The Abdus Salam
International Centre for Theoretical Physics

United Nations
Educational, Scientific
and Cultural Organization

International Atomic
Energy Agency

Spring Colloquium on
'Regional Weather Predictability and Modeling'
April 11 - 22, 2005

1) Workshop **on Design and Use of Regional Weather Prediction Models,** *April 11 - 19*

2) Conference on **Current Efforts Toward Advancing the Skill of Regional Weather Prediction. Challenges and Outlook,** *April 20 - 22*

301/1652-1

ETA Land-Surface, Surface Layer and PBL Parameterization Schemes
Lecture I

F. Freedman
San Jose State University
CA, USA

Strada Costiera 11, 34014 Trieste, Italy - Tel. +39 040 2240 111; Fax +39 040 224 163 - sci_info@ictp.it, www.ictp.it

ETA Land-Surface, Surface Layer and PBL Parameterization Schemes (Lecture One)

by

Dr. Frank R. Freedman*

San Jose State University

freedman@met.sjsu.edu

for

ITCP Spring Colloquium on

Weather Predictability and Modeling

* NRC Postdoctoral Fellow: NCEP, 2003-2004

Acknowledgements

Appreciation expressed to Curtis Marshall, Eric Rogers and Michael Ek (NCEP) for allowing use of several slides contained in this presentation.

Outline

- Overview of schemes …
  - Land Surface Model (LSM)
  - Surface Layer (SL)
  - Planetary Boundary Layer (PBL)

Lecture 1

- Noah LSM
- Surface Layer
- Planetary Boundary Layer

Lecture 2

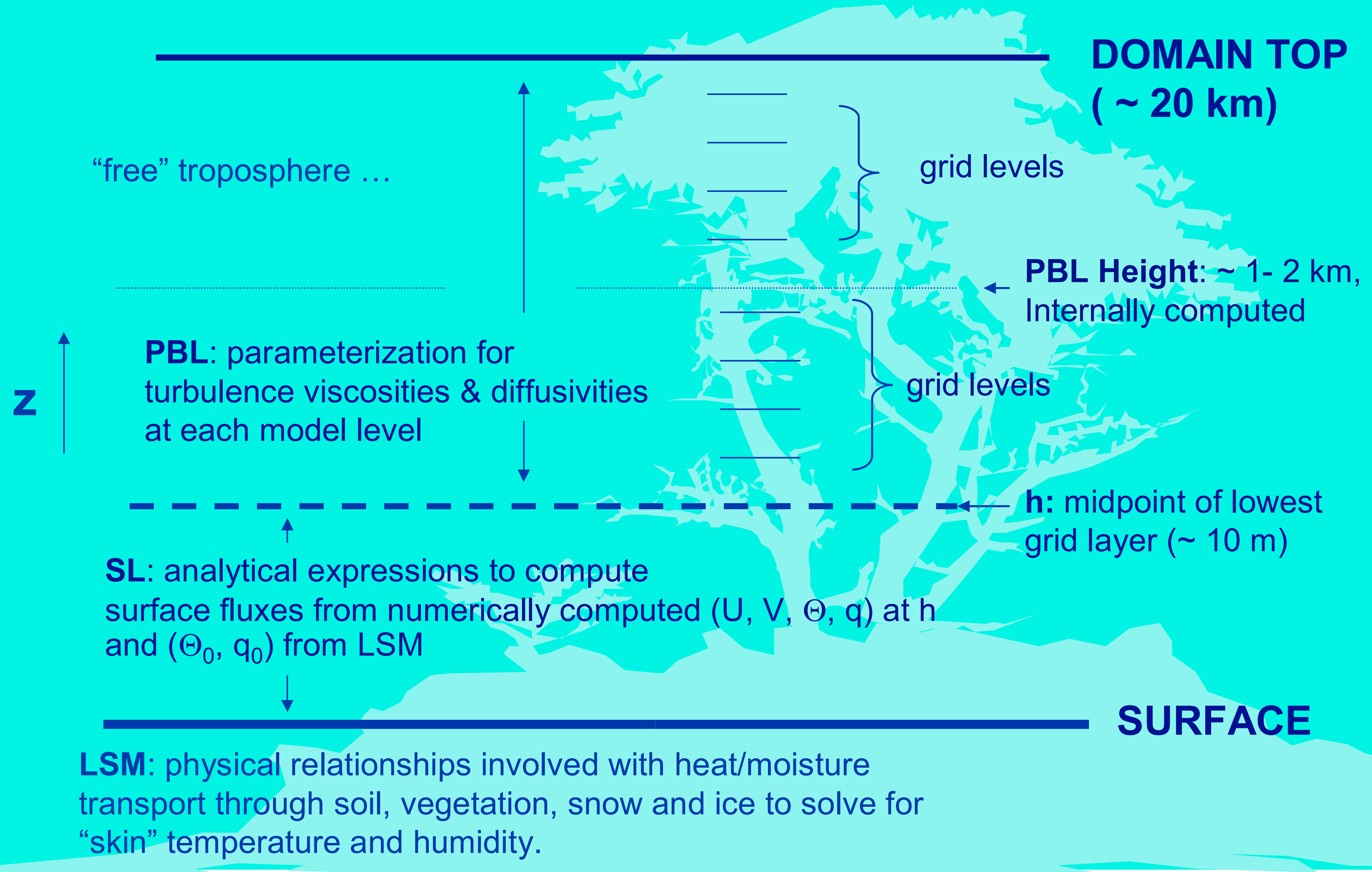
General Physical Process …

- **Vertical transport by turbulence** of momentum, heat & moisture to & from surface and atmosphere

- **LSM:** Calculate surface temperature & moisture (lower boundary condition)

- **SL and PBL schemes:** calculate transport
  - SL: surface through lowest grid layer
  - PBL: remainder of grid layers above

1D (vertical) Architecture



Coupling I

LSM

Surface temperature & humidity (i.e. @ z = 0)

PBL SCHEME

[U, V, Θ, q] @ z = h

SL SCHEME

Surface heat flux & evaporation rate

Coupling II

Turbulent fluxes @ first model level
(via PBL scheme)

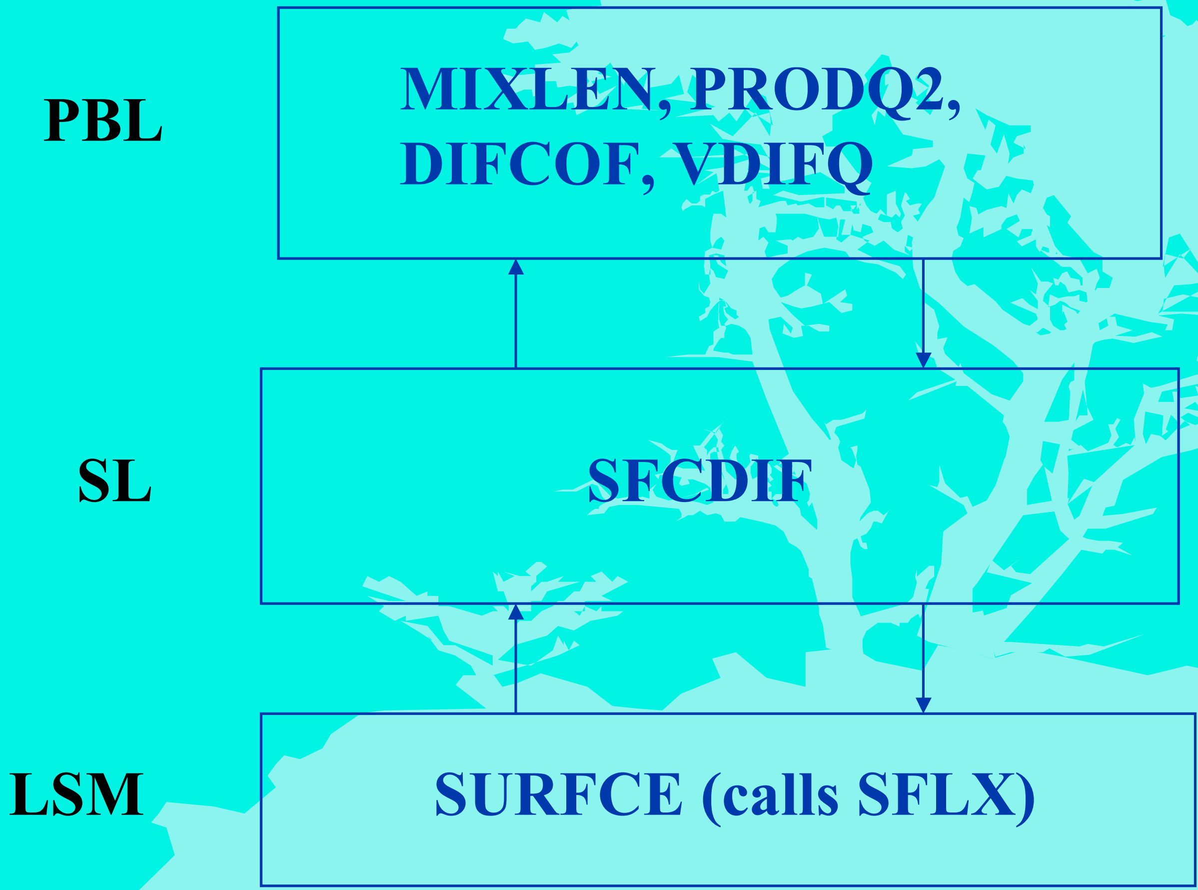
↓

[U, V, Θ, q] @ z = h

↑

Surface fluxes
(LSM, SL, PBL interaction, see previous slide)

Subroutines in ETA



LAND SURFACE SCHEME

So what does the LSM do?

