Fellowship of the Rain (Gauge Network)

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Atmospheric Sciences Department
UNC Asheville

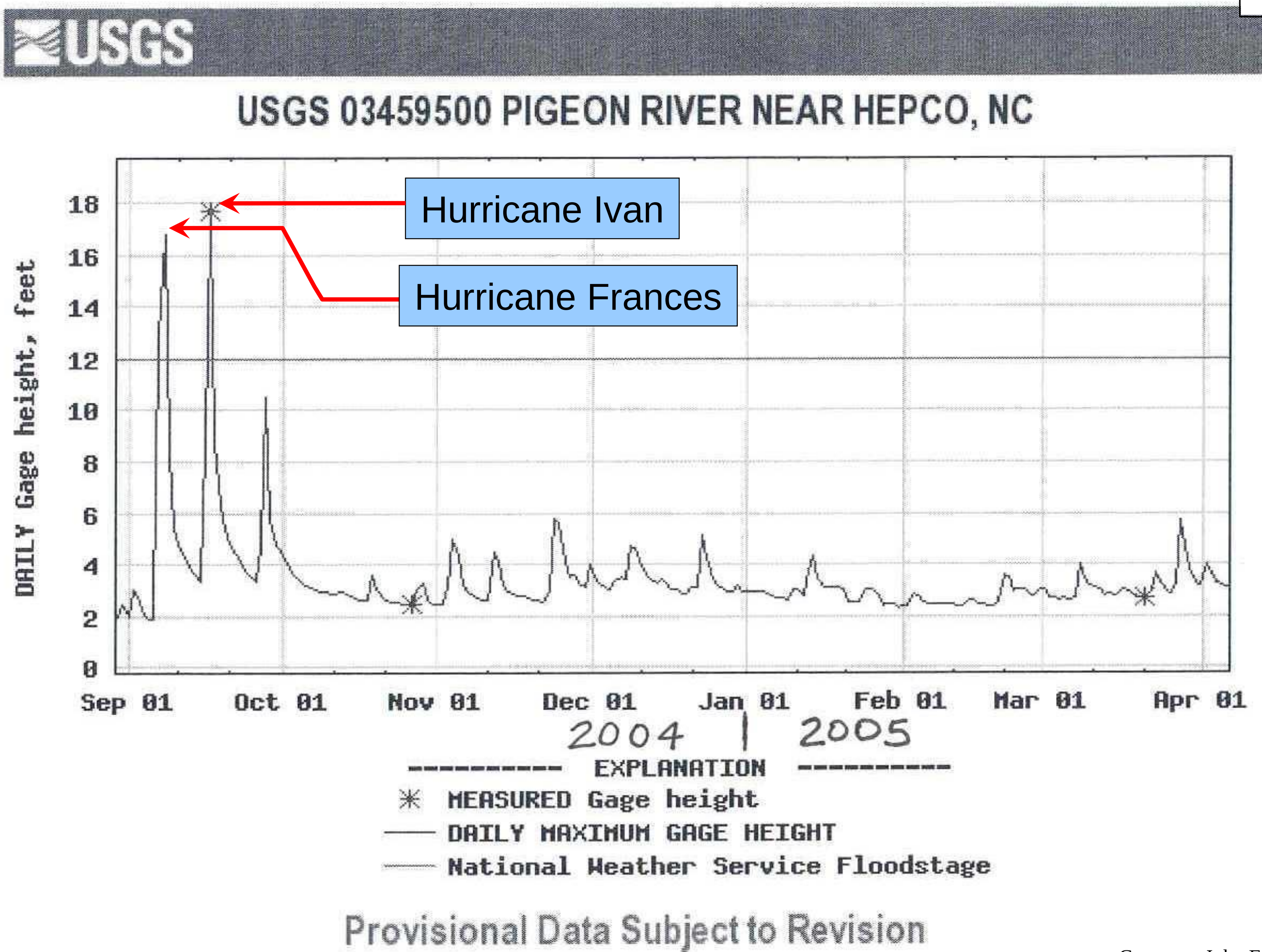
In collaboration with…

Ana Barros
Civil Engineering Department
Duke University

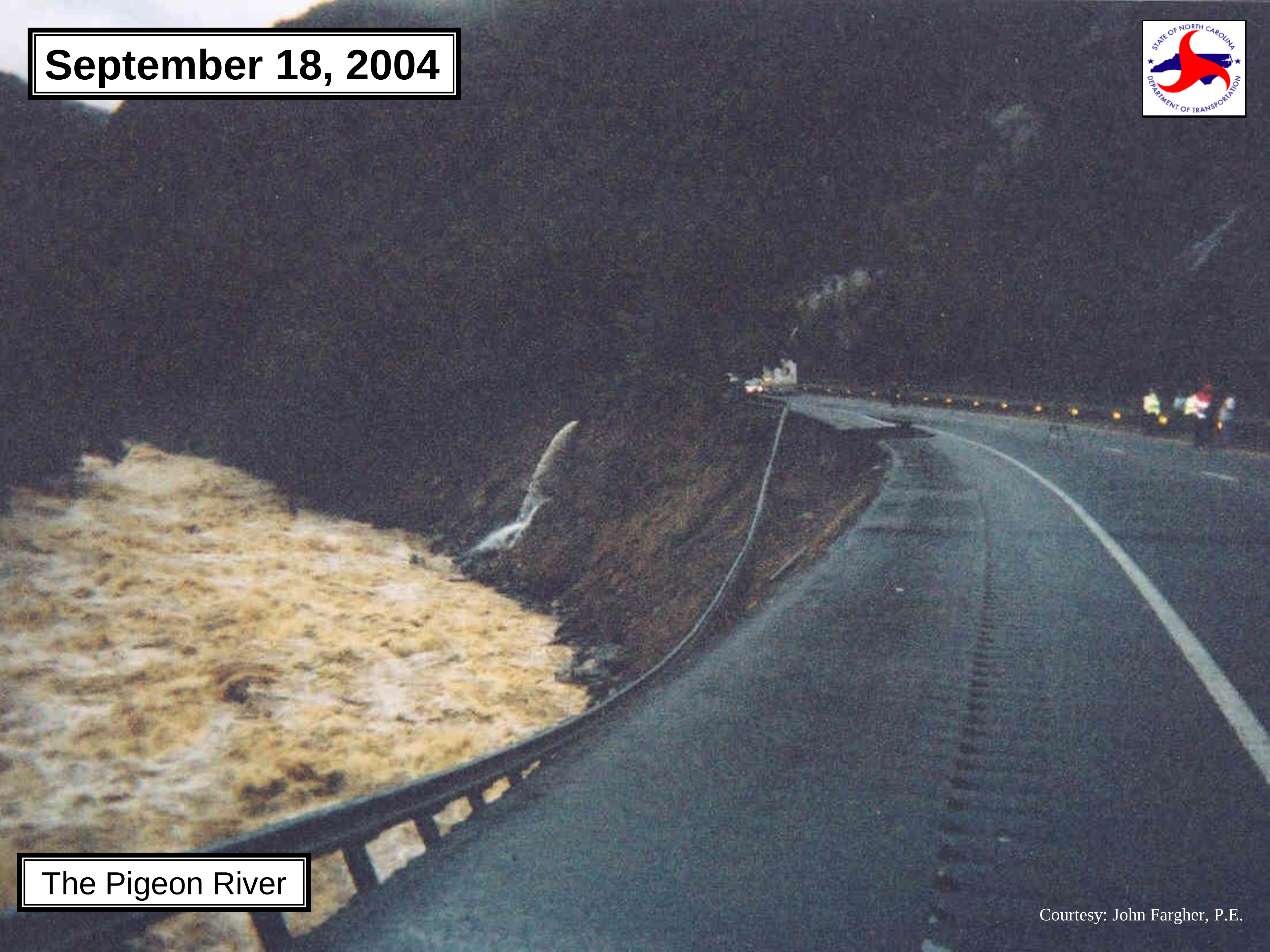
Outline

- High elevation rain gauge network in the Pigeon River Basin and Great Smoky Mountains National Park (Duke GSMRGN)
  - Founding
    - Why the Pigeon River Basin?
    - Purpose
    - Installation and maintenance and challenges
  - Findings
    - Pigeon River Basin
    - Pigeon v. Coweeta River Basin
  - Future
    - Climate-related questions

Flood Data



Courtesy: John Fargher, P.E.


September 18, 2004
STATE OF NORTH CAROLINA
DEPARTMENT OF TRANSPORTATION
The Pigeon River
Courtesy: John Fargher, P.E.

Aerial Photographs

Courtesy: John Fargher, P.E.

Original purpose - funding

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- NASA
  - Provide ground validation (GV) at high elevation locations in the mid-latitudes for NASA's Global Precipitation Mission (GPM)

GPM LAUNCH: 27 FEBRUARY 2014, 1:37 PM EST, TANEGASHIMA SPACE CENTER, JAPAN

http://www.nasa.gov/mission_pages/GPM/main/#.Ux9ynM65Hws

- Improves upon the capabilities of the Tropical Rainfall Measurement Mission (TRMM), a joint NASA-JAXA mission launched in 1997 and still in operation.
- **Expands coverage area** from 40° N to 40° S (TRMM) to from the Arctic Circle to the Antarctic Circle.
- **Detect light rain and snowfall**, a major source of available fresh water in some regions.
- Collect information that unifies and improves data from an international constellation of existing and future satellites by mapping global precipitation **every three hours**.

Wilson et al. (2014)

GPM Ground Validation Program

Purpose

- Provide ground and airborne precipitation datasets supporting **physical validation** of satellite-based precipitation retrieval algorithms
- Determine the **measurement uncertainty** for GPM measurements to allow users of GPM data to interpret observations
- Improve the **retrieval algorithms** used by GPM and future space-based precipitation measurement missions
- Improve understanding of precipitation processes and the ground-based GV measurements themselves, which have historically been beset with difficulties

seek to advance our physical understanding of precipitation processes and assure consistency between this understanding and the representation of those physical processes in NASA GPM retrieval algorithms

Wilson et al. (2014)

Installation and Maintenance

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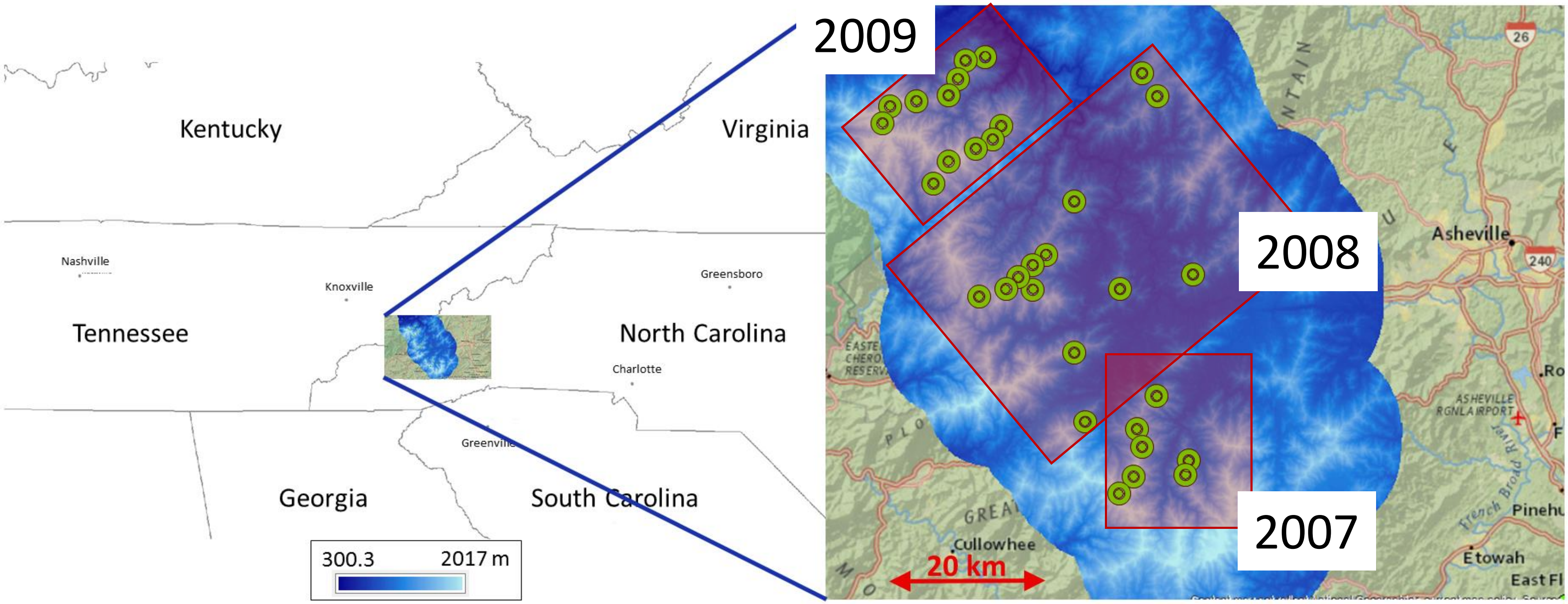
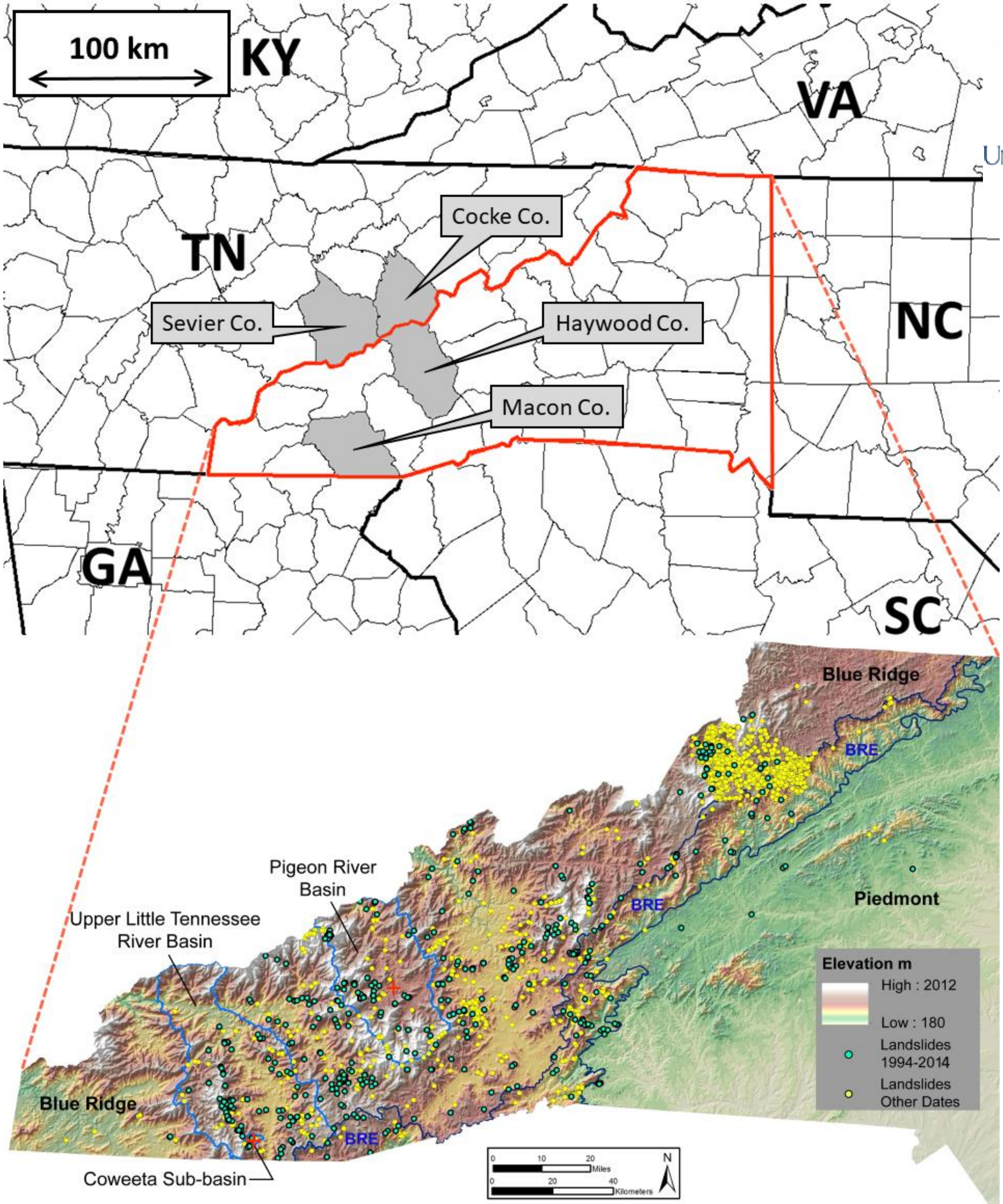
pc: Daniel Martin

