ESPM 228
Advanced Topics in Biometeorology and Micrometeorology

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Biometeorology@Berkeley

- Mission
  - To Measure and Model Trace Gas Exchange between Vegetation/Soil and the Atmosphere for the sake of diagnosis, prediction and assessment of coupled and non-linear biosphere processes associate with problems of climate and weather, the biogeochemical cycles of carbon, water and nitrogen, the exchange of air pollutants and the dynamics of ecosystems.

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This class is about Fluxes between ecosystems and the atmosphere. Measuring and modeling them to understand, diagnose and predict them in space and time.

Topics:
Advanced Topics in Biometeorology and Micrometeorology

- History/Background
- Flux Measurement Methods
  - Flux-Gradient
  - Eddy Covariance
  - Alternatives
- Modeling Plant-Canopy Micrometeorology and Ecophysiology
- Landscape Micrometeorology
- Planetary Boundary Layer
- Trace Gas Deposition/Emission

Course Goal

- To turn you into Scientists and Scholars of Biometeorology
  - Not to be defined Solely as an Experimentalist or Modeler
  - Scientists need Theory to designed Experiments and Interpret Data; The Theory needs Data to validate/falsify, Parameterize and Discover Emergent Processes

Viewing an Ecosystem as a Biometeorologist

- Field Studies
  - Measure across Spectrum of time scales
  - Measure across Spectrum of space scales
- Look Under the Hood
  - Study Components (soil, leaves, plants)
  - Perform Laboratory Studies
  - Perform Manipulative, Gradient or Chronosequence Studies at Ecosystem Scale
  - Quantify the Environment of the Organ or Cells, explicitly
- Develop Models
  - Distill data, develop and test hypotheses
  - Predict Future Conditions and Management decisions
- Develop Instruments and Experimental and Analytical Methods

Syllabus

Section 1. Micrometeorological Methods of Measuring Mass and Energy Flux Densities

Jan 27, Lecture 1, Micrometeorological Flux Measurement Methods, Background and History

Jan 31 (Friday), Lecture 2. Micrometeorological Flux Measurement Methods, K-theory

Feb 10, Lecture 3, Micrometeorological Flux Measurement Methods, Eddy Covariance, part 1: Theory.

Feb 21 (Friday+, Lecture 4, Micrometeorological Instrumentation, Eddy covariance, part 2: Application

Feb 24 , Lecture 5, Micrometeorological Instrumentation, Eddy covariance, part 3: Interpretation

Mar 3, Lecture 6, Lessons and Results from FluxNetworks

Section 2. Biosphere/Atmosphere Interactions

Mar 10, Lecture 7, Integrating or Scaling Information from Leaves to Canopy Scales, part 1: Background, History and Principles

Mar 17, Lecture 8, Integrating or Scaling Information from Leaves to Canopy Scales: Multi-Layer Models, Part II

Mar 31 , Lecture 9, Integrating or Scaling Information from Leaves to Canopy Scales: Multi-Layer Models, Part III

Apr 11 (Friday), Lecture 10, Leaf Photosynthesis/Transpiration/Stomatal Conductance Models

Apr 14, Lecture 11, Landscape Micrometeorology: Integrating or Scaling Information from Canopy to Landscape Scales, part 1

Apr 21, Lecture 12, Landscape Micrometeorology: Integrating or Scaling Information from Canopy to Landscape Scales, part 2

Apr 28 Student Presentations

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Course Information

- Web site: bcourse or nature.berkeley.edu/biometlab/espm228
- Grade
  - Class Readings and Participation in Lectures/Discussion, 10%
  - Data Analysis and Modeling Homework Assignments, 30%
  - Class Project, 50%
  - Project Presentation, 10%