- Provides albedo for calculating reflected shortwave radiation
- Calculates evapotranspiration (latent heat flux, surface humidity) from soil and vegetation canopy
- Provides ground surface ("skin") temperature for determining surface sensible heat flux and upward longwave radiation
- Includes effects of precipitation, ice, snow, soil & vegetation types, fractional grid area coverage, others …

ETA uses Noah LSM

From original NOAH model

- National Weather Service (U.S.)
- Oregon State University
- Air Force (U.S.)
- Office of Hydrology

Other groups get involved … 'Noah' (no acronym)

References:

a) Chen & Dudhia (2000, Monthly Weather Review)

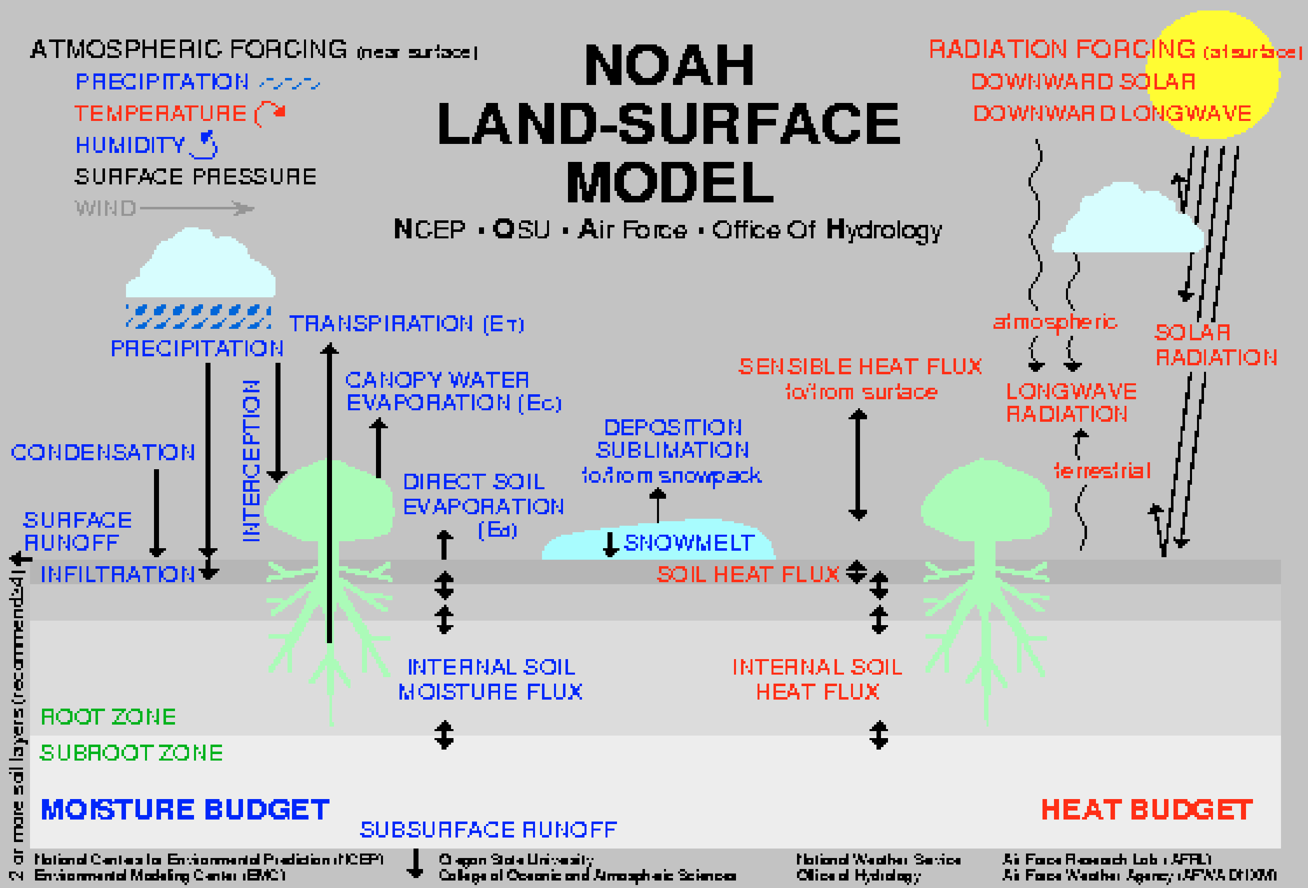
b) Ek et al. (2003, Journal of Geophysical Research)

Attributes of Noah LSM

- **4 Soil Layers (10, 30, 60, 100 cm thick)**
  - Predict volumetric soil moisture (cm^3 liquid/cm^3 soil) and soil temperature in each layer
  - Involves parameters that depend on soil & vegetation “classes”
- **Bare Soil**
  - 16 distinct soil classes (based on % clay content)
- **Vegetation**
  - 24 vegetation/land type classes (short grass, forest, tundra, etc …)
  - Annual cycle of vegetation greenness
  - Accounts for fractional coverage (seasonally dependent)
- **Snow & Ice**
  - Prognostic treatment of snowmelt → snow depth
  - Treatment of frozen ground (soil ice) and patchy snow
  - Strongly effects surface albedo
- **Continuous 3-hour update in fully cycled Data Assimilation System (EDAS)**

NOAH LAND-SURFACE MODEL

NCEP · OSU · Air Force · Office Of Hydrology



STATE VARIABLES

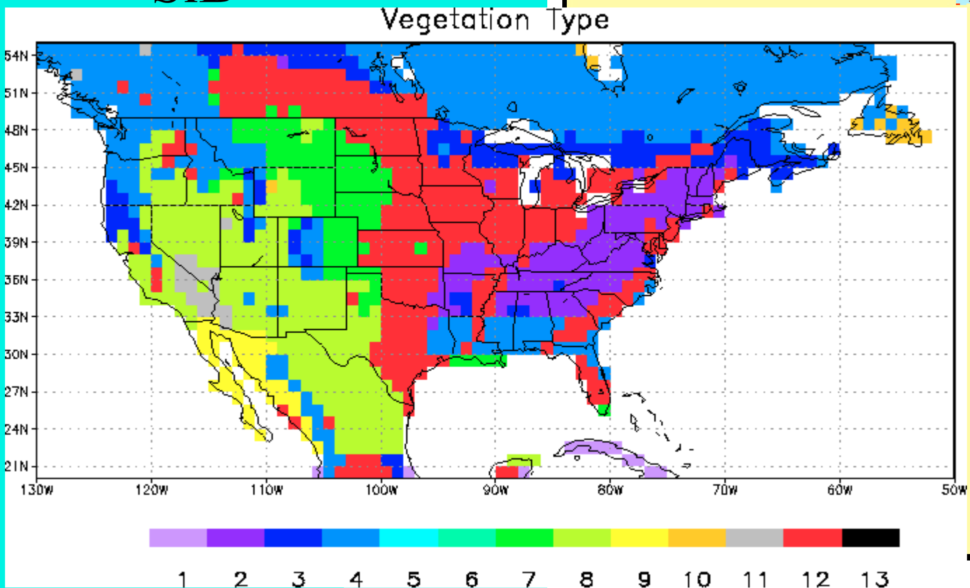
- SKIN TEMPERATURE
- SOIL TEMPERATURE
- SOIL WATER
- SOIL ICE
- CANOPY WATER
- SNOW WATER
- SNOW DENSITY

