A GIS Approach to Modeling Orographic Ascent across the Southern Appalachian Mountains, Specifically in Northwest Flow Snowfall Regimes

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Outline

- Intro to Northwest Flow Snowfall (NWFS) across the Southern Appalachian Mountains (SAMs)
  - Georgraphy
  - Climatology
  - Orographic Ascent
- Literature Review
- Research Questions and Hypothesis
- Datasets Used
  - Climatology, NARR, USGS DEM
- Methods
  - Overview (Steps)
    - Data Acquisition
    - Data Pre/Post Processing
    - Data Analysis
    - Final Model
- Results
- Conclusions

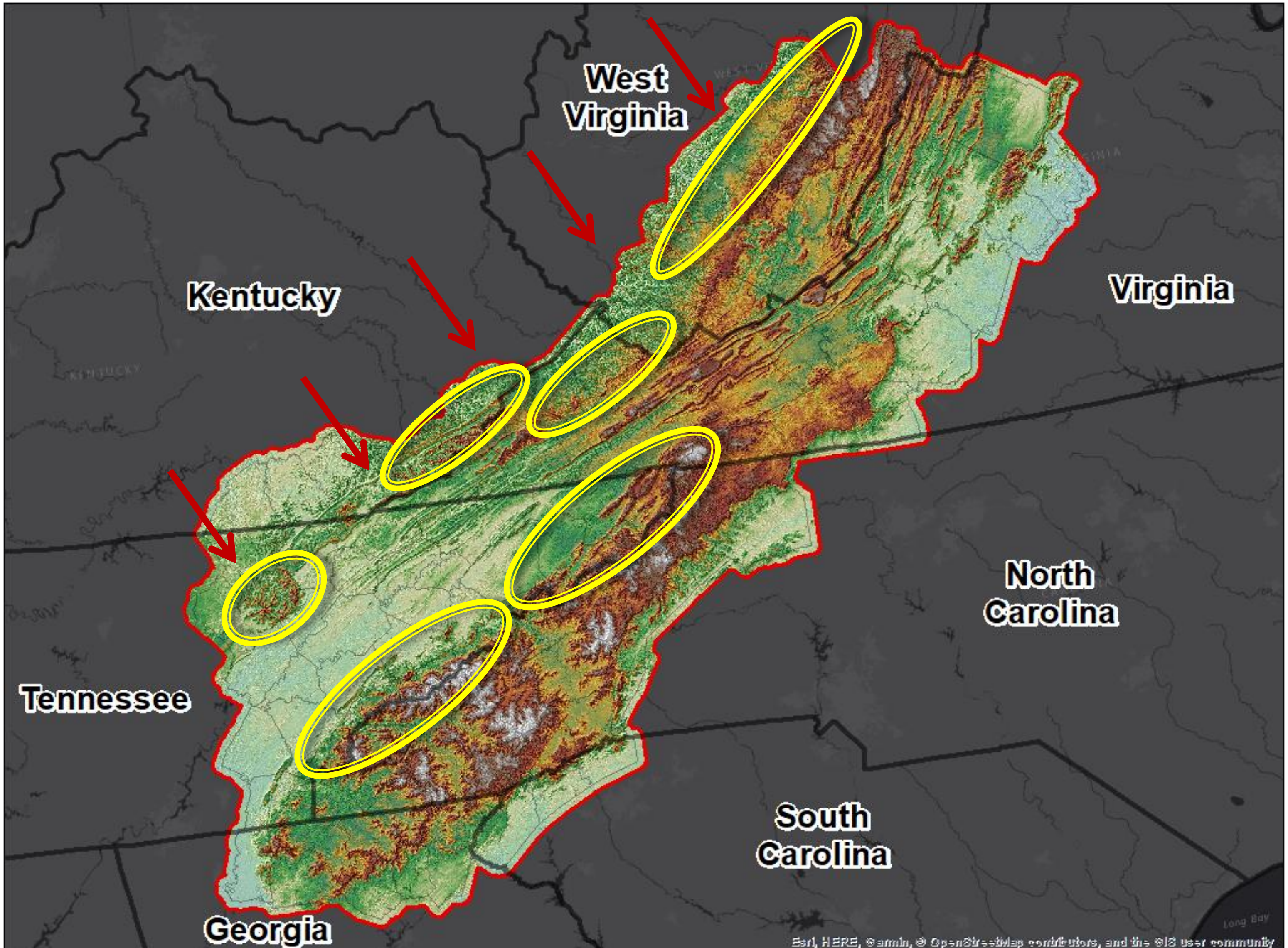
Intro to NWFS Across the SAMs

- Geography of the SAMs
  - Oriented generally from southwest to northeast from North Georgia into West Virginia
  - Elevation range from approximately 183m to 2037m (Martin et al, 2015)
  - Highest peak east of the Mississippi River, Mount Mitchell in North Carolina (Martin et al, 2015)
- Climatology
  - NWFS is the most frequent type of snowfall occurring across the SAMs, accounting for nearly 50% of the average snowfall (Perry et al, 2006)
  - NWFS can result in annual snowfall totals up to 250cm (Perry & Konrad, 2006)
  - Approximately 15 NWFS events occur seasonally across the SAMs (Keighton et al, 2009)

Intro to NWFS Across the SAMs (cont'd)

- Orographic Ascent
  - A moist (sometimes conditionally unstable) airmass in the low levels (< 700hpa)
  - Mechanical lift along windward upslope regions (varies with wind dir) favors cloud formation and eventually precipitation (convective if unstable) given sufficient moisture (wintry if thermal profiles are supportive)
  - New cloud generation anchors along windward slopes with older cloud advection downstream leading to weakened precipitation process
  - Eventual downslope drying leeward

Intro to NWFS Across the SAMs (cont'd)



Intro to NWFS Across the SAMs (cont'd)

Literature Review

- Donley and Mitchell (1939) found a positive linear relationship between elevation and precipitation across the SAMs
- Queney et al. (1960) note that wind flow oriented within 30 degrees of orthogonal to the ridge line was the optimal flow pattern for upsloping
  - Aspect
- Terrain- induced lift is expected to be strongest where NW slopes are the steepest in the case of NWFS (Perry & Konrad, 2006)
  - Slope

Literature Review (cont'd)

- Lifting of air parcels could initiate adiabatic processes (latent heat release), thereby transforming or combining both mechanical and thermodynamic lifting mechanisms if said parcels reach their Level of Free Convection or LFC (Miller, 2012)
  - Especially in Great Lakes Connection (GLC) regimes
- Moisture is deemed to be sufficient if the moist layer Relative Humidity (RH) is above a critical threshold, which can range from mean layer RH >= 80% (Perry et al, 2007) to values >= 90% (Kusunoki et al, 2004)
  - Which Layer?

Literature Review (cont'd)

- Perry and Konrad (2006) sought to quantify this using a subset of NWFS events (188) and daily snowfall records for the period of 1988-2000
- Perry et al (2006) conducted another study to analyze moisture by way of the "Great Lakes Connection" (GLC) which will be covered below. A more comprehensive subset of events (1,641) covering the period 1975-2000
- Both focused on 850hpa given relation to 1000-2000m elevation range that is relevant to terrain across the SAMs

Literature Review (cont'd)

- Ryan et al. (1976), Pruppacher and Klett (1977), and Fukuta and Takahashi (1999) determined that optimal snow dendrite growth typically occurs in the thermal layer between -14°C to -17°C, while some more loosely-placed bounds locate that region in the -10°C to -20°C range

Research Questions & Hypotheses

- So why study this?
- NWS forecasters use Graphical Forecast Editor (GFE)
  - Ingests gridded model data
  - Local toolsets to aid in production of forecasts
- Recent advancements in geospatial tools and datasets allow for detailed analysis of specific geographic/topographic regions

Research Questions & Hypotheses (cont'd)

Questions

- Would a Geographical Information System (GIS) model for Northwest Flow Snowfall in the Southern Appalachians prove beneficial in locating regions of potential orographically induced snowfall on small temporal and spatial scales?
- If so, could a Northwest Flow Snowfall Potential Index (NWFSPI) be derived?
- Finally, would that model transpose from the GIS domain into the GFE for NWS operations?

