## Eastward-propagating planetary waves in SuperDARN radar wind observations

**Supervisors: Yvan ORSOLINI (Assoc. Prof.), Patrick ESPY (Prof.)**

Stratospheric sudden warmings (SSW) are spectacular events during which the wintertime eastward polar night jet abruptly weakens and reverses, turning the mean flow in the polar stratosphere westward, while polar temperatures rise by tens of degrees. Recent SSWs occurred in February 2018 and January 2019.

The mesosphere-lower thermosphere (MLT) region (roughly at altitudes between 50 and 120 km) is characterised by travelling planetary waves, in particular eastward-propagating planetary waves (EPW) likely generated in that region by the instability of the strong zonal jets. Bursts of such EPWs have been observed in satellite data prior to the occurrence of some SSWs. They may thus indicate high-altitude precursors to the development of the SSW events that ultimately affect our weather in very significant way.

This project aims to characterize the sources and characteristics of such EPWs in the MLT region using wind observations from a network of high-latitude radars. Wind data from this SuperDARN radar network has been extensively used by our group to study PWs and atmospheric tides. The climatology of EPWs and their behavior around the time of SSW occurrences will be examined. Winters characterised by strong SSW may be contrasted with winters without occurrences of SSWs. Supporting diagnostics from existing simulations with a whole-atmosphere climate model may be used to further the interpretation of those radar observations in terms of jet instability.

**Bibliography**

Hibbins, R., Espy, P.J., Orsolini, Y., Limpasuvan, V., Barnes, R. J. (2019), SuperDARN observations of semidiurnal tidal variability in the MLT and the response to sudden stratospheric warming events. J. Geophysical Research-Atmospheres,Vol. 124. s.4862-4872

Iida, C., Hirooka, T., Eguchi, N. (2014), Circulation changes in the stratosphere and mesosphere during the stratospheric sudden warming event in January 2009. Journal of Geophysical Research, 119, 7104–7115. https://doi.org/10.1002/2013JD021252

Limpasuvan, V., Orsolini, Y. J., Chandran, A., Garcia, R. R., & Smith, A. K. (2016), On the composite response of the MLT to major sudden stratospheric warming events with elevated stratopause. Journal of Geophysical Research, 121, 4518–4537. https://doi.org/10.1002/2015JD024401

Stray, N. H., Orsolini, Y. J., Espy, P. J., Limpasuvan, V., Hibbins, R. E. (2015) Observations of planetary waves in the mesosphere-lower thermosphere during stratospheric warming events. Atmos. Chem. Phys., 15, 4997-5005. doi:10.5194/acp-15-4997-2015.

## The secondary ozone layer and energetic particle precipitation

**Supervisors: Yvan ORSOLINI (Assoc. Prof.), Patrick ESPY (Prof.)**

Ozone abundance has a global peak in the upper mesosphere (near 90-95 km), known as the secondary ozone layer. Ozone at that altitude is easily photo-dissociated in daytime and is hence more abundant in nighttime. It is in a state of chemical equilibrium, with its abundance governed by temperature and by longer-lived species that act as chemical sinks and sources, namely atomic hydrogen and oxygen.

The ozone abundance is also impacted by the solar and geomagnetic variability that modulates both the radiative ultraviolet flux and the energetic particle flux into the upper atmosphere. The solar radiative variability manifests in the 11-year solar cycle or in the more rapid 27-day cycle associated with the solar rotation. While auroral electron precipitation occurs routinely down to near 90 km, the precipitation of medium-energy electrons (MEE) -that are able to penetrate further into the mesosphere- during sporadic geomagnetic storms is more frequent during the declining phase of the 11-year solar cycle. Electron precipitation leads to neutral and ionic reactions that alter the background chemistry.

This project aims to quantify the ozone destruction in the secondary layer associated with the precipitation of MEE at the high latitudes of both hemispheres. Existing, idealized numerical simulations with a comprehensive whole-atmosphere model over one solar cycle will be used to quantify and investigate the underlying chemical loss mechanisms. The simulation-based results will be benchmarked by ozone satellite observations taken by the NASA's Sounding of the Atmosphere using Broadband Emission Radiometry (SABER) instrument during case studies of observed geomagnetic storms events.

**Bibliography**

Guttu, S., Y. Orsolini, F. Stordal, V. Limpasuvan, D. R. Marsh (2020), WACCM simulations: Decadal winter-to-spring climate impact on middle atmosphere and troposphere from medium energy electron precipitation, Journal of Atmospheric and Solar–Terrestrial Physics, 209, 105382.

Smith A.K. et al (2015), Nighttime ozone variability in the high latitude winter mesosphere, J. Geophys. Res.-Atmospheres,Vol. 119,. 1-18

Smith-Johnsen C., Y.J. Orsolini, V. Limpasuvan, F. Stordal, K. Pérot (2018), Nighttime mesospheric ozone enhancements during the 2002 southern hemispheric major stratospheric warming, Journal of Atmospheric and Solar–Terrestrial Physics, 168, 100–108

Tweedy, O., V. Limpasuvan,Y. J. Orsolini, A. K. Smith, R. R. Garcia, D. Kinnison,C. E. Randall, O.-K. Kvissel, F. Stordal, V. L. Harvey and A. Chandran (2013), Nighttime secondary ozone layer during major stratospheric sudden warmings in specified-dynamics WACCM, J. Geophys. Res. -Atmospheres., 118, doi:10.1002/jgrd.50651

## Planetary waves over Antarctica

**Supervisors: Patrick Espy (Prof.), Yvan Orsolini (Assoc. Prof.)**

Planetary waves, as the name implies, are global oscillations of pressure and temperature that progress slowly around the world. As they pass over a station, they create periodic temperature and wind fluctuations with periods between 2 and 20 days. While atmospheric instabilities can give rise to planetary-wave generation, land-sea temperature differences are one of the major causes. Thus planetary wave activity is generally low in the Antarctic due to the zonal symmetry of ocean and land mass. However, there are occasions when strong planetary wave activity occurs over Antarctica. This project will entail first localizing these planetary-wave breakouts, and then characterizing the conditions contributing to its cause. The project will involve analysis of both ground-based radar and satellite remote-sensing data, as well as modelling using whole atmosphere models.

