Understanding rapid changes in phase partitioning in an Arctic stratiform mixed-phase cloud

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Motivation
Understanding phase transitions in mixed-phase clouds consisting of liquid droplets and ice particles is of great importance because hydrometeor phase controls the lifetime and the radiative effects of clouds. These cloud radiative effects have a crucial impact on the surface energy budget and thus on the evolution of land- and ocean-based ice cover.

For a springtime low-level mixed-phase stratiform cloud case at Barrow, Alaska, observed on 11-12 March, 2013, a sophisticated combination of instruments and retrieval methods is combined with multiple modeling perspectives to determine key processes that control transitions in cloud phase partitioning. The interplay of local cloud-scale vs. large-scale processes is considered.

Observations

<table>
<thead>
<tr>
<th>Instrument Specifications</th>
<th>Observed/derived quantities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weather station sensors</td>
<td>T, RH, horizontal wind</td>
</tr>
<tr>
<td>Ka-band ARM radar (KAZR)</td>
<td>35 GHz</td>
</tr>
<tr>
<td>High Spectral Resolution</td>
<td>Cloud base, cloud phase, Dp, LWC, Ra, Nd</td>
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<tr>
<td>Microwave radiometer</td>
<td>23.8 GHz and 31.4 GHz</td>
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<tr>
<td>Polarimetric X-band</td>
<td>Dual polarization</td>
</tr>
<tr>
<td>TMI 3553 Nephelometer</td>
<td>Total aerosol scattering and backscattering</td>
</tr>
<tr>
<td>Particle Size/Absorption</td>
<td>467 nm, 530 nm, 660 nm</td>
</tr>
<tr>
<td>TMI 3010 Condensation</td>
<td>Aerosol number concentration</td>
</tr>
</tbody>
</table>

Models

- WRF V3.5 (Nested Weather Research and Forecasting)
- Resolution: (horizontal: 12/30.5 km (nested grids), vertical: 20 m)
- Boundary conditions: Echoux ECMWF 16 km analysis
- Microphysics: Morrison bulk two-moment scheme; combined ice-snow particle number related to 1/L,
- ECMWF radiation scheme
- Shortwave (SW) and longwave (LW) calculations using Monte Carlo Independent Pixel Approach
- Used to determine radiative impacts of a cirrus and the solar cycle
- MACC (Monitoring Atmospheric Composition and Climate)
- Chemical transport model including 12 aerosol species
- Used to estimate aerosol transport and aerosol properties
- HYSPLIT
- Hybrid Single-Particle Lagrangian Integrated Trajectory model
- Used to estimate air mass origins via back trajectory calculations

Radar and lidar observations

Evolution of cloud properties

Microphysicals

| Time series of (a) layer-mean retrieved vertical velocity W, and time-averaged height of all clouds above liquid-dominated cloud base, (b) observations of RH and (c) turbulent kinetic energy dissipation rate ε. Black line in (d-e) represents liquid cloud base observed by ceilometer. The drop in IWP and NdcS with time is consistent with the change in surface-coupling and wind direction. |

| Time series of (f) retrieved IWC, (g), NdcS, (h), (i) turbulent kinetic energy dissipation rate ε, and (j) relative humidity RH over Barrow had a relatively high aerosol concentration and was supported by moist southerly flow. The cloud was eventually replaced by a drier southeasterly flow characterized by a reduced aerosol load as well as increasing cloud and surface temperatures and decreasing water vapor supply. |

Factors influencing phase transitions

Three main factors were found to contribute to the abrupt change in phase partitioning for this case:

1. Large-scale advection of different air masses with different moisture content and aerosol properties played a major role. During the time of highest ice and liquid water contents, the air mass over Barrow had a relatively high aerosol concentration and was supported by moist advection of cloud level from W-SW. This aerosol was eventually replaced by a drier southeasterly flow characterized by a reduced aerosol load as well as increasing cloud and surface temperatures and decreasing water vapor supply.

2. Cloud-scale processes, specifically the cloud-surface thermodynamic coupling state, changed at the time of the air mass change. Prior to the transition a higher IWP was maintained when the cloud was decoupled from the surface with a relatively dry near-surface layer below the cloud. This structure likely supported sub-cloud sublimation for ice crystals such that IWP was not lost to the surface and may have continued to be available to the cloud via recycling. After the transition the cloud became coupled to the surface with an increased water flux extending down to the surface. As a result precipitating ice, including the limited supply of IWP, was lost from the cloud system to the surface.

3. WRF simulations suggest that the residence time of ice particles, which is linked to local-scale dynamics, was also important in the change of phase partitioning. Simulated IWP was found to be higher during times of strong updrafts that dominated during the early part of the case. After the transition updrafts weakened and ice crystals fell more quickly from the cloud system.

- The radiative shielding of a cirrus on 12 March as well as the influence of the solar cycle were found to be of minor importance for turbulence modulation in the mixed-phase cloud (not shown), and thus likely did not play key roles in the transition.

Observations of aerosol properties, including IN concentrations and vertical profiles of aerosol particle concentrations are ultimately needed to unravel the role of aerosol-cloud interactions in driving transitions in cloud phase partitioning.