Duke University Great Smoky Mountain Rain Gauge Network (Duke GSMRGN)



Miller et al. (2018)



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32 gauges

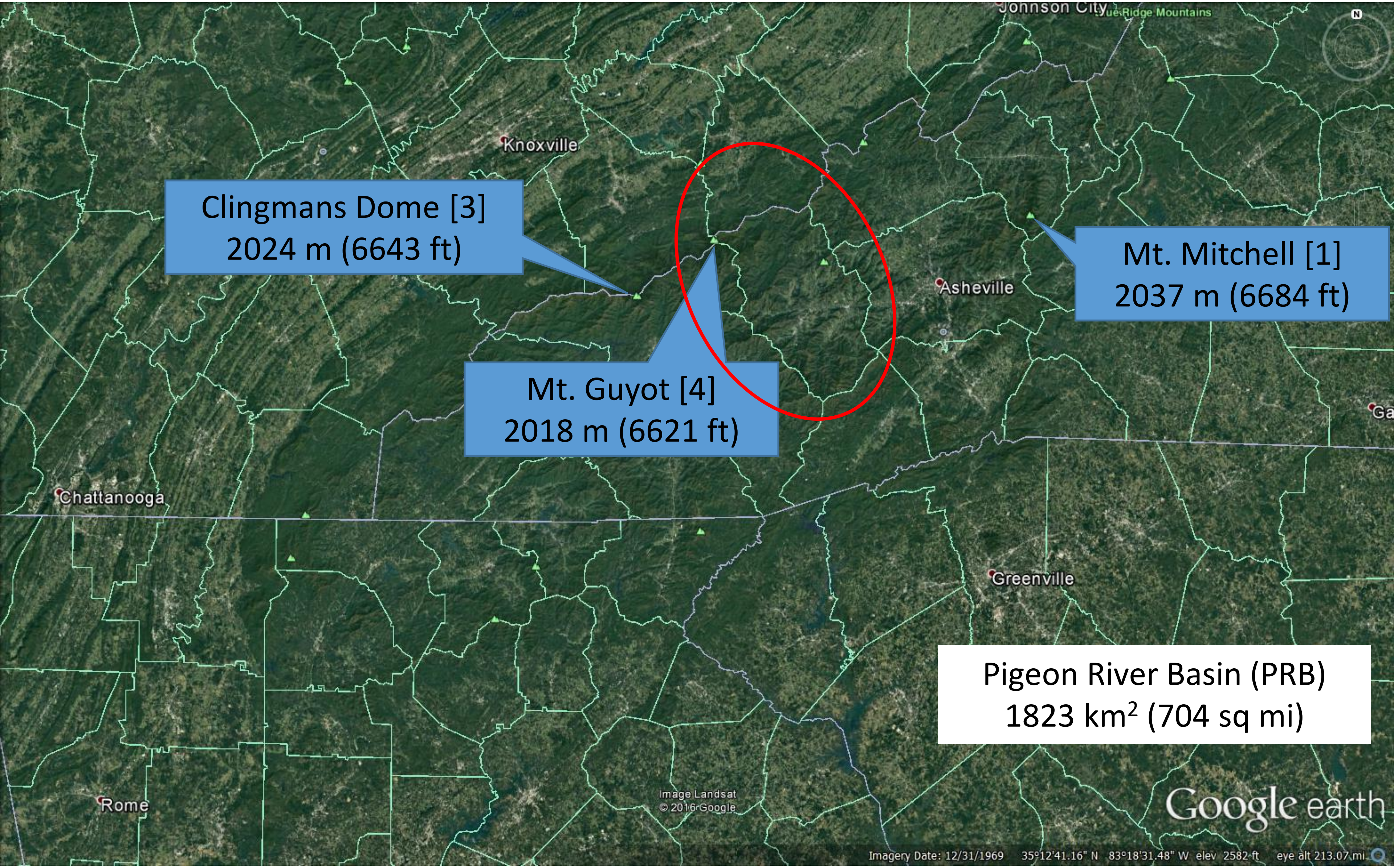
6570 ft

3398 ft

Table 1: Location and elevation of the 32 tipping bucket rain gauges comprising the Duke GSMRGN.

Rain gauge number	Latitude	Longitude	Elevation (m)
RG001	35°2	82°5	1156
RG002	35°2	82°5	1731
RG003	35°2	82°5	1609
RG004	35°2	82°5	1922
RG005	35°2	82°5	1520
RG008	35°2	82°5	1737
RG010	35°2	82°5	1478
RG100	35°3	83°0	1495
RG101	35°3	83°0	1520
RG102	35°3	83°0	1635
RG103	35°3	83°0	1688
RG104	35°3	83°0	1587
RG105	35°3	83°0	1345
RG106	35°2	83°0	1210
RG107	35°3	82°5	1359
RG108	35°3	82°5	1277
RG109	35°2	83°0	1500
RG110	35°3	83°0	1563
RG111	35°4	82°5	1394
RG112	35°4	82°5	1184
RG300	35°4	83°1	1558
RG301	35°4	83°1	2003
RG302	35°4	83°1	1860
RG303	35°4	83°0	1490
RG304	35°4	83°1	1820
RG305	35°4	83°0	1630
RG306	35°4	83°1	1536
RG307	35°3	83°1	1624
RG308	35°4	83°1	1471
RG309	35°4	83°0	1604
RG310	35°4	83°0	1756
RG311	35°4	83°0	1036

