Atmospheric boundary layer structure and turbulence in heterogeneous terrain:

Potential relevance for QPF.

Suggested hypotheses for COPS.

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outline

- Importance of ABL processes for COPS.
- Note on my background/biases/expertise.
- (My) view of ABL processes, potential relevance to QPF, past research.
- (My) IHOP hypotheses and results.
- Hypotheses for COPS?

ABL’s significance

- Reservoir for most of the H_2O in the atmosphere.
- Point of origin for a great deal of deep convection.
- Locus of interaction between the earth’s surface and the atmosphere – primary integrator of the complexity of the earth’s surface.

Overarching questions for ABL studies in COPS

- What are current limits in our ability to observe and simulate the ABL?
- Are these limits related to our lack of progress in improving QPF skill?
  - particularly in heterogeneous terrain and during summer convective conditions?
- If so, what targeted ABL studies might contribute to improving QPF skill?

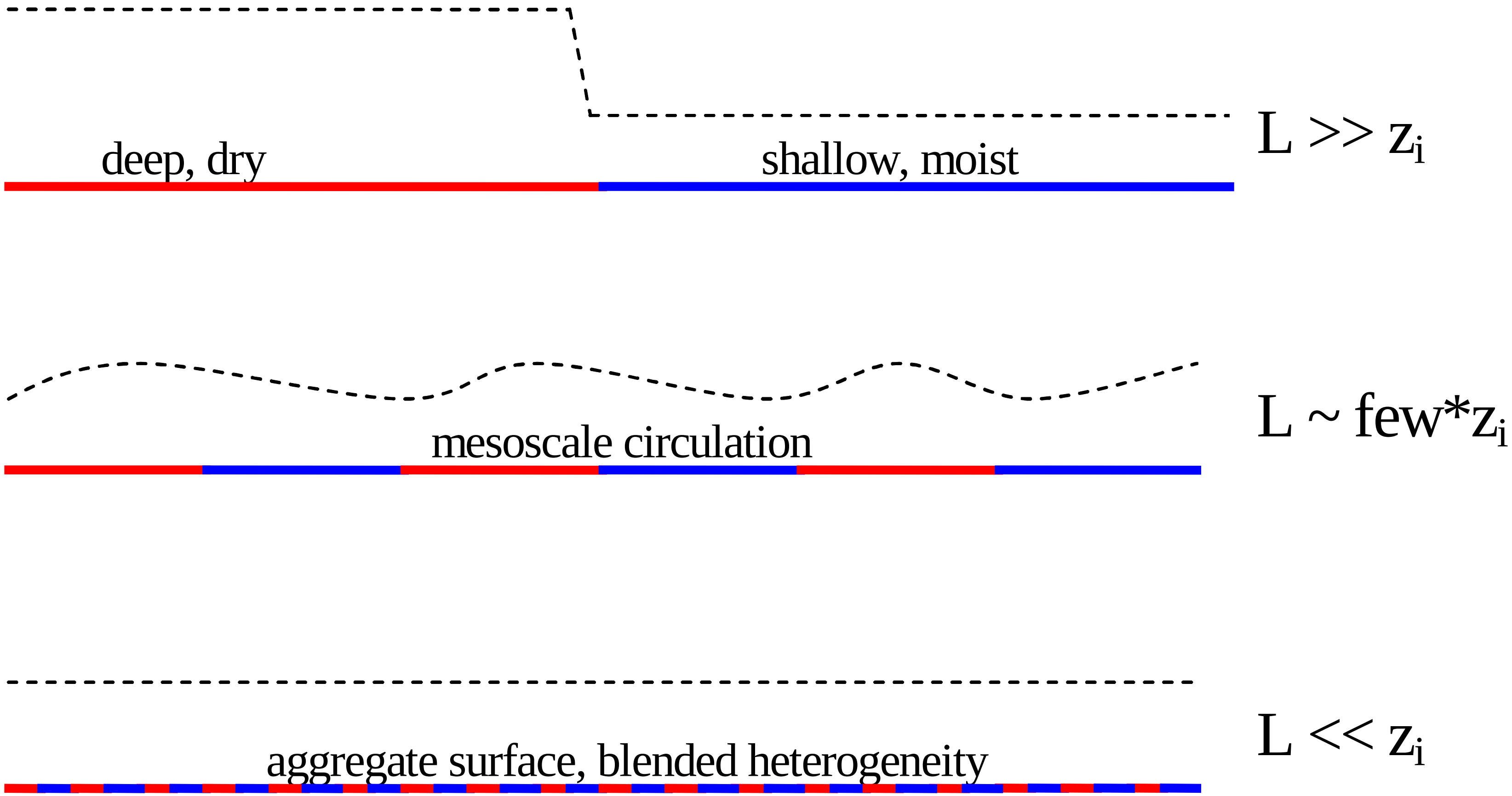
Statement of personal bias

- Flux measurement methodology origins, including lidar
- Many biogeochemical applications
- Airborne lidar studies in BOREAS (1994) – apparent contradiction of Avissar/Pielke results.
- Involvement in SGP97, IHOP 2002. Focus on role of heterogeneous land surface in daytime ABL structure.
  - An observational skeptic in flat terrain

Factors that influence ABL structure and turbulence

- surface fluxes (lower boundary),
- surface orography (lower boundary),
- ABL fluid dynamics and thermodynamics,
- entrainment zone/free tropospheric structure (upper boundary),
- ABL-top clouds (upper boundary),
- synoptic-scale advection (horizontal and vertical).

Three regimes of coupled surface-ABL heterogeneity



deep, dry

shallow, moist

L >> z_i

mesoscale circulation

L ~ few*z_i

aggregate surface, blended heterogeneity

L << z_i

See, for example, Patton et al, (2004); Mahrt (2000).

ABL research/current limits

- Homogeneous regimes. ($L >> z_i$, $L << z_i$)
  - ABL parameterizations are imperfect. Particularly difficult problems include:
    - entrainment,
    - surface fluxes.
  - Direct observations of surface fluxes are not available in most locations.
  - Surface fluxes not mapped ($L << z_i$ case).
  - ABL depth is often not observed.

ABL research/current limits

- Heterogeneous surface regime
  - Middle scale (what is L?) is uncertain

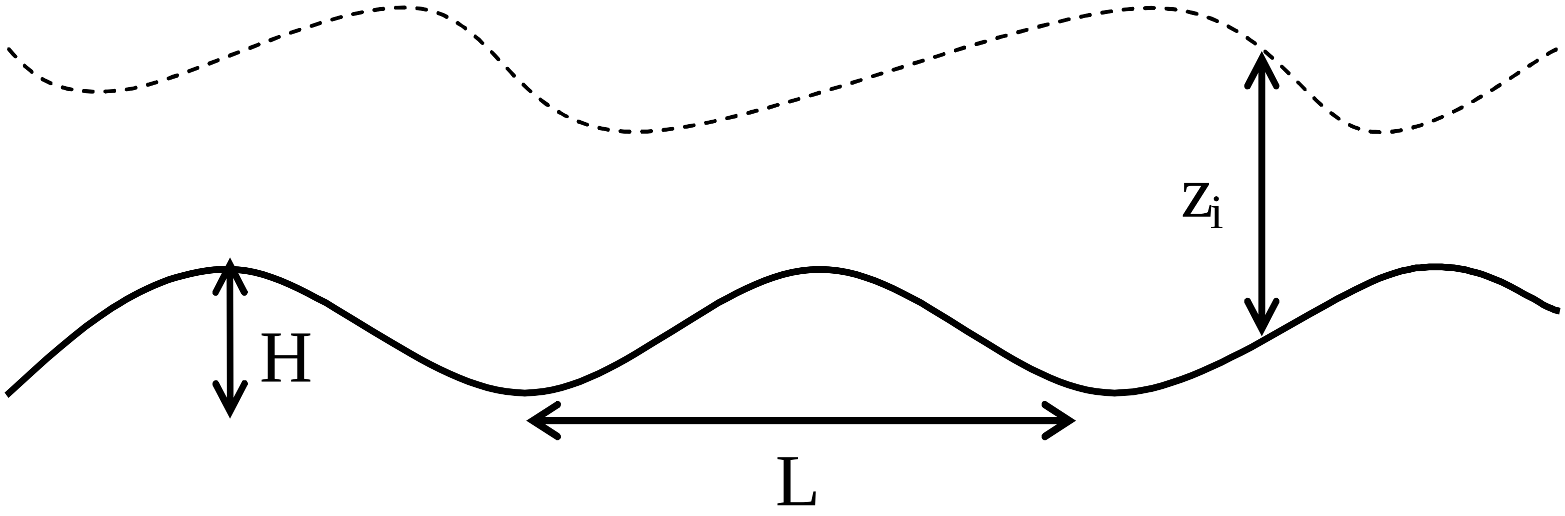
  - Ability to observe mesoscale structure in ABL (moisture, z_i, temperature, wind) is limited
  - Ability to explicitly simulate (e.g. Large Eddy Simulation) mesoscale flow is limited
    - Large domain, high-resolution needed in both cases

  - Mesoscale models predict that surface heterogeneity has a strong influence on convective initiation (CI),
    - but this finding is difficult to evaluate with detailed field data.