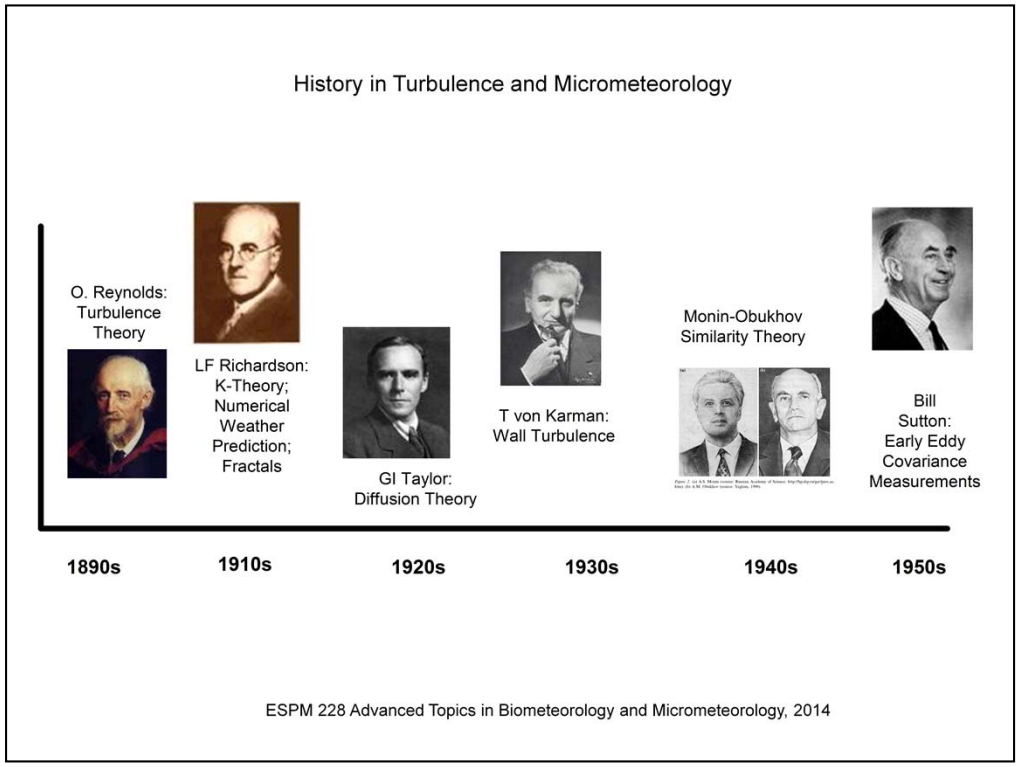
Lecture 1
History and Background

- Key Scientists
- Key Experiments
- Experimental Design
- Future

If I have seen a little further it is by standing on the shoulders of Giants."

Original saying attributed to Bernard of Chartres, 'nos esse quasi nanos, gigantium humeris insidentes..'

..we are like dwarfs on the shoulders of giants, so that we can see more than they, and things at a greater distance, not by virtue of any sharpness of sight on our part, or any physical distinction, but because we are carried high and raised up by their giant size



Osborne Reynolds, as in the Reynolds number, laid out much of the fundamental equations we use today. Richardson gave us theories on computing fluxes in the lower boundary of the atmosphere to predict weather by hand. Also fundamental in describing atmospheric stability and fractals. Taylor leader in diffusion theory. Von Karman turbulence exchange near walls. Monin Obukhov similarity theory for predicting fluxes and profiles in the atmosphere. Sutton, early eddy covariance flux measurements.

Factors affecting Historical Developments of Field Measurements

- Micrometeorological Instruments
  - Net radiometer, soil heat flux plates, psychrometer, cup anemometers, lysimeters, analog dataloggers, IRGAs
    - Suomi, Tanner
- Sonic anemometers
  - Businger, Suomi
- Digital Data-logging systems
  - Integrated circuits
    - Campbell Scientific
- Microcomputers and PCs
  - IBM, DEC
- Fast Responding Sensors
  - Solid state electronics
    - LICOR

*'Micrometeorologists are like Dorothy in the Wizard of Oz—
they always want to go back to Kansas'*

Dave Fitzjarrald, SUNY Albany

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A lot of key micrometeorological experiments were conducted in Kansas.

