3.1 DEVELOPMENT OF AUTOMATED AVIATION WEATHER PRODUCTS FOR OCEANIC/REMOTE REGIONS: SCIENTIFIC AND PRACTICAL CHALLENGES, RESEARCH STRATEGIES, AND FIRST STEPS

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1. INTRODUCTION

From the common and recognizable occurrence of convection, to the sporadic and far less visible reach of volcanic ash, meteorological phenomena impose diverse challenges to the efficiency, economic viability, and safety of flight operations across the global oceans. Those challenges are compounded by special difficulties associated with nowcasting and forecasting for remote areas, such as expansive voids in surface observations and soundings, large forecast domains, communications difficulties, and long-duration flights often needing significant forecast updates. Conspicuously lacking over oceans are the observational capabilities that provide key information about the internal structure of convection – notably radar and lightning detection systems.

The long-term oceanic weather development program (OW) outlined here seeks to use improved understanding of the phenomenology of oceanic weather hazards along with new observations, model information and processing tools to fashion automated forecast/briefing products supporting remote oceanic routes. A parallel OW objective (outlined by Lindholm and Burns, 2002, this conference volume) supports in-flight product transfer to the cockpit.

Established in March, 2001, the OW program is still in its infancy. Thus, we concentrate here upon strategy and the scientific basis for our plans. Although our work has begun with a focus on low and middle latitudes (Pacific, Atlantic and Gulf of Mexico regions), increasing use of polar routes is likely to raise the priority for products tailored to high latitude regions over the next several years.

2. DEVELOPMENT STRATEGY OVERVIEW

OW products are targeted for use directly by the pilot, dispatcher, controller, and other end-user. Since automation is key to enabling frequent product updates and round the clock operation, our work relies upon *(i)* expert system techniques to conditionally manipulate data inputs and manage functional interactions among them, and *(ii)* fuzzy logic techniques to formulate a consensus product (*e.g.*, diagnosis, nowcast or forecast), generally based upon the selective merging of individual data and product sub-elements. Three of our primary thrusts (products addressing hazards associated with deep convection, turbulence, and volcanic ash) are outlined below.

3. DEEP CONVECTION OVER THE OCEANS

Although deep convection over the oceans is typically less energetic (and thus less hazardous) than that over land (LeMone and Zipser, 1980; Jorgensen and LeMone, 1989), the practical need for avoidance of maritime convection remains strong due to hazards associated with turbulence, lightning, icing, and even hail. While icing and hail are quite local to the cloudy area, turbulence and lightning may affect an ill-defined region up to tens of km from the feature itself. None of these hazards can be reliably assessed by visual inspection or by satellite observations alone, which lack information about internal cloud conditions. Thus, distinguishing between benign and hazardous convection over the oceans in real time is extremely difficult to do – both for the operational meteorologist (who has a variety of data sources to consider) and for the on-site pilot.

3.1 *Convection Products*

The OW development plan for deep convection (summarized in conceptual form in Fig. 1) targets the products and capabilities outlined below.

First: An automated real-time display of cloud top height (CTH) serving as a first-order indicator of the presence of deep convection. The selection of cloud top height as a meaningful indicator of aviation hazard over oceans is based on decades of research experience with continental convection. On average, the deeper the cloud, the stronger is its updraft (Williams, 1985), the greater its lightning flash rate (Williams, 2001), and the higher the probability for severe weather (Darrah, 1978).

A test-phase CTH display is shown in this conference volume in Figs. 1 and 2 of Lindholm and Burns (2002), and is available as an exploratory prototype product for the Pacific and Gulf of Mexico regions at: www.rap.ucar.edu/projects/owpdt/realtime_systems.html

OW's CTH product is derived via three steps: *(i)* Cloud top temperature is obtained from IR satellite measurements; *(ii)* The cloud top temperature is converted to cloud top pressure through use of model-produced local temperature/pressure soundings; *(iii)* Finally, cloud top pressure is converted to cockpit-equivalent pressure altitude through application of the standard atmosphere sounding utilized in aircraft altimeters.

The use of model-derived soundings in step (*ii*) follows from product development carried out at the Naval Research Laboratory (Monterey), where model soundings supplied by the Naval Operational Global Atmospheric Prediction System (NOGAPS) were used. With the product now transitioned to trials in a quasi-operational configuration, sounding data is taken from the NCEP/AVN.