- Does surface heterogeneity lead to favored spots for convective initiation/precipitation?
- Analogous discussion exists for low mountains?

Analogous limits for terrain?

- $H/L << 0.1$ or $H/z_i << 0.1$ – “flat”
- $H/L >= 0.1$, $H/z_i >= 0.1$ – terrain-induced ABL flow, “low mountains”
- $H/L >> 0.1$, $H/z_i >> 0.1$ – “alpine” (or night)



(My) IHOP hypotheses

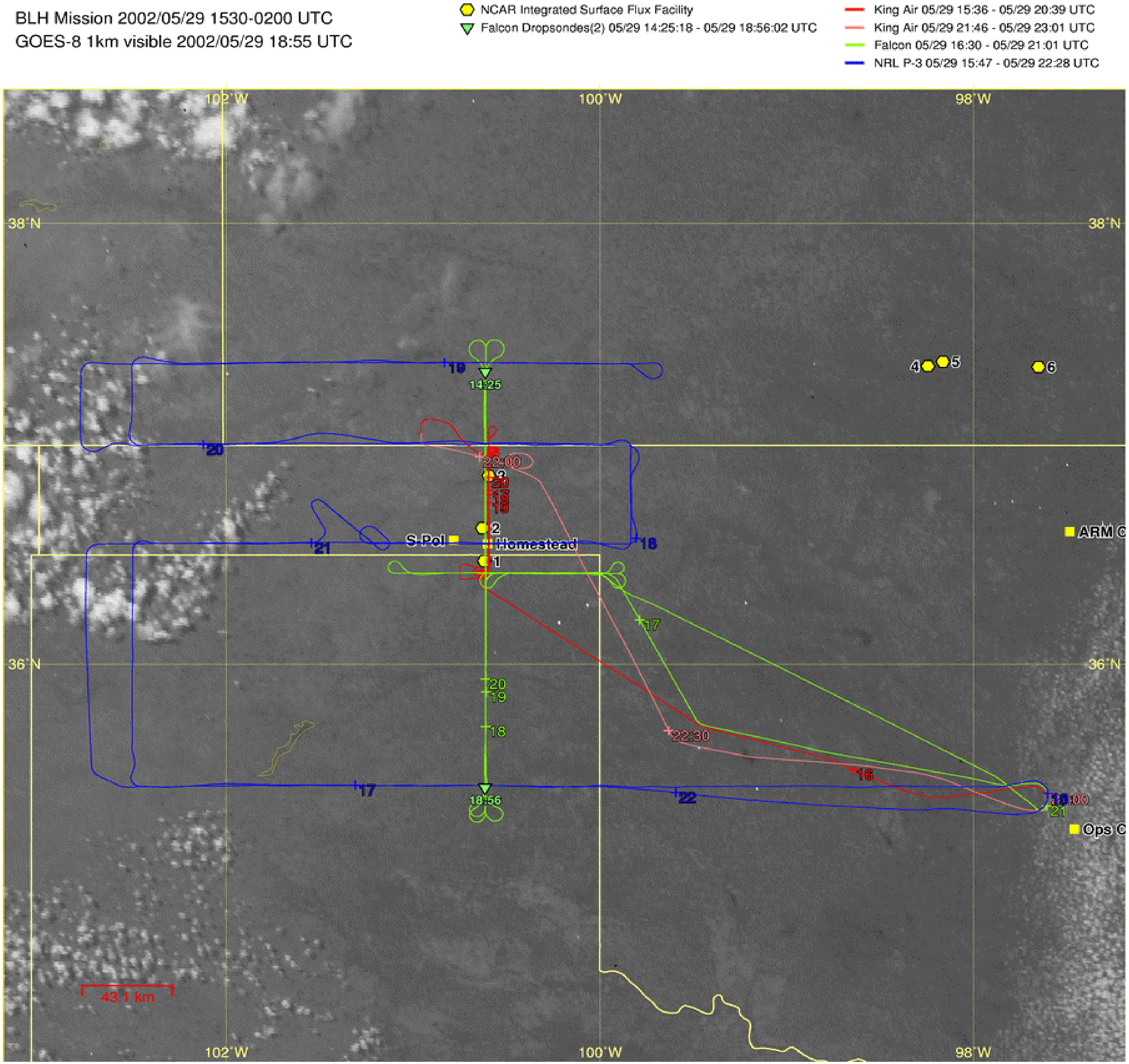
focus on daytime, summer, convective conditions

- At some L (fairly large), surface heterogeneity creates mesoscale flow.
- This flow will often create favored locations for CI.
- At very large L, separate 1-D ABLs develop.
- Mesoscale NWP models can reproduce these surface-ABL interactions given accurate boundary conditions.
- Simulating these 1-D ABLs well is necessary for accurate CI/QPF.
- The scale of ABL heterogeneity is smaller than the scale of the operational observing network.
- More dense observations/better modeling of ABL heterogeneity (especially ABL H_2O vapor) will improve prediction of CI/QPF.