Hypothesis

- This research will prove the validity of a newly produced NWFSPI by way of development of a GIS based NWFS model

Datasets Used

- Standard GIS Vector Data
  - NWS Shapefiles of states and forecast zones
- USGS 30m DEM
  - Resampled to 2.5km (Bilinear) to match GFE
- NWFS Climatology (Perry 2006)
  - 121 Daily Snowfall Observations (intermittent)
  - 1950–2000 = 1,641 events
  - Reduced to 1979–2000 = 727 event (NARR Availability)

Datasets Used (cont'd)

- North American Regional Re-Analysis (NARR)
  - Resampled from 32km to 2.5km (Bilinear)

Parameter (Model Variable)	Level	Unit
Geopotential Height	925,900,875,850,825	Hectopascal (hpa)
Temperature	Surface,925,900,875,850,825	Kelvin (K)
Specific Humidity	925,900,875,850,825	Kilogram/Kilogram (kg/kg)
U Wind	925,900,875,850,825	Meters/Second (m/s)
V Wind	925,900,875,850,825	Meters/Second (m/s)

Methods – Step 1

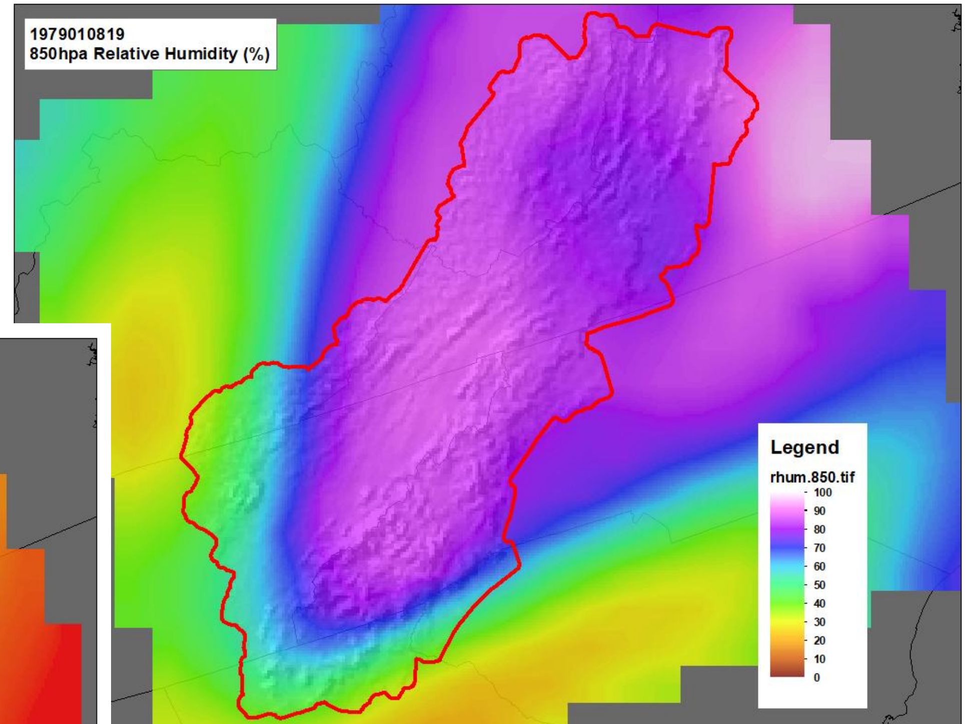
- Data Acquisition
  - Manual one time downloading of the standardized vector and DEM data
  - **AcquireNARRData.py** script to automate downloading multiple NARR datasets that correlate with NWFS Climatology
  - NWFS Climatology was acquired from the author (Perry 2006)

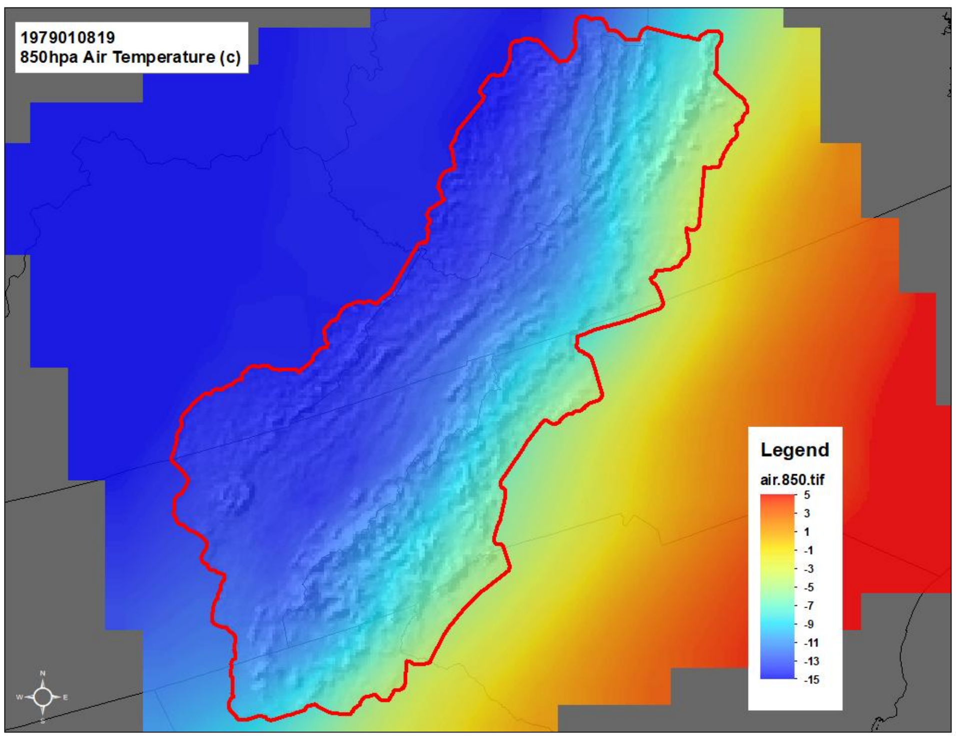
Methods – Step 2

- Data Pre/Post Processing
  - Create "Study Area" polygons from the standardized vector data
  - DEM mosaic TIFF is generated/resampled
  - Elevation, Slope, Aspect, and Hillshade TIFFs generated
  - **PrePostProcessNARR.py** script converted all acquired NARR data into TIFF, clipped, resampled
  - At this point, all data used for further analysis will be in the same projection, cover the same domain, and have the same pixel resolution

Methods – Step 2 (cont'd)

- Examples of extracted/converted NARR data





Methods – Step 3

- Data Analysis
  - Relied on the **GetDataDetails.py** script.
  - Creation of the two primary terms of the final NWFSPI equation was executed
    - "Upslope Term" (UT), and the "Dendritic Term" (DT)

Methods – Upslope Term (UT)

- Relied on event wind direction relative to terrain aspect and slope.
  - Geopotential Height compared to Elevation
  - "PixelHeightValues" or "Best Layer" determined for needed wind directional components

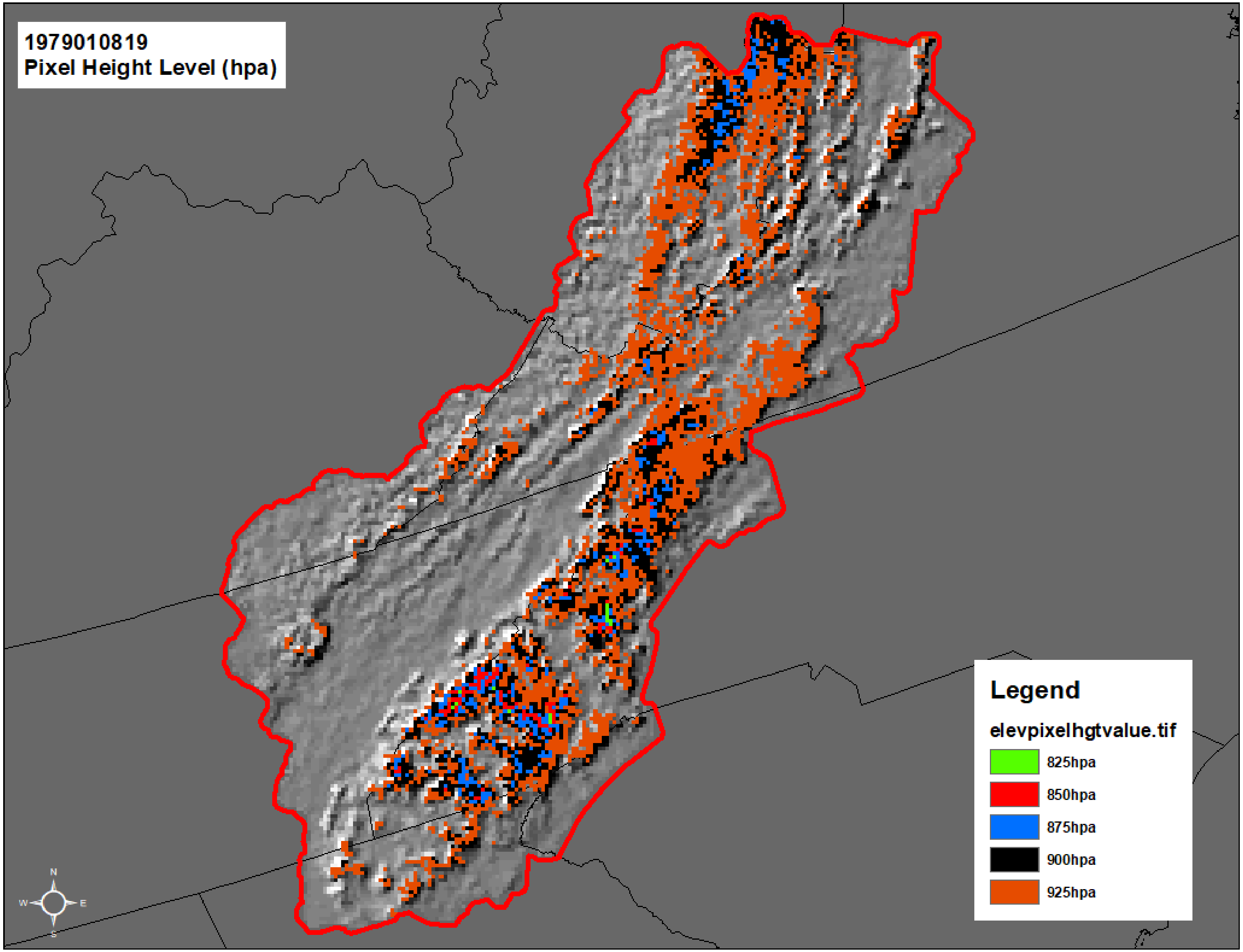
Elevation (m)	Geopotential Height (m)	Best Layer (hpa)
<	925hpa Height	Null
<	900hpa Height	925hpa
<	875hpa Height	900hpa
<	850hpa Height	875hpa
<	825hpa Height	850hpa
>=	825hpa Height	825hpa

