New Quantitative Constraints on Orographic Gravity Wave Stress and Drag

Satisfying Emerging Needs in Seasonal-to-Subseasonal and Climate Prediction

Abstract. This project will utilize recent advances in the analysis of high-resolution satellite data for studies of the full three-dimensional (3D) properties of orographic gravity wave (OGW) events, and evaluation of existing and new parametrizations of OGW drag in global models. We will bring together an international team of experts on (1) the satellite data and their analysis, (2) high-resolution wave-resolving models, (3) global prediction models, and (4) parametrization methods.

OGW drag is one of the fundamental physics parametrizations employed in every global prediction model across timescales from weather to climate. Orographic waves are part of the complex dynamical interaction of winds with topography, and one piece in the puzzle that is topography's effect on global circulation. Parametrized OGW drag provides an important control on model wind biases at levels from the surface through the middle atmosphere, and these alterations in winds in turn affect stationary and synoptic Rossby wave propagation and dissipation. Thus properly tuned OGW drag parameterzations can improve weather model prediction skill from synoptic to seasonal timescales [Sigmond et al.~2013; Shaw et al.~2014]. Climate models have long relied on OGW drag for improved representations of both the mean climate and variability [Alexander et al. 2010]. In the stratosphere in particular, the circulation changes associated with OGW drag reduce winter temperature biases that affect ozone chemistry, so OGW drag is also fundamental to chemistry-climate modelling [Eyring et al.~2010]. Despite its importance in global models, OGW parametrization tuning is still only weakly constrained by observations in today's models, while new issues related to shortcomings in OGW parametrization are arising.

ISSI facilities in Bern provide an ideal forum for our diverse international group to roll up their sleeves and perform the difficult task of determining uncertainties in existing observations and parametrization methods, and evaluating new state-of-the-art techniques for representing OGW drag in global models. The international (5-nation) team is well-balanced in gender (5 women including team leader) and career stage (4 within five years of PhD), and members are all actively working on projects that will feed the team's joint work. Several members provide links to relevant international projects within the World Climate and World Weather Research Programmes (WCRP and WWRP), ensuring the team's results will be disseminated for broad scientific impact.

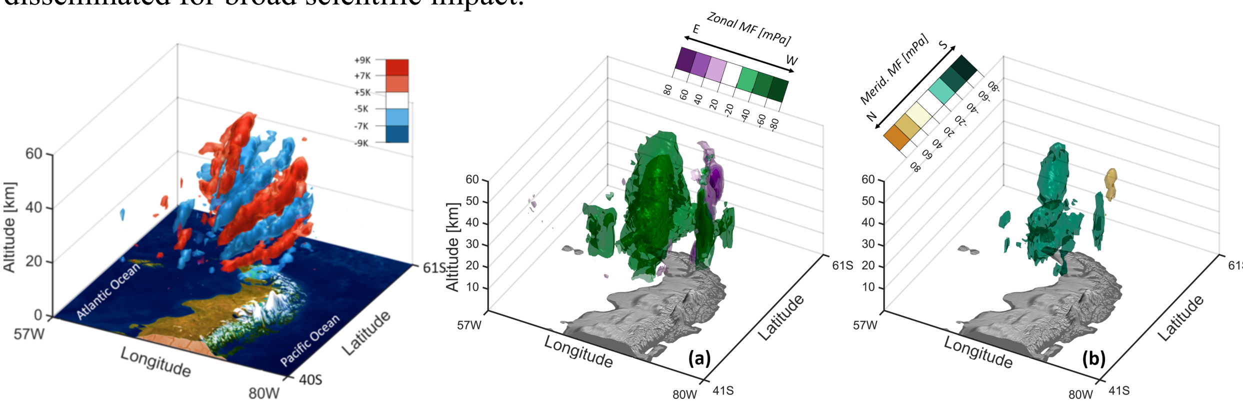

Figure 1: High-resolution 3D satellite retrieval of an Andean OGW event in the stratosphere (left) and analysis of the vector momentum flux ("MF") or stress (center & right). [Wright et al. 2017]

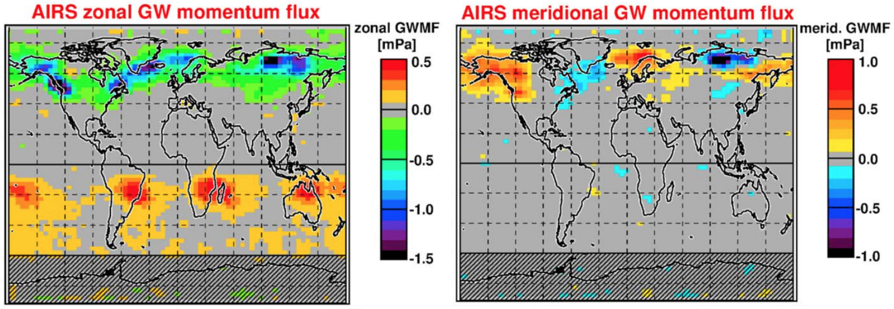

Figure 2: *Gravity wave zonal (left) and meridional (right) momentum flux at 36 km altitude averaged over the month of January 2009. [Ern et al. 2017]*

Science Rationale and Goals

The interaction of winds with mountainous terrain leads not only to drag forces in the boundary layer, but also exchanges of momentum between the surface and the overlying atmosphere. Part of the momentum is carried vertically by orographic gravity waves (OGW), which grow in amplitude exponentially with height (through decreasing density ρ) to conserve energy. At some point aloft, the waves break or dissipate, and exert forces on the flow in the troposphere and middle atmosphere. The key variable in this momentum exchange is the wave stress (or momentum flux) $\tau = \rho(\overline{u'w'}, \overline{v'w'})$. Drag forces $\mathbf{F} = \rho^{-1} d\tau/dz$ are exerted on the flow where there is wave breaking or dissipation. These OGW stresses and forces can be locally quite large with important nonlinear circulation effects [Sacha et al. 2016]. Wind anomalies (u', v', w') are historically difficult to measure from space, particularly the vertical wind w', which can be orders of magnitude smaller than horizontal wind. Ern et al. [2004] related the stress to the more directly measured wave temperature anomalies:

$$\tau = \frac{\rho}{2} \frac{(k,l)}{m} \left(\frac{g}{N}\right)^2 \left(\frac{\hat{T}}{\bar{T}}\right)^2 \tag{1}$$