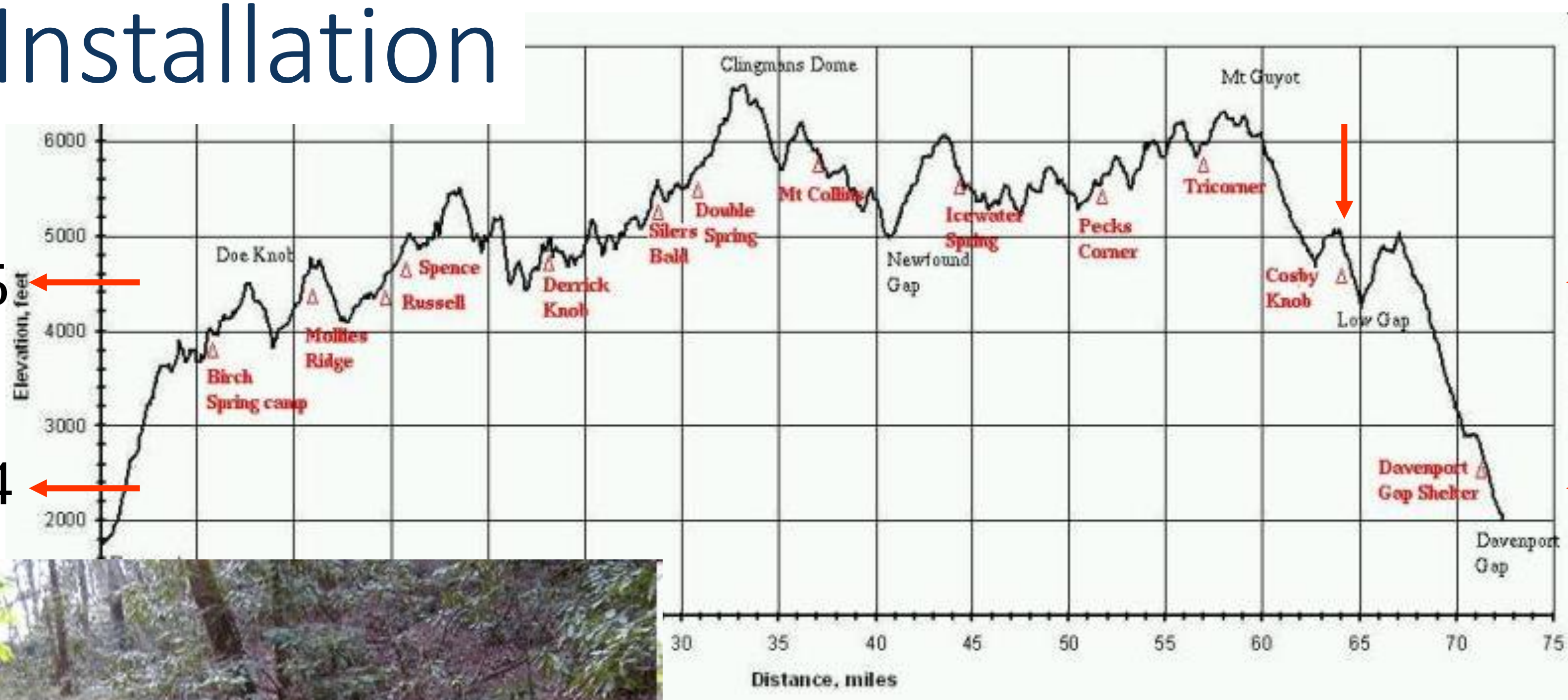
Southern Appalachians



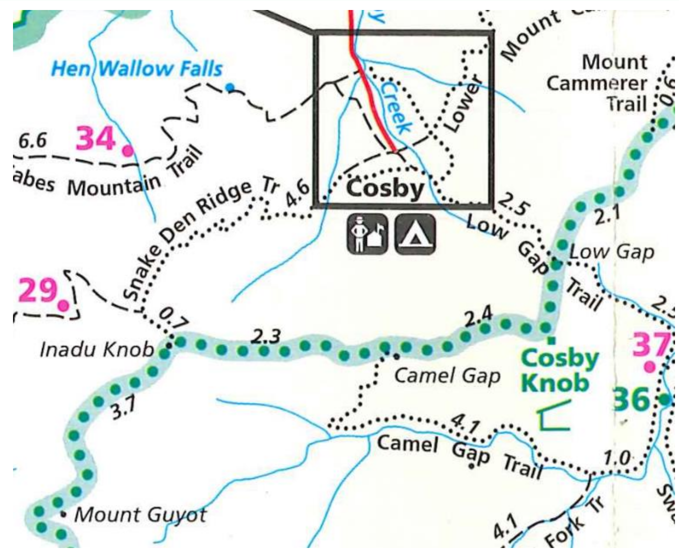
Installation

4525

2354



Backcountry Horsemen of NC



http://www.hikinginthesmokys.com/_wizardimages/at%20-%20elev%20profile.jpg

Day One

Day One

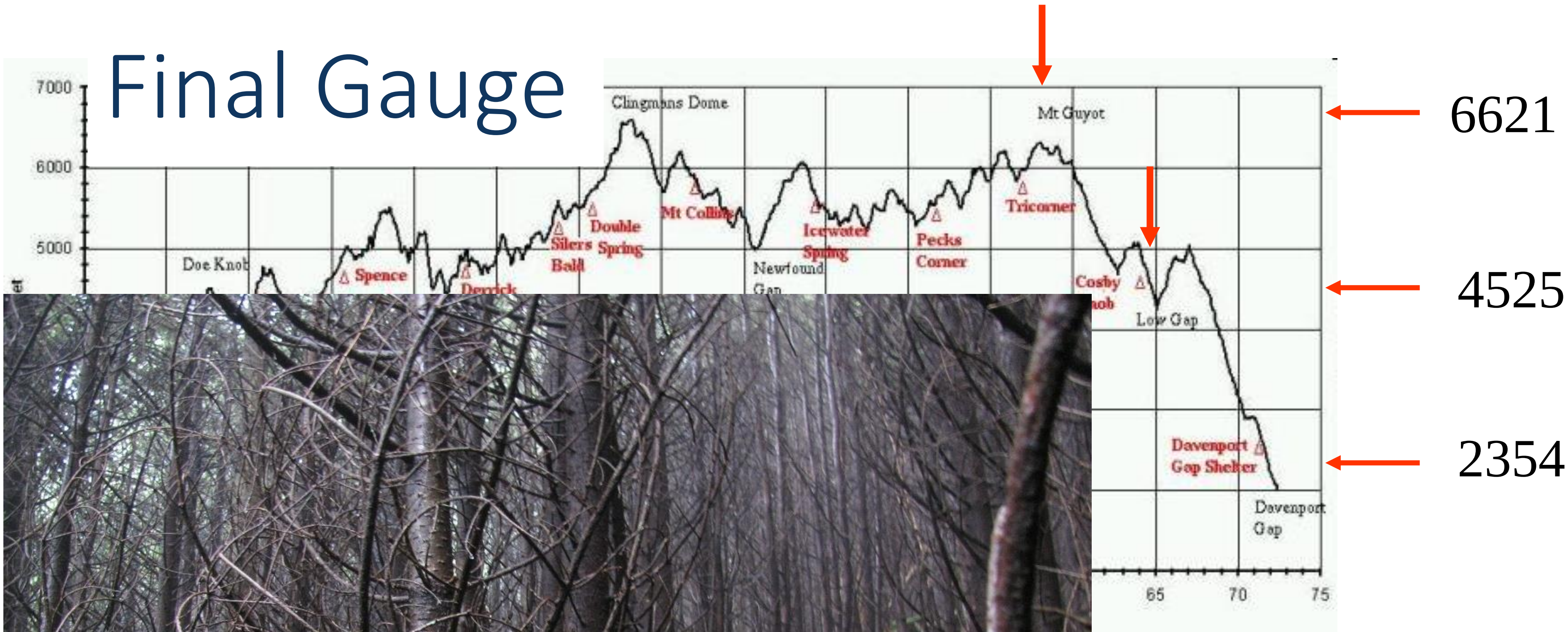
pc: Daniel Martin

Day Two

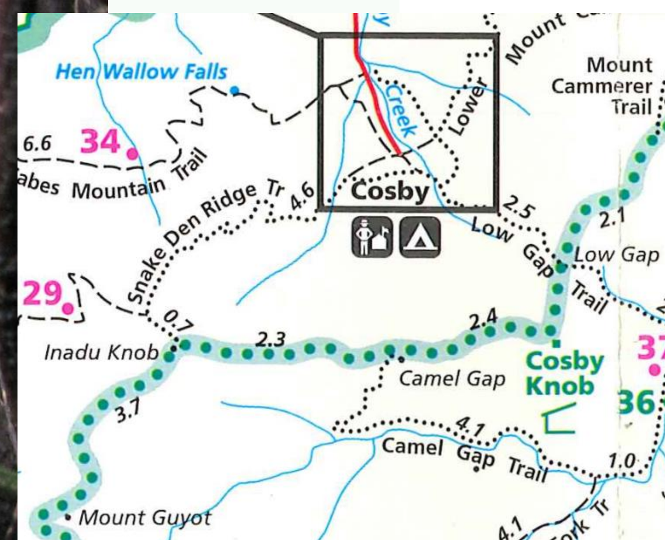
pc: Daniel Martin

Day Two

Final Gauge



pc: Daniel Martin

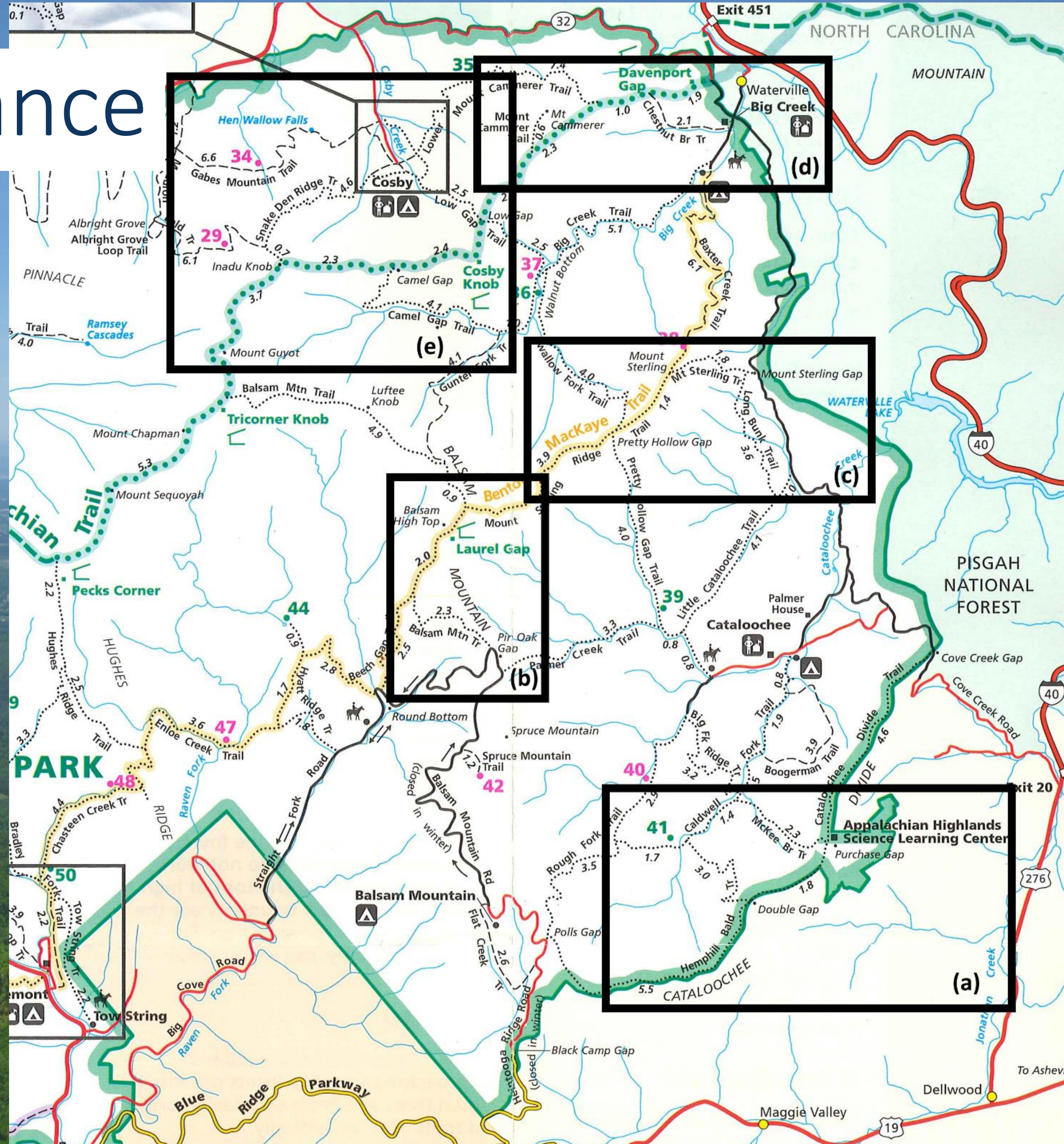


http://www.hikinginthesmokys.com/_wizardimages/at%20-%20elev%20profile.jpg

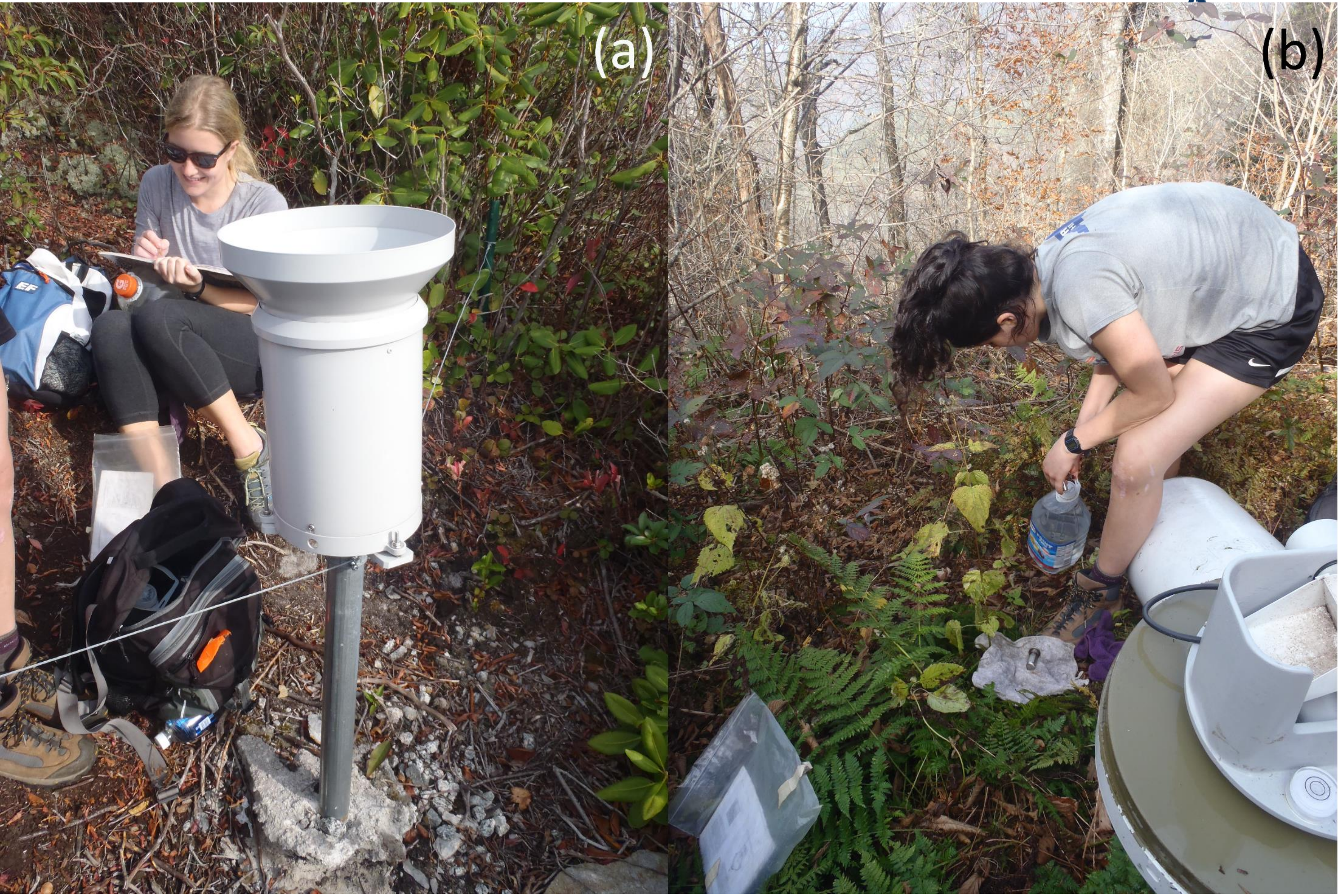
Finished!! 12 June 2009

pc: Daniel Martin

Maintenance



pc: Daniel Martin


(a)
(b)

Maintenance

Maint

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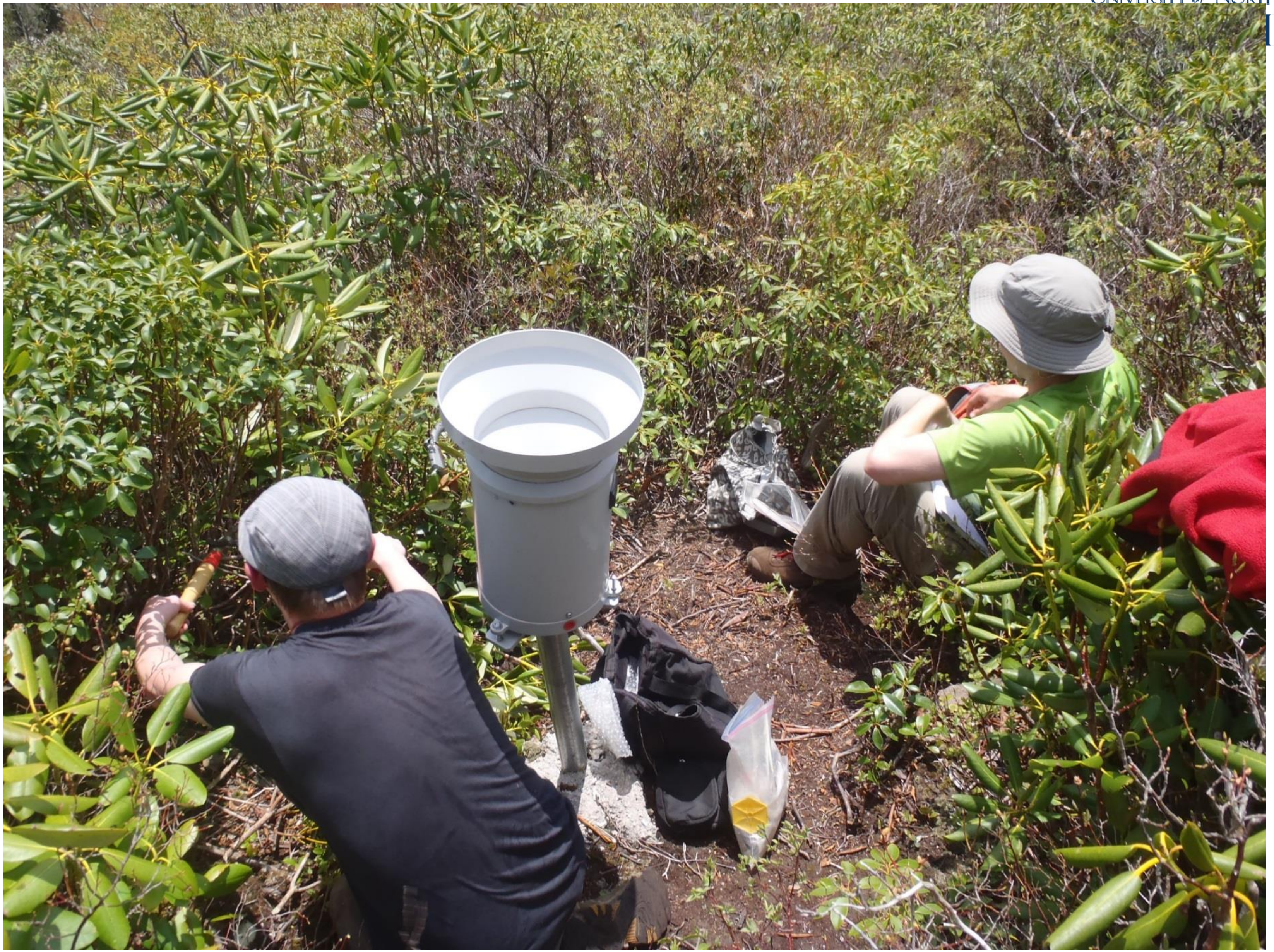
Maintenance



Maintenance

Challenges

University of North Carolina
ILLE

Challenges

University of North Carolina
ILLE

Challenges

University of North Carolina Asheville

Challenges

University *of* North Carolina

Challenges

https://www.hgtv.com/outdoors/gardens/animals-and-wildlife/the-gray-squirrel-411

Challenges

Challenges

Challenges


pc: Daniel Martin

Challenges

http://blizzard.atms.unca.edu/dmiller/MFDC0135.AVI

Challenges

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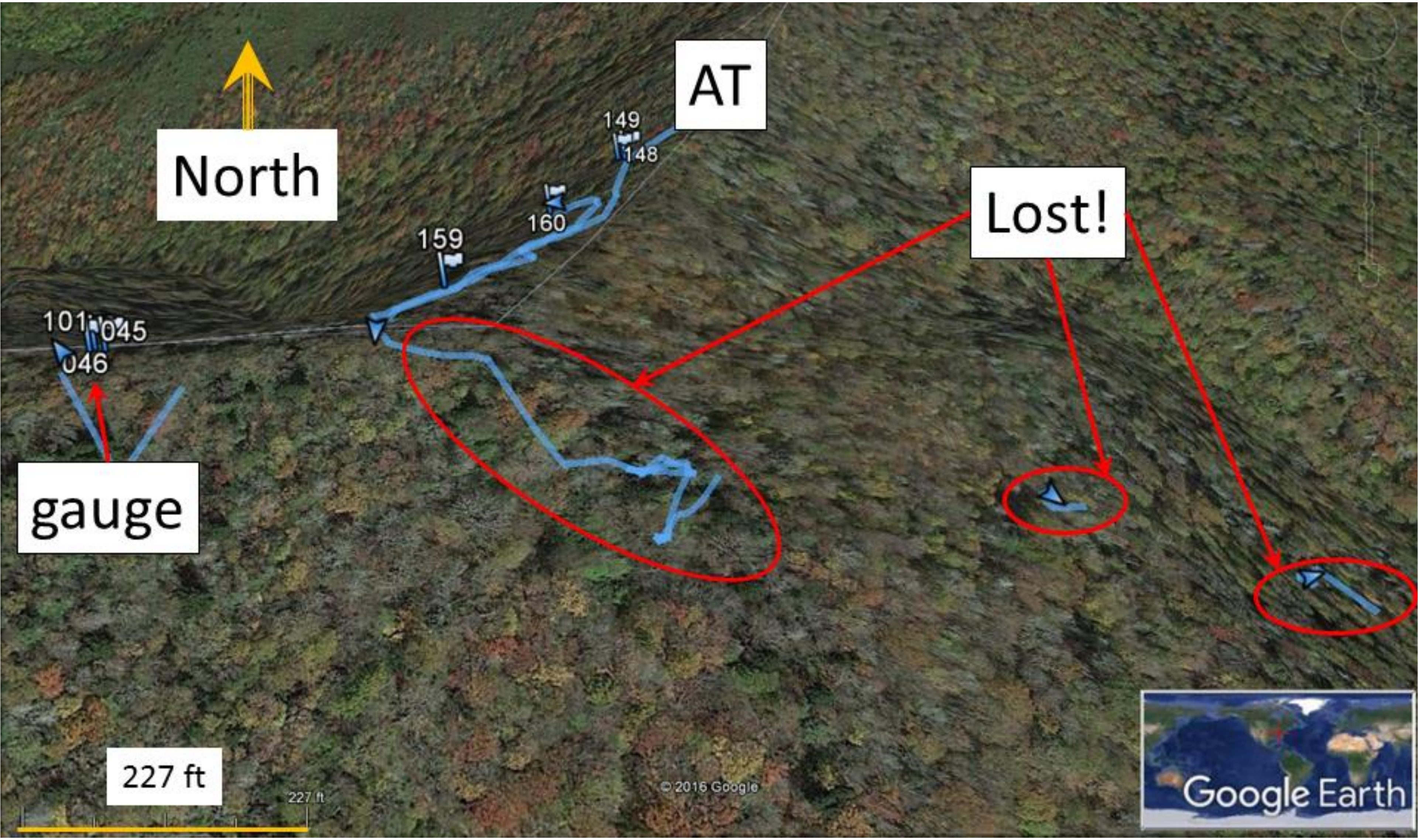
Challenges

Challenges

Challenges

Challenges



North
AT
149
148
160
159
101
045
046
Lost!
gauge
227 ft
227 ft
© 2016 Google
Google Earth