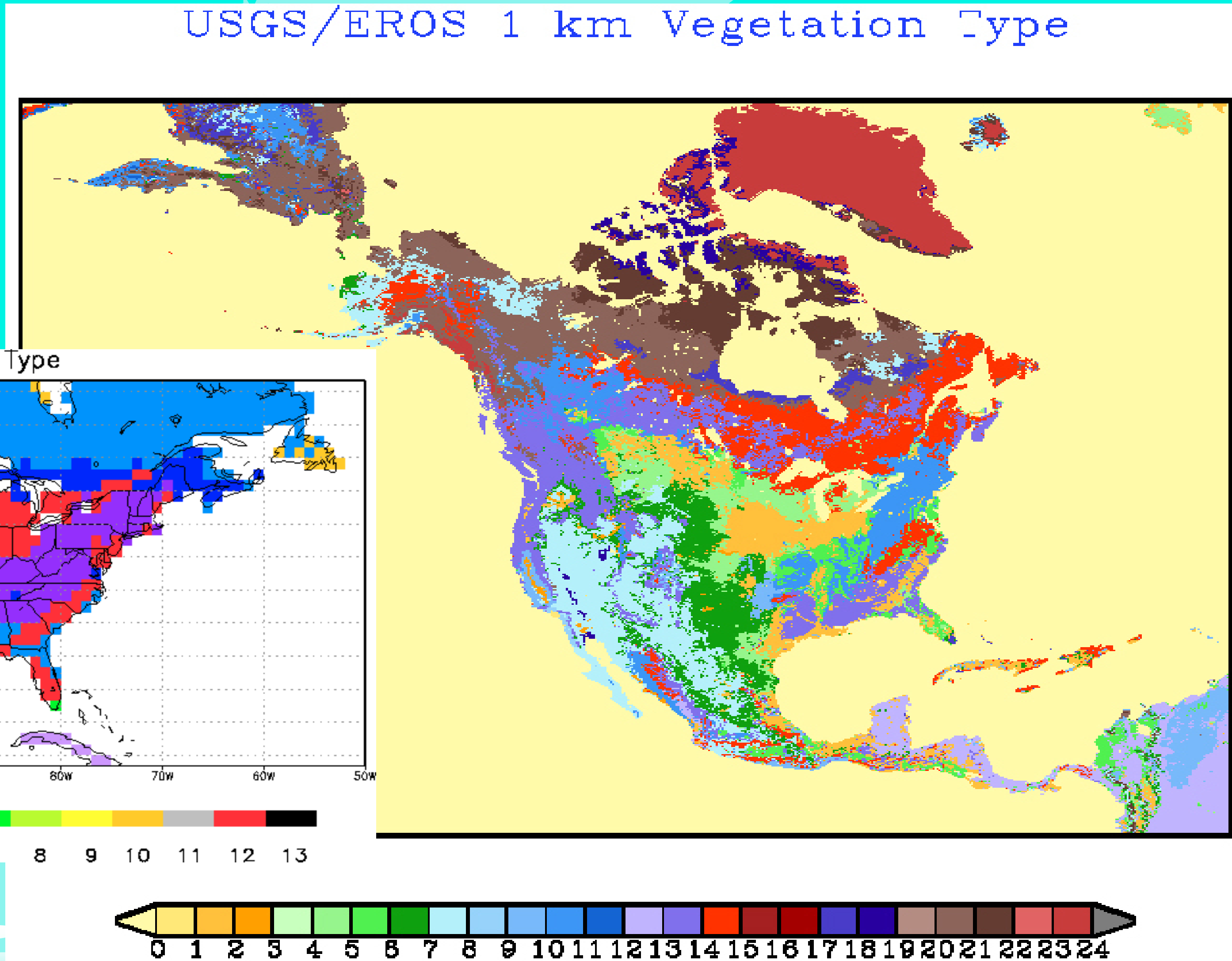
SURFACE PARAMETERS

- VEGETATION TYPE
- GREEN VEGETATION FRACTION
- SOIL TEXTURE
- ROUGHNESS
- ALBEDO
- SLOPE FACTOR

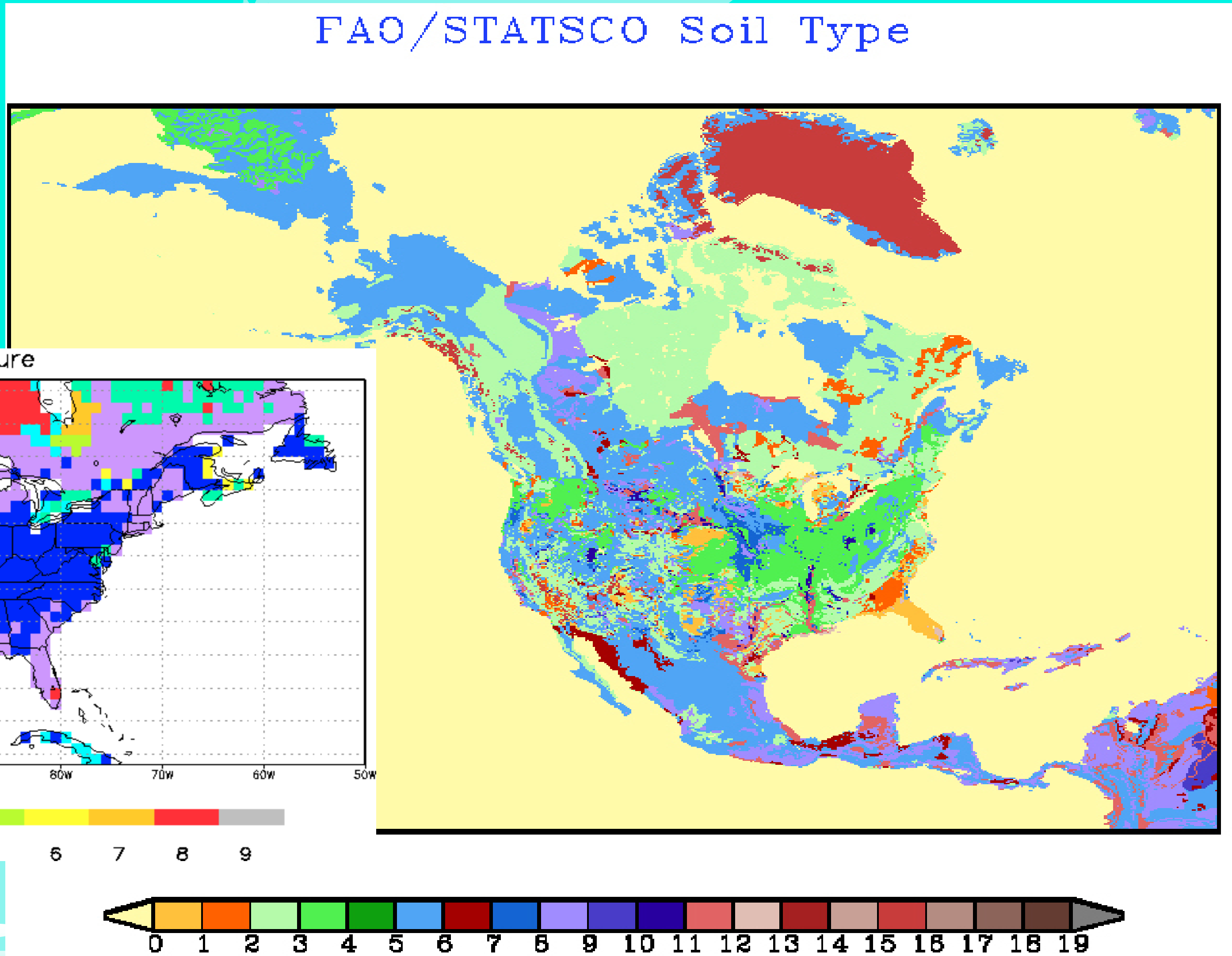
<u>Latest Version</u>: USGS 24-class high-resolution (1-km) vegetation data set replaces old SiB 13-class 1-degree data set

SiB

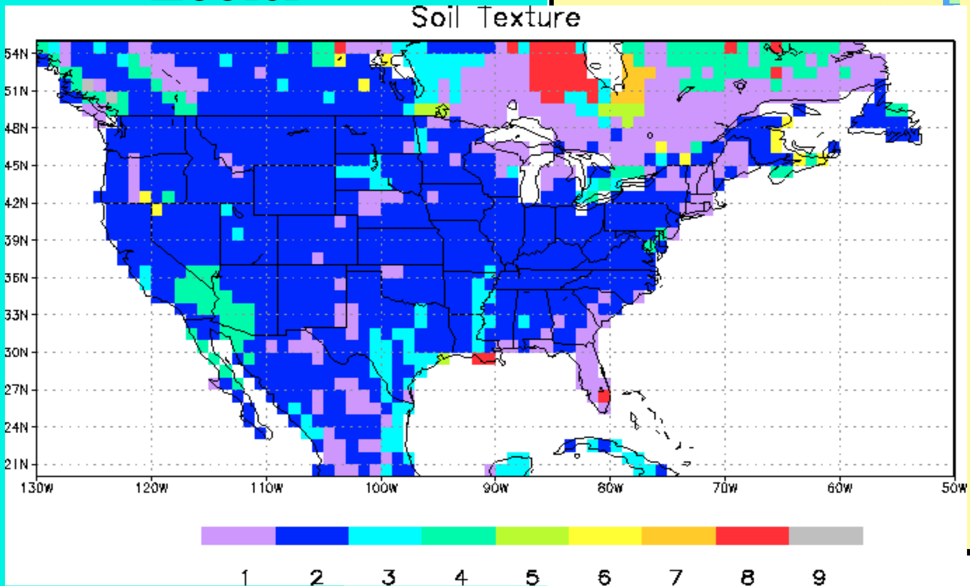




<u>Latest Version</u>: New STATSGO 16-class high-resolution (1-km) soils data base replaces old Zobler 9-class 1-degree data set



Zobler



Surface Energy Balance (SEB) Equation

$$Rn = H + LE + G$$

Rn = Net Radiation
H = Surface Sensible Heat Flux
LE = Surface Latent Heat Flux
G = Ground Heat Flux

$$Rn - G = H + LE$$

"Available Energy" for Turbulent Fluxes

SEB Equation solved for surface temperature

Soil moisture, soil & vegetation class, snow physics, etc … used to calculate each term

Soil Moisture & Temperature Equations

- Soil Moisture (Θ):

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z}\left(D \frac{\partial \theta}{\partial z} \right) + \frac{\partial K}{\partial z} + F_{\theta}$$

  - "Richard's Equation" for soil water movement
  - D, K functions (depends on soil class)
  - F_θ represents sources (rainfall) and sinks (root extraction)

- Soil Temperature

$$C(\theta)\frac{\partial T}{\partial t} = \frac{\partial}{\partial z}\left(K_t(\theta)\frac{\partial T}{\partial z} \right)$$

  - C, K_t functions (depend on soil texture, soil moisture)
  - Soil temperature information used to compute ground heat flux

Evapotranspiration

$$E = E_{dir} + E_t + E_c$$

WHERE:

E = total evapotranspiration from combined soil/vegetation

E_{dir} = direct evaporation from soil

E_t = transpiration through plant canopy

E_c = evaporation from canopy-intercepted rainfall

Note: SL equations incorporated into each term so that equation solved for E (rather than surface humidity)