- Percent Slope was standardized (0-1)
  - $Slope_{standard} = (Slope - Slope_{min}) / (Slope_{max} - Slope_{min})$

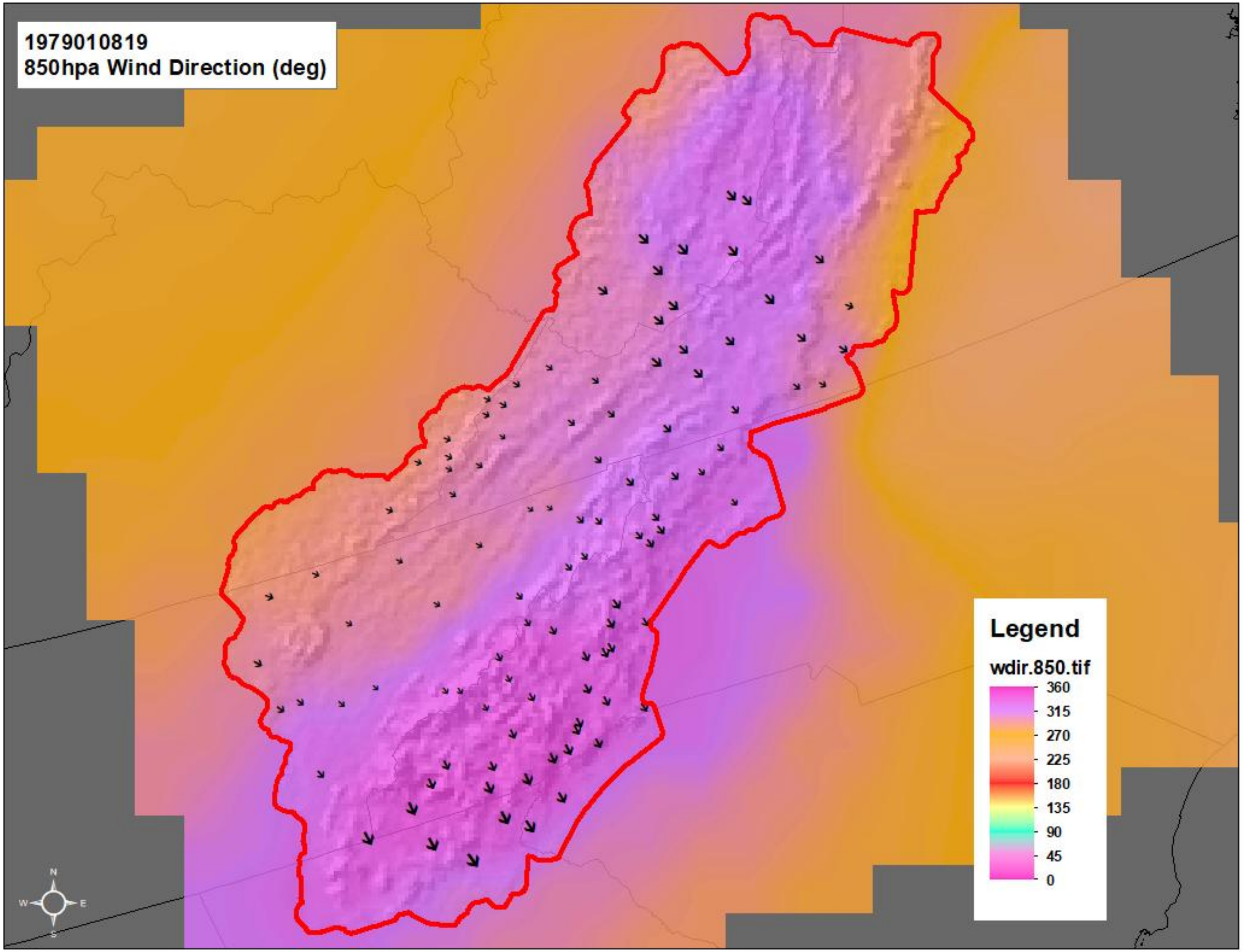
Methods – Upslope Term (UT)

- Aspect of terrain was compared to wind direction at “Best Layer” height.
  - Quadrants were defined as 0° – 89° (quadrant 1), 90° – 179° (quadrant 3), 180° – 269° (quadrant 4), and 270° – 360° (quadrant 2) which allowed for a full 90° of northwest flow component
  - Matching quadrants with wind direction given value of 1, else 0
- Multiplied by $Slope_{standard}$ to enhance regions of steepest slope.

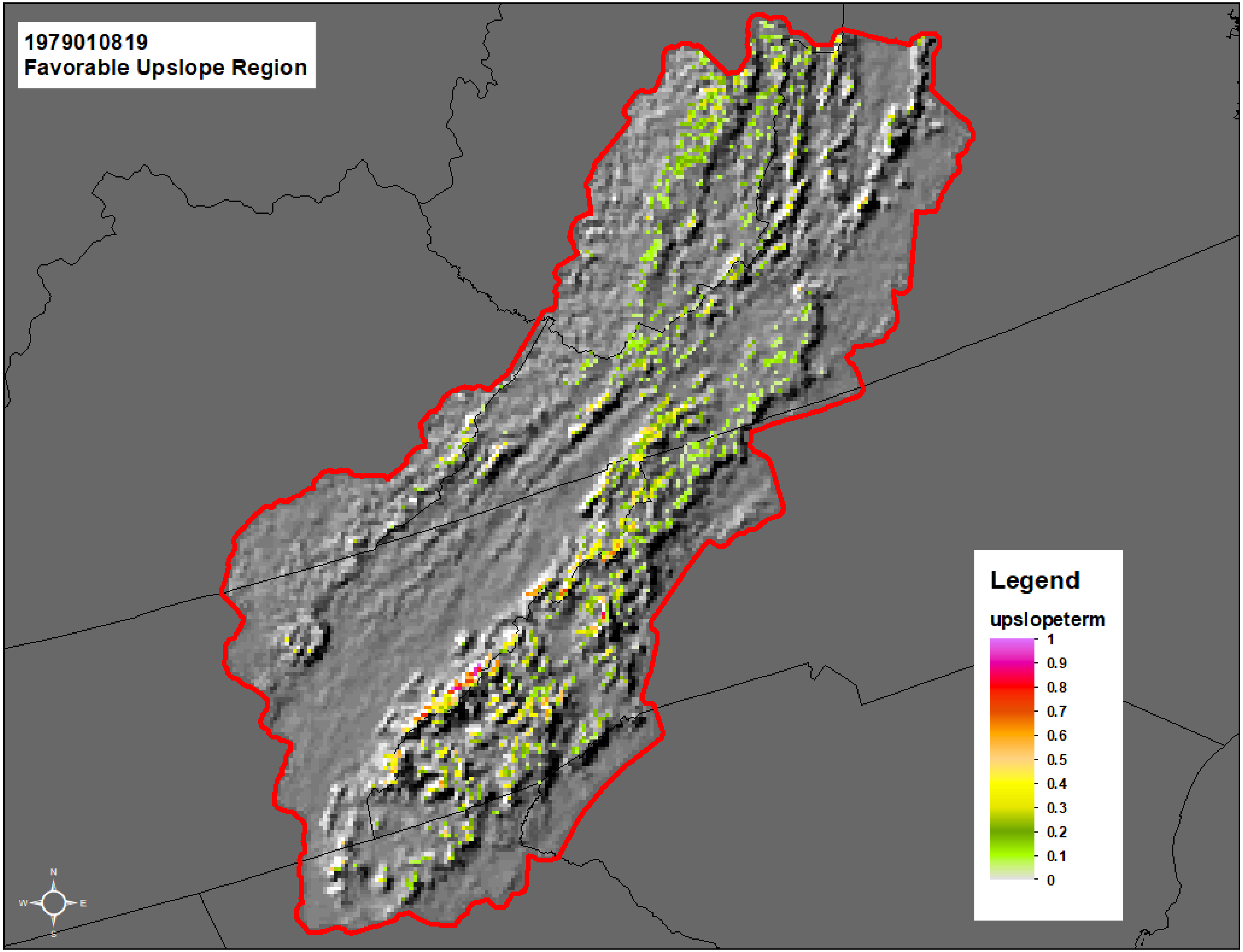
Methods – Upslope Term (UT)



Methods – Upslope Term (UT)



Methods – Upslope Term (UT)