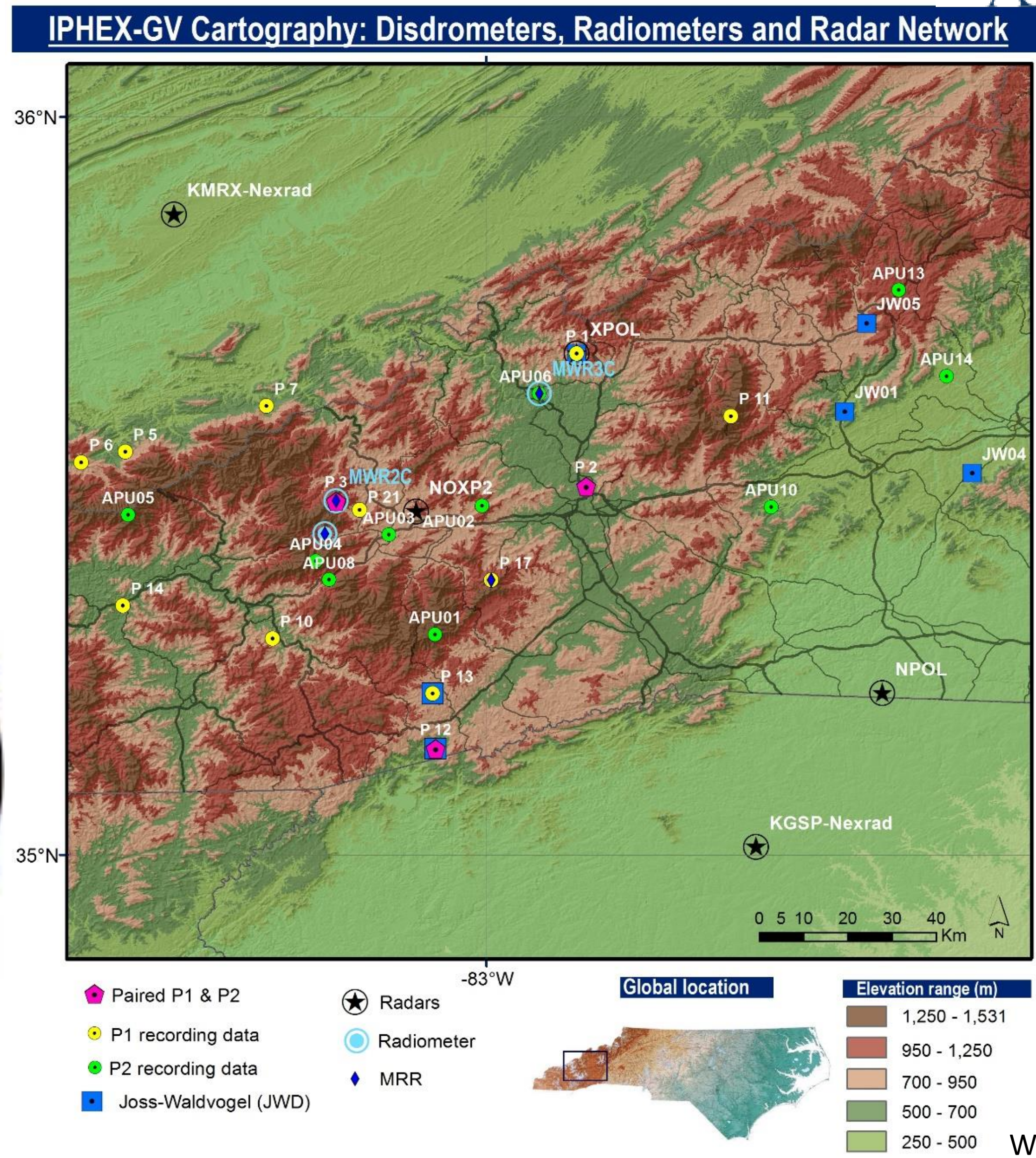
Local Research

- Findings…

Findings

- IPHEx

1 May – 15 June 2014



Wilson et al. (2014)

Findings

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ghrc.nsstc.nasa.gov/hydro/details/gpmrgsaiphx

EARTHDATA Other DAACs ▾ Feedback

GHRC Global Hydrology Resource Center

FIND DATA | MEASUREMENTS | FIELD CAMPAIGNS | PROJECTS | RESOURCES | MULTIMEDIA | ABOUT | CITE | CONTACT

HyDRO Hydrology Data Search Tool

GPM Ground Validation Southern Appalachian Rain Gauge IPHEx

The GPM Ground Validation Southern Appalachian Rain Gauge IPHEx dataset was collected during the Integrated Precipitation and Hydrology Experiment (IPHEx) field campaign consisting of 45 observation sites. The main goal of IPHEx were to characterize warm season orographic precipitation regimes and hydrologic processes in regions of complex terrain, to contribute to the development, evaluation, and improvement of remote sensing precipitation algorithms in support of the GPM mission. These data are available in ASCII-csv format from January 3, 2008 thru December 31, 2014. Data collection began in 2008 due to the entire network being funded by the NASA Precipitation Measurement Missions (PMM) to make these observations of orographic precipitation in preparation for the IPHEx field campaign.

This same dataset is also publicly available at the Duke Data Repository. If you obtained the Duke Data Repository dataset, please use the following citation: Barros, A.P., Miller, D., Wilson, A.M., Cutrell, G., Arulraj, M., Super, P., Petersen, W.A. (2017). IPHEx-Southern Appalachian Mountains -- Rainfall Data 2008-2014. Duke Digital Repository. https://doi.org/10.7924/G8CJ8BJK

Please include the following citation in your publications:
Barros, Ana P, Douglas Miller, Anna M Wilson, Gregory Cutrell, Malarvizhi Arulraj, Paul E. Super and Walter A Petersen. 2017. *GPM Ground Validation Southern Appalachian Rain Gauge IPHEx* [indicate subset used]. Dataset available online from the NASA Global Hydrology Resource Center DAAC, Huntsville, Alabama, U.S.A.
DOI: http://dx.doi.org/10.5067/GPMGV/IPHEX/GAUGES/DATA301

Download Citation

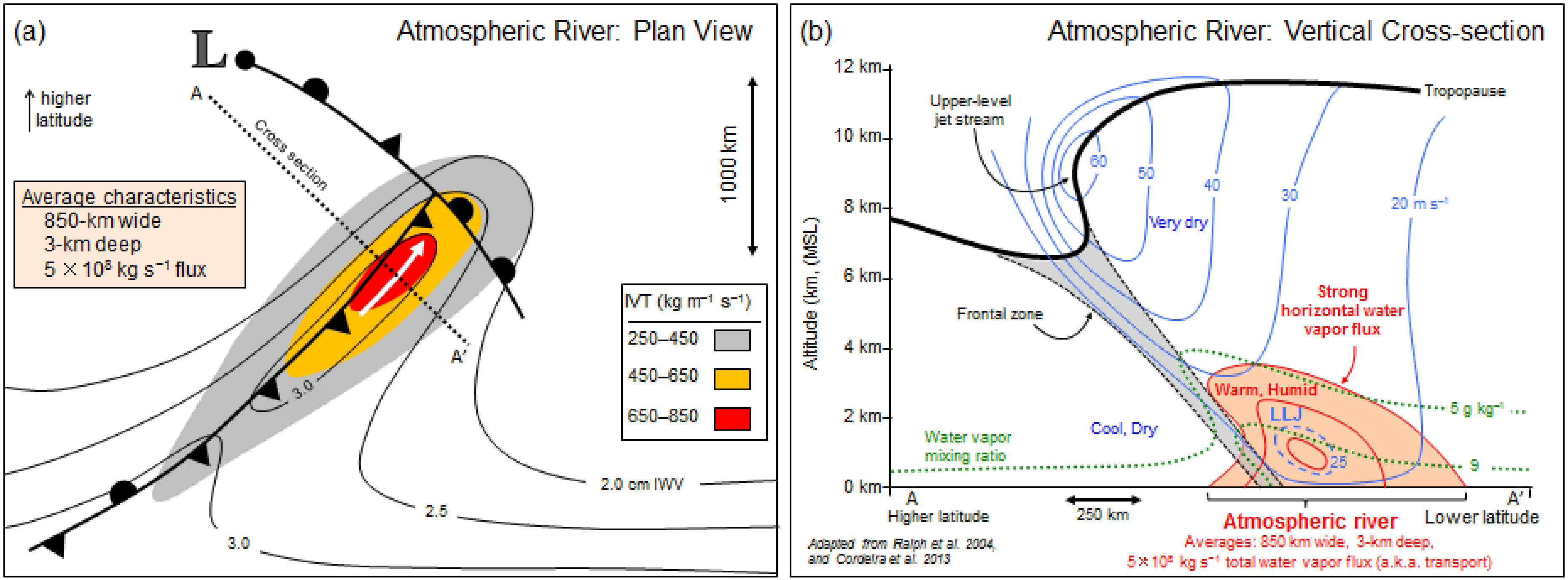
Barros, Ana P, Douglas Miller, Anna M Wilson, Gregory Cutrell, Malarvizhi Arulraj, Paul E. Super and Walter A Petersen. 2017. GPM Ground Validation Southern Appalachian Rain Gauge IPHEx [*indicate subset used*]. Dataset available online from the NASA Global Hydrology Resource Center DAAC, Huntsville, Alabama, U.S.A. DOI: http://dx.doi.org/10.5067/GPMGV/IPHEX/GAUGES/DATA301

Background on Atmospheric Rivers

- In the western United States…

Atmospheric River

IVT = Integrated Vapor Transport

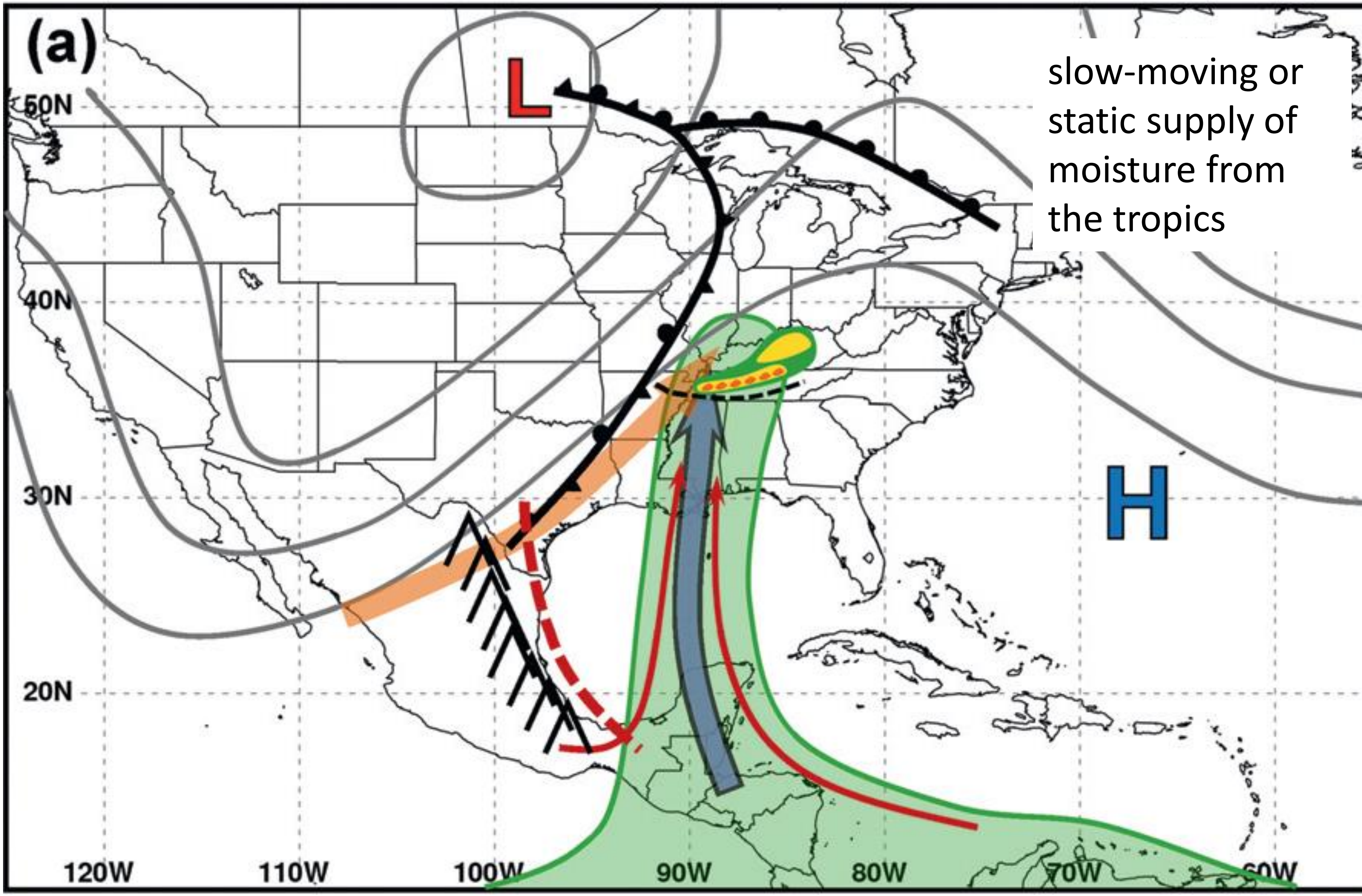


A long, narrow, and transient corridor of strong horizontal water vapor transport that is typically associated with a low-level jet stream ahead of the cold frontof an extratropical cyclone. The water vapor in atmospheric rivers is supplied by tropical and/or extratropical moisture sources…Horizontal water vapor transport in the midlatitudes occurs primarily in atmospheric rivers and is focused in the lower troposphere.

http://glossary.ametsoc.org/wiki/Atmospheric_river

Background on Atmospheric Rivers

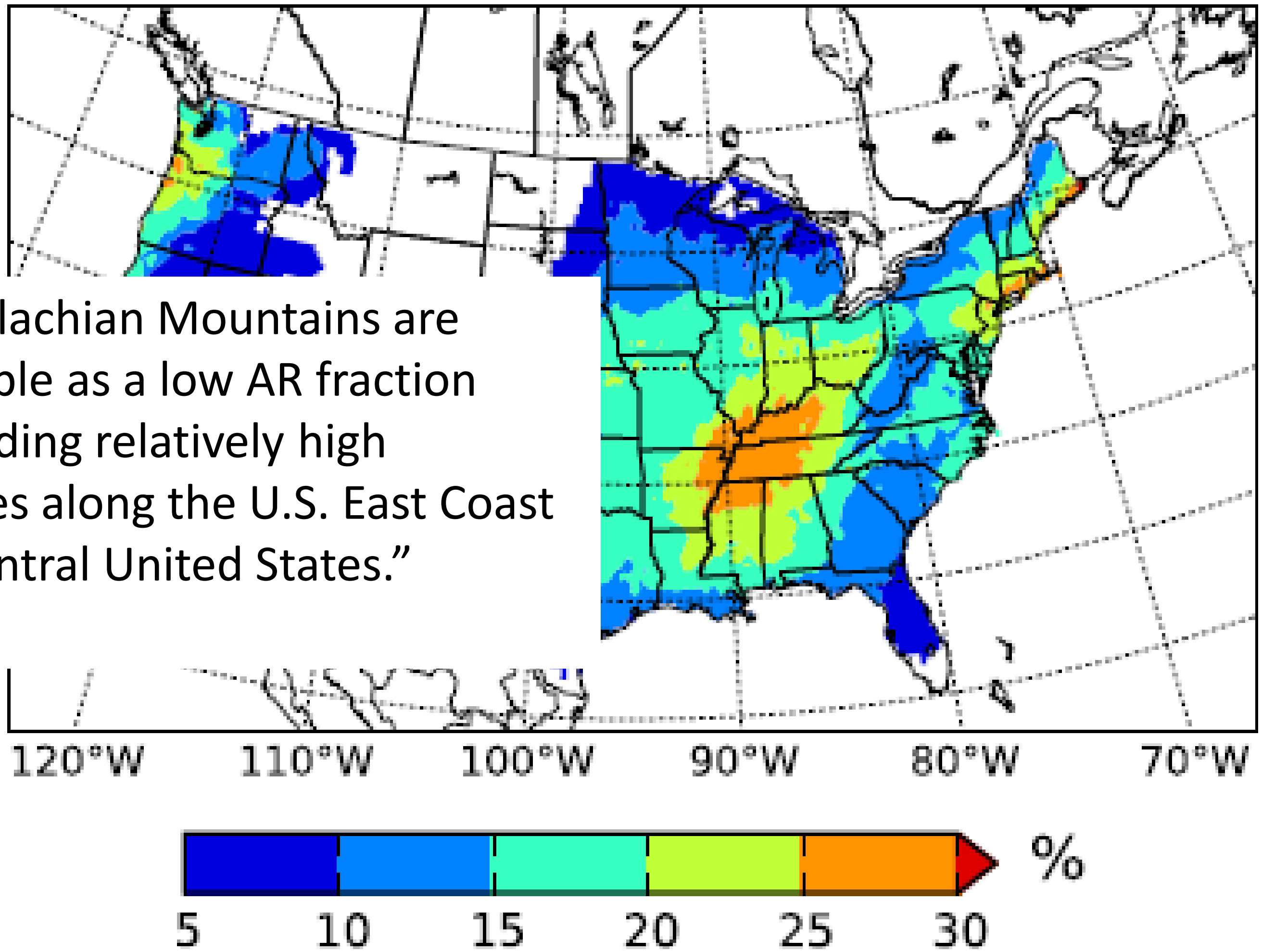
- In the southeastern United States…



1 – 2 May 2010

Moore et al. (2012)

Climatology in SE U.S.



