Collaborative decision making in METOC

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Abstract:

Reducing the time spent to generate accurate weather forecasts will produce significant value for Naval forces (Ballas, 2001). Forecasters rely on deterministic models (Palmer, 2000), a problem when forecast uncertainty increases. This solution bias is less of a concern during fair weather. But as weather warnings increase, collaboration has been found to counter solution bias to improve weather forecasts and air traffic flow for commercial carriers (Nadler, 2000). Naval forces collaborate over weather products, too, but often *ad hoc*. This research addresses the value of collaboration for weather forecasts in the fleet and social computational models to improve collaboration.

Background:

Traditional artificial intelligence (AI), game, or social learning theories offer little practical guidance to improve collaboration. Rational theories, constructed and applied from an individual perspective (Luce & Raiffa, 1967), have been unable to predict decision-making outcomes (e.g., Klein, 1999). While many scientific facts have been discovered for both individual and group processes, such as cooperation (Axelrod, 1984), bargaining, and non-cooperation (Nash, 1950, 1951), fitting these facts into a theory of individual and social processes remains the defining problem in social science (e.g., Allport, 1962). The problem has been attributed to the difference between individual and group observations (Levine & Moreland, 1998), to an interaction between perceived and actual behavior (Cook, 1994), and to finding that survey questions can be phrased to produce any desired effect (Eagly, & Chaiken, 1993).

Arguably, artificial intelligence is representative of the best of approaches in rational decision-making. However, the Naval Studies Board (NSB, 2000) concluded that methods developed in the field of artificial intelligence, including commonsense reasoning, non-monotonic logic, circumspection, algorithms used in neural networks, and extensions to Bayesian calculi, have largely failed to provide the understanding required to extract information from large data sets, to reason in the face of uncertainty and to fuse information from disparate sources. Regarding game theory, Simon (1996, p. 38) stated that its "most valuable contribution has been to show that rationality is effectively undefinable" for agents with unlimited computational capability. To overcome these limitations in the field at the individual level, weather forecasters must interpret model predictions to improve forecast accuracy (Palmer, 2000). From what little is known, forecasters visually extract information, *I*, from large, multiple data sets to construct qualitative models as they integrate *I* to brief aviators (Trafton et al., 2000, p. 827).

Even less is known about decision-making in groups, although it is common in democratic societies (Arrow, 1970). Yet the evidence for collaboration indicates that the end products of group decision-making in the field are superior (see Nadler, 1998, for weather products; Lawless, Castelao, & Ballas, 2000, for environmental remediation decisions). In the laboratory, group decision-making methods have been applied to artificial agents with majority (e.g., Lam & Suen,

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1997), consensus (Hannebauer, in Tessier et al., 2001), and cost-based collaboration rules planned for the reactive closed loop sensor-shooter of the next AEGIS upgrade (Laddaga, 1998).

The goal of individual rational logic is to produce a consensus, characterized by a lack of disagreement (Popper, 1992). Current perspectives of computational autonomy are built on a consensus view of a reality, *R*, that is stable. However, the evidence indicates that consensus decisions are too slow for multiple agent systems (Hannebauer, in Tessier et al., 2001), produce suboptimal decisions for humans (Lawless, Castelao, & Abubucker, 2000a), and generate conflict (Lawless et al., 2000b). After observing his operational system of artificial agents (Pynadath, Scerri & Tambe, 2001), Tambe concluded that computational autonomy is currently not feasible.

The traditional method in social science was derived from Campbell to establish construct validity based on a convergence of evidence from stable *R*. However, Campbell (1996) rejected his own method of data convergence before his death. He had argued that his method marginalized contradictory evidence. The lack of supporting evidence for consensus decision-making coupled with Campbell's rejection has opened the way for a view of bistable reality first put forth by Bohr (1955), which Von Neumann believed could overturn traditional rationality (Von Neumann & Morgenstern, 1953, p. 147-8). Bistability is difficult to understand because human meaning also relies on convergence (e.g., Anderson, 1993). But the value of a model is determined by its predictions, not its capability to explain (Hawking, in Penrose, 1997). Bohr's model accounts for the common presence of competition and disagreement in science, law, and between cultures. Further, by definition, autonomy precludes a shared view of *R*. We have concluded that adversarial collaboration as a competition of ideas is integral to how human groups process *I* to solve ill-defined problems (Lawless & Castelao, 2001).

The interaction produces interdependent *I* from the fundamental behaviors of action and observation. Consequently, any model of the interaction must account for complementary or bistable aspects of *R*, such as framing (Tversky & Kahneman, 1981). Measurements like self-reports lose significant *I* as behavior and self-interests interact (e.g., the reluctance of air traffic flow managers to disclose justifications for their decisions; in Nadler, 1998). Because humans can focus on only one bistable aspect of *R* at a time (Cacioppo, Berntson & Crites, 1996), beliefs in bistable *R* easily separate into incommensurable beliefs (e.g., Israeli-Palestinian), forming communication barriers. By breaking through barriers to produce shared imagery, collaboration facilitates the solution of problems (e.g., Trafton, Trickett, & Mintz, submitted). We have postulated that an interdependent tension between groups with opposing beliefs acts as an *I* processor that increases the likelihood of solving an ill-defined problem (Lawless et al., 2000b).

Given action, Δa, and observational uncertainty, ΔI (where $I = \sum_x p(x) \log_2 p(x)$, and $p(x)$ is the probability of state *x*), the interdependent uncertainty relation becomes

$$\Delta a \Delta I \approx c. \qquad (1)$$

As an inverse relationship, Equation (1) indicates that the maximum uncertainty in one factor occurs when the uncertainty in the other is at a minimum. Not knowing *c*, the quantum of social action, a solution for Equation (1) requires the use of boundary conditions: e.g., as $\Delta I \to 0$, $\Delta a \to \infty$ (e.g., ideology). Support came from an experiment with Air Force combat pilots. In this field study, air combat performance was found not to be associated with scores from a written examination of air combat maneuvers (Lawless, Castelao, & Ballas, 2000).

Reversing boundary conditions for Equation (1) leads to a counterintuitive prediction: as $\Delta I \to \infty$, $\Delta a \to 0$; i.e., the solution to ill-defined problems occurs by bringing incommensurable views together before neutral observers to *reduce* the certainty in each belief with a "competition of ideas", contradicting Nash (1950). This result occurs often in a democracy: courtroom conflict between adversarial interests, opposing viewpoints in scientific journals, and foils in the theater to illuminate the character of a "hero". From a field study, a comparison of environmental remediation decisions at the Department of Energy's Savannah River Site in South Carolina versus its Hanford Site in Washington, and the Citizen Advisory Boards at both sites, indicated that a competition of ideas between opposing viewpoints led to better environmental results than cooperation under consensus rules designed to promote a single worldview (Lawless, Castelao, & Ballas, 2000). This boundary condition suggests not only that orthogonal social operators (adversarial advocates) are fundamental mechanisms employed by social organisms to process *I* and make decisions (Tessier et al., 2000, p. 24-26), but also that computational Decision Centers (DC) may be progenitors of social autonomy (Lawless & Castelao, 2001).

