Overview of Overarching Data/Instrument Needs – Role of UAS

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Workshop on Current and Future Uses of Unmanned Aircraft Systems (UASs) for Improved Forecasts/Warnings and Other Scientific Studies

Norman, OK

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Observational Needs

- Nearly every sub-discipline in the atmospheric science and related disciplines (hydrology, oceanography, cryosphere, space weather, etc.) has written documents on the observational needs in their areas of interest.
- For the PBL, the 2009 NRC report "Observing Weather and Climate from the Ground Up: A Nationwide Network of Networks" stated the case for increased spatiotemporal sampling of the lower troposphere
- This has been updated by a NRC Workshop report "The Future of Atmospheric Boundary Layer Observing, Understanding, and Modeling: Proceedings of a Workshop" held in 2018

Observational Needs (cont.)

Even the NRC Decadal Survey report for NASA "Thriving on Our Changing Planet: A Decadal Strategy for Earth Observation from Space" (2018) emphasized that the PBL could not be adequately sampled by satellites alone - there needs to be complementary surface-based instrumentation to obtain the necessary vertical and temporal resolution of quantities such as mass, momentum, temperature, moisture, aerosols, ozone and other chemical species, etc.

What measurements should be obtained and from which instruments?

Survey Approach to Addressing Previous Questions

- I will describe a survey done to assess community observational needs at the 2017 American Meteorological Society Annual Meeting in Seattle

- Then we will summarize the preliminary results and what they say for the PBL and lower troposphere

- Then we will discuss the role of UAS among competing observing systems

“Observations Lead the Way”

- Theme of the 2017 Annual AMS Meeting in Seattle
- NSF provided partial support for 100 students to attend 426 sessions in 31 scientific conferences to “harvest” observational needs from both oral and poster sessions
- Stacey Hitchcock (CSU) was the “shepherd” of the harvesters:
  - Made all the session assignments
  - Collected all of the 1729 student reports of oral talks
  - Poster information and Powerpoint slides were also collected;
  - Created an enormous Google spread sheet that organizes all the information
- Additional conferences/workshops also included in tabulations

Goals of the Observation Harvesting

- Goal is to produce a **community consensus** on the **greatest observational needs** in most disciplines within **atmospheric science and related fields** (hydrology, space weather, etc.)
- **Dissemination**:
  1. Two articles planned for *BAMS*:
     a. Summary of the observational recommendations
     b. Going Forward (update of "NoN" NRC and other reports)
  2. Summary for agencies that develop and/or support observations
  3. Summary for policy makers (OMB; Congress)
- Hope to create strong enough value proposition to develop support for increasing our nation's observing capacity (Infrastructure!)

Information/Questions Requested

- Date, Conference, Session
- Author, Title, Paper Number
- Does this talk contribute to or use observations?
- What measurements are discussed?
- What problem is being addressed?
- What is the greatest unmet observation need for this topic?
- Recommendations for improving instruments or designing new ones?
- Additional points related to observations

Conferences/Symposia at 2017 Annual AMS Meeting (43)

- **17th Presidential Forum: Earth System Observations in Service to Society**
- **Special Symposium on Individual, Social, and Cultural Observations in Weather and Climate Contexts**
- **Observation Symposium: Progress, Problems, and Prospects**
- Lance Bosart Symposium
- Robert A. Houze, Jr. Symposium
- 33rd Environmental Information Processing Technologies
- 31st Conference on Hydrology
- 29th Conference on Climate Variability and Change
- 28th Conference on Weather Analysis and Forecasting
- 24th Conference on Numerical Weather Prediction
- 26th Symposium on Education
- 21st Conference on Integrated Observing and Assimilation Systems for Atmosphere, Oceans, and Land Surface
- 20th Atmospheric Science Librarians International Conference
- 19th Conference on Atmospheric Chemistry
- 18th Conference on Aviation, Range, and Aerospace Meteorology
- 16th Annual AMS Student Conference
- 15th Conference on Artificial and Computational Intelligence and its Applications to the Environmental Sciences
- 15th History Symposium
- 15th Symposium on the Coastal Environment
- 14th Conference on Polar Meteorology and Oceanography
- 14th Conference on Space Weather
- 13th Symposium on New Generation Operational Environmental Satellite Systems
- 13th Symposium on the Urban Environment
- 12th Symposium on Societal Applications: Policy, Research and Practice

Conferences/Symposia at 2017 Annual AMS Meeting (cont.)

- Ninth Symposium on Aerosol–Cloud–Climate Interactions
- Eighth Conference on Environment and Health
- Eighth Conference on Weather, Climate, Water and the New Energy Economy
- Eighth Conference on the Meteorological Applications of Lightning Data
- Eighth Symposium on Lidar Atmospheric Applications
- Seventh Conference on Transition of Research to Operations
- Seventh Symposium on Advances in Modeling and Analysis Using Python
- Fifth Annual AMS Conference for Early Career Professionals
- Fifth Symposium on Building a Weather-Ready Nation: Enhancing Our Nation's Readiness, Responsiveness, and Resilience to High Impact Weather Events
- Fifth Symposium on Prediction of the Madden–Julian Oscillation: Processes, Prediction, and Impact
- Fifth Symposium on the Joint Center for Satellite Data Assimilation
- Third Symposium on High Performance Computing for Weather, Water, and Climate
- Fifth Symposium on the Weather, Water, and Climate Enterprise
- Second Symposium on Multi-scale Atmospheric Predictability
- Second Symposium on Special Sessions on US-International Partnerships
- Symposium on Greening the Built Environment
- **Special Symposium on Meteorological Observations and Instrumentation**
- Major Weather Impacts of 2016
- **Special Symposium on Severe Local Storms: Observation Needs to Advance Research, Prediction, and Communication**

How to Organize?

- By **Variable**? (**V**, T, p, radiance, fluxes, moisture, etc., etc.)
- By **Instrument**? (radars, satellite sensors, profilers, mesonet, etc., etc.)
- By **Phenomena**? (cyclones, convection, fronts, jet streams, etc., etc.)
- By **Scientific problem**? (cloud physics, radiation, turbulence; etc., etc.)
- By **Application need**? (better NWP; warnings; climate services; verif.; etc.)
- By **Location**? (surface, PBL, soil, troposphere, cryosphere, etc., etc.)
- **By Most Needed Observations (recommendations)**

Organizing Decisions

- Decided to organize by all 7 categories!
- Will reduce original spread sheet by 50% and use common terms to make the columns searchable
- Still 2000+ rows
- Searched for common terms in columns to produce histograms, word clouds, etc. Welcome suggestions for presentation summaries, graphics, statistics, etc.
- Following slides represent results so far from the largest conferences that emphasized observations.

