Diagnostic evaluation of the ECMWF model using observations

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[*Contributors: Beljaars, Miller, Viterbo, van den Hurk, Jakob, Kőhler & Zhang]
Tony Hollingsworth’s vision

- For 17 years I have visited ECMWF annually
  - to work on the evaluation of the model physics using observational data, especially field data.
  - A time of rapid model development.
  - Tony was an early enthusiastic supporter. He would say:

  “The more errors you find, the more we can fix!”

  - He understood the science

  - He understood science management
Brief Timeline

• 1984: Betts-Miller scheme
• 1992: FIFE data comparison [Kansas prairie; 1987-89]
  - soil & vegetation model, BL model.
• 1994: ASTEX [Atlantic stratocumulus transition]
• 1993-1996: BOREAS [Boreal forest, SK & MB, Canada]
  - snow albedo, forest processes, frozen ground
• 1999-2002: LBA [Amazon forest]
  - diurnal precipitation, clouds and model climate
• 2000-2007: ERA-40 comparisons
  - new land-surface scheme
  - river basin hydrometeorology
  - biases against flux-tower data [BERMS]
  - coupling of land-surface processes to clouds – “cloud albedo”
  - shortwave cloud forcing against ISCCP data
  - NBL, diurnal cycle and LW\textsubscript{net}
• 2007-2008 ERA-Interim
  - hydrometeorology and SWCF
FIFE-1987 data

• 30-min averaged surface data time series prepared for 15 x 15 km FIFE site; Konza prairie, KS; summer, 1987.
  [10 AMS sites and 20 flux sites: downloaded at 2400 baud & manually edited] [Betts & Ball, 1994, 1995, 1998]

• Compared with 48 hr forecasts from ECMWF model; July, Aug., Oct. 1987 [Betts et al. 1993]

• Identified model errors in
  – the incoming short-wave radiation in clear skies [5-10% too high]
  – the ground heat flux [2-3X too large – time truncation]
  – the formulation of surface evaporation [time-scale too fast]
  – the soil moisture model [layering – climate layer control]
  – the entrainment at boundary layer top. [too low – giving BL moist bias]

• Input to new land-surface scheme [Viterbo & Beljaars, 1995]
• Input to new BL scheme [Beljaars & Betts, 1992]
Error 5 - BL entrainment low

9-day August average

Surface fluxes
Agreement good

(θ, q) plot
Too moist

(q, z) plot
Too shallow BL

[Beljaars & Betts, 1992]
July 1993 Mississippi flood

- Vast improvement in 48-72h forecasts of 1993 flood; July 9-25
Evaporation-precipitation feedback

- Difference in monthly forecast precip. (July 1993) starting with wet and dry soils

[Beljaars et al. 1996]
Impact of BOREAS

- Tony was my co-I on my NASA BOREAS grant
- For years the ECMWF model had had high-latitude surface temperature errors
- Surface scheme had been changed
  - Viterbo and Beljaars [1995]
- During BOREAS we realized
  - surface albedo with snow was too high
  - surface evaporation was too high
- Input to the new tiled land-surface model for ERA-40 [TESSEL]

Surface albedo

- Impact of landscape differences (forest/grass) on $R_{\text{net}}$ are large in spring
Impact of reducing boreal forest $\alpha_{\text{surf}}$ from 0.8 to 0.2 (snow)

- Large systematic bias reduction; NH forecast skill improved
Aside on ECMWF 4-10 year plans

• Bottom-up & top-down planning
  - Real strategic plans, carefully drafted with detailed, realistic timelines and budgets; reviewed and updated regularly

http://www.ecmwf.int/about/programmatic/index.html
Aside on ECMWF 4-10 year plans

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• Pedro Viterbo over-ruled the ‘plan’
  - **tested snow albedo changes** for two months, and presented a ‘fait accompli’ to Tony

• Tony was first annoyed and then grateful!
Boreal forest evaporation

- ERA-40 land-surface matches data better

- Global impact:
  - ERA-40 - Control
  - large reduction over boreal forest
LBA- Brazil

- Spurious model precipitation peak 2h after sunrise [Betts and Jakob 2002]
Surface Energy Balance

\[ R_{\text{net}} = SW_{\text{net}} + LW_{\text{net}} = H + \lambda E + G \]

- the split between surface processes and atmospheric processes
- the split between SW and LW processes
- the partition between clear-sky and cloud processes in the atmosphere
- the partition of the surface \( R_{\text{net}} \) into \( H \) and \( \lambda E \), which is controlled largely by the availability of water for evaporation and by vegetation
River basin archive

*ERA-40 and ERA-Interim*

Evaluation on river basin scale, starting from *hourly archive*
Clouds & Surface $SW_{net}$

$SW_{net} = SW_{down} - SW_{up} = (1 - \alpha_{surf})(1 - \alpha_{cloud}) \ SW_{down}(clear)$

- **surface albedo**
  
  $\alpha_{surf} = \frac{SW_{up}}{SW_{down}}$

- **effective cloud albedo**
  
  - scaled surface *short-wave cloud forcing, SWCF*

  $SWCF = SW_{down} - SW_{down}(clear)$

  $\alpha_{cloud} = - \frac{SWCF}{SW_{down}(clear)}$

[Betts and Viterbo, 2005; Betts, 2007]
Cloud albedo: *ERA-40 data*

- Transformation: $\alpha_{\text{cloud}} = \frac{\text{SWCF}}{\text{SW}_{\text{down}}(\text{clear})}$
- Seasonal cycle OK: small daily variability: *Is it biased?*
Cloud albedo: ISCCP data

- Different clear-sky flux: Aerosol differences
- ERA-40 systematic high bias in $\alpha_{\text{cloud}} \approx +7\%$
- ISCCCP has more daily variability
Amazon – Shortwave & $\alpha_{\text{cloud}}$

**SW$_{\text{down}}$**

**Cloud albedo**

Clear-sky differences

All-sky differences are larger

ERA-Int > ERA-40 > ISCCP
Tropics vs. mid-latitudes

- Amazon: reanalyses $\alpha_{\text{cloud}}$ biased high
- Mississippi: different bias signature
Surface $LW_{net}$

- Point comparison: stratified by RH/LCL & $\alpha_{cloud}$
- Quasilinear clear-sky and cloud greenhouse effects
- Amazon similar
Land-surface-BL Coupling

- $SMI-L1 = (SM - 0.171)/(0.323 - 0.171)$
- $P_{LCL}$ stratified by Precip. & SMI-L1 or EF
- Highly coupled system: only $P_{LCL}$ observable
Precipitation and cloud coupling to vertical motion in ERA-40 reanalysis

- Partition of moisture convergence into TCWV, $\alpha_{\text{cloud}}$, and precipitation
- Note high bias of $\alpha_{\text{cloud}}$ from ISCCP; while precip. generally low
Themes

• Evaluating models against independent data
• FIFE (grassland);
• BOREAS/BERMS (boreal forest)
• GEWEX (river basins)
• ERA-40 river basin & grid-point comparisons
• ISCCP surface shortwave estimates
• *Land-surface climate*
• Diurnal, daily mean, annual cycle
• *Precipitation, evaporation, dynamics*
• *Cloud radiative impacts*
Philosophical Summary

• Look for relationships and information in the coupling of processes/observables
• Observations important for evaluation & to suggest processes that are simply missing
• Every model cycle needs analysis of relationships, diurnal, daily mean and seasonal, against observations
• Improved understanding of the coupling of physical processes leads to improved models
• A challenge: but tractable as both global, regional and point time-series datasets improve

• Tony Hollingsworth deeply understood this challenge
References