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Learning EAS from BOREAS

a BOREAS grad’s (?) experience of how FIFE and BOREAS changed the world

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How FIFE and BOREAS Changed the World

6 – 7 October, 2016

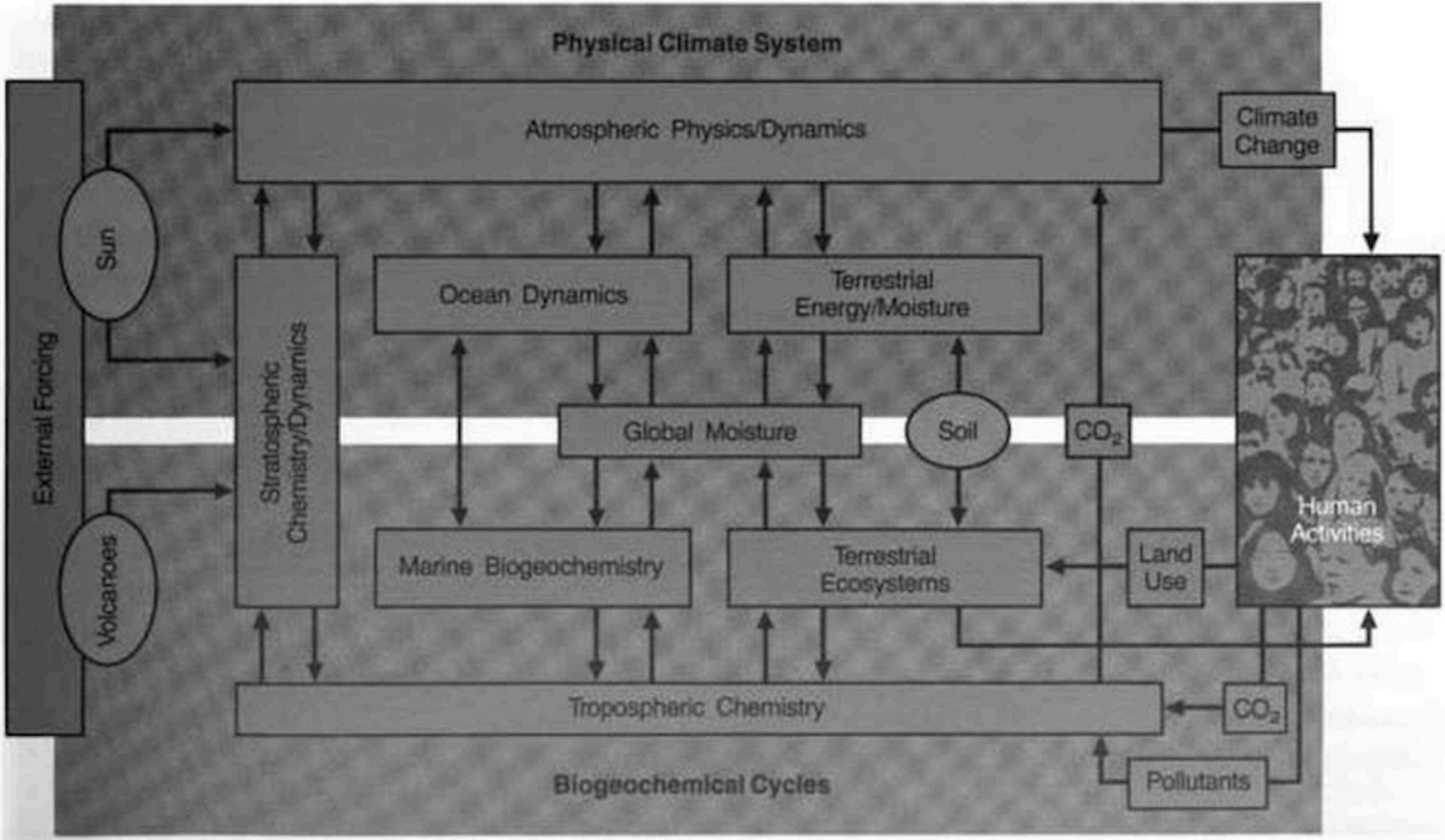
NASA Goddard Space Flight Center

BOREAL ECOSYSTEM - ATMOSPHERE STUDY

BOREAS

My trajectory to BOREAS

- (“You were in BOREAS?”)
- Physics undergrad – graduated during FIFE
- Grad student in astrophysical, planetary and atmospheric science @ U. Colorado – found a copy of Bretherton, “Earth System Science: A Closer View”


Physical Climate System
Atmospheric Physics/Dynamics
Climate Change
External Forcing
Sun
Volcanoes
Stratospheric Chemistry/Dynamics
Ocean Dynamics
Terrestrial Energy/Moisture
Global Moisture
Soil
CO_2
Human Activities
Marine Biogeochemistry
Terrestrial Ecosystems
Land Use
Tropospheric Chemistry
CO_2
Pollutants
Biogeochemical Cycles

Where could you find observational earth system science in the early 1990s?

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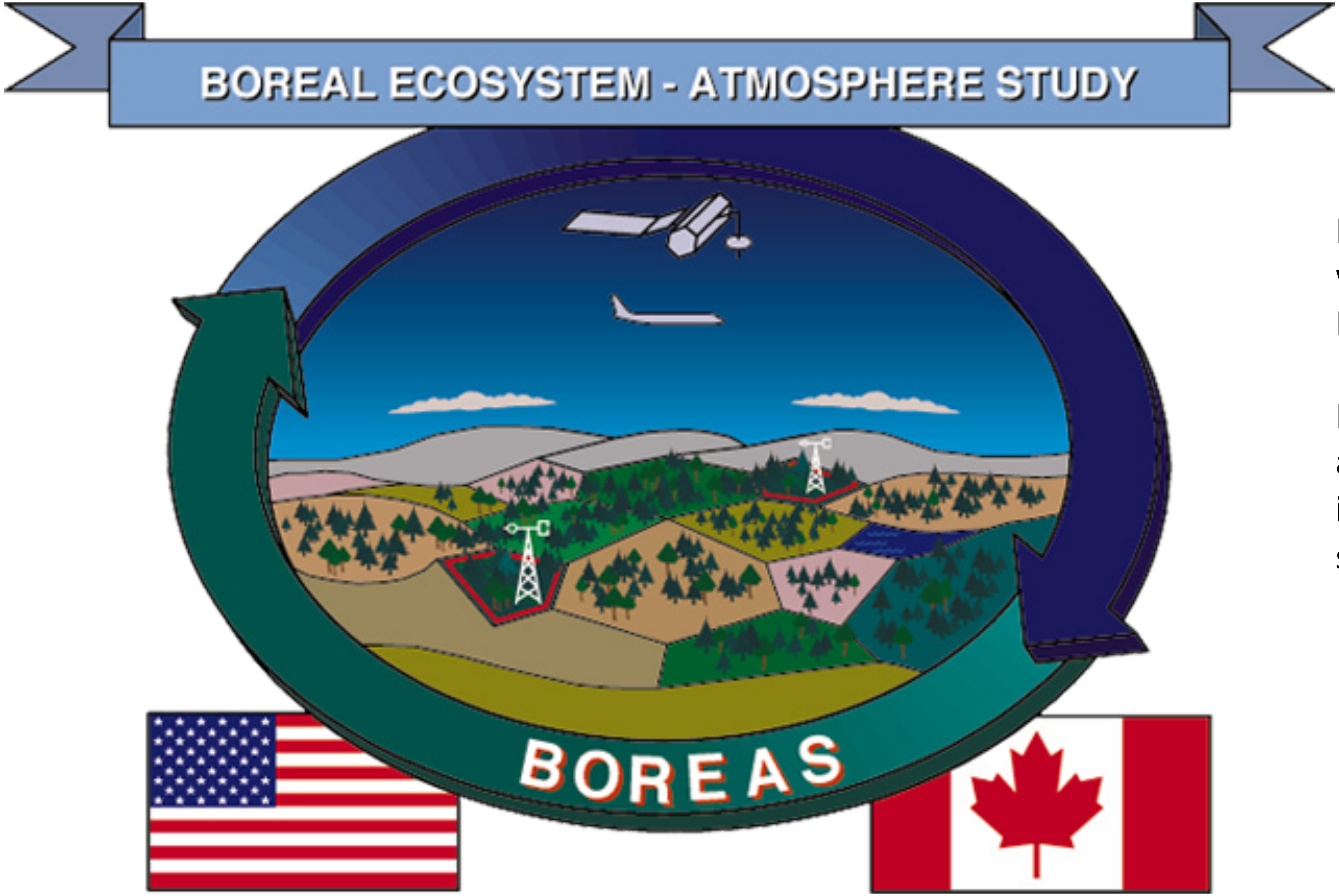

I joined as a postdoc working with Don Lenschow at NCAR.

I first did a little FIFE data analysis, having been introduced to the data set by Bob Grossman.

BOREAS - among other things, a training program for a new generation of earth scientists

- I watched ”senior scientists” from different disciplines learning to speak with each other.
- I learned to take such interdisciplinary communications for granted.
- FIFE and BOREAS helped to create a new discipline, a natural discipline – earth system science.

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My BOREAS experience

- BOREAS (and FIFE) led to a great deal of scientific and community development progress
- But they also pointed beyond their (my) scope (and ability).
- These experiments opened our eyes to many objectives that BOREAS and FIFE (and I) alone couldn’t accomplish.
- They motivated future work for many ongoing careers.

AFM-13(?)

- Don Lenschow, NCAR, PI

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- Team: Steve Oncley, Jakob Mann, Ken Davis, Jielun Sun, Al Cooper, Teresa Campos, Gerhard Ehret, Andreas Giez, Christoph Kiemle.
- Eddy covariance and boundary layer analyses, disjunct flux sampler, CO2 instrumentation, water vapor lidar.

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- Don Lenschow, NCAR, PI
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- Team: Steve Oncley, Jakob Mann, Ken Davis, Jielun Sun, Al Cooper, Teresa Campos, Gerhard Ehret, Andreas Giez, Christoph Kiemle.
- Eddy covariance and boundary layer analyses, disjunct flux sampler, CO_2 instrumentation, water vapor lidar.
- Bugs? Just on the windshield of the Electra. (some bits of Scott Goetz on our windshield?) (You were in BOREAS?)

AFM-13 research objectives

1. Tie together the North and South study areas. Fly the entire transect. Upscale the study areas into one large boreal forest region.
   - Nice idea, very ambitious given the number of disciplines and groups that would need to be bridged.
2. Document atmospheric boundary layer development and its interaction with surface fluxes.

Flux mapping

Oncley, S.P., D.H. Lenschow, K.J. Davis, T.L. Campos and J. Mann, 1997: Regional-scale surface flux observations across the boreal forest during BOREAS. *J. Geophys. Res.*, 102, 29147-29154.

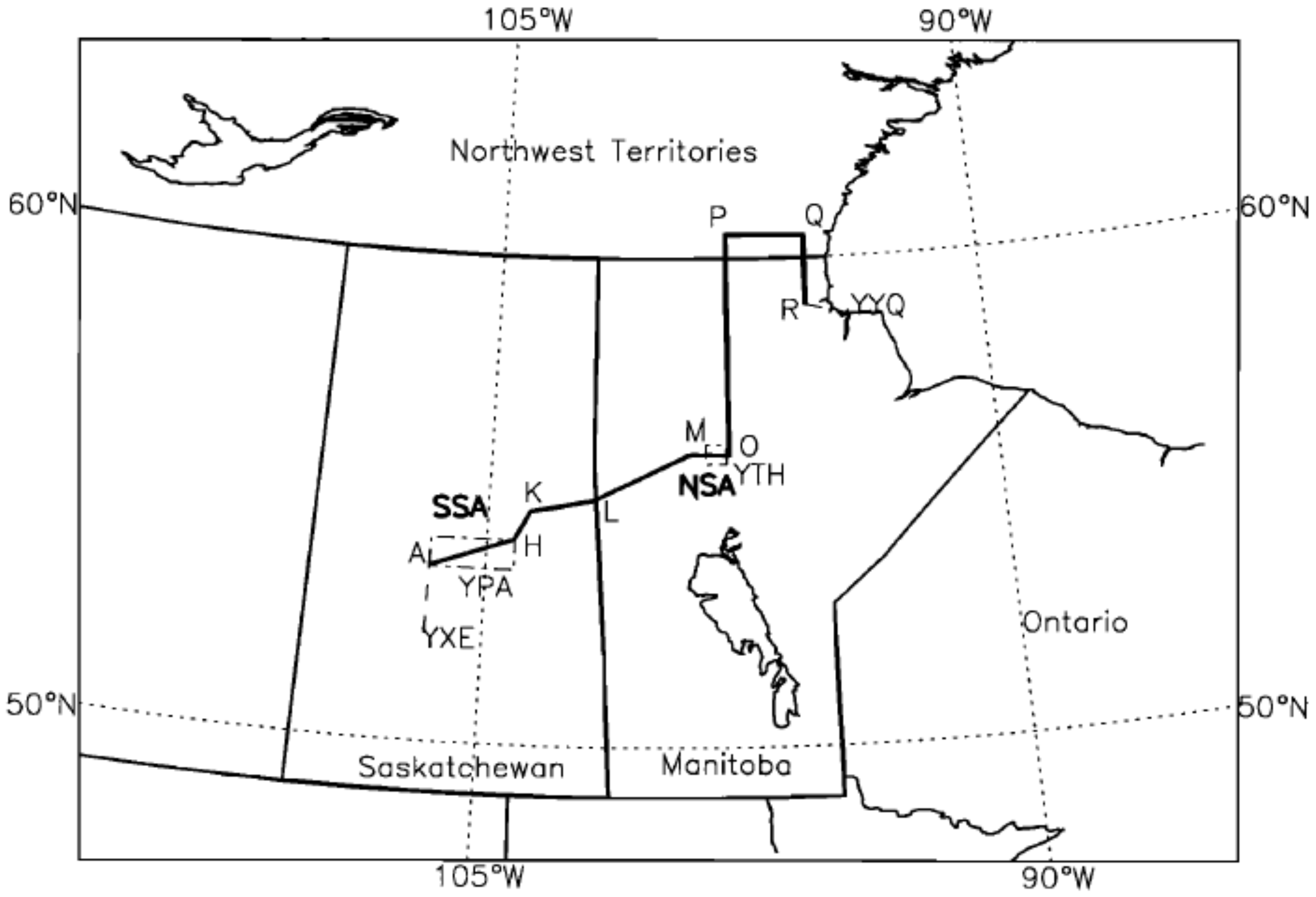

Figure 1. Flight pattern of the Electra during BOREAS. Most flights were on this track which started at Saskatoon, Saskatchewan (YXE), passed through the BOREAS southern study area (SSA) near Prince Albert (YPA), continued along a transect to the northern study area (NSA) near Thompson, Manitoba (YTH), and overflew the subarctic tundra on the way to Churchill (YYQ). Turns were made only at the points (A, H, K, L, M, O, P, Q, and R).

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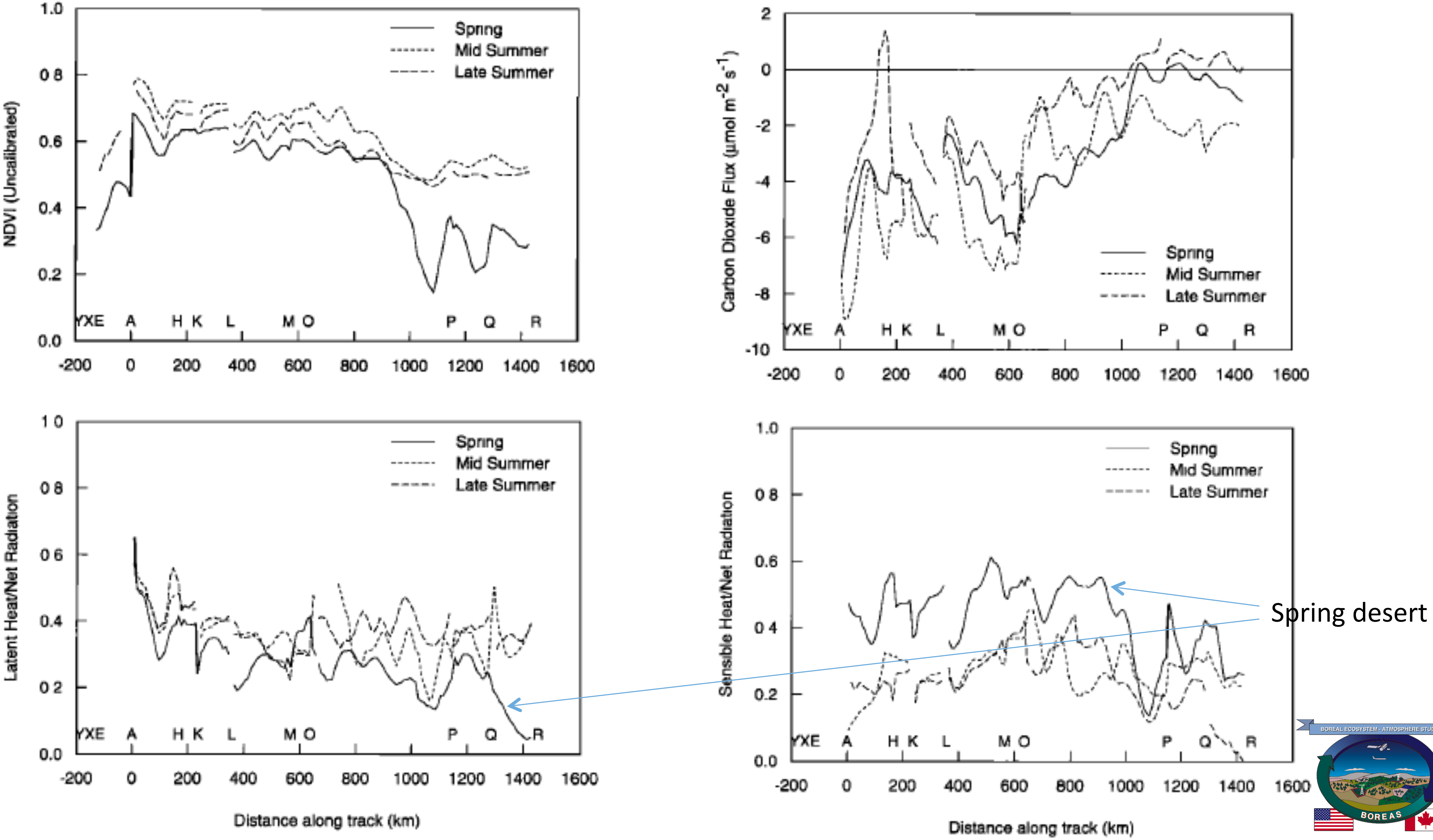
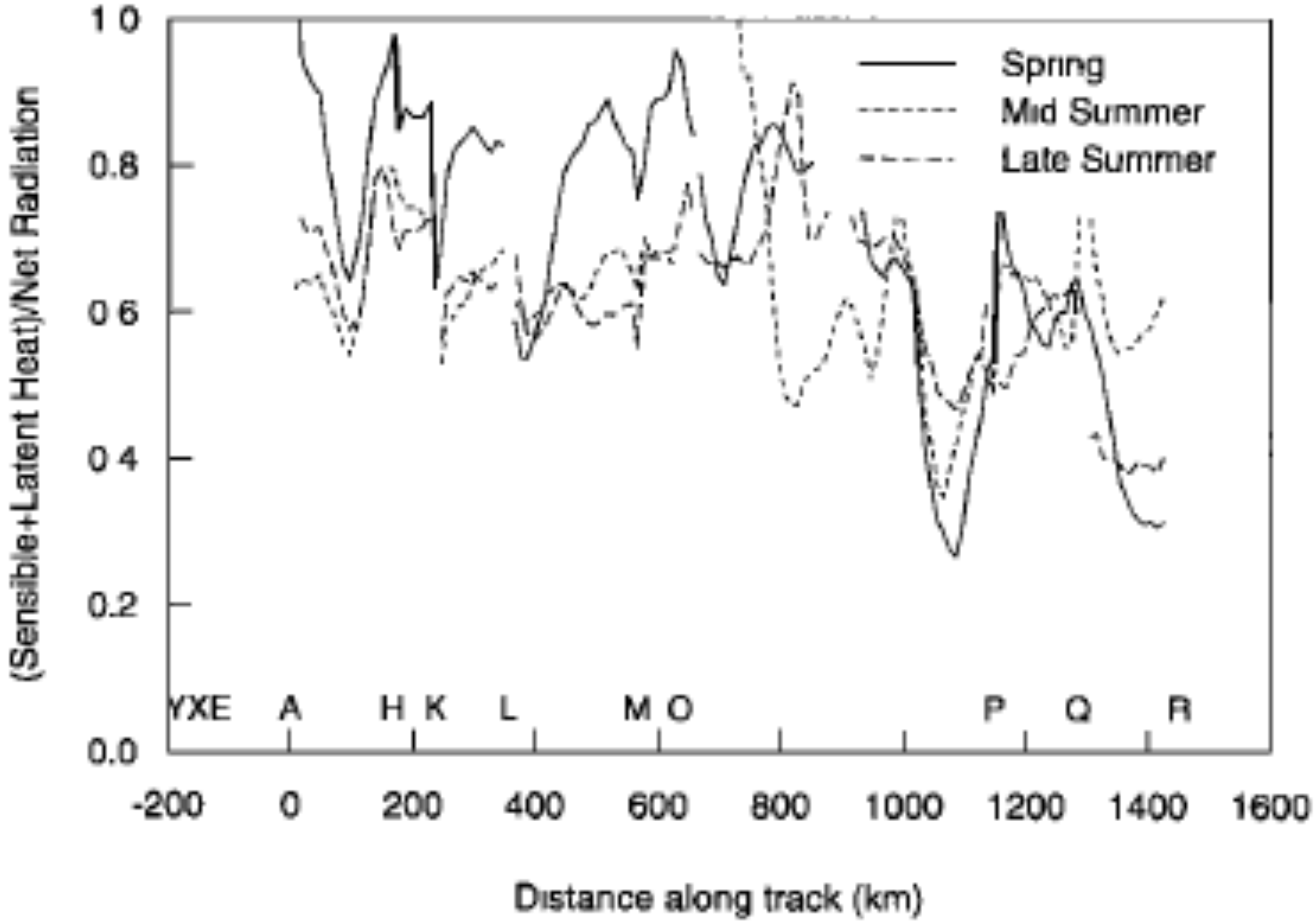
Oncley et al, 1997