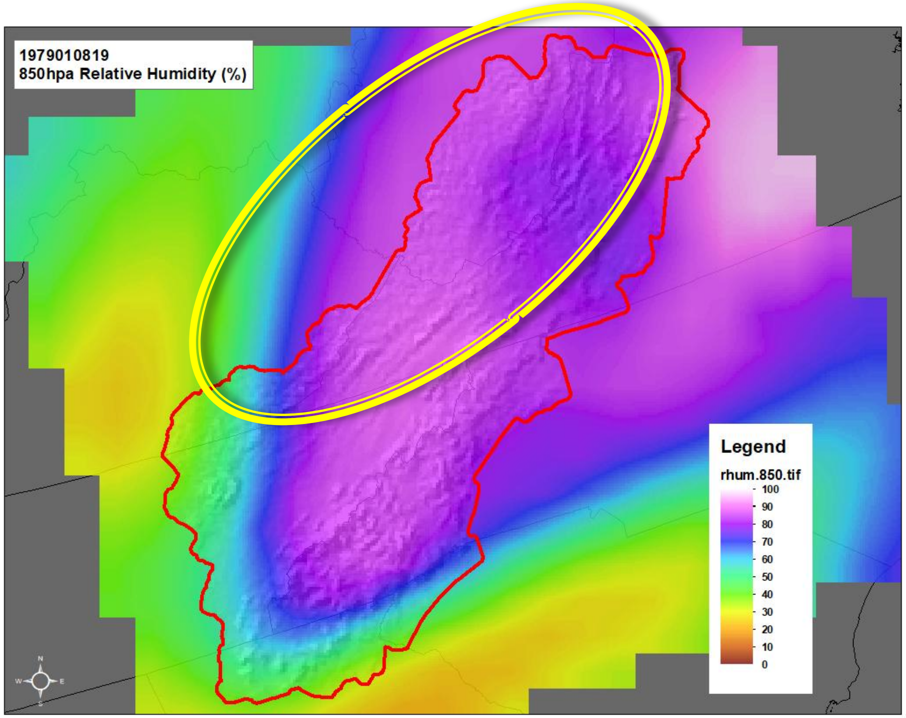


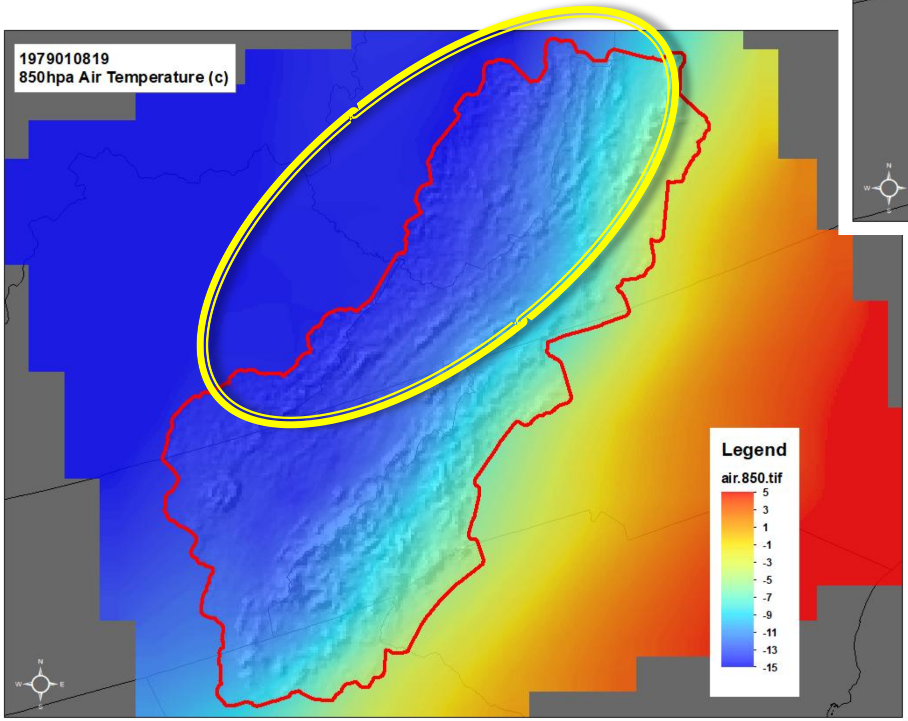
Methods – Denritic Term (DT)

- Calculated at each level (although focused on 850hpa)
  - Value 0 – 1
- Relied on previous research
  - −10°C to −20°C most favorable region for dendritic ice crystalization
    - Mostly researched over deep synoptic scenarios (NWFS are not)
  - Relative Humidity >=80% most favorable for precipitation processes
- Conditonal statements (Python/ArcPy)

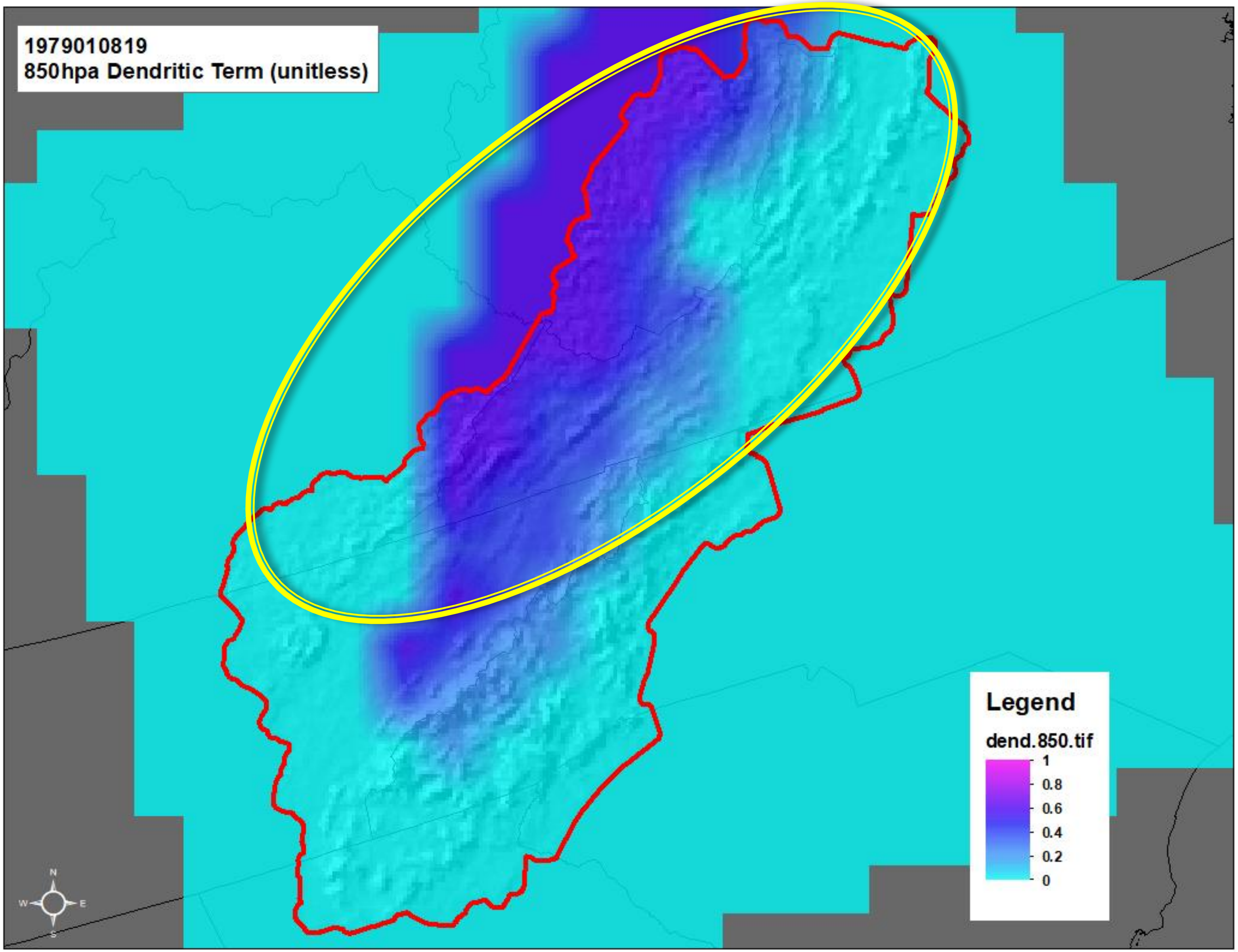
```
D = Con((T < -18), 1.0,
        Con((T >= -18) & (T < -16), 0.8,
            Con((T >= -16) & (T < -14), 0.6,
                Con((T >= -14) & (T < -12), 0.4,
                    Con((T > -12) & (T <= -10), 0.2, 0.001)))))
DendriticTerm = Con(RH >= 80.0, D, 0.001)
DendriticTerm.save(DendriticTif)
```

Methods – Dendritic Term (DT)





Methods – Dendritic Term (DT)



Methods – Step 4

- Final NWFSPI Equation Construction & Application (using MDT)