Challenges

- Number of key words/phrases in the 7 different columns currently totals about 900! Illustrates breadth and complexity of the atmospheric measurement enterprise.
- Effort doesn't make distinctions w.r.t. Cost, Availability, Technical feasibility, Readiness, Support/Maintenance, etc.
- Additional issues w.r.t. data such as QC; accuracy; metadata; etc. not addressed. Issues of increased coverage/resolution are noted
- Need for field programs (research and/or testing); long-term testbeds
- Didn't cover all AMS disciplines (will make effort to get most important needs from these areas)

LET'S TAKE A LOOK AT SOME OF THE KEY or COMMON WORDS:

Variables being measured (alphabetical within groups)

Atmosphere

AOD aerosol optical depth
aerosol
- PM1 particulate matter, 1 µm
- PM2.5 particulate matter, 2.5 µm
- PM10 particulate matter, 10 µm
- dust
- smoke
- aerosol tracer
- aerosol composition
- aerosol concentration
- aerosol size
- aerosol source

backscatter
boundary layer height
charged particles
chemical tracers
clouds
- cloud cover
- cloud base
- cloud height
- cloud ice
- cloud water
- cloud optical depth
- cloud albedo
- cloud properties
- cloud microphysics
- cloud type

convective transport
droplet size
dual-pol
- ZDR differential reflectivity
- CC correlation coefficient
- KDP differential phase shift

eddy dissipation rate
electrical charge
electric field
extinction
fall speed
flux divergence
gases
- C2H6 ethane
- C3H8 propane
- CH3I methyl iodide
- CH4 methane
- CO carbon monoxide
- CO2 carbon dioxide
- HCHO formaldehyde
- HNO3 nitric acid
- H2SO4 sulfuric acid
- isoprene
- NH3 ammonia
- NOx nitrogen oxides
- NO nitric oxide
- NO2 nitrogen dioxide
- O3 ozone
- propane
- SO2 sulfur dioxide
- VOC volatile organic compound

geopotential height
GHG greenhouse gases
graupel
hail
hydrometeor properties
hydrometeor size distribution
ion density
ice crystal orientation
IPW Integrated Precipitable Water
leaf-gas exchange
lightning
- lightning discharge
- CG cloud-to-ground
- IC in-cloud
- CC cloud-to-cloud
- flash energy
- flash rate
- polarity

mass flux
Moisture
- dewpoint
- precipitable water
- RH relative humidity

PBL height planetary boundary layer height
plant properties
pressure
pressure perturbations
radial velocity
Radiance
- infrared
- microwave

Radiation
- shortwave
- solar
- longwave
- IR infrared

radiative flux
- shortwave
- longwave

RO radio occultation
reflectivity
refractivity gradient
spectra
- temperature
- horizontal wind

spectrum width
supersaturation
temperature
turbulence
turbulence kinetic energy (TKE)
updraft/downdraft properties
vertical fluxes
- mass
- horizontal momentum

vertical profiles
vertical velocity
wind

Variables being measured (continued)

Land surface

albedo
elevation
emission sources
emissivity
fuel moisture
infrared radiation
Precipitation
- precipitation type
- precipitation rate

road surface
shortwave radiation
- direct
- diffuse

snow depth
snow cover
solar radiation
soil temperature
soil moisture
soil properties
soil water
surface roughness
surface topography
SWE snow water equivalent
subsurface temperature
subsurface moisture
surface fluxes
- heat flux
- moisture flux
- momentum flux
- radiative flux

surface hydrology
- river discharge
- river stage
- stream discharge
- stream stage

vegetative cover
visibility

Ocean and lake

algal blooms
biological activity
currents
ice cover
ice thickness
lake ice
ocean wind
salinity
sea ice
sea surface altimetry
SST sea surface temperature
wind
water temperature
thermocline
wave heights

Space weather

electron density
energetic particles
ion density
solar magnetic field
solar radiation
- x-ray
- EUV extreme ultraviolet
- ultraviolet
- VIS visible

solar spectrum
solar wind

Instruments (alphabetical within groups)

In Situ

accelerometer
air chemistry - surface
Below is a list of major programs that collect and analyze surface chemistry measurements.
– CMAS Copernicus Atmospheric Monitoring System, European Union
– GAW-SIS Global Atmospheric Watch – Station Information System
– IGGGIS Integrated Global Greenhouse Gas Information System, WMO
aircraft measurements of temperature, wind, and moisture
– AMDAR Aircraft Meteorological Data Relay (WMO)
– ASDAR Aircraft to Satellite Data Rela
– ACARS Aircraft Communication Addressing and Reporting System (US version of AMDAR)
– TAMDAR Tropospheric Airborne Meteorological Data Reporting (Panasonic)
– WVSS Water Vapor Sensing System
storm penetrating aircraft
aircraft platform
anemometer
balloons for measuring particle charge
buoy platform
chaff tracers
counterflow virtual impactor
drifting balloons
driftsondes
dropsondes
eddy covariance
electrical field mills
gas samplers
gust probe
mini-drifters
mobile observing systems
moored buoys
nano-driftsonde
particle samplers
pilot balloons
ocean surface and below
– Argo Floats
– ALAMO Air Launched Autonomous Micro Observer (like Argo but smaller - Woods Hole)

radiation measurements – surface
– cavity radiometer
– pyranometer
– pyrgeometer
– pyrheliometer
– silicon cell photodiode
– sun photomet
– thermopile radiometer

radiosondes
rivers and streams
– ADCP Acoustic Doppler Current Profilers
– Index Velocity Method - microwave radar aimed obliquely at roughened water surface
– LSPIC Large-Scale Particle Image Velocimetry
ship platform
sonic anemometer
surface observing (most comprehensive example: OK Mesonet)
– all-sky camera
– anemometer
– barometer
– COSMOS Cosmic-ray Soil Moisture Ob serving System
dewpont sensor
disdrometer
– forward scatter visibility sensor
– frostpoint sensor
– LEDWI Light-Emitting Diode Weather Identifier, ASOS
– mesonet
precipitation gauge
rain gauge
– road sensors
– soil measurements: time-domain reflectometry, heat dissipation, impedance,
capacitance. Manual sampling: gravimetric method (destructive), neutron probe,
soil heat flux plate
(Strictly speaking, these are not instruments but rather methods of measurement.)
– thermometer
– transmissometer
tethered balloon
tower
unmanned aeronautical vehicles, e.g., drones –
– drone
– RPV Remotely Piloted Vehicle
– UAS Unmanned Aerial System
– UAV Unmanned Aeronautical Vehicle
– SHOUT Sensing Hazards with Operational Unmanned Technology (dropsondes released from
Global Hawk, in development

Remote sensing from the ground

infrared interferometers (for clear-air sensing)
– AERI Atmospheric Emitted Radiance Interferometer
G-band Vapor Radiometer Profiler
GPS integrated moisture measurements
infrared spectrometer

Instruments (alphabetical within groups)