This conversion of temperature to stress requires measurement of the local 3D wave properties: horizontal wavenumber vector (k, l), vertical wavenumber (m), and wave amplitude $\hat{T}$. (g=gravity and N=buoyancy frequency.) Orographic waves with significant stress can have horizontal wavelengths as short as $\sim$10 km, so the satellite measurements must have very high resolution. Earlier attempts with high-density limb-viewing satellite measurements from CRISTA, HIRDLS, SABER, and MLS [Ern et al. 2004; Alexander et al. 2008; Ern et al. 2011; Wright et al. 2011; Wright et al. 2016a; 2016b] provided only 2D measures of an apparent horizontal wavenumber and crude measure of stress magnitude. A 2010 ISSI team found these 2D limb-viewing estimates to not only be low-biased, as expected, but also highly uncertain depending on the method applied [Geller et al. 2013].

Hyper-spectral infrared nadir sounding instruments with cross-orbital scan patterns like the Atmospheric Infrared Sounder (AIRS) and the Infrared Atmospheric Sounding Interferometer (IASI) can provide the necessary information on the 3D structure of OGW [Hoffmann et al. 2014], but standard retrieved temperature products but at degraded resolution due to cloud-clearing procedures [Susskind et al. 2003]. Full horizontal resolution brightness temperatures, which give vertically integrated measures of wave temperature anomalies, were used by Alexander et al. [2009] together with supplementary wind information from global reanalyses to compute the missing wave vertical wavenumber m and vector stress for OGW above isolated SH islands, and the wave analysis method has also now been applied globally [Holt et al. 2017]. Hoffmann and Alexander [2009] recognized that full resolution temperature retrievals at altitudes in the stratosphere above clouds could be accomplished, providing the 3D structure of small-scale gravity wave temperature anomalies. Team member Hoffmann has processed the entire AIRS record from 2002-present, and these data have recently been exploited to compute vector stress at stratosphere levels [Ern et al. 2017; Wright et al. 2017]. Thus different measures of OGW vector stress are now documented, but the uncertainty

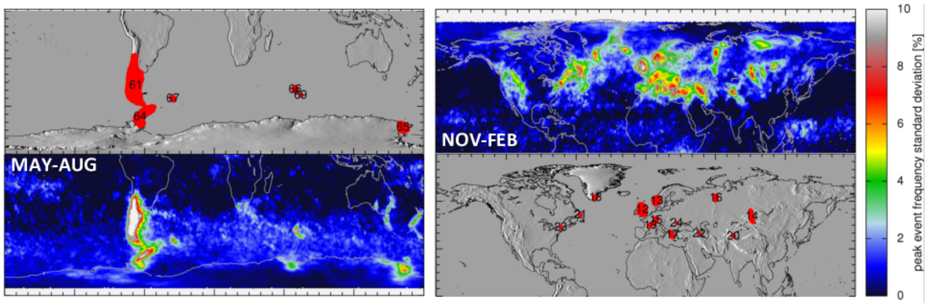

Figure 3: *AIRS winter season OGW "hotspots" shown both as frequency of extreme events (color scale) and as numbered regions (red on gray topographic relief). [Hoffmann et al. 2013].*

in these methods is extremely difficult to quantify. A first goal of this ISSI team is:

• ***To plan and execute direct comparisons among different analyses of OGW vector stress from satellite measurements to quantify uncertainties and biases.***

Early OGW drag parametrizations (e.g. Palmer et al. [1986]; McFarlane [1987]) used a simple scaling for OGW surface stress as the subgrid-scale orographic variance. The schemes were coupled to a propagation and drag scheme based on Lindzen [1981] for gravity wave dissipation to compute the drag force in the column of atmosphere above, and many climate models still use these simple formulations (e.g. Garcia et al. [2017]). A next major advance in orographic drag parametrizations dates to Lott and Miller [1997] whose scheme accounted for low-level blocking and associated form drag, which led to historic improvements in forecast model skill. (See e.g. Charron et al. [2012].) While many further advances in understanding the complex dynamics of flow interactions with orography have followed from other field measurement campaigns and modelling studies, these have not yet led to any consensus on parametrized OGW surface stress or atmospheric drag aloft, and major model differences persist [Zadra et al. 2013; Geller et al. 2013].

New topography datasets and orographic wave parametrizations have been developed and implemented in state-of-the-art models used for weather forecasting and climate prediction [Lauritzen et al. 2015; Amemiya and Sato 2016; van Niekerk et al. 2016]. Recent advances in satellite data analysis providing vector OGW stress at stratospheric levels (e.g. Figs. 1 and 2) open up the possibility of a new global approach to validation of OGW parametrizations, which leads us to the second goal of this ISSI International team proposal:

• ***To validate mean stress and daily variability in global models with current and state-of-the-art OGW parametrizations.***

While the 3D satellite measurements are necessarily limited to stratospheric altitudes, our approach offers several other advantages compared to field observational campaign approaches to validation. Our project offers a significant advancement in the science for minimal cost. Validation will be possible at multiple orographic hotspots all across the globe (Figure 3) and throughout the seasons. The long record of data also means that the effects of important modes of circulation variability on OGW can also be studied [Gisinger et al. 2017; Sacha et al. 2018]. The key to success for this second goal is the use of models that have their winds and temperatures constrained to remain close to observations because the OGW are highly sensitive to the regional wind and stability conditions. Team members Bacmeister, van Niekerk, and Plougonven have already prepared nudged global and initialized regional high-resolution simulations that will be brought to the ISSI team for their work [Plougonven et al. 2013; 2015; van Niekerk et al. 2016; 2017]. Team member Holt has examined OGW in the MERRA-2 [Holt et al. 2016] global "Replay" simulation [da Silva et al. 2015], relaxing only the larger scales while leaving the small-scales (including gravity waves) to evolve freely. (See Figure 4.) MERRA-2 Replay with 12-km global resolution is available for years 2005-2015, a significant overlap with AIRS observations.

