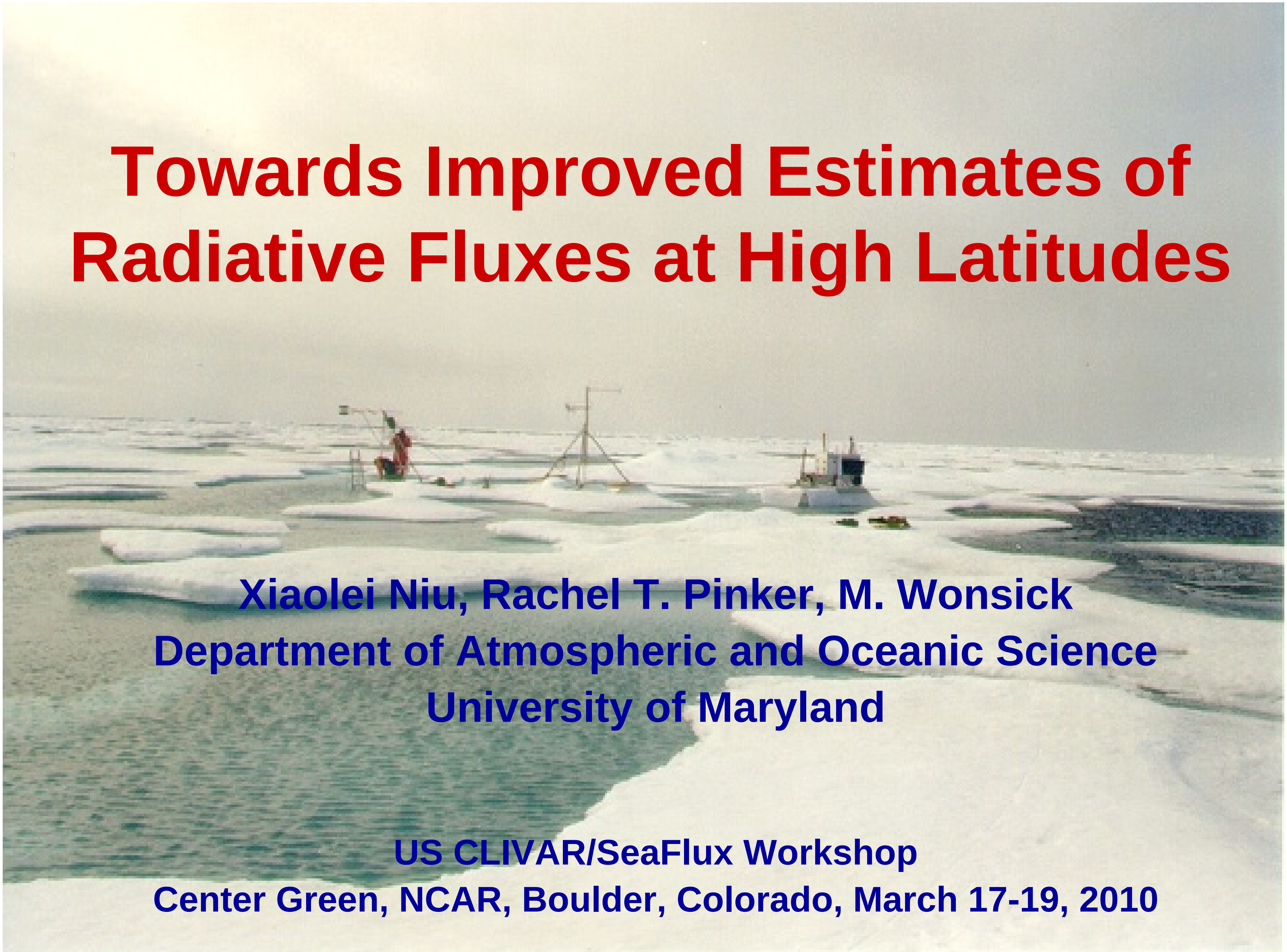

Towards Improved Estimates of Radiative Fluxes at High Latitudes

Xiaolei Niu, Rachel T. Pinker, M. Wonsick
Department of Atmospheric and Oceanic Science
University of Maryland

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Context of Talk

- Lack of accurate information on radiative fluxes at High Latitudes
- The shortwave (SW) radiative fluxes are the main energy source during Summer
- Need for high resolution observations in flux inference schemes to account for ice loss
- Need for long term information to address climate issues such as the Ice-Albedo Feedback

Changes in Solar Input to Polar Ice-ocean System

The areally averaged solar input to the ice-ocean system can be calculated as:

$$F(t) = F_s(t)\overline{\alpha}(t)$$

$$\overline{\alpha}(t) = \alpha_{ice}(t)A_{ice}(t) + \alpha_{ocean}A_{ocean}(t)$$