Illustrative Example

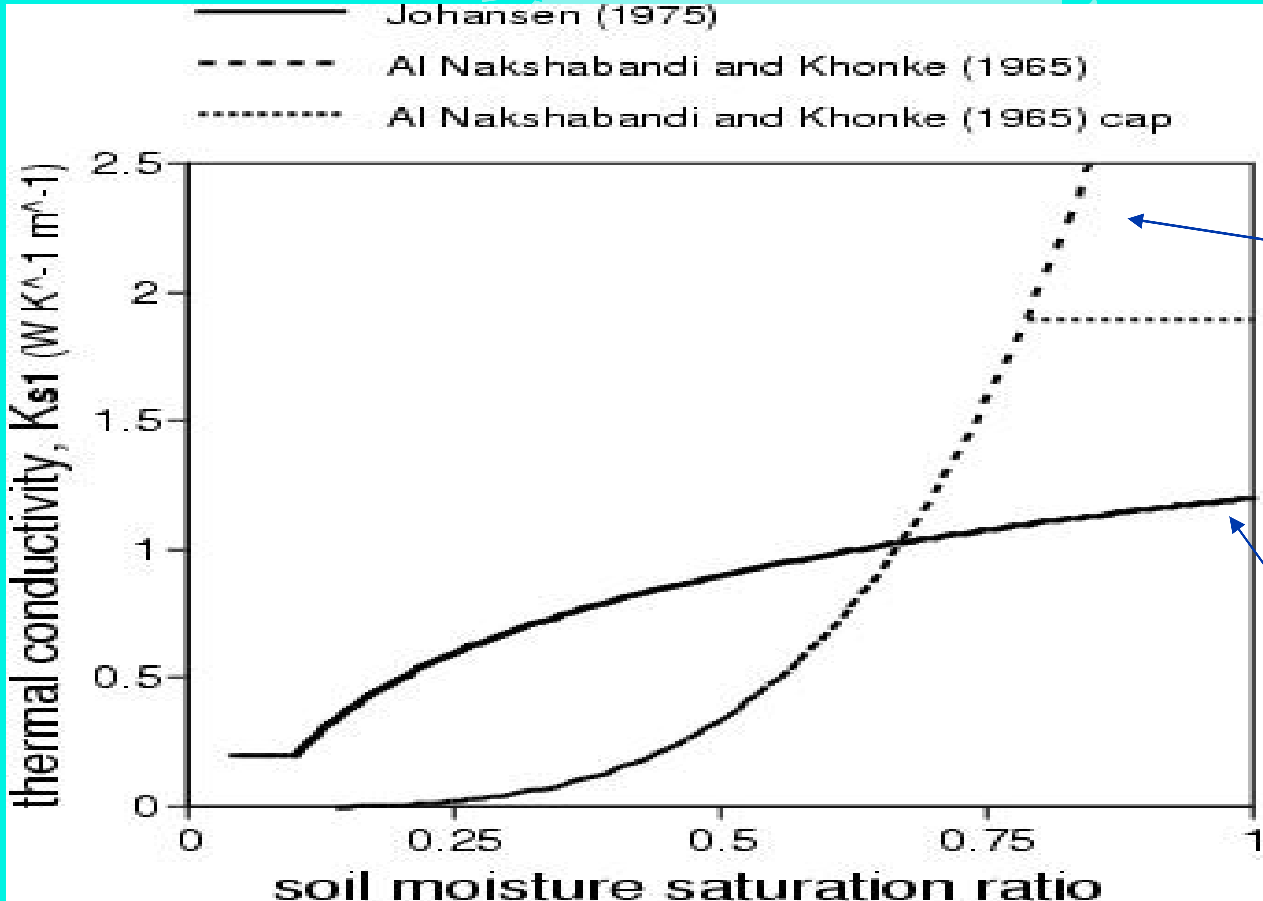
Ground Heat Flux (G) & Thermal Conductivities (K)

$$G = \frac{K_{eff}(T_s - T_{s1})}{\Delta z_s + \Delta z_{s1}}$$

- where K_{eff} is a grid-area ("effective") thermal conductivity
- involves weighted averages of bare soil, vegetation and snow values
- weights dependent on fractional vegetation and snow coverage
- T_s (surface temperature), T_{s1} (temperature in first soil layer)
- Δz_s (snow depth), Δz_{s1} (depth of first soil layer)

Soil Parameters

Example #1: Thermal conductivity through bare soil



traditional expression

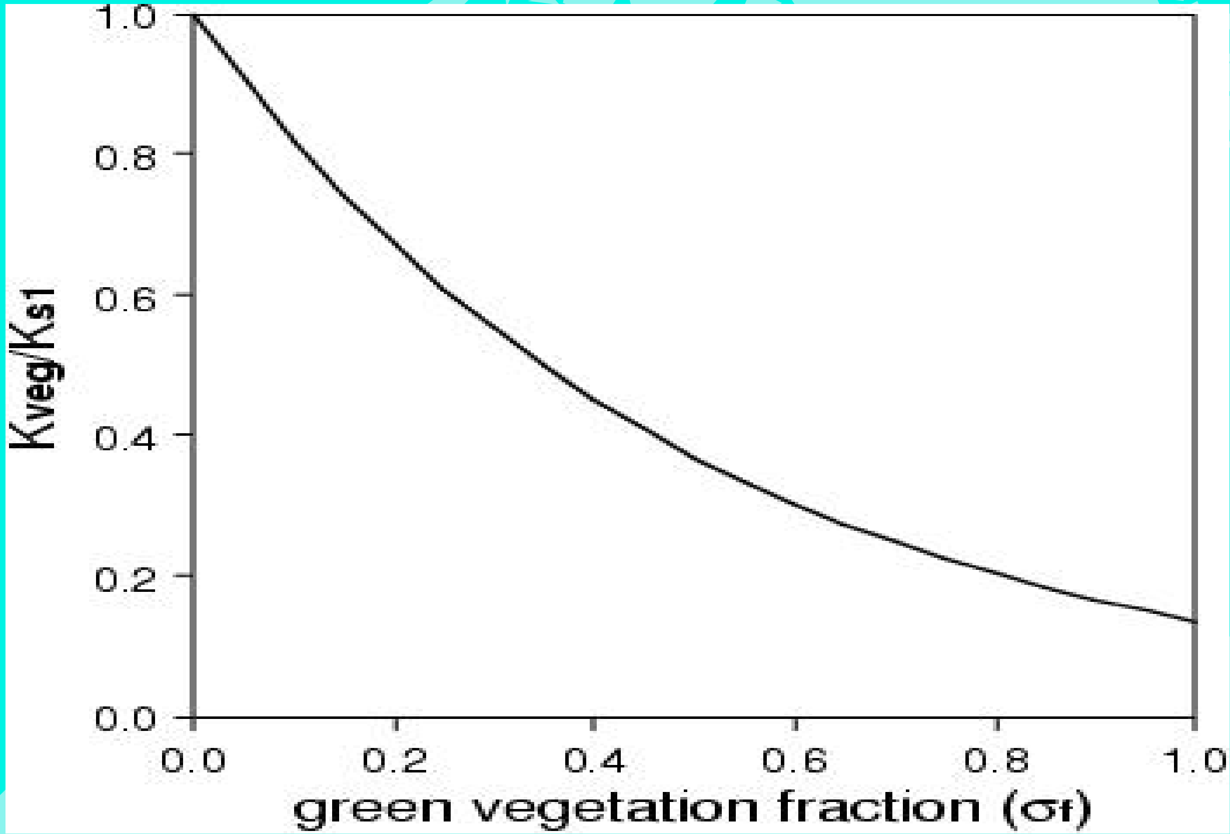
Current function in Noah

Θ/Θ_s

Source: Ek et al. (2003, JGR)