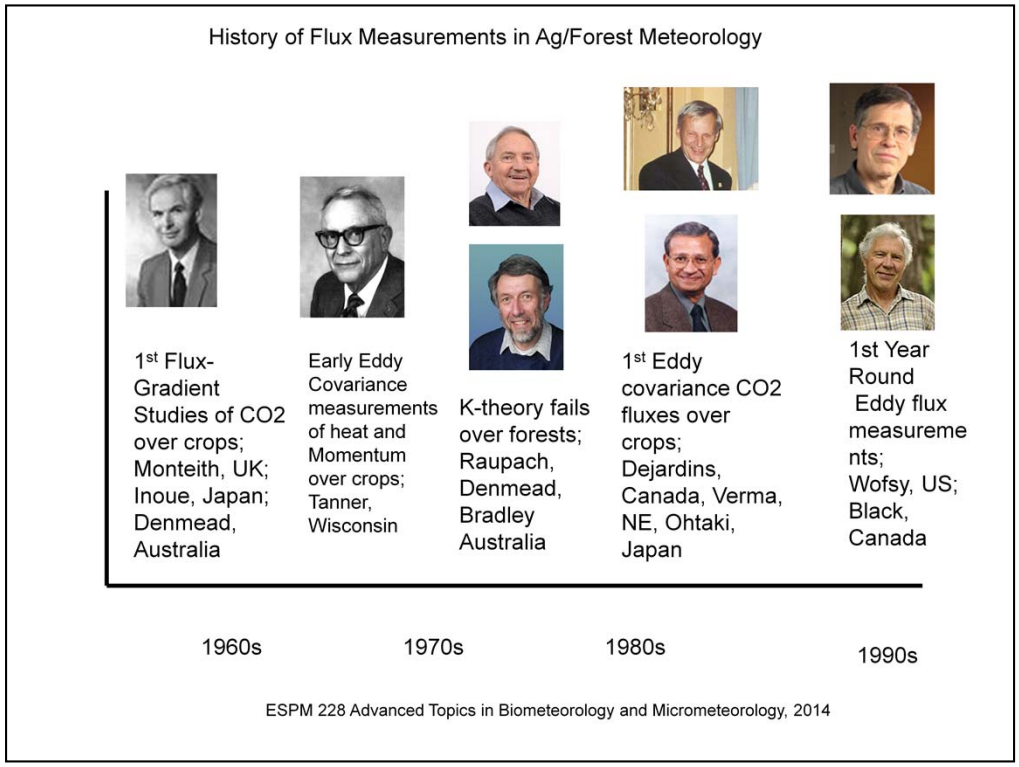
Major Field Campaigns/Programs

- First Eddy Covariance and Flux-Gradient Studies, UK, 1930-40s (Sutton, Scrase)
- O'Neill, NE, Kansas & Wangara, Australia 1960s
  - Probing boundary layer processes (US: Kaimal, Businger, Wyngaard; Australia: Swinbank, Dyer, Hicks)
- Hapex-Mohibly: France, 1980s
  - Land-atmosphere scaling (France, Andre)
- FIFE: Kansas, 1980s
  - Water, energy fluxes and satellites (US, Sellers, Verma, Wesely)
- BOREAS: Canada; HAPEX-Sahel, 1990s
  - Water, energy, carbon, satellites and aircraft (US, Sellers, Black, Jarvis, Baldocchi, Wofsy, Fitzjarrald, et al)
- FLUXNET, mid-90s to now
  - Long-term network of carbon, water and energy fluxes
  - AmeriFlux, CarboEuroFlux, Fluxnet-Canada, AsiaFlux, ChinaFlux, LBA, OzFlux, etc

Major field campaigns have changed how we conduct our work. Fewer frontiers are being crossed by individual scientist as opposed to groups working on large field campaigns or through the auspices of flux networks.

