Arctic Field Experiments

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Prior International Polar Years

1982-1983: 12 countries participated; advances in meteorology and geographical exploration

1932-1933: 40 countries participated; jet stream, ionosphere, numerous permanent observing stations established

1957-1958 (IGY): emphasized new technologies; contributions to aurora and airglow, cosmic rays, geomagnetism, glaciology, gravity, ionospheric physics, precision mapping, meteorology, oceanography, seismology, solar activity.
What’s been going on since the IGY?
(not much meteorology)

Arctic:
1960s -1980s: sea ice and oceanography, surface meteorology and radiation (Russians)
1980s-present: atmospheric chemistry
1995 - present: clouds and radiation
1990s-present: interdisciplinary research, climate change, social and biological sciences
Major field expeditions since the IGY
(of some relevance to NWP)

POLEX (FGGE; 1976-1977): Arctic ice dynamics
(surface pressure buoys)

SHEBA (1997-1998): Arctic Ocean surface energy
balance, clouds, radiation, sea ice thermodynamics,
ocean mixed layer
U.S. expenditures: $20M

SHEBA Surface Heat Budget of the Arctic
Surface-based Instrumentation: May 1-8 time series

35 GHz cloud radar
ice cloud properties
depolarization lidar-determined liquid cloud base

Microwave radiometer-derived liquid water paths

4X daily soundings. Near-surface T ~ -20 C, inversion T ~ -10 C

lidar cloud base
Arctic Mixed-Phase Clouds

- Dominate cloud fraction of Arctic throughout year, occurring ~ 60% of the time clouds were present at SHEBA
- Persist on average for 12 hrs, but often last for several days.
- Much larger cloud radiative forcing compared to ice clouds
- Within mixed-phase clouds, liquid dominates ice in terms of radiative impact
- Common at temperatures down to -30°C.

![Graph showing probability of ice, mixed, and liquid clouds as a function of temperature](image)

Percent of time during SHEBA that clouds were classified as all-ice, mixed-phase, or all-liquid as a function of minimum in-cloud temperature (from Morrison et al. 2005, GRL).
What did SHEBA accomplish?

Test bed for:

- Radiative transfer models
- Cloud microphysics models
- Sea ice models
- Surface heat flux models
- Evaluation of satellite products
- Process studies
What did JC learn from SHEBA?

Confirmed qualitatively many of my preconceived notions; firmed up quantitative understanding

1998 different from 1980; different phase of the AO and thin ice

Feedbacks are complex interplay of hemispheric circulation patterns and local thermodynamics
  • Example: onset of spring melt associated storm in late May that had liquid precipitation

Mixed phase clouds are ubiquitous and cloud phase varies substantially with temperature

Greatest impediment to testing cloud parameterizations is inadequate dynamics (boundary layer, synoptic)
Northern Hemisphere Extent Anomalies Sep 2004

1979-2000 mean = 7.0 million sq km

slope = -7.7(+/-3.3) % per decade
DJF trends 1982-1999

Wang et al. 2005
Wintertime Trends
Arctic Ocean
Wang et al. (2005)
What’s going on in winter over the AO?

✓ surface COOLING
✓ decrease in cloud cover, precipitable water
✓ larger cloud particles, more ice phase clouds
✓ decreased downwelling LW radiation at surface

Hypothesis:

✓ Changing aerosol composition/concentration changes ice nucleation in clouds
✓ Altered ice nucleation is resulting in less water vapor and more precipitation
✓ This cools the surface during winter
✓ This mechanism requires a trend in aerosol composition/concentration
Impact of surface cooling on sea ice

If hypothesis is correct, it implies:

- Increased wintertime snowfall
- Reduced wintertime sea ice growth
- More rapid melting of thinner ice during summer
- Increased freshening of the Arctic Ocean
Looking ahead to IPY 2007-2008

Improved observations to support meteorological analysis (data assimilation and model evaluation)

New technologies:
- CLOUDSAT and CALIPSO (space radar & lidar)
- unmanned vehicles

Aerosol/cloud/precipitation interactions
International Polar Year (IPY) Activity

International Arctic Systems for Observing the Atmosphere (IASOA)

NOAA/SEARCH Arctic Atmospheric Observatories Program
Establishing Intensive Atmospheric Observatories In the Arctic is the component of NOAA/SEARCH being directed by ESRL
Arctic HYDRA: ARCTIC HYDROLOGICAL CYCLE MONITORING, MODELLING AND ASSESSMENT PROGRAM

A. Snorasson (Iceland; lead) participation from U.S., Europe, Canada, Japan

- Characterize variability in the Arctic Hydrological Cycle and examine linkages between atmospheric forcing and continental discharge to the ocean;

- Focus on land hydrology and its interaction with the atmosphere and ocean; river basin focus

- Arctic HYCOS is a lead project
Hydrological Impact of Arctic Aerosols: HIAA

J. Curry (lead)
GEWEX project to integrate clouds/radiation with land surface hydrology

Sources of Arctic aerosols:

Biomass burning in northern forests
Pollution aerosol
Biogenic aerosol
Desert dust
Motivation

– Changes in the Arctic hydrological cycle likely arise from a complex interplay between natural modes of climate variability and anthropogenic activity; what is the relative role of aerosols in the recent warming observed in the Arctic.