Fireweed
Churchill, Manitoba
July, 1994


NDVI (Uncalibrated)
Spring
Mid Summer
Late Summer
YXE A H K L M O P Q R
Carbon Dioxide Flux (µmol m-2 s-1)
Spring
Mid Summer
Late Summer
YXE A H K L M O P Q R
Latent Heat/Net Radiation
Spring
Mid Summer
Late Summer
YXE A H K L M O P Q R
Distance along track (km)
Sensible Heat/Net Radiation
Spring
Mid Summer
Late Summer
YXE A H K L M O P Q R
Distance along track (km)
Spring desert



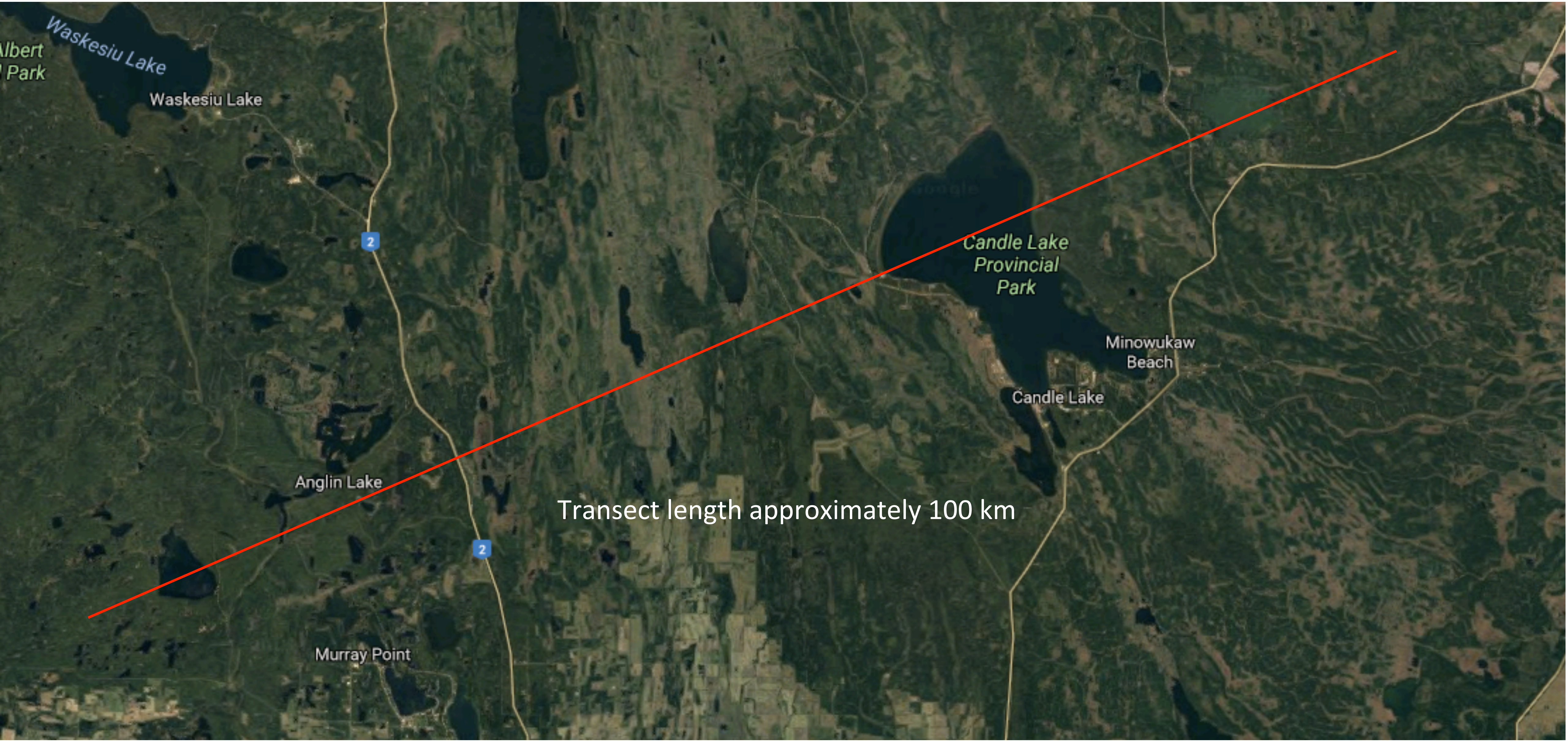
Residual highly correlated with lake fraction.

ABL flux profiles and ABL development

Davis, K. J., D. H. Lenschow, S. P. Oncley, C. Kiemle, G. Ehret and A. Giez, 1997: The role of entrainment in surface-atmosphere interactions over the boreal forest. *J. Geophys. Res.*, 102, 29219-29230.

Kiemle, C., G. Ehret, A. Giez, K. J. Davis, D. H. Lenschow and S. P. Oncley, 1997: Estimation of boundary-layer humidity fluxes and statistics from airborne DIAL. *J. Geophys. Res.*, 102, 29189-29204.

Approximate NCAR Electra flight pattern across the Southern Study Area



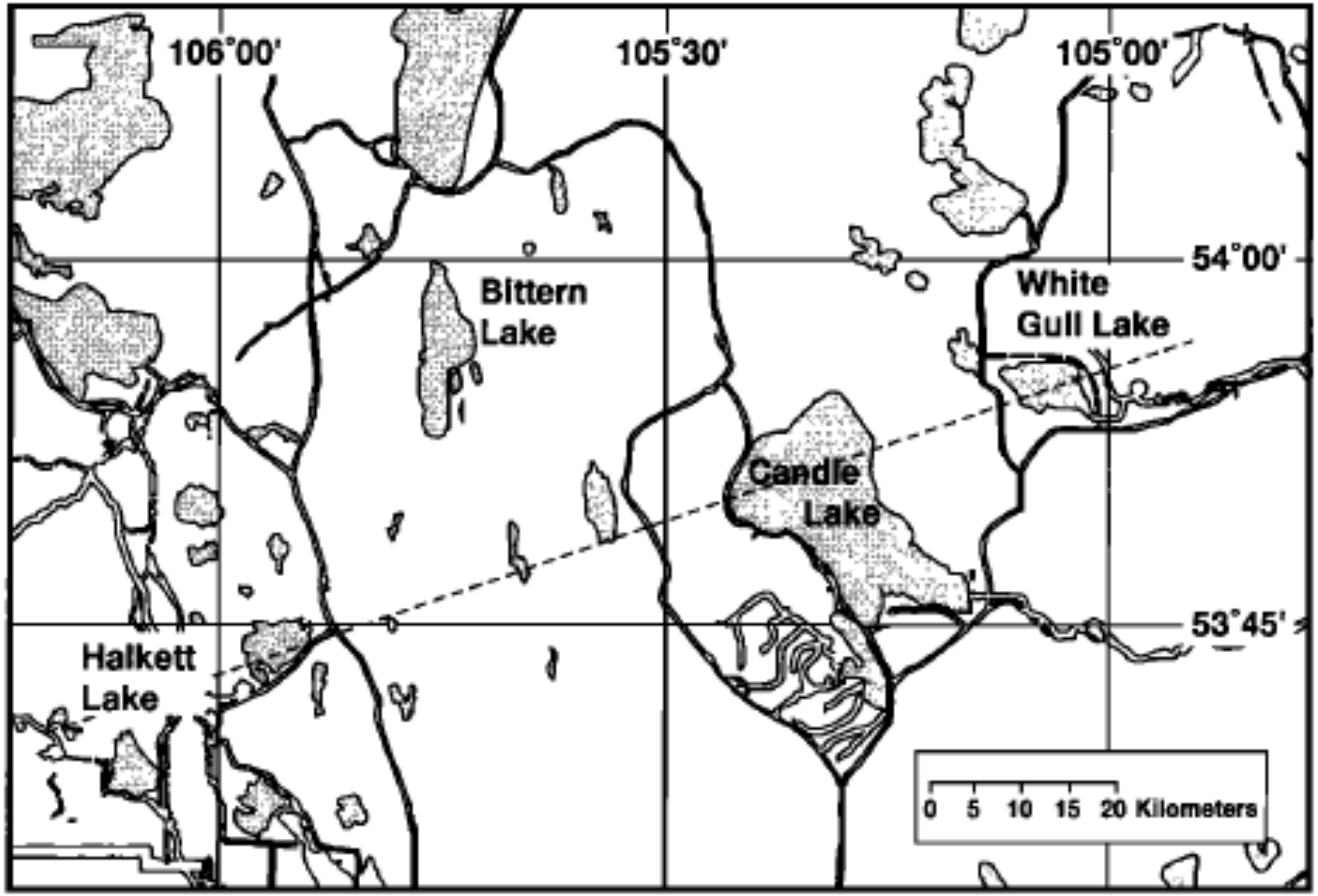
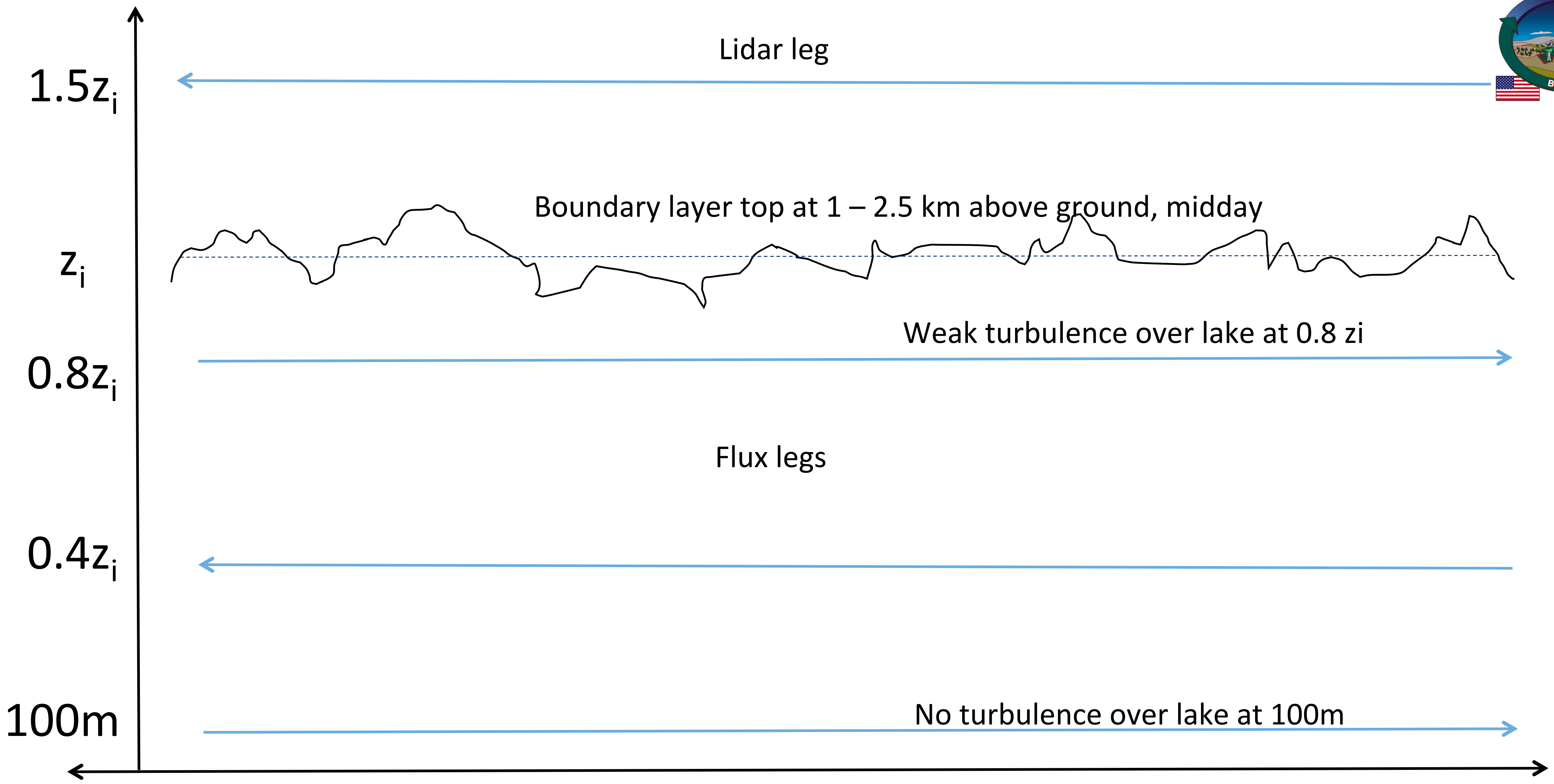


Figure 1. Schematic of Candle Lake flight track.

Sun et al., 1997



Typical NCAR Electra ABL “stack” pattern over the Southern Study Area

Transect length about 100 km

Table 1. Catalogue of Vertical Stack Patterns Flown Over the Boreal Forest by the NCAR Electra During BOREAS

Stack	Day	Time, LST	L, m	w_*, ms^{-1}	u_*, ms^{-1}	$\bar{\theta}_v$, K	$\bar{u}$, ms^{-1}	z_i, m	σ_{z_i}, m	A_r	Q_r	$\bar{h}/h_0 - 1$	$\Delta h/h_0$	Clouds, %
1	145	9.5	−62	2.2	0.51	297.9	6.5	1970	···	0.28	2.8	···	···	2
2	145	12.0	−46	2.4	0.49	299.2	6.3	2050	···	0.14	1.6	···	···	12
3	145	14.4	−46	2.2	0.46	300.1	6.5	2110	129	0.10	2.3	0.116	0.264	18
4	150	9.2	−41	1.9	0.43	294.4	5.7	1400	···	−0.39	3.2	···	···	1
5	150	12.2	−33	2.2	0.42	295.9	6.4	2000	···	−0.18	10.3	···	···	33
6	150	14.4	−12	2.1	0.27	297.0	5.9	2170	···	−0.07	1.0	···	···	30
7	151	10.1	−3	2.2	0.18	295.5	3.1	1960	108	0.02	3.0	0.102	0.211	0
8	151	15.5	−3	2.3	0.18	297.7	3.3	2320	151	−0.14	0.3	0.132	0.267	1
9	157	12.7	−35	1.9	0.45	293.3	6.4	1110	74	−0.38	0.6	0.131	0.259	0
10	160	13.8	−2	2.4	0.15	302.8	0.9	2480	···	0.11	1.0	···	···	0
11	200	10.3	−73	1.4	0.45	300.7	7.1	910	···	−0.31	1.9	···	···	14
12	200	13.3	−45	1.5	0.35	302.3	7.2	1470	···	−0.42	7.2	···	···	30
13	201	13.4	−12	2.1	0.29	304.0	4.7	2020	156	0.08	1.1	0.138	0.414	8
14	201	15.5	−38	2.0	0.38	306.7	7.0	2090	96	0.46	−0.9	0.061	0.147	0
15	212	9.5	−1	1.1	0.08	303.0	2.4	630	···	−0.78	18.5	···	···	12
16	212	12.6	−2	1.4	0.13	305.0	2.8	930	···	−0.46	1.8	···	···	21
17	213	13.6	−26	1.7	0.32	304.7	6.1	1440	···	−0.24	1.0	···	···	25
18	214	11.6	−111	1.8	0.50	285.9	8.4	2050	···	1.10	1.2	···	···	84
19	214	13.2	−94	1.9	0.51	286.4	8.3	1990	···	0.64	0.6	···	···	74
20	214	14.9	−18	2.0	0.33	291.9	5.6	1640	···	0.24	0.5	···	···	0
21	215	11.8	−45	2.2	0.49	293.9	7.0	1650	91	0.15	1.4	0.102	0.198	0
22	215	13.6	−69	2.2	0.57	295.2	6.7	1700	66	0.04	1.3	0.088	0.152	0
23	241	10.9	−7	1.2	0.18	289.6	4.8	930	···	−0.60	−9.0	···	···	83
24	241	12.5	−6	1.5	0.19	289.0	4.5	1060	···	−0.03	0.6	···	···	73
25	242	11.4	−4	2.0	0.20	292.3	2.6	1630	···	0.13	2.1	···	···	10
26	242	14.0	−1	2.1	0.09	293.6	2.0	2010	···	0.36	0.6	···	···	6
27	244	11.2	−20	1.9	0.33	294.7	4.8	1420	69	0.01	13.4	0.108	0.229	0
28	245	12.5	−356	2.2	0.93	295.3	10.7	2000	···	0.25	1.5	···	···	16
29	248	14.6	−22	1.9	0.31	298.5	6.0	1900	···	0.34	2.2	···	···	3
30	249	13.1	−17	1.4	0.28	299.8	6.2	930	77	0.58	1.8	0.177	0.336	0
31	249	15.2	−39	1.4	0.33	301.7	6.3	1110	65	−0.01	1.5	0.124	0.266	0
32	251	14.3	−7	1.1	0.18	301.4	4.6	750	···	2.48	−1.1	···	···	0
33	255	13.0	−28	1.8	0.36	299.1	6.6	1410	93	0.13	0.3	0.111	0.223	1

Virtual potential temperature and wind speed are boundary-layer mean values.

