Convective Boundary Layers and Entrainment Processes

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with contributions from many colleagues

Science objectives

Objectives:
Clouds
Transitions
Sub-grid heterogeneity
BL-top processes (shear, waves, clouds)
Physics-chemistry-vegetation interactions
Aerosol interactions with land, clouds, and chemistry
Large scale forcing and context (subsidence, advection)

Clouds and non-canonical boundary layers

BL types from Harvey et al., QJRMS (2015) – Lidar observations at a UK site

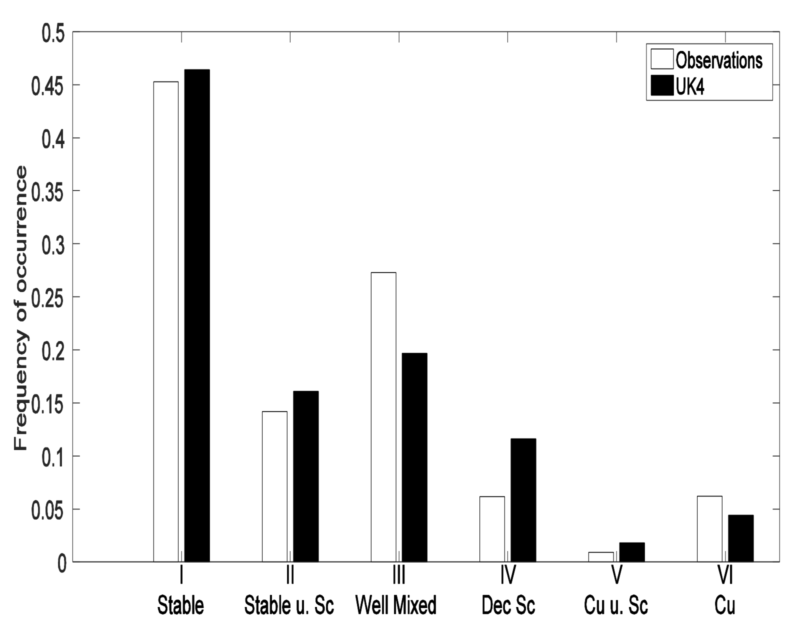
Types with clouds occur at significant frequencies (clear sky ~20% global average over land)

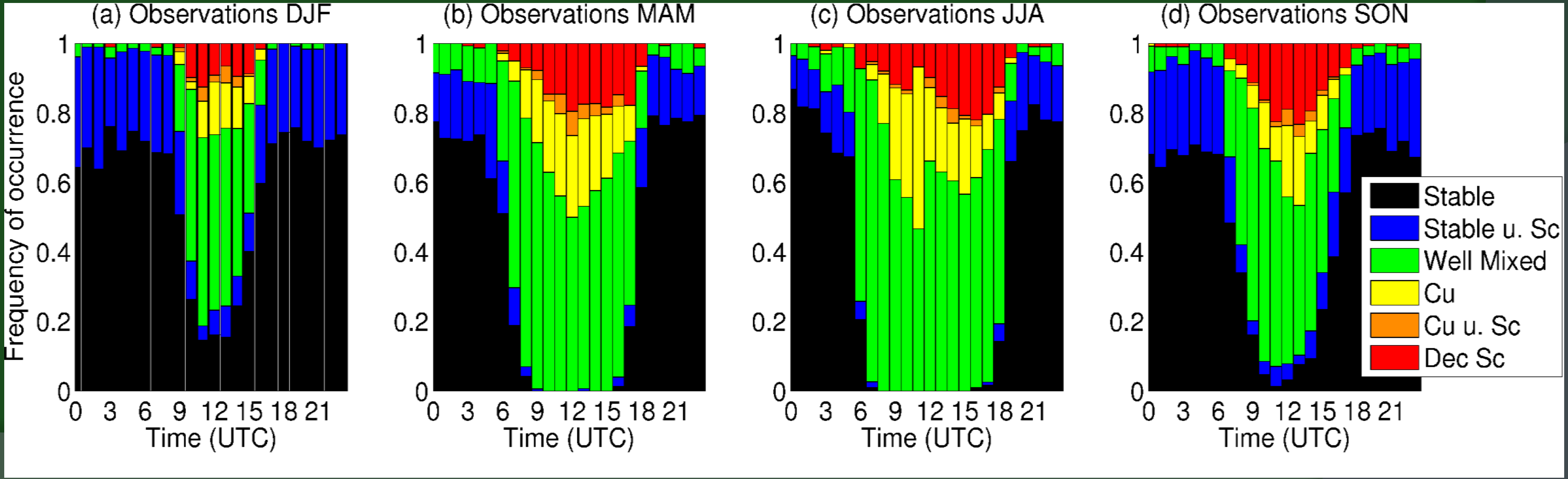
Standard convective BLs are globally rare