The initial plan was to compare collaboration among METOC forecasters. Because of limited data available for METOC, the method expanded to include forecasting in commercial aviation.

Results:

1. METOC Collaboration data was collected from fleet exercises in July 1997 (Ballas, 2001). Six sessions were held of varying lengths and numbers of participants with both increasing in later sessions. Overall, an average of 74.3 messages were sent per session; the average number of weather statements were 10.7, with an average number of 5.3 shared agreements and 0.63 disagreements per session. However, there were no subjective or objective data collected to test the usefulness of collaboration in METOC.

2. Delays in commercial aviation due to weather are the most disruptive force in the National Airspace System. The Collaborative Convective Forecast Product (CCFP) seeks to reduce these disruptions with a more accurate forecast (FAA, 2001). It is generated four times a day beginning with the First Guess (FG) Forecast made by the Aviation Weather Center (AWC) with input from its own and participating airline meteorologists, Center Weather Service Units (CWSU), and staff at the FAA Air Traffic Control System Command Center (ATCSCC). Its goal is to create a common situational awareness of convective weather. It provides a timely review of weather activity, and traffic flow coordination during severe weather. The CCFP does not use consensus decision-making because of time constraints and the need for single accountability with weather related decisions. It begins when an FG forecast made by AWC meteorologists drawing upon numerical predictions is submitted to a web chat room for a 30 minute moderated discussion that, after incorporating feedback, ends with the generation of a final forecast graphic published on the web. If CCFP forecasts predict severe weather, playbooks are implemented to reroute air traffic. During its development, Nadler (1998) found substantial endorsement for the CCFP among participants. Based on 16 forecasts, 88.9% of respondents agreed or strongly agreed that forecasted convection areas were close to where convection actually occurred; 85.2% agreed or strongly agreed that the CCFP forecasts improved during the thunderstorm season; and 92.6% agreed or strongly agreed that the CCFP was a good planning tool.

3. In the next thunderstorm season, Browne, Phaneuf and Nestoros, (1999) reported that the CCFP was produced by an average of 15.16 collaboration participants (16.71 morning, 14.34 afternoon) through an average number of 19.63 messages (21.07 morning, 17.97 afternoon), resulting in an average of 6.46 CCFP iterations (6.58 morning, 5.97 afternoon). These products were generated with an average of 5.76 expressed agreements (6.16 morning, 5.06 afternoon), 9.21 default agreements (9.45 morning, 8.93 afternoon), and an average of 0.52 expressed disagreements (0.45 morning, 0.23 afternoon). The discussions averaged 49.83 minutes (47.58

morning, 53.45 afternoon). Over 57% of respondents agreed or strongly agreed that the CCFP was useful for planning purposes, and 79% agreed or strongly agreed that the CCFP was accurate.
4. Based on forecasts from 1 June to 31August 1999, a more objective test of the CCFP was conducted by the Forecast System Laboratory's (FSL) Real Time Verification System (RTVS). The RTVS data (Mahoney et al., 2000) are summarized in Table 1 below.

Table 1. In this table, better forecasts have a lower convective area covered by the forecast, a greater PODy, a lower FAR, and a Bias closer to one (bias greater than one over-predicts convection; less than one under-predicts). [SIGMET is significant meteorological information; NCWF is the automated computer generated numerical prediction; POD-y is the probability of a forecast being observed = Y(forecast)Y(observed)/(YY+NY); FAR is the false alarm ratio = YN/(YY+YN); and Bias is the tendency to over or under predict convection = (YY+YN)/(YY+NY).]

Product	Issued (UTC)	Forecast Length	Human/ Automated	Average % area covered by Forecast	Average PODy	FAR	Bias
CCFP	1500, 1900	1,3,5 and 3,5,7 h	H	5.2%	.28	.84	1.9
Convective SIGMET	Hourly	1,2 and 0-2 h	H	2.3%	.28	.70	1.0
SIGMET Outlook	Hourly	2-6 h and 6 h	H	14.9%	.04	.92	6.1
NCWF	5 min	1 and 2 h	A	0.5%	.09	.41	.10

5. FSL did not test whether commercial air traffic improved. From data published by the Department of Transportation (DOT, 2001) for May through July 2000 and 2001, flight delays improved approximately 6% (also, PBS, 2001).
6. CDM forecasts were not significantly different from the convective forecasts of individual experts; but as a trade-off for greater passenger comfort, collaborative forecasts provided larger safety margins than individual experts. However, a closer look found significant disagreement among successful collaborators in environmental remediation and virtually no disagreement among collaborative forecasters.
Conclusion.
The surveys demonstrated strong subjective support for CCFP products. Probably the comparatively larger areas reflected in the CCFP represented a preference by airline participants to avoid areas around thunderstorms (e.g., severe turbulence, icing, hail). However, the objective RTVS tests found that although the CCFP was much better than numerical models, which significantly underreported convection, both products pointed to the difficult nature of forecasting during unstable conditions (Palmer, 1999). In contrast to isolated convection, the more defined a line of thunderstorms or longer lived an individual storm, the easier it was to predict. In turn, RTVS overlooked the increased uncertainty that occurs for human users of automated systems (Helmreich, 1997). Thus, a better understanding of the automated products that were used by collaborators is reflected in greater endorsement and a subsequent improvement in on-time flight arrivals. However, one area for future exploration is the low levels of disagreement among

forecasters during collaboration. Because higher levels of disagreement improved the value of collaboration for environmental remediation decisions, a future study should analyze varying levels of disagreement during collaboration on METOC products.

Clearly the assumption that collaboration improves with cooperation is problematic (e.g., Axelrod, 1984). In our research, we have found that the best decision-making occurs in DC's which combine cooperation with a competition of ideas to solve problems. Instead of interference, information processing from adversarial collaboration produces shared views. But for collaboration to work, research must address the degree of agent reactivity sufficient to draw acceptable comparisons and to overcome the barriers of communication between agents and groups without promoting either "social loafing" or the conflict that breaks down communication.