Davis et al, 1997

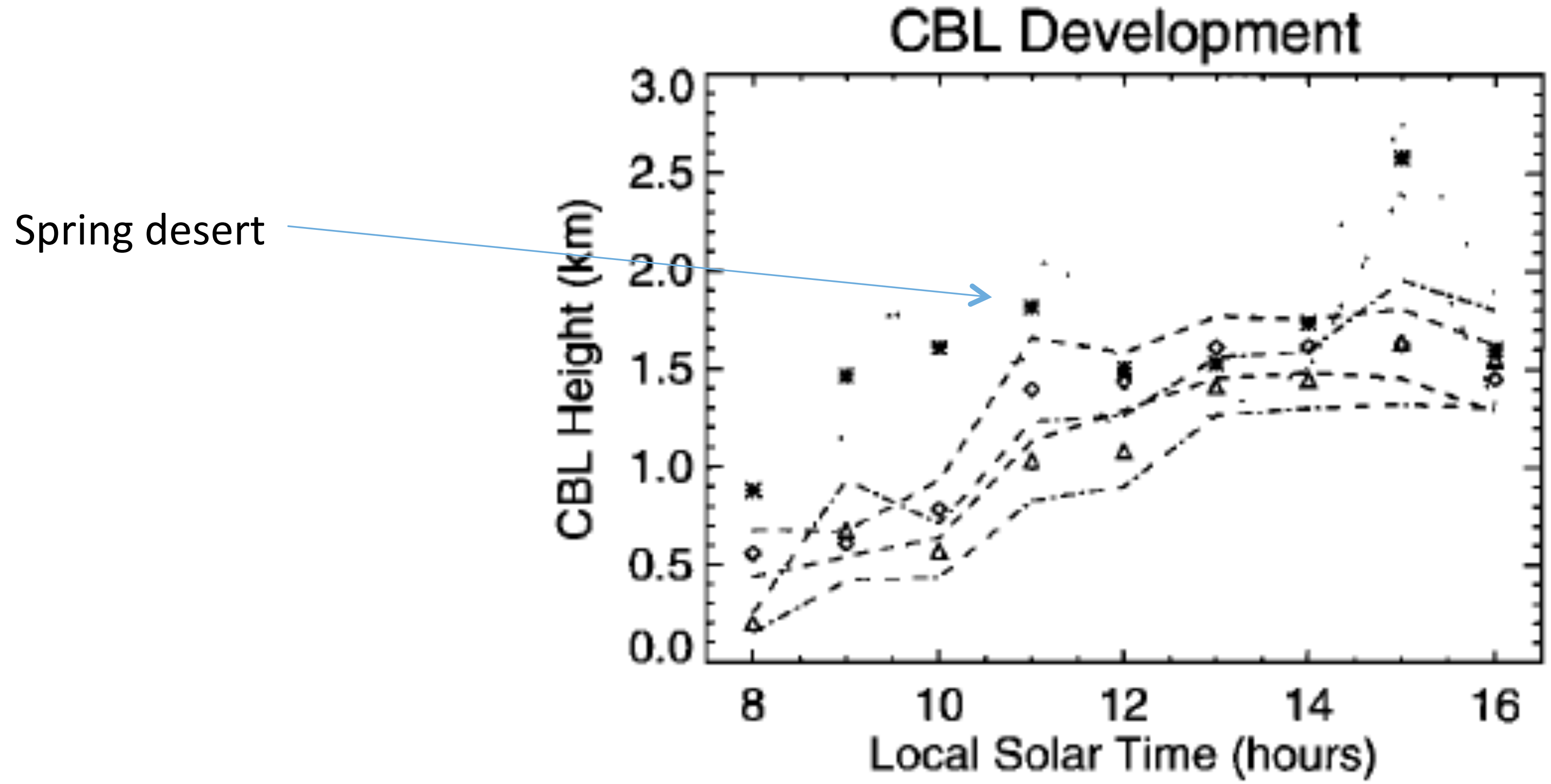
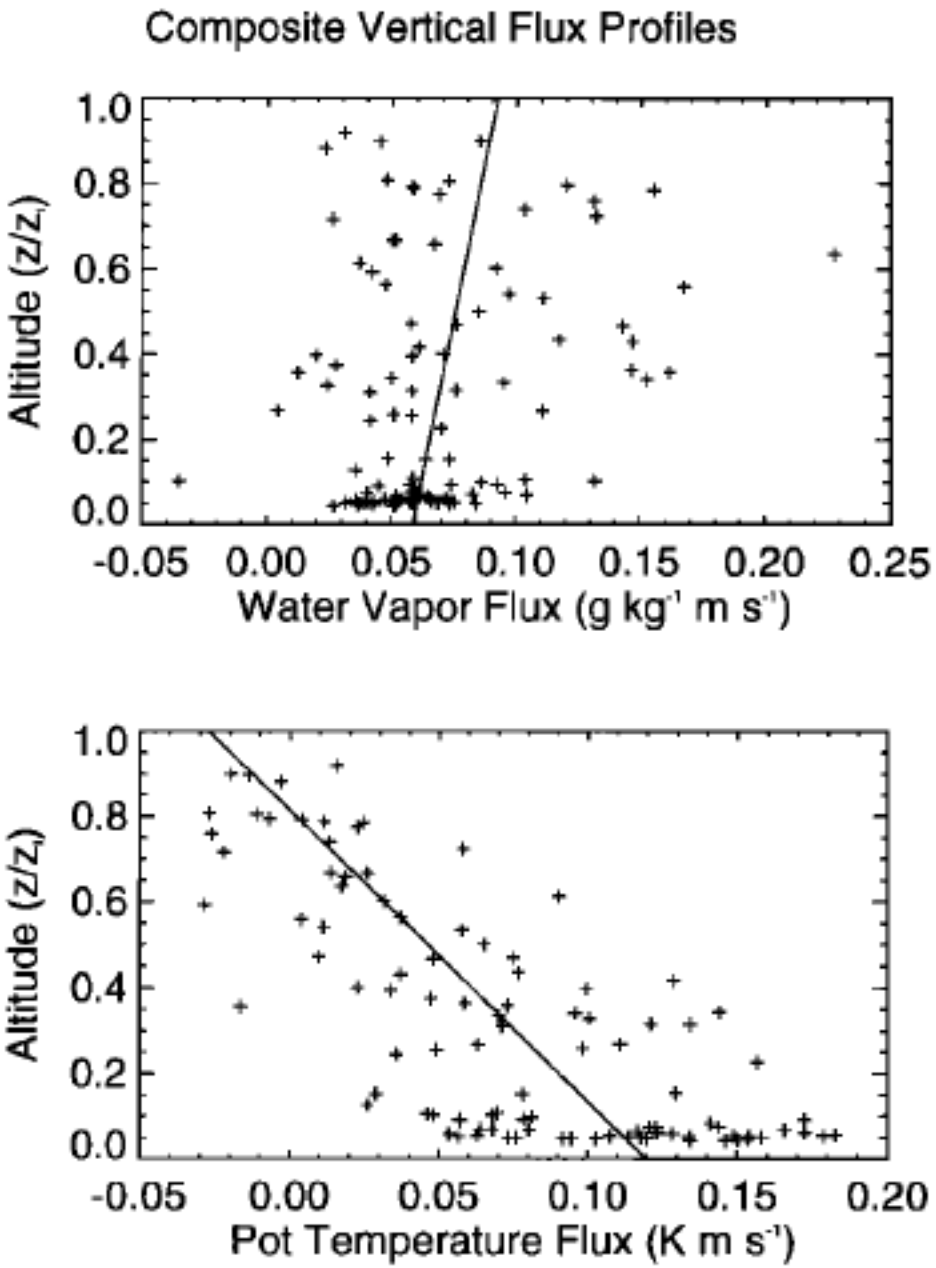
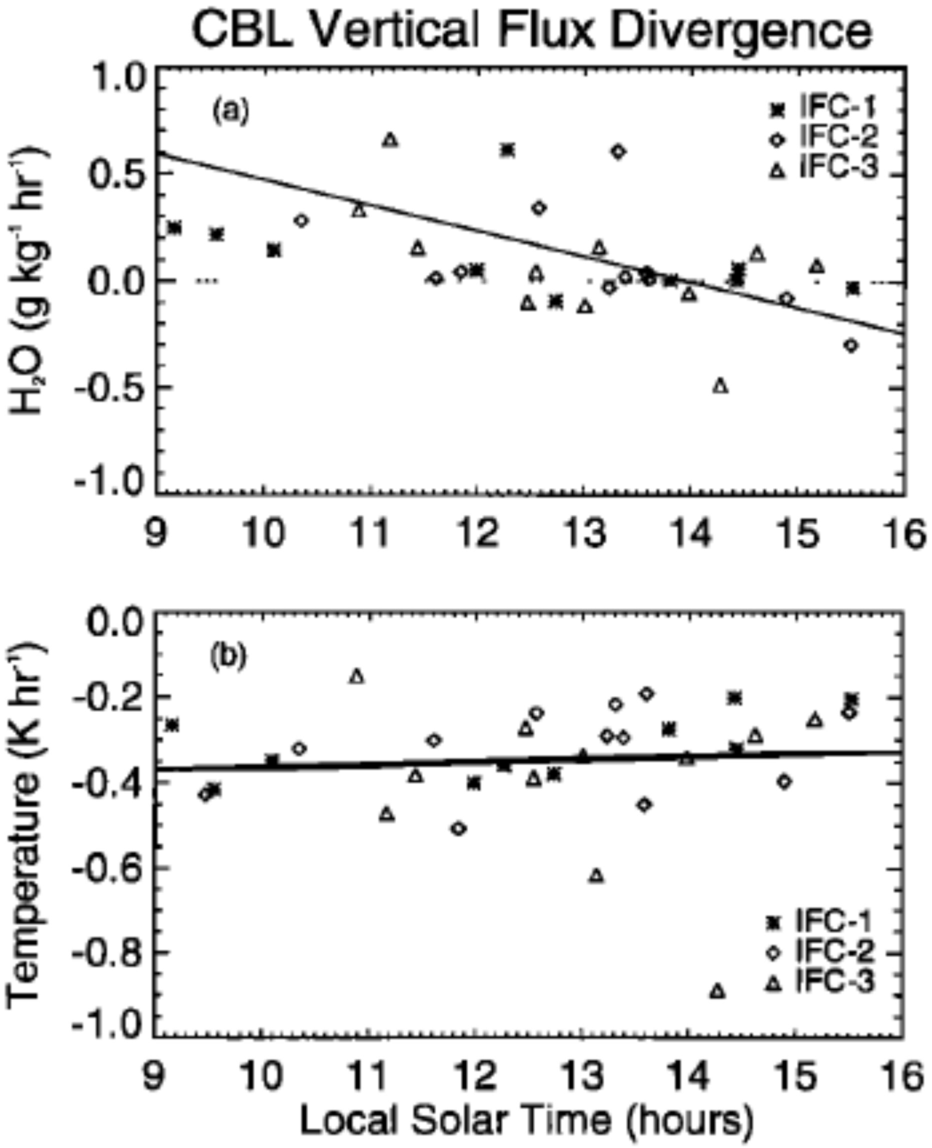


Figure 1. Midday evolution of the convective boundary layer (CBL) height (z_i) with time. CBL height is interpolated from vertical in situ soundings and lidar observations which are interspersed throughout the Electra flights. Asterisks, diamonds, and triangles represent IFC-1, IFC-2, and IFC-3 (intensive field campaigns). The dotted, dashed, and dotted-dashed lines are standard deviations around these averaged points for IFC-1, IFC-2, and IFC-3, respectively.

Davis et al, 1997

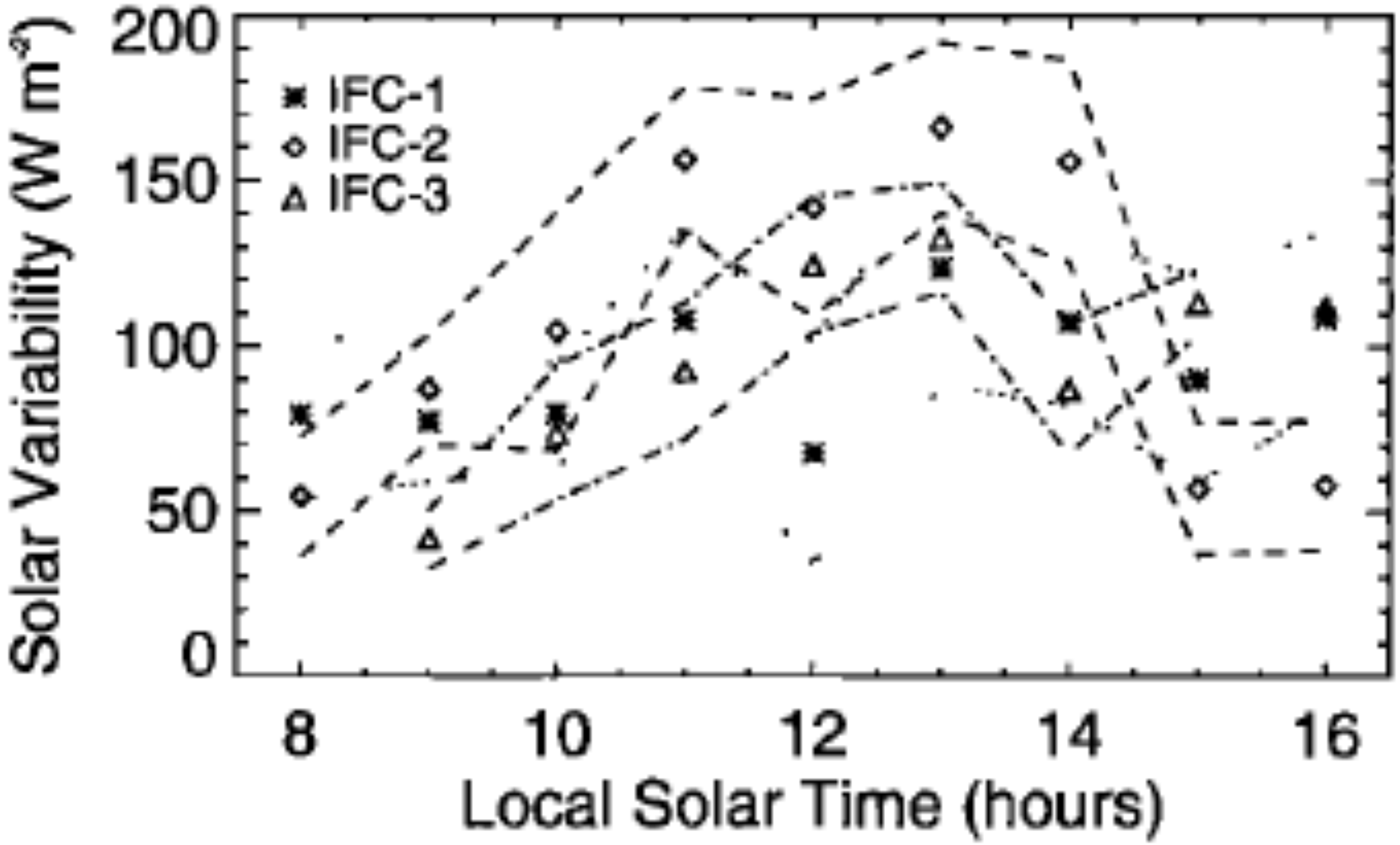
Flux profiles lead to net warming, drying during the day





Davis et al, 1997

Peak ABL cumulus development at midday, decrease later in the afternoon



Davis et al, 1997

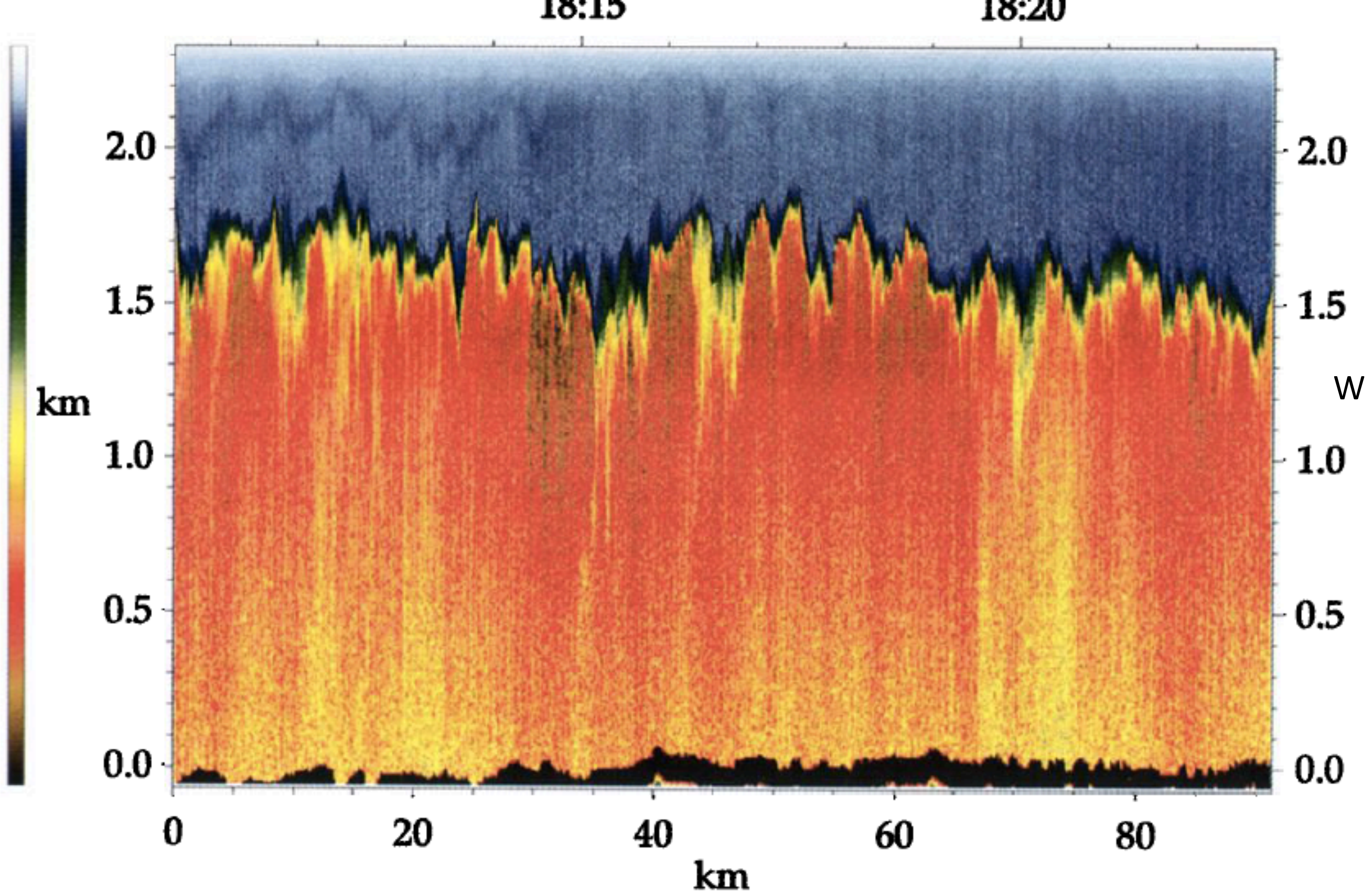


Plate 1. Aerosol backscatter from the lidar looking downward from 2400 m above ground, on August 4, 1994. The color scale is linear and goes from light blue for weak backscattering to black for strong backscattering. Clearly visible is the irregular top of the aerosol loaded convective boundary layer (CBL). The black curve in the bottom is the ground return. The ordinate values are the altitude above ground in kilometers. The lower abscissa indicates the distance from the leg start point in kilometers, the upper abscissa gives the time in UTC. The local solar time is approximately 6.7 hours behind UTC, so the flight leg is centered around 1130 LT.

Where's the lake?

