Similar to how dewdrops form on cooled surfaces on the ground, cloud drops form on pre-existing aerosol particles in cooled ascending air streams. Polluted air provides many of these cloud drop condensation nuclei (CCN). Cloud water is comprised of many water drops 10-20 microns in size that are small relative to the range of droplet size in a cloud, float in the air, and are too small to combine into raindrops. Rain might be enhanced by seeding such clouds with two- to five-micron hygroscopic particles (relatively large compared to many aerosols) that nucleate large cloud drops, and then can become embryos of rain drops.

Small drops are also slower to freeze into ice crystals and are less efficiently collected by the ice crystals that do form.
so they produce less snow. Therefore, cloud seeding to augment precipitation is most effective in “super-cooled” water clouds, clouds that are composed of small water drops that remain liquid at subfreezing temperatures. Because super-cooled clouds of small drops are slow to freeze, precipitation can also be enhanced by seeding with ice nuclei, such as silver iodide, that initiate the ice crystals that subsequently collect the remaining cloud water into snowflakes.

Pollutant Seeds Have Opposite Effect

Cloud seeding for enhancing precipitation is the opposite of inadvertent suppression of precipitation caused by small CCN aerosols from smoke and urban particulate air pollution. We “seed” the clouds negatively with pollution aerosols on a much grander scale than we do positively with silver iodide and large hygroscopic particles. Thus, we can learn much about how to intentionally enhance rain by observing how we inadvertently suppress it.

The recently acquired ability to detect the composition of clouds from weather satellites revealed tracks of super-cooled small drops in clouds downwind of major urban and industrial areas over many parts of the world (see image opposite, left). The same satellite technique was used to show how cloud seeding with silver iodide has the opposite effect of converting the small super-cooled cloud drops into falling snow (see image opposite, right).

The western United States is particularly vulnerable to the effects of pollution, because much of its water comes from pristine oceanic air masses that become polluted by the major urban areas during their trek inland. When the polluted air ascends the mountain ranges it forms new clouds with reduced drop size, which dissipate when they pass the ridge line and are forced to descend on the lee side. The short lifetimes of clouds mean that pollution-induced slowing of the conversion of cloud drops to precipitation translates to a net loss of water on the ground. Consequently, we would expect urbanization and the resulting added aerosols during the last century to have caused a reduction in mountain precipitation with respect to coastal and upwind lowland precipitation, defined here as the orographic enhancement factor, Ro.

The Evidence

This hypothesis was validated, as reductions of 10 to 25 percent in Ro were recorded during the past decades in much of the mountain ranges of the western United States, including the California Sierra Nevada, the Cascades east of Seattle, the Wasatch Mountains east of Salt Lake City, the Sandias east of Albuquerque, and parts of the Rocky Mountains west of Denver and Colorado Springs (see Givati and Rosenfeld, 2004 and Rosenfeld and Givati, 2006). The estimated loss of precipitation at the central Sierra Nevada alone is estimated at 4x10^6 cubic meters per year (3.2 million acre-feet per year [afy]).

A new study by Rosenfeld documented similar effects over Israel, with losses of usable water to the Lake of Galilee amounting to about 1x10^6 m^3 per year (81,000 afy), approximately six percent of the overall water potential of Israel.

These alarming findings prompted the California Energy Commission to support cloud physics aircraft measurements of pollution aerosols and their interactions with the potential rain clouds over California. These measurements, which took place during the latter part of the winters of 2005 and 2006, confirmed that urban aerosols are ingested into potential rain clouds and suppress their precipitation (Rosenfeld, 2006). Model simulations of these processes provide additional support and insights.

