A BLENDED HIGH RESOLUTION SNOW DEPTH ANALYSIS FOR NEXT GENERATION GLOBAL PREDICTION SYSTEM

Cezar Kongoli

***ESSIC,* University of Maryland**

NGGPS/MAPP PI MEETING

August 3, 2017

PROJECT TEAM

- ***Dr. Cezar Kongoli (PI), ESSIC, University of Maryland College Park; Dr. Peter Romanov Co-I, NOAA-CREST, City University of New York***

- ***NOAA/NCEP Collaborators: Michael Ek and Jiarui Dong***

- ***Other Collaborators: Sean Helfrich (NOAA/National Ice Center), Thomas Smith (NOAA/NESDIS), Ivan Csiszar (NOAA/NESDIS)***

RELEVANCE AND MOTIVATION

- Observations of snow cover area and snow depth are routinely used as primary inputs to initialize snowpack models within GFS and other NWP models at world's major weather forecast centers.

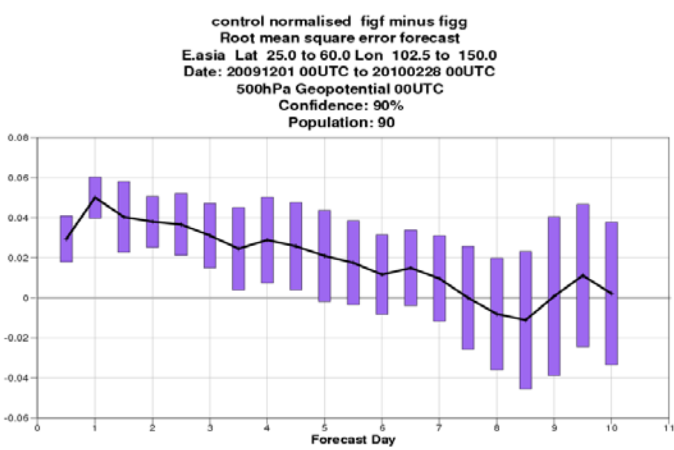
- For snow depth, NCEP has been relying on the SNODEP product (currently at 25-km resolution). A major deficiency of SNODEP is the use of a simple interpolation method of station in-situ data.

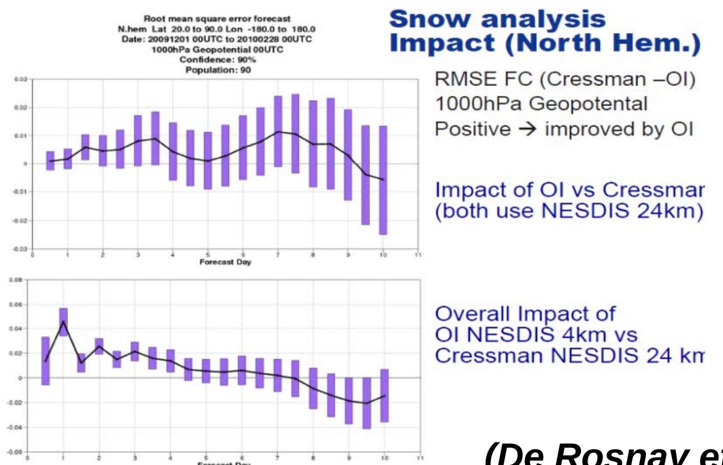
- An advanced, reliable, more accurate and higher-resolution snow depth analysis is urgently needed for NCEP NWP models capable of utilizing multiple observing systems.

SNOW DATA ASSIMMILATION FOR OTHER NWP MODELLING SYSTEMS

- Snow Cover extent:
  - NOAA's 4-km IMS product (UKMET and ECMWF)
- Snow Depth:
  - Mostly 2-Dimensional Optimal Interpolation (2D-OI) of station data (ECMWF, Env. Canada, Japan Meteorological Agency)

Positive impact of the 2D-OI snow analysis on atmospheric forecasts compared to simpler methods such as CRESSMAN interpolation.





(De Rosnay et al., 2012)

PROJECT OBJECTIVES

Overarching Goal: Demonstrate the benefit of a higher-resolution blended Snow Depth (SD) analysis based on 2D-OI method. The desirable end-goal would be the operational use of the new product for NGGPS.