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Individual Rationality = Sequential Interaction Uncertainty

- Classical Physics and Traditional Social Science based on **stable R**
- **Correspondence** between L concepts and physical objects in R
  - Game theory (VN&M, 1953)
  - Exchange theory (K&T, 1959; 1978)
  - Social learning theory (behaviorism+modeling; B,'71)
  - Polit. science (Marxism; central d.m.; consensus d.m.)
  - **Social measurement theory (x-validation; Campbell, 1959)**
  - Classical mechanics (Planck, 1905; EPR, 1935)
  - Machine learning (Brooks, 1990)
  - Truth is accessible to mind (Pinker, 1990)
- Emotion replaced w/rational constructs (e.g., game configurations)
  - The cost of emotion is an inefficient executive (Minsky, 2001)
- LP: convergence -> best decisions and agreement
- **H (LP): collaboration works best under cooperation**

Problems w/cooperation & CC's

- Hitler: sidelined superior AC + pilots
- Korea: Soviet "welded wing" GIC v. NATO "loose deuce" (Randall, 1997)
- After captains feigned incapacity, 25% of first officers failed to intervene (Foushee & Helmreich, 1988)
- Others: Shuttle explosion (1985); USS Vicennes & Iranian airbus (1989); AWACS authority to fire BVR, visual contact -> Sudanese airliner & later 2 Blackhawks down w/malfunctioning IFF (1994)

When cooperation works best

- For well-defined problems

When cooperation does not work

- Social loafing (Latane, 1981)
- Asymmetric *I* (e.g., deception: WTC 9/11; Enron -> $20 billion loss)
- Corruption (Lawless, 2001)

Benefits of Competition

	1	2	3	4	5	6	7
1. SW	1.0						
2. H	-.72**	1.0					
3. E	.73**	-.66**	1.0				
4. pc's	.93**	-.70**	.78**	1.0			
5. web	.61*	-.37	.74**	.71**	1.0		
6. EF	.88**	-.79**	.70**	.84**	.48	1.0	
7. CPI	.81**	-.72**	.73**	.89**	.60*	.82**	1.0

- **Competition incr. SW, H, EF, less corruption**
- Notes (CM: *E* use among nations; Lawless & Castelao, 2001):

SW Scientific Wealth (May, 1997, Science)
H Poor Health (infant mortality per 1000 births, World Bank)
E Energy consumption in Energy kg OE per capita, World Bank
pc's personal computers per 1,000 capita, World Bank
web Internet web hosts per 10,000 capita, World Bank
EF Economic Freedom, Cato Institute with Milton Friedman
CPI Corruption Perceptions Index, Transparency International

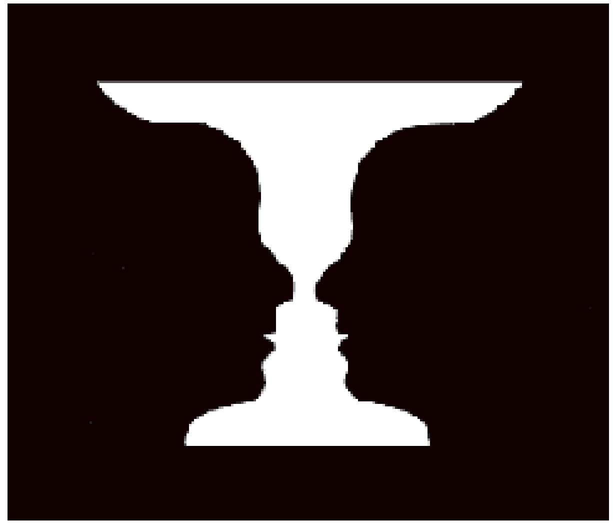
Competition => Bistable *R* + Conjugate Interaction *U*

Aeschylus (struggle -> wisdom; court -> justice)
Copernicus (the transformed perspective)
Descartes (mind-body split)
Newton (actual versus perceived inertia)
Bergson + James (perceived R ≠ experience)
Einstein (1909: wave-particle duality)
Heisenberg + Bohr (uncertainty in atomic χ's)
Bohr (uncertainty in social χ's = actor v spectator)
Lewin (1951: observed group a ≠ perceived group a)
Arrow (1951: rat individual preferencess ≠ rat group prefs)
Poincare (1952): Educ. => K is log. + organized ≠ discovery
Allport (1962: discontinuity betw individual and group)
Kahneman & Tversky (1981: frames of reference)
Kelley (1979: given matrix ≠ effective matrix)

Campbell (1996):

- **x-validation fails w/incommensurability**
- **=> multiple *R*'s**

Bistable Reality



1. **Multiple convergences => multiple cultures (Bohr, 1955)**
2. **Observers see faces (culture A) or vase (culture B), but not both simultaneously**
3. **Promotes disagreement during decision making**

Social Uncertainty Relations

- We are actors or spectators (Bohr, 1955)
- M's -> Convergence to reduce U ->
  + Ingroup-Outgroup U
- Let $\Delta a = \Delta I / \Delta t$ = action uncertainty;
- Let ΔI = information uncertainty;

$$\Delta a \Delta I \approx c \qquad (1)$$

Bistable R difficult to understand b/c meaning comes from convergence into mutually exclusive cultural belief A or B
(Lawless, 2001)