F : the solar input to ice-ocean system

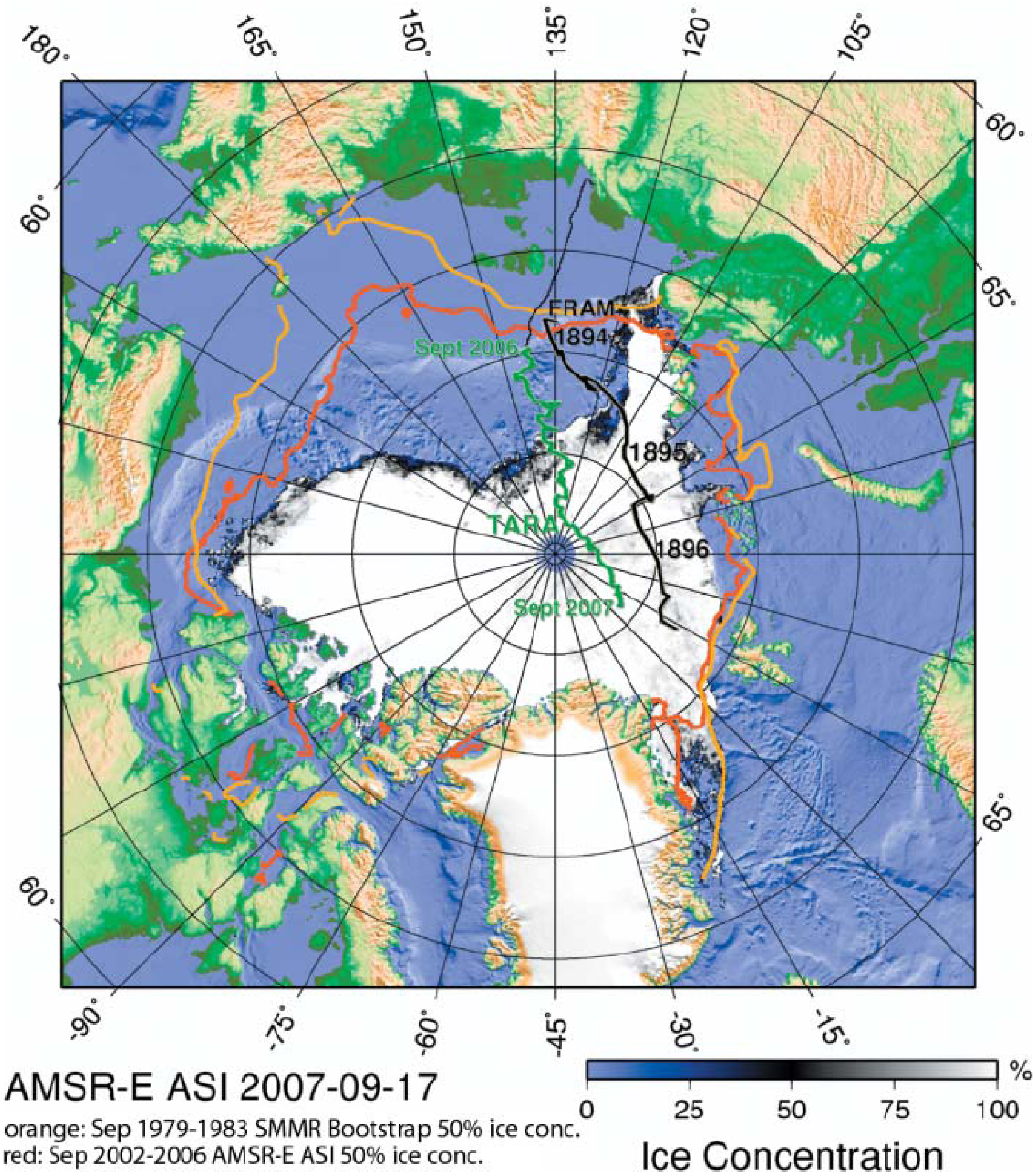
Fs : the surface solar irradiance

$\overline{\alpha}$: the areally averaged albedo

α_{ocean} : the albedo of ocean (~0.07)

Perovich et al. (2007)

At Issue in estimating SW fluxes: Changes in Ice Extent



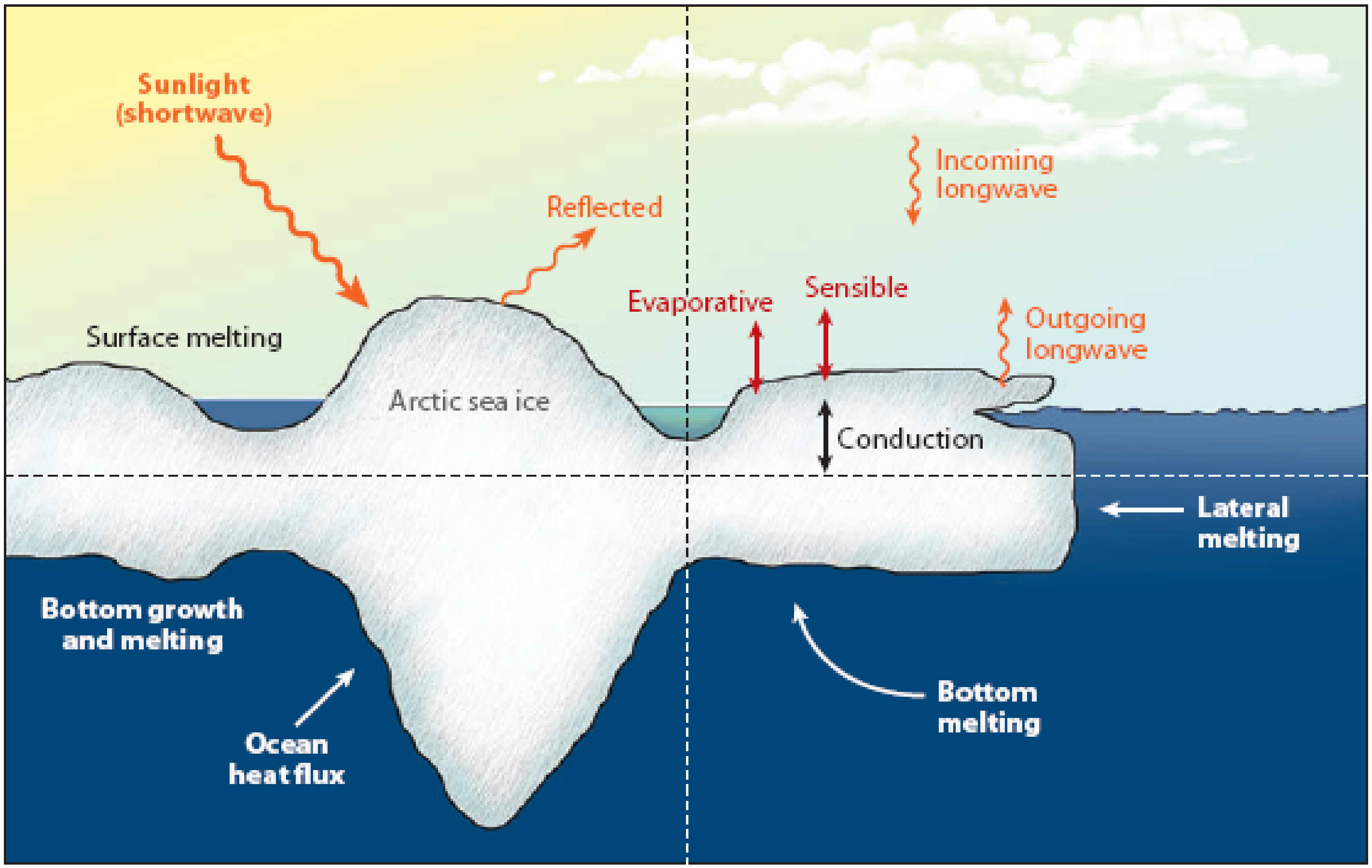
The drift track of ice station Tara from Sep 2006 through Sep 2007 and the sea ice summer minimum extent in 2005 and 2007 (*Gascard et al., 2008*):

Orange line: Sep 1979-1983 SSMR Bootstrap 50% ice conc.

Red line: Sep 2002-2006 AMSR_EASI 50% ice conc.

Another issue: formation of leads

Radiative fluxes + Turbulent fluxes = Melt / Freeze



Perovich and Richeter-Menge (2008)

Location of observing sites in Arctic: complicates evaluation against ground observations

IPY IASOA 10 surface observation sites

collect data on:

radiation, surface energy balance, aerosol, surface meteorology, precipitation, snow and ice

To take into account changes in surface type along the coastlines, high resolution satellite observations are needed.