Kiemle et al, 1997

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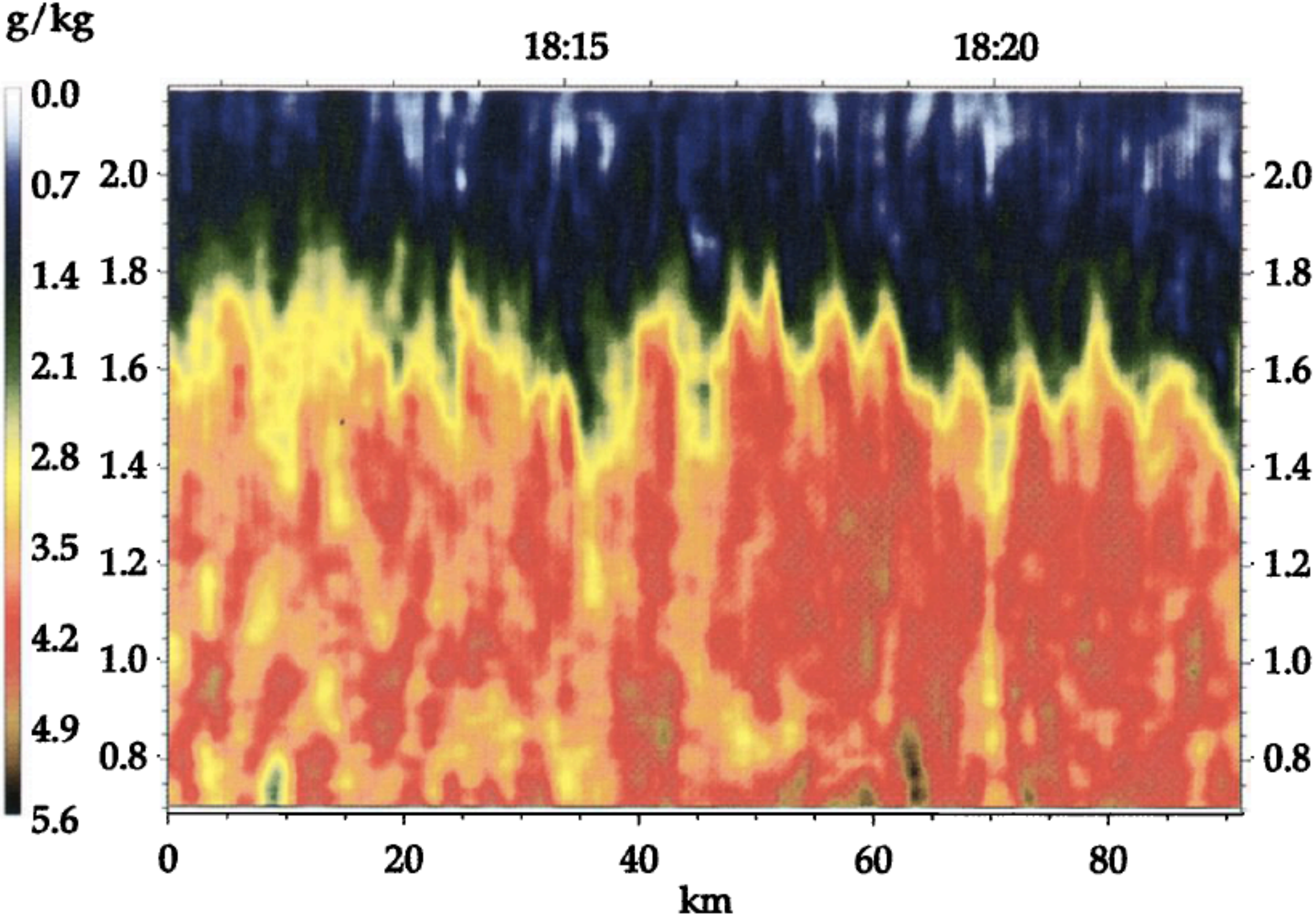


Plate 7. Water vapor mixing ratio on August, 4, 1994, corresponding to Plate 1. Same axes as for the aerosol plot, except the vertical extent has been limited somewhat due to differential absorption lidar (DIAL) data retrieval and noise constraints. The mixing ratio (g/kg) is encoded in the color scale. For better visualization, the noisy raw data have been smoothed vertically by 134 m and horizontally by 2 km. The CBL top is well

Kiemle et al, 1997

BOREAL ECOSYSTEM - ATMOSPHERE STUDY

BOREAS

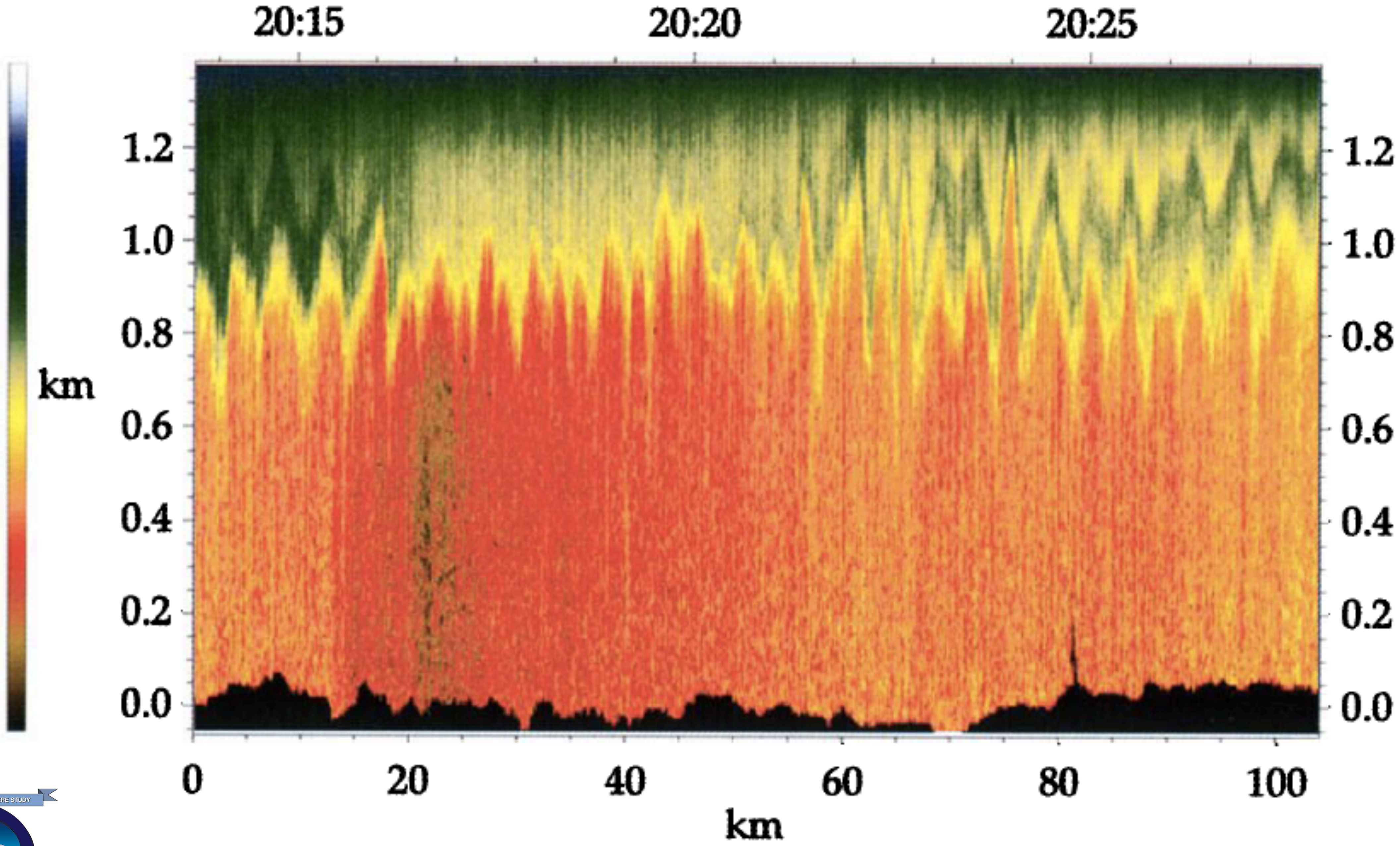
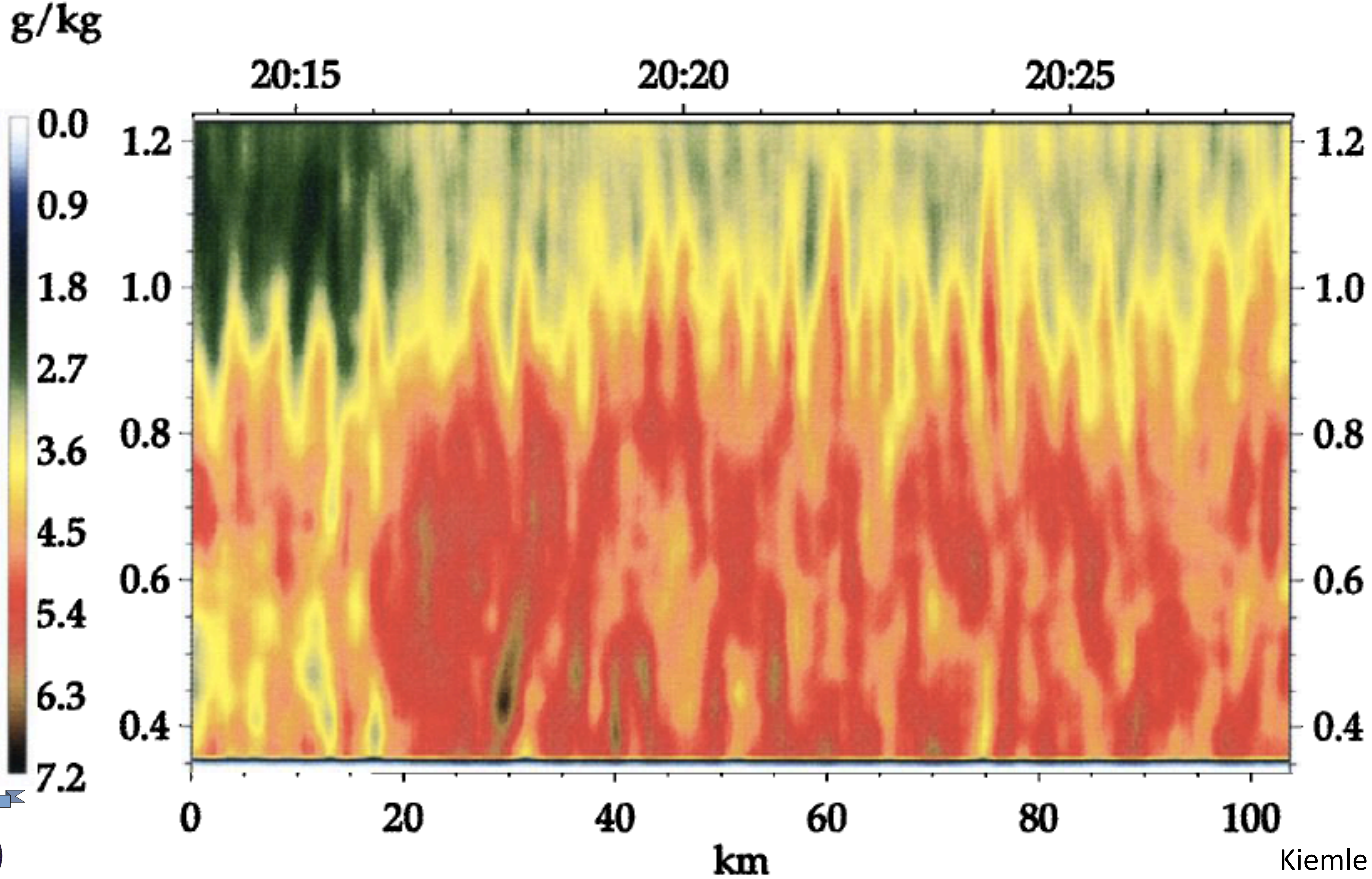


Plate 2. Lidar aerosol backscatter for September, 7, 1994, around local 1330. See also caption of Plate 1.

Kiemle et al, 1997



Kiemle et al, 1997

Plate 8. Water vapor mixing ratio on September, 7, 1994, corresponding to Plate 2. See also caption of Plate 7.

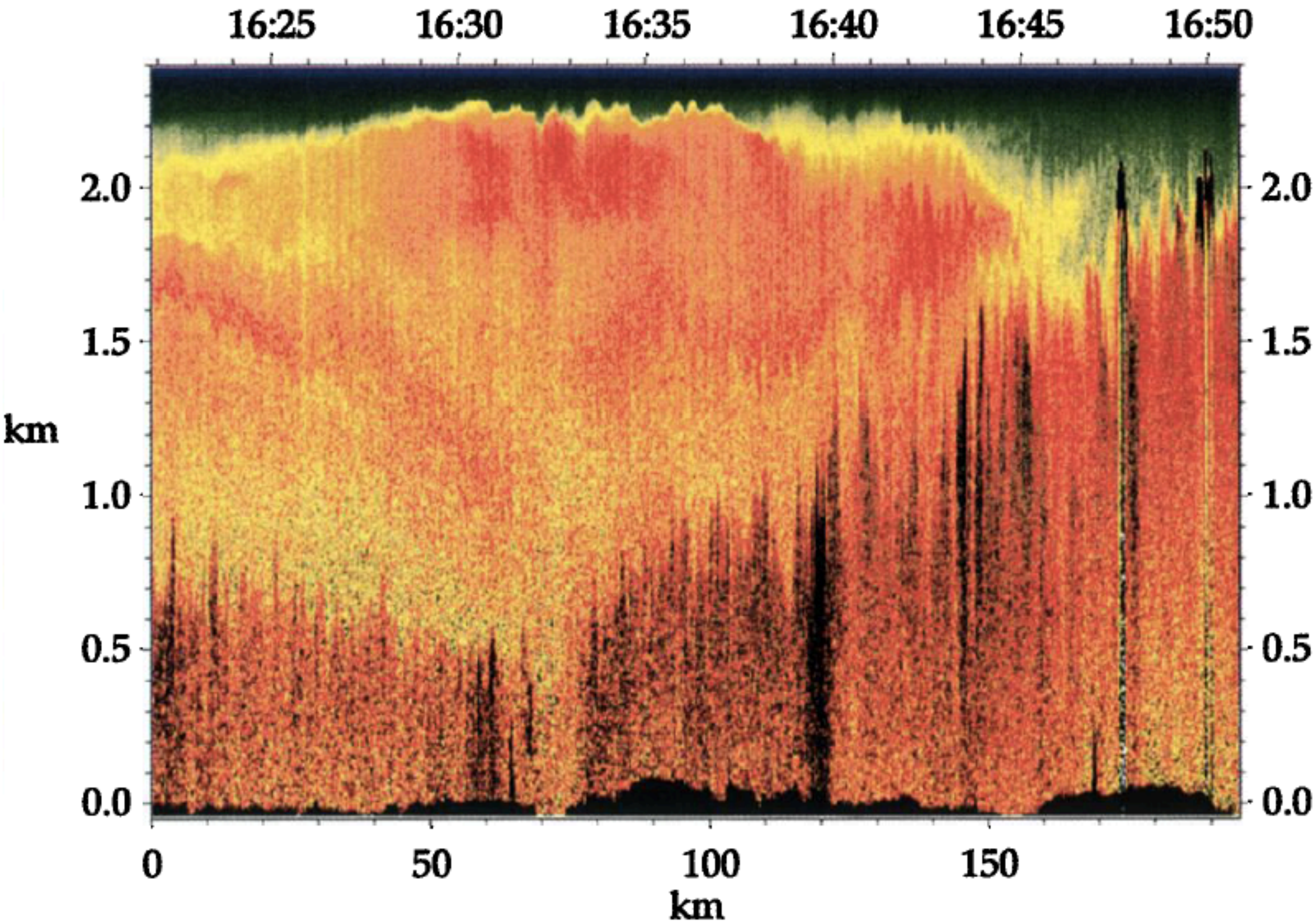
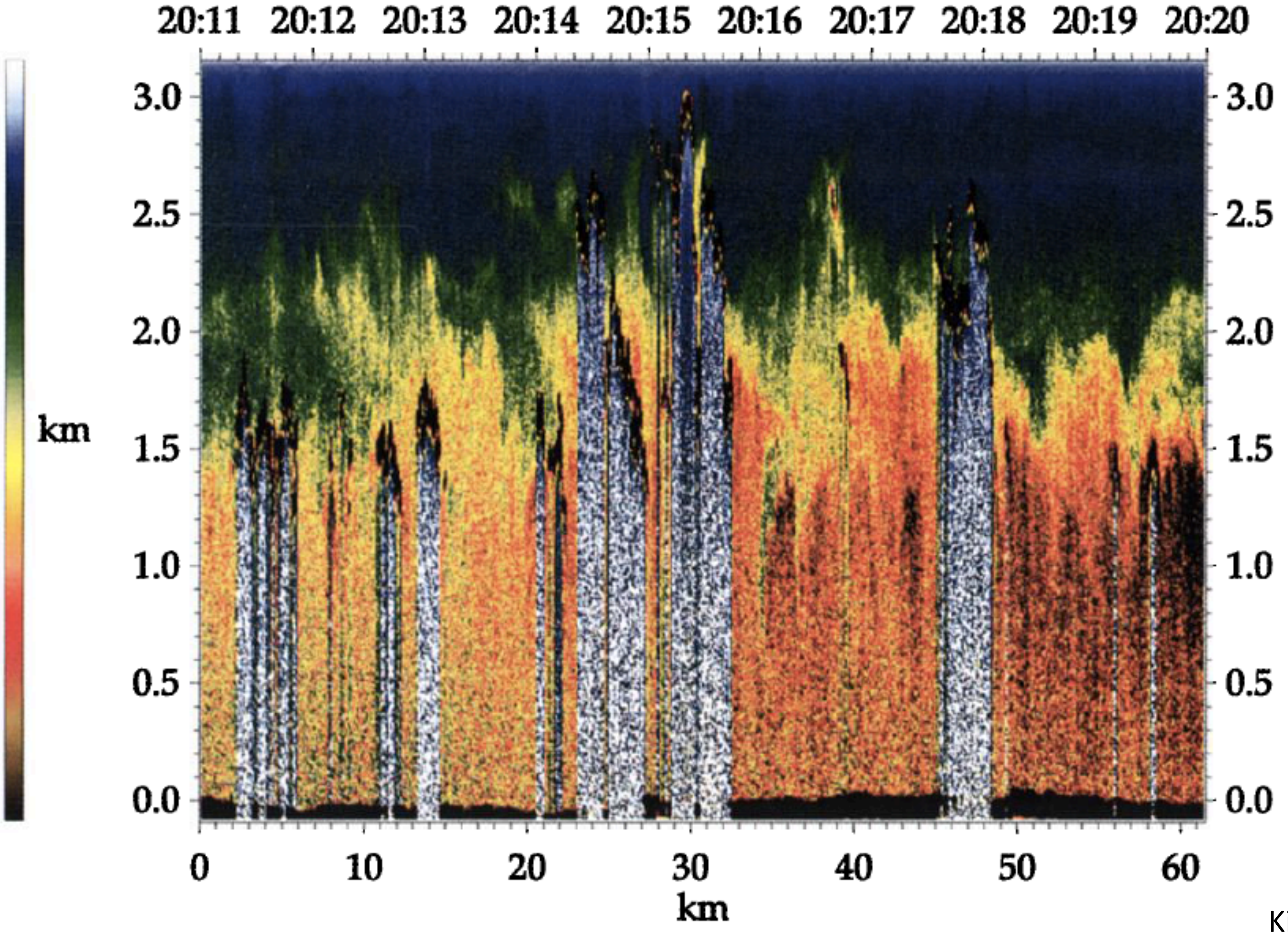


Plate 3. Lidar aerosol backscatter for May, 26, 1994, around local 1000. See also caption of Plate 1.

Kiemle et al, 1997



Kiemle et al, 1997

Plate 4. Lidar aerosol backscatter for July, 20, 1994, around local 1330. The low return beneath clouds is due

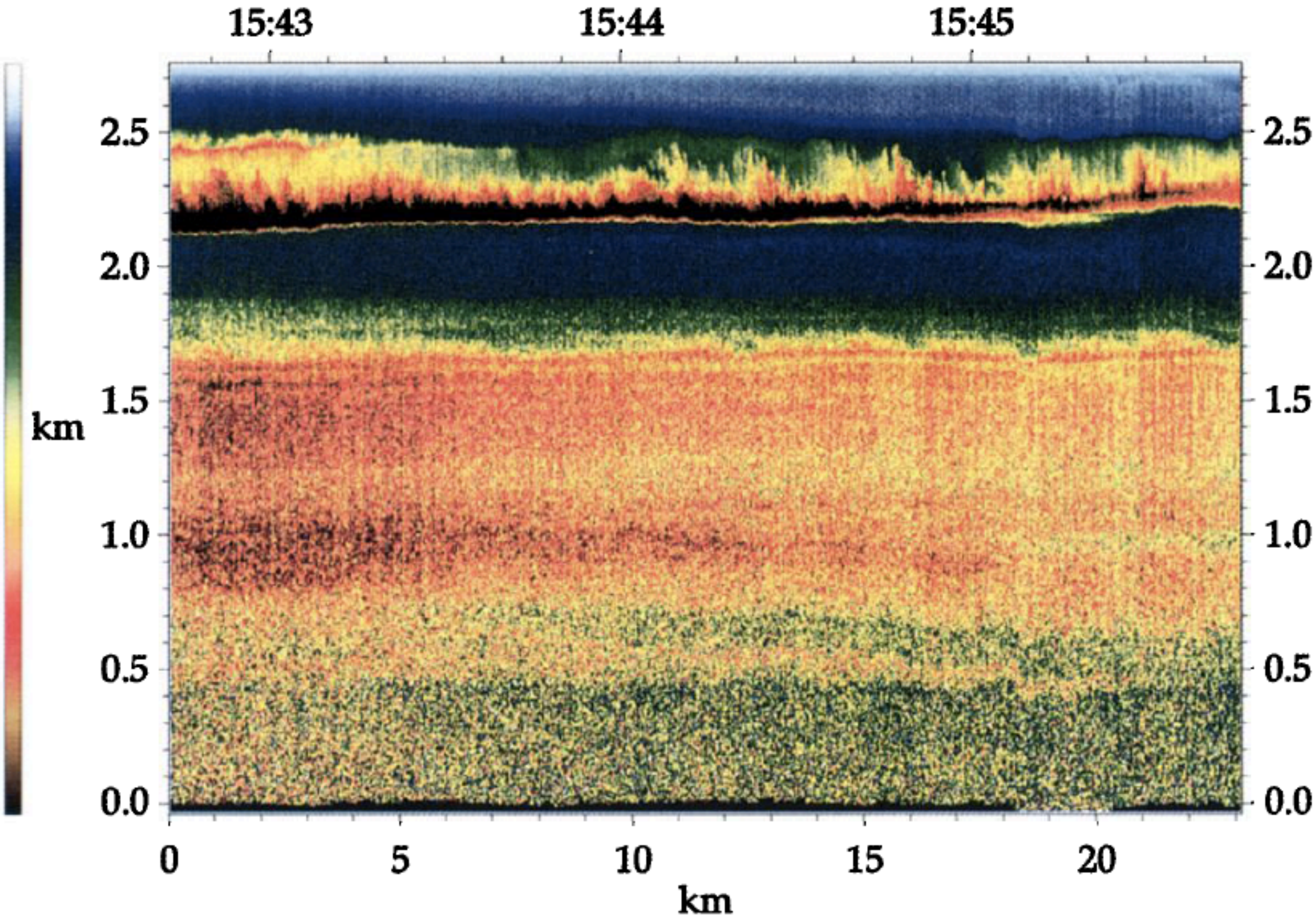


Plate 5. Lidar aerosol backscatter for July, 30, 1994, around local 0900. See also caption of Plate 1.