Lidar
aerosol lidar
– ceilometer
– wind lidar
– Raman
– DIAL Differential Absorption Lidar
– water vapor DIAL
– High Spectral Resolution Lidar (HSRL)
lightning sensors, ground-based
– VLF Very Low Frequency detection
– LF/VLF Low Frequency / Very Low Frequency detection
– VHF Very High Frequency detection
– magnetic direction finding
– time-of-arrival
– LMA Lightning Mapping Array
– NLDN National Lightning Detection Network
microwave radiometer (looking up)
microwave scintillometer
radars
Doppler radar
– wind profilers (UHF)
– S-band
– WSR-88D
– C-band
– L-band
– X-band
– cloud radar
– FMCW cloud radar
– W-band
dual-Doppler radar
– dual-pol radars
– mobile radars
– phased array
Radio Acoustic Sounding System
sodar
solar properties measured from Earth's surface
– magnetometers
– coronographs

Remote sensing within the atmosphere
airborne lidar
airborne radar
airborne radiometer
high-altitude balloons
HAMSR High Altitude Monolithic Microwave Integrated Circuit (MMIC) Sounding Radiometer (NASA, on UAVs)
HIRAD Hurricane Imaging Radiometer (NASA, aboard NOAA P-3)
– microphysical measurements
UAV

Remote sensing from space, satellites

Note: Key words only in subheadings
atmospheric motion vectors
atmospheric turbidity and chemical composition
– MODIS Moderate Resolution Imaging Spectroradiometer, Aqua, Terra, EOS
– MLS Micro Limb Sounder, Aura, EOS
– OMI Ozone Monitoring Instrument, Aura, EOS
– SBUV-2 Solar Backscatter Ultraviolet Instrument, NOAA-19
– IASI Infrared Atmospheric Sounding Interferometer, METOP-A, METOP-B, EUMETSAT
– MOPITT Measurement of Pollution in the Troposphere, Terra, EOS
– GOME-2 Global Ozone Monitoring Experiment, METOP-A, METOP-B, EUMETSAT
– OMPS Ozone Mapping Profiler Suite, Soumi NPP, NOAA
– PMAp Polar Multi-Sensor Aerosol Optical Properties, METOP-A, EUMETSAT
– SEVERI Spinning Enhanced Visible and Infrared Imager, METEOSAT, EUMETSAT
– TROPOMI TROPOspheric Monitoring Instrument, Copernicus Sentinel-5 Precursor satellite, ESA
– MIS Multispectral Imaging Spectrometer, Sentinal-5P, ESA

clouds
– cloud drift winds
– IR image, infrared image
– VIS image, visible image
– AVHRR Advanced Very High Resolution Radiometer - NOAA polar orbiters
– VIIRS Visible Infrared Imaging Radiometer Suite (aboard NOAA polar orbiters)
FRP Fire Radiative Power, GOES-11, GOES-12 imager *and* an imager on MTSAT-2, JMA
gravitational anomalies
hyperspectral sounders
– AIRS Atmospheric Infrared Sounder, NASA
– IASI Infrared Atmospheric Sounding Interferometer, Metop-A, Metop-B, EUMETSAT
– CRiS CRoss-Track Infrared Sounding, Soumi NPP (see above)
– HIRAS Hyperspectral InfraRed Atmospheric Sounder, Fengyun 3D satellite (above)
– GOES infrared sounder
– INSAT-3D Indian Space Research Organization (an Indian geosynchronous satellite launched in July 2013)
– GIIRS Geostationary Interferometric InfraRed Sounder, FengYun 4A satellite, China
– MET-IRS METEOSAT Third Generation (MTG) InfraRed Sounder (IRS), EUMETSAT
– COSMIC Constellation Observing System for Meteorology, Ionosphere, and Climate, Radio Occultation (RO), Metop
lightning
– GLM Geostationary Lightning Mapper, GOES
precipitation measurements from space
– Ku band radar aboard various satellites
– Ka band radar aboard various satellites
– W band radar aboard various satellites
– passive microwave radiometers - over a dozen in orbit on various satellites
– VIS/IR radiometers , on both LEO and GEO satellites
– GPM Global Precipitation Measurement Core Observatory (NASA) carries Ku and Ka band dual-frequency radars
– GPM Dual-frequency Precipitation Radar

Instruments (alphabetical within groups)

Instruments listed below are operating now or will be in the next few years.

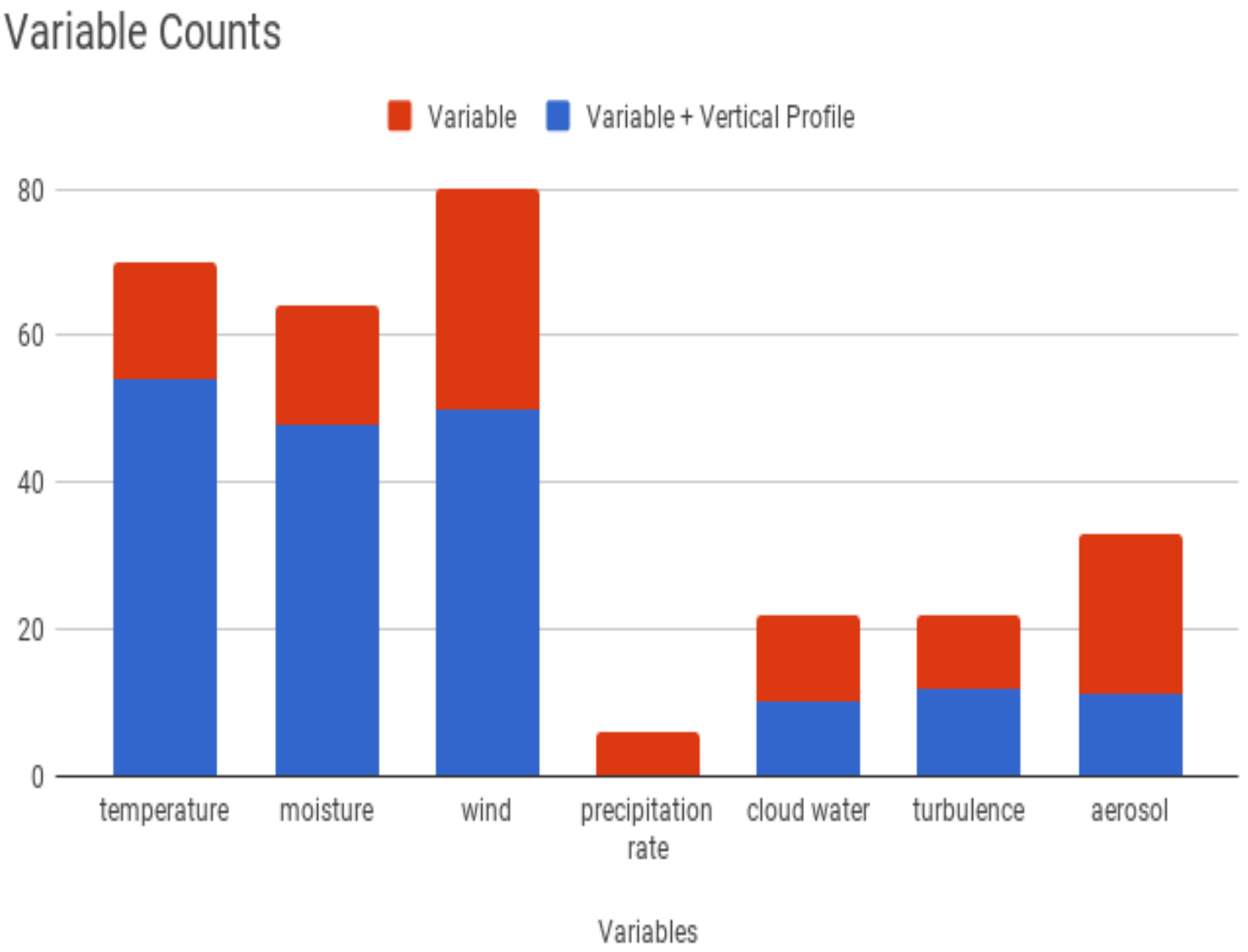
– SSMIS Special Sensor Microwave Imager Sounder, DMSP (Defense Meteorology Satellite Program, F15
– SSMIS, DMSP F16 (see above)
– SSMIS, DMSP F17 (see above)
– SSMIS, DMSP F18 (see above)
– MHS Microwave Humidity Sounder, NOAA 18
– MHS Microwave Humidity Sounder, NOAA 19
– MHS Microwave Humidity Sounder, Metop-A, EUMETSAT
– MHS Microwave Humidity Sounder, Metop-B, EUMETSAT
– SAPHIR Megha-Tropiques, launched in 2011 to study water cycle of tropical atmosphere; collaborative effort between Indian Space Research Organisation (ISRO) and French Centre National d'Etudes Spatiales (CNES),
– ATMS Advanced Technology Microwave Sounder, NPP (National Polar Orbiing Partnership)
– ATMS Advanced Technology Microwave Sounder, JPSS-1 (Joint Polar Satellite System), NOAA.
– AMSR2 Advanced Microwave Sounding Radiometer 2, GCOM (Global Change Observation Mission 1st – Water, Japan
– GMI GPM Microwave Imager. GPM (Global Precipitation Measurement). Joint effort between NASA and the Japan Aerospace Exploration Agency (JAXA).