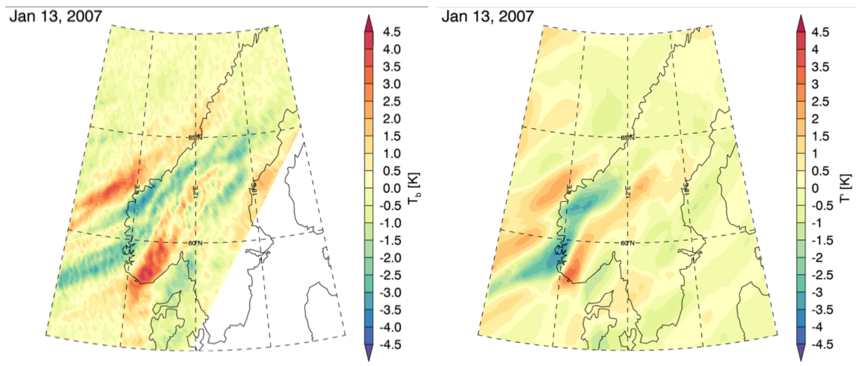

Figure 4: *(left) AIRS observation of OGW brightness temperature anomalies T_b' on Jan 13, 2007 over Norway. (right) NASA MERRA-2 "replay" simulation (12-km resolution) of T_b'.*

Global model resolutions are generally improving with time, and different applications require flexible model resolution for studying various time scales. Developments in scale-aware physics are urgently needed. Several studies have shown that linear scaling of OGW stress with resolution often fails, particularly for small-scale hotspots like SH islands [Vosper et al. 2016]. Figure 3 shows a 12-km resolution global simulation of OGW over Norway compared to an AIRS observation at the same time. There are remarkable similarities in pattern and amplitude. Closer inspection reveals there are shorter scale coherent wave features in the observations that are missing in the simulation. This is not due to atmospheric model resolution, but is due to the specification of smoothed surface orography, which is common in such global models [Laurizten et al. 2015]. This issue of resolved versus unresolved scales is an extremely important one since the smaller scale waves have larger stress for a given amplitude. This issue of wave scale motivates a third goal of the team:

• ***To assess contributions of different scale groups to total wave stress for improving scale-aware parametrization across a range of model resolving power.***

Addressing this goal will additionally utilize long-duration balloon observations obtained in the stratosphere during the Vorcore and Concordiasi field campaigns [Plougonven et al. 2015; Jewtoukoff et al. 2015]. These data are global in scale (SH only) and Concordiase data include the full spectrum of gravity waves, providing an absolute measure against other observed and modelled metrics, which are restricted to limited scales. This work will involve case studies during the Vorcore (2005-6) and Concordiasi (2010-11) observation periods.

Another issue arising as model resolutions increase is that parametrizations assume the waves propagate purely vertically through the column directly above the source topography. Due to parallel computation methods, requiring communication of parametrized physics across multiple grid cells can be costly [Amemiya and Sato, 2016]. Observations and wave-resolving models instead show significant horizontal propagation of OGW [Sato et al. 2012]. Team member Sato's theoretical and modelling work combined with Hoffmann et al. [2013] analyses of observed OGW hotspots will guide choices for validation areas.

Timeliness of the Project. A recent activity of the WCRP/WWRP Working Group on Numerical Experimentation (WGNE) called the WGNE Drag Project [Zadra et al. 2013] brought attention to wide differences in parametrization of surface drag processes among numerical weather prediction systems and climate models [Zadra et al. 2013], and a new initiative proposed in 2018 to another WCRP group called Global Atmosphere System Studies (GASS) seeks to examine the momentum budget more broadly on a project titled Surface Drag and Momentum Transport. The new project, led by Drs. Irina Sandu, Annelize van Niekerk, and Louise Nuijens, has prepared a broadly distributed white paper[1], and the project was officially proposed at the 2nd PanGASS

[1] http://singh.sci.monash.edu/Pan-GASS/GASS_white_paper_momentum.pdf

Conference held in Lorne, Australia Feb 26-Mar 2, 2018. Our new ISSI project includes members of both of these groups as well as connections to the SPARC Gravity Wave Activity[2].

Expected Output

We plan to produce at least 2-4 influential publications on OGW stress, drag, and global circulation from the teams work, to be completed by the end of the 2-year project limit. Topics will include:

- Quantifying uncertainties in existing observational analyses,
- Constraints for existing parametrization schemes and new state-of-the-art methods,
- Case studies examining the roles of different scale groups to inform seamless parametrization,
- Documenting the range of forcing from local intermittent events to long-term variations, and
- Evaluating the circulation responses associated with the team's findings.

We realize that we may not complete all five of the above topics in two years' time, but given the state of readiness of the project, a prolific output is possible. The observational analyses and most of the model simulations already exist or are in an advanced state of production as of March 2018. The enthusiasm of the group is also very high, and even more new ideas than these five have emerged during the development of this proposal. It seems likely that the materials collected and collaborations forged during the project will lead to a number of publications.

We also hope to publish a stratospheric OGW climatology as a data product that can be accessed by other model groups for future validation efforts. We will ensure acknowledgement of ISSI's role in all publications and products.

