RESEARCH OVERVIEW - Alan K. Betts

A brief overview of my research. (15 February, 2023)

My recent 2021 paper **"Climate Change and Society"** is of a different kind: this will be obvious from the first paragraph. I review climate change, but I then address why and how for decades our society has delayed dealing with it - by listening to the webs of lies from the Fossil Empire and conservative neoliberalism. Going back 1700 years to the Council of Nicea and the suppression of the Aramaic gospels, I map in outline the history of the abuse of human power by western society, religion and science that has contributed to the present climate and extinction crises.

My 2022 paper followed **"The Earth's View of climate change"**. This discusses how my search to merge science and wisdom , starting in 1980, has led me to understand that the Indigenous world view is correct. The living Earth system is really in charge, not foolish humans with our misuse of power and destruction of the Earth for profit.

My 2023 paper **"Accelerating Climate Change and the Living Earth"**, updates and reframes the discussion in terms of **Mother Nature** and four key issues; and adds some updates of recent extraordinary events.

From 2013-2020, I worked with the remarkable 58-yr hourly datasets from the Canadian Prairies to understand

1. How clouds determine the diurnal cycle in summer and winter (**Betts et al. 2013**) - **AGU Research Spotlight**
2. How the change to annual cropping in the past 25 years on 5 MHa has cooled and moistened the Prairie climate in summer (Betts et al. 2013b)
3. How the rapid transitions with snow determine the winter climate (Betts et al. 2014a)
4. How the summer climate temperature and humidity are linked to precipitation and clouds on monthly timescales (Betts et al 2014b)
5. Separating the forcing of daily climate linked to radiation/clouds, and RH, wind, and precipitation anomalies (Betts et al, 2015)
6. Careful extraction of diurnal cycle from monthly means clarifies difference between snow and no-snow BLs. "Annual Climatology of the Diurnal Cycle on the Canadian Prairies" (Betts and Tawfik, 2016)
7. The Impact of Clouds, Land use and Snow Cover on Climate in the Canadian Prairies - a review (Betts et al., 2016)
8. How cloud/radiation information changes our understanding of hydrometeorology and shows that memory of precipitation goes back as much as 5 months in spring and summer. "Revisiting hydrometeorology using cloud and climate observations" - Betts et al. 2017. J. Hydrometeor.
9. "Analysis of near-surface biases in ERA-Interim over the Canadian Prairies". Looking at reanalysis biases for agricultural modeling and forecast model improvement.
10. A synthesis of the most significant results from the first 8 papers dealing with the land-atmosphere-cloud-climate coupling on the Canadian Prairies. "Understanding Land-Atmosphere-Climate Coupling from the Canadian Prairie dataset."

11. Analysis of near-surface biases in ERA5 over the Canadian Prairies Revisiting 9, with the latest reanalysis (ERA5) from ECMWF showing the substantial reductions in the temperature biases.

Papers 10, 7, 6 and 8 are a good introduction.

Betts and Tawfik (2016) and Betts et al. (2019) [on ERA5] have been reprinted in readable book form by Vide Leaf (Hyderabad, India) for improved access in Asia. Vide Leaf is also archiving a dataset

These Canadian data are remarkable because, in addition to standard hourly meteorological data, they have 58-yr homogeneous records of hourly opaque (reflective) cloud fraction (in tenths), which can be calibrated against incoming shortwave and longwave on daily timescales, to give the coupling between diurnal and seasonal climate and cloud radiative forcing. They show how snow cover acts as a climate switch between cold and warm seasons; and also between a stable BL dominated by longwave cloud forcing with snow to an unstable BL controlled by shortwave cloud forcing in the warm season with no snow cover. This is transforming our understanding of hydrometeorology, because we can now see how temperature and humidity are coupled to precipitation and the surface radiation budget across season and all timescales, based on observations, rather than models with embedded parameterizations. The 8th paper shows that in April there is memory of precipitation back to freeze-up in November; and in the summer back to the March thaw.

A recent paper discusses the analysis of **solar flux data** from Vermont solar power arrays and diurnal climate. My collaboration with UVM on understanding the impact of climate change on the Lake Champlain basin led to a study showing that **high rainfall events** are increasing in the Northeastern US and rain events are lasting longer - so the risk of rivers flooding is growing.

This decade, I have revisited the BL cloud and climate change problem over land with the equilibrium BL model and a coupled carbon cycle, and completed a review of LBA research insights into land-atmosphere coupling. I have contributed to two global studies, one comparing land surface heat flux estimates and a second looking at recent trends in the tropical hydrological cycle. I contributed to a paper that evaluates the cloud fields in three reanalyses using ARM data from the Southern Great Plains site. I contributed to the development of a new probabilistic plume model for the growth of the mixed layer, shallow and deep convection.
I have also addressed the impact of global change locally in Vermont. I wrote **Vermont climate change indicators**; and used the **Seasonal climate transitions** to explain climate feedback processes to an interested public. I worked with the State Agency of Natural Resources on **climate change adaptation planning**. This work was initially supported by my National Science Foundation Grant, AGS-0529797 (2005-2012). Now it is partially supported by NSF grant OIA 1556770 to the University of Vermont.