EVI-3 Earth Venture-Instrument program (NASA) 12 CubeSats with microwave radiometers
radar altimetry
radio occultation
satellite altimeter
solar properties measured from space
– SDO Solar Dynamics Observatory, in geosynchronous orbit
– EVE EUV Variability Experiment, part of SDO
MEGS Multiple EUV Grating Spectrograph
ESP EUV SpectroPhotometer
– HMI Helioseismic and Magnetic Imager, part of SDO
– AIA Atmospheric Imaging Assembly (images the sun), part of SDO
– SOHO Solar and Heliospheric Observatory (launched 1995)
12 different instruments abord; at Lagrange Point L1
– STEREO Solar Terrestrial Relations Observatory (launched 2006)
– STEREO-A leads the Earth in its orbit around the sun
– STEREO-B follows the Earth in its orbit (lost contact in 2014)
– SECCHI Sun-Earth Connection Coronal and Heliospheric Investigation, part of STEREO
EUVI Extreme UltraViolet Imager
COR1 Inner Coronograph
COR2 Outer Coronograph
HI Heliospheric Imager
– SWAVES STEREO WAVES, tracks bursts of radio waves, part of STEREO
– IMPACT In-situ Measurements of Particles and CME transients. CME – Coronal Mass Ejection, part of STEREO
– PLASTIC Plasma and Suprathermal Ion Composition (protons, alpha particles, heavy ions), part of STEREO

surface properties
– GSIP GOES Surface Insolation Product
– DSR Downward Solar Radiation product, from MODIS on NASA Terra and Aqua satellites
– PAR Photosynthetically Active Radiation product from MODIS
– surface skin temperature infrared radiometers on GOES and polar orbiters
– GPS multipath measures surface moisture
– AMSR-E Advanced Scanning Microwave Radiometer (e.g. on NASA Aqua)
– SMOS Soil Moisture and Ocean Salinity, ESA
– SMAP Soil Moisture Active Passive (L-band radiometer + L-band radar on satellite)
– scatterometer
– SWOT Surface Water and Ocean Topography (satellite altimeter, Ka-band radar, microwave radiometer - NASA, launch in 2021)

temperature/humidity profiles
– MLS Microwave Limb Sounder, Aqua, NASA
– AMSU Advanced Microwave Sounding Unit (GOES)
– ATOVS Advanced TIROS Operational Vertical Sounder, NOAA-19, Metop-A, Metop-B
– Soumi NPP Soumi National Polar-orbiting Partnership
– FengYun 3 Chinese polar-orbiting satellite launched Sep 2013
– MWHTS - 15-channel microwave radiometer aboard FengYun 3
– FengYun 3D Chinese polar-orbiting satellite launched 14 Nov 2017
wind
– ALADIN Atmospheric LAser Doppler Instrument, Eolus Mission, ESA
– AMV Atmospheric Motion Vector
– ASCAT Advanced SCATterometer, Metop-B (ocean surface winds)
– DWL Doppler Wind Lidar
– CYGNSS) Cyclone Global Navigation Satellite System (NASA - sea-sfc winds from reflected GPS signals))