Specific Goals (green completed; yellow in progress, black not started):

- Integrate station SD from the Global Historical Climatology Network (GHCN);
- Develop a satellite-bias correction method and apply it to SD from the Advanced Microwave Scanning Radiometer 2 (AMSR2) instrument;
- *Develop an off-line snow accumulation and melt model for first guess SD;*
- Assess enhanced algorithm against independent snow depth observations;
- Evaluate the enhanced algorithm through NWP model runs with the current SNODEP and the new product as the input.

2-DIMENSIONAL OPTIMAL INTERPOLATION

- **SD** increment *at analysis point k* Δ***SD***$_{\boldsymbol{k}}$ is computed as the weighted average of observed increments Δ***SD***$_{\boldsymbol{i}}$ surrounding *k*:

$$\Delta SD_k = \sum_{i=1}^{N} w_i \Delta SD_i$$

ΔSD_i is the difference between the ***observed SD*** *and the* ***first guess SD*** *at each observation point i [i = 1, N]*

- The vector of optimum weights at ***k*** is given by solving the set of N linear equations of the matrix form:

$$\underline{w} = (\underline{B} + \underline{O})^{-1} \underline{b}$$

$\underline{B}$ *is correlation matrix of background field errors between all pairs of observations*

$\underline{b}$ *is the correlation vector of background field errors between pairs of of observations and analysis point k*

$\underline{O}$ *is the covariance matrix of observational errors (normalized by the background error variance) between all pairs of observations*

2-DIMENSIONAL OPTIMAL INTERPOLATION (CON'T)

- Correlation coefficients for each term in $\underline{B}$ and $\underline{b}$ are computed following *Brasnett 1999. J of Applied Meteorol.*:

$$\mu_{ij} = \alpha(r_{ij})\beta(\Delta z_{ij})$$

μ_{ij} is the correlation coefficient between each pair of observations or between each observation and analysis point, r_{ij} is the horizontal distance between pairs and Δz_{ij} elevation difference between pairs:

2nd order autoregressive correlation function for distance

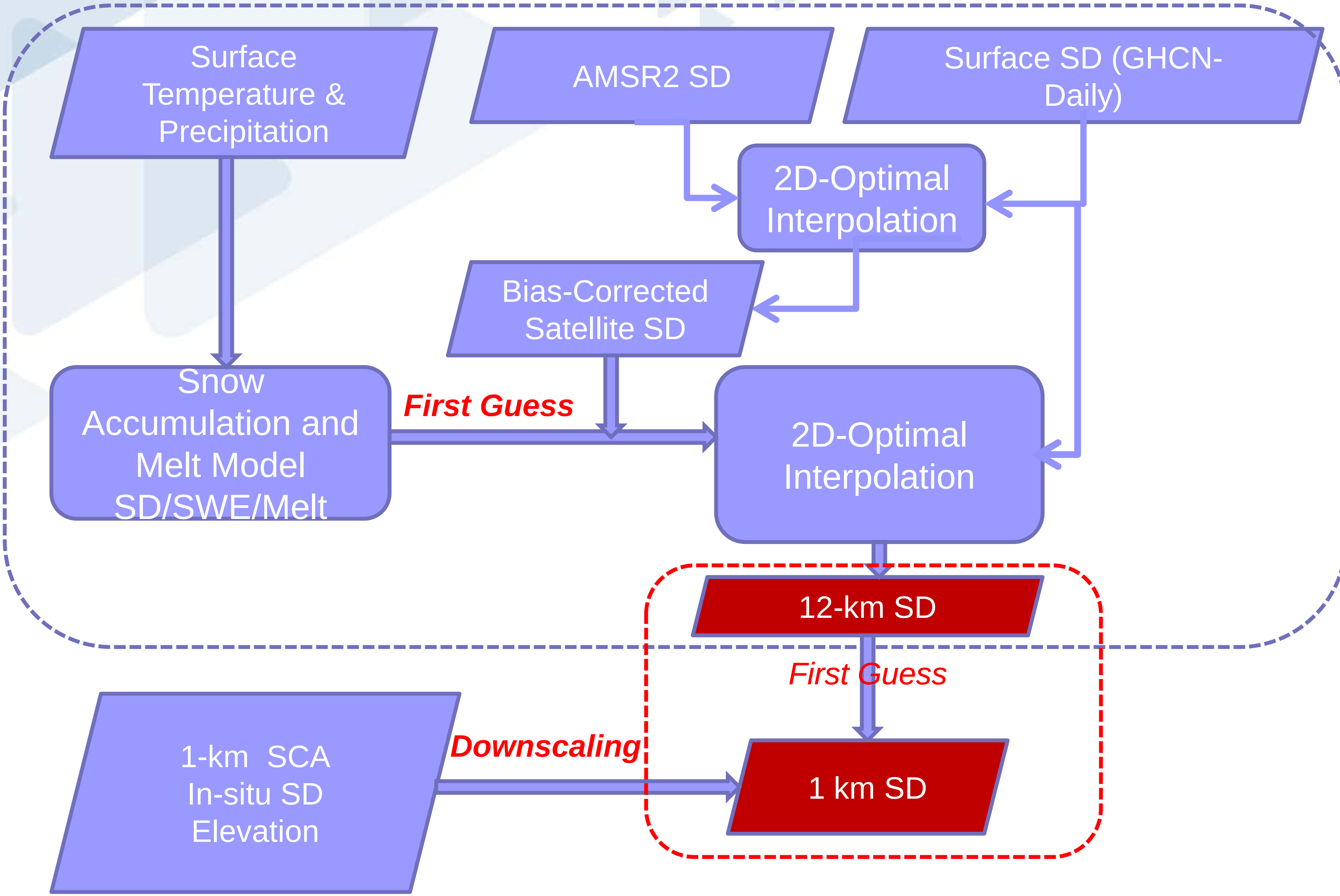
$\alpha(r_{ij}) = (1 + c r_{ij}) \exp(- c r_{ij})$ $\quad c = 0.018\ km^{-1}$ *(horizontal scale ≈ 120 km)*