Kiemle et al, 1997

BOREAL ECOSYSTEM - ATMOSPHERE STUDY

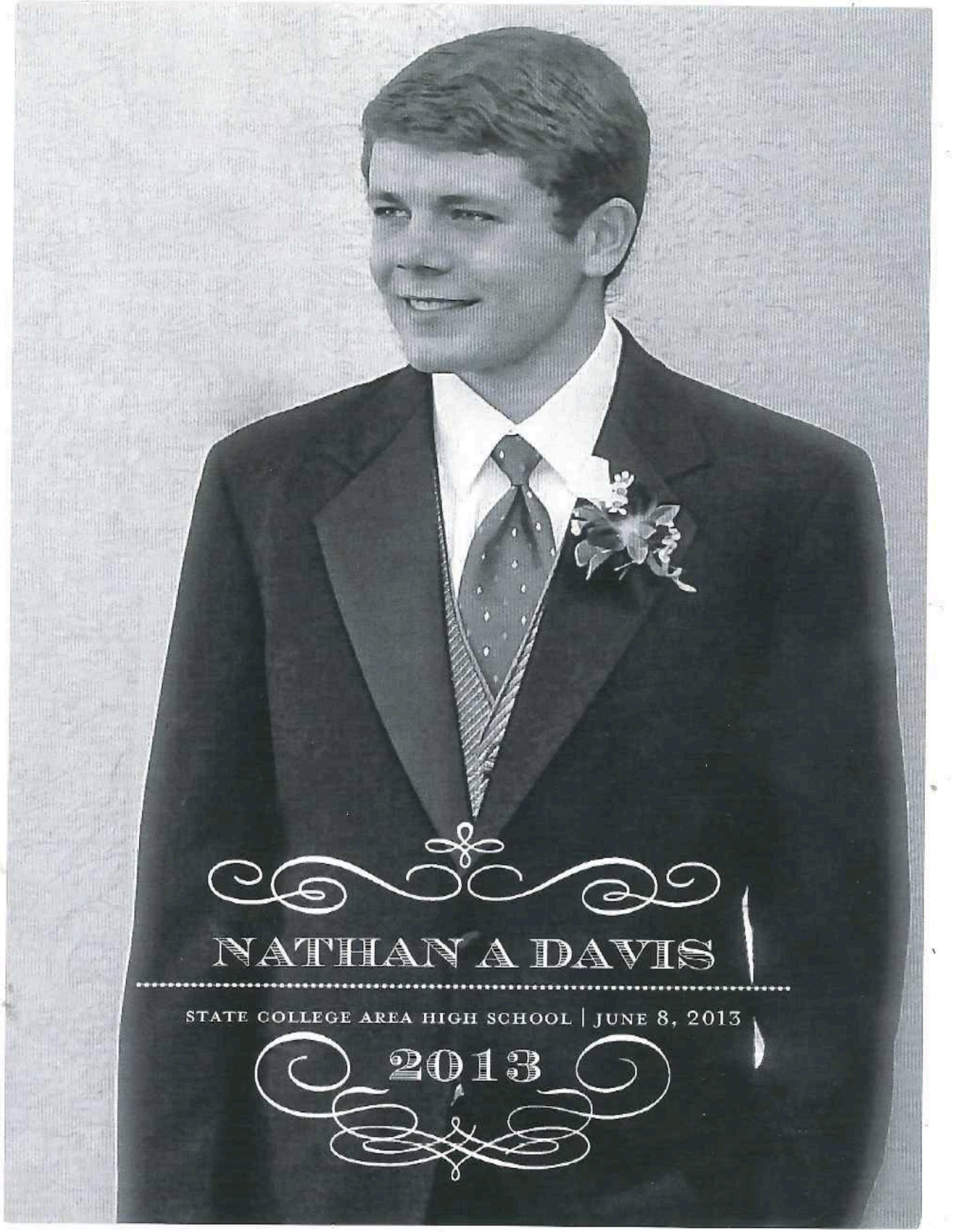
BOREAS

Lake-flows over the forest

Sun, J., D. H. Lenschow, L. Mahrt, T. L. Crawford, K. J. Davis, S. P. Oncley, J. I. MacPherson, Q. Wang, R. J. Dobosy, and R. L. Desjardins, Lake-induced atmospheric circulations during BOREAS, 1997: *J. Geophys. Res.*, 102, 29155-29166.

Born about
one week after
IFC-3 ended.

Pictured at left
on trip visiting
Ehret, Giez and
Kiemle in 1996.



BOREAS also pointed to what else we (I) should try

- Flux mapping – extrapolate eddy covariance across space with remote sensing
- Link eddy covariance and atmospheric inversions – highly-calibrated [CO_2]

- Long-term studies – years – climate time scales.

- Model-data synthesis.
- Ecosystem data assimilation, with multiple observational constraints

- Additional studies of land surface heterogeneity impacts on ABL development.

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BOREAS / FIFE follow-ons

- AmeriFlux / Fluxnet. Primed by FIFE/BOREAS.
  - Continental and global flux maps constructed from these data.
  - High uncertainty. Still challenging today. Flux tower network under-samples ecosystem variability. PFTs insufficient.
- Chequamegon Ecosystem Atmosphere Study - WLEF tall tower, stand level flux towers, ground-level observations, remote sensing.
  - Like BOREAS, but for years to explore upscaling. Tall tower – large flux footprint. Difficult to explain spatial variability in fluxes even in this densely instrumented regional experiment. Stand age, forest type stretch number of towers. Interannual variability in fluxes also difficult to explain.
- North American Carbon Program Midcontinent Intensive regional study
  - Regional atmospheric inversion study. [CO_2] linked to flux towers, ecosystem models. Success with regional (~10^6 km^2), annual net CO_2 flux estimates via atmospheric inversions.

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WLEF tower, Park Falls, Wisconsin

Lynchpin of the Chequamegon Ecosystem Atmosphere Study (ChEAS)

NOAA highly calibrated CO2 (Peter Bakwin, another BOREAS grad) and a long-term, eddy covariance flux profile (me). Initiated in 1995.

Link between eddy covariance and atmospheric inversions

Now part of AmeriFlux, Ankur Desai, U. Wisconsin, Principal Investigator

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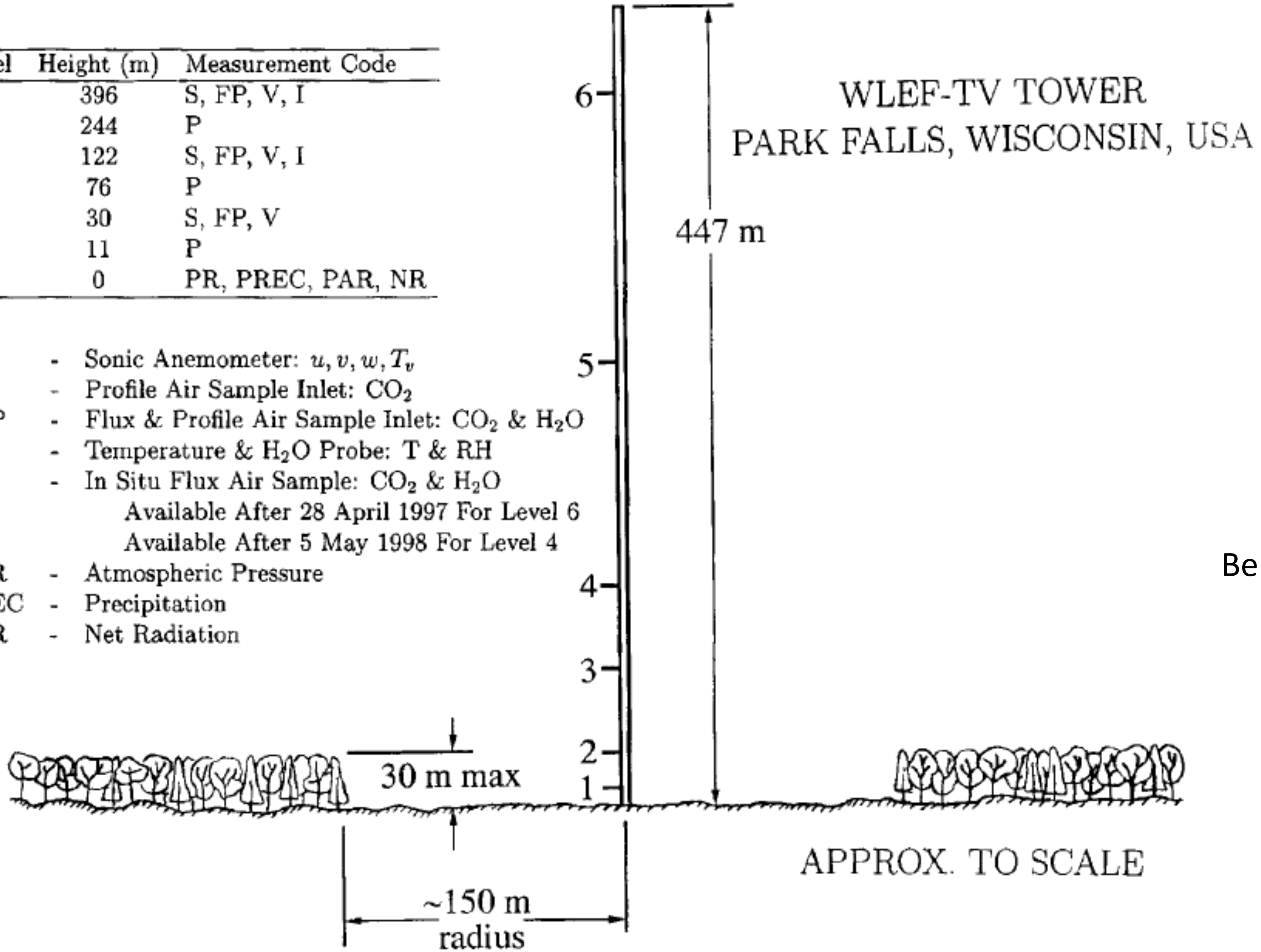
Level	Height (m)	Measurement Code
6	396	S, FP, V, I
5	244	P
4	122	S, FP, V, I
3	76	P
2	30	S, FP, V
1	11	P
0	0	PR, PREC, PAR, NR

S - Sonic Anemometer: u, v, w, T_v
P - Profile Air Sample Inlet: CO_2
FP - Flux & Profile Air Sample Inlet: CO_2 & H_2O
V - Temperature & H_2O Probe: T & RH
I - In Situ Flux Air Sample: CO_2 & H_2O
Available After 28 April 1997 For Level 6
Available After 5 May 1998 For Level 4
PR - Atmospheric Pressure
PREC - Precipitation
NR - Net Radiation



Berger et al, 2001

FIG. 1. Schematic of instrument configuration. WLEF-TV tower is located in the Chequamegon National Forest, about 15 km east of Park Falls, Wisconsin. High-rate flux measurements are made at 30, 122, and 396 m. Slow-rate profile measurements are made at 11, 30, 76, 122, 244, and 396 m. Instrument housing at base of tower not shown.

ChEAS:

17 stand-level flux towers

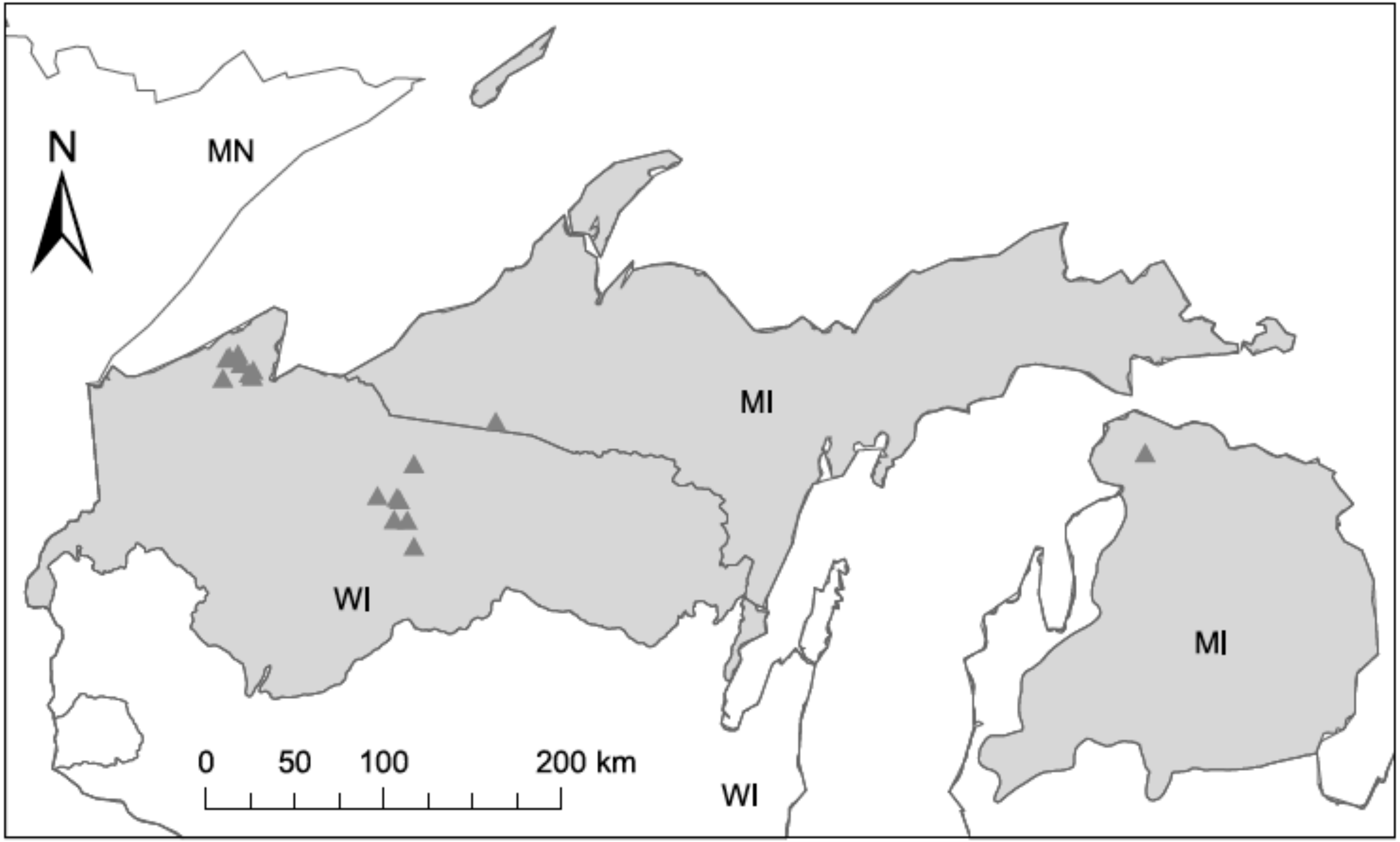


Figure 1. The study region and the location of eddy covariance flux towers. Symbols are the eddy flux sites. The shaded area is the northern forests ecoregion across northern Wisconsin (WI) and Michigan (MI). The dotted line stands for state boundaries.

Xiai et al, 2011, 2014

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Table 1. Location and Site Characteristics of Eddy Covariance Flux Sites in the Chequamegon Ecosystem-Atmosphere Study (ChEAS) Region Across Northern Wisconsin (WI) and Upper Peninsula of Michigan (MI)[a]

PFT	Site	ID	State	Lat	Lon	Data Period	Stand Age (years)	Dominant Cover	Reference
Evergreen forests (EF)	Intermediate Red Pine	IRP	WI	46.687	−91.153	2003	30	Red pine	*Noormets et al.* [2008]
	Mature Red Pine	MRP	WI	46.739	−91.166	2002–2005	70	Red pine, aspen	*Noormets et al.* [2008]
	Red Pine Clearcut	RPC	WI	46.649	−91.069	2005	7	Red pine	*Noormets et al.* [2008]
	Young Jack Pine	YJP	WI	46.619	−91.081	2004–2005	22	Jack pine	*Noormets et al.* [2008]
	Young Red Pine	YRP	WI	46.619	−91.081	2002	17	Red pine, jack pine	*Noormets et al.* [2008]
Deciduous forests (DF)	Intermediate Hardwood	IH	WI	46.730	−91.233	2003	26	Aspen	*Noormets et al.* [2008]
	Riley Creek	RC	WI	45.910	90.116	2005–2006	10	Aspen	This study
	Thunder Creek	TC	WI	45.671	90.053	2005–2006	7	Aspen	This study
	Willow Creek	WC	WI	45.806	−90.080	2000–2006	70	Sugar maple, basswood, green ash	*Cook et al.* [2004]
	Young Hardwood Clearcut	YHC	WI	46.722	−91.252	2002	13	Aspen, red maple	*Noormets et al.* [2008]
Mixed forests (MF)	Park Falls/WLEF	WLEF	WI	45.946	−90.272	2000–2005	~45	Northern hardwoods, aspen	*Davis et al.* [2003]
	Sylvania Wilderness Area	SWA	MI	46.242	−89.348	2001–2006	200	Eastern hemlock, sugar maple, birch	*Desai et al.* [2005]
	University of Michigan Biological Station	UMBS	MI	45.560	−84.714	2000–2003	79	Aspen, white pine, red oak, sugar maple	*Gough et al.* [2008]
Shrublands (Sh)	Pine Barren 1	PB1	WI	46.625	−91.298	2002–2003		Sweet fern, black cherry, willow, red pine	*Noormets et al.* [2008]
Woody wetlands (WW)	Lost Creek	LC	WI	46.083	−89.979	2001–2006	45	Alder-willow shrubs	*Sulman et al.* [2010]
Herbaceous wetlands (HW)	Wilson Flowage	WF	WI	45.817	90.172	2005–2006		Sedges and marsh grass	*Sulman et al.* [2010]
	South Fork	SF	WI	45.925	90.131	2005–2006		Sphagnum bog with Labrador Tea and LeatherLeaf	*Sulman et al.* [2010]

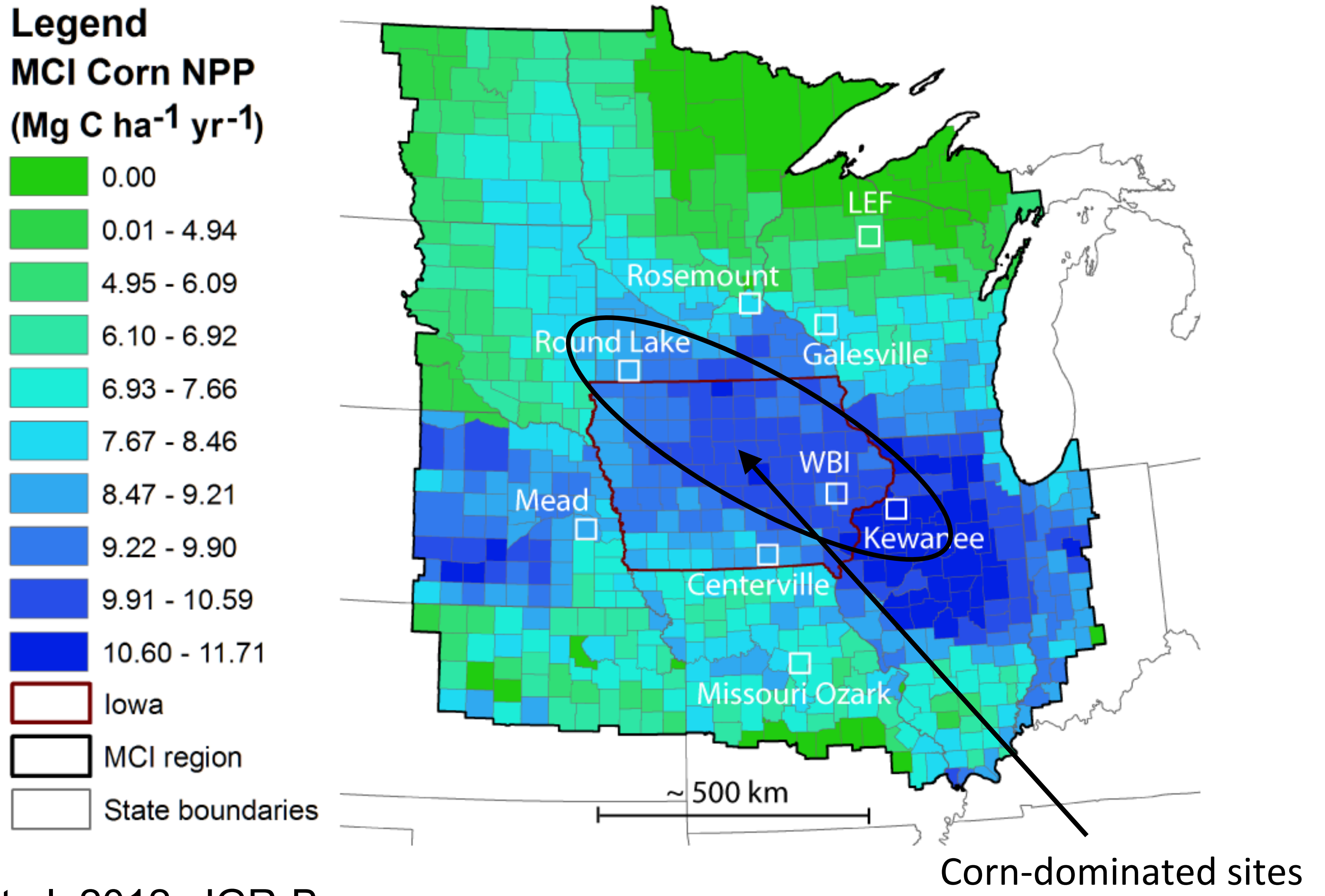
[a]The complexity of the WLEF flux footprint [e.g., *Desai et al.*, 2008] makes it difficult to assign a single stand age. This value should be viewed with caution.