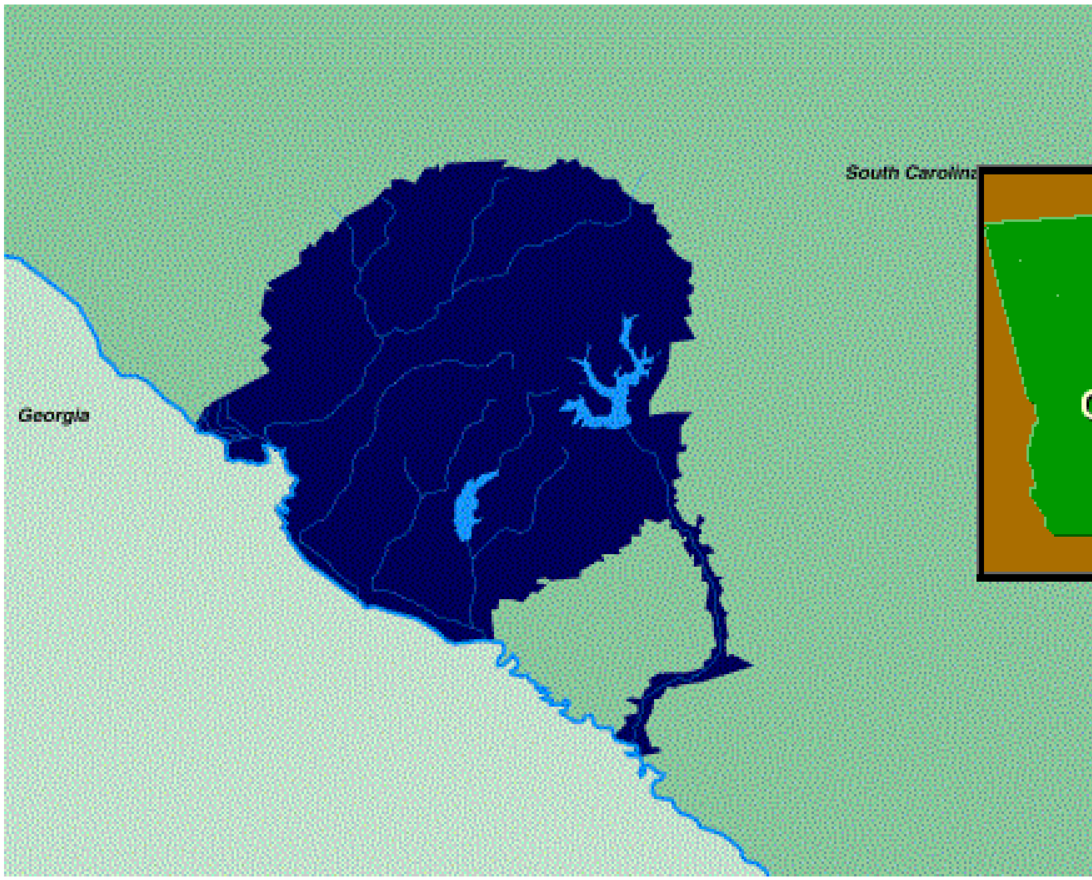
Solving $\Delta a \Delta I \approx c$

- Case i: ΔI -> 0 (K), Δa -> ∞
  - **USAF (*E* availability $\propto$ SME $\propto$ *B* $\neq$ *K*)**
  - Math (perc'd math skills $\propto$ S.E. $\neq$ math scores)
- Case ii: Δa -> 0, ΔI -> ∞
  - Logic underdetermines *R*; clusters of convergence $\approx$ incommensurable wv's + tension betw them at SRS CAB improved ER and nuclear waste mgt decisions (i.e., DC's):
    - **SRS CAB: maj. rule d.m. + min. rpts (Δa -> 0)**
      - » **SAB: + internal conflict, + mbr liking**
    - **HAB: consensus rule d.m. (ΔI -> 0)**
      - » **HAB: + external conflict, - mbr liking**
  - **National Airspace System**

Case i: ΔI -> 0, Δa -> ∞

- 125 USAF combat pilots in eight 3-min ACM encounters against machines and human. *K* of air combat = multiple-choice exam. Experience = flight-time histories + training.
- Multiple regressions => experience predicted wins-losses (R=.34, p<.03), total aircraft relative E availability (R=.37, p<.01), and expert rating of performance (R=.47, p<.0001).
- ***K*** **did not predict wins-losses,** ***E*** **availability, or expert ratings** (R=0.0, p n.s.). (Lawless et al., 2000a)

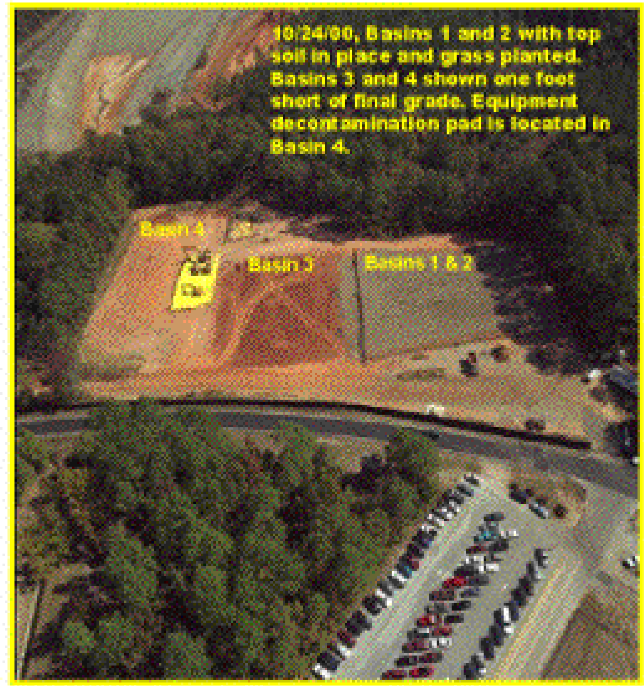
Case ii: $\Delta a \to 0$, $\Delta I \to \infty$



SRS along the Savannah River, Eastern USA

Contaminated Soils

Remediated



SRL basins before-after CAB (DC) saved 2 years on environmental cleanup -> plug-in-rods (i.e., *idp*'s -> *wdp*'s)