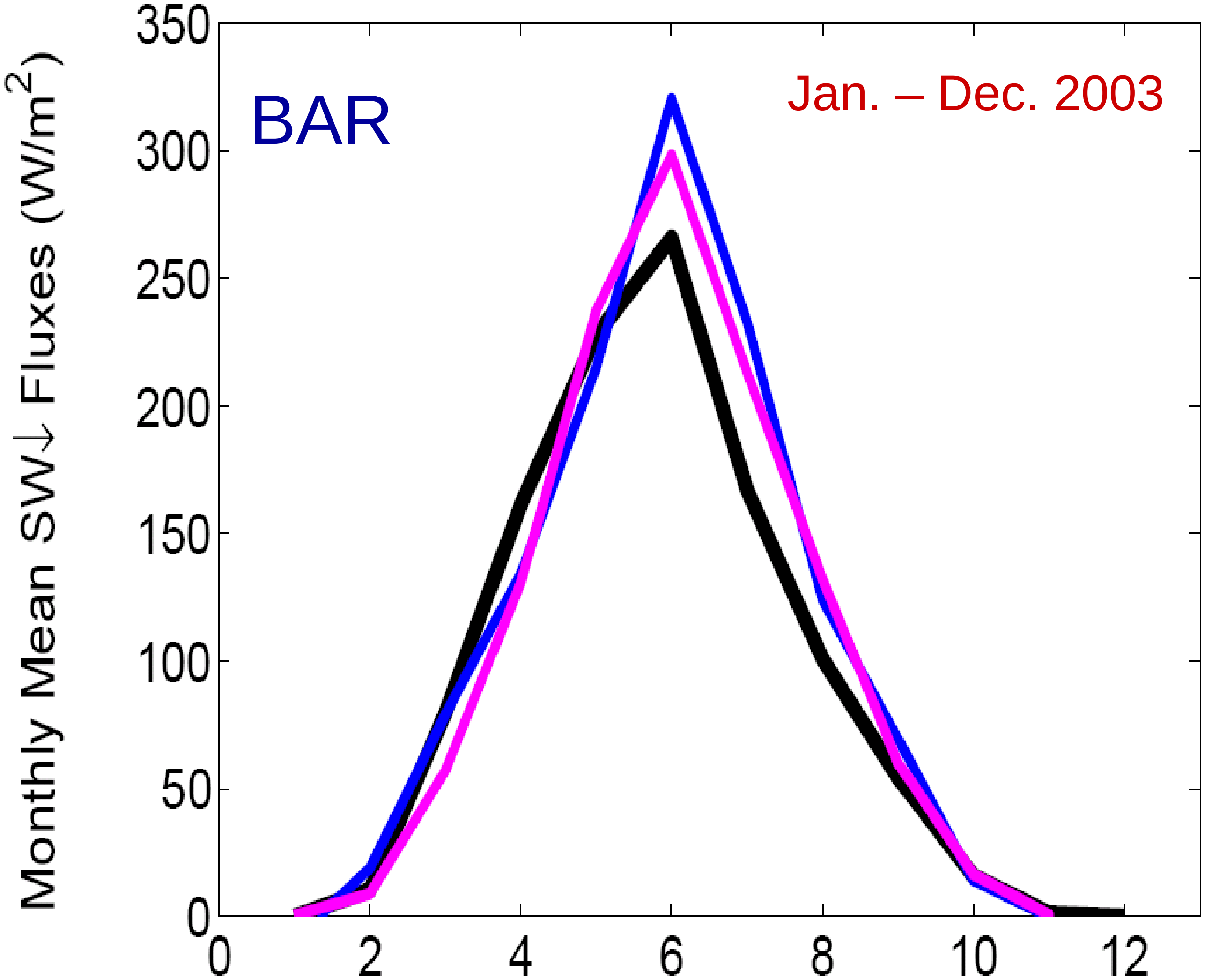
http://iasoa.org/iasoa/

Available Satellite Products

- To address climate issues - requires long term time series – such as currently available from:
  - AVHRR Started from 1981
    - *Extended AVHRR Polar Pathfinder (APP) products at 25 km resolution twice per day*
  - ISCCP Started from 1983
    - *Several products available: ISCCP_FD, 2.5^0; ISCCP GEWEX/LaRC, 1^0; UMD/SRB, 2.5^0 and 0.5^0*

Data	Spatial Reso.	Temporal Resolution	Time Period
AVHRR	25 km	Twice per day	1981–present
ISCCP	2.5^0 ; 1^0; 0.5^0	3-hourly	1983–present
CERES	FOV: ~20 km	Up to 7 obs per day	2000-present
MODIS	1^0, 5 km	Up to 7 obs per day	2000-present
CALIPSO	FOV:~300; 70m	Lags CloudSat by 15$\pm$2.5 s	2006-present
CloudSat	FOV: ~1.4 km	Lags Aqua less than 120 s	2006-present

No full agreement between products



Black line: Ground observation; Blue line: AVHRR; Magenta line: ISCCP-FD
BAR (Barrow, 71.32^{0}N, 156.61^{0}W)

Prospects for Improvement

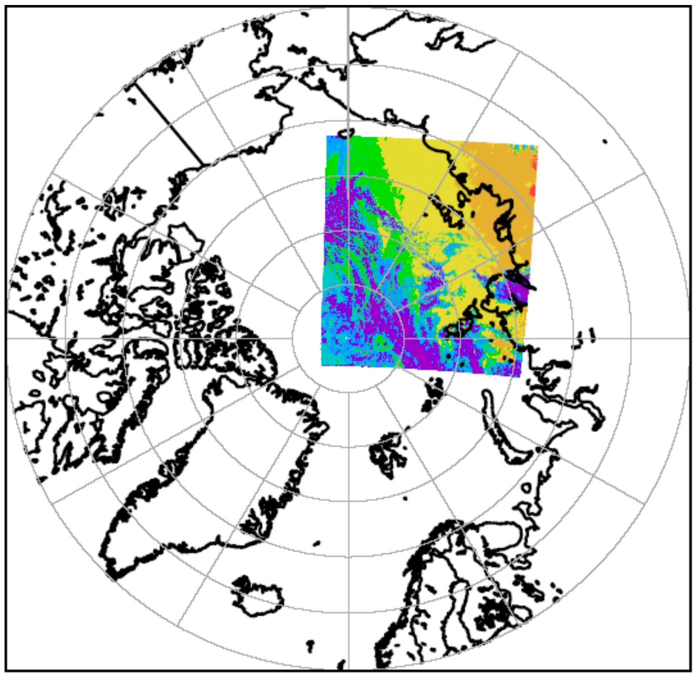
– MODIS provides data since 2000:
  • *spatial resolution (5-km) and temporal resolution (up to 7 observations per day from Terra or Aqua at high latitudes);* allows to address changes in ice extent
– CALIPSO, CloudSat provide data since 2006 (*Stephens et al., 2002; Kay et al., 2008, 2009*):
  • *Available flux product: CloudSat 2B-FLXHR (CloudSat Level 2 Fluxes and Heating Rates Product) at 500m ~ 1km resolution*