Xiai et al, 2011, 2014

BOREAS / FIFE follow-ons

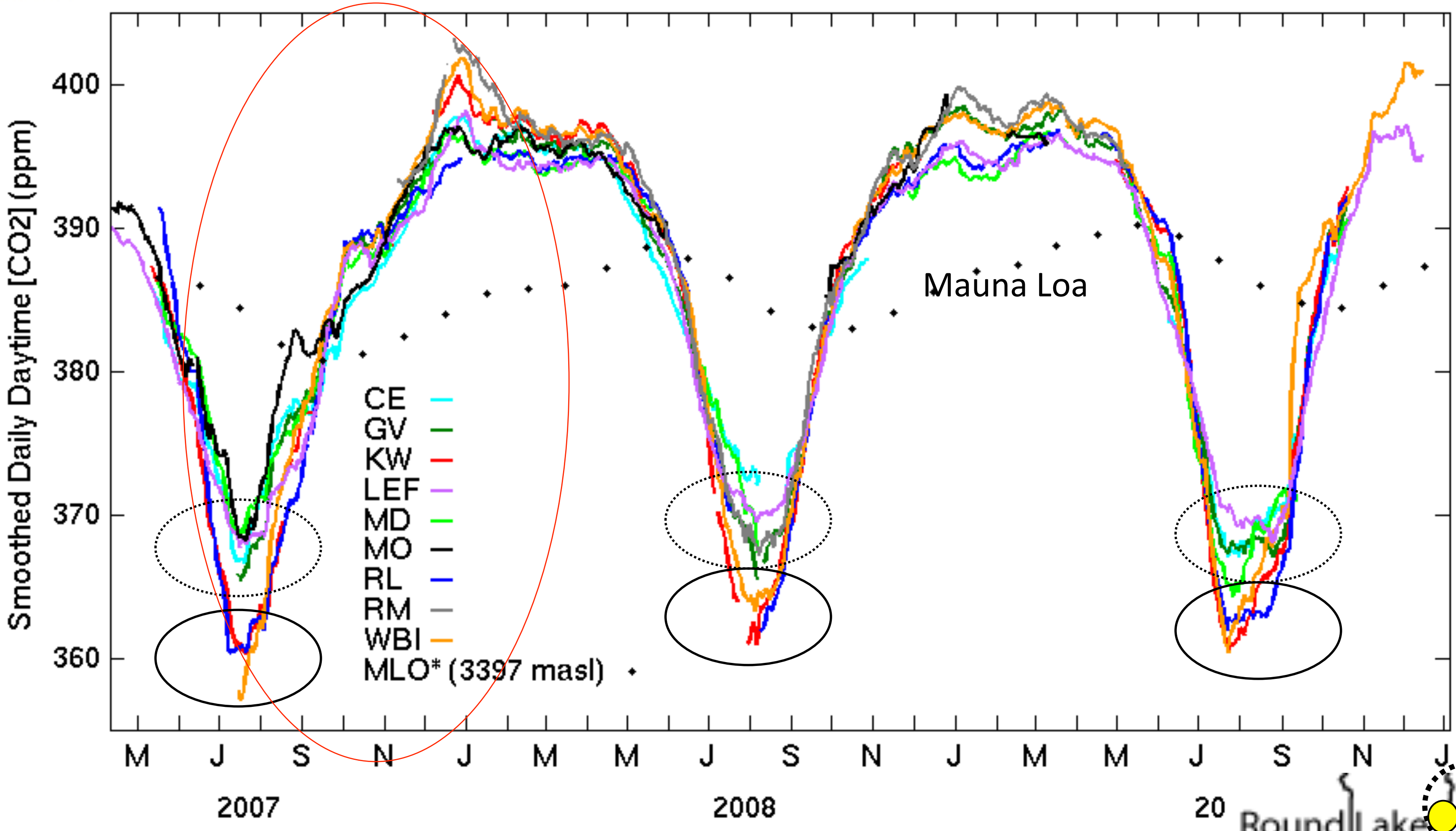
- AmeriFlux / Fluxnet. Primed by FIFE/BOREAS.
  - Continental and global flux maps constructed from these data.
  - High uncertainty. Still challenging today. Flux tower network under-samples ecosystem variability. PFTs insufficient.
- Chequamegon Ecosystem Atmosphere Study - WLEF tall tower, stand level flux towers, ground-level observations, remote sensing.
  - Like BOREAS, but for years to explore upscaling. Tall tower – large flux footprint. Difficult to explain spatial variability in fluxes even in this densely instrumented regional experiment. Stand age, forest type stretch number of towers. Interannual variability in fluxes also difficult to explain.
- North American Carbon Program Midcontinent Intensive regional study
  - Regional atmospheric inversion study. [CO_2] linked to flux towers, ecosystem models. Success with regional (~10^6 km^2), annual net CO_2 flux estimates via atmospheric inversions.

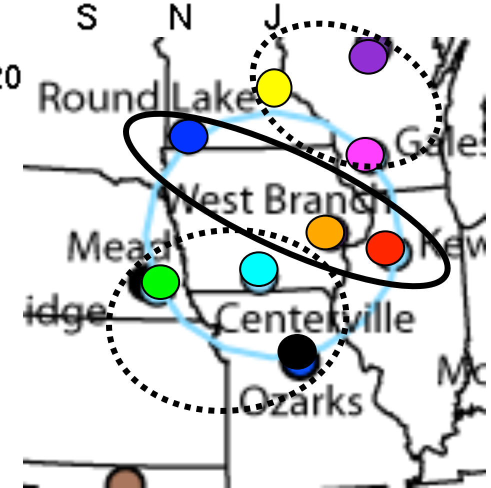
MidContinent Regional Intensive Tower-Based CO_2 Observational Network



Miles et al, 2012, JGR-B

MCI 31 day running mean daily daytime average CO2

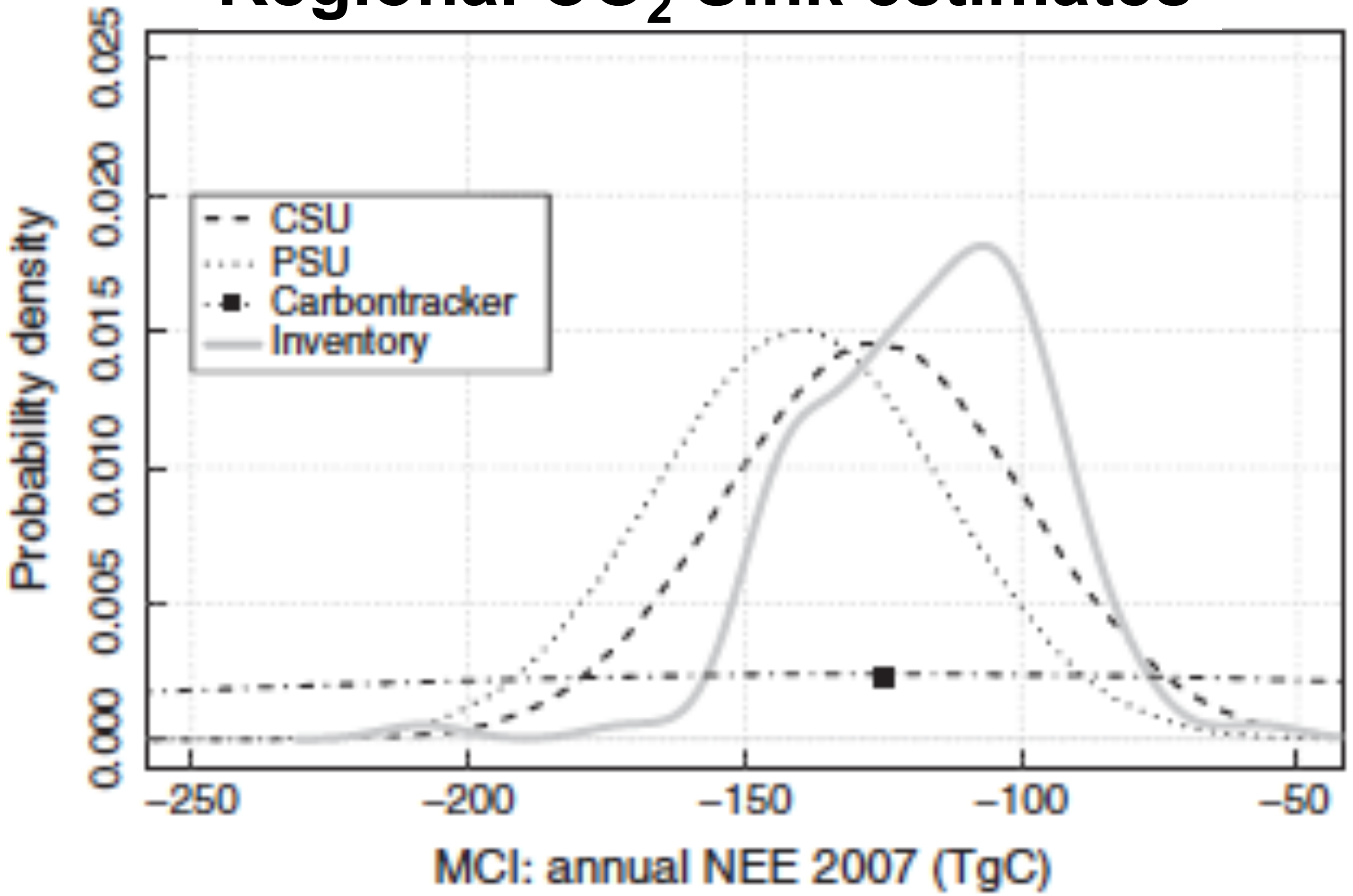




- Large differences in seasonal drawdown of CO_2
- 2 groups: 33-39 ppm drawdown and 24 – 29 ppm drawdown. Tied to density of corn.

Miles et al, 2012, JGR-B

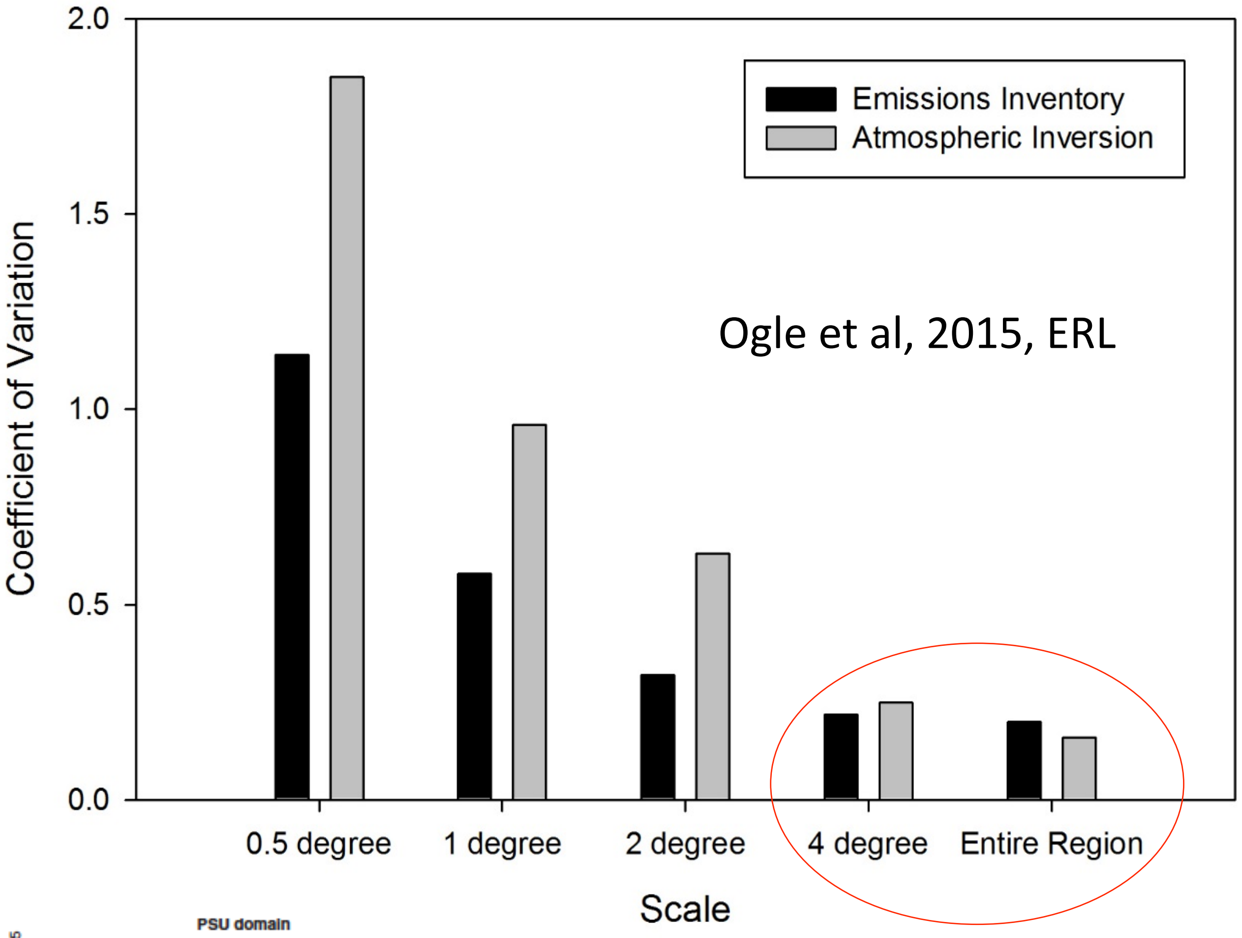
Regional CO_2 Sink estimates



Schuh et al, 2013, GCB

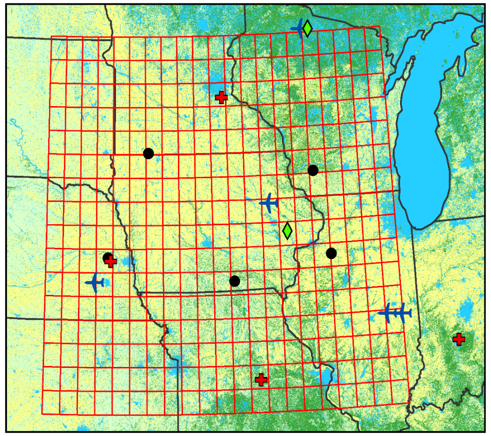
Atmospheric inversions and agricultural inventory agree.
Regional inversions and inventory have similar uncertainty bounds!
Atmospheric inversions have great potential for carbon balance inference given suitable data density.

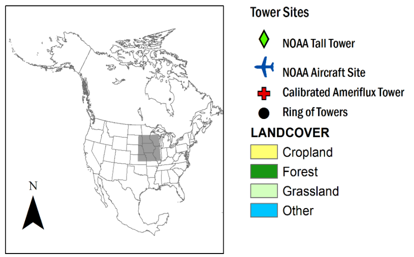
Cross-over point? Inversion vs. inventory

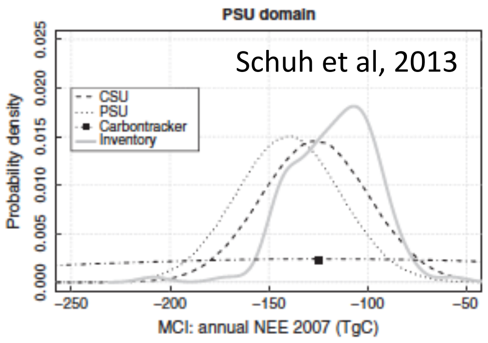


Atmospheric inversions provide great insights at global scale. Emissions inventories are very informative at small scales. Can we bridge the gap?