Square exponential correlation function for elevation

$\beta(\Delta z_{ij}) = \exp(- (\Delta z_{ij}/h)^2)$ $\quad h = 800\ m$ *(vertical scale = 800 m)*

$\underline{O}$ **=** $(\sigma^2_{o}/\sigma^2_{b})$ X *I where I is the identity matrix and* $(\sigma^2_{o}/\sigma^2_{b})$ is the observation error variance normalized by the background error variance

NEW BLENDED ANALYSIS SCHEME FOR NGGPS

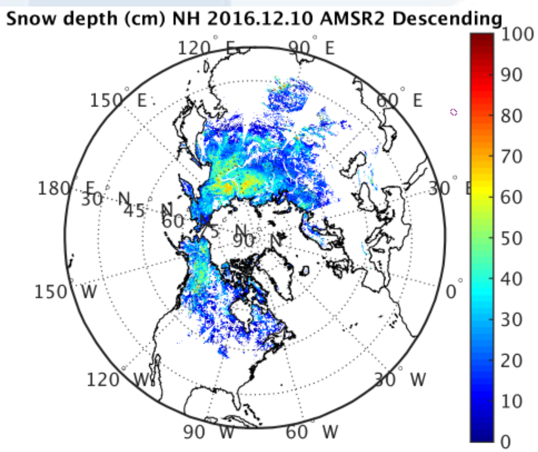


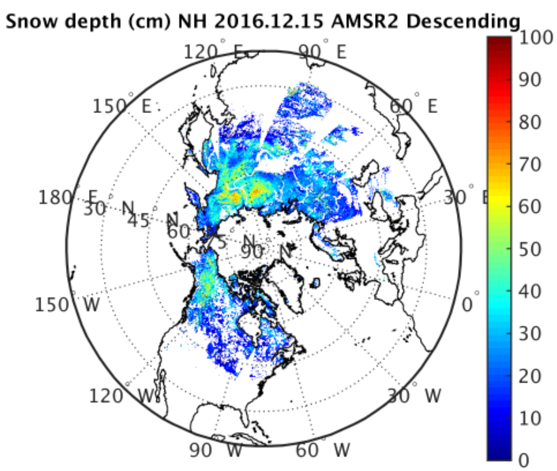
MAJOR ACCOMPLISHMENTS

- ➢Satellite bias-correction of AMSR2 SD using 2D-OI
  - ✓ *Daily 12-km resolution product*
- ➢ Off-line snow accumulation and melt model
  - ✓ Calibration and testing over US Midwest
- ➢ Application of the snow model to GFS-forecast temperature and precipitation
  - ✓*12-km resolution SD/SWE/Melt every 3-hour*
- ➢Improved estimation of SD correlation functions
  - ✓*Over Continental US*