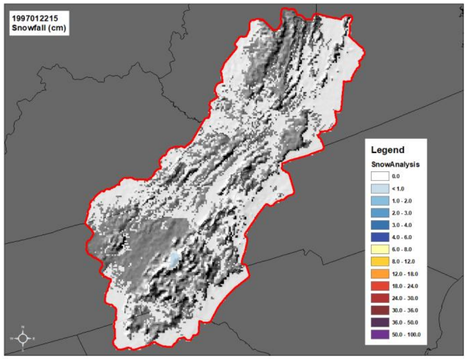
```
ModifiedDendriticTif = datadir + 'dendmod.850.tif'
UpslopeTerm = datadir + 'upslopeterm.tif'
NWFSPI = datadir + 'nwfspi.tif'
MDTras = (Raster(ModifiedDendriticTif))
UTras = (Raster(UpslopeTerm))

#Create NWFSPI
nwfspiras = ((UTras + MDTras)/2)
```

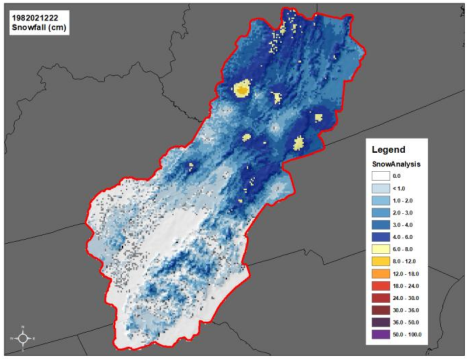
- Since both UT and MDT are values between 0 and 1, adding then dividing by two would yield a mean value between 0 and 1 for NWFSPI.

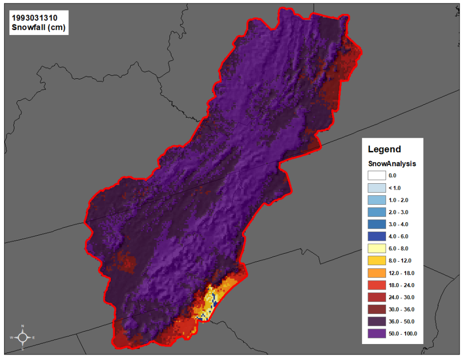
Results

- Created and compared NWFPI and all NARR imagery for three events in the NWFS Climatology
  - Minimum, maximum, and mean of the overall means of snowfall

Minimum Event (MinE)	Mean Event (MeanE)	Maximum Event (MaxE)
January 22nd, 1997 15 UTC Overall Mean = 0.002 cm	February 12th, 1982 21 UTC Overall Mean = 1.385 cm	March 13th, 1993 09 UTC Overall Mean = 50.939 cm

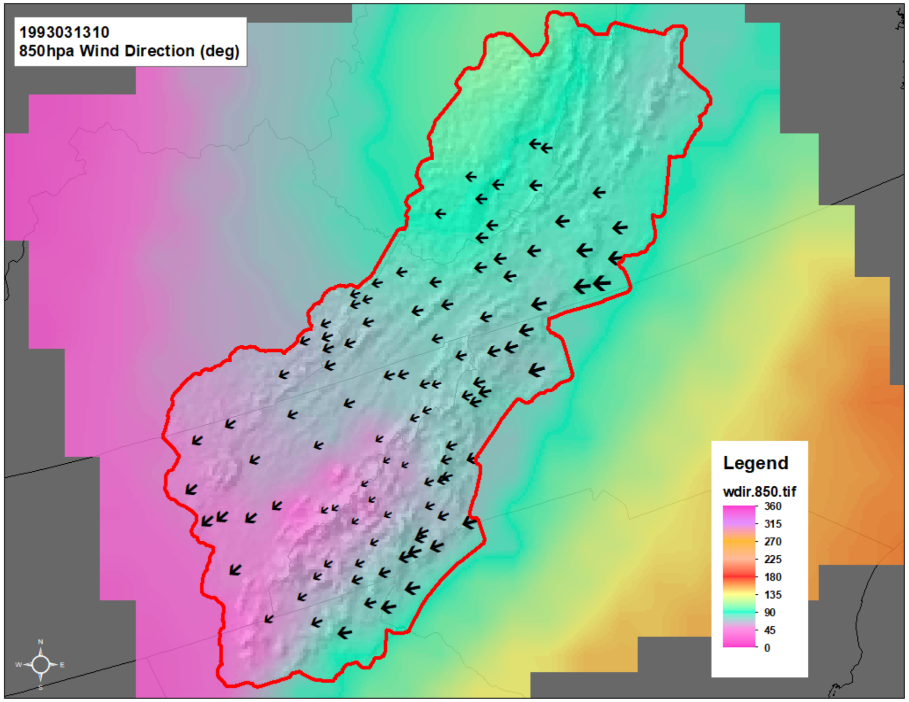






Results (UT)

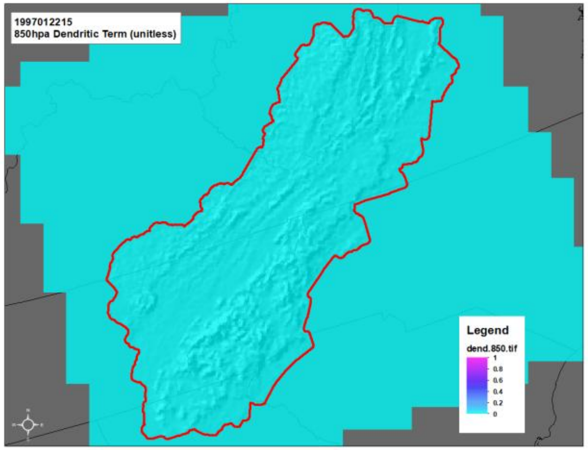
- One of the most immediate observations is the lack of an elevated UT for the MaxE event.
- Further investigation reveals the reasoning
  - 850hpa winds at that time instance revealed a northeasterly component
  - Presence of an 850hpa cyclone directly southeast?
  - Anticyclonic flow centered over the northeast in the classical or hybrid CAD regime.
- MinE and MeanE looked good



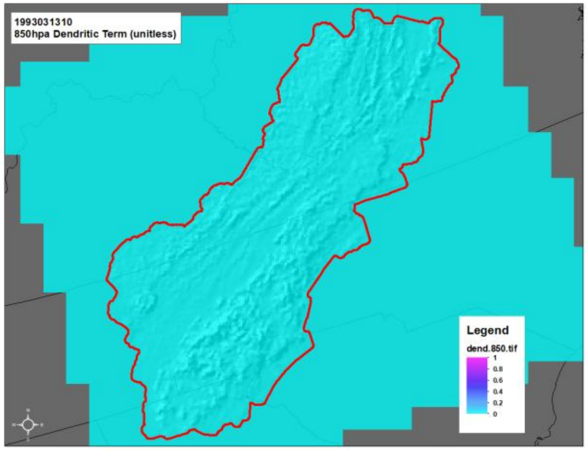
Results (DT)

- Major warm bias for all three test cases
- Thoughts?

