LAOF and Frontiers of Tropospheric Physics

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Outline

• Tropospheric climate science issues/trends for the next decade
• Role of exploratory observations
My fingers in the climate science business

• I’m mainly a process modeler interested in clouds, turbulence and cumulus convection.
• Helped develop the CAM5 boundary layer, shallow cumulus and subgrid cloud parameterizations.
• I’m currently working on gaining a richer physical understanding of both boundary layer cloud feedbacks on global warming and cloud-aerosol interaction, using LES, and with NCEP on GFS moist physics parameterizations.
• Helped plan and analyze data from some field programs:
  - Hawaiian Rainband Project (1990)
  - Atlantic Stratocumulus Transition Experiment (1992)
  - Monterey Area Ship Tracks experiment (1994)
  - East Pacific Investigation of Climate (2001)
  - VOCALS Regional Experiment (2008)
VOCALS REx (2008)

- SE Pacific cloud/aerosol/precipitation interaction
- EOL: C130, Iquique GAUS
- Great suite of EOL and PI aerosol/chemical/cloud measurements on C130
- U. Wyo. cloud radar/lidar
- C130 range a key advantage
Tropospheric issues and trends in climate science

- High-resolution modeling
  - orography and surface heterogeneity
- Scale interaction
  - multiscale Cu convection, extreme weather
- Weather-climate synergy
- Sophisticated simulation of trace chemicals and isotopes
- Aerosols and cloud microphysics over remote oceans
- Ice and mixed-phase microphysics
- Reducing biases and uncertainty through testing and improvement of parameterizations and their interaction.

- Biosphere/atmosphere interaction
- Stable multidecadal climate observing system
High-resolution climate modeling

Global atmospheric model grid spacing  2012 ➔  2022

Typical
100 ➔ 25 km

Cutting edge
5 ➔ 1 km
Higher resolution, continued

- Brings better representation of multiscale interactions, surface heterogeneity and orography, local variability, extreme weather, chemical transport, cloud systems.
- Enhanced interest in measurements in complex terrain (NAME, T-REX) and near coastlines (TWP-ICE)
- Relevant interacting processes: boundary layer, cloud formation/microphysics, convective initiation/precipitation, chemical transport, gravity waves/breaking/drag… and many parameterizations poorly suited to complex terrain.
- Orography is a challenge for observing systems, needs a suite of coordinated measurement platforms.
Scale interaction
Scale interaction

- 1 km: Cumulus updrafts/downdrafts
- 10 km: Gust fronts and cold pools
- 100 km: Stratiform anvils and small MCSs
- 1000 km: Superclusters, westerly wind bursts
- 10000 km: MJO scale

- Projects like DYNAMO try to address this with multiscale observations (point, radar, aircraft, satellite)

- What is the most effective way to deploy such observations to test models that simulate an increasing range of scales? To gain multiscale science insight?
Weather-Climate Interface

• See 2012 ASP summer colloquium…
• ‘Fast physics’ of climate models like CESM are increasingly tested in weather forecast mode.
• Weather forecast models such as GFS and WRF have become the basis of climate models.
• At UKMO, one unified code is used for regional and global weather and climate modeling.
• Allows direct testing of climate models against IOP data, with meteorology mostly controlled for.
• Allows more effective comparison of an integrated suite of measurements (e.g. aerosol, clouds, chemistry) vs. model.
Chemistry and Isotopes

- Earth system models predict aspects of tropospheric chemistry and are starting to incorporate physically-based water isotope fractionation capability.
- Provide insight into transport and mixing processes as well as chemistry/aerosols/radiation. (e. g. CO$_2$, CO, O$_3$, DMS, black carbon).
- Different climate models can predict strikingly different tracer distributions (superparameterized CAM vs. CAM5 distribution of black carbon over the Arctic, or of vertical distribution of CO$_2$ in the tropics)
- This will provide increasing demand for chemical measurements in support of convection and dynamics-oriented experiments.
Aerosols and cloud microphysics over remote oceans

• Over the past 5-10 years, many global climate models (e.g. GFDL, NCAR) introduced physically-based predictions of aerosol concentrations and aerosol-cloud interactions.

• Key modeling issue for aerosol indirect effect on climate:
  What processes control cloud condensation nucleus concentrations over remote oceans (e.g. Southern Ocean)?
  - CCN driven locally (e.g. by salt or DMS) or remotely?
  - How do anthropogenic aerosols modify this regime?
  - Role of supercooled, mixed-phase and ice clouds that are common in midlat ocean storm tracks?

• Need more in-situ measurements in these remote locations
How much should we trust the satellite retrieval?

Wang et al. 2011

Fig. 6. PD annual-averaged cloud-top droplet number concentrations (cm$^{-3}$) derived from the MMF (upper panel), CAM5 (middle panel) and MODIS (lower panel).
Testing and improvement of parameterized physics

• Three long-standing climate change science problems:
  - Cloud feedbacks & climate sensitivity
  - Aerosol-cloud interaction
  - Precipitation biases/trends
• These problems involve interaction of boundary-layer turbulence to global scale circulations with complex cloud physics – will require parameterization a decade hence.
• Parameterization systems are ‘cartoons’ with many user assumptions built in that need observational testing.
• To improve them requires sustained dedicated effort.
• Optimal experimental designs for doing this may be different than those for inquiry-driven science, and emphasize small-scale relationships between variables.
More thoughts

• Need integrated measurement suites (clouds and precipitation and aerosol) combining remote sensing and in-situ measurements to get maximum value out of survey missions to remote locations. In particular, the combo of multiwavelength radar, lidar, multichannel microwave on G-V would complement in-situ cloud/aerosol measurements.

• Data synthesis (field data, satellites, NWP) needs to be an important part of project planning/execution.

• EOL ground-based precipitation radars are great, but would be useful to have a top-notch precipitation radar on a long-range platform.

• Continued need for distributed sensor systems and remote sensing (e.g. Doppler lidar) to sample atmospheric physics/chemistry in complex terrain.