AMSR2 SNOW PRODUCTS

➢ NOAA has developed a suite of AMSR2-based snow algorithms that became operational recently (Lee et al., 2015). The SD algorithm is adopted from the heritage AMSR-E NASA product.





AMSR2	Center Freq (GHz)	6.9	10.7	18.7	23.8	36.5	89.0
	Band Width (MHz)	350	100	200	400	1000	3000
	IFOV (km x km)	35x62	24x42	14x22	15x26	7x12	3x5
AMSR-E	Center Freq (GHz)	6.9	10.7	18.7	23.8	36.5	89.0
	Band Width (MHz)	350	100	200	400	1000	3000
	IFOV (km x km)	76x44	49x28	28x16	31x18	14x8	6x4
SSM/I	Center Freq (GHz)			19.4	22.2	37.0	85.5
	Band Width (MHz)			240	240	900	1400
	IFOV (km x km)			69x43	60x40	37x29	15x13

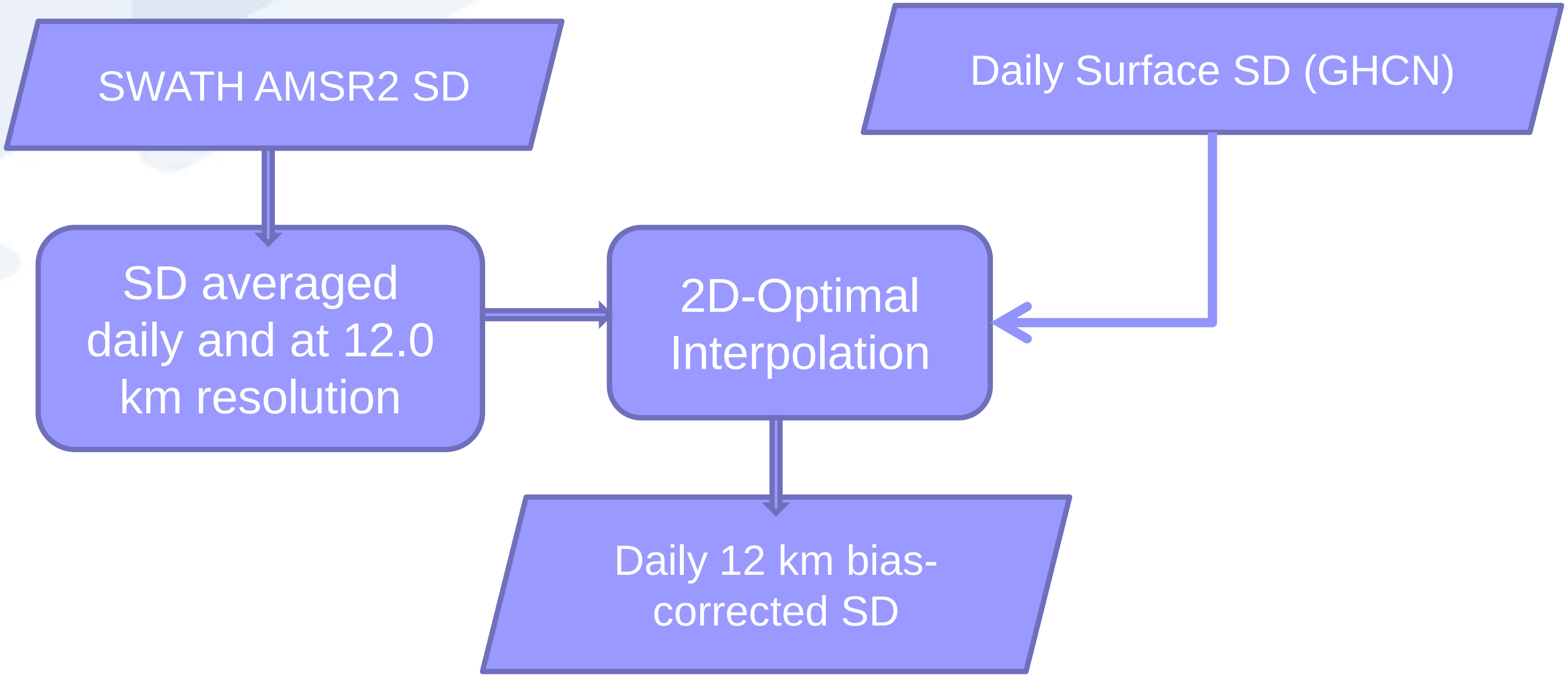
$$\mathrm{SD} = ff * \left[p1 * \frac{(T18V - T36V)}{(1 - b * fd)} \right] + (1 - ff) * [p1*(T10V\text{-}T36V) + p2*(T10V\text{-}T18V)]$$