Testing Ro Sensitivity

Cloud seeding for precipitation enhancement is being conducted extensively in the western United States, but assessment of its efficacy requires a randomized seeding scheme, yet to be conducted here in a scientific manner that benefits these new insights. Experimental randomized cloud seeding with silver iodide in northern Israel, which was reported to enhance rainfall there by 13 to 16 percent, has continued operationally since 1975. Givati and Rosenfeld (2005) analyzed the orographic enhancement factor over the hills of northern Israel for the whole period of 1950 to 2002, during which time Ro decreased by 15 percent despite the reported positive seeding effect over the hills there. When separating the time series to seeded and

see Pollution, page 33
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unseeded conditions they found that the
trend line of Ro shifted upward by 12 to 14 percent for the seeded rain time series
compared to the unseeded time series.
The sensitivity of Ro to both seeding and
pollution effects was greatest in the hilly
areas with the greatest natural orographic
enhancement factor and practically non-
existent in the low-lying areas where
no orographic enhancement occurs.

The double-sided sensitivity of clouds
to the damaging effects of pollution aerosols
and potential corrective effects of cloud
seeding provides another powerful tool for
assessing the potential for enhancement
of orographic precipitation. Areas that
have experienced significant reductions in
the trends of the orographic enhancement
factor are likely manifesting the sensitivity
of the clouds to aerosols, and hence
could benefit from cloud seeding.

Satellites Offer Great Opportunities
The multispectral capabilities of recently
commissioned satellites have provided
new insights into the impacts of aerosols
in reducing cloud drop size and in slowing
the process of precipitation formation.
These satellite capabilities can provide
further insights into the efficacy of
cloud seeding for rain enhancement.
They also can be used to direct seeding
operations to the clouds that likely
will be most responsive to the process.
Given the severe shortage of water in
the southwestern United States, the
time is right to start a new generation
of cloud seeding research so the region
can benefit from the new methodologies
and insights it will produce.

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details.asp?option=3&kind=149.

Understanding, continued from page 27
Yet, changing levels of background
aerosols associated with inadvertent
weather modification in a region can
influence or change the potential for
deliberate weather modification and
render previous cloud seeding results
inapplicable. This finding and other
recent work has raised critical questions
about the microphysical processes
leading to precipitation, the transport
and dispersion of seeding material
in the cloud volume, the effects of
seeding on the dynamical growth of
clouds, and the logistics of translating
storm-scale effects into an area-wide
precipitation effect. Questions such as
the transferability of seeding techniques
or whether seeding in one location can
“steal” rain from other locations can only
be addressed through sustained research
on the underlying science combined
with carefully crafted hypotheses and
physical and statistical experiments.

Significant and exciting advances in
observational, computational, and
statistical technologies have occurred
over the past two to three decades. These
include capabilities to: 1) detect and
quantify relevant variables on temporal
and spatial scales not previously possible; 2) acquire, store, and process vast
quantities of data; and 3) account for
sources of uncertainty and incorporate
complex spatial and temporal relationships.
Increased computing power has enabled
the development of models that range in
scale from a single cloud to the global
atmosphere. However, because of lack
of funding, few of these tools have been
applied in any collective and concerted
fashion to resolve critical uncertainties
in weather modification activities.

Future Directions
Capitalizing on these advances and
especially adding new remote and in situ
observational tools to existing or new
experiments could yield substantial new
insights and at last simultaneously provide
the necessary physical and statistical
data on the efficacy of cloud seeding to
enhance precipitation or mitigate hail.
Some especially promising areas include:
• Hygroscopic seeding to enhance
rainfall. The small-scale experiments
and larger-scale coordinated field efforts
proposed by the WMO (2000) could
serve as a starting point for such efforts.
• Orographic cloud seeding to
enhance precipitation. A randomized
program that includes strong
modeling and observational
components and employs advanced
computational and observational
tools could substantially enhance our
understanding of seeding effects and
winter orographic precipitation.
• Studies of specific seeding effects.
These could include studies of initial
droplet broadening, the formation
of drizzle and rain associated with
natural hygroscopic seeding, and
anthropogenic sources of particles.
• Improving modeling. Special
focus is needed on modeling cloud
microphysical processes.

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