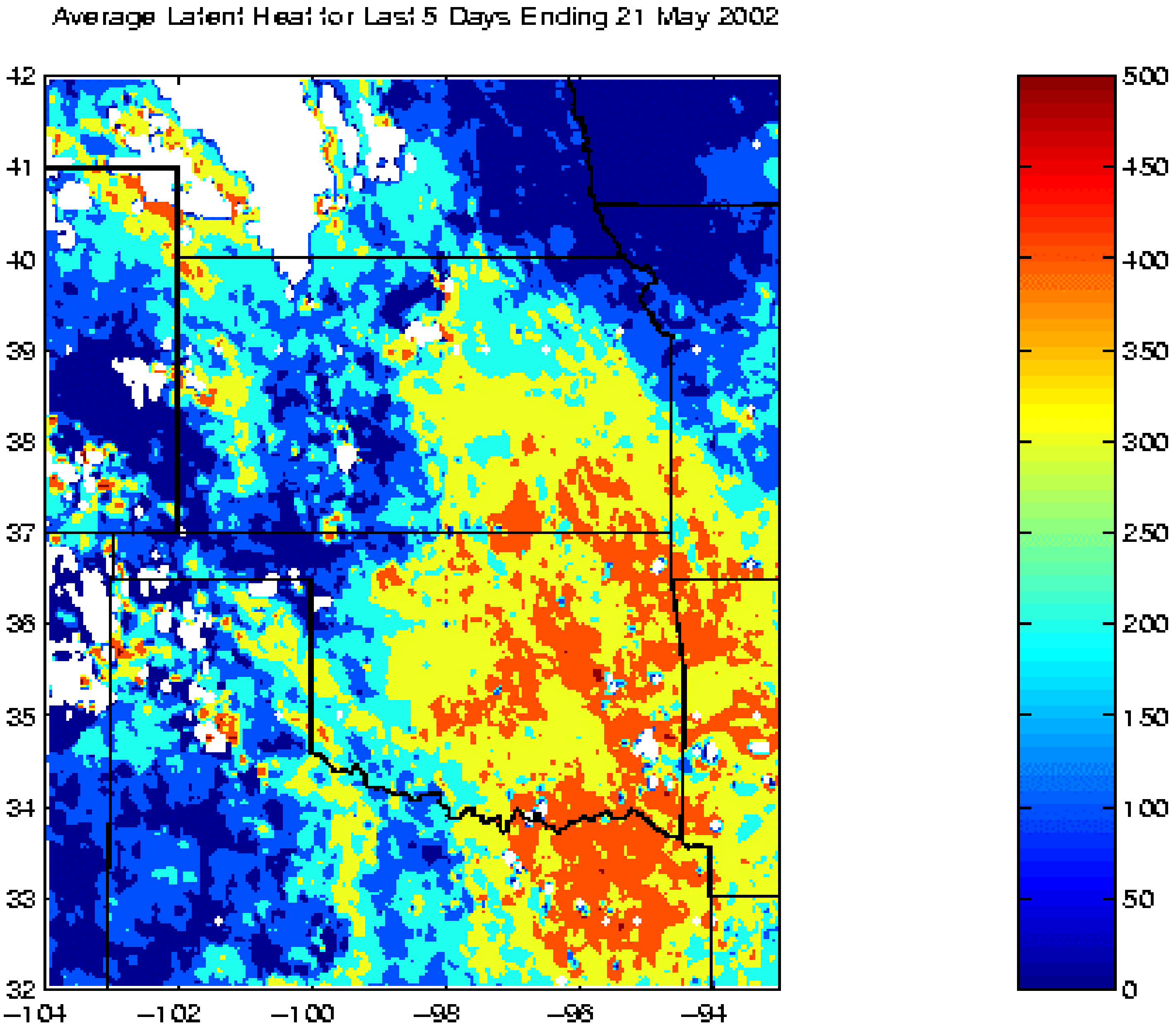
(My) IHOP approach

1. Find a way to map surface sensible and latent heat fluxes over a mesoscale domain.
2. Observe ABL depth and moisture content over the same domain. ABL turbulence and flow also, if possible.
3. Repeat step 2 until the pilots are sick of you, and/or flight time runs out.
   – go beyond case studies. E.g., L = f(U).
4. Hope that CI happens some time.
5. When this doesn’t work, write another proposal.

BL Heterogeneity Mission Example
29 May, 2002

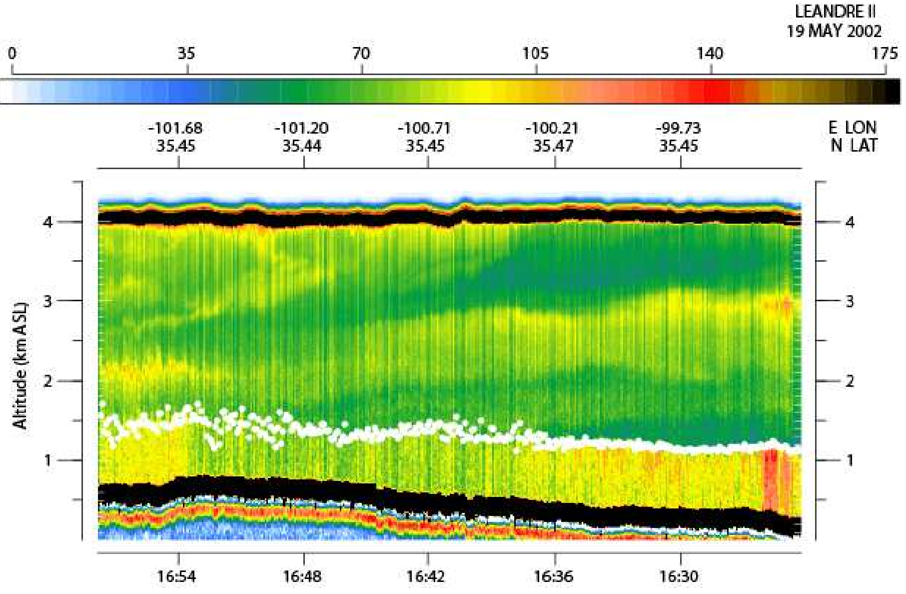


East-west soil moisture gradient surface flux gradient based on satellite surface temps.



LEANDRE LIDAR IMAGERY (5/19)

1



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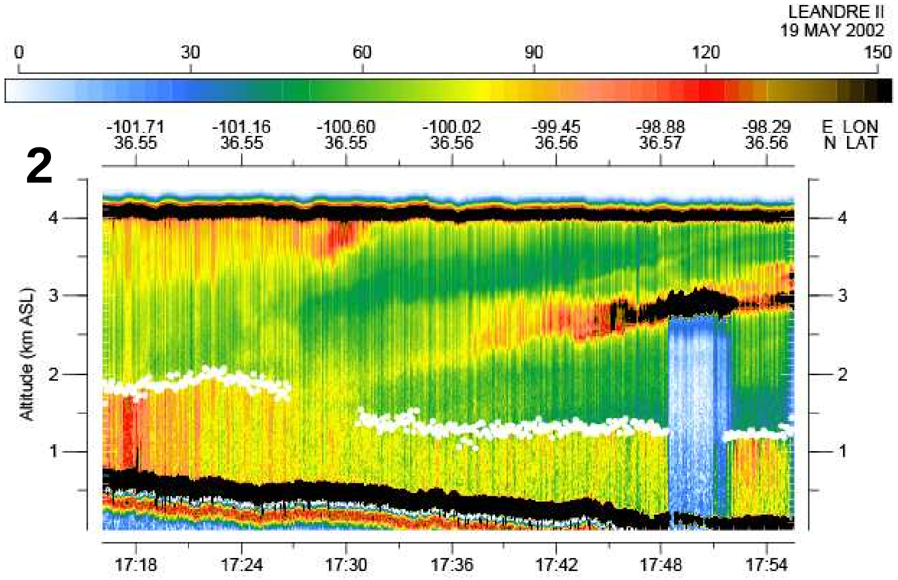

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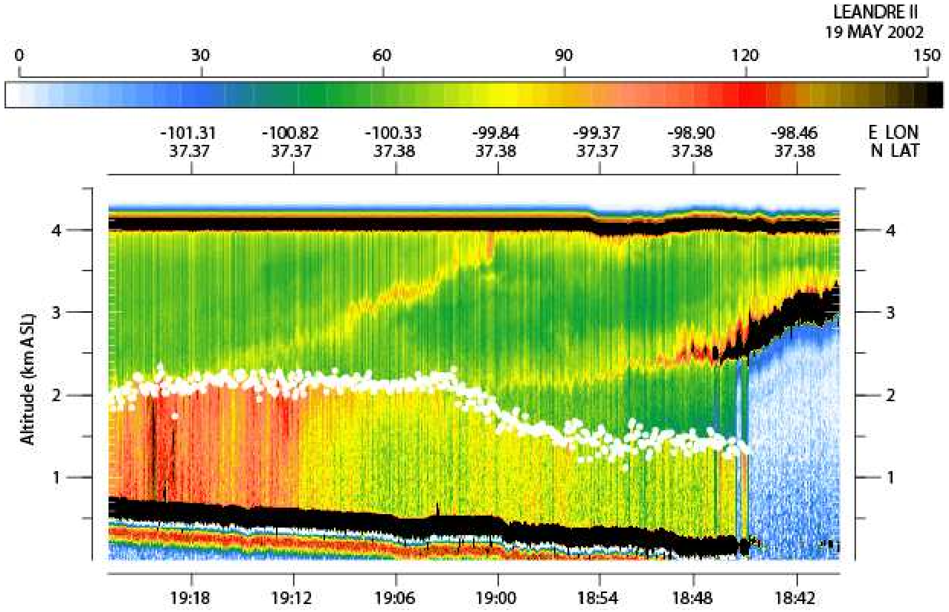