Second: An automated *convective diagnosis* product to identify and display regions of convection embedded in widespread cloud systems. The diagnosis product will

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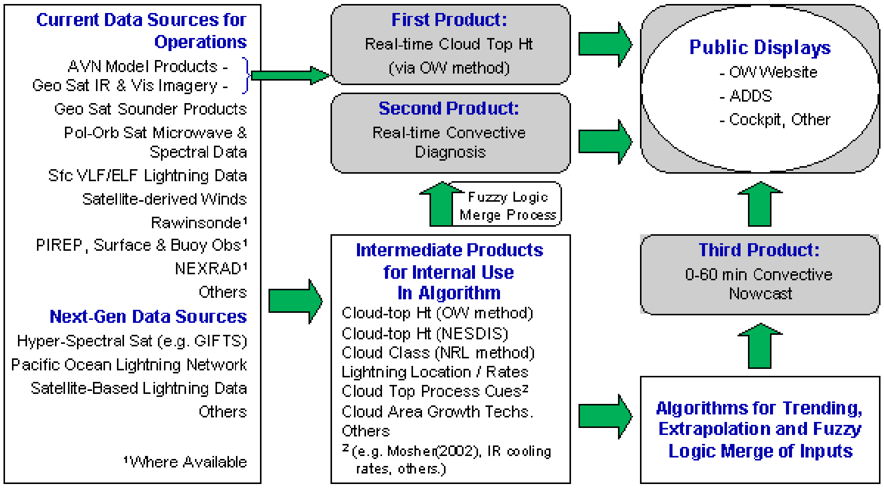

Figure 1. *Schematic flow of data and processing steps associated with planned oceanic convection products. Overall flow is left to right, beginning with source data in the left column, through intermediate processing steps, finally yielding the operational displays at upper right. The ADDS website cited supports meteorological data for aviation and is found at http://adds.aviationweather.noaa.gov/projects/adds/.*

include an indication of the severity of convection to aid in distinguishing hazardous from benign systems. Diverse data inputs and component algorithms are conceptually represented in Fig. 1. We plan first implementation of an exploratory in-house demonstration product by September, 2002. This should transition to a more robust test-phase prototype product supporting web access displays in FY 03.

Third: An *automated 0-1 h nowcast of convection* using tracking, extrapolation and other techniques. The product will target capability to represent change in position, size and strength of convection. Nowcast development may later target a 0-2 h forecast period. See Fig. 1 for conceptual representation of nowcast product generation. Nowcast work in FY03 will center around an in-house, exploratory prototype product.

Ultimately: An improved methodology for *automated forecasts from 1 to 6 h* (and perhaps eventually to 12 h). This long-term goal is conceived to blend model forecast results with observations-based heuristics and human forecast rules. Very much in the conceptual stage today, we consider this forecast product a prospect for development in the 3-6 year timeframe.

For simplicity, we discuss products relating to convectively-induced turbulence in Section 4.

3.2 *Convection R & D*

Our research and development work related to convection focuses on a limited number of issues critical to product development. We briefly summarize a sampling of these below.

Phenomenology:

- Climatology and diagnosis of the land-ocean lightning difference in tropical and sub-tropical convective clouds. Thunderstorms over land and ocean are widely regarded as hazardous to aviation, but they are presently not readily identified in satellite vis/IR imagery alone. Williams and Stanfill (2002) bring improved understanding of the physical basis for the reduced occurrence of lightning over the oceans relative to that over land. These and further results will enable better use of lightning data over the oceans to help diagnose the physical characteristics of electrified maritime clouds.

  This work utilizes the NASA TRMM (Tropical Rainfal Measuring Mission) satellite-borne Lightning Imaging Sensor (LIS) and coincident ELF ground-based global sensing of total lightning. Early results will be available at the time of the conference.
- Diagnosis of electrified vs. non-electrified convective clouds over the oceans. This planned work will further explore the physical differences between electrified and non-electrified oceanic clouds with intent to link (where possible) these differences and related indicators of convective strength to observables derived from visible and IR satellite imagery, including the CTH product. The availability of the TRMM precipitation radar over the oceans is a particularly valuable tool for these studies as these radar data provide access to the internal structure of oceanic convection.