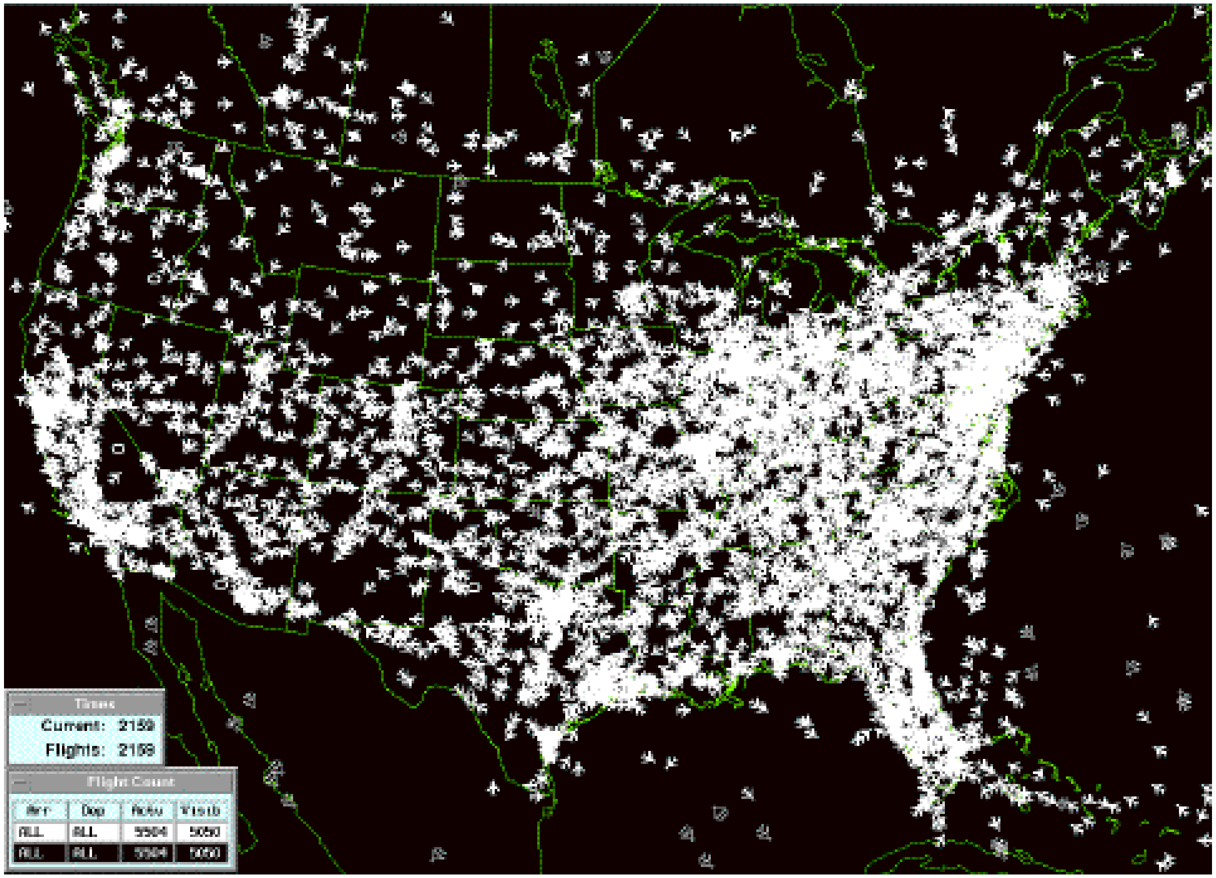
DWPF/GWSB

New Engineered Trenches

F&H and LLW-BG

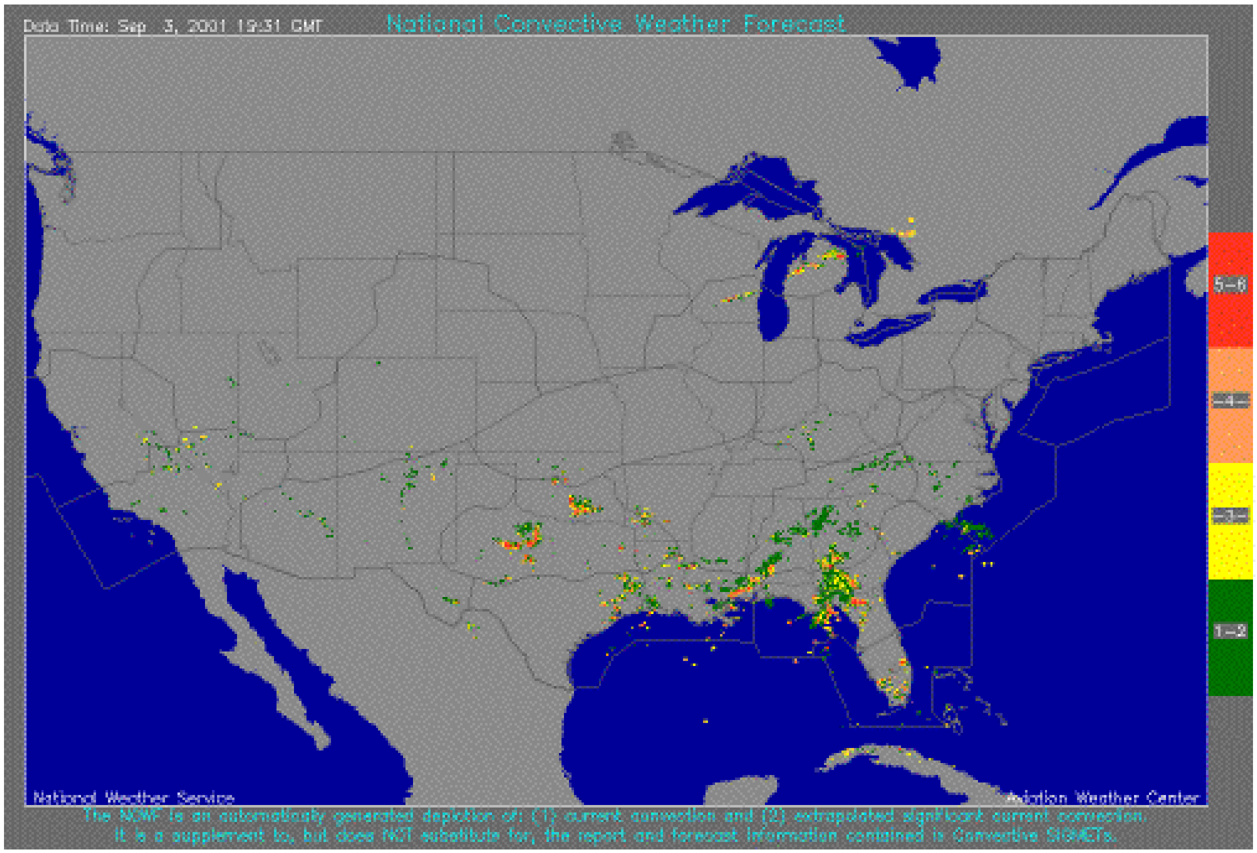
2 HLW tanks closed, 1200 cans (Lawless et al., 2000a)

Case ii: $\Delta a \to 0$, $\Delta l \to \infty$ (National Airspace System)

