Interdisciplinary Field Experiments: their role in supporting land-surface modelling

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President of WMO Commission for Climatology (CCl) from 2005 to 2010

Motivations for field experiments dedicated to Land-Surface processes : a WCRP- ISLCP initiative (1983)

- Recognized the need for improved knowledge and modeling of land-surface energy exchange and evaporation at the scale of the grids at which GCMs operate, considering the emerging capability in predicting weather and climate variability at all timescales, including seasonal to interannual (World Climate Programme, 1985, *WCP n°96*)

- Urged to implement pilot field experiments, to be reproduced under a wide range of environments, learning from pilot field campaigns, in order to provide calibration/verification data for land-surface processes modelling (e.g. the early SIB model)

- The field experiments exhibit a systematic progression, with the early experiments focusing on i) understanding the fundamentals processes of the Earth system and then ii) systematically progressing onto model development and simulations, with an emphasis on theoretical and operational prediction in the out years. The comprehensive data collected are being used for study by the research community, for operational model validation and evaluation, and for education and outreach purposes (NOAA)

EXPERIMENTAL VIEWPOINT

From an experimental viewpoint : timely decision, because of existing « aerodynamic » methods for fluxes estimates and the new availaibility of «eddy covariance systems» allowing direct estimation of turbulent fluxes of heat, moisture, and chemical species:

i) 3D sonic anemometers (Young, Gill, Campbell) offering sonic temperature, speed of sound and U, V & W vector outputs, at an output rate of up to 100 Hz

ii) High-speed digital gas analyzers measuring fast fluctuations in atmospheric water vapor content, and other species (e.g. CO2, CH4, aerosols…)

Iii) autonomous dataloggers suited for outside and remote operations, and to rather complex real-time calculations

iv) field experiments/modelling complementarity : has something to do with « trial and error », and QM « continuous improvement » approaches

Traditional contribution of CNRM experimental teams during cooperative field programmes

- Portable meso-network with real-time data collection (Meteosat) for describing the meso-scale environmental conditions
- Profilers (intensive radio-sounding, ST radars)
- Aircraft measurements, especially instrumented for the eddy-correlation measurements in that case
- Implementation of a maintained campaign database dedicated to all observations, made available to users

Specific contribution for providing calibration/verification data for land-surface processes modelling