Over land, the BL is in transition much of the time

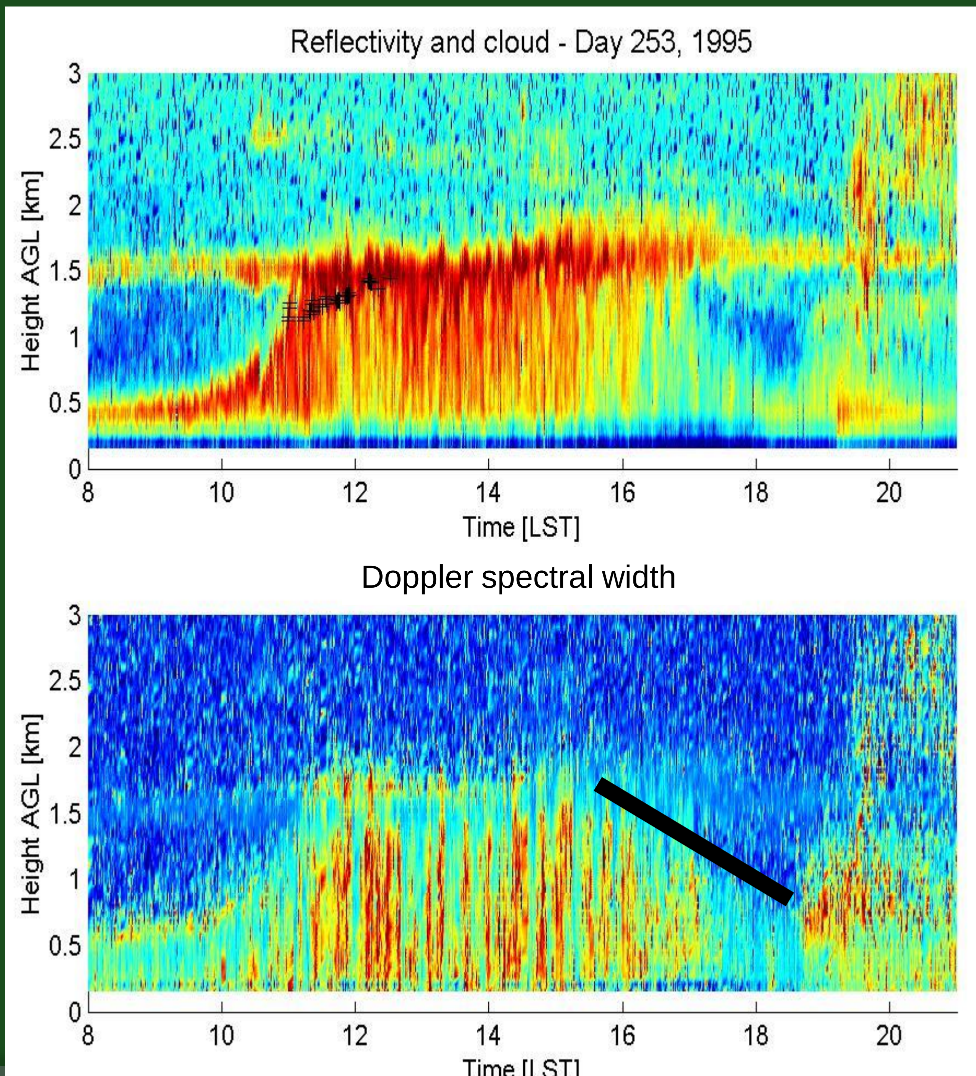
Population density is near coasts

Advection is never negligible (well, hardly ever)





Afternoon transition



Timing and shape of transition are critical to initiation of inertial oscillation / low-level jet, nighttime transport, distribution of pollutants, etc.

Unforced transition – all budget terms are important, few simplifications are possible

Radar wind profiler observations from 1995 Flatland boundary layer campaign

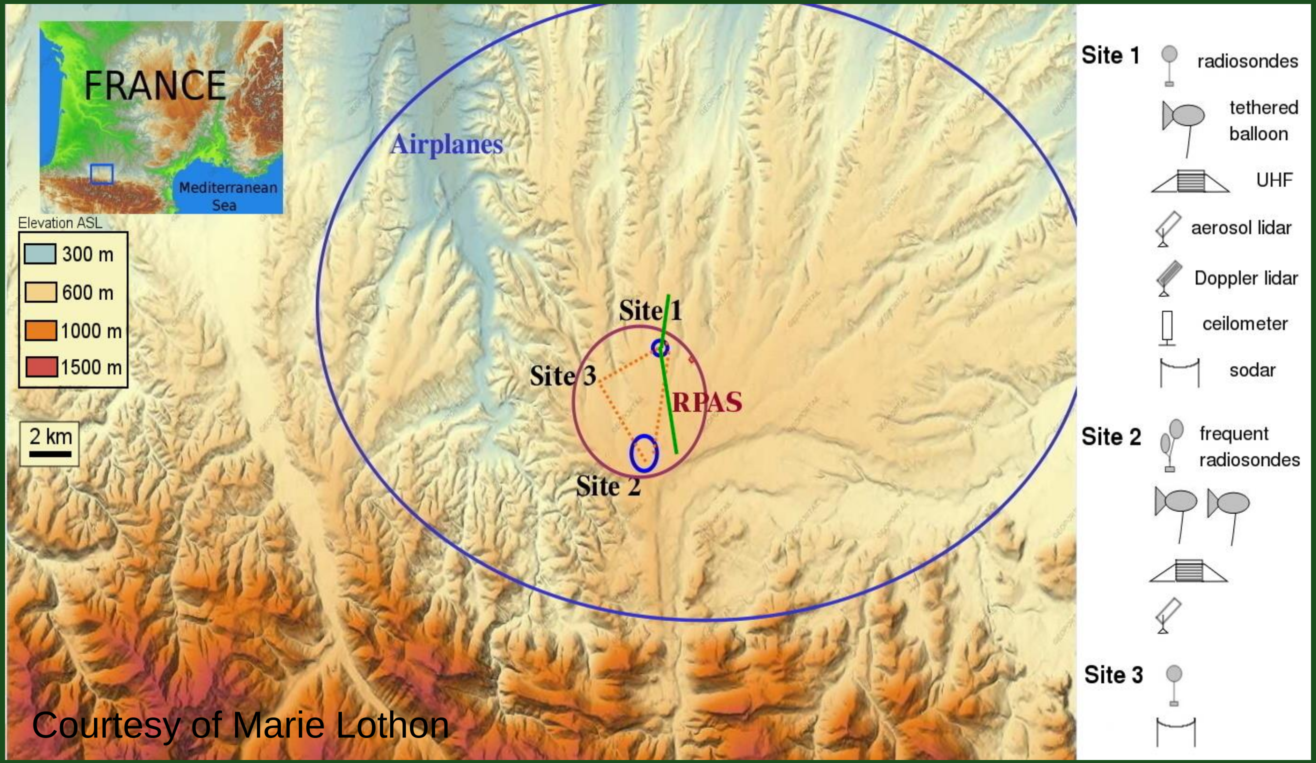
Turbulence decreases from the top down, starting well before sunset

Radar wind profiler reflectivity is roughly the product of humidity gradient and turbulence intensity

Spectral width is a measure of the turbulence intensity within the sampling time and volume

See Grimsdell and Angevine (2002), Angevine (2008)

Afternoon transition – BLLAST campaign France, 2011 (Lothon et al. 2014, ACP)