Key Contributions

- O'Neil and Kansas:
  - Non-dimensional functions to adjust wind and temperature gradients for stability classes
  - Defined turbulence spectra for momentum and energy exchange
- Hapex-MOHIBLY
  - 1st large scale energy balance study across different land classes
    - Forests, crops, vineyards, pastures
- FIFE
  - 1st large scale field study relating energy balance measurements and satellite observations; over grassland
- BOREAS
  - 1st large scale field study relating CO2 and energy balance measurements with satellite observations, over boreal forest



John Monteith famous for Penman Monteith equation for evaporation and early CO2 flux measurements over crops with K theory

Champ Tanner, consider father of American Agrometeorology

Raupach and Denmead caused paradigm shift with measurements and models showing failure of K theory in the surface layer

Verma, Desjardins and Ohtaki, first eddy flux measurements of CO2 exchange over crops

Wofsy and Black extended these measurements to forests and on yearly basis.

Influential Micrometeorologists: Surface and Planetary Boundary Layers

- John Wyngaard
- J.C Kaimal
- John Garratt
- Don Lenschow
- Joost Businger
- Chin Hoh Moeng
- Verner Suomi





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Names to consider for looking at past literature. Wyngaard has great book and leading reviews

Other Influential Ag/Forest Meteorologists

- John Monteith
  - ET, CO_2 Flux
- Roger Shaw and George Thurtell
  - Canopy Turbulence Models
- Tom Denmead
  - CO_2 and trace gas fluxes
- Marvin Wesely
  - Dry deposition
- Ray Desjardins
  - CO_2 fluxes from towers and airplanes
- Juhan Ross
  - Radiative transfer theory
- Keith McNaughton
  - ET and PBL Models
- Andy Black
  - Forest Meteorology







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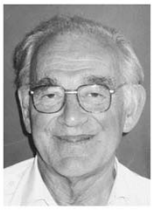
Through the 1970s and 1990s these were the leaders and innovators in producing high quality research that advanced the field

•Ag/Forest Meteorology Merges with Global Biogeosciences:
•Those with the Big Picture & Vision that Led the Way

•Dave Keeling



•Bert Bolin

Hal Mooney

James Lovelock

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Dave Keeling is famous for the Mauna Loa CO2 curve that started in the late 1950s and shows the continual build up of CO2 and the seasonal cycles due to the breathing of the biosphere

Bert Bolin was a professor at University of Stockholm. He was a pioneer in atmospheric dynamics, climate prediction, atmospheric chemistry and global carbon cycle, that went to form Earth System Science. He was an international leader of several early programs. Like Global Atmospherice Research Program (GARP), Intergovernmental Panel on Climate Change (IPCC).

Hal Mooney is a ecophysiologists at Stanford. Was early proponent of the idea of functional convergences, especially with ecosystems across different Mediterranean type climates. Played major roles in developing the IGBP, International Geosphere-Biosphere Program and the Millennial Assessment of Ecosystems

James Lovelock, proponent of the Gaia hypothesis. Showed the way how the state of the atmosphere and life coevolved and how biosphere-atmosphere interactions are a coupled and complex system. Noted for recognizing that the existence of life can be viewed by the chemical dis-

equilibria of a planets atmosphere.

To avoid repeating the past it is important to know what the pioneers did and who they were. Champ Tanner is considered to be the Father of Ag Meteorology. He produced a corps of students who went on to be professors or postdoc mentors for my generation of scientists (e.g Andy Black, Univ British Columbia; John Norman, Nebraska/Wisconsin; George Thurtell, Guelph; Marv Wesely, Argonne National Lab; Ed Kanemasu, Kansas State/Georgia; Wayne Jury, UC Riverside.

Raupach and Finnigan overturned flux gradient theory, which was failing in the plant surface layer, with advances in Lagrangian theory of turbulent diffusion and higher order closure models

Verma and Leuning were among the pioneers of implementing and advancing the science of measuring carbon exchange with eddy covariance

Bruce Hicks, along with Marv Weseley, pioneered the measurement of trace gas fluxes of pollutants, ozone, NOX, SO2, with eddy covariance. Bruce was a student of Swinbank and Dyer and was involved in many of the pioneering micromet studies on Flux-gradient theory.

Farquhar and Berry are pioneers in developing models on leaf photosynthesis, stomatal conductance, water use efficiency and the use of stable istopes. They both have gone on towards global integration of water and carbon fluxes, being among the few who can span knowledge from the cell, to leaf, plant, canopy and globe.

