G1–O1

ATMOSPHERIC REMOTE SENSING IN THE ARCTIC BY INCOHERENT SCATTER TECHNIQUE USING THE EISCAT AND EISCAT 3D RADARS

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EISCAT Scientific Association runs incoherent scatter radars in the Arctic of Northern Scandinavia. The present EISCAT facilities include the UHF and VHF radars, as well as the Heating Facility and dynasonde in Tromso Norway, EISCAT Svalbard radar with 2 antenna dishes and a dynasonde in Longyearbyen Svalbard, UHF receivers in Sodankyla Finland and Kiruna Sweden and an EISCAT_3D demonstrator receiver in Kiruna. Moreover, the EISCAT users have installed significant new instrumentation to be used together with EISCAT, such as the Japanese Lidar observatory and Norwegian MORRO radar in Tromso, EASI interferometry receiver in Svalbard operated in a Norwegian-British-Swedish collaboration, and the Finnish KAIRA wide-band astronomy and EISCAT_3D demonstrator receiver in Kilpisjarvi. We review the recent science highlights based on all of the EISCAT facilities. The incoherent scatter method importantly addresses the interactions between geospace and the atmosphere, as well as between the atmospheric layers themselves. The EISCAT radars offer a unique opportunity to study the atmospheric energy budget and solar system influences, such as the effects of solar wind, meteors, dust, energetic particles and cosmic rays in the atmosphere. New continuous measurements with the proposed EISCAT 3D radar will support studies of upward energy flow from the stratosphere, to the mesosphere, and thermosphere, lower atmospheric tidal variability and interactions with the mean atmospheric circulation, gravity waves, planetary waves, and ionospheric variations, gravity wave excitation mechanisms, the implications of significant observed gravity wave geographical and temporal variability, and the impacts of stratospheric warming events on the ionosphere. We expect novel quantitative results on atmospheric coupling processes also from above to below, such as is the transport-chemistry effect of odd nitrogen created by high-energy particle precipitation into the Arctic atmosphere, demonstrated here using the EISCAT Svalbard radar data from 2007-2008.

G1–O2

Polar ionosphere and thermosphere cooling over the past 30 years

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The upper atmosphere is strongly affected by variations in the solar EUV radiation, geomagnetic activity, and energy and mass exchange with the near Earth space. Trends over longer terms are predicted to be rather caused by anthropogenic increases of greenhouse gases and the global increase of the atmospheric temperature near the Earth's surface. The thermosphere is expected to on average cool down [e.g., Roble and Dickinson, 1989]. From European Incoherent Scatter (EISCAT) radar data gathered in the polar ionosphere above Tromsø we have derived the first significant temperature trends over 30 years (1981-2011). The results are a cooling of 10-15 K/decade near the *F*-region peak (around 220-380 km altitude). Height profiles of the observed trends are close to those produced by recent atmospheric general circulation model. Our results are a first quantitative confirmation of the simulations and so far rather qualitative expectations.

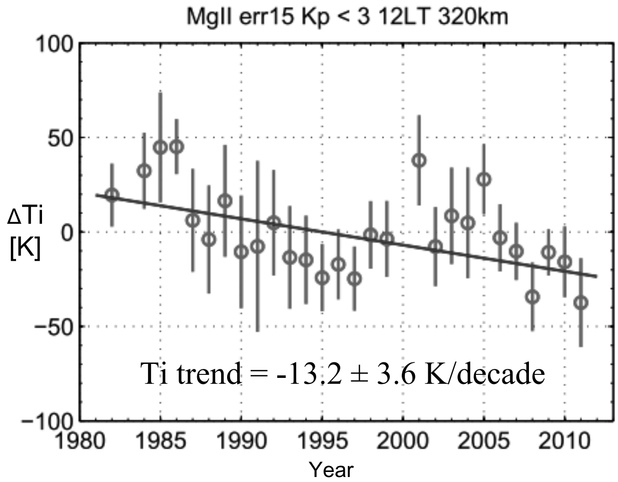

Figure: Yearly averaged ion temperature (residual variations after removing solar influenced variation pattern) at an altitude of 320 km measured with the EISCAT Tromsø UHF radar over 30 years and fitted trend (blue line).

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G1–O3

CHARACTERISTICS OF THE MESOSPHERIC GRAVITY WAVES DERIVED FROM OH AIRGLOW IMAGES AT TROMSØ, NORWAY

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An important aspect of the wind dynamics in the mesosphere is to know characteristics of the atmospheric gravity waves, such as propagation direction, horizontal wavelength, phase speed, and wave amplitude, because it is widely known that the atmospheric gravity waves transport momentum from the lower atmosphere to the upper atmosphere. Statistical analysis of the OH airglow images measured with all-sky cooled-CCD imagers suggest seasonal and geographical dependencies, in particular, of the wave propagation direction.