Many observing sytems

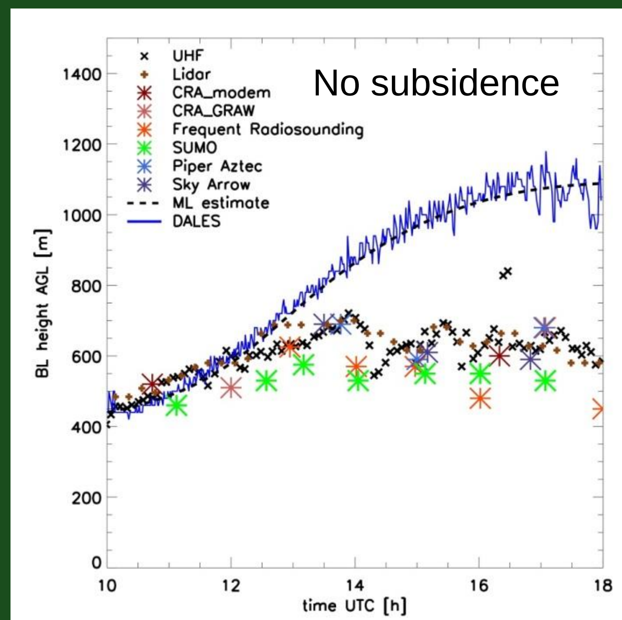
Careful design to cope with spatial heterogeneity and complex terrain

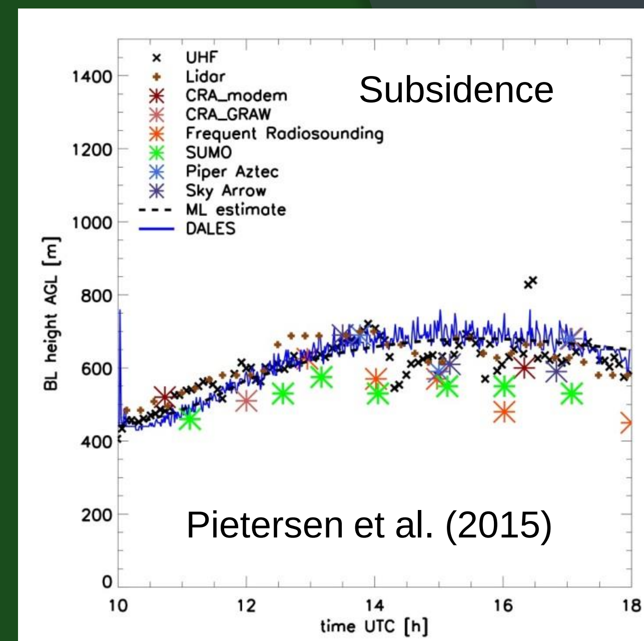
Findings

Afternoon transition duration
Diurnal evolution of the PBL depth
Turbulence decay
Evolution of integral scales
TKE budget (Nilsson)
Turbulence vertical structure (Darbieu)
Countergradient heat flux? (Blay)
Residual layer and subsidence (Blay)
Evaluation of NWP models (Couvreux)

Large-scale forcing

Boundary-layer height on one day of BLLAST
Specified subsidence is needed to make mixed-layer model work
Unfortunately, subsidence is not measurable

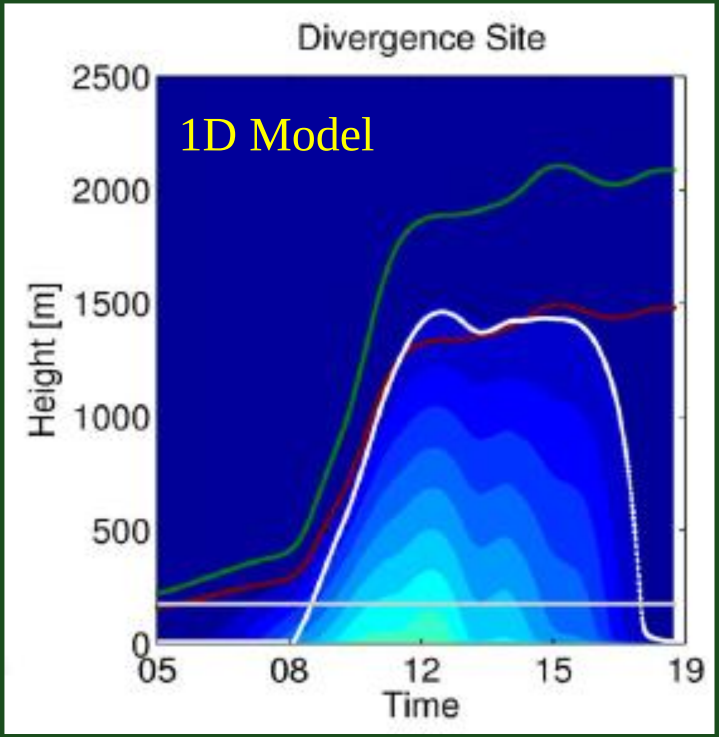


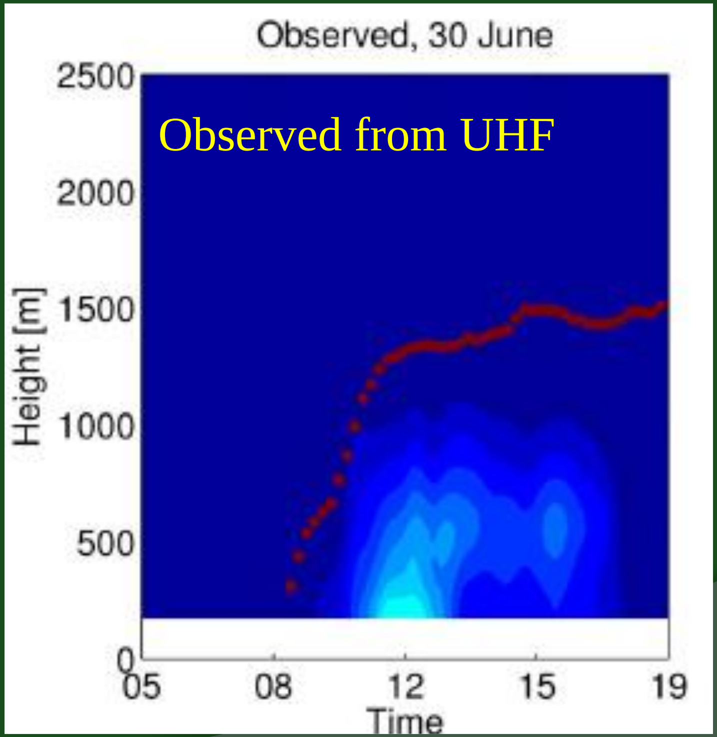


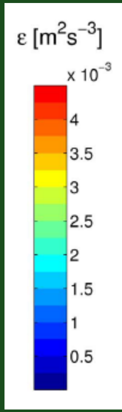
TKE above the surface layer

A simple 1D TKE model was used to explore the reduced amounts of TKE found in the upper boundary layer during still unstable conditions