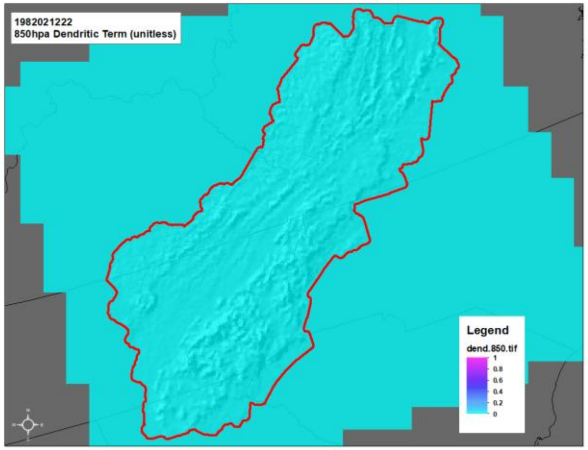
MinE



MaxE

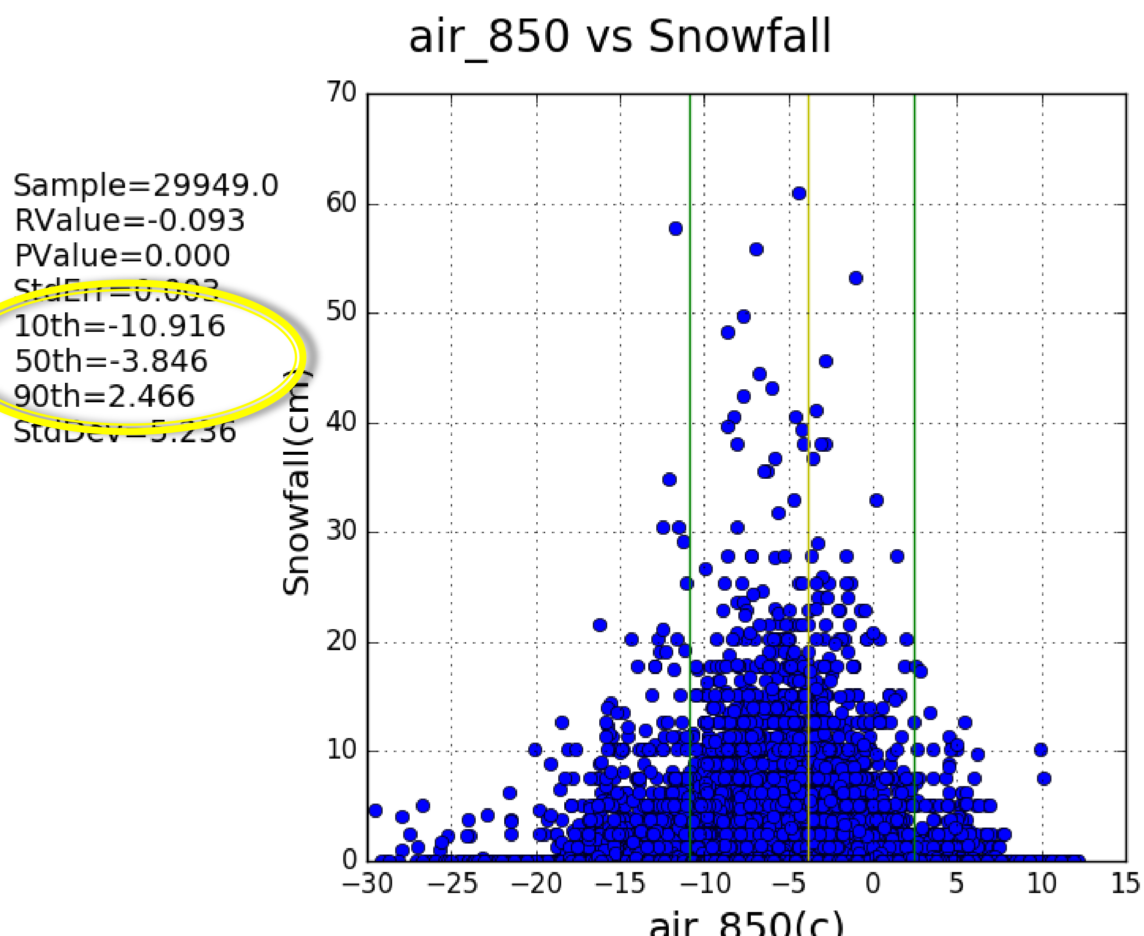


MeanE



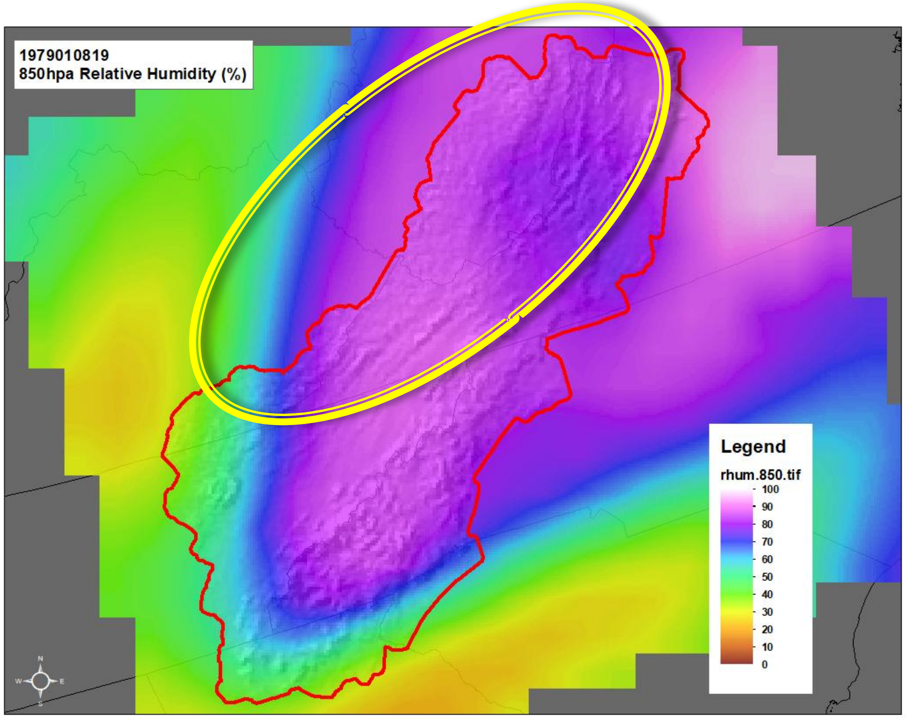
Results – Modified Denritic Term (MDT)

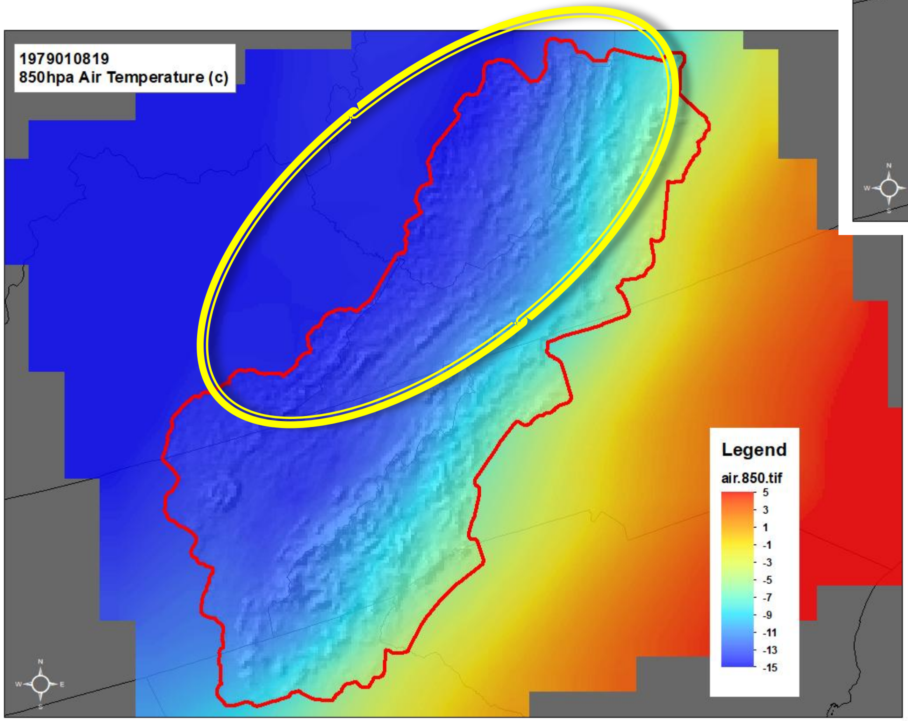
- Felt DT was too restrictive based on
  - Operational Experience (−5°C ice riming, −8°C snow)
  - Scatter plots skewed warmer



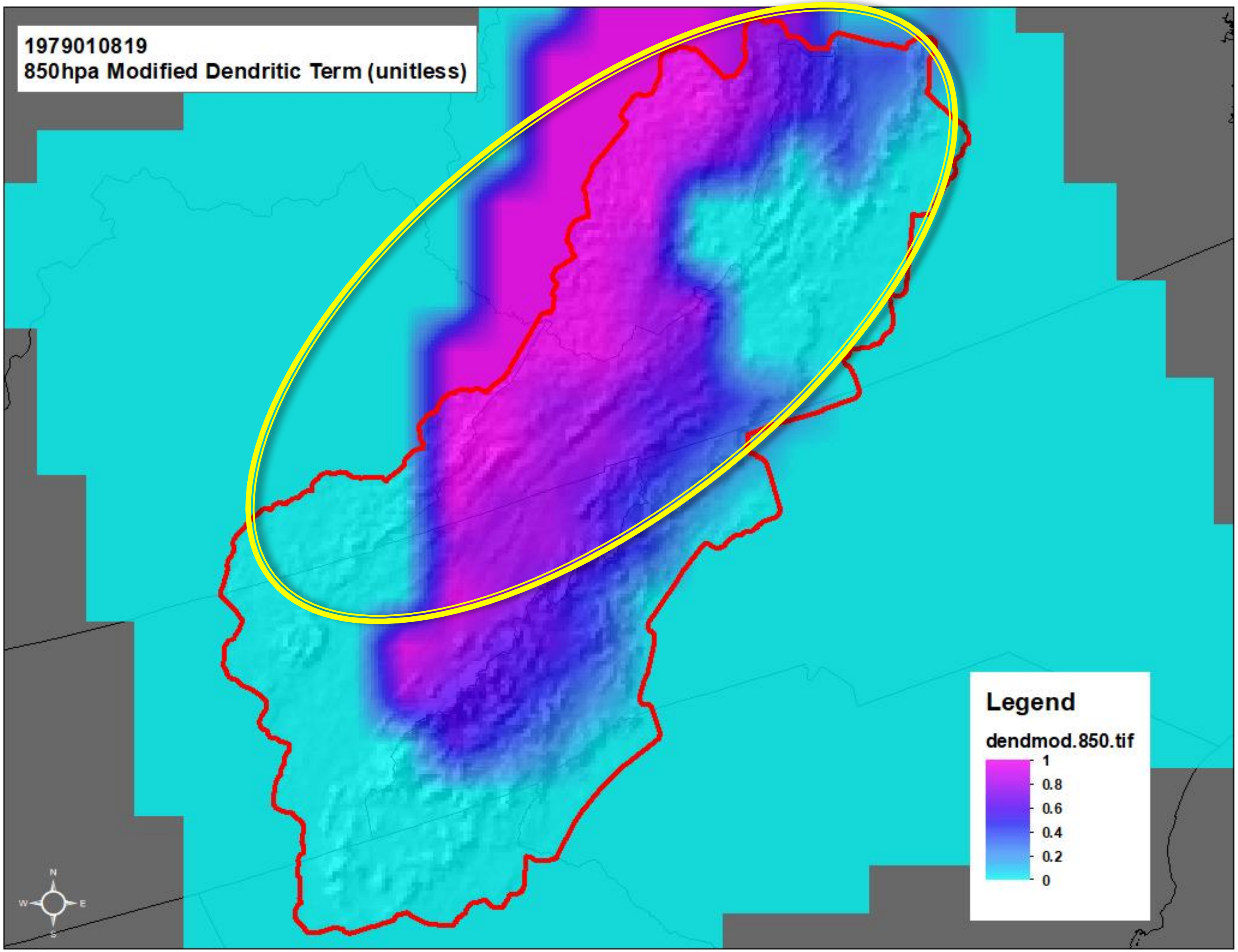
Results – Modified Denritic Term (MDT)

Same case as when describing original DT in Methods.