- Components of the surface energy budget

$$Rn = H + LE + G$$

- Components of the local hydrologic budget

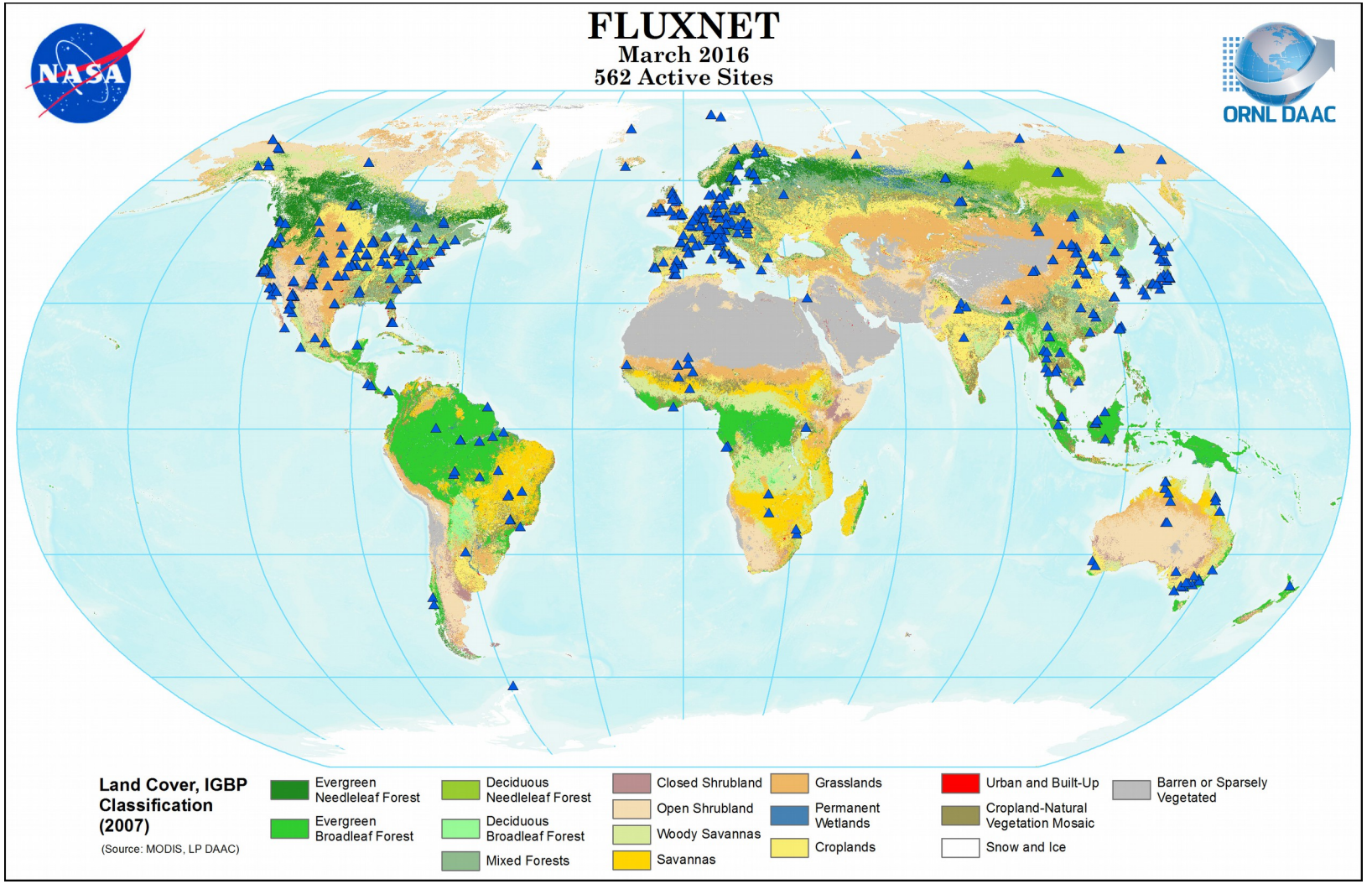
$$dw/dt = P - R – E \text{ where :}$$

where dw/dt= variation of the soil moisture content derived from the evolution of its vertical profile ; P and E the amount of precipitation and evaporation, respectively, R the runoff

- Primary parameters needed as inputs in SVAT models :
  - soil properties : respective percentage of gravels, silt and clay, and sand
  - land-cover : leaf area index, vegetation fraction and albedo.

FLUXNET

https://doi.org/10.3334/ORNLDAAC/1530



HAPEX MOBILHY Objectives

André J.C., J.P. Goutorbe, A. Perrier (1986) : HAPEX-MOBILHY: A Hydrologic Atmospheric Experiment the Study of Water Budget and Evaporation Flux at the Climatic Scale. *BAMS*, Volume 67, Number 2, February 1986, pp 138-144

In brief : HAPEX-MOBILHY was a **pilot** program aimed at studying the hydrological budget and evaporation flux **at the scale of a GCM grid square**

Different **surface and subsurface networks** were operated during the year 1986, to measure and monitor soil moisture, surface-energy budget and surface hydrology, as well as atmospheric properties.

A two-and-a-half-month **special observing period** (SOP) allowed for detailed measurements of atmospheric fluxes and for intensive remote sensing of surface properties using instrumented aircraft.

The main objective of the programme aimed at providing a **data base** against which parameterization schemes for the land-surface water budget will be tested and developed, including upscaling methods encompassing the surface heterogeneity.