$$p1 = \frac{1}{\log 10(T36V - T36H)}, \quad p2 = \frac{1}{\log 10(T18V - T18H)}$$

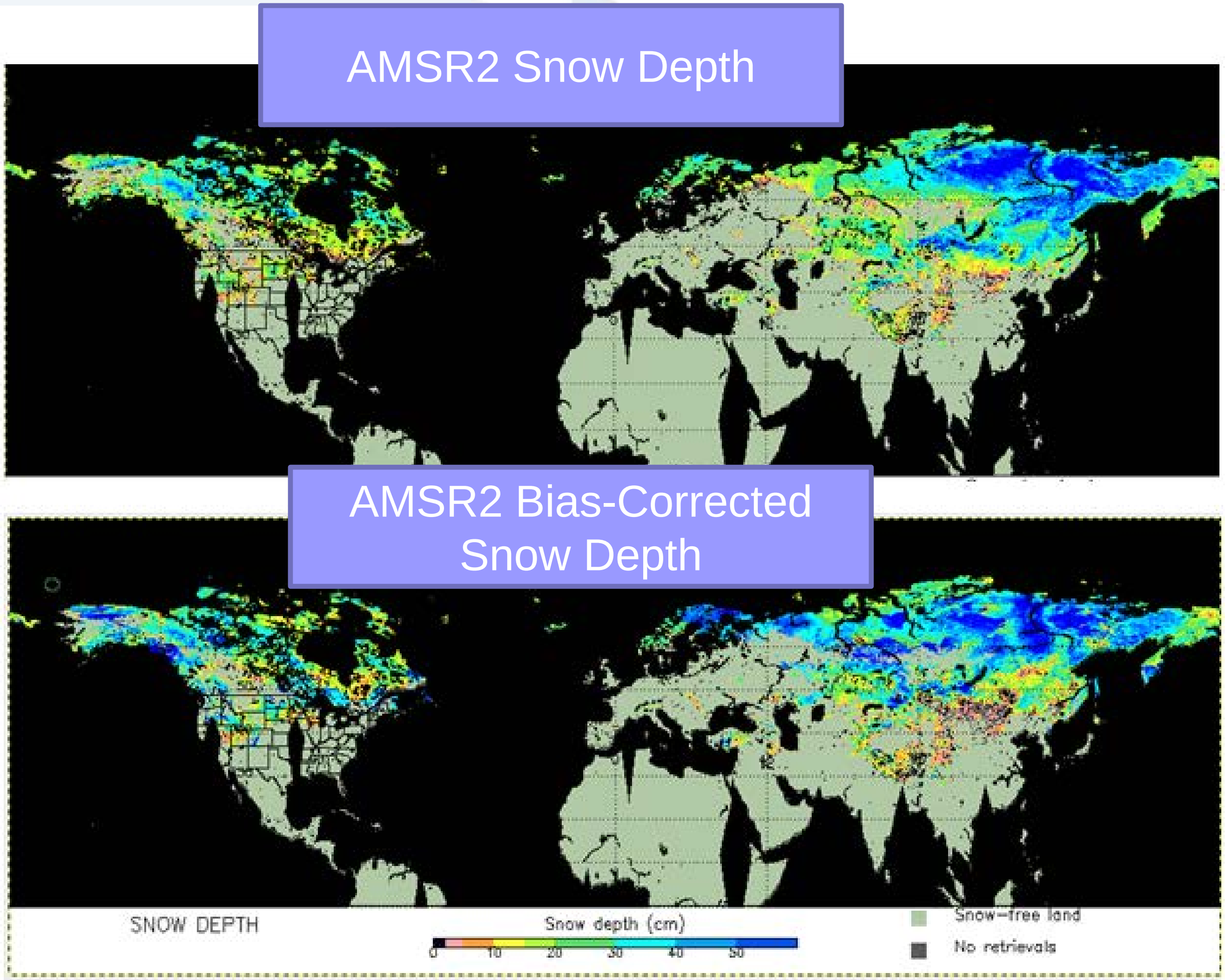
ff: forest fraction product from MCD12Q1 (7km radius averaged)
fd: Vegetation Continuous Field product from MOD44B (7km radius averaged)
b = 0.6 from the SD comparison with 80 WMO snow measuring stations
T18V: Brightness temperature at 18 GHz , vertically polarized.
T18H: Brightness temperature at 18 GHz, horizontally polarized.