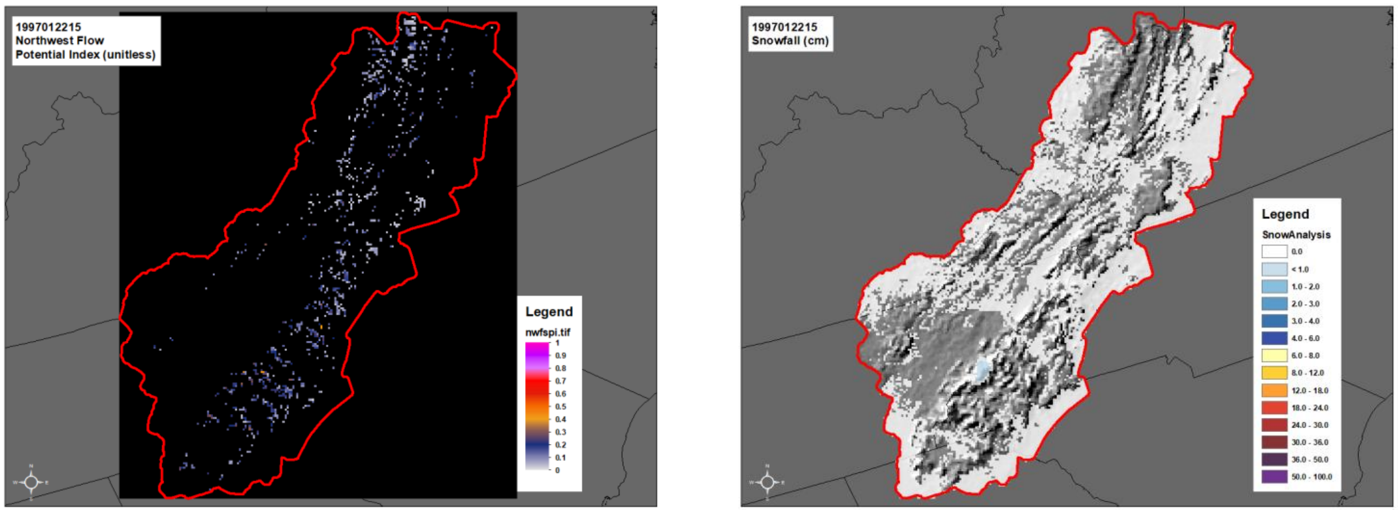
Results – Modified Denritic Term (MDT)