A new all-sky imager was installed at the Tromsø EISCAT (European Incoherent Scatter) radar site in Norway (69.6°N, 19.2°E) in January 2009. The imager has six optical filters (557.7 nm, 630.0 nm, near-infrared OH band, 589.3 nm, 572.5 nm, and 732.0 nm), and this study focuses on the OH airglow images to study the mesospheric gravity waves in winter (from October to March). A typical emission layer of the OH band may be located around 85 km height. Statistical analysis has been made of data for 48 nights with clear sky and no auroral emissions, selecting gravity waves with horizontal wavelength of 20-100 km. The statistics suggest that predominantly propagation directions are north-to-northeastward, southeastward, and southwest-to-westward. Of particular interest in this statistical result is dependence of the propagation direction on the horizontal wavelength. Gravity waves propagating north-to-northeastward and southwest-to-westward are more clearly appeared with decreasing the horizontal wavelength; by contrast, those of southeastward-propagating component becomes more noticeable with increasing the horizontal wavelength. Winds from a collocated MF radar below 85 km height show gaps of the direction in northeast and southwest, mainly flowing east-to-southeastward. (for reference, winds from NCEP below ~50 km have smaller wind speeds than the MF-radar winds). This result suggests that the wind-filtering effect plays an important role to decide the propagation direction of the gravity waves with relatively shorter horizontal wavelengths. The horizontal phase speed of the gravity wave with relatively longer horizontal wavelengths tends to be larger than the MF radar winds. In this case horizontal propagation directions of the gravity waves can be identical to the background-wind direction. This may be the case for gravity waves with longer wavelengths.

G1–O4

UPPER ATMOSPHERIC OBSERVATION AT RESOLUTE CANADA

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Long-term changes in the upper atmosphere in the polar region may be a reflection of changes in the lower atmosphere. However, such a link is not easy to establish, because the upper atmosphere is also affected by solar cycle. Stratosphere warming events also generates large inter-annual variations. Furthermore, it is hard to find long data set of upper atmosphere observation in the polar region. In this study we examine the changes in the mesosphere over 10-year period and their possible link to solar and other middle and lower atmosphere changes. The data set is mesosphere observation from a Fabry-Perot interferometer at Resolute from 2003 to 2012. The instrument has operating during every winter seasons.

G1–O5

Studies of vertical coupling processes in the Arctic region using a GCM

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It is considered that the Arctic is one of the most sensitive regions to climate change where the temperature rise due to the increase of greenhouse gas is most distinct. On the other hand, the increase of greenhouse gas does not only warm the troposphere, but also cool the middle and upper atmosphere. The cooling trend of the middle and upper atmosphere increases the appearance frequency of polar stratospheric clouds and slows down the recovery of the Antarctic ozone hole. In addition, it could be partly responsible for the tropospheric climate change through the interaction with some dynamical and chemical processes. It suggests that the effect of coupling processes between the Arctic troposphere and the middle and upper atmosphere should be examined in detail as a possible mechanism of the Arctic climate change.

In order to examine the change of vertical coupling processes due to the CO_2 increase and its impact on the Arctic warming, our research group plans to perform several kinds of model experiments (e.g., CO_2 control run, CO_2 doubling, and runs with variable model tops) as a part of the GRENE Project using the Kyushu GCM covering the height region from the ground up to 500 km. The Fortran codes of the Kyushu GCM were already installed on the supercomputer of National Institute of Polar Research (NIPR), and preliminary runs in which the JCDAS reanalysis data below 30 km was nudged into the GCM have been performed. Hereafter, we intend to perform several kinds of experiments mentioned above, and advance the collaborative research with many researchers in the research community using the obtained model datasets. In our presentation, we will introduce the status of model experiments and their preliminary results concerning the vertical coupling processes in the Arctic region.