BIAS-CORRECTION OF SATELLITE-SD

A satellite bias-correction method has been developed based on 2D-OI The method is being applied to AMSR2-SD using GHCN data as follows:



BIAS-CORRECTION OF SATELLITE-SD (CON'T)



SNOW ACCUMMULATION AND MELT MODEL

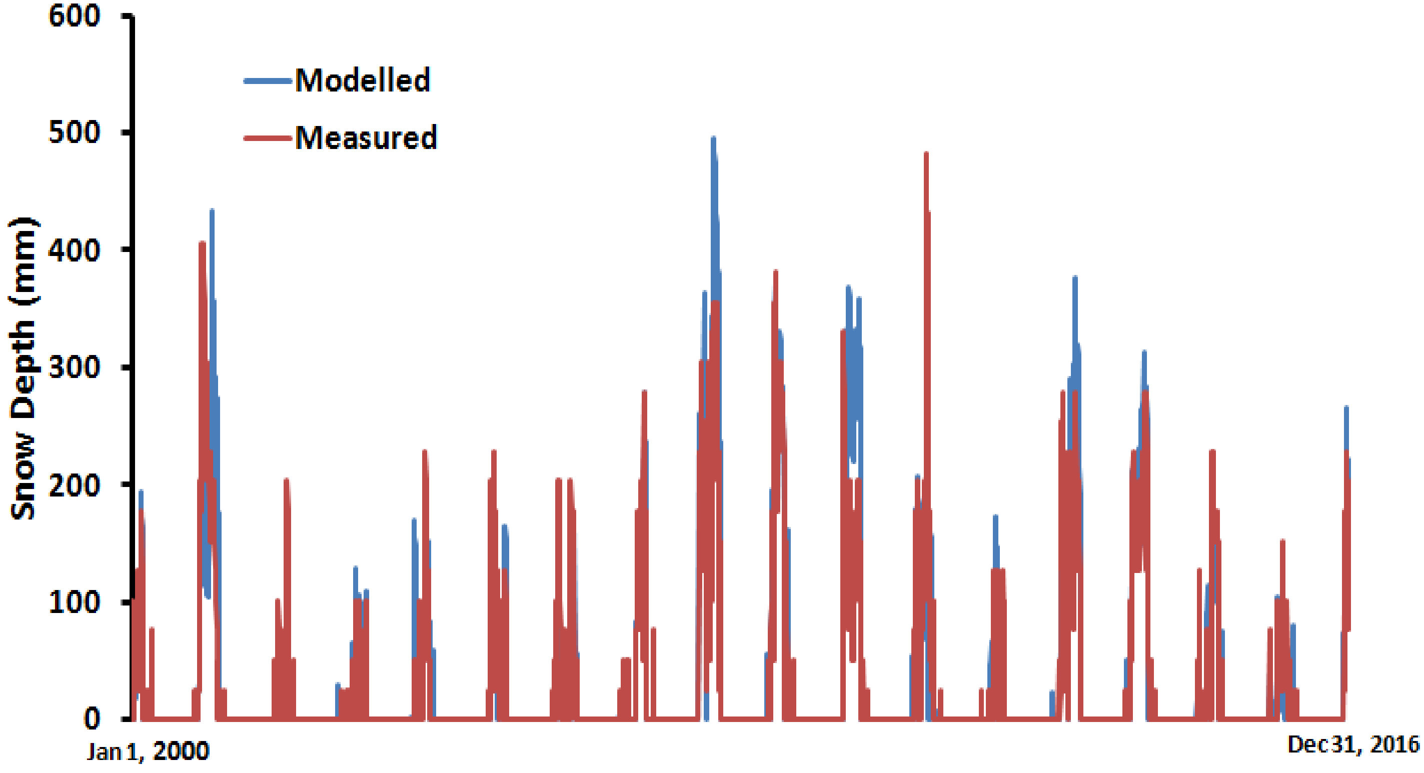
- The one-layer snow model generates first guess snow depth, driven by (forecast) precipitation and temperature. Routines include snow accumulation, compaction, melt and refreezing. Melt/refreezing is computed using a simple degree-day factor approach, as in the operational seNorge model (Solantra, 2012). Compaction is modeled using Anderson (1976) parameterizations. Model prognostic outputs are snow depth, density, SWE, ice and liquid content.