Schedule

The first meeting will span 5 days, during which we will bring the data and model tools together, share perspectives, develop publication plans and assign leaders. Early career members will be encouraged to lead on a manuscript most relevant to their interests. To maintain momentum for the work, we will schedule bimonthly telecons to identify any obstacles, and brainstorm solutions or redirect plans as necessary. A second meeting 6-12 mos. later will be a 5-day working meeting to exchange collected results, and refine manuscript outlines. This meeting may include small subgroup breakouts on different publications as needed. We will seek a final meeting of opportunity (not funded by ISSI) at a conference that will be jointly attended by members of the GASS and WGNE groups and our ISSI team, where we can present our final results and link them to the broader context.

Added Value of ISSI

The Bern office of ISSI provides a central location for this diverse team to meet, yet the location is remote enough to facilitate the focus that will be needed for the team to plan and execute their work. There may be some difficult discussions during the meetings if, for example, some team member results emerge as more promising than others. The ISSI facilities will permit the sort of focused, indepth discussions that will be needed, and past experience with ISSI-Bern suggests that the close collaborative time together can facilitate camaraderie among the team, which may be important to a successful outcome.

Facilities Required

Facilities required include (1) A quiet room to facilitate round table discussion; (2) Projection capability for the team to share their results (from their own laptops) and view emerging planning documentation as the team's plan develops; (3) Wireless internet access for sharing results and collecting research materials (e.g. journal articles); (4) White board for capturing important discussion points; (5) Power outlets for multiple laptops.

[2] sparc-climate.org

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MEMBERS TEAM CV – Leader

NAME, First Name: **ALEXANDER, M. Joan**

Affiliation: NorthWest Research Associates, and University of Colorado—Boulder

Role in the project: International Team Leader with expertise in satellite observational analysis of gravity waves and gravity wave parameterization in climate models.

Current positions:
Sr. Research Scientist, Vice President & Director at NorthWest Research Assoc., and
Adjoint Professor at University of Colorado Atmospheric and Oceanic Sciences

Former Positions: Research Scientist NorthWest Research Associates, 1998-2003
Lecturer – University of Colorado, Atmospheric and Ocean Sciences, 1999-2003
Affiliate Professor – University of Washington, Atmospheric Sciences, 1998-2011
Research Professor – University of Washington, Atmospheric Sciences, 1994-98
Postdoctoral Researcher, University of Washington, Atmospheric Sciences, 1992-94

Education: Purdue University, B.S. Chemistry, 1981
University of Colorado—Boulder, M.S. Astrophysical, Planetary & Atmospheric Sciences 1989
University of Colorado—Boulder, Ph.D., Astrophysical, Planetary & Atmospheric Sciences 1992

Services in National and/or International Committees (last ones):
Gravity Wave Activity Lead, World Climate Res. Programme (WCRP)/SPARC 2008-
Co-Chair and Science Steering Group, WCRP/SPARC, 2012-16
Advisory Committee, Atmospheric Chemistry, Observations and Modelling, National Center for Atmospheric Research, 2015-16
WCRP Modelling Advisory Council 2013-2015
Lecturer, SPARC Training School on Stratosphere-Troposphere Interactions 2017
ISSI International Team Leader, 2010 and 2013
Associate Editor, Journal of the Atmospheric Sciences, 2010-
Board on Atmospheric Science & Climate, NRC/National Academies 2005-2008
President/V.P. Atmospheric Sciences – American Geophysical Union, 2002-2006

Honors:
Fellow of the American Geophysical Union 2017
Fellow of the American Meteorological Society 2006
Marie Tharp Fellow, Columbia University, New York, 2006-2007
Visiting Professor, L'Ecole Polytechnique, Paris, 2017
Southgate Fellow, University of Adelaide, Australia, 2017
Visiting Professor, L'Ecole Normale Superieure, Paris, 2011
Coupling, Energetics & Dynamics of Atmospheric Regions Tutorial Lecturer 2002
Bjerknes Lecturer, American Geophysical Union, 2000
University of Washington, Atmospheric Sciences Annual Teaching Award, 1998

Selected Publications:

Williams, P.D., M.J. Alexander, E.A. Barnes, A.H. Butler, H.C. Davies, C.I. Garfinkel, Y. Kushnir, T.P. Lane, J.K. Lundquist, O. Martius, R.N. Maue, W.R. Peltier, K. Sato, A.A. Scaife, and C. Zhang, 2017: A census of atmospheric variability from seconds to decades, *Geophys. Res. Lett.*, **44**, doi.org/10.1002/2017GL075483.

Alexander, M. J. 2015: Global and seasonal variations in three-dimensional gravity wave momentum flux from satellite limb sounding temperatures. *Geophys. Res. Lett.*, **42**, doi:10.1002/2015GL065234.

Lyapustin, A., M. J. Alexander, L. Ott, A. Molod, B. Holben, J. Susskind, and Y. Wang, 2014: Observation of mountain lee waves with MODIS NIR column water vapor, *Geophys. Res. Lett.*, **41**, 710-716, doi:10.1002/2013GL058770.

Alexander, M. J. and A. W. Grimsdell, 2013: Seasonal cycle of orographic gravity wave occurrence above small islands in the Southern Hemisphere: Implications for effects on general circulation, *J. Geophys. Res*. **118**, 1–11, doi:10.1002/2013JD020526.

Alexander, M. J., and H. Teitelbaum, 2011: Three-dimensional properties of Andes mountain waves observed by satellite: A case study. *J. Geophys. Res*., **116**, D23110, doi:10.1029/2011JD016151.

Alexander, M. J., M. Geller, C. McLandress, S. Polavarapu, P. Preusse, F. Sassi, K. Sato, S. Eckermann, M. Ern, A. Hertzog, Y. Kawatani, M. Pulido, T. A. Shaw, M. Sigmond, R. Vincent and S. Watanabe, 2010: Recent developments in gravity-wave effects in climate models and the global distribtuion of gravity-wave momentum flux from observations and models, *Q.J.Roy. Met. Soc.*, **136**, 1103-1124.

