trails — theory and observations, *Planetary and Space Science*, 237, 105 768, <https://doi.org/https://doi.org/10.1016/j.pss.2023.105768>, 2023b.
- Taylor, M. J., Pendleton, W. R., Clark, S., Takahashi, H., Gobbi, D., and Goldberg, R. A.: Image measurements of short-period gravity waves at equatorial latitudes, *Journal of Geophysical Research: Atmospheres*, 102, 26 283–26 299, <https://doi.org/10.1029/96JD03515>, 1997.
- 405 Torrence, C. and Compo, G. P.: A Practical Guide to Wavelet Analysis, *Bull. Amer. Meteor. Soc.*, 79, 61–78, 1998.
- Vadas, S. L. and Becker, E.: Numerical Modeling of the Excitation, Propagation, and Dissipation of Primary and Secondary Gravity Waves during Wintertime at McMurdo Station in the Antarctic, *Journal of Geophysical Research: Atmospheres*, 123, 9326–9369, <https://doi.org/10.1029/2017JD027974>, 2018.
- Vadas, S. L., Zhao, J., Chu, X., and Becker, E.: The Excitation of Secondary Gravity Waves From Local Body Forces: Theory and Observa-
410 tion, *Journal of Geophysical Research: Atmospheres*, 123, 9296–9325, <https://doi.org/10.1029/2017JD027970>, 2018.
- Volz, R., Chau, J. L., Erickson, P. J., Vierinen, J. P., Urco, J. M., and Clahsen, M.: Four-dimensional mesospheric and lower thermospheric wind fields using Gaussian process regression on multistatic specular meteor radar observations, *Atmospheric Measurement Techniques*, 14, 7199–7219, <https://doi.org/10.5194/amt-14-7199-2021>, 2021.
- Zeng, J., Yi, W., Xue, X., Reid, I., Hao, X., Li, N., Chen, J., Chen, T., and Dou, X.: Comparison between the Mesospheric Winds Observed
415 by Two Collocated Meteor Radars at Low Latitudes, *Remote Sensing*, 14, <https://doi.org/10.3390/rs14102354>, 2022.
- Zeng, J., Stober, G., Yi, W., Xue, X., Zhong, W., Reid, I., Adami, C., Ning, B., Li, G., and Dou, X.: Mesosphere/Lower Thermosphere 3-Dimensional Spatially Resolved Winds Observed by Chinese Multistatic Meteor Radar Network Using the Newly Developed VVP Method, *Journal of Geophysical Research: Atmospheres*, 129, e2023JD040 642, <https://doi.org/https://doi.org/10.1029/2023JD040642>, e2023JD040642 2023JD040642, 2024.
- 420 Zhang, J., Zhao, Y., Pautet, P.-D., Scherliess, L., Taylor, M. J., and Liu, H.: Gravity Wave Activity During the 2024 Sudden Stratospheric Warmings Observed by Atmospheric Waves Experiment (AWE), *Geophysical Research Letters*, 52, e2024GL114 187, <https://doi.org/https://doi.org/10.1029/2024GL114187>, e2024GL114187 2024GL114187, 2025.