Summary of Discussions during the IMPROVE Meeting in Seattle on 13 July 2005

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A. Precipitation Mechanisms

1. Four "scales" of precipitation formation

- In various talks and subsequent discussions, we seem to be focusing on four somewhat distinct "scales" (with associated distinct mechanisms) through which orographic precipitation forms:
    1. Turbulent cellularity at a scale of ~1 km or less, induced by shear, or perhaps by terrain perturbations at this scale
    2. Flow response to ridge-valley structures on the ~10 km scale (in both cross-barrier and along-barrier directions).
    3. Barrier-scale (~100 km) mountain-wave and blocking response to cross-barrier flow
    4. Meso/synoptic-scale (~200 km) baroclinically forced bands of upward motion
- Confidence was expressed in the model's ability to capture observed upward motion fields. However, it was also suggested that this is only really true for scale/mechanism #2 above; at the other scales, we really don't have precise enough measurements of upward motion to say the model is capturing these scales of upward motion well.

<u>Further points about the "four scales":</u>

<u>Turbulent cellularity (~1 km):</u>

- It was predicted that the enhancement of precipitation by the ~10-km ridge/valley topography (see below) would be even greater for the ~1-km turbulent cellularity. However, we do not yet have a modeling strategy to test this speculation.
- Recent work by Kirshbaum (not presented here) using a high-resolution model simulation of a shear layer over terrain reproduces something that looks like the cellularity seen in observations.
- A conundrum is that, if the small-scale cellularity is necessary for orographic precipitation enhancement, why does the MM5, which cannot be resolving this mechanism, still *overpredict* windward precipitation? One possible answer offered is that schemes have been deliberately or inadvertently "tuned" to match (or possibly even exceed) observed upslope precip values, to compensate (or possibly even overcompensate) for the absence of a physically necessary mechanism (i.e., turbulence)

<u>Ridge-valley scale (~10 km):</u>

- Matt Garvert showed evidence that the model is capturing the kinematic and liquid water response to flow over the ~10-km-scale ridge/valley structure.
- Removal of the ridge/valley-scale terrain from the model simulation decreased overall precipitation production by ~10%.

- There was some discussion as to whether this amount of enhancement was surprisingly large or surprisingly small.

Barrier-scale (~100 km):

- There is evidence of a secondary reflectivity maximum aloft, hypothesized to be associated with ascent forced by a barrier-scale mountain wave
- A search for the possible presence of a similar feature in non-orographic situations (IMPROVE-1, or IMPROVE-2 upstream of Cascades) should be conducted, to ascertain if this feature is indeed unique to orographic precipitation

Meso/synoptic-scale (~200 km):

- Various statements (e.g., questioning the utility of showing frontal features on vertical cross sections, hypothesizing the "dominance" of orographic mechanisms over baroclinic/frontal mechanisms) led to an expression of concern that we might be moving toward overemphasizing purely orographic mechanisms over baroclinic/frontal forcing for precipitation over the mountains.
- In support of this concern, it was pointed out that
    (1) Ground observers of snow particles consistently noted distinct and abrupt transitions in particle types that were tied to synoptic transitions.
    (2) Chris Woods' analysis of rain gauges relative to orography and to the transient frontal structure for the 13-14 December case showed that, while there was clearly orographic enhancement, it should not be characterized as dominance.
    (3) We should certainly be cautious about interpreting "orographic dominance" from the model, since the model seems to generally overpredict the contrast between upstream and upslope precipitation (both underpredicting upstream and overpredicting upslope precipitation).

2. The importance of aerosols (CCN) in controlling cloud droplet spectra and the onset of collision/coalescence

- Droplet concentrations in IMPROVE-2 were consistently very low (~10s cc^{-1}) compared to concentrations measured in the past over the Washington Cascades.
- These observations have some bearing on the currently "hot" issue of the potential for high aerosol concentrations to reduce windward precipitation
- IMPROVE data may be of some use in addressing this question for the Cascade Range, and Art Rangno plans to look into this

3. Future observational needs to address the orographic precipitation problem

- We need a better distribution (i.e., more) raingauges in studies such as IMPROVE. A "picket fence" of closely spaced rain gauges along a cross-barrier highway was suggested as a good strategy, although the importance of ridge-valley variability also indicates a need for gauges on more remote slopes and ridges.
- A general need was expressed for low-level or ground-based observations of cloud microphysical quantities over terrain, to overcome restrictions on flying in the important lowest ~1-2 km over terrain. Various ideas were discussed:
    - A video disdrometer, in conjunction with human observers of snow crystal type, as is being conducted by NCAR in the Rocky Mountains