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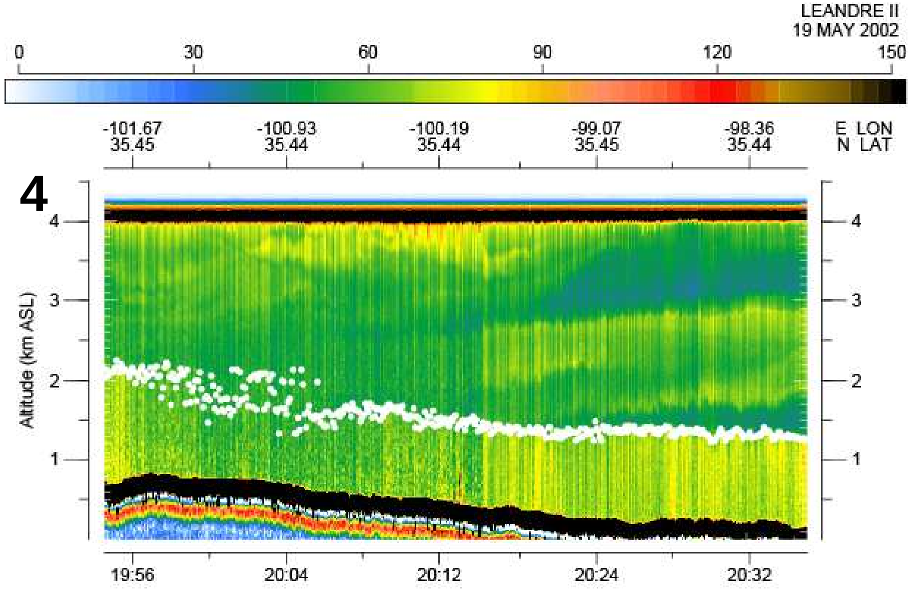
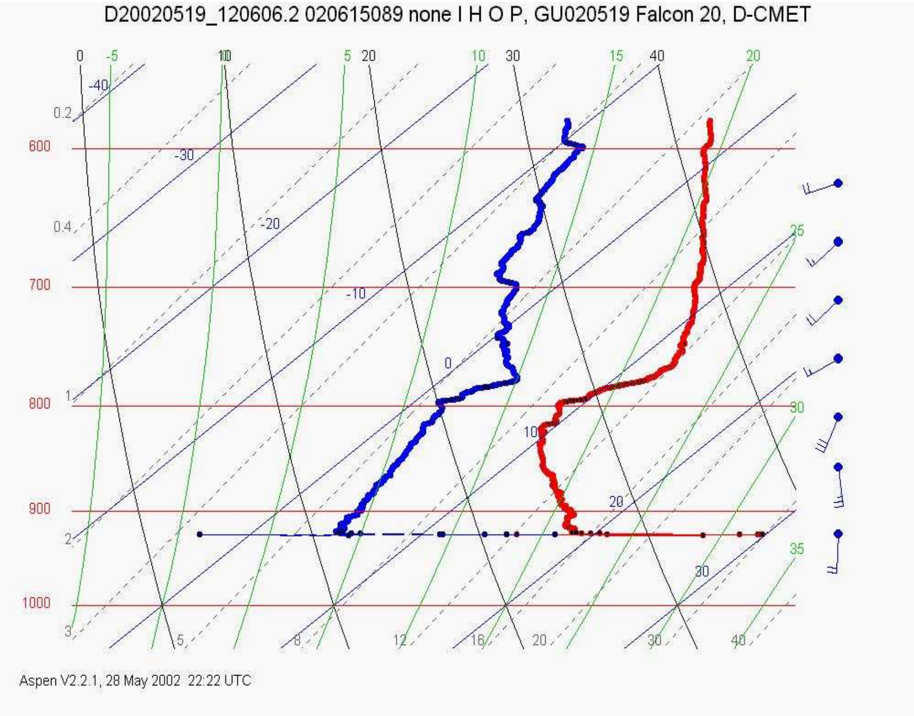


19 May 2002

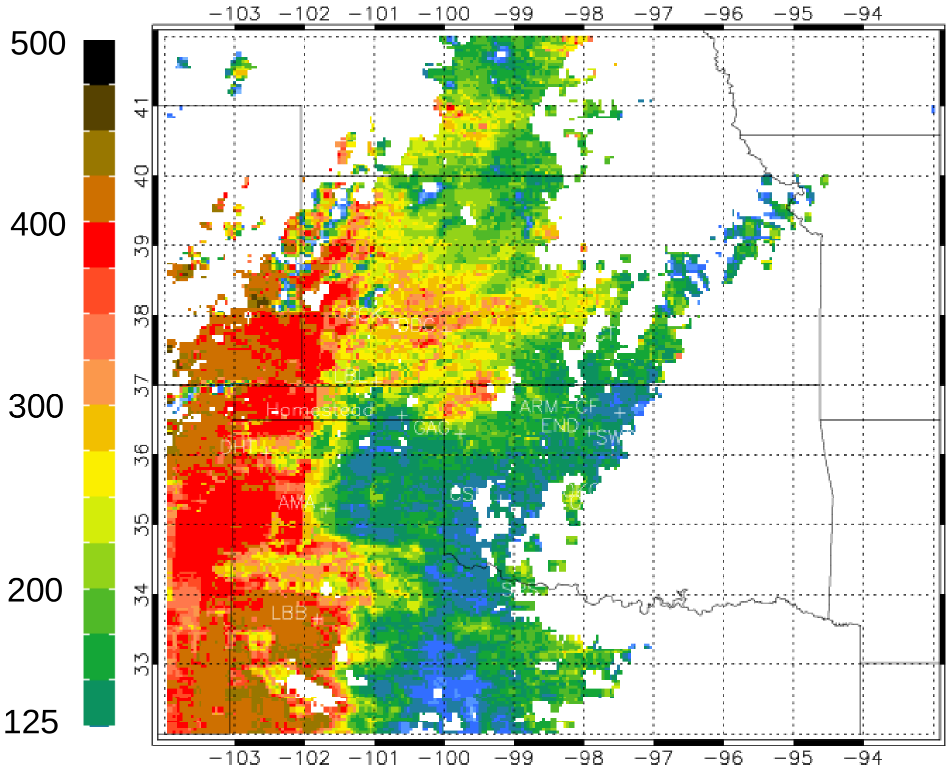
Frontal Passage leaves IHOP region under a cool, dry, and well-capped airmass



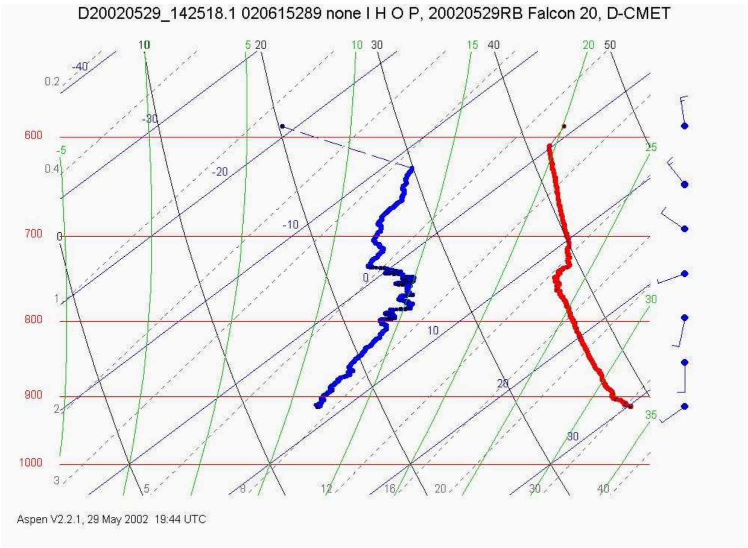
DLR Falcon morning Dropsonde

On LEANDRE track north of Homestead

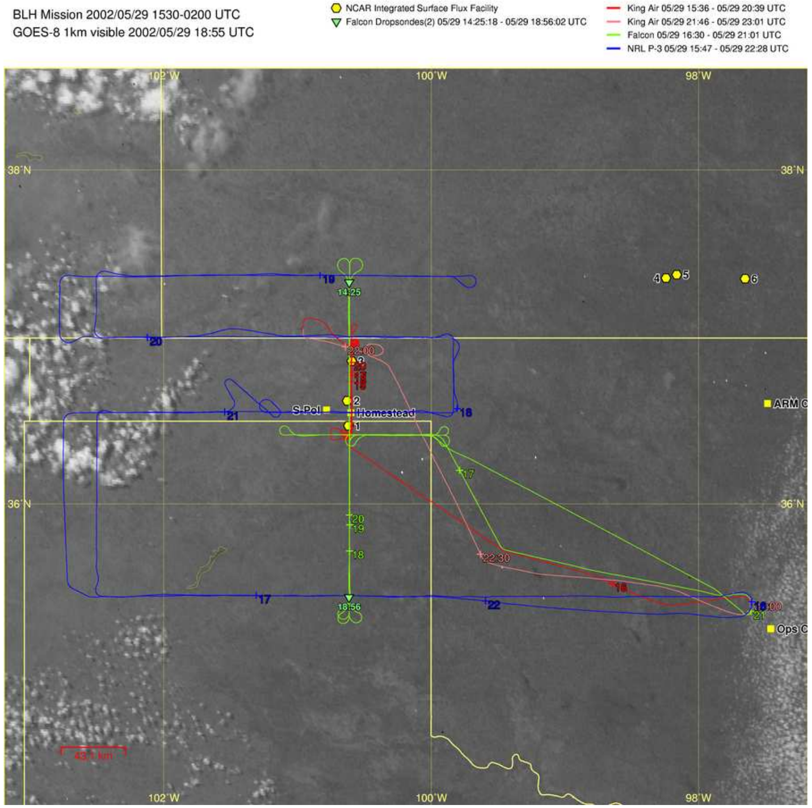
29 May 2002



ALEXI Sensible Heat flux indicates a *sharp* discontinuity on western end of P-3 track (but ALEXI predicts <u>lower</u> fluxes than on 19 May)