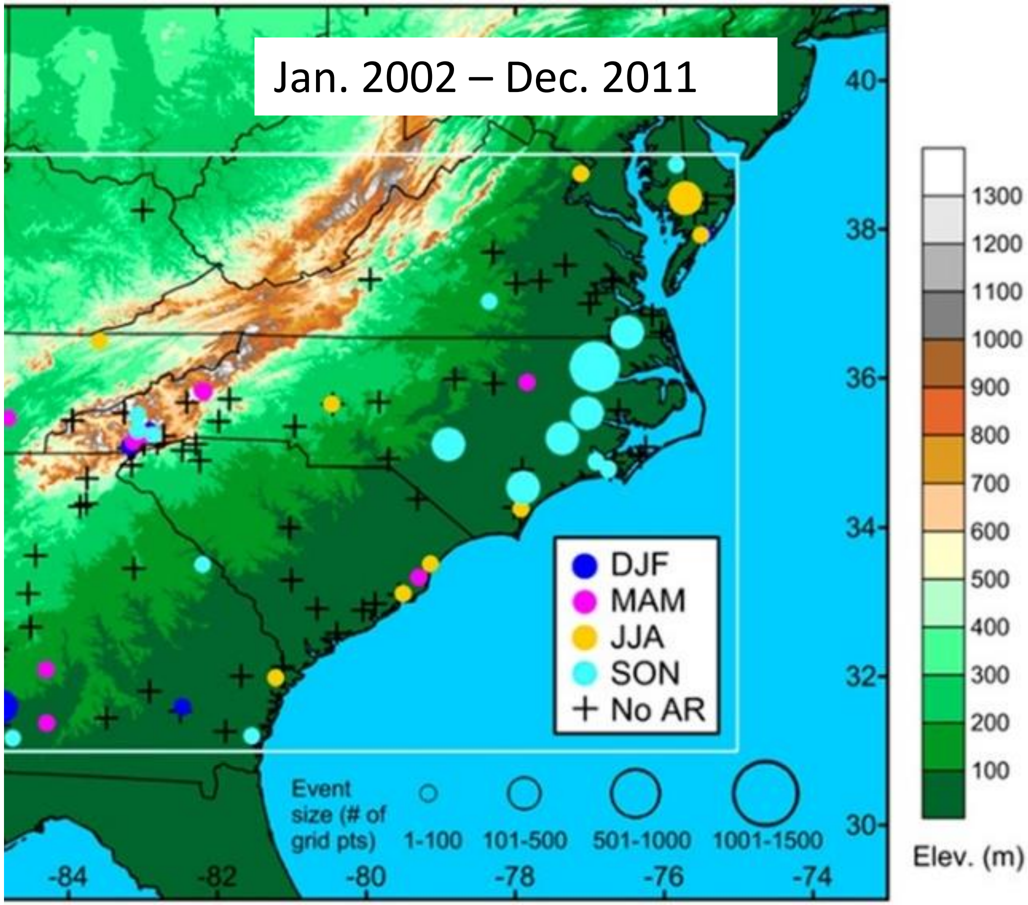
"The Appalachian Mountains are clearly visible as a low AR fraction region dividing relatively high percentages along the U.S. East Coast and the central United States."

Lavers and Villarini (2015)

Background

<u>S.E. U.S. (SEUS) findings…</u>

- IVT ~500 kg m^{-1} s^{-1} reasonable threshold for defining ARs
- clear connection between ARs and heavy precipitation events in non-summer months
- AR conditions in SEUS have a less direct influence on heavy precipitation relative to the U.S. west coast



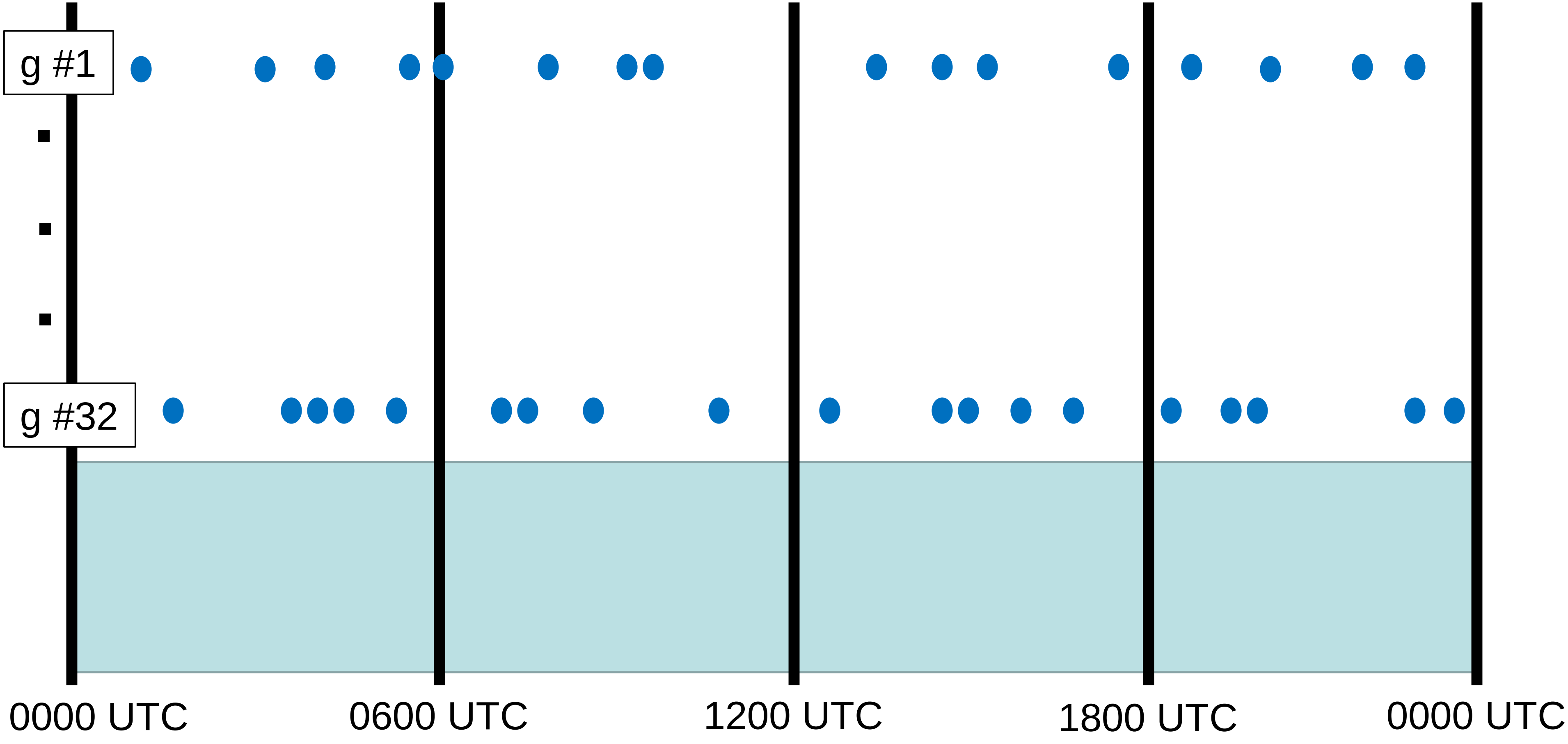
Mahoney et al. (2016)

Findings…

- Pigeon River Basin

Methodology

- Rainfall accumulation binned in 6-h periods



Methodology

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- Rainfall events (observed by the Duke GSMRGN)
  - Rank events by event total per gauge accumulation
  - Extreme (top 2.5%) rainfall events
  - Normal (middle 33%) rainfall events

Methodology

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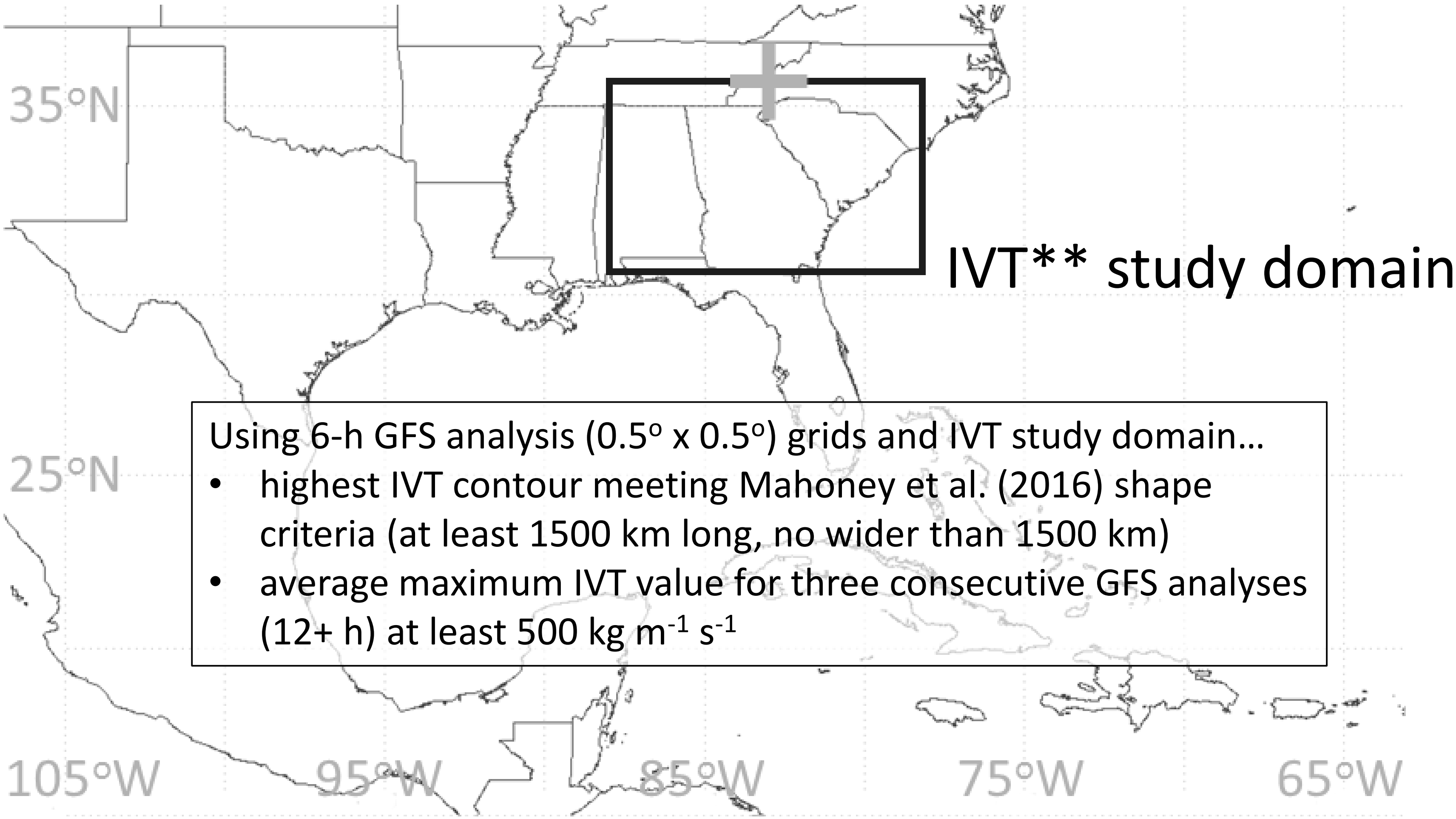
Asheville

- Investigate systematic differences between Extreme and Normal rainfall events ("Connections")
  - Atmospheric Rivers (ARs)
  - Observed flooding at Newport, TN river gauge
  - Storm event reports in TN, NC along common state border

Methodology



Using 6-h GFS analysis (0.5° x 0.5°) grids and IVT study domain…

- highest IVT contour meeting Mahoney et al. (2016) shape criteria (at least 1500 km long, no wider than 1500 km)
- average maximum IVT value for three consecutive GFS analyses (12+ h) at least 500 kg m^{-1} s^{-1}

IVT** = Integrated Vapor Transport (vapor movement in lowest layer)

Results

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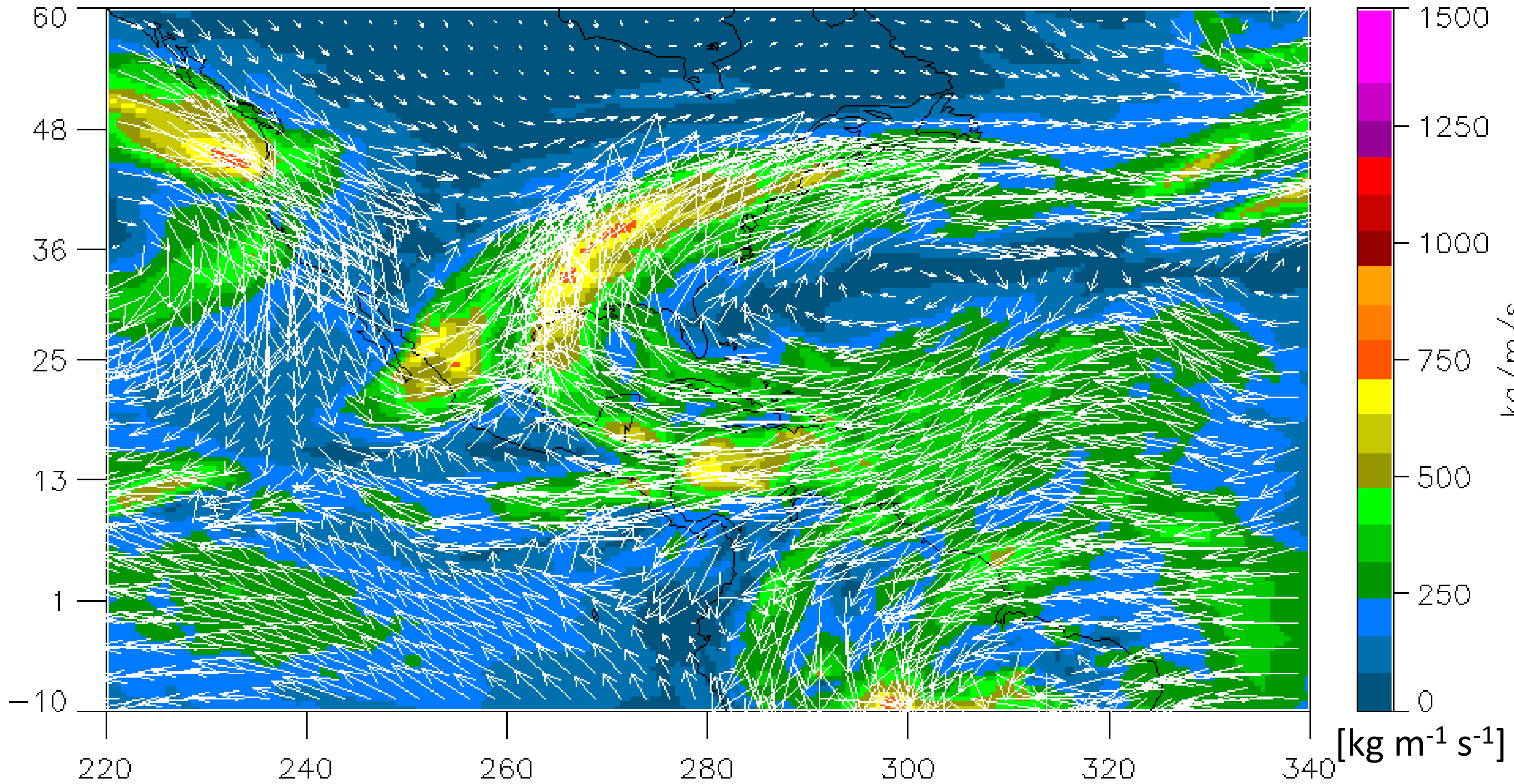
Integrated Vapor Transport