LES indicate that, in the second, rapid phase of decay, turbulence characteristics and spectra change first in an upper weak turbulence layer *(Darbieu et al. 2015)* which we refer to as a ***Pre-Residual Layer***







TKE dissipation rate. Red: BL top, White: TKE=0.3 m^2s^{-2}, Green: no turbulence

See Nilsson et al. (2015) part 2
Figures courtesy of Erik Nilsson

Afternoon transition summary after BLLAST

Old boundary layers don't collapse, they fade away

Turbulence decreases at ABL top first and fastest

- Surface flux decreases so thermals are less energetic
- Upper ABL stabilizes due to entrainment (driven by shear)
- Subsidence and advection are important
- Few simplifications are possible

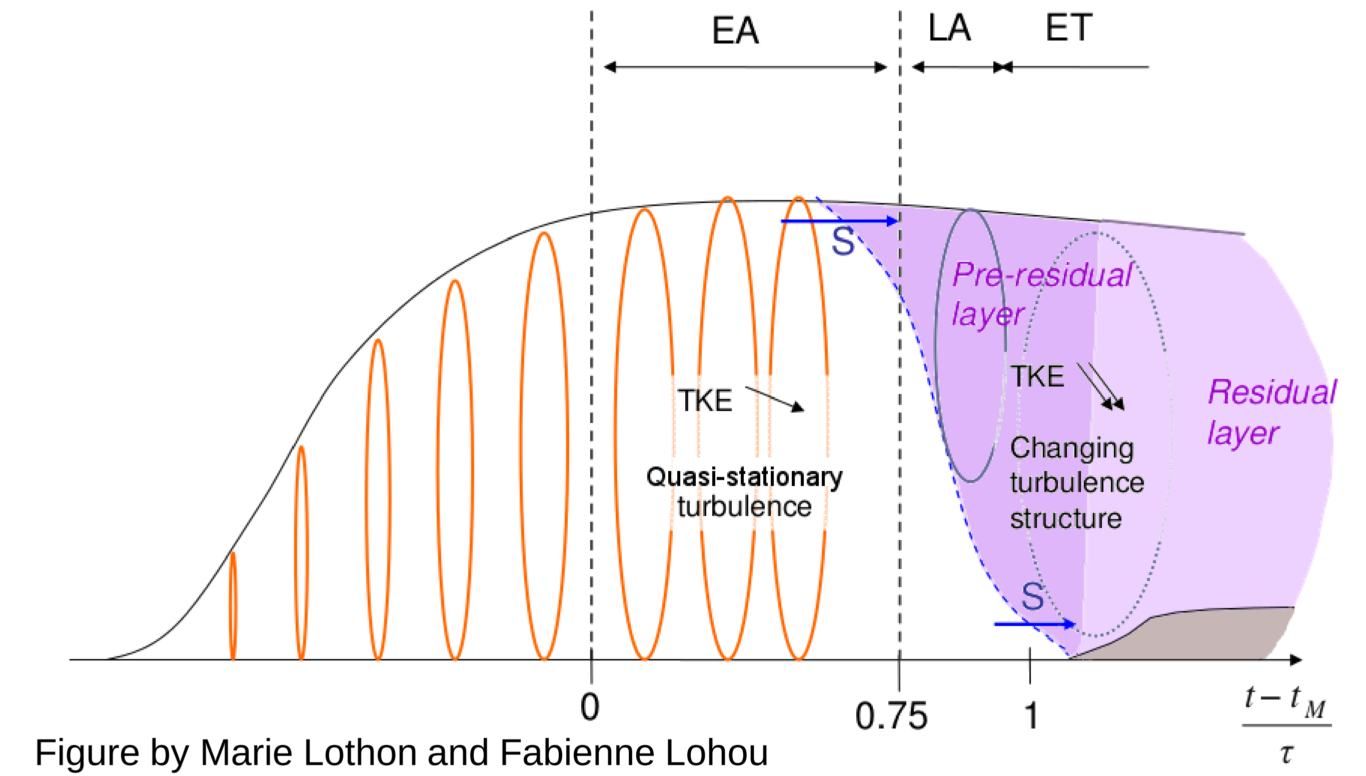
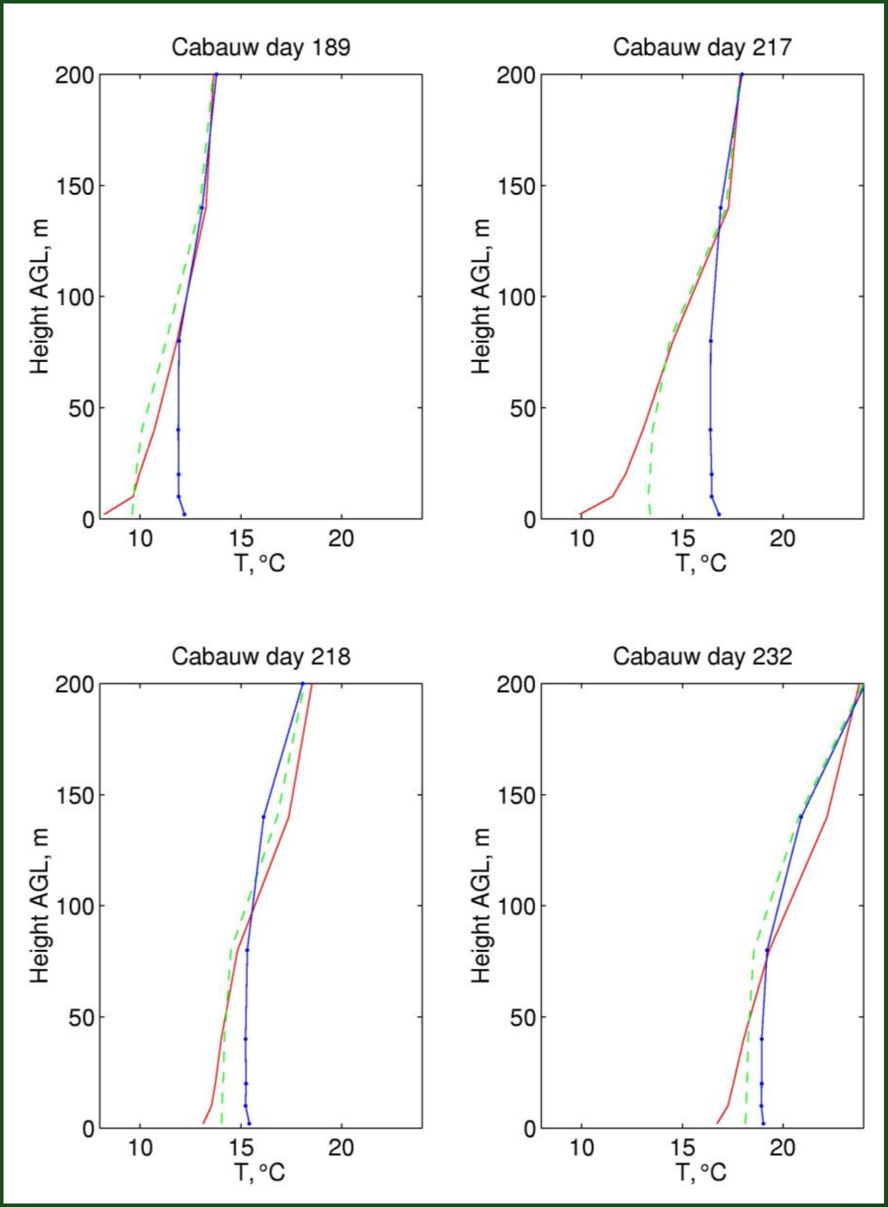