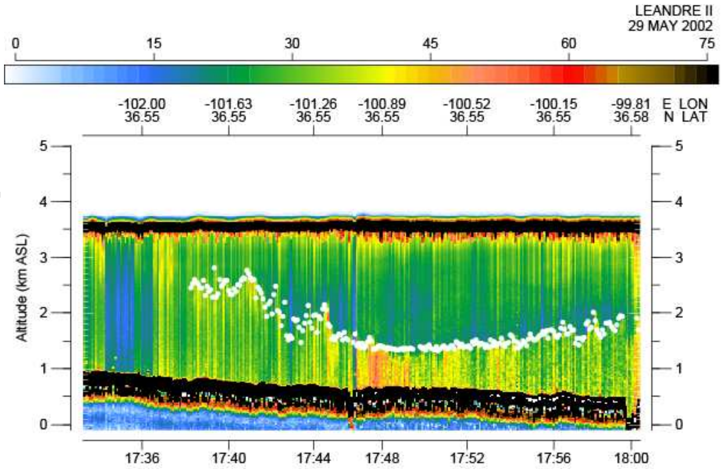
Dropsonde north of Homestead indicates a *<u>weaker cap</u>* than on 19 May



29 May

LEANDRE Images

2



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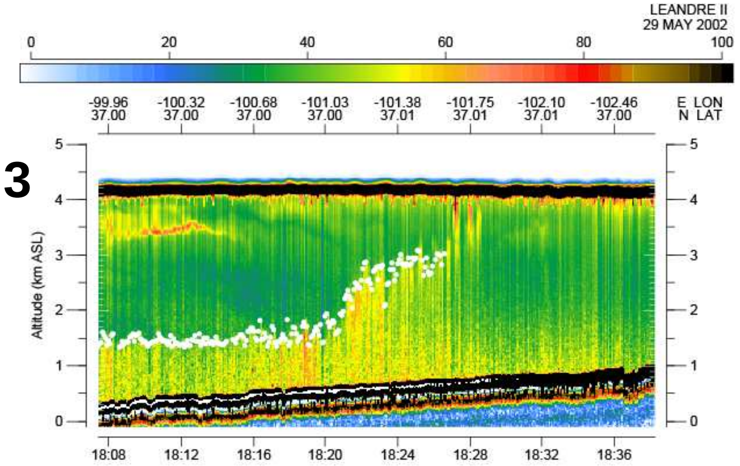
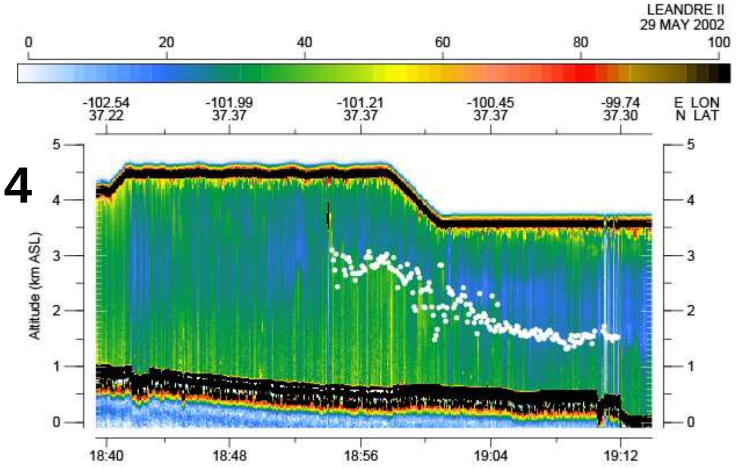


P-3 flies *into* CBL

4



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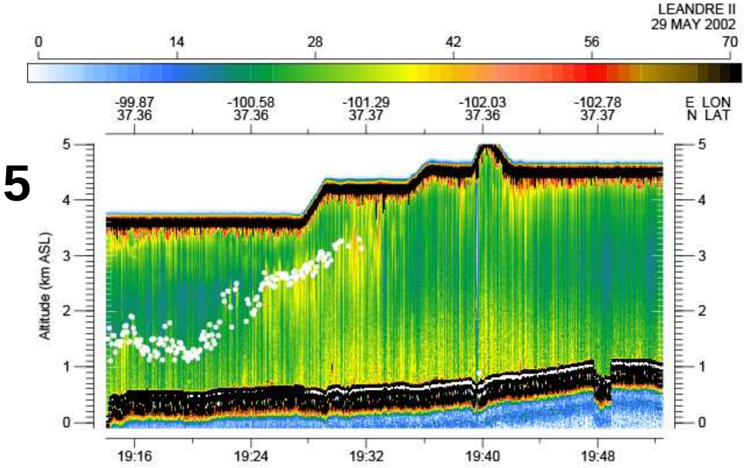

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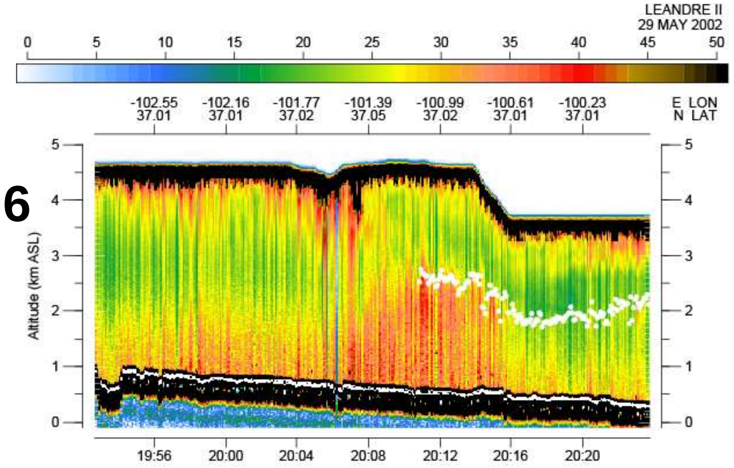

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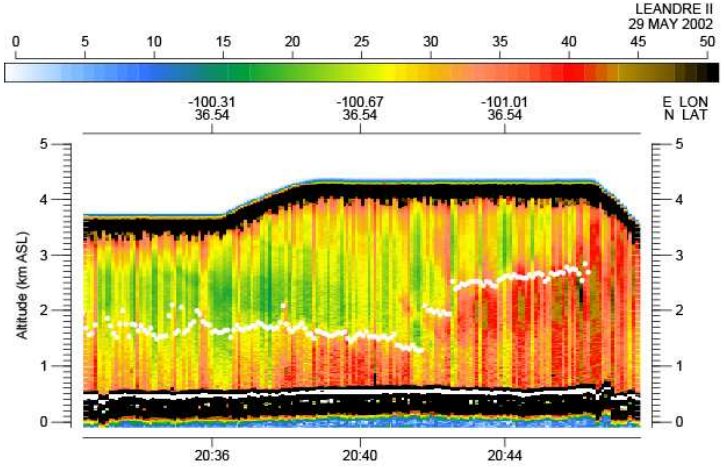
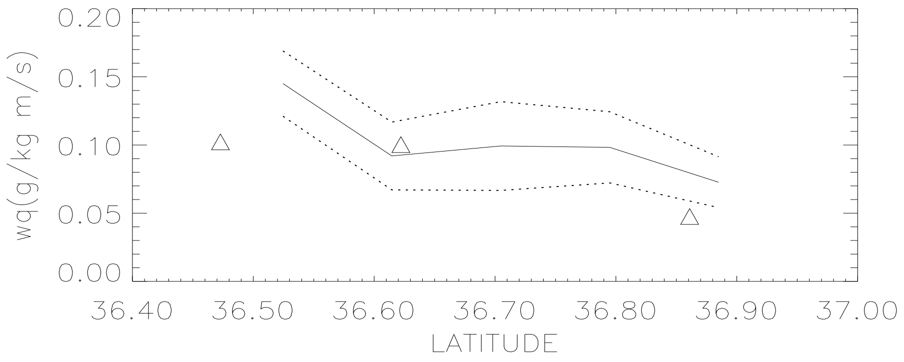
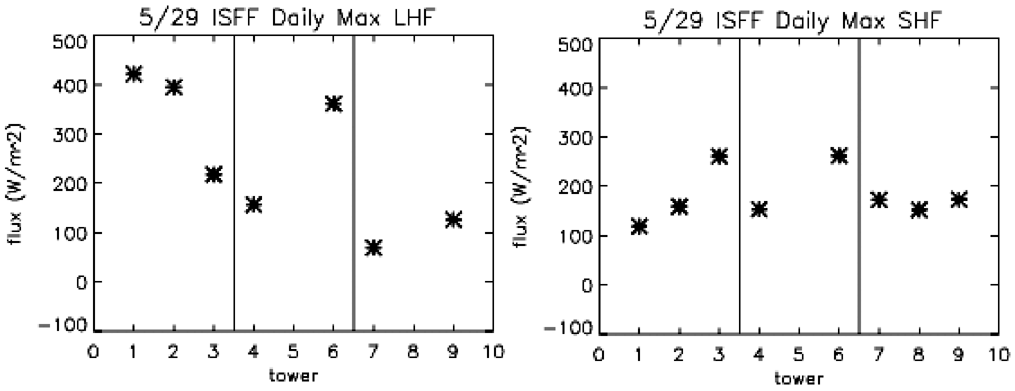