Midcontinent Intensive study area







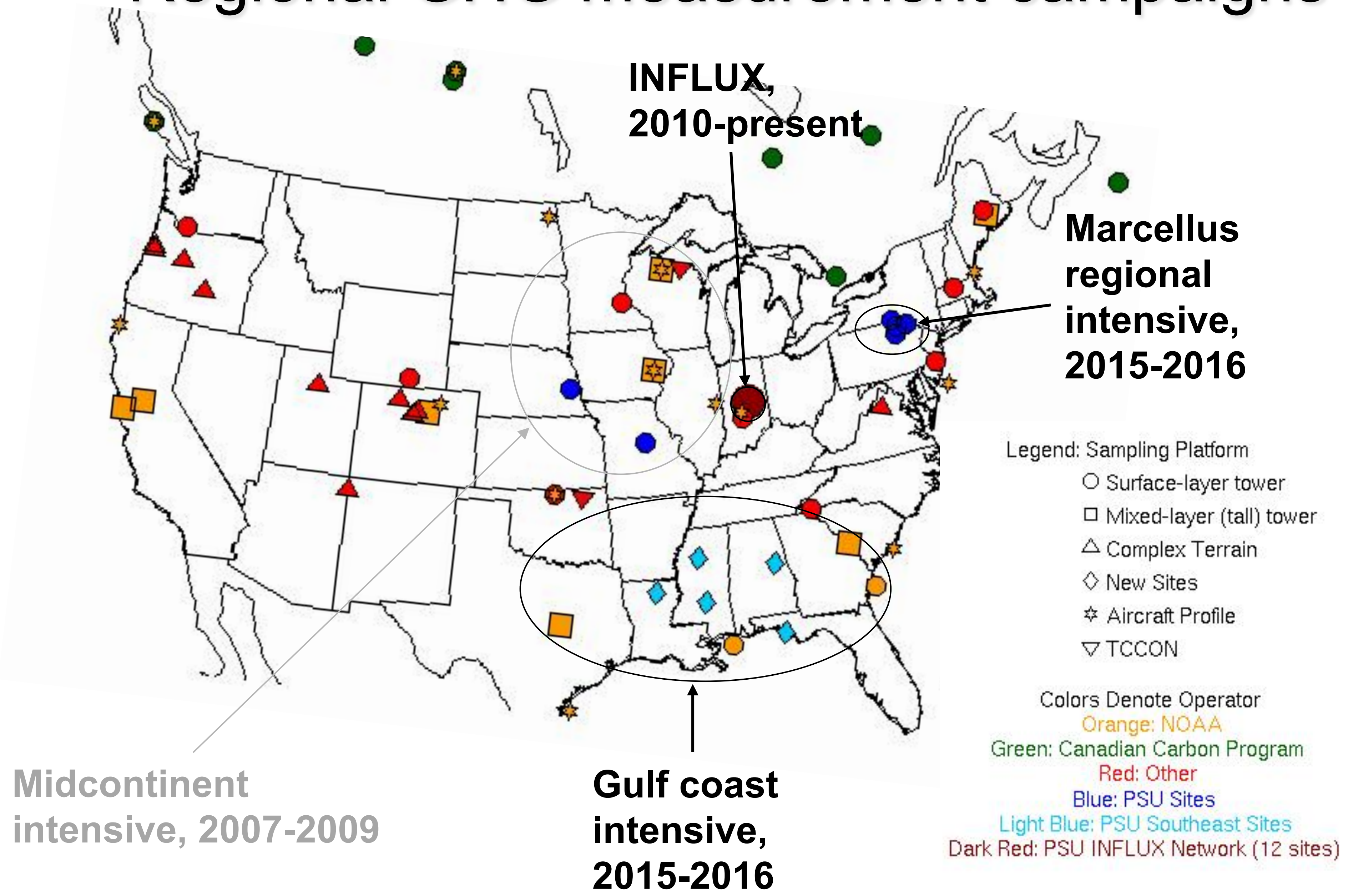
MCI results suggest that uncertainty in an atmospheric inversion equals the uncertainty in an agricultural inventory at (several 100 km)^2 resolution for this inventory and these atmospheric data

More follow-ons like the NACP MCI

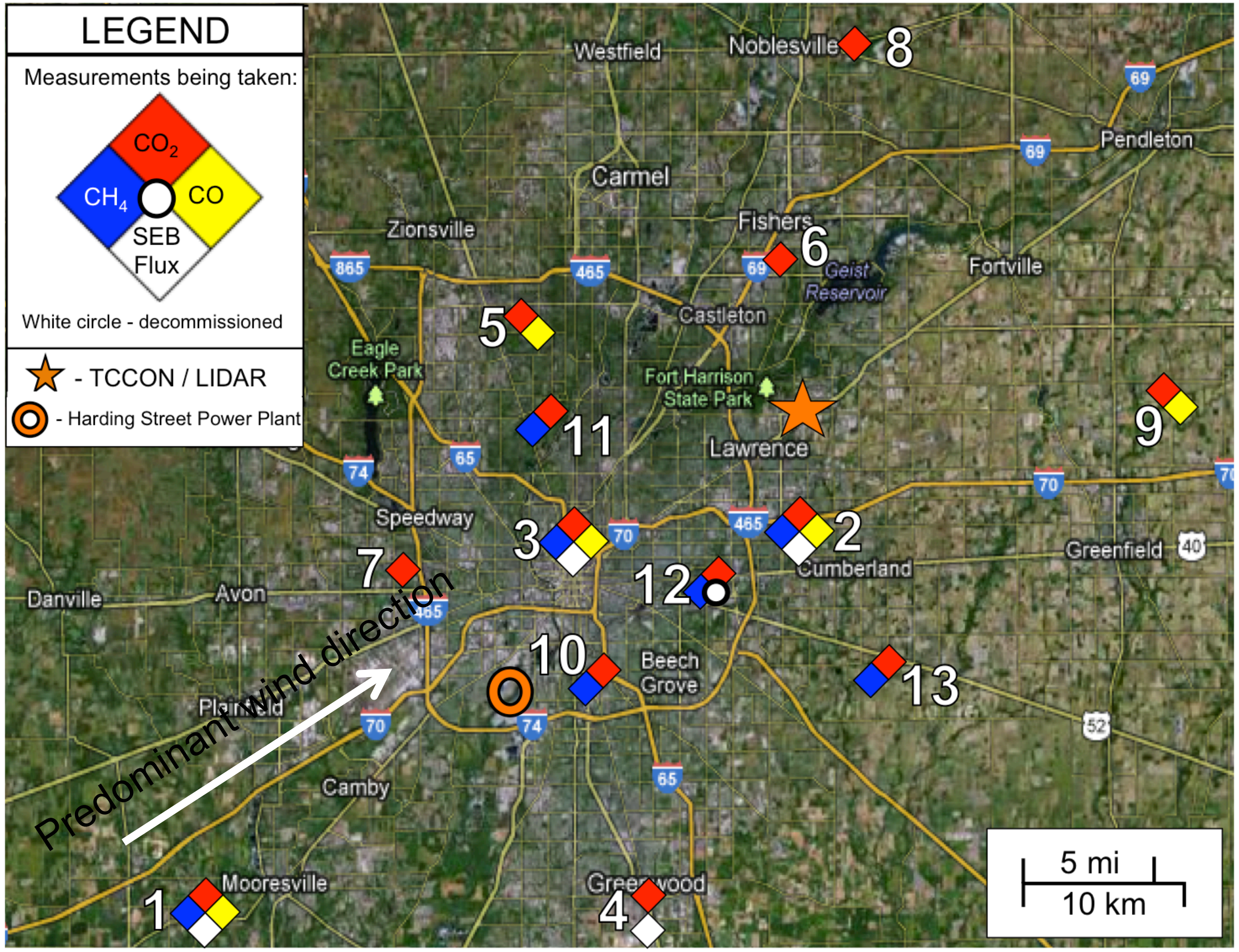
All tower-based CO_2 / CH_4 measurements. Multiple year measurement campaigns. Limited eddy covariance flux work from aircraft or towers.

- INFLUX – urban CO_2 and CH_4 emissions from Indianapolis
- Marcellus – natural gas production CH_4 emissions from the Marcellus shale gas fields
- Gulf Coast Intensive – CO_2 budget of the Gulf Coast forests

Regional GHG measurement campaigns



INFLUX GROUND-BASED NETWORK

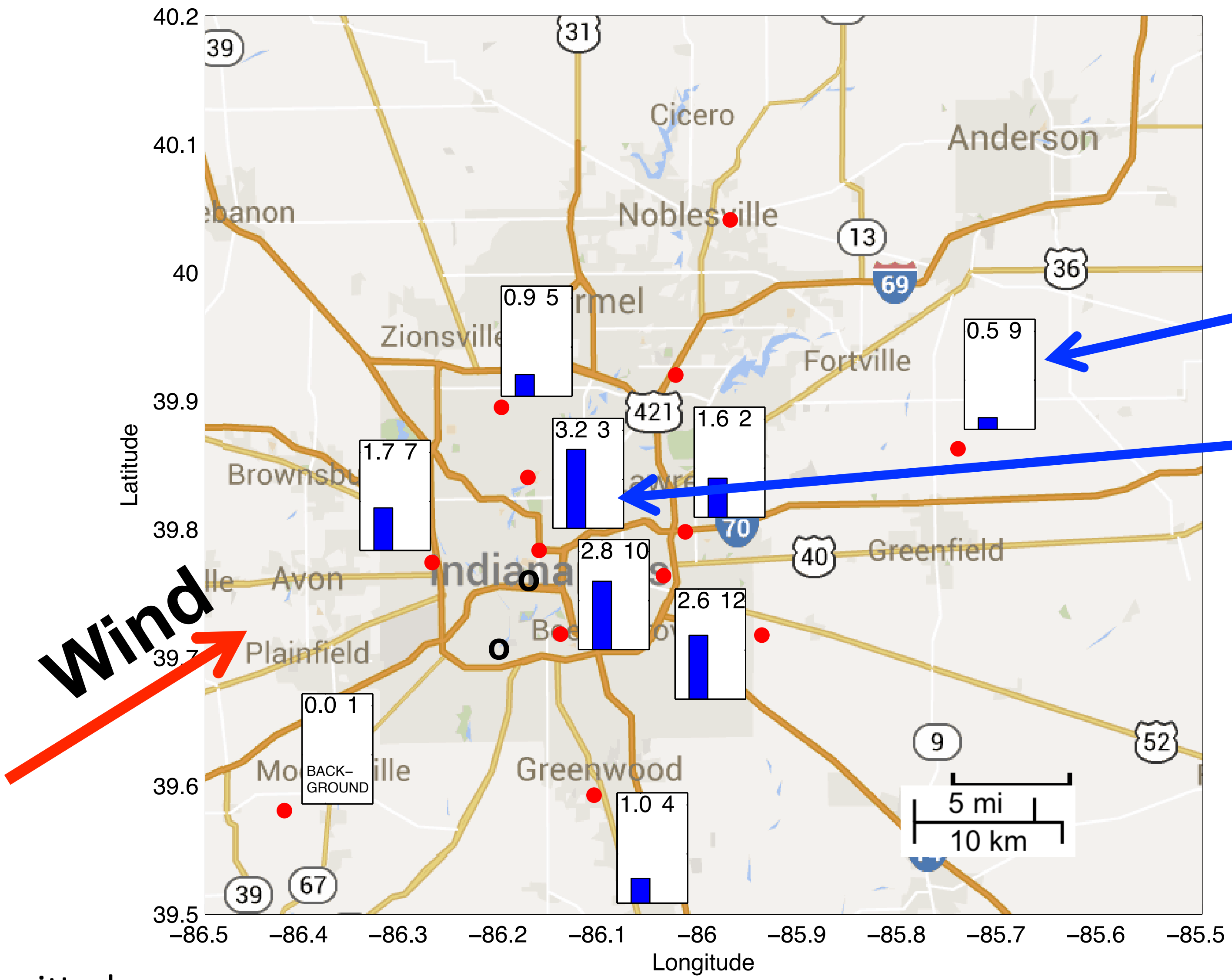


- Communications towers ~100 m AGL
- Picarro, CRDS sensors
- 12 measuring CO2, 5 with CH4, and 5 with CO

- NOAA automated flask samplers
- NOAA LIDAR
- Eddy flux at 4 towers

NIST
Miles et al, submitted

Observed spatial structure of urban CO_2



- Observed CO_2: afternoon values, averaged Jan-April 2013
- Site 09: 0.5 ppm larger than Site 01
- Site 03: measures larger $[CO_2]$ by 3.2 ppm

NIST

Miles et al, submitted

Atmospheric Carbon and Transport – America
an Earth Venture Suborbital mission

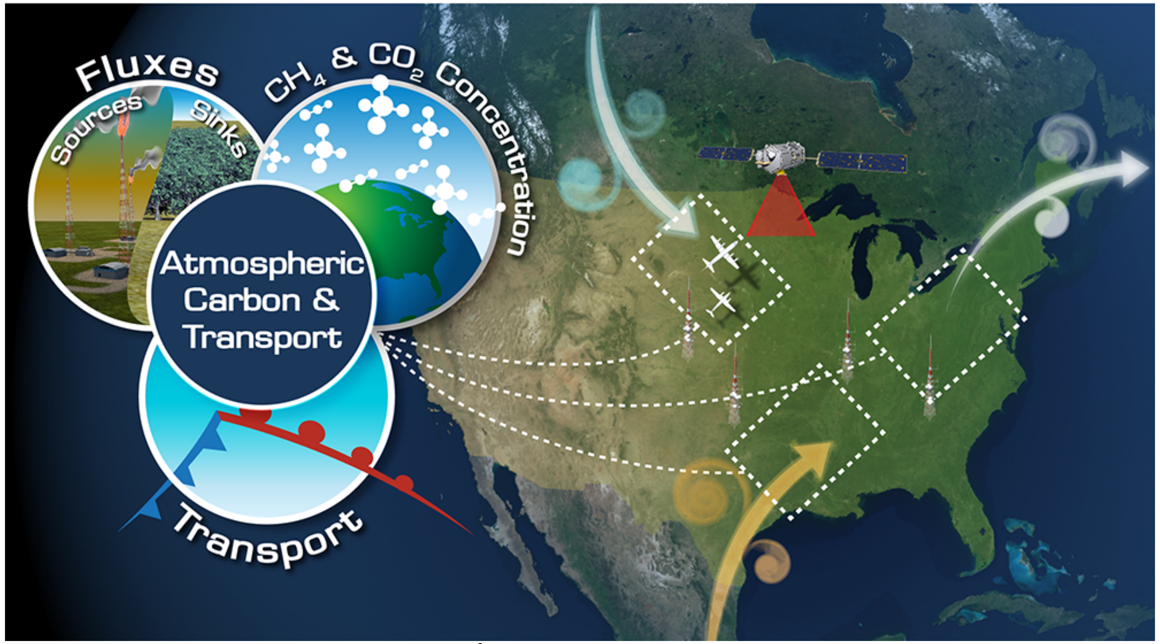


Image credit: Tim Marvel / NASA Langley

Five, 6-week long aircraft campaigns targeting the transport of CO_2 and CH_4 by synoptic weather systems across four seasons and three regions of the continental U.S. 2016-2019.

In situ CO_2 and CH_4 and associated trace gas measurements. Column CO_2 measured with airborne lidar. Wallops C-130 and Langley B200 aircraft. Investigators from 10 institutions.

Model-data synthesis using a multi-model ensemble for flux and transport model pruning.

Overarching goal of greatly reducing uncertainty in regional atmospheric inverse estimates of CO_2 and CH_4 fluxes.

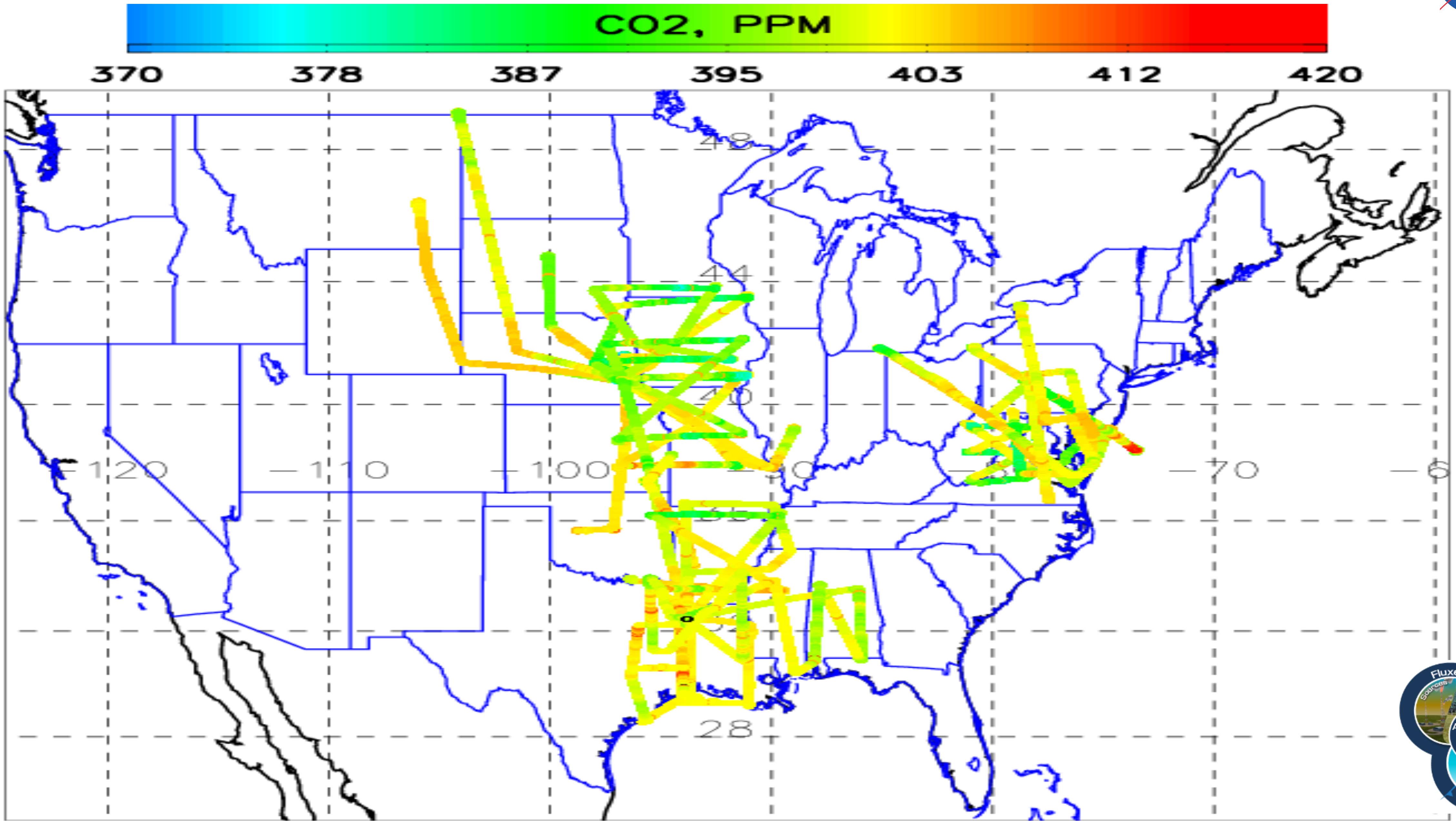
Three mission goals:

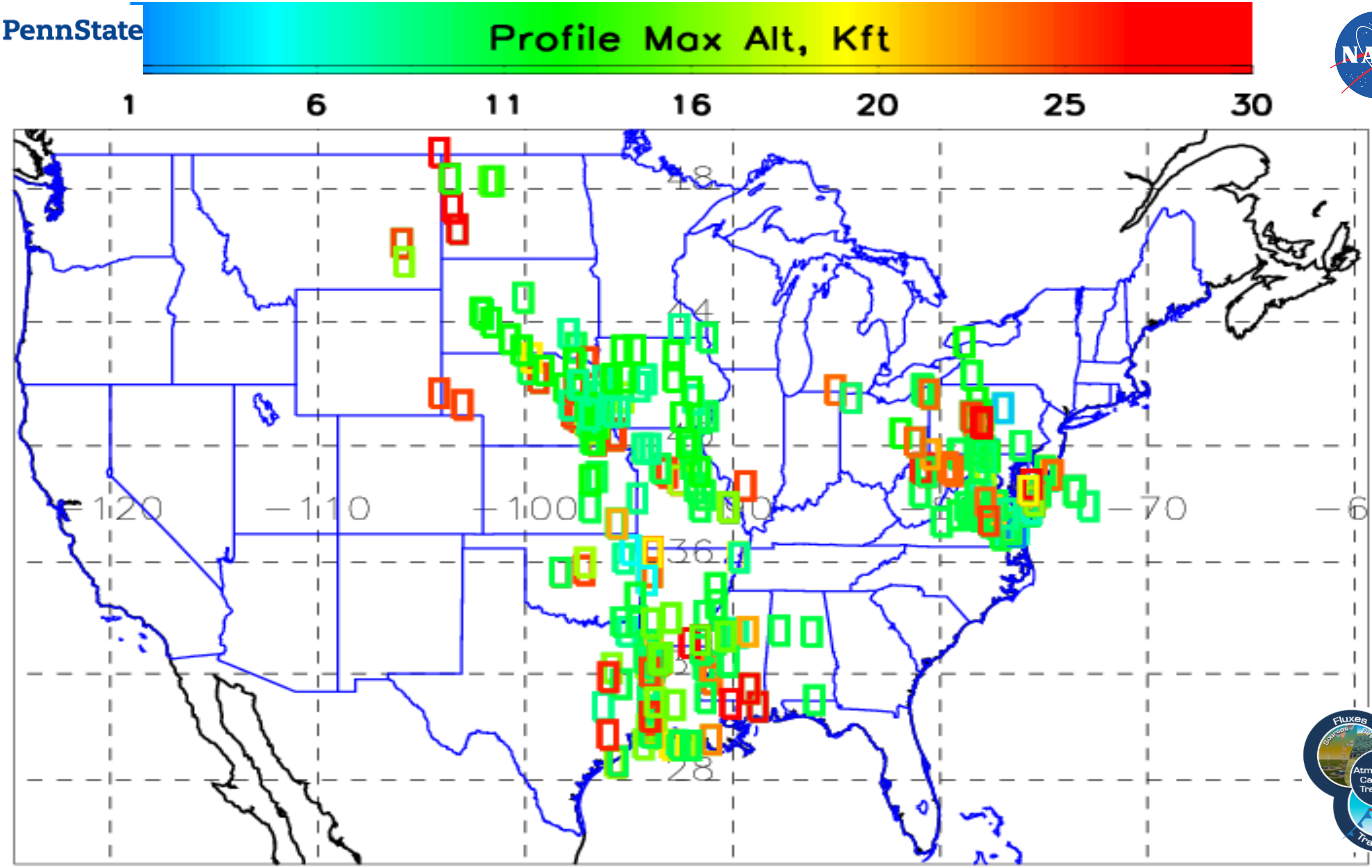
1. Reduce atmospheric transport uncertainty.
2. Improve regional-scale prior CO_2 and CH_4 flux estimates.
3. Evaluate the sensitivity of Orbiting Carbon Observatory-2 column CO_2 measurements to regional variability in tropospheric CO_2.