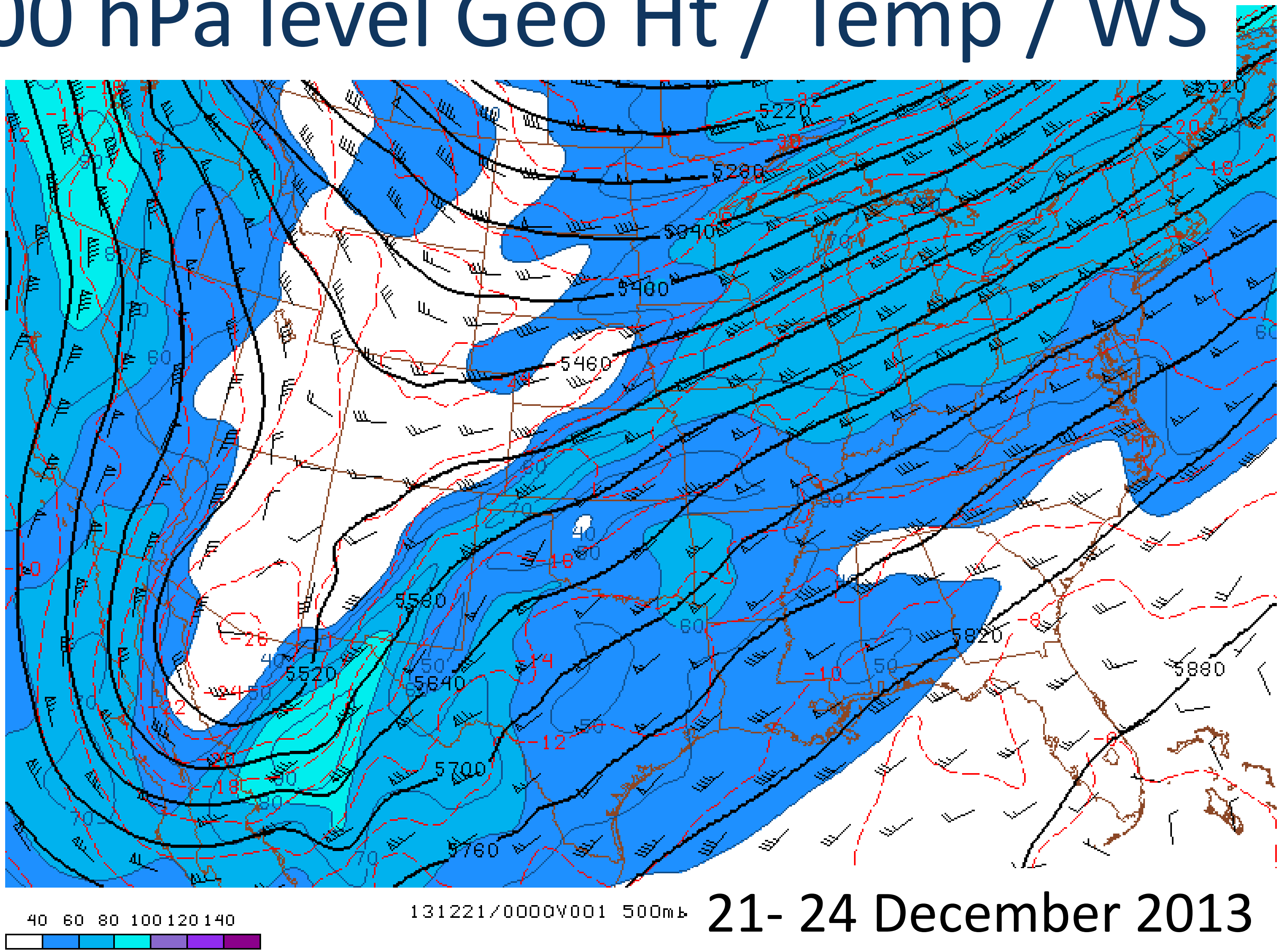
0000 UTC 21- 0600 UTC 24 December 2013

(moderate flooding)

GFS gridded analyses

NOAA - NOMADS

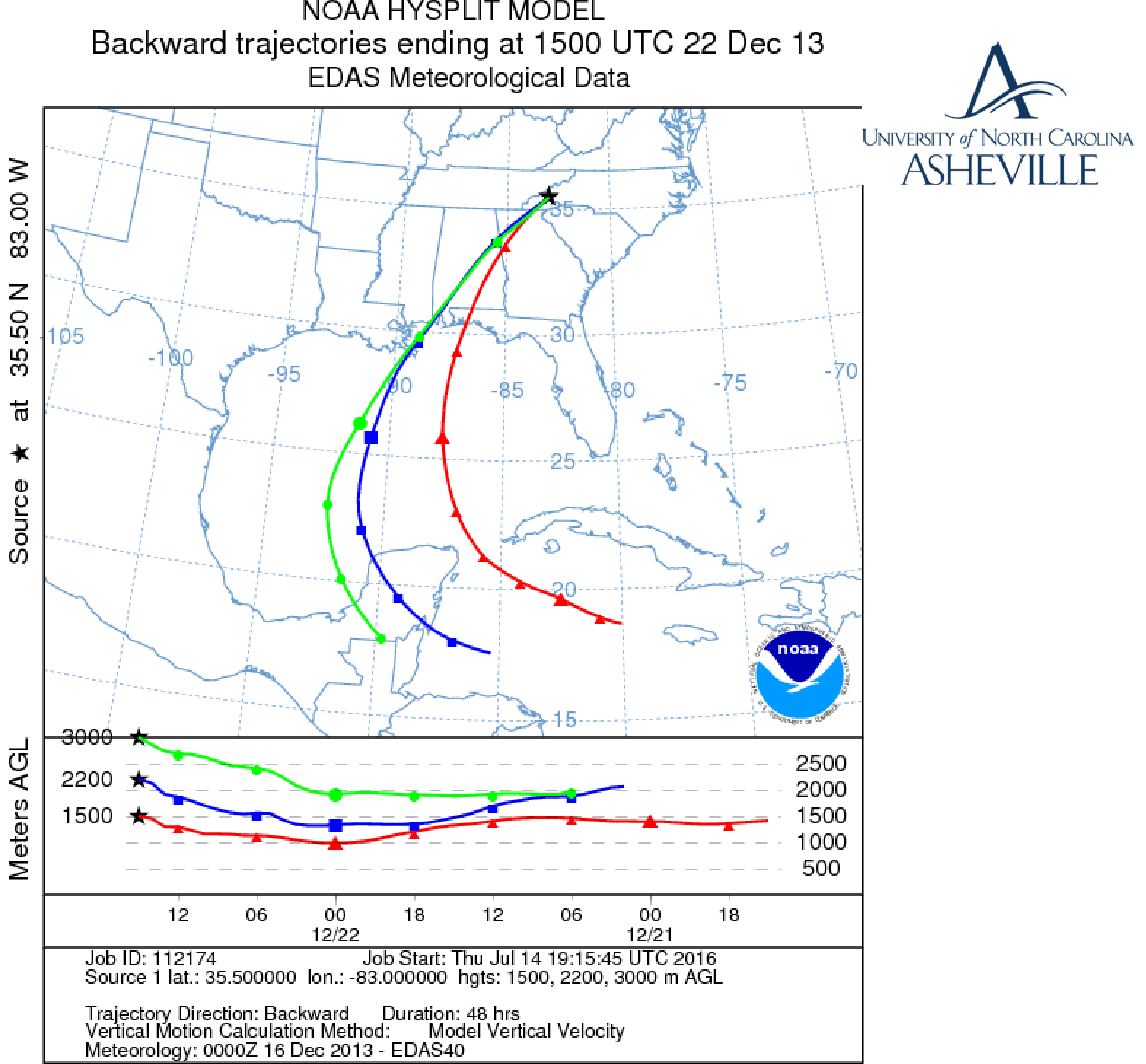
500 hPa level Geo Ht / Temp / WS



21- 24 December 2013

(moderate flooding)

NOAA - SPC


NOAA HYSPLIT MODEL
Backward trajectories ending at 1500 UTC 22 Dec 13
EDAS Meteorological Data
University of North Carolina Asheville
Source ★ at 35.50 N 83.00 W
Meters AGL
3000
2200
1500
2500
2000
1500
1000
500
12
06
00
12/22
18
12
06
00
12/21
18
Job ID: 112174
Job Start: Thu Jul 14 19:15:45 UTC 2016
Source 1 lat.: 35.500000 lon.: -83.000000 hgts: 1500, 2200, 3000 m AGL
Trajectory Direction: Backward
Duration: 48 hrs
Vertical Motion Calculation Method: Model Vertical Velocity
Meteorology: 0000Z 16 Dec 2013 - EDAS40

Findings

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- Do Atmospheric Rivers impact the southern Appalachians?
  - Half of Extreme events are AR-influenced
    - Most likely in cool season environments
      - Slow-moving high amplitude atmospheric wave
        - » Rapidly moving humid air at low-levels (from the Gulf of Mexico)
  - Extreme events having no AR-influence
    - Most likely in warm season environments
      - Cut-off low level cyclone southwest of southern Appalachians
        - » Low-level winds blow normal to mountains – orographically-enhanced precipitation

Findings

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- Do Atmospheric Rivers impact the southern Appalachians?
  - 12-25% ARs are associated with a societal hazard (flooding, flash flooding, heavy rainfall reports)
  - Normal rainfall events with an AR, <u>not</u> associated with a societal hazard? ["non-threatening" ARs]

Climatology [8-yr]

- Seasonal count of number of ARs impacting the IVT study domain using available 11463 GFS 6-h analysis periods of the 8-yr study (of 11688 maximum 6-h periods; 98.1% of a complete archive) [1 July 2009 – 30 June 2017].

Meteorological Season	AR Events	6-h Periods	Avg Duration (h)
Winter (DJF)	79	451	34.25
Spring (MAM)	49	258	31.59
Summer (JJA)	24	175	43.75
Autumn (SON)	40	247	37.05
Total/avg	192	1294	35.34

Findings…

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- Comparison between the Pigeon River Basin (PRB) and the Coweeta River Basin (CRB)…

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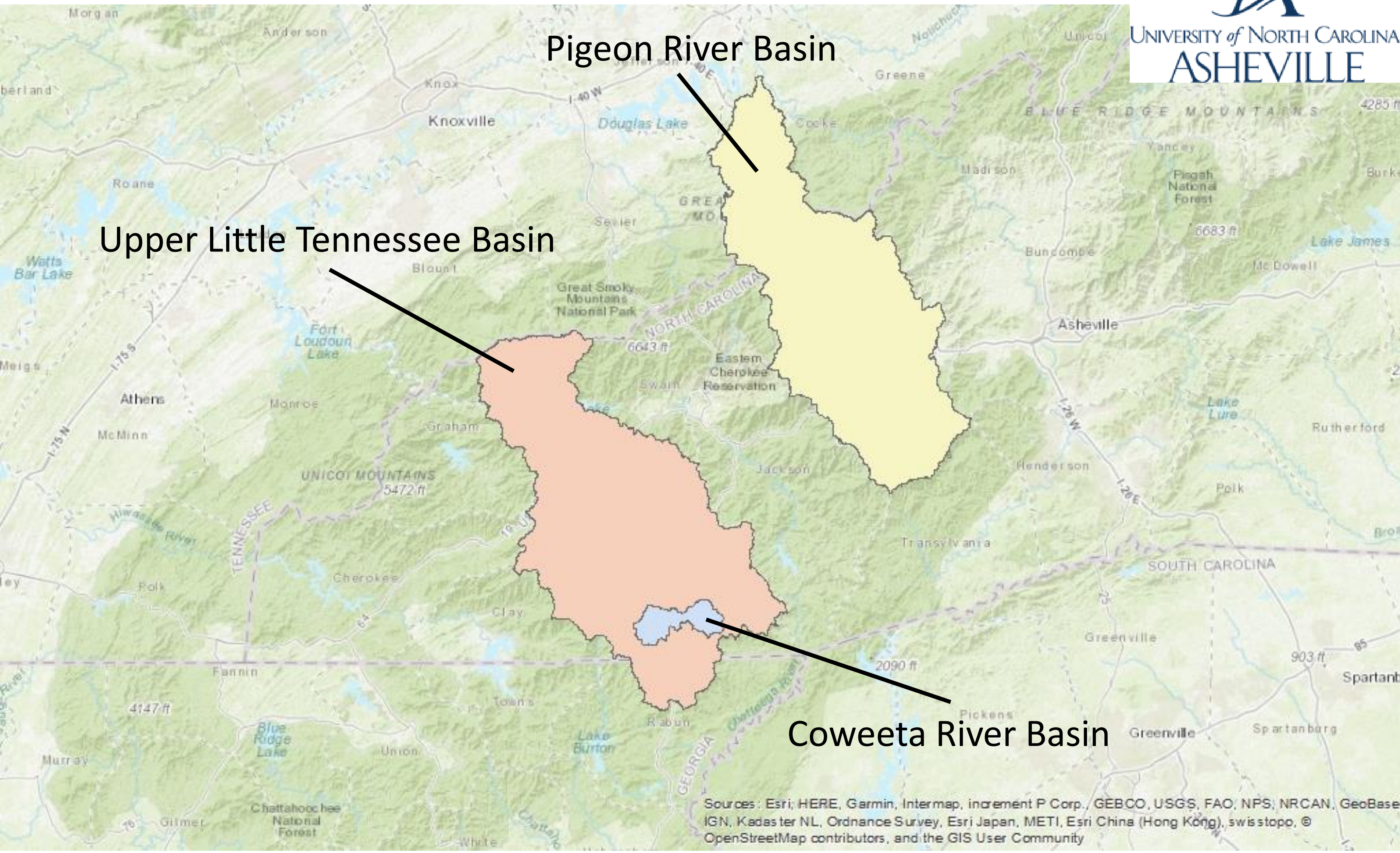

Methodology

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- Methodology
  - Pigeon River Basin – displaced north and west of the Blue Ridge escarpment
  - Coweeta River Basin – adjacent to the Blue Ridge escarpment

8-yr comparison; PRB v. CRB

- Results

  Number of extreme (top 2.5%) rain events of the 8-yr study [1 July 2009 – 30 June 2017].