UYKA Latent Heat Flux

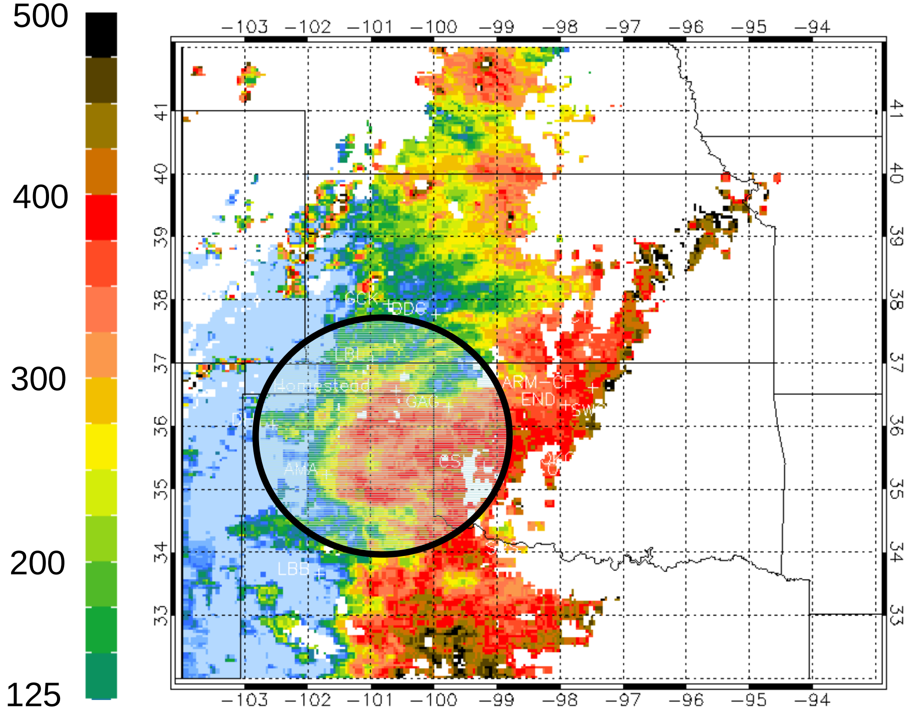


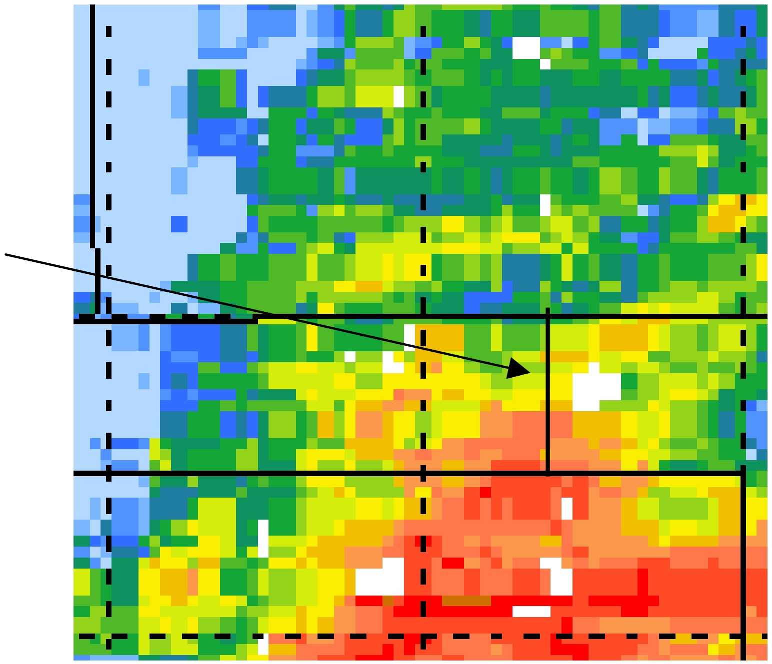
TOWER Sensible and Latent Heat Flux



SURFACE FLUX HETEROGENEITY at <50km scale documented by multiple data sources

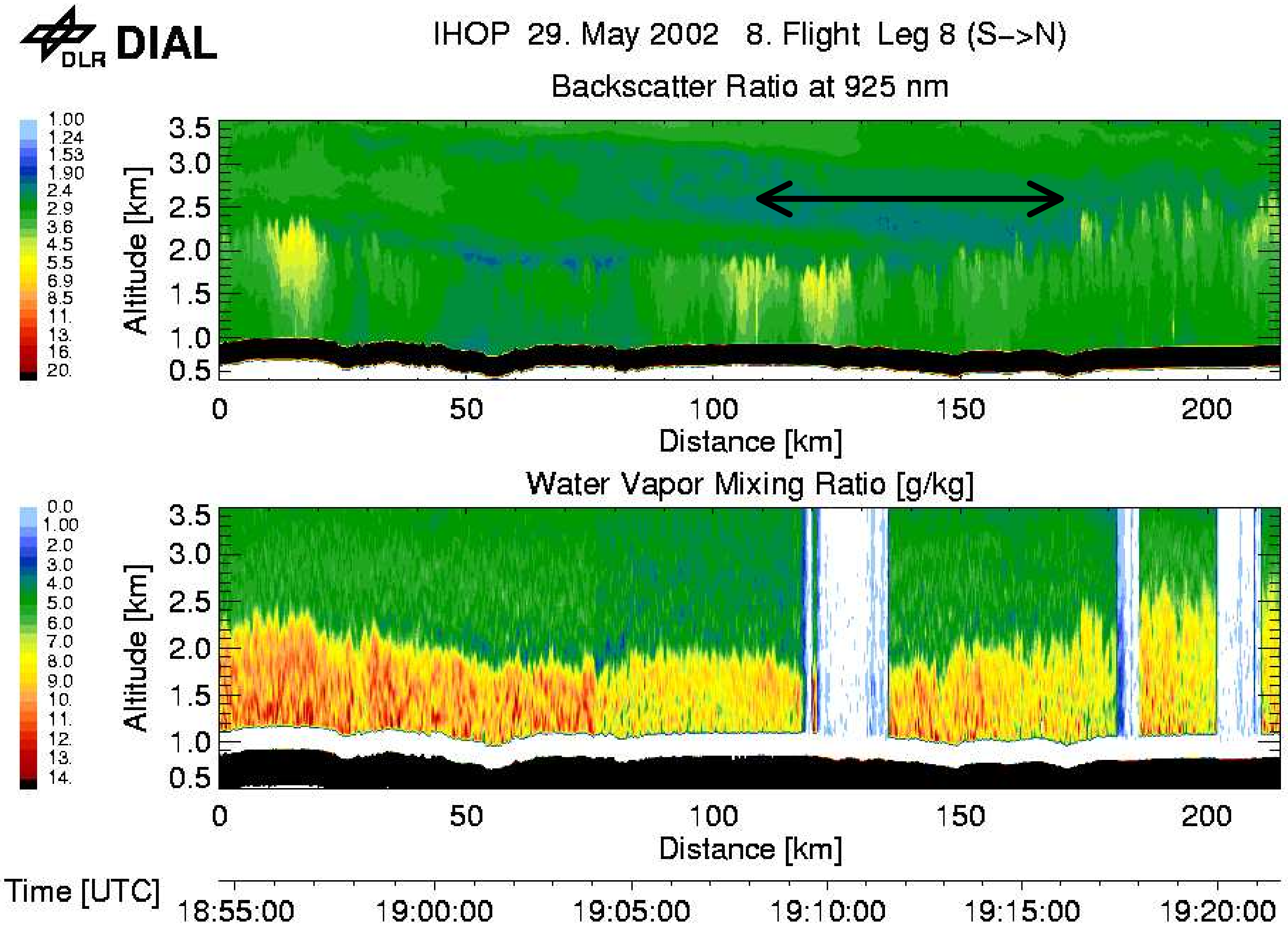
ALEXI Latent Heat Flux




UYKA Western Track

DLR lidar observations along this N-S gradient.

South



North

Pattern was repeated on multiple DLR Falcon passes over 3 hours.