Alexander, M. J., S. D. Eckermann, D. Broutman, and J. Ma, 2009: Momentum flux estimates for South Georgia Island mountain waves in the stratosphere observed via satellite, *Geophys. Res. Lett*., **36**, L12816, doi:10.1029/2009GL038587.

Alexander, M. J., J. Gille, C. Cavanaugh, M. Coffey, C. Craig, V. Dean, T. Eden, G. Francis, C. Halvorson, J. Hannigan, R. Khosravi, D. Kinneson, H. Lee, S. Massie, B. Nardi, A. Lambert, 2008: Global Estimates of Gravity Wave Momentum Flux from High Resolution Dynamics Limb Sounder (HIRDLS) Observations, *J. Geophys. Res*., **113**, D15S18, doi:10.1029/2007JD008807.

Alexander, M. J. and H. Teitelbaum, 2007: Observation and analysis of a large amplitude mountain wave event over the Antarctic Peninsula, *J. Geophys. Res*., **112**, D21103, doi:10.1029/2006JD008368.

Alexander, M. J., and C. Barnet, 2007: Using satellite observations to constrain parameterizations of gravity wave effects for global models, *J. Atmos. Sci*., **64**, 1652-1665.

Alexander, M. J. and T. J. Dunkerton, 1999: A spectral parameterization of mean-flow forcing due to breaking gravity waves. *J. Atmos. Sci*., **56**, 4167-4182.

MEMBERS TEAM CV

Julio Bacmeister

Affiliation: National Center for Atmospheric Research

Role in the project: Conduct and analyze data constrained (nudged) atmospheric model runs to evaluate performance of orographic gravity wave parameterizations.

Current position:

Scientist III, National Center for Atmospheric Research	2009 -

Former Position(s):

Associate Research Scientist, NASA Goddard Space Flight Center	1998-2009
Research Physicist (GS-13) Naval Research Laboratory	1992-1998
Postdoctoral Researcher John Hopkins Unvisersity	1989-1992
NASA GSFC National Research Council Fellow	1987-1989

Education:

Swarthmore College B.A., Physics	1982
Princeton University Ph.D., Geophysical Fluid Dynamics	1987

Services in National and/or International Committees (last ones):

Chair, Atmospheric Modeling Working Group of CESM	2017 -
WMO Working Group for Numerical Experimentation	2010 -

Honors:

Cited in Roosevelt Gold Medal for Science awarded to Naval Research Laboratory DC (June 2006) for development of Mountain Wave Forecast Model (MWFM). Cited as a one of the key contributions made between 1923-2004

Selected Publications:

Bacmeister, J.T.**,** Reed, K.A., Hannay, C. et al. 2018: Projected changes in tropical cyclone activity under future warming scenarios using a high-resolution climate model. *Climatic Change* 146: 547. https://doi.org/10.1007/s10584-016-1750-x

Lauritzen, PH, Bacmeister, JT, Callaghan, PF and Taylor, MA. 2015: NCAR_Topo (v1. 0): NCAR global model topography generation software for unstructured grids. *Geosci. Model Dev.*, *8*, 3975–3986, doi:10.5194/gmd-8-3975-2015.

Bacmeister, J. T., M. E. Wehner, R. B. Neale, A. Gettelman, C. Hannay, P. H. Lauritzen, J. M. Caron, and J. E. Truesdale, 2014: Exploratory high-resolution climate simulations using the community atmosphere model (CAM), *J. Clim.*, doi: /10.1175/JCLI-D-13-00387.1

Bacmeister, J. T., P. A. Newman, B. L. Gary, and K. R. Chan, 1994: An algorithm for forecasting mountain wave related turbulence in the stratosphere. *Weather and Forecasting*, 9, 241-253

Bacmeister, J. T., 1993. Mountain-wave drag in the stratosphere and mesosphere inferred from observed winds and a simple mountain-wave parameterization scheme. *J. Atmos Sci*, *50*(3), 377-399.

Bacmeister, J. T**.,** & Schoeberl, M. R., 1989. Breakdown of vertically propagating two-dimensional gravity waves forced by orography. *J. Atmos. Sciences*, *46*(14), 2109-2134.

NAME, First Name: **ERN, Manfred**

Affiliation: Institute of Energy and Climate Research – Stratosphere (IEK-7), Forschungszentrum Juelich

Role in the project: International Team Member, role in providing specialized retrievals of orographic gravity wave stress in the stratosphere from nadir and limb-viewing satellites for comparison to other methods.

Current position: 2002-present: Research Scientist at Forschungszentrum Juelich

Former Position(s): 2000-2002: Post-doc Scientist at Wuppertal University

Education:

1987 – 1993	University of Wuppertal, Germany (Physics)
1993	Diploma (M. Sc.) in Physics
2000	Ph.D. in Physics (magna cum laude), University of Wuppertal

Services in National and/or International Committees (last ones):

- Member of the VarSITI program (2014 – present)
- Member of the SPARC gravity wave initiative (since 2007)

Honors:

1995: DARA (German Space Agency) award (for the CRISTA-SPAS satellite team)
2013: Certificate of Excellence in Reviewing by J. Atmos. Solar-Terr. Phys.
2014: AGU Editor's Citation for Excellence in Reviewing

Selected Publications:

(1) Ern, M., L. Hoffmann, and P. Preusse (2017), Directional gravity wave momentum fluxes in the stratosphere derived from high-resolution AIRS temperature data, Geophys. Res. Lett., 44, 475–485, doi:10.1002/2016GL072007.

(2) Ern, M., et al. (2016), Satellite observations of middle atmosphere gravity wave absolute momentum flux and of its vertical gradient during recent stratospheric warmings, Atmos. Chem. Phys., 16, 9983–10019, doi:10.5194/acp-16- 9983-2016.

(3) Ern, M., et al. (2014), Interaction of gravity waves with the QBO: A satellite perspective, J. Geophys. Res. Atmos., 119, 2329–2355.