HAPEX-MOBILHY EXPERIMENTAL SETUP (1986)

Took advantage of operational/permanent equipment in SW France :

59 raingauge stations, 33 stations measuring river flows

Meteorological radars at Bordeaux and Toulouse ;

100 «PATAC » regional AWS network

and specific to the campaign :

12 SAMER flux stations at representative constrated sites, the most important component ;

Neutron sondes measuring soil moisture;

2 instrumented masts over the Landes forest.

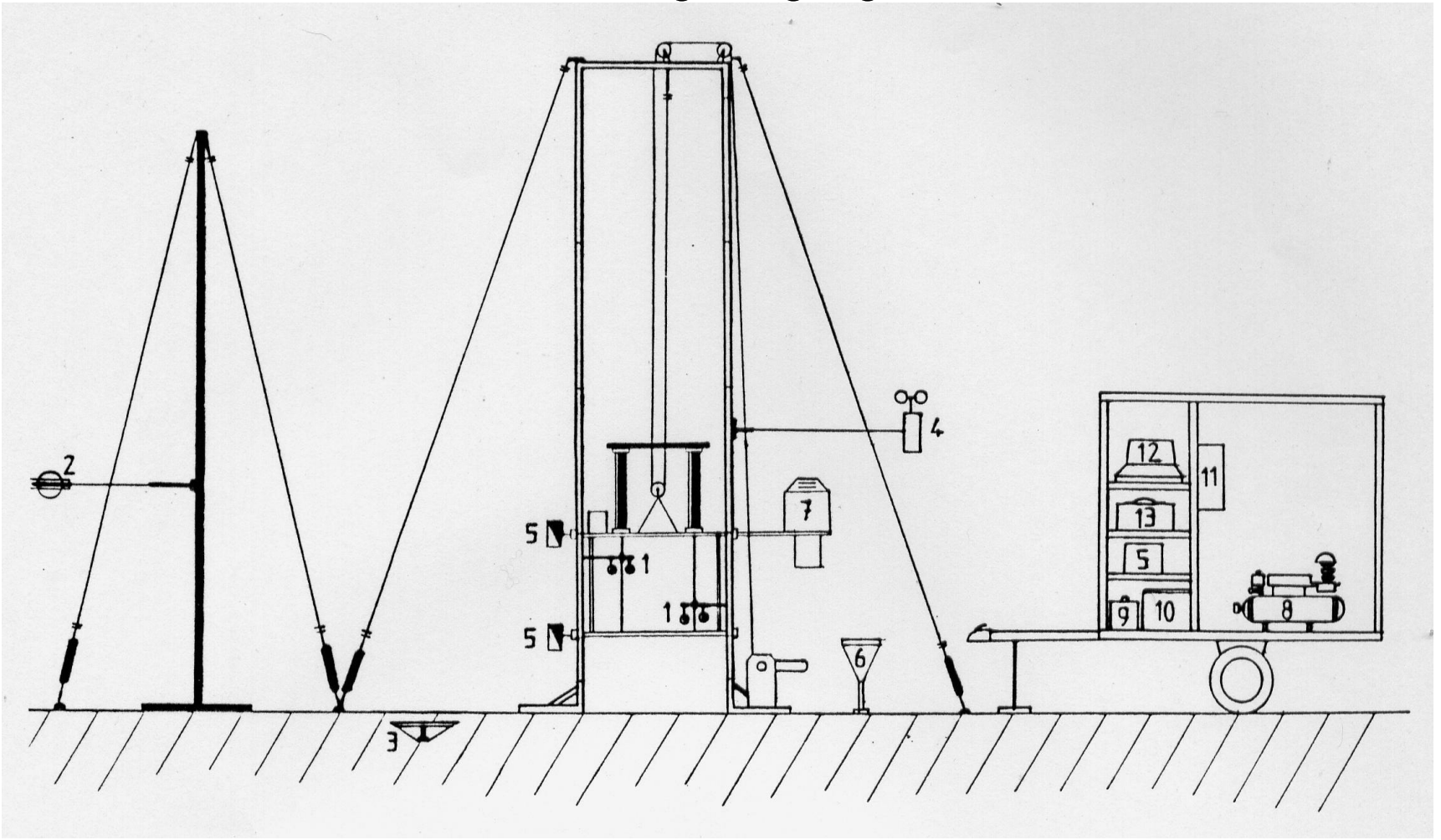
NCAR King Air aircraft conducting fluxes estimates at scales 10-100 km