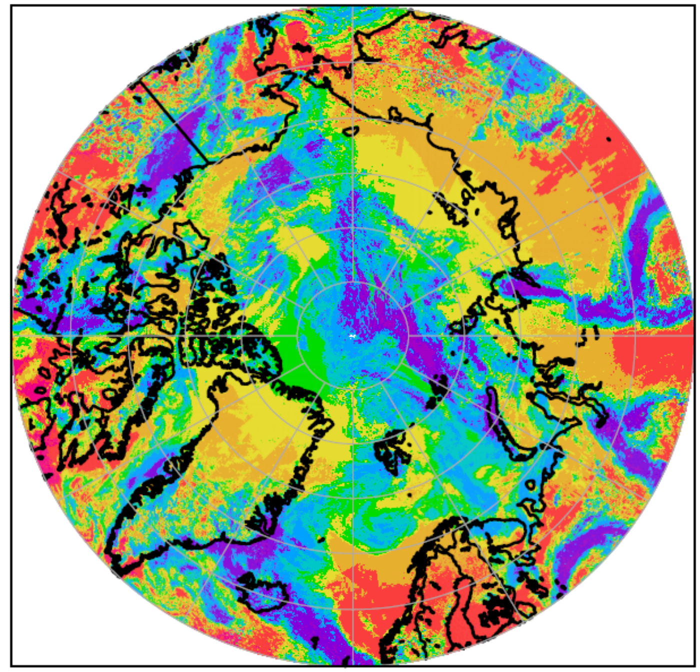
Approach

- Use MODIS 5-km data to evaluate the accuracy of longer term records of lower resolution (AVHRR)
- Revisit AVHRR by implementing improved methodologies to derive surface radiative fluxes
- New information on surface properties and viewing geometry allows to improve:
  – *narrow-to-broadband (n/b) transformations; to take into account changes in surface features at High Latitudes (ice extent and melting ponds)*
  – *Implement angular corrections based on CERES*

Example of Surface Shortwave Radiative Flux from MODIS 5-km Data

UTC 04:35, July 1, 2005





"Stitched" map of SW fluxes using 28 granules; overpass around 11:30 am (Local Time) on July 1, 2005

(W/m^2)

The inference scheme for MODIS 1^0 and 5-km data to derive radiative fluxes at both TOA and surface is based on *Wang and Pinker (2009)*

Evaluations of MODIS SW fluxes at 1^0 resolution against land and buoy observations is presented in *Pinker et al. (2009)*

For use with longer time series of satellite observations such as AVHRR, need to develop improved methodologies for using the narrow-band observations

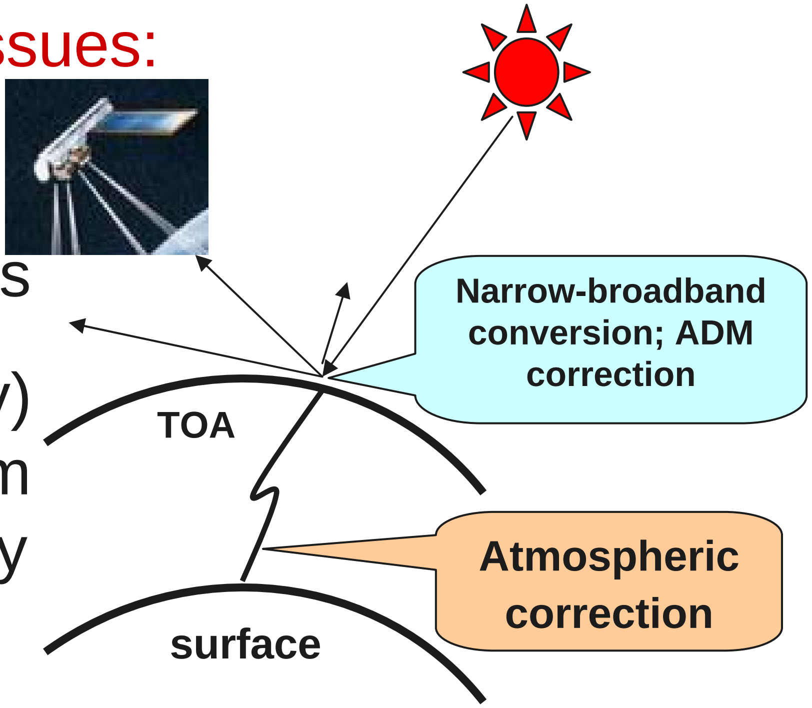
Critical elements in formulating radiative flux estimates from satellite radiance observations:

- Transformation of narrow-band observations into broadband values (n/b)
- Application of Angular Distribution Models (ADMs)

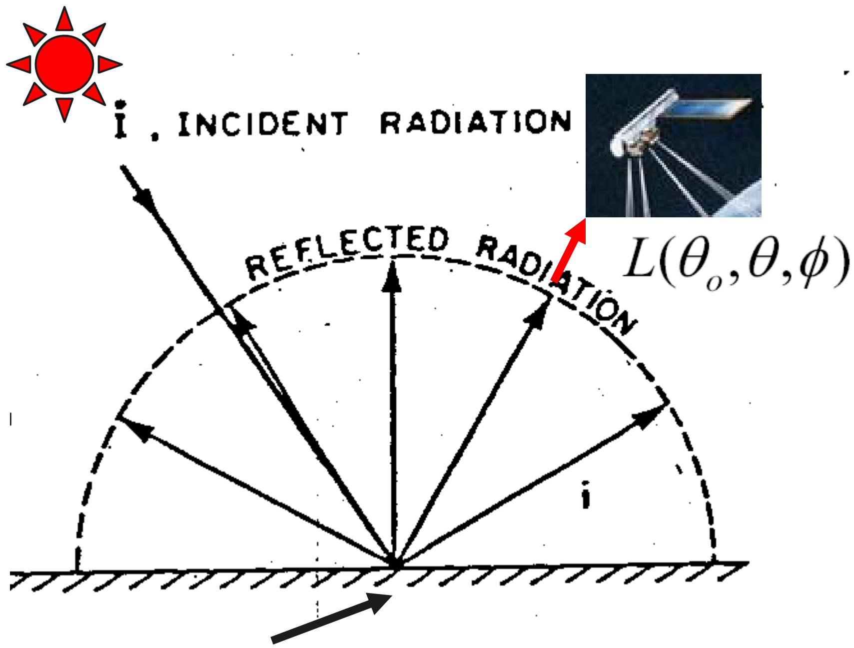
Work done to address High Latitude issues:

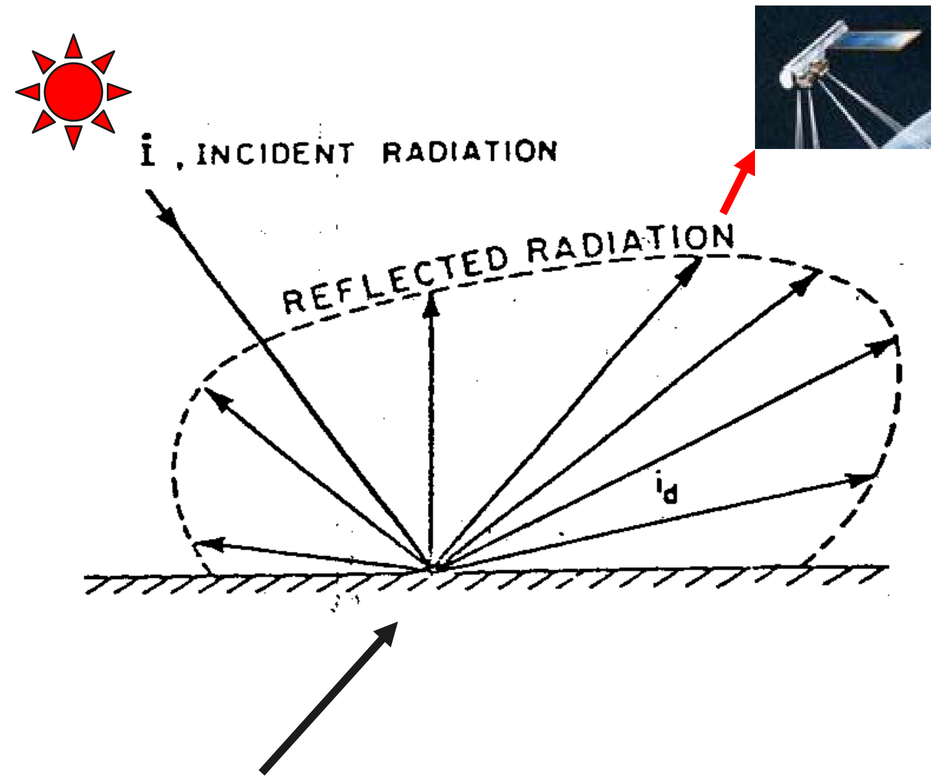
- Prepare n/b transformation based on surface features (snow, ice, melting ponds, water) at High Latitudes

- Prepare ADMs for (clear and cloudy) Conditions based on observations from Clouds and the Earth's Radiant Energy System (CERES) and simulations



Anisotropic Correction



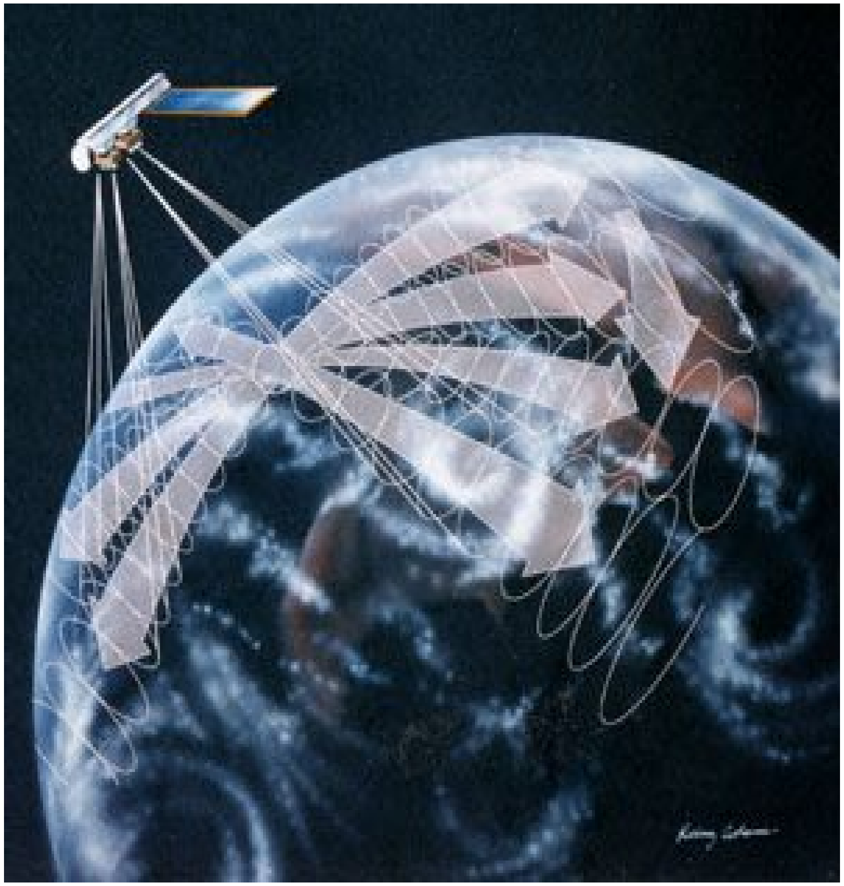


$$F(\theta_o) = \pi L(\theta_o,\theta,\phi)$$

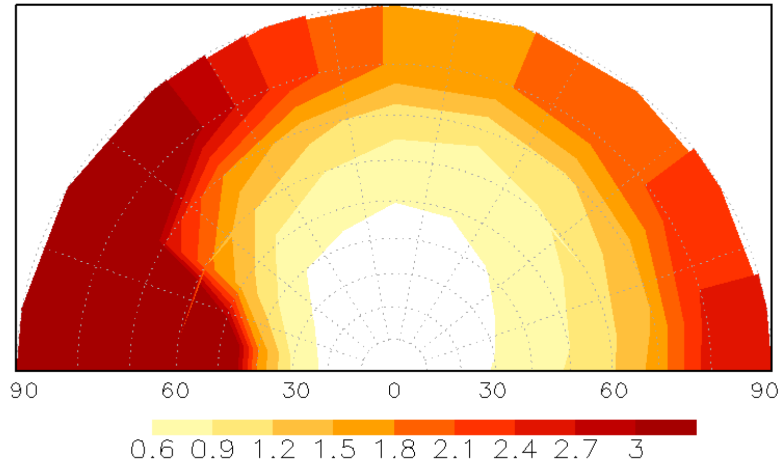
$$R_j(\theta_o,\theta,\phi) = \frac{\pi \overline{L}_j(\theta_o,\theta,\phi)}{\int_0^{2\pi}\int_0^{\frac{\pi}{2}} \overline{L}_j(\theta_o,\theta,\phi)\cos\theta \, \sin\theta \, d\theta d\phi}$$

$R_j(\theta_o,\theta,\phi)$ - Angular Distribution Model (ADM) for the "j[th]" scene type

