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Interactions Between Arctic Sea Ice and Atmospheric Boundary Layer in the Presence of Leads

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1. Total papers submitted and/or published in refereed journals by June 1, 1993:

Curry, J.A. and E.E. Ebert, 1992: Annual cycle of radiative fluxes over the Arctic ocean: Sensitivity to cloud optical properties. *J. Climate,* **5**, 1267-1280.

Ebert, E. and J.A. Curry, 1993: An intermediate one-dimensional thermodynamic sea ice model for investigating ice-atmosphere interactions. *J. Geophys. Res.*, **98**, 10085-10109.

Wilson, L.D., J.A. Curry, and T.P. Ackerman, 1993: On the satellite retrieval of lower tropospheric ice crystal clouds in the polar regions. *J. Climate*, **6**, 1467-1472.

Curry, J.A., J. Schramm and E.E. Ebert, 1993: Impact of clouds on the Arctic Ocean surface radiation budget. *Meteor. and Atmos. Phys.* (invited), **51**, 197-217.

Curry, J.A., J. Schramm and E.E. Ebert, 1993: On the sea ice albedo climate feedback mechanism. *J. Climate,* in press

2. Total papers scheduled to be published at a later date in refereed journals:

Curry, J.A., J. Schramm and E.E. Ebert: Cloud-climate feedback processes in the arctic. *J. Climate,* to be submitted Sept 1993

Pinto, J.O., J.A. Curry and K.L. McInnes: Atmospheric convective plumes emanating from leads. Part I: Thermodynamic structure. *J. Geophys. Res.* (special issue on Leads and Polynyas), to be submitted Oct 1993

Pinto, J.O. and J.A. Curry: Atmospheric convective plumes emanating from leads. Part II: Microphysical and radiative processes. *J. Geophys. Res.* (special issue on Leads and Polynyas), to be submitted Oct 1993

McInnes, K.L. and J.A. Curry: Modelling the mean and turbulent structure of the Arctic cloudy boundary layer. *Bound. Layer. Meteor.*, to be submitted Nov 1993

Tilley, J.S., G. Liu and J.A. Curry: Atmospheric hyrological processes occuring in intense cyclonic storms in the North Atlantic marginal ice zone: comparison of results from a mesoscale model with satellite microwave retrievals. *Mon. Wea. Rev.*, to be submitted Nov 1993

Alam, A. and J.A. Curry: Modelling the clear-sky atmospheric boundary layer in the presence of Arctic leads. *J. Atmos. Sci.*, to be submitted Dec 1993.

Alam, A. and J.A. Curry: Formulation of a second-order turbulence closure model for mixed-phase clouds. *J. Atmos. Sci.*, to be submitted Mar 1994.

Alam, A. and J.A. Curry: Modelling the horizontally inhomogeneous cloudy boundary layer in the presence of Arctic leads. *J. Atmos. Sci.*, to be submitted July 1994.

3. Total papers published in non-refereed journals:

Pinto, J.O, J.A. Curry, and K. McInnes, 1992: Microphysical processes occurring in ice crystal plumes emanating from Arctic leads. Preprints, 3rd Conference Polar Meteorology and Oceanography, Portland OR, 29 Sept-2 Oct, American Meteorological Society, 17-20.

Ebert, E.E. and J.A. Curry, 1992: Spectral interactions of radiation and sea ice. Preprints, 3rd Conference Polar Meteorology and Oceanography, Portland OR, 29 Sept-2 Oct, American Meteorological Society, 21-24.

McInnes, K.L. and J.A. Curry, 1992: Modeling of the mean and turbulent structure of the arctic atmospheric boundary layer. Preprints, 3rd Conference Polar Meteorology and Oceanography, Portland OR, 29 Sept-2 Oct, American Meteorological Society, J13-J15.

Alam, A. and J.A. Curry, 1992: Modelling the horizontally inhomogeneous cloudy boundary layer in the presence of leads. Preprints, 3rd Conference Polar Meteorology and Oceanography, Portland OR, 29 Sept-2 Oct, American Meteorological Society, J41-J44.

Curry, J.A., 1992: Status of Arctic clouds. ARCSS Ocean-Atmosphere-Ice Interactions Modelling Workshop Proceedings, Monterey, CA, 13-17 July 1992, 25-28.

4. Significant presentations

Curry, J.A. and E.E. Ebert, 1992: Cloud-radiative forcing over the Arctic Ocean. 3rd Conference Polar Meteorology and Oceanography, Portland OR, 29 Sept-2 Oct, AMS.

Alam, A. and J.A. Curry, 1992: Modelling convective plumes over Arctic leads. 3rd Conference Polar Meteorology and Oceanography, Portland OR, 29 Sept-2 Oct, AMS.

Pinto, J.O, J.A. Curry, and K. McInnes, 1992: Microphysical processes occurring in ice crystal plumes emanating from Arctic leads. 3rd Conference Polar Meteorology and Oceanography, Portland OR, 29 Sept-2 Oct, AMS.

Ebert, E.E. and J.A. Curry, 1992: Spectral interactions of radiation and sea ice. 3rd Conference Polar Meteorology and Oceanography, Portland OR, 29 Sept-2 Oct, AMS.

McInnes, K.L. and J.A. Curry, 1992: Modeling of the mean and turbulent structure of the arctic atmospheric boundary layer. 3rd Conference Polar Meteorology and Oceanography, Portland OR, 29 Sept-2 Oct, AMS

Pinto, J.O. and J.A. Curry, 1992: Microphysical properties of convective plumes emanating from Arctic leads. 11th International Conference on Clouds and Precipitation, Montreal, August 1992.