(4) Ern, M., et al. (2011), Implications for atmospheric dynamics derived from global observations of gravity wave momentum flux in stratosphere and mesosphere, J. Geophys. Res., 115, D19107, doi:10.1029/2011JD015821.

(5) Ern, M., P. Preusse, M. J. Alexander, and C. D. Warner (2004), Absolute values of gravity wave momentum flux derived from satellite data, J. Geophys. Res., 109, D20103, doi:10.1029/2004JD004752.

MEMBERS TEAM CV

NAME, First Name:	**Gisinger, Sonja** (ORCID ID: 0000-0001-8188-4458)
Affiliation	German Aerospace Center (DLR) Institute of Atmospheric Physics, Oberpfaffenhofen Germany

Role in the project:	International Team Member role in interpretation of global OGW results in the context of local atmospheric conditions with methods in Gisinger et al. 2017.
Current position:	**German Aerospace Center (DLR)** Institute of Atmospheric Physics, Oberpfaffenhofen, Germany Research Scientist

Former Position(s):

11/2013-11/2017	**German Aerospace Center (DLR)** Institute of Atmospheric Physics, Oberpfaffenhofen, Germany PhD-student
07-09/2012	**German Aerospace Center (DLR)** Institute of Atmospheric Physics, Oberpfaffenhofen, Germany Student research assistant
07/2011	**Austrocontrol** Air weather service, Innsbruck, Austria Trainee

Education:

11/2013-current	**PhD Studies** at DLR Institute of Atmospheric Physics; PhD-thesis submitted on March 1st, 2018 at the Ludwig-Maximilians-University Munich [Faculty of Physics (Meteorology)]; thesis defense scheduled for May 15th, 2018 Supervisor: Prof. Markus Rapp
10/2011-11/2013	**Master's Program Atmospheric Sciences** at the University of Innsbruck
10/2008-09/2011	**Bachelor's Program Geo- and Atmospheric Sciences** at the University of Innsbruck

Selected Publications:

Gisinger, S., et. al., 2017: Atmospheric Conditions during the Deep Propagating Gravity Wave Experiment (DEEPWAVE). *Mon. Weather Rev.*, doi:10.1175/MWR-D-16-0435.1

Ehard, B., et al., 2017: Horizontal propagation of large-amplitude mountain waves into the polar night jet. *J. Geophys. Res.*, doi:10.1002/2016JD025621

Dörnbrack, A., et al., 2016: Multilevel cloud structures over Svalbard. *Mon. Weather Rev.*, doi:10.1175/MWR-D-16-0214.1.

Name, First name: **HOFFMANN, Lars**

Affiliation: Forschungszentrum Jülich,
Jülich Supercomputing Centre, Jülich, Germany

Role in the project: Expertise on satellite observations of gravity waves, in particular regarding 3-D temperature retrievals for for infrared nadir sounders such as AIRS and IASI.

Current position: Senior scientist at Jülich Supercomputing Centre, Team leader `Simulation Laboratory Climate Science' (since 2010)

Former Position(s): Postdoc at Institute of Energy and Climate Research, Forschungszentrum Jülich (2008-2009)

Visiting scientist at NorthWest Research Associates, Research scholar at Univ. of Colorado, Boulder (2007)

Education: PhD student at Institute of Chemistry and Dynamics of the Geosphere, Forschungszentrum Jülich (2003-2006)

Physics student, Univ. of Wuppertal (1997-2002)

Selected Publications:

L. Hoffmann, A. W. Grimsdell, and M.J. Alexander, Stratospheric gravity waves at Southern Hemisphere orographic hotspots: 2003-2014 AIRS/Aqua observations, Atmos. Chem. Phys., 16, 9381-9397, 2016.

L. Hoffmann, M. J. Alexander, C. Clerbaux, A. W. Grimsdell, C. I. Meyer, T. Rößler, and B. Tournier. Intercomparison of stratospheric gravity wave observations with AIRS and IASI. Atmospheric Measurement Techniques, 7, 4517-4537, 2014.

L. Hoffmann, X. Xue, and M. Alexander, A global view of stratospheric gravity wave hotspots located with Atmospheric Infrared Sounder observations. J. Geophys. Res., 118, 416-434, 2013.

L. Hoffmann and M.J. Alexander, Retrieval of stratospheric temperatures from Atmospheric Infrared Sounder radiance measurements for gravity wave studies, J. Geophys. Res., 114, doi:10.1029/2008JD011241, 2009.

P. Preusse, S. Schroeder, L. Hoffmann, M. Ern, F. Friedl-Vallon, J. Ungermann, H. Oelhaf, H. Fischer, and M. Riese, New perspectives on gravity wave remote sensing by spaceborne infrared limb imaging. Atmos. Meas. Tech., 2, 299-311, 2009.

S. Eckermann, L. Hoffmann, M. Höpfner, D. Wu, and M. Alexander. Antarctic NAT PSC belt of june 2003: Observational validation of the mountain wave seeding hypothesis. Geophys. Res. Lett., 36, doi:10.1029/2008GL036629 , 2009.

NAME, First Name: **HOLT, Laura**

Affiliation: NorthWest Research Associates

Role in the project: International Team Member expertise in validation of high-resolution, global modeling of gravity waves with satellite observations.

Current position: Research Scientist

Former Position(s):

2016-Present: **Research Scientist**, *NorthWest Research Associates*, Boulder, CO.

2014—2016: **Postdoctoral Research Scientist**, *NorthWest Research Associates*, Boulder, CO.

2013—2014: **Postdoctoral Research Scientist**, *University of Colorado Boulder / Laboratory for Atmo- spheric and Space Physics*, Boulder, CO.

2007—2013: **Graduate Research Assistant**, *University of Colorado Boulder / Laboratory for Atmospheric and Space Physics*, Boulder, CO.

Education:

Bachelor of Arts, *St. Cloud State University*, 2005, Mathematics.

Bachelor of Science, *St. Cloud State University*, 2005, Physics.