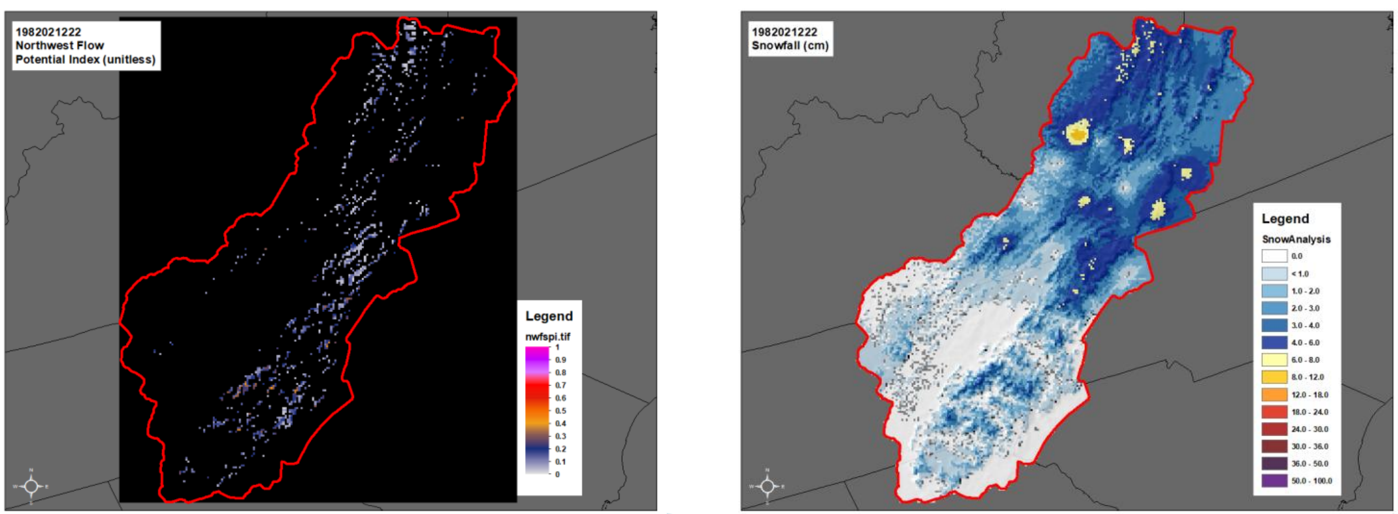
Results NWFSPI

- MinE and MeanE correlated well with eventual snowfall patterns

MinE

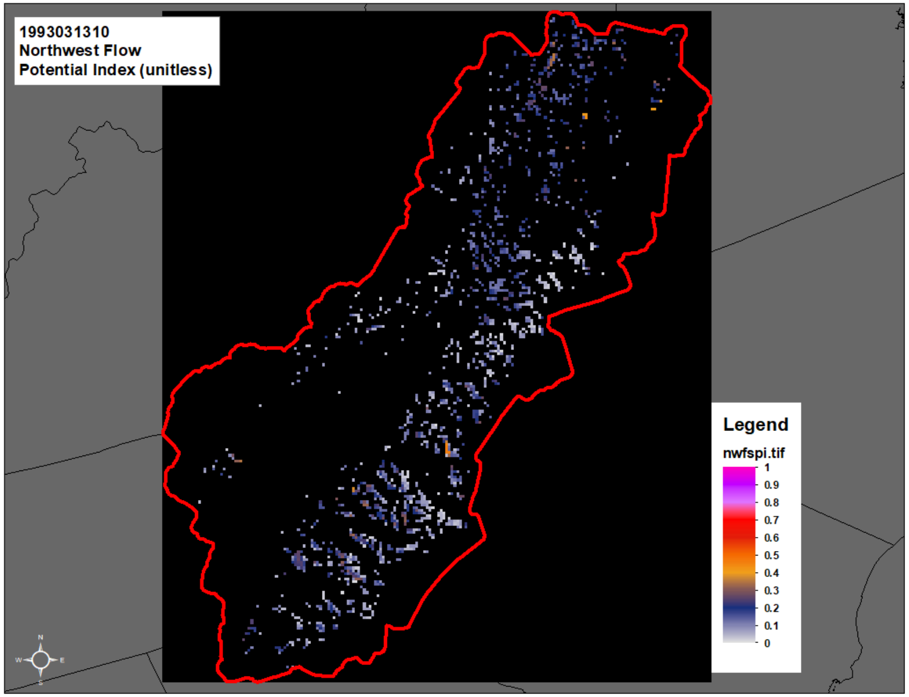


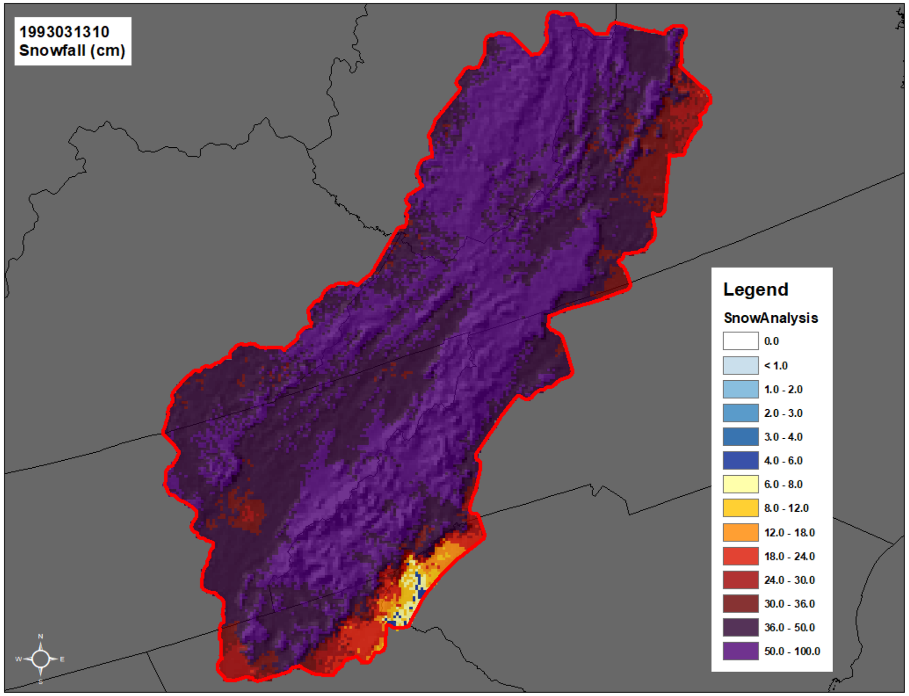
MeanE



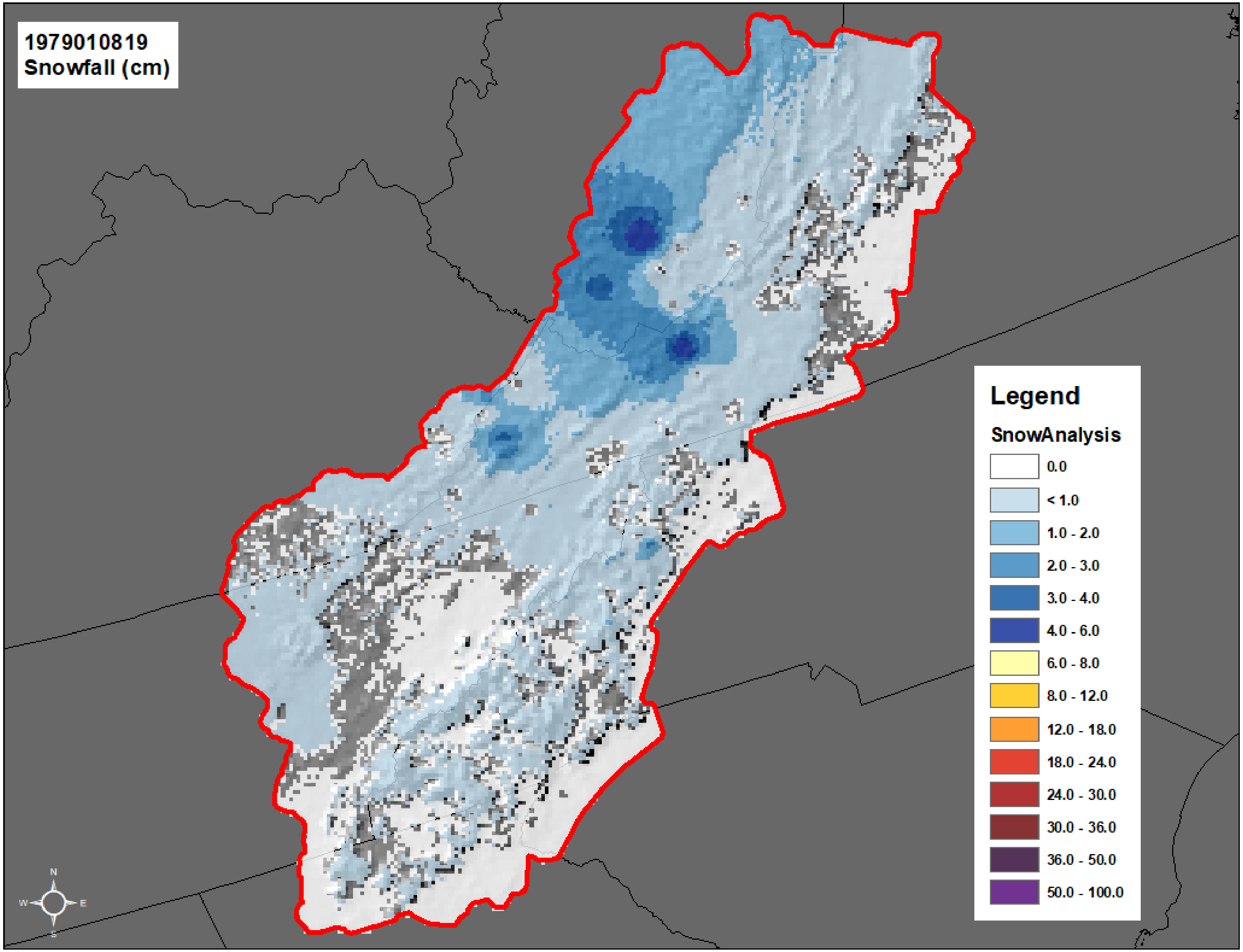
Results NWFSPI

- MaxE contaminated by incorrect flow/timing of data

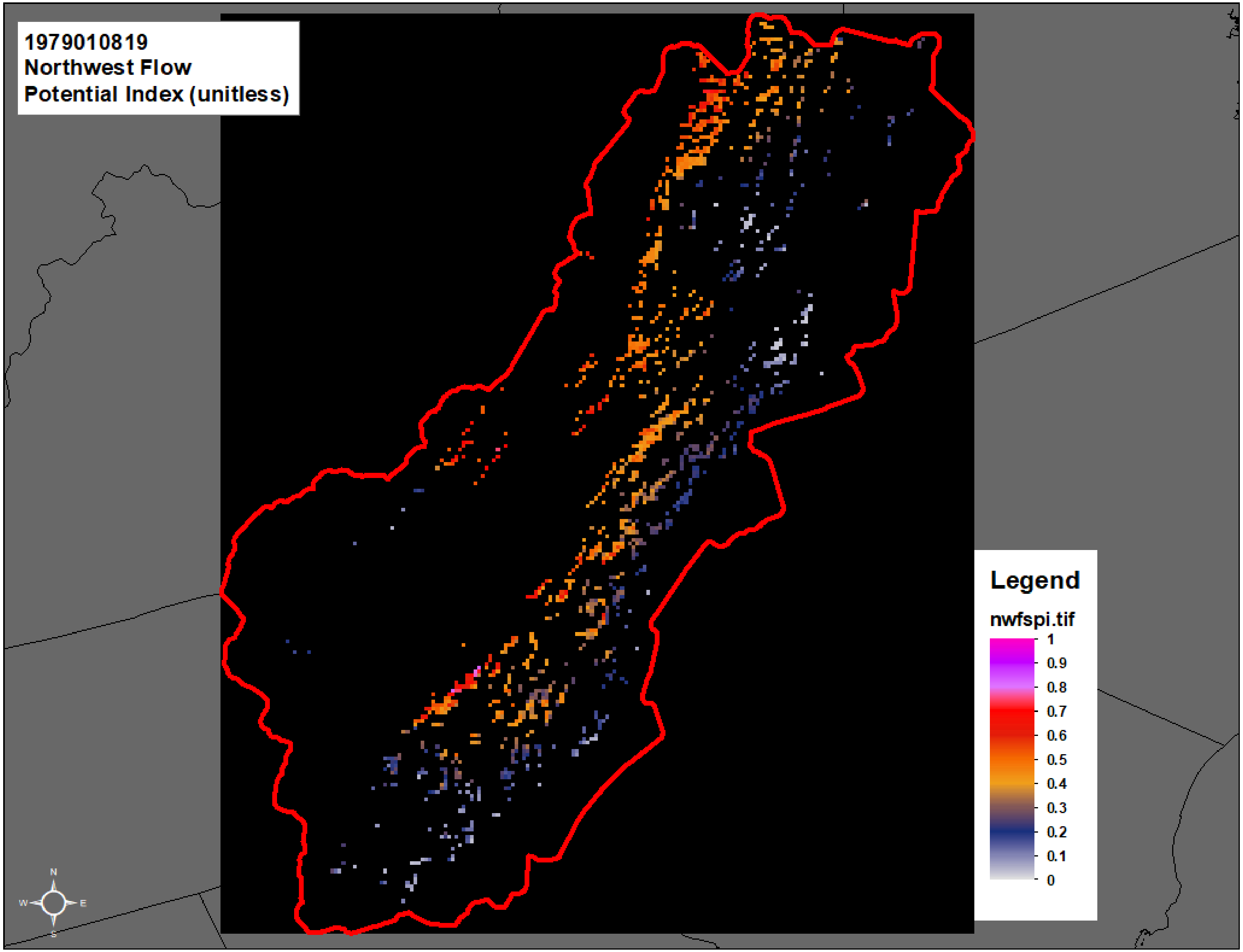




Results – Earlier Sample Snowfall



Results – NWFSPI Earlier Sample



Conclusions

- Revisiting the research questions proposed in earlier sections, this research was able to:
  - Utilize new geospatial tools, techniques, and datasets via ArcMap and Python processes
  - Develop NWFSPI
- However there were some inconsistencies that need addressed before any operational validity is obtained
  - "Maturation Dates/Times" dataset versus the "Beginning Dates/Times"
  - Hypothesis not proven
- Future work
  - Refinement of sample data
  - Add "Convective Term"