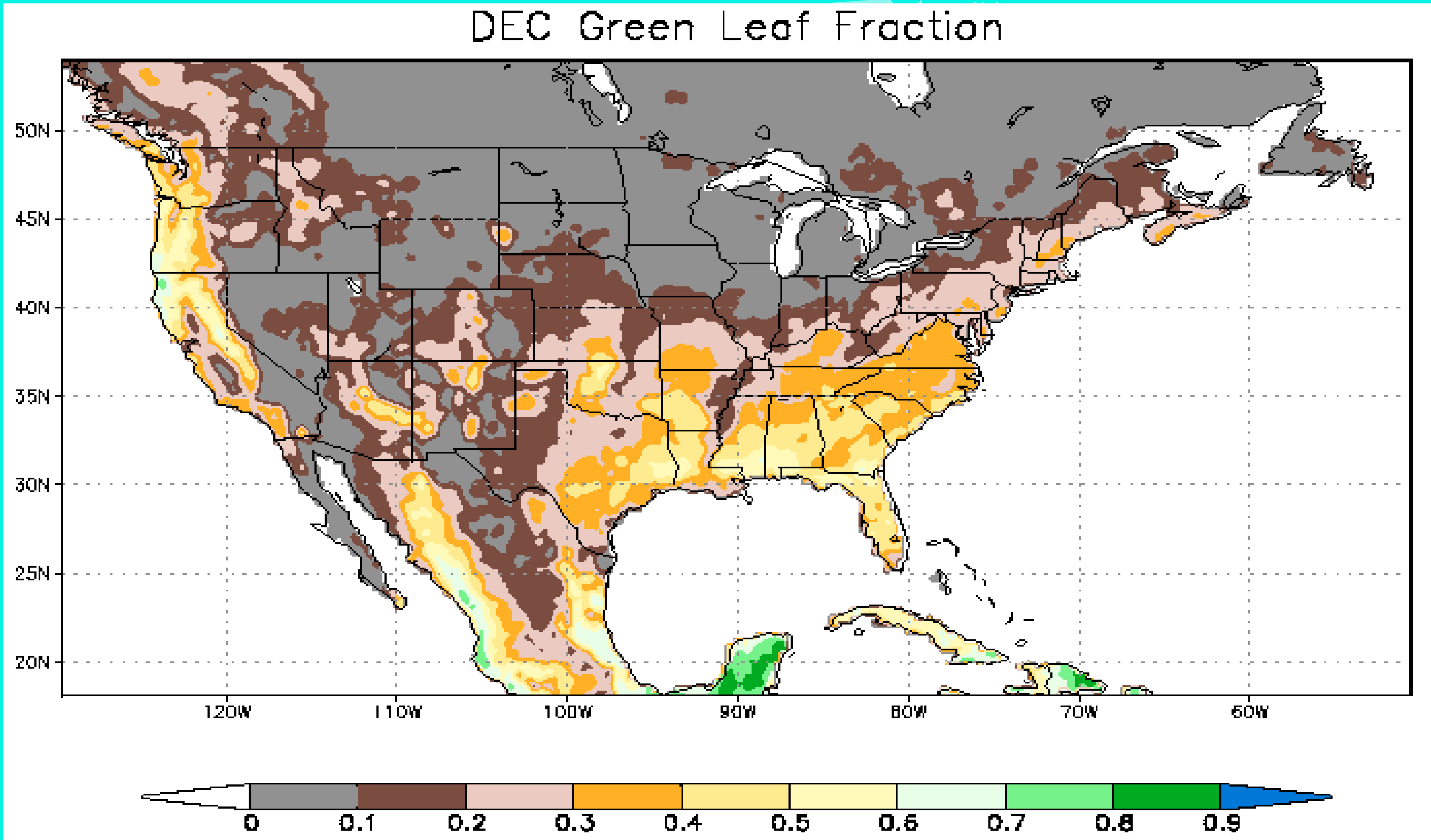
Soil Parameters

Example #2: Thermal conductivity through vegetation canopy (expressed as ratio to bare soil value)



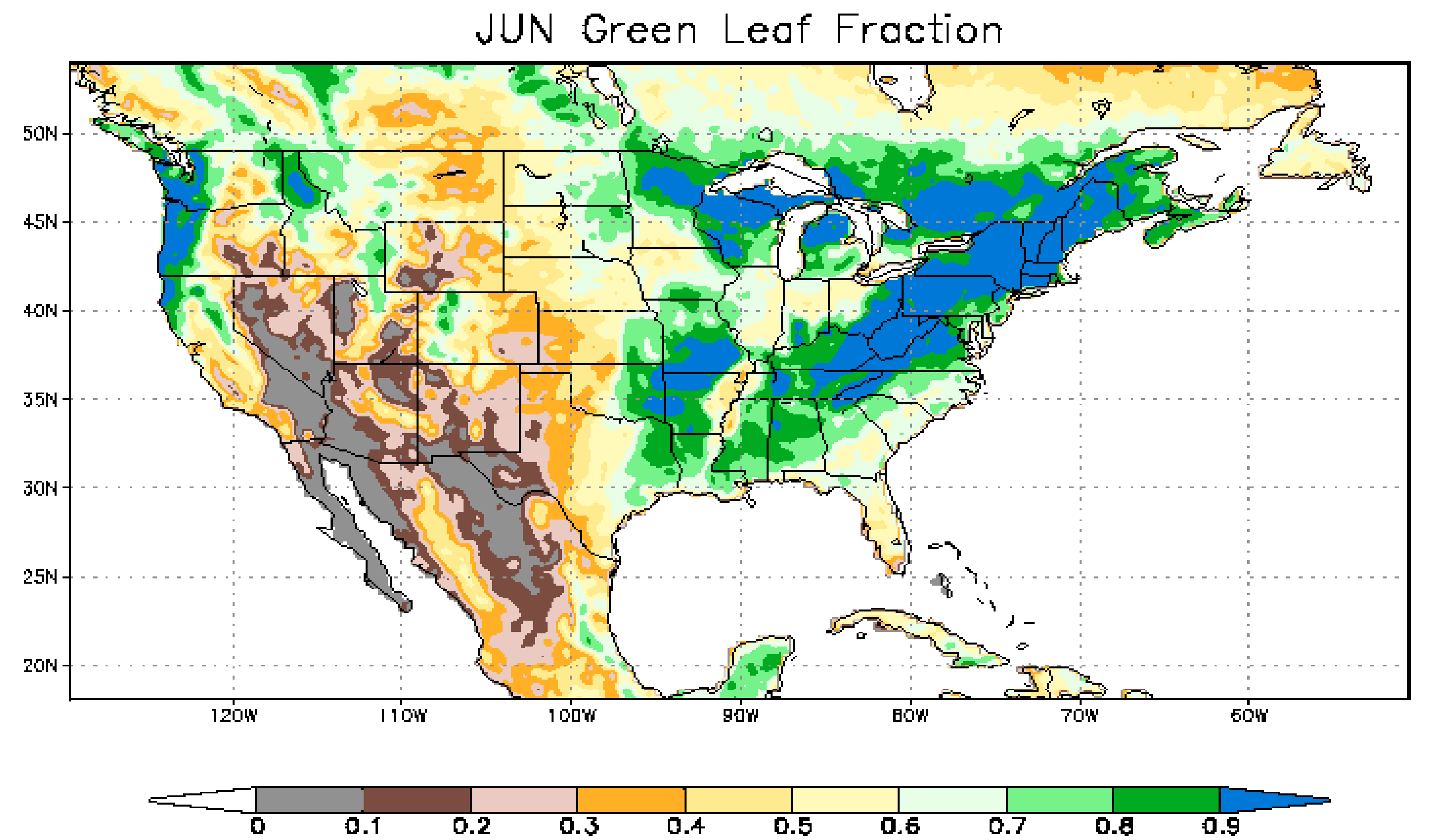
Source: Ek et al. (2003, JGR)

December Green Vegetation Fraction

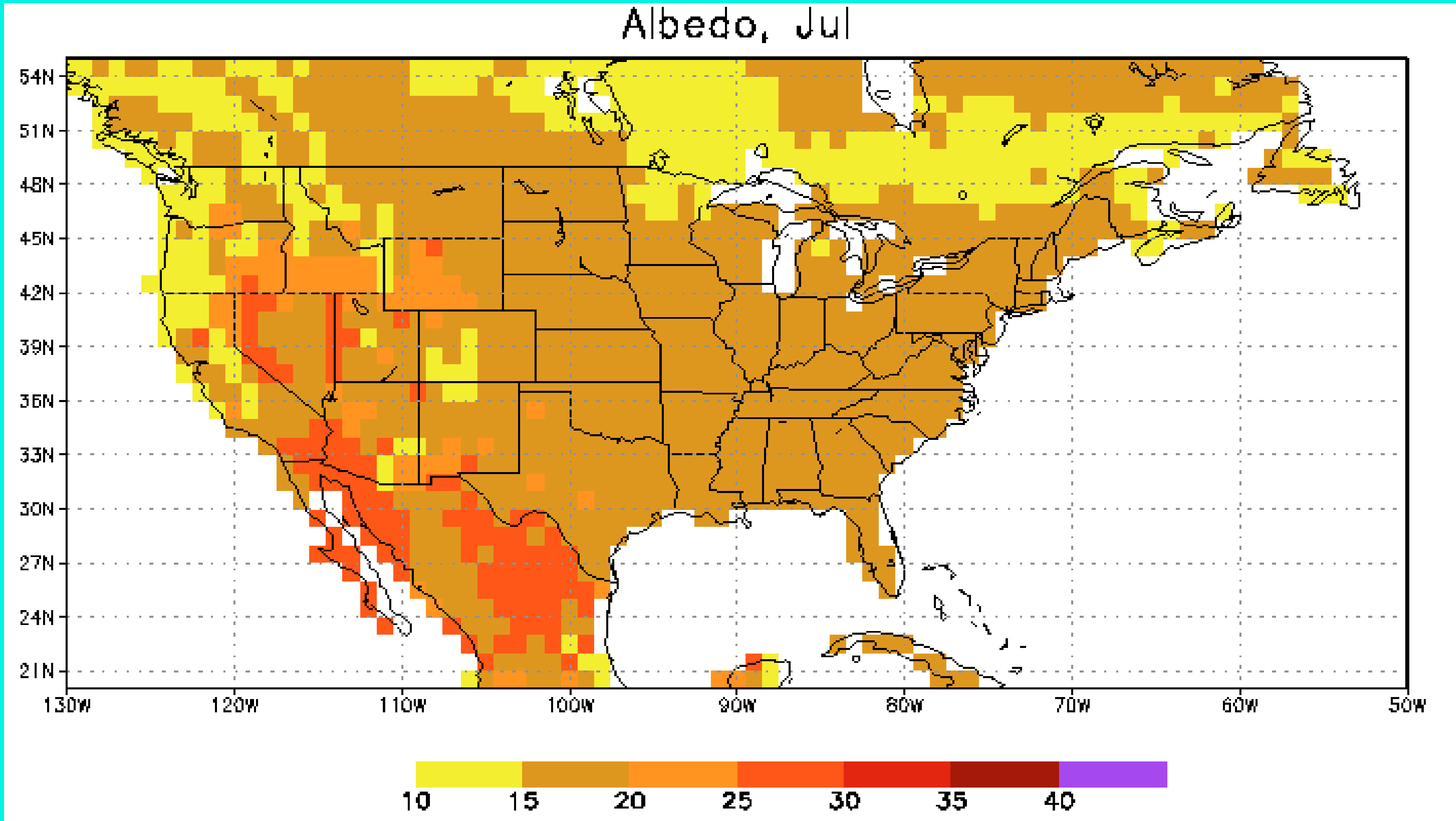


based on NESDES monthly 15 x 15 km, 5 year climatology

June Green Vegetation Fraction



Surface Albedo (snow free)