Observing / Analysis Techniques – especially those targeting use of satellite observations and NCEP/AVN global model results over remote regions:

- Interpretation of visible, IR and passive microwave satellite observations as they relate to storm characteristics (*e.g.*, structure, circulation, lifecycle, etc.), atmospheric stability, 4D wind field, and other characteristics.
- Interpretation of lightning data in the diagnosis of maritime convection. Lightning occurrence provides informative cues related to updraft strength, cloud top height, and hydrometeor phase. Interpretation here (and as augmented through our phenomenology results) is thus one key to distinguishing hazaous/benign oceanic convection.
- Use of correlation tracking of satellite vis/IR imagery, and use of local derivative analysis to reveal regions of convective hazard embedded in more benign cloud.
- Use of expert system techniques to automate real-time

interpretations such as those outlined above.

- Use of multi-spectral satellite data in algorithms such as that by Mosher (2002) and others to diagnose active convection.
- Use of automated (expert system) cloud classification techniques as an extension to the work of Tag *et al*. (2000) to distinguish among stratiform regions, shallow and deep convection, etc.

Nowcast / Forecast Techniques:

- Use of tracking, trending and extrapolation techniques to derive 0-1 h nowcasts.
- 3-6 years in the future – fuzzy logic integration of 1-12 h forecast elements drawn from nowcast results, expert system-based forecast rules and numerical model forecasts.

Product Integration / Synthesis:

- Engineering associated with timely data access, product generation, and dissemination.
- Fuzzy logic integration of product elements (*e.g.*, estimators of convective strength, cues to distinguish convection from stratiform cloud, etc.) according to component weighting, which is based upon static and dynamic measures of component skill and confidence.

Verification Techniques:

- Establish a strategy for objective verification of product performance relative to independent measures of derived fields. Our first priority will be verification of the cloud top height product. Likely verification data for use in this work include CLOUDSAT satellite radar, AIREPS, soundings, the independent GOES sounder cloud top product, and surface radar observations when available.

4. TURBULENCE

Operational forecast products do not explicitly target turbulence hazards for oceanic routes. Thus, pilots rely upon AIREPS, SIGMETS and their own observations to guide their avoidance of turbulence hazards. Experience-based practices and procedures outline valuable flight guidelines for avoidance, specifying standoff ranges to skirt convection, for example. More explicit nowcasts and forecasts of turbulence hazards would significantly aid avoidance.

The challenges to the detection and forecasting of turbulence are formidable. The phenomenon itself is typically ephemeral, and is thus difficult to reliably observe and report (Ferris, 1999). The spatial/temporal resolution of operational regional or global forecast models is marginal at best in ability to capture needed small-scale (0.5-10 km) features related to turbulence generation and location. The small-scale nature of turbulence phenomenology similarly limits our ability to acquire wind field and stability measures on the scales needed to represent turbulence potential explicitly.

4.1 Turbulence Products

Our strategy is to leverage the work of the FAA/AWRP Turbulence Product Development Team (PDT), which has developed the Integrated Turbulence Forcasting Algorithm (ITFA) for clear air turbulence (CAT) at altitudes greater than 20,000 ft. ITFA is described in this volume by Sharman *et al.* (2002). Thus, while initial OW capability will be oriented toward CAT associated with the jet stream and upper-level fronts, subsequent development of an oceanic ITFA will seek to address the occurrence of convectively-induced turbulence (CIT) as well.

Planned turbulence products are outlined conceptually in Fig. 2 and address diagnosis, nowcast and 1-12 h forecast needs. These will likely be implemented first in the North Atlantic region, where climatology work (see below) indicates a substantial rate of moderate or greater turbulence AIREPS.

4.2 *Turbulence R & D*

Research and development work related to an operational turbulence product over oceanic regions is briefly outlined below.

Phenomenology:

- Climatology and inferred character of oceanic turbulence (CAT and CIT) as revealed by AIREPS over the Pacific, N. Atlantic and Gulf of Mexico. This work by B. Sharman has revealed markedly higher reporting rates of moderate or greater turbulence over the N. Atlantic and Gulf of Mexico compared to N., S. and equatorial Pacific regions. Both the N. Atlantic and Gulf of Mexico showed high reporting rates in the fall and winter, and lower rates (approximately half) in the spring and summer. Further results will be presented at the time of the conference.
- Further work by Sharman and Turbulence PDT collaborators is yielding an exploratory study of the propagation of convectively-induced gravity waves, believed to be a key cause of CIT. This work will support the development of predictors to be used for identifying conditions favorable for the generation and propagation of gravity waves.