**Bibliography**

Kleinknecht, N. H., P. J. Espy, and R. E. Hibbins (2014), The climatology of zonal wave numbers 1 and 2 planetary wave structure in the MLT using a chain of Northern Hemisphere Super- DARN radars, J. Geophys. Res. Atmos., 119, doi:10.1002/2013JD019850.

Palo, S. E., J. M. Forbes, X. Zhang, J. M. Russell III, C. J. Mertens, M. G. Mlynczak, G. B. Burns, P. J. Espy, and T. D. Kawahara (2005), Planetary wave coupling from the stratosphere to the thermosphere during the 2002 Southern Hemisphere pre-stratwarm period, Geophys. Res. Lett., 32, L23809, doi:10.1029/2005GL024298.

Espy, P. J., R. E. Hibbins, D. M. Riggin, and D. C. Fritts (2005), Mesospheric planetary waves over Antarctica during 2002, Geophys. Res. Lett., 32, L21804, doi:10.1029/2005GL023886.

## Coupling of chemistry and dynamics

**Supervisors: Patrick Espy (Prof.), Robert Hibbins (Assoc. Prof.)**

During the day, hard UV radiation dissociates many molecular species into their atomic components in the mesosphere and lower thermosphere (80-110 km). At night, these atoms recombine into molecules in a series of "chemi-luminescent" reactions, where the bond energy released creates the nightglow. One of these reactions between atomic hydrogen and ozone results in the formation of hydroxyl (OH), which subsequently radiates strongly in the near infrared. So strongly, in fact, that night-vision equipment uses this infrared emission from the MLT to see at night. At the same time, the MLT is constantly under the influence of strong, rapidly varying wind systems that can mix and transport chemically active species. In this project, we will compare the winds derived from the Trondheim meteor radar with OH airglow fluctuations observed by a spectrometer located at the same site. This will involve primary data reduction from the instruments, followed by time-series and correlative analyses. Finally, we will use both steady-state and coupled chemistry-dynamic atmospheric models to quantify the factors driving the airglow.

**Bibliography**

Espy, P.J., and J. Stegman, (2002) Trends and variability of mesospheric temperature at high-latitudes, Physics and Chemistry of the Earth 27(2002) 543–553.

Espy, P. J., R.E. Hibbins, G. O. L. Jones, D. M. Riggin, and D. C. Fritts, Rapid, large-scale temperature changes in the polar mesosphere and their relationship to meridional flows, Geophys. Res. Lett., 30 (5), 1240, doi:10.1029/2002GL016452, 2003.

# Modeling and observing the 8-hour atmospheric tide

**Supervisors: Wim van Caspel (3rd year PhD), Patrick Espy (Prof.)**

Atmospheric tides are global-scale oscillations in the winds, temperature and density. The tides are excited by heating related to the daily insolation cycle, and have periods of an integer fraction of a solar day. The most dominant atmospheric tides are known as the diurnal (24 hr), semidiurnal (12 hr) and terdiurnal (8 hr) tide. The focus of this project lies on the terdiurnal tide.

The terdiurnal tide is predominantly forced by the absorption of shortwave radiation by stratospheric ozone, but obtains its largest amplitudes in the mesosphere-lower-thermosphere (MLT, 80-120 km altitude). There, the tide impacts a wide range of dynamical and chemical processes, and is thus of considerable scientific interest. This is further compounded by the tide effectively linking short- and long-term (climate) variability in the lower atmosphere to atmospheric variability at the interface between Earth and outer space.

In this exciting and ambitious project, you will perform numerical experiments using a state-of-the-art atmospheric tide model. The experiments will investigate how the tide is modified by the winds and temperatures of the background atmosphere, and how its seasonal characteristics are shaped by dissipation processes. You will compare the model results to wind measurements made by a global-scale array of SuperDARN meteor radars, as well as by a meteor radar operating in Trondheim.

This project offers a unique opportunity to learn about a broad range of topics in atmospheric physics, atmospheric measurement techniques, and numerical mathematics. For further information, please do not hesitate to contact willem.e.v.caspel@ntnu.no.

**Recommended / useful courses**

- FY3201 - Atmospheric Physics and Climate Change
- TFY4280 - Signal Processing
- TMA4212 - Numerical Solution of Differential Equations by Difference Methods

**Other useful prerequisites**

- Programming experience in Python and possibly FORTAN 77
- TMR4230 – Oceanography
- Access to a computer running a Linux operating system

**Literature**

Smith, A. K. (2012). Global dynamics of the MLT. *Surveys in Geophysics*, *33*(6), https://doi.org/10.1007/s10712-012-9196-9

Lilienthal, F., Jacobi, C., & Geißler, C. (2018). Forcing mechanisms of the terdiurnal tide. *Atmospheric Chemistry and Physics*, *18*(21), https://doi.org/10.5194/acp-18-15725-2018