NASA Lockheed C-130 Hercules for remote sensing activities (IR + microwave)

NOAA-AVHRR.Satellite

SAMER Station Design (INRA)

- Radiation budget: upward and downward short and long-wave radiation
- Temperature and wind velocity gradients between two levels 1.5 m from each other mounted on an adjustable frame in the vertical to adapt to vegetation growth
- Soil heat flux, temperature and humidity at screen height
- Recording raingauge



SAMER Station Principle

- Based on Monin-Obukhov similarity theory : vertical gradients are depending only on z and z/L :

$$du/dz = U_*/kz.\ \Phi_m(z/L) \quad d\Theta/dz = \Theta_*/kz.\Phi_h(z/L)$$

* use of Businger's universal functions

* $L = \Theta/g.\ U_*^2/k\Theta_*$ * $H = -\rho C_p u_* \Theta_*$

* $LE = R_N - H - G$

* Limitations : LE cumulates errors on other parameters

See e.g.*Riou C. (1982) : Une expression analytique du flux de chaleur sensible en conditions sur-adiabatiques à partir de mesures du vent et de la température à deux niveaux. J. Rech. Atmos., 1, 15-22*

Bessemoulin P. (1993) : Méthodes expérimentales de détermination des flux de surface. CNRM Technical Note n°6

BOWEN ratio method (« BEARN »)

Comparable device using psychrometers instead of single temperature measurements :

$$H + LE = -R_N - G$$

B= H/LE expressed in terms of vertical gradients of dry and wet-bulb temperatures

$$H = B.\ (R_N - G)/(1+B) \quad LE = (R_N - G)/(1+B)$$

Overview of the field campaign

CHALLENGES WITH THOSE « EARLY » METHODS

- displacement height estimates for tall vegetation and possibly fast growth (e.g. maize)

- dry and wet-bulb temperatures gradients estimates over small distance

- keep moist wet-bulb thermometers

André, J.-C., Goutorbe, J.-P., Perrier, A., Becker, F., Bessemoulin, P., Bougeault, P., Brunet, Y., Brutsaert, W., Carlson, T., Cuenca, R., Gash, J., Gelpe, J., Hildebrand, P., Lagouarde, J.P., Lloyd, C., Mahrt, L., Mascart, P., Mazaudier, C., Noilhan, J., Ottlé, C., Payen, M., Phulpin, T., Stull, R., Shuttleworth, J., Valencogne, C. (1988). Evaporation over land-surfaces: first results from HAPEX-MOBILHY special observing period. *Annales Geophysicae, 6* (5), 477-492

Eddy covariance system (Li-Cor)

SUBSEQUENT PROGRAMMES

FIFE (1987-1989)

Sellers, P.J., H all, F.G., Asrar, G., Strebel, D.E., and Murphy, R.E. (1988) : The first ISLSCP (*) field experiment (FIFE). *BAMS*, 69, 22-27.