Counts for selected measured variables

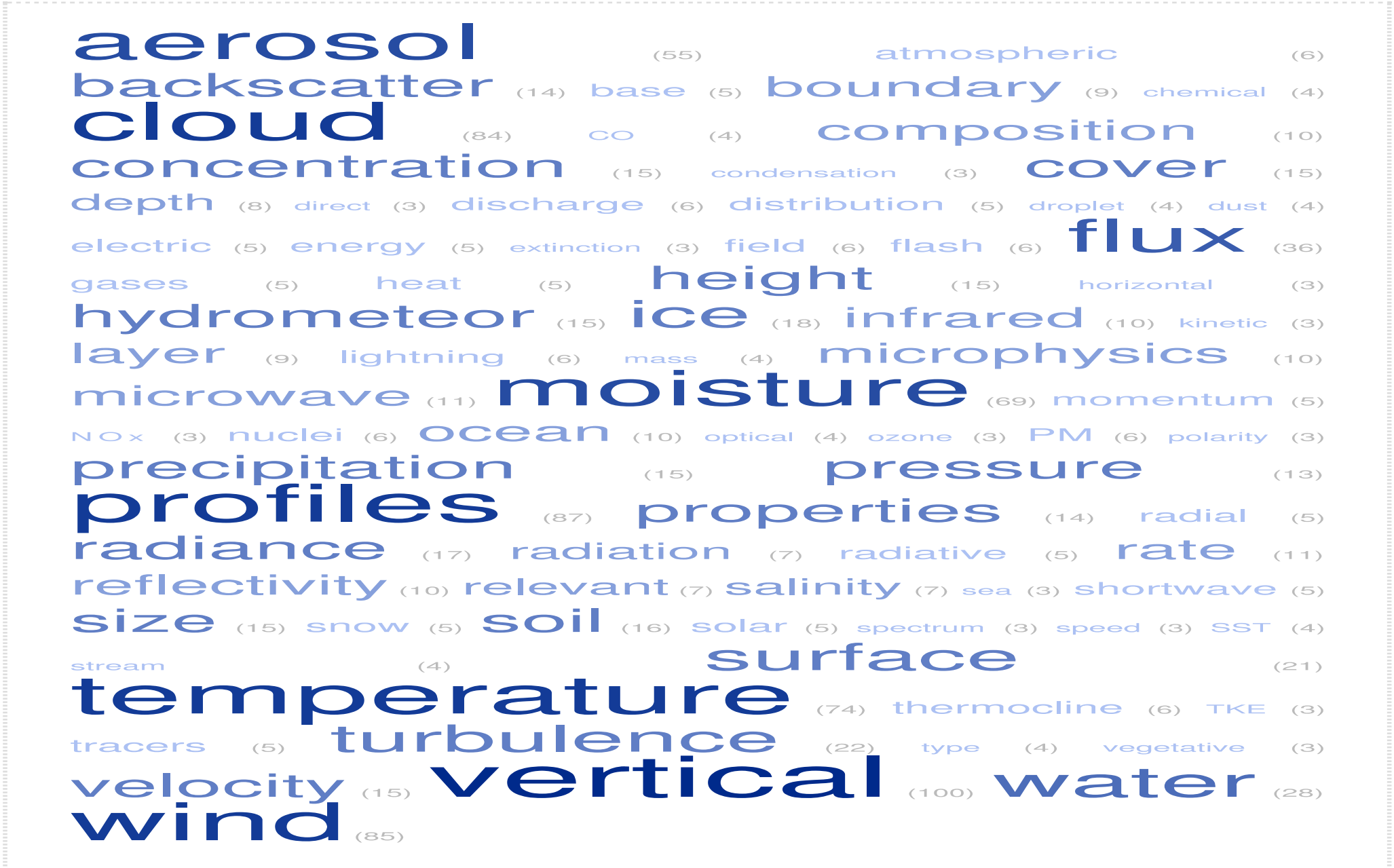


Note that the majority of the counts are for vertical profiles of these variables

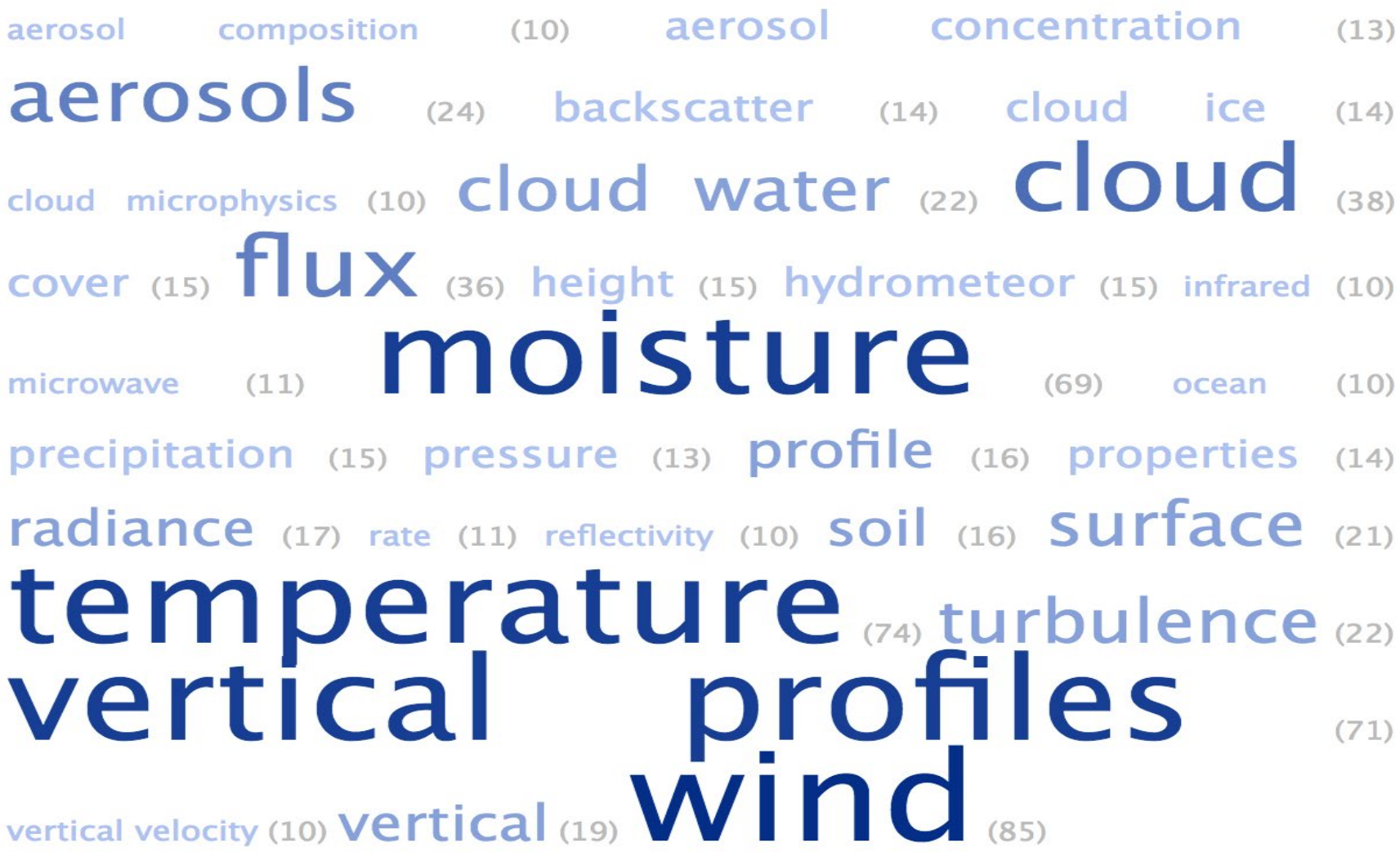
Word Clouds

- One way to display counts of common words in each column is to create word clouds
- One can display all of the words or just retain counts above certain numbers - here we will use limits of 3 and 10. [However, we have clouds that contain all the words, so nothing will be lost.]
- Word counts reveal winners of the popularity contest; - what about the new or leading edge technologies (with a count of 1 or 0) that may revolutionize observing in the future? We will try to create a list of those in the *BAMS* paper.
- Here are some sample word clouds:

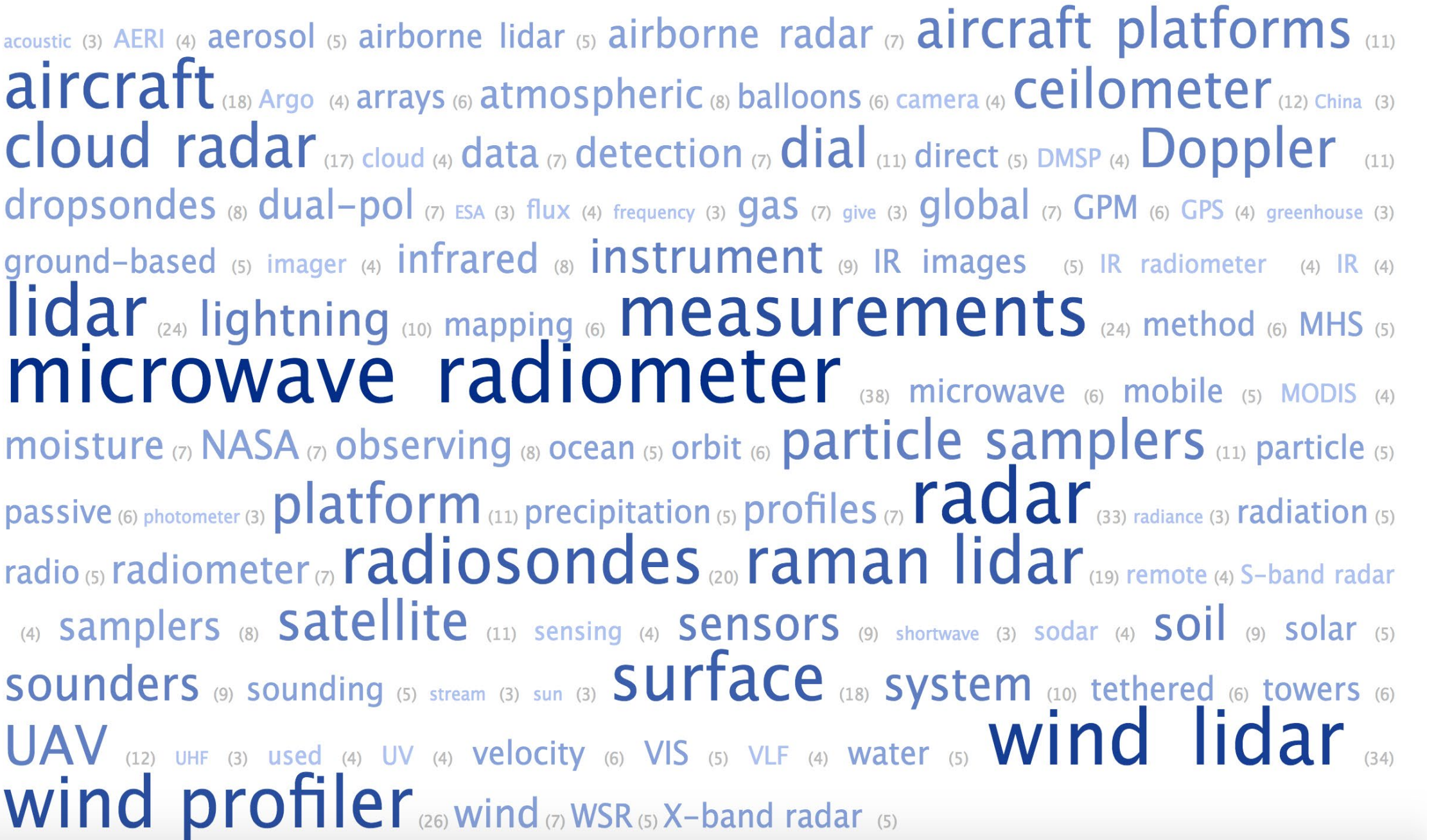
Measured Variables (counts 3 and above)



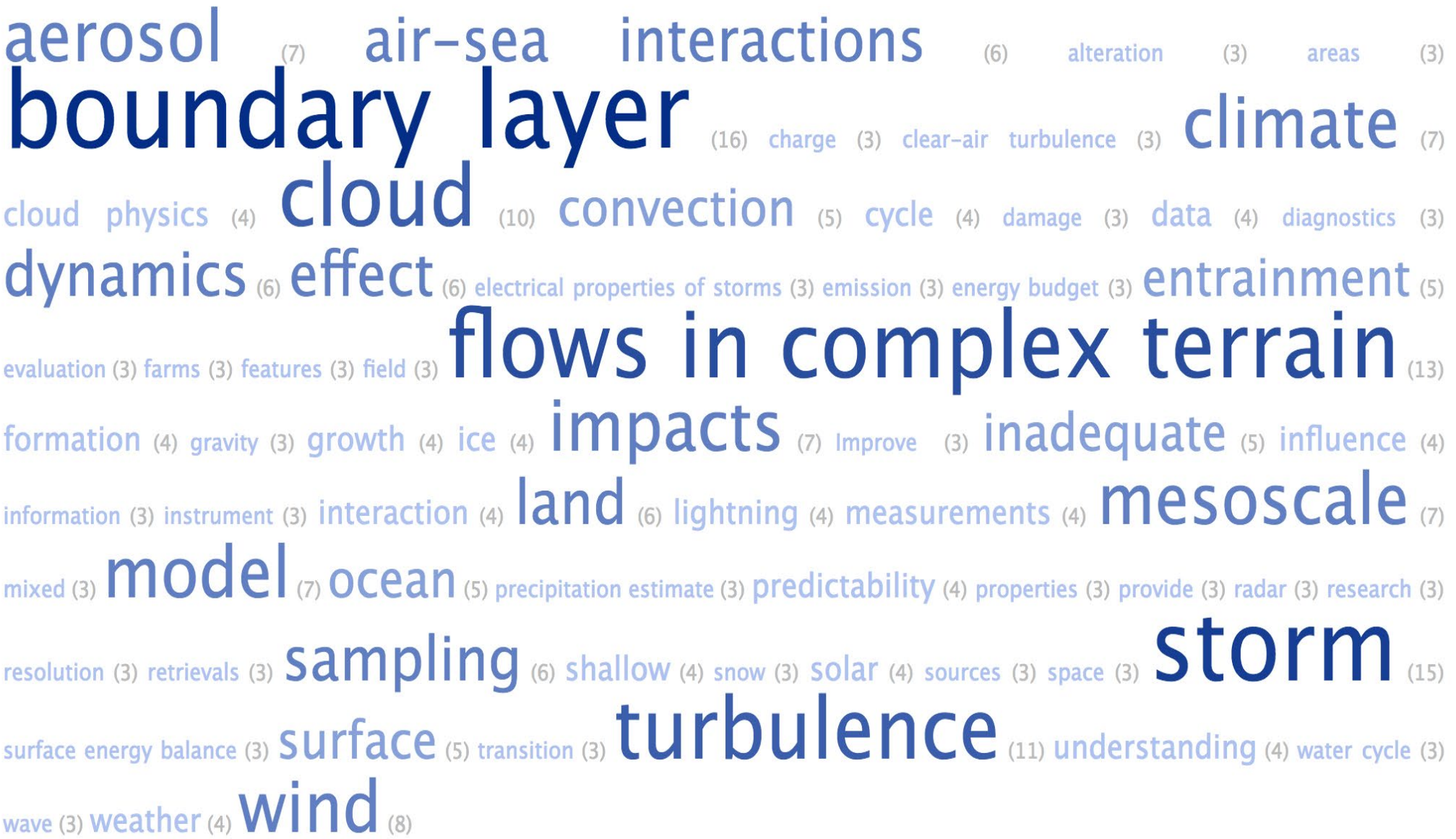
Measured Variables (10 and above)



