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

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NGGPS/MAPP PI MEETING

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PROJECT TEAM

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- **Other Collaborators: Sean Helfrich (NOAA/National Ice Center), Thomas Smith (NOAA/NESDIS), Ivan Csiszar (NOAA/NESDIS)**
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 ASSIMILATION 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 \( k \) \( \Delta SD_k \) is computed as the weighted average of observed increments \( \Delta SD_i \) surrounding \( k \):

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

\( \Delta SD_i \) 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 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 $\mathbf{B}$ and $\mathbf{b}$ are computed following Brasnett 1999. J of Applied Meteorol.:

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

$\mu_{ij}$ 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 $\Delta z_{ij}$ elevation difference between pairs:

2nd order autoregressive correlation function for distance

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

Square exponential correlation function for elevation

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

$Q = (\sigma^2_o/\sigma^2_b) \times I$ where $I$ is the identity matrix and $(\sigma^2_o/\sigma^2_b)$ is the observation error variance normalized by the background error variance.
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
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.

\[
SD = ff \times \left[ p_1 \times \frac{(T_{10V} - T_{36V})}{(1-b \times d)} \right] + (1 - ff) \times \left[ p_1 \times (T_{10V} - T_{36V}) + p_2 \times (T_{10V} - T_{18V}) \right]
\]

\[
p_1 = \frac{1}{\log_{10}(T_{36V} - T_{36H})}, \quad p_2 = \frac{1}{\log_{10}(T_{18V} - T_{18H})}
\]

- **ff**: Forest fraction product from MCD12Q1 (7 km radius averaged)
- **fd**: Vegetation Continuous Field product from MOD44B (7 km 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.
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:

1. SWATH AMSR2 SD
2. SD averaged daily and at 12.0 km resolution
3. 2D-Optimal Interpolation
4. Daily 12 km bias-corrected SD
5. Daily Surface SD (GHCN)
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\(^{-1}\) °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.
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.
A study was undertaken to test the SD spatial correlation model with respect to horizontal distance - 
\[ a(r_{ij}) = (1 + c_{rij})^* \exp(- c_{rij}) \] – 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.
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