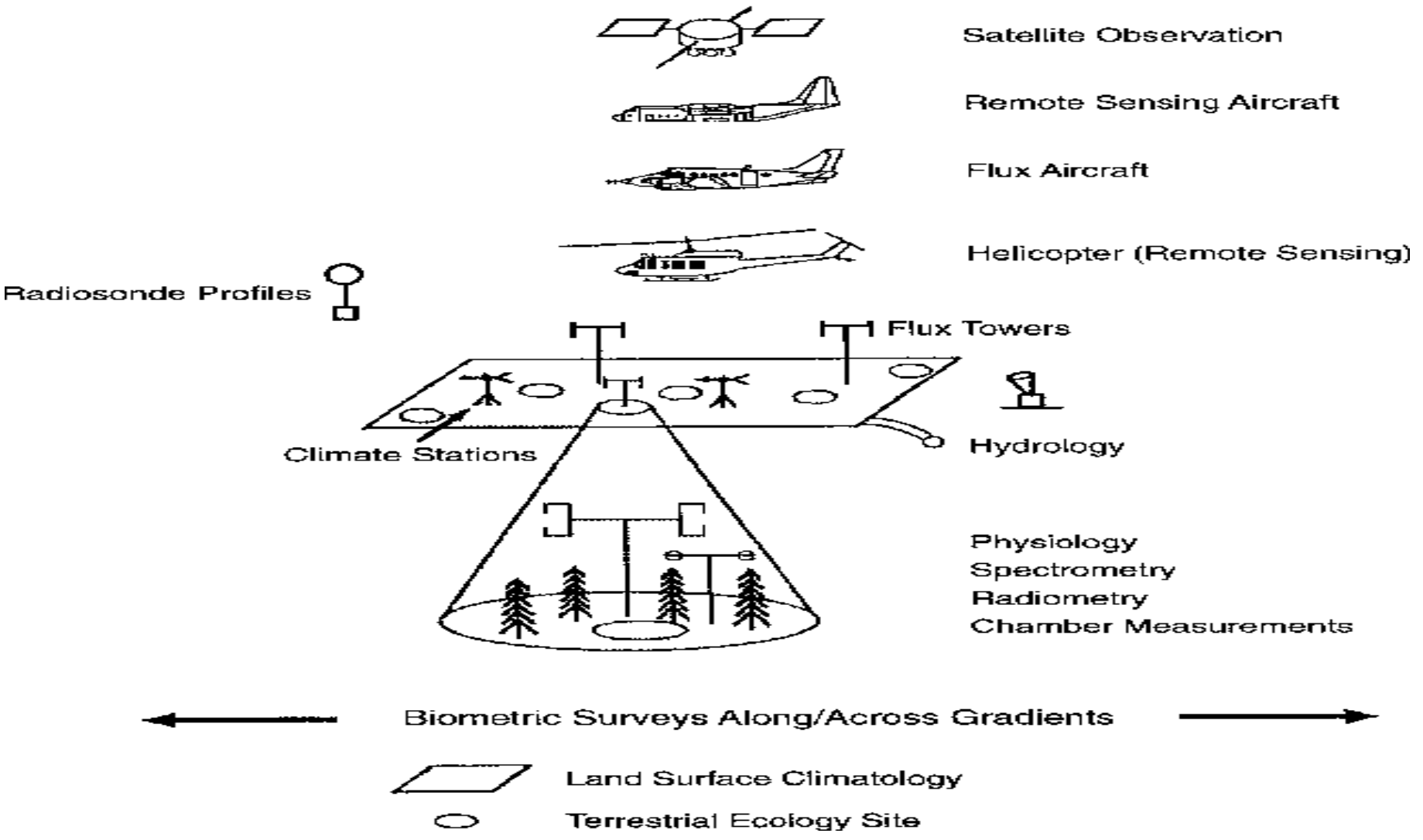
The objectives of FIFE were « to better understand the role of biology in controlling the interactions between the atmosphere and the land surface, and to investigate the use of satellite observations to infer climatologically significant land-surface parameters. »

FIFE took place at and around the 15-km by 15-km Konza Prairie Long Term Ecological Research (LTER) site near Manhattan, Kansas.