ADMs from CERES

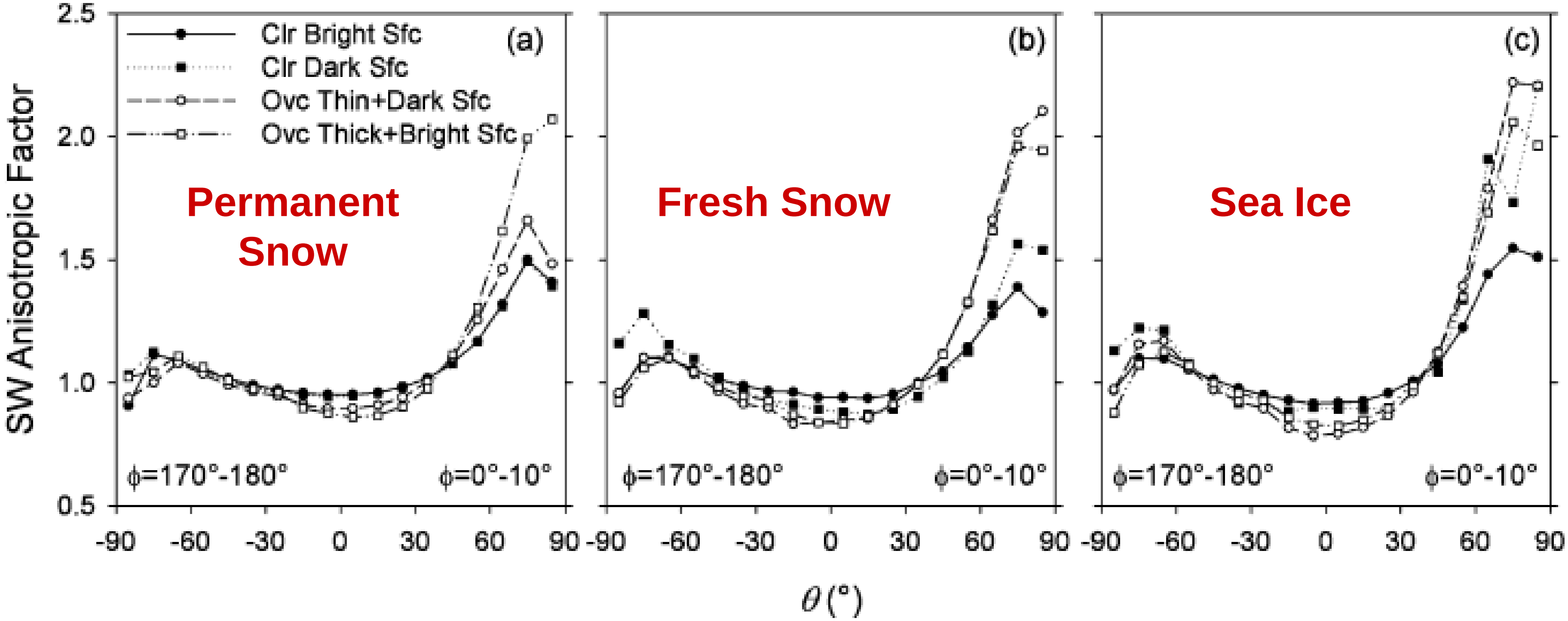


- Multi-angle radiance data are collected using the rotating azimuth plane scanning (RAPS) mode of CERES
- One CERES instrument dedicated to RAPS observations on **TRMM**, **Terra and Aqua**



CERES ADMs for Ocean (Clear sky), SZA (60^0- 70^0)

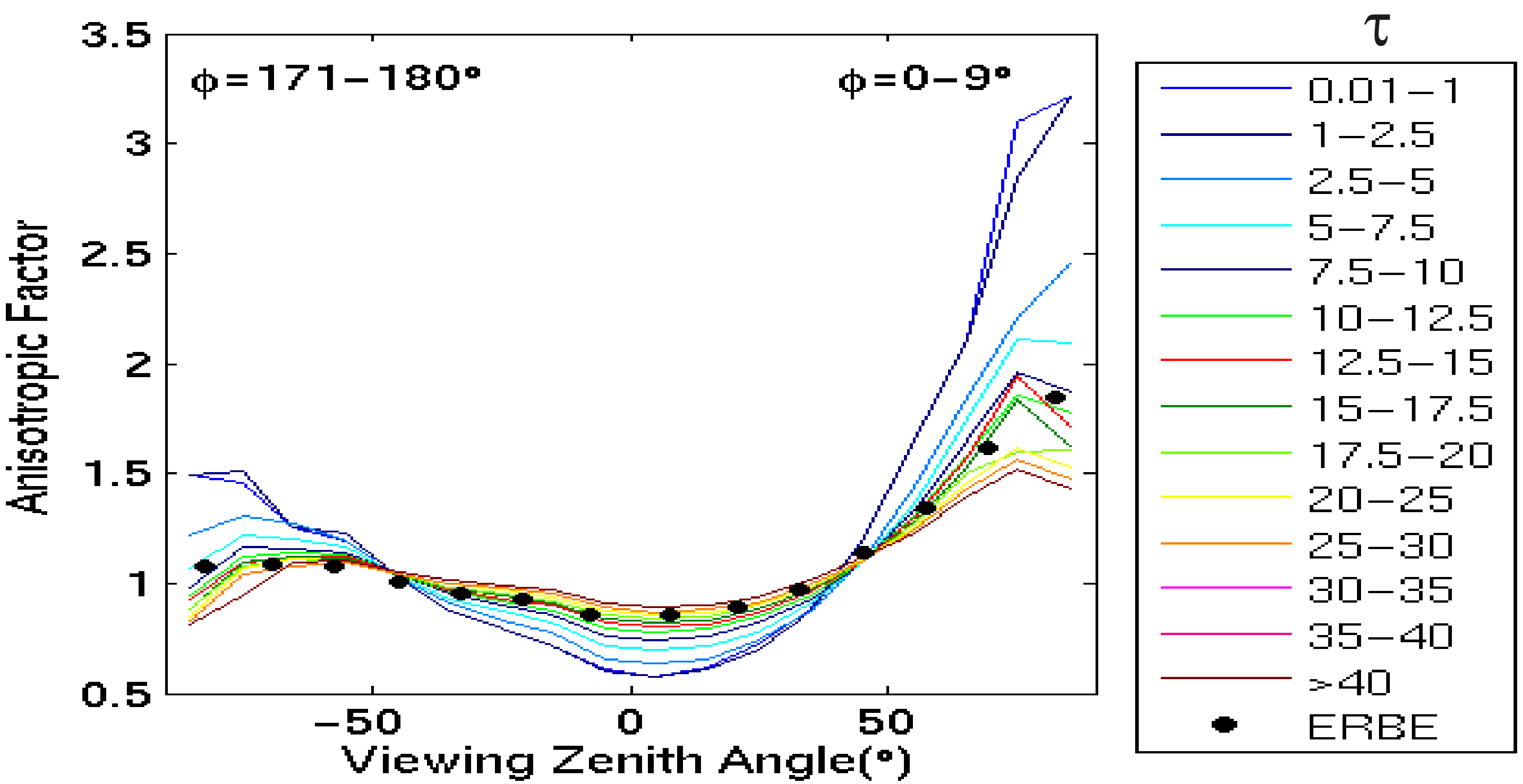
CERES ADMs for Surface Features at High Latitudes