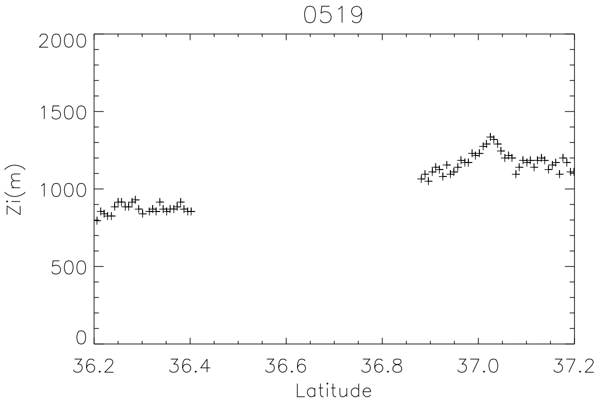
N-S variability in ABL depth

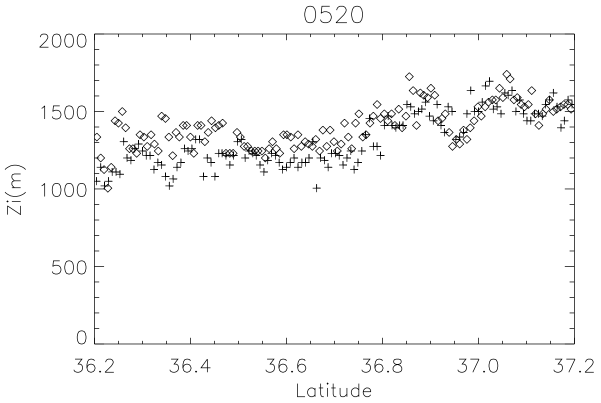
DLR lidar backscatter data

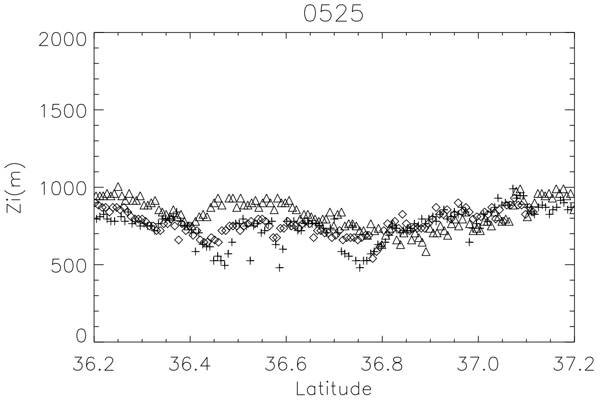
- On 19, 20, and 29 May, the ABL depth increases with latitude.

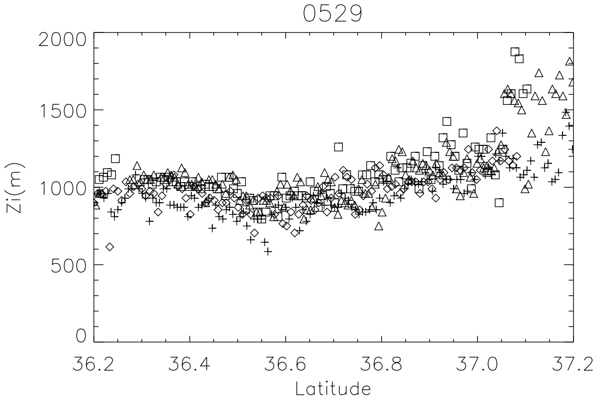
- On 25 May, and 7 June, ABL depth is more homogeneous.

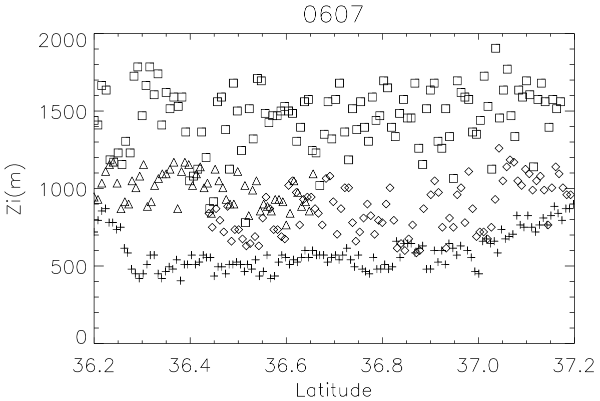
- ABL depth patterns match the surface H patterns surprisingly well.