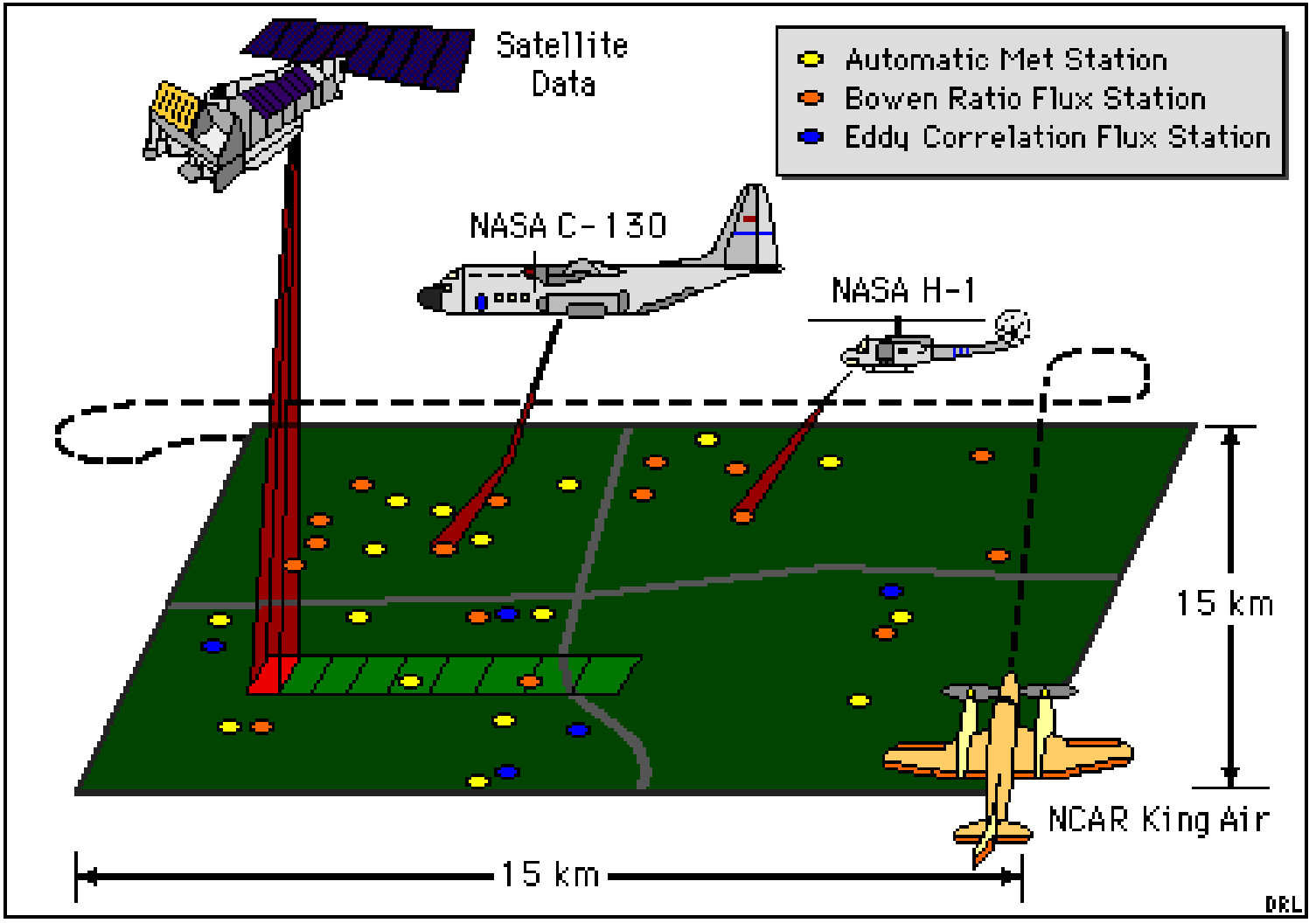
(*) International Satellite Land-Surface Climatology Project

STANDARD DESIGN WHICH EMERGED FROM PILOT CAMPAIGNS: A MULTI-SCALE APPROACH

INTENSIVE FIELD CAMPAIGNS



FIFE Observing Procedure



EFEDA (1991)

Bolle, H.J. et al. (1993). European Field Experiment in a Desertification threatened Area. *Annales Geophysicae* (11), 173-189.