SW anisotropic factors for SZA=$62^0 - 64^0$ (permanent snow) and for SZA=$60^0 - 65^0$ (fresh snow and sea ice);
"Clr" =clear sky; "Ovc"=overcast. (*Loeb et al., 2005*)

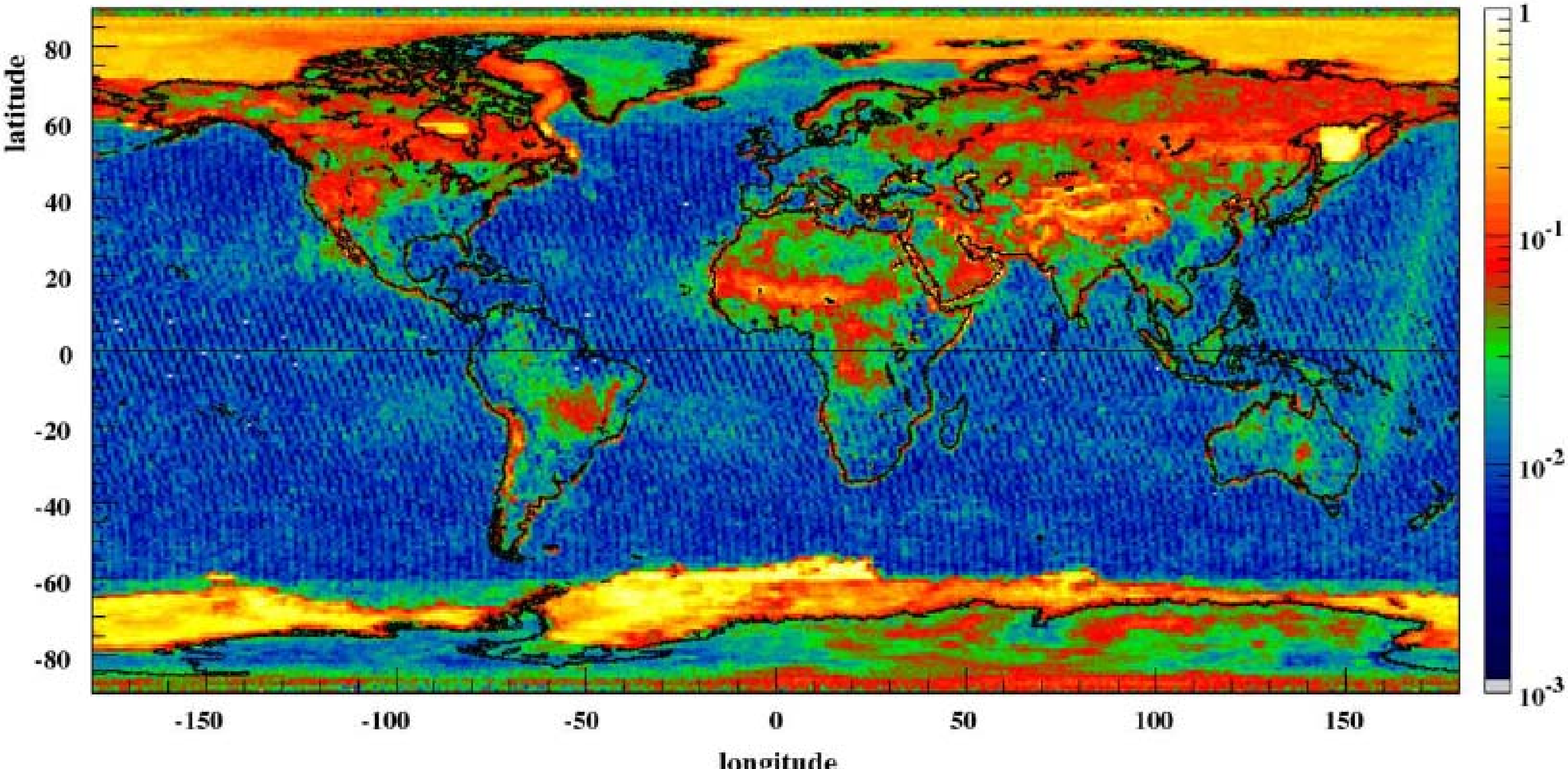
Large Differences are at viewing angles > 60^0

Cloud Sky: CERES Cloud ADMs are Dependent on Cloud Optical Depth (COD)



Anisotropic factors: overcast water clouds over ocean as a function of COD (SZA: 50^0-60^0)

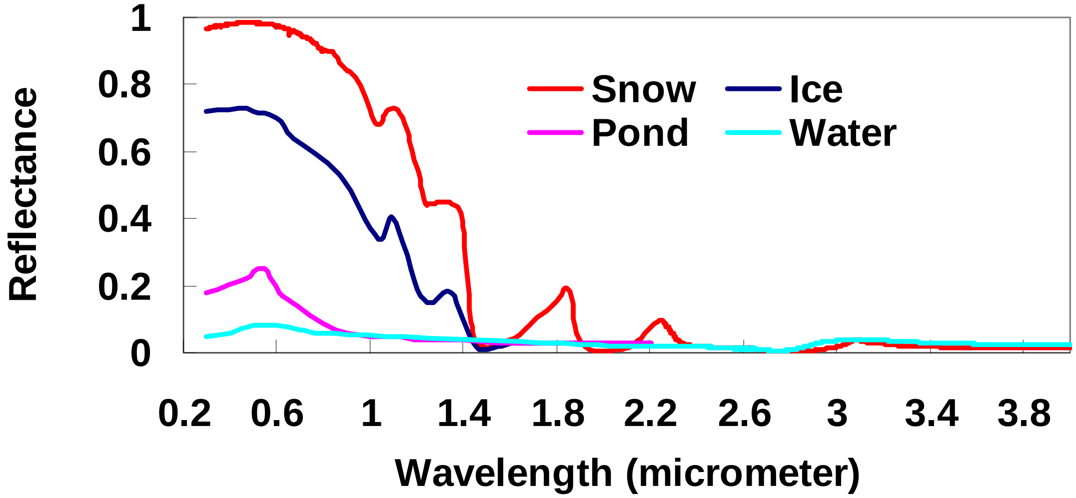
Under-Sampling of Satellite Observations at High Latitudes