My aim is to write papers that can be understood by both traditional scientific audiences, other professionals and the public. This is an interesting challenge, since few of our traditional journals accept that 'plain English' has real advantages over technical jargon! So in parallel, I have tried to broaden our collective understanding of our **responsibility as Earth scientists** for **clear, open public communication**. For the past 10 years, I have written articles for the **weekend edition** of two Vermont newspapers, based on the philosophy summarized in **Environmental journalism**

revisited. Recently I have been writing articles for the **Green Energy Times**. I also lecture extensively around Vermont. Humanity will be unable to deal with climate change, both in terms of mitigation and adaptation, until a broad spectrum of society is fluent in discussing the issues and the choices we face. Scientists should fully accept their responsibilities to society and to the Earth in explaining these **climate change issues.**

My research in the **2000s** addressed **land-surface-atmosphere-cloud** coupling, the field programs **LBA** and **BOREAS**, and **reanalysis evaluation**. This was partly data analysis, partly evaluation of models with data, and partly developing new conceptual frameworks. I contributed to the development at ECMWF of a new land-surface parameterization for ERA-40, a revised surface hydrology scheme, and to improved modeling of the diurnal cycle of convection. I worked on an idealized framework for studying the diurnal cycle over land over Amazonia. I worked extensively on quantifying the surface SW impact of clouds, using the concept of **effective cloud albedo**. This gives symmetric roles to the surface and clouds in the surface energy budget. I developed several important idealized models which coupled land-surface processes to radiative processes: models for the **equilibrium BL over land** (with and without vegetation coupling) and for the **nocturnal BL and the diurnal cycle**. I wrote several important reviews: on **understanding global hydrometeorology**, **land-atmosphere coupling**, and the **Amazonian boundary layer**.

My research in the **1990's** was primarily on land-surface processes: stemming from my participation in **FIFE** [grassland in Kansas] and **BOREAS** [boreal forest in Saskatchewan and Manitoba]. A second thread was the **evaluation of model errors** in operational forecast models and reanalyses at ECMWF and NCEP using these field experiment data and **GEWEX** data. Major discoveries were the importance of **soil water** on BL diurnal evolution; soil water-**evaporation-precipitation feedback** in models, and the hemispheric impact in spring on short-range forecasts of **snow albedo** errors over the boreal forest (the snow-albedo feedback impact on the forecast problem). This work led to the **correction** of many forecast model errors. There were a few papers relating to earlier work on tropical climate equilibrium, and two reviews which extended the Betts-Miller scheme. I have archived a copy of the historically important US Senate hearing on "*The Role of Clouds in Climate Change*", October 7, 1991, which includes my testimony and discussion with Richard Lindzen (*otherwise unavailable on the web*).

My research in the **1980's** started with a review of convection over the tropical ocean in **GATE**. I then developed the thermodynamics of **air parcel saturation point** for conceptually organizing convective and BL processes (an extension of my work in the 1970s). This was applied to several datasets and convective regimes. It led to two important models: the **Betts-Miller** convective parameterization scheme (which is still in use today) and, when coupled to a radiation code, the **Betts-Ridgway** model for tropical BL equilibrium for the present climate, a doubled CO2 climate and the ice-age climate.

My research in the **1970's** stemmed:

1) From my PhD work on "**Cumulus Convection**", which introduced or extended many important concepts: a **mixed layer model** for dry convection and the sub-cloud layer; the **liquid water potential temperature**; and **mass, enthalpy and water transport models** for shallow convective BLs. This was largely conceptual, but it would be fair to say that it was inspired by my spending a summer in Venezuela in 1969 with Herbert Riehl and the VIMHEX-1969 experiment. I saw each day that afternoon convection was not predictable - until it appeared on the radar!

2) From my field experiment work in the tropics in Venezuela with **VIMHEX**-1969 and 1972 (the **sub-cloud layer**, **mesoscale systems** and **traveling squall-lines**); and in **GATE** in the tropical Atlantic – where I was the 'Convection Subprogram Scientist' and an 'Airborne Mission Scientist' for this very large international program.

So my 70's research deals with convection and BLs over both the tropical land and the tropical ocean.

My only paper on the **1960's** (and my only paper on atmospheric dynamics!) - Betts and McIlveen (1969) - came from noticing that the energy equation is not invariant in a moving reference frame on a rotating planet.