G1–O6

INTERHEMISPHERIC DIFFERENCES ON THE WINTER POLE- EQUATOR CONNECTION IN THE UPPER STRATOSPHERE/LOWER MESOSPHERE

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A dynamical connection between the equatorial semiannual oscillation (SAO) around the stratopause and the polar night jet (PNJ) in the austral winter is investigated using a gravity wave-resolving general circulation model data and a reanalysis (MERRA) data. The contributions of gravity waves and planetary waves to the connection are separately examined. The stratopause defined as vertical temperature maximum is discrete around a latitude of 60°S, which is influenced by the upwelling above and equatorward of PNJ core. The upwelling is maintained by a combination of a poleward flow driven by planetary wave forcing around the stratospheric SAO level, a poleward flow driven by the gravity wave drag above the PNJ, and a relatively equatorward flow above the SAO easterly in the mesosphere, through the mass continuity. The variability of the upwelling significantly affects the easterly shear above the PNJ core due to the adiabatic heating/cooling through the thermal wind balance. A variation of the upper part of PNJ leads to an adjustment of PNJ height along the seasonal evolution. Since interseasonal and interannual variations of the SAO modulate the subtropical momentum deposition in the mesosphere, the variation in the upwelling is dominated by the SAO. In contrast, it seems that PNJ core height variation has no significant effect on the SAO variation. It is concluded that PNJ core tends to be phase-locked to SAO when the easterly phase of stratospheric SAO is strong in the austral winter. On the other hand, It may be difficult to apply the mechanism of the winter pole-equator coupling for the Northern Hemisphere. The PNJ often breaks in the boreal winter due to the sudden stratospheric warming, leading to transient changes in the residual circulation.

G1–O7

Analysis of vertical profiles of CO_2, CH_4, N_2O, SF_6 in the arctic atmosphere

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Airmass in the arctic region is a complex mixture of emissions from boreal land regions in the northern hemisphere, fluxes across the air-sea/ice, and stratosphere- troposphere exchange within the polar vortex. To elucidate interactions between these processes, we use continuous measurements of three species, namely, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and sulphur hexafluoride (SF_6), during the five Hiaper Pole-to-Pole Observations (HiPPO) campaigns and an atmospheric general circulation model (AGCM)-based chemistry transport model (ACTM). The ACTM simulations at T42 (~2.8x2.8 degrees) and T106 (~1.125x1.125 degrees) and 67-sigma model layers have been completed. We will analyse the model results in comparisons with HiPPO measurements soon after the QA/QC of data from all the five campaigns is completed (within 2012). Detailed results will be presented during the symposium.

G1–O8

SIMULTANEOUS OCCURRENCE OF POLAR STRATOSPHERIC CLOUDS AND UPPER-TROPOSPHERIC CLOUDS CAUSED BY BLOCKING ANTICYCLONES

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This study statistically examines the simultaneous appearance of polar stratospheric clouds (PSCs) and upper tropospheric clouds (UCs) using satellite lidar observations for five austral winters of 2007-2011. The time series of PSC occurrence in the height range of 15-25 km are significantly correlated with those of UC in 9-11 km. The UCs observed simultaneously with PSCs reported in previous case studies are possibly located around and slightly above the tropopause (~7-8 km) rather than in the troposphere. It is shown that the simultaneous occurrence of PSCs and UCs is frequently associated with blocking highs having large horizontal scales (several thousand kilometers) and tall structure (up to a height of ~15 km). The longitudinal variation of blocking high frequency accords well with that of the simultaneous occurrence frequency of PSCs and UCs. This coincidence is clearer when the analysis is limited to the latitudinal regions inside the stratospheric polar vortex. This fact suggests that the blocking highs provide a preferable condition for the simultaneous occurrence of PSCs and UCs. Moreover, PSC compositions are investigated as a function of relative-longitude of the anticyclones including blocking highs. It is seen that relatively high proportions of STS (super-cooled ternary solutions), Ice, and Mix2 (mixture of nitric acid trihydrate and STS) types are distributed to windward of, around, and to leeward of the anticyclones in the westerly background flows, respectively.

PROJECTED CHANGES IN ARCTIC SUMMER STORM-TRACK ACTIVITY BY CMIP3 CLIMATE MODELS

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Model reproducibility and future projection of summer-time storm-track activity in the Arctic region and associated climate components are investigated on the basis of Coupled Model Intercomparison Project Phase 3 (CMIP3) climate models. Most of the models underestimate storm-track activity over the Arctic Ocean measured locally as the variance of subweekly SLP fluctuations, and its large inter-model diversity is related to that of the lower-tropospheric westerlies in the Arctic region and the storm-track activity over the entire extra-tropics. As a multi-model mean, the CMIP3 models project the enhancement of storm-track activity over the Arctic Ocean off the eastern Siberian and Alaskan coasts, the region called the Arctic Ocean Cyclone Maximum (AOCM), in association with the strengthening of the westerlies projected in the warmed climate. This intensifying storm-track activity is likely due to enhancing ocean-land contrast in surface air temperature (SAT) across the Siberian coast, which reflects greater surface warming over the Siberian continent with increasing surface sensible heat flux and slower warming over the Arctic Ocean with reduction in sea ice cover. The projections of these variables nevertheless exhibit large inter-model variability, although their model biases are correlated significantly in the same manner as among their multi-model means.