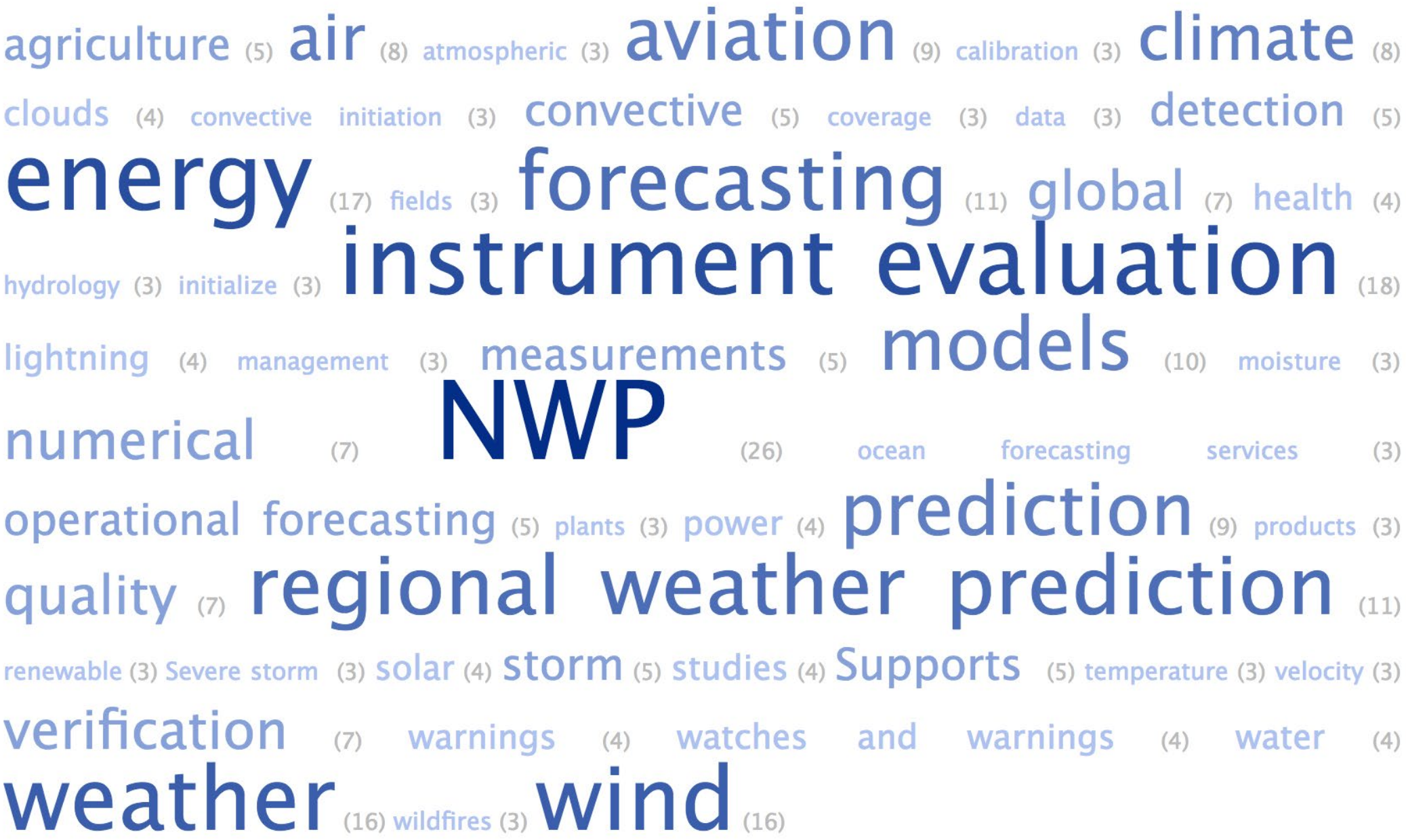
Instruments (counts 3 and above)



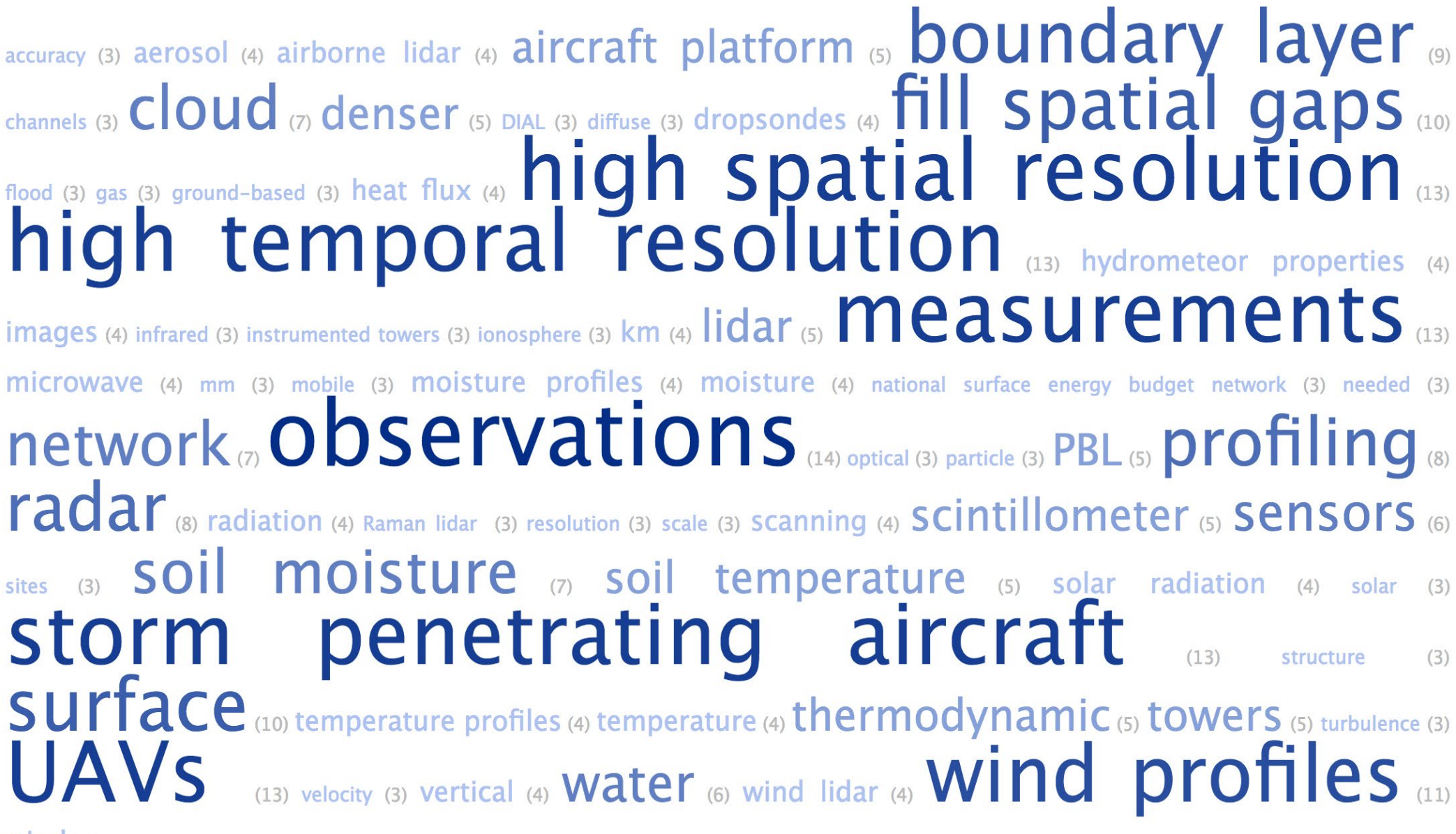
Scientific problem (3 or greater)