- Aircraft-type imaging probe(s), deployed in novel ways:
  - on the ground, stationary, with fan-forced airstream
  - on the ground, on a rotating arm
  - mounted on a car
  - mounted on a tethered balloon
- Vertically pointing radar in both the pre-orographic and orographic environments, to help identify orographically enhanced signatures (e.g., secondary reflectivity maximum aloft)
- A need for remotely-sensed, quantitative information on cloud liquid water, for which a few ideas were discussed:
  - A microwave radiometer. This was used in IMPROVE. However, it has drawbacks, namely, it only gives a column-integrated value, and has problems in rain.
  - A dual-wavelength (or triple-wavelength) radar, which uses differential attenuation to retrieve liquid water 3-dimensionally (e.g., "S-Polka", NCAR's combined S-band/K_a-band radar).

B. Modeling Issues

1. The current hierarchy of microphysical parameterization schemes

- Bulk schemes are, and will continue to be for some time, the primary tool for simulating cloud and precipitation microphysics in NWP models, especially in the realm of operational forecasting
- Double-moment schemes may be advantageous for representing size distribution evolutions in some circumstances, but use is generally limited to research applications
- Bin schemes are prohibitively expensive for anything but spatially and temporally limited research simulations, but they have been useful tools for testing bulk schemes
- Bin schemes are useful tools for testing the relationship between aerosol/CCN properties and precipitation, as, for example, shown in Barry Lynn's presentation
- A trade-off between bin and bulk schemes is that with bulk schemes, the size distributions are forced to conform to "realistic" looking exponential forms, but are not free to evolve in the model, whereas in bin schemes, the size distributions are free to evolve, but there is no guarantee that they will look "realistic"

2. Snow overprediction

- Brian Colle (in absentia) stressed that a ubiquitous problem with the model microphysics appears to be an overprediction of snow mixing ratio aloft on the upslope side of a barrier in orographic precipitation situations
- Possible causes include:
  - a positive bias in upstream moisture (although model/obs comparisons in the 13-14 December case seem to show reasonably good verification of upstream moisture)
  - excessive vertical velocity associated with either the baroclinic band or barrier-scale mountain wave
  - over-active depositional growth of snow (although the potential error here is quite limited if vertical velocity and moisture are correct)

    - too slow a fall velocity for snow. In other words, we need to look at precipitation rate (PR) instead of just mixing ratio (q), since PR (specifically, its vertical derivative) is more directly related to precipitation mass growth than is q. The variable that connects PR to q is fall velocity, so if PR verifies better than q, this suggests that fall velocity is the problem, rather than the precipitation mass growth rate.
- The snow overprediction aloft generally coincides with overprediction of windward precipitation, though a causal relationship has not been established
- We need to establish whether the overprediction of snow aloft is also occurring in non-orographic, baroclinic precipitation bands (i.e., IMPROVE-1 cases).

3. Integration with studies from other related field programs

- It was emphasized that, while IMPROVE gathered a large data set for many different storm systems, studies of IMPROVE cases must be carried out in conjunction with, and results compared to, studies from related field programs that have gathered similar data sets in different meteorological situations.
- To date, this work is essentially limited to the efforts of Colle et al. looking at IPEX and Houze et al. looking at MAP. Another field study that was mentioned is CALJET/PACJET, although other candidate studies certainly also exist.

4. Development and testing of actual improvements in the MM5/WRF bulk scheme(s)

- General strategic philosophies for testing and improving bulk schemes were expressed. One approach was to start from simple situations such as widespread stratiform precipitation over non-complex terrain (i.e., IMPROVE-1), evaluating, improving, and testing the improved scheme, and then moving on to more complex situations where processes on many scales interact.
- The UW Real-time MM5 forecast system is ideally suited (and ready when needed) to test proposed improvements to bulk schemes, by incorporating one or more "altered physics" members into the real-time ensemble system over an extended period of time (a season, a year, etc.). Possible candidate changes for testing include:
    - A different temperature-dependent intercept for snow arising from Chris Woods' analysis of particle imagery during IMPROVE-1 and -2
    - Choosing reasonable snow particle habits, and enforcing habit-consistency for snow particle properties (e.g., mass-diameter and fallspeed-diameter relationships), as discussed in Chris Woods' talk
    - Testing some of the recent changes that Greg Thompson has employed in the MM5's single-moment bulk scheme
- The importance of drizzle in orographic situations was emphasized, with the suggestion of adding drizzle as a fifth hydrometeor species, because it is difficult to represent the unique aspects of drizzle with a single liquid precipitation species.