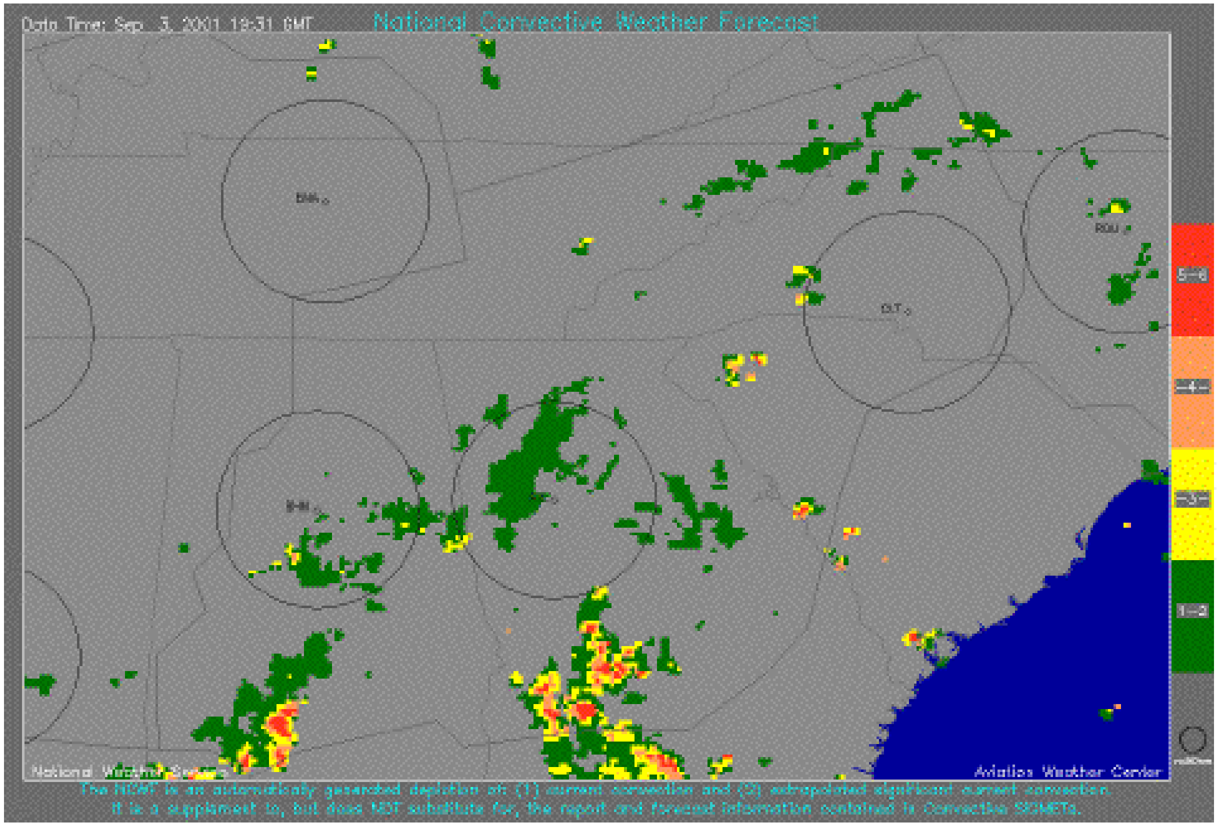


Convection Weather = Single most disruptive force within NAS

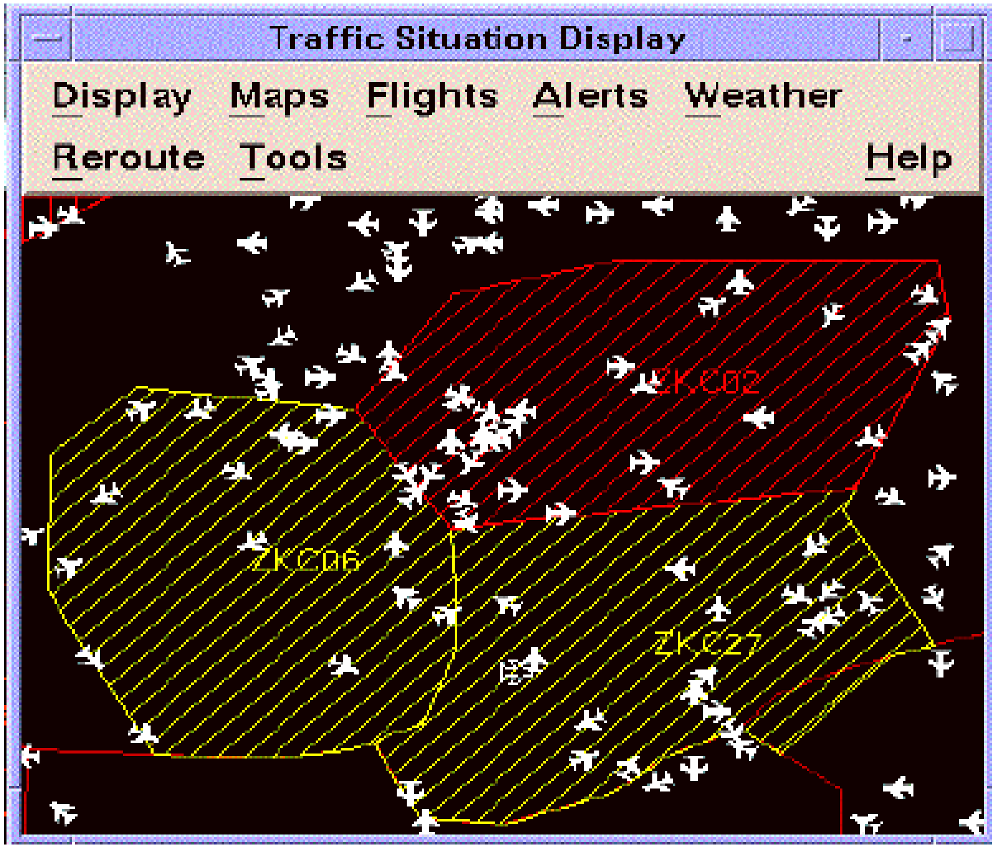
NCWF: Automated Forecast



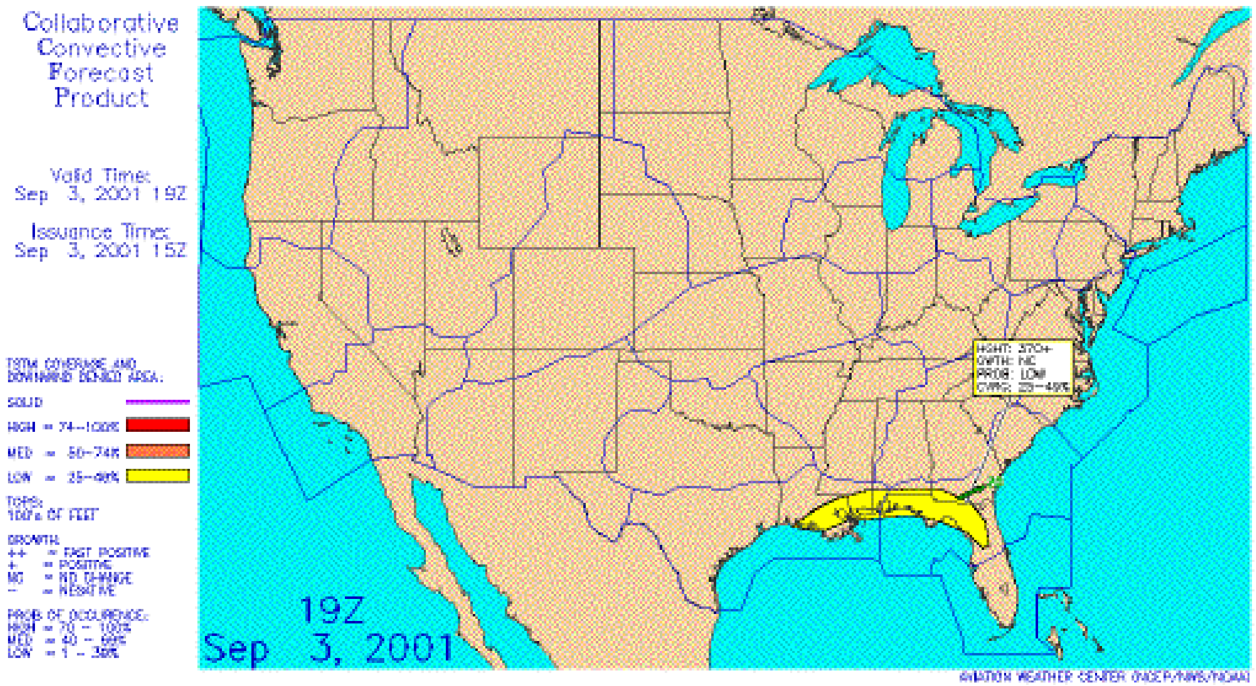
NCWF: Convective Cells



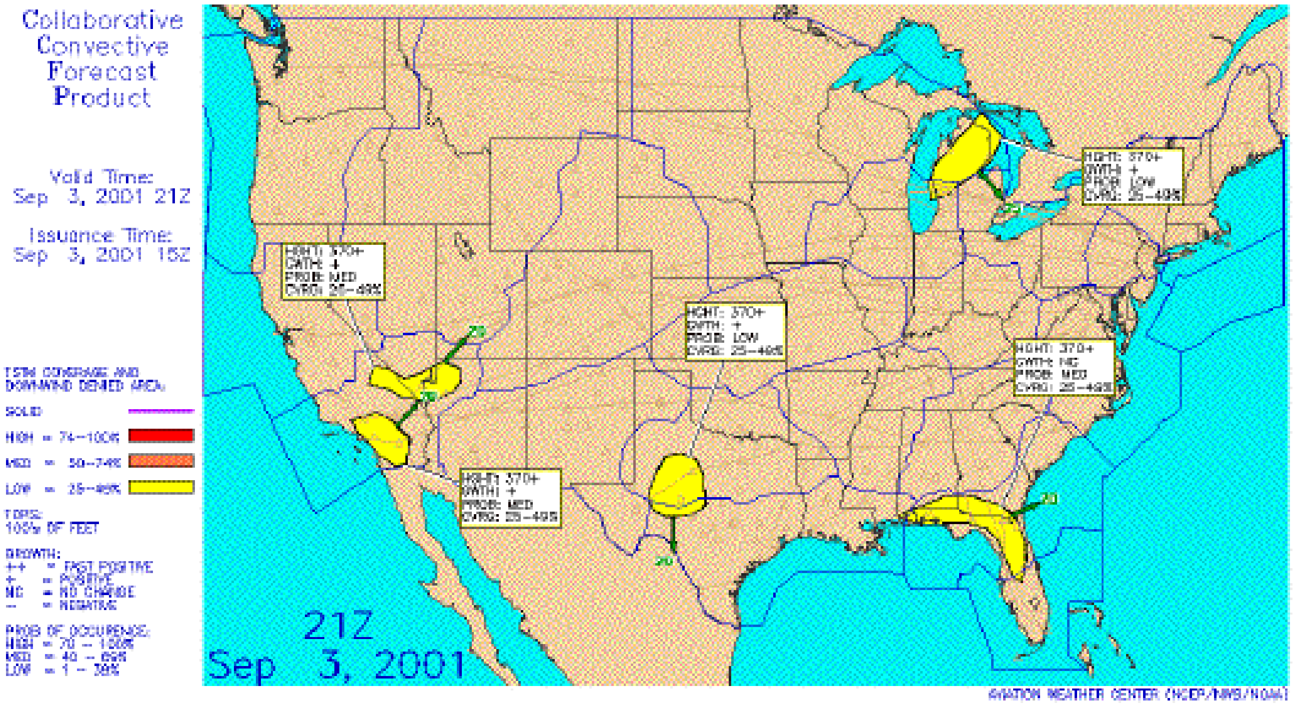
Traffic Situation Displays



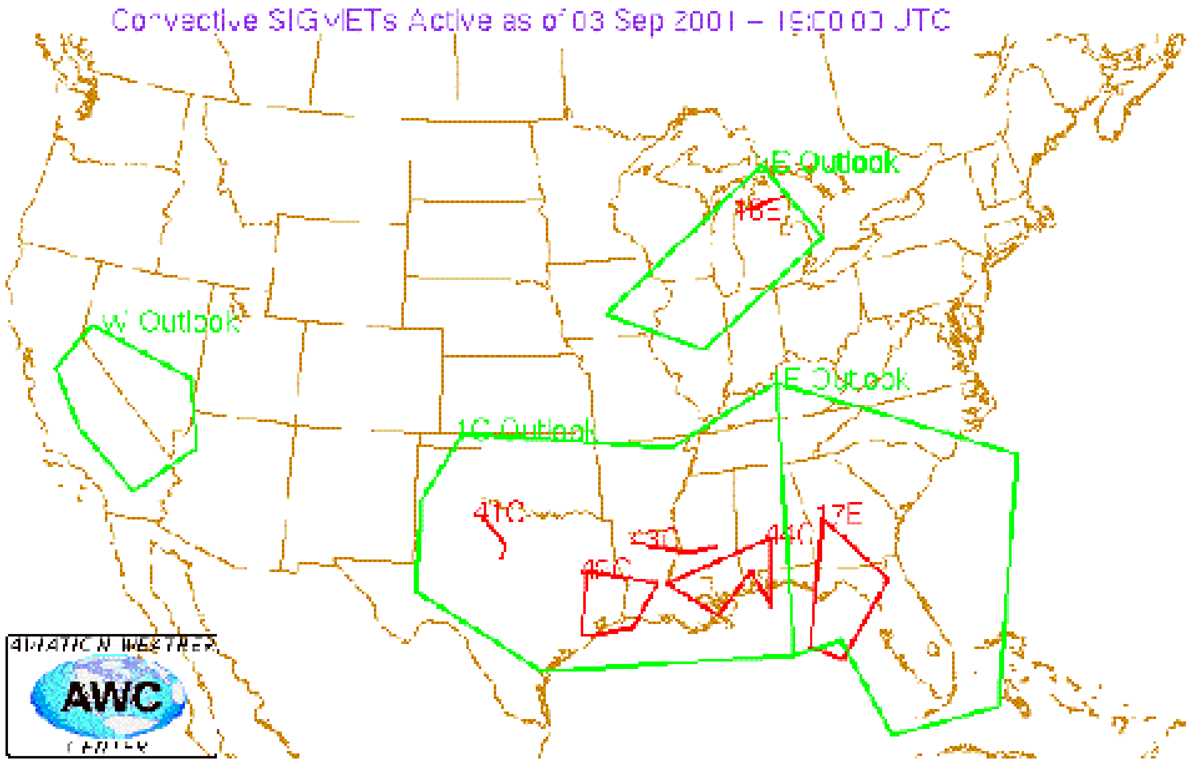
CCFP: 19Z, Sep 3, 2001



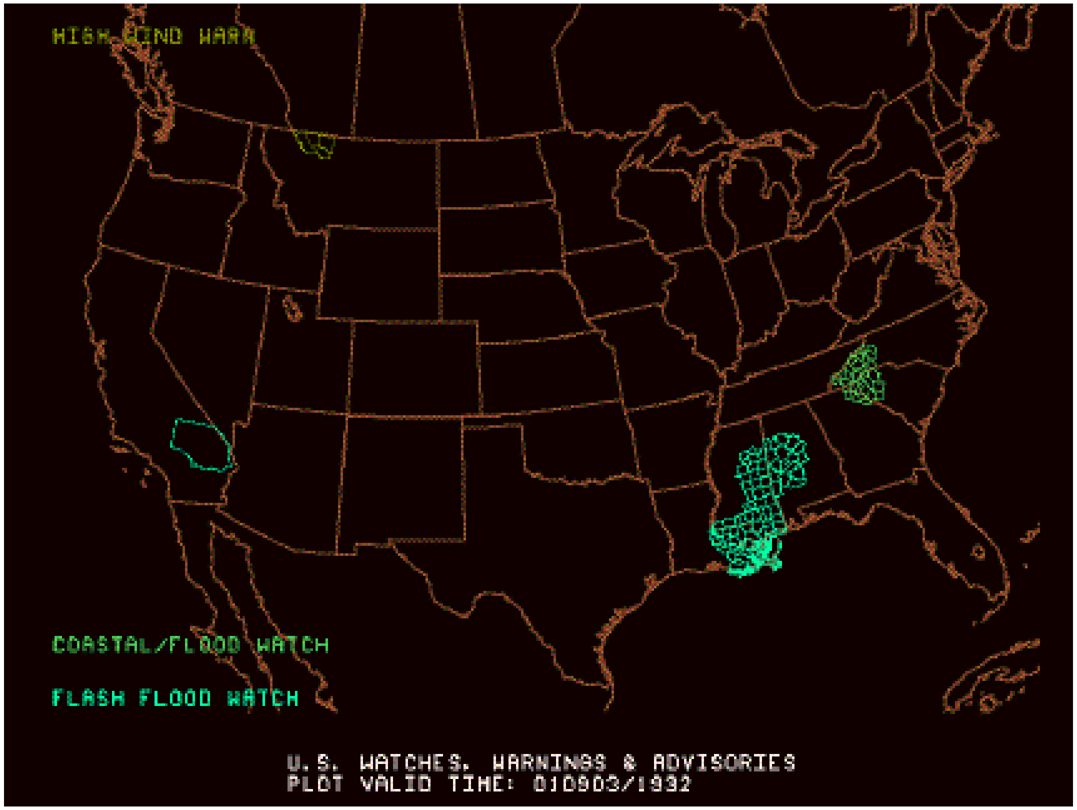
CCFP: 21Z, Sep 3, 2001



SIGMET Outlook (Convection)



Watches, Warnings, & Advisories



RTVS (FAA's FSL)

Product	Issued (UTC)	Forecast Length	Human/ Automated	Ave area Forecast covered	Average PODy	FAR	Bias
CCFP	1500, 1900	1,3,5 and 3,5,7 h	H	5.2%	.28	.84	1.9
Convective SIGMET	Hourly	1,2 and 0-2 h	H	2.3%	.28	.70	1.0
SIGMET Outlook	Hourly	2-6 h and 6 h	H	14.9%	.04	.92	6.1
NCWF	5 min	1 and 2 h	A	0.5%	.09	.41	.10

Table 1. In this table, better forecasts have a lower convective area covered by the forecast, a greater PODy, a lower FAR, and a Bias closer to one (bias greater than one over-predicts convection; less than one under-predicts). [SIGMET is significant meteorological information; NCWF is