River Basin	AR-influenced	TC-influenced	NOT AR- or TC-influenced	Total
Pigeon	23 (53.5%)	3 (7.0%) {Ida, Lee, Andrea}	17 (39.5%)	43
Coweeta	20 (83.3%)	2 (8.3%) {Ida, Lee}	2 (8.3%)	24

TC = tropical cyclone

8-yr comparison; PRB v. CRB

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- Results

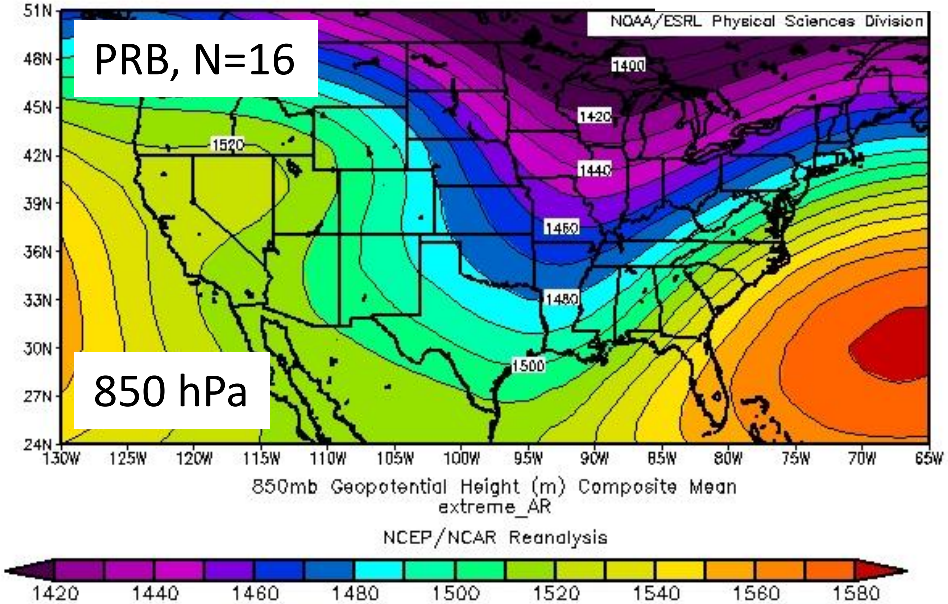
  Seven rainfall events qualify as extreme in the Coweeta River Basin and less-than-extreme in the Pigeon R.B.

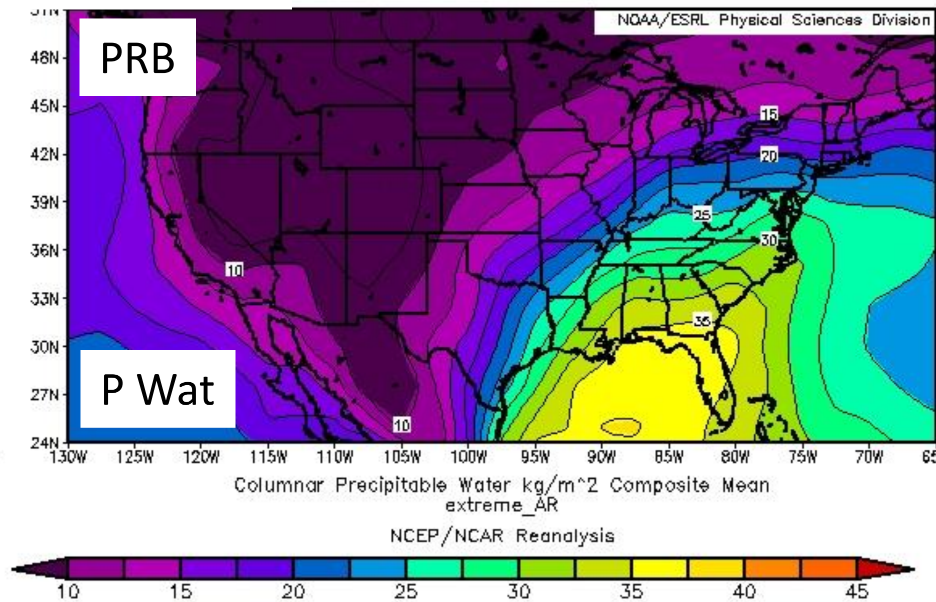
    - Six events = AR influenced (5 Feb 2012, 16 Apr 2011, 28 Nov 2011, 14 Oct 2014, 18 Nov 2015, and 3 Feb 2016)
    - One event = squall line and severe weather (26 Oct 2010)

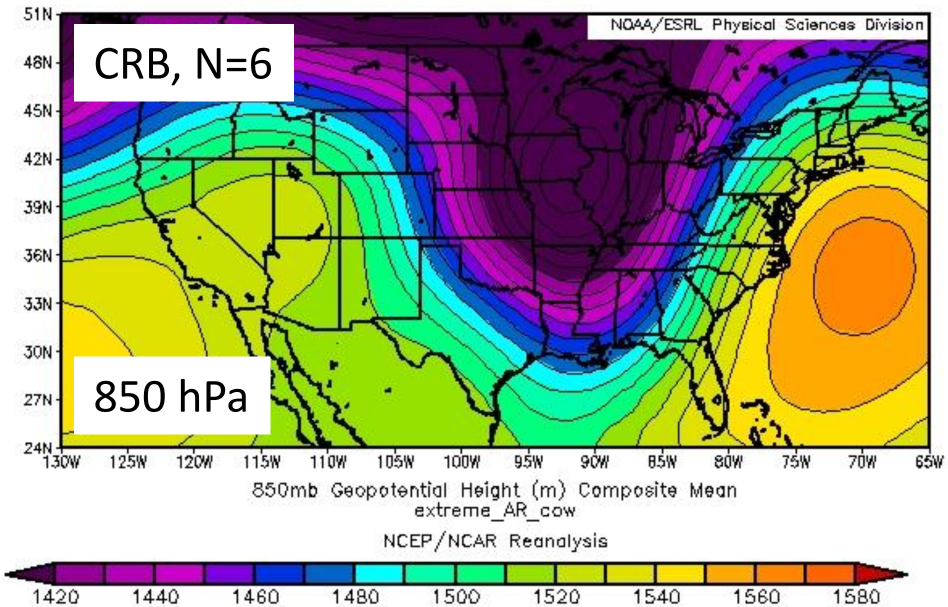
  Examination of geopotential height and precipitable water composite means and anomalies of

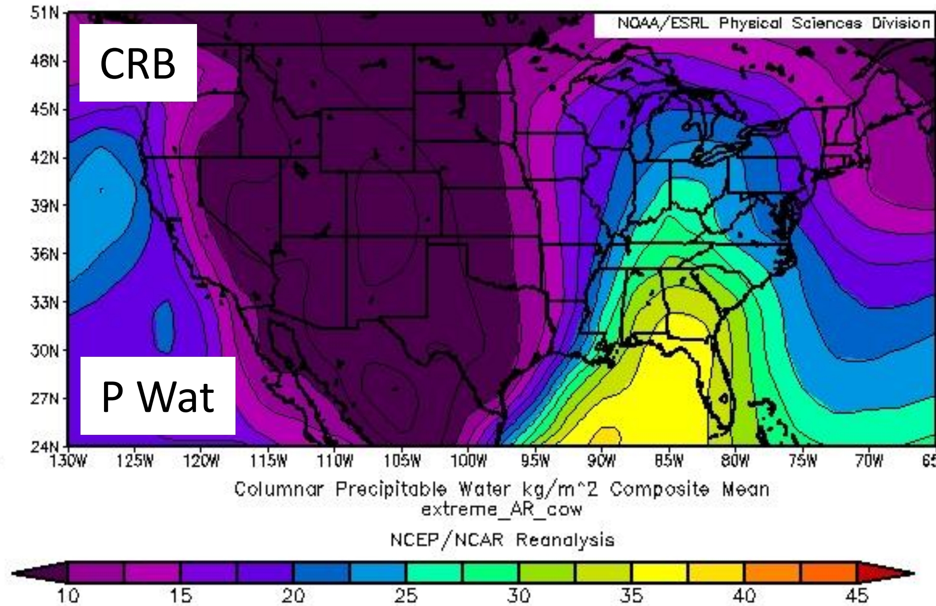
    - six AR-influenced extreme rainfall events (CRB)
    - 16 AR-influenced extreme rainfall events (PRB, Miller et al. 2018)

Composite means

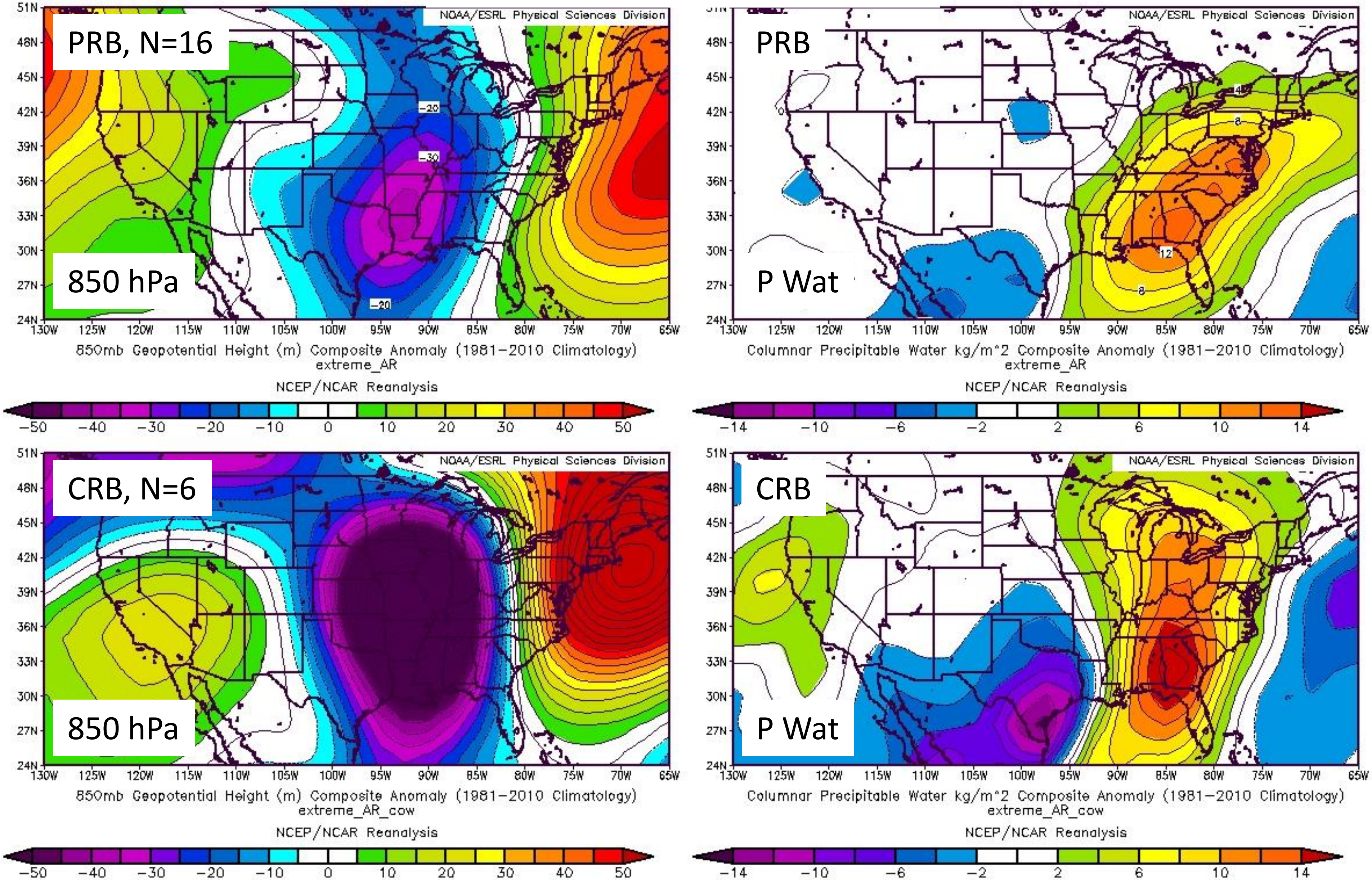








Composite anomalies



8-yr comparison; PRB v. CRB

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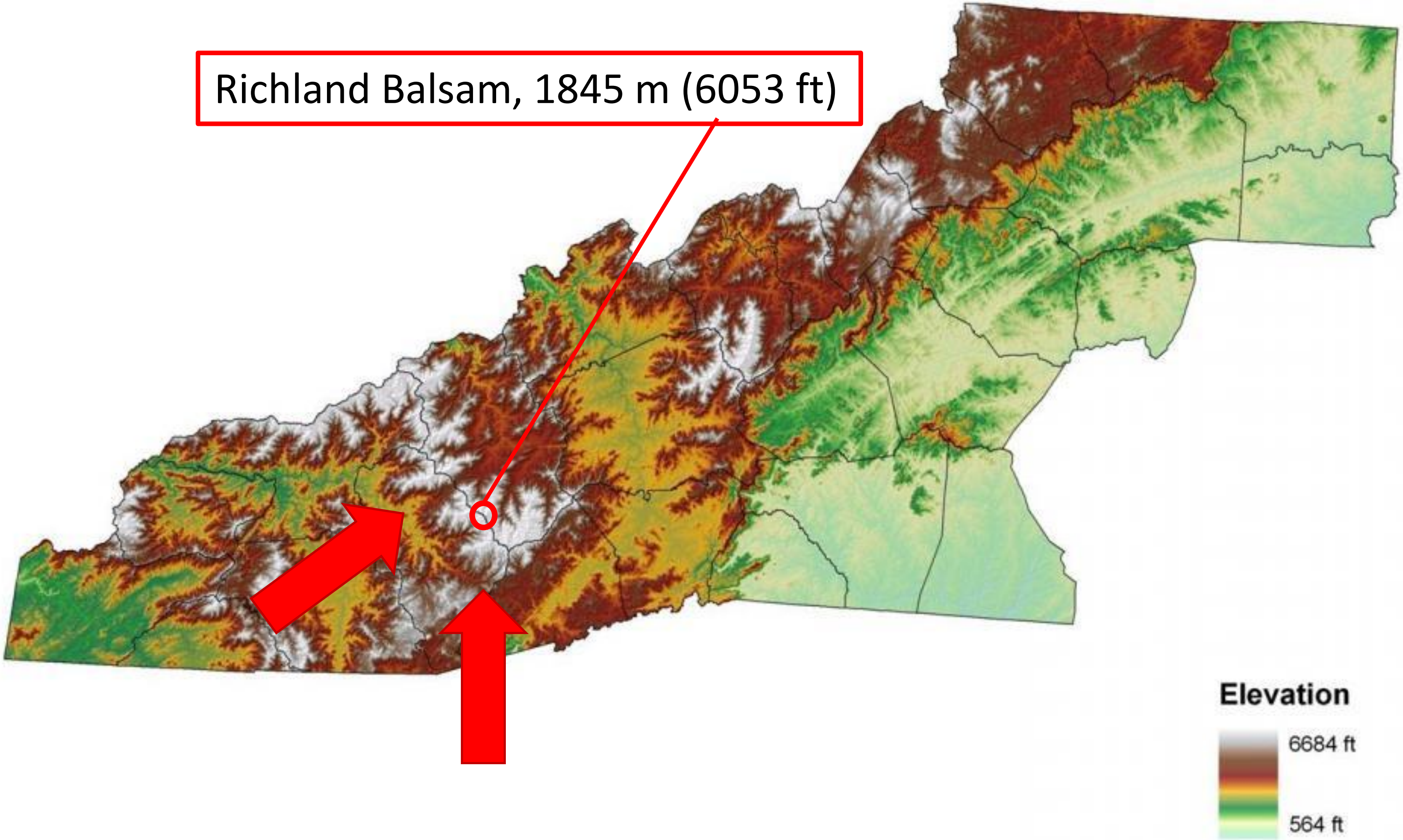
- Results
  - Disagreement between two river basins on ‘extreme’ events
    - Much smaller record (8-yr [v. 82-yr]) in the Pigeon River Basin
    - Difference in position relative to the Blue Ridge escarpment
    - Relative landform homogeneity of the Coweeta River Basin; 8-9 [32] gauges spread over 16.26 km^2 [1823 km^2, PRB]
  - Composite weather AR pattern differences
    - Southwesterly flow favors extreme events in the PRB
    - Southerly flow inhibits extreme events in the PRB



http://www.wncvitalityindex.org/topography/mountain-topography-and-geomorphology

Future…

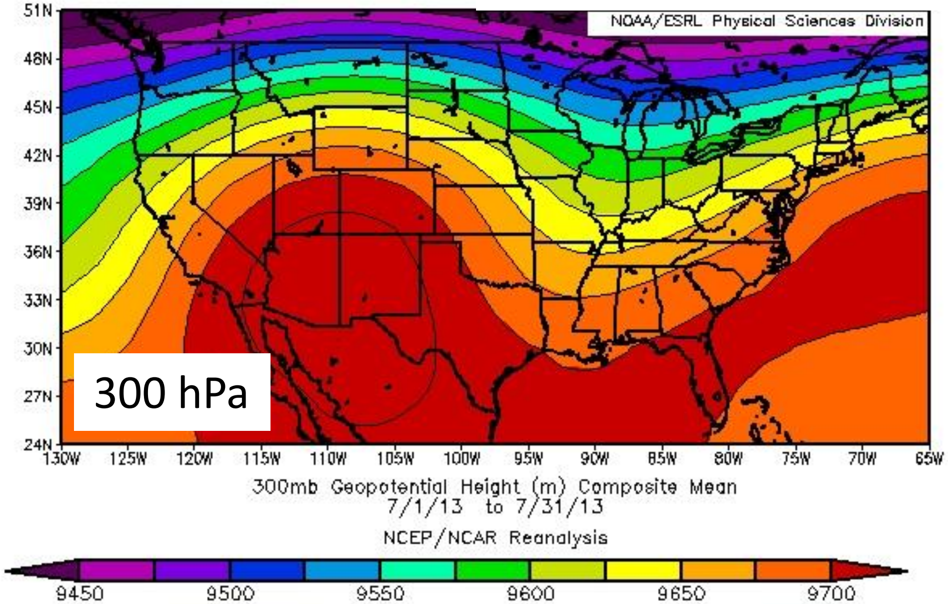
- Hypothesis; another way Atmospheric Rivers can cause a disruption in the southern Appalachian Mountains…