– Variations in aerosol characteristics potentially modulate the Arctic climate through impact on precipitation, radiation fluxes, and surface albedo.

– Atmospheric aerosols influence the nucleation of cloud particles, in turn the cloud cover and precipitation processes, and hence river runoff, snow cover, permafrost, glacial accumulation, and surface temperature.
Proposed deployment of ARM Mobile Facility In Alaskan Oil Fields (Prudhoe/Kuparuk)

North Slope Oil & Gas Activity & Discoveries
January 2006
Prudhoe Bay is the largest oilfield in North America

- Permanently altered more than 400 square miles of formerly pristine wilderness
- Hosts one of the world's largest industrial complexes
- Provides an opportunity to investigate the impact of pollution aerosol from resource extraction activities) on clouds, radiation, and precipitation

The number of days that the tundra is frozen has decreased 50% over the past 30 years.

Early melting of snow eliminates travel over land on ice roads

Serious impact on oil, gas, forestry industries, and leads to degradation of landscape and ecosystems
New satellite observations:
- Calipso: lidar
- CloudSat: cloud radar (attempt snowfall rate retrievals)

Relevant IPY aircraft obs:
- POLar study using Aircraft, Remote sensing, surface measurements and modelling of Climate, chemistry, Aerosols and Transport (POLARCAT)
- Indirect and Semi-Direct Aerosol Campaign (ISDAC)
- Unmanned Aerial Vehicles (UAVs)
Indirect and Semi-Direct Aerosol Campaign (ISDAC)

Primary Motivation

• Well known that anthropogenic aerosols are advected into Arctic in springtime
• Indirect effect: more aerosols → smaller droplets → longer cloud lifetime and enhanced cloud albedo
• Semi-direct effect: more absorbing aerosols → more local heating → shorter cloud lifetime
• Impacts on surface fluxes/properties and melting rates, as well as atmospheric heating rate profiles
Proposed ISDAC Observations

• Aircraft with 50-60 flight hours for science
  – Full suite of aerosol in-situ observations, including size distributions
  – Full suite of cloud microphysical instruments
  – CCN and IN observations
• Additional radiosondes (at least 4/day)
• 90 GHz MWR
• Molecular lidar (Raman or HSRL)
• Additional surface aerosol observations,
• Chemical composition of aerosols at surface and aloft
NEW TECHNOLOGIES
Logistical Issues in Polar Observations

- Harsh, dangerous environment
- Observations are expensive
- Manpower shortage
- Satellite remote sensing is confounded by snow/ice surface
Solution Parameters

- Autonomous, robust, low cost measurements with telemetry
  - Small unmanned aerial vehicles
  - Autonomous underwater vehicles
  - Land-based sensors
- Adaptive and staged targeting
  - Target key seasonal periods, locations
The Aerosonde

- Sat or Radio Comms
- 24cc Fuel Injected Engine
- Wingspan 2.9 m
- Autonomous
- Range > 3000km
- GPS navigation
- Endurance > 30 h
- Surface to 7 km
- 13-15 kg
First Barrow Deployment (1998) - Icing results in downing of two aircraft.

- **2000**: 45 research hours flown. Camera and Icing flights.
- **2002**: First KT11 flights.
- **2004**: 250 Flight Hours During 2 deployments.
- **2006**: 325 Flight Hours During 2 deployments.

Three Months of Ops:
- # of new payloads (incl. VIPS, HHPC), 400+ hours (incl. ops @ - 40 C!)

Timeline:
- **1998**
- **2000**
- **2002**
- **2004**
- **2006**
Melt Pond Mapping and Satellite Validation using Aerosondes

Aerosonde image mosaic
(Pond fraction: 33%)

Aerosonde image at ~0.2-m pixel size ("medium resolution")

MODIS at 1-km pixel size

MODIS Image (20 July 2003)

Barrow

Courtesy J. Maslanik
Sea Surface Temperature Studies

Inoue, Maslanik & Curry 2004
Figure 10. Examples of VIPS-acquired images showing ice particles, as observed within “diamond dust” (relatively low-density ice crystals in the lower polar atmosphere).
MPACE Data Intercomparison - J. Pinto

Lidar Data:

Video Imaging Particle Sampler (VIPS) - A. Heymsfield

\[ T = -8 \, ^\circ C \]

5.5 mm
HHPC-6 large particle counter
Aerosol size distribution - M. Bergin

The graph shows the concentration of aerosols in microns over the days of March. The concentration is measured in liters (L). The graph indicates peaks in concentration for aerosols of 0.4, 0.6, 0.85, and 1.5 microns.
• Built in partnership with NASA, the ALTAIR has an 86 ft wingspan, can fly up to 52,000 ft and can remain airborne for well over 30 hours.

• Marked as the first remotely piloted aircraft that will meet aviation authority requirements for unmanned flights in National Air Space.
Integrated Global Observing

The global observing system must be designed to support the scientific questions inherent in long term climate diagnosis and prediction.

The strategic triad of global observing:

Satellites – UAVs - Buoys
Unmanned Aircraft Systems could routinely measure the Arctic ice changes at the same points for decades.
Challenges for IPY Arctic field experiments:

- Coordination among projects, particularly across disciplines
- Funding
- Logistics
- Technology readiness