First field campaign complete: July-August 2016.

10 frontal passages, 10 fair weather flights, 2 Gulf inflow flights, 3 OCO-2 under flights.

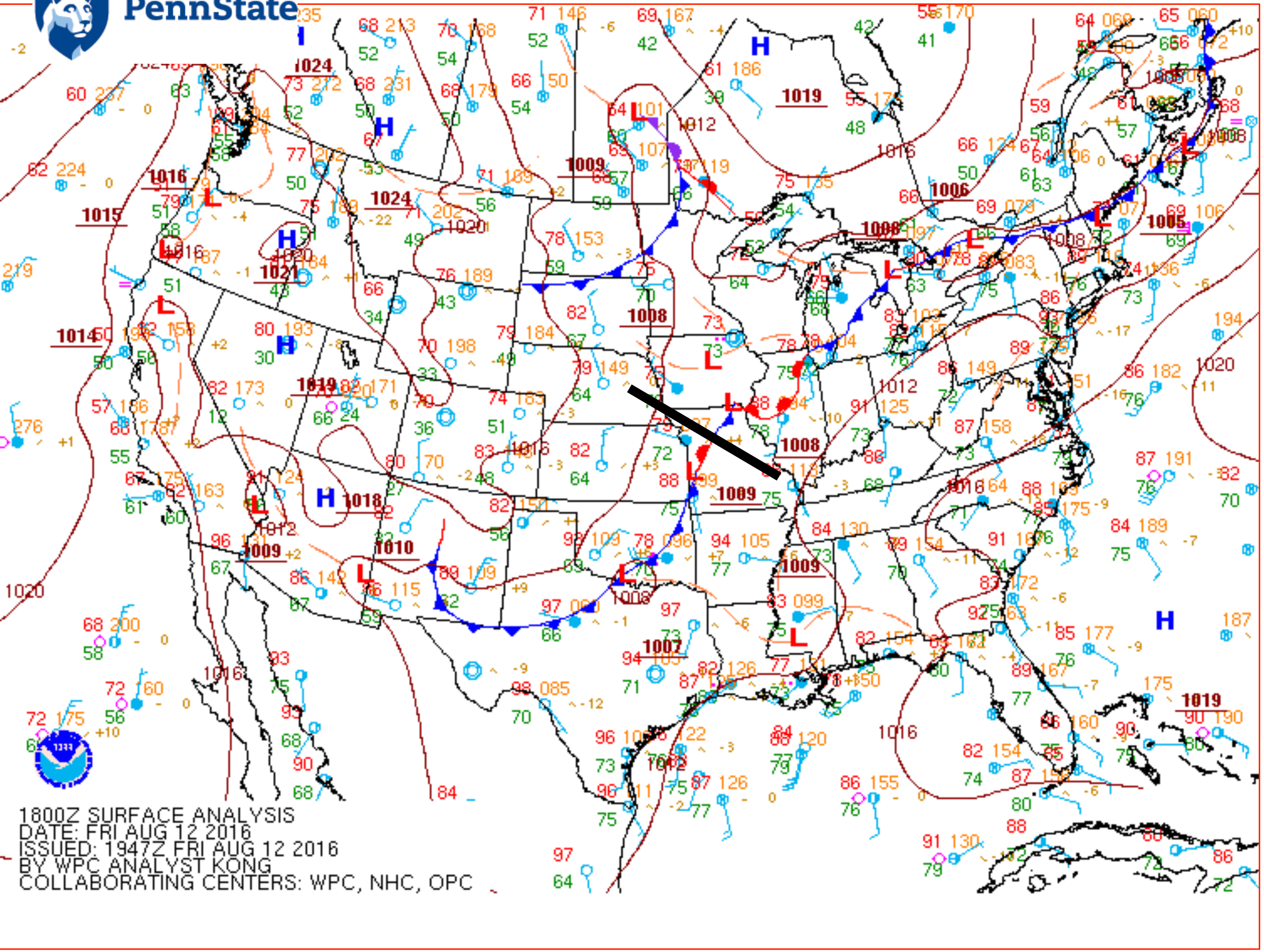
2016-07-18 to 2016-08-28




Profile Max Alt, Kft
1
6
11
16
20
25
30
48
44
36
28
-120
-110
-100
-70

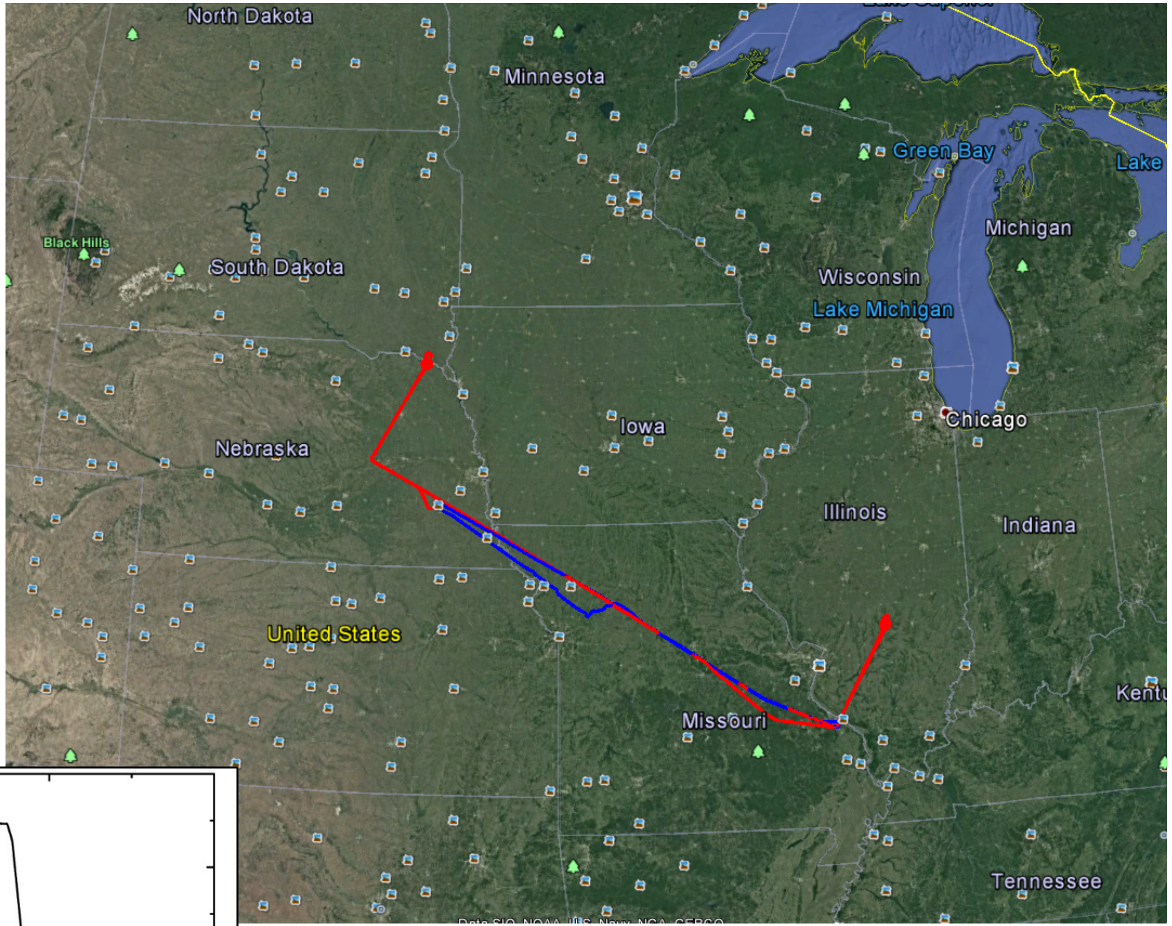
ACT America
12 Aug: Frontal Passage in Missouri
[RF 14]

Preliminary data: Please do not cite or reproduce.

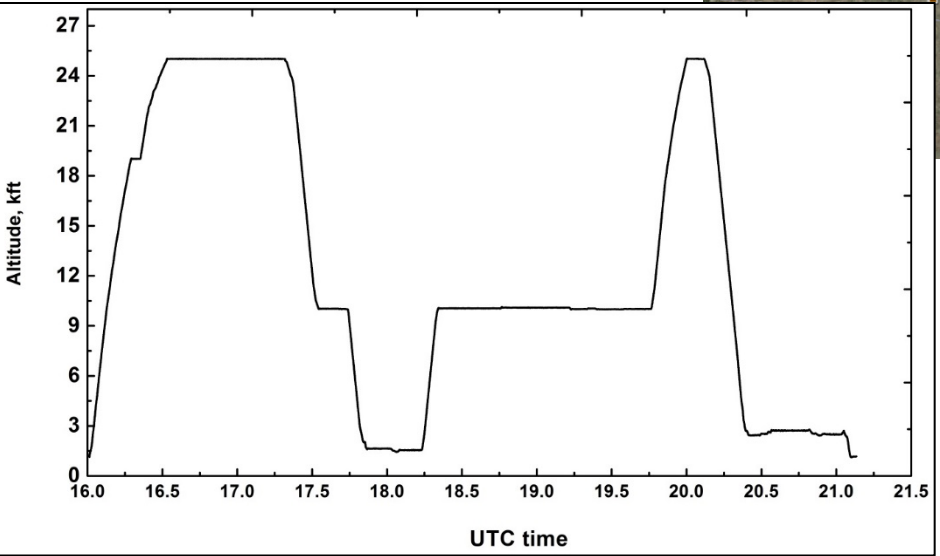


Cross-frontal legs at four different altitude (1 kft AGL, 9, 15, 25 kft MSL)

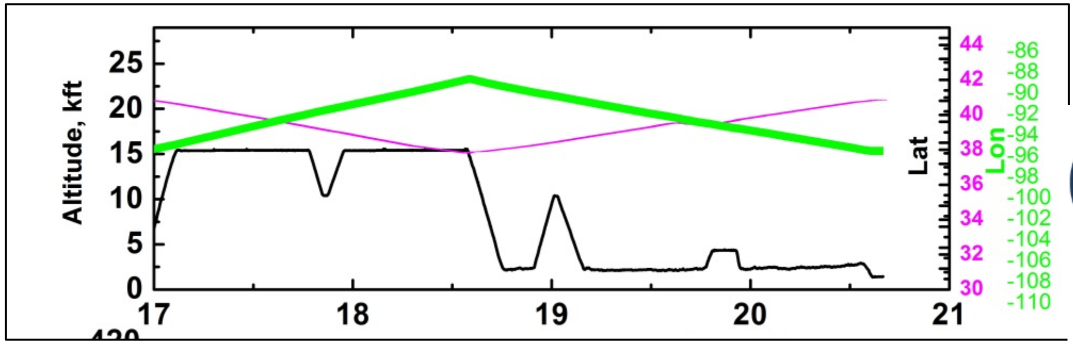
12 Aug 2016

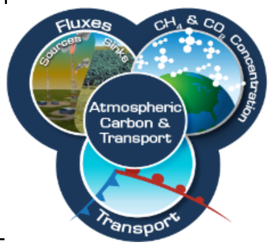


C-130

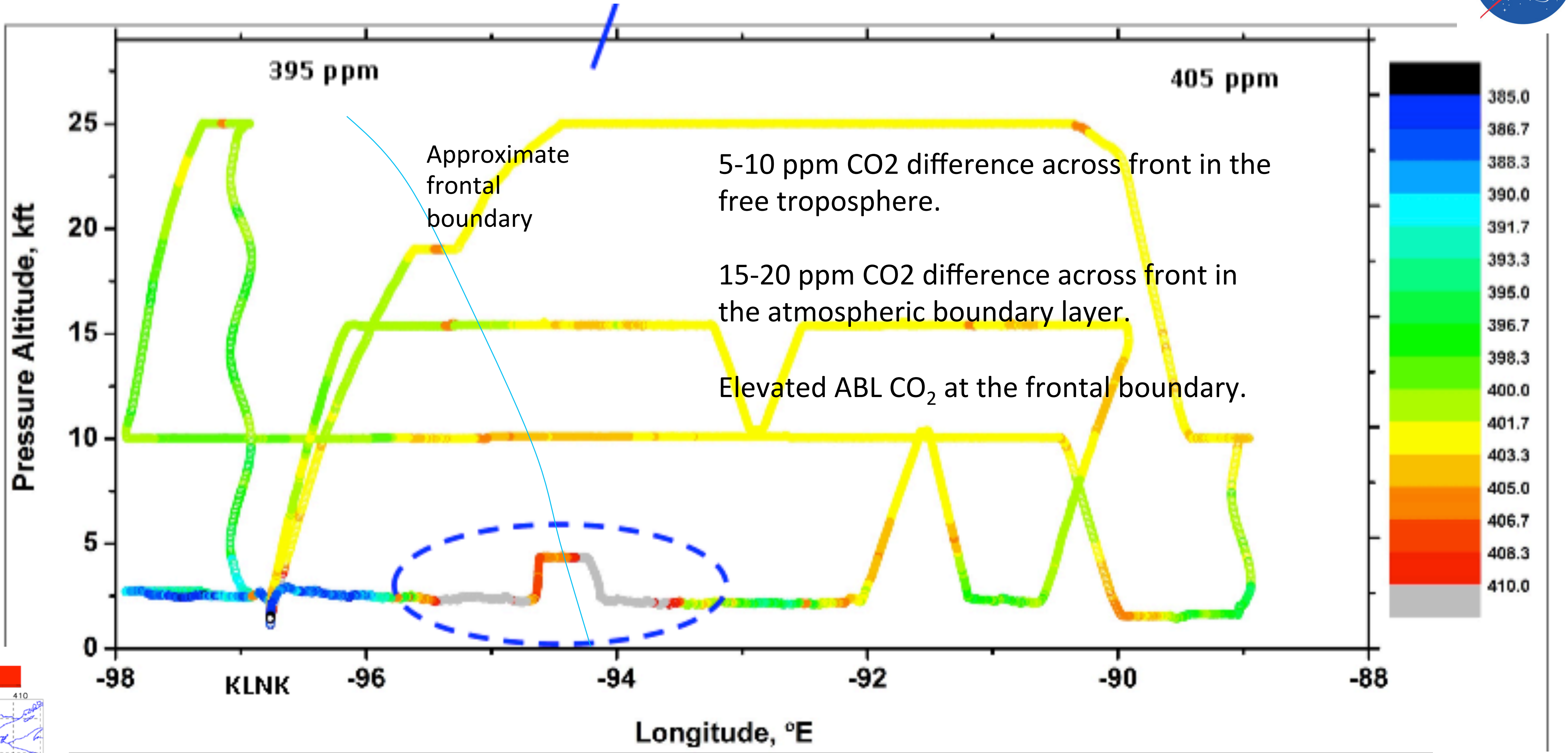


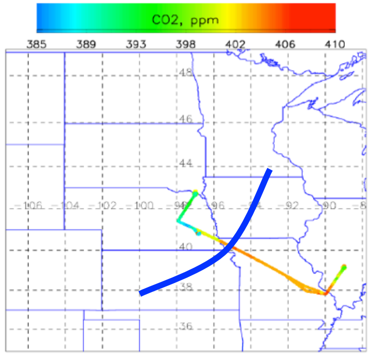
King Air





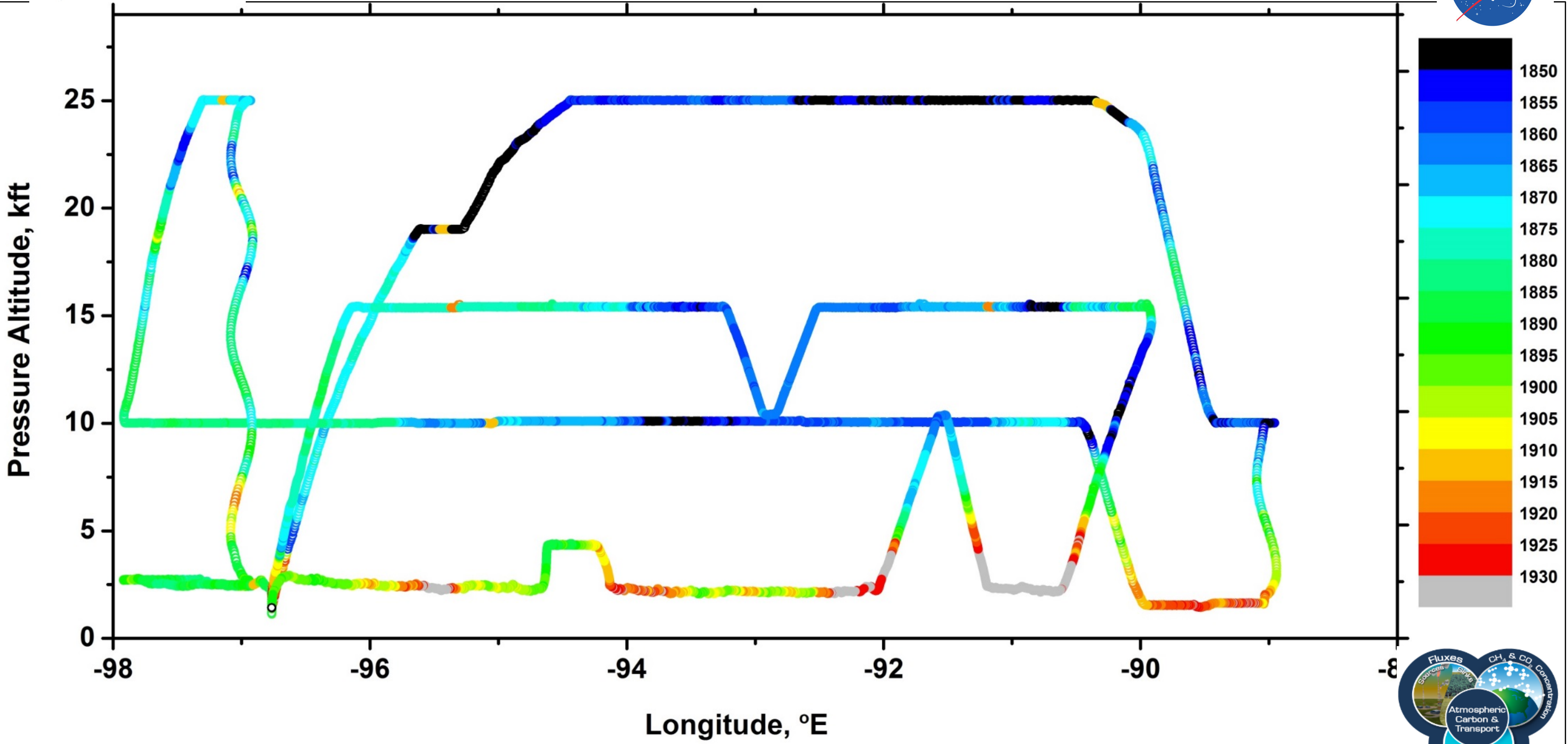
August 12, 2016, Midwest cold front





Data will be linked to the long-term tower-based and satellite measurement networks, and used to evaluate greenhouse gas transport models.

CH4 Longitude-Height Cross-section



Reflections

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- We need long-term study areas, like the SSA and NSA and FIFE. Mapping is hard. Single flux towers aren't sufficient. Climate-scale observatories.
- We need intensives to "oversample" and determine what long-term observations are needed to understand carbon-water-climate-nutrient interactions.

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FIFE and BOREAS:

- Changed us, created a new community, showed us how to do more ambitious, more comprehensive, more collaborative, earth system science.
- Maintaining that community and growing those capabilities are our responsibilities.
- Let’s watch where we’re going, keep balance, speak out,
- and keep up the good work!