Jarvis and Norman merged micrometeorology theory and leaf modeling to produce some of the first truly integrated canopy flux models.

Sellers, a biometeorologist, turned astronaut, was bold enough to put the models of canopy fluxes into global models of climate change. Revolutionized on how we see land-atmosphere-climate interactions.

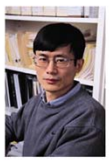
Among the Most Active Biometeorology Research Groups

Gaby Katul
Duke University

Tim Vesala
University of Helsinki

Mike Goulden
UC Irvine

Andrew
Richardson
Harvard



Xuhui Lee
Yale

Jingming Chen
Univ Toronto

Tim Griffis
Univ Minnesota

Marcy Litvak
New Mexico

Bev Law
Oregon State

Paul Stoy
Montana State

Dan Yakir
Weizmann

List of other Top Biomet groups: http://nature.berkeley.edu/biometlab/weblink_other.html

These scientists are among the most active and creative in the areas of agro and biometeorology. Of course this list is not limited to this group.

ToolBox of Younger/Future Scientists

- Remote sensing
- Eddy flux Measurements
- Stable Isotopes
- Inverse modeling
- Global Change Experimentation
- Plant to Ecosystem to Globe Process Modeling and Integration

Jim Randerson
UC Irvine

Markus Reichstein
Max Planck, Jena

Youngryel Ryu
Seoul National University

Mat Williams
Edinburgh

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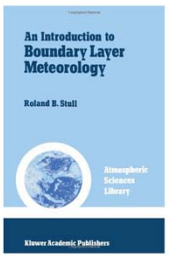
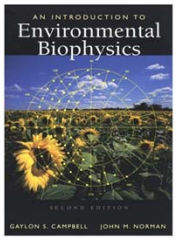
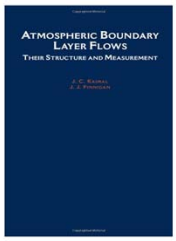
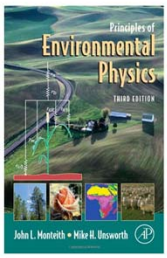
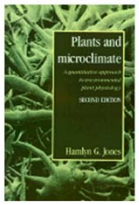
Micrometeorology Book Shelf

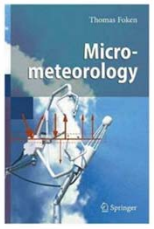


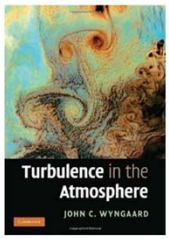












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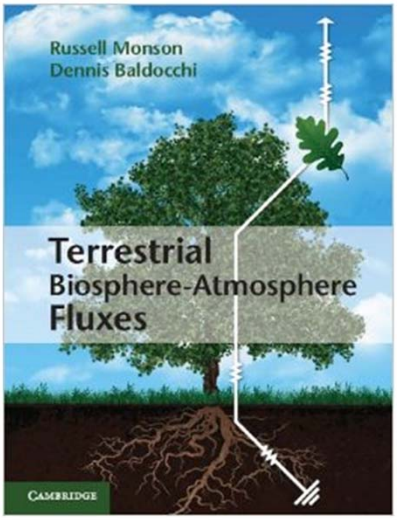
The Big Book on Fluxes



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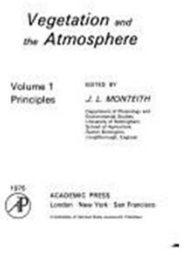
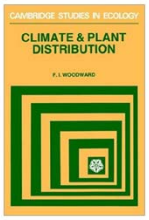
New book will come out this spring. Resource book if interested in Fluxes, though not compulsory for this class.

http://www.amazon.com/Terrestrial-Biosphere-Atmosphere-Fluxes-Russell-Monson/dp/1107040655

Classic Books





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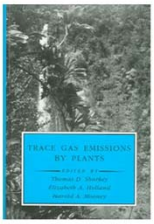
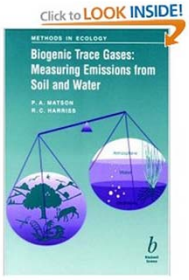
I got my start in this field with Vegetation and the Atmosphere edited by Monteith