Figure by Marie Lothon and Fabienne Lohou

Residual layer

- Doesn't just sit there waiting for morning!
- Advection can never be neglected
- Layer does not remain neutral because of stability – instability asymmetry, among other effects
- Different levels are released from restraint by surface-based turbulence at different times and places – equivalently, think of different timescales at different heights?
- Residual layer wind controls SBL state by providing energy for shear production (or not)
- Low-level jets have been much studied but:
  - are not the only form of advection
  - are an example of complex wind behavior
- Handling of stable layers aloft is important but neglected – are they really the same as surface-based stable layers?



Morning transition

Entrainment is key

Classical picture of filling inversion from below does not hold

Red at sunrise

Green at crossover (w’Tv’ = 0)

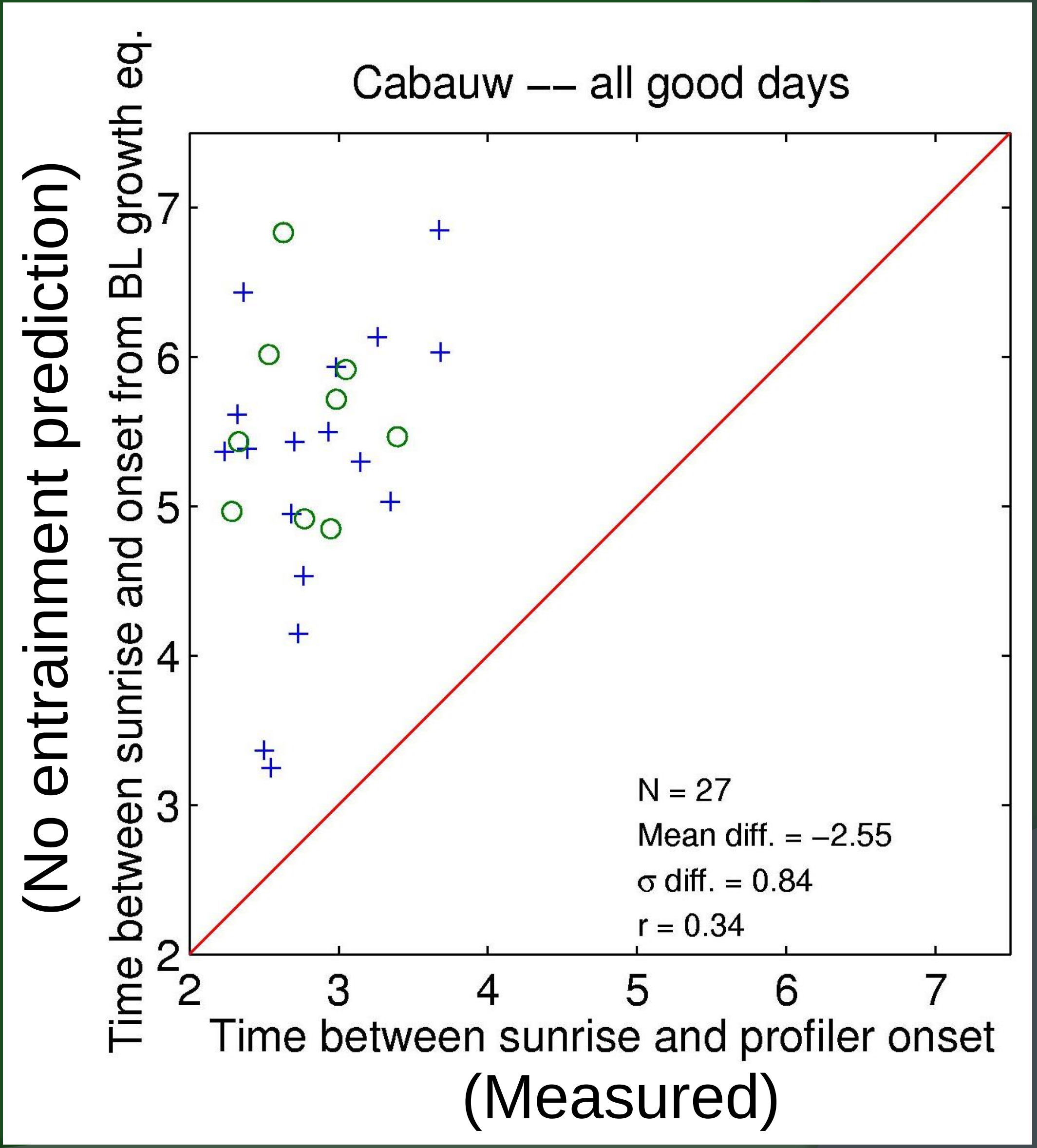
Blue at onset (turbulent at 200 m)