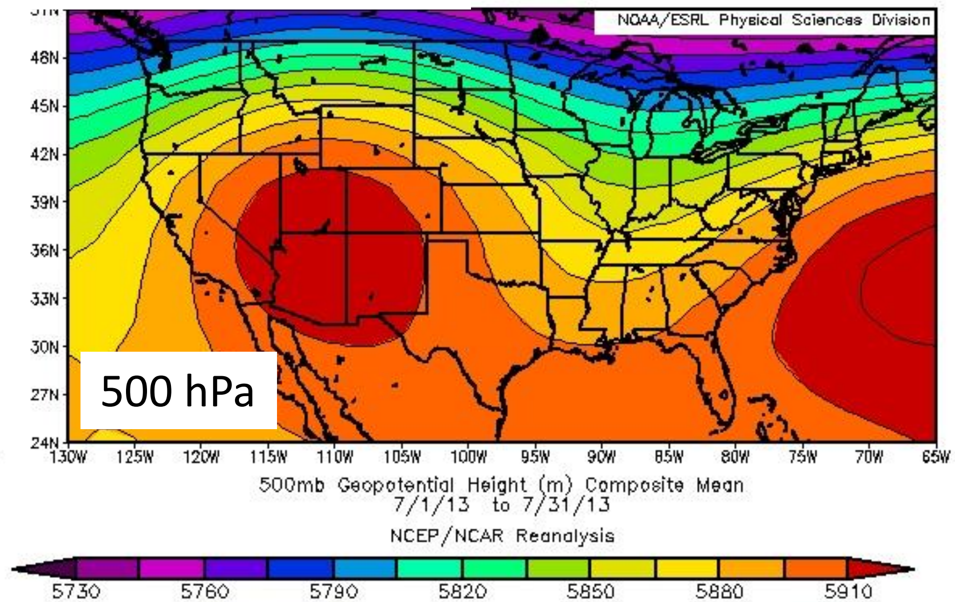
Future

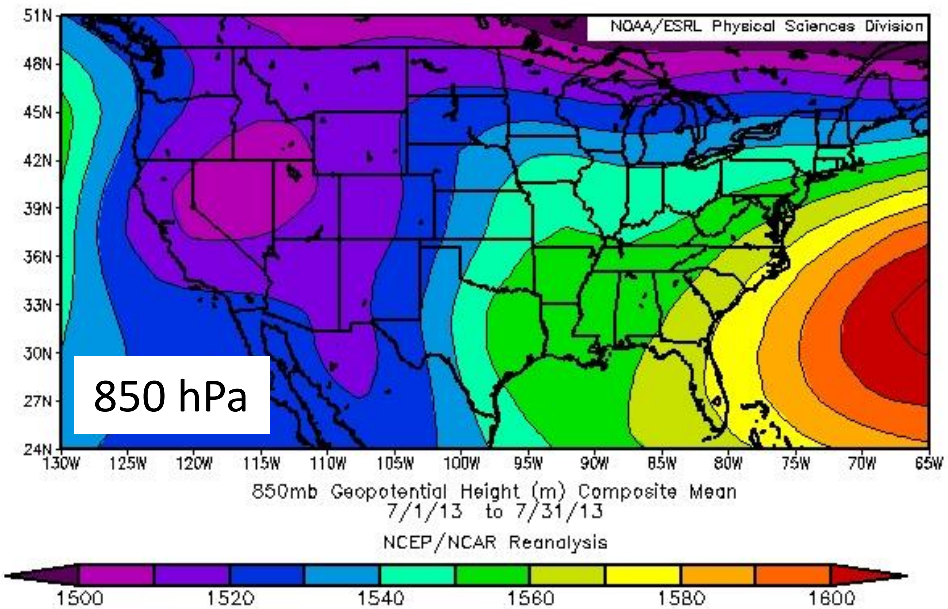
- Methodology
  - Longer time-scale precipitation events; Elevated Rain Time Clusters [ERTCs]

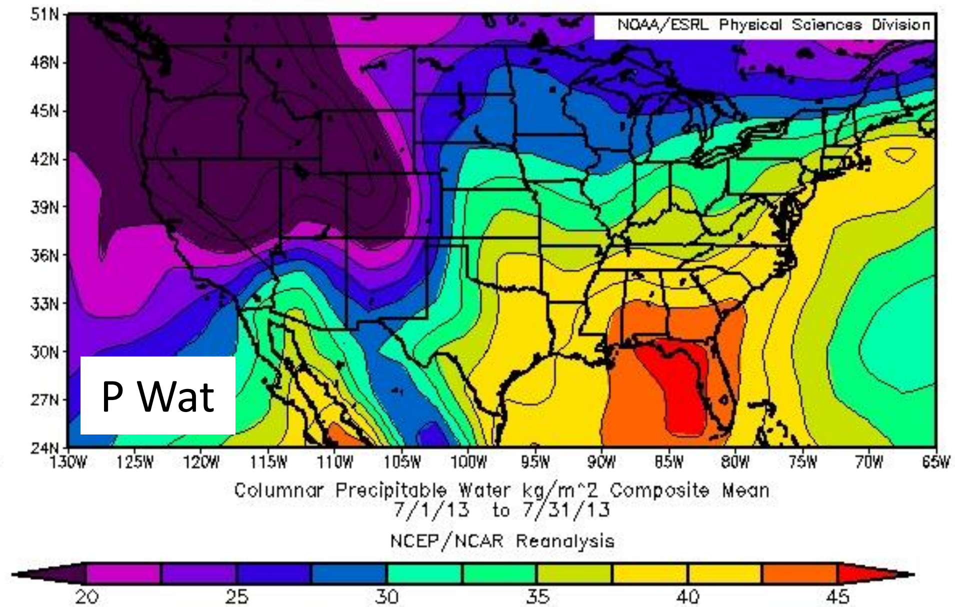
Δt = 30-h

Composite means – July 2013

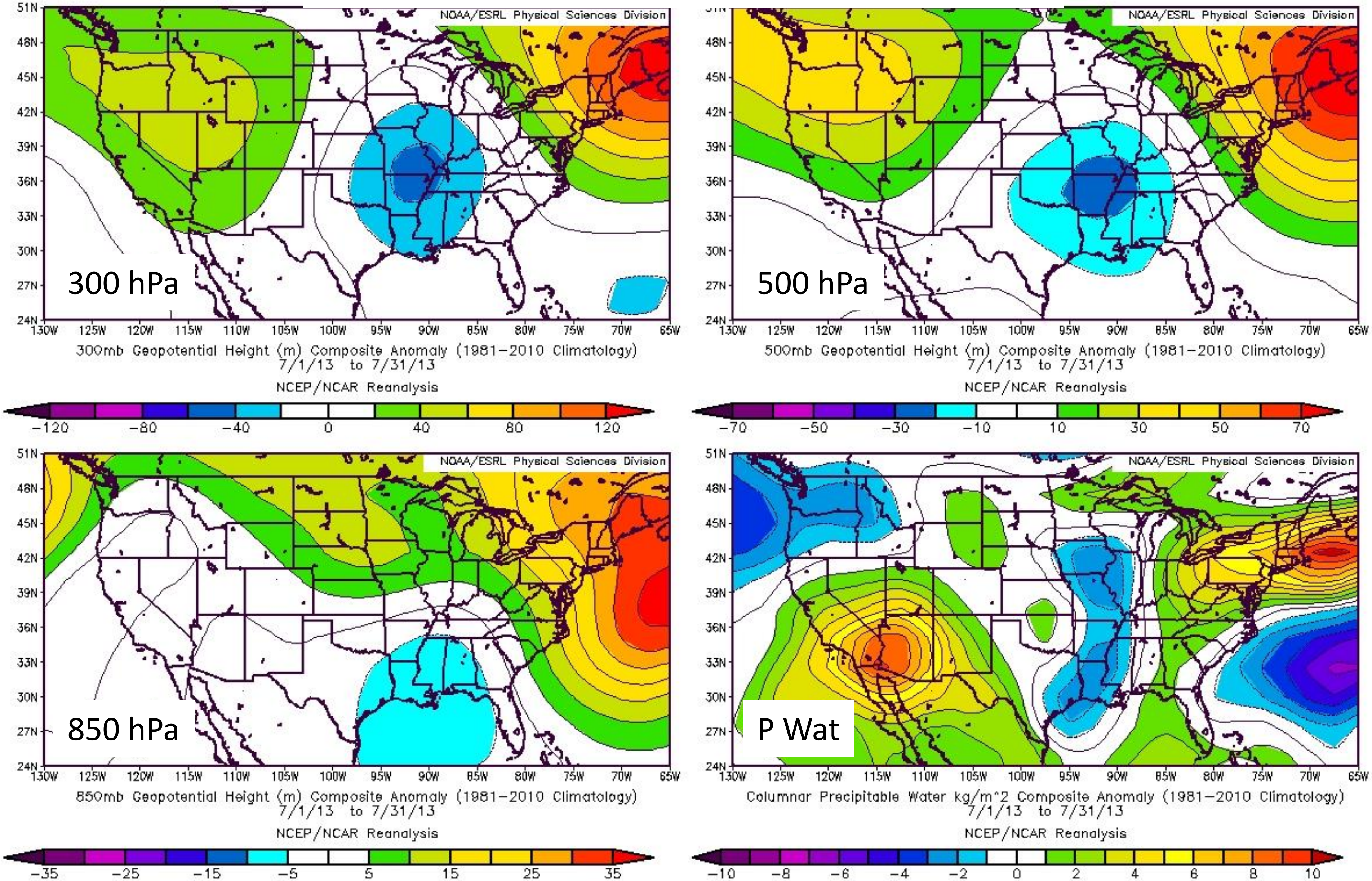




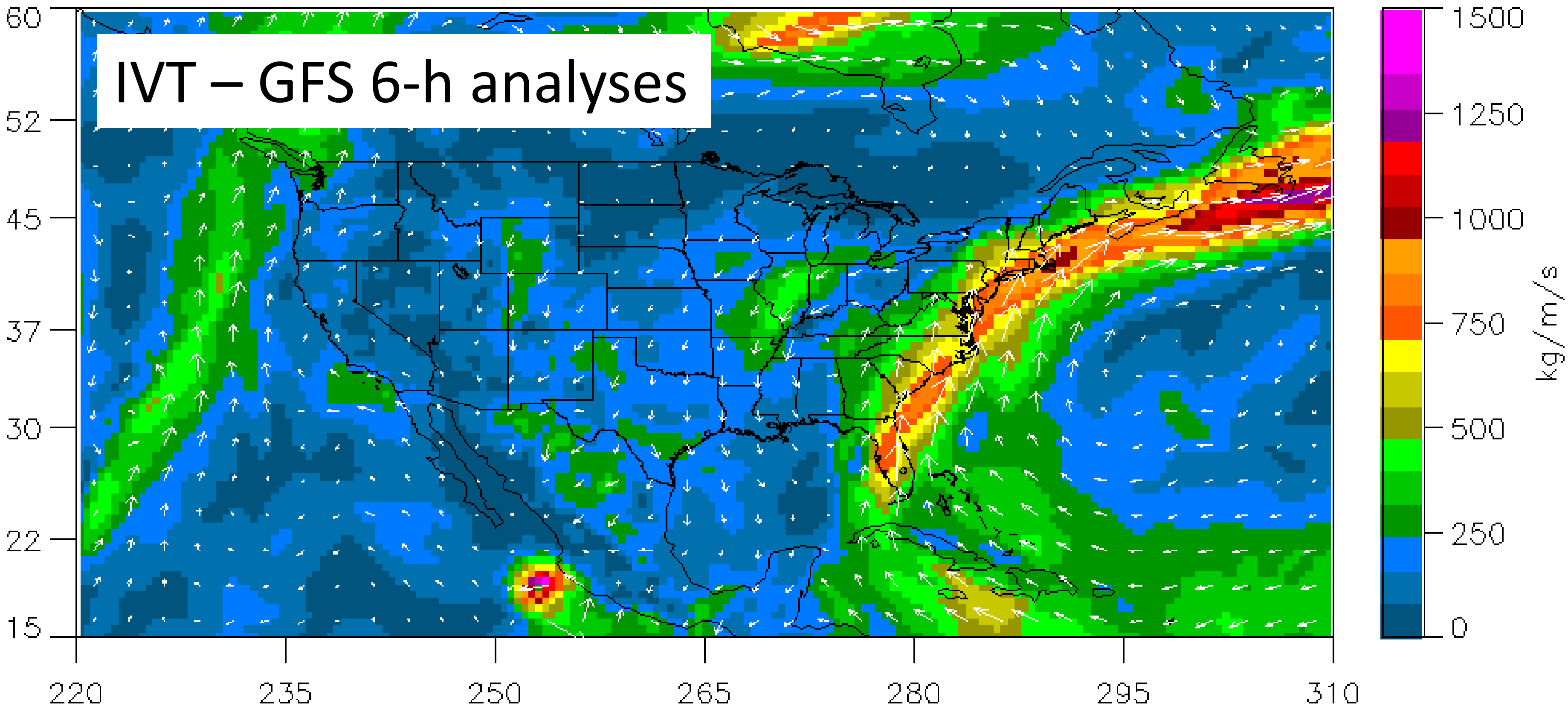




Composite anomalies – July 2013



Future – mud slides, debris flows



0000 UTC 2 July 2013

Future…

- ‘Maya Corridor’ hypothesis
  - ridge-building provided via the diabatic process of latent heat release as the sub-tropical moisture of the ARs was converted to cloud water and precipitation
  - as the ridge continued to build, the large-scale weather pattern became increasingly stagnant
  - repeated propagation of successive ARs over the same pathway and increased ridge-building through continued latent heating
  - provided a mechanism for ‘training’ rainfall events over the southern Appalachian Mountains that pre-conditioned the soil and/or triggered landslides

Future…

University of North Carolina Asheville

- Warm season studies (Duke GSMRGN is now past 10 year mark)
  - Regional WRF simulation of July 2013 – impact of diabatic heating – confirm/refute Maya Corridor hypothesis
  - Identify convection "hot spots" in the PRB with events stratified by the 850 – 700 hPa layer winds
  - Systematic change of the initiation time of convection in the PRB?

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Near Purchase Knob, credit: Michael Goldsbury

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- Details of slides #10 – 41 are described in Chapter 11 of the book to be published in 2020…