Curry, J.A., 1992: Cloud-climate feedback processes in the Arctic. Department of Atmospheric Sciences, Colorado State University, Nov 19.

5. Honors and awards received by principal investigators:

Henry G. Houghton Award, the American Meteorological Society, Jan 1992:

"for basic contributions to our understanding of the interactions among clouds, radiation, and dynamics in the polar regions".

6. Total number of different post-docs supported at least 25% of the time:

Kathleen McInnes (PhD Monash University 1991): May 1991-May 1992, 50%.

Jeffrey Tilley (PhD Penn State University 1989): Aug 1992-May 1993, 100%.

7. **Number of different graduate students supported at least 25% of the time**

James O. Pinto

Afshan Alam

8. Most significant publications

Ebert, E. and J.A. Curry, 1992: An intermediate one-dimensional thermodynamic sea ice model for investigating ice-atmosphere interactions. *J. Geophys. Res.*, **98**, 10085-10109.

Details of lead physical processes are incorporated into a sea ice model for the first time: solar flux through leads warms water adjacent to and below the sea ice, resulting in lateral and bottom ablation; cooling of water in leads results lateral and bottom freezing. Two important positive feedback processes involving leads were identified:
The *lead solar flux feedback*: Thinner ice allows a greater proportion of the solar flux entering the ocean to be absorbed below the level of the ice where it contributes to warming of the mixed layer and greater basal ablation.
The *lead fraction feedback*: A thinner ice cover experiences greater lateral ice ablation and acretion, resulting in a greater lead fraction in summer and a smaller lead fraction in winter. This allows more solar radiation to be absorbed by the ocean in summer, and insulates the ocean more effectively in winter, both of which contribute to a warmer ocean mixed layer and greater basal ablation.

Curry, J.A., J. Schramm and E.E. Eber, 1993: On the sea ice albedo climate feedback mechanism. *J. Climate*, in press

The ice albedo climate sensitivity parameter is determined for different levels of sea ice model complexity. The ice albedo climate sensitivity parameter is shown to be high for the Semtner-type models that are currently employed in global climate models. The ice albedo climate sensitivity parameter decreases when the following physical processes are included in the sea ice model: temperature and salinity dependence of the ice thermal conductivity; leads; and melt ponds. The significance of this result is that the overly simplistic thermodynamic sea ice models currently used in global climate models may give a reasonable present-day equilibrium ice thickness, but do not give the correct climate sensitivity.

Curry, J.A. and E.E. Ebert, 1992: Annual cycle of radiative fluxes over the Arctic ocean: Sensitivity to cloud optical properties. *J. Climate,* 5, 1267-1280.

The annual cycle of cloud optical properties over the Arctic Ocean is derived by constraining the results to reproduce the annual cycle of observed shortwave and longwave radiative fluxes at the surface and the top of the atmosphere. The modeled total cloud optical depth (weighted by cloud fration) ranges from a low value in winter of 2 to a high summertime value of 8. Infrared emissivities for liqid water clouds are shown to be substantially less than unity during the cold half of the year. Values of modeled surface cloud radiative forcing are positive except for two weeks in midsummer; over the course of the year clouds have a net warming effect on the surface in the Arctic. Surface longwave fluxes are shown to be very sensitive to the presence of lower-tropospheric ice crystal precipitation during the cold half of the year.

Pinto, J.O, J.A. Curry, and K. McInnes, 1992: Microphysical processes occurring in ice crystal plumes emanating from Arctic leads. Preprints, 3rd Conference Polar Meteorology and Oceanography, Portland OR, 29 Sept-2 Oct, American Meteorological Society, 17-20.

A one-dimensional model has been used to investigate the radiative and cloud microphysical processes occuring in convective plumes associated with leads. Significant results include: the lower troposphere is heated strongly by infrared radiation, comparable to sensible heating at the lowest levels; and the active condensation layers do not form a continuous plume, although precipitation may give the appearance of a continuous plume.

9. Major Accomplishments

I. <u>Modelling radiation and cloud microphysical processes in plumes associated with leads</u>: We have formulated a one-dimensional model with detailed radiative transfer and cloud microphysical processes that, when combined with suitable sensible and latent heat fluxes coming from the lead, that simulates the evolution of the plume (Pinto et al., 1992). This work comprises Pinto's M.S. thesis, which will be completed in March 1993.

II. <u>Formulation and modelling of atmospheric turbulence in convection associated with leads</u>: The 2-dimensional nonhydrostatic model has been formulated to incorporate the appropriate boundary conditions, radiative transfer, and cloud processes. This model is currently working. The turbulence for a horizontally inhomogeneous mixed-phase cloudy atmosphere has been formulated (Alam and Curry 1992), but has not yet been incorporated into the 2-D model This project comprises Alam's PhD thesis, which is scheduled to be completed May 1994.

III. Mesoscale modelling in the Arctic:

Parameterizations of second-order turbulence, radiative transfer, and cloud processes have been formulated for use in the PSU/NCAR MM5 model (McInnes and Curry, 1992; Pinto et al 1992). The first project we will do using this model is to test the cloud scheme in some storms in the North Atlantic MIZ using SSM/I satellite microwave retrievals over open water (Tilley et al., 1993). We are collaborating with R. Grumbine at NMC to incorporate the Ebert and Curry (1992) sea ice thermodynamics into the Hibler sea ice model; this coupled model will eventually be coupled to the MM5 model.