Warming below 50 m occurs before heat flux is positive on most days

Advection matters

Morning transition

Time to full CBL development is about half what it would be if no entrainment



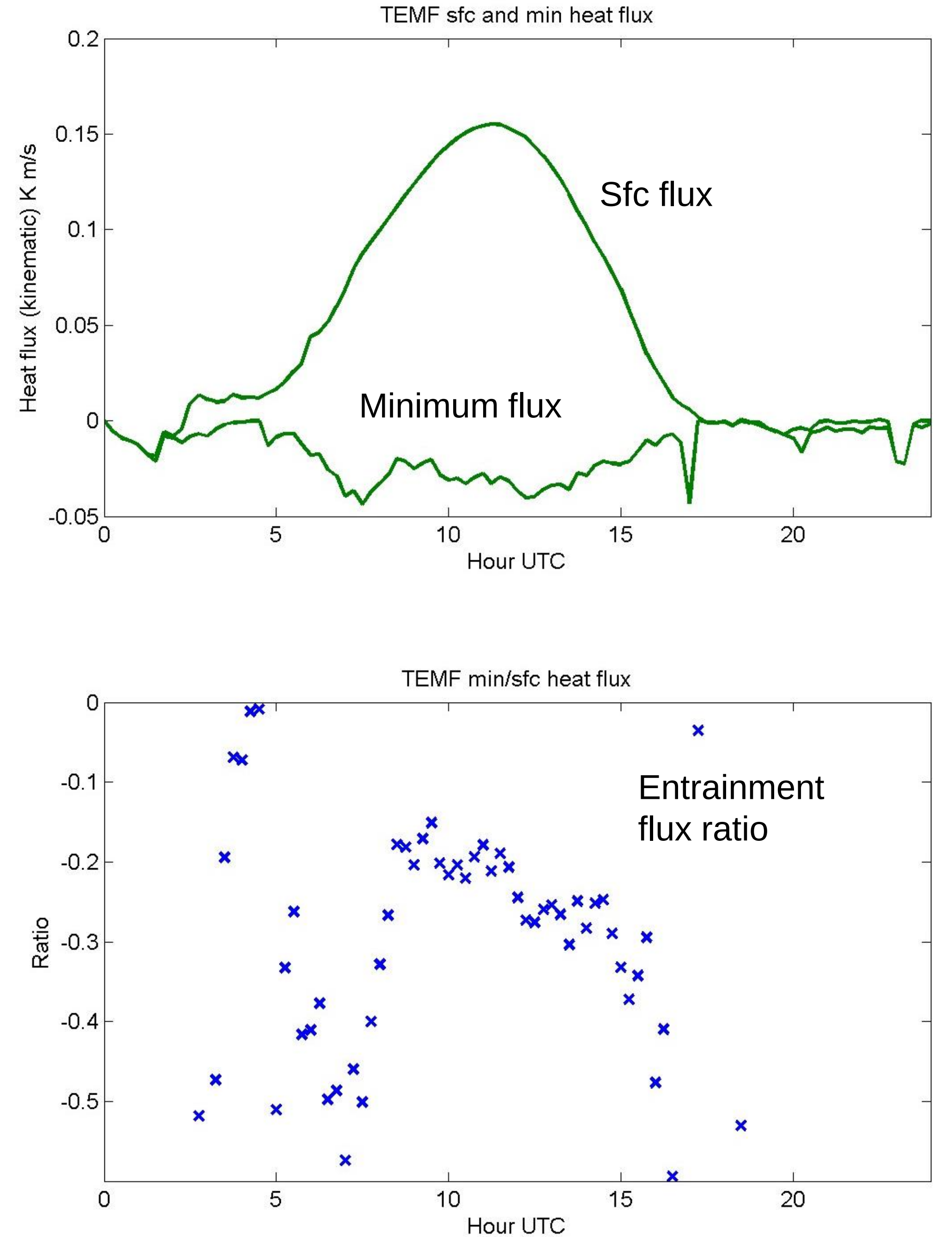
Can models do this?

BLLAST case

TEMF PBL scheme

Entrainment flux ratio is about -0.2 midday but larger early and late

Reinforces hypothesis that entrainment depends on various processes, which are more important when surface flux is less