Applications (3 or greater)



Greatest Observation Needs (3 or greater)



Comments on Survey

- Breadth and complexity of observing enterprise is even larger than we anticipated. Will need to create broader categories to summarize all the information.
- Hope to finish summary by early 2020 - submit to *BAMS* in spring
- Will make use of published reports and review articles on observational needs in specific areas (such as the NASA Decadal Study; IOOS) (Welcome information on these)

Goal is to provide an update to the NAS "Network of Networks" report and begin dialog on how best to move forward on increasing observational capacity across the weather, water and climate enterprise.

WELCOME ALL SUGGESTIONS ON ORGANIZATION, HOW TO SUMMARIZE, WHO SHOULD RECEIVE THIS INFORMATION, ETC.

Comments on Role of UAS

- Many competing systems for low-troposphere in-situ or remote sensing
- E.g., automatic radiosonde systems, radiometers, AERI, wind lidars, water vapor DIAL, wind profilers, sodars, ……. and UAS
- Pros and cons with each system w.r.t. cost, spatial and temporal resolution, reliability, siting constraints, deployment restrictions, accuracy, maintenance, performance in clouds and precipitation, etc.
- Two primary goals of observing systems:
  - Understanding the structure of and processes occurring in the atmosphere (often obtained from field experiments/programs)
  - Providing initial conditions for analyses and forecasts (here, need sustained operational network; e.g., for UAS: "3D Mesonet"

Comments on Role of UAS (cont.)

- Observing System Simulation Experiments (OSSEs) can be used to assess relative merits of each system or combination of systems for either of these two objectives
- OU SoM/CAPS using OSSEs to assess value of UAS to storm-scale weather prediction (Brewster talk)
- What needs to be done is to perform OSSEs with UAS and all other potential PBL observing systems to assess relative merits of each, and to see what combinations of observing systems work best
- When UAS (and other) observations become available, then OSE studies can be performed to validate the OSSEs

Comments on Role of UAS (cont.)

- When UAS (and other) data are used in Numerical Weather Prediction systems that use 4DVar or EnKF data assimilation, we can assess their value via Forecast Sensitivity to Observations (FSO) or EFSO if use EnKF DA.
- **This work should inform national decision making on the future U.S. observing system portfolio**
- **Thus, need programs to deploy candidate observing systems (e.g. autonomous UAS - 3D-Mesonet) so optimal observing mix experiments can begin.**

Thank You

Extra Slides

Observations Most Needed

- Air pollution
  - satellite measurements at high spatial resolution to detect weaker emission sources; higher temporal resolution to detect diurnal variations in emissions and transport
  - multispectral measurements with multi-angle polarization to detect aerosol microphysical properties
  - vertical profiles of pollutants
  - Improve inventory of emission sources from coal and gas power generation and other industries; from agriculture and land use; from natural sources.
- Vertical wind profiles, worldwide (Doppler Wind Lidars)
- Exploit Geostationary Lightning Mapper
- Denser mesoscale observations in sparsely populated areas
- National network of solar observing sites measuring diffuse and direct solar radiation, upwelling and downwelling infrared radiation, aerosol optical depth
- Fill in large spatial gaps in observations of soil temperature and moisture; develop more stable and accurate moisture sensors.

Observations Most Needed (continued)

- Lightning: Expanded use of 3-D volumetric lightning mapping data over land; merge Geostationary Lightning Mapping data with land-based lightning data.
- Weather radar: Need better radar coverage close to the ground in the US; need enough Doppler radars to get two view angles of a given air volume.
- Need hyperspectral sounders on geosynchronous satellites (currently only on a few Low-Earth Orbiting satellites).
- Space weather
  - SOHO and STEREO missions near end-of-life. Need follow-on missions.
  - Sun observations needed at L5 Lagrange point
  - Need solar wind monitoring much closer to the sun than the L1 Lagrange point.
  - Better characterization of the space radiation environment especially during solar storms.
  - Denser observations of the ionosphere
- Boundary-layer: many more wind, temperature and moisture profiles

Observations Most Needed (continued)

- Hydrology
  - accurate long-term information on flood discharges
  - stream gages rapidly deployed in advance of an expected flood
  - observations river channel alterations
  - improved accuracy of water surface velocity sensors
  - bathymetric lidars
- Precipitation
  - W-band radar on satellites should be scanning, not just nadir look only.
  - Snow retrievals: additional passive microwave channels
  - Preserve satellite constellation and surface gauge networks.
- Oceans
  - Denser observations in tropics to better resolve intraseasonal variability and upper ocean structures
  - Major blind spot in Global Climate Observing System: seasonal sea-ice zone
  - More observations along western boundary currents (high eddy activity)
  - Observations below 2000-m depth, especially in Southern Hemisphere
  - Biogeochemical sensors

Other Issues w.r.t. Obs Rec. Harvesting Summary

Should we consider:

- Cost
- Technical feasibility
- QC; coverage/resolution; accuracy; metadata
- Research needs vs operational NWP needs (converging?)
- Weather vs climate observing standards/variables
- Field programs necessary to make progress; long-term testbeds
- Information from sources outside AMS AM (answer is “Yes”)
- Great comments

Goal is to provide an update to the NAS “Network of Networks” report and begin dialog on how best to move forward on increasing observational capacity across the weather, water and climate enterprise