G1–O10

INTERANNUAL VARIABILITY OF THE EAST ASIAN WINTER MONSOON

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Interannual variability of the East Asian winter monsoon has been investigated on the basis of observational data over the recent 50 years. Although the winter monsoon activities themselves are confined within the lower troposphere, their variability in mid-winter tends to be associated with upper-tropospheric geopotential height anomalies similar to the Eurasian (EU) pattern and the Western Pacific (WP) pattern. In the “EU-like” pattern, a wavy signature similar to the EU pattern can be found over the Eurasian continent. Interestingly, source regions of the wavy signature may be found over the North American continent, implying co-occurrence of temperature anomalies over the Far East and the North America. In the “WP-like” pattern, a meridional dipole pattern similar to the WP pattern can be found over the Far East region.

The variability of the atmospheric circulations may relate to modulations of the planetary wave formations associated with a seasonal march from late autumn to midwinter. In the climatological seasonal march, geopotential height in the upper troposphere generally lowers since temperature in the lower troposphere also decreases toward midwinter. Decreasing tendencies are especially strong in the mid-latitudes. They are, however, very weak in high latitudes, especially over the eastern Siberia and Alaska, and even a positive tendency can be found over the Bering Straight. Such an asymmetry in the height tendencies corresponds to evolutions or formations of the planetary waves: weak (strong) decreasing signals mean anticyclonic (cyclonic) tendencies, which tend to form ridges (troughs) of the planetary waves. In the seasonal marches in the WP-like patterns, anticyclonic tendencies over the eastern Siberia and Alaska region are strengthened (weakened) in cold (warm) Januaries over the Far East. Even for the EU-like patterns, we can verify similar patterns of the seasonal march.

G1–O11

ARCTIC OSCILLATION AND EAST ASIAN CLIMATE CHANGE

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As the leading mode of climate variability in the northern hemisphere winter, the Arctic Oscillation (AO) is the north-south oscillation of the atmospheric mass and largely influences the mod latitude climate. When the AO is in positive phase, the Siberia and East Asia tend to be warmer than normal years and vice versa. Therefore, efforts on skillful prediction of the AO phase are important in forecasting the surface temperature over the Arctic and mid latitudes, especially during winter. Until middle of 1990s, the AO was in increasing trend and this led to the marked arming over the rim of the Arctic regions. In the 2000s, however, the AO shows more frequently negative phases with the extremely large negative AO amplitude in 2009/2010 winter. From the data analysis, we found several links between AO and East Asian climate variabilities, which can be useful for seasonal prediction. Firstly, more frequent occurrences of strong negative AO event, especially in recent decade, lead to more frequent and longer lasting extreme cold surges over East Asia. Second, the AO phase in spring time influences the Asian summer monsoon through a teleconnection by the North Pacific. Third, the amplitude of the AO appears to be modulated by the amount and coverage of snow over Siberia and Tibetan Plateau. Finally, the recent frequent occurrences of negative AO in late winter can be, in part, caused by unprecedented Arctic sea-ice loss in early winter and this lagged connection between sea-ice and AO is established by stratosphere-troposphere dynamic coupling: Enhanced upward propagation of the Rossby wave generated by sea-ice melting, especially over Barents/Kara Sea, in early winter is one of the key factors for the weakening of stratospheric polar vortex, which, in turn, induces a negative AO anomaly at the surface.

G1–O12

Impact of Arctic sea-ice retreat on the recent change in cloud-base height during autumn

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Cloud-base observations over the ice-free Chukchi and Beaufort Seas in autumn were conducted using a shipboard ceilometer and radiosondes during the 1999-2010 cruises of the Japanese R/V Mirai. To understand the recent change in cloud base height over the Arctic Ocean, these cloud-base height data were compared with the observation data under ice-covered situation during SHEBA (the Surface Heat Budget of the Arctic Ocean project in 1998). Our ice-free results showed a 30 % decrease (increase) in the frequency of low clouds with a ceiling below (above) 500 m. Temperature profiles revealed that the boundary layer was well developed over the ice-free ocean in the 2000s, whereas a stable layer dominated during the ice-covered period in 1998. The change in surface boundary conditions likely resulted in the difference in cloud-base height, although it had little impact on air temperatures in the mid- and upper troposphere. Data from the 2010 R/V Mirai cruise were investigated in detail in terms of air-sea temperature difference. This suggests that stratus cloud over the sea ice has been replaced as stratocumulus clouds with low cloud fraction due to the decrease in static stability induced by the sea-ice retreat. The relationship between cloud-base height and air-sea temperature difference (SST-Ts) was analyzed in detail using special section data during 2010 cruise data. Stratus clouds near the sea surface were predominant under a warm advection situation, whereas stratocumulus clouds with a cloud-free layer were significant under a cold advection situation. The threshold temperature difference between sea surface and air temperatures for distinguishing the dominant cloud types was 3 K. Anomalous upward turbulent heat fluxes associated with the sea-ice retreat have likely contributed to warming of the lower troposphere.