Doctor of Philosophy, *University of Colorado Boulder*. 2013, Atmospheric Science.

Services in National and/or International Committees (last ones):

Honors:

IAGA Young Scientist Award 2013

Best student poster, 2012 ATOC Student Poster Conference

Best student paper, 2011 3rd Annual International HEPPA Workshop

Selected Publications:

Laura A. Holt, M. Joan Alexander, Lawrence Coy, Andrea Molod, William M. Putman, Steven Pawson, and Chuntao Liu. An evaluation of gravity waves and gravity wave sources in the Southern Hemisphere in a 7-km global climate simulation. *Quart. J. Roy. Met. Soc.*, 143:2481–2495, 2017. doi:10.1002/qj.3101.

Laura A. Holt, M. Joan Alexander, Lawrence Coy, Andrea Molod, William M. Putman, and Steven Pawson. Tropical waves and the quasi-biennial oscillation in a 7-km global climate simulation. *J. Atmos. Sci.*, 73:3771–3783, 2016. doi:10.1175/JAS-D-15-0350.1.

MEMBERS TEAM CV

NAME, First Name: **PLOUGONVEN, Riwal**

Affiliation: Laboratoire de Météorologie Dynamique (LMD), Ecole Polytechnique

Role in the project: High-resolution modeling of gravity waves; superpressure balloon observations

Current position: Associate Professor

Former Position(s): Assistant Professor at Ecole Normale Supérieure, Paris

Education: Diplome de l'Ecole Polytechnique (1995-1998); PhD supervised by Vladimir Zeitlin at Université Pierre et Marie Curie (2002)

Services in National and/or International Committees (last ones):

Review Panel of the Research Unit 'MS-GWaves', for the DFG (German Research Foundation), June 2017; Convener or co-convener of the "Internal gravity waves" session at the EGU Gen. Ass. since 2006; Member of 6 PhD juries since 2015; Associate Editor for Monthly Weather Review, reviewer for many journals (JAS, JGR, QJRMS..) and funding agencies (NSF, ANR); Deputy director of LMD since Sept. 2016

Honors: Advanced Study Program fellowship at the National Center for Atmospheric Research, 2002-2004

Selected Publications:

R. Plougonven & C. Snyder. (2007) Inertia-gravity waves spontaneously generated by jets & fronts. Part I: Different baroclinic life cycles. J. Atm. Sci., 64, p2502-2520.

R. Plougonven, A. Hertzog & H. Teitelbaum (2008). Observations and simulations of a large-amplitude wave breaking over the Antarctic Peninsula. J. Geophys. Res., 113, D16113, doi:10.1029/2007JD009739.

R. Plougonven, A. Hertzog & L. Guez. (2013) Simulations of gravity waves above Antartica and the Southern Ocean and comparisons to balloon observations. Quart. J. Roy. Meteor. Soc., DOI:10.1002/qj.1965.

R. Plougonven & F. Zhang (2014). Internal gravity waves from atmospheric jets and fronts Rev. Geophys, 52, doi:10.1002/2012RG000419.

R. Plougonven, A. de la Camara, V. Jewtoukoff, A. Hertzog and F. Lott (2017). On the relation between gravity wave and wind speed in the lower stratosphere. J. Atmos. Sci., 74, p1075-1093, 10.1175/JAS-D-16-0096.1

MEMBERS TEAM CV

NAME, First Name: **Šácha, Petr**

Affiliation Universidade de Vigo, Facultade de Ciencias (ES)

Charles University, Faculty of Mathematics and Physics (CZ)

Role in the project: International Team Member with expertise in global modeling of OGW drag effects on circulation and sensitivity to local conditions.

Current position:

(from 02/2017) Researcher at Universidade de Vigo working on the project Stratospheric circulation in models: generation, diagnostics and impacts, funded by the Spanish Ministry of Economy.

(from 02/2015) Research associate at Charles University working on the project Middle atmosphere effects of localized gravity wave forcing funded jointly by the Czech and German grant agencies.

Former Position(s): None

Education:

01/2017 Ph.D. degree in Meteorology and Climatology at Charles University in Prague, Faculty of Mathematics and Physics.

Thesis: New Perspective on the Role of Gravity Waves in the Stratospheric Dynamics and Variability.

Supervisor: doc. RNDr. Petr Pišoft, Ph.D.

Selected Publications:

Sacha, P., Miksovsky, J., and Pisoft, P.: Interannual variability of the gravity wave drag – vertical coupling and possible climate links, Earth Syst. Dynam. Discuss., https://doi.org/10.5194/esd-2018-1, 2018.

Šácha, P., Lilienthal, F., Jacobi, C., and Pišoft, P.: Influence of the spatial distribution of gravity wave activity on the middle atmospheric dynamics, Atmos. Chem. Phys., 16, 15755-15775, doi:10.5194/acp-16-15755-2016, 2016.

Šácha, P., Kuchař, A., Jacobi, C., and Pišoft, P.: Enhanced internal gravity wave activity and breaking over the northeastern Pacific–eastern Asian region, Atmos. Chem. Phys., 15, 13097-13112, doi:10.5194/acp-15-13097-2015, 2015.

MEMBERS TEAM CV

NAME, First Name: **SATO, Kaoru**

Affiliation: Department of Earth and Planetary Science, Graduate School of Science, The University of Tokyo, Tokyo 113-0033, Japan.

Role in the project: International team member with particular expertise in horizontal propagation of OGW and state-of-the-art parameterization methods [Amemiya and Sato, 2016].