the automated computer generated numerical prediction; POD-y is the probability of a forecast being observed = Y(forecast)Y(observed)/(YY+NY); FAR is the false alarm ratio = YN/(YY+YN); and Bias is the tendency to over or under predict convection = (YY+YN)/(YY+NY).]

January 16, 2002

Results

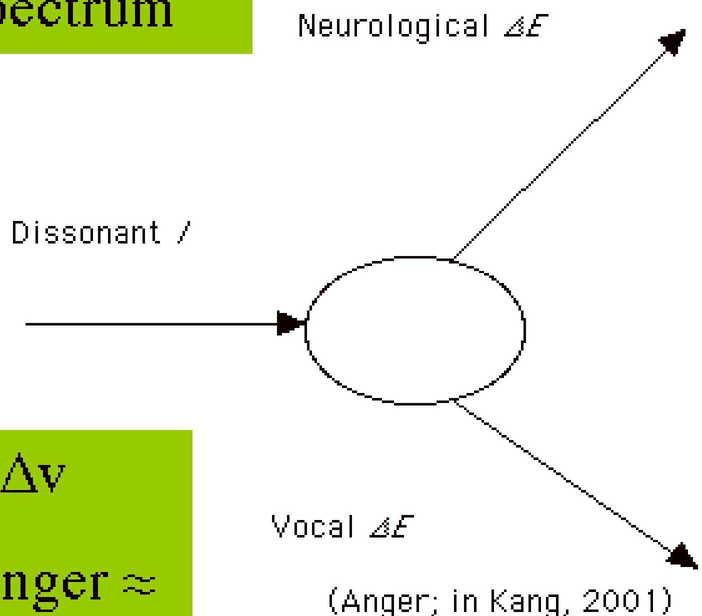
- METOC: 6 sessions at sea, 74.3 msgs, 10.7 wx, 5.3 shared agreements, 0.63 disagreements
- CCFP (1998): 88.9% believe accurate; 92.6% good tool
- CCFP (1999): 15.2 collaborations/product; 19.63 msgs; 6.5 iterations; 5.76 expressed agreements, 0.52 disagreements; 49.8 min sessions; 79% believe accurate;
- DOT (2000-2001): 6% improved ontime arrivals
- ER: sign. disagreement, quicker & better decisions, + liking (SAB v. HAB)

Collaboration Conclusions

- DC => bistable R => best d.m. from orthogonal operators (**"competition of ideas"**), multiple convergences, spontaneous consensuses, dissonance arousal sufficient to produce and process I
- Resonance tunnels thru social barriers (**"compromise"**)
- Converts *idp*'s to *wdp*'s ≈ K or technology