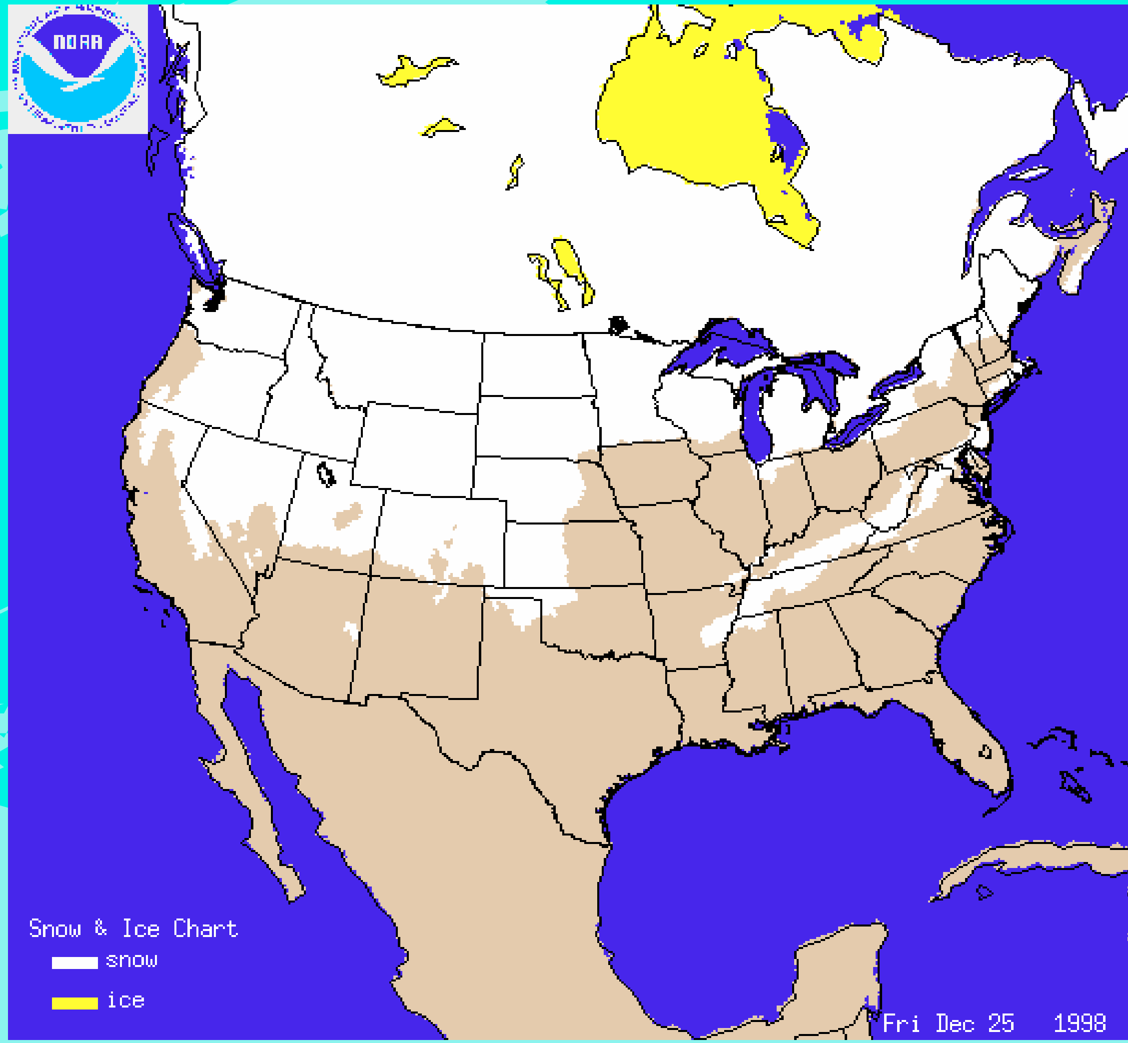
Snow Information

- cover: 23-km N. Hemisphere grid
- produced daily by human analyst
- multiple data sources:
  - GOES visible
  - SSMI snow cover
  - station reports
  - NIC ice cover
  - AVHRR visible

cover:
http://hpssd1en.wwb.noaa.gov/SSD/DATA/snow/archive

depth:

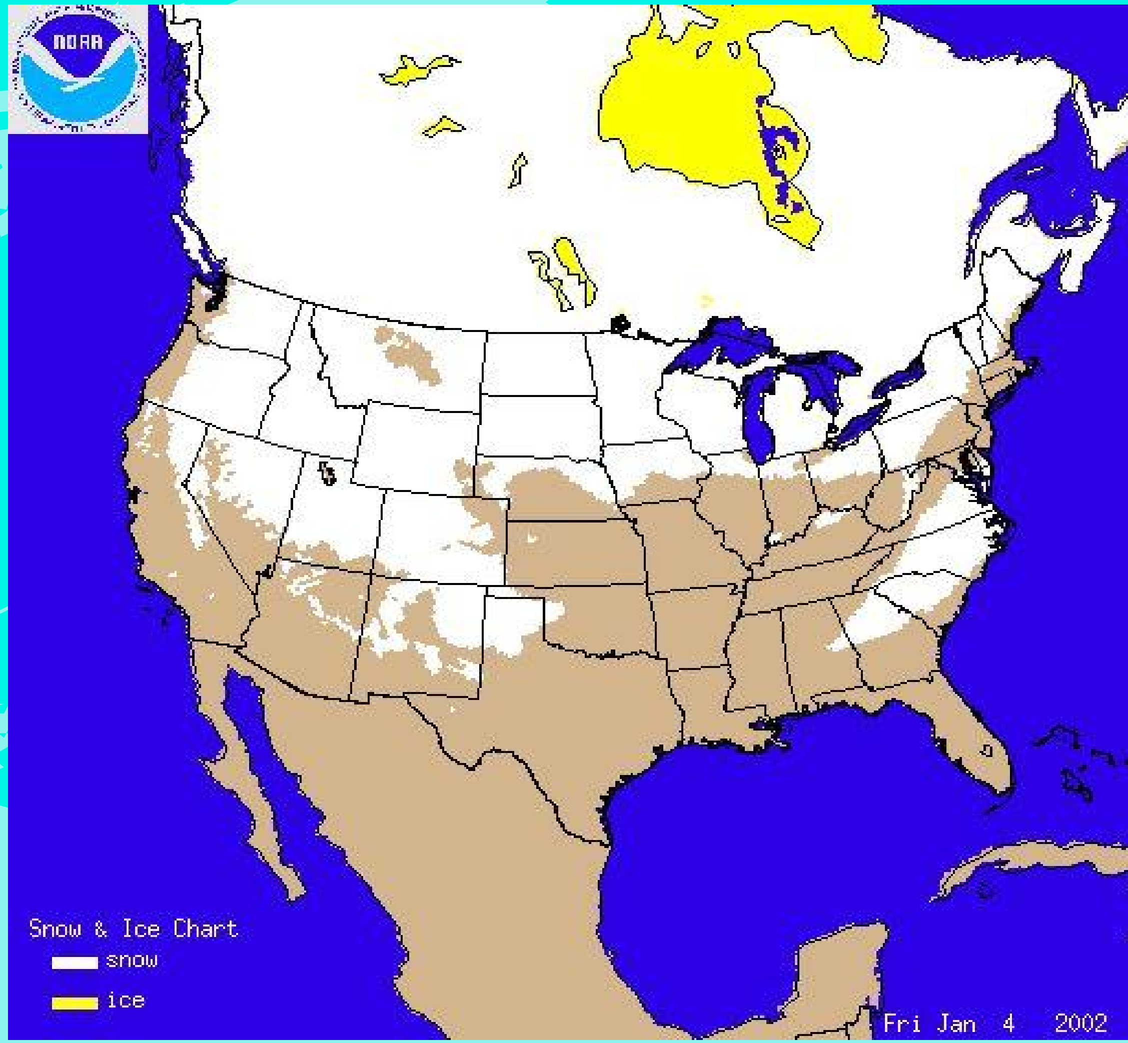
http://lnx29.wwb.noaa.gov



Example NESDIS snow/ice cover

Snow Information on another day

- cover: 23-km N. Hemisphere grid
- produced daily by human analyst
- multiple data sources:
  - GOES visible
  - SSMI snow cover
  - station reports
  - NIC ice cover
  - AVHRR visible