- Testing of the model was carried out using daily snow observations at a first-order station located in Dane County Regional Airport, Madison, Wisconsin over a 16-year period (2000-2016). A correction factor of 1.3 was initially applied to solid precipitation inputs to account for gauge under-catch (Kongoli and Bland (2000). A correction factor of 1.1 was selected since it improved overall statistics compared to the previously established mean value of 1.3. A melt degree-day factor of 5 mm day^{-1} $^{0}C^{-1}$ was found to produce reasonable snow depth simulations during melt.

NOTE: The first-guess snow depth could also come in-line from GFS Noah snow model. The off-line simpler model is desirable especially when using external observations of precipitation and temperature as inputs.

SNOW ACCUMMULATION AND MELT MODEL (CON'T)

Daily time series of modeled versus measured snow depth at the Madison, Wisconsin first-order station between January 1, 2000 and December 31, 2016. Snow depth evolution is simulated well. Bias is -2.1 cm and Root Mean Square Error (RMSE) is 7.6 cm.



IMPROVED ESTIMATION OF SD CORRELATION FUNCTION

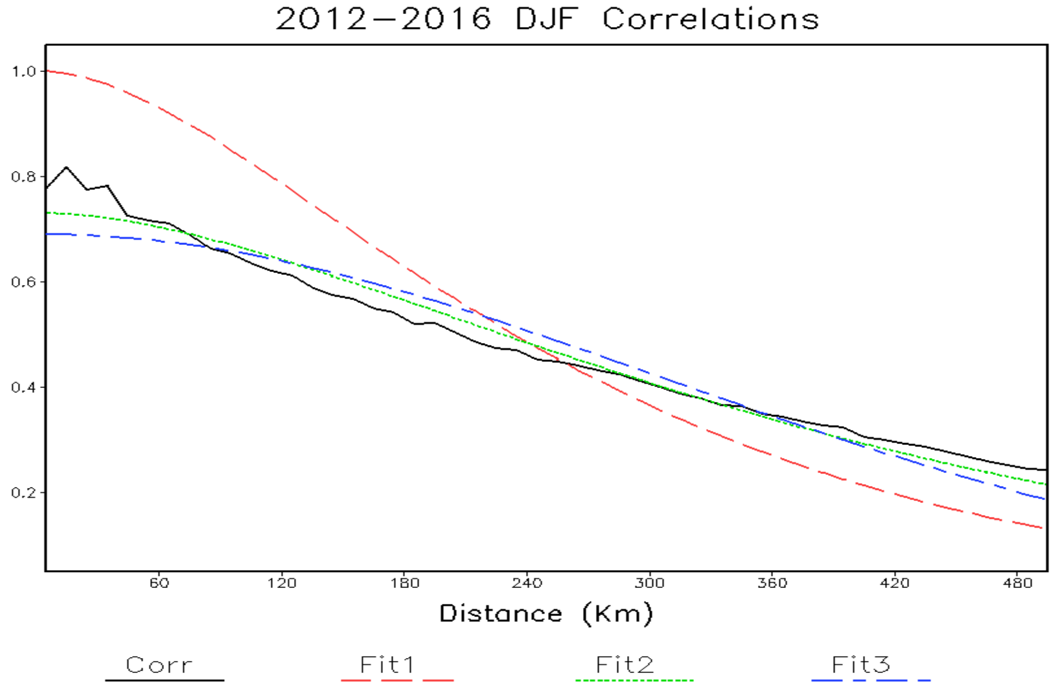
- A study was undertaken to test the SD spatial correlation model with respect to horizontal distance - $\alpha(r_{ij}) = (1 + cr_{ij})^* \exp(- cr_{ij})$ – *widely adopted since Brasnett (1999) introduced it.*