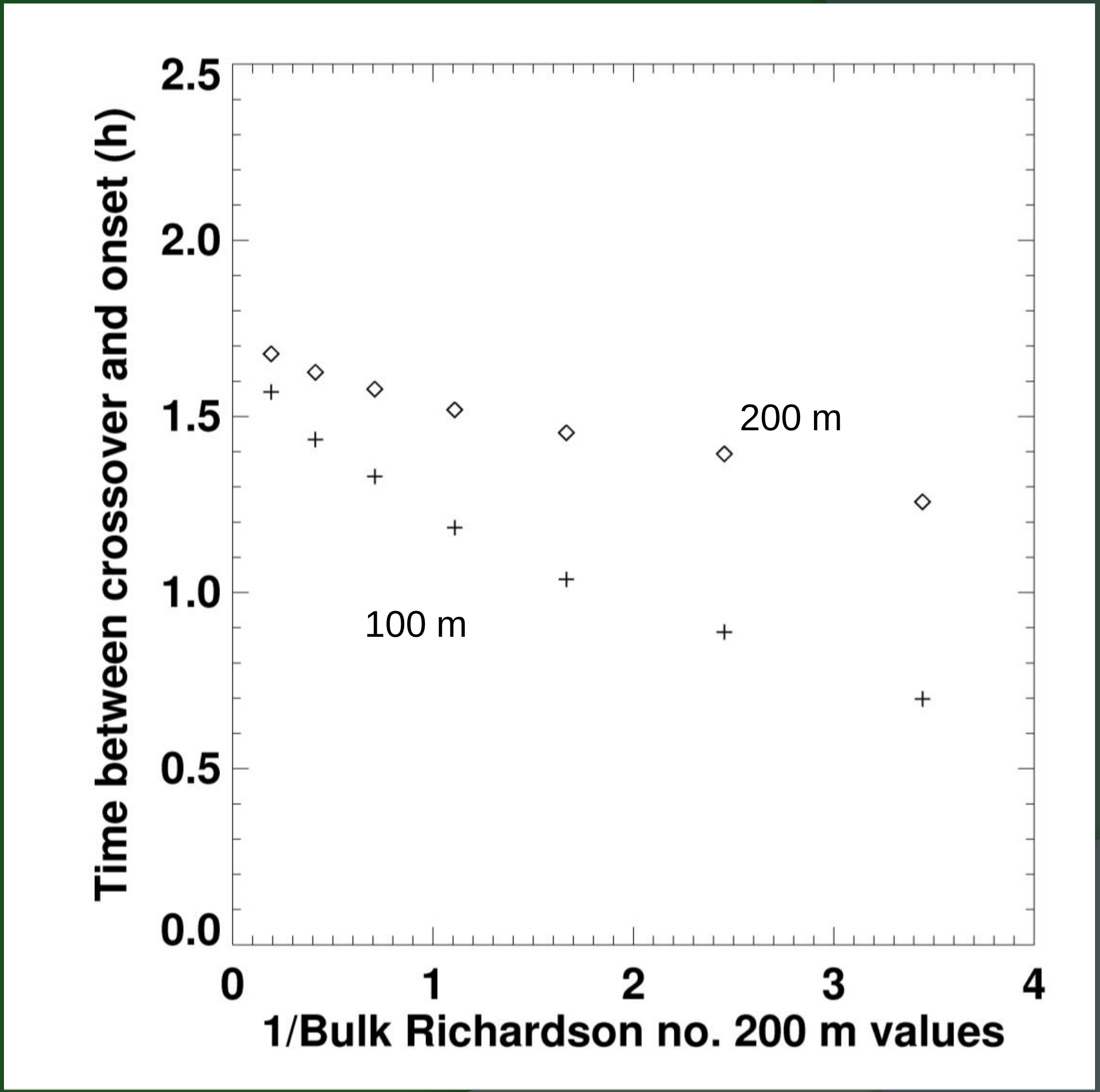
LES and other observations

Beare (2008)
“Mixed CBL-SBL state” during transition

Increased shear or reduced stratification decrease time between crossover and onset

Paper also shows dependence of entrainment flux ratio on geostrophic wind (approx. 1 at 10 m/s)

Lapworth (2006) gives extensive analysis of tethered balloon measurements
Wildmann et al. (2015) analyze UAS measurements



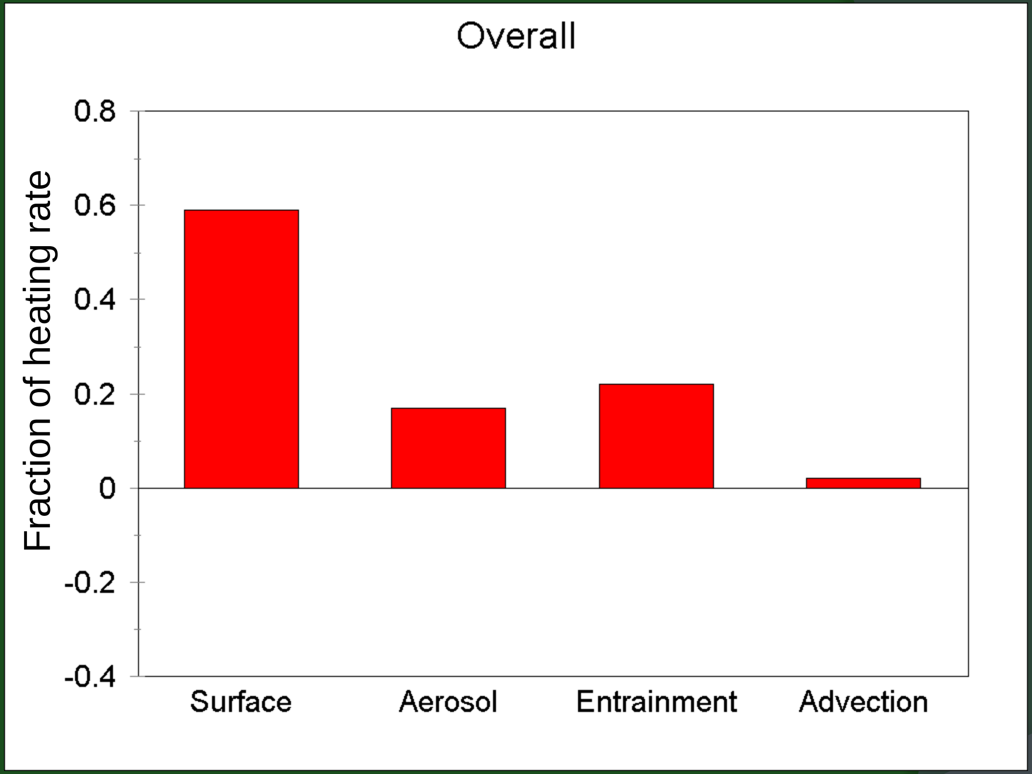
Aerosol heating of the BL

BL budget from the Flatland experiments at Bondville, Illinois

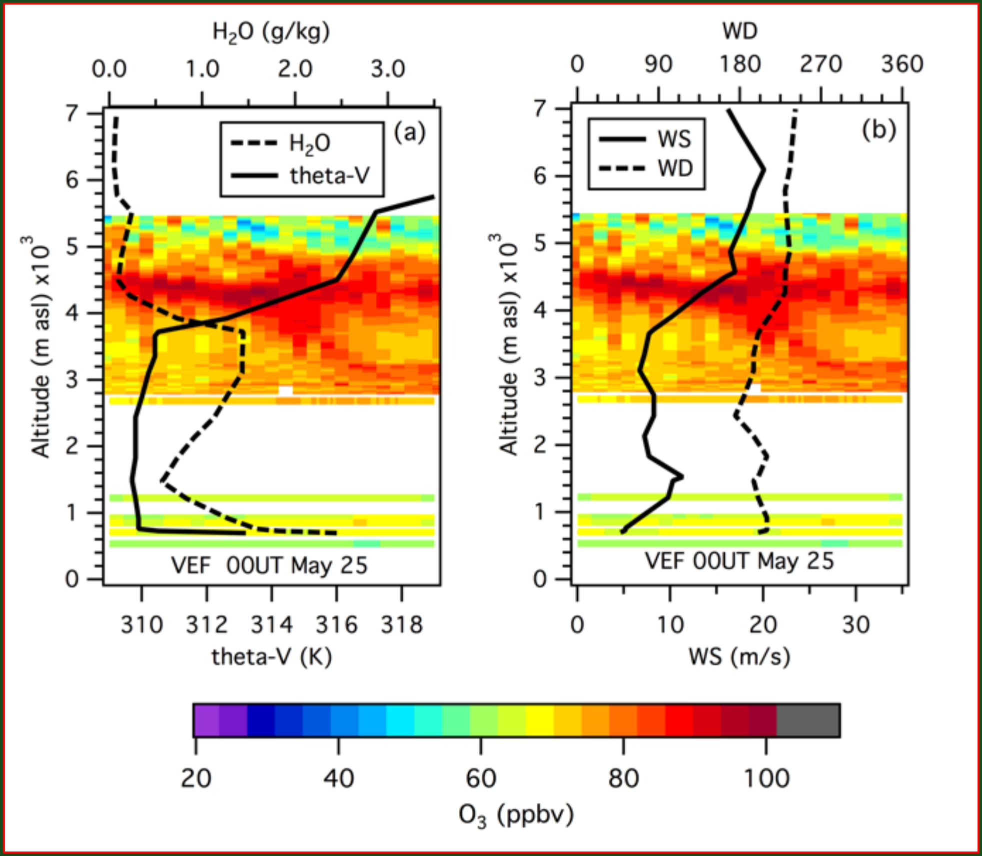
Very high aerosol loading and low single-scattering albedo