- In June 1991 in Castilla-La Mancha, Spain (very few rainfall, subject to heavy irrigation resulting in large lowering of water tables)

- Large European participation : FUB, DLR, Institut f. Meteorologie u. Klimaforschung, Universität Karlsruhe, (D), IH, Reading Univ. (UK), CNRM, INRA (F), WAU, Delft Tech Univ. (NL) TUD (DK), Castilla Univ. (E),

- CNRM : meso-scale network, flux stations

HAPEX-Sahel (1991-1992)

Goutorbe, JP., Lebel, T., Tinga, A. et al. (1994): HAPEX-Sahel: a large-scale study of land-atmosphere interactions in the semi-arid tropics. *Annales Geophysicae*, January 1994, Volume 12, Issue 1, pp 53–64

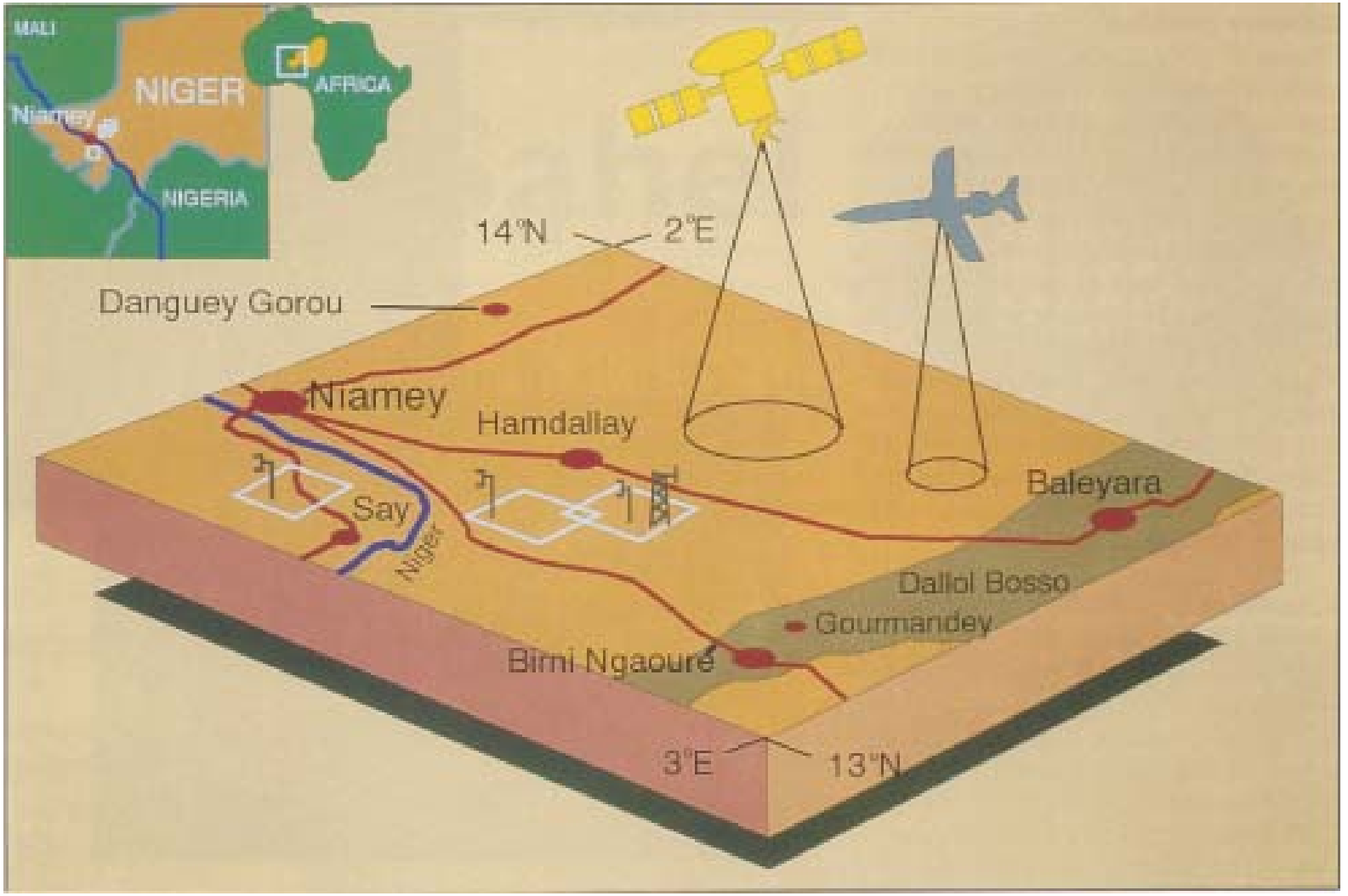
Carried out in Niger, West Africa, during 1991 - 1992, in a 1° by 1° square close to Niamey, with an intensive observation period (IOP) in August - October 1992, i.e. the transition period of the rainy to the dry season.