- A 5-year daily snow depth dataset between 2012 and 2016 was compiled from GHCN-daily.

- Several spatial autocorrelation functions including the model of Brasnett (1999) were fitted to measurements using least squares estimation. The study was restricted to CONUS US and low elevation areas.

IMPROVED ESTIMATION OF SD CORRELATION FUNCTION (CON'T)

DJF refers to December, January and February
Fit1 – the existing function gives the largest *RMSE (0.13)* compared to measured spatial correlation **Corr** (*e-folding distance = 120 km*)
Fit2 - Includes an amplitude (*e-folding distance = 200 km, Amplitude = 0.73 and RMSE = 0.03*)
Fit3 – a Gaussian function also gives good results



ON-GOING/FUTURE WORK

- Complete testing and final adjustments to the algorithm for generating global 12-km resolution SD product;

- Evaluate the algorithm through NWP model runs with the current SNODEP and the new product as the input. The existing NASA Land Information System (LIS) Ensemble Kalman Filter-based Data Assimilation tool will be used to assimilate the SD product within GFS/CFS.

REFERENCES

Anderson, E.A. (1976), A Point Energy and Mass Balance Model of a Snow Cover, NOAA Technical Report NWS 19, 150 pp., U.S. Dept. of Commerce, Silver Spring, Maryland.

Brasnett B,1999. A global analysis of snow depth for numerical weather prediction. *J Appl Meteorol* 38:726–740.

Cressman G.,1959.An operational objective analysis system. *Mon Weather Rev* 87(10):367–374.

de Rosnay P. , G. Balsamo, C. Albergel , J. M-S. Lars I, 2012. Initialisation of land surface variables for Numerical Weather Prediction, *Surv Geophy*s DOI 10.1007/s10712-012-9207-x .

Kongoli, C. and S. Helfrich, 2015.A multi-source interactive analysis approach for Northern hemispheric snow depth estimation Proceedings of the Geoscience and Remote Sensing Symposium (IGARSS), IEEE International, Milan, Italy, DOI: 10.1109/IGARSS.2015.7325878

Kongoli, C. Romanov, P. S. Helfrich, J. Dong, M. Ek and T. Smith, 2017. Blended high-resolution snow depth analysis for NOAA's Next Generation Global Prediction System (NGGPS), 2017 NOAA Satellite Conference, July 16-18, College University of New York (CUNY), New York

Kongoli, C. Romanov, P. S. Helfrich, J. Dong, M. Ek and T. Smith, 2017. Proceedings of the 7th International Conference on Ecosystems (ICE2017), ISBN: 978-9928-4248-7-7 *DOI: 10.13140/RG.2.2.10618.49601*, June 2-5, Tirana, Albania

Lee, Y-K, C. Kongoli, and J. Key, 2015. An in-depth evaluation of NOAA's snow heritage algorithms", *J. Atmos. Oceanic Technol.*, **32**, 2319–2336.

Solantra, T. M. 2012: Simulating snow maps for Norway: description and statistical evaluation of the seNorge snow model. *The Cryosphere* 6, 1323-1337.