- Optimum: I_R = *f(1/(max emotional agitation that preserves cooperation - min competition that precludes social loafing))*

Future Research

Picard: Liquid model of Emotion -> Spectrum



$\Delta E \approx h * \Delta v$

(Hameroff: 2E6 Neurons ≈ 40 Hz, gamma)

$\Delta E \approx h * \Delta v$

(Kang: Anger ≈ + 100 Hz)

Additional Reading

Lawless, W.F. (2001). The quantum of social action and the function of emotion in decision-making, Emotional Agent II. The Tangled Knot of Cognition, AAAI Fall Symposium, Cape Cod, MA, November 2, 2001.

Lawless, W.F. & Castelao, T. (2001), The University as Decision Center, IEEE Technolgy and Society Magazine (special issue: University as Bridge Between Technology and Society), 20(2), 6-17.

Lawless, W.F., Castelao, T., & Abubucker, C.P. (2000), Conflict as a Heuristic in Development of Interaction Mechanics, In C. Tessier, H.J. Muller, & L. Chaudron, Conflicting agents: Conflict mgt in multi-agent systems, pp. 279-302, Boston: Kluwer).

Lawless, W.F., Castelao, T., & Ballas, J.A., (2000), Virtual knowledge: Bistable reality and solution of ill-defined problems, IEEE Systems, Man, & Cybernetics, 30(1), 119-124).