Current position: Professor

Former Position(s):

JSPS Research Fellow, Graduate School of Science, Kyoto University, 1991-1993
Assistant Professor, Center for Climate System Research, The University of Tokyo, 1993-1995
Assistant Professor, Graduate School of Science, Kyoto University, 1995-1999
Associate Professor, National Institute of Polar Research, 1999-2005
Professor, Graduate School of Science, The University of Tokyo, 2005-present

Education:

B.S. (Geophysics), The University of Tokyo, 1984
M.S. (Geophysics), The University of Tokyo, 1986
PhD (Geophysics), Kyoto University, 1991

Services in National and/or International Committees (last ones):

Director of the Meteorological Society of Japan, 2008-
Vice-president of the Atmospheric and Hydrospheric Science section, Japan Geoscience Union
Member of Science Council of Japan, 2005-
Member of Scientific Steering Group of SPARC/WCRP, 2013-
Co-leader of Gravity Wave Activity of SPARC/WCRP, 2014-

Honors:

Yamamoto-Syono Award for Outstanding Papers, the Meteorological Society of Japan, 1991
The Award of the Meteorological Society of Japan, the Meteorological Society of Japan, 1998
Commendation for Science and Technology by the Minister of Education, Culture, Sports, Science and Technology, Japan, 2014
Commendation of the Contributor of the Promotion of Building the Maritime Nation of Japan by the Prime Minister, Japan, 2015

Selected Publications:

Sato, K., M. Kohma, M. Tsutsumi, and T. Sato (2017), *J. Geophys. Res. Atmos.,* **122,** 3-19.
Sato, K., C. Tsuchiya, M. J. Alexander, and L. Hoffmann (2016), *J. Geophys. Res.,* **121,** 7622-7640.
Amemiya, A., and K. Sato (2016), *J. Meteor. Soc. Japan,* **94,** 237-256.
Sato, K., S. Tateno S. Watanabe, and Y. Kawatani (2012), *J. Atmos. Sci.,* **69,** 1378–1396.
Sato, K., S. Watanabe, Y. Kawatani, Y. Tomikawa, K. Miyazaki, and M. Takahashi (2009), *Geophys. Res. Lett.,* **36,** L19801.
Sato, K. (1990), *J. Atmos. Sci.,* **47,** 2803-2817.

MEMBERS TEAM CV

NAME, First Name: **van Niekerk, Annelize**

Affiliation: UK Met Office, Exeter, Devon, EX1 3PB

Role in the project:

International Team Member role as expert in parametrized orographic gravity wave stress and drag in the Met Office Unified Model across a range of resolutions (van Niekerk et al. 2016).

Performing targeted experiments with and providing output from the Met Office Unified Model. These may include high resolution limited area modelling experiments and initialised/ constrained simulations for model and parametrization validation.

Current position: Orographic impacts scientist in Atmospheric Processes and Parametrizations group

Former Position(s): PhD Student at University of Reading, Meteorology Department

Education:

PhD 'The role of orographic drag in modelled atmospheric circulation', University of Reading (2014-2017)

Msc Astrophysics, Queen Mary University of London (2011-2012)

Undergraduate Mathematics and Philosophy, University of Liverpool (2007-2010)

Services in National and/or International Committees (last ones):

Co-leader of proposed WCRP/GEWEX/PanGASS project on drag and momentum transport

Honors:

Selected Publications:

van Niekerk, A., Scinocca, J. F., and Shepherd, T. G. (2017). The modulation of stationary waves, and their response to climate change, by parameterized orographic drag. Journal of the Atmospheric Sciences, 74(8):2557–2574.

van Niekerk, A., Shepherd, T. G., Vosper, S. B., and Webster, S. (2016). Sensitivity of resolved and parametrized surface drag to changes in resolution and parametrization. Q. J. R. Meteorol. Soc., 142(699):2300–2313.

Name, First name:	**WRIGHT, Corwin**
Affiliation:	University of Bath, Bath, UK
Role in the project:	Team Member focusing on observational measurements of atmospheric gravity waves by satellite
Current position:	Royal Society University Research Fellow (since 2017) *[independent full-time research position equivalent to Lecturer (UK)/Assistant Professor (USA)]*
Former Position(s):	Research Officer at University of Bath, UK (2013-2017) Postdoctoral Researcher at National Center for Atmospheric Research, USA (2010-2011,2012-2013) Postdoctoral Researcher at University of Western Brittany, France (2011-2012)
Education:	DPhil (PhD) in Atmospheric Physics, University of Oxford, UK (2006-2010) MSc in Photonics and Optoelectronics, University of St Andrews, UK (2005-2006) MSci in Physics, University of Durham, UK (2001-2005)

Selected Publications:

Exploring gravity wave characteristics in 3-D using a novel S-transform technique: AIRS/Aqua measurements over the Southern Andes and Drake Passage
CJ Wright, NP Hindley, L Hoffmann, MJ Alexander and NJ Mitchell
Atmospheric Chemistry and Physics (2017), doi:10.5194/acp-17-8553-2017

Multi-instrument gravity-wave measurements over Tierra del Fuego and the Drake Passage – Part 1: Potential energies and vertical wavelengths from AIRS, COSMIC, HIRDLS, MLS-Aura, SAAMER, SABER and radiosondes
CJ Wright, NP Hindley, AC Moss, DC Fritts, D Janches and NJ Mitchell
Atmospheric Measurement Techniques (2016), doi:10.5194/amt-9-877-2016

Combining AIRS and MLS Observations for Three-Dimensional Gravity Wave Measurement
CJ Wright, NP Hindley and NJ Mitchell
Geophysical Research Letters, doi:10.1002/2015GL067233 (2016)

Global observations of gravity wave intermittency and its impact on the observed momentum flux morphology
CJ Wright, SM Osprey and JC Gille
Journal of Geophysical Research (Atmospheres), doi:10.1002/jgrd.50869 (2013)

Intercomparisons of HIRDLS, COSMIC and SABER for the detection of stratospheric gravity waves
CJ Wright, M Belmonte Rivas and JC Gille
Atmospheric Measurement Techniques, doi:10.5194/amt-4-1581-2011 (2011)

Financial Support Requested

The Team will request hotel and per diem support for 11 participants for two 5-day meetings at ISSI Bern.

In addition, we request travel support for the Team Leader or one alternative participant as need arises.