Budget terms shown as fractions of the total temperature rate of change over all days

Individual days have large advection contributions of both signs



Entrainment of transported ozone by deep boundary layer



Las Vegas Ozone Study (LVOS)
May 24-25, 2013

Deep (>3 km) afternoon mixed layers can entrain tropopause folds and transported pollution that passes over the Sierra Nevada

Observations from ground-based TOPAZ ozone lidar (colors) and KVEF radiosonde (black)

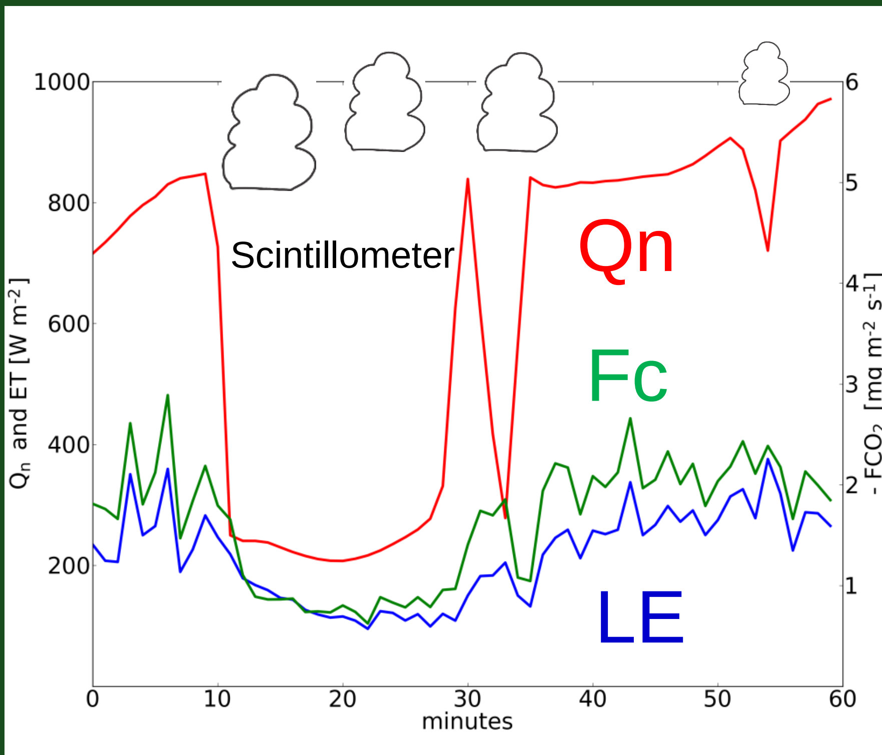
Not all cases of ozone layers aloft result in surface impacts!

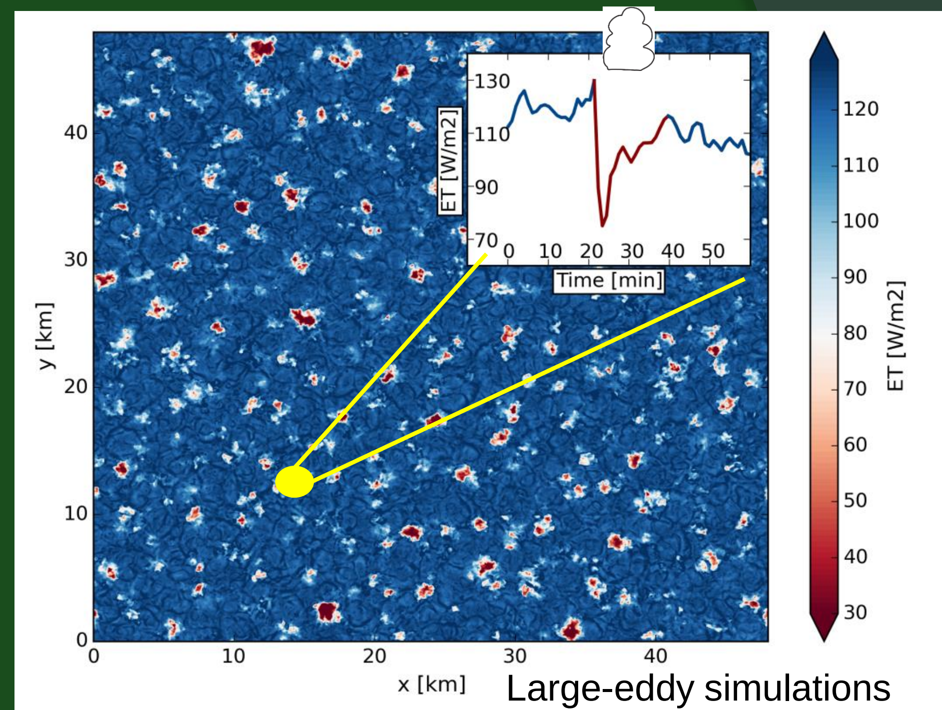
Langford, A. O., et al. (2017), Entrainment of stratospheric air and Asian pollution by the convective boundary layer in the southwestern U.S, *J. Geophys. Res.*, *122*(2), 1312-1337, doi:10.1002/2016JD025987.

Slide courtesy of Andy Langford

Cloud-vegetation interaction

Perturbation of available net radiation, evaporation and NEE due to cloud shading





Vilà-Guerau de Arellano et al. (2014)

van Kesteren et al. (2013)

Observational issues

Data quality, uncertainty, and careful flagging are vital

Arrays of instruments are needed to address heterogeneity

- Must be inter-calibrated and provide uniform data

Radiosondes are useful and essential for credibility

- Pursue frequent sounding technique from France?

Model-data interface is difficult

- (personnel and culture, not instrumentation)

Chemistry – meteorology balance in campaign resources

Continuous measurements are needed for some objectives

PBL height is ill-posed (ask a better question)

- Direct measurement of turbulence (e.g. by Doppler lidar) makes for clarity

(Some) References

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