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G1–O13

PAN EURASIAN EXPERIMENT (PEEX) – TOWARDS A NEW MULTINATIONAL ENVIRONMENT AND CLIMATE RESEARCH EFFORT IN EURASIA

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ABSTRACT Boreal forests are the major source of greenhouse gases, biogenic volatile organic compounds (BVOCs) and natural aerosols, the critical atmospheric components related to climate change processes. Major fraction of boreal forests of the world is situated in Siberian region. Representative measurements of carbon dioxide (CO_2) and methane (CH_4) concentrations, BVOC emissions and aerosols production from Siberian are of special importance when estimating global budgets of climate change relevant factors. The scope of a new concept of the Pan Eurasian Experiment (PEEX) is to set up a process for planning of a large-scale, long-term, coordinated observations and modeling experiment in the Pan Eurasian region, especially to cover ground base, airborne and satellite observations together with global and regional models to find out different forcing and feedback mechanisms in the changing climate. University of Helsinki together with Finnish Meteorological institute are organizing the Pan-Eurasian Experiment and to gather all the European and Russian key players in the field of climate and Earth system science to plan the future research activities in the Pan-Eurasian region. The approach starts with the series of workshops in October 2012 and writing the overall Science Plan for Pan-Eurasian experiment. This series of workshops is linked to several national and international research actions and projects. In the European scale PEEX is part of the JPI Climate Fast Track Activity 1.3. “Changing cryosphere in the climate system – from observations to climate modeling”. PEEX research topics are closely related the NordForsk’s Top Research Initiative CRAICC – Cryosphere – atmosphere interaction in the changing Arctic climate. PEEX is also a central part of the ongoing the Finnish Cultural Foundation – Earth System modeling Working Group activity (2012-2013). PEEX scientific aims and future actions to develop Pan Eurasian research infrastructure can be linked to several EC and ESA funded activities aiming to develop next generation research infrastructures and data products: EU-FP7-ACTRIS-I3-project (Aerosols, Clouds, and Trace gases Research InfraStructure Network-project 2011-2015); ICOS a research infrastructure to decipher the greenhouse gas balance of Europe and adjacent regions; EU-FP-7 e-infra ENVRI “Common Operations of Environmental Research Infrastructures” project. New Siberian research infrastructure and data products should be developed in line with the ACTRIS, ICOS and ENVRI approaches. Furthermore, The Pan-Eurasian Experiment will be supported iLEAPS (Integrated Land Ecosystem – Atmosphere Processes Study) bringing the PEEX under umbrella of the International Geosphere-Biosphere Programme (IGBP). The permafrost regions and boreal forests of the Pan Eurasian area can be identified as a hot spot of climate change research in a global scale. PEEX experiment can be considered as a crucial part of the strategic aims of several international and national roadmaps for climate change research and the development of next- generation research infrastructures.

G1–O14

ENHANCED POLEWARD ATMOSPHERIC MOISTURE TRANSPORT AMPLIFIES NORTHERN HIGH-LATITUDE WETTING TREND

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Observations and greenhouse-gas-emissions-forced climate change projections have indicated a wetting trend in northern high latitudes and Arctic, evidenced by increasing Eurasian Arctic river discharges. The increase in river discharge has accelerated in the latest decade, and an unprecedented, record-high discharge occurred in 2007 along with an extreme Arctic summer sea-ice-cover loss. Studies have ascribed this increasing discharge to various factors attributable to local global-warming effects, including intensifying precipitation minus evaporation, thawing permafrost, increasing greenness, and reduced plant transpiration. However, no agreement has been reached and causal physical processes remain unclear. Here we show that enhancement of poleward atmospheric moisture transport (AMT) decisively contributes to increased Eurasian Arctic river discharges. Net AMT into the Eurasian Arctic river basins captures 98% of the gauged climatological river discharges. The trend of 2.6% net AMT increase per decade accounts well for the 1.8% per decade increase in gauged discharges, and also suggests an increase in underlying soil moisture. A radical shift of the atmospheric circulation pattern induced an unusually large AMT and warm surface in 2006-07 over Eurasia, resulting in the record high discharge. The result from this study has significant implications for better understanding Arctic climate system changes and its interplay with global climate system.