The Arctic Middle Atmosphere in the Earth System: IPY Observations and Recent Model Results


2010 State of the Arctic Conference: Interactions between the Arctic and Earth System
Miami, Florida
March 17, 2010
Circulation of the Polar Middle Atmosphere

Studies of the polar middle atmosphere driven by studies of the stratospheric vortex and ozone depletion.

Vortex is more stable in the Antarctic than Arctic.

Arctic vortex disturbed by large-scale planetary waves that cause displacement and splitting of the vortex.

Arctic middle atmosphere temperatures warmer than Antarctic - less ozone depletion.
Vortex in Both Hemispheres

Arctic

Antarctic

Arctic Vortex 2005 ~6 million km²

Antarctic Vortex 2006 ~18 million km².

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Two Wave-Driven Circulations

Small-scale gravity wave driven circulation is “embedded” in large-scale planetary wave circulation.
Both circulations impact mean flow → Nonlinear Feedbacks

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The Arctic vortex in 2005 was highly stable and supported significant ozone depletion.

Single site lidar temperature soundings show WARM stratosphere.
The Arctic vortex in 2004 was highly disturbed and supported little ozone depletion.

Single site lidar temperature soundings show UNUSUAL stratosphere.
Synoptic View during IPY

Snapshot of daily conditions at 800 K (~30 km, 10 hPa).

Different sites under different flow conditions.

Conditions at:
Chatanika, Alaska (65°N, 147°W)
Kangerlussuaq, Greenland (67°N, 51°W)
Kühlungsborn, Germany (54°N, 12°E).
Lidar Measurements of Gravity Waves

Lidar (Laser radar) systems make precise measurements of atmospheric density at high resolution.

Lidar density profiles also yield temperature profiles.

Use 15-min and nightly average profile to quantify wave activity in the middle atmosphere.
Interannual Variations in Wind and Waves at Chatanika

Measurements at Chatanika are correlated with wind fields. Reversal of zonal winds yields reduction in gravity wave activity.

Low gravity wave energies correlate with weak winds.

Blocking of upward flux of small-scale waves by large-scale wind structure.
Interannual Variations in Wind and Waves at Kangarlussuaq and Kühlungsborn

Again low gravity wave energies correlate with weak winds.

Highest energies at Kangarlussuaq and lowest at Chatanika (JF 2008) and similar energies at Kühlungsborn and Chatanika (FM 2009).
Whole Atmosphere Community Climate Model (WACCM)

Contemporary chemical-climate model that has been used to simulate 1950-2003 to investigate secular trends.

WACCM successfully simulates cooling trends that have been observed in middle atmosphere.

WACCM simulates secular secular trend in globally averaged column and shows variability due to volcanic aerosol (post Mt. Pinatubo) and variations in planetary wave activity (model year 1991).
WACCM
Circulation Trends

WACCM simulations for 1980-2050 (using IPCC scenario 1b).

Model shows acceleration of the Brewer-Dobson circulation due to both planetary-scale waves (resolved) and mesoscale gravity waves (parameterized).

Model shows increase NOT due to wave sources but due to changes in wind filtering by zonal winds that increase as the meridional temperature gradients increase.

A more variable middle atmosphere?
WACCM-IPY Studies

Recent Arctic winters show significant interannual variability in both planetary and gravity wave activity.

Modulation of wave activity by winds is a significant source of variability in the general circulation.

Current studies show that differences between model and observations are related to gravity wave parameterization.

Goal is to use recent Arctic winters as benchmark for studying gravity wave parameterizations in WACCM.
Acknowledgements

The authors thank the staff at Poker Flat Research Range, Sondrestrom Atmospheric Research Facility, and the Leibniz-Institute of Atmospheric Physics for their ongoing support of the lidar programs. The authors thank Agatha Light and Brita Irving for their assistance in making the IPY lidar observations at Chatanika.

The authors acknowledge support from the United States National Science Foundation under grants ATM 0334122, ARC 0632387 and ATM 0640340. PFRR is a rocket range operated by Geophysical Institute of the University of Alaska Fairbanks with support from the United States National Aeronautic and Space Administration.

The observations at Kühlungsborn were conducted as part of the International Leibniz Graduate School for Gravity Waves and Turbulence in the Atmosphere and Ocean with support from the Mecklenburg-Vorpommern Ministry of Education, Science and Culture and the German Federal Ministry of Education and Research.