Oceanic ITFA

- Implementation of an oceanic version of ITFA will provide initial OW functionality for turbulence analysis. The implementation will focus on selection of predictors and formulation of a fuzzy logic weighting scheme to yield best results (relative to AIREPS or other verification data) in a variety of conditions over the N. Atlantic.
- Extending ITFA to incorporate CIT. The initial implementation of CIT will follow a simplistic interpretation of hazard potential based upon the location and characteristics of convection (as indicated by the OW convective diagnosis). This CIT capability will become more robust as further research (in OW and elsewhere) better defines the physical mechanisms and conditions associated with CIT phenomena, including gravity waves and their breakdown into turbulence.

5. VOLCANIC ASH

The concentration of active volcanoes around continent/ocean margins and the significant safety and economic impacts of an aircraft encounter with an ash plume yield strong need to integrate volcanic ash advisory and warning information with other oceanic weather products. This problem spans a variety of issues (*e.g.*, observer and satellite detection of ash, determination of plume horizontal and vertical extent and characteristics; quantifying the hazard severity of ash plumes; forecasting plume position and characteristics; others).

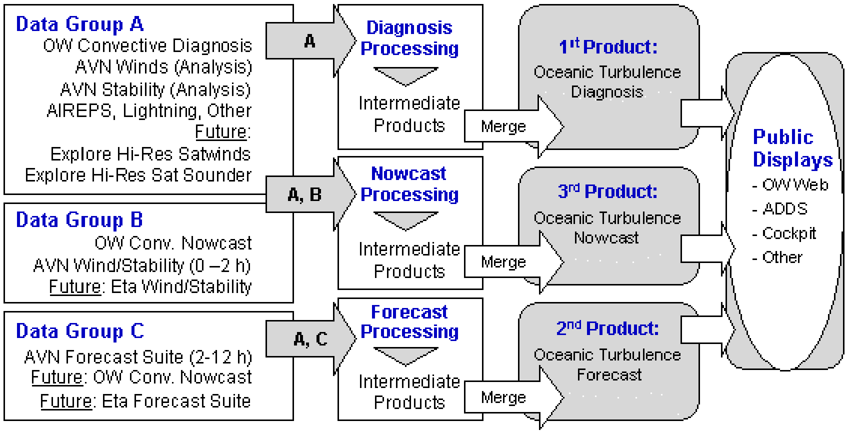

Figure 2. *Schematic view of data flow and processing steps for planned oceanic turbulence products.*

The OW program is currently in the early stages of effort to explore the best ways to support and extend the volcanic ash advisory/warning activities undertaken by the global network of nine ICAO-sanctioned Volcanic Ash Advisory Centers (VAACs). Ongoing and planned efforts are outlined below.

Near-Term (~ 1yr) Objectives

- Concept development (to begin) with the Washington and Anchorage VAACs, associated operational watch offices in Anchorage and Kansas City, and airline operators to outline best paths to integrate existing OW capabilities to augment and extend current ash detection, warning and dissemination activities.
- Development of automated tools to ingest and decode current ash advisories and SIGMETS, represent these graphically, and broaden their availability and distribution through inclusion as a first-generation web-based OW volcanic ash warning product.
- Research existing techniques for plume satellite detection, tracking, height determination and model/obs-based forecasting of plume dispersion. Facilitate partnership/collaboration among groups able to contribute to next-generation capabilities.
- Explore the viability of techniques for improved real-time distribution of products for plume warning/alert to the cockpit, in parallel with other OW weather products.

Longer-Term Objectives

- Explore the development of tools to enhance the automation of existing techniques for ash plume detection, tracking and characterization.
- Explore the viability of a next-generation plume forecast technique that utilizes real-time observations and trends related to plume extent/characteristics in a high-resolution numerical model that accommodates dispersion, scavenging and sedimentation.

6. SUMMARY

This first-year work of the Oceanic Weather PDT defines strategies for development of automated products to inform and alert pilots, dispatchers, controllers and others of oceanic weather hazards associated with deep convection, turbulence and volcanic ash. Additional work (not reported here) will deal with development of high-resolution satellite-derived 4D wind field products tailored for use in flight planning, convective nowcasting, volcanic ash trajectory prediction and other applications. While our work begins at low and mid-latitudes in the Atlantic, Pacific and Gulf of Mexico, we anticipate subsequent development at higher latitudes to support polar routes. The current exploratory product of the PDT and related project material is available at

www.rap.ucar.edu/projects/owpdt/realtime_systems.html.

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