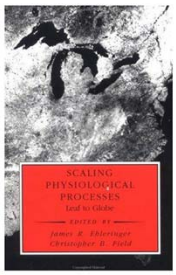
Ross's book on Radiation regime and architecture of plant stands is a tour de force. It is now online or available for $25

http://link.springer.com/book/10.1007%2F978-94-009-8647-3

Pioneering Trace Gas Books







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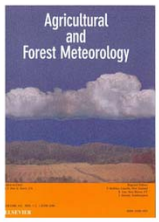
These books derived from workshops I attended and changed the field. The Dahlem Conference on Exchange of Trace gases, circa 1989, before the fall of the Berlin Wall, set the stage for much of the research that continues today. The Asilomar conference on Trace Gas emissions lead to a number of collaborations that have continued through my career, such as studies with the group of Zimmerman and Guenther on vocs and with Russ Monson on exchange of isotopes and vocs, plus co-authorship of our reference book. The Scaling workshop at Snowbird proved you can produce cutting edge research at a ski resource. Here is where I first heard of stable isotopes and met many of our leading scientists like Joe Berry, Chris Field and Dan Yakir

Journals



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Among the top journals where many of us publish our work.

Reading

- Dabberdt, W. F., D. H. Lenschow, T. W. Horst, P. R. Zimmerman, S. P. Oncley, and A. C. Delany. 1993. Atmosphere-Surface Exchange Measurements. Science **260:1472-1481.**

Future Problems

- Measure, Diagnose and Predict the Effects of Change…Disturbance, Land Use, Climate, Biodiversity
  - Potential to Refine Climate Reconstructions with Tree Rings and Isotopes
- Couple Carbon, Water, Nitrogen, VOCs and other biogeochemical cycles and climate-ecosystem coupling
  - New generation of laser spectrometers and mass specs are revolutionizing fast analytical measurements of trace gases
  - Data Assimilation Models with Bayesian Parameterization using Flux Networks and Satellite Remote Sensing give us the potential to produce Flux Fields nearly 'Everywhere, All the Time'.

This is a short list. I'd like to hear more of your opinions on unsolved questions and problems. Where the science should go. What problems in your field can be served better with biometeorological information?

Future Tools

- Measurement Networks
  - MesoNets, Landscape Gradients, Chronosequence
- Remote sensing
  - Spectral and spatial resolution increases
- Wireless Motes
  - spatial temporal scaling
- Tunable diode lasers, PTR-MS
  - Isotopes, multiple trace gases (CO_2, NOx, O_3, VOCs, aerosols
- Coupled Models
  - Micrometeorology, Biogeochemistry, Ecosystem Dynamics
- Desktop parallel processors
- Cyber Infrastructure, virtual ecosystems
- Fluxes of DNA, microbes!
- New Soil Moisture Sensors for Spatial Fields
  - EMI, COSMOS

Global Flux Networks, FLUXNET

http://www.fluxdata.org/default.aspx

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Net set of slides gives you a list of some top international programs and data archives as resources. Fluxnet is a project I have coordinated since about 1997. At present the data archive has curated and vetted datasets with over 1000 site-years of flux and meteorological data from over 200 sites world wide. The next version is to be launched sometime this year with over 2000 site years of data from over 400 sites. We will have a lecture on fluxnet, what we have learned and how it functions.

http://www.nacarbon.org/nacp/

http://ameriflux.lbl.gov/Pages/default.aspx

Distributed Achive Archive For Biogeochemical Data

http://daac.ornl.gov/

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Oak Ridge Daac is one of the Go-To places for Data.

International Land Ecosystem Atmosphere Process Study

http://www.atm.helsinki.fi/ILEAPS/

http://www.globalcarbonproject.org/

Global Carbon Project

http://www.gewex.org/

Global Energy and Water Cycle Experiment GEWEX WCRP

About GEWEX

http://www.essp.org/