Fraction of CERES footprints lacking imager information for a reliable scene identification;

It can reach up to 50% lacking at High Latitudes, Mountains or Coastal Regions. (*Loukachine and Loeb, 2004*)

Surface Types and Albedos Implemented in MODTRAN Simulations



Spectral reflectance of different surface types (snow, sea ice, melting ponds, water) at High Latitudes

Surface Type	Data Source of Surface Spectral Reflectance
Snow	ASTER SPECTRAL LIBRARY; MODIS products (*Moody et al., 2007*)
Sea Ice	ASTER SPECTRAL LIBRARY; Cloud Absorption Radiometer from Univ. of Washington (*King et al., 1986; Arnold et al., 2002*)
Melting Pond	Spectral Reflectance measurements near Barrow, Alaska, June 2004 (*Tschudi et al., 2008*)
Water	ASTER SPECTRAL LIBRARY

The n/b transformations and new ADMs were implemented with MODIS observations for high latitudes

Channel Number	Channel Name	Spectral band (μm)
		MODIS (36)
1	VIS 0.6	0.62-0.67
2	VIS 0.8	0.84-0.88
3	NIR 1.6	1.63-1.65
4	VIS 0.4	0.46-0.48
5	NIR 1.3	1.36-1.39
6	NIR 2.2	2.11-2.16

Narrowband reflectance:

$$\rho_{nb}(\theta_0,\theta,\phi) = \frac{\pi \int_{\lambda 1}^{\lambda 2} I(\lambda,\theta_0,\theta,\phi) G(\lambda) d\lambda}{\int_{\lambda 1}^{\lambda 2} \cos(\theta_0) S_0(\lambda) G(\lambda) d\lambda}$$

Broadband reflectance:

$$\rho_{bb}(\theta_0,\theta,\phi) = \frac{\pi \int_{0.2\,\mu m}^{4\,\mu m} I(\lambda,\theta_0,\theta,\phi) d\lambda}{\int_{0.2\,\mu m}^{4\,\mu m} \cos(\theta_0) S_0(\lambda) d\lambda}$$

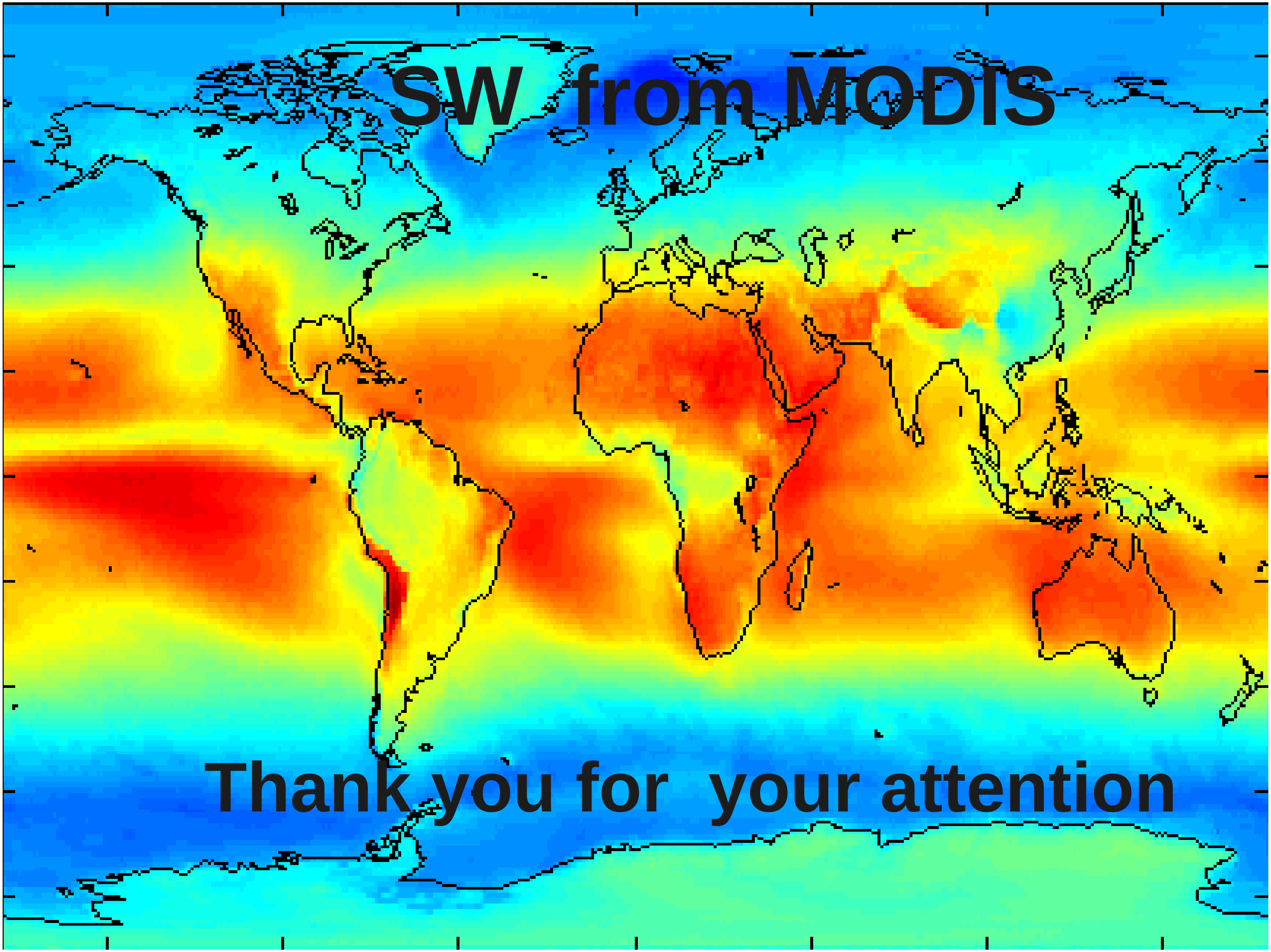
n/b transformation coefficients c and offset d:

$$\rho_{bb}(\theta_0,\theta,\phi) = c(\theta_0,\theta,\phi) \times \rho_{nb}(\theta_0,\theta,\phi) + d(\theta_0,\theta,\phi)$$

Summary

- At high latitudes, there is a need in:
  - High resolution information on radiative fluxes
  - Long term information on such fluxes
- Satellites observations do not meet both objective simultaneously.
- In this study an attempt has been made to develop tools that will allow to synthesize information from numerous sources to better meet such needs

- Specifically, attention was given to:
  - Changing surface conditions at high latitudes
  - Viewing geometry unique to high latitudes
- The new approach has been implemented with MODIS observations and the impact of the modifications are being evaluated.
- An effort will be made to utilize observations made during the IPY, ships and buoys


SW from MODIS
Thank you for your attention