Large European and US participation.

CNRM : meso-scale network, flux stations, intensive R/S, Merlin IV aircraft

Main results : J.P. Goutorbe, A.J. Dolman, J.H.C. Gash, Y.H. Kerr, T. Lebel, S.D. Prince, J.N.M. Stricker (February 1997): *J. Hydrology, Special issue on HAPEX-Sahel*, volumes 188–189, **pp 1-1079**

HAPEX-Sahel 1° x 1° area



BOREAS (1993-1996)

Sellers, P., F. Hall, H. Margolis, B. Kelly, D. Baldocchi, G. den Hartog, J. Cihlar, M. G. Ryan, B. Goodison, P. Crill, K. J. Ranson, D. Lettenmaier and D. E. Wickland (1995) : *BAMS*, Vol. 76, No. 9, pp. 1549-1577

Overall goal of BOREAS was « to improve our understanding of the interactions between the boreal forest biome and the atmosphere, clarifying their **roles in global change**» :

i) Improve the process models which describe the exchanges of radiative energy, water, heat, carbon and trace constituents between the boreal forest and the atmosphere ;

ii) Develop methods for applying the process models over large spatial scales using remote sensing and other integrative modeling techniques.

iii) Two supersites in Manitoba and Saskatchewan (Canada). CNRM : 1 flux site during IOP in 1994

MUREX (1995-1997)

Calvet J.-C., Bessemoulin P., Noilhan J., Berne C., Braud I., Courault D., Fritz N., Gonzalez-Sosa E., Goutorbe J.-P., Haverkamp R., et al. (1999) MUREX: a land-surface field experiment to study the annual cycle of the energy and water budgets. *Annales Geophysicae*, 17, 838–854

- Designed to **provide continuous time series of field data over a long period,** in order to improve and validate the SVAT parameterisations employed in meteorological models.

- Intensive measurements were performed for more than three years over fallow farmland in southwestern France

- Local climate was fully characterised ; energy fluxes and surface water, vegetation biomass, soil moisture profiles, surface soil moisture, surface and soil temperature, were monitored.

- Additional physiological measurements were carried out during selected periods to describe the biological control of the fluxes.

Requirements for reliable and comparable measurements

- Intercomparison between fluxes measurements at same or similar sites :
  - In Toulouse for all CNRM equipments prior to any campaign (+ Carpentras for radiation sensors)
  - during dedicated inter-comparisons at one place (Wageningen, 1992 for most of European teams involved in cooperative programs ; EFEDA between WAU and CNRM)
  - during field experiments for similar sites (e.g. HAPEX-Sahel for fallow bush sites/see J. Hydrology special issue ; BOREAS)
- Intercomparison between measurements and outputs from validated models

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CONCLUSION

- Thanks to dedicated field campaigns since the mid-eighties, the European community of micro-meteorologists has provided a major contribution to the knowledge of mechanisms related to ocean/land-surface processes ;
- The cooperation with both weather and climate modellers was quite efficient and fruitful ;
- At CNRM level, I would like to acknowledge the excellent relationships with the meso-scale team, especially with Philippe Bougeault, Joël Noilhan, Jean Paul Goutorbe, Jean Christophe Calvet and Jean Louis Roujean.