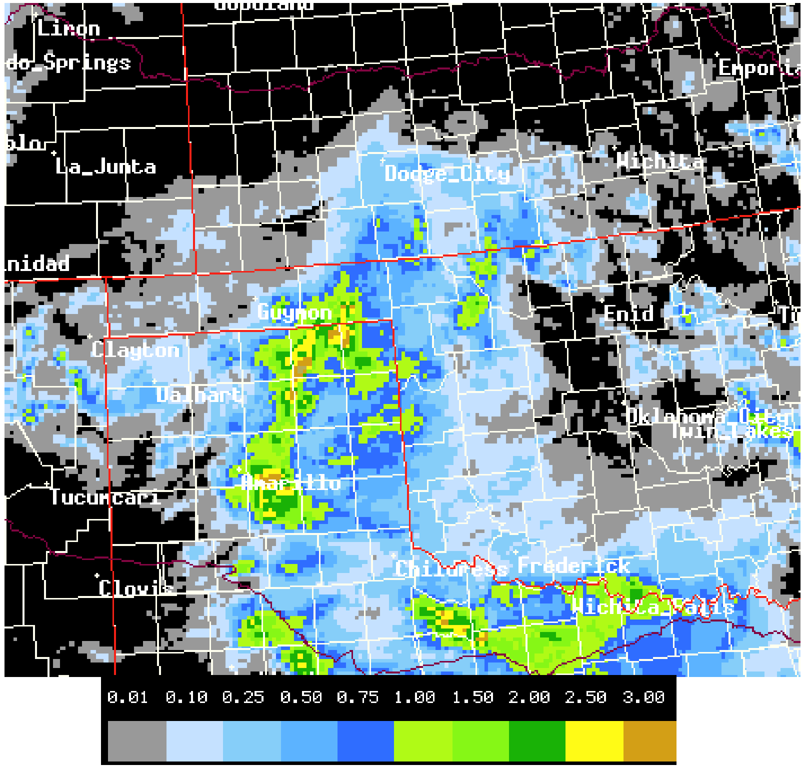




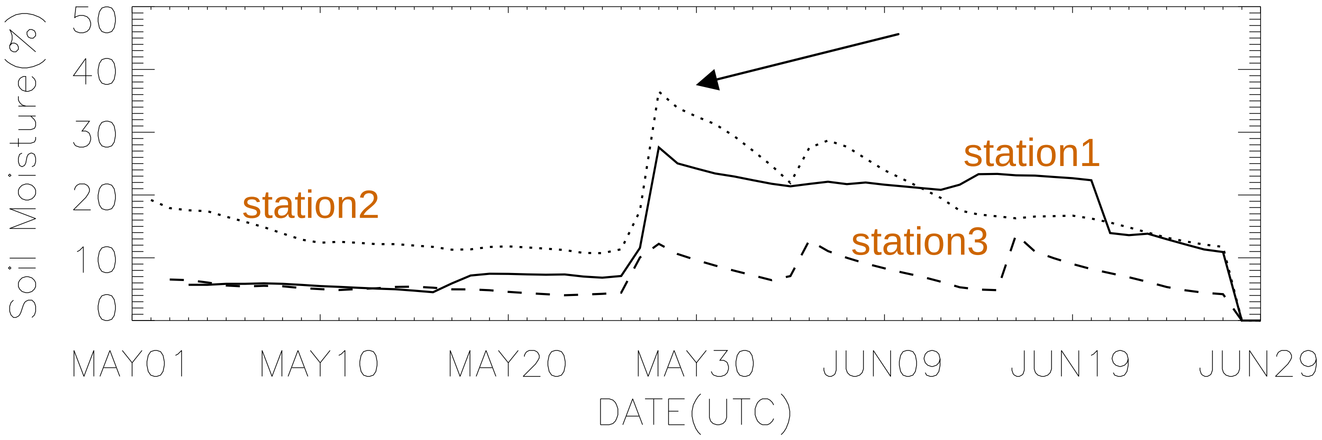
29 May 2002

Surface conditions in parts of western IHOP domain affected by antecedent rainfall

Rainfall: 27 May 12Z to 28 May 12Z



UYKA Western Track Soil Moisture



Blending heights for western track UWKA flight days

Date	M (ms^{-1})	Θ (K)	u_* ($m\ s^{-1}$)	$w'\theta_v'$ (Kms^{-1})	L_{blend} (m)	L_{wm} (m)	$-z_i/L$
May 19	13.2	299.7	0.76	0.31	12769	2869	12.8
May 20	13.2	300.4	0.76	0.29	12449	2958	12.2
May 25A	1.1	296.5	0.26	0.19	704	366	117.8
May 25B	3.4	300.3	0.29	0.21	5677	1070	113.4
May 29	4.9	308.3	0.39	0.14	7030	2879	37.4
June 7	10.2	310.3	0.54	0.17	13434	4135	20.5

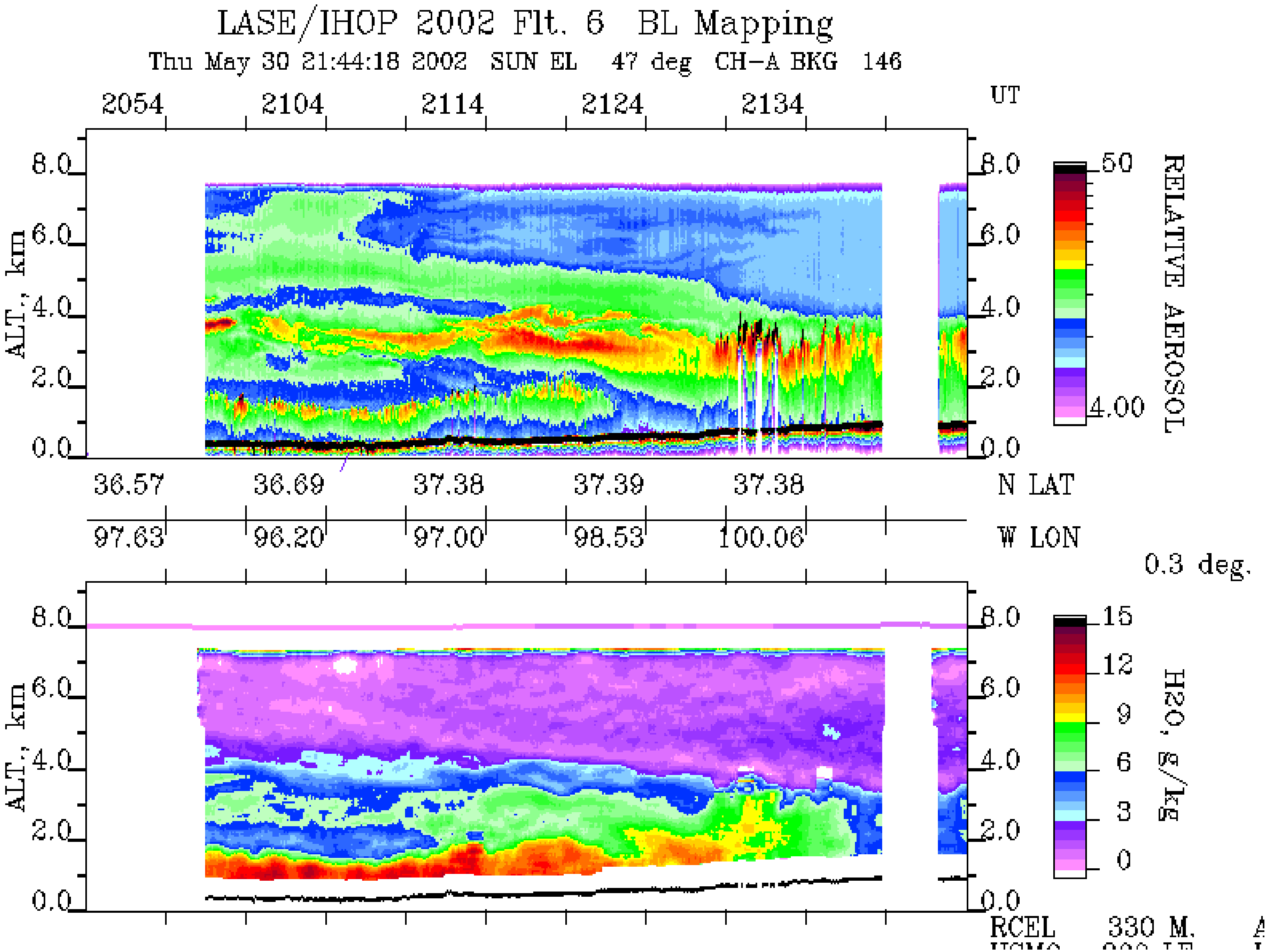
(My) IHOP conclusions

- At some L (fairly large), surface heterogeneity creates mesoscale flow. Yes, at 60 km scale, L = f(U).
- This mesoscale flow will often create favored locations for CI. Never (obvious) during IHOP?
- At very large L, separate 1-D ABLs develop. Yes, across entire 300 km domain.
- Mesoscale NWP models can reproduce these surface-ABL interactions given accurate boundary conditions. Still a hypothesis.
- Simulating these 1-D ABLs well is necessary for accurate CI/QPF. Still a hypothesis.
- The scale of ABL heterogeneity is smaller than the scale of the operational observing network. Yes, see lidar z_i, moisture data.
- More dense observations/better modeling of ABL heterogeneity (especially ABL H_2O vapor) will improve prediction of CI/QPF. Still a hypothesis.

Other IHOP conclusions

- Do not neglect the importance of thin elevated layers
  - entrainment zone structure varies across space.

LASE: 30 May, 2002



Potential hypotheses for COPS

- Improved ability to predict ABL depth/T/Q will lead to systematic improvement in CI *timing.*
  - Homogeneous ABL. Improve modeled surface fluxes, entrainment?
- Improved simulation of spatial heterogeneity in surface fluxes will have only slightly improve CI. Will primarily influence *location*.
- Improved simulation of mesoscale flow induced by low mountains will improve CI significantly. Will influence *location, timing* and *intensity*.

More potential hypotheses for COPS

- Terrain and surface heterogeneity will alter the ABL and thus significantly modulate the development of existing precipitation systems. (?)
- Incorporating the statistical properties of ABL turbulence into forecast models will more accurately simulate the stochastic nature of CI. (?)
- Increased observation/assimilation of large-scale ABL heterogeneity will improve CI/QPF prediction.
- Entrainment zone structure will prove to be an important factor in predicting CI/QPF.

Suggestions for greatest progress in QPF

(from a skeptical, flatland, observational ABL biogeochemist)

- Target observations and modeling of regions where complex mesoscale flow is important
  - High resolution observations and modeling required cannot be maintained operationally?
- Improve link between convective parameterization and surface latent heat flux(?)
- Expand data assimilation – rainfall, water vapor.
- Treat CI as a stochastic problem.