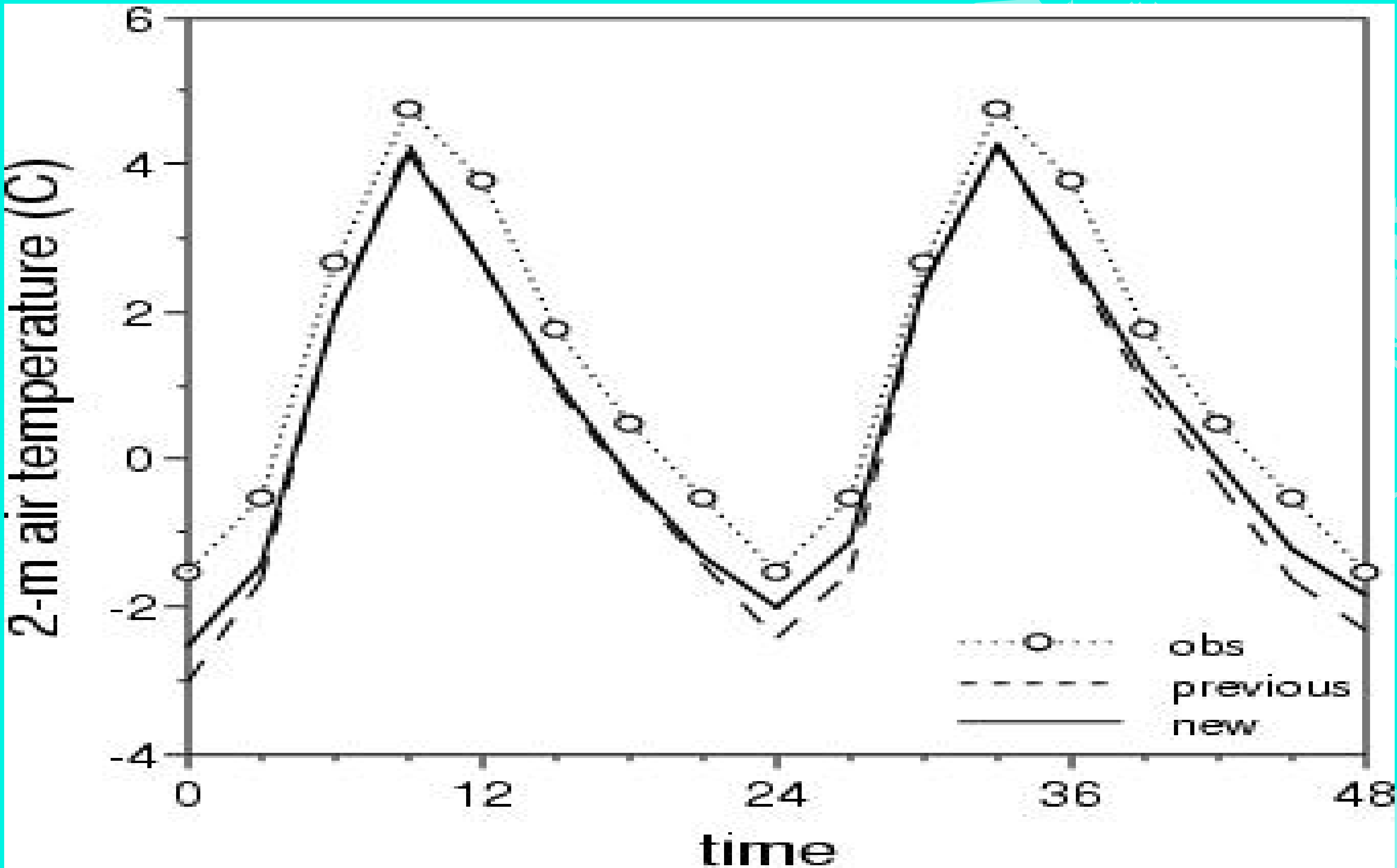
cover:
http://hpssd1en.wwb.noaa.gov/SSD/DATA/snow/archive

depth:

http://lnx29.wwb.noaa.gov

Example NESDIS snow/ice cover

Two-meter Temperature Forecasts (Winter)

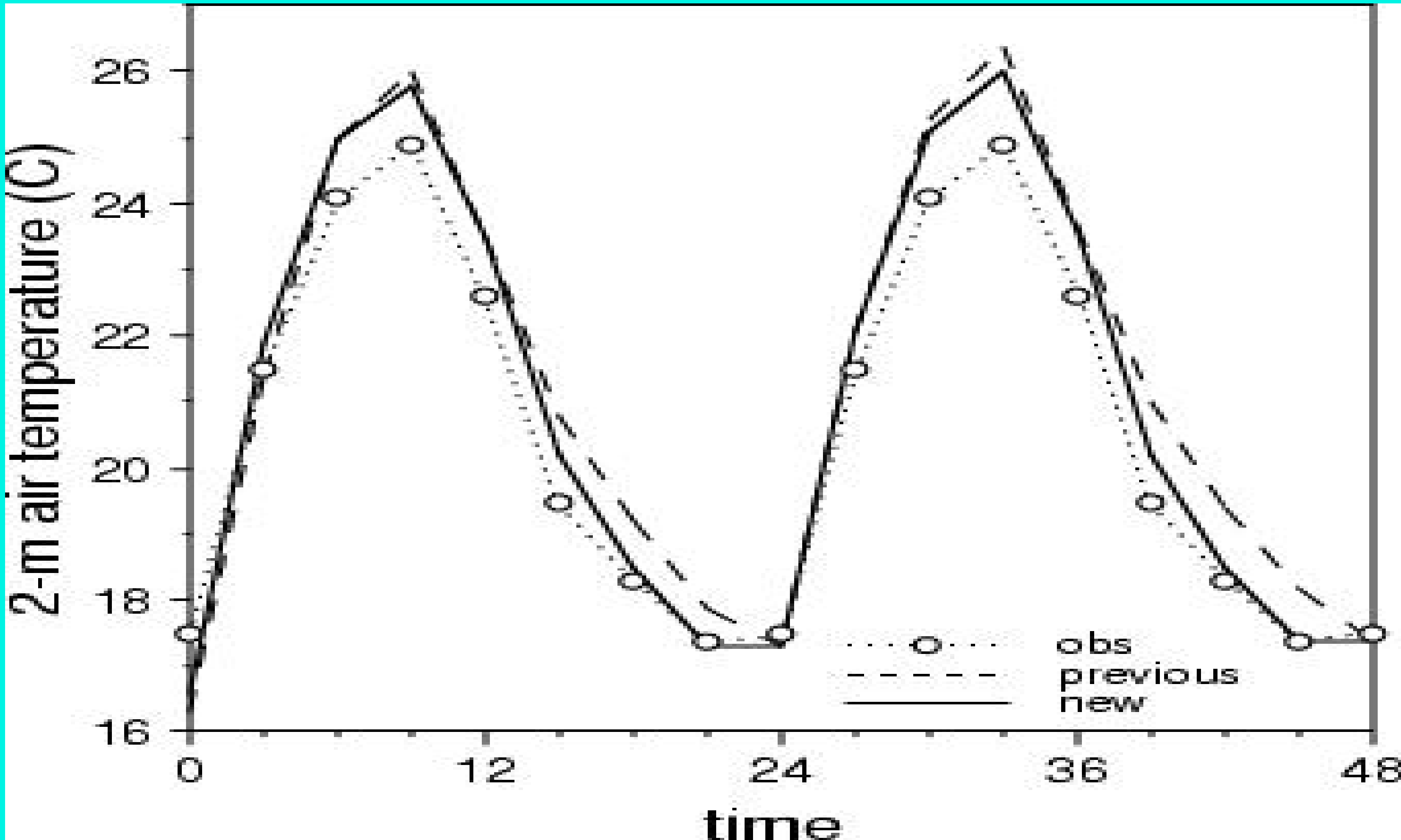


Pre vs. post 2001 Noah

January - February 2002
Western U.S. Region

Source: Ek et al. (2003, JGR)

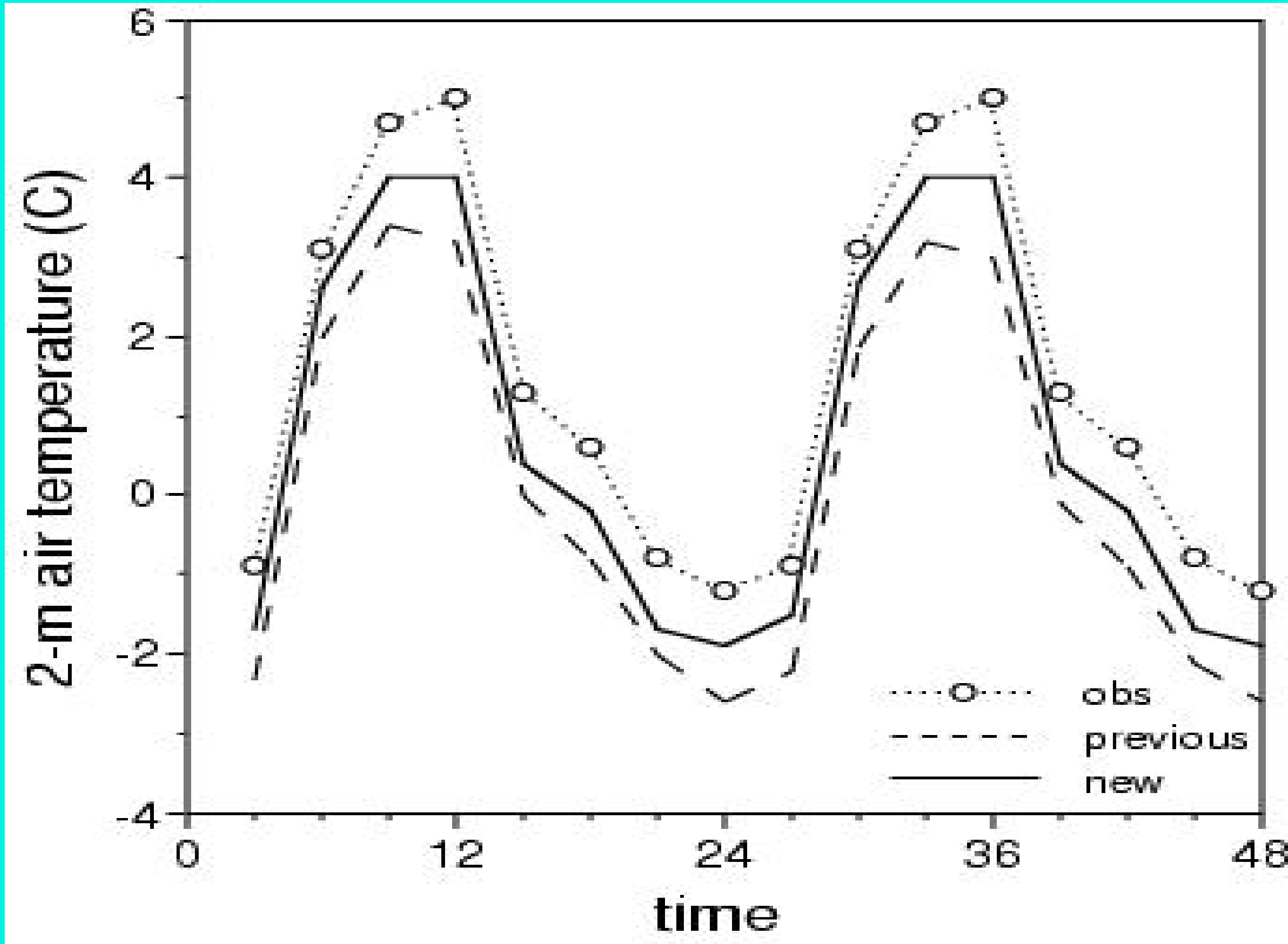
Two-meter Temperature Forecasts (Summer)



August - September 2000
Upper Midwest U.S. Region

Source: Ek et al. (2003, JGR)

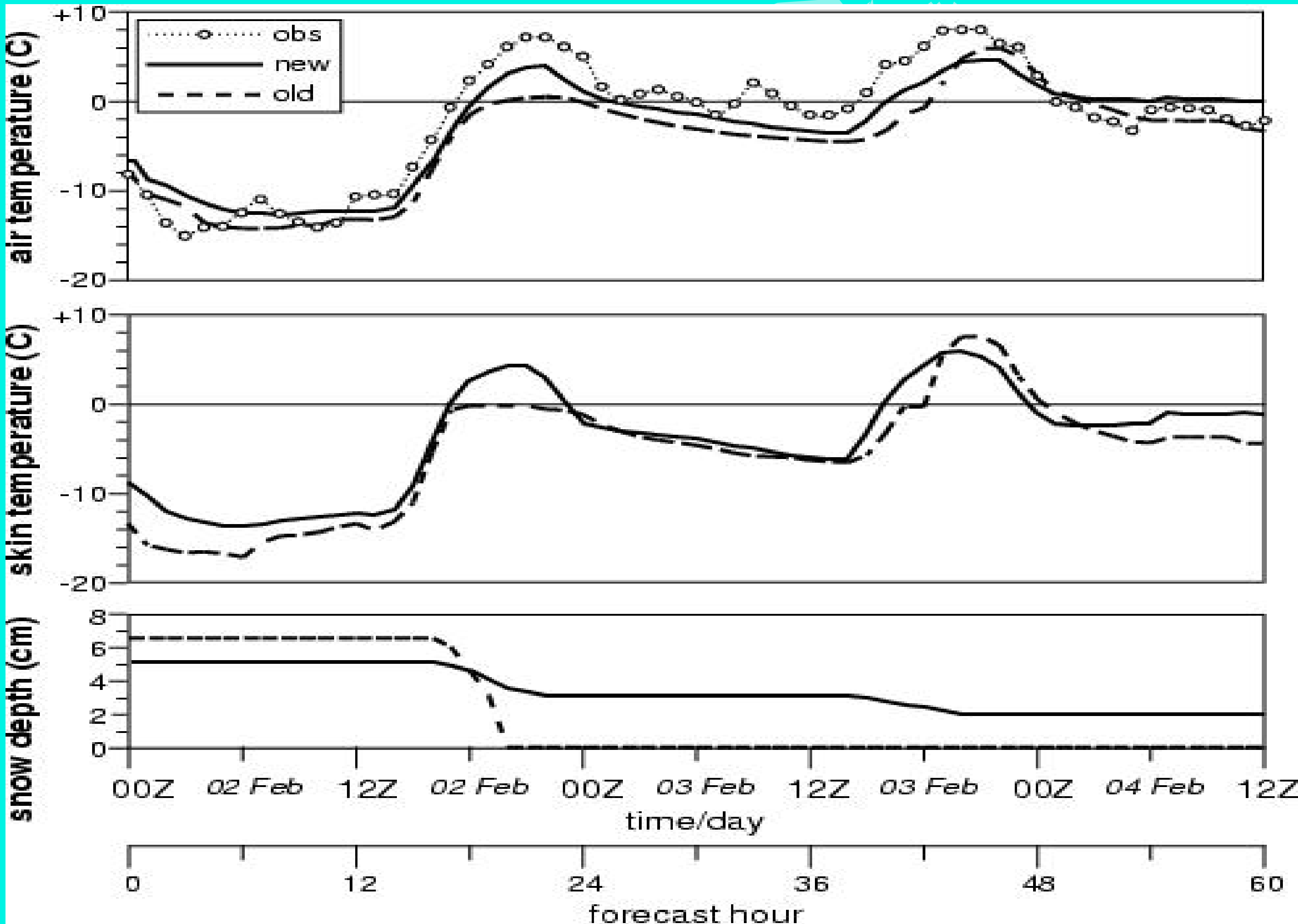
More results …



February 2001
Eastern U.S. Region

Source: Ek et al. (2003, JGR)

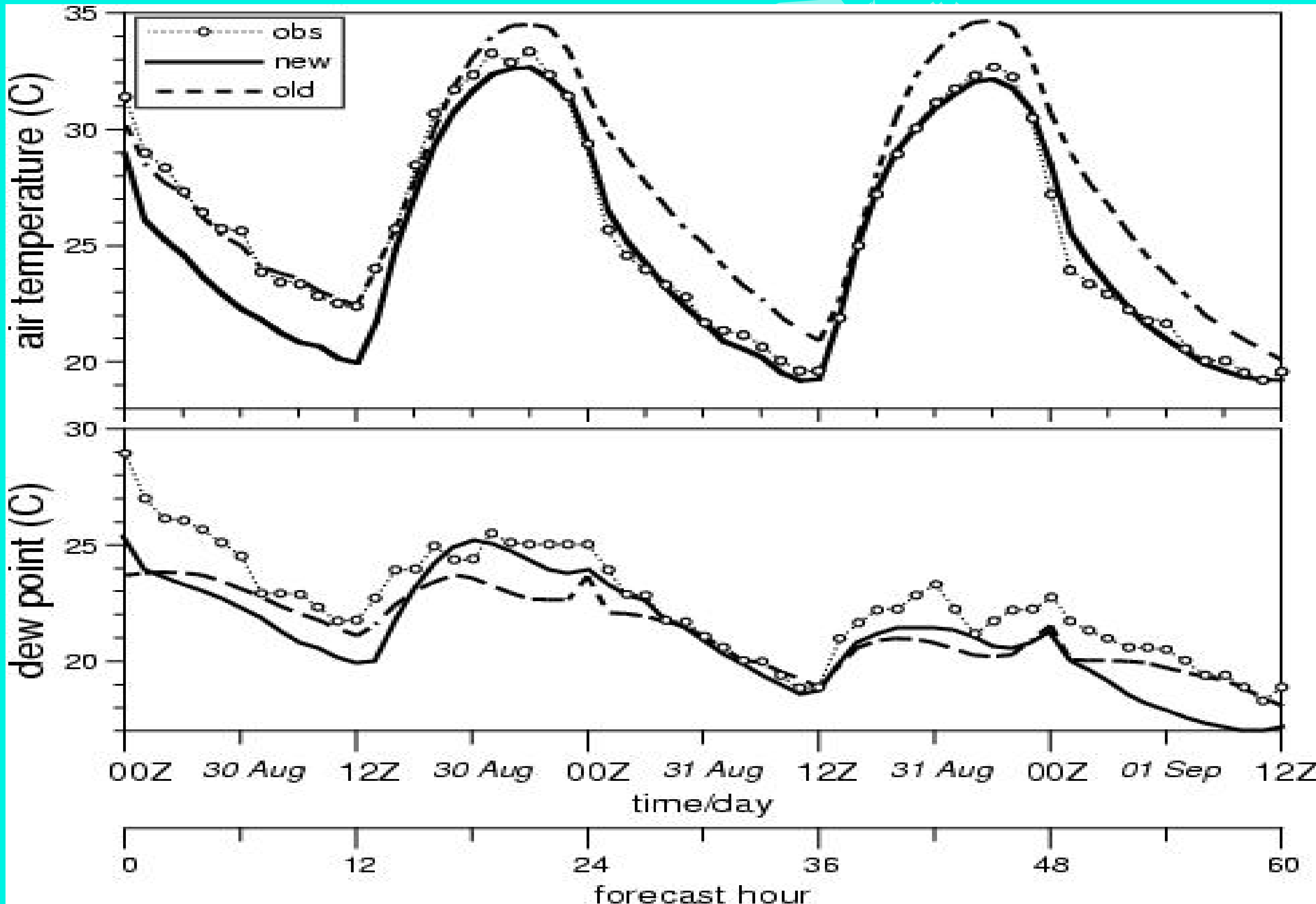
Specific Site (Winter)



North Platte, Nebraska
02 February 2001

Source: Ek et al. (2003, JGR)

Specific Site (Summer)



Champaign, Illinois
30 August 2000

Source: Ek et al. (2003, JGR)

LECTURE TWO …

- SURFACE LAYER